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GEM-based Thermal Neutron Detector Prototype Using Boron-carbide Converter

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1. Introduction

Since the last decade, with the shortage [1] of ^{3}He, the most common isotope used in neutron detection, the scientific community started to pursue viable neutron detection methods using alternative isotopes such as ^{157}Gd, ^{10}B, and ^{6}Li, which also have high neutron capture cross-section. At the same time the interest in neutron science increased due to the several advances in scattering techniques, widely used in many areas such as chemistry, physics, biology, medicine, and engineering research. These advances depends on detector development which also grew in the last years, together on the ability to obtain bright monochromatic neutron sources, whether in large or small facilities [2].

Gaseous detectors are still an important choice for several applications, mainly the ones that require big volumes. Technologies like the Gas Electron Multipliers (GEMs) [3] became widely used in several experiments [4–7]. Some approaches combine neutron converters with GEMs, several of them requiring advanced electronics that have to be considered within the experiment project [8–10].

In this project, we present our detector prototype that consists of a 10 cm $\times$ 10 cm double GEM stack with an aluminum cathode, coated with a 2.2 µm thick $^{10}B_4C$ layer, which deposition was provided by the European Spallation Source (ESS). Thermal neutrons are absorbed by the boron via $^{10}B(n,\alpha)^7Li$ reaction, helium and lithium ionize the $ArCO_2$ (90/10) gas of the detector active volume, which is about 1 L in open flow. After passing the two-stage multiplications in the GEMs, the electrons are captured in a 256$\times$ 256 strips readout manufactured by CERN. The strips are read using resistive chains, using therefore only 4 DAQ channels, which provides the versatility of detection without the need for advanced electronics. A fifth channel is then used to collect the share of electrons from the multiplication that reaches the lower GEM's bottom.

2. Methodology

Our prototype was tested at the IEA-R1 nuclear reactor at the Nuclear and Energy Research Institute (IPEN), in São Paulo, with a 1.4 Å wavelength monochromatic neutron beam, same used in AURORA diffractometer [11]. The neutron image is reconstructed using the four signals collected at the end of the resistice chains, shown in Fig. 1.

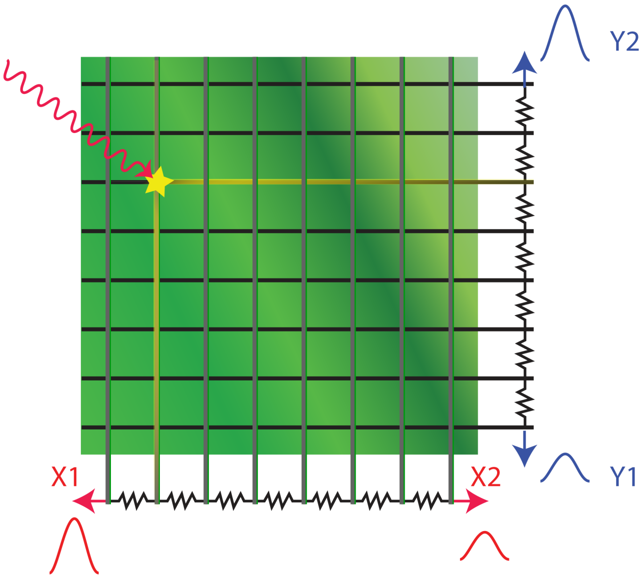


Figure 1: Sketch of the strip readout, representing the intensity of the four signals at each end of the resistive chains for each direction (X and Y), due to the electrons collected at the yellow star location.

The image is constructed using [7]:

$$X = A\frac{X_2 - X_1}{Q}, \qquad Y = B\frac{Y_2 - Y_1}{Q} \tag{1}$$

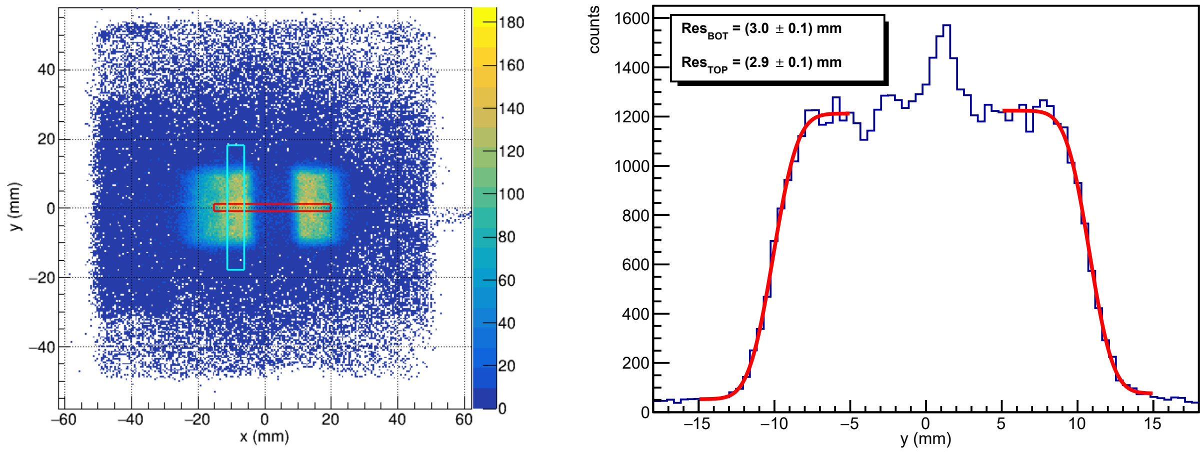
where A and B are constants to fine adjust the image proportions, and Q is the event charge information, read at the bottom of the lower GEM.

Since our detector has position sensitivity, the position resolution was evaluated. We used two methods: the first consists of fitting edge spread functions (ESF) to the image of steps created by adding cadmium masks with straight borders in front of the neutron beam, as shown in Figure 2. The second method use the images of cadmium masks with circular holes, studying how the full width at half maximum (FWHM) varies as function of the hole diameter (Fig. 4).

The detection efficiency is defined as the ratio between the number of detected neutron and the integrated neutron fluence on the sensitive area of the detector:

$$\varepsilon = \frac{N_{det}}{N_{tot}} = \frac{n}{\phi A \Delta t}, \tag{2}$$

where N_{tot} is the total of neutrons that encountered the sensitive area of the detector, n is the number of events collected, ϕ is the measured neutron flux of the beam, A is the effective area exposed to the beam, N_{det} the number of events, and Δt the time of acquisition. The neutron flux equals $6.22(19) \times 10^4\,\mathrm{n\,cm^{-2}s^{-1}}$ and was measured by the nuclear metrology laboratory of the reactor facility using the $^{197}\mathrm{Au}(n,\gamma)^{198}\mathrm{Au}$ reaction.



(a) (b)

Figure 2: Evaluating the spatial resolution of two regions of the readout by using edges. One of the images obtained with cadmium masks with the regions used for analysis highlighted by the rectangles **(a)**. Projections of the vertical (cyan) rectangle of **(a)**, with the two ESF fits **(b)**.

3. Results and Discussion

As discussed in the previous section, we used two methods to determine the spatial resolution. The first consists of fitting an ESF (the Erf function in this case), as shown in Figure 2. This method was applied to different regions of the detector and proved to be simpler and more convenient than using calibration slits, which are difficult to be produced due to the softness of the cadmium.

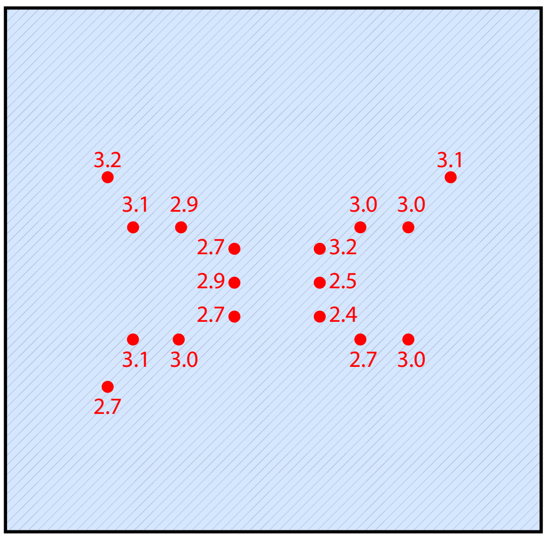
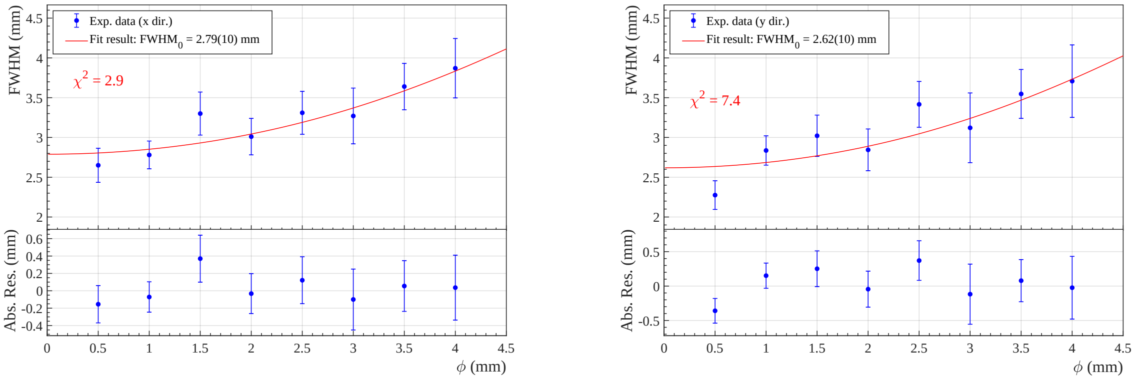


Figure 3: Spatial resolution (in millimiters), obtained via the edge method, for some position over the detector plane.

The reconstructed image of a circular beam equals the convolution between a flat profile inside the circular region and the response function of the detector, which can be considered a gaussian. Considering the image profiles of holes with different diameters, we can fit this dependence (that is not expressed in terms of commons functions) and obtain the FWHM of the response function that corresponds to the spatial resolution, by definition. This process was performed for both directions x and y, as shown in Figure 4.



(a) $R_X = 2.79(10)\,\text{mm}$. (b) $R_Y = 2.62(10)\,\text{mm}$.

Figure 4: Fits of the dependence between holes diameter and its FWHM, for holes with different diameters, in X **(a)** and Y **(b)** directions.

The two methods consistently provided spatial resolution better than 3 mm for the whole detector. The obtained detection efficiency for this prototype was 2.66(30) %, compatible with theoretical calculations that predicted it to be 2.79(49) %.

4. Conclusions

Our prototype showed the capability of detecting neutrons with interesting spatial resolution and efficiency using just 5 electronic channels and presented nice detection stability (rate and tensions) for long runs. Last but not least, the detector has negligible sensitivity to the gamma rays spectrum present in a nuclear reactor environment, a key feature for research carried out in these facilities. In this work, we will also discuss further steps to enhance detection efficiency.

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