Spatial resolution of a MPGD TPC using the charge dispersion signal

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MPGD-TPC resolution with charge dispersion

•ILC TPC challenge: Using ~ 2 mm wide pads, measure ~ 200 points with ~ 100 µm resolution for all tracks (max. TPC drift length ~ 2.5 m).

•Transverse diffusion sets the ultimate limit on TPC resolution.

•ILC tracker resolution goal is near the ultimate limit from diffusion for a gaseous TPC.

•Conventional TPCs with proportional wir/cathode pad endcap readout systems limited by ExB & track angle systematics.

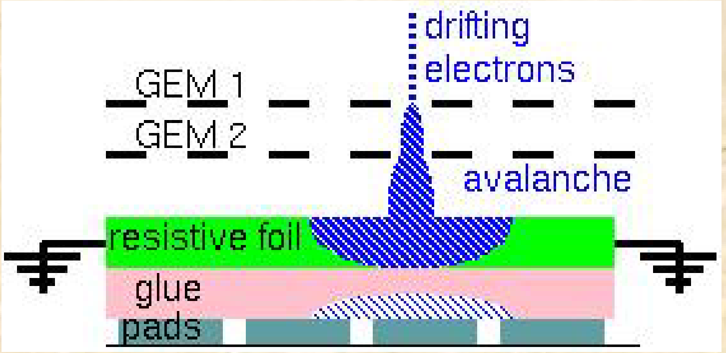
•A TPC read out with a MPGD endcap could achieve the ILC resolution goal with ~ 2 mm wide pads if the precision of pad charge centroid determination could be improved.

•Ideas to improve the MPGD TPC resolution:

- Narrower pads would lead to increased complexity & a larger number of readout channels.
- Controlled dispersal of track avalanche charge after over a larger area to improve determination of pad centroids with wide pads.

Charge dispersion in a MPGD with a resistive anode

- Modified MPGD 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.

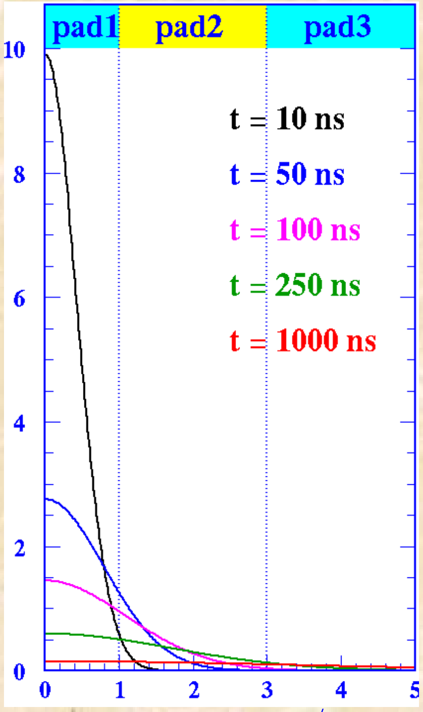


Equation for surface charge density function on the 2-dim. continuous RC network:

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

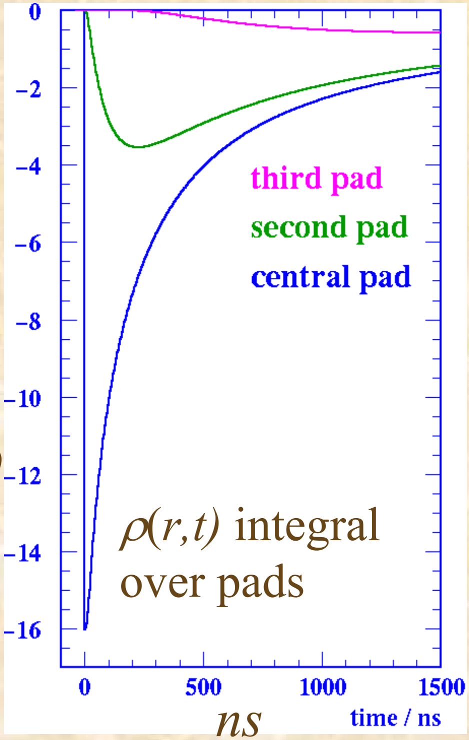
$$\Rightarrow \rho(r,t) = \frac{RC}{2t} e^{\frac{-r^2 RC}{4t}}$$

$\rho(r)$



mm

Q

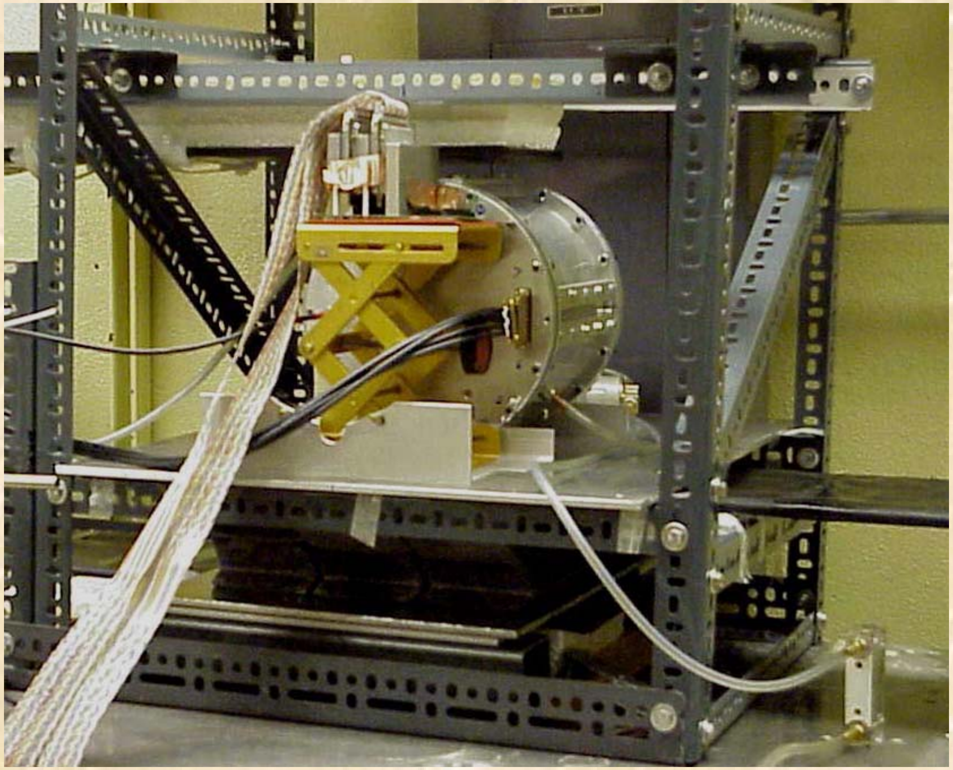


$\rho(r,t)$ integral over pads

ns

Cosmic ray resolution of a MPGD-TPC

- 15 cm drift length with GEM or Micromegas readout, B = 0
- Ar:CO_2/90:10 chosen to simulate low transverse diffusion conditions in a high magnetic field.
- Aleph charge preamps. τ_{Rise}= 40 ns, τ_{Fall} = 2 µs.
- Digitization effectively at 25 MHz by combining 200 MHz FADC time bins.
- 60 tracking pads (2 x 6 mm^2) + 2 trigger pads (24 x 6 mm^2).

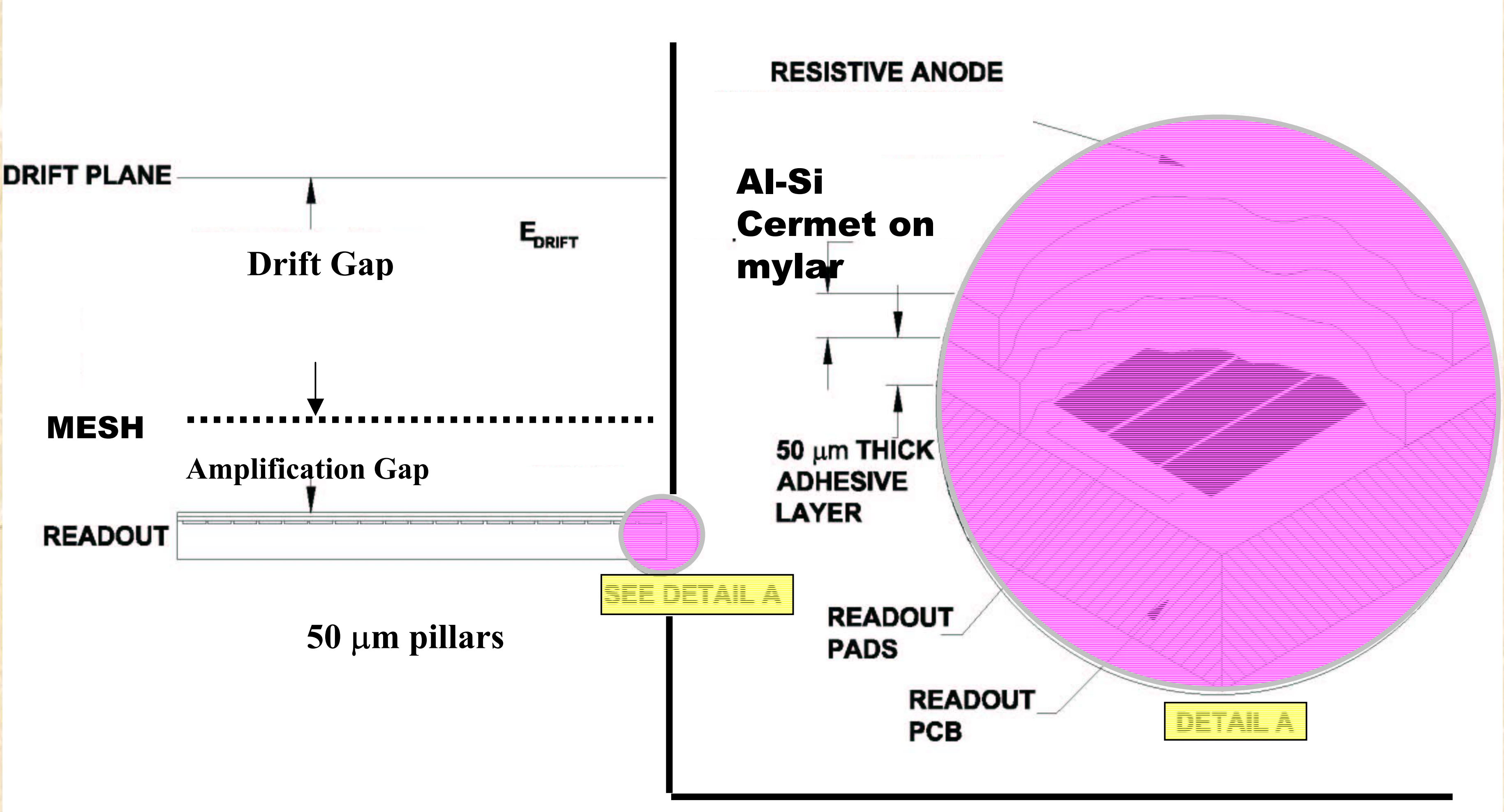


The GEM-TPC resolution was first measured with conventional direct charge TPC readout.

The resolution was next measured with a charge dispersion resistive anode readout with a double-GEM & with a Micromegas endcap.

Resistive anode Micromegas

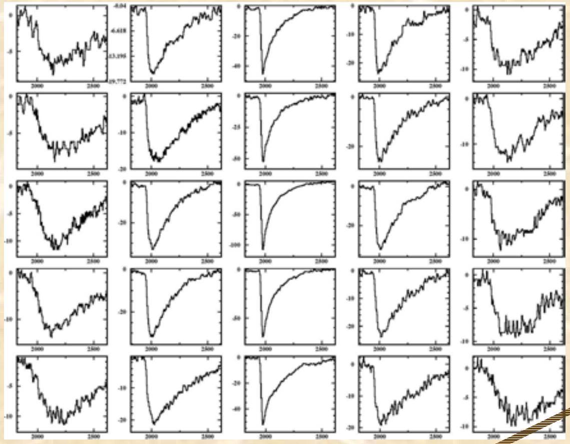
530 kΩ/□ Carbon loaded Kapton resistive anode was used with GEM. This was replaced with more uniform higher resistivity 1 MΩ/□ Cermet for Micromegas.

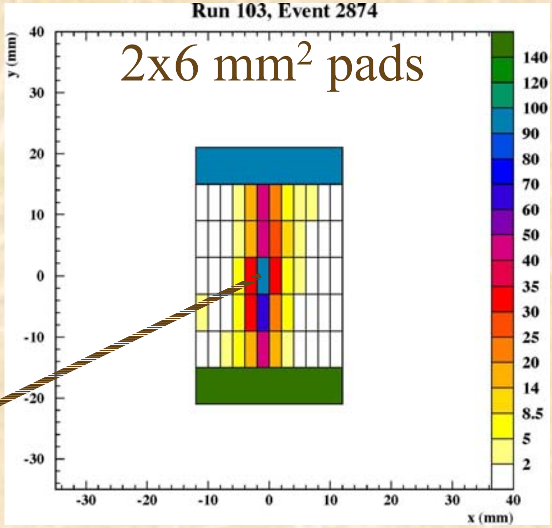


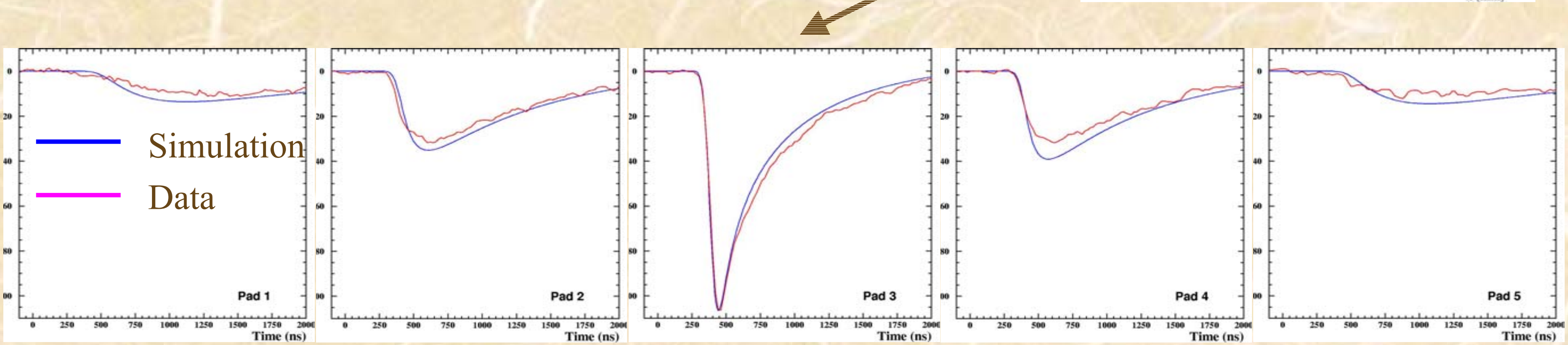
Simulation - GEM TPC cosmic event with charge dispersion

(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.

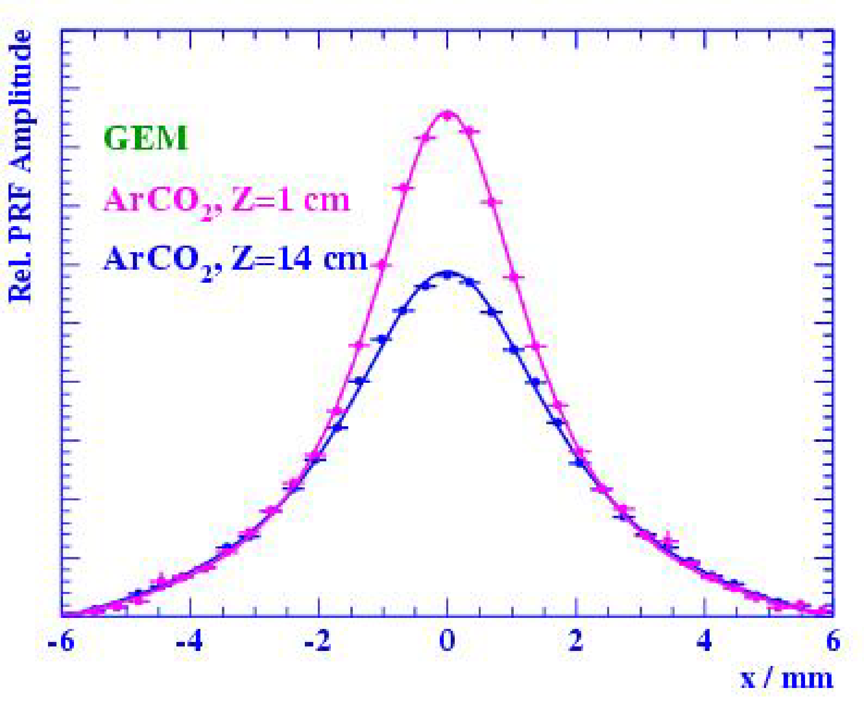
The pad response function (PRF)

- 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.

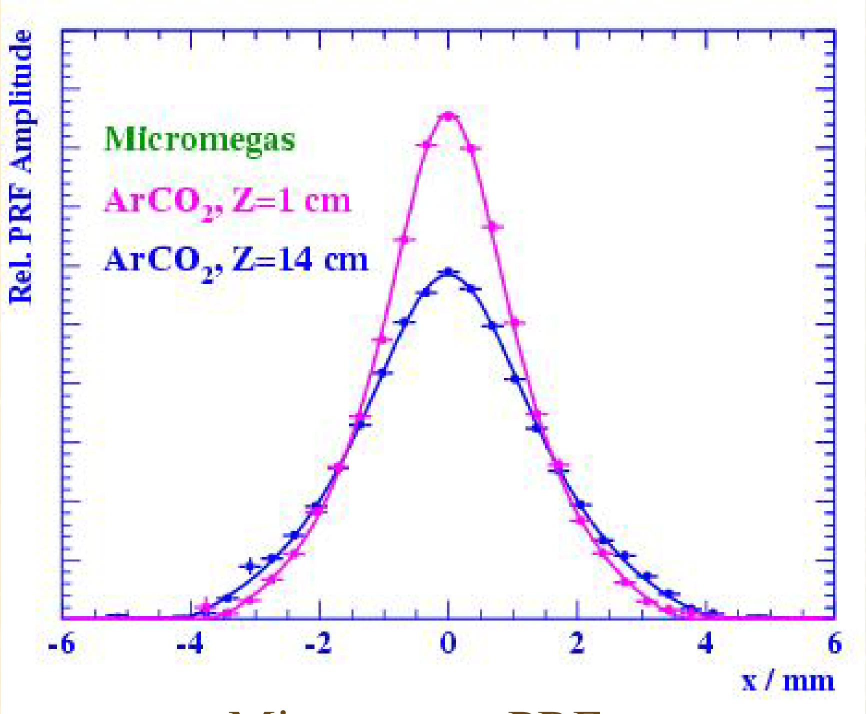
GEM & Micromegas PRFs for TPC track

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 the use of higher resistivity anode & smaller diffusion after avalanche gain

PRFs with the GEM & the Micromegas readout

- The PRFs are 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.

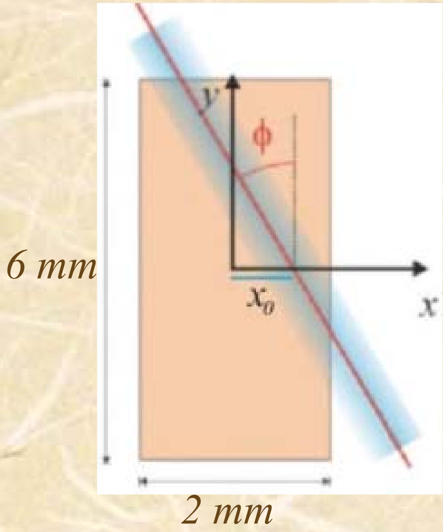
$$PRF[x,\Gamma(z),\Delta,a,b]=\frac{(1+a_2x^2+a_4x^4)}{(1+b_2x^2+b_4x^4)}$$

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

Track fit using the the PRF

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

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



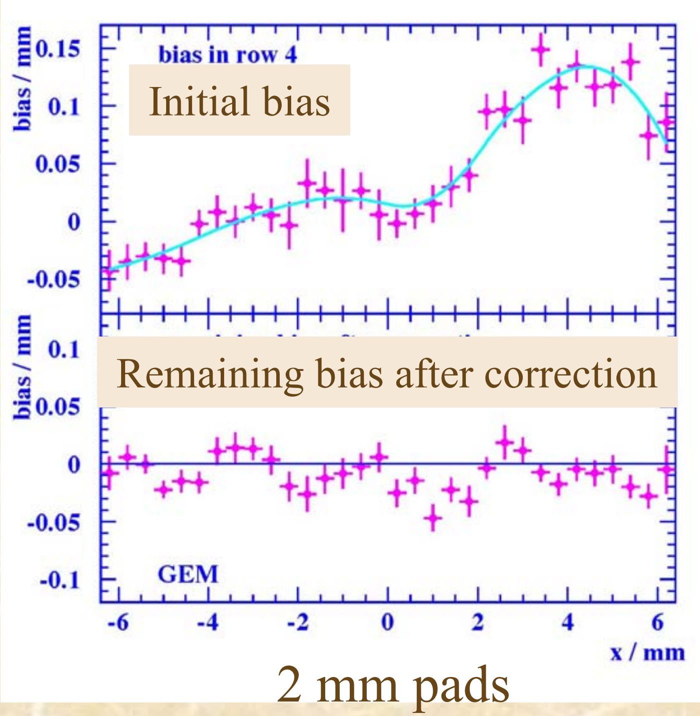
Determine x_0 & ϕ by minimizing χ^2 for the entire event

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

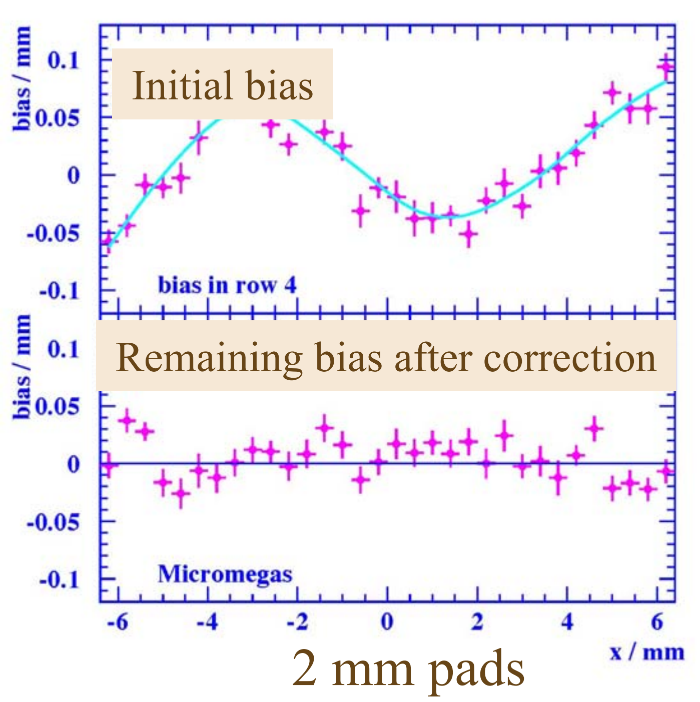
Bias = Mean of residuals (x_{row}-x_{track}) as a function of x_{track}

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

Bias corrections with GEM & with Micromegas



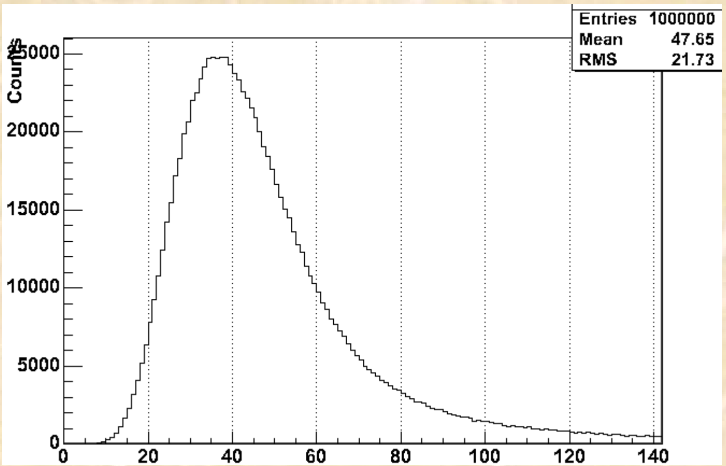
GEM

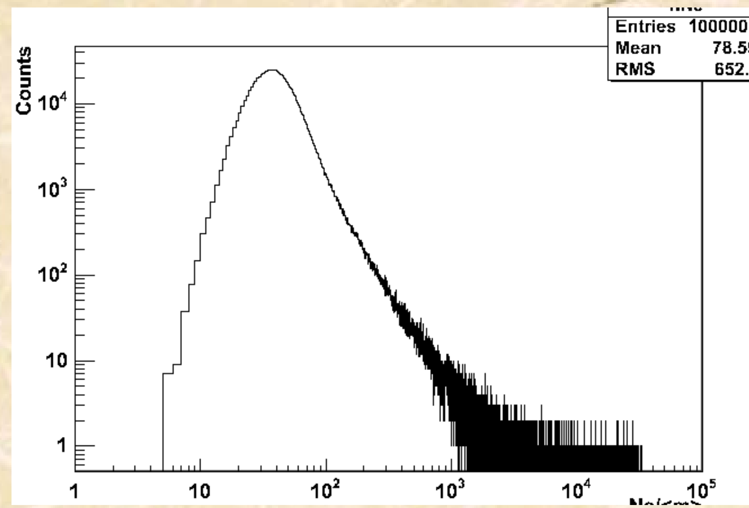


Micromegas

What is the diffusion limit of resolution for a gaseous TPC?

Resolution depends on electron statistics.
Electron number N fluctuates from event to event.





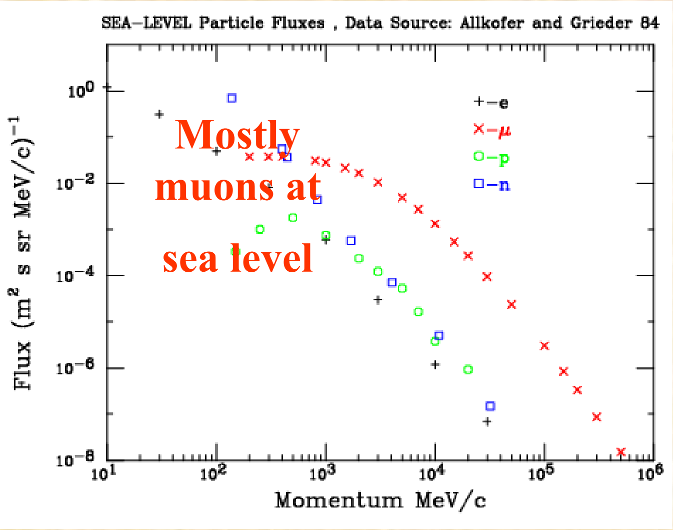
$$\sigma_x^{\ 2} = \sigma_0^{\ 2} + \frac{C_d^{\ 2} \cdot z}{N_{eff}}$$

σ_0 includes noise & systematic effects.
C_d = diffusion constant; z = drift distance

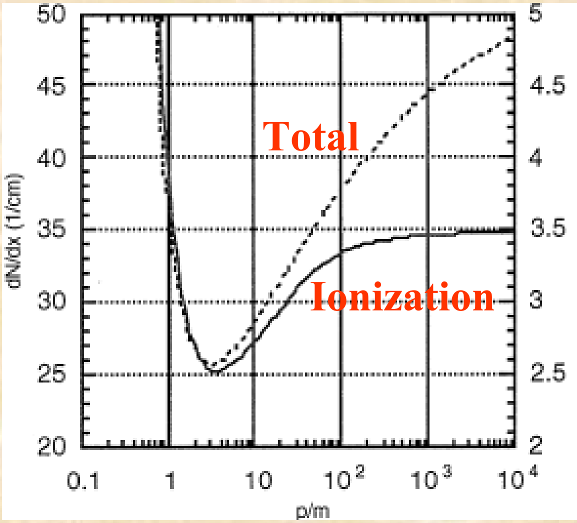
$N_{eff} \neq \langle N \rangle$ the average number of electrons
$= 1/\langle 1/N \rangle$ the inverse of average of $1/N$
Gain fluctuations also affect N_{eff}

Simulation to determine N_{eff}
2 mm x 6 mm pads - Ar/CO_2 90/10

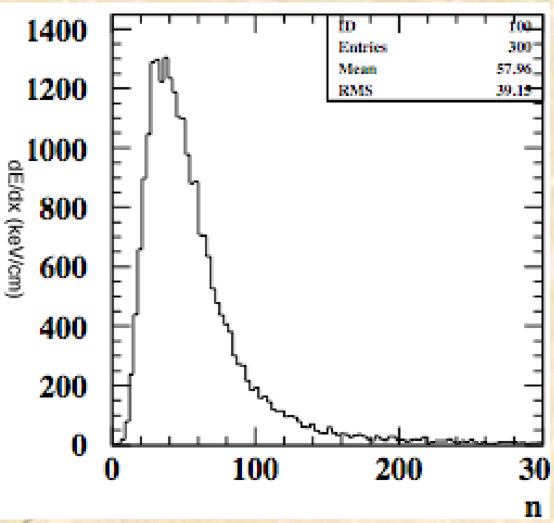
Cosmic ray momentum spectrum



dE/dx in Argon



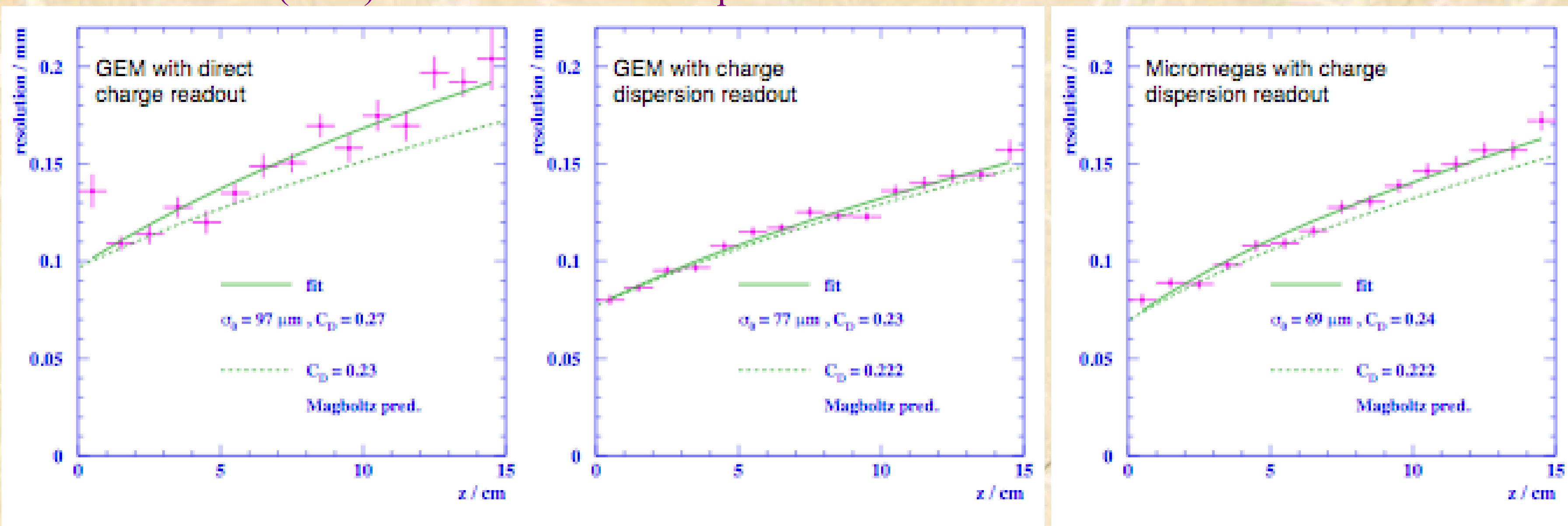
Measured pad pulse height distribution



- Statistics of primary ionization & cluster size distribution.
- dE/dx dependence on momentum.
- Account for track angle & detector acceptance effects.
- Use simulation to scale measured pulse heights to electron number.
- $N_{eff} = 1/<1/N>$ determined from pulse height distribution.
- **$N_{eff} \approx 38.9 \pm 10\%$ ($N_{average} = 57$)**

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

R.K.Carnegie et.al., NIM A538 (2005) 372 | R.K.Carnegie et.al., to be published | New results



$$\sqrt{\sigma_0^{\ 2} + \frac{C_D^{\ 2}}{N_e} z} \quad [N_{eff} = 38.9]$$

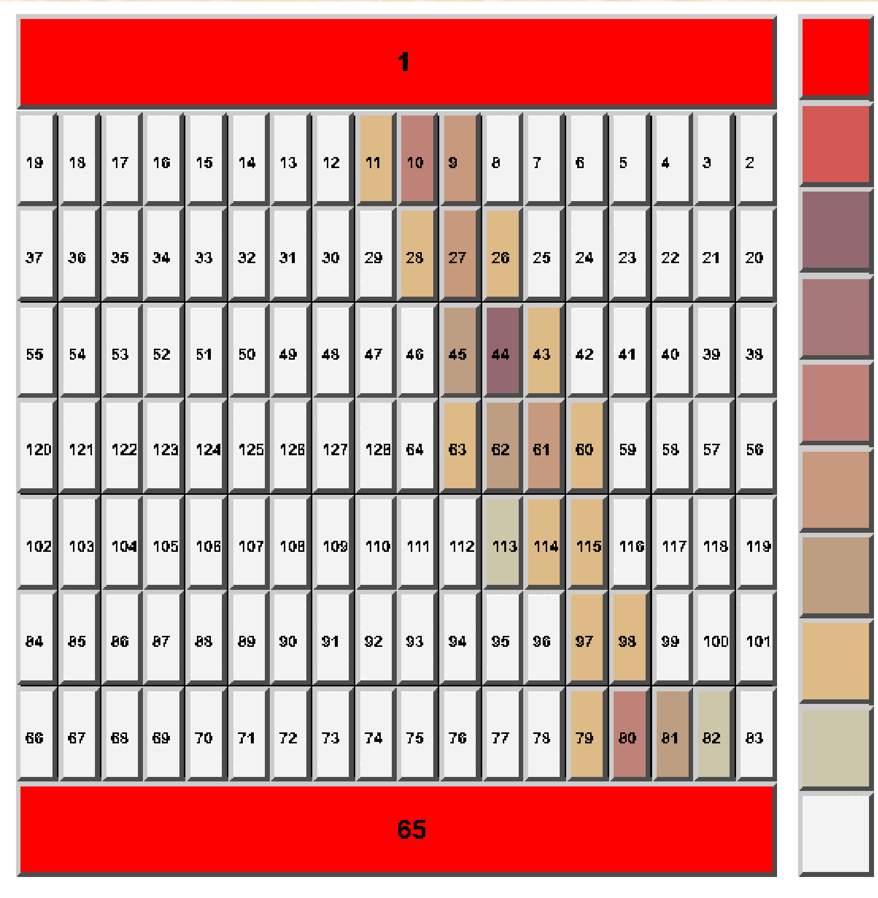
Compared to conventional readout, resistive readout gives better resolution for the GEM and the Micromegas readout. The z dependence follows the expectations from transverse diffusion & electron statistics.

What's next?

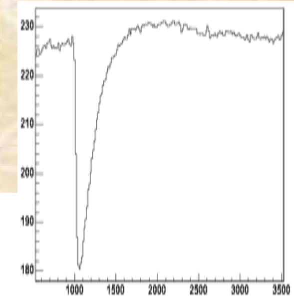
- Beam test at KEK in October 2005 to demonstrate good resolution in a magnetic field using ~ 2 mm wide pads.
- Two TPCs will be tested in the 1.2 T Jacee magnet.
  - Carleton TPC with a Micromegas with a resistive anode using a new 128 pad PCB designed for tracking in a magnetic field.
  - Ron Settles (MPI) has designed a TPC to facilitate comparison of different readout options under similar conditions. The MPI-TPC will also be tested at KEK using a resistive anode readout both with GEMs and the Micromegas.

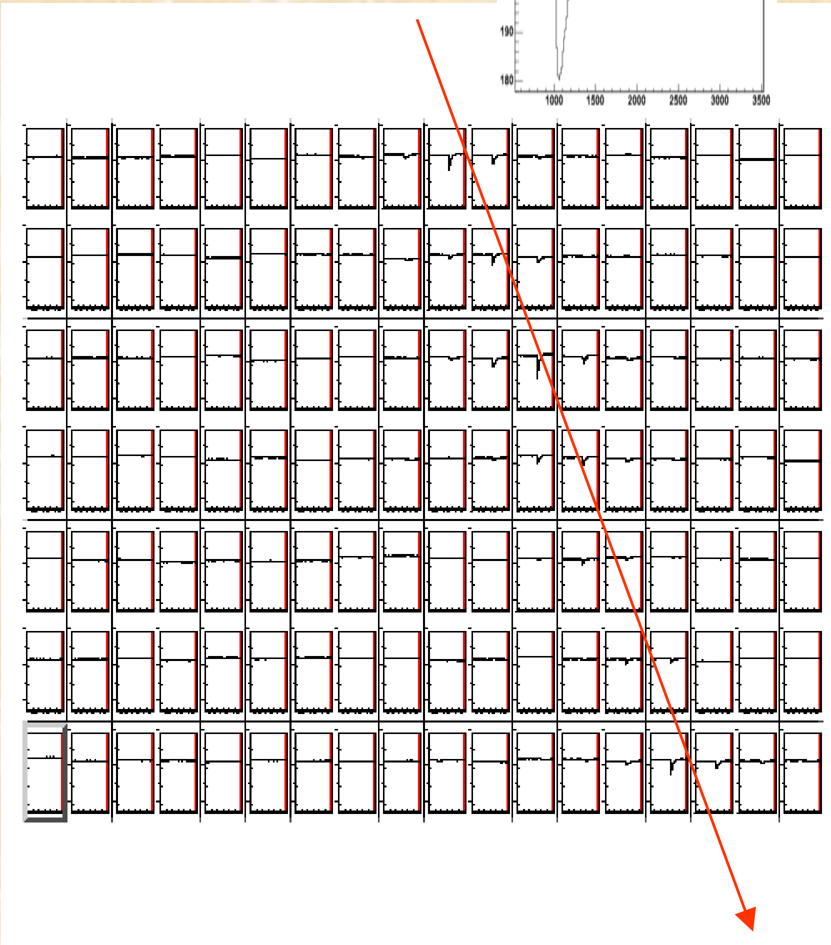
A cosmic ray event in the new Carleton 128 pad TPC

Relative amplitudes



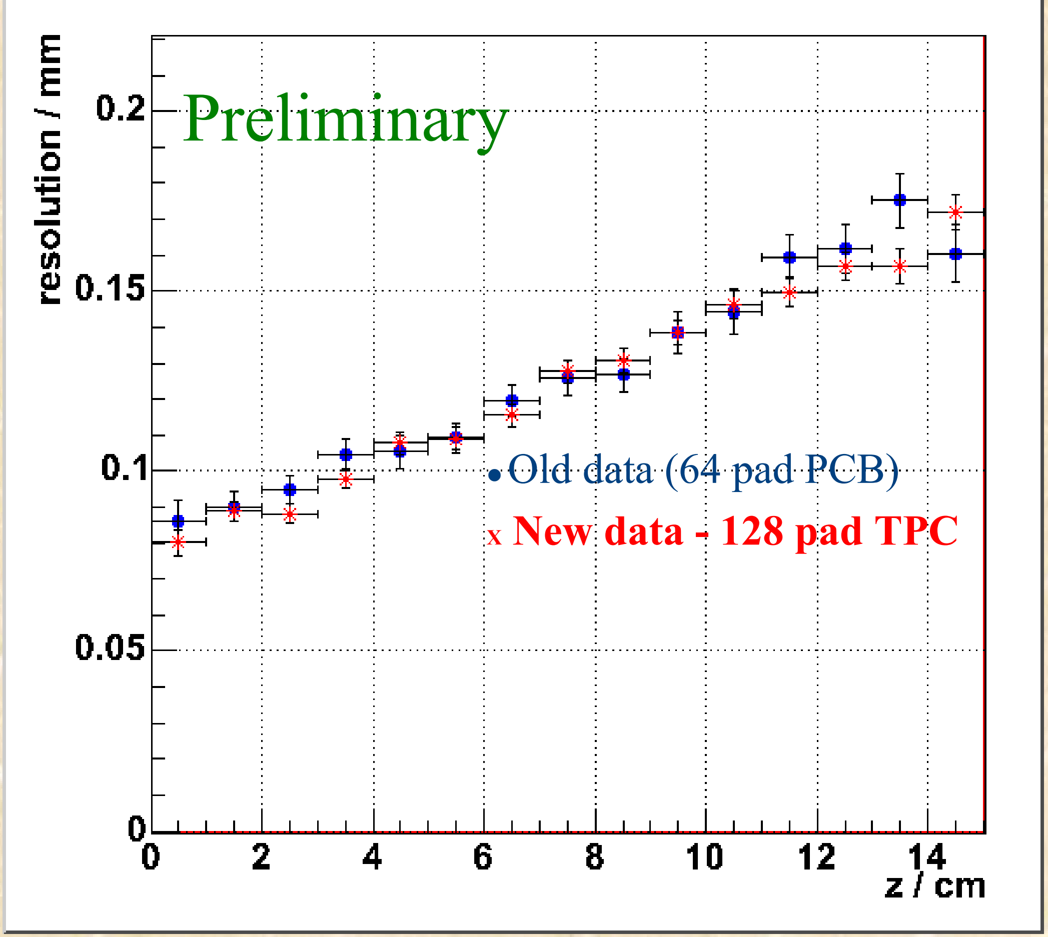
Cosmic track





Resolution for cosmic ray tracks for the new 128 pad TPC

$Ar:CO_2$ (90:10)



The new 128 pad TPC is ready for KEK beam test

Summary & outlook

- Using 2 mm wide pads, we have demonstrated better GEM/Micromegas-TPC resolution with a resistive anode readout than has been achieved with conventional MPGD TPC readout systems.
- The resolution is near the diffusion limit of resolution for a gaseous TPC. In cosmic tests with no magnetic field, the measured resolution follows the expectations from transverse diffusion & electron statistics.
- Beam tests in a magnet next to demonstrate good resolution for a TPC in a magnetic field.
- A resolution of ~ 100 μm for all tracks (2.5 m drift) using ~ 2 mm wide pads appears feasible for the ILC TPC.