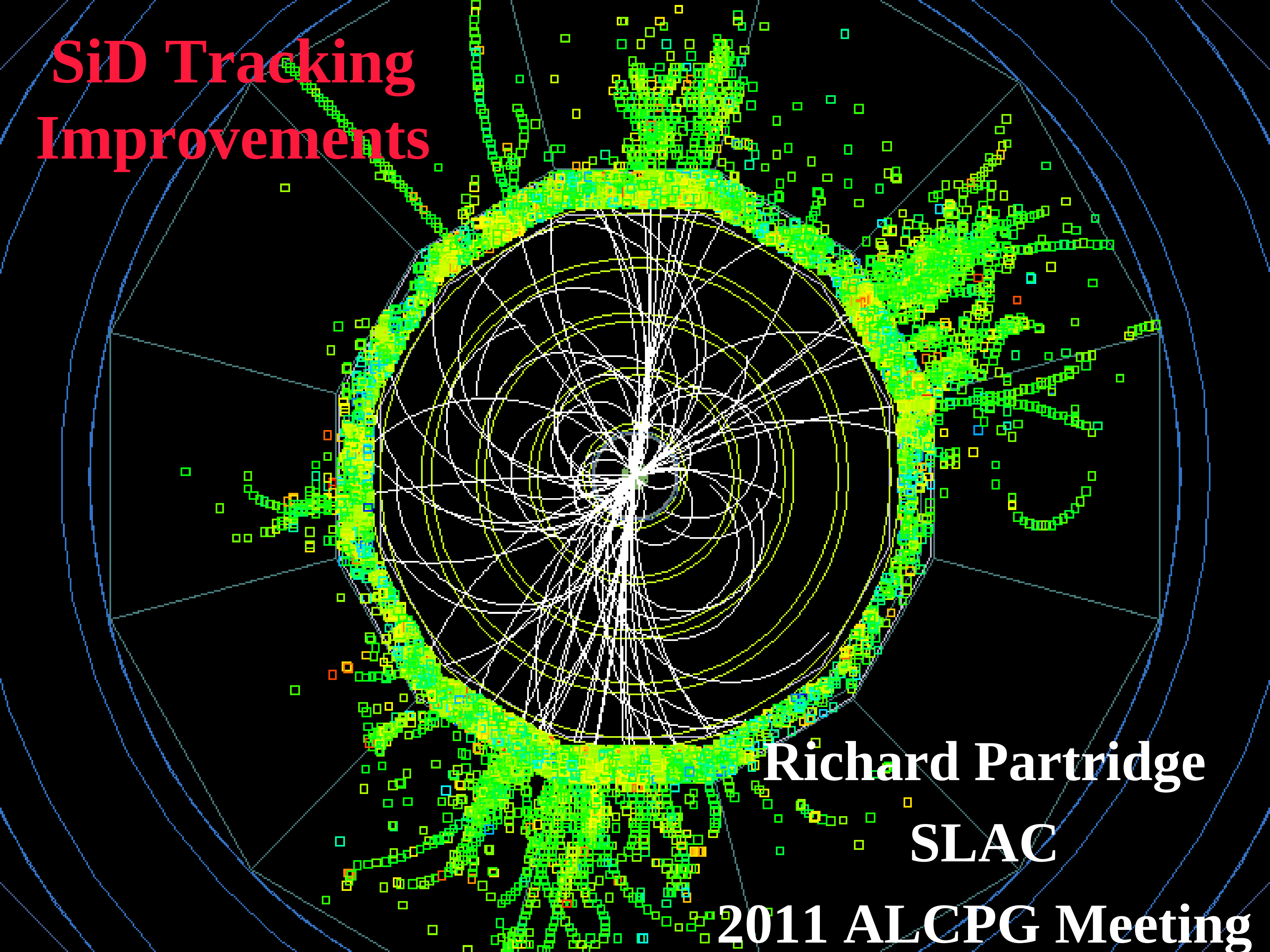
SiD Tracking Improvements



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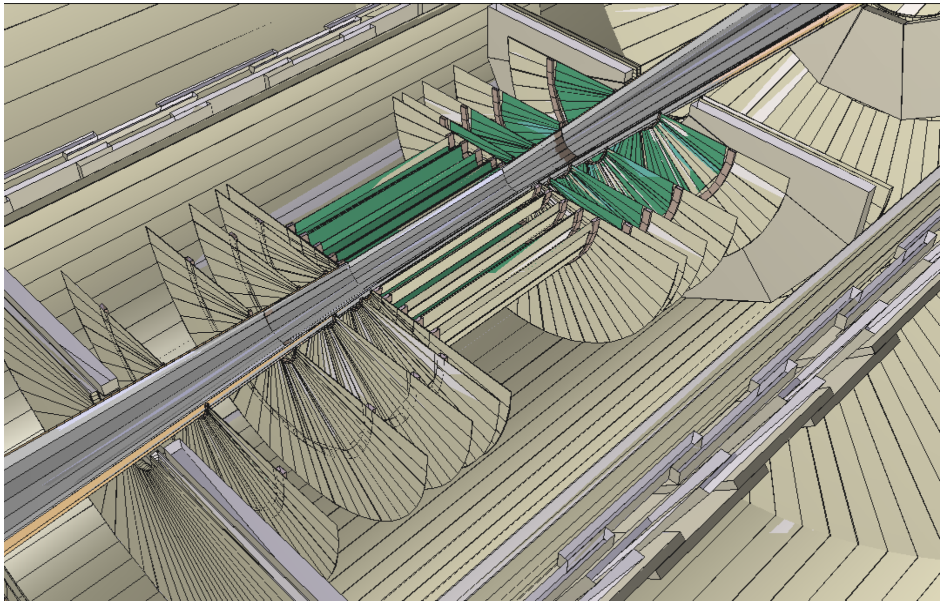
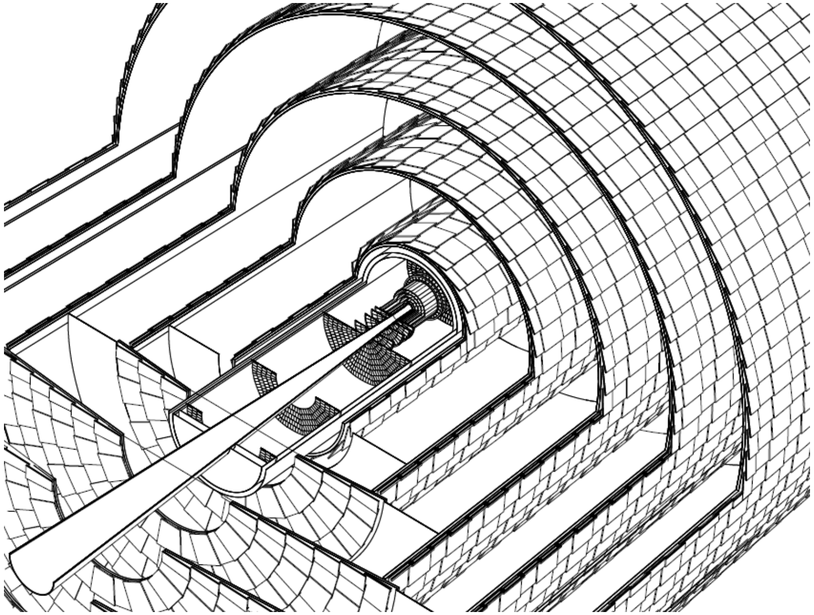
2011 ALCPG Meeting

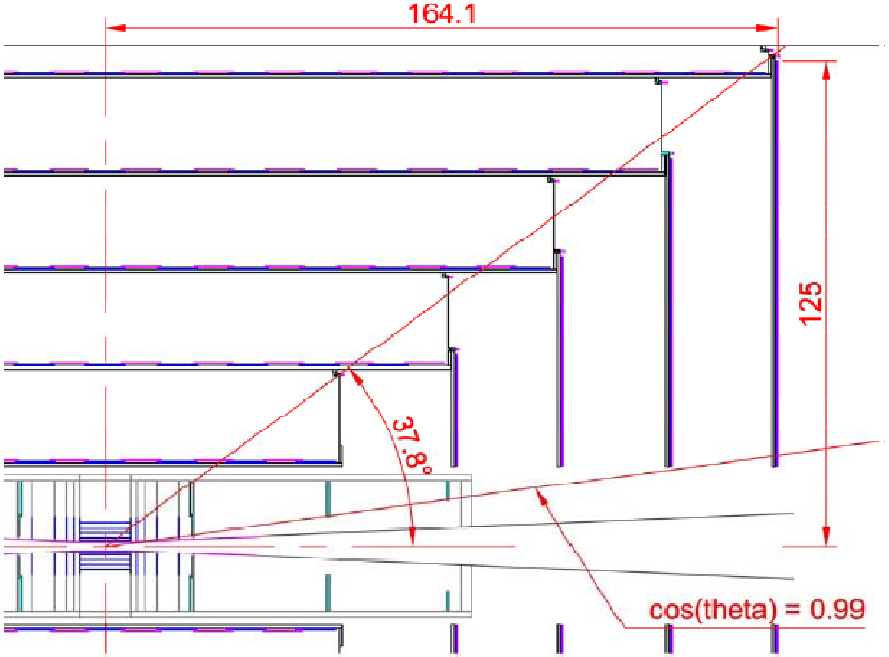
Tracking in SiD

- 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



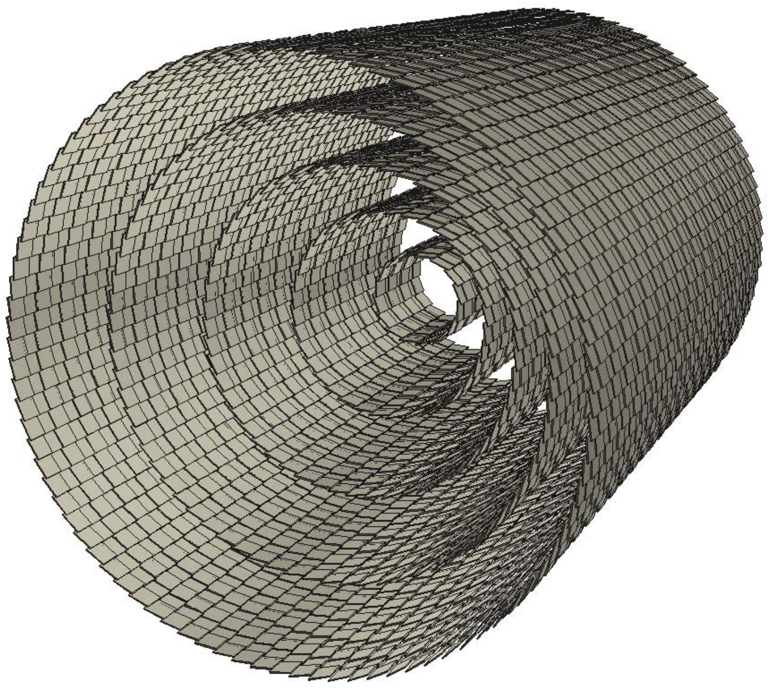


New Planar Geometry



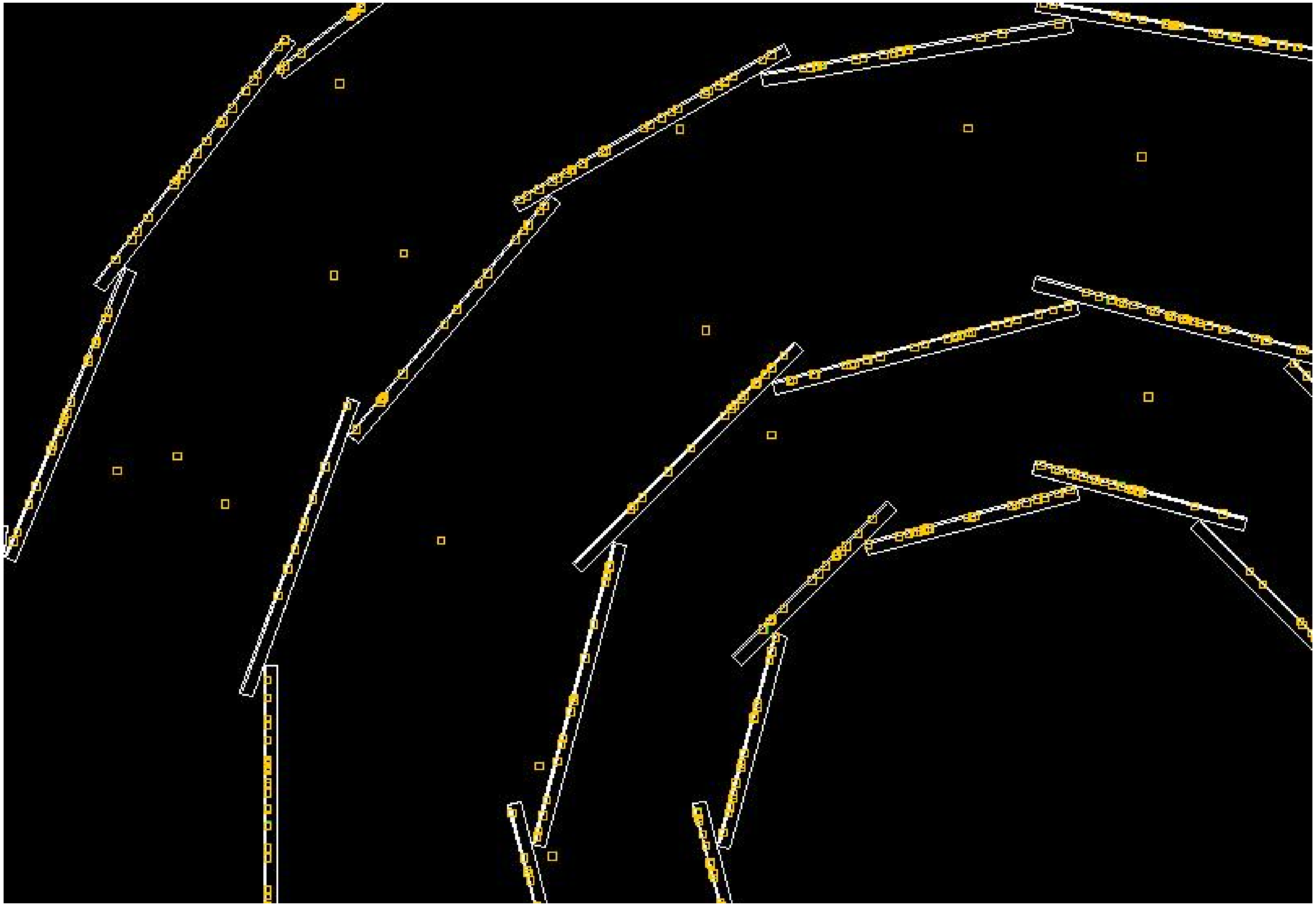
LOI geometry consisted of cylinders and disks with virtual segmentation

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

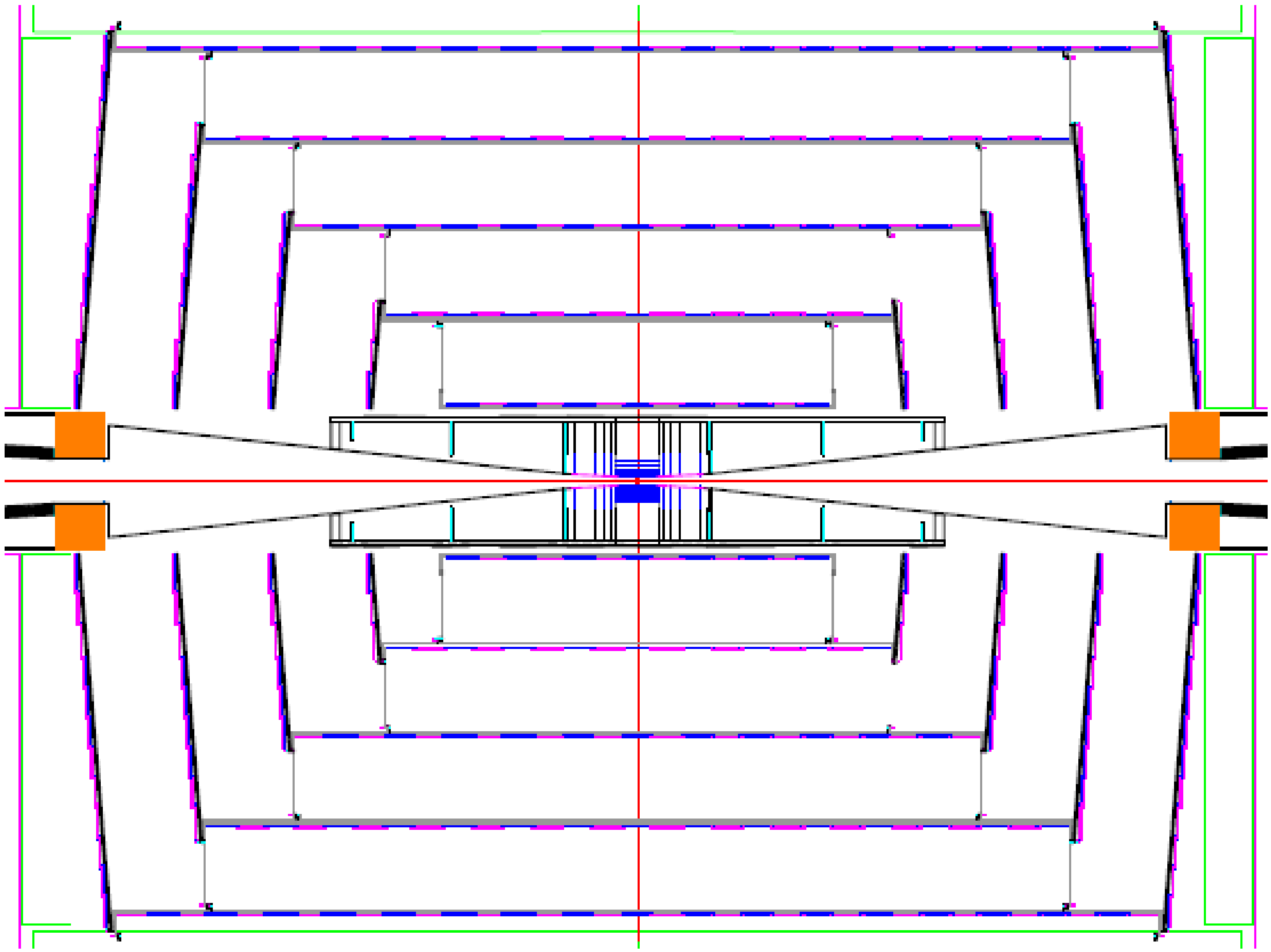


Realistic Detector Geometry

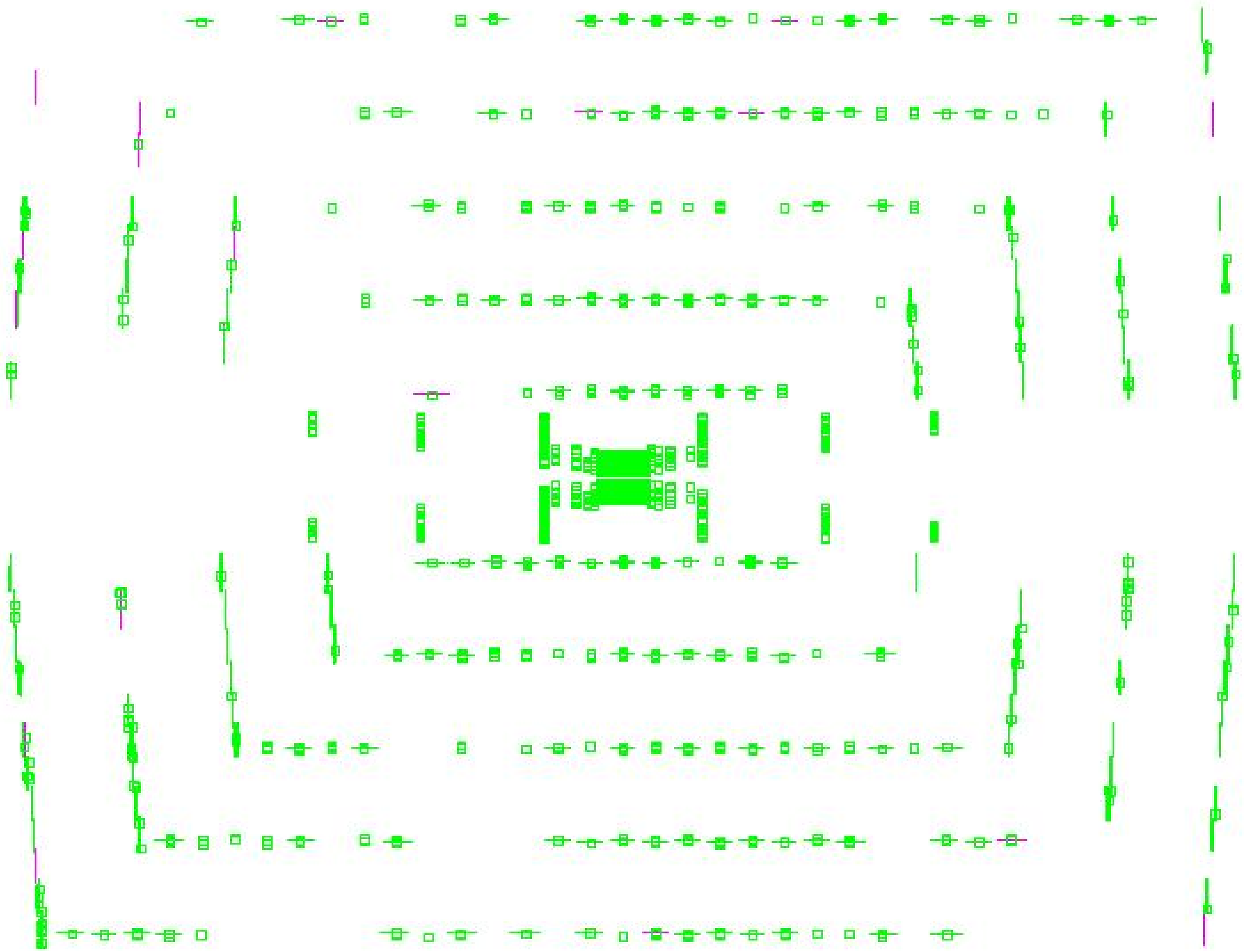
- Blow-up of vertex detector showing hits on planar sensors



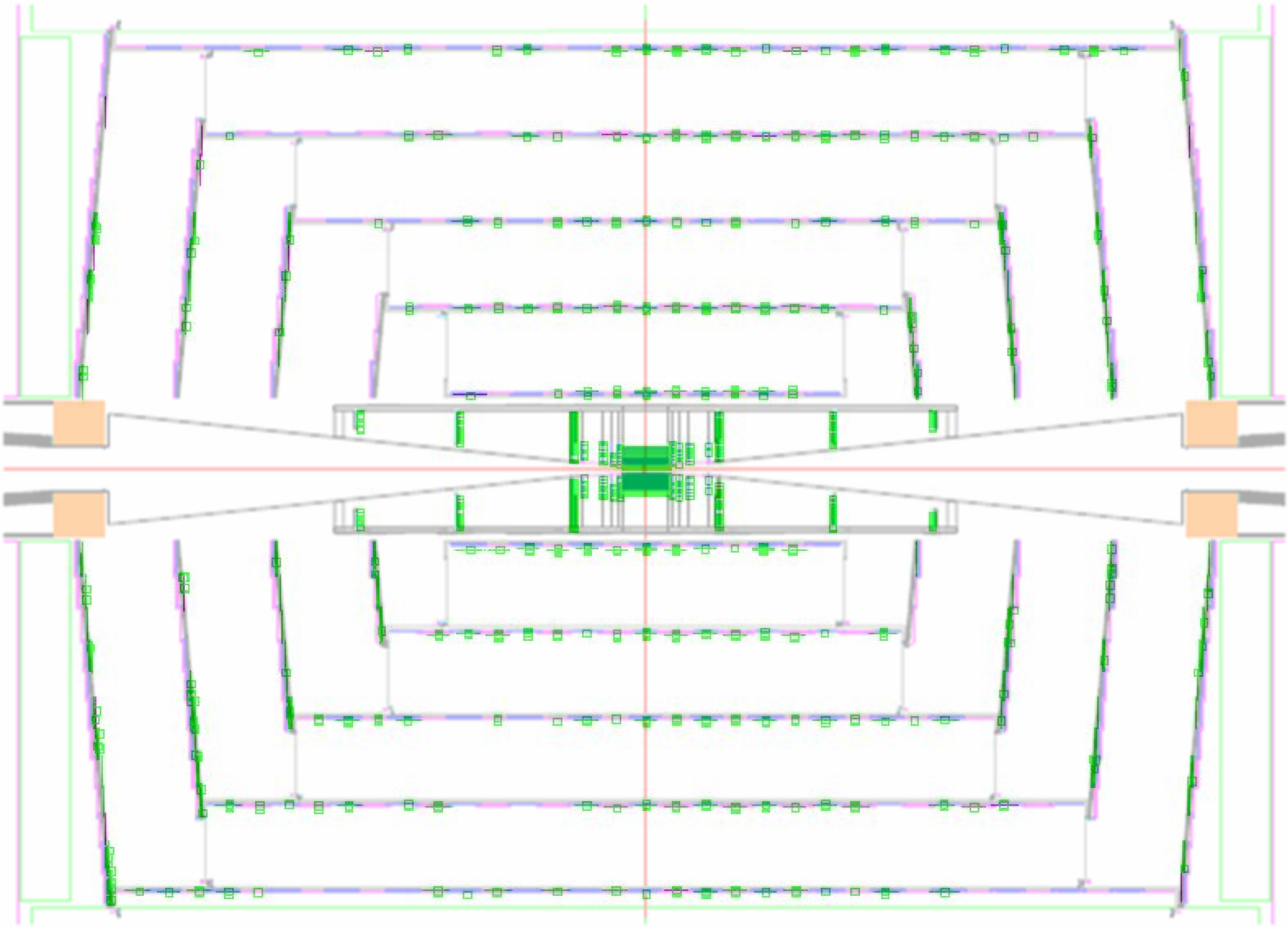
SiD LOI Geometry – CAD Drawing



SiD LOI Geometry – Event Display



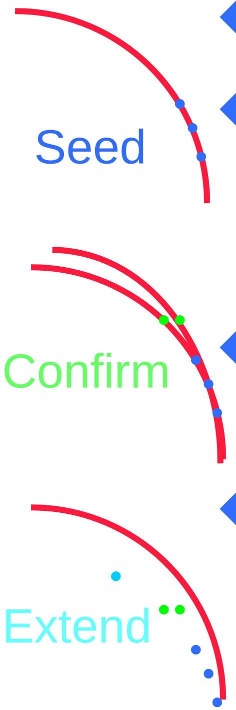
Event Display / CAD Drawing Overlay



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

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

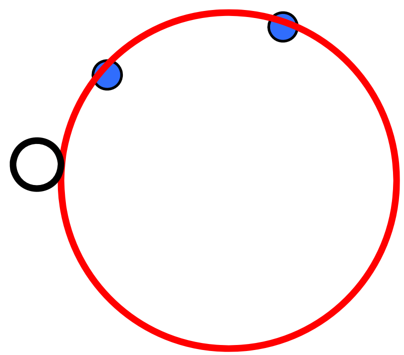
- The user interacts with the track reconstruction program by specifying one or more "strategies"
- Typical strategy requirements:
  - At least 7 hits on the track
    - Only 1 hit per layer
    - Special barrel only strategy with 6 hits used to pick up low-p_T particles in the central region
  - $p_T > 0.2$ 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)

Efforts to Improve Tracking Speed

- Sectoring of detector
  - Detector partitioned into sectors in azimuth and z coordinate
  - Ignore hits in sectors that can't contribute to a trial track
- Improved fast check on hit pairs before doing a helix fit
  - Details on next slide
- Identify track candidates that will not survive merge criteria
  - If a track seed shares 2 or more hits with a track candidate, the seed will have to be judged a better track candidate in order for it to survive
  - Can often terminate process of adding hits to the track early if it is destined to be judged a poorer track candidate (fewer hits or larger χ^2)
- Grouping of endcap sensors in multiple scattering calculation
  - Sensors for a given tracker layer are grouped together for estimating the multiple scattering uncertainty
  - At some point, a change in the geometry infrastructure resulted in the endcap sensors being treated individually rather than as a group
  - Total material was correct – just slowed down track finding

FastCheck Criteria

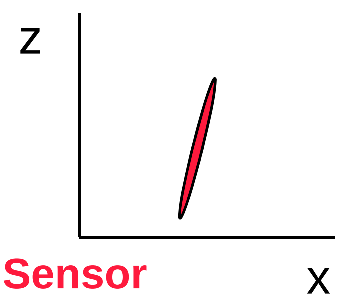
- The FastCheck class is used to see if a given pair of hits is consistent with the p_T and DCA requirements for the strategy
- This algorithm was "improved" when I finally figured out how to solve for the circle(s) passing through 2 hits that is tangent to a circle whose radius is the maximum DCA
  - Can use this to determine the allowed p_T range for these two hits
  - Reject hit pairs inconsistent with the minimum p_T cut



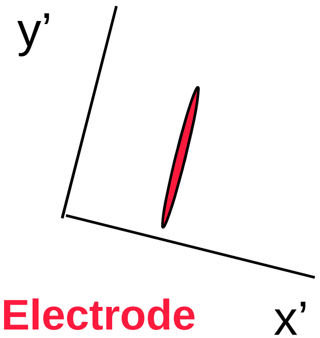
- New algorithm was also gave accurate determination of range in arc lengths s_1, s_2 used to check consistency with the impact parameter in the s-z plane

Endcap Hit Digitization Bug

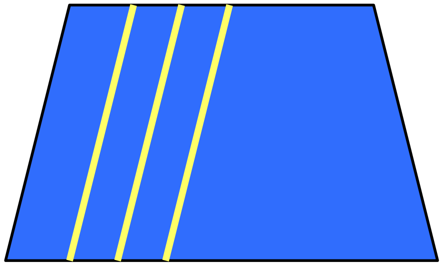
- 3 coordinate systems used in digitization
  - Global – lab coordinates
  - Sensor – used to specify sensor geometry
  - Electrode – aligned with strips, not part of the geometry infrastructure
- Hit code used sensor coordinates to get position uncertainty
  - At the time, the sensor and electrode coordinates were identical ⇒ no problem
  - As endcap detectors were made more realistic, we switched to trapezoidal sensors with strips parallel to one side and electrodes rotated relative to sensor
- Uncertainty in x coordinate used for hit uncertainty
  - Uncertainty in sensor x coordinate >> uncertainty in electrode x coordinate
  - Hit uncertainty found to be a few mm – roughly a factor of 100 too large



Sensor Coordinates



Electrode Coordinates



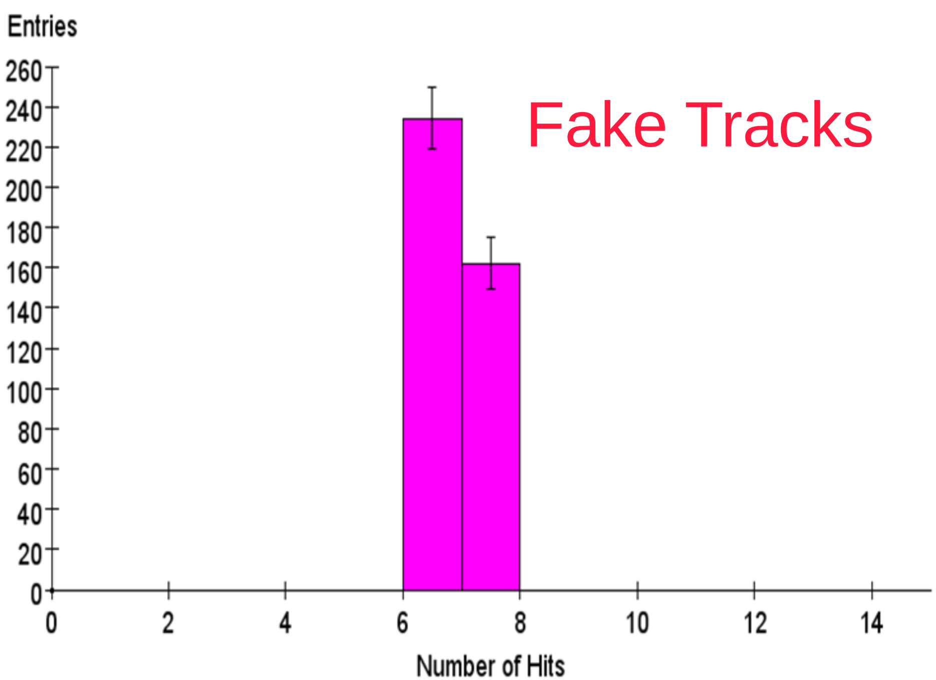
Trapezoidal Endcap Strip Sensor

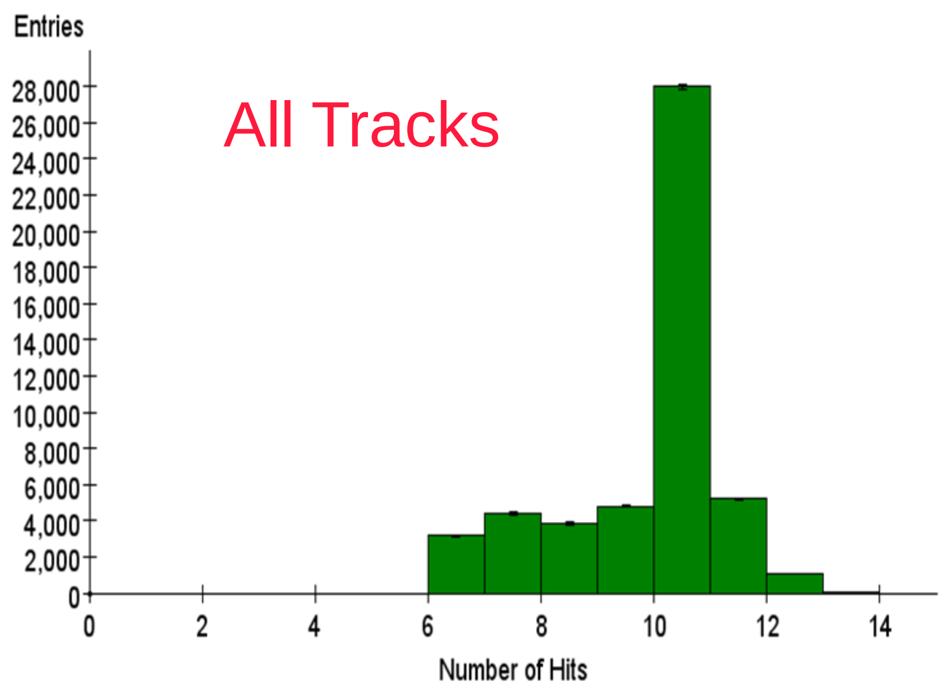
Impact of Digitization Bug

- Bug didn't break the tracking code in an obvious way
  - Hits were still found
  - Tracks were formed with good efficiency
- Fake track rates were larger than for the LOI for complicated events, but some increase was expected
  - ~1.6% for 1 TeV ttH events vs 0.07% for 500 GeV tt events
  - High momentum fake tracks were impacting Ron's PFA studies, tracking this down led to finding / fixing this bug
  - With large hit uncertainties, fake track rate is greatly increased since the χ^2 penalty for picking a random nearby hit is small if the uncertainty is large
- Bug has been present in all sidloi3 and CLIC SiD' studies prior to March 17
- Bug also had a significant impact on the Tracking time
  - Many more track candidates needed to be followed through the tracker
  - Especially large impact on dense forward jets, giving long tails to CPU time/event

Fake Tracks Rates after Bug Fix

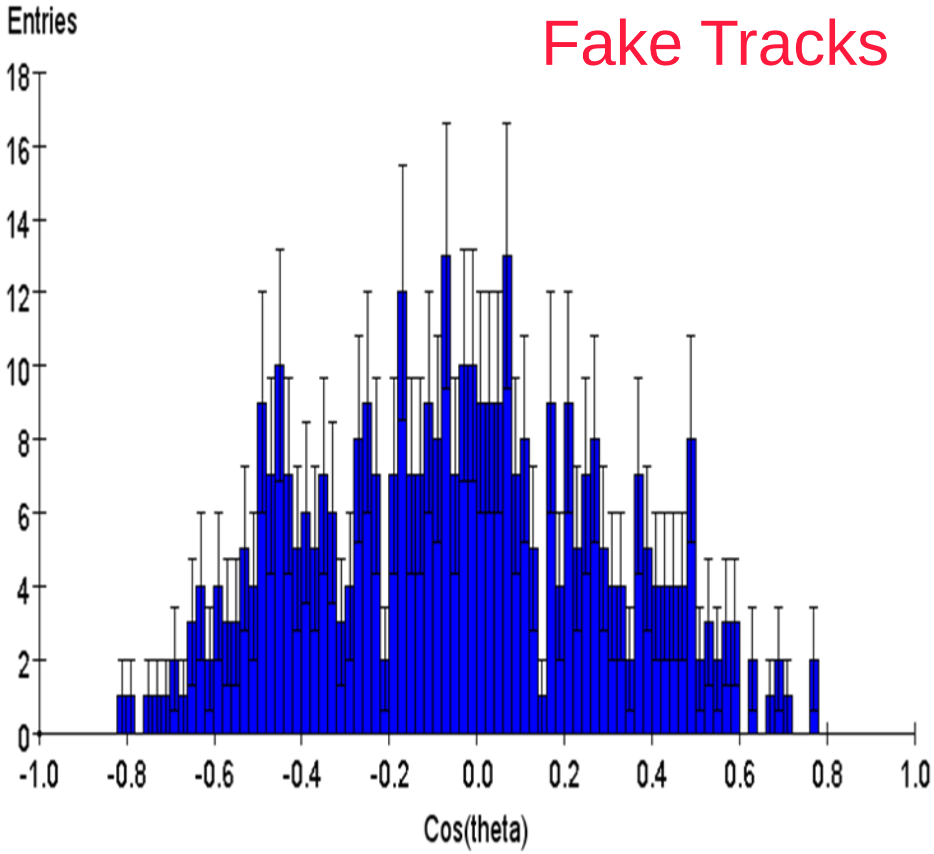
- Define a fake track as one that has fewer than half of its hits from a single MC particle
- Fake track rate in 1 TeV ttH sample (0.79%) is considerably higher than seen in the LOI for 500 GeV tt sample (0.07%)
- Fake tracks have minimum number of hits allowed

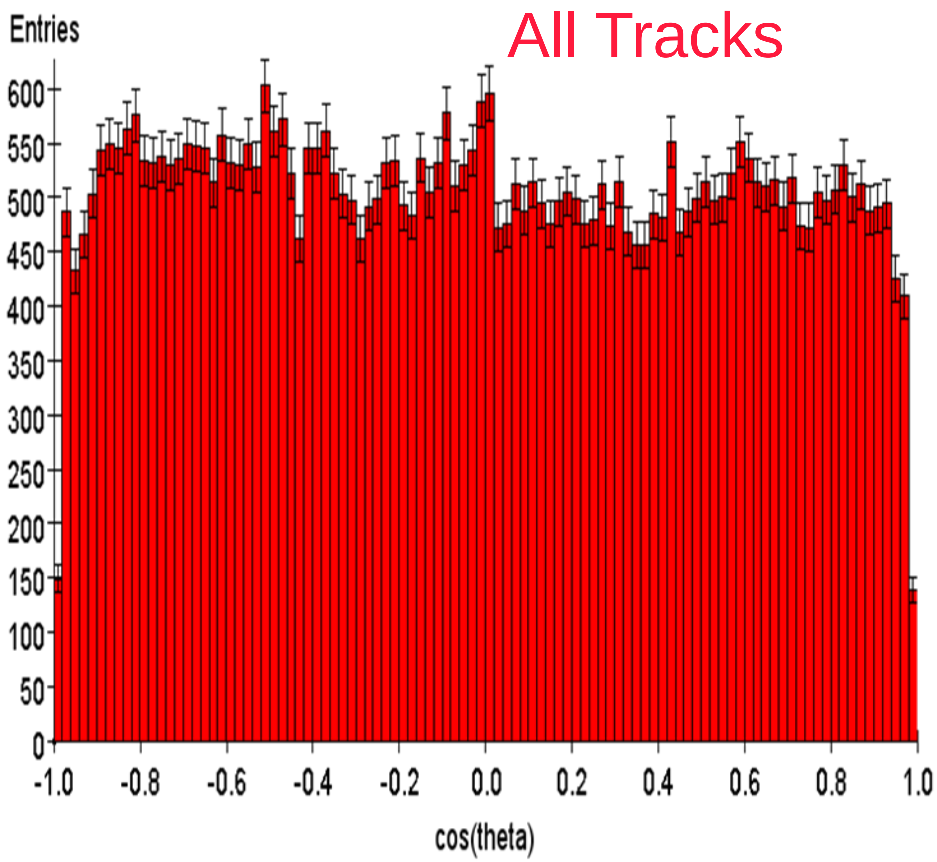




Where are Fake Tracks Located?

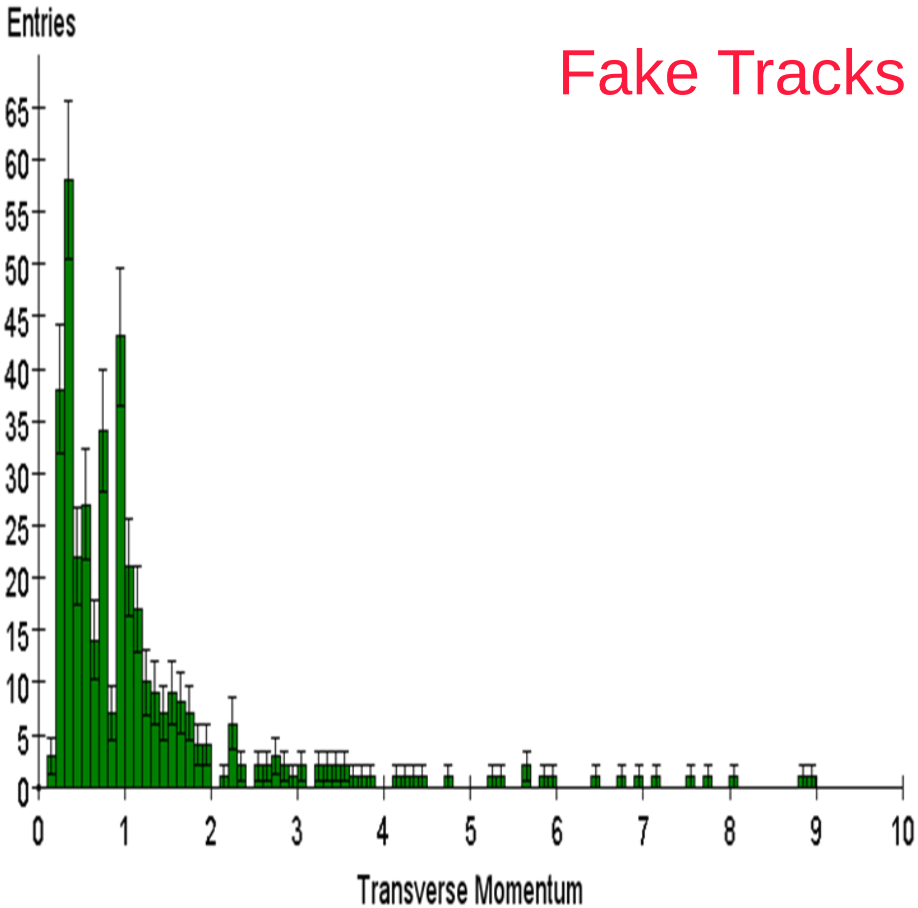
- Fake tracks are generally in the central region where the tracker has only axial strips – z coordinate is only constrained by ~92 mm length of strip

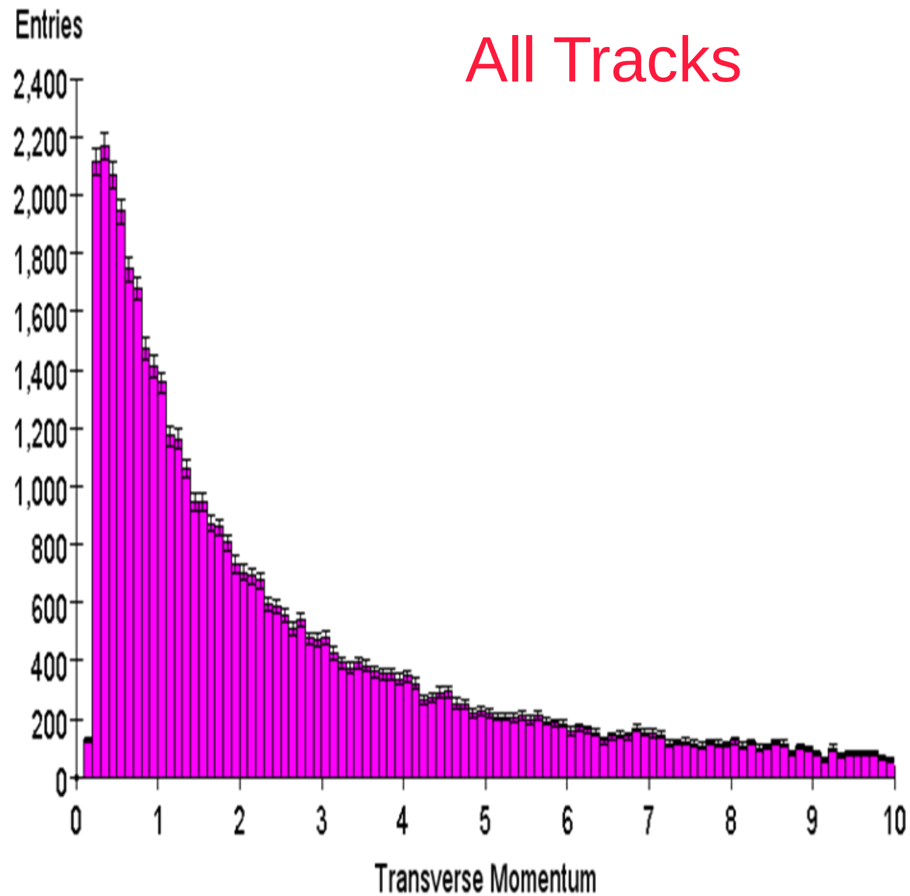




Fake Track Momentum

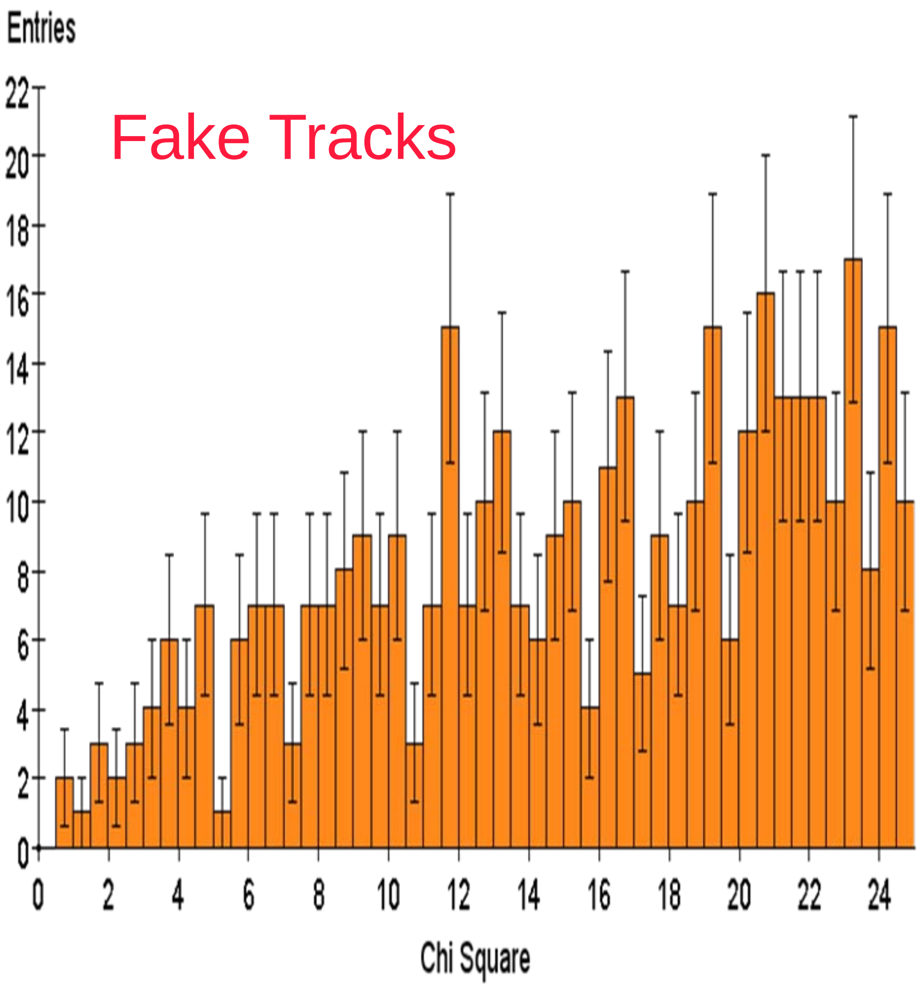
- Fake tracks tend to be low momentum, but there is a tail to high momentum

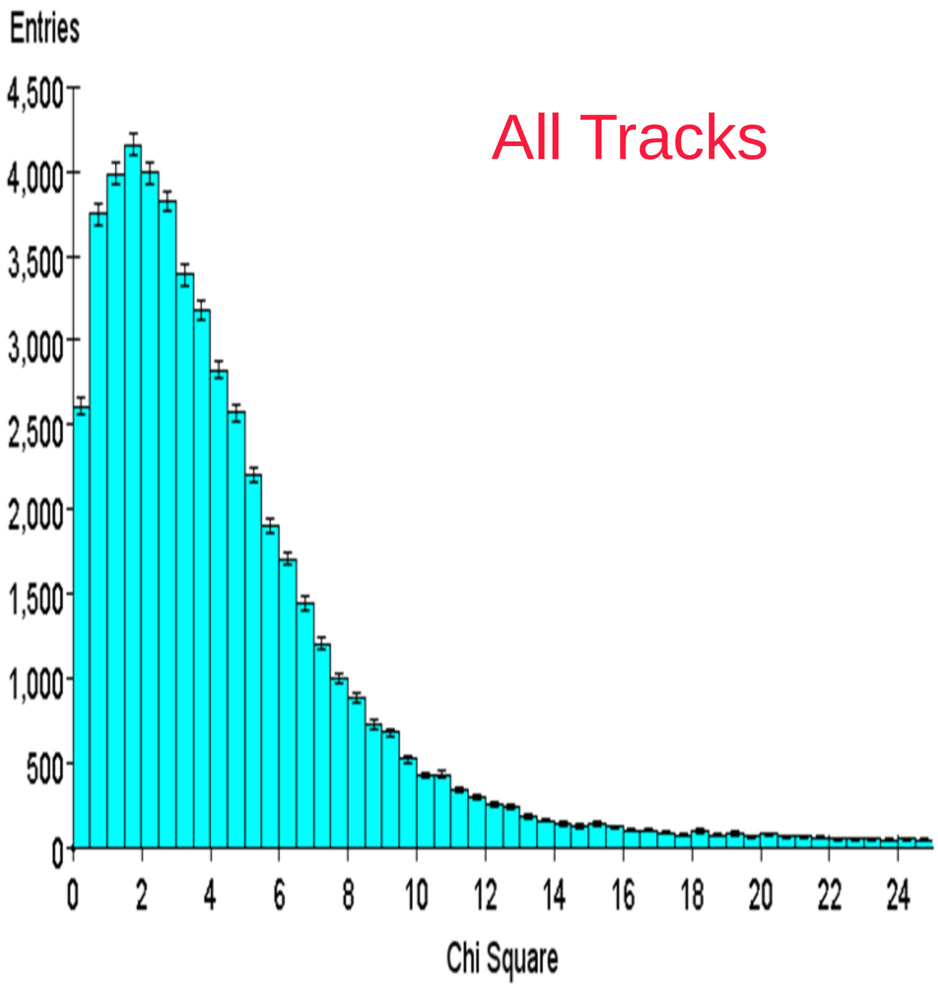




Goodness of Fit

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





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

Summary

- LOI demonstrated that an all-silicon tracker with ~10 hit measurements would give excellent performance at the ILC
- Substantial effort in developing a more realistic detector
  - Planar sensors model each individual sensor
  - Detailed charge collection modeling, strip clustering, and hit making
- Several efforts to improve tracking speed
- From Norman Graf:
  - w33005 (t tbar h @ 1 TeV) 1.58
  - uds500 (light quarks @ 500GeV cms) 1.85
  - w33129 (W+W- -> jj e nu @ 1TeV) 8.97
  - w33133 (W+W- -> jjjj @ 1TeV) 29.33
- From Christian Grefe:
  - 1 TeV dijets improved from 73seconds/event to 13.7 seconds/event
  - Jobs no longer time out due to reduced tails of timing distribution