EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Addendum of the INTC-P-629 to the ISOLDE and Neutron Time-of-Flight Committee

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

October 2, 2024

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CERN-INTC-2024-057 / INTC-P-629-ADD-1
02/10/2024

Abstract: We propose to repeat the ^{12}C(n, cp) measurements at the n_TOF facility at CERN. The measurement will be held in the EAR1 experimental hall with different conditions, aiming to optimise both the detection setup and data collection process. By fine-tuning the experimental conditions, we aim to achieve more accurate results minimizing all the up-to-now known background contribution.

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

1 Introduction

This addendum reports on the INTC-P-629 approved proposal [1], concerning the characterisation of two detection setups dedicated to studies of neutron induced reactions, where one of the products is a light charged particle (lcp): an annular neutron Transmutation-Doped (nTD) silicon and a GEMpix detector. The nTD detector is a single stage double-sided stripped one, chosen to determine the angle of the reaction products and measure the double differential cross sections. A Pulse Shape Analysis (PSA) technique is applied to discriminate the reaction products, through an innovative analysis of the charge collection [2]. This experiment campaign marks the first implementation of the PSA technique at a neutron facility, representing the "proof-of-principle" experiment, to validate both the experimental approach and the analysis procedure. In addition, a GEMpix detector is employed for the first time to measure neutron-induced reactions. By exploiting the particle track morphology, the GEMpix detector is able to discriminate light charged particles [3] from 0.5 to 2 MeV, a range difficult to explore with other diagnostic systems.

Based on the results obtained from the data analysis conducted so far, we request additional beam time to implement specific improvements in the experimental setup that will lead to cleaner background conditions.

2 Detectors and read-out electronics

2.1 nTD Annular detector

The initial campaign with the nTD annular detector was conducted in the first experimental area (EAR1) of the n_TOF facility in September 2023 [4]. The setup and beam-line configuration adopted is shown in Figure 1. Starting from the concrete wall on the left, the neutrons travel through a carbon-fiber vacuum chamber hosting the neutron flux Silicon based Monitor (SiMon-1) [5]. This setup is followed by a steel bellow and a carbon-fiber pipe that is 40 cm long and 6 cm diameter, terminating in a 100 µm thick kapton window. Beyond this, an air gap of 30 cm is present leading to the aluminum chamber that hosts the annular detector. The chamber's entrance window consists of a 25 μm kapton foil coated by 400 nm aluminization.

During the experimental campaign many samples were employed, with the majority of the beam time dedicated to the 250 μm graphite sample to study neutron-induced reactions on ^{12}C.

2.2 GEMpix detector

The GEMpix detector [6] is a small triple-GEM chamber with a Timepix1 (TPX1) quad readout, consisting of a matrix of 2×2 TPX1 chips [7]. A TPX1 quad covers a surface of 28×28 mm^2 with 512×512 pixels, each with a dimension of 55×55 μm^2. It can operate separately in three different modes: counting, charge (Time over Threshold mode) and time (Time of Arrival mode). In all three cases, the acquisition is frame-based: the pixel matrix acquires in a given time window and integrates all over the acquisition time.

GEMpix has been proposed for the measurements of charged particles with kinetic energy from 0.5 to 2 MeV. The first prototype was realized in its standard configuration: a 15 μm thick aluminized mylar window and a 4.6 mm thick active gas volume with $ArCO_2$ (70/30) gas mixture.

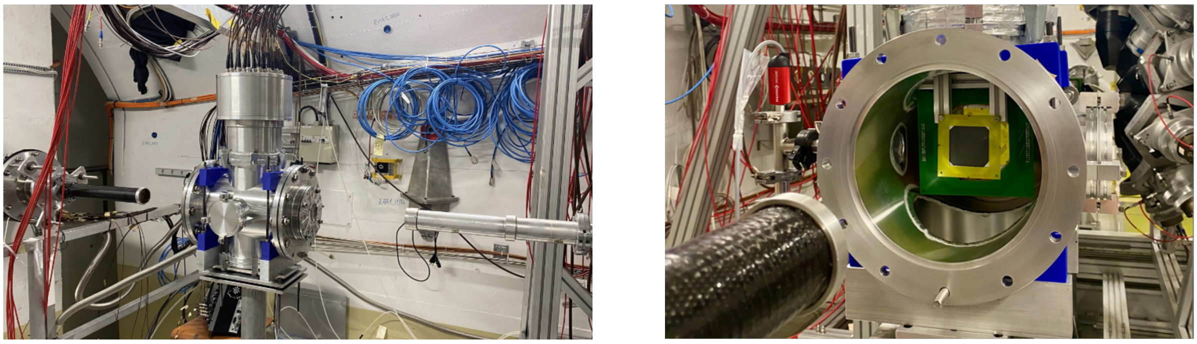

(a) (b)

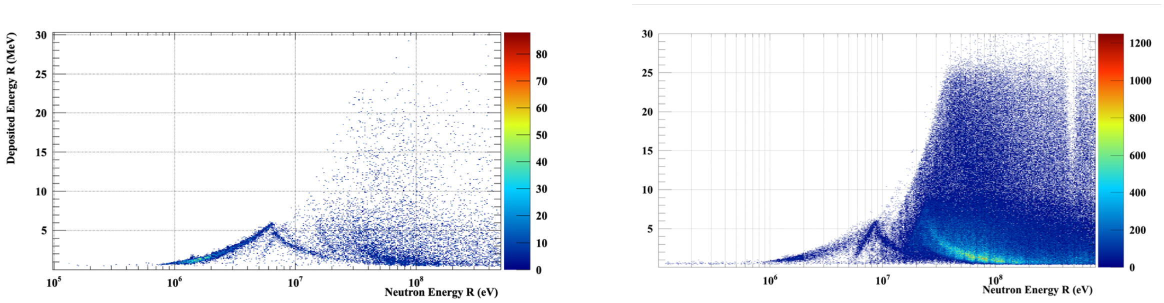
Figure 1: Experimental setup in EAR1: (a) the beam-line adopted for the (n, lcp) measurements using an annular silicon detector, and (b) the inside of the chamber, where each target is positioned upstream relative to the silicon detector.

3 Preliminary results

3.1 nTD annular

Following the first experimental campaign in EAR1, the results from the preliminary analysis are depicted in Figure 2, illustrating the deposited energy versus the neutron energy in two configurations: (a) without a sample (or "empty") and (b) with a carbon sample. As it is depicted, the silicon detector operates successfully up to several hundreds MeV (corresponding to a few hundreds of ns), meeting the objectives of the proposal; further analysis details are available in [8]. In the left panel, a well-defined structure arises starting at around 1 MeV in neutron energy and reaching a maximum energy deposition of 6 MeV. Similar structures are observed at higher neutron energies, representing a relevant source of background. Based on the rise time values of these pulses, this structure is identified as Z=1, specifically protons, most likely produced by (n,p) scattering in the the kapton windows present along the beam-line. In Figure 2(b), the same plot is represented for the carbon sample. As expected, a higher number of events is observed, in particular above 6 MeV, corresponding to the opening of the ^{12}C(n,a) reaction channel. It is important to note that the background introduced by the windows is more broadened and shifted to slightly higher neutron energies due to the presence of the carbon sample, which introduces an additional energy loss.

A limit of the used configuration is due to the background introduced by the windows, that was validated through detailed Geant4 Monte Carlo simulations, and cross-checked with SRIM calculations [9]. In Figure 3 the simulated deposited energy versus neutron energy from protons with the "empty" sample is shown. Three proton-groups



(a)

(b)

Figure 2: Both figures represent the 2D matrix of the deposited energy versus neutron energy for two cases: (a) without sample or "empty" and (b) with carbon targets.

are numbered: the first one refers to the protons produced in the chamber window, passing though the hole of sample holder and reaching the silicon detector, maintaining their initial energy. The second group, starting at around 4-5 MeV, corresponds to protons generated in the beam-line window and degraded mainly from the air gap between the pipe and chamber window. The third group located above 10 MeV is due to the protons crossing the sample holder and coming from both windows. The simulations are in very good agreement with the matrix of Figure 2(a), where the first two structures are well defined. These protons are impinging on the detector with a wide variety of angles, imposing additional difficulties for applying the PSA technique for particle identification. According to the simulations, adopting a windowless configuration would eliminate the main proton contribution produced by the kapton windows.

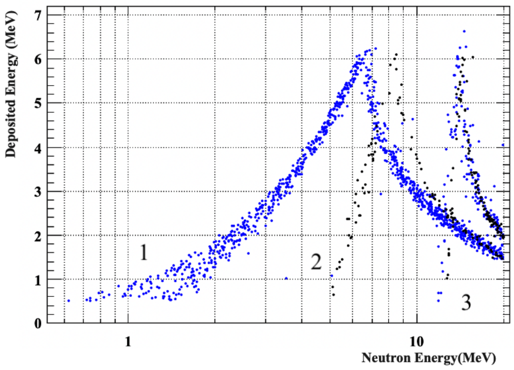


Figure 3: Simulated protons deposited energy versus neutron energy. The protons are generated from the chamber window and beam-line window. The origin of the three group of protons is explained in the text.

3.2 GEMpix detector

A sample of graphite with thickness of 500 μm and an area of 5×5 cm^2 was used as target and placed outside the GEMpix chamber in front of the entrance window. By applying an appropriate software delay and a minimum time window of 100 μs, energy spectra from about 10 keV until to a maximum of 20 MeV were selected with the goal to identify the charged particles produced by well-known reaction channels of carbon, in particular, the ^{12}C(n,α)^{9}Be and ^{12}C(n,3α) reactions and the carbon recoil.

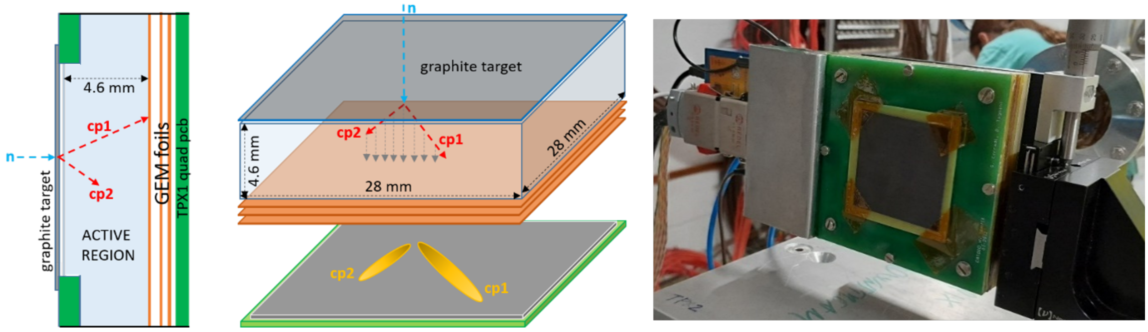


Figure 4: GEMpix layouts with the graphite target outside the detector window and a photo of the installation in the n_TOF EAR1, downstream respect to the annular detector.

The interaction of a particle in the active volume produces a track made by a cluster of pixels, where each one measures the released charge after the GEM amplification (Figure 4). In particular, by applying specific cuts on the solidity (Sdl) and roundness (Rnd) parameters, it is possible to identify at least three regions in the plane of Time over Threshold (ToT) versus Cluster Size (CS) as shown in Figure 5: the ion, alpha, and proton regions.

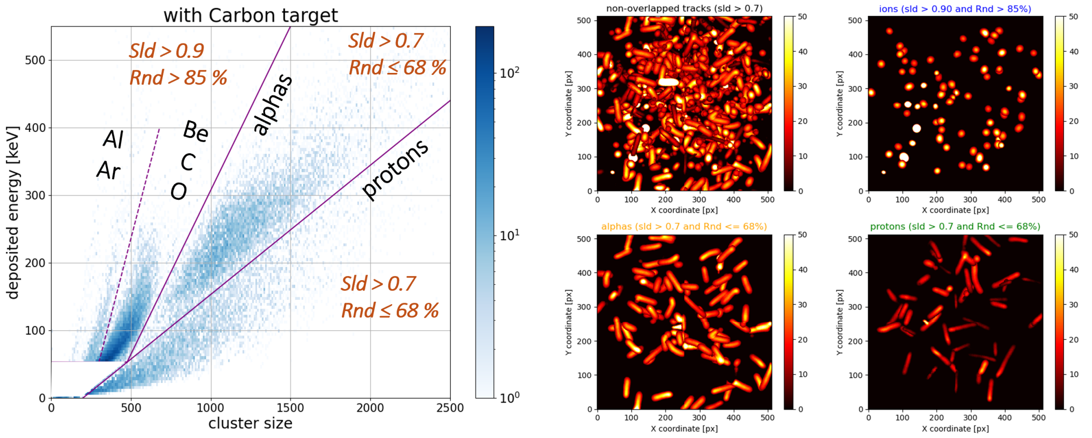


Figure 5: 2D histogram obtained with the Carbon target after applying appropriate cuts on the Sld and Rnd parameters and a corresponding visualization of the observed tracks for all particles together, alphas, protons and ions after 30 triggers.

The fraction of discriminated tracks among all the non-overlapped ones is about 18%. As observed, different populations have been identified: alphas, protons and ions contribution. In this last population, more than one family can be distinguished and, according to some preliminary Monte Carlo simulations, the corresponding ions have been assigned. The difference between the two configurations with and without the carbon target is not significant. It has been observed that when the target is present, the number of discriminated particles varies about 8 %, primarily due to the contribution of alphas and ions, as shown in the table where a quantification has been provided.

Configuration	protons [$\times 10^3$]	alphas [$\times 10^3$]	heavy ions [$\times 10^3$]	total [$\times 10^3$]
Carbon sample	8.98 ± 0.09	12.2 ± 0.1	14.4 ± 0.1	35.6 ± 0.2
No sample	8.52 ± 0.09	11.2 ± 0.1	13.3 ± 0.1	33.0 ± 0.2

These results show that this configuration with the target outside heavily affects the measurement of the produced particles. In particular, Fluka Monte Carlo simulations demonstrated that the main contribution coming from the background is due to the mylar window composed of Hydrogen (4.2%), Carbon (62.5%), and Oxygen (33.3%). Nevertheless, the application of GEMpix in this type of experiments is a novelty and these first results demonstrate its optimal ability to identify different types of charged particles at low energies.

4 Conclusions

A first measurement to validate the two new detection setups has been successfully carried out at the n_TOF facility in September 2023. Preliminary results indicate that the nTD silicon detector met the desired performance in terms of neutron energy and particle discrimination for different low Z. Nevertheless, a relevant source of background due to the n-p scattering taking place in the beam windows affects the present data. While a background subtraction method strongly based on MC simulations may be applied, it would introduce substantial uncertainties. Therefore, we propose to extend the investigation by integrating the current data with a windowless configuration, directly coupling the aluminum chamber with the beam pipe. By eliminating this background component and reducing the angles of the incoming particles, particle identification will be enhanced, making the overall bench-marking of the technique more effective.

The GEMpix operated with the carbon target outside the detector window. Although this is sub-optimal, it allowed for the assessment of its potential for measuring the ^{12}C(n, cp) reaction products. The preliminary analysis of the experimental results demonstrates its ability to discriminate among protons, alpha particles, and ions, in an energy range that extends from 0.1 to 2 MeV. The use of the GEMpix chamber for this purpose represents a significant advancement, and these preliminary results will be valuable for designing a more appropriate geometry to reduce background contributions, especially from the detector window. A new prototype is under construction with a side-on geometry and a Timepix3 [10] quad read-out. This new geometry will increase the active volume by at least 10 mm, allowing for the target to be inserted inside and perpendicular to the GEM foils. Additionally, the use of Timepix3 will enable simultaneous measurement of charge and time with the possibility of a 3D reconstruction of the tracks in the active gas volume.

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

References

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

Please describe here below the main parts of your experimental set-up:

Part of the experiment	Design and manufacturing
SiMON, Annular nTD detector, GEMpix	☒ To be used without any modification
If relevant, describe here the name of the flexible/transported equipment you will bring to CERN from your Institute [Part 1 of experiment/ equipment]	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[Part 2 of experiment/ equipment]	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[insert lines if needed]	

HAZARDS GENERATED BY THE EXPERIMENT
Additional hazard from flexible or transported equipment to the CERN site:

Domain	Hazards/Hazardous Activities		Description
Mechanical Safety	Pressure	☐	[pressure] [bar], [volume][l]
	Vacuum	☒	10^{-3} mbar
	Machine tools	☐	
	Mechanical energy (moving parts)	☐	
	Hot/Cold surfaces	☐	
Cryogenic Safety	Cryogenic fluid	☐	[fluid] [m3]
Electrical Safety	Electrical equipment and installations	☒	annular: [170] [V]
	High Voltage equipment	☒	GEMpix: [4] [kV]
Chemical Safety	CMR (carcinogens, mutagens and toxic to reproduction)	☐	[fluid], [quantity]
	Toxic/Irritant	☐	[fluid], [quantity]
	Corrosive	☐	[fluid], [quantity]
	Oxidizing	☐	[fluid], [quantity]
	Flammable/Potentially explosive atmospheres	☐	[fluid], [quantity]
	Dangerous for the environment	☐	[fluid], [quantity]
Non-ionizing radiation Safety	Laser	☐	[laser], [class]
	UV light	☐	
	Magnetic field	☐	[magnetic field] [T]
Workplace	Excessive noise	☐	
	Working outside normal working hours	☐	
	Working at height (climbing platforms, etc.)	☐	
	Outdoor activities	☐	
Fire Safety	Ignition sources	☐	
	Combustible Materials	☐	
	Hot Work (e.g. welding, grinding)	☐	
Other hazards			