

Numerical Studies on Time Resolution of Micro-Pattern Gaseous Detectors

Purba Bhattacharya¹, Nayana Majumdar^{2, a}, Supratik Mukhopadhyay², and Sudeb Bhattacharya³.

¹ School of Physical Science, National Institute of Science Education and Research, Jatni, Khurda, India 752050

² Applied Nuclear Physics Division, Saha Institute of Nuclear Physics, 1/AF, Bidhannagar, Kolkata, India 700064

³ Retired Professor, Applied Nuclear Physics Division, Saha Institute of Nuclear Physics, 1/AF, Bidhannagar, Kolkata, India 700064

Abstract. The Micro-Pattern Gaseous Detectors offer excellent spatial and temporal resolution in harsh radiation environments of high-luminosity colliders. In this work, an attempt has been made to establish an algorithm for estimating the time resolution of different MPGDs. It has been estimated numerically on the basis of two aspects, statistics and distribution of primary electrons and their diffusion in gas medium, while ignoring their multiplication. The effect of detector design parameters, field configuration and the composition of gas mixture on the resolution have also been investigated. Finally, a modification in the numerical approach considering the threshold limit of detecting the signal has been done and tested for the RPC detector for its future implementation in case of MPGDs.

1 Introduction

Owing to the use of typical manufacturing techniques for microelectronics, the new genre of Micro-Pattern Gaseous Detectors (MPGDs) with high granularity and very small distances between the electrodes can offer high spatial and time resolutions and good counting rate capability [1]. The requirement of fast collection of data in various applications of the MPGDs has necessitated a thorough optimization of their time resolution through the modification of their design parameters and choice of gas mixture. In this context, the study of the time resolution of these detectors and its dependence on various parameters turns out to be an interesting aspect of MPGD development for many of the current and future applications.

The time resolution of a detector can be defined as the precision with which the detector can distinguish between two overlapping events in terms of time. It depends on the transit of electrons from their generation point to the collecting electrode. The spread on the duration of transit leads to a finite time resolution of the detector [2, 3]. The main two factors that contribute to the spread are the statistics and distribution of the primary electrons and their diffusion in gas medium.

From event to event, the electron is not produced at the same distance from the read-out plane of the detector under consideration. The general expression for the space distribution of the electron-ion pair j , closest to the read-out plane, when \bar{N}_p is the average number of pairs produced, is obtained as follows [2, 3]:

$$A_j^{\bar{N}_p}(x) = \frac{x^{j-1}}{(j-1)!} \bar{N}_p^j e^{-\bar{N}_p x} \quad (1)$$

^ae-mail: nayana.majumdar@saha.ac.in

In particular, the distribution of the pair closer to one end of the detection volume, is given by

$$A_1^{\bar{N}_p}(x) = \bar{N}_p e^{-\bar{N}_p x} = \bar{N}_p e^{-\bar{N}_p u_e t} \quad (2)$$

where u_e is the electron drift velocity. The distribution is shown in figure 1(a) with variance $= \frac{1}{\bar{N}_p u_e}$.

Again, due to the diffusion, the electrons produced at the same position in the gas arrive at the read-out plane at different times. The arrival time distribution, from a particular distance is Gaussian, as shown in figure 1(b). The mean of this distribution gives the mean arrival time and the variance is equal to $D \sqrt{z_{dist}} / u_e$. Here D is the diffusion coefficient, z_{dist} is the traveled distance. With varying distance from the read-out plane, the mean drift time, as well as the variance, changes accordingly.

Considering the above two factors, if the first cluster is always assumed to generate signal that is detected by the read-out, the temporal resolution can be defined as:

$$\sigma_T^2 = \left(\frac{1}{\bar{N}_p u_e} \right)^2 + \left(\frac{D \sqrt{z_{dist}}}{u_e} \right)^2 \quad (3)$$

In the present work, a numerical simulation of the time resolution of a few MPGDs, is reported. A comprehensive study on the dependence of time resolution on detector design parameters and field configuration, has been made in addition.

2 Simulation Tools

The Garfield [4] simulation framework has been used in the following work. The 3D electrostatic field simulation

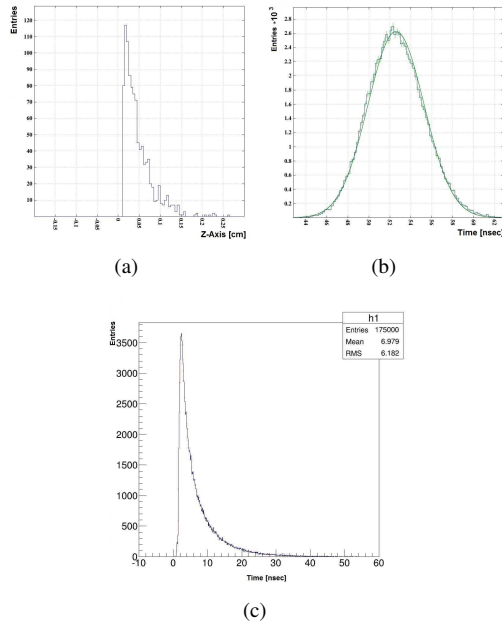


Figure 1. For a bulk Micromegas detector (a) minimum distance of an electron from the mesh plane, (b) the distribution of drift time of electron from a single point at fixed position above the mesh plane, (c) final time spectrum.

has been carried out using neBEM [5] toolkit. Besides neBEM, HEED [6] has been used for primary ionization calculation and Magboltz [7] for computing drift, diffusion, Townsend and attachment coefficients.

3 Simulation Models

In this work, Micromegas and GEM detectors have been opted as two cases of the MPGD genre for studying their temporal resolution. The design parameters of the bulk Micromegas detectors are compiled in table 1, whereas that for single and triple GEM detectors are listed in table 2.

Table 1. Design parameters of the bulk Micromegas detectors. Micromegas-wire diameter in all cases is $18 \mu\text{m}$.

Amplification Gap (in μm)	Mesh Hole Pitch (in μm)
64	63
128	63
128	78
192	63

In our calculation, cosmic muon ($1 - 3 \text{ GeV}$) tracks with different inclinations have been considered in the drift volume. In the first approximation, the resolution has been estimated on the basis of above two aspects while ignoring the electron multiplication. Rather, it has been assumed that the electrons which hit the readout plane first were multiplied adequately to produce a significant signal. For a particular track, the drift time of those primary electrons

Table 2. Design parameters of GEM-based detectors.

Polymer substrate	$50 \mu\text{m}$
Copper coating thickness	$5 \mu\text{m}$
Hole diameter (copper layer)	$70 \mu\text{m}$
Hole diameter (Polymer substrate)	$50 \mu\text{m}$
Hole to hole pitch	$140 (S)$
Drift Gap	3 mm
1 st Transfer gap	1 mm
2 nd Transfer gap	2 mm
Induction gap	1 mm

which hit the readout plane first to produce a considerable signal, has been recorded. Due the reasons mentioned above the time for the first hit varies from track to track and the final spectrum looks like as shown in figure 1(c), with a mean equal to the average drift time of the first hit and r.m.s (σ_T) equals to the time resolution.

Table 3. Design parameters of RPC detector.

Bakelite thickness	2 mm
Graphite coating thickness	$20 \mu\text{m}$
Copper strip thickness	$200 \mu\text{m}$
Gas gap	2 mm

In our calculation, some effects of electronics, such as shaping, noise etc., have not been considered. However, a modified simulation approach has been adopted where a threshold limit of detecting signal has been considered which is related to the gain variance of a detector.

4 Results

4.1 Bulk Micromegas

The temporal resolution of bulk Micromegas detector and its dependence on gas mixture, electrostatic field configuration and geometrical parameters have been simulated numerically [8]. Since the mean drift time of the first hit depends on the starting position of the electron, the inclination of the muon track plays an important role. The mean drift time for different inclined tracks and the corresponding resolutions have been plotted in figure 2. The electrons from the track which makes an angle of 5° with the XY-plane, are produced close to the micromesh plane and so these electrons traverse less path without being affected much by the diffusion. As a result the first hit time is less and also the resolution is better. With the increase of the inclination angle, the electrons have to travel much longer path which causes the worsening of the resolution and larger drift time.

The variation of the temporal resolution with drift field (E_{Drift}) has been plotted in figure 3(a) for the bulk Micromegas detector having amplification gap of $128 \mu\text{m}$ and pitch of $63 \mu\text{m}$ in Argon-Isobutane mixture with different

mixing ratios. At the lower drift field, the larger transverse diffusion is responsible for worsening of resolution. At the higher drift field, due to poor funneling, the electrons traverse larger path and thus increase the drift time and temporal resolution [9]. For a particular drift field, the variation of resolution has been plotted with the change in amplification field, or with the mesh voltage (V_{Mesh}) in figure 3(b). The resolution is clearly improving because of better funneling and less transverse diffusion due to higher field in the amplification gap.

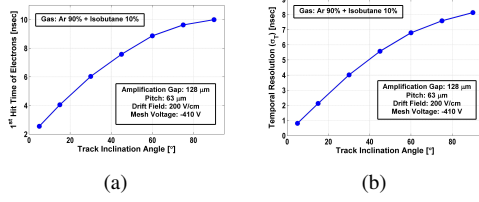


Figure 2. Variation of (a) first hit time and (b) r.m.s. with track angle in Argon-Isobutane (90 : 10) mixture for bulk Micromegas detector having amplification gap of 128 μm and pitch of 63 μm.

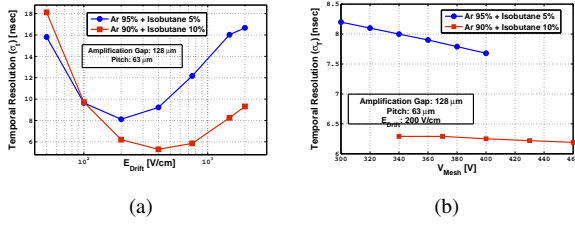


Figure 3. Variation of r.m.s. with (a) E_{Drift} , (b) V_{Mesh} in different Argon-Isobutane mixtures for bulk Micromegas detector having amplification gap of 128 μm and pitch of 63 μm.

The effects of the variation of geometrical parameters such as variation of the amplification gap and mesh hole pitch have been also studied. The variation of the resolution with the drift field for several bulk Micromegas detectors has been estimated. However, no significant effect on the resolution has been observed except at higher drift fields where the detectors with larger pitch and smaller gap show comparatively better resolution (figure 4).

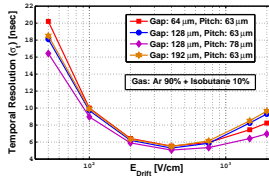


Figure 4. Variation of r.m.s. for bulk Micromegas detectors having different amplification gap and mesh hole pitch in Argon-Isobutane (90 : 10) mixture. Gap = 64 μm, pitch = 63 μm, mesh voltage = -330 V; gap = 128 μm, pitch = 63 μm, mesh voltage = -410 V; gap = 192 μm, pitch = 63 μm, mesh voltage = -540 V; gap = 128 μm, pitch = 78 μm, mesh voltage = -450 V.

4.2 Single GEM

To study the performance of GEM-based MPGDs, the temporal resolution of a single GEM detector and its dependence on the electrostatic configuration have been numerically simulated at first. The variation of temporal resolution with E_{drift} , V_{gem} and E_{ind} (induction field) has been carried out in Ar- CO_2 (70 : 30) mixture. Starting from the lower drift field, the resolution improves to a flat plateau. At lower drift fields, larger diffusion is responsible for a larger drift time and worsening of resolution (figure 5(a)). The variation with E_{ind} and V_{gem} reveals that the lower drift time and better temporal resolution can be obtained with higher induction field (figure 5(b)) and higher GEM voltage (figure 5(c)), respectively. At a higher induction field and high GEM voltage, the funneling of the electrons is such that the electrons have to travel smaller path to reach the readout plane. Also, at these higher field values, the transverse diffusion is low, whereas the drift velocity has an increasing trend. So the electrons take smaller time to reach the readout plane without much distortion.

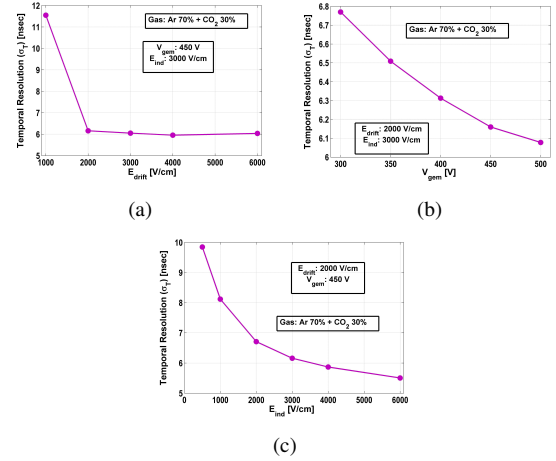


Figure 5. For a single GEM detector in Argon- CO_2 (70 : 30) mixture, the variation of temporal resolution with (a) E_{drift} , $V_{\text{GEM}} = 450$ V, $E_{\text{ind}} = 3000$ V/cm; (b) V_{GEM} , $E_{\text{drift}} = 2000$ V/cm, $E_{\text{ind}} = 3000$ V/cm; (c) E_{ind} , $E_{\text{drift}} = 2000$ V/cm, $V_{\text{GEM}} = 450$ V.

4.3 Triple GEM

The time spectrum of the triple GEM detector as a second case of GEM-based detector, is shown in figure 6(a) for two different Argon-based gas mixture. Due to higher drift velocity, the electrons in Ar- CO_2 - CF_4 mixture take less time to hit the readout plane. Also, the lower transverse diffusion coefficient in this mixture helps to obtain a better temporal resolution. It may be noted here that the numerical estimates (~ 11 nsec for Ar- CO_2 and ~ 7 nsec for Ar- CO_2 - CF_4) are quite close to experimentally measured values reported earlier [10–12].

The variation of the corresponding time resolution with applied high voltage for these two gas mixtures have been plotted in figure 6(b). As discussed in the case of

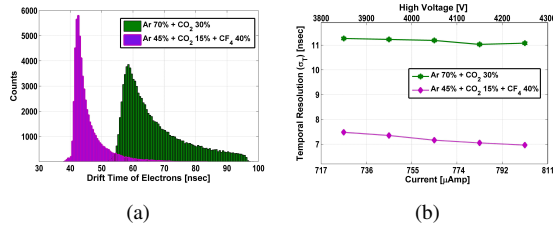


Figure 6. For a triple GEM detector: (a) time spectrum, the variation of (b) temporal resolution with current and applied high voltage in different Argon-based gas mixture.

single GEM, an increase of the drift field, hole voltage and the induction field reduce the time taken by the electron to reach the readout plane, as well as improve the time resolution. For the triple GEM also, a larger value of the applied high voltage increases the field in the respective regions which in turn make the drift time less and the resolution better.

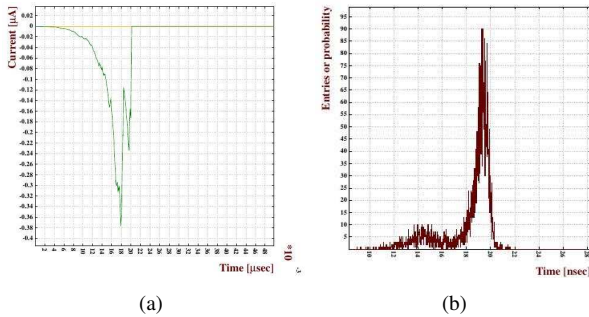


Figure 7. For RPC, (a) induced signal; (b) time spectrum

5 Modified Simulation Approach

In the modified model, a threshold limit of detecting the signal has been considered which is related to the gain variance of the detector. At first, the new approach has been applied on a RPC detector. The detector dimension is listed in table 3. High voltages of ± 5800 V have been applied in this detector to generate the signal in Freon-Isobutane-SF₆ (95 : 4.5 : 0.5) gas mixture. A typical induced signal for a cosmic muon track of 1 GeV is shown in figure 7(a). For the present calculation, $0.1 \mu\text{A}$ current at the rising edge of the signal has been considered as a lower threshold. For each track, the time to cross this threshold has been recorded and the final spectrum looks like as shown in figure 7(b). The r.m.s of this distribution has been found to 1.2 nsec which is very close to the

experimental value. But this is only a preliminary calculation and further investigation is going on before drawing any firm conclusion. In future, this approach will be used to simulate the time resolution for the MPGDs.

6 Conclusion

In this paper, an attempt has been made to establish an algorithm for estimating the time resolution of an MPGD. A comprehensive numerical study on the dependence of time resolution on detector design parameters, field configuration and relative proportions of gas components has been made for a few MPGDs. The simulated results have been compared with available experimental data and the agreement between them is very encouraging. Please note that, gas composition used for Micromegas and GEM are made different to compare them with the available experimental data. Thus, a comparison between these two MPGDs is not possible here. The present work aims to accomplish a comprehensive characterization of the time resolution of the MPGDs on the basis of numerical as well as experimental measurements. In addition to further improvement in the numerical work, development of a test bench for studying the MPGDs individually for their characteristics time resolution and its dependence on the design parameters and gas composition has been planned.

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