Time resolution of GEM detector with cosmic muons and X-ray photons

S. Swain[1,2,*] S. K. Sahu[1,2], and P. K. Sahu[1,2]
[1] *Institute of Physics, HBNI, Sachivalaya Marg, P.O: Sainik School Bhubaneswar - 751 005, Odisha, India and*
[2] *Homi Bhabha National Institute, Training School Complex, Anushakti Nagar, Mumbai 400094, India*

Introduction

When radiation passes through a gas detector, atoms present along its track are locally ionised. In this process of primary ionisation, significant number of produced electron-ion pairs migrate in the anode and cathode directions. This process is influenced by drift velocity, diffusion, attachment variables and also by the electric field intensity. When the field is strong enough, electrons obtain sufficient energy for the secondary ionisation, resulting in the avalanche process. The ionisation electrons eventually accumulate at the anode, producing a distinct signal pulse. In this report, the spread in this signal distribution and the electron avalanche are simulated along with the influencing parameter. The signal distribution depends on factors such as the drift field inside the chamber and electron drift velocity. We attempted to create an alternate environment for detector functioning equivalent to an experimental condition. Numerous studies have used single electron simulations with a fixed position, energy, and direction. We mostly used a calibrated 5.9 KeV Fe^{55} X-ray or cosmic source for the experimental analysis. To do a similar investigation, we employed a 5.9 KeV photon and cosmic muons with energies of 1 MeV, 1 GeV, 100 GeV, and 1 TeV. The data for the created primary electrons from both particles are saved and utilised in the main simulation software with their position and energy information.

*Electronic address: sagarikaswain.swain2@gmail.com

Gas Electron Multiplier

For our calculation, we have opted a single GEM detector [1]. It consists of a single GEM foil with a drift gap of 3.5 mm and an induction gap of 2 mm, as displayed in Figure 1. The drift field, which is the electric field between the drift plane and the GEM top, is optimised from 0.1 kV/cm to 0.6 kV/cm during the calculation. The GEM voltage is set at 450 V, and the induction field between the GEM bottom and induction plane is set at 4 kV/cm.

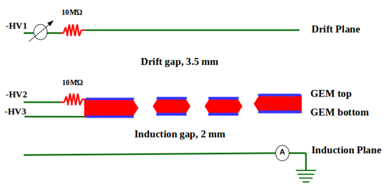

FIG. 1: A simplified representation of the single GEM prototype.

Time resolution

The intrinsic time resolution can be simply written as the following equation.

$$\sigma_i = \frac{1}{n v_d}. \quad (1)$$

Where n is the number of clusters per unit path length, and v_d is the drift velocity. The actual spread of the signal is also influenced by the detector set-up, including the choice of gas and the various fields between the electrodes. In this work, we have studied the time response of the detector with above-said parameters along with changing incident particle energies. The convoluted signal is calculated from the raw signal with a transfer function. Then a specific threshold value is set for the current signal in order to define the time resolution. The time, the signal crosses that set threshold is measured for different current pulses. The mean value of that distribution is considered as the arrival time for the signal, and the RMS value corresponds to the time resolution. The Garfield++ simulation package with a known field solver, ANSYS, is used here [2]. To examine the impacts of gas mixture and electron transport characteristics inside the detector, two other software, Magboltz, and Heed, are utilized.

Results

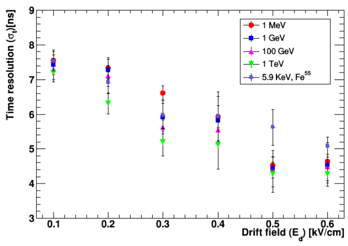

FIG. 2: Time resolution with drift field (induction field and GEM voltage are kept fixed at 4 kV and 450 V, respectively).

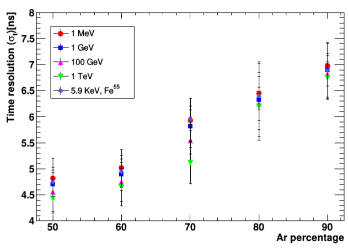

FIG. 3: Time resolution with the variation of percentage of Ar in the gas mixture.

Figure 2 presents the variation of GEM time resolution with drift field for both X-ray photon and muon. The time resolution improves with the drift field as the electrons' drift velocity also rises with increasing field strength.

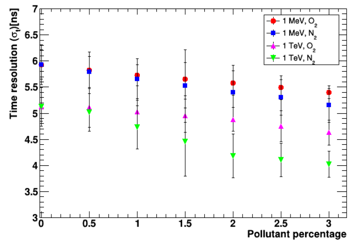

FIG. 4: Time resolution with the variation of pollutant percentage.

When initial particle energy is considered, there is very little variation in the time resolution performance but we observe a drop in its value for muon. Calculation is also done by increasing the Ar percentage while maintaining the field configuration constant. With increasing Ar content, the time resolution shown in Figure 3 worsens. Since CO_2 restricts the production of electrons to a small area, the signal spreads more with increasing Ar component. We also calculated with a gas combination containing a small amount of pollutants with the addition of O_2 and N_2 in proportions vary from 0.5% - 3%. As shown in Figure 4, the time resolution decreases and improves with the addition of O_2 and N_2. To examine the variation, muons with two sets of energy, 1 MeV and 1 TeV, are considered. Compared to O_2, adding N_2 resulted in a lower time resolution with a better signal output. This is caused by the fact that even a small addition of N_2 to the gas mixture significantly increases the electron drift velocity, [4, 5].

References

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