Simulation of the ILD TPC with pixel readout

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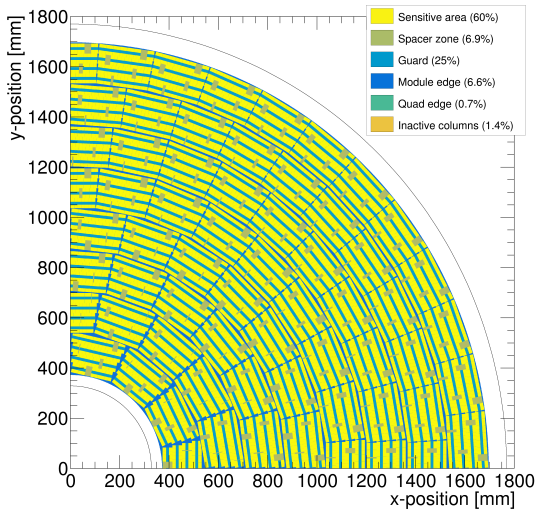
Introduction

In order to study the tracking performance of a large pixelised TPC, the pixel readout was implemented in the full ILD DD4HEP (Geant4) simulation

Pixel readout simulation was build upon the pad readout simulation in ILCSoft version 02-01

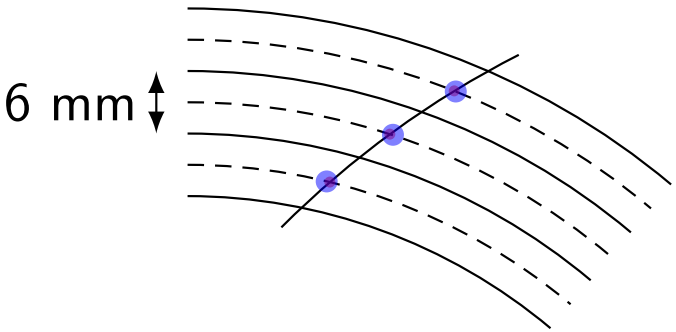


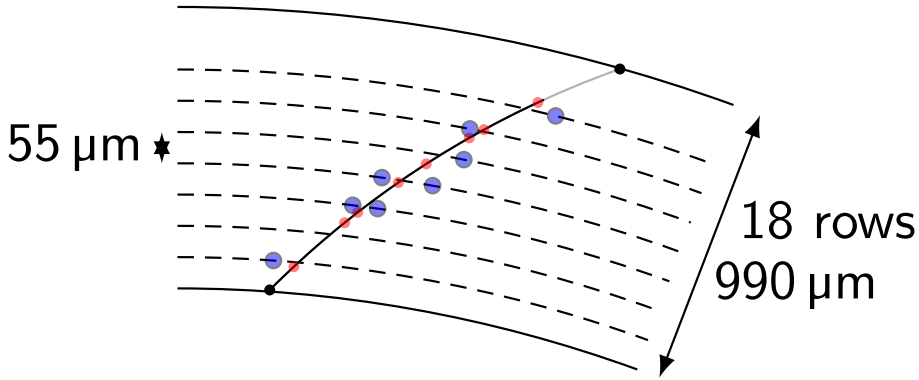
Tiling of the ILD TPC with a quad module

Outline

- Summary of pad and pixel TPC simulations (see also last year's presentation)
- Changes since last year

Simulation of pad hits compared to pixel hits





Pad hits	Pixel hits
6 mm × 1 mm	55 µm × 55 µm
Exactly one hit per layer	Multiple or no hits per layer
22 electrons per hit	1 electron per hit
Only diffusion in $r\phi$ and z	Diffusion in x, y and z
∼200 hits per track	∼10 000 hits per track

Diffusion and hit resolution for pads and pixels

As found in the latest code of DDTPCDigiProcessor

Diffusion and hit resolution are simulated by smearing the hits by the expected resolution

$$\sigma_{r\phi}^{\text{pads}} = \sqrt{\sigma_{r\phi 0}^2 + \sigma_{\phi 0}^2 \sin^2(\phi_{\text{pad}}) + \frac{D_{r\phi}^2}{N_{\text{Eff}}} \sin(\theta_{\text{pad}}) \left(\frac{6\ \text{mm}}{h_{\text{pad}}}\right) \left(\frac{4.0\ \text{T}}{B}\right)^2 L}$$

$$\sigma_{r\phi}^{\text{pixels}} = \sqrt{\sigma_{r\phi 0}^2 + D_{r\phi}^2 \left(\frac{4.0\ \text{T}}{B}\right)^2 L}$$

$$\sigma_z = \sqrt{\sigma_{z0}^2 + D_z^2 L}$$

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	Pads	Pixels
$\sigma_{r\phi 0}$	0.05 mm	0.016 mm
σ_{z0}	0.4 mm	0.17 mm
$\sigma_{\phi 0}$	0.9 mm	
$D_{r\phi}$	0.025 mm/$\sqrt{\text{cm}}$	0.025 mm/$\sqrt{\text{cm}}$
D_z	0.08 mm/$\sqrt{\text{cm}}$	0.226 mm/$\sqrt{\text{cm}}$
N_{Eff}	22	

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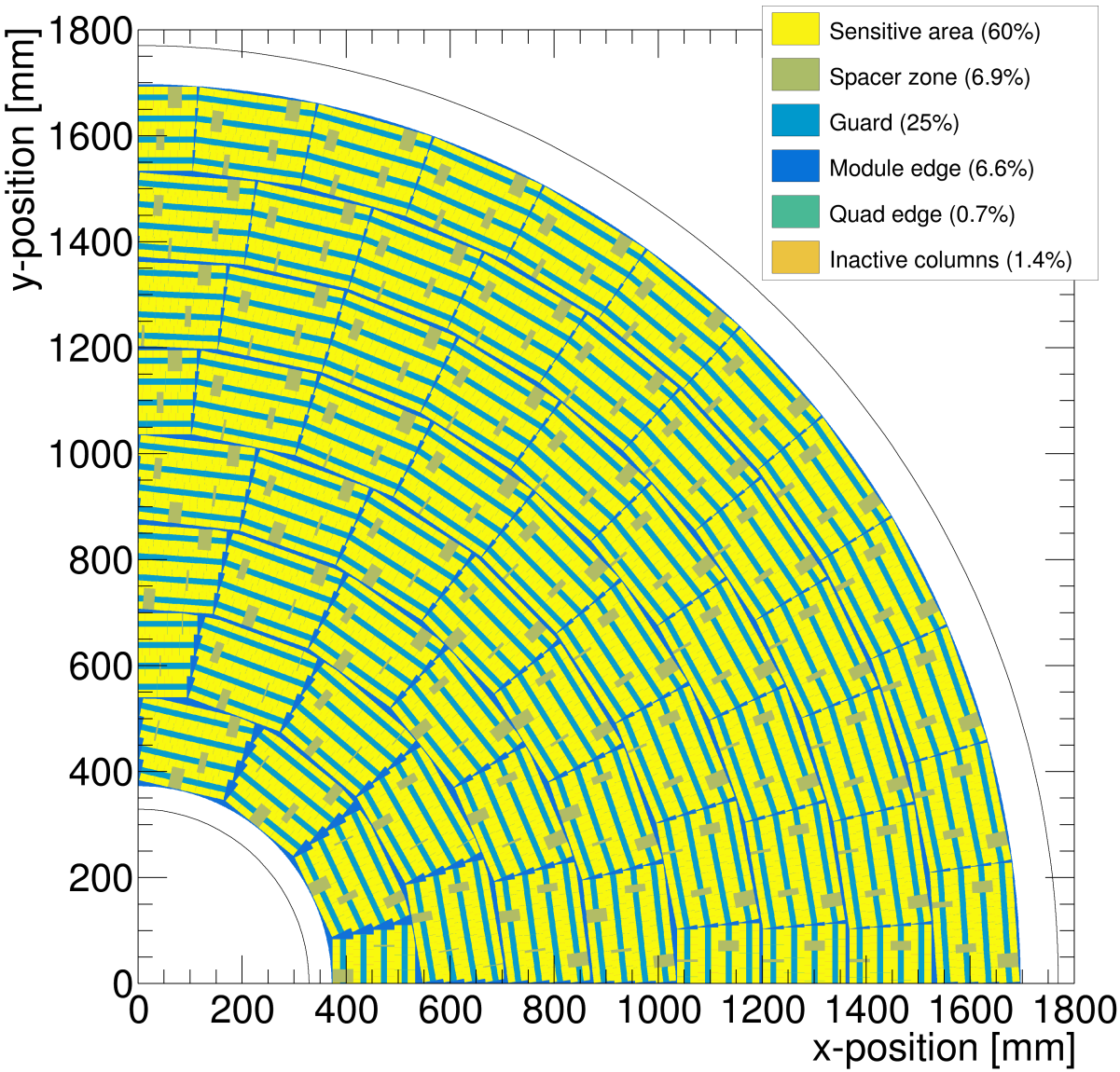
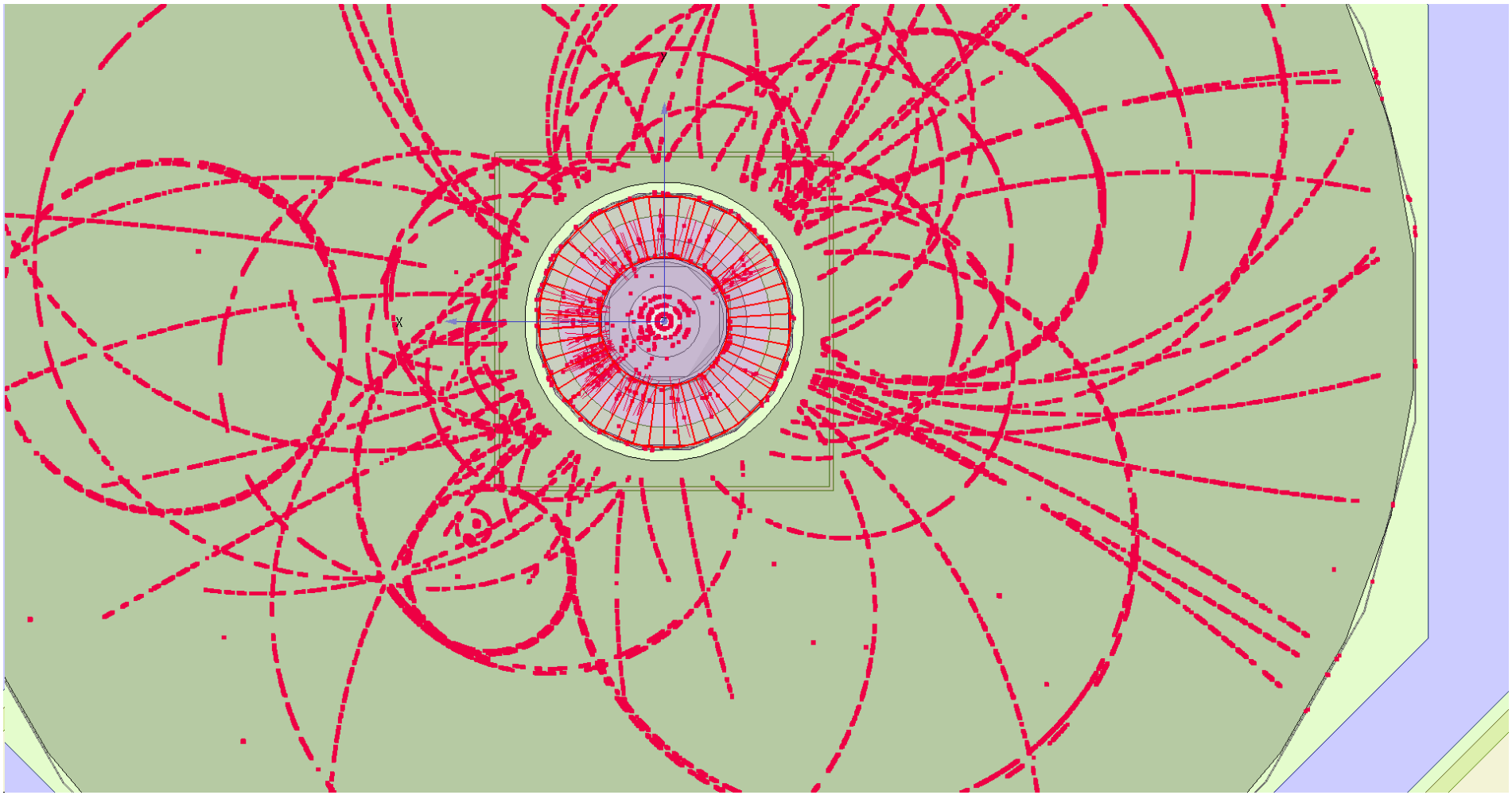
Tiling of ILD end plate with GridPix quads



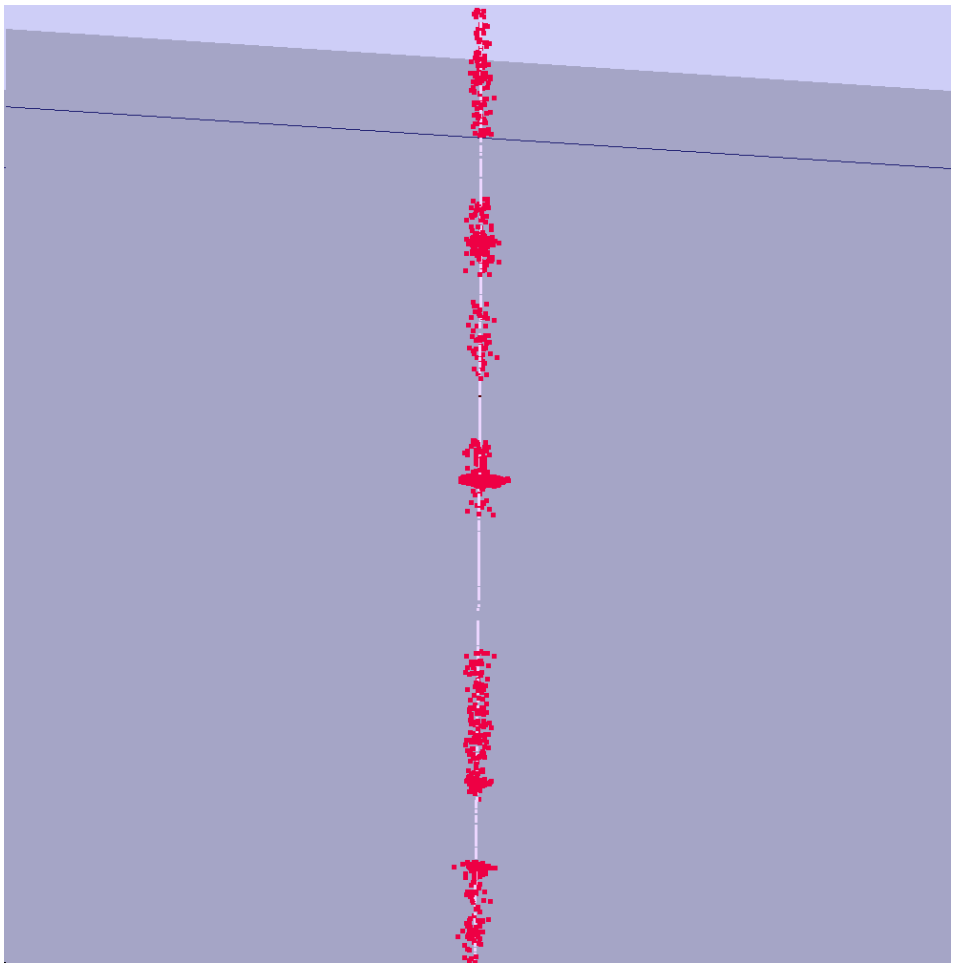
ILD end plate mask in simulation



Delta hit removal

Before removal

Remove hits if local density is more than 100 per $1.5^2 mm^2$

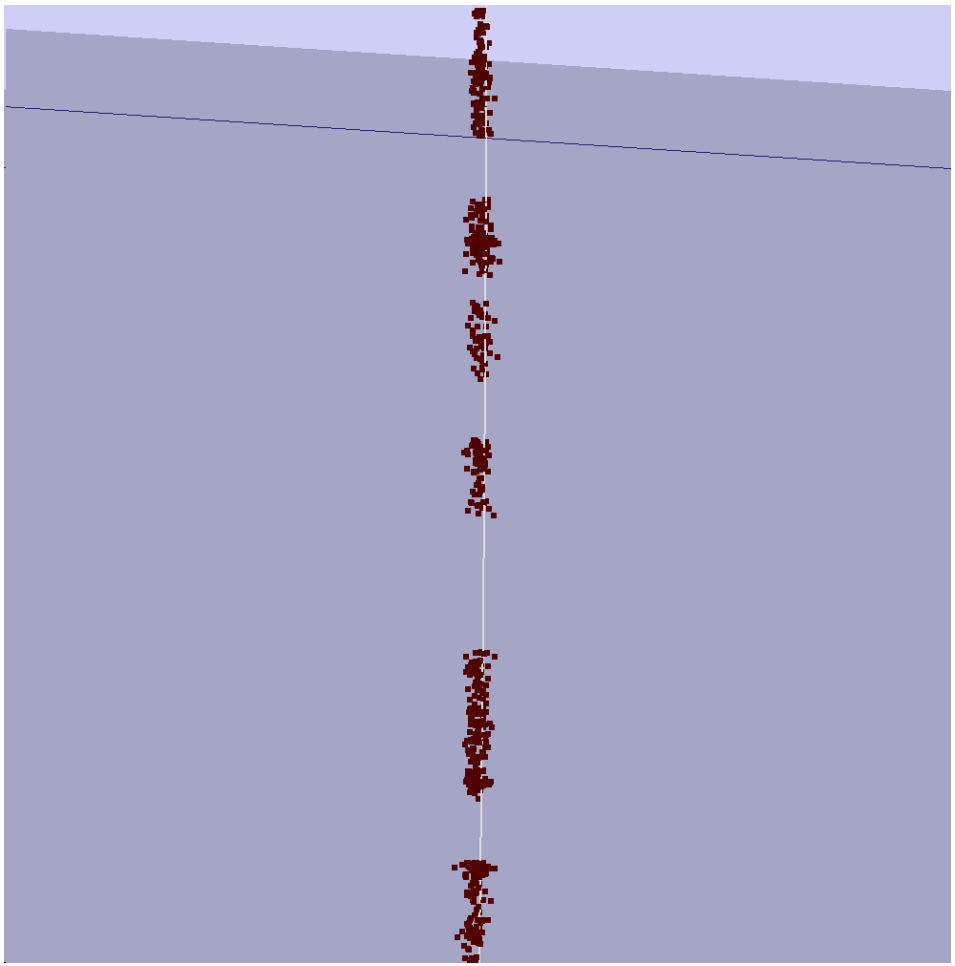


Track digitisation with delta electron

Delta hit removal

After removal

Remove hits if local density is more than 100 per $1.5^2 mm^2$



Track reconstruction without delta electron

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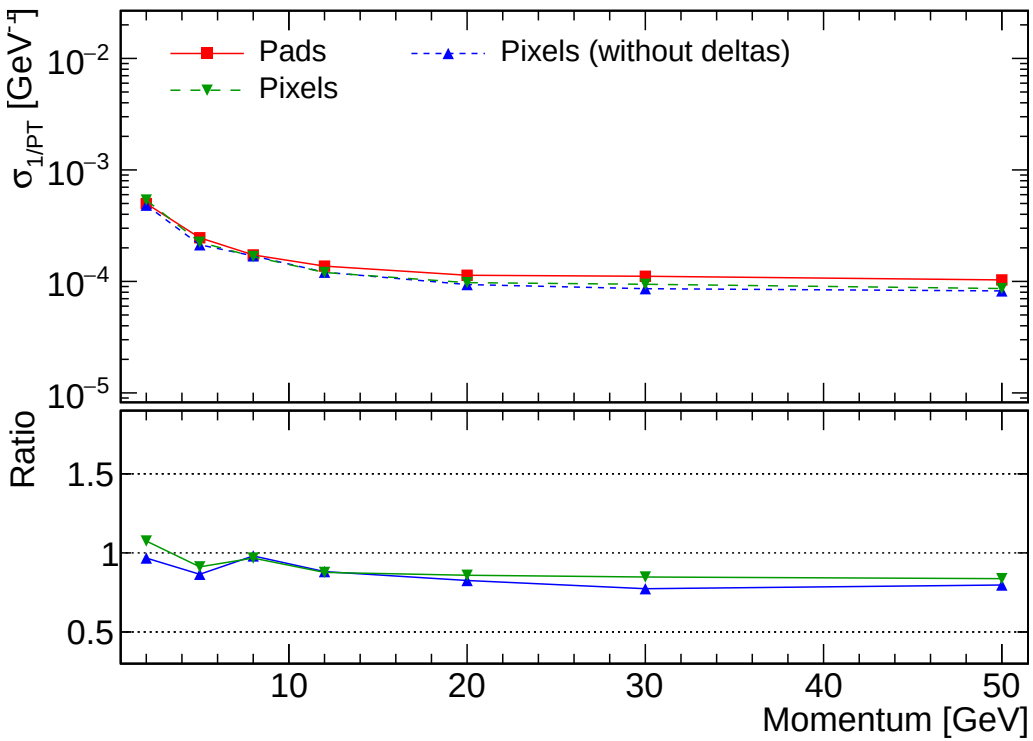
Momentum resolution of the TPC with delta removal and coverage

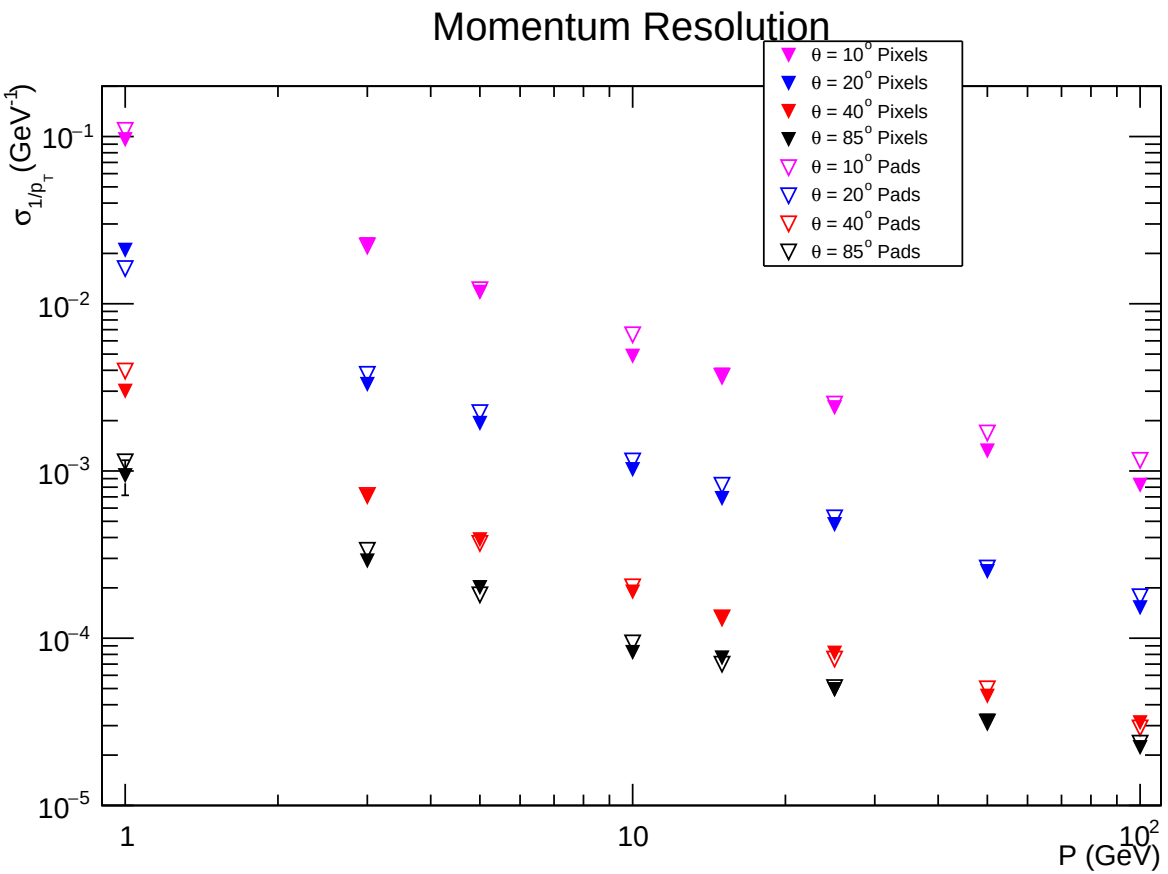
For low momentum tracks performance of pads and pixels is similar, because the resolution is limited by multiple scattering
For high momentum tracks pixels are $\sim 20\%$ better



Simulated muons at $\phi = 0.01$ and $\theta = 85°$ with coverage mask

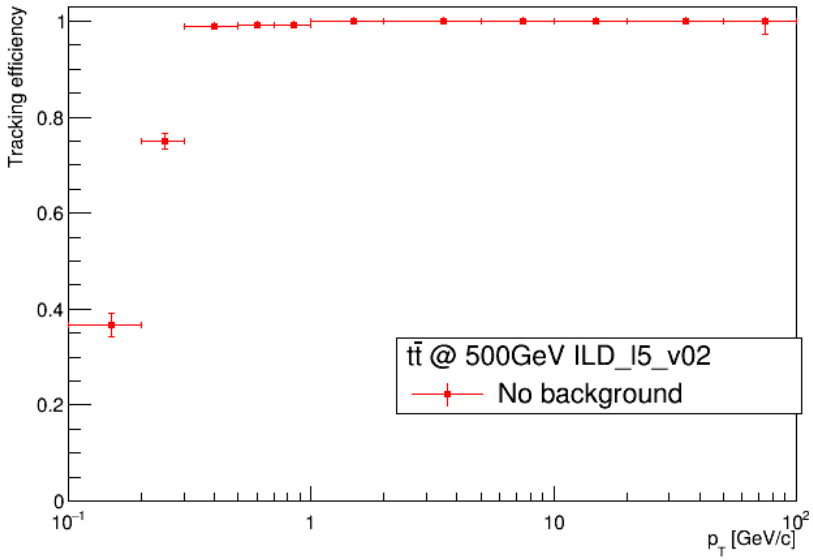
Tracking with silicon

- Full ILD tracking with the TPC and silicon detectors is functional
- Pixel and pad performance is similar

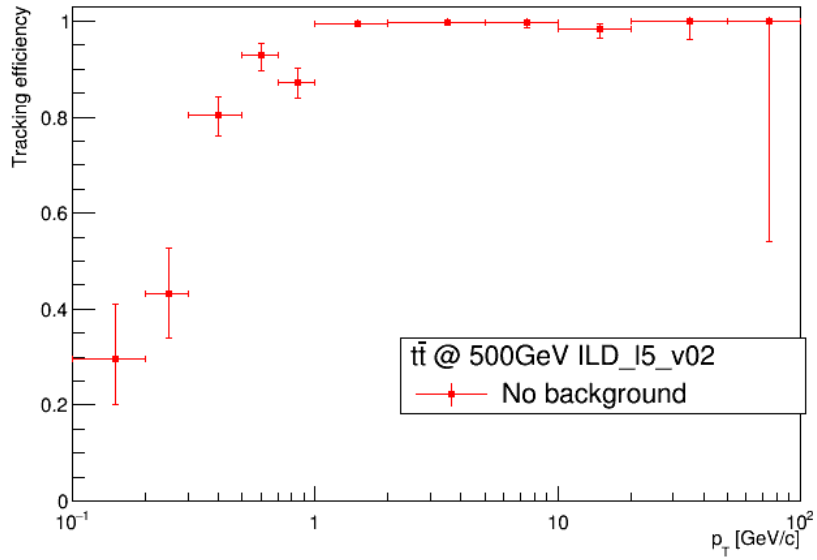


Momentum resolution of muons without delta electrons

Tracking efficiency in a $t\bar{t}$ event



Pads



Pixels

- High momentum tracking is efficient for pixels
- The efficiency of low momentum tracks is under investigation

Conclusions

A full pixel simulation for the ILD TPC is implemented
Work on the pixel TPC simulation has progressed

- A coverage mask was implemented
- A simple delta electron removal algorithm was added
- Tracking in combination with the silicon detectors is being developed

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Backup

Seed finding for pixel TPC

Pad seed finding is not suitable for a pixel TPC because the nearest neighbour clustering algorithm scales as $\mathcal{O}(N^2)$

Instead, perform clustering by ϕ (Hough-transform like)

- Fill histogram of hits by ϕ in pad row range of 750 pixel rows
- Maximum bin is cluster with track candidate if more than 200 hits
- construct a straight line from the detector center to the average position
- Cut hits on distance from this line (10mm in $r\phi$ and 3mm rz)
- initialise track fit with this line

Tracks are found and fitted by extending seeds inwards using a Kalman filter, which has been adapted for pixels (see last year's presentation)

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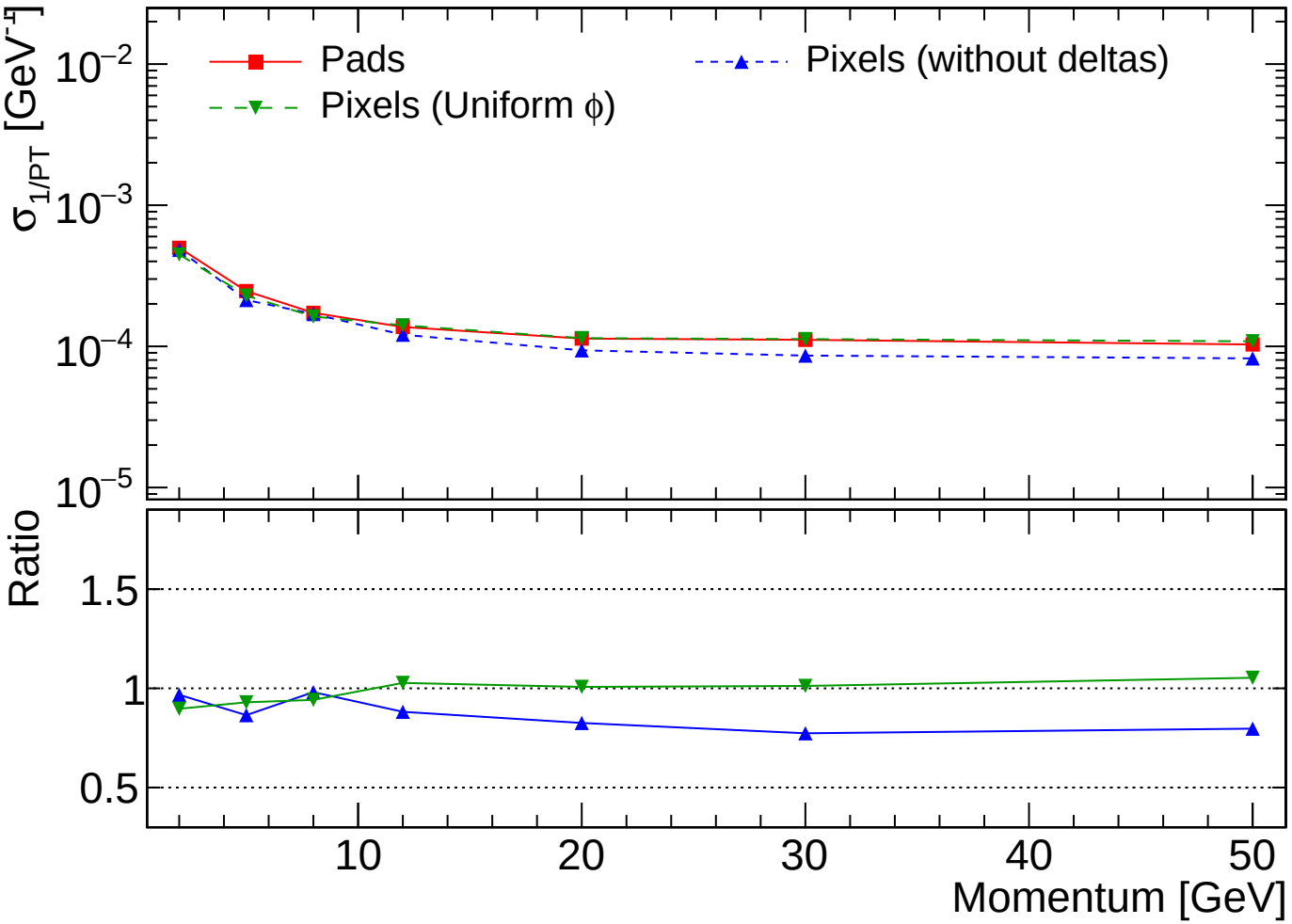
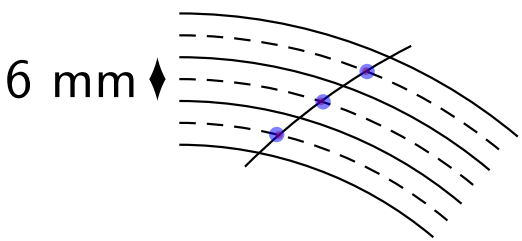
Tracking at a uniform angle



Simulation of pad TPC



- Detector is described by DD4HEP geometry
- Pads have have inter-module gaps in the radial direction
- Geant4 processes interactions of particle(s) from gun or event
- Single hit in TPC is deposited if energy is above threshold (32eV) in a single pad. Position of pad centre crossing is recorded
- Diffusion and hit resolution is simulated by smearing the hits by the expected resolution in $r\phi$ and z directions
- Tracks are found and fitted by extending seeds inwards using a Kalman filter

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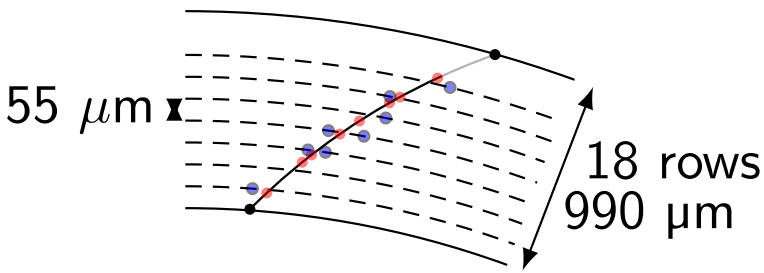
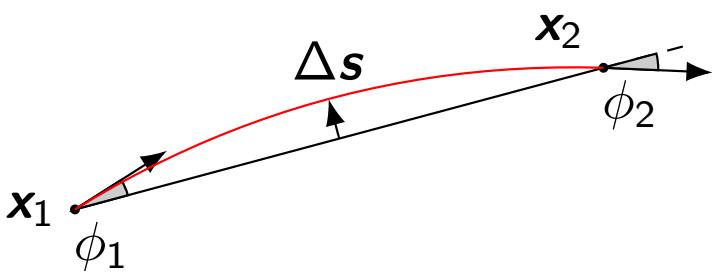
Simulation of pixel TPC





- Pixels are described by the same cylindrical volumes in DD4HEP
- Pixels have ideal 100% coverage (to be scaled)
- Multiple hits per row can be deposited
- In order to simulate diffusion, hits are smeared transverse to track in r, ϕ and z directions
- Optional: interpolate the track with a parabola over a volume of 0.99 mm (18 pixel rows)
- Tracks are found and fitted by extending seeds inwards using a Kalman filter

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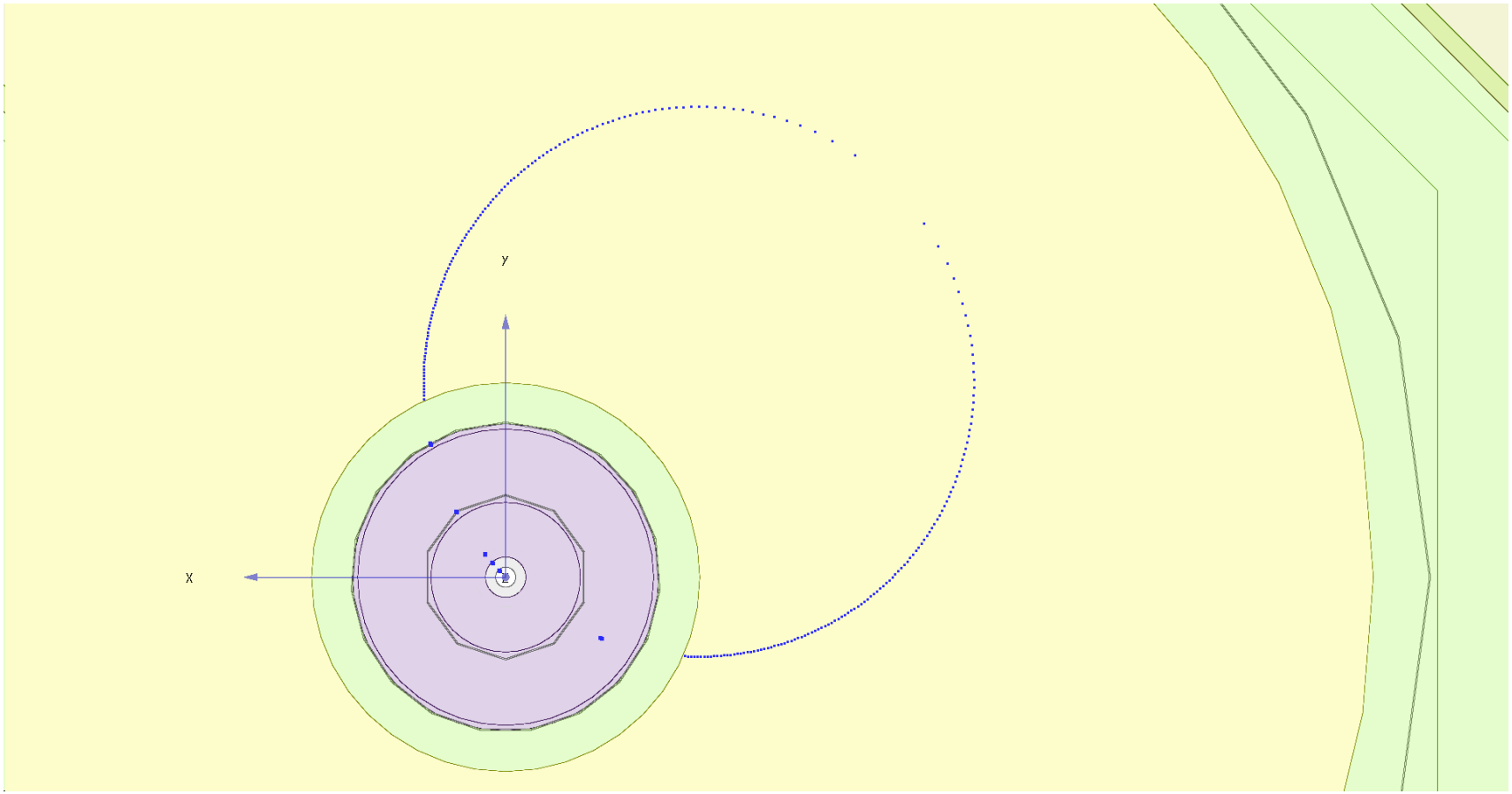
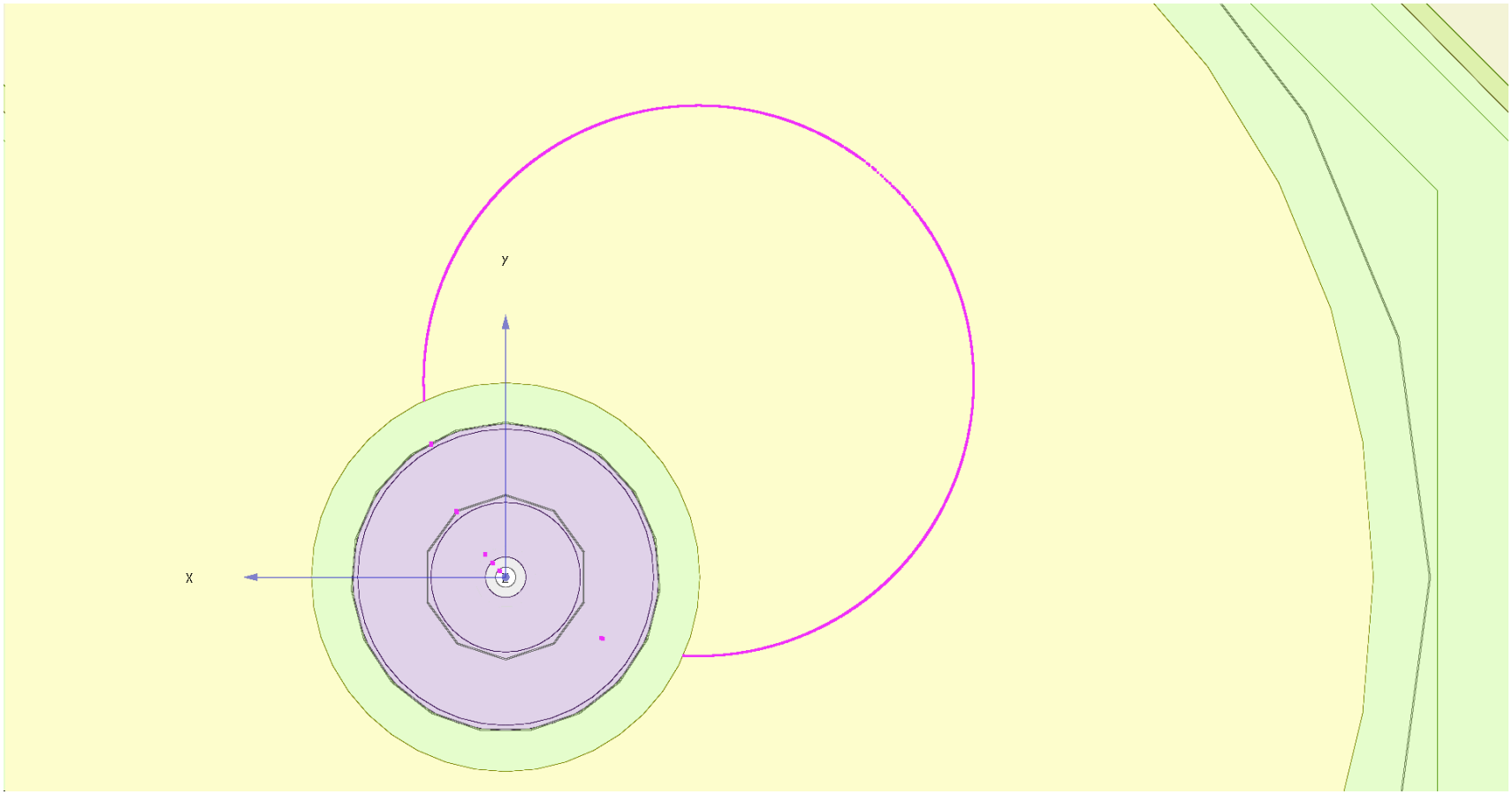
Pad simulation of a 700 MeV muon



Simulated pad hits are only at layer centre crossing

Pixel simulation of a 700 MeV muon



Interpolated pixel hits are placed everywhere along the track