STAR Forward Upgrade & Tracking

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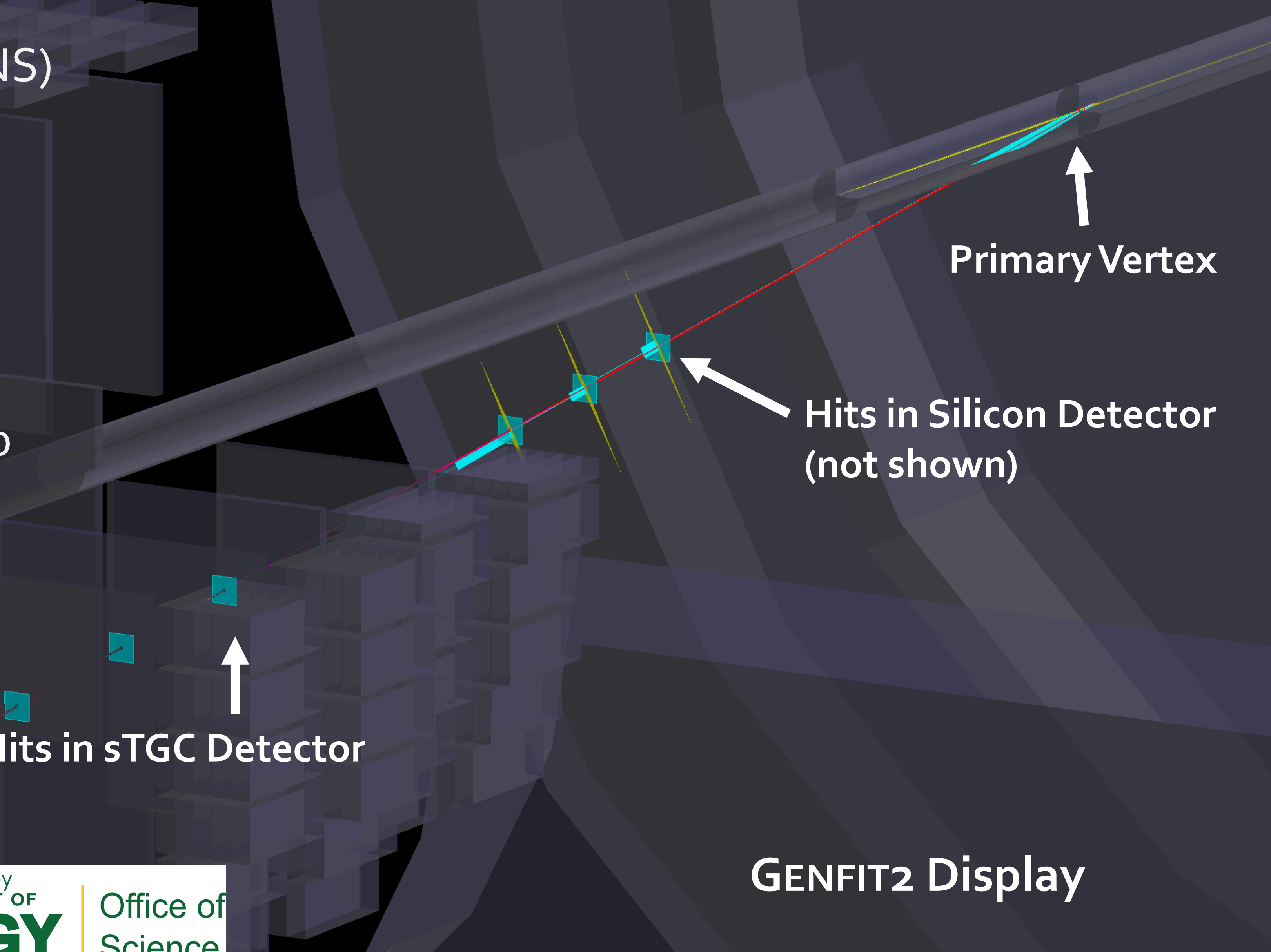
for the STAR Collaboration

Division of Nuclear Physics,
American Physical Society
October 29 - November 1, 2020

Mini-Symposium: Novel detector Technologies, from detectors to data analysis III



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Center for Frontiers in Nuclear Science

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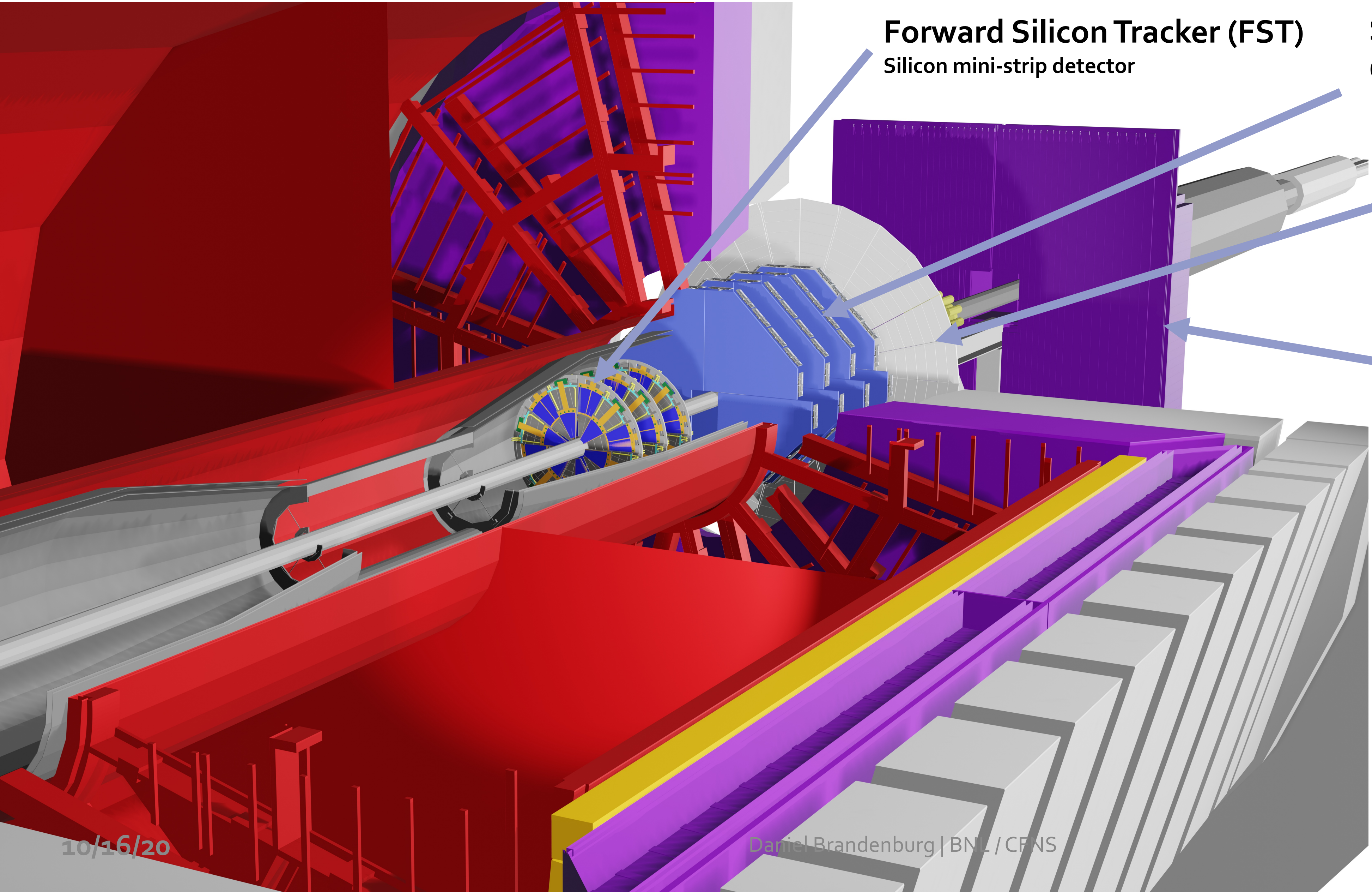
The STAR Forward Detectors



Forward Silicon Tracker (FST)
Silicon mini-strip detector

Small-strip Thin Gap Chambers (sTGC)

Event Plane Detector
Used for triggering

Electromagnetic & Hadronic Calorimetry

Coverage:

$$2.5 < \eta < 4.0$$

STAR Forward Rapidity Physics Program

Measurements planned for 2021+ with the STAR forward upgrade
→Address important topics in hot & cold QCD

Forward-rapidity 2.5<η<4

pp, pA

Beam:
500 GeV: p+p
200 GeV: p+p and p+A

Physics Topics:

- TMD measurements at high x transversity → tensor charge
- Improve statistical precision for Sivers through Drell-Yan
- $\Delta g(x, Q^2)$ at low x through Di-jets
- Gluon PDFs for nuclei
  - R_{pA} for direct photons & DY
- Test of Saturation predictions through di-hadrons, g-Jets

Au+Au

Beam:
200 GeV: Au+Au

Physics Topics:

- Temperature dependence of viscosity through flow harmonics up to h~4
- Longitudinal decorrelation up to h~4
- Global Lambda polarization
  → Test for strong rapidity dependence

Forward Tracking System

	Requirement	Motivation
Momentum Resolution	< 30%	A+A goals
Tracking Efficiency	> 80% @ 100 tracks / event	A+A goals
Charge Separation	–	p+p / p+A goals

Forward Calorimeter System

Detector	Resolution p+p and p+A	Resolution A+A
ECal	$\sim 10\%/\sqrt{E}$	$\sim 20\%/\sqrt{E}$
HCal	$\sim 50\%/\sqrt{E} + 10\%$	–

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0648

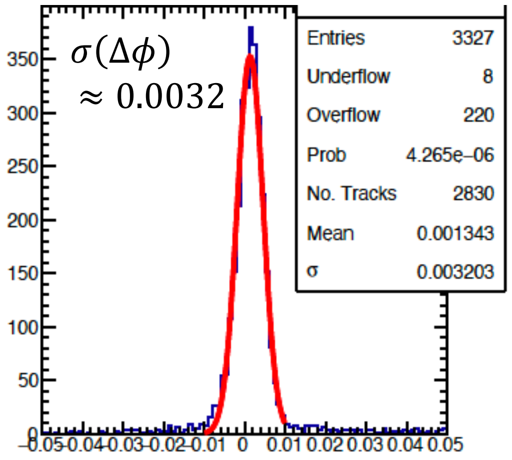
STAR Forward Silicon Tracker (FST)

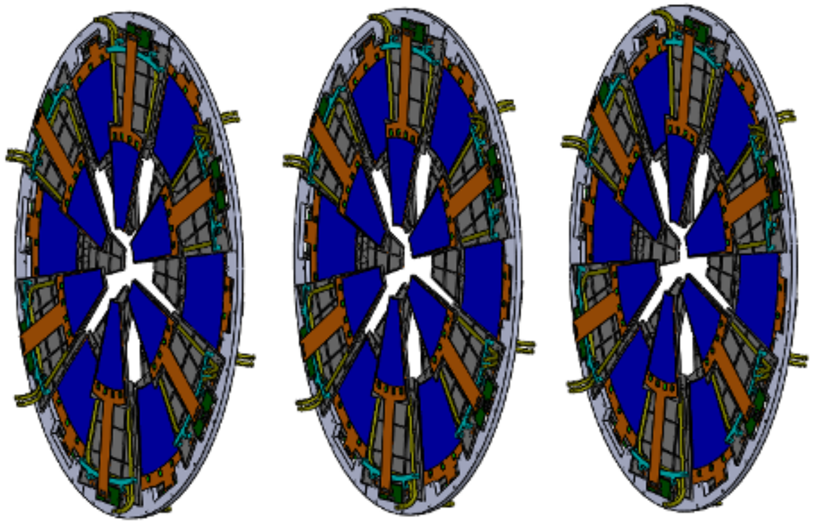
Full installation: 3 identical disks

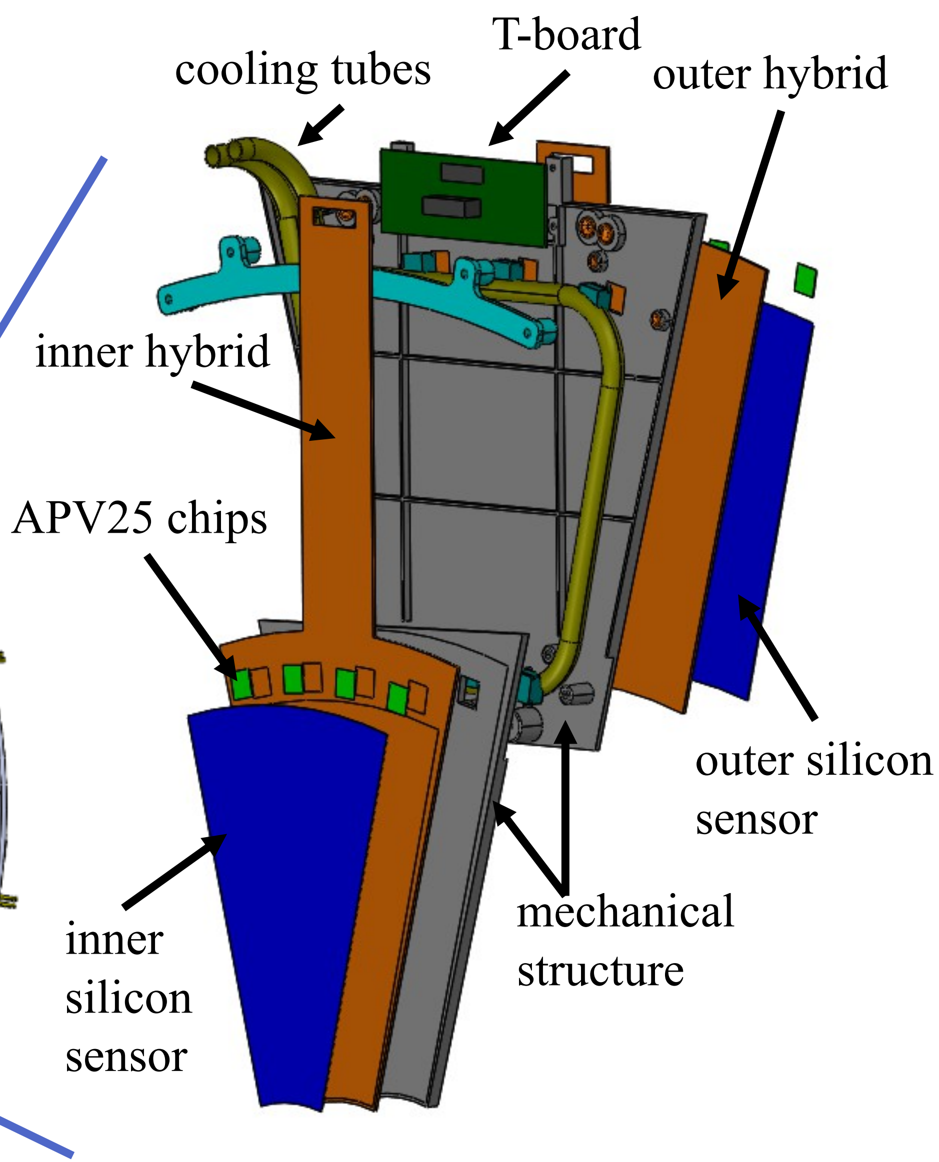
- Acceptance:
  $0 < \phi < 2\pi,$
  $2.5 < \eta < 4.0$
- 12 wedge modules / disk
- APV25 frontend readout chips
- Flexible hybrid

Silicon strips:

- 2.85 cm long in $r-$ direction
- $2\pi\ /\ (12\ *\ 128)$ $\phi-$segmentations≈ .0041 radians / strip





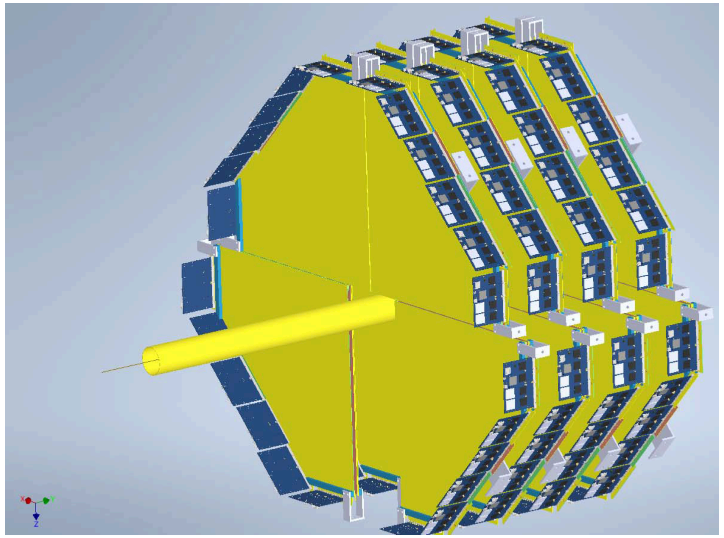


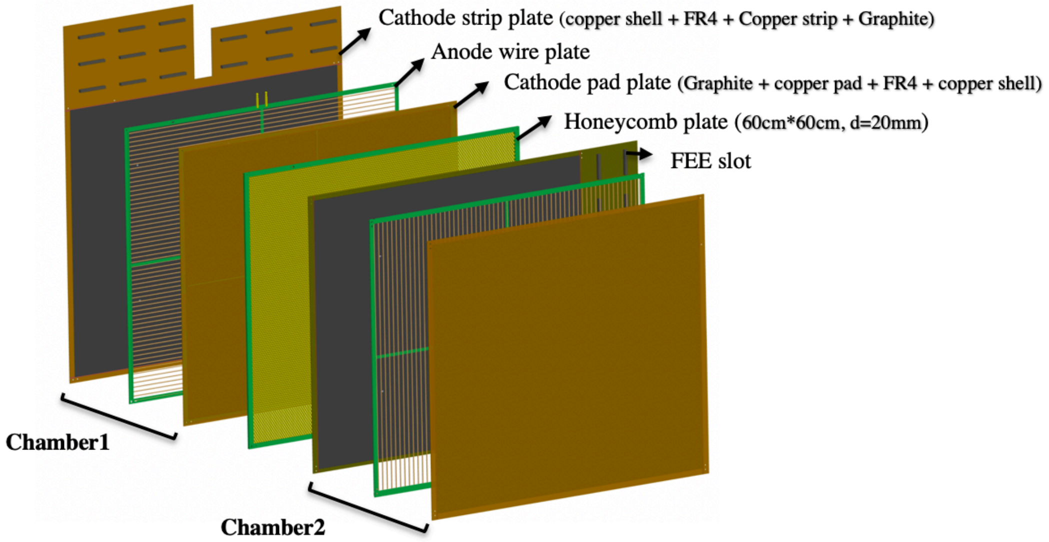
Small-Strip Thin Gap Chambers (sTGC)

Detector Technology:

- Based on ATLAS sTGC design
- 4 layers in total
  - 4 modules/layer
  - 2 chambers/module
- Position resolution: ~100 μm
- Use VMM3 electronics

- ϕ −Acceptance: $0 < \phi < 2\pi$ ("hole" at $-\pi/2$)
- Symmetric Pentagonal design:
- "Sandwich" of X, Y, and diagonal strips





Wire: Au-plated tungsten wire
ø 50μm, 1.8mm pitch
Copper strip: 3.2mm pitch
Height of one layer: 5.8mm
Gas: 55% n-pentane+45%CO_2
HV: 2900V

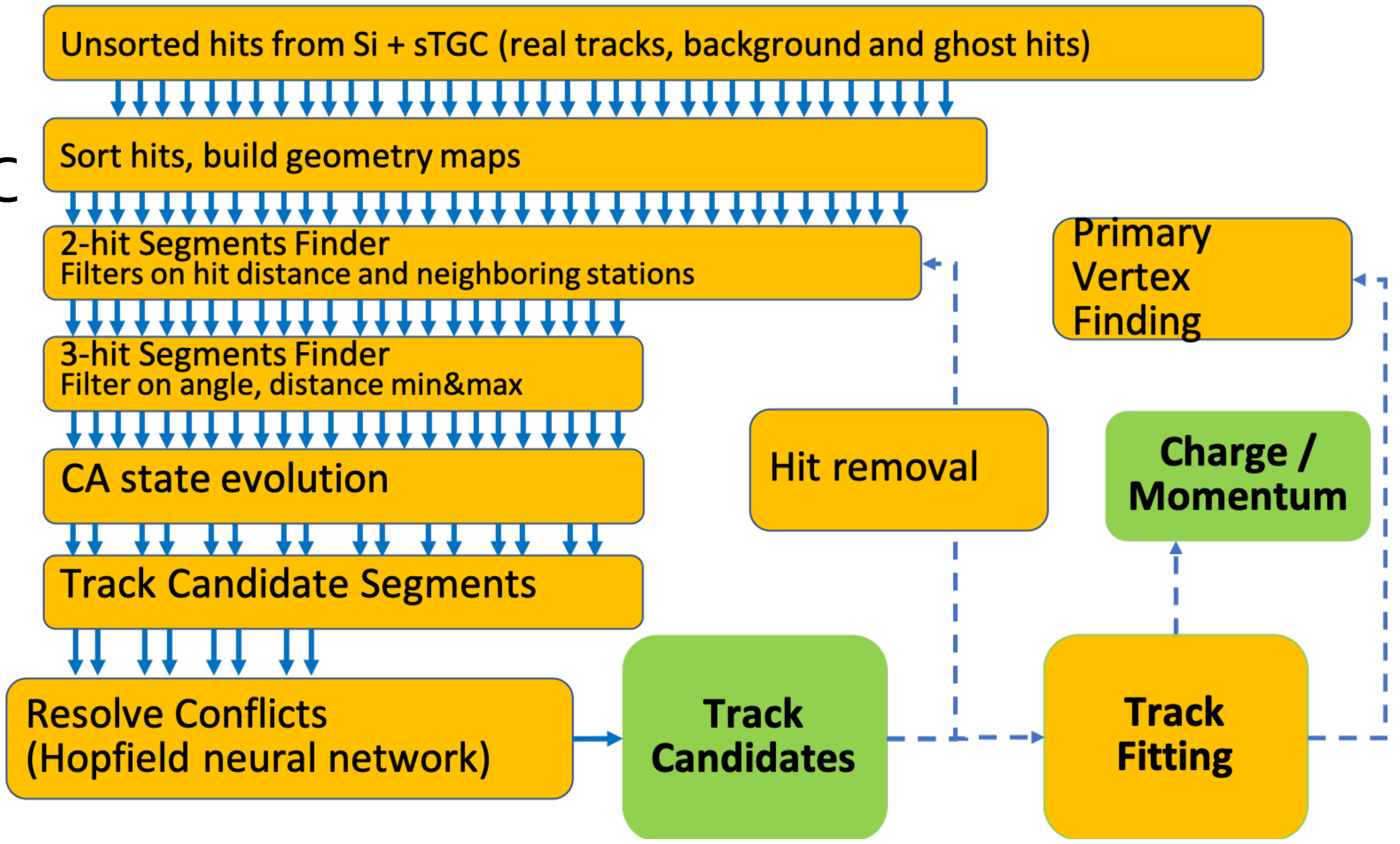
Requires dedicated gas system

Forward Tracking

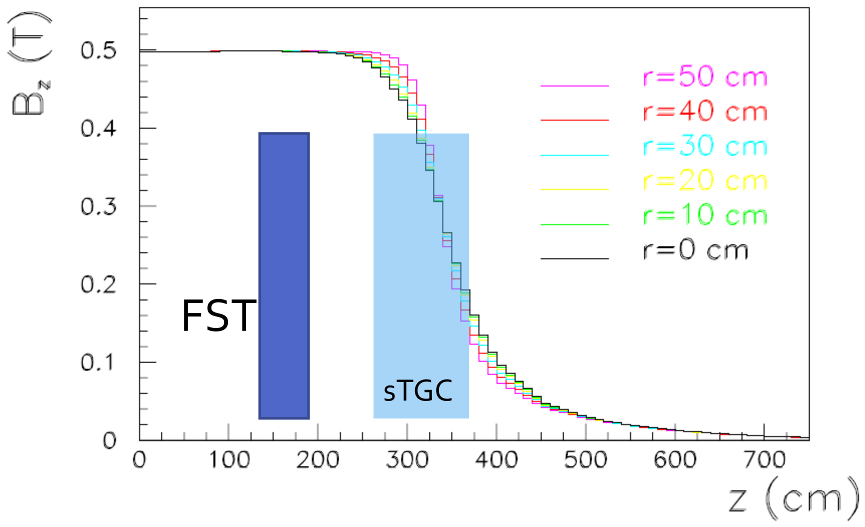
Unique Challenges:

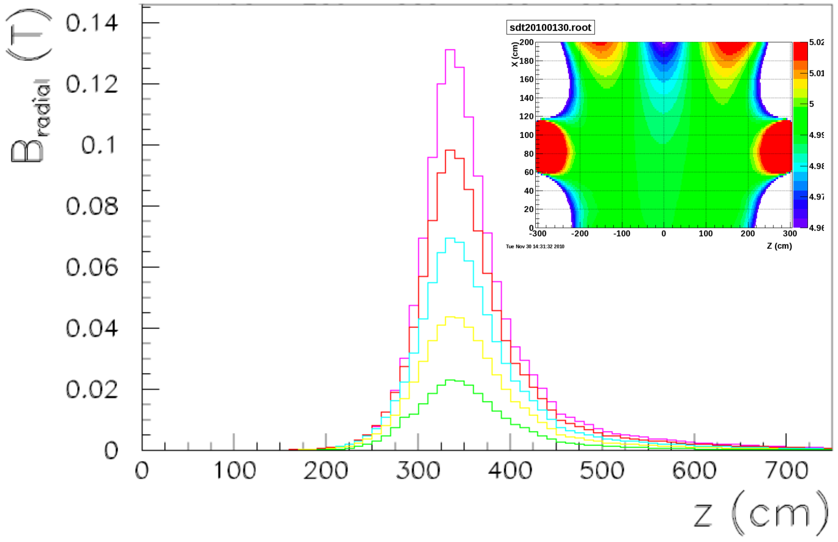
- Combination of detector technologies: Silicon & sTGC
- Changing magnetic field
- Large hit density

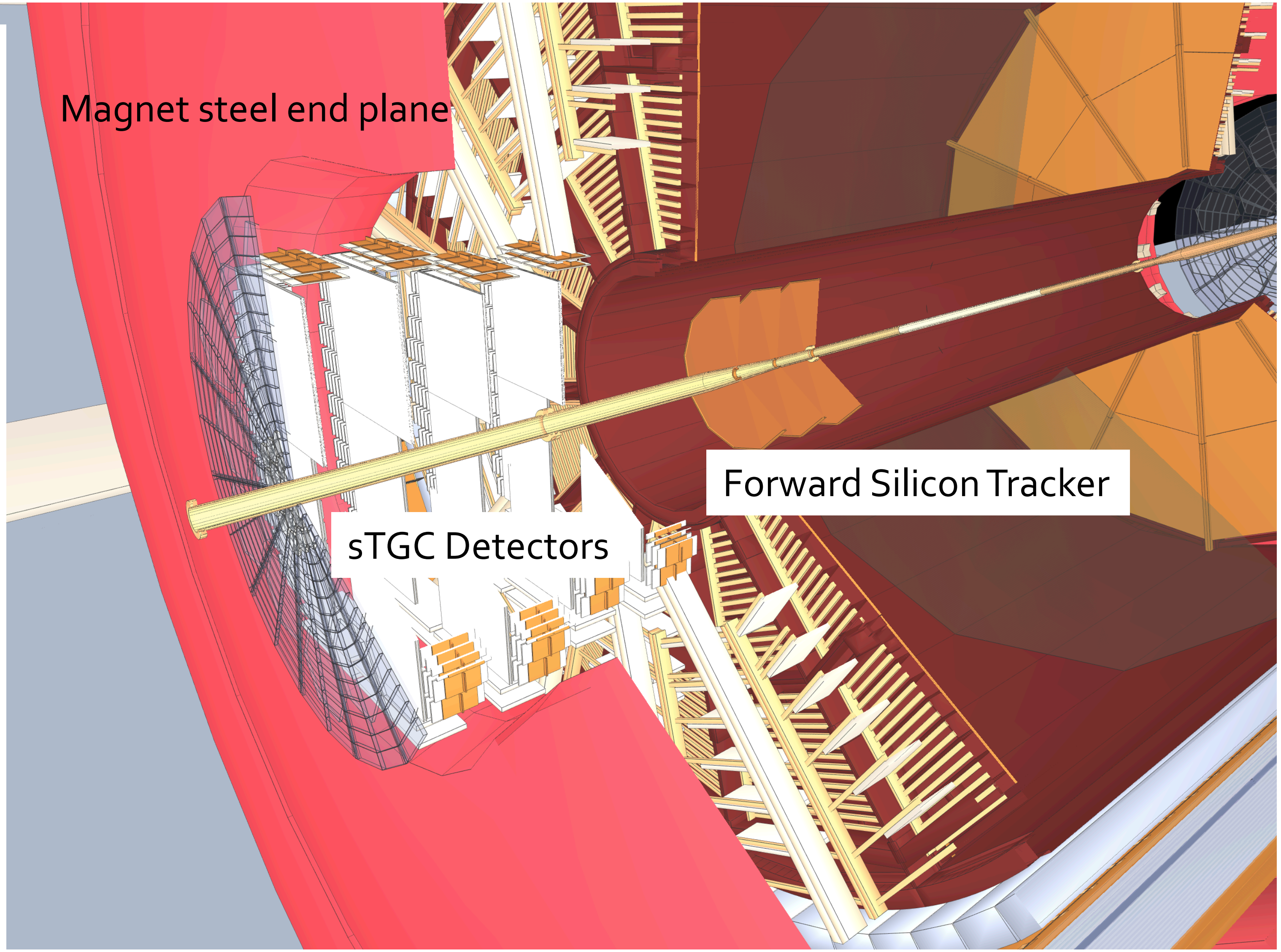
- Track finding:
  - Cellular Automata
- Track Fitting:
  - GENFIT2 (a multi-experiment tracking framework)



Magnetic Field in Forward Region







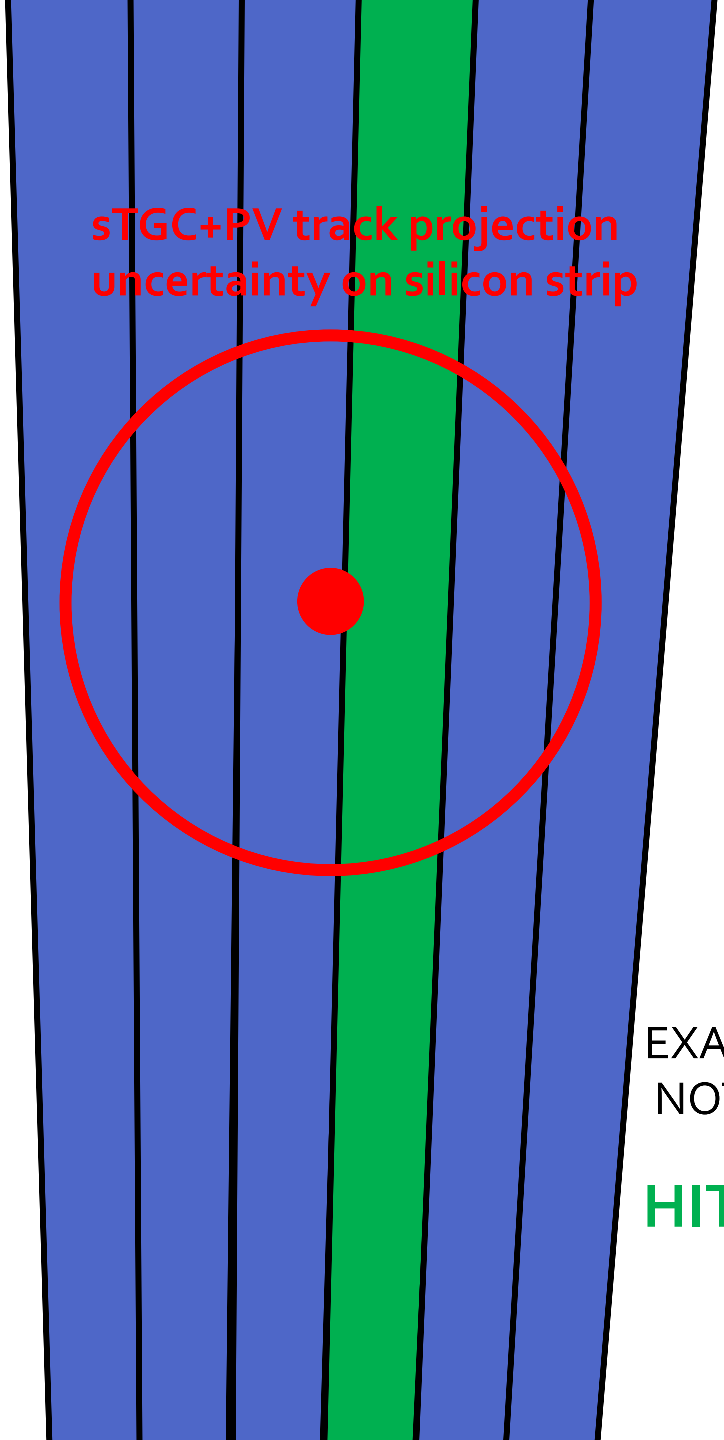
Tracking Algorithm

Track Finding

- Cellular Automata based
- Uses hits from sTGC detector (4 space-points)

Track Fitting procedure

1. Fit primary vertex + sTGC hits
2. Swim along track, find hits in Si planes
3. Refit with primary vertex + FST + sTGC

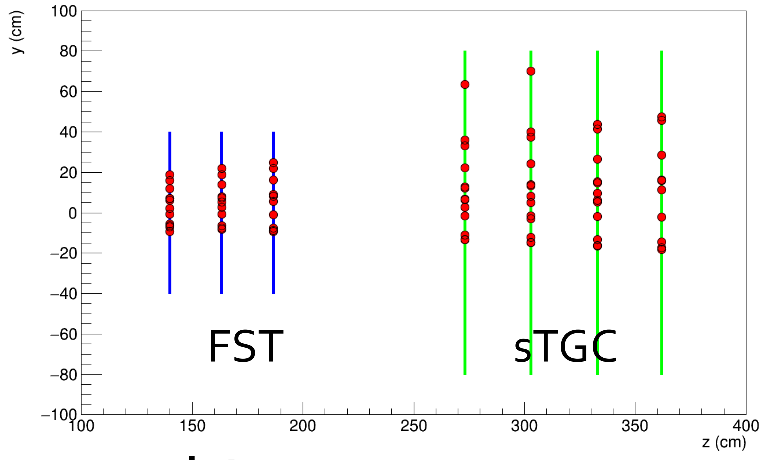


EXAMPLE ONLY:
NOT to SCALE

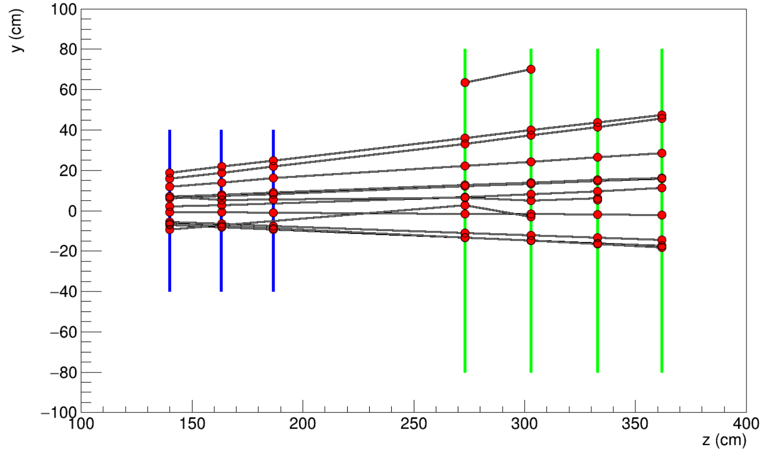
HIT Strip

Track Finding Procedure

- How do we go from this:



- To this:



Naïve approach : make all possible connections

- Very slow due to combinatorial blow up
- Still need to <u>distinguish real track</u> segments from combinatorial

Cellular Automation

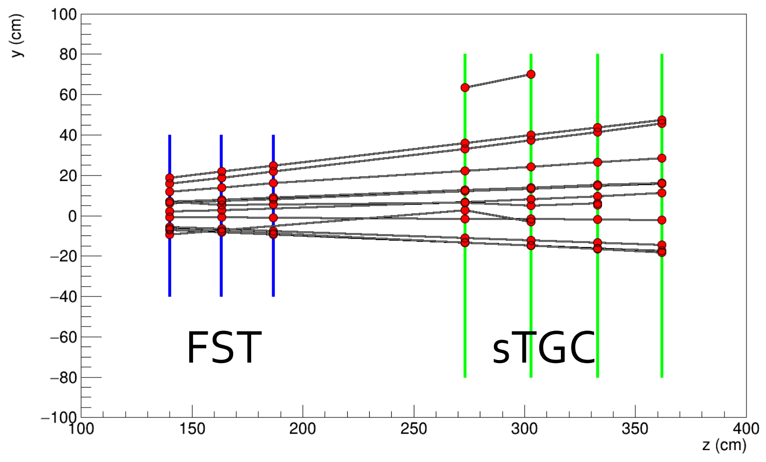
- Use simple "criteria" to build up longer segments of hits
- Build small segments, then grow them according to additional criteria
- <u>Very performant & easily parallelized</u>

Criteria for Finding Track Segments

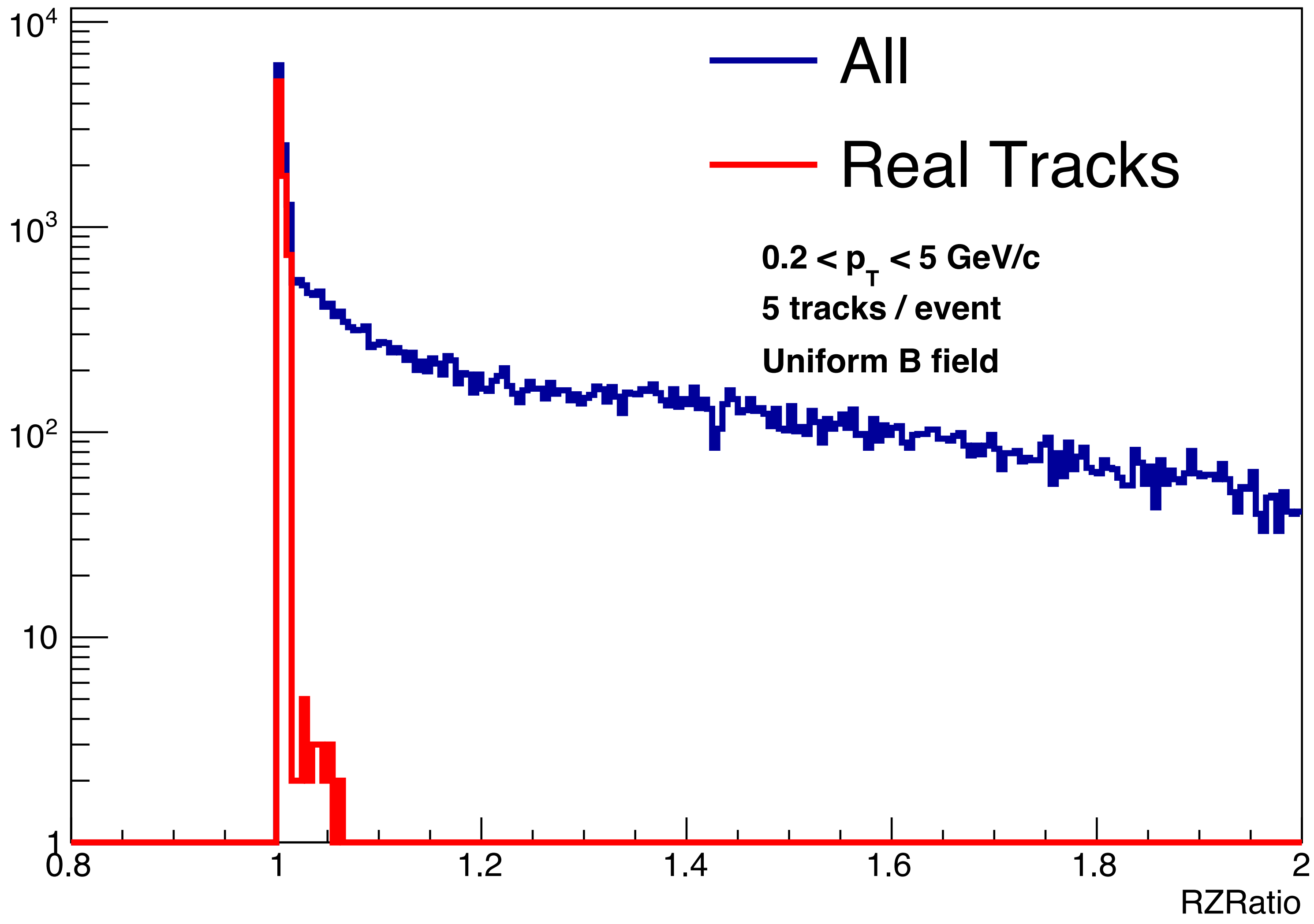
Example Criteria RZRatio :

$$\left(\frac{\Delta R}{\Delta z}\right)^2 = \frac{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2}{(\Delta z)^2}$$

RZRatio is a strong discriminator for real tracks in forward region since tracks are nearly straight in $R - z$ plane



Two-Segment Criteria : RZRatio



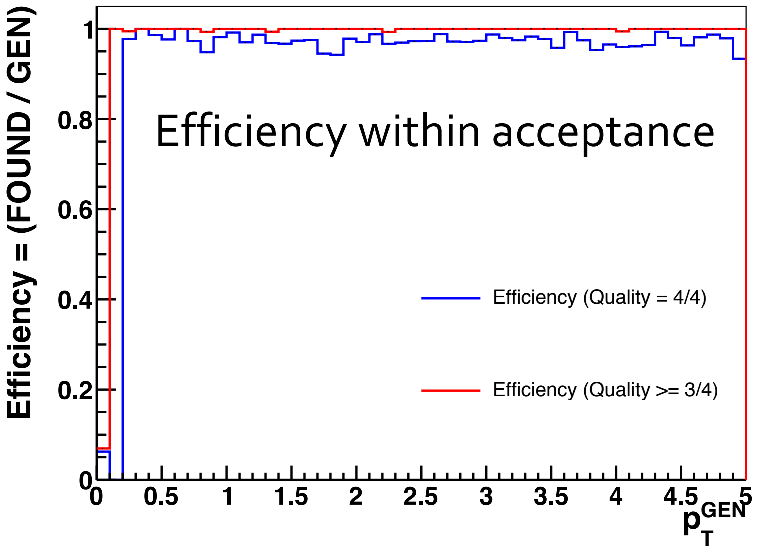
Track Finding Efficiency

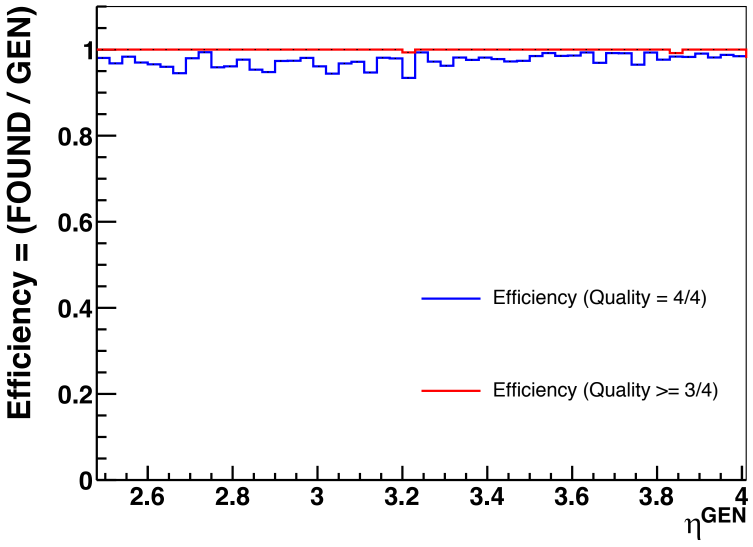
Evaluate performance under ideal conditions

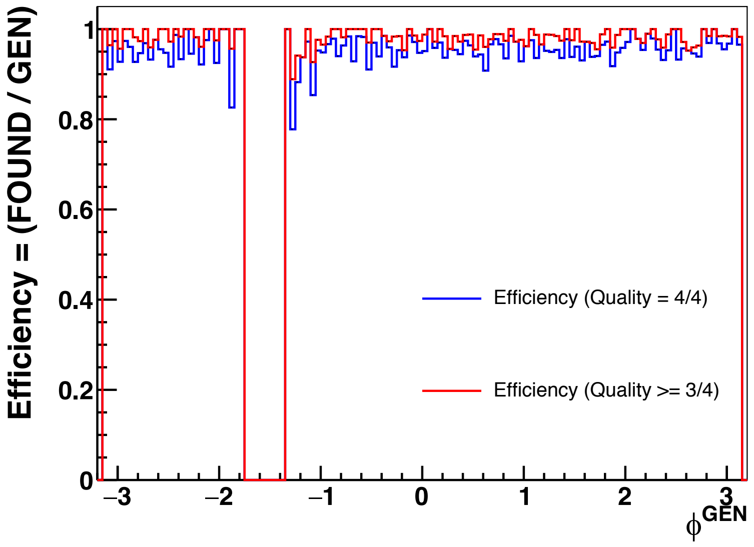
- Track finding efficiency (perfect 4/4 correct hits) is ≈ 98%
- Track finding efficiency (3/4 or more correct hits) is ≈ 99.5%
- **Full material effects**
- **Real STAR B-field map**

Simulation Parameters:

- $1\ \mu^{+}$ / Event
- $2.45 < |\eta| < 4.05$
- $0.2 < p_T < 5\ GeV/c$
- B Field : **REAL** (StarMagField)
- Primary Vertex distribution μ = (0, 0, 0), σ =(0.05, 0.05, 5) cm.

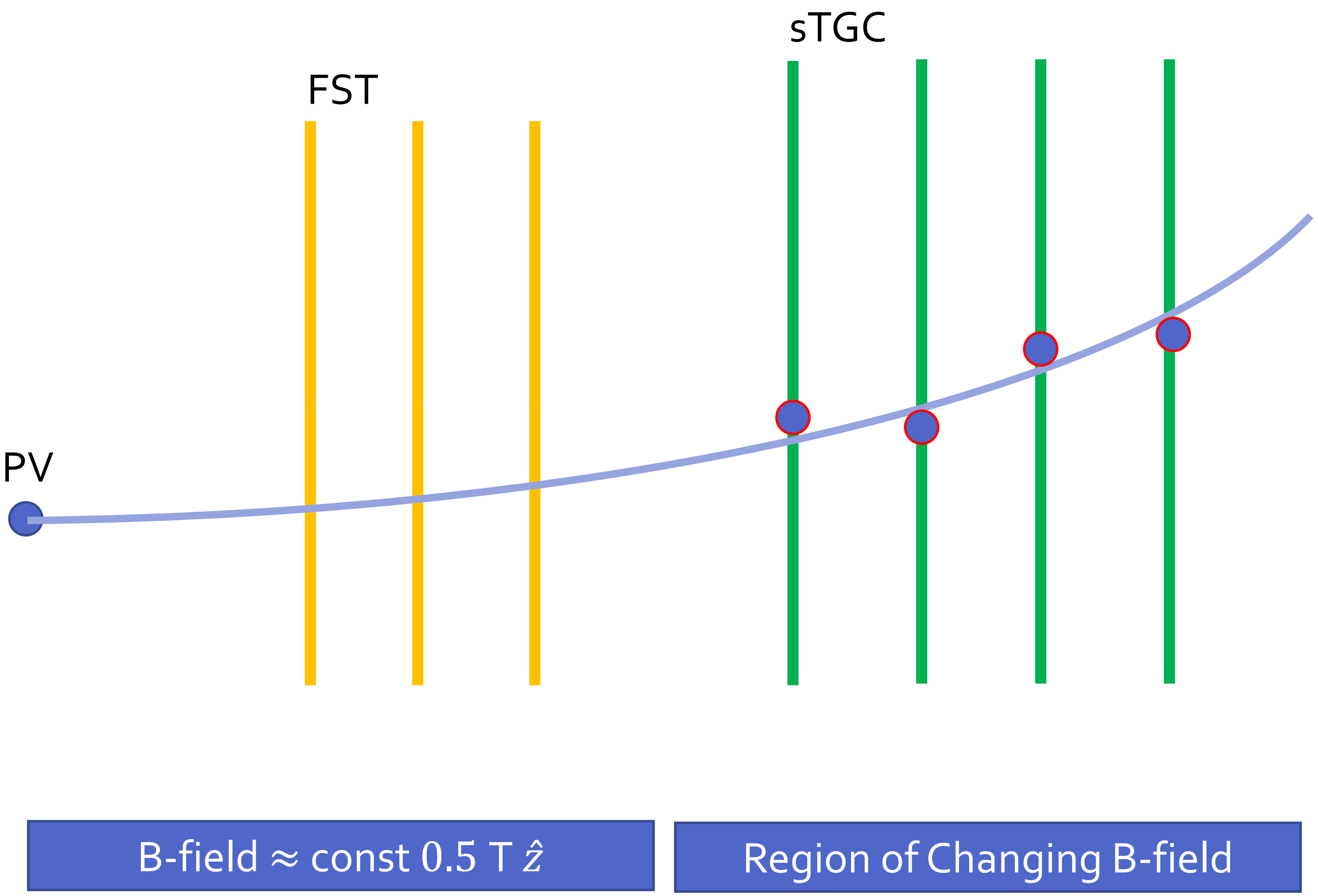






Track Fitting Procedure

Step 1 : Fit track seed from sTGC + PV

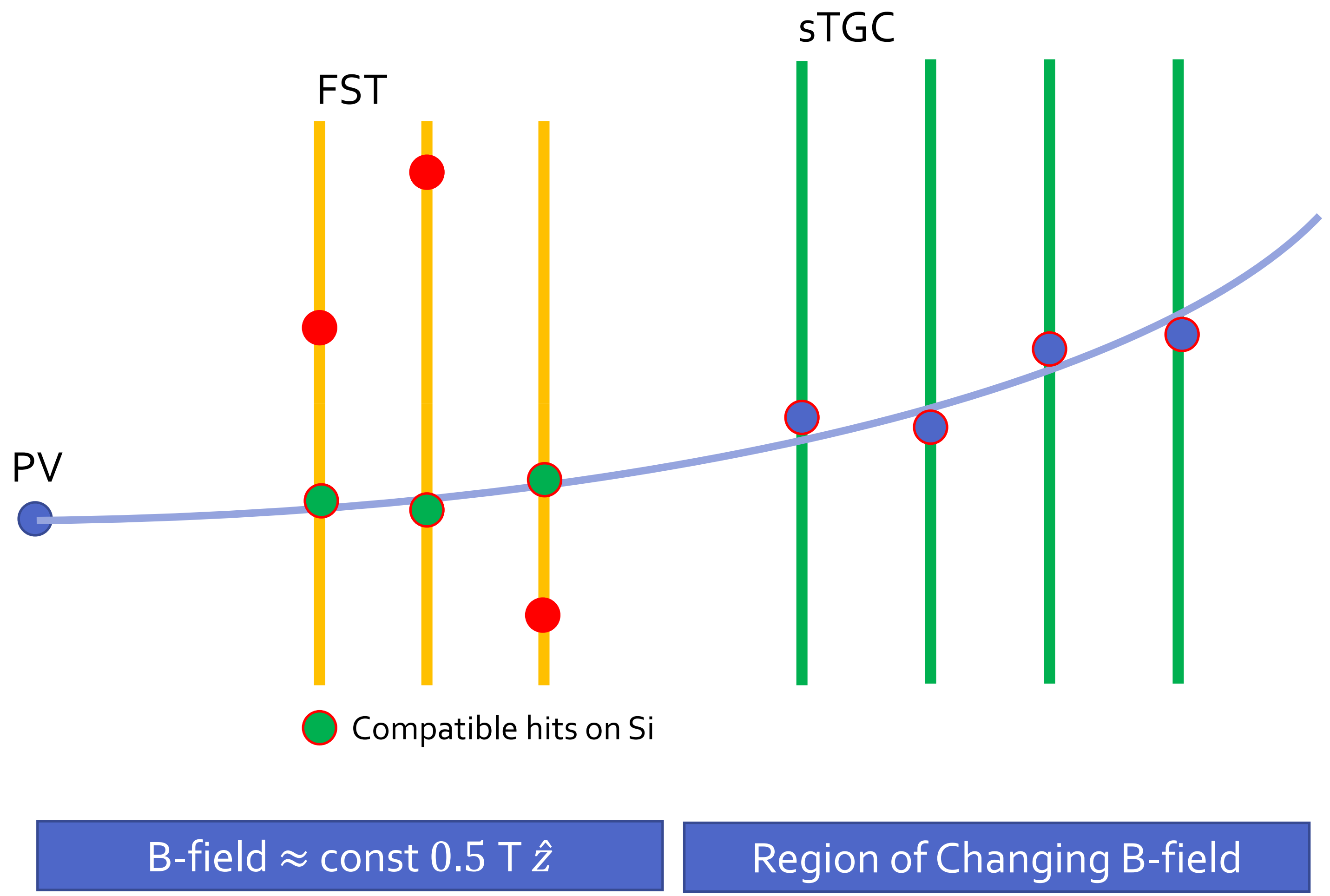


Track Fitting Procedure

1. Fit track seed with sTGC hits and primary vertex (PV)
2. Project tracks to Silicon detector layers and search for hits along track
3. Refit tracks with PV + FST + sTGC

Track Fitting Procedure

Step 2 : Project track onto silicon detectors, search for hits



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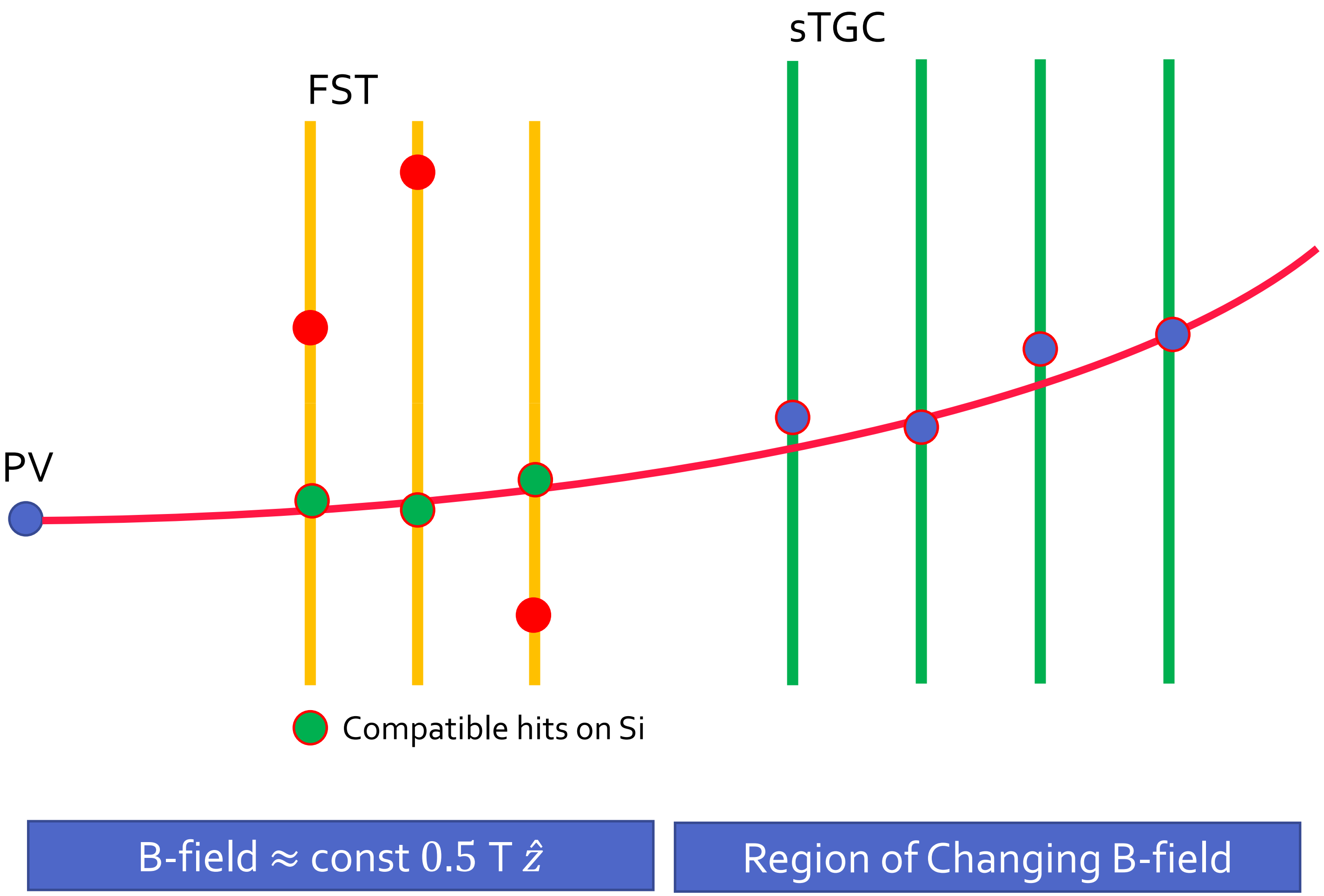
Track Fitting Procedure

Step 3 : Refit track with all information : PV + Si + sTGC



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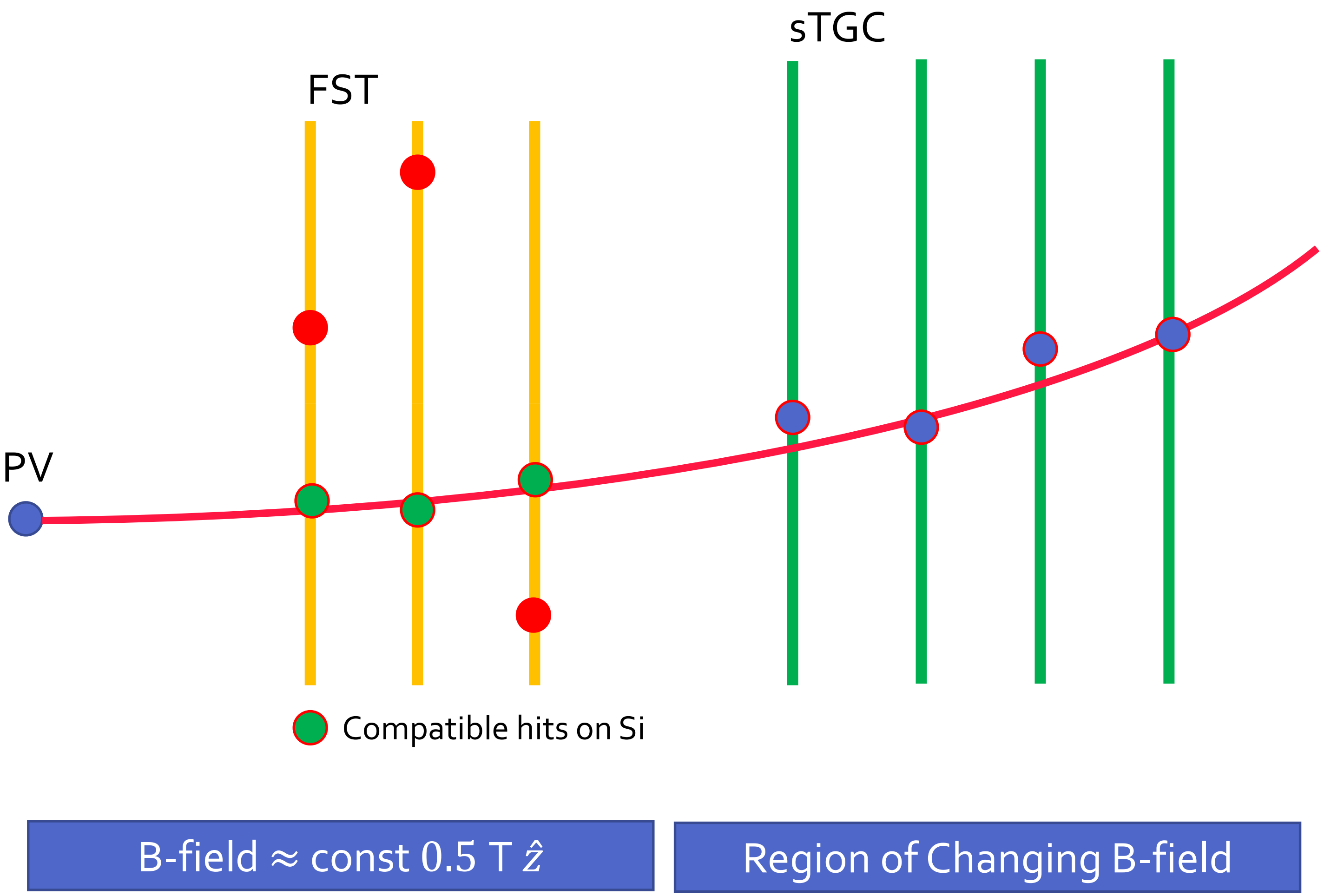
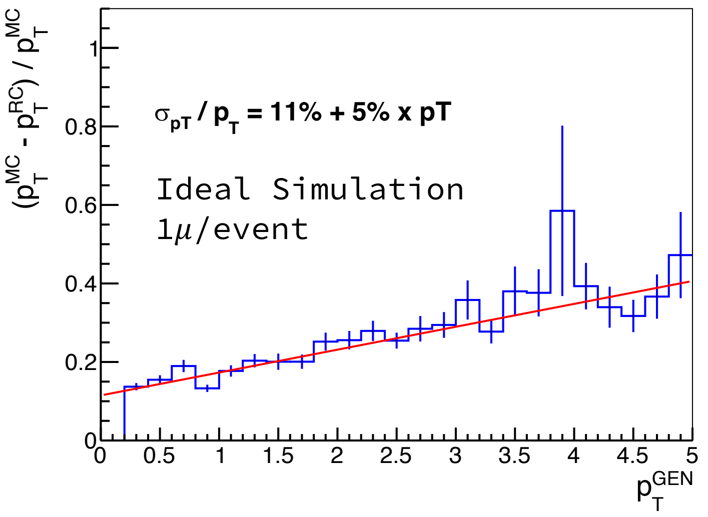
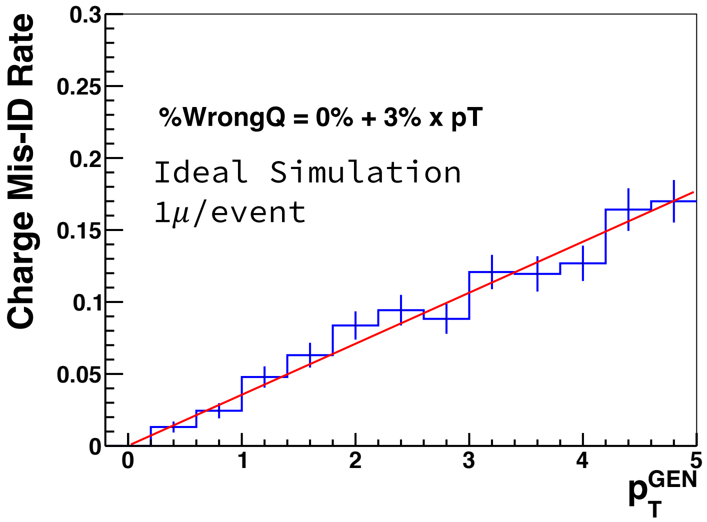


Performance from Simulation

Momentum Resolution





Summary

- STAR Forward physics program is approaching fast!
  - Measurements planned for 2021+ with the STAR forward upgrade
    → Address important topics in hot & cold QCD
- Dedicated forward tracking package being integrated in STAR
  - Cellular automata based track finding
  - GENFIT2 track fitting in non-uniform magnetic field region
- Forward tracking system meets or exceeds goals needed to address the physics goals of the STAR forward upgrade physics program

STAR Forward Upgrade Institutions

Large project → **Dedicated manpower & expertise for each system**

sTGC
- Brookhaven National Laboratory
- Shandong University
- University of Science and Technology of China

Silicon
- UIC University of Illinois at Chicago
- Brookhaven National Laboratory
- National Cheng Kung University
- Shandong University
- Indiana University

ECal
- Kentucky
- Valparaiso University
- Abilene Christian University

HCal
- UCLA
- Texas A&M University
- Indiana University
- Rutgers
- Abilene Christian University
- Ohio State

Calorimeter Funded by NSF

DAQ / Readout
- Brookhaven National Laboratory
- Indiana University
- Kentucky
- UCLA
- Texas A&M University

Software
- Brookhaven National Laboratory
- UIC University of Illinois at Chicago
- Indiana University
- Texas A&M University
- National Cheng Kung University

Integration
- Brookhaven National Laboratory

Calibration
- UC Riverside
- Temple University

Slow Controls
- Valparaiso University
- Abilene Christian University
- Creighton University

And support from the entire STAR Collaboration