Developments in Tracking with STAR's Heavy Flavor Tracker

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STAR Office of Science U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY

Outline

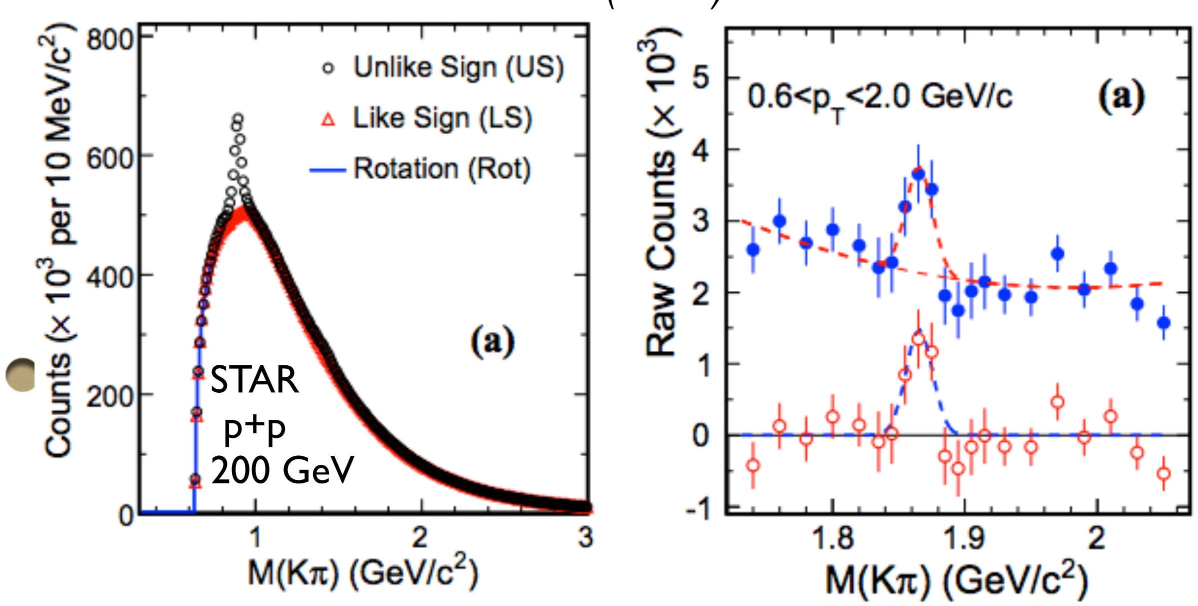
- Introduction: STAR's Heavy Flavor Tracker (HFT) Program
- Alignment calibrations
  - HFT internal
  - HFT-to-TPC (global)
- Tracking
  - Material accounting
  - Using HFT hits
- Conclusions
  - Early results
  - Summary

Introduction

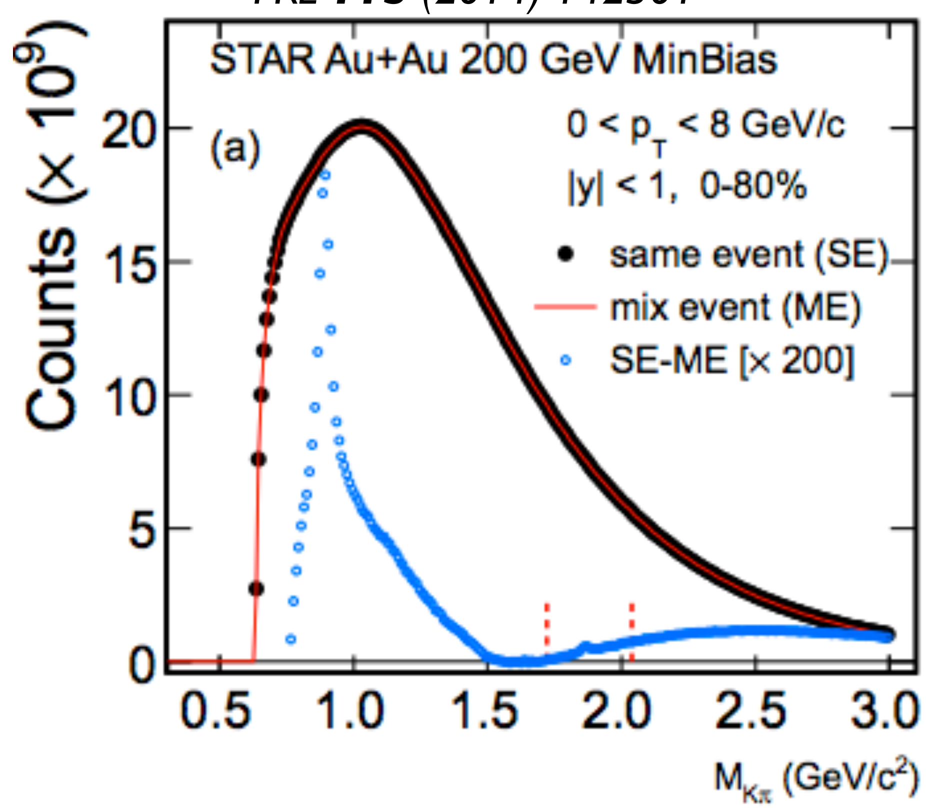
Physics

- Combinatorial D^0 reconstruction without topology is possible, but with low signal-to-noise, physics measurements beyond cross sections are challenging at best

*PRD **86** (2012) 72013*

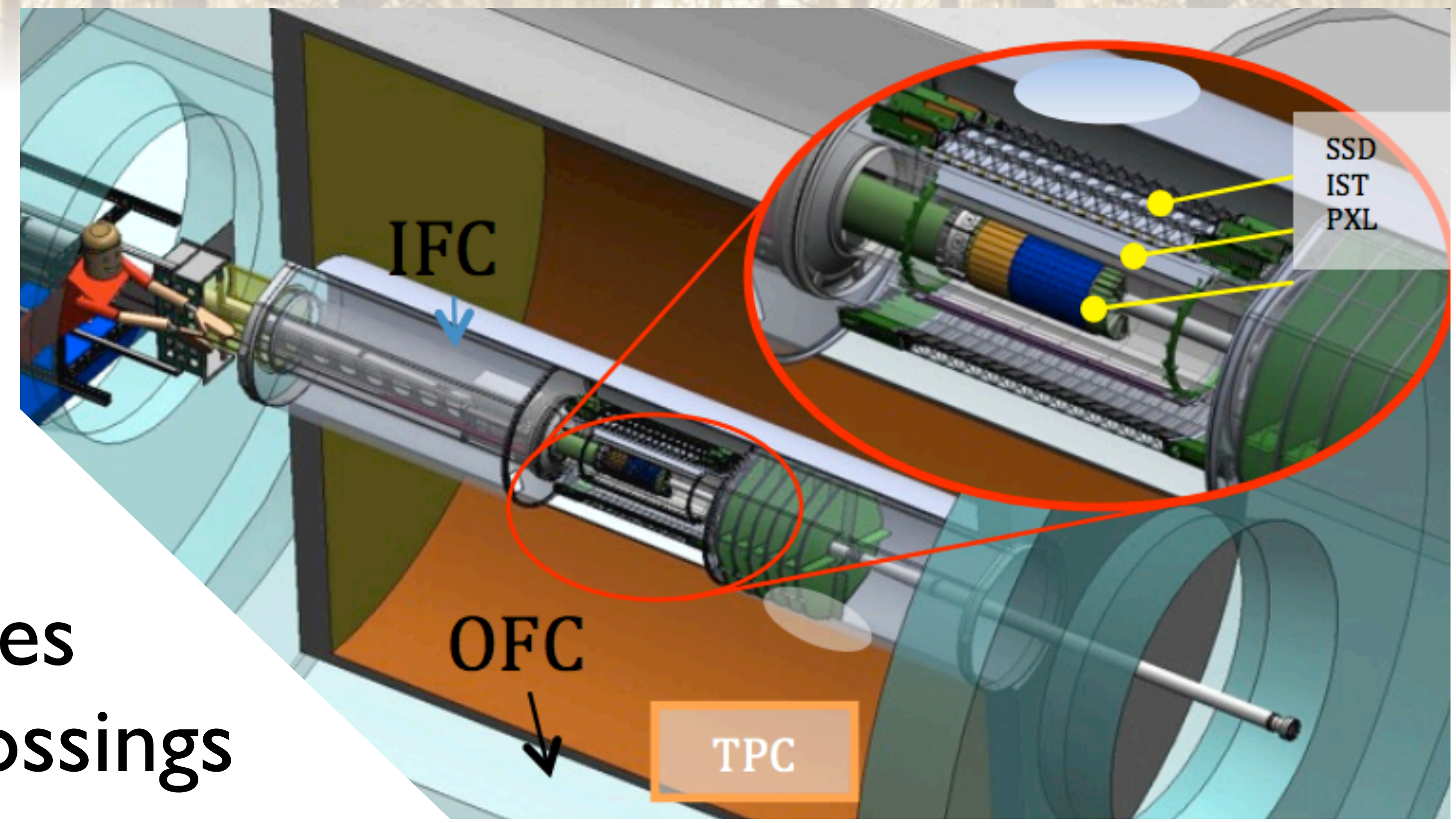


*PRL **113** (2014) 142301*



- Goal: topologically identify charm decays with sufficient signal-to-noise to clearly determine heavy flavor behavior in the medium produced in high energy heavy ion collisions

Mid-rapidity tracking



- Quick STAR overview:
  - 0.5 T solenoidal B field
  - "TPC": readout at radii of ~60-190 cm, integrates ~400 collider bunch crossings
  - "SSD": fast double-sided (stereoscopic) silicon strips at radii of ~22 cm (not presented in this talk)
  - "IST": fast single-sided silicon pads at radii of ~14 cm
  - "PXL": 20.7 x 20.7 micron Monolithic Active Pixel Sensors (MAPS) at radii of ~2.8 cm and ~8 cm, integrates for ~1750 collider bunch crossings

HFT

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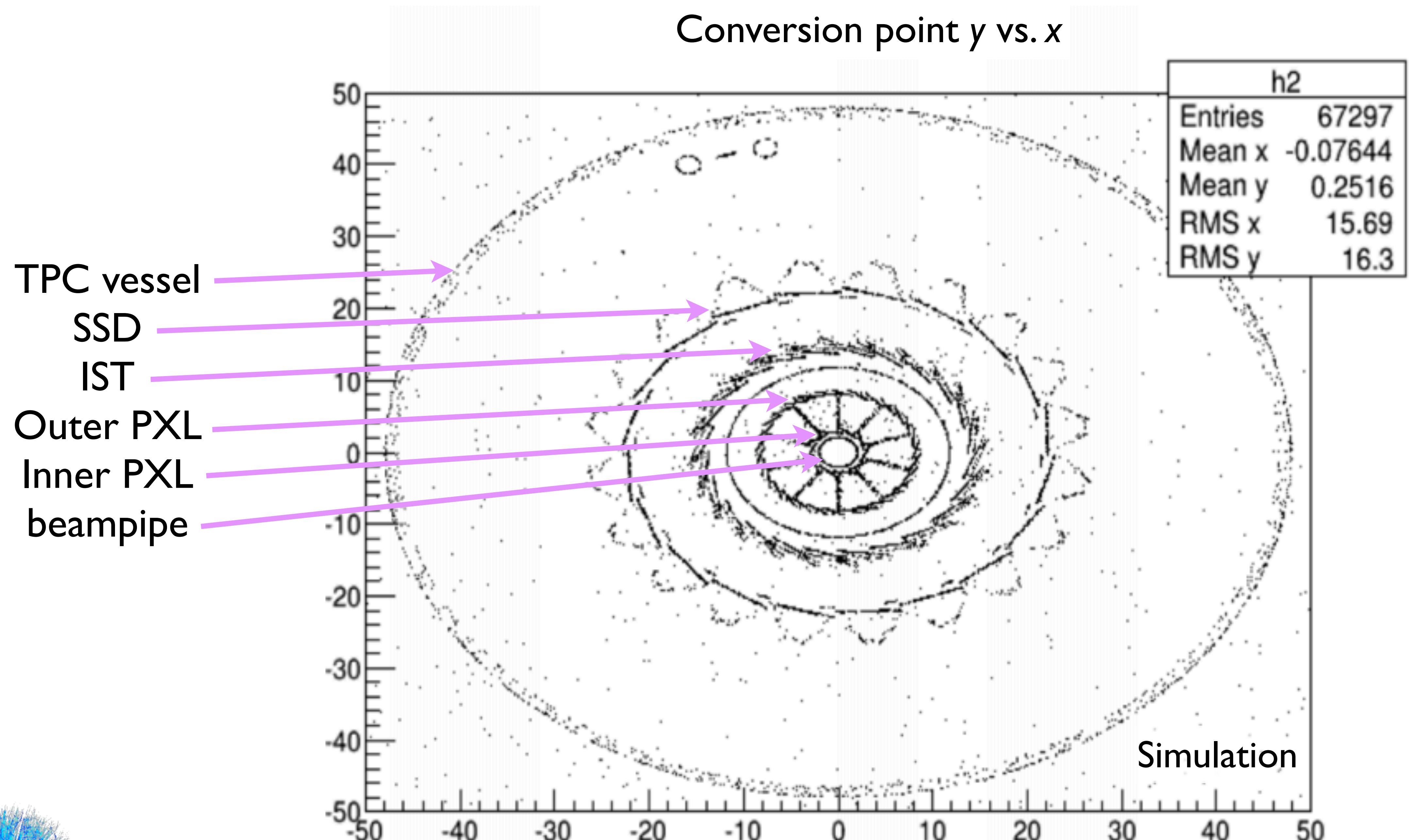
STAR structures

- A less typical way to show geometries: inner-STAR via conversions tomography



Alignment Calibrations

Primary contributors:

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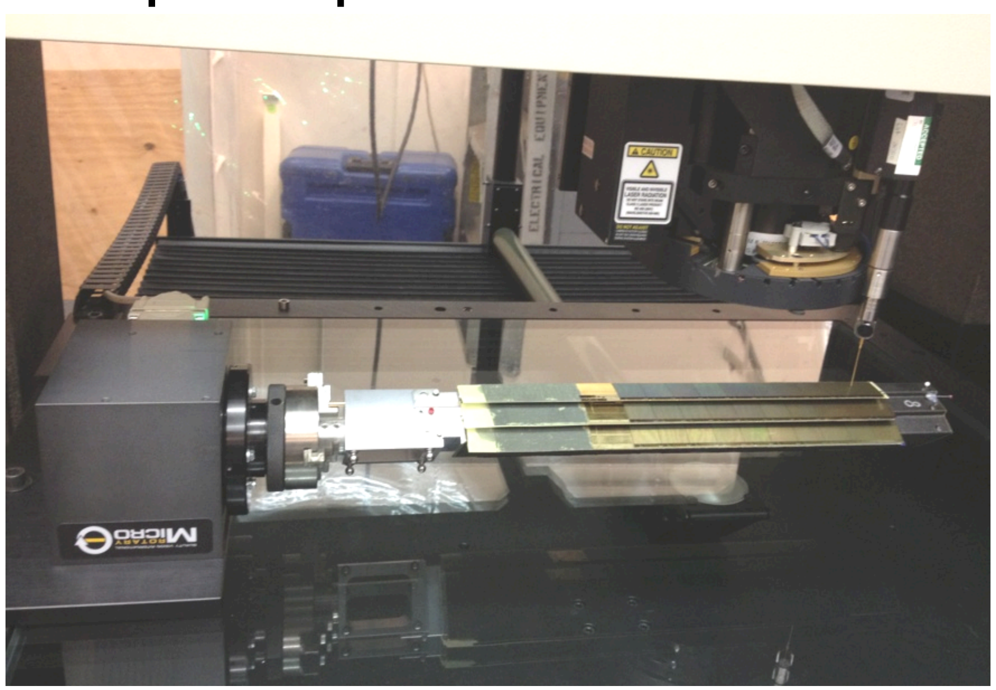
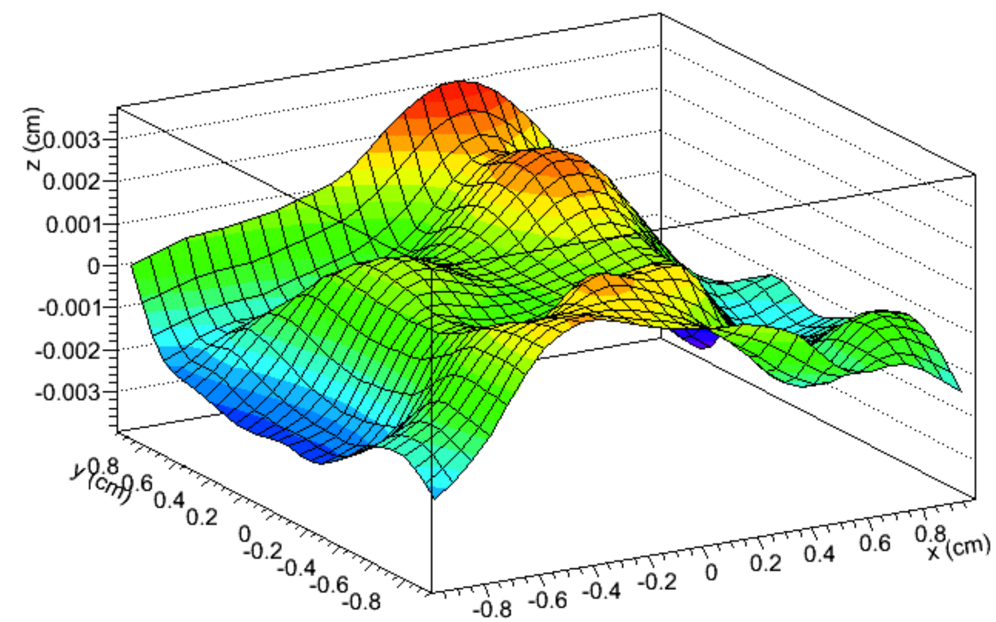
Survey

- Survey serves as the starting point
- Visual & stylus scan of the PXL sensor surfaces on-sector
  - Deviations from planarity (of order few tens of microns - a little larger than hit reconstruction errors, though projectively a little smaller) fit with thin plate spline

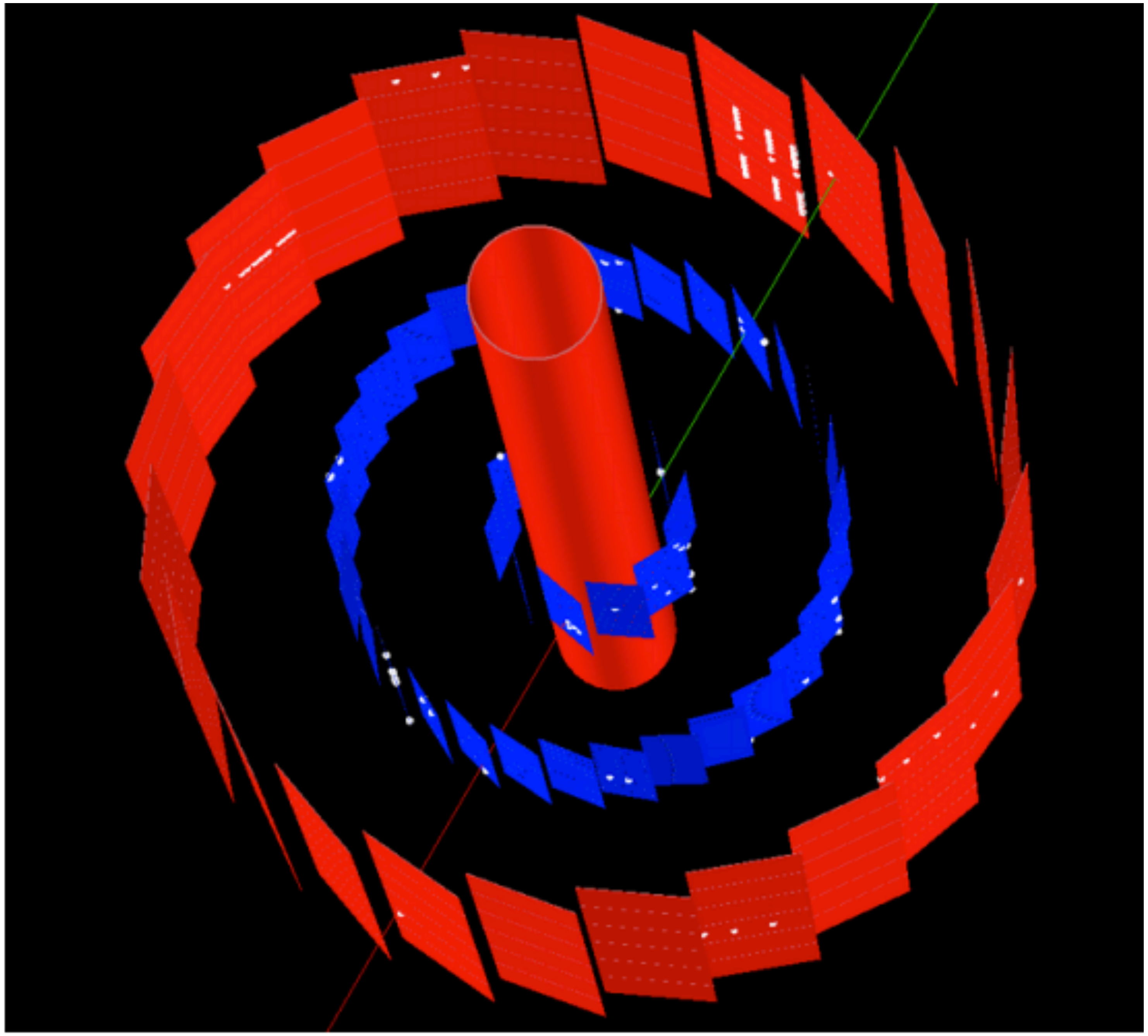




- PXL sensor-to-ladder and ladder-to-sector alignment fixed from survey

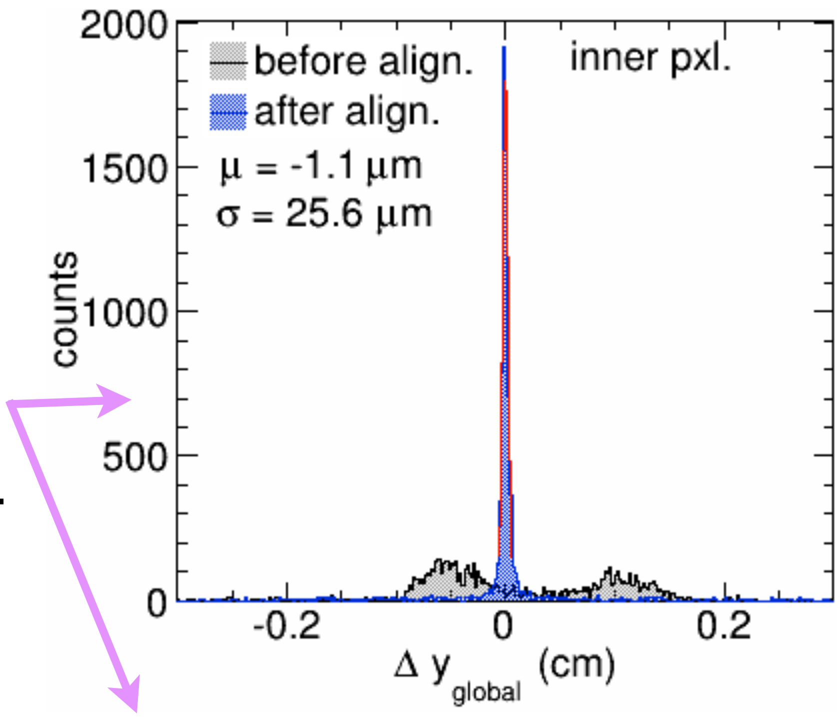
HFT internal alignment

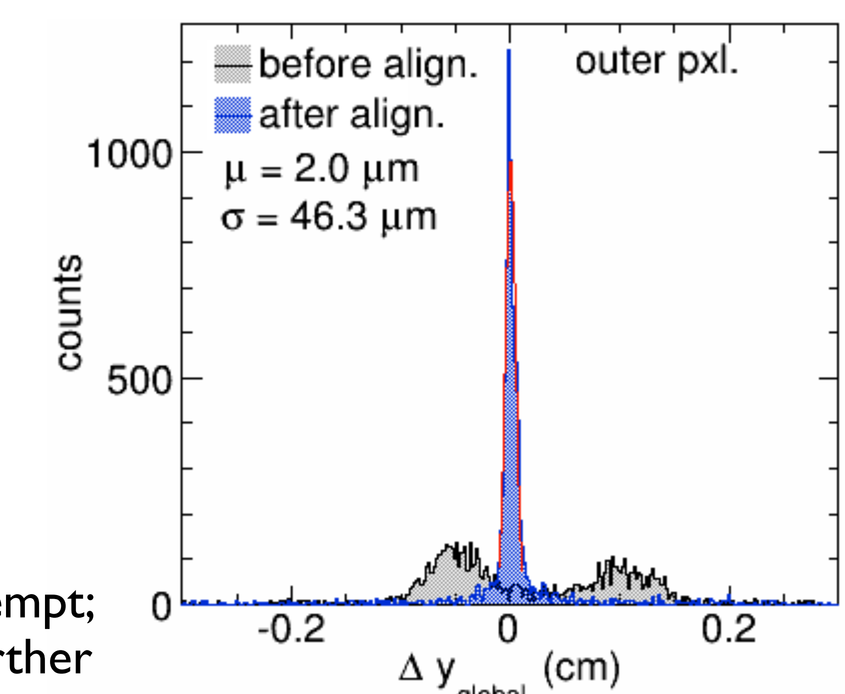
- Zero magnetic field cosmics
  - Straight-line tracklets formed with HFT hits alone which cross through ~middle of HFT



HFT internal alignment

- Zero magnetic field cosmics
  - PXL internal alignment
    - Coarse alignment: PXL-half-to-PXL-half
    - Fine scale: each sector aligned through residual minimization with multiple sectors on opposite side, using a single sector as the primary reference
    - Achieved hit errors: ~10-20 microns for inner PXL and ~15-30 microns for outer PXL
  - Whole-IST aligned to whole-PXL
  - Attempt to align individual IST ladders showed no notable improvement over survey: retained survey parameters
- Data samples taken at beginning, middle, and end of our Run year showed consistency: alignment was stable



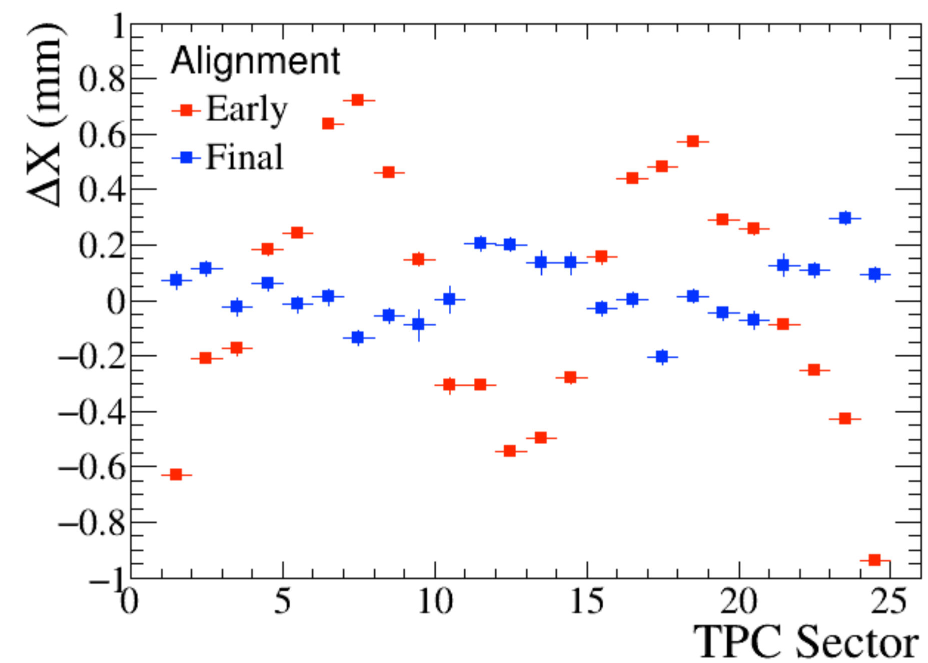


Note: plots show first sector alignment attempt; subsequent attempts improved residuals further

HFT-to-TPC: global alignment

- Field-on cosmics (both B polarities examined)
  - TPC precision is significantly better with field on
  - Use HFT residuals to (high p_T) TPC track projections
- Interdependence between HFT-to-TPC rotation, internal TPC super-sector rotations, and static TPC distortions found to be important
  - Degeneracies remained when attempting to self-calibrate distortions and alignment in TPC
    - HFT-to-TPC alignment exposed TPC issues that were found to improve through iteration between distortion and alignment calibrations
    - Last ambiguities of TPC super-sector alignment determined by HFT itself
- HFT also provided checks/improvement on TPC T_0 and drift velocities

Mean PXL residuals in global *x* vs. TPC sector of track



- Sine wave represents global rotation
- Remaining systematics reflect compromise between what TPC wants and what HFT wants

Tracking

Primary contributors:
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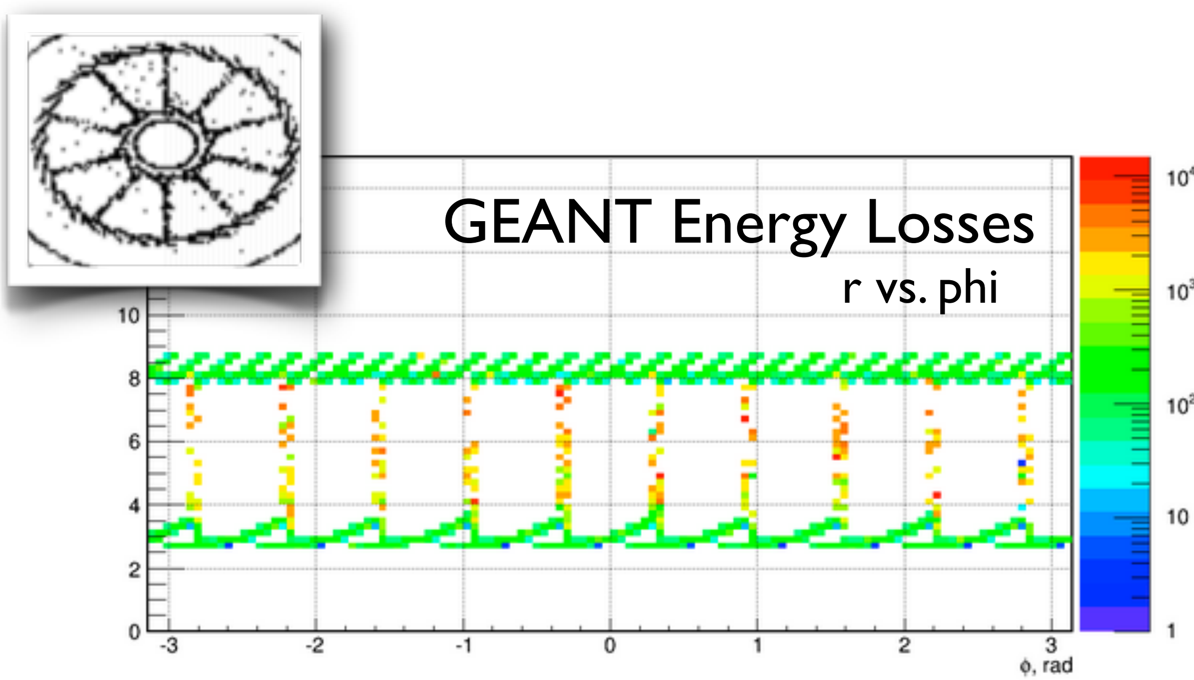
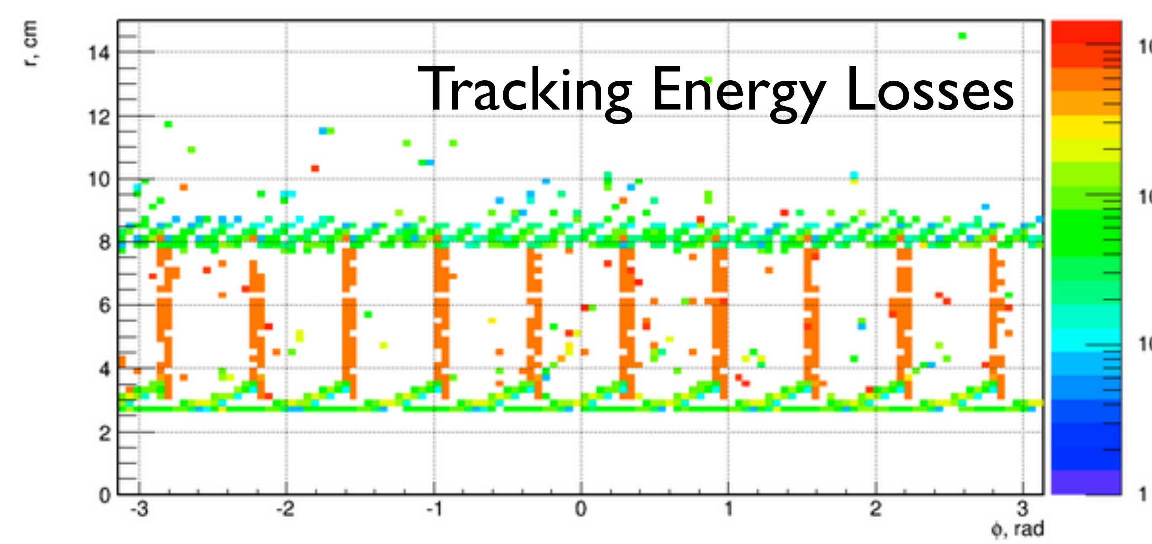
Tracking in STAR

- STAR track reconstruction for final physics has historically focused on transverse physics, using simplified versions of the detector geometries to attain reasonably quick reconstruction times given preciously finite CPU resources
  - Shortcomings in accuracy were sufficient for ~1 millimeter scale precision in mid-rapidity tracking; forward tracking not possible
  - Work needed to advance performance to the requisite sub-hundred microns scale without sacrificing (much) speed
- Effort begun a few years ago to revamp the tracking as part of a larger project extending into simulations *J. Phys. Conf. Ser.* ***396*** *(2012) 022058*
  - Goals: unify geometries in simulation and reconstruction (single abstract interface to GEANT *and* ROOT/TGeo); standard energy loss accounting (GEANT propagator); agnostic to track orientation (e.g. forward detectors, far-from-orthogonality)
  - Concerns: significant QA work to make reconstruction match simulation, and perform at least as well as old tracking; speed (roughly ~twice as slow on just TPC alone)
- Priority given to pushing historical tracker: fewer unknowns with an established foundation, clearer comparability with past results

Geometry QA

- TGeoChecker valuable to find issues with GEANT (TGeo) volumes (e.g. undeclared overlaps and illegal extrusions)
- Tool developed in-house to compare (in simulation) energy losses in tracking in physical space with GEANT proved useful in finding and isolating details of discrepancies

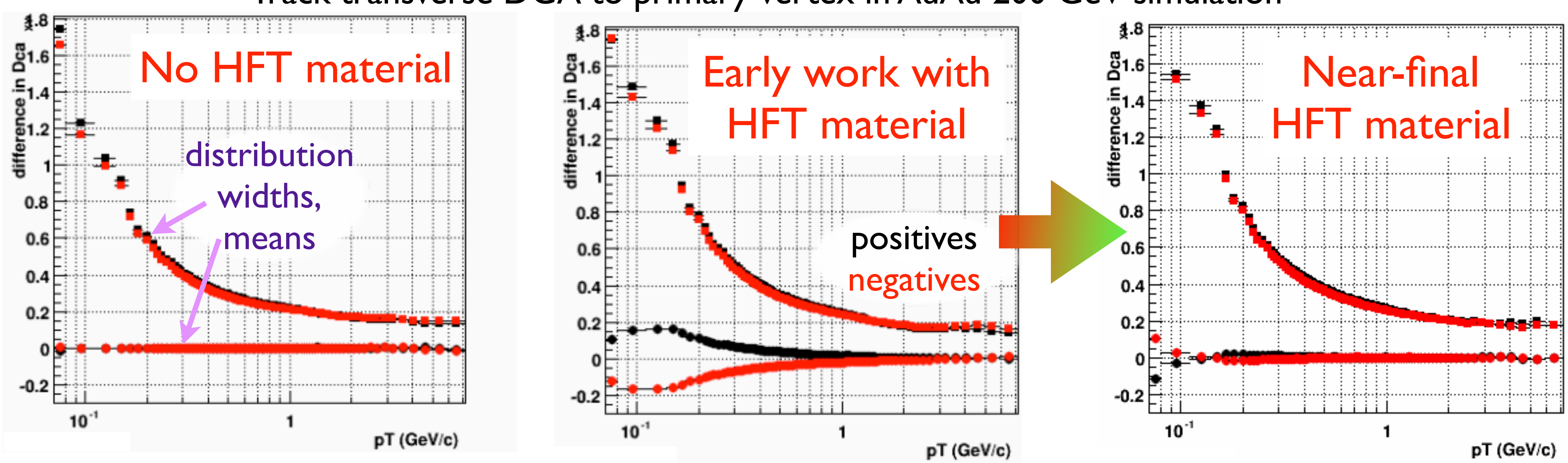




Performance QA

- Automated nightly tests of development libraries on old datasets
- Reconstruction time monitoring
- Extended in-house tools for comparing reconstructed track parameters (e.g. curvature [q/p_T], eta), projections (e.g. distance of closest approach [DCA] to primary vertex), and efficiencies differentially with respect to numerous variables (e.g. p_T, eta, phi, # of fit points)

Track transverse DCA to primary vertex in AuAu 200 GeV simulation

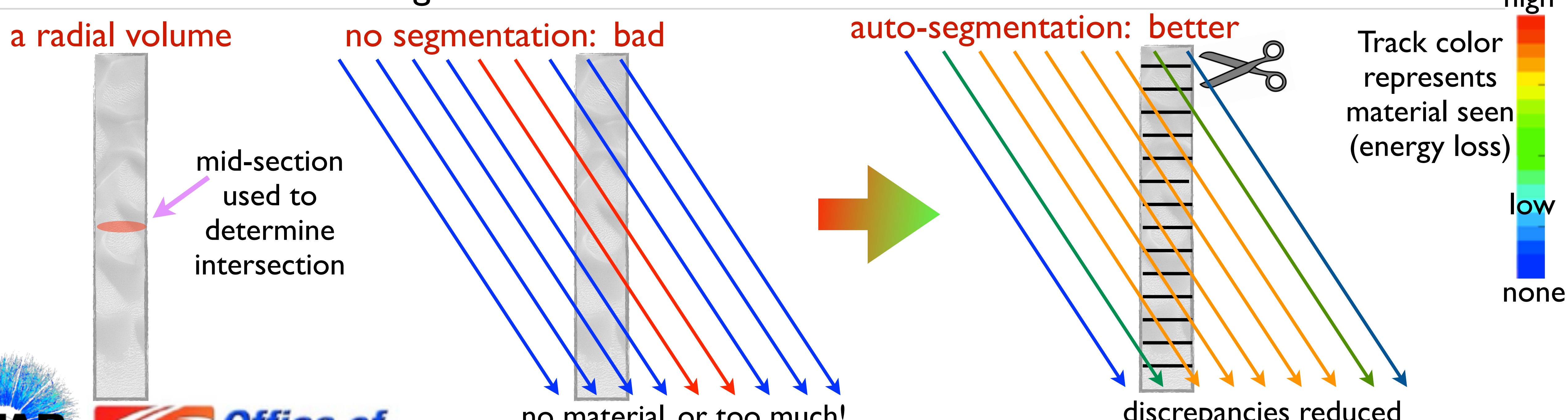


Geometry approximations

- GEANT geometry is rich (as it should be), with many thousands of intricate little, oddly-oriented and -shaped volumes and sub-volumes
  - Vast majority are support structures - not unimportant!
- Only simple geometries implemented in tracker:
  - Planes (with depth, e.g. box, no z-sloping allowed) & cylinders / cylindrical sections (centered at (0,0))
    - Anything else would require significant re-writes
  - Only limited misalignments of volumes allowed in this scheme
- Options for translation from simulation geometry (all were used):
  - Exact copy (e.g. solid simple tube, like the beampipe)
  - Automatically averaged mother volumes: material mass spread evenly through an approximated simple volume; internal structures and variation lost
  - User-specified substitute using simple geometries
- SSD: need geometry well-represented *now* even if not yet using hits

Intersecting materials

- Track projection error consideration not helpful: introduces more false positive intersections than true ones
- Limitation of old tracker: volume intersection decided only by whether a track crosses a volume's mid-section, i.e. the transverse area *at* the radius of the volume's center
  - Too "all-or-nothing" for radially oriented structures: some tracks see all (too much) material, while others see no material
    - Solution: automatic volume segmentation for averaged volumes into multiple sub-volumes along radial direction



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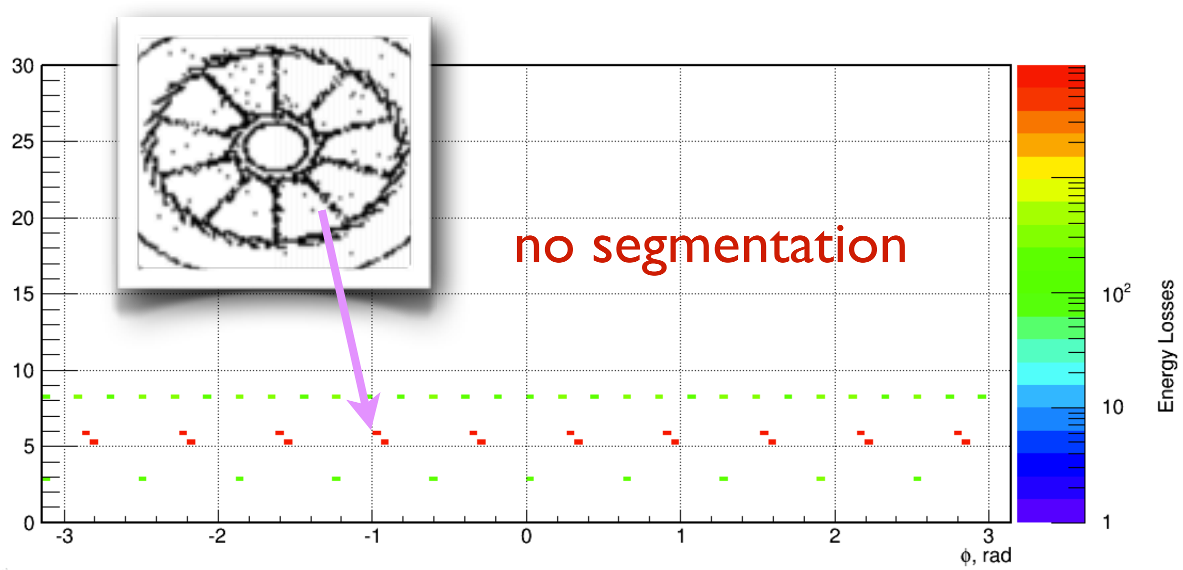
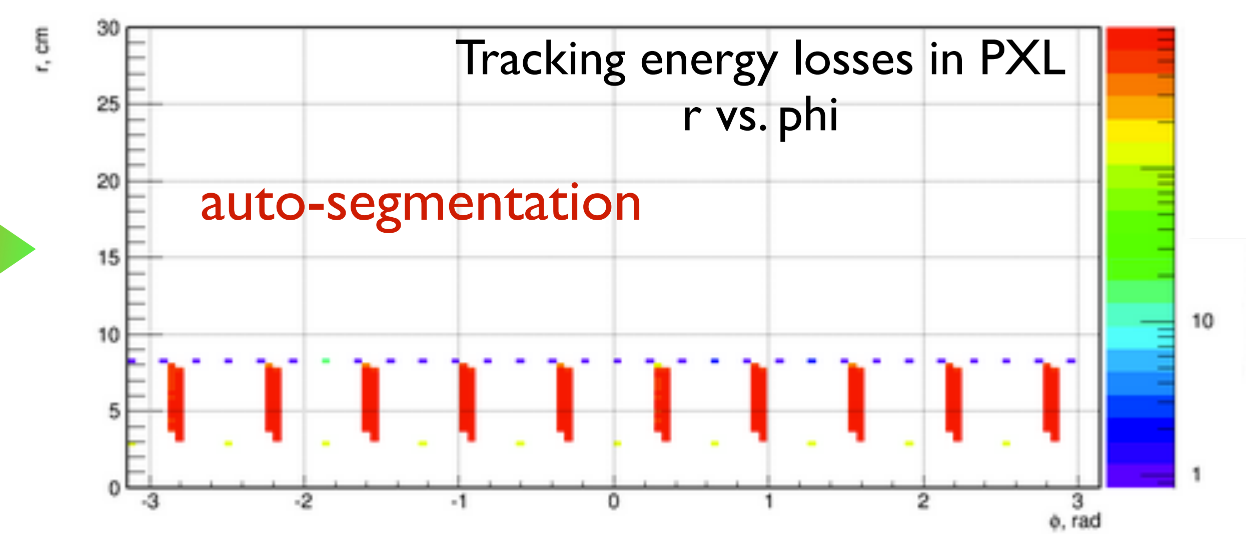
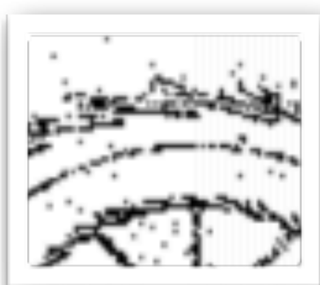


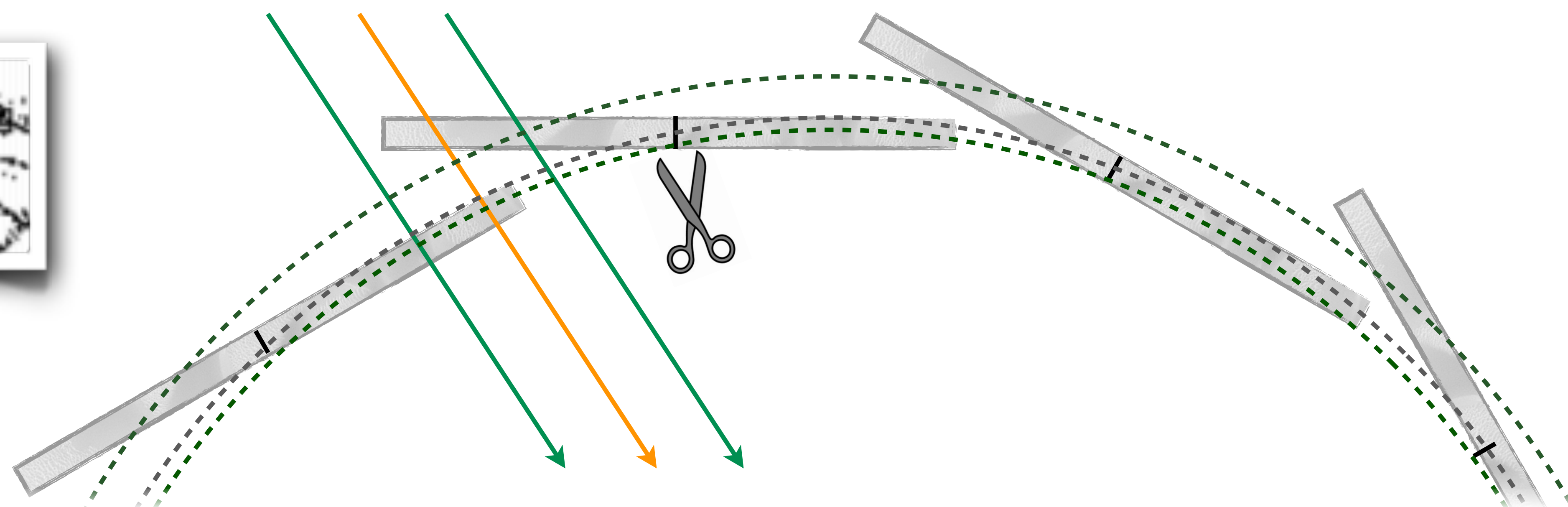


Segmented PXL ribs "seen" much more accurately

Intersecting materials

- Limitation... (continued)
  - Non-ideal alignment mandates a finite tolerance for defining radial layers
    - Not perfect: out-of-radial-order misalignment can make track propagate backwards
  - Overlapping tilted layers (ladders) must be split into two, such that a track can see them as two different radial layers (and find two hits!)

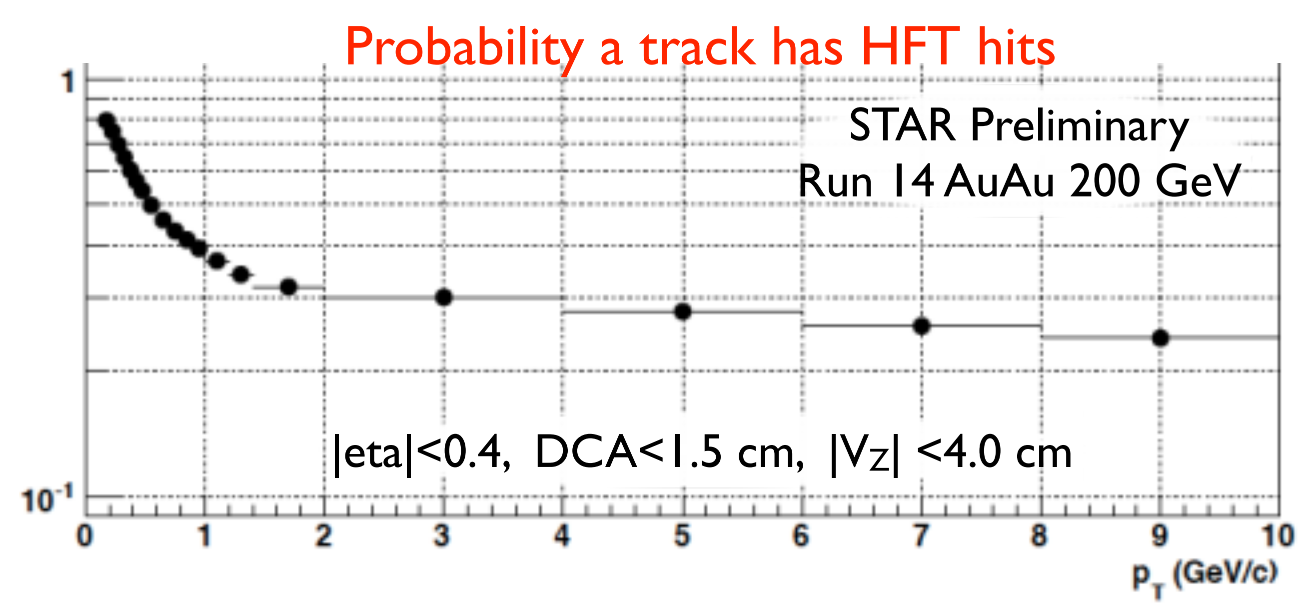




  - Prioritize active volumes for any ambiguity at any given radial layer to give best chance of finding a hit
- Found several small bugs along the way (dust under the old rugs)

Hits: improving the signal

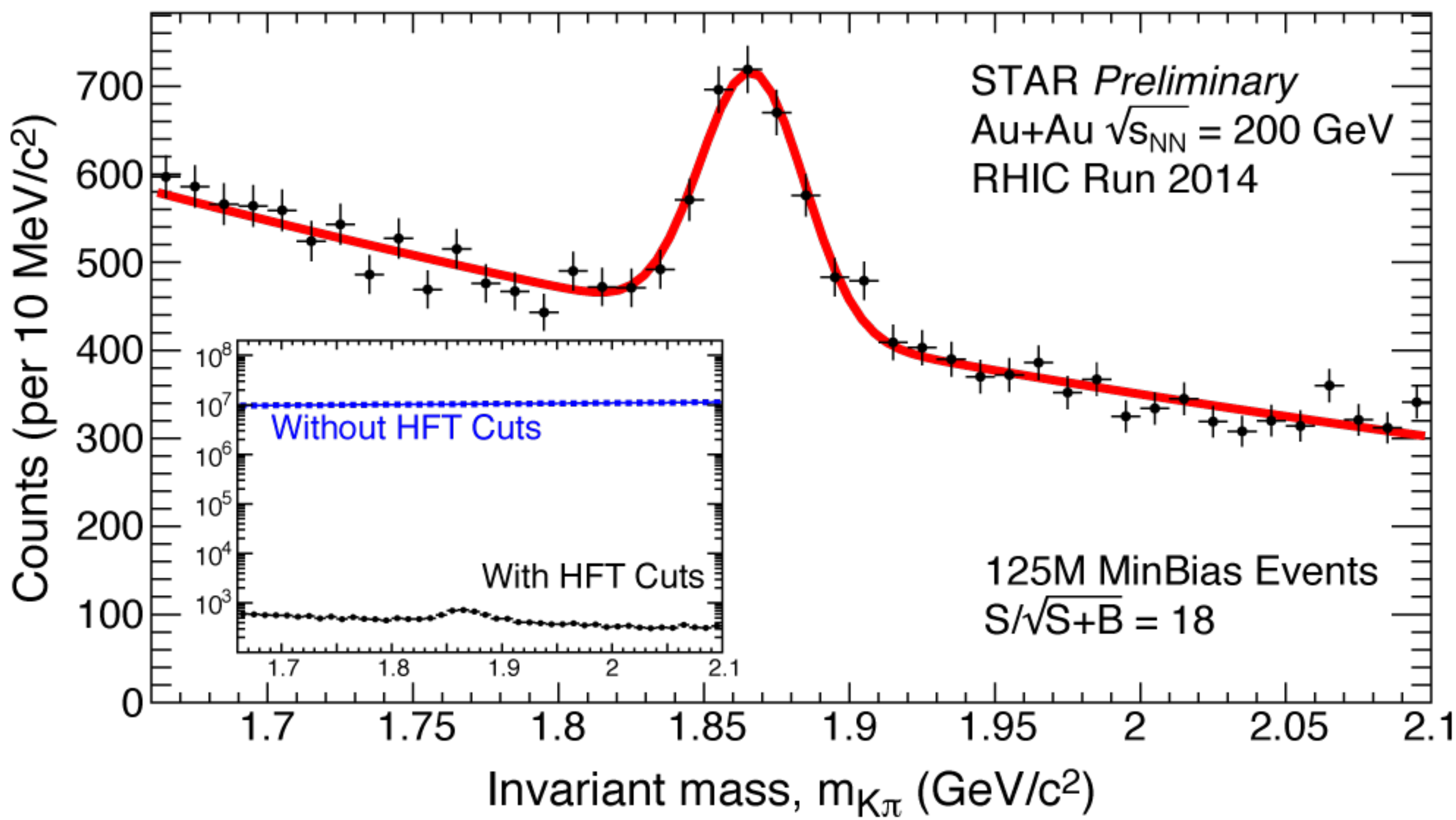
- Hits, while associated with volumes, must be allowed to deviate from the alignment constraints of the tracker (e.g. hit can be "off" the volume) to represent true misalignments & hit positions
  - Tracker already allowed this for TPC distortions & misalignments
- Allowed re-use of HFT detector hits
  - Does more good than harm, despite low HFT occupancy [maximum under 0.1% for inner PXL], more an issue of TPC pile-up; physics emphasis is on tracks *with* HFT hits
- Requirement of having 3+ HFT hits if at all
  - Missing HFT layers found to be a strong indicator of picking up wrong HFT hits
- Still see some potential for further improving efficiency of picking up HFT hits



Conclusions

Physics: D^0 signal

- Lots more to come: ~1.2B AuAu 200 GeV and ~1.6B pp 200 GeV events on tape! ...and more data arriving...



Summary

- Calibration delivered
  - Excellent internal alignment of HFT subsystems achieved
  - Global alignment between HFT and TPC achieved, with constructive improvement of TPC internal alignment
- Tracking delivered
  - Reasonable reconstruction time using tracker with simplified geometry (inclusion of HFT materials adds only ~10% net to whole reconstruction chain)
  - Energy loss in STAR materials sufficiently well-accounted
  - Some optimization of HFT hit usage
- Physics...in progress, and looking good for studying behavior of heavy flavor produced in high energy nuclear collisions!