Studies on GEM modules for a Large Prototype TPC for the ILC

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Abstract

The International Linear Collider (ILC) is a future electron-positron collider with centre of mass energy of 500-1000 GeV. The International Large Detector (ILD) is one of two detector concepts at the ILC. Its high precision tracking system consists of Silicon sub-detectors and a Time Projection Chamber (TPC) equipped with micro-pattern gas detectors (MPGDs). Within the framework of the LCTPC collaboration, a Large Prototype (LP) TPC has been built as a demonstrator. This prototype has been equipped with Gas Electron Multiplier (GEM) modules and studied with electron beams of energies 1-6 GeV at the DESY test beam facility. The performance of the prototype detector and the extrapolation to the ILD TPC is presented here. In addition, ongoing optimisation studies and R&D activities in order to prepare the next GEM module iteration are discussed.

1. Introduction

The International Large Detector (ILD) is one detector concept for the International Linear Collider (ILC) using as its main tracker a combination of Silicon detectors and a Time Projection Chamber (TPC). The tracking requirements for the ILD include a momentum resolution of $\sigma(\frac{\Delta p_T}{p_T^2}) = 2 \cdot 10^{-5}$ GeV^{-1}, minimum material and tracking efficiency close to 100% even down to low momenta for efficient usage of Particle Flow Algorithms and full angular coverage and high hermeticity. The TPC, of dimensions approximately 4.7 m in z-direction and 1.8 m outer radius, will provide ~ 200 space points along the track, a point resolution of $\sigma_{r\phi} < 100$ μm and σ_z between 0.4 − 1.4 mm and dE/dx measurements for particle identification.

The endplates of the ILD TPC will be equipped with MicroPattern Gas Detector (MPGD) modules. Currently, there are three technologies under study: MicroMesh Gaseous detectors (Micromegas), Gas Electron Multiplier (GEM) modules and GridPix. This document will focus on the GEM module performance and ongoing R&D [1].

2. GEM module design and performance

The GEM module is designed to provide maximum active area and minimum material budget while ensuring high homogeneity in drift field and gain. For these reasons, the GEM module is composed of a triple GEM stack ensuring flexibility and high gain stability. The anode side of the GEM is divided into four sectors while there is no division on the cathode side, and is mounted on a ceramic grid frame acting also as an integrated support structure. Each module (~ 17 × 22 cm^2) is composed of 28 pad rows and is read out by 4828 channels of pad pitch 1.26×5.85 mm^2. A guard ring has been introduced around each module to shape the electric field at the edges of the module and minimise field distortions, resulting in a higher collection efficiency and smaller signal displacements.

This GEM module design was extensively tested during test beam campaigns at DESY. A Large Prototype TPC (LPTPC) [2] [3] has been built and installed at DESY to compare different readout technologies. The endplate of the LPTPC is able to host seven identical modules. For this campaign, three GEM modules were used, partially equipped with ~ 7000 readout channels allowing for track lengths of ~ 50 cm (Figure 1). The gas mixture used was 95% Ar, 3% CF_4, 2% iC_4H_{10}. Measurements at two values of drift field were taken (130 V/cm and 240 V/cm corresponding to the minimal diffusion and approximately maximum drift velocity respectively) with both the magnetic field off (0 T) and on (1 T).

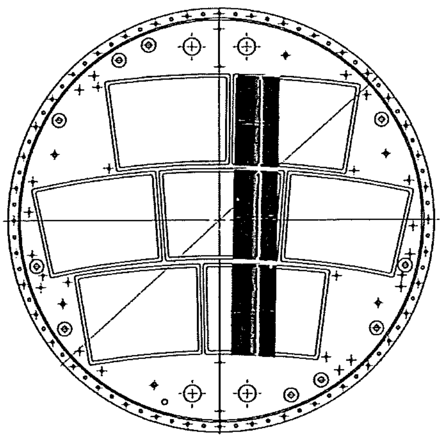

Figure 1: Drawing of the Large Prototype endplate with three GEM modules partially equipped with readout channels. This figure shows the profile of the beam, from an overlay of a full measurement run, superimposed onto a CAD drawing of the endplate (seen from the inside of the TPC) [4].

The results of the test beam campaign have been analysed using the MarlinTPC [5] software implemented with General

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Broken Lines [6] and Millepede [7]. The tracks are fitted using either a straight line for data taken at 0 T magnetic field or a helix for data taken with magnetic field. Minimal selection requirements are applied on data. In particular, the selected tracks need to have at least 60 hits out of the 71 operational rows, be nearly perpendicular to the pad rows and events with only one track present are selected.

The point resolution is determined by the width of the residual distribution of the track fits calculated both from a track fit including the hit under study, as well as a track fit excluding this hit. The best estimate of the resolution is the geometric mean of these two distributions [8]. The mean of the residual distribution shows strong systematic effects due to misalignment and more importantly distortions caused by inhomogeneities in the electric and magnetic fields. These distortions are more pronounced close to the boundaries between the modules leading to larger biases as shown in Figure 2. To correct for these effects, first data taken without magnetic field are used to determine the alignment corrections through a multi-dimensional χ^2 minimisation. The obtained alignment corrections are of the order of 0.1 mm for displacements in the x and y directions and a few mrad for rotations in the xy plane. These corrections are applied to all collected data.

Following that, the remaining systematic shifts in the residuals, which cannot be explained by misalignment, are determined for each pad row using data with magnetic field 1 T. These terms are mainly due to field inhomogeneities and $\vec{E}\times\vec{B}$ effects and are largely pronounced at the edges of the modules. The residuals for these distortion corrections are obtained from a sub-sample (10%) of the available data for statistical independence and applied to the remaining events. The results of the alignment correction and additionally, of the distortion corrections are shown in Figure 2.

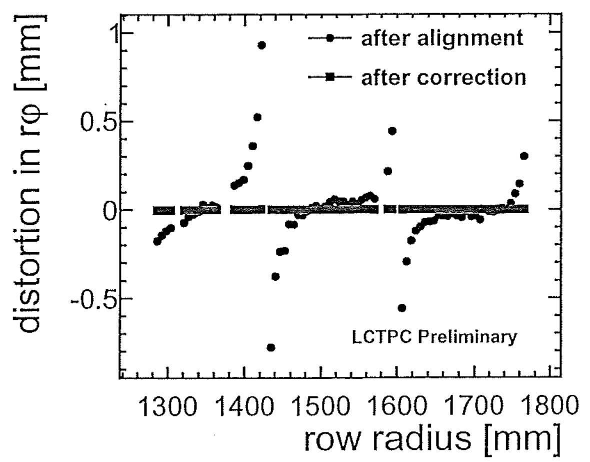

Figure 2: Data points showing the mean hit position in $r\phi$ with respect to the track position at 1 T after the alignment corrections (blue) and the result after the distortion effects have been corrected for (green) [4].

Once the distortions have been corrected for, the single point resolution can be determined. The single point resolution in the

σ	$\sigma_{0,r\phi/z}$ [μm]	N_{eff}	A [m^{-1}]
$r\phi$	71.0 ± 1.2	39.8 ± 2.0	0.495 ± 0.097
z	306.3 ± 0.8	39.5 ± 1.6	0.529 ± 0.084

Table 1: Results of the fit of equation 1 to the measured point resolution in $r\phi$ and z respectively shown in Figure 3a,b [4].

$r\phi$ and z direction is expressed as

$$\sigma_{r\phi/z}(z) = \sqrt{\sigma^2_{0,r\phi/z} + \frac{D^2_{t/l}}{N_{eff}\cdot e^{-Az}} z} \quad (1)$$

where $\sigma_{0,r\phi/z}$ describes the intrinsic resolution of the readout at zero drift distance in $r\phi/z$, $D_{t/l}$ the transverse and longitudinal diffusion, N_{eff} the effective number of primary signal electrons and e^{-Az} the loss due to the attachment of signal electrons to gas molecules during drift [9].

A fit of equation 1 is performed to the data where the above mentioned quantities are considered as free parameters with the exception of the diffusion terms $D_{t/l}$. The longitudinal diffusion term has been derived from a Magboltz simulation, $D_l = 0.226$ mm/$\sqrt{cm}$, and the transverse diffusion has been determined from data from the measured width of the pad response function (PRF) [9]. The PRF describes the average signal shape measured along the pads in a row and its width depends, among other parameters, on the diffusion of the charge cloud. The measured value of the transverse diffusion term is $D_t = 0.1032 \pm 0.0004$ mm/$\sqrt{cm}$. The data points and fit of the point resolution in the $r\phi$ and z directions are shown in Figure 3. They both meet the ILD TPC requirements stated in Section 1. The ILD TPC should provide an $r\phi$ point resolution of < 100 μm for full drift length and a 3.5 T magnetic field which translates to a point resolution of < 150 μm for the Large Prototype TPC. Respectively for the z point resolution, the ILD TPC should provide a point resolution in z of 400 μm at zero drift distance. The fitted values of the parameters are shown on Table 1. The terms N_{eff} and A are in good agreement for the fits of the point resolution in the $r\phi$ and z directions.

The results of the fit have been extrapolated to the conditions of the ILD TPC assuming a 3.5 T magnetic field and a 2.35 m drift length (Figure 4). It is evident that the goal of $r\phi$ point resolution of < 100 μm can be achieved if the gas quality and purity are tightly controlled [4].

3. GEM module R&D optimisation studies

To improve the GEM modules, extensive studies are currently under investigation concerning the longterm high voltage stability and mounting procedure of GEMs. At the end of the test beam campaign and under extreme testing of the modules, destructive discharges were observed. To further investigate, both optical and electrical experimental setups have been used at DESY. Such an example is shown in Figure 5 where accumulated discharges on a GEM are shown. In order to accumulate events, extreme high voltage settings were used (~ 650 V between the GEM sides), instead of normal operation settings (~ 250 V). Initially, trips occurring simultaneously (within a

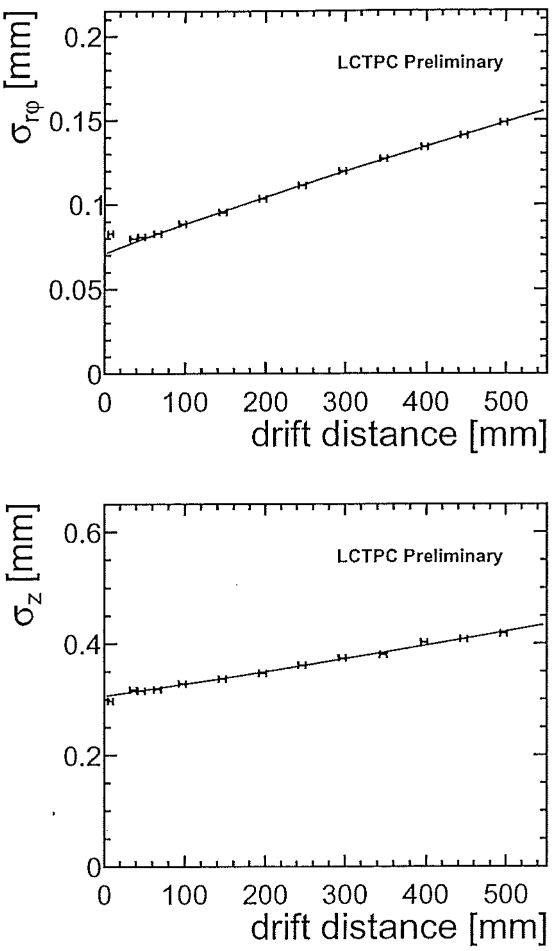

Figure 3: Point resolution of LPTPC depending on drift length for measurements at 1 T magnetic field a) in $r\phi$, b) in z. The data points (blue) and the fit (red) are shown [4].

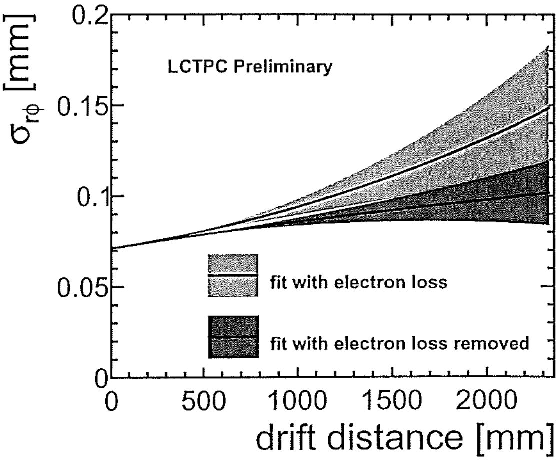

Figure 4: Extrapolation of the point resolution to a magnetic field of 3.5 T and plotted over the full ILD TPC drift length of 2.35 m including 1σ error bands. In red, the extrapolated value with the measured attachment rate and in green without any attachment considered are shown [4].

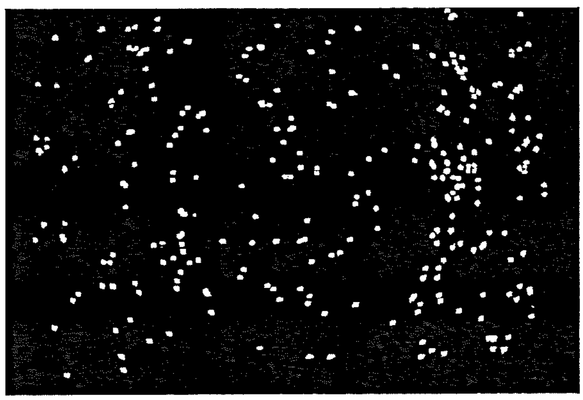

Figure 5: Long term monitoring picture of sparks on a four-sector unframed GEM plane. Each light blue dot corresponds to a discharge of the GEM.

few 100 ns) in more than one of the four sectors of the GEM were observed. These discharges cause current oscillations on the surface of the GEM that are reflected by the border of the sectors and module and can cause high local charge concentration. In an attempt to damp the oscillations, a setup with an RC circuit added on the electrodes of the GEM sectors was built and tested. Simulations of the system were performed and confirmed by electrical measurements of the setup. The rate of single and multiple (occurring simultaneously in more than one sector) discharges was significantly reduced when the RC circuit was introduced, however, destructive discharges were still observed. Furthermore, on framed GEMs, a high concentration of discharges was observed close to the frame indicating that there could be glueing, stretching or frame effects present. Therefore, there is an ongoing effort to optimise the mounting procedure of the GEM module.

Along with the new mounting procedure, the flatness of the GEM once they are glued to the frame is under study. In order to obtain a high electric field homogeneity in the drift volume above the top most GEM, inbetween the three GEM stack and achieve a uniform gain distribution for precise dE/dx measurements, a flatness of the GEM of the order of 100 μm is required. For this reason, an experimental setup with a laser measurement head was used to precisely measure the height profile of GEMs. Such a profile is shown in Figure 6. The obtained standard deviation is at the level of 150 μm, slightly higher than the desired value. Currently, different frame designs more robust against deformation, and with layouts minimising GEM foil deflections, are investigated while new mounting and stretching techniques are set in place for the next iteration of the GEM modules.

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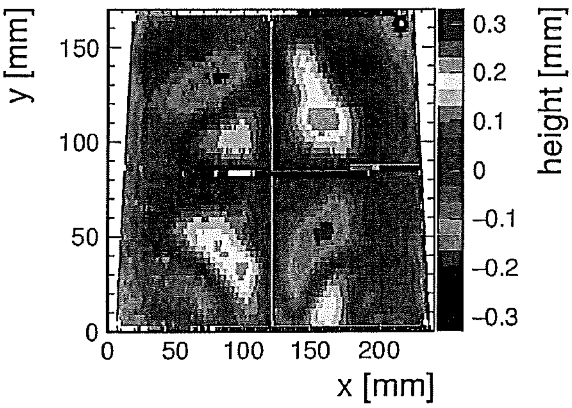

Figure 6: Profile height measurement using a laser measurement head showing the flatness of a GEM mounted on the ceramic frame.

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