TPC Momentum Resolution
- a full simulation

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Introduction

- Several groups (including Victoria) are using small prototype TPCs to characterize the performance for a LC TPC
  - Our data taking run with cosmics and laser tracks in the DESY magnet last summer was very successful
    - presentation at Durham LCWS showed preliminary results
    - full analysis is getting underway – hope to have more complete results for the SLAC LCWS
- This talk presents a simulation study of momentum resolution for a large GEM/MM TPC
  - extrapolation of small prototypes to a full size TPC

Goals

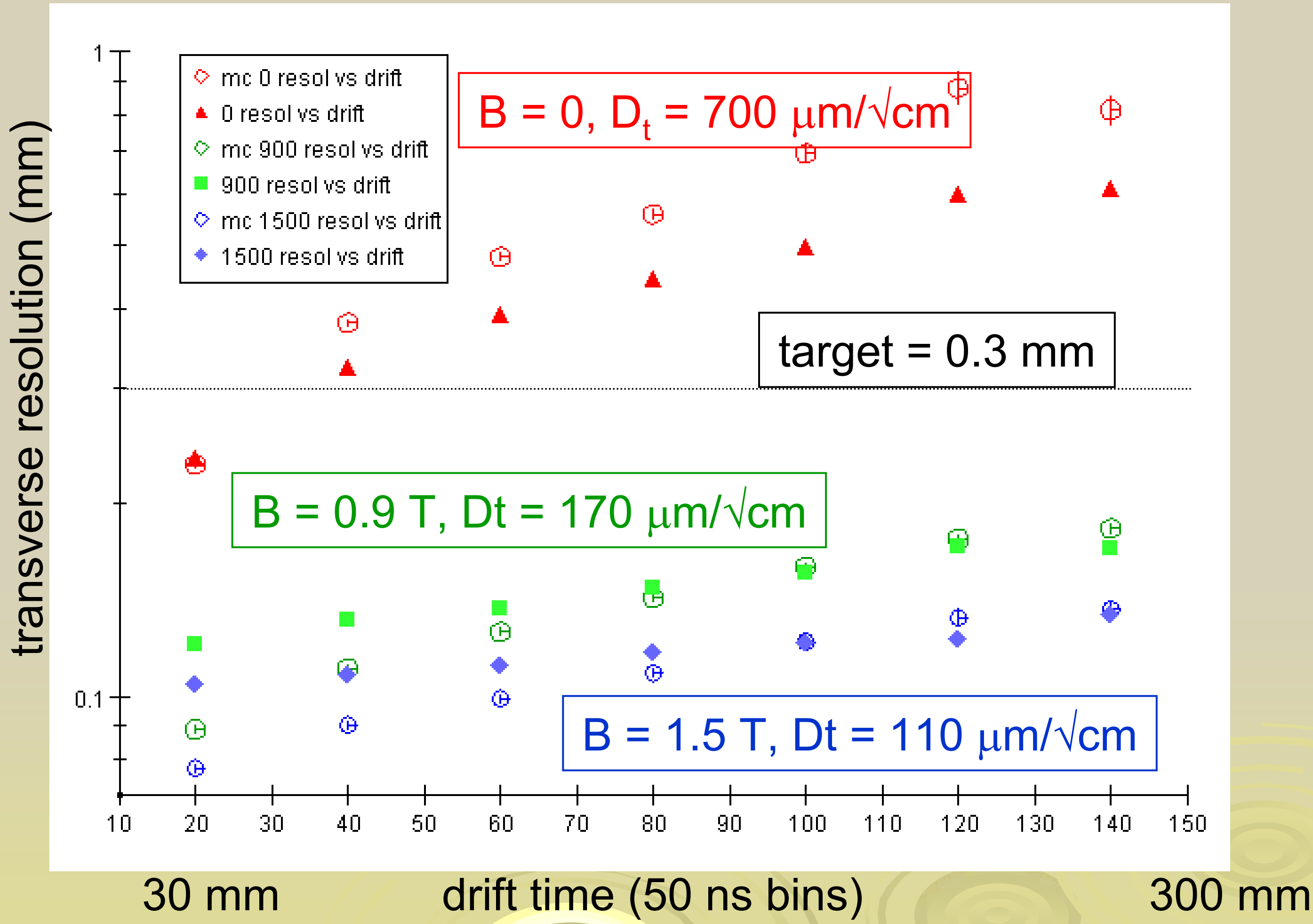
- Check that the track fit can achieve desired momentum resolution
- Test resolution dependence on
  - pad sizes
  - channel to channel gain variations
  - electronics noise
  - thresholds
  - other systematic effects…

Momentum resolution study

- Full simulation scheme:
  - GEANT3 simulation of muon propagation and energy loss in a 140 cm length of TDR gas in 4.0 T field
    - energy losses in 1 mm segments are saved to flat files
  - jtpc simulation program:
    - reads energy losses and converts to electron/ion pairs
    - electrons drift, diffuse, pass through GEM holes, are amplified, diffuse, get collected on pads, pad signals generated, digitized, and signals stored in data files
  - jtpc data analysis program:
    - read data files, signals converted to charge estimates
    - likelihood track fit performed to estimate track parameters
    - momentum resolution determined

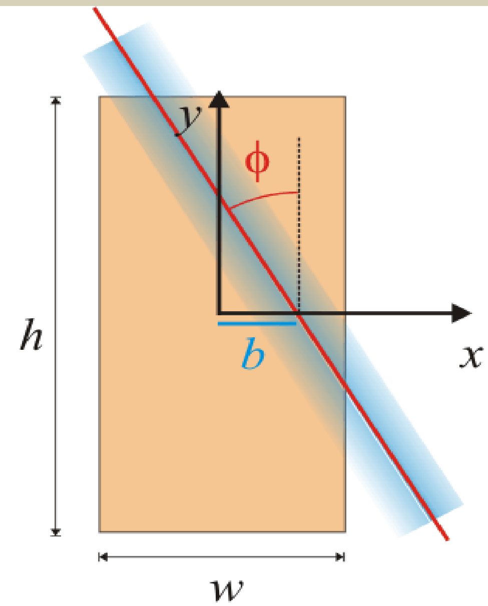
Comparison of prototype and simulation

- agreement is reasonably good



jtpc tracking details

- Pad response function
  - in a GEM (or micromegas) TPC this can be parameterized analytically, using a simple model
  - Four track parameters:
    - x_0 (x at y=0)
    - ϕ_0 (azimuthal angle at y=0)
    - σ (transverse s.d. of cloud)
    - 1/r (radius of curvature)



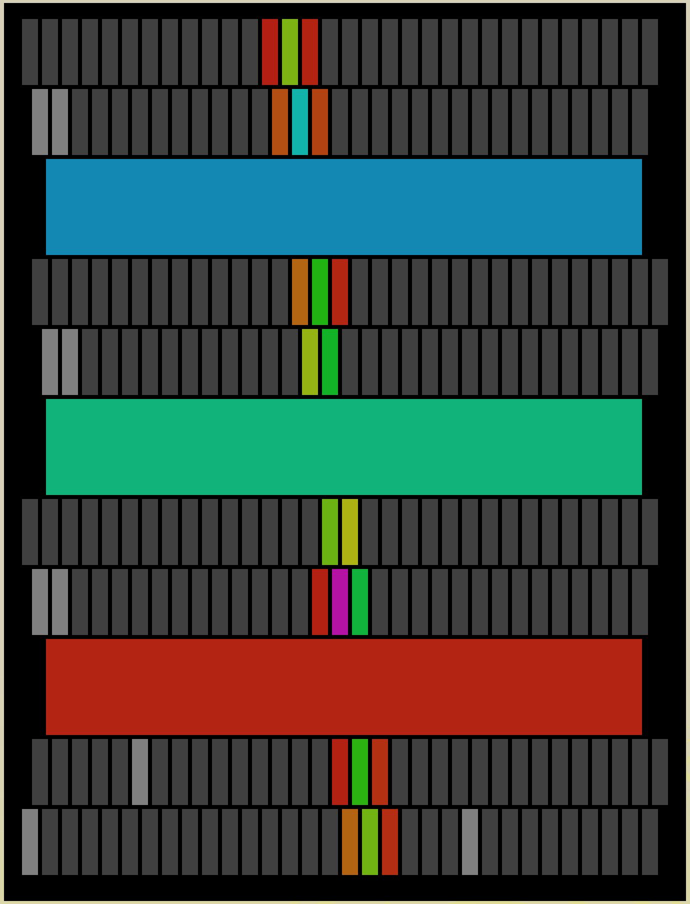
$$I(b,\phi,\sigma,h,w) = \int_{-w/2}^{w/2} dx \int_{-h/2}^{h/2} dy \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{[(x-b)\cos\phi + y\sin\phi]^2}{2\sigma^2}}$$
$$= \eta(b,\phi,\sigma,h,w) - \eta(b,\phi,\sigma,-h,w) + \eta(b,\phi,\sigma,-h,-w) - \eta(b,\phi,\sigma,h,-w)$$

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

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

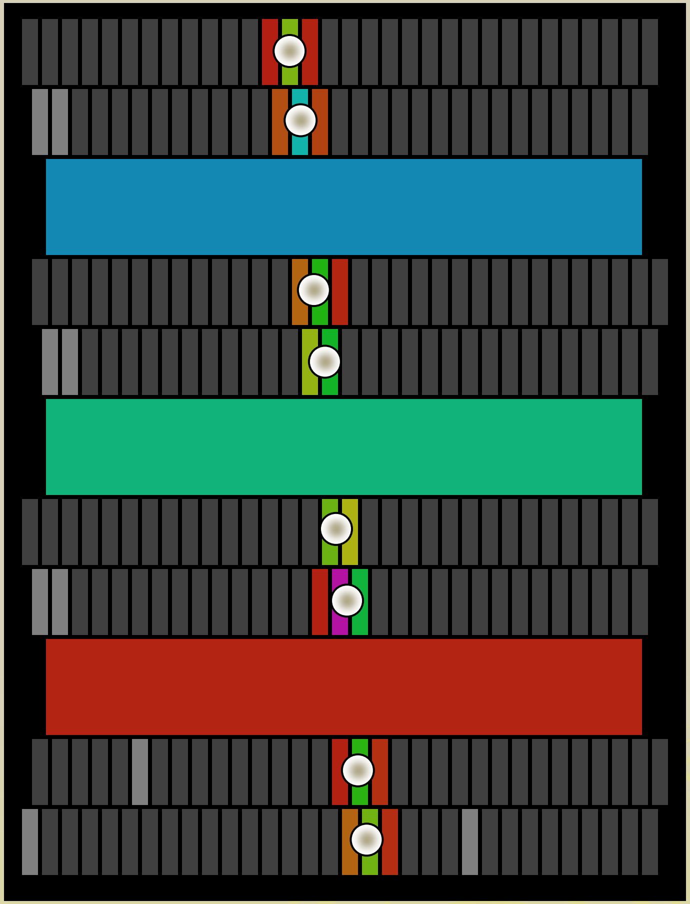
Traditional tracking

- The traditional approach:
  - examine data from each row separately: define a point along the track



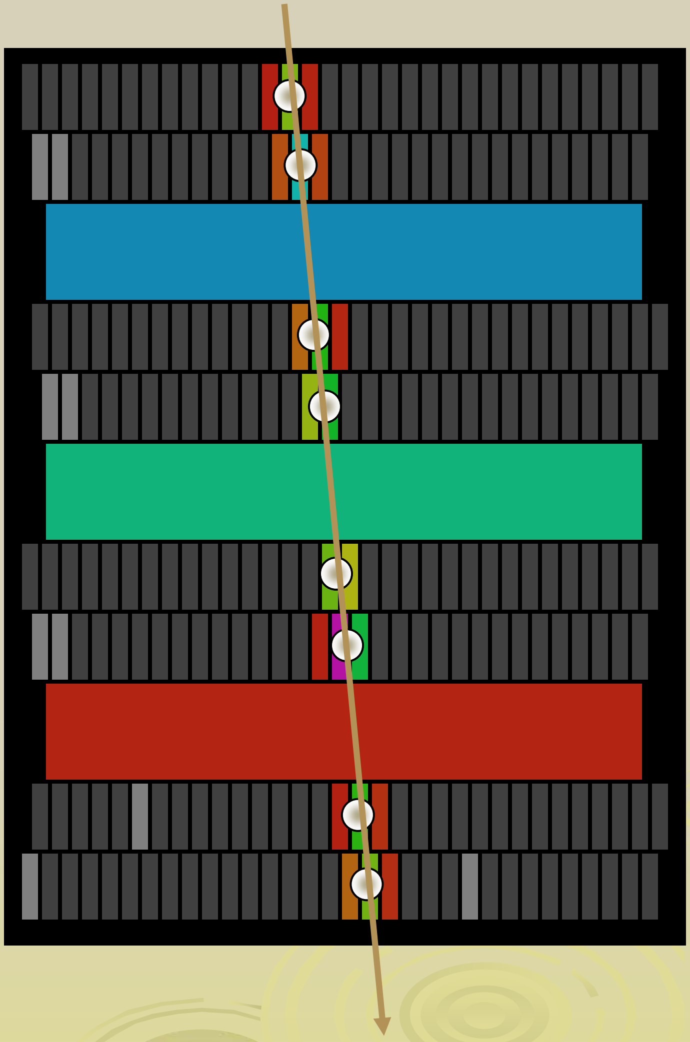
Traditional tracking

- The traditional approach:
  - examine data from each row separately: define a point along the track
  - find best track that goes through points



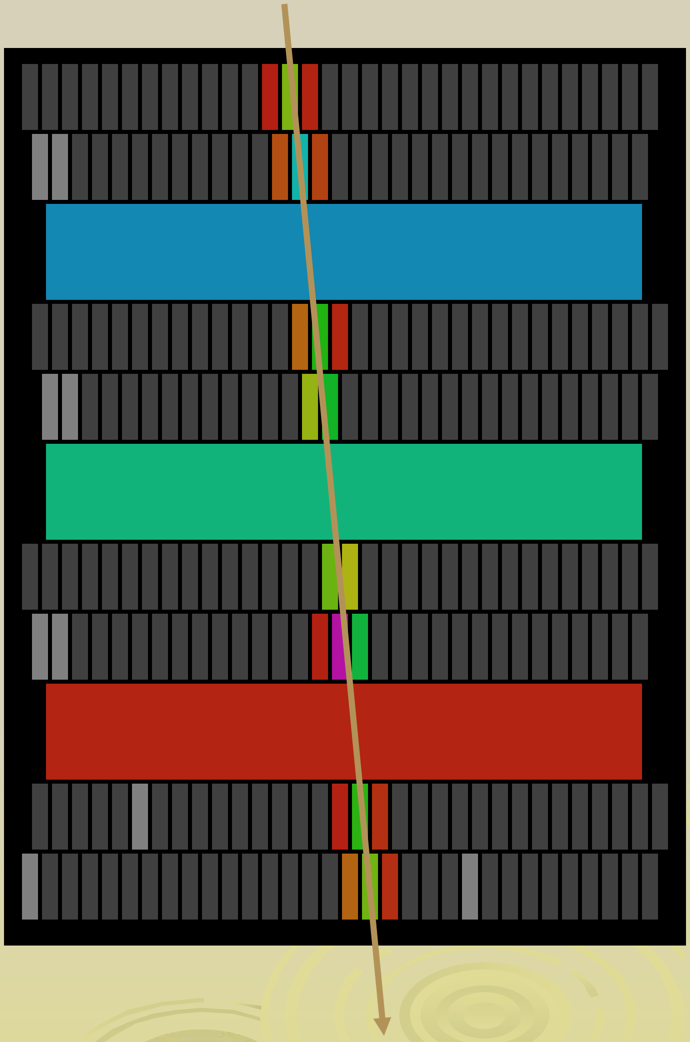
Traditional tracking

- Problem with the traditional approach:
  - information in one row is not sufficient to define a point along the track:
    - charge sharing depends on
      - x coordinate
      - local azimuthal angle
      - width of charge cloud
    - effect is largest when few pads hit per row
  - dependence is non-linear
    - linear centroid finding degrades resolution



Whole track approach

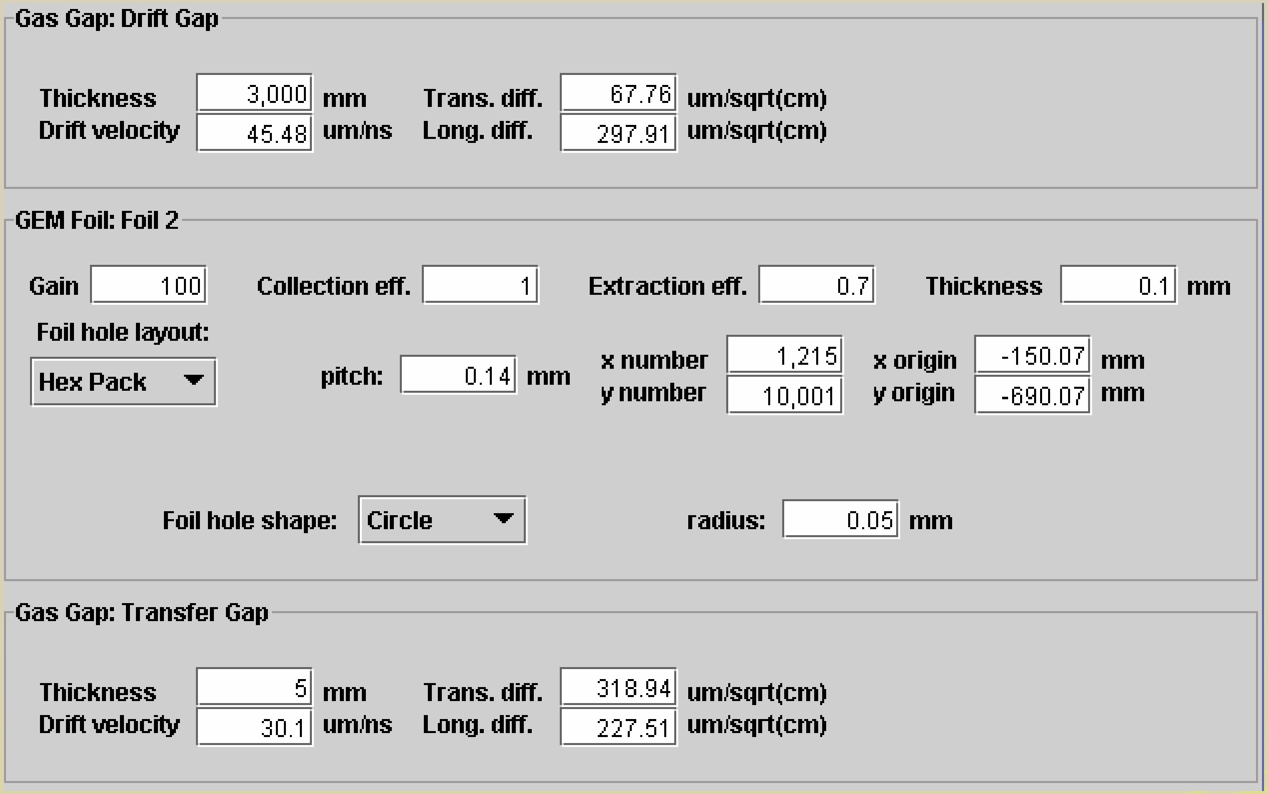
- The whole track approach:
  - fit information from all rows to determine the track parameters at once



- Benefits of the whole track approach:
  - no empirical parameters
    - less calibration
  - reasonable estimates for error matrix
  - better resolution

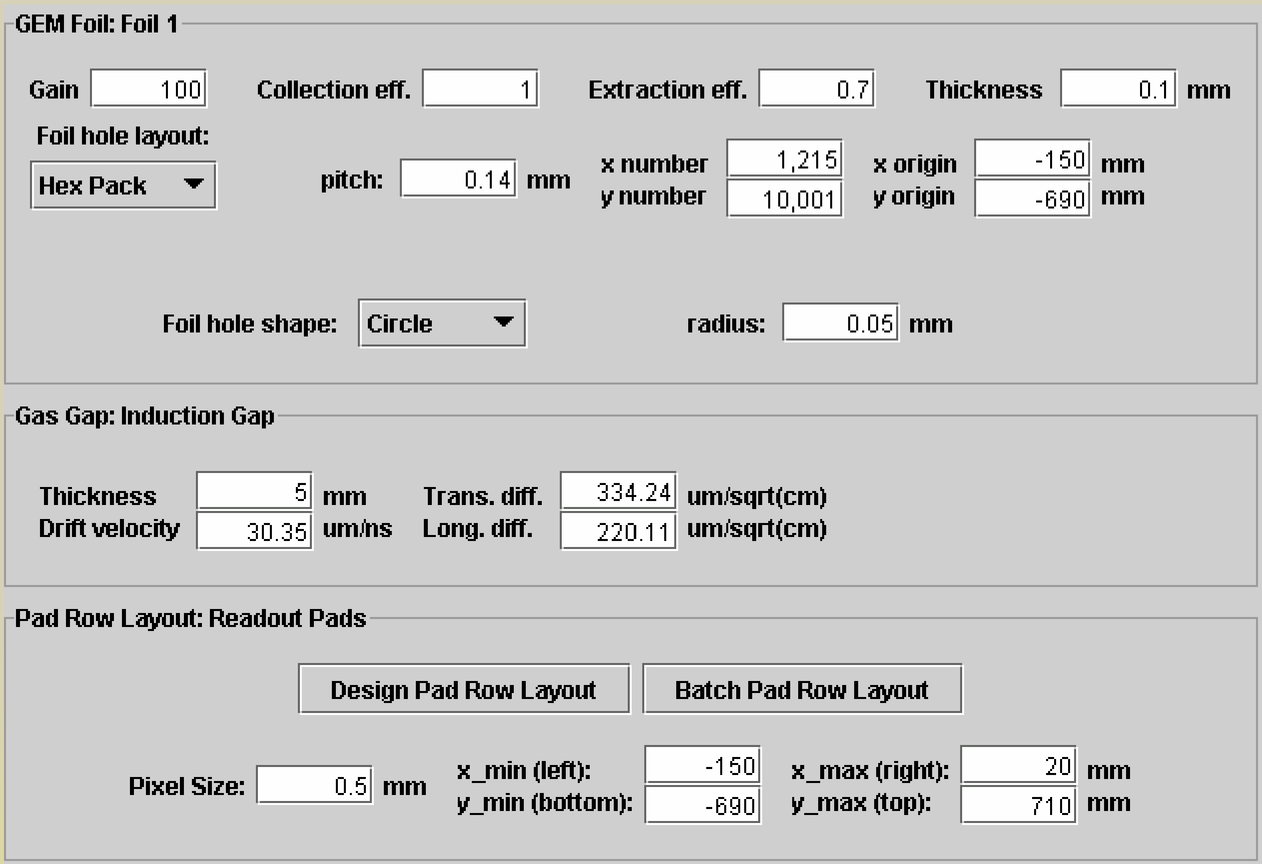
TPC simulation

- TDR gas at 4 T assumed:



TPC simulation

- cont…



Simulation

- Other parameters:

Geant parameters

☑ use geant file **Geant File Name:** data/tesla_10GeV_hits.dat

x offset (mm)	0.0	particle code	6
y offset (mm)	0.0	Wi (eV)	26.0
z offset (mm)	2500.0		

Pre-Amp parameters

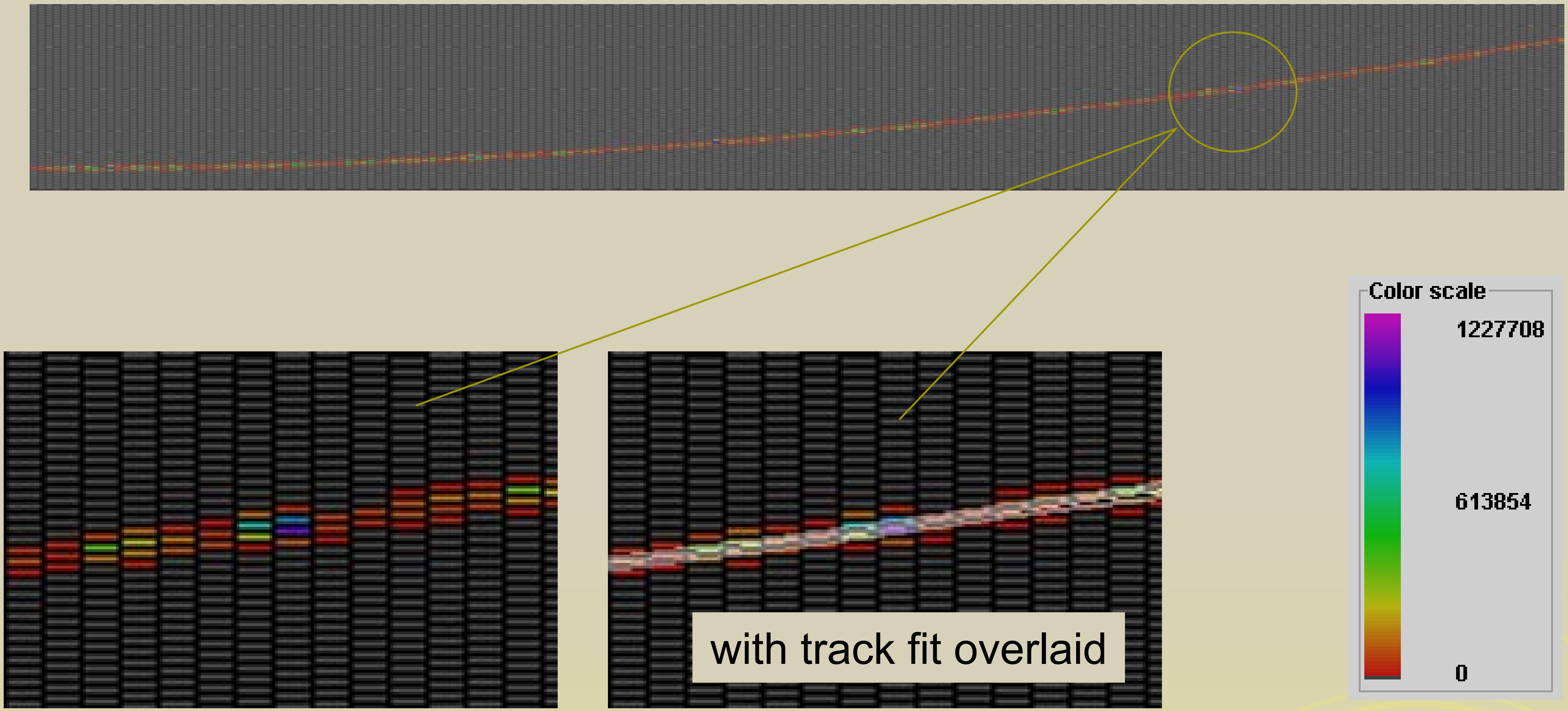
gain (mV/fC)	14.0	gain s.d. (rel)	0.0
rise time (ns)	500	fall time (ns)	500

FADC parameters

gain (ch/mV)	2.0	# bits	10
delta t (ns)	100.0	# bins	800

Example 10 GeV muon event

- Pad size: 2 × 7 mm^2 Drift distance: 2.5 m



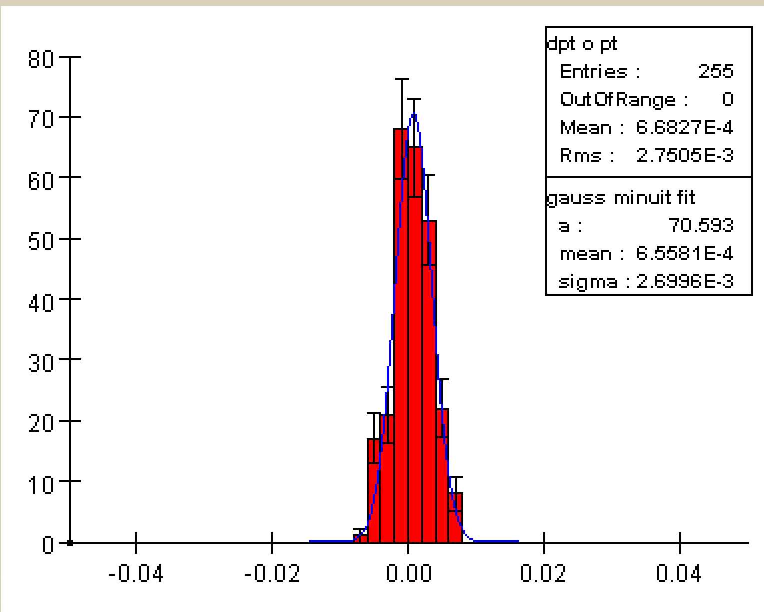
Event #1: true p_t: 10.0013 GeV/c fit p_t: 10.0017 GeV/c (Too good!)

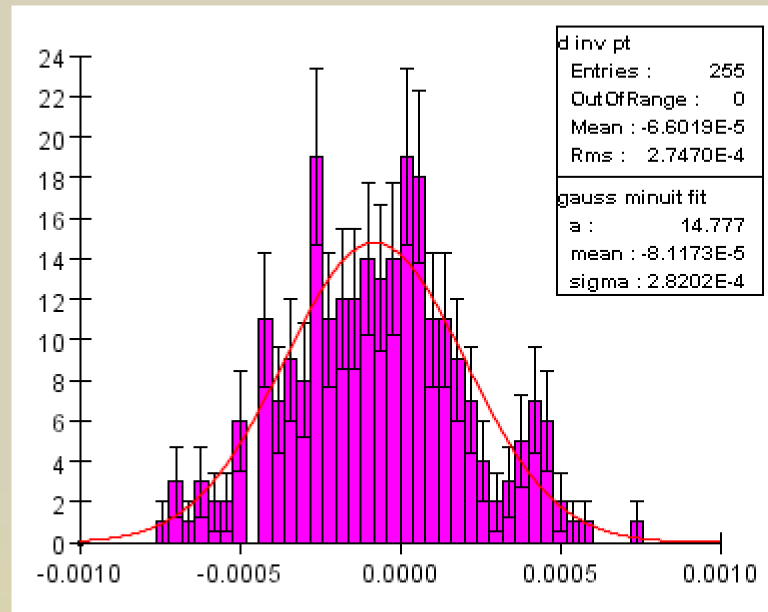
Momentum resolution

- repeated events (same track parameters)

$$\frac{p_\perp^{\text{fit}} - p_\perp^{\text{true}}}{p_\perp^{\text{true}}}$$

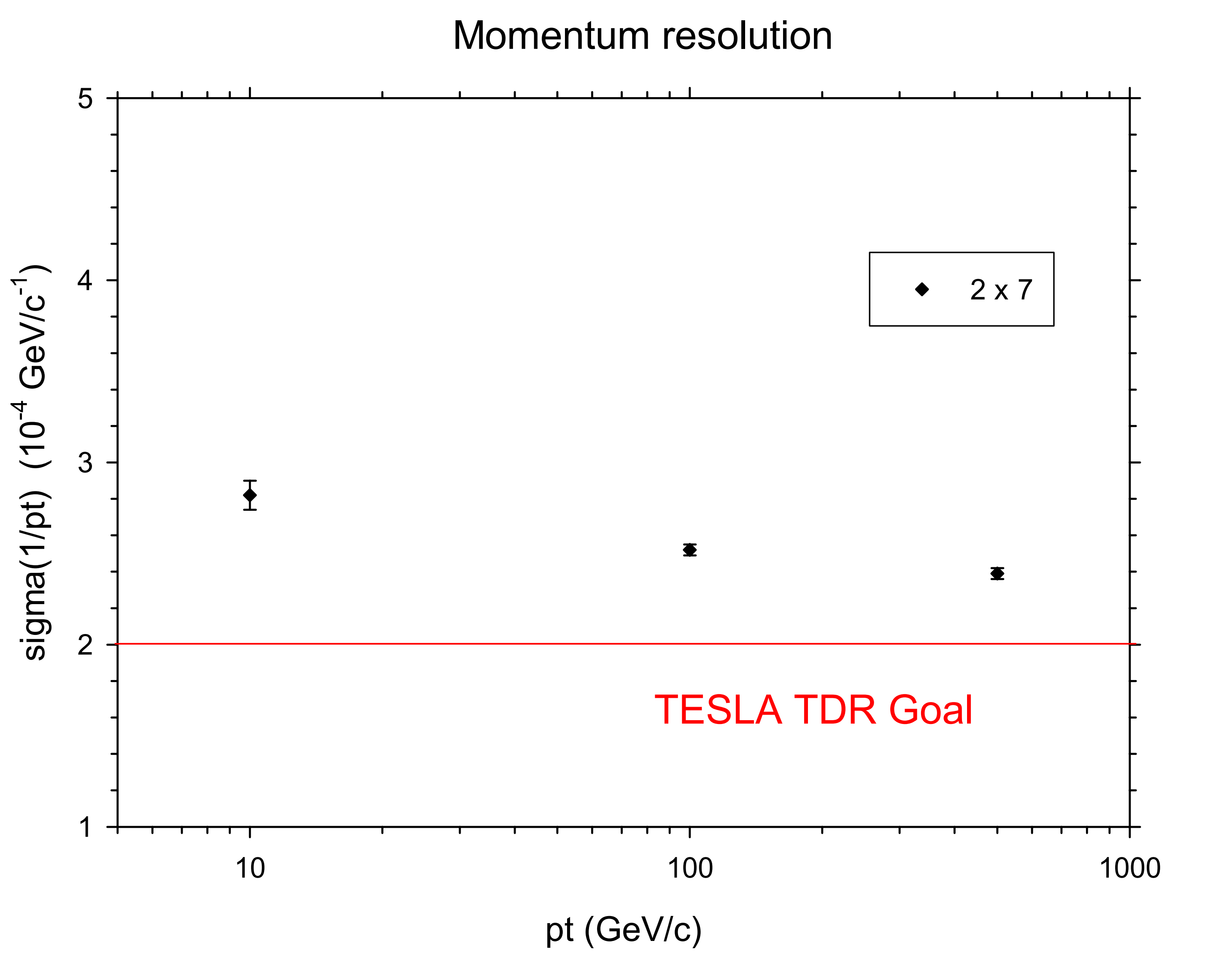
$$\frac{1}{p_\perp^{\text{fit}}} - \frac{1}{p_\perp^{\text{true}}}$$





$$\delta\left(\frac{1}{p_\perp}\right) = 2.8 \times 10^{-4} \left(\text{GeV/c}\right)^{-1}$$

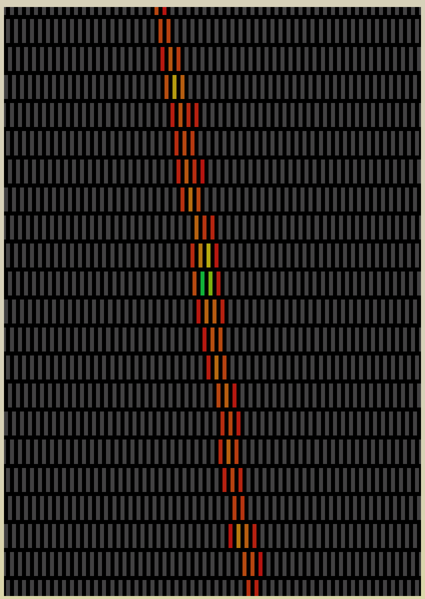
Resolution vs pt



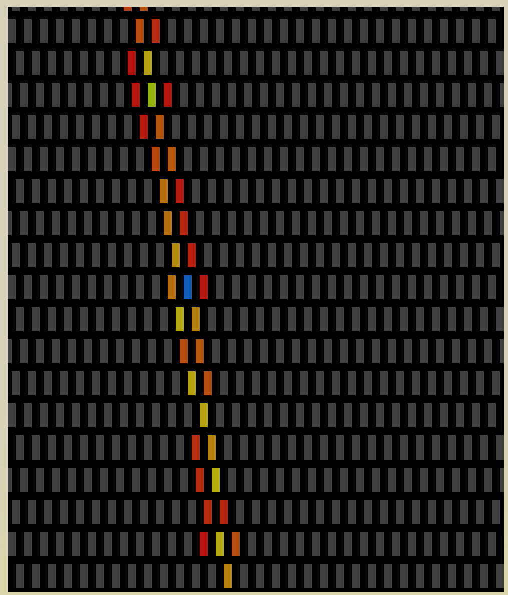
Wider pads

- Charge sharing is less effective for wider pads:

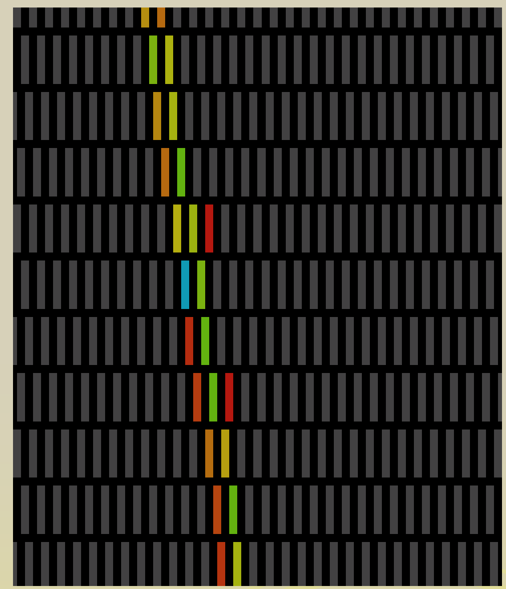
$2 \times 7\ mm^2$



$4 \times 8\ mm^2$

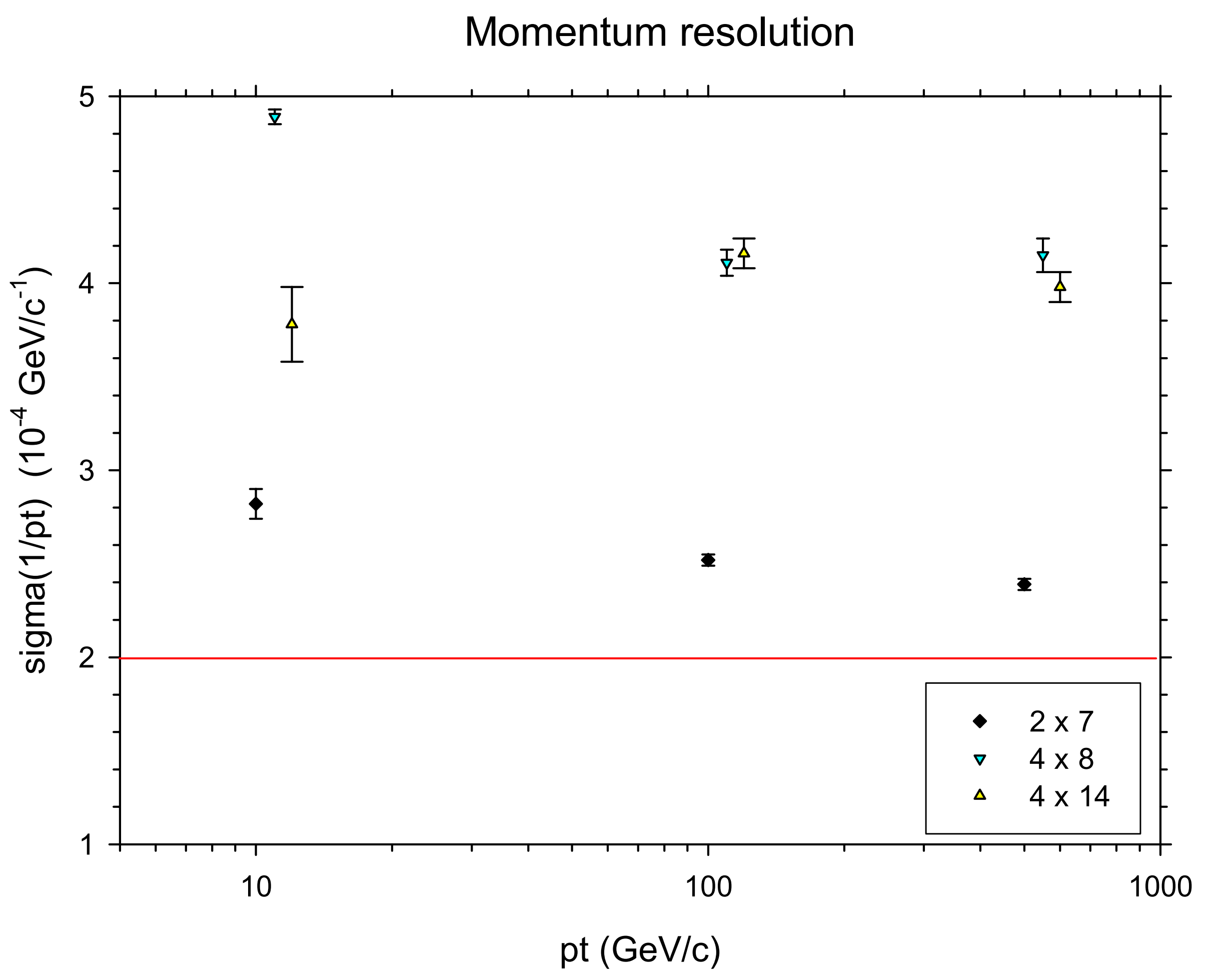


$4 \times 14\ mm^2$



Wider pads

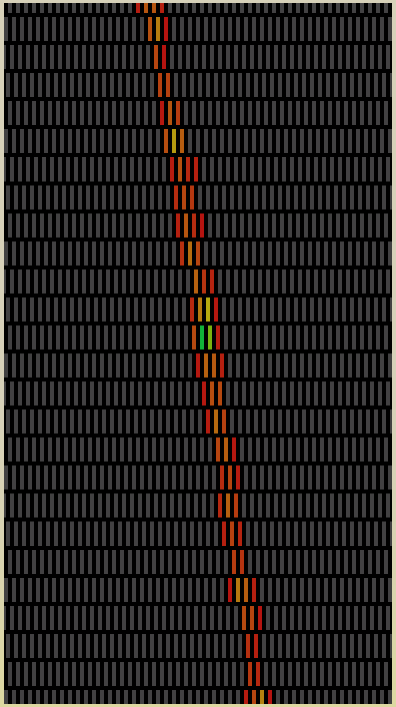
- 4 mm appears to be too wide



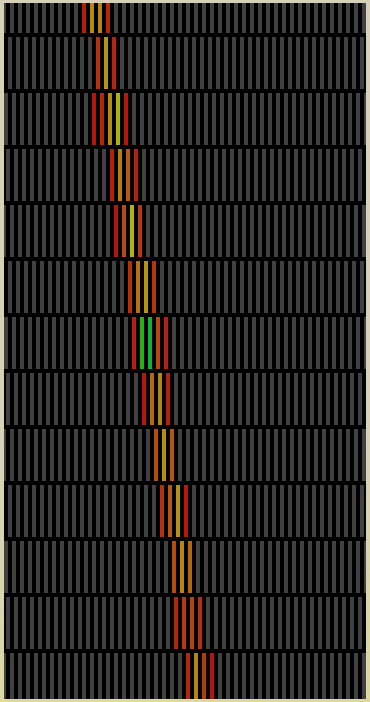
Other pad sizes

- Longer or narrower…

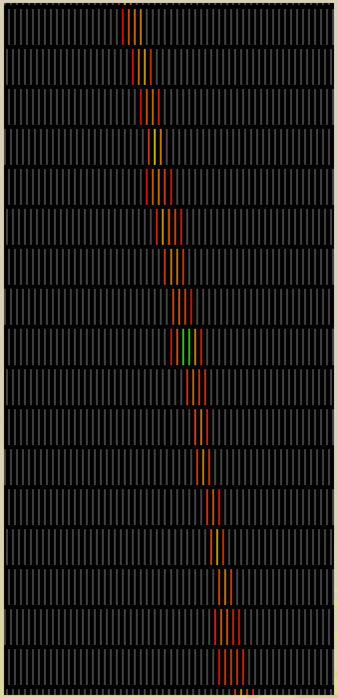
2 × 7 mm^2



2 × 14 mm^2

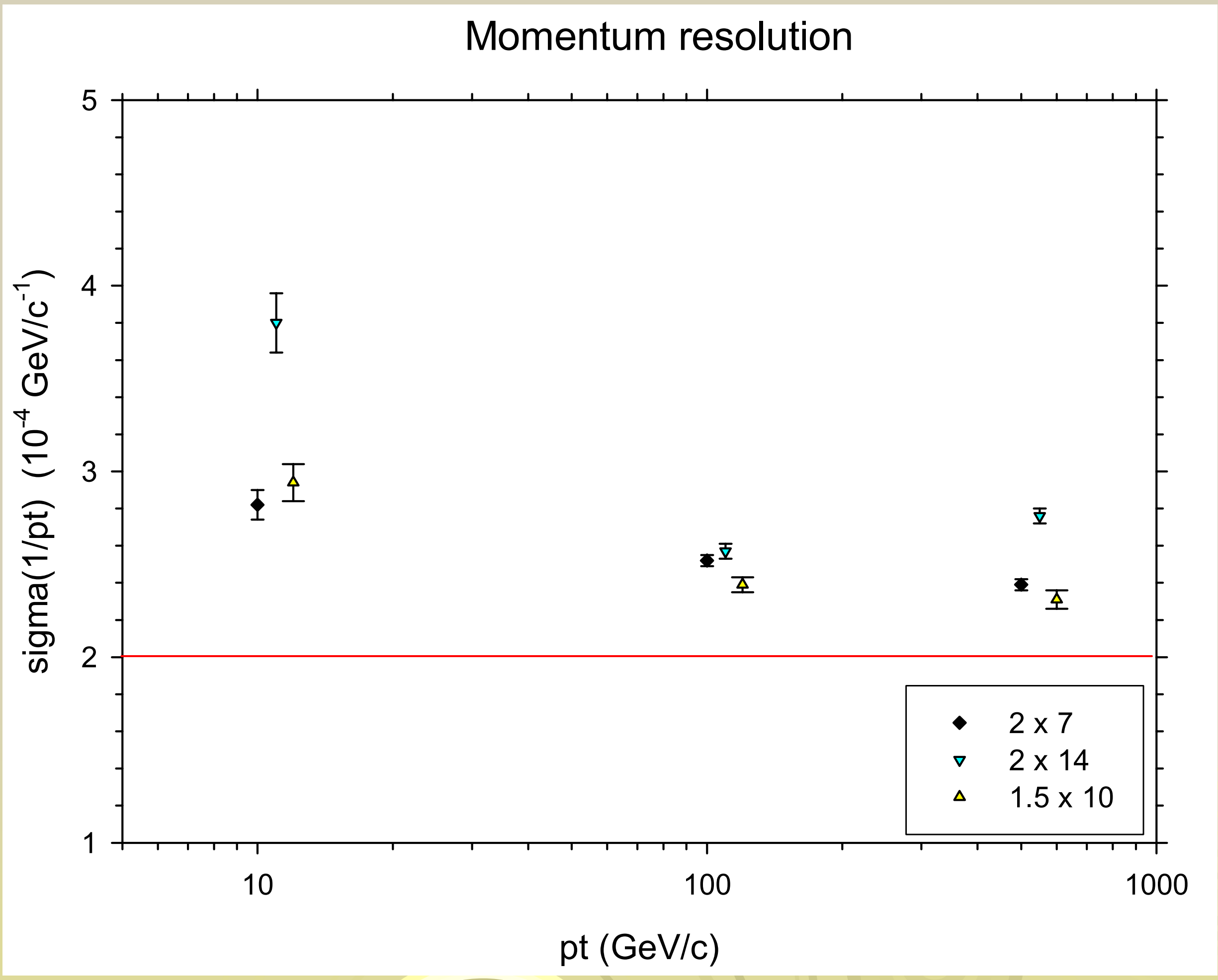


1.5 × 10 mm^2



Other pad sizes

- 2mm x 7 mm seems reasonable

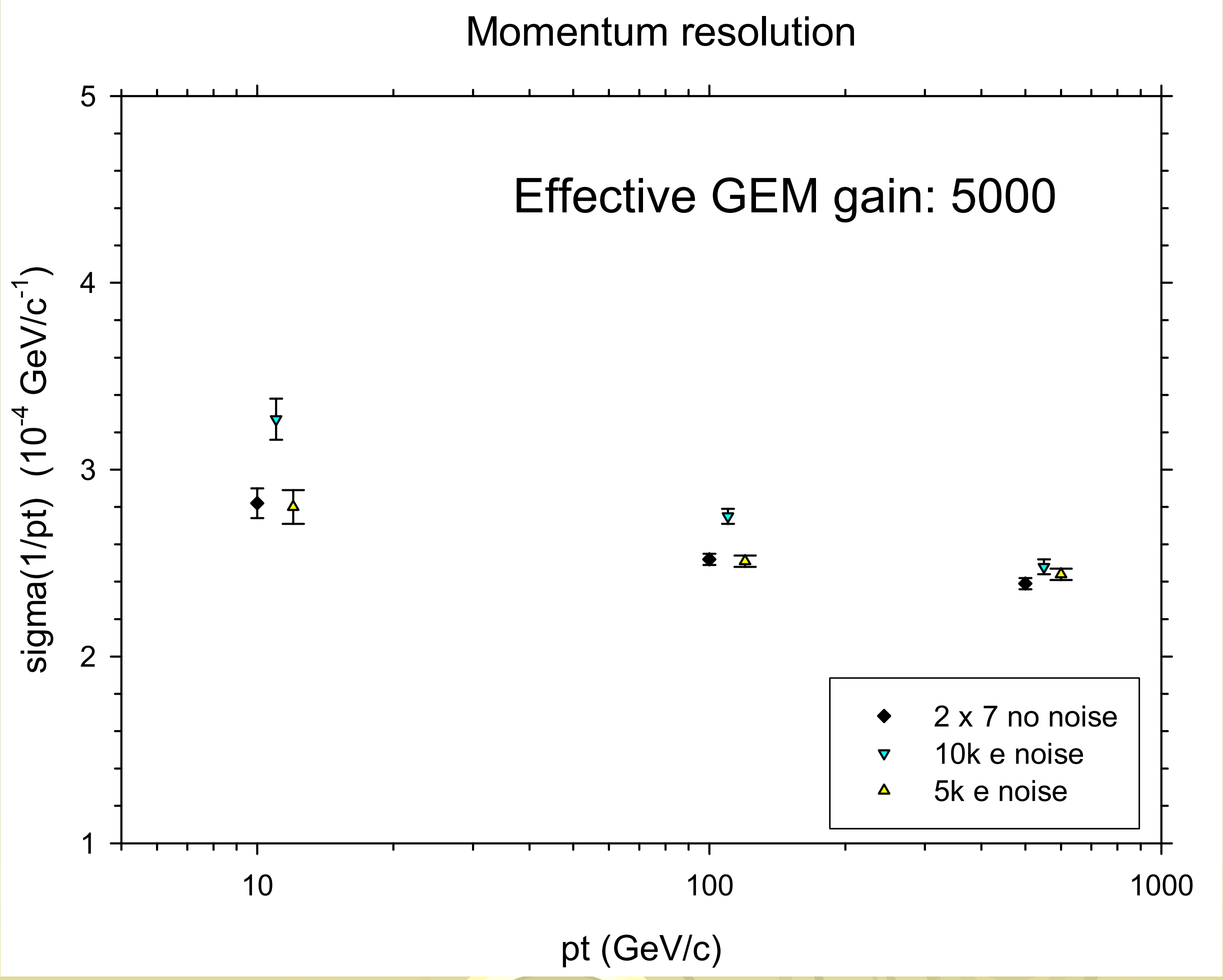


Influence of noise

- Number of electrons collected by a pad is estimated by integrating the pulse over 7 time bins (peak +/- 3).
  - Prior to fitting, Gaussian noise is added
  - Noise on each channel assumed to be independent (no common mode included)

Influence of noise

- Significant noise can be tolerated in this case

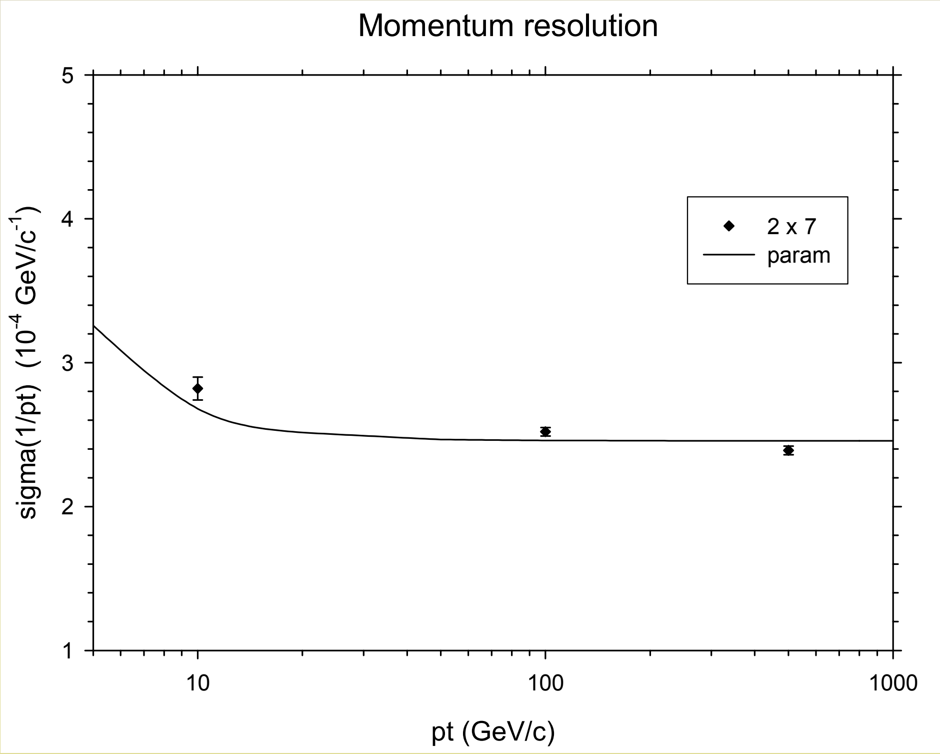


Comparison to standard parameterizations

- Agreement with point resolution ~ 300 μm

$$\delta\left(\frac{1}{p_\perp}\right)_{\rm res} = \frac{1}{0.3B}\frac{\varepsilon}{L^2}\sqrt{\frac{720}{N+4}} = 0.78\times10^{-4}\,({\rm GeV/c})^{-1}\,\frac{\varepsilon}{100\mu{\rm m}}$$

$$\delta\left(\frac{1}{p_\perp}\right)_{\rm ms} = \frac{1}{0.3B}\frac{0.016}{Lp_\perp\cos\lambda}\sqrt{\frac{L}{X_0}} = \frac{10.7\times10^{-4}}{p_\perp}$$



Summary

- Initial results encouraging:
  - likelihood track fit appears to work reasonably well
    - resolution roughly agrees with parameterization
  - TDR resolution goal nearly attained with TDR gas
  - with large diffusion: relatively insensitive to noise at 5-10k e level

- To do:
  - repeat analysis with lower diffusion gas: eg. P10
  - move tracks around
  - look at inclined tracks
  - look at other systematics?