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# Track distortion in the Large prototype of a Time Projection Chamber for the International Linear Collider

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**Abstract.** A Micromegas (MM) based Time Projection Chamber (TPC) can meet the ILC requirements of continuous 3-D tracking, excellent spatial resolution and efficient pattern recognition. Seven MM modules which are commissioned on the end-plate of a Large Prototype TPC (LPTPC) at DESY, have been tested with a 5 GeV electron beam, under a 1 T magnetic field. Due to the grounded peripheral frame of the MM modules, at short drift, the electric field near the detector edge remain no longer parallel to the TPC axis. This causes signal loss along the boundaries of the MM modules as well as distortion in the reconstructed track. In presence of magnetic field, the distorted electric field introduces  $E \times B$  effect. A detailed numerical study has been accomplished to understand the features of this distortion. Four Micromegas modules have been simulated resembling the experimental setup. The field lines, drift line of electrons considering diffusion in gas, nature of track distortion, residuals are numerically calculated in presence and in absence of magnetic field. The  $E \times B$  effect has been simulated as well. Simulated results follow the experimental observations.

## 1. Introduction

The International Linear Collider (ILC) [1] is proposed to be a discovery and precision measurement machine where  $e^-$  and  $e^+$  will collide initially up to 500 GeV at the electron center of mass frame. It provides opportunities to measure Higgs couplings at different energies and Higgs self-coupling at the upgraded 1 TeV energy scale. The International Large Detector [2] is one of the two detector concepts at the ILC. A Time Projection Chamber [3] has been foreseen to be installed just beyond the vertex detectors to accomplish continuous 3-D tracking for the ILC. Within a high luminosity collider, the TPC is supposed to register events at a very high rate and the physics measurements demand the position resolution of the detectors around 100  $\mu\text{m}$ . Micro-pattern Gaseous Detectors (MPGD) [4] at the TPC anode plane can meet such challenges. A Large Prototype of the Time Projection Chamber (LPTPC) has been installed



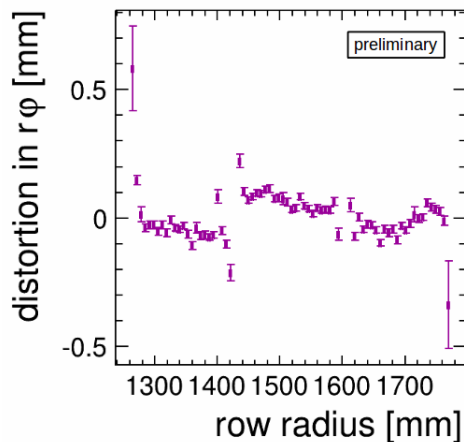


Figure 1: After the alignment correction, the observed distortion at  $B = 0$  T [6].

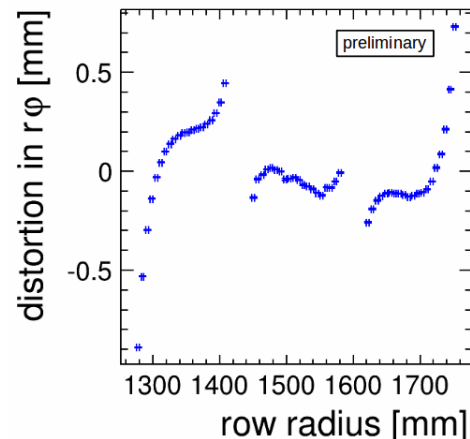


Figure 2: Observed distortion at  $B = 1$  T. The  $E \times B$  effect can be seen near the edges [6].

[5] at DESY since 2008 and different MPGDs have been tested on the LPTPC end-plate [6]. Upto seven resistive Micromegas (MM) [7] modules have been studied at the LPTPC end-plate from 2009 through 2015 and they have shown promising performance [6, 8] as required for the ILD-TPC. The keystone-shaped modules have identical size of  $17 \text{ cm} \times 22 \text{ cm}$  so as to fit in the end-plate. The amplification gap and the micro-mesh wire pitch have been chosen to be  $128 \mu\text{m}$  and  $63 \mu\text{m}$  respectively. Different types of resistive layers with surface resistance around  $3 - 5 \text{ M}\Omega/\text{sqr}$  have been tested [9] at the LPTPC with an electron beam of energy ranging from  $1 - 6 \text{ GeV}$ , under a magnetic field of  $1 \text{ T}$ . The anode read out of a Micromegas module is segmented in 1726 pads of size  $3 \text{ mm} \times 7 \text{ mm}$  and arranged in 24 rows. The gas composition of the LPTPC is an admixture of  $\text{Ar}:\text{CF}_4:\text{Isobutane}$  (95:3:2).

In case of Micromegas, a supporting thin frame that holds the detector along its boundaries to the metal structure of the module, lies in ground potential. During analysis, it is found that the residual of the pad hits (explained in section 3.3) on the extreme rows of the MM modules have larger magnitude with respect to the other rows. Figure 1 shows the row-wise distribution of the residuals (an alignment correction is performed) when the magnetic field is not applied and in figure 2 the row-wise distribution of the residuals are plotted when a magnetic field of  $1 \text{ T}$  is applied. Near the boundaries of the modules, in case of applied magnetic field, the residuals take a ‘S’-like shape [6].

In the present report, an attempt is taken to investigate the track distortion for the Micromegas modules by means of numerical calculations. In a previous report [10], we have addressed the simulation of three MM modules to explain the observed track distortion as an effect of distorted electric field ( $E \times B$  effect) near the edge of the detectors. In this report, we have further broadened the scope by investigating the effect on four MM modules which represents the experimental set-up [6] more closely.

## 2. Numerical Modeling

The work has been accomplished within the Garfield [11] simulation frame work. The field solver used for this calculation is the *nearly exact Boundary Elementary Method* (neBEM) [12]. HEED [13] is used to calculate primary ionization and Magboltz [14] is used for computing drift, diffusion, Townsend and attachment coefficient. The Garfield framework provides suitable interfaces to the software components neBEM, HEED and Magboltz among others.

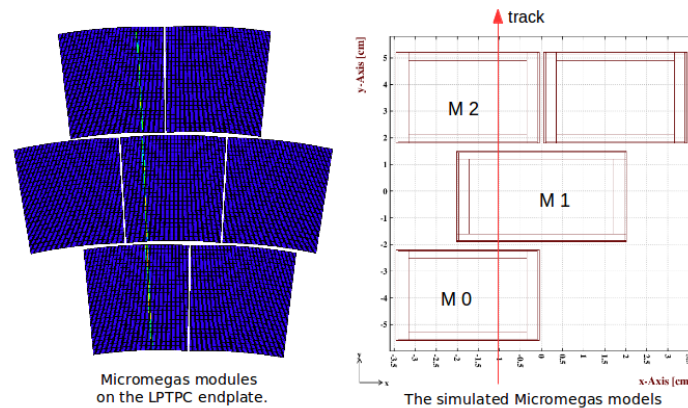


Figure 3: The simulated Micromegas models are arranged in a manner similar to the MM modules on the LPTPC end-plate.

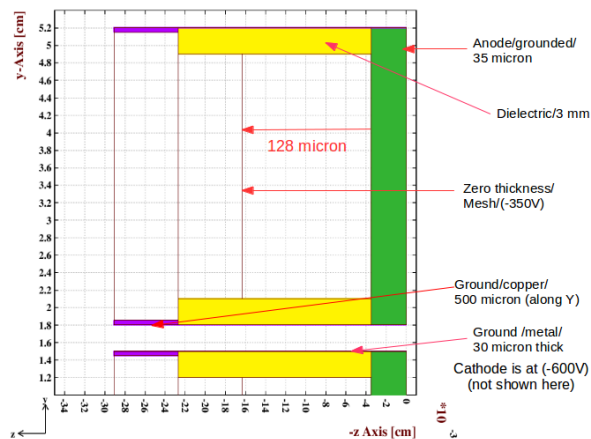


Figure 4: Detailed geometry of the simulated Micromegas models (a section in the Y-Z plane).

### 2.1. Geometry

The model geometry used for this calculation is simpler than that of real Micromegas on the LPTPC end-plate mainly to reduce computational complexity. Four standard Micromegas are taken instead of the seven resistive Micromegas. The shapes of the models are  $3.4 \text{ cm} \times 3.4 \text{ cm}$  squares instead of the  $17 \text{ cm} \times 22 \text{ cm}$  keystone-shaped Micromegas. However, few critical parameters are taken unchanged. The amplification gap is taken  $128 \mu\text{m}$ . The photoresist support for the mesh is taken to be  $3 \text{ mm}$  thick. The vertical copper frame, which is grounded, is taken to be  $30 \mu\text{m}$  thick (figure 3). The gaps between two Micromegas models are taken as  $3 \text{ mm}$ . Zero thickness model of the micro-mesh has been used. The anode lies in ground potential. The micro-mesh and the cathode (drift plane) are biased to  $-350 \text{ V}$  and  $-600 \text{ V}$  respectively. The cathode rests  $1 \text{ cm}$  above the micro-mesh. A challenging part of this computation is to deal with such geometry that is extended to a few centimeters in one axis and only few micro meter in the perpendicular direction.

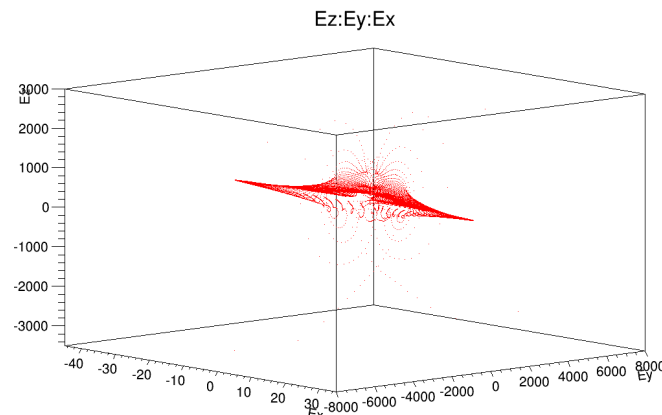


Figure 5:  $E_X, E_Y$  and  $E_Z$  (in V/cm) on the gap between the models are plotted. The  $E_X$  and  $E_Y$  components has significant magnitude that cause distortion.

### 3. Results

#### 3.1. Electric Field

The electric field between the cathode and the micro-mesh near the middle of the detector is perpendicular to the anode plane, i.e., parallel to the TPC axis. Because of the grounded frame and the dielectric support on the boundaries of the detector, the electric field at the vicinity of the detector edge does not remain parallel to the TPC axis. There exist transverse components of the field (in X and Y direction) near the gap between the modules. Because of these transverse components of the field, the electrons near the edge of the detector follow a transverse path and mostly hit the dielectric. This causes signal loss for the pads on the edge. This also leads to increase of the residual for the hits near the edges. In figure 4 the X, Y and Z components of electric fields on a plane perpendicular to the anode at  $X = -1$  cm are plotted. A large value of the Y component of the field can be seen.

#### 3.2. Drift of electrons

A track is defined out of the electrons on 456 equidistant points along  $X = -1$  cm (figure 2) and  $Z = 0.5$  cm (the drift distance). The same gas as used in the LPTPC is considered for the gas transport calculations. As the field solver has computed the field values for the entire model, the track drifts towards the anode accordingly. 100 such tracks have been considered from the same position to generate statistics. The drift lines and their end points (figure 5) clearly show that due to the distortion in the electric field, a significant number of electrons do not hit the anode pad near the edge and are lost on the dielectric. Magnetic field is applied to reduce the transverse diffusion as well.

#### 3.3. Distribution of residuals

The residual of a pad hit is defined [15] as,  $\Delta X = X_{hit} - X_{track}$ , where,  $X_{hit}$  is the measured position of the hit and  $X_{track}$  is the position of the hit according to the track fitting. In present calculation, the track has the true coordinates and that is why reconstruction and track fitting is not necessary. The coordinates of the individual electrons that finally hit the anode are obtained from the calculation. From the initial positions of the electrons on the track ( $X_{track}$ ) and from the final positions ( $X_{hit}$ ), the residuals of individual hits are obtained. The residuals are then averaged over the number of events (tracks). When plotted, the distribution of the residuals along the direction of the track length shows (figure 6) the effect of electric field distortion near the edges of the detectors. The magnitude of the residuals are high near the module gaps.

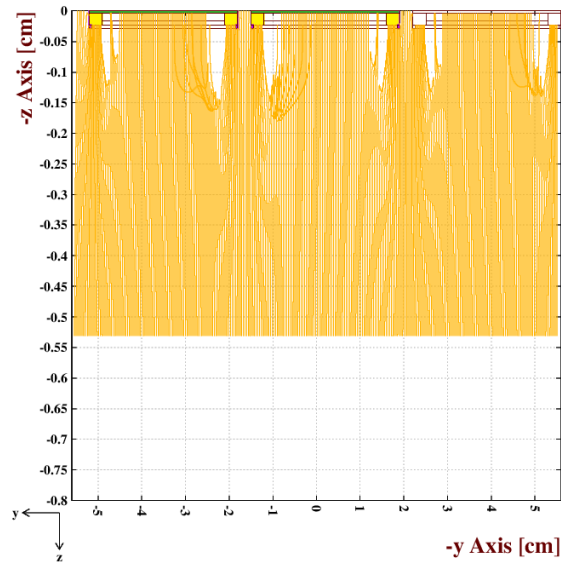


Figure 6: Drift of the electrons is shown at  $B=1T$ . A small area adjacent to the dielectric is devoid of hits while significant signal loss can be seen on the dielectric.

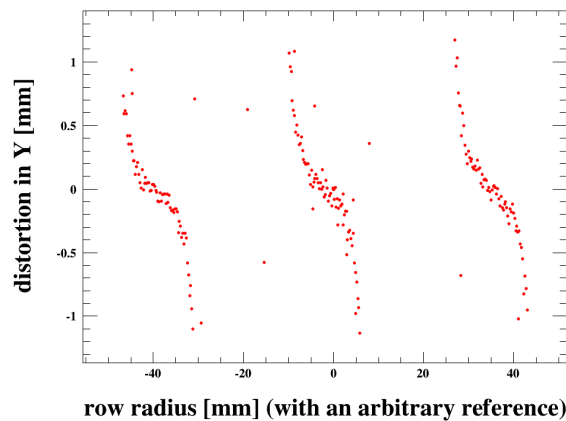


Figure 7: Simulated distortion at  $B=0T$ . The residuals are plotted against the row radius (along the direction of the track). Drift,  $z = 0.5$  cm.

On application of a magnetic field of 1 T, the signs of the residuals change (figure 7). The reason of such change is because of the Lorentz force that comes to play once the magnetic field is applied. Near the gap, the magnetic field together with the transverse components of the electric field introduce the Lorentz force. Therefore, the electrons, when the magnetic field is applied, are moved in a different direction by the Lorentz force. And hence the change in sign occurs.

#### 4. Conclusion

The entire simulation is done with a number of simplifications in the geometry of the detectors. Hence, a direct comparison with the experimental results is possibly not applicable. However, the intrinsic parameters, like amplification gap, thickness of the dielectric and the ground frame, the inter-modular distances and the TPC gas are maintained true to the experimental values in

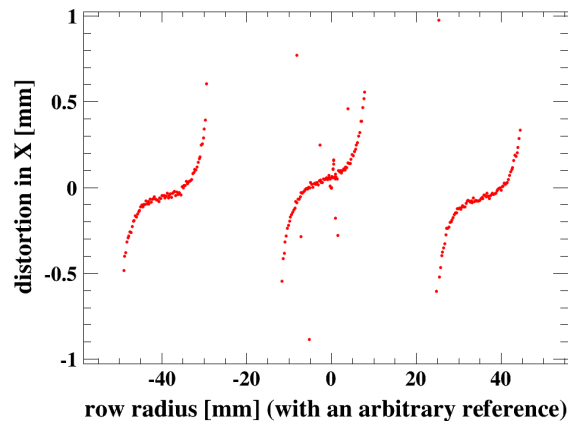


Figure 8: Simulated distortion at  $B=1T$ . The residuals are plotted against the row radius (along the direction of the track). Drift,  $z = 0.5$  cm. The sign of the residual changes with respect to the case of  $B=0T$ .

this calculation. The miniaturization of the detector modules in X-Y dimensions are made only to avoid computational delay and complexities. The nature and the magnitude of the distortion closely match the results as seen in the Micromegas based LPTPC. The prime motivation of the study have been to understand the distortion and to explore possibilities for improvements. Further study will be continued in more details.

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