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A numerical investigation on the track distortion at the Micromegas based LPTPC endplate

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Abstract. The R&D activities for the Linear Collider TPC (LCTPC) are currently focused on the adoption of the Micro-Pattern Gaseous Detectors (MPGDs). Different MPGD modules which are commissioned on the endplate of a Large Prototype TPC (LPTPC) at DESY, were tested with a 5 GeV electron beam, under a 1 T magnetic field. During the tests, reduced signal sensitivity as well as distortion in the reconstructed track, were observed at the boundary of these modules.
We have numerically investigated the origin of the track distortions observed close to the edges of the Micromegas modules. The study clearly shows that the electric field non-uniformity near the inter-modular gaps is responsible for such track distortion. We have been able to simulate the observed patterns and magnitudes of distortion successfully. The obtained agreements with 2015 beam test data encourage us to continue with the study and, to propose module design modifications that can alleviate the problem of electrostatic field distortion at the module boundaries.

1. Introduction

The clean background of an electron-positron collider provides a favorable environment for studying Higgs couplings. At the International Linear Collider (ILC), where the electron and positron beam will collide in a range of 200-500 GeV center of mass energy, a model independent determination of the total Higgs width will be possible [1]. The golden channel at 250 GeV gives the unique opportunity of detecting Higgs events even without looking at its decay. Higgs mass can be determined with excellent precision from the measurement of Z boson, decaying in leptons. Of course, precise momentum reconstruction of the leptons is a strict requirement to reach the goal. This can be achieved by the Time Projection Chamber (TPC) that can realize truly continuous 3 dimensional reconstructions of the lepton tracks.

One of the two detector concepts for the ILC is the International Large Detector (ILD) [2]. The central tracker of the ILD, which will be installed just beyond the vertex detectors, is foreseen to be a Time Projection Chamber [3]. Micro-Pattern Gaseous Detectors (MPGD) [4] are proposed for the charge amplification at the endplates of the International Large Detector TPC (ILD-TPC) [2]. The inner and outer radii of the ILD-TPC will be around 33 cm and 181 cm respectively. The cathode will be at the center and the length of the TPC will be 235 cm

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$\times$ 2. It will work under a magnetic field of 3.5 T. The physics goals set the requirement of momentum resolution around 10^{-4} $(\mathrm{GeV/c})^{-1}$, which translates to a required spacial resolution less than 100 μm and two-hit resolution less than 2 mm.

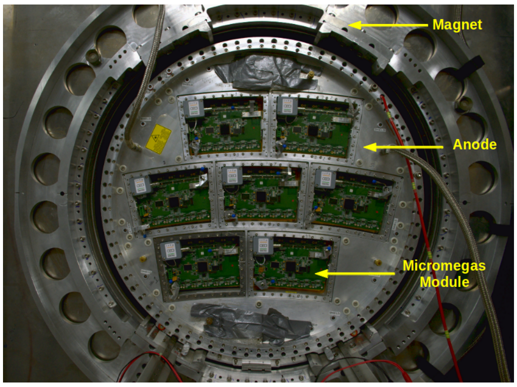

Figure 1. The Micromegas based endplate of the LPTPC.

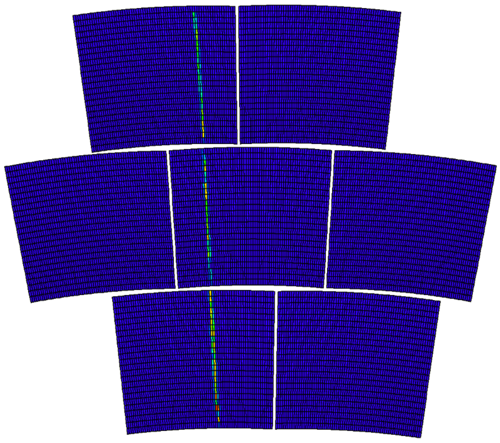

Figure 2. An electron track passing over three Micromegas modules. Event display example.

To match the requirements of high rate capability, low ion feedback and high special resolution, the obvious choice came out to be the Micro-Pattern Gaseous Detectors (MPGD) for the charge amplification at the TPC endplate. To realize such a large tracking device in a collider, a Large Prototype TPC (LPTPC) was introduced in 2008 at the DESY test beam facility of Hamburg [5]. Since then, different MPGDs have been tested [6] at the LPTPC endplate with a 5 GeV electron beam under a 1 T magnetic field. Along with other MPGDs, Micro Mesh Gaseous Structures (Micromegas) [7] have also been tested (figure 1). Several beam tests have been conducted so far to test the performance of the Micromegas based LPTPC. Many developmental activities on the hardware, like testing different resistive material, implementing two-phase CO_2 cooling for the electronics [8], employing multiple (up to seven) modules on the endplate etc. (figure 2) have been conducted [5]. A continuous development on the software framework for track reconstruction and analysis is also being perused. The performance of the Micromegas at the LPTPC during the last decade has proved that Micromegas is a potential candidate for the ILD-TPC [5,9].

During the R&D process, a few interesting challenges came up. One of which is the distortion of the reconstructed track on MPGD based readout. It is believed that the distortion occurs due to the localized non-uniformity of the electric field around the boundary of the MPGD modules. The electric field inhomogeneity, in presence of magnetic field, gives rise to $\vec{E} \times \vec{B}$ effect. The problem is general and affects the overall performance of the TPC. Although, a considerable improvement on the performance of the TPC can be achieved during the analysis work of track reconstruction, it is always better to remove the problem at its cause.

To validate the reasons behind the occurrence of the track distortion as well as to estimate its effects, a numerical investigation is always very helpful. Not only it may bring adequate understanding of the problem but may also suggest possible ways to improve the situation. The usefulness of such model has been reported by the group previously [10] and this report is a continuation of that study. In this study a few major geometrical modifications have been made and another interesting case, where we bias the anode plane, has also been investigated.

2. The Micromegas based Large Prototype TPC

At DESY, Hamburg, a Large Prototype of the ILD-TPC has been constructed and installed in 2008. A superconducting magnet solenoid (Persistent Current superconducting MAGnet or the PCMAG), which can produce a magnetic field up to 1 T has been accommodated inside the test beam area T24/1. The TPC field cage is 61 cm in length and 77 cm in diameter. Its inner length and diameter are 57 cm and 72 cm respectively. The admixture of 95% Ar, 3% CF_4 and 2% nC_4H_{10}, which is also known as the T2K gas, is a candidate for the ILD-TPC. The anode plane of the LPTPC is made of aluminum alloy. It is capable to house seven keystone-shaped MPGD modules of identical size of 22 cm × 17 cm, in three module rows (figure 1, figure 2). The Micromegas modules for the LPTPC have the keystone shape and the size of about 22 cm in width and 17 cm in height. The amplification gap is 128 μm. The read out of Micromegas module is segmented in 1726 pads of size 3 mm × 7 mm [5]. The readout plane of a Micromegas (MM) for the LPTPC is surrounded by a thin copper frame which is connected to the resistive foil of the readout. The frame is maintained at ground potential along with the readout. Geometrically, the copper frame and the micro-mesh rest very close to each other. A magnified photograph of the corner of a Micromegas module is shown in figure 3. The array of dots are the dielectric pillars those hold the micro-mesh, the dark border is the dielectric wall, and then the bright frame is the copper frame. The dielectric border is 3 mm thick, the copper frame is 30 μm thick on the sides and on top of the dielectric it is 500 μm thick. It should be mentioned here that these geometrical specifications are according to the 2014-2015 test beam setup [5,9].

3. Simulation Framework

The numerical study has been performed within the Garfield [11] simulation framework. The 3-dimensional electrostatic field simulation has been carried out using neBEM [12,13] toolkit. To estimate the charge transportation properties like, drift, diffusion, attachment etc. the Magboltz tool [14] is used.

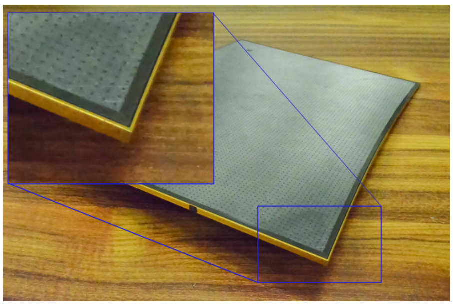

Figure 3. The supporting copper frame around the Micromegas module.

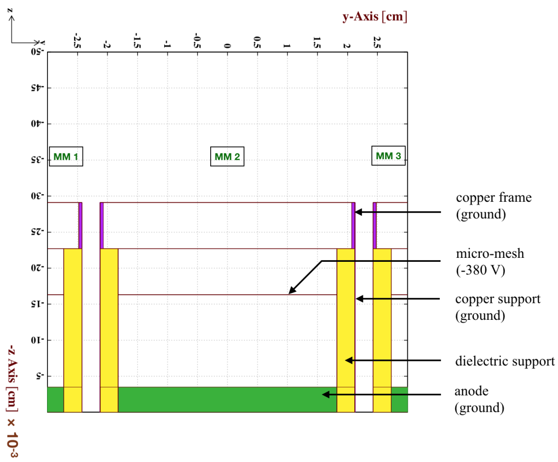

Figure 4. Cross-sectional view of the modeled geometry on the YZ plane. Different parts are labeled on the figure.

4. Simulation Configuration

In the beam tests, the electron track, in general, is reconstructed with three Micromegas modules. An example of such event is illustrated in figure 2. Therefore, in our simulation we have modeled only three Micromegas modules to study the distortion. It is a known fact that in simulation, the geometry is modeled as a miniature of the actual size to save computation cost and time. In present case, the X and Y dimensions of the modeled geometry is taken quarter to their actual sizes, that is, 5.5 cm × 4.25 cm. This choice of geometry is a new feature of this study. A few other minor simplifications, which do not contribute in track distortion, are also made: the anode is taken continuous and non-resistive, the mesh is taken as a zero thickness plane, the cathode is placed 1 cm above the mesh. Nevertheless, the critical dimensions like the amplification gap, thickness of the boundary copper frame and the dielectric wall, inter modular gaps etc are taken true to the actual geometrical specifications. For the charge transportation, the same T2K gas is taken. The cross-sectional view of the simulated geometry is shown in figure 4 where different parts of the geometry are explained. The view of the geometry on the X-Y plane is shown in figure 5 where the positions of all the three modules can be understood.

In this report, the track distortion is studied for a few different configurations of potentials. We have started with the specifications as used in the experiment, e.g., the micro-mesh is at -380V and the anode is at ground potential. To ensure a drift field of 230 V/cm, the cathode is kept at -610 V. The copper frame which supports the read out and sits next to the micro-mesh is at ground potential. In the next case the anode is kept at +380 V and the micro-mesh is at ground potential. The cathode voltage is changed accordingly. A few other cases are also studied where the anode is at ground, micro-mesh is at -380 V, cathode is at -610 V as usual, but the potential of the copper frame is changed to -380 V, and then to -480 V. Note, the potential of the copper frame is varied around the potential of the micro-mesh as they are sitting close to each other. The motivation for this change in potential configuration is obviously to observe any change or improvement in distortion. The results are discussed in the following section.

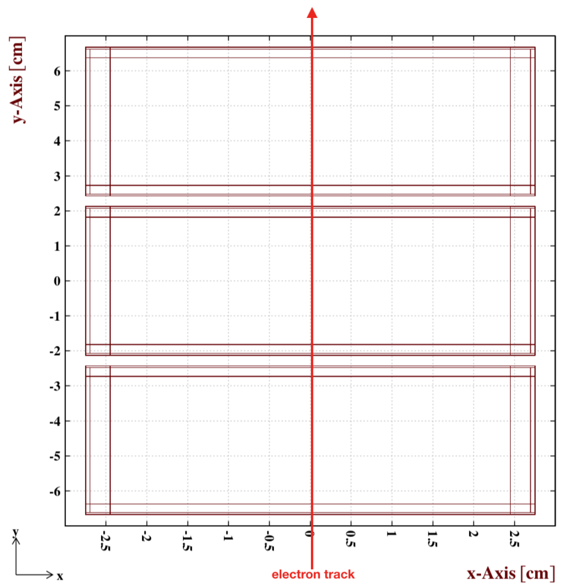

Figure 5. The modeled geometry. View on the X-Y plane.

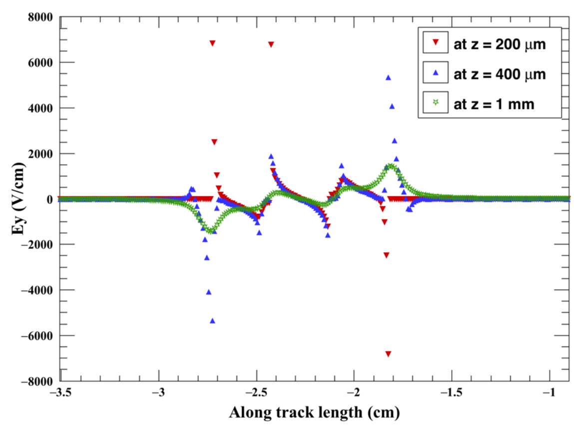

Figure 6. E_y component of electric field near the edges of the modules at different drift distances. In ideal situation, there should not exist any transverse component of electric field.

5. Results

5.1. *non-uniformity of the field lines*

The structure of the field lines in a gaseous detector is very important. It guides the electrons towards amplification and ions to get collected. In a TPC, with the help of the field cage, the

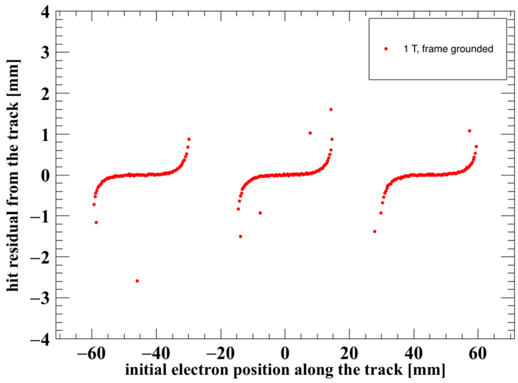

Figure 7. Distortion as obtained from simulation.

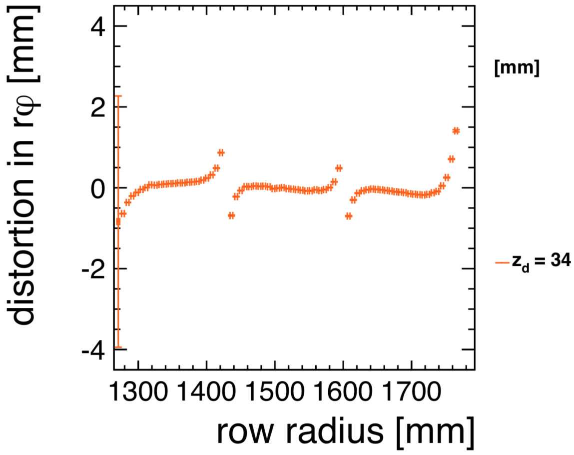

Figure 8. Distortion as observed in 2015 beam test [5].

electric field is made parallel to the axis of the cylinder, e.g., the drift direction. The electric field between the cathode and the first electrode on the readout side (which is the micro-mesh) is desired to be homogeneous and parallel. But, of course the electrode on the readout side is not continuous because it is formed with several detector modules. Now, as in present case, the supporting copper frame around the micro-mesh is kept at ground potential, it is easily understandable that the drift field, close to the endplate is not as uniform as desired. The situation is quite similar for other MPGD modules as well [15,16]. It should be noted here that the non-uniformity of the electric field is due to the structure of the detector geometry and is highly localized close to the anode plane.

The non-uniformity of the electric field near the inter modular gaps (or in other words around the edge of the Micromegas modules) can be clearly seen in simulation. The Micromegas modules in the modeled geometry lie in the X-Y plane and the field is ideally expected to be only along Z direction. Now, because of the presence of the peripheral copper frame and the dielectric support, the transverse components (E_Y and E_X) of the field also appear close to the micro-mesh. The Y component of the field is probed along a line which is parallel to the Y axis at X=0 cm (the field is probed along the arrow line as shown in figure 5). The probing is done at different drift distances (Z values). In figure 6, E_Y is plotted along the line segment, in one of the inter modular regions. It can be seen that as we go closer towards the micro-mesh (from Z = 1 mm to Z = 400 μm), the transverse field is becoming stronger (up to 8000 V/cm). The situation becomes even complicated when the magnetic field, which is applied parallel (or anti parallel) to the TPC axis, is taken into account. Since a strong transverse component of electric field exists, the cross product of the applied electric field and the magnetic field gives rise to the Lorentz force. As a result, the electrons are dragged along X direction and that is how the projected track on the readout is distorted near the edges.

5.2. distortion

To measure the track distortion in Garfield, Monte-Carlo drift technique is used. At a drift distance of 5 mm, a track is defined by 427 points with one electron at each point. The line goes parallel to Y axis (in reference to the modeled geometry, see figure 5) at X = 0 mm. Therefore, track passes through all the three modules. The track is repeated for 50 times and the electrons are allowed to drift down towards the micro-mesh.

In the drift Monte-Carlo (MC), the start and end coordinates of all the electrons are recorded.

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Reconstruction of the electron track on readout is done from the end coordinates of the electrons. Since the initial or the actual track position in the simulation is a declared entity, the absolute determination of the residuals of the reconstructed hits on the readout can be directly done: $\delta X = X_s - X_e$, where X_s and X_e are respectively, the start and end x coordinates of the electrons.

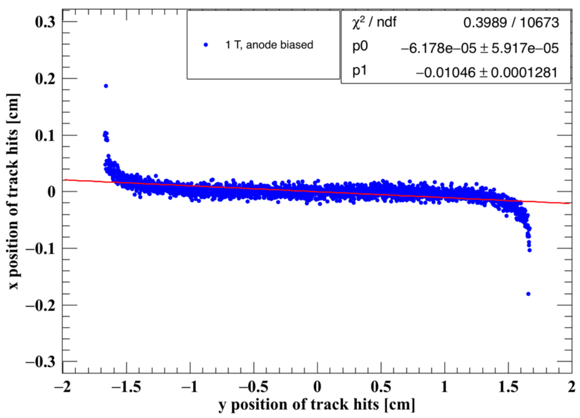

Figure 9. Projection of the track on the middle module. The anode is at +380V and mesh is at ground.

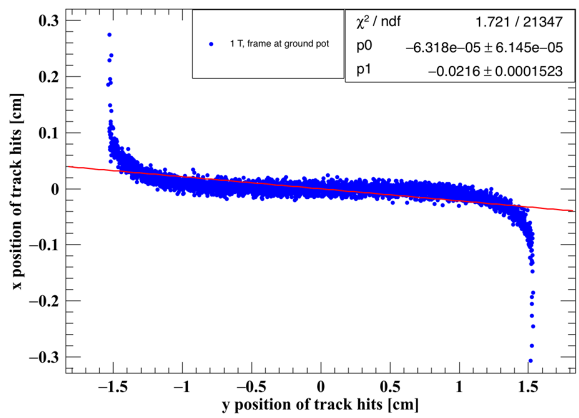

Figure 10. Projection of the track on the middle module. The anode and the mesh is at ground potential and mesh is at -380V.

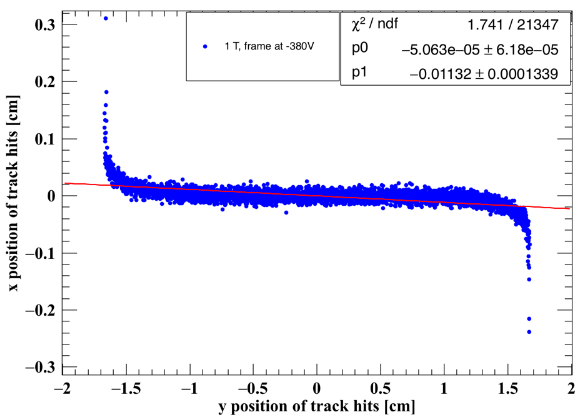

Figure 11. Projection of the track on the middle module. The copper frame is at -380V.

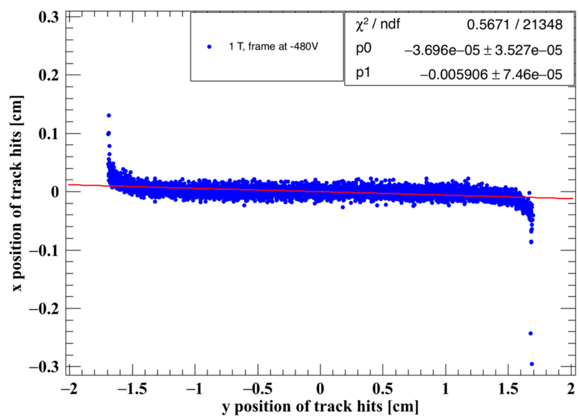

Figure 12. Projection of the track on the middle module. The copper frame is at -480V.

In figure 7, the average of the residuals are plotted along the track length, as usually presented in experimental plots (figure 8) [5,6]. The configuration of the electric potential of the Micromegas module for this plot represents the regular case, as it was in the 2015 test setup, where the micro-mesh is at -380 V and the anode is at ground potential. Clearly the nature and the magnitude of the simulated distortion plot follows what is observed experimentally in 2015 beam test (figure 8). The agreement confirms the assumption that the track distortion arises owing to the copper frame kept at ground potential.

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The result inspires us to continue with the study and to make some modification in the modeled geometry. Three different cases have been studied. In the first case, the potential configuration is altered. The anode is biased to +380 V, the mesh is kept at ground potential and the cathode is biased to -230 V, therefore, keeping the drift and the amplification field exactly the same. This way, since the micro-mesh and the copper frame are both at ground potential, the effect of distortion should be reduced. To compare, the end points of the electrons, which are hitting the anode are plotted. In figure 9, simply the x and the y positions of the electrons are plotted and fitted with a linear function. A similar plot is made for the regular case, where the anode is at ground and the micro-mesh is at -380 V (figure 10). From the χ^2 and the offset of the linear fits, it is quite clear that the track reconstruction is improved when the bias potential was reversed. Two other cases were also studied, where the copper frame is biased to -380 V (figure 11) and -480 V (figure 12) respectively. The rest of the electrodes are at the same potentials. The end positions of the electrons on the readout are plotted and fitted with a linear function for both the cases. The χ^2 and the offsets for these two cases also suggest improvement as compared to the regular case (figure 10).

6. Conclusion

The results suggest that biasing the copper frame could be a solution to recover track distortion. However, the idea of biasing the copper frame involves challenge in terms of hardware implementation. On the other hand, reversing the potentials between the micro-mesh and the anode is easy to implement and also is very effective to reduce the distortion effect.

7. Acknowledgment

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References

[1] T. Behnke (ed.) et al., International Linear Collider TDR: Executive Summary vol. 1 (2013)
[2] T. Behnke (ed.) et al., International Linear Collider TDR: Detectors vol. 4 (2013)
[3] D. R. Nygren et al., Phys. Today 31 (1978) 46
[4] M. Hoch, Nucl. Instrum. Method A 535 (2004) 1
[5] D. S. Bhattacharya, PhD. Thesis, Jadavpur Univ. (2017)
[6] D. S. Bhattacharya et al., Proc. Science (EPS-HEP2015) 277 (2015)
[7] Y. Giomataris et al., Nucl. Instrum. Meth. A 29 (1996) 376
[8] D. S. Bhattacharya et al., JINST, 10:P08001 (2015)
[9] W. Wang, Ph. D Thesis, Univ. of Paris-Sud, (2013)
[10] P. Bhattacharya et al., EPJ Web Conf. Vol. 174, (2018) 06007
[11] R. Veenhof, Nucl. Instr. and Meth. A 419 (1998) 726
[12] N. Majumdar et al., Nucl. Instr. and Meth. A 566 (2006) 489
[13] S. Mukhopadhyay et al., Eng. Anal. Boundary Elem. 30 (2006) 687
[14] S.F. Biagi, Nucl. Instr. Meth. A 421 (1999) 234
[15] R. Diener, Nucl. Instr. Meth. A 856 (2017) 109
[16] K. Zenker, PhD thesis, University of Hamburg, DESY (2014)