The STAR Forward Detector System Upgrade Status

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Supported in part by:
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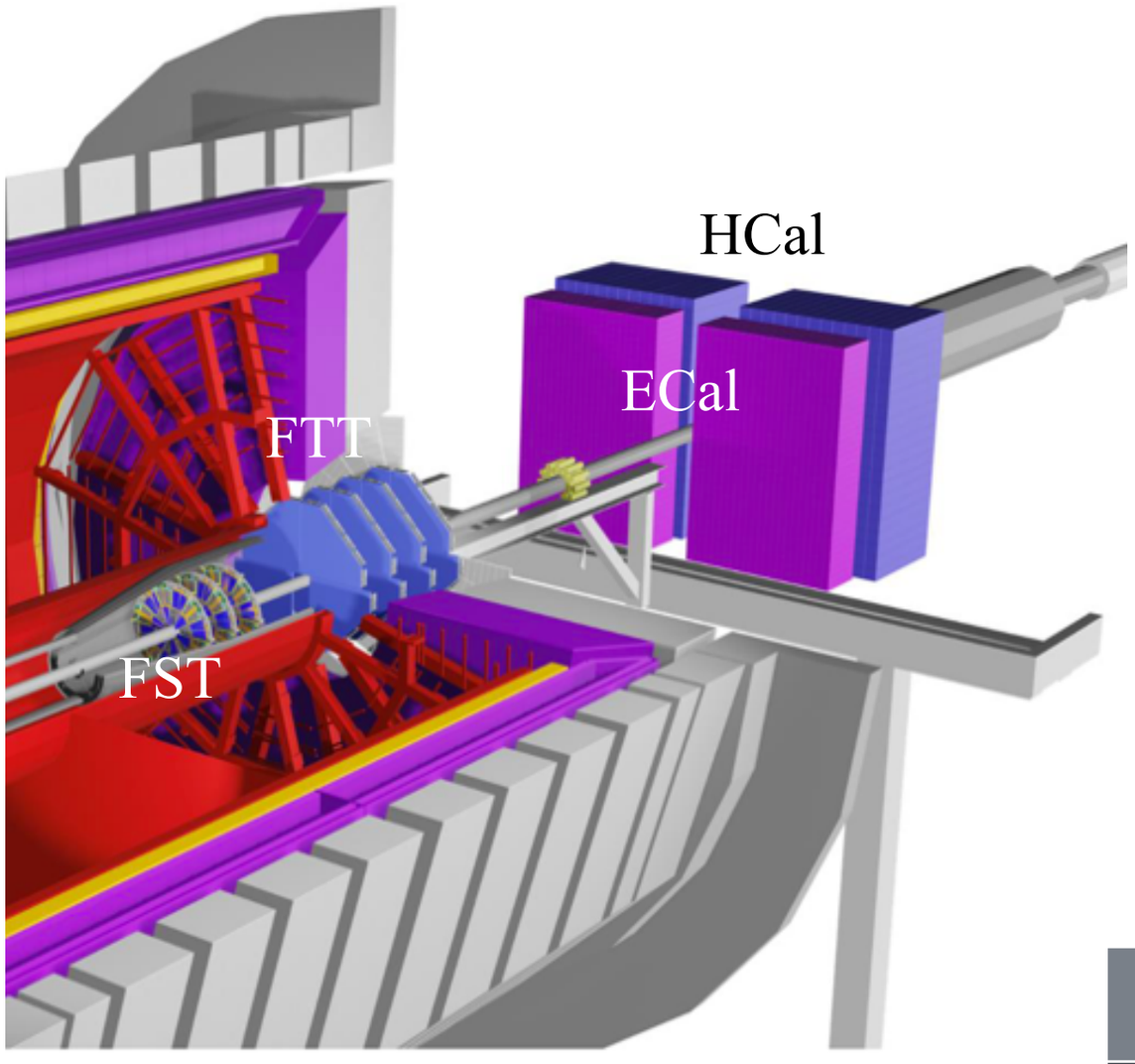
STAR Forward Upgrade: Detectors



Combines:

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 from Physics:

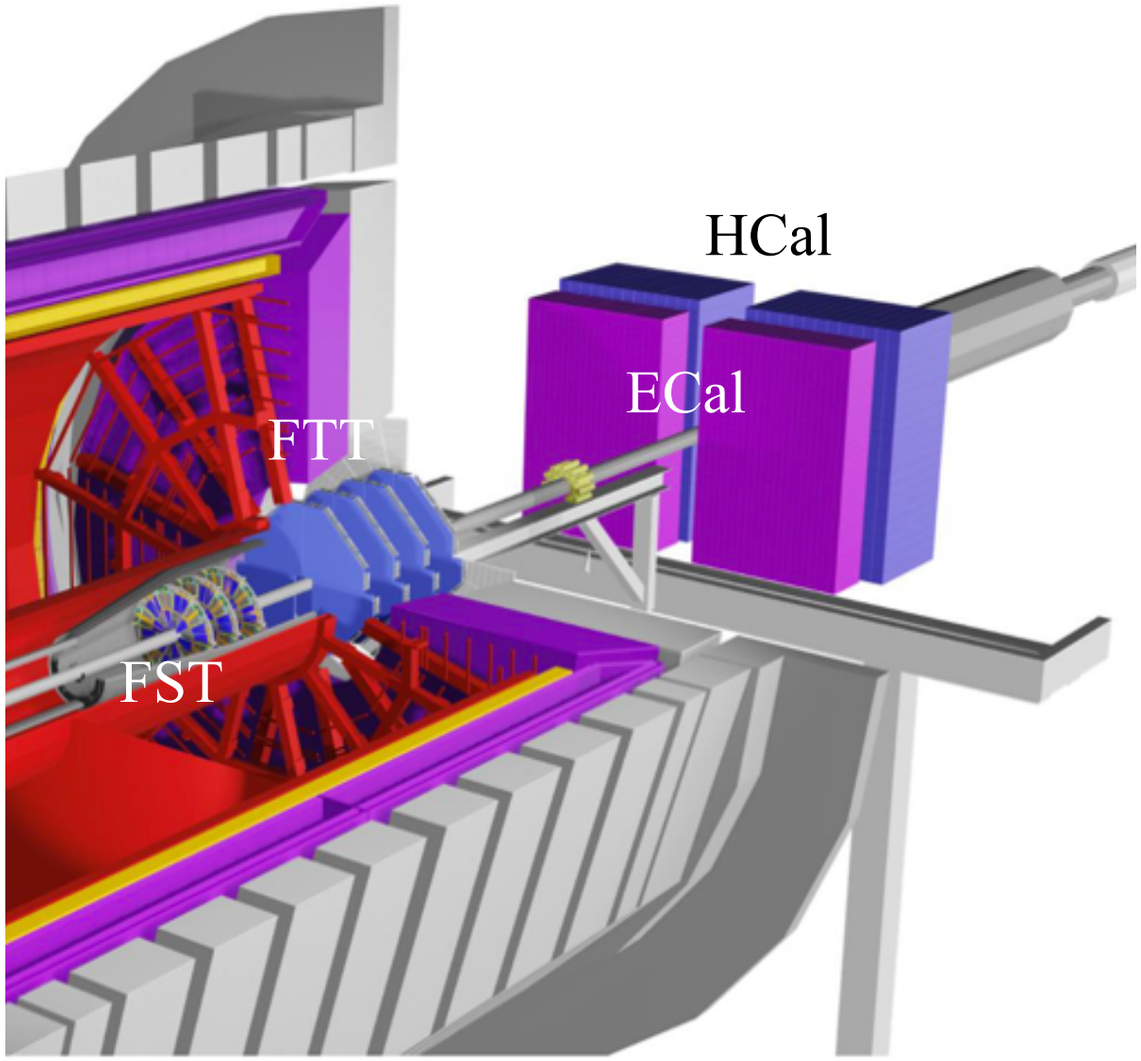
- Good e/h separation
- Photon, π^0 identification

STAR forward upgrade: $2.5 < \eta < 4$

- Locate at STAR west side
- Rapidity coverage similar to the EIC hadron endcap

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	$\delta p_T/p_T \sim 20-30\,\%$ $for\ 0.2 < p_T < 2 GeV/c$

STAR Forward Upgrade: Physics Program



STAR forward upgrade: $2.5 < \eta < 4$

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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
- Test of Saturation predictions through di-hadrons, γ-Jets …

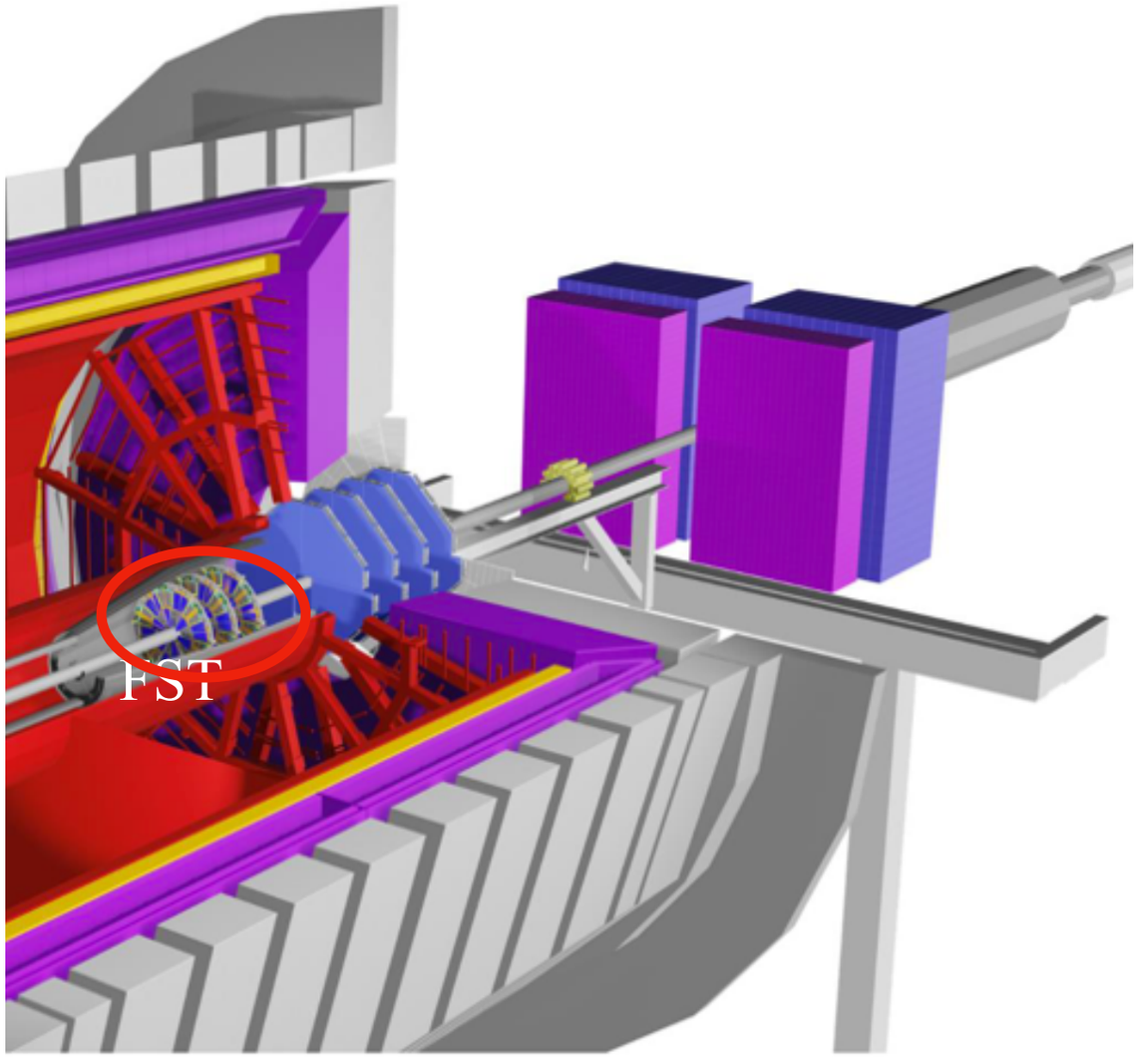
Hot QCD

- 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: strong rapidity dependence …

Observables:

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

Forward Silicon Tracker



STAR forward upgrade: $2.5 < \eta < 4$

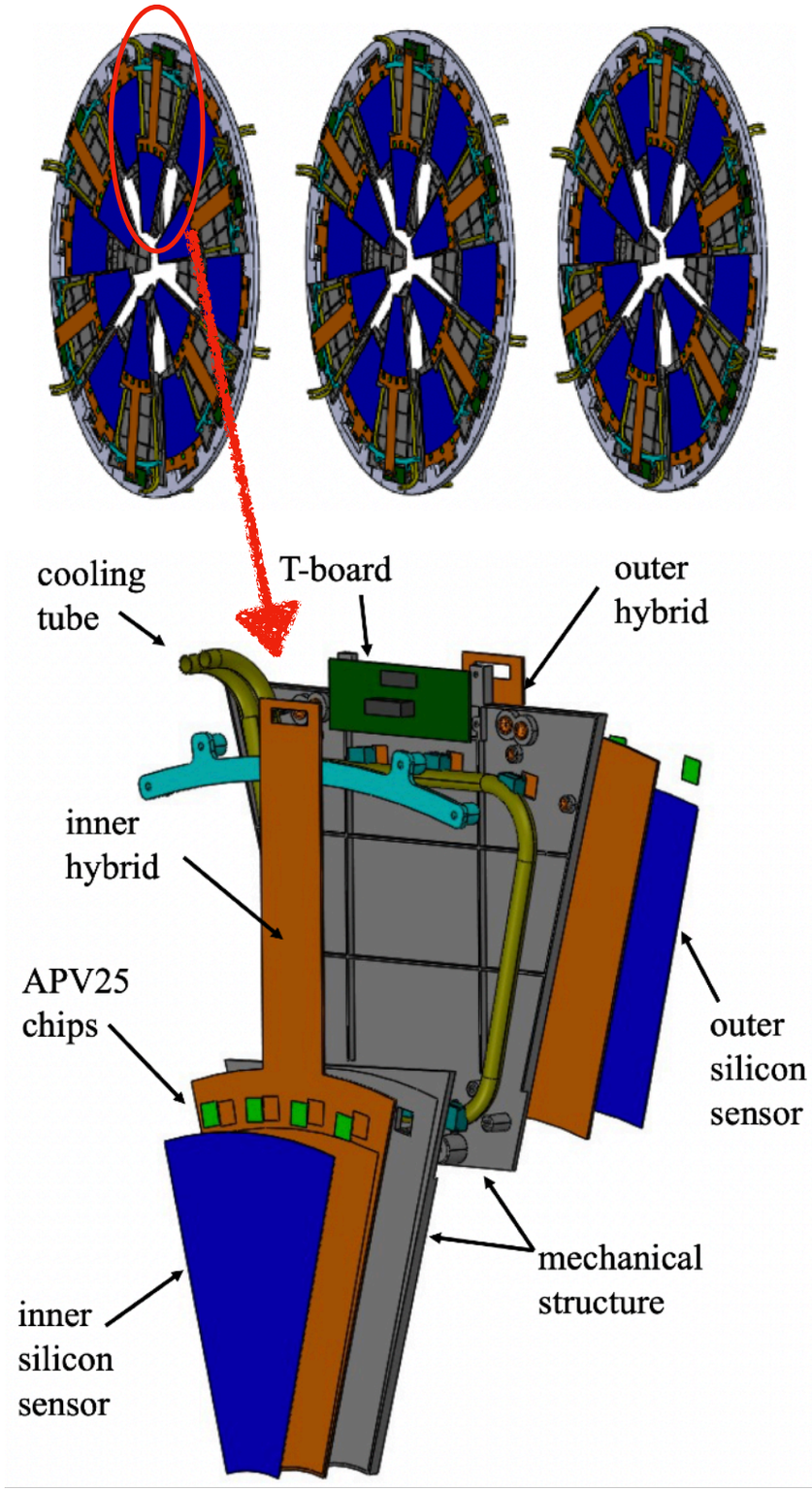
- faces blue RHIC beam
- rapidity coverage similar to the EIC hadron endcap

3 Silicon disks: at 152, 165, and 179 cm from IP

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

- Locate inside STAR TPC cone
- Single-sided double-metal mini-strip sensors
  - Granularity: fine in ϕ and coarse in R
  - Si from Hamamatsu
- Frontend chips: APV25
- Material budget: ~1% per disk
- Reuse
  - IST DAQ system
  - IST cooling system

FST Module Design



Each module splits into two regions

- Inner-radius region: 5<R<16.5 cm
  - 1 Kapton flexible hybrid
  - 1 Si sensor: 128 × 4 (ϕ×R) strips
  - 4 APV chips
- Outer-radius region: 16.5<R<28 cm
  - 1 Kapton flexible hybrid
  - 2 Si sensors: 128 × 4 (ϕ×R) strips
  - 4 APV chips

Mechanical structure is made of

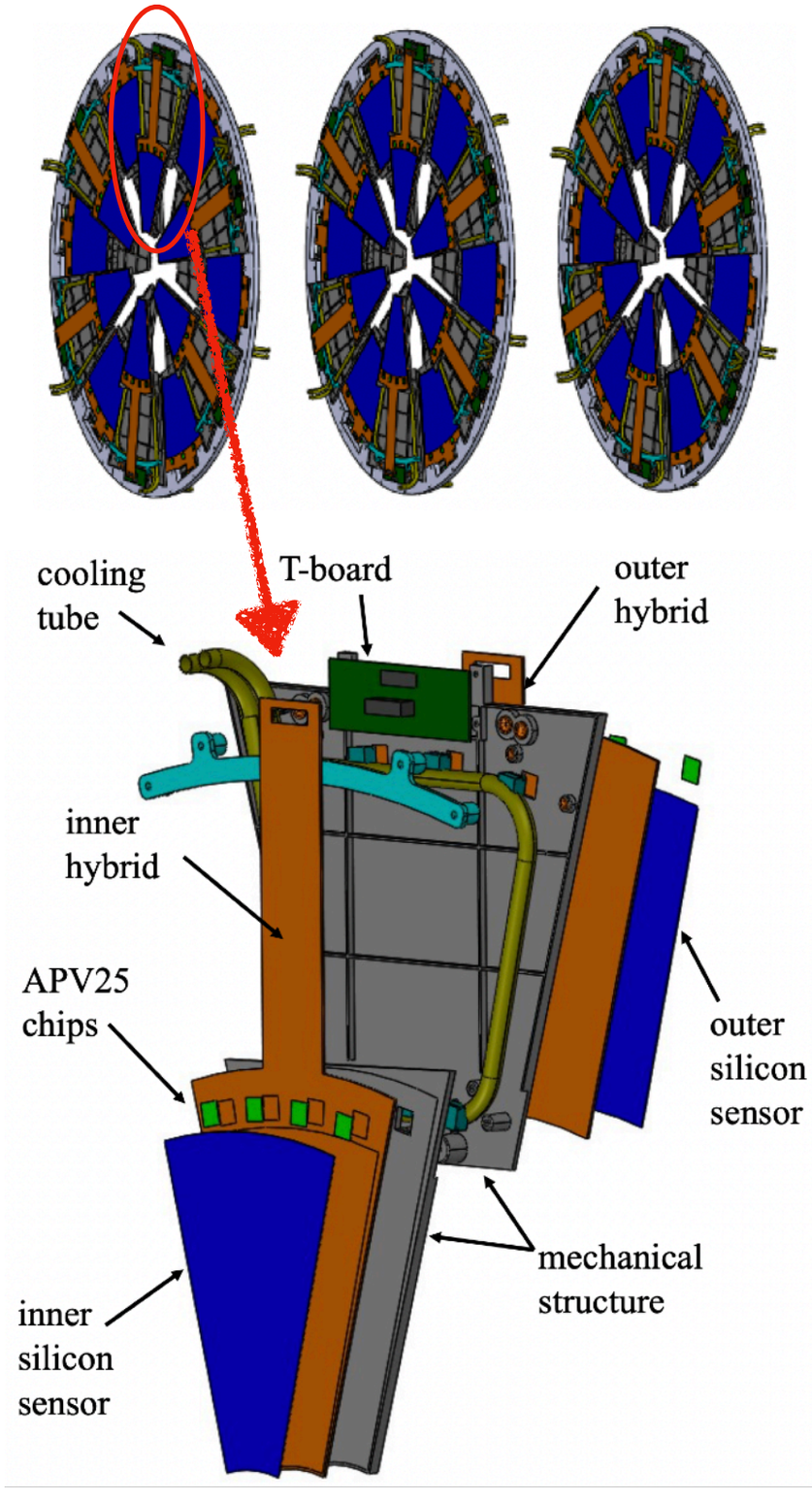
- PEEK (main structure, tube holder)
- Stainless steel (cooling tube)
- Aluminum (heat sinks)

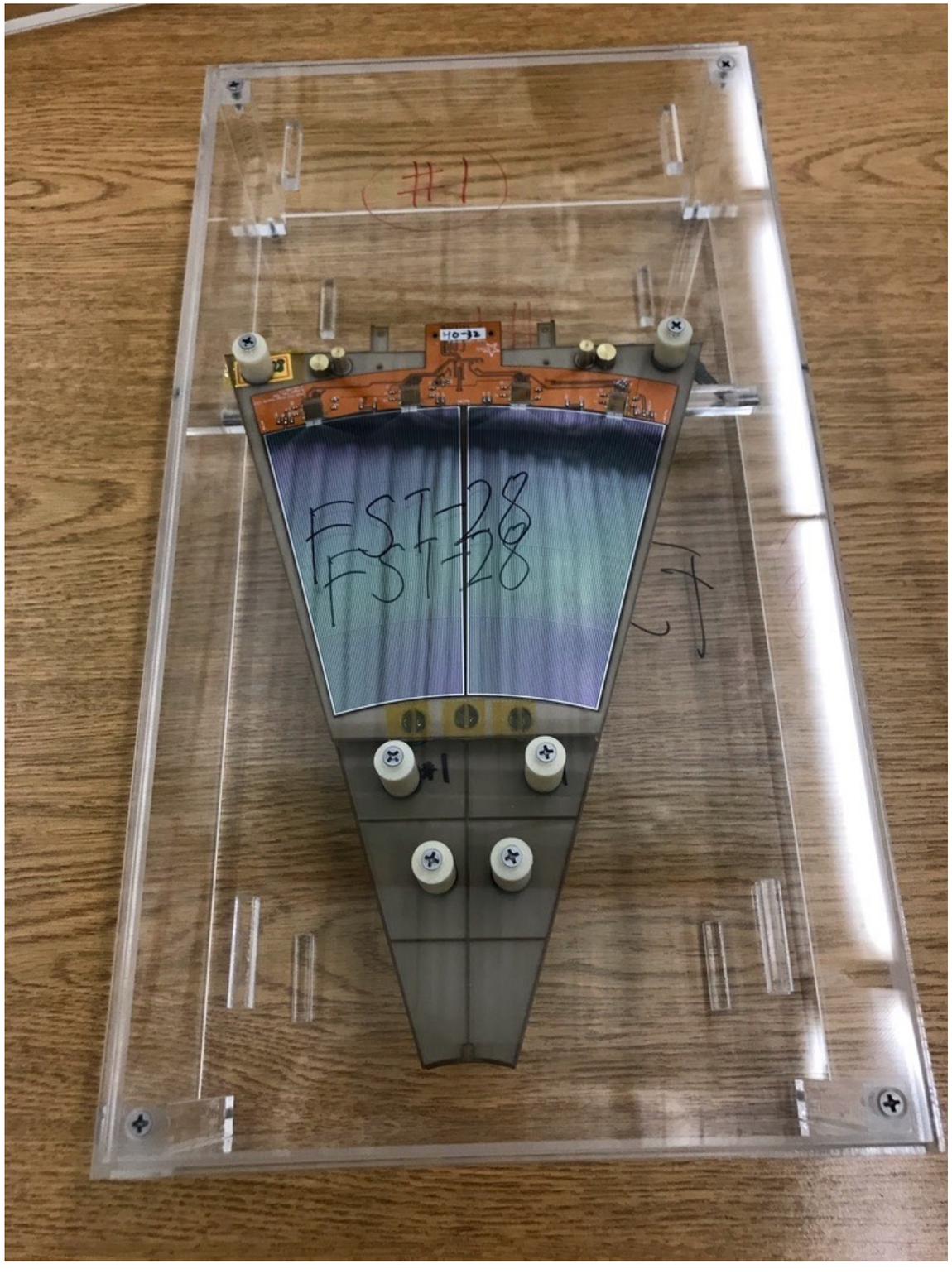
Module assembly is done in two steps

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

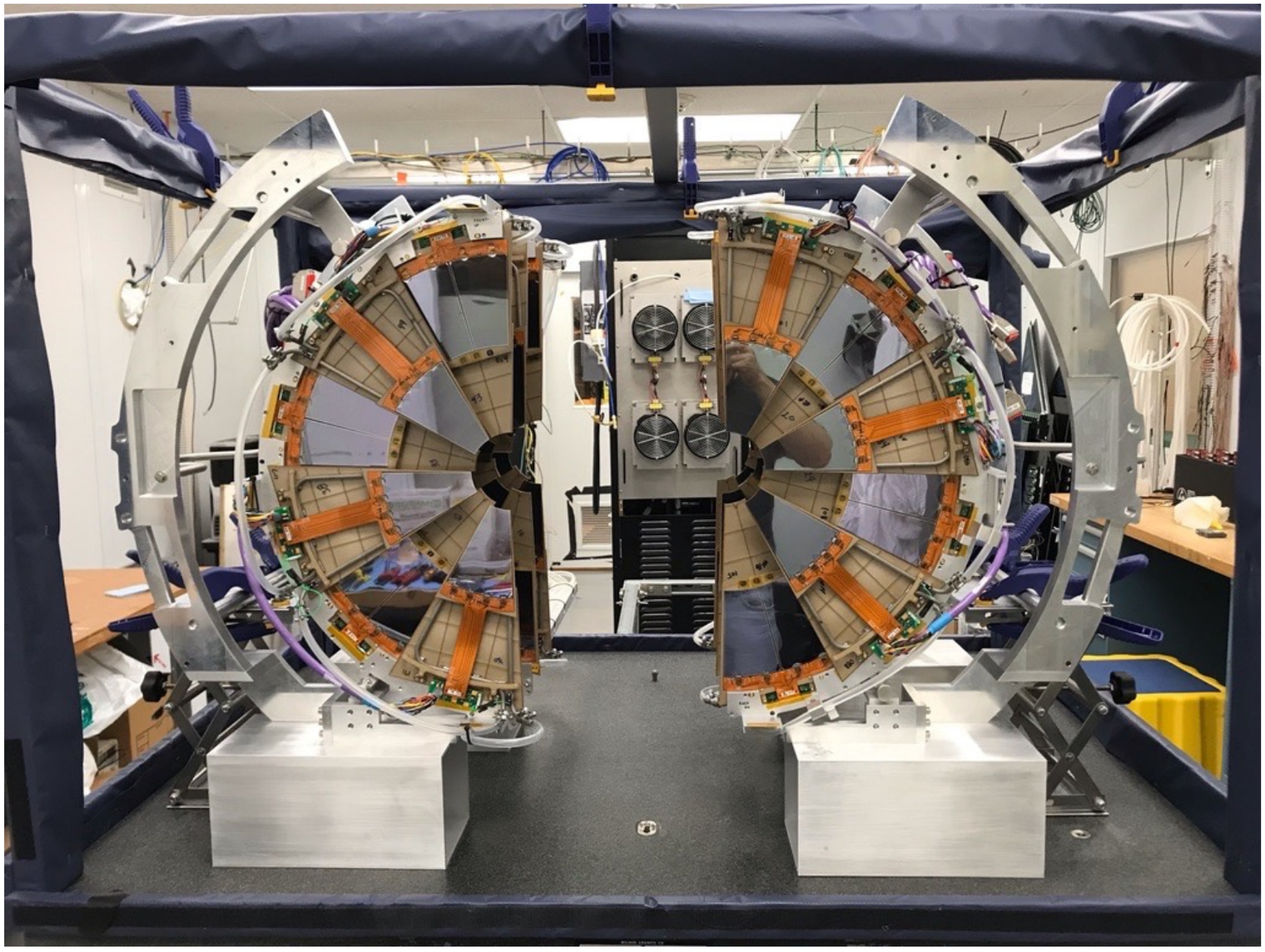
material budget: ~1% X_0 per disk

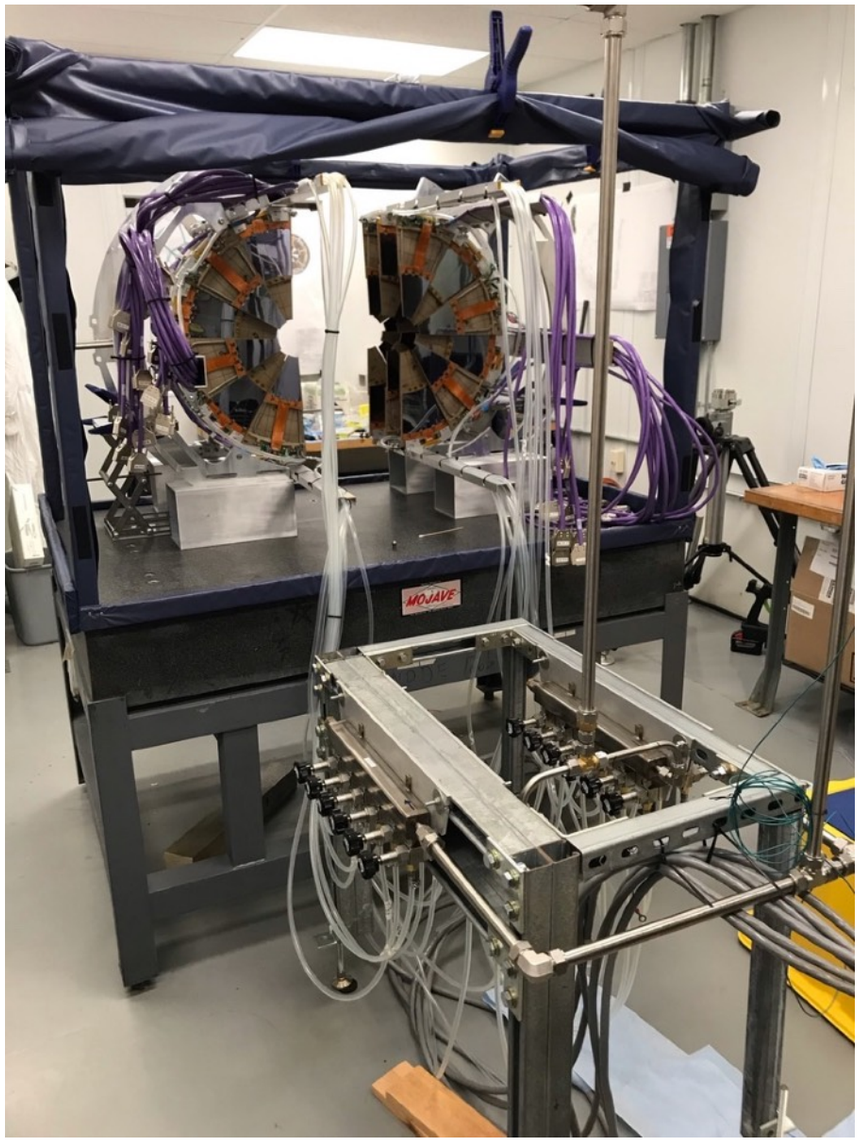
FST Module Design





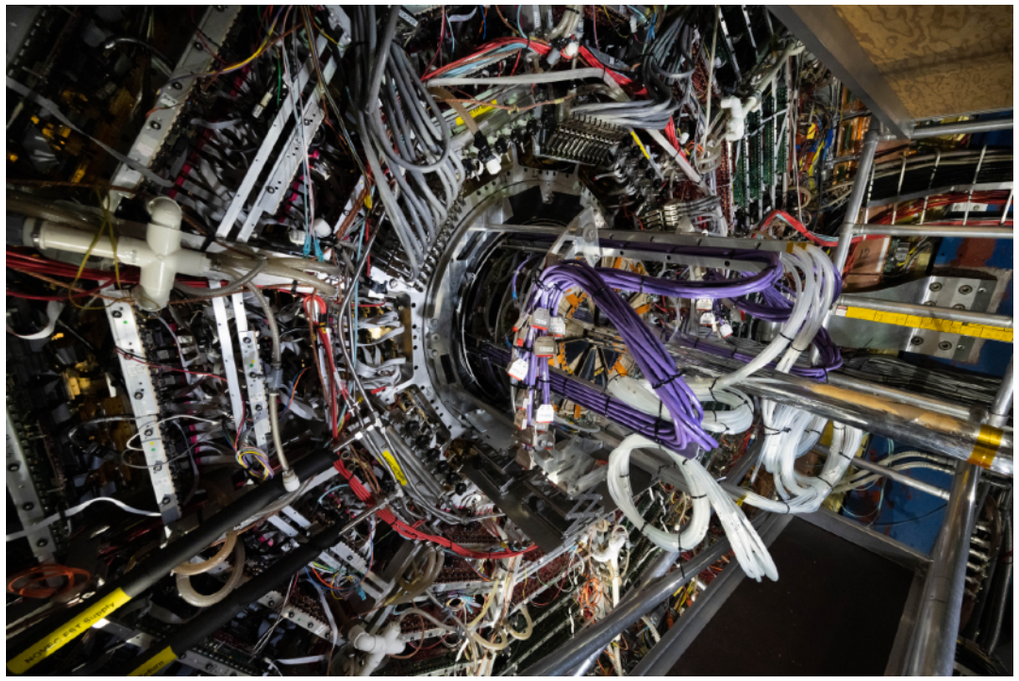
FST pre-Installation and Test

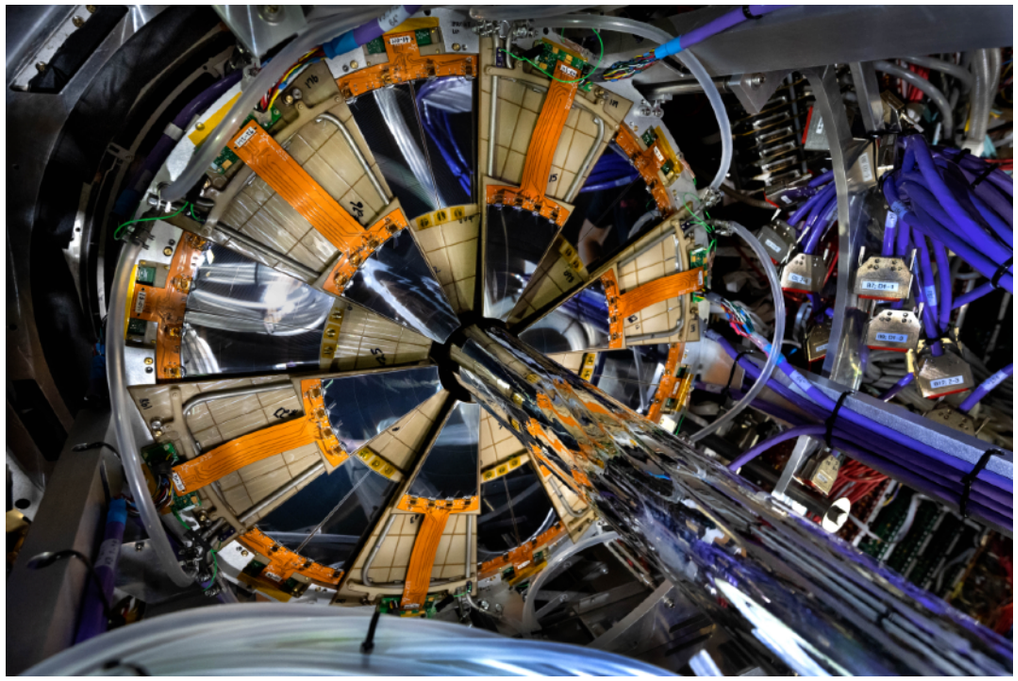


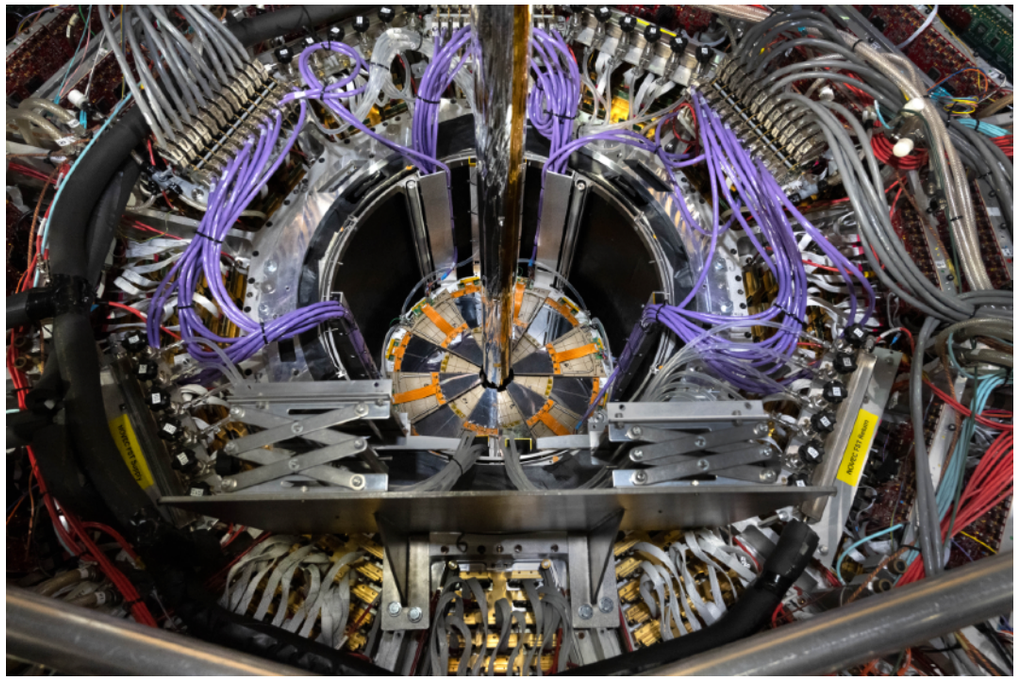


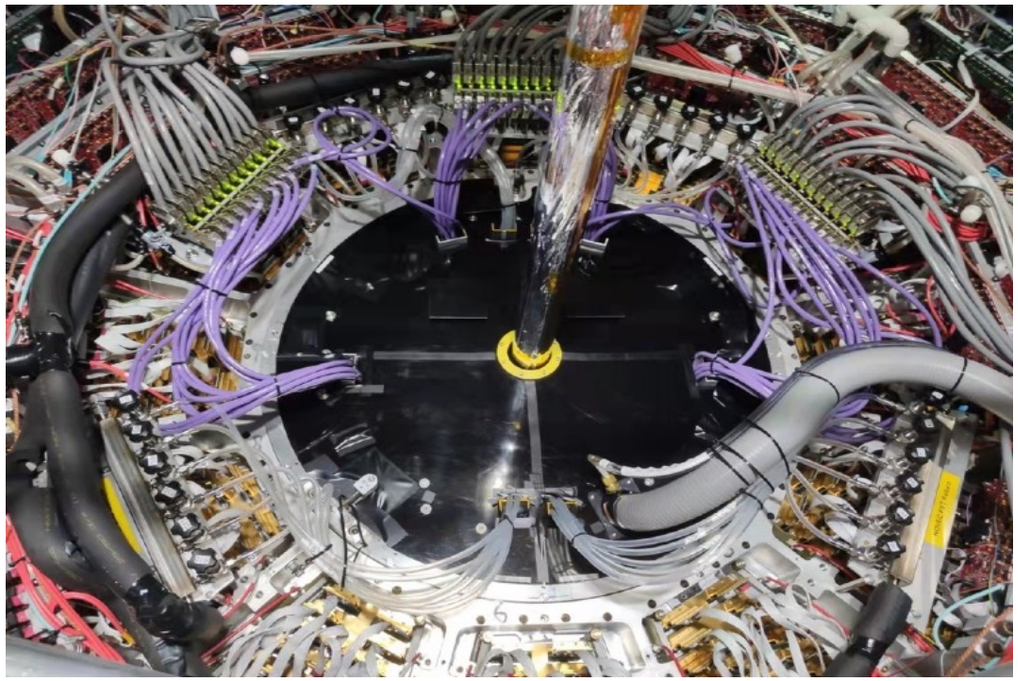
- FST modules installed into the support structure in the clean room (April - July 2021).
- Survey was done after each half plane completed (mid-plane has surveyed both sides).
- Readout and cooling test in the clean room for all 36 installed modules.

FST Installation



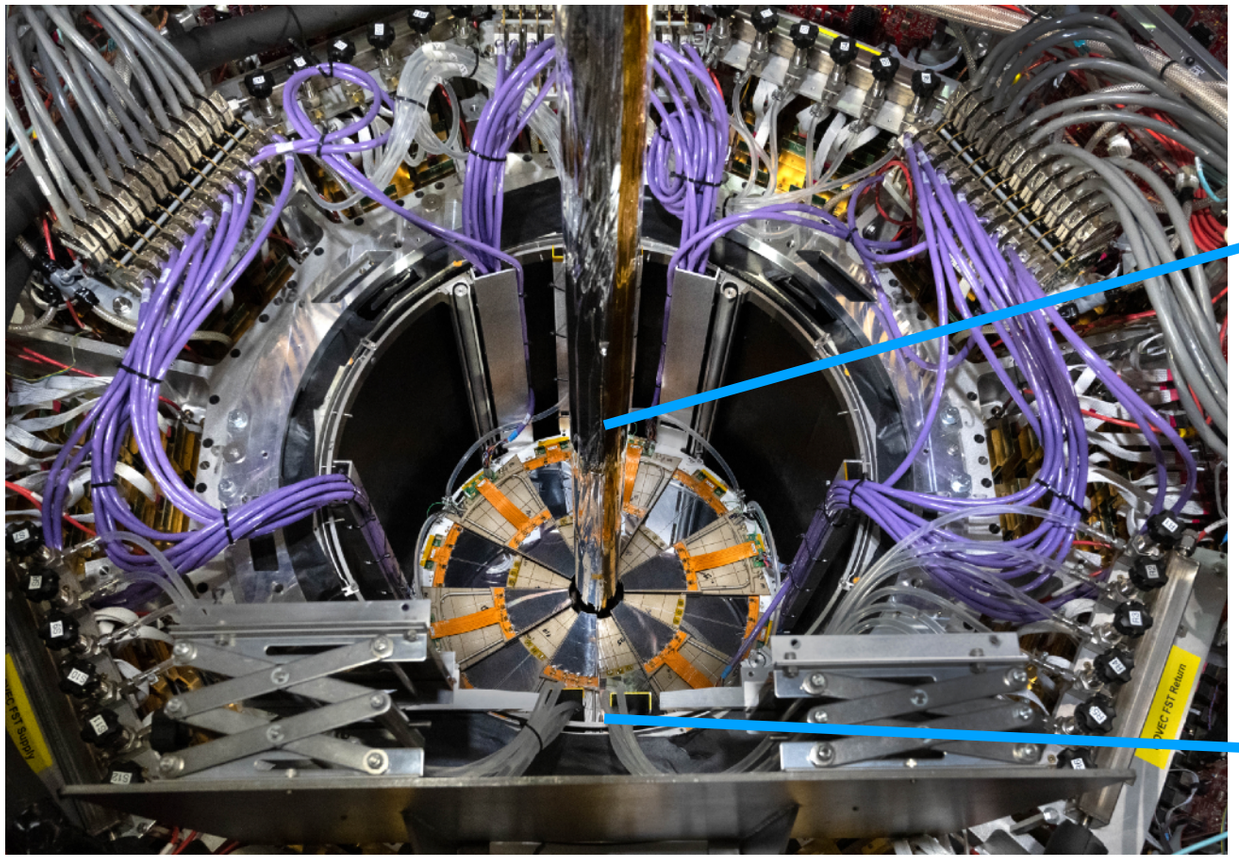




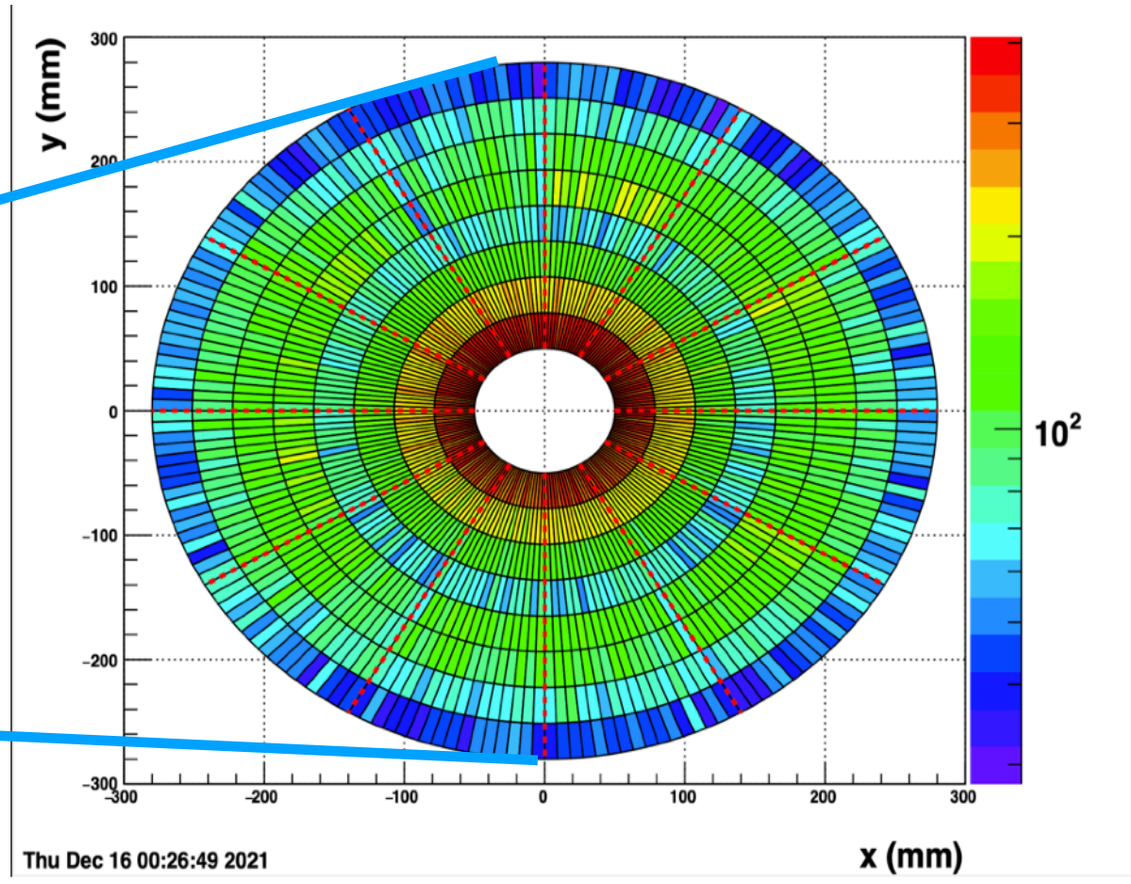


FST Installation completed on 08/13/2021

FST Operation

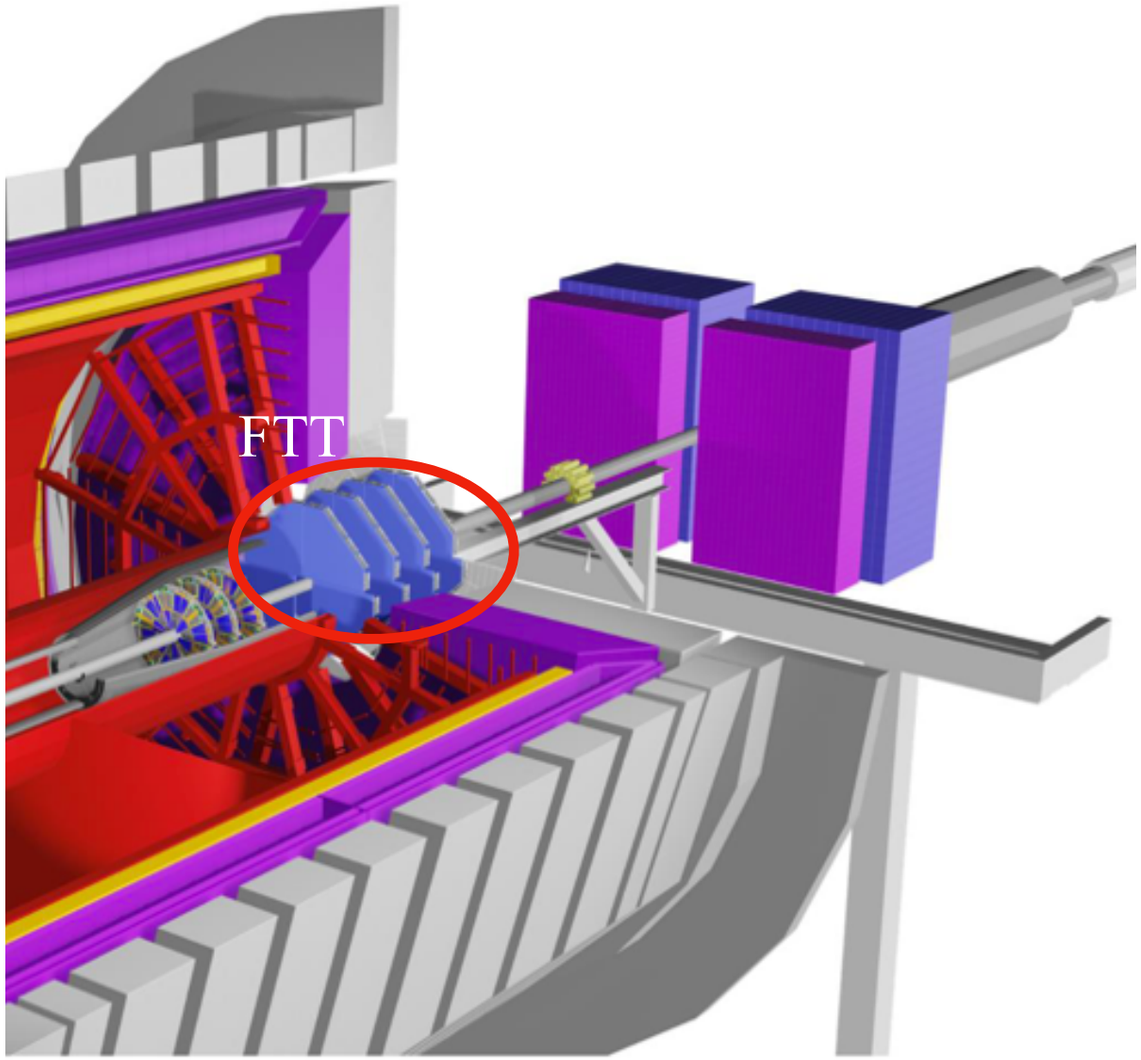


FST event display in run22 p+p 510GeV



- Operation HV: 140V for inner sensor and 160V for outer sensors
- FST is commissioned and currently taking data in STAR run 22

Forward sTGC Tracker



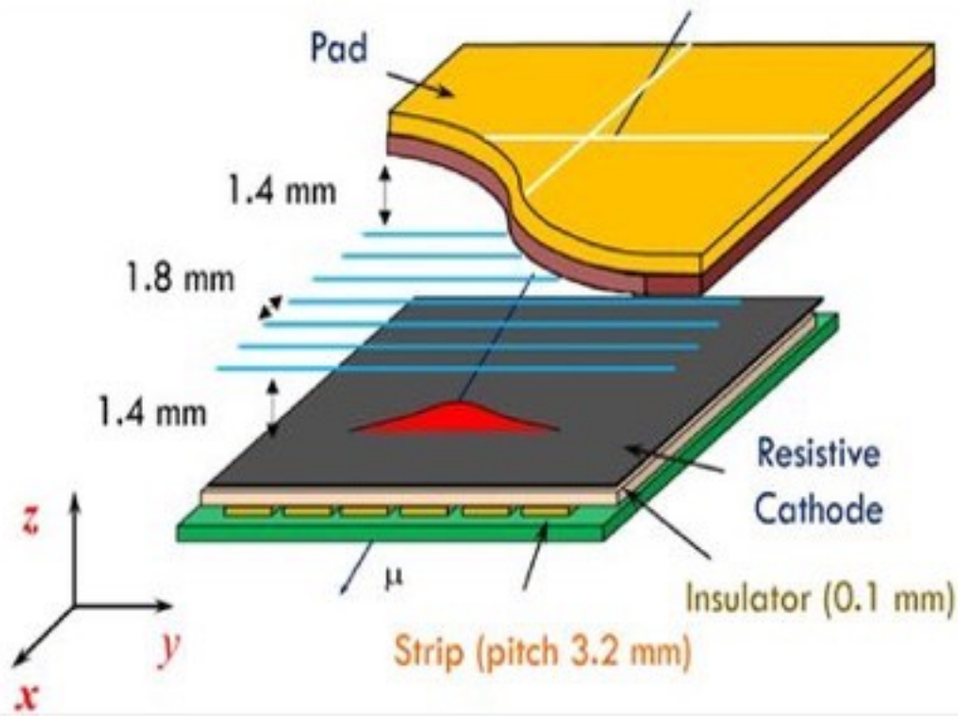
4 sTGC disks: at 307, 325, 343 and 361 cm from IP

- Locate inside STAR magnet pole tip opening
  - Inhomogeneous magnetic field
- 4 quadrants double sided sTGC => 1 layer
  - Diagonal strips to break ambiguities in the sTGC
- Position resolution: ~100μm
- Material budget: ~0.5% per layer,
- Readout: based on VMM-chips
  => Following ATLAS design

STAR forward upgrade: $2.5 < \eta < 4$

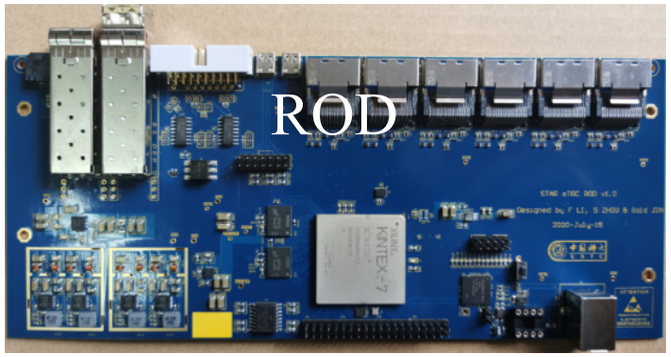
- faces blue RHIC beam
- rapidity coverage similar to the EIC hadron endcap

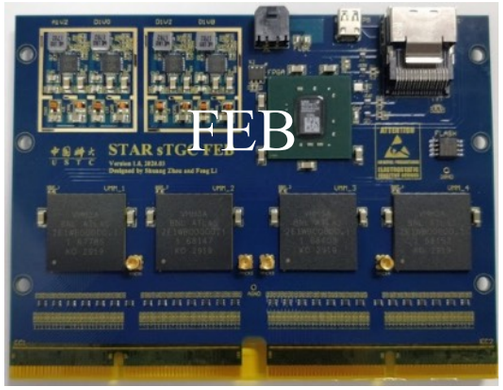
sTGC Design

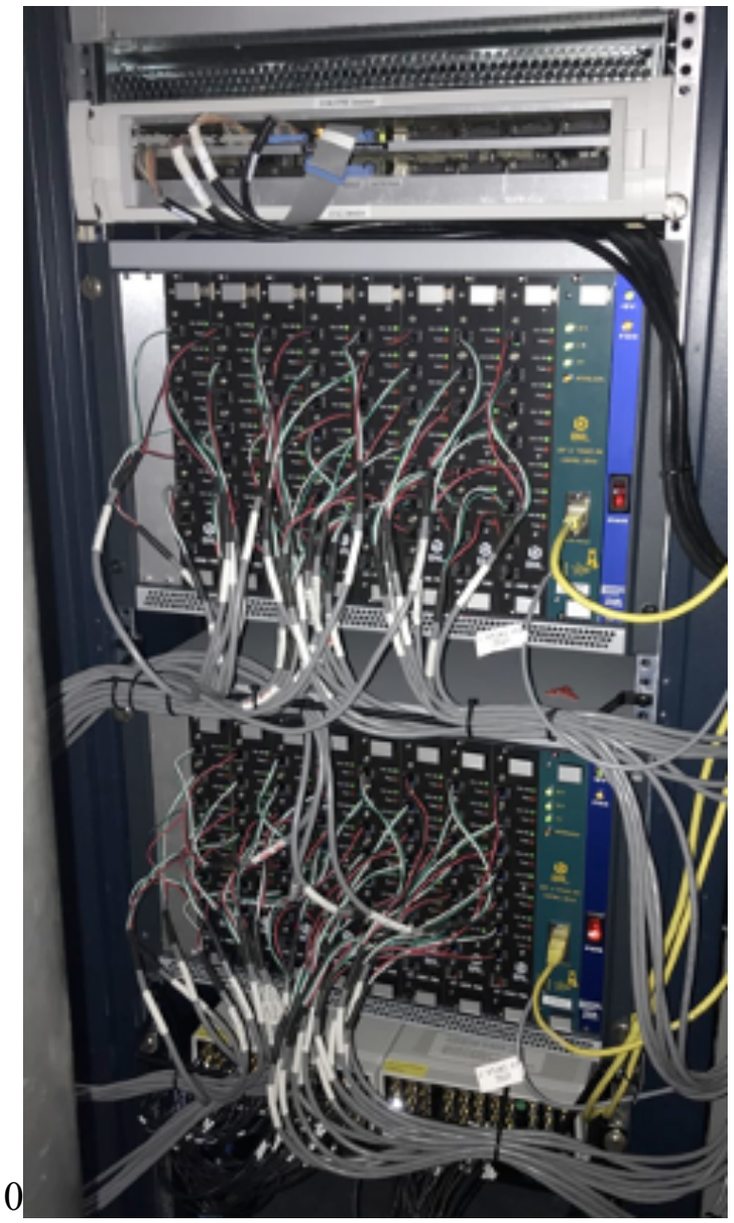


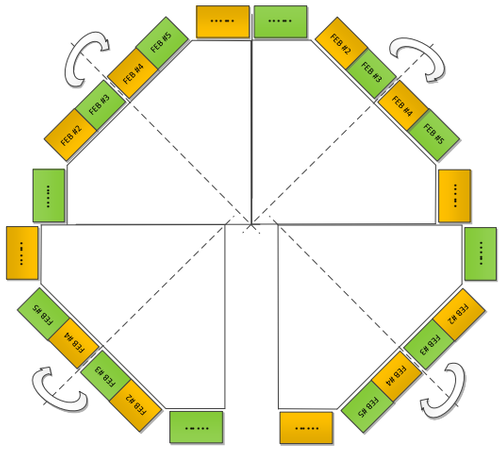
- Provides tracking and position resolution less than 100 μm, at high luminosity and background
- Anode (HV): 50 μm gold-plated tungsten wires held at a potential of ~2900 V
  - TPC 20 μm wires
- Working gas: n-Pentane+CO_2 = 45:55% by volume
- Cathode(Ground): graphite-epoxy mixture with a typical surface resistivity of 100 to 200 kΩ sprayed on G-10
- Readout: Small copper strips, perpendicular to anode wires, behind the cathode

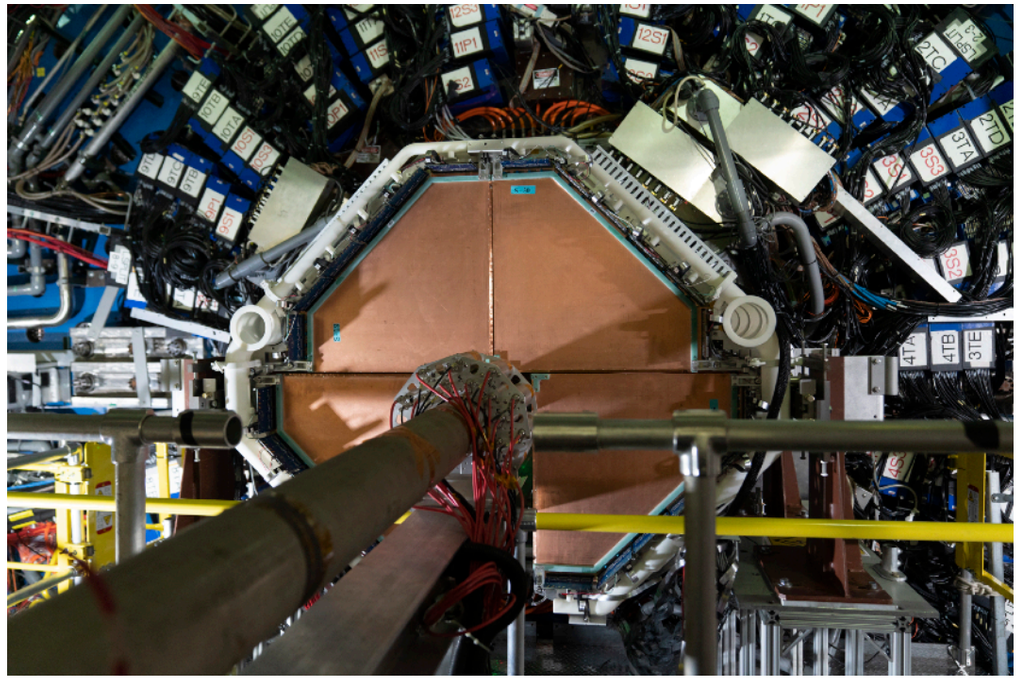
FTT Electronics Design











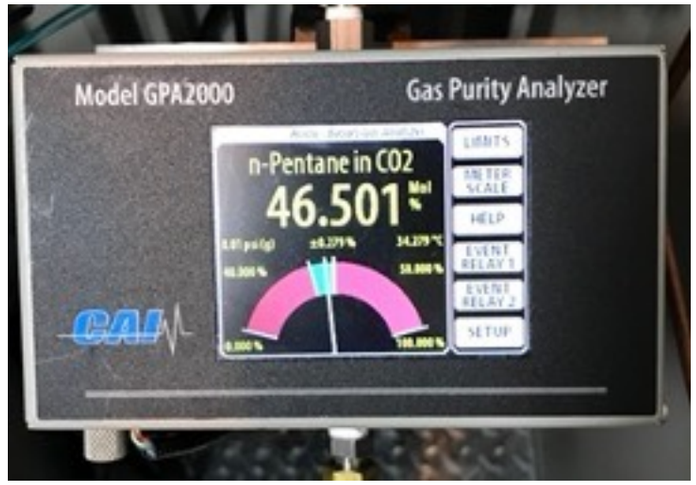
- Read Out Driver modules are designed based on Standard VME 6U Crate (with DC power supply)
- 16 ROD module => one for every 6 FEBs & 1 quadrant
- Front-End Boards are designed based on VMM-3A chips. 4 VMM-3A chips/board, 212 channels
- 96 FEBs => 24 FEBs for each layer

FTT Gas and Safety System

Gas Cabinet

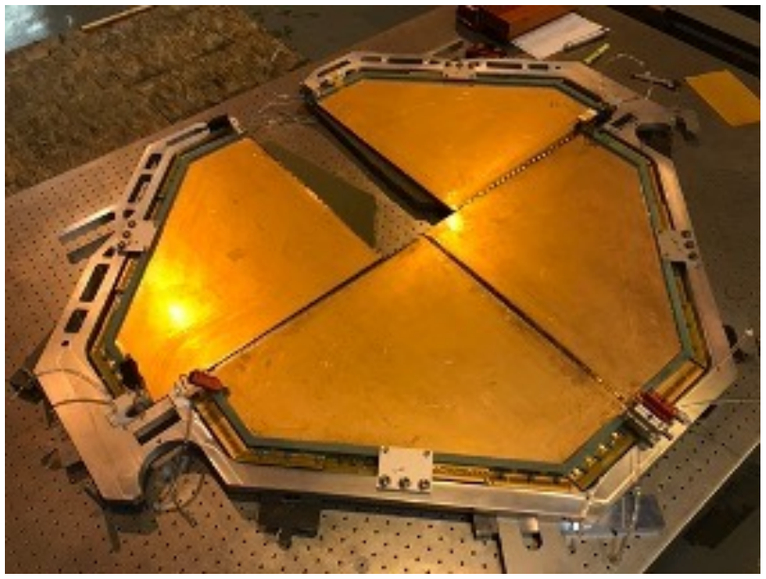
Gas Distribution Panel

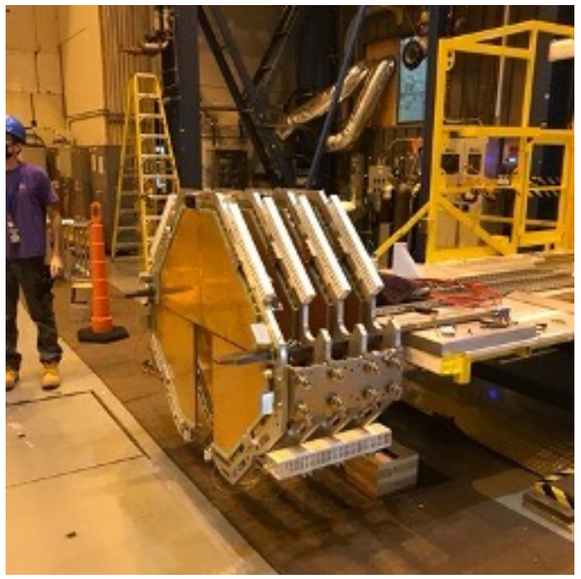
Gas Purity Analyzer

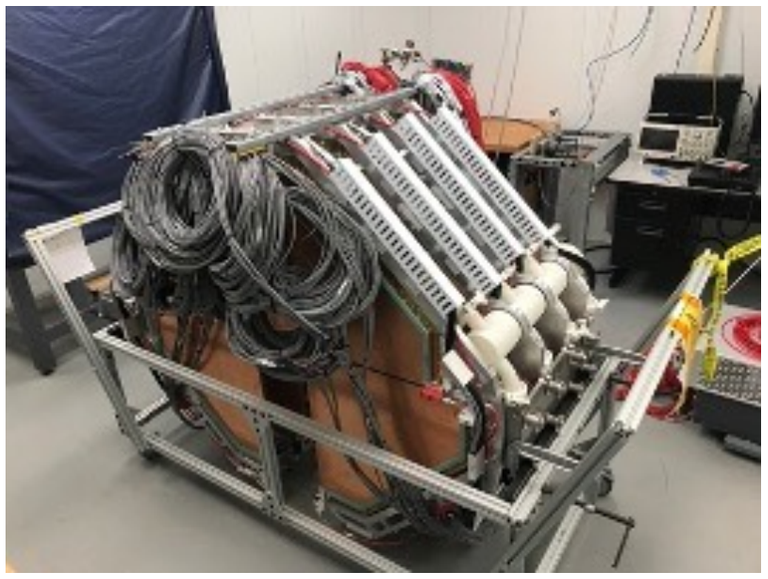


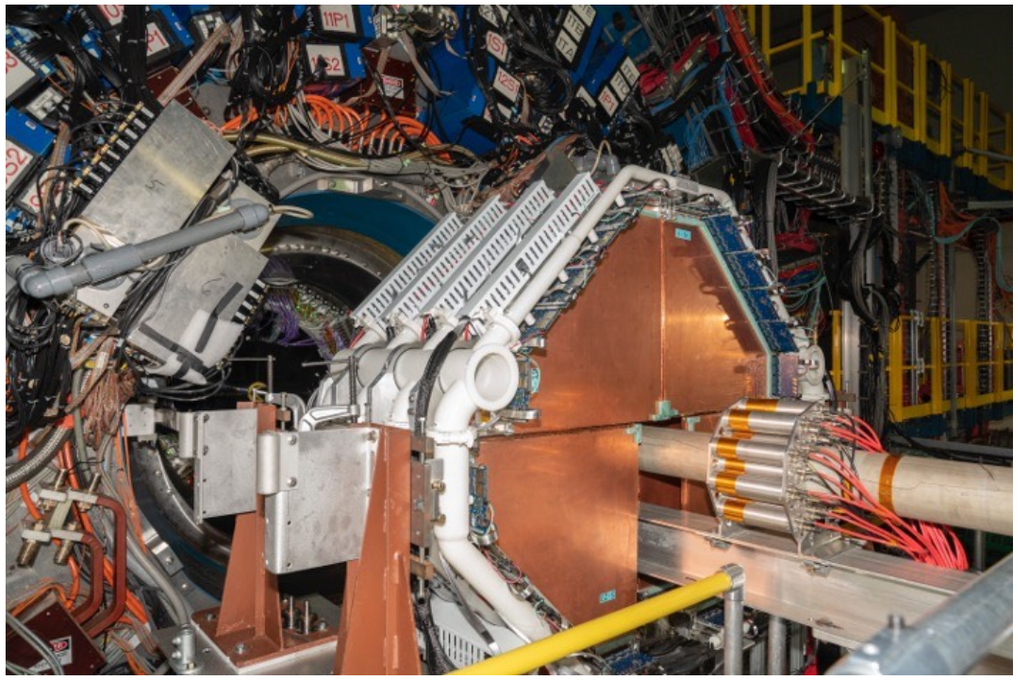
- FTT use a mixture of CO_2 and n-pentane
  - n-pentane isomer formula C5H12
  - Extreme care needed for the highly flammable n-pentane!
  - Flash point –49 ^{0}C; explosive limits 1.5 – 7.8%
  - Boiling point of 36.1 ^{0}C further complicates things
- Has operated extremely well through major power failures and big storms

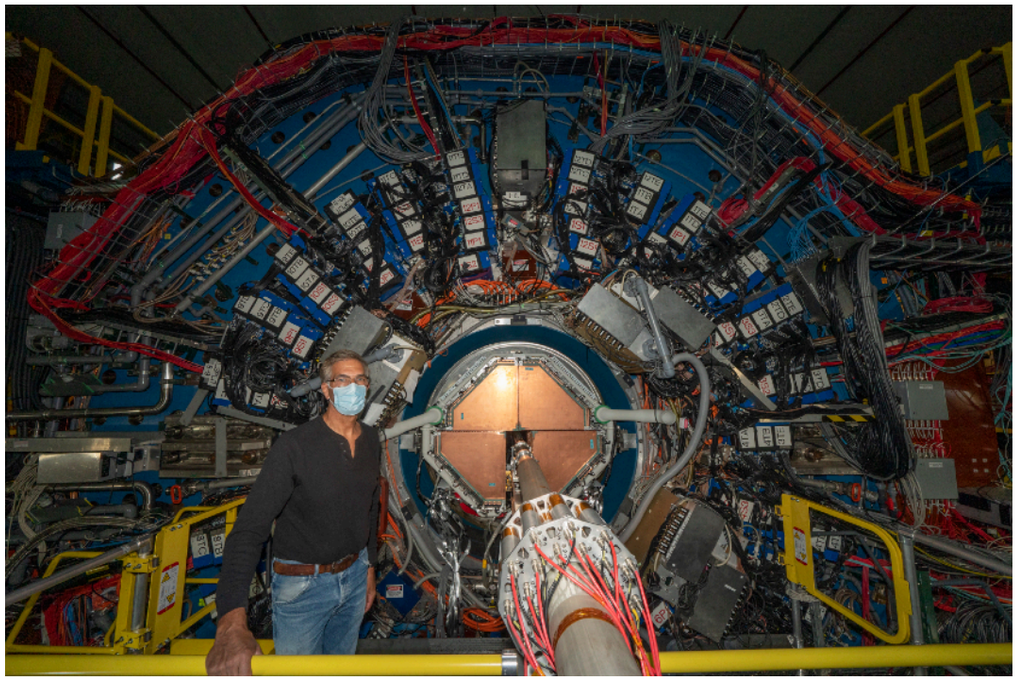
FTT Installation



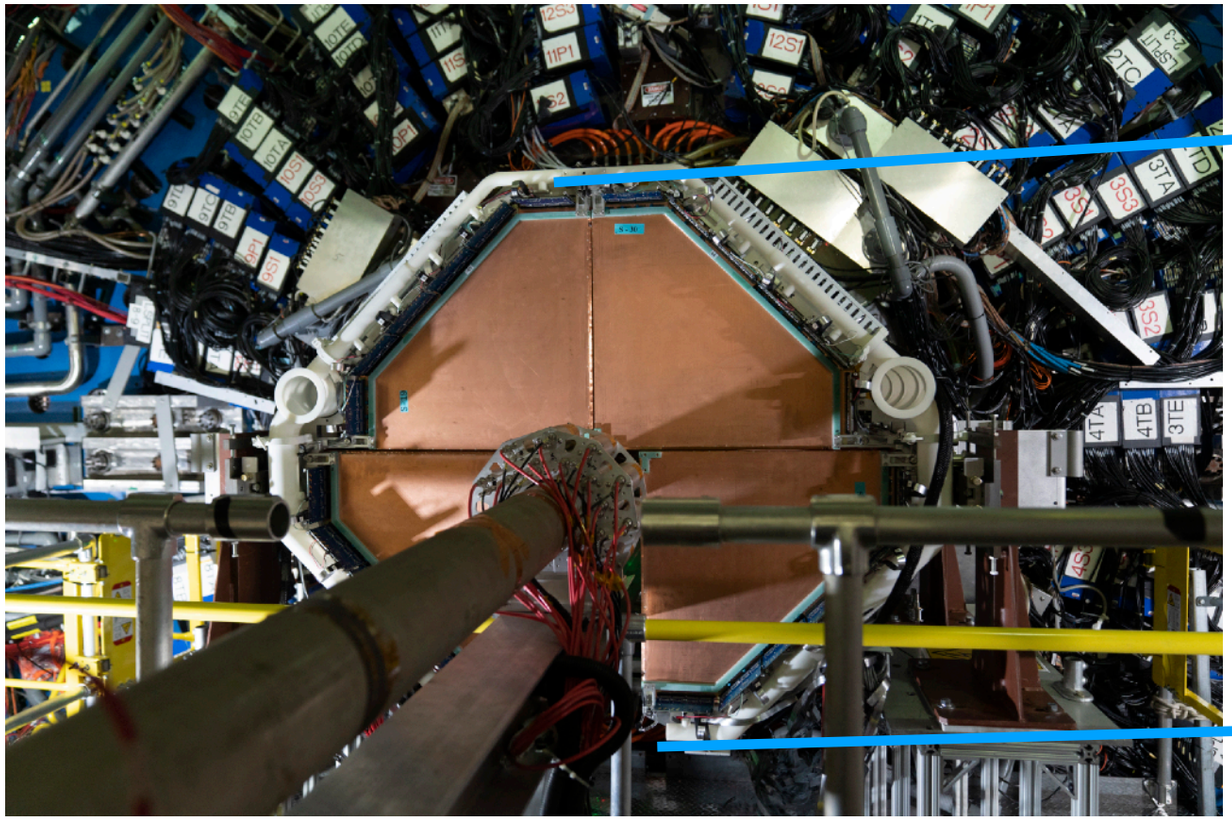




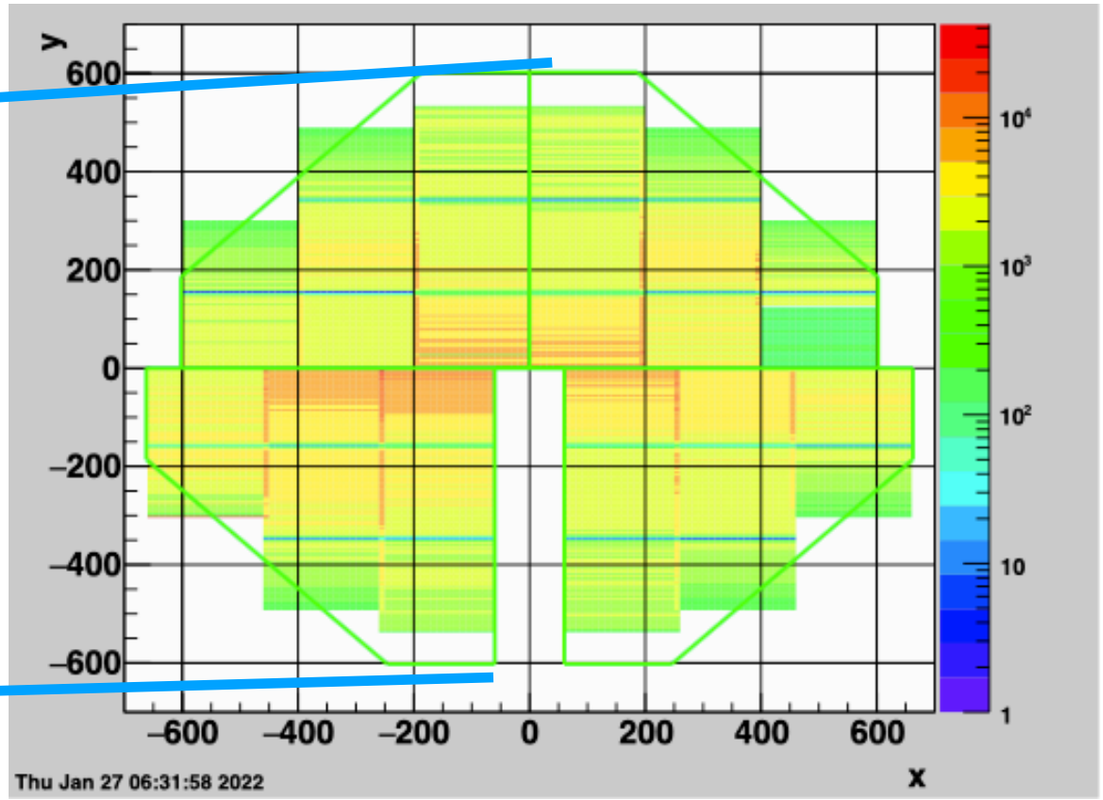




FTT Operation

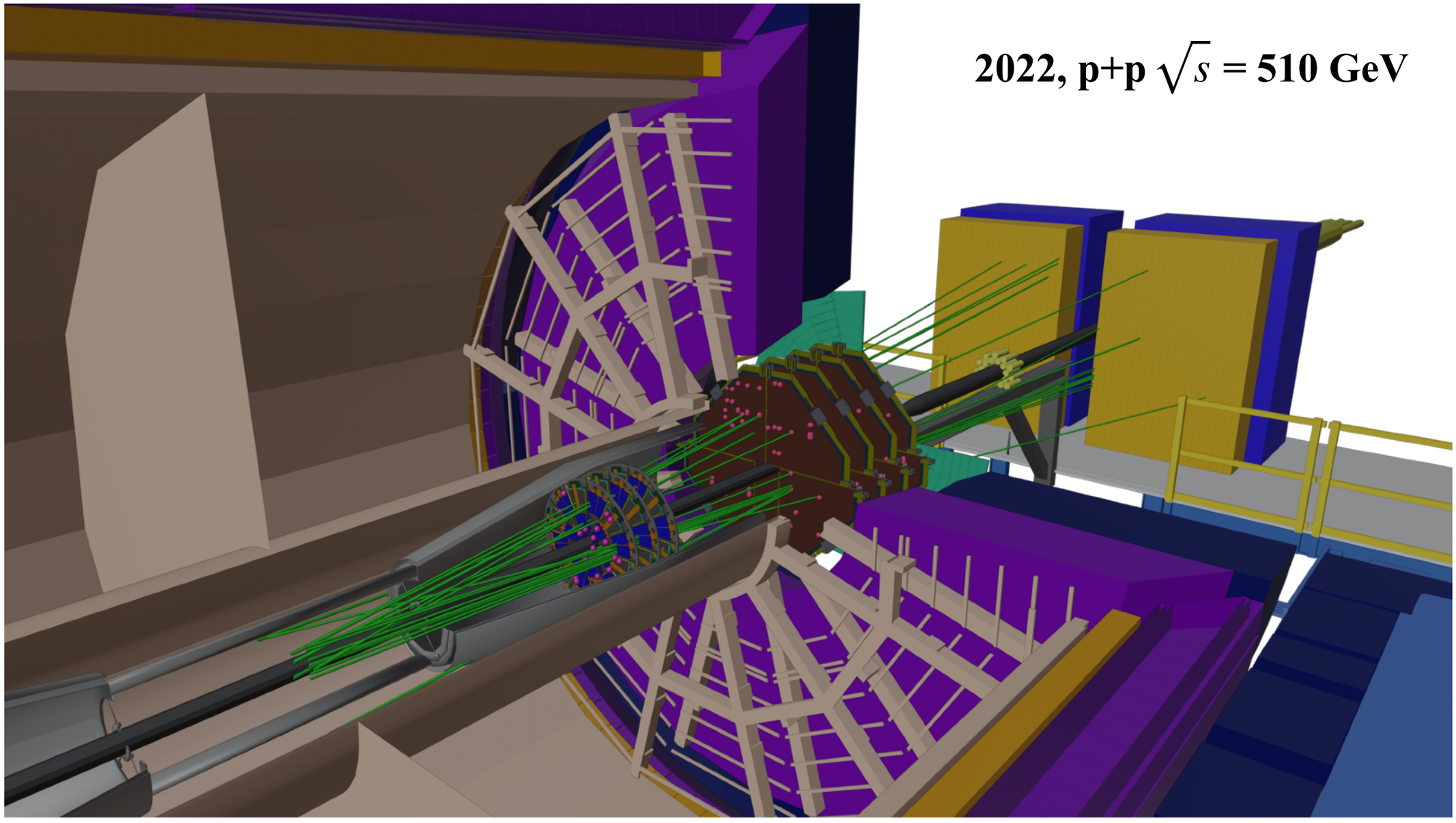


FTT event display in run22 p+p 510GeV



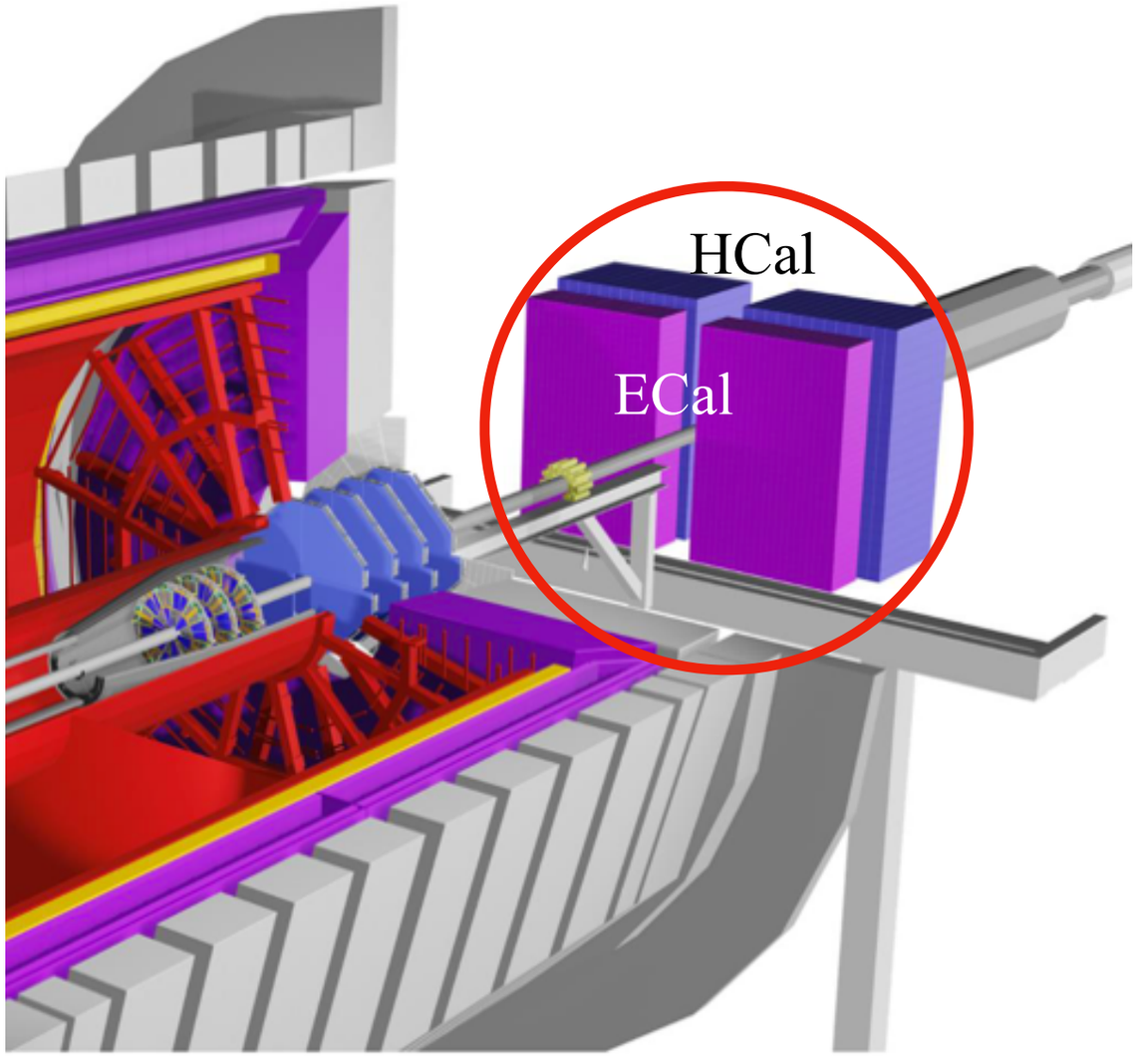
- Operation HV: 1500 V for standby and 3000 V for data taking
- Safety and gas mixing is automated through interlock logic
- Refill pentane, every three weeks by experts
- CO_2 change every two months by experts
  - Backed up by reserve tank online—no run out
- FTT is commissioned and currently taking data at STAR run22

FTS Performance



- FTS is commissioned and currently taking data at STAR run22
- Preliminary tracking from FTT is promising

Forward Calorimeter System



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
- Brief runs with O+O and d+Au at $\sqrt{s_{NN}}$ = 200 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 cm^3
  - 66 sampling cells with 1.5 mm Pb/4 mm Sc
  - 36 wavelength shifting fibers per cell
  - 18 X_0; 0.85 λ
- replaced PMTs with SiPM readout

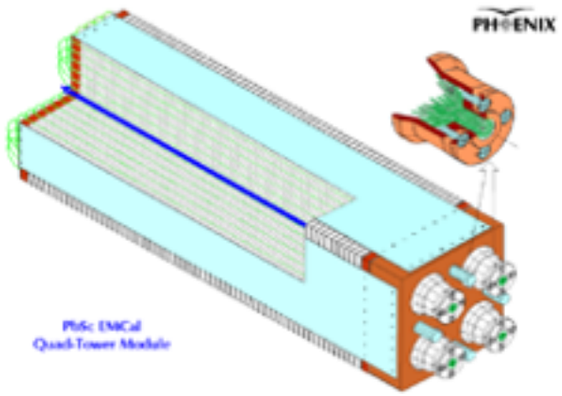
HCal:

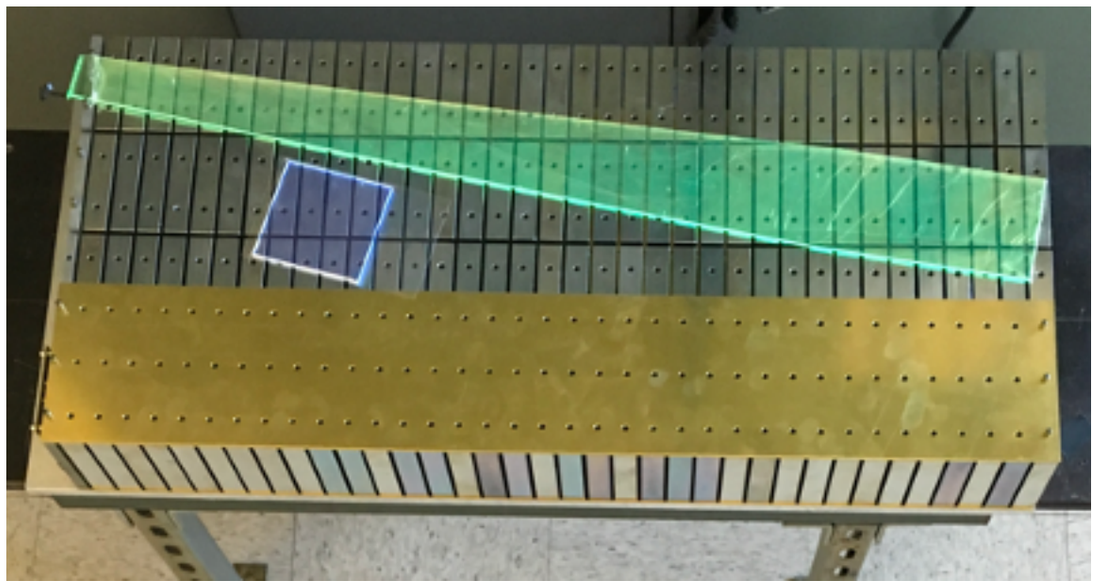
- Fe/Sc (20mm/3 mm) sandwich.
  - 520 readout channels: 10 x 10 x 84 cm^3
  - ~ 4.5 λ
- Uses same SiPM readout as ECal
- In close collaboration with EIC R&D

Preshower:

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

Forward Calorimeter System





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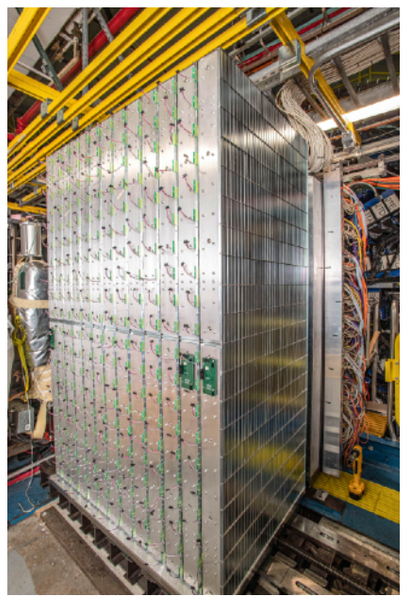
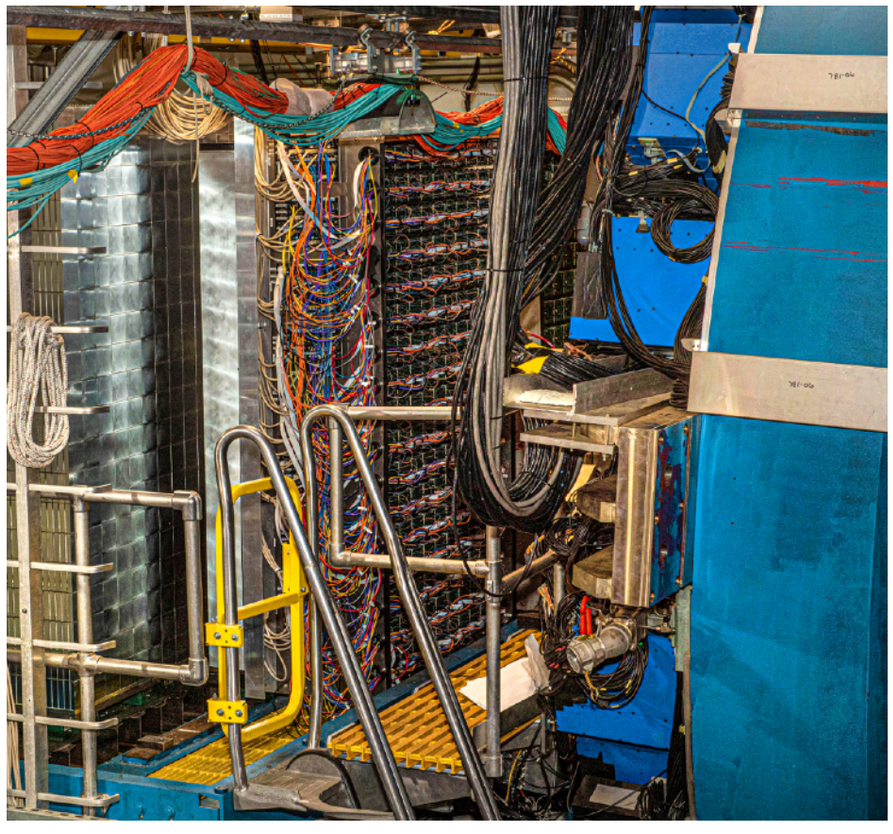
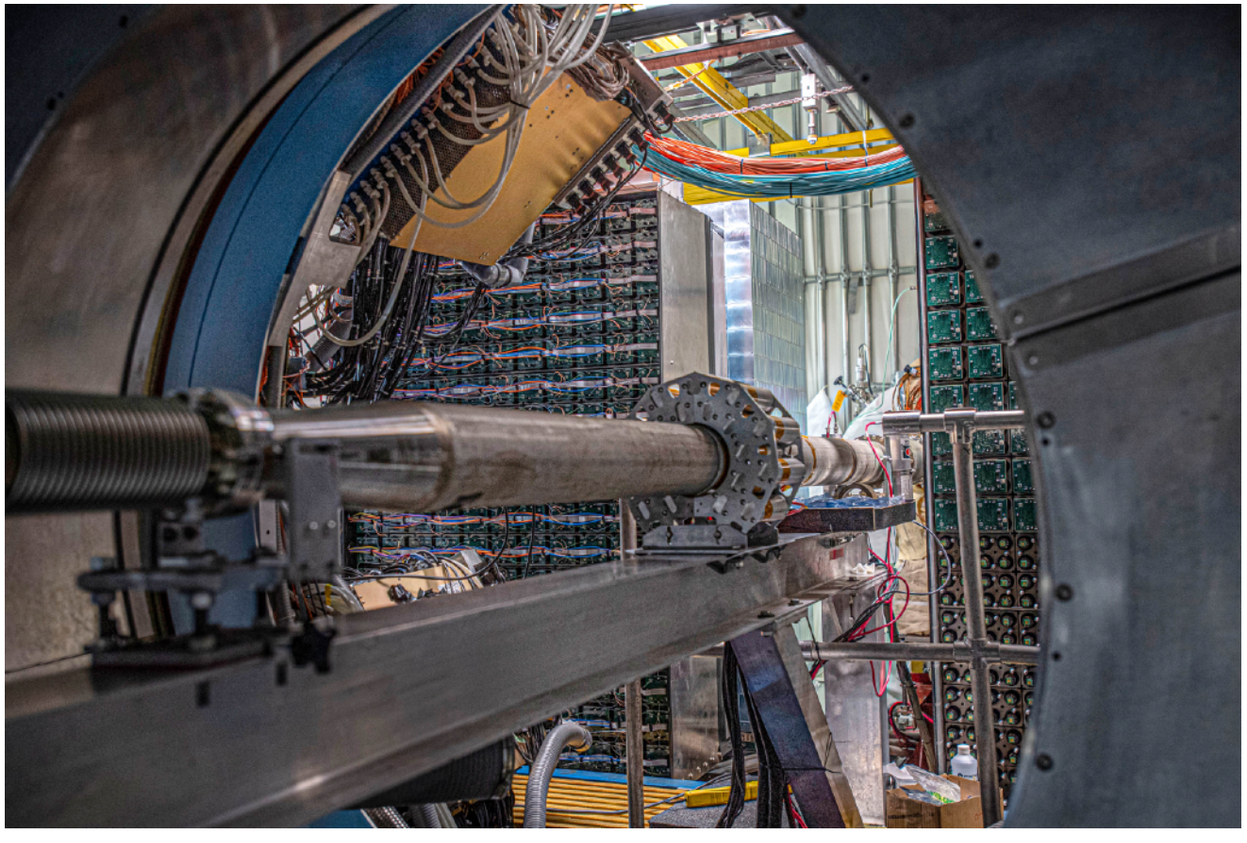
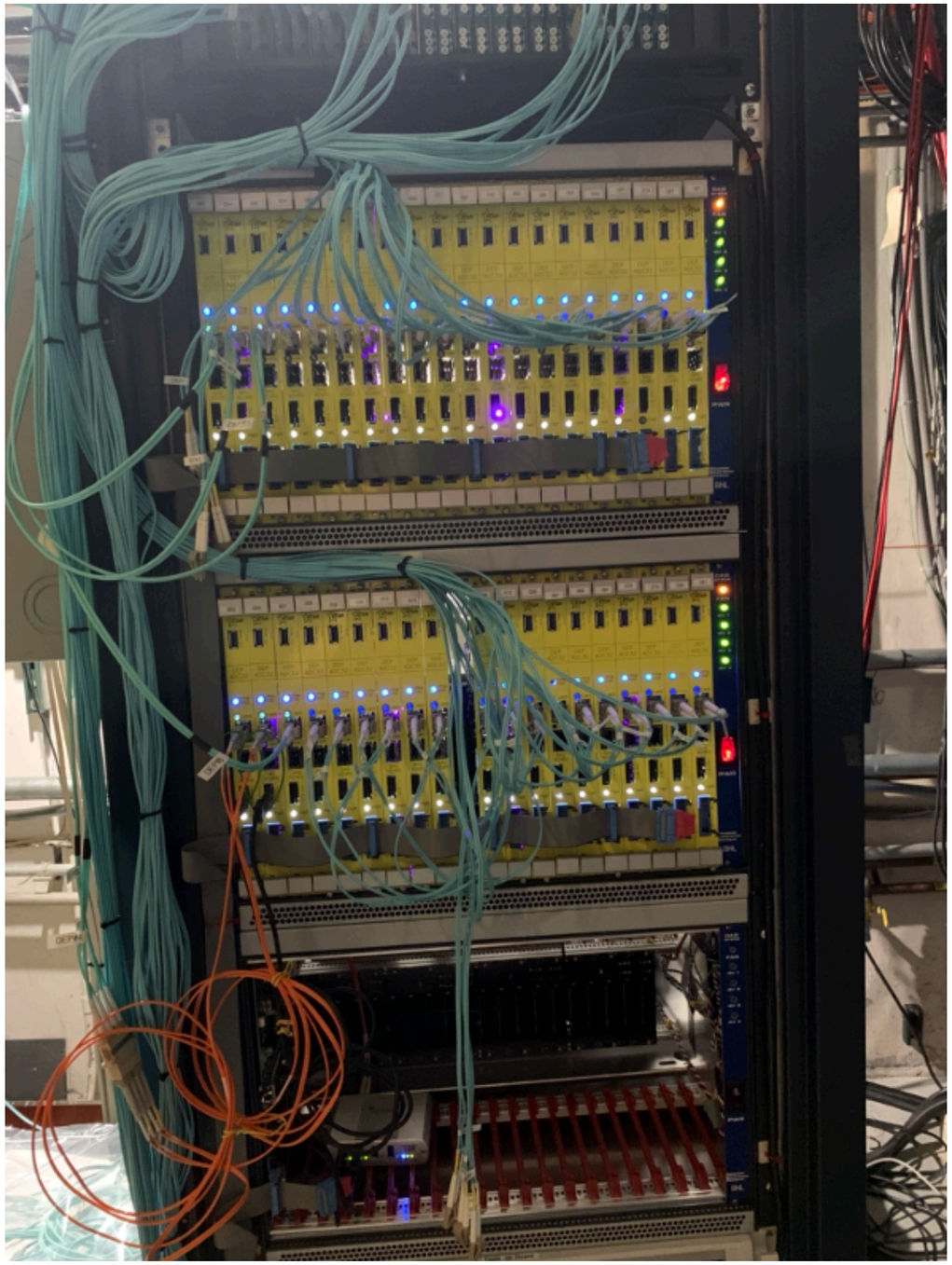
FCS Assembly





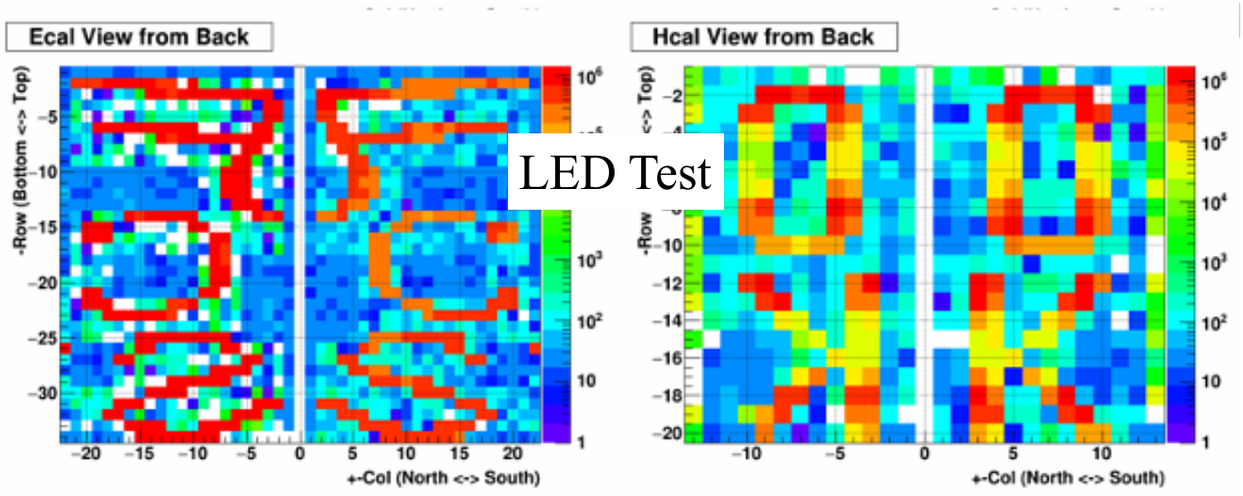


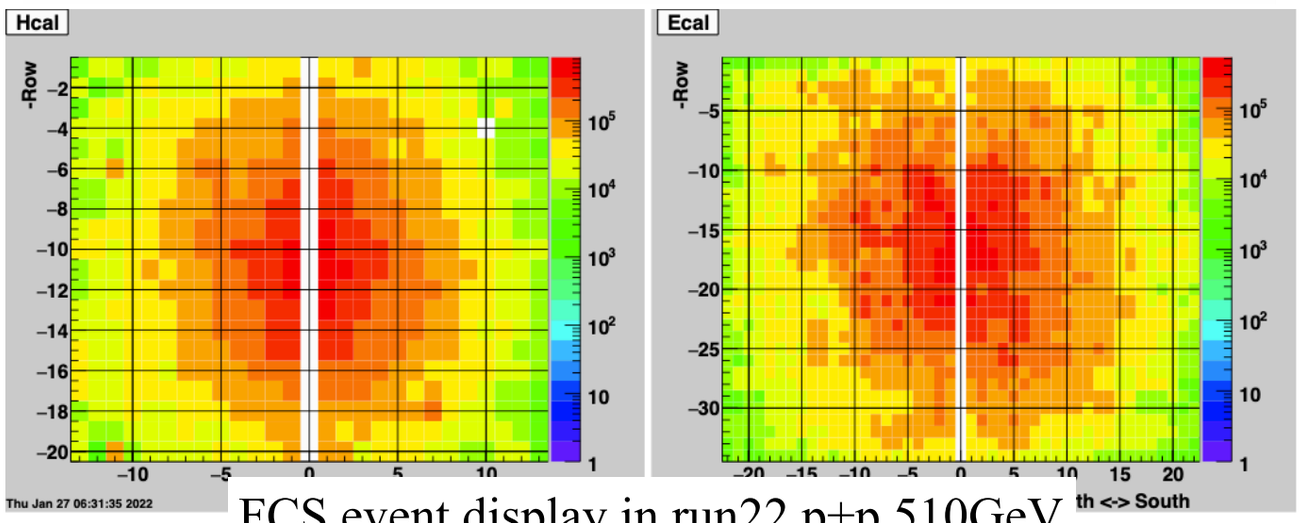
FCS Readout and Commissioning, Run 21



During Run21:

- 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

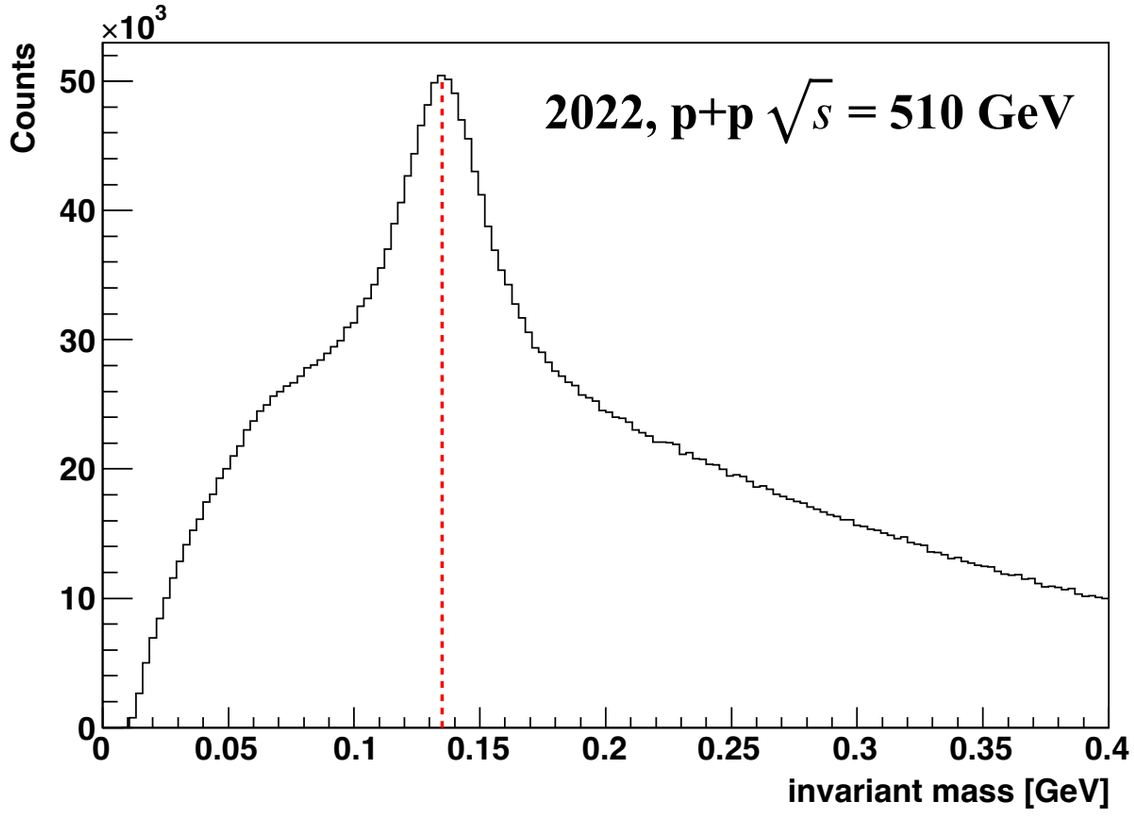




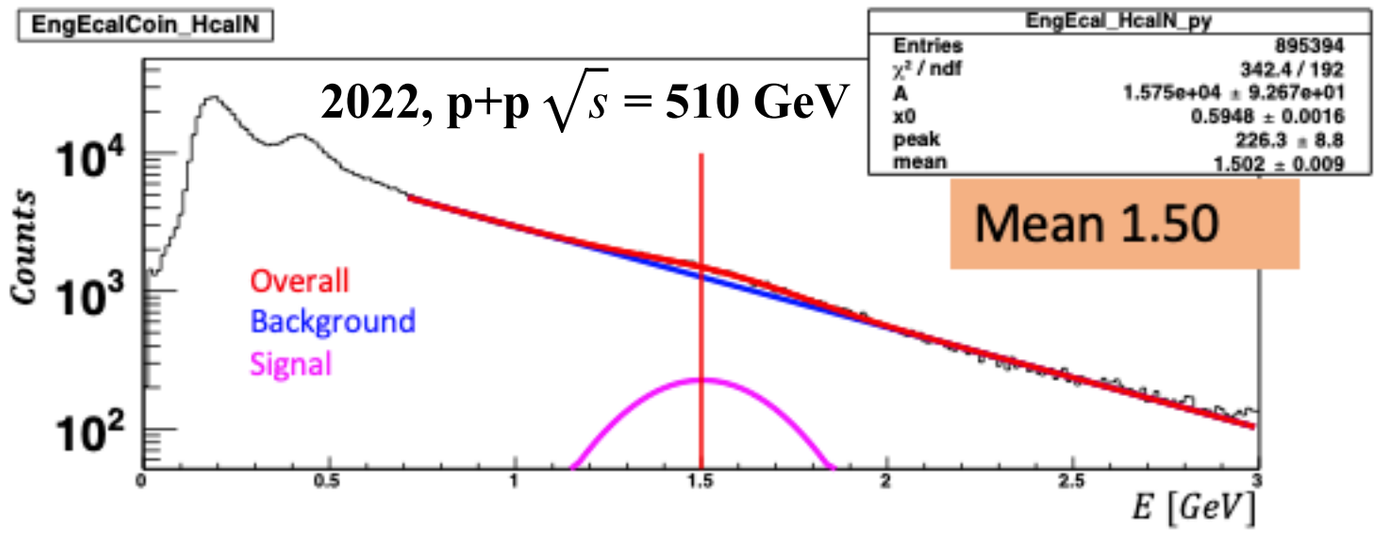
FCS event display in run22 p+p 510GeV

FCS Performance

π^0 reconstructed by Di-photon from ECal



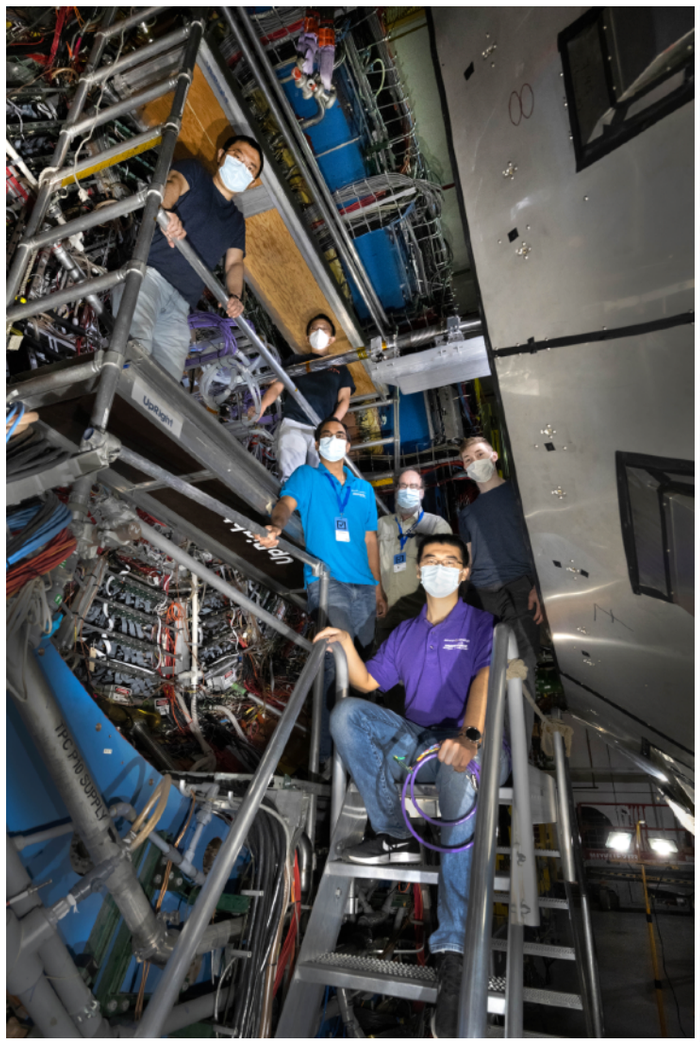
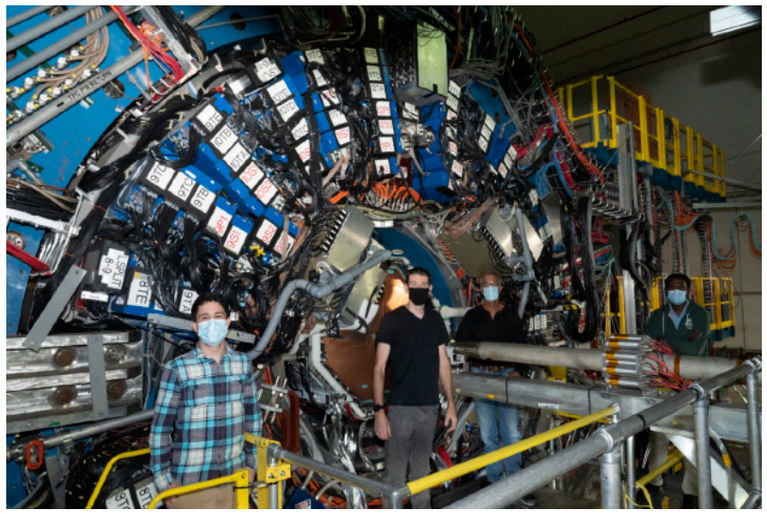
MIP peak from HCal (Matched with ECal MIP)

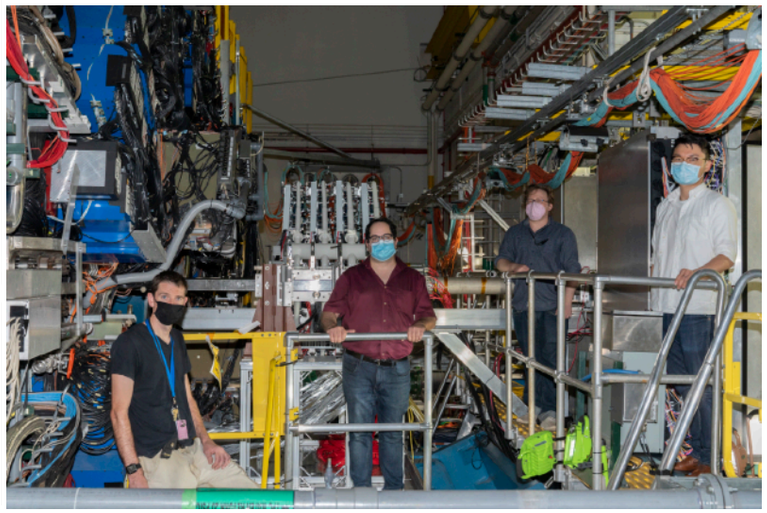


- FCS is commissioned and currently taking data at STAR run22
- FCS performance is as expected

Summary

- Despite of COVID, all the Forward upgrade subsystems were installed on time
- All forward detectors were commissioned on time and taking data
- 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

University of 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

University of 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

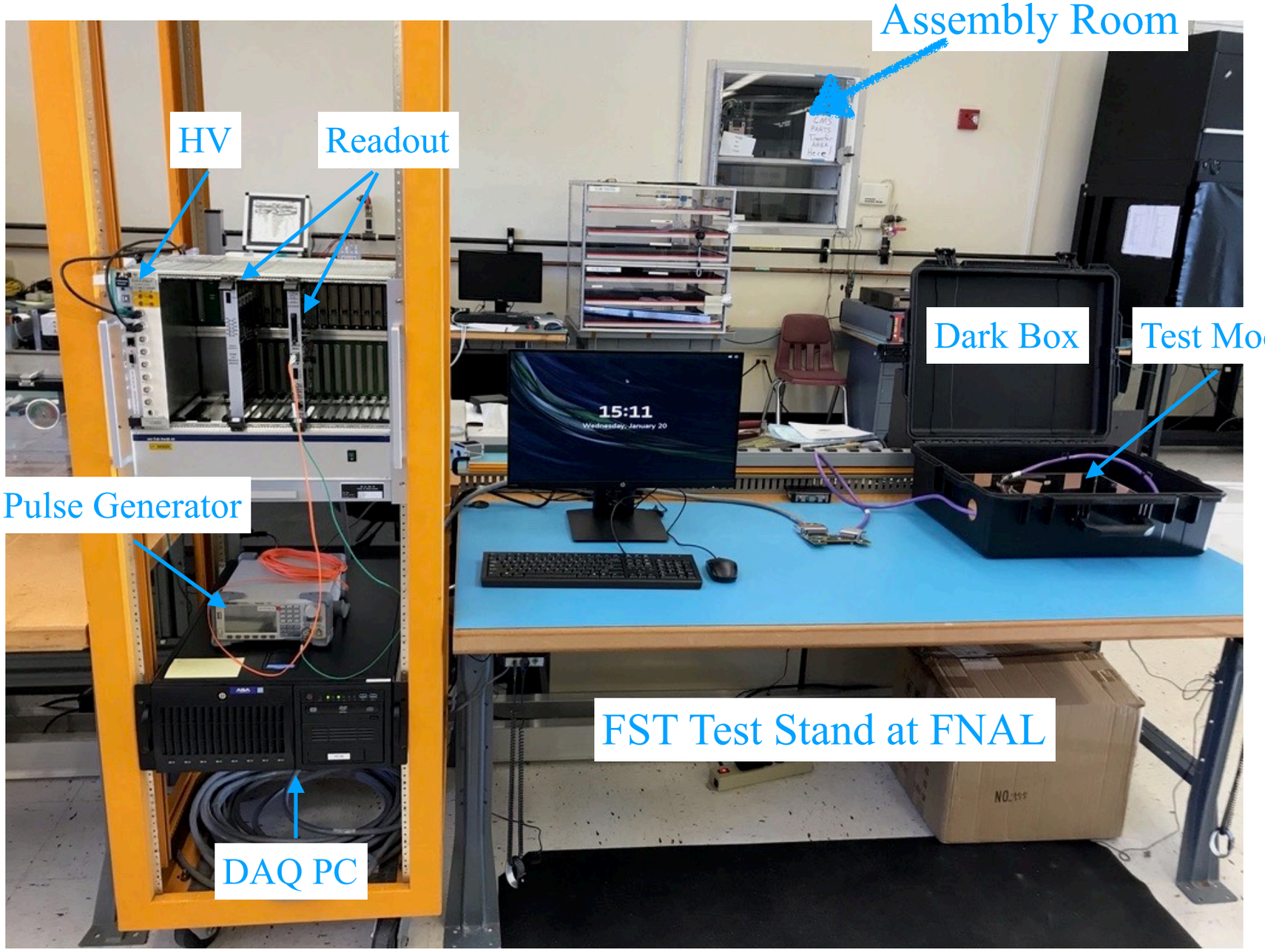
Creighton University

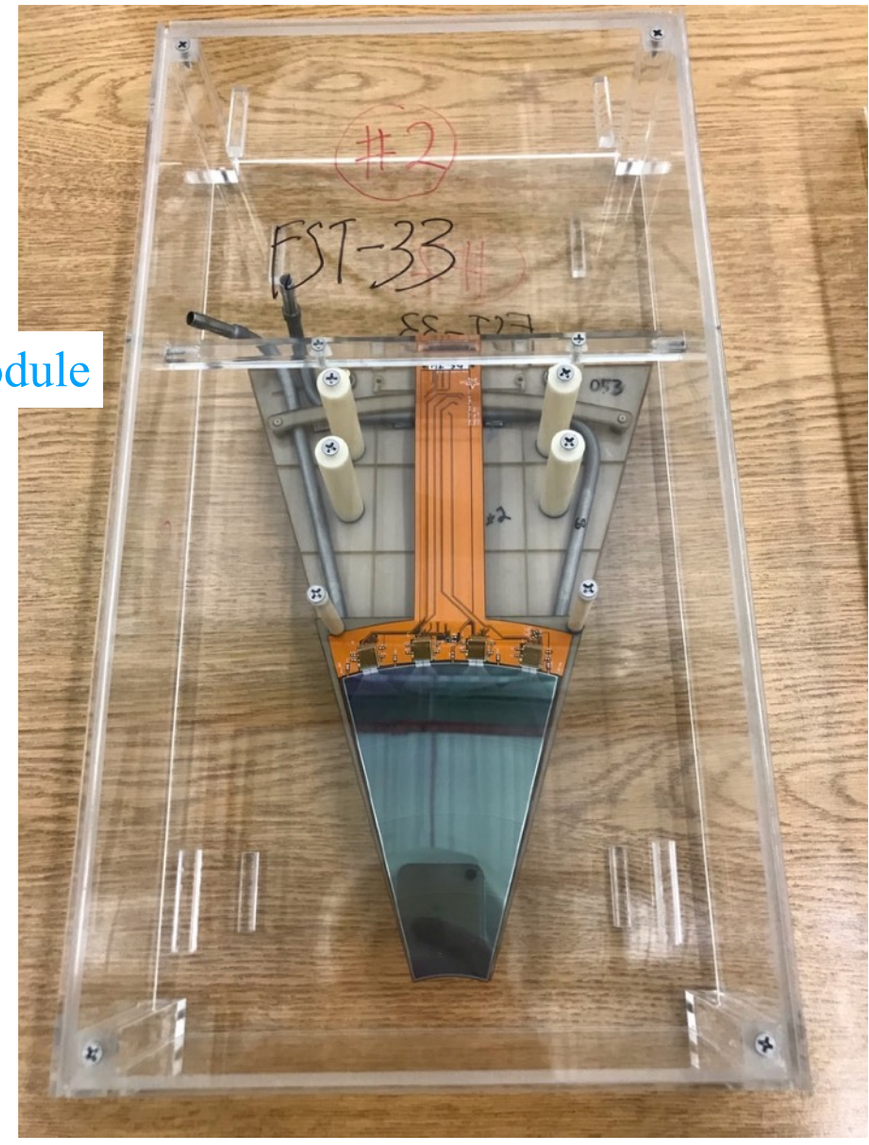
and the STAR collaboration, which stands enthusiastically behind the upgrade

Thanks for your attention!

Backups

FST Module Assembly

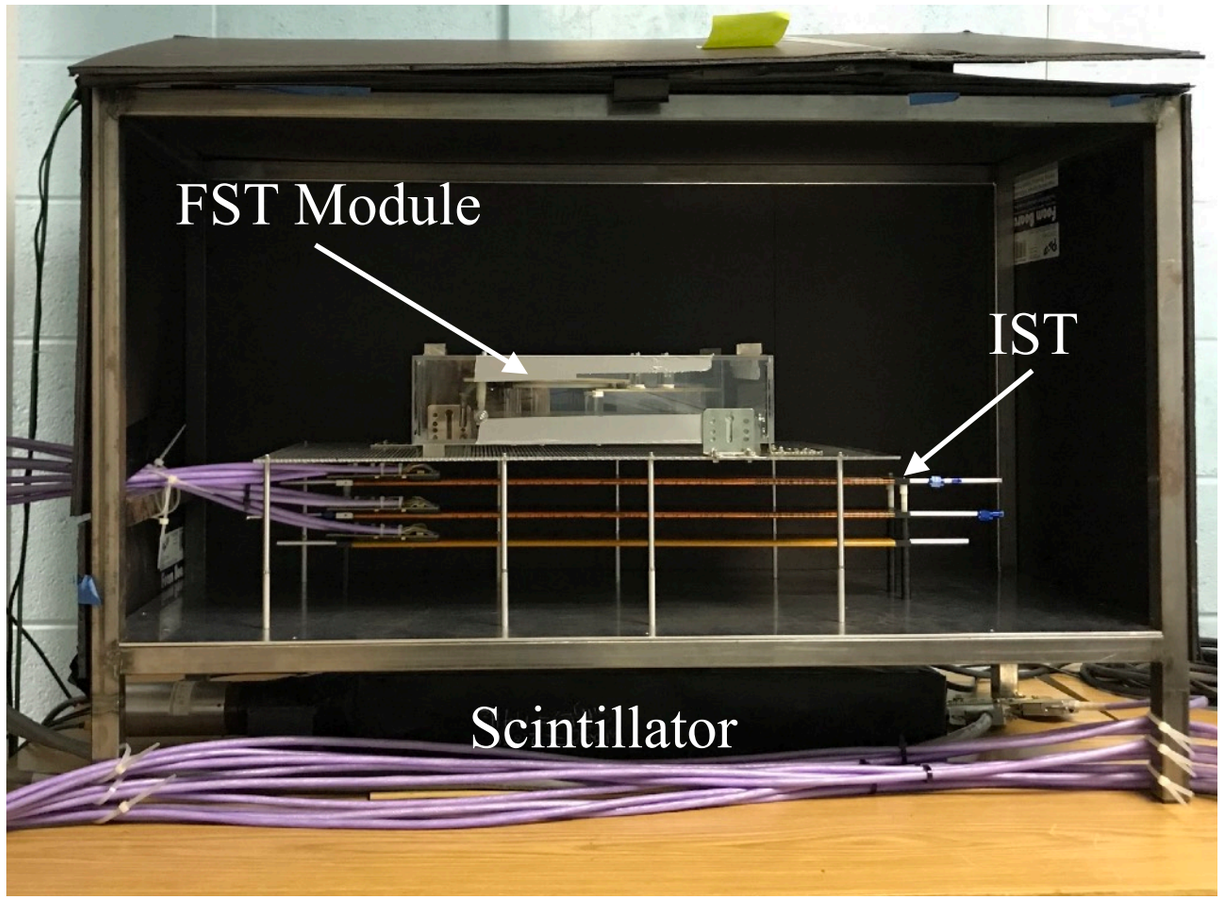




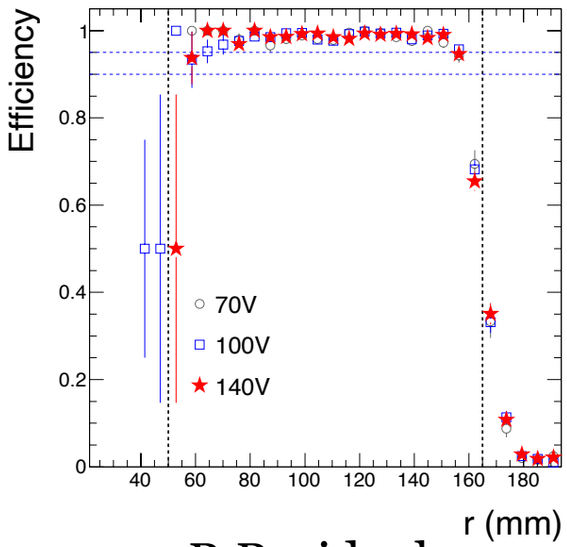
- Module assembly at FNAL from January 2021 to June 2021.
- 48 modules assembled: 43 good + 5 problematic.
- All the modules arrived at BNL on June 11, 2021.

FST Module Performance Test

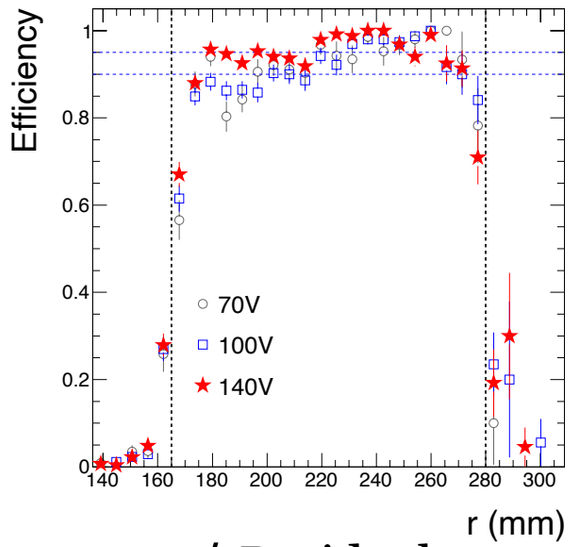
FST Cosmic Test Stand at UIC



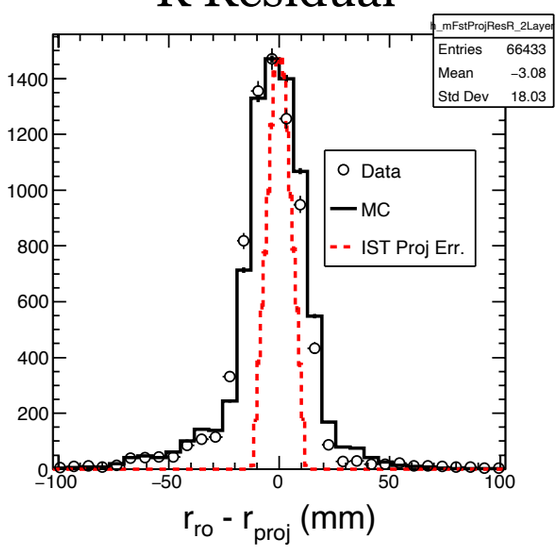
Inner Sensor



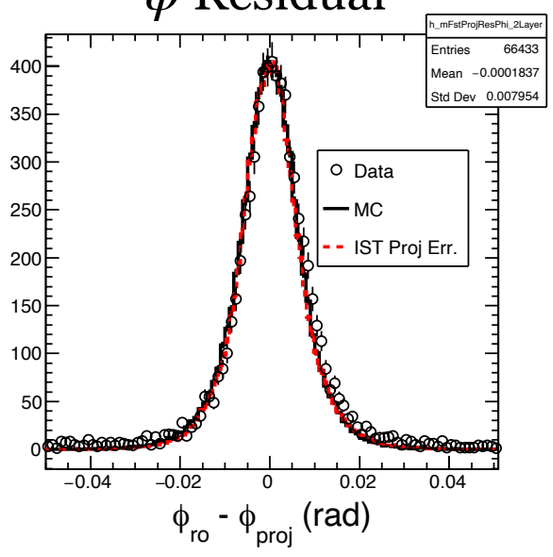
Outer Sensor



R Residual

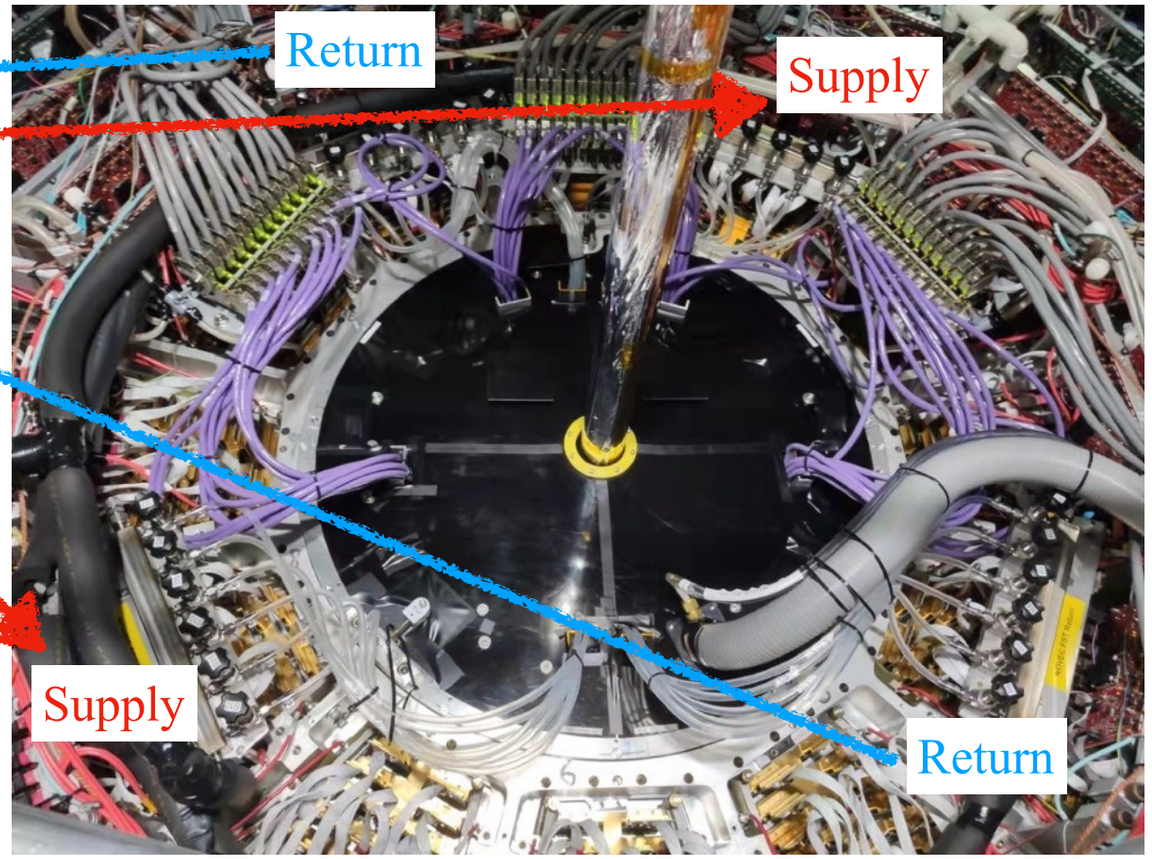


ϕ Residual

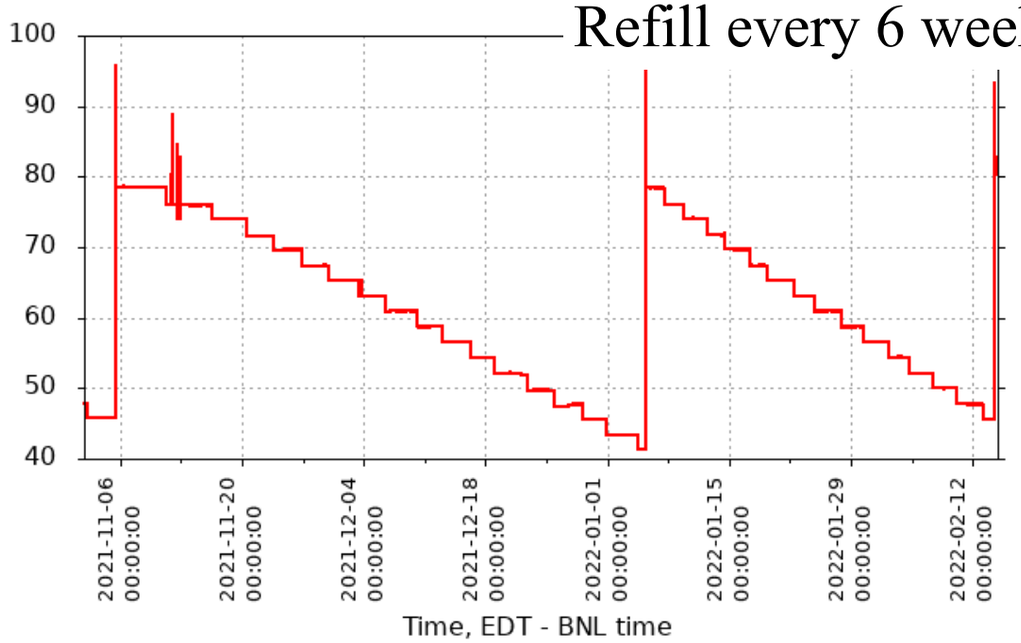


- Performance of FST modules are evaluated with cosmic ray:
  - All channels can be read out
  - Efficiency higher than 90%

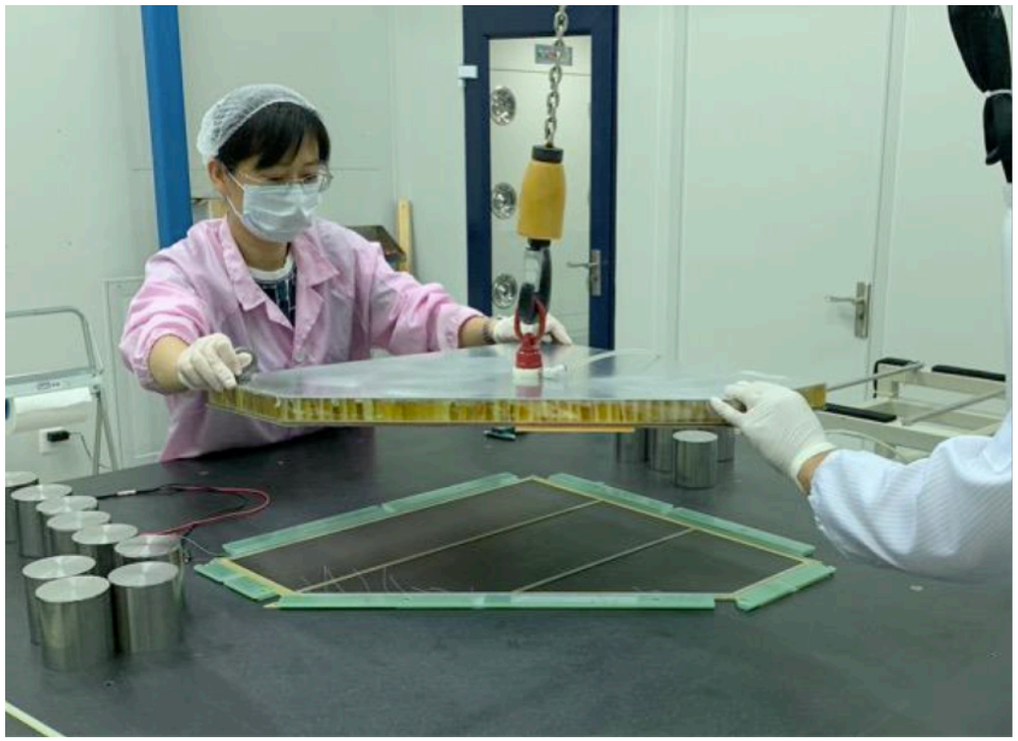
FST Cooling System



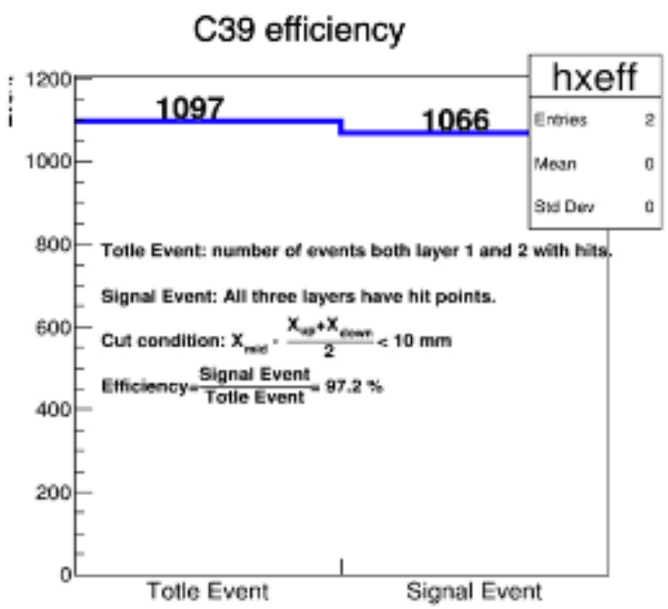
Refill every 6 weeks

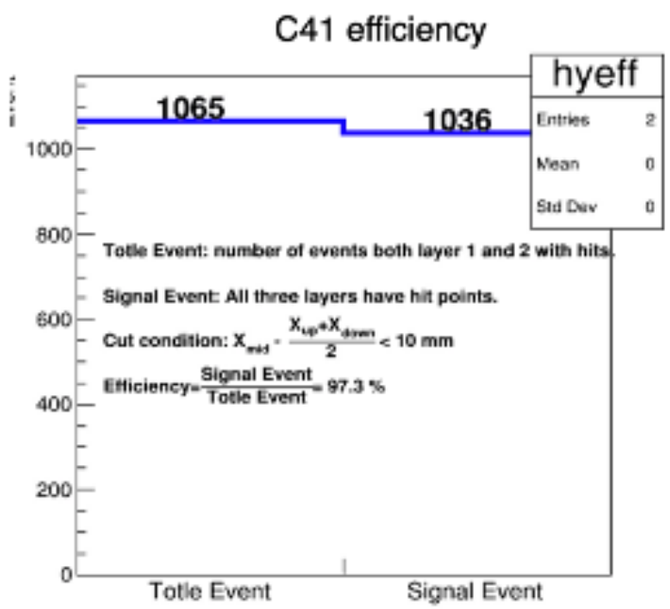


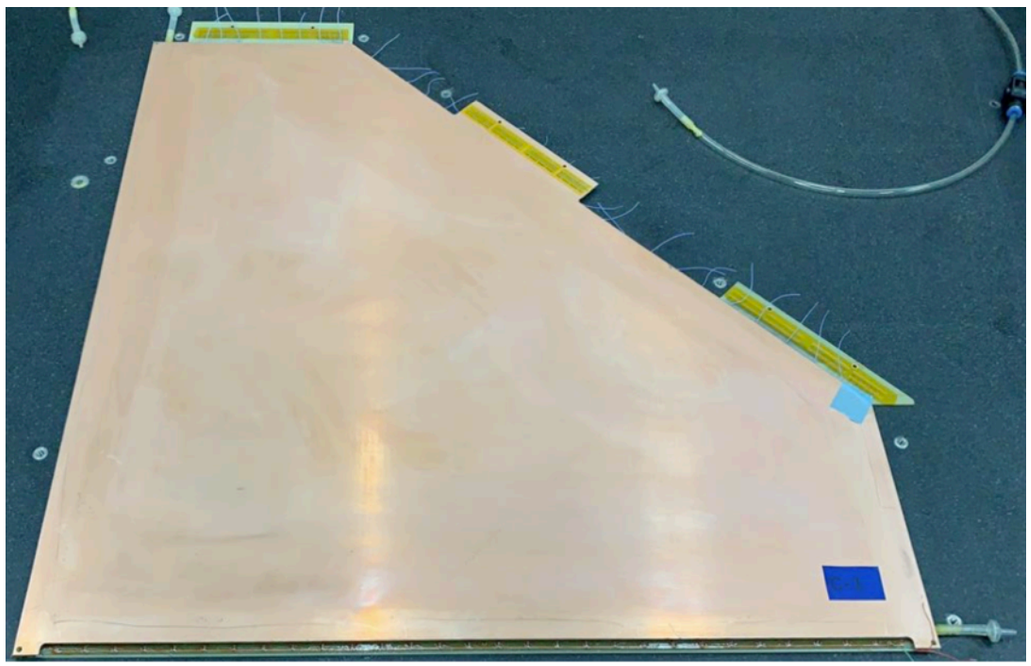
sTGC Assembly



Efficiency > 97%







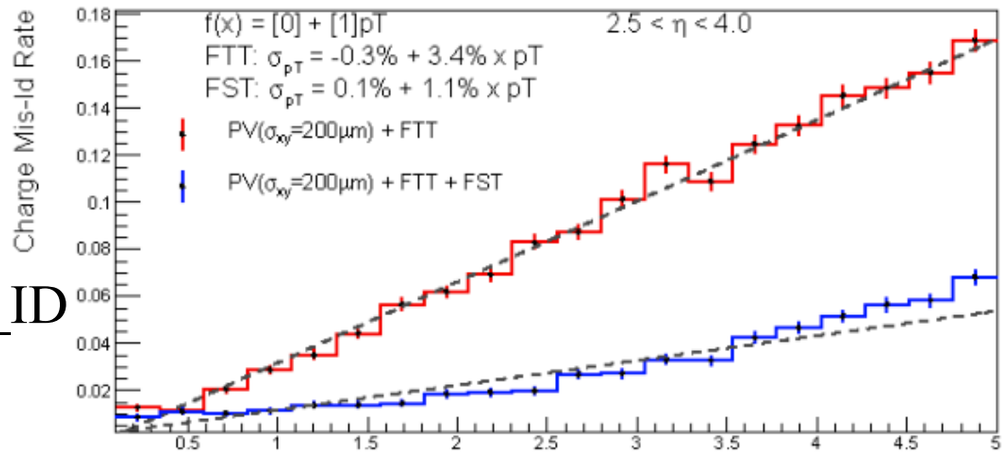
- Four planes, each consisting of four 55cm*55cm pentagonal modules
  - Double-sided sTGC with diagonal strips
  - Position resolution < 100 μm
  - performed cosmic ray test at SDU
- Material budget ~0.5% X_0 per layer
- 19 pentagon modules are produced and arrived at BNL on 08/06/2021.

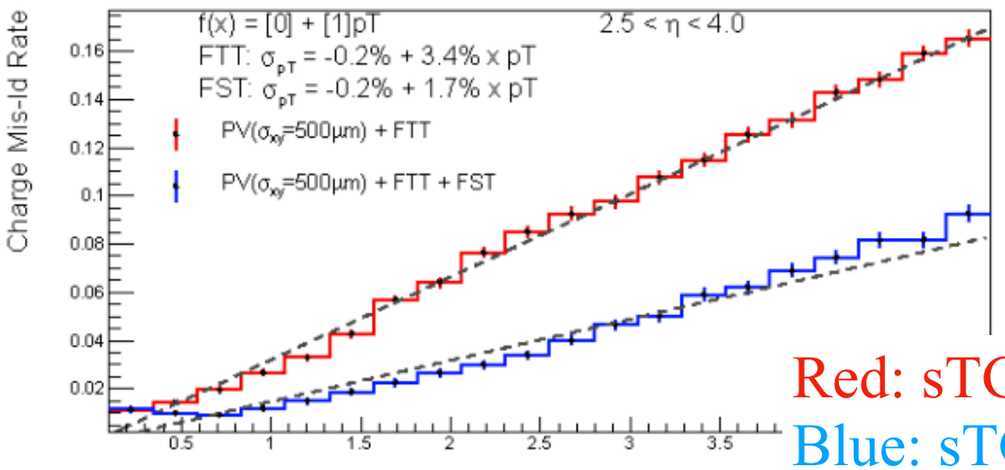
Simulated Performance of the Forward Tracker

vertex resolution = 500 μm

vertex resolution = 200 μm

Charge mis_ID rate vs. p_T

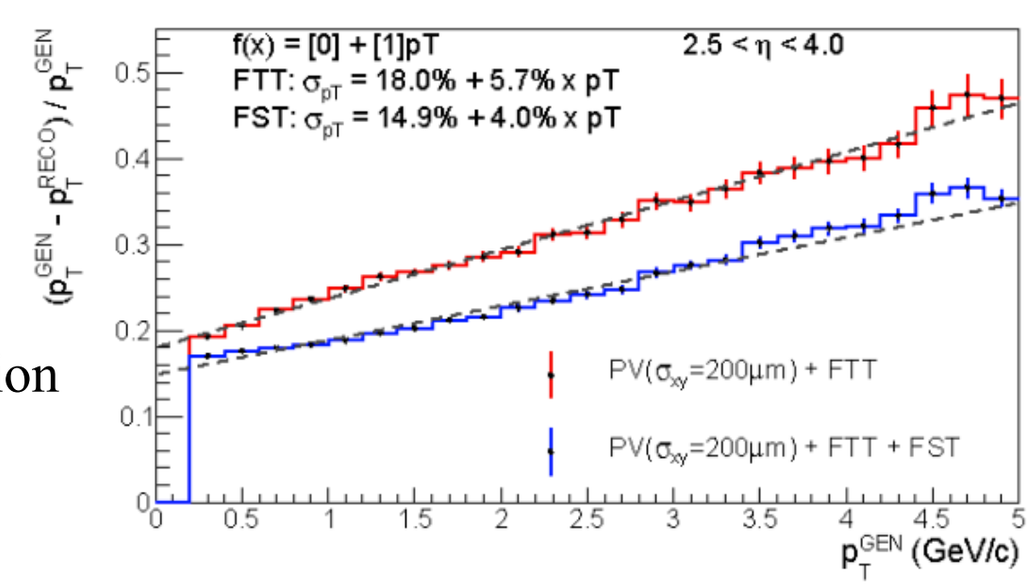


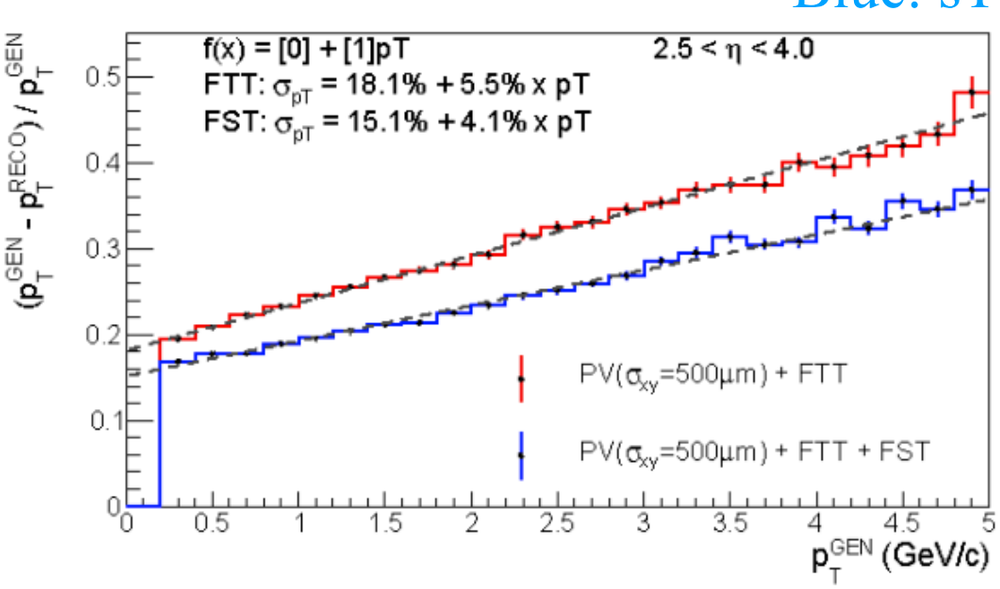


Red: sTGC only

Blue: sTGC + FST

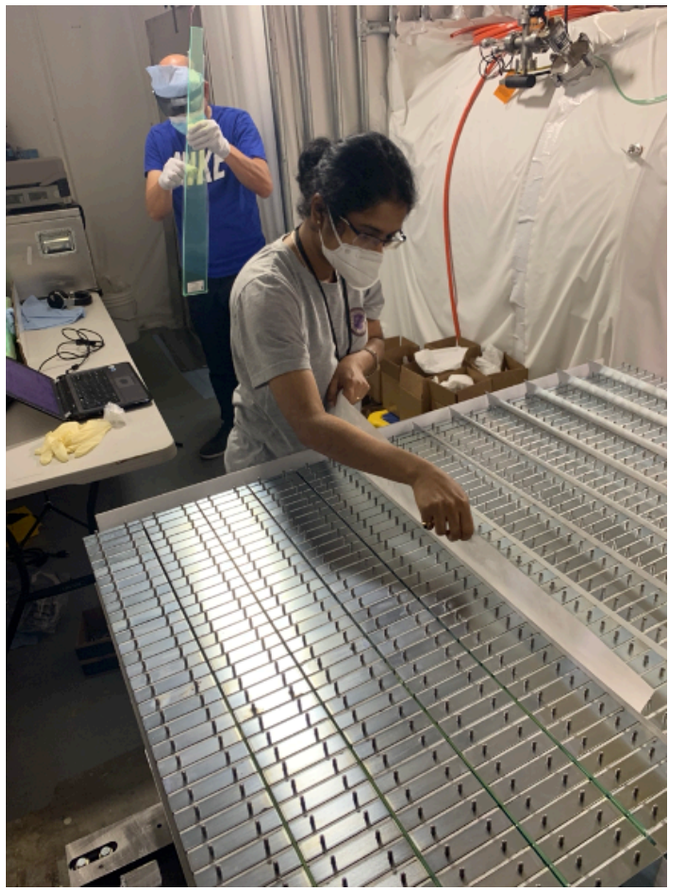
p_T resolution vs. p_T





- Charge mis-ID rate less than 6% (8%) for $p_T < 5$ GeV/c and 500 (200) μm vertex resolution
- p_T resolution better than 35% for $p_T < 5$ GeV/c for both beam energies

Forward Colorimeter System



Members of UC EIC Consortia
Assembling FCS in Autumn 2020 at BNL

Forward Calorimeter System (FCS)

- ECal – 1496 channels ~ 8 tons
- HCal – 520 channels ~ 30 tons.
- SiPM Readout Bias ~ 67V
- New digitizers + Trigger FPGA = DEP boards

Large group of STAR collaborators actively engaged in all aspects of the project:
ACU, BNL, UCLA, UCR, Indiana University CEEM, UKU, OSU, Rutgers U., Temple U., Texas A&M U., Valparaiso U.