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Performance and Optimization of a GEM-based Neutron Detector Using a Parameterized Fast Simulator

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1. Introduction

In view of the lack of ^{3}He [1], widely used in neutron gaseous detectors, substitutes need to be studied to continue producing this kind of detectors. Some common isotopes are under investigation like ^{10}B, ^{6}Li and ^{157}Gd due their high cross-section to neutron capture.

Gas Electron Multipliers (GEM) [2] belong to the family of Micro-Pattern Gaseous Detectors (MPGD), which are widely used in particle tracking systems, as the Time Projection Chamber of the ALICE experiment in the LHC-CERN [3], and can be used for many other applications, including neutron detection.

Neutrons can be detected indirectly through a nuclear reaction where the products are ionizing radiation. In our application, we are using ^{10}B as a neutron converter to induce the nuclear reaction:

$$^{10}\mathrm{B} + \mathrm{n} \longrightarrow \begin{cases} ^{4}\mathrm{He} + ^{7}\mathrm{Li}: & 2.792\ \mathrm{MeV}\ \text{(ground state, about 6\%)} \\ ^{4}\mathrm{He} + ^{7}\mathrm{Li}^{*}: & 2.310\ \mathrm{MeV}\ \text{(excited state, about 94\%).} \end{cases} \tag{1}$$

In this study, we are investigating the performance and optimization of a GEM-based detector to measure thermal neutrons from a nuclear reactor by means of computer simulation, using Geant4 [4] and Garfield++ [5]. These two frameworks allow us to study the GEM in various conditions and with a detailed description of electron avalanche through the gas and its induced signal. To perform the simulations in adequate computing time, we developed a strategy using a parameterization of the response function that describes the charge collection at the detector's anode.

2. Methodology

The nuclear reaction, as described in Eq. 1, was simulated in the Geant4 tool using a physics list with high precision models for low energy neutrons [6], *QGSP_BERT_HP*, impinging 41.8 meV thermal neutrons perpendicularly to a ^{10}B layer.

A full description of the GEM structure was performed by employing the Garfield++, with the electric field calculated in Elmer [7], using the finite element method. The ionization that occurs in the gas due to low-energy ions was simulated using SRIM[8], while the properties of electrons in the gas mixture was determined with Magboltz [9].

A complete simulation of the transport of the electrons in the gas following the $^{10}\mathrm{B}(n,\alpha)^{7}\mathrm{Li}$ reaction is very time consuming due the high ionizing power of these products. Thus, we developed a fast simulator that uses a parameterization of the response function describing the charge deposited at the detector's read out plane. Fig. 1 shows a schematic view of this strategy.

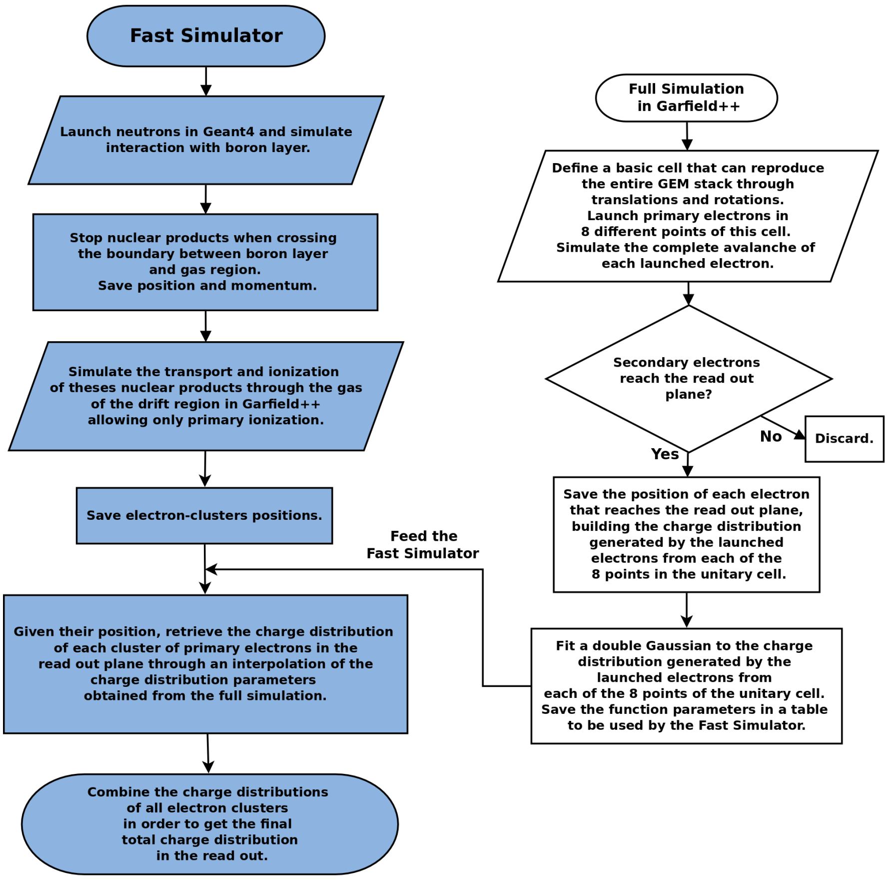


Figure 1: Fast simulator diagram flow.

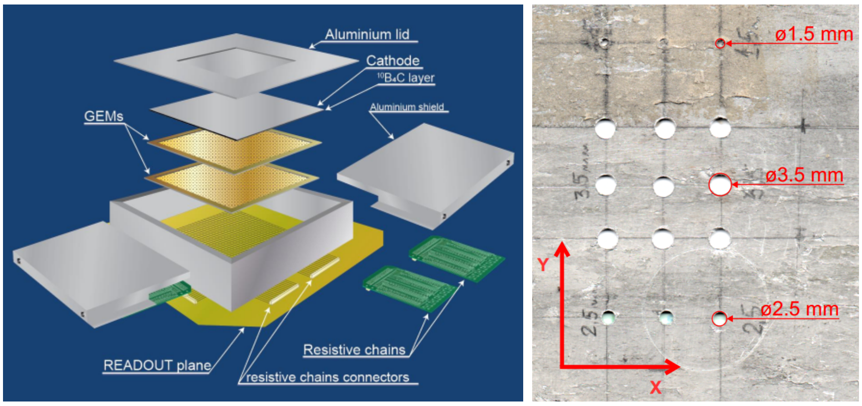
In order to validate the simulations we used the experimental data obtained with a double-GEM prototype operating with $\mathrm{Ar/CO_2}$ (90/10) gas mixture. The apparatus consists of two GEM foils with a stack of 0.5 mm thick aluminum cathode coated with enriched boron carbide. The distance between the aluminum lid and the cathode is 3 cm. The drift, transfer and induction regions were set to 2 mm, 1 mm and 1 mm thick and bias of 100 V, 300 V and 400 V, respectively. A schematic view can be seen in the Fig. 2a.

In order to obtain the position calibration and give an estimate for the position resolution, a cadmium mask was inserted right in front of the detector. The mask has a set of holes with diameters of 1.5 mm, 2.5 mm and 3.5 mm, shown in Fig. 2b.

3. Results and Discussion

The charge distribution at the read out given by the fast simulator and the experiment is shown in Fig. 3a. The experimental spectrum presents an energy threshold corresponding to a charge collection of approximately 100 fC. The neutron hit position for the three central holes is shown in an x-axis projection in Fig. 3b.

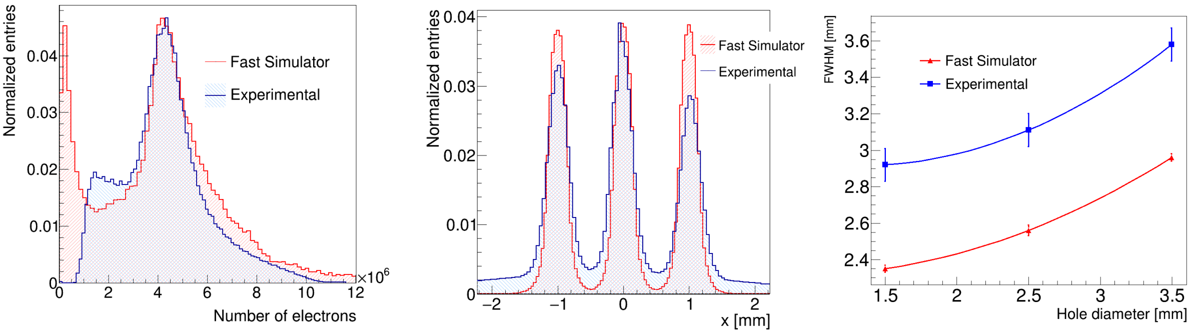
A comparison between the FWHM of simulated charge distributions and the measured ones for



(a) Double-GEM detector prototype. (b) Cadmium mask.

Figure 2: Experimental prototype.

the 3 different holes is shown in Fig. 3c. The differences observed in this comparison can be due to noise, lack of homogeneity in neutron beam and other effects that were not considered in the simulation and are under investigation.



(a) Spectrum of charge collected at the read out plane. (b) Projection in x-axis for the three central holes and same diameter. (c) FWHM for 3 diameters.

Figure 3: Preliminary results. Fast simulator results in red and experimental results in blue.

In order to evaluate the performance of the fast simulator, a benchmark shows that the fast simulator is 4 orders of magnitude faster than the full simulation, using a Intel Core i5-8265U CPU @1.60 GHz and 8GB of RAM. The full simulation spend an average of 42 hours against 16 seconds of the fast simulator for 1 event (or 1 thermal neutron).

4. Conclusions

The parameterized fast simulator shows a great improvement in the processing time allowing more detailed analyses of such detectors through simulations. The comparison between the fast simulation and the experimental data shows good overall agreement but further investigations on the influence of the background and electronic noise must be carried on to improve the simulations.

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