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HiSPANoS facility and the new neutron beam line for TOF measurements at the Spanish National Accelerator Lab (CNA)

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Abstract. HiSPANoS (HiSPAlis Neutron Source) is the first accelerator-based neutron facility in Spain, installed at the Centro Nacional de Aceleradores (CNA), where different experiments have been performed related to nuclear astrophysics, detector characterization, electronic devices irradiation, imaging, etc. An upgrade of the neutron facility has been carried out recently, installing a pulsing system at the 3 MV tandem accelerator at CNA. Such system, composed by a chopper and buncher unit, can provide nanosecond proton and deuteron pulsed beams. A new experimental line dedicated to neutron time-of-flight (n-TOF) technique has been installed at the tandem accelerator. Proton and deuterium pulse width of 1 ns have been measured with a repetition rate in the range of 62.5 kHz to 2 MHz. The commissioning of the n-TOF line has consisted of the measurement of the neutron field generated by ^{7}Li(p,n) reaction with proton energy of 1912 keV.

1. Introduction

HiSPAlis Neutron Source (HiSPANoS) is the first accelerator-based neutron source (ABNS) installed in Spain. It is located at the 3 MV tandem accelerator at the Spanish National Accelerator Lab (Centro Nacional de Aceleradores, CNA) placed in Seville. Such accelerator is a pelletron, model 9SDH-2 from National Electronics Corporation (NEC)[1]. Since 2013, HiSPANoS is set up at the end of the experimental basic nuclear physics line (FNB). FNB line is one of the seven experimental lines of the tandem and is positioned at the +30° accelerator exit. At HiSPANoS, it is possible to deliver epithermal neutrons by means of the ^{7}Li(p,n) reaction near the threshold, fast neutrons with energy less than 9 MeV produced by D(d,n) fusion reaction or by ^{9}Be(d,n) reaction and thermal neutrons (by moderation).

During these years, several experiments with continuous beam have been carried out at HiSPANoS for different applications. Some integral measurements applied to nuclear astrophysics were realized using ^{7}Li(p,n). Different stellar neutron beams were produced for nuclear astrophysics studies[2][3]. Also this reaction was used for producing thermal neutrons by moderation. Such thermal neutrons were employed to characterize dosimeters used in radiotherapy halls[4]. Fast neutrons generated by D(d,n) reaction were used for studies of single event effects (SEE) induced by neutrons in electronic devices[5]. Thermal and fast neutrons have also been used to investigate the possibilities of HiSPANoS facility for imaging techniques, due to the fact that neutrons are an excellent complement to another imaging techniques using x rays or gammas rays (both available at CNA also)[6].

The success of HiSPANoS pushed the enhancement of the facility. The main purpose is to develop experimental measurements applying the neutron time-of-flight (TOF) technique. For this reason, proton and deuteron pulsed beams with 1 ns pulse width are desirable. If neutrons are produced with a pulsed ion beam, time information is added, so neutron velocities may be measured. This fact facilitates neutron-induced cross sections or neutron spectra determination as a function of the neutron energy.

In this paper, the upgrade carried out at the 3 MV tandem accelerator at CNA, with the aim of pulsing ion beams, will be described. Moreover the new experimental line designed for n-TOF experiments will be detailed. Finally, n-TOF commissioning performed at HiSPANoS will be presented.

2. Tandem accelerator upgrade

The upgrade performed at the 3 MV tandem accelerator could be divided in two stages. The first one was the installation of a chopper and buncher system for pulsing the ion beams and the second one consisted of setting up the new beam line dedicated to apply n-TOF technique.

2.1. Pulsing system

Two new devices were designed and installed in collaboration with NEC[7] to produce nanosecond proton and deuteron pulsed beams: a chopper and a buncher unit. They were positioned at the low energy region of the tandem, before the accelerator tank.

Chopper: it is made up of two deflecting plates located at the exit of the ion source. One plate is connected to a fast electronic switch and a voltage of 650 V dc is supplied through it. When the chopper is on the beam is always deflected. Then, thanks to a selection time (pulse width) the beam passes through an aperture defined by the slits placed between the chopper and buncher unit. Thus, a pulsed beam of tens of nanosecond width is produced. The main characteristics of the chopper are a repetition rate from 62.5 kHZ to 2 MHz, and a pulse width in a range of 40ns to 250 ns.

Buncher: it consists of two tubular electrodes coaxial to the beam. An 8 MHz Radio Frequency (RF) field is created across them that compresses the pulses delivered by the chopper by accelerating/decelerating the slow(retarded)/fast(ahead) particles entering the gap. The final pulse width is around 1 ns at the neutron target production.

2.2. New beam line for neutron TOF technique

With the aim to perform n-TOF experiments, not only a pulsing system was installed at the 3 MV tandem accelerator at CNA, but also a new and dedicated beam line at the accelerator. In figure 1, an image of the new experimental line is shown. This line is located after the 90° analysing magnet of the tandem and at the same direction of the accelerator tank. It has been equipped with all the diagnostic devices necessary. The first element is a beam profile monitor model BPM80. It provides information about the shape and position of the beam. It is followed by two steerers, each one to control one beam direction (X and Y). After that, the pulsed beam finds the slits XY model BDS8. Such slits allow to control and define the beam size at the target position with a precision of 0.1 mm. Then, a Faraday Cup model FC18 was mounted in the experimental line for beam current information. These devices are commercial and purchased from NEC[7]. A capacitive pick up, designed in collaboration with NTG[8], is located at the end of the line before the neutron target production. It is a non-intercepting diagnostic device. The capacitive pick up is a very important element because it gives us information about the pulsed beam quality: frequency, time width and charge per pulse.

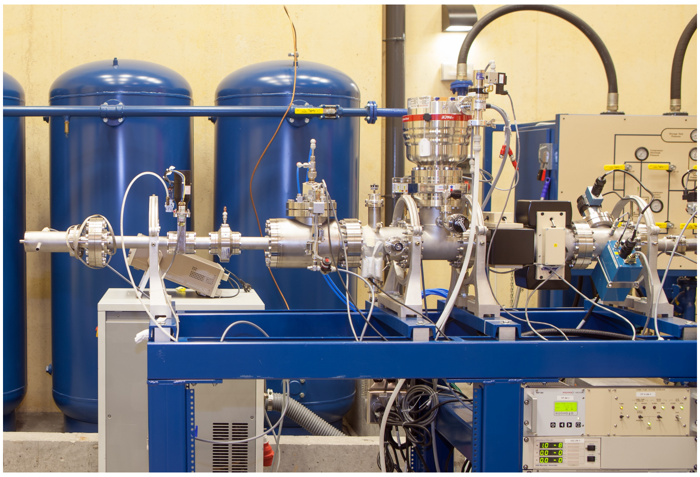

Figure 1. Image of the new experimental line for n-TOF measurements installed at the 3 MV tandem accelerator at CNA

3. HiSPANoS n-TOF commissioning

3.1. Pulsed ion beam commissioning

The goal of this commissioning was to achieve a nanosecond proton and deuteron pulsed beams. Different tests were carried out to verify the performance of the complete pulsing system[9]. The pulse frequency and average current was measured for every selected repetition rate of the

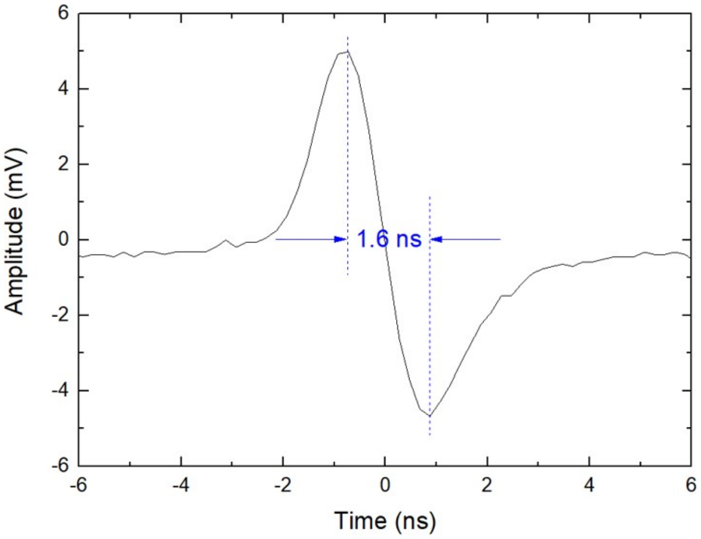

Figure 2. Pick up signal induced by a proton pulse with a peak to peak width of 1.6 ns

chopper. A peak to peak width of 1.6 ns for proton pulses and 1.7 ns for deuteron ones was measured with the pick up. The correct synchronisation between the chopper and buncher unit was successfully done, providing a nanosecond proton and deuteron pulsed beams. Figure 2 shows the pick up output signal induced by the nanosecond proton pulse.

3.2. Measuring a well-known neutron spectrum

The commissioning of the neutron TOF at HiSPANoS facility has consisted of the measurement of the well-known neutron field generated by the ^{7}Li(p,n)^{7}Be reaction with protons at the energy of 1912 keV. Such field has been extensively used in nuclear astrophysics since 1988[10]. In addition, in the last years there has been some experimental works performed at different neutron facilities to establish this field as a standard neutron field in astrophysics and other applications[11][12].

For this experiment, neutrons were produced when the proton pulse impinges on a thick lithium target which was placed at the end of the new n-TOF line. ^{6}Li glass detector was used for neutron detection. A flight path of 35 cm and a repetition rate of 62.5 kHz was established in this case. The pick up was used as start signal of the acquisition system, and the neutron detector signal as stop one.

For the conversion from TOF to neutron energy the complete set-up must be carefully simulated. This conversion is associated to each particular experiment. All the processes suffered by the neutrons were simulated by means of the MCNPX code[13]. The 0° neutron spectrum is very important because it contains the most energetic neutrons. In Figure 3, a comparison with the spectrum acquired at 0° and the 0° spectrum of Lederer et al.[11] (available at the EXFOR data base[14]) is shown. Neutron energy bins are 5 keV and the statistical uncertainty is lower than 2%. It can be seen clearly the good agreement between both.

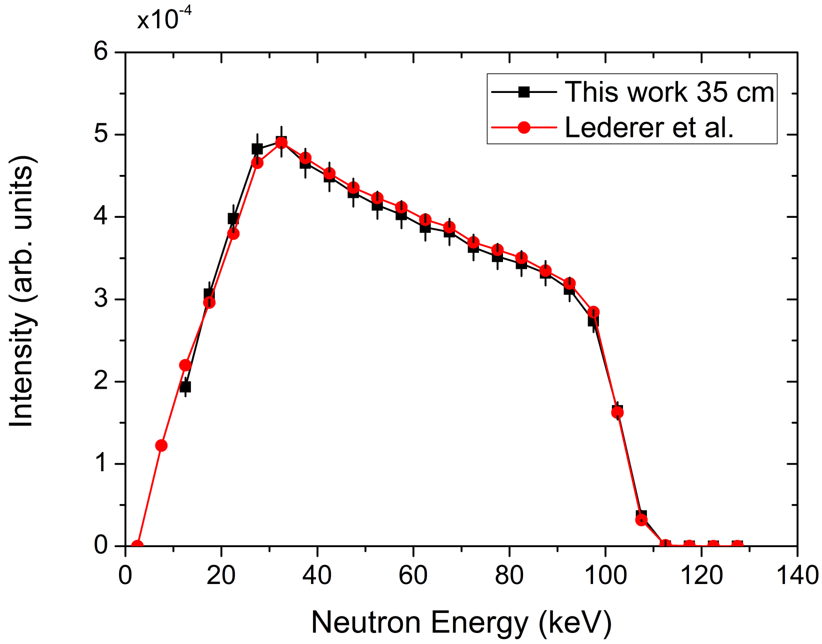

Figure 3. Experimental neutron spectrum at 0°, 35 cm flight path and repetition rate of 62.5 kHz (black line+squares) measured at HiSPANoS, compared to Lederer et al. results (line+circle)

3.3. Exploring fast neutrons TOF at HiSPANoS

After the good performance of HiSPANoS as n-TOF facility with epithermal neutrons, a study to establish the facility limits for fast neutrons was started. For fast neutron production, two different reactions were used: D(d,n)^{3}He and ^{7}Li(p,n)^{7}Be. For the first tests the influence of the neutron scattering from the walls of the accelerator hall was explored. Measurements varying the flight path were done at 0°. For neutron detection a liquid scintillator detector model BC501 from Scionix Ltd.[15] was employed. In figure 4 the normalized neutron energy spectra obtained for 1 and 2 m of flight paths are shown. The proton pulsed beam energy was 3.9 MeV. When the flight path increases, the detector signals are more affected by the neutron wall rebounds and therefore the background is higher. In order to increase the maximum flight path available for n-TOF measurements of fast neutrons some tests were performed at 90°, which demonstrated that a flight path of 4 m is achievable by minimizing the walls rebounds.

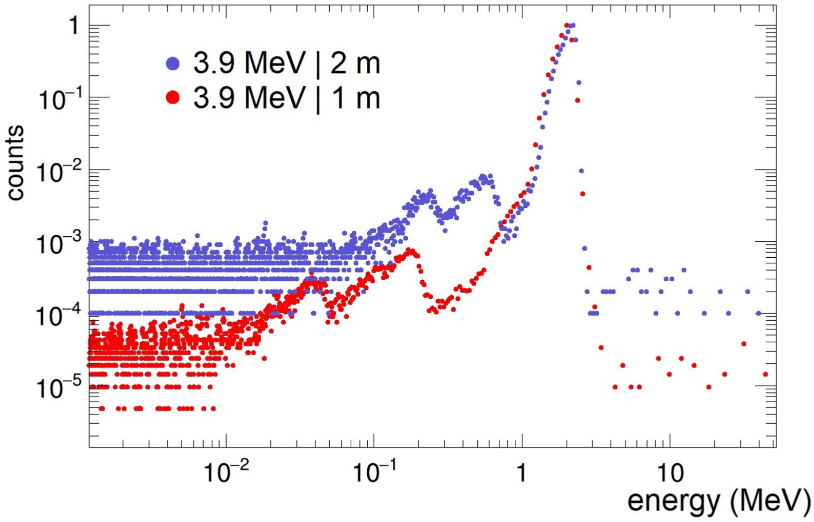

Figure 4. Experimental fast neutron energy spectra at 0°, 3.9 MeV proton pulsed beam energy and 500 kHz (repetition rate) measured at HiSPANoS for two different flight paths: 1 m (red dots) and 2 m (blue dots)

4. Conclusions

For several years, HiSPANoS is operating as the first accelerator based neutron source in Spain. In order to improve its possibilities by means of neutron time-of -flight technique, an upgrade has been realized. A pulsing system has been installed at the 3 MV tandem accelerator for pulsing ion beams, which includes a chopper designed to pulse beam with a variable repetition rate among 62.5 kHz and 2 MHz and time width from 40 ns to 250 ns. Then, the pulse beam is compressed by a buncher, achieving nanosecond proton and deuteron pulses width. The whole system has been tested and the pulse width has been measured at the end of the new experimental line dedicated for n-TOF measurements. A peak to peak pulse width of 1.6 ns for protons and 1.7 ns for deuterons has been measured with a capacitive pick up. A very well-known neutron field generated by ^{7}Li(p,n)^{7}Be reaction with protons at the energy of 1912 keV has been measured. It has been employed the n-TOF technique. The neutron energy spectrum obtained at HiSPANoS at 0° has been compared to Lederer et al data. Our results are in a good agreement, as an indication of the good performance of HiSPANoS as n-TOF facility. To explore the HiSPANoS n-TOF limits for fast neutrons several tests are being carried out with different targets productions and flight paths.

Acknowledgments

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