Results from a TPC Prototype with GEM Encap for the Linear Collider Tracker (backtobackDraftNo.2/7Feb2009)

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Abstract

A Time Projection Chamber is being investigated as central tracker for a detector at the International Linear Collider. To provide a comparison and explore the potential improvements using Micro-Pattern Gas Detectors compared with Multi-Wire Proportional Chambers used up to now in TPCs, a small prototype chamber capable of being equipped with different gas-amplification techniques was built at MPI-Munich and exposed to cosmics in the 5 T magnet at DESY and subsequently to a testbeam in a 1 T magnet at KEK. The chamber was operated with four different endplate technologies during four beam periods in 2004–2005. This paper reports on results from the second test using GEM gas-amplification.

Key words:
International Linear Collider (ILC), Time Projection Chamber (TPC), Multiwire Proportional Chamber (MWPC), Micropattern Gas Detector (MPGD)

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1. Introduction

The introduction to this R&D series has been given in the preceeding paper[1] in this journal. The motivation for studying a TPC for the linear collider is covered there, and the present set of R&D tests using the MP-TPC is described. To put the present test in perspective, an overview of the tests is reiterated next.

2. The present series of R&D tests

TPCs have employed Multi-Wire-Proprotional-Chamber (MWPC) gas-amplification in previous large collider detectors. The thrust of the R&D program [2][3] is to develop a TPC based on Micro-Pattern Gas Detectors (MPGDs) which promise to have better point and two-track resolution than wire chambers and to be more robust in high backgrounds. In the present series of experiments, several techniques were compared, gas amplification using MWPC, Micromegas (Micro-mesh gaseous structure)[4] and GEM (Gas Electron Multiplier)[5], and the resistive-anode technique[6].

To research the performance of these technologies, a small prototype chamber was built at MPI-Munich, initially with an MWPC endplate, tested using cosmics at DESY in a 5 T magnet and subsequently exposed in four test-beam runs at KEK using MWPC, GEM, Micromegas and resistive-anode endplates in a 1 T magnet. The chamber will be called MP-TPC, for MultiPrototype-TPC, in the related publications. The runs were performed in the following order: MWPC (January-June 2004), GEM (April 2005), Micromegas (June 2005) and MPGD with resistive anode (October 2005).

The Micromegas results have been published [7], preliminary results have been shown at various workshops (see for example [8]) and the MWPC results are the subject of the preceeding paper in this issue/citeb2bmwpc. The present paper describes the the GEM results and is organized as follows.

The prototype with GEM is described in the Sec. 3, the analyses in Sec. 4, results are presented in Sec. **??** and conclusions are drawn in Sec. 6.

3. The MP-TPC chamber

In December 2004, the MWPC plane was replaced by triple-GEM modules seen in the blown-up view of Fig. 1.

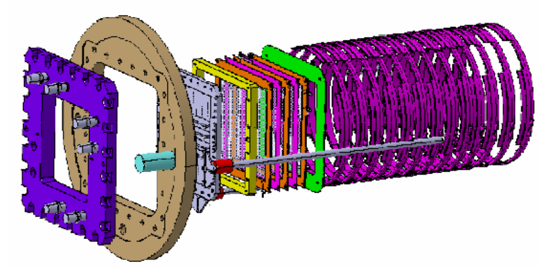

Fig. 1. The MP-TPC with triple-GEM.

For the GEM endcap in Fig. 1, the MP-TPC used gas-amplification provided by a three-layer stack of of CERN GEMs (50 μm thickness) with a spacing of 1.5 mm GEM-to-GEM and GEM-to-pads. The pad pitch was 1.27 mm$\times$6.3 mm which covered the full 10 cm$\times$10 cm pad plane. The GEMs were run at typically 320-335 V leading to amplification fields of $\sim$60 kV/cm and transfer/induction fields of $\sim$2 kV/cm.

During the June 2004 data-taking in the $\pi 2$ beam, several different configurations of GEM gain and transfer/induction fields were tried out, again at B-fields of B=0 T and 1 T. The DAQ system collecting a total of about 10^5 triggers with GEM.

subsectionThe beam tests KEK

Fig. 2. The chamber inside the 1 T PCMAG at KEK.

The setup at KEK is seen in Fig. 2. which was situated in the $\pi 2$ beam line at the KEK 12-GeV PS. The 1 T Persistent Current solenoidal Magnet (PCMAG) [12] has a bore diameter of 85 cm, length of 1.3 m and very thin coil windings of 20 % X_0.

The $\pi 2$ beam provided a secondary beam of electrons, pions and protons with momenta up to 4 GeV/c derived from the PS beam incident on a Be target. The beam spill had a flat top of 1.5 s and a repetition rate of 0.25 Hz. More details may be found in the preceeding paper[1]

4. Resolution studies

The diffusion constant C_D is important for the single-point and two-track resolutions and was measured using the behaviour of signal-charge spread as a function of drift distance z. In the simplest model, the r.m.s. of the charge spread (also called "Pad Response") is parametrized by

$$\sigma_{PR}^2(z) = \sigma_{PR}^2(0) + C_D^2 \times z, \tag{1}$$

and the point resolution by

$$\sigma_x^2(z) = \sigma_0^2 + C_D^2/N_{eff} \times z. \tag{2}$$

In the case of GEM $\sigma_{PR}(0)$ depends mainly on the induction field gradient and spacing which determine the diffusion spreading of the charges arriving at the pads, and on the pad pitch.

The point resolution σ_0 is related to signal-to-noise: electronics and signal-charge spread at $z = 0$. The quantity N_{eff} is the effective number of electrons contributing to the resolution as determined by primary ionization statistics, gain fluctuations and the electronics performance [7][9]. These quantities are also affected by the crossing-angles of the projected track relative to the pads.

The charge width was drived from a Gaussian fit to the distribution of charge around the center-of-gravity of a hit. The point resolution was calculated using the Double-Fit program [10] in which standard deviations of hits for a pad row are calculated twice with respect to track-fits ("Double-Fit"), first with and second without the given pad row. The correct point resolution is the geometric mean of the standard deviations of hits with respect to the two fits [11].

Equations 1 and 2 represent the ideal situation and give reasonable agreement with the measurements for a TPC with MPGD gas amplification as can be seen in [7][9] and will be shown in this paper.

5. Results

The gases used were the TDR gas[?], Ar-CH_4-CO_2 (93:5:2)%, and P5, Ar-CH_4 (95:5)%. The chamber was again operated at atmospheric pressure, and the pressure and the ambient temperature were continuously monitored. The drift velocities for the two gases were measured and found in agreement with the expected values[13]. The TDR drift velocity measurement is described in [1], Sec. 5, and was found to be 4.52±0.04 cm/μs at the drift field of 220 V/cm. For P5, it was measured to be 4.16±0.04 cm/μs at a drift field of 100 V/cm during the tests.

5.1. *Charge spread and point resolution*

The 4 GeV/c π^- beam data at 0 T and 1 T magnetic fields are used for this section. As in the MWPC case, after the data was corrected for dead channels and edge effects, the tracking efficiency was essentially 100%. The final samples selected for the diffusion and point-resolution comparisons contain about 10^5 tracks.

The two plots of Fig. 3 compare the charge width σ_{PR}^2 versus z for for the TDR and P5 gases at 1 T magnetic field. Figure 4 shows the point resolution σ_x versus z for the two gases. The fits to the data in Figs. 3 and 4 yeild the parameters in Table 1. Again the diffusion constants measure agree with

Runs	B(T)	No.tracks	C_D	$\sigma_{PR}(0)$	$\frac{C_D}{\sqrt{N_{eff}}}$	σ_0
TDR	1	5486	212±0.4	485±2	47±0.6	64±4
P5	1	4172	173±0.3	533±1	36±0.5	62±3

Table 1
Parameters fit to the data. The units are μm/$\sqrt{\text{cm}}$ for C_D and μm for $\sigma_{PR}(0)$ and σ_0.

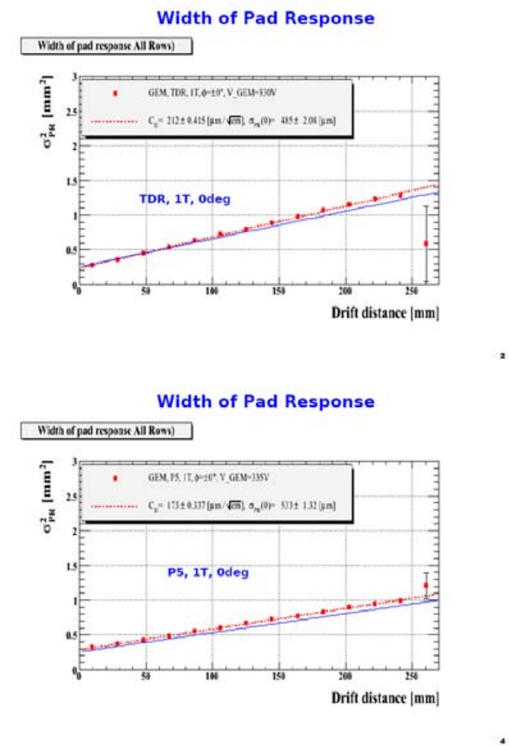

Fig. 3. Diffusion results for the TDR gas (upper) and P5 (lower) at 1 T b-field.

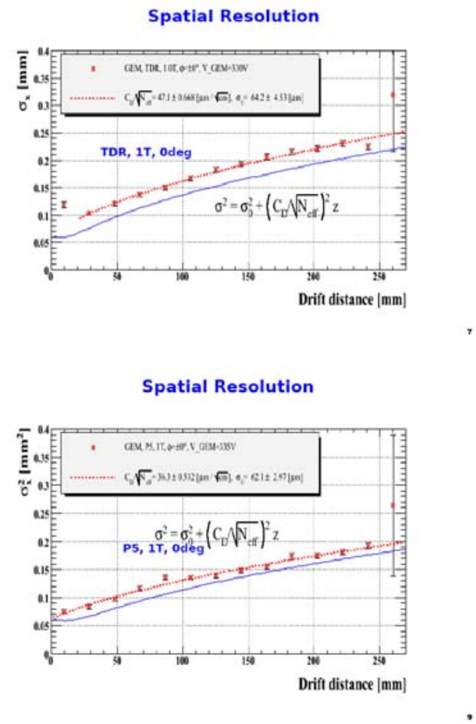

Fig. 4. Point-resolution results for the TDR gas (upper) and P5 (lower) at 1 T B-field.

predictions by Magboltz, 200 and 160 μm/$\sqrt{\text{cm}}$ for TDR and P5 gases respectively, while the satistical errors are too small, as found in [1].

5.2. *Systematics*

We should be able to estimate the systematic erros by comparing results from different runs with similar conditions...

5.2.1. *N.B.*

N.B. The figures 11 and 12 are "place holders" for the final figures we decide to include. Keisuke thought we also have a comparison with his analytic formulae. This will mean adding a few sentences describing his formulae and referring to the Micromegas paper again and putting the curves on the GEM plots. Otherwise, please make more suggestions as to which figures we should present and discuss...

6. Conclusions

The GEM point resolutions for the two gases are very good at 1 T B-field, as the results in Table 1 demonstrate, and within the goals for the LCTPC [2]. This is in contrast to the MWPC point resolution which is unfavorably affected by E×B effects for large magnetic field [1]. Therefore the GEM technology is one of the leading options for the linear collider central tracker.

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overview of the groups, of design issues for the LCTPC and of the R&D work to address the issues. It is published as LC Note LC-DET-2007-005 at http://flcweb01.desy.de/lcnotes.

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