Establishing nTOF Tagged Cross Section Measurements at TIFR Pelletron

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Introduction

Recent advancements in theoretical and computational methods have improved our understanding of elemental abundances through nucleosynthesis, particularly highlighting the role of neutron-induced reactions in the synthesis of heavy elements via r and i processes. Nucleosynthesis calculations are sensitive to nuclear reaction rates, which are derived by folding excitation functions with the neutron spectrum at specific temperatures, often using experimental data. The active folding method depends on a neutron spectrum similar to astrophysical conditions but is sensitive to spectrum and challenges in rescaling cross sections. In contrast, passive folding requires point cross sections, which are challenging to obtain due to the lack of δ-function neutron sources; thus, quasi-monoenergetic neutrons are used. These quasi-monoenergetic neutrons have a finite energy spread that can bias resonance averaging in neutron capture. Consequently, neutron time-of-flight (nTOF) measurements are preferred for their precision. Facilities like CERN nTOF, GELINA [1], and NFS-Ganil [2]provide high-resolution data but face limitations. To overcome these challenges, the feasibility of establishing an nTOF system in existing accelerators has been explored, focusing on producing pulsed neutrons and optimizing their transport to minimize background noise. A configuration

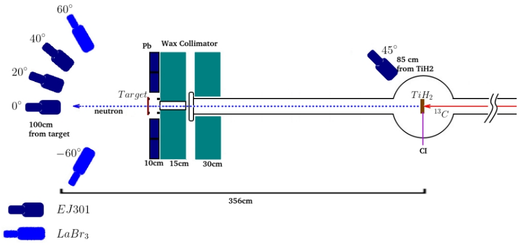

FIG. 1: Schematic of the experimental setup.

has been developed at the BARC-TIFR Pelletron Linac facility, generating a pulsed neutron beam with a time structure of 750 ps using a pulsed ^{13}C beam. Further details are presented in the following sections.

A. Materials and Methods

The neutron beam of desired quality was produced using a 75 MeV ^{13}C beam from the BARC-TIFR Pelletron linac facility, employing the ^{13}C(p,n) reaction in inverse kinematics mode.The ^{13}C beam was bunched into 750 ps width using a three-plate buncher system, with a repetition rate of 4 MHz. The neutron-producing target, collimators, and reaction target were specially designed and optimized using Geant4 simulations. The schematics of the setup is shown in Fig.1.

A thick TiH_2 target with a mass thickness of 88 mg/cm^2 was used for neutron production, fully stopping the 75 MeV ^{13}C beam and generating a neutron spectrum from 6.2 MeV to 13 MeV. Most neutrons were confined within a 5° emission cone, eliminating ambiguity in the neutron production point. However, TiH_2

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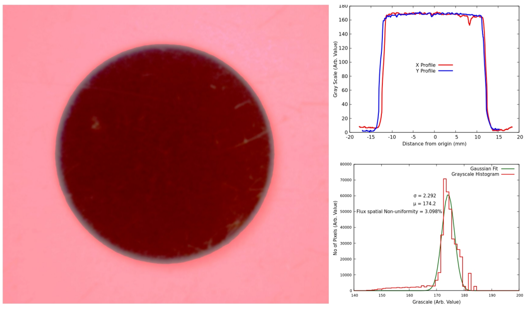

FIG. 2: Measured Neutron beam profile

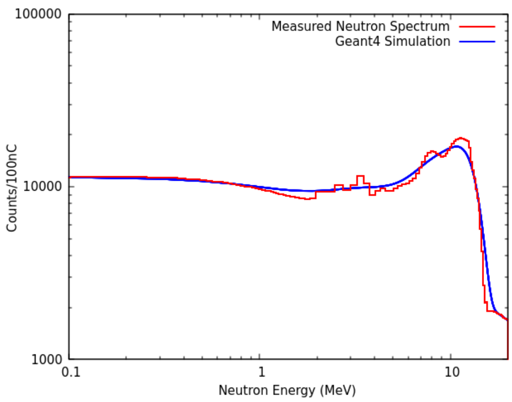

FIG. 3: Measured neutron spectrum with Geant4 simulation

targets are prone to radiation damage, which can lead to dissociation and loss of hydrogen. To mitigate this, a thick TiH_2 target was prepared under high pressure, enhancing its electrical and thermal conductivity.

The target station was located 253 cm from the neutron-producing target, with neutrons traveling through a vacuum at 2×10^{-6} mbar. A paraffin collimator, optimized via Geant4 simulations, was used to collimate the beam and reduce neutron leakage. A 3×3 $\mathbf{cm^2}$ target was placed 3 cm from the collimator, achieving a uniform beam profile, as shown in Fig.2., with a neutron flux of approximately 10^3 neutrons/keV. Beam profile was measured with Radiochromic film, to achieve spatial resolution of few μm. Neutrons were detected using EJ301 scintillators positioned at various angles, with n-γ discrimination performed using MPD-4 modules. Time Calibration of the detection system allowed for the measurement of a neutron energy spectrum from 20 keV to 13 MeV, resulting in a taggable average neutron flux of about 10^3 neutrons/keV. The neutron spectrum thus obtained is shown inFig.3. Further $LaBr_3$ scintillators are used to measure the prompt γ events.

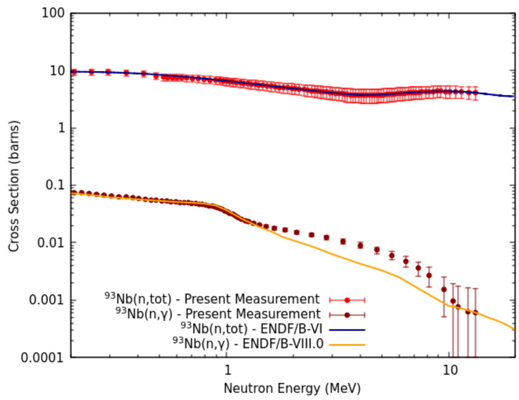

FIG. 4: Measured cross sections for (n, γ) and $(n, total)$

Results and Discussion

A high-quality white neutron spectrum was achieved with a timing precision of 750 ps and a neutron flux uniformity within 3% up to 13 MeV. Absolute cross-section measurements for ^{93}Nb(n, total) and ^{93}Nb(n, γ) reactions were performed over the energy range of 200 keV to 13 MeV.The measured cross sections were compared with ENDF/B-VIII.0 evaluations, showing good agreement across most energies, as illustrated in Fig. 4. These results provide valuable data for refining nuclear models and enhancing the accuracy of neutron-induced reaction databases.

References

[1] Patronis et al., EPJ Techn Instrum 10, 13 (2023).

[2] Ledoux et al.,EPJ Web of Conferences 146, 03003 (2017)