STAR Reconstruction Improvements for Tracking with the Heavy Flavor Tracker

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STAR

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BROOKHAVEN NATIONAL LABORATORY

The HFT Program

Charm quarks:

- Created early in heavy ion collisions through hard scattering
- Experience the full evolution of the system

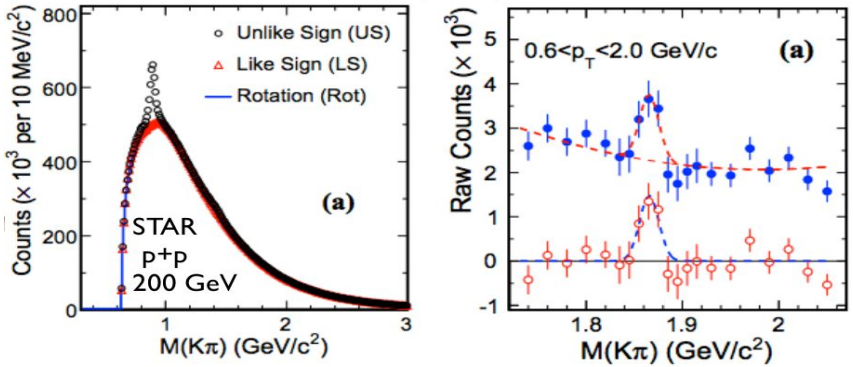
Physics:

- High-pT provides test of energy loss mechanisms
- Low-pT extract medium properties from motion of heavy quarks in medium

Combinatorics are a challenge.

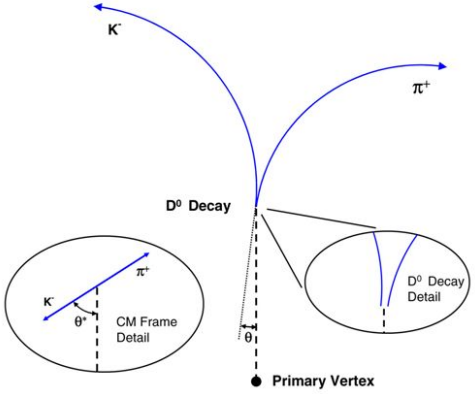
Topological reconstruction, i.e. associating decay daughters with a displaced vertex, necessary to bring backgrounds under control.

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



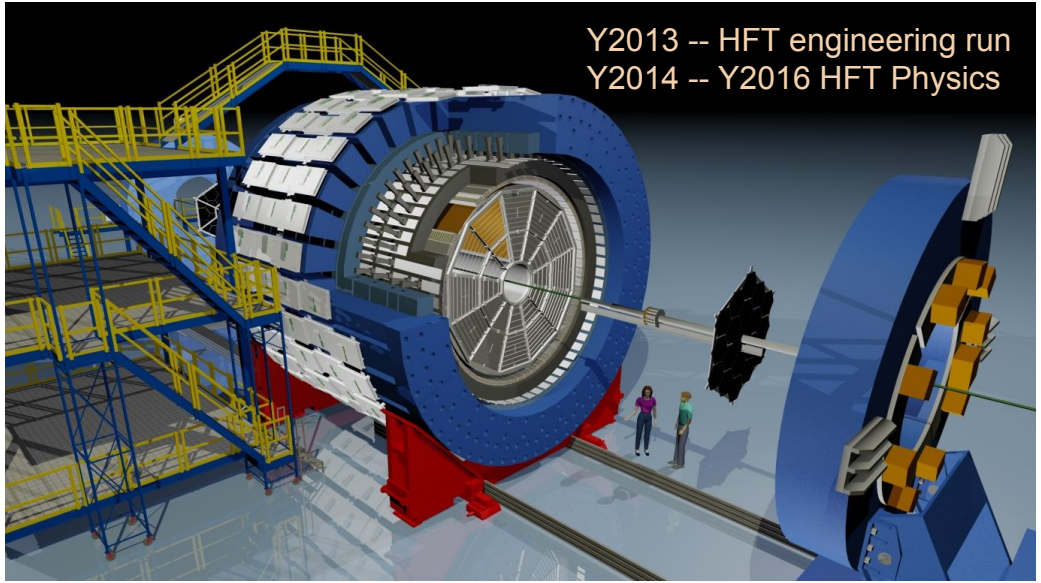
$D^0 \rightarrow K^- \pi^+$

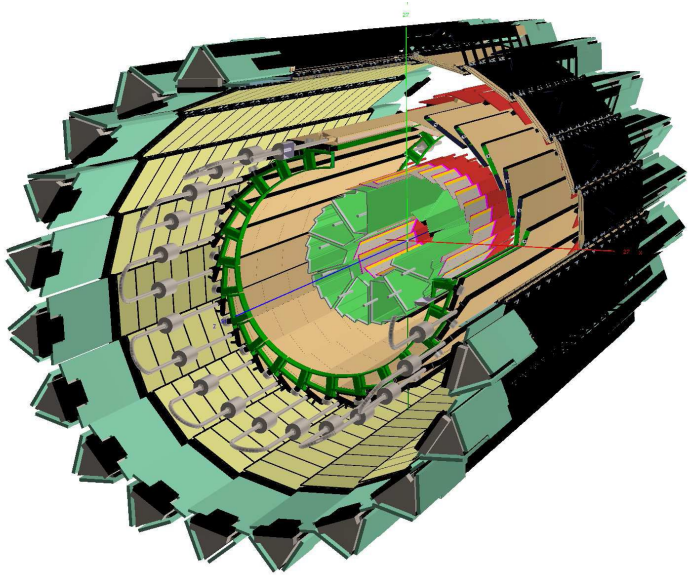
$c\tau$ ~ 100 μm



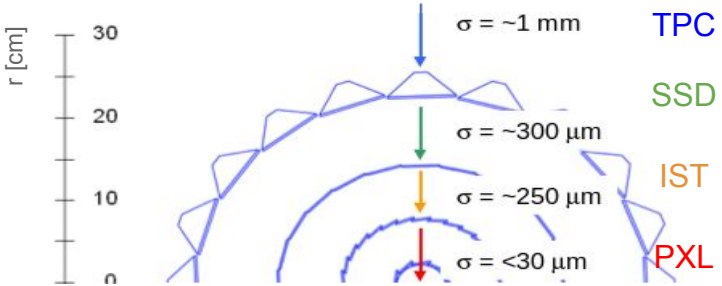
Requires precision tracking -- 50 μm DCA pointing resolution for 750 MeV kaons

STAR: The Solenoidal Tracker At RHIC





0.5 T Solenoid Magnet	BBC / ZDC / VPD	Heavy Flavor Tracker o Silicon Strip Detector o Intermediate Silicon Tracker o Pixel Detector
Time Projection Chamber -1 < η < 1	Barrel Time-of-Flight	
Barrel and Endcap EMC -1 < η < 2	Muon Telescope Detector	



The STAR Production Tracker: Sti

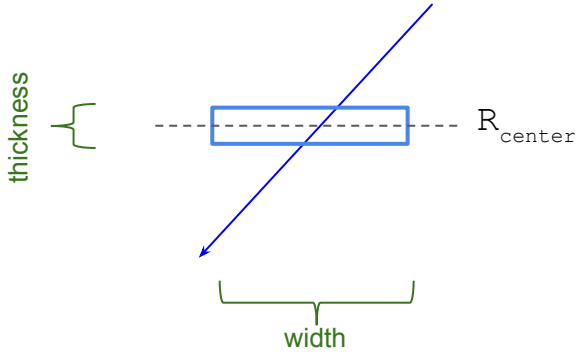
- Code well vetted, delivering world-class physics results for over a decade
- Follow-your-nose seed finder (default), CA beginning production
- Kalman-filter track fitter
- Simplified geometry and track propagation
  - Speed prioritized over accuracy of the geometry model and track propagation
  - Optimized for transverse physics at mid-rapidity ($\eta \lesssim 1.5$)
  - Performance has been sufficient for ~1mm resolution of TPC
- Automatic converter creates most of our Sti geometry model from our primary (AgML) geometry description (AgML 2014 J. Phys.: Conf. Ser. 513 022036)

Investigated alternative tracker using full AgML/ROOT geometry with GEANT3 propagators -- found to be a factor-of-two slower than Sti.

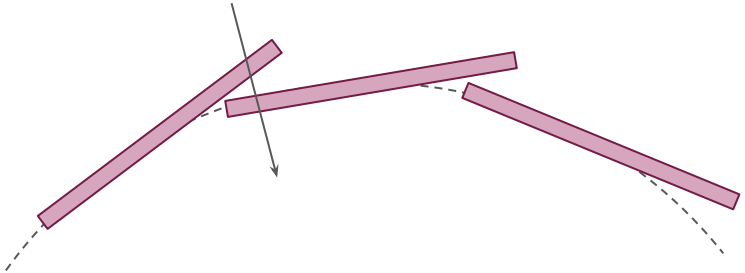
Geometry and Track Propagation in Sti

- Tracks propagate inward through a set of user-defined radial layers
- Each concentric layer contains a list of volumes which a track may intercept
- The test for intersection *assumes a thin scatterer*
  - Track is within the *width* of the volume
  - Full thickness of material is assumed
- Only one intersection allowed per layer

Track propagating through thin volume



Track propagating through a layer

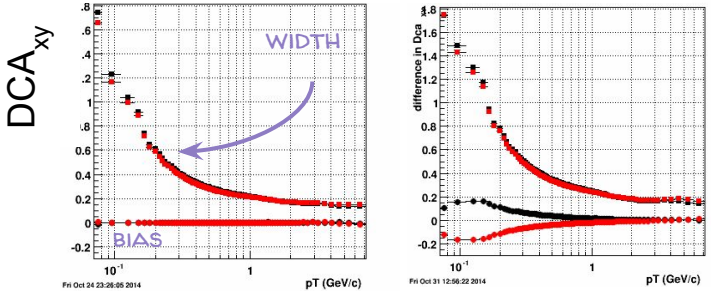


Initial Experience with HFT Integration

The HFT was inserted into STAR for the last half of the 2013 run. This engineering run provided initial hints that there would be obstacles to integration:

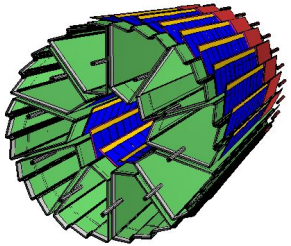
Observed large z-dependent DCA issues during the two time periods w/out HFT in track reconstruction.

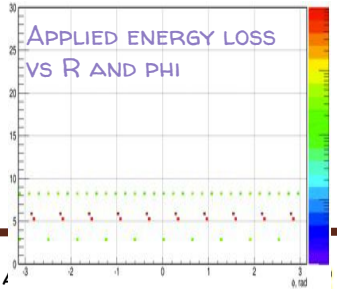
No HFT 2010 | With HFT 2014



Other Issues

- Saw evidence that dead material was skipped, especially radially-oriented volumes
- Missing second hits expected on “gapless” IST detector
- Significant reduction in speed: track reconstruction taking 2.5x longer with HFT as a *passive* detector. Longer if active.

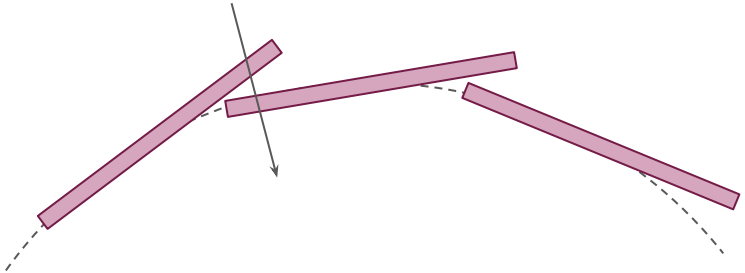




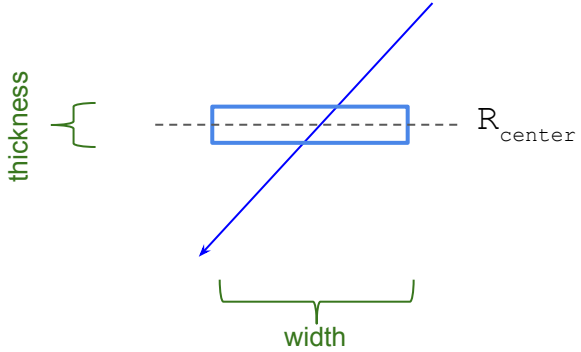
Some of the observed misbehaviors a natural consequence of the Sti geometry and track propagation

- Intersection with a single volume per layer may miss material, or worse, hits
- Propagation through thin volumes works well, with minor edge effects.
- Tracks will usually miss a radially oriented layer, but those which intersect will see too much material.

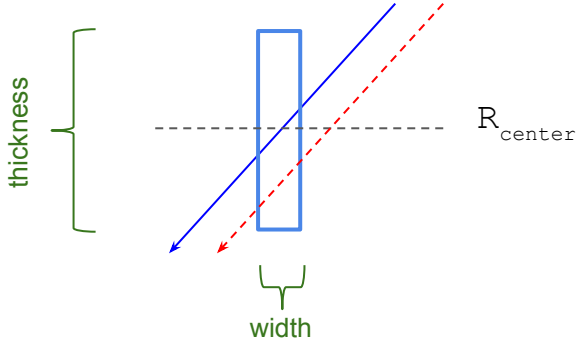
Track propagating through a layer



Track propagating through thin volume



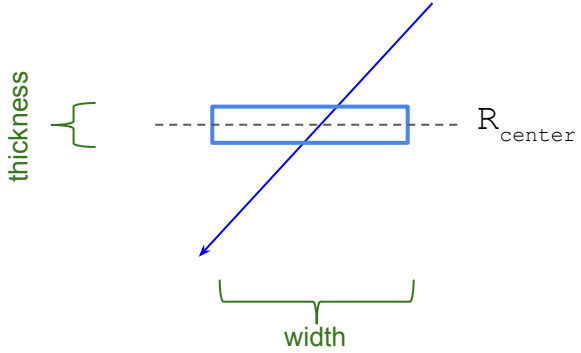
Track propagating through radial volume



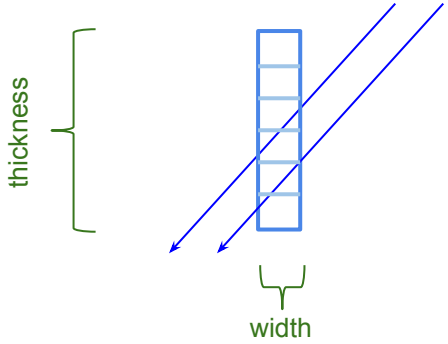
Solutions were fairly straightforward to implement

- To ensure hits are not shadowed, search modified to only prioritize active detectors over dead material
- Radially-oriented volumes split into multiple thin layers.
- Recovered multiple hits in overlap regions of the IST by splitting sensors and assigning to different layers.
- *However, speed and DCA issues persisted*

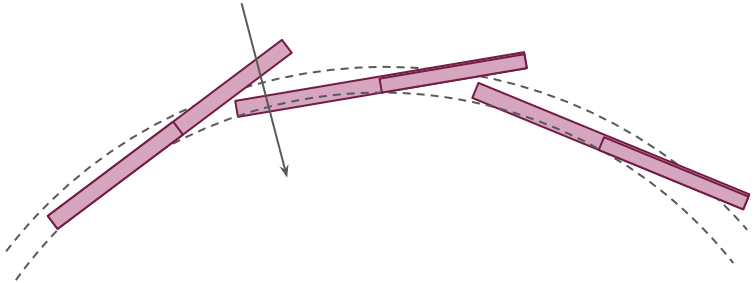
Track propagating through thin volume



Track propagating through radial volume

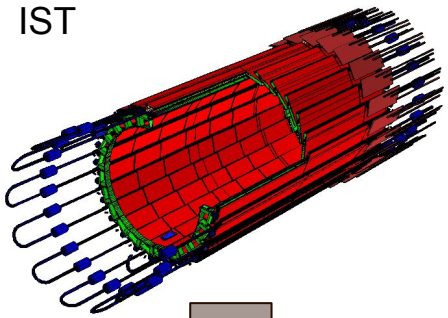


Track propagating through a gapless detector



Geometry Conversion Issues

IST

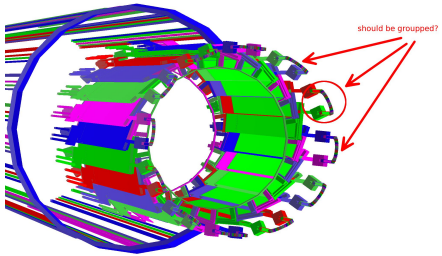


AgML/ROOT Model

IST	20.96 kg
PXL	21.04 kg
SST	11.16 kg

Automated Conversion

IST



Converted Sti Model

IST	23.30 kg
PXL	10.53 kg
SST	21.23 kg

The AgML/ROOT geometry model provides a detailed description of the detector. For example, the IST

- 10k physical nodes
- Composition of shapes (overlapping volumes)
- Uses most of the 16 GEANT3 shapes

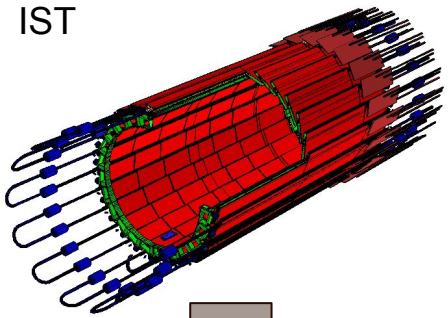
The automated conversion averages over the daughters of a user-supplied list of physical nodes to generate the corresponding Sti volume.

Several issues with this scheme

- Averaging double counts overlapping “MANY” volumes
- Everything contained in a mother volume gets averaged in (can pull in heavy support materials into lightweight ladder assemblies).
- Material density was preserved, but volume (thus mass) of the objects may change
- Produces too many STI volumes, slowing down track reconstruction

Geometry Conversion Issues

IST



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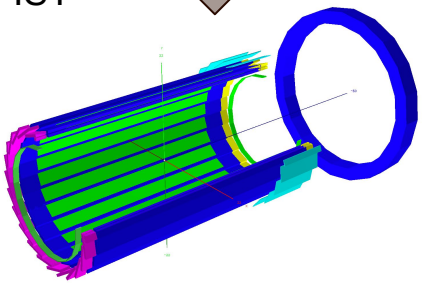
IST



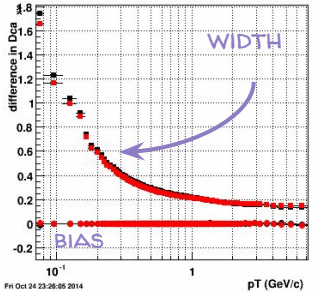
Native Sti Model

IST	21.09 kg
PXL	22.52 kg
SST	11.40 kg

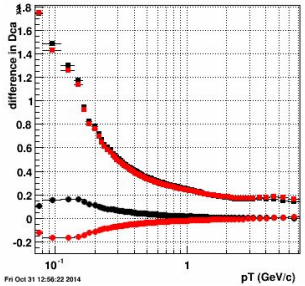
Implementation of a native Sti geometry resulted in

- Significant simplification: 100x fewer volumes
- Nearly doubled reconstruction speed
- Resolved issues with DCA and detector resolution.

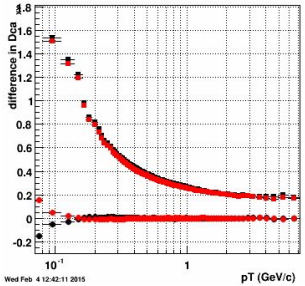
Pre-HFT



Auto Conversion



Sti Native



Plot DCAz vs pT for TPC-tracking with the HFT geometry in place.

Using HFT Hits

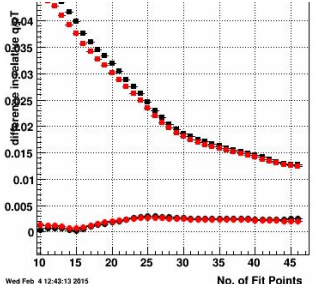
After track-finding is performed in the TPC, tracks are propagated to the beamline, adding hits found in the HFT. Several incremental improvements investigated and applied --

- Increase tolerance for hits outside of volumes, accounting for misalignments of detectors
- Nudge hit to local-x position of detector before fit
- Adjust floor and ceiling (minimum and maximum) hit errors for HFT
- Allow HFT hits to be reused on multiple track candidates

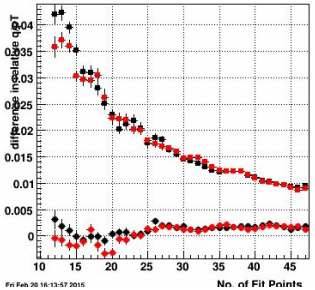
Finding the *right* hits in the innermost layers was an issue with our previous silicon vertex tracker. That experience led us to…

- Enable tree search within the HFT (considers all possible track roads)
- Evaluate tracking resolution and quality with different numbers of HFT hits

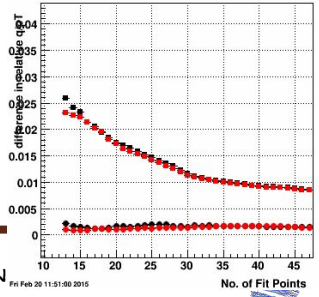
ΔQ/pT TPC only



ΔQ/pT TPC+PXL hits



ΔQ/pT TPC+3 HFT hits



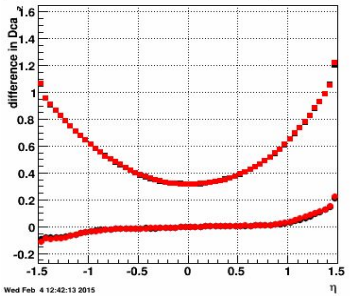
Results and Summary

The HFT detector has been successfully integrated into the STAR track reconstruction package, enabling charm measurements from the 2014 -- 2016 runs.

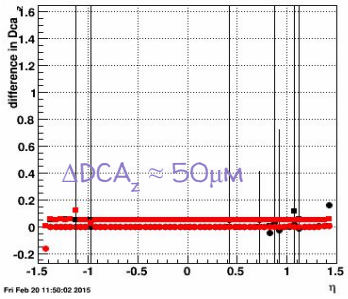
The Sti tracking software provides a streamlined geometry model and track propagation engine, providing better speed than general purpose solutions such as ROOT.

The tracker provides sufficient precision to meet the stringent tracking requirements for topological reconstruction of charmed hadrons, but requires significant effort on the part of developers to tune the software.

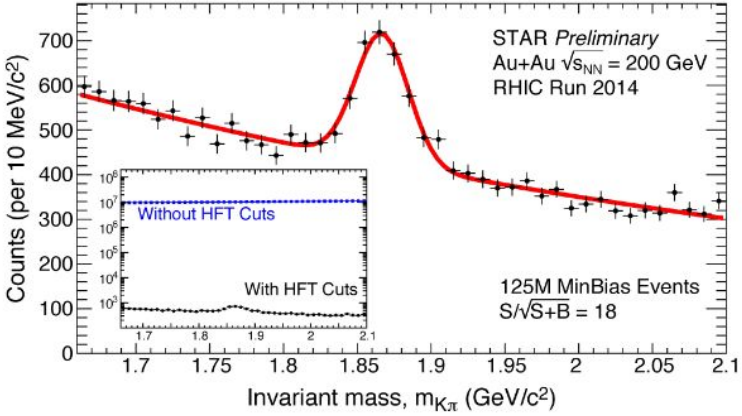
ΔDCA_z TPC Only



ΔDCA_z TPC+3HFT



Beautiful charm results presented at QM'15...



Stay tuned for new results at QM'17. Thank You!