Numerical Simulation of Gaseous Ionization Detectors

Supratik Mukhopadhyay
Applied Nuclear Physics Division, Saha Institute of Nuclear Physics, Kolkata 700064, INDIA

Introduction

Gaseous ionization detectors are detectors that depend on the ionization of the gaseous media due to the passage of ionizing radiation, amplification and transport of the primary ions / electrons through the application of suitable electromagnetic configuration and, finally, registration of the ionization in the form of electronic signal. Due to their excellent capability in terms of spatial, temporal and energy resolution leading to reliable particle identification, gaseous ionization detectors are extensively used in both basic research and different applied fields.

During the first half of the 20th Century, there were three predominant types of gaseous ionization detectors, namely, Geiger-Muller counters, proportional counters and radiation detectors. With the invention of the multi-wire proportional chamber (MWPC) in 1960s, the possibility of localizing an ionization in space became a reality and changed the pace of development of gaseous ionization detectors, forever. The MWPC was followed by several remarkable new design concepts, including the time projection chamber (TPC), resistive plate chamber (RPC) and micro-pattern gaseous detectors (MPGD). Among these, studies on the last three detectors will be presented here.

As mentioned above, several interesting and complex physics processes occur within the gaseous ionization detectors that demands close inspection to ensure proper understanding of the physics of these devices. A thorough understanding, in its turn, can help a) in precise interpretation of the data acquired using these detectors, b) in improved design of an experiment based on them, c) to propose new and improved design of gaseous ionization detectors and d) allow improved simulation of the entire experiment based on codes, such as Geant4, that rely on user-specified device response, without making an attempt to estimate the response by itself.

Here, we will discuss about various approaches adopted to numerically simulate the detailed device physics of gaseous ionization detectors. Related experimental efforts will also be mentioned. Mathematical formulations, algorithms and simulation frameworks will be touched upon, in general. In particular, we will focus on several physics issues that we have addressed in recent times, such as, a) effects of non-uniformities and imperfections on device response, b) estimation of gain, spatial, temporal and energy resolutions, c) effects of electronic heating on device performance, and d) estimation of ion backflow in Micromegas- (single and double mesh) and GEM- (single and layered) based detectors.

Numerical simulation

There are too many complex physics (and, often, chemistry) processes occurring within gaseous detectors, simulation of which easily qualifies itself as among the grand challenge problems of computing. Each of these processes are usually tackled using different computational packages. Some of the more common packages are, Heed (ionizaition), ANSYS / COMSOL / Elmer / neBEM (electromagnetic field), Magboltz (transport and amplification), Garfield (signal induction; it also provides a simulation framework to integrate the packages mentioned earlier) and PSpice (electronic signal processing and collection). It should be mentioned here that a number of physics and chemistry processes are still out of reach of these simulation packages. For example, algorithms capable of analyzing processes related to ageing (which involve significant amount of chemistry, in certain situations, plasma chemistry), charging up of dielectrics, charge dispersion in media having finite conductivity, space charge effects etc. are yet to be properly formulated and implemented. However, despite the short-comings, it is possible to use the existing frameworks to a surprising number of useful studies, as mentioned below.

Non-uniformities and imperfections

The former are by design, while the latter are unavoidable artifacts. We have studied the effect of these real-life features present in gaseous ionization detectors on their response. For example, in Fig. 1, we have presented the distortion of electron drift lines due to the presence of spacers in a bulk Micromegas.

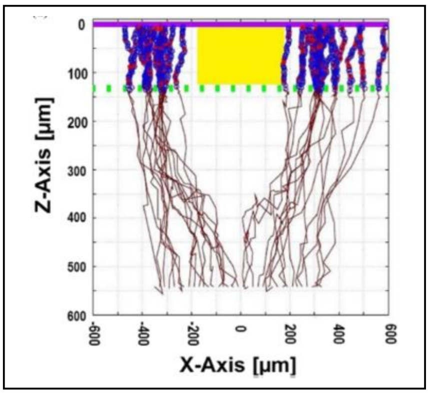

Figure 1Distortion of drift lines due to the presence of spacer in a bulk Micromegas

Gain and resolutions

These are some of the most important figures of merit for these detectors. As a result, it is extremely important to be able to estimate them and their dependence on various experimental parameters, including detector geometry, electromagnetic field configuration and gas mixture used. In Fig. 2, we present the variation of gain in bulk Micromegas detectors of different geometrical design parameters, in which detailed comparison of experimental and numerical estimates have been made.

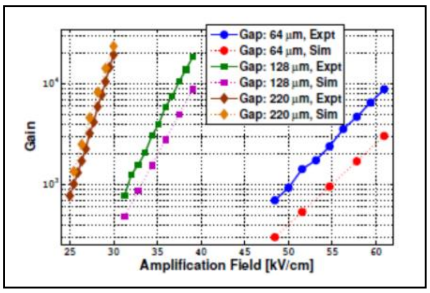

Figure 3Variation of gain of bulk Micromegas detectors of different geometries

Electronic heating

Electronic heating can be a serious concern if it alters the detector performance significantly. For example, it can modify the drift velocity of the ions / electrons or, setup a flow in the gas disturbing the stability of the detector. With these possibilities in view, we carried out experiments and simulation of a possible cooling scheme to be employed in a TPC, as shown in Fig. 3.

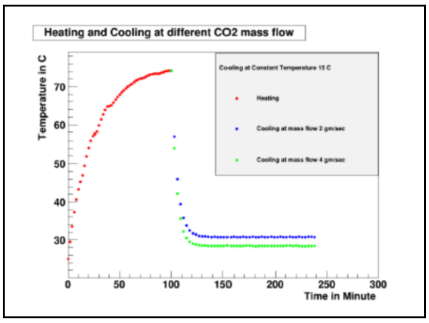

Figure 4Simulation of heating and cooling at different mass flows

Ion backflow

Effective operation of gas detectors is often limited by several secondary effects, such as the ion backflow, which is the drift of the positive ions produced in the avalanche from the amplification region towards the drift volume. Uncontrolled ion backflow can result in significant amount of space charge build-up and field distortion that are especially damaging in devices such as the TPCs. In Fig. 4, the backflow of ions for a single GEM detector, as estimated by rigorous computations, has been depicted.

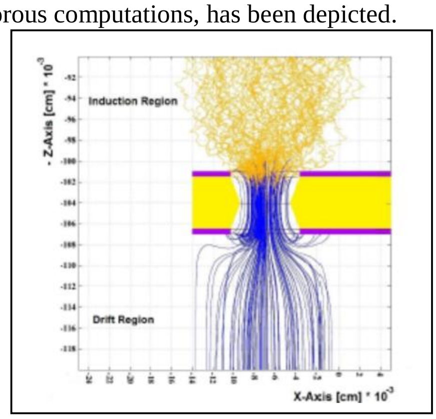

Figure 2Electron avalanche and ion drift lines for a single GEM detecor