Quark Matter 2023

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STAR Forward Detector Upgrade Status and Performance

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for the STAR collaboration

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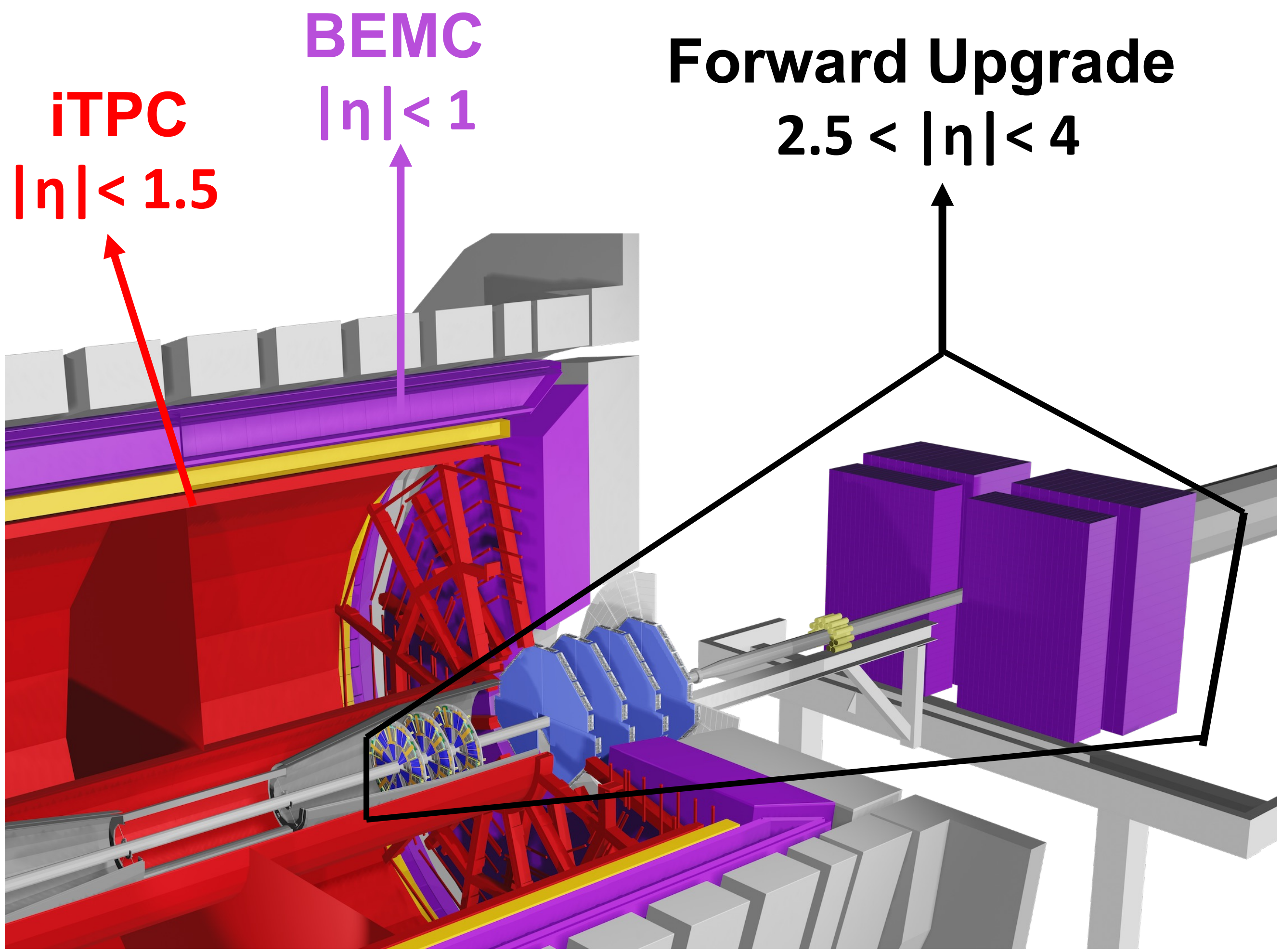
U.S. DEPARTMENT OF ENERGY | Office of Science

STAR

山东大学 SHANDONG UNIVERSITY

NSFC

STAR Forward Upgrade: Overview



Locate at STAR west side, 2.5 < η < 4
Similar coverage as the EIC detector's hadron endcap

Installed at STAR successfully in 2021, and started taking data from 2022 (Run 22)

Forward Tracking System:

Forward Silicon Tracker (FST)
Forward small-strip Thin Gap Chamber Tracker (FTT)

- ✓ Charge separation
- ✓ $\delta p_T/p_T$ ~ 20-30% for 0.2 < p_T < 2 GeV/c

Forward Calorimeter System:

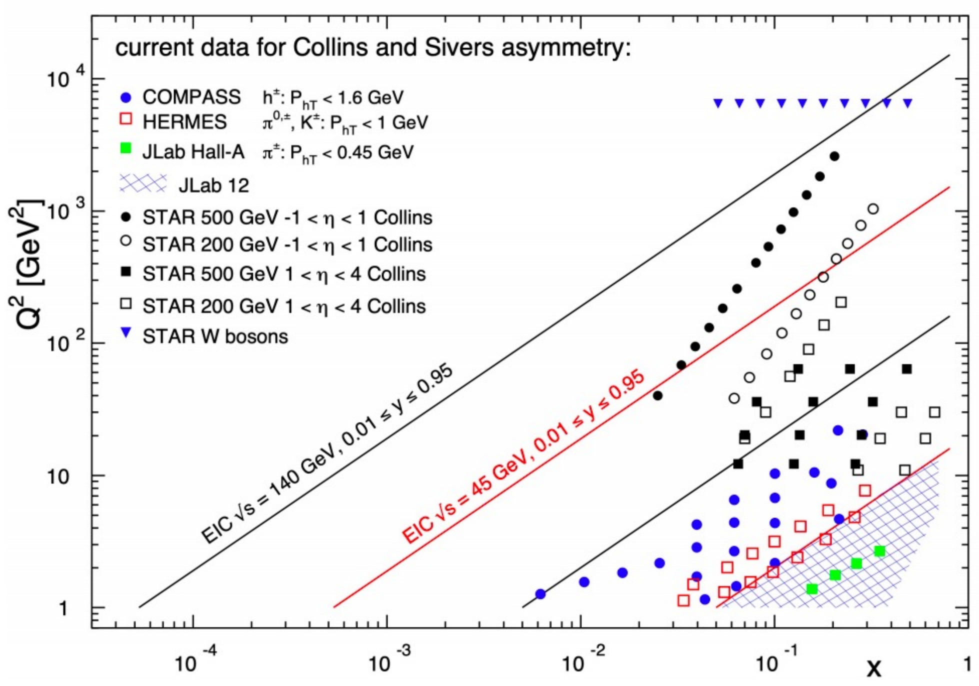
Forward Electromagnetic Calorimeter (ECal)
Forward Hadronic Calorimeter (HCal)

- ✓ Good e/h separation
- ✓ Photon, π^0 identification
- ✓ ECal: $\sim 10\%/\sqrt{\mathrm{E}}$ for pp and pA, $\sim 20\%/\sqrt{\mathrm{E}}$ for AA
- ✓ HCal: $\sim 50\%/\sqrt{\mathrm{E}}$ for pp and pA

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

STAR Forward Upgrade: Physics Program

arXiv:1602.03922



Observables:

- ✓ Charged and neutral hadrons
- ✓ Inclusive jets and di-jets
- ✓ Photons and electrons
- ✓ Mid-forward and forward-forward rapidity correlations

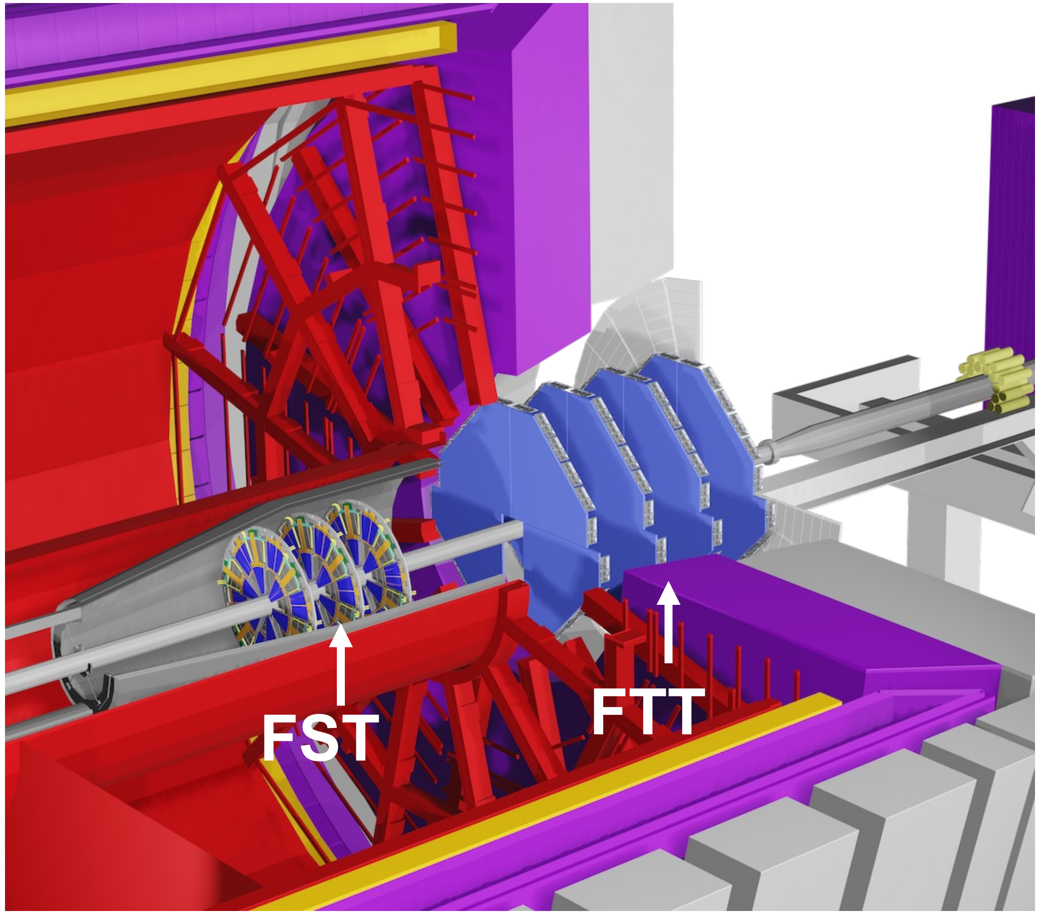
Cold QCD:

- ✓ Beam :
  - p+p 510 GeV (2022)
  - p+p & p+Au 200 GeV (2024)
- ✓ Spin asymmetries for hadrons, (tagged) jets, and di-jets
- ✓ Gluon PDFs for nuclei: R_{pA} for direct photons & DY
- ✓ Tests of saturation predictions through di-hadrons, γ-jets

Hot QCD:

- ✓ Beam :
  - Au+Au 200 GeV (2023 and 2025)
- ✓ Temperature dependence of viscosity through flow harmonics up to η ~ 4
- ✓ Longitudinal decorrelation up to η ~ 4
- ✓ Global Lambda Polarization: test predictions of strong rapidity dependence ...
- ✓ Extension of the $W_{\gamma p}$ range of measurement in UPC

Forward Tracking System



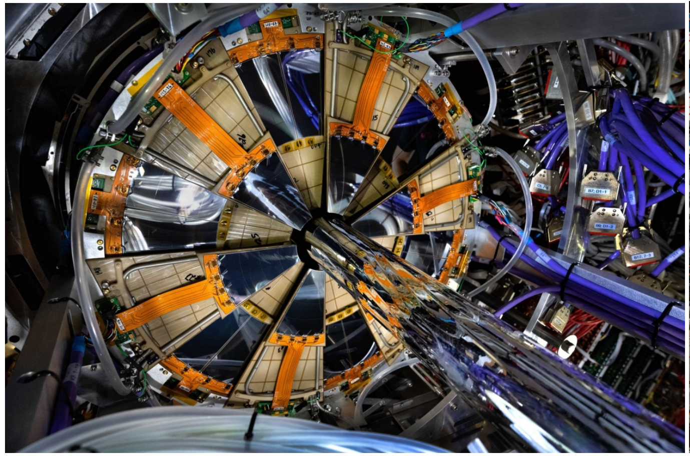
2.5 < η < 4

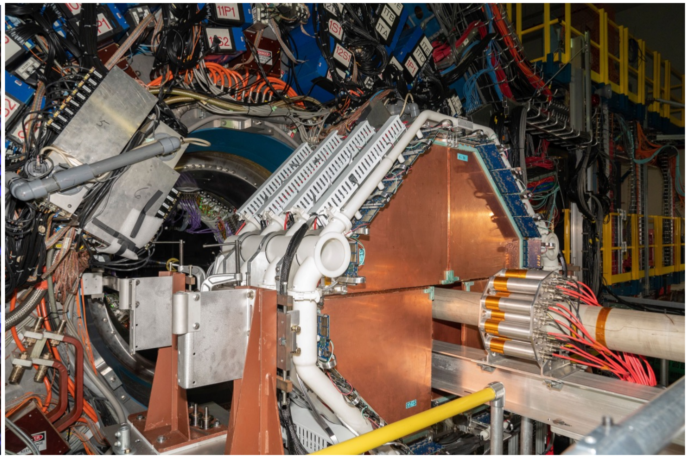
Forward Silicon Tracker:

- ✓ 3 disks, at 152, 165, and 179 cm from IP
- ✓ Locate inside STAR TPC cone

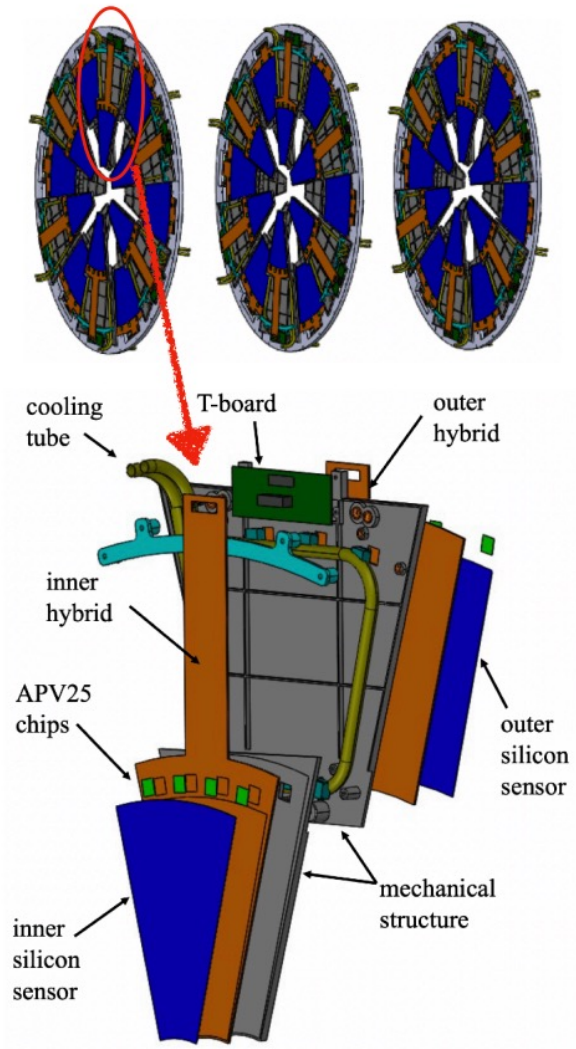
Forward small-strip Thin Gap Chamber Tracker:

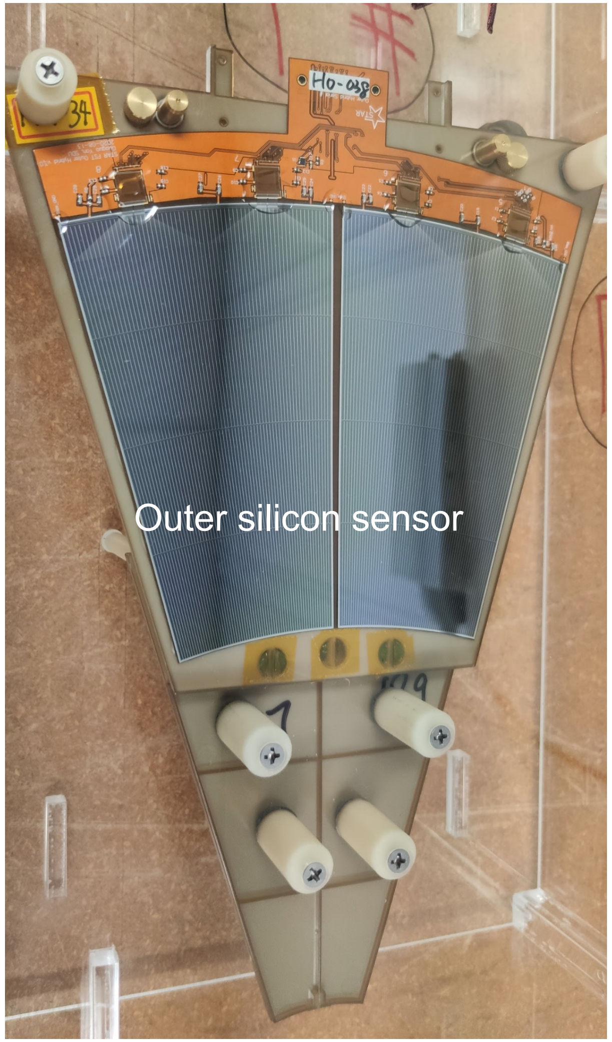
- ✓ 4 disks, at 307, 325, 343 and 361 cm from IP
- ✓ Locate inside STAR magnet pole tip opening





Forward Silicon Tracker





3 Silicon disks:

- ✓ 152, 165, and 179 cm from IP
- ✓ Locate inside STAR TPC cone
- ✓ 12 modules per disk
- ✓ Si from Hamamatsu

Granularity:

- ✓ fine in ϕ and coarse in R

Front-end chips:

- ✓ APV25

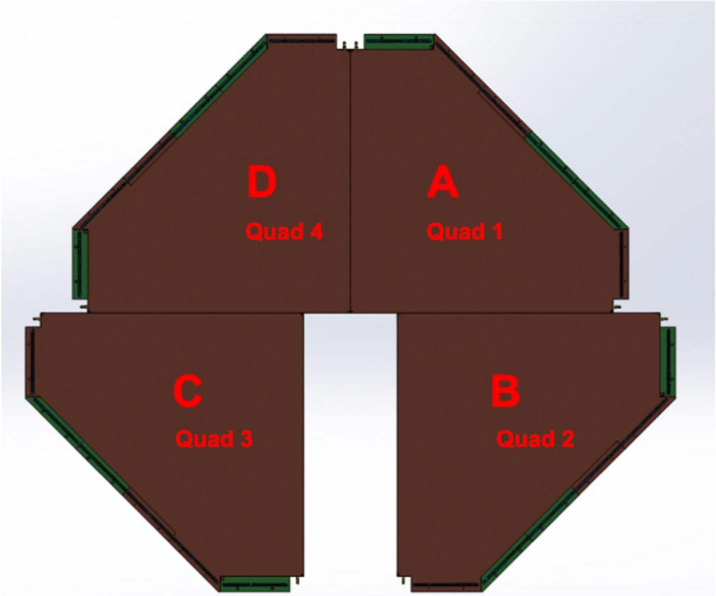
Material budget:

- ✓ ~1% per disk

Reuse:

- ✓ IST DAQ system & IST cooling system

Forward sTGC Tracker



4 sTGC disks:
- ✓ 307, 325, 343 and 361 cm from IP
- ✓ 4 pentagon module per disk
- ✓ sTGC technique developed by ATLAS

Working gas:
- ✓ 45% n-pentane + 55% CO_2

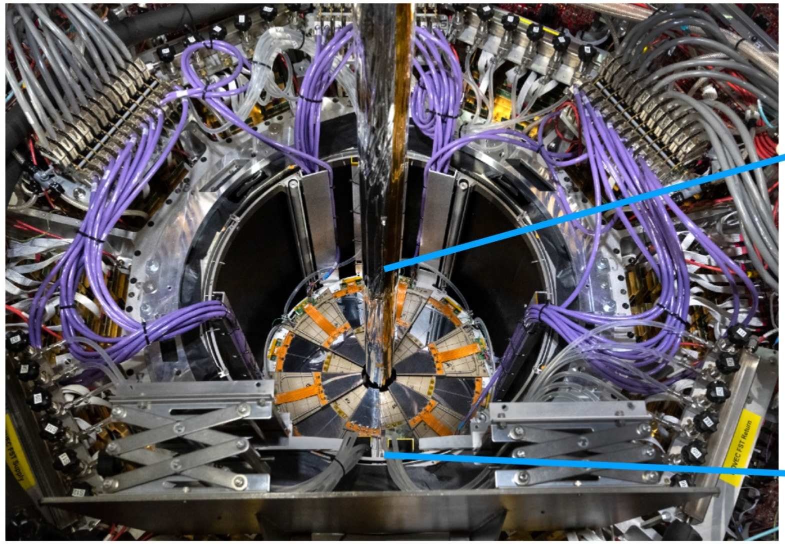
Position resolution:
- ✓ < 200 um

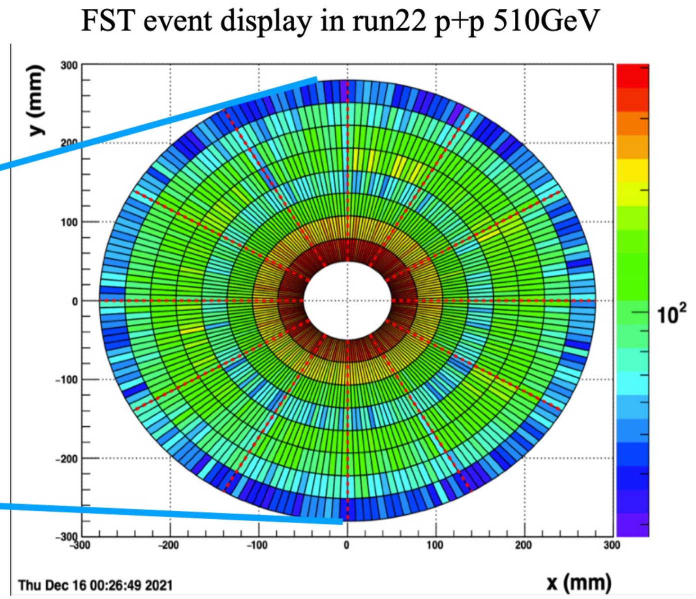
Material budget:
- ✓ ~0.5% per layer

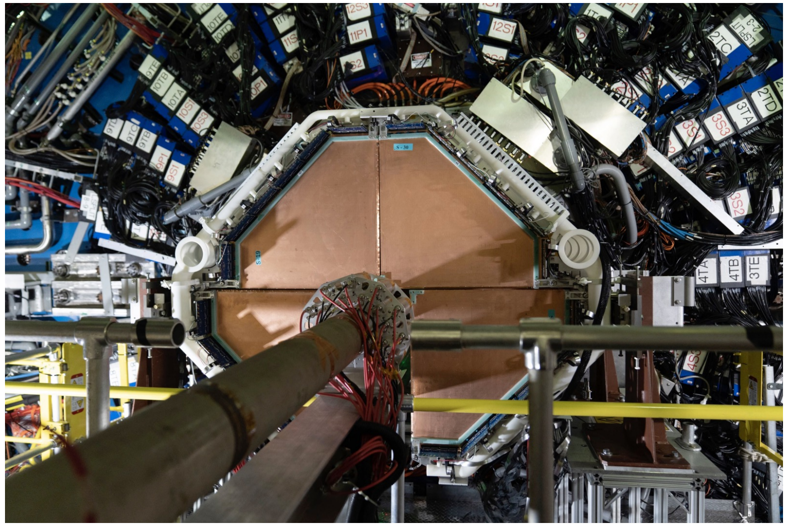
Readout:
- ✓ VMM chips

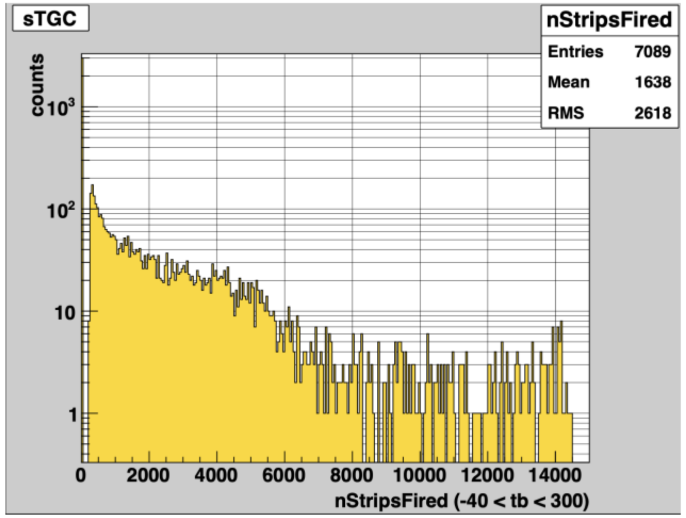
A. Abusleme, et al. NIM.A 817 (2016) 85-92

Operation









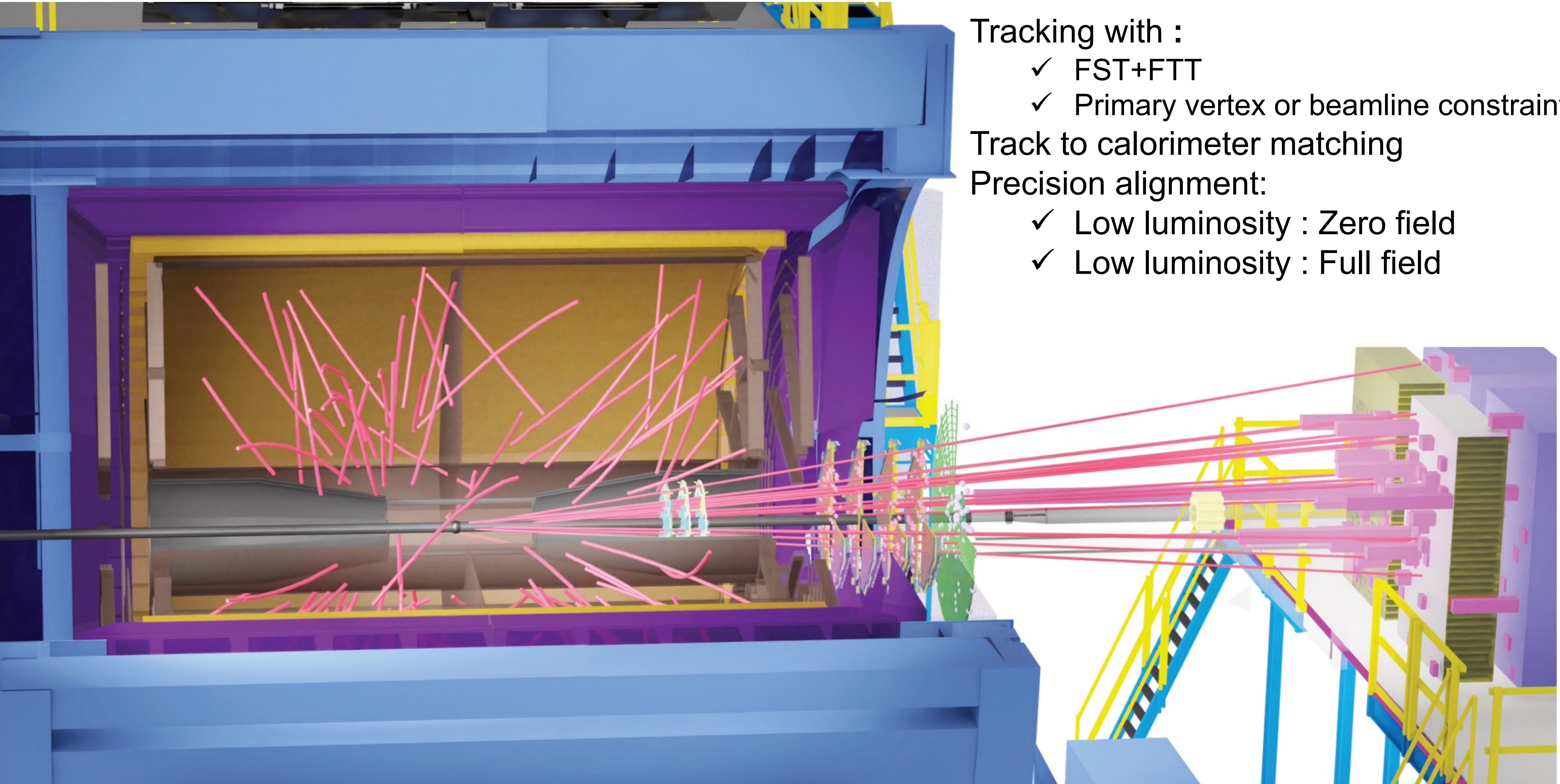
FST :

- ✓ HV:
  - 140V for inner module
  - 160V for outer module
- ✓ Hit map:
  - Match expectations given known missing APVs and lower bias voltages on a few of the sensors

FTT :

- ✓ HV:
  - 2900V for data taking
- ✓ Hit multiplicity:
  - Consisting of predominately minimum bias triggered events

STAR Forward Tracking

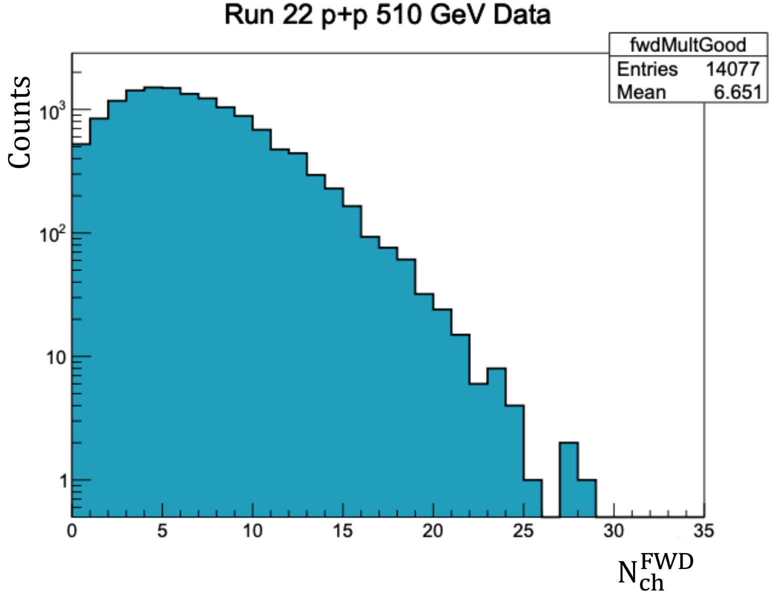


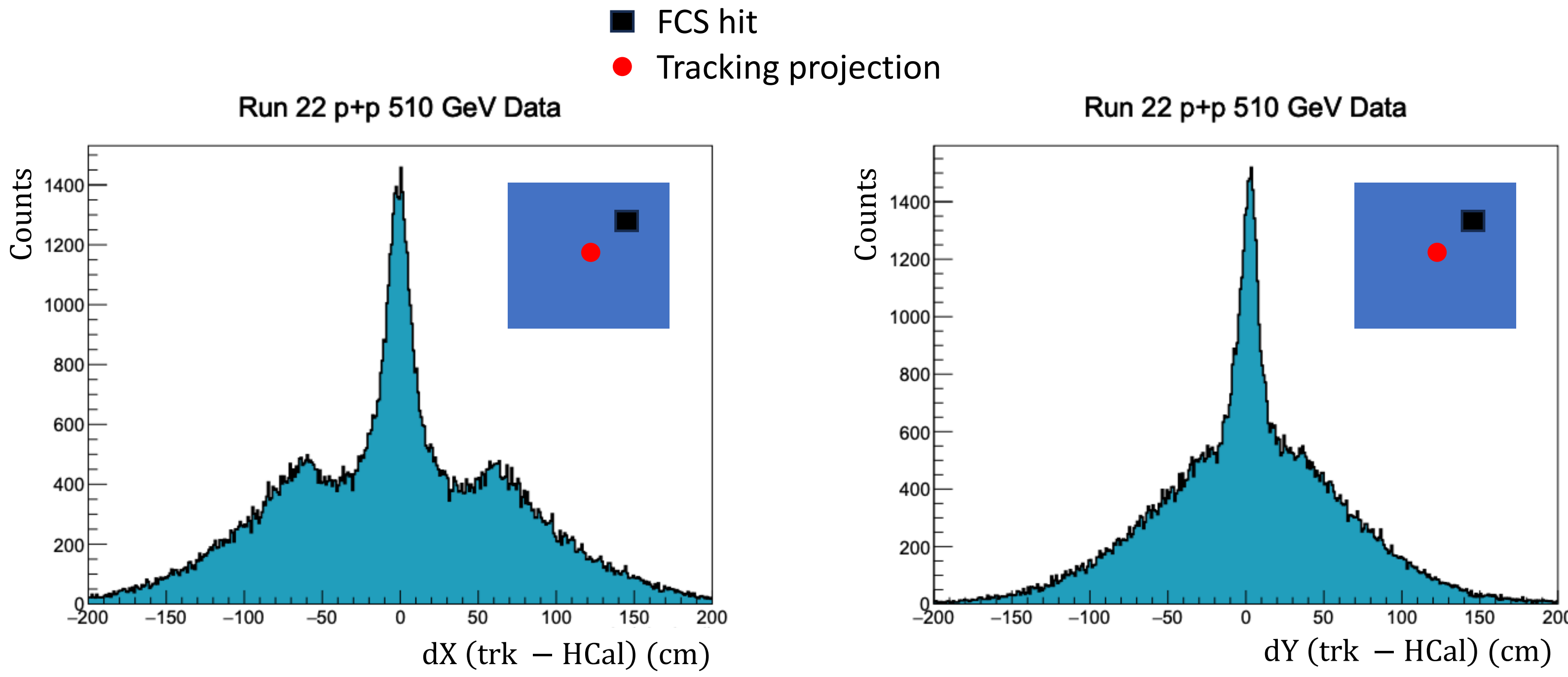
Tracking with :
- ✓ FST+FTT
- ✓ Primary vertex or beamline constraint

Track to calorimeter matching

Precision alignment:
- ✓ Low luminosity : Zero field
- ✓ Low luminosity : Full field

Charge track multiplicity & Match to FCS





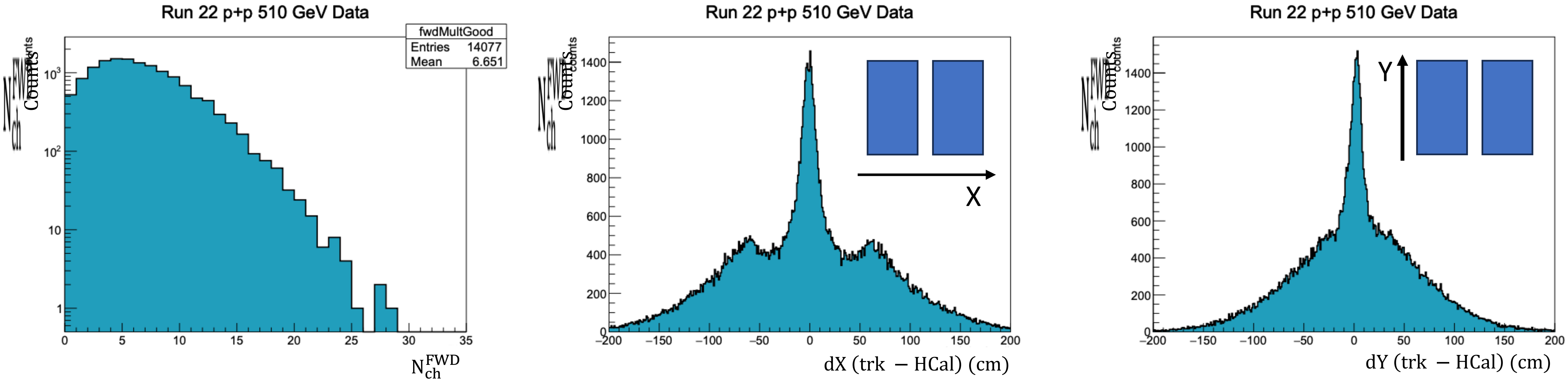
Charged track multiplicity:

- ✓ Reasonable result

Match to FCS:

- ✓ Matched(narrow peak) + Random background(wide peak)
- ✓ Good alignment between FTS and FCS
- ✓ More analysis is ongoing

Charge track multiplicity & Match to FCS



Charged track multiplicity:

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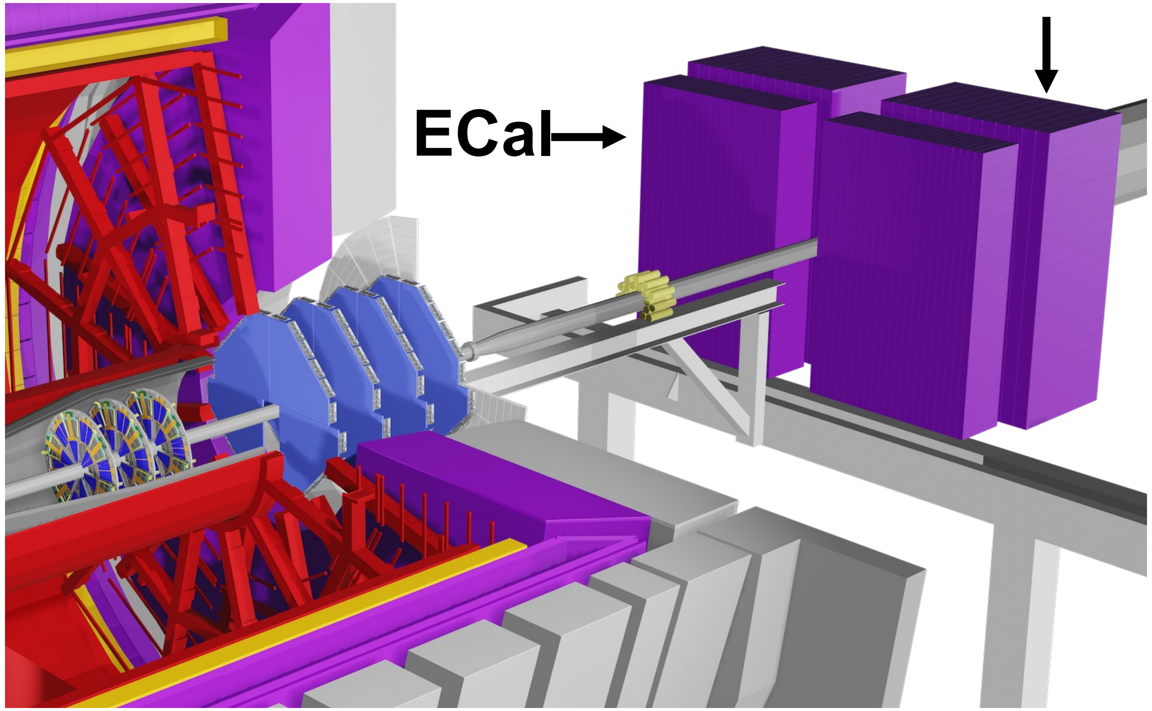
Forward Calorimeter System

2.5 < η < 4



Location: 7m from the IP

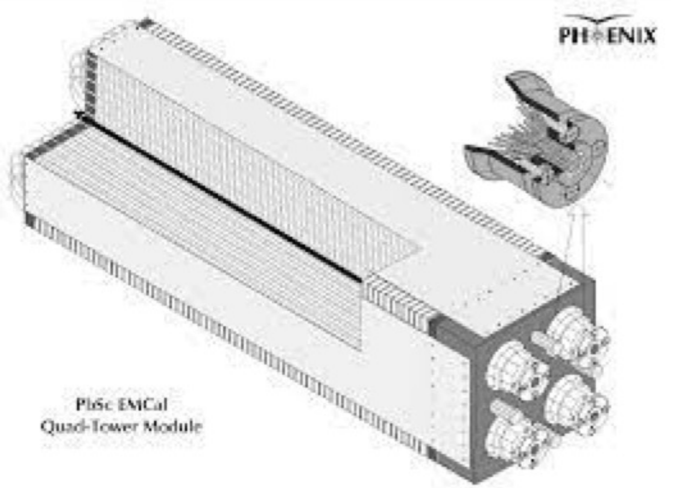
Preshower:
- ✓ Split signals off from STAR EPD for triggering

ECal:
- ✓ Reuse PHENIX Pb-Scintillator calorimeter
- ✓ 1496 channels: 5.52 x 5.52 x 33 cm^3
- ✓ 66 sampling cells with Pb/Sc(1.5 mm/4 mm)

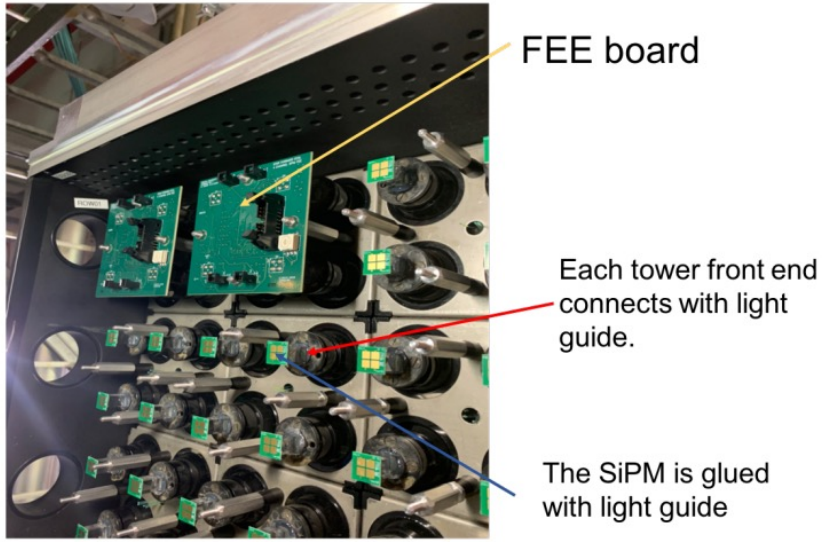
HCal:
- ✓ Fe/Sc (20 mm/3 mm) sandwich
- ✓ 520 channels: 10 × 10 × 84 cm^3

Readout:
- ✓ SiPMs
- ✓ Developed in collaboration with EIC R&D

Forward Calorimeter System



ECal module



Refurbished ECal tower front end display

Location: 7m from the IP

Preshower:

- ✓ Split signals off from STAR EPD for triggering

ECal:

- ✓ Reuse PHENIX Pb-Scintillator calorimeter
- ✓ 1496 channels: 5.52 x 5.52 x 33 cm^3
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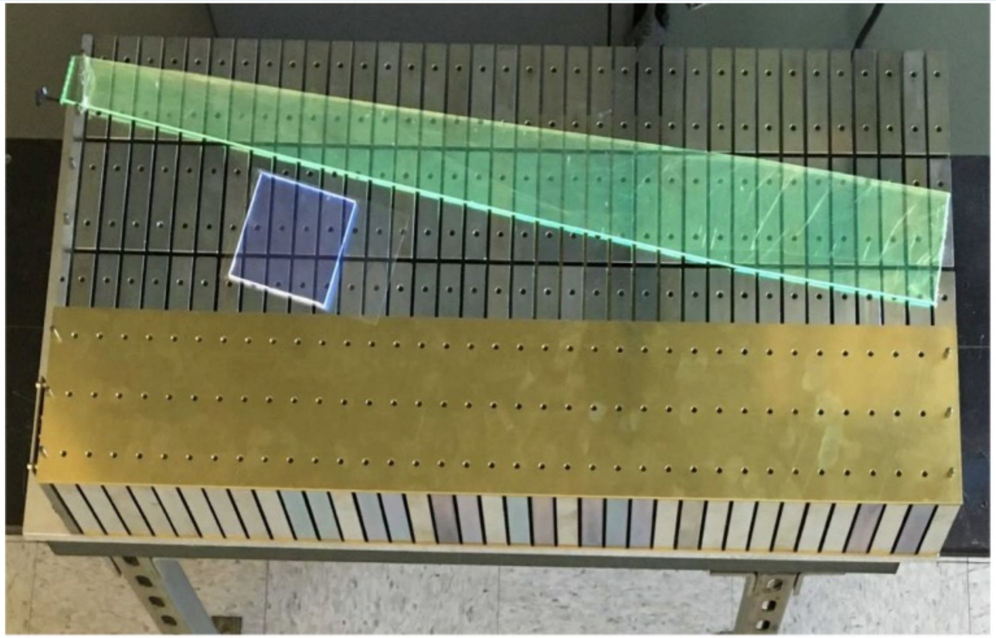
Forward Calorimeter System



HCal: Absorber, Scintillator, WLS Bars, Interlink Plates

Installing WLS bars

Installing LED

Location: 7m from the IP

Preshower:

- ✓ Split signals off from STAR EPD for triggering

ECal:

- ✓ Reuse PHENIX Pb-Scintillator calorimeter
- ✓ 1496 channels: 5.52 x 5.52 x 33 cm^3
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HCal:

- ✓ Fe/Sc (20 mm/3 mm) sandwich
- ✓ 520 channels: 10 × 10 × 84 cm^3

Readout:

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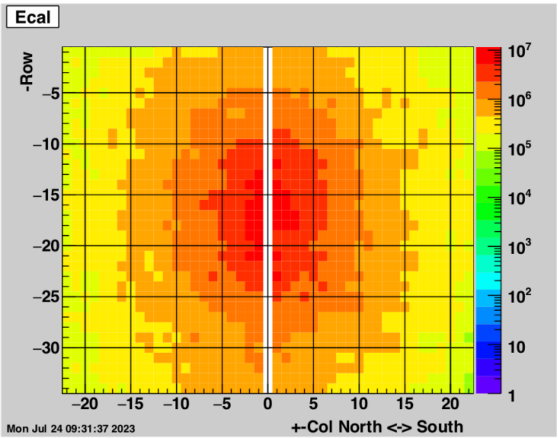
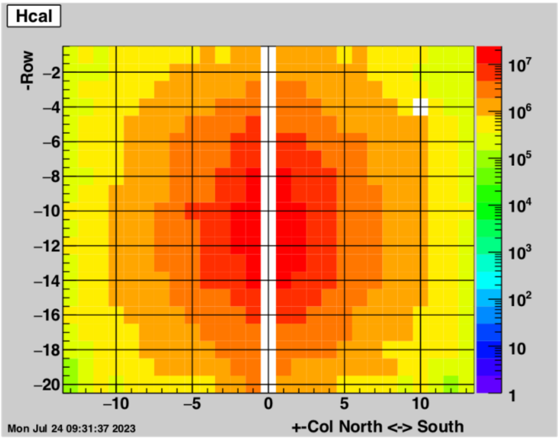
Operation

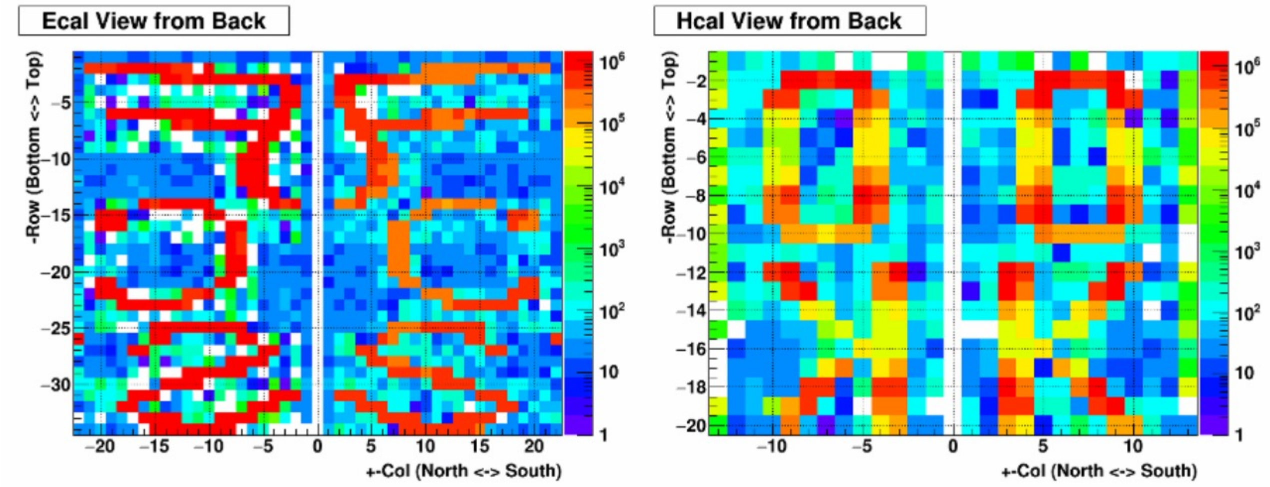
ECal monitoring plot



HCal monitoring plot

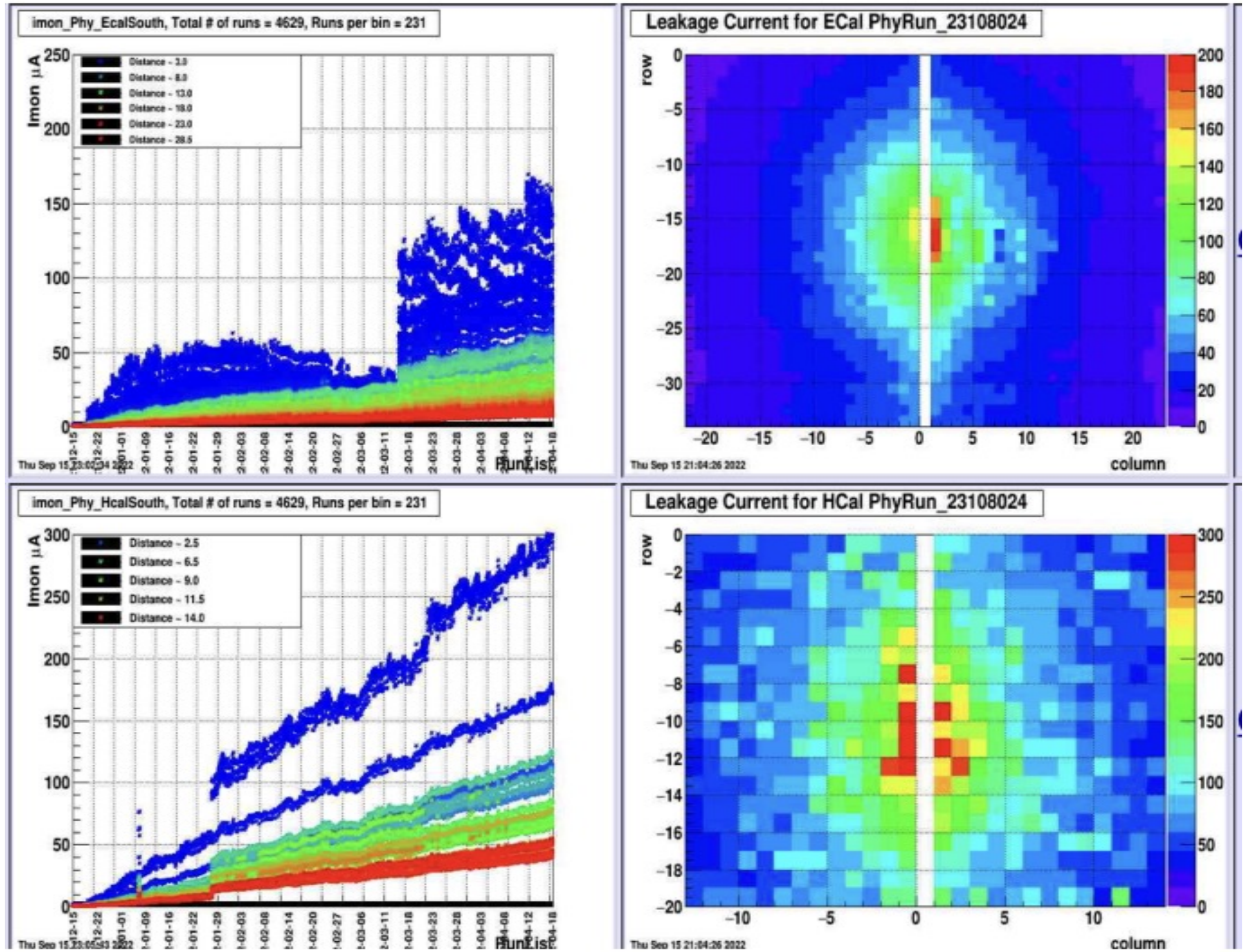


LED system testing plot



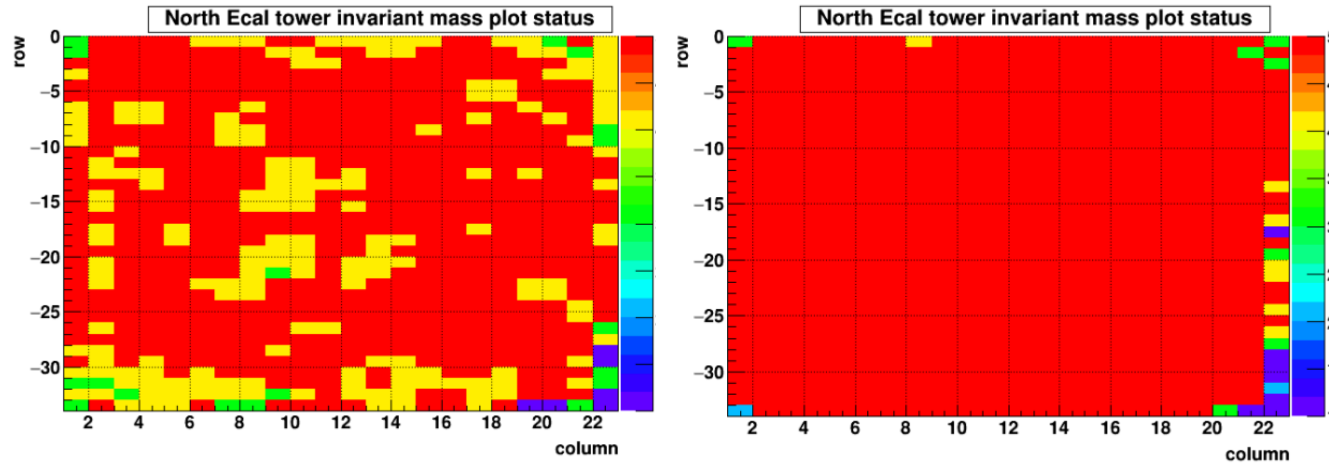
- ✓ Online data monitoring and slow control systems well established
- ✓ LED system used to track the radiation damage

Radiation Damage Monitor



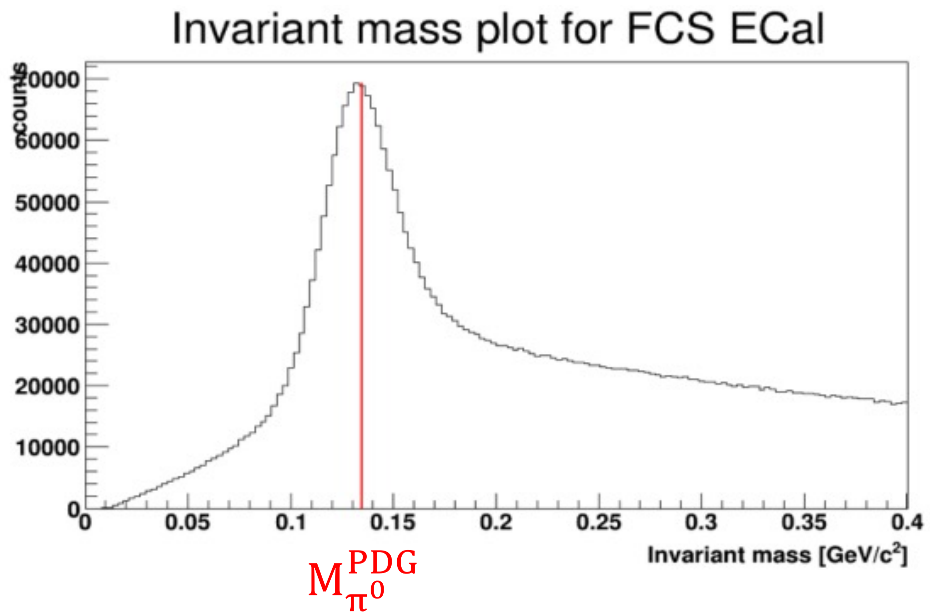
- ✓ Radiation plots are set up to monitor and qualify the radiation damage
- ✓ Towers closer to beam pipe show higher radiation damage than towers far away from beam pipe
- ✓ Every tower throughout the run 22 shows that leakage current increases drastically towards the end of the run

FCS Calibration



Channel status

Red: Mass peak at π^0 mass
Blue: Mass peak away form π^0 mass



ECal:

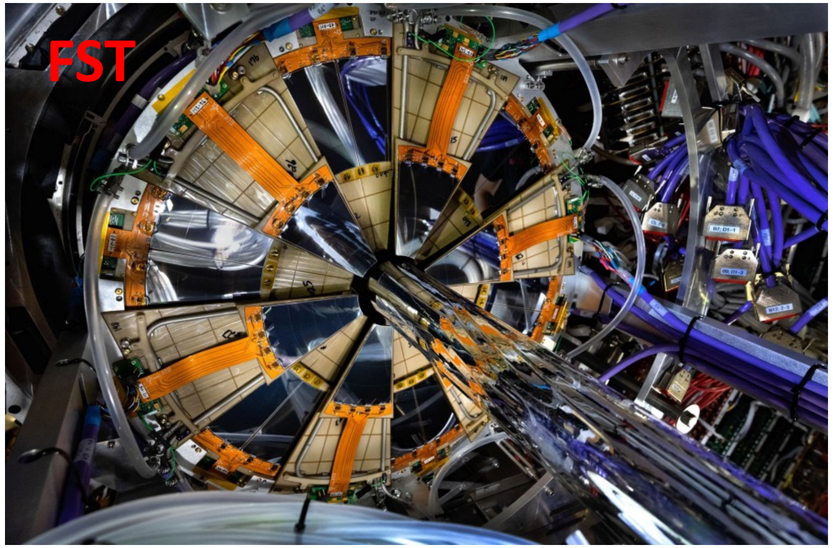
✓ π^0 reconstruction method is used to do the gain correction
✓ Tower-by-tower gain correction
✓ Invariant mass peak right at π^0 mass after calibration

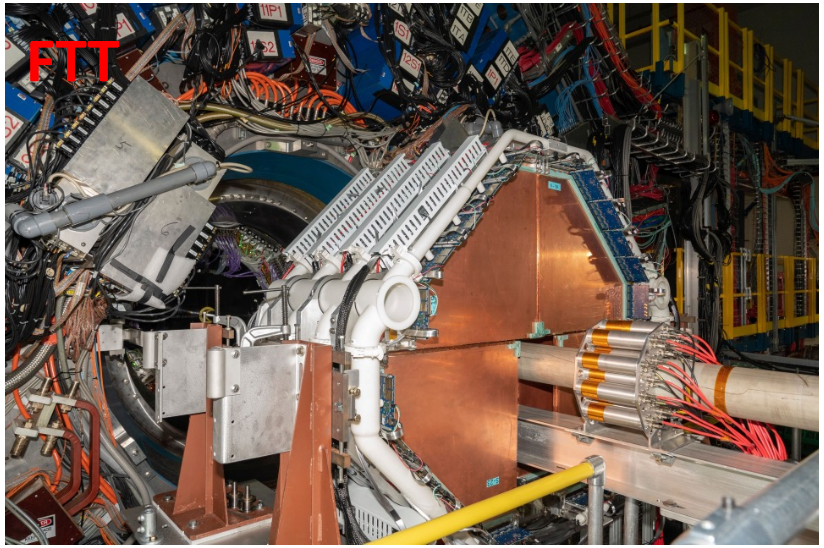
HCal:

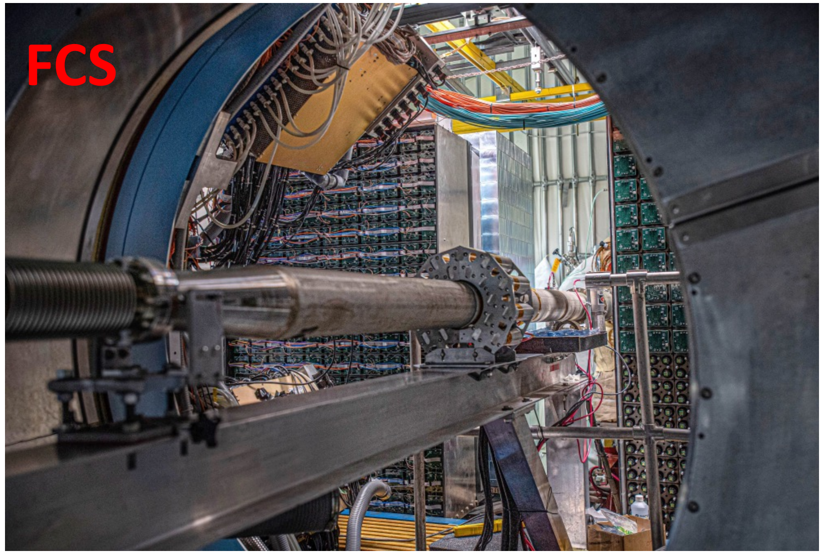
✓ Calibration is ongoing

Summary

✓ The STAR forward detectors installed and taking data
✓ Forward tracking algorithm established and being optimized
✓ Calibration completed for FCS ECal and ongoing for HCal





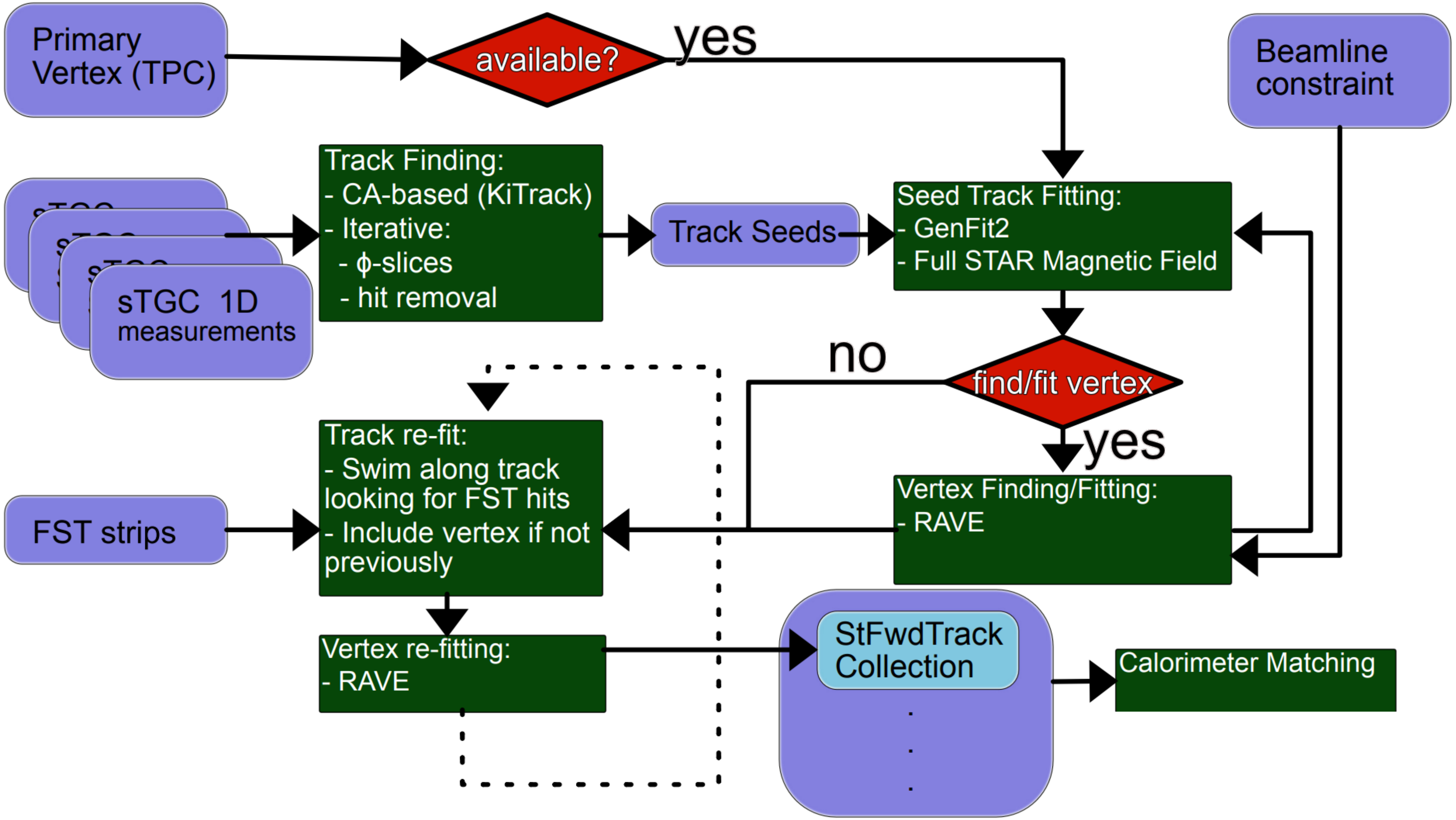


✓ Stay tuned to physics analysis with forward data

Thanks for your attention!

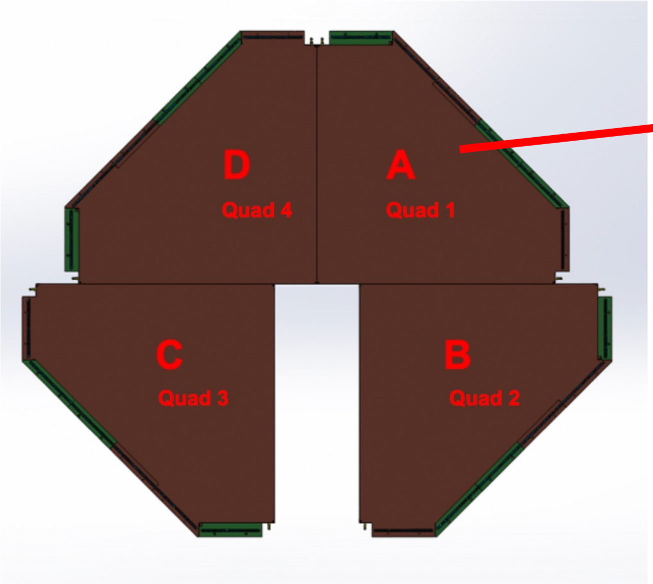
Backup

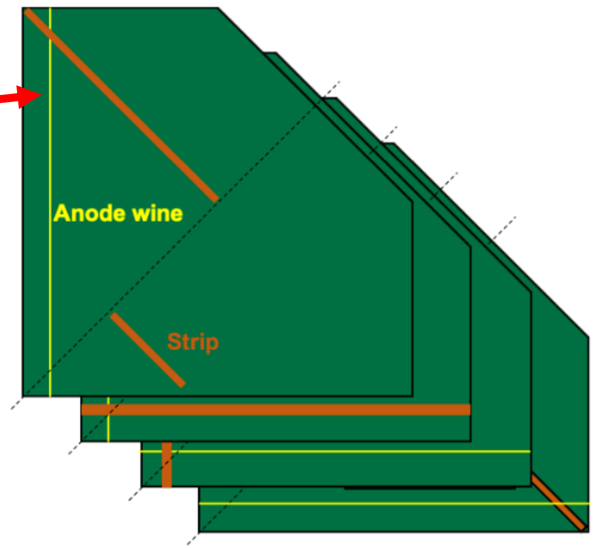
STAR FWD Tracking

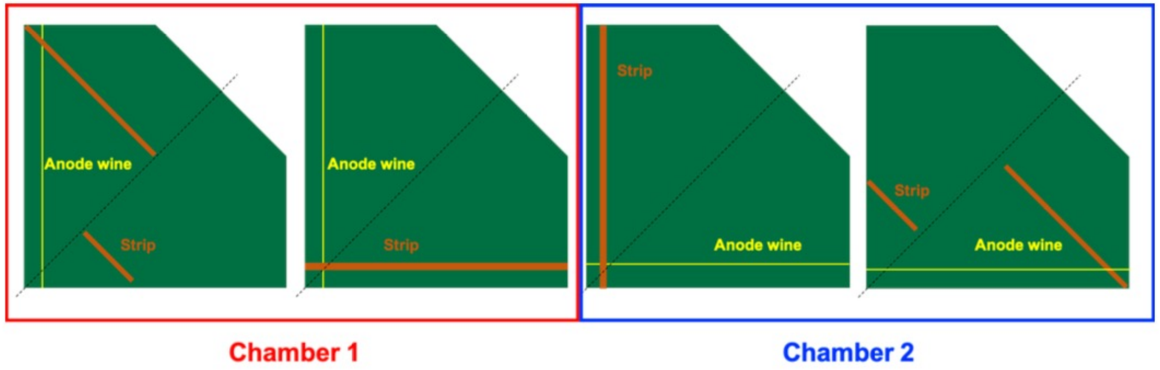


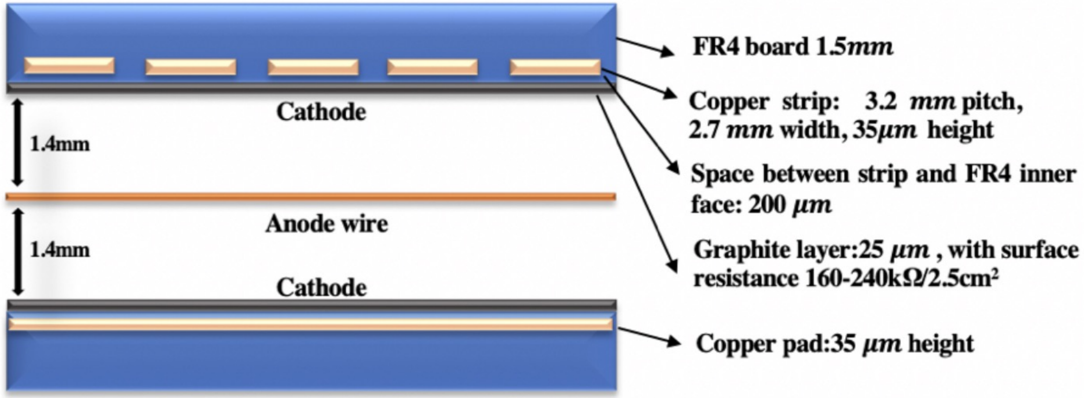
Daniel Brandenburg @ STAR collaboration meeting

Forward sTGC Tracker Module Design









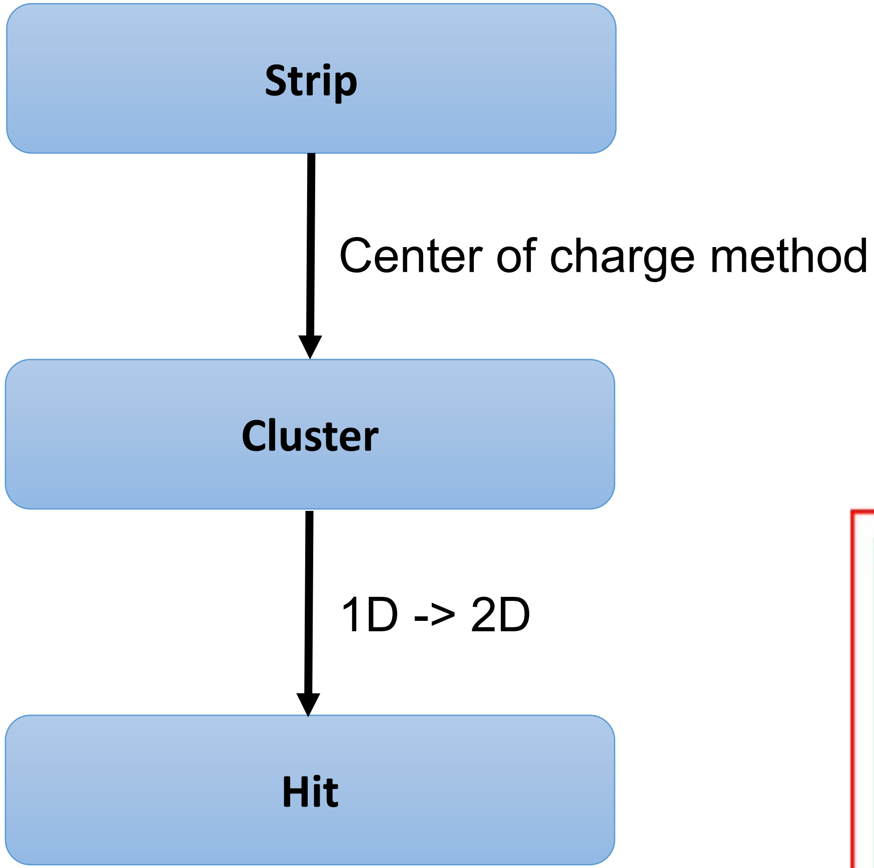
Y. Shi @ INSTR 20

FTT layer combine with 4 pentagon modules:

Center of charge method to get hit position
- ✓ Perpendicular to strip

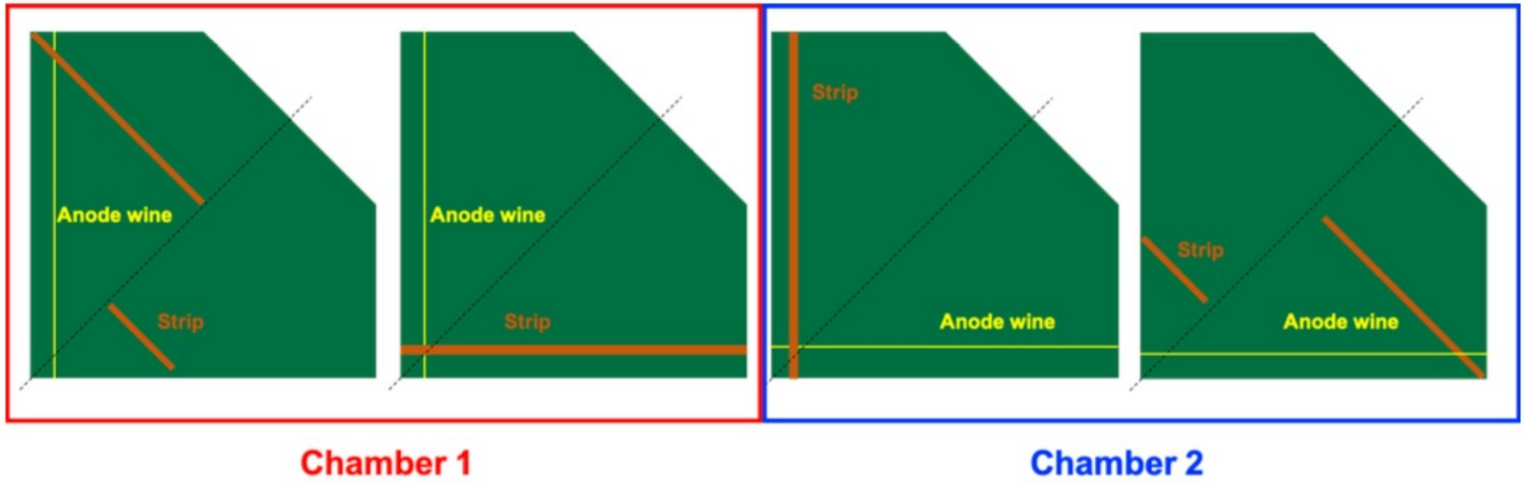
2 independent chambers per module
- ✓ Read X and Y position separately
- ✓ Diagonal strips to reject ghost hits
- ✓ Same position resolution for each directions

FTT Hit Reconstruction

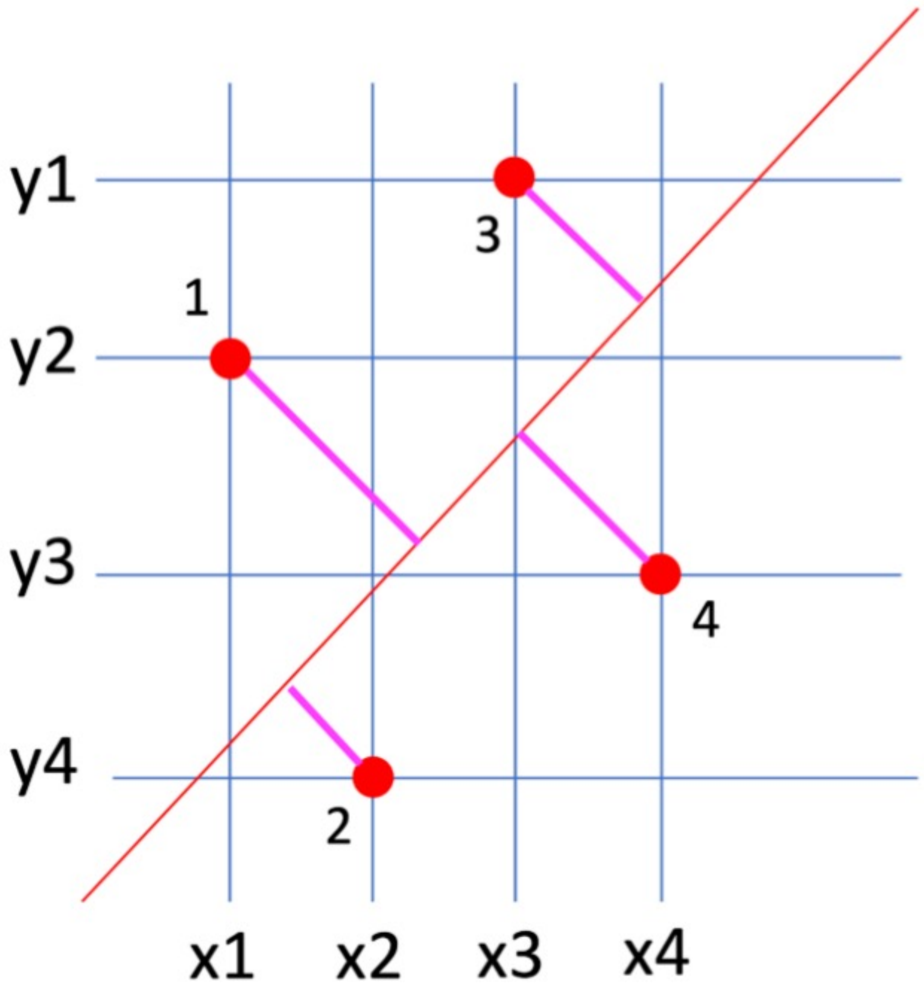


FTT Hit :

- ✓ 1D cluster reconstruction in X, Y and diagonal
- ✓ Combine (X,Y) pairs
  - 2D hits with precise 1D + unprecise 1D information
  - 2D hits with shift in Z direction



FTT Hit Reconstruction



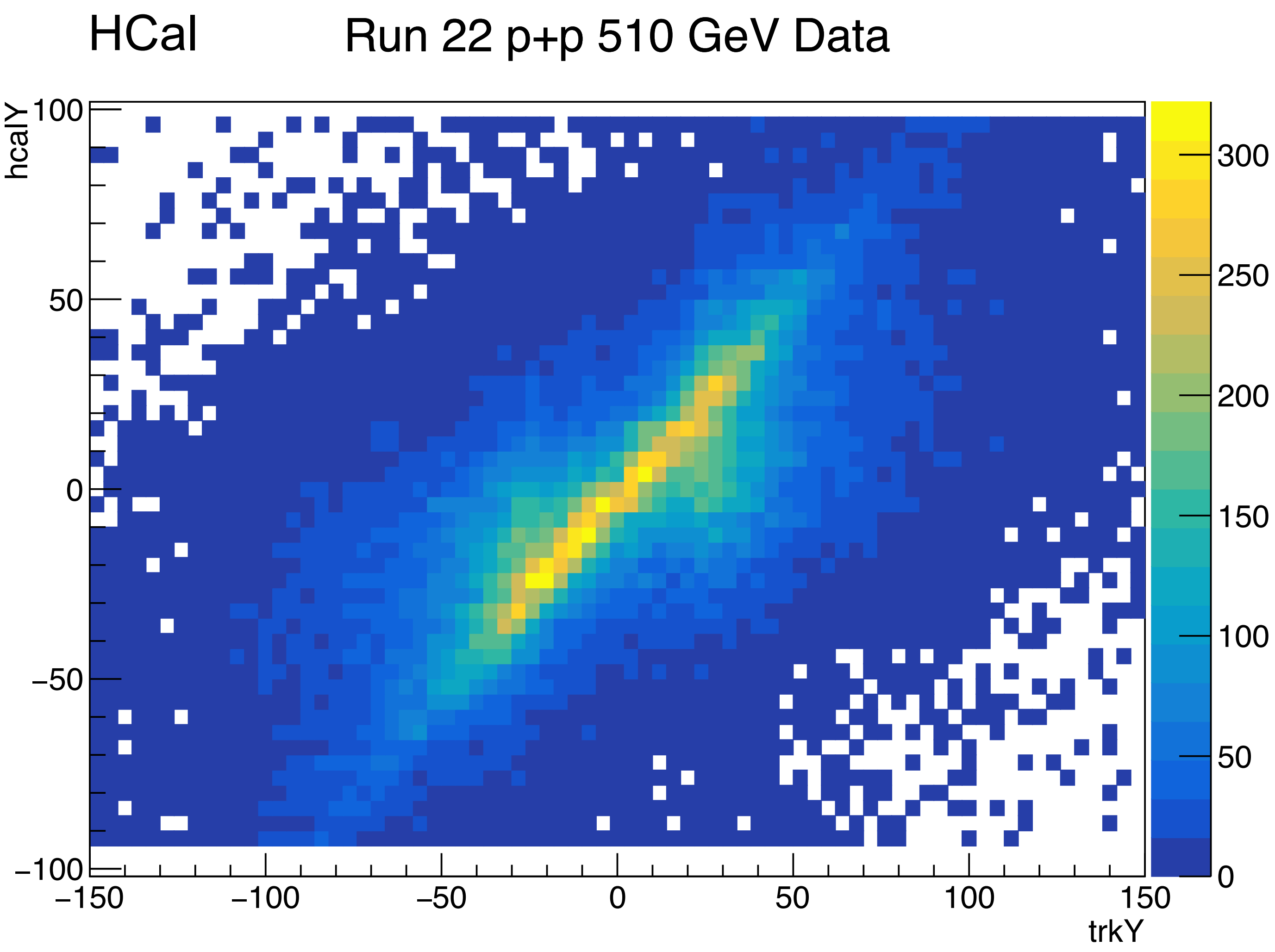
FTT Hit :

- ✓ 1D cluster reconstruction in X, Y and diagonal
- ✓ Combine (X,Y) pairs
  - 2D hits with precise 1D + unprecise 1D information
  - 2D hits with shift in Z direction

Ghost(fake) hit :

- ✓ Ghost hits from random pair
  - N real hits will induce $N*(N-1)$ ghost hits
- ✓ Reject ghost hits with diagonal matching

Matching to Calorimeter

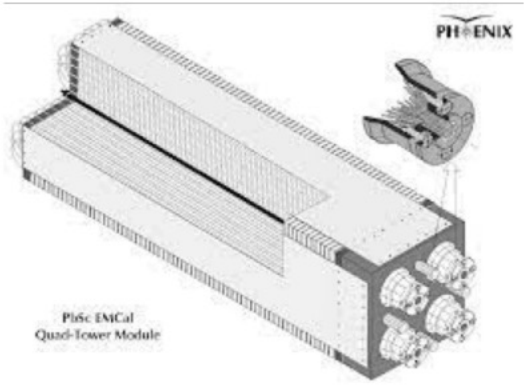


Project forward track to calorimeter:

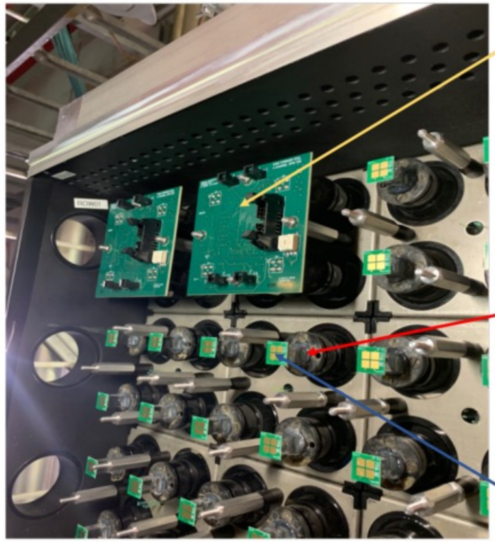
- ✓ Good correlation between the forward track and calorimeter hits

LED System

- ✓ 4 independent towers in each module
- ✓ Penetrating WLS fibers for light collection

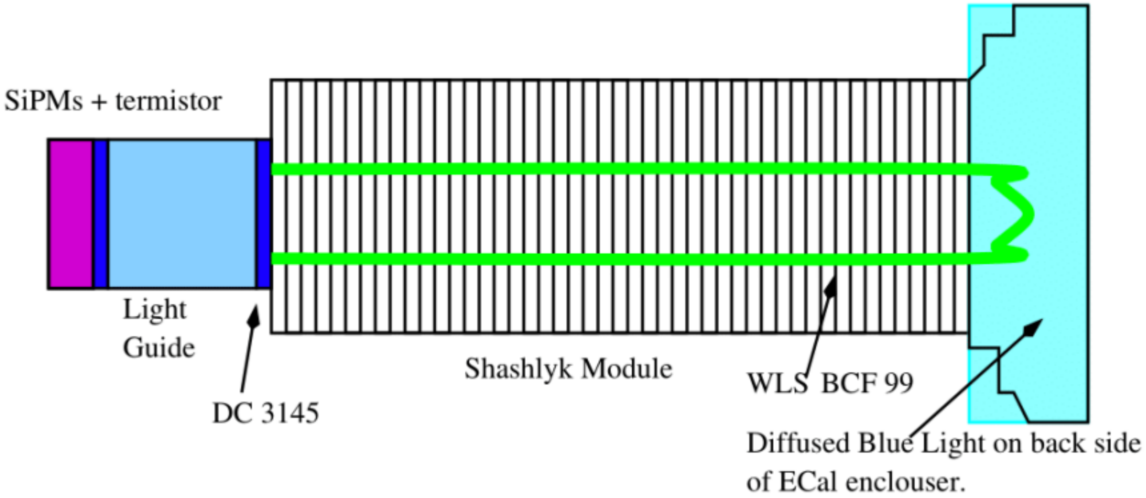


PHENIX ECal module



Refurbished ECal tower front end display

- ✓ There are blue LED at the back side of ECal stack, which shine light to enclose cover. Some light will be absorbed by exposed loops of Wavelength Shifting fibers at the back side



LED system

LED Radiation Damage Monitor

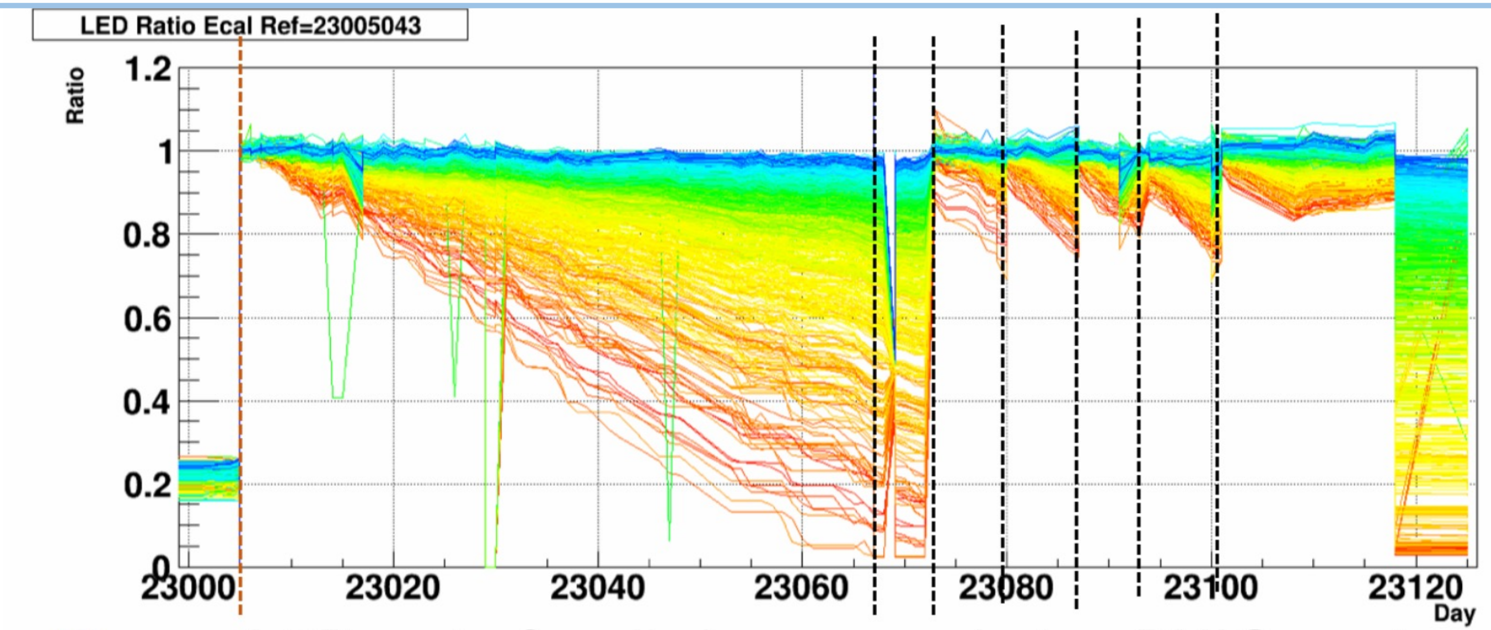
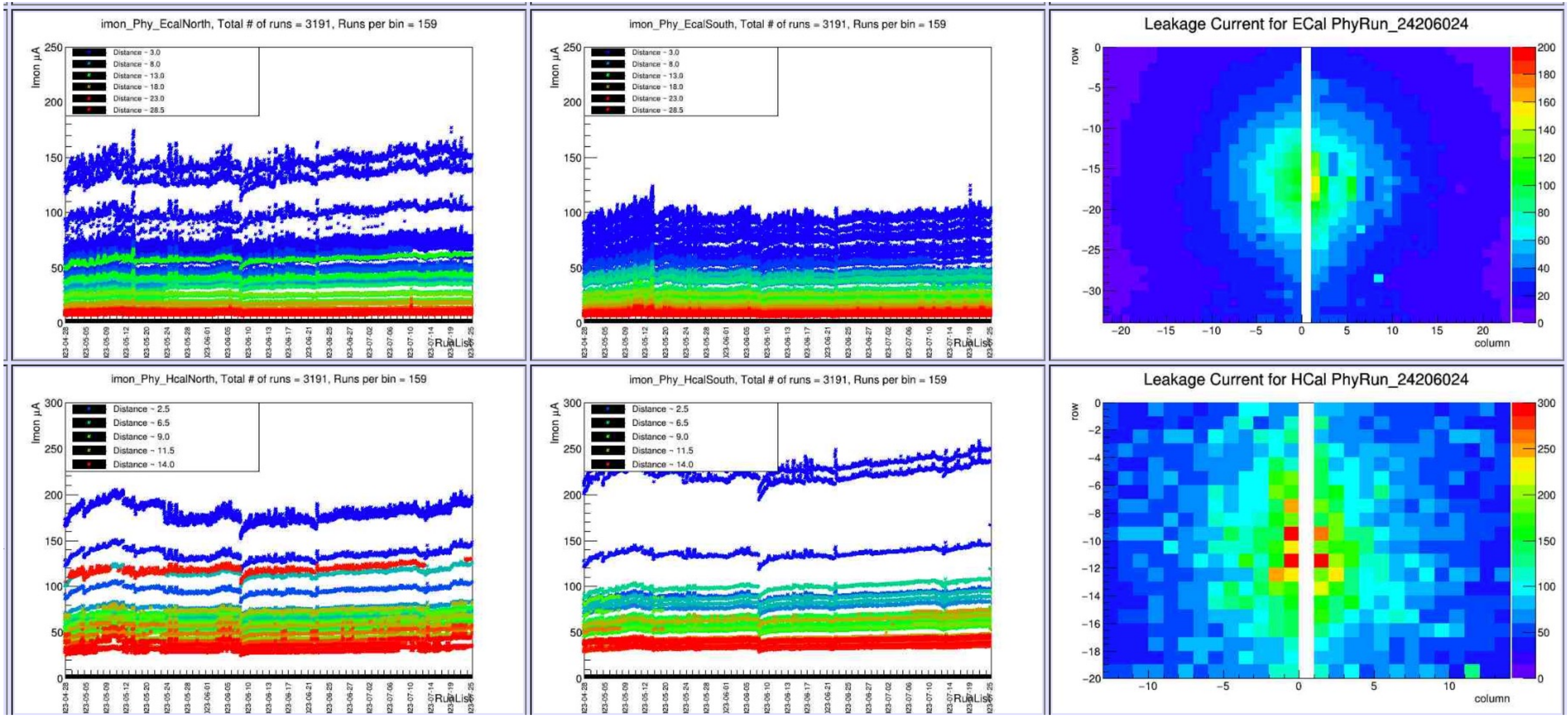


Figure: LED ratio for all the towers during RHIC run in run 22

- Gain loss due to the radiation damage to FEE boards can be observed from the LED system
  - LED ratio: ratio of LED readout between each LED test run and the reference test run in a period (between dash line)
    - Change the attenuator and SiPM bias set voltage on FEE boards to adjust the LED readout between periods
  - For each tower, LED ratio drops → the tower suffers radiation damage
  - Higher LED ratio drop rate → more serious radiation damage

Radiation Damage Monitor



Run 23 Au+Au collisions

ECal Calibration Procedure

- ✓ π^0 reconstruction method is used to calibrate the ECal
  - ✓ $\pi^0 \rightarrow \gamma + \gamma$ ECal cluster is the photon candidate
  - ✓ Gain correction factor for each ECal tower is obtained from π^0 reconstruction

- ✓ Iterative tower-by-tower gain correction factor calculation:
  - ✓ Extract the invariant mass peak for the invariant mass plot of each individual tower
  - ✓ Gain Correction Factor for each tower :

$$Gain\ Corr_{org} \ * \frac{M_{\pi^0}}{M_{fit}}$$

  - ✓ Apply corrected gain correction values for another iteration of π0 reconstruction
  - ✓ Repeat the iterations until most of the tower invariant mass peaks converge at π0 invariant mass