Proton-recoil spectrometer for fast neutron spectrum based on GEM gas detector

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Measurement of neutron energy spectra can provide information on various plasma parameters, such as: ion temperature, plasma rotation or fuel ion ratio n_T/n_D [1]. The measurement of the intensity of the various components of the neutron spectrum produced by plasma heating is of particular interest as it allows determining the fuel ion ratio distribution in the plasma core of a fusion reactor, such as ITER [2].

The common types of neutron spectrometer make use of the Time-of-Flight (ToF) or thin-foil proton recoil (TPR) techniques. Neutron spectroscopy results have been shown for a number of different ToF designs on different tokamaks [2-4]. Besides, several systems have been installed and used during deuterium-tritium campaigns at JET and TFTR, specifically the TANDEM and MPR systems at JET [5]. More recent experimental results with a synthetic (CVD) single crystal diamond detector, during pure deuterium JET plasma operation, have shown the spectroscopic capability of diamond detectors for both 2.5 and 14 MeV neutrons [6].

An important part of the ITER neutron diagnostics system will be the High Resolution Neutron Spectrometer (HRNS), whose main task is to provide the measurement of the fuel ion ratio n_T/n_D. The following requirements for the HRNS should be met: recording a sufficient number of counts at a fixed time resolution, ensuring adequate count rate capability for individual detectors and providing a sufficiently large dynamic range for the fusion power. The method proposed in the HRNS conceptual design [7] to measure the fuel ion ratio is based on precise measurement of thermal and beam-thermal components of the neutron spectrum. For this purpose, the HRNS system must include a set of four different neutron spectrometers to achieve the range of parameters required by ITER, see Fig. 5 in [7].

One of these spectrometers is based on the Thin-Proton-Recoil (TPR) method, in which elastic collisions between incident neutrons and recoil protons in a thin polyethylene film are exploited to estimate the energy of neutrons. The kinetic energy of recoil protons is:

$$E_p = E_n \cos^2 \theta, \tag{1}$$

where E_n is the incident neutron kinetic energy, E_p is the energy of the recoil proton and θ its scattering angle. For the detection of recoil protons in a TPR spectrometer, segmented silicon detectors are assembled into three independent systems placed in vacuum, see Fig. 6 in [7]. Such a spectrometer based on a narrow range of proton recoil directions is generally known as proton recoil telescope and has been used for a wide variety of fast neutron measurements. One of the issues of such system is poor resistance of silicon detectors to the strong background of neutron radiation. Hence, the idea of using a Gas Electron Multiplier (GEM) type detector in this technique, so-called NS-GEM, has been worked out. Using a neutron collimator, this type of GEM could allow recording the proton tracks in the detector drift space, as well as estimating the proton energy loss in the gas mixture. Such measurement in the GEM detection volume will always be associated with errors in both the proton angle $\theta + \delta\theta$ and the kinetic energy $E_p + \delta E_p$. The reconstructed neutron energy will be estimated as follows:

$$E_{n,rec} = \frac{E_p + \delta E_p}{\cos^2(\theta + \delta\theta)}, \tag{2}$$

and therefore

$$E_{n,rec} \approx \frac{E_p + \delta E_p}{\cos^2(\theta)} \left(\frac{1}{1 - \delta\theta \tan\theta}\right)^2 \approx E_n + \frac{\delta E_p}{\cos^2(\theta)} + 2E_n \delta\theta \tan\theta. \tag{3}$$

Hence, the relative error is expressed by the formula:

$$\frac{E_{n,rec} - E_n}{E_n} \approx \frac{\delta E_p}{E_p} + (2\tan\theta)\delta\theta. \tag{4}$$

One can see from the above formula that the highest energy resolution can be obtained for protons scattered in the same direction as the incident neutrons. The layout of the baseline measurement geometry of the considered NS-GEM detector and the cross-section of the detector structure is shown in Fig. 1.

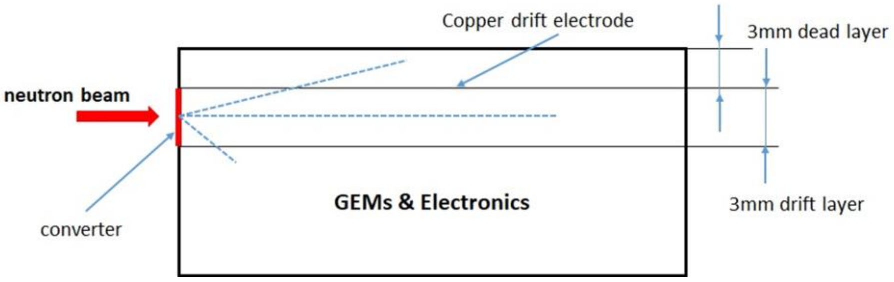

Figure 1. Detector geometry - conceptual sketch of the NS-GEM detector design

For the demonstrator detector, we use a compact GEM chamber of dimensions $10 \times 10\ cm^2$, which is not sufficiently large to measure the total energy of recoil protons. Therefore, the proton energy is estimated from measurement of specific energy losses *dE/dx* in the active detector volume. Note that the range of 14 MeV protons in the used $ArCO_2$ gas mixture is about 2 meters at 1 atm. pressure. The simulations of energy losses along the proton tracks in the 10 cm long active detector volume were done for $ArCO_2$ 70/30 gas mixture at pressure of 1, 2 and 3 atm. An example of simulation at the gas pressure of 1 atm. is presented in Fig. 2.

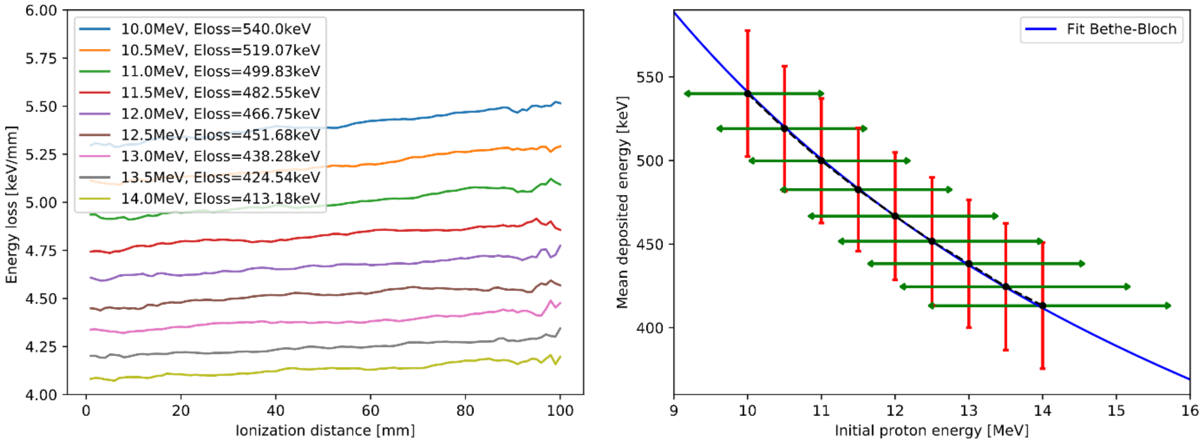

Figure 2. Proton energy losses in active detector volume flushed with $ArCO_2$ gas mixture at pressure of 1 atm.: (left) energy losses along the tracks, (right) total energy loss vs initial proton energy.

By integration of these energy losses, one obtains the total mean energy deposited in the active detector volume for a given initial proton energy. In the right plot, red error bars represent the statistical fluctuation of deposited energy, while green error bars indicate the resulting precision of reconstructed proton energy. Thus, these results confirm the possibility of using specific energy losses for reconstructing the recoil protons energy, although measurements at higher gas pressure would allow obtaining a better resolution of specific energy losses *dE/dx* (see Fig. 3).

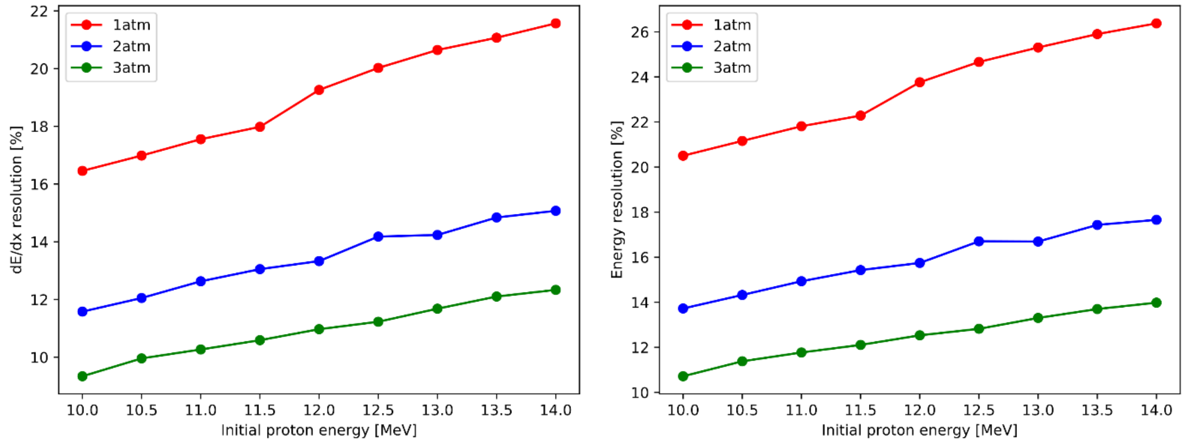

Figure 3. Resolution of specific energy losses *dE/dx* (left) and resulting resolution of initial proton energy identification (right) for 10 cm absorption distance in $ArCO_2$ at three different pressures.

One can summarize the NS-GEM compact detector concept in the following:

- The highest energy resolution will be obtained by selecting the protons scattered in the same direction as the incident neutrons.
- A horizontal geometry was proposed with the converter placed directly on the inner wall of the drift area of the GEM detector.
- The results of the simulation of energy losses along the proton tracks in the 10 cm long drift area of the detector clearly confirm the possibility of using specific energy losses to estimate the total proton recoil energy; the resulting resolution of the energy loss *dE/dx* is between 10 and 12% FWHM at 3 atm. pressure.
- The energy resolution can be improved further by building a larger GEM chamber.

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