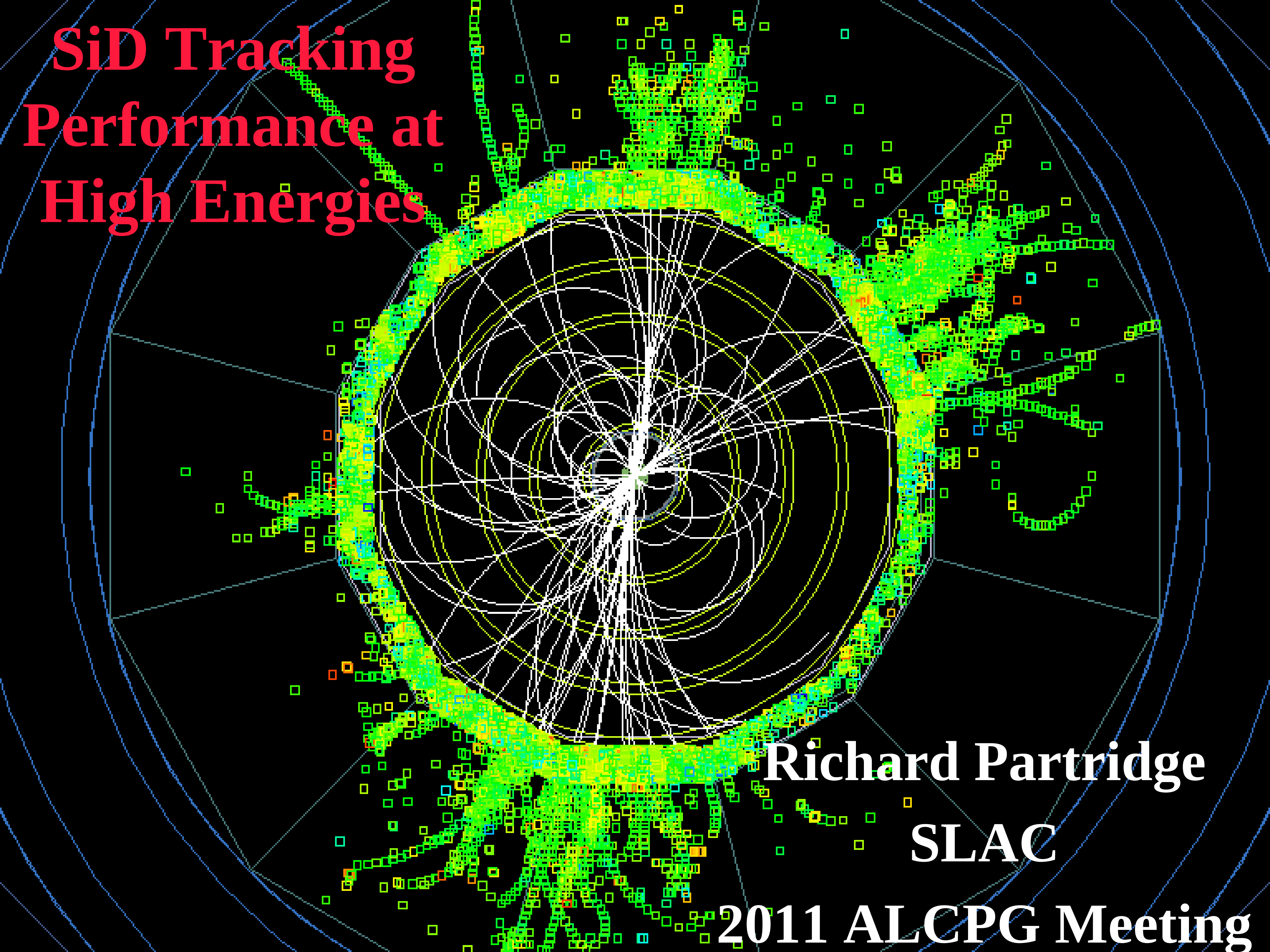
SiD Tracking Performance at High Energies



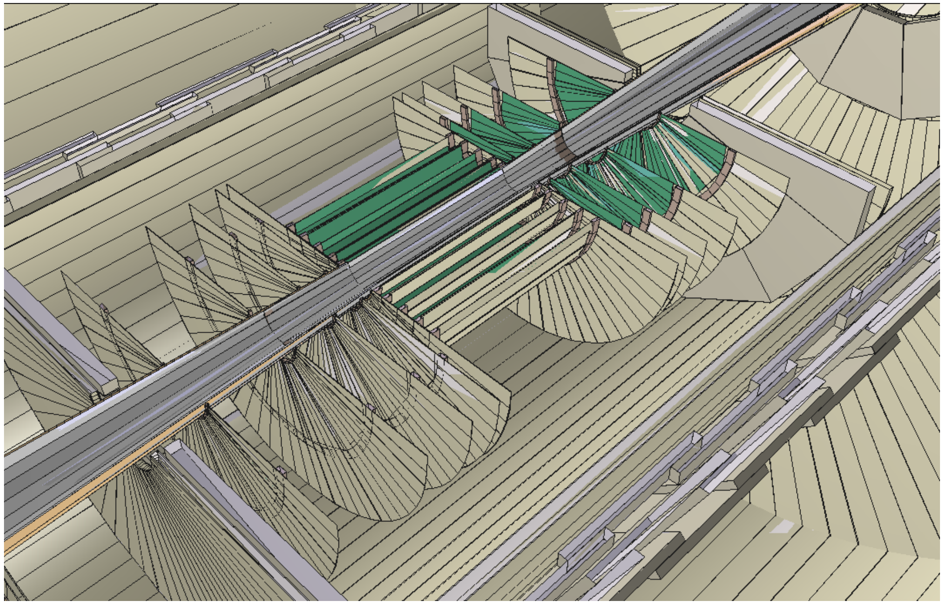
Richard Partridge

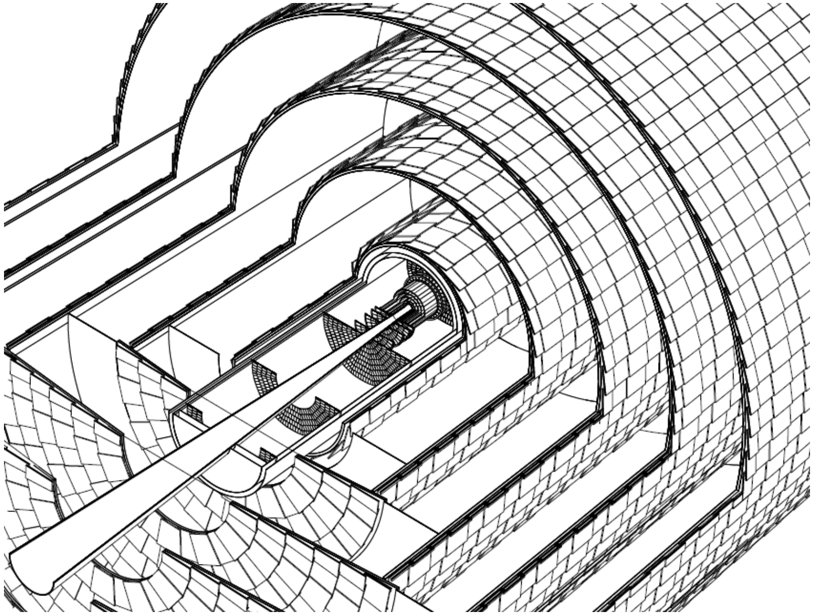
SLAC

2011 ALCPG Meeting

Tracking in SiD

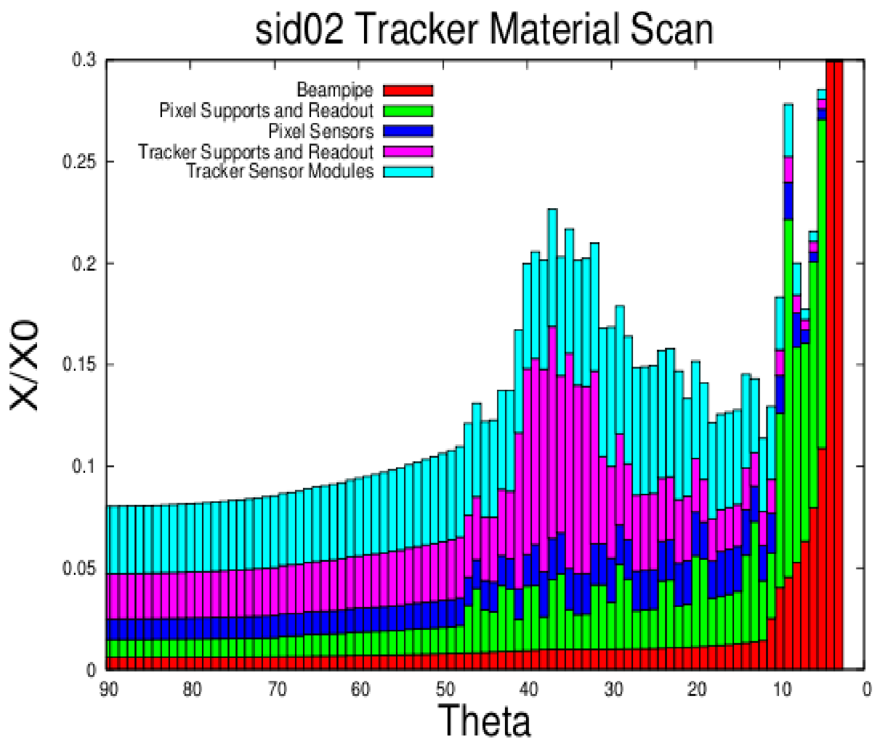
- SiD has a 100% silicon tracker composed of inner pixel layers and outer strip layers treated as an integrated tracking system
  - Pixel sensors covers r < 200mm region with 5 barrel and 7 endcap layers
  - Strip sensors cover r > 200mm region with 5 barrel and 4 endcap layers
  - Barrel strip layers have axial strips that only measure the bend coordinate
  - Endcap strip layers have pairs of trapezoidal sensors with 12^{o} stereo angle to measure both the bend and non-bend coordinates

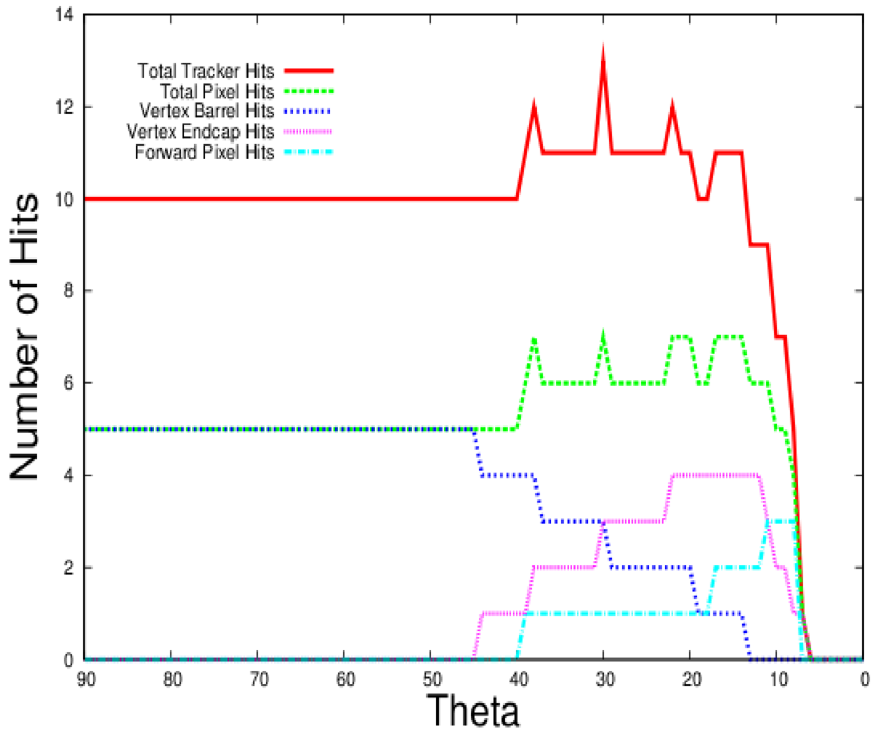




Tracker Design Metrics

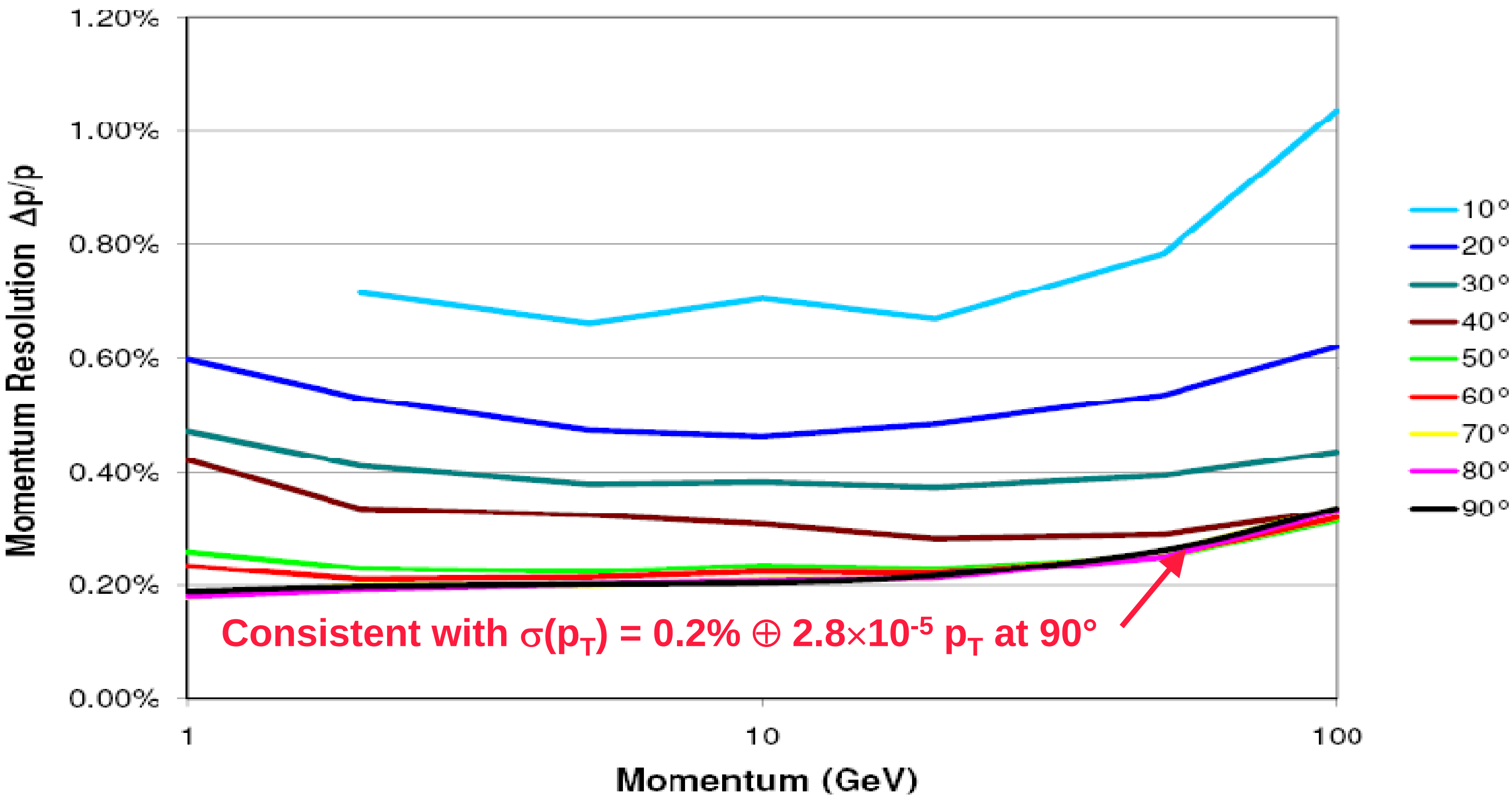
- Low-mass silicon vertex and tracking detectors to minimize the effect of multiple scattering
  - Roughly 10% X_0 except for barrel/endcap transition and far forward regions
- ~10 tracking layers with excellent resolution and 2-hit separation to provide robust pattern recognition capabilities





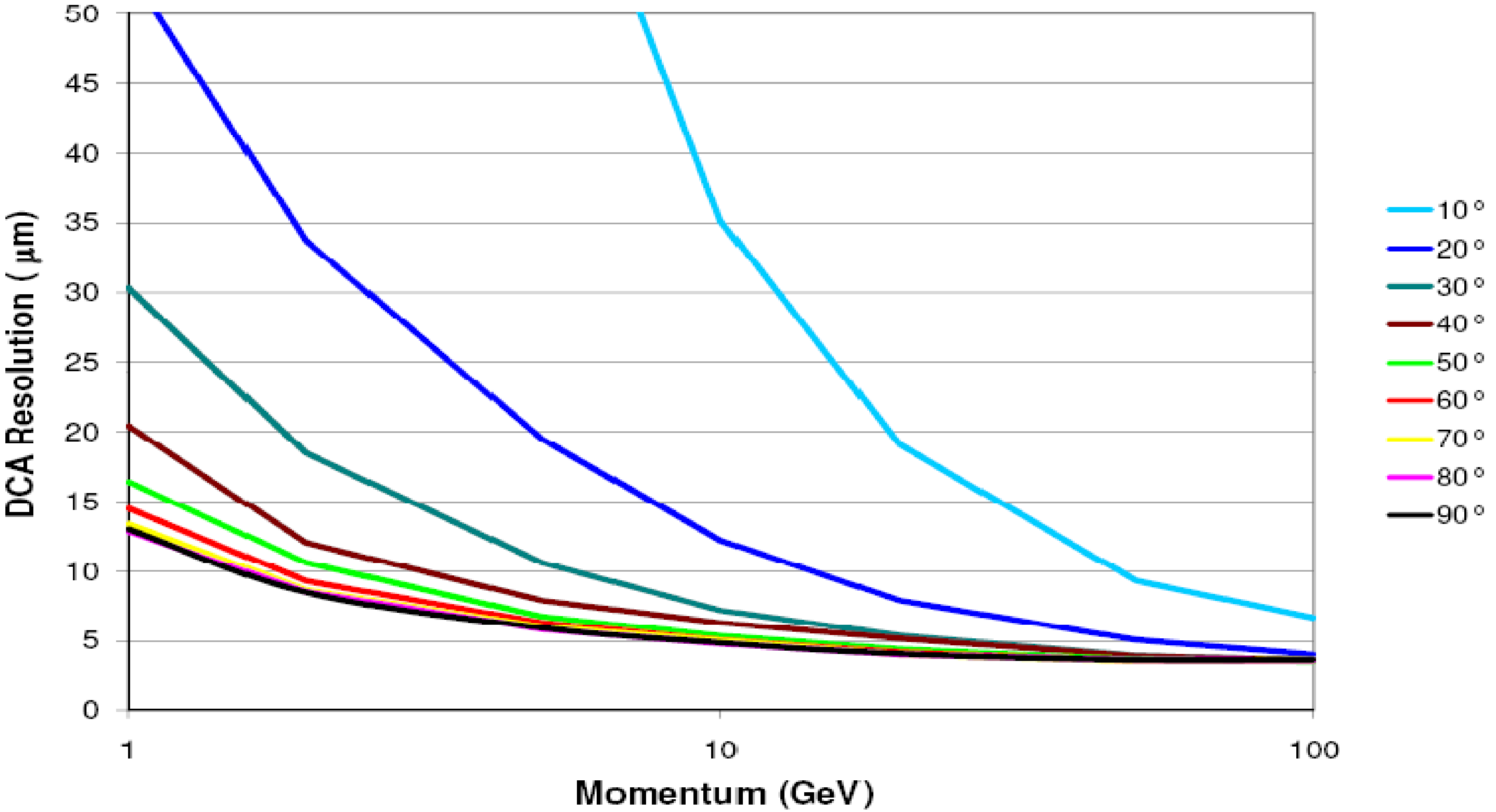
Momentum Resolution

- Momentum resolution typically ~0.2% for |cos(θ)| < 0.65
  - $\sigma(p_T) / p_T < 0.5\%$ over most of solid angle for 1 GeV < p_T < 100 GeV



Impact Parameter Resolution

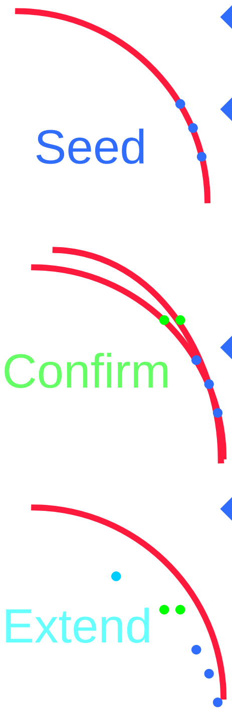
- DCA resolution typically ~15μm for p_T = 1 GeV, |cos(θ)| < 0.65
  - Most tracks multiple scattering limited – resolution approaches ~4μm at high p_T



Tracking Pattern Recognition

- Determining track-finding performance in complex physics events requires:
  - Detailed simulation of the tracking sensors to transform GEANT energy deposits into tracker hits
  - Pattern recognition code that finds tracks among the constellation of hits
- SiD has developed tracking code (SeedTracker) in the lcsim framework explicitly intended for detector design studies
  - Tracking code makes no assumptions about detector geometry, so new detector designs can be tried without modifying/re-tuning the tracking code
  - User control of tracking algorithm is through a list of tracking "strategies" to be tried, with each strategy specifying which layers to use in track finding, the role of each layer, constraints on p_T and impact parameter, and a χ^2 cut
  - SeedTracker algorithm then provides an exhaustive search of all combinations of hits that could potentially form a track to find the best track candidates

SeedTracker Algorithm

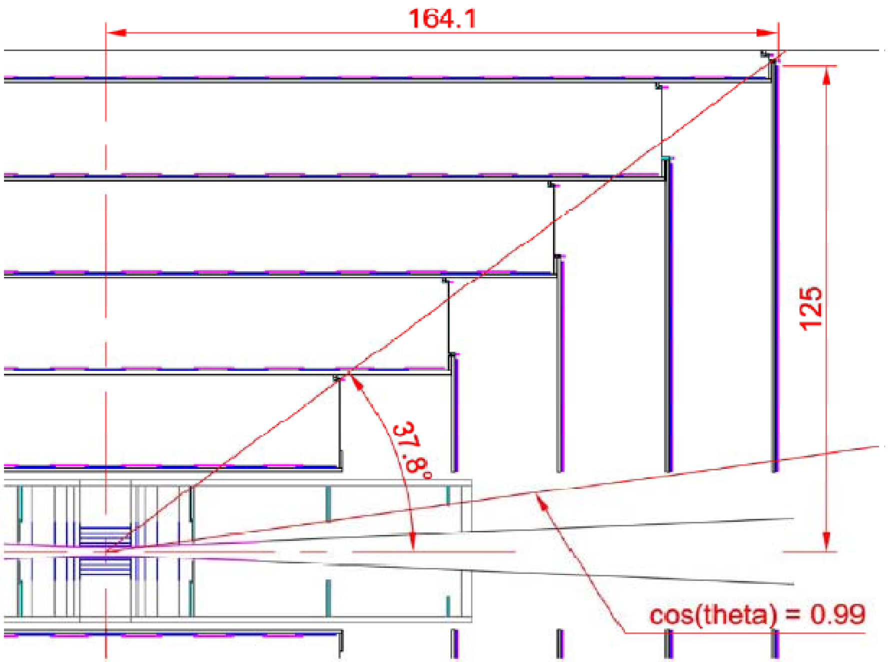


- SiD has developed track finding code in the lcsim framework
- Track finding begins by forming all possible 3 hit track seeds in the three “Seed Layers”
  - Brute force approach to finding all possible track seeds
- Require the presence of a hit in a “Confirmation Layer”
  - Significantly reduces the number of candidate tracks to be investigated
- Add hits to the track candidate using hits on the “Extension Layers”
  - Discard track candidates with fewer than 7 hits (6 hits for barrel only tracks)
  - If two track candidates share more than one hit, best candidate is selected
- Upon each attempt to add a hit to a track candidate, a helix fit is performed and a global χ^2 is used to determine if the new track candidate is viable

Track Finding Strategy

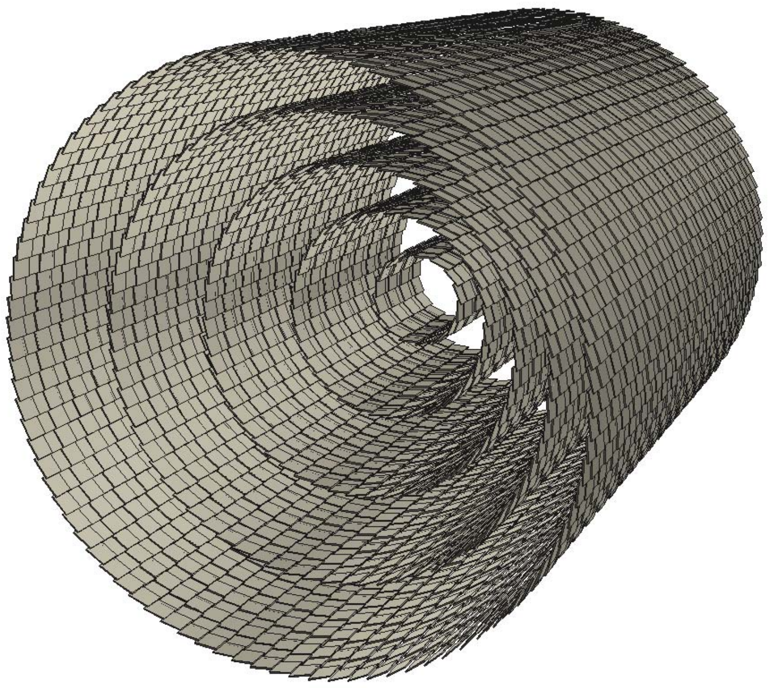
- The user interacts with the track reconstruction program by specifying one or more "strategies"
- Typical strategy requirements:
  - At least 7 hits on the track
    - Only 1 hit per layer
    - Special barrel only strategy with 6 hits used to pick up low-p_T particles in the central region
  - $p_T > 0.2$ GeV
  - $r - \phi$ and $s - z$ impact parameter cuts $|d_0| < 10$ mm and $|z_0| < 10$ mm
  - $\chi^2 < 25$
  - Bad hit χ^2 parameter = 10 (used to ignore a single outlier hit)
- "Strategy Builder" used to find optimized sets of seed and confirm layers used for efficient track finding
- The remainder of this talk will focus on post-LOI improvements to the tracking code and performance measurements for complex events (ttH @ 1TeV)

New Planar Geometry



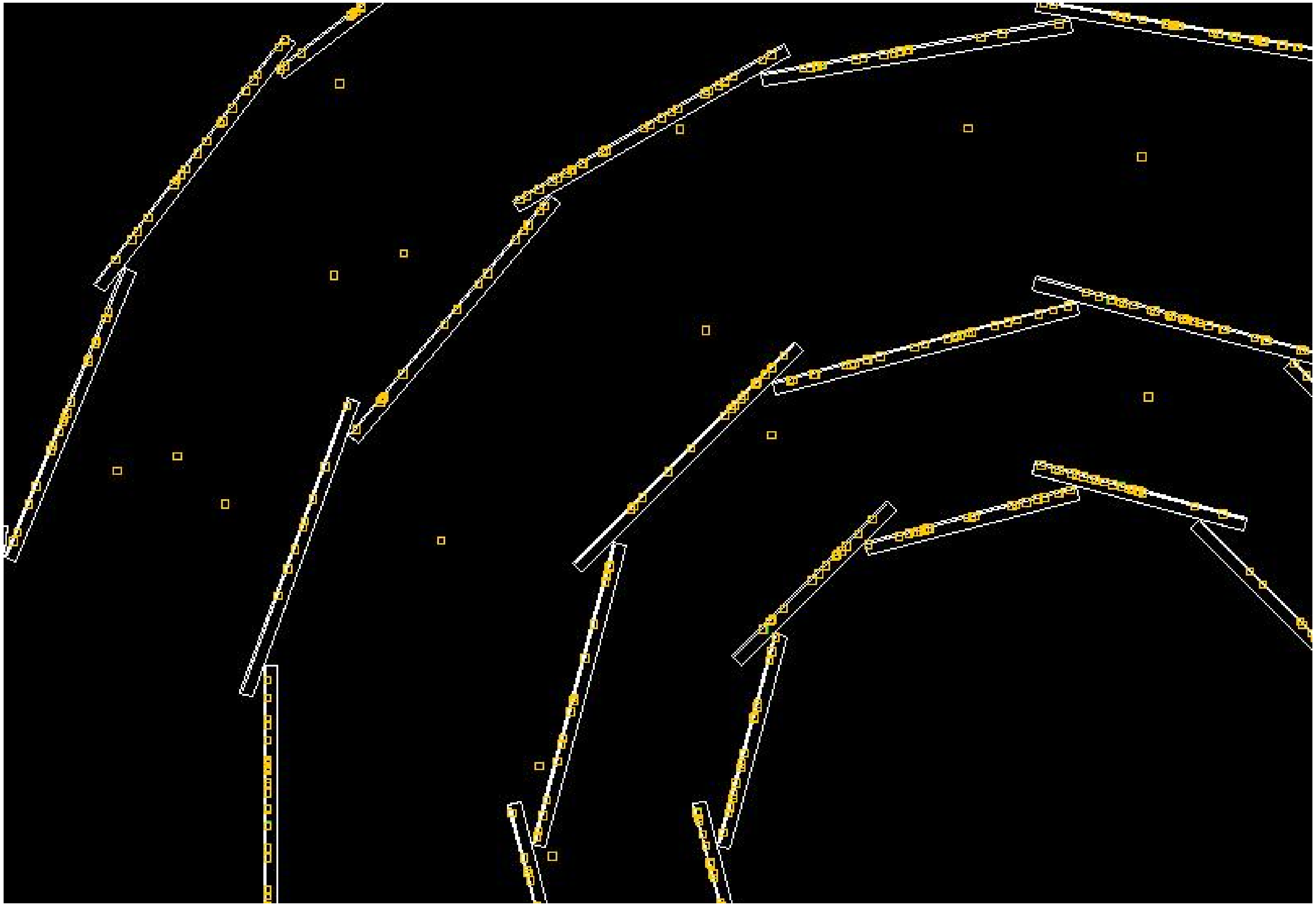
LOI geometry consisted of cylinders and disks with virtual segmentation

New geometry models each silicon sensor – rectangular detectors in barrel, trapezoidal detectors in endcaps

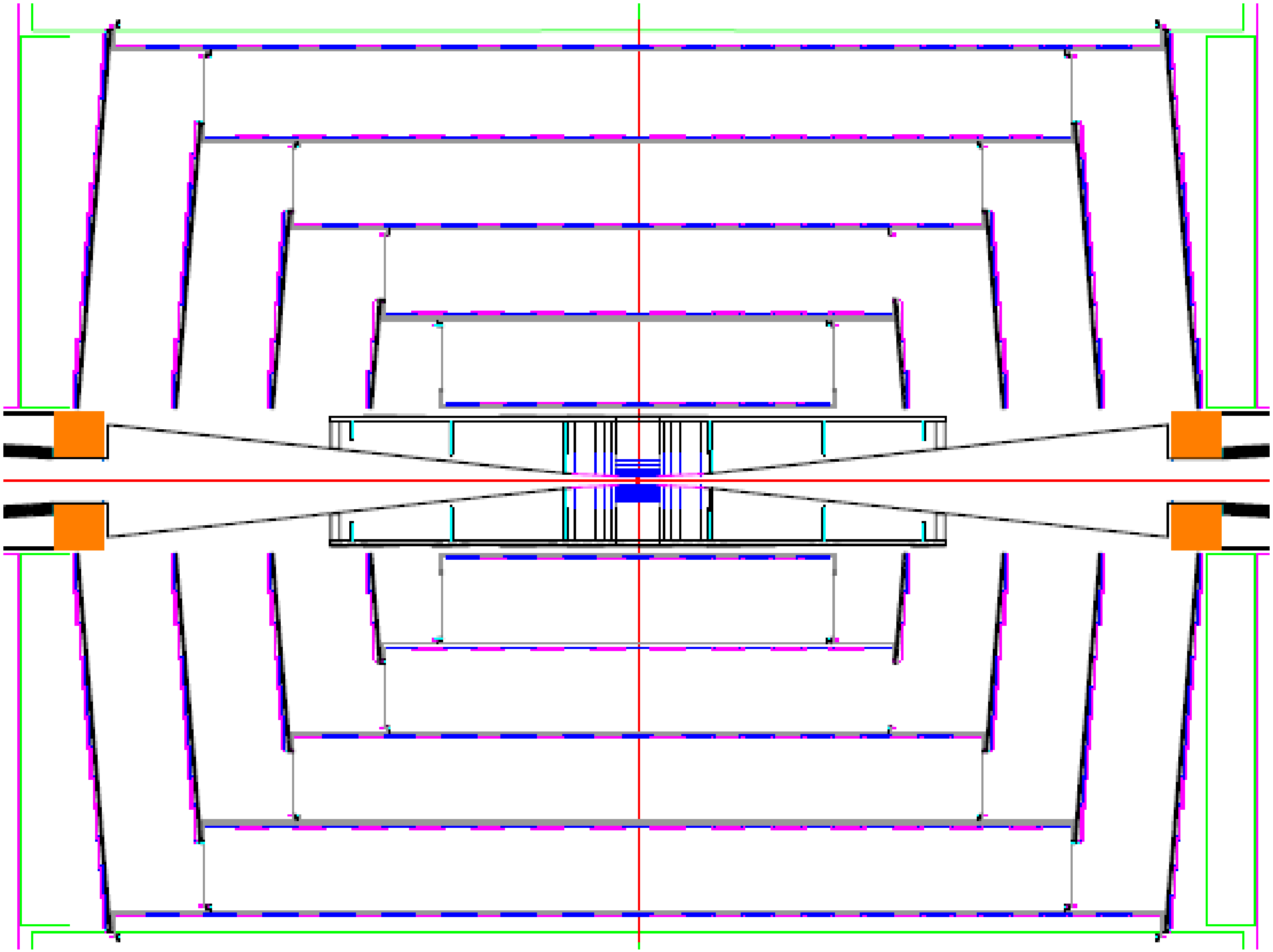


Realistic Detector Geometry

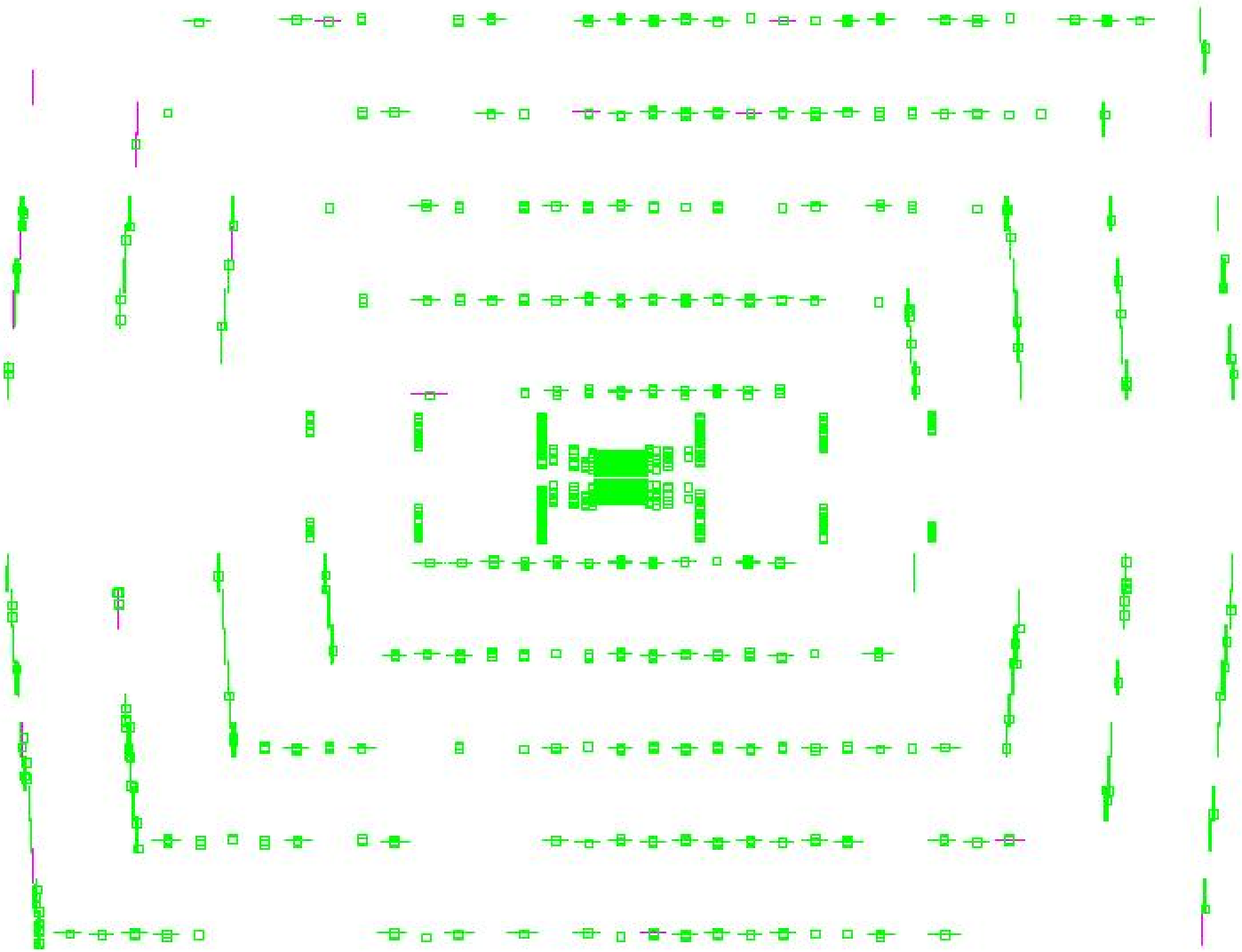
- Blow-up of vertex detector showing hits on planar sensors



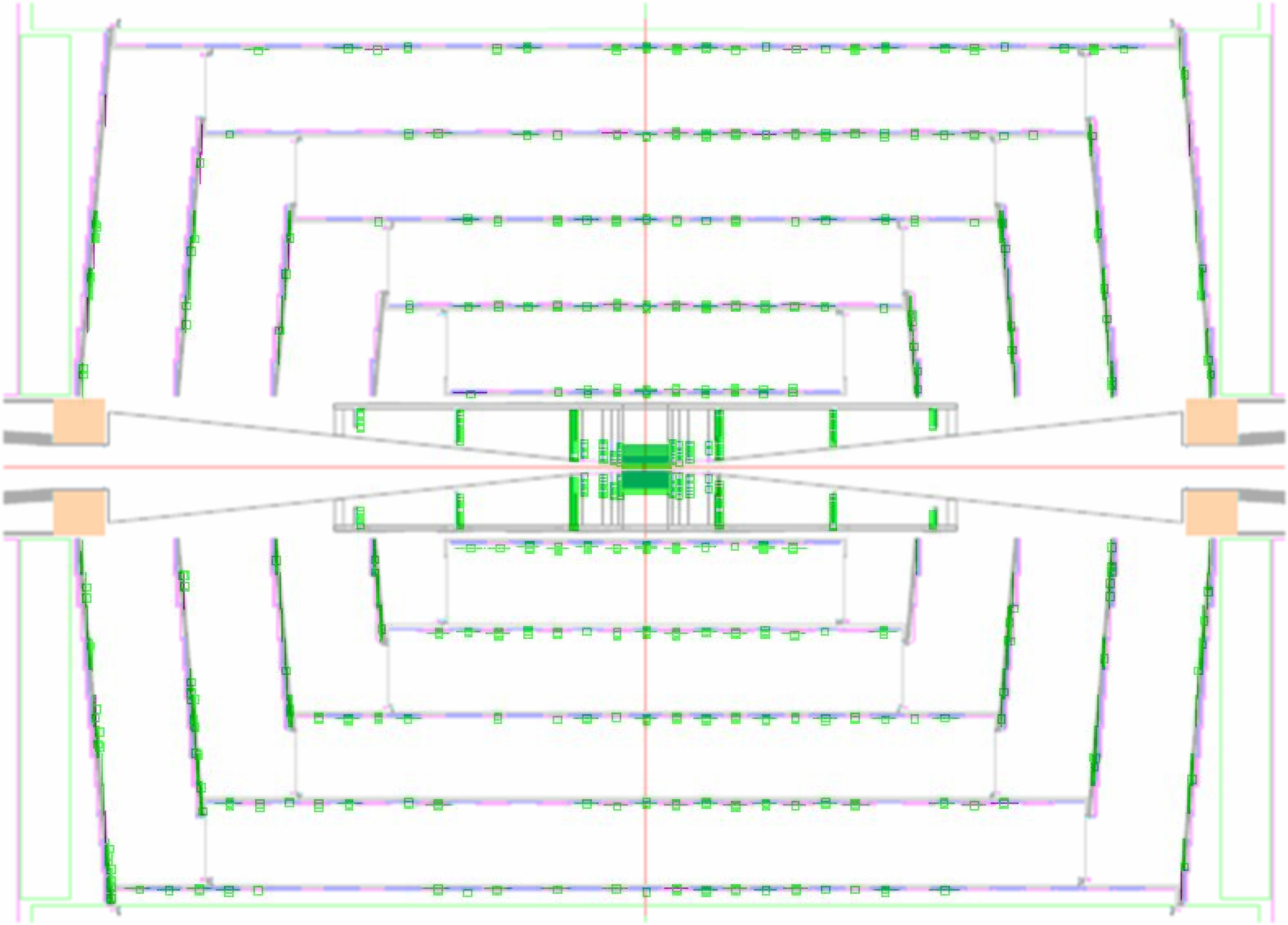
SiD LOI Geometry – CAD Drawing



SiD LOI Geometry – Event Display



Event Display / CAD Drawing Overlay



Realistic Hit Digitization

- In LOI studies, charge was deposited on the nearest strip/pixel
- New code provides detailed simulation of charge deposition, Lorentz drift, diffusion, and charge sharing between adjacent strips/pixels
  - Charge deposition for strip detectors based on CDF Si sensor simulation algorithm
  - For pixels, can either use strip deposition model extended to pixels or detailed modeling using electric field maps
- Readout chip code accounts for noise and readout threshold and produces raw hits
- Raw hits are clustered using a nearest neighbor algorithm
- Tracker hits are formed giving hit position and uncertainty

Tracking Efficiency

- Some tracks are not findable by the tracking algorithm
  - p_T too low, not enough hits on the track, impact parameter too big, etc.

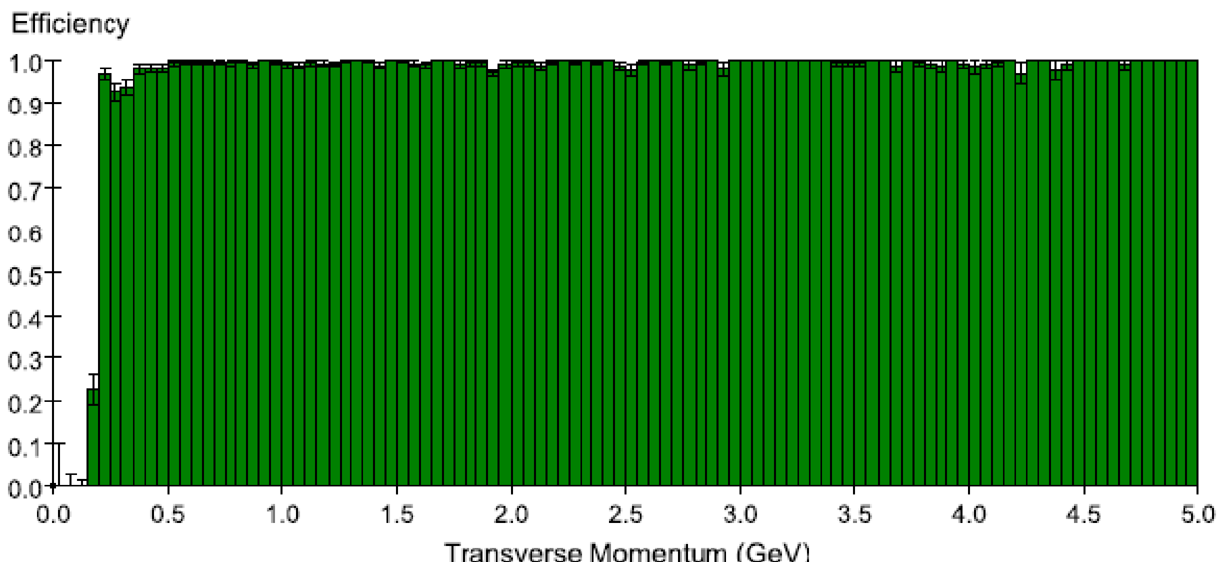
Breakdown of reasons a track isn't found

Selection	LOI: $t\bar{t}$ @ 500 GeV	New: $t\bar{t}H$ @ 1 TeV
$p_T \geq 0.2$ GeV	$(93.45 \pm 0.11)\%$	$(94.02 \pm 0.11)\%$
Nhit ≥ 6	$(90.77 \pm 0.13)\%$	$(91.54 \pm 0.12)\%$
Seed Hits Present	$(99.77 \pm 0.02)\%$	$(99.76 \pm 0.02)\%$
Confirm Hit Present	$(99.96 \pm 0.01)\%$	$(99.97 \pm 0.01)\%$
$\lvert d_0 \rvert \leq 1$ cm	$(99.83 \pm 0.02)\%$	$(99.80 \pm 0.02)\%$
$\lvert z_0 \rvert \leq 1$ cm	$(99.72 \pm 0.03)\%$	$(99.81 \pm 0.02)\%$
Track Reconstruction	$(99.05 \pm 0.05)\%$	$(98.78 \pm 0.05)\%$

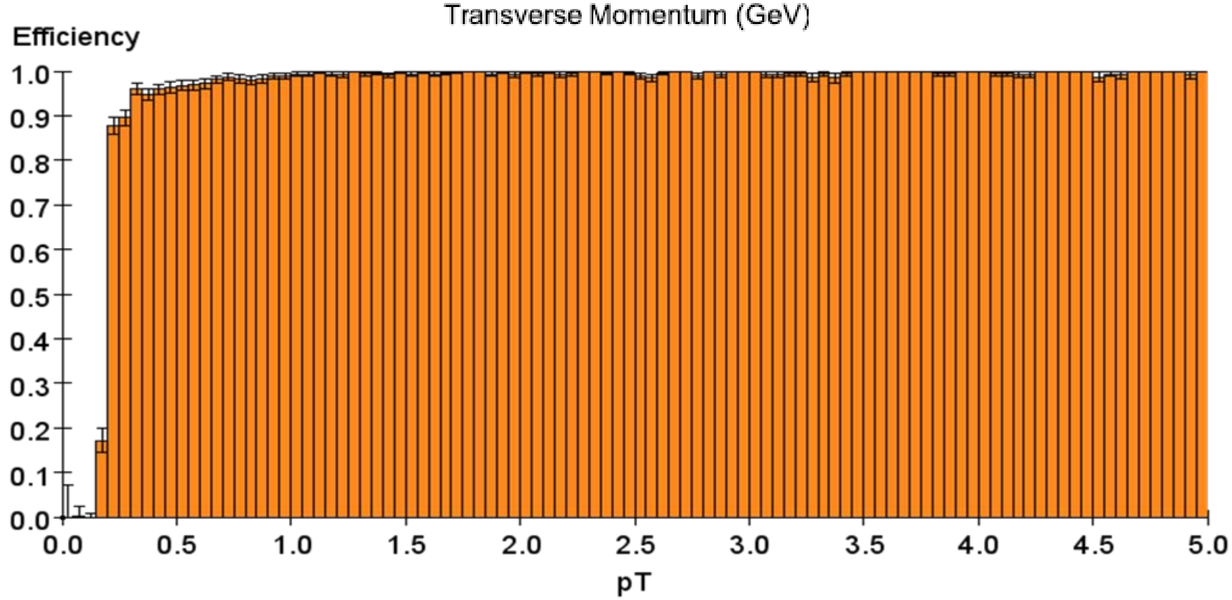
- Tracking performance is very similar to LOI
- Track reconstruction algorithm has ~99% efficiency for findable tracks

Tracking Efficiency vs p_T

LOI
(tt @ 500 GeV)

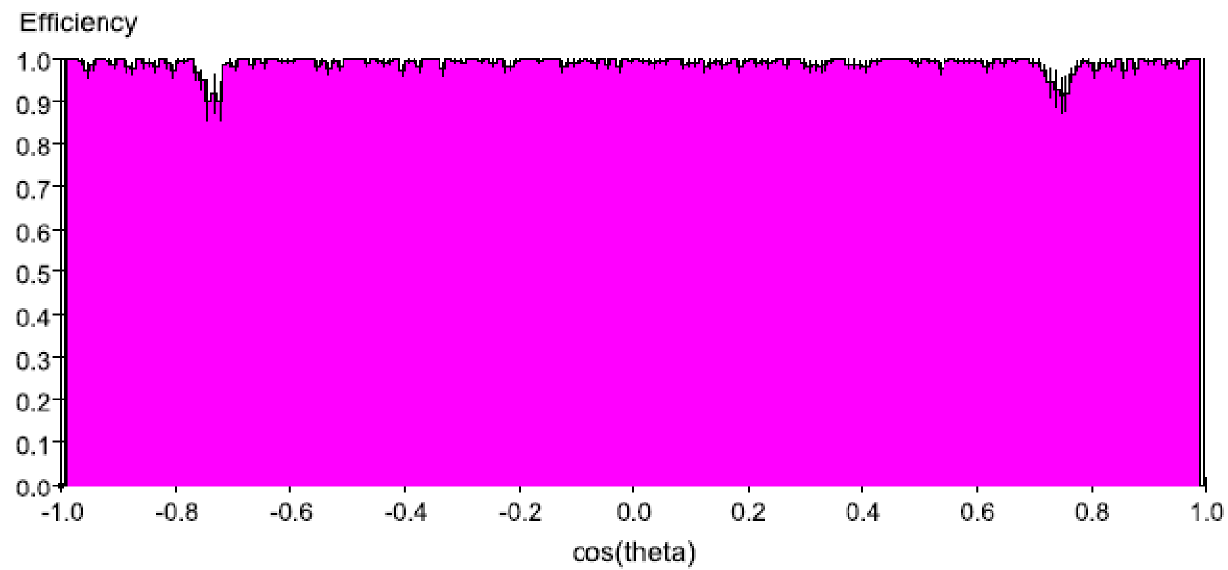


Planar Sensors and Realistic Digitization
(ttH @ 1 TeV)

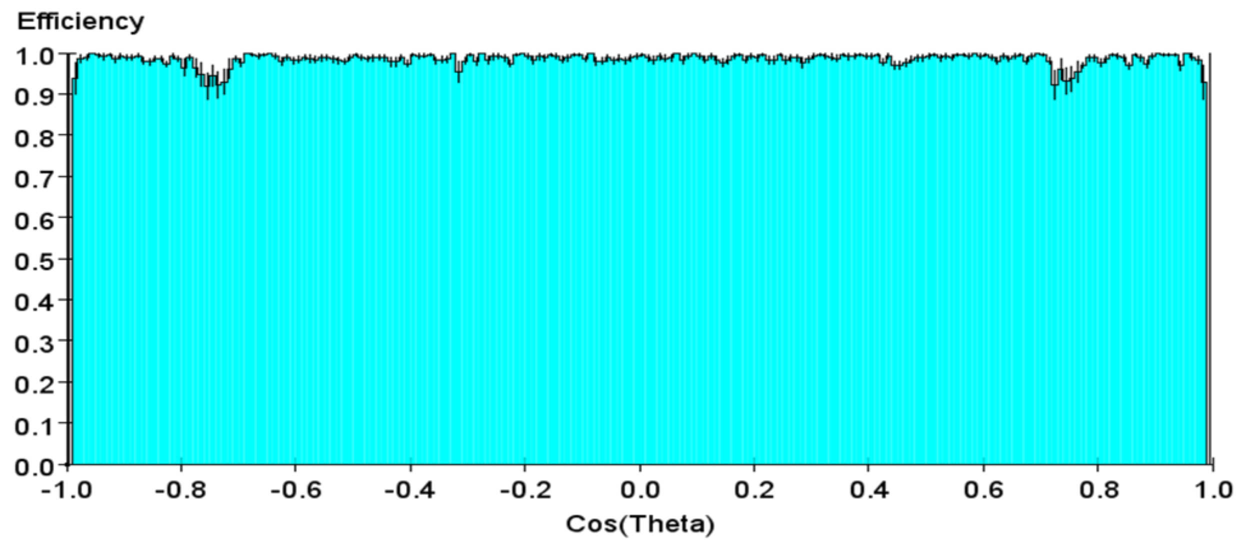


Tracking Efficiency vs cos(θ)

LOI
(tt @ 500 GeV)

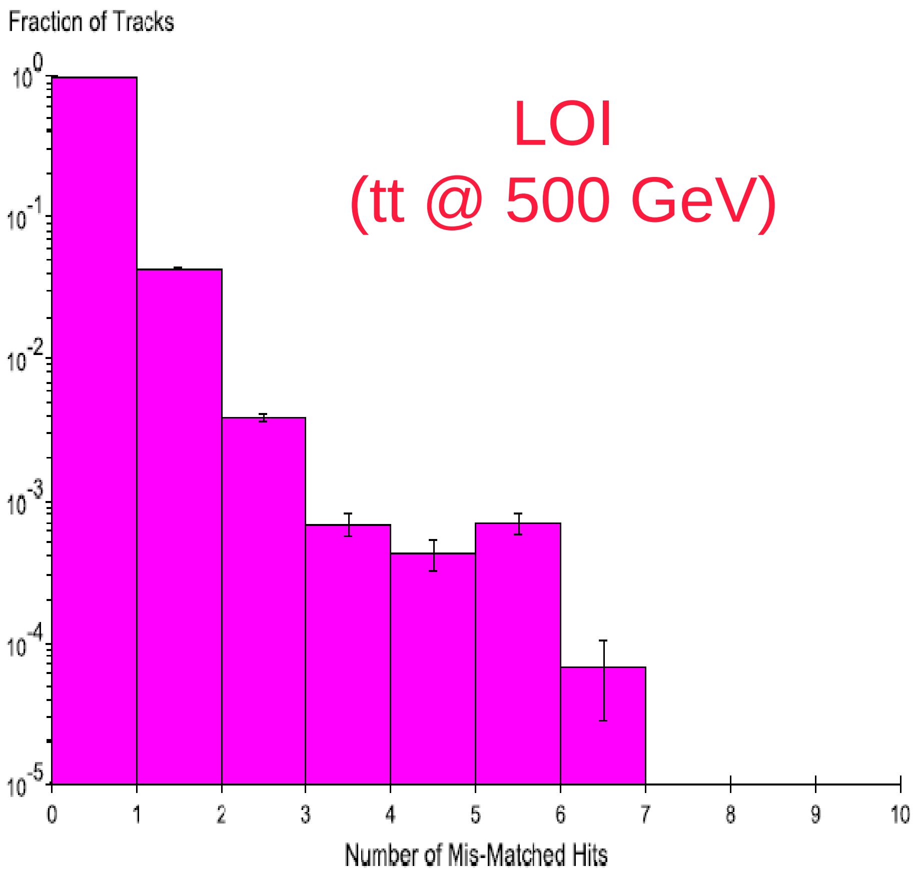


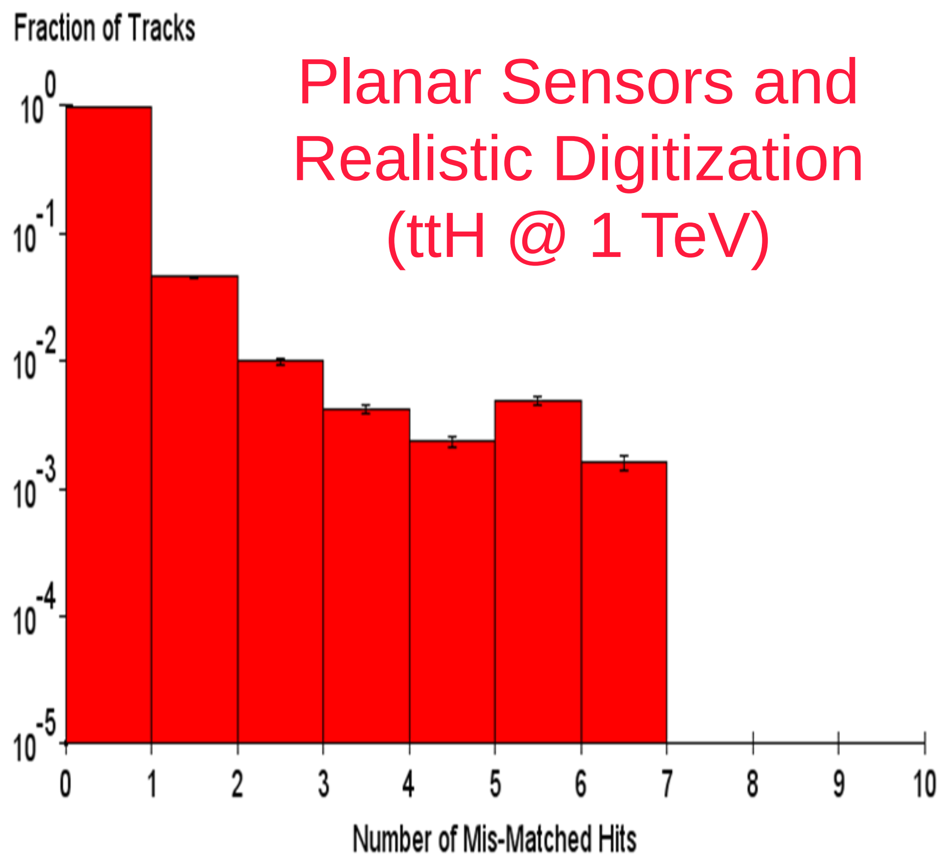
Planar Sensors and Realistic Digitization
(ttH @ 1 TeV)



Comparison with MC Truth

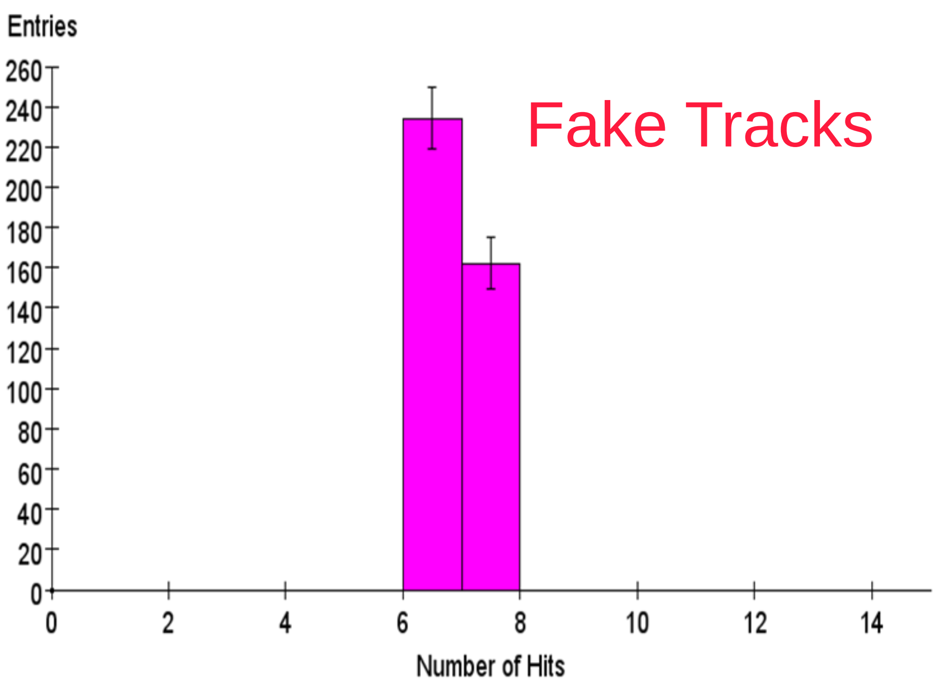
- Identify which MC particles are associated with each hit
- Assign track to the MC particle that contributes the most hits
- Count how many hits on the track are from other MC particles

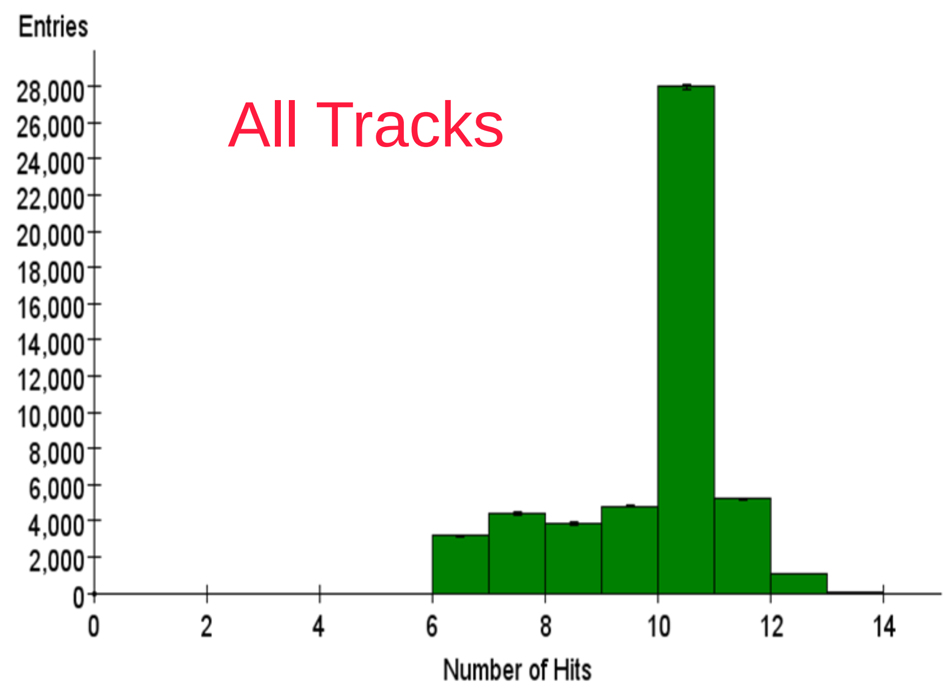




Fake Tracks

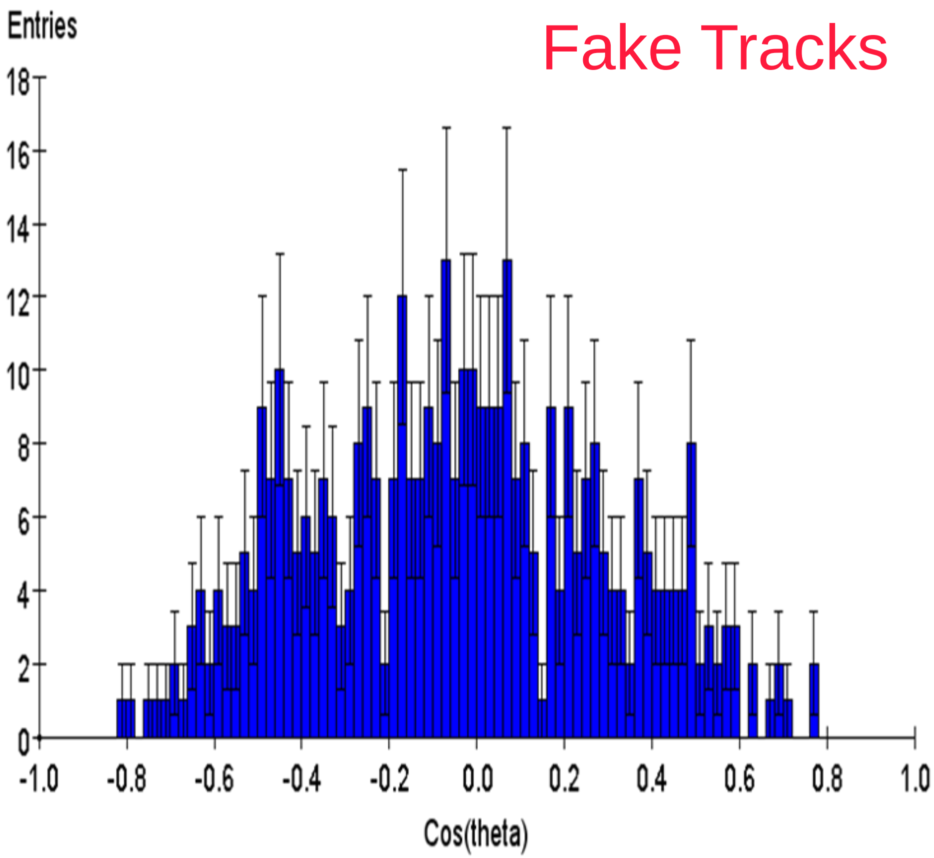
- Define a fake track as one that has fewer than half of its hits from a single MC particle
- Fake track rate in 1 TeV ttH sample (0.79%) is considerably higher than seen in the LOI for 500 GeV tt sample (0.07%)
- Fake tracks have minimum number of hits allowed

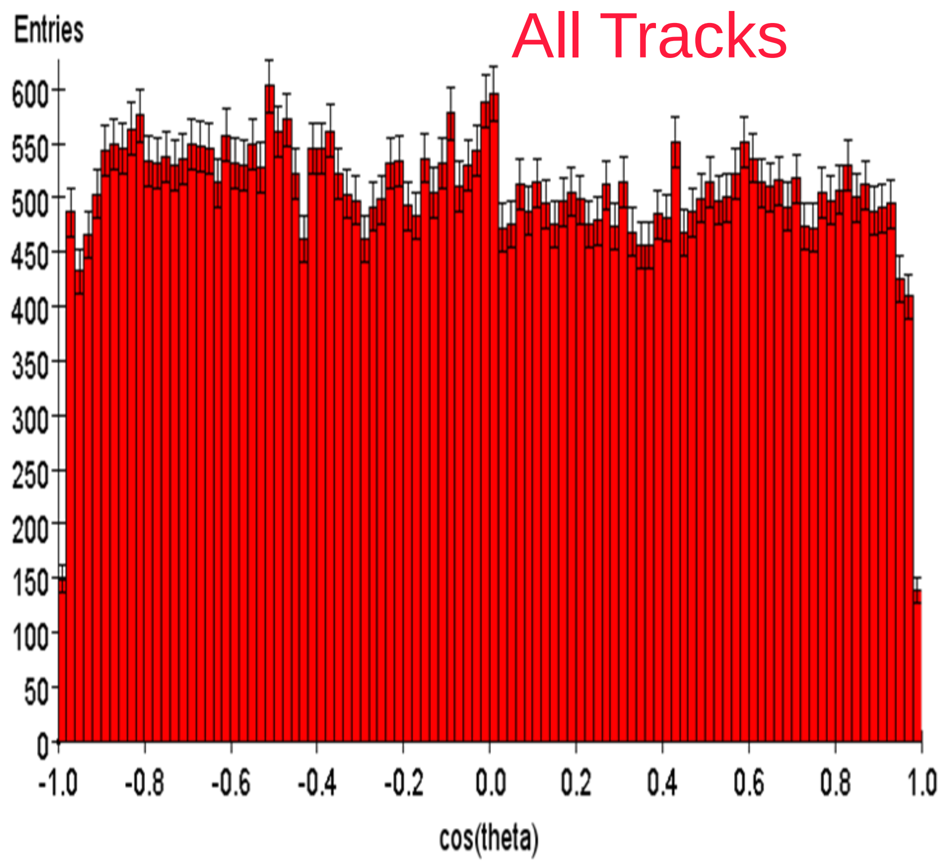




Where are Fake Tracks Located?

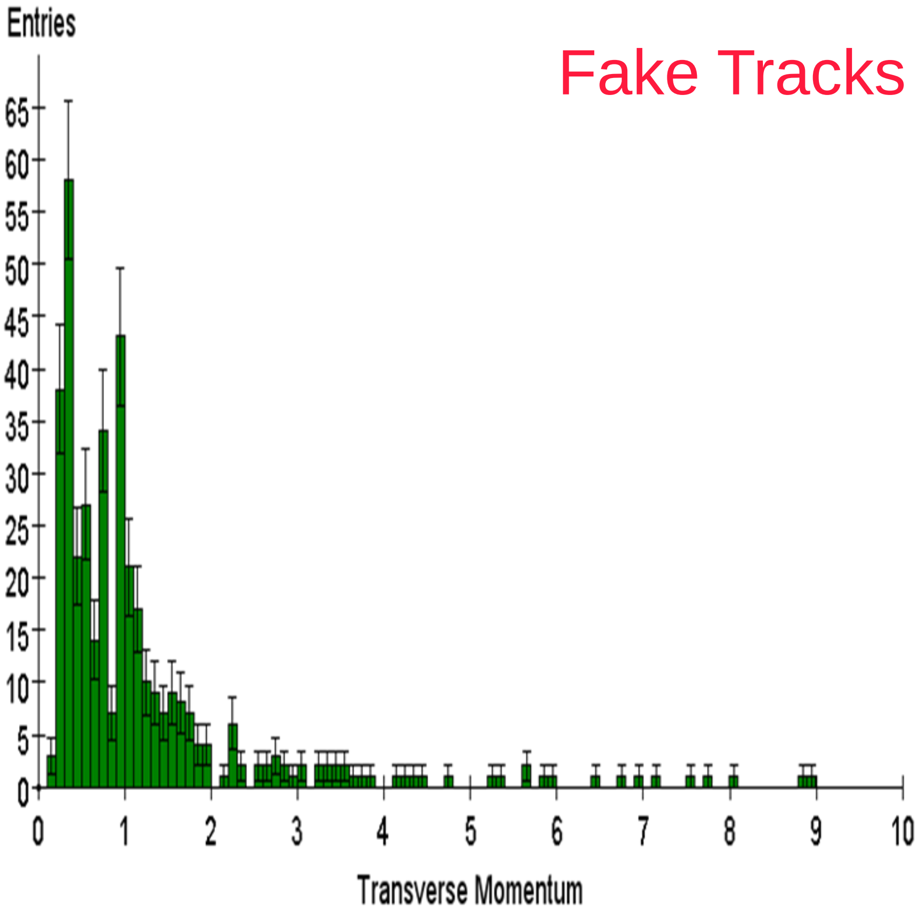
- Fake tracks are generally in the central region where the tracker has only axial strips – z coordinate is only constrained by ~92 mm length of strip

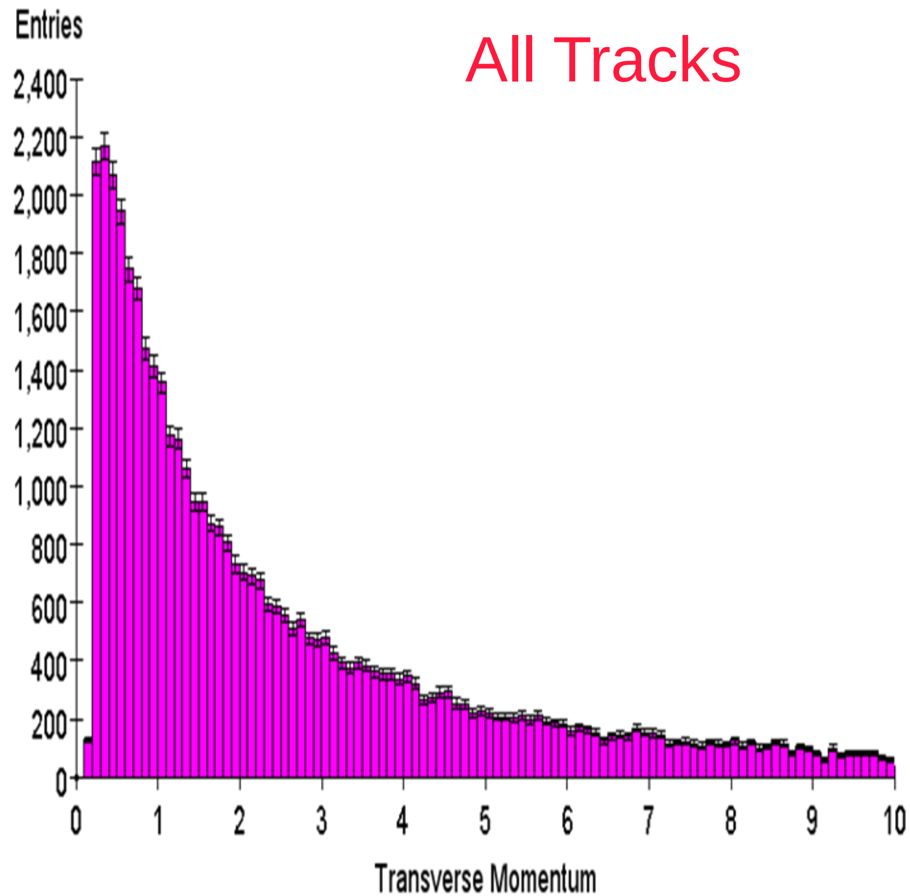




Fake Track Momentum

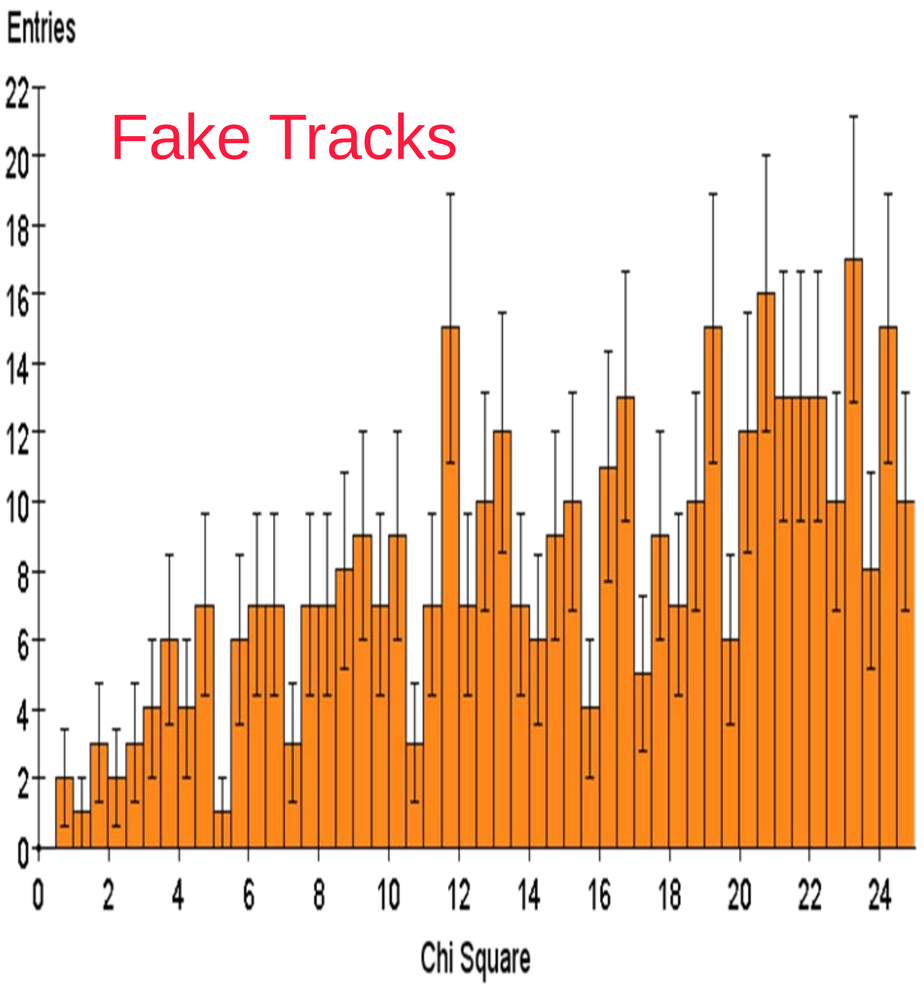
- Fake tracks tend to be low momentum, but there is a tail to high momentum

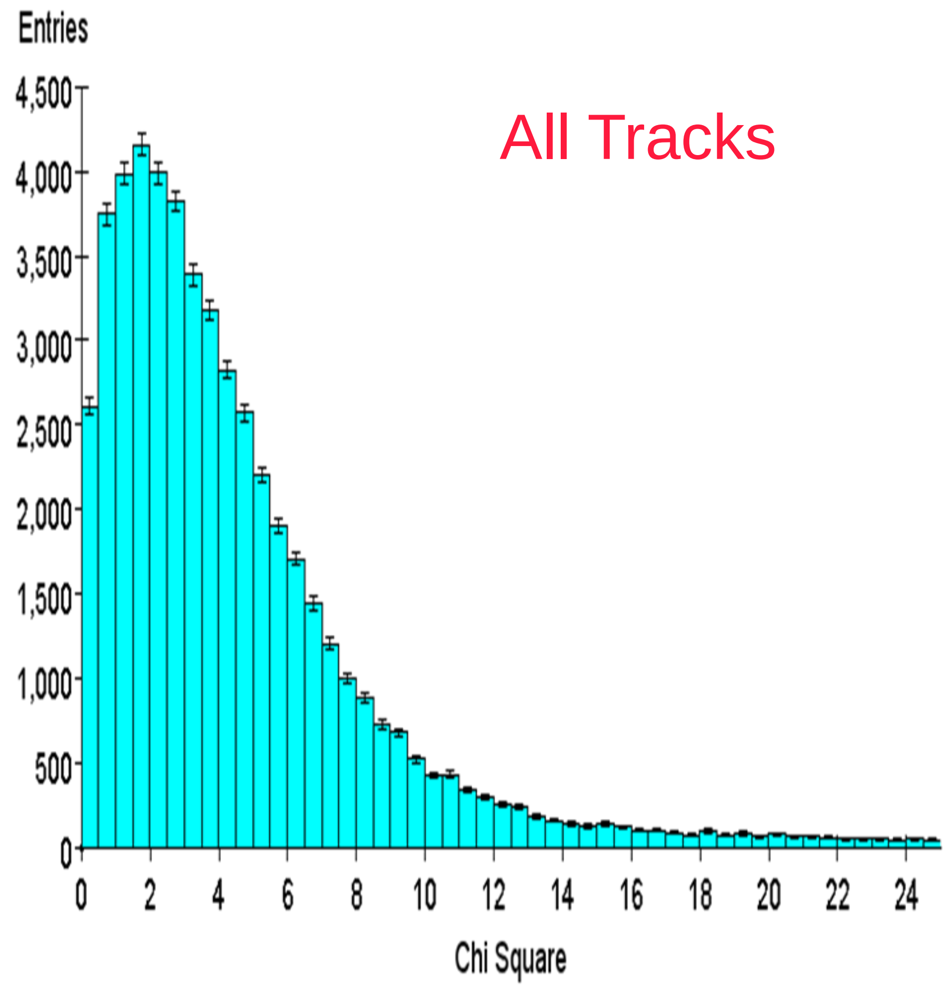




Goodness of Fit

- Fake tracks typically have larger χ^2 than non-fake tracks





Summary

- Introduction of planar sensors and realistic hit digitization has improved realism of SiD tracking simulations
- Tracking efficiency for findable tracks in 1 TeV ttH events is ~99% with these improvements
  - Very similar to what was achieved in the LOI for 500 GeV tt events
- Fake track rate for 1 TeV ttH events is ~0.8%
  - Roughly an order of magnitude higher than in the LOI
  - Fakes have minimum multiplicity, concentrated in barrel region
  - If this fake rate proves problematic, can either increase number of hits required for a track (with some loss of efficiency at low momentum) or introduce additional measurements (stereo or pixel layers in tracker)
- Algorithm improvements (and a few bug fixes) have substantially improved track reconstruction speed
  - Average of 120 seconds / event for complex 1 TeV ttH events
  - See talk in software session later today