EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Clarification to the ISOLDE and Neutron Time-of-Flight Committee

Measurement of (n,cp) reactions in EAR1 using an enhanced experimental setup

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Abstract: We submit a letter of clarification regarding the addendum P-629-ADD-1 to the proposal. The primary objective of the proposal was the benchmarking of two innovative experimental approaches for the determination of challenging (n, charged particles) reactions. The addendum focuses on improving the results from the first measurement by reducing the significant background proton contribution, which arises from the proton recoils on the Kapton windows along the neutron beam line. To mitigate this background, through the P-629-ADD-1, we proposed two alternative configurations: a windowless setup for the annular detector and a side-on configuration for the GEMpix. Following to the INTC request, this document summarizes the conditions of the proposed experimental setup, providing additional details concerning Monte Carlo simulations.

Requested protons: 1.5×10^{18} protons on target
Experimental Area: EAR1

1 Introduction

There is a increasing request of accurate data for (n,cp) reaction for a wide range of application, from Nuclear Astrophysics to Nuclear Technologies. In particular, neutron induced reactions leading to the production of light charged particles are one of the main open question in the Nuclear Fusion Reactors, due to the damages induced to structural materials through gas production and embrittlement. We are developing two detector setups dedicated to (n,cp) reactions within the n_TOF collaboration: an annular neutron Transmutation-Doped (nTD) silicon and a GEMpix detector.

The first setup is based on a signle stage double-sided stripped neutron-transmuted silicon detector and the use of Pulse Shape Analysis (PSA) for the identification of charge particles. This is the first application of PSA at a neutron facility, while the segmentation of the detector will allow to measure double-differential cross sections. In parallel to the silicon detector, for the first time a GEMpix is used to measure neutron induced cross sections. More specifically, the GEMpix discriminates charge particles on the basis of their tracks morphology, investigating the energy range from 0.5 to 2 MeV, difficult to access with other detectors.

The performances of the two detectors were investigated in 2023 with the approval of the initial proposal INTC-P-629[1], aiming to measure the ^{12}C(n,cp) cross sections as *poof-of-principle* of the apparatus and analysis techniques. Both detectors showed great responses, confirming the possibility to apply them to measure (n,cp) cross section. Nevertheless, the physics results are affected by a relevant proton background arising from the material present along the beam line. The sources of background were identified by detailed Monte Carlo simulations using GEANT4 and FLUKA simulation toolkits [2, 3]. The same simulation models and packages were used to define the proposed mitigation strategy and its results.

On the basis of the results, in the addendum P-629-ADD-1[4] we request additional beam time to repeat the measurement in low-background conditions and produce more accurate results.

2 Answers to the Questions of the INTC

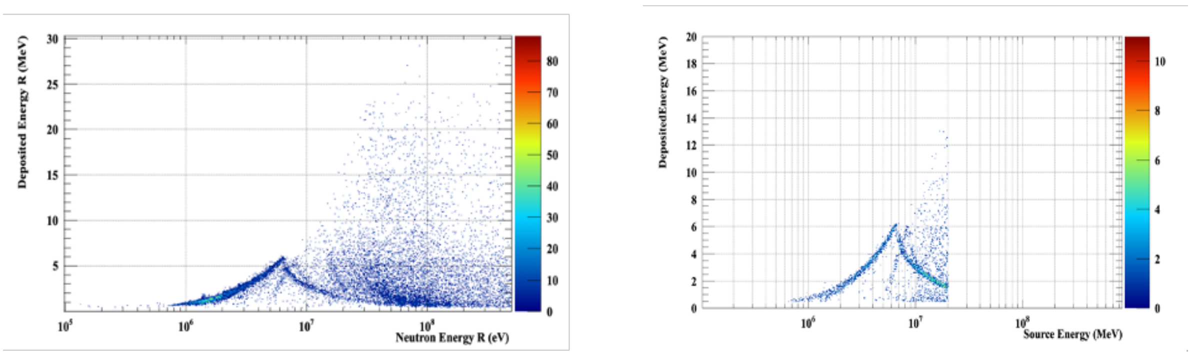
The Committee requests a letter of clarification that includes a detailed Monte Carlo simulation to account for all potential background sources. Additional mitigation strategies should also be presented if necessary.

2.1 nTD annular Detector

This section provides a summary and clarification of the performance of the silicon detector in EAR1 at the n_TOF facility. Specifically, it outlines the expected improvements from a "windowless" measurement as proposed in the addendum. For this purpose, detailed Geant4 MC calculation were performed. The experimental results using a silicon detector in two configurations: (a) with no sample ("empty") and (b) with a carbon sample, have the following characteristics:

1. **Detector Performance**: The silicon detector demonstrated excellent functionality up to several hundreds of MeV in neutron energies, fully accomplishing the purpose outlined in the proposal. The particle discrimination based on pulse characteristics and particle energy deposition patterns was confirmed.

2. **Energy Deposition Structures**: Even with the "empty" configuration, the proton recoils induced from the chamber window and the beam line end-cup window created a considerable background that was nicely reproduced from the simulations. This is shown in the next two figures.



(a) (b)

Figure 1: Both figures represent the 2D matrix of the deposited energy versus neutron energy for the empty target: (a) experimental results and (b) using Geant4 toolkit.

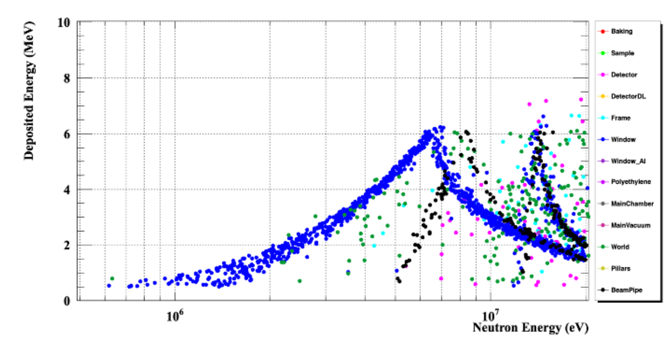


Figure 2: Simulated protons deposited energy versus neutron energy for the adopted configuration in the previous measurement. As can be seen, the large fraction of protons are generated from the chamber window and beam-line window.

3. **Simulation and Background**: In particular these simulations confirmed that the dominant background contribution originates from the (n,p) scattering in the

kapton windows along the beam line. As can be seen in Figure 2, three distinct proton groups were identified in the "empty" configuration: protons produced in the chamber window, protons from the beam-line window, and protons from both windows passing through the sample holder.

4. **Simulation in windowless configuration**: In Figure 3, is clear that adopting a windowless configuration eliminates the proton background generated by the kapton windows.

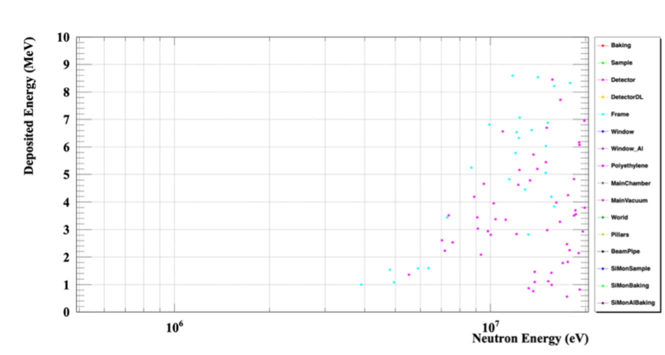


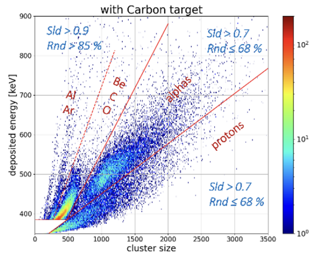
Figure 3: GEANT4 simulation results for the windowless configuration. By comparing with Figure 2, the dominant background component of recoiled protons coming from the beam-line windows is removed.

2.2 GEMpix detector

This section provides further information on the results obtained with GEMpix detector at n_TOF, and presents accurate FLUKA MC simulations on the experimental tests performed in 2023. In order to improve the discrimination capabilities of this detector, also reducing the background contributions, a side-on geometry was proposed as an alternative approach. FLUKA MC simulations demonstrate the expected improvements in comparison to the used head-on geometry.

1. **Detector performances**: In the test performed in 2023 in EAR1, the target was a 400 µm graphite sheet placed outside the detector, precisely in front of the entrance mylar window, at a distance of 1 mm. Unfortunately, with this set-up were not possible to insert the target inside the chamber. By this configuration, the most significant results were obtained in the energy range from 10 keV to 10 MeV, and the capability of particle discrimination has been accomplished by measuring the deposited energy of tracks and performing a track morphological analysis. It was carried out by defining a set of parameters such as: cluster size, ToT volume (ToTv), Solidity (Sld) and Roundness (Rnd). By applying specific cuts on these parameters, the detector demonstrates its capability to identify at least three particle groups.

   The presence of the graphite target produces an enhancement of detected particles, around 8 % more than the background recorded particles. Simulations demonstrated that the main sources of background come from protons by Mylar window and epoxy



particles	without target	with target
protons [×10³]	8.52 ± 0.09	8.98 ± 0.09
alphas [×10³]	11.2 ± 0.1	12.2 ± 0.1
heavy ions [×10³]	13.3 ± 0.1	14.4 ± 0.1
Total [×10³]	33.0 ± 0.2	35.6 ± 0.2

Figure 4: Matrix for particle identification (left) and table reporting the number of particles measured with and without the carbon target.

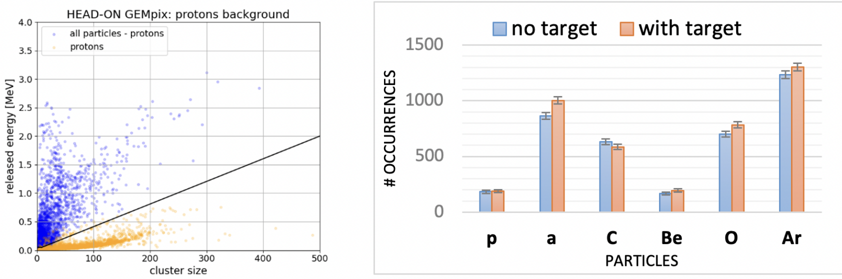


Figure 5: Matrix for particle identification obtained by the FLUKA simulation (left) in the old configuration and comparison of the particles with and without target (right).

frames of the chamber, as well as by Oxygen and Argon ions due to the gas mixture filling the active region. Simulations demonstrate that this background can be significantly reduced by means of a suitable cut in the 2D plot deposited energy vs cluster size.

MC simulation of the experimental set-up are depicted in Figure 5, the target increment the detected particles of 6.8 $\pm$ 0.2 %, substantially in agreement with the experimental results. In particular, it has been found a slight increase on alpha particles and ions like Be, O and Ar.

2. **The new proposed configuration**: side-on GEMpix chamber: In order to improve the discrimination capabilities of this detector and further reducing the background contribution, a new GEMpix chamber detector is under construction. It will be based on a side-on geometry, with a larger active volume of 1 cm and two side windows of thickness 400 µm made of Alumina (Al2O3). In this configuration, as depicted in Figure 6, the target will be placed just after the entrance window inside the gas volume at the beginning of the active volume. In addition, the TPX1 quad will be replaced by a TPX3 quad that can also perform 3D track reconstructions, thus to improve the particle identification capability and extend the sensitivity of the neutrons energy range.

   In order to reduce the proton background coming from the epoxy glass structures, the drift frame will be made of stainless steel. Moreover, a 2 mm sheet of stainless steel will be inserted inside the chamber, as a shielding for protons coming from the GEM Kapton and the cathode PCB. Simulations demonstrated that with this

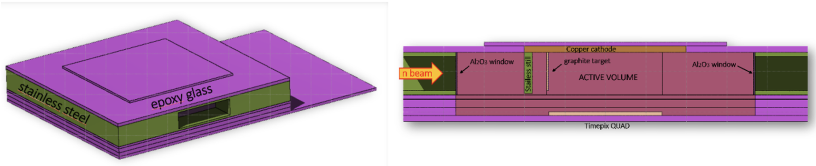


Figure 6: Sketch of the GEMpix side-on configuration.

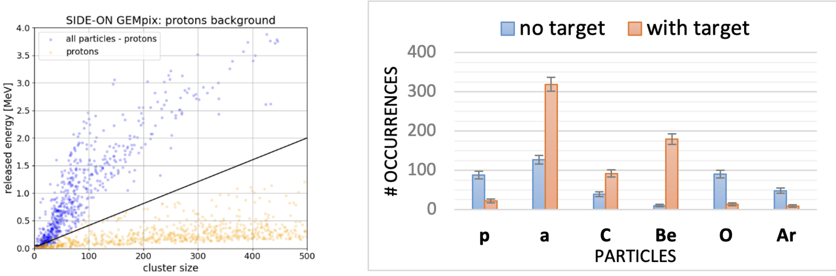


Figure 7: Simulated Matrix for particle identification in side-on configuration (left) and comparison of the expected counts with and without target.

configuration the proton background can be reduced by a factor 6.

3. **Simulations with side-on GEMpix**: In order to evaluate the background and the contribution of the particles coming from the target, simulations with the same neutron beam of the test in EAR1 have been performed and presented in Figure 7. The same cut applied for the head-on configuration has also been applied to this geometry. Given that the target is placed on one side, among the tracks reconstructed in the active volume, only those having one endpoint on the target area have been considered.

   The present results provide two important information: the presence of the target inside, reduces the background and produces a significant increment of the tracks due to the particles from the target. It has been calculated an increase of more than 60% for alphas particles, C ions and Be ions.

3 Conclusions

Based on the analysis of the first measurement, the silicon detector is considered as an innovative and reliable apparatus dedicated to particle detection and identification. This development is expected to create new avenues of research within the n_TOF facility. With further improvements, like the proposed windowless configuration, its performance will be further optimized.

The use of a side-on configuration for the GEMpix with the target inside is expected to provide a significant improvement, due to the large increase in particles coming from neutron-target interactions that will be detected, and to the reduction of the background. The new measurement in EAR1 will allow to definitively validate this configuration, in order to plan the first experiments with this detector.

The requested number of protons for this additional measurement is: 1.5×10^{18}

References

[1] L. Cosentino et al., Measurement of (n, cp) reactions in EAR1 and EAR2 for characterization and validation of new detection systems and techniques, INTC-P-629 (2022).

[2] https://geant4.web.cern.ch/

[3] https://fluka.cern/

[4] S. Goula et al., Measurement of (n,cp) reactions in EAR1 using an enhanced experimental setup, INTC-P-629-ADD-1 (2024).