Development of a fast simulator for GEM-based neutron detectors

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Introduction

Due to the shortage of helium-3, widely used in neutron gaseous detectors, alternatives need to be studied to continue producing this kind of detectors. The Gas Electron Multiplier (GEM) detectors [1] are a type of Micro-Pattern Gaseous Detectors (MPGD), widely used in particle tracking systems, as the Time Projection Chamber of the ALICE experiment in the LHC-CERN [2], and proposed 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:

$$^{10}B + n \longrightarrow ^{4}He + ^{7}Li$$

Most of the time this reaction occurs in the excited state, producing ^{4}He and ^{7}Li with energies about 0.84 MeV and 1.47 MeV, respectively.

Simulation Tools

A common strategy to simulate this kind of detector is based on two frameworks: GEANT4 [3] and Garfield++ [4].

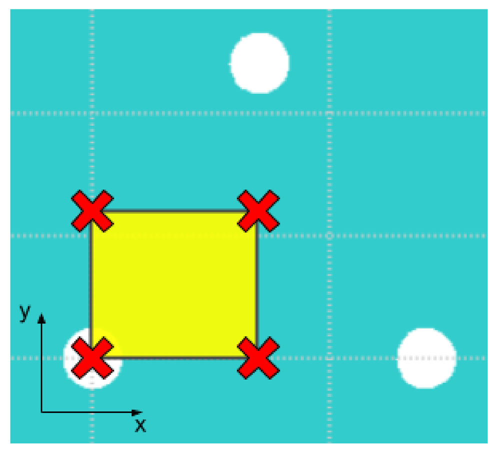
- GEANT4 - Using the physics list *QGSP_BERT_HP*, which has high precision models for low energy neutrons [5], we simulate the nuclear interaction of thermal neutrons with the boron layer, producing charged particles, as well as the transport of these particles inside the detector.
- Garfield++ - The electric field was interfaced with ELMER. The ionization pattern produced by low-energy ions using SRIM [6]. And Magboltz [7] to calculate the transport properties of electrons in gas mixture.

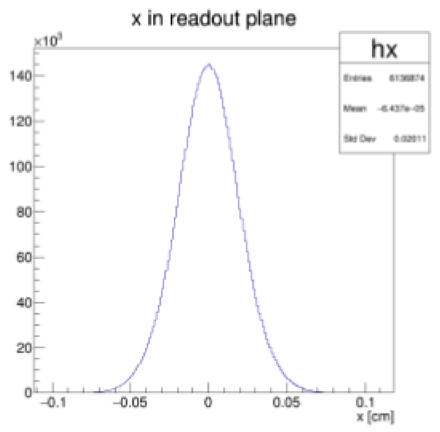
CPU time consuming

Given the high ionizing power of the nuclear reaction products from $^{10}B(n,\alpha)^{7}Li$, a full simulation is very time consuming and must be optimized to become viable.

In this work, we present a strategy to develop a fast simulator based on these two frameworks that will allow to generate enough data for a proper evaluation of the expected performance and optimization of this kind of detector.

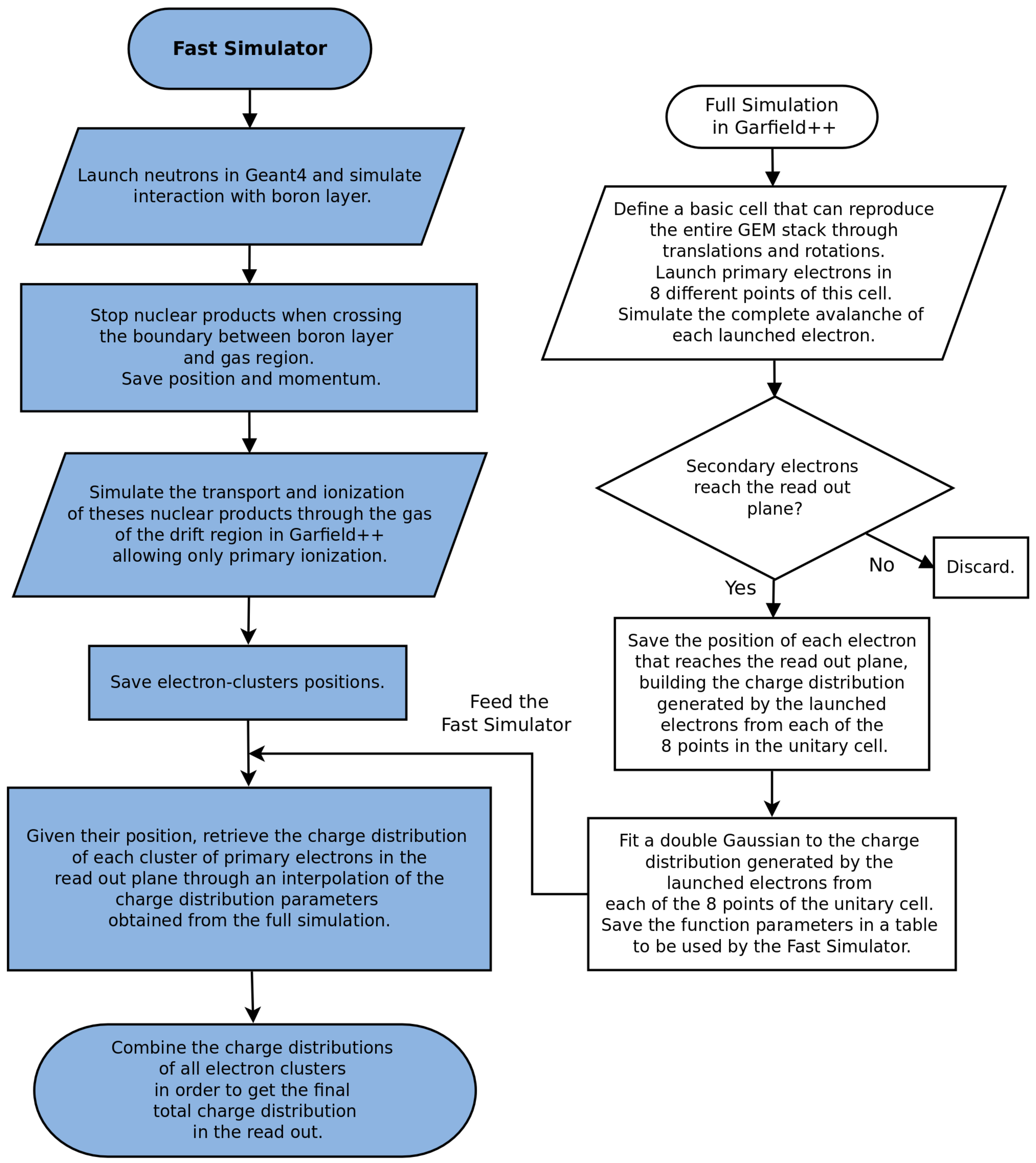
Parametrization Strategies





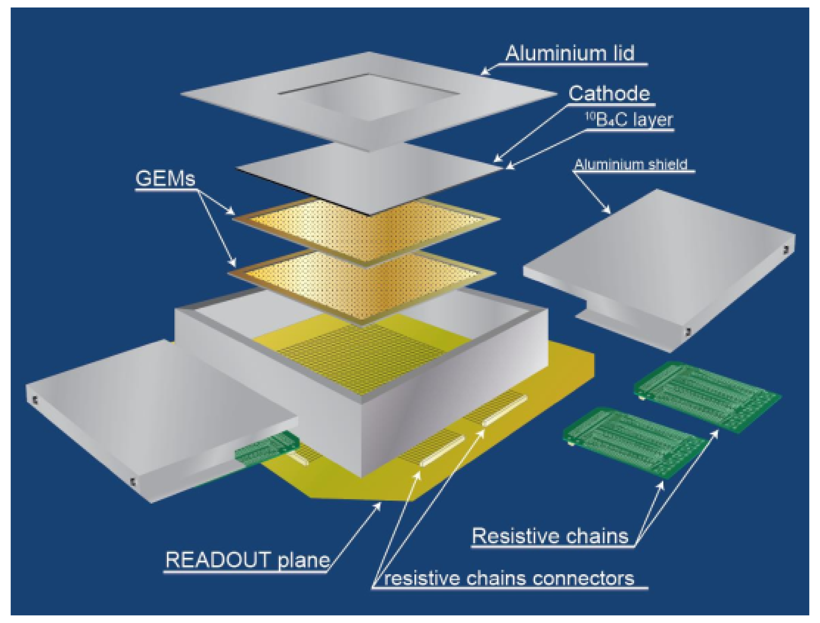
- Basic Cell - Given the symmetry of the GEM foil, the entire detector can be represented by translations and rotations of a unitary basic cell, as represented in the left figure. There is 3 white circles representing the GEM holes. Four points are marked with a red X, corresponding to the positions where the primary electrons are launched in the full simulation in two different z positions. The rectangular area in yellow can be translated and rotated to map the entire GEM.
- Fit - The charge distribution at the read out, as shown in the histogram at left, is better fitted with a double Gaussian.
- Primary ionization - Only in the drift region.

Fast Simulator Flow



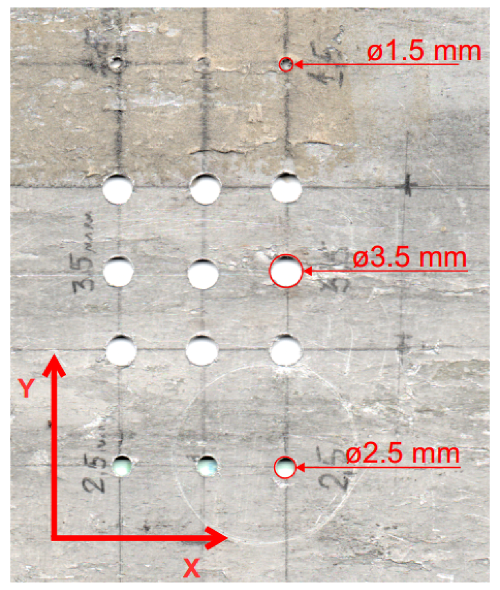
Double-GEM Detector Prototype

In order to validate the simulations, data from a experimental prototype, sketched in the Figure at right, was used. It is a double GEM composed of a stack with a 0.5 mm thick aluminum cathode coated with enriched boron carbide and two GEM foils. The drift, transfer and induction regions was set 2 mm, 1 mm and 1 mm thick and bias 100 V, 300 V and 400 V, respectively. Working with Ar/CO_2 (90/10) gas mixture.



Preliminary Results and Perspectives

A cadmium mask, shown at right, with 1.5 mm, 2.5 mm and 3.5 mm hole diameters was inserted between the neutron beam and the detector to obtain the position calibration and estimate the position resolution. We evaluate the fast simulator with these experimental results. In Fig. 1 we have the comparison of the charge distribution at the read out. An electronic threshold filters signals below, approximately 100 fC. The measurement of the neutron hit position in one of the axis is shown in Fig. 2.



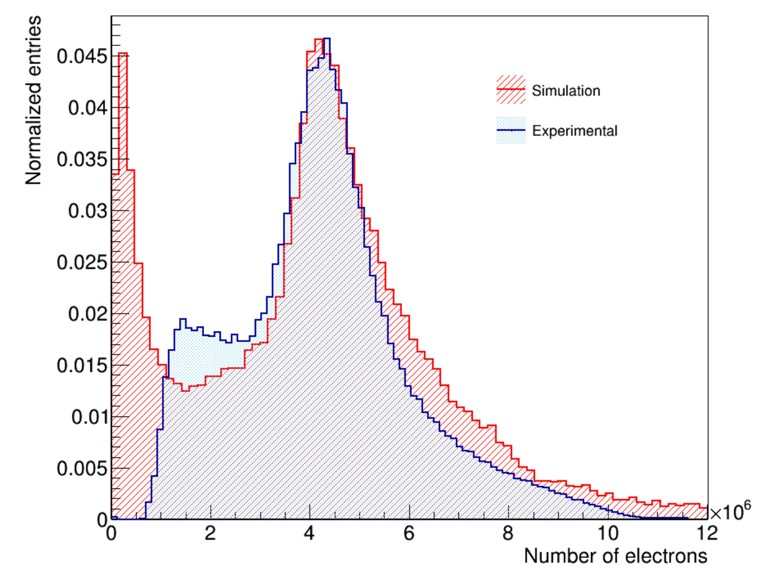


Figure 1. Charge distribution.

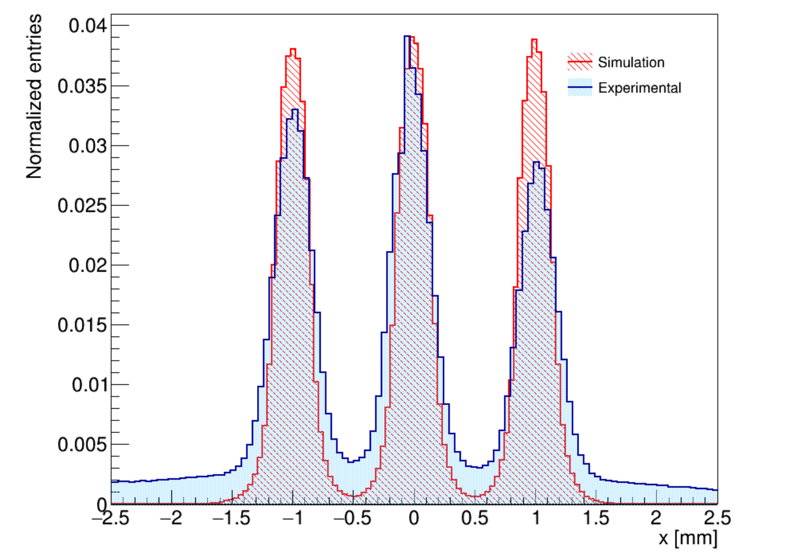


Figure 2. Projection in x axis for the three central holes and same diameter.

Given a set of holes with 3 different diameters we compared the FWHM of the simulated result with the one obtained in the experiment, given in Fig. 3. The differences between the experimental and fast simulator data are largely due to noise, lack of homogeneity in the neutron beam and others effects that were not considered in the simulation.

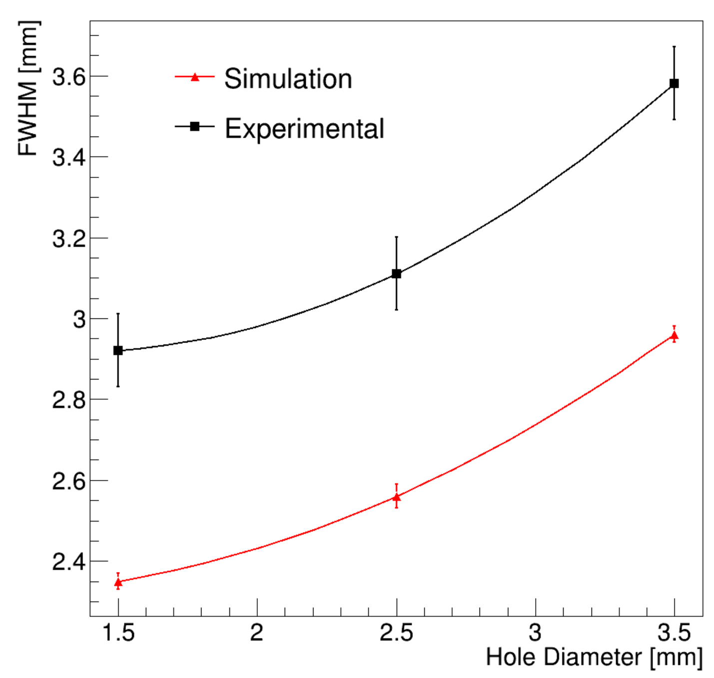


Figure 3. FWHM for 3 diameters.

A benchmark of a full and fast simulator shown that the fast simulator is 4 orders of magnitude faster. Testing in a Intel Core i5-8265U CPU @1.60 GHz and 8GB of RAM, the full simulation spend an average of 42 hours while the fast simulator spend an average of 16 seconds for 1 event.

The next steps in this work consist in a better understanding of the experimental background and electronic noise in order to improve the simulation and to study possible optimization of the detector mainly in terms of position resolution.

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