EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Direct measurement of the n_TOF NEAR neutron fluence with diamond detectors

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Abstract:

We propose to measure the neutron fluence of the recently built n_TOF NEAR station with an active diamond detector. To-date, the neutron flux characterization of NEAR relies on Monte Carlo simulations and on the multiple foil activation and moderation-absorption techniques.With the use of an active diamond detector loaded with a ^{6}Li converter for enhancing its response to epithermal neutrons we aim to gain direct access to the dependence of the neutron flux on the time-of-flight and thus neutron energy. The harsh radiation environment – a consequence of the proximity to the spallation target – poses a challenge for any detector. Single neutron interactions in the diamond detector are expected to be unresolved due to the extremely intense neutron flux. Thus, a direct measurement of the continuous detector current is proposed.

Requested protons: 7×10^{17}.
Experimental Area: NEAR

1 Introduction

The new experimental area of the n_TOF facility, namely NEAR, has been built at a very short distance from the Pb spallation target (approximately 2.5 m) in order to take advantage of the very high neutron fluence expected and to perform various challenging measurements for various applications [1]. These include activation measurements of extremely small-mass samples and radioactive isotopes and/or of very low reaction cross sections [2]. Furthermore, the high-flux, wide-energy neutron beam can be used for other applications, such as integral measurements relevant to nuclear energy production studies (fission and fusion), irradiation of various materials for radiation damage studies (MGy doses) etc. The neutron beam is transported into the NEAR station through the movable shielding wall of the newly built target-moderator assembly and there is the possibility to use a suitable filter in order to exclude certain energy ranges of the white neutron energy spectrum. Extensive Monte Carlo simulations have been performed in order to optimize the NEAR station beam characteristics and to extract the main features (neutron flux and beam profile, photon and other relativistic particles background etc). The design development and technical characteristics can be found in [3]. The NEAR station has been recently commissioned and a first characterisation has been performed (measurements in 2021, analysis ongoing), on one hand with use of the well established multiple foil activation technique and on the other hand with the moderation-absorption technique, with use of activation samples (Au) at different positions inside a block of polyethylene. Nevertheless, up to date, no measurements have been attempted with an active detector, limiting the possible applications of this unique facility. With the present Letter of Intent we propose to directly measure the neutron fluence at NEAR with use of diamond detectors. The necessary detector development will be undertaken in order for it to cope with the harsh environment. An additional measurement of the beam spot homogeneity will be attempted by varying the detector position perpendicularly to the beam axis, thanks to the small active surface of the detector (4x4 mm^2) with respect to the expected beam spot ($\approx$3-4 cm radius).

2 Experimental conditions and proposed setup

The simulated neutron fluence at the NEAR station with respect to neutron Time-of-Flight (TOF) and energy can be found in Fig. 1 (for a flight path of approximately 2.3 m). The neutron pulse at NEAR, generated by the spallation of a proton pulse (containing 8.5×10^{12} protons), is 10 ms long and the expected neutron fluence presents a severe drop of approximately an order of magnitude below 1 MeV. From simulations, a background of γ-rays and other relativistic particles is expected. Whilst we do not expect an influence on the measurement from relativistic and other MIP (Minimum Ionising Particles) due to their prompt nature, we estimate the delayed γ-background

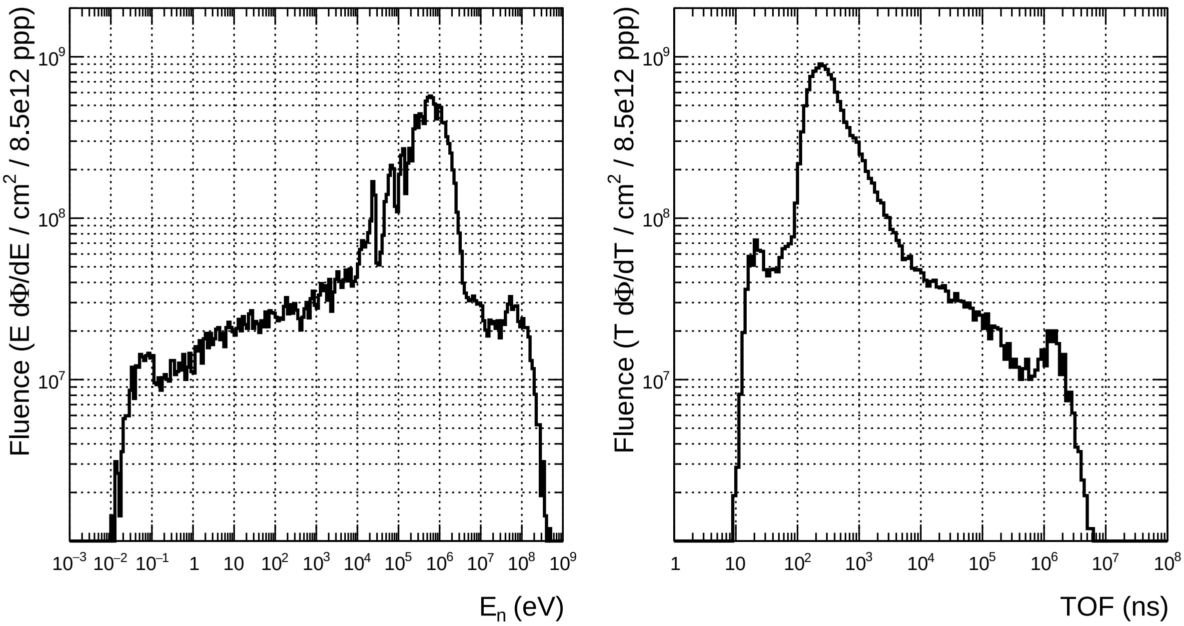

Figure 1: Simulated neutron flux (using the FLUKA Monte-Carlo code) in the center of the beam at the n_TOF NEAR station in neutron energy (left) and time-of-flight for a flight-path of approx. 2.3 m (right).

to not have a severe effect on the measurement of the neutron flux due to the smaller efficiency/deposited energy in the detector.

On the other hand, diamond detectors have been extensively used for neutron induced reaction studies and for neutron fluence measurements (for example [4, 5] etc.). The diamond sensor (allotrope of carbon) is characterised by high radiation resistance, high thermal conductivity and low thermal expansion coefficient (very important for the NEAR station conditions), but also high rigidity, and biological and chemical inertia.
The synthetic diamond that will be used for the measurement proposed in this LoI will be fabricated via the CVD (Chemical Vapour Deposition) technology, from CIVIDEC Instrumentation [6], a company with a longstanding experience of in-beam measurements at the n_TOF facility [7, 8], but also at other neutron beam facilities [9, 10]. The sensor surface will be 4x4 mm^2 and its thickness is chosen to be 50 µm in order to minimise the charge deposited by the background of γ-rays and other minimum ionising particles and due to mechanical considerations. The detection system will be mounted on a specially designed XY-table with the possibility to remotely move the detector perpendicularly to the neutron beam axis and perform the neutron beam profile measurements.
The neutron detection method will depend on the energy of the incoming neutron which spans several orders of magnitude (see Fig. 1). For the detection of fast neutrons (energies greater than 1 MeV) the elastic and inelastic scattering reactions with diamond will be used, which lead to recoil ^{12}C nuclei that deposit energy in the sensor and create the detector signal. Furthermore, the various ejectiles from ^{12,13}C(n,xα/p) reactions will deposit energy in the detector at higher neutron energies. For the detection of low energy

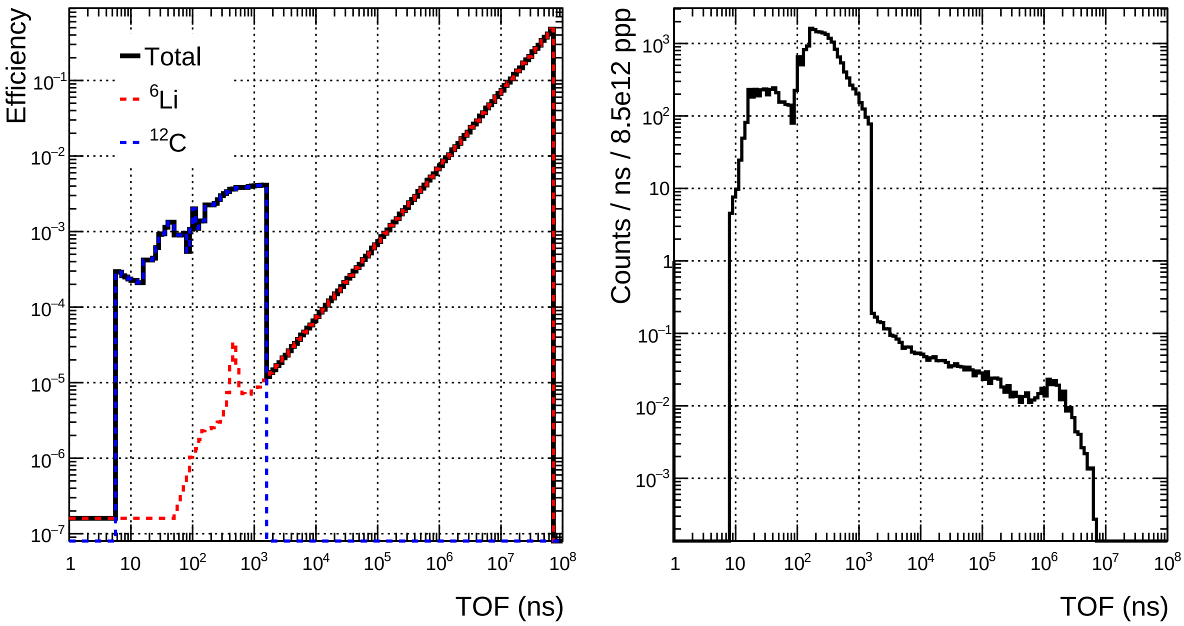

Figure 2: Detector efficiency as a function of neutron energy, distinguishing regions with different neutron reactions (left). Expected count rate in the detector for a dedicated proton pulse of 8.5×10^{12} protons (right).

neutrons, the ^{6}Li(n,t)^{4}He reaction will be used; to this end, a ^{6}LiF converter will be put in front of the diamond sensor and the tritons (t) and ^{4}He will deposit energy inside the detector volume. The resulting efficiency for neutron detection is shown in the left panel of Fig. 2. Taking into account the expected simulated fluence at NEAR (Fig. 1) and the detection efficiency for a single neutron with a given energy, the expected counting rate in the detector can be estimated as shown in the right panel of Fig. 2.

The expected counting rate up to a time-of-flight of approximately 10 µs is too high to resolve individual signals with a width of approx. 1 ns. Instead, the measurement of the detector current will be to used to obtain the neutron flux, at least above approx. 1 MeV. Nevertheless, at lower neutron energies and/or lower proton beam intensities the measurement of the detector charge will also be attempted if an AC readout turns out to be successful.

In order to estimate the detector current, the detection efficiency has to be multiplied by the expected mean charge per interacting neutron in the respective energy region and the neutron fluence which results to the so-called conversion yield corresponding to the charge created in the detector at a given time-of-flight, see left panel of Fig. 3. Whilst for low neutron energies (i.e. large time-of-flight values) the mean charge per interacting neutron is given by a percentage of the Q-value of the ^{6}Li(n,t)^{3}He reaction, the situation for energies above 1 MeV is different and depends on mainly two factors, i.e. the ionizing ejectiles and the incident neutron's energy, and has been determined by Monte-Carlo simulations with GEANT4 [4]. This results in a strong dependency of the detector current with the neutron energy and varies over five orders of magnitude, as shown in the right panel of Fig. 3. The dark current of the detector is well below pico-Ampere.

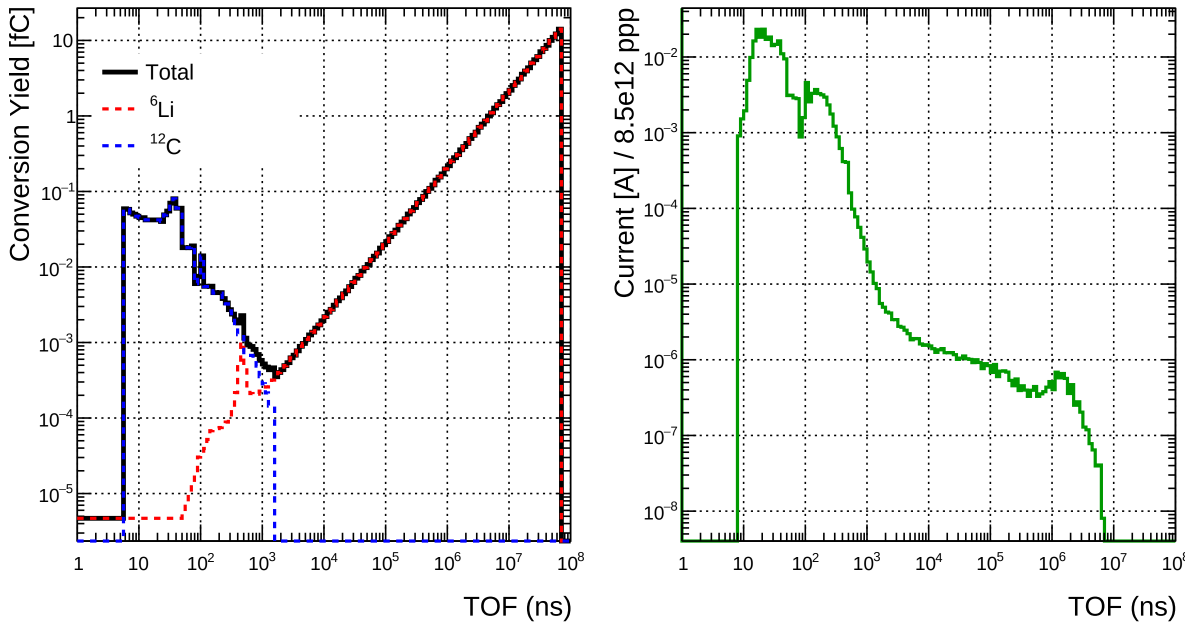

Figure 3: Conversion yield caused by neutrons in the detector (left). Expected detector current for a nominal proton pulse (right).

Due to this strong variation with respect to the TOF, the detector signal will be treated with different preamplifier gains depending on the neutron energy range. For slow neutrons with a time-of-flight longer than 1 μs a high gain readout system will be coupled to the sensor whilst for fast neutrons a low gain readout system will be employed, see for example Fig. 4. The storage of the waveforms of the detector response is foreseen with 10-12 bit oscilloscopes or similar devices well suited for this dynamic range, and will be analysed with existing software.

For this measurement, we request 7×10^{17} protons split between the following tasks (indicative planning, depends on the progression of the measurement):

- 2×10^{17} – debugging + intensity ramp
- 2×10^{17} – central position
- 1×10^{17} – beam homogeneity scan of the NEAR collimator $10 \times 10\,\mathrm{cm}^2$ in 0.5 cm steps
- 1×10^{17} – with B_4C filter to evaluate filtered neutron fluence, useful for activation measurements [2]
- 1×10^{17} – no ^{6}Li converter, central position (elastic ^{12}C + delayed photons estimation)

Summary of requested protons: 7×10^{17}.

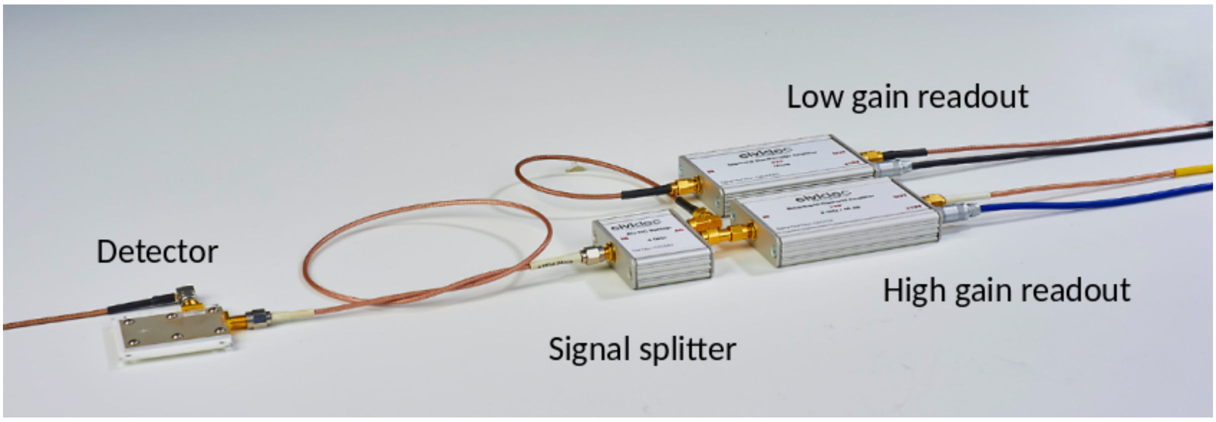

Figure 4: Symbolic image of the whole detector chain with the different electronics.

References

[1] A. Mengoni et al., CERN-INTC-2020-073; INTC-I-222 (2020)

[2] E. Stamati et al., CERN-INTC-2022-008; INTC-P-623 (2022)

[3] M. Ferrari et al., arXiv (2022)

[4] P. Kavrigin, PhD TU Wien 2018, Neutron Spectroscopy with sCVD diamond detectors

[5] M. Angelone and C. Verona, Review-Properties of Diamond-Based Neutron Detectors Operated in Harsh Environments, J. Nucl. Eng. 2021, 2, 422–470

[6] CIVIDEC Instrumentation, https://cividec.at/ (2022)

[7] C. Weiss, PhD TU Wien (2014), A CVD Diamond Detector for (n,α) Cross-Section Measurements (2014)

[8] C. Weiss et al., Nucl. Instr. Meth. A 732 (2013), 21, 190–194

[9] C. Cazzaniga and C. D. Frost, J. Phys.: Conf. Ser. 1021 012037 (2018)

[10] E. Griesmayer, International Conference on Research Reactors: Safe Management and Effective Utilization; Vienna (Austria); 16-20 Nov 2015; IAEA-CN–231-A.17