Charge sharing in single and double GEMs

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ABSTRACT: The Gas Electron Multiplier (GEM) has become a widely used technology for high-rate particle physics experiments like COMPASS, LHCb and are going to be used for the upgrade of the detectors of other experiments, such as ALICE TPC. Radiation hardness, ageing resistance and stability against discharges are main criteria for long-term operation of such detectors in high-rate experiments. In particular, discharge is a serious issue as it may cause irreversible damages to the detector as well to the readout electronics. The charge density inside the amplification region is one of the limiting factors for detector stability against discharges. By using multiple devices, and thus sharing the electron multiplication in different stages, the maximum sustainable gain can be increased by several orders of magnitude. A common explanation for this is connected to the transverse electron diffusion, which causes widening of the electron cloud and reducing the charge density in the last multiplier. This has been verified experimentally [1] but numerical investigations, as far as we know, are scarce. In our work, we are using Garfield simulation framework as a tool to extract the information related to the transverse size of the propagating electron cloud and thus to estimate the charge density in the GEM holes for multiple stages. For a given gas mixture, we will present the initial results of charge sharing using single and double GEM detectors under different electric field configurations and its effect on other measurable detector parameters such as single point position resolution.

KEYWORDS: Charge transport and multiplication in gas; Gaseous detectors; Radiation-hard detectors

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1 Introduction

Gas Electron Multiplier (GEM) is one of the Micro Pattern Gaseous Detectors (MPGDs) which are high granularity gaseous ionization detectors with very small gap between cathode and anode electrodes [2]. High granularity of these detectors offers good position resolution, close to 100 μm [3] and small gaps between the electrodes allow fast evacuation of positive ions (100 ns) which offers high rate capability [4]. Thus, they are widely used for tracking and timing purposes in various high energy physics experiments.

GEM detectors have very thin dielectric foil(s) coated with copper on both sides (called GEM foil), placed in between cathode and anode. This GEM foil has numerous holes, across which high voltage is applied to allow the multiplication of electrons. A GEM detector has a separate drift gap, multiplication gap(s), transfer gap(s) and an induction gap. However, the applied high voltage can result in electric discharge across the foil under several circumstances, which in turn can affect the long-term operation of these detectors. It has been proposed that the development of electric discharge across GEM foils depend on the charge density within the configuration [1, 5, 6]. This motivates us to explore the influence of detector geometry and field configuration on charge sharing within GEMs and study the dependence of various other figures of merits on this parameter.

2 Simulation tool

We have used the Garfield [7] framework as simulation tool for the detailed study of gaseous detectors where we have used Monte Carlo and microscopic tracking methods for simulating the charge transport. The 3D electrostatic field has been estimated by neBEM [8]. Furthermore, HEED [9] and MAGBOLTZ [10] have been used for simulating primary ionization and electron transport properties respectively.
3 Results and discussion

A single GEM detector with 1.5 mm drift and 500 μm induction gap has been studied. In addition, a double GEM detector with drift gap of 3 mm, transfer gap of 2 mm and induction gap of 1 mm has been studied. For both the detectors, standard GEM foils have been considered with 50 μm thick kapton foil, 5 μm copper coating on both sides, 140 μm hole pitch and 70 μm hole diameter.

We have simulated the spread of electrons, estimated average charge density at different holes and computed single point spatial resolutions for single and double GEM detectors being operated with a mixture of Ar and CO₂ gases in the ratio 70:30. In figure 1, a double GEM detector has been illustrated. Some of the important processes and nomenclatures are also shown in this figure. Variation of transverse and longitudinal diffusion coefficients with electric field has been plotted in figure 2.

![Figure 1](image1.png)

**Figure 1.** 2D model of a double GEM.

![Figure 2](image2.png)

**Figure 2.** Variation of diffusion coefficients with electric field.

3.1 Spread of electron cloud

Starting from a single prefixed location, the spread of the electron cloud has been studied at various locations of each simulated detector. For a single GEM detector, the spread has been estimated at the top and bottom of the GEM foil and at the anode readout by counting the number of electrons and their positions on these surfaces. For a double GEM detector, the same has been estimated at all the four surfaces of the two GEM foils and on the anode readout. In addition, numbers of electrons in each GEM hole have been computed. For this purpose, the geometry of a GEM foil has been considered as shown in figure 3 and one event corresponds to an initial electron starting at a fixed location right above the centre of hole A.

As expected, a large fraction of the total electronic charge in the GEM foil is present in the central hole A, as shown in figure 4. Only a small fraction passes through the adjacent holes in the second ring. This fraction for the central hole increases slightly with the increase in GEM voltage, possibly due to improved focusing of the electric field and increasing electron multiplication factor (α). For instance, around 50% of total electrons pass through hole A when the GEM voltage is 500 V, while the number is 45% when the voltage is 480 V. However, once an electron enters a particular hole, the number of electrons in that hole is similar to that obtained at other holes and the number increases as the applied voltage is increased. This is natural, since the voltage across each hole is the same. This effect is presented in figure 5. So, summed over a large number of
such events, the electron load on the central hole remains almost ten times the one on each single adjacent holes, for single GEM detector.

![Figure 3](image)

**Figure 3.** Schematic of holes of a GEM foil.

![Figure 4](image)

**Figure 4.** Fraction of electrons in the central and in each of its adjacent holes of GEM foil in a single GEM.

![Figure 5](image)

**Figure 5.** Charge density in the central and in each of its adjacent holes of GEM foil in a single GEM.

For a double GEM detector, the top GEM (GEM-I) experiences similar charge distribution as for a single GEM detector. There is one important difference though — the voltage applied across each GEM foil of a double GEM detector is significantly less in comparison to a single GEM detector. As a result, the electron load on the central hole of GEM-I is significantly less than the central hole of a single GEM detector. For instance, it is around 25% in the central hole and 10% in each of the holes of second ring for GEM-I (figure 6). This distribution of charge also depends on the initial position of the electron above hole A. For all the single GEM calculations, electrons are released from a height of 1.5 mm above the GEM foil and for double GEMs, they are released from a height of 1.7 mm above the top GEM foil.

For GEM-II of the double GEM detector, the distribution is little different, as shown in figure 7. Although a larger percentage of electrons still enter through the central hole of GEM-II, the fraction is almost half of that in GEM-I and the difference between central and adjacent holes are also reduced in comparison to the earlier situations, i.e. the charge distribution is more uniform in GEM-II. For instance, when VGEM-I and VGEM-II both are equal to 400 V, the average fraction of electronic charge in the central hole A out of total charge in GEM-II is 11%, in each of the holes of second ring (B and others) is 8.5% and that on each of the holes of third ring(Q and others) is 2.5%. The number shown in figure 7 is the average over 1000 initial electron events. This figure also shows the variation of the fractions when VGEM-I and VGEM-II are varied individually keeping the other one constant.
It may be noted here, that adding a second GEM foil has led to a more even distribution of electron load among the holes. As a result of this sharing of electron cloud, the maximum effective load per hole is significantly reduced for a double GEM detector, which in turn reduces the probability of discharges.

Spread of electrons at anode increases with increase in GEM voltages for both single and double GEM, as shown in figure 8. Varying GEM-I voltage at constant GEM-II voltage changes the spread of electrons on top of GEM-II whereas there is little change when GEM-II voltage is varied keeping GEM-I constant which can be attributed to the improved focussing of electric field. Also it is interesting to note that, despite the minor gain, the magnitude of electron spread on the top of GEM-II is similar to that of anode spread in single GEMs.

### 3.2 Spatial resolution

In this work, an intrinsic single point spatial resolution of the detectors under study has been defined to be the sigma of the fitted gaussian distribution of the electron spread at the readout anode. From figure 9, we see that spatial resolution for single GEM is around 65 μm (0.0065 cm) and that of double GEM is 185 μm (0.0185 cm). While the sharing of electrons among a larger number of holes in multi-GEM structures seems to reduce the probability of discharges, the position resolution seems to significantly suffer due to the same process.
4 Conclusion

Spread of electron cloud at various stages of single and double GEM detectors and their effects have been studied. In general the addition of multiple stages has been found to influence the electron cloud’s spread significantly and leads to less electron load per GEM hole. Spread of electron cloud at the anode is also strongly influenced by the geometry and electric configuration of the detectors which could affect the position resolution of these detectors.

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