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Results with Micromegas modules at LP-TPC

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Abstract

For the International Linear Collider (ILC), the transverse spatial resolution goal of Time Projection Chamber (TPC) is 100 µm for the full 2.3 m drift distance in a 3.5 T magnetic field. Within the LC-TPC collaboration, 5 Bulk Micromegas-TPC detector modules have been studied with magnetic field and without magnetic field at DESY. The results presented here show that, thanks to the charge spreading technique, the resolution can be better than 100 microns with wide pads size (3×6.8 mm^2). This confirms the technology potential of the resistive anode for a Micromegas-TPC.

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1. Introduction

In the future experiments at the International Linear Collider (ILC), the Time Projection Chamber (TPC) is a leading candidate for the central tracker. It will be required to measure about 200 track points with a transverse resolution better than 100 μm for the full 2.3 m drift distance in a 3.5 T magnetic field. A large TPC prototype has been built and operated at DESY within the LC-TPC collaboration to achieve the best possible point resolution and to provide a platform to ensure understanding of the technologies properties and behavior. The Micro-Pattern Gas Detectors (MPGD), Micromegas and GEM are being studied respectively. Five Bulk Micromegas modules have been tested without or with a 1 T magnetic field in a 5 GeV electron beam at DESY. The preliminary analysis results of data taking proved that spatial resolution could be better than 100 microns even with wide pads size (3×6.8 mm^2). The results demonstrate a significant improvement in spatial resolution by charge dispersion by means of a resistive cover layer.

2. Micromegas TPC Modules

Since 2008, 5 Bulk Micromegas detectors (figure 1) have been tested respectively as the large TPC prototype endplate in the beam, one with standard anode (named module 1), one with resistive ink anode (~3 MΩ/□, named module 2), one with resistive carbon-loaded polyimide anode (~5 MΩ/□, named module 3), and two with same resistive carbon-loaded polyimide but different routings and different PCB structures (~3 MΩ/□, named module 4 and module 5). These detectors were made in Rui de Oliveira's workshop at CERN. Each time, only one detector module was mounted at the centre of TPC endplate as figure 2. Each module has 1728 pads arranged in 24 rows (with pitch of 6.8 mm) by 72 columns (with varying pitch from 2.7 mm to 3.2 mm) shown in figure 3. Two of the pads are used to connect the high voltage to the mesh, other pads are used to record electron signal. The beam direction is parallel to the centre of columns.

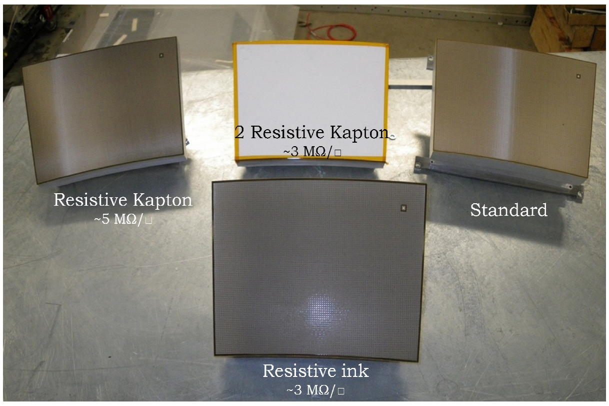


Figure 1. The five Bulk Micromegas detector modules.

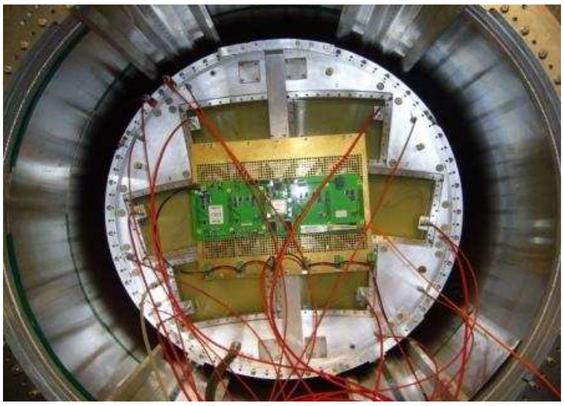


Figure 2. The Large Prototype with one module installed in the centre.

The AFTER-based electronics designed for the T2K experiment was adopted to read out signal. It provides a full-wave sampling over 511 time buckets for each channel and a 12-bit ADC for each sample. The sampling frequency can be varied between 10 MHz and 100 MHz and 16 values between 100 ns and 2 μs can be chosen for the peaking time of the shaper.

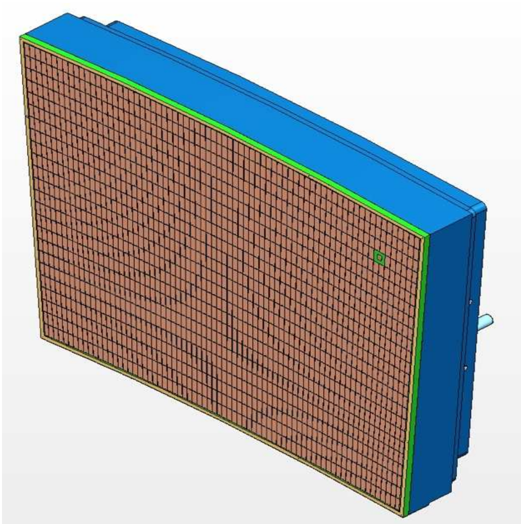


Figure 3. The Micromegas detector module (24 pad rows × 72 columns).

3. Preliminary analysis results

From December 2008 to March 2010, data have been taken without magnetic field and in a 1 T magnetic field with a 5 GeV electron beam in several test periods. The gas mixture was Ar/CF_4/Isobutane (95:3:2), so-called T2K gas. Data was taken with different drift distance by moving the detector perpendicular to the beam, along the magnet axis.

3.1 Drift velocity

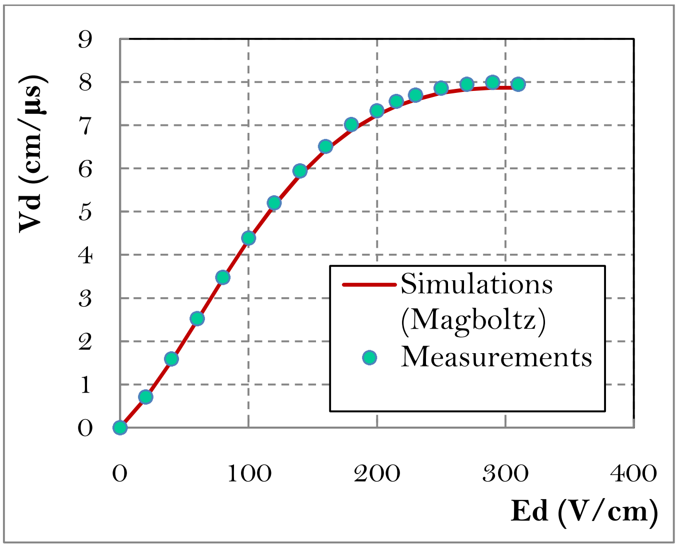


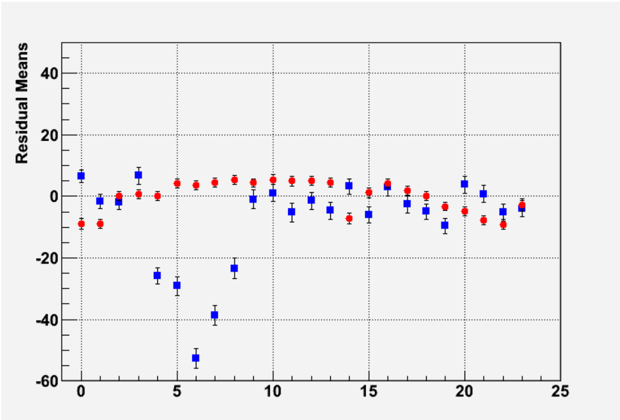
Figure 4. Drift velocity measurements (B=0T).

With B=0T, the electron drift velocity in T2K gas has been measured as a function of the drift electric field, as shown in figure 4. The gas temperature was stable at 19^{o}C during the measurements, and the pressure remained around 1035 hPa. The water content of the gas mixture was measured to be 35 ppm. The measurements are compared with simulations.

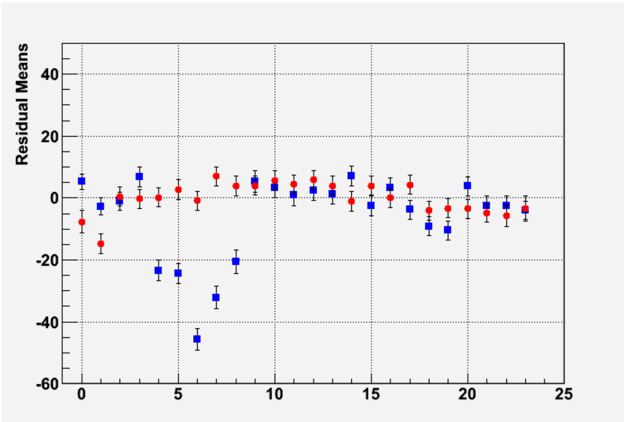
From figure 4, we can see the simulation results are a little lower than the experiment results. This was also found in the GEM TPC preliminary study[1]. At the drift electric field of 230 V/cm, the measured drift velocity is 7.698±0.040 cm/μs, compared with the Magboltz simulation result of 7.583±0.025 cm/μs (the error on the simulation is dominated by the uncertainty on the gas composition). The different is small but significant: 1.5±0.6%.

3.2 Uniformity of rows

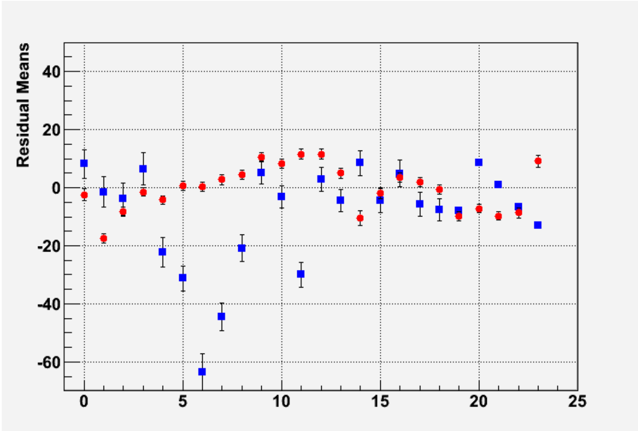
The mean residual for each row at three different drift distances are shown in figure 5. The distortions are independent of the drift distance. The mean residual was found to be consistent with zero for module 3 (carbon-loaded polyimide anode) and reached 40 μm for module 2 (resistive ink anode). The uniformity of 24 rows in module 3 is very good, with no edge effect or dead area up to the edge of the module. The distortions of module 2 are probably caused by the non-uniformity of the resistive layer.



(a) Z = 5 cm



(b) Z = 35 cm



(c) Z = 50 cm

Figure 5. Mean residual in µm for each row (from 0 to 24) at three different drift distances at B = 1 T. Blue points are for module 2 (resistive ink anode) and red points are for module 3 (carbon-loaded polyimide anode).

3.3 Spatial resolution

Using the resistive anode, the signal is dispersed onto several pads. The Pad Response Function (PRF) was parameterized with a ration of two symmetric 4th order polynomials [2]:

$$\mathrm{PRF}(x,\Gamma,\Delta,a,b)=\frac{1+a_2x^2+a_4x^4}{1+b_2x^2+b_4x^4}$$

Where the coefficients of the two 4th order polynomials a_2 and a_4, b_2 and b_4 can be expressed in term of the full width half maximum (FWHM) Γ, the base width Δ of PRF, and two scale parameters a and b.

The resolution is given by the geometric mean of standard deviations of residuals from track fits done in two different ways: including and excluding the row for which the resolution is being determined. Figure 6 and figure 7 show the resolution as a function of drift distance with B=0T and B=1T respectively. Using a fit function as follow to the measured resolutions, we can get the resolution at drift distance Z=0.

$$\sigma^2=\sqrt{\sigma_0^2+\frac{C_D^2 Z}{N_{eff}}}$$

Where σ_0 is the resolution at Z=0, C_D is the transverse diffusion constant, taken from Magboltz, and N_{eff} is the number of effective electrons over the length of a pad.

From the fit results, we can see the resolution at Z=0 was found to be about 56µm for module 4 without magnetic field (C_D = 315.1 µm/$\sqrt{cm}$) and 61µm for module 3 with 1T magnetic field (C_D = 94.2 µm/$\sqrt{cm}$), which are about 50 times smaller than the pad size. Averaging the values obtained at B=0T and B=1T, the number of effective electrons N_{eff} per row is 38.0 ±0.2 (stat) ±0.8 (C_D syst). The systematic error comes from the uncertainties on the magnetic field and the input diffusion coefficient from Magboltz. Using the Heed simulation, the value of 1/<1/N> is expected to be 47.1 for 5GeV electrons on 6.84 mm long pads. N_{eff} as a function of gain fluctuation is as follow [3],

$$N_{eff} = \left[\langle \frac{1}{N} \rangle \langle \left(\frac{G}{\bar{G}} \right)^2 \rangle \right]^{-1} = \frac{1}{\langle 1/N \rangle} \left(\frac{1+\theta}{2+\theta} \right)$$

In the case of Snyder's model, gain fluctuation is exponential and θ equal 0, and the number of effective electrons is expected to be 23.5. The high measured value of N_{eff} indicates that the gain fluctuations are not exponential but smaller. This is also supported by detailed studies of single electron avalanches [4,5], though quantitative conclusions are still premature as dependence of the fluctuations with average gain and gas composition are not known. Extrapolating these measurement results, we obtain that the resolution will be about 90 μm at Z=2.3 m in a 3.5 T magnetic field (C_D is about 25-30 μm/$\sqrt{cm}$), well within the goal for the ILD detector.

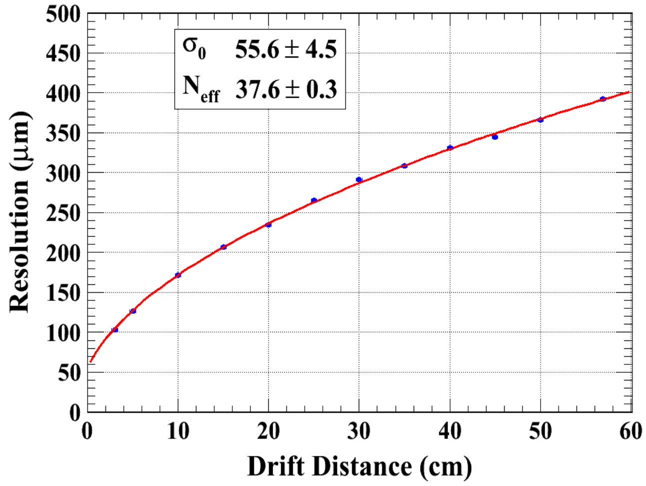


Figure 6. Measured resolution as a function of drift distance Z for module 4 at B=0 T.

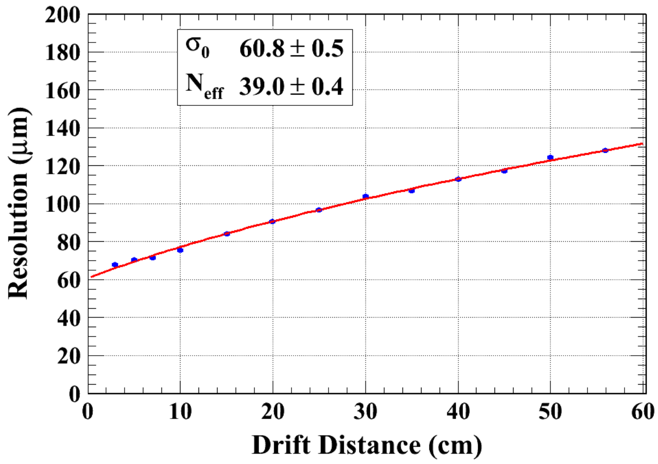


Figure 7. Measured resolution as a function of drift distance Z for module 3 at B=1 T.

4. Conclusion

Since 2008, five Micromegas modules for ILC-TPC have been studied. A lot of experience has been gathered in building and operating Micromegas TPC panels. The uniformity of carbon-loaded polyimide detector is excellent, while the use of resistive ink gives less good results. The goal spatial resolution of less than 100 µm can be achieved with 3 mm wide pads. These results demonstrate that the Micromegas TPC meets ILD resolution needs.

The next step is to equip the whole endplate with full integration of the electronics flat behind the panels.

Acknowledgement

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