Journal of Physics: Conference Series

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To cite this article: R. Felix dos Santos *et al* 2022 *J. Phys.: Conf. Ser.* **2340** 012048

XLIV Brazilian Workshop on Nuclear Physics IOP Publishing
Journal of Physics: Conference Series 2340 (2022) 012048 doi:10.1088/1742-6596/2340/1/012048

# Performance and optimization of a GEM-based neutron detector using a parameterized fast simulator

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**Abstract.** Neutrons can be detected indirectly through a nuclear reaction where the products are ionizing radiation. Due to the shortage of $^3$He, several studies are searching for alternatives, where the Gas Electron Multiplier (GEM) detector using a layer of $^{10}$B as a neutron converter is a very promising option. The GEM detectors 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, and proposed for many other applications, including neutron detection. A common strategy to simulate this kind of detector is based on two frameworks: Geant4 and Garfield++. Given the high ionizing power of these nuclear reaction products, a full simulation is very time consuming then a fast simulator was developed using a parameterization strategy based on these two frameworks that allowed to generate enough data to study an optimized version of this detector. In this proceeding, it is shown the optimization that improves the position resolution by changing the gas mixture and/or its pressure.

## 1. Introduction

Due to the absence of electrical charge the detection of thermal neutrons needs to be intermediated by a layer of a material that produces ionizing radiation from a reaction with neutrons. This converter should have a high cross-section for thermal neutrons and the $Q$-value must be as high as possible allowing good discrimination against $\gamma$-rays.

Considering gaseous detectors, the helium-3 was widely used until the early 2000s when the increasing demand for this gas for homeland security and basic research has caused a shortage in the supply [1]. This problem led the researchers to look for a replacement.

As an alternative, we are using a Gas Electron Multiplier (GEM) structure, used in many applications such as particle tracking systems, the Time Projection Chamber of the ALICE experiment [2], and many others, including neutron detection. Combined with a $^{10}$B converter layer, the GEM-detector can detect the reaction products that come from the transmutation reaction, as described in Eq. 1:

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

## 2. Simulation Tools

The combination of Geant4 [3] and Garfield++ [4] is the most common strategy used to deal with the simulation. However, the CPU consumption in this approach is prohibitive due to the large number of primary electrons left by the reaction products to produce the avalanches and track all its secondaries. To overcome this problem a fast simulator was developed to generate enough data for a proper evaluation of the performance and the optimization of neutron detectors based on GEMs.

This fast simulator is based on the parametrization of the charge distribution at the readout, which steps can be seen in Fig. 1. Further details about the fast simulator, as well as its validation, can be found in [5], while this proceeding aims to present preliminary detector optimizations obtained using this tool.

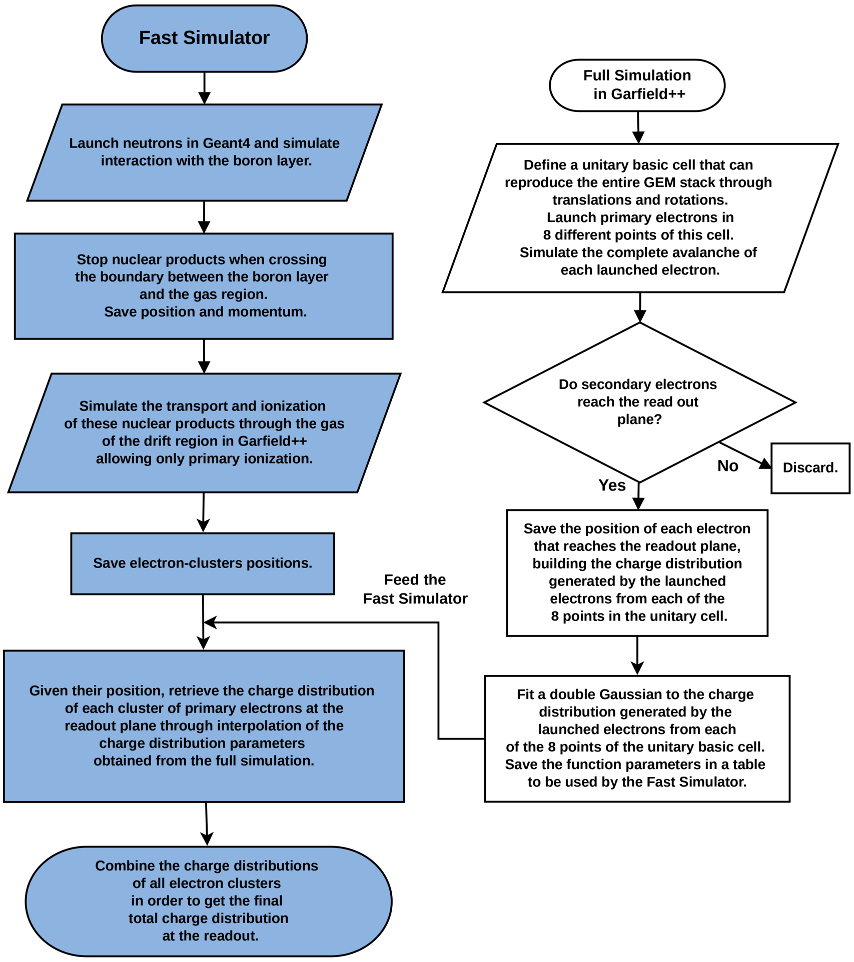


Figure 1: Fast simulator diagram flow.

## 3. Detector Simulation and Optimization

The simulated detector is a double-GEM as sketched in Fig. 2. It consists of a stack of two GEM foils, a 0.5 mm thick aluminum cathode coated with enriched boron carbide, which is used as a neutron converter. 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, all inside a gas mixture.

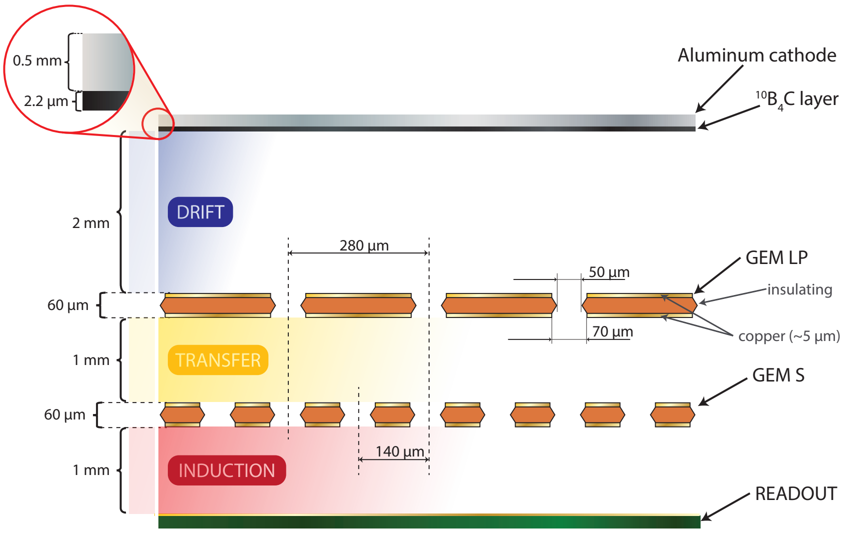


Figure 2: Double-GEM detector prototype sketch. Figure from [6].

When dealing with a position-sensitive detector, the position resolution is a key factor to keep in mind. The strategy to improve the position resolution relies on the main features that define it in a detector like this as the angles that the nuclear products are emitted in a reaction, the path length in the gas mixture, the electron diffusion, and the readout strips pitch [7].

Therefore, one option to improve the position resolution is to make the path length of the reaction products shorter and increasing the stopping power result in losing energy in a shorter path traveled by ions leading to an improvement in the position resolution. This can be achieved by changing the working gas to one with a higher atomic number. Also, it is possible to shorten the mean free path of the ions by applying a higher gas pressure. Both possibilities were studied, using two noble gases, argon and xenon, and changing the pressure.

An initial simulation in SRIM confirms that the projected range of the $\alpha$-particle can be decreased if we change the argon to xenon, as well as increasing the pressure, as can be seen in Fig. 3.

In Fig. 4, Garfield++ was used to simulate the ionization in the drift region to illustrate the motivation for increasing the pressure in argon. In the left panel of Fig. 4a is shown the path of an ionizing particle ($\alpha$-particle or $^7$Li) through the drift region for different values of pressure showing that when the pressure increases the track of the particle, as well as its electrons depositions, is restricted to a smaller range in the x-axis. The right panel of Fig. 4b shows the position distribution of electron-clusters in the x-axis due to 500 neutrons with 41.8 meV hitting always perpendicularly the same point of the GEM foil. These results indicate that the distribution gets narrower as the pressure increase. Both examples of Fig. 3 and Fig. 4 indicate that the position resolution can be improved by increasing the pressure and/or changing the gas composition to one with a higher atomic number.

In order to quantitatively estimate the modification in the position resolution due the gas composition and pressure, simulations of $2 \times 10^6$ thermal neutrons with 41.8 meV for each configuration of gas and pressure, were performed. Two gas mixtures: $Ar/CO_2$ (90/10) and $Xe/CO_2$ (90/10) and three values of pressure $(1, 2,$ and $3\,atm)$.

Using the *point spread function* (PSF) the position resolution was estimated in terms of the *full width at half maximum* (FWHM). The set of simulations with the respective position resolution obtained is shown in Fig. 5.

The results shown in 5 reveal the complex dependence of the position resolution on different aspects of the detector design. In principle, since the $\alpha$-particles range is similar in the argon

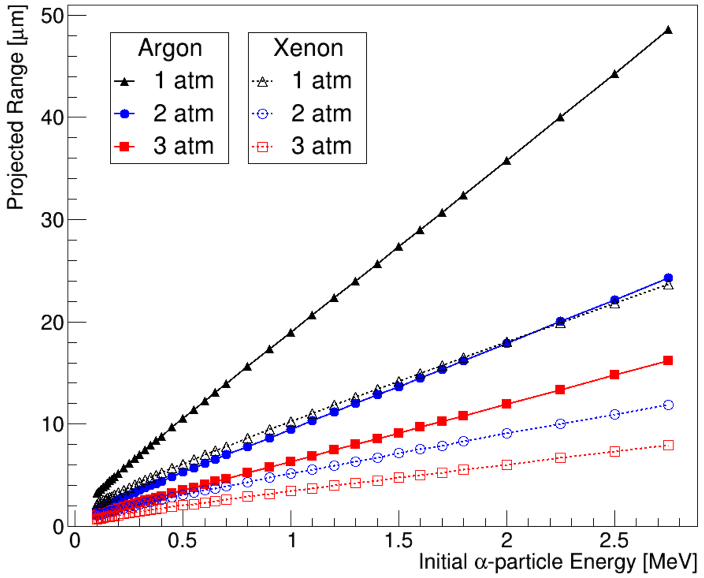
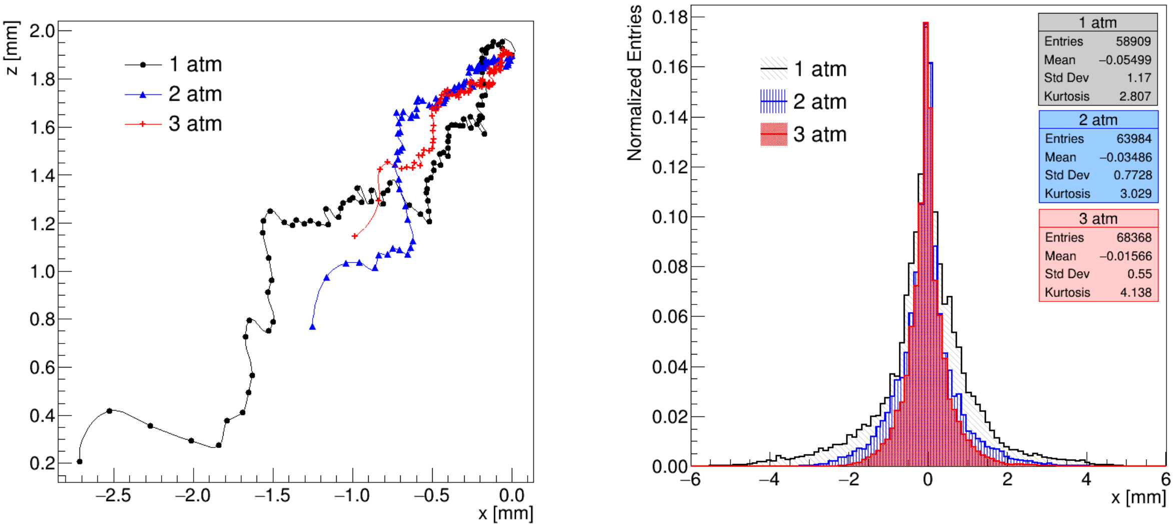


Figure 3: Alpha particle range depending on its initial energy, for different pressures. Close and open marks represent argon and xenon gas, respectively. Simulated using SRIM.



(a) A visual example of the decrease in the ionization region for one particle.

(b) Electron-cluster position on the x-axis in the drift region, considering 500 neutrons starting at the same point.

Figure 4: Analysis of the relation between argon gas pressure and the position resolution.

case with pressure of 2 atm and xenon case with 1 atm (shown in Fig. 3), the position resolution in both situations was expected to be similar. However, the simulation indicates a significant improved resolution for the argon case with 2 atm pressure. The extra aspect that was probably missing and should be considered is the diffusion of electrons in gases, which is a limiting factor

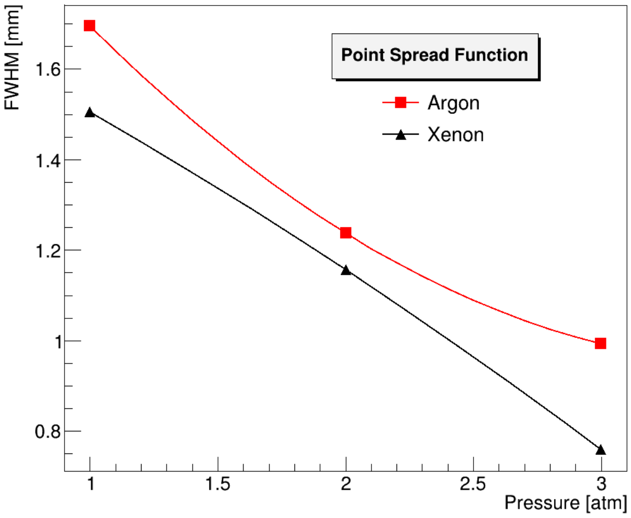


Figure 5: Position resolution with respect to gas pressure.

to position resolution.

The electron diffusion along an axis can be described by a Gaussian distribution with a standard deviation $\sigma = \sqrt{\frac{2Dx}{w}}$, where $D$ is the diffusion coefficient and $w$ is the drift velocity [8]. Thus, the drift velocity is an important factor to diffusion effects. In our case, consider Fig. 6, which presents the drift velocity of the electron in both gas mixtures simulated in Magboltz [9] through Garfield++ integration, the electrons have a higher drift velocity in argon.

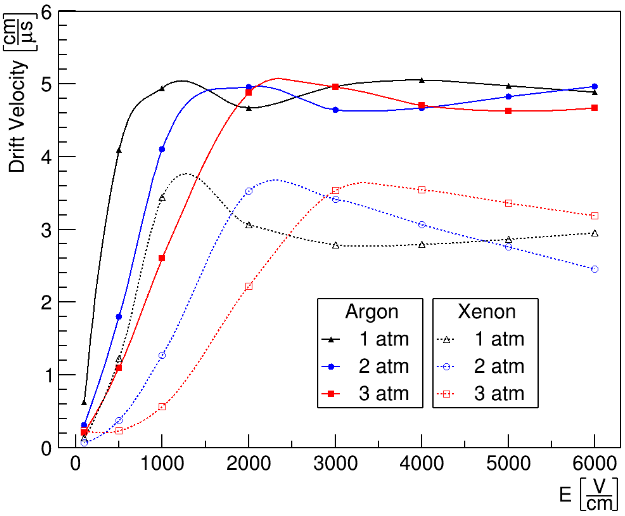


Figure 6: Drift velocity as a function of the drift field for gas mixtures at different pressures. Close and open marks represent argon and xenon gas, respectively.

## 4. Perspectives

It was shown in this proceeding the first attempt to optimize the position resolution of a thermal neutron detector built by a collaboration between groups in IFUSP and IPEN [6] using a recently created fast simulator based on Geant4 and Garfield++. The code accelerates the simulation process parameterizing the charge distribution in the detector readout plane for specific hit points obtained from a full simulation and interpolating these distributions for neutron hitting the detector in any position. Given the expectation that the main aspect that determines the position resolution is the ionizing radiation range within the detector, different gas mixtures and pressure were studied in order to achieve better resolution. However, the simulation pointed out that the electron gas drift velocity is also essential for the position resolution optimization. This study shows the importance of a detailed simulation for detector optimization and the utility of the recently created code.

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