Development of high resolution Micro-Pattern Gas Detectors with wide readout pads

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MPGD2009, 14 June 2009
Kolympari, Crete, Greece

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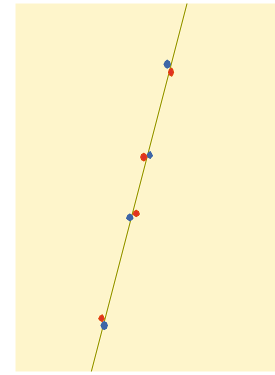
MPGD resolution with conventional readout



1) Primary ionzation in drift or conversion gap

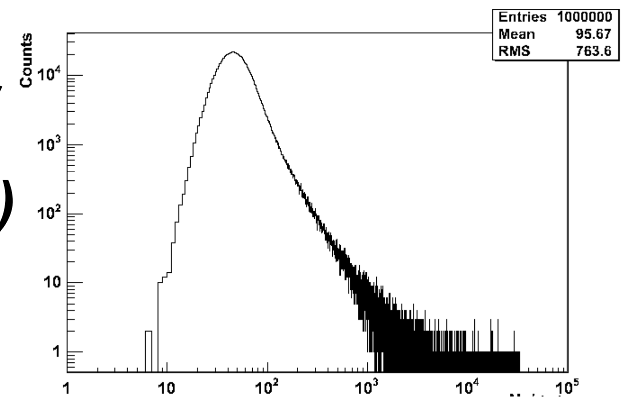
$$P(n) = \langle N \rangle^{n} e^{-\langle N \rangle}/n!$$

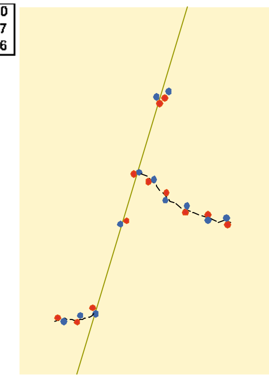
$\langle N \rangle$ = average no. primary clusters

2) Number of electrons per cluster

fluctuates (cluster size distribution)

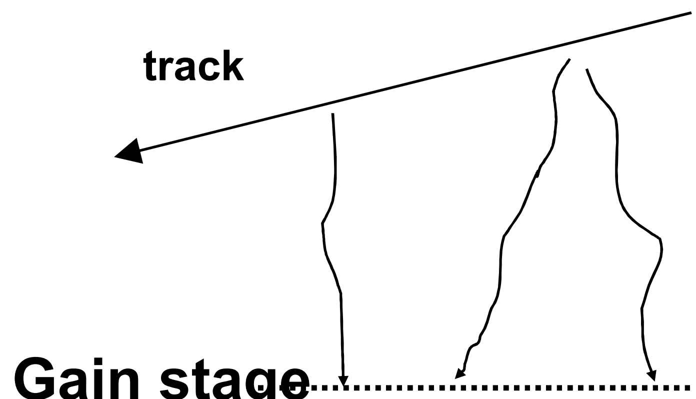
Fischle et al (A301, 202 (1991)



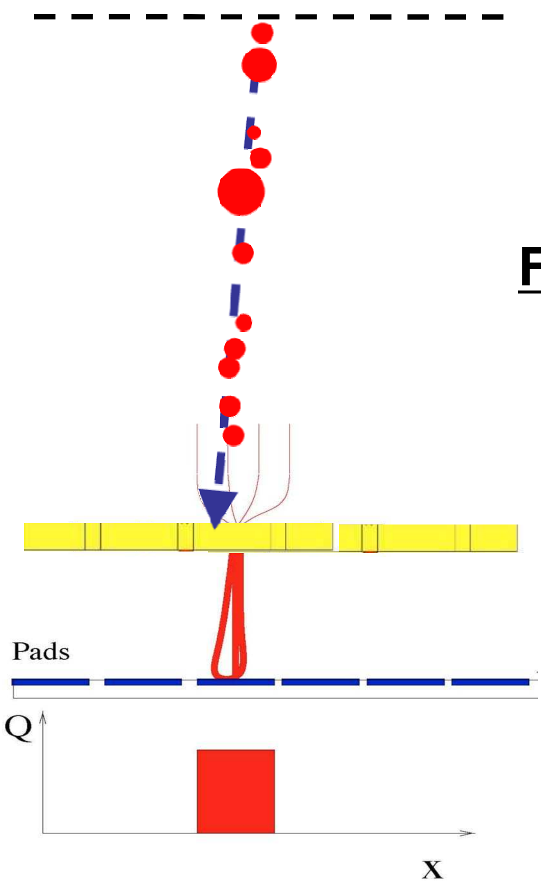


3) Electrons drift with Gaussian diffusion

Towards gas amplification stage



MPGDs need narrow pads for good resolution



2-4 mm conversion gap
No. primary clusters <N> ≈ 3-4

For a 90° track & all clusters aligned & correlated, the resolution would be box like:

$$\sigma_x^2 \approx \sigma_0^2 + \left[w^2/12 \right]$$

But resolution usually better due to small track angles, delta rays, diffusion

$$\sigma_x^2 \approx \sigma_0^2 + \left[w^2/12 \right] / \left\langle N_{eff}^{cl} \right\rangle$$

e.g. COMPASS GEMs & Micromegas; w = 400 μm: $\sigma_x \approx$ 70 μm

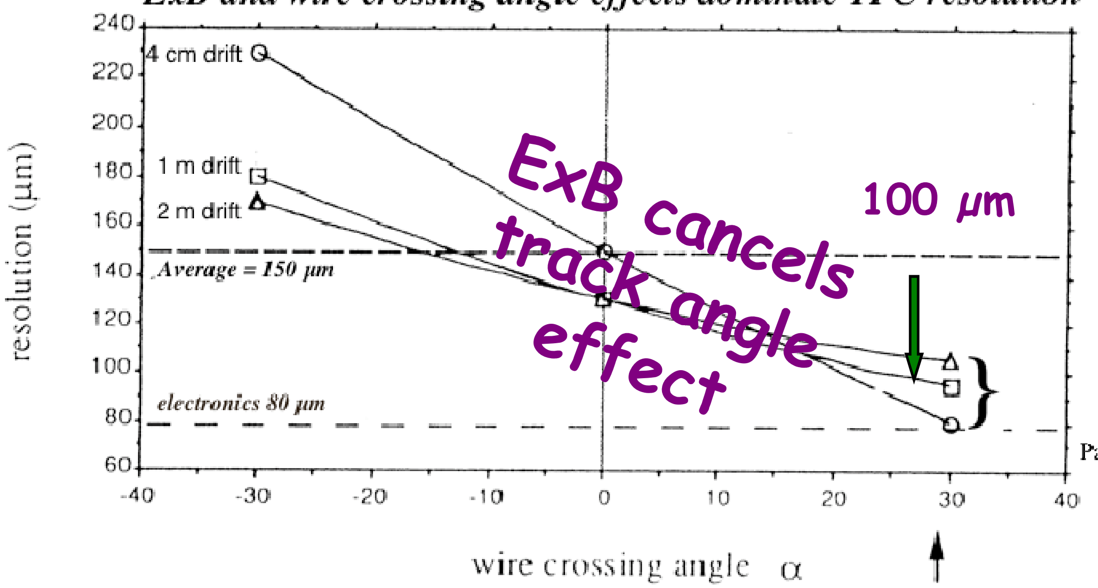
MPGDs in charged particle tracking applications

- **MPGDs need sub-mm pads for < 100 μm resolution**
- **Large high resolution (~100 μm) MPGD systems proposed for many new applications**
- **For too many channels, $$, rad. length, electronics heat load!!**
- **ILC TPC, 1.5 M channels, even with 2 mm x 6 mm pads T2K TPC: 100,000 channels, even with 7 mm x 9 mm pads to get only ~ 500 μm**
- **Super LHC ATLAS Micromegas muon chambers will have to cover several hundred square meters**
- **Can one achieve high resolution with wide MPGDs pads?**

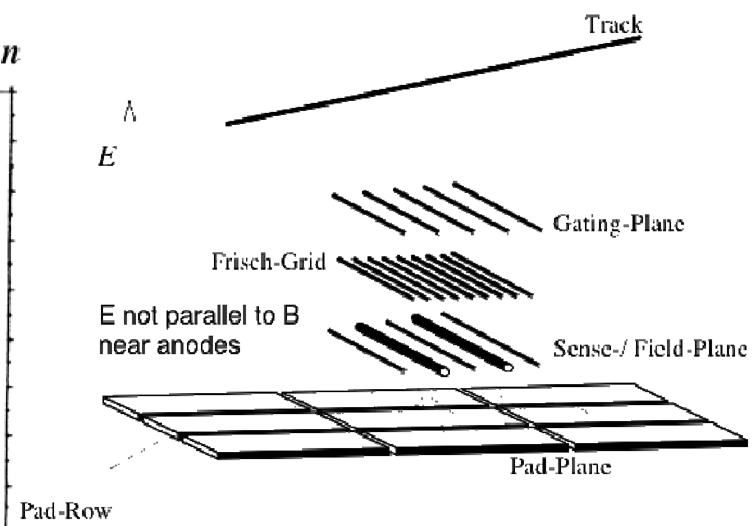
The classical TPC could do it with geometry!

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



But for the ExB effect, the conventional proportional wire TPC could achieve excellent resolution (~7 mm pads for ALEPH TPC at LEP)

A geometrical way to use wide MPGD pads with precision

Finding the avalanche position on a proportional wire

Charge division on a proportional wire

Telegraph equation

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

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 charge division to charge dispersion in

Finding the avalanche location on a MPGD resistive anode surface

Telegraph equation 2-D generalization

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

Solution for charge density in 2-D

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

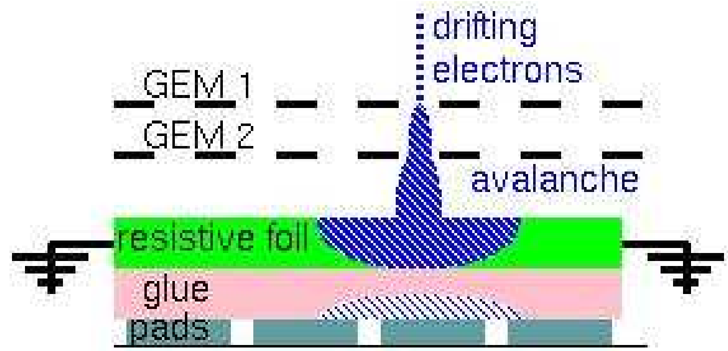
Charge dispersion in a MPGD with a resistive anode

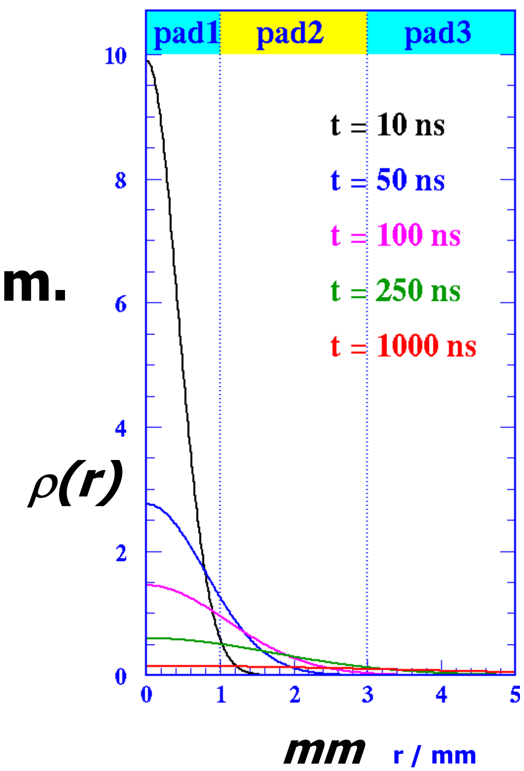
- **Modified GEM anode with a high resistivity film bonded to a readout plane with an insulating spacer.**
- **2-dimensional continuous RC network**
- **Point charge at r = 0 & t = 0 disperses with time.**
- **Time dependent anode charge density sampled by readout pads.**

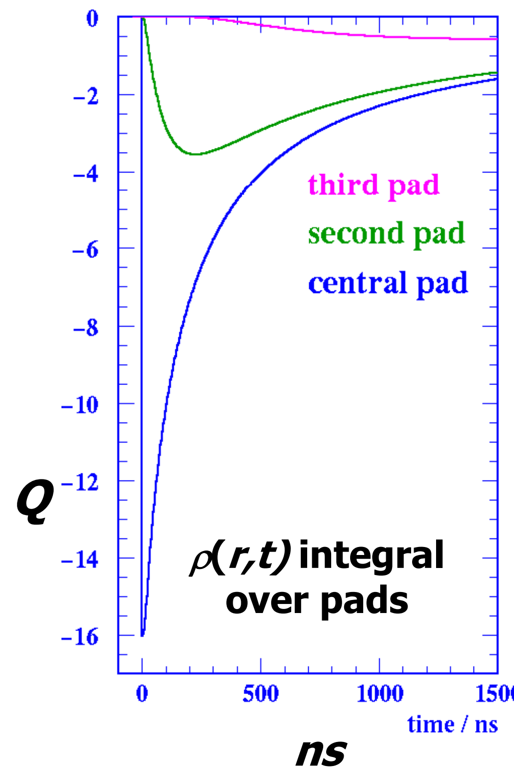
Equation for surface charge density function on the 2-dim. continuous RC network:

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

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

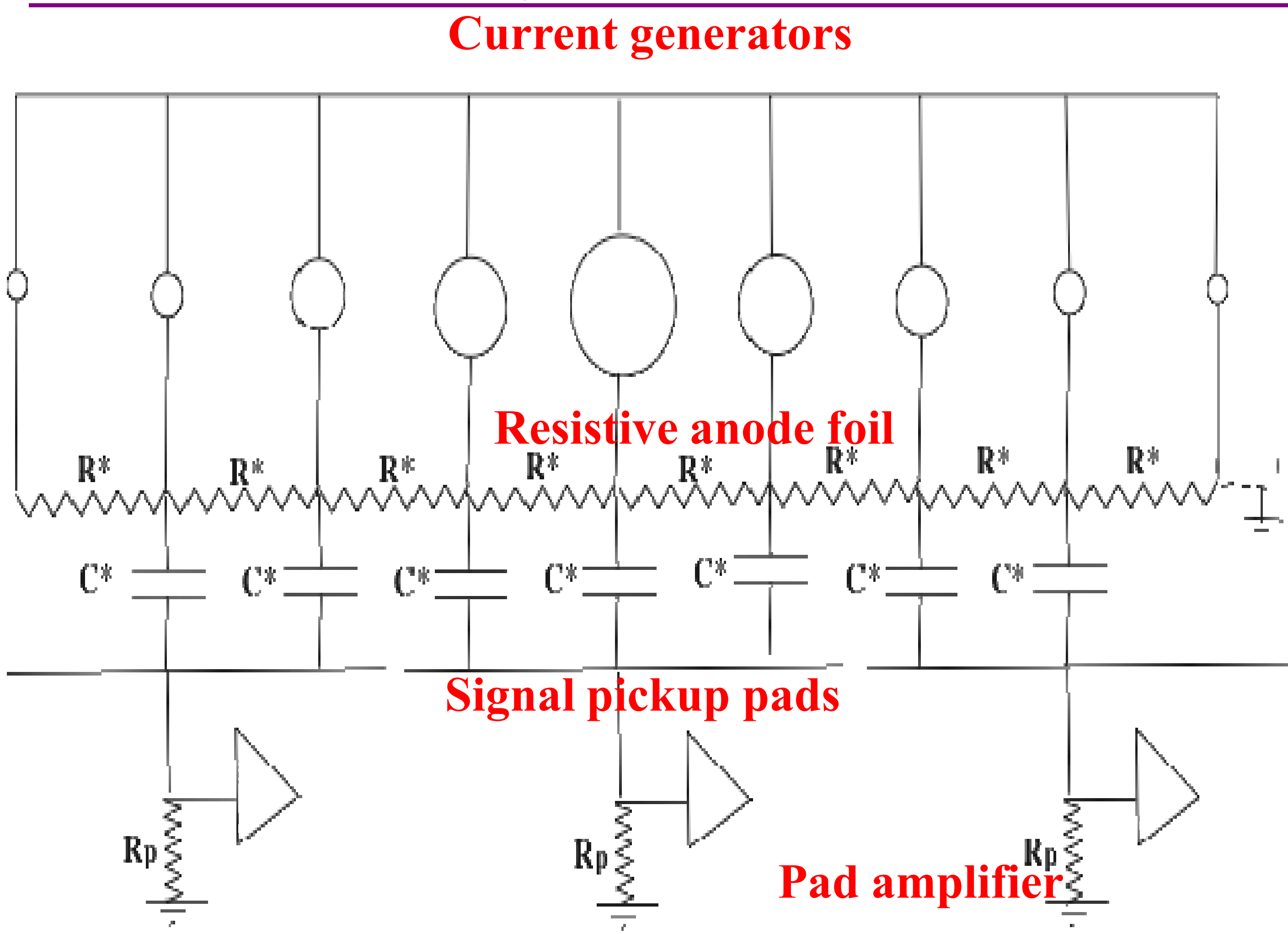






M.S.Dixit et.al., Nucl. Instrum. Methods A518 (2004) 721.

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

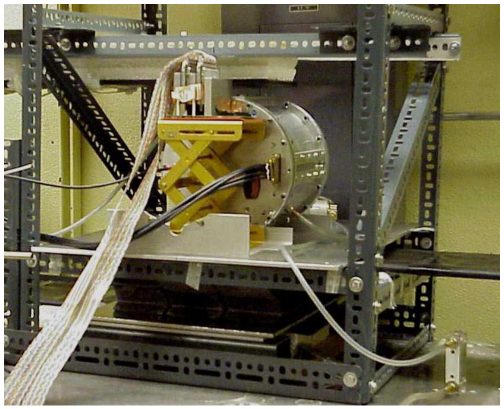


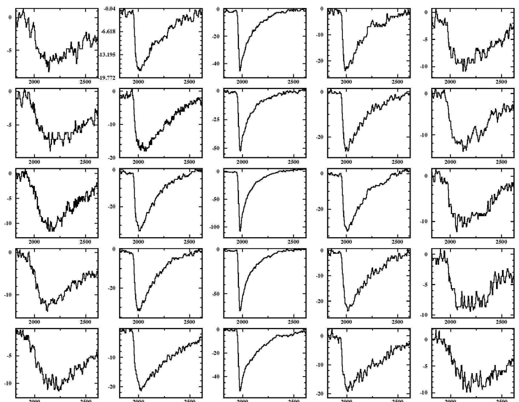
Simulating the charge dispersion phenomenon

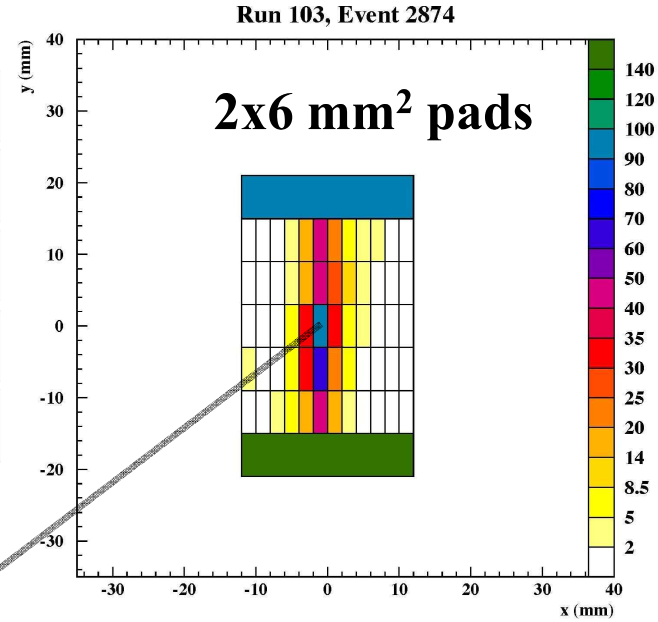
M.S.Dixit and A. Rankin, Nucl. Instrum. Methods* A566 *(2006) 281.

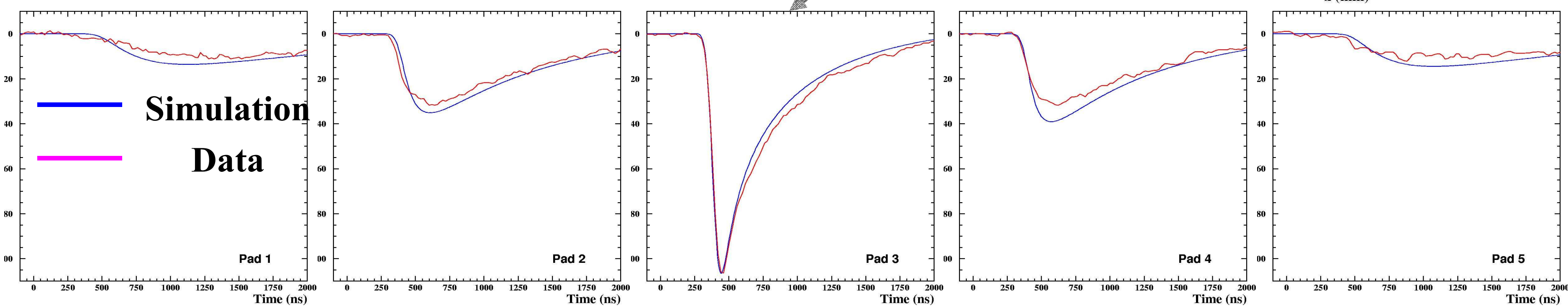
- **The charge dispersion equation describe the time evolution of a point like charge deposited on the MPGD resistive anode at $t = 0$.**
- **A full simulation done including the effects of:**
    - **Longitudinal & transverse diffusion in the gas.**
    - **Intrinsic rise time T_{rise} of the detector charge pulse.**
    - **The effect of preamplifier rise and fall times t_r & t_f.**
    - **And for particle tracks, the effects of primary ionization clustering.**

GEM TPC charge dispersion simulation (B=0)
Cosmic ray track, Z = 67 mm Ar+10%CO_2







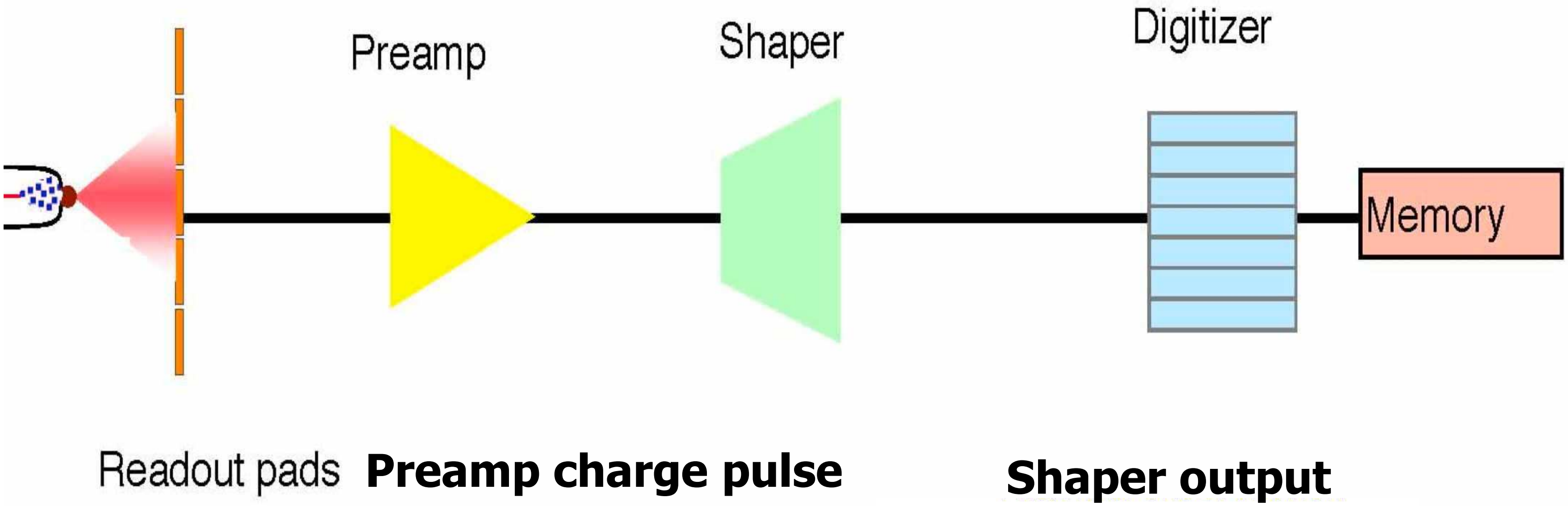


Centre pulse used for normalization - no other free parameters.

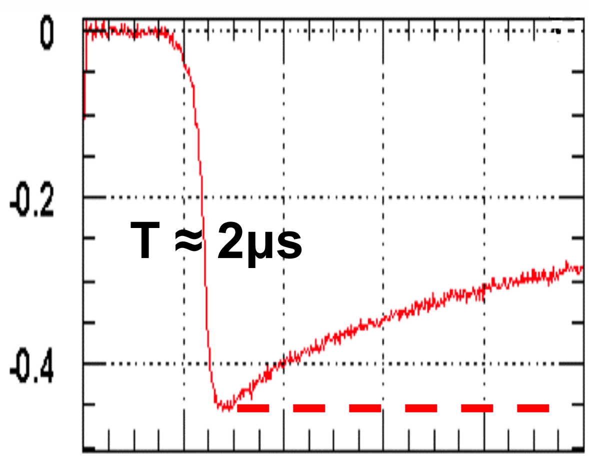
Tracking with the charge dispersion signal

- **Unusual highly variable charge pulse shape.**
- ***Pulses on charge collecting pads*: Large pulses with fast fixed rise-time. The decay time depends on the system RC, the pad size & the initial charge cluster location.**
- ***Pulses on other pads:* Smaller pulse heights & slow rise & decay times determined by the system RC & the pad location.**
- **Need to learn how to analyze such data**

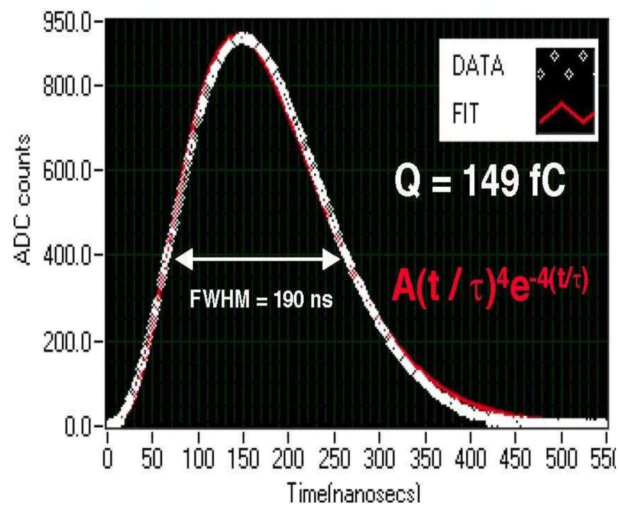
Conventional MPGD-TPC pulse processing



Preamp charge pulse

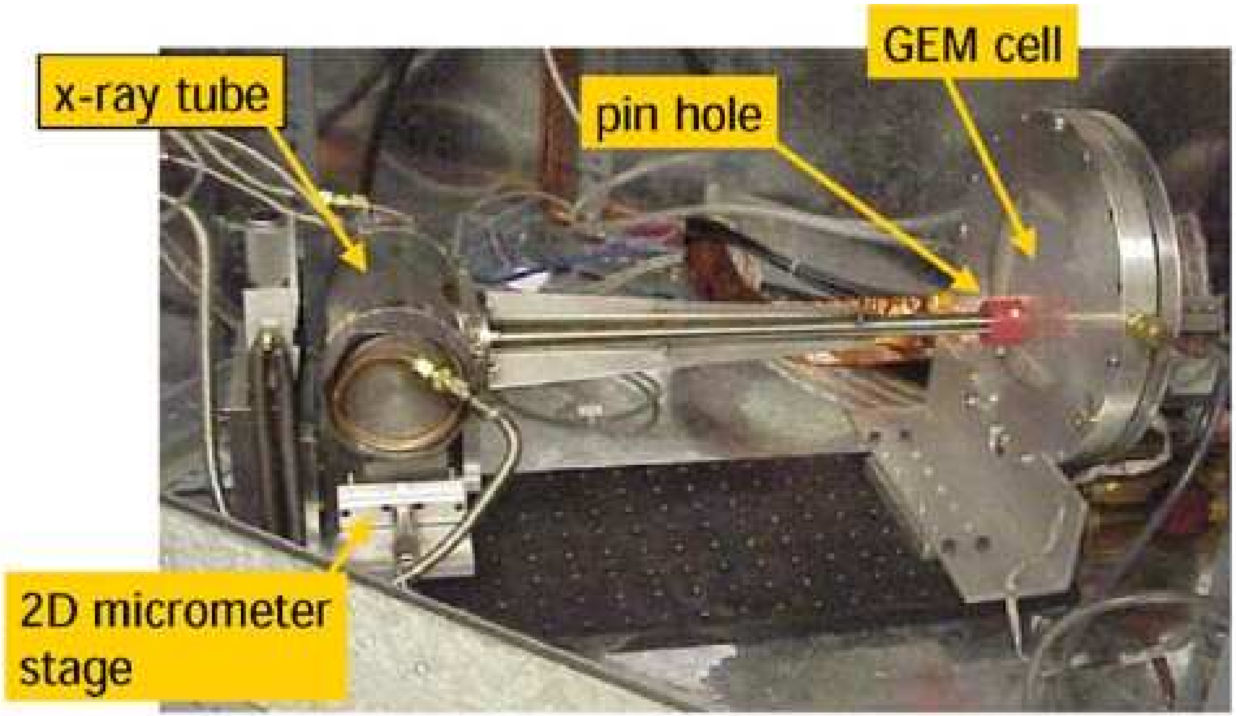


Shaper output



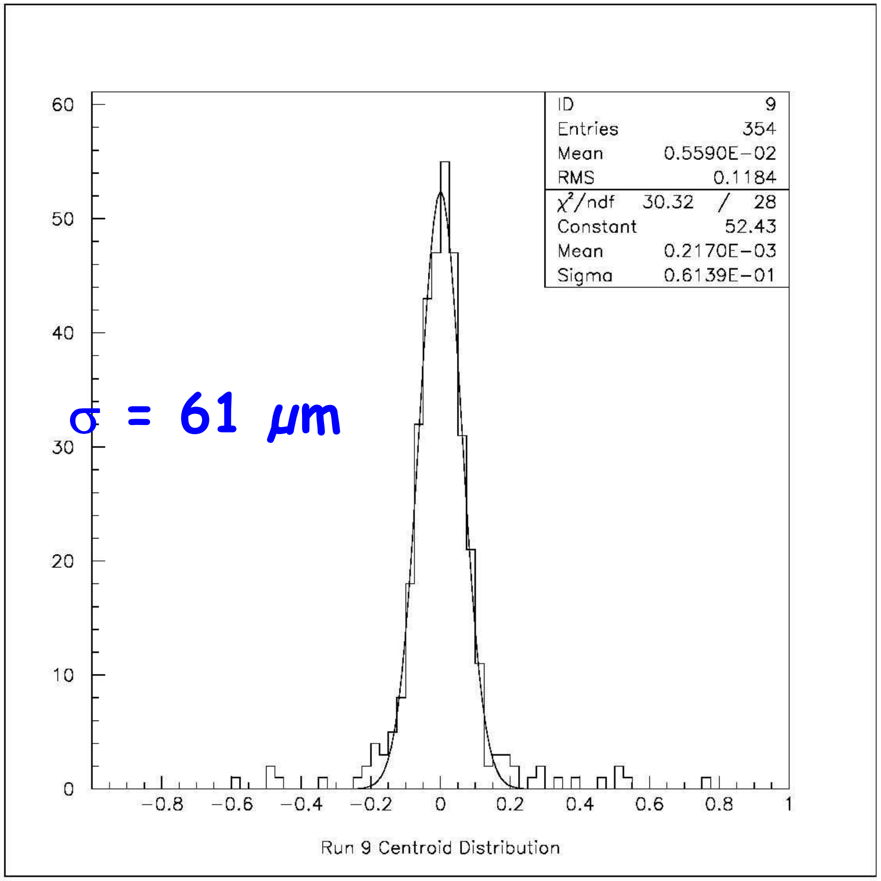
Digitize non-standard charge dispersion pulses directly to start

Resolution studies with 1.5 mm x 8 cm strips Double GEM with charge dispersion readout

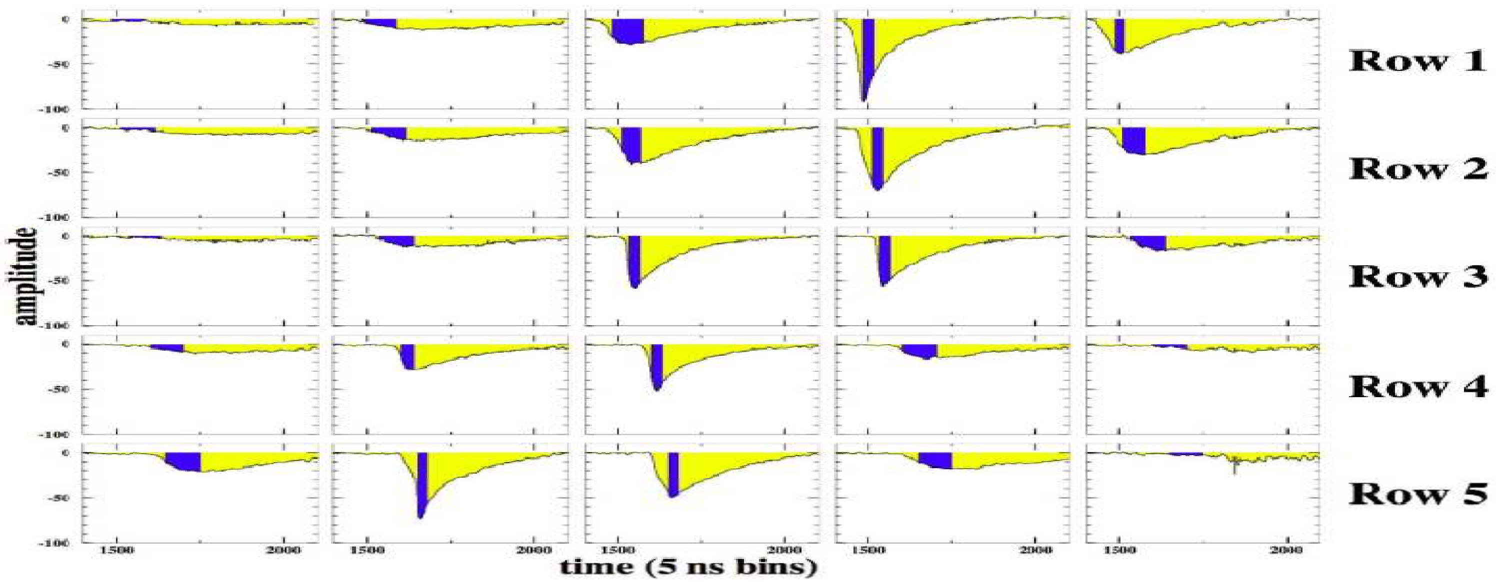


Point source ~ 50 μm collimated 4.5 keV x rays.

Resolution measurement for 1.5 mm x 8 cm strip



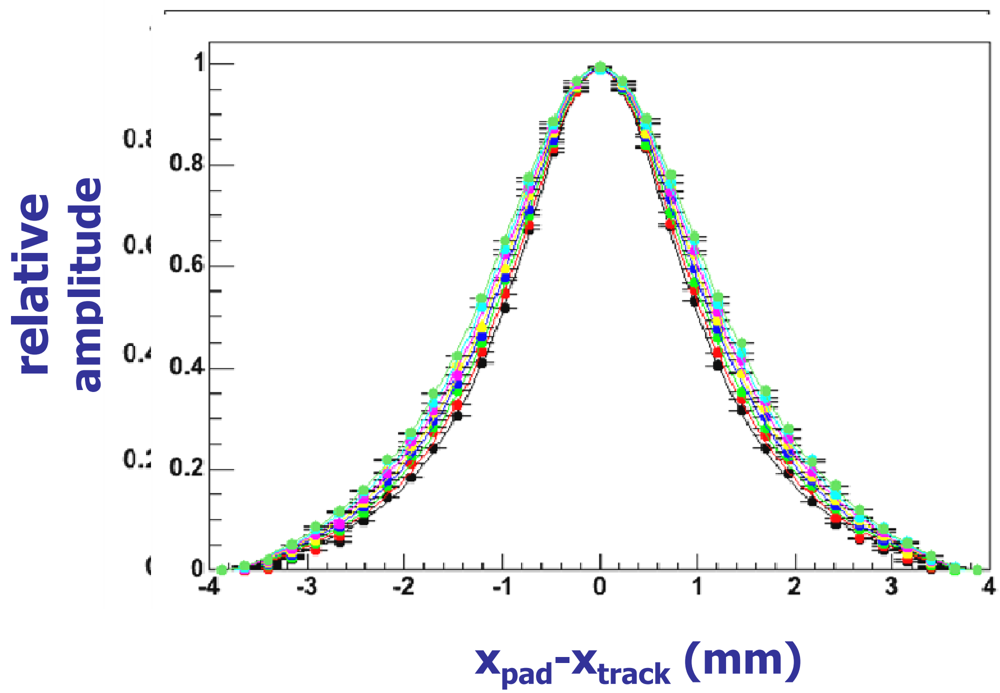
Track pad response function (PRF)

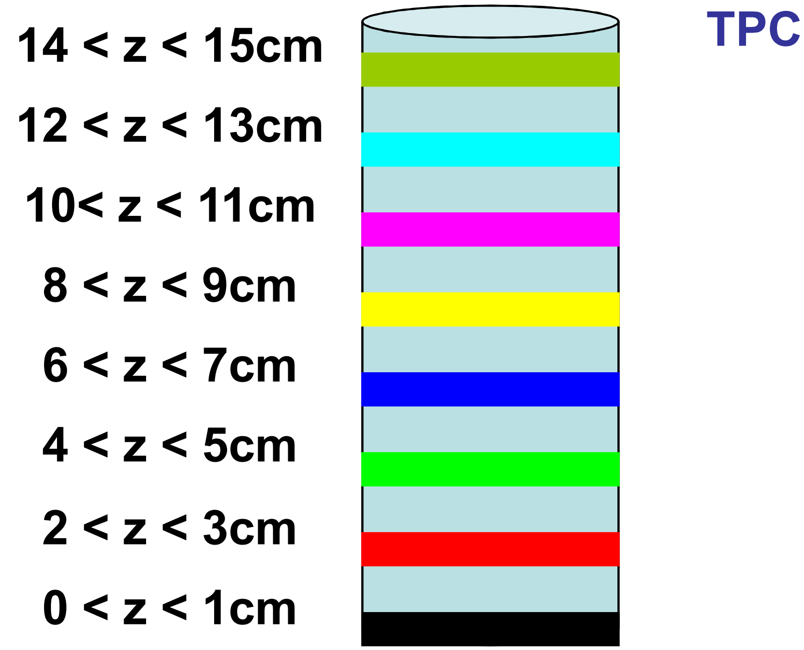


•A knowledge of PRF enables one to deduce track parameters from observed pulses

•Our first ideas to compute the PRF "amplitude" – integrate pad pulses over variable width windows following a recipe.

The pad response function (PRF) measures pad signal amplitude as a function of track position



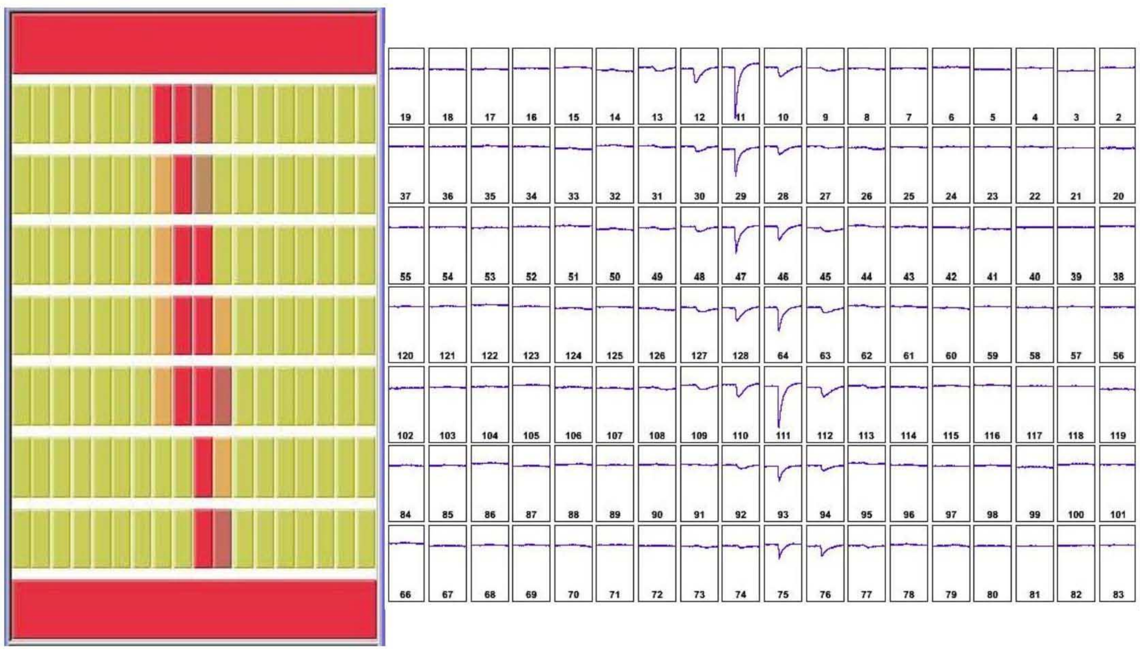


PRFs are determined from the data.
PRF parameterized in terms of FWHM Γ & base width Δ

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

COSMo TPC cosmic ray tests at 5 T Nov-Dec 2006

B = 5 Tesla Cosmic ray tests at DESY (Nov-Dec 2006)



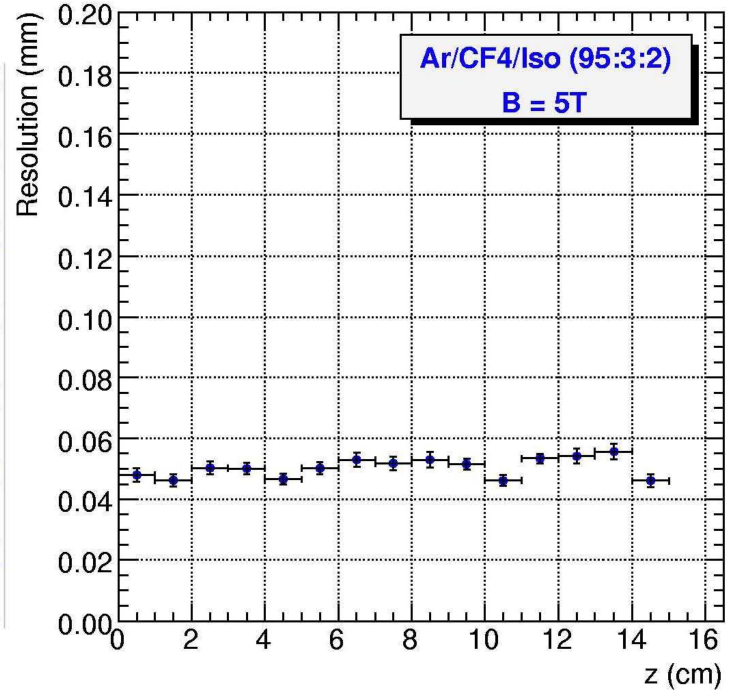


Fig. 4. Cosmic ray signals with charge dispersion observed for seven rows of 2 mm x 6 mm readout pads. At 5 Tesla, the track charge width is negligible compared to the pad width.

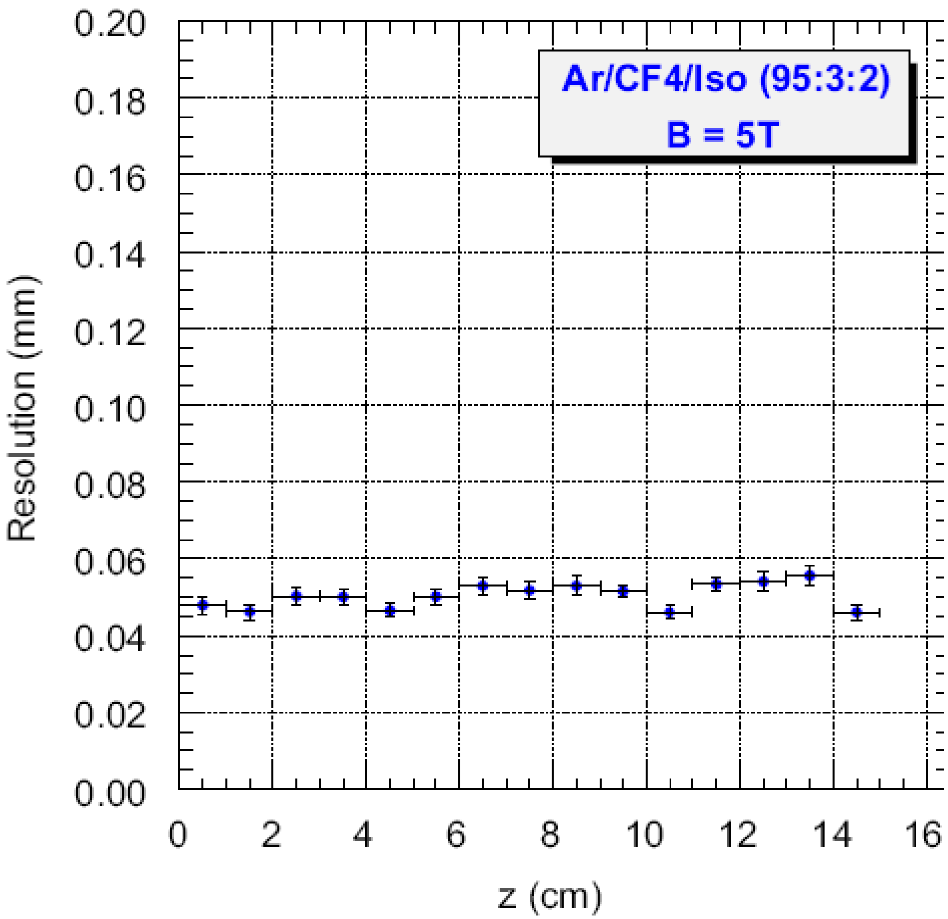
Fig. 5. With diffusion effects negligible, a flat ~ 50 μm resolution was measured over the full 15 cm TPC drift length.

An better way to analyze charge dispersion data

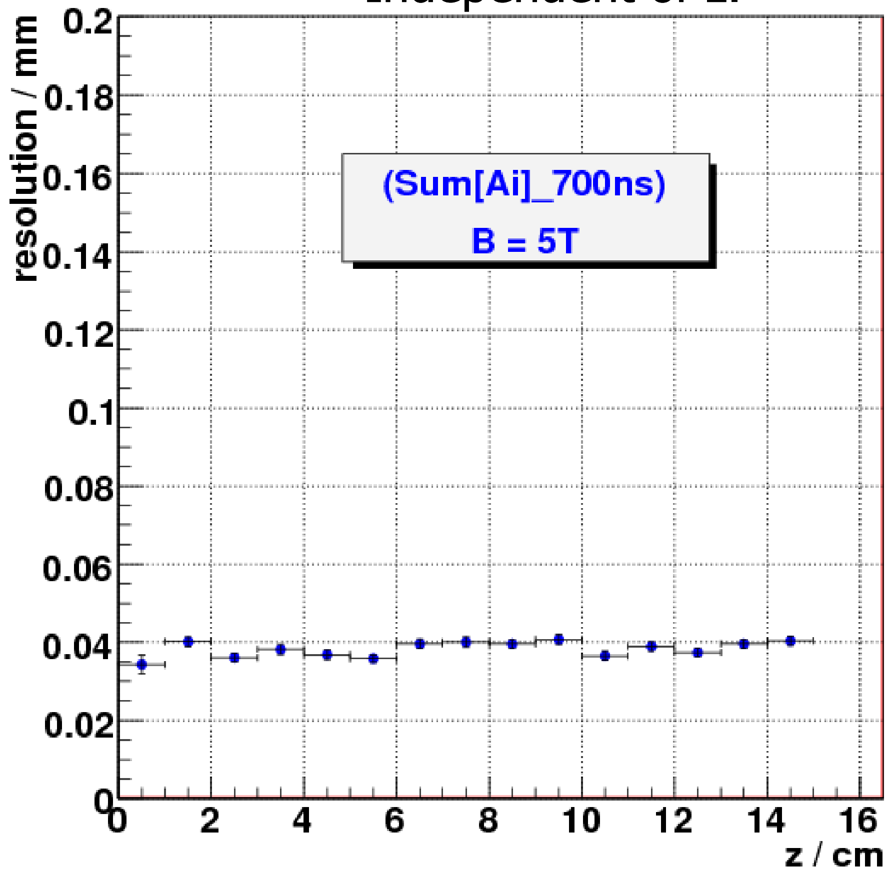
- The original PRF “amplitude” dependent on TPC operational parameters
- Develop a standard way not requiring fine tuning
- Tested several new ideas with simulated data
- Apply and test new algorithm to reanalyze DESY 5 T magnetic field results.
- Criteria: PRF can be applied consistently and easily over a wide range of TPC operating conditions.
- Observed resolution function is Gaussian.
- New Measured resolution is as good or better then obtained previously
- A simple fixed window integration works the best!

Resolution comparison:
Old Method Vs average(700ns)

Old Method **3652/17669**
Flat 50 µm Resolution
Independent of z over 15 cm.



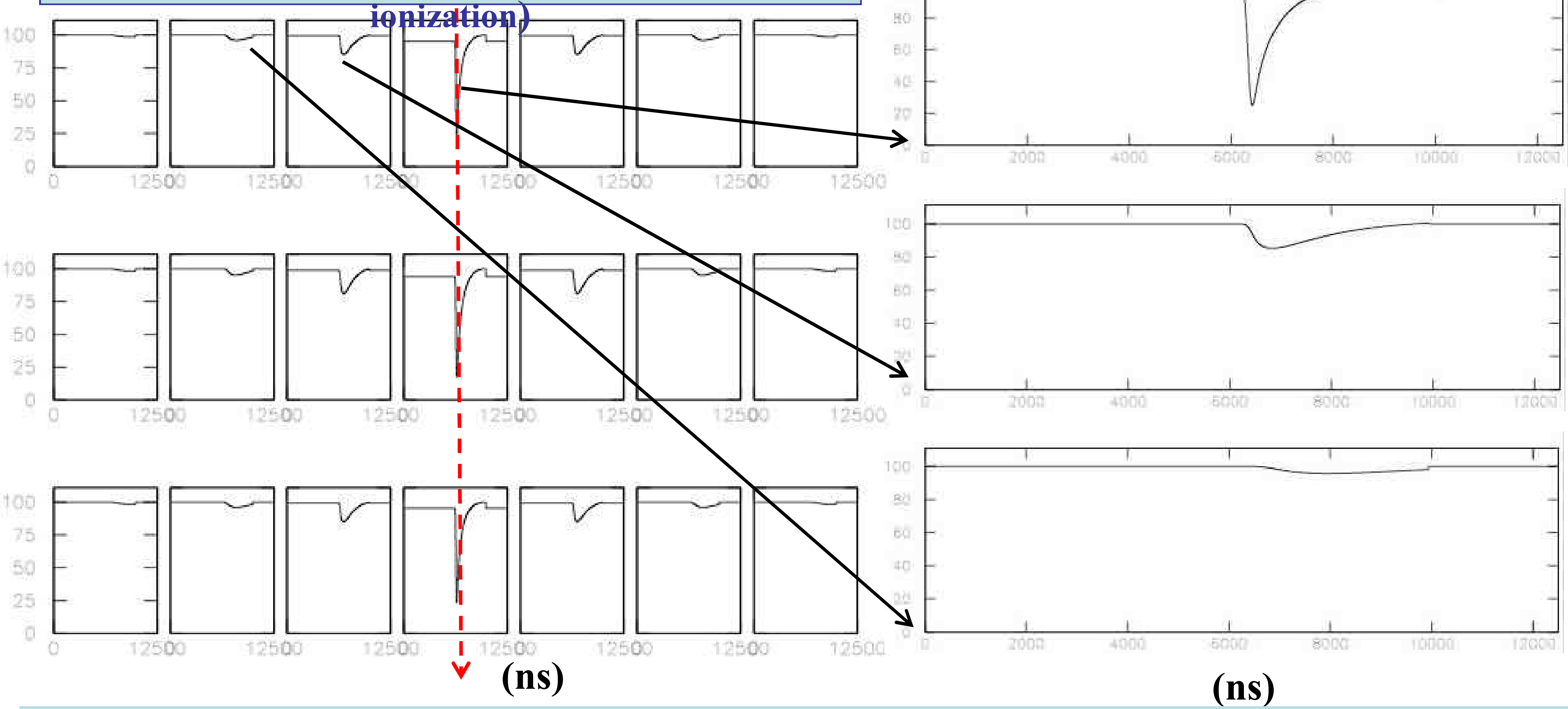
New method **5663/17669**
Flat 40 µm Resolution
Independent of z.



Simulating the T2K with charge dispersion
(8 mm x 8 mm pads)

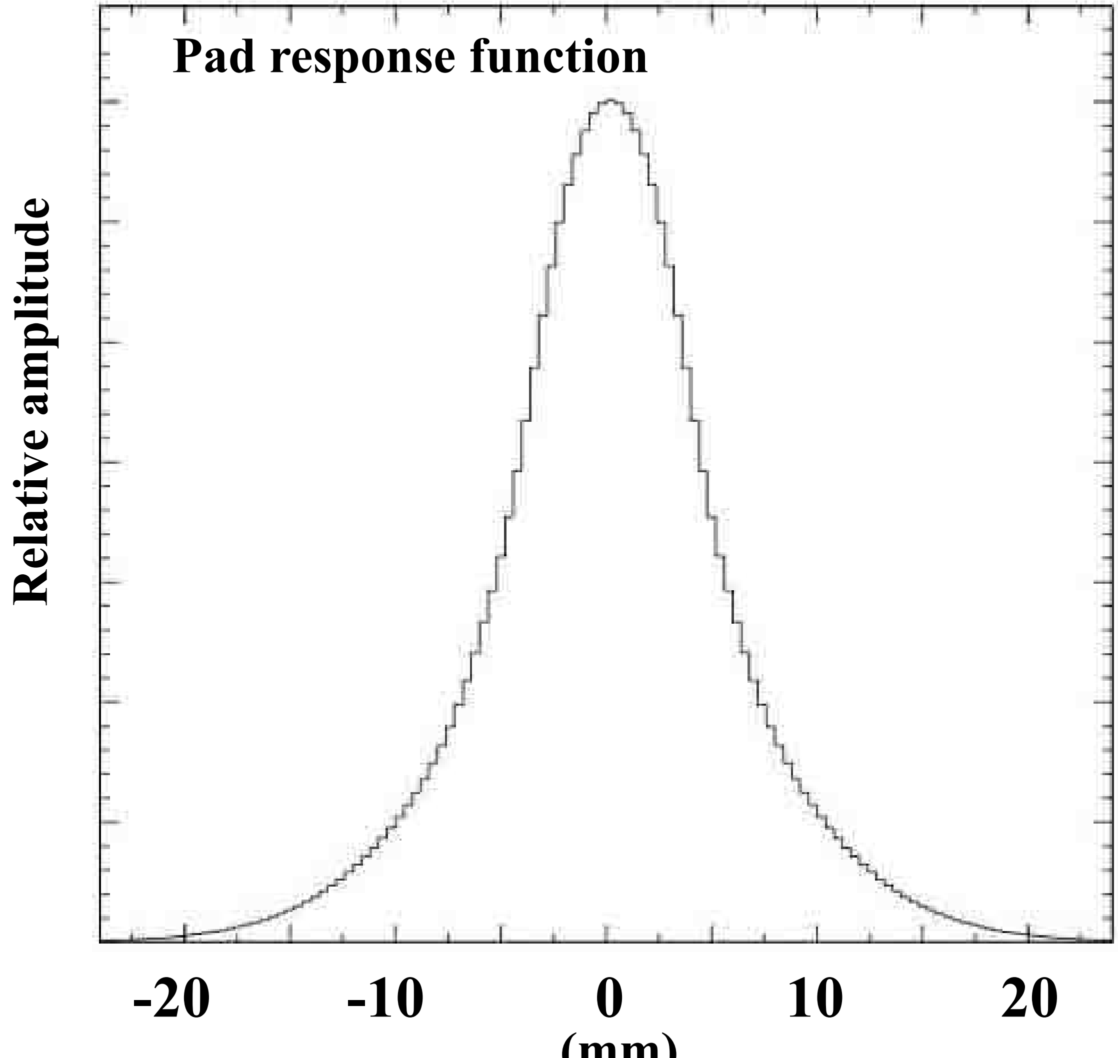
Anode surface resistivity 150 KΩ/□, dielectric gap = 75 μm, K = 2

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



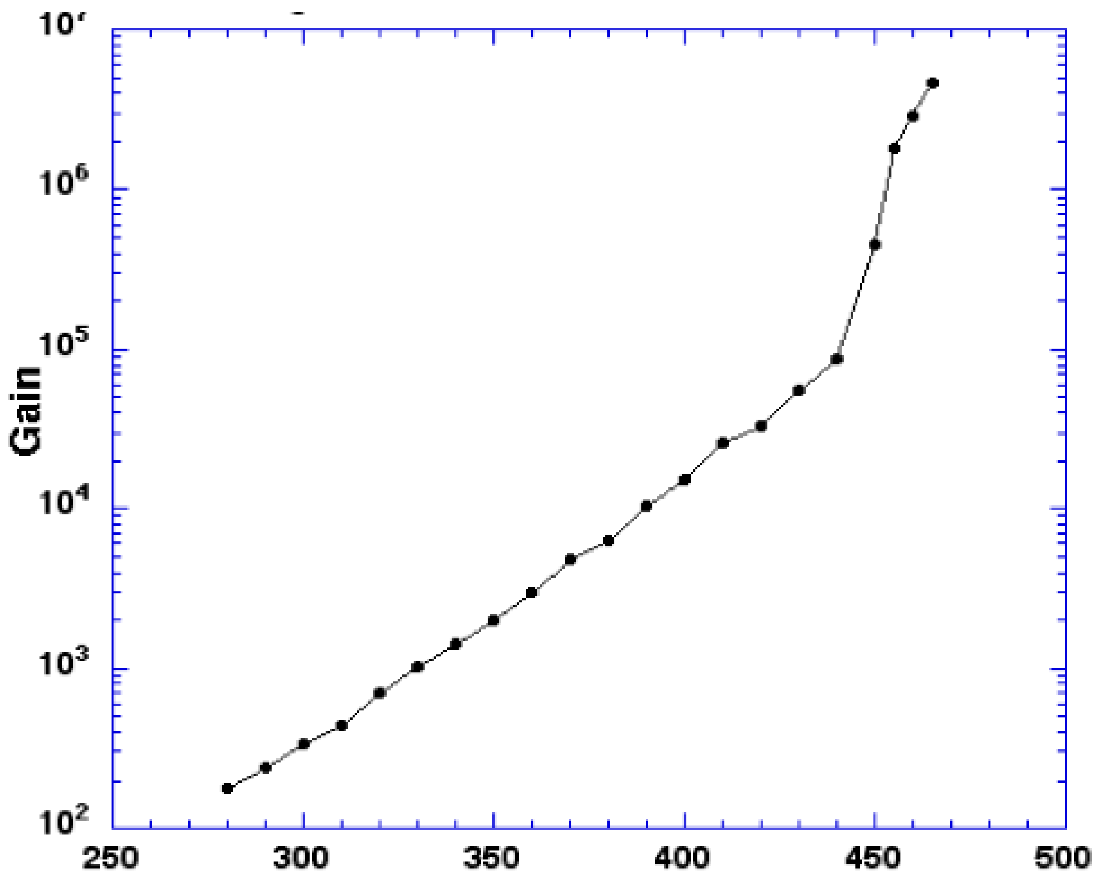
Pulses with very similar rise/fall times give $\sigma_0 \approx 50$ μm for 2 x 6 mm^2 pads

T2K TPC with charge dispersion readout - Simulated PRF
8 x 8 mm² pads



Micromegas gain with charge dispersion

Argon/Isobutane 90/10



Suppression of sparking & improved HV stability

Summary

- **Charge dispersion makes MPGD position sensing independent of pad width and high resolution can be achieved independent of pad width:** $\sigma_x^{\ 2} \approx \sigma_0^{\ 2} + \frac{D_{Tr}^2 \cdot z}{N_{eff}}$
- **At 5 T, an unprecedented ~ 40 μm resolution for 2 x 6 mm² pads for drift distances up to 15 cm.**
- **With the charge dispersion, large TPCs like T2K could achieve better resolution with existing channel counts**
- **Channel counts could be reduced for large high resolution systems such as Micromegas muon chambers proposed for ATLAS at SLHC**
- **Significant reduction of detector cost and complexity possible with charge dispersion.**

SLHC Micromegas Muon chambers

Capacitance 100 pF/cm^2 for 100 micron gap

Strip width = 1 mm = 0.1 cm

Assume 50 cm long strips = > Area = 5 cm^2 => capacitance 500 pF

Will need to use MOSFET, since one can get better trans-conductance => faster risetime at larger capacitance

MOSFET can be incorporated readily as part of ASIC, and can be made with radhard process

Will need big MOSFET. One can live with that since high density readout is not needed

Front-end preamplifier risetime better than 100 ns under these conditions

For charge dispersion, risetime will determine pulse pair resolution in case of pulse pileup on long strips

Consider area of 2 strips = > 10 cm^2 for pileup considerations

Muon chamber rates 1E4/(sec.cm^2) max

Count rate for 10 cm^2 area => 1E5/sec =0.1 hit/micro.sec = 10 micro.sec between hits

Assume resolving time = 100 ns

nbar = average rate per 100 ns = 0.01

P(n) = exp(-nbar). (nbar)^(n)/n!

P(0) ~ 0.99

P(1) ~ 0.01

P(2) ~ ~0.01*0.01/2

Pile up probability ~ 0.01 => 1%

1% of hits will be unresolved at this rate.

Resolution achievable should be better than 100 microns