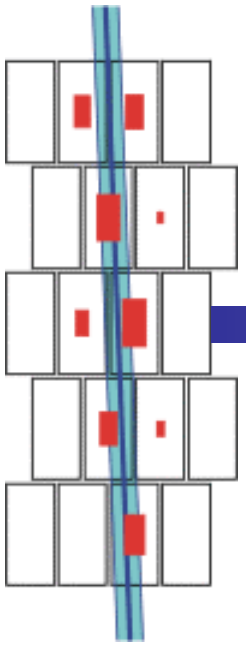


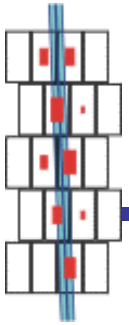
GEM R&D for TPC Readout

RHIC Detector Workshop
BNL, November 14, 2001

Dean Karlen
Carleton University

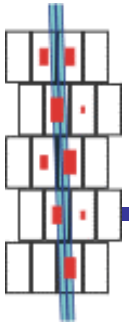
Carleton GEM/TPC group: Bob Carnegie, Jacques Dubeau, Madhu Dixit, D.K., Hans Mes

http://www.physics.carleton.ca/~karlen/gem



Outline

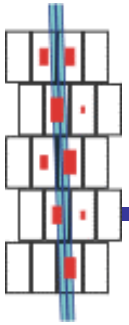
- Brief summary of LC tracking issues
- TPC readout with GEMs
- GEM R&D studies at Carleton
  - space point resolution (x-rays)
  - tracking resolution (cosmics)
- Summary



LC tracking systems

- Tracking requirements:
  - good momentum resolution for high energy isolated charged particles
    - recoil mass resolution for dileptons in HZ
    - end-point resolution for leptonic susy decays

      $\Rightarrow \Delta(1/p_t) \approx 5\times10^{-5}\ (\mathrm{GeV/c})^{-1}$
  - reconstruction of hadron jets
    - good two-track separation
    - energy flow requires good absolute position resolution with minimal mass



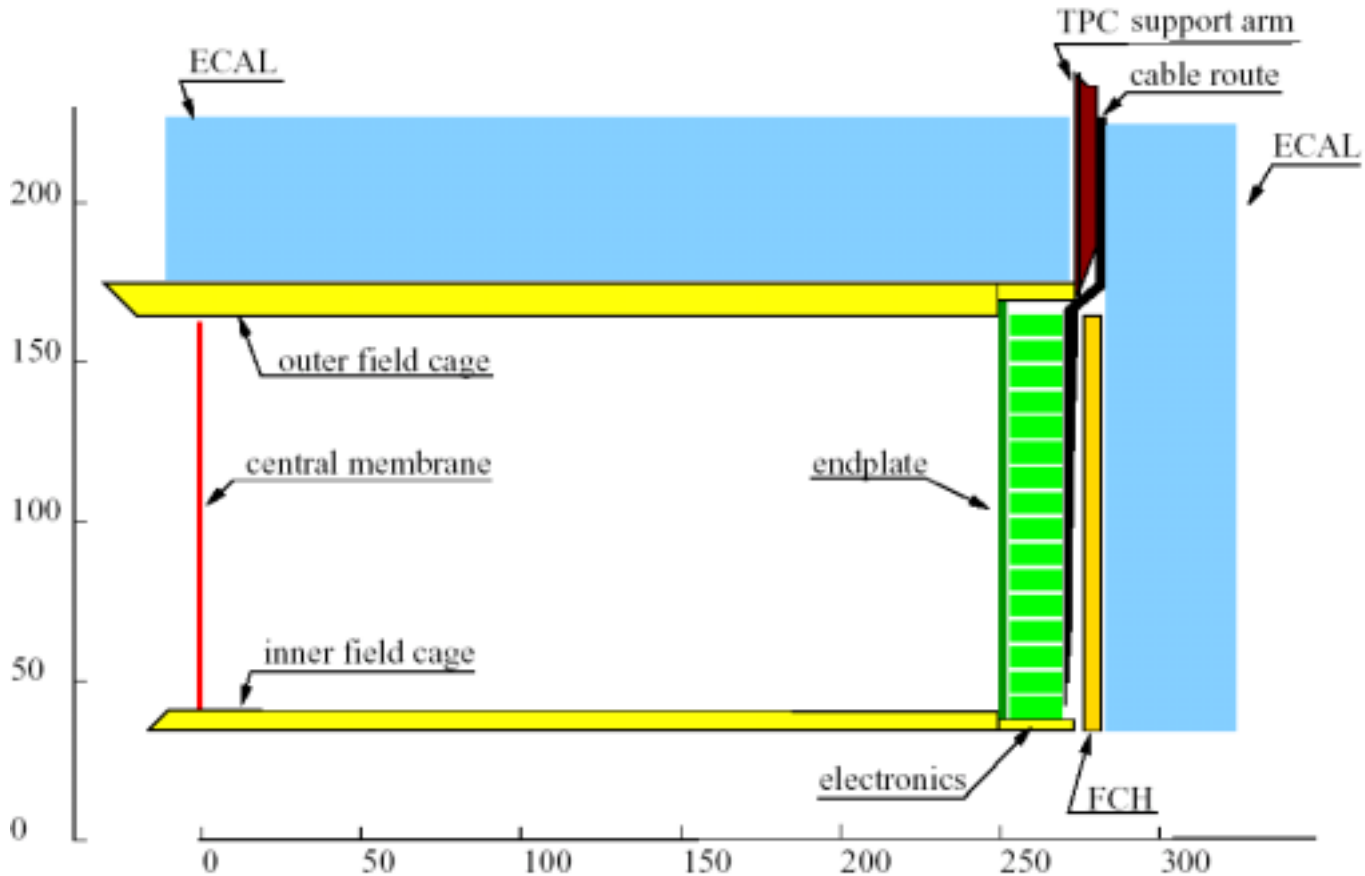
LC tracking systems

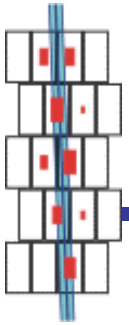
- To achieve these requirements:
  - High magnetic fields (~ 4 T)
  - Large tracking volume
  - 3D space point measurements
    - less sensitive to accelerator backgrounds

European and US baseline
LC detector designs include a
large Time Projection Chamber

TPC tracker for a future LC

- European design:

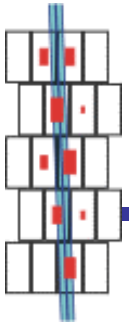




LC TPC R&D underway

- International collaboration formed:
  - Aachen, Carleton, CERN, DESY, Hamburg, Karlsruhe, Krakow, LBNL, Orsay, Saclay, MIT, NIKHEF, Novosibirsk, MPI Munich, Rostock
  - Several issues:
    - gas choice
    - readout technology (emphasis of R&D):
      - Gas Electron Multiplier (GEM)
      - Micromesh Gaseous Structure (micromegas)
      - conventional pads or silicon
      - conventional wire chamber
    - pad geometry
    - electronics
  - goal: complete R&D and prototype: 2-3 years

see: DESY-PRC R&D 01/03
October 4, 2001



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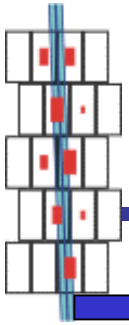
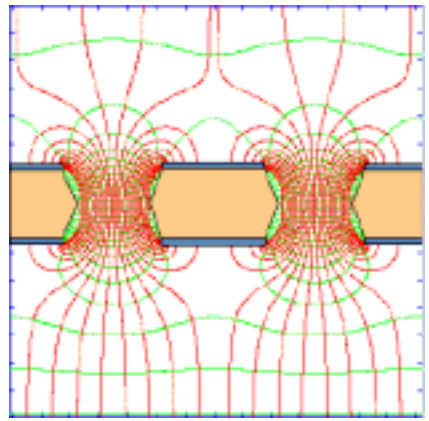
Gas Electron Multiplier (GEM)





E_{drift} = 0.2 – 1.0 kV/cm

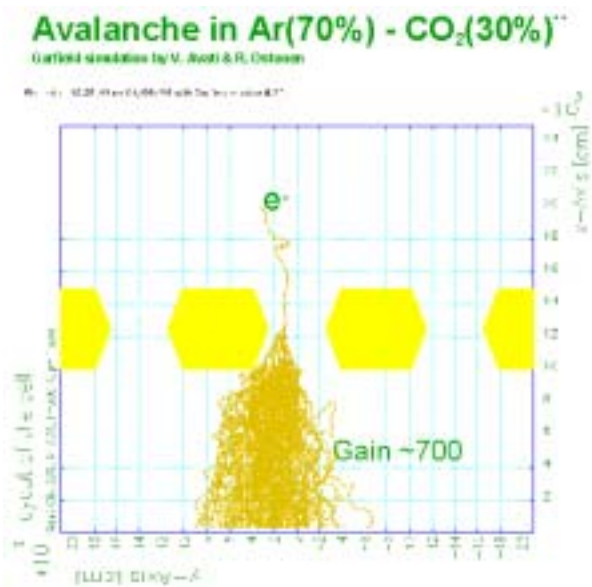
$\Delta V \cong 400$ V

$E_{transfer} \cong 3$ kV/cm

$\Delta V \cong 400$ V

$E_{induction} \cong 3.5$ kV/cm

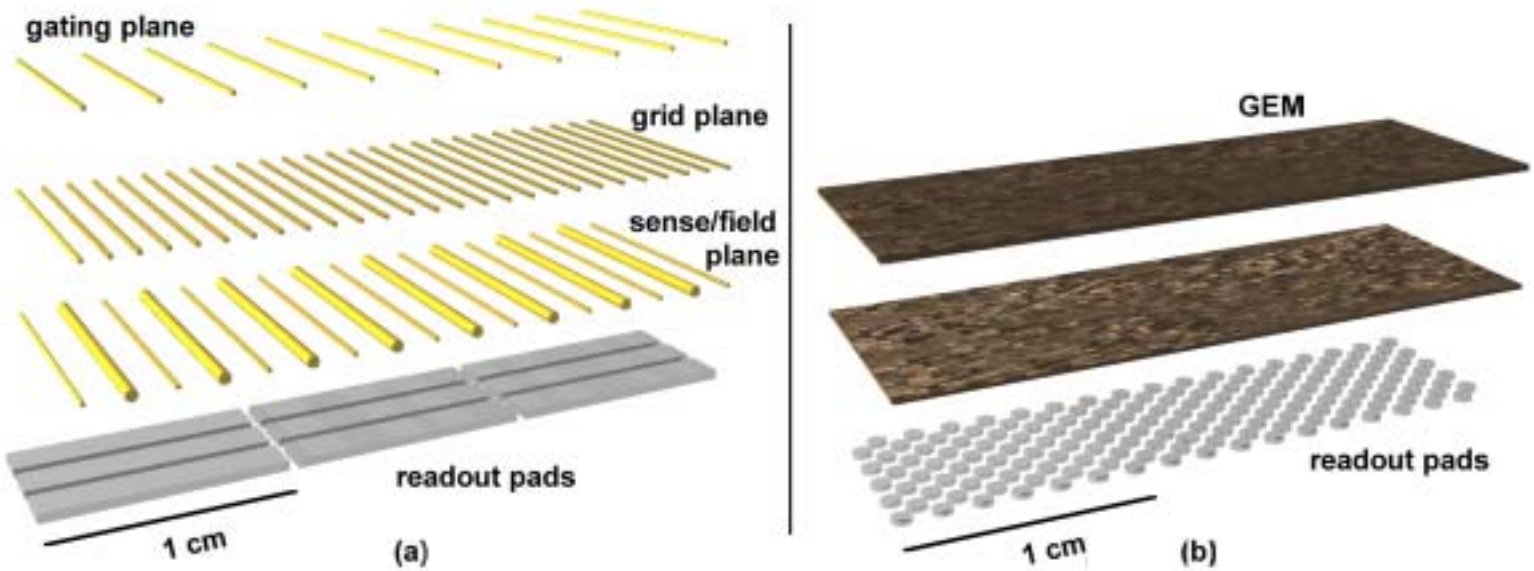
Readout pads



Using a GEM for TPC readout

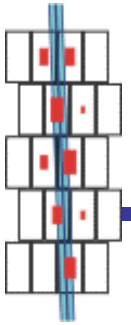
Conventional TPC readout

GEM TPC readout



Induced signals (motion of positive ions) spread over large area.

Direct signals (electrons on pads) spread over smaller area. Induced signals (e^- motion) also present.

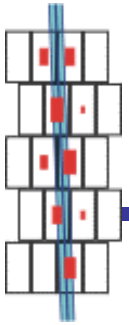


Potential advantages for GEM readout

- Improved space point resolution
  - **E**×**B** and track angle systematics suppressed

present focus

- Improved two particle separation power
  - r -ϕ : signals distributed over smaller area
  - z : faster pulses (v_e > v_{ion})
- Natural ion feedback suppression
  - no gating required (non-triggered expt.)
- Less mass in TPC endcap
  - no wires held under tension



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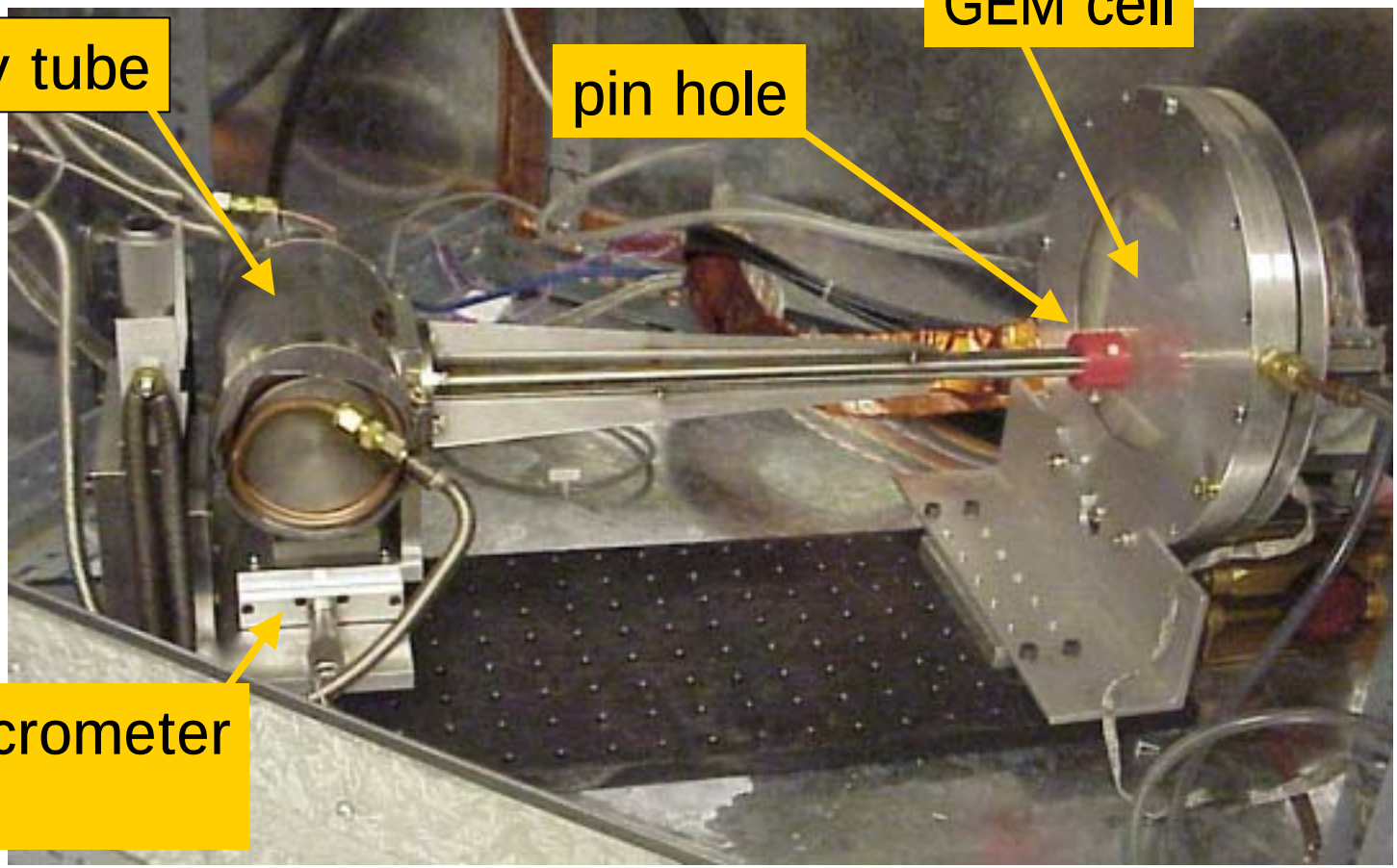
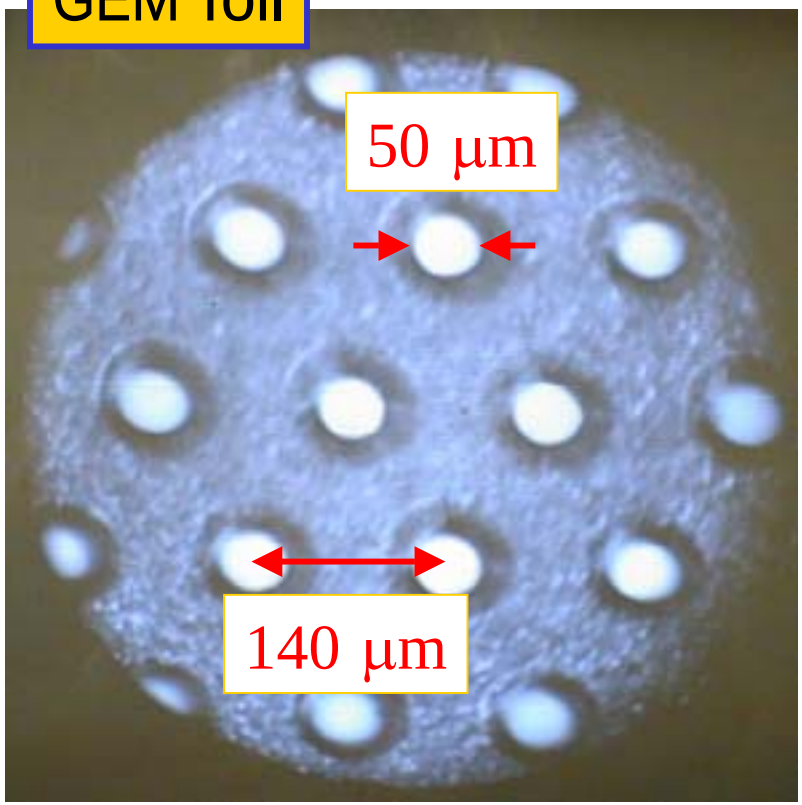
Point resolution studies at Carleton



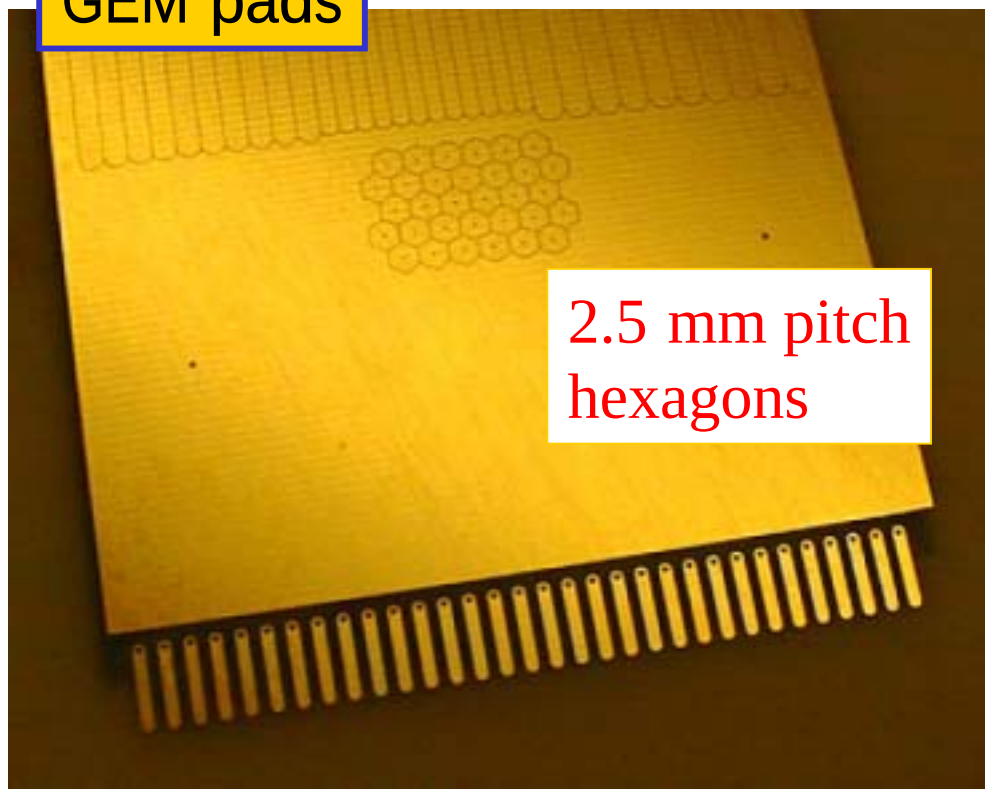
GEM foils and pads for this study

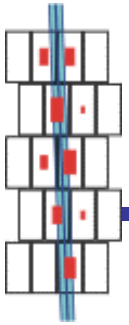
fabricated at the CERN PCB workshop

GEM foil



GEM pads



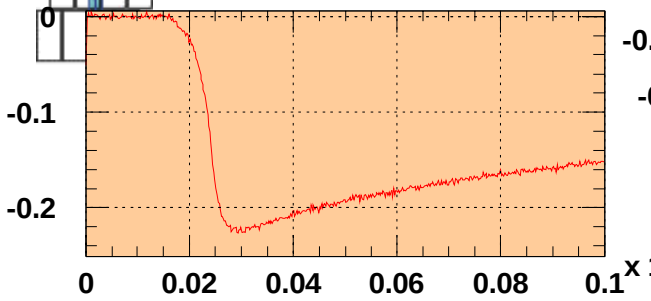


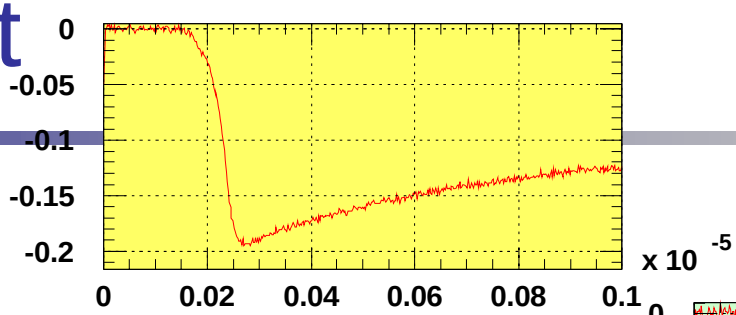
Details

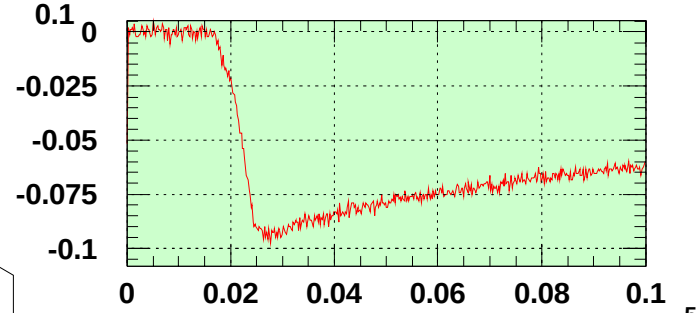
- x-ray mean energy: 4.5 keV
- pinhole diameter: ~50 μm
- Gas: Ar CO_2 (~90:10) / P10 : Ar CH_4 (90:10)
- pre-amps:
  - fast Lecroy HQV 810 with Ar CO_2
  - slower ALEPH TPC pre-amp with P10
- readout:
  - two 4-channel digital scopes (9 bit ADC)
    - 500 MHz sampling for HQV 810
    - 125 MHz sampling for ALEPH preamps

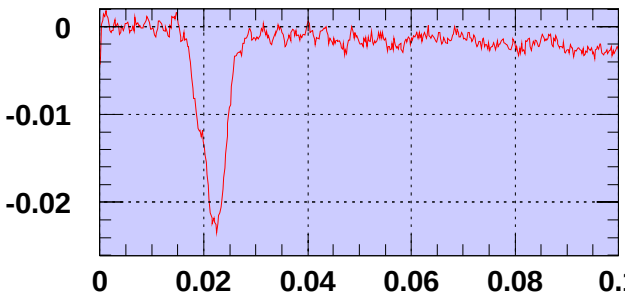
An event

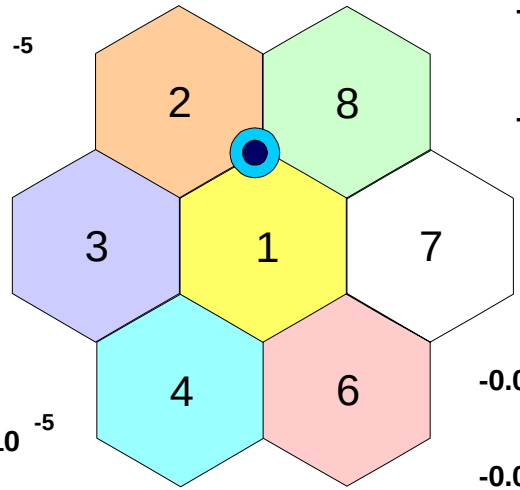
Ar CO_2 (90:10)
HQV810 preamps

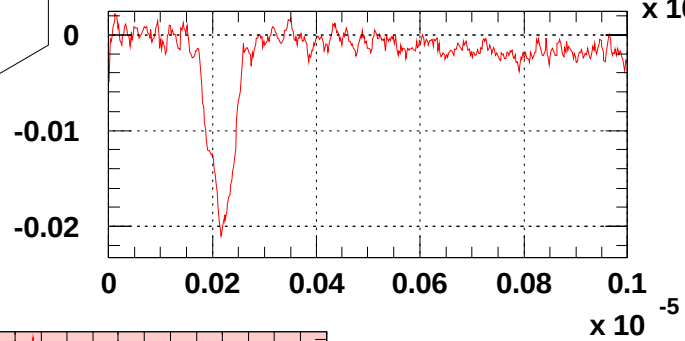


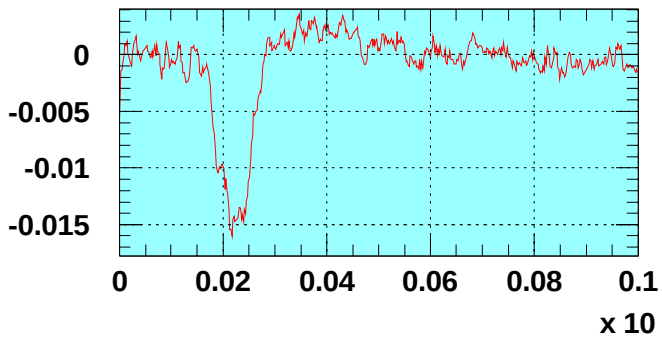


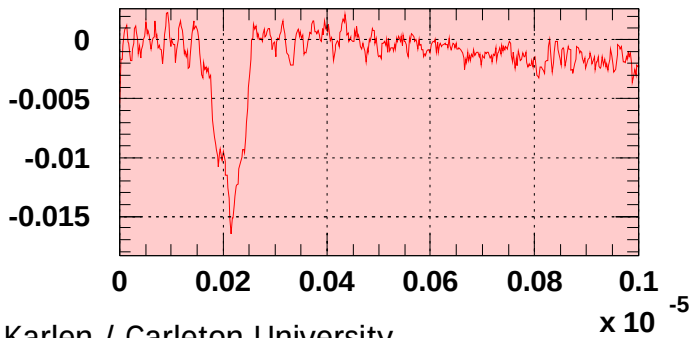




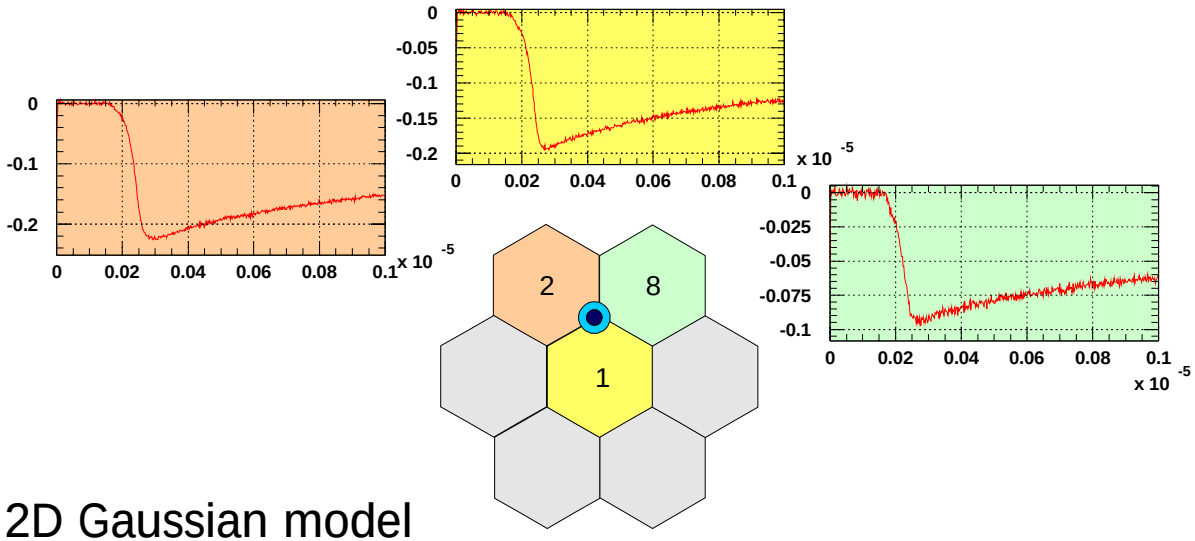




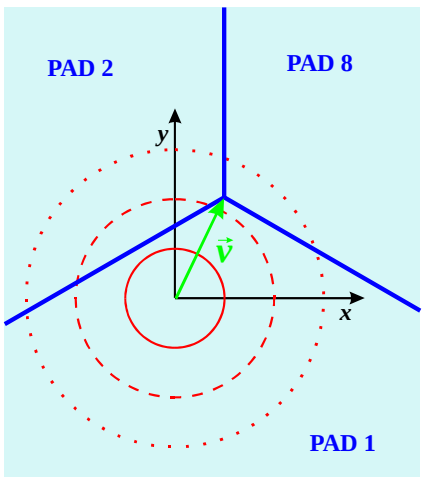


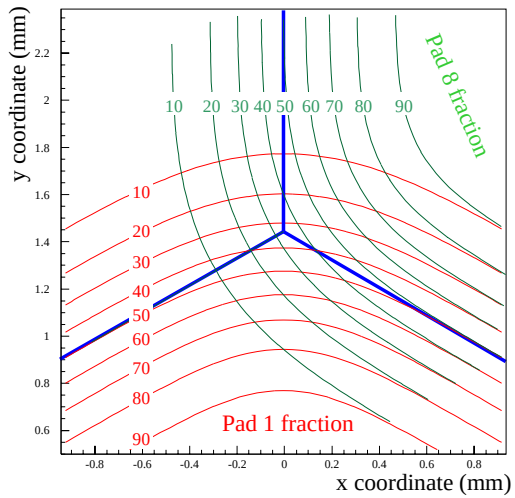


Localization from charge sharing



2D Gaussian model



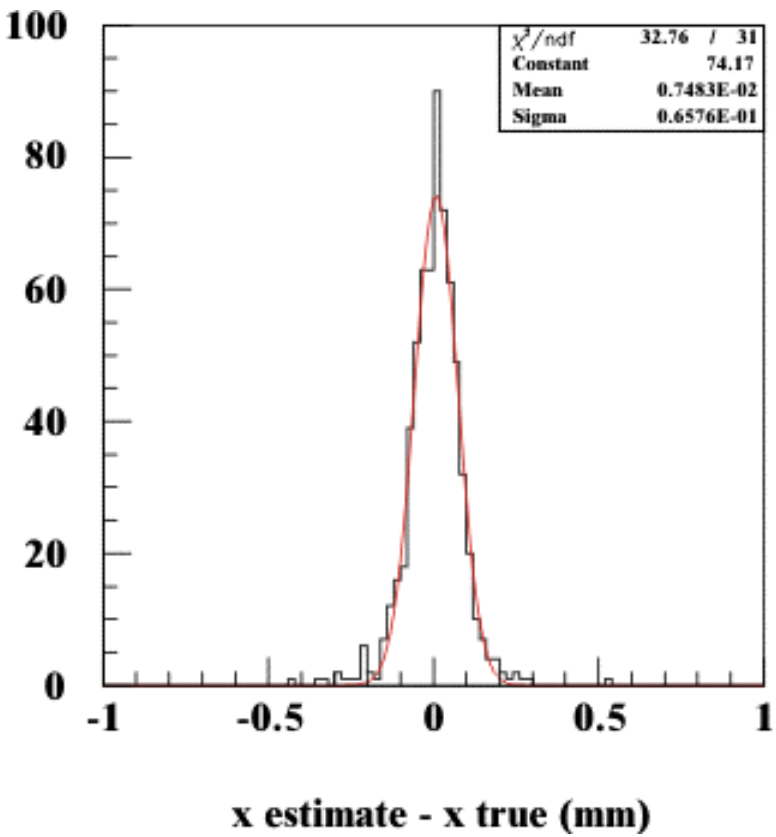


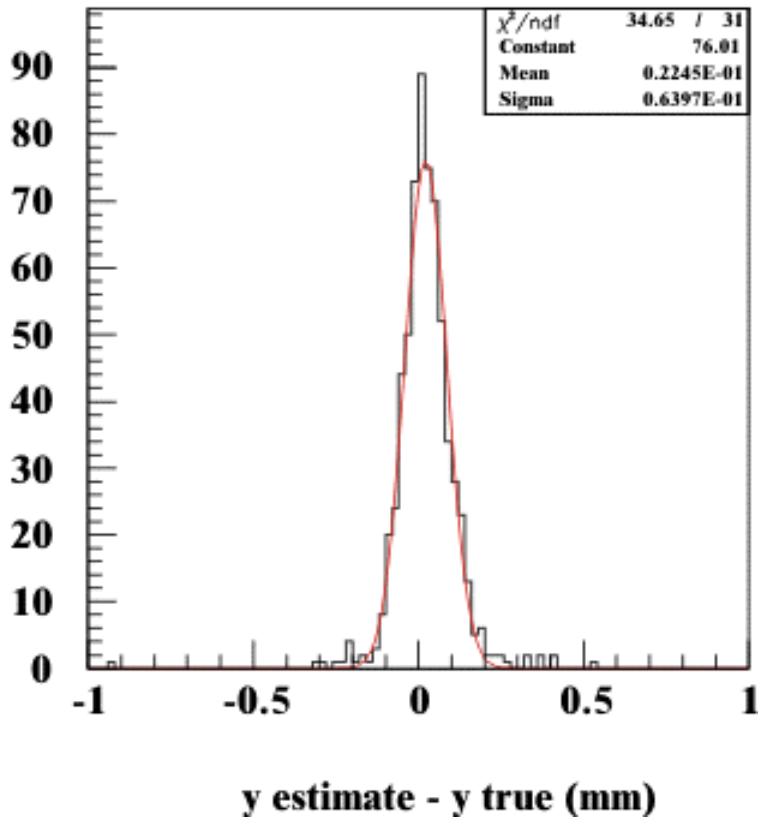
Charge sharing result – P10

$(x,y)_{col}$ = (0.4,1.243) mm

$\bar{x}$ = 0.408 mm
σ_x = 0.066 mm

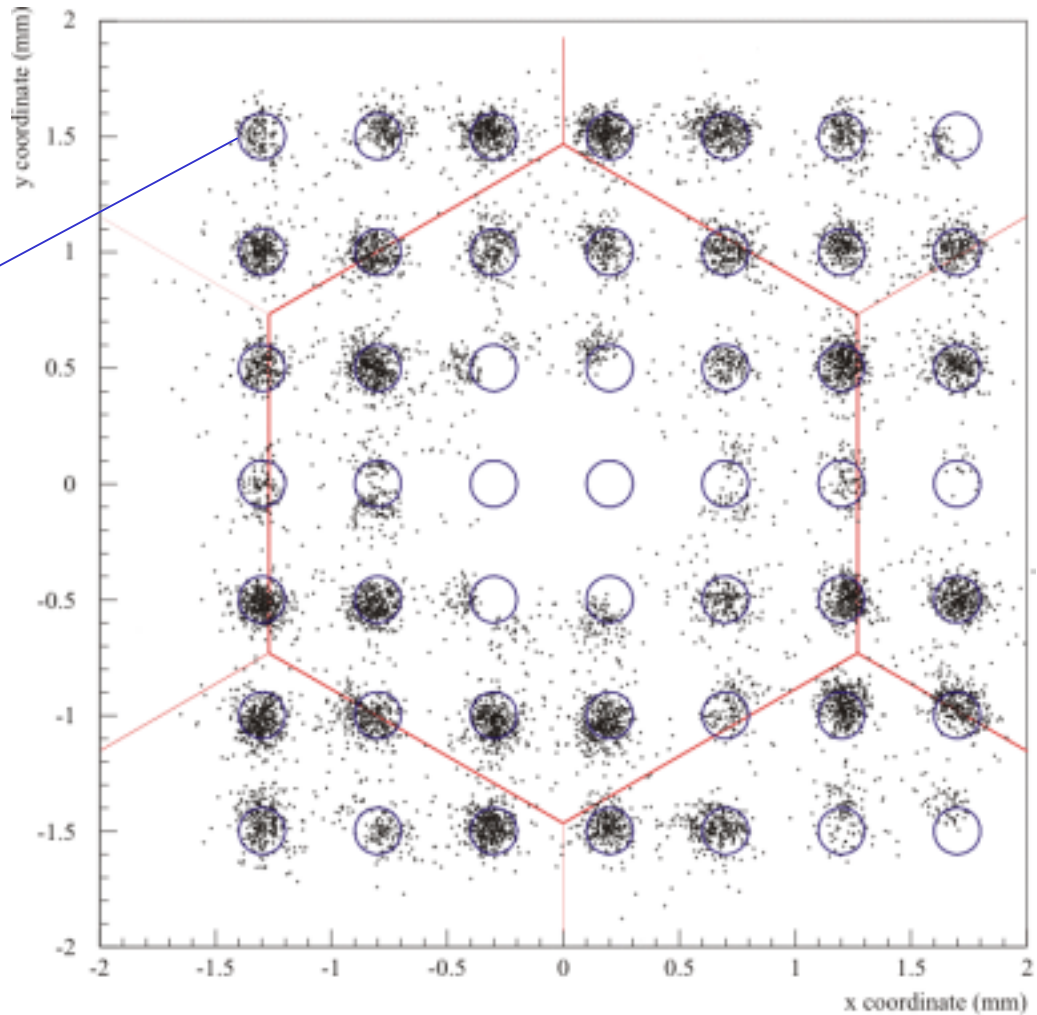
$\bar{y}$ = 1.265 mm
σ_y = 0.064 mm





Scan over entire pad

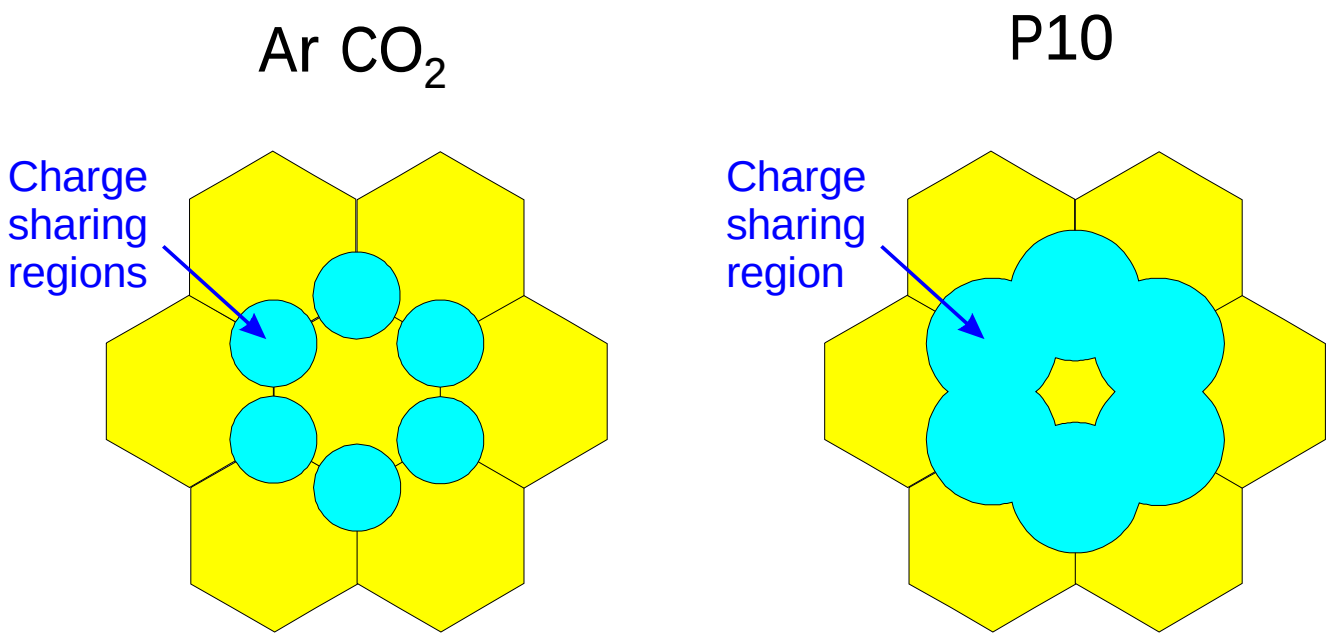
100 μm circles centred at pin hole locations during scan



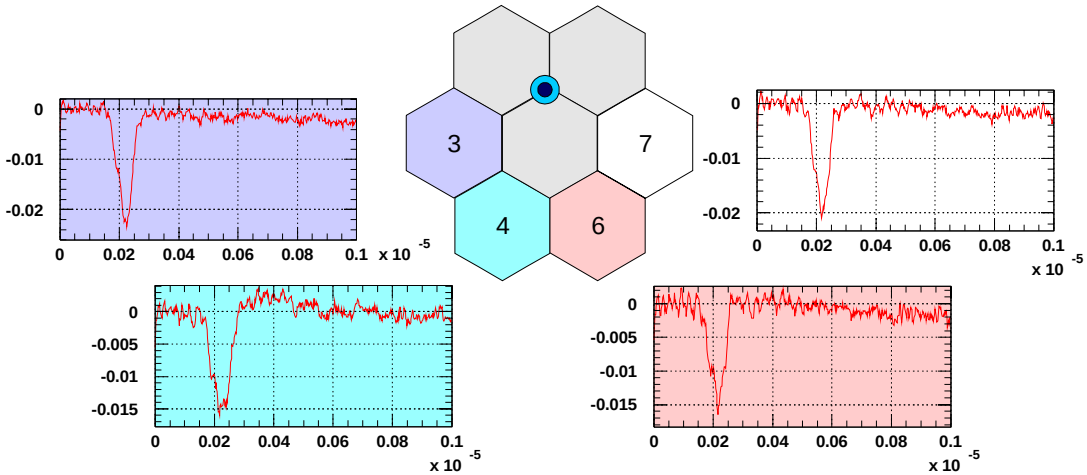
- With P10 gas:
  - cloud size 550 μm
  - x,y standard deviations: ~70 μm

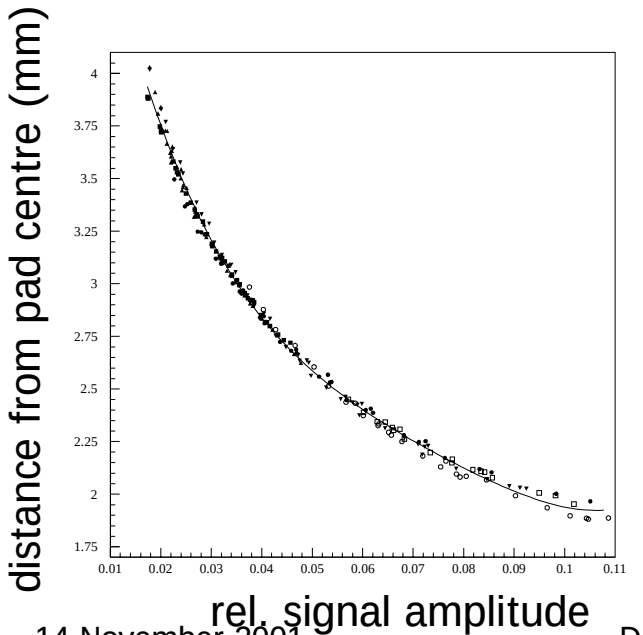
Localization from charge sharing

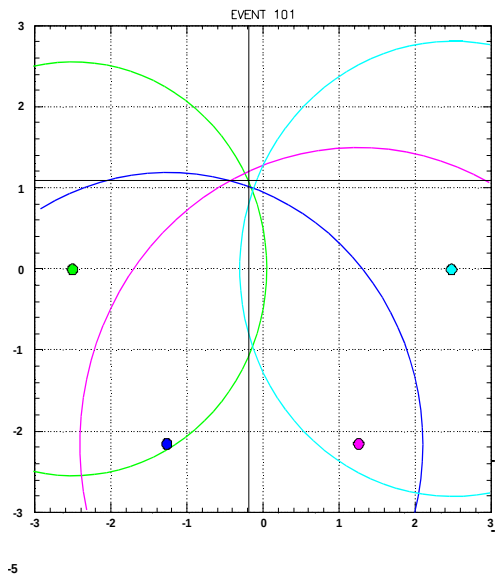
- Method works only in regions where significant charge is deposited on 3 pads



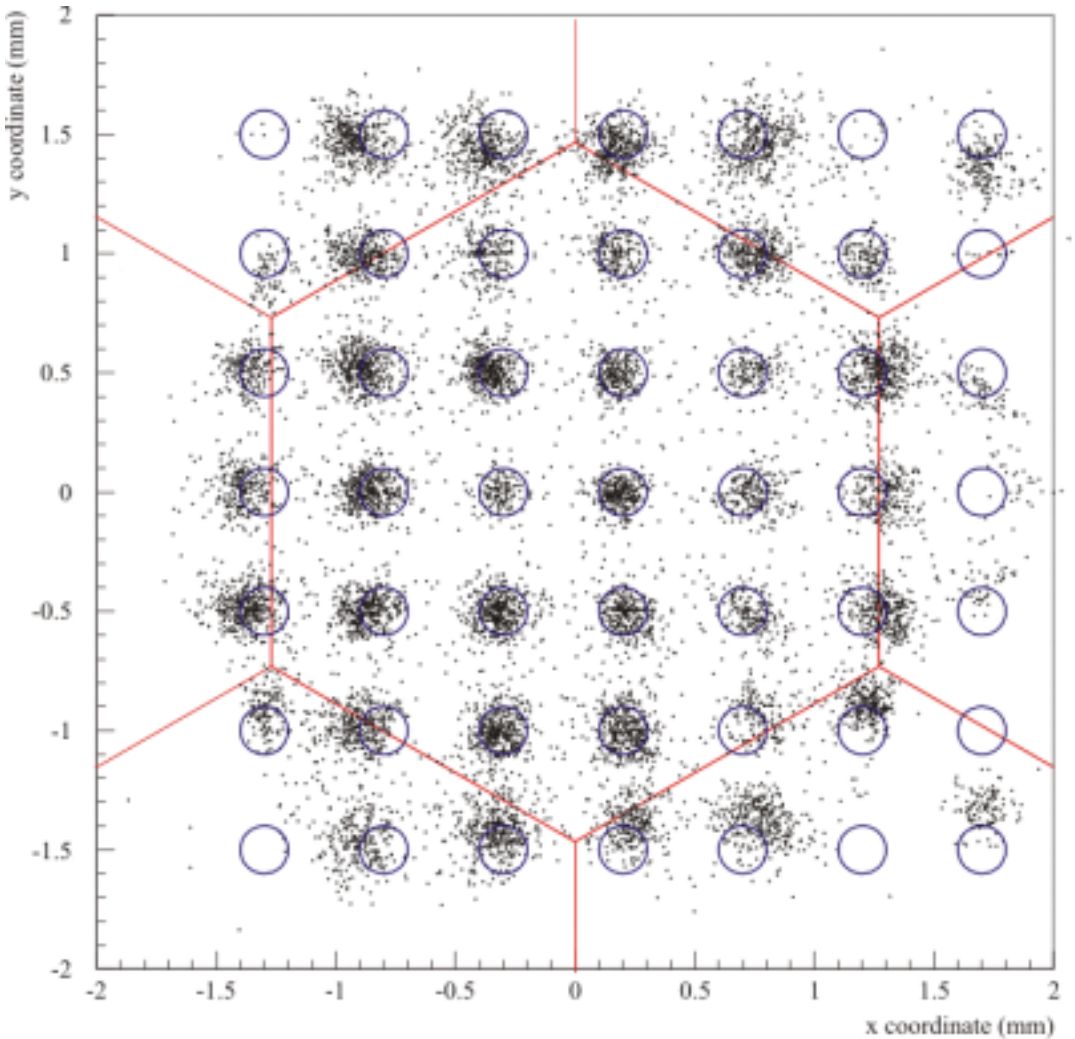
Localization from induced signals





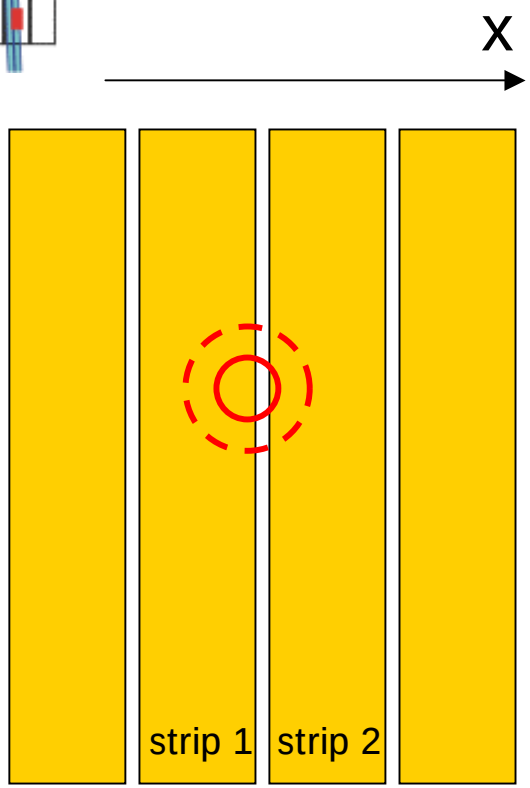


Scan over entire pad

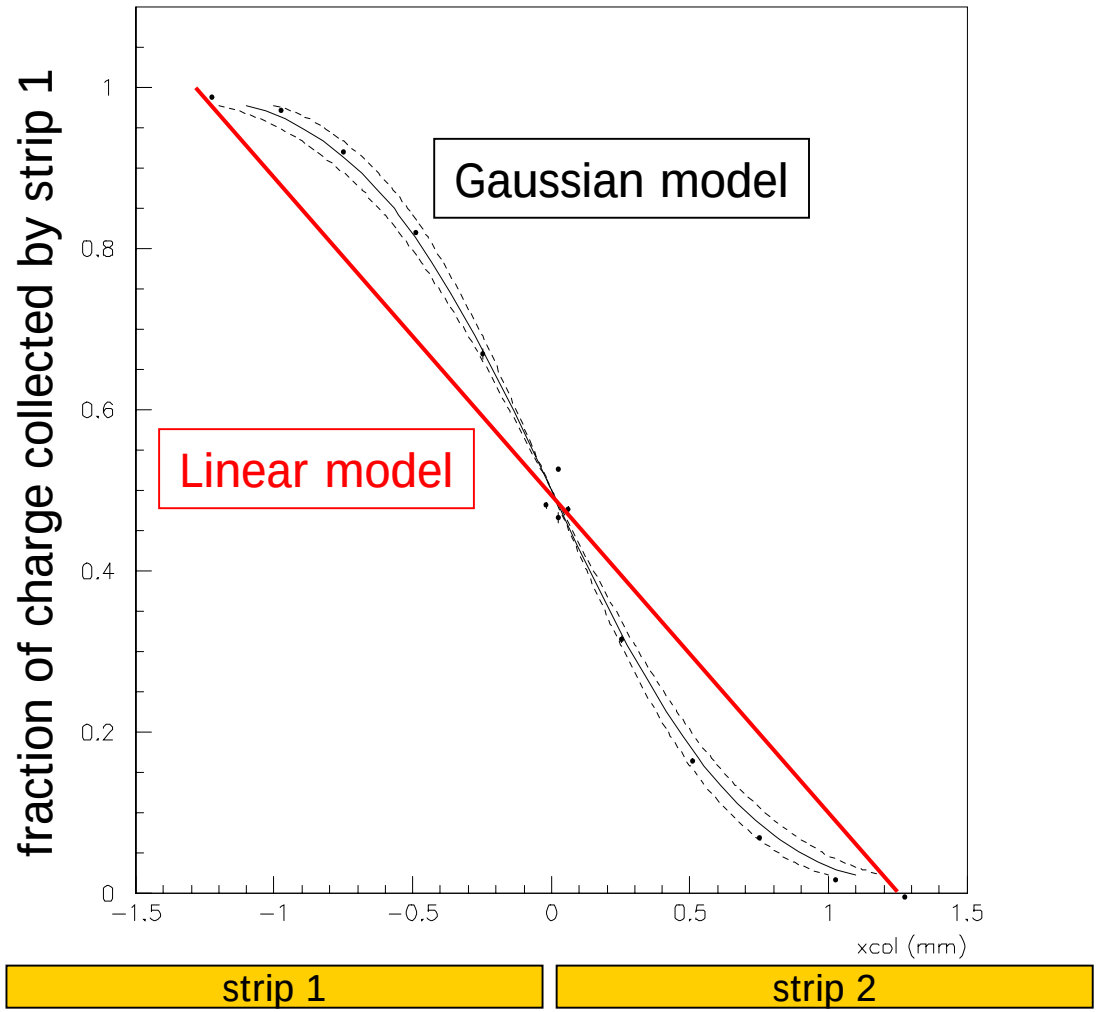


- With P10 gas:
  - x,y standard deviations: ~80 μm
  - note: systematics in x clearly seen

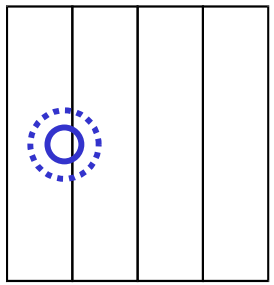
Strip geometry – charge sharing

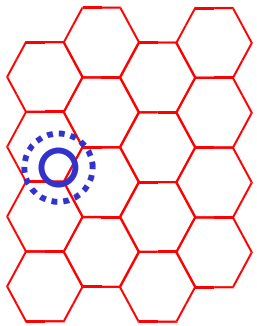


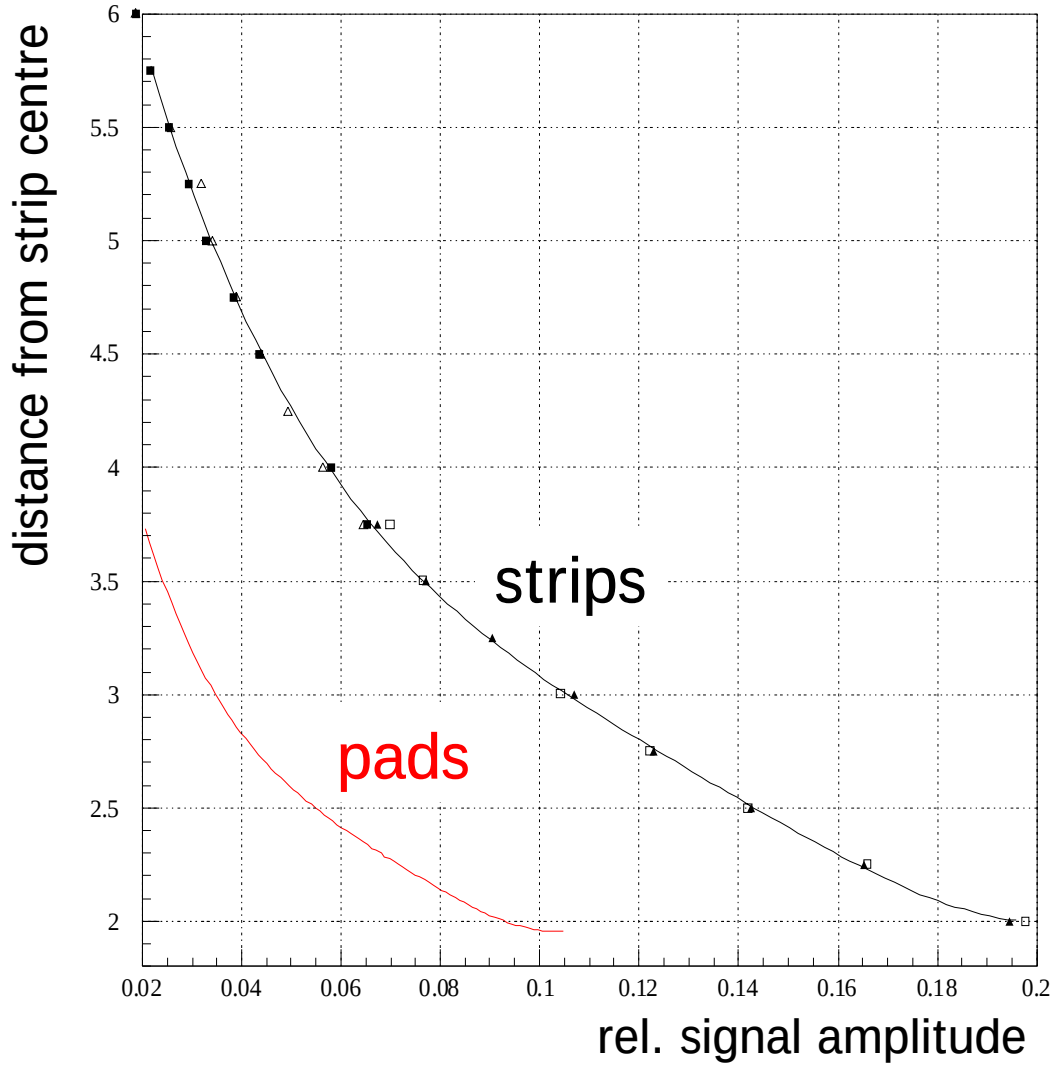
- With P10 gas:
  - x standard deviation: ~70 μm



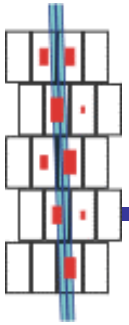
Strip geometry – induced signals







- Strip geometry has larger induced signals by factor of 2 – 3
  - x standard deviation: ~70 μm



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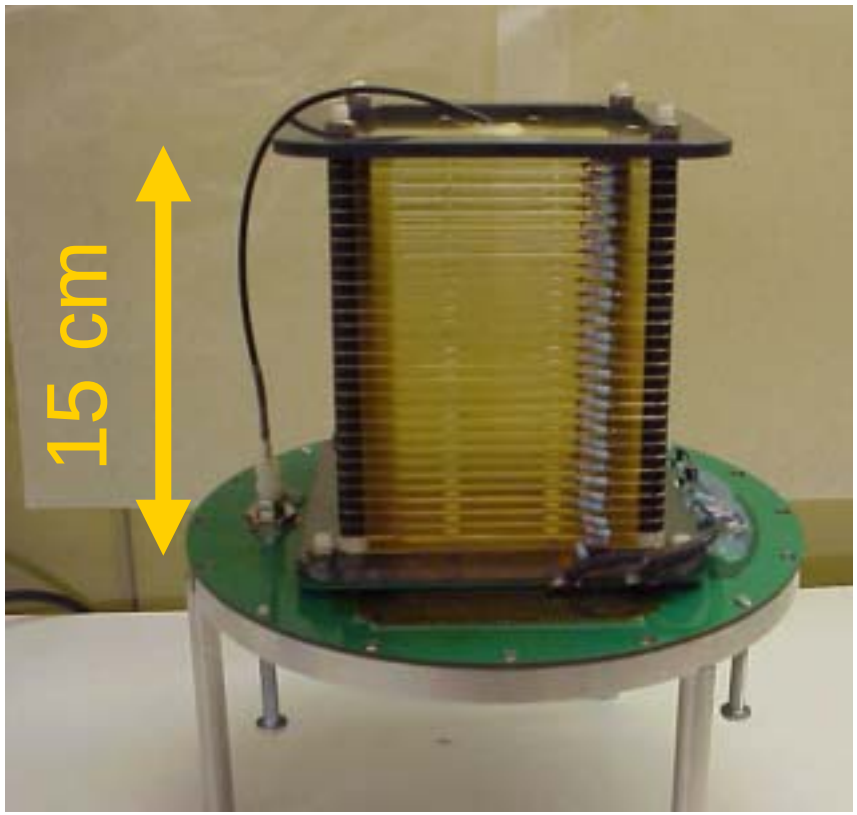
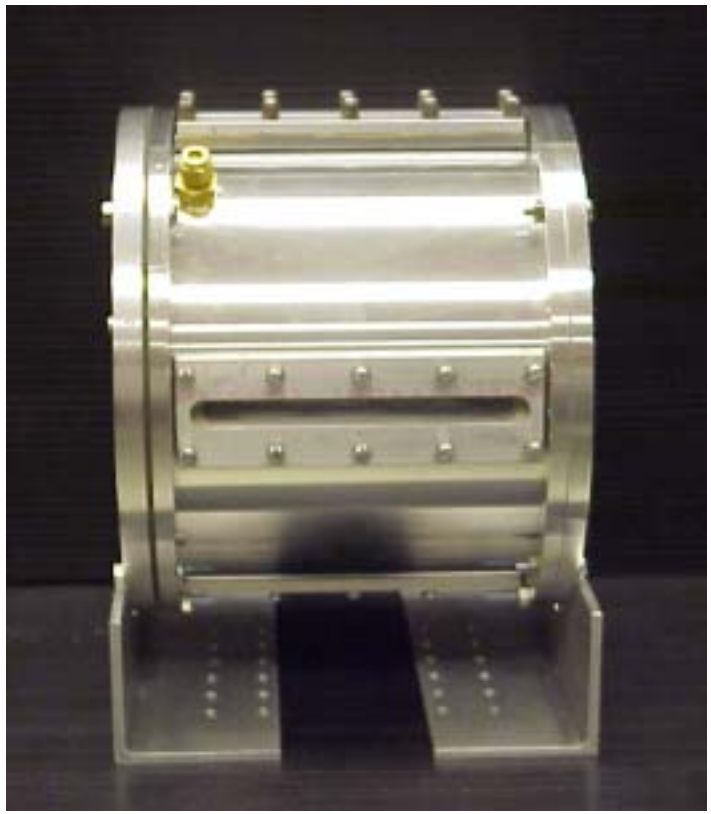
Tracking studies

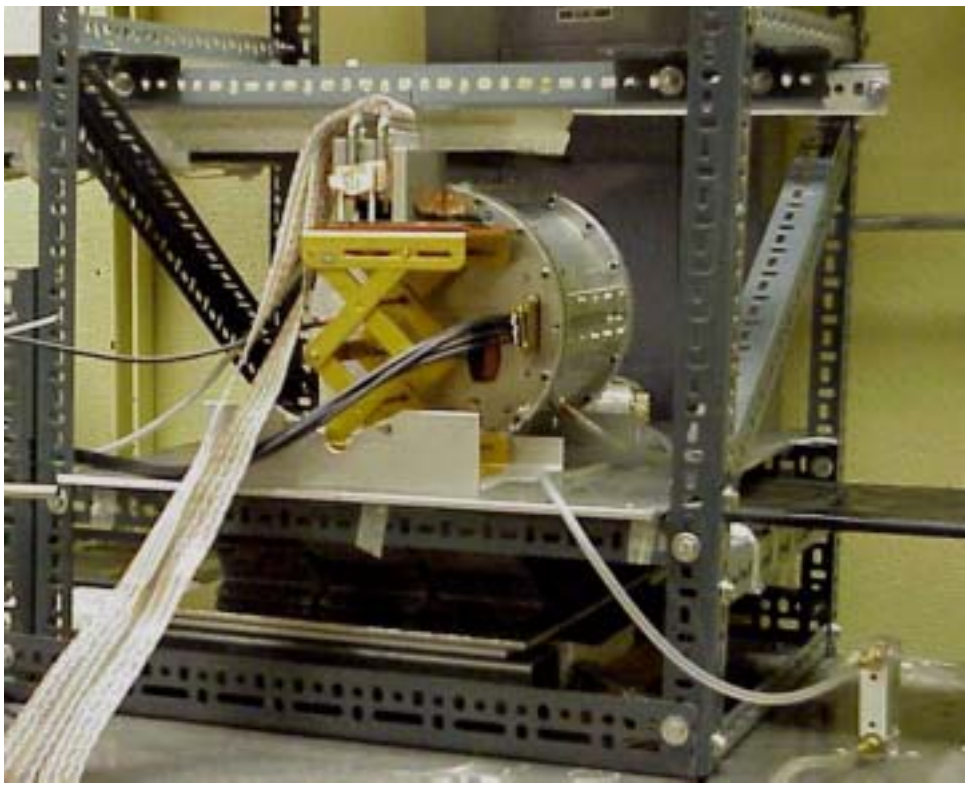
- Mini-TPC constructed



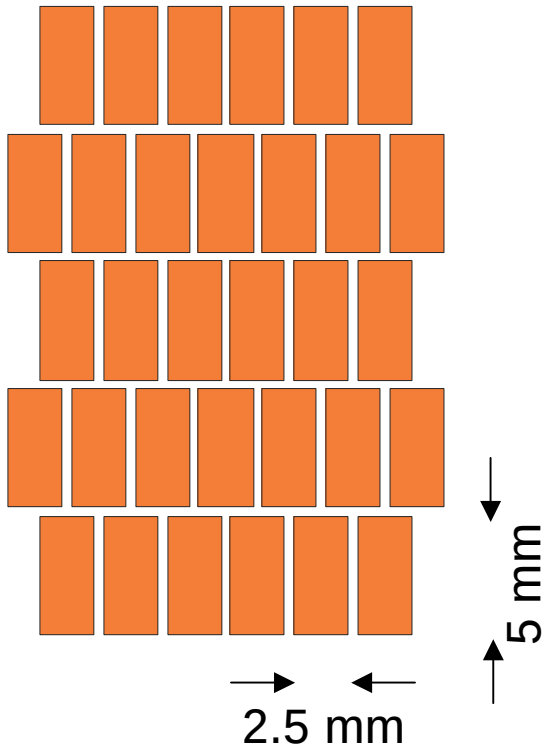


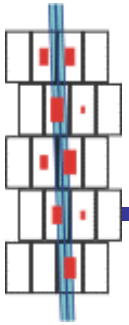
Tracking studies

- Cosmic ray telescope



- Readout pad layout

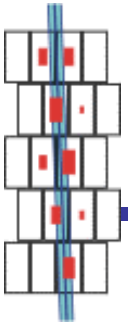


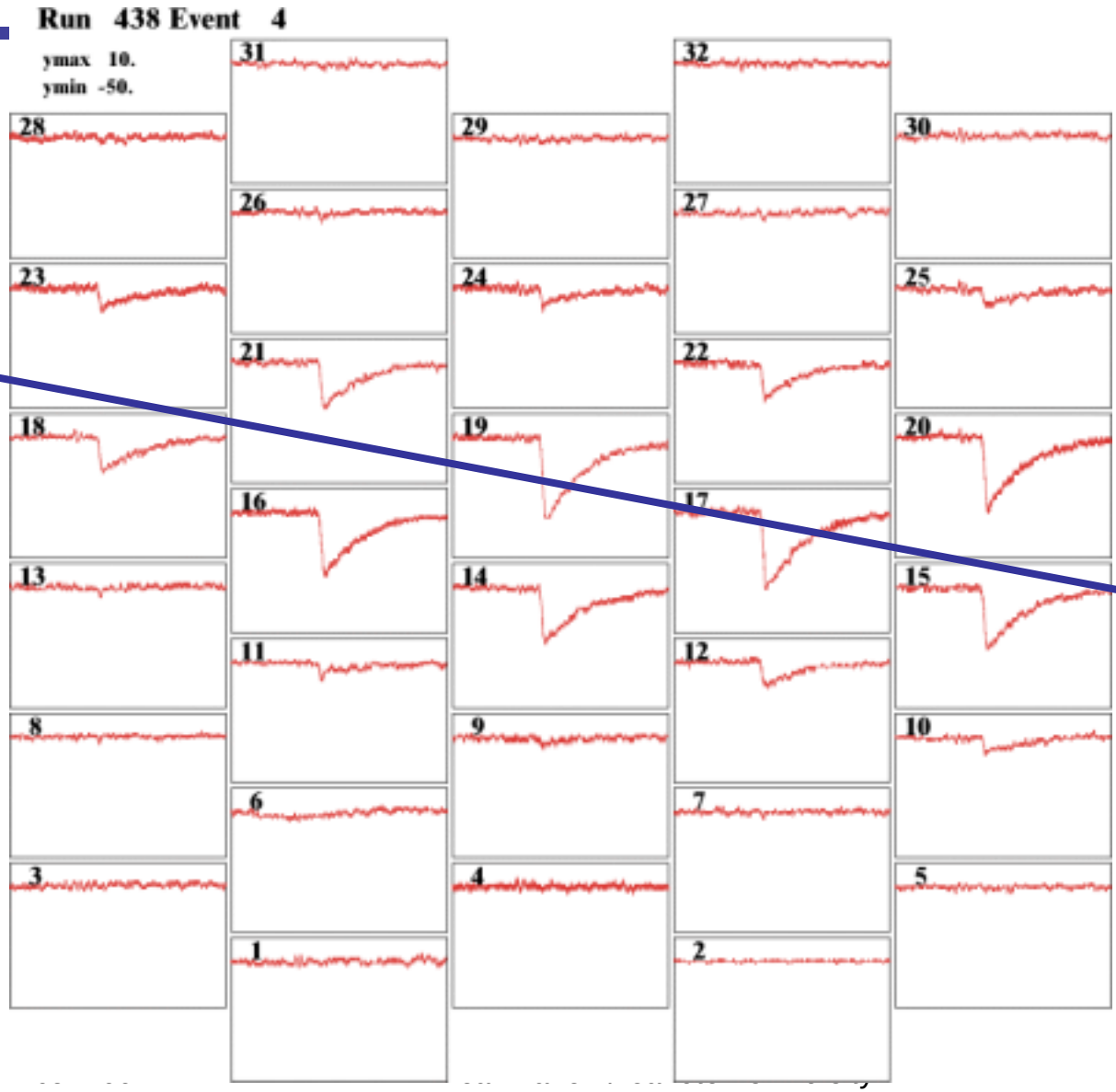


Details – cosmic data taking

- Gas: Ar CH_4 (90:10)
- Drift field: 135 V/cm
- pre-amps: ALEPH TPC pre-amp
- readout: 32 channel custom FADC
  - 200 MHz sampling
  - 8 bit
- trigger rates:
  - cosmic telescope: 0.4 Hz
  - require at least one pad hit: 0.04 Hz
- Data:
  - 6 days of running (end of October, 2001)

First event



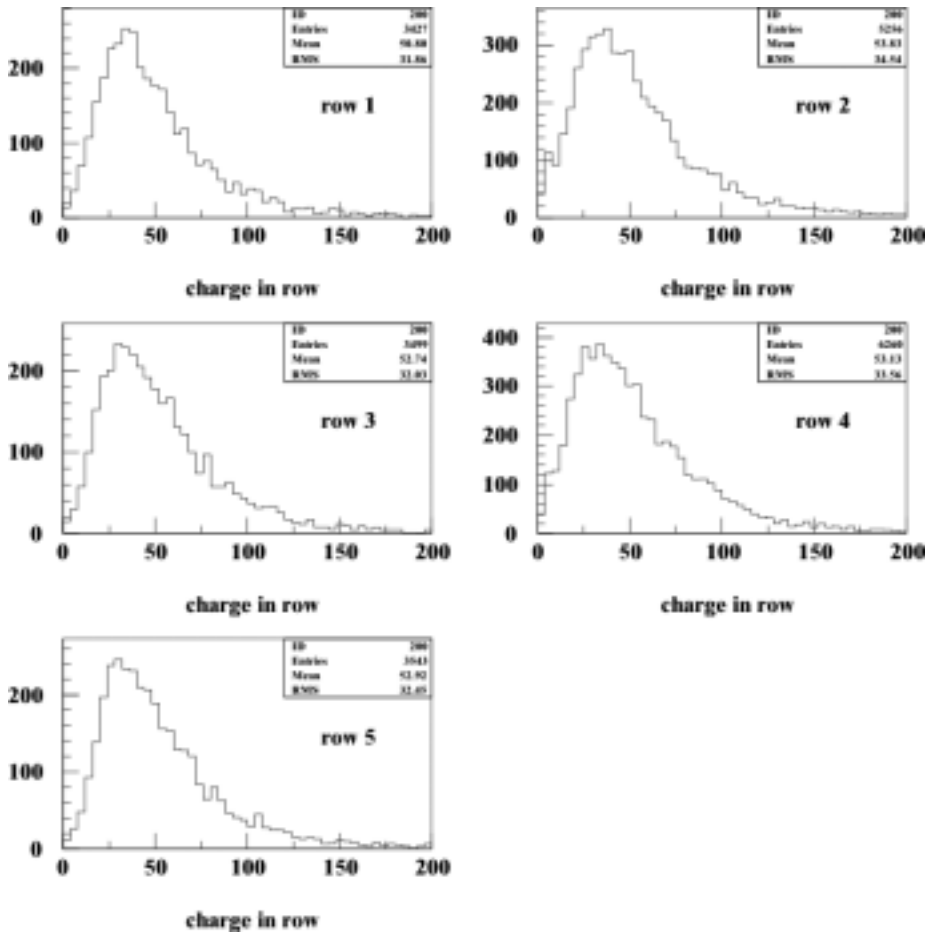


TOP

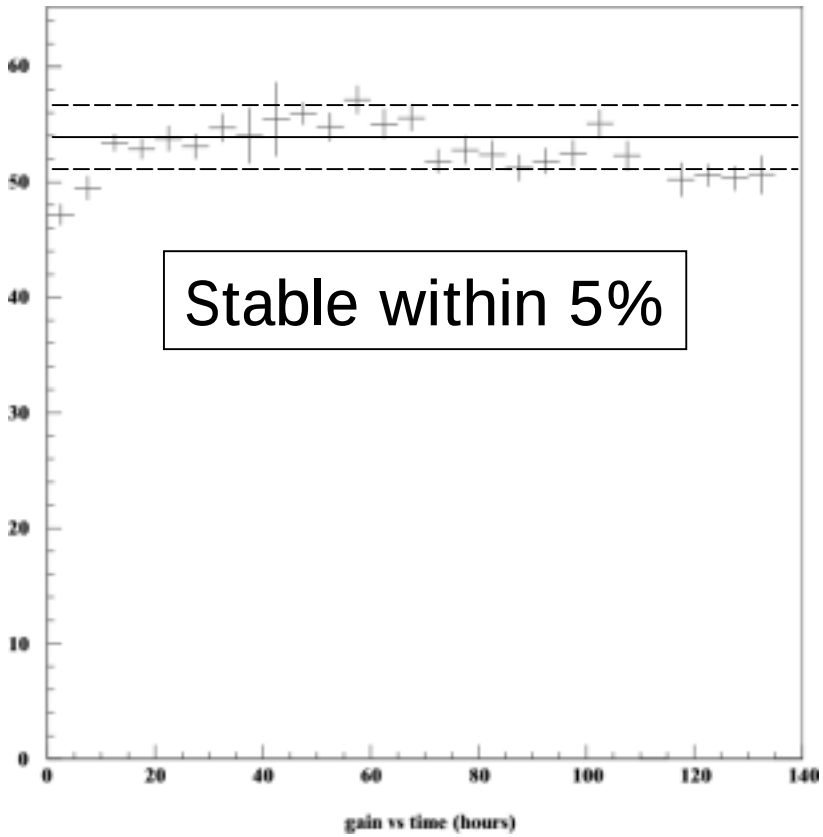
BOTTOM

Gain stability

- Charge per row

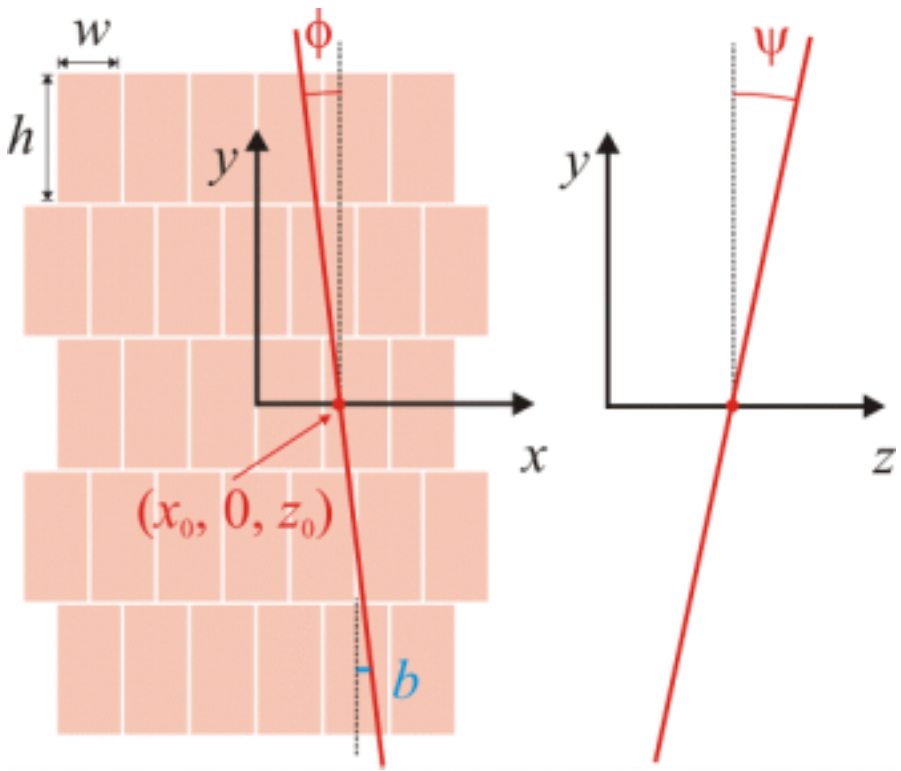


- Charge vs time



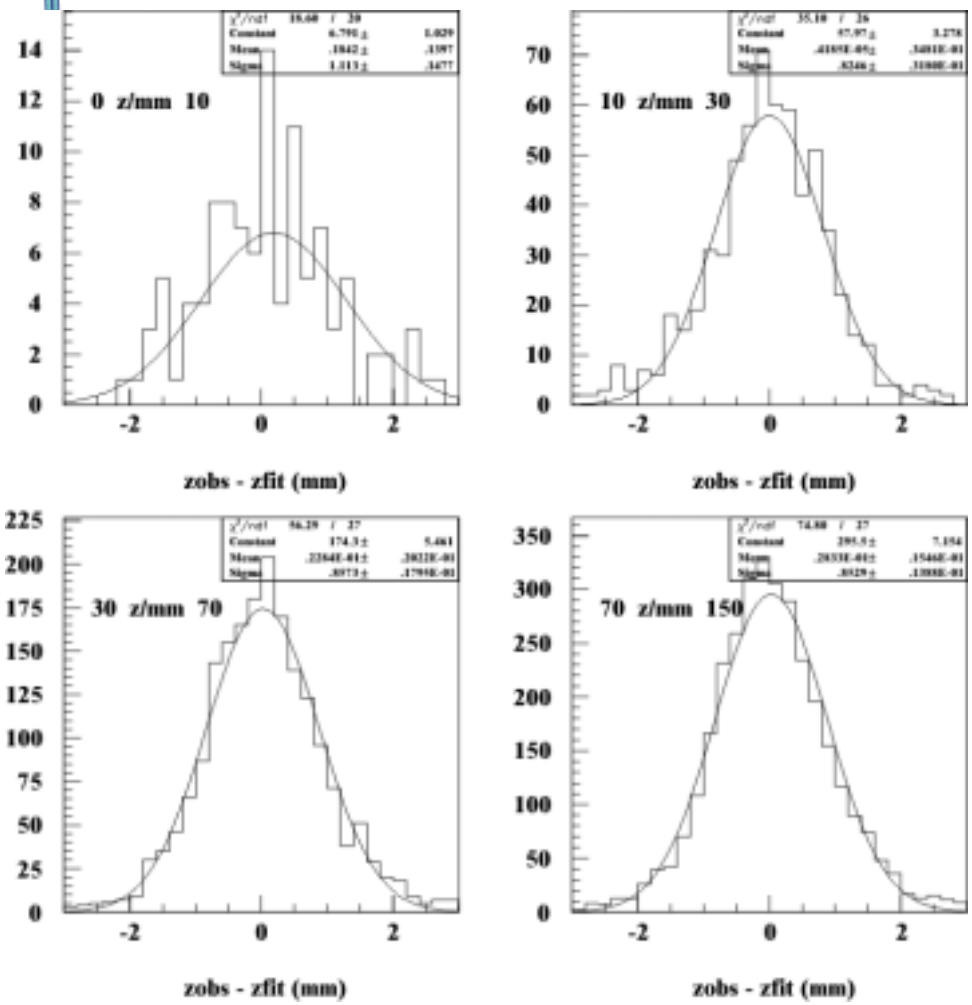
Tracking studies

- Fit x-y and y-z separately



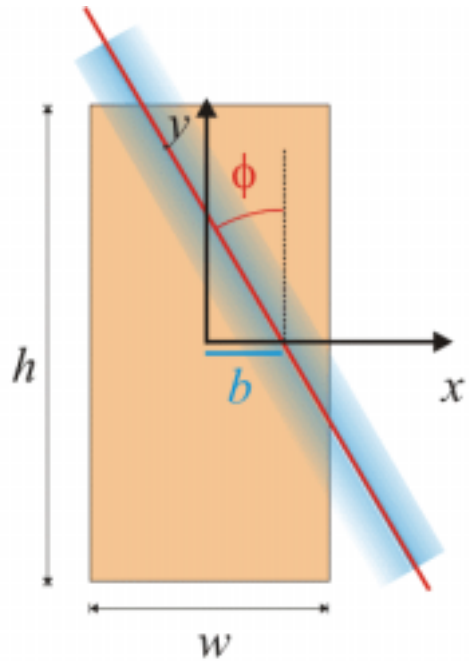
- y-z fit:
  - for each row form weighted average of pulse arrival time
  - perform unweighted linear fit of the 5 row y-coordinates vs row times
  - pulse arrival time (50% rise) dependant on pulse amplitude
    - needs further study

y-z fit results



- Not diffusion limited
  - pulse arrival time definition needs improving
  - 800 micron resolution independent of drift length

x-y fit



$$I(b,\phi,\sigma,h,w) = \int_{-w/2}^{w/2} dx \int_{-h/2}^{h/2} dy \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{[(x-b)\cos\phi + y\sin\phi]^2}{2\sigma^2}}$$
$$= \eta(b,\phi,\sigma,h,w) - \eta(b,\phi,\sigma,-h,w) + \eta(b,\phi,\sigma,-h,-w) - \eta(b,\phi,\sigma,h,-w)$$

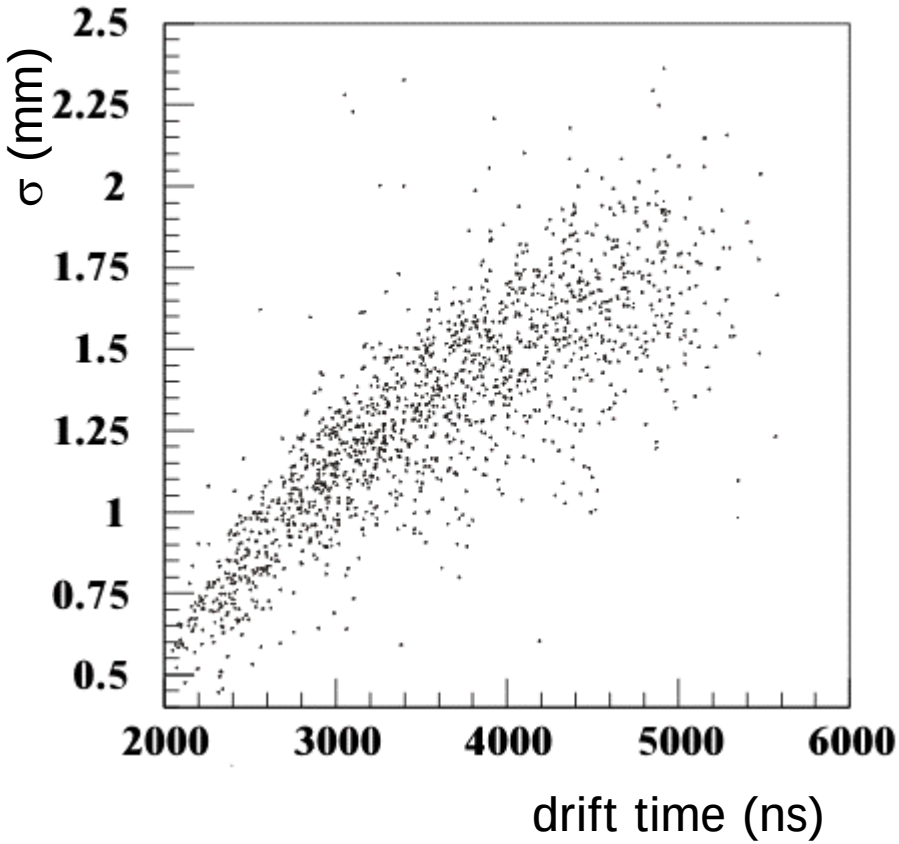
$$\eta(b,\phi,\sigma,h,w) = \frac{1}{\cos\phi\sin\phi}\xi\left((b+\frac{w}{2})\cos\phi + \frac{h}{2}\sin\phi, \sigma\right)$$

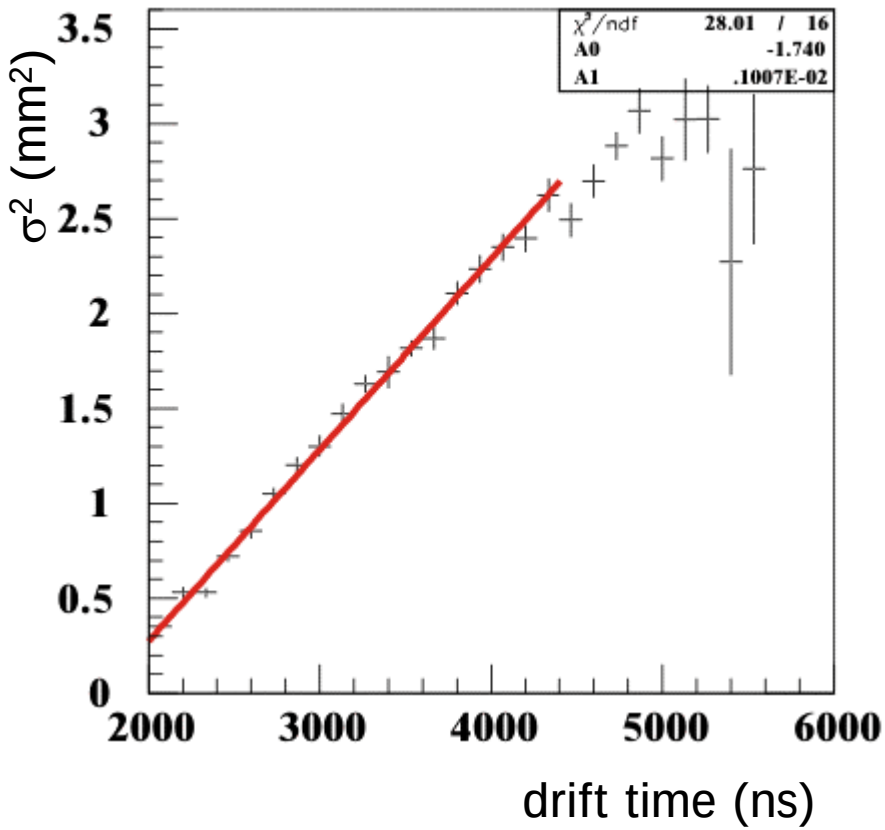
$$\xi(u,\sigma) = \frac{u}{2}\mathrm{erf}\left(\frac{u}{\sqrt{2}\sigma}\right) + \frac{\sigma}{\sqrt{2\pi}}\exp\left(\frac{-u^2}{2\sigma^2}\right)$$

- use model of uniform line of charge, with Gaussian transverse spread, σ
  - charge fractions given by integral over pad
- fit uses observed charge fractions within each row
  - min χ^2 with x_0, ϕ and σ free
- ionization fluctuations
  - not included in model
  - unimportant for $\phi = 0$
  - leads to track angle effect on resolution

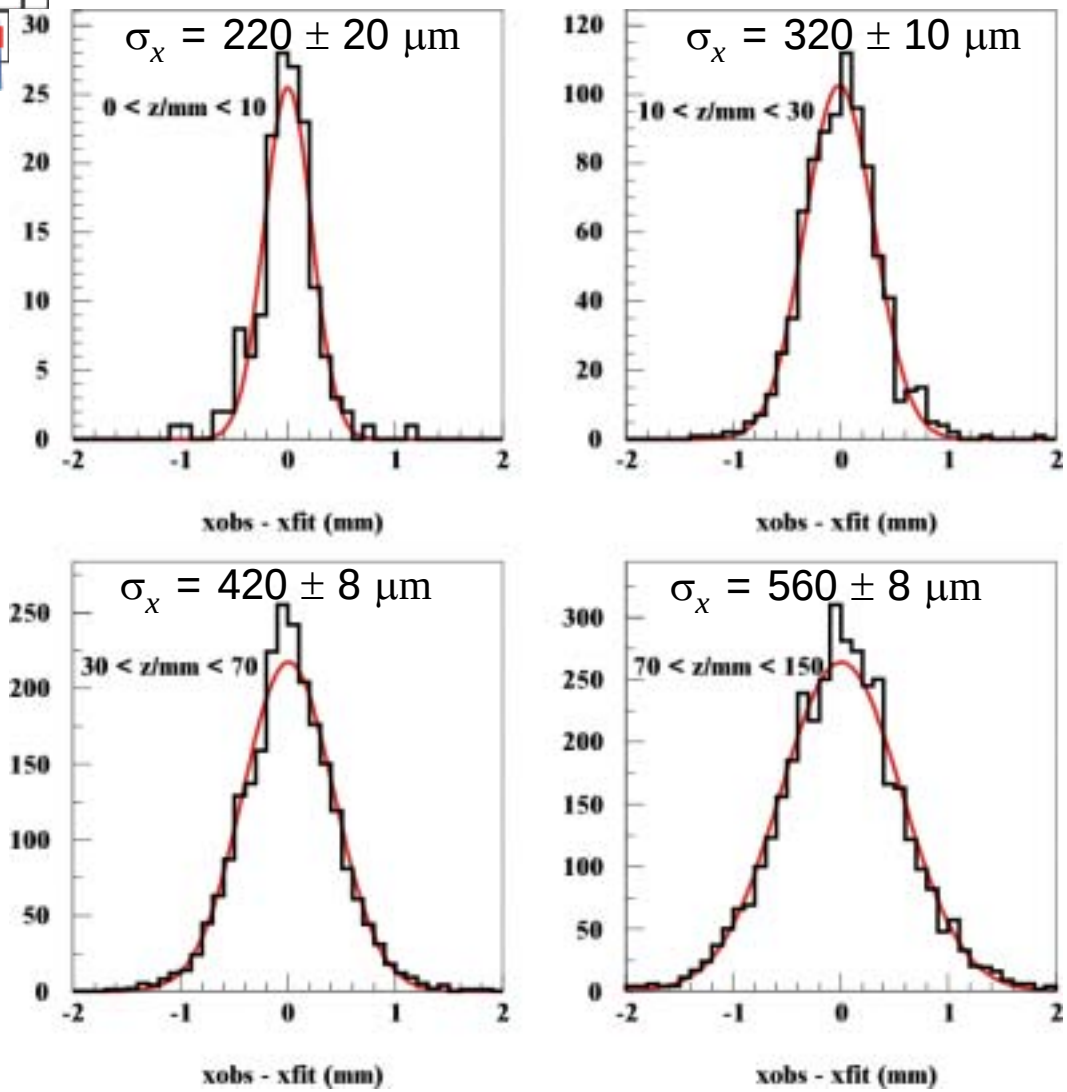
Transverse width of line charge

- Results from fit of data: diffusion apparent





Track x_0 resolution

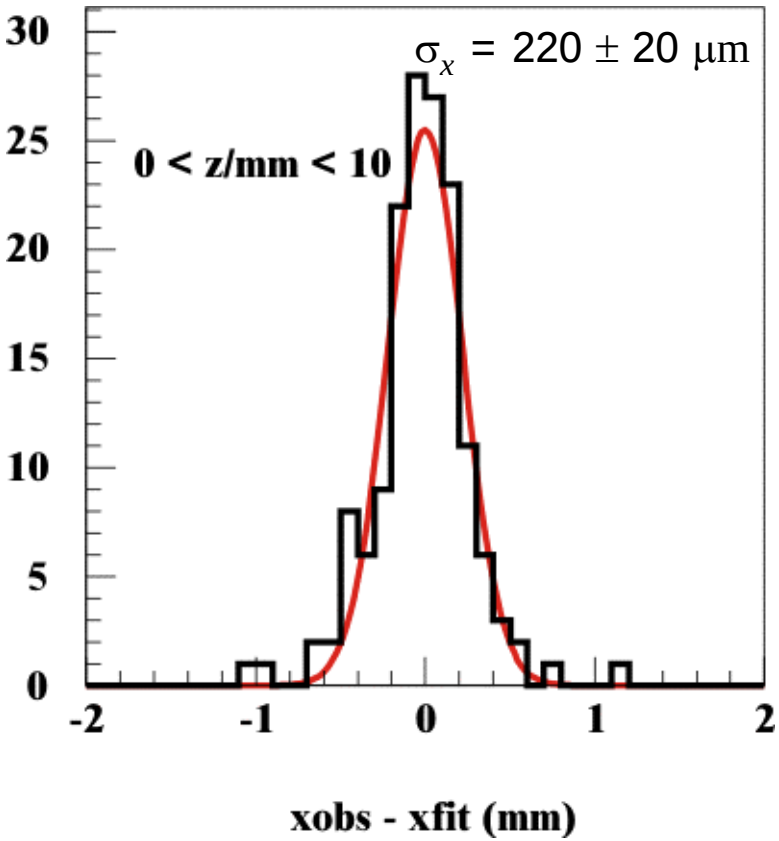


- x_0 resolution from single row:
  - do fit excluding the row: x_0, ϕ, σ free
  - do fit for single row: only x_0 free
  - compare 1 row x_0 to 4 row x_0

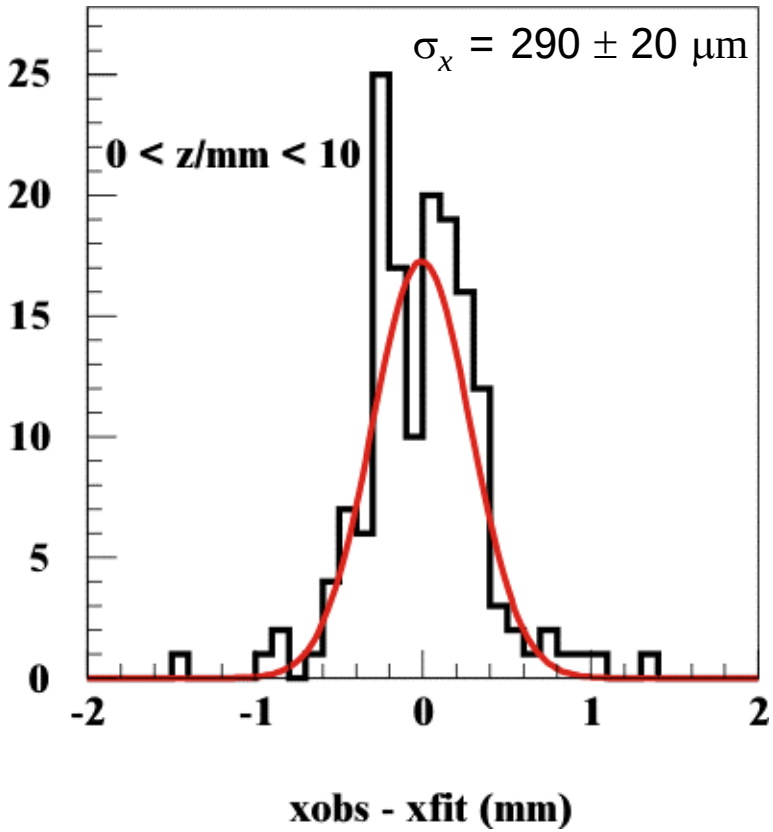
Centroid finding

- Linear weighted x_0 coordinate less accurate

Gaussian model



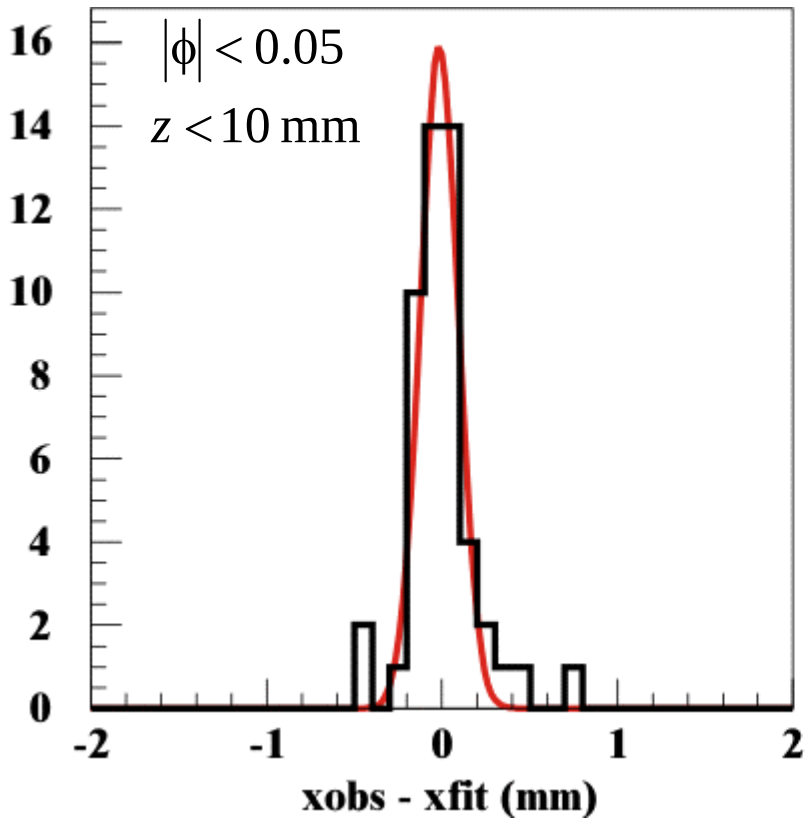
linear weighting



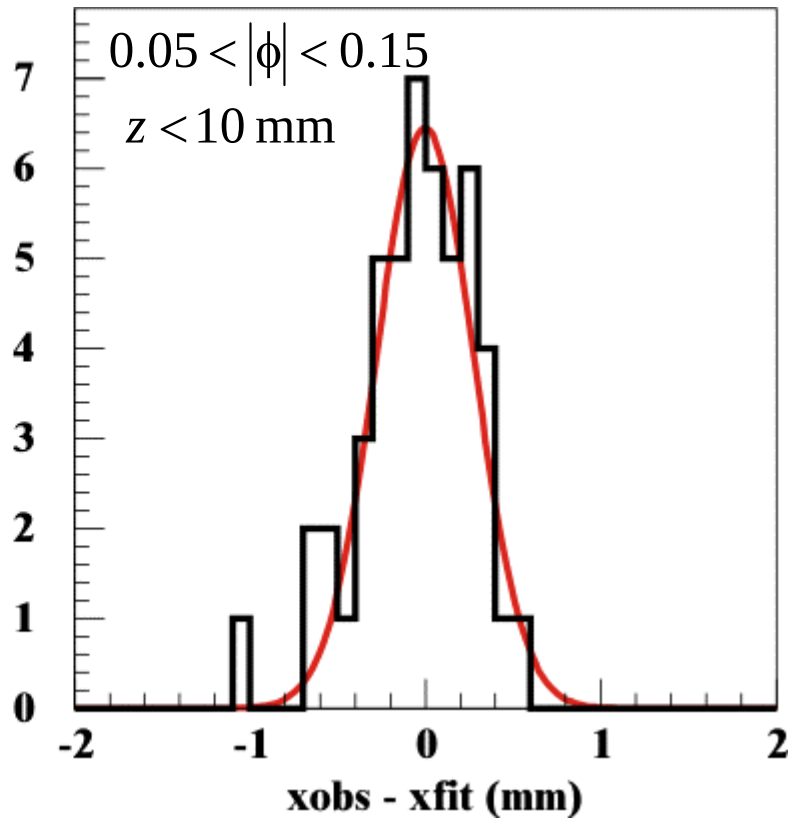
Track angle effect

- Appears to be significant, but small statistics

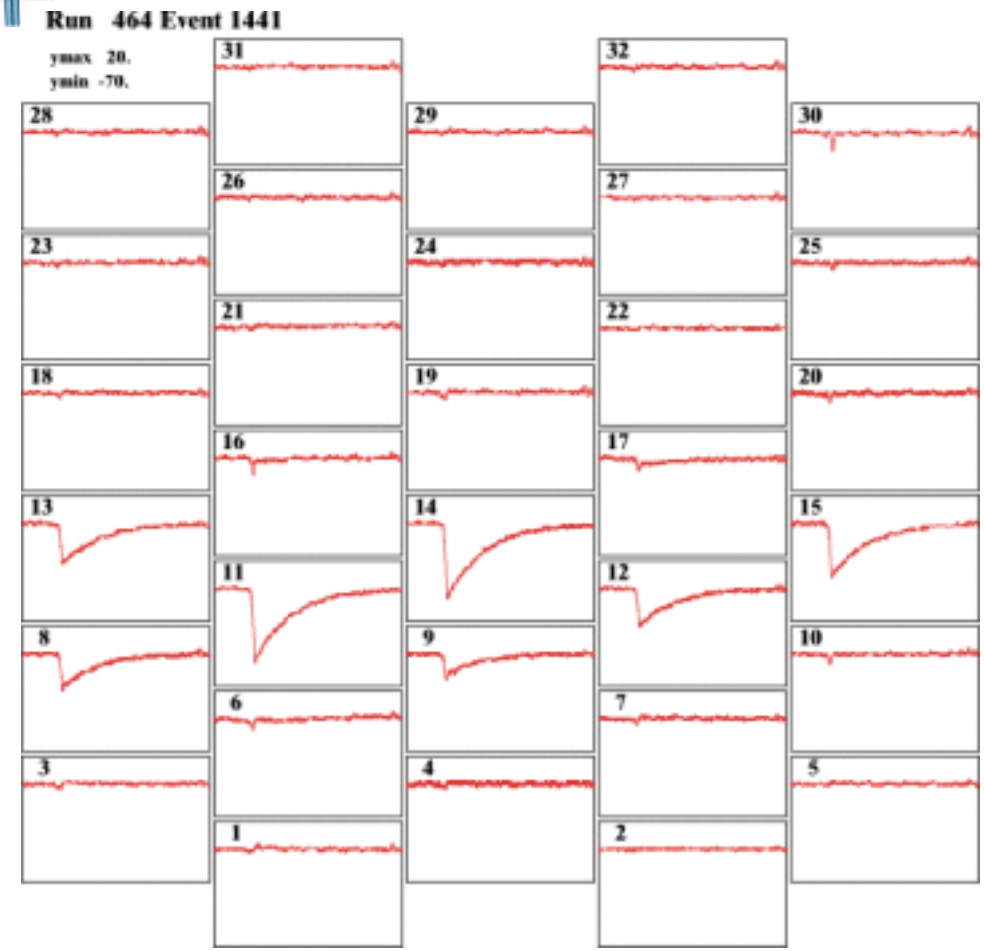
$\sigma_x = 110 \pm 15$ μm

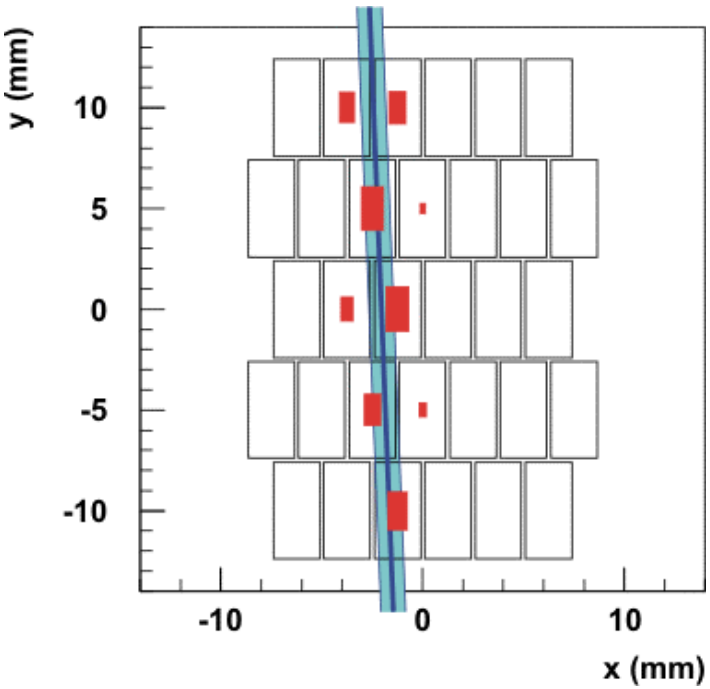


$\sigma_x = 280 \pm 50$ μm

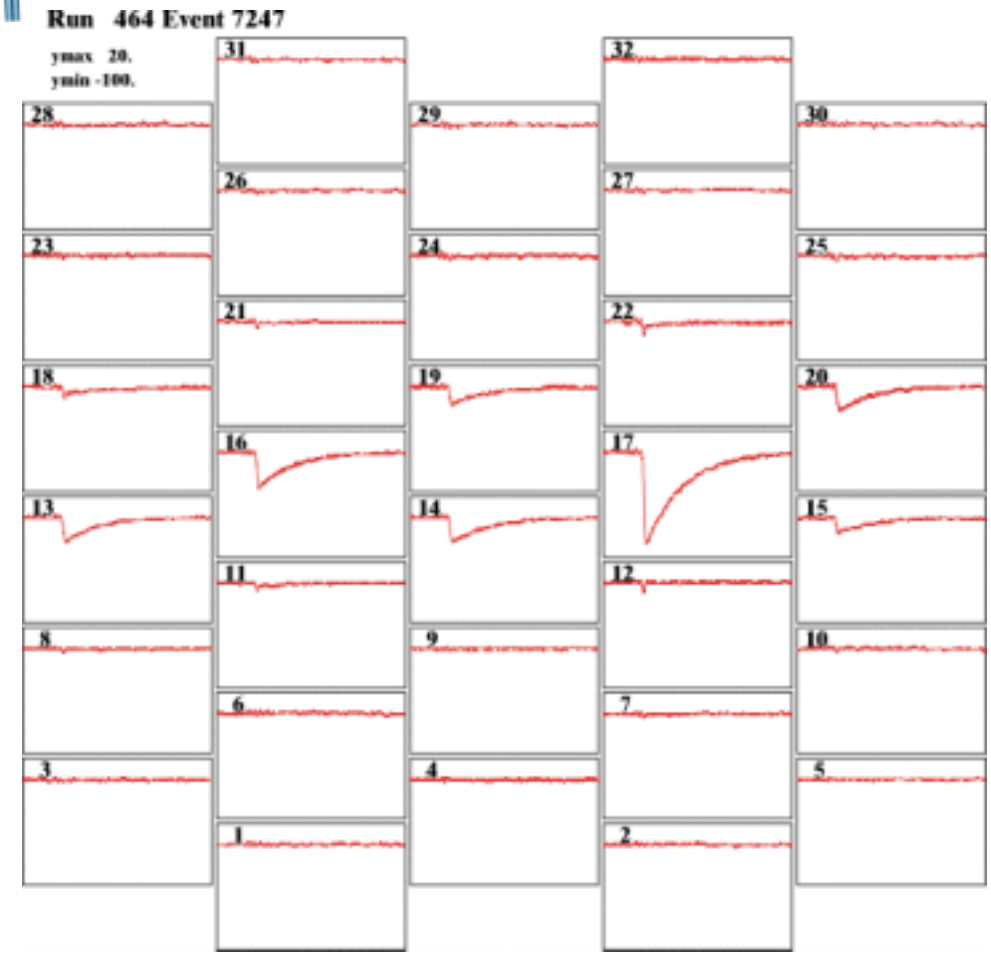


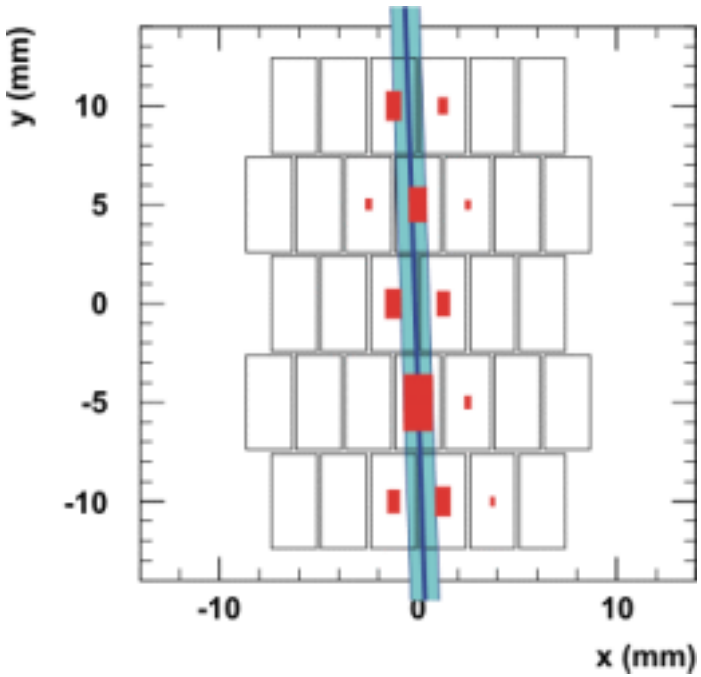
Sample events ($z < 10$ mm, $|\phi| < 0.05$)



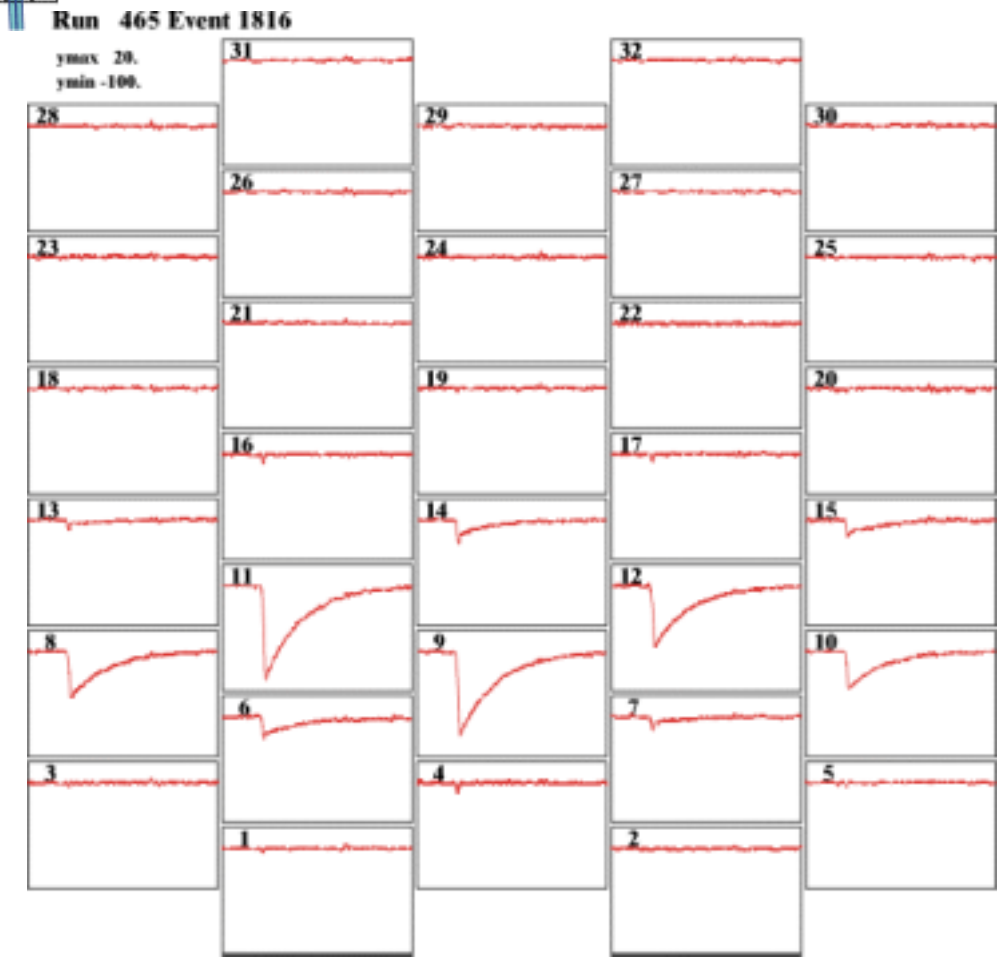


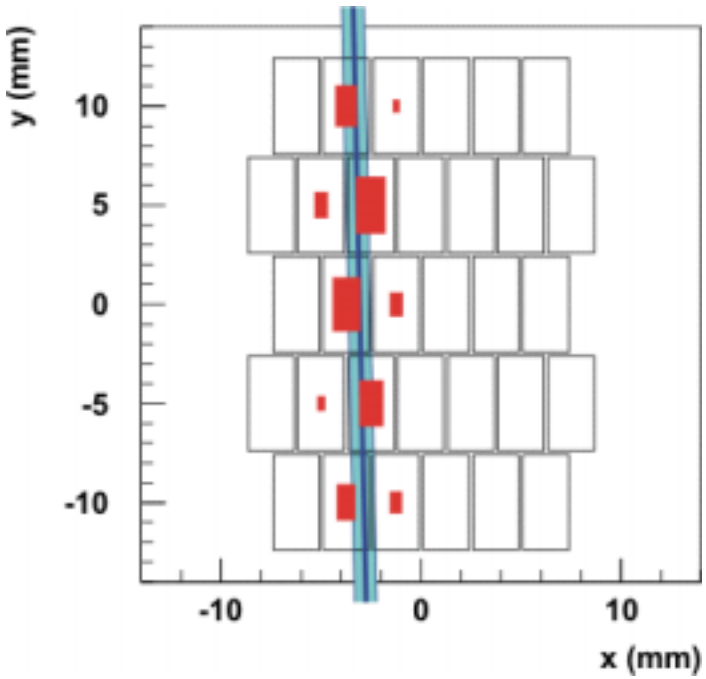
Sample events ($z < 10$ mm, $|\phi| < 0.05$)



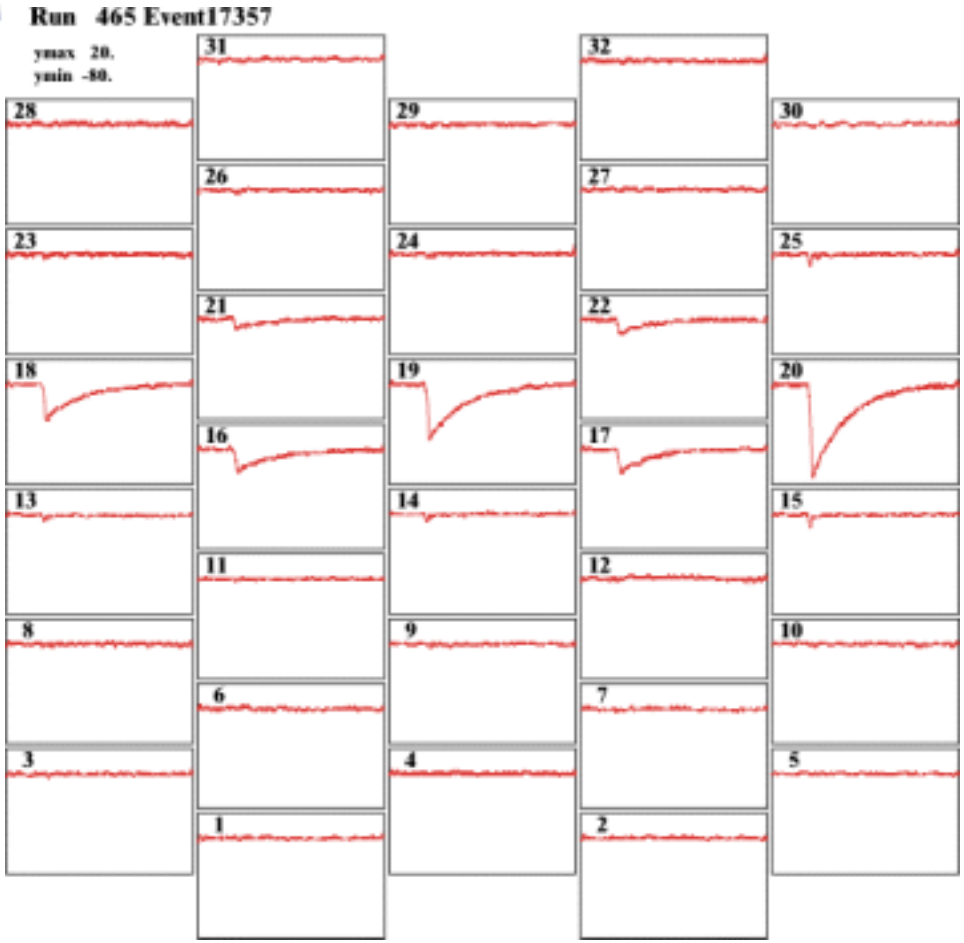


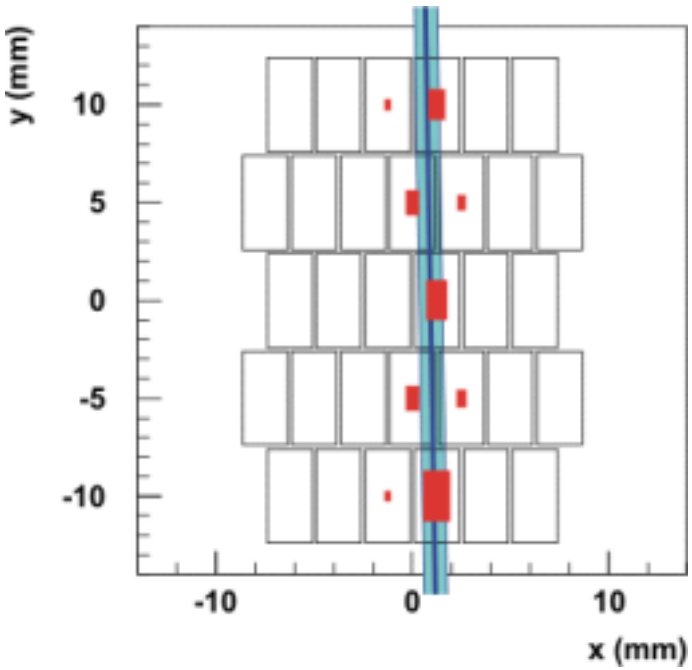
Sample events ($z < 10$ mm, $|\phi| < 0.05$)



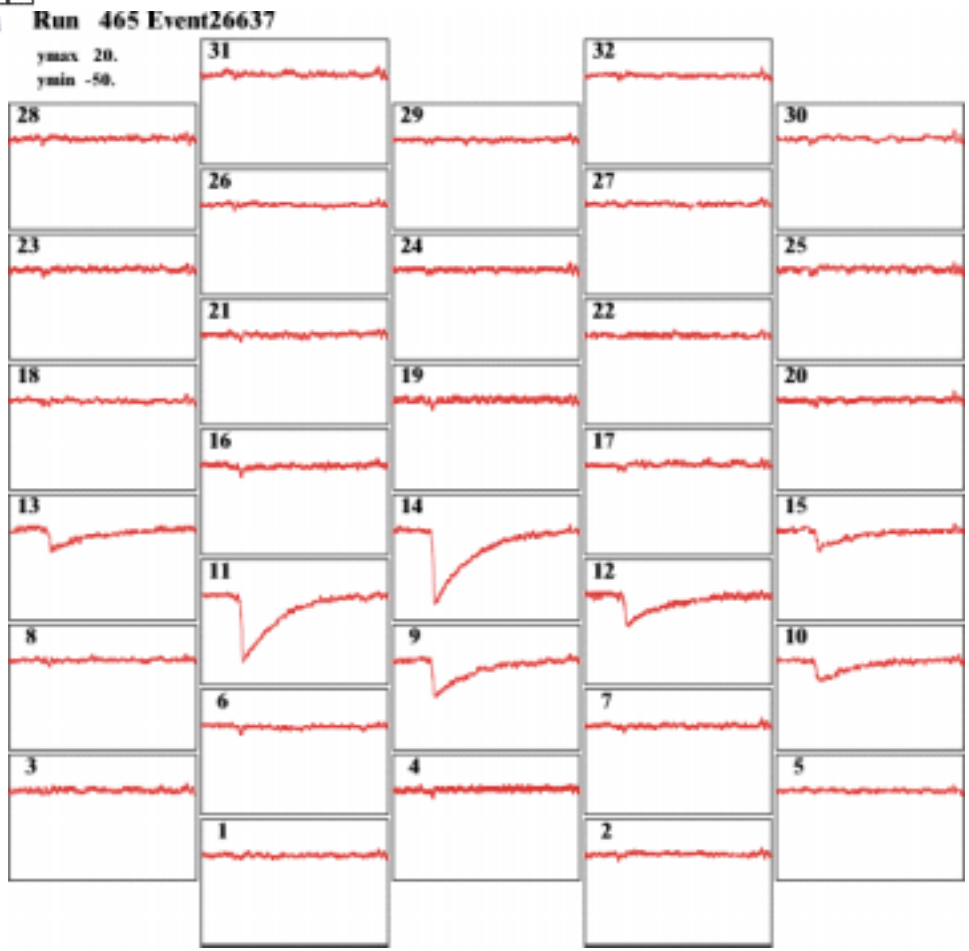


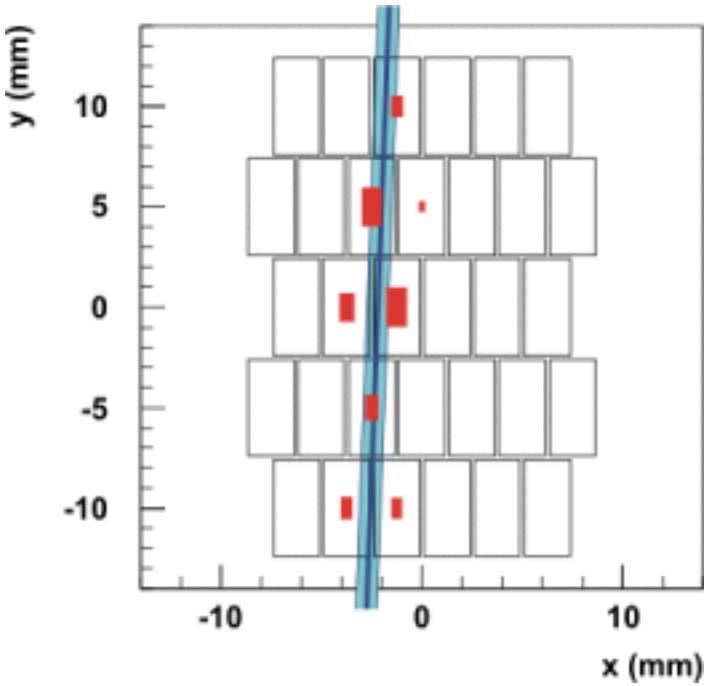
Sample events ($z < 10$ mm, $|\phi| < 0.05$)



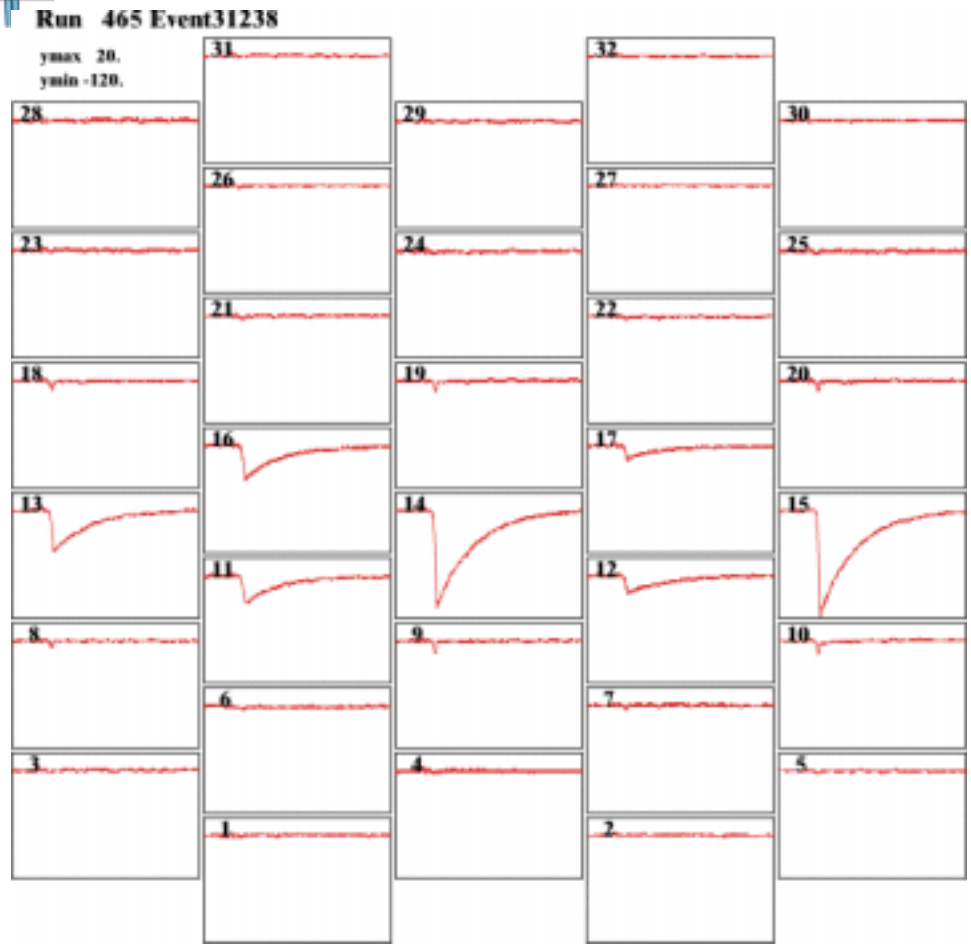


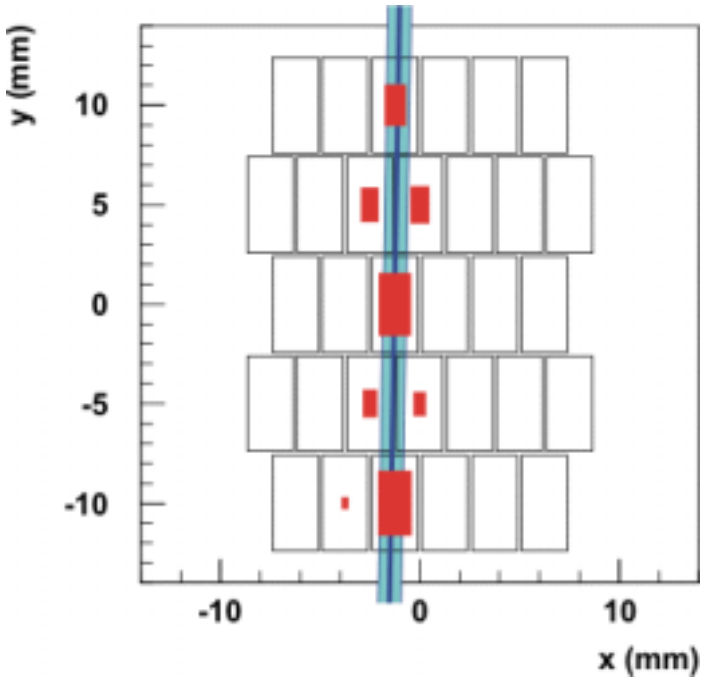
Sample events ($z < 10$ mm, $|\phi| < 0.05$)

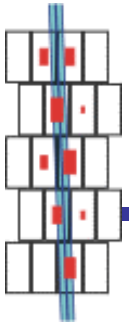




Sample events ($z < 10$ mm, $|\phi| < 0.05$)

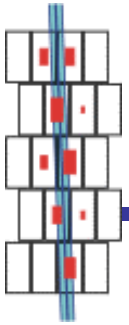






Future plans for Carleton studies

- Continue cosmic tracking studies
  - alternative gases (lower diffusion)
  - include calibration constants (none so far!)
  - alternative readout pad geometries
  - Q: can direct charge signals alone provide optimal resolution and two particle separation?
  - Q: are the small induced signals helpful?
- Try new ideas for spreading signal over more pads
  - resistive layer above pads that absorbs charge and leave only induced signals



Summary

- TPC is the leading candidate for a future linear collider
- Coordinated international effort for R&D for a LC TPC
  - emphasis is on new readout methods involving micro-pattern gas detectors
- Findings from Carleton GEM/TPC R&D:
  - Good space point resolution and tracking resolution achieved with relatively large pads
    - pad diameter ~ 4 x transverse diffusion is ok
- GEM readout for TPCs looks promising