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

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MPGD-TPC resolution with charge dispersion

- ILC TPC tracker challenge: Measure about 200 track points with a resolution of 100 μm or less for all tracks (max drift ~ 2.5 m).
- *Resolution goal near the ultimate limit from diffusion & electron statistics.*
- Conventional wire/pad TPCs cannot achieve the resolution goal due to **ExB** & track angle effects.
- MPGD-TPCs do not have the **ExB** & track angle effects. Existing MPGD-TPCs using *conventional direct charge readout techniques* have, however, not achieved the resolution goal in & outside a magnet.
- The MPGD-TPC may be able to get the desired resolution with sub-mm pads at the expense of a large increase in the detector cost & complexity.

▪ *A readout option to improve resolution: Disperse the MPGD avalanche charge for better centroid determination with wide pads.*

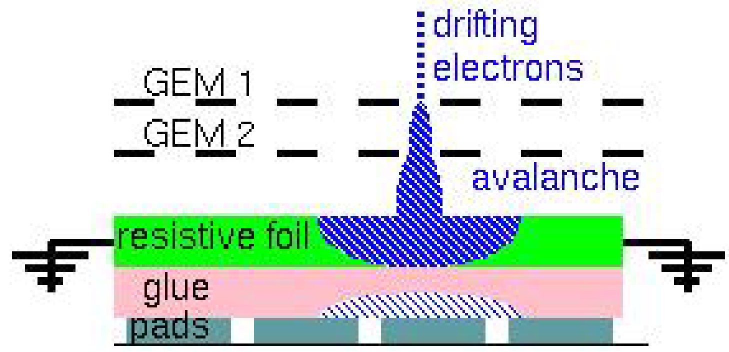
▪ In cosmic tests with no magnetic field, a prototype GEM-TPC with a charge dispersion readout has previously been shown capable of achieving the diffusion limit of resolution.

▪ The concept of charge dispersion, our preliminary results on Micromegas-TPC resolution and a comparison with earlier GEM-TPC results presented here.

Charge dispersion in a MPGD with a resistive anode

Concept & first results:M.S.Dixit et.al., Nucl. Instrum. Methods A518 (2004) 721.

- Modified GEM anode with a high resistivity film bonded to a readout plane with an insulating spacer.
- 2-dimensional continuous RC network defined by material properties & geometry.
- Point charge at $r = 0$ & $t = 0$ disperses with time.
- Time dependent anode charge density sampled by readout pads.

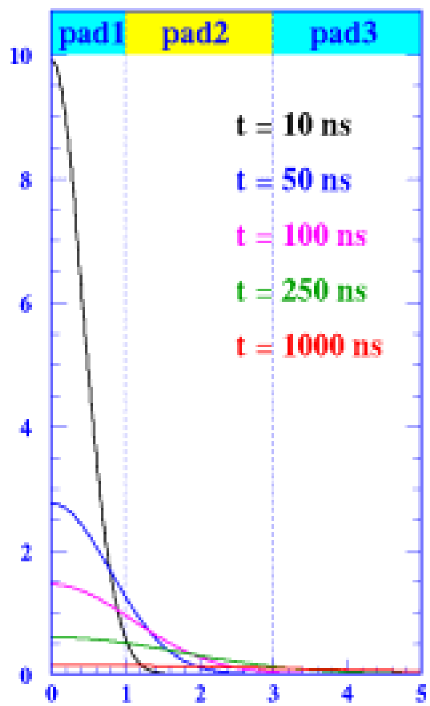


Equation for surface charge density function on the 2-dim. continuous RC network:

$$\frac{\partial \rho}{\partial t} = \frac{1}{RC}\left[\frac{\partial^2 \rho}{\partial r^2} + \frac{1}{r}\frac{\partial \rho}{\partial r}\right]$$

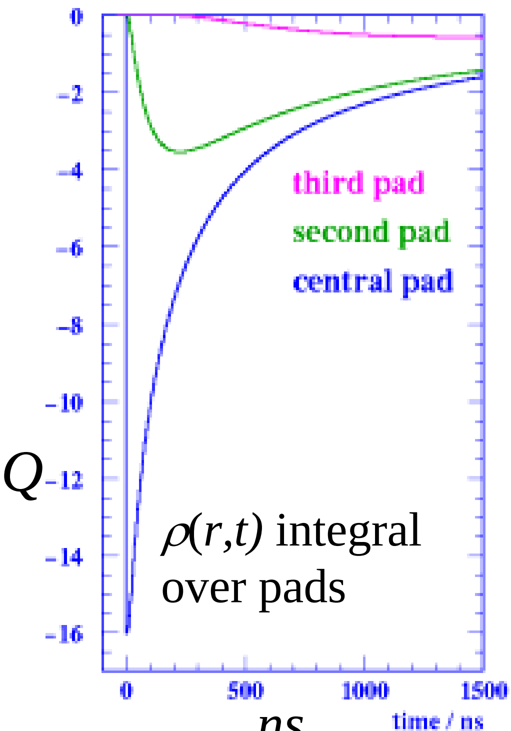
$$\Rightarrow \rho(r,t) = \frac{RC}{2t} e^{\frac{-r^2 RC}{4t}}$$

$\rho(r)$



mm

Q

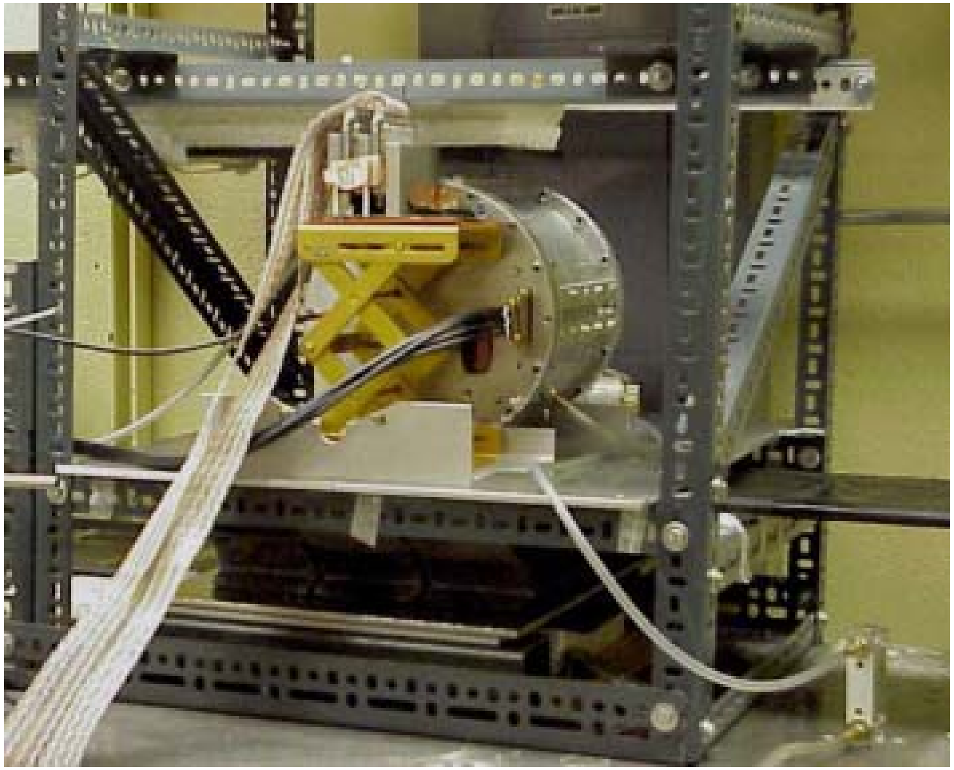


$\rho(r,t)$ integral over pads

ns

Cosmic ray resolution of a MPGD-TPC

- 15 cm drift length TPC. GEM or Micromegas readout, B=0
- Ar:CO_2/90:10 chosen to simulate low transverse diffusion in a magnetic field.
- 200 MHz custom 8 bit FADCs.
- Aleph preamps. τ_{Rise}= 40 ns, τ_{Fall} = 2 μs.
- 60 tracking pads (2 x 6 mm^2) + 2 trigger pads (24 x 6 mm^2).



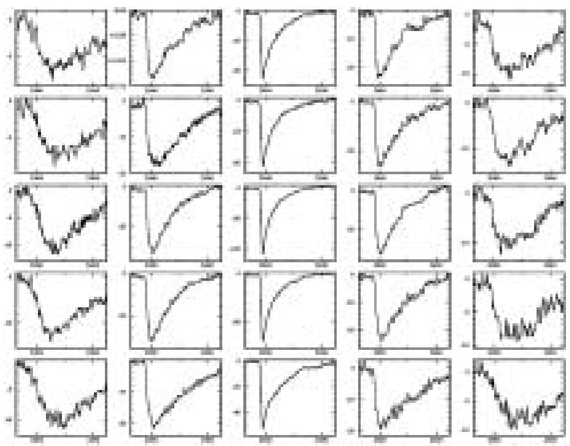
The GEM-TPC resolution was first measured with conventional direct charge TPC readout for Ar/CO_2 (90/10) gas mixture.

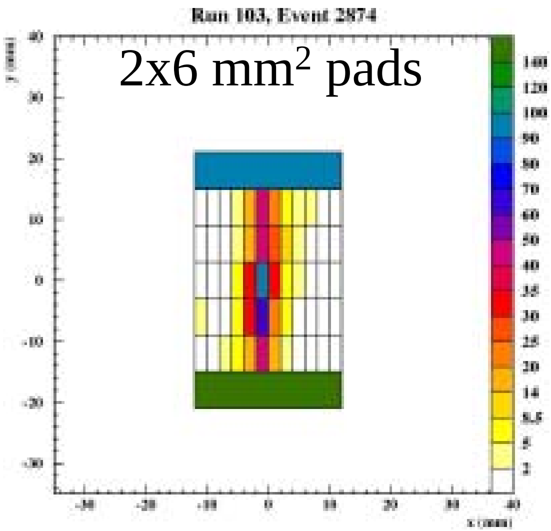
The resolution was next measured with a charge dispersion resistive anode readout with a GEM and with a Micromegas TPC.

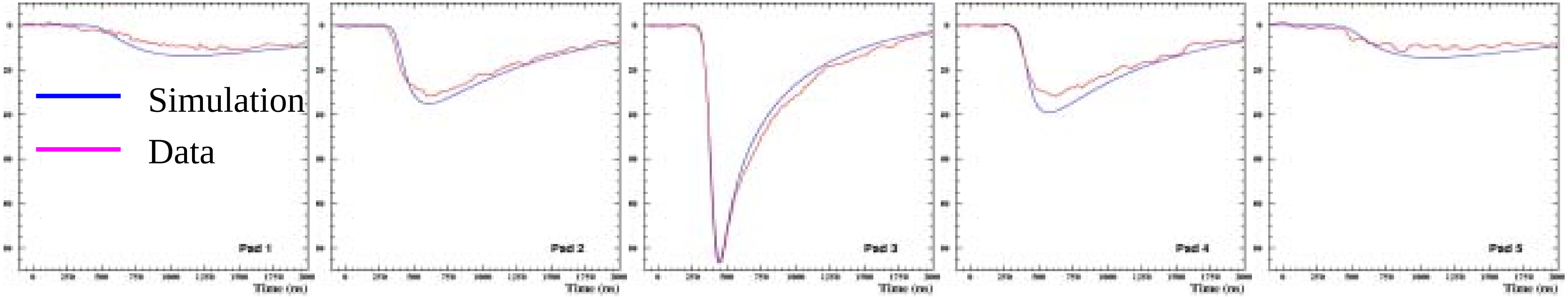
Simulation - GEM TPC cosmic event with charge dispersion

(track Z drift distance ~ 67 mm, Ar/CO_2 90/10 gas)

Detailed model simulation including longitudinal & transverse diffusion, gas gain, detector pulse formation, charge dispersion & preamp rise & fall time effects.



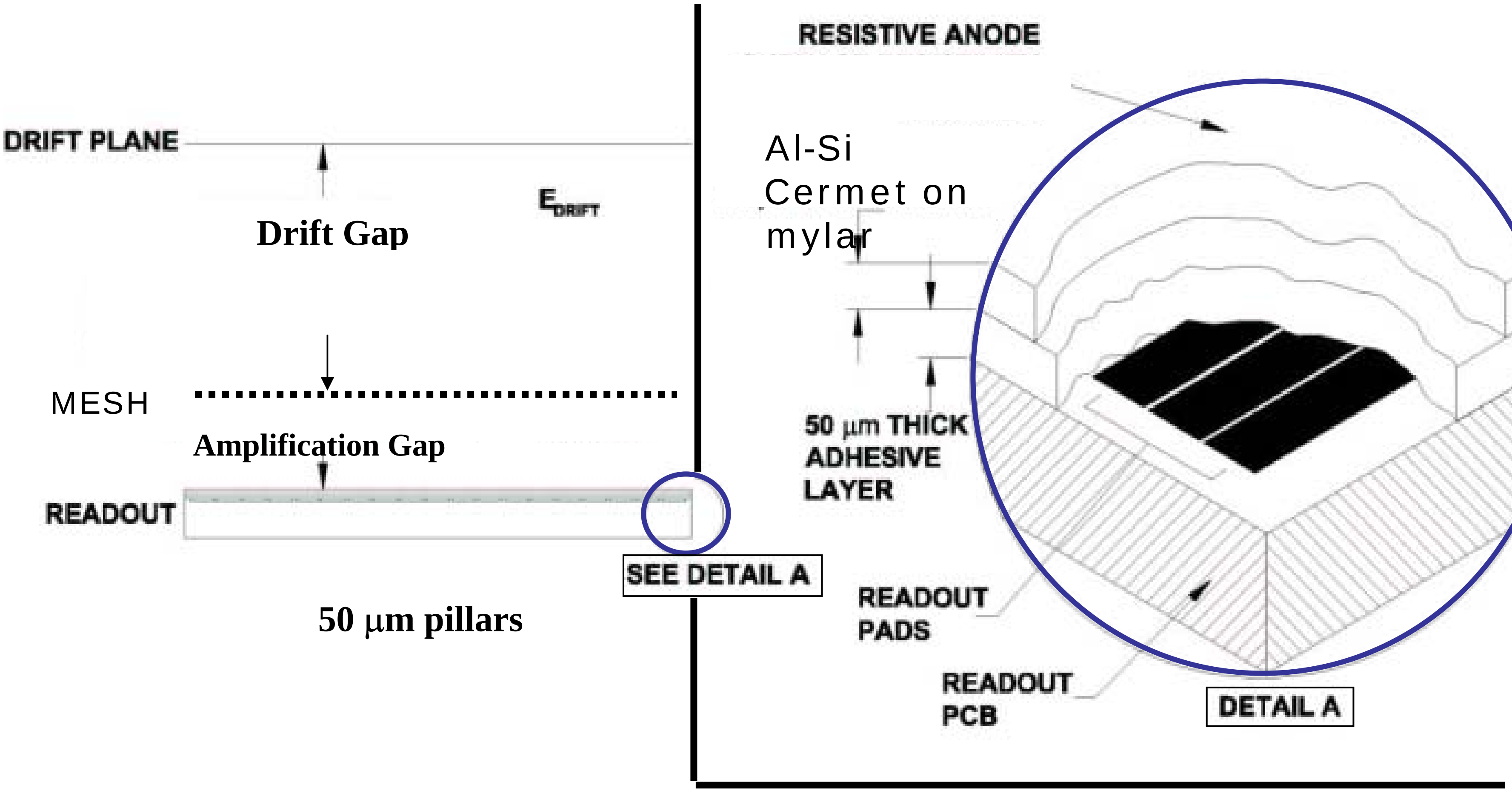




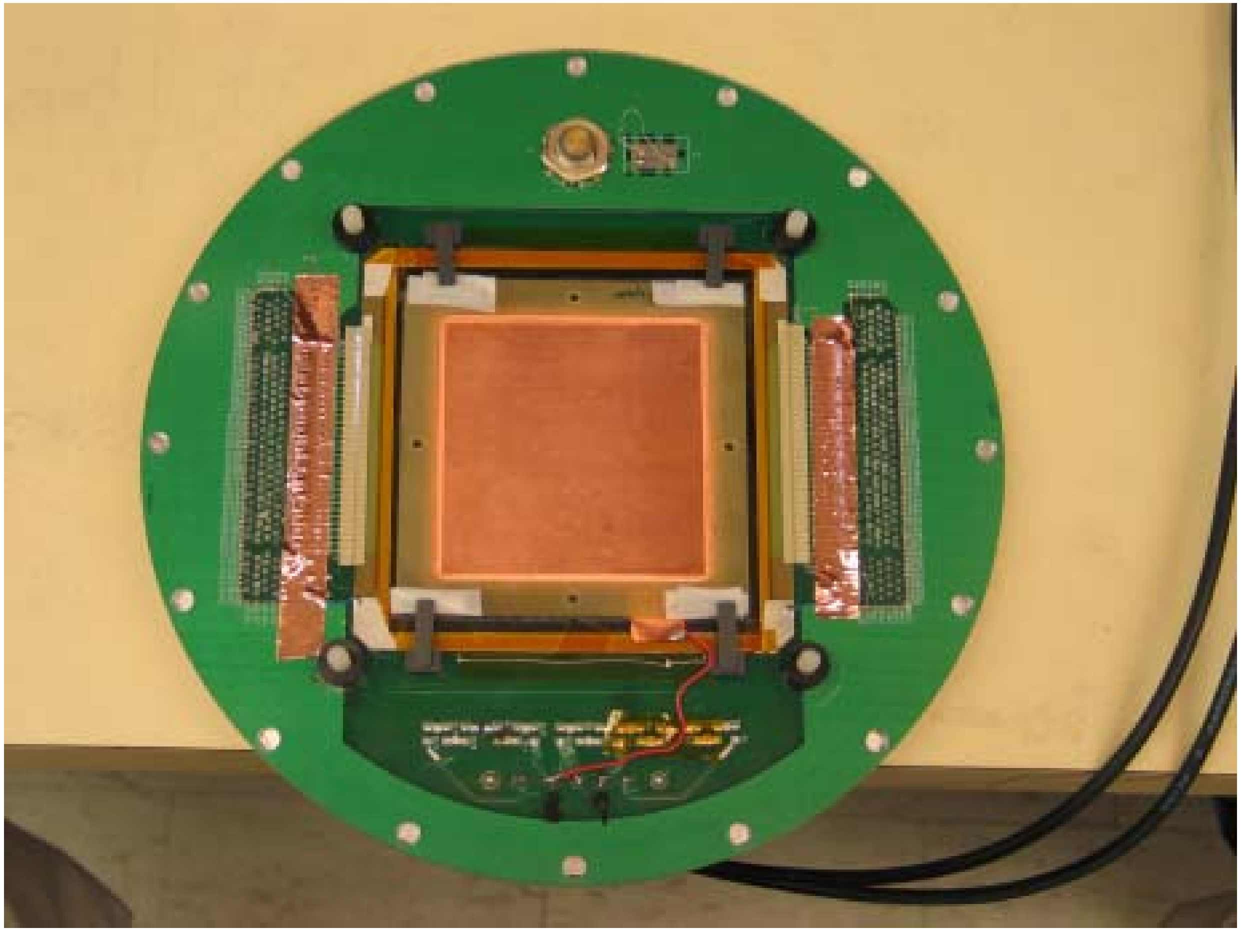
Centre pad amplitude used for normalization - no other free parameters.

Resistive anode Micromegas

530 kΩ/☐ Carbon loaded Kapton resistive anode was used with GEM. This was replaced with more uniform higher resistivity 1 MΩ/☐ Cermet for Micromegas.



Resistive anode Micromegas TPC readout



The pad response function (PRF)

- The PRF is a measure of signal size as a function of track position relative to the pad.
- *For charge dispersion non charge collecting pads have signals* in contrast to conventional direct charge readout.
- *Unusual highly variable charge dispersion pulse shape;* both the rise time & pulse amplitude depend on track position.
- We use pulse shape information to optimize the PRF.
- The PRF can, in principle, be determined from simulation.
- However, *system RC nonuniformities & geometrical effects introduce bias in absolute position determination.*
- The position *bias can be corrected by calibration.*
- PRF and bias determined empirically using a subset of data which was used for calibration. The remaining data was used for resolution studies.

TPC track PRFs with GEM & Micromegas

- The PRF is not Gaussian.
- The PRF depends on track position relative to the pad. *PRF = PRF(x,z)*
- PRF can be characterized by its *FWHM $\Gamma(z)$ & base width $\Delta(z)$.*
- PRFs determined from the data have been fitted to a functional form consisting of a ratio of two symmetric 4th order polynomials.

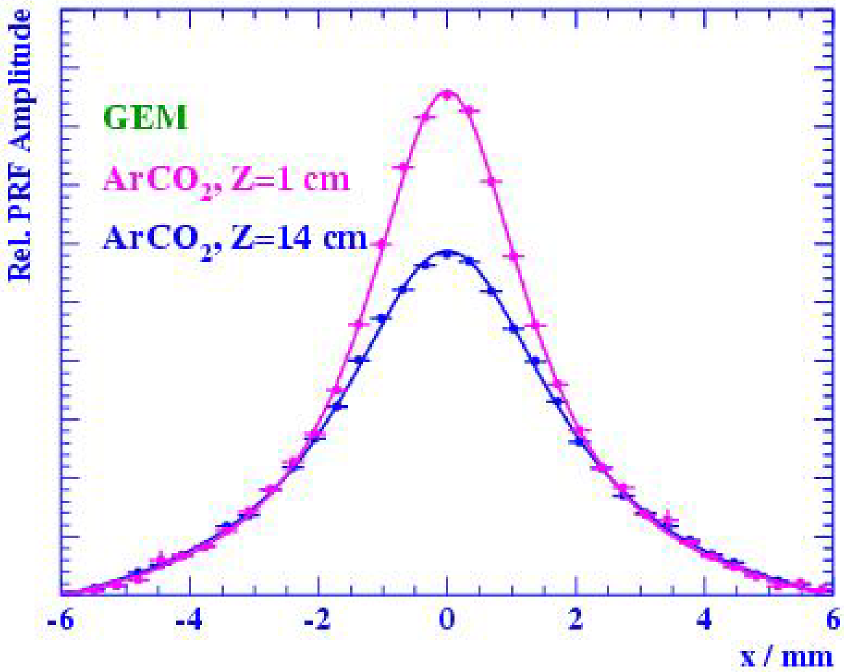
$$PRF[x,\Gamma(z),\Delta,a,b] = \frac{(1 + a_2 x^2 + a_4 x^4)}{(1 + b_2 x^2 + b_4 x^4)}$$

a_2 a_4 b_2 & b_4 can be written down in terms of Γ and Δ & two scale parameters a & b.

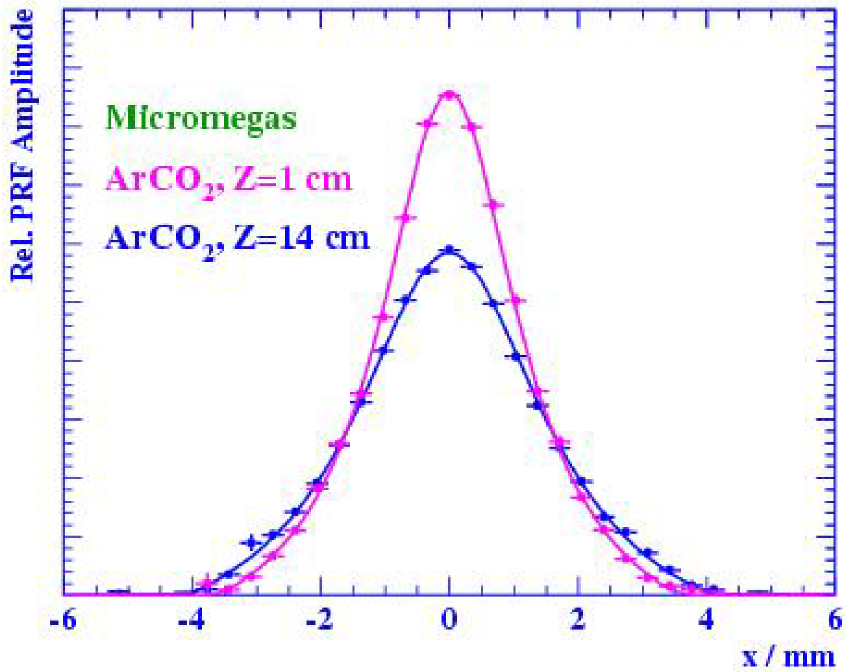
TPC track PRFs with GEM & Micromegas

Ar:CO_2 (90:10) 2x6 mm^2 pads

The pad response function maximum for longer drift distances is lower due to Z dependent normalization.



GEM PRFs



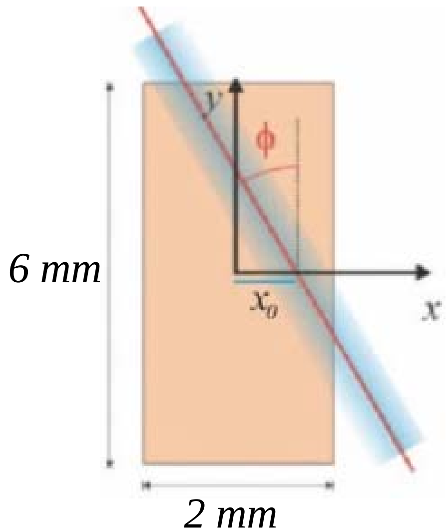
Micromegas PRFs

Micromegas PRF is narrower due to higher resistivity & little diffusion after gain

Track fit with charge dispersion

Track at: $x_{track} = x_0 + \tan(\phi)\, y_{row}$

$$\chi^2 = \sum_{\text{rows}} \sum_{\text{i=pads}} [(A_i - PRF_i)/\partial A_i]^2$$



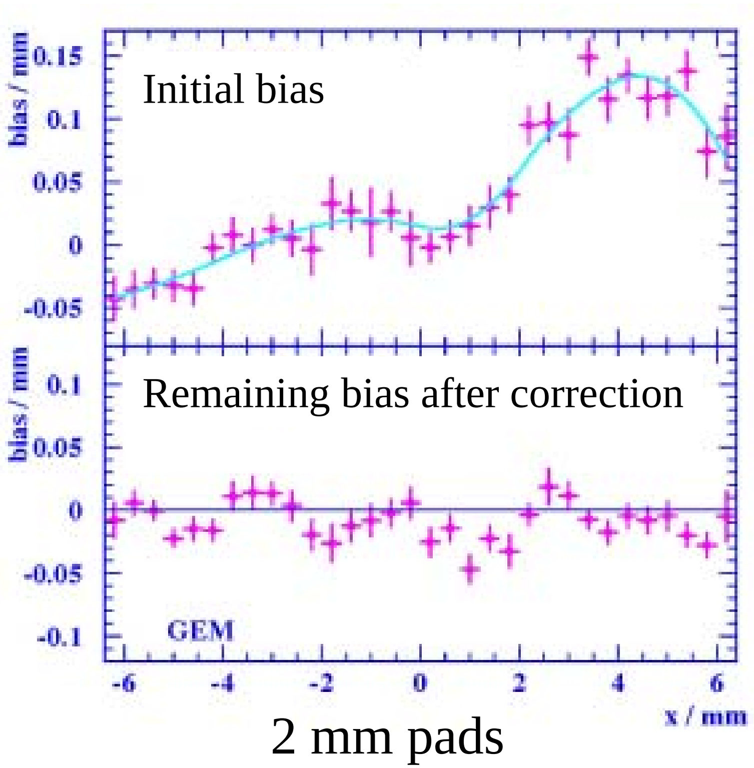
Determine x_0 & ϕ by minimizing χ^2 for the entire event

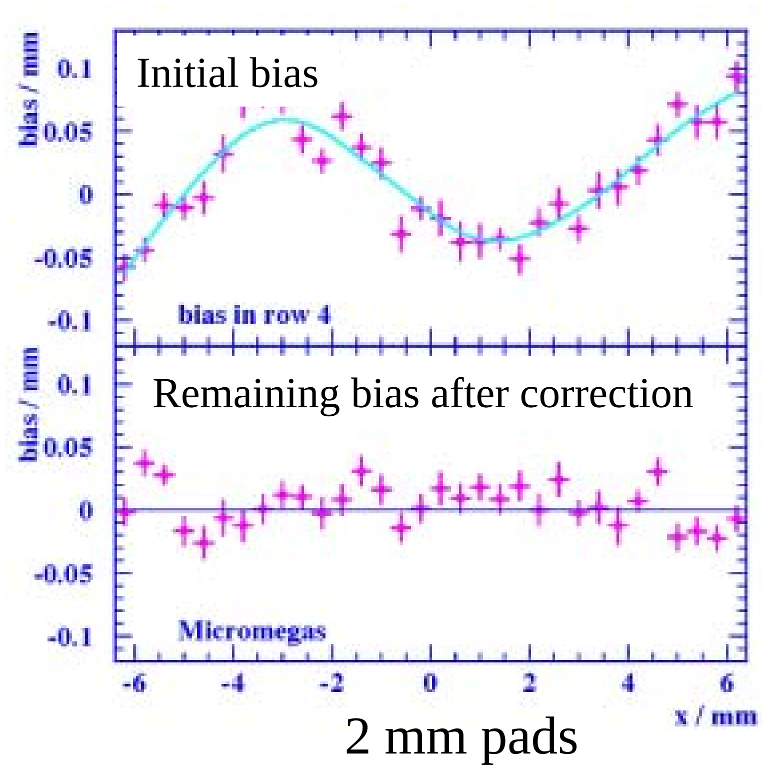
One parameter fit for x_{row} (track position for a given row) using ϕ

Bias = Mean of residuals $(x_{row}-x_{track})$ as a function of x_{track}

Resolution = σ *of track residuals* for tracks with $|\phi| < 5°$

Bias corrections with GEM & with Micromegas



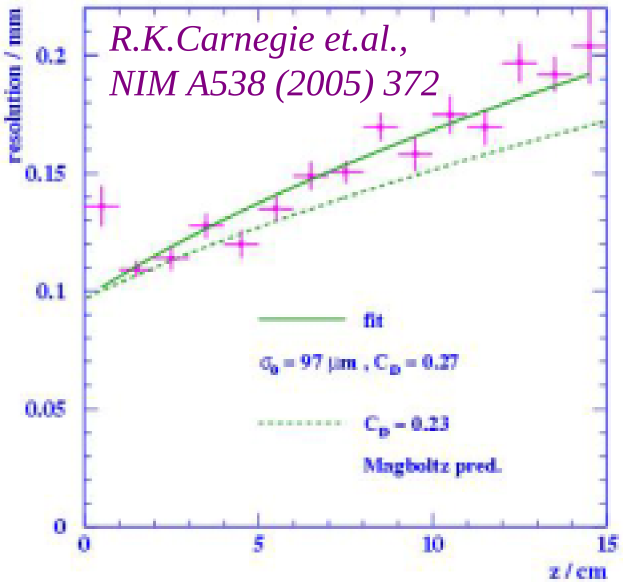


GEM *Bias for row 4*

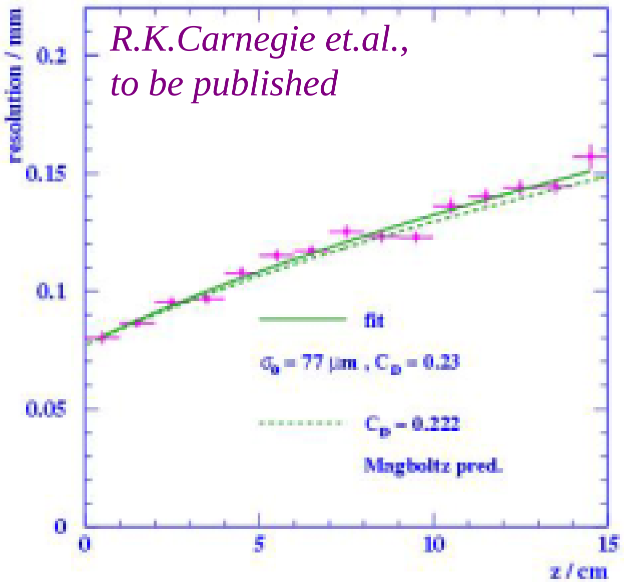
Micromegas *Bias for row 4*

TPC transverse resolution for Ar:CO_2 (90:10)

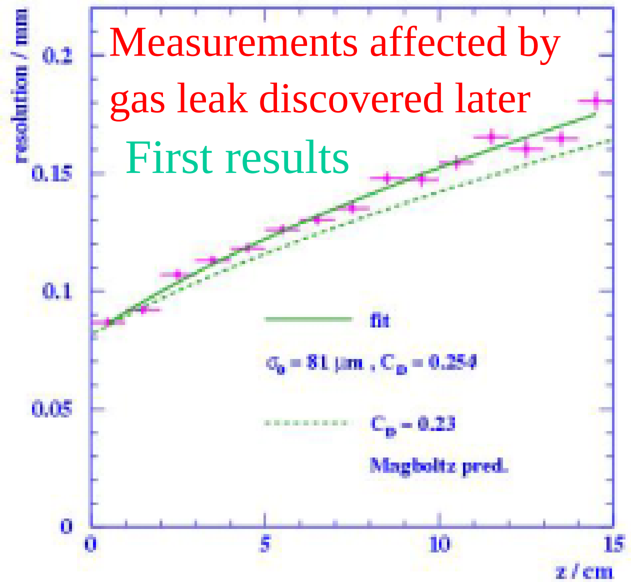
GEM with direct charge readout



GEM with charge dispersion readout



Micromegas with charge dispersion readout



$$\sqrt{\sigma_0^2 + \frac{C_D^2}{N_e} z}$$ (Diffusion limit of resolution)

Compared to direct charge readout, charge dispersion gives better resolution for GEM with Z dependence close to the diffusion limit. For Micromegas, the resolution, even with electron loss, is better than for direct charge GEM readout.

Summary & outlook

- *Better space point resolution has been achieved for GEM & Micromegas readout TPC with a resistive anode than for the conventional direct charge readout TPCs.*
- Measured resolution near the diffusion limit in cosmic tests with no magnetic field.
- The diffusion limit will be lower in a magnetic field. Cosmic & beam tests planned for 2 track studies and to confirm the diffusion limit of resolution for a TPC in a magnet.
- *With suitable choice of gas & electronics, a resolution of ~ 100 μm for all tracks (2.5 m drift) appears within reach for the ILC TPC.*
- Charge dispersion signals are slow. Inexpensive 30-40 MHz digitizers will be developed to replace the 200 MHz FADCs being used presently.