STAR Forward Upgrade: Design, Measurements, and Future Plans

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for the STAR Collaboration

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Outline

- Physics Goals and Interests
  - Physics Requirements
- Relativistic Heavy Ion Collider (RHIC)
- STAR experiment and Forward Upgrade
  - Tracking Upgrade
  - Calorimetry Upgrade
- Tracking performance
- Calorimeter Performance
  - Transverse Single Spin Asymmetry of π^0

Physics Goals

Forward-Pseudorapdity $2.5<\eta<4$

Beam:
- 200 GeV AuAu (2023, 2024, 2025)

Physics Topics:
- Temperature dependence of viscosity
- Longitudinal decorrelation
- Global Lambda Polarization

Beam:
- 200, 500 GeV polarized pp (2022, 2024)

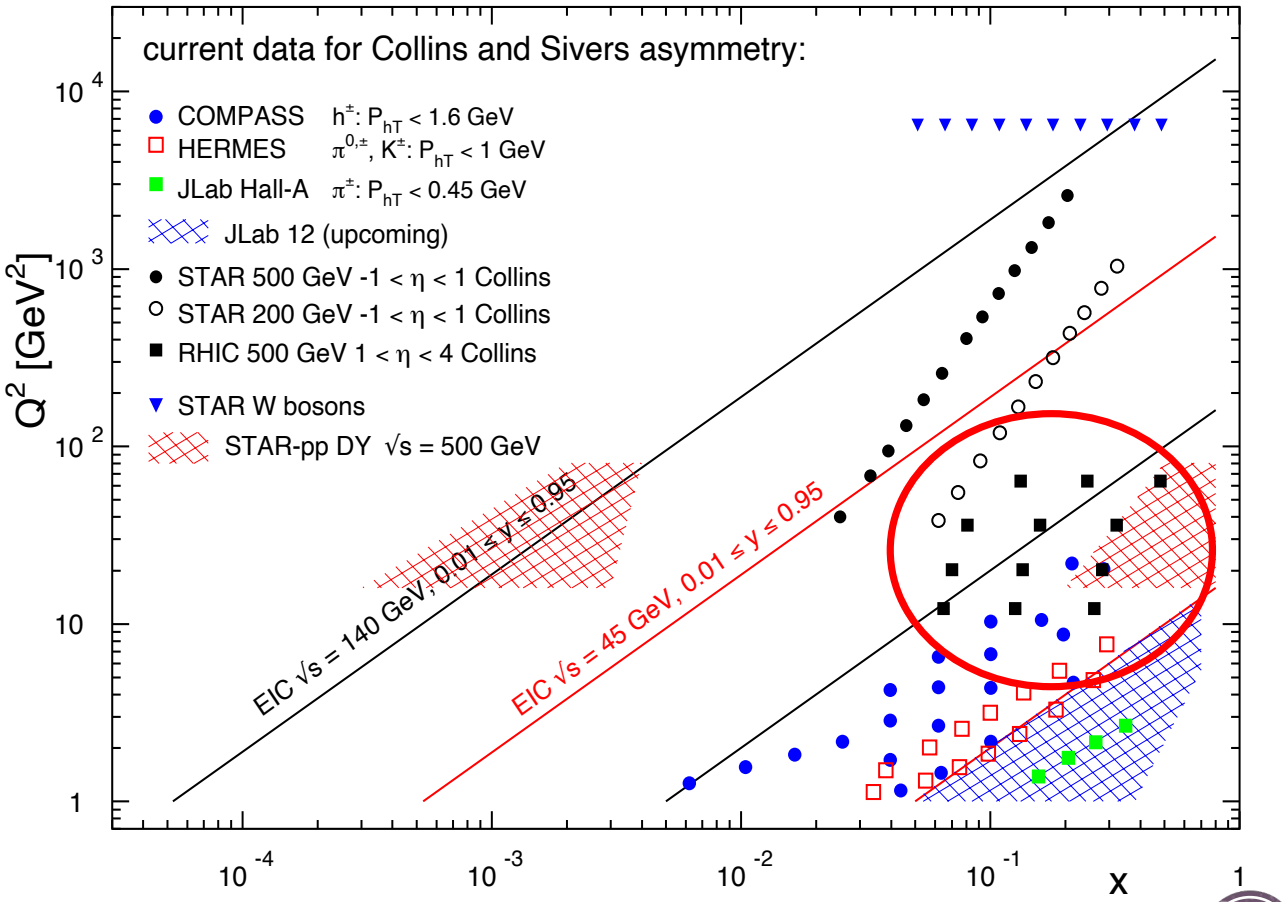
Physics Topics:
- Sivers Asymmetries for hadrons, jets, di-jets, Drell Yan
  - Transverse Momentum Dependent PDFs (TMD)
- Collins Asymmetry
  - Hadrons in jets

- Observables
  - Charged and neutral hadrons
  - Inclusive jets and di-jets
  - Hadrons in jets
  - Photons
  - Drell Yan, J/ψ (di-electrons)
  - Lambda's
- Detector Requirements for physics

Detector	pp	AuAu
Ecal	$\sim 10\%/\sqrt{E}$	$\sim 20\%/\sqrt{E}$
Hcal	$\sim 60\%/\sqrt{E}$	
Trackers	Charge Separation Photon Suppression	$0.2 < p_T < 2$ GeV/c with 20-30% $1/p_T$

TMDs at Large Pseudorapidities

- Need high precision data in pp to complement ep data to establish universality of TMDs
- The pp data will complement what can be achieved by the Electron Ion Collider (EIC)
- Upgrade allows access to broad x $(0.05 - 0.5)$ at high Q^2 $(10 - 100\ GeV^2)$



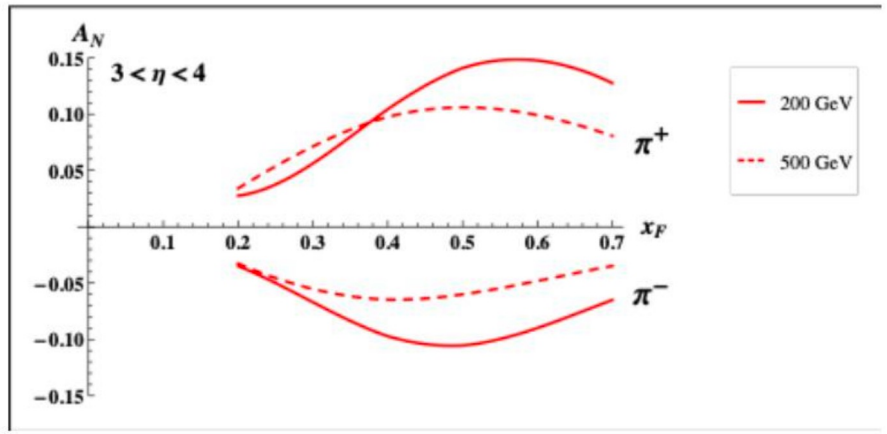
arxiv: 1602.03922

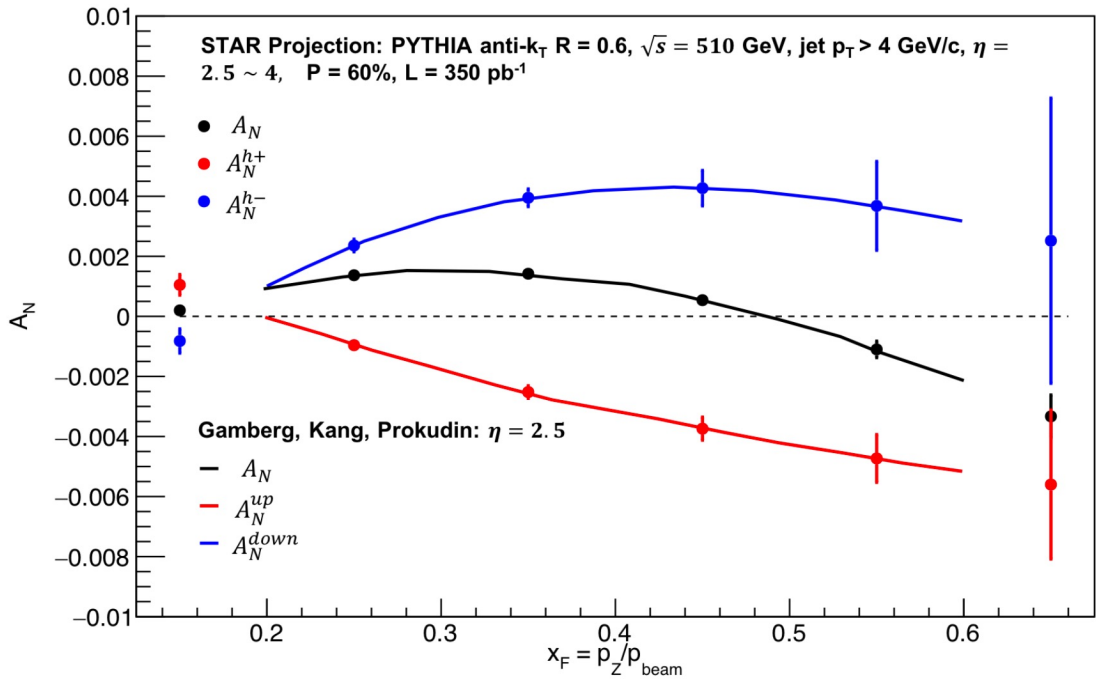
Hadron Transverse Single Spin Asymmetries

- Transverse Single Spin Asymmetries (TSSA or A_N) of charged hadrons will become possible because of newly installed trackers and hadronic calorimeter

$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

Predicted asymmetries for $\pi^{+/-}$ from Kanazawa et al, PRD 89, 111501

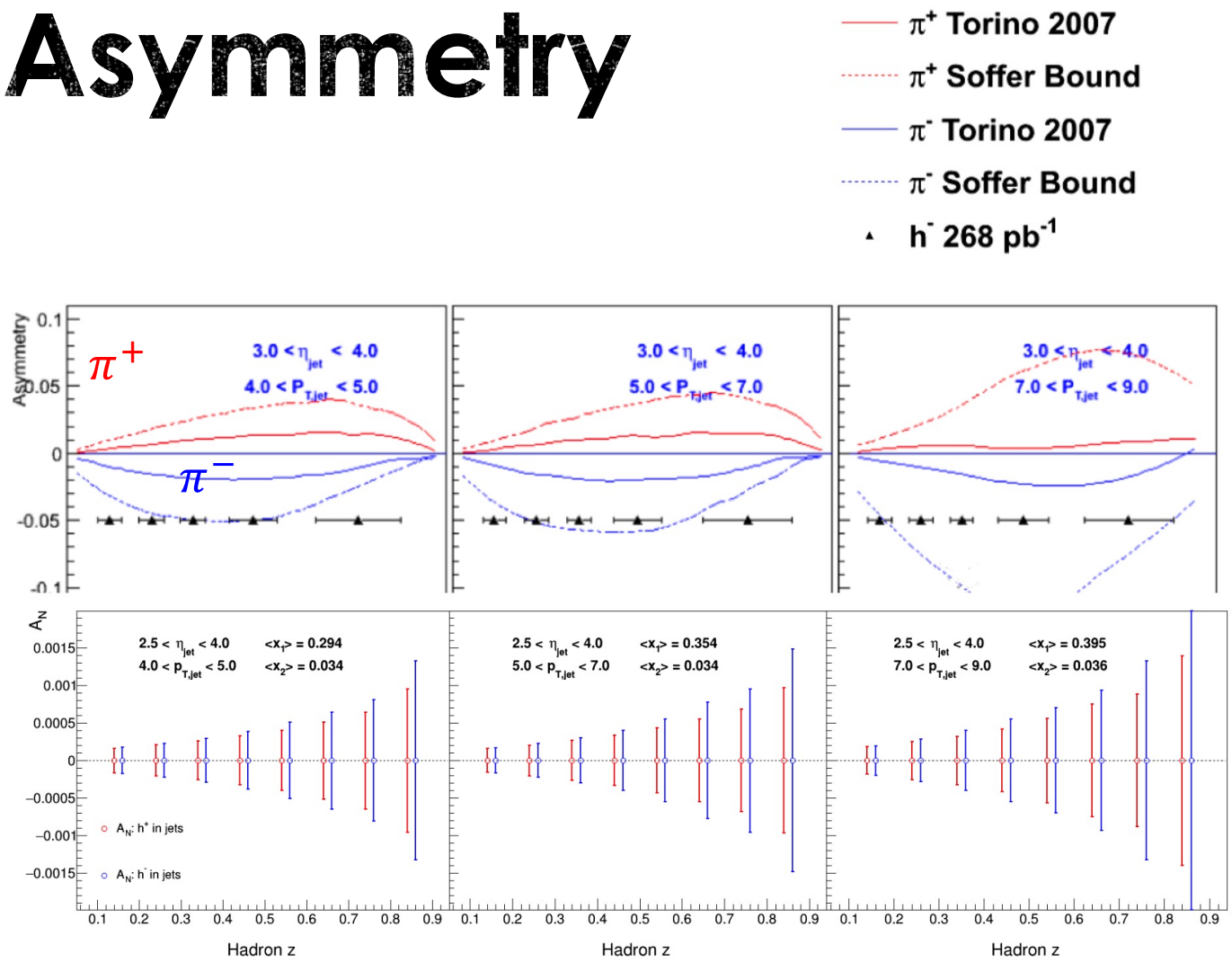




STAR Beam Use Request Run22-25

Collins Asymmetry

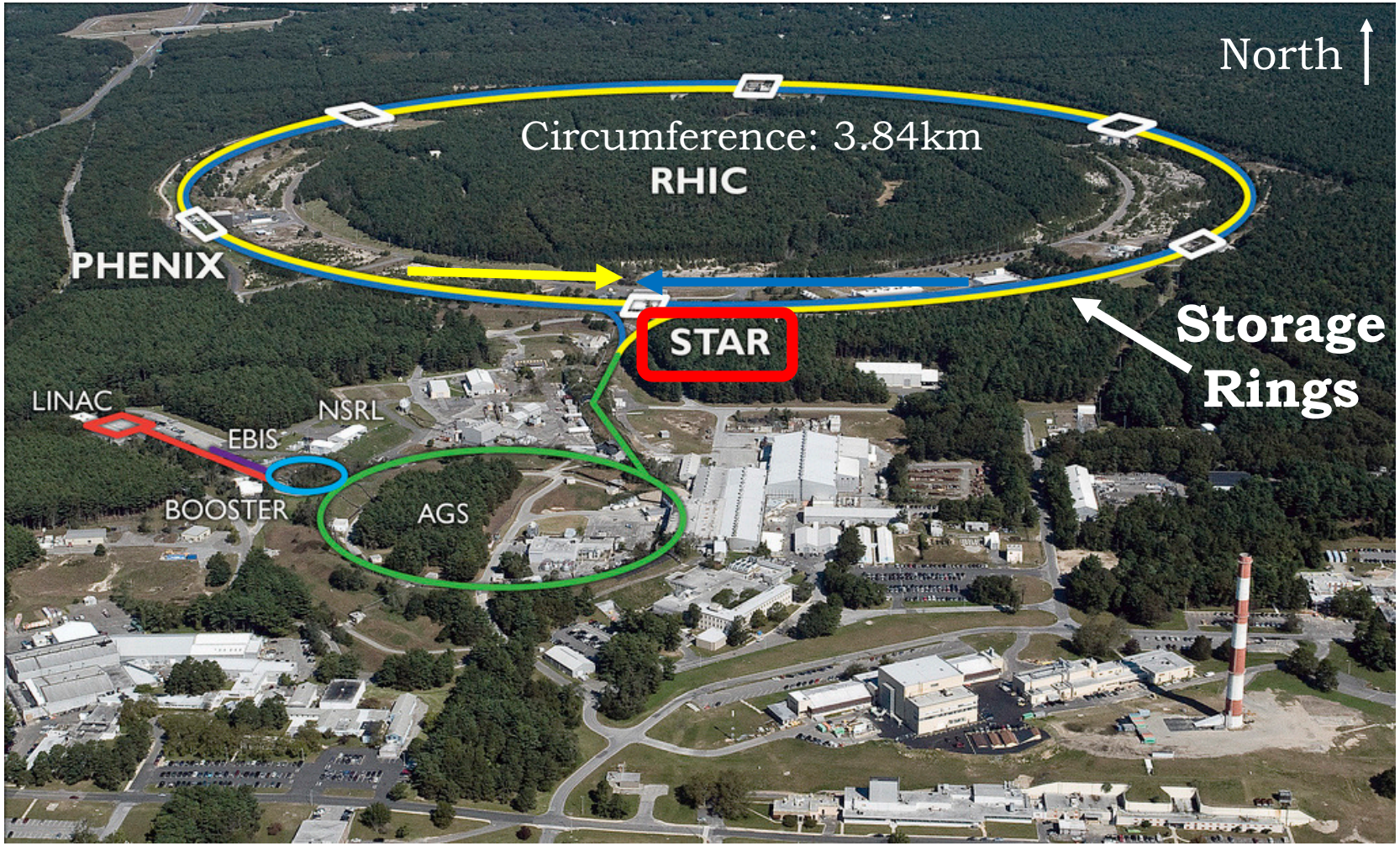
- Improve Transversity × Collins FF through hadrons in jets
  - Access to transversity in region $0.3 < x < 0.5$
  - Has not been explored in SIDIS
- Projected Collins Asymmetry for π^+/π^- with projected asymmetries in black



STAR Beam Use Request Run22-25

Brookhaven National Lab (BNL) and Relativistic Heavy Ion Collider (RHIC)

- The only polarized pp collider in the world!
- Very versatile Collider
  - p, d, Al, Cu, Zr, Ru, Au, U
  - Polarized pp $\sqrt{s}$
    - 62, 200, 510 GeV
  - Nucleon $\sqrt{s}$ up to 200 GeV
  - Fixed target with STAR Nucleon $\sqrt{s}$ down to 3 GeV

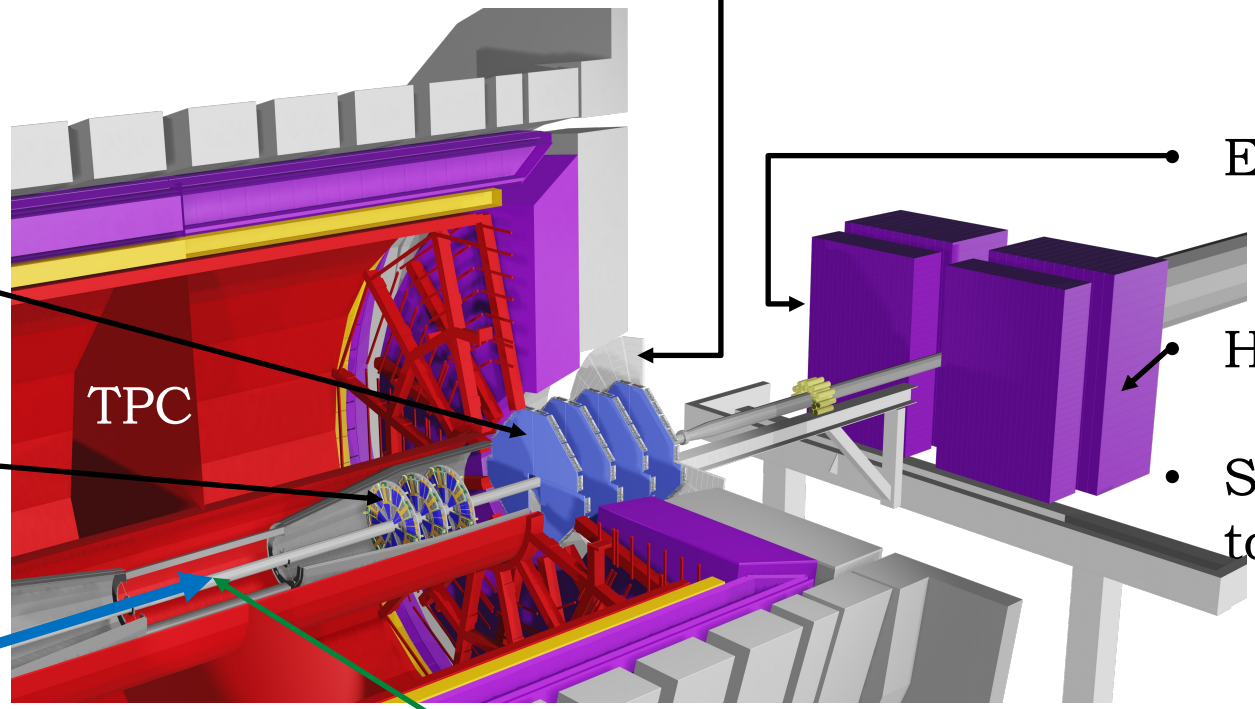


STAR Forward Upgrade

- Upgrades STAR capabilities in $2.5<\eta<4$
- Almost full 2π coverage in azimuth

Tracking

- small-strip Thin Gap Chambers (sTGC or FTT)
  - 4 layers
- Silicon Disks (FST)
  - 3 layers

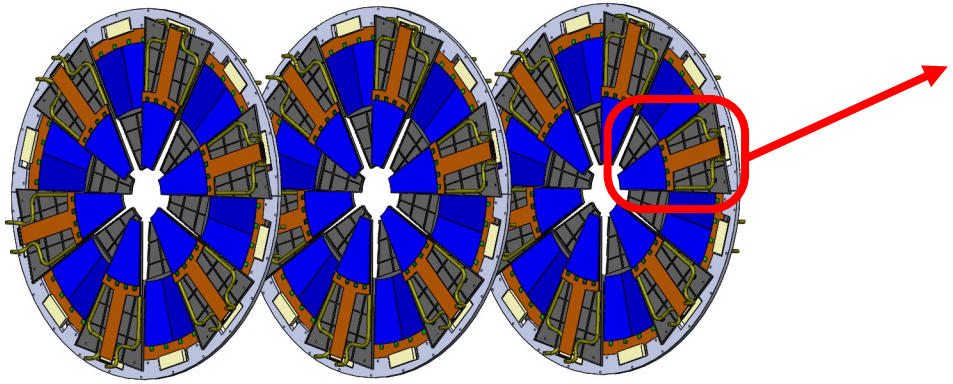


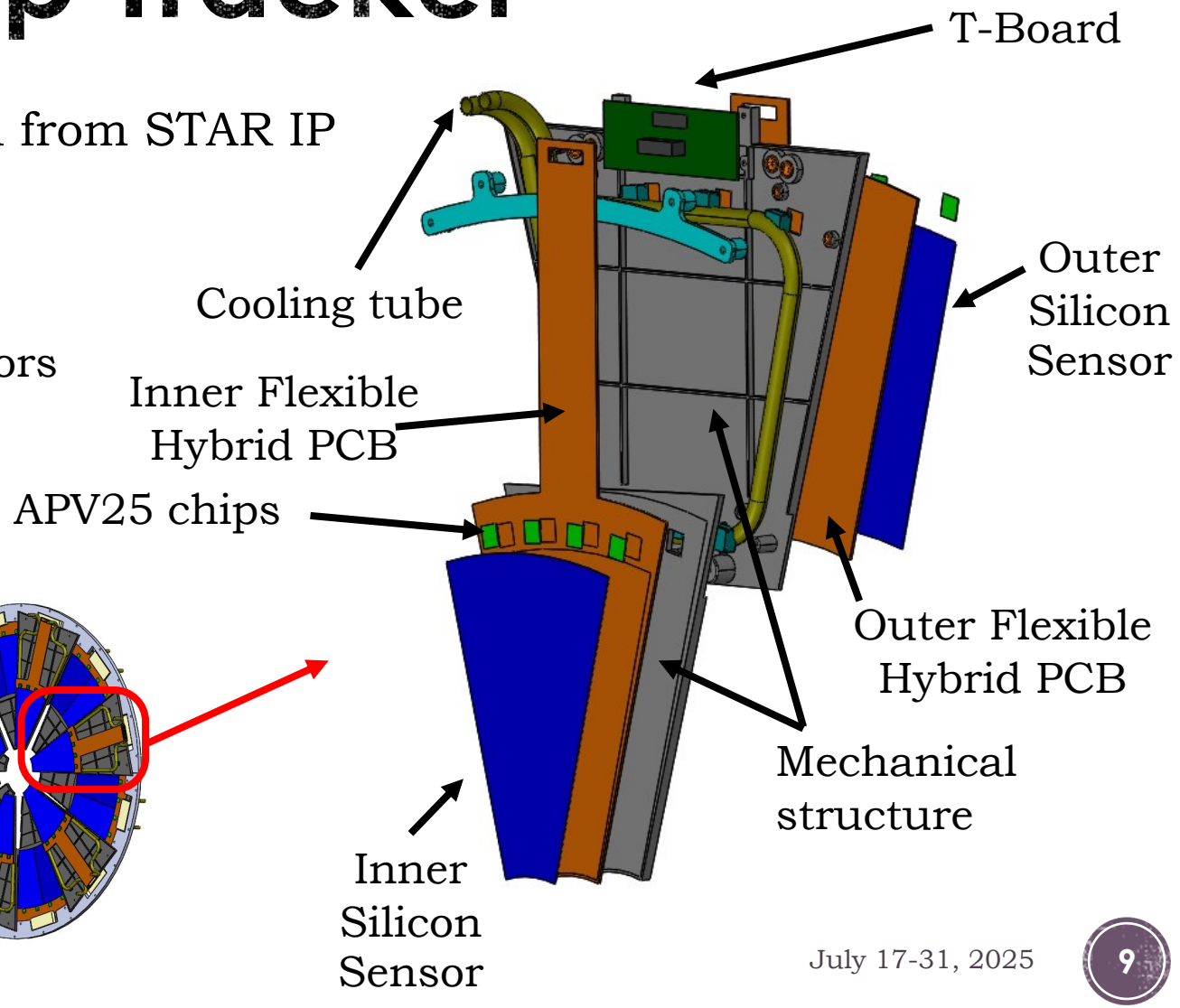
Forward Calorimeter System (FCS)

- Preshower
  - Reuse STAR Event Plane Detector (EPD)
- Electromagnetic (Ecal)
  - PbSc Re-purposed from PHENIX
- Hadronic (Hcal)
  - FeSc, built in 2021
- Sit on movable platforms to allow access to back

Silicon Microstrip Tracker

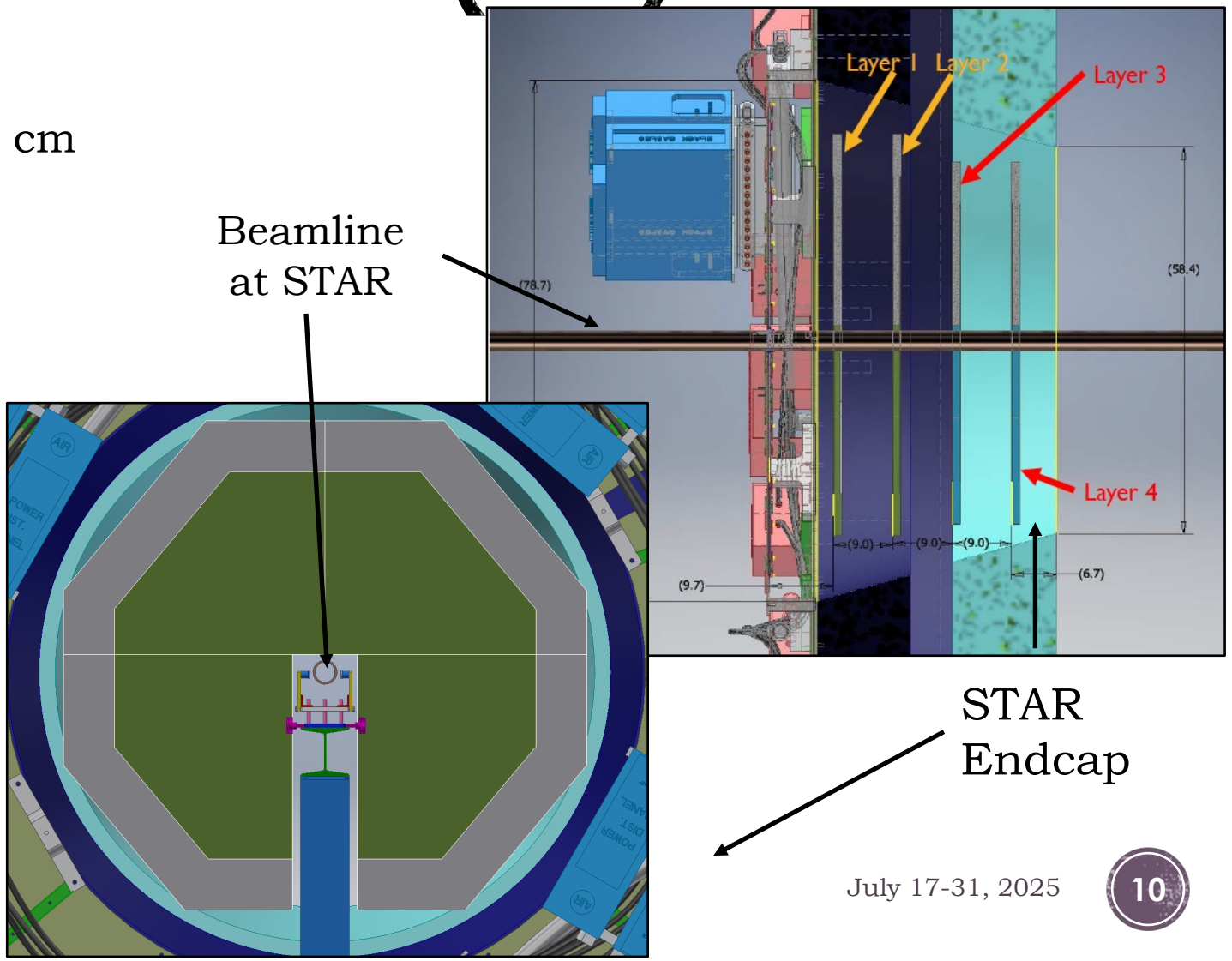
- 3 disks located at 152, 165, and 179 cm from STAR IP
  - Each disk has 12 Single Modules
    - Inner region: 5 < R < 16.5 cm
    - Outer region: 16.5 < R < 28 cm
  - Single-sided double-metal mini-strip sensors
  - 128x4 (ϕxR) strip sensors
    - Inner: 1 Si Sensor
    - Outer: 2 Si Sensor
  - ~1% X_0 per disk
- Full 2π azimuthal





Forward sTGC Tracker (FTT)

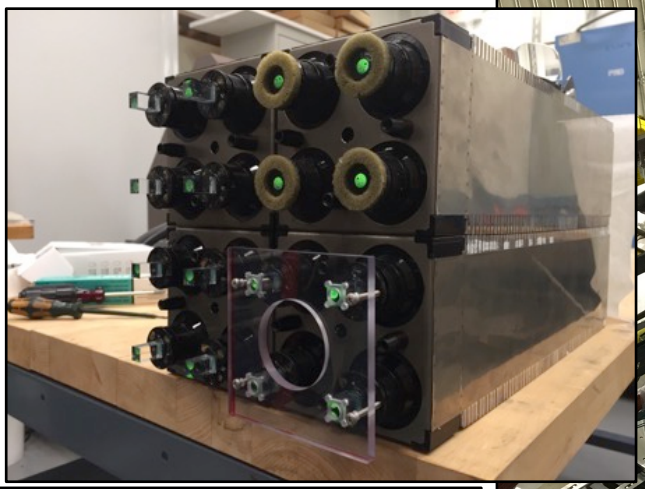
- Inspired by ATLAS sTGCs
- 4 layers located 307, 325, 343 and 361 cm from STAR IP
  - Inhomogeneous magnetic field
  - Each layer made up of four quadrants
    - Each quadrant is double sided to break ambiguities in hit location
- Position resolution ~100 μm
- Roughly full 2π coverage
  - Need room for beam pipe support
- ~0.5% X_0 per layer material budget
- Readout: VMM-chips
- Gas Mixture: CO_2 and n-pentane
- Operating voltage: 3000 V

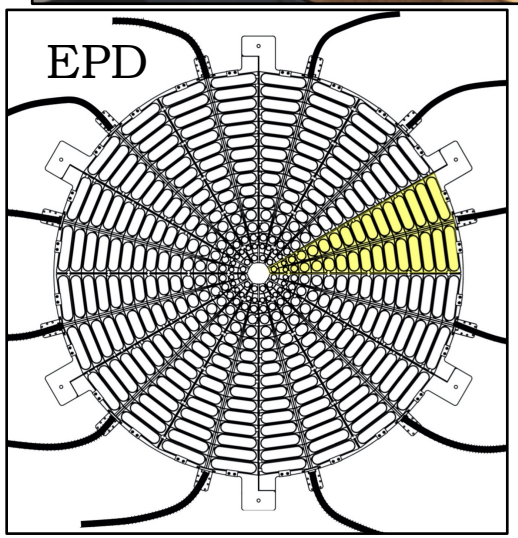


Ecal and Preshower

- Ecal Split into two halves
  - Misses above and below beam pipe
  - Projective geometry
  - ~7m from STAR IP
  - Pb/Sc sandwich Ecal
    - Repurposed from PHENIX
    - 66 sampling cells with 1.5 mm Pb/4 mm Sc
  - 1496 towers, 5.52 cm x 5.52 cm x 33 cm
    - 18 X_0, 0.85 λ
  - Utilize LED system to monitor gains
- Preshower: Existing STAR detector, EPD
  - Scintillator (Sc) Hodoscope Preshower
  - Split signals to utilize new electronics
- Both utilize SiPM readout
  - Build on successful use of SiPMs at STAR
  - New electronics to capture signal better

Ecal towers



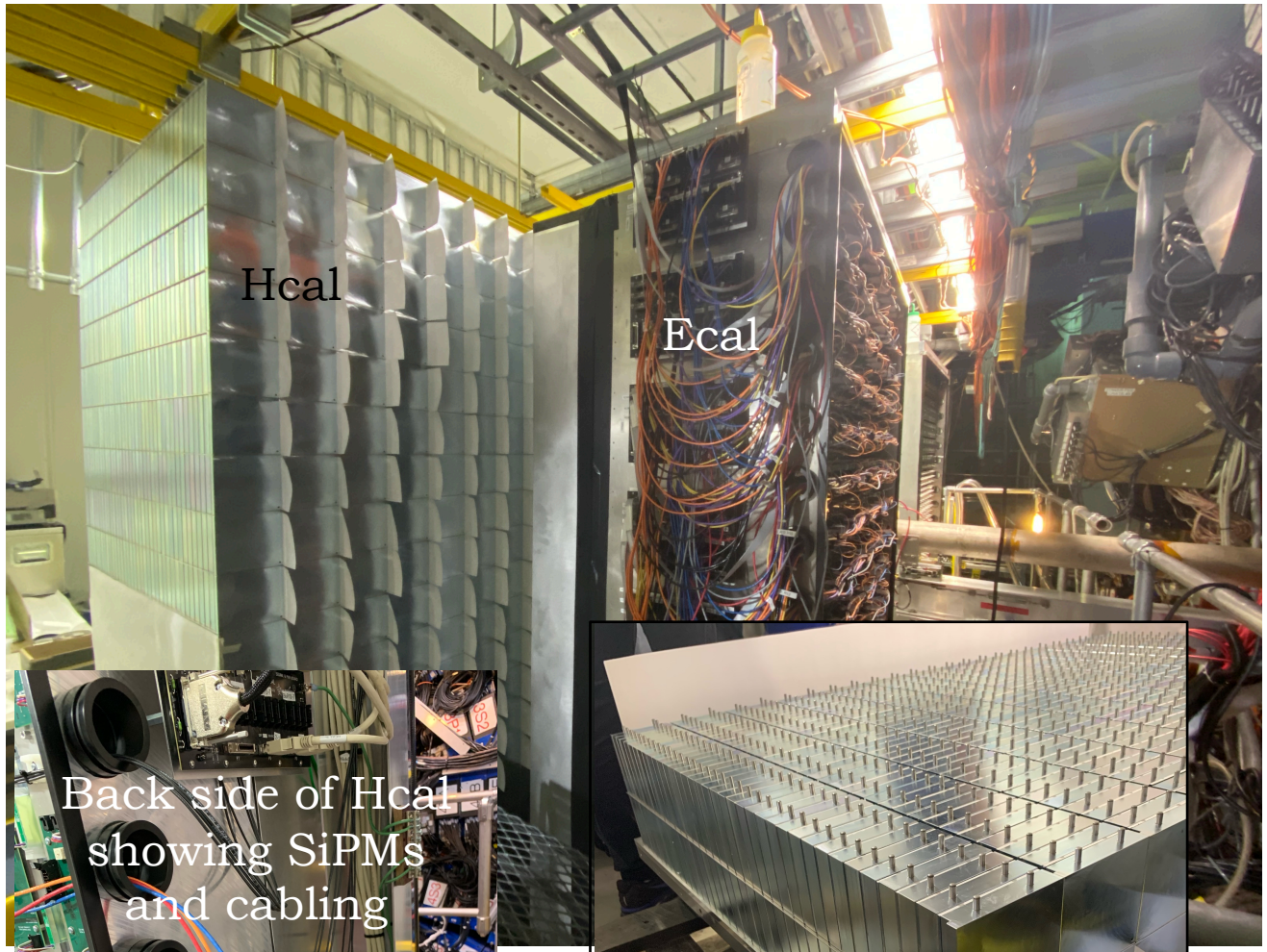


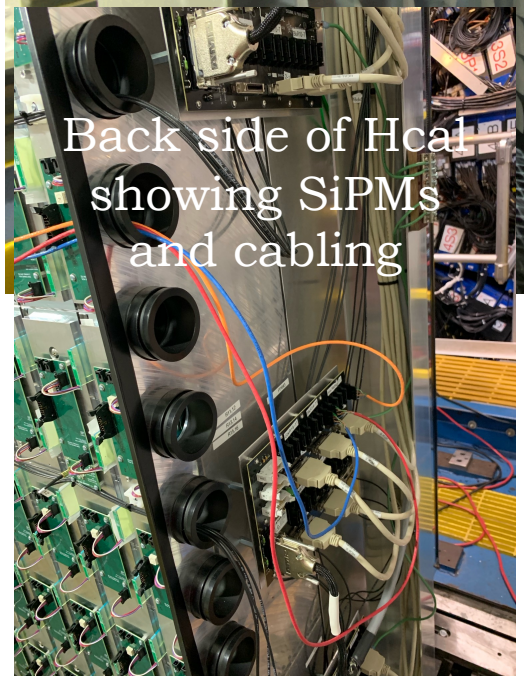
Ecal installed at STAR (Oct 2019)

Adams et al NIM A (2019) *968*, 163970

Hcal

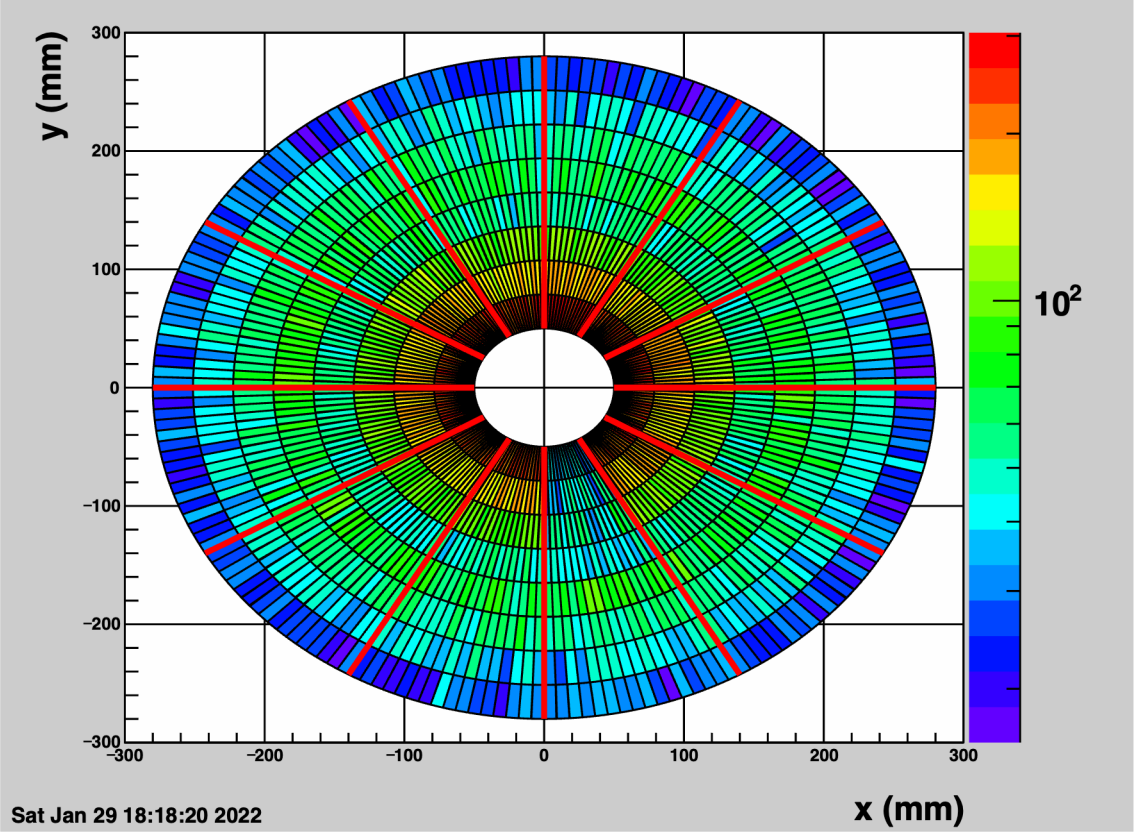
- First hadronic calorimeter at STAR
- Fe/Sc sandwich
  - Lego style construction to speed up assembly
  - 36 sampling cells with 20 mm Fe / 3 mm Sc
  - Use SiPM readout and LED system for monitoring gain
  - Utilize same electronics as Ecal
  - Directly behind ECal (projective)
- Consists of 520 towers
  - 10 cm x 10 cm x 84 cm
    - ~4.5 λ
    - Covers 2x2 towers of Ecal



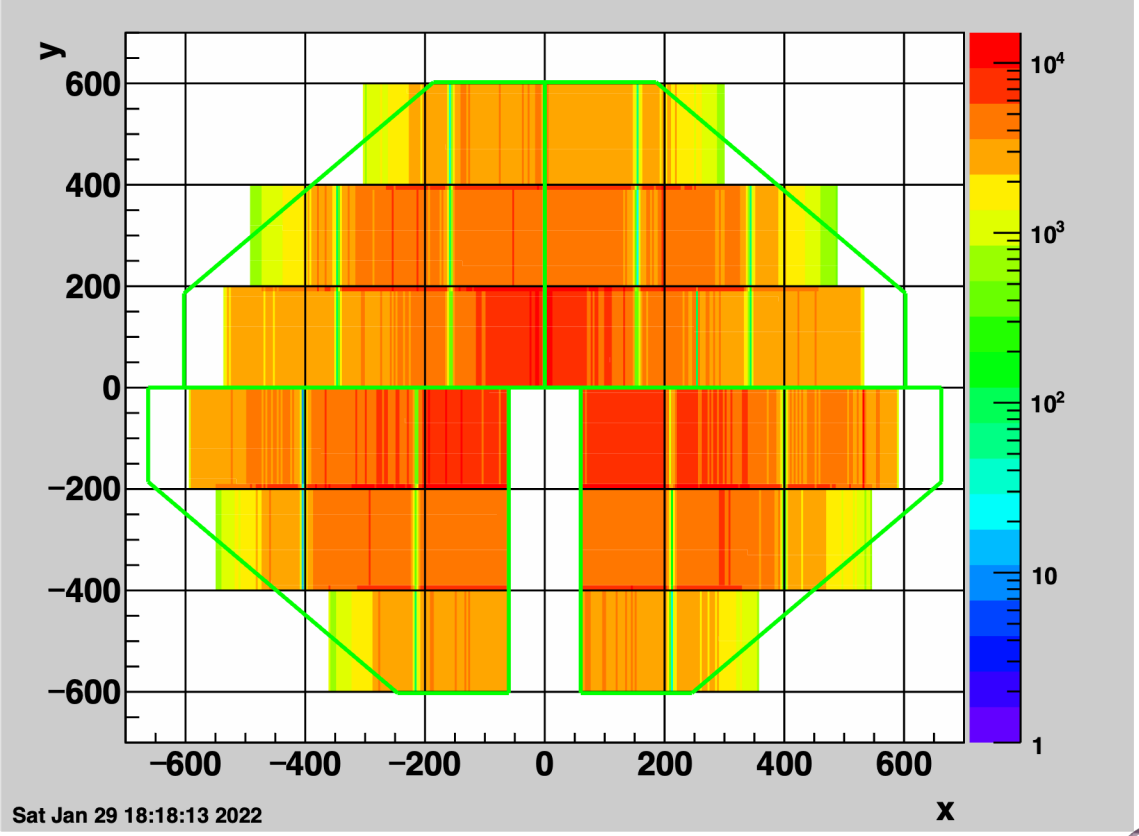


FST and FTT Monitoring

FST Hit Map Run 22



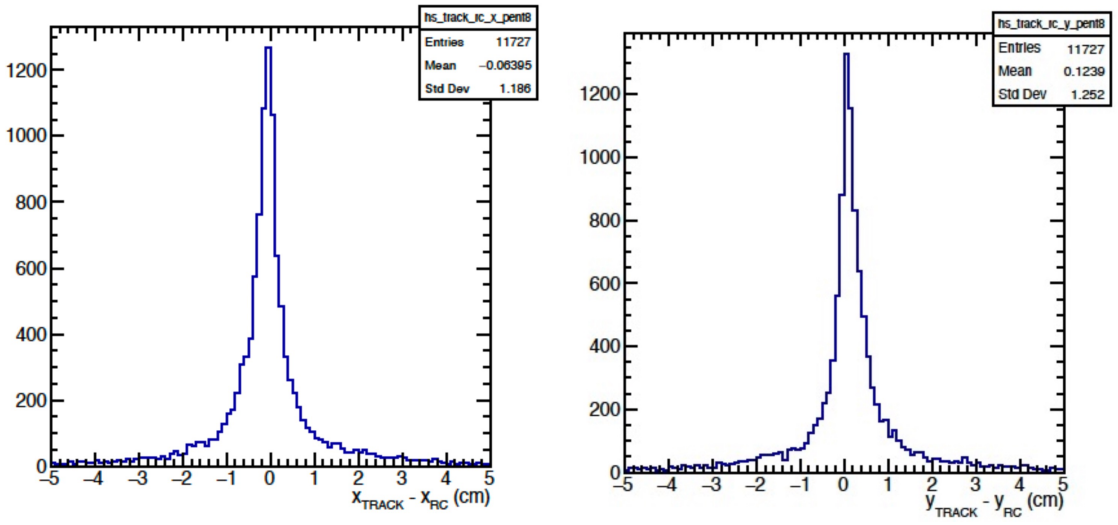
FTT Hit Map Run 22



Tracking: Data Driven Alignment

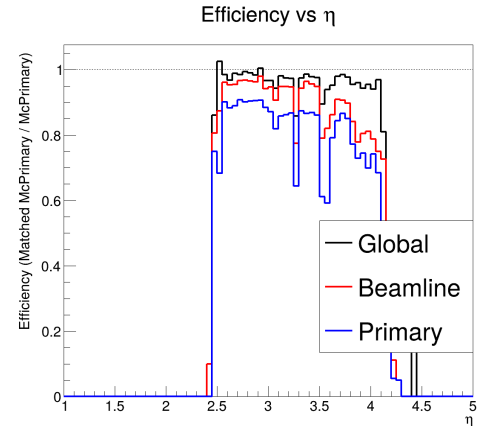
- Do a data driven alignment using zero field data from Run 22 and 23
- Tracking software utilizes GenFit2 using the Kalman Filter method to fit tracks
- Alignment is preformed by taking the reconstructed tracks and refit using a General Broken Lines (GBL) track fit
  - The GBL method allows a description of the track trajectory using a singular set of parameters
  - Utilize Millipede II minimization of the parameters from the GBL
- Study is ongoing but shows promise

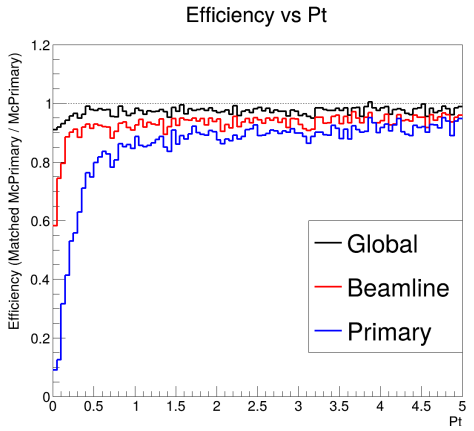
sTGC Pentagon Residuals

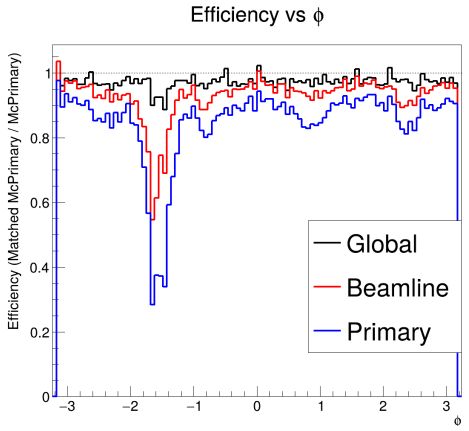


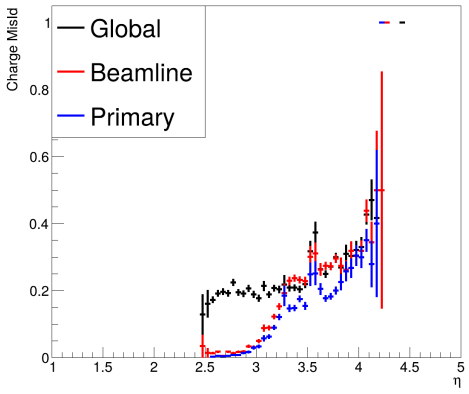
Tracking: Single Particle Studies

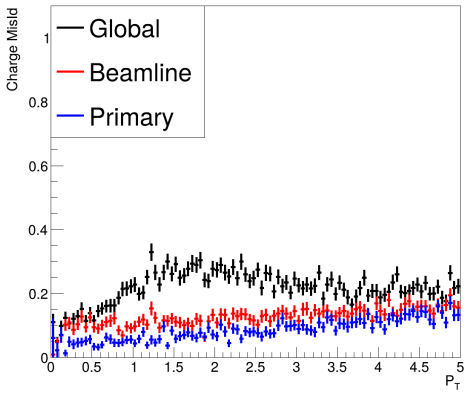
- Tracking software is mostly ready
- Single Particle studies show positive results
  - Global tracks don't use a fixed vertex
  - Beamline tracks are global tracks that have their vertex constrained in the fits
  - Primary tracks use the collision vertex as an additional parameter
- PYTHIA studies ongoing

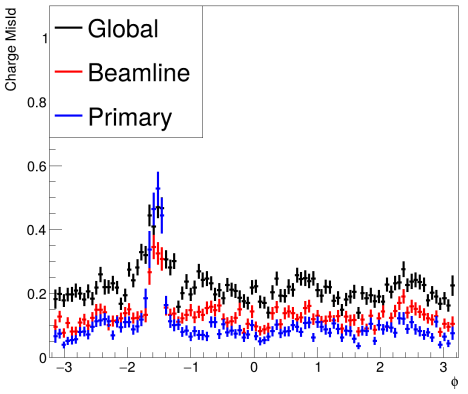






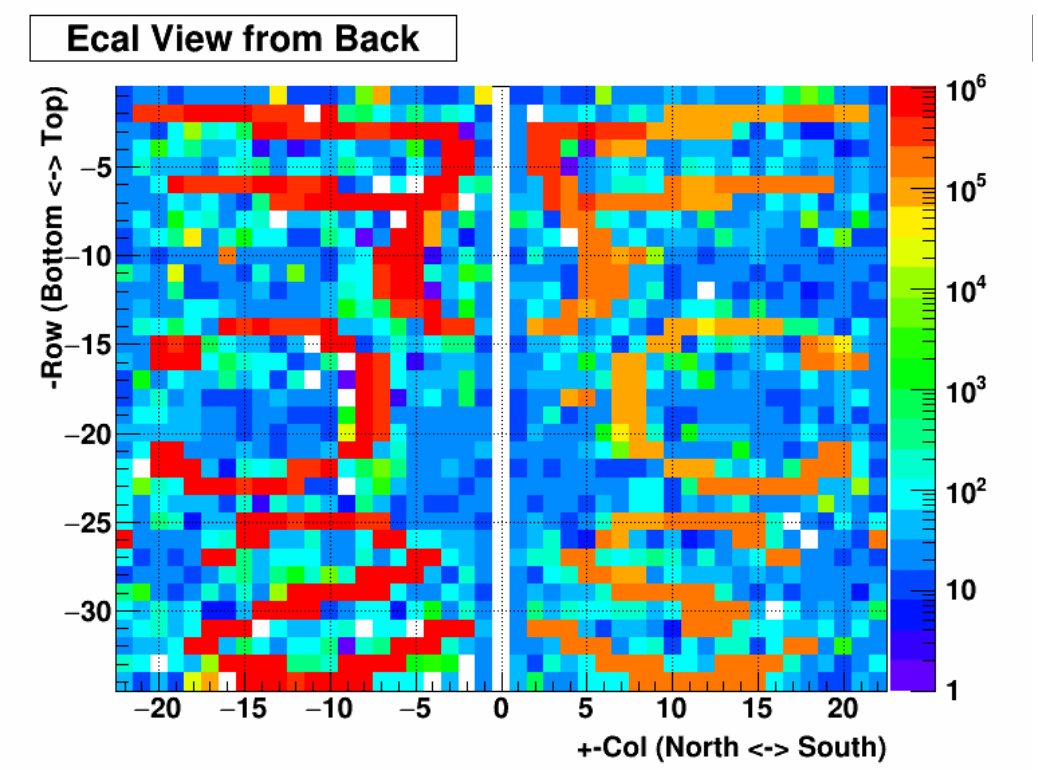




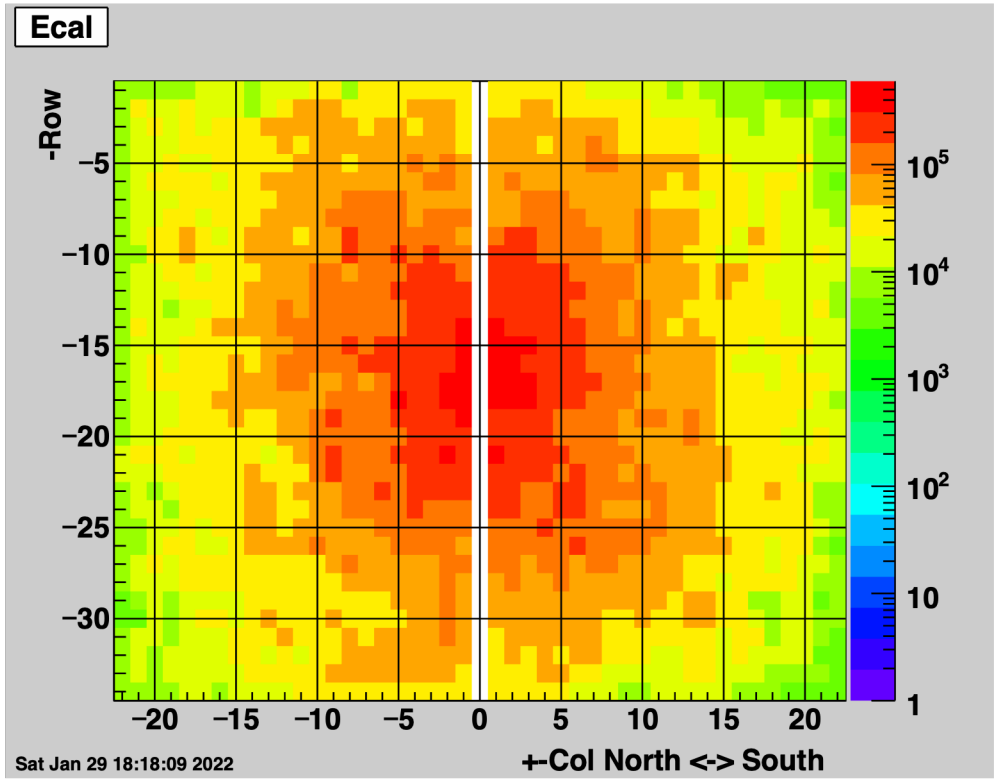


FCS Ecal Monitoring

Ecal LED Test

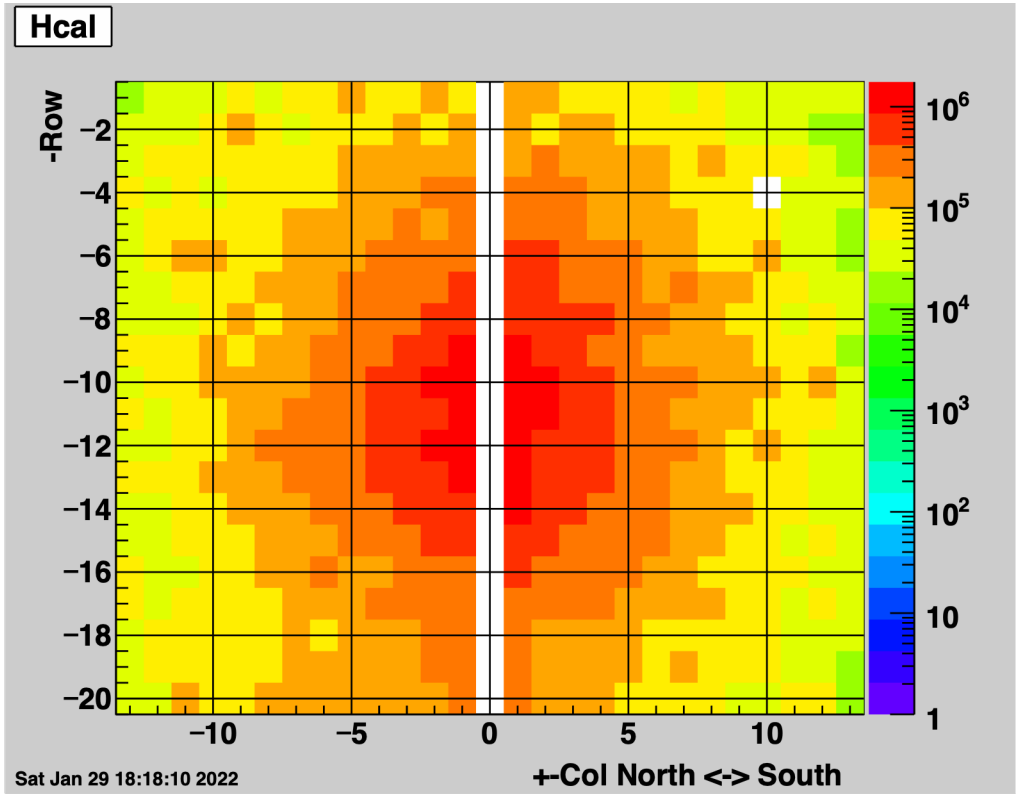


Ecal Hit Map Run 22

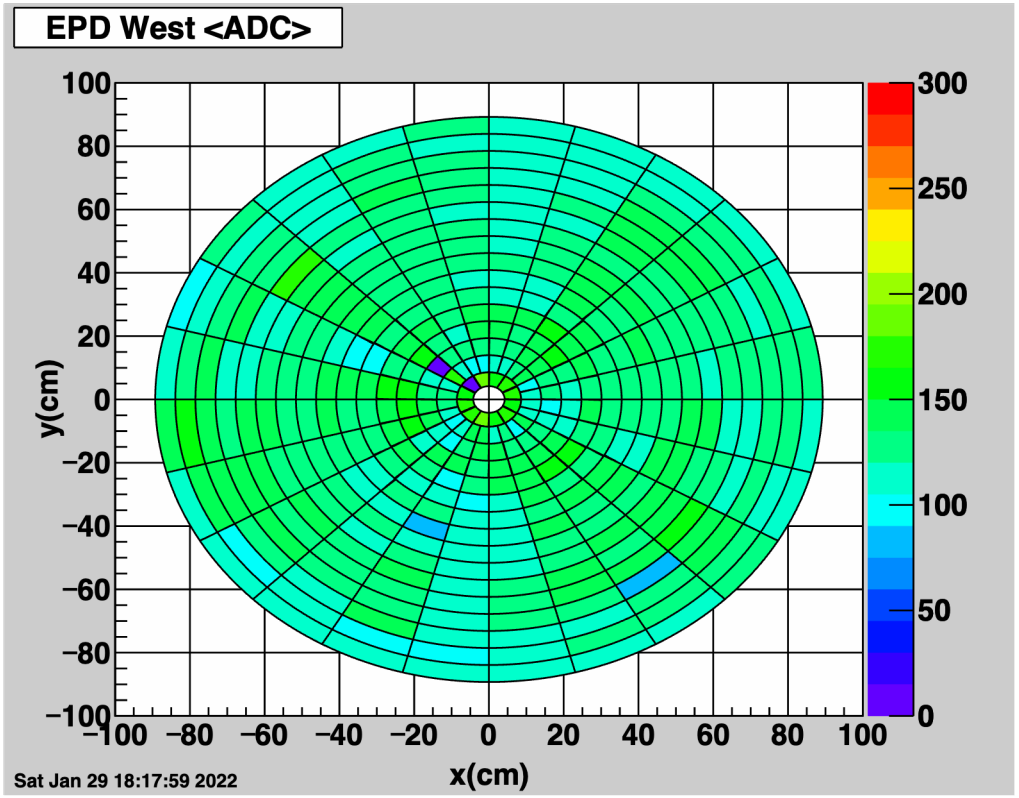


FCS Hcal and Preshower Monitoring

Hcal Hit Map Run 22

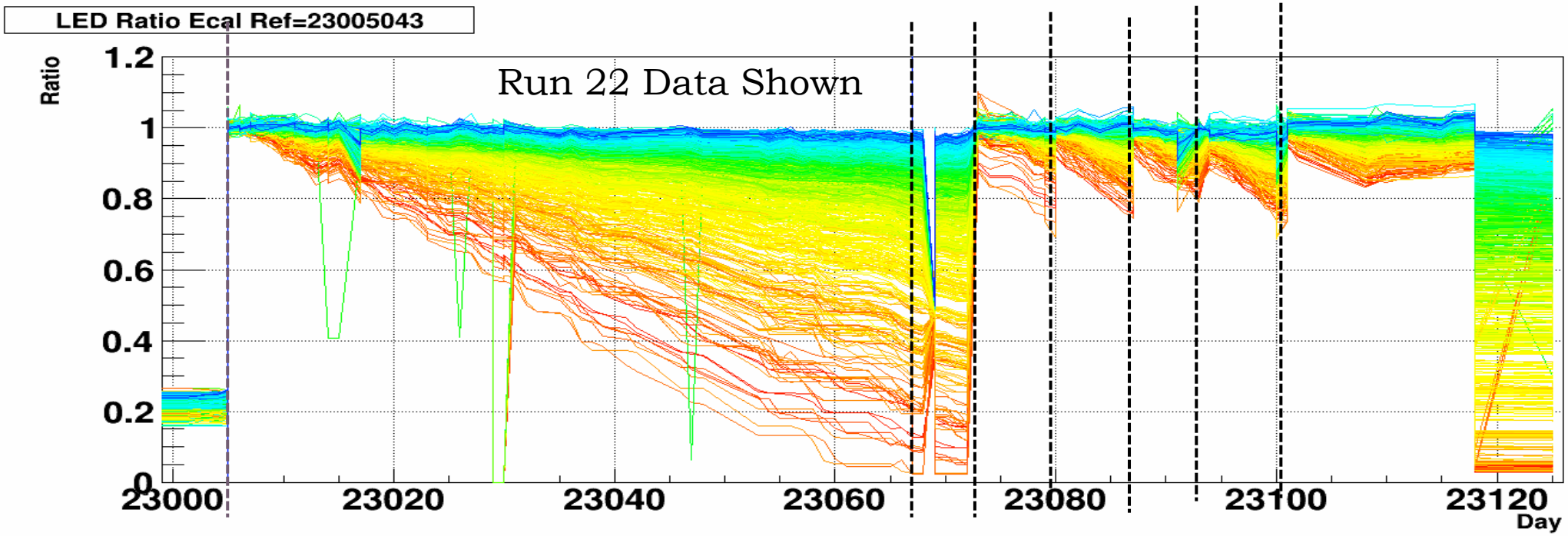


Preshower (EPD) Hit Map Run 22



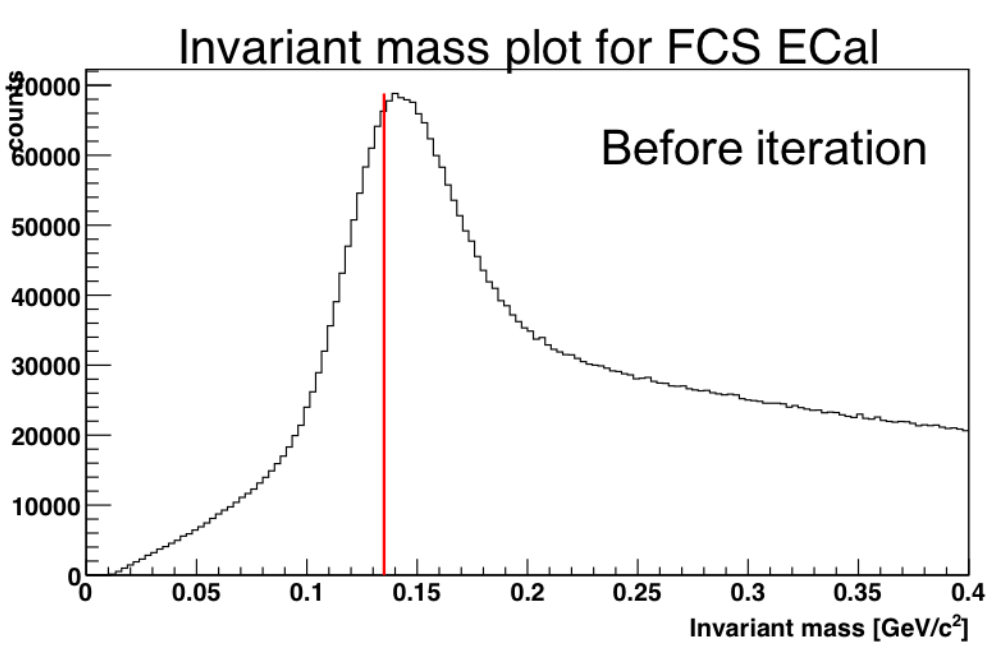
FCS LED Gain Correction

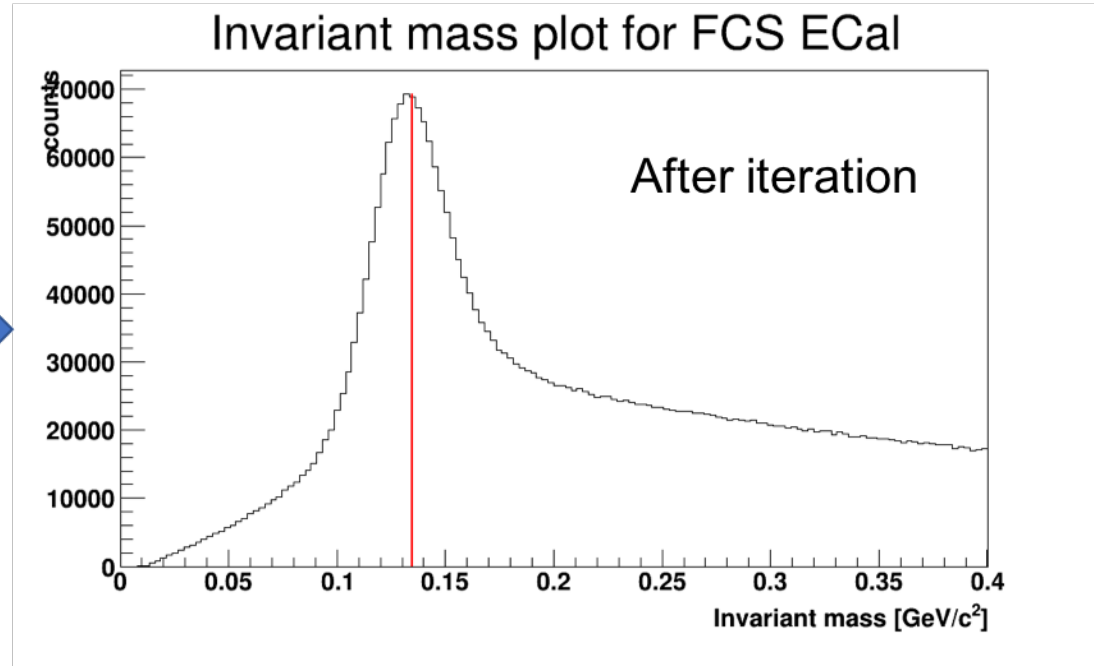
- LEDs were used to track radiation damage over time
- Periodically adjusting gains allowed us to compensate for radiation damage



Calibration of FCS using π^0

- Modify gains over many iterations over the same data until the invariant mass peak of di-photon candidates is at the right π^0 invariant mass

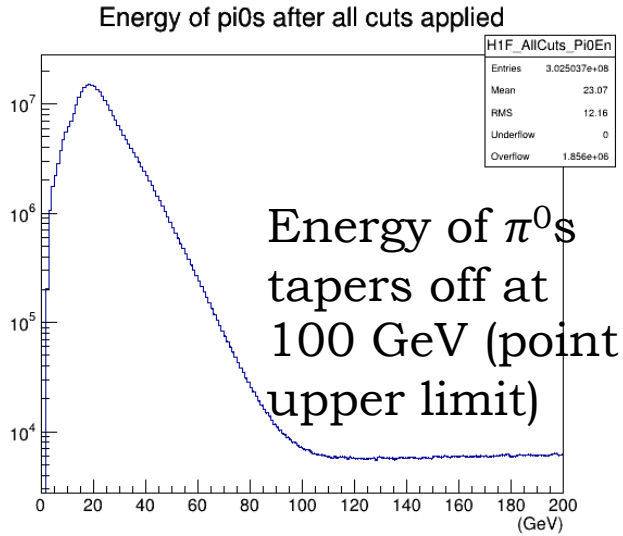




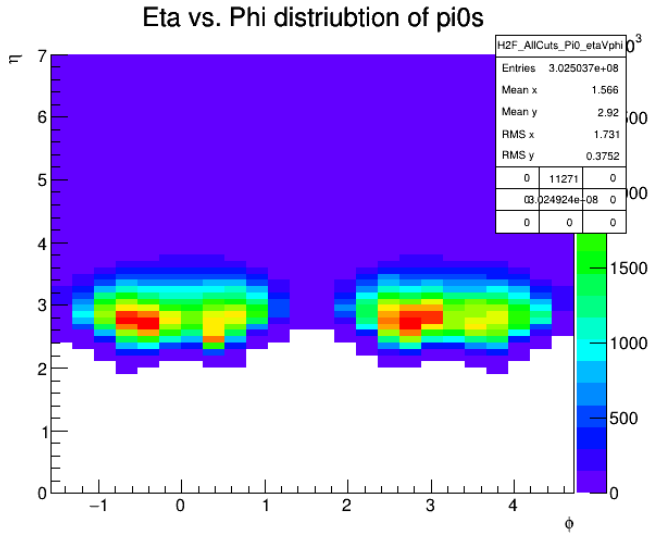
Run 22 TSSA of π^0

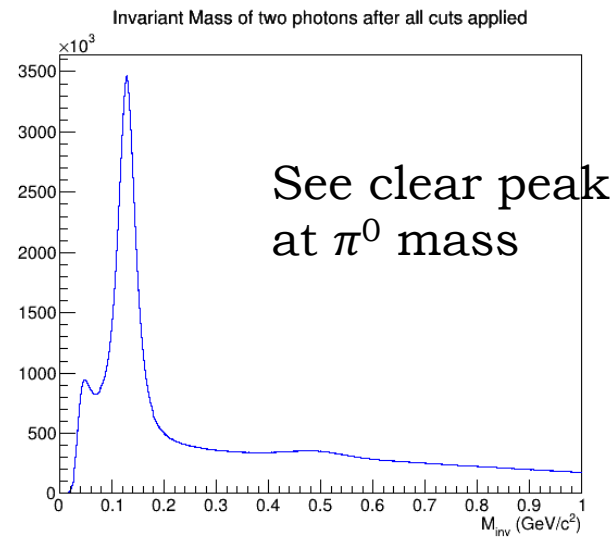
- The A_N of π^0 is undergoing analysis using Ecal and preshower information
- Form photon candidates (points) in Ecal using shower shape reconstruction
  - Form π^0's from pairs of points
  - Cut on energy asymmetry of two points, $Z_{\gamma\gamma} = \frac{|E_1 - E_2|}{E_1 + E_2} < 0.7$
  - Use preshower to veto points that are charged particles
    - Project point to preshower and check that value falls below the MIP energy

QA Plots Relevant to analysis

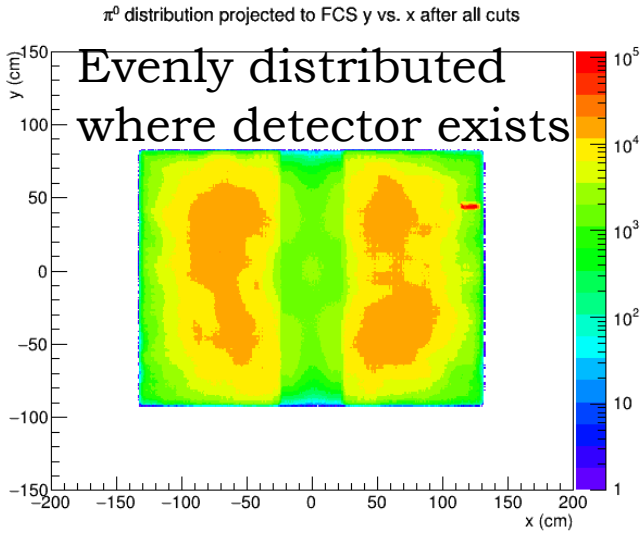


Energy of π^0s tapers off at 100 GeV (point upper limit)

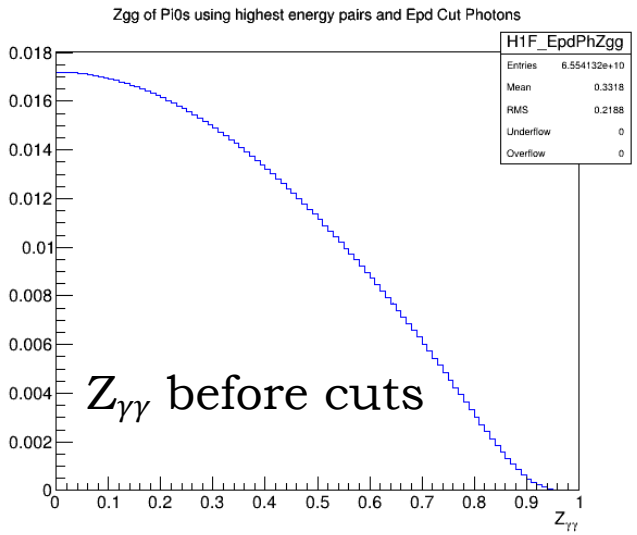




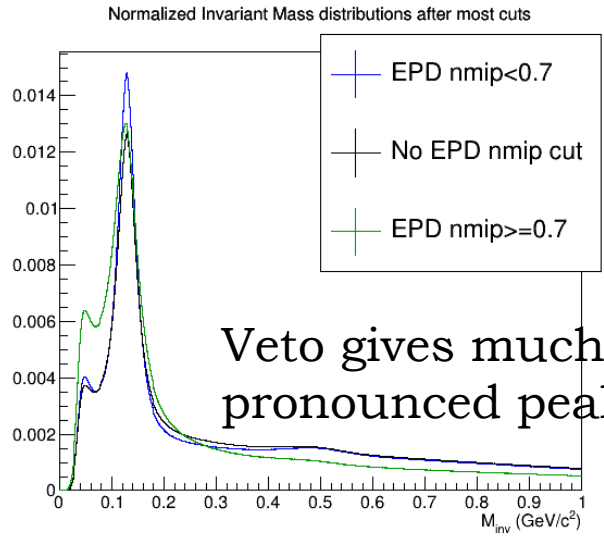
See clear peak at π^0 mass



Evenly distributed where detector exists



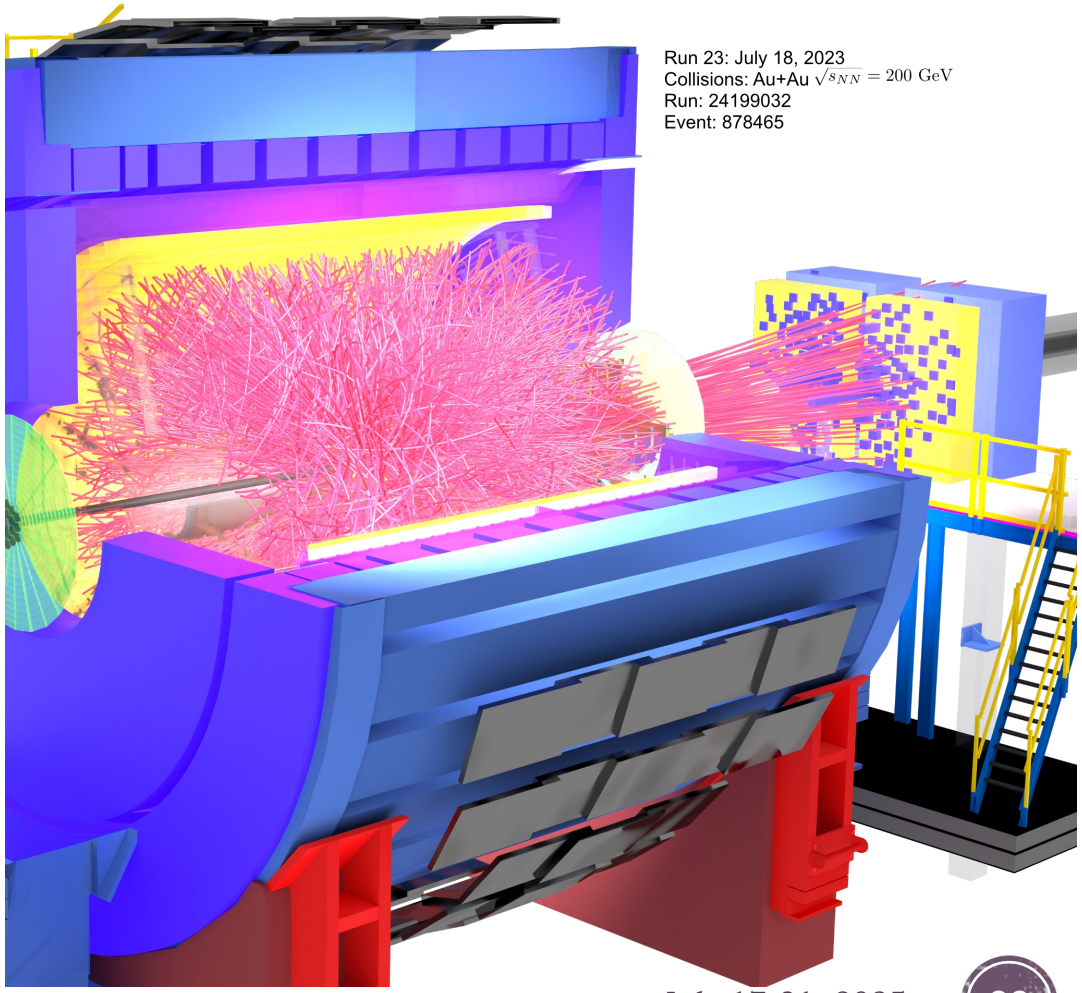
$Z_{\gamma\gamma}$ before cuts



Veto gives much more pronounced peak at π^0 mass

Looking Ahead

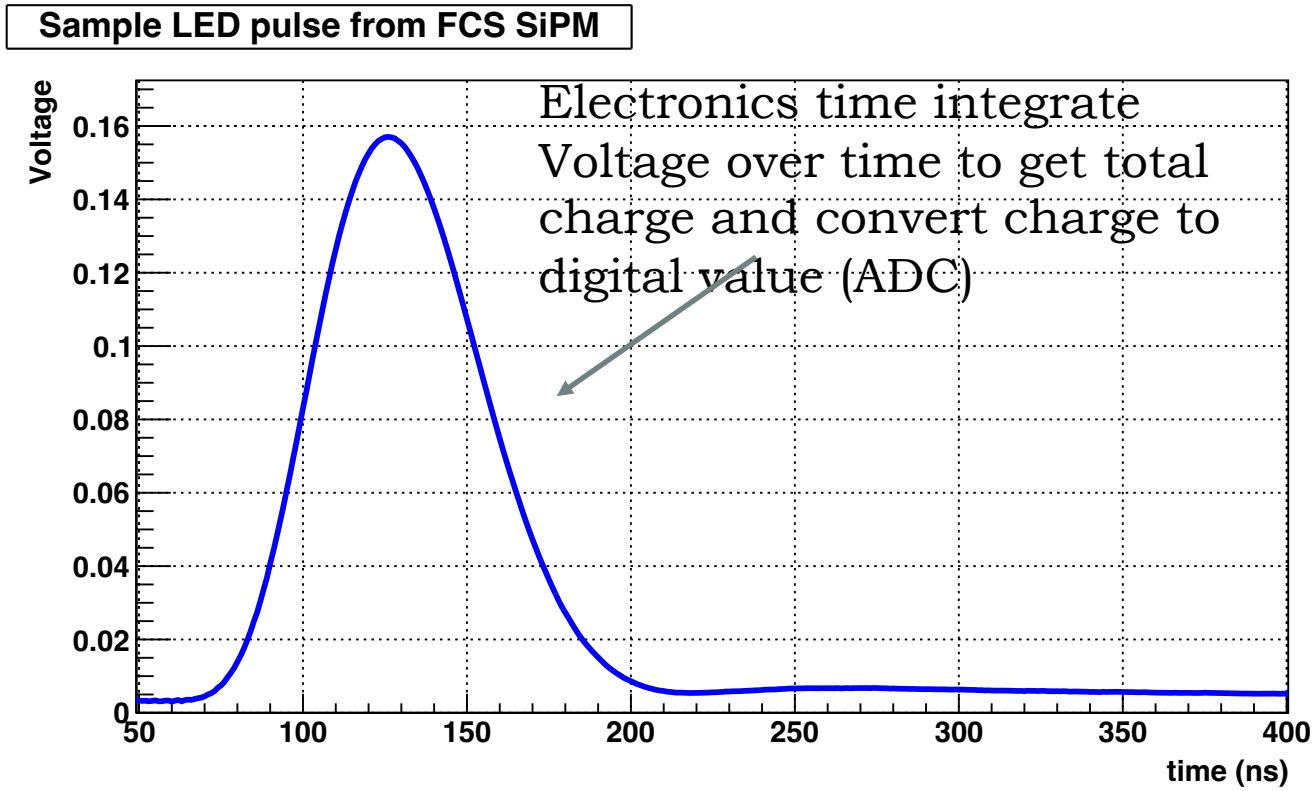
- Lots of interesting physics observables
  - A_N of hadrons, jets, dijets
  - Drell-Yan, J\ψ
  - Global Lambda Polarization
- Successful installation in 2021 and smooth data taking in RHIC runs 2022-2025
  - Alignment of trackers ongoing
  - Tracking software mostly ready
  - Calibration of Ecal finished
  - Calibration of Hcal ongoing
- First physics results to come out soon
  - A_N of π^0



Backup

Getting the energy

- Signals from a detector are digitized by time integrating the voltage (ADC) of the signal over the whole time of a trigger window
- STAR trigger windows are defined by the time between RHIC bunches (bunch crossing)
- The energy deposited in the detector (E)=ADC*Gain
  - Gain needs to be calibrated



Digitization of Signal

- DEP boards digitize signal every ~13.5 ns
- This comprises 1 timebin (Tb)
- There are 8 Tb in 1 RHIC bunch crossing
- There is up to 100 Tb of data for every channel in every event
- Energy = (Fitted signal integral)*Gain
  - Each signal/peak is fitted to a Gaussian
  - Fitted signal to all peaks shown in black
  - Amplitude of Gaussian is proportional to integral
- Peaks found using discrete second derivative test

Sample Signal from DEP showing multiple RHIC bunch crossings