TPC prototypes results II (mostly Micromegas) & Electronics Developments

Madhu Dixit

(Carleton University & TRIUMF)

On behalf of LCTPC collaboration

9th ACFA ILC Physics and Detector Workshop & ILC GDE Meeting

Feb. 4-7， 2007， IHEP， Beijing

http://bilcw07.ihep.ac.cn/

ILC tracking review - Beijing 5 February, 2007

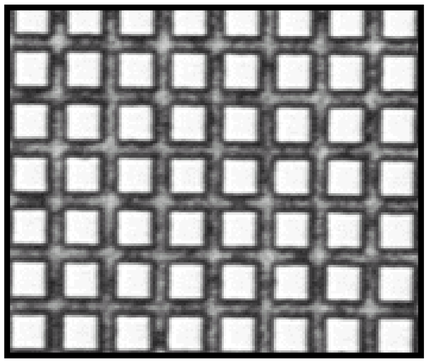
Micro-Pattern Gas Detector development for the ILC TPC

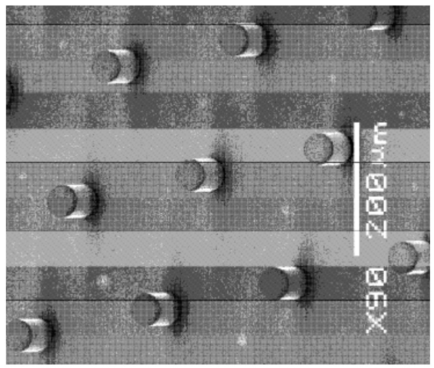
- ILC tracker challenge: $\sigma_{Tr} \sim 100\ \mu m$ (all tracks 2 m drift)
- Classical anode wire/cathode pad TPC limited by ExB effects
- Micro Pattern Gas Detectors (MPGD) not limited by ExB effect
- TESLA TPC proposal : 2 mm x 6 mm pads (1,500,000 channels) GEMs or Micromegas development for TPC readout
- R&D: 2 mm pads too wide if standard TPC readout is used
    - Need ~ 1 mm wide pads with GEM (~3,000,000 channels)
    - Narrower pads would be needed for the Micromegas
- New MPGD readout concept of charge dispersion developed to achieve good resolution with wide pads.
- R&D summary - mainly on the Micromegas readout option

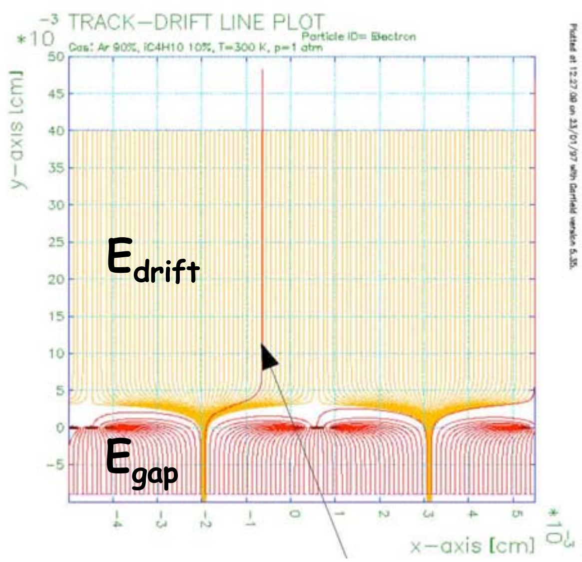
Micromegas

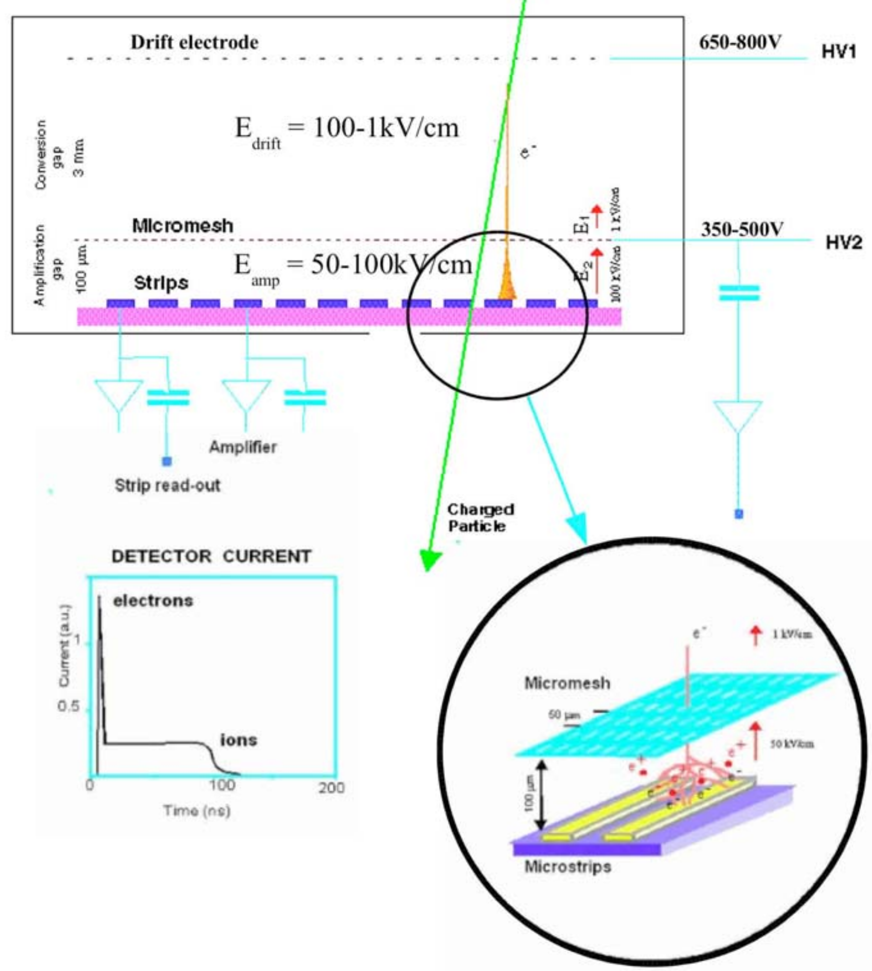
Single stage parralel gap gas proportional detector

Micromesh supported by ~ 50 µm pillars above anode



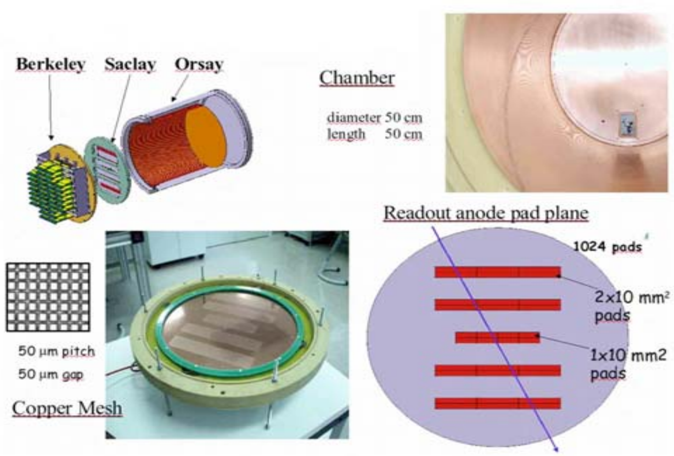




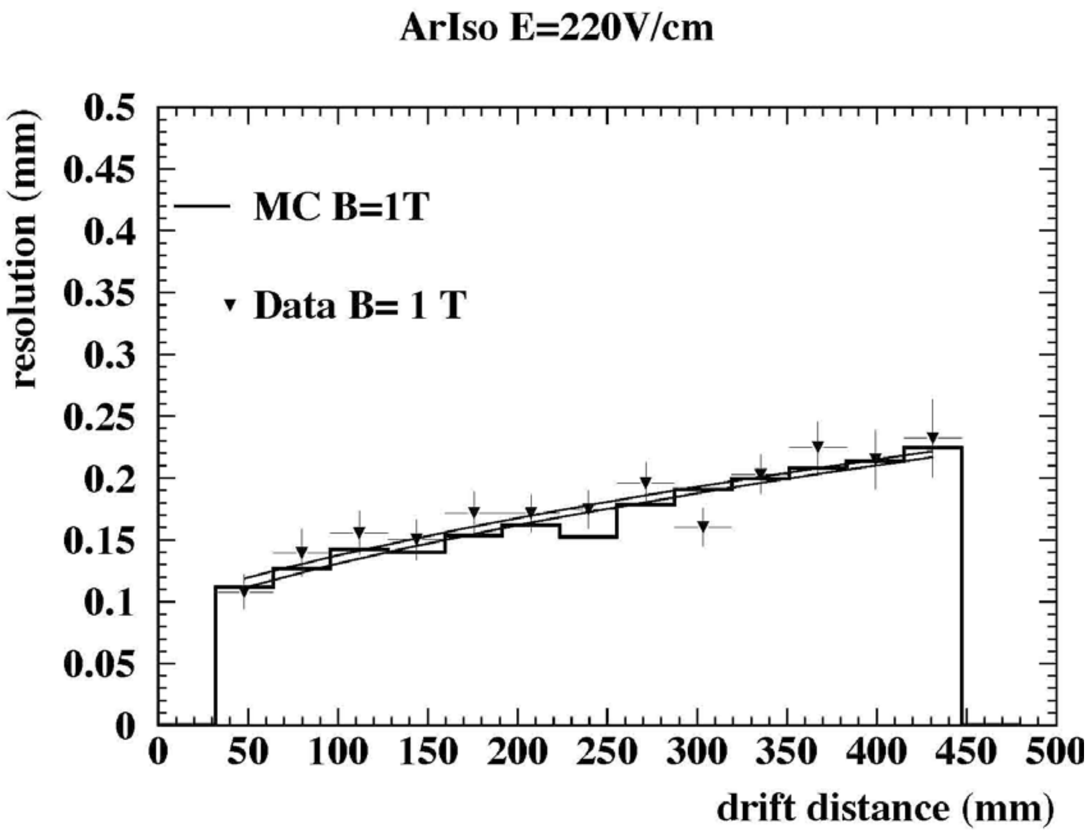


Ion backflow reduction ~ E_{drift}/E_{gap}

Berkeley Orsay Saclay cosmic ray TPC tests

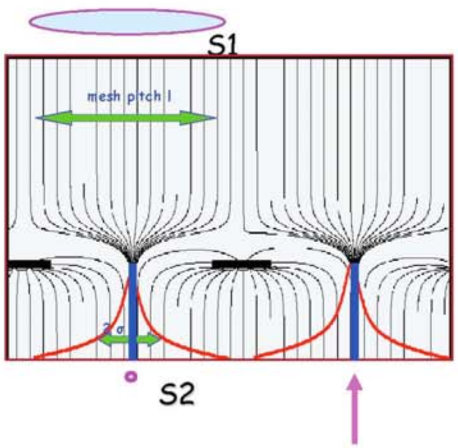


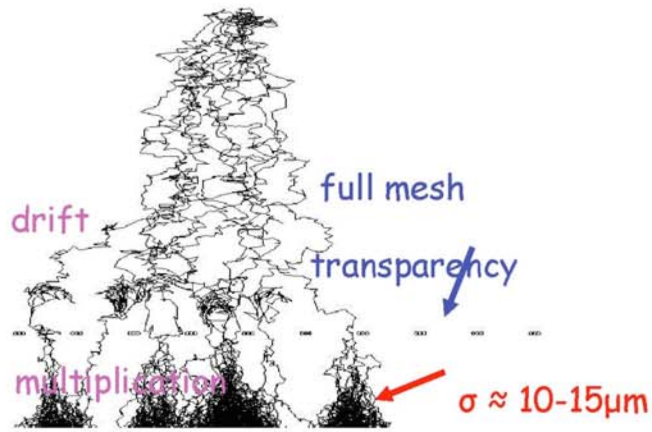
2 T superconducting magnet



50 cm diameter Micromegas, 50 cm max. drift distance
1024 read out pads, Star TPC 20 MHz 10 bit digitizers

ion back-flow studies in Micromegas



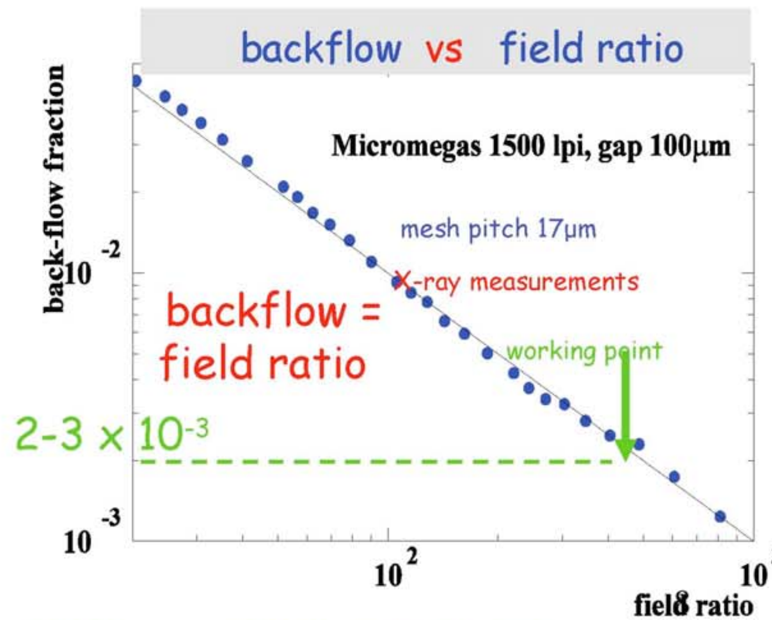


electrons diffuse, but ions do not !

only ions created in the very small funnel (1-2 µm in radius) flow back into the drift volume

it can be shown that:
ion backflow = field ratio if 2σ≥ l

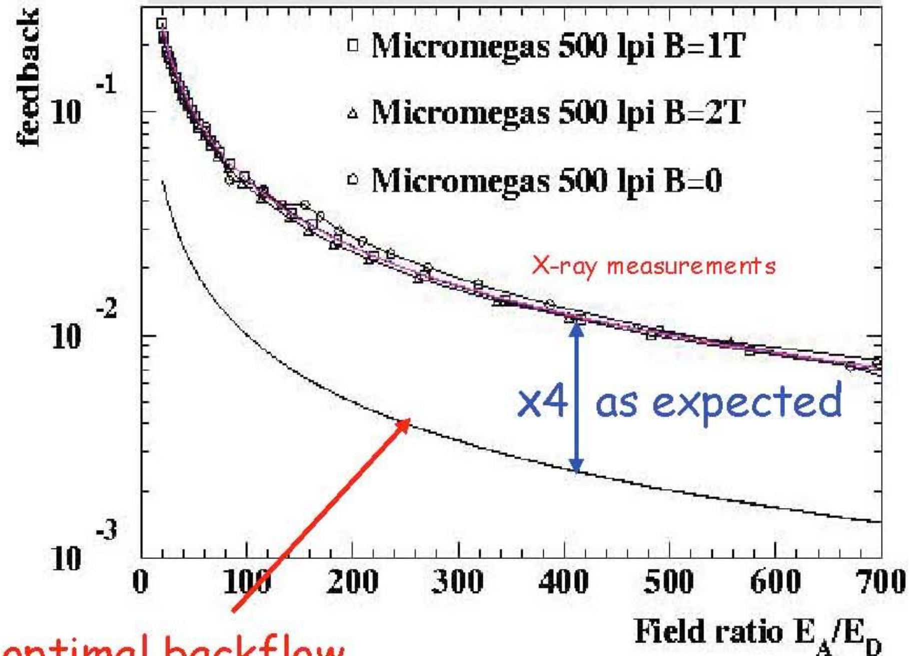
for a gain of 300-500
ion backflow ≈ prima



Vincent Lepeltier LAL-Orsay-France TPC R&D meeting LBNL March 23-24th 2005

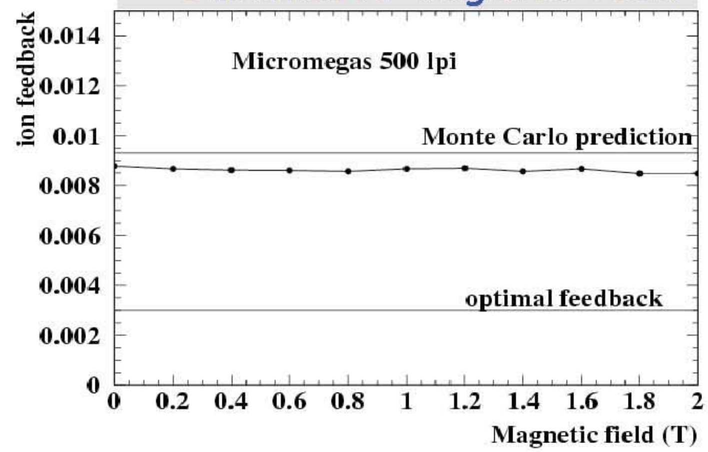
ion back-flow studies in Micromegas

backflow vs field ratio



optimal backflow
reached for a mesh with
≥1000 lpi (pitch≤ 25μm)

backflow vs magnetic field



as expected:
no effect of the magnetic
field on the ion backflow

- good understanding of the ion backflow in Micromegas
- need for manufacturing large grids with a 25 micron pitch.

4 Gev/c beam tests at KEK with standard readout

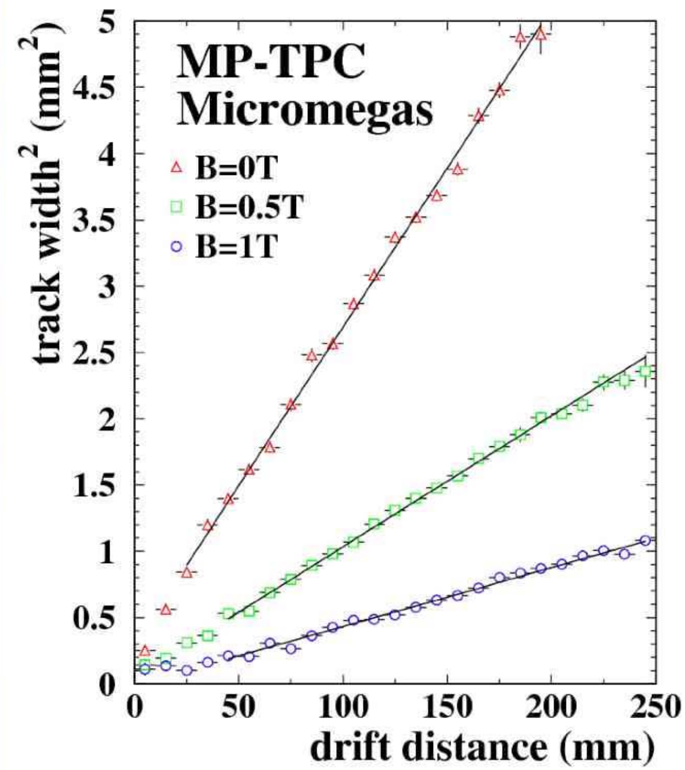
Measurement of the diffusion coefficient at B=0, 0.5 and 1T

2 methods: global likelihood fit of the track width to all pad charges (shown here), or width of the PRF (slope at large distance is unbiased)

in μ/√cm

Magnetic field	0 T	0.5 T	1 T
Global likelihood	488 ± 11	314 ± 15	209 ± 7
PRF width (stat.only)	475 ± 3	293 ± 4	194 ± 18
Magboltz	469.3	284.1	192.6

(2.3 mm x 6.3 mm pads)

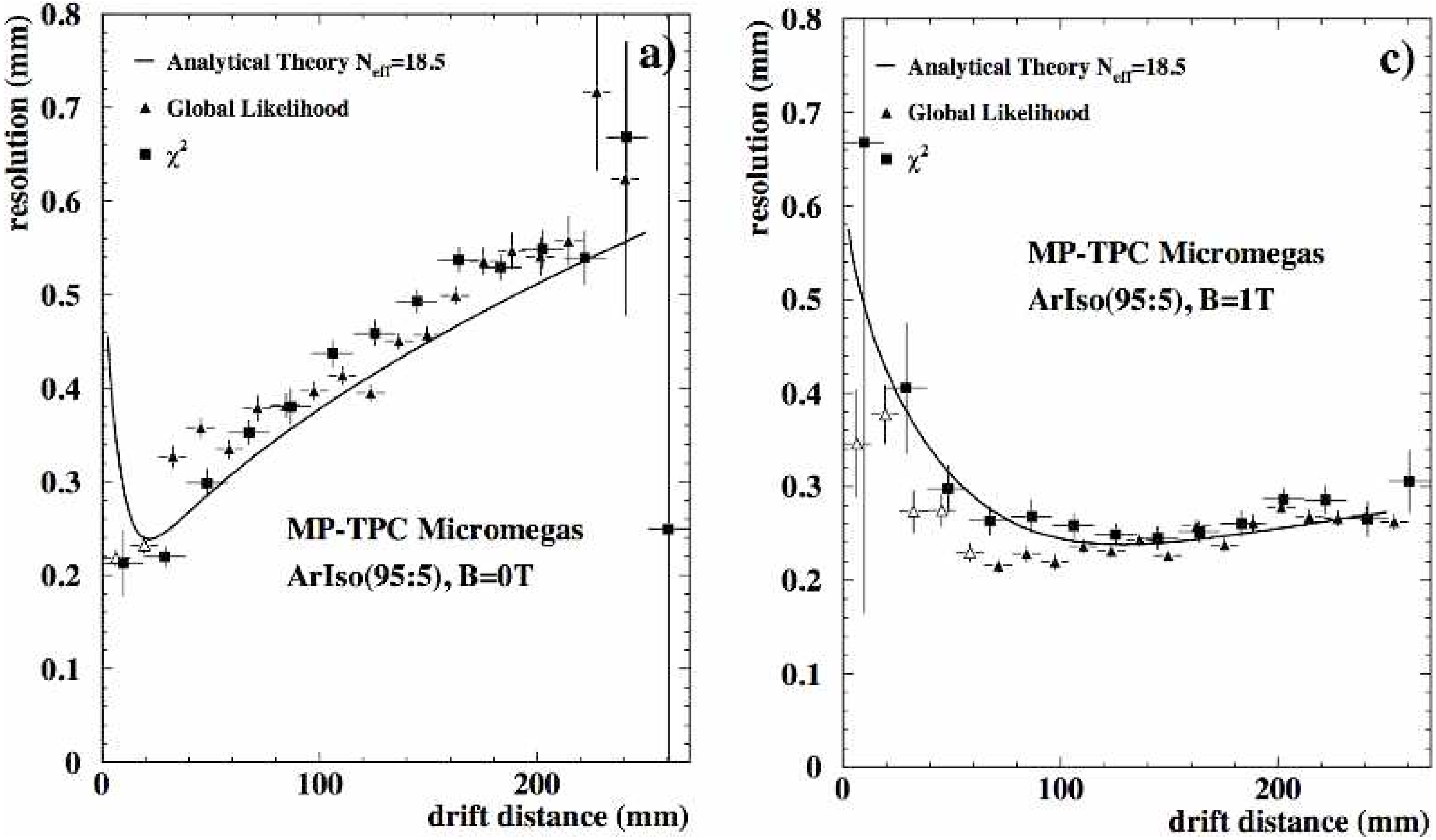


Good agreement between the two methods and good agreement with Magboltz.

October 30, 2006 IEEE/NSS San Diego. P. Colas - Micromegas TPC resolution 6

MP TPC with Micromegas - standard readout

KEK PS 4 Gev/c hadron test beam (2.3 mm x 6.3 mm pads)



Micromegas TPC resolution clearly limited by pad width especially at higher magnetic fields

Improving MPGD TPC resolution without resorting to narrower pads

- Disperse track charge after gas gain to improve centroid determination with wide pads.
- For the GEM, large transverse diffusion in the high E-field in transfer & induction gaps provides a natural mechanism to disperse the charge which improves the resolution.
- No such mechanism for Micromegas
- The GEM readout will still need ~ 1 mm wide pads to achieve ~ 100 μm ILC resolution goal

Charge dispersion - a geometrical pad signal induction mechanism. It makes position sensing insensitive to pad width. The technique works for both the GEM and the Micromegas

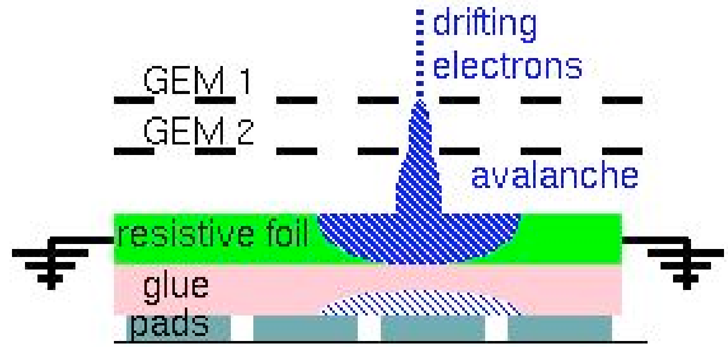
Charge dispersion in a MPGD with a resistive anode

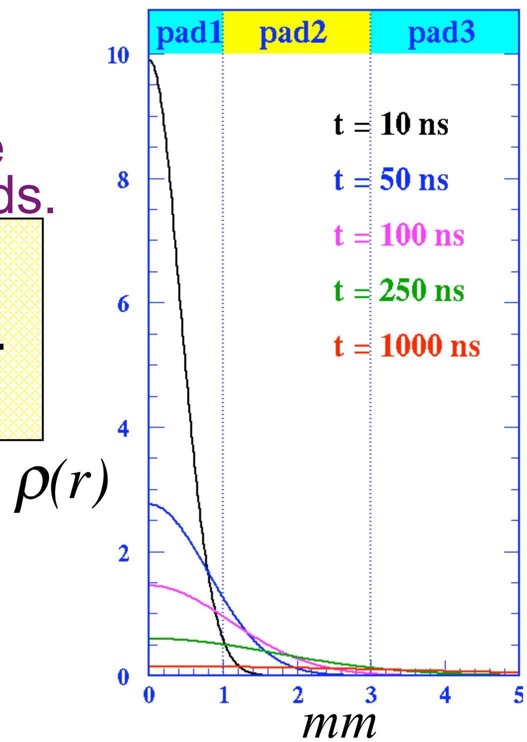
- Modified MPGD anode with a high resistivity film bonded to a readout plane with an insulating spacer.
- 2-dimensional continuous RC network defined by material properties & geometry.
- Point charge at *r = 0 & t = 0* disperses with time.
- Time dependent anode charge density sampled by readout pads.

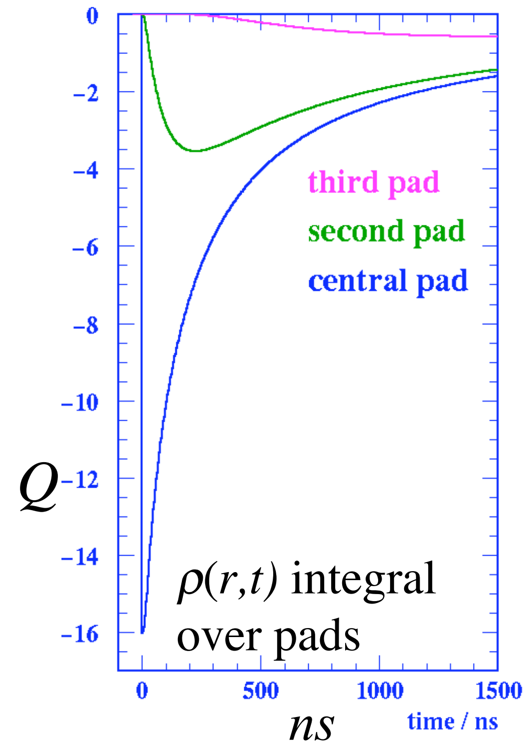
Equation for surface charge density function on the 2-dim. continuous RC network:

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

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

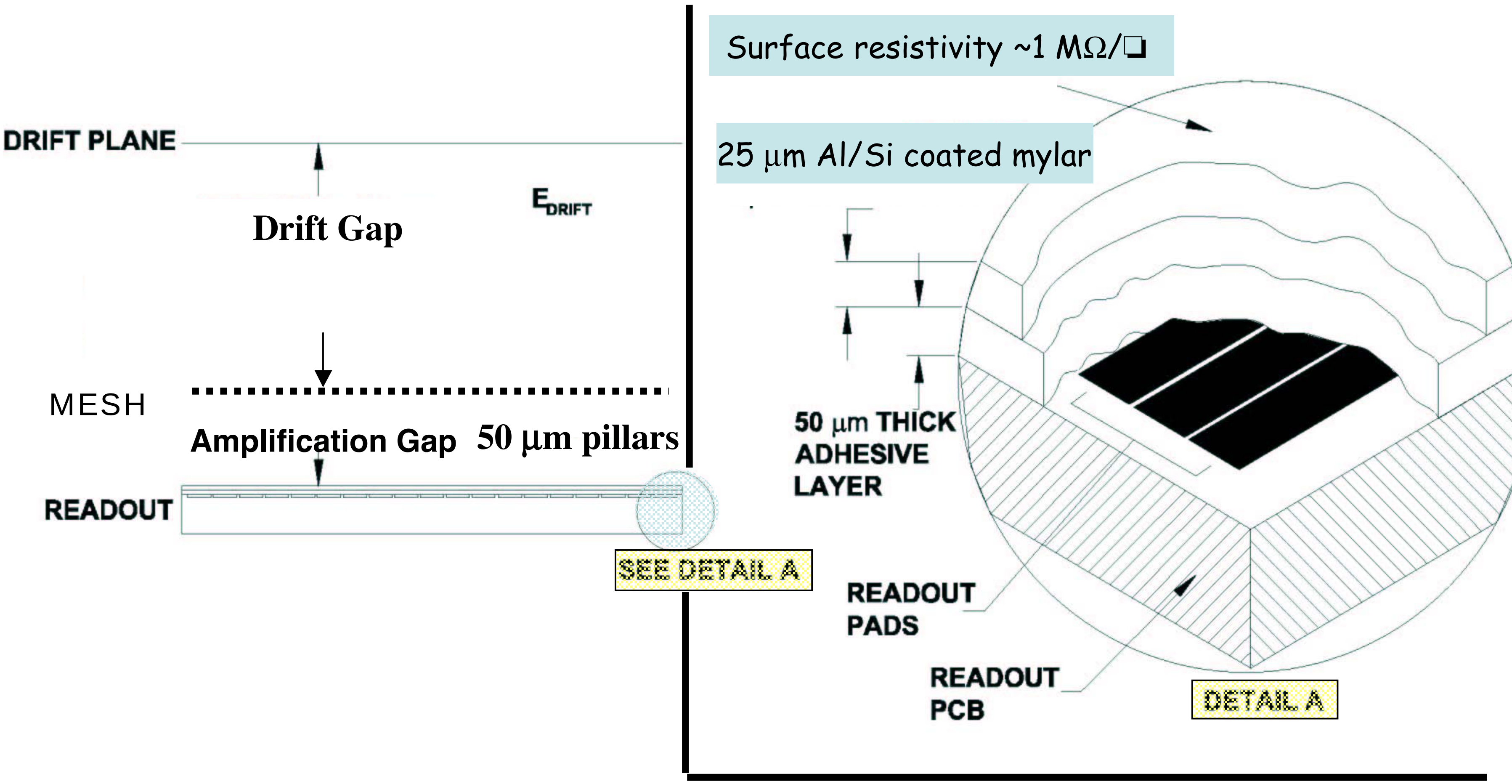






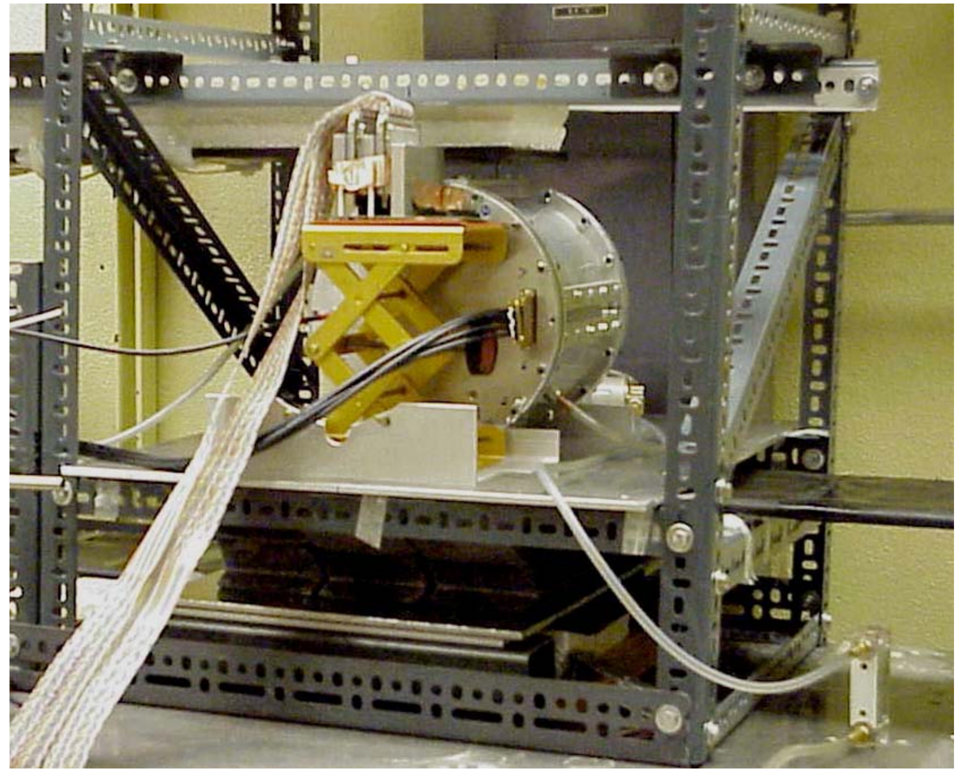
M.S.Dixit et.al., Nucl. Instrum. Methods A518 (2004) 721.

Micromegas resistive anode readout structure



Cosmic ray tests of charge dispersion readout

•15 cm drift length with GEM or Micromegas readout
•B=0
•**Ar+10% CO2 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.

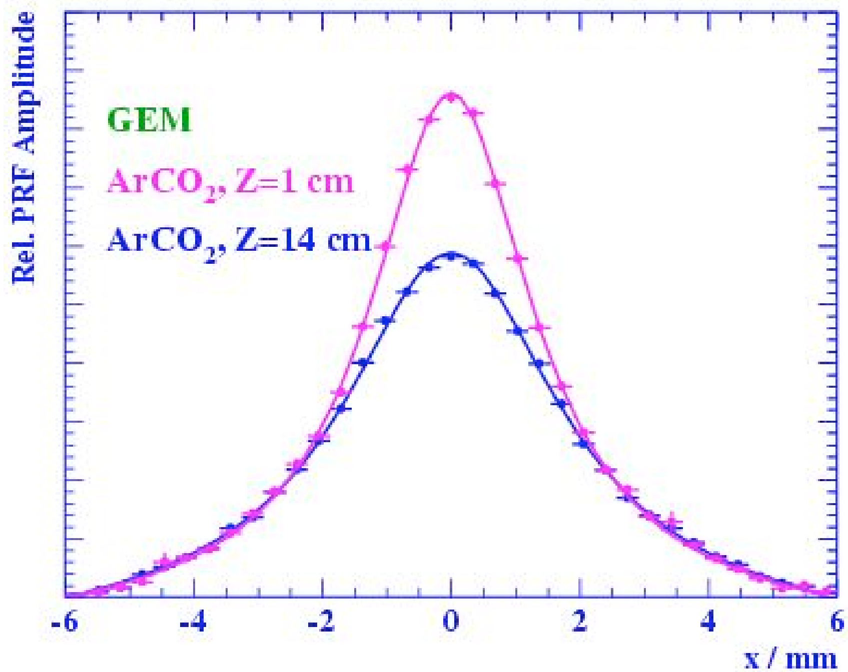
The resolution was next measured with a charge dispersion resistive anode readout with a double-GEM & with a Micromegas endcap.

Charge dispersion pulses & pad response function

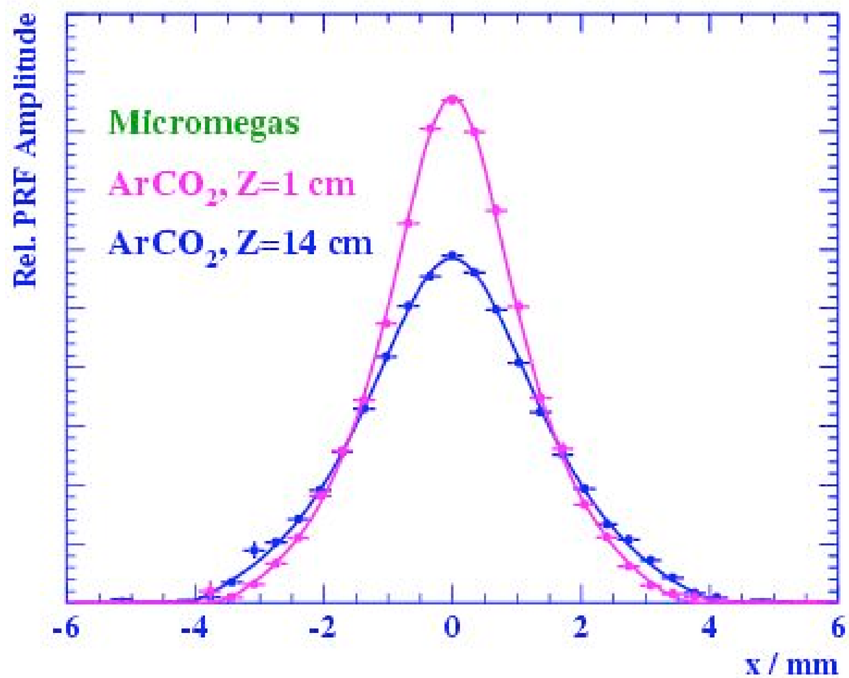
- Unusual highly variable charge dispersion pulse shape; both the rise time & pulse amplitude depend on track position.
- The PRF is a measure of signal size as a function of track position relative to the pad.
- We use pulse shape information to optimize the PRF.
- The PRF can, in principle, be determined 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 used for resolution studies.

GEM & Micromegas track Pad Response Functions
Ar+10%CO_2 2x6 mm^2 pads

The pad response function (PRF) amplitude 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 than GEM after avalanche gain

Track PRFs with GEM & 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.

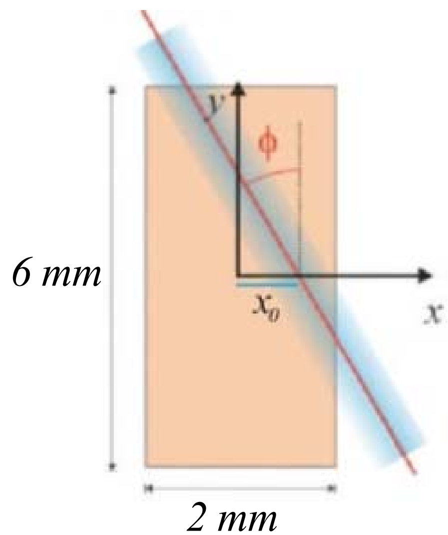
$$PRF[x,\Gamma(z),\Delta,a,b] = \frac{(1+a_2x^2+a_4x^4)}{(1+b_2x^2+b_4x^4)}$$

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

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

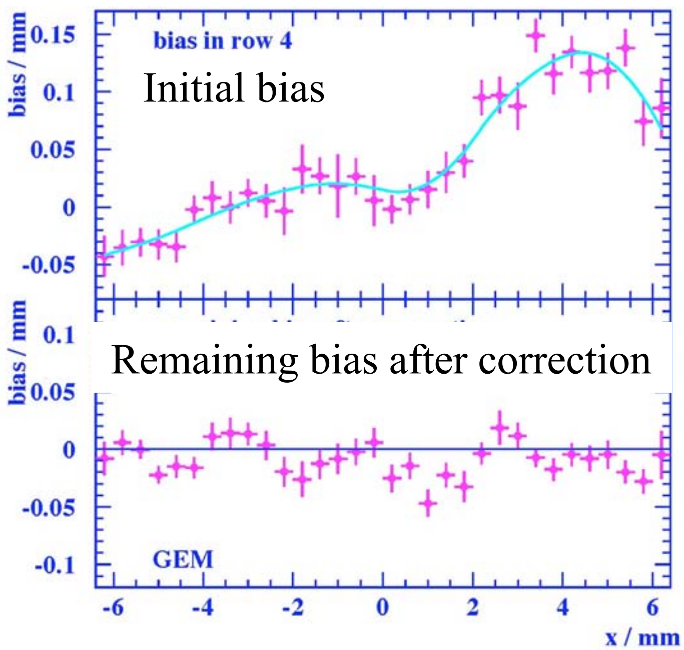


Determine x_0 & ϕ by minimizing χ^2 for the entire event

Definitions:

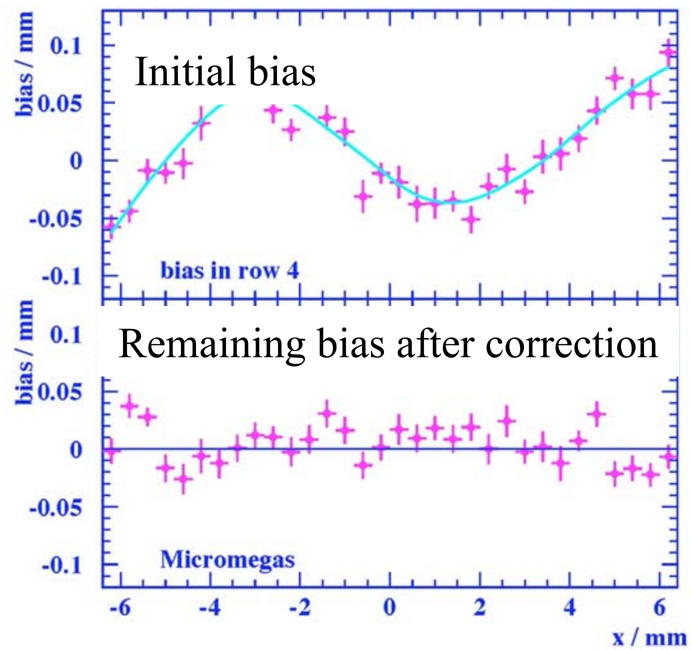
- residual: xrow-xtrack
- bias: mean of x_{row}-x_{track} = $f(x_{track})$
- resolution: σ of the residuals

Bias corrections for the GEM & for Micromegas



2x6 mm² pads

GEM

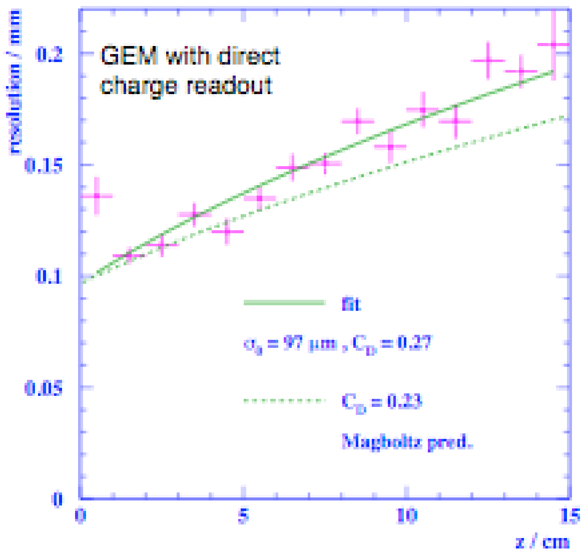


2x6 mm² pads

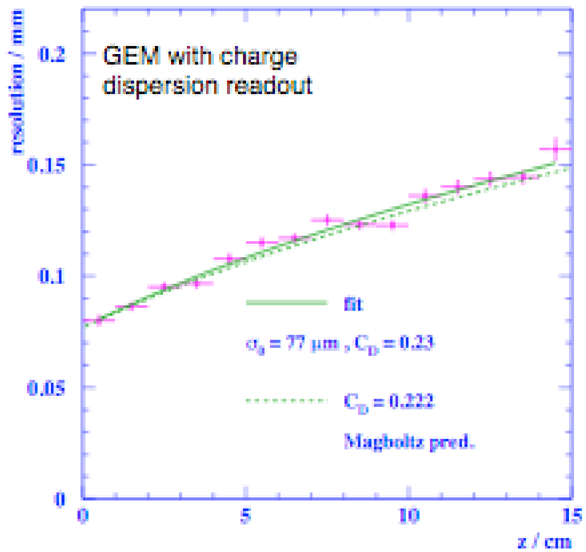
Micromegas

Transverse resolution (B=0) for cosmic rays $Ar+10\%CO_2$

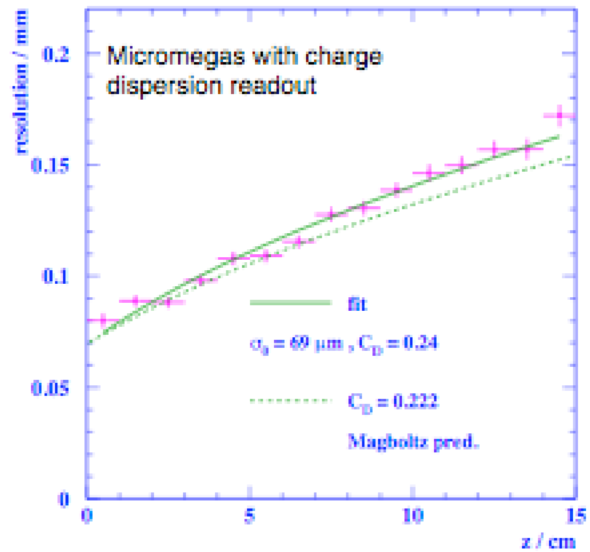
R.K.Carnegie et.al.,
NIM A538 (2005) 372



K. Boudjemline et.al.,
NIM A - in press



To be published

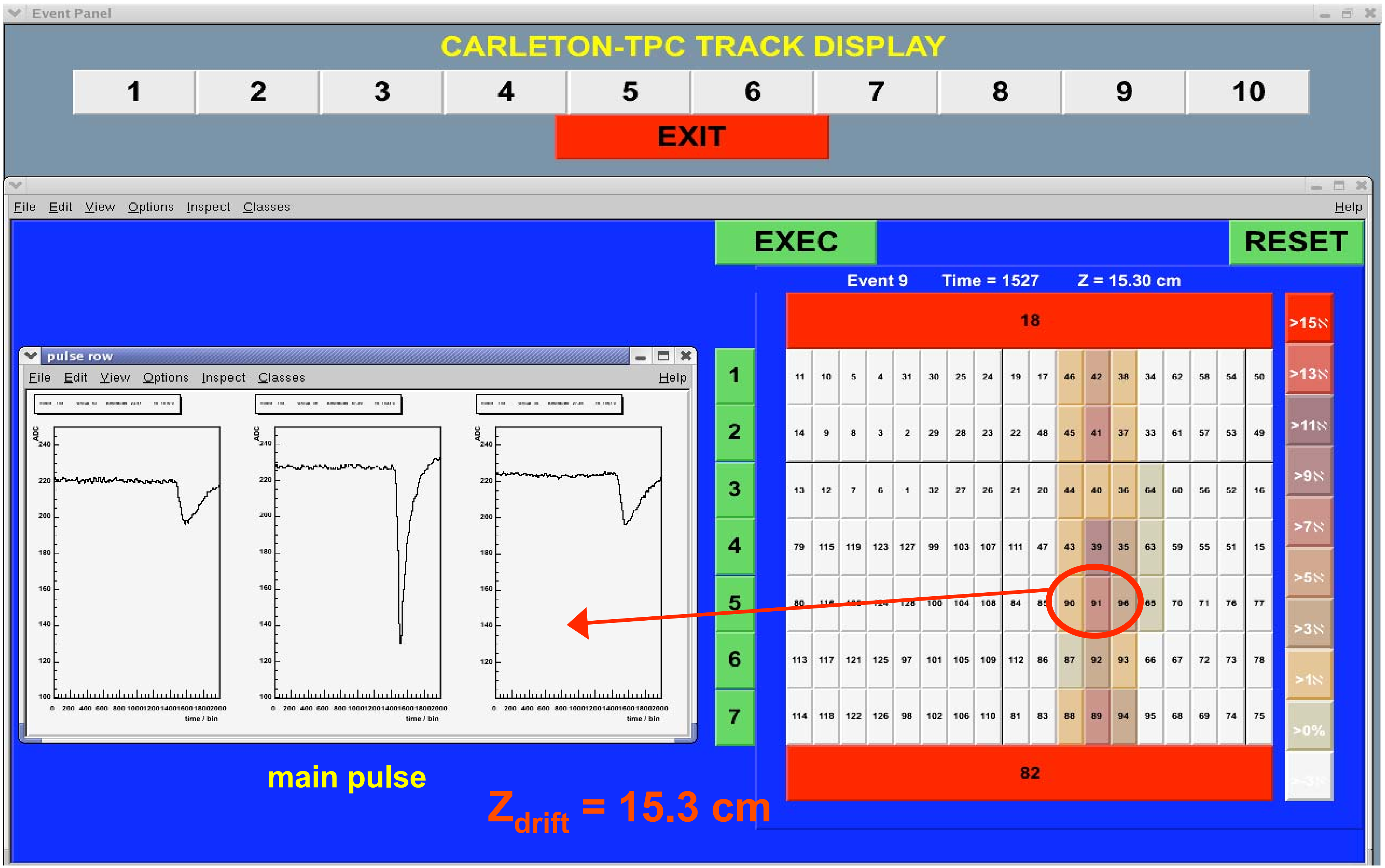


$$\sqrt{\sigma_0^{\,2} + \frac{C_D^{\,2}}{N_e} z}$$

Compared to conventional readout, charge dispersion gives better resolution for the GEM and the Micromegas.

Track display - Ar+5%iC4H10 KEK 4 GeV/c hadrons

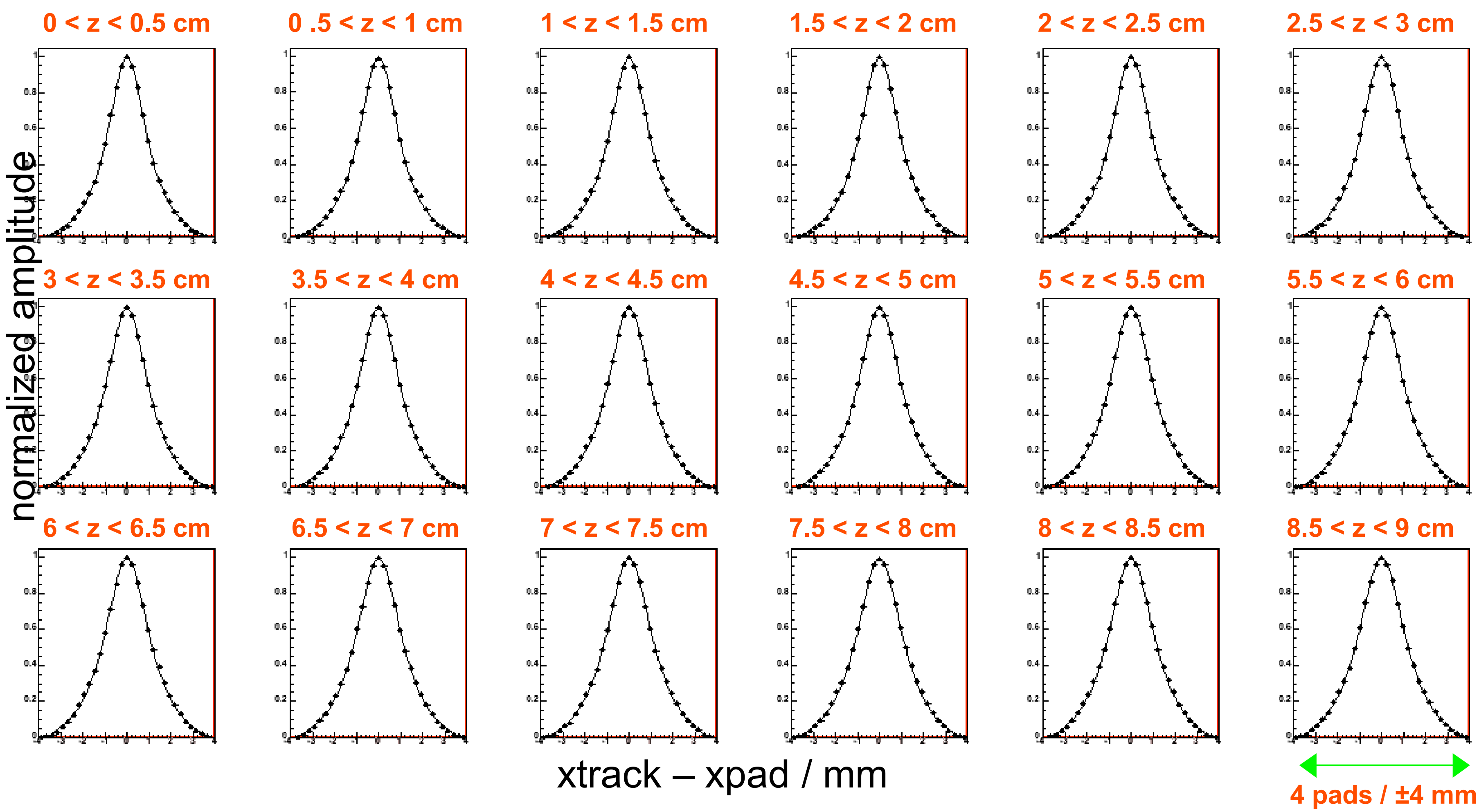
Micromegas 2 x 6 mm² pads B = 1 T



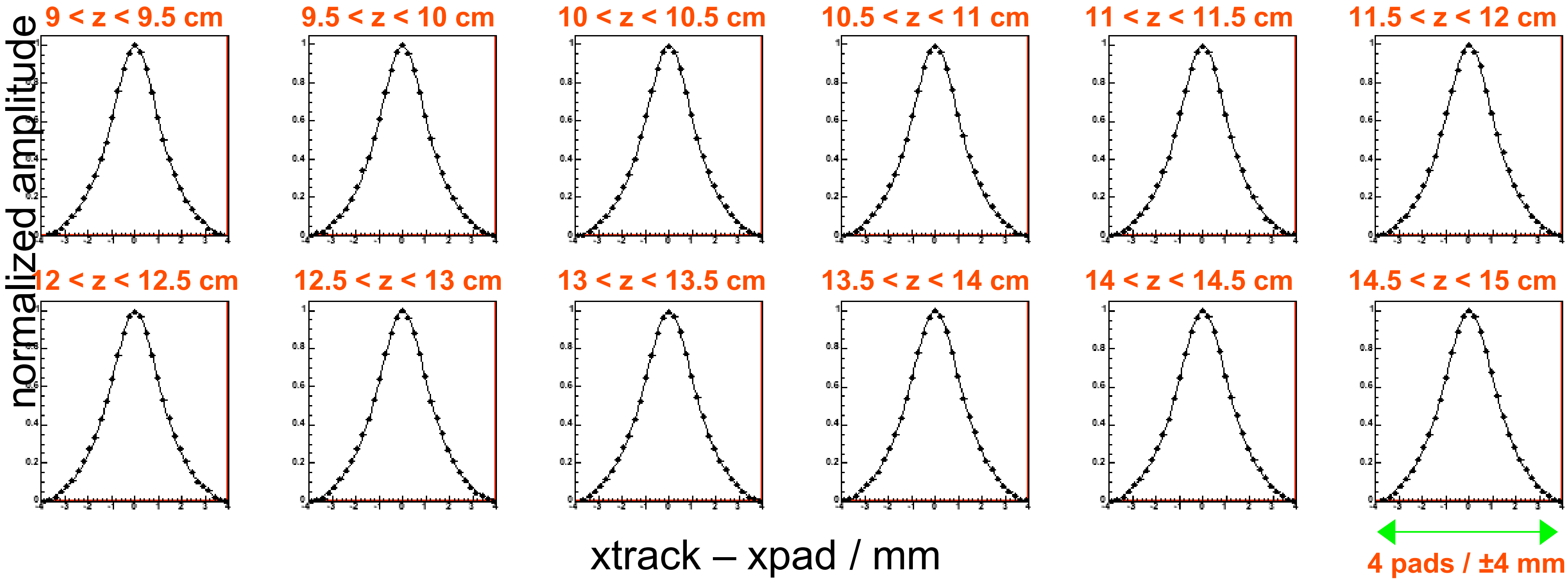
Pad Response Function / Ar+5%iC4H10

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

30 z regions /
0.5 cm step



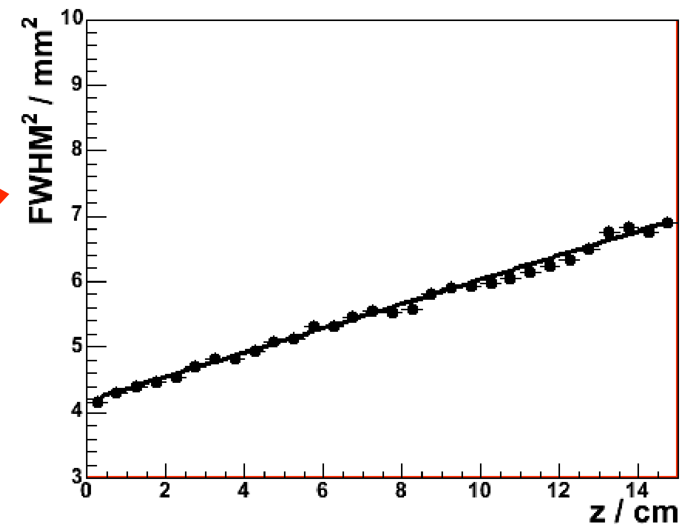
Pad Response Function / Ar+5%iC4H10



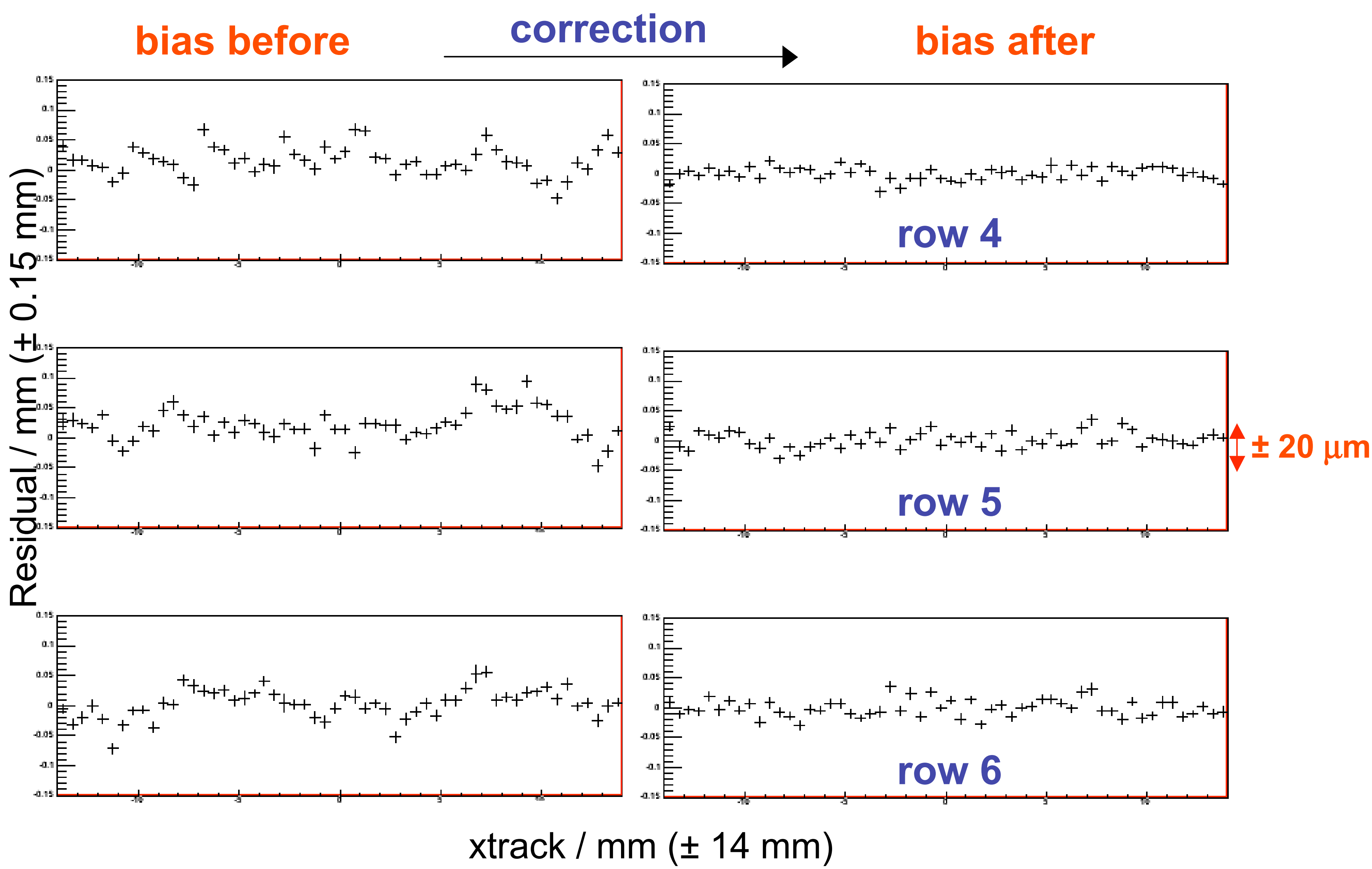
PRF parameters

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

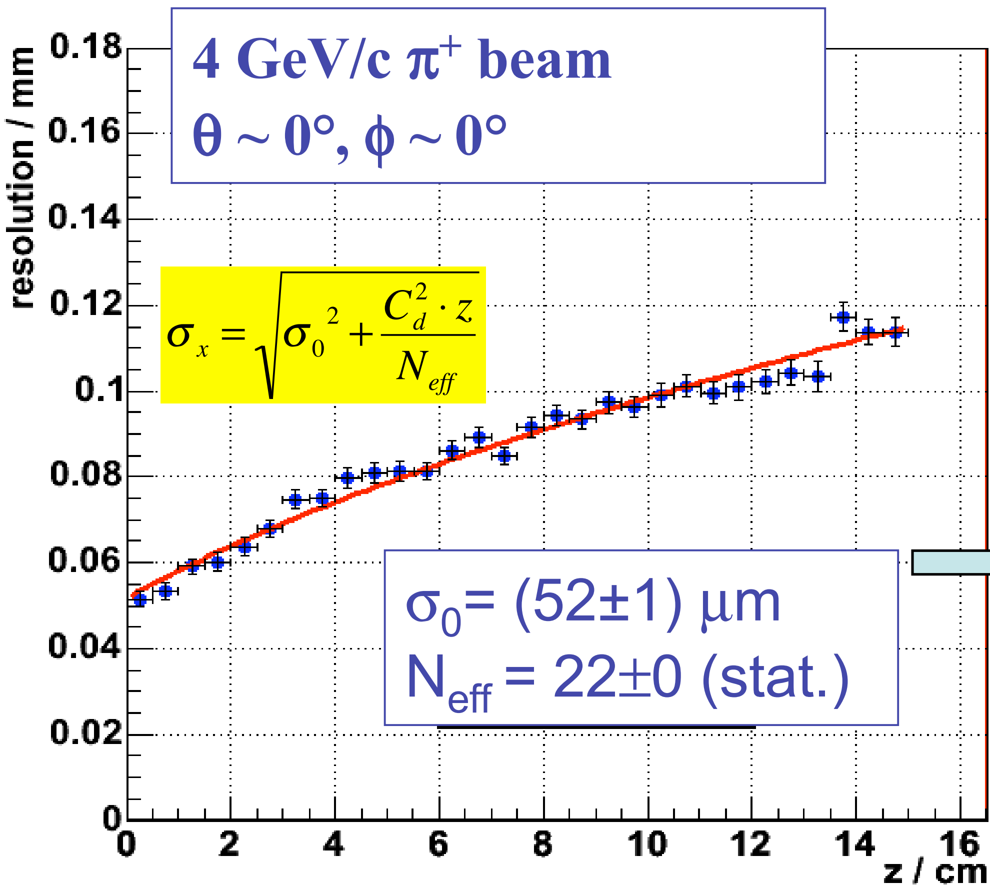
The parameters depend on TPC gas & operational details



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 TPC 2 x 6 mm^2 pads



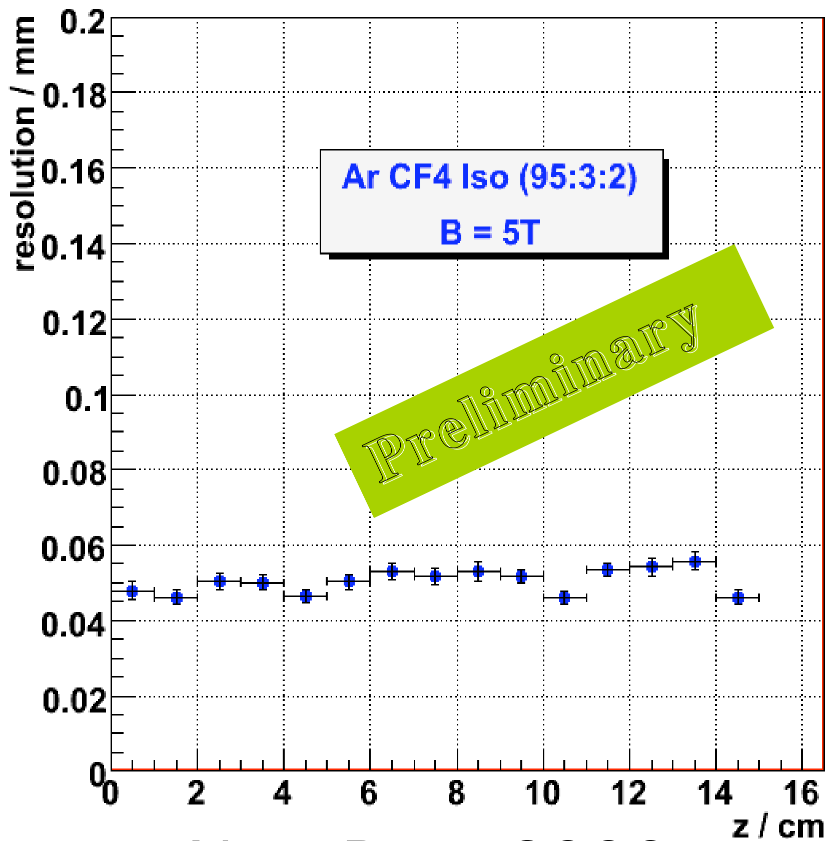
•Strong suppression of transverse diffusion at 4 T.
Examples:
D_{Tr}~ 25 µm/√cm (Ar/CH4 91/9)
Aleph TPC gas
~ 20 µm/√cm (Ar/CF4 97/3)

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

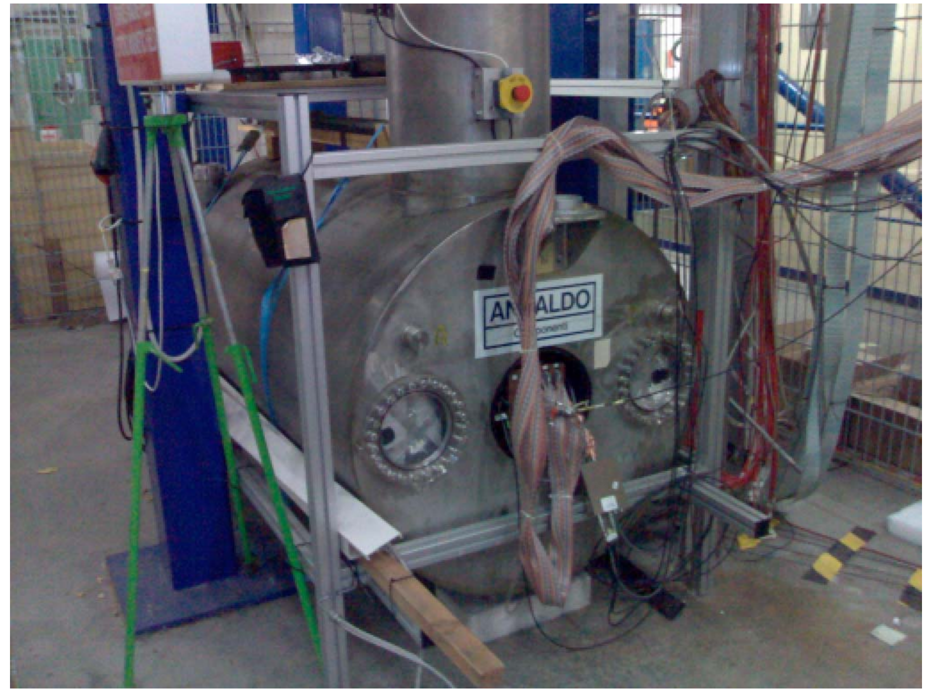
5 T cosmic tests with charge dispersion at DESY

COSMo (Carleton, Orsay, Saclay, Montreal) Micromegas TPC

D_{Tr}= 19 μm/√cm, **2 x 6 mm² pads**



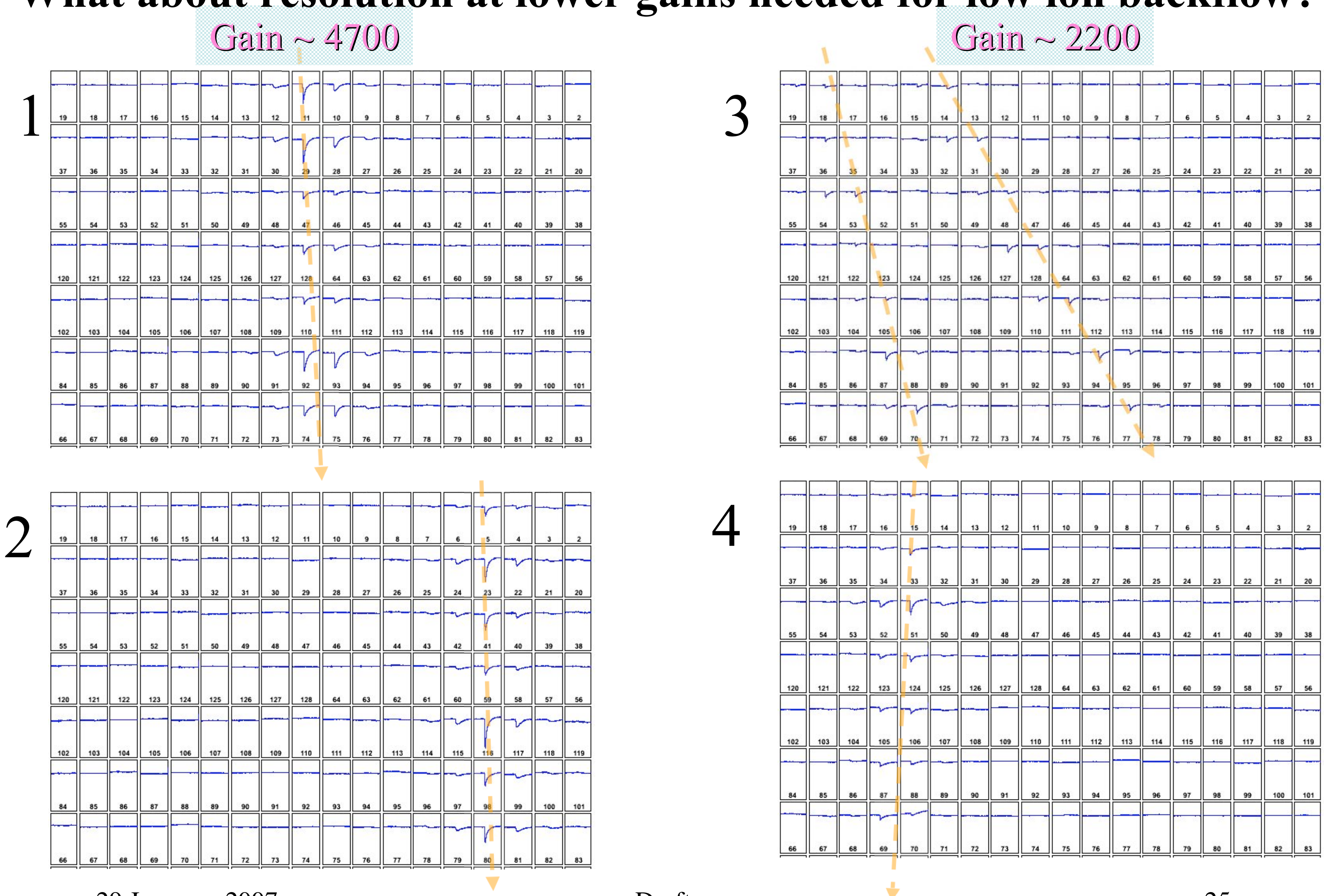
Nov-Dec, 2006



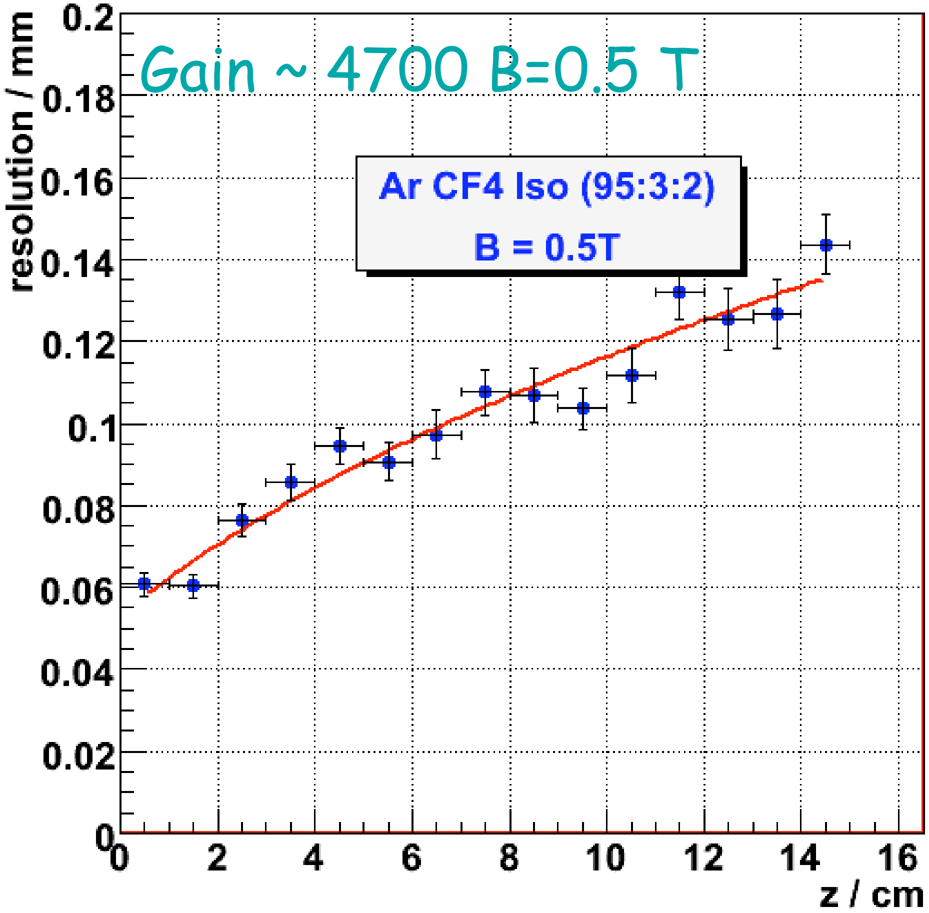
~ 50 μm av. resolution over 15 cm (diffusion negligible)

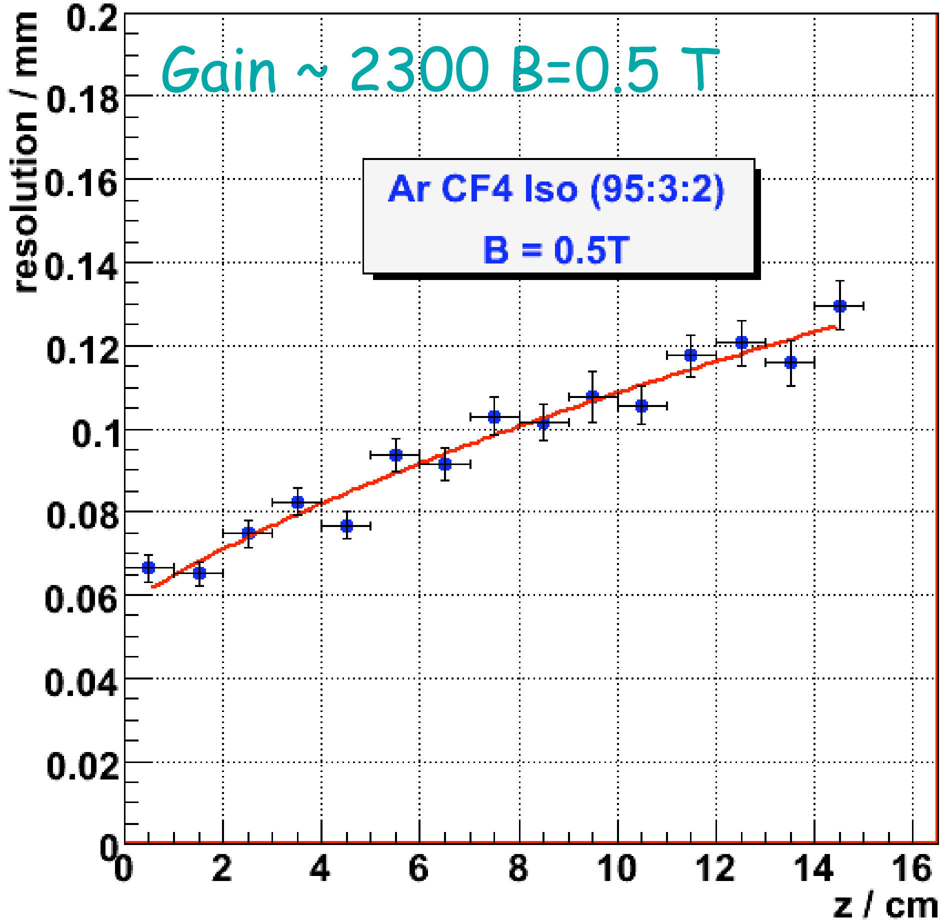
100 μm over 2 meters appears feasible

What about resolution at lower gains needed for low ion backflow?



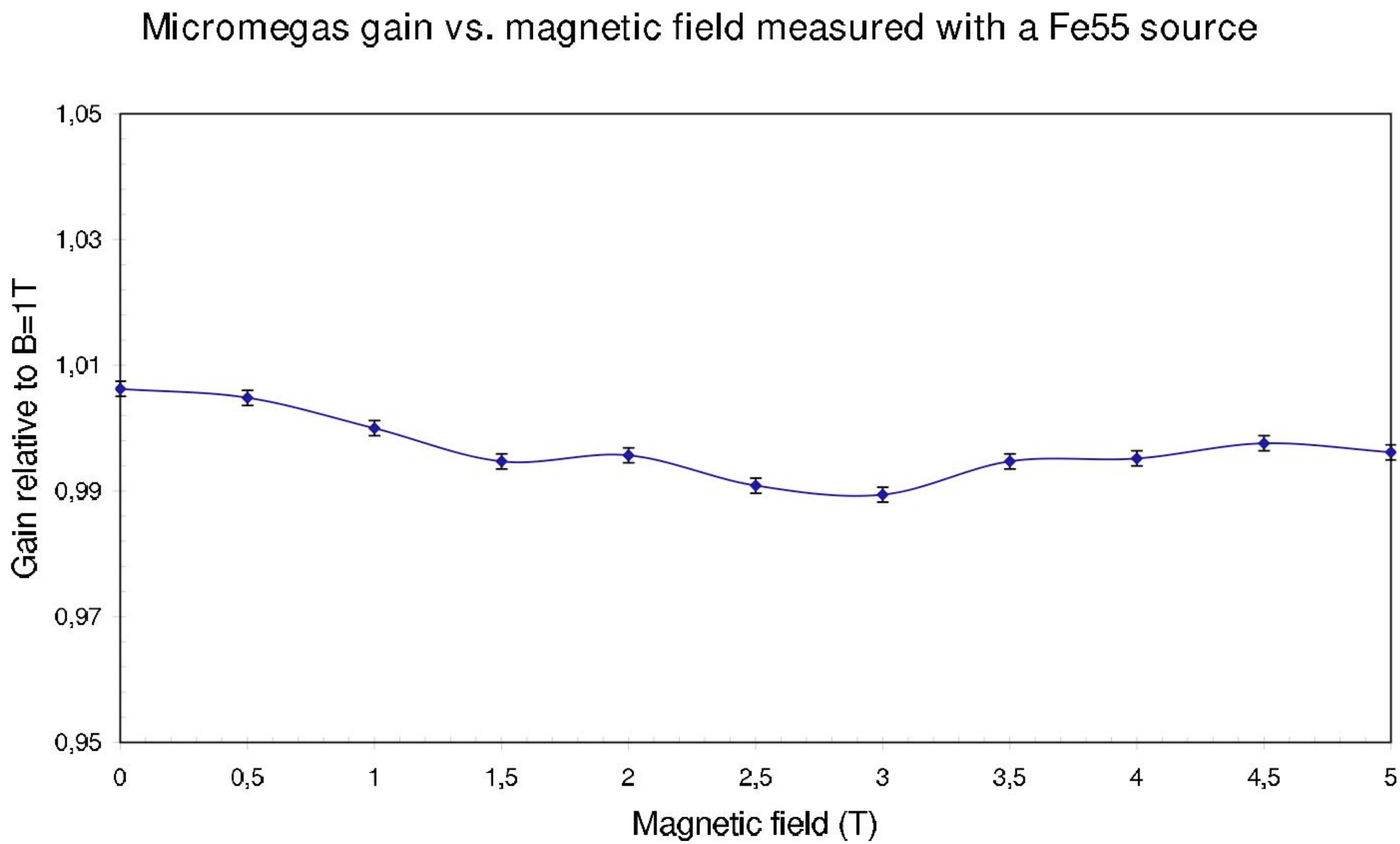
Sample pulses for a few tracks B= 0.5 T at high and low gains





The resolution and σ_0 still good at low gain

Micromegas gain measurement in the DESY magnet



Gain constant to ~ 0.5% up to 5 T

Simulating the charge dispersion phenomenon

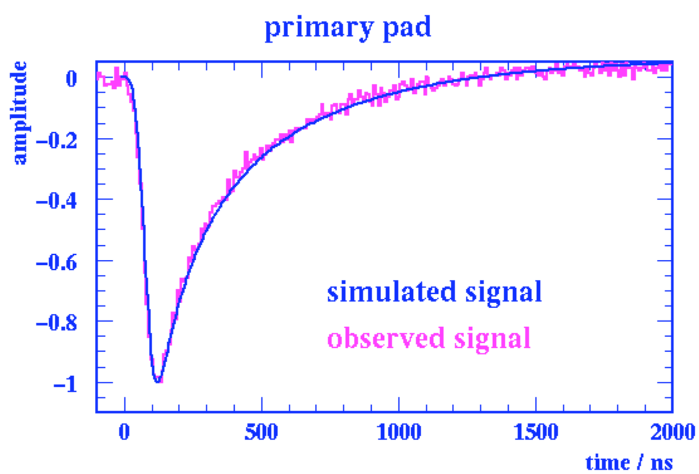
M.S.Dixit and A. Rankin, Nucl. Instrum. Methods* A566 *(2006) 281.

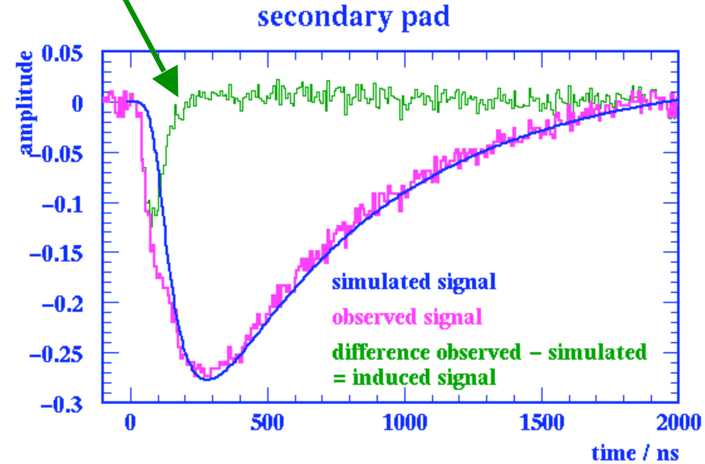
- The charge dispersion equation describe the time evolution of a point like charge deposited on the MPGD resistive anode at $t = 0$.
- No standard pulse shape. For a better understanding & to compare to experiment, one must include the effects of:
    - Longitudinal & transverse diffusion in the gas.
    - Intrinsic rise time T_{rise} of the detector charge pulse.
    - The effect of preamplifier rise and fall times t_r & t_f.
    - And for particle tracks, the effects of primary ionization clustering.

Charge dispersion spot x-ray signal for GEM
Simulation versus measurement (Ar+10%CO2)

(2 x 6 mm^2 pads) Collimated ~ 50 μm 4.5 keV x-ray spot on pad centre.

Difference = induced signal (not included in simulation) studied previously:
MPGD '99 (Orsay), LCWS 2004 Paris

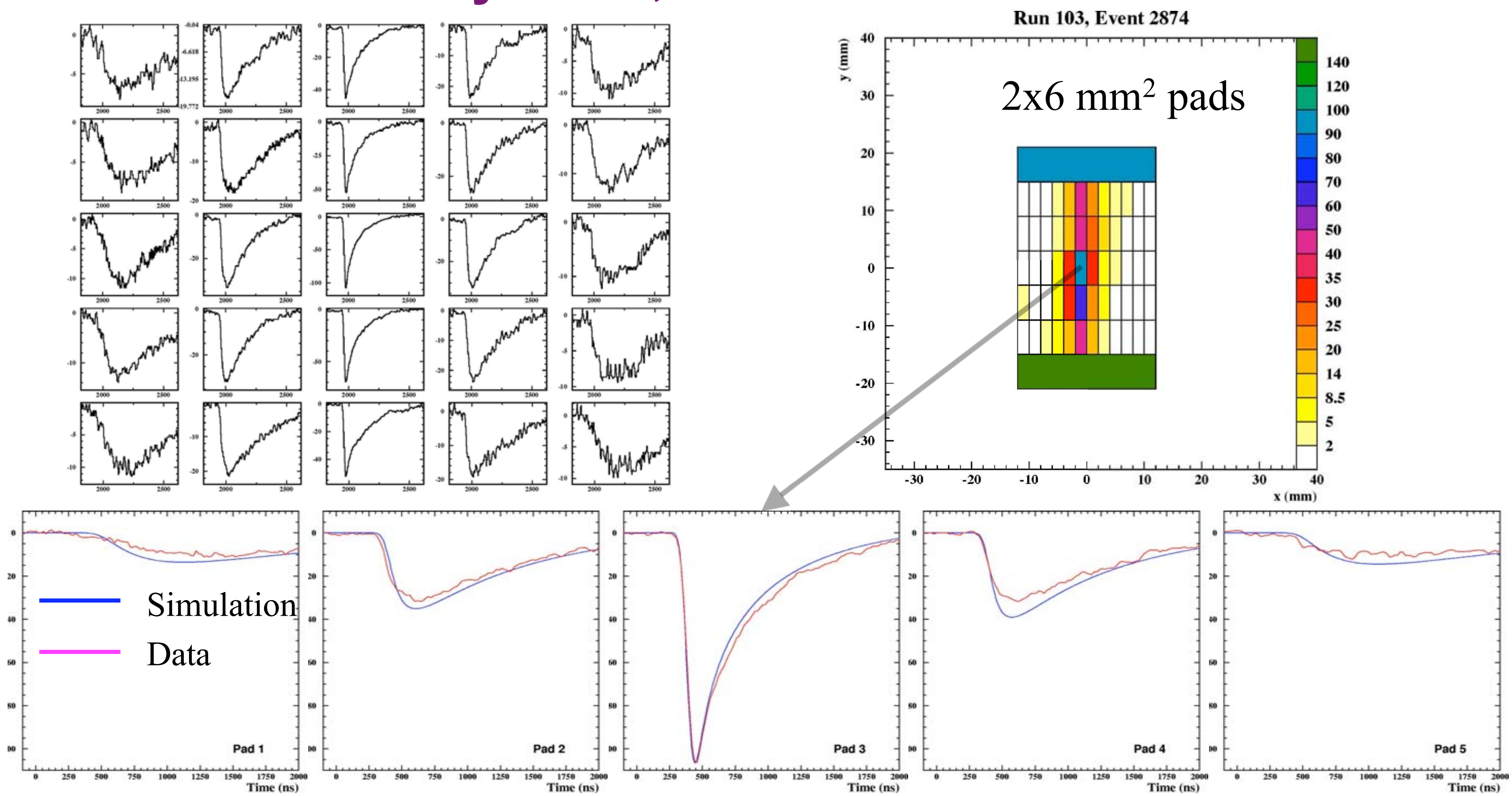




Simulated primary pulse is normalized to the data.

Primary pulse normalization used for the simulated secondary pulse

GEM TPC charge dispersion simulation (B=0)
Cosmic ray track, Z = 67 mm Ar+10%CO2



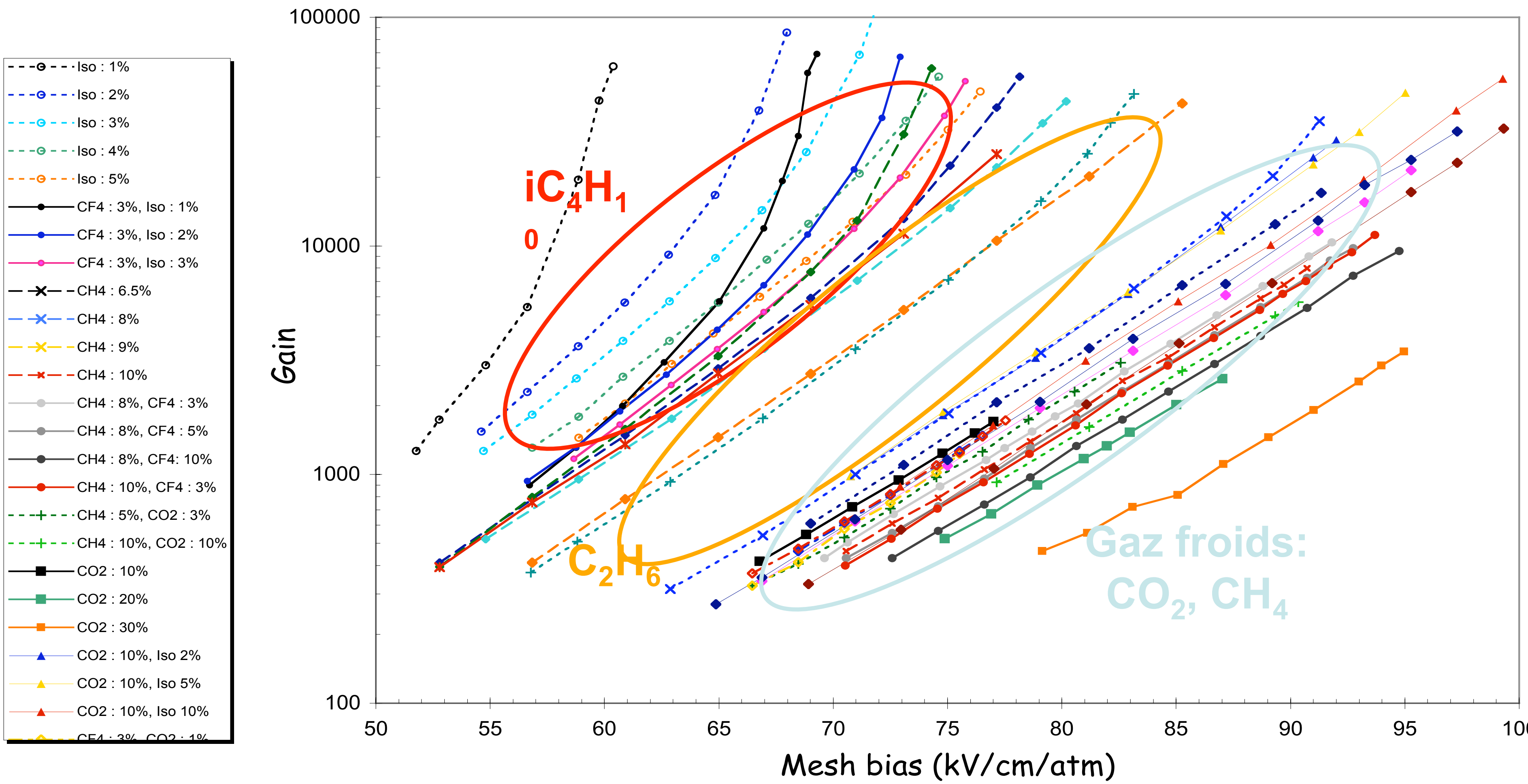
Centre pulse used for simulation normalization - no other free parameters.

Micromegas gas gain measurements at Saclay

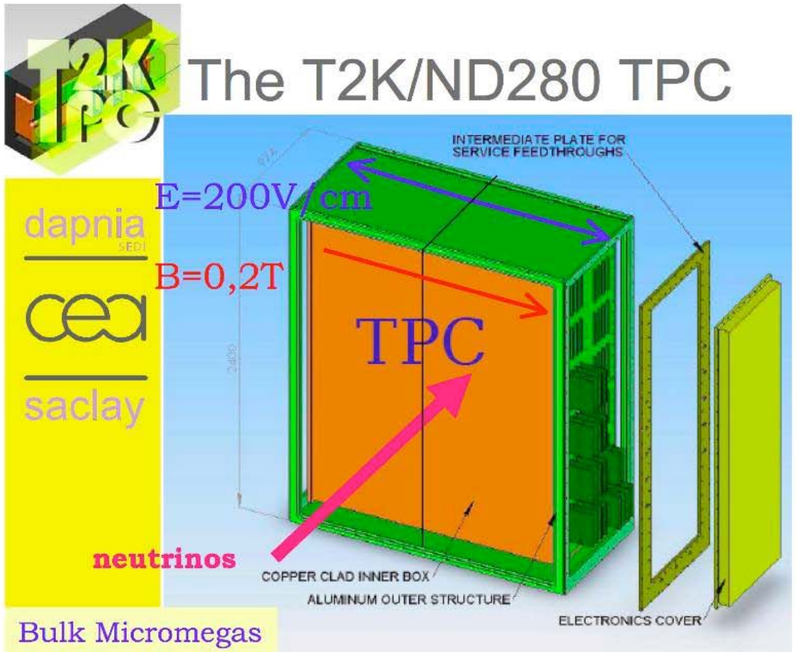
(David Attie, EUDET Meeting, Munich 18 October, 2006)

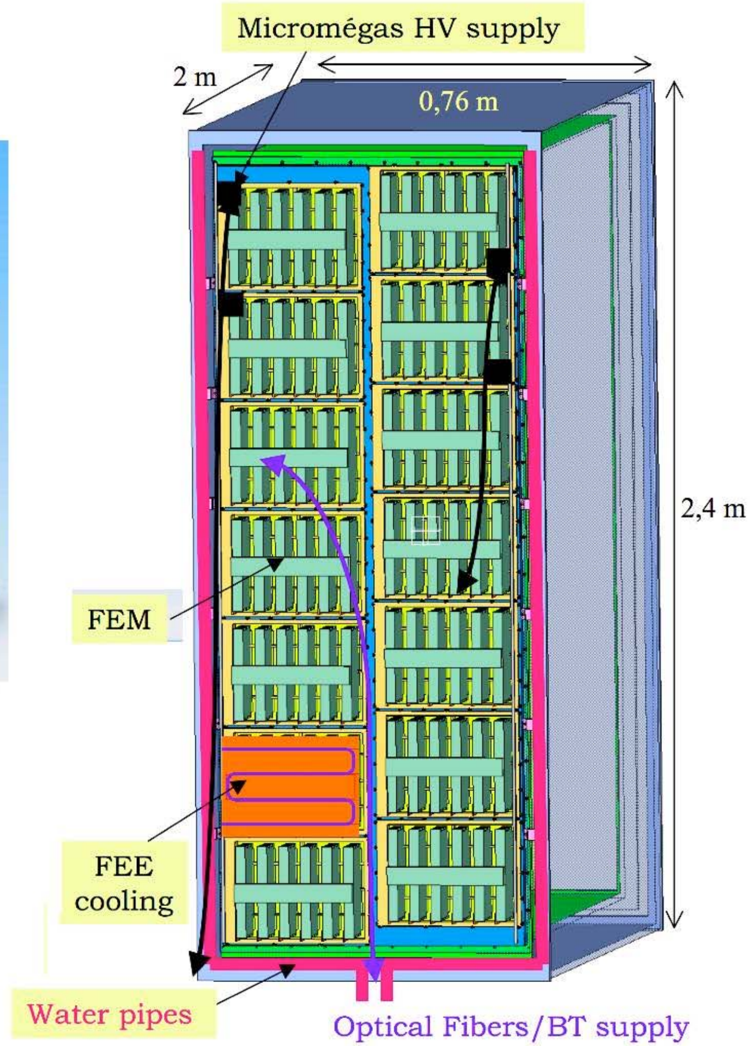
Mesh : 50 μm gap of 10x10 size

Mixtures of gases containing argon



Large panel Micromegas development for T2K TPCs





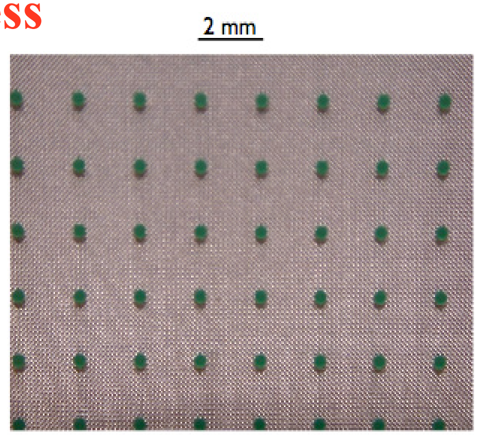
- T2K will have 3 TPCs
- 72 Micromegas modules
- Total area ~ 9 m^2
- 124416 readout channels

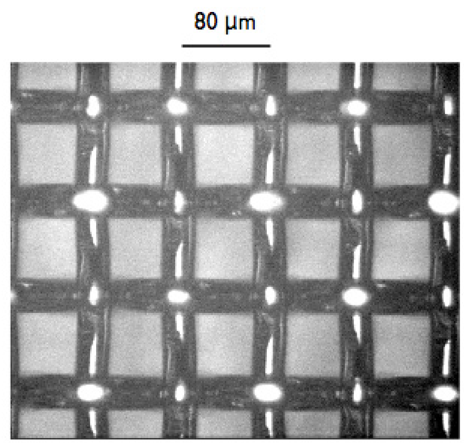
New development
Bulk Micromegas

I. Giomataris, R. De Oliveira et al., DAPNIA-04-80

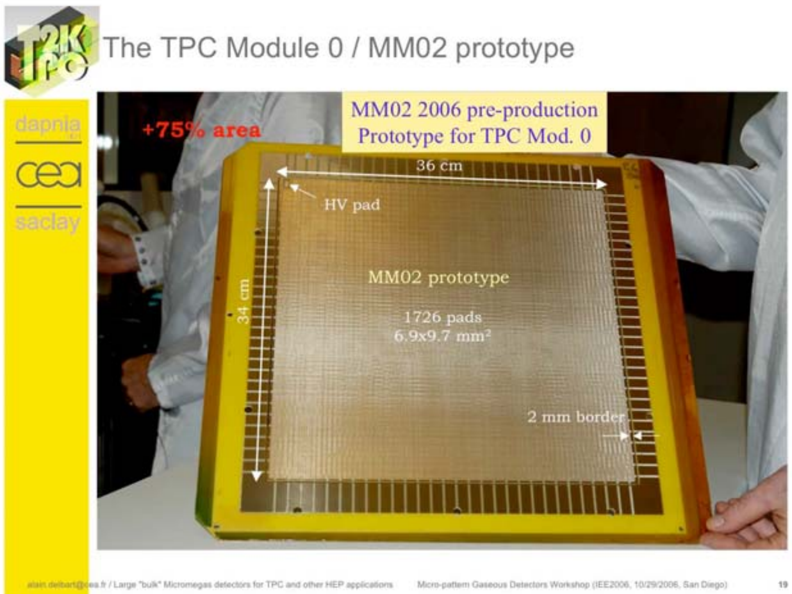
- **Large area and robustness**
  Good uniformity
  Easy implementation
  Low cost
  Industrial process

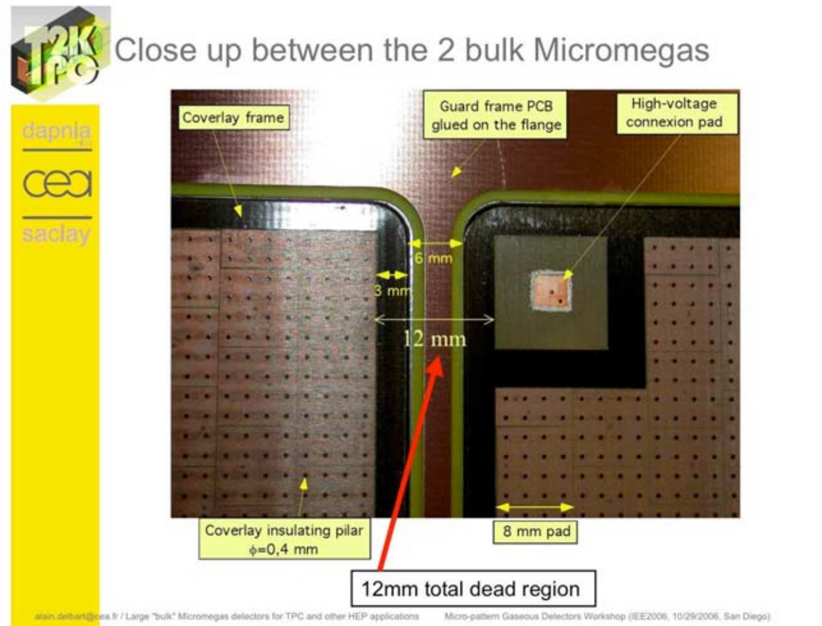
- Bulk Micromegas obtained by lamination of a woven grid on an anode with a photo-imageable film





Bulk Micromegas development for T2K



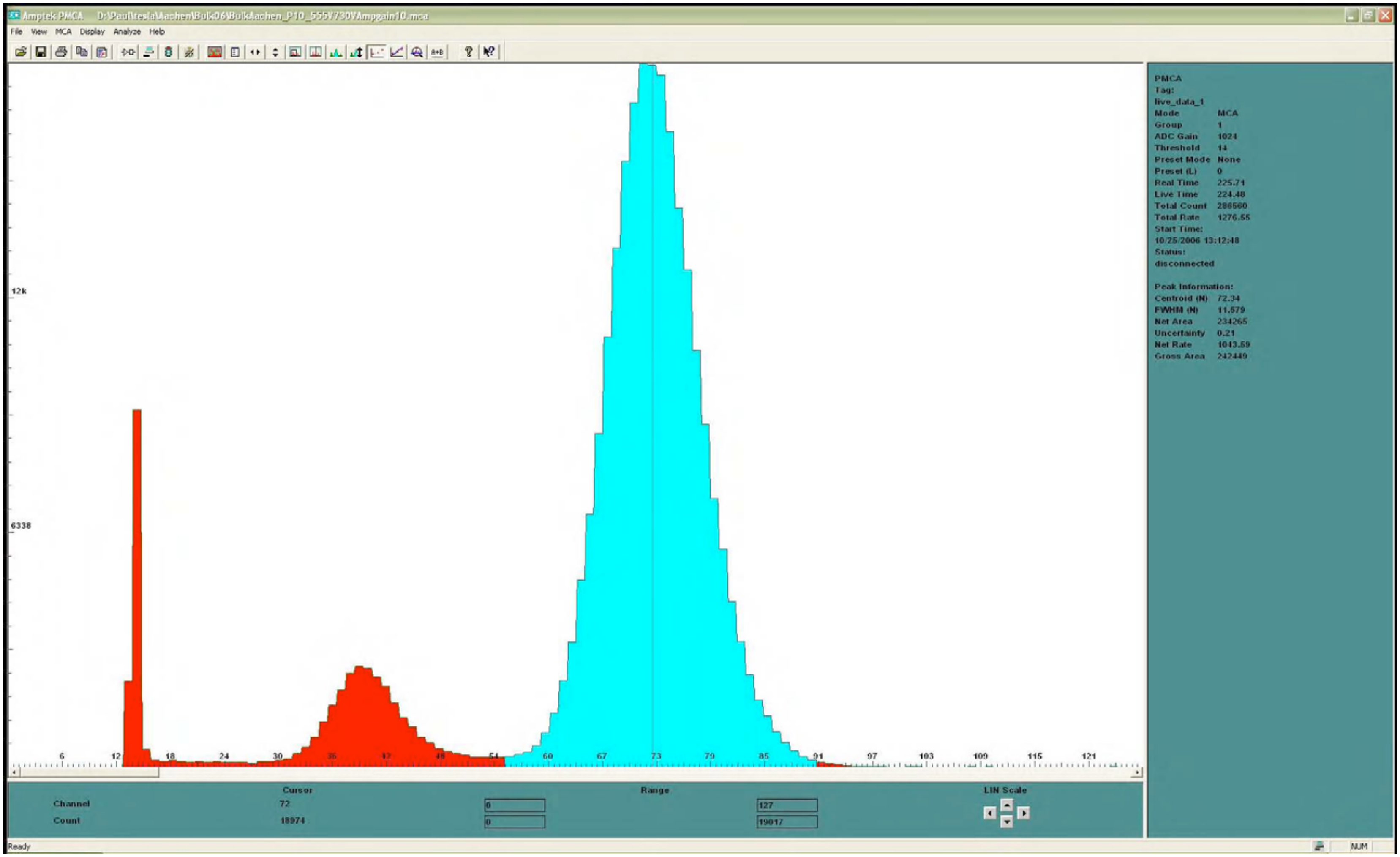


Bulk Micromegas is cut with a 2 mm border

Fully engineered project

Bulk Micromegas are self supporting

Minimum dead space between panels ~ 8 mm



Bulk Micromegas - 6 keV ^{55}Fe x-rays

Electronics
to be provided by Luciano

Summary

- MPGD-TPC has difficulty achieving good resolution with wide pads
- With charge dispersion, the charge can be dispersed in a controlled way. Wide pads can be used without sacrificing resolution. Charge dispersion works both for the GEM and the Micromegas.
- At 5 T, an average ~ 50 μm resolution has been demonstrated with 2 x 6 mm^2 readout pads for drift distances up to 15 cm.
- The ILC-TPC resolution goal, ~100 μm for all tracks, appears feasible.