n_TOF Detector Developments

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1 Introduction

Since the first year of operation (2001) of the n_TOF facility,[1] a continuous effort has been made to improve the experimental conditions and to obtain the best possible experimental data. Significant steps have been taken in this direction. In recent years, the high interest and growth of the n_TOF community have resulted in the launching of a large number of detector development projects. Currently, more than 20 detector development projects are underway. Most of these projects are expected to deliver fully operational setups in the coming few years, either before or just after the 3rd CERN Long Shutdown (LS3). A few setups are in a more initial stage of development and will be operational only after LS4. A comprehensive presentation of these detector developments is provided in this codiMD file.

In the next sections, a summary of these developments is given, focusing mainly on the significant expansion of the Physics horizon of the n_TOF facility anticipated as a result of these developments.

2 Detector Developments

2.1 (n,γ) reaction studies

The study of neutron capture reactions for nuclear astrophysics and neutron applications has always been one of the pillars of the n_TOF research activities.[2] Since the inception of experimental studies on (n,γ) reactions, the detection of emitted γ-rays has among others relied on total energy detectors (TED), and in particular on large volume (approximately 1 liter) deuterated benzene (C_6D_6) detectors. Alternatively, particularly at low neutron energies, Total Absorption Calorimeter (TAC)[3] measurements have

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been utilized for the same purposes. The excellent time resolution combined with the high efficiency provided by TAC facilitates (n,γ)/(n,f) measurements through γ-tagging. These measurements, which are uniquely feasible at n_TOF, represent an advanced capability of the facility.

A pioneer study was carried out at n_TOF to explore the possibility of combining the TED technique with simple γ-ray imgaging techniques in order to disentangle spatially localized sources of background and thus enhance detection sensitivity. Very first measurements with a mechanical (pin-hole) collimator were conducted at EAR1[4] with a $CeBr_3$ scintillator and demonstrated the feasibility of this idea. Empowered by these results, a more advanced imaging system was later proposed[5] and developed,[6,7] the so called Total-Energy Detector with γ-ray imaging capability (i-TED). This rather complex system comprised a total of 1280 SiPM readout channels and was based on an array of four Compton modules optimized for high γ-ray efficiency and low-sensitivity to scattered-neutron induced backgrounds (see Fig. 1). The developed system was successfully commissioned at EAR1, thus demonstrating a background rejection capability of up to a factor of ∼4.[8] Subsequently, i-TED was used at EAR1 for the first measurement of the s-process branching nucleus ^{79}Se(n,γ).[9] At present, the main limitation of this system is related to the total count-rate capability of each detector (∼500 kHz). The latter aspect posses a challenge for its implementation at EAR2, where one could take full advantage of such idea. Research is now going on to explore different alternatives, like pixelated crystals.

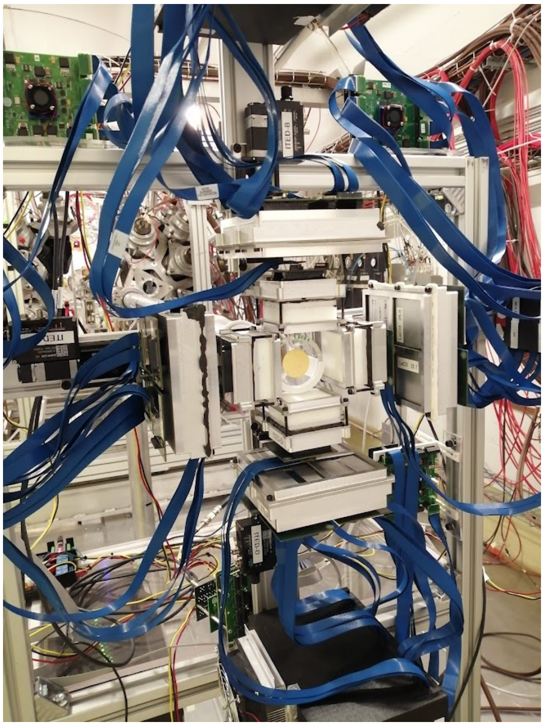

Figure 1: Photograph of the full i-TED array installed in EAR1.

Recently, it has been demonstrated that a closed geometry of nine small (2.5 x 2.5 x 5 cm) C_6D_6 (sTED) modules,[10] positioned a few centimeters from the target, can offer good detection efficiency along with a significant improvement in the Signal to Noise (S/N) ratio .[11,12] The sTED modules are now routinely employed for measuring (n,γ) capture reactions, sometimes operating in conjunction with the large-volume C_6D_6 detectors. This advancement has been crucial for maintaining the high counting rates of EAR2.[?]

Beyond these recent developments, **five new setups** are being devised **to further enhance the detection capabilities for neutron capture reaction studies at n_TOF**. These developments are expected to provide: enhanced detection efficiency, lower neutron sensitivity, improved response with respect to the gamma flash, an extended neutron energy range for measurements, and the ability to perform other types of measurements that were previously inaccessible at n_TOF. These setups are:

- Stilbene Array:

  The stilbene detector array is a promising candidate to replace C_6D_6 detectors. This detector is characterized by an outstanding time response, which is instrumental for Time-Of-Flight (TOF) measurements and is important when high counting rates are necessary. Additionally, stilbene detectors are known for their excellent neutron/γ discrimination abilities. This feature allows the same detectors to be used for (n,el) and (n,inl) reaction studies. More details are given in section 2.4.

  Currently, eight cylindrical detectors (1" x 1") are fully operational, and they are depicted in Fig. 2. The geometrical configuration is versatile and can be adjusted according to the specific needs of each physics case. The low mass housing and support construction result in a low neutron sensitivity, which can be further reduced thanks to the n/γ discrimination abilities. Moreover, the cost of the crystals is low enough to allow for high-efficiency, versatile multiple-crystal configurations.

Figure 2: The eight stilbene detectors: 4 by INRAD (left) and 4 by PROTEUS (right).

- d-Stilbene Array:

  The same favorable characteristics regarding time response and efficiency as previously mentioned are expected for this detector. This is the deuterated version of stilbene detectors, which offers reduced neutron sensitivity. It is also a strong candidate to replace the C_6D_6 detectors, with an expected 15% increase in efficiency compared to sTED. Its dimensions match the current version of sTED. The first crystal is expected to arrive from LLNL before December 2024. Additionally, 10 detectors are projected to be operational during the 2025 campaign.

- High efficiency sTED Array:

Eighteen additional sTED modules have been acquired. Through these additional modules, the total efficiency will be three times higher than the current one. These new modules have the same dimensions as the current version of sTED.

- $LaBr_3$ and $LaCl_3$ detectors:

  In addition to the TED and TAC techniques to address (n,γ) reactions, the use of in-beam γ-ray spectroscopy can also be applied for this purpose. Fast lanthanum-based scintillators have much better resolution than C_6D_6 or BaF_2 detectors, although still not as good as HPGe detectors. More details are given in section 2.4.

- High-efficiency HPGe clover detectors:

  Two segmented n-type High Purity Germanium (HPGe) clover detectors with (BGO) anti-Compton shields will be available at n_TOF for activation measurements and characterization of radioactive samples. Each clover consists of four crystals, each measuring 50 mm in diameter and 70 mm in length, with a relative efficiency of 23% and a resolution of 1.5 keV at the 1.33 MeV ^{60}Co γ-ray energy. When operating in add-back mode, each clover achieves a relative efficiency of 130%.

  In a typical activation experiment, samples are irradiated with a well-characterized neutron field, often at the NEAR station of n_TOF. These samples are then moved to the decay station, where they are positioned between the two clovers arranged in a 4π geometry. This configuration facilitates the determination of spectrum-averaged cross-sections and the half-lives of the resulting daughter products.

In addition to the mentioned developments that are expected to be fully operational before or shortly after CERN LS3 two more setups are under study as to be fully functional during the post LS4 running period of n_TOF:

- High efficiency TED detectors:

  The high-efficiency TED uses an extended C_6D_6 detector in a close geometry. The design is currently in progress, featuring a versatile setup that can be adapted to each specific physics case. This system strikes a balance between efficiency and neutron sensitivity. Some considerations of the detection geometry are depicted in Fig. 3.

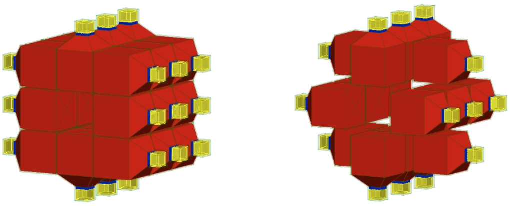

Figure 3: Some possible configurations for the High efficiency TED detectors

- Highly segmented calorimeter: This development aims to replace the existing TAC detector with a highly segmented one that has improved performance in relation to gamma flash implications, thereby extending the operational neutron energy range to higher neutron energies. The objectives of this design include adopting several layers of detectors with small scintillator crystal volumes, using readouts with low-mass photosensors, and combining fast timing (nanoseconds) with optimized electronics (low electronic noise). An indicative configuration of this development can be seen in Fig. 4.

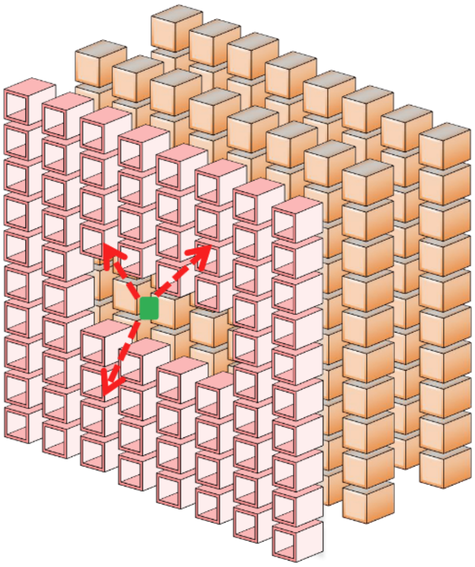

Figure 4: A conceptional design of the highly segmented calorimeter

2.2 Fission reaction studies

The second pillar of nuclear physics research successfully conducted using the n_TOF facility focuses on fission reaction studies.[13] By exploiting the high energy resolution, high luminosity, and wide energy range of the neutron beam, along with specialized detection and data acquisition systems, an extensive fission research program is underway and continuously expanding. While long-lived isotopes are studied along the 185 m flight path, the construction of a second experimental area (EAR2) at a distance of about 19 m has enabled challenging measurements of short-lived actinides.

Most fission reaction studies conducted so far have been based on the measurement of fission yields over an extended energy range. The unique characteristics of the n_TOF facility allow for measurements from meV up to GeV, significantly contributing to the required fission cross-section data for numerous isotopes. These studies have been performed[13] using various detection setups and by recording different observables. Gas detectors such as Micromegas[14, 15] and fission ionization chambers are used frequently, while setups like STEFF, a 2E2v device, are applied occasionally.

Despite the wealth of experimental data on fission reaction cross-sections for several fissile and fissionable isotopes, nuclear fission remains one of the most exotic and intriguing phenomena, still largely unexplored. To enhance our understanding, more observables must be recorded. In this regard, by taking advantage of the unique characteristics of n_TOF EAR1 and EAR2, new detector developments are ongoing:

- The Fission Fragment Identification (FiFI) device:

The Fission Fragment (FF) mass measurement detector employs a Time-of-Flight (TOF) arm equipped with two MCP timing detectors in a vacuum to determine the velocity of the fission fragments. An isobutane-filled ionization chamber is used to measure the energy of these fragments. The anticipated energy resolution for the recorded FFs is 800 keV. Thanks to excellent time resolution (FWHM: 700 ps), the expected mass resolution is 1.2%. The FiFI device is still under development and is expected to be fully operational even before CERN's LS3. Initial tests will be performed during the late 2024 and 2025 n_TOF campaigns.

The potential of this detection setup at n_TOF is significant considering the provided high neutron flux in EAR2. This setup enables FF mass spectroscopy for all isotopes for which fission reaction cross-section measurements have been conducted. A simplified drawing and a picture of the current status of the FiFI device can be seen in 5.

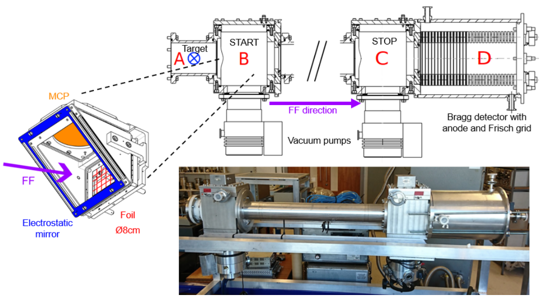

Figure 5: A simplified drawing and a picture of the current status of FiFI device

- Compact Fission Detector

  The development of a compact fission detector is currently underway. This detector will be small enough to be placed inside n_TOF-TAC and will be equipped with specially designed fast electronics. This allows for the recording and tagging of emitted gamma rays, facilitating the distinction between gamma rays induced by capture and those induced by fission. Such measurements can be performed at n_TOF and are crucial for enhancing our understanding of the competitive reaction channels—fission and capture in both minor and major actinides. These insights are also vital for energy applications, such as the design of next-generation reactors. The first measurement, focusing on Pu-241, is anticipated in 2025. A depiction of this development can be seen in Fig. 6.

- X-Y Micromegas

  The X-Y Micromegas is a gas position-sensitive Micromegas detector. The path and angular distribution of the recorded fission fragments (FF) will be reconstructed using a framework of 256 X-Y strips, accompanied by specially designed fast electronics and a multichannel data acquisition (DAQ) system. Initial tests of this detector are planned for the late 2025 n_TOF campaign. Over the past two decades, Micromegas detectors[14, 15] have been extensively used as FF counters in fission reaction studies at n_TOF due to their lightweight construction, which makes them almost transparent to neutron fields, and their excellent radiation hardness. The significant advancement of this new development is its ability to record the angular distribution of emitted FFs, which is crucial for improving our general understanding of the nuclear fission phenomenon. A simplified depiction of the detector, which also provides information on its working principle, can be found in Fig. 7.

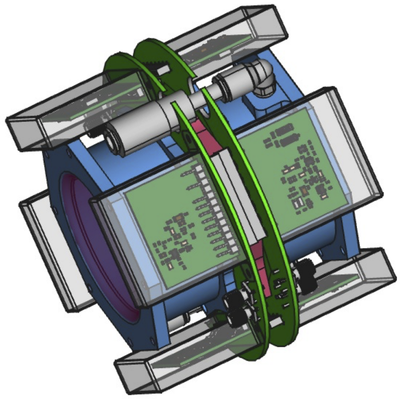

Figure 6: A simplified drawing of the compact fission detector

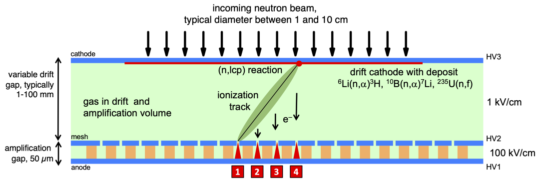

Figure 7: The X-Y Micromegas detector.

2.3 (n,lcp) reaction studies

Neutron-induced reactions that produce light charged particles, commonly referred to as (n,lcp) reactions, are of significant interest in fundamental physics research and nuclear astrophysics. Accordingly, several studies on (n,lcp) reactions have been conducted at n_TOF, and specialized setups have been developed for these investigations. One such development is a compact ΔE-E setup, which has been successfully utilized to explore various (n,lcp) reactions at n_TOF EAR-2, specifically for applications in nuclear astrophysics.[16–18]

Beyond their fundamental physics significance, these reactions have garnered considerable attention in recent years due to their implications for medical dosimetry and their effects on the radiation hardness of materials intended for use in emerging fusion technologies. Specifically, understanding gas production, as well as potential swelling and embrittlement of materials, is crucial and necessitates detailed study and modeling. Given that experimental data on these reactions is currently limited, the unique characteristics of the n_TOF beams can be utilized to address this critical information gap. Consequently, significant efforts have been underway for the past few years within the n_TOF collaboration to efficiently and accurately investigate these (n,lcp) reactions. In this context, ongoing detector developments tailored to the n_TOF characteristics are summarized below.

- High solid angle silicon detector array:

  A high solid-angle, position-sensitive silicon detector array is currently under development. This detector comprises annular neutron-Transmutation Doped (nTD) double-sided silicon strip detector (DSSSD) and rectangular shapes arranged in a barrel configuration, as illustrated in Fig. 8 Initial tests on the annular portion of the detector have demonstrated that particle identification is achievable even with single-layer detection, without the need for the ΔE-E technique, by employing pulse shape identification methods. This setup is specifically designed for use under n_TOF neutron beam conditions, with a focus on detecting and identifying low-energy charged particles emitted from neutron-induced reactions. The position sensitivity and capacity for particle identification even at very low particle energies (2 MeV) enable the recording of angular distributions and, consequently, accurate deductions of total reaction cross-sections.

The first prototype, comprising the annular section of the detector, has been successfully tested in both experimental areas of the n_TOF facility, and the particle identification software is well-developed. The setup is already operational, at least in its forward annular section form, and the complete assembly, which will cover a wider angular range, is expected to be fully operational after CERN's LS3.

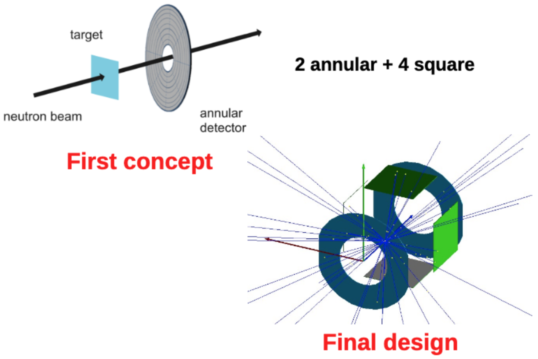

Figure 8: The first prototype of the nTD DSSSD detector array consisting only of the annular detector and the concept of the final configuration covering a much higher angular range.

- GEMpix:

The GEMpix detector is a small triple-GEM chamber with a Timepix1 (TPX1) quad readout, that is a matrix of 2×2 TPX1 chips. Unlike the standard TPX1 detectors that use a semiconductor layer of a few hundred micron thick active material, in GEMpix there are only the bare chips and the active material is substituted by a layer of gas with the addition of a sequence of three GEM foils to amplify the charge produced in the gas. 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 works 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. Then all the fired pixels are not free until the end of the acquisition window and the transfer time of matrix data. GEMpix has been proposed for the detection of charged particles from neutron induced reactions in the energy range 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 that can be ArCO$_2$ (70/30) or ArCO$_2$CF$_4$ (45/15/40). The material target under analysis can be placed outside or inside the detector active volume right after the detector window. A layout of the GEMpix detector is shown in Fig. 9.

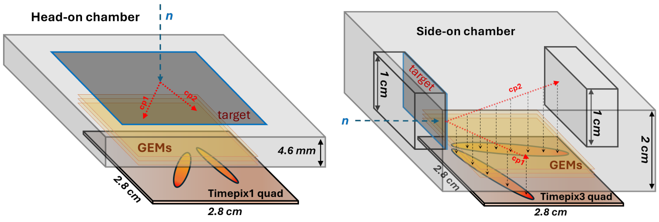

Figure 9: Layout of the first realized prototype of head-on GEMpix with TPX1 readout and the new side-on GEMpix with TPX3 readout under costruction.

- DDX Chamber:

This ΔE-E setup is designed to measure the double-differential cross-section of neutron-induced light charged particle emission at high energies, specifically between 20 MeV and 200 MeV. These measurements are crucial for producing high-accuracy cross-section data for (n,lcp) reactions, which are urgently needed for medical and dosimetry applications. The experimental setup (Fig. 10) features a vacuum chamber equipped with holders for six triple-stage particle telescopes (ΔE-ΔE-E) arranged at angles of 20 degrees, 60 degrees, and 120 degrees. Currently, four telescopes are available. The detectors comprise silicon diodes of various thicknesses, from 50 µm to 1000 µm, while the E detectors are plastic scintillators with an 8 cm diameter and lengths ranging from 50 mm to 150 mm. The proof of principle was demonstrated in October 2024 through an experiment at n_TOF EAR1 for determining the double-differential cross-section of carbon. The results will guide the further development of the setup.

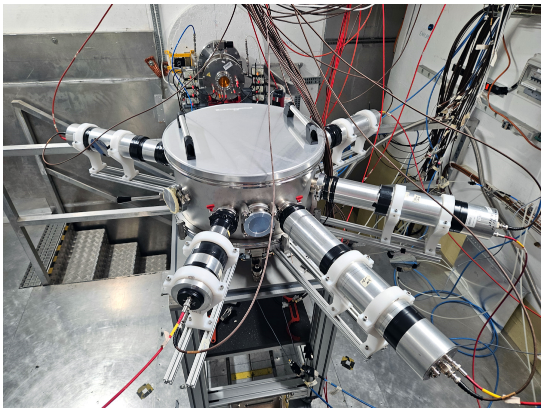

Figure 10: The vacuum chamber of the DDX setup that can host Silicon detectors (ΔE stage inside) and the plastic scintillators (E stage, arms outside) at 20 degrees, 60 degrees, and 120 degrees.

- High-efficiency silicon telescopes for charged particle detection

This detector development project is currently in the design phase. The aim is to build a setup consisting of two or three silicon telescopes for charged particles, equipped with dedicated electronics. The primary goal is to design and construct a detection setup with high efficiency, while simultaneously considering the angular distribution of outgoing particles in reactions induced by neutrons with energies of at least 10 MeV. Silicon telescopes will be used to detect charged particles as well as to differentiate between protons, alphas, and deuterons emitted from nuclear targets. One possible option is to use two telescopes (with an optional magnetic field), while another is to use three telescopes to cover the largest possible solid angle. Testing at n_TOF EAR2 is planned for the end of 2025.

2.4 (n,n') and (n,xn) reaction studies

The study of neutron inelastic reactions and the corresponding γ-ray production yield is crucial for enhancing our understanding of nuclear reaction mechanisms, as well as for neutron transport calculations related to energy applications or medical and dosimetry studies. Similarly, there is a high demand for studying (n,xn) reactions across a wide range of isotopes. As with the previously discussed (n,lcp) reactions, experimental data in this area is limited. The unique capabilities of the n_TOF facility, combined with high-efficiency experimental setups, can address this gap and significantly improve nuclear data evaluations. The recording of (n,n') and (n,xn) reactions relies on detecting the γ-rays emitted during the de-excitation of the daughter nucleus. Therefore, it is essential to develop highly efficient, high-resolution detection setups with excellent time response and proper electromagnetic shielding to function under the specific conditions of the n_TOF experimental areas. Initial tests with $LaBr_3$ and specially designed HPGe detectors at n_TOF have shown promising results. Below, we list these developments along with the expected advantages and challenges identified so far from ongoing in-beam tests.

- $LaBr_3$ and $LaCl_3$ detectors:

  Preliminary tests (see Fig. 11) on $LaBr_3$ scintillators conducted under the specific conditions of the EAR1 at the n_TOF facility demonstrated that small-volume crystals (e.g. 1.5" x 1.5") provide a rapid recovery from gamma flash, enabling in-beam γ-ray spectroscopy even at high neutron energies in the range of 100-200 MeV. The fast time resolution of approximately 200 ps, combined with a good energy resolution of about 3% at 662 keV, facilitates the study of a significant number of neutron inelastic reactions and (n,xn) reactions by capitalizing on the unique characteristics of the EAR1 n_TOF neutron beam. This approach represents one of the "physics paths" set to be initiated very soon.

  However, the main limitation arises when dense level schemes are present among the reaction products, as the energy resolution provided is insufficient to distinguish between potential de-excitations through γ-rays of similar energies. This issue can be addressed by employing a hybrid experimental setup that combines scintillators (such as $LaBr_3$ and $LaCl_3$) with HPGe detectors, which offer an energy resolution that is ten times better.

- HPGe detectors:

  Efforts to capitalize on the exceptional energy resolution provided by HPGe detectors, combined with the unique characteristics of the neutron beam at the n_TOF facility, have been ongoing for some time, with a consistent focus on studying neutron inelastic and (n,xn) reactions. The application of HPGe detectors was initially impeded by saturation effects resulting from the intense energy deposition caused by the γ-flash present in the n_TOF experimental areas. Fortunately, this issue was completely resolved through the implementation of a specially designed circuit[19] on the detector preamplifier. This modification was successfully achieved through a long and productive collaboration with MIRION Technologies, culminating in the delivery of the first fully functional and characterized prototype in 2018.[20]

  To date, this HPGe detector (relative efficiency 26%, p-type) has been extensively utilized for in-beam spectroscopy and activation measurements across various n_TOF experimental activities. Specifically, tests conducted for in-beam γ-ray spectroscopy have demonstrated that the detector can effectively be employed for numerous physics cases involving (n,n') and (n,xn) reaction studies, especially in conjunction with $LaBr_3$ or $LaCl_3$ detectors.

  Although the issue of signal saturation has been fully addressed through the implementation of the switcher circuit, the energy deposition from energetic scattered particles in the detector's active volume still produces a strong (albeit smooth) background that requires special treatment during pulse shape analysis. Additionally, a significant challenge emerged in 2022 due to strong electromagnetic (EM) "ringing" in the n_TOF EAR1.

  Today, after extensive trials and tests, the pathway for the successful application of HPGe detectors at n_TOF has become clear. It is essential to implement careful EM shielding for the detector electronics, utilize low-volume and/or highly segmented crystals, and focus on finalizing the pulse shape analysis software. This software must enable the preservation of the excellent energy resolution while effectively subtracting the strong background component in the detector signal present at short time-of-flight (TOF), specifically at neutron energies of a few MeV.

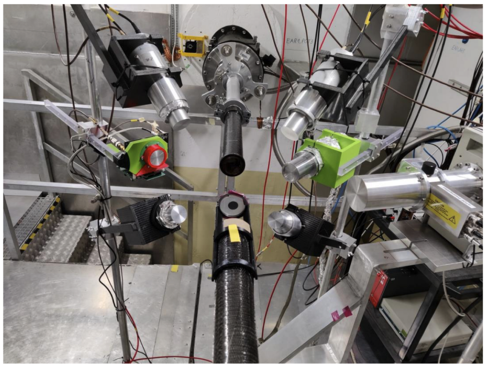

Figure 11: Picture of one the tests recently performed in EAR1 with LaBr3 detectors of different sizes. The gated HPGe prototype can also be seen in the right side of the image

- Stilbene detectors:

  As already mentioned, the operative cluster of eight stilbene detectors (fig.2) will be also used in order to perform measurements involving (n,n') and (n,xn) reaction studies in the

0.2-100 MeV n-energy range. Moreover, by exploiting the excellent n/γ discrimination abilities and the compact design, these detectors can be combined with the $LaBr_3$ detectors in order to perform, for the first time at the n_TOF facility, n-γ exclusive measurements. The possibility of measuring in the high-energy range in EAR1 (E_n=1-100 MeV) has been already verified on October 2024.[21] During this test (n,n) and (n,n') reaction channels were measured at four different backward angles in EAR1 (see figure 12) on Carbon-12 and Boron-11 targets. During this measurement, no baseline ringing was observed due to the use of the unique DC-DC converters operating at 5 V by ultra low noise power-supplies. In this context it is important to underline that the relatively small active volume (1"x1") allows a dramatic reduction of the γ-flash component and consequently a fast baseline restoration in the high-energy TOF dynamic range. As a matter of fact, (n,n) elastic scattering channel excitation function on Carbon-12 has been preliminary deduced and compared with the existing data in literature in the 1-5 MeV n-energy range. Due to the full availability of the array, we expect to perform (n,n) and (n,n') measurements for the ongoing n+^{63,65}Cu measurement campaign.[22]

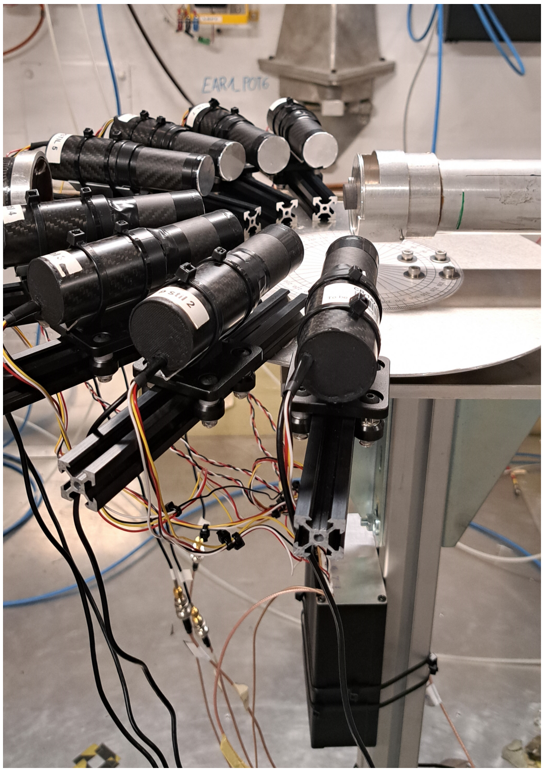

Figure 12: The stilbene array installed ia EAR1 for (n,n) and (n,n') measurements on C-12 and B-11.

2.5 Other detector developments

The previously mentioned detector developments are dedicated to specific current and future physics exploration paths of the n_TOF Collaboration. In addition to these developments, there is a significant research component that leverages the unique characteristics of the n_TOF beam to advance state-of-the-art detector technologies. These advancements can be utilized at the n_TOF facility to support beam diagnostics and enhance the acquisition of physics data by introducing additional observables. Some of these developments that the n_TOF teams are actively working on are listed below:

- Diamond detector:

  The diamond detector, consisting of a 4 mm x 4 mm x 50 μm sensor, offers unique radiation hardness capabilities along with excellent time characteristics. These attributes have enabled the use of the detector for beam spatial profile mapping at the NEAR station, employing a ^{6}Li foil that is 1.6 μm thick. In this context, the ^{6}Li(n,^{3}H)^{4}He reaction serves as a converter, increasing the detector's efficiency in the low neutron energy region. Throughout this campaign, several improvements have already been made; however, a significant effort continues from the involved teams to enhance detector performance and expand the range of its applications. The diamond detector is depicted in Fig. 13

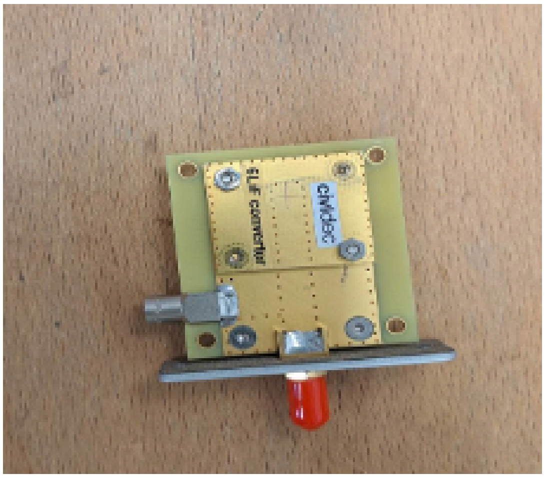

Figure 13: Picture of the diamond detector and the supporting board.

- Re-TOF detector:

  This detector will be used to measure neutron flux in the extreme high energy region of several hundreds of MeV by exploiting n-p elastic scattering. The secondary TOF of the emitted protons will be recorded. For this purpose, a plastic scintillator 4x4 cm² will be utilized as a "start detector", alongside a plastic scintillator wall 60x60 cm² wide. This wall is divided into 20 bars to serve as the "stop detector". The first detector test will take place by the end of October 2024

- Fibres neutron detector:

  A neutron detector based on scintillating fibers is currently under development, featuring improved neutron/gamma discrimination capabilities. This detector may be used for measuring total reaction cross-sections at n_TOF using the transmission technique. This detector development will be fully operational during the post-LS4 phase of n_TOF.

3 General considerations

3.1 Beams

The n_TOF neutron beams are well-defined, with unique characteristics that make n_TOF a one-of-a-kind facility worldwide. One consideration for the future, especially for EAR2, is the possibility of having a smaller beam aperture collimator (e.g. ⌀ 8 mm) as an option. This can be instrumental when angular distributions need to be recorded, as a smaller beam aperture better defines the interaction points and consequently provides improved angular resolution in the recorded events. This improvement can be very important in (n,cp) reaction studies.

Another point for possible beam improvement is the potential for increased flexibility in both dedicated and parasitic pulses. In this way, the proton budget can be optimized according to the specific physics case. For instance, in some occasions, extreme dedicated bunch intensities (e.g. 10^{13}) ppp are ideal or parasitic beam bunches can have just slightly lower intensities, e.g., (6×10^{12}) ppp instead of (3.5×10^{12}) ppp.

3.2 Experimental Areas

In addition to individual detector developments aimed at paving new avenues for physics exploration within the n_TOF facility, there is a concerted effort to generally improve experimental conditions. By enhancing these conditions, low-background and high-accuracy measurements can be achieved. Accordingly, several improvements are being considered for the future to significantly enhance detector performance and the quality of physics data:

- Mitigate neutron scattering from the walls of experimental areas by covering them with a Li-PE layer.
- Improve the background conditions in EAR2 by adding an additional Li-PE floor that covers a larger area around the beam line.
- Enhance the mechanical structures supporting detectors to ensure more stable measurement geometries, faster installation, and reproducible setups.
- Upgrade or replace the EAR1 patch panel to provide better electromagnetic conditions, as several experiments have reported issues stemming from reflections and electromagnetic noise originating from the current panel.
- Enhance the quality of signal cables to improve performance for high-frequency signals, such as replacing NEAR signal cables CC50 with CK50.
- Replace both signal and HV cables with alternatives that offer superior electromagnetic shielding.
- Installation of Moderator at n_TOF NEAR station: Following the work of Stamati et al.,[23–25] the conclusion was that the NEAR station can play a significant role in the study of previously unexplored physics cases involving low mass samples (e.g., radioactive isotopes). One of the most important conclusions was that the integrated spectrum-averaged cross section (SACS) can be more accurately converted to the necessary Maxwellian-averaged cross section (MACS) when a moderated neutron spectrum is used instead of the direct neutron field employed until now. Accordingly, a study for the installation of a moderator at the NEAR station should be pursued.

3.3 DAQ

The increasing need to record an ever-expanding array of observables to maximize the physics outcomes of each n_TOF measurement has already pushed the n_TOF DAQ system to its limits (e.g.[26])in three key aspects: 1) the required number of DAQ channels, 2) the rate of data transfer and 3) the rate of digitization. Furthermore, the recognized need to increase the segmentation of various detection setups—to minimize the impact of the γ-flash and maintain instantaneous high counting rate capabilities—has resulted in a substantial demand for a large number of DAQ channels. Taking all these factors into account, along with the detector developments described in the previous section, it is clear that a minimum of 256 DAQ channels should be made available in EAR1 and EAR2. This requirement should be supported by necessary upgrades across the entire CERN data storage chain.

For detection setups or specific measurements that demand an even larger number of DAQ channels or have other specialized requirements, alternative DAQ technologies (e.g., ASICs) should be explored to evaluate their performance under n_TOF EARs conditions (e.g., γ-flash, high instantaneous counting rates).

4 Conclusions

This report briefly presents the current detector development efforts within the n_TOF Collaboration. More than 20 new detection setups will become fully operational, with most being ready either before or shortly after CERN's LS3, while others will reach full functionality after CERN's LS4. The potential and growth of the n_TOF Collaboration are demonstrated by the impressive number of detector system developments. This endeavor will open new avenues for physics exploration within the n_TOF facility, and the potential for new types of measurements will pave the way towards previously unexplored or only partially explored physics regions.

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