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Combination of two Gas Electron Multipliers and a Micromegas as gain elements for a time projection chamber

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A B S T R A C T

We measured the properties of a novel combination of two Gas Electron Multipliers with a Micromegas for use as amplification devices in high-rate gaseous time projection chambers. The goal of this design is to minimize the buildup of space charge in the drift volume of such detectors in order to eliminate the standard gating grid and its resultant dead time, while preserving good tracking and particle identification performance. To characterize this micro-pattern gas detector configuration, we measured the positive ion back-flow and energy resolution at various element gains and electric fields, using a variety of gases, and additionally studied crosstalk effects and discharge rates. At a gain of 2000, this configuration achieves an ion back-flow below 0.4% and an energy resolution better than $\sigma/E = 12\%$ for ^{55}Fe X-rays.

1. Introduction

A critical issue for time projection chamber (TPC) detectors is space charge distortion (SCD) due to the accumulation of positive ions in the TPC drift volume [1]. This arises primarily from the ion back-flow (IBF) of positive ions from the gas amplification region, along with a contribution from primary ionization (from charged particles traversing the gas volume). Slow-moving positive ions distort the electric field uniformity and consequently distort the ionization electron drift trajectories, even for perfect external electric and magnetic field alignment and small transverse diffusion of the gas mixture.

The contribution of the primary ionization to the SCD can be minimized by two approaches. First, one can increase the electric field in the TPC drift volume, as ion drift speed is approximately proportional to the electric field. Second, one can select a gas mixture to decrease the primary ionization itself, and to increase the ion mobility [2].

To minimize IBF, wire grid structures called gating grids (GGs) have traditionally been used [3]. In the open state, GGs have a high transparency for ionization electrons to pass through to the gas amplification unit, typically a multi-wire proportional chamber. The GG can then be closed to collect ions from the gas amplification (gain) step. As a result, the IBF due to the gas amplification is very low. However, since the GG must remain closed until the positive ions from the avalanche at the anode wire have drifted to the grid, the TPC has an intrinsic dead time that limits the readout rate. Also, since the GG is a triggered element, there is a loss of track information near the readout planes during the time it takes to trigger and open the grid.

For current experiments employing large TPCs (e.g. STAR, ALICE) and those of the future, it is desirable to find a solution to minimize dead time by eliminating the GG or perhaps using a modified GG structure [4,5]. The challenge is to minimize IBF from the gas amplification region to a level acceptable from the perspective of distortion corrections, such that track reconstruction and analysis have comparable performance to a GG solution [6,7]. One possible solution is to use micro-pattern gas detectors (MPGDs), which have intrinsically low IBF. In particular, multilayer MPGDs are promising candidates, as a stack of such elements allows multiple IBF-suppressing layers as well as flexibility in operational voltages and alignment, with only a small loss in electron transparency [8,9]. Simulations for the ALICE TPC [10] have shown that at the foreseen gain of 2000 ($Ne+CO_2+N_2$ (90–10–5)[1]), with IBF as high as 2% and energy resolution of 14% (σ/E)

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[1] This notation reports the relative proportions of each gas in the mixture.

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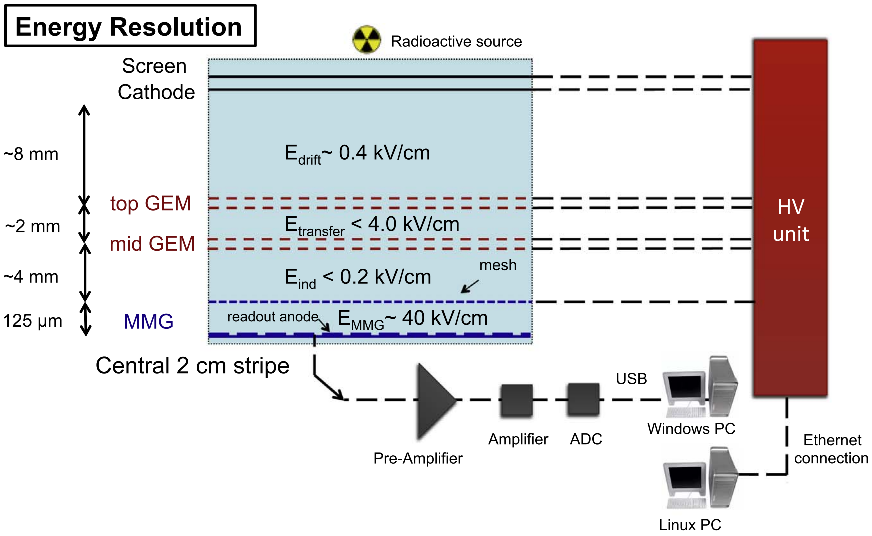
or better (for ^{55}Fe X-rays), TPC SCD can be corrected to an acceptable level in terms of TPC track finding, PID capability, and momentum resolution. In this paper, we report our investigation of the performance of a gain configuration for TPC gas amplification using two Gas Electron Multipliers (GEMs) [11] plus a Micromegas (MMG) [12] in terms of IBF, energy resolution, and stability.

2. Experimental technique

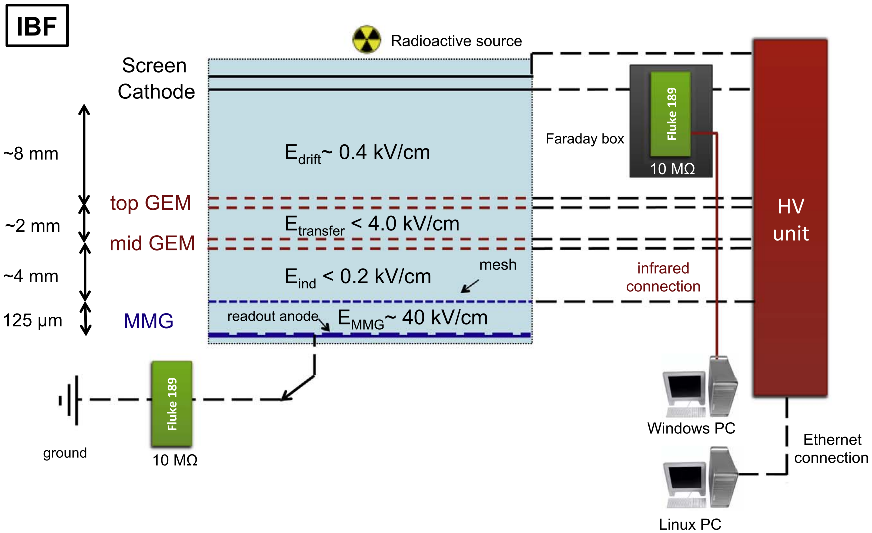
2.1. Operating principles

Fig. 1 illustrates the 2-GEM + MMG setup used for these studies and defines the various elements and fields. The foremost operating principle is that the MMG provides most of the gain while the GEMs pre-amplify the signal for the MMG, so that it can be run at a relatively low voltage in order to reduce its discharge probability [13]. In addition, the GEMs help spread ionization electrons through diffusion and hole pattern misalignment so that a particularly dense cluster is less likely to cause a discharge in the MMG; it has been demonstrated both in measurements [14] and simulation [15] that additional electron spread above the MMG mesh reduces the discharge rate and can improve track or ionization cluster spatial reconstruction precision.

The goal is then to tune the gains and fields in order to reduce IBF and increase energy resolution. The optimum effective gain of the GEMs is a compromise between better energy resolution, which would favor higher gain, and lower IBF from the GEMs, which would favor lower gain; the IBF contributed by a single GEM can be as much as 20% of the ionization it produces. The top GEM is particularly sensitive to this trade-off, as it is the first gain element in the stack. Note that the effective GEM gain (total charge exiting the GEM divided by total charge drifting to the GEM) is a function of the voltage across the GEM, as well as the electric fields above and below the GEM [6]. The IBF of the MMG scales with the ratio of the induction field to the MMG amplification field, $E_{\mathrm{ind}}/E_{\mathrm{MMG}}$ [7], so the induction field is typically kept as low as possible. The primary purpose of the mid GEM is therefore to transfer electrons from the strong field in the transfer gap between the GEM foils to the lower field in the induction gap above the MMG. Accordingly, we operated the mid GEM with an effective gain less than 1. This feature can be seen clearly in the example spectrum shown in Fig. 2. In addition to tuning the voltages, the IBF can be further suppressed by arranging the GEM hole patterns to assure maximum mis-alignment. The top GEM foil was rotated by 90° relative to the mid GEM to increase the hole mis-alignment.



(a) Energy resolution measurement setup.



(b) IBF measurement setup.

Fig. 1. Experimental setup for a chamber with two stacked GEM foils and one MMG. The listed electric fields are the nominal values.