Moving Forward with Tracking & Simulations

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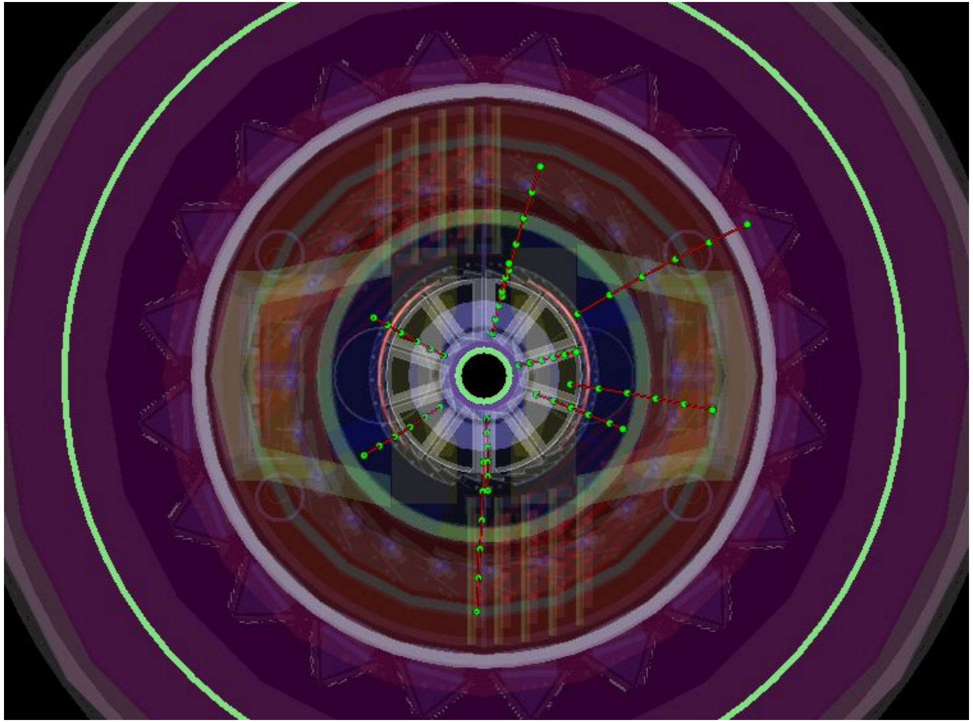
for the STAR S&C Group

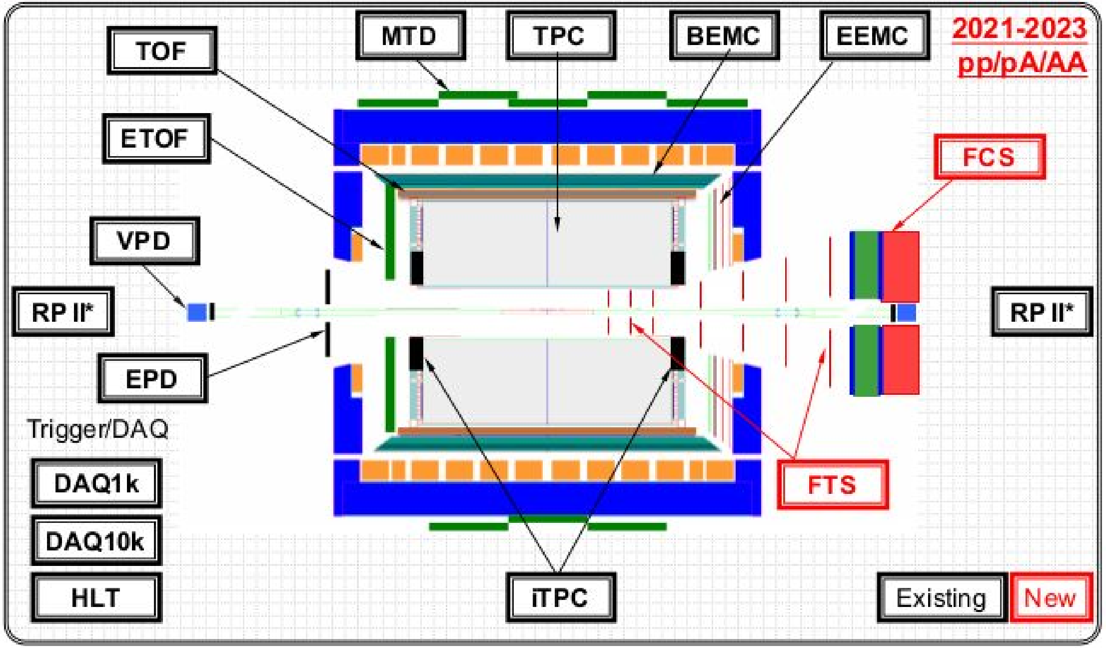
Outline

- STAR Forward Upgrade
  - Physics and required instrumentation
- From Concept to Proposal
  - Simulations of FTS
  - Tracking Algos / Studies
  - Plans
- Integration into the Framework
- Plans and Summary



Forward Upgrade

Years	Beam Species and Energies	Science Goals
2014-16	p+p, p+Au, p+Al, d+Au, He^{3}+Au, and Au+Au at 200 GeV 15 GeV Au+Au	Heavy quark energy loss, flow, thermalization Quarkonium studies Transverse spin physics Extract eta/s + initial quantum fluctuations Search for QCD critical point
2017	p+p at 510 GeV Au+Au at 62 GeV	Transverse spin physics Energy dependence of parton energy loss
2018	^{96}Ru+^{96}Ru and ^{96}Zr+^{96}Zr at 200 GeV	Chiral Magnetic Effects
2019-20	Au+Au at 5-20 GeV (BES II)	Search for QCD critical point and onset of deconfinement
2021	p+p at 510 GeV (?)	Low-x gluon helicity, TMD
2022-23	p+p, p+Au, Au+Au at 200 GeV	Transverse spin physics, gluon saturation, nuclear PDF, longitudinal flow decorrelation, initial conditions, eta/s, multiple haromoics Jet probe of parton transport and energy loss, Color-screening of Upsilon
2024-	No Runs	



FCS: Forward Calorimeter System, FTS: Forward Tracking System

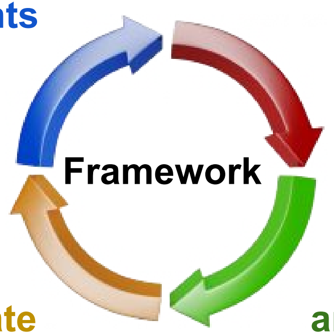
Forward Tracking Proposal

Given the opportunity to present an upgrade proposal (on a tight deadline).

From conceptual design to quality tracking results in 3 months. Twice.

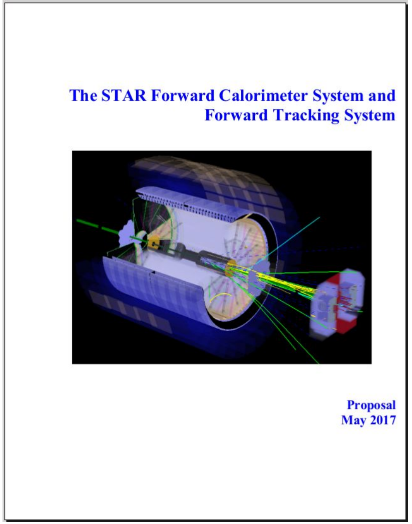
Physics Requirements

Detector Concept



Review, Refine, Iterate

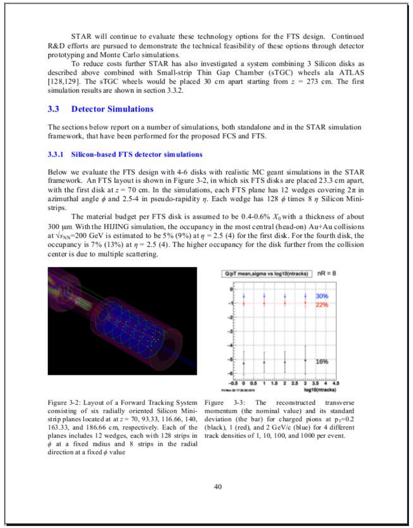
Simulation and Tracking



The STAR Forward Calorimeter System and Forward Tracking System

Proposal
May 2017

STAR note sn0648



STAR will continue to evaluate these technology options for the FTS design. Continued R&D efforts are pursued to demonstrate the technical feasibility of these options through detector prototyping and Monte Carlo simulations.

To reduce costs further STAR has also investigated a system combining 3 Silicon disks as described above combined with Small-strip Thin Gap Chamber (sTGC) wheels ala ATLAS [128,129]. The sTGC wheels would be placed 30 cm apart starting from z = 273 cm. The first simulation results are shown in section 3.3.2.

3.3 Detector Simulations

The sections below report on a number of simulations, both standalone and in the STAR simulation framework, that have been performed for the proposed FCS and FTS.

3.3.1 Silicon-based FTS detector simulations

Below we evaluate the FTS design with 4-6 disks with realistic MC geant simulations in the STAR framework. An FTS layout is shown in Figure 3-2, in which six FTS disks are placed 23.3 cm apart, with the first disk at z = 70 cm. In the simulations, each FTS plane has 12 wedges covering 2π in azimuthal angle ϕ and 2.5-4 in pseudo-rapidity η. Each wedge has 128 ϕ times 8 η Silicon Mini-strips.

The material budget per FTS disk is assumed to be 0.4-0.6% X_0 with a thickness of about 300 μm. With the HIJING simulation, the occupancy in the most central (head-on) Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV is estimated to be 5% (9%) at η = 2.5 (4) for the first disk. For the fourth disk, the occupancy is 7% (13%) at η = 2.5 (4). The higher occupancy for the disk further from the collision center is due to multiple scattering.

Figure 3-2: Layout of a Forward Tracking System consisting of six radially oriented Silicon Mini-strip planes located at at z = 70, 93.33, 116.66, 140, 163.33, and 186.66 cm, respectively. Each of the planes includes 12 wedges, each with 128 strips in ϕ at a fixed radius and 8 strips in the radial direction at a fixed ϕ value

Figure 3-3: The reconstructed transverse momentum (the nominal value) and its standard deviation (the bar) for charged pions at p_T=0.2 (black), 1 (red), and 2 GeV/c (blue) for 4 different track densities of 1, 10, 100, and 1000 per event.

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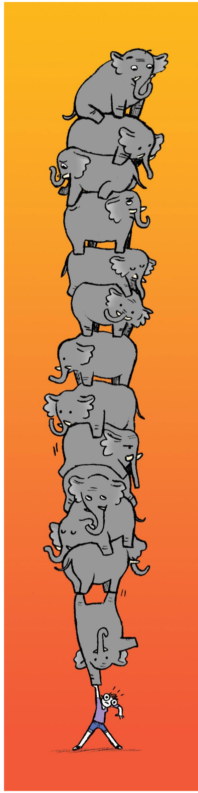
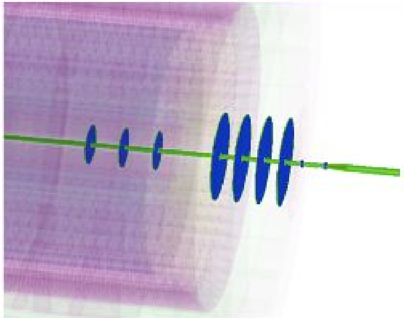
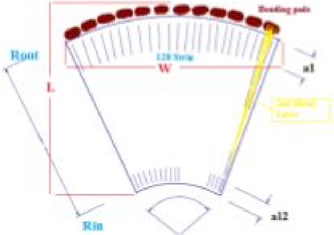
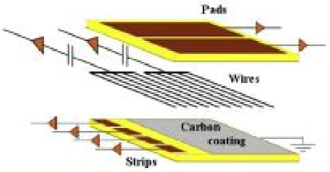


Forward Tracker Upgrade

- Requirement:
  - Full azimuthal in $2.5 < \eta < 4$
  - good resolution in ϕ for charge separation and momentum measurement
  - low material to reduce multiple scattering and conversional background
- Current design (**Si only or Si+sTGC**):
  - inside TPC: 3 (6) **Si** disks at z=70-140 cm
    - Single-sided double-metal pad sensor: pad size depends on (R, z) - minimum size is ~ 3 mm x 100 μm in R-ϕ
    - APV25 FEE, HFT-IST DAQ and cooling
    - 0.5-1.0% X_0 per plane
  - Outside TPC: 4 **sTGC** at z=2.4-7 m
    - Modified ATLAS orward design
    - Position resolution: <300 μm in x-y
    - 0.5% X_0 per plane







Z.Ye, 3/18/2017

Simulation and Tracking Studies

Simulations of the FTS have been carried out in the STAR framework to inform technology choices based on results of realistic simulations and tracking codes

- Conceptual designs implemented in AgML
  - Provides concrete geometry representation to both simulation and tracking codes
- Fast simulation converts the GEANT energy deposition into x,y,z hits with the anticipated detector resolution at the center of the struck element
  - Detector segmentation applied at the fast simulator stage
  - Allows rapid evaluation of changes to the readout design
- Event reconstruction using the Stv tracking package
  - Production-quality track finding / fitting
  - Automated association of hits to detector planes / streamlines integration of new detectors
  - Supports Kalman track following, CA track finders

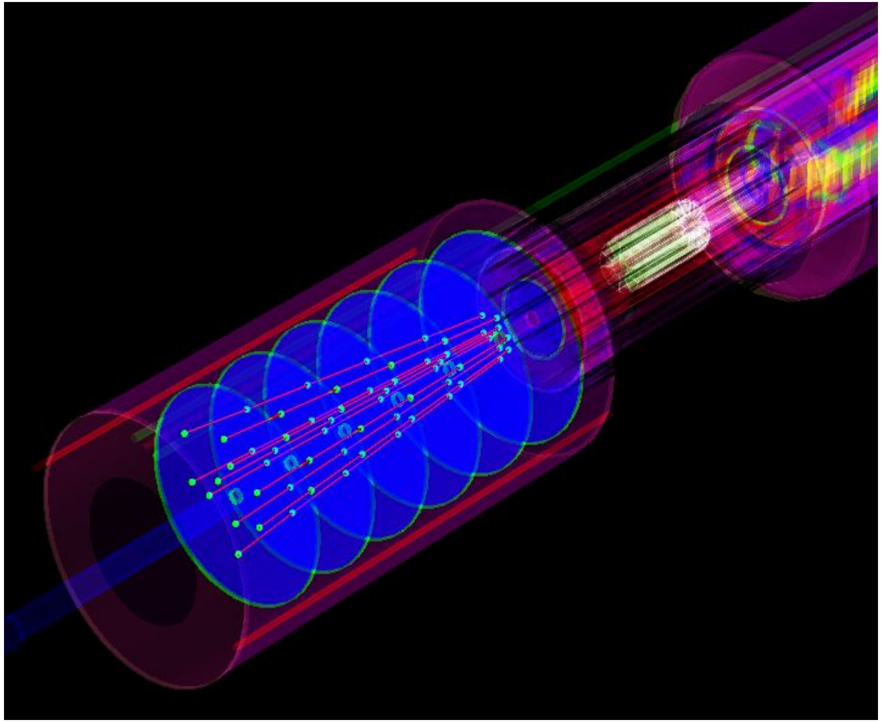
Concept: Si tracker

Install 4, 5 or 6 Si disks evenly spaced from 70 to ~140 cm

- 12 sectors x 128 strips x 8 radial divisions (baseline segmentation)
- stereo angle introduced by shifting x,y center of each disk by 1mm

Simulated charged pions thrown with fixed momentum of 0.2, 1 and 2 GeV

- 1,10,100,1000 pions / event
- Full STAR magnetic field map
- Fast simulation, energy deposition → hit at center of struck Si strip



Track Finding Algorithm

Historically STAR utilizes Kalman Track filter (KF) in track finding (recently begun using CA + KF in data production). Forward tracking studies utilize a KF algo:

- Seeds are formed in the last three layers (disks or wheels)
- Seed is fit to a helix
- Propagate inwards along the helix
  - Add best hit found within an uncertainty band around the track prediction
  - Except for outermost layer, hits may be used on multiple tracks
- Track finding complete once all hits in outermost layer have been visited

Once all track candidates have been found, hits are uniquely assigned to the “best” track, based on length and chi2. Tracks with fewer than 4 hits are eliminated.

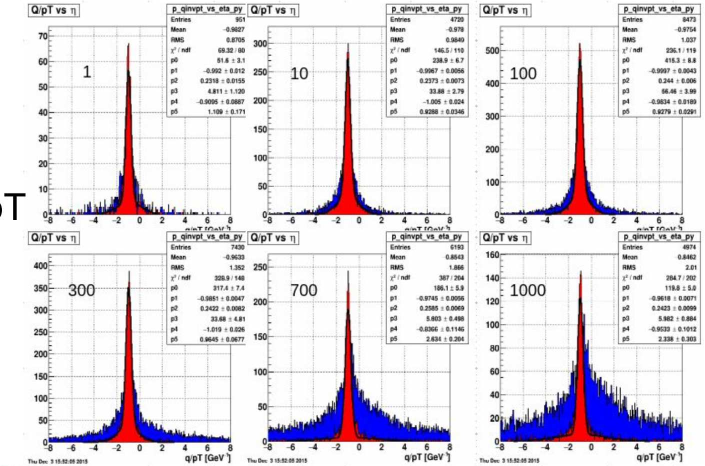
Resulting global tracks refit with the MC vertex to form primary tracks.

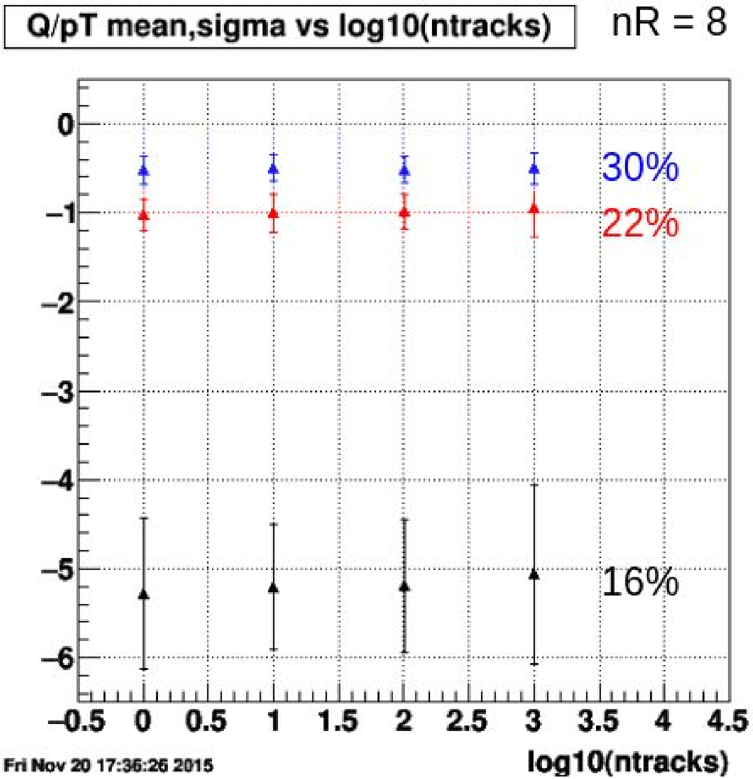
Si Tracker Results

Studies various configurations of the detector (strip segmentation, number of disks, rastering) over a wide range of track multiplicities.

Both primary (red) and global (blue) tracking resolution was studied, for event multiplicities ranging from 1 to 1000 tracks / event.

Q/pT

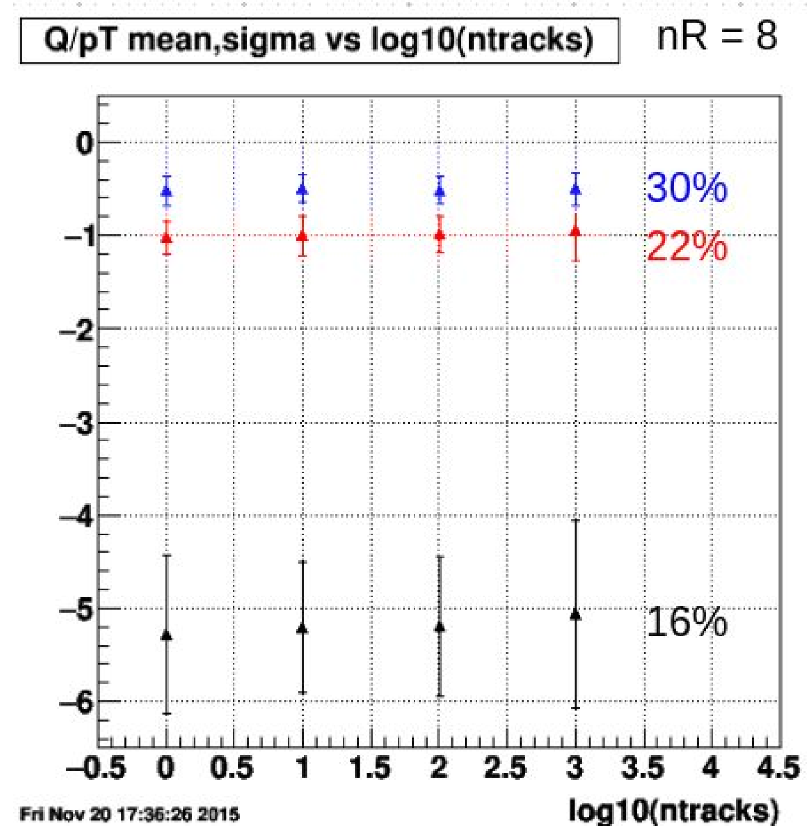




Si Tracker Results

With 4-6 Si planes we found that

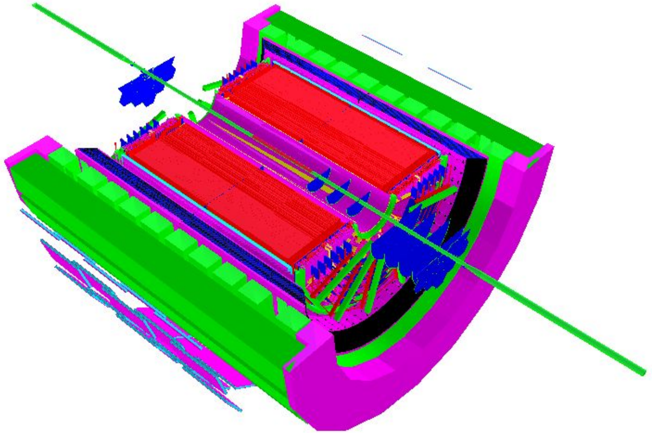
- Kalman track finder performs well in this environment
- Momentum resolution and charge sign discrimination sufficient to address the physics goals in pp and AA
- Low multiplicity tracking efficiency > 95% for 6 planes, with modest reduction at 4 planes
- High multiplicity achieves ~80% tracking efficiency, falls significantly for 1k track / event.
- Inclusion of the event vertex crucial to performance in AuAu.



Concept: Si disks + sTGC wheels

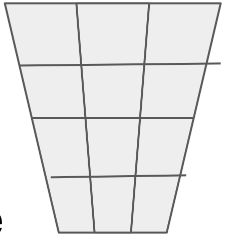
Utilize small thin-gap wire chambers (modified ATLAS design) outside the STAR magnet

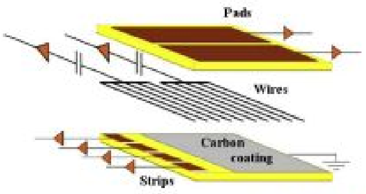
- Modified ATLAS forward design
- Good position resolution (~100 microns)
- Less expensive than Si
- Reasonably low material budget



Concept: Use complementary tracking subsystems

- 3 Si disks for precision tracking near the IP
- 4 sTGC wheels at larger distance / increased lever arm for momentum measurement / remove integration constraints on detector size





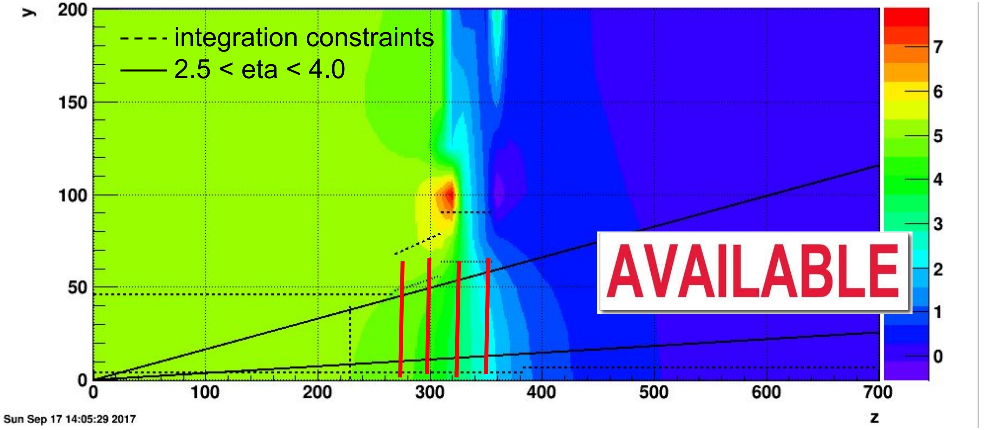
6cm tall pads, 3 across per octant

sTGC Evaluation

sTGC is the *first* tracker in 17 years of STAR to be proposed *outside* of the magnetic field.

- Helix track model *deeply* embedded in our tracking code (and psyche)
- Our studies with the sTGC technology to date have placed the detector within the STAR magnetic field

|Bz| vs z position

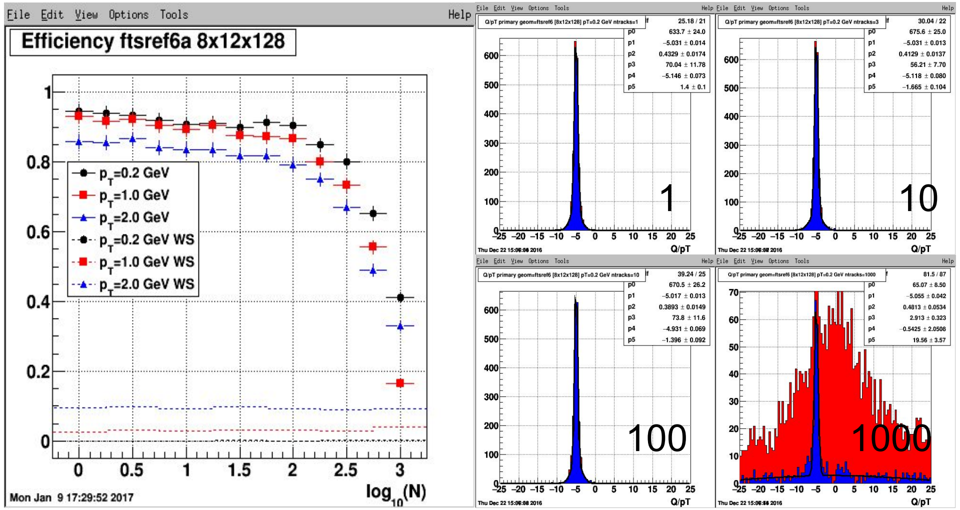


- Parallel effort to update the Stv tracker with the Runga-Kutta track model launched. Currently in final testing phase.
- Next round of studies will investigate placing the detector planes outside the STAR magnet.

sTGC Simulation and Tracking Results

With 4 sTGC wheels + 3 Si disks we found

- Momentum resolution and charge sign discrimination comparable to Si only option
- With sTGC wheels, optimal segmentation of Si disks may change from Si only tracker
- Kalman track finder performs well, providing good efficiency at track multiplicities relevant for both the pp and AA programs.



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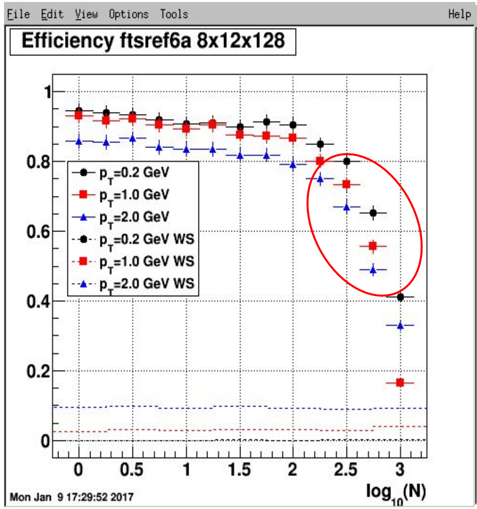
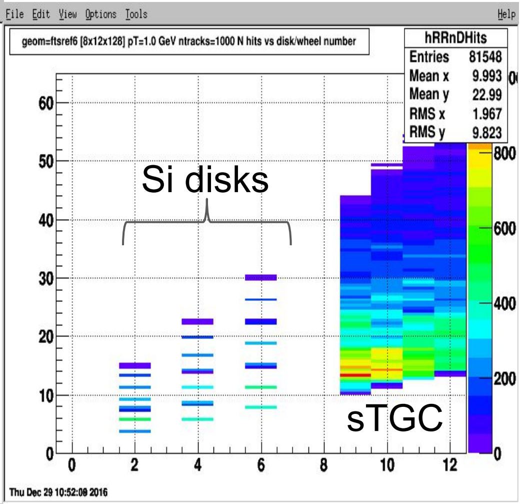




- Tools allow us to quickly understand efficiency losses:
  - Drop in efficiency for > 100 tracks / event associated with random hits (largely secondaries produced in beam pipe) in the sTGC wheels.
  - May be mitigated by moving planes to larger z.
  - May provide opportunity to apply sophisticated techniques, e.g. Deterministic Annealing Filter
  - Always open to hearing new ideas and working on solutions to common problems

Getting Started

I would like to speak briefly about what software components are needed to process data and simulations through the STAR framework.

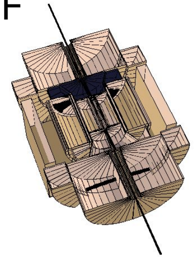
- ➢ Geometry Model
- ➢ Simulations
- ➢ Embedding

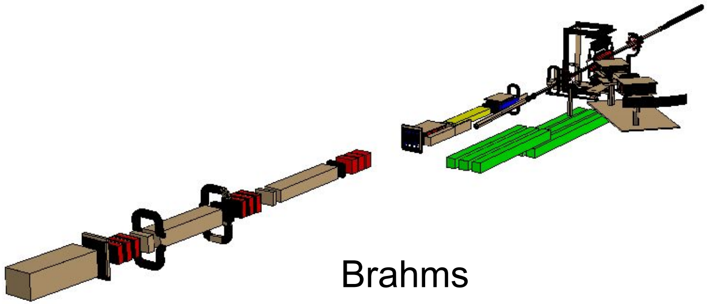
Getting Started

The Abstract Geometry Modeling Language: Experience and Roadmap to eRHIC

- Geometry Model
  - Software coordinators are responsible for developing (with HW expert input) the geometry model, and implementing it in AgML.
  - Responsibility of the S&C team to integrate and maintain the model within the STAR geometry description, ensuring consistency across all consumers in STAR.
  - We have tools that can read ROOT geometries and provide a starting point for integration, e.g.
    - `root2agml --file=eTOF.root --export=AgML --module=EtofGeo`

CDF





Brahms

CMS

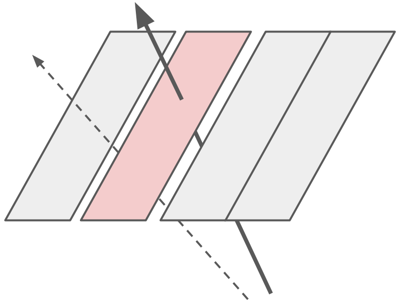
converted from root files found here: http://root.cern.ch/files

Getting Started

- Track matching to eTOF (~ free with geometry)
- Simulations
  - Hit scoring
    - What information gets saved and how? → data structure
  - Unique ID for sensitive element
    - Geometry path → single integer
  - Fast simulator
    - Geant hits → x, y, z, tof, adc, … (possibly w/ simple smearing)
  - Slow simulator adds in...
    - Complete simulation of detector response, cross talk, electronics, etc...
    - Online conditions (e.g. pedestals, gains, status tables, …)
    - Presents data suitable for offline reconstruction, e.g. cluster finders, ...

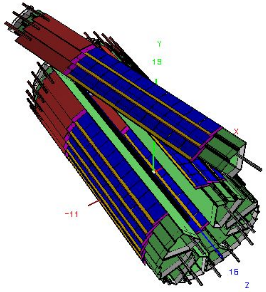
Getting Started

- Embedding
  - Account for the systematics associated with hardware noise, detector pileup, and the collision and ambient backgrounds present during experimental operations
  - Technique
    - Simulate an event of interest (hijing, pythia, single particle,...)
    - Merge the output of the slow simulators *in each hardware channel* with the readout from a real triggered event at STAR (zero bias or minimum bias)



  - Software Requirements
    - Slow simulator is *essential* to properly account dead channels, low gains, and fully exploit the physics potential of the data
    - Mixer is responsible for merging signals from simulated and triggered events
    - Accurate geometry model accounting for the misalignments of the *active material* and *dead layers* in the detector setup

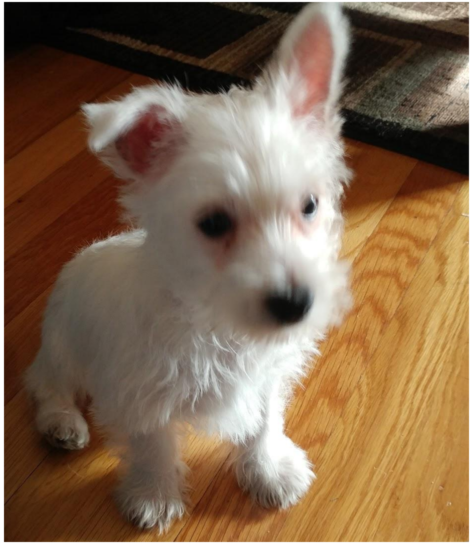
Getting Started



- Misalignments
  - Ultimate resolution, efficiency of high precision trackers depend on simulation of the small deviations of the actual detector from the ideal design
  - AgML provides support for application of detector misalignments during the construction of the geometry model, enabling precision simulations
- Lesson learned with the HFT
  - Importance of ensuring that detector misalignments are measured w/ respect to the reference systems defined in the geometry model

Summary and Path Forward

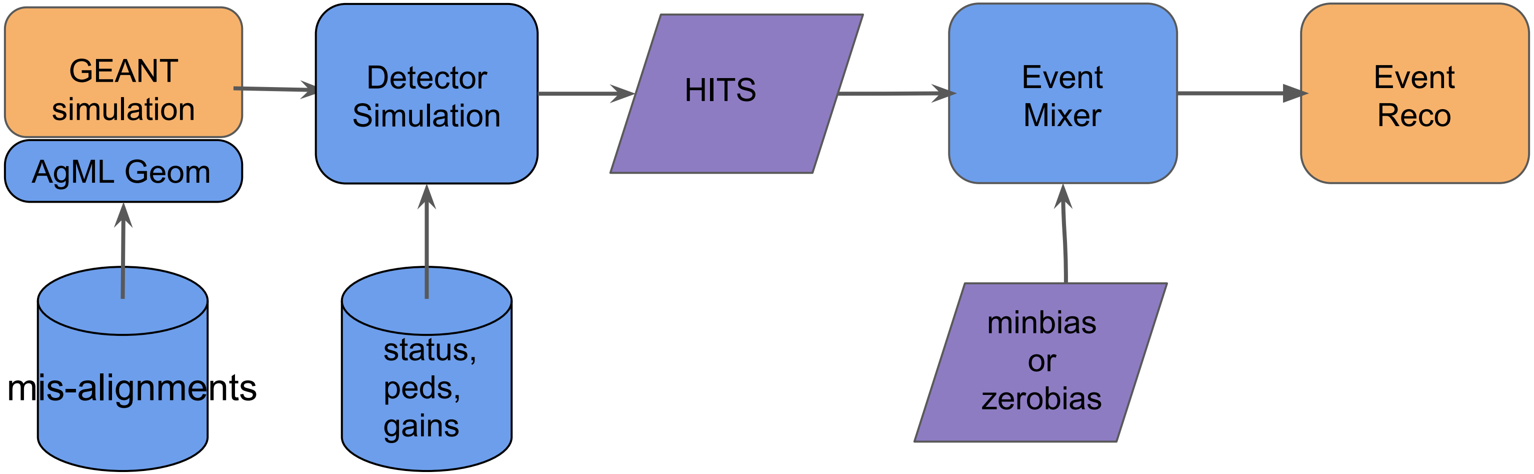
- The STAR framework has a proven track record for well over a decade supporting a world class physics program
- When hardware and software experts collaborate closely, able to quickly test new concepts, integrate new subsystems, and deliver results
  - FTS from initial concept to concrete proposal in three months
  - Demonstrated the feasibility of both detector concepts with production quality track finding and reconstruction
- Always interested in discussing and learning about solutions to common problems, and look forward to having conversations with those involved in STS tracking
- We have developed the tools to help integrate new detector models into our framework, and have summarized some of the key components
  - *If anyone is interested in working on this, we can have the eTOF fully integrated into STAR simulations by the end of the week*



Thank You

Summary and Plans

Simulation / Embedding Chain



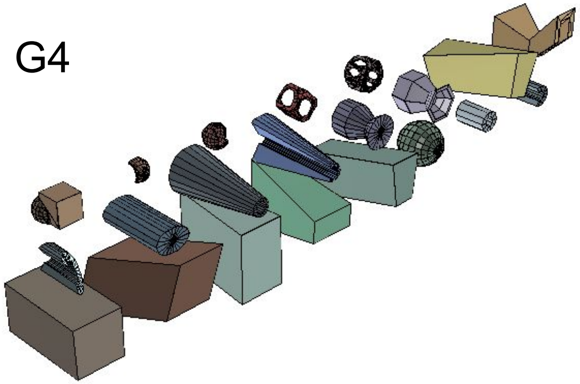
STAR Simulation (*starsim*) Upgrade: status

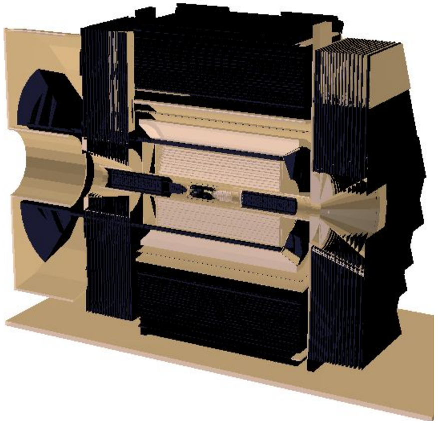
Maintain, extend and update the simulation stack to support the physics requirements of the STAR experiment and upgrade programs:

- AgML: Abstract Geometry Modeling Language [2012]
    - Provides single source geometry and MC transport configuration for STAR simulations and reconstruction
- StarGenerator [2013]
    - Provides uniform interface for event generators in STAR, event record
    - Supports pythia6, pythia8, hijing, herwig, starlight, kinematics, …
- StarDecayManager [2015]
    - Provides support for external decayers
    - Pythia8 decayer, EvtGen from 2016
        - e.g. Bc+ → J/psi e+ nu, D0 → K-pi+, D0→ K-pi+pi+pi-, ...
- AgML 2.0 [2016] -- improved data model, versioning support
- Misalignment Support [2017]
    - AgML extended to support misalignments of both active and passive detector elements using tables stored in STAR DB
    - Enables precision simulation / embedding in silicon tracking detectors (HFT, FTS, …)

More Developments

- AgML 3.0 -- Add support for features found in ROOT and G4
  - Volume assemblies [done]
  - Composite shapes [done]
  - Extrusions [done]
  - Tessellated shapes [TBD]



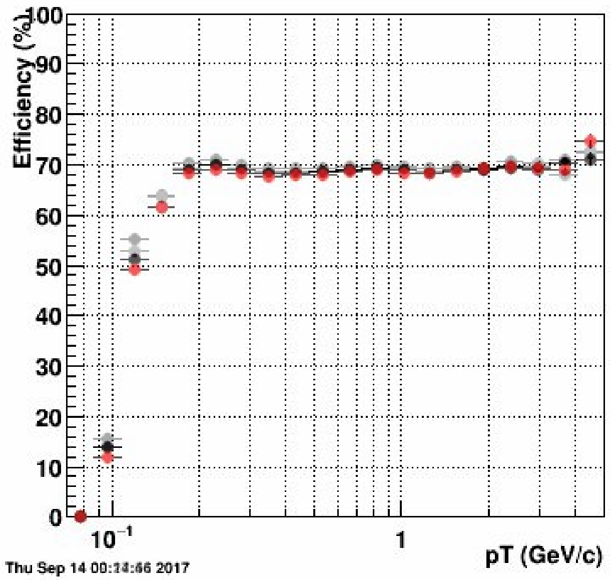


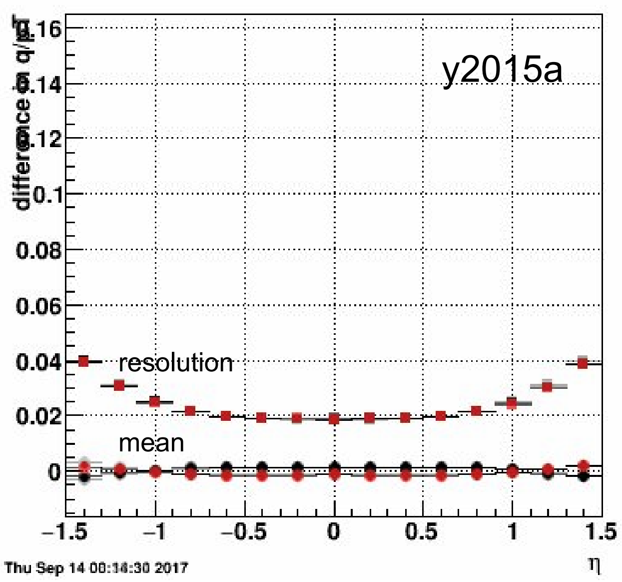
- root2agml -- Add support for importing external geometry models
  - ATLAS sTGC wheels
  - CBM/eTOF

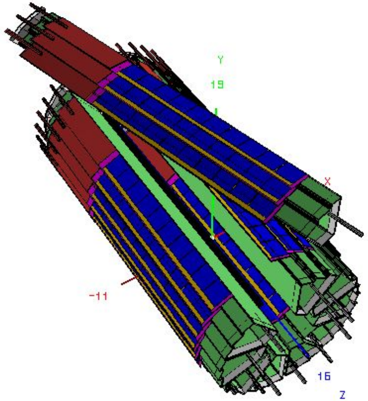
(at left is babar… wget http://root.cern.ch/files/babar.root)

Misalignment

Evaluation of tracking quality, resolution and efficiency in 200 GeV AuAu simulations with and without misalignment.







black: + misaligned
red: - misaligned
grey: +/- ideal