# Charge Dispersion in Micro Pattern Gas Detectors with a Resistive Anode

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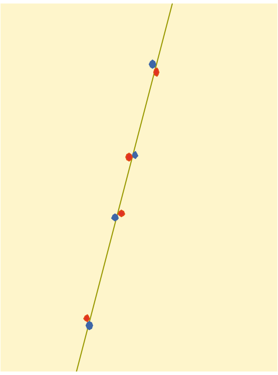
**Special focus workshop on New Developments in Micro-Pattern Gas Detectors**
**2007 IEEE Nuclear Science Symposium & Medical Imaging Conference, Hawaii**

# Resolution of a gaseous charged particle counter with pad/strip readout

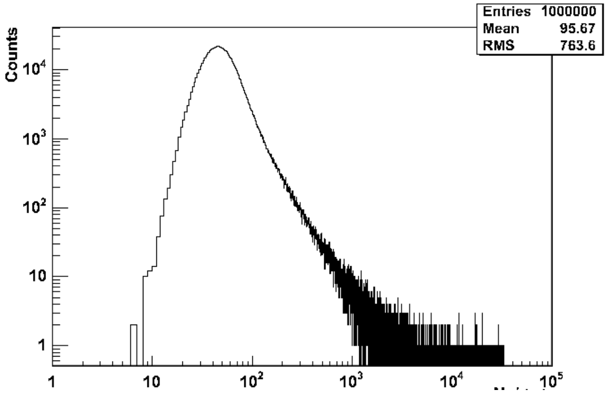
*1) Primary ionizing interactions (Poisson Distribution)*

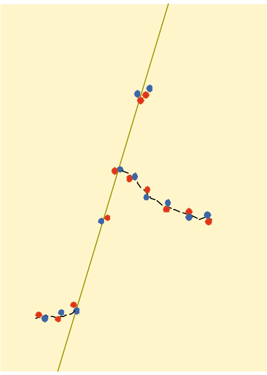
$$P(n) = \langle N\rangle^{n}\, e^{-\langle N\rangle}/n! \quad (\langle N\rangle = \text{average})$$



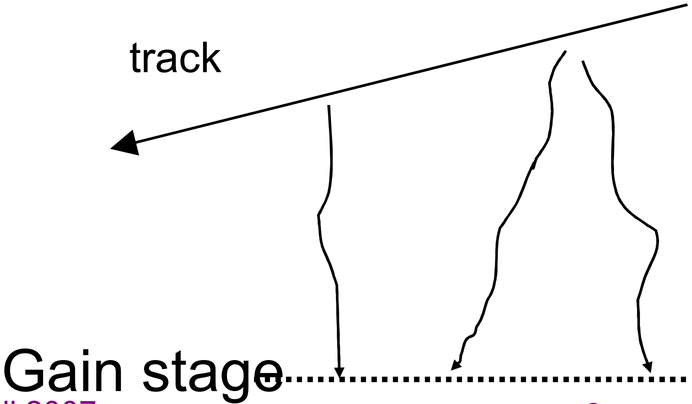
*2) Number of electrons per cluster fluctuates (cluster size distribution)*

*Fischle et al (A301, 202 (1991)*

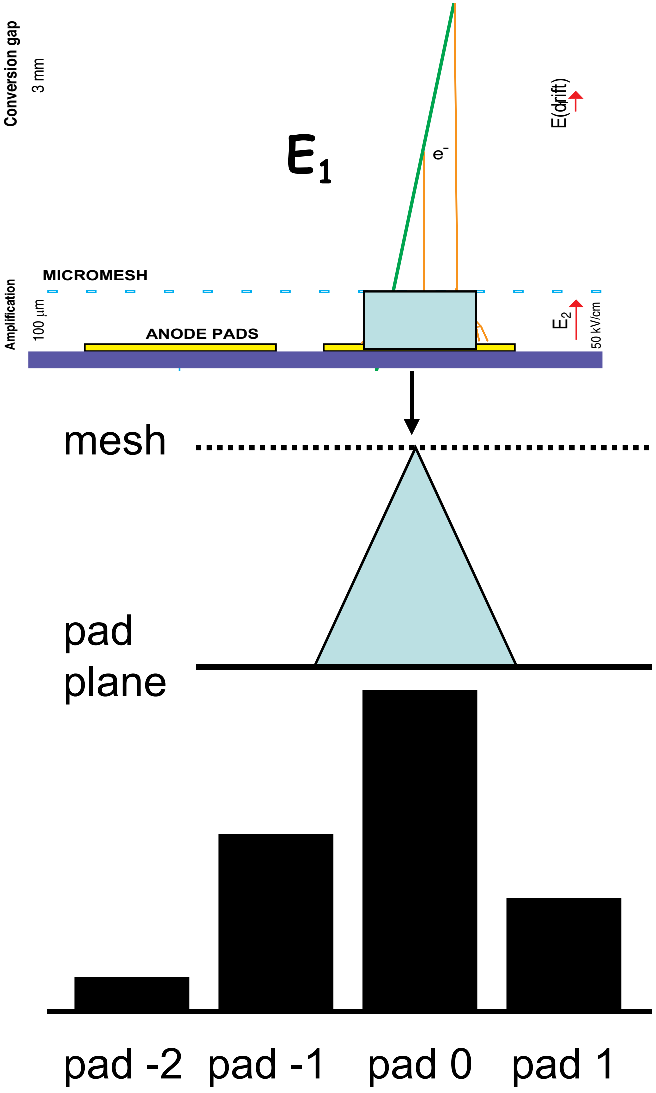




*3) Electrons drift with Gaussian diffusion toward the readout amplification stage*



# MPGD resolution with conventional readout Micromegas example



*Electron drift distance from ~ mm to meters*

*4) Gas avalanche (Gain fluctuations)*

*5) Readout (pad size depends on application)*

**Resolution from centre of gravity**

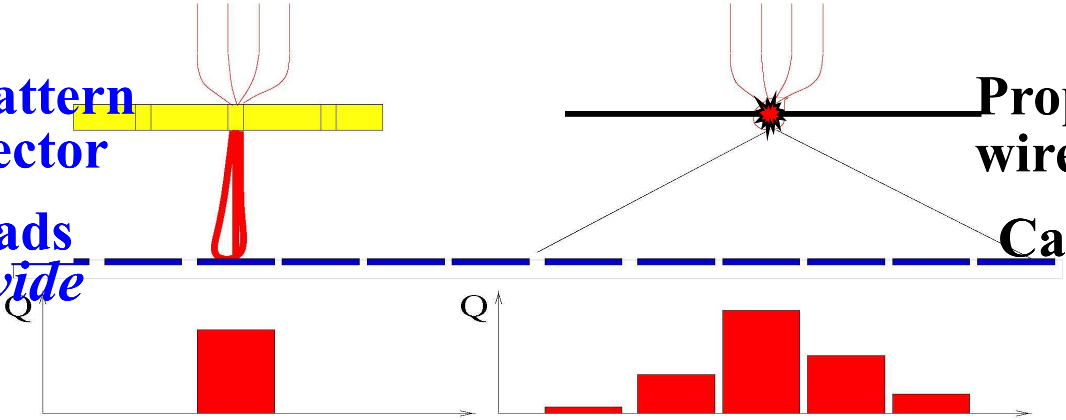
$$\sigma_x^2 \approx \sigma_0^2 + \frac{1}{N_{eff}}\left[D_{Tr}^2 z + w^2/12\right]$$

*$N_{eff}$ is less than <N> (average number of electrons)*

*= 1/<1/N>*

*$N_{eff}$ ~20 to 30% of <N>*

# Pad width limiting factor for a MPGD-TPC in a high B field
# Wire/pad TPC not limited by pad width but by ExB effects



**Micro Pattern Gas Detector**

**Anode pads** *2 mm wide*

**Proportional wire**

**Cathode pads** *2 mm wide*

**Direct signal on the MPGD anode pad**

**For small diffusion, less precise centroid for wide pads**

**Induced cathode signal determined by geometry**

**Accurate centroid determination possible with wide pads**

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

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

# MPGDs in charged particle tracking applications

- For standard tracking applications, to achieve good resolution, MPGDs require high density sub-mm pad readout structure: $\sigma_x \approx w/\sqrt{(12\ N_{eff})}$
- GEMs & Micromegas (e.g.COMPASS)
  - $w = 400\ \mu m$ & $\sigma_x \approx 70\ \mu m \Rightarrow N_{eff} \approx 3$
  - Number of readout channels manageable
- Several large volume MPGD-TPCs proposed for HEP and for rare event detection; e.g.
  - ILC TPC: 1,500,000 channels (2 mm x 6 mm pads)
  - At B = 4 Tesla; **$D_{Tr}$~ 25 $\mu$m/$\sqrt{}$cm; $\sigma$(z=2m) ~ 350 $\mu$m** **&** signal confined to 1 or 2 pads
  - T2K TPC: 100,000 channels (7 mm x 9 mm pads)

# The large TPC challenge:
# How to reduce complexity and achieve good resolution at an affordable costs

- Unprecendented resolution challenge for the ILC TPC. To measure 200 track points; σ(r, φ) ~ 100 μm at 2 m drift including stiff 90 degree tracks.
- For the GEM, large transverse diffusion in the transfer & induction gaps provides a natural mechanism to disperse the charge and facilitate centroid determination.
- **GEMs with standard readout will need ~ 1 mm wide pads to achieve ~ 100 μm resolution goal with ~3,000,000 readout channels**
- With standard readout, even narrower pads would be needed for the Micromegas

# How to get good MPGD resolution with wide pads?

- Find a mechanism similar to proportional wire induced cathode pad signals
- Charge dispersion - a new geometrical pad signal induction mechanism for the MPGD readout that makes position determination insensitive to pad width.
- Development of a new concept of charge dispersion in a MPGD with a resistive anode The technique works for both the GEM and the Micromegas

# Position sensing from charge dispersion in a MPGD with a resistive anode

Position sensing on a anode proportional wire from charge division

Telegraph equation (1-D):

$$\frac{L}{R}\frac{\partial^2 Q}{\partial t^2} + \frac{\partial Q}{\partial t} = \frac{1}{RC}\frac{\partial^2 Q}{\partial x^2}$$

Deposit point charge at t=0

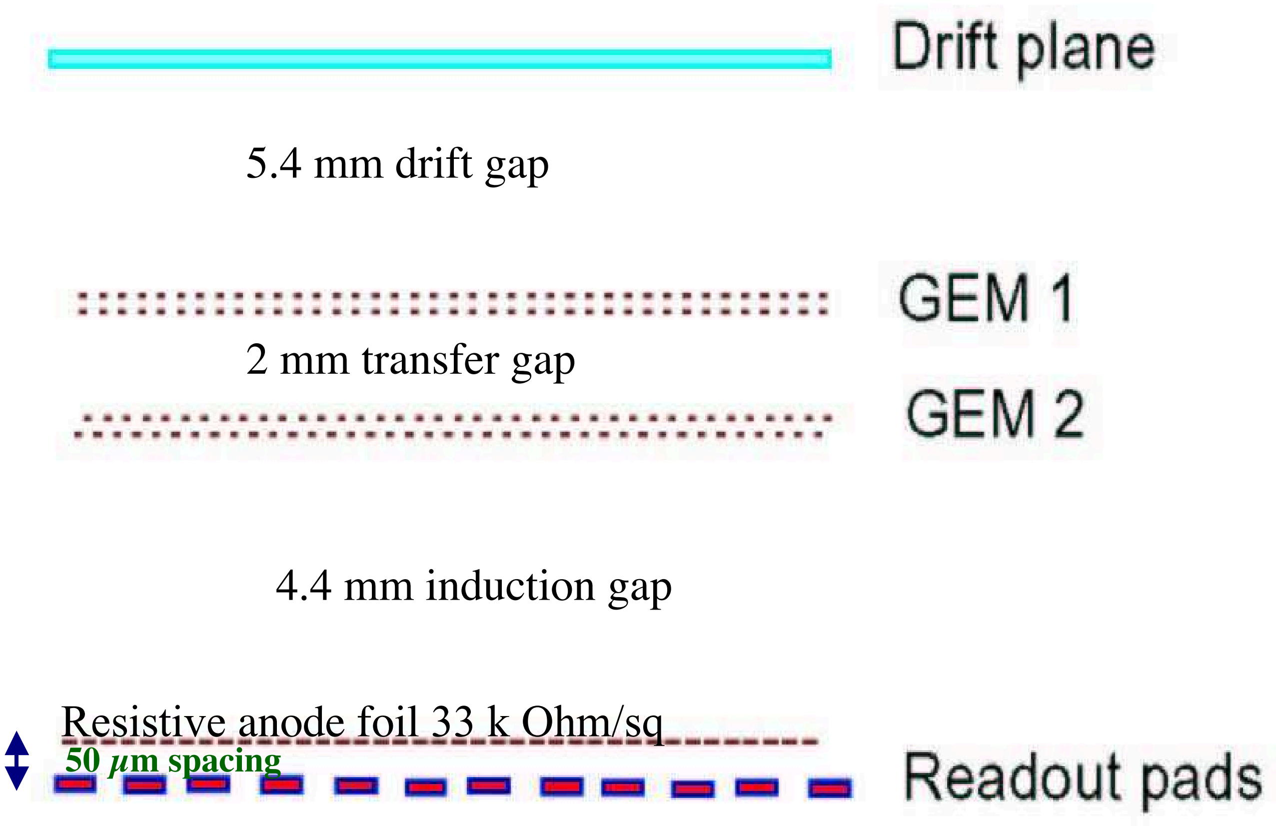
Solution for charge density (L ~ 0)

$$Q(x,t) = \sqrt{\frac{RC}{4\pi t}}\, e^{\frac{-x^2 RC}{4t}}$$

Generalize 1 D wire charge division to a 2 D RC network

# Charge dispersion readout concept test for GEM

## GEM Setup for Resistive Anode Tests


Drift plane

5.4 mm drift gap

GEM 1

2 mm transfer gap

GEM 2

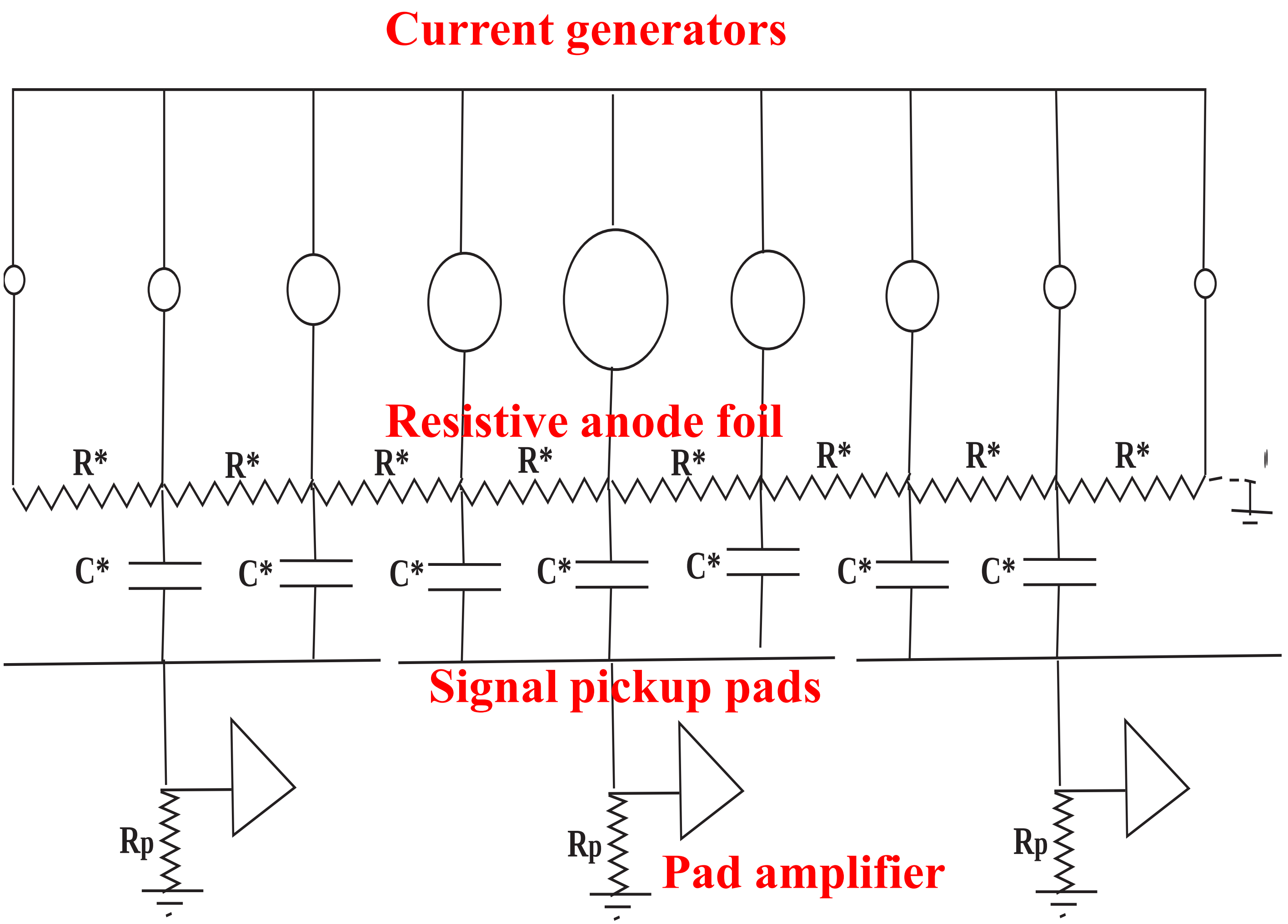
4.4 mm induction gap

Resistive anode foil 33 k Ohm/sq

50 $\mu$m spacing

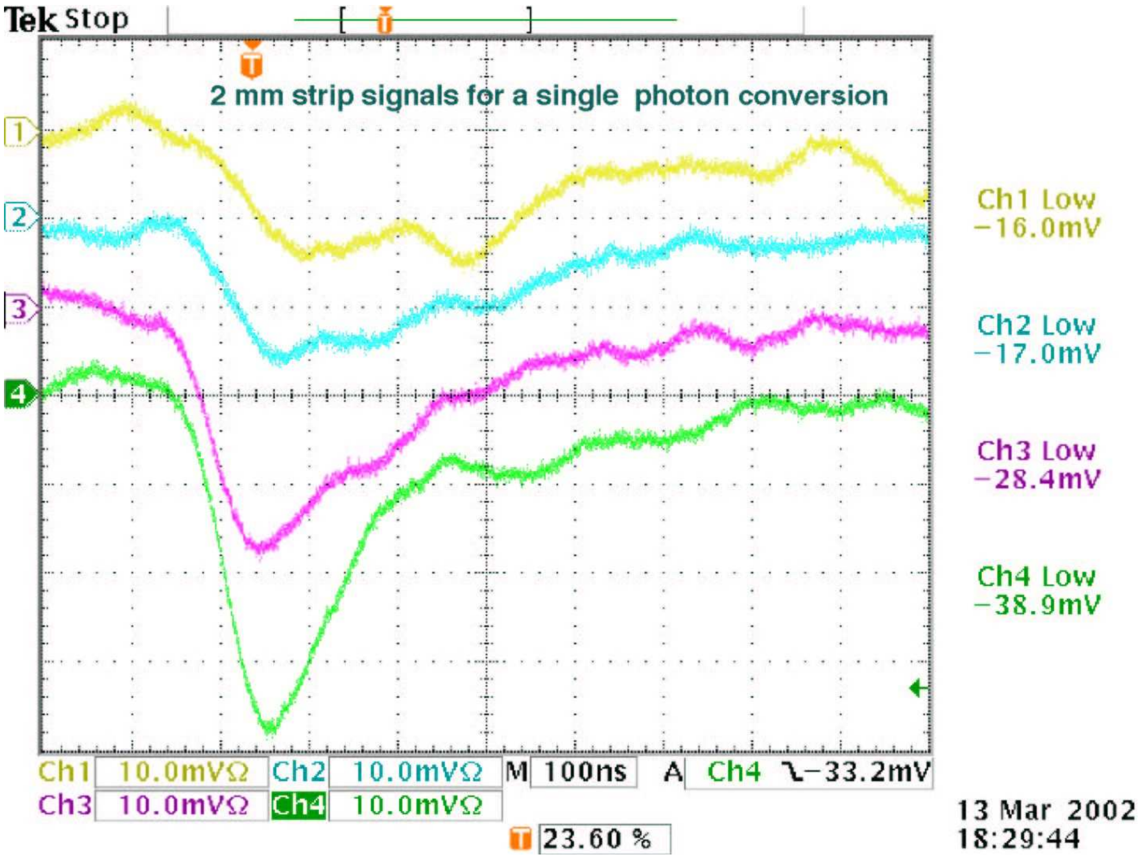
Readout pads

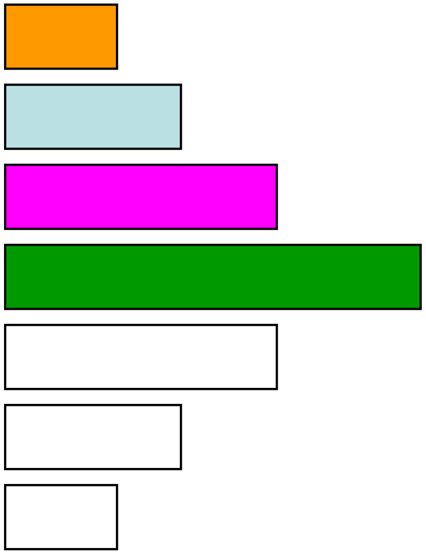
# Equivalent circuit for currents in a MPGD with an intermediate resistive anode



# Observation of a 6 keV $^{55}$Fe x-ray photon event in a double GEM test cell with a resistive anode

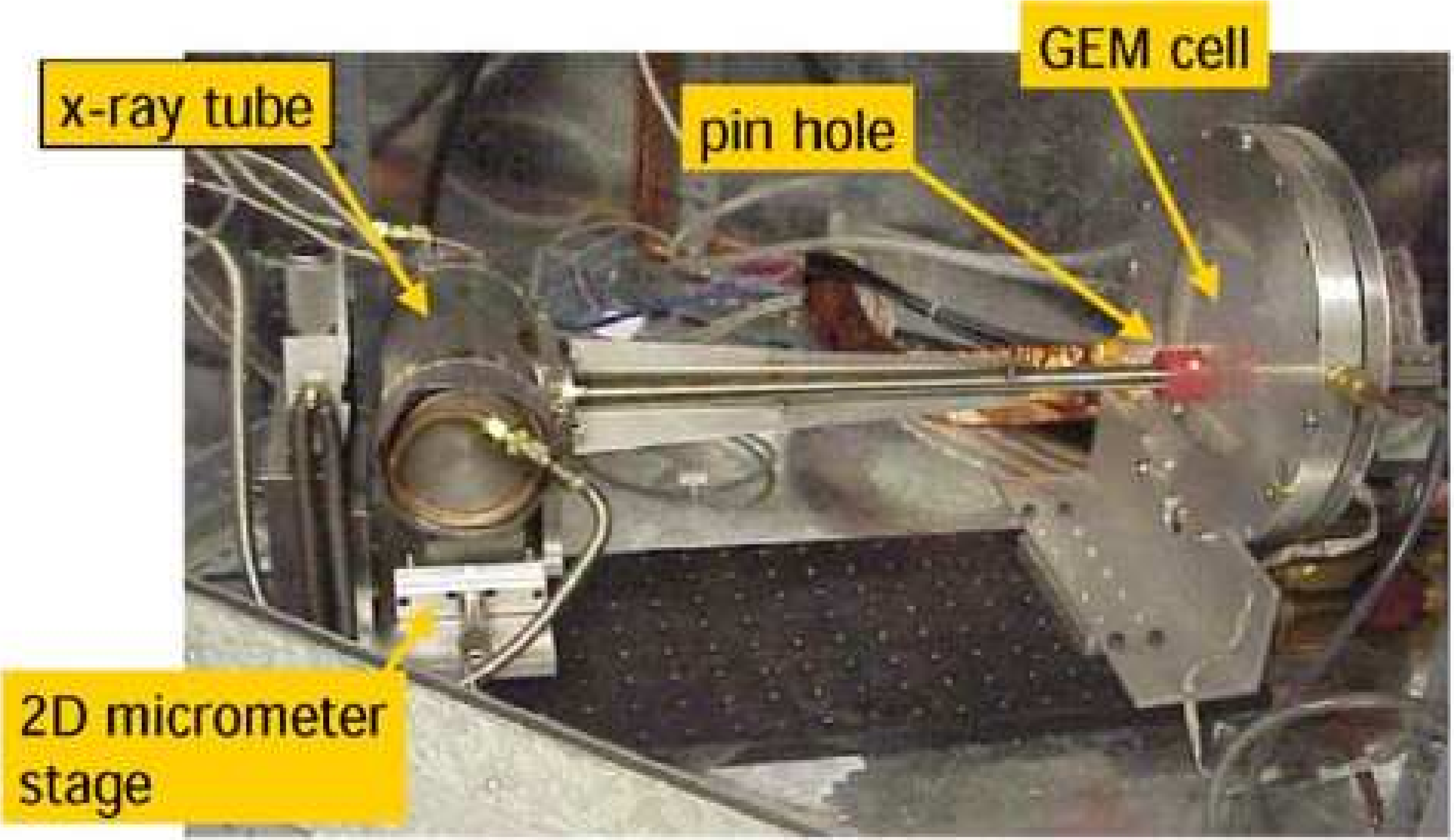
Collimator size ~ 1 mm ; signal detected by ~7 anodes (2 mm width)





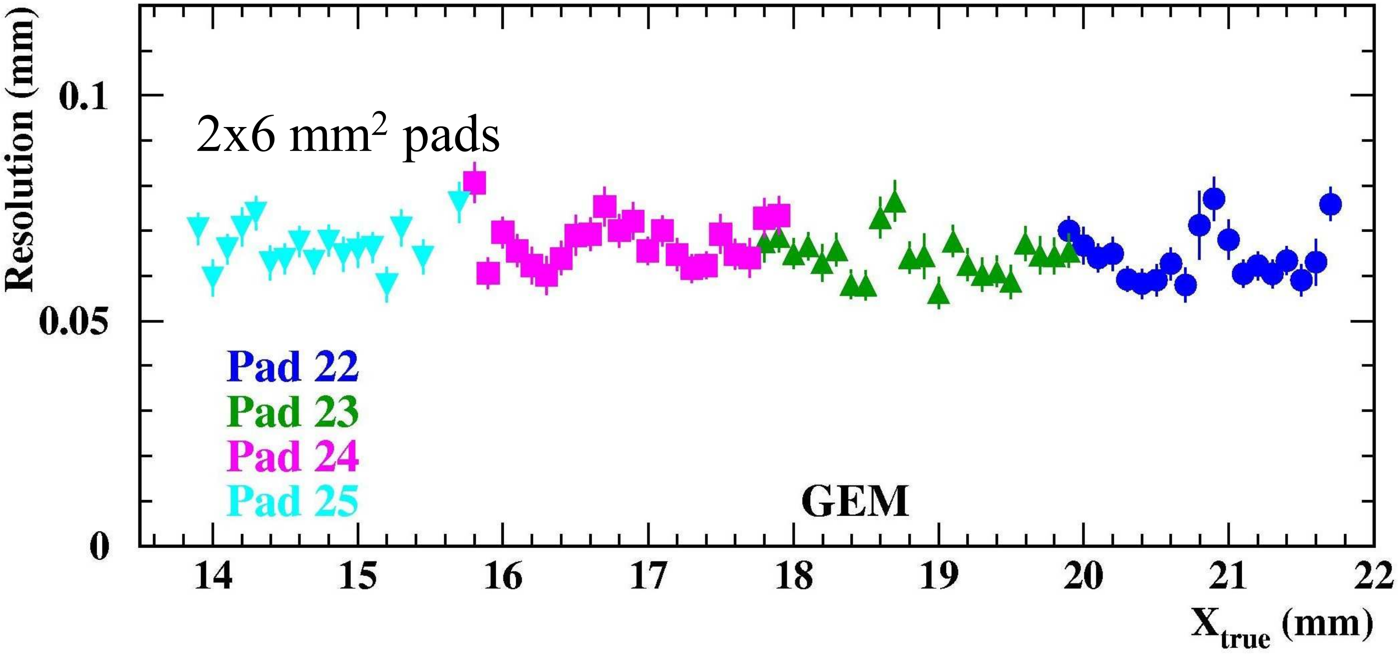
# GEM proof of concept tests with charge dispersion

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



# Point resolution for GEM
# Charge dispersion readout (Ar+10%CO2)

**Collimated ~ 4.5 keV x rays, Spot size ~ 50 μm**



- GEM resolution ~ 70 μm.
- Similar resolution measured for a Micromegas with a resistive anode readout using 2 mm x 6 mm pads

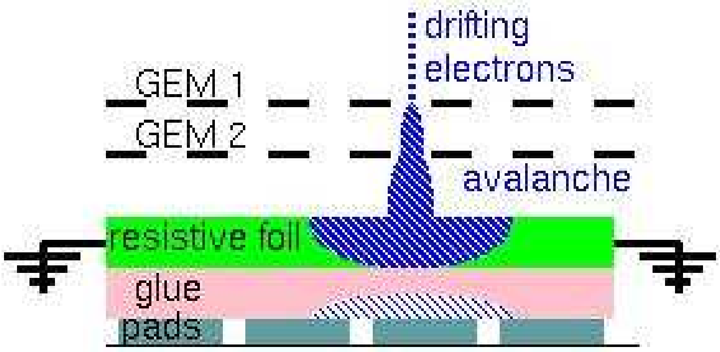
# Charge dispersion in a MPGD with a resistive anode

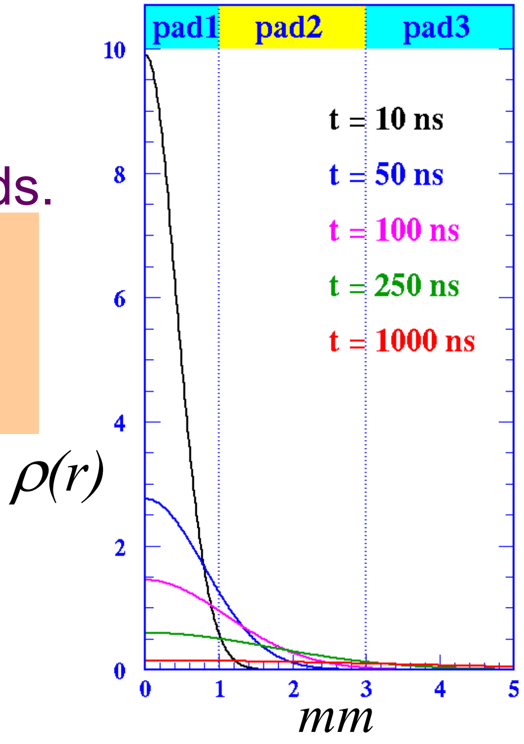
- Modified MPGD anode with a high resistivity film bonded to a readout plane with an insulating spacer.
- 2-dimensional continuous RC network defined by material properties & geometry.
- Point charge at *r = 0 & t = 0* disperses with time.
- Time dependent anode charge density sampled by readout pads.

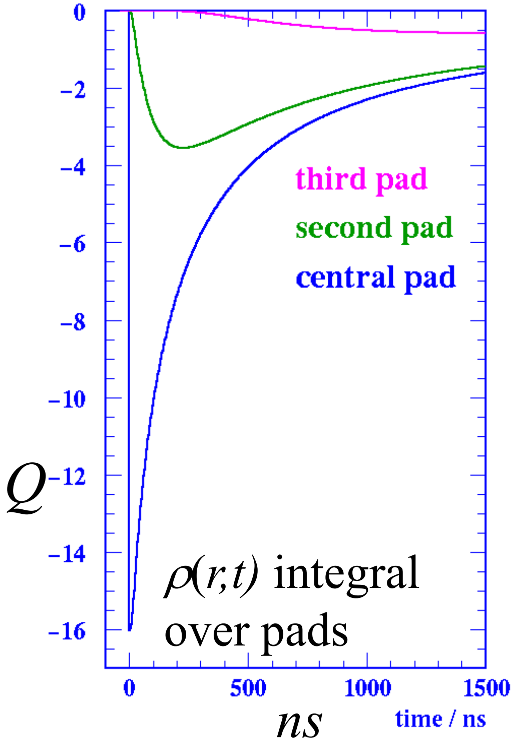
Equation for surface charge density function on the 2-dim. continuous RC network:

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

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

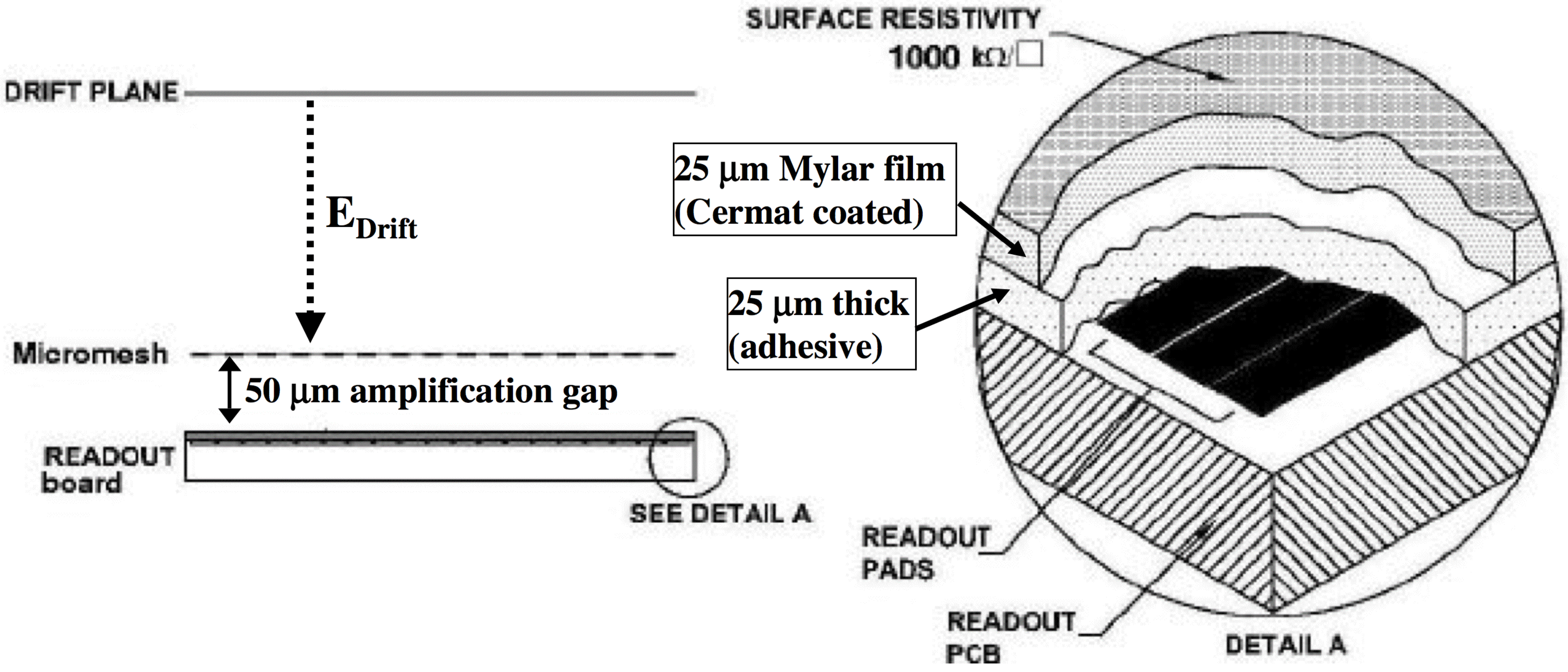






**M.S.Dixit et al, Nucl. Inst. Meth A518, 721 (2004)**

# Micromegas with a resistive readout



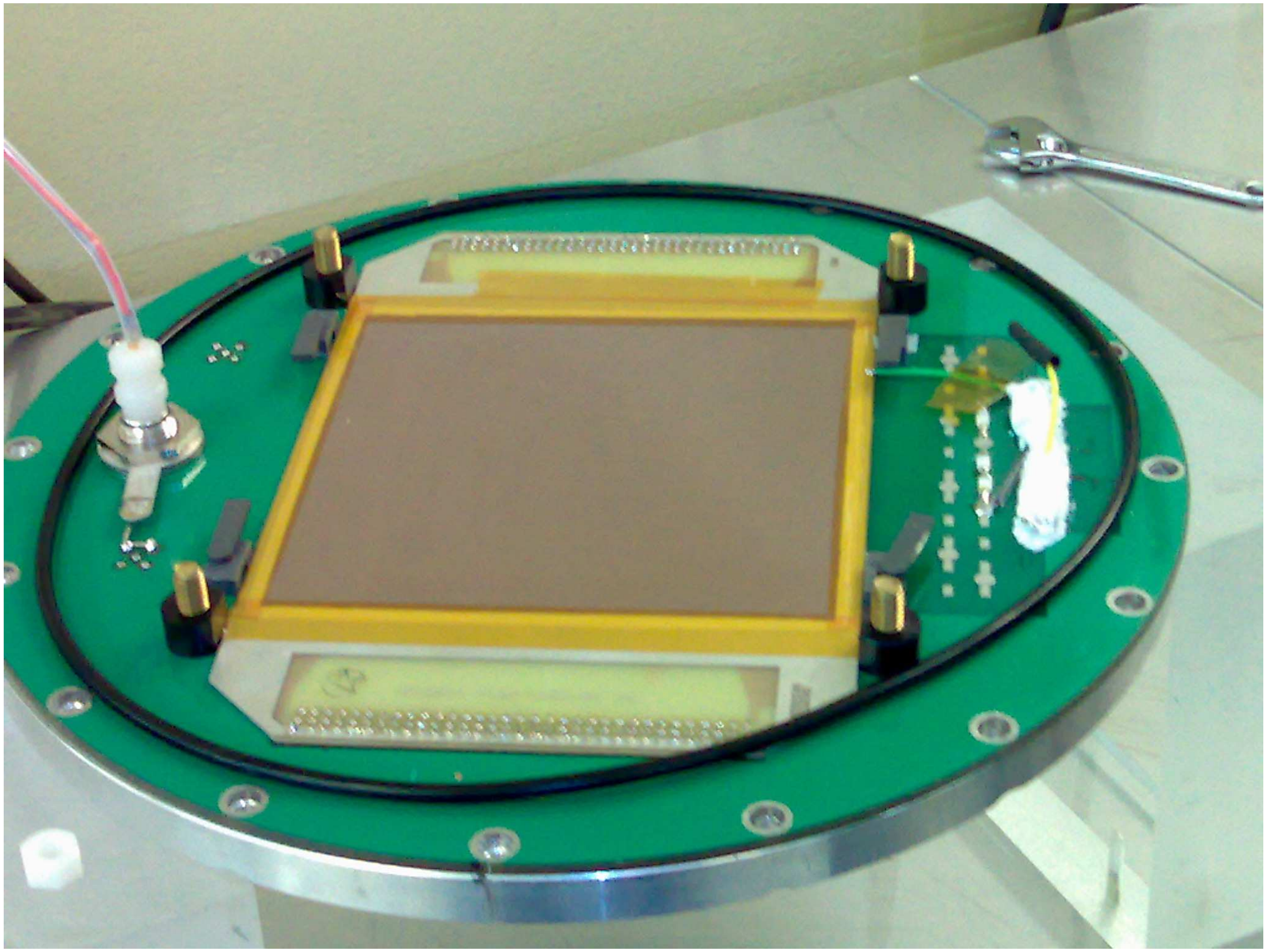
$E_{Drift}$

50 µm amplification gap

25 µm Mylar film
(Cermat coated)

25 µm thick
(adhesive)

# A resistive anode MPGD readout



# Simulating the charge dispersion phenomenona

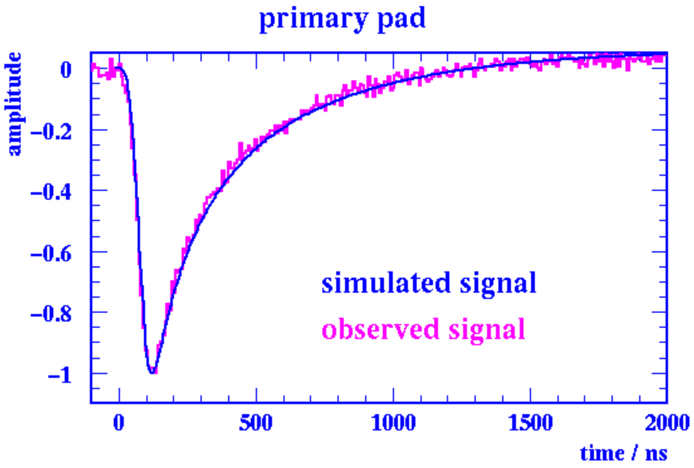
***M.S.Dixit and A. Rankin, Nucl. Instrum. Methods* A566 *(2006) 281.***

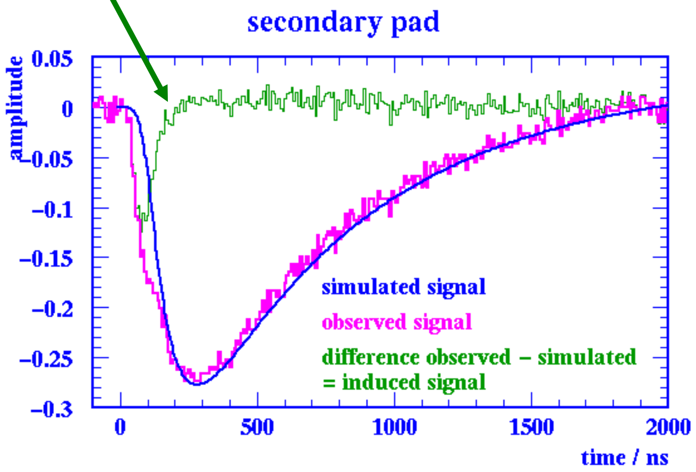
- The charge dispersion equation describe the time evolution of a point like charge deposited on the MPGD resistive anode at $t = 0$.
- To compare to experiment, one needs to include the effects of:
  - Longitudinal & transverse diffusion in the gas.
  - Intrinsic rise time $T_{rise}$ of the detector 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 signal for GEM - Collimated x-ray spot Simulation versus measurement (Ar+10%CO2)

## (2 x 6 mm$^2$ pads) Collimated ~ 50 $\mu$m 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

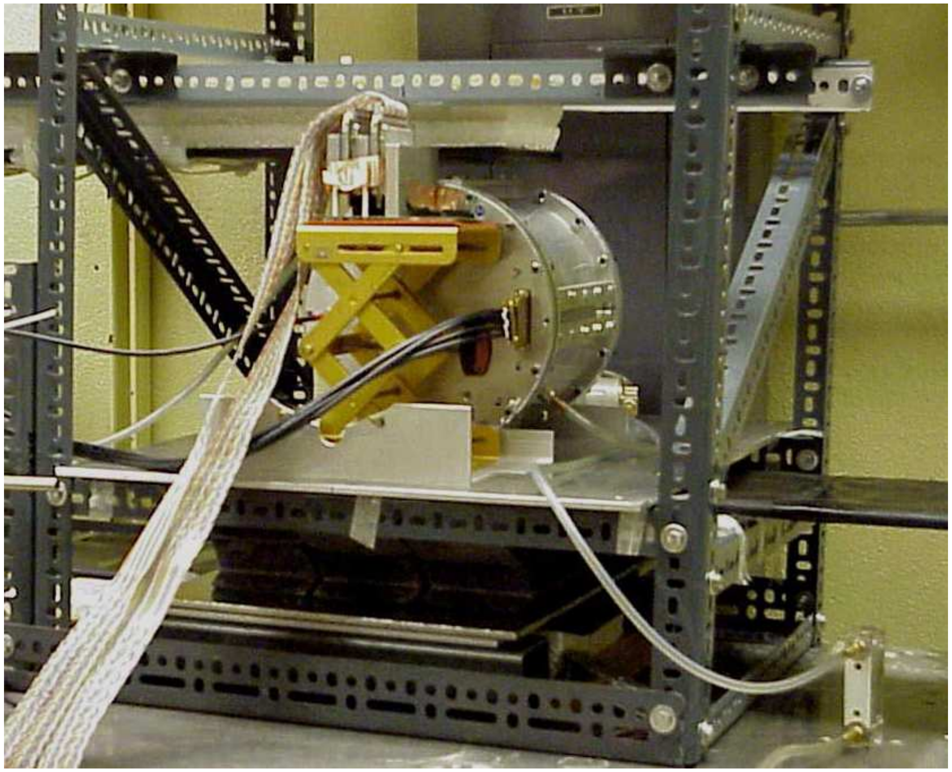
# Learning to track with charge dispersion Cosmic ray tests – no magnetic field

- 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.

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

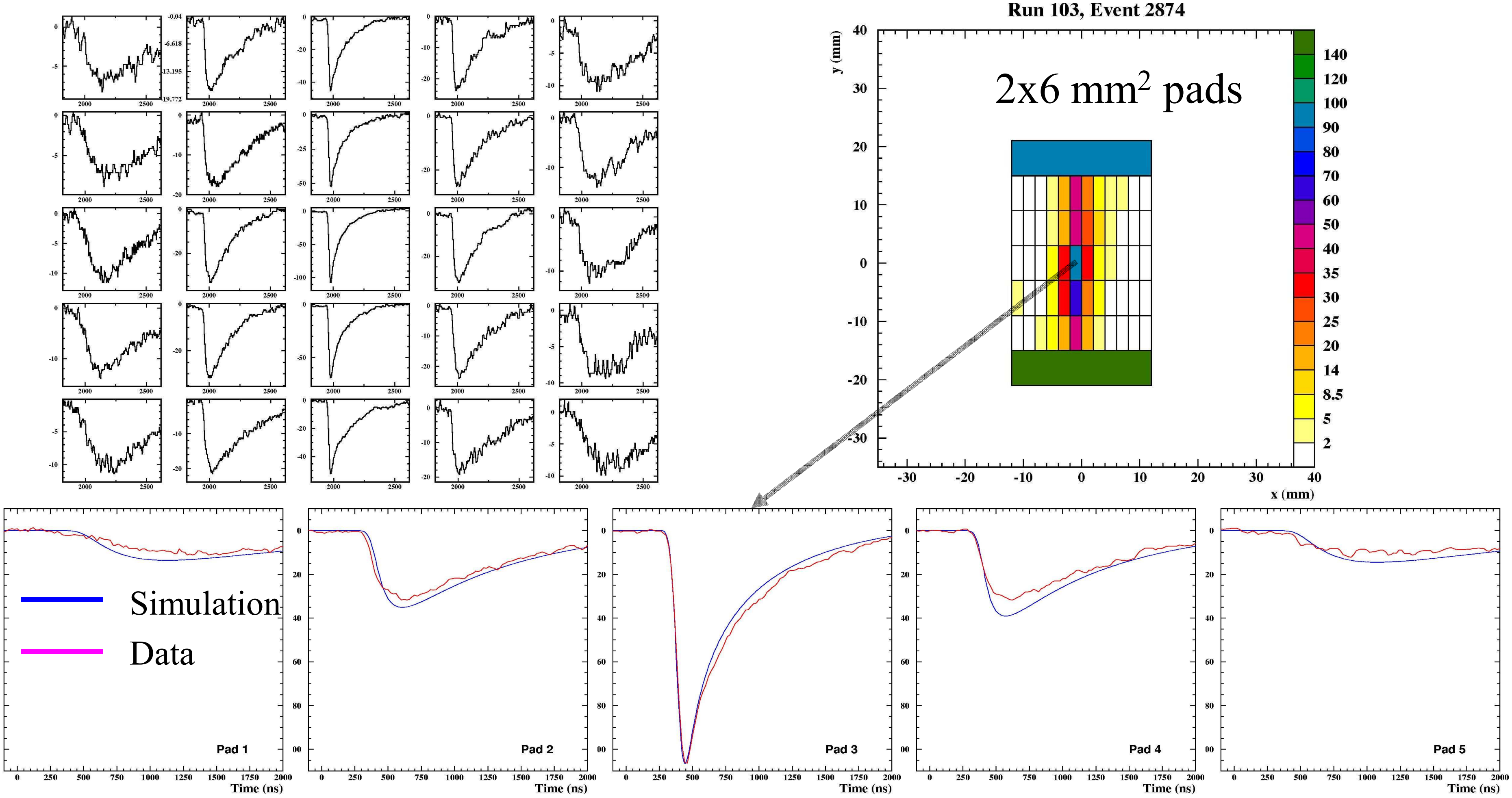
- 60 tracking pads ($2 \times 6$ mm$^2$) + 2 trigger pads ($24 \times 6$ mm$^2$).

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.

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



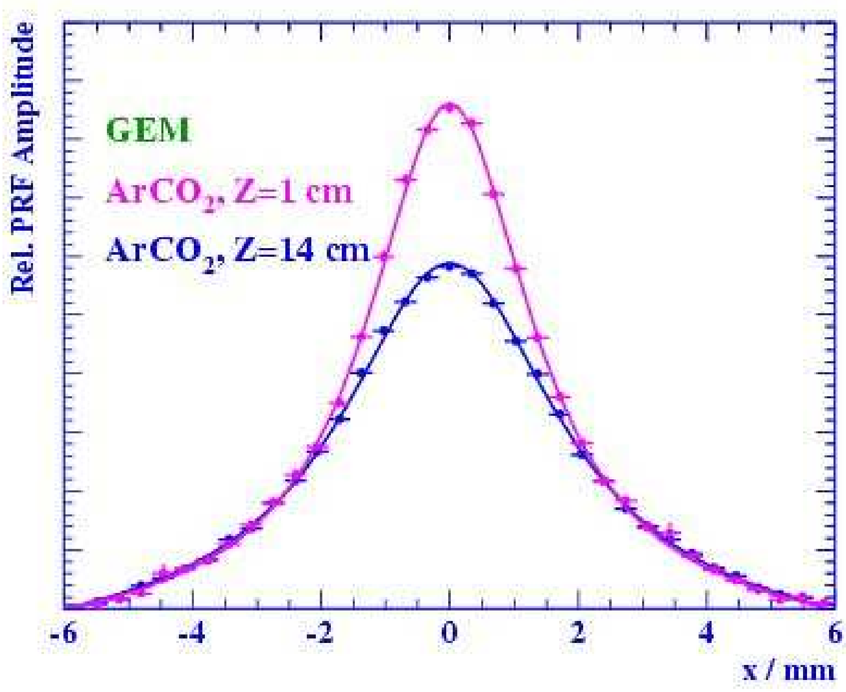
Centre pulse used for simulation normalization - no other free parameters.

# Charge dispersion pulses & pad response function (PRF)

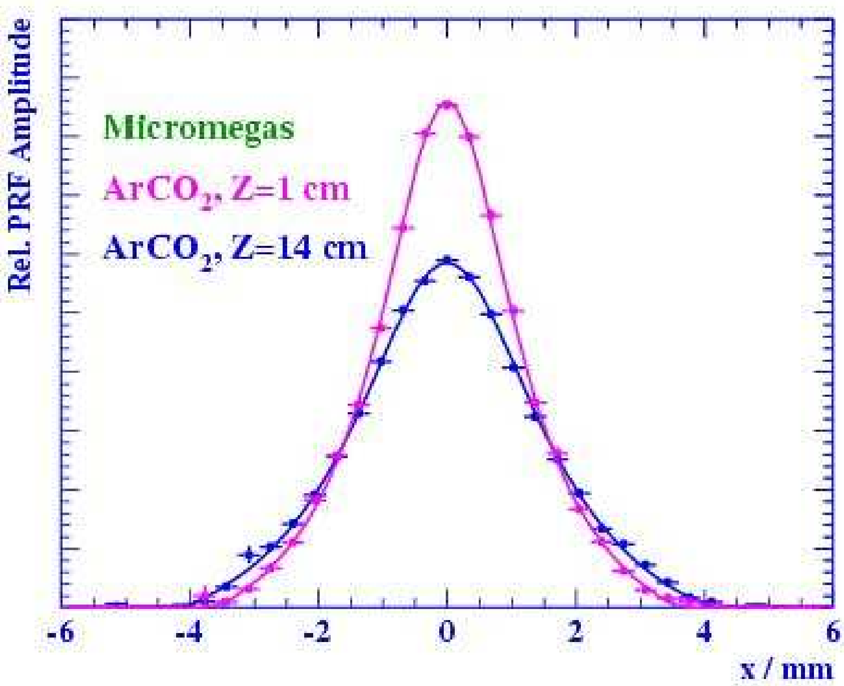
- Non-standard variable pulse shape; both the rise time & pulse amplitude depend on track position.
- The PRF is a measure of signal size as a function of track position relative to the pad.
- We use pulse shape information to optimize the PRF.
- The PRF can, in principle, be determined from simulation.
- However, existing fabrication techniques introduce a bias in the measured position.
- The position bias is geometrical and reproducible. The bias is corrected by calibration.
- PRF and bias determined empirically using a subset of data.

# 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 FWHM $\Gamma(z)$ & base width $\Delta(z)$.
- PRFs determined from the data parameterized by a ratio of two symmetric 4th order polynomials.

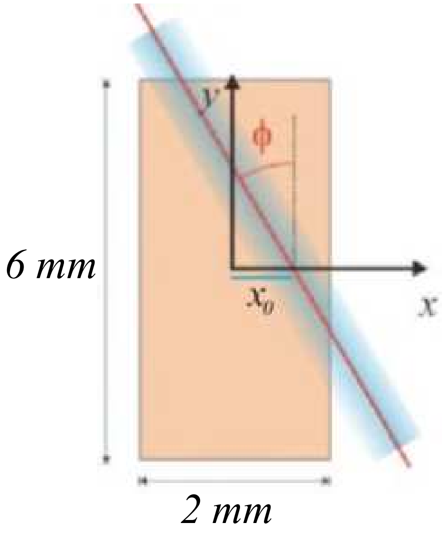
$$PRF[x,\Gamma(z),\Delta(z),a,b]=\frac{(1+a_2x^2+a_4x^4)}{(1+b_2x^2+b_4x^4)}$$

$a_2$ $a_4$ $b_2$ & $b_4$ can be written down in terms of $\Gamma$ and $\Delta$ & 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 $x_0$ & $\phi$ by minimizing $\chi^2$ for the entire event*

*Definitions:*

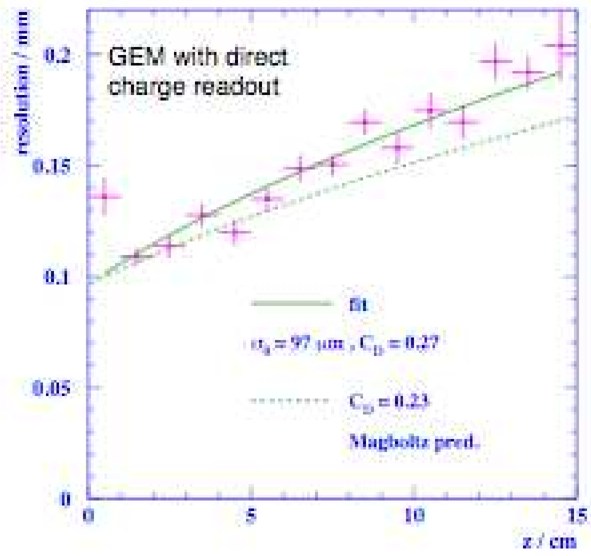
*- residual: $x_{row}$-$x_{track}$*

*- bias: mean of $x_{row}$-$x_{track}$ = $f(x_{track})$*

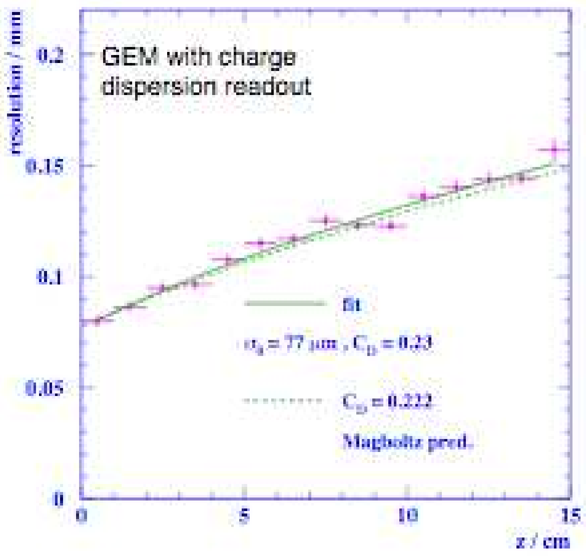
*- resolution: standard deviation of residuals*

# B=0 Cosmic Ray Transverse Resolution $Ar+10\%CO_2$

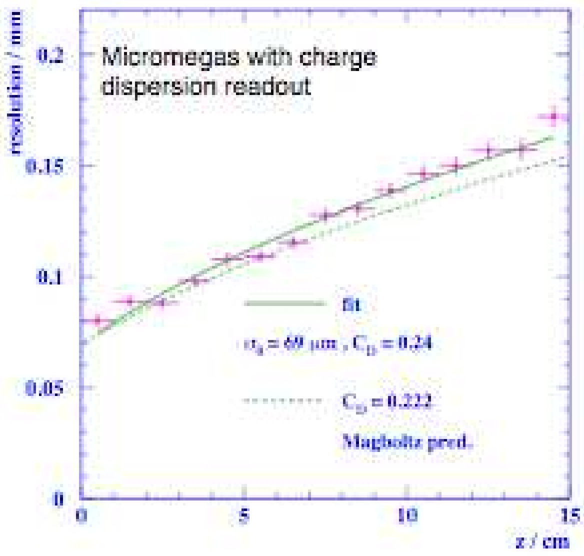
R.K.Carnegie et.al.,
NIM A538 (2005) 372



K. Boudjemline et.al.,
NIMA 574, 22 (2007)



A. Bellerive et al,
LCWS 2005, Stanford



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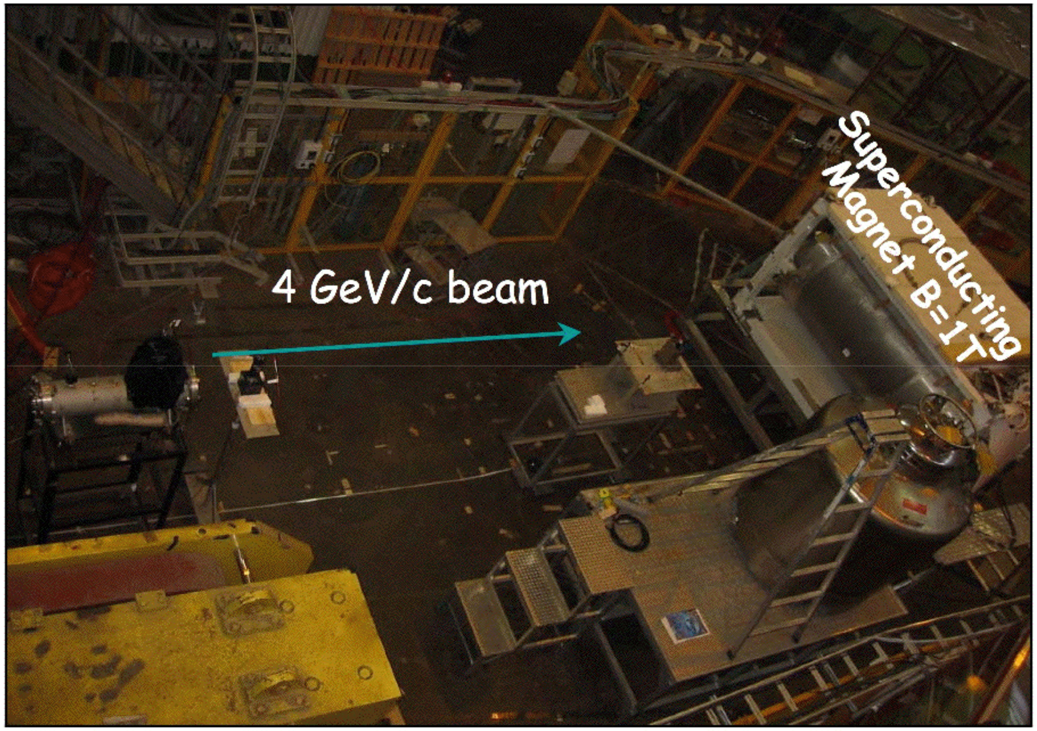
$$\sqrt{\sigma_0^{\,2} + \frac{C_D^{\,2}}{N_e} z}$$

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

# First tests in a magnetic field (Oct, 2005)

## Micromegas TPC - charge dispersion readout



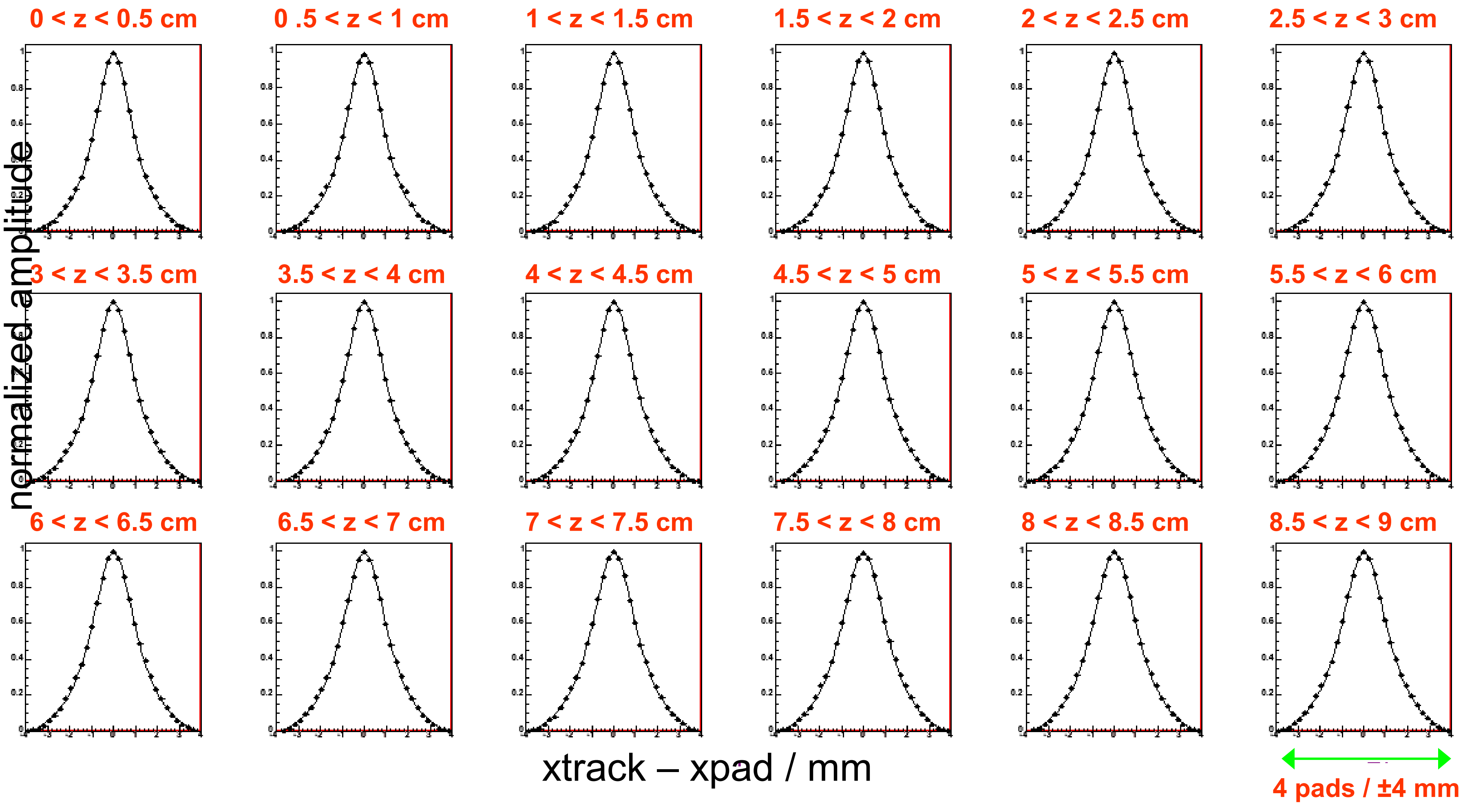
- 4 GeV/c KEK PS $\pi$2 hadron test beam
- Super conducting 1.2 T magnet
- Inner diameter : 850 mm
- Effective length: 1 m

**Canada, France, Germany, Japan (Carleton, Montreal, Saclay, Orsay, MPI (Munich), KEK, Kinnki, Kogakuin, Saga, Tsukuba and TUAT)**

# Pad Response Function / Ar+5%iC4H10

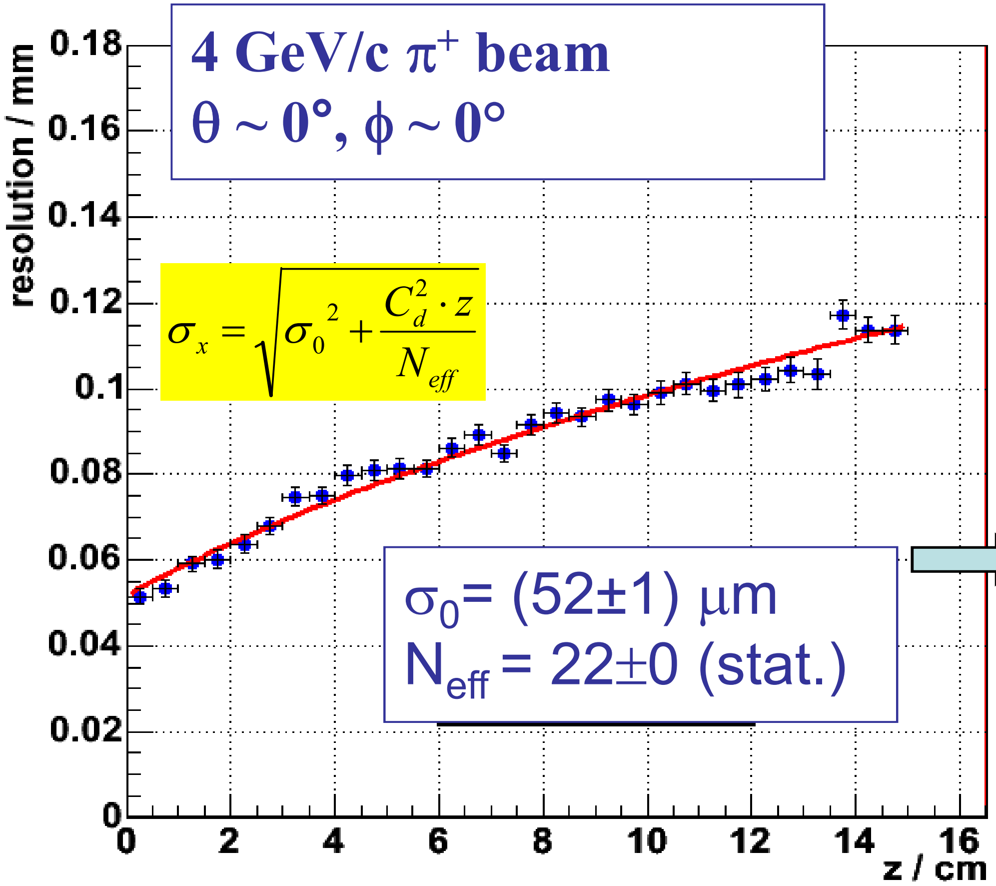
# MicromegasTPC 2 x 6 $\text{mm}^2$ pads, B = 1 T

30 z regions /
0.5 cm step



0 < z < 0.5 cm
0 .5 < z < 1 cm
1 < z < 1.5 cm
1.5 < z < 2 cm
2 < z < 2.5 cm
2.5 < z < 3 cm
3 < z < 3.5 cm
3.5 < z < 4 cm
4 < z < 4.5 cm
4.5 < z < 5 cm
5 < z < 5.5 cm
5.5 < z < 6 cm
6 < z < 6.5 cm
6.5 < z < 7 cm
7 < z < 7.5 cm
7.5 < z < 8 cm
8 < z < 8.5 cm
8.5 < z < 9 cm

# 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



4 GeV/c π$^+$ beam
θ ~ 0°, φ ~ 0°

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

$\sigma_0$= (52±1) μm
$N_{eff}$ = 22±0 (stat.)

- Strong suppression of transverse diffusion at 4 T.

**Examples:**

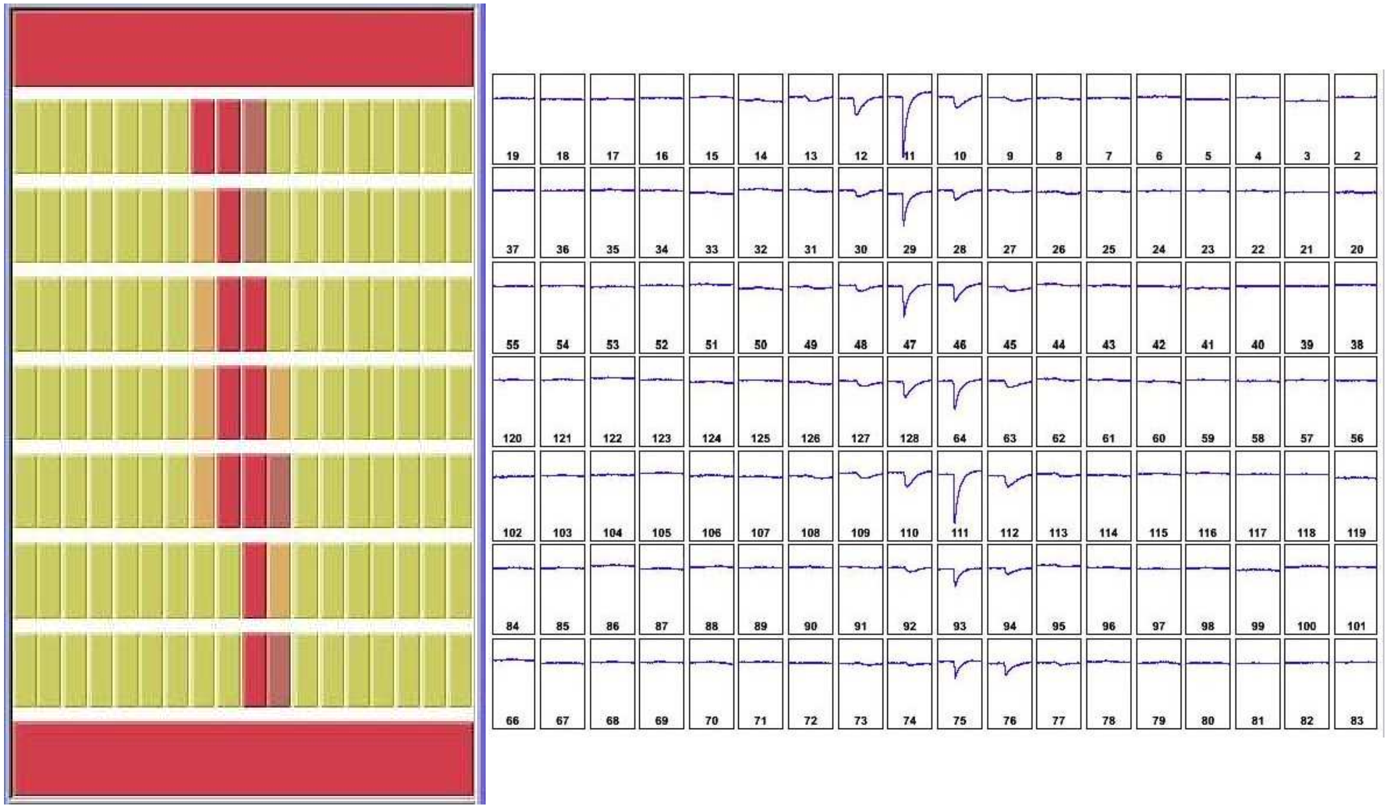
$D_{Tr}$~ 25 μm/√cm (Ar/CH4 91/9)
Aleph TPC gas
~ 20 μm/√cm (Ar/CF4 97/3)

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

# **Tests in the 5 T magnet at DESY** 2 mm x 6 mm pads

The track charge width is negligible compared to the pad width.

(Carleton-Orsay-Saclay-Montreal) COSMo TPC track display

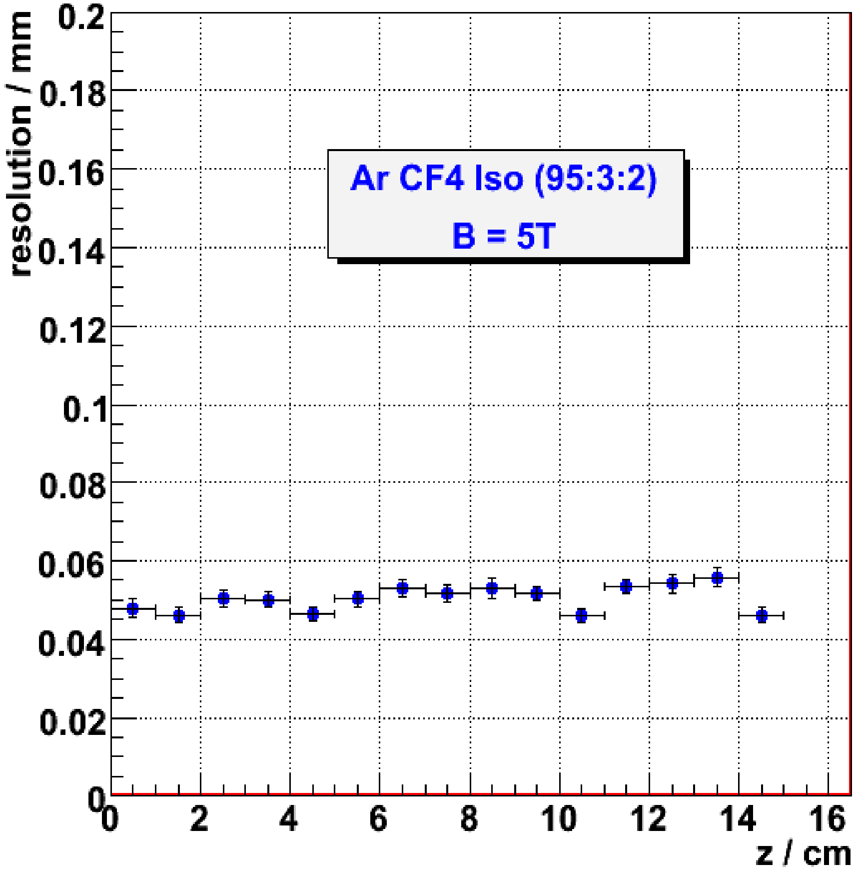


A cosmic track with charge dispersion.

# 5 T cosmic tests with charge dispersion

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

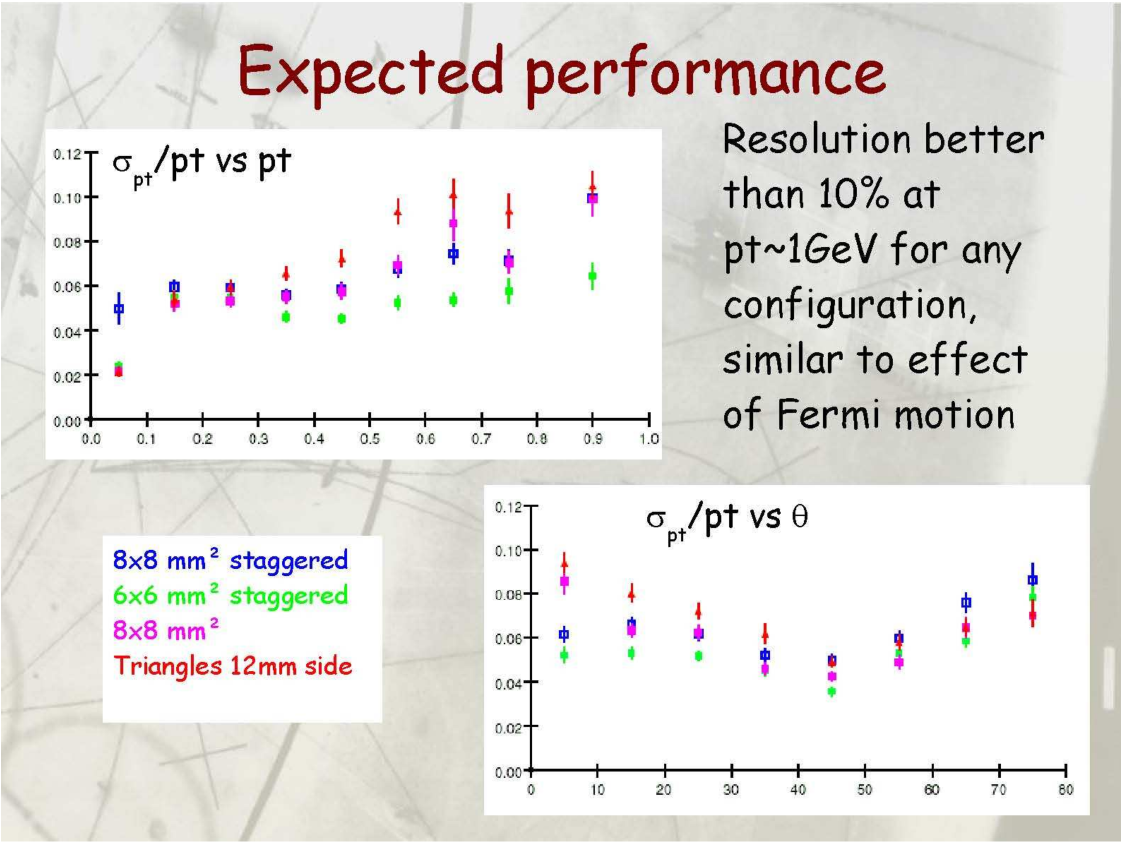
**$D_{Tr}$= 19 μm/√cm, 2 × 6 mm² pads**



M. Dixit et. al, NIM A 581, 254 (2007)

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

# Application to T2K TPC



## Expected performance

Resolution better than 10% at pt~1GeV for any configuration, similar to effect of Fermi motion

8x8 mm² staggered
6x6 mm² staggered
8x8 mm²
Triangles 12mm side

- 7x9 mm² pads
- 10% Δp/p (1 GeV/c)
- Good enough!
- Requirement limited by Fermi motion

(from a talk by F.Sánchez (Universitat Autònoma de Barcelona)

**But better momentum resolution would be useful:**

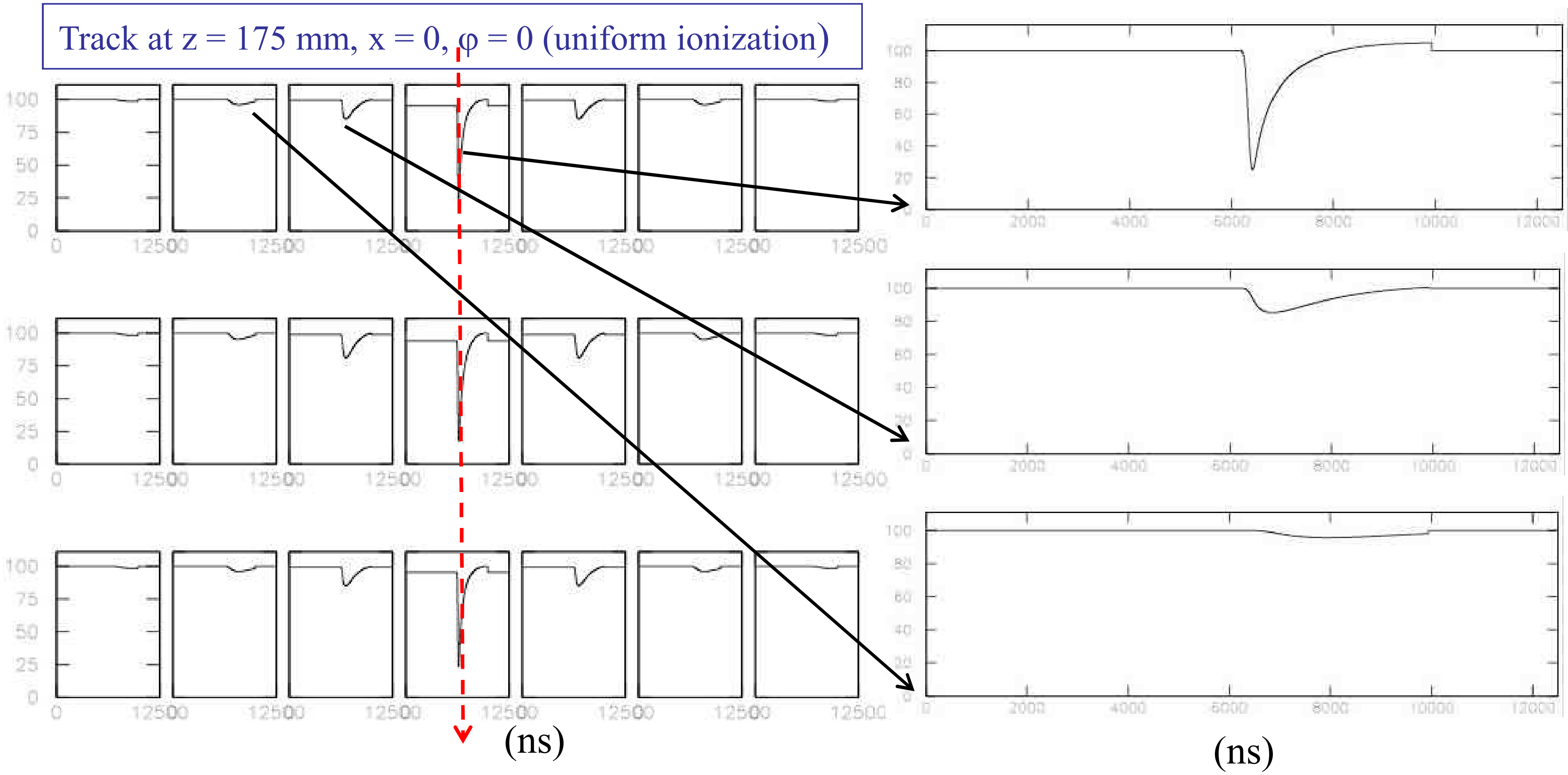
**Better background rejection = More channels => $$?**

**Can one do it with the presently chosen pad dimensions?**

# T2K simulation for 8 x 8 mm$^2$ pads
# Track crosses no pad row or column boundaries

## Ar+10% $CO_2$ , $v_{Drift}$ = 28 μm/ns (E = 300 V/cm)

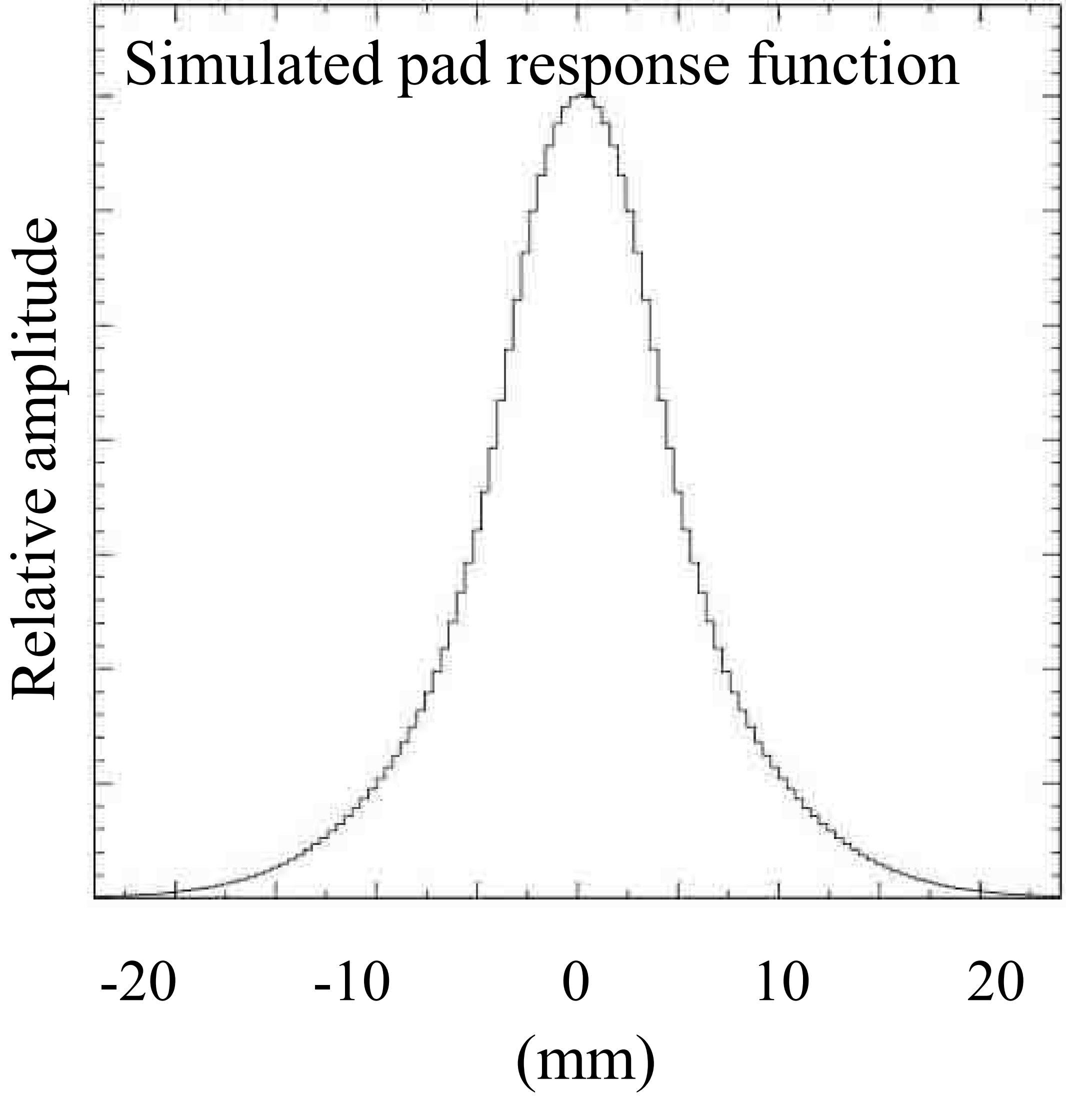
Anode surface resistivity 150 KΩ/□, dielectric gap = 75 μm, K = 2



Track at z = 175 mm, x = 0, φ = 0 (uniform ionization)

# Micromegas TPC with resistive readout - Simulated PRF

8 x 8 mm$^2$ pads, Ar+10% CO$_2$@ 300 V/cm, 175 mm drift distance



# Summary

- Traditional MPGD-TPC has difficulty achieving good resolution with wide pads
- With charge dispersion, the charge can be dispersed in a controlled way such that wide pads can be used without sacrificing resolution. One can achieve excellent resolution with wide pads both for the GEM and the Micromegas.
- It will enable large TPCs like the ILC TPC to achieve good resolution with a smaller number of readout channels, keep the endplate mass low and also the electronics heat loads manageable.
- For low rate large TPCs like T2K, it appears feasible to achieve better resolution with existing number of channels with the charge dispersion readout.
- Good understanding of charge dispersion. The simulation can be used to optimize charge dispersion TPC readout.