Position sensing in a GEM from charge dispersion on a resistive anode

Bob Carnegie, Madhu Dixit, Steve Kennedy, Jean-Pierre Martin, Hans Mes, Ernie Neuheimer, Alasdair Rankin, & Kirsten Sachs

Carleton University, University of Montreal & TRIUMF

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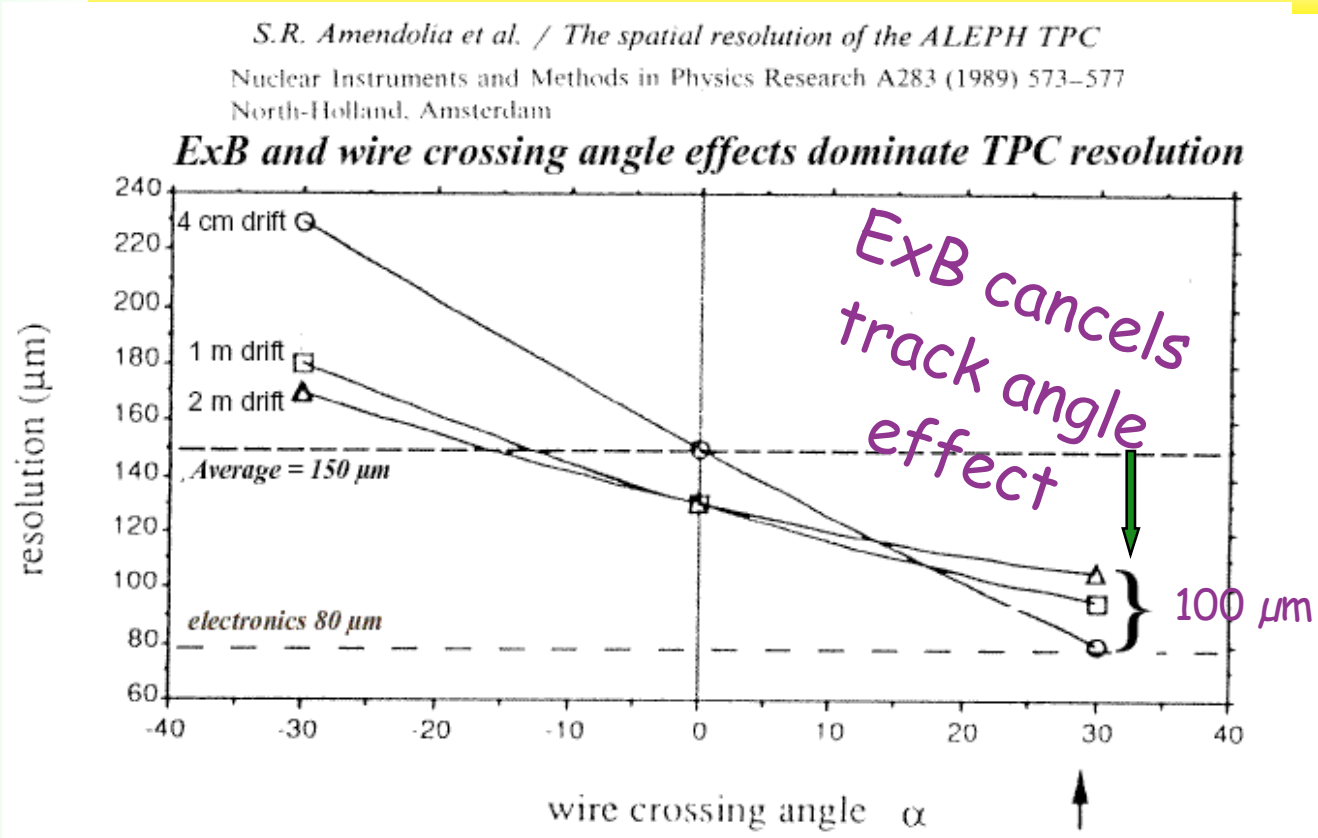
New MPGD Readout Concepts - R&D at Carleton

- A wire/pad readout for the TPC can get ~ 140 μm resolution with wide pads (6 mm pads - Aleph TPC)
- MPGD resolution ~ 40 μm with 200-400 μm wide pads with conventional electronics - prohibitive channel count, increased cost & complexity
- New ideas to get ~ 70 μm resolution with wide pads for all TPC drift distances:
  - Use GEM induction signal?
  - Disperse the avalanche charge in an MPGD with a resistive anode for better position sensing
  - GEM resistive cell results using collimated x-rays

Conventional TPCs never achieve their potential!

Example:Systematic effects in Aleph TPC at LEP



- Average Aleph resolution ~ 150 μm
- About 100 μm best for all drift distances
- Limit from diffusion □ (10 cm drift) ~ 15 μm; □ (2 m drift) ~ 60 μm
- 100 μm limit for all drift distances comes from wide pad response

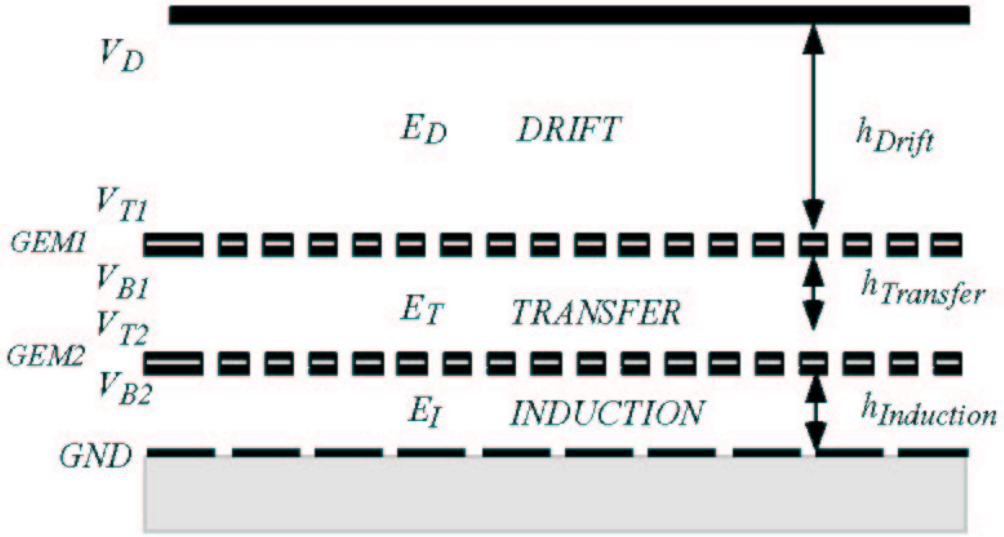
An MPGD Readout TPC for the LC

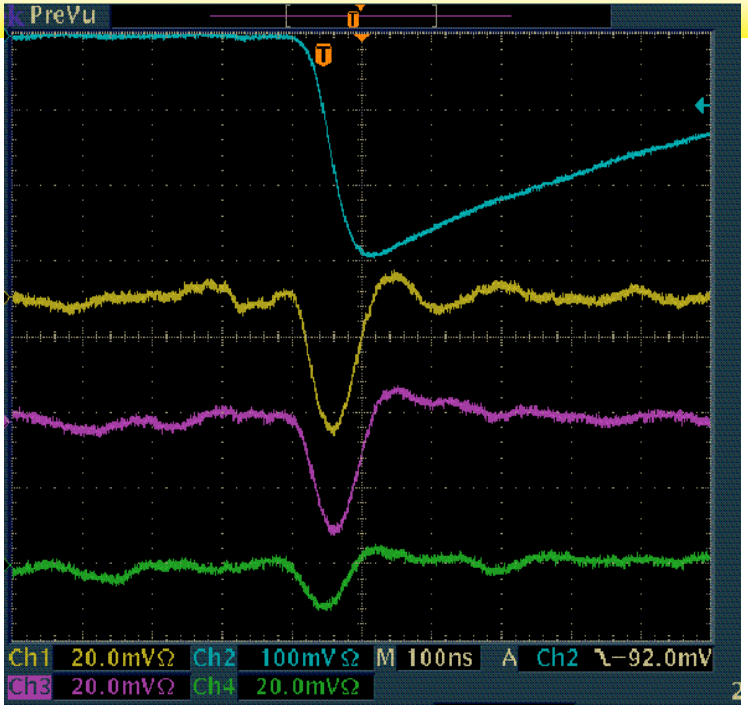
- Large systematic effects cannot be avoided in a conventional wire readout TPC
- Even when systematics cancel, resolution worse than diffusion
- A micro-pattern gas detector (MPGD*) readout TPC has

  Such as Gas Electron Multiplier (GEM), Micromegas

  - Negligible systematic effects
  - Feasibility of resolution approaching diffusion limit
  - Natural suppression of positive ion space charge effects

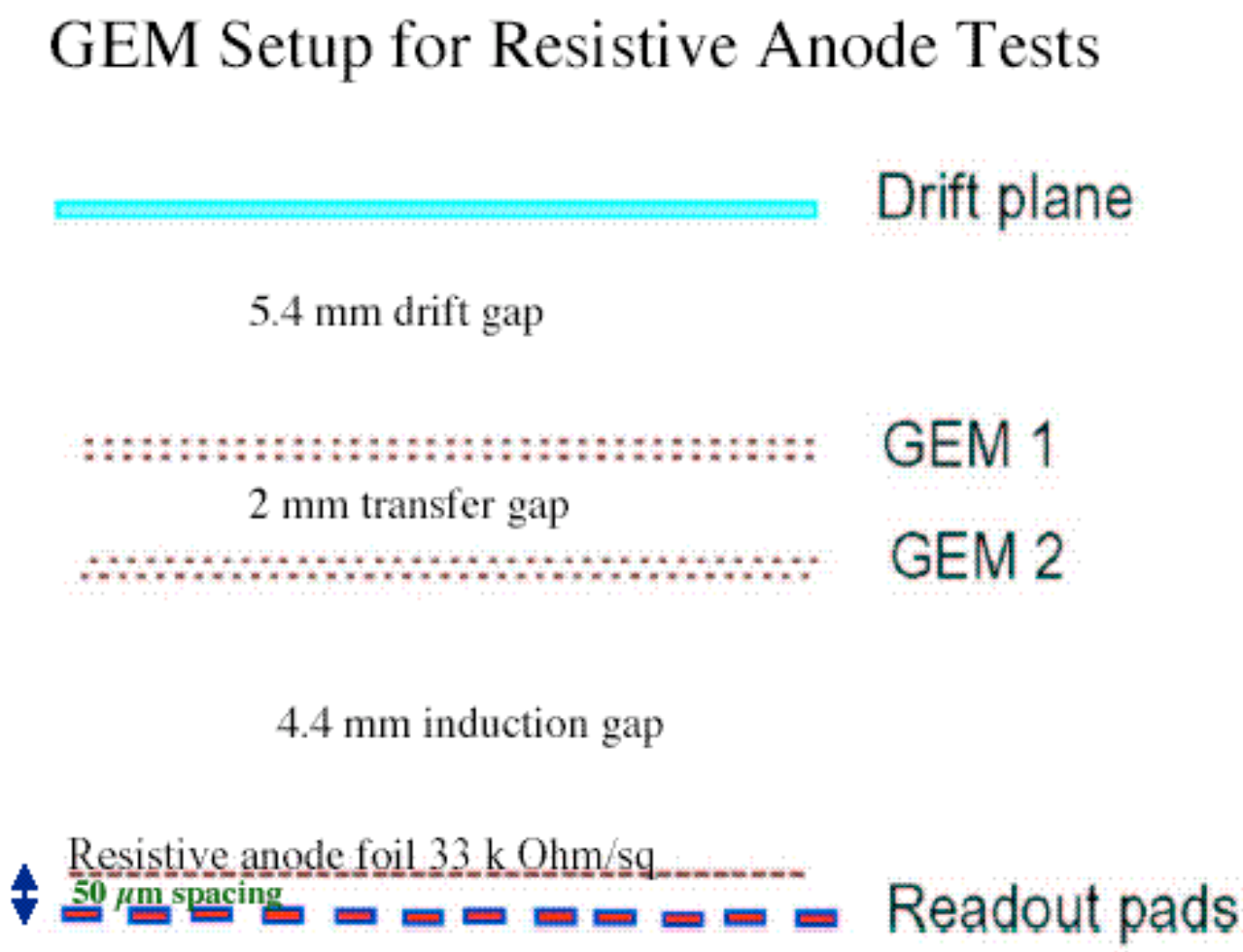
Use signals induced by electron motion in the GEM induction field?



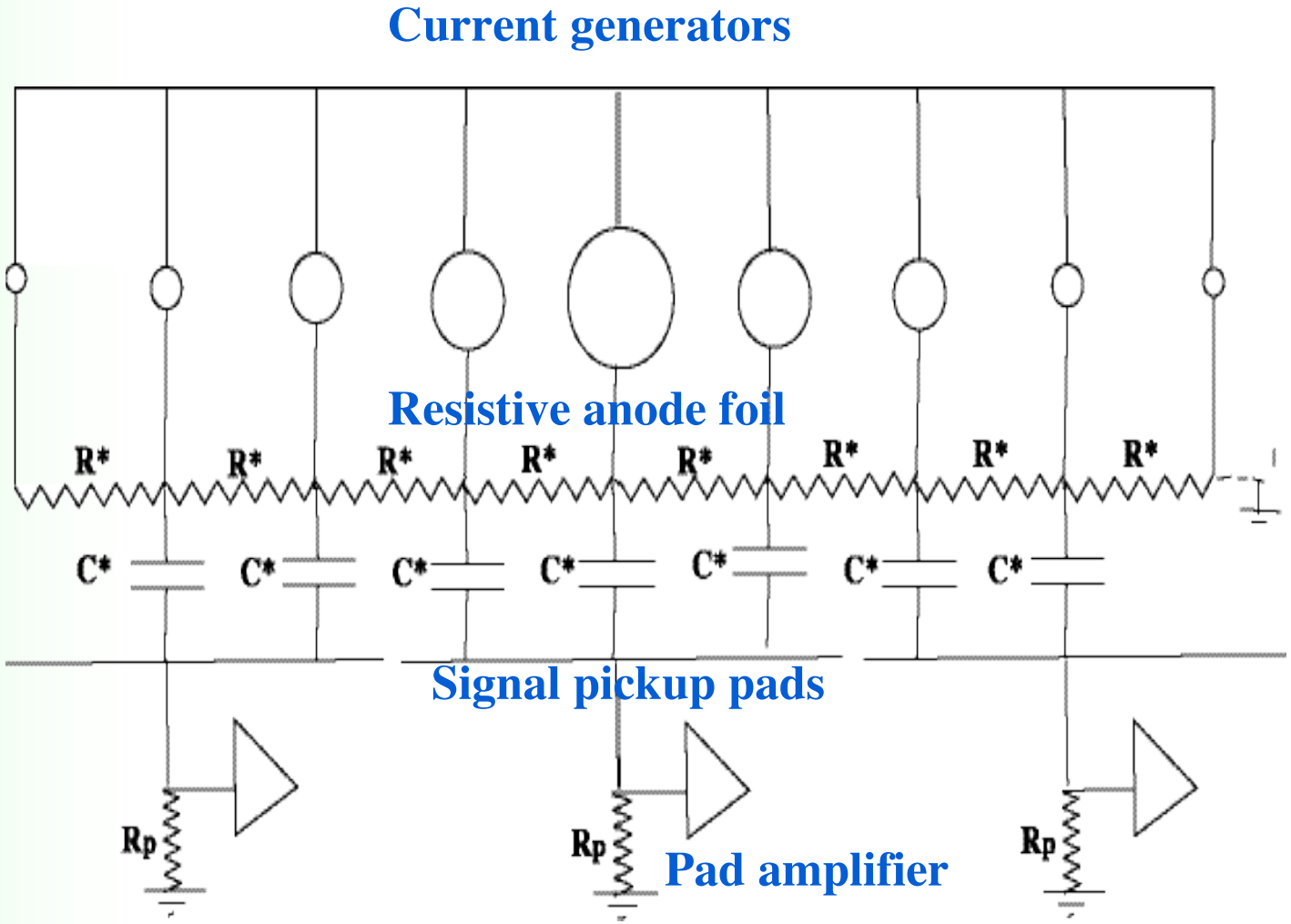


- Main charge collecting pad sees a large charge signal
- Neighbors see a small short duration (~ 200 ns) pulse of different shape
- Spatial resolution $\sigma_x \sigma_y \sim 70$ μm attainable
- But needs fast large dynamic range FADCs- complex analysis

Charge dispersion in a GEM with a resistive anode



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



How to calculate pad signals in a GEM with a resistive anode film close above readout pads?

- Lumped parameter approximation - The resistive anode layer close above readout pads forms a 2-D network of resistors and capacitors
- Finite element calculation with Spice as for Iorache tubes with external readout pads - the hard way!
- Solve the diffusion equation in 2-D (Radeka) - much simpler!

Position sensing in a GEM from charge dispersion on a resistive anode

Analogy: position sensing in 1-D in a proportional wire by 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)

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

Position sensing in 2-D in an MPGD with a resistive anode

Telegraph equation in 2-D

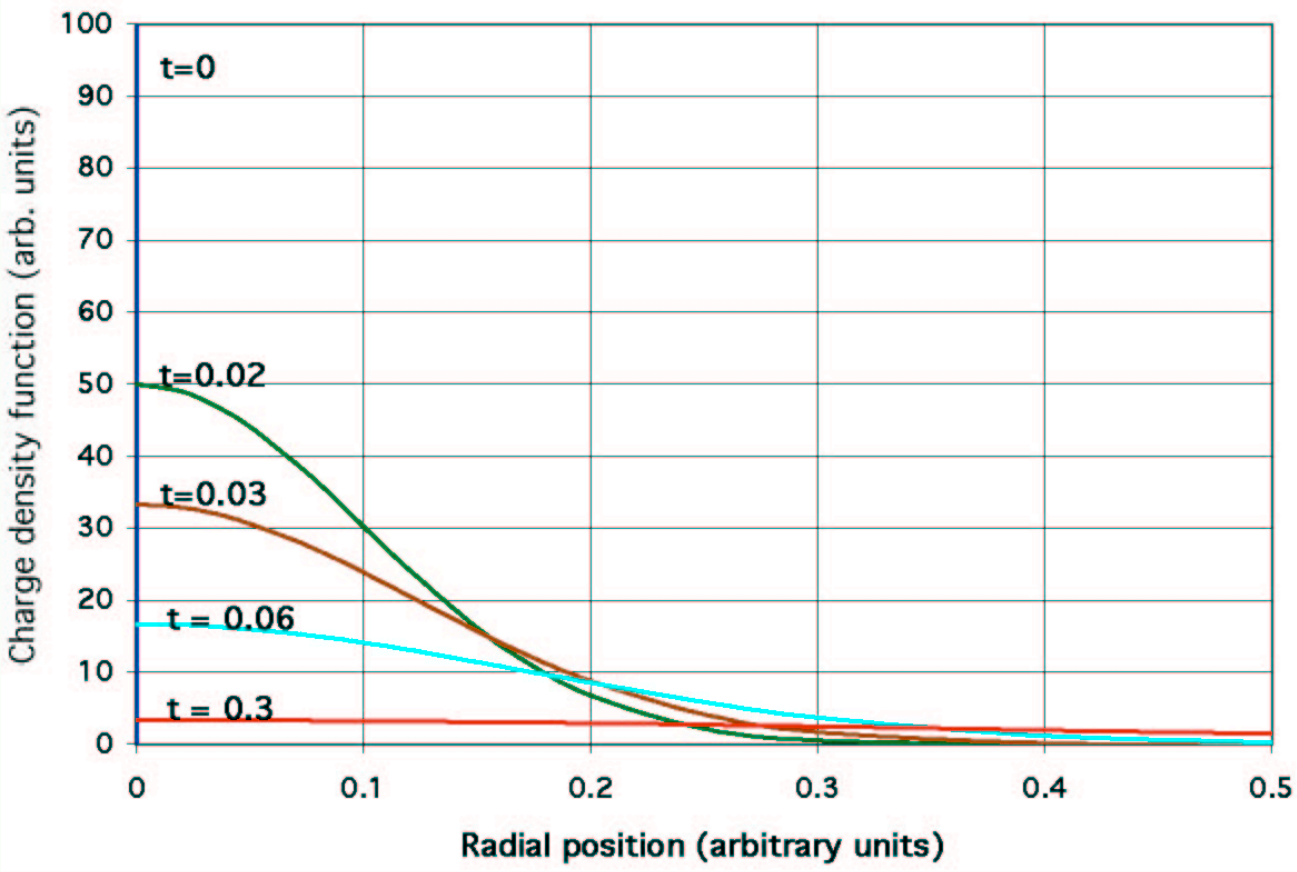
$$\frac{\partial Q}{\partial t} = \frac{1}{RC}\left[\frac{\partial^2 Q}{\partial r^2} + \frac{1}{r}\frac{\partial Q}{\partial r}\right]$$

Solution for charge density in 2-D

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

for simulation include finite charge cloud size + rise and fall time effects

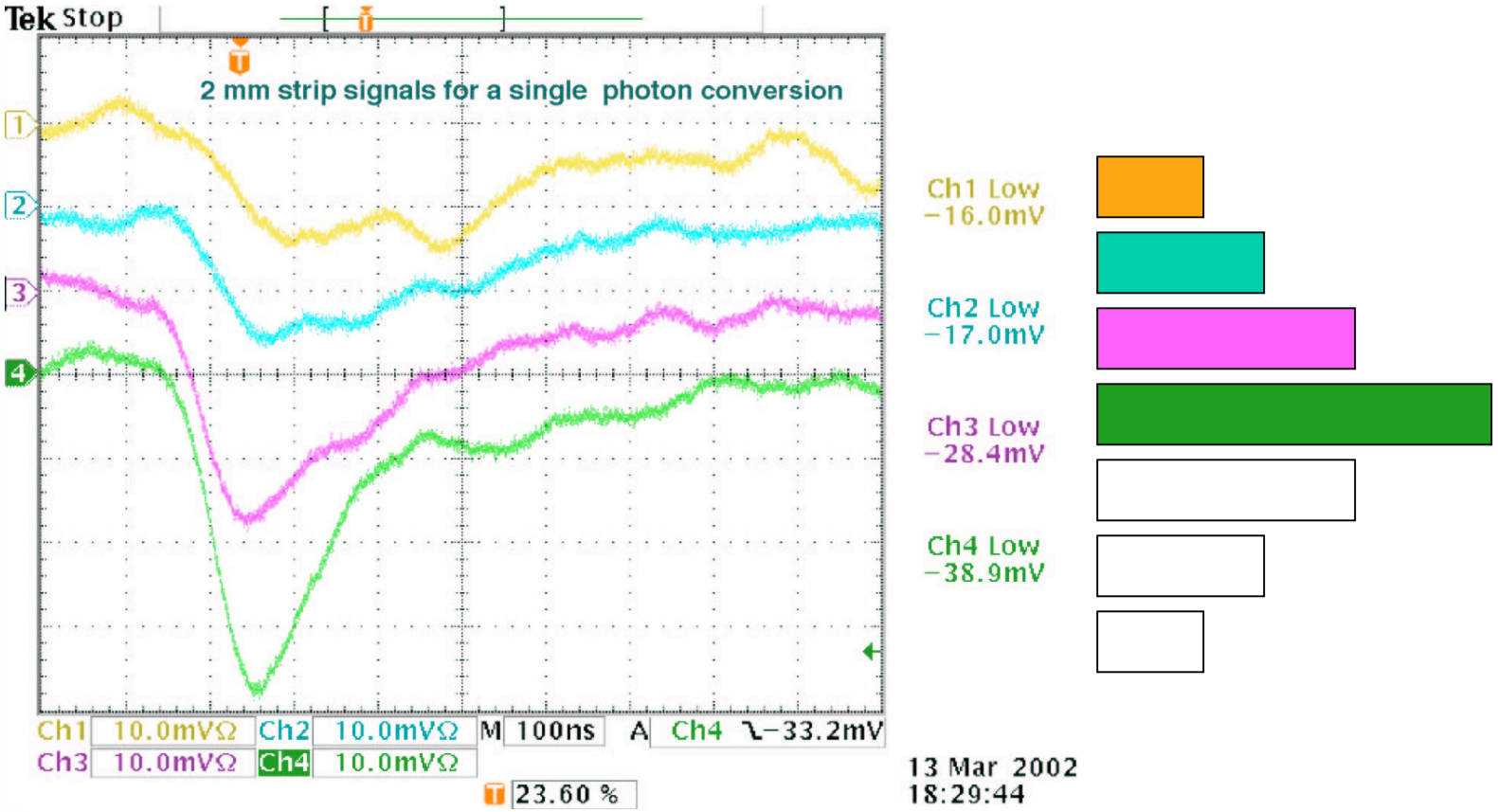
Time evolution of an initially localized charge in a GEM with a resistive anode



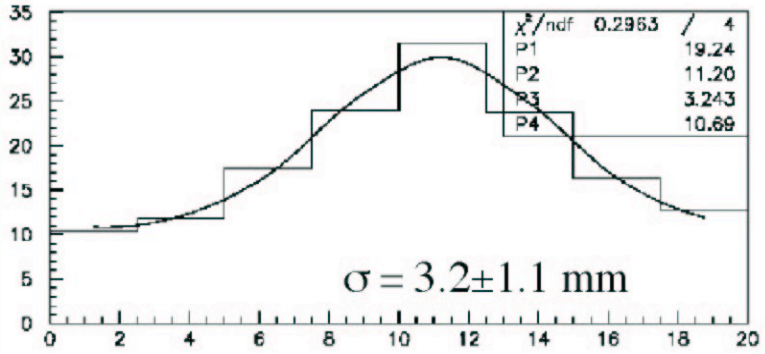
The time dependent charge density distribution on the resistive sheet is capacitively sampled by readout pads below

An event in the resistive anode GEM test cell

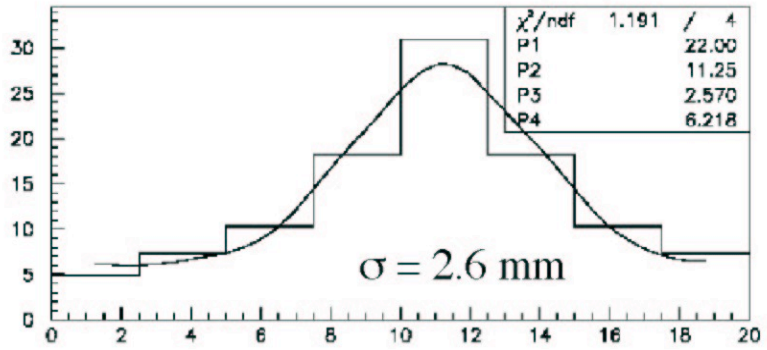
Charge cluster size ~ 1 mm ; signal detected by ~7 anodes (2 mm width)



Pad response function
Simulation versus Measurement



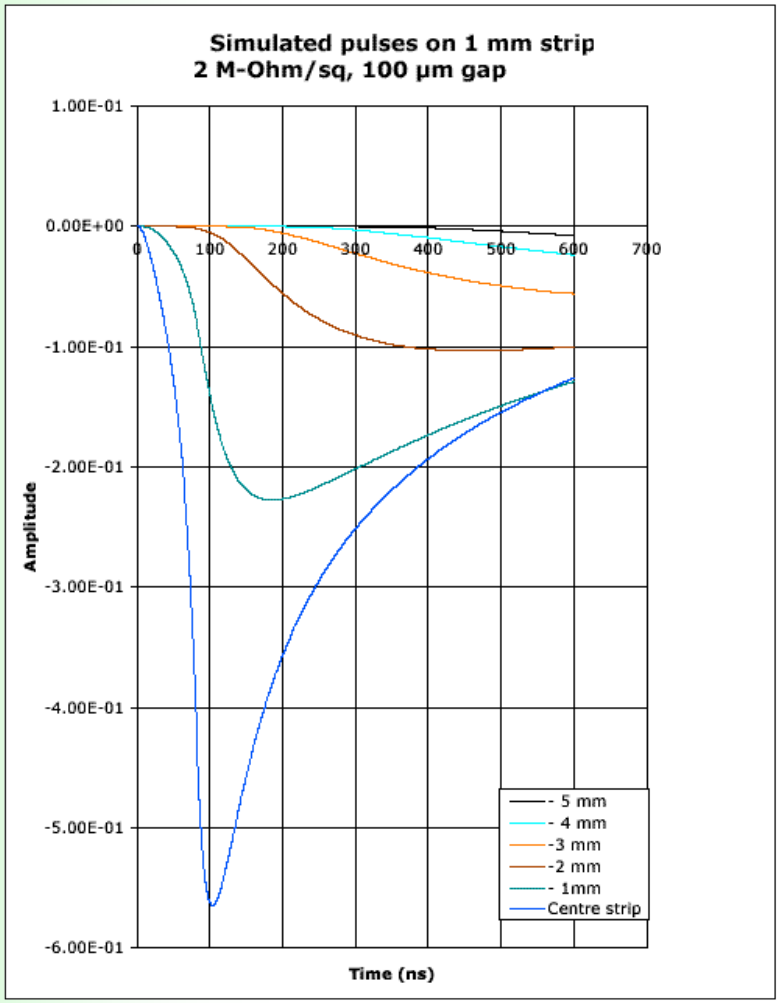
Measured pad response function

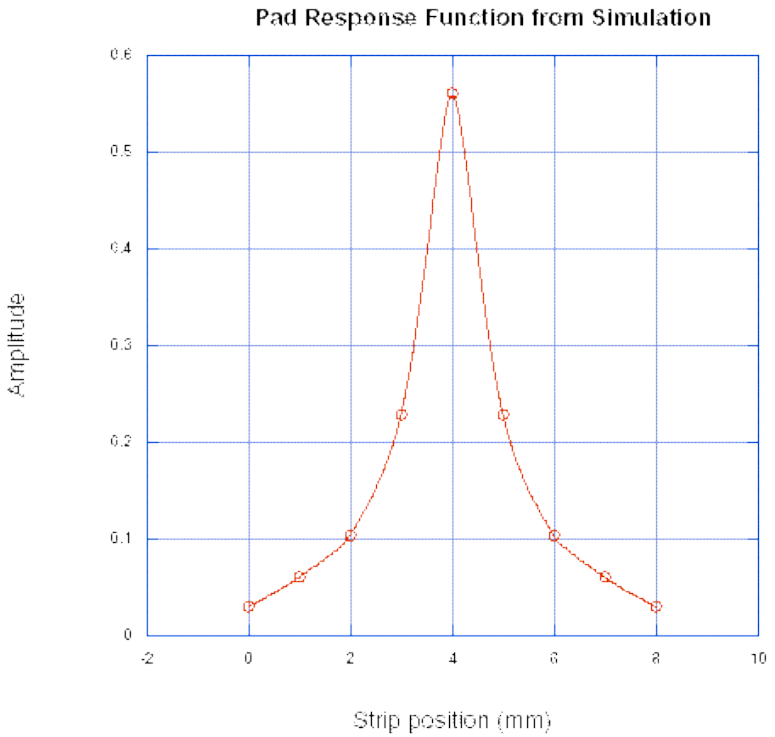


Simulated Pad Response Function

- *Width & shape of signal distributions on pads can be simulated*
- *The pad response function σ_{PRF} depends on anode resistivity & the gap between anode and readout pad plane*
- *This PRF is too wide*
- *Require $\sigma_{PRF} \sim \sigma_{diffusion}$ for optimum resolution*

Design simulation for σ_{PRF} ~ 700 μm



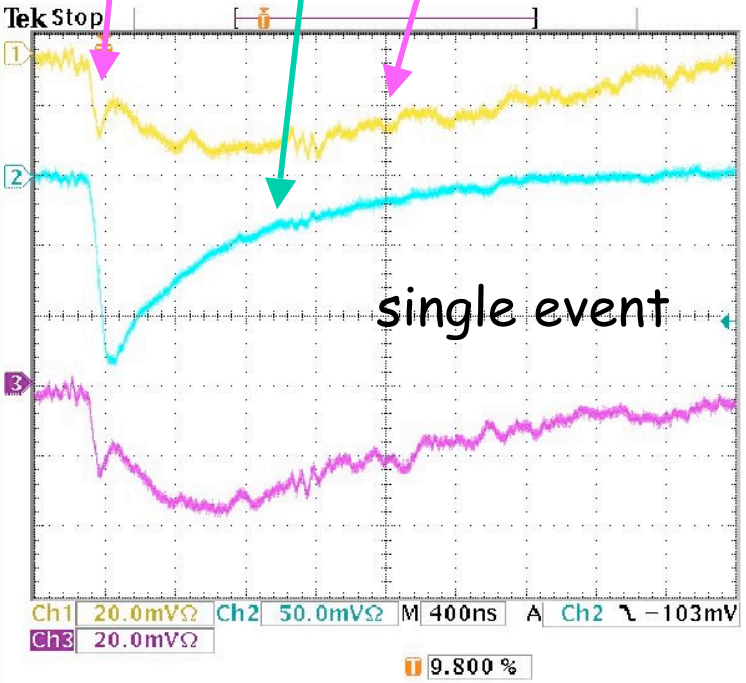


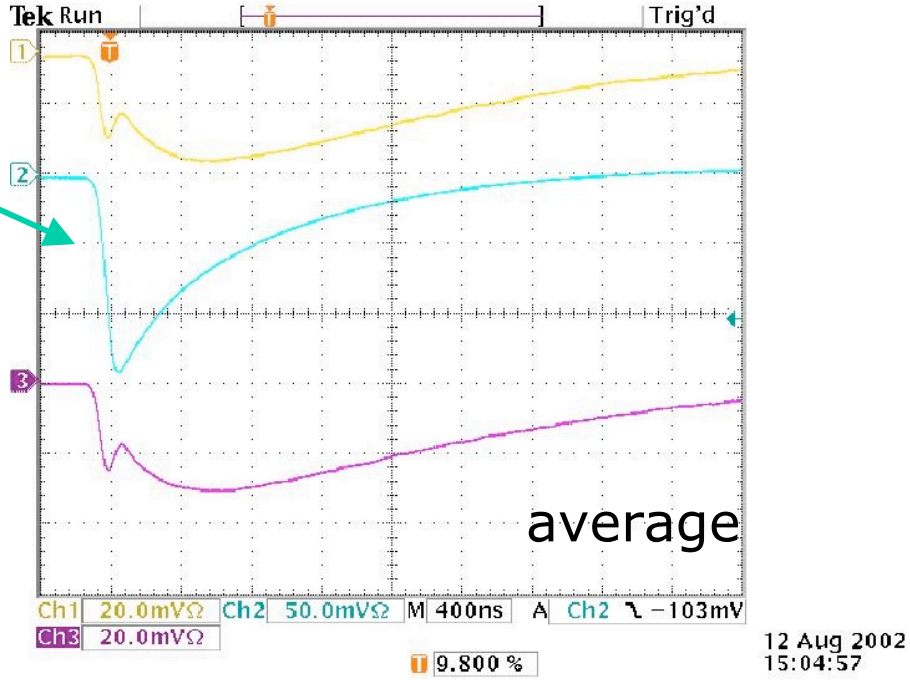
Resolution tests with σ_{PRF} ~ 700 μm design

central strip: main pulse

adjacent strips with induced pulse

+ charge dispersion





2.5 M /❑ resistivity

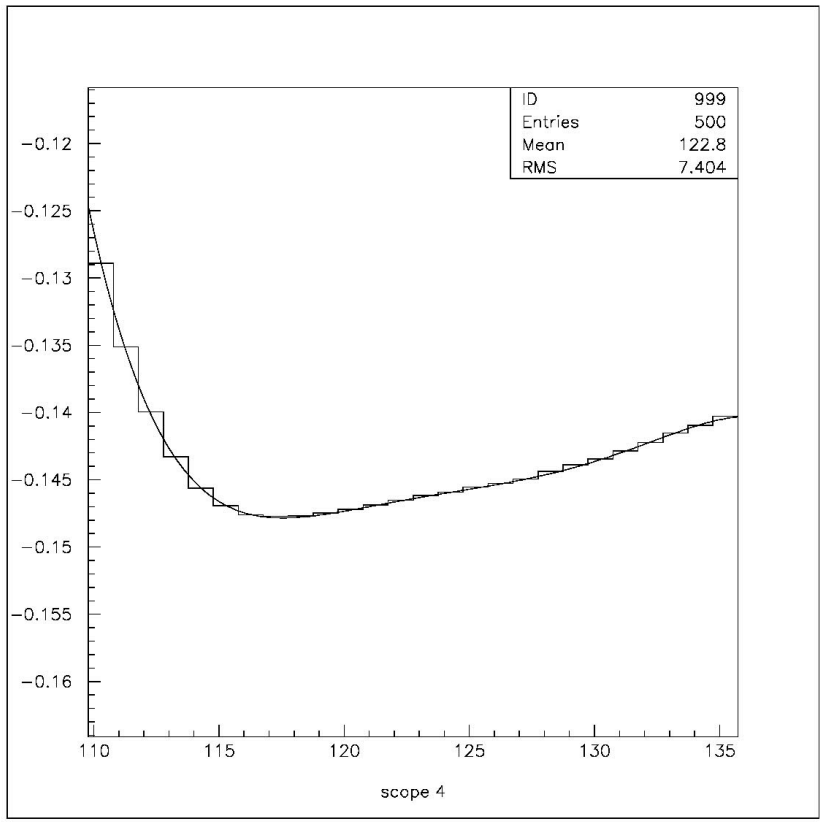
100 μm gap

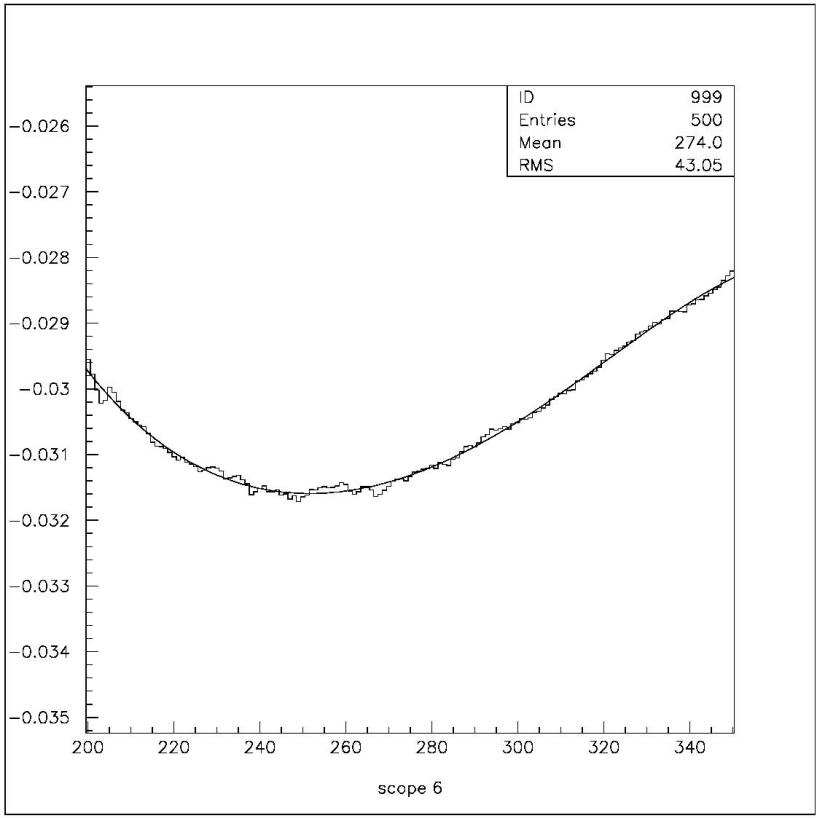
1.5 mm strips are too wide for σ_{PRF} ~ 700 μm!

GEM charge dispersion resolution study

- 50 μm collimated x-ray spot
- Scan across 1.5 mm wide strips
- Record 1000 events with Tektronix digitizing scope
- Single event produces measurable signal on 3 strips
- Early charge pulse, delayed charge dispersion pulse
- Use 500 events to define pulse shape polynomials
- Measure signal amplitudes for remaining 500 events
- Compute 3 pad centre of gravity for each event
- Correct for bias in CG determination

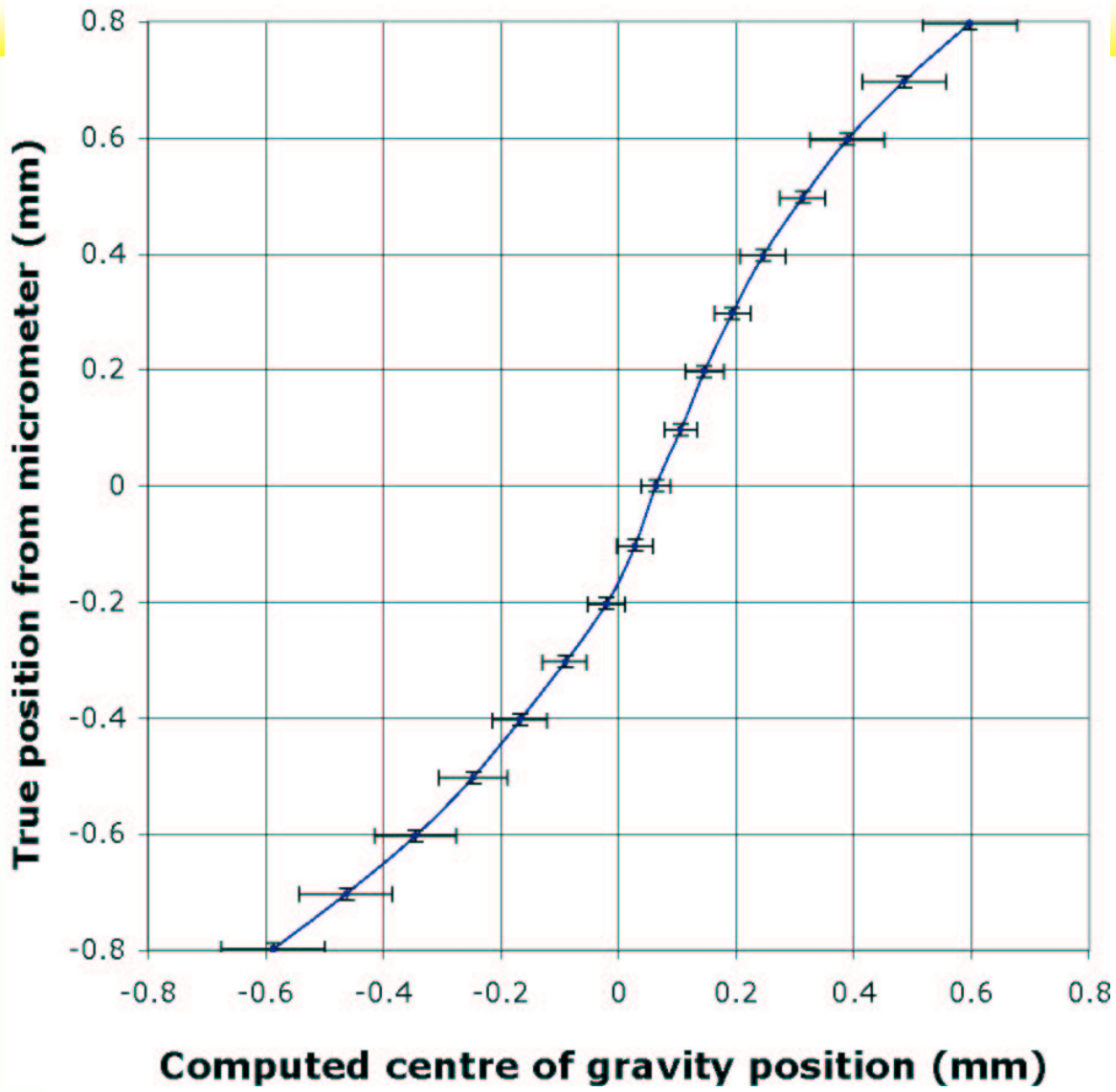
Polynomial fits define pulse shapes



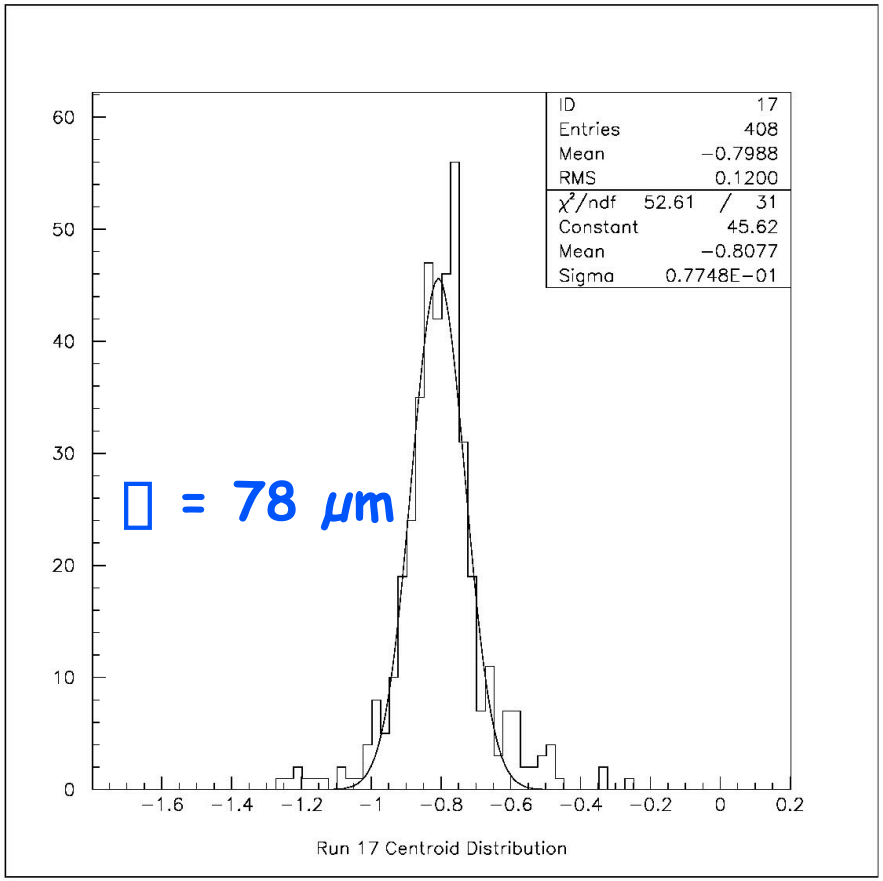


Use 500 events to define standardized pulse shapes for ***early*** **charge pulse (left),** and **delayed** charge **dispersion pulse (right)**

Bias correction to measured centre of gravity

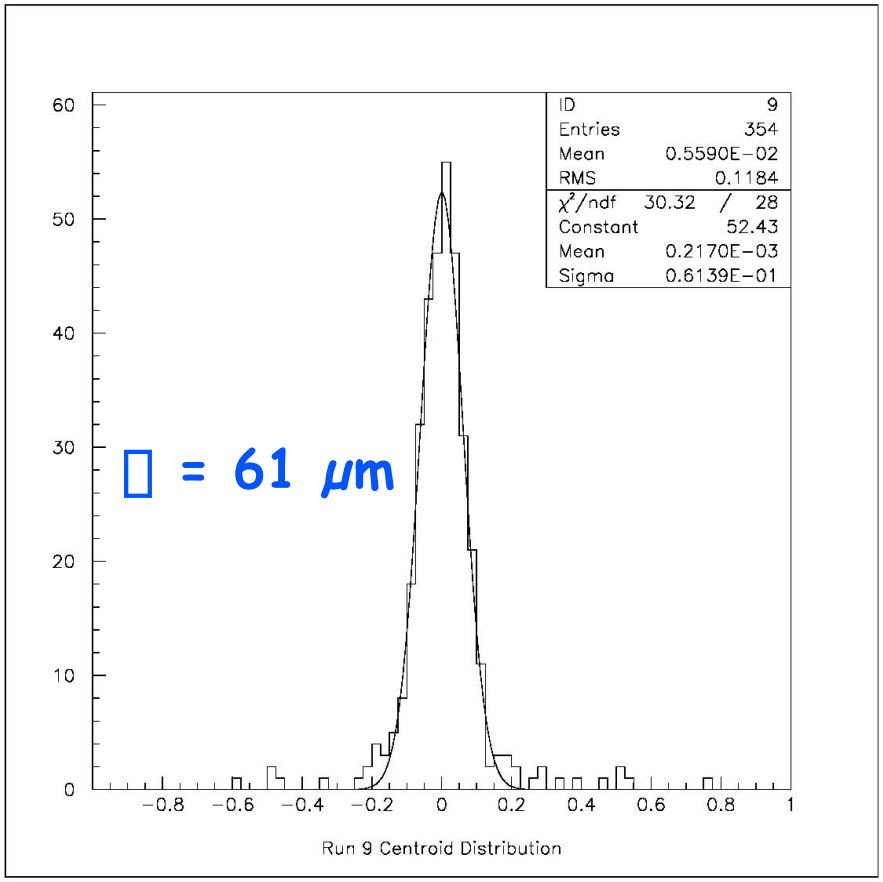


Resolution near a strip edge

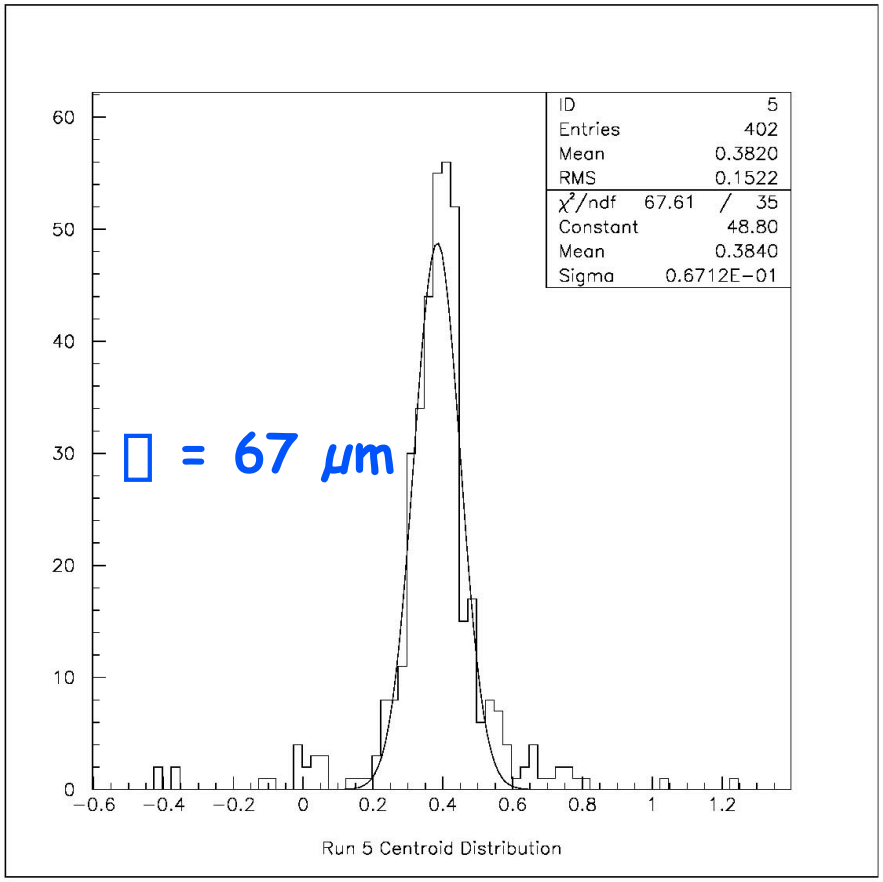


 = 78 μm

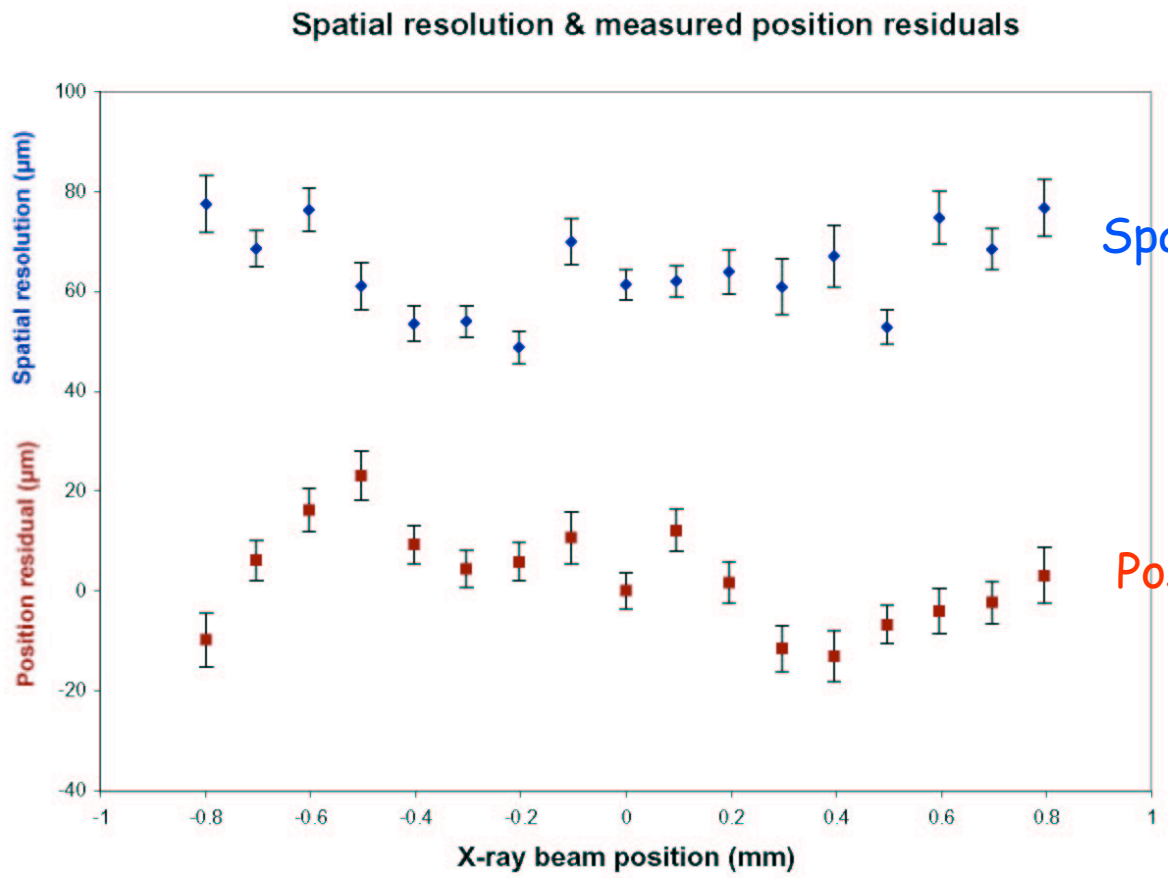
Resolution near the centre of a strip



Resolution between edge & centre



Resolution scan - summary



Spatial resolution

Position residuals

X-ray spot position (mm)

Outlook & summary

- Promising preliminary results for position sensing from charge dispersion in a GEM test cell with resistive anode
- Resistive anode concept applicable to other MPGDs; e.g. Micromegas
- Further tests in progress to optimize parameters and establish viability
- Proof of principle cosmic rays tests with mini-TPC