
Proceedings Paper:

(2024) The n_TOF facility at CERN. In: Cerutti, Francesco, Kawano, Toshihiko, Marin, Stefano, Pujol, Francesc Salvat and Talou, Patrick, (eds.) 16th Varenna Conference on Nuclear Reaction Mechanisms, NRM2023. 16th Varenna Conference on Nuclear Reaction Mechanisms, NRM2023, 11-16 Jun 2023 EPJ Web of Conferences . EDP Sciences , ITA

https://doi.org/10.1051/epjconf/202429212002

EPJ Web of Conferences **292**, 12002 (2024) https://doi.org/10.1051/epjconf/202429212002
NRM2023

The n_TOF facility at CERN

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Abstract. The neutron Time-of-Flight facility (n_TOF) is an innovative facility operative since 2001 at CERN, with three experimental areas. In this paper the n_TOF facility will be described, together with the upgrade of the facility during the Long Shutdown 2 at CERN. The main features of the detectors used for capture fission cross section measurements will be presented with perspectives for the future measurements.

1 Introduction

The n_TOF facility is based on a proposal by Carlo Rubbia [1], the neutrons in a wide energy range, from thermal to a few GeV, are generated by spallation induced by 20 GeV/c protons on a lead target. The high instantaneous neutron flux, low duty cycle, high resolution and low background make this facility unique for high-accuracy and high-resolution cross-section measurements relevant to Nuclear Astrophysics, Nuclear Technology and fundamental Nuclear Physics. Thanks to its features, n_TOF is particularly suited for measurements on radioactive isotopes, such as those involved in the branching of s-process nucleosynthesis, as well as in projects of nuclear waste incineration and for the design of Generation IV nuclear reactors.

Since 2001, the first year of operation, up to 2020 the n_TOF facility went through many significant upgrades, in particular, during the second long shutdown period of the CERN accelerator complex (LS2), several improvements were done in order to extend the performance and capabilities of the facility.

A brief description of the facility will be given in the next section, while following sections the upgrade of the facility and the detectors will be described. Finally, in the last section, some indicative current and future measurements are briefly reported.

2 The n_TOF facility

The n_TOF facility is a pulsed neutron source located at CERN. It is based on a 20 Gev/c proton beam, delivered by the Proton Synchrotron (PS) accelerator. The pulsed proton beam is directed through the FTN beam line towards the n_TOF nitrogen-cooled lead target. Each proton pulse has a nominal intensity of 8.5×10^{12} protons. For each proton impinging on the lead target, approximately 300 neutrons are produced through spallation reaction mechanisms. The maximum repetition rate of the delivered proton pulses is 0.8 Hz while the time width of each pulse is 7 ns (rms) allowing for excellent energy resolution of the produced neutron beam, even for the GeV neutron energy region.

There are two experimental areas devoted to the neutron reaction measurements, Figure 1 shows the layout of the facility, the first experimental area (EAR1) is located at 185 m from the spallation target, it was commissioned in 2001 and it is used for neutron capture and fission measurements requiring very high neutron energy resolution.

The second experimental area (EAR2) is located above ground level, at a distance of 20 m from the spallation target in the perpendicular direction with respect to the incoming proton beam, EAR2 was commissioned in 2014, in this experimental area, thanks to its unique features, it is possible to measure small and/or radioactive samples, even when the mass of the sample is a tenth of mg.

In both experimental areas, charged particles are removed from the beam by “sweeping magnets”, while the beam aperture is defined through collimators and additional shielding elements. The final diameter of the beams, in both experimental areas, is defined by a shaping, downstream collimator, located just before the experimental area. Two options of beam apertures are available for each area, while the beam optical elements allow for a well-defined and sharp spatial profile of the neutron beams for optimal low background conditions.

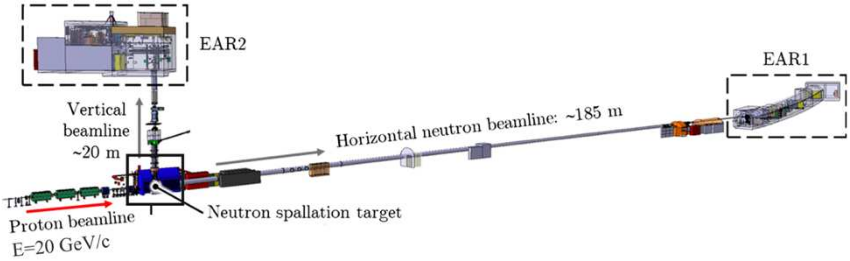

Fig. 1. Schematic view of the neutron beamlines and the experimental areas of the n_TOF facility.

3 The upgrade during the LS2

During CERN's Long Shutdown 2 many upgrades to the facility were performed, including the construction of a third-generation spallation target [2, 3], the consolidation of the neutron collimation systems, the complete overhaul of the target pit shielding as well as the construction of a new irradiation station in the NEAR area, close to the neutron spallation target (see Figure 2).

The NEAR station has two sub-stations [4], the irradiation station (i-NEAR), located next to the target and the activation station (a-NEAR) located outside the shielding, approximately at 3 meters from the target.

The NEAR experimental area was commissioned in 2021 [5], with the aim of studying the effect of radiation on material and electronics, as well as performing cross-section measurements with the activation technique. An example of an activation spectrum is given in Figure 3 [5].

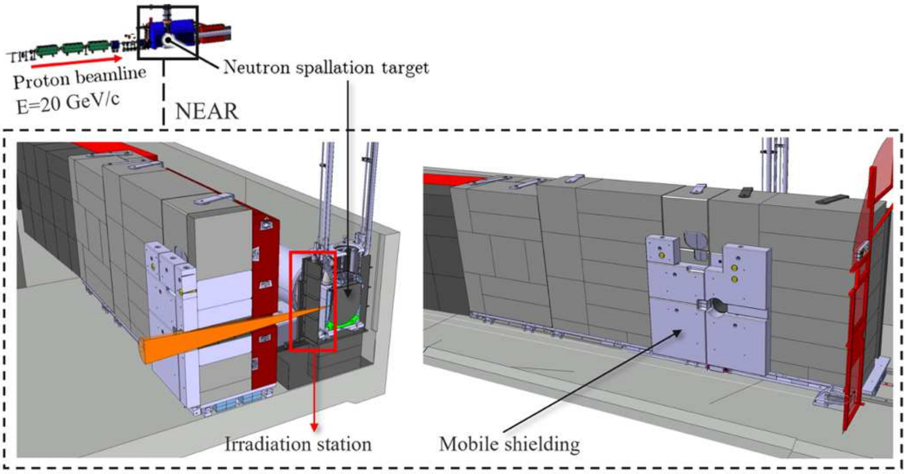

Fig. 2. Schematic view of the NEAR station at n_TOF.

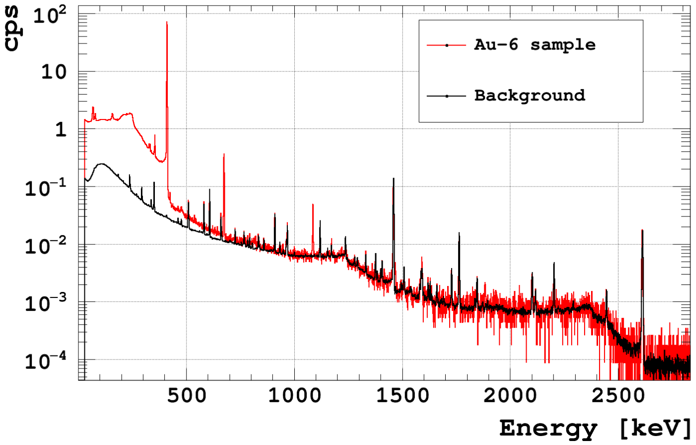

Fig. 3. Activation spectrum, in counts per second, for the Au-6 (^{197}Au(n,2n)^{196}Au) foil (in black). A background spectrum is also shown (in red)[5].

4 n_TOF detectors

To match the convenient characteristics of the neutron beam, the facility has been complemented with state-of-the-art detectors and data acquisition systems. The n_TOF facility at CERN uses a variety of detectors to measure the neutron beam and the products of neutron-induced reactions. The choice of detector depends on the specific experiment and the type of measurement being made. In particular, for the measurements of capture reactions, a high-performance 4p Total Absorption Calorimeter (TAC), made of 42 BaF$_2$ crystals has been built (Figure 4) and extensively used, while innovative gas detectors, such as Fast Ion Chamber (FIC) [5], Parallel plate avalanche chambers (PPACs, Figure 4), and fission detectors, such as MICRO-Mesh-Gaseous Structure (Micromegas) [6,7,8], have been developed for measurements of fission cross-sections.

Fig. 4. Left panel the Total Absorption Calorimeter (TAC), Right panel Parallel Plate Avalanche Chamber PPAC.

During the LS2 period, the n_TOF collaboration developed, characterized and delivered innovative detection setups that provide the ability to perform new series of measurements and to investigate previously unexplored physics cases. One of those developments is the imaging-Total Energy Detector (i-TED) setup [9], see Figure 5 right panel. i-TED is a γ-ray

detection system based on the Compton imaging technique. In this way, the emitted γ-rays from capture events within the sample volume can be identified and selected. Accordingly, the signal to background ratio can be significantly enhanced allowing for measurement with minimal sample masses [10].
The high instantaneous flux of EAR2, while in principle beneficial for neutron capture measurements, at the same time, causes high counting rates and strong pile-up events in the detection systems.

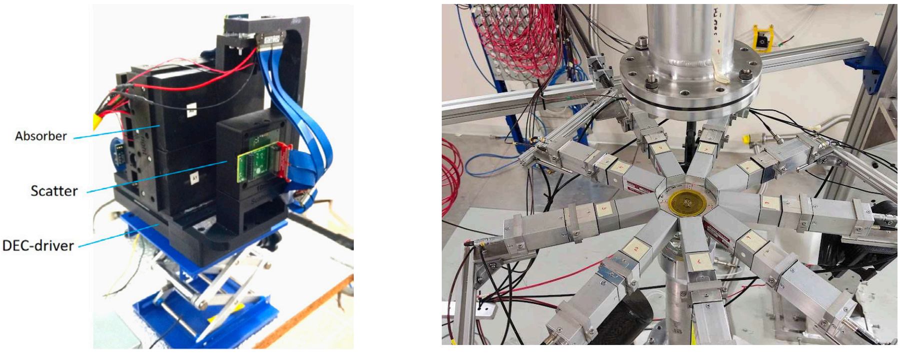

Fig. 5. Left panel: schematic view of i-TED detector. Right panel: the s-TED detectors in EAR2.

These issues were solved through the implementation of small-volume segmented Total Energy Detectors (sTED, Figure 5 left panel), arranged in a compact configuration around the capture sample [11]. The high segmentation of low volume detectors allowed for the shortening of the sample to detector distance resulting in better signal to background ratio, keeping at the same time the counting rates at well manageable levels.

5 Future and Conclusion

Thanks to the upgrade of the facility and the development of innovative detection setups during LS2, the experimental investigation of previously unexplored physics cases became feasible (e.g. measurement of the ^{79}Se(n,γ), reaction cross section) [12]. A significant part of the available beam time is devoted to further detector developments and tests that revealed the abilities of the n_TOF facility to launch new type of measurements in the near future.
The future experimental campaigns are quite ambitious, the physics program is already being followed, aiming mostly to nuclear astrophysics studies, fission reactions studies and detector development and proof-of-principle studies (e.g. [13], [14]).

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