Simulation of the ILD TPC with pixel readout

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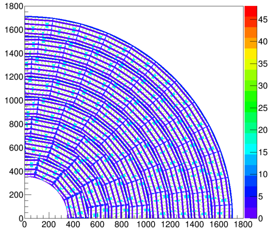
Introduction

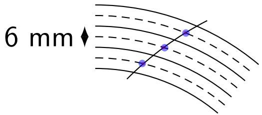
In order to study the tracking performance of a large pixelised TPC, the pixel readout was implemented in the full ILD DD4HEP (Geant4) simulation

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



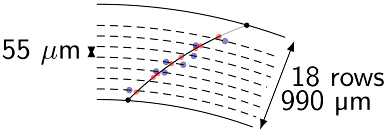
Tiling of the ILD TPC with a quad module

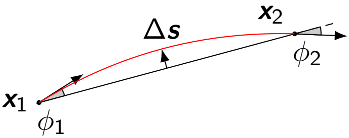
Simulation of pad TPC



- 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

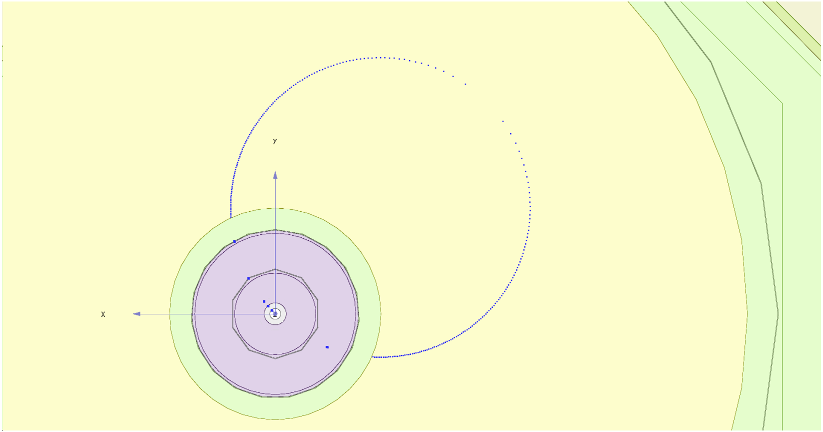
Simulation of pixel TPC





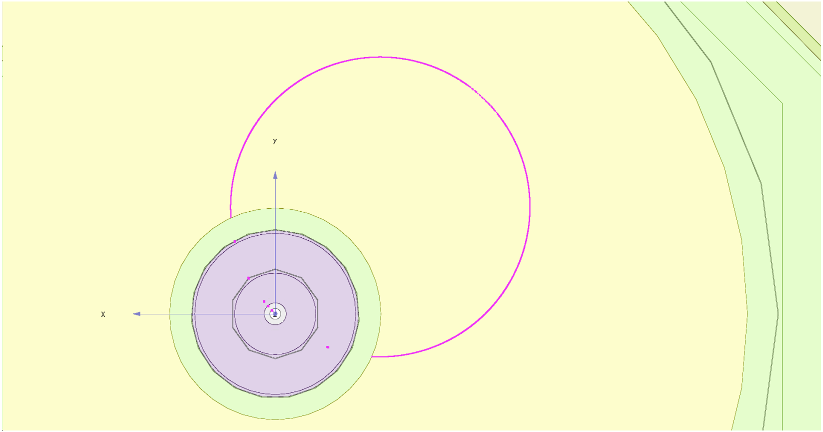
- Pixels are described by the same cylindrical volumes in DD4HEP
- Pixels have ideal 100% coverage (to be scaled)
- Multiple hits per row can be deposited
- In order to simulate diffusion, hits are smeared transverse to track in r, ϕ and z directions
- Optional: interpolate the track with a parabola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

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

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

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

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

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

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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	

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

Track finding

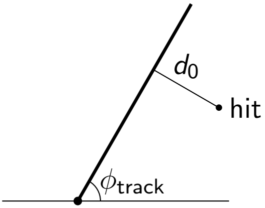
Tracks are found by extending seeds inwards using a Kalman filter

Fit tracks by Extended Kalman filter

Extend and fit track by an Extended Kalman Filter: a recursive fitting algorithm working in steps:

- Predict state at next site using propagator $\boldsymbol{a}_k^{k-1} = \boldsymbol{f}_k(\boldsymbol{a}_k)$
  - $\boldsymbol{a}_k$ contains track parameters $(d_\rho, \phi_0, \kappa, d_z, \tan\lambda)$
- Update with measurement $\boldsymbol{m}_k$ using state-to-measurement projector $\boldsymbol{h}_k(\boldsymbol{a}_k^{k-1})$
  - Add hit and update if $\chi^2 < \chi^2_{\text{threshold}}(=35)$
  - $\boldsymbol{m}_k$ are coordinates of a cylindrical surface $(r\phi, z)$

Track fitting for pixel hits



Define alternative measure with $\boldsymbol{m}_k$ as a function of $\boldsymbol{a}_k^{k-1}$

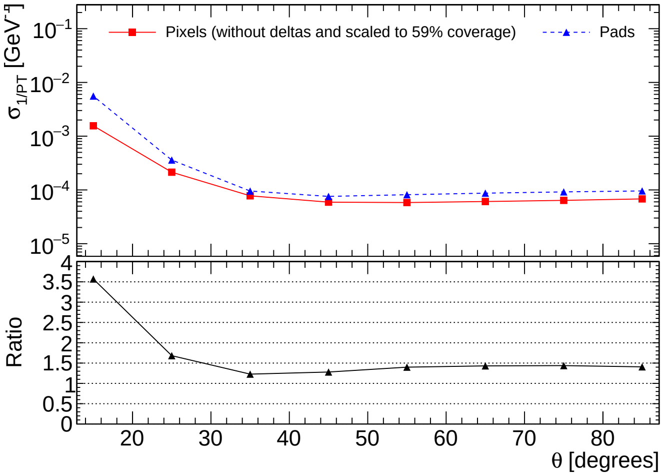
$$\boldsymbol{m}_k(\boldsymbol{a}_k^{k-1}) = \begin{pmatrix} d_0 \\ z \end{pmatrix} = \begin{pmatrix} \Delta x \sin(\phi_{\text{track}}) - \Delta y \cos(\phi_{\text{track}}) \\ z_{\text{hit}} + \tan\lambda(\Delta x \cos(\phi_{\text{track}}) + \Delta y \sin(\phi_{\text{track}})), \end{pmatrix}$$

The distance to the track d_0 better represents the measurement

Nikhef

Momentum resolution

Scaled to 59% coverage

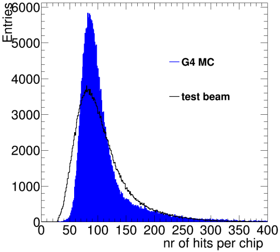


Simulation for comparison with test beam results

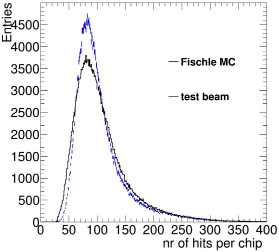
From 2017 single chip test beam

- Use 55 μm gas layers in DD4HEP (No interpolations)
- Use resolution parameters as found in the analysis

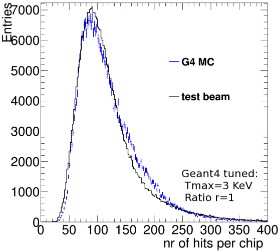
Tune Geant4 (v10.02.p02) G4UniversalFluctation model to our data



Default tune ($r = 0.55$, $T_{\text{max}} = 0.99$ KeV, $e_{\text{threshold}} = 31$ eV)



Comparison with Fischle et al (NIM A 301 (1991) 202)

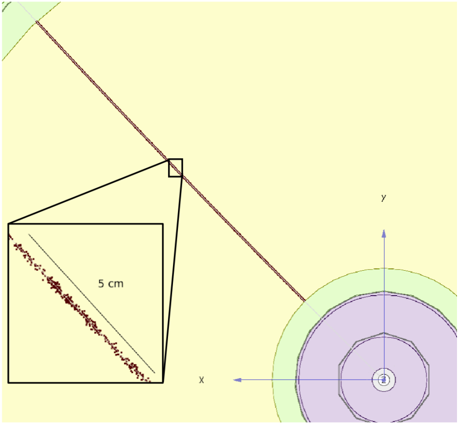


Tuned to out data ($r = 1$, $T_{\text{max}} = 3$ KeV, $e_{\text{threshold}} = 27$ eV)

See dE/dx talk by Peter Kluit

Conclusions

- Tracks can be simulated and reconstructed for a pixel readout of the ILD detector
- Estimates show a factor 1.3 to 3.5 improvement in momentum resolution compared to the pad readout for a 59% coverage
- Geant4 was tuned to test beam data



50 GeV muon track

Pulls of momentum resolution