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Development of a GEM-based High Resolution TPC for the ILC

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The physics goals and the expected enviroment at the ILC requires the development of a detector with unprecedented tracking capabilities. A high resolution TPC with gas amplification based on micro pattern gas detectors is a promising candidate for the main tracker at the ILC detector. Significant progress has been achieved on the development of a TPC concept with Gas Electron Multipliers (GEM) used for gas amplification. Significant ion-backdrift reduction was obtained using special settings of the GEM structures. The influence of the space charge, produced by the remaining ions, on the track reconstruction has been investigated. To further study the spatial resolution of a GEM-based TPC, prototypes with low-mass field cages were constructed. They were operated within a high-resolution silicon hodoscope, in high magnetic fields and in test beams. Here, emphasis is placed on the spatial resolution, which can be achieved with diminished pad sizes or varied pad geometries. Additionally, extensive effort is spent on the development of an accurate numerical simulation of the TPC porperties, such as drift, diffusion and gas amplification.

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1. Introduction

In many particle physics experiments a Time Projection Chamber (TPC) has been chosen as the main tracking device. It combines the advantages of having a large sensitive volume and many reconstructed space points together with a very small material budget. The ionisation tracks produced in the drift volume are projected onto the endplates where a readout structure reconstructs a 2D image of the track. The z coordinate is measured using the drift time information. Traditionally wire grids streched across the endplates are used for gas amplification where pad structures pick up the signals produced by the motion of the positive ion clouds. These devices are limited in momentum and double-track resolution due to the large wire distances, $\vec{E} \times \vec{B}$ effects near the wires and the slow ion signal.

The use of micro pattern gas detectors has been proposed in order to improve the capabilities of the TPC. For example using Gas Electron Multipliers (GEM) [1] as the charge amplifying system could solve some of the drawbacks of wire planes. Here, the pads directly detect the amplified electron cloud and the slow ion tail is cut off since the ion cloud does not reach the induction region which results in a fast and narrow charge signal. These devices show no preferred direction, thus any $\vec{E} \times \vec{B}$ effects are isotropic. And finally the back drift of the produced ions can be suppressed to a large extend using highly asymmetric electric fields between drift and amplification region.

For the detector at the International Linear Collider (ILC) the usage of a TPC with micro pattern readout using GEM foils is discussed [2]. To reach the required momentum resolution of $\delta(1/p_t) < 2 \cdot 10^{-4}$ GeV^{-1} for the stand-alone TPC, readout planes with the finest possible granularity are needed. The TPC has to provide a single point resolution of 100 – 150 μm and systematic distortions must be controlled to better than 10 μm over the full track length of about 1.5 m. Sufficient charge amplification has to be provided by the system to keep the signals well above the noise level of modern readout electronics. At the same time the produced ions have to be suppressed intrinsically, because active gating is impossible within the bunch spacing of only 0.3 μs.

2. Ion backdrift

Ions drifting back from the amplification region into the drift volume of the TPC could result in a severe distortion of the drift field. Therefore, one important parameter of the gas amplification structure is the ion backdrift which describes the fraction of ion charge transferred into the drift volume per electron charge collected on the anode plane.

The ion backdrift varies with the setting of the electrical fields within the GEM structure. From extensive measurements of the charge transfer in a triple GEM structure [3], a parametrisation model was developed. Using a setting with highly asymmetric fields in the GEM structure deduced from that model allows to minimise the ion backdrift. It is further reduced by a magnetic field perpendicular to the GEM surface. On the left of Figure 1 the minimum ion backdrift achieved is shown as a function of the magnetic field. In a 4 T magnetic field an ion backdrift as small as 2 permille was observed [4].

In a seperate study the ion backdrift for this optimised setting is measured for different total gains of the GEM structure. The result is shown on the right of Figure 1. Within the uncertainty of the measurement the ion backdrift is found to be independent of the total gain. For total gains

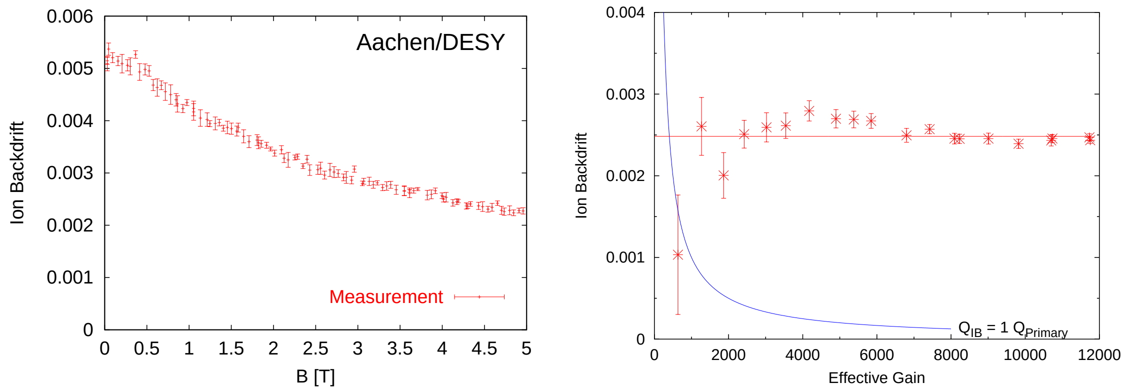

Figure 1: Dependence of ion backdrift on magnetic field and total gain

at values below 500 the ion charge drifting back into the TPC volume becomes smaller than the unavoidable primary ionisation which is present in the TPC drift volume.

3. Spatial resolution

To prove the anticipated performance of a GEM TPC the position resolution, the double-track resoltion and systematic effects such as the field homogeneity are studied in detail. For these studies several prototypes of a GEM-based TPC have been constructed. Minimising the material budget yielded a field cage construction with a wall thickness as small as 1% of a radiation length. The prototypes are operated using cosmic rays, particle test beams or an UV laser beam. Part of the measurements were performed in magnetic fields up to 4 T.

A silicon hodoscope has been built to give an external reference to each measured track. Four silicon strip detectors, two above and two below the prototype TPC, are used to obtain two independent and very precise reference points of the particle track. This setup allows to investigate systematic distortions of the position measurement of the TPC.

On the left of Figure 2 the position resolution as a function of the drift distance is shown for various magnetic fields [6]. One observes an improvement of the position resolution with increasing magnetic field caused by the reduction of the transverse diffusion. Position resolutions well below 100 μm have been achieved.

To study the capability of the GEM TPC to reconstruct and resolve two nearby tracks, a UV laser beam was split and the two parts were brought into the field cage close together at the same drift distance. On the right of Figure 2 the degradation in transverse resolution is shown as a function of the separation between the two parallel tracks produced by the split laser beam. The measurements and simulations indicate good resolving power for a track separation above 3 mm.

The investigation of the position measurement in drift direction yields position resolutions of the order of 1 mm. Systematic effects caused by inhomogeneities of the drift field are currently under study. Here, data are taken at special values of the electric field, where the dependence of the drift velocity on the field strength is large. The position measurement of the TPC is then compared with the prediction from the hodoscope.

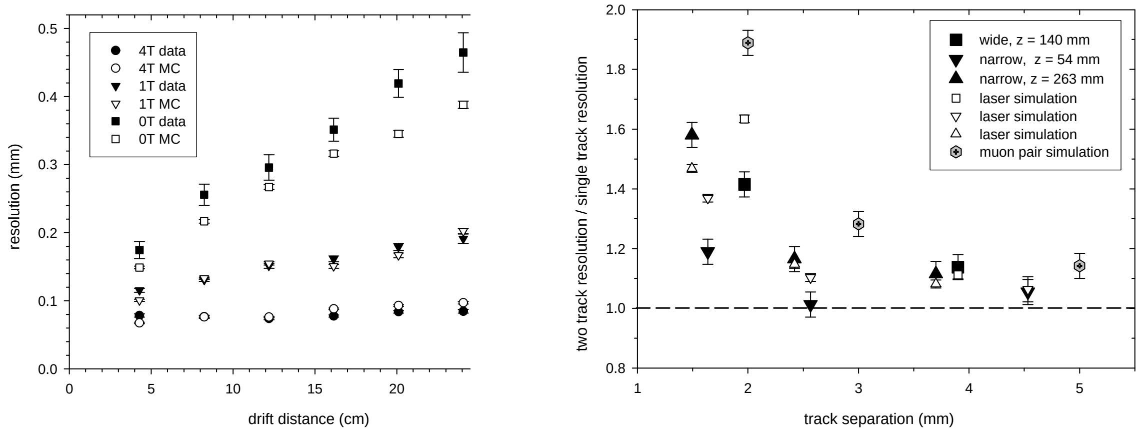

Figure 2: Position resolution as a function of the drift distance for various magnetic fields

Additionally various pad geometries were used to study their effect on the track reconstruction [7]. Especially the postition resolution achieved with conventional rectangular pad shapes was compared to the results obtained from chevron-shaped pads. Due to the improved charge sharing between adjacent pads the chevron pads improve the uniformity of the position resolution. The overall resolution is not improved when going from rectangular to chevron-shaped pads, a result which is not yet understood.

4. Conclusions

The results obtained within the presented R&D project indicate that a GEM-based TPC is a very promising candidate for a high-resolution tracker at the ILC. When operated in 4 T magnetic field the ion backdrift is suppressed to the level of 2×10^{-3} and position resolutions of better than 100 μm are achieved. Systematic limitations due to the field homogeneity and potential improvements due to optimised pad shapes are under study.

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