Measurement of MPGD-TPC resolution with charge dispersion in a beam test in a magnet

Vancouver Linear Collider Workshop 19-22 July 2006

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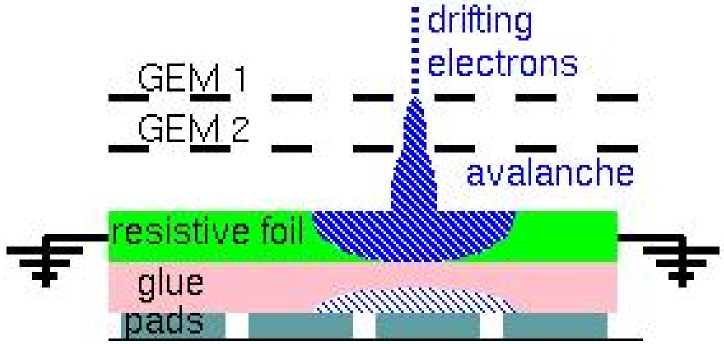
Motivation & overview

- ILC tracker goal $\Delta(1/p_T) \leq 5.10^{-5}$ (GeV/c)$^{-1}$
  => MPGD-TPC $\Delta(1/p_T) \leq 1.5 \times 10^{-4}$ (GeV/c)$^{-1}$
- TDR TPC: 200 pads; σ_{Tr} ~ 100 μm (≈ 2 m drift), pad size 2 x 6 mm^2
  => Total TPC pad count ~1.5 x 10^6
- R&D shows 2 mm too wide for 100 μm resolution with normal readout. Ways to improve the MPGD-TPC resolution:
  - Under consideration - narrower 1 mm x 6 mm pads (3 x 10^6 total). R&D issues: High density electronics, larger heat load, TPC endcap mass etc.
  - Alternative: Disperse avalanche charge to improve resolution for 2 mm wide pads. Development of a TPC readout with charge dispersion in MPGDs with a resistive anode.
    - Charge dispersion demonstrated in cosmic ray TPC tests with no magnet.
  - B = 1 T 4 GeV/c beam test at KEK PS in October 2005. Two TPCs: MP TPC (MPI Munich, Saclay, SAGA, KEK) with GEMs & Micromegas & Canadian TPC with Saclay Micromegas.
    - Update of results reported at LCWS 2006 Bangalore.
    - Progress in simulation.
    - Summary & outlook.

Charge dispersion in a MPGD with a resistive anode

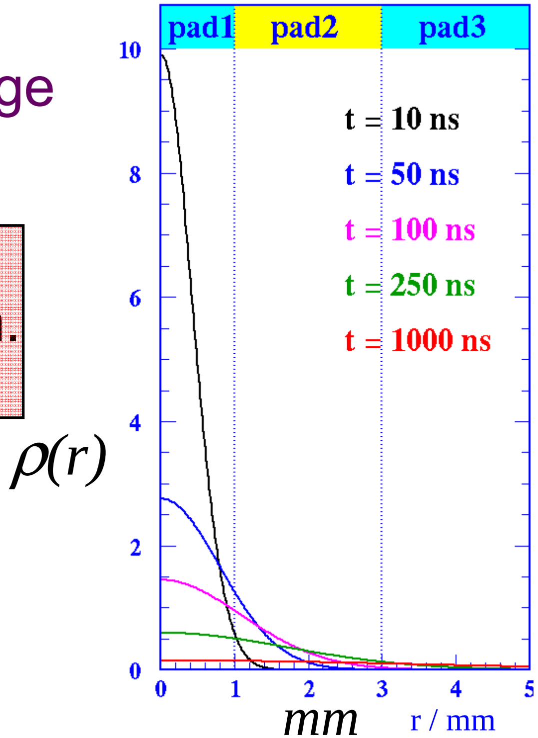
- Modified MPGD anode with a high resistivity film bonded to a readout plane with an insulating spacer.
- 2-dimensional continuous RC network defined by material properties & geometry.
- Point charge at *r = 0 & t = 0* disperses with time.
- Time dependent anode charge density sampled by readout pads.

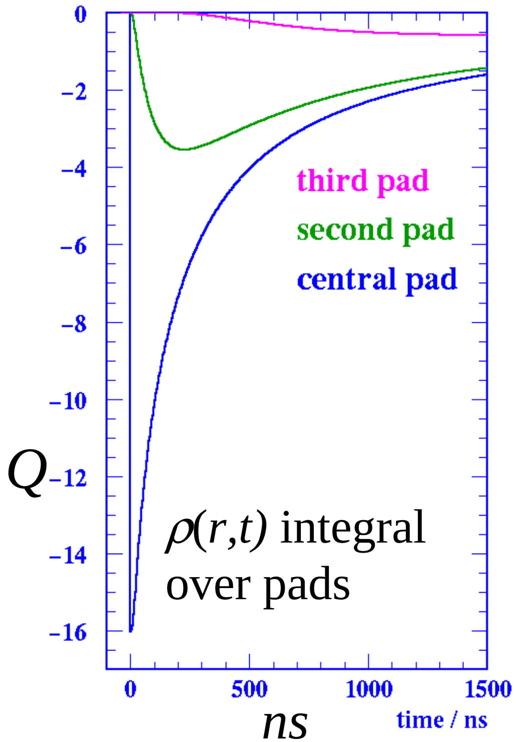


Equation for surface charge density function on the 2-dim. continuous RC network:

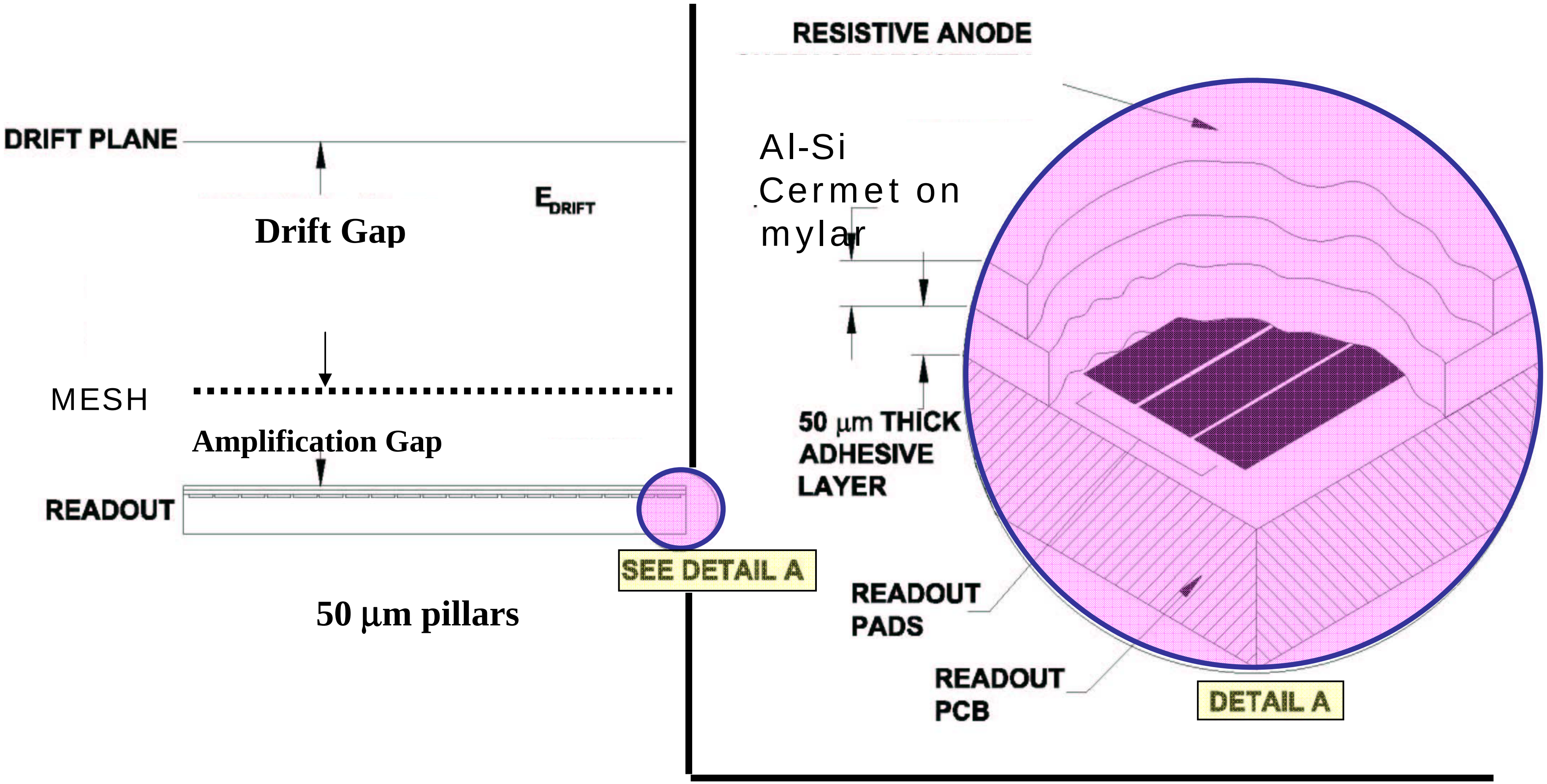
$$\frac{\partial \rho}{\partial t} = \frac{1}{RC}\left[\frac{\partial^2 \rho}{\partial r^2} + \frac{1}{r}\frac{\partial \rho}{\partial r}\right]$$

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

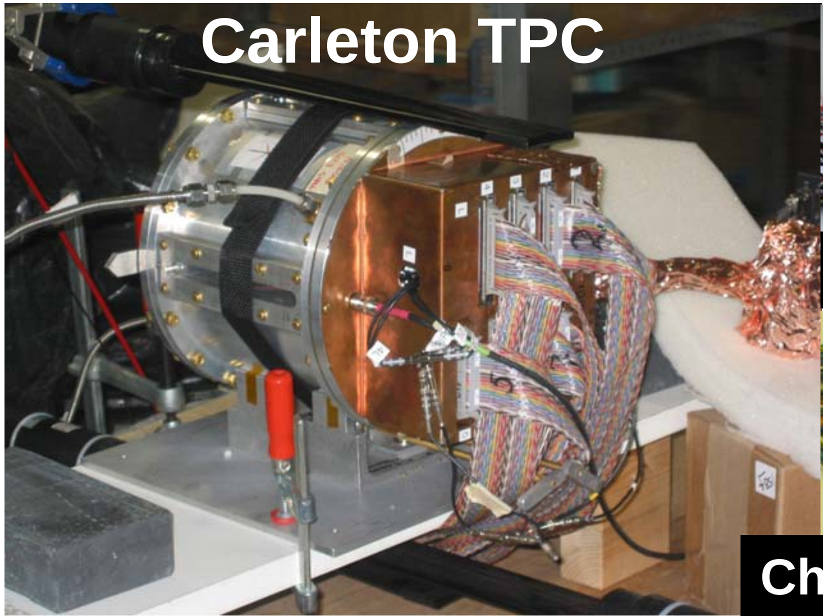


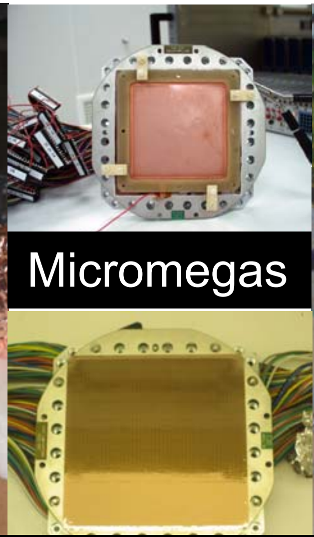


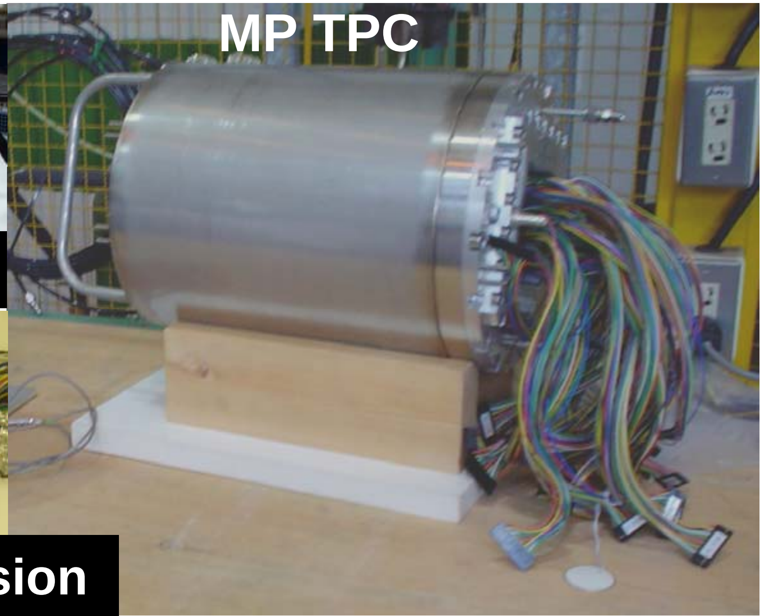
Micromegas with a resistive anode for the charge dispersion readout



The two beam test TPCs





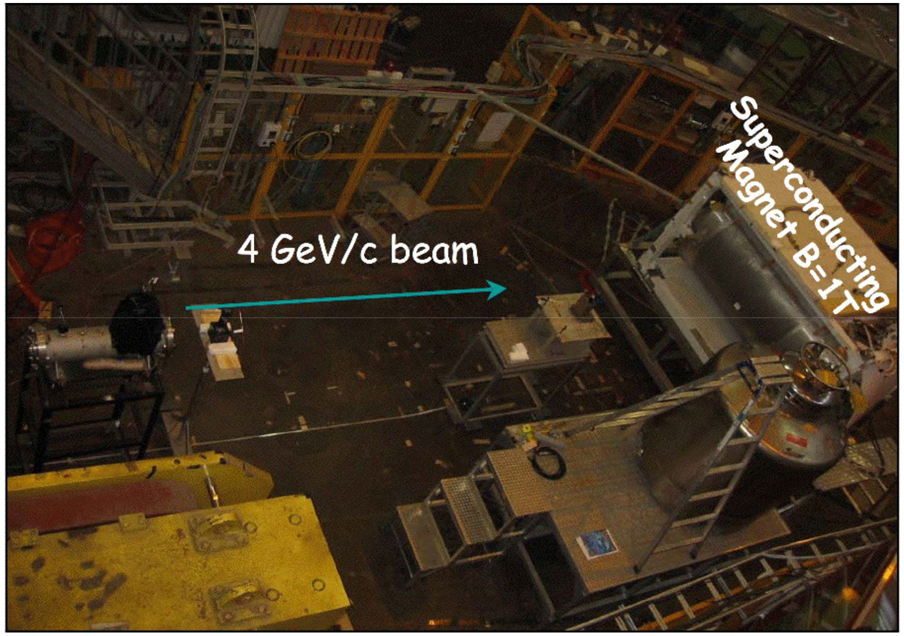


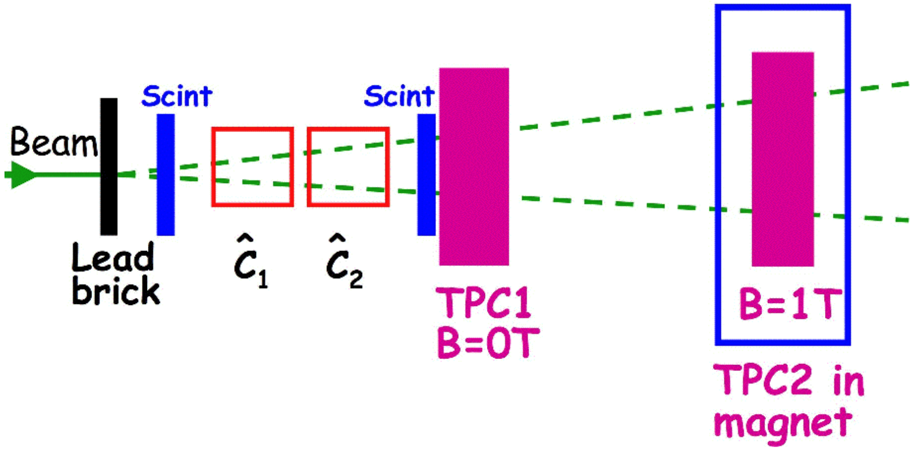
- Micromegas 10 x10 cm^2
- Drift distance: 16 cm
- 126 pads, 2 x 6 mm^2 each in 7 rows
-ALEPH preamps + 200 MHz FADCs rebinned to 25 MHz

-Micromegas & GEMs 10 x10 cm^2
-Drift distance 25.9 cm
- 384 pads 2.3 x 6.3 mm^2 each in 16 rows
-ALEPH preamps + 11 MHz Aleph Time Projection Digitizers

KEK PS π2 test beam set up with Carleton & MP TPCs

Beam data taken both in & outside the magnet for the two TPCs





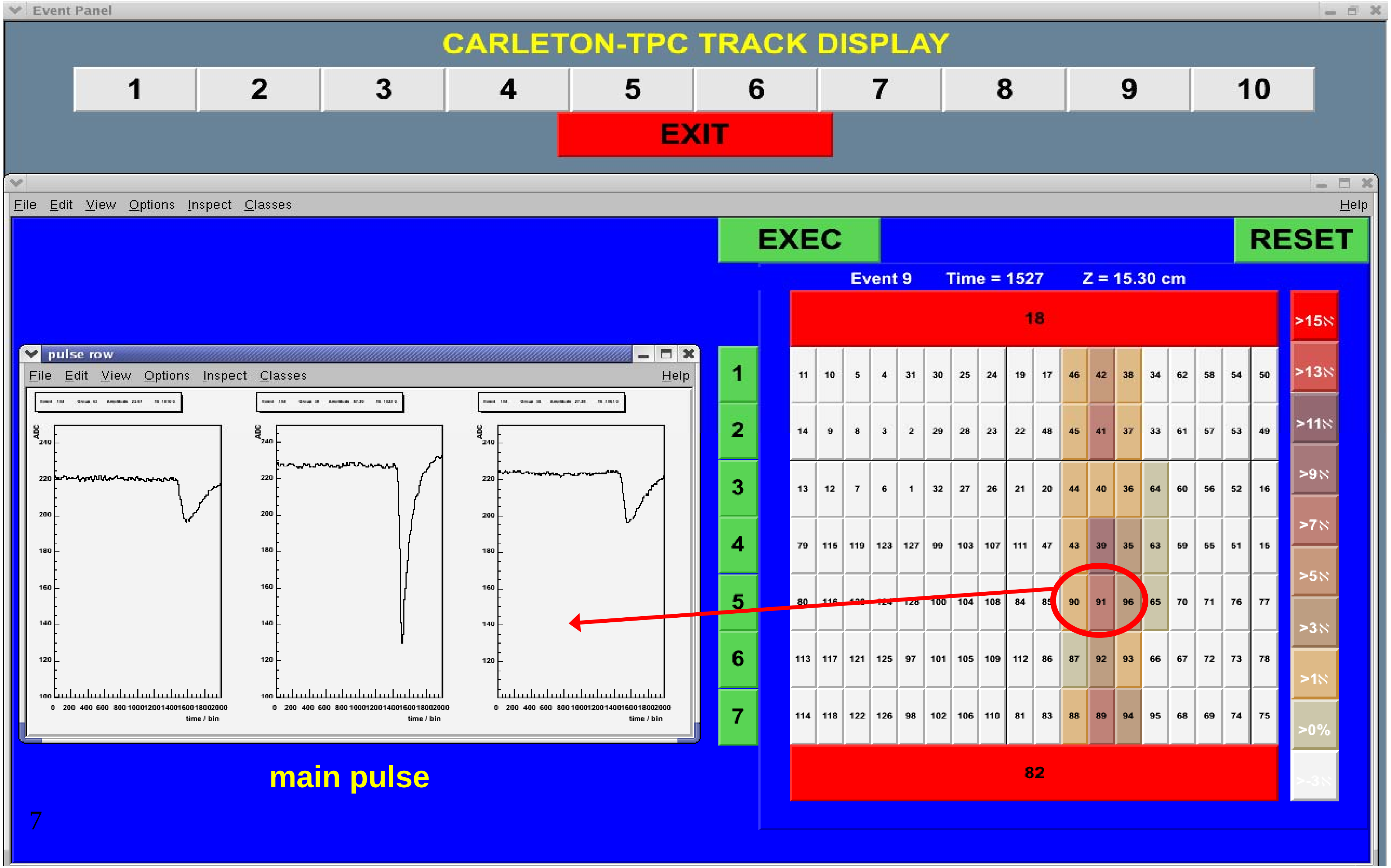
- 4 GeV/c hadrons (mostly πs)
- 0.5 & 1 GeV/c electrons
- Super conducting 1.2 T magnet without return yoke
- Inner diameter : 850 mm
- Effective length: 1 m

Carleton TPC in the beam outside the magnet

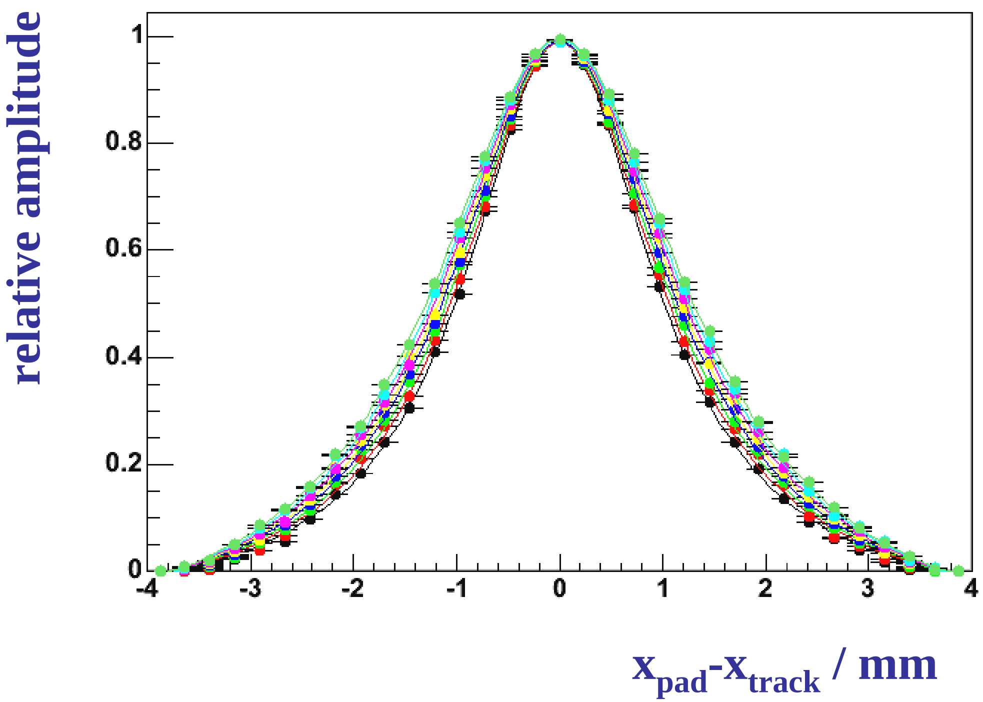
Track display - Ar+5%iC4H10

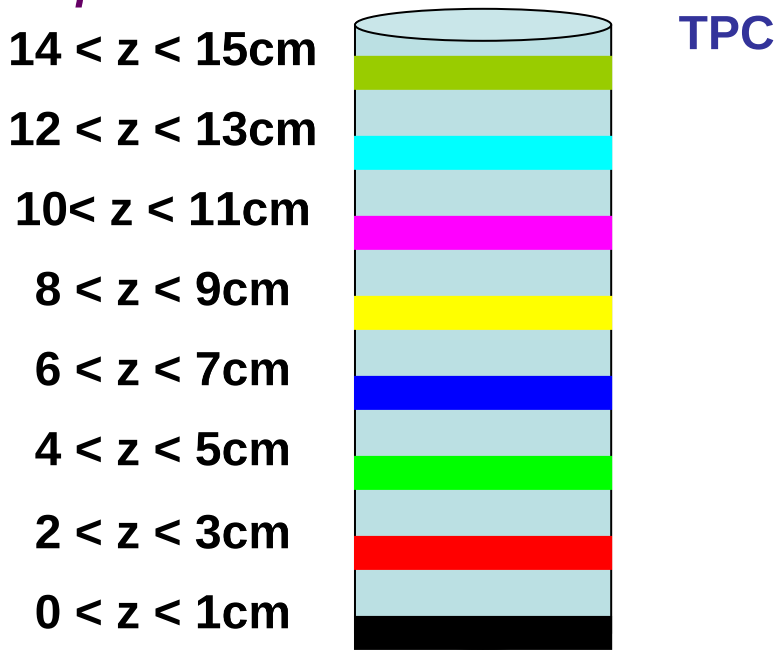
Micromegas 2 x 6 mm² pads B = 1 T

Z_{drift} = 15.3 cm



The pad response function (PRF) - a measure of pad signal as a function of track position





- PRF determined empirically from self consistency of track data.
- PRF parameterized in terms of FWHM Γ & base width Δ

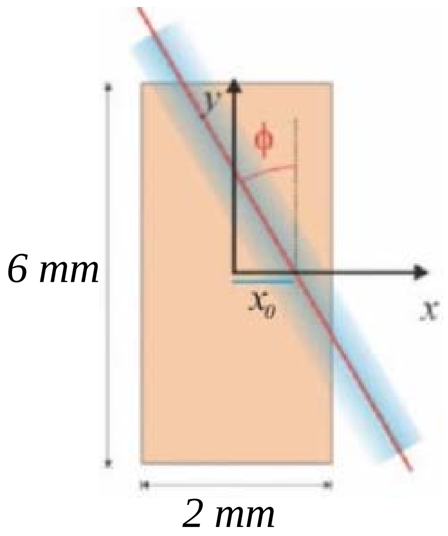
$$PRF[x, \Gamma(z), \Delta, a, b] = \frac{1 + a_2 x^2 + a_4 x^4}{1 + b_2 x^2 + b_4 x^4}$$

M. Dixit

Track fit using the PRF

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

$$\chi^2 = \sum_{rows} \sum_{i=pads} \left(\frac{A_i - PRF_i}{\partial A_i} \right)^2$$

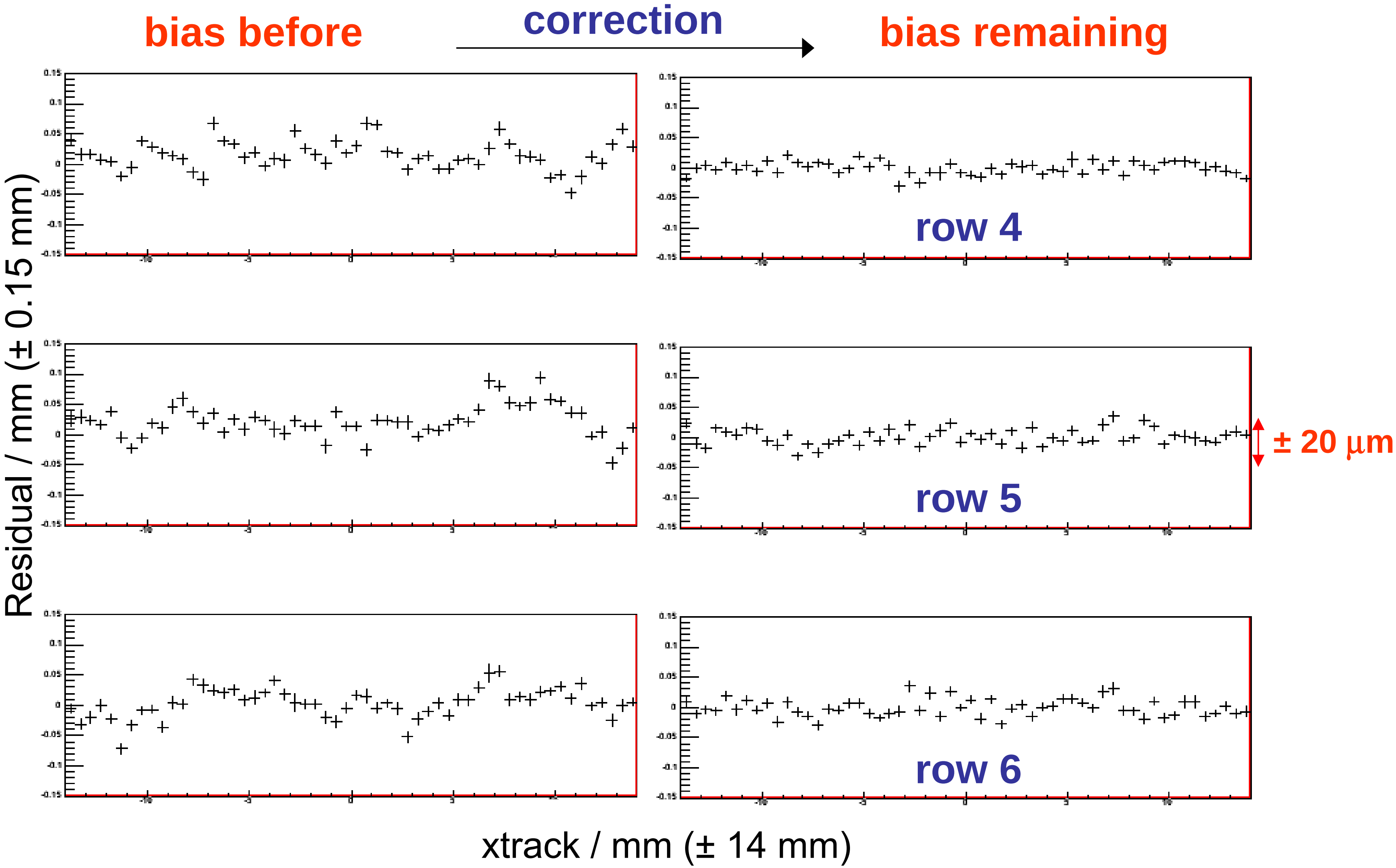


Determine x_0 & ϕ by minimizing χ^2 for the entire event

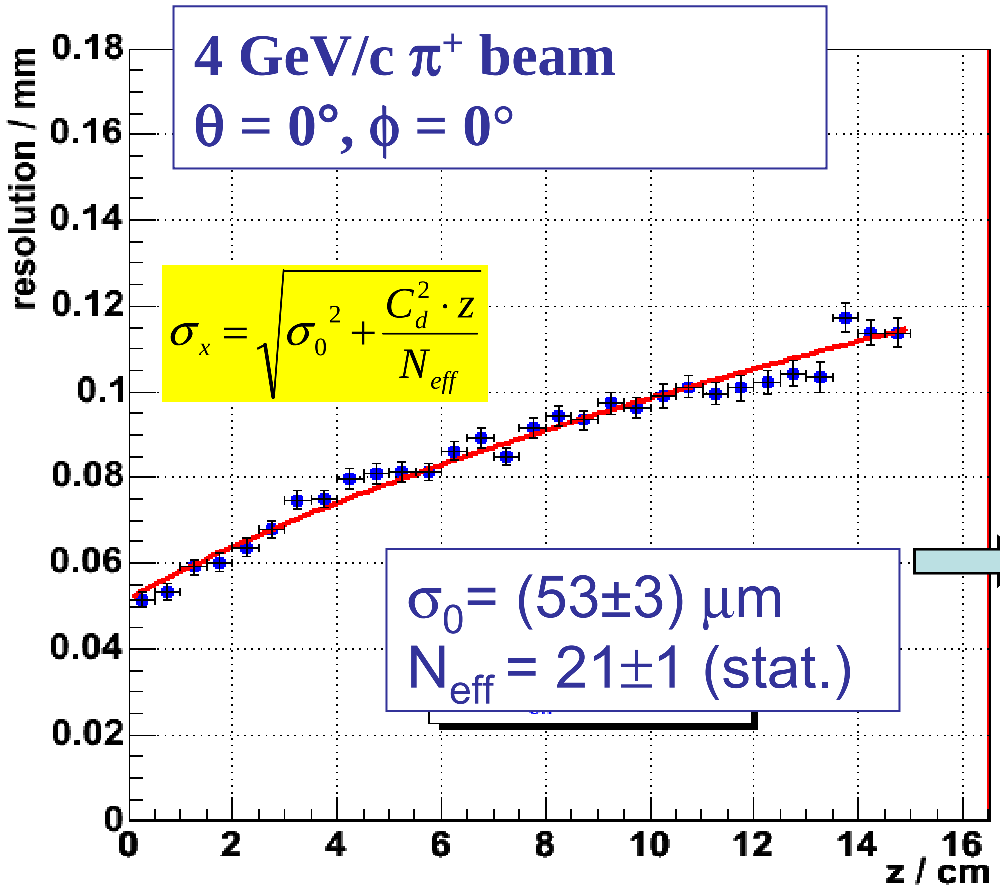
Definitions:

- residual: $x_{row} - x_{track}$
- bias: mean of $x_{row} - x_{track} = f(x_{track})$
- resolution: σ of the residuals

Bias for central rows / Ar+5%iC4H10 B = 1 T



Transverse spatial resolution Ar+5%iC4H10
E=70V/cm D_{Tr} = 125 μm/√cm (Magboltz) @ B= 1T
Micromegas+Carleton TPC 2 x 6 mm² pads



- **Strong suppression of transverse diffusion at 4 T. Examples:**
  D_{Tr}~ 25 μm/√cm (P10)
  ~ 20 μm/√cm (Ar/CF4 97/3)

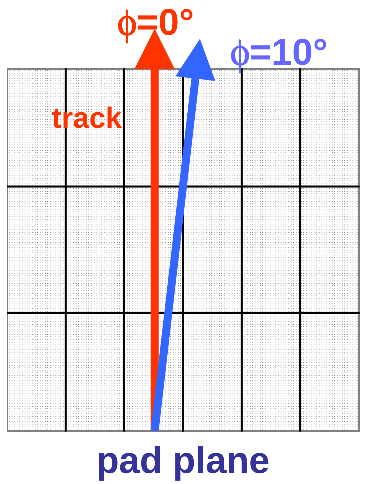
Extrapolate to B = 4T
Use D_{Tr} = 25 μm/√cm
Resolution (2x6 mm² pads)
$\sigma_{Tr} \approx$ 100 μm (2.5 m drift)

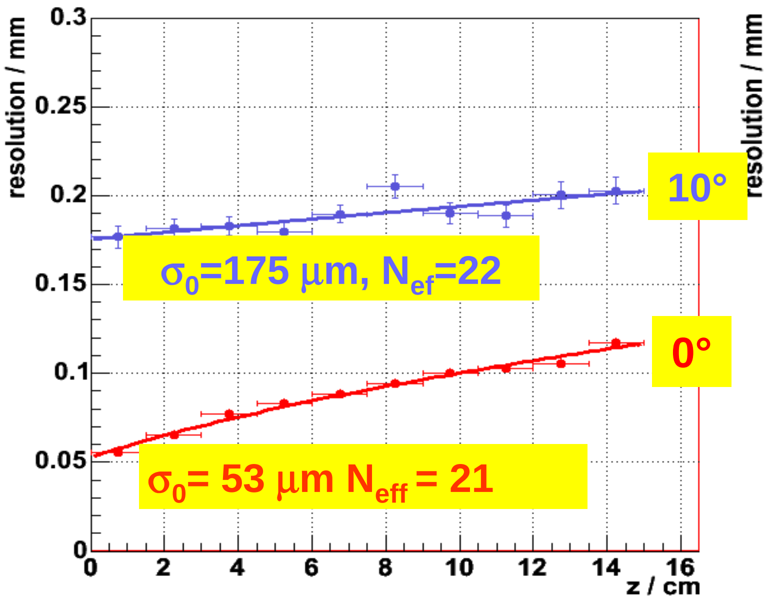
Is extrapolating high-gain 0° Ar/C_4H_{10} data to ILC-TPC operating conditions credible?

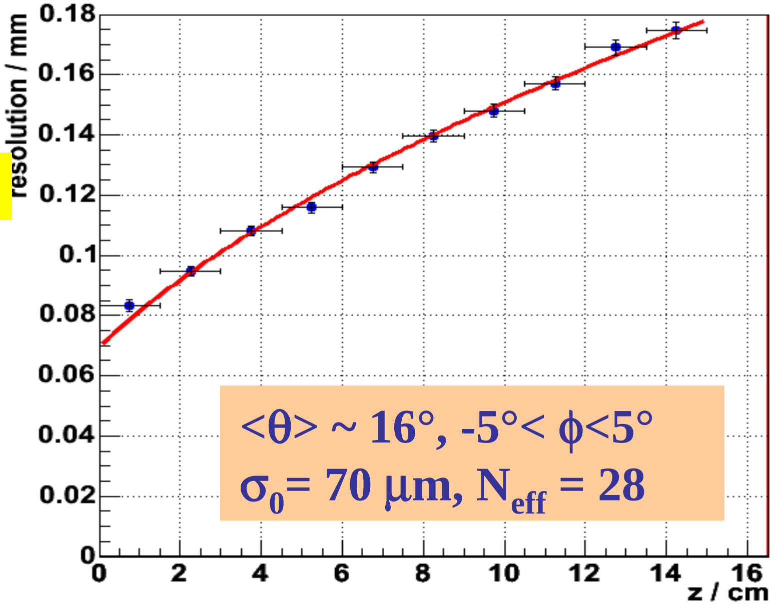
Effect of track angles & gain on resolution

Ar+5%iC4H10 4 GeV/c π^+ beam B = 1 T
2 x 6 mm² pads <u>Gain ~ 8000</u>

Ar+10%CO2, Cosmics, B = 0 T
2 x 6 mm² pads, <u>Gain ~ 3500</u>



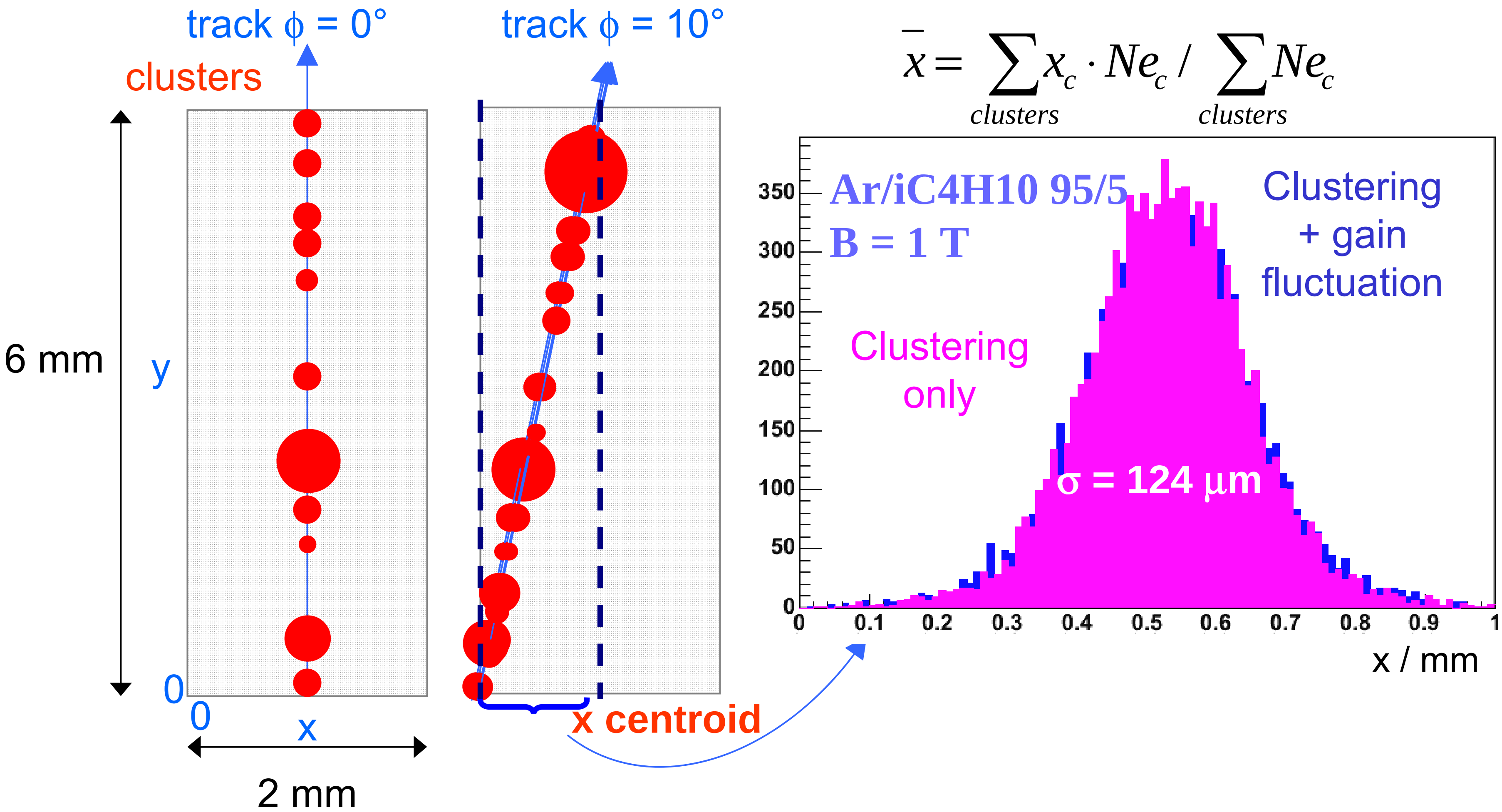




Gain for Ar/C4H10 was ~ 2 times larger than for ArCO2

Significantly worse σ_0 for 10° tracks for Ar/C4H10 than 0°

Track angle effect is mostly due to clustering



-For angled tracks, y centroid wanders due to ionization clustering.

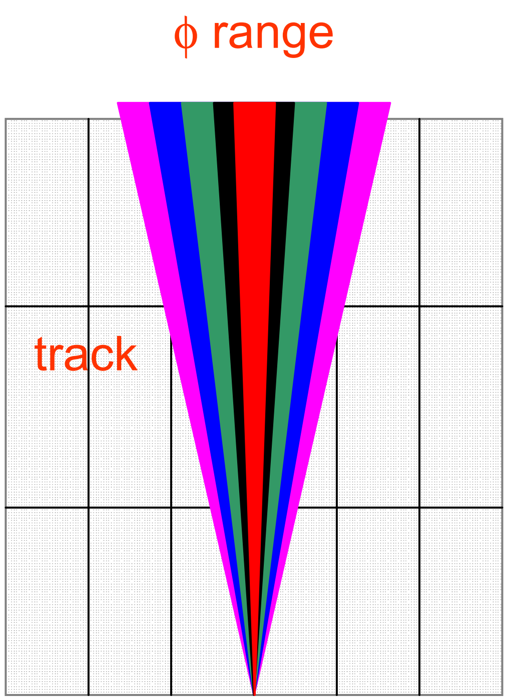
-y centroid movement affects x centroid position.

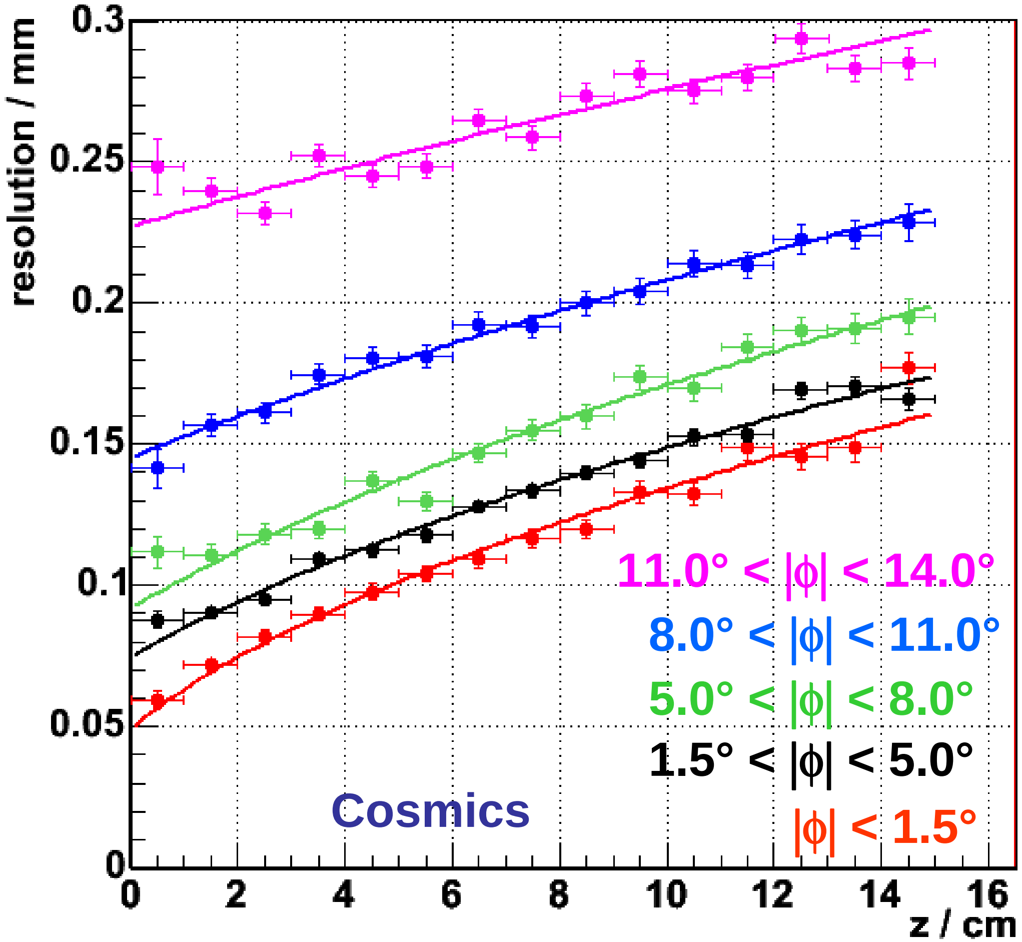
To the track angle effect, one must add $\sigma_0 \approx 50\ \mu m$ for noise & systematics

Re-analyze Ar/CO_2 90/10 cosmic ray data for track angles

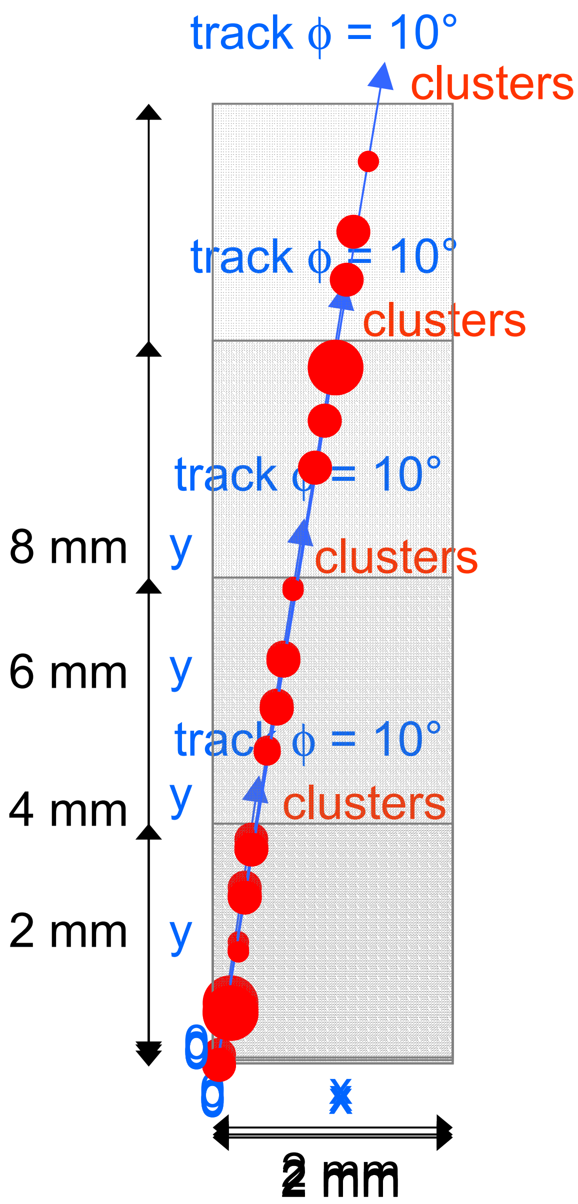
2 x 6 mm² pads, D_{Tr} =223 μm/√cm B = 0 T

For |ϕ| < 1.5° σ_0= 50 μm! Gain ~ 2 times lower than Ar/C_4H_{10}
Track angle effect similar to that observed for Ar/C_4H_{10}



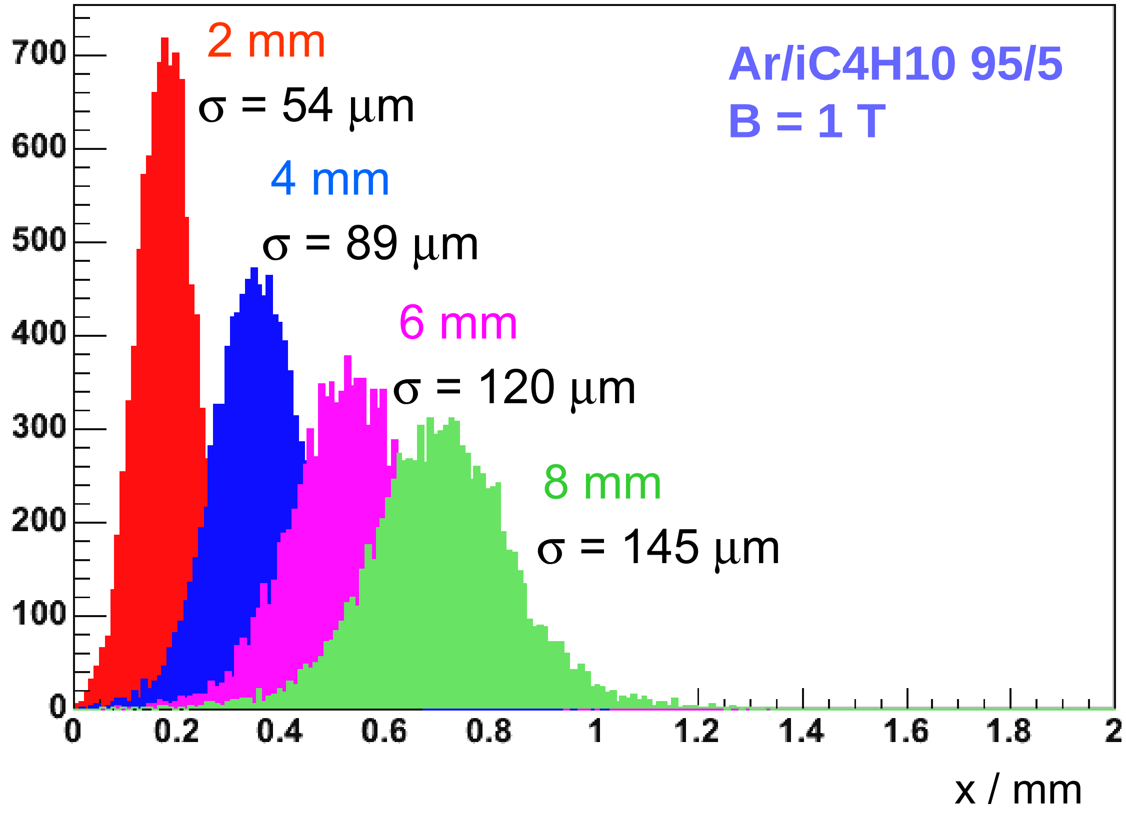


Track angle effect will be smaller for shorter pads



For longer pads, this can be accomplished effectively by segmenting the cathode into ~ 2 mm width strips in y.

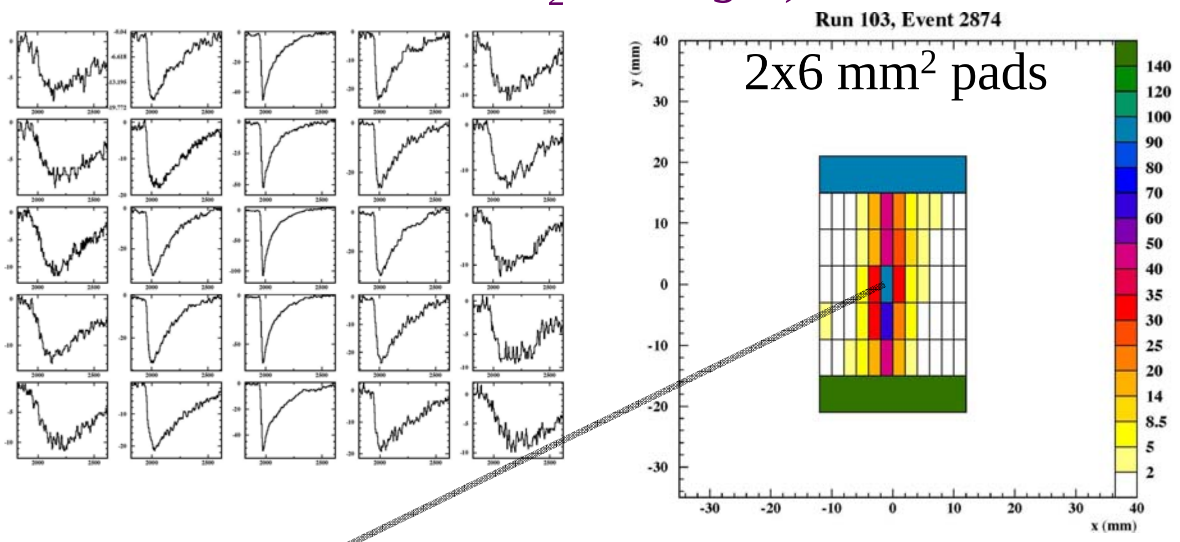
$$\bar{x} = \sum_{clusters} x_c \cdot Ne_c \,/ \sum_{clusters} Ne_c$$

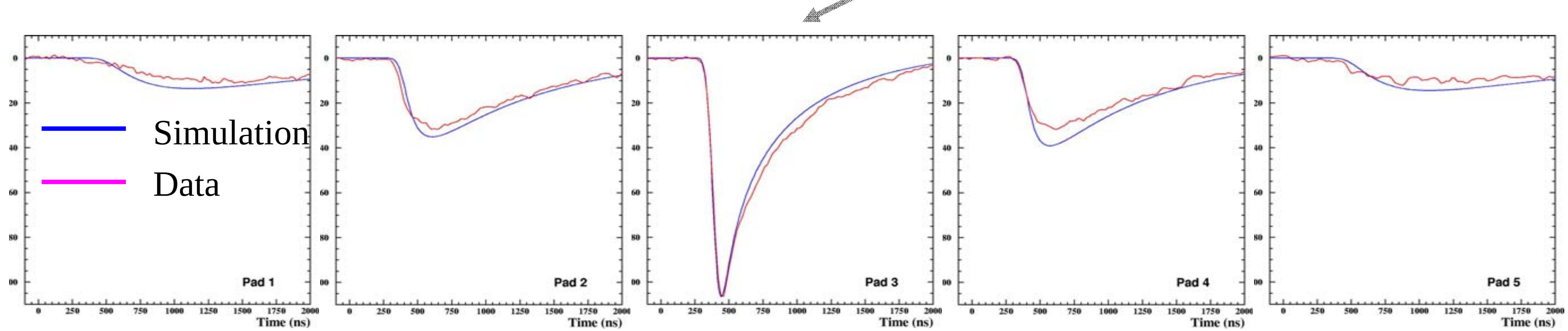


First principles TPC simulation (stand alone) Cosmic track with charge dispersion - GEM TPC

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

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

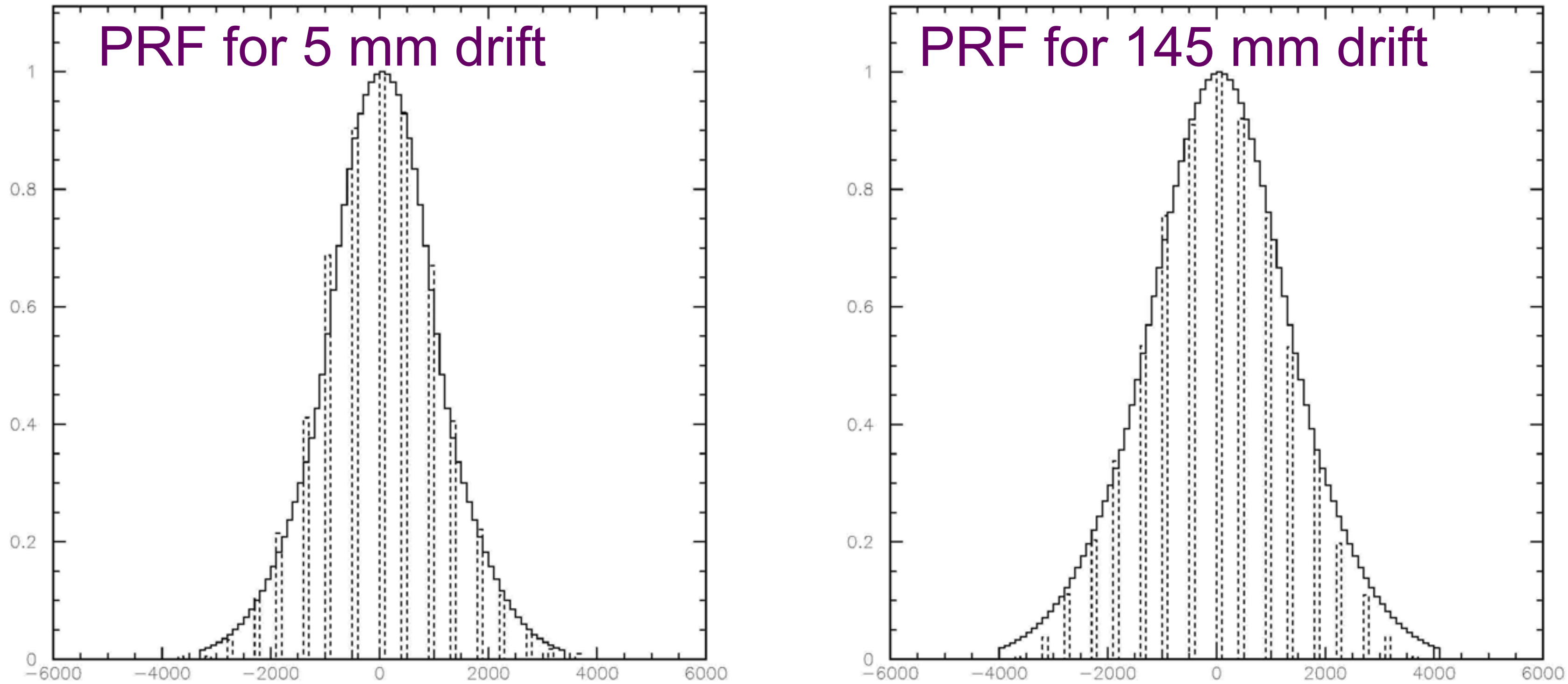




Centre pad amplitude used for normalization - no other free parameters.

Micromegas -TPC track PRF (histogram) versus PRF determined experimentally (------- lines)

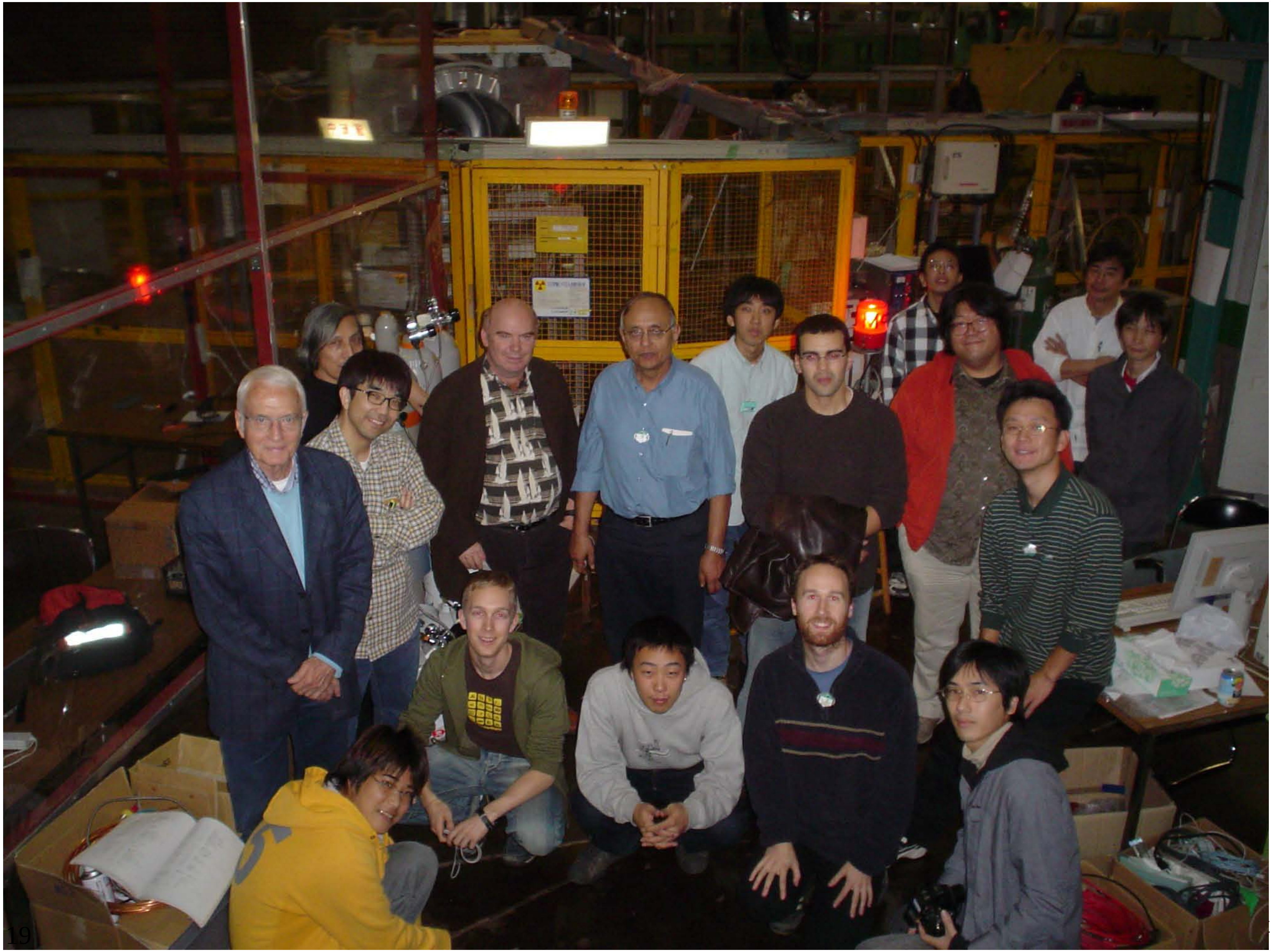
Ar/CO_2 90/10 V_{drift} = 22.8 μm/ns D_{Tr}=223 μm/$\sqrt{\text{cm}}$ D_L=263 μm/$\sqrt{\text{cm}}$



Resistivity = 1000 kΩ/☐, Dielectric spacer thickness = 50 μm, K = 4
Intrinsic Micromegas pulse risetime = 50 ns
Aleph preamp rise time = 37 ns, Fall time = 1980 ns

Summary & outlook

- Successful demonstration of charge dispersion readout concept for the MPGD-TPC in a magnetic field in a beam test.
- σ_0~ 50 μm in Ar/C_4H_{10} 95/5 with 2x6 mm^2 pads at B=1 T for 4 GeV/c pions.
- No loss of performance for Ar/CO_2 90/10 for cosmic rays at B = 0 T at lower gain.
- Track angle effect ~ 20 μm for 100 mR tracks possible with cathode segmentation in y as 2 mm wide strips.
- Extrapolation of Ar/C_4H_{10} results to ILC-TPC should be valid.
- Charge dispersion works with GEMs and Micromegas both. The ILC-TPC resolution goal of ~100 μm with 2 mm x 6 mm pads for all tracks appears feasible.
- Charge dispersion phenomena well understood. Stand alone simulation will be incorporated into GEANT4 framework.
- 4 T cosmic tests at DESY this year. Two track resolution tests at Fermilab planned for next year.

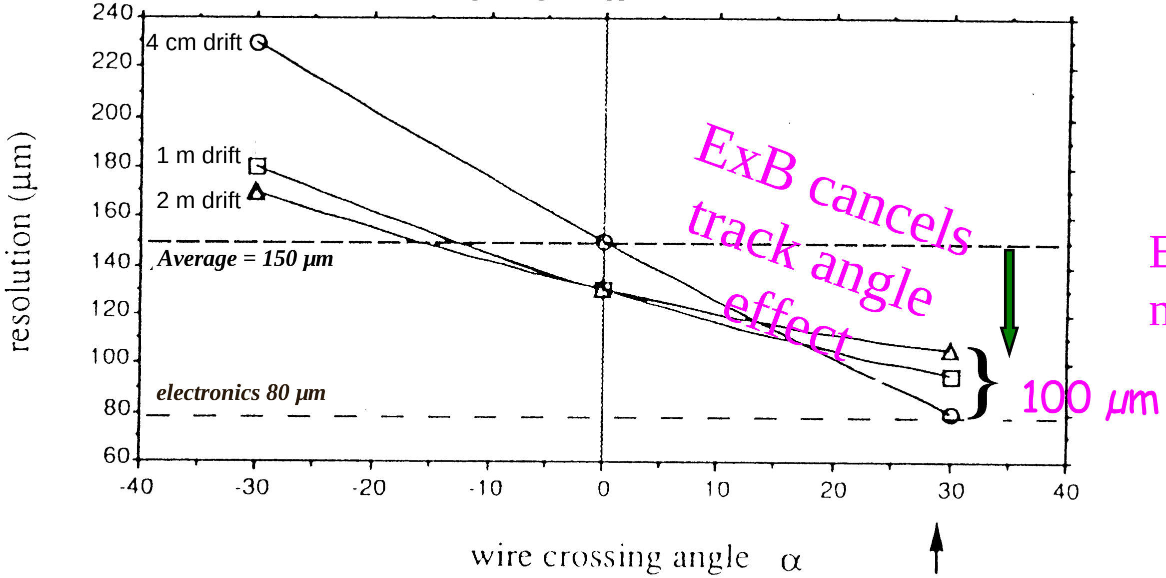


Additional slides

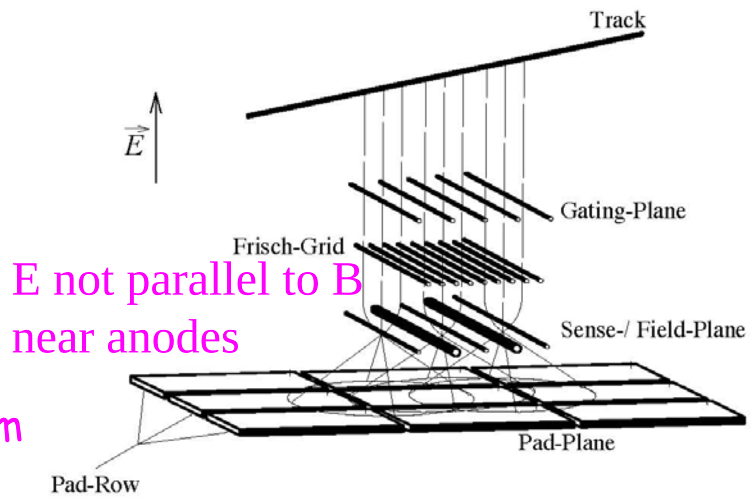
When there is no ExB effect, the wire/pad TPC resolution approaches the diffusion limit for the Aleph TPC

S.R. Amendolia et al. / The spatial resolution of the ALEPH TPC
Nuclear Instruments and Methods in Physics Research A283 (1989) 573–577
North-Holland, Amsterdam

ExB and wire crossing angle effects dominate TPC resolution



TPC wire/pad readout



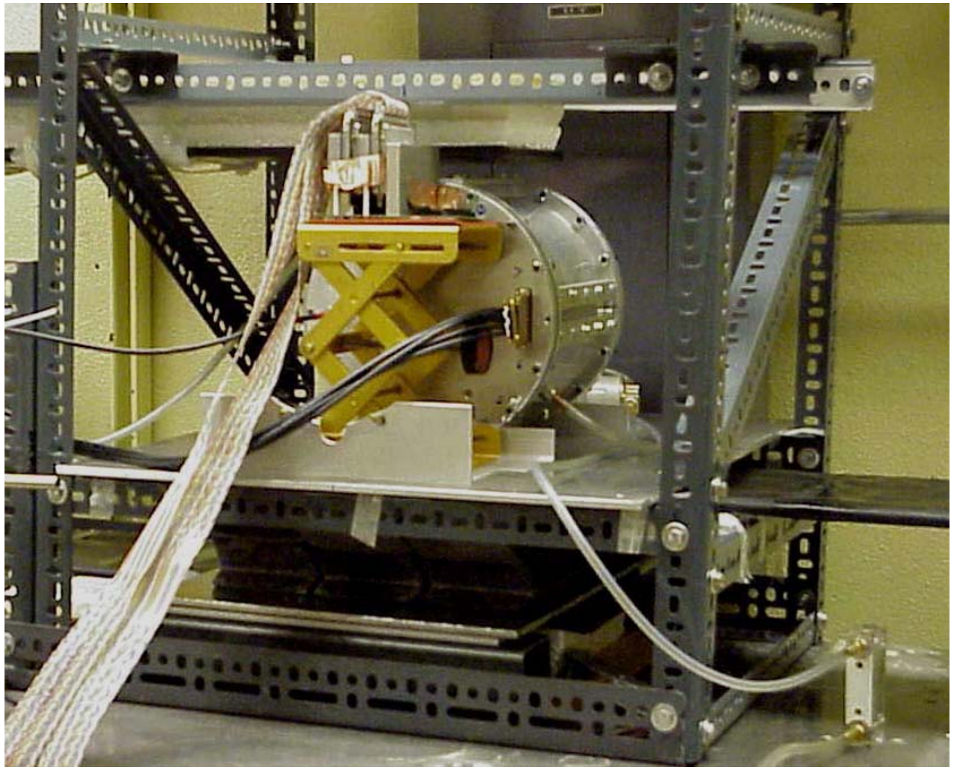
Average Aleph resolution ~ 150 µm.
Resolution ~ 100 µm even for 2 m drift.
Limit from diffusion σ (10 cm drift) ~ 15 µm; σ (2 m drift) ~ 60 µm.

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 in a magnetic field.
- Aleph charge preamps.

τ_{Rise}= 40 ns, τ_{Fall} = 2 μs.

- 200 MHz FADCs rebinned to digitization effectively at 25 MHz.
- 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.

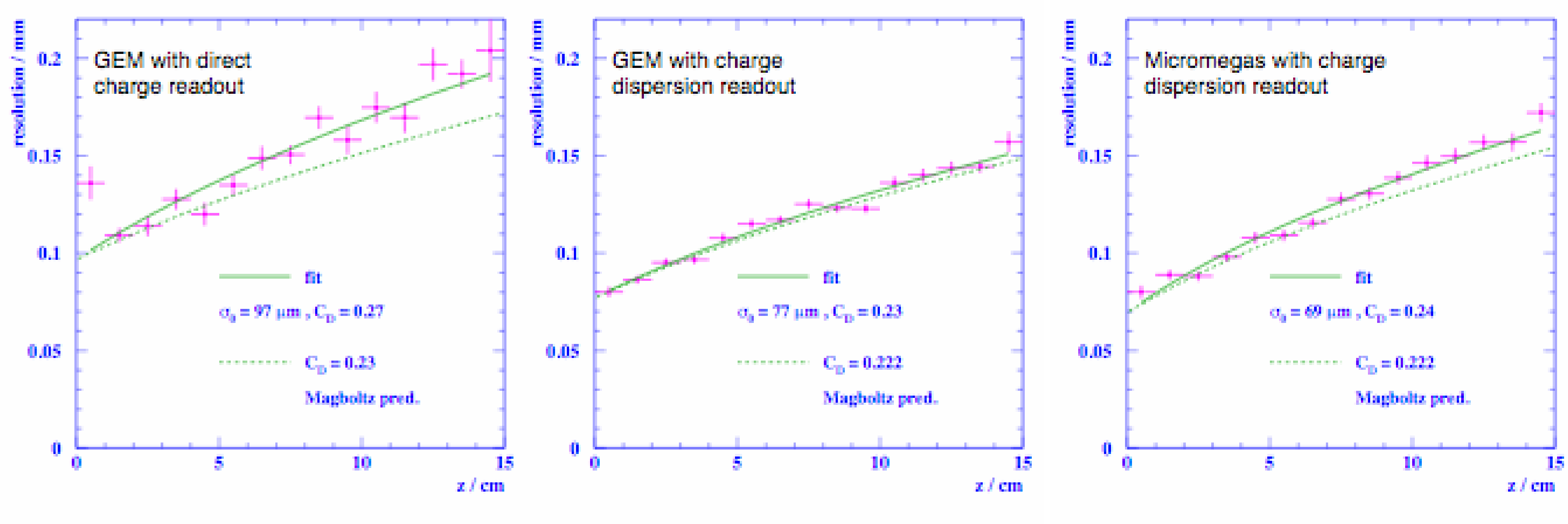
The resolution was next measured with a charge dispersion resistive anode readout with a double-GEM & with a Micromegas endcap.

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

Unpublished



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.