Spatial Resolution Studies with a GEM-TPC in High Magnetic Fields

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A large volume Time Projection Chamber (TPC) has been proposed as main tracking device at the International Linear Collider (ILC). Gas electron multipliers (GEMs) are studied as potential replacement of the conventional wire based gas amplification system of TPCs. This talk presents recent results from R&D activities with a small GEM-TPC prototype. The spatial resolution was measured for different magnetic fields up to 4 T.

1. INTRODUCTION

The ambitious physics program at the International Linear Collider (ILC) poses stringent requirements on the performance of the detector. An accurate momentum measurement and a good particle identification relies crucially on precise tracking information. Therefore the development of the tracker needs special attention. As main tracker for a detector at the ILC, a large Time Projection Chamber (TPC) is being studied. It allows the instrumentation of a large volume with many voxels and represents only a minimum amount of material before the calorimeters. Moreover it has good particle identification capabilities, a genuine three-dimensional track reconstruction without ambiguities, and concentrates its sensitive parts to the endplates, allowing easy maintainability. Contrary to previous TPCs with multi-wire proportional chambers (MWPCs) for gas amplification, future TPCs are likely to make use of Micro Pattern Gas Detectors (MPGDs). One promising MPGD candidate is the Gas Electron Multiplier (GEM) [1]. Among its advantages are amplification structures of order 100 μm giving rise to only tiny $\vec{E} \times \vec{B}$ effects, a fast and narrow electron signal and intrinsic ion backdrift suppression.

2. THE DESY TPC PROTOTYPE

In order to investigate the potential of TPCs with GEM amplification, a small prototype has been built at DESY. The chamber has a maximal drift length of 800 mm and a diameter of 270 mm. Its size has been chosen such that it fits into a superconducting 5 T magnet available for detector R&D studies at DESY. The chamber endplate is equipped with $24 \times 8 = 192$ readout pads of size 2.2×6.2 mm^2. Two different pad layouts are investigated: First a layout where the pads in each row are shifted by half a pitch with respect to the pads in the two neighboring rows (staggered) and a second setup with aligned pads (non-staggered). The maximal drift length amounts to 670 mm. Gas amplification is provided by a triple GEM structure with two 2 mm transfer gaps and a 3 mm induction gap. The readout electronics is based on modules developed for the ALEPH experiment at LEP.

3. MEASUREMENTS IN HIGH MAGNETIC FIELDS

One of the most important quantities of a TPC is the achievable spatial resolution. It depends on various chamber parameters such as the diffusion of the chosen gas, the pad size, the electronics, the gas amplification settings, etc. Since the transverse diffusion coefficient of gases strongly depends on the magnetic field, it is necessary to perform spatial resolution measurements in magnetic fields in order to get reliable estimates of the performance of the final detector. A good quantity to compare spatial resolutions of different small prototypes and to extrapolate to a large-scale device is the single point resolution.
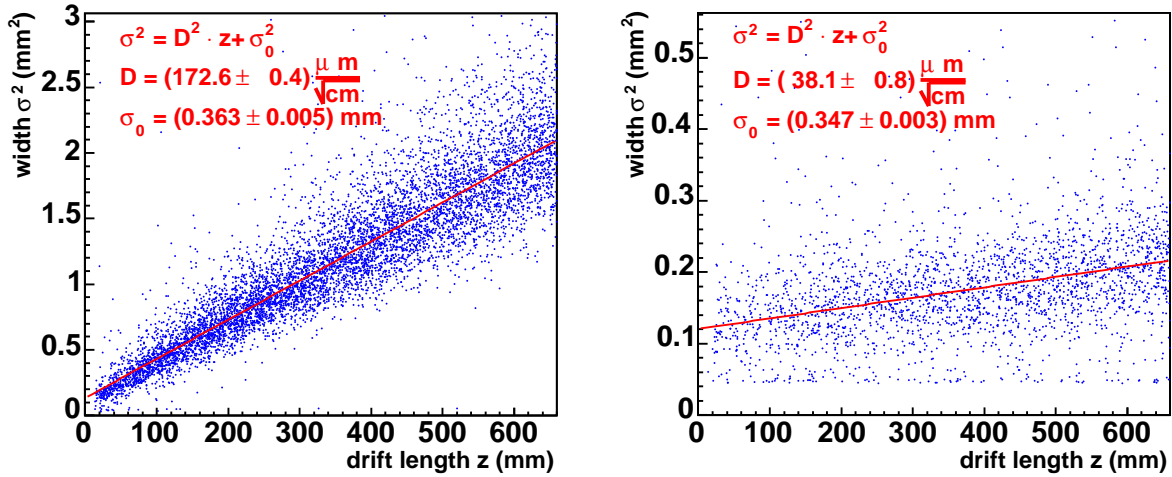
Figure 1: Square of charge cloud width on the pads versus drift length for Ar-CH$_4$-CO$_2$ (93-5-2) at 1 T (left) and for Ar-CH$_4$ (95-5) at 4 T (right).

To find out what single point resolution might be feasible, a series of measurements was carried out with cosmic muons at various magnetic fields up to 4 T, the value proposed in the technical design report for TESLA [2]. These runs were performed for two different gases, namely Ar-CH$_4$-CO$_2$ (93-5-2) and Ar-CH$_4$ (95-5).

3.1. Analysis Technique

The reconstruction of tracks is done in three steps. First three-dimensional space points are reconstructed from the pulses in each row. In a second step, these space points are combined to tracks using a three-dimensional track following algorithm. Finally the track parameters are fitted using a maximum likelihood fit which takes the pad response function into account [3]. To determine the spatial resolution, the following procedure is applied: One row is chosen and the horizontal track position is re-fitted using only data from that row keeping all other track parameters (inclination, width and curvature) fixed to the values obtained from a fit to all pad rows. The distribution of the difference of this re-fitted horizontal position and the original horizontal position is stored. Subsequently the same method is repeated with the only modification that the fixed parameters are set to the values obtained from a track fit excluding the information from the chosen row. This is done for all rows. A good estimate of the spatial resolution is obtained by calculating the geometric mean of the widths of the two distributions determined in the described way.

3.2. Diffusion Coefficient

As mentioned above, diffusion is an important factor influencing the spatial resolution of a TPC. It leads to a spread of the primary charge cloud due to collisions with gas atoms/molecules. Therefore the width σ of the charge cloud on the pads increases with increasing drift distance z:

$$\sigma^2 = D^2 z + \sigma_0^2. \tag{1}$$

D is the diffusion constant and σ_0 the defocussing term describing the charge widening in the amplification system. D varies with the magnetic field according to the formula

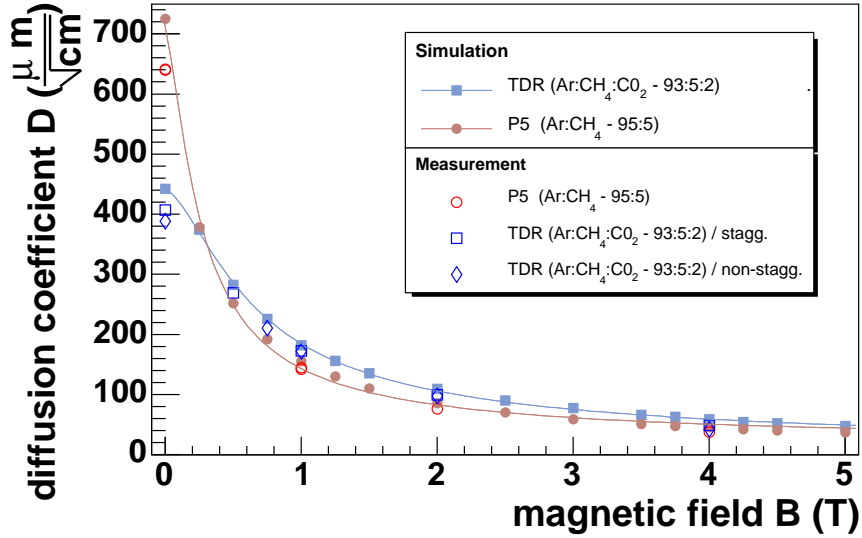$$\frac{D(B)}{D(0)} = \frac{1}{\sqrt{1 + \omega^2 \tau^2}} \tag{2}$$

Figure 2: Diffusion coefficient versus magentic field for Ar-CH$_4$-CO$_2$ (93-5-2) and for Ar-CH$_4$ (95-5). Both the measurements and the values from a Garfield simulation are shown.

where $\omega = eB/m$ is the cyclotron frequency and τ the mean time between collisions.

Figure 1 shows the square of the fitted charge cloud width versus the drift length for two examples, Ar-CH$_4$-CO$_2$ (93-5-2) at 1 T and for Ar-CH$_4$ (95-5) at 4 T. The data is well described by Equation 1. The diffusion coefficient and the defocussing terms are obtained from a linear fit to the data. The results are shown in the plots. Such measurements are accomplished for various magnetic fields for both gases. The outcome is shown in Figure 2 where the diffusion coefficient is plotted versus the magnetic field. In addition to the measurements, results from a Garfield simulation [4] are included. The diffusion coefficient drops in accordance with Equation 2 with the magnetic field. Qualitative agreement is achieved between measurement and simulation, although quantitatively the simulation seems to provide systematically slightly higher values than the measurement. This phenomenon has been observed by various groups [5].

3.3. Spatial Resolution

Using the procedure described in Section 3.1, the transverse single point resolution is determined for various magnetic fields. Figure 3 shows the results for Ar-CH$_4$ (95-5) as a function of the drift length for 1 T, 2 T and 4 T. Due to diffusion the spatial resolution gets worse for increasing drift length. This effect is significantly suppressed for high magnetic fields because of the reduced diffusion coefficient. For 2.2×6.2 mm^2 pads, the current preliminary analysis yields about 120 μm transverse resolution for Ar-CH$_4$ (95-5) at 4 T. This is in full agreement with the requirements listed in [2]. Nevertheless further studies are under way to gain a deeper understanding of the systematics involved in the reconstruction method.

4. CONCLUSIONS

A small TPC prototype with GEM foils for gas amplification has been successfully built to measure the spatial resolution in high magnetic fields. Cosmic muon runs were carried out in B fields up to 4 T. For 2.2×6.2 mm^2 pads, the present preliminary analysis yields about 120 μm transverse resolution with Ar-CH$_4$ (95-5) at 4 T, in full agreement with the TESLA TDR requirements. These are encouraging results revealing the potential of GEMs as TPC gas amplification system.
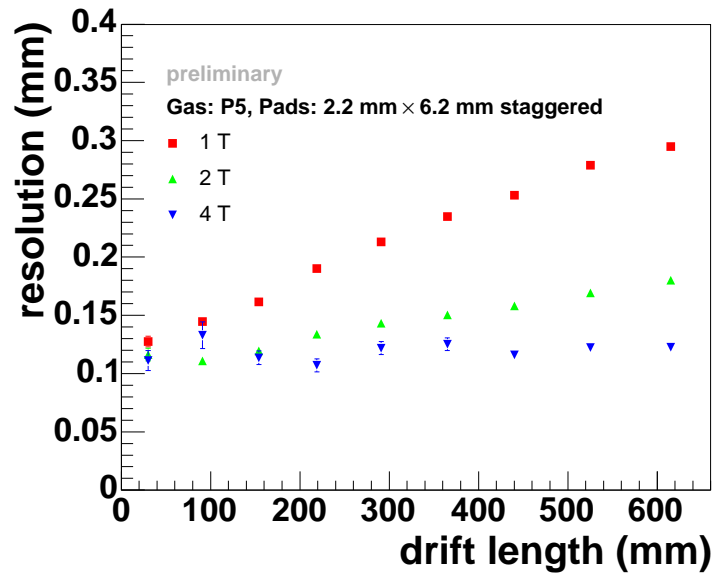
Figure 3: The transverse resolution versus drift length for Ar-CH$_4$ (95-5) gas.

References

[1] F. Sauli, "GEM: A new concept for electron amplification in gas detectors", *Nucl. Instrum. Methods*, A 386, 1997.

[2] T. Behnke, S. Bertolucci, R.-D. Heuer, and R. Settles, "TESLA Technical Design Report", DESY, Hamburg, Germany, DESY 2001-011 and ECFA 2001-209, 2001.

[3] D. Karlen, "Pad geometry study for a linear collider TPC", published in the proceedings of the International Workshop on Linear Colliders (LCWS 2002), Jeju Island, Korea, 2002.

[4] R. Veenhof, "Garfield - simulation of gaseous detectors", `http://cern.ch/garfield`.

[5] See e. g. A. Münnich, "R&D for a TPC with GEM Readout", talk given at International Linear Collider Workshop 2005, Stanford, USA and D. Karlen, "GEM-TPC performance in magnetic field", talk given at International Linear Collider Workshop 2004, Paris, France.