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Spatial Resolution of a Micromegas-TPC Using the Charge Dispersion Signal

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The Time Projection Chamber (TPC) for the International Linear Collider will need to measure about 200 track points with a resolution close to 100 μm. A Micro Pattern Gas Detector (MPGD) readout TPC could achieve the desired resolution with existing techniques using sub-millimeter width pads at the expense of a large increase in the detector cost and complexity. We have recently applied a new MPGD readout concept of charge dispersion to a prototype GEM-TPC and demonstrated the feasibility of achieving good resolution with pads similar in width to the ones used for the proportional wire TPC. The charge dispersion studies were repeated with a Micromegas TPC amplification stage. We present here our first results on the Micromegas-TPC resolution with charge dispersion. The TPC resolution with the Micromegas readout is compared to our earlier GEM results and to the resolution expected from electron statistics and transverse diffusion in a gaseous TPC.

1. INTRODUCTION

The Time Projection Chamber (TPC) for the future International Linear Collider will need to measure about 200 track points with a resolution of better than 100 μm. The resolution goal, close to the fundamental limit from ionization electron statistics and transverse diffusion in the gas, is nearly two times better than what has been achieved by conventional wire/pad TPCs. A TPC with a Micro Pattern Gas Detector (MPGD) readout could, in principle, reach the target resolution. However, it may require sub-millimeter wide pads resulting in a large increase in the number of electronics channels, detector cost and complexity over conventional TPCs.

We have recently developed a new concept of position sensing from charge dispersion in MPGDs with a resistive anode [1]. With charge dispersion wide readout pads similar in width to the ones used with proportional wire/cathode pad TPCs can be used without sacrificing resolution. This was demonstrated recently with cosmic ray tracks for a TPC read out with a GEM with a resistive anode [2]. We present here new results on the cosmic ray track resolution of a TPC read out with a Micromegas instrumented for charge dispersion with a resistive anode. The GEM and the Micromegas TPC resolution measurements made with the resistive readout are compared to our earlier GEM-TPC resolution results with a conventional readout [3] and to the expected resolution from transverse diffusion and ionization electron statistics in a gaseous TPC.

2. MEASUREMENT SETUP AND ANALYSIS

A small 15 cm drift length test TPC used earlier with a conventional direct charge GEM readout [3] was modified for charge dispersion studies. The readout endcap was modified such that it could accommodate either a GEM or a Micromegas with a resistive anode [2] readout system. The gas used, Ar:CO_2/90:10, was chosen to simulate the

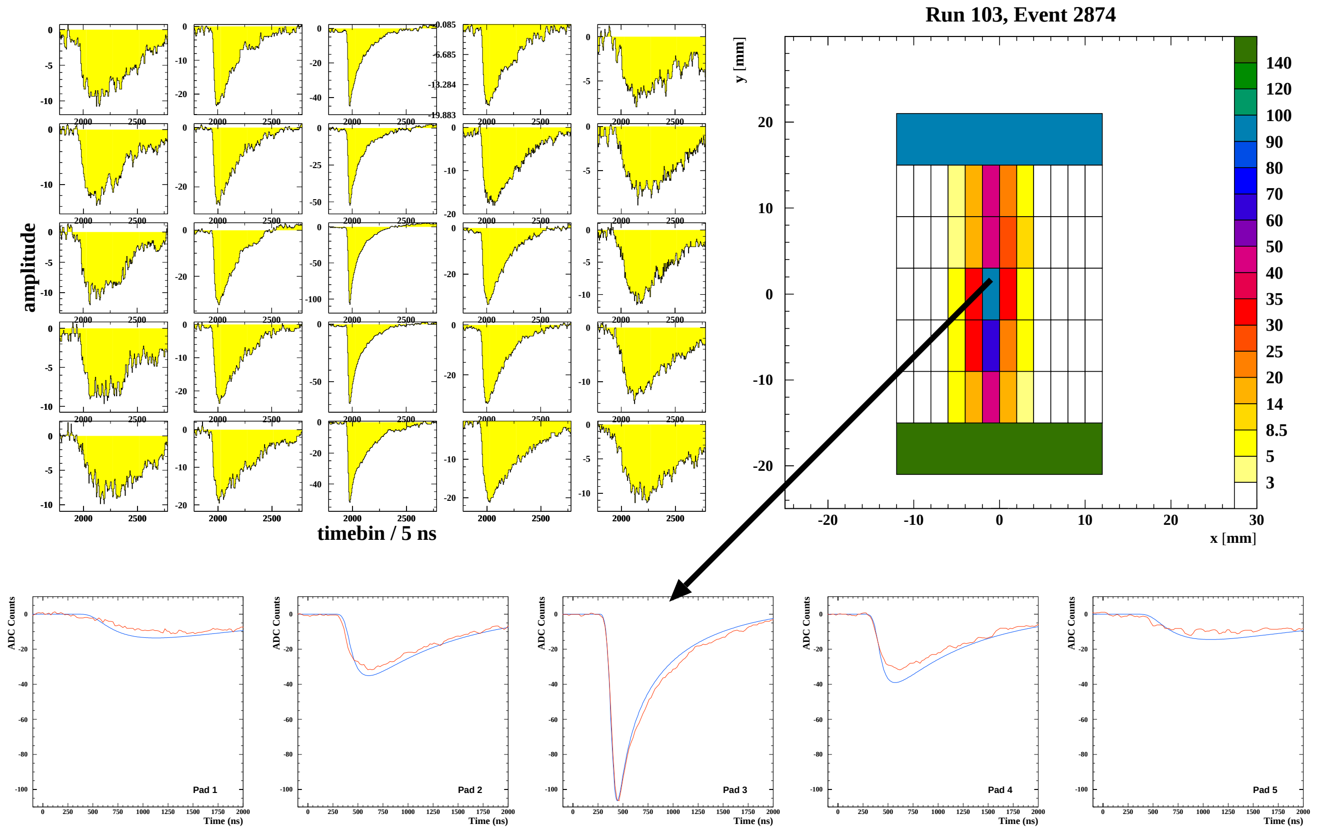

Figure 1: Pad layout and observed signals for a cosmic ray track in a GEM-TPC with a resistive anode readout. Also shown are simulated signals for the central row of pads. Detailed model simulation includes longitudinal and transverse diffusion, gas gain, detector pulse formation, charge dispersion on a resistive anode and preamplifier rise and fall time effects.

reduced transverse diffusion conditions of a TPC in a magnetic field. Charge signals on 60 pads, 2 mm x 6 mm each (see Figure 1), were read out using Aleph wire TPC preamplifiers and digitized directly using 200 MHz custom built 8 bit FADCs.

Track reconstruction techniques used for the conventional direct charge GEM-TPC readout [3] cannot be used for the resistive anode MPGD readout since non charge collecting pads nearby also have measurable signals. Not only the observed amplitude, but also the pulse shape depends on the relative location of the pad with respect to the track path. In theory, a first principle determination of the track PRF is possible. For the present, we have chosen to determine the PRF empirically from the internal consistency of cosmic ray track data.

For the purpose of analysis, the cosmic ray data were divided into two parts; one used for calibration and the other for resolution studies. We use the calibration data set to determine the PRF associated with the pads in a given row. The PRFs were determined for 15 seperate 1 cm wide regions in drift distance. Figure 2 shows examples of PRFs for the GEM and the Micromegas readout. The measured PRFs have been parameterized with a ratio of two symmetric 4th order polynomials:

$$PRF(x,\Gamma,\Delta,a,b) = \frac{1 + a_2 x^2 + a_4 x^4}{1 + b_2 x^2 + b_4 x^4}\ , \tag{1}$$

The coefficients of the two 4th order polynomials a_2 and a_4, and b_2 and b_4 can be expressed in terms of the FWHM Γ, the base width Δ of the PRF, and two scale defining parameters a and b.

The track fitting parameters x_0 and ϕ are determined by fitting the PRF to the pad amplitudes for the full event by χ^2 minimization. The position in a row $x_{\rm row}$ is determined from a seperate one-parameter track fit to this row

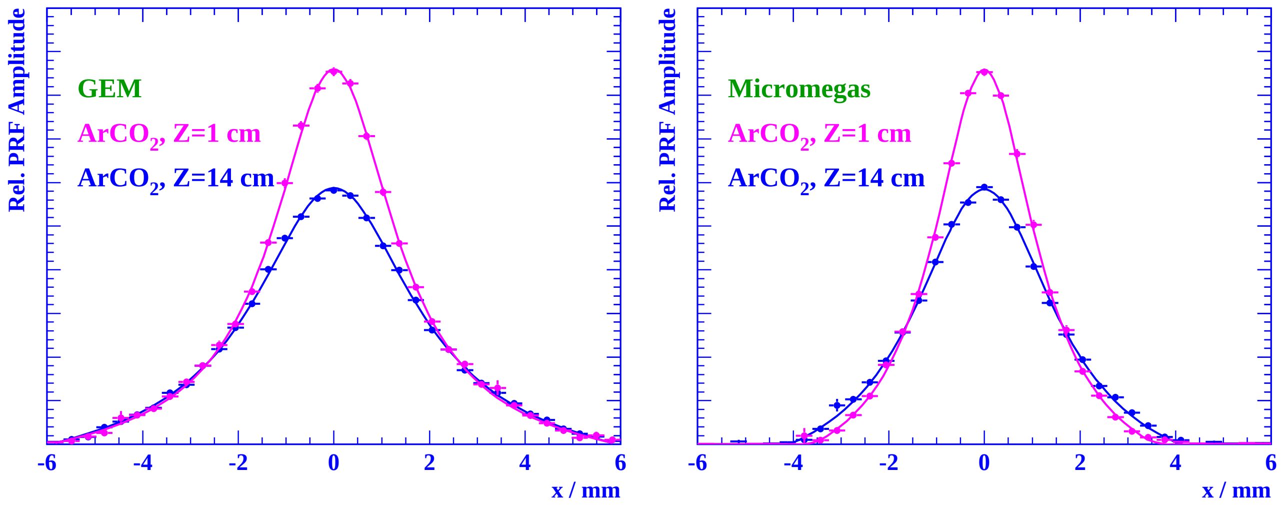

Figure 2: Examples of the pad response function (PRF). The PRFs were determined from a subset of the cosmic ray data set. The PRF peak for longer drift distances is lower due to Z dependent normalization. Compared to the GEM, the PRF width for the Micromegas is narrower due to the use of a higher surface resistivity anode and smaller diffusion after gain.

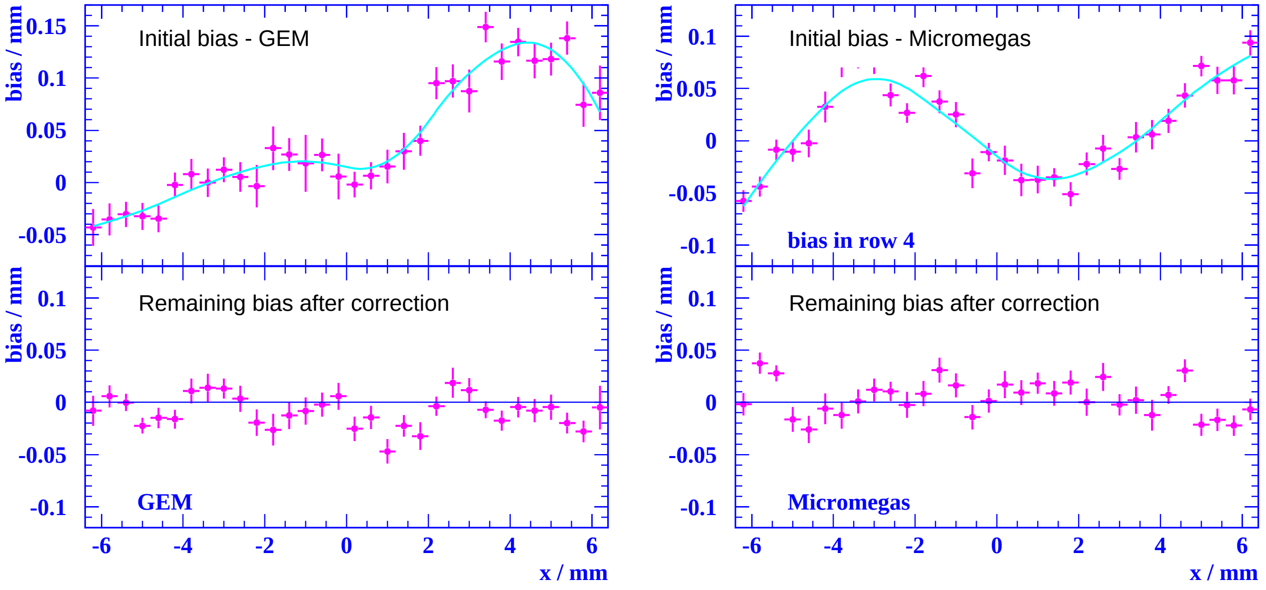

Figure 3: Bias corrections for pads in row 4 for the GEM and the Micromegas resistive anode TPC cosmic ray data. The lower set of figures show the remaining bias after correction.

only using the known track angle ϕ. Figure 3 shows examples of bias in position determination with GEMs and Micromegas. The bias is the mean difference $x_{\mathrm{row}} - x_{\mathrm{track}}$ as a function of $x_{\mathrm{track}} = x_0 + \tan\phi * y_{\mathrm{row}}$, where y_{row} is the y position of the row. A bias of up to 150 μm is observed which may be attributed to a non-uniform RC constant due to inhomogeneities in the gap size and the resistivity of the foil. However, this bias is due to geometry only and can easily be corrected. Figure 3 also shows the remaining bias after correction, which is negligible.

Figure 4 shows the measured resolution for Ar:CO_2/90:10. With GEMs we have results with and without the

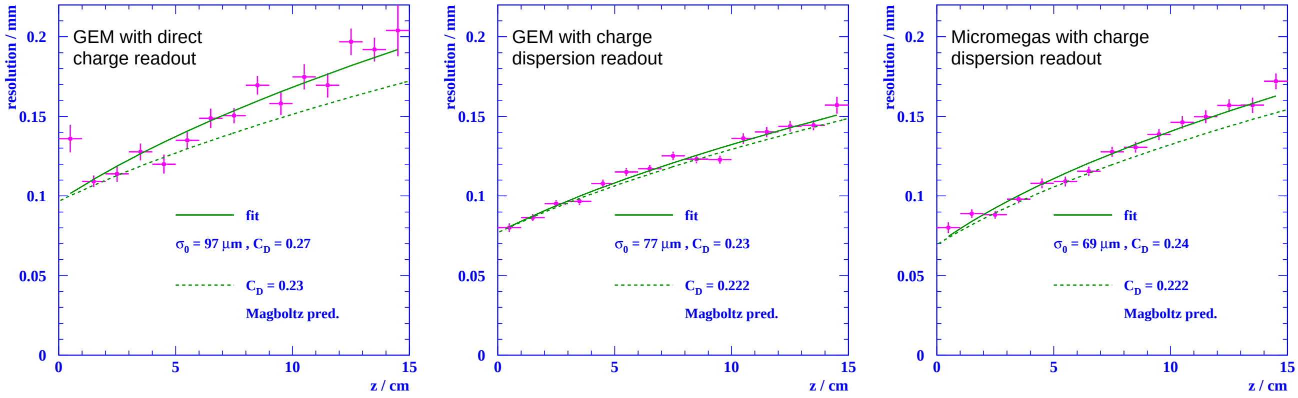

Figure 4: Charge dispersion improves TPC resolution over that from direct charge for low diffusion gases like Ar:CO$_2$ with limited charge sharing between pads. Compared to direct charge readout, resistive readout gives better resolution for the GEM and for the Micromegas both.

resistive anode; for Micromegas we have results with the resistive anode only. The resolution is fitted to the function:

$$s = \sqrt{s_0^2 + C_\mathrm{D}^2/N_\mathrm{eff} * z} \,, \tag{2}$$

where s_0 is the resolution at zero drift distance z. Here C_D is the diffusion constant and N_eff is the effective number of track ionization electrons over the length of a pad. N_eff is not the average number of electrons. Rather, it is given by: $N_\mathrm{eff} = 1/\langle\sqrt{1/N}\rangle^2$, where N is the number of electrons following the Landau distribution. N is determined from the measured pad-signal amplitudes scaled using the most probable number of track ionization electrons obtained from simulation.

Electronic noise and remaining systematic effects contribute to the constant term s_0. The constant term s_0 is about 75μm for the resistive readout for both the GEM and the Micromegas. It can be compared to the larger 97μm constant term for the normal GEM readout.

As shown in Figure 4, the TPC resolution obtained with the resistive anode readout for both the GEM and the Micromegas is better than our previous result with a conventional GEM readout [3], where at long drift distance the observed resolution was about 40% worse than expected. Apart from the constant term, the dependence of resolution on drift distance with the resistive readout follows the expectation from transverse diffusion in the gas and electron statistics.

3. SUMMARY AND OUTLOOK

In summary, the charge dispersion on a resistive anode improves the MPGD-TPC resolution significantly over that achievable with conventional direct charge readout for 2 mm wide pads. Bias errors due to RC inhomogeneities can be corrected. With no magnetic field, the measured dependence of resolution on drift distance follows the behavior expected from transverse diffusion in the gas.

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