Characterization of GEM detectors using Garfield++

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Abstract

The Gas Electron Multiplier (GEM) is a type of gaseous ionization detector which is proposed as one of the upgrades in the muon detection region of the CMS experiment at CERN. GEM detectors provide an excellent spatial and time resolution, along with good chemical resistance and radiation hardness. Therefore, for an effective implementation of the upgrade process, it is necessary to characterize the GEM detectors for various properties to have an estimate of their performance while they are being used in the actual detector. This report aims to characterize the GEM detectors using Garfield++, which is one of the simulation softwares used for particle detectors that use gas and semi-conductors as sensitive medium. Using Garfield++, multiple configurations of the GEM detectors were characterized against various design parameters to measure their efficiency as a detection unit.

I. Introduction

The Gas Electron Multiplier (GEM), developed by the Gas Detector Group (GDD) at CERN, has a huge potential as one of the upgrades to the CMS muon detection system for the high η region of the muon endcaps. The GEMs have an excellent spatial and time resolution, making them a viable candidate to improve the muon tracking and triggering capability in the high η region. This upgrade will also lead to an improvement in the muon triggering capability of the muon detection unit. Before performing the actual upgradation process, it is useful to have an estimate of the capability of the new detector upgrade, making way for performing various simulations and experimental studies.

Garfield++ was utlized to perform numerical simulations for characterizing the various configurations of the GEM detectors, which is one of the major tools for performing simulations involving micropattern gaseous detectors. Some of the simulations were performed for different gas mixtures, which are among the potential candidates for the mixture to be used in the actual detector.

II. Gas Electron Multiplier (GEM)

The GEM is a thin metal coated kapton foil, having a high density of holes developed using the photo-lithographic technology. By applying a large voltage across it's ends, it is possible to produce a very high electic field into the holes, which act as channels for producing electron avalanches from the electrons produced in the gas by the ionizing radiation. This makes it possible to achieve high gains, even with a single GEM foil. Much higher gains can be obtained by cascading multiple GEM foils.

Typically, GEMs are constructed using a 50-70 micrometre thick Kapton foil clad in copper on both sides. Using photolithography and acid etching process, holes having a diameter of 30-50 micrometer are produced which act as the electron amplification channels. The ionizing radiation ionizes the gas producing the primary ionization, which subsequently undergoes the amplification process in these holes to produce gains as high as 100-1000, in presence of the appropriate gas mixture and applied voltages.

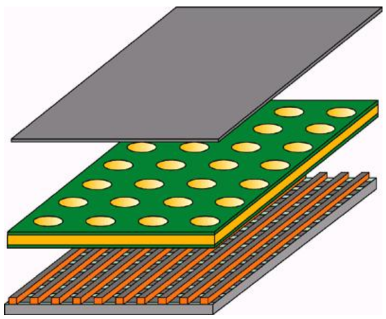

Figure 1: *Layers in a GEM detector*

A GEM based detector involves various independent voltage settings, which includes the drift voltage to guide the electrons from the ionization point to the GEM foil, the amplication voltage across the GEM foil and the induction voltage to guide the avalanche elctrons coming out of the GEM foil to the readout plate.The readout for the GEM is characterized by conductive strips laid across the readout plane, and can have various possible layouts such as the hexagonal or radial configuration, which helps in futher in further localization of the position of the moving charge.

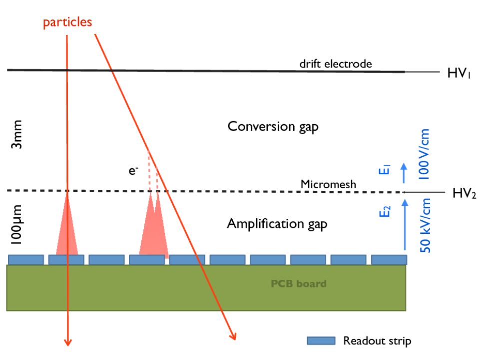

Figure 2: *Different electric fields in a GEM detector*

III. Methodology

ANSYS13 was used to model different geometries and configurations of the GEM detector and for the calculation of the electric field in a GEM, using the finite element method. The value of various parameters used in the design of the GEM foil for the Garfield++ simulation are given in the following table.

Parameter Name	Size (in mm)
Pitch (P)	0.14
Kapton Thickness (K)	0.05
Metal Thickness	0.005
Outer Diameter (D)	0.07
Mid Diameter (d)	0.05

Table 1: *Values of size parameters used in simulation.*

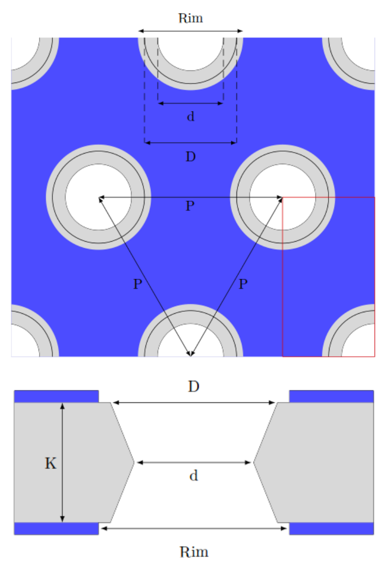

Figure 3: *Size parameters of GEM detector*

Using the field map obtained from ANSYS13, the drift of electron and ions in GEM was simulated using Garfield++. The field map was imported into Garfield++ using the *ComponentAnsys123* class. Subsequently, the gas mixture was defined using *Magboltz* and the classes *AvalancheMicroscopic* and *AvalancheMC* were used for simulating the drift of electrons and ions in the GEM respectively. After the calculation, it is possible to extract information such as the number of electrons/ions produced in the avalanche and their endpoints using the above mentioned classes.

IV. Results

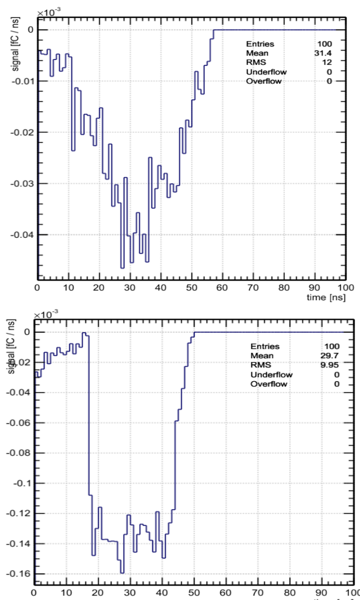

Figure 4: *Sample electron signals at the readout plate*

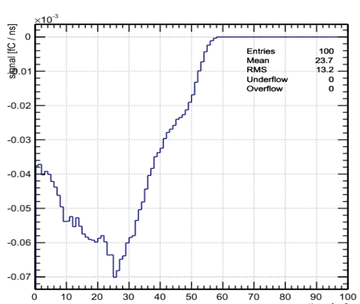

Figure 5: *Average electron signal at the readout plate*

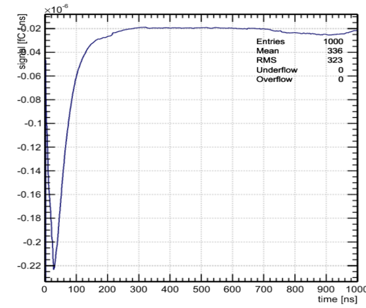

Figure 6: *Average ion signal at the readout plate*

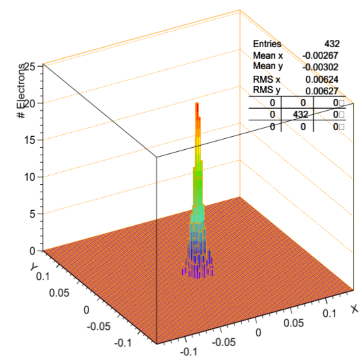

Figure 7: *Distribution of electrons reaching the readout plate*

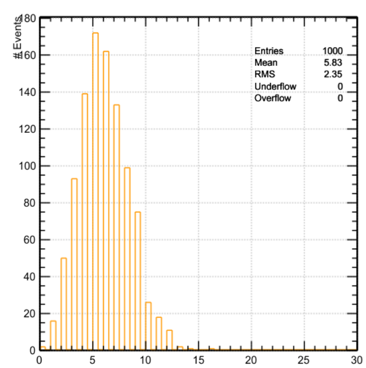

Figure 8: *Distibution of number of clusters formed per event.*

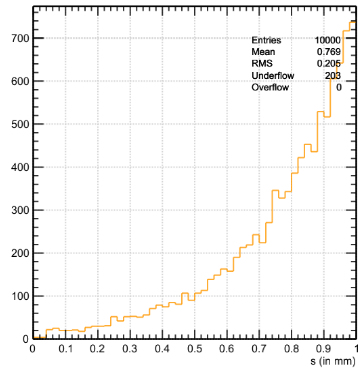

Figure 9: *Distribution of the point of first ionization (s)*

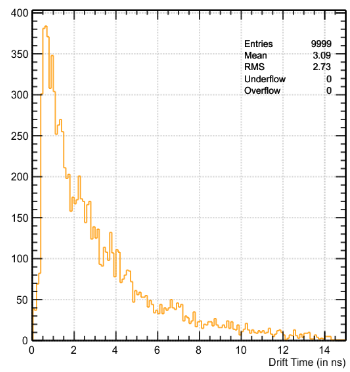

Figure 10: *Drift Time for Ar/CO2*

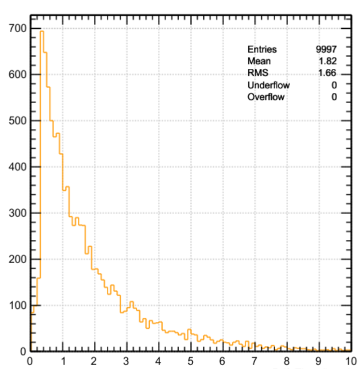

Figure 11: *Drift Time for Ar/CO2/CF4*

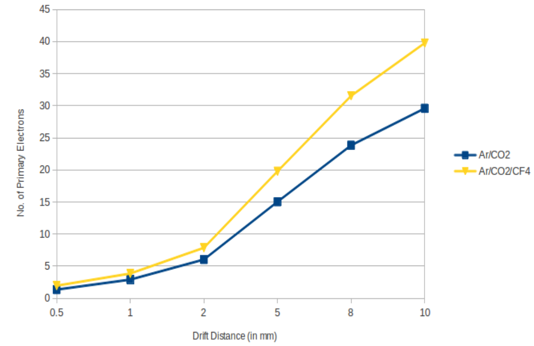

Figure 12: *Primary electrons/muon vs. Drift distance*

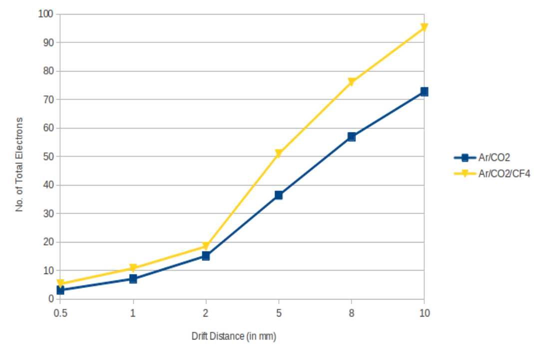

Figure 13: *Total electrons/muon vs. Drift distance*

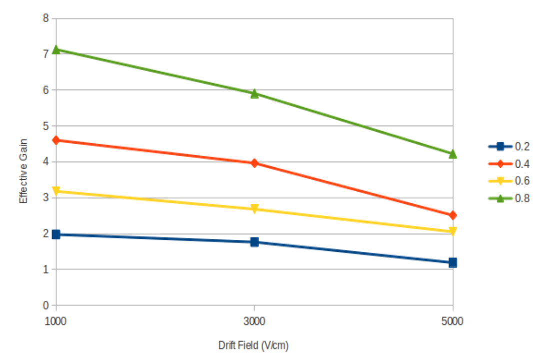

Figure 14: *Effective Gain vs. Drift Field for different Penning Transfer Efficiencies*

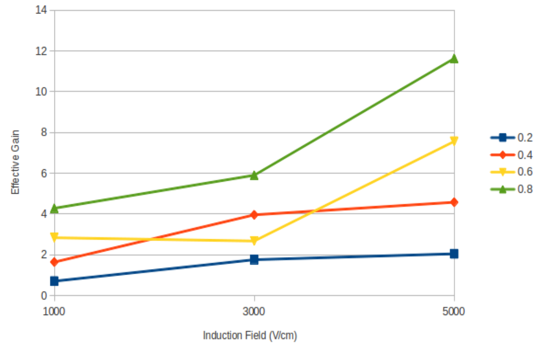

Figure 15: *Effective Gain vs. Induction Field for different Penning Transfer Efficiencies*

V. Conclusion

As indicated by the various plots presented in the results section, the single GEM was entirely characterized for its various properties, which will help in the implementation of the various improvements to the current design and to identify the point of inefficiencies in the current setup. Also, the current analysis is to be extended to various other configurations of the GEMs which use the single GEM as their building block. As of now, the modelling of these designs is complete on ANSYS13 and the analysis code is in a working state. Plans in the future include the calibration of the code against the existing figures and then comparing the performance of the new designs with the existing ones based on various performance parameters. Also, the extended code for the single GEM used for the analysis in this report will be presented on the Garfield++ website as an example, once the documentation is complete for the same.

References

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