A numerical study on gaseous detectors for high energy physics

S. S. Sahoo, P. Bhattacharya,* S. Biswas, and B. Mohanty
School of Physical Sciences, National Institute of Science Education and Research, Jatni, Bhubaneswar - 752050, India

Introduction

A Time Projection Chamber (TPC) [1] is a well-known detector used in different experiments including ALICE [2], for 3-dimensional tracking and particle identification for ultra-high multiplicity events. In standard TPCs, Multi Wire Proportional Counters (MWPCs) [3] are used as gas amplification stages. But, for future experiments with high-flux and high-repetition rates, the large volume TPC with MWPC as readout will suffer from the space charge effect originating from high fluxes of the backflowing ions. In very recent time, after the development of the Micro Strip Gas Chamber based on the semiconductor technology processes, the genesis of the gaseous detectors has undergone a rapid improvement in terms of rate capability, radiation hardness, low ion feedback etc. ushering in a new genre of micro-structured devices, commonly known as Micro-Pattern Gas Detectors (MPGDs) [4]. Among the different MPGDs, Gas Electron Multiplier (GEM) [5] fulfill the needs of high-luminosity colliders with increased reliability in harsh radiation environments. Different R&D activities are currently concentrated on the adoption of the Gas Electron Multiplier (GEM) as the gas amplification stage of the ALICE-TPC upgrade version. In this presentation, we plan to demonstrate and discuss our detailed numerical study of GEM-based detectors and will try to make an attempt to relate the above studies in the context of the high luminosity experiments. In the process we have also simulated a MWPC. A comprehensive comparison of their characteristics, achieved through the design variation among these detectors, will be presented. The results compare closely with the available experimental data. This suggests the efficacy of the framework to model the intricacies of these micro-structured detectors in addition to providing insight into their inherent complex dynamical processes.

*Electronic address: `purba.bhattacharya85@gmail.com`

Simulation Tools

We have used the Garfield [6] simulation framework. This framework was augmented in 2009 through the addition of the neBEM (nearly exact Boundary Element Method) toolkit to carry out 3D electrostatic field simulation. Besides neBEM, the Garfield framework provides interfaces to HEED and Magboltz.

Results for MWPC

The standard MWPC consists of a plane of equally spaced anodes wires centered between two cathode planes. The electrons formed by the ionization of the gas, drift inward and toward the plane of the anode wires, initially in a nearly uniform field. As they approach the wires, they are accelerated toward the nearest wire into its surrounding high field region where the avalanches are formed. The ions which are produced in a large number during the amplification process drift back towards the cathode and distort the drift field. A plane of gating wire is used in between the anode wire and the drift region to catch the ions. For a proper operation of gating, a trigger is needed to open the gate for read out of the chamber. But, the use of gate is difficult for experiments with high-rate. The electron electron and ion drift line for a standard MWPC is shown in Figure 1(a).

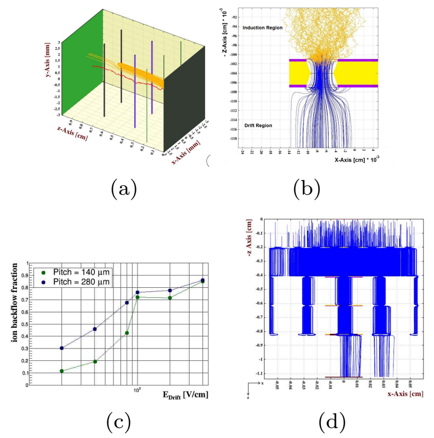

FIG. 1: (a) Ion drift lines for a MWPC; (b) Electron avalanche and ion drift lines and (c) variation of ion backflow fraction with drift field for a single GEM detector; (d) ion drift lines for a quadruple GEM detector.

Results for GEM-based Detectors

The GEM is a composite grid structure consisting of two metal layers separated by a thin insulator which is etched with a regular matrix of holes. Applying a voltage between the two conductive plates, a strong electric field is generated inside the holes. It separates the gas volume in three regions: a low field drift region above the GEM where the primary charge is produced, a high field region inside the holes where the electrons are multiplied and an induction region below the GEM where about 50% of the avalanche electrons drift to the readout electrodes. The electron avalanche and the ion drift lines in case of GEM detector for a particular field configuration is shown in Figure 1(b). In order to prevent those ions from entering the drift volume, a proper optimization of the field in the drift volume, GEM hole and induction regions is necessary. For example, the variation of backflow fraction as a function of the drift field is shown in Figure 1(c).

The single GEM can operate up to gains of several hundreds. The assembly of two, three or four GEMs has been proposed and used to greatly increase the avalanche gain since the total gain of multi GEM structures should be close to the product of the individual gain. A second characteristics of this multi structure is the intrinsic ion gating, which can be reached with appropriate voltage settings. As an example, in case of a quadruple GEM device, with a proper optimization of field configuration and placements of GEM foils, the backflow fraction can be reduced to $\sim 1\%$ (Figure 1(d)).

A detailed numerical study has been performed to simulate the ion backflow of quadruple GEMs containing foils with different hole pitch and different field configuration in presence of magnetic field to get an optimum configuration. In this presentation, we plan to demonstrate and discuss our detailed numerical results and will try to make an attempt to relate the above studies in the context of the high luminosity experiments.

Acknowledgments

We are thankful to Dr. Rob Veenhof, Prof. Supratik Mukhopadhyay and Prof. Nayana Majumdar for their valuable suggestions and comments. We also wish to acknowledge the members of the RD51 Collaboration for their help and suggestions. Finally, we thank our Institution for providing us with the necessary facilities.

References

[1] V. Lepeltier; "Review on TPC's"; Jour. Phys. Conf. Ser. Vol. 65 (2007) 012001.
[2] ALICE Collaboration; "Technical design report for the upgrade of the ALICE Time Projection Chamber"; ALICE-TDR-016 (2014).
[3] G. Charpak et al.; "Multiwire proportional chambers and drift chambers"; Nucl. Instrum. Meth. Vol. 162 (1979) 405.
[4] M. Titov; "Perspective of MPGD technologies for future physics projects"; arXiv:1308.3047[physics.int-det] (2013).
[5] F. Sauli; "GEM: A new concept for electron amplification in gas detectors"; Nucl. Instrum. Meth. A Vol. 386 (1997) 531.
[6] R. Veenhof; "Garfield-simulation of gas detectors"; http://cern.ch/garfield.