Resolution of a MPGD readout TPC using the charge dispersion signal

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Introduction

- Transverse diffusion sets the ultimate limit on the TPC resolution.
- Wire/pad TPCs do not reach this limit due to ExB & track angle effects.
- MPGD TPC has the potential to reach the diffusion limit but is limited by imprecise pad centroid determination due to insufficient charge sharing.
- Options:
  - Narrower pads, increased complexity & a much larger channel count.
  - Disperse avalanche charge for improved centroid determination.
- GEM operated with large diffusion in transfer and induction gaps. R.K.Carnegie et.al., LCWS'02, physics/0402054 (to be published in NIM).

➢ Charge dispersion on a resistive anode: concept and 1st tests published: *M.S.Dixit et.al., NIM A518 (2004) 721.*

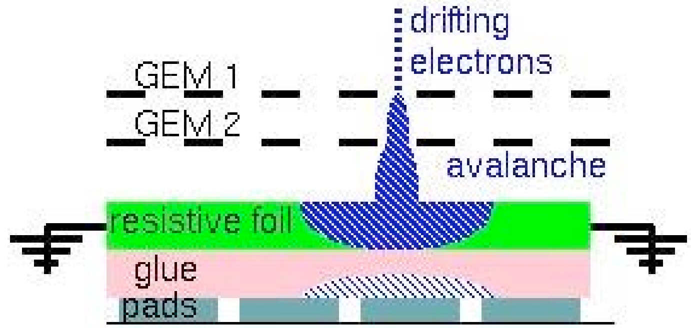
➢ First results on TPC resolution with charge dispersion in a low diffusion gas (Ar/CO_2:90/10, σ_{Trans}= 230 μm/√cm) presented at *LCWS 2004, Paris*.

➲ *New results on resolution from charge dispersion in Ar/CO_2:90/10 & in a high diffusion gas (P10, σ_{Trans}= 560 μm/√cm).*

➲ *Simulation - progress in understanding the charge dispersion phenomenon.*

Charge dispersion in a MPGD with a resistive anode

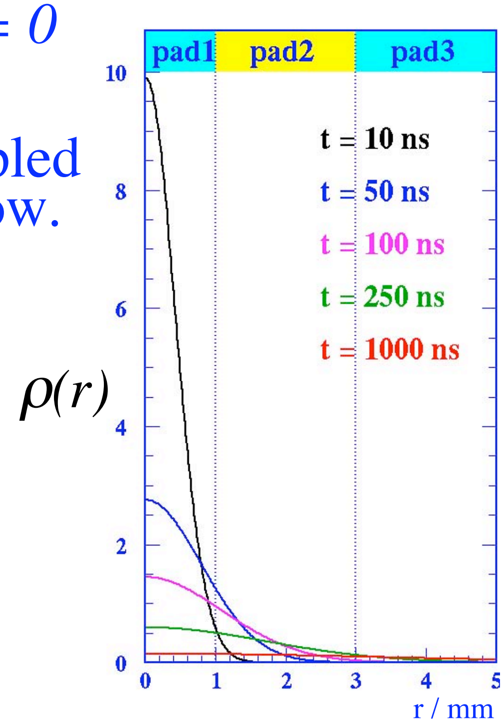
- Modified GEM anode structure with a high resistivity film bonded to the readout plane with an insulating layer of glue.
- 2-dim RC network defined by material properties & geometry.
- Point charge at *r = 0 & t = 0* disperses with time.
- Measure capacitively coupled charge signals on pads below.

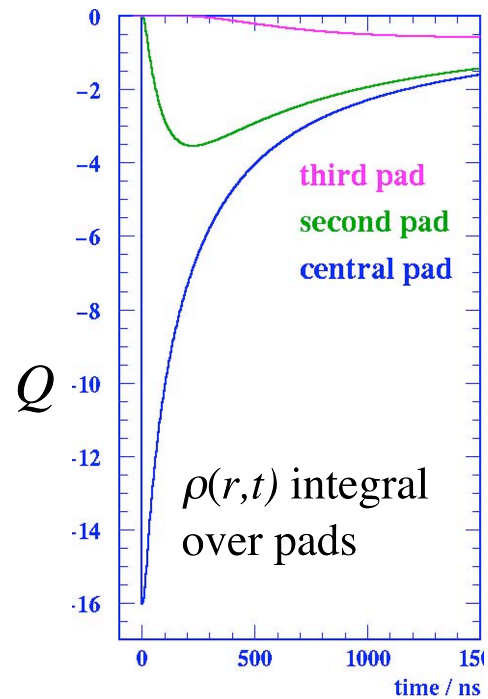


Telegraph equation for the charge density function:

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

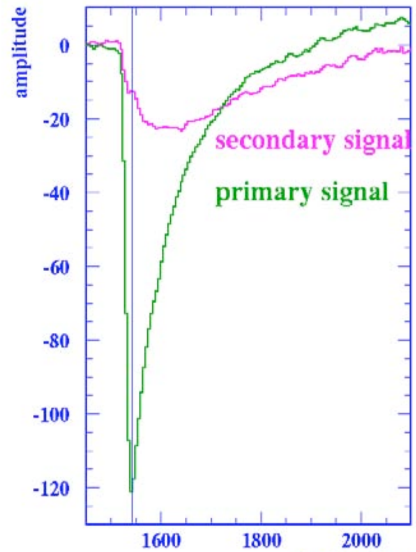
$$\Rightarrow \rho(r,t) = \frac{RC}{2t} e^{\frac{-r^2 RC}{4t}}$$

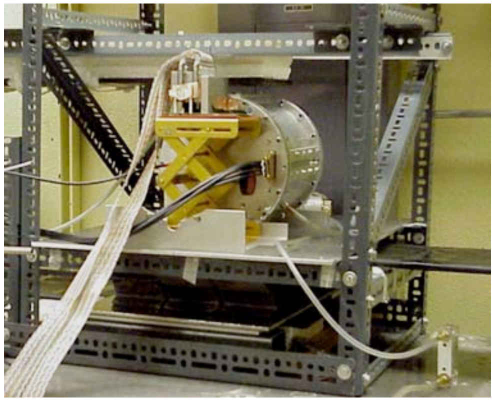


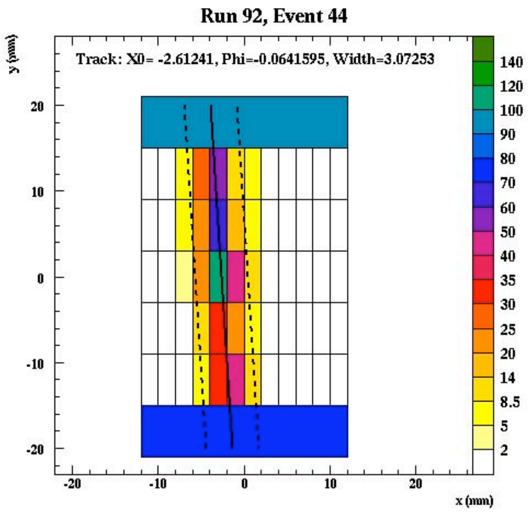


Cosmic ray track resolution of a GEM TPC using the charge dispersion signal

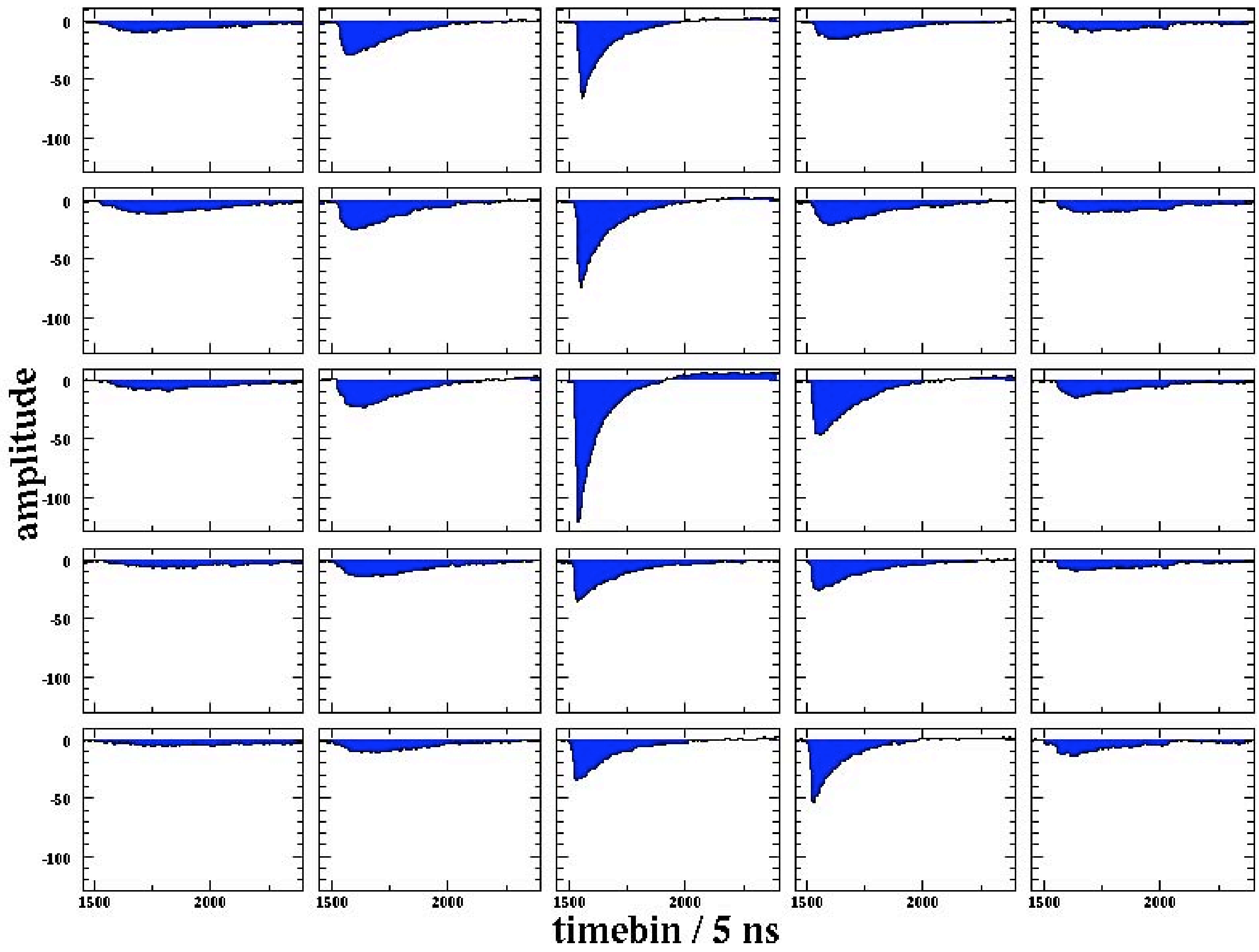
- 15 cm drift double GEM-TPC.
- Ar/CO_2 (90/10) & P10 gas mixtures.
- 60 readout pads (2 x 6 mm^2).
- Anode resistivity ~ 530 kΩ/□
- C ~ 0.22 pF/mm^2.
- TPC charge preamps from Aleph. τ_{Rise}= 40 ns, τ_{Decay}= 2 µs.
- 200 MHz custom 8 bit FADC readout.







A TPC track signal with charge dispersion



Tracking with the charge dispersion signal

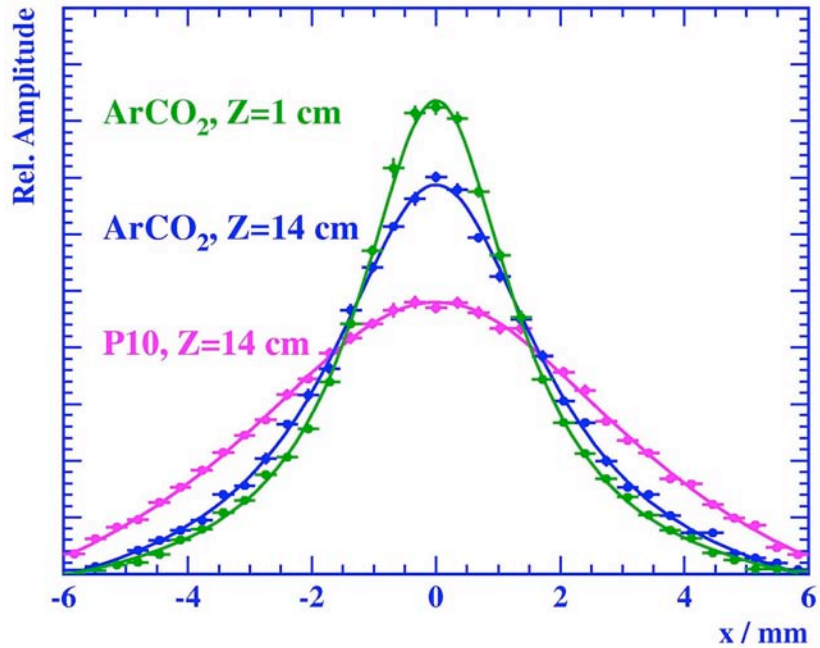
- Unusual highly variable charge pulse shape.
- *Pulses on charge collecting pads*: Large pulses with fast fixed rise-time. The decay time depends on the system RC, the pad size & the initial charge cluster location.
- *Pulses on other pads:* Smaller pulse heights & slow rise & decay times determined by the system RC & the pad location.
- Many possible ways to define & use the pad response function (PRF) since both the peak pulse amplitude & the pulse rise time depend on the initial charge cluster position.
- Present recipe for the PRF uses only the peak pulse height independent of the pulse rise time.
- Part of the cosmic ray data used for calibration to determine the PRF & the bias correction. The remaining cosmic ray data used for resolution studies.

The pad response function for TPC tracks determined from the calibration data set

The PRF shape well described by a generalized Lorentzian.

$$PRF(x, FWHM) = \frac{1 + a_1 x + a_2 x^2}{1 + b_1 x + b_2 x^2}$$

Parameters: x, $\Gamma(z)$

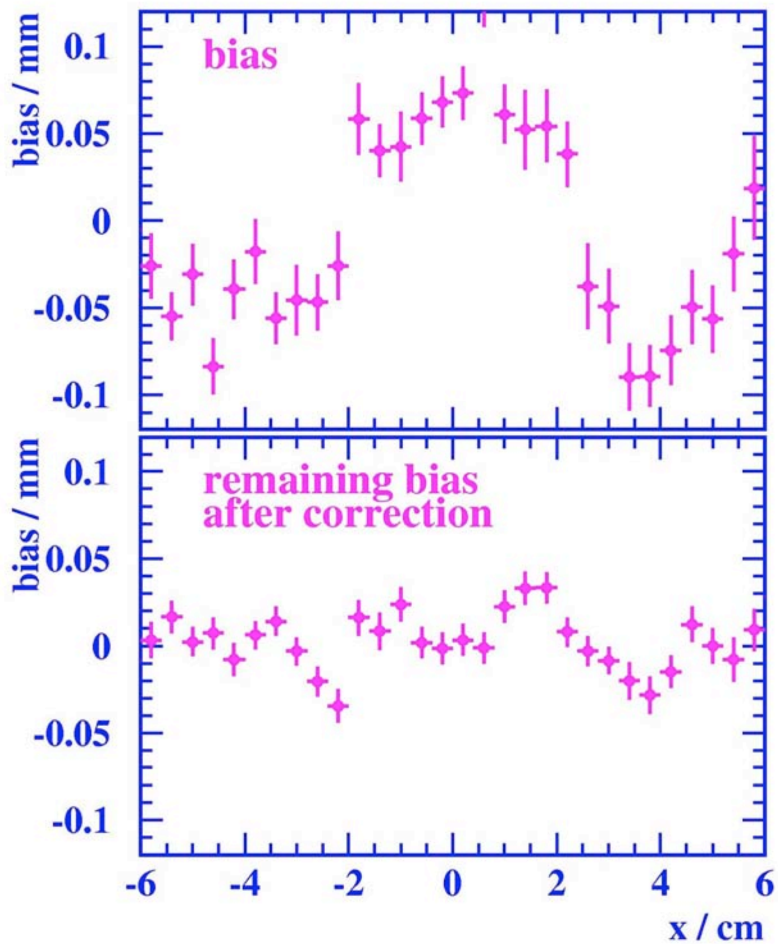


Γ_{PRF}(Ar/CO_2 90/10) ~ 3 - 3.7 mm depends on the drift distance.
Up to 3 pads in a row contribute.

P10 has large diffusion.
Γ_{PRF}(P10) for long drift ~ 6 mm.
Up to 6 pads contribute.

Bias in reconstructed positions from the PRF

- Local variations in the system RC time constant lead to biases of ~100 μm which can be corrected.
- Bias correction determined from the calibration data set.
- P10 has very wide PRF & many effects accumulate which become difficult to correct.
- Need a more uniform detector to keep systematic effects small.

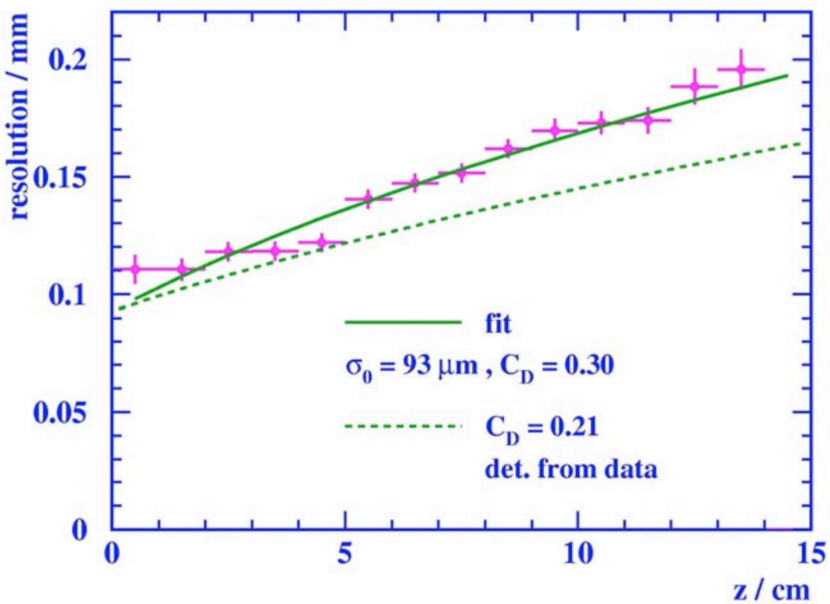


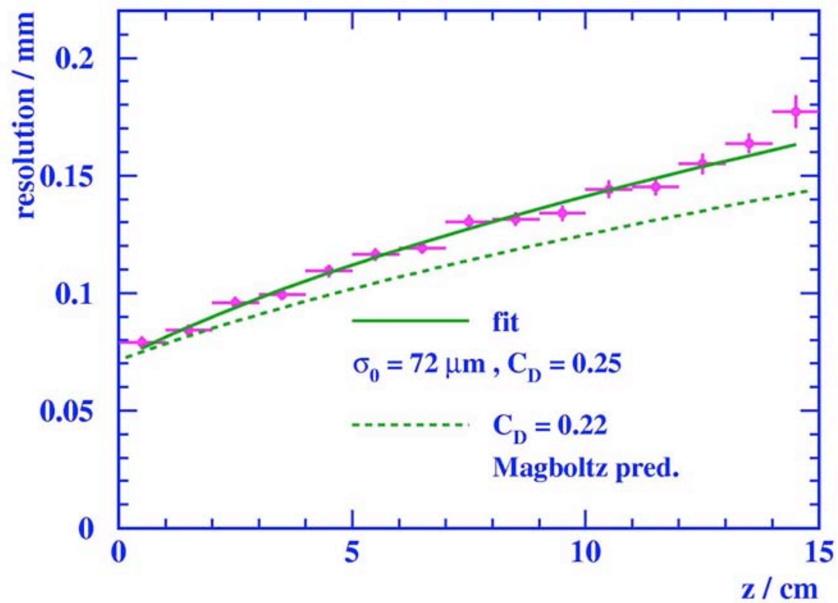
Bias for row 4 in Ar/CO_2 90/10

Ar/CO_2 (90/10) resolution

Direct charge	*Charge dispersion*

R.K.Carnegie et.al.,
physics/0402054 (submitted to NIM).



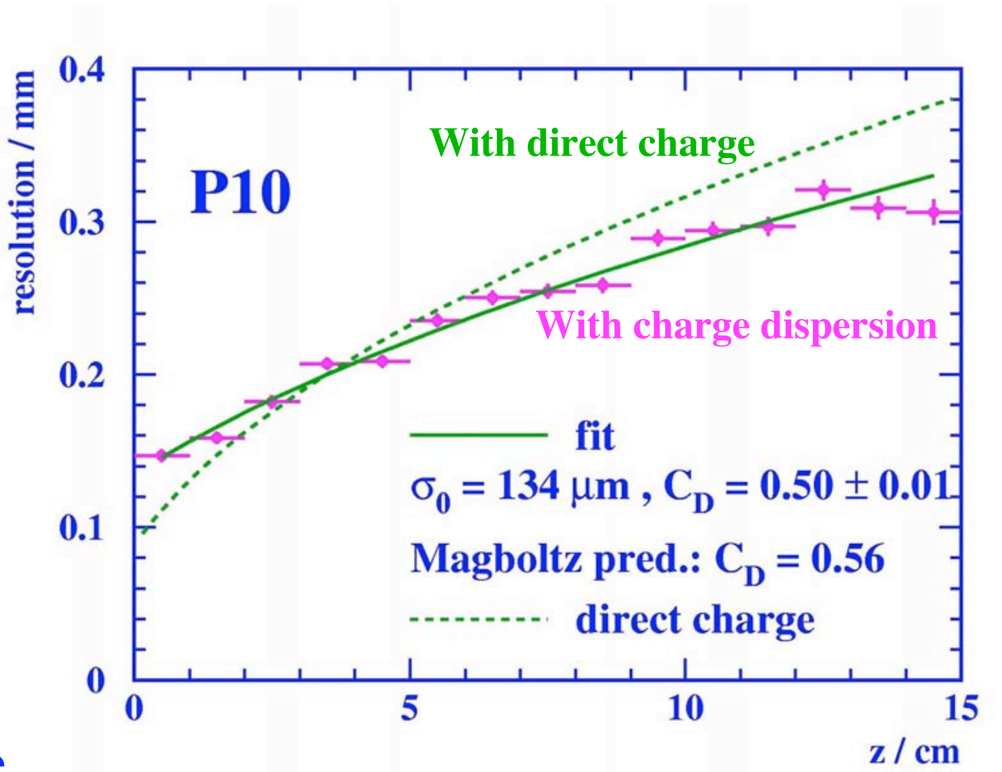


- - - - - $\sqrt{\sigma_0{}^2 + \frac{C_D{}^2}{N_e} z}$

Charge dispersion improves resolution even if the track charge is shared between pads due to transverse diffusion.

Resolution for P10

- The P10 PRF is too wide & local *RC* nonuniformities lead to biases which can not be completely removed.
- Larger systematic errors compared to direct charge; visible at short drift dist.
- At large drift distance better resolution closer to the diffusion limit.

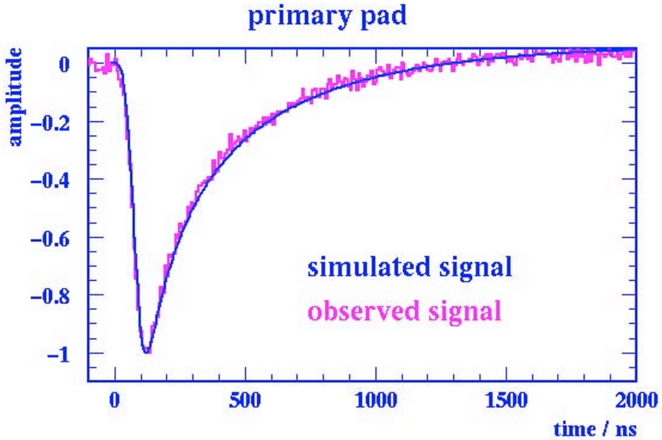


Confirmation of improved resolution with charge dispersion seen for $ArCO_2$ (90/10.)

The GEM charge dispersion signal
Simulation versus measurement

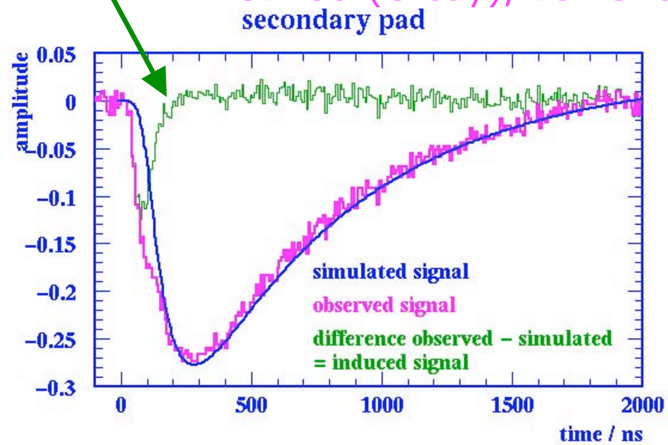
(2 mm x 6 mm pads) ~ 4.5 keV collimated x ray spot at the pad centre

Detailed simulation, includes effects of intrinsic detector charge pulse shape, diffusion in the gas, and the preamp (Aleph) rise and decay time effects.



Fast rising direct signal on charge collecting pad.

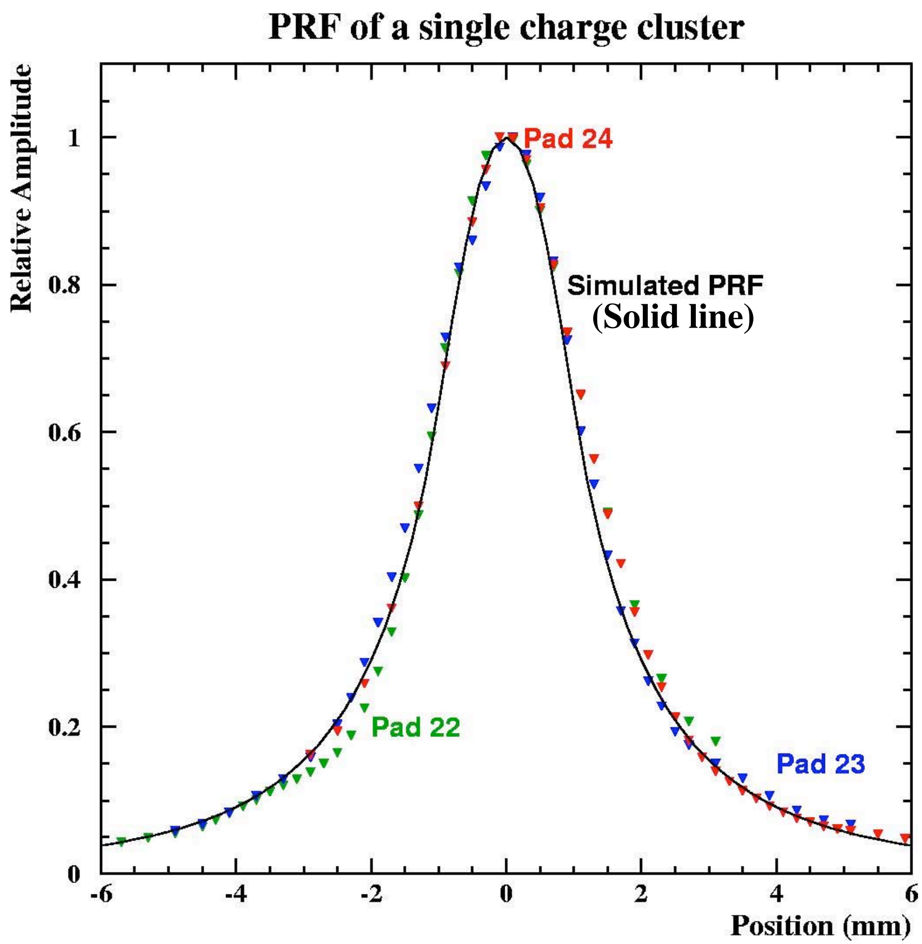
Difference (induced signal not included in simulation) studied previously MPGD '99 (Orsay), LCWS '00



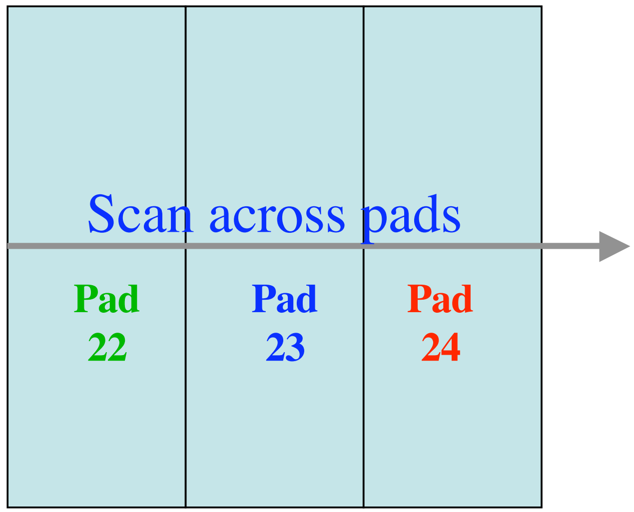
Neighboring pad dispersion signal peaks later (~150 ns) has slower decay time.

GEM pad response function for a charge cluster
Simulation versus measurement

(2 mm x 6 mm pads)



Ionization from 50 μm collimated x-rays.

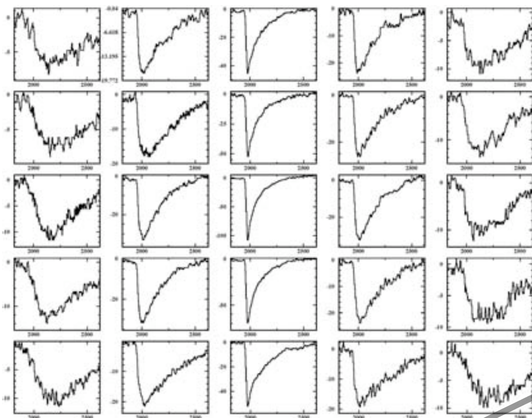


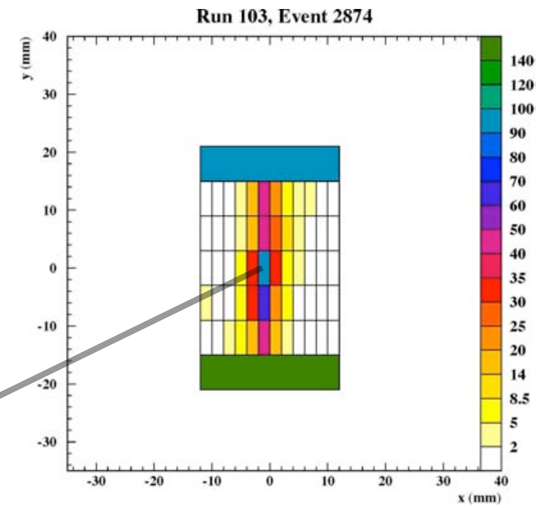
Simulated PRF deviates from the data due to RC nonuniformities. The deviations are consistent with observed biases.

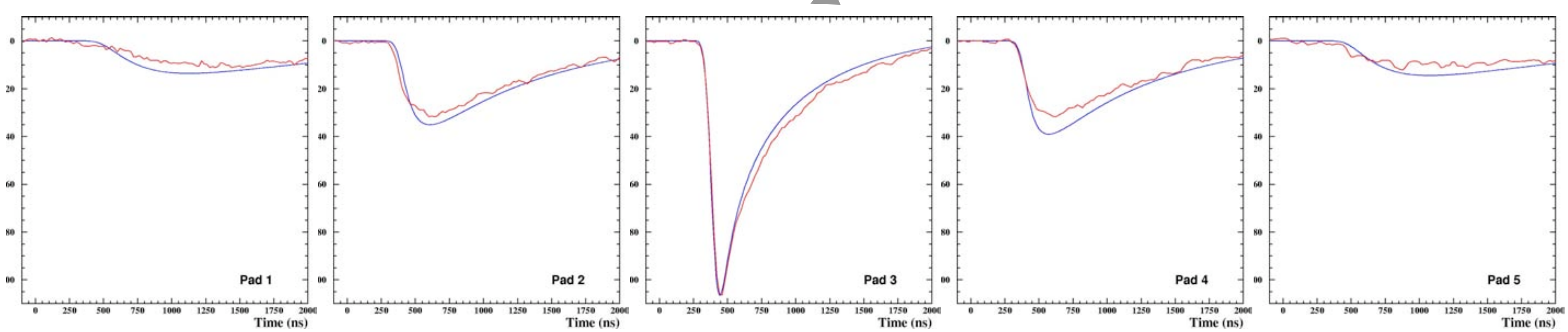
Cosmic ray track simulation - compared to the data

(67 mm drift, Ar/CO_2 90/10 gas)

- An exact simulation requires specifying the position & the size of all primary ionization clusters for the track.
  - ➢ *Uniformly spaced equal size charge clusters assumed here.*





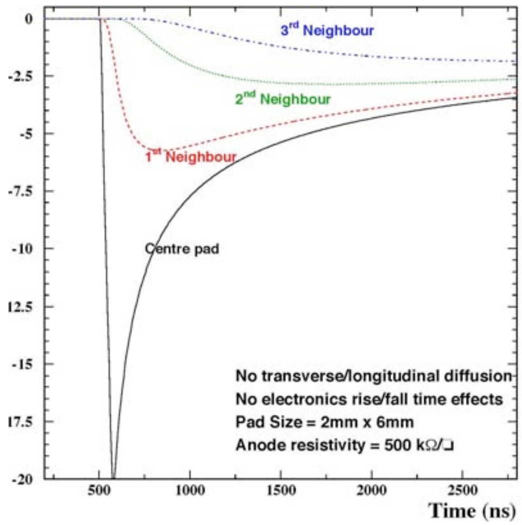


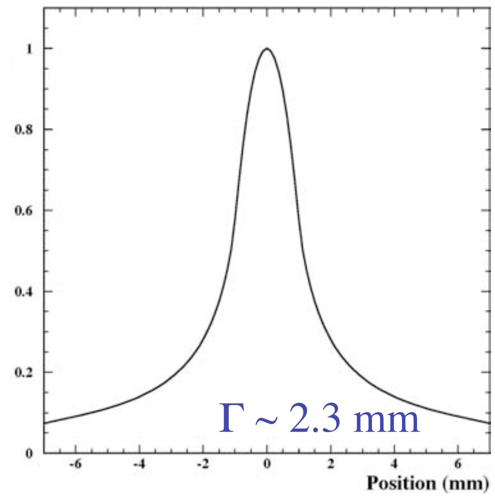
Single free parameter - normalization from the centre pad amplitude.

Optimizing charge dispersion for the best resolution

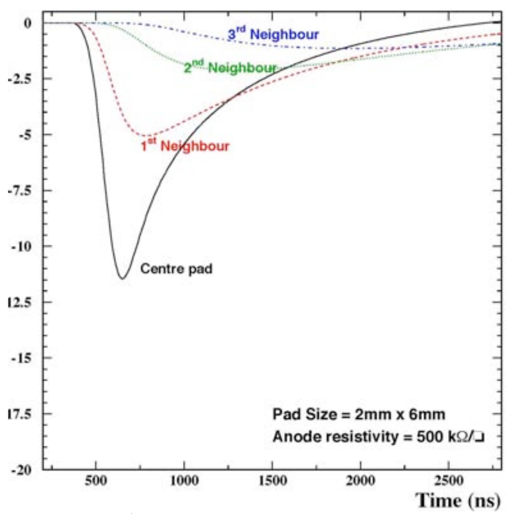
- High anode surface resistivity to minimize the resistor noise contribution to the signal (~ 200 e^-, 200 *ns* integration, 1000 KΩ/□).
- Large capacitance per unit area for maximal signal coupling (important for Micromegas).
- Narrow intrinsic charge dispersion PRF width consistent with accurate centroid determination.

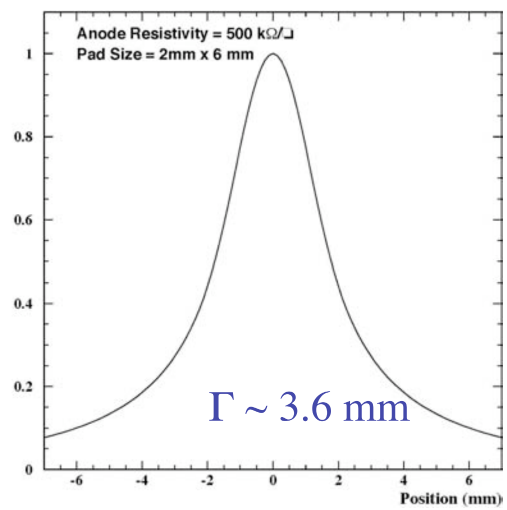
Diffusion effects & electronics shaping modify the charge dispersion measurement significantly





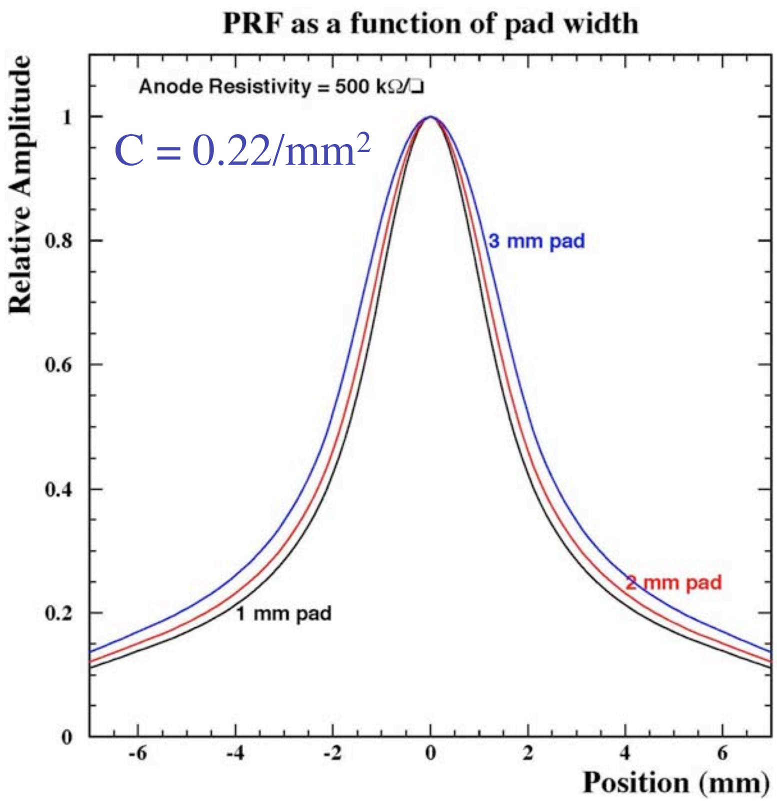
Intrinsic pulse shapes and PRF (no diffusion and electronics effects).

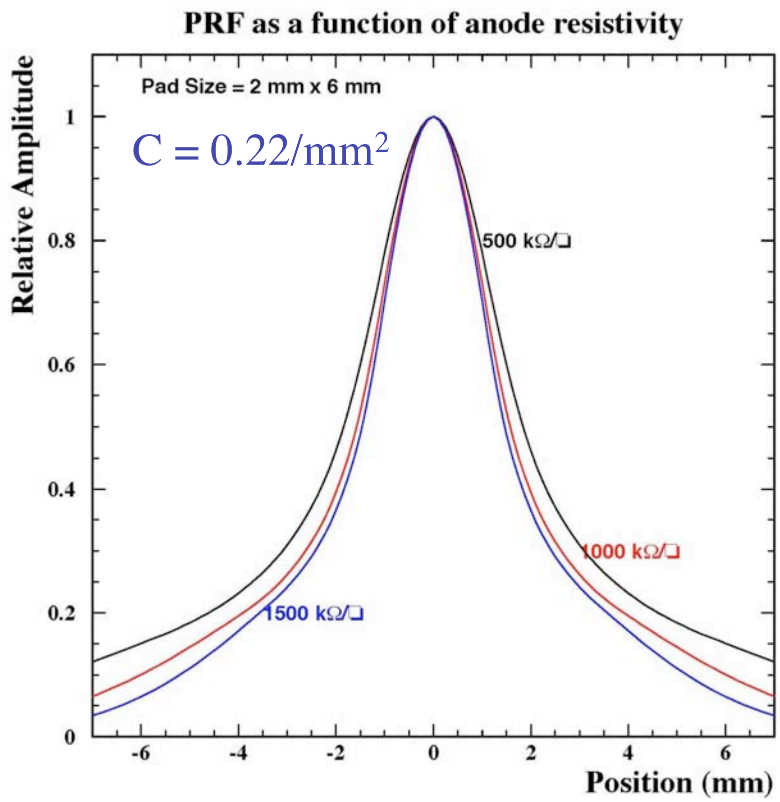




Simulated pulses & PRF with electronics & diffusion in Tesla TPC TDR gas ($Ar/CH_4/CO_2$ 93/5/2) @ 4 T for 1 m drift with Aleph TPC preamp shaping.

Pad width and RC effects on charge dispersion





Conclusion & future plans

- Better resolution with charge dispersion than with direct charge for large & small transverse diffusion gases - P10 & Ar/CO_2.
- The variation with drift distance of the TPC charge dispersion resolution is near the limit from the transverse diffusion in the gas.
- Nonuniform anode RC leads to ~ 100 μm bias corrections.
- We understand the complexities of charge dispersion. The simulation agrees well with the data.
- A spatial resolution of less than 100 μm may be feasible for all tracks independent of angle for a TPC in a magnetic field.
- Future plans:
  - Improved anode structure with more uniform RC properties.
  - Charge dispersion studies with the Micromegas.
  - TPC magnetic field & beam tests with charge dispersion.
  - Preamps better matched to the charge dispersion signal.
  - 25 MHz digitizers to replace 200 MHz FADCs.