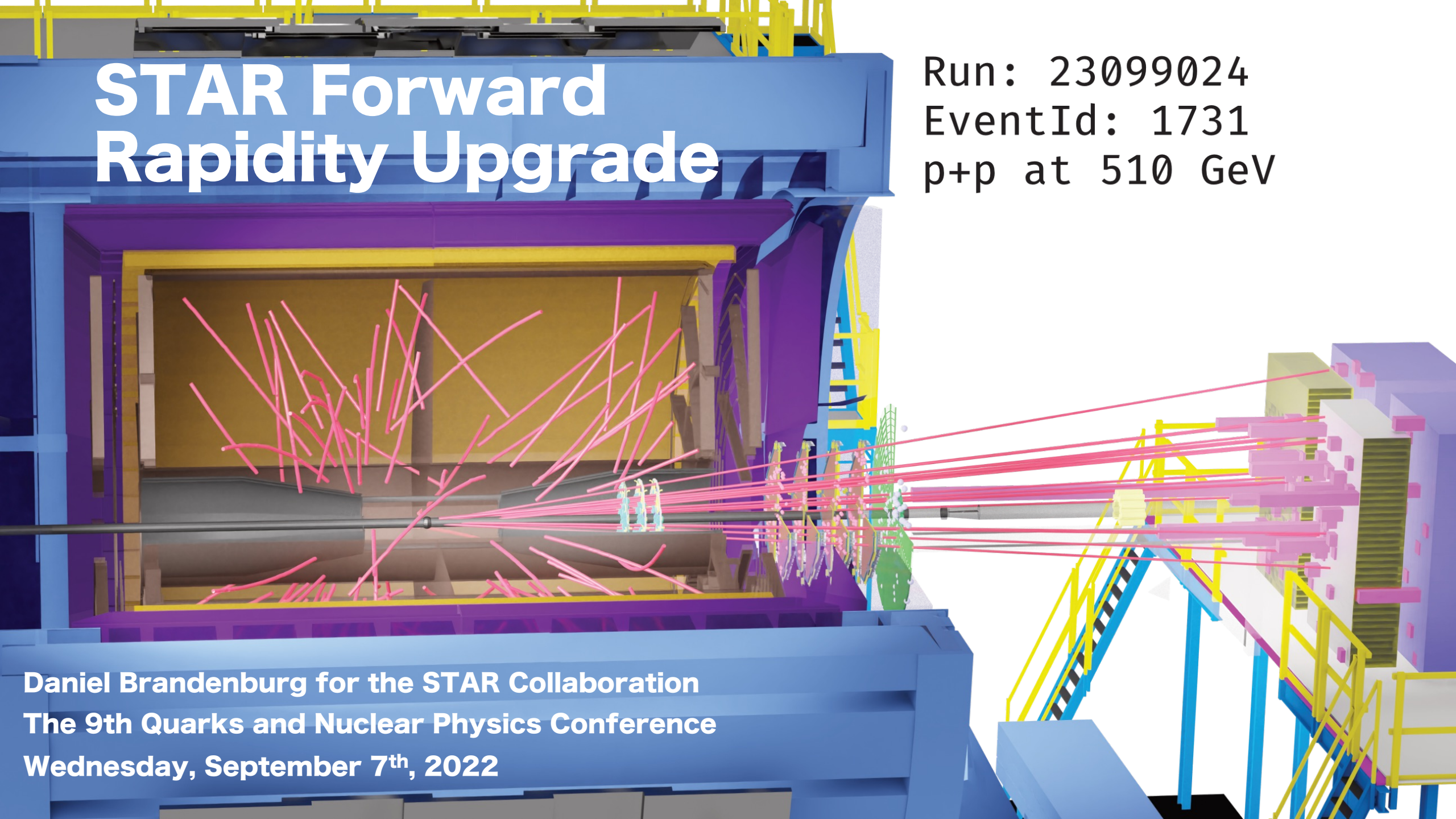
STAR Forward Rapidity Upgrade

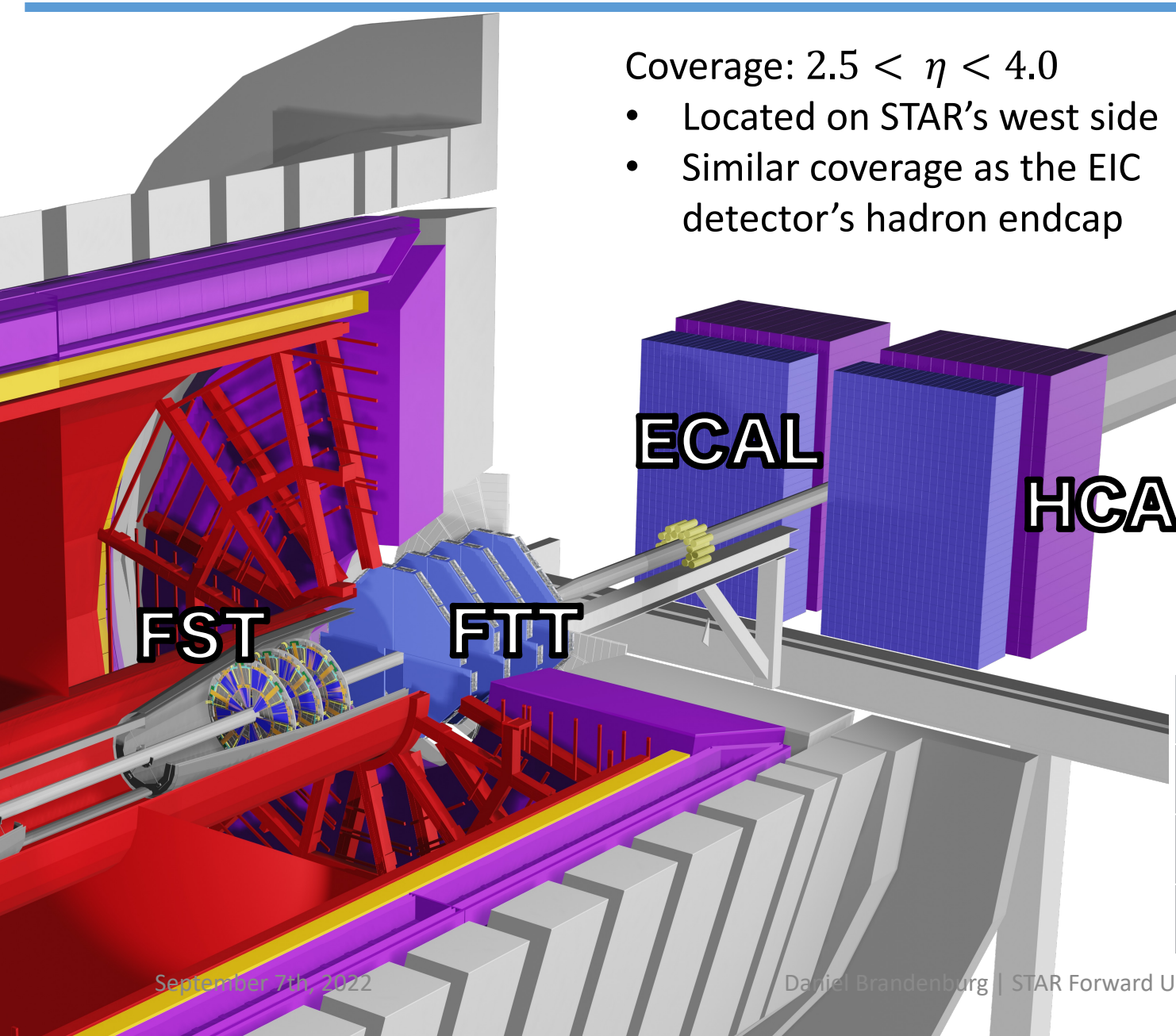


Daniel Brandenburg for the STAR Collaboration

The 9th Quarks and Nuclear Physics Conference

Wednesday, September 7th, 2022

STAR Forward Rapidity Upgrade : Overview



Coverage: $2.5 < \eta < 4.0$

- Located on STAR's west side
- Similar coverage as the EIC detector's hadron endcap

Forward Tracking System (FTS)
Forward Silicon Tracker (FST)
Forward Small-strip Thin Gap Chambers Tracker (FTT)

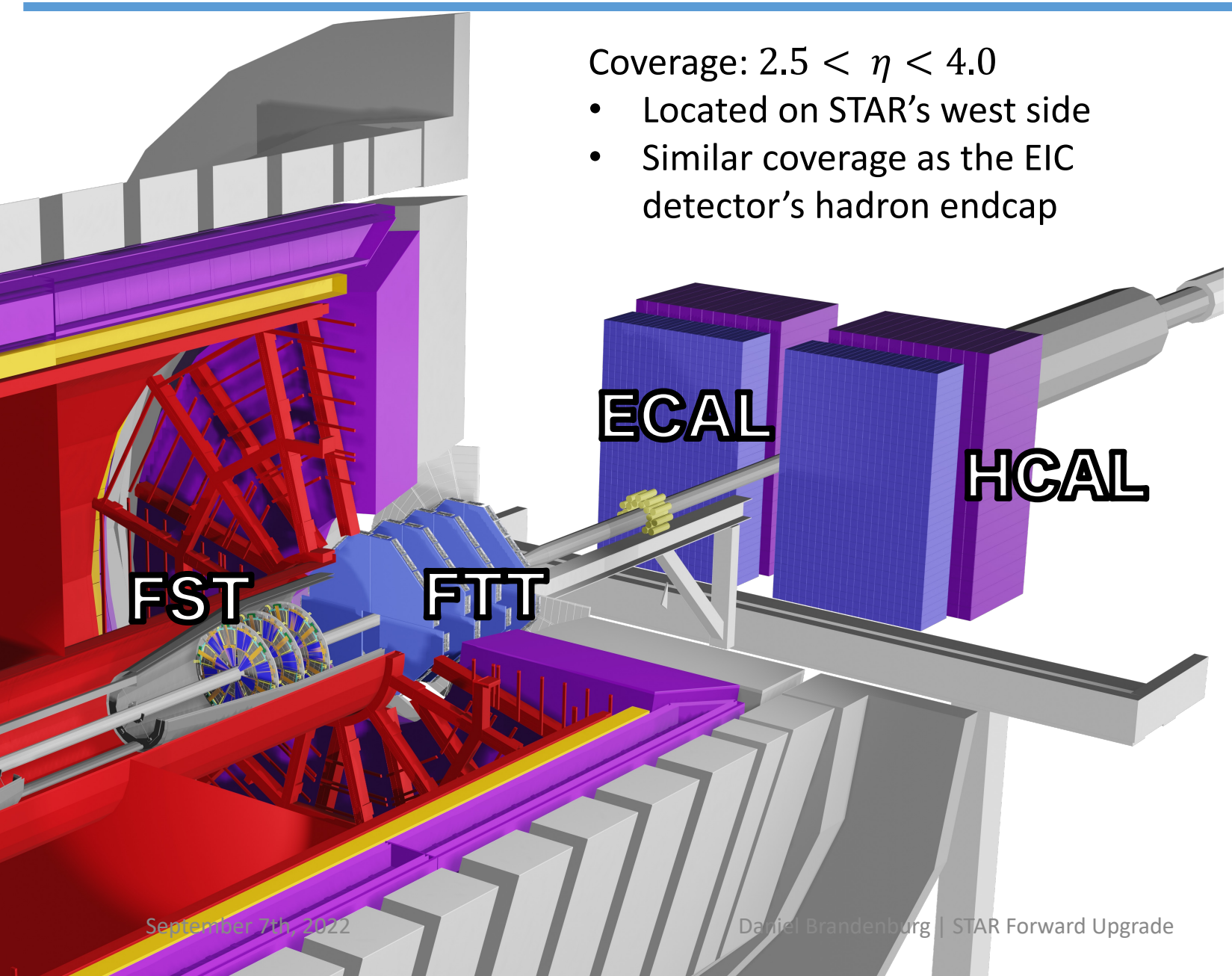
Forward Colorimeter System (FCS)
Electromagnetic Calorimeter
Hadronic Calorimeter

Requirements for physics:

- Good e/h separation
- Photon & π^0 identification

Detector	pp and pA	AA
ECal	$\sim 10\,\%/\sqrt{E}$	$\sim 20\,\%/\sqrt{E}$
HCal	$\sim 50\,\%/\sqrt{E} + 10\,\%$	–
Tracking	Charge separation photon suppression	$\delta p_T/p_T \sim 20 - 30\,\%$ $for\ 0.2 < p_T < 2GeV/c$

STAR Forward Rapidity Upgrade : Physics Program



Coverage: $2.5 < \eta < 4.0$

- Located on STAR's west side
- Similar coverage as the EIC detector's hadron endcap

Cold QCD

- p+p 510 GeV (2022) and p+p & p+Au 200 GeV (2024)
- Sivers asymmetries for hadrons, (tagged) jets, and di-jets
- Gluon PDFs for nuclei: RpA for direct photons & DY
- Tests of Saturation predictions through di-hadrons, γ-jets

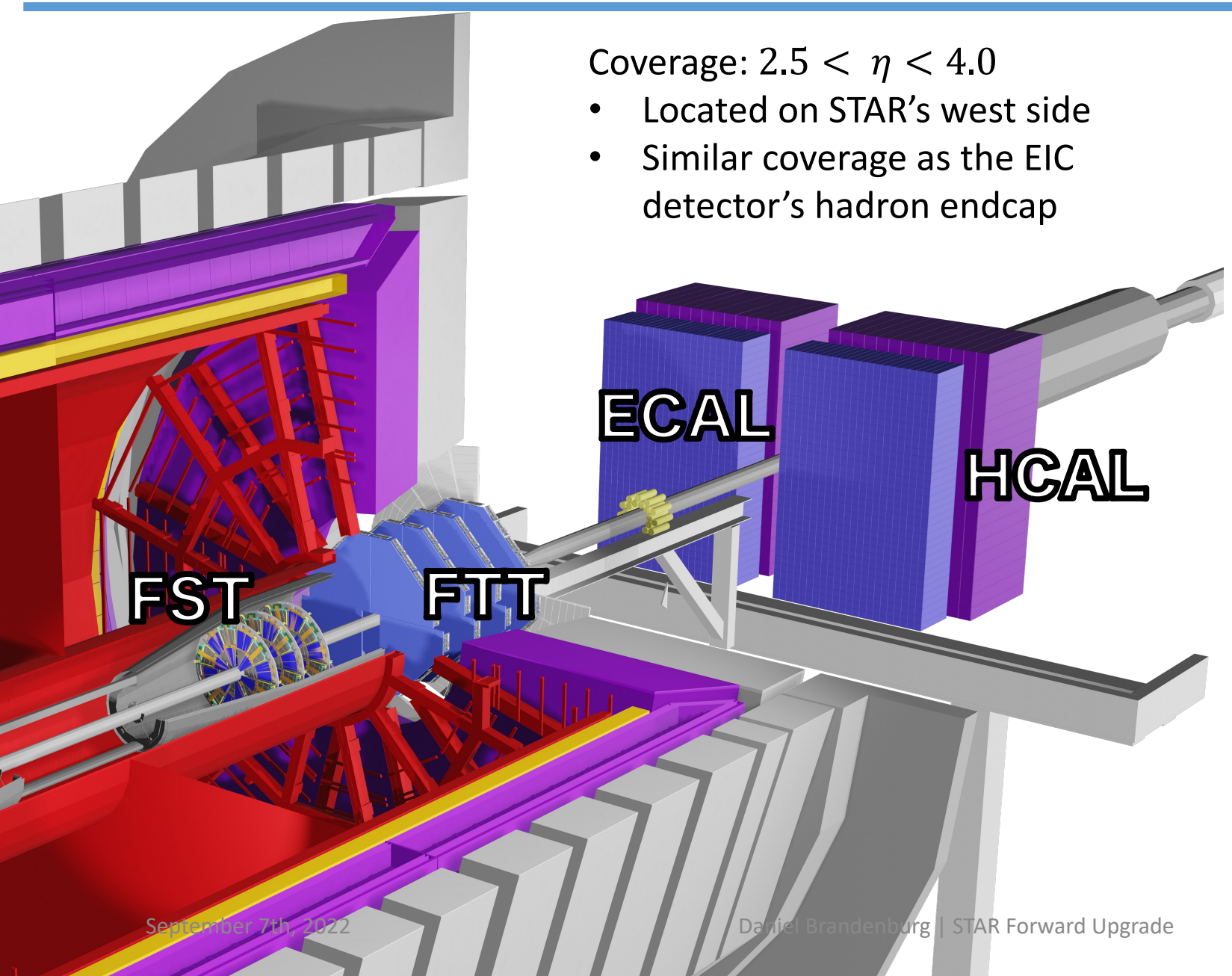
Hot QCD

- Au+Au 200 GeV (2023 and 2025)
- Temperature dependence of viscosity through flow harmonics up to $\eta \sim 4$
- Longitudinal decorrelation up to $\eta \sim 4$
- Global Lambda Polarization: test predictions of strong rapidity dependence ...

Observables

- Charged and neutral hadrons
- Inclusive jets and di-jets
- Lambda polarization
- Mid-forward and forward-forward rapidity correlations

The Forward Silicon Tracker (FST)



Coverage: $2.5 < \eta < 4.0$

- Located on STAR's west side
- Similar coverage as the EIC detector's hadron endcap

Structure

- 3 Silicon disks: at 152, 165, and 179 cm from the interaction point
- Locate inside STAR TPC cone
- Single-sided double-metal mini-strip sensors
- Granularity: fine in ϕ and coarse in R
- Material budget: ~1% per disk

Sensors & Electronics

Si from Hamamatsu

Frontend chips: APV25

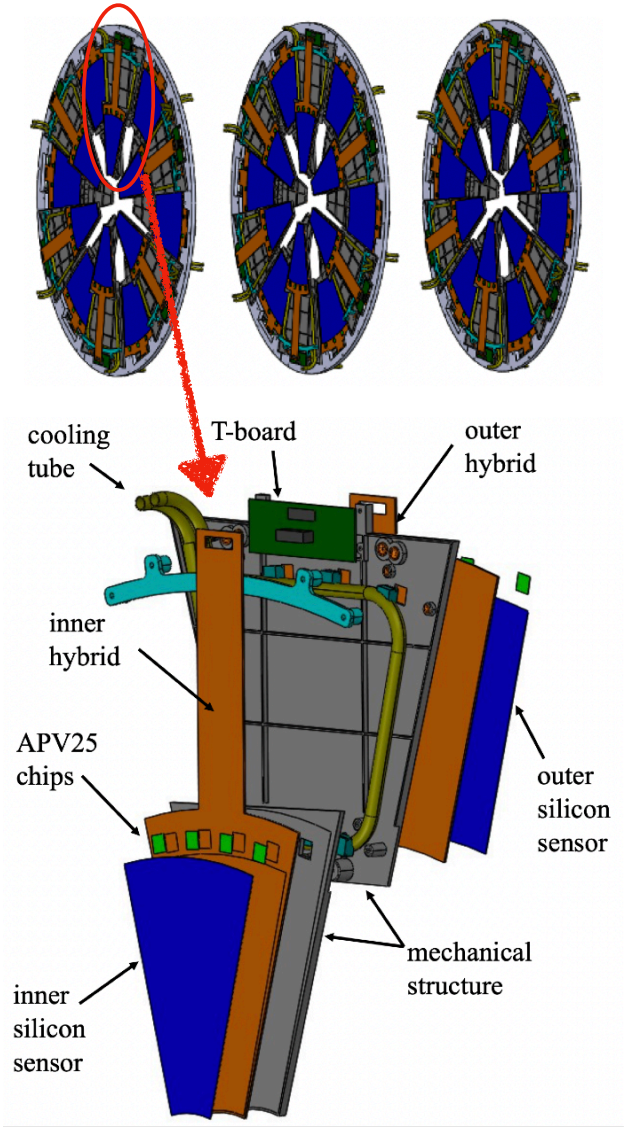
Built on successful experience with STAR Intermediate Silicon Tracker (IST)

Reused components:

IST DAQ system

IST cooling system

Forward Silicon Tracker : Module Design



Split Module Design

- Inner-region: 5<R<16.5 cm
  - 1 Kapton flexible hybrid
  - 1 Si sensor: 128 x 4 ($\phi \times R$) strips
  - 4 APV chips
- Outer region: 16.5 < R < 28 cm
  - 1 Kapton flexible hybrid
  - 2 Si sensor: 128 x 4 ($\phi \times R$) strips
  - 4 APV chips

Mechanical Structure

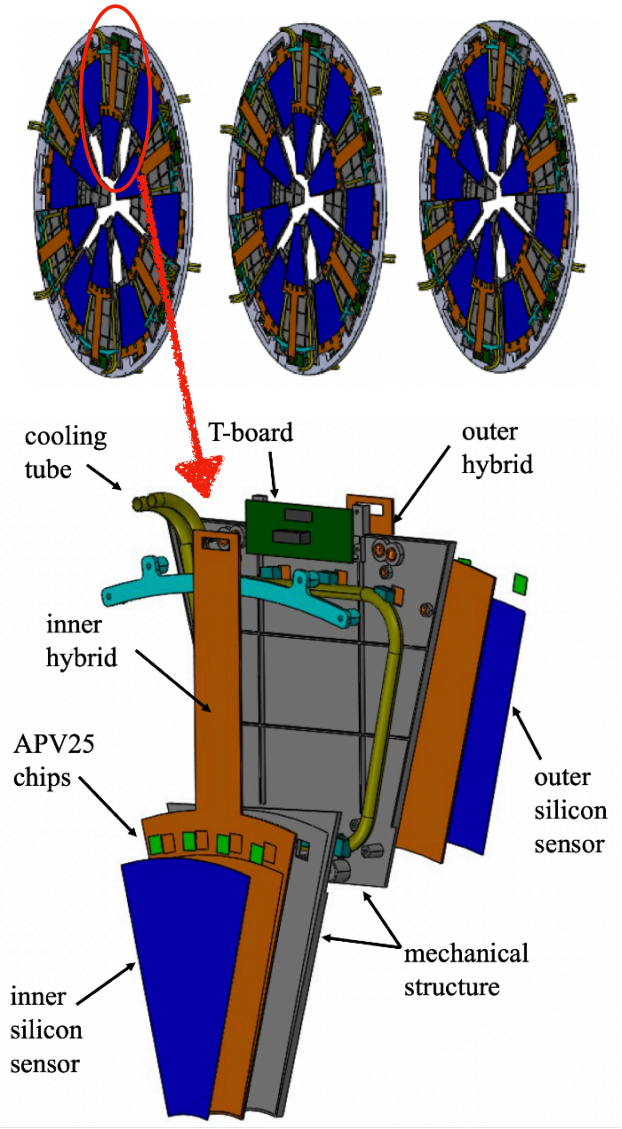
- PEEK (main structure + tube holder)
- Stainless steel (cooling tubes)
- Aluminum (heat sinks)

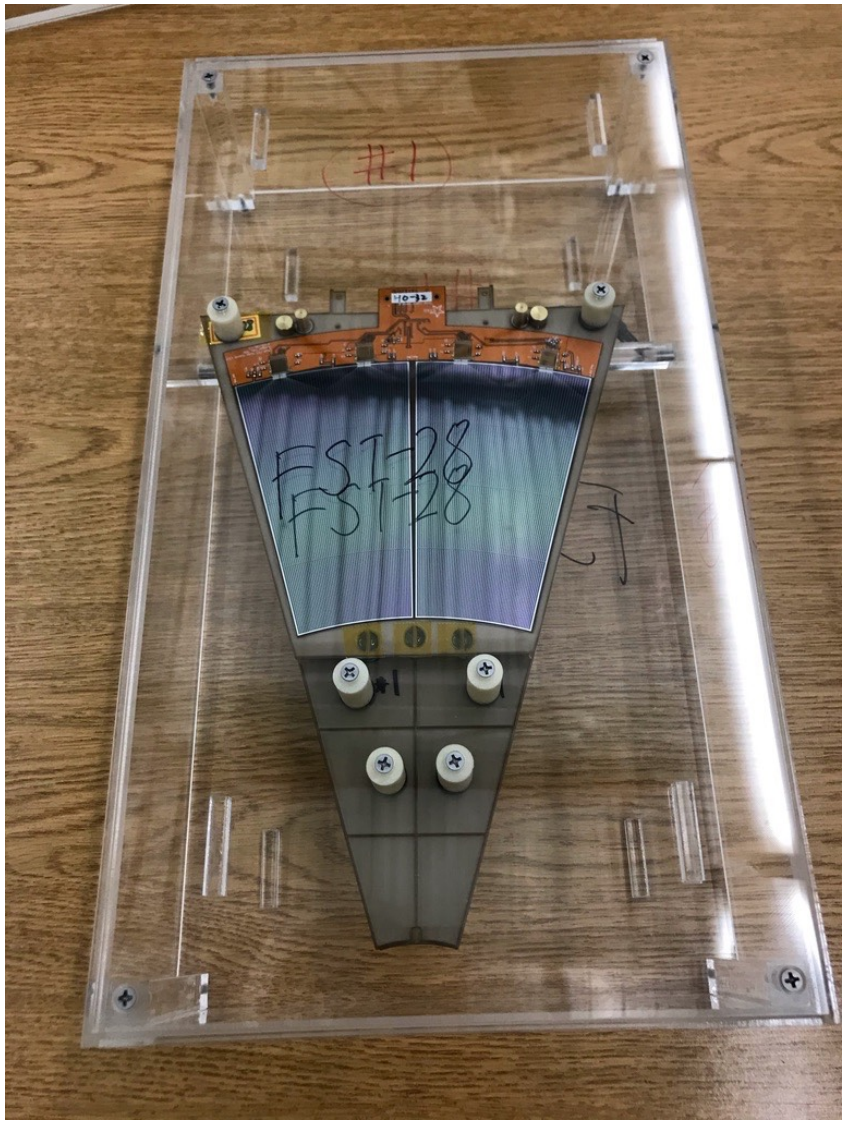
Total material budget : $\sim 1\% \, X_0$ per disk

Module Assembly

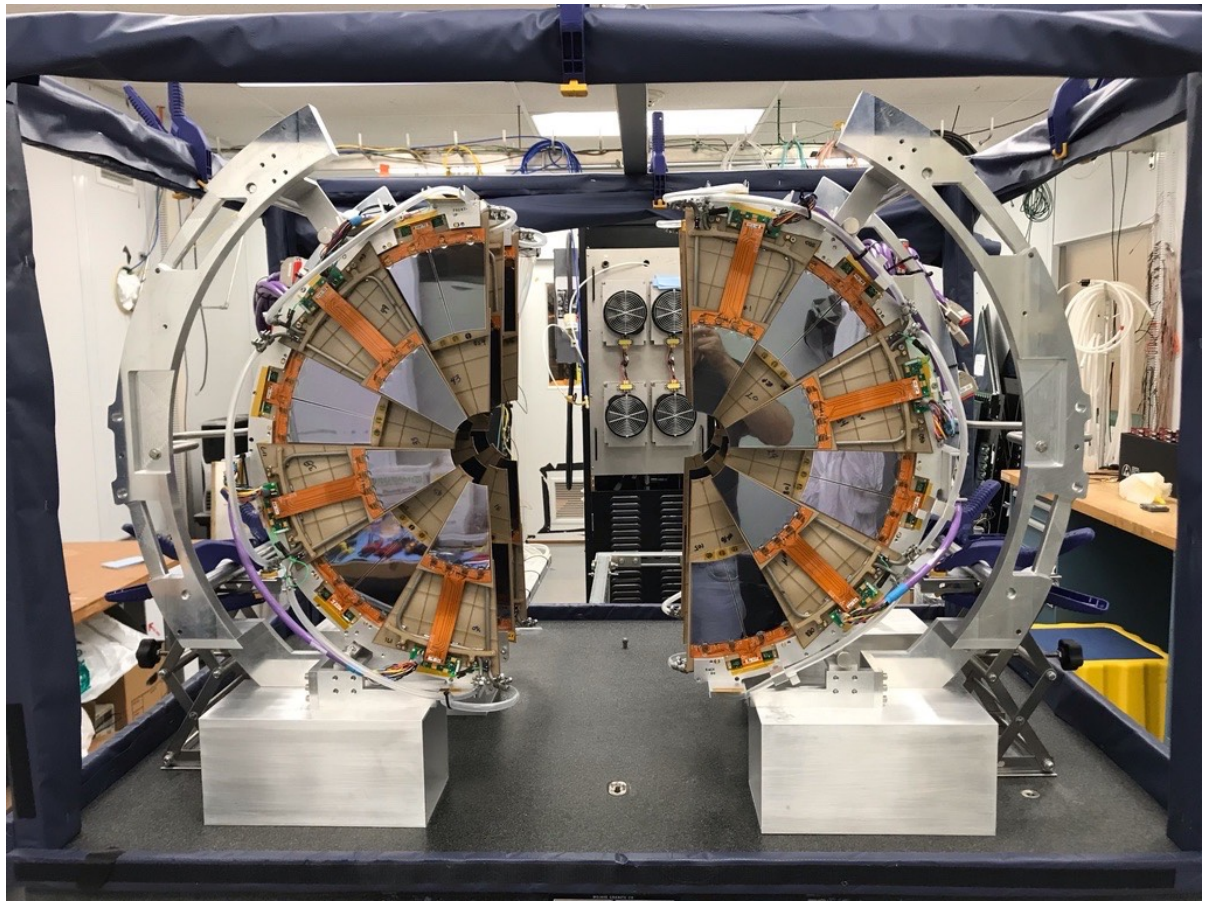
1. Gluing inner/outer hybrids and mechanical structures together
2. Mount/wire-bond APVs and Silicon sensors on hybrids

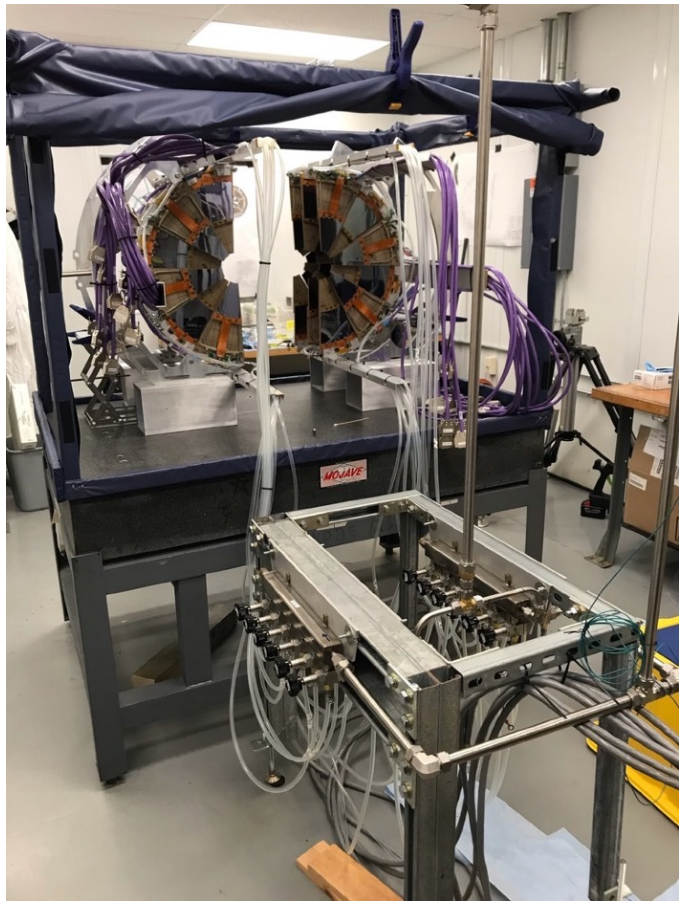
Forward Silicon Tracker : Module Design





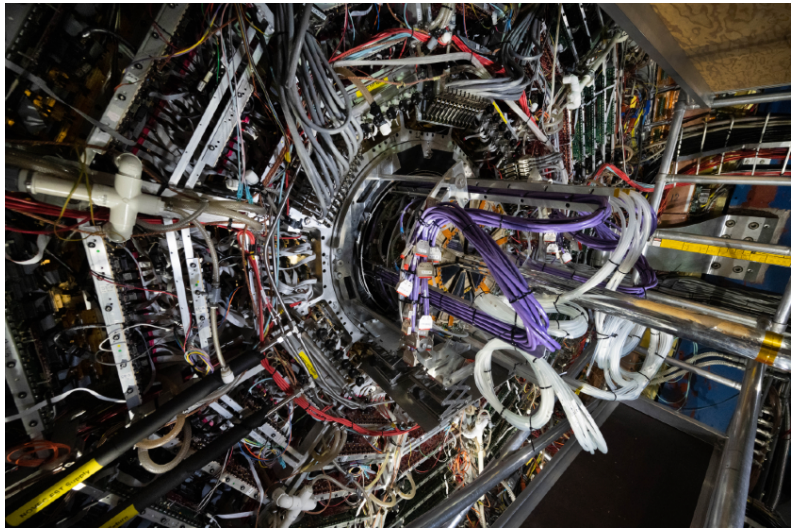
FST pre-installation & Tests

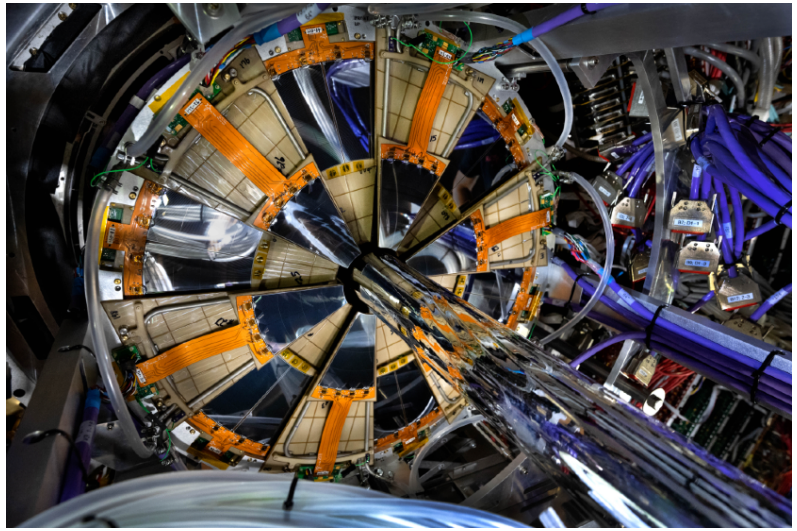


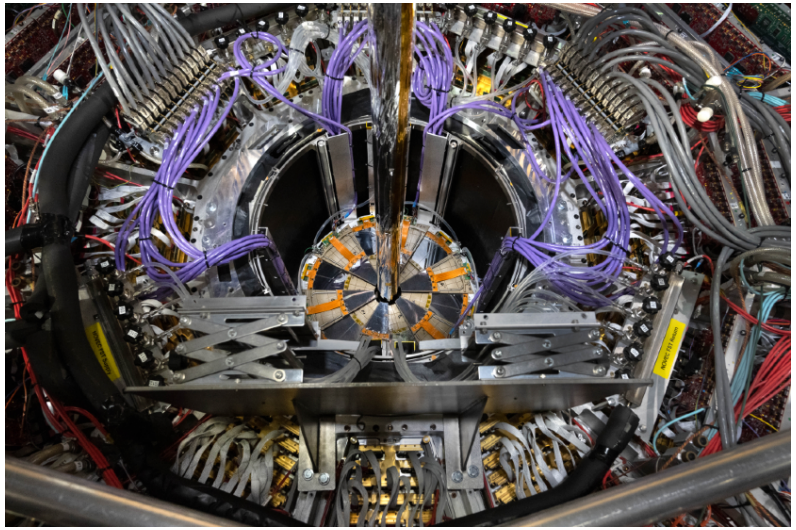


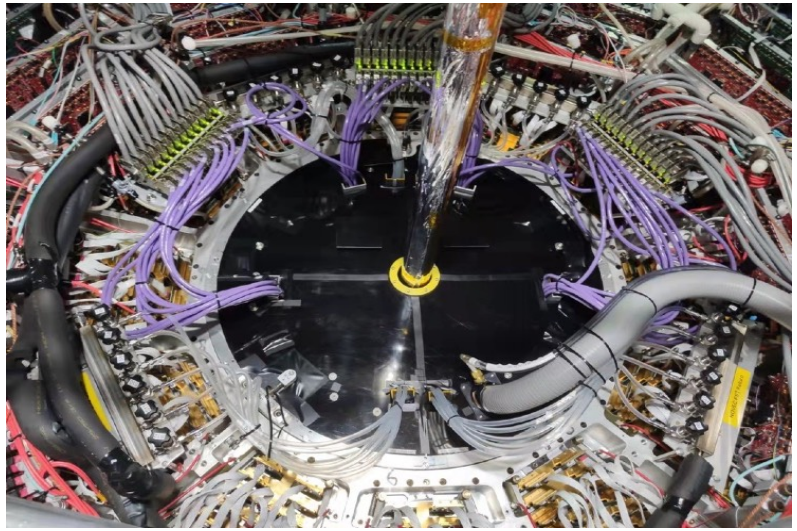
- FST modules installed into the support structure in the clean room (April - July 2021).
- Survey was done after each half plane completed (mid-plane has surveyed both sides).
- Readout and cooling test in the clean room for all 36 installed modules.

Installation into STAR West side





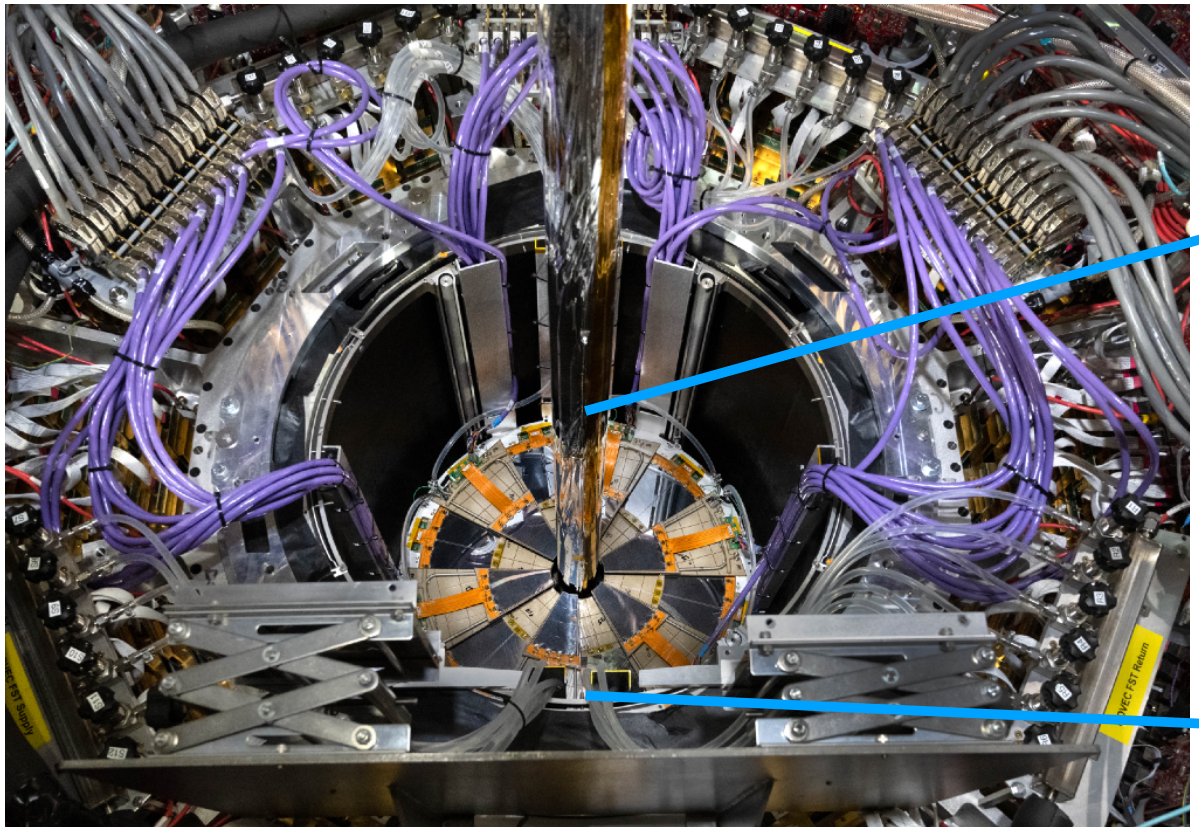




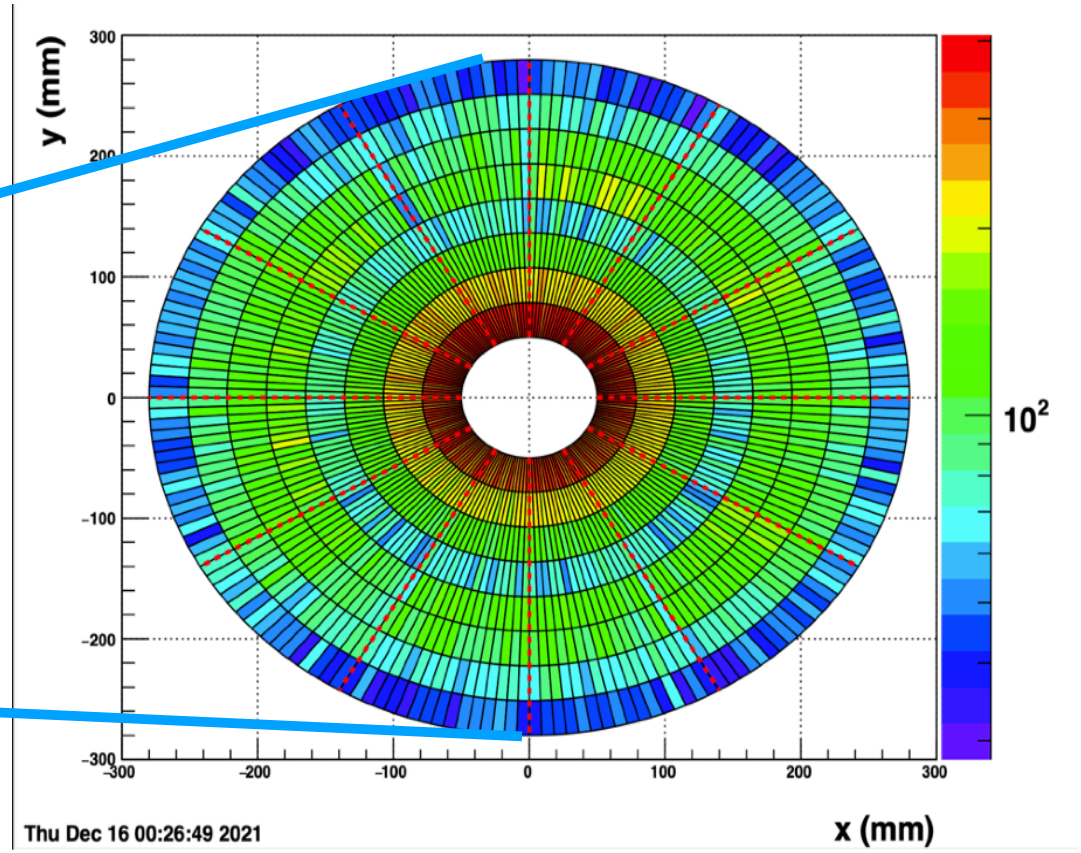
Installation completed on 08/13/2021

Forward Silicon Tracker : Operation

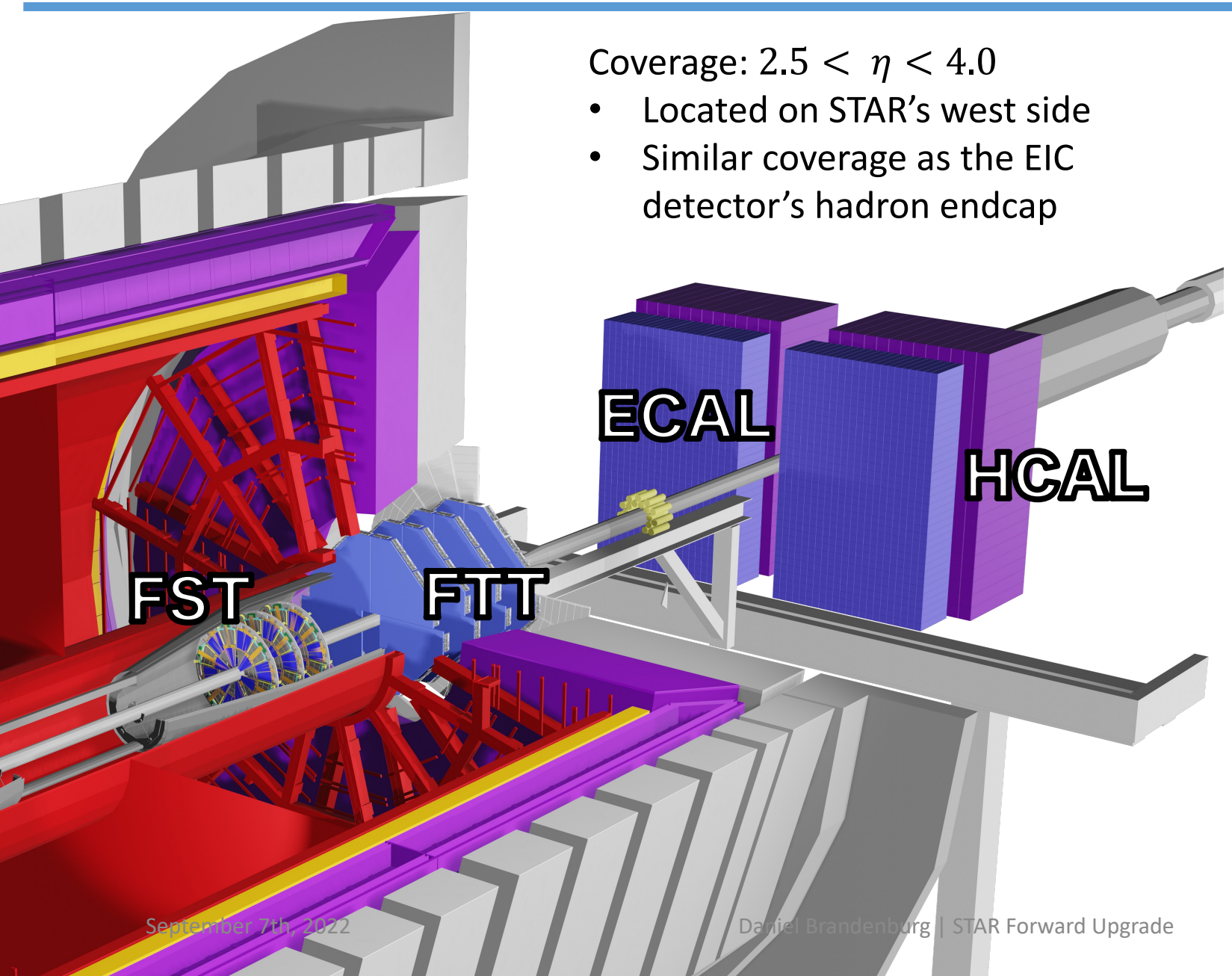
- Operation HV: 140V for inner sensor and 160V for outer sensors
- FST was commissioned took datain STAR run 22



FST event display in run22 p+p 510GeV



The Forward sTGC Tracker (FTT)



Coverage: $2.5 < \eta < 4.0$

- Located on STAR's west side
- Similar coverage as the EIC detector's hadron endcap

Structure

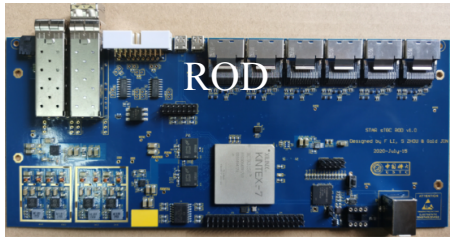
- 4 sTGC disks: at 307, 325, 343 and 361 cm from IP
- Locate inside STAR magnet pole tip opening
  - Inhomogeneous magnetic field
- 4 quadrants double sided sTGC => 1 layer
  - Diagonal strips to break ambiguities in the hit location

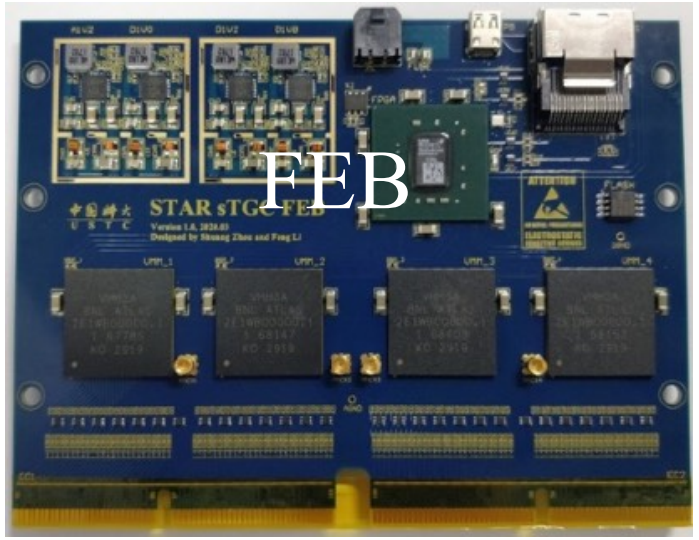
Specifications

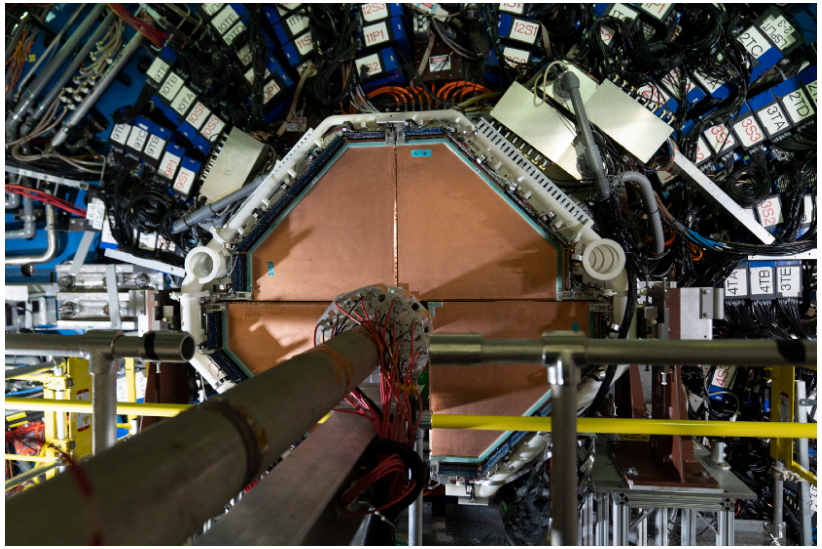
- Position resolution: ~100µm
- Material budget: ~0.5% per layer
- Readout: based on VMM-chips

=> Based on ATLAS design

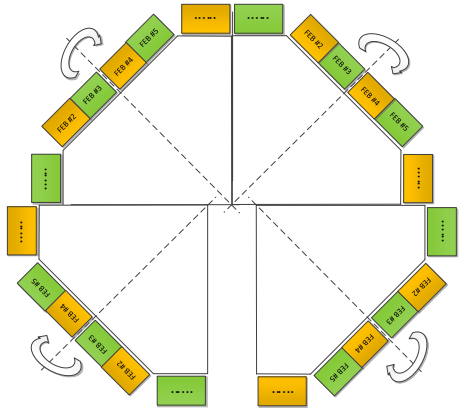
Forward sTGC Tracker : Electronics







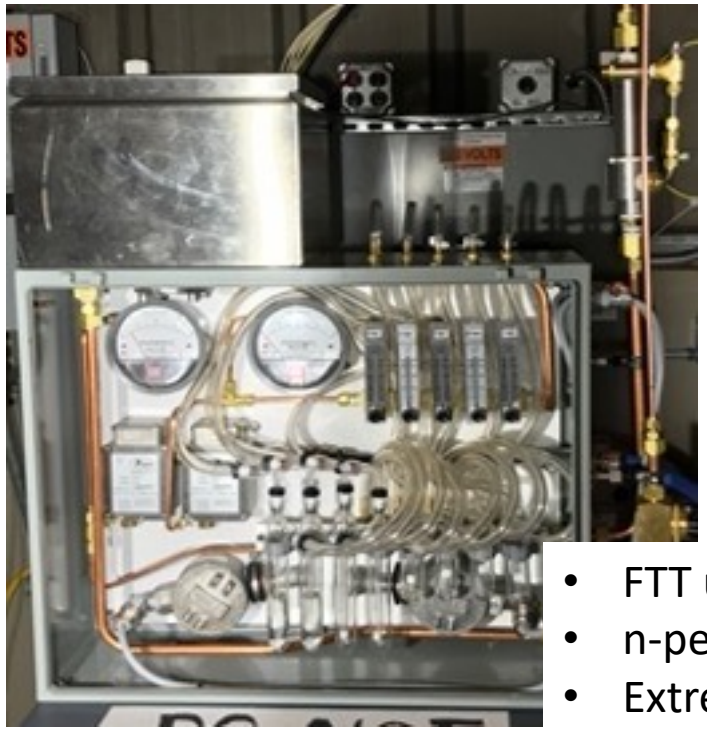
- Read Out Driver modules are designed based on Standard VME 6U Crate (with DC power supply)
- 16 ROD module => one for every 6 FEBs & 1 quadrant
- Front-End Boards are designed based on VMM-3A chips. 4 VMM-3A chips/board, 212 channels
- 96 FEBs => 24 FEBs for each layer



Forward sTGC Tracker : Gas & Safety

Gas Cabinet

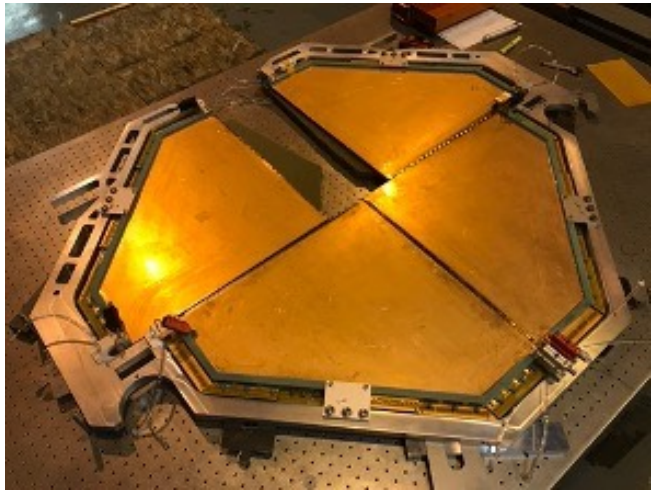
Gas Distribution Panel

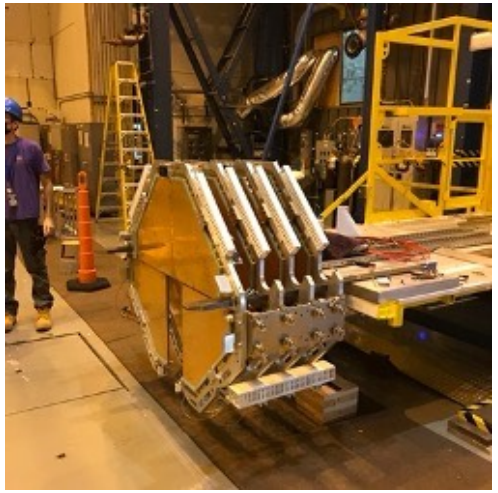


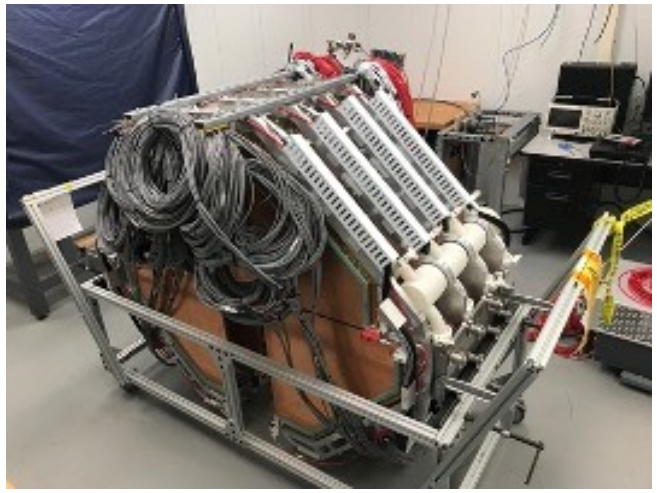
Gas Purity Analyzer

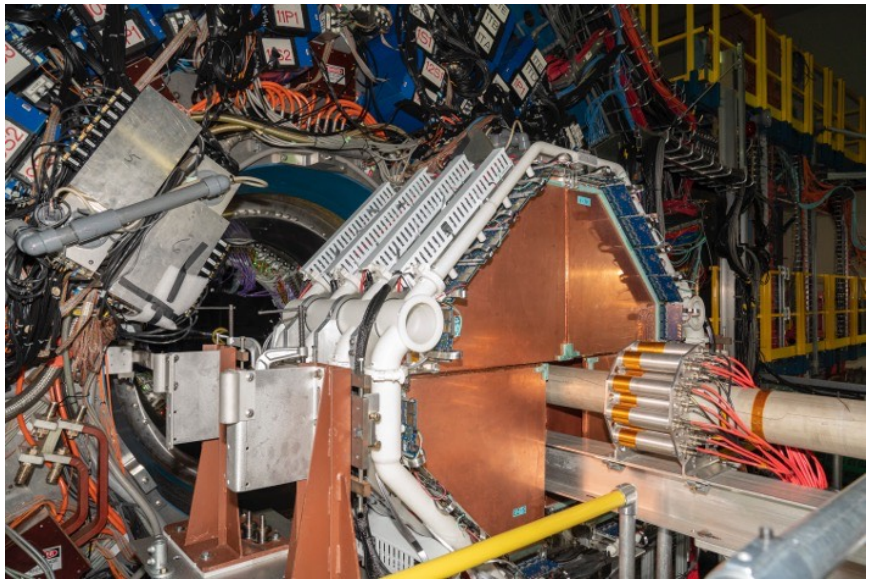
- FTT use a mixture of CO2 and n-pentane
- n-pentane isomer formula C5H12
- Extreme care needed for the highly flammable n-pentane! Flash point –49 0C; explosive limits 1.5 – 7.8%
- Boiling point of 36.1 0C further complicates things
- Has operated extremely well through major power failures and big storms

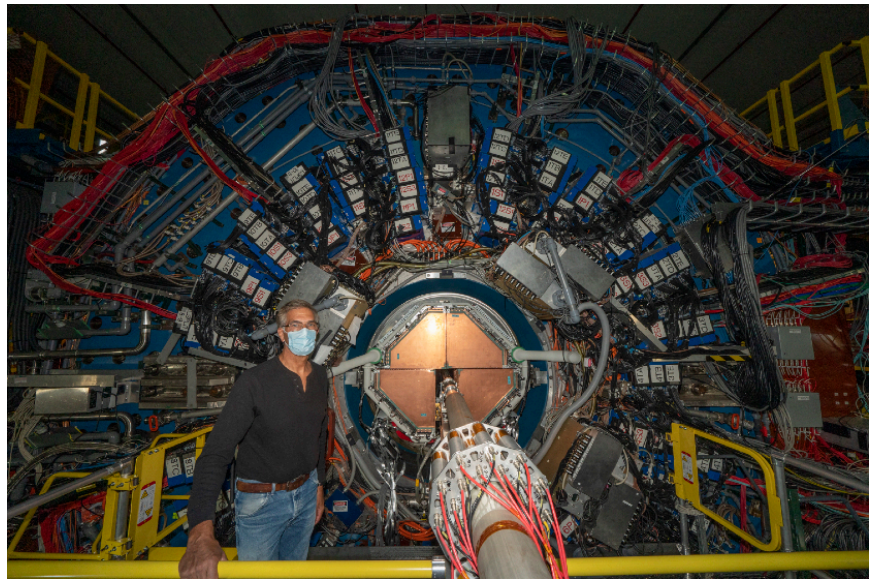
Forward sTGC Tracker : Installation





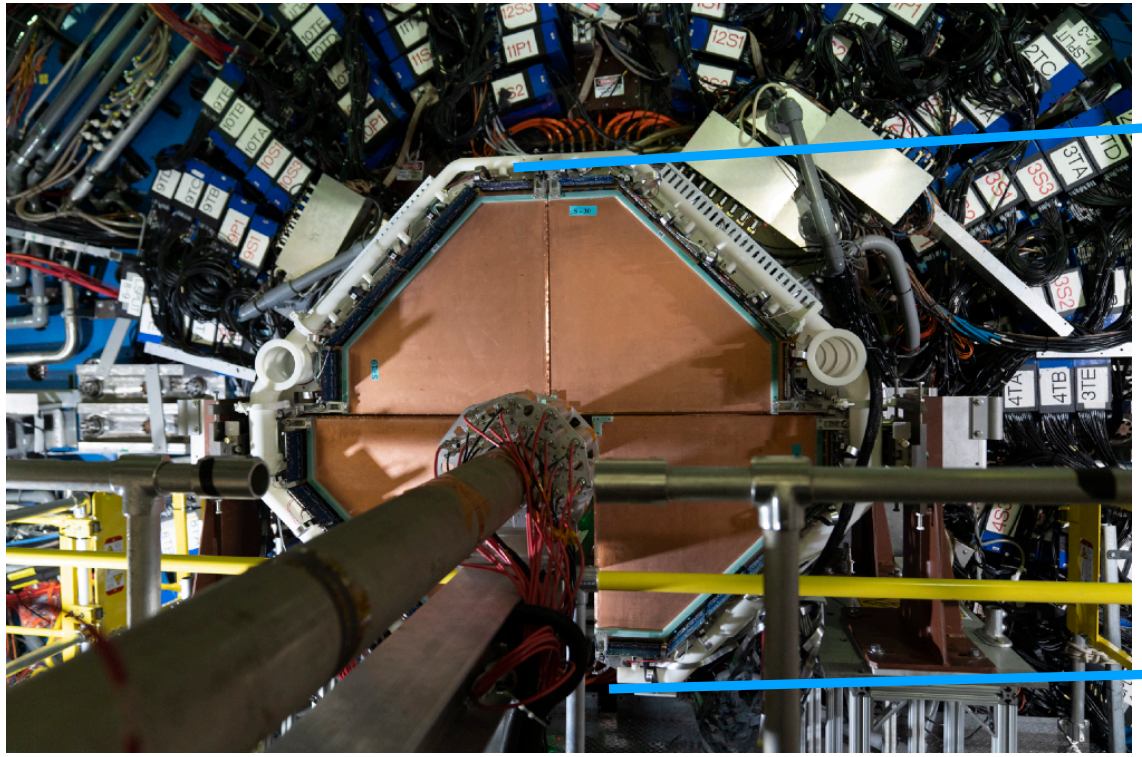




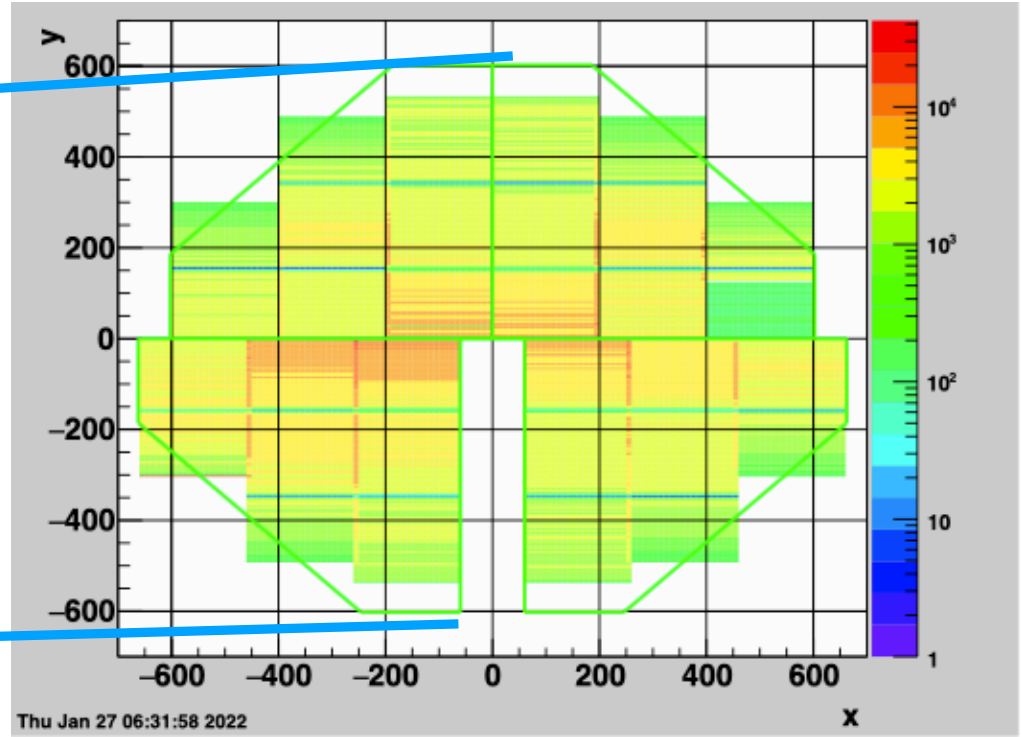


Forward sTGC Tracker : Opperation

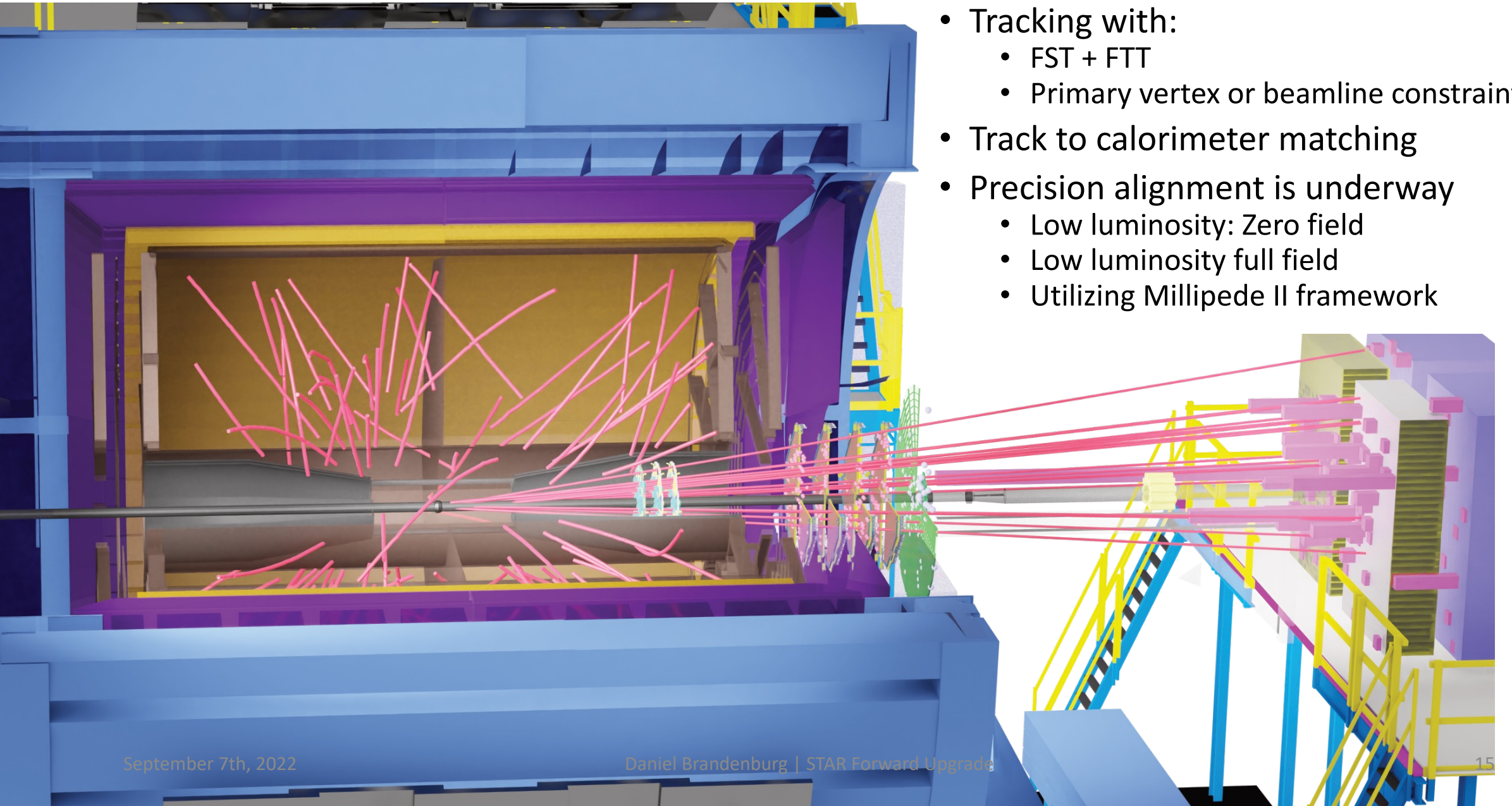
- Operation HV: 1500 V for standby and 3000 V for data taking
- Safety and gas mixing is automated through interlock logic
- Refill pentane, every three weeks by experts
- CO2 change every two months by experts
  - Backed up by reserve tank online—no run out
- FTT is commissioned and currently taking data at STAR run22



FTT event display in run22 p+p 510GeV

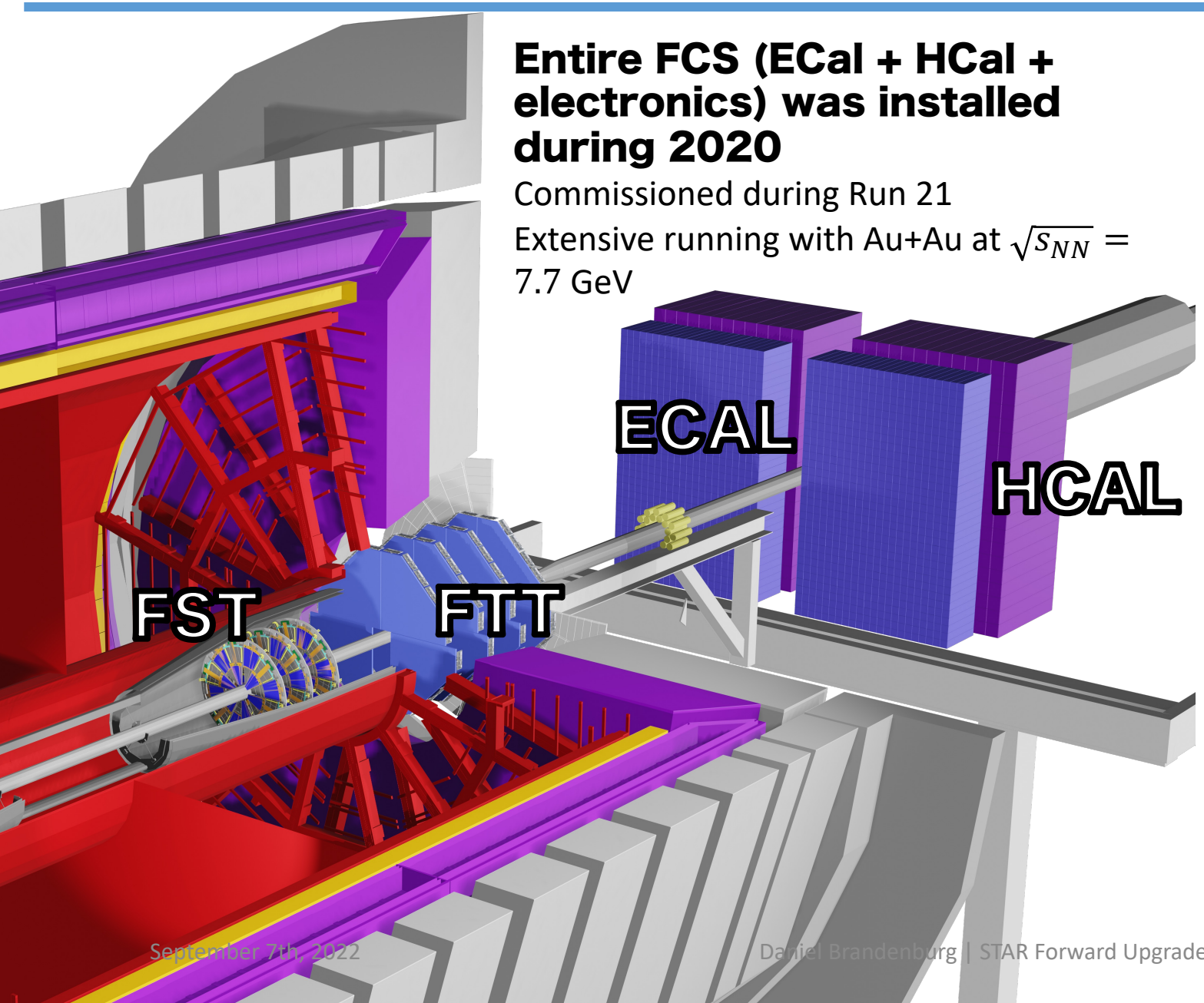


Forward Tracking Performance



- Tracking with:
  - FST + FTT
  - Primary vertex or beamline constraint
- Track to calorimeter matching
- Precision alignment is underway
  - Low luminosity: Zero field
  - Low luminosity full field
  - Utilizing Millipede II framework

The Forward Calorimeter System (FCS)



Entire FCS (ECal + HCal + electronics) was installed during 2020

Commissioned during Run 21

Extensive running with Au+Au at $\sqrt{s_{NN}} =$ 7.7 GeV

Location: 7 m from the IP on the "FMS platform"

Readout: SiPMs

- Used in Trigger
- Split in 2 movable halves inside and outside of ring
- Slightly projective

ECAL:

- reuse PHENIX PbSC calorimeter
  - 1496 channels: 5.52 x 5.52 x 33 cm3
  - 66 sampling cells with 1.5 mm Pb/4 mm Sc
  - 36 wavelength shifting fibers per cell
  - 18 X0; 0.85 λ
- replaced PMTs with SiPM readout

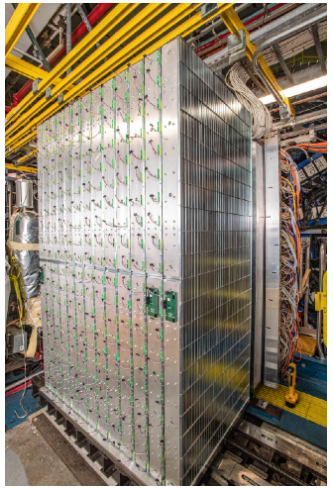
HCAL:

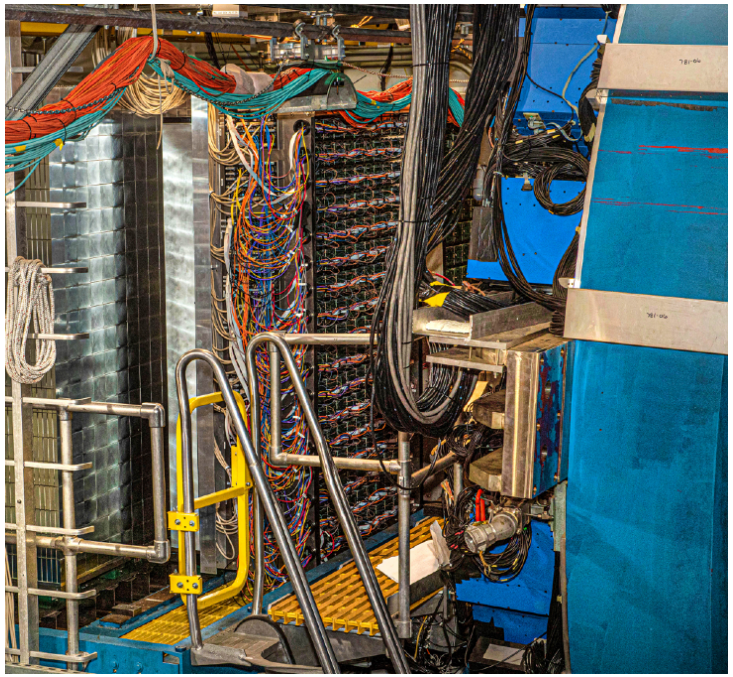
- Fe/Sc (20mm/3 mm) sandwich.
  - 520 readout channels: 10 x 10 x 84 cm3
  - ~ 4.5 λ
- Uses same SiPM readout as ECAL
- In close collaboration with EIC R&D

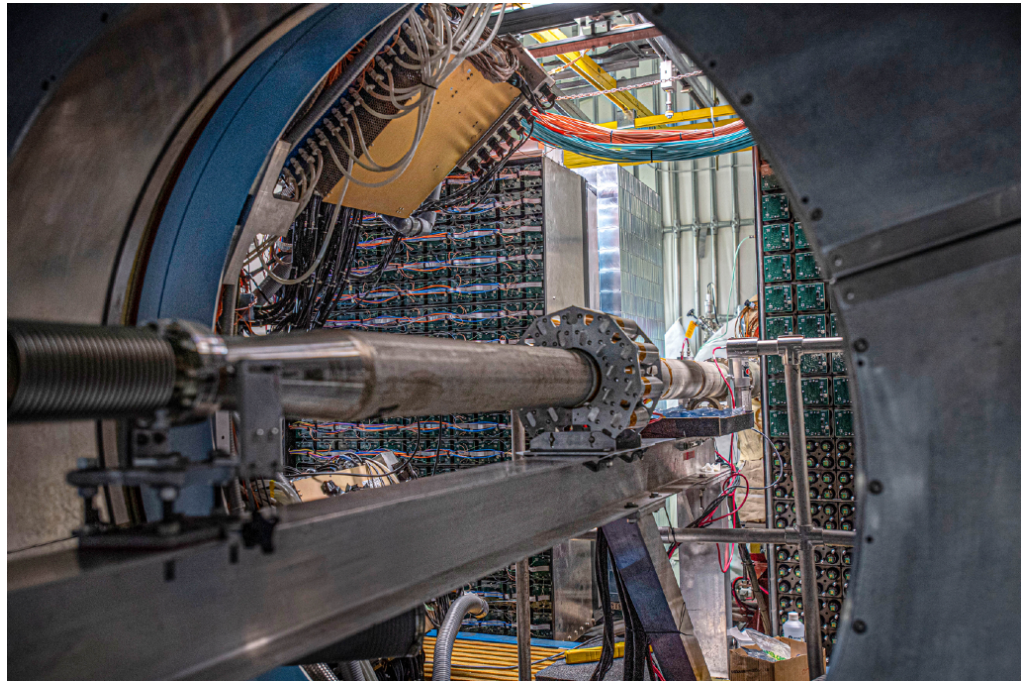
Preshower:

Use EPD => split signals, using FCS readout & trigger boards

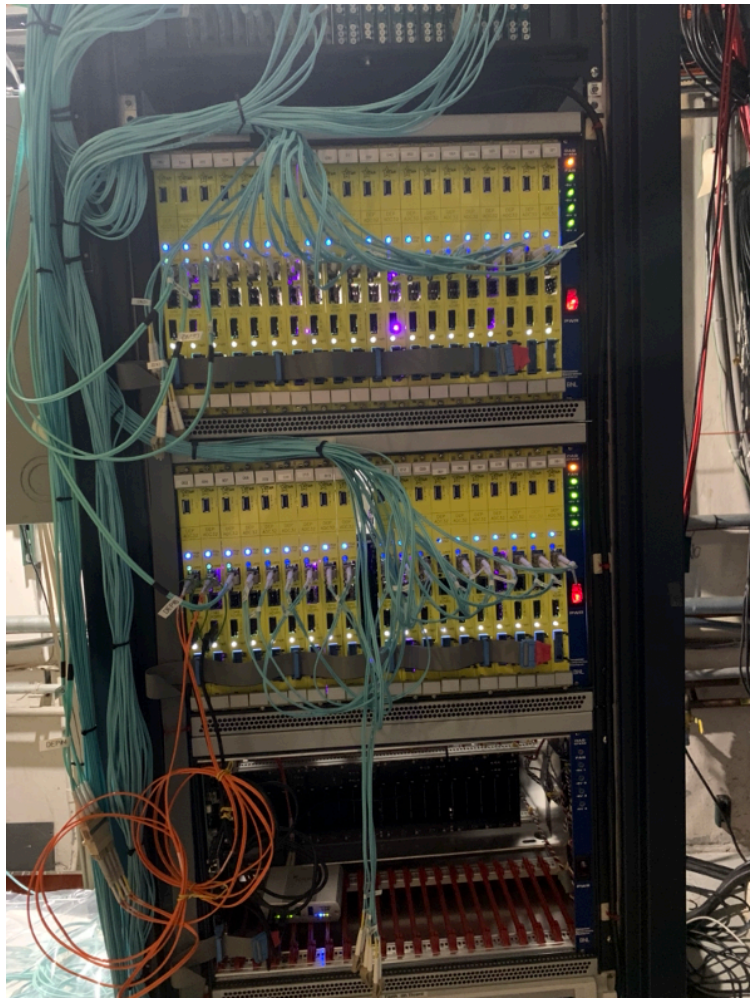
Forward Calorimeter Assembly





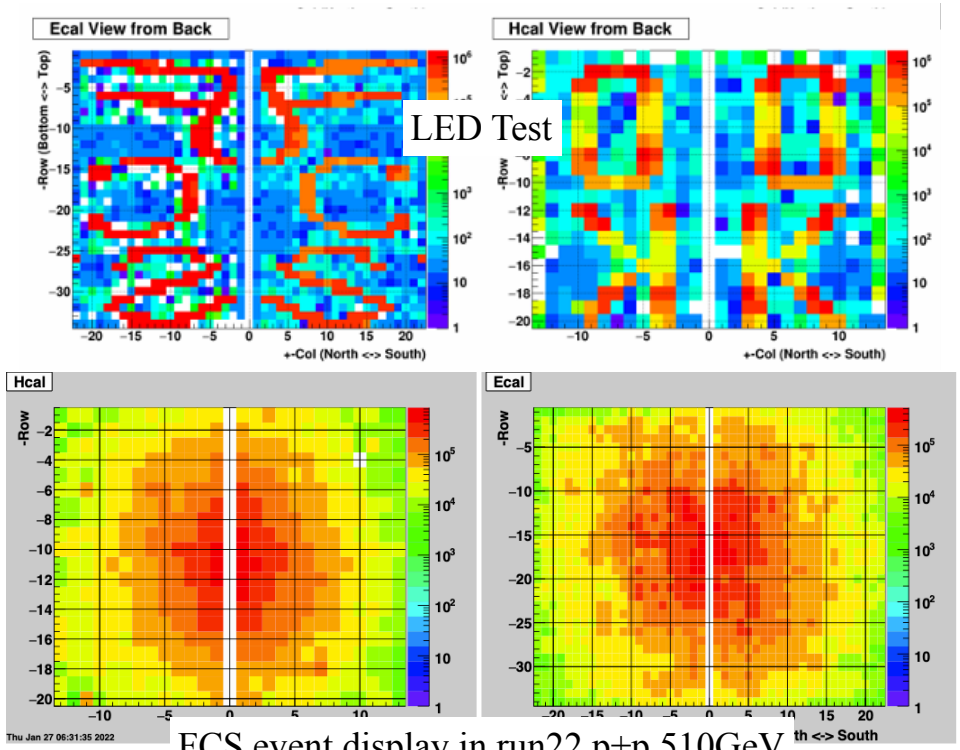


Forward Calorimeter Readout & Commissioning



Commissioning during Run 21

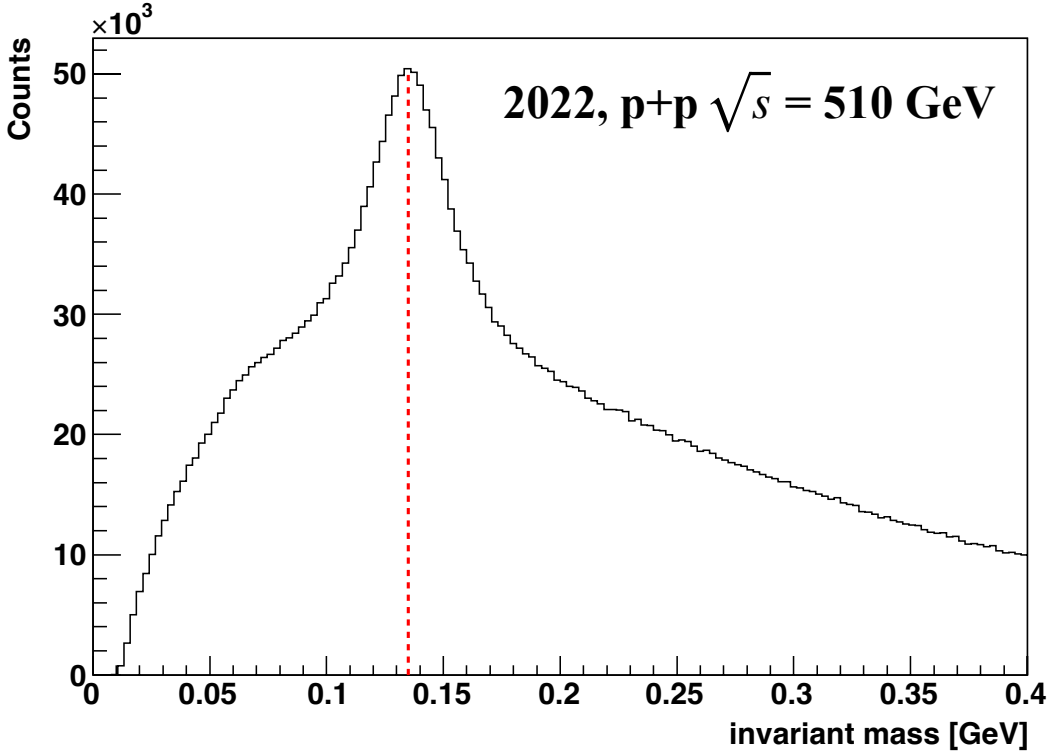
- Exercised the on-line data quality monitoring, and slow controls
- Off-line software and Monte Carlo also in place Trigger system fully commissioned
- System fully ready at Day-1 for Run 22 Day-1



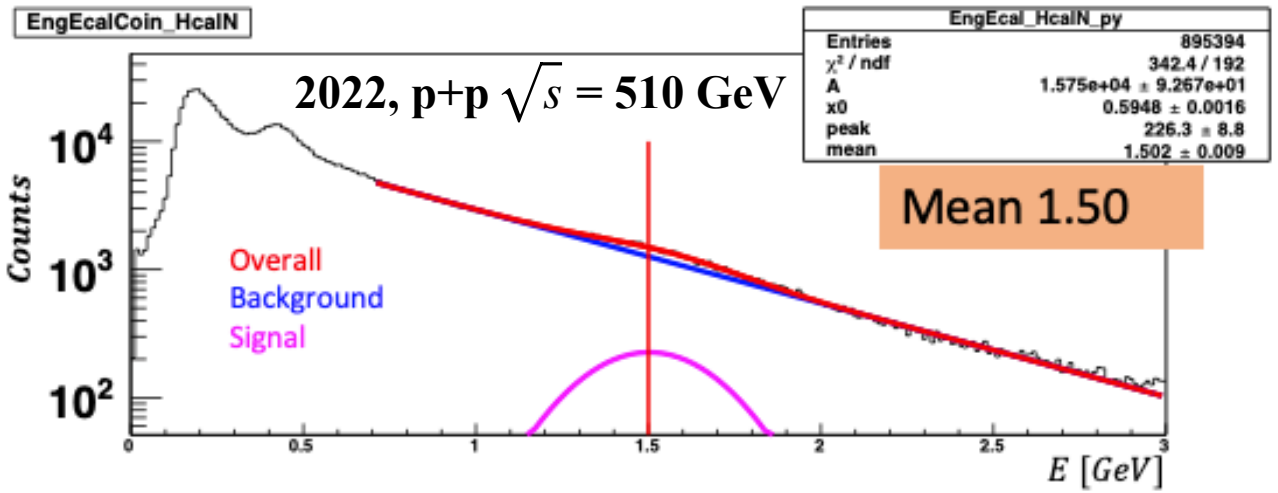
FCS event display in run22 p+p 510GeV

Forward Calorimeter Performance

π^0 reconstructed by Di-photon from ECal

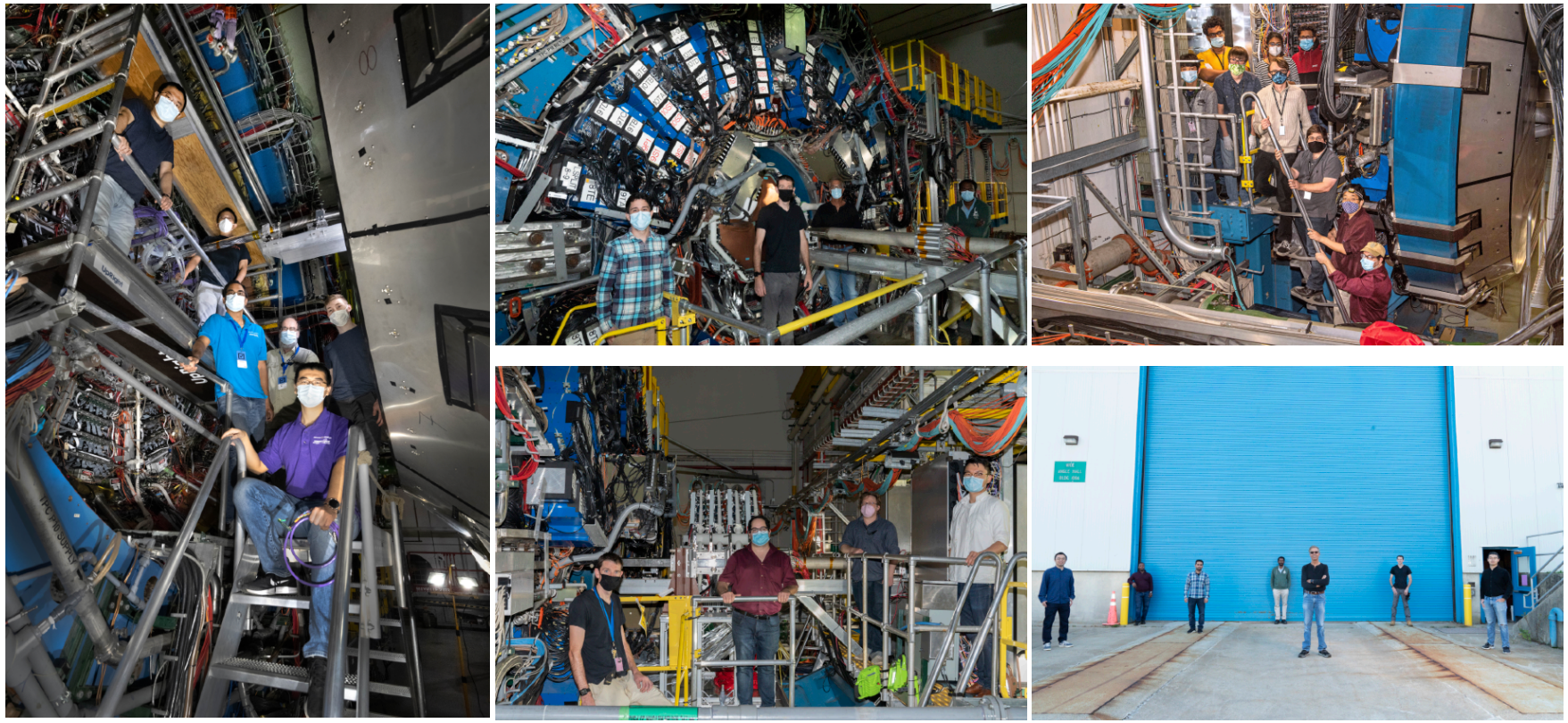


MIP peak from HCal (Matched with ECal MIP)



STAR Forward Upgrade : Summary

- Despite COVID, all of the Forward upgrade subsystems were installed on time
- All forward detectors were commissioned on time and were ready to take data in RHIC Run 22
- Thanks and Congratulations to those who made this happen!
- Looking forward to Au+Au (2023 & 2025) and p+p & p+Au (2024) with STAR forward upgrades



STAR Forward Upgrade Institutions

Dedicated personnel for each subsystem

sTGC
- Brookhaven National Laboratory
- Shandong University
- Tsinghua University

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

ECal
- Kentucky
- Valparaiso University
- Abilene Christian University

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

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 the STAR collaboration, which stands enthusiastically behind the upgrade

Thanks for your attention!