Pad Geometry Study for a Linear Collider TPC

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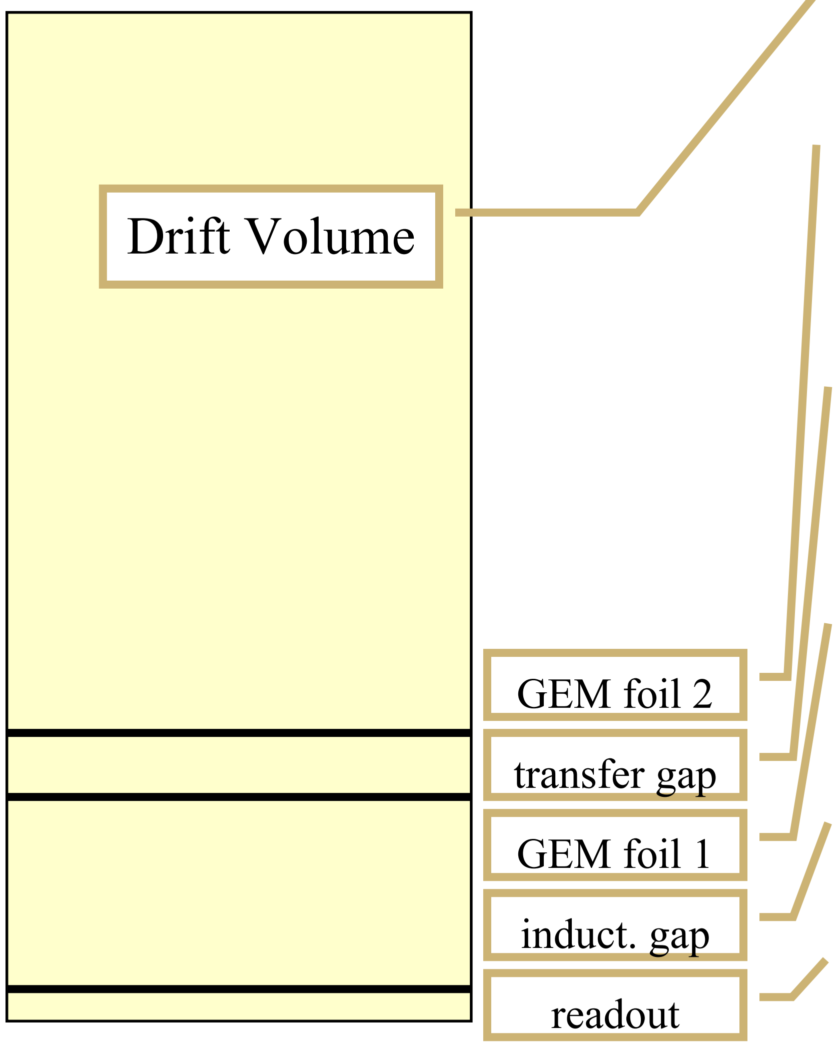
TPC Pad Geometry Study

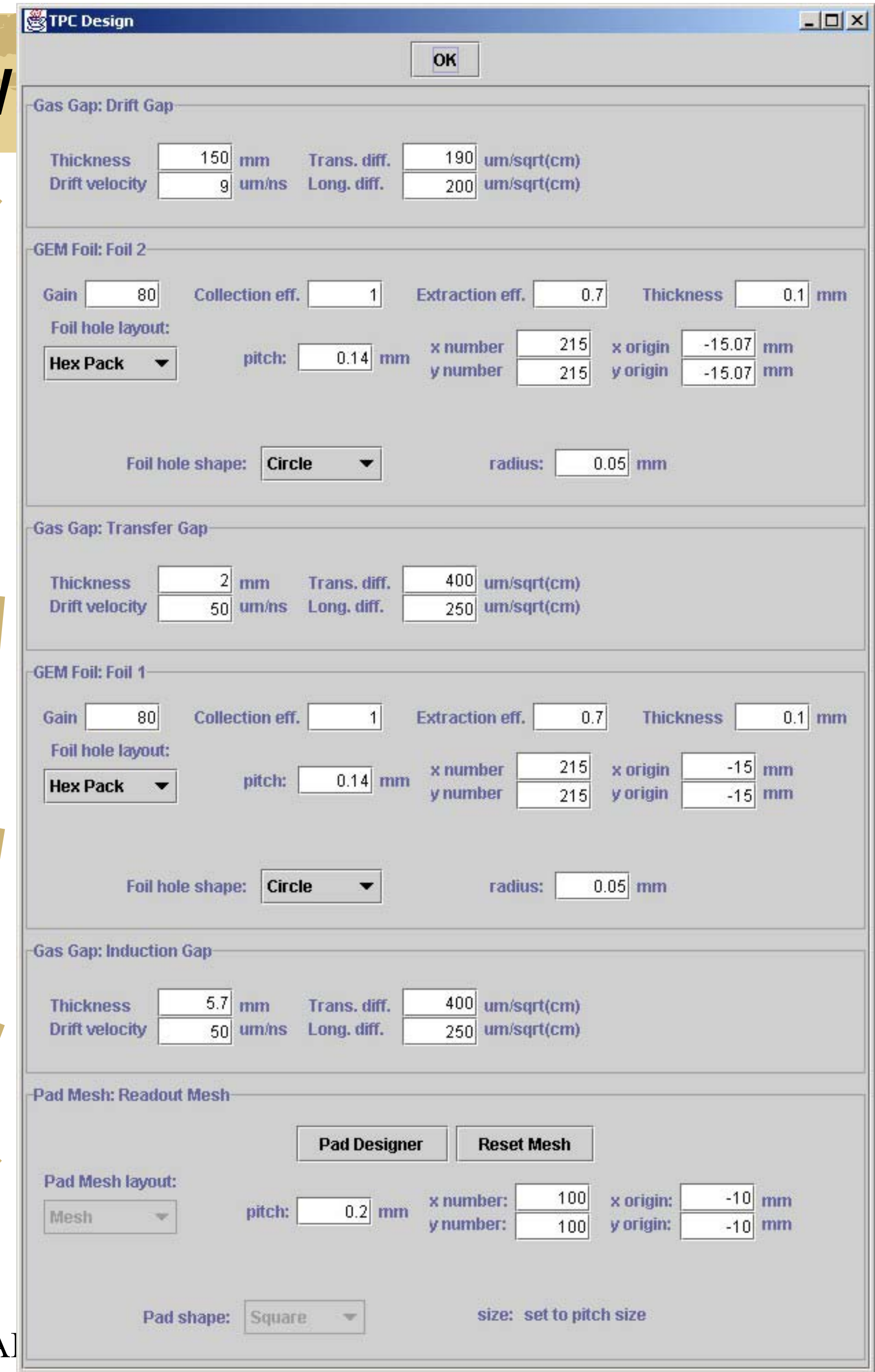
- A study using a java based simulation and analysis package: jTPC
- Outline:
  - How to use jTPC for simulations
  - Track fitting in jTPC
  - Comparisons of pad geometries
    - rectangles vs. chevrons (GEM and MM)
    - rectangular pad width optimization
    - benefit of staggering rectangular pads

Using jTPC: Building a TPC

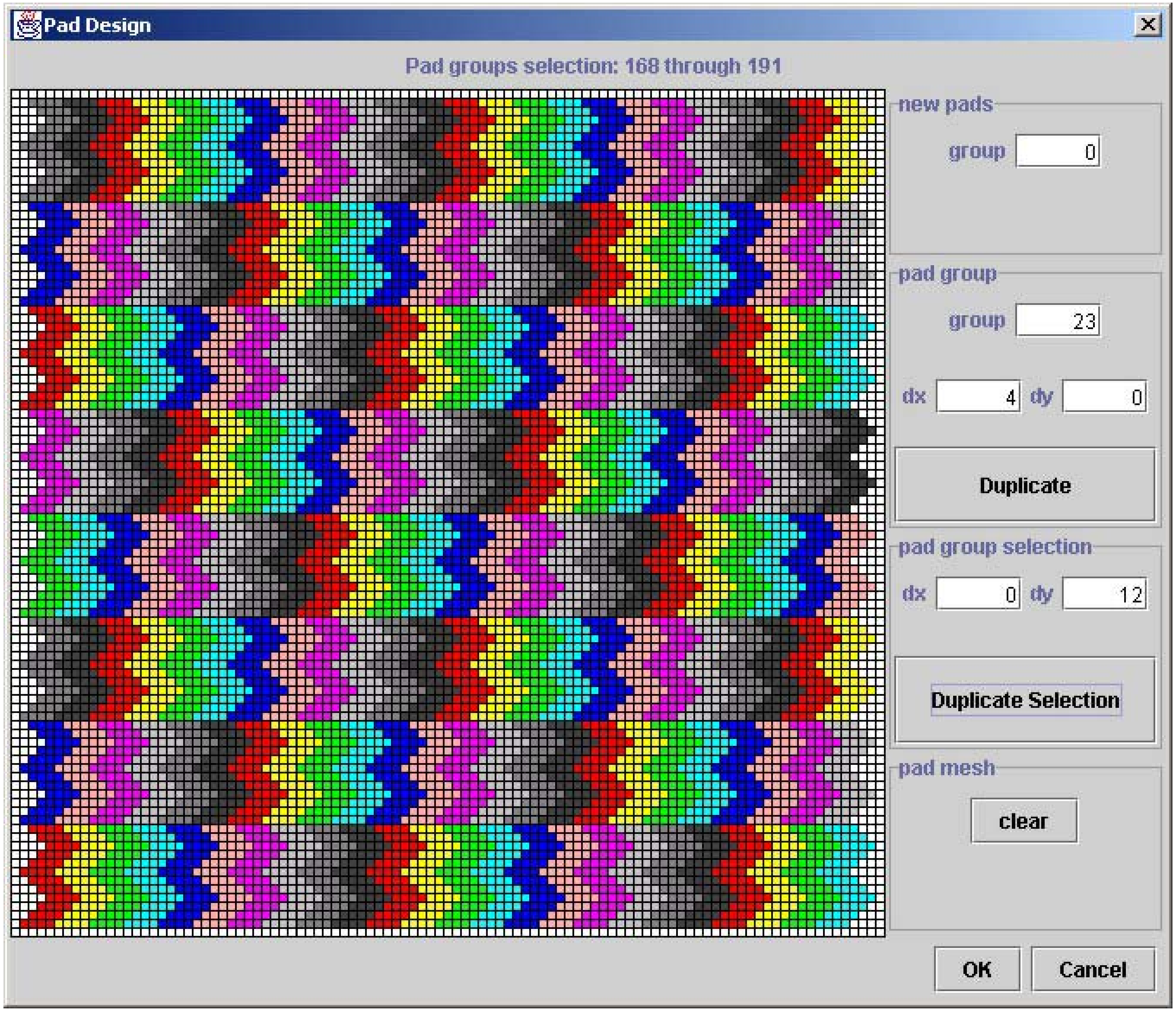
- The TPC is built from a set of TPC parts
  - gas volumes
  - GEM foil amplification stages
  - readout pad structures
- TPC parts have methods to transport electron clouds through them
- The parameters for each TPC part are accessible through a single design window

TPC design window

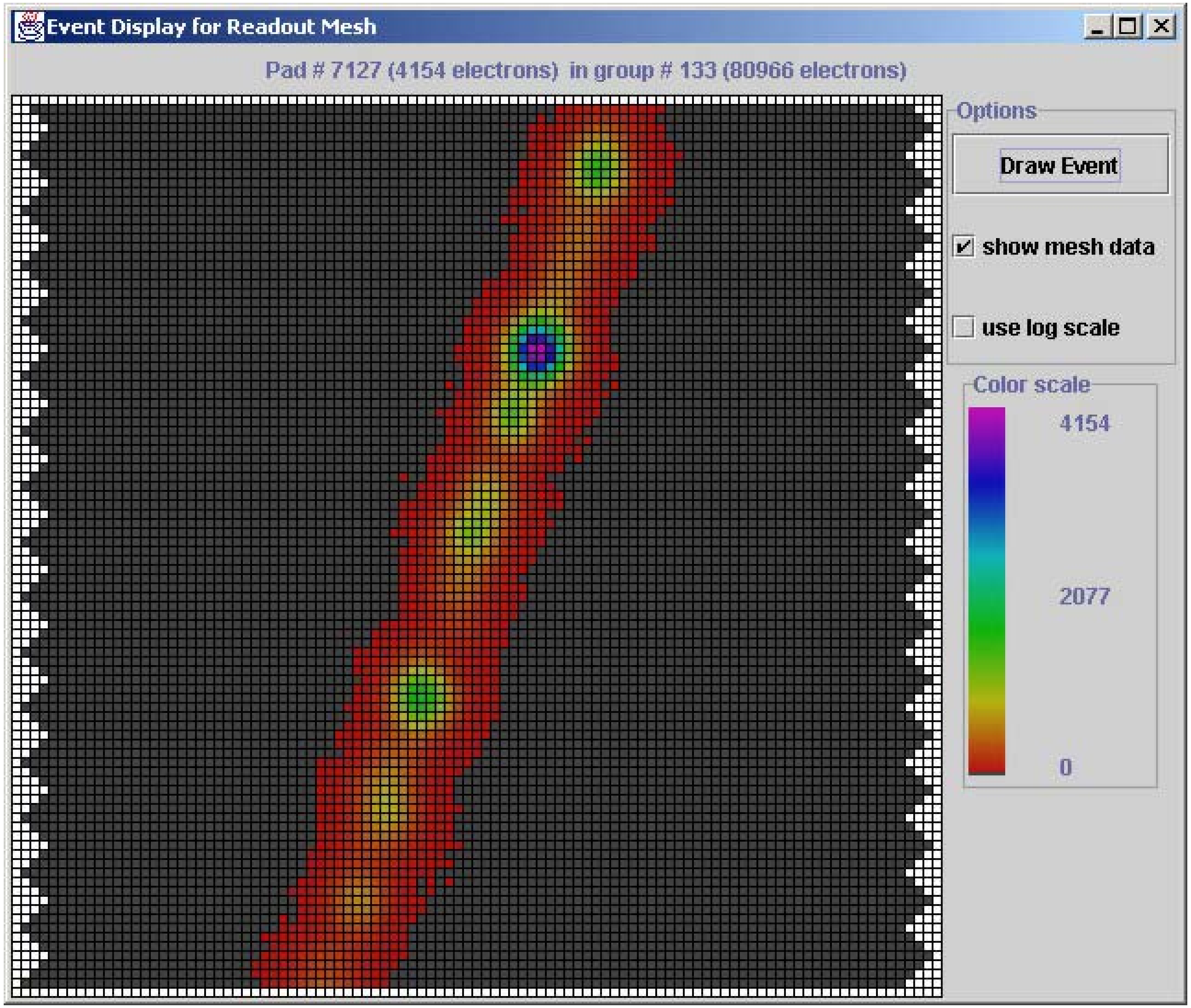




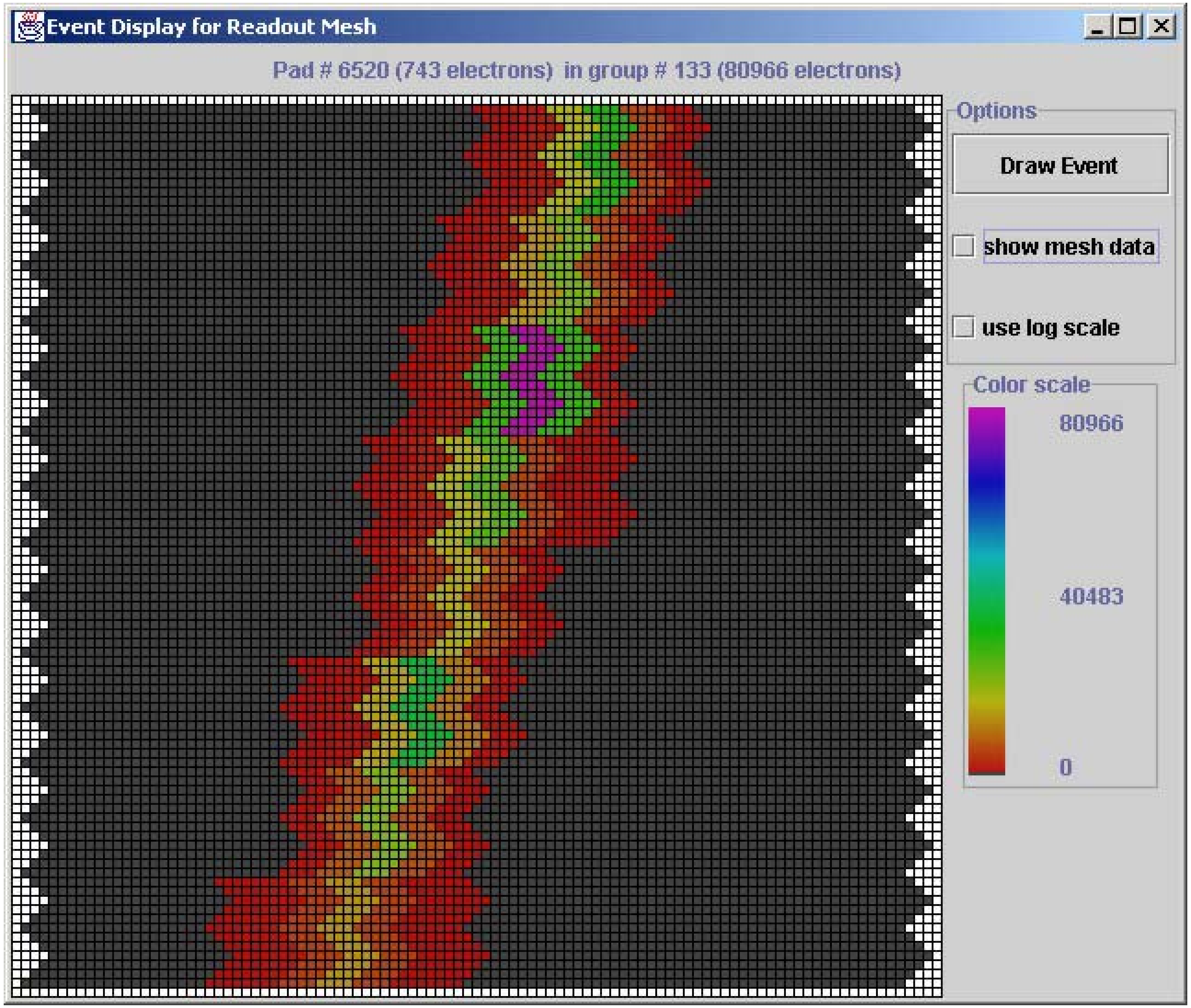
Designing readout pads



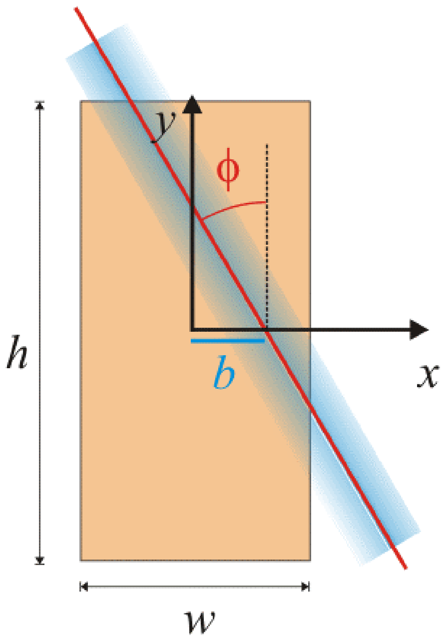
Adding an ionization track



Signals on pads



Track fitting



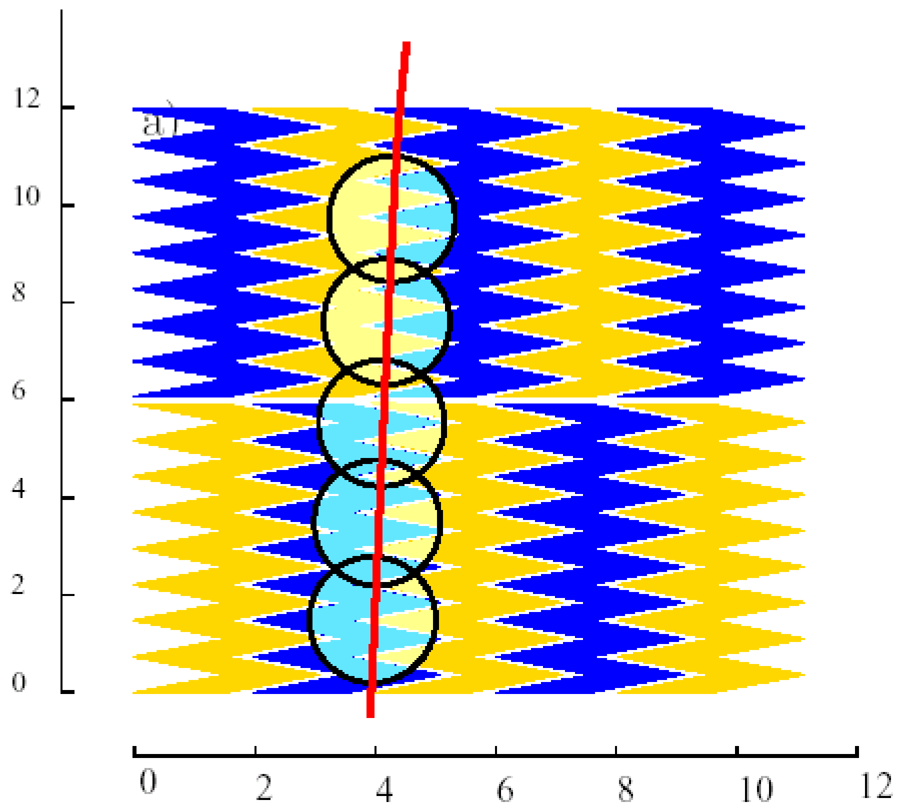
$$I(b,\phi,\sigma,h,w) = \int_{-w/2}^{w/2} dx \int_{-h/2}^{h/2} dy \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{[(x-b)\cos\phi + y\sin\phi]^2}{2\sigma^2}}$$
$$= \eta(b,\phi,\sigma,h,w) - \eta(b,\phi,\sigma,-h,w) + \eta(b,\phi,\sigma,-h,-w) - \eta(b,\phi,\sigma,h,-w)$$

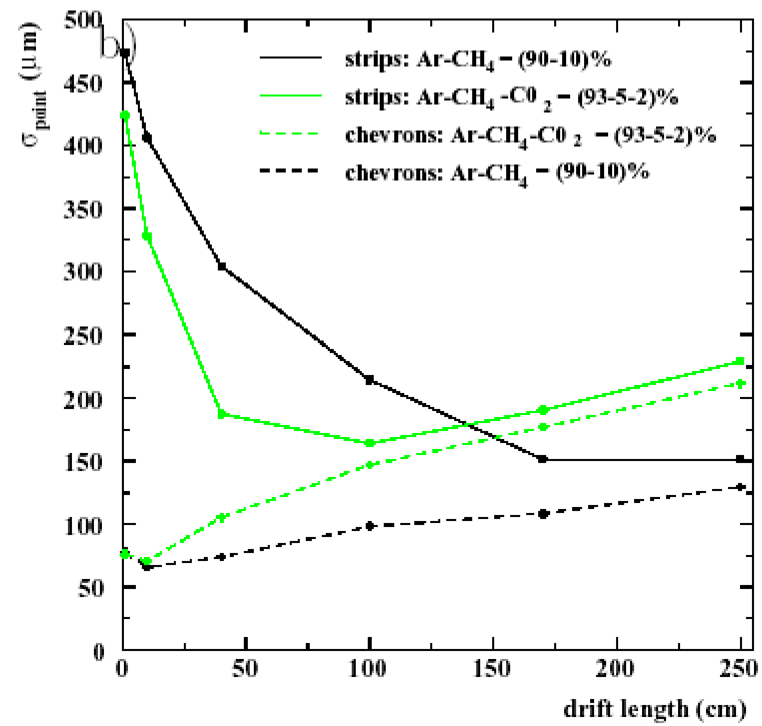
$$\eta(b,\phi,\sigma,h,w) = \frac{1}{\cos\phi \sin\phi} \xi\left((b + \frac{w}{2})\cos\phi + \frac{h}{2}\sin\phi, \sigma \right)$$
$$\xi(u,\sigma) = \frac{u}{2}\mathrm{erf}\left(\frac{u}{\sqrt{2}\sigma}\right) + \frac{\sigma}{\sqrt{2\pi}}\exp\left(\frac{-u^2}{2\sigma^2}\right)$$

- x-y track fit uses a linear Gaussian model for the ionization cloud
  - ie. no fluctuations
- three parameter fit:
  - x_0 (x at y=0)
  - ϕ (azimuthal angle)
  - σ (transverse size of cloud)
- maximize the likelihood of the observed charge fractions from each row

Comparison of GEM pad geometries

From TESLA TDR: advocates chevrons

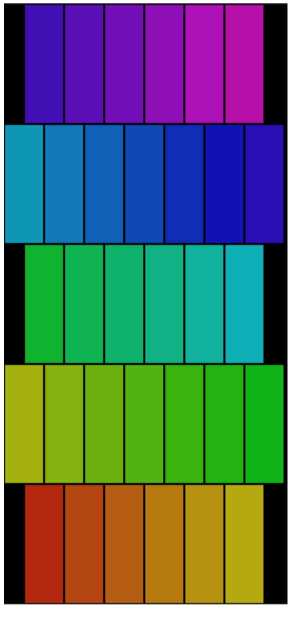




Comparison of Pad Geometries

- Compare rectangular pads with low and high frequency chevrons: including the design proposed in the TESLA TDR
  - 2 x 6 mm^2 pads, 10 spikes per pad, no stagger
- Single track analysis:
  - -2 mm < x < 2mm, -0.1 < ϕ,ψ < 0.1
  - pads sample the same ionization
  - define chevrons on 100 μm mesh
  - use analytic form for rectangles

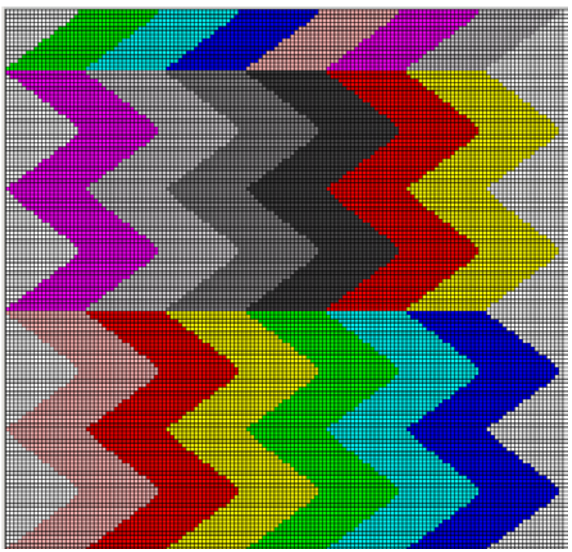
Standard Layout: 5 rows, 2 x 6 mm^2



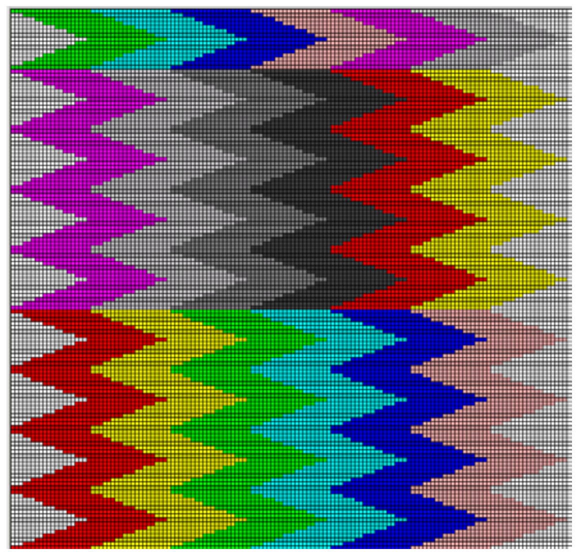
Comparison of Pad Geometries (2)

- Three chevron designs (5 rows 12 mm^2 area)
  - Only lower parts of the 5 row structures shown…

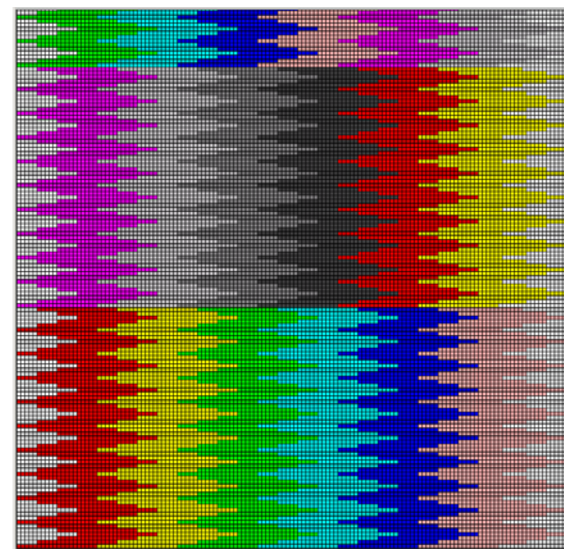
Chevron 2



Chevron 4

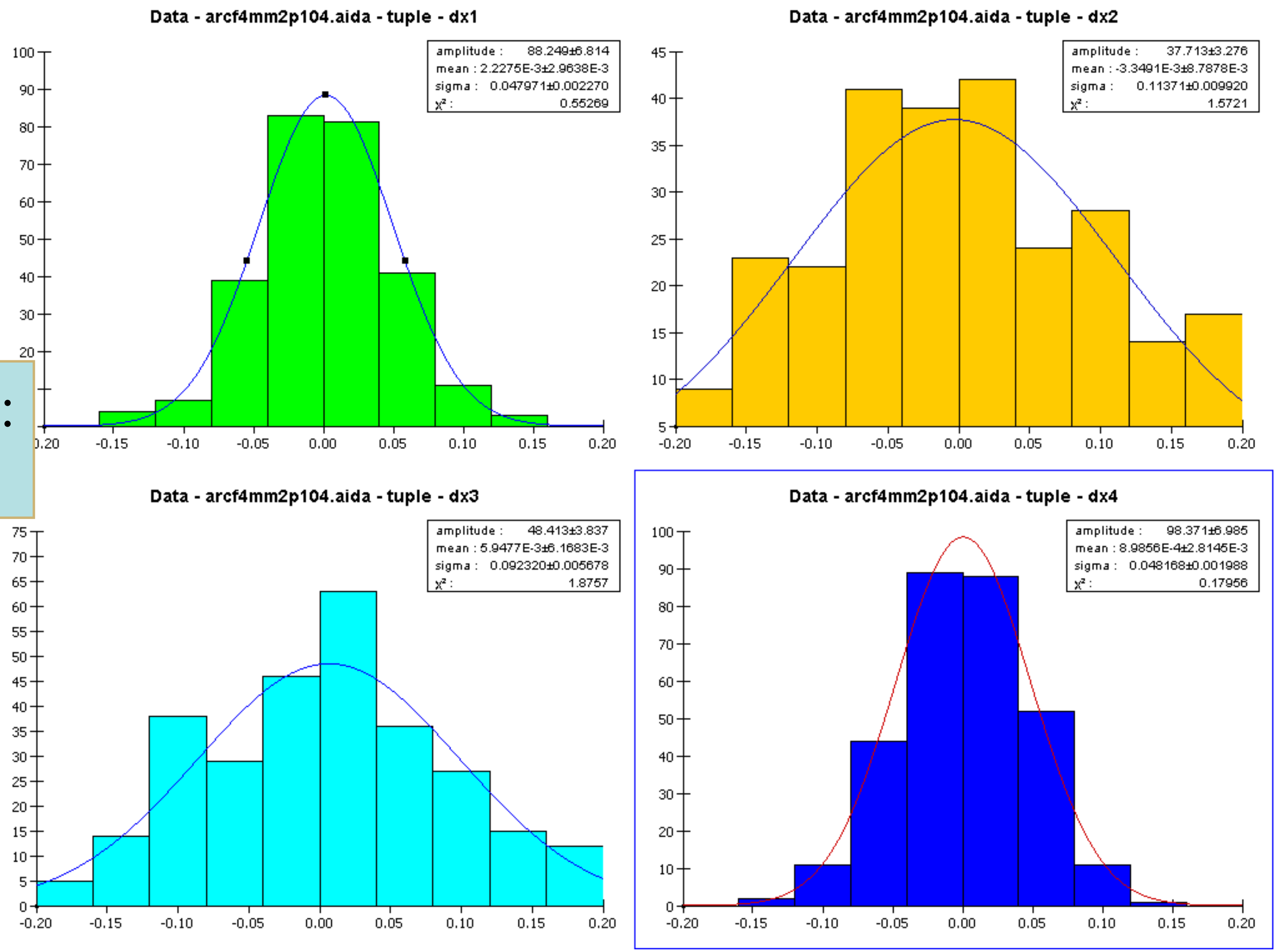


Chevron 10



Geometries defined on a mesh of 100 μm squares

Resolution determination

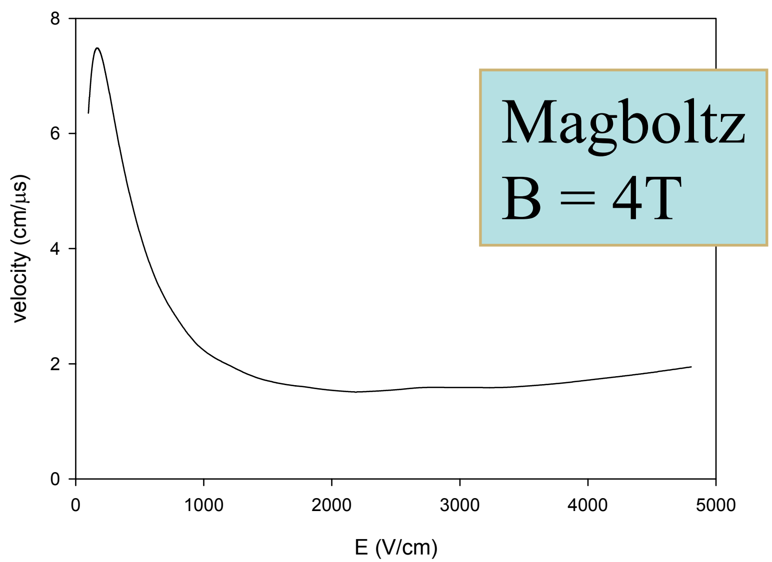


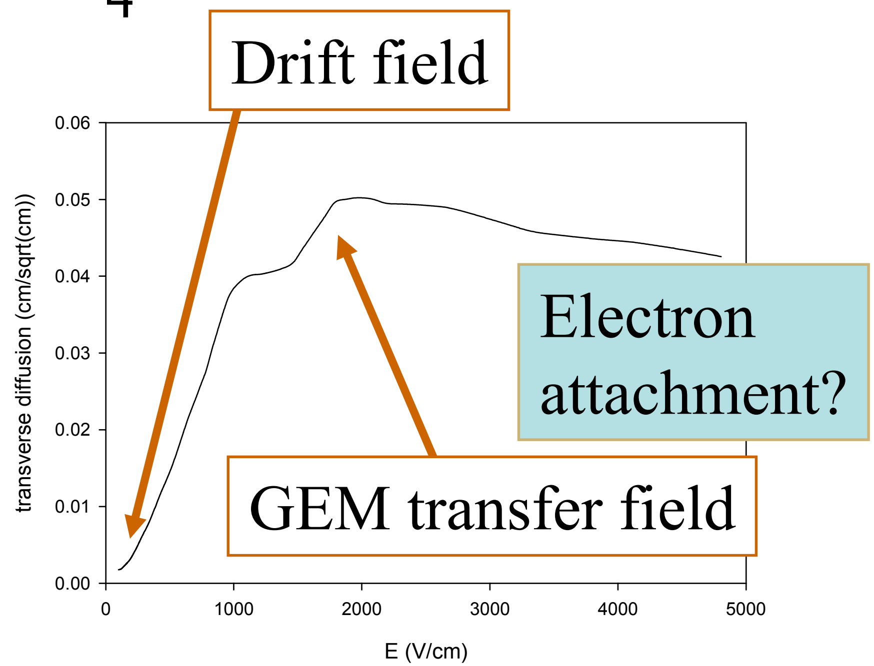
residuals:

$x_{fit} - x_{true}$

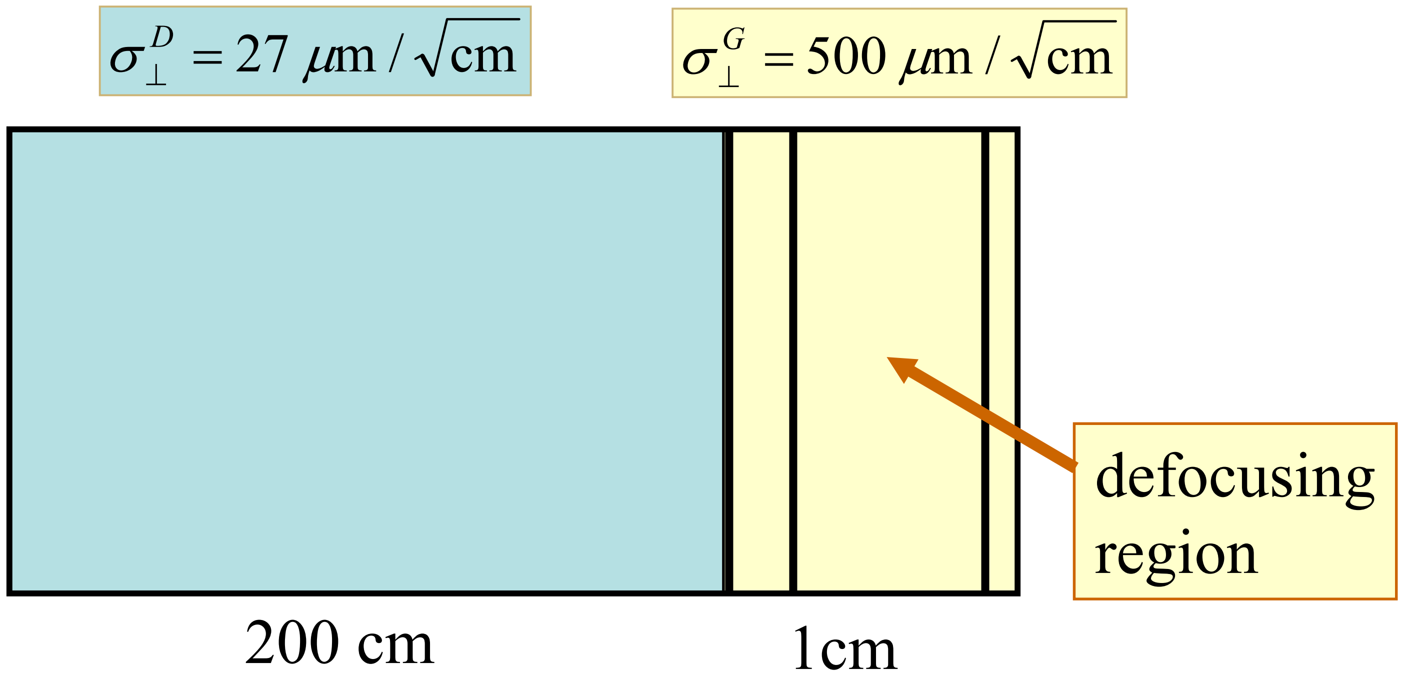
Comparison of GEM pad geometries

- Gas mix considered: Ar CF_4
  - fast at low fields
    - low transverse diffusion in magnetic fields
  - larger diffusion at higher fields
- Example: 98% Ar, 2% CF_4





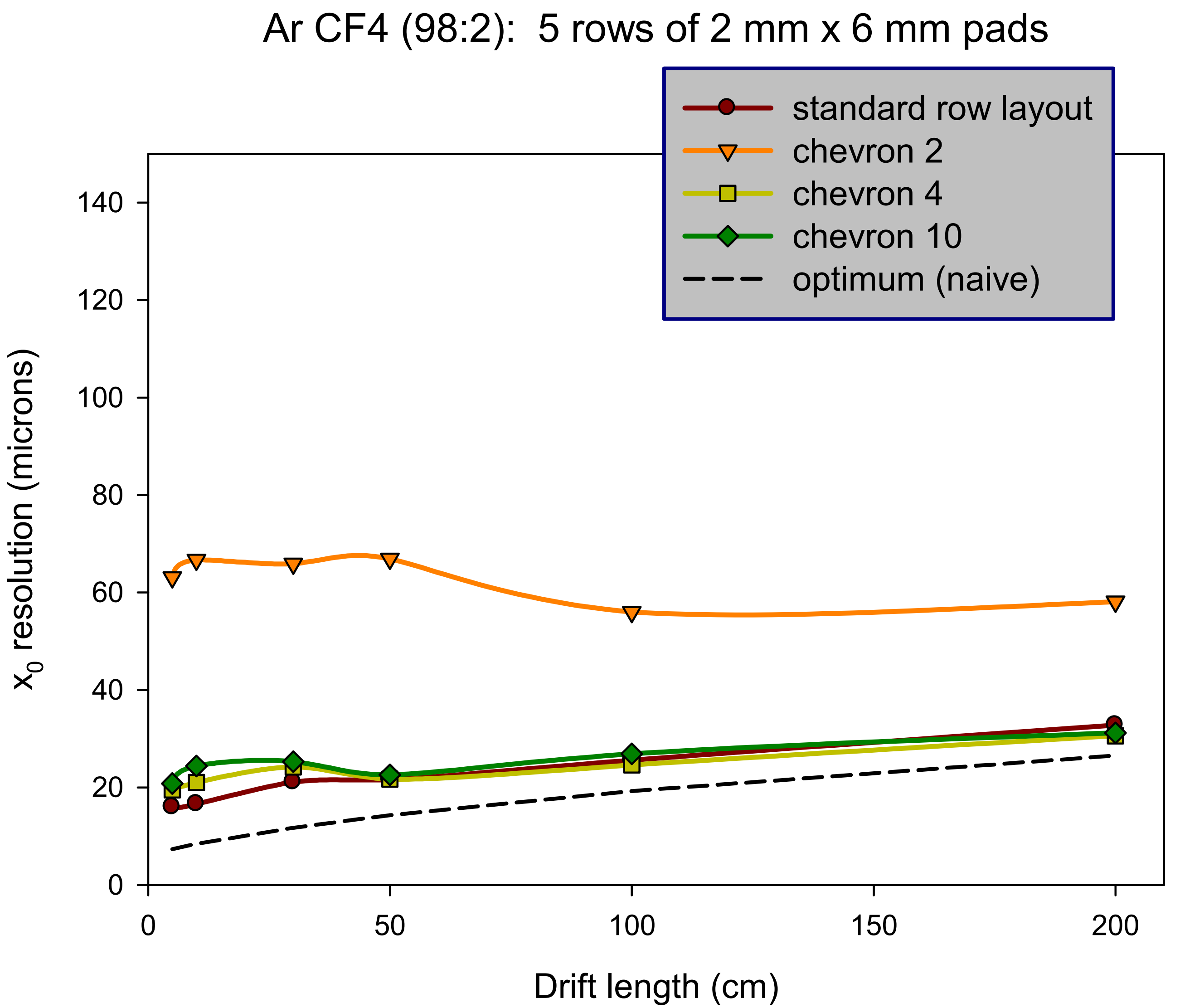
GEM TPC



- Naïve calculation for optimum resolution:

$$\delta x = \frac{\sigma_\perp^D \sqrt{\ell\,[\text{cm}]}}{\sqrt{N_{\text{primary}}}} = \frac{27\,\mu\text{m}\,\sqrt{200}}{\sqrt{30\ \text{mm} \times 9\ \text{e}/\text{mm}}} = 23\,\mu\text{m}$$

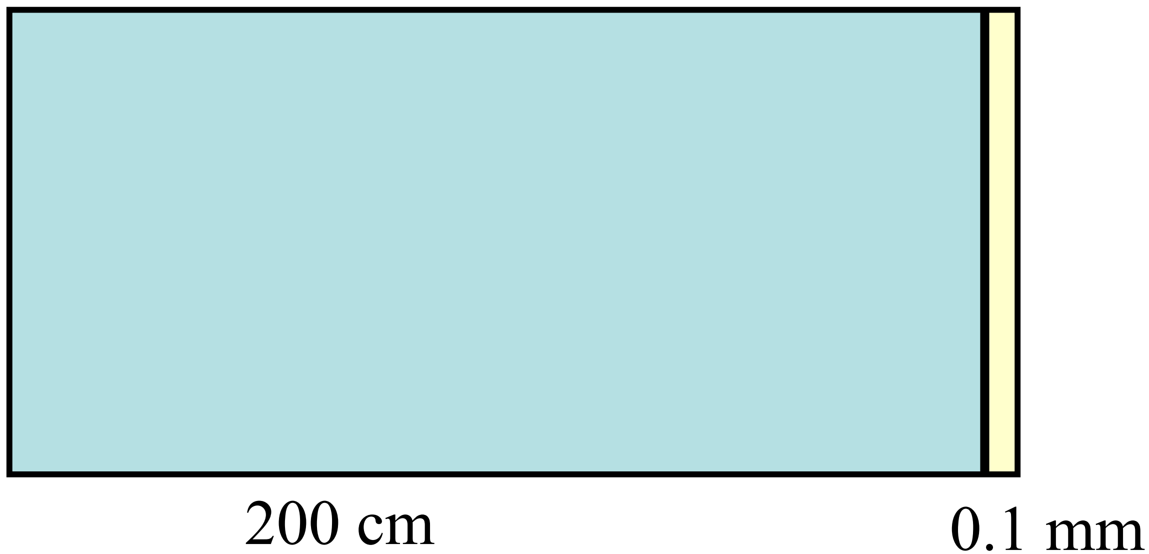
Comparison of GEM pad geometries



Chevrons unnecessary in Ar CF_4 GEM TPC

Micromegas TPC without defocusing

$$\sigma_{\perp}^{D} = 27\ \mu\text{m} / \sqrt{\text{cm}}$$



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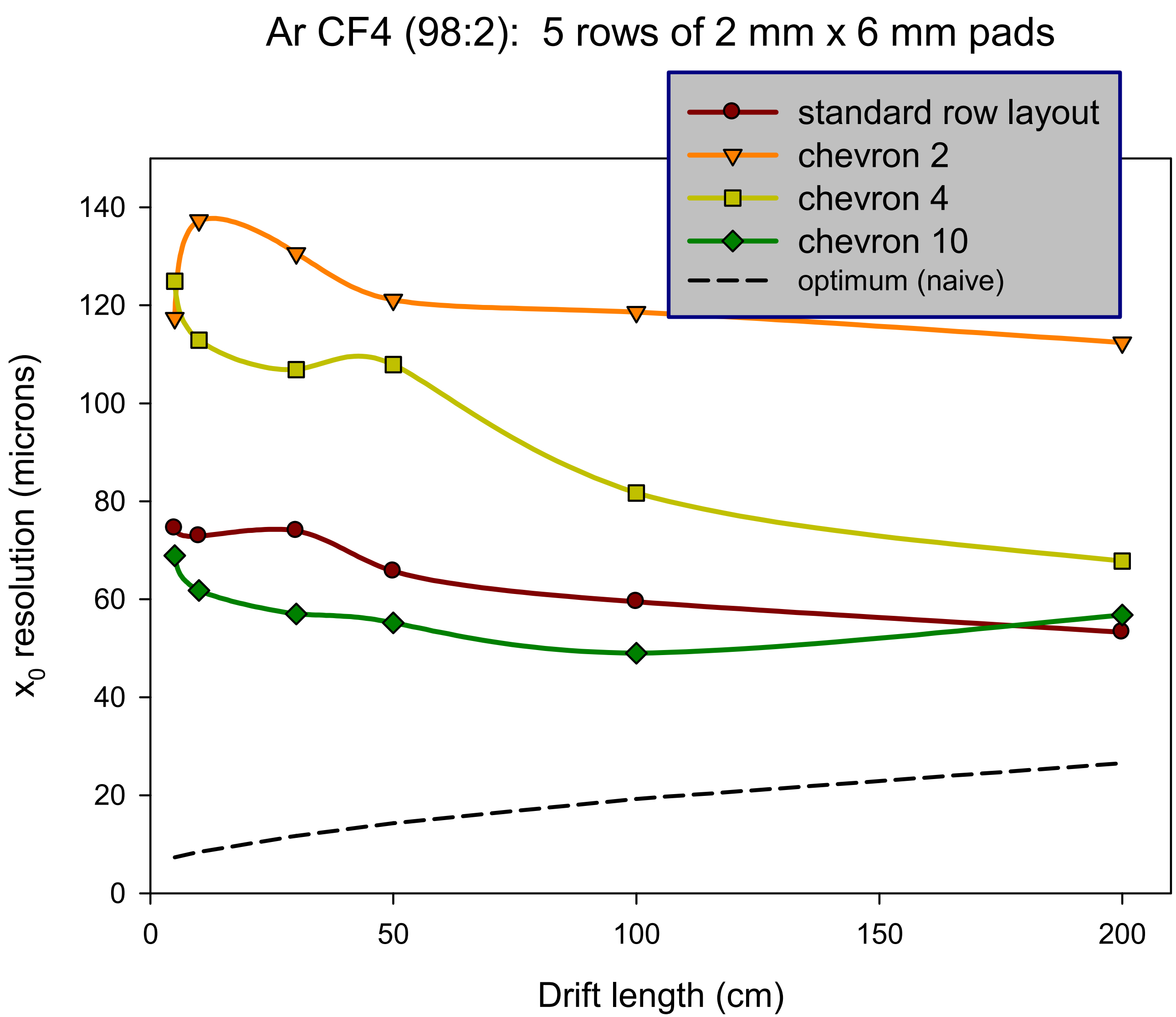
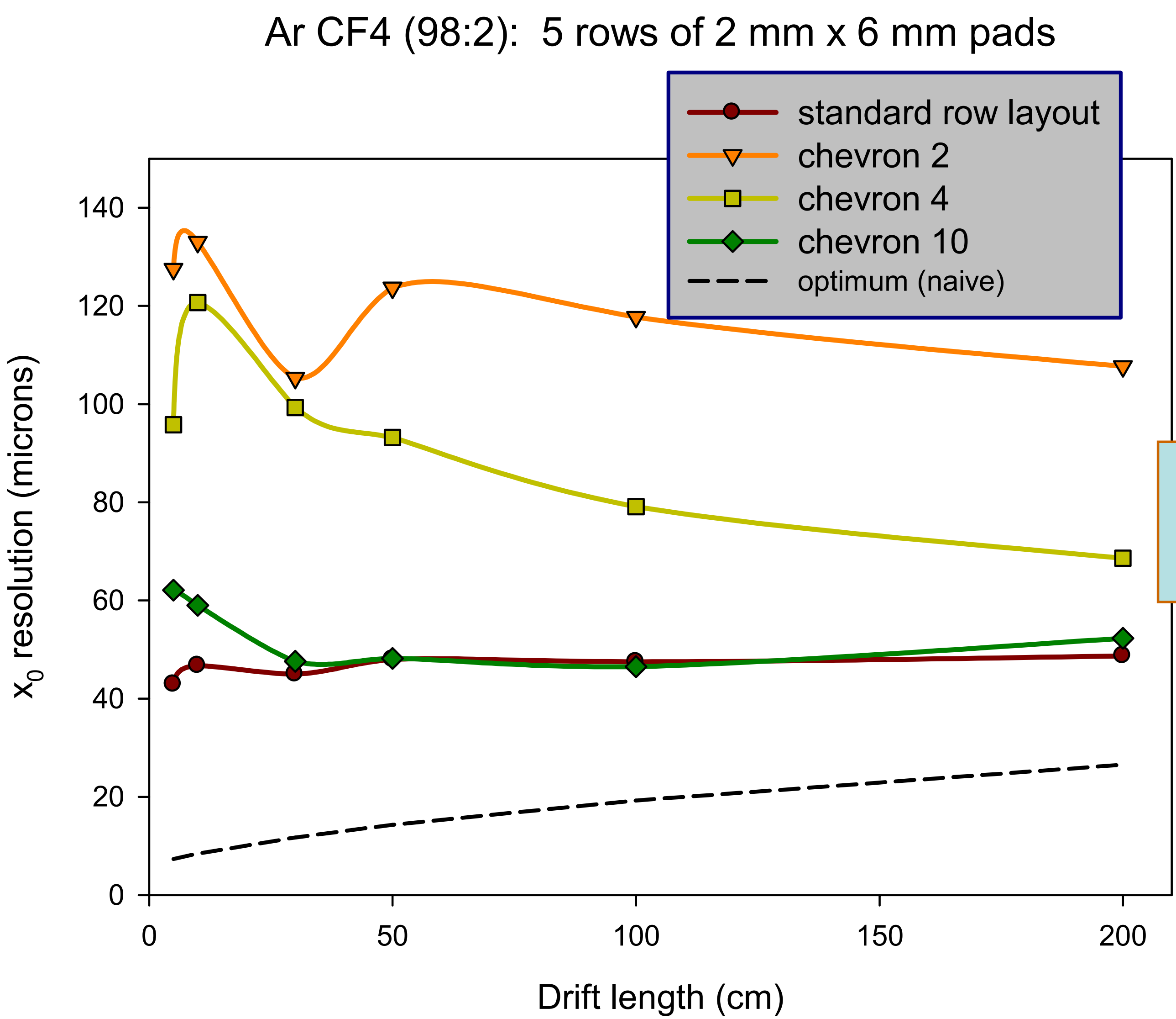
Comparison of pads for Micromegas



Defocusing required for micromegas

Comparison of pads for Micromegas



2 parameter fit:
(σ fixed)

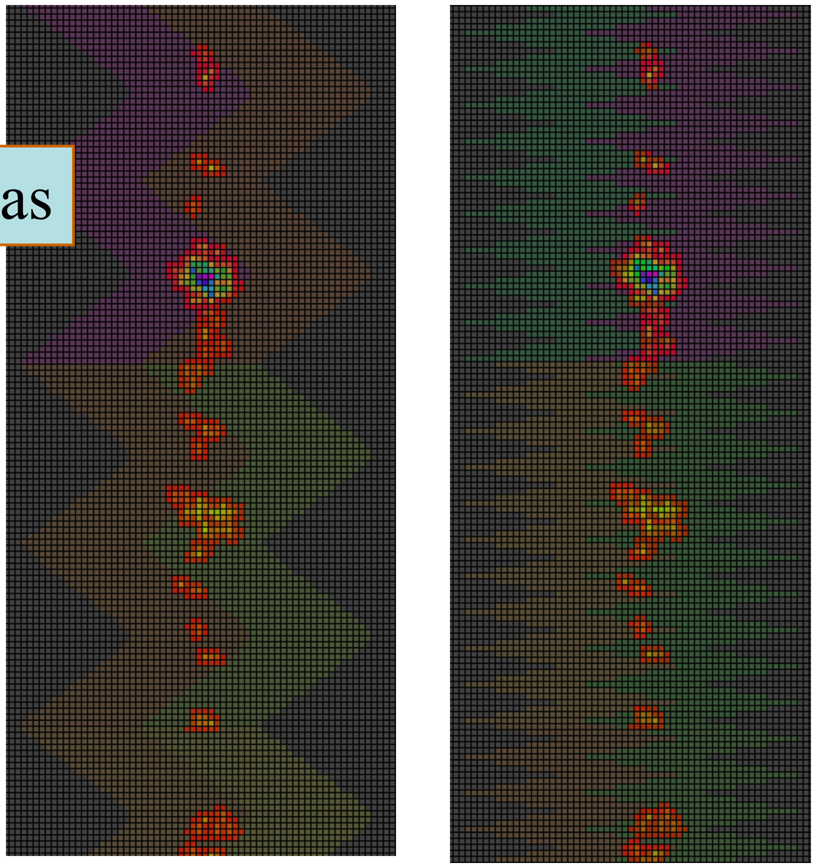
same conclusions

Chevrons and defocusing

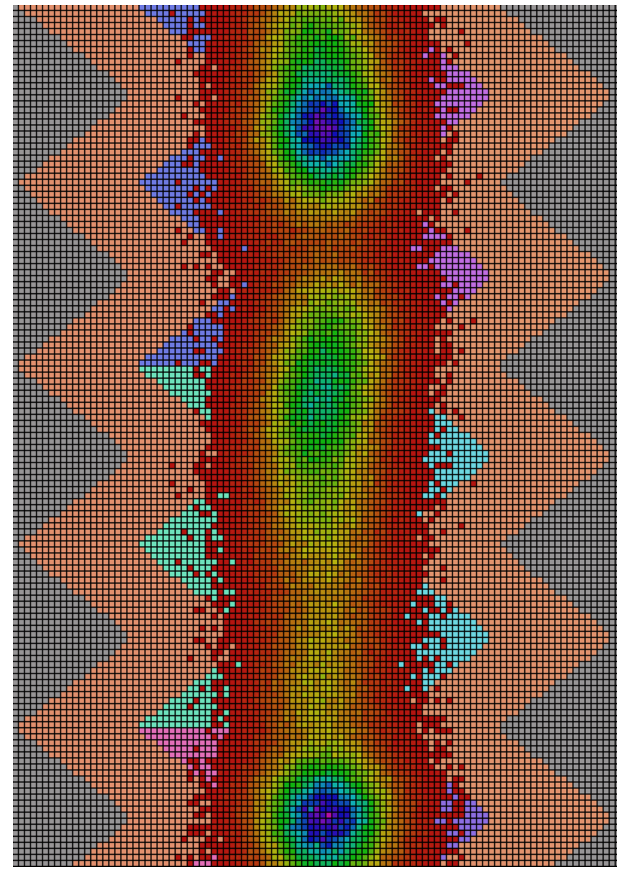
- 30 cm drift in $ArCF_4$

an event with no defocusing

bias



an event in GEM TPC

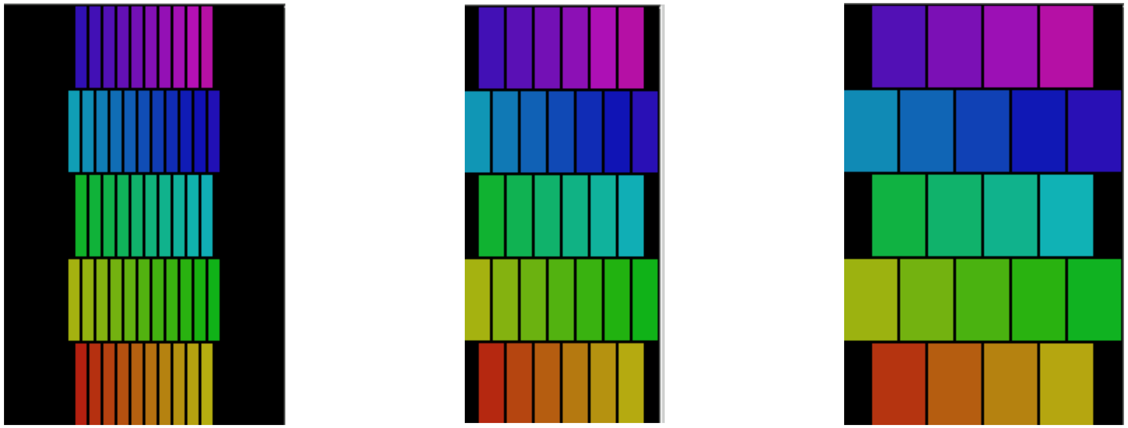


Summary of geometry comparison

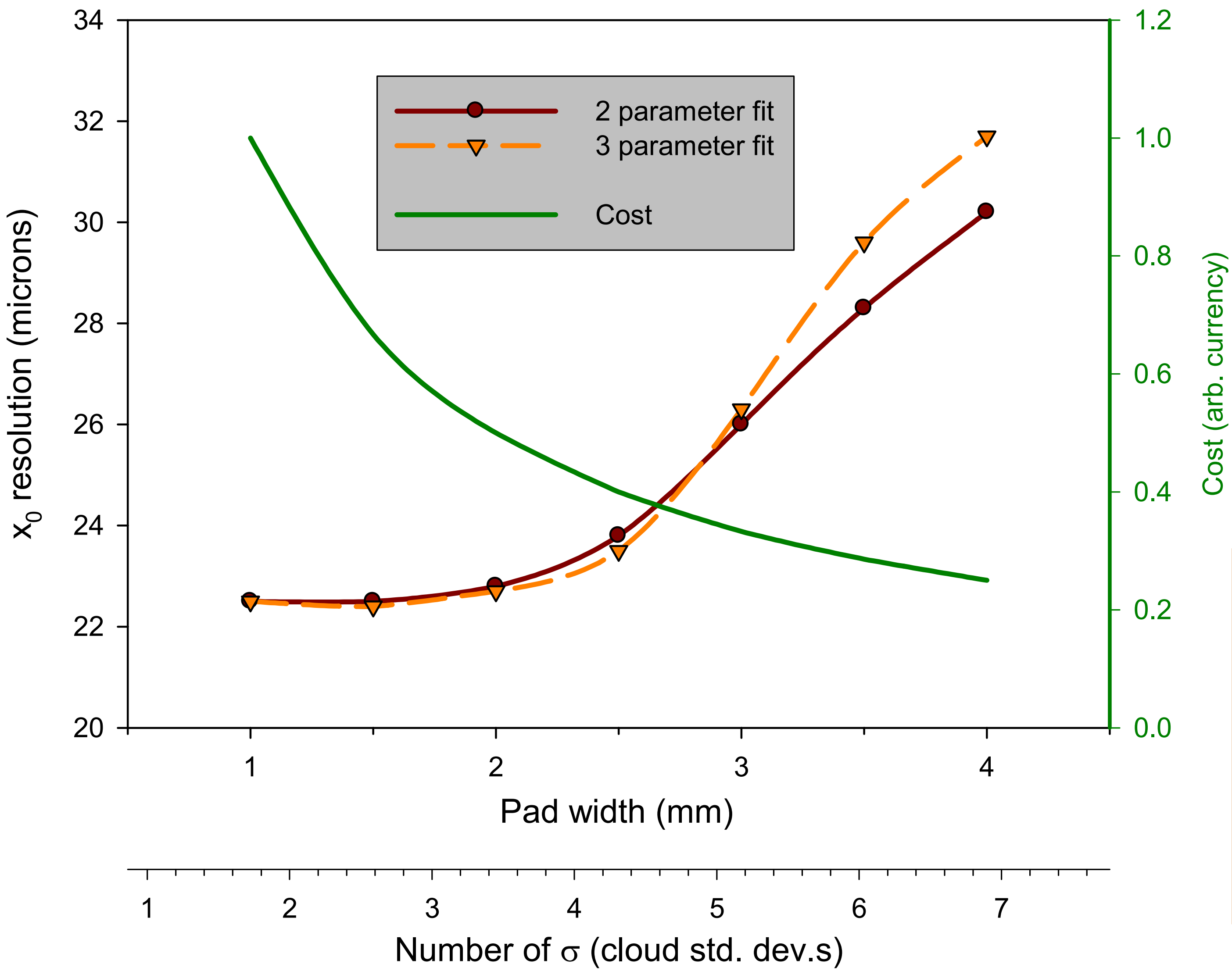
- Rectangular pads give as good resolution as the chevrons considered.
  - true for two extremes: with/without defocusing
- Defocusing (after gain stage) is essential to achieve the optimum resolution.
  - Defocusing provided by the transfer gaps in the GEM appears to be sufficient
  - A micromegas design without defocusing has poorer resolution – various solutions to provide defocusing are under consideration
  - Chevrons do not appear to be a solution for the micromegas design

Optimum pad width

- To reduce channel count, need pads as wide as possible, without degrading resolution
  - degrades when pad width >> cloud width
- Compare resolution for $ArCF_4$ (98:2) GEM TPC with different pad widths
  - 50 cm drift: std. dev. of cloud on pads is 0.58 mm
  - consider various pad widths: 1 mm – 4 mm



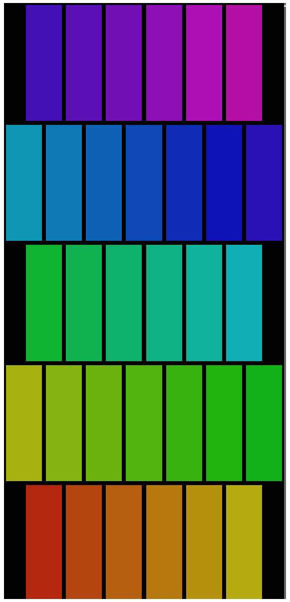
Comparison of pad widths



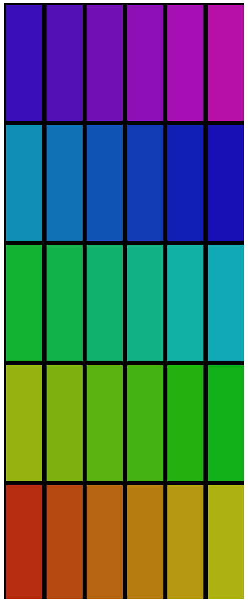
The optimal pad width will also depend on the signal to noise ratio: need to include noise in the simulation.

Staggering possibilities

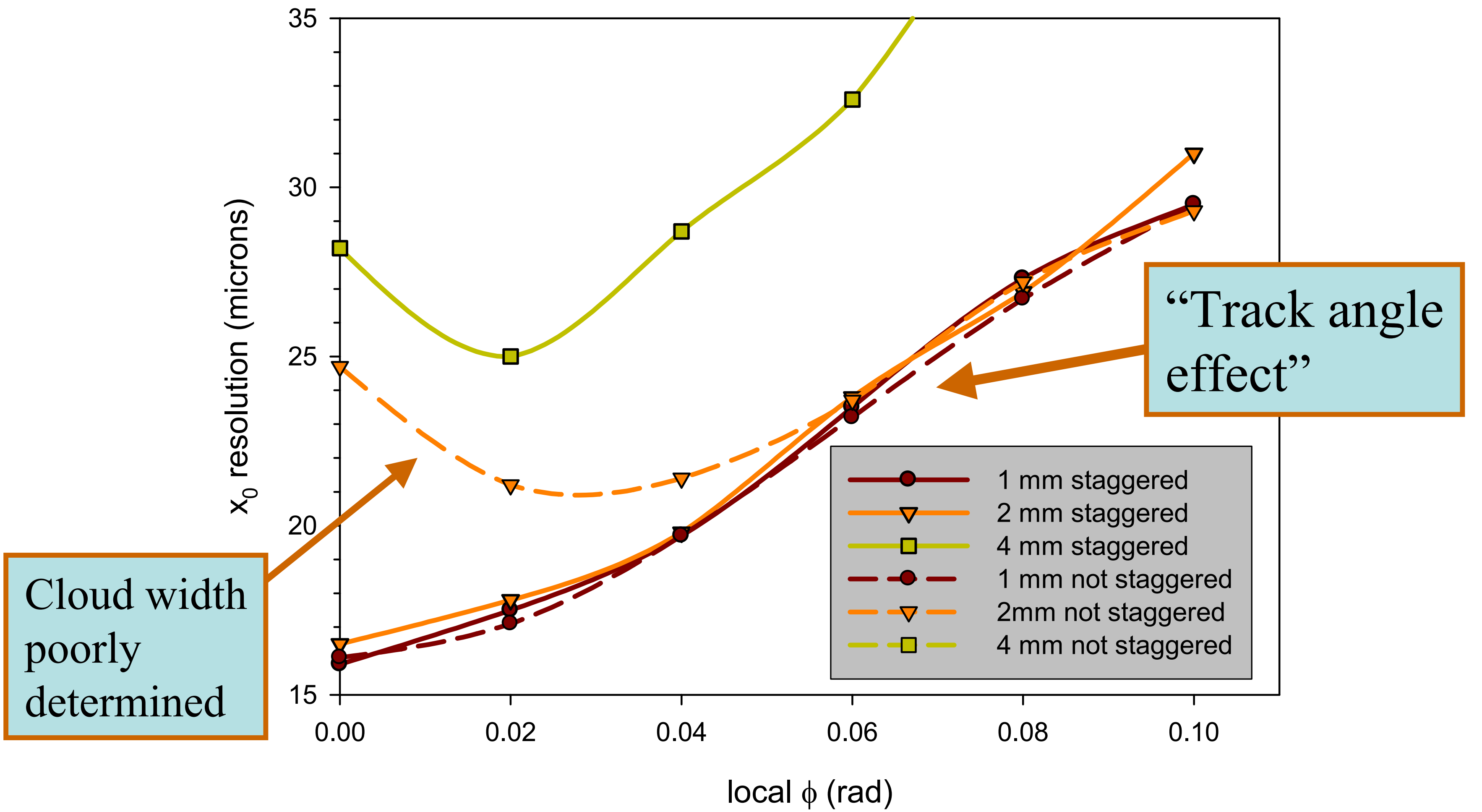
- Compare staggered and non-staggered layouts, for different local ϕ:
  - 50 cm drift: std. dev. of cloud on pads is 0.58 mm
  - consider pad widths: 1, 2, and 4 mm



vs.

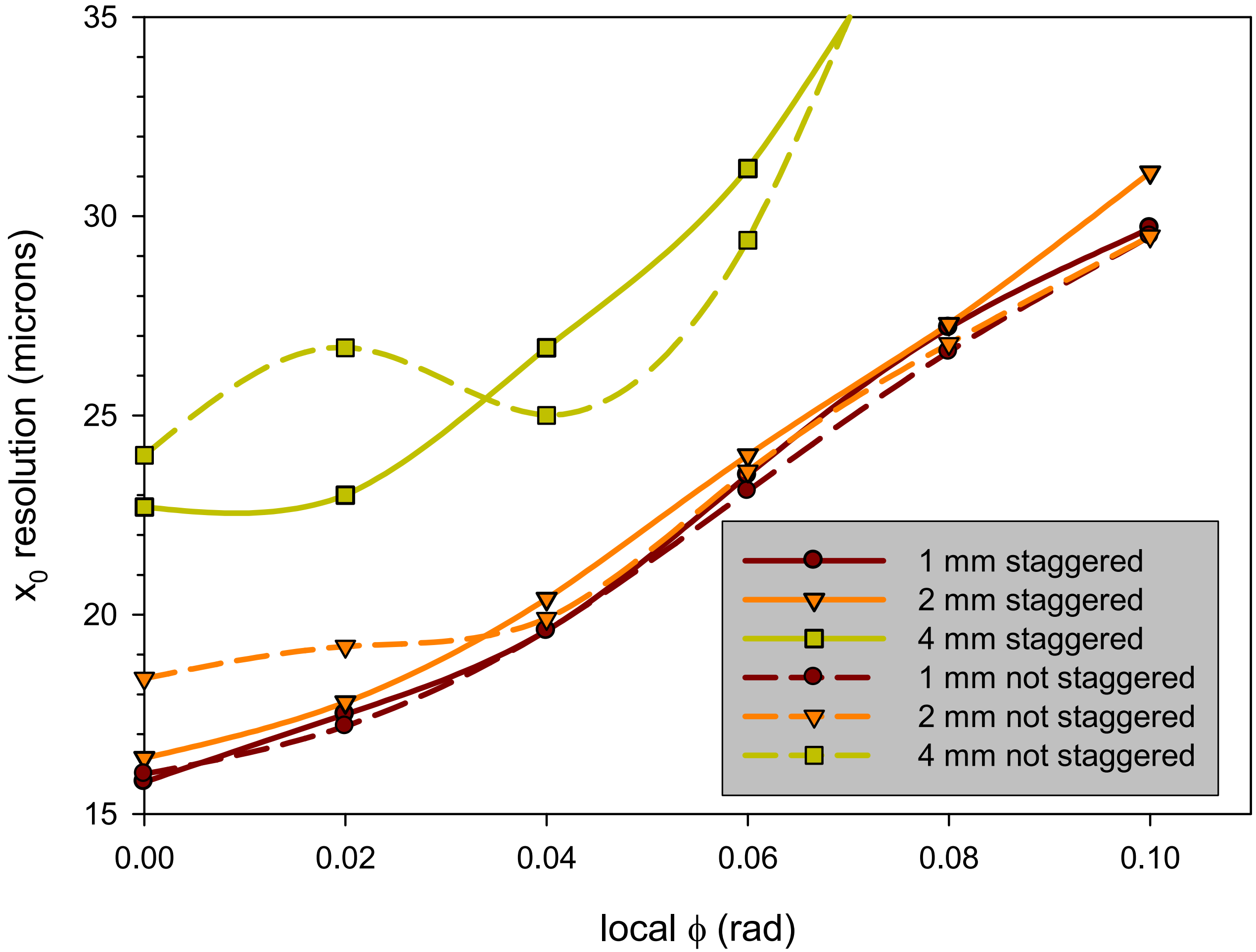


Staggering comparison (3 par. track fit)



Staggering comparison (2 par. track fit)

cloud width fixed to 0.58 mm



Conclusions

- The results of this study differ significantly from those presented in the TESLA TDR
  - at least one is probably wrong!
  - need a careful comparison with the TDR analysis to understand where the difference comes from…
- This analysis suggests that rectangular pads provide good resolution and that pads should be no wider than ~3-4 times the cloud σ
- Staggering helps for wide pads

To download the jTPC program, visit:
http://www.physics.carleton.ca/~karlen/gem