Pierre Auger Observatory

studying the universe's highest energy particles

PIERRE AUGER OBSERVATORY

Neutrino Astrophysics with the Pierre Auger Observatory

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Universidad de Granada

VII TeV Particle Astrophysics Conference

"AlbaNova University Center", Stockholm.

August 1-5 2011

The Oskar Klein Centre and AlbaNova University Center announce the

7th TeVPA Conference

August 1-5 2011

Stockholm, Sweden

Primary objective of the Pierre Auger Observatory

"Measure the properties of Ultra High Energy Cosmic Rays ($E > 10^{18}$ eV) with unprecedented statistics and accuracy"

Energy

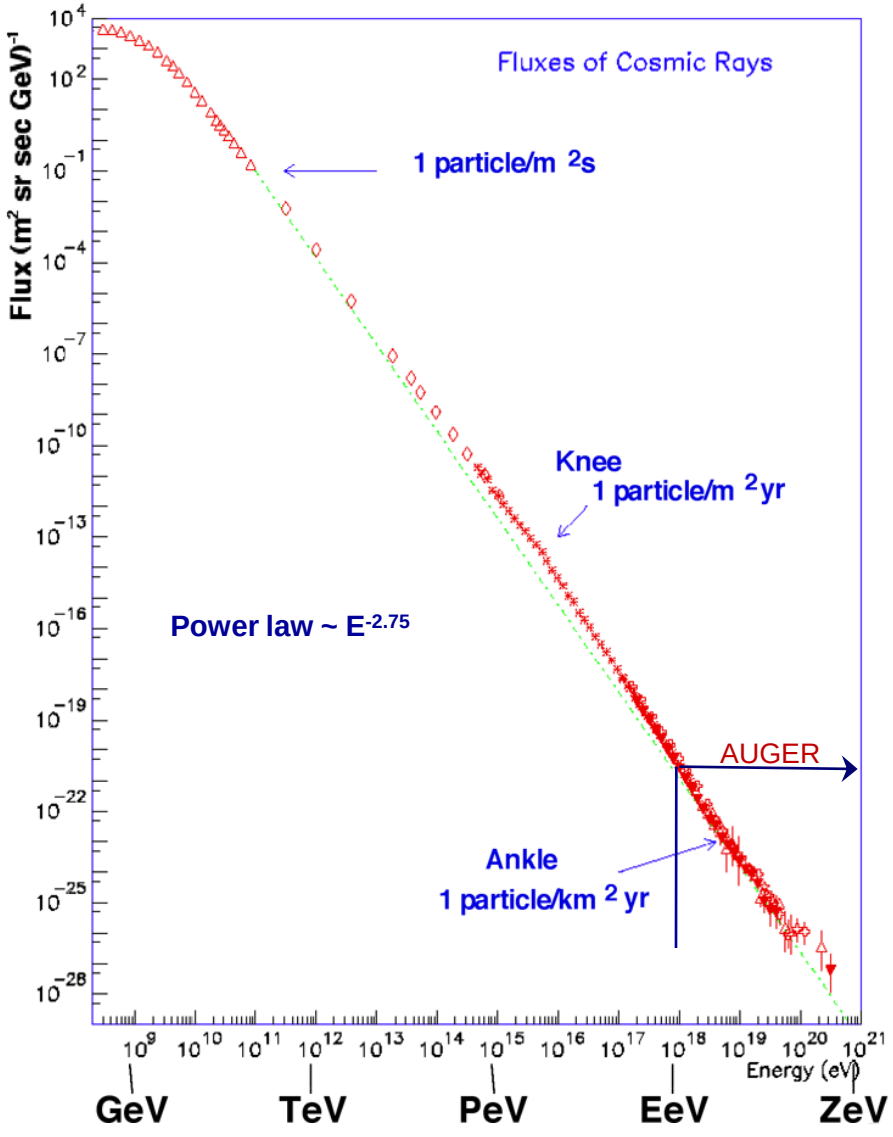
- Cutoff at the highest energies? Ankle?

Direction

- Is the UHECR flux isotropic ?
- Which are the UHECRs sources?

Mass composition

- Is the UHECR flux proton/iron-dominated?



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Visit:

www.auger.org/technical_info

for interesting results on these areas

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Neutrino and photon detection (!) →

Astropart. Phys. 31 (2009) 399-406

Phys. Rev. D 79 (2009) 102001

- As a bonus, the Observatory has the capability to detect UHE ν and γ

Expected sources of UHE neutrinos

Astrophysical Neutrinos

- Neutrinos are expected as a product of pion decays produced in hadronic interactions of cosmic rays with radiation or matter near the astrophysical sources (AGNs…)

"Cosmogenic Neutrinos"

$$p + \gamma_{CMB} \rightarrow \pi^{\pm} + X$$
$$\hookrightarrow \mu^{\pm} + \nu_{\mu}\,(\overline{\nu_{\mu}})$$
$$\hookrightarrow e^{\pm} + \nu_{\mu}\,(\overline{\nu_{\mu}}) + \nu_{e}\,(\overline{\nu_{e}})$$

- ≡ GZK neutrinos: produced by high-energy cosmic rays with the microwave background.

Predicted in "top-down" scenarios

- Decay of ultra massive objects (topological defects, super heavy dark matter, Z burst…): harder spectrum & high γ and ν fluxes predicted.

- Neutral ⇒ propagation in straight line (point to the source)
- Weakly interacting ⇒ low probability to interact (cosmological distances)

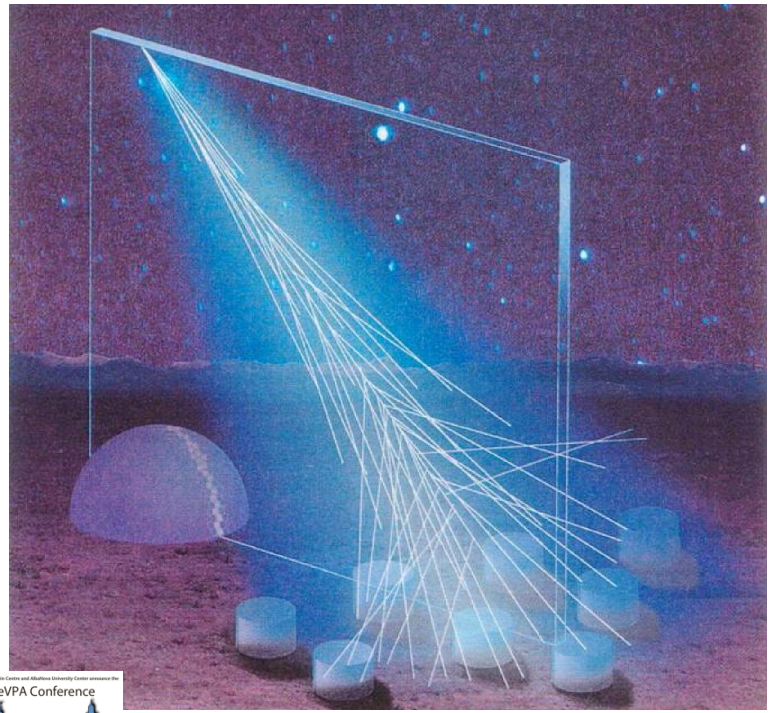
} ν *astronomy*

The Pierre Auger Observatory

- Detector completed in June 2008
- 70 institutions and 17 countries

Argentina, Australia, Bolivia, Brazil, Czech Republic, France, Germany, Italy, Mexico, Netherlands, Poland, Portugal, Slovenia, Spain, U.K., U.S.A., Vietnam

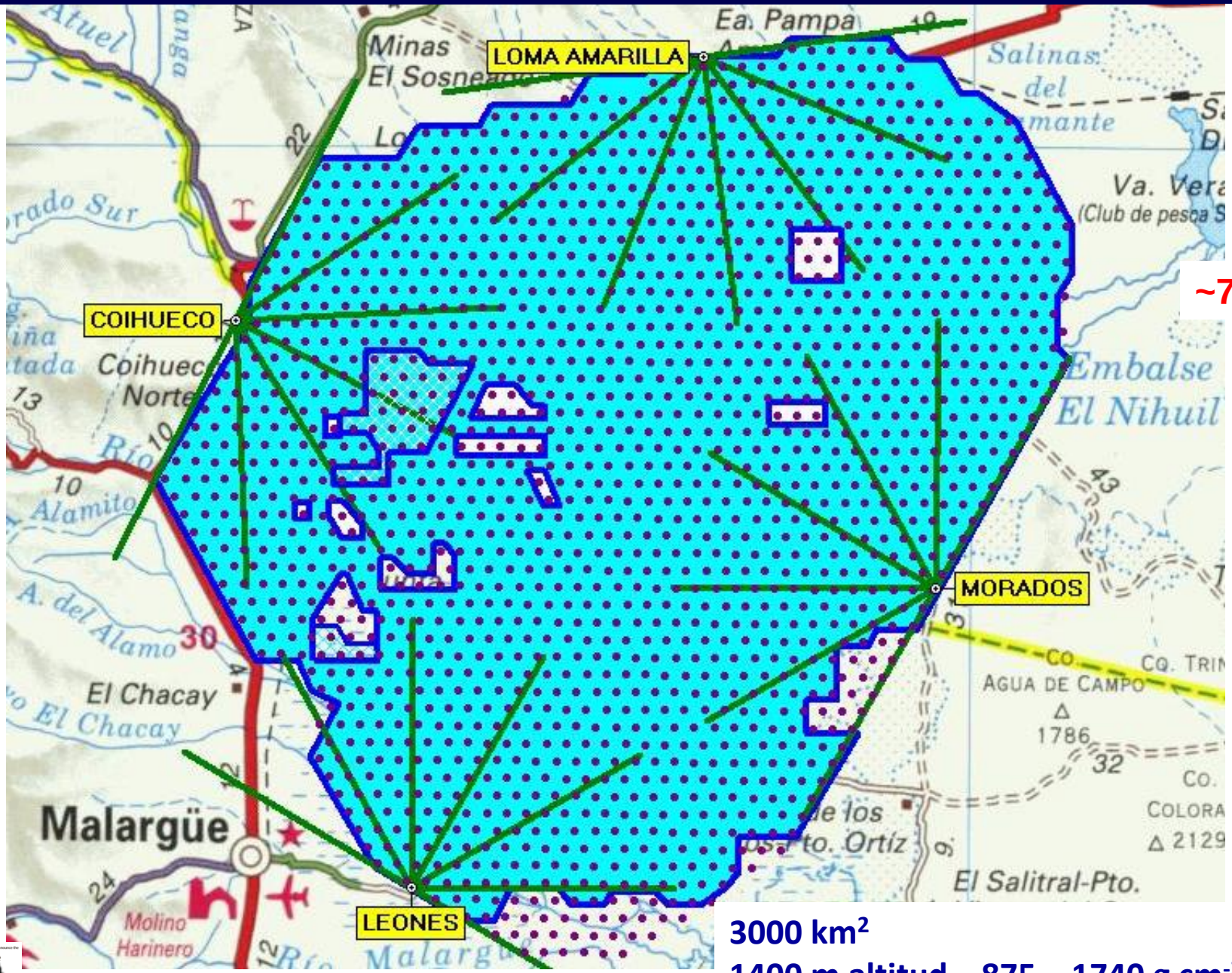
- **HYBRID** detection technique



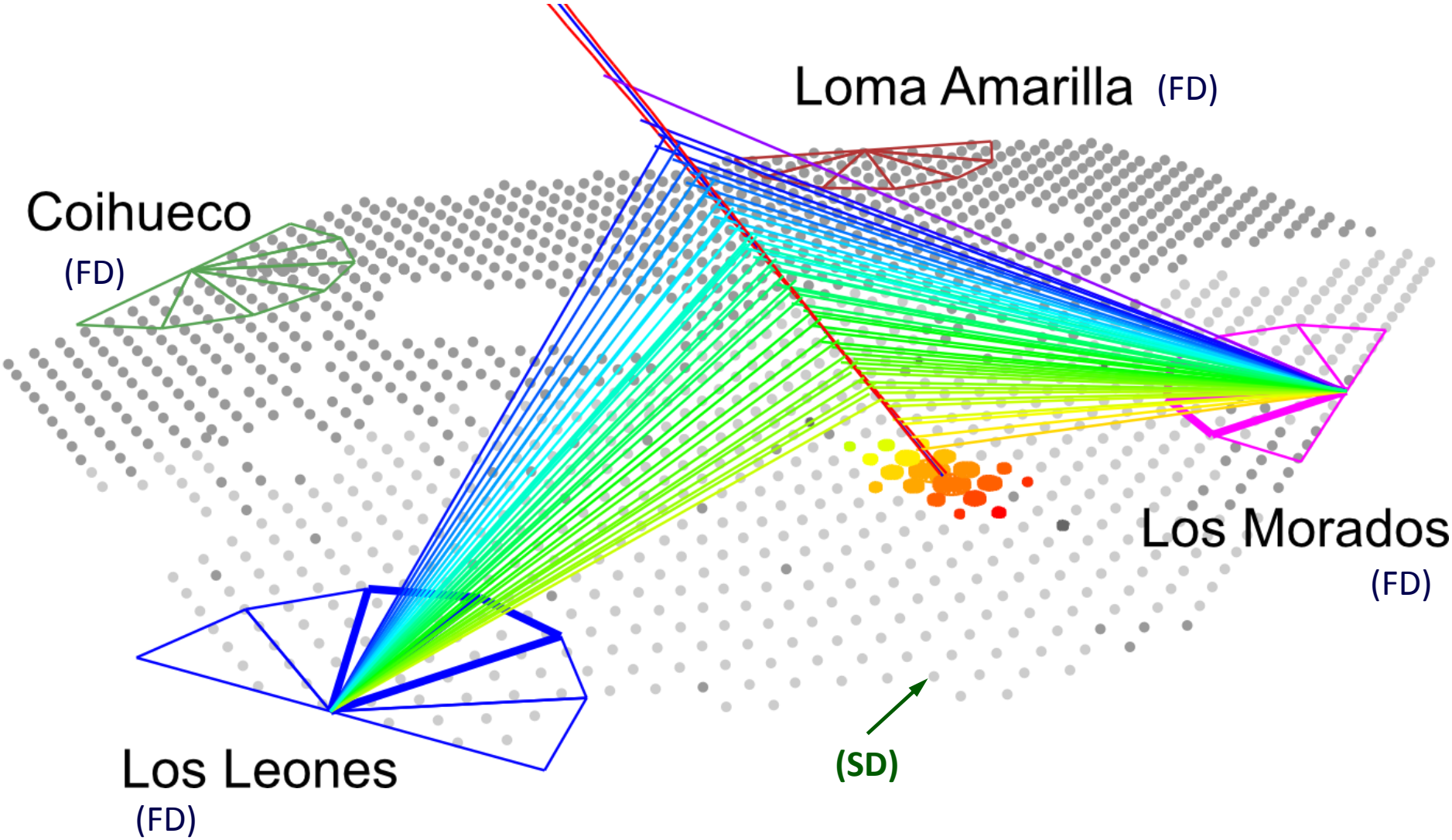
J.L. Navarro for The Pierre Auger Collaboration

Malargüe – Argentina (Pampa Amarilla)

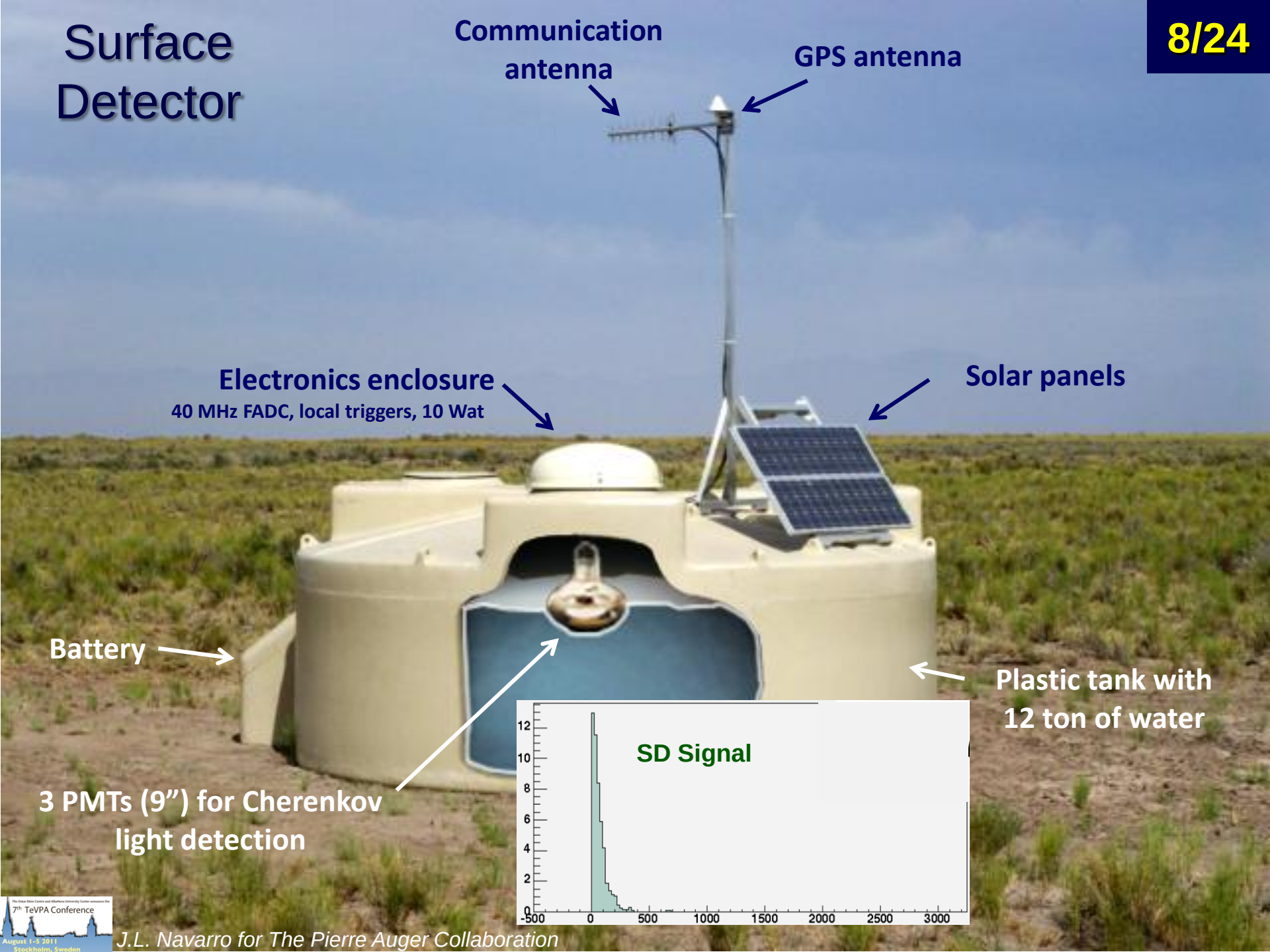
The Observatory layout ("dynamic")



Example of “hybrid” event



Surface Detector



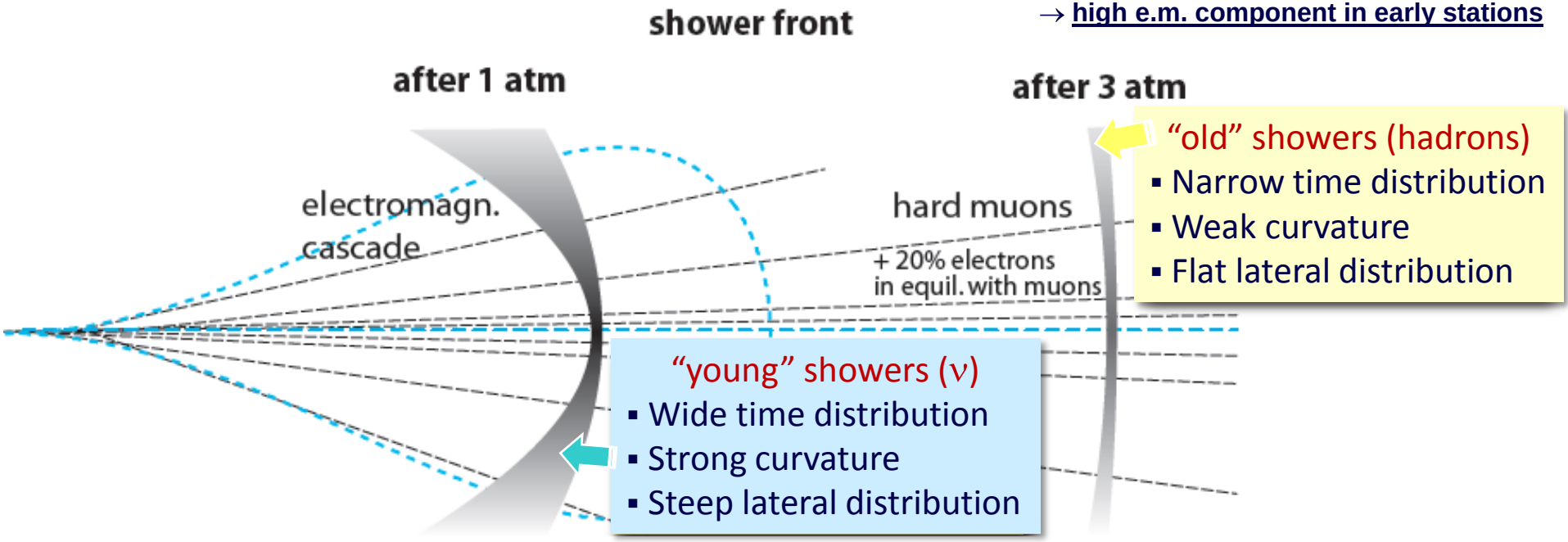
What is a "detectable" neutrino in the Pierre Auger Observatory?

ν = deep inclined shower

ν = deep inclined shower

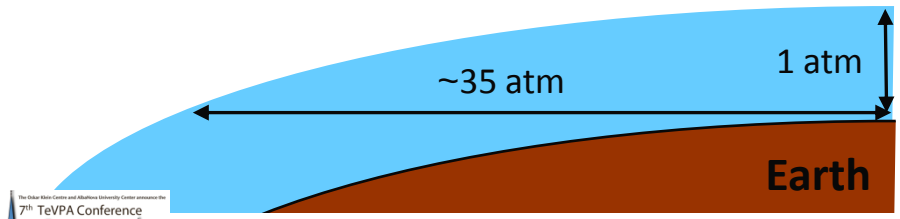
✓ Why deep ?

→ ν interact deep in the atmosphere
→ look for **young** showers
→ **high e.m. component in early stations**



✓ Why inclined ?

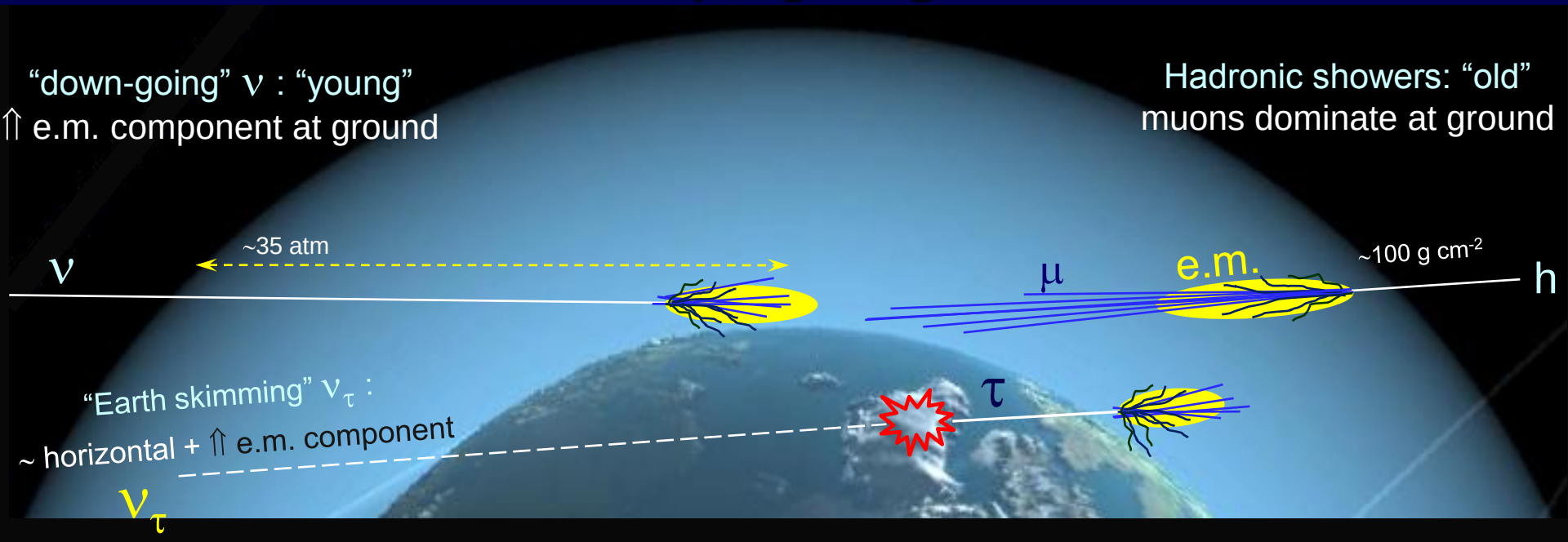
Due to the low neutrino cross-section → large amount of matter for interaction
→ **inclined** neutrinos are likely to induce EAS close to ground



Atmosphere @ Auger site

Vertical ≈ 880 g cm^{-2}
Horizontal ≈ 32000 g cm^{-2}

Two search channels: "down" and "up" going neutrinos …



"down going" neutrinos

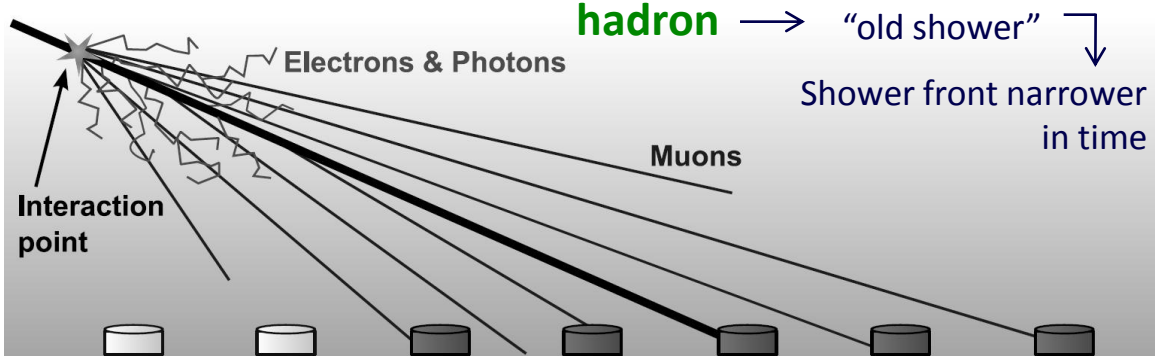
- ↑ Sensitivity to ALL ν flavours
- ↑ Sensitive to ALL interaction channels (CC & NC)
- ↑ Large solid angle ($75^o \rightarrow 90^o$)
- ↓ Dilute mass target (air)

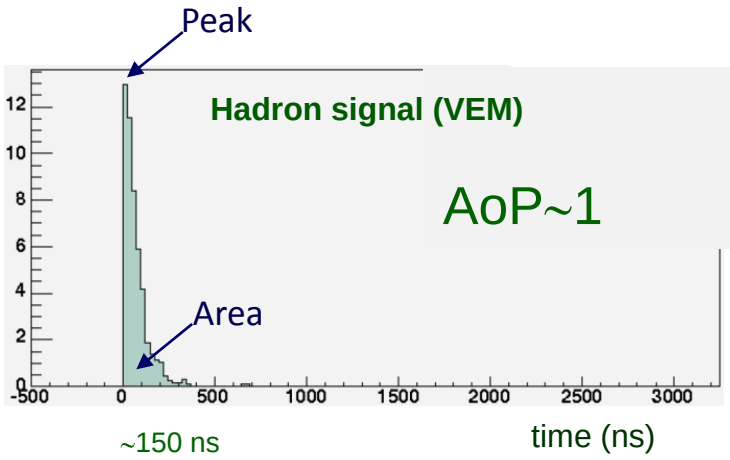
"Earth skimming" tau neutrinos

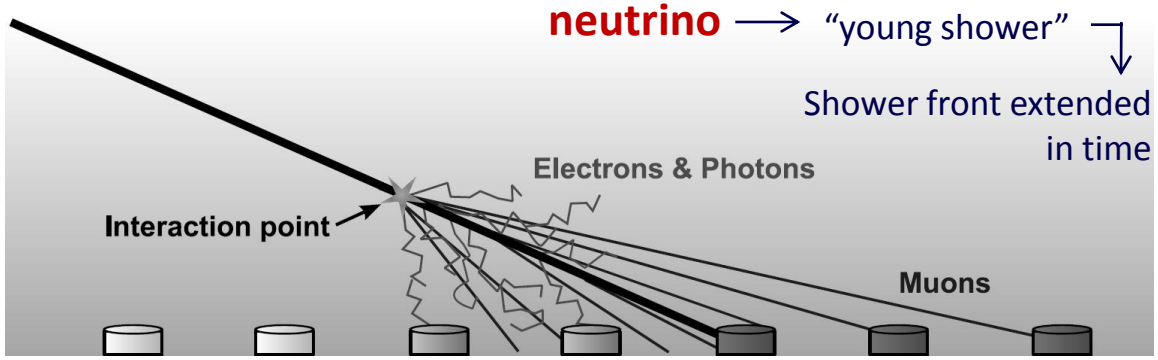
- ↑ τ travels long distances in the Earth without losing too much E before decay
- ↓ Sensitivity to ν_τ CC channel
- ↓ Small solid angle (90^o – 95^o)
- ↑ Dense mass target (Earth crust)

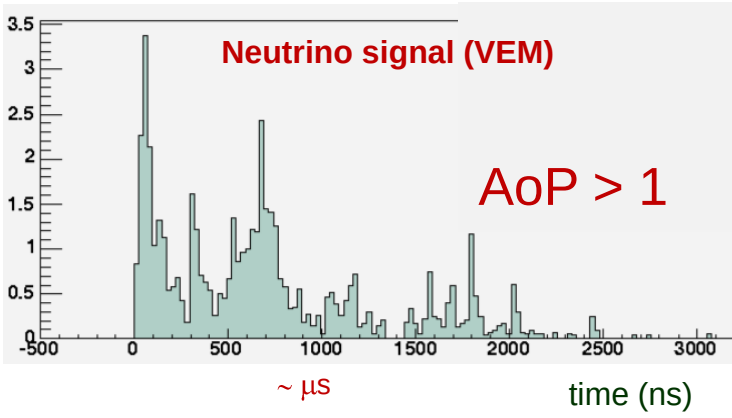
The neutrino *signature* in the SD array

Main observable ⇒ AoP = Area / Peak









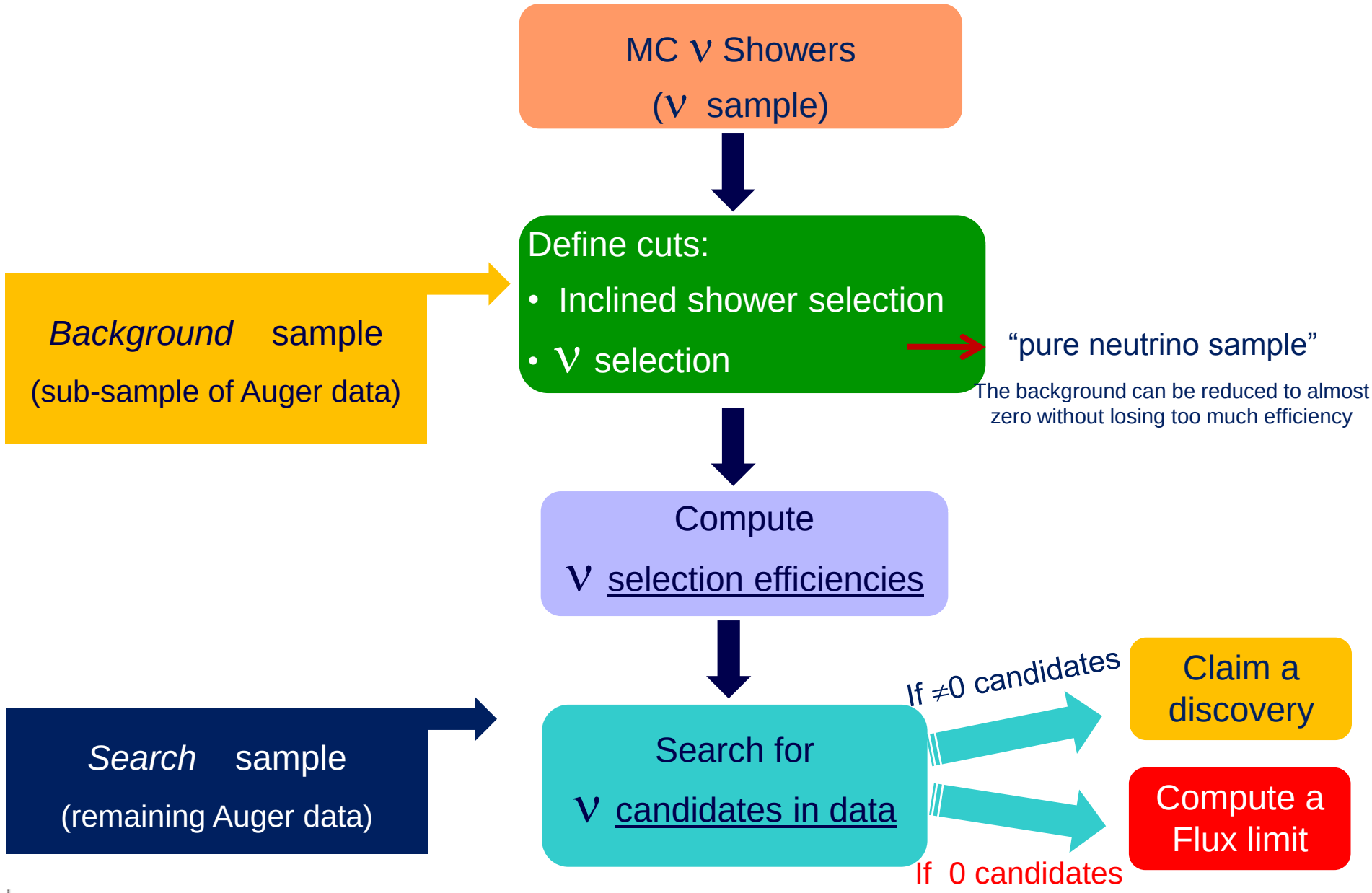
Broader signals in few first triggered tanks → early stations

late stations ← Larger grammage of atmosphere

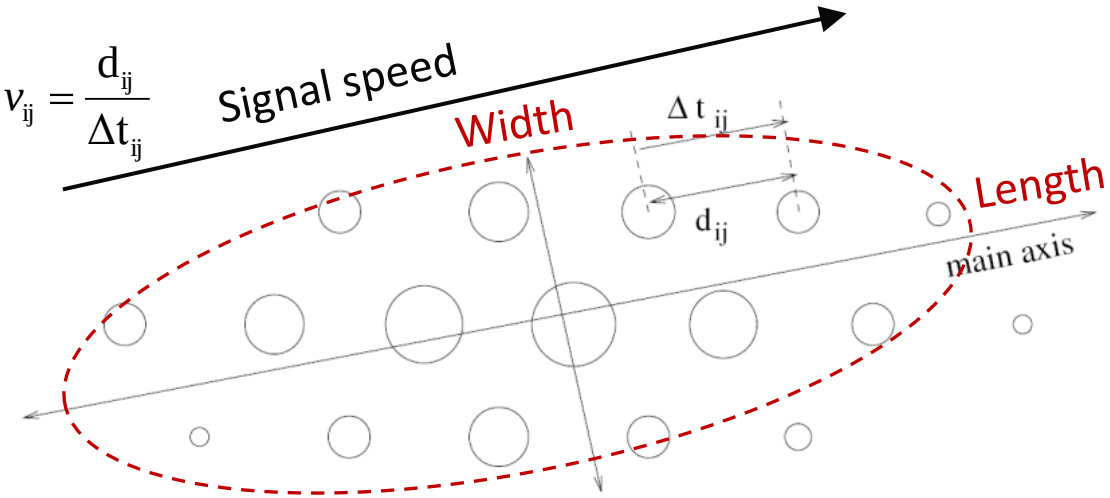
SIGNATURE

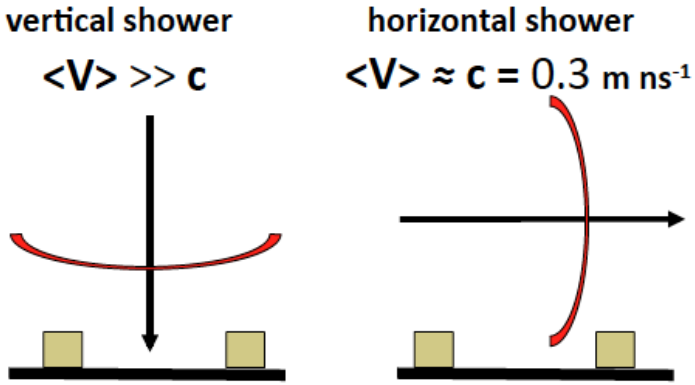
⇒ inclined shower with significant electromagnetic content, mainly in the "early" stations

Search strategy : Blind analysis



✓ Inclined shower selection:





- **Down-going** ($\theta > 75^o$)
  - At least 4 triggered stations
  - <*signal speed*> **<** 0.31 m ns^{-1}
  - L/W **>** 3
- **Earth-skimming** ($90 < \theta < 95^o$)
  - At least 3 triggered stations
  - 0.29 m ns^{-1} **<** <*signal speed*> **<** 0.31 m ns^{-1}
  - L/W **>** 5

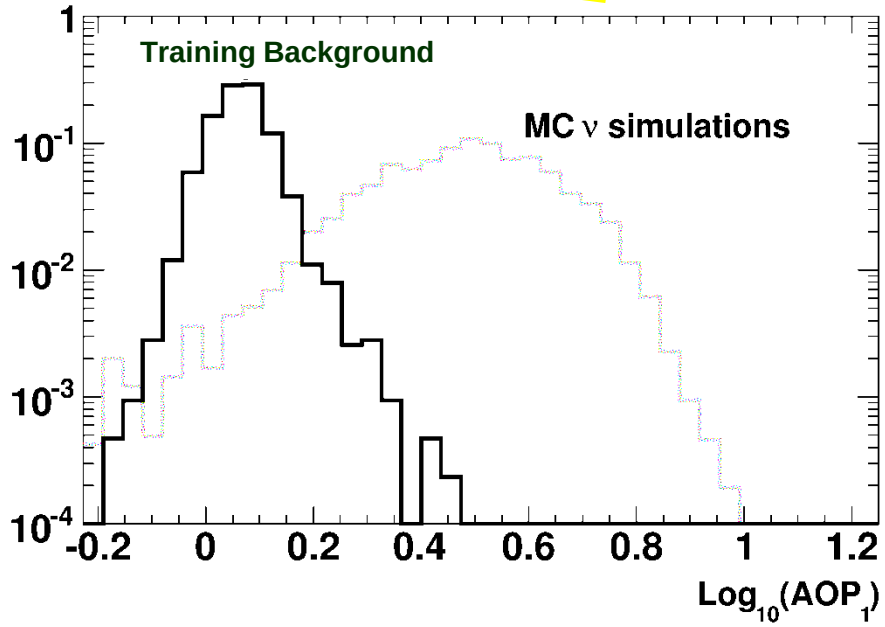
- <*signal speed*> relative error < 0.08 m ns^{-1}

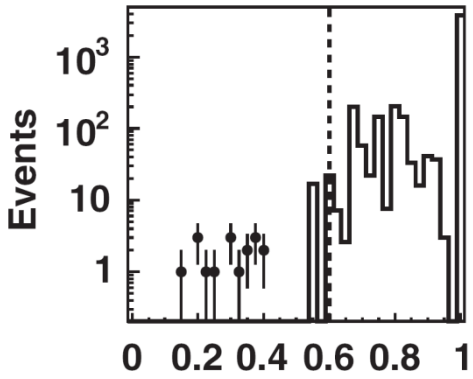
✓ Selection of deep showers:

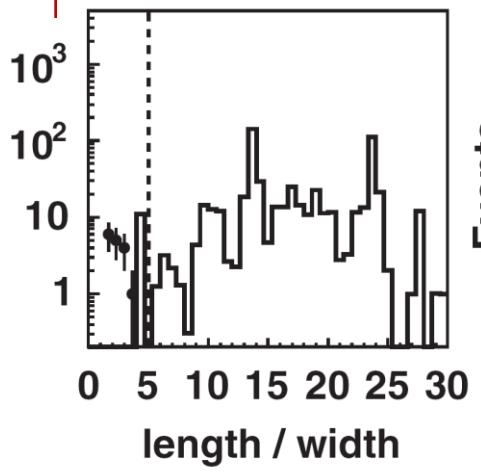
- **Down-going**
  - Area over Peak (AoP) of first four tanks
  - Combinations of them
  - Asymmetry: <Early AoP> – <Late AoP>

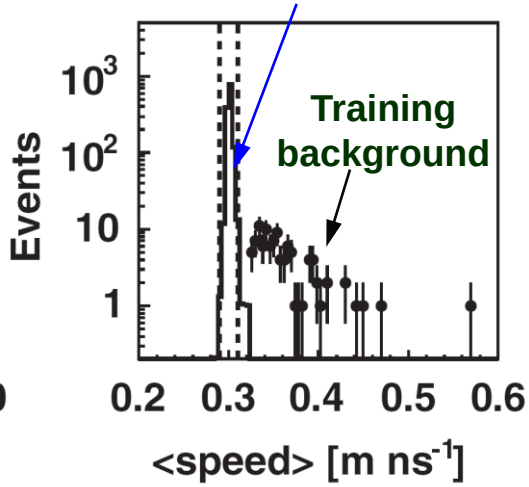
- **Earth-skimming**
  - Minimum fraction of stations with broad signals and high AoP

Fisher analysis



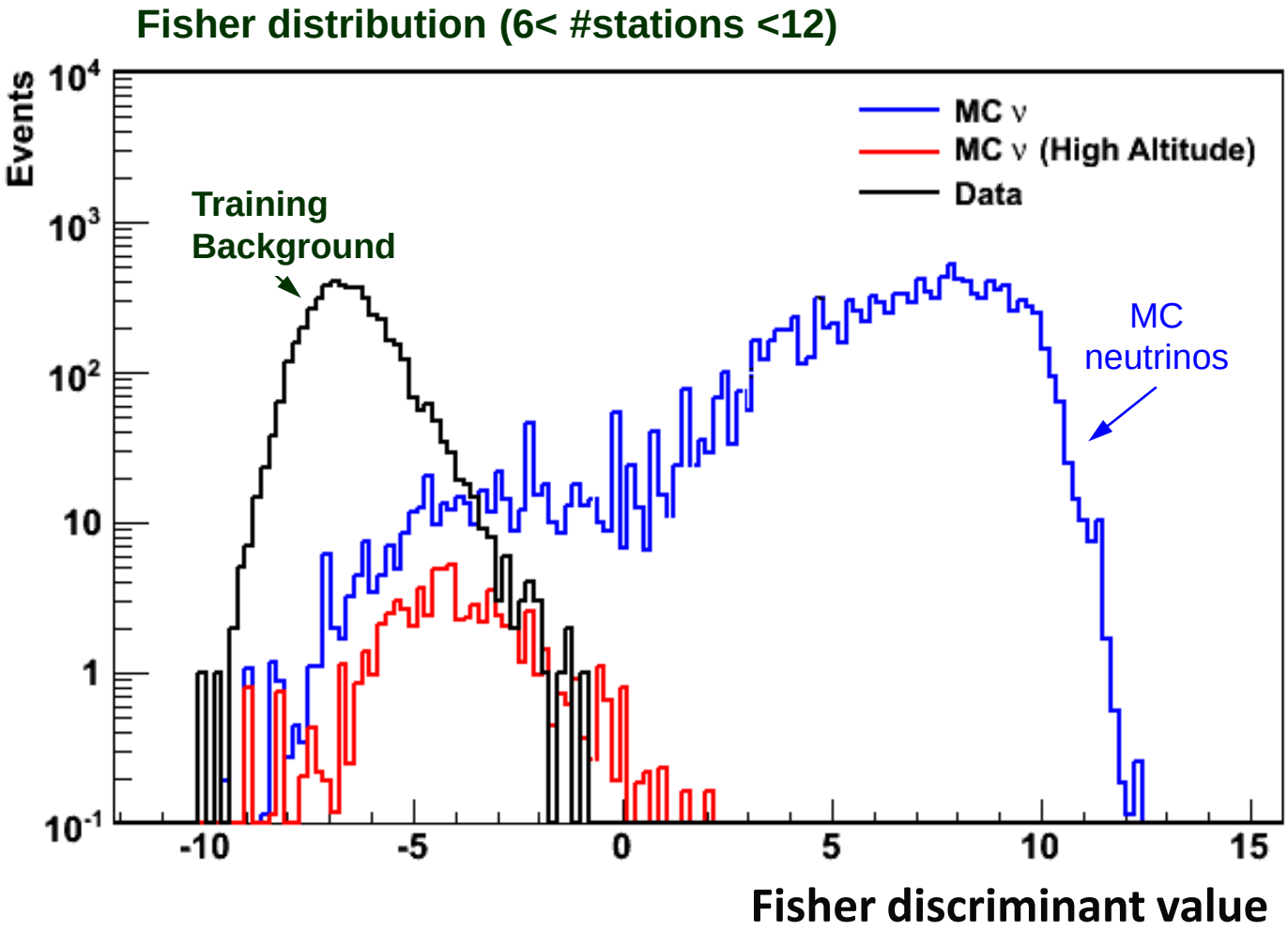






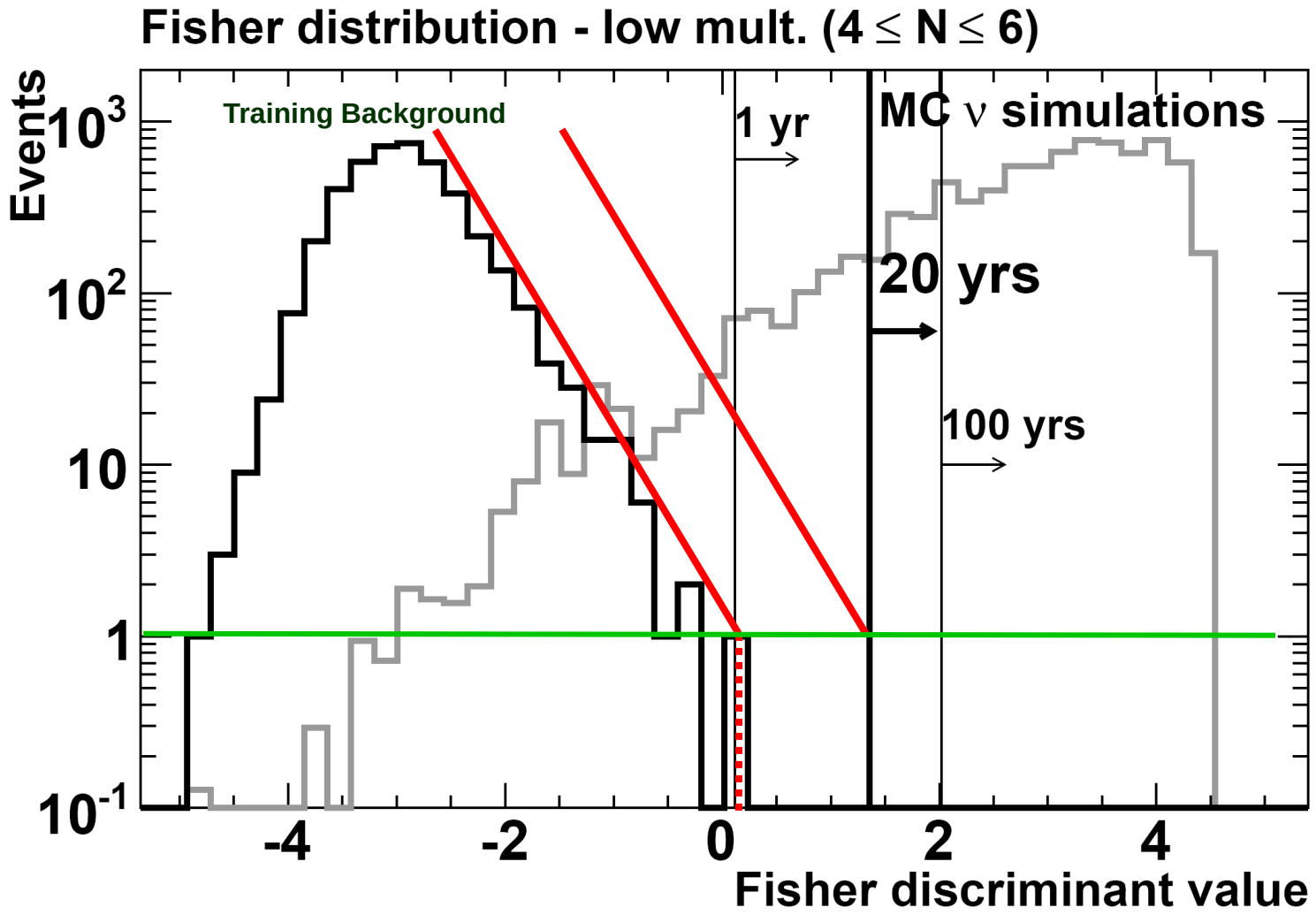
Signal / Background discrimination

- ✓ Very good separation between the two event categories.
- ✓ The selection is now done on the basis of a **single cut** on the *Fisher* value.
- ✓ *Improved discrimination:* split sample in sub-samples according to the number of selected stations



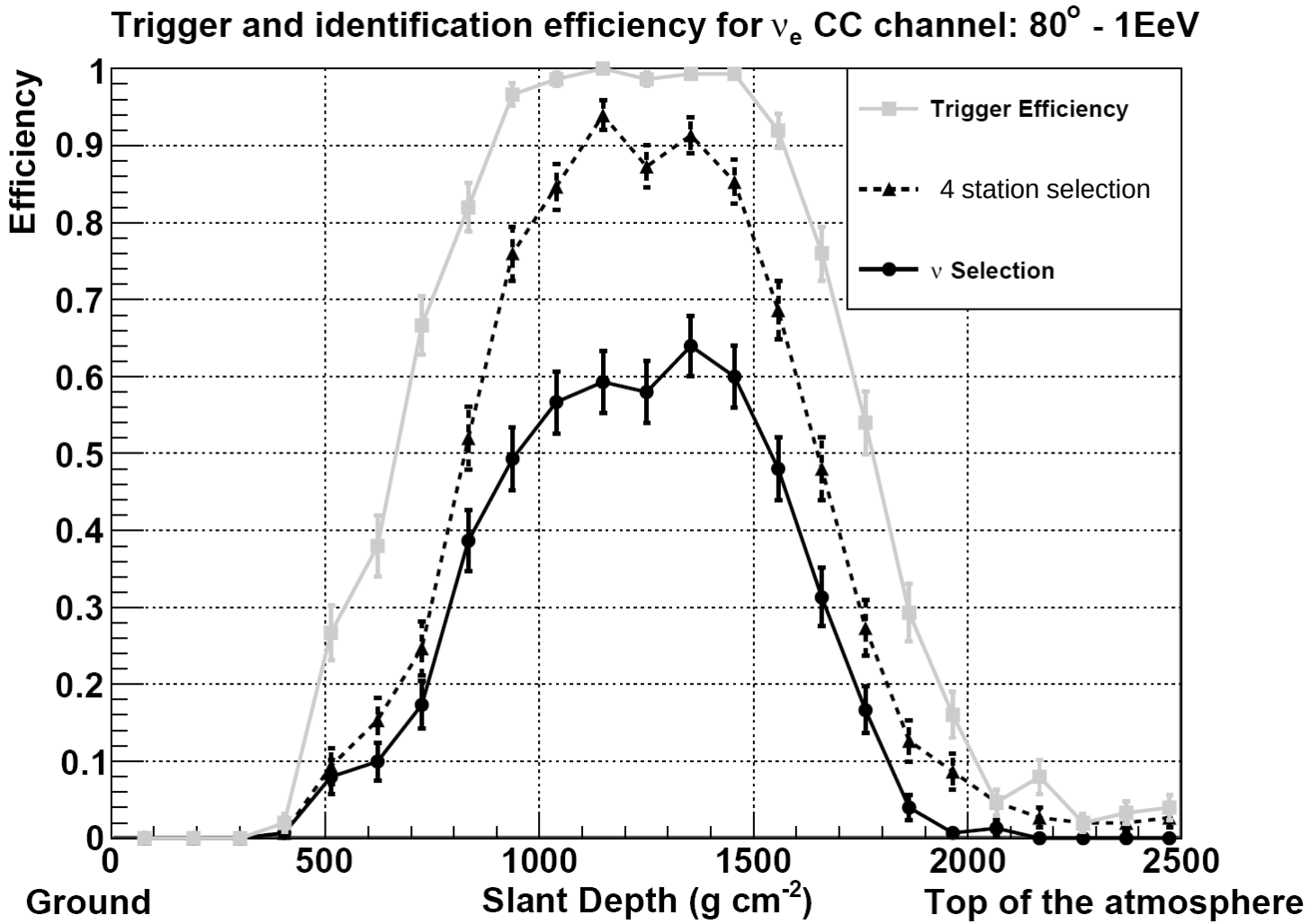
Fisher cut

- "safe" cut on *Fisher* value such that expected background **< 1 event / 20 years** of Auger data



Down-going selection efficiency

- Fraction of neutrino-induced showers triggering the SD and passing the identification criteria (quality, *Fisher*…)



Exposure calculation

- The **Exposure** is computed through the **time integral of the Mass Aperture** × **the interaction cross section** (sum over the three neutrino flavors and interaction channels)

$$\text{Exposure} \Rightarrow \quad \mathcal{E}(E_\nu) = \frac{1}{m}\sum_i \left(\sigma^i(E_\nu)\int \mathrm{M}^{\mathrm{i}}_{\mathrm{ap}}(E_\nu,t)\,\mathrm{dt}\right)$$

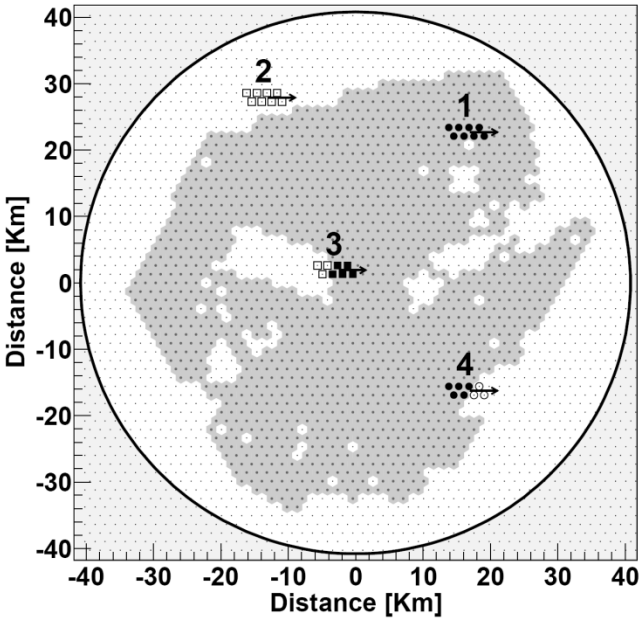
Sum over three ν channels and CC&NC

$$\mathrm{M}^{\mathrm{i}}_{\mathrm{ap}}(E_\nu,\mathrm{t}) = 2\pi \int\int\int\int \sin\theta\cos\theta\,\varepsilon^i_{ff}(\vec{r},\theta,D,E_\nu,t)\;\mathrm{d}\theta\,\mathrm{dD}\,\mathrm{dx}\,\mathrm{dy}$$

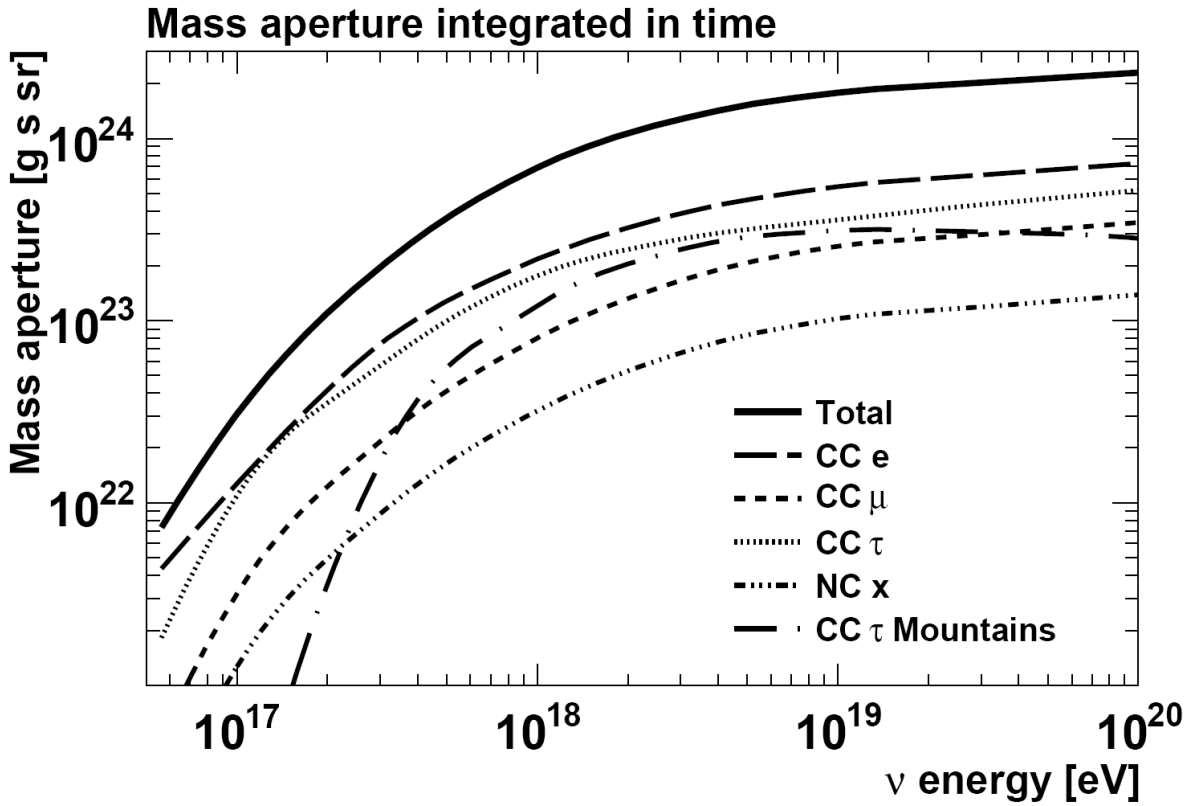
Mass aperture for each channel

ν detection efficiency

The array configuration varies with time !



Snapshot of the array configuration in October 27th , 2007



After unblinding..

0

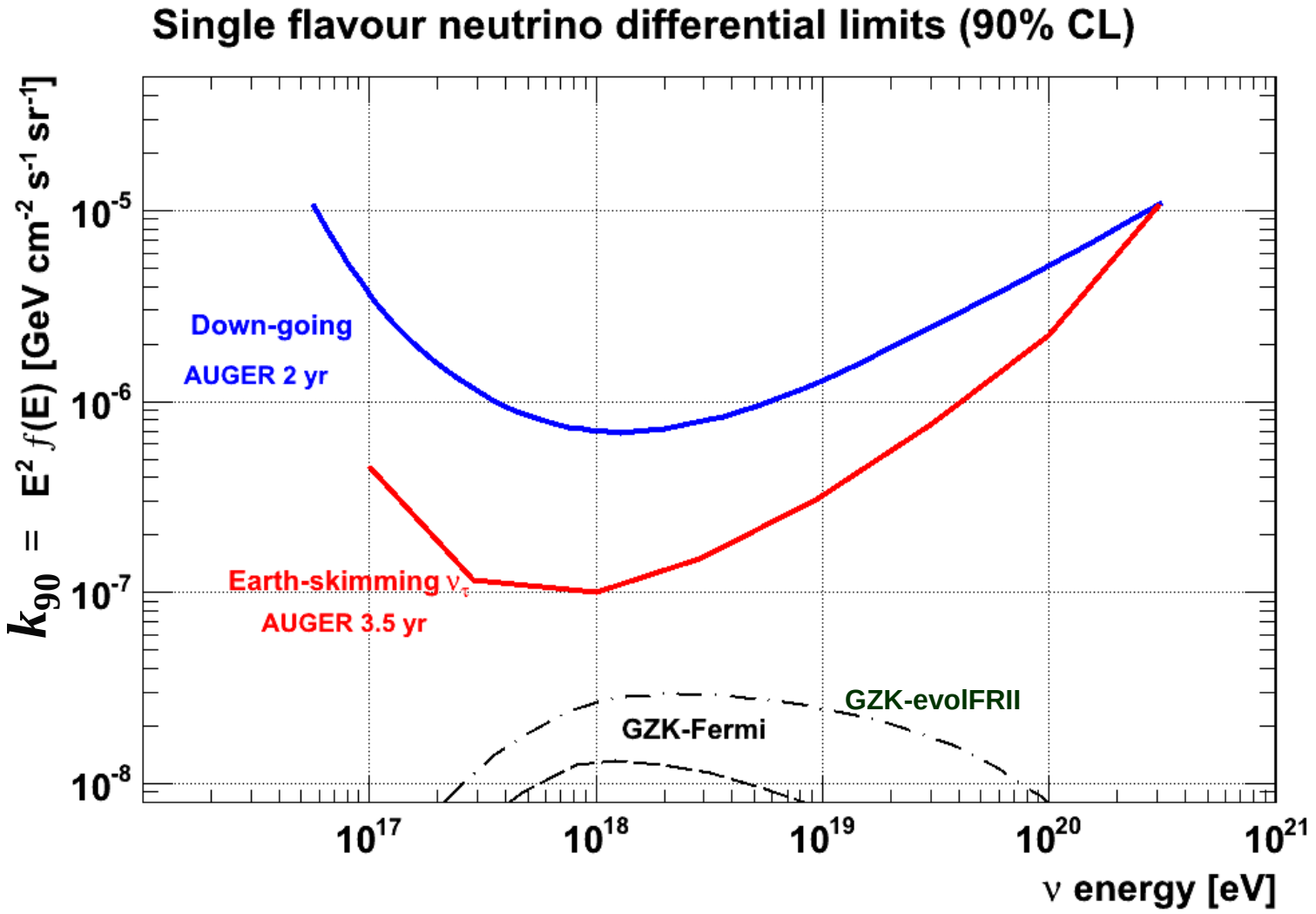
candidates for the search period

Down-going ν : Nov 07 to May 10

Up-going ν : Jan 04 to May 10

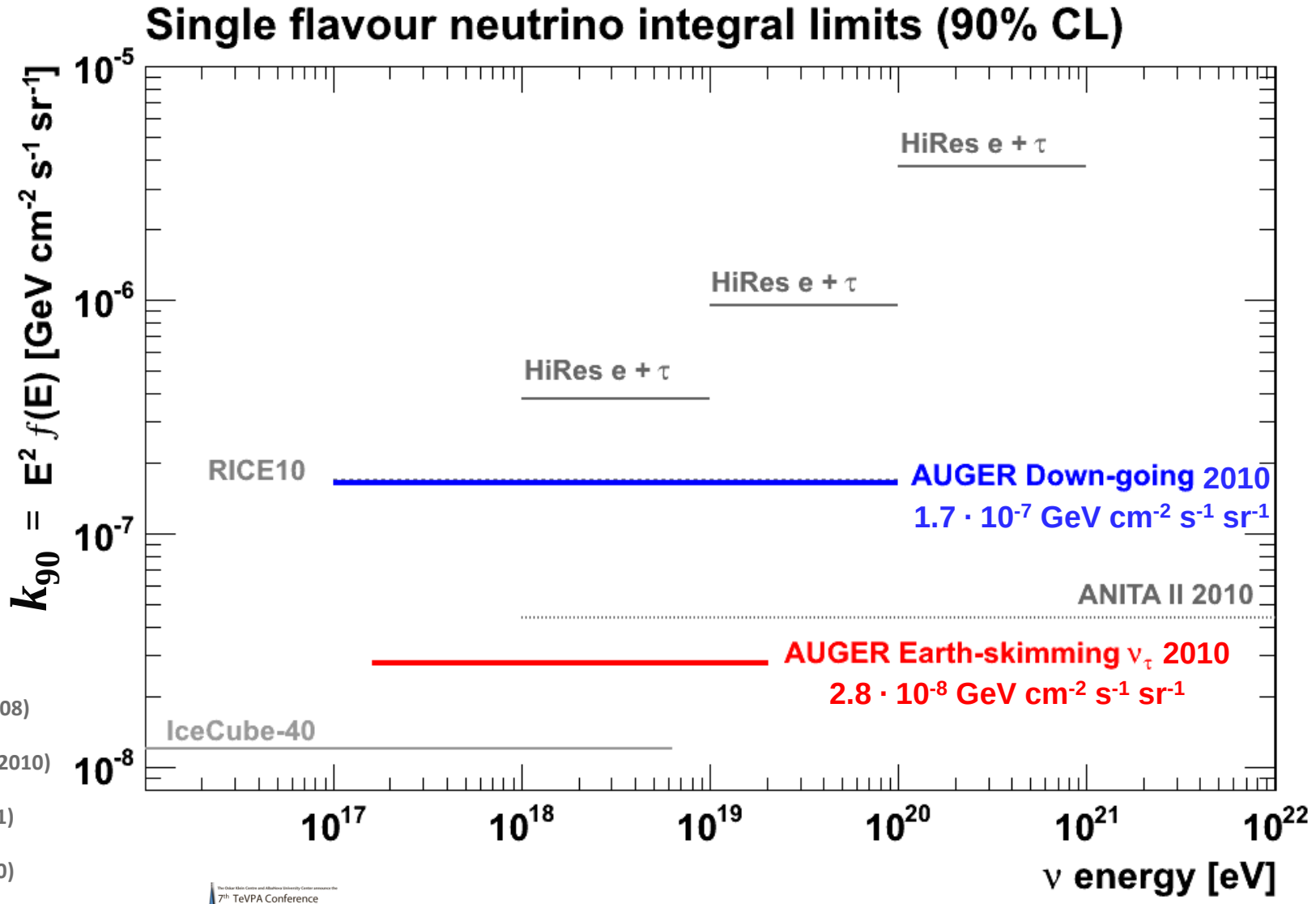
Differential flux limit

Assuming $\frac{dN}{dE} \equiv f(E_\nu) = k \cdot E_\nu^{-2}$ ⇒ $f(\mathrm{E}_\nu)_{\mathrm{lim}} = \frac{\mathrm{N}_{\mathrm{exp}}}{\mathrm{E}_\nu \cdot \mathfrak{E}(\mathrm{E}_\nu) \cdot \Delta \ln \mathrm{E}_\nu}$



Integrated flux limit

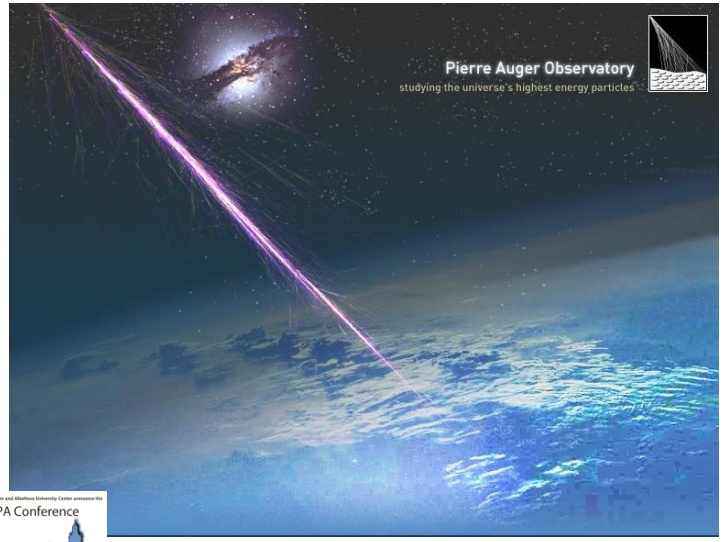
$$N_{exp} = \int f(E_\nu) \cdot \mathcal{E}(E_\nu) \cdot dE_\nu \quad \text{and assuming} \quad f(E_\nu) = k \cdot E_\nu^{-2}$$



HiRes:
Astrophys. J. 684 (2008)
RICE10:
arXiv: 1106.1164v1 (2010)
IceCube40:
Phys. Rev. D 83 (2011)
ANITA II:
Phys. Rev. D 82 (2010)
Auger:
arXiv: 1107.4805v1 (2010)

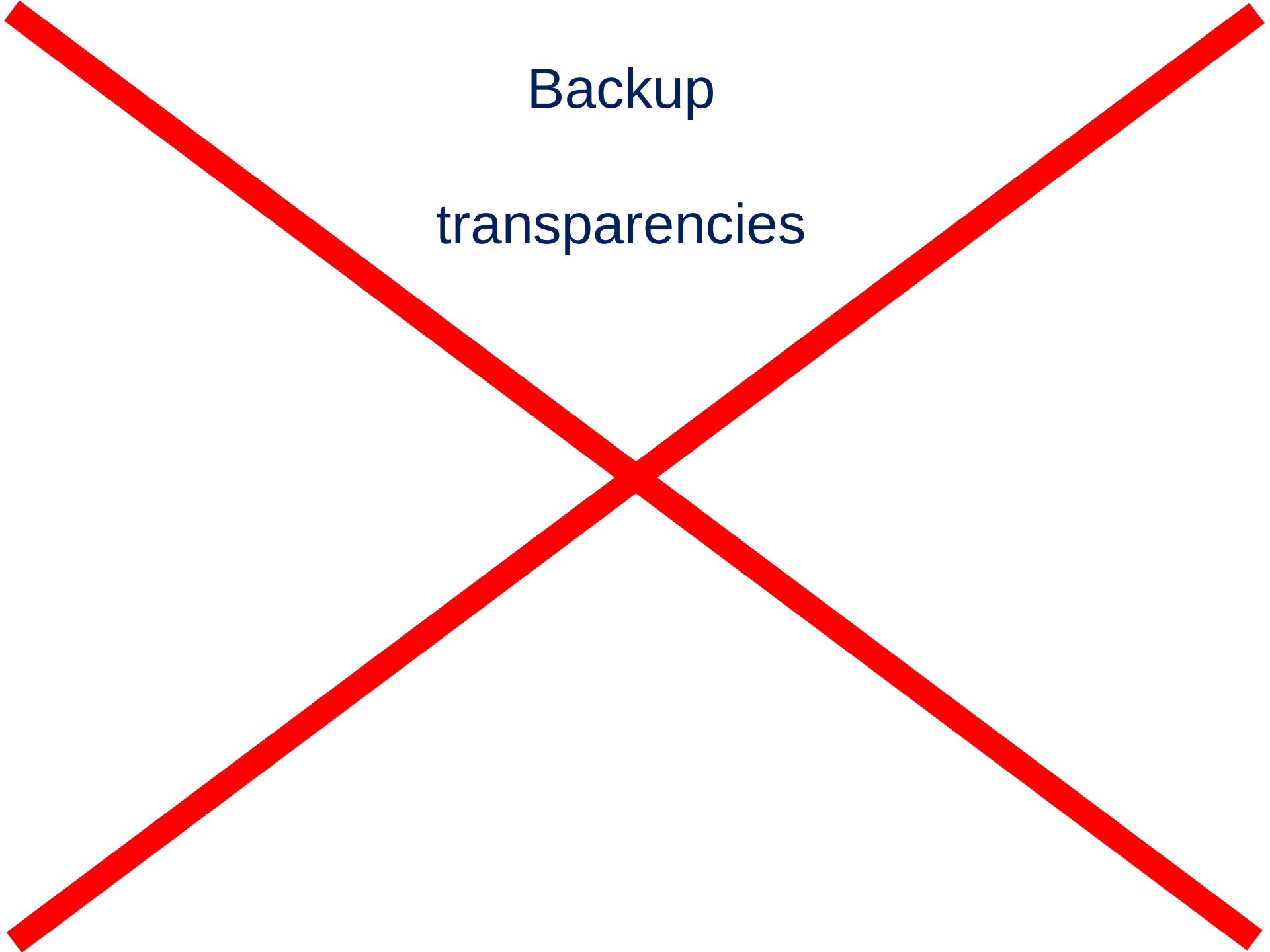
Summary

- The Pierre Auger Observatory is sensitive to UHE neutrinos:
  - ✓ "down-going" neutrinos ($\theta \in [75^o - 90^o]$) : three flavours and CC&NC
  - ✓ "Earth-skimming" neutrinos ($\theta \in [90^o - 95^o]$) : ν_τ CC
- Main signature: "very inclined showers with significant electromagnetic content"
- **ZERO** neutrino candidate found ⇒ Limits on UHE ν flux
  - down-going: **$1.7 \cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}**
  - Earth-skimming: **$2.8 \cdot 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}**
- Maximum sensitivity at the most relevant range for GZK neutrinos (~1 EeV)



Backup

transparencies



Systematic uncertainties

Transport equation

Modeling UHE had. interac.

Triggering/selection efficiency, Aperture…

Andes, Pacific Ocean…

Depends on PDFs…

Interactions in Earth		±5%
Extensive Air Shower		+20% , –5%
Acceptance		±2%
Topography		±6%(↓) ±18%(↑)
Cross section		±10%
Energy Losses	(Breemstralhung, pair prod., DIS)	+25% , –10%

MC Simulations

Pierre Auger Observatory

Theory

Relative contribution of different channels (down-going analysis)

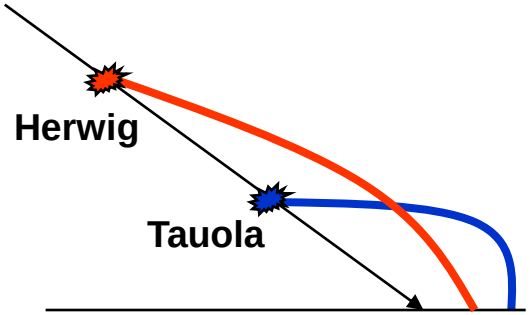
(%)	ν_e	ν_μ	ν_τ	Total
CC	33	13	39	85
NC	5	5	5	15
CC + NC	38	18	44	100

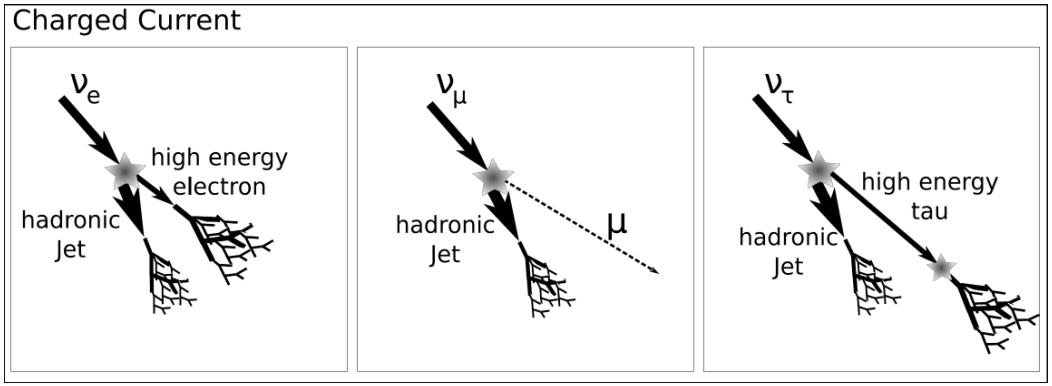
Expected number of events using current exposure of down going ν measured by Auger for several models

	Reference		N expected
"cosmogenic"	**GZK - Fermi**	JCAP 10, 013 (2010)	0.12
	GZK – evolFRII	Astropart. Phys. 34 (2010) 106	0.30
"astrophysical"	**MPR – max**	Phys. Rev. D 63 (2001) 23003	2.08
	BBR	Astropart. Phys. 23 (2005) 355	0.89
"exotics"	**TD – Necklaces**	Phys. Rev. D 66 (2002) 063004	0.84
	Z – Bursts		8.16

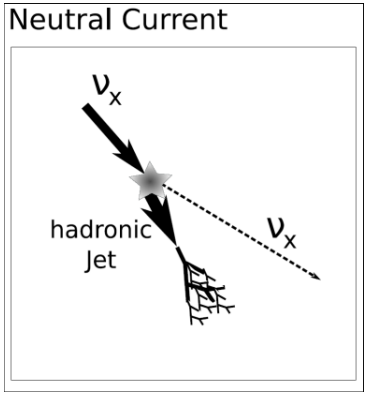
Neutrino simulation technical details

- First interaction: HERWIG
- Tau decay: TAUOLA
- Shower development: AIRES 2.8.0 + QGSjetII.03
- Detector simulation: Auger Offline
- All flavours (ν_e , ν_μ , ν_τ) and channels (NC & CC):





~ 150.000 showers ~ 200.000 showers

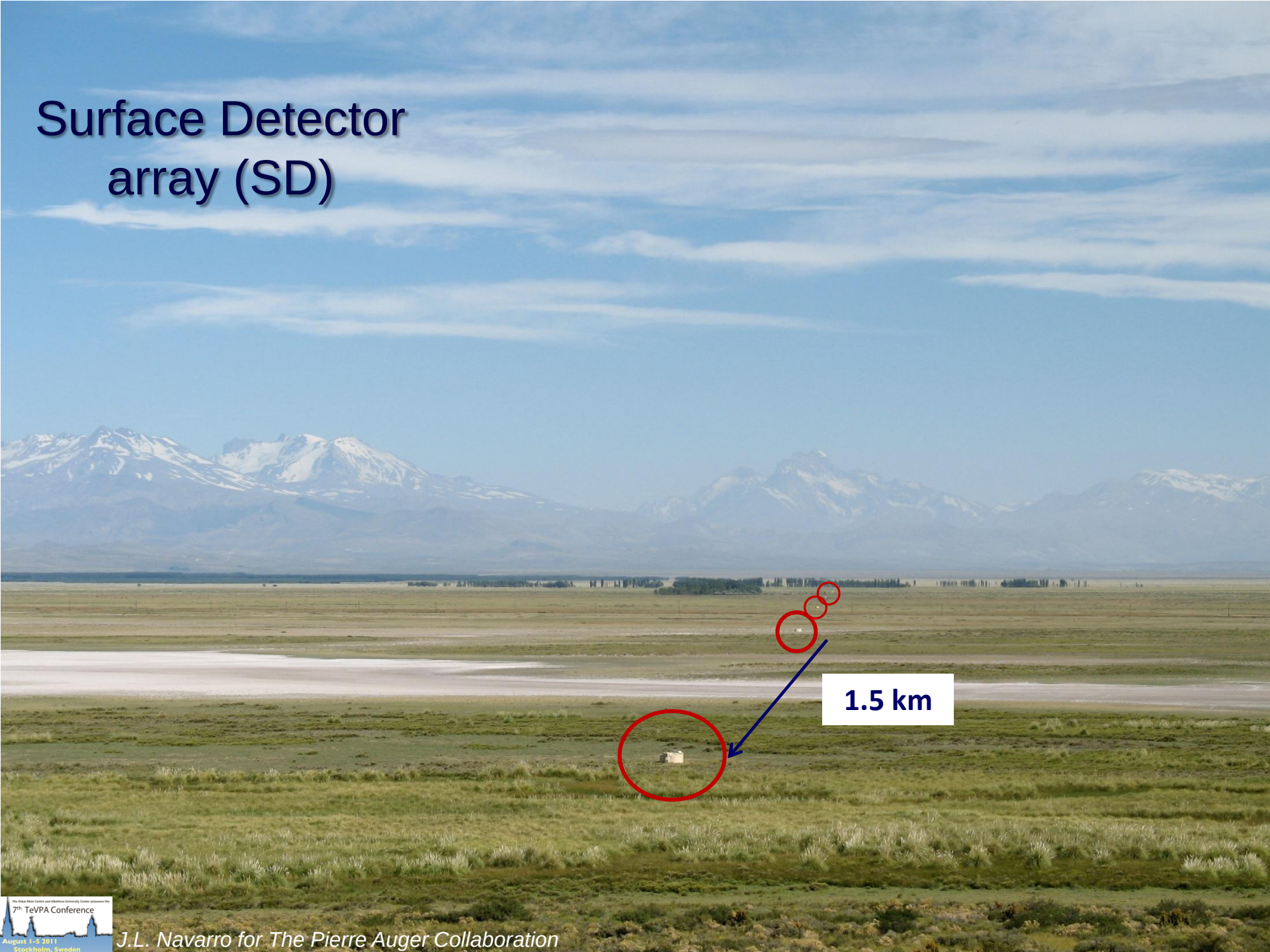


~ 150.000 showers

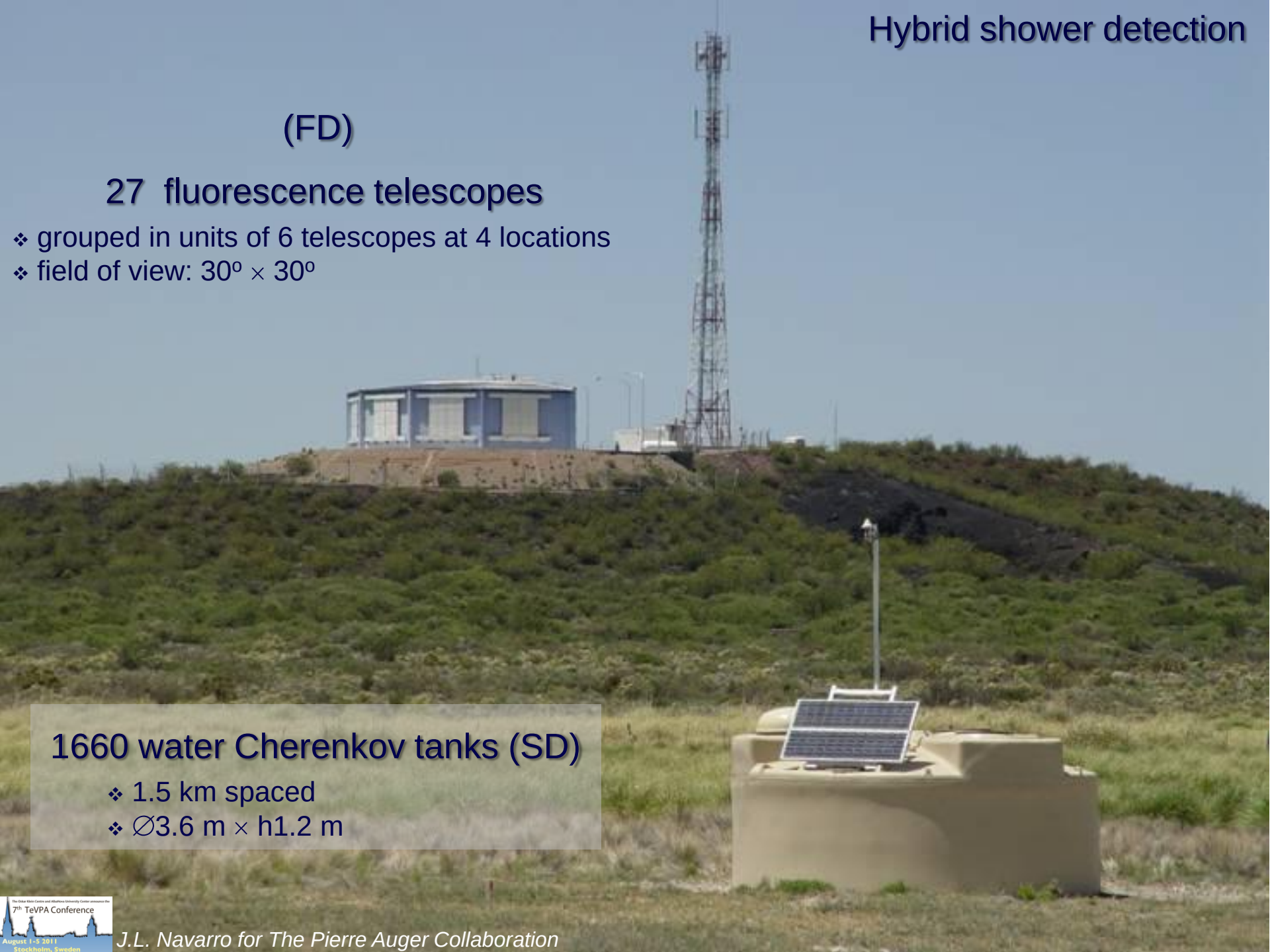
Parameters of simulations:

- Energy: E = 10^{17} eV – 10^{20} eV
- Zenith: $\theta_{\text{down-going}}$ = 75º – 89º (6 bins in sec(θ))
- Depth of 1st interaction: X_{inj} = 0 – 8000 g cm^{-2} (slanted from ground)

Surface Detector array (SD)



Hybrid shower detection



(FD)

27 fluorescence telescopes

- grouped in units of 6 telescopes at 4 locations
- field of view: $30^o \times 30^o$

1660 water Cherenkov tanks (SD)

- 1.5 km spaced
- ∅3.6 m × h1.2 m