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DIAMOND DOSIMETER FOR THE MEASUREMENT OF THE PROTON BEAM IMPACT POSITION ON A NEUTRON SPALLATION TARGET

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Abstract

In close proximity to the spallation neutron source of the neutron time-of-flight facility n_TOF at CERN, diamond dosimeters were installed to characterise the fast neutron beam. The intensity of the 20 GeV/c proton beam from CERNs Proton Synchrotron (PS) is monitored with a beam current transformer (BCT) installed in the PS extraction line to n_TOF. The proton beam position is measured using a SEM grid 3 m before the spallation target. A linear correlation between the horizontal proton beam impact position on the Pb-target and the measured dose of the secondary radiation at the measurement station for each pulse is observed. While the proton beam impact position varies by 22 mm, the normalised dose varies by 17 %. The linearity of the diamond dosimeter and the correlation of proton beam position and detector response are presented.

INTRODUCTION

Close to the n_TOF Pb-spallation target at CERN [1, 2], as shown in Fig. 1, the high-flux irradiation station NEAR is in operation since 2021 [3]. The measurement station for neutron activation measurements a-NEAR is located 2.3 m from the center of the spallation target at 100° with respect to the impinging proton beam. The measurement station is installed behind a shielding wall with embedded neutron collimator. At this measurement station two diamond dosimeters were installed to measure the neutron flux as function of time-of-flight (TOF).

The PS accelerator [4] delivers 20 GeV/c proton bunches with a maximum repetition rate of 0.8 Hz on the spallation target. The proton beam intensity can be varied, with a nominal value of 8.5e12 protons/bunch in 16 ns FWHM for dedicated bunches to n_TOF. The beam size on target is σ = 34 mm horizontally and σ = 16 mm vertically for dedicated bunches [5, 6].

The simulated neutron fluence spectrum [7] of the neutron beam at a-NEAR as a function of TOF is shown in Fig. 2. The integrated neutron flux at the center of the collimator at a-NEAR is ≈1.51e9 n/cm^2/7e12 protons/bunch. Neutrons arriving within the first 100 ns have an energy of 3 MeV < E_n < 300 MeV and can be measured with a diamond detector without additional neutron converter [8, 9]. The neutron rate in this TOF window is 100-1000 n/ns/cm^2. This very high neutron rate allows a direct dosimetric measurement of the neutron beam, without the need of amplification.

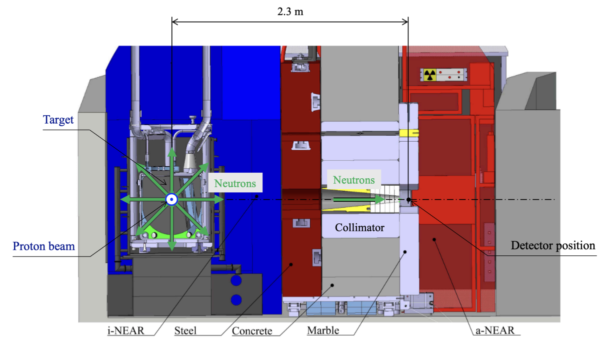

Figure 1: Model of the n_TOF spallation target with the neighboring measurement station for neutron activation measurements, the so-called ”a-NEAR”, where diamond dosimeters were installed to measure the fast neutron beam.

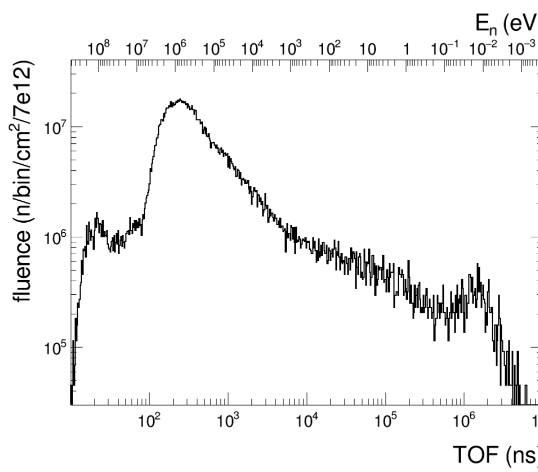

Figure 2: Neutron fluence at a-NEAR as function of time-of-flight. Neutrons with E_n > 3 MeV arrive in the first 100 ns at the detector position.

EXPERIMENTAL SETUP

Two diamond dosimeters equipped with single-crystal chemical vapour deposition (sCVD) diamond sensors with 50 µm thickness and 4 mm × 4 mm active area were used for fast-neutron beam monitoring at a-NEAR. The detectors

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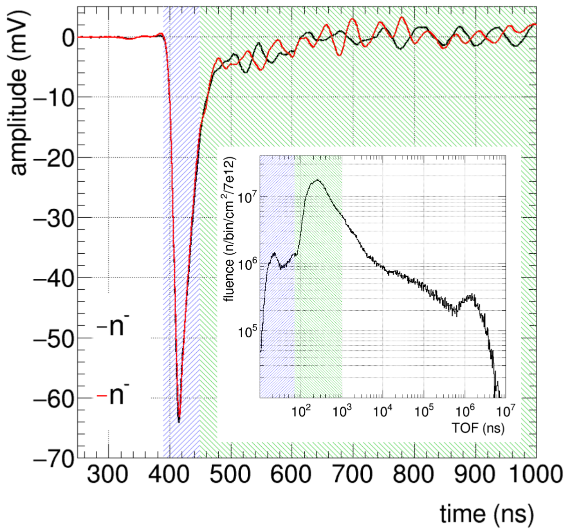

Figure 3: Diamond detector responses of the two diamond dosimeters (n^- and n^+) to the secondary neutron beam at a-NEAR. The integration window is marked in blue.

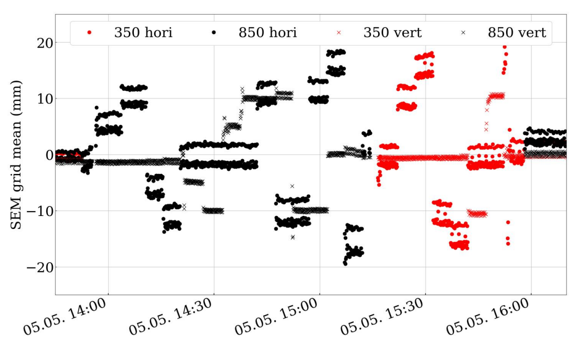

Figure 4: SEM grid data for the proton beam position during the horizontal and vertical scan. Two different beam intensities were used, 350e10 (red) and 850e10 (black) protons/bunch.

are read out on the low-voltage side of the sensor. The sensors are biased with 50 V, corresponding to 1 V/µm, and both detectors (n^+ and n^-) feature charging capacitances of 111 nF to support the electric field in the sensor during high ionization.

Fast neutrons as well as charged particles arriving in the first 100 ns at a-NEAR induce a strong ionisation signal in the diamond sensor. The induced current signal is transmitted without amplification by an 80 m long readout cable to the n_TOF data-acquisition-system (DAQ).

Examples of recorded direct signals from the two dosimeters are shown in Fig. 3, together with the simulated TOF-neutron spectrum. The time window marked in blue corresponds to the sum signal induced by fast neutrons. The signals are integrated in this time window to determine the deposited charge in the sensors and recorded together with the proton beam intensity of the spill.

The proton beam intensity is determined using a beam current transformer (BCT) [10], installed in the PS extraction line, 5.5 m before the n_TOF spallation target. The proton beam position on the spallation target is measured with a SEM grid [11], 3 m before the spallation target. A detailed description of the n_TOF facility and beam monitoring equipment is given in Ref. [12].

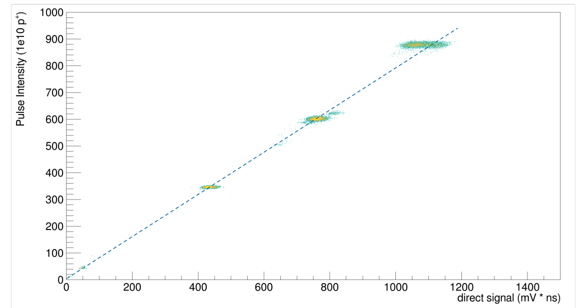

Figure 5: Diamond detector response as function of the proton beam intensity at a-NEAR.

The mean beam impact position on target was varied by ± 20 mm horizontally and ± 10 mm vertically, to study the correlation between proton beam position on target and diamond dosimeter response. The SEM-grid measurements of the proton beam positions during the experiment are shown in Fig. 4.

A scatter plot of the integrated direct signals, marked in blue in Fig. 3, in relation to the proton beam intensity of the spills is shown in Fig. 5. Each spill is one entry in the histogram and the occurrence is encoded in color. The relation between detector signal and proton beam intensity is linear.

RESULTS

A scan of the horizontal and vertical proton beam position on target was performed. The secondary neutron beam was measured using the diamond dosimeter at a-NEAR.

The proton beam intensity was switched between 3.5e12 and 8.5e12 protons/bunch. The diamond signal was integrated over 100 ns, to measure the contribution of fast neutrons and normalized to the proton beam intensity.

The normalized diamond signal as a function of horizontal proton beam position is shown in Fig. 6. Each spill is shown as one point in the scatter plot. The proton beam intensity is encoded in color.

The relation between beam position h_{SEM} and detector signal Q_{det} is linear. A linear fit to the data results in

$$Q_{det} = 1.225 - 0.01 \cdot h_{SEM}, \tag{1}$$

where h_{SEM} is given as beam position at the SEM grid.

According to the operation team of the PS accelerator [5], the beam position on target is $1.12 \cdot h_{SEM}$ [mm]. This results in 1% change in detector response per 1.3 mm horizontal beam position shift on target.

A vertical position scan of the proton beam was performed, with a variation of ± 10 mm. Results are shown in Fig. 7. The variation of the vertical proton beam position on the

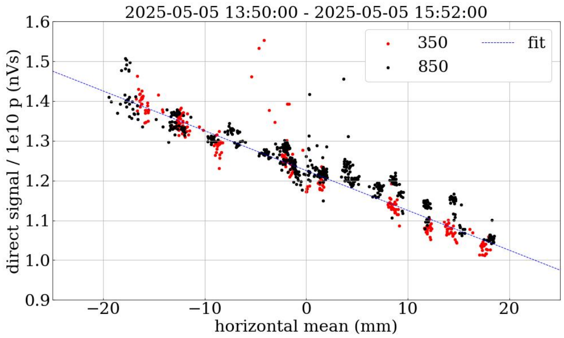

Figure 6: Diamond dosimeter response as function of the horizontal proton beam position at the SEM grid, for proton beam intensities of 350e10 and 850e10 protons/bunch, where negative x-values are closer to the detector.

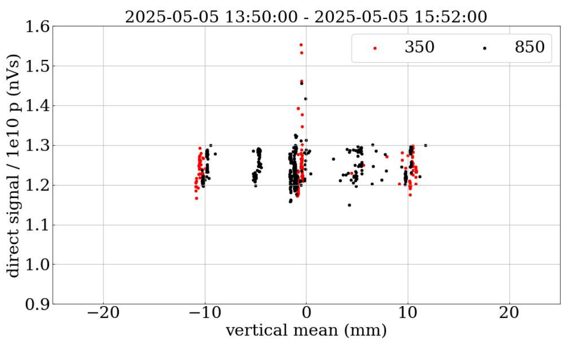

Figure 7: Vertical scan of the proton beam on the n_TOF spallation target and the corresponding diamond detector response. The vertical proton beam position does not influence the fast-neutron beam at a-NEAR.

spallation target does not have an effect on the fast-neutron beam at n_TOF NEAR.

CONCLUSION

The beam impact position of the primary proton beam of CERNs PS accelerator on the n_TOF Pb-spallation target was measured using diamond dosimeters, installed in the secondary neutron beam of the a-NEAR measurement station. The dosimeters were located horizontally, 2.3 m from the center of the spallation target. Due to the high neutron rate of the fast-neutron beam at a-NEAR, the diamond detector signals could be read-out directly, without additional amplification.

For redundancy, two diamond dosimeters of the same type were used for the measurements at a-NEAR. The detectors show comparable results to the fast-neutron beam.

The linearity of the diamond detectors was tested with varying proton beam intensities, as shown in Fig. 5. A linear correlation between dosimeter response and proton beam intensities is observed.

The mean proton beam impact position was varied in the experimental campaign by ±20 mm horizontally and ±10 mm vertically on the SEM grid, installed 3 m before the target. The nominal beam size on target is $\sigma = 34$ mm horizontally and $\sigma = 16$ mm vertically.

The proton beam intensity on target was changed between 3.5e12 and 8.5e12 protons/bunch, to identify a potential beam intensity dependence of the measurement results.

The vertical scan of the proton beam position does not have an impact on the response of the diamond dosimeter. On the other hand, a linear correlation is observed between detector response and horizontal proton beam position, as shown in Fig. 6.

A 1.3 mm horizontal beam position shift on target results in a 1 ‰ change in detector response to the secondary neutron beam. This gives an indication on the change of neutron flux of the fast-neutron beam at a-NEAR, as function of the proton beam impact position.

The results of this measurement campaign show the feasibility of using diamond dosimeters for indirect measurements of the primary beams impact position on a neutron spallation source, with a sensitivity of 1 ‰ per 1.3 mm beam position change on target.

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