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Letter of Intent ISOLDE and Neutron Time-of-Flight Committee

Commissioning of a new sTED setup with 27 modules for capture measurements at CERN n_TOF EAR2

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Abstract:

The segmented Total Energy Detector (sTED) consisting of 9 compact C_6D_6 modules has been built, commissioned and used in capture measurements at n_TOF EAR2. The commissioning was performed in 2022 in a dedicated campaign, showing a correct performance for neutron energies up to at least 400 keV. After its commissioning, the detector has been already used in five capture cross-section measurements. We have recently acquired 18 additional sTED modules, for building an array of 27 detectors. This new sTED setup with all the modules needs to be tested and commissioned at EAR2. The well-known ^{197}Au(n,γ) cross-section will be used for this purpose, in combination with other samples, for determining the levels of the different backgrounds in a more efficient array.

Requested protons: $7.0 \cdot 10^{17}$ protons on target
Experimental Area: EAR2

1 Introduction and motivation

The neutron time-of-flight facility n_TOF at CERN is focused on performing measurements of neutron-induced reaction cross-sections of interest to nuclear technologies, astrophysics, and other applications. The facility uses as a neutron source a massive lead spallation target coupled to the CERN-PS 20 GeV/c proton beam [1] and is endowed with three experimental areas: Experimental ARea 1 (EAR1) with $\sim 8 \cdot 10^5$ neutrons per nominal pulse of $\sim 8 \cdot 10^{12}$ protons, located at ∼185 m horizontally from the spallation target [2], Experimental ARea 2 (EAR2) with $\sim 4 \cdot 10^7$ neutrons per pulse, located vertically at ∼20 m from the spallation target [3], and the recent NEAR station with $\sim 4 \cdot 10^9$ neutrons per pulse, at ∼3 m from the target currently under commissioning [4, 5]. EAR2 was constructed to carry out challenging cross-section measurements with low mass samples, reactions with small cross-sections and/or highly radioactive samples. As evident from the numbers above the neutron flux in EAR2 is ∼50 times higher than in EAR1 and the neutrons take ∼10 times less time to arrive at the experimental area. As a consequence, the signal-to-background ratio is increased by a factor of ∼500 when considering the constant room background or the radioactivity of the samples. Accordingly, the counting rate in the detectors is also increased by approximately the same factor which implies considerable experimental challenges.

Capture cross-section measurements with C_6D_6 detectors have been performed successfully at n_TOF EAR1 for about 20 years [6, 7]. In most cases, the analysis of the C_6D_6 detector data was done by applying the Pulse Height Weighting Technique (PHWT) [8, 9, 10], which allows the C_6D_6 to mimic the behavior of an ideal Total Energy Detector (TED) [11]. The measurements were mainly performed with commercial BICRON detectors (0.621 liters of C_6D_6) [12] and self-made and customized detectors with carbon-fiber housing (1.0 liters of C_6D_6) [13]. The photomultipliers and the sizes of the two detectors were not optimized for the high count rates at EAR2. The measurements performed with these detectors have considerable pile-up effects and are affected by gain shifts in the detectors due to the counting rate and the prompt spallation *flash* of ultra-relativistic particles and γ-rays [14]. These corrections made almost impossible to perform capture cross-section measurements above a few keV at EAR2 with these detectors.

To overcome these limitations, the sTED [14] has been developed. It consists of an array of small active volume C_6D_6 modules coupled to photomultipliers optimized for high counting rate applications. In 2022 a dedicated campaign was performed with three sTED modules to validate the detector. The excellent results achieved are detailed in Ref. [14]. Due to his good performance, the detector was used to perform capture measurements at EAR2 with a configuration consisting of 9 sTED modules. Recently, 18 additional sTED modules have been acquired for increasing the detection efficiency of the capture system at EAR2 by a factor of ∼3, thus allowing to perform capture cross-section measurements with lower mass samples and/or with smaller cross-sections. The purpose of this LOI is to commission the new modules and setup with the neutron beam.

2 The sTED detector

The sTED has been specifically designed to improve the capture detection setup at EAR2, following the simple idea of reducing the counting rate per module by about one order of magnitude, while keeping the same efficiency of large volume C_6D_6 detectors with an array of a larger number of smaller modules. Each sTED module has an active volume of 0.044 liters. In addition, small photomultipliers optimized for high counting rate applications are used to provide additional robustness.

Figure 1: Picture of one sTED module.

The linearity and the energy resolution of the modules were characterized with six γ-ray sources: ^{133}Ba, ^{137}Cs, ^{207}Bi, ^{60}Co, ^{88}Y and AmBe using the Compton edge clearly visible in the spectra. The modules show a linear behavior and have a resolution comparable to previous C_6D_6 detectors. The analysis of the sTED capture data is carried out with the Pulse Height Weighting Technique (PHWT) [8, 9, 10]. In Ref. [15], it is shown that the technique can be applied to an array of modules as a whole, as long as the efficiency of each module is low. For the sTED, the efficiency of each module is lower than 1% for the typical capture cascades. The accuracy of the PWHT requires knowing with high accuracy the detector response to γ-rays. For this reason, the detector has been simulated in high detail with Geant4. Fig. 2 shows the excellent reproduction of the experimental response functions to different γ-ray sources achieved by Monte Carlo simulations.

The most reasonable method to commission the sTED is by performing a capture experiment and compare the results with the evaluated cross-section data. The well-known ^{197}Au(n,γ) cross-section is correctly suited for this purpose and hence has been used extensively at n_TOF as a reference and for calibration purposes, as it was the case for the commissioning in 2022.

Fig. 4 shows the comparison of the evaluated and experimental ^{197}Au capture yields (i.e. analogous to the capture cross-section) for the sTED setup used in 2022 (left panel in Fig. 3). As it can be seen, the evaluated data for ^{197}Au are very well reproduced until at least 400 keV. Beyond that value, the experimental data include the contribution of the inelastic channels and, at higher energies, of the prompt spallation *flash*.

Due to its very good performance, the sTED has been used in the capture cross-section measurements of ^{79}Se, ^{94}Nb, ^{160}Gd and ^{94,95,96}Mo [17, 18, 19, 20, 21] and would be used to measure the capture cross-section of ^{209}Bi, ^{146}Nd, and ^{28,29}Si. The setup used consists of nine sTED modules and can be seen in the middle panel of Fig. 3.

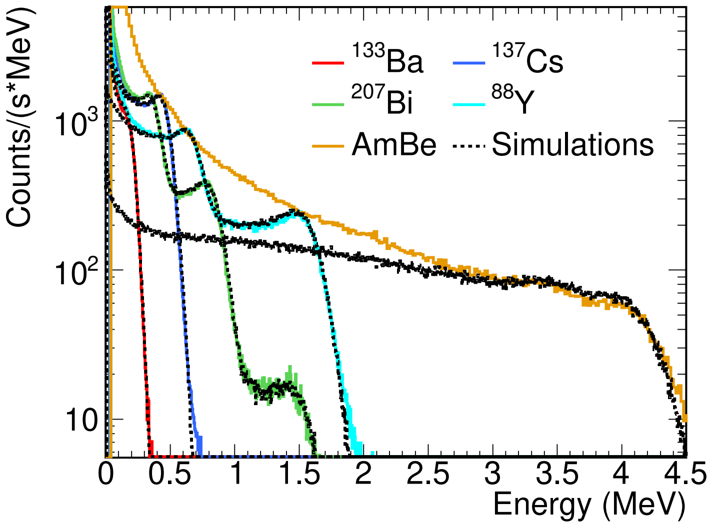

Figure 2: Experimental deposited energy spectra obtained with an sTED module for various γ-ray sources (^{133}Ba, ^{137}Cs, ^{207}Bi, ^{88}Y and AmBe) compared with Geant4 simulations.

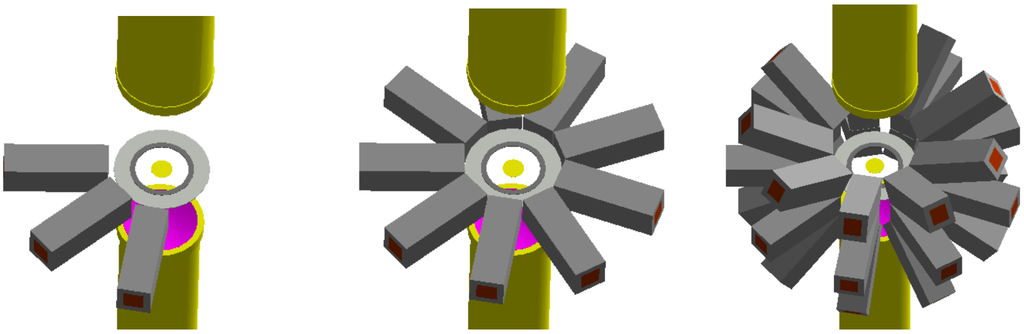

Figure 3: Schematic views of various sTED setups simulated in Geant4. At the left the setup with 3 modules, at the center with 9 modules and at the right with 27 modules.

3 Working plan

The 27 modules setup has the clear advantage of increasing the efficiency by almost a factor of 3 compared to the present setup with 9 modules. A possible configuration of the array is shown in the right panel of Fig. 3. In this configuration, the modules are placed at different angles with respect to the neutron beam direction, hence providing additional information on the possible anisotropic γ-ray emission. However, the use of this setup may have some negative aspects. A larger number of modules increases the dead material and may modify the detector response to γ-rays and increase the background. In particular, the beam-on background, defined as the background with no sample on the beam, and the scattered neutron background, produced when neutrons scattered by the samples are detected directly or indirectly in the sTED module, can increase.

We propose a commissioning at n_TOF EAR2 for ensuring the correct performance of the 27 module sTED and quantifying the background levels. This setup will be mounted

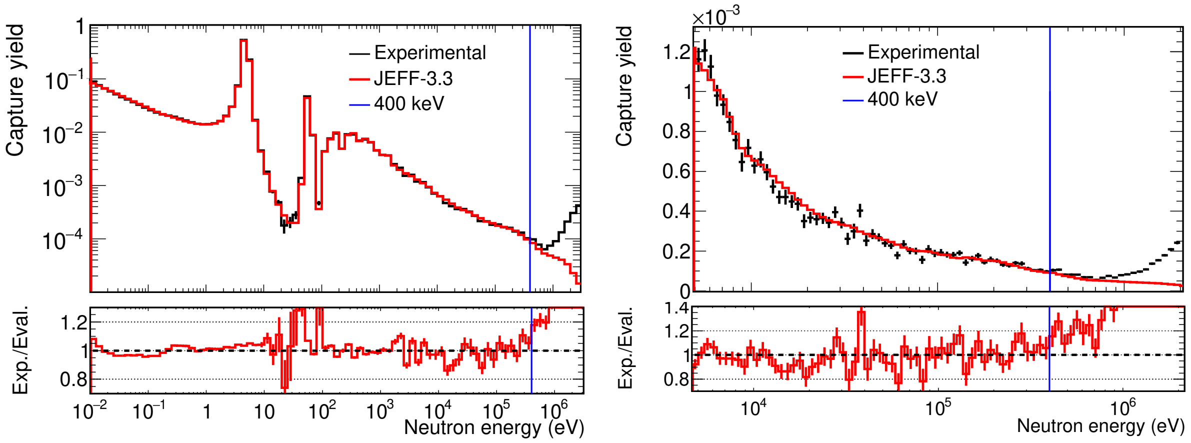

Figure 4: sTED experimental capture yield obtained with a ^{197}Au sample (Experimental) compared with the yield obtained from the JEFF-3.3 nuclear data library (JEFF-3.3) [16]. The top figure has ten bins per decade and the bottom one thirty bins per decade. The vertical blue line indicates the neutron energy of 400 keV. In the bottom panels, the ratios between the two yields are presented. The error bars consider only the uncertainties due to counting statistics.

in place and calibrated with γ-ray sources, for assuring the linearity and resolution of the new modules and characterizing the response, which will be compared with Geant4 simulations, as shown in Fig. 2 for one sTED module. Measurements with the neutron beam will be carried out with different samples, to determine the levels of the different background components and to obtain the reference ^{197}Au capture cross section. The measurements will be performed with the setups with 9 and 27 modules, for comparison between previous and actual experiments. The measurements will be:

- **Empty position**, with the detectors mounted and no sample in the beam.
- **Carbon sample**, for determining the background due to scattered neutrons.
- **Lead sample**, for determining the background due to scattered in-beam γ-rays.
- ^{197}**Au**, for obtaining the reference capture cross-section.

The requested protons for each sample are given in Table 1. The number of protons for the background measurements have been estimated to have enough statistics to compare the results of the two setups module by module. Concerning the measurement of ^{197}Au, the number of protons have been chosen to have statistics similar to the ones obtained in the previous commissioning.

Summary of requested protons: 7·10^{17}

	9-modules	27-modules
Empty	$1{\cdot}10^{17}$	$1{\cdot}10^{17}$
Lead	$0.75{\cdot}10^{17}$	$0.75{\cdot}10^{17}$
Carbon	$0.75{\cdot}10^{17}$	$0.75{\cdot}10^{17}$
^{197}Au	-	$2{\cdot}10^{17}$
Total	$7{\cdot}10^{17}$	

Table 1: Beam time request and distribution.

4 Acknowldegments

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

Part of the experiment	Design and manufacturing
C6D6 setup at EAR2 with 27 sTED modules	To be used without any modification
Stable natural samples of carbon, lead and gold	Standard equipment supplied by a manufacturer

HAZARDS GENERATED BY THE EXPERIMENT
Additional hazard from flexible or transported equipment to the CERN site:
Only the two stable samples of Ta would be transported to CERN the detectors are already at the n_TOF facility.