Test beam performance of MPGD-TPC readout concept of charge dispersion in a magnetic field

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IISc

Tracking

Madhu Dixit ***Carleton University & TRIUMF***

Canada	**A.Bellerive, K.Boudjemline, J.Miyamato, E.Neuheimer, E.Rollin, K.Sachs &Y.Shin**	***Carleton University***
	J.-P. Martin	***University of Montreal***
France	**D.Burke, P.Colas, A.Giganon & I.Giomataris**	***DAPNIA CEA Saclay***
	V.Lepeltier & Th.Zerguerras	***LAL Orsay***
Germany	**R. Settles**	***MPI (Munich)***
Japan	**H.Kuroiwa & T.Takahashi**	***Hiroshima University***
	K.Fujii, M.Kobayashi, T.Matsuda & H.Yamaoka	***KEK/IPNS***
	Y.Kato	***Kinnki University***
	T.Watanabe	***Kogakuin University***
	T.Araki, H.Fujishima, T.Higashi, , K.Kodomatsu, A.Sugiyama, T.Yamamoto & Y.Tanaka	***Saga University***
	A.Yamaguchi	***Tsukuba University***
	M.Habu, S.Matsushita, K.Nakamura & O.Nito	***Tokyo University of Agriculture &Technology***

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:

1) Under consideration - narrower 1 mm x 6 mm pads (3 x 10^6 total). R&D issues: High density electronics, increased heat load, TPC endcap mass etc.
2) Alternative: Disperse avalanche charge to improve resolution for 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.
   - International collaboration to test the concept in a magnet.
   - 1 T superconducting magnet & 4 GeV/c hadron test beam at KEK PS.
   - Two TPCs: Multi Technology Test TPC - MT3 TPC (MPI Munich) + Carleton TPC with Micromegas (Saclay) & GEMs(Saga University).
   - Two weeks of beam data in October2005.

- First results on magnetic field performance of MPGD-TPC with charge dispersion readout in a test beam reported here.

TPC resolution should only be limited by transverse diffusion

•The physics limit of TPC resolution comes from transverse diffusion:

$$\sigma_x^{\ 2} \approx \frac{D_{Tr}^2 \cdot z}{N_{eff}}$$

N_{eff} = effective electron statistics.

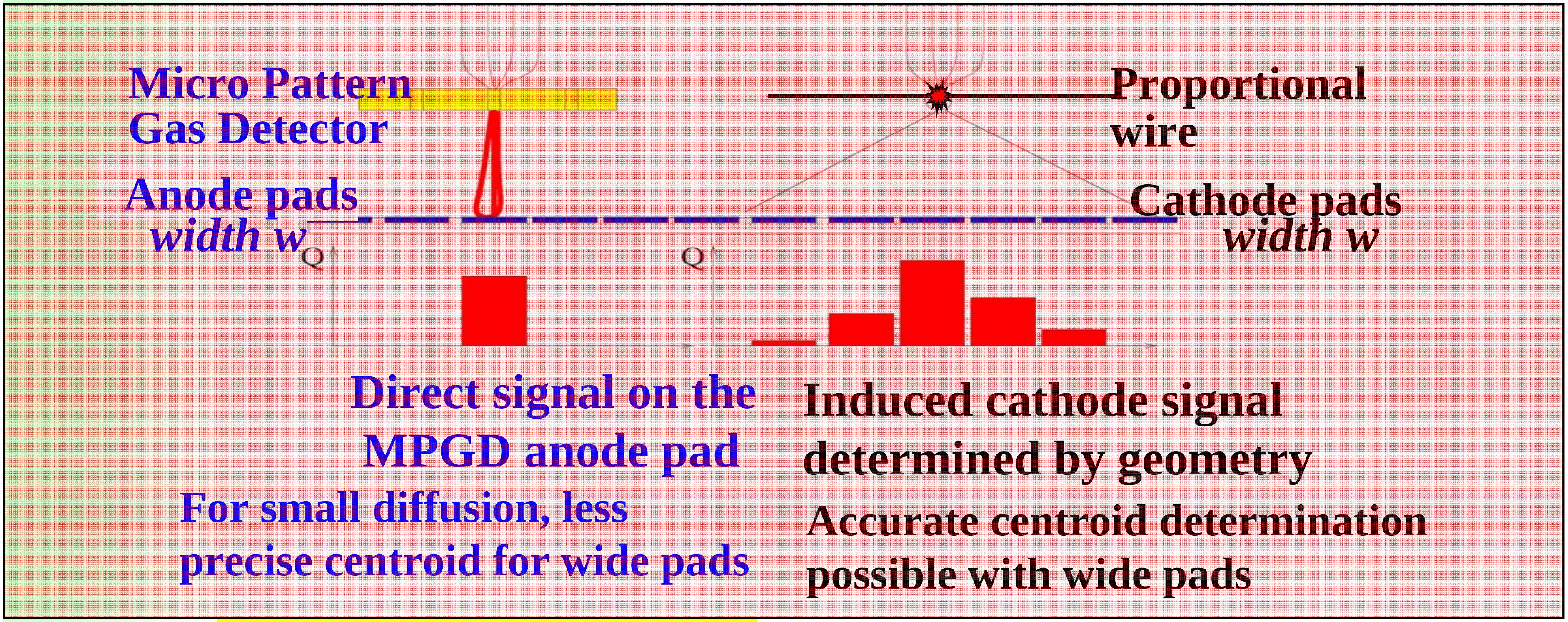
•For best resolution, choose a gas with smallest diffusion. Applicable to the wire TPC which uses induced cathode pad signals for position determination. Main factors limiting wire TPC resolution are the **ExB** & track angle systematic effects.

•There is no **ExB** effect to limit the MPGD-TPC. But also no induced pad signals for precise position determination. The MPGD-TPC resolution is limited by pad width & gets worse for smaller diffusion.

$$\sigma_x^{\ 2} \Rightarrow \frac{w^2}{12} \ \ as\ z \Rightarrow 0$$

Charge dispersion - a pad signal induction mechanism to make position determination insensitive to pad width.

Pad width limits the MPGD-TPC resolution
ExB angle effects limit the wire/pad TPC resolution



$$\sigma_x^{\ 2} \approx \sigma_0^{\ 2} + \frac{1}{N_{eff}}\left[D_{Tr}^2 z + w^2/12\right]$$

$$\sigma_x^{\ 2} \approx \sigma_0^{\ 2} + \frac{D_{Tr}^2 \cdot z}{N_{eff}}$$

$N_{eff} \neq \langle N \rangle$ (average no. of electrons) $\sim 1/\langle 1/N \rangle$

Gain fluctuations affect N_{eff}, the effective number of electrons.

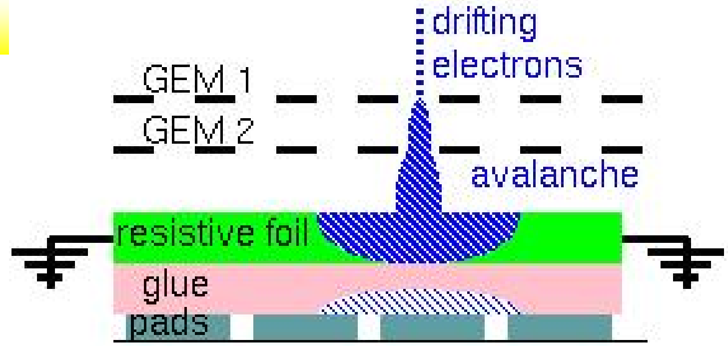
Charge dispersion in a MPGD with a resistive anode

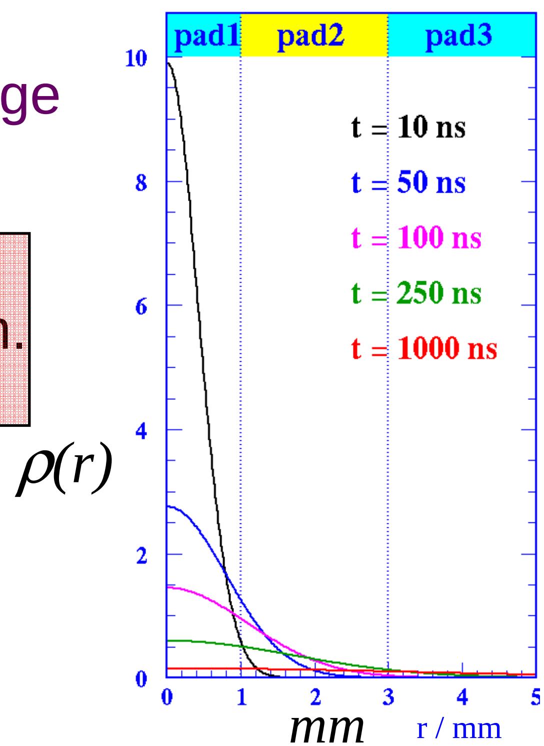
- Modified MPGD anode with a high resistivity film bonded to a readout plane with an insulating spacer.
- 2-dimensional continuous RC network defined by material properties & geometry.
- Point charge at *r = 0 & t = 0* disperses with time.
- Time dependent anode charge density sampled by readout pads.

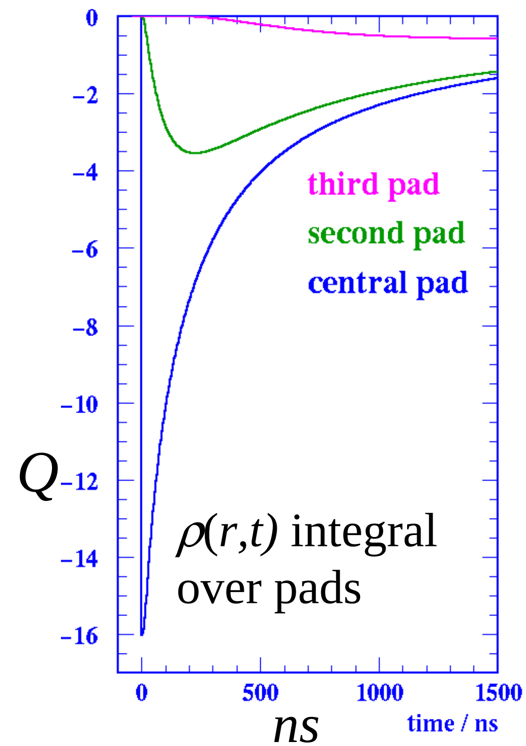
Equation for surface charge density function on the 2-dim. continuous RC network:

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

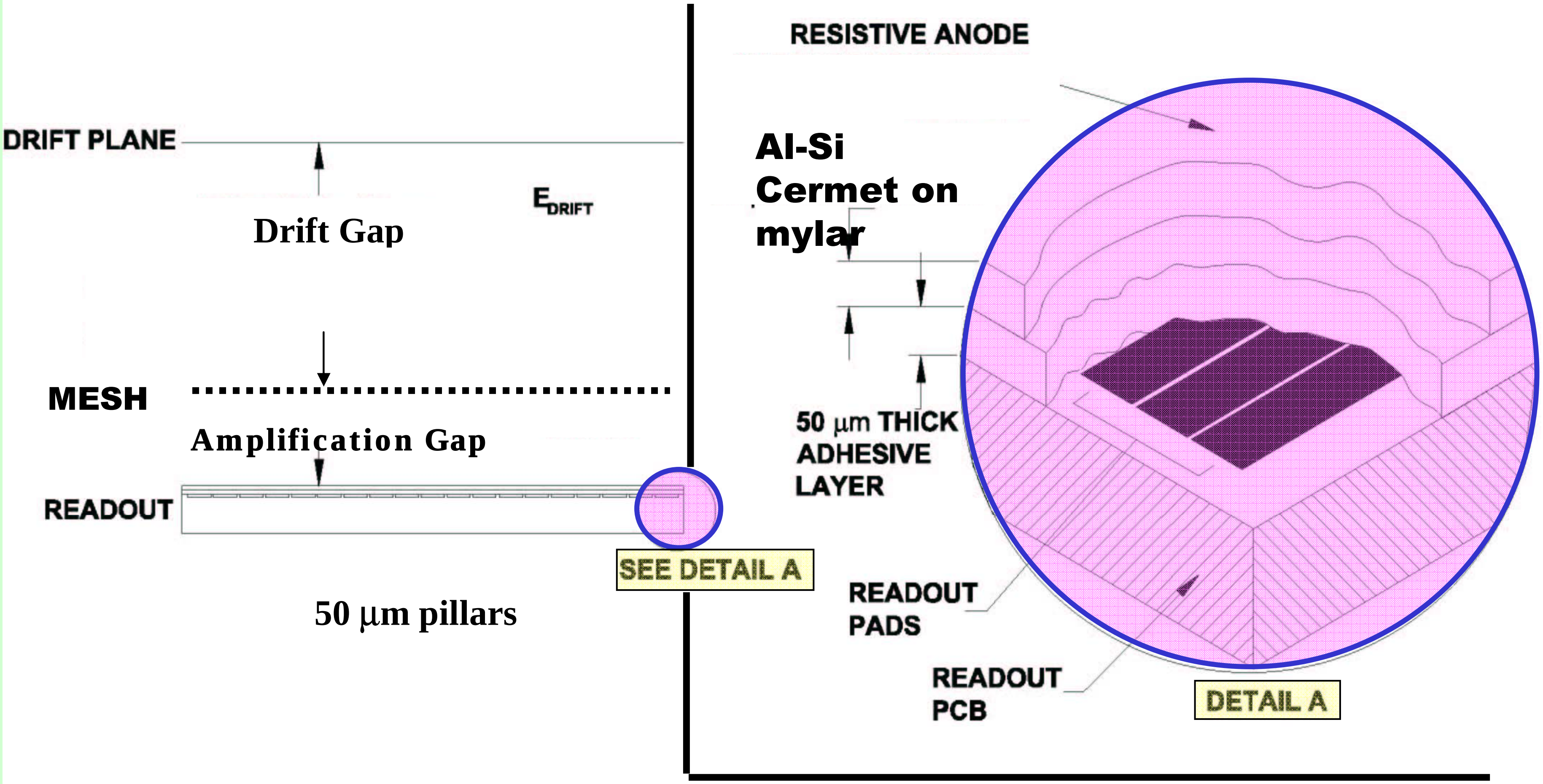
$$\Rightarrow \rho(r,t) = \frac{RC}{2t} e^{\frac{-r^2 RC}{4t}}$$



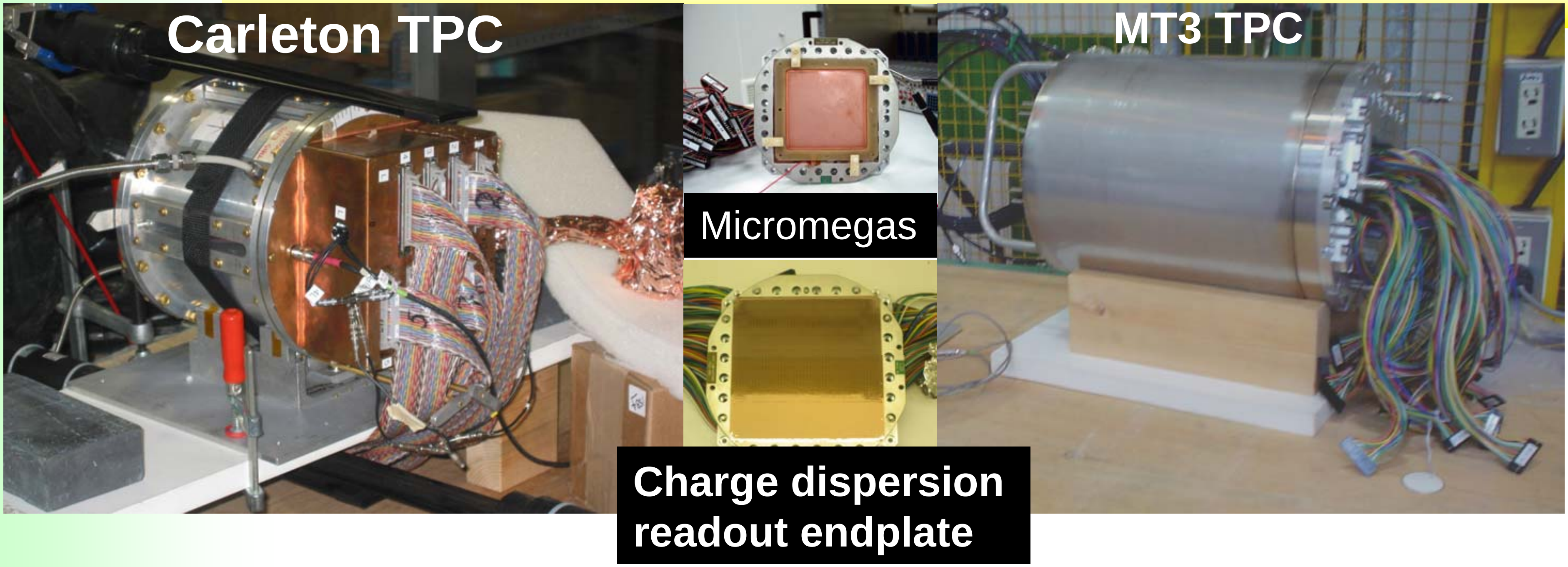




Micromegas with a resistive anode for the charge dispersion readout



The two beam test TPCs

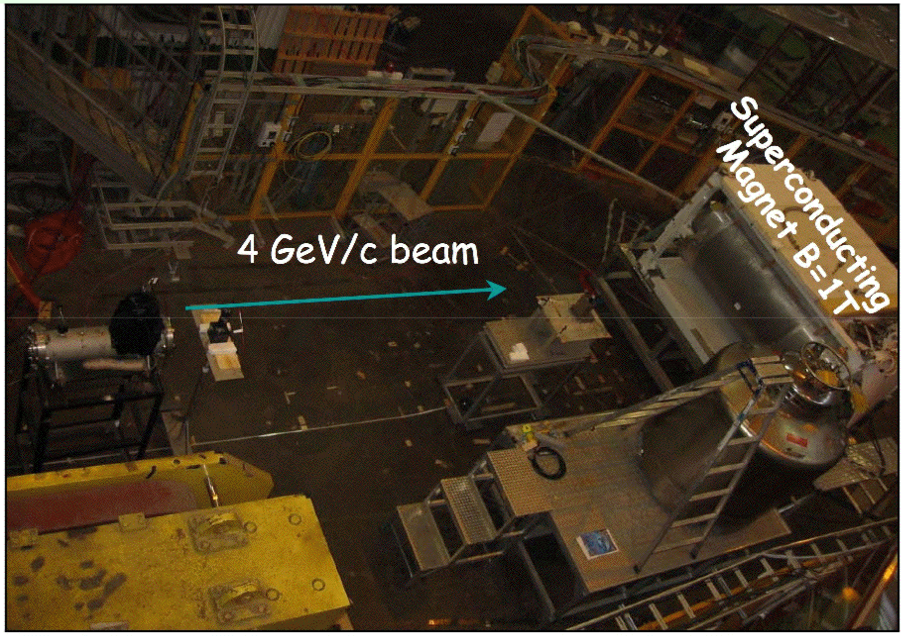


- Micromegas 10 x10 cm^2
- Drift distance: 16 cm
- 126 pads, 2 x 6 mm^2 each in 7 rows
- ALEPH preamps + 200 MHz FADCs rebinned to 25 MHz equivalent FADCs

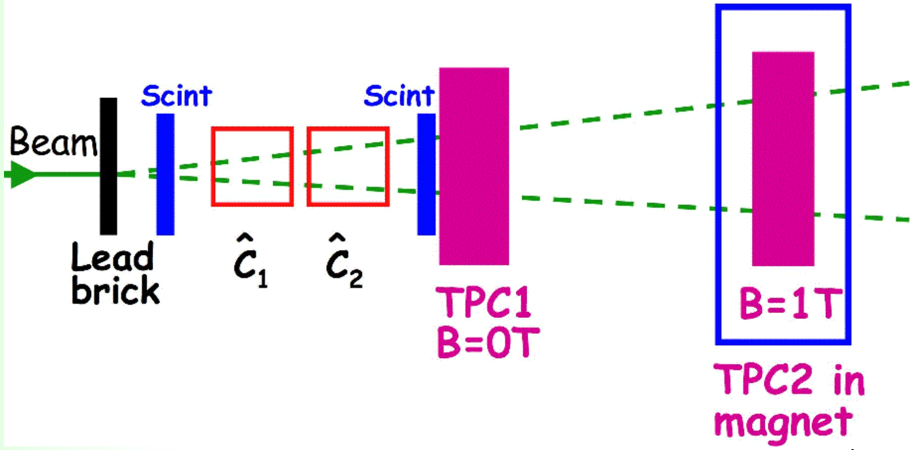
- Micromegas & GEMs 10 x10 cm^2
- Drift distance 25.9 cm
- 384 pads 2.3 x 6.3 mm^2 each in 16 rows
- ALEPH preamps + 11 MHz Aleph Time Projection Digitizers

KEK PS π2 test beam set up with Carleton & MT3 TPCs

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



- 4 GeV/c hadrons (mostly π s)
- 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

The pad response function (PRF)

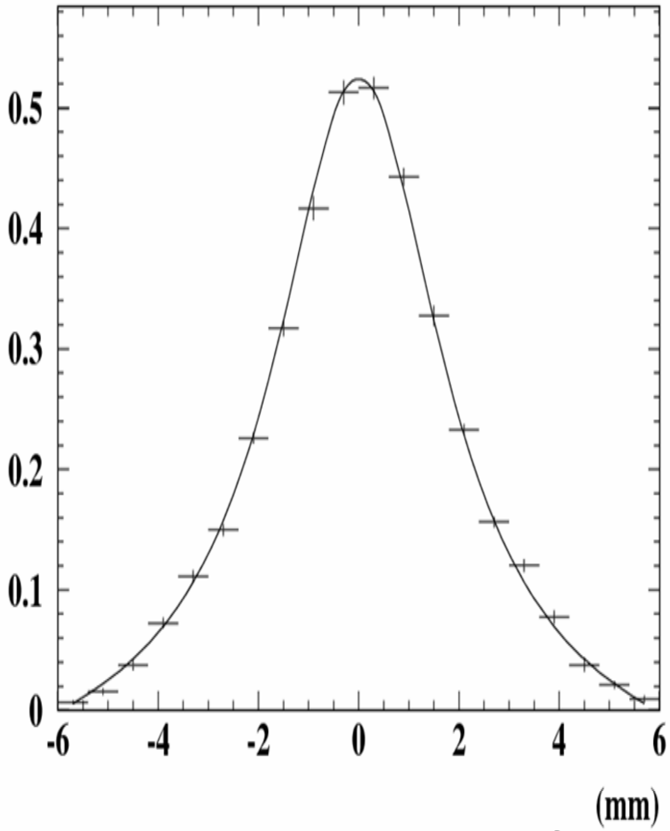
- PRF - a measure of pad signal as a function of track position.
- PRF determined empirically from track data itself.
- PRF parameterization:

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

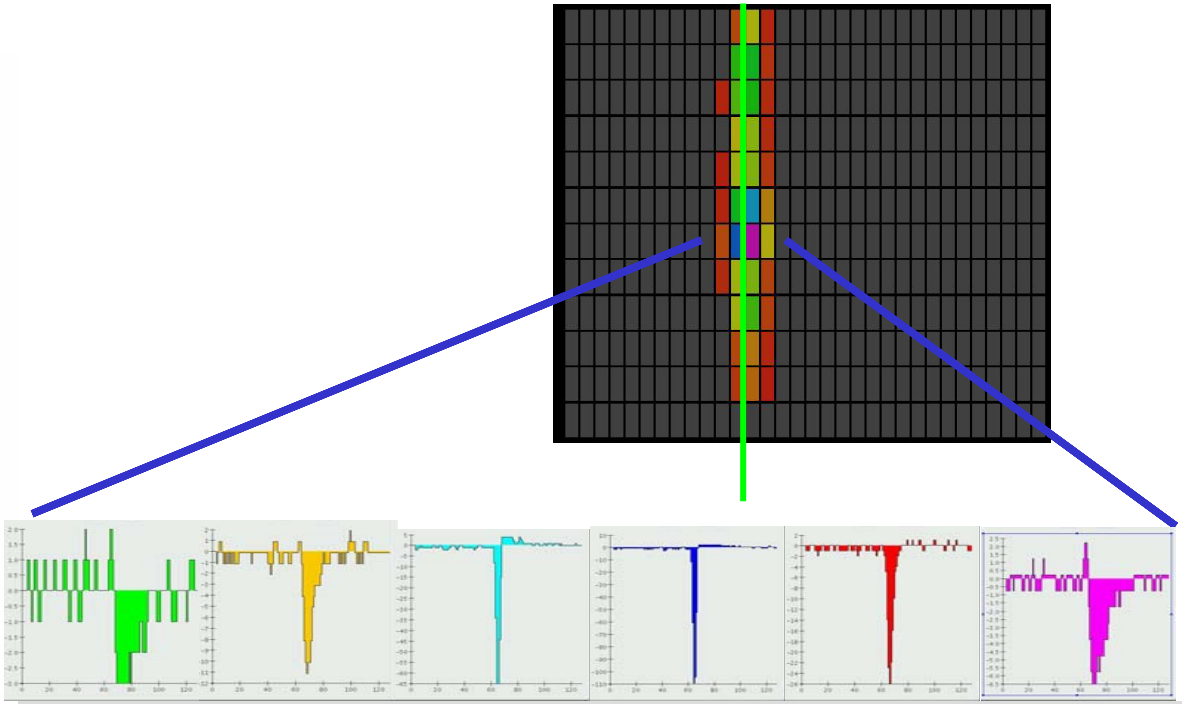
- Parameters functions of FWHM Γ & Δ the base width.
- Position determined from the PRF fit has bias.
- The bias correction is determined from calibration.

MT3 TPC event display + Micromegas read out with Aleph TPDs 2.3 x 6.3 mm² pads Ar+5%iC4H10

E=220V/cm D_{Tr}=193 μm/√cm @ B= 1T



Example pad response function



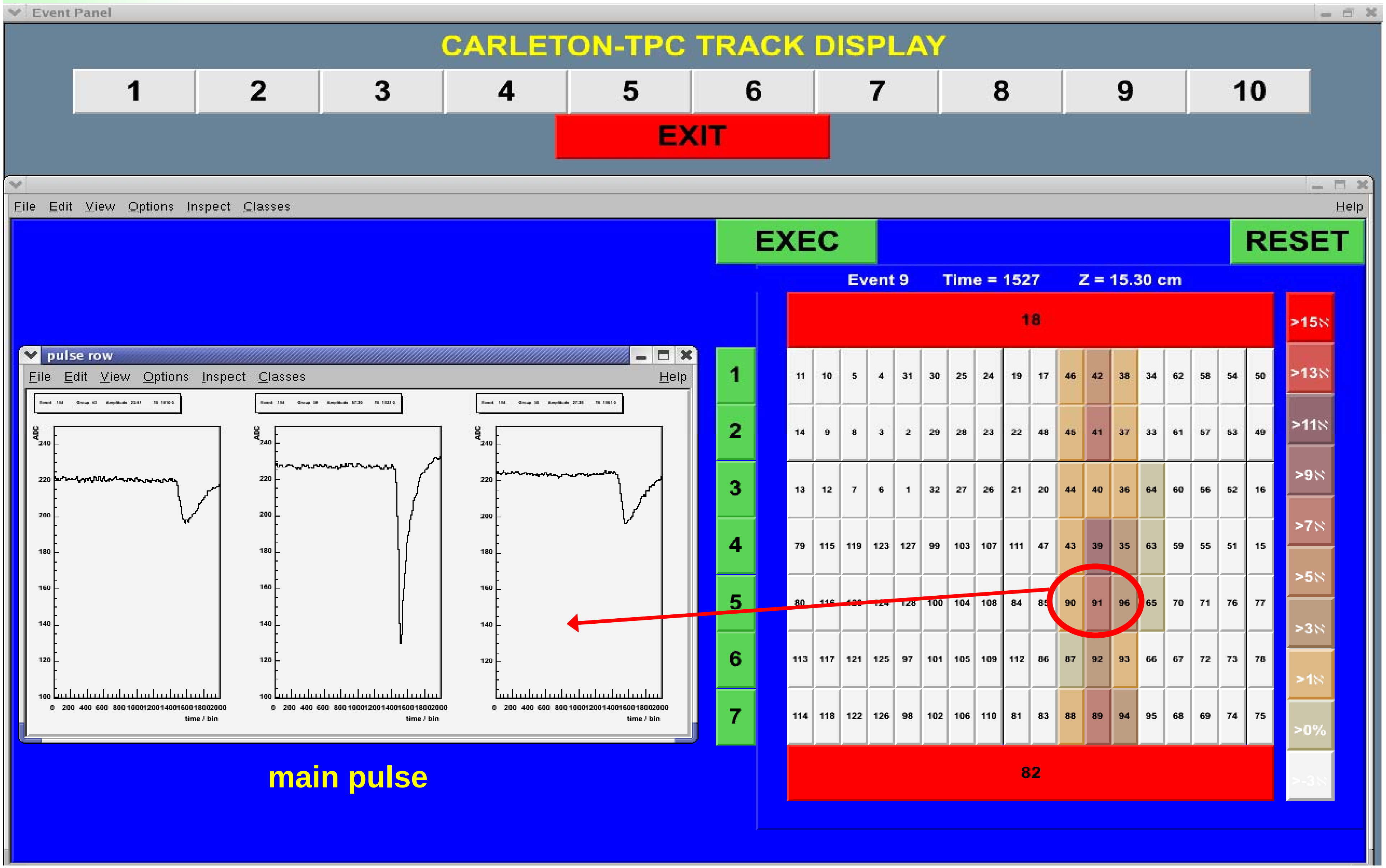
spreading of charge due to foil can be seen across six pads

Data analysis is in progress

Track display - Ar+5%iC4H10

Micromegas 2 x 6 mm^2 pads B = 1 T

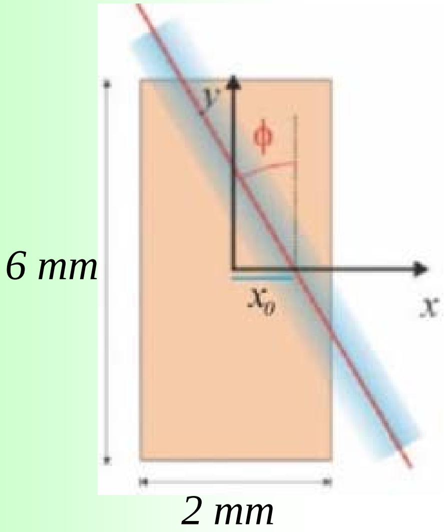
Z_{drift} = 15.3 cm



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

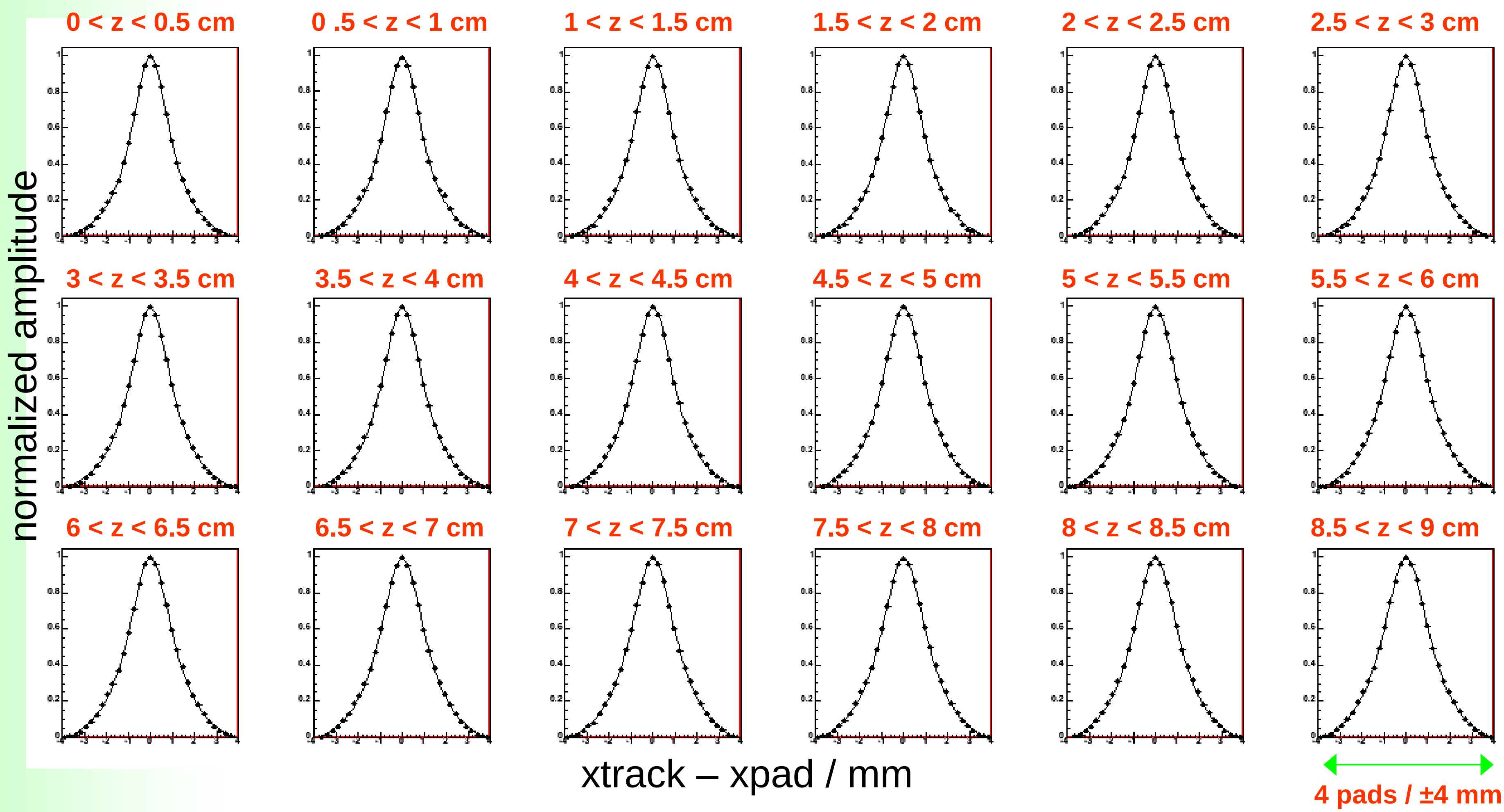
Bias = Mean of residuals (x_{row}-x_{track}) as a function of x_{track}

Resolution = σ of track residuals

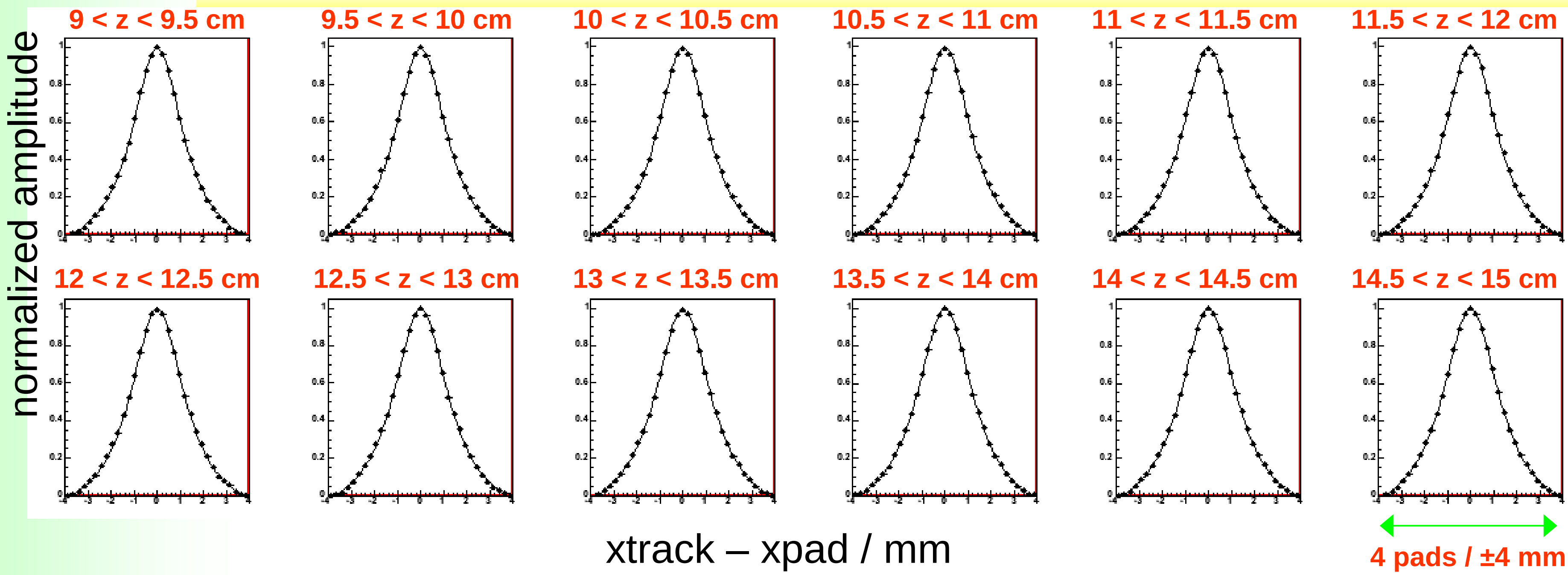
Pad Response Function / Ar+5%iC4H10

Micromegas+Carleton TPC 2 x 6 mm^2 pads, B = 1 T

30 z regions /
0.5 cm step

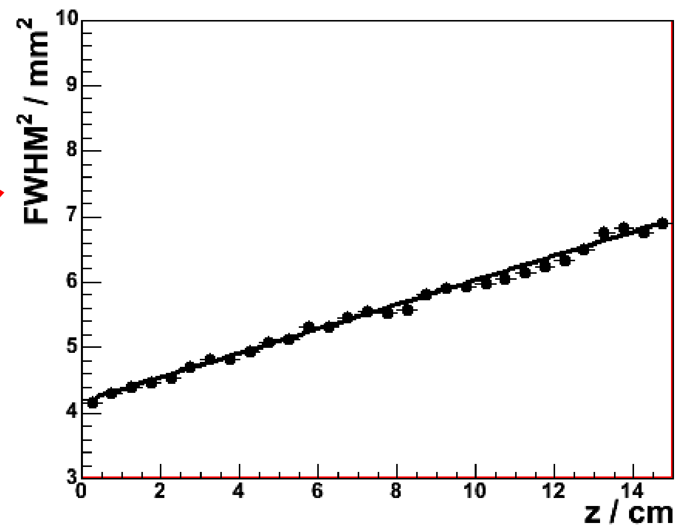


Pad Response Function / Ar+5%iC4H10



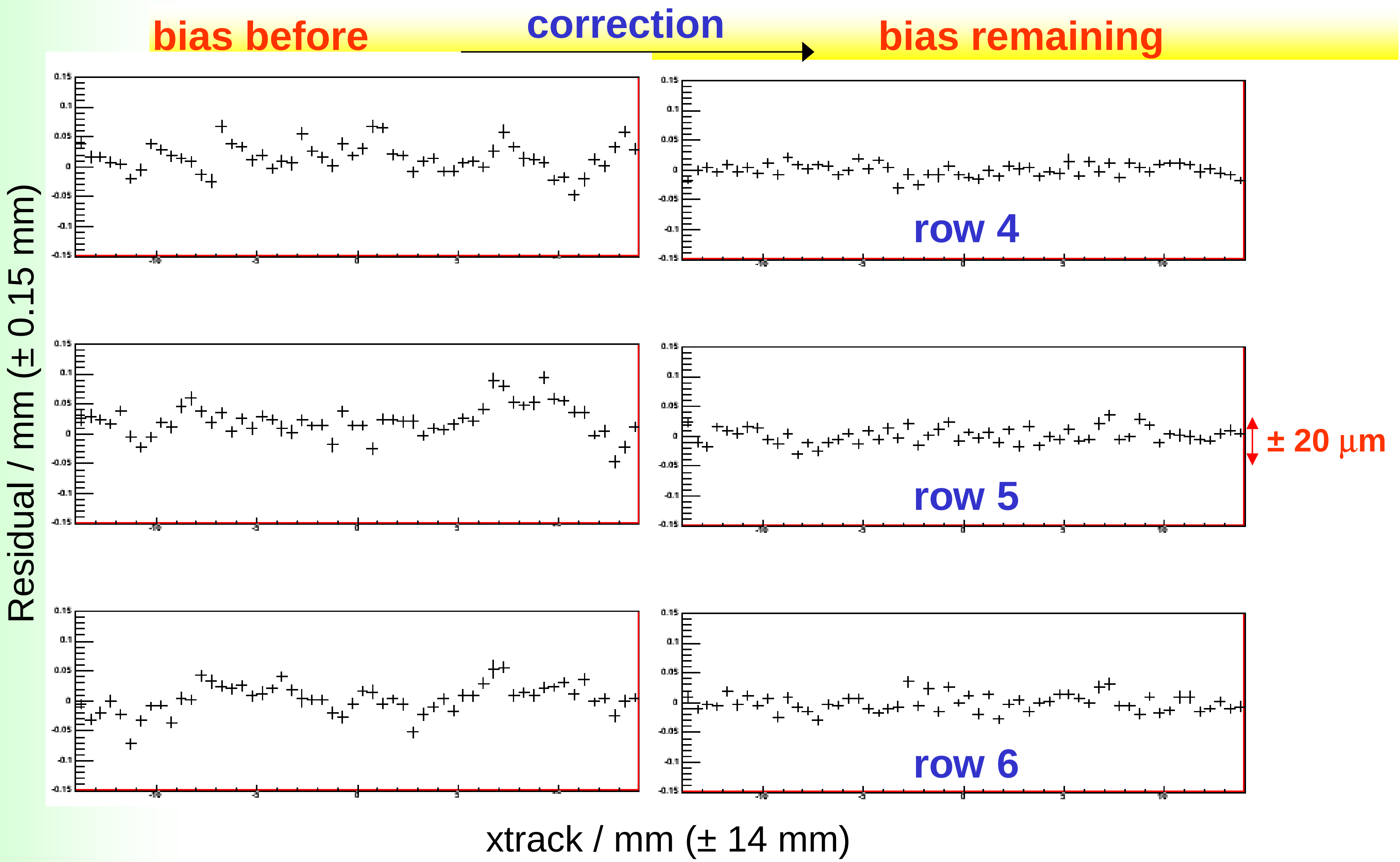
PRF parameters

- **a = b = 0**
- **Δ = base width = 7.3 mm**
- **Γ = FWHM = f(z)**

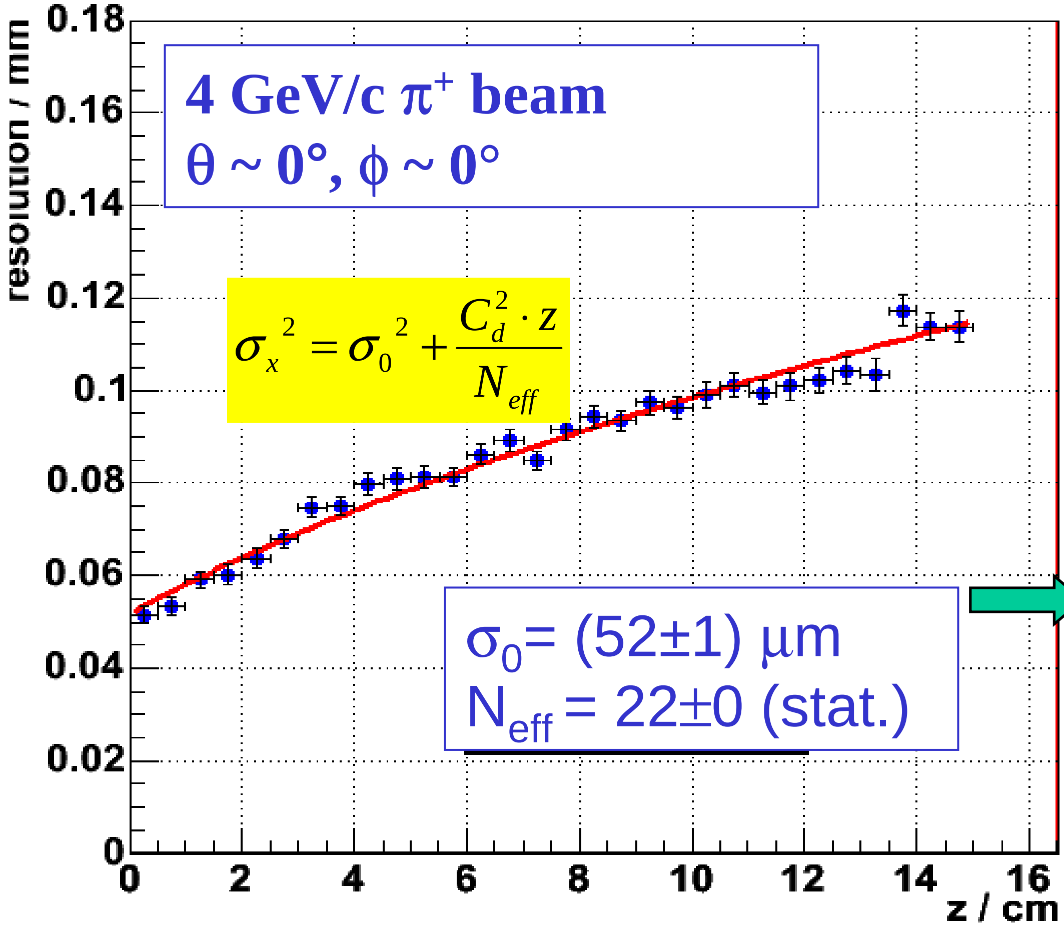


The parameters depend on TPC gas & operational details

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 mm^2 pads



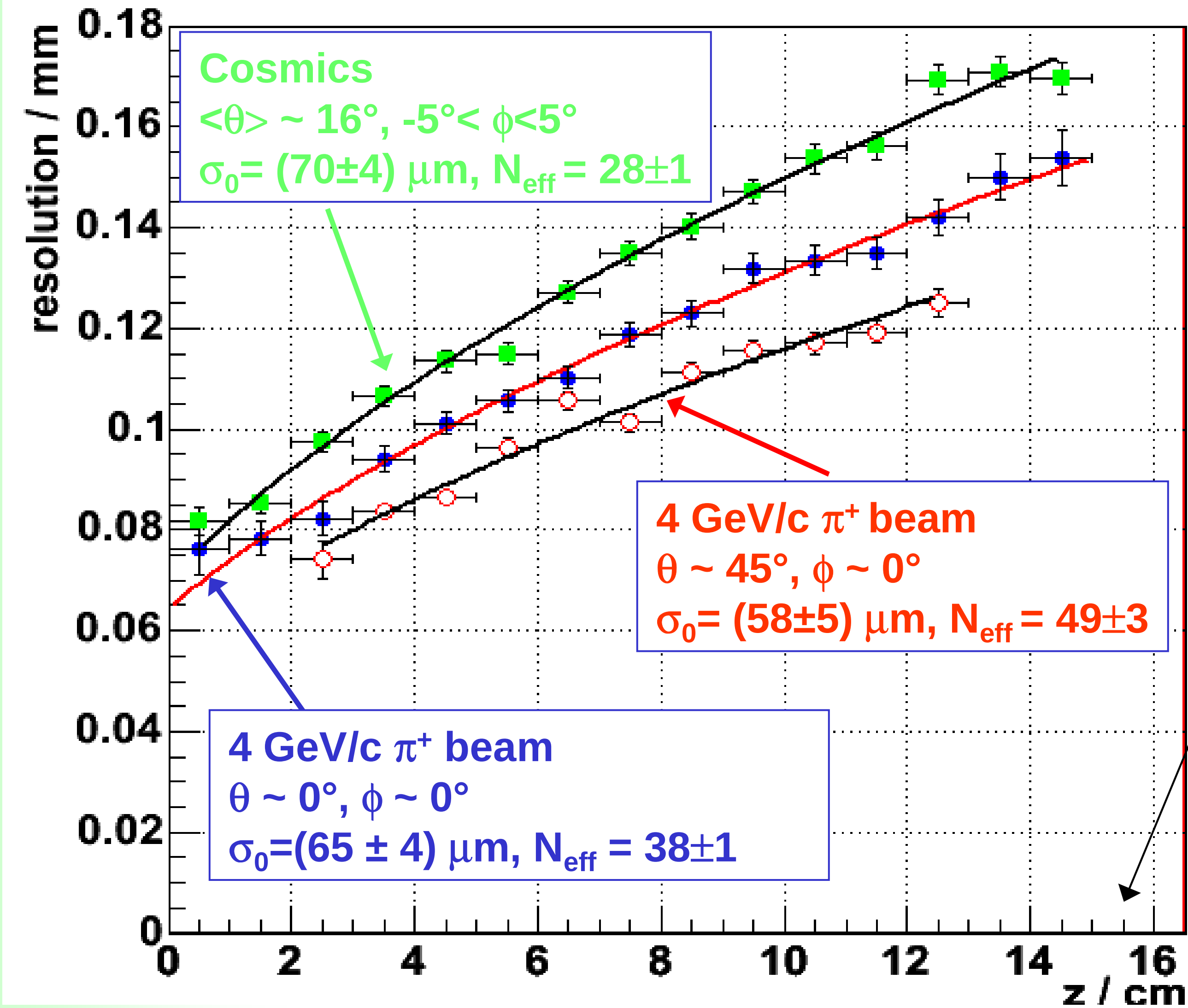
- Significant suppression of transverse diffusion at 4 T. Example gases:
  D_{Tr} ~ 32 µm/√cm (P10)
  ~ 20-30 µm/√cm (Ar/CF4 mixtures)

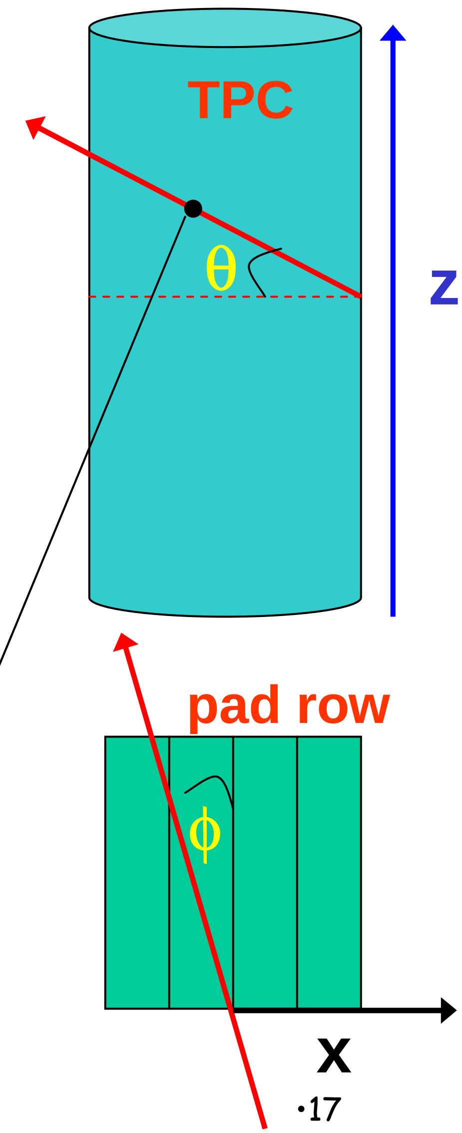
Extrapolate from present data to B = 4T
Use D_{Tr} = 32 µm/√cm
Resolution (2 mm pads)
$\sigma_{Tr} \approx$ 100 µm (2 m drift)

Transverse resolution with no magnet - Angle dependence

Ar+10% CO_2, D_{Tr} = 222 μ/√cm (Magboltz) E=300 V/cm

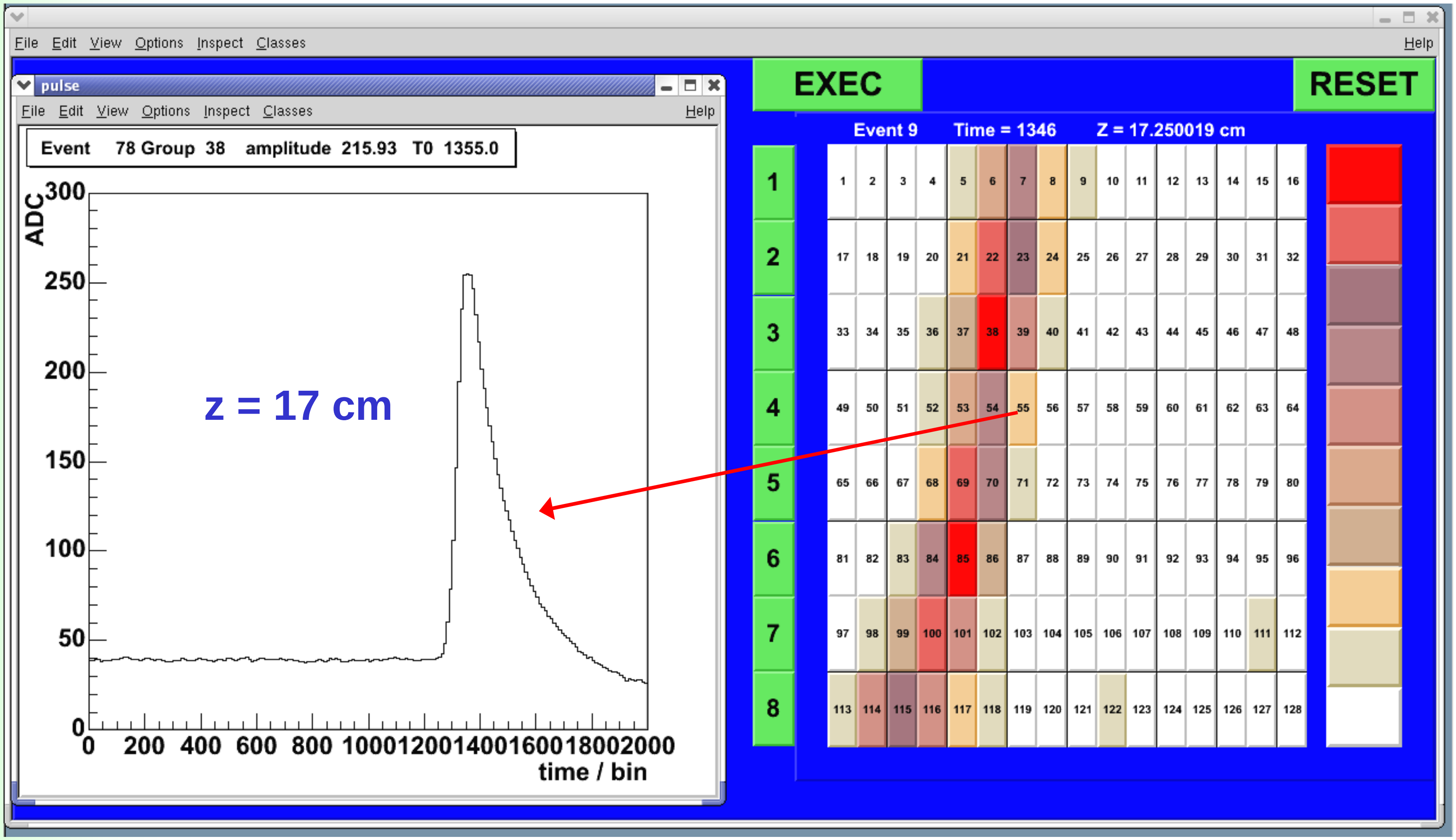
Carleton TPC 2 x 6 mm^2 pads





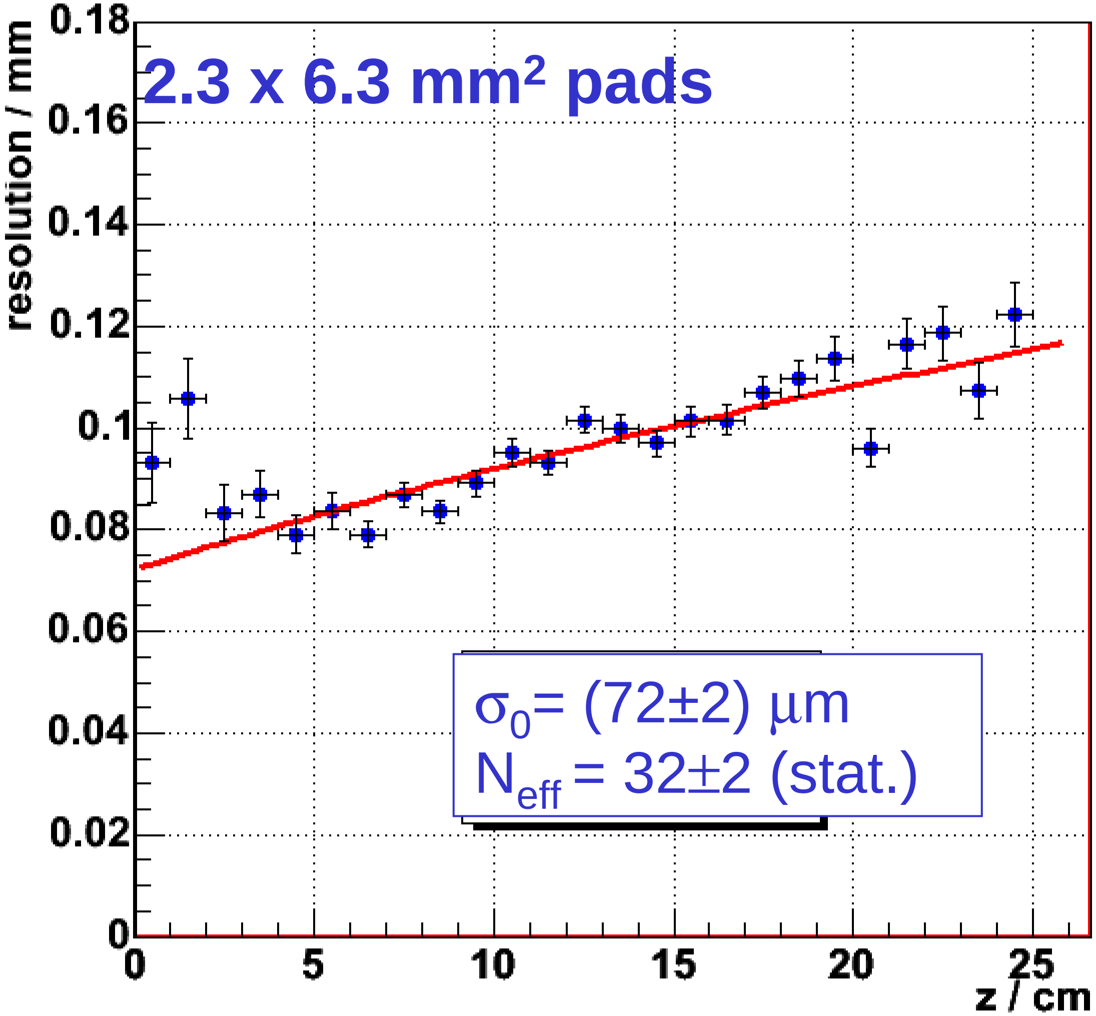
Track display MT3 TPC with triple GEM readout

Part of MT3-TPC read out with Carleton FADCs 4 GeV/c π+ beam
2.3 mm pitch x 6.3 mm pads 25 cm maximum drift distance
Ar/CH_4 (95/5) E = 50 V/cm D_{Tr} = 102 μ/√cm (Magboltz) @ 1T



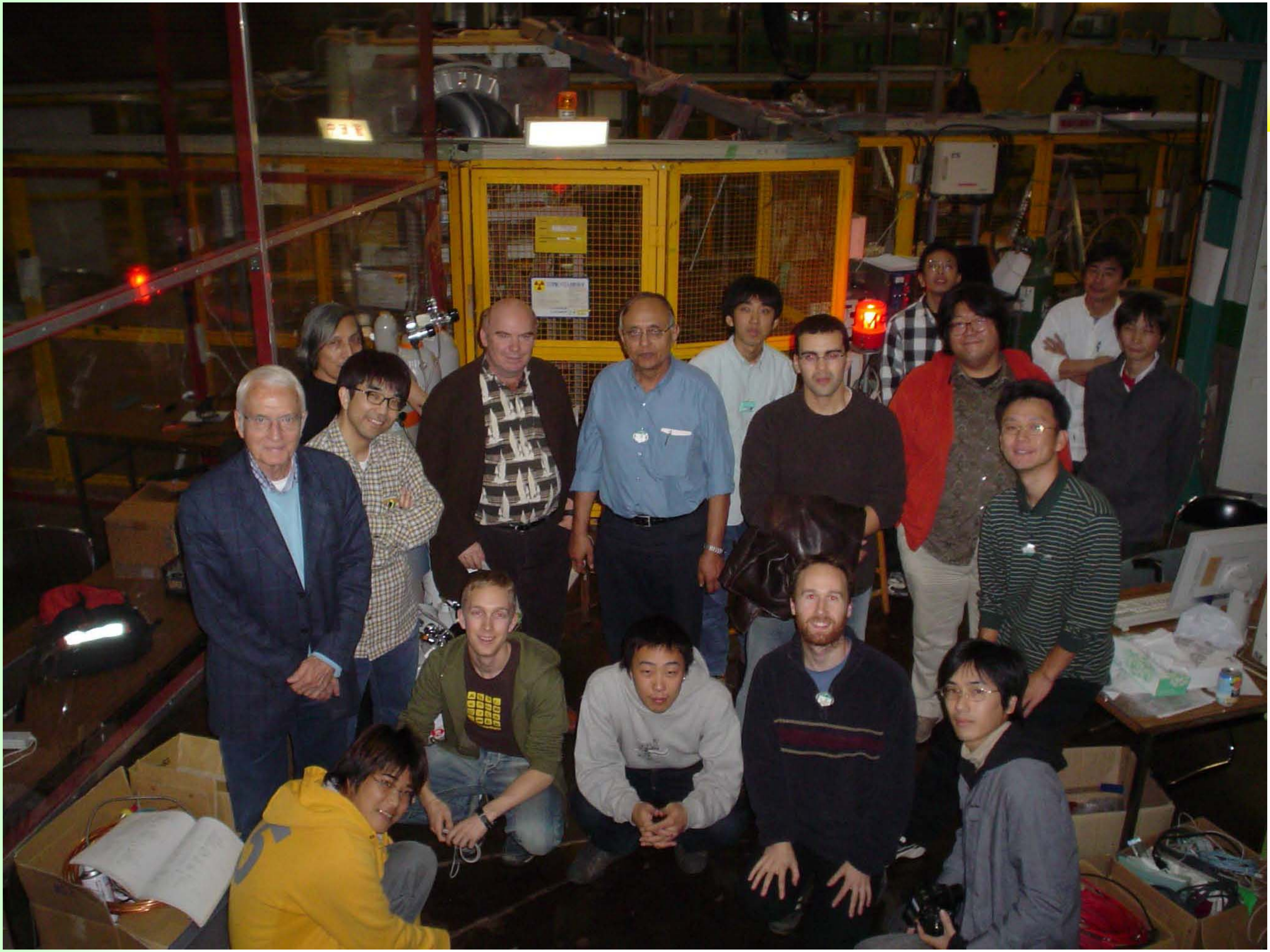
Transverse resolution - MT3-TPC with Triple GEM

Ar+5%CH4 E = 50 V/cm D_{Tr} = 102 μ/√cm (Magboltz) @ 1T



Summary & outlook

- A first demonstration of the charge dispersion readout for the MPGD-TPC in a magnetic field in a KEK beam test.
- Two TPCs tested using GEMs with 2.3 mm wide pads & Micromegas with 2 mm and 2.3 mm pads: about 500,000 events recorded for the Carleton TPC, & about 100,000 for the MPI-TPC.
- Data analysis is in progress - promising first results. ~ 50 μm resolution with Micromegas for short drift distances with 2 x 6 mm^2 pads at 1 T.
- Charge dispersion TPC readout works with GEMs & Micromegas both.
- With proper choice of gas, the ILC-TPC resolution goal of ~100 μm with 2 mm x 6 mm pads for all tracks appears within reach.
- R&D plans - cosmic ray TPC tests at 4 T & two track resolution studies in beam.
- R&D issues: New technology issues of fabrication & quality control, develop analysis techniques. As charge dispersion pulses are slow, ~25 MHz digitizers could be used.
- Thanks to KEK and all the groups from Germany, France & Japan working together to make this test successful.

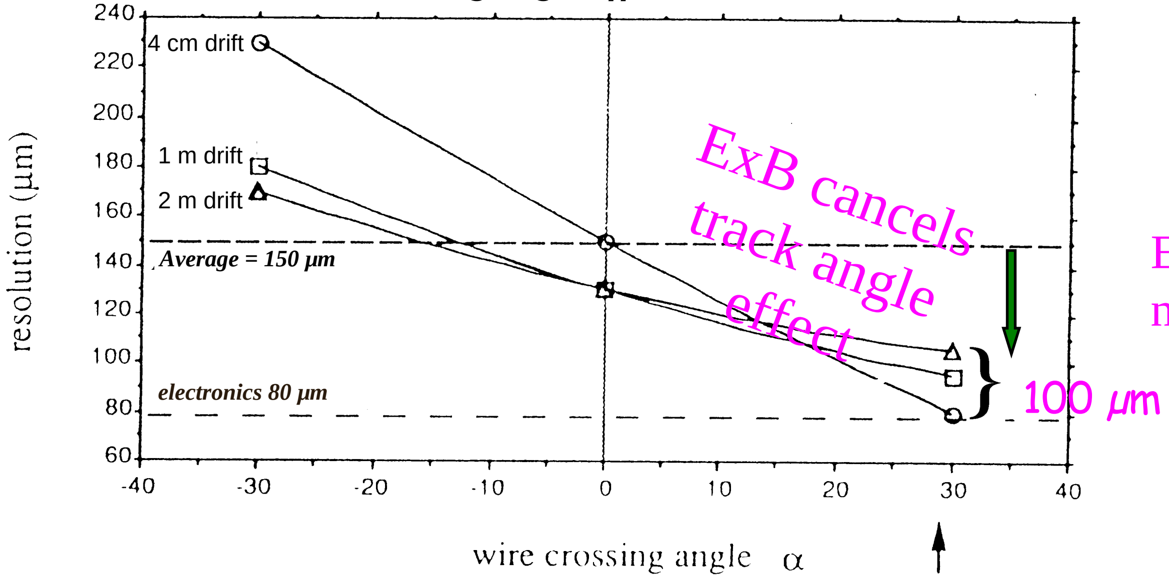


Additional slides

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

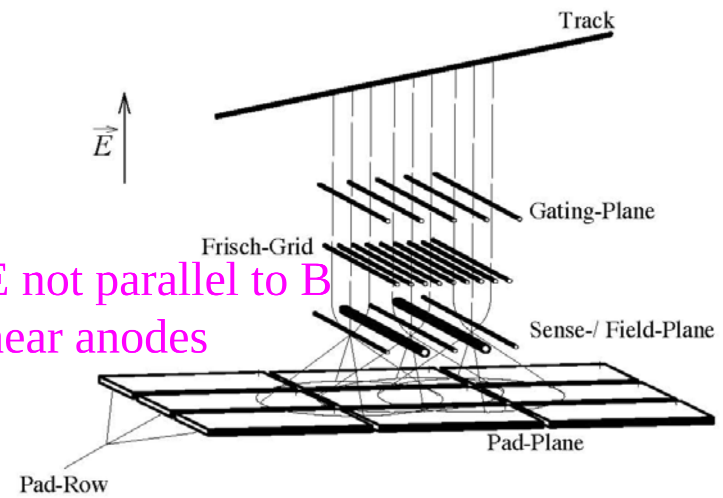
S.R. Amendolia et al. / The spatial resolution of the ALEPH TPC
Nuclear Instruments and Methods in Physics Research A283 (1989) 573–577
North-Holland, Amsterdam

ExB and wire crossing angle effects dominate TPC resolution



TPC wire/pad readout

E not parallel to B near anodes



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.

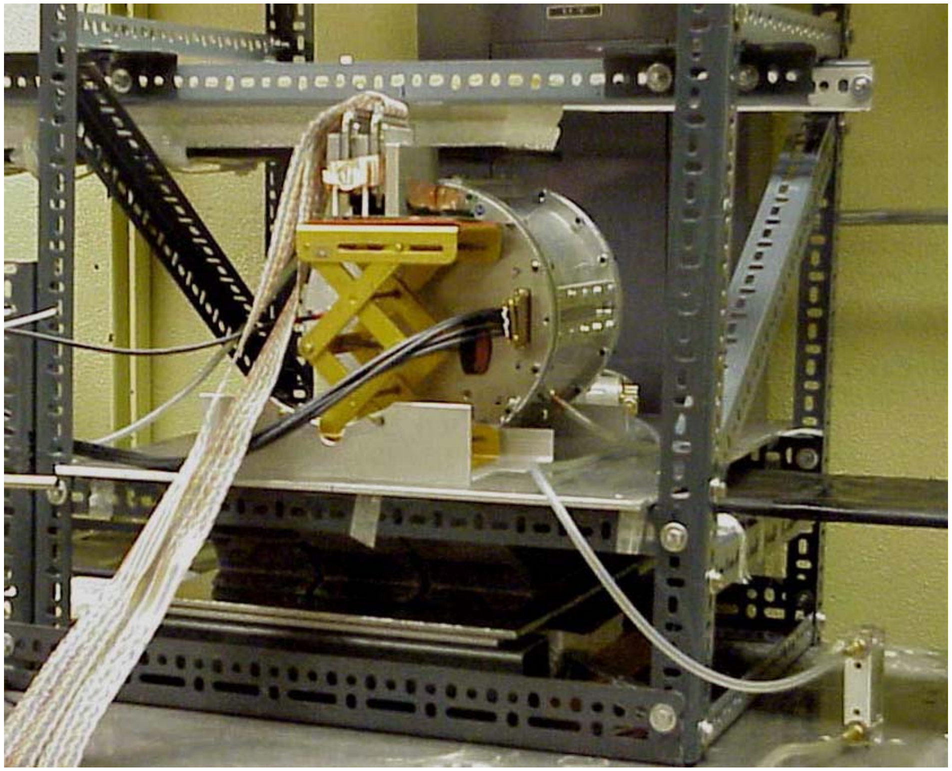
Cosmic ray resolution of a MPGD-TPC

- 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.

$\tau_{Rise} = 40$ ns, $\tau_{Fall} = 2$ 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.

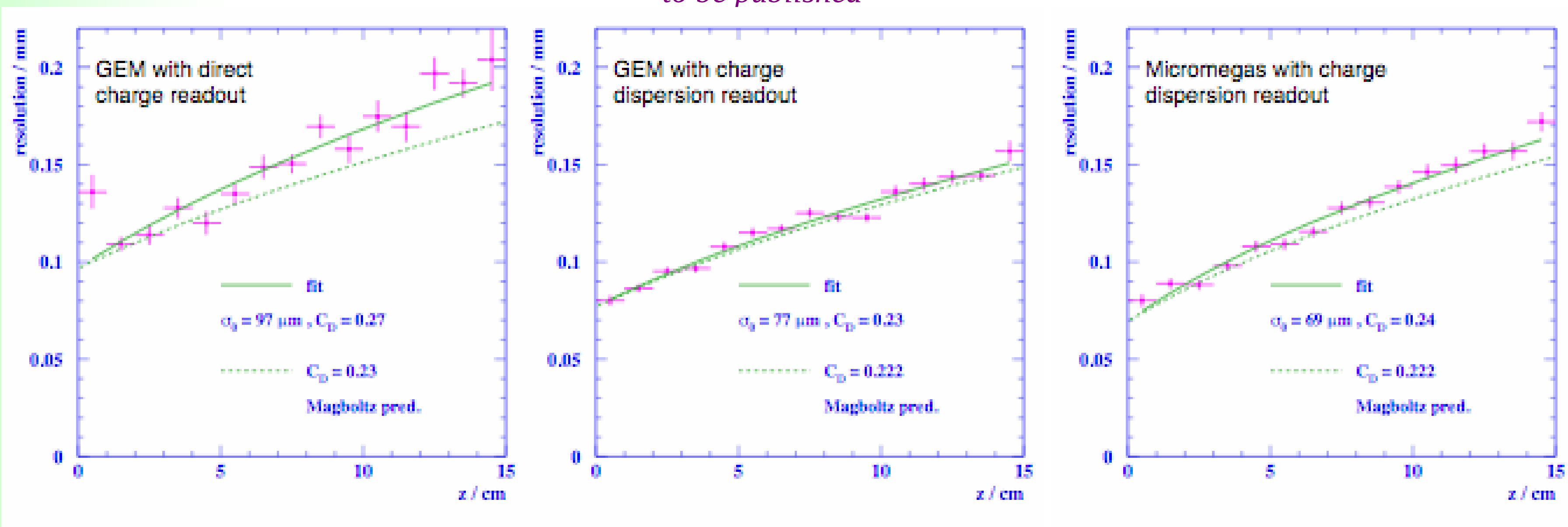
The resolution was next measured with a charge dispersion resistive anode readout with a double-GEM & with a Micromegas endcap.

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

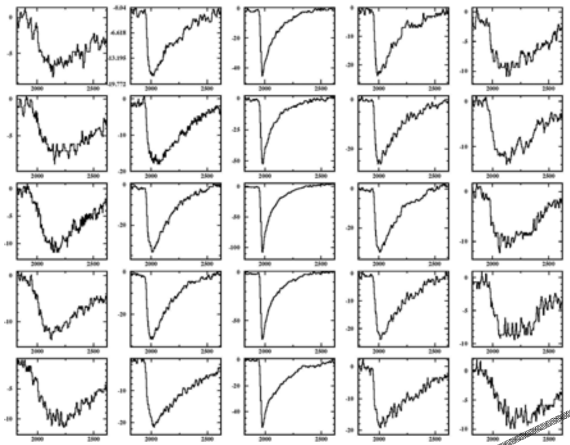


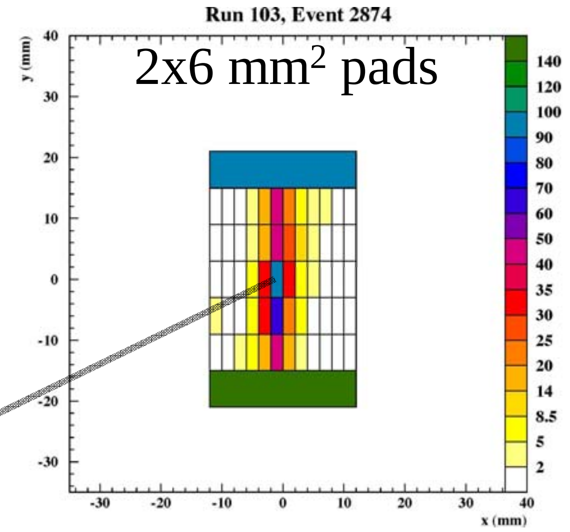
Compared to conventional readout, resistive readout gives better resolution for the GEM and the Micromegas readout. The z dependence follows the expectations from transverse diffusion & electron statistics.

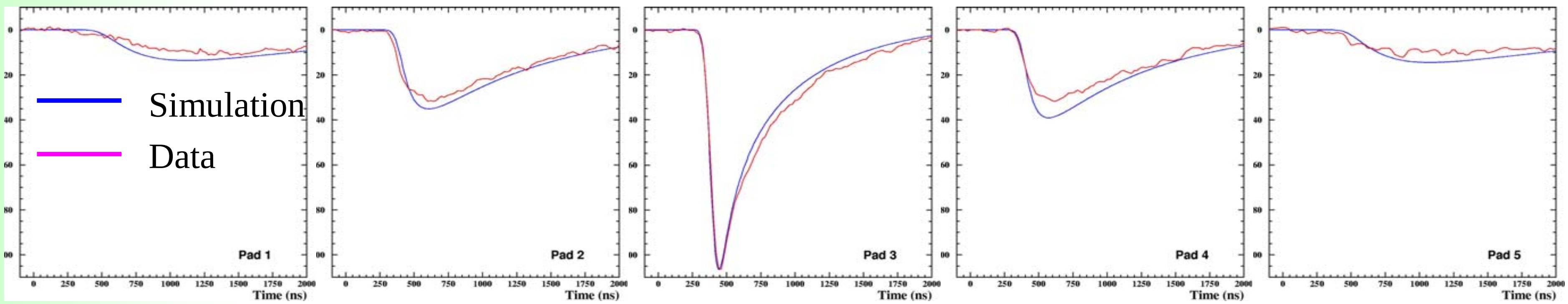
Simulation - GEM TPC cosmic event with charge dispersion

(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.