EPJ Web of Conferences **146**, 03001 (2017) DOI: 10.1051/epjconf/201714603001
ND2016

The n_TOF facility: Neutron beams for challenging future measurements at CERN

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Abstract. The CERN n_TOF neutron beam facility is characterized by a very high instantaneous neutron flux, excellent TOF resolution at the 185 m long flight path (EAR-1), low intrinsic background and coverage of a wide range of neutron energies, from thermal to a few GeV. These characteristics provide a unique possibility to perform high-accuracy measurements of neutron-induced reaction cross-sections and angular distributions of interest for fundamental and applied Nuclear Physics. Since 2001, the n_TOF Collaboration has collected a wealth of high quality nuclear data relevant for nuclear astrophysics, nuclear reactor technology, nuclear medicine, etc. The overall efficiency of the experimental program and the range of possible measurements has been expanded with the construction of a second experimental area (EAR-2), located 20 m on the vertical of the n_TOF spallation target. This upgrade, which benefits from a neutron flux 30 times higher than in EAR-1, provides a substantial extension in measurement capabilities, opening the possibility to collect data on neutron cross-section of isotopes with short half-lives or available in very small amounts. This contribution will outline the main characteristics of the n_TOF facility, with special emphasis on the new experimental area. In particular, we will discuss the innovative features of the EAR-2 neutron beam that make possible to perform very challenging measurements on short-lived radioisotopes or sub-mg samples, out of reach up to now at other neutron facilities around the world. Finally, the future perspectives of the facility will be presented.

1. Introduction

The neutron time-of-flight facility n_TOF at CERN [1,2] is a pulsed white neutron source for high-accuracy neutron cross-section measurements over a wide neutron energy range. The neutrons are produced in a monolithic Pb-spallation target, where a pulsed 20 GeV/c proton beam provided by the CERN Proton Synchrotron (PS) [3] impinges with a maximum repetition rate of 0.8 Hz. The primary proton beam has a width of 7 ns rms. The Pb-target is surrounded by an additional moderator layer to generate a neutron beam with energies ranging from thermal up to several GeV. At the facility in operation since 2000 the measurements take place in an experimental area placed at the end of a horizontal beamline, 200 m in length. The experimental conditions and neutron beam characteristics at this horizontal flight path are presented in full detail in Ref. [4]. The horizontal 200 m flight path, with its record instantaneous neutron beam intensity, has allowed very important cross-sections to be measured, getting unprecedented energy resolution in both neutron capture [5,6] and fission [7] as well as extending the measurement range to previously unreachable neutron energies [8]. However, there are more challenging experiments that require an even more intense neutron beam.

To address the needs of data for short-lived radioisotopes, or for stable isotopes available in extremely small amounts, the n_TOF Collaboration proposed the construction of a new experimental area (EAR-2) at a shorter distance from the spallation target to exploit a much higher neutron flux [9]. Since the spallation target is placed underground at approximately 20 m under the surface, a very convenient solution was to build the new experimental area just on top of the pit hosting the target, in the vertical direction.

The large gain in the neutron flux, of about a factor of 30 relative to the first experimental area, allows one to perform measurements with samples of correspondingly smaller mass or in a shorter time. Most importantly, the combination of the higher flux and shorter time-of-flight, a factor of 10 relative to EAR-1, is particularly convenient when measuring radioactive isotopes, as it results in an increase of the signal-to-background ratio of more than two orders of magnitude for the background related to the radioactive decay of the sample. As a consequence, in EAR-2 it becomes feasible to perform challenging measurements with isotopes of half-life as short as a few tens of years, offering the unique opportunity to address some open questions in nuclear astrophysics, in applications related to energy production, both from fission and fusion, in nuclear medicine, in fundamental nuclear physics, and in related fields.

With these goals in mind, the construction of the second beam-line started at the beginning of a long accelerator shut-down at CERN, in December 2012, and was completed, with almost perfect timing, before the restart of the PS accelerator, in July 2014.

2. EAR-2 neutron flux

The neutron flux is one of the most important features of the n_TOF facility not only for the characterization of the experimental areas but also because it is essential on the yield ascertainment for determining the energy dependence of the neutron induced cross section. Furthermore, the beam time requested in any experiment proposed at n_TOF relies on the precision of the flux. In order to reach the desirable high accuracy, a combination of three different neutron induced reactions considered standards, for instance, $^{10}B(n,\alpha)^{7}Li$, $^{6}Li(n,t)^{4}He$ and $^{235}U(n,f)$, is required to cover the wide energy range of the n_TOF neutron spectrum; in addition, a combination of several detection systems based on different working principle allows reducing the overall uncertainties. Gaseous detectors as micromegas [10], Parallel Plate Avalanche Chamber (PPAC) [11] and Physikalisch Technische Bundesanstalt (PTB) [12] as well as solid state detectors like Silicon Monitor [13,14],

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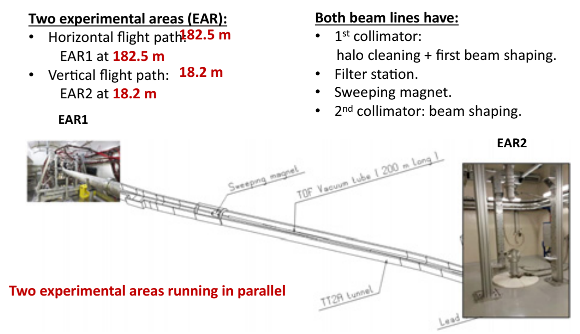

Figure 1. The n_TOF facility.

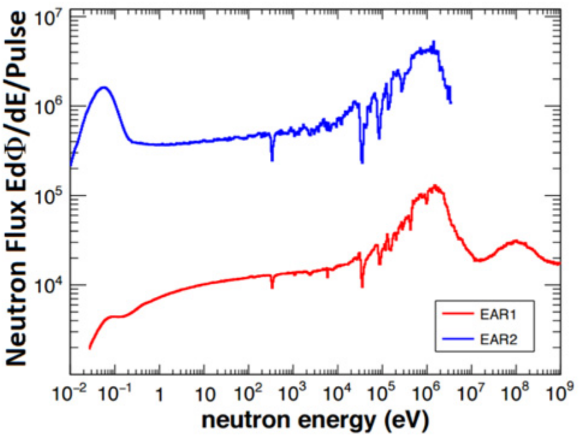

Figure 2. Comparison of the n_TOF neutron flux integrated over the whole beam profile at EAR-1 [15] and EAR-2 [16] for the small collimator.

especially designed for monitoring purpose at n_TOF, are used. Figure 2 shows a comparison of the n_TOF neutron flux at EAR-1 (red) and EAR-2 (blue); highlighting the main advantage of the new experimental facility EAR-2 respect to the existing one, i.e., the flux is two order of magnitudes bigger in EAR-2 around 0.0253 eV besides exhibiting a 30–40 times higher value in the rest of the neutron energy range.

3. Two measurements demonstrating the performance of EAR-2

3.1. ^{7}Be(n,α)

The expanded measurement capability of the n_TOF facility has allowed to perform for the first time the measurement of the ^{7}Be(n,α) reaction cross-section in a wide energy range. The reaction is of particular interest in Big Bang Nucleosynthesis (BBN), and in particular for the Cosmological Lithium Problem (CLiP): it refers to the large discrepancy between the abundance of primordial ^{7}Li predicted by the standard theory of Big Bang Nucleosynthesis (BBN) and the value deduced from the observation of galactic halo dwarf stars.

A possible solution in Nuclear Astrophysics is related to the incorrect estimation of the destruction rate of ^{7}Be, which is responsible for the production of 95% of primordial Lithium. While the role of charged particle induced reactions has mostly been ruled out by recent measurements, data on the ^{7}Be(n,α) and ^{7}Be(n,p) reactions are scarce or completely missing, thus affecting the abundance of ^{7}Li predicted by the standard theory of Big Bang Nucleosynthesis.

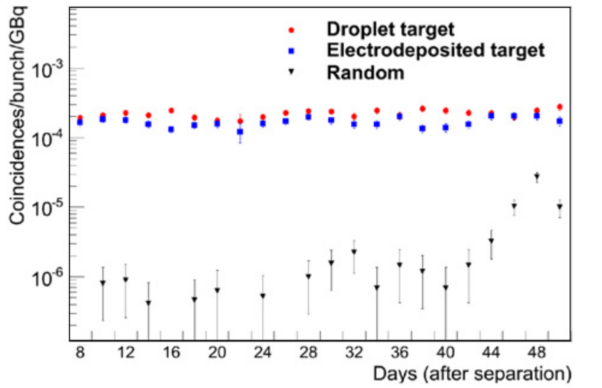

Figure 3. Detected number of coincidences as a function of time during measurement.

Recently, (n,α) and (n,p) reaction cross-sections have been measured at n_TOF-EAR-2 with two different silicon detection systems, providing for the first time nuclear data on the ^{7}Be(n,α) and ^{7}Be(n,p) cross-section in a wide neutron energy range, namely in the energy range of interest for Nuclear Astrophysics.

In the case of the ^{7}Be(n,α)^{4}He reaction, a sandwich of two silicon detectors has been used to detect the two alpha-particles that are emitted back-to-back with a maximum energy of 9.5 MeV (the Q-value of the reaction is 18.99 MeV).

Each sandwich hosted a target consisting of an extremely thin backing (0.6 μm Polyethylene and 5 μm Aluminum) with the nitrate solution of ^{7}Be on one of the surfaces, for a total activity of about 40 GBq. The measurement relied on the coincident detection of the two alpha particles emitted back-to-back in the reaction with several MeV energy each, that ensured a strong rejection of any other source of background (Fig. 3) and allowing measuring the desired cross-section from 10 meV to 10 keV.

The results of the n_TOF measurement hint to a minor role of the ^{7}Be(n,α)^{4}He reaction in BBN, leaving the Cosmological Lithium Problem unsolved [17].

3.2. ^{240}Pu(n,f)

The measurement of the ^{240}Pu fission cross-section is the first measurement to be performed at the newly commissioned Experimental Area II of the CERN n_TOF facility. Data were collected from thermal energies up to at least several MeV. Most notably, data showing clear resonant structures have been obtained even in the sub-threshold region (up to a few tens of keV) where the cross-section is lowest and where evaluations show a smooth behaviour of the cross-section. The success of this measurement is largely due to the favourable characteristics of EAR-2, in particular the increased neutron flux and stronger background suppression compared to EAR-1, where the measurement was not feasible (see Fig. 4). These features will allow n_TOF to expand Its measurements capabilities to even

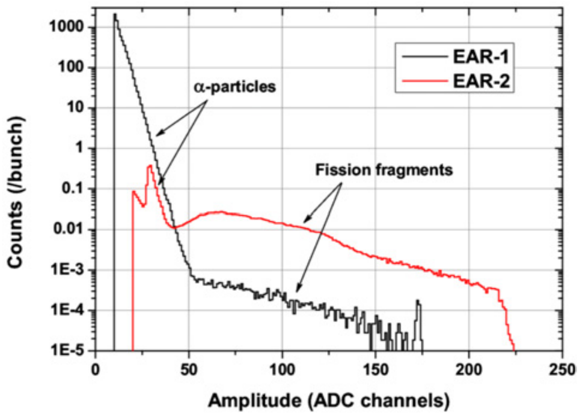

Figure 4. Pulse-height spectra obtained from a ^{240}Pu sample during the measurements in EAR-1 (black) and EAR-2 (red). Counts are normalised per beam bunch for direct comparison. The significant suppression of the sample- induced α-background is evident, as is the much higher rate of fission events.

more short-lived and rare isotopes such as ^{230}Th, ^{232}U, ^{238,241}Pu and ^{244}Cm.

4. Conclusions

There is need of accurate new data on neutron cross-section both for astrophysics and nuclear technology. Since 2001, n_TOF is contributing to the world efforts aimed at collecting high quality data, mostly on capture and fission. Main advantage of n_TOF is the high instantaneous neutron flux and high performance detectors. The new EAR-2 offers the unique opportunity to perform challenging measurements involving short-lived radioisotopes or sub-mg samples.

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