Development of a simulation framework for gas detectors using GEANT4 and GARFIELD++ interface

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Introduction

Exploring the structure of exotic nuclei lying near the drip lines provides unprecedented information on nucleon–nucleon interactions. Study of such nuclei through binary reactions, specifically multi-nucleon transfer reactions, has proven to be an effective tool [1]. Precise information on the mass (A), charge (Z), energy (E) and energy loss (DE) of the reaction products is essential for such investigations. Previously, electromagnetic spectrometers have been employed to implore transfer reactions. However, time of flight and kinematic coincidence set-ups using detector telescopes (E-DE) [2] have proven to be as efficient as the spectrometers, particularly for reactions above Coulomb barrier.

The present work includes the design optimization of a component of such a telescope, namely a Multi Wire Proportional Counter (MWPC), through simulations using GEANT4 toolkit with GARFIELD++ interface [3]. The intended investigations need a transmission type MWPC with the aim to achieve event by event particle tracking. Various factors influence the spatial and timing resolution of a MWPC including the structural design of the electrodes, type of counter gas used and voltage applied at the timing electrode. The effects of some of these factors on the resolution of the detector have been investigated in order to optimize the design, shorten the experimental period and save cost during the detector development.

Detector Modeling and Simulation Framework

The geometry of the MWPC was constructed in GEANT4. To see the effect of electrode geometry on timing resolution and particle tracking applications, both three and four electrode geometries were simulated in all the cases. All the electrodes, each with an active area of 5*5 cm^2, were constructed using 80 equally spaced tungsten wires, spacing between each wire being 0.5 mm. The spacing between each electrode was kept 3 mm. The diameter of each wire was set as 20 μm to achieve faster rise times and hence optimal timing resolution. GEANT4 and GARFIELD++ interfaces—Heed and Magboltz—were used for imploring the particle interactions and for modeling the electron transport parameters in gases, respectively. The framework implemented the interfaces in two steps: first the primary ionization, electron transport and multiplication were investigated for the generated particles, in GARFIELD and then the avalanche information was utilized to track the trajectory of the particle, in GEANT4.

Results and Discussion

Effect of counter gas: For current applications, the design features of the detector were optimized for the detection of low energy heavy ions at very low gas pressures (~2–5 mbar). However, at such low gas pressures, the density of the gas plays an important role in primary ionization and energy loss in the gas. Furthermore, the variation of electron drift velocity as a function of electric field in the gas determines the pulse shape and, in turn, the resolution of the detector. Therefore, the behavior of different gas mixtures at low gas pressures was studied through drift velocity distributions. Three gas types i.e. Ar (70 %) + CH_4 (30 %), Ar (70 %) + isobutane (30 %) and isobutane, each at 5 mbar pressure were used for the analysis. Under an electric field between 0.1 to 10 kV/cm, the largest drift velocity was observed for the case of isobutane in the whole range. An exponential increase in the velocity was observed at 1 kV/cm for isobutane (FIG. 1**)** whereas no exponential rise was observed even after 10 kV/cm for the remaining two gases.

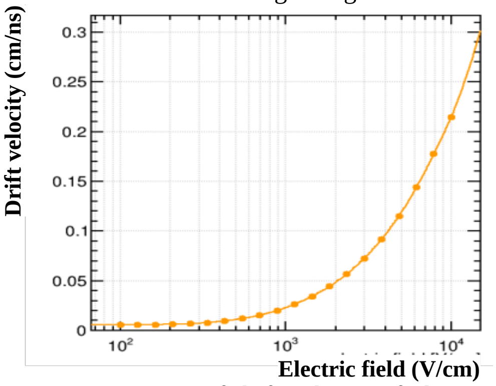

FIG. 1: Variation of drift velocity of electrons with electric field for isobutane at 5 mbar.

Electric field distribution around anode wires: Although closely spaced wires lead to better spatial resolution, the spacing for the current design was optimized based on the pitch of the wire, its tensile strength and space for soldering purposes. Also, in MWPCs, each wire acts a counter, thus a uniform electric field between each wire is essential for faster charge collection and higher gains.

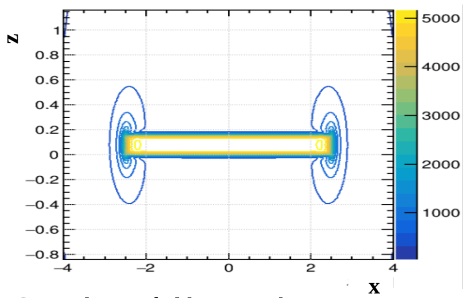

FIG. 2: Electric field contour between the two wire frames kept 0.5 mm apart.

The electric field distribution between each wire frame was evaluated by operating the detector at a gas pressure of 5 mbar (isobutane) and a potential of +400 V and -200 V at the anode frame and cathode frame, respectively. FIG. 2 shows that a uniform field of ~ 4 kV/cm is maintained between the two wires kept 0.5 mm apart, the distortions being seen only at distances < 0.1 mm from the wire.

Particle tracking: The multistep geometry with three to four electrodes provides a high gain even at low pressures. However, for a transmission-type detector to be used in a E-DE telescope, the particle must reach the last electrode and deposit the remaining energy in the E detector. In addition to the three electrode, a four electrode geometry was also simulated, and an event track was recorded.

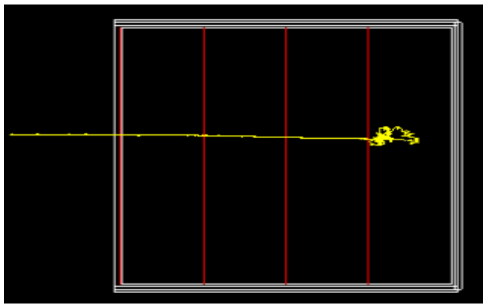

FIG. 3: Track of a 5 MeV α particle after traversing through a four-electrode geometry.

As shown in FIG. 3**,** after traversing through a four electrode geometry a 5 MeV α particle is losing 70 % of its energy in the detector and only 30 % is being transmitted further. The simulated detector can thus be used as a component of a E-DE telescope for this case. In future, the existing framework will be refined for medium mass nuclei with energies upto 50 MeV. A similar framework will be developed to optimize the remaining components of the E-DE telescope.

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References

[1] Alvarez *et al*, PRC**100**, 064602 (2019) 1-12.
[2] Kalkal *et al*, PRC**85**, 034606 (2012) 1-6.
[3] *Pfeiffer et al*, NIM A **935** (2019) 121.