The STAR Forward Upgrade Status

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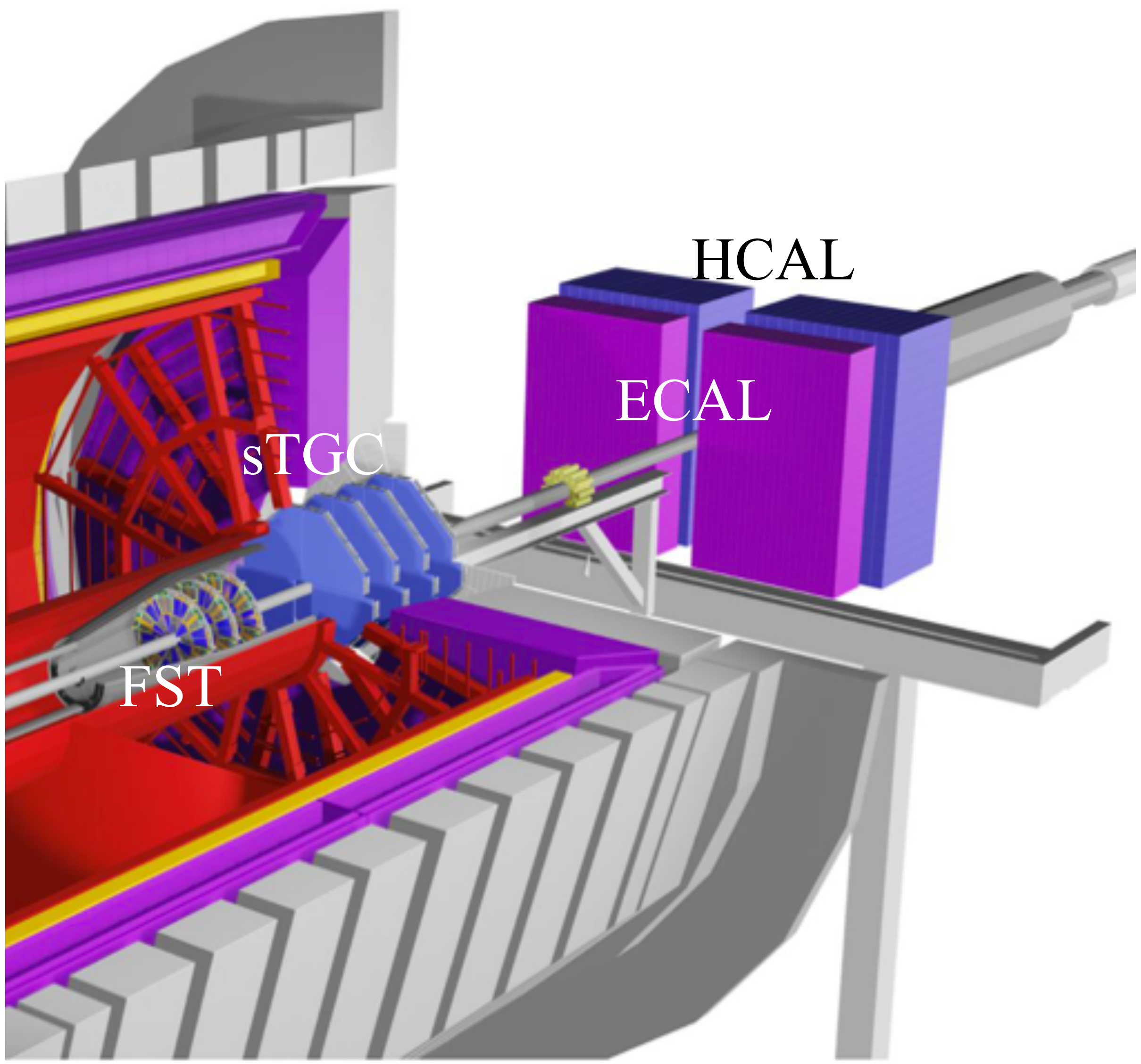
University of Illinois at Chicago

Supported in part by:
U.S. DEPARTMENT OF ENERGY | Office of Science

The STAR Forward Upgrade



Combines:

Forward Colorimeter System (FCS)
Electromagnetic Calorimeter
Hadronic Calorimeter

Forward Tracking System (FTS)
Forward Silicon Tracker (FST)
small-strip Thin Gap Chambers (sTGC)

Observables:

- inclusive and di-jets
- hadrons in jets
- Lambda Polarization
- correlations mid-forward & forward-forward rapidity

Requirements from Physics:

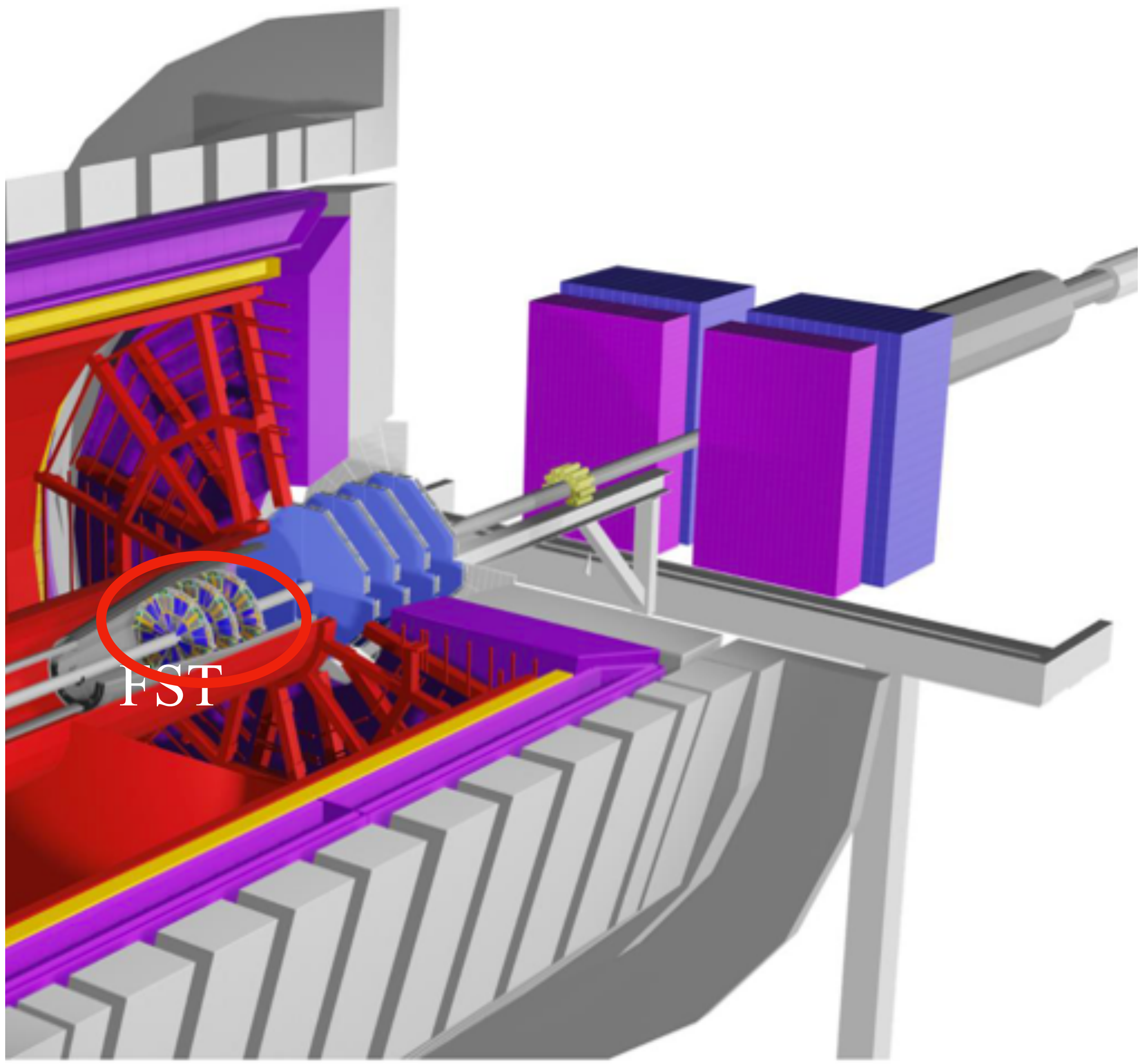
- good e/h separation
- photon, π^0 identification

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

- faces blue RHIC beam
- rapidity coverage the same as EIC hadron Arm

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

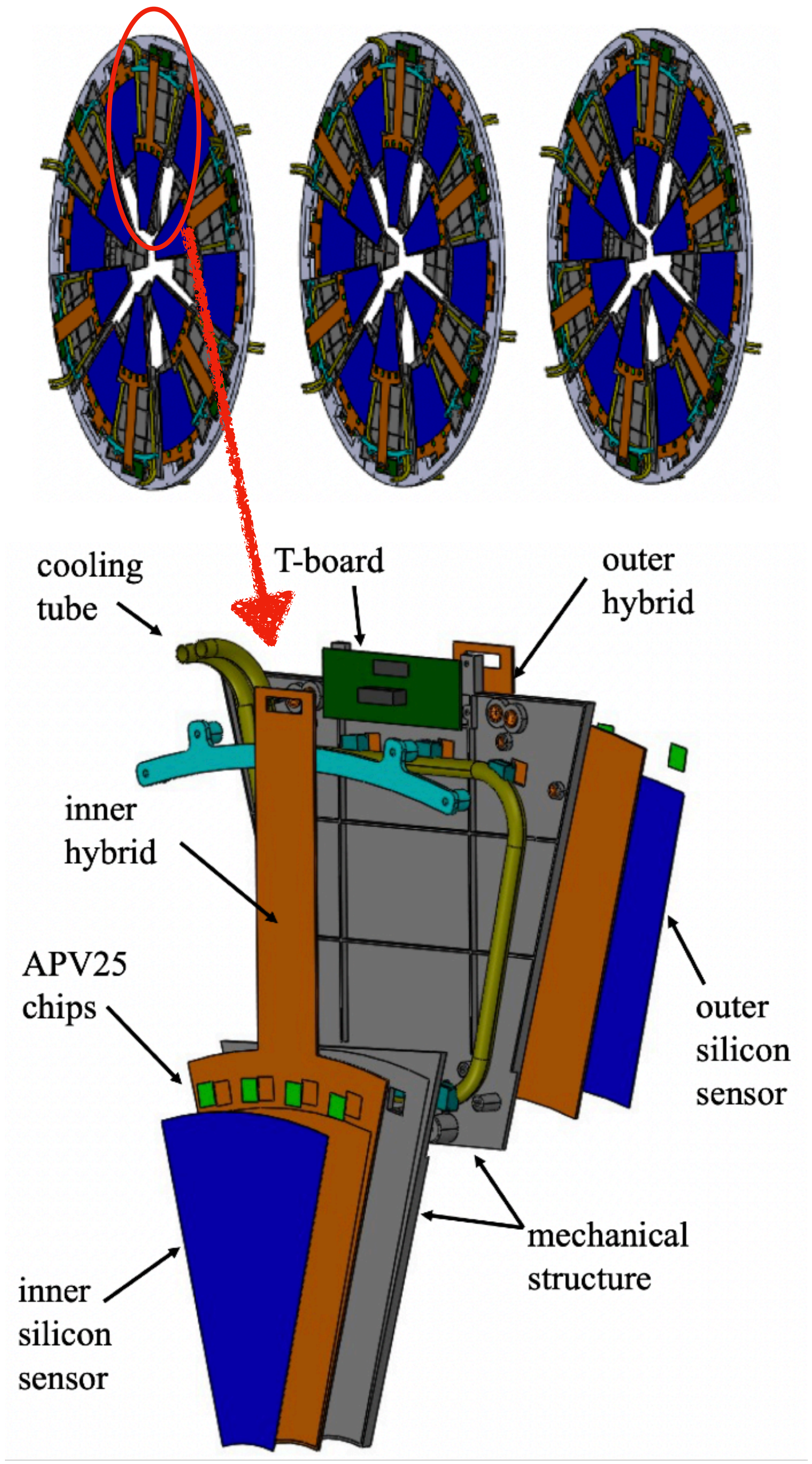
Forward Silicon Tracker



STAR forward upgrade: $2.5 < \eta < 4$
- faces blue RHIC beam
- rapidity coverage the same as EIC hadron Arm

3 Silicon disks: at 152, 165, and 179 cm from IP
Built on successful experience with STAR 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

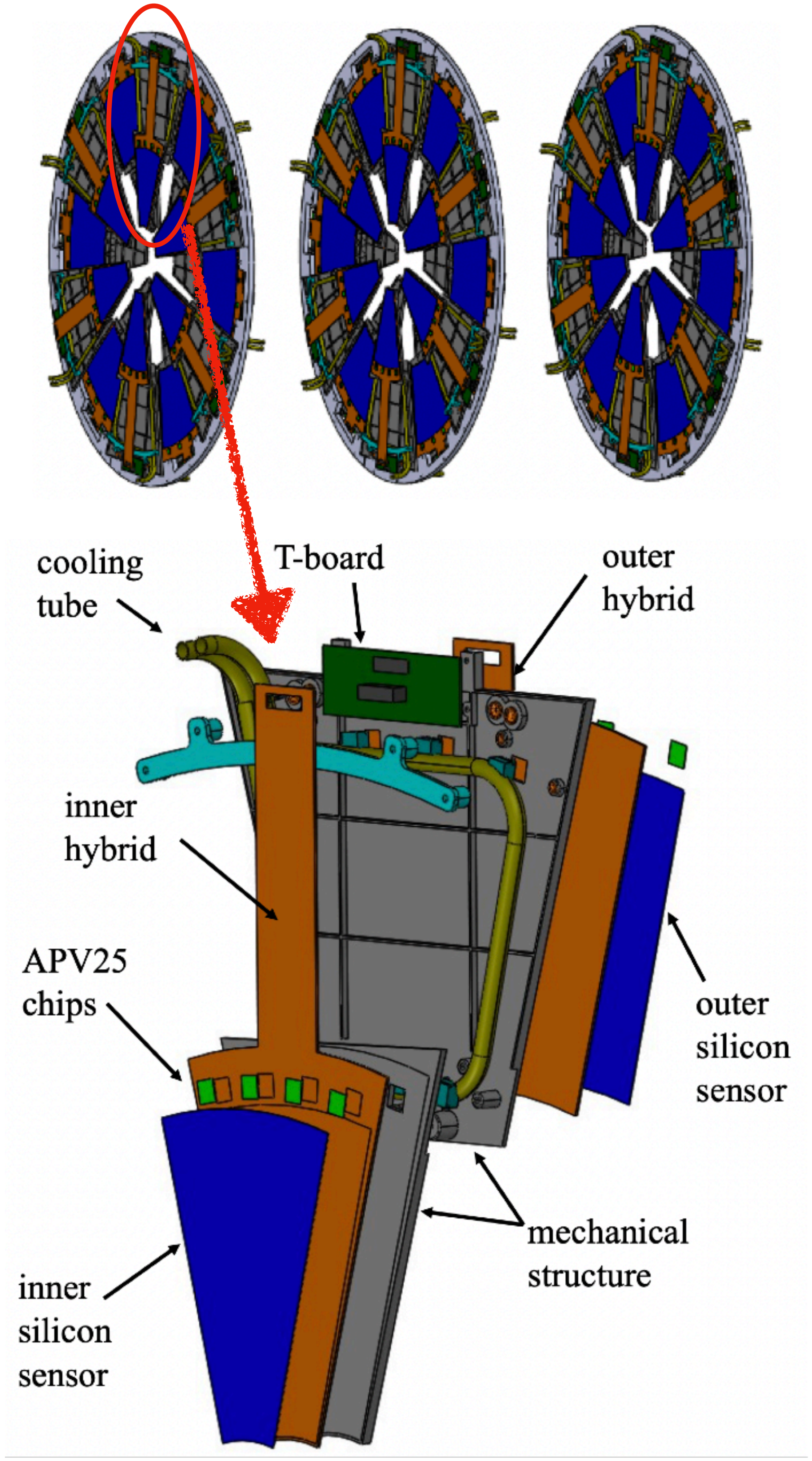
- PEEK (main structure, tube holder)
- Stainless steel (cooling tube)
- Aluminum (heat sinks)

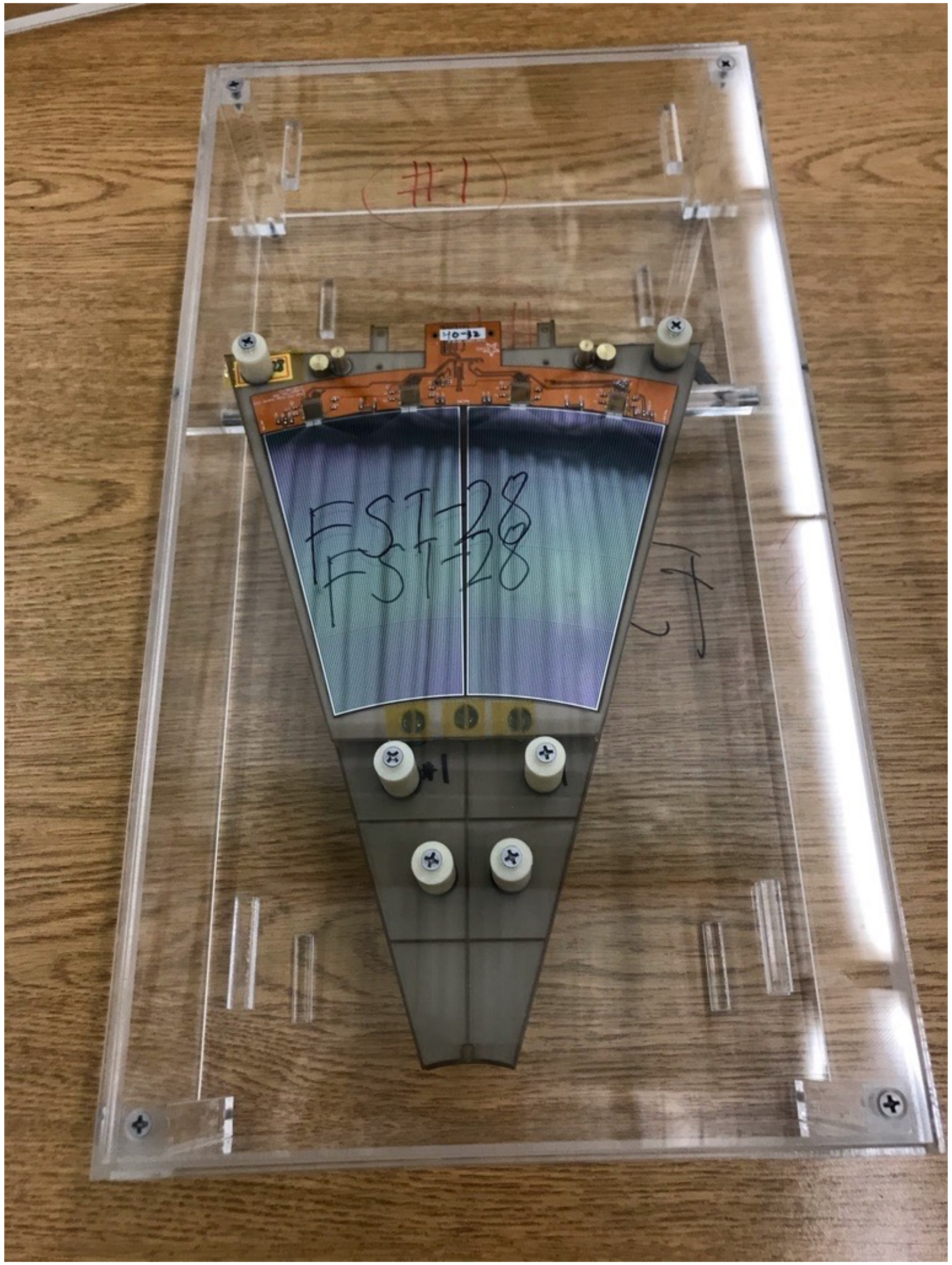
Module assembly is done at two sites

- TiDC (NCKU): gluing inner/outer hybrids and mechanical structures together
- FNAL (UIC): mount/wire-bond APVs and Silicon sensors on hybrids

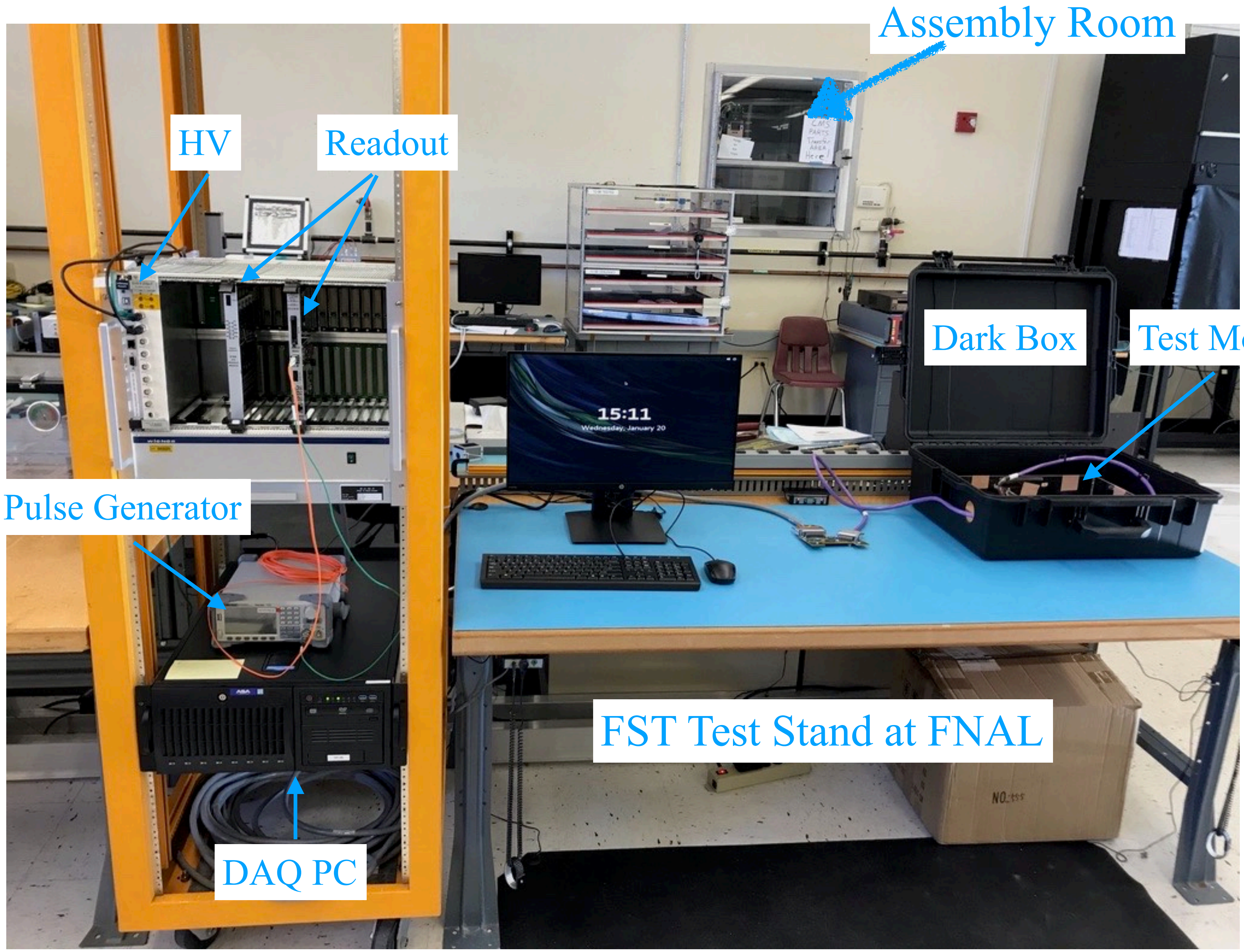
material budget: ~1% X_0 per disk

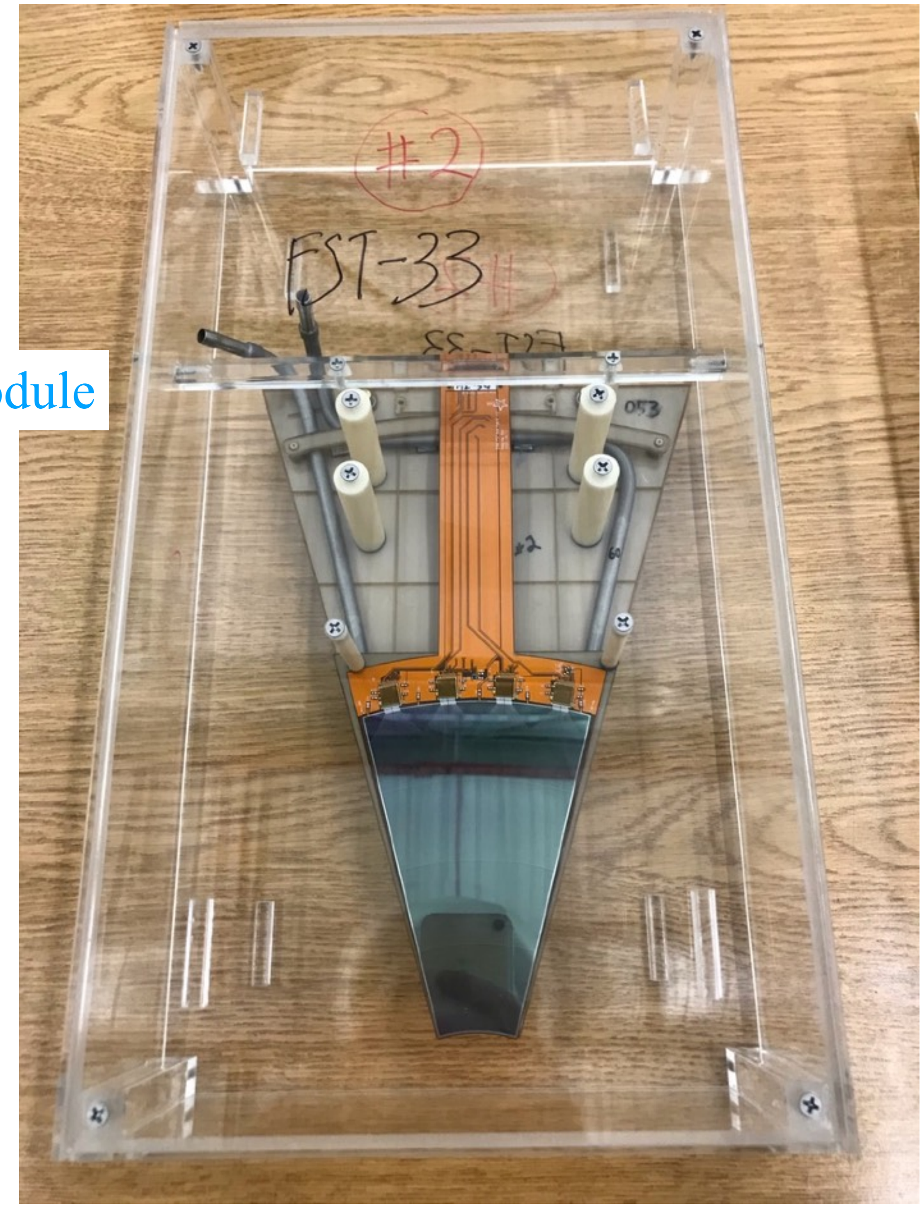
FST Module Design





FST Module Assembly at FNAL

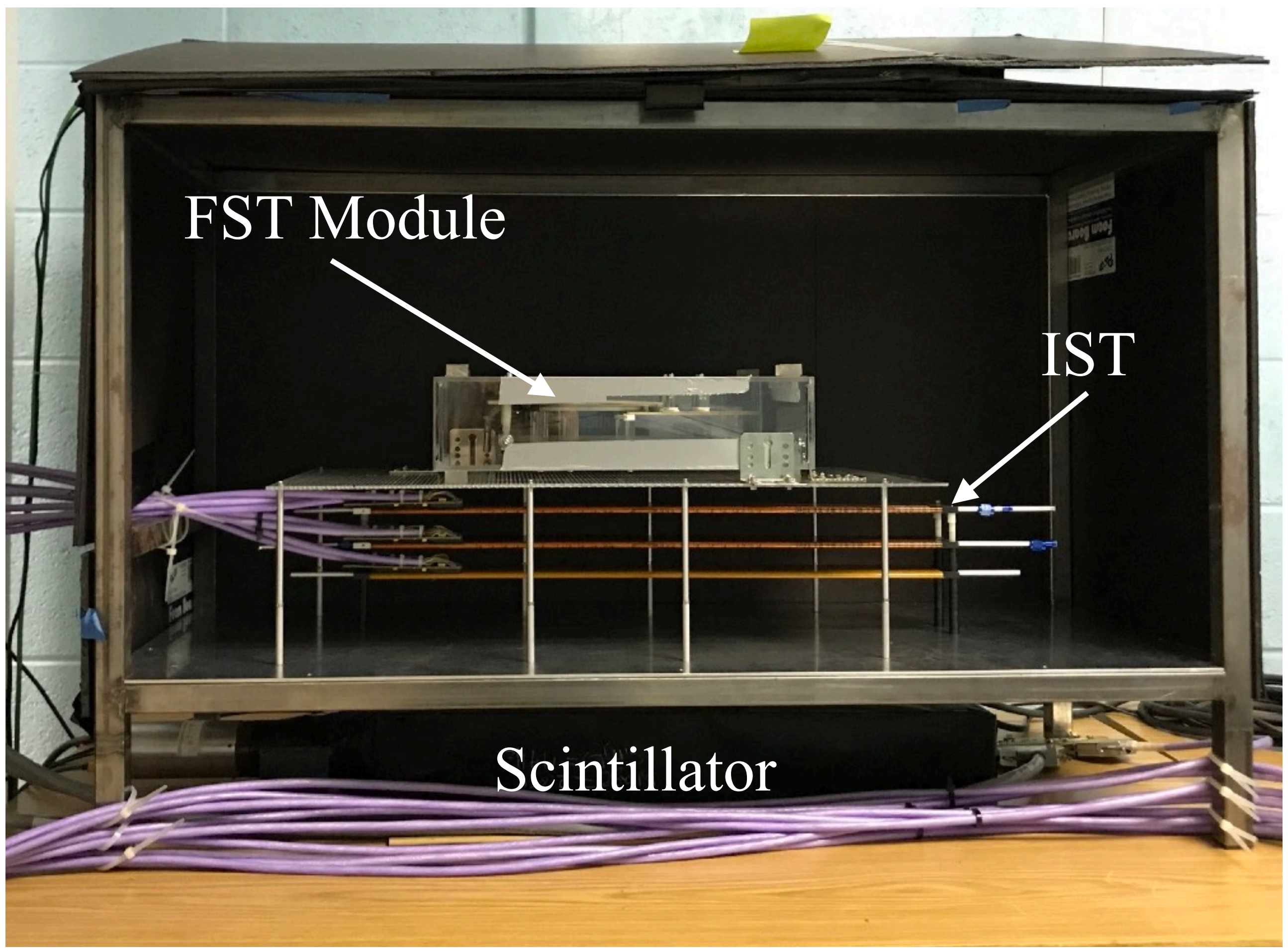




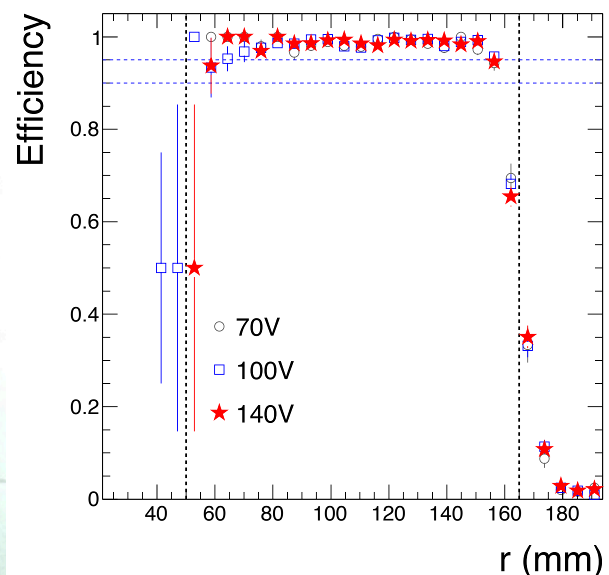
- Module assembly at FNAL from January 2021 to June 2021.
- 48 modules assembled: 43 good + 5 problematic.
- All the modules arrived at BNL on June 11, 2021.

FST Module Performance Test at UIC

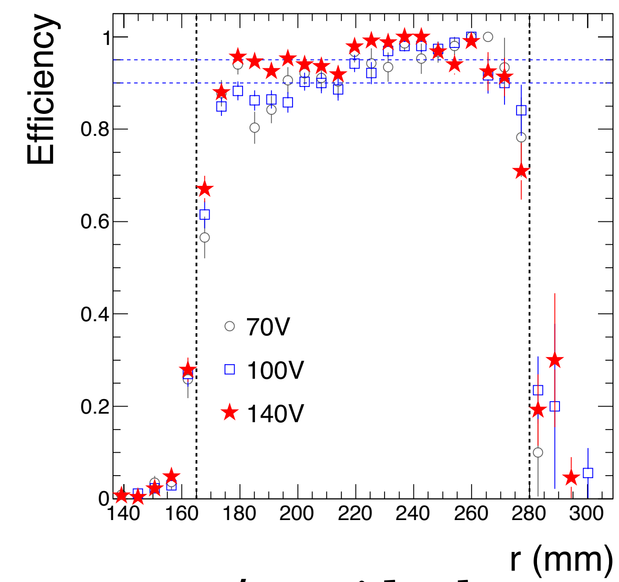
FST Cosmic Test Stand at UIC



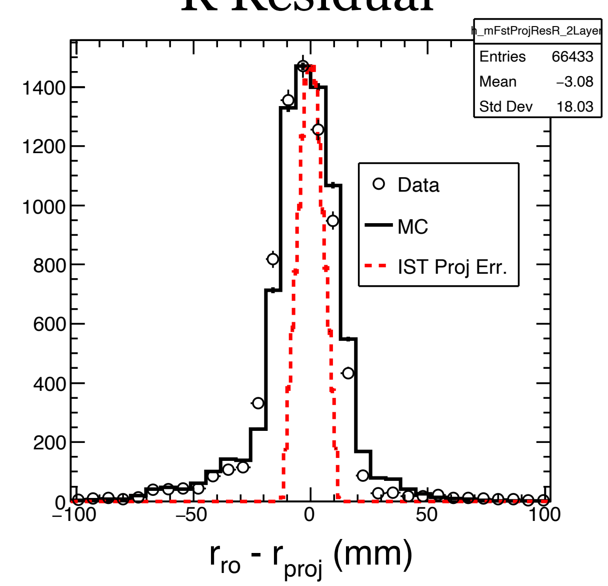
Inner Sensor



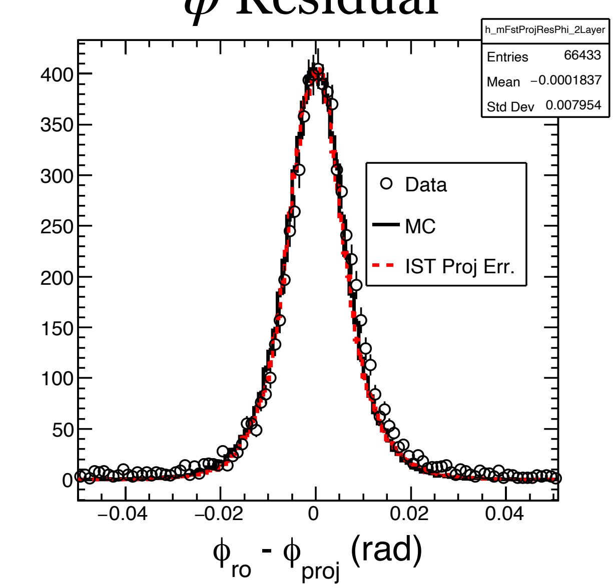
Outer Sensor



R Residual

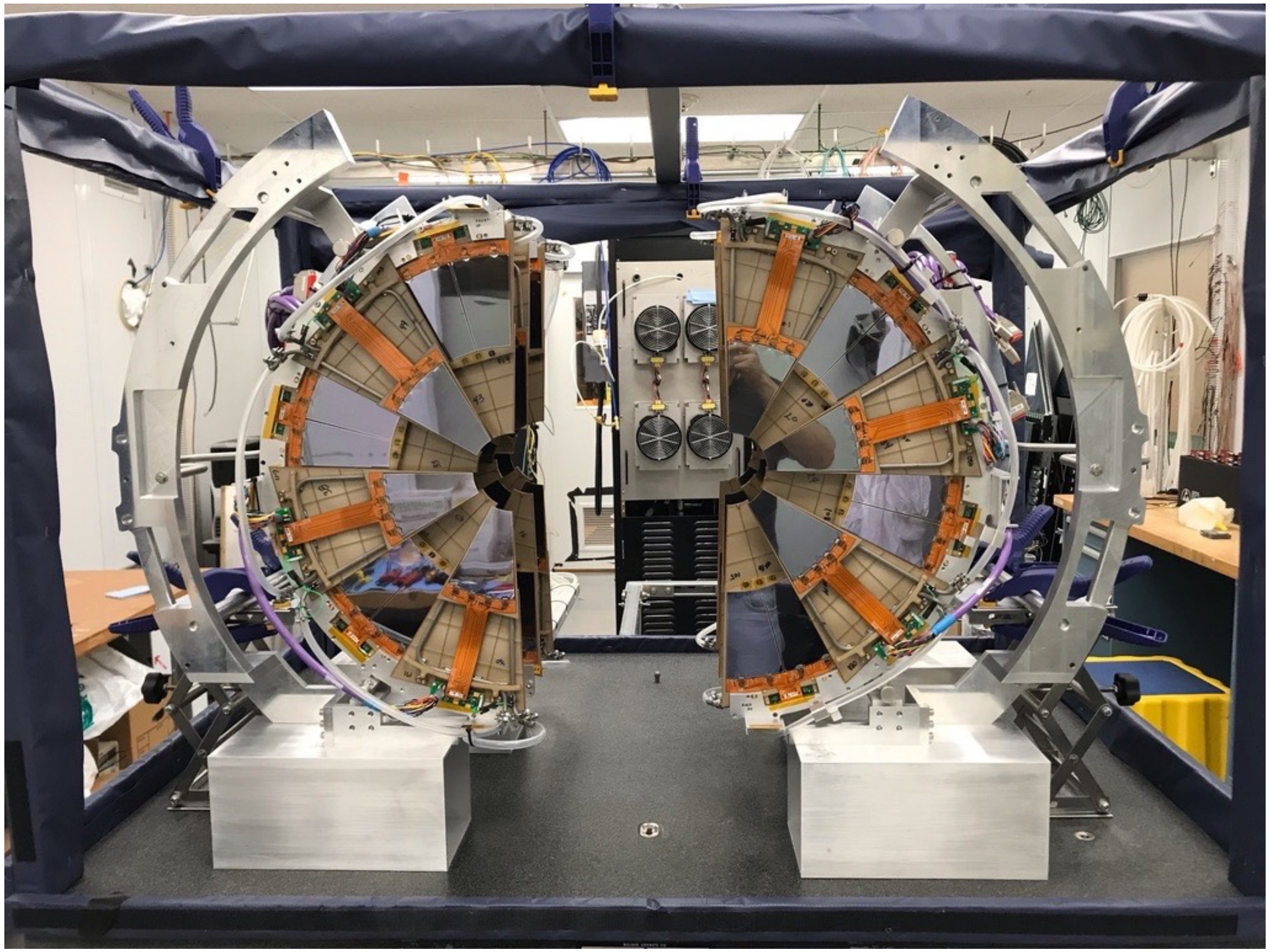


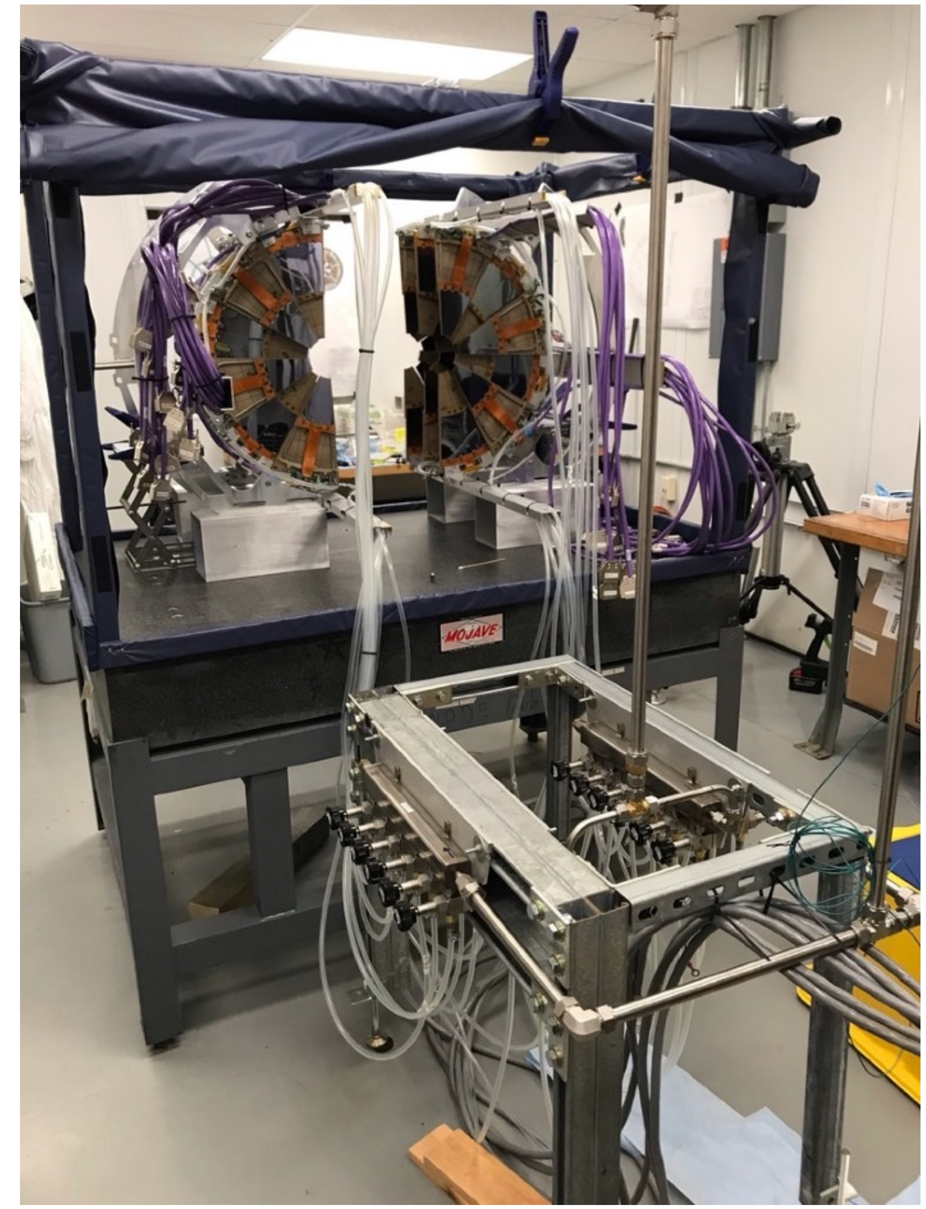
ϕ Residual



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

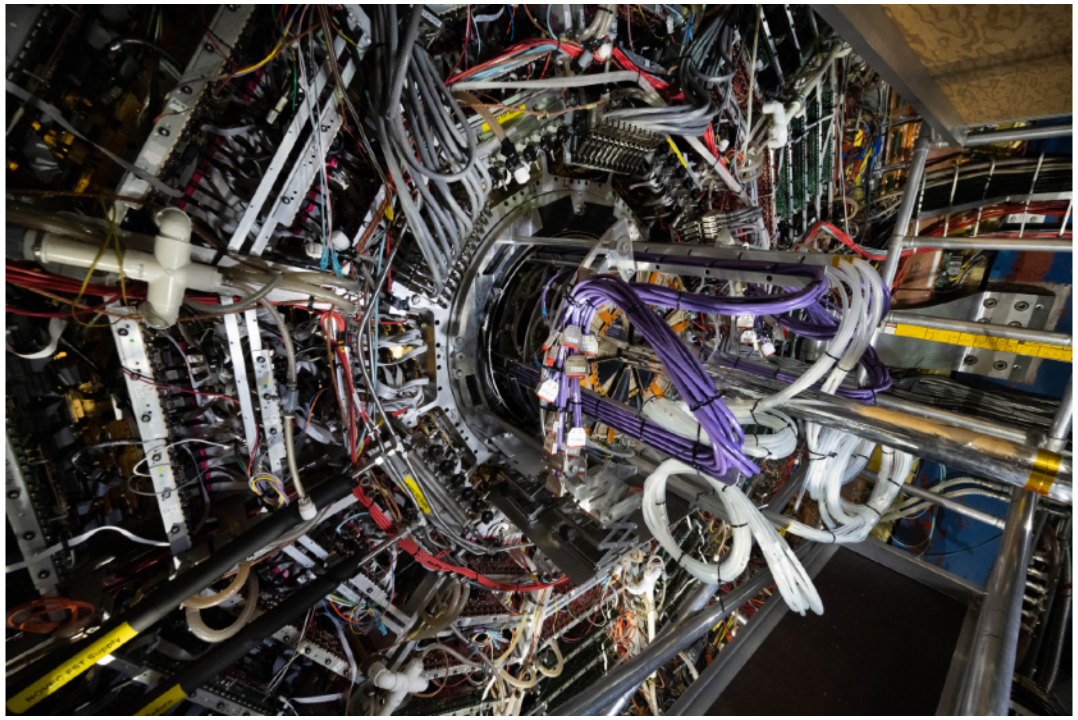
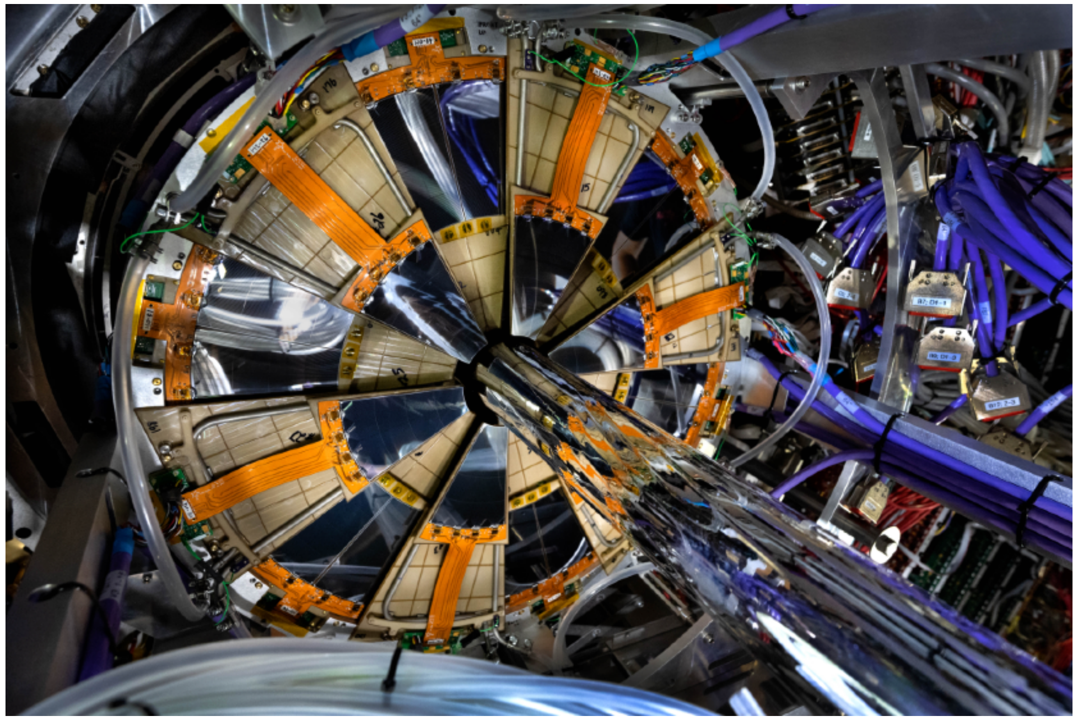
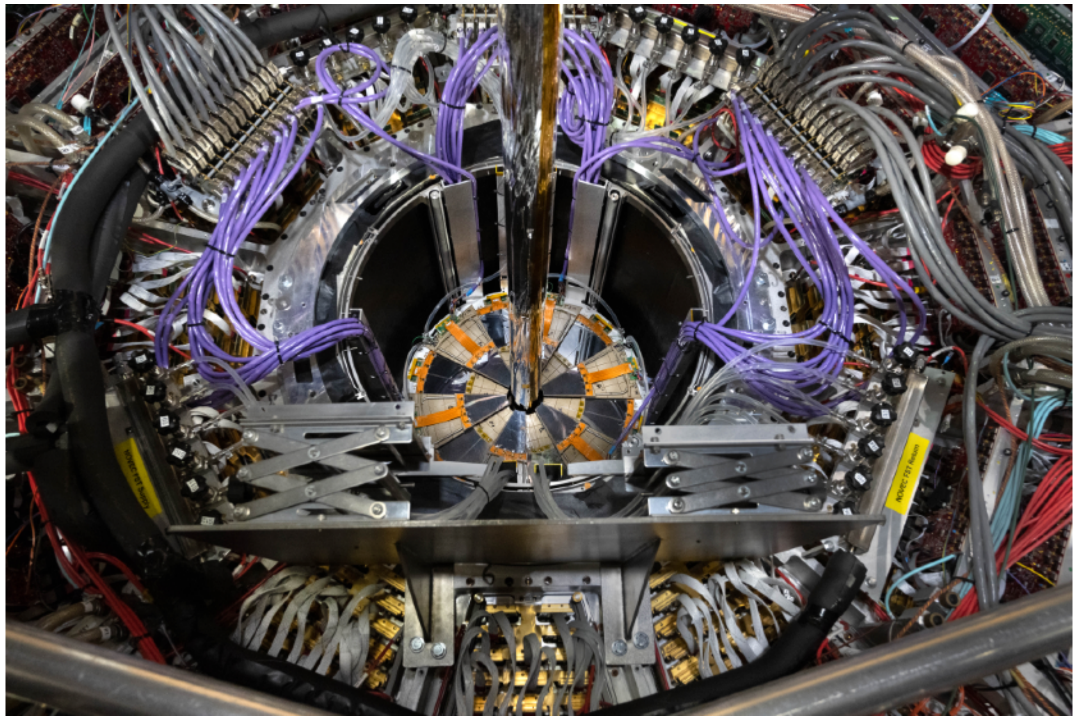
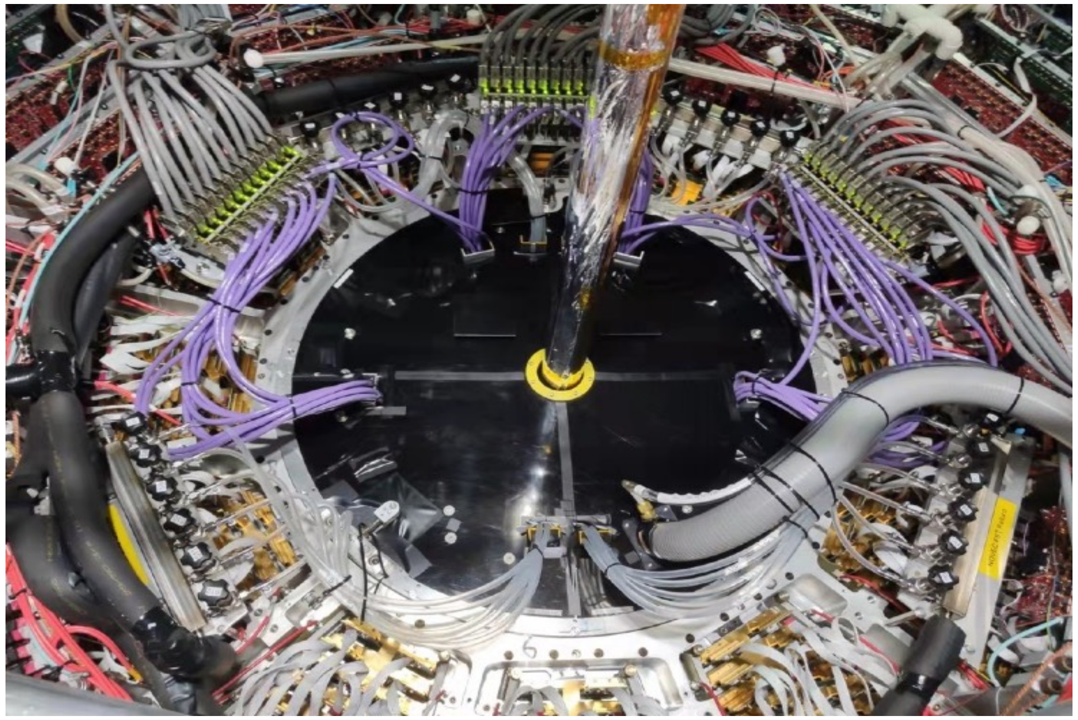
FST pre-Installation and Test at BNL





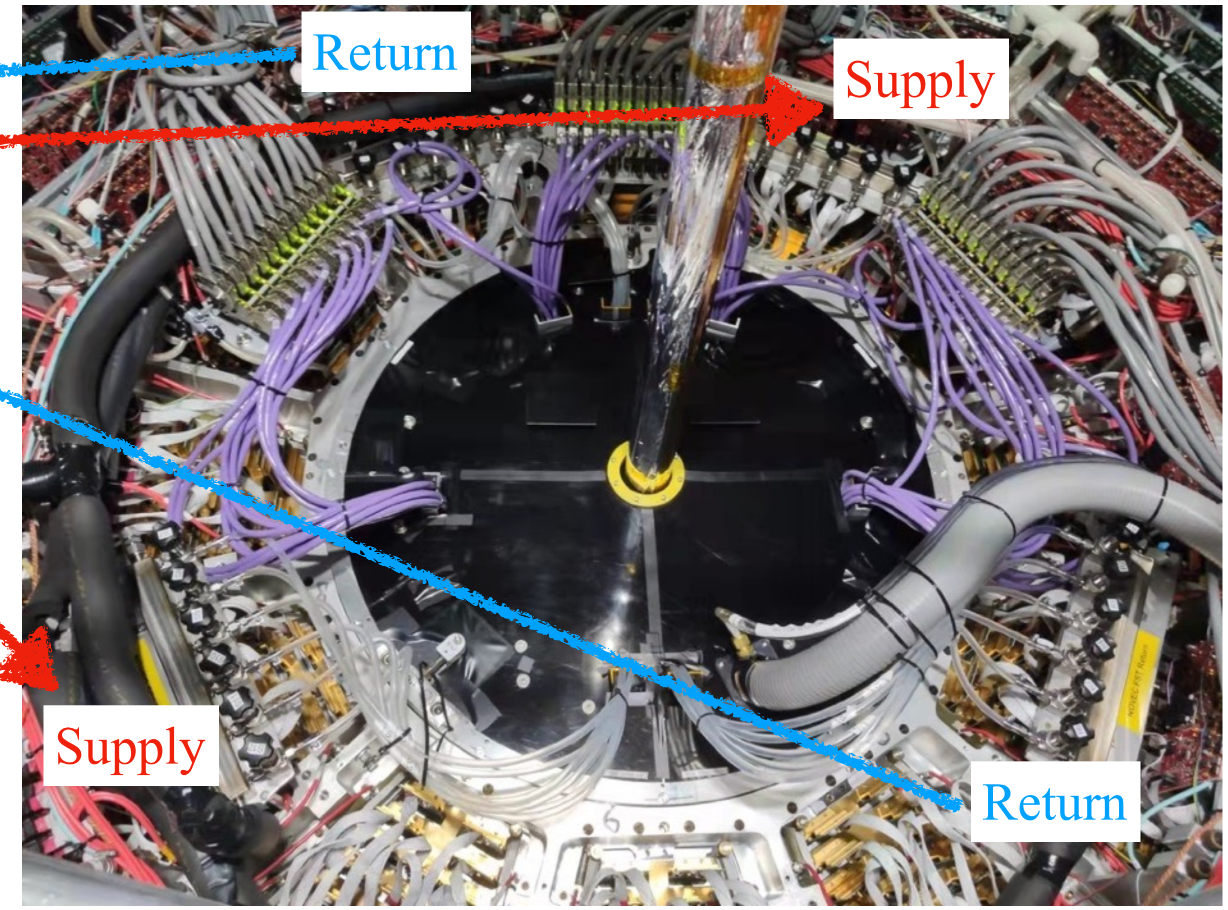
- FST modules installed into the support structure in the clean room (April - July 2021).
- Survey was done after each half plane completed (mid-plane has surveyed both sides).
- Readout and cooling test in the clean room for all 36 installed modules.

FST Installation at BNL

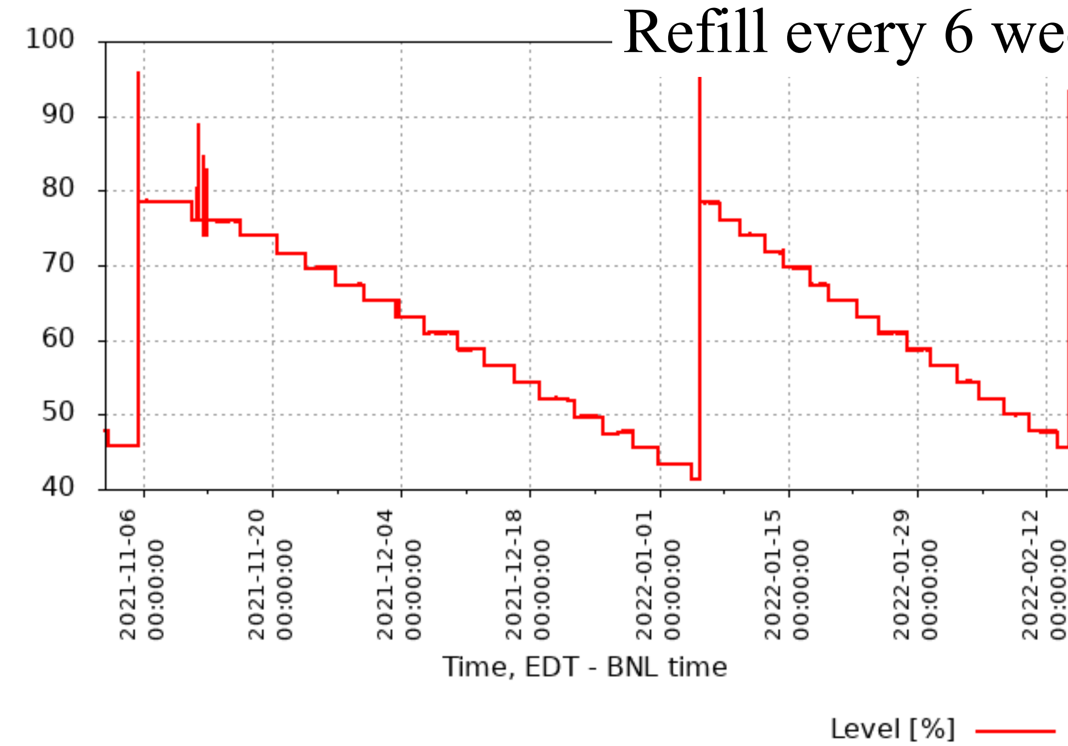





- FST Installation completed on 08/13/2021 and partition closed on 08/31/2021.

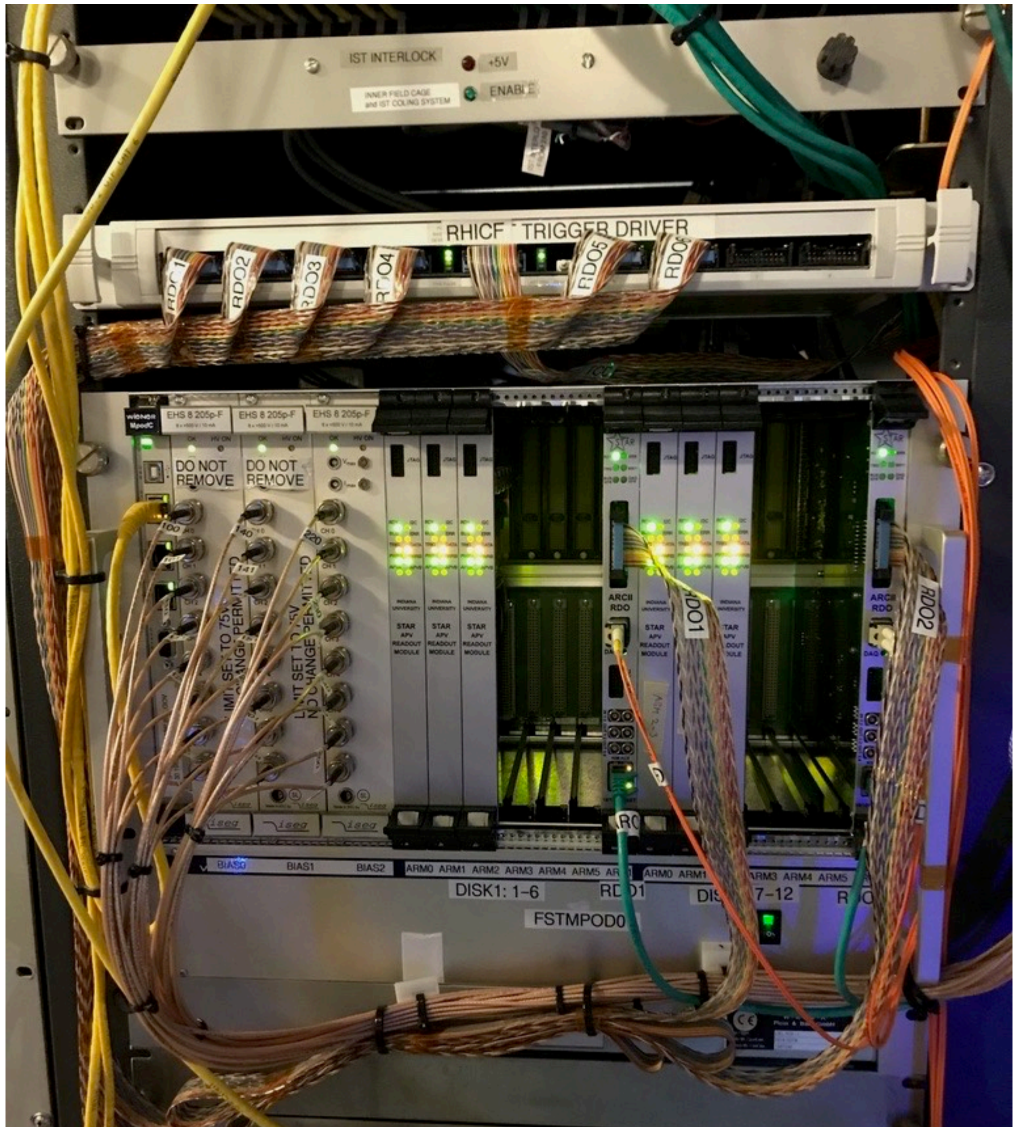
FST Cooling System

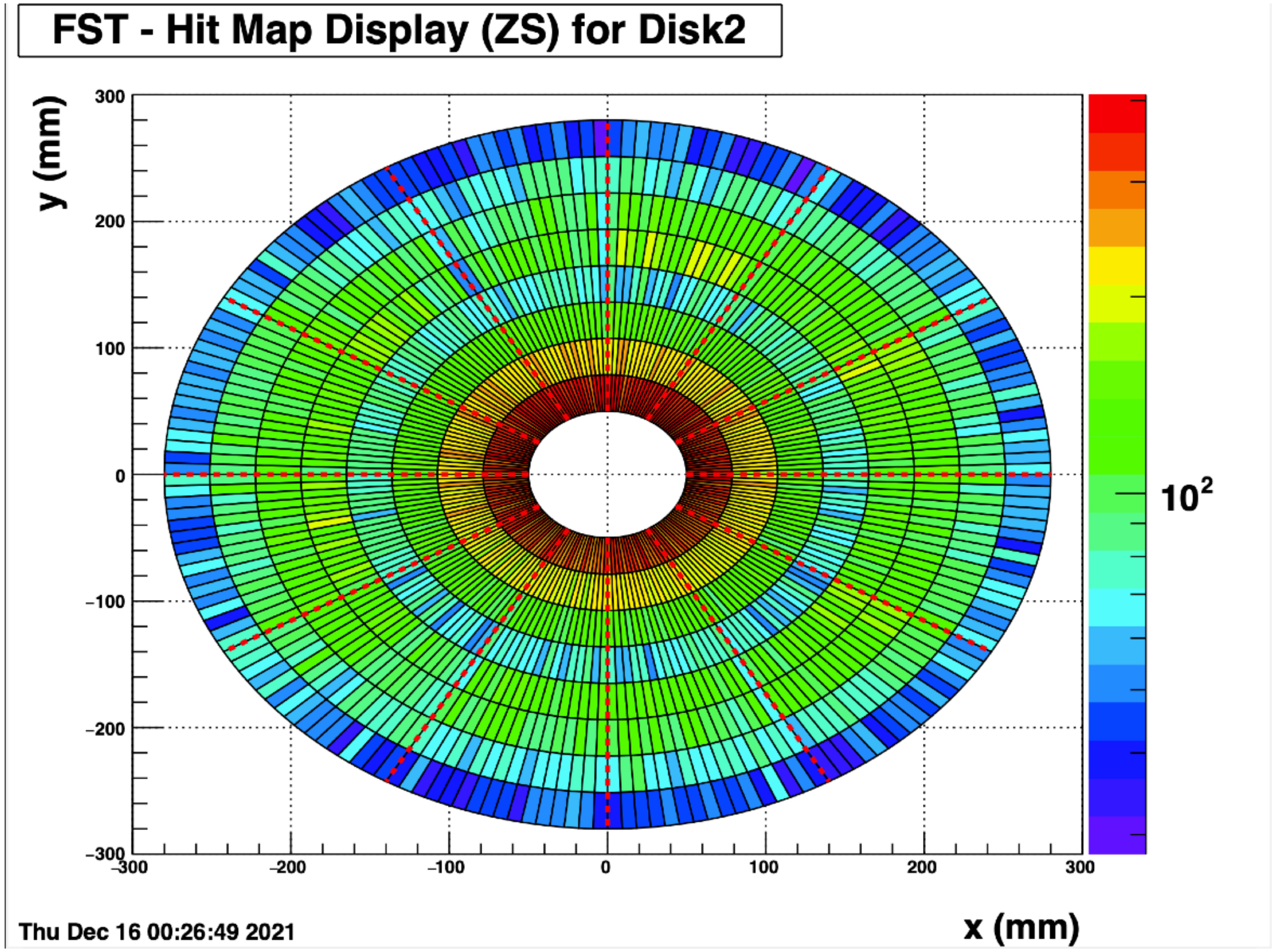


Refill every 6 weeks



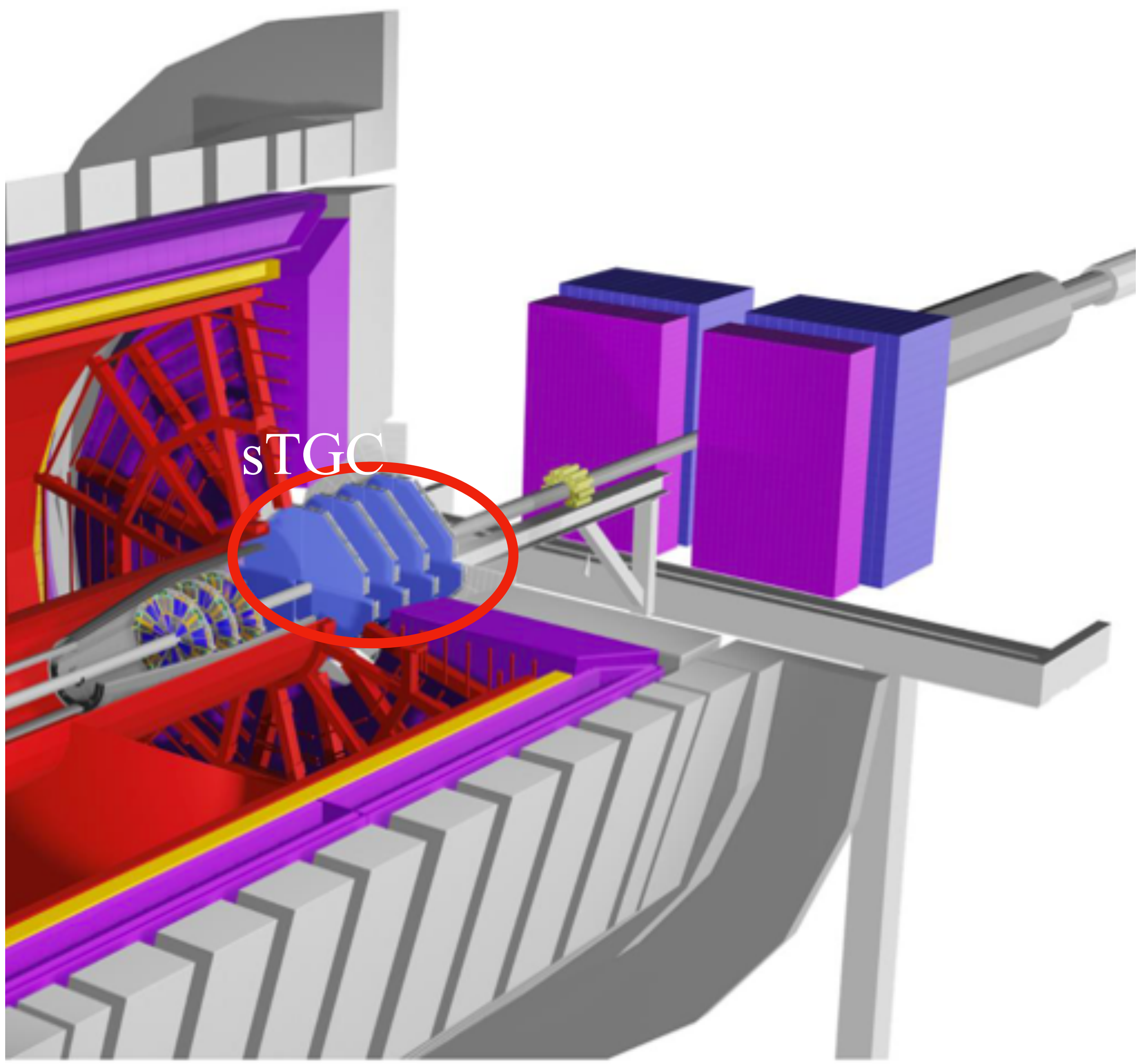
FST Operation





- Each FST disk is readout by 2 ARC & 6 ARM boards, reused IST system
- Operation HV: 140V for inner sensor and 160 for outer sensors
- FST is commissioned and currently taking data at STAR run 22

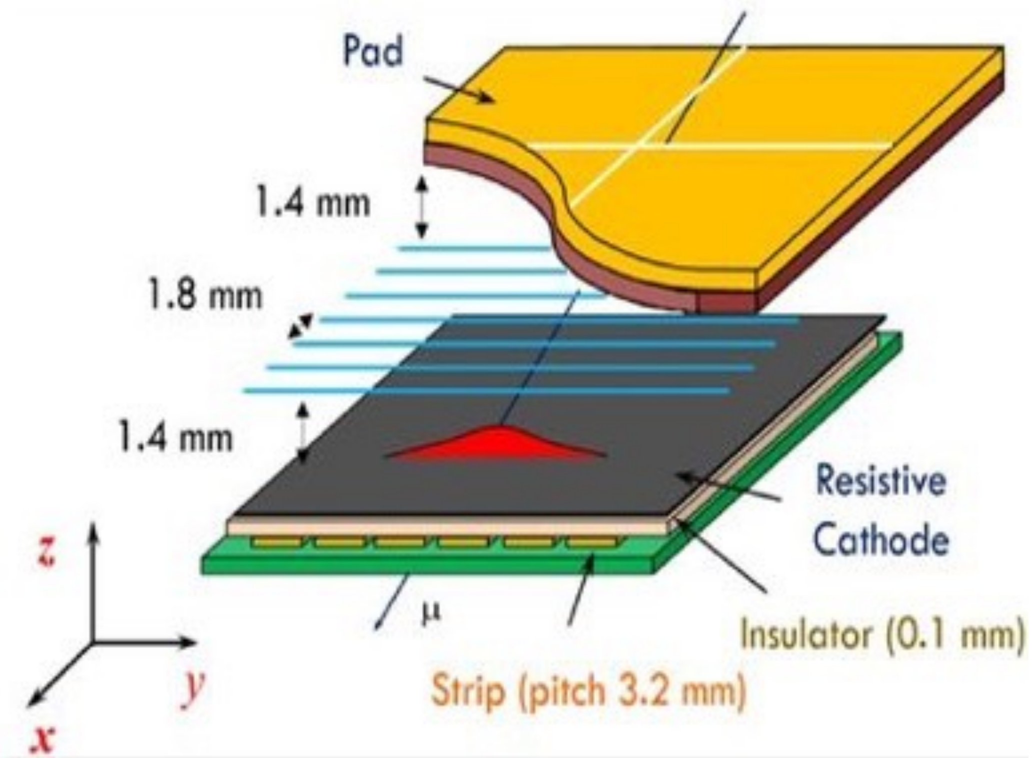
small-Strip Thin Gap Chamber



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: ~$100\mu m$
- Material budget: ~0.5% per layer,
- Readout: based on VMM-chips
  => following ATLAS design

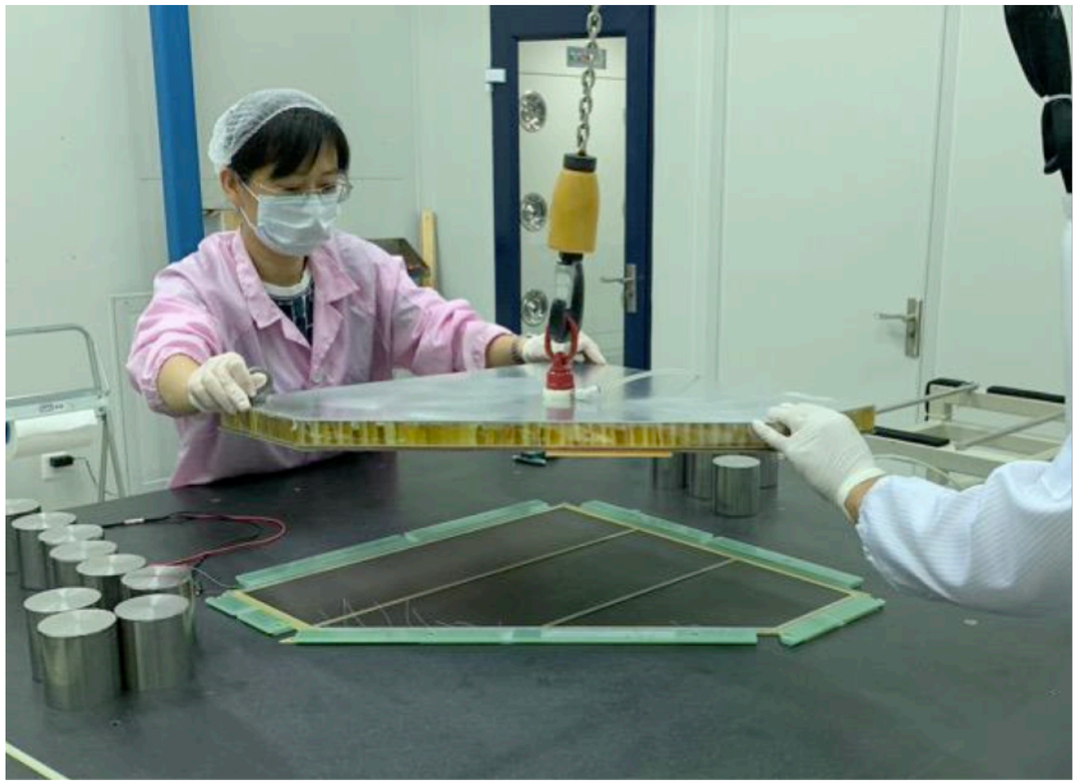
STAR forward upgrade: $2.5 < \eta < 4$
- faces blue RHIC beam
- rapidity coverage the same as EIC hadron Arm

sTGC Design

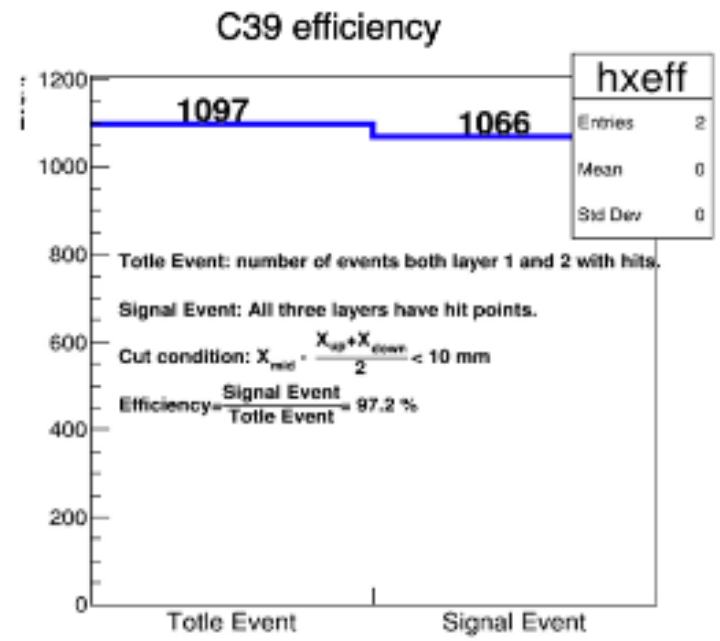


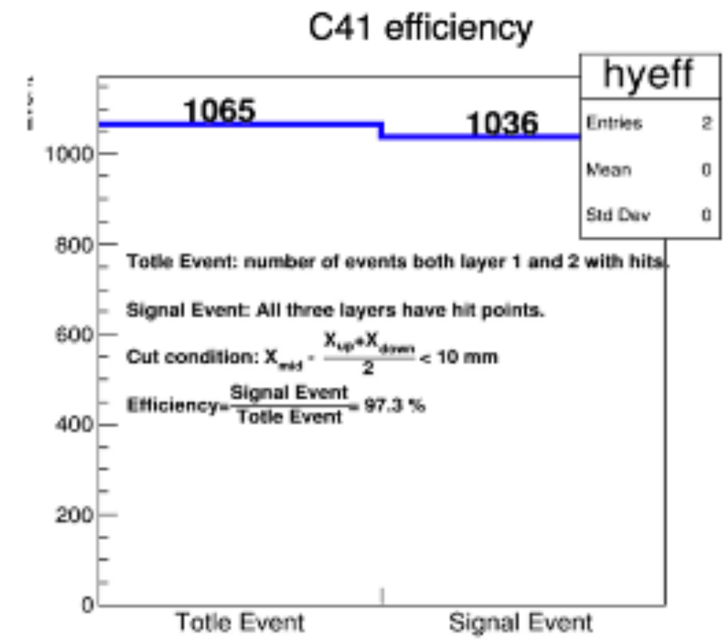
- Provides tracking and position resolution less than 100 μm, at high luminosity and background
- Anode (HV): 50 μm gold-plated tungsten wires held at a potential of ~2900 V
  - TPC 20 μm wires
- Working gas: n-Pentane+CO_2 = 45:55% by volume
- Cathode(Ground): graphite-epoxy mixture with a typical surface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

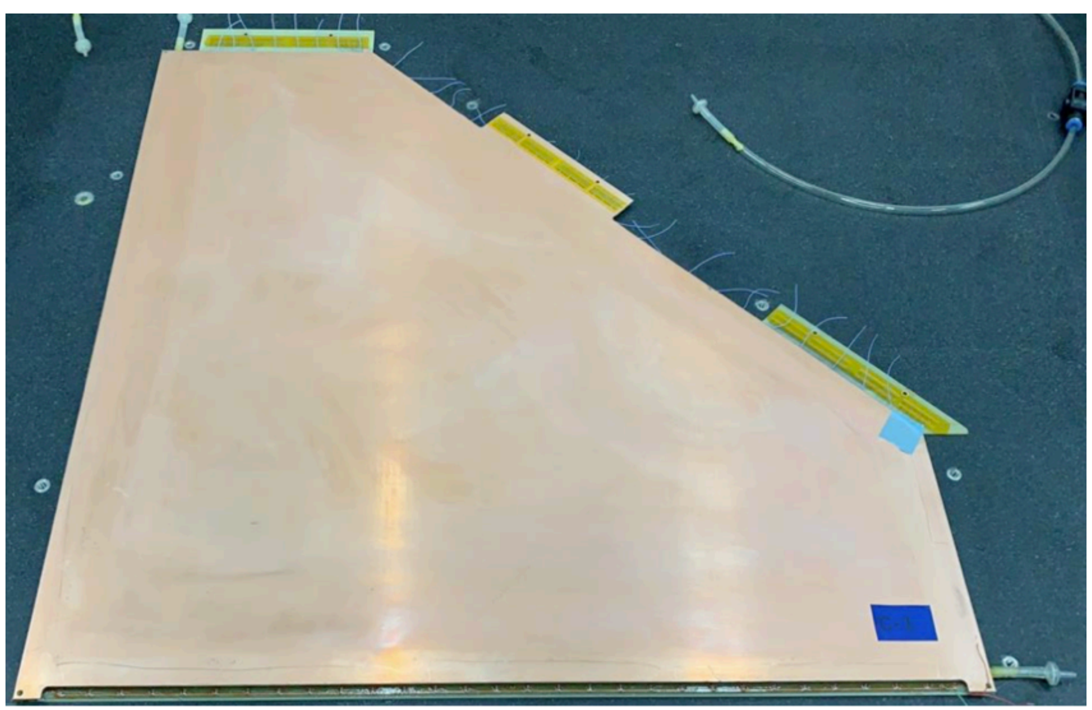
sTGC Assembly at SDU



Efficiency > 97%

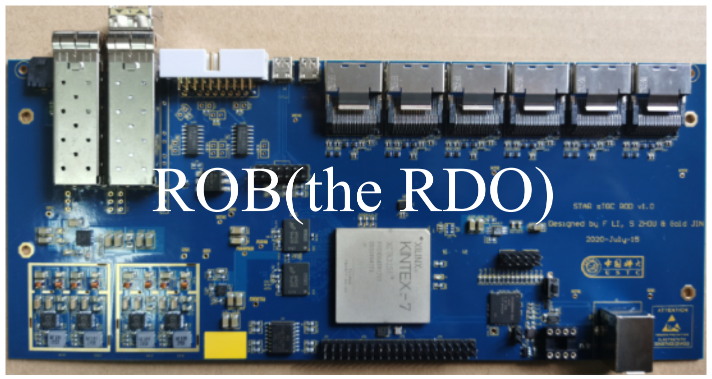


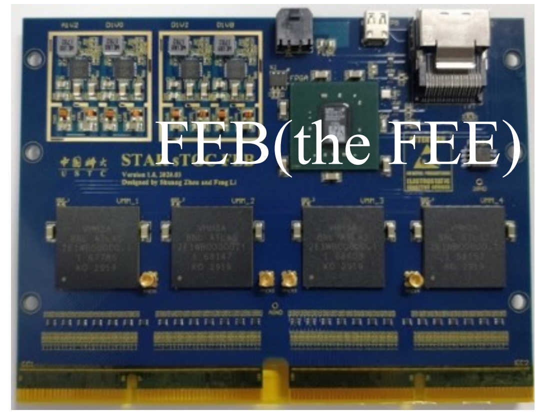


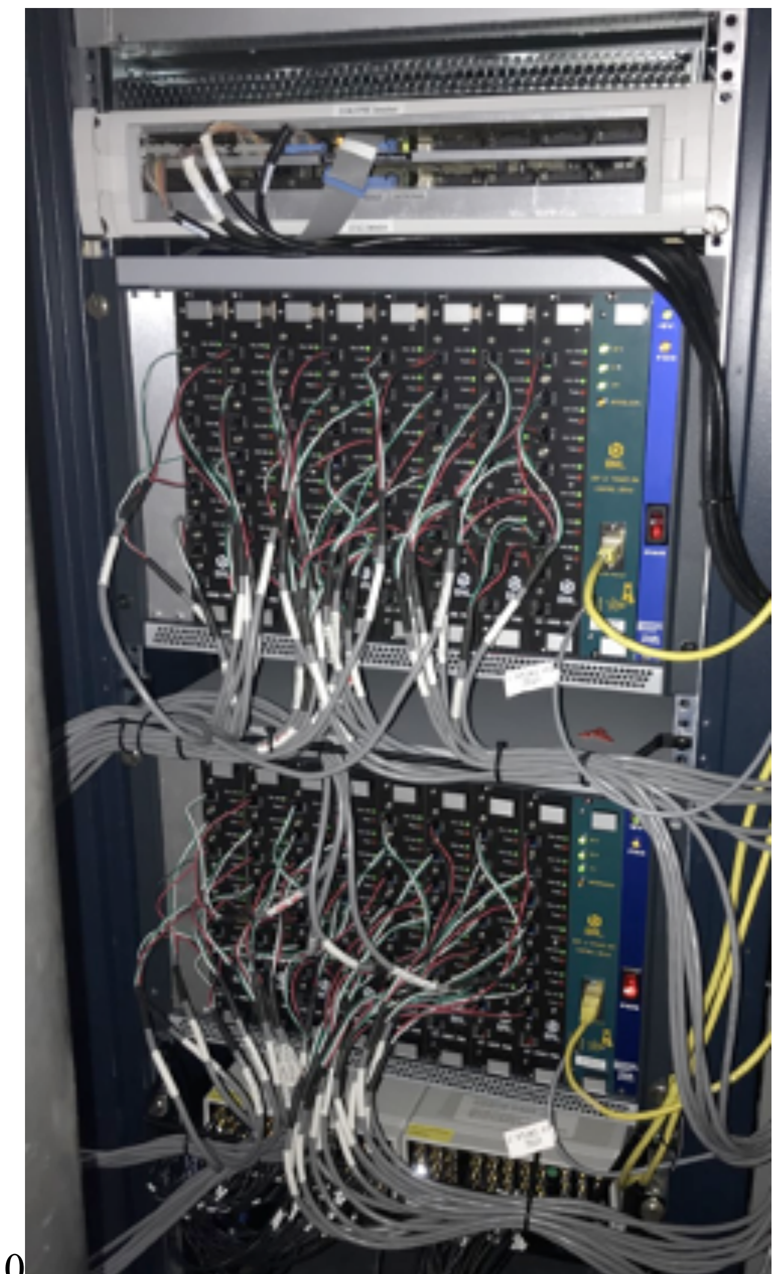


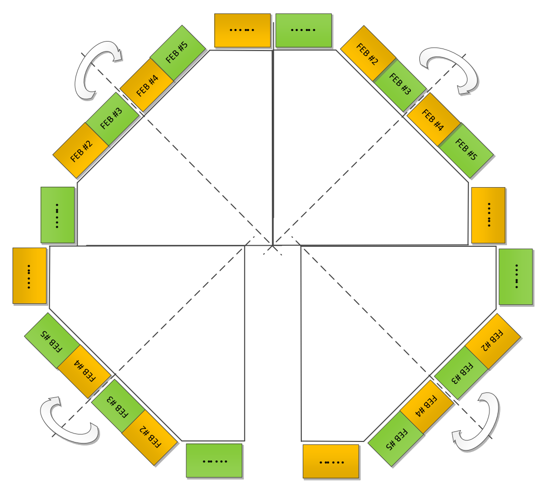
- Four planes, each consisting of four 55cm*55cm pentagonal modules
  - Double-sided sTGC with diagonal strips
  - Position resolution < 100 μm
  - performed cosmic ray test at SDU
- Material budget ~0.5% X_0 per layer
- 19 pentagon modules are produced and arrived at BNL on 08/06/2021.

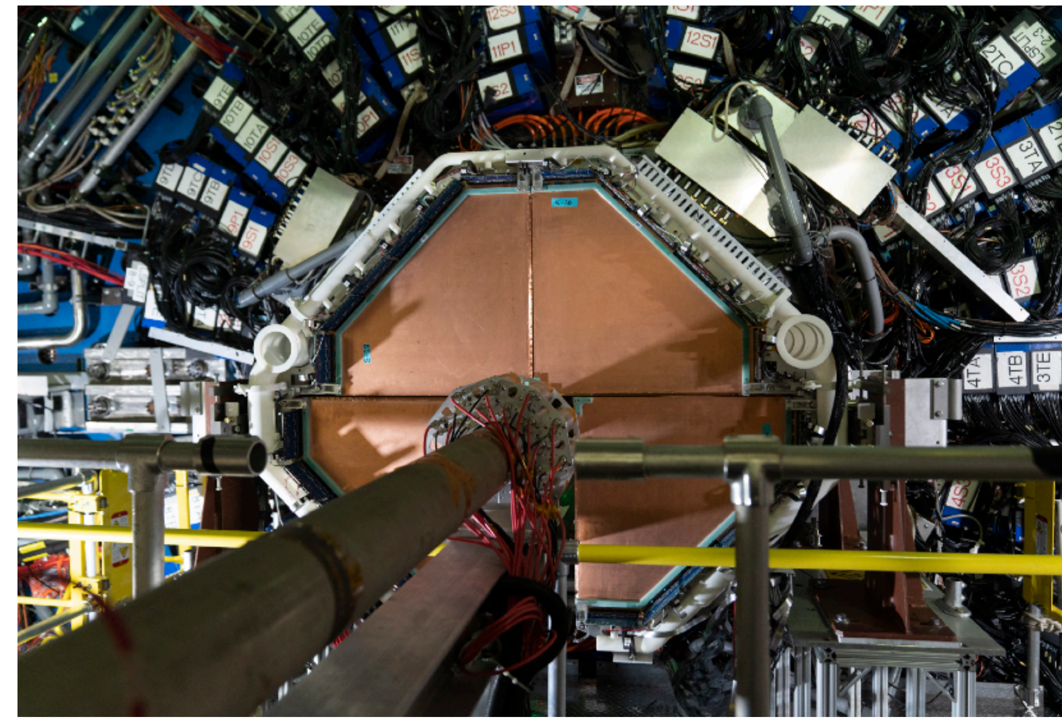
sTGC Electronics Design at USTC





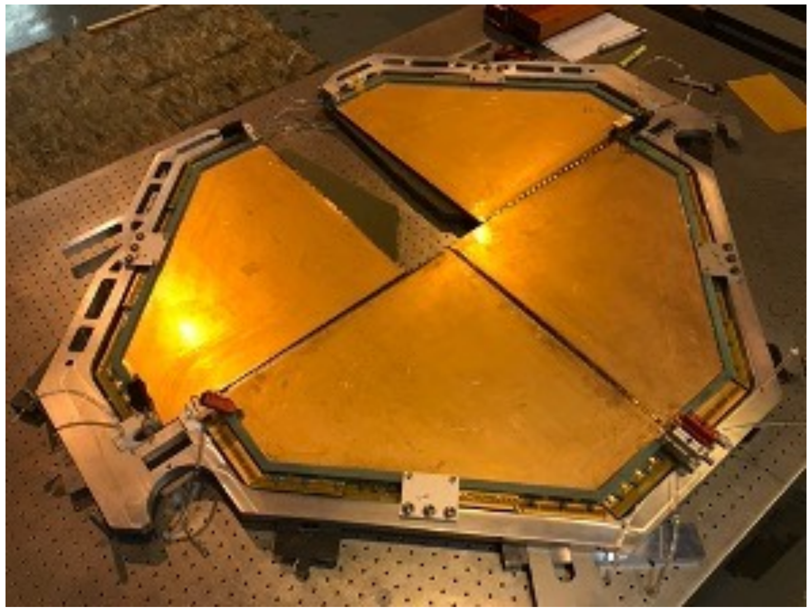


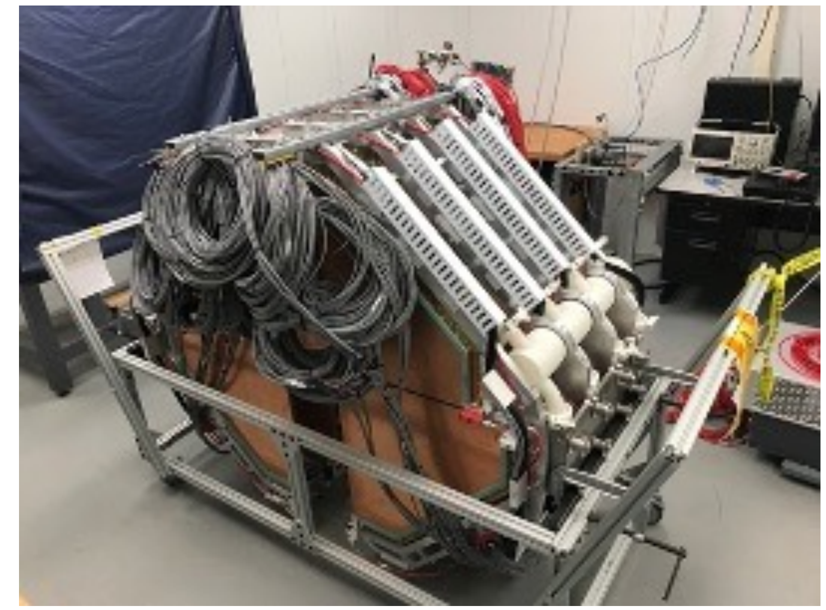
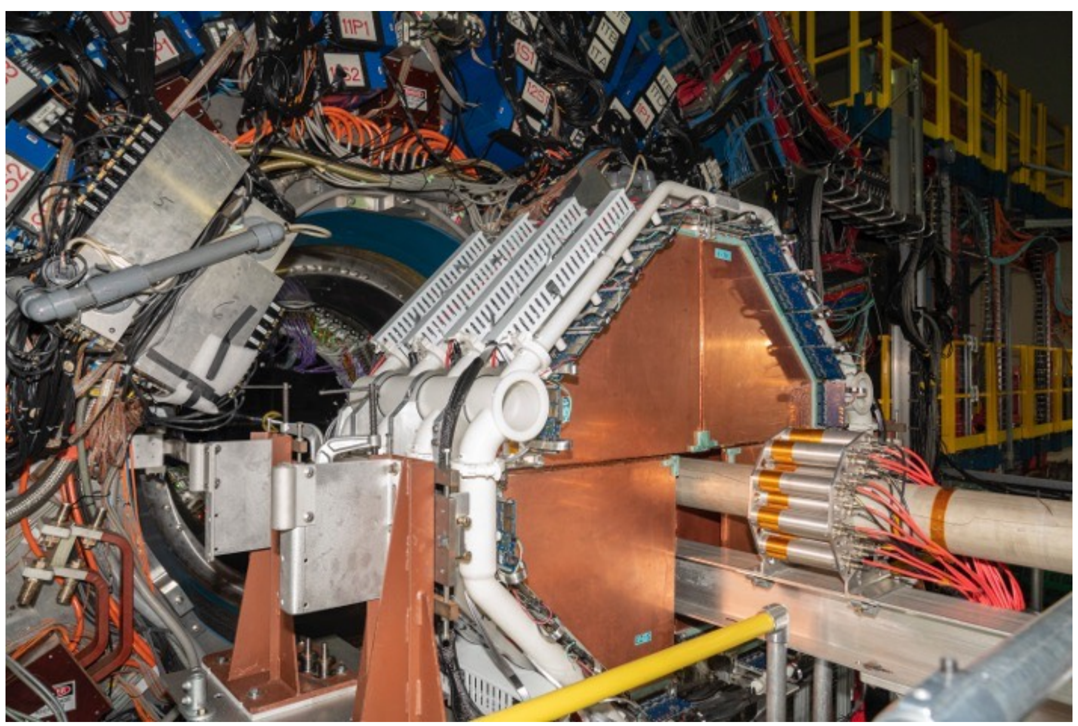
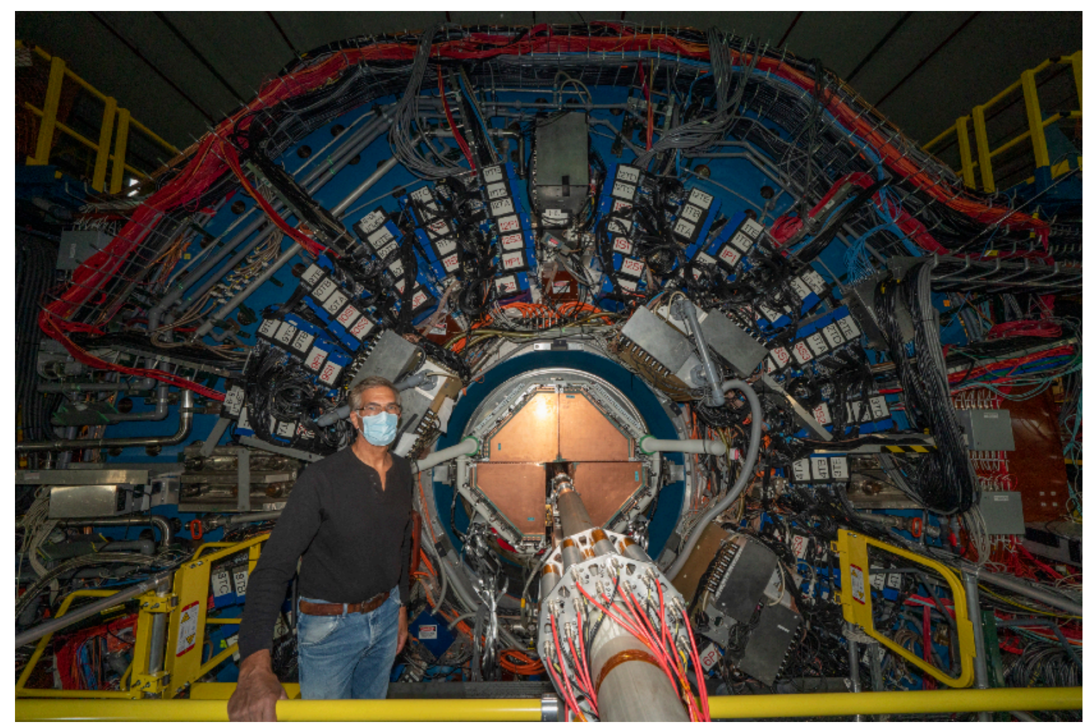




- FEBs are designed based on VMM chips. 4 VMM chips/ board, 212 channels.
- 96 Front-End Boards => 24 FEBs for each layer.
- 16 Read Out Driver Module => one for every 6 FEBs.
- ROD modules are designed based on Standard VME 6U Crate (with DC power supply).

sTGC Installation at BNL



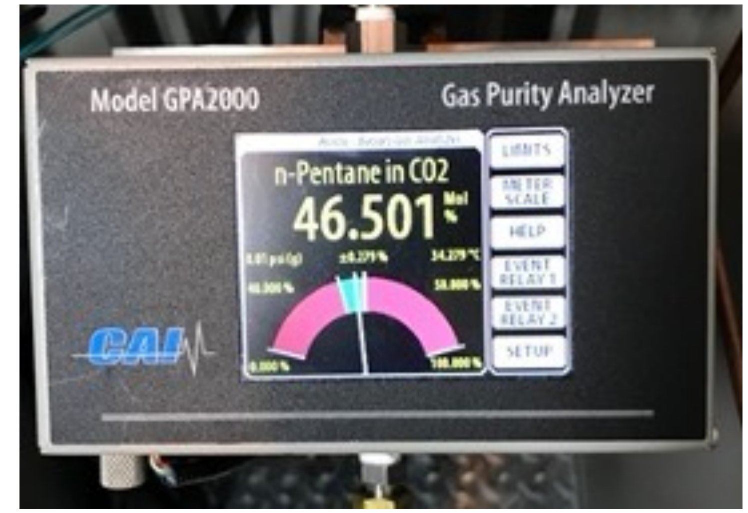




sTGC Gas and Safety System at BNL

Gas Cabinet

Gas Distribution Panel

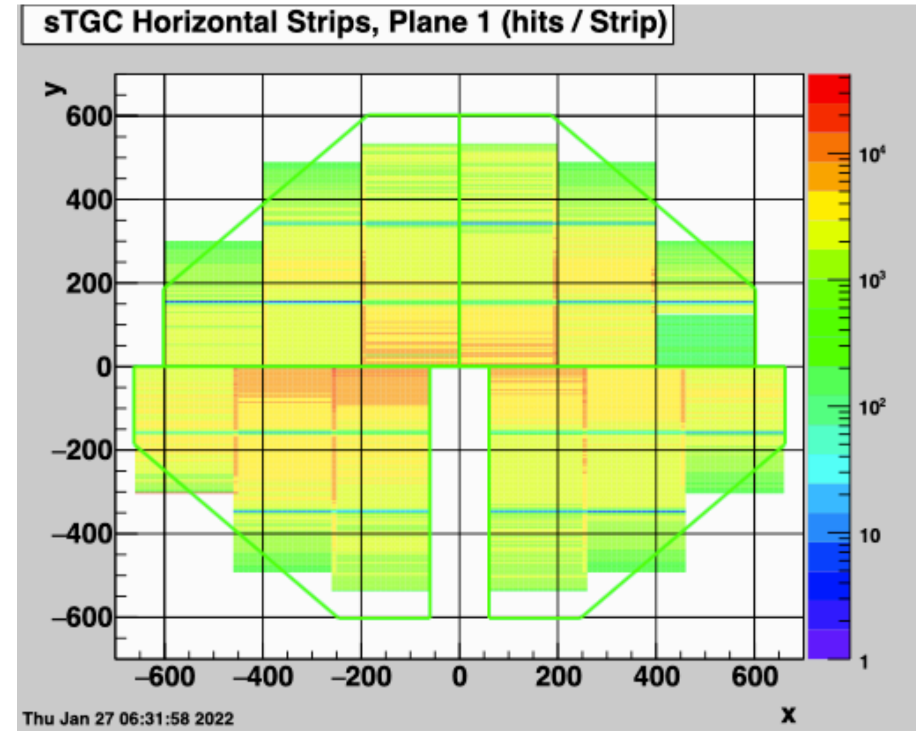
Gas Purity Analyzer

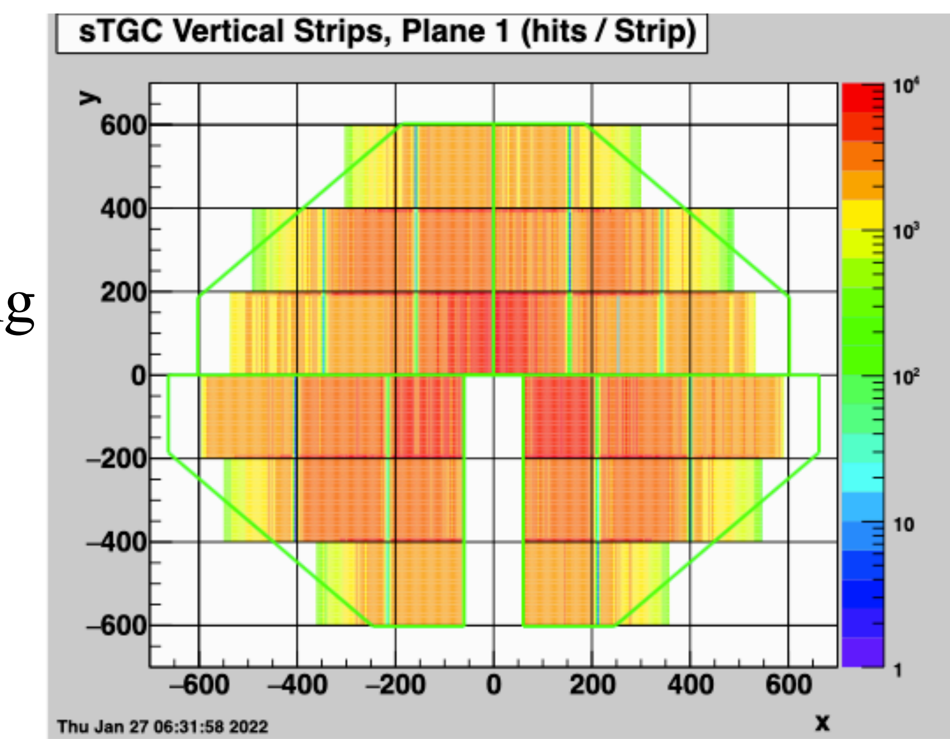


- sTGCs use a mixture of CO_2 and n-pentane
  - n-pentane isomer formula C5H12
  - Extreme care needed for the highly flammable n-pentane!
  - Flash point –49 ^{0}C; explosive limits 1.5 – 7.8%
  - Boiling point of 36.1 ^{0}C further complicates things
- Has operated extremely well through major power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

sTGC Operation

sTGC HV Slow Control





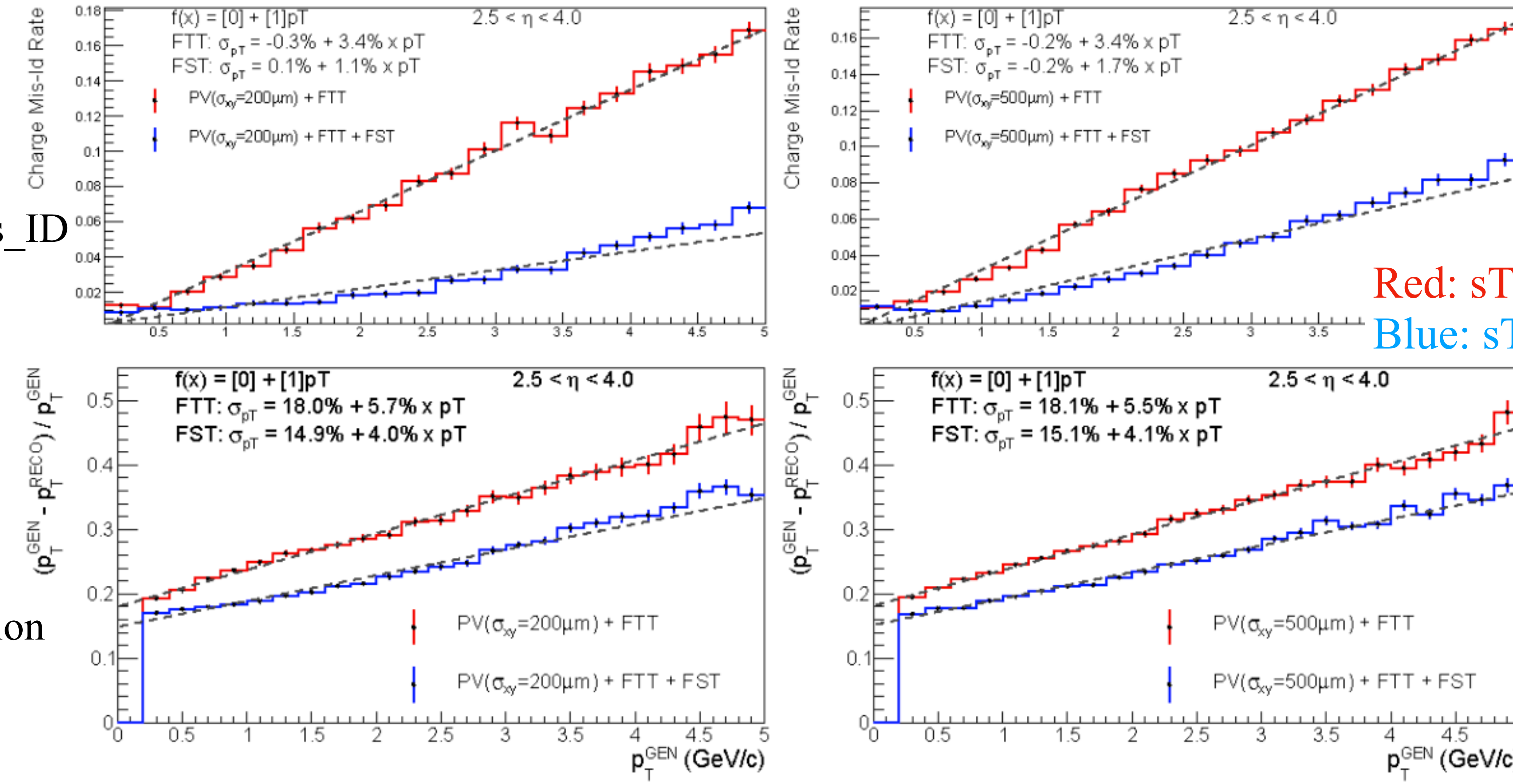
- Operation HV: 1500 V for standby and 3000 V for data taking
- Safety and gas mixing is automated through interlock logic
- Refill pentane, every three weeks by experts
- CO_2 change every two months by experts
  - Backed up by reserve tank online—no run out
- sTGC is commissioned and currently taking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

Simulated Performance of the Forward Tracker

vertex resolution = 500 μm | vertex resolution = 200 μm

Charge mis_ID rate vs. p_T

p_T resolution vs. p_T

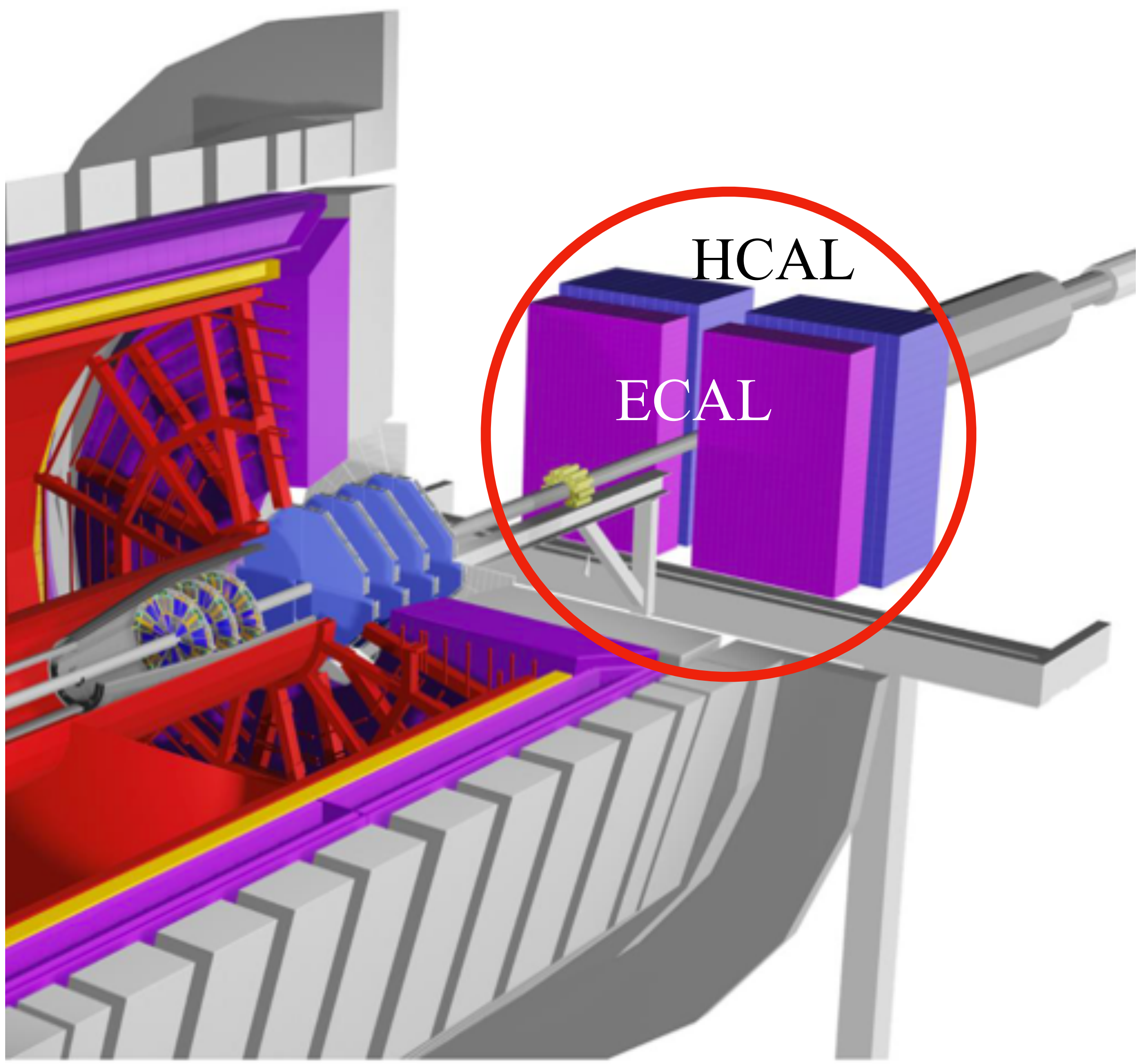


Red: sTGC only

Blue: sTGC + FST

- 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 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

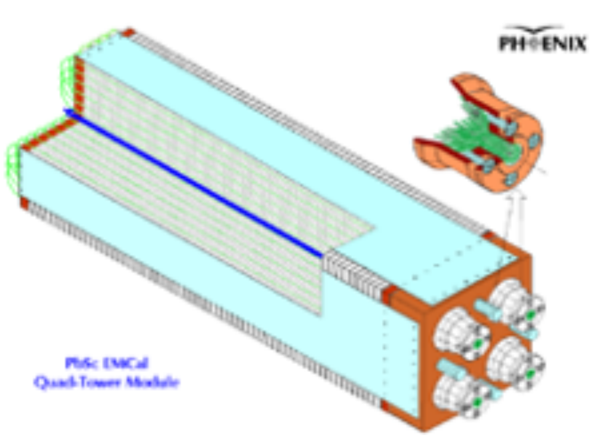
Location: 7 m from the IP on the "FMS platform"
Readout: SiPMs
- Used in Trigger
- Split in 2 movable halves inside and outside of ring
- Slightly projective

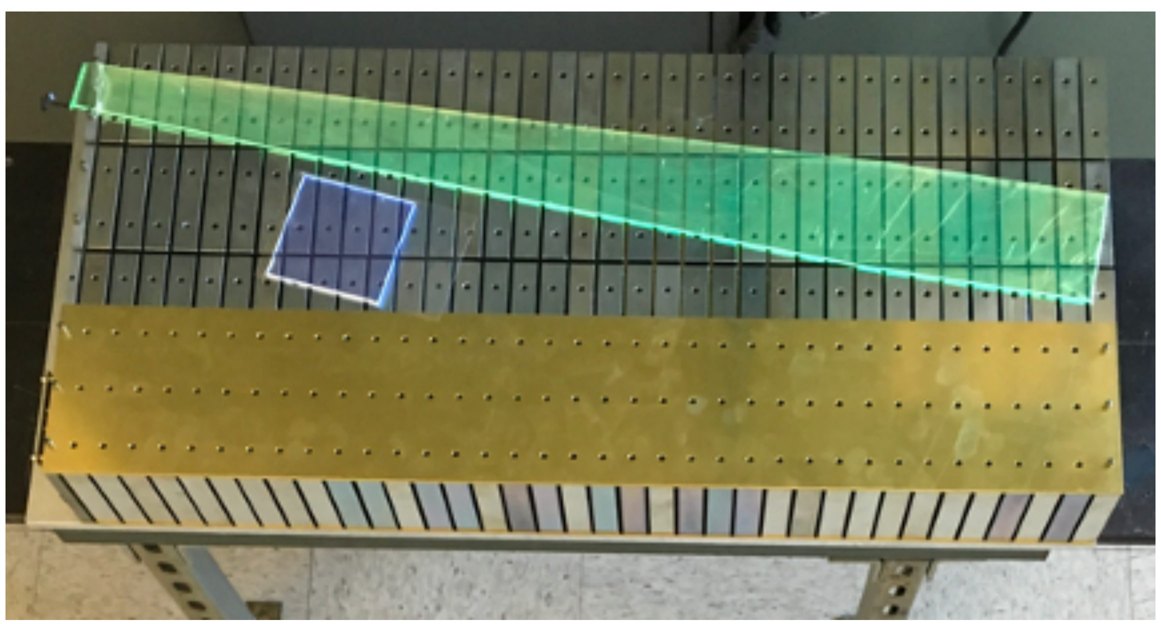
ECal:
- reuse PHENIX PbSC calorimeter
  - 1496 channels: 5.52 x 5.52 x 33 cm^3
  - 66 sampling cells with 1.5 mm Pb/4 mm Sc
  - 36 wavelength shifting fibers per cell
  - 18 X_0; 0.85 λ
- replaced PMTs with SiPM readout

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 => Splitter prototype tested and final ones currently built

Forward Calorimeter System





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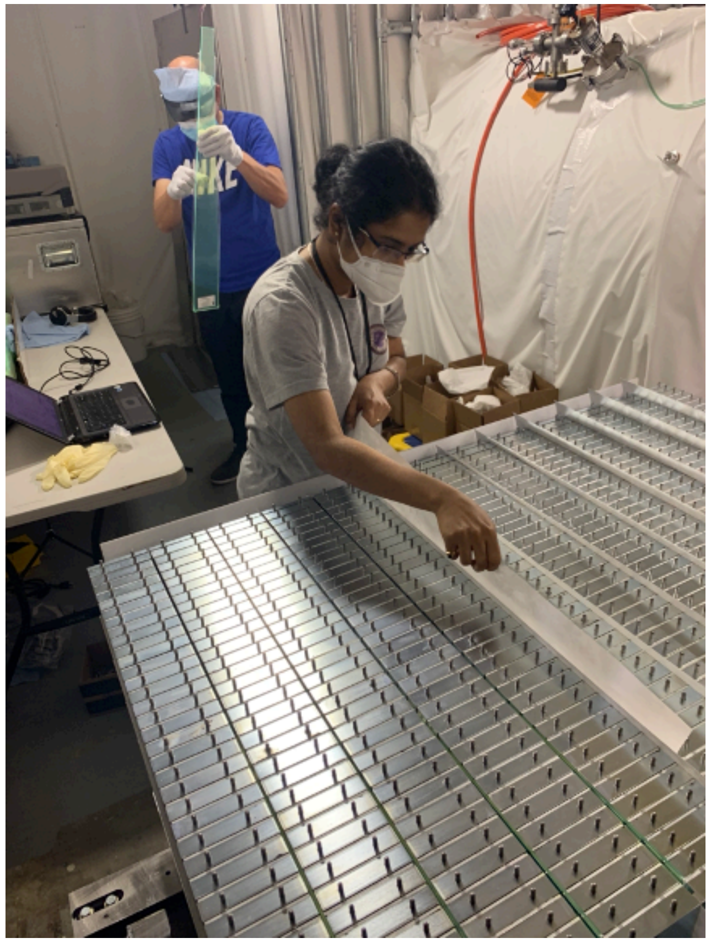
Forward Colorimeter System



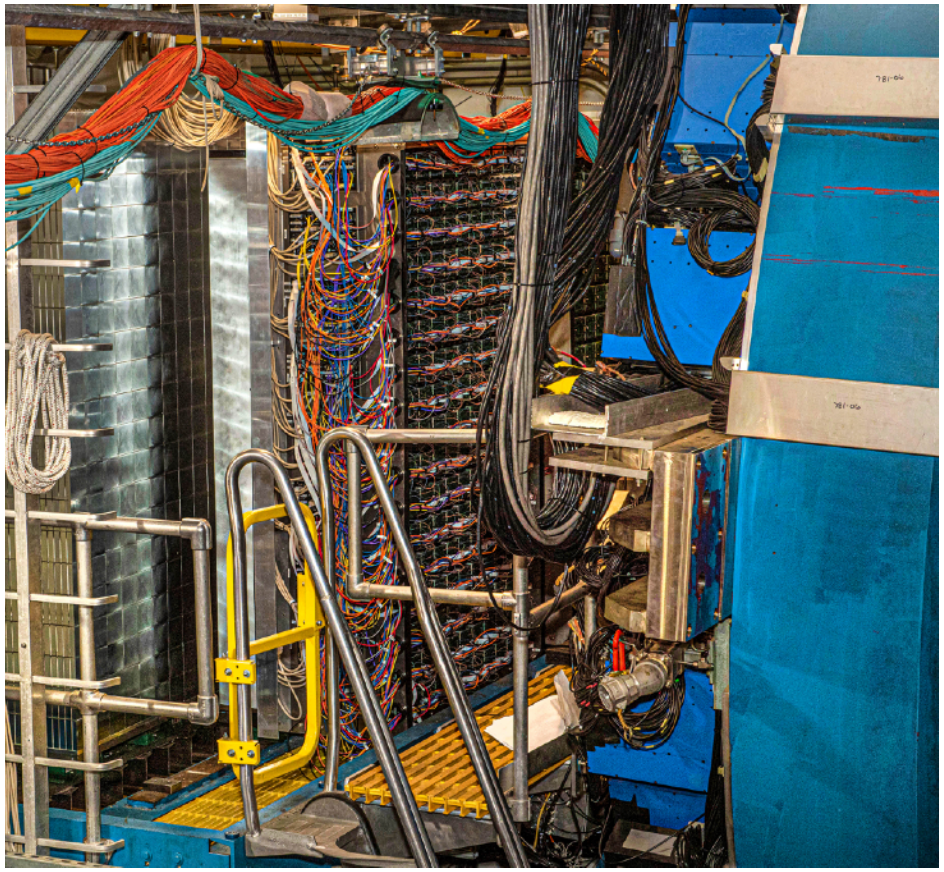
Members of UC EIC Consortia
Assembling FCS in Autumn 2020 at BNL

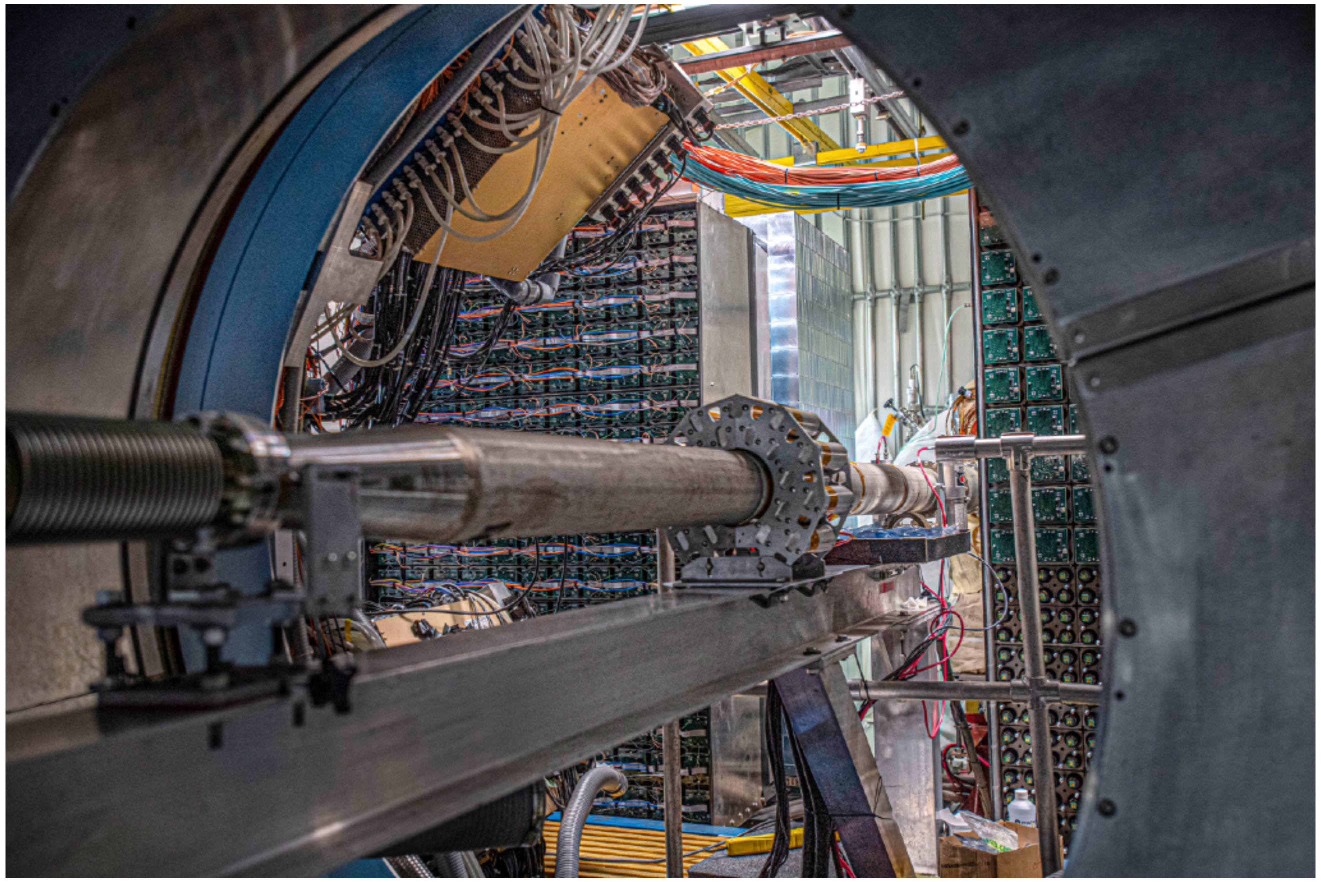
Forward Calorimeter System (FCS)

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

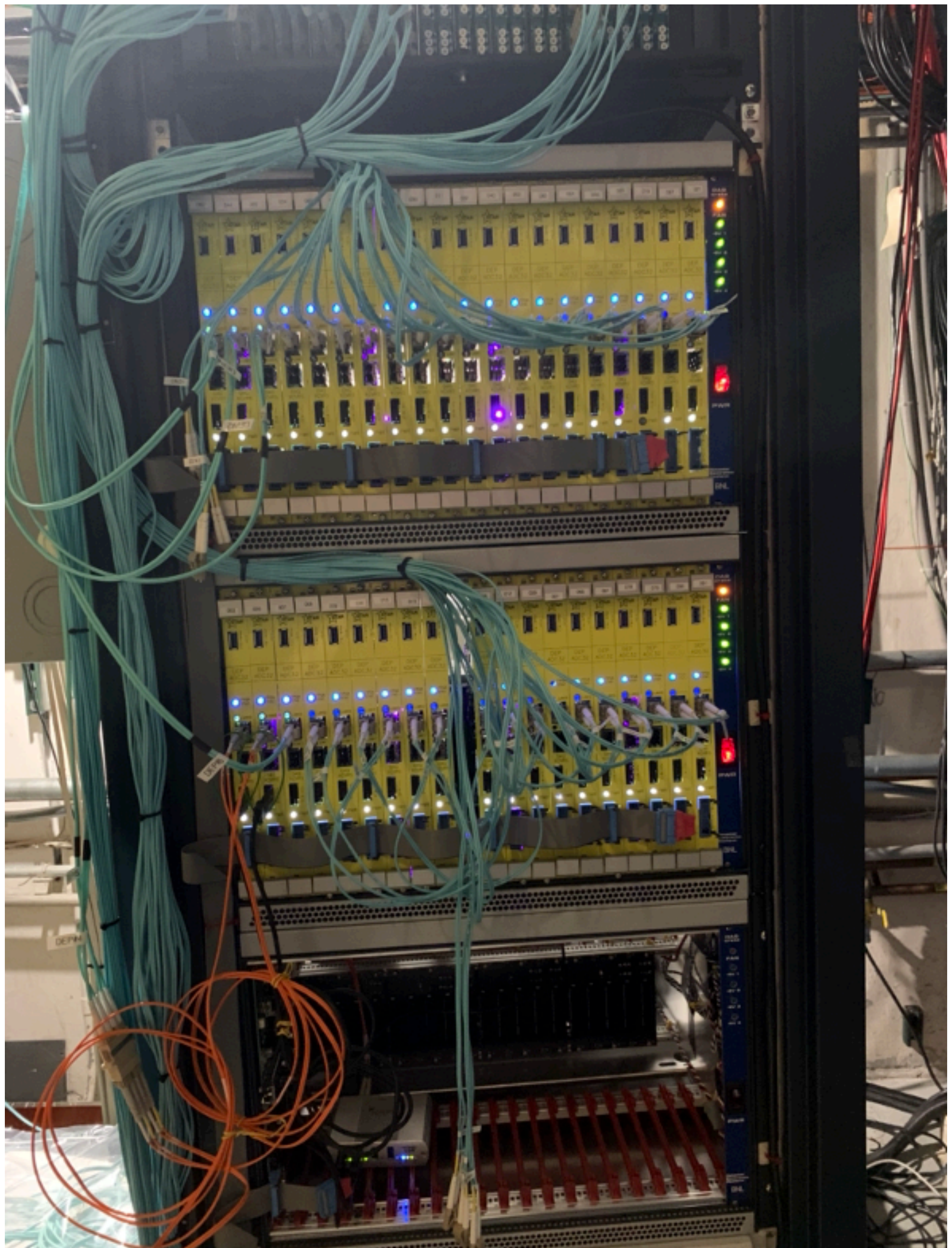
Large group of STAR collaborators actively engaged in all aspects of the project:
ACU, BNL, UCLA, UCR, Indiana University CEEM, UKU, OSU, Rutgers U., Temple U., Texas A&M U., Valparaiso U.

FCS Assembly



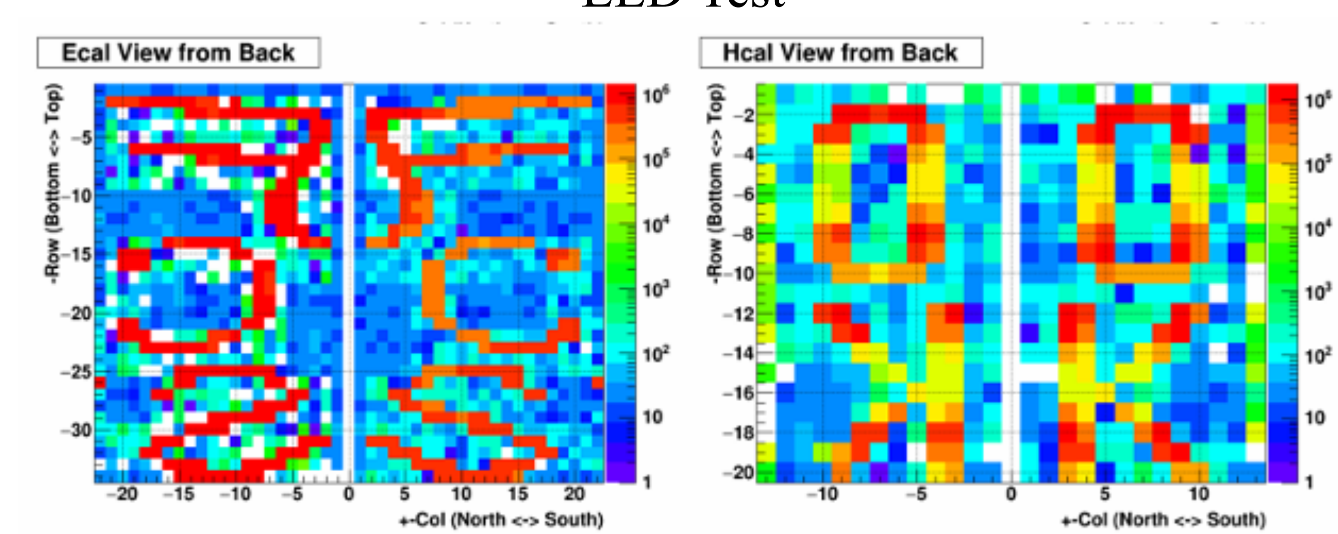


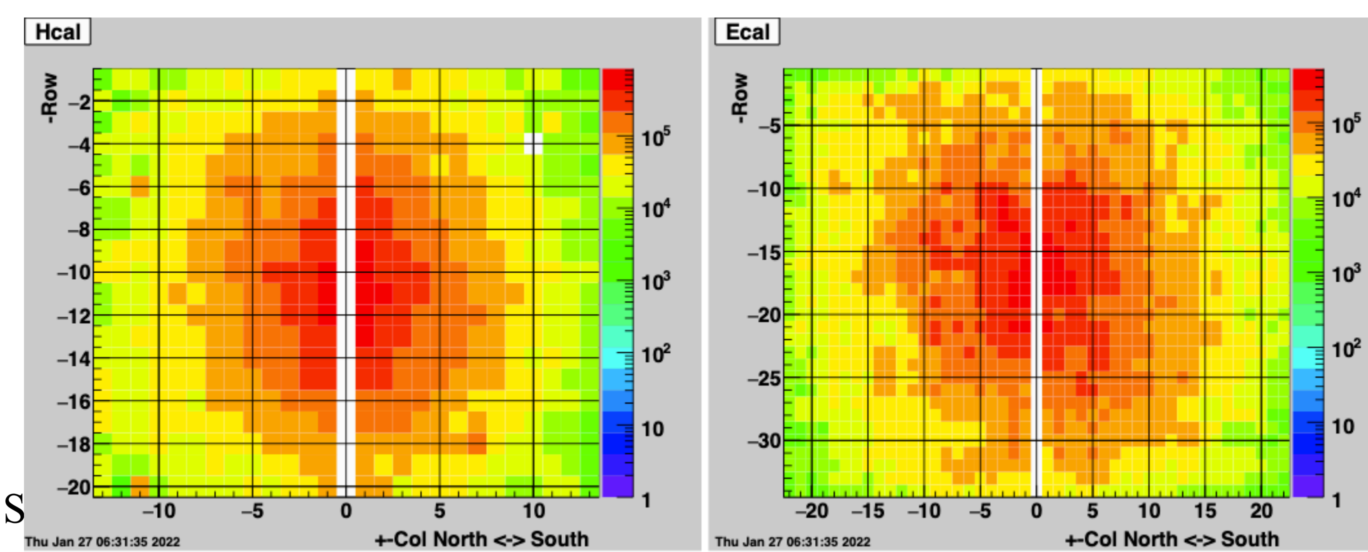
FCS Readout and Commissioning, Run 21



- During Run21:
  - Exercised the on-line machinery, monitoring systems, and slow controls
  - Off-line and Monte Carlo machinery also in place
  - Trigger system was commissioned
- Was ready to go on Run 22 Day-1 (except for some gain tweaks)

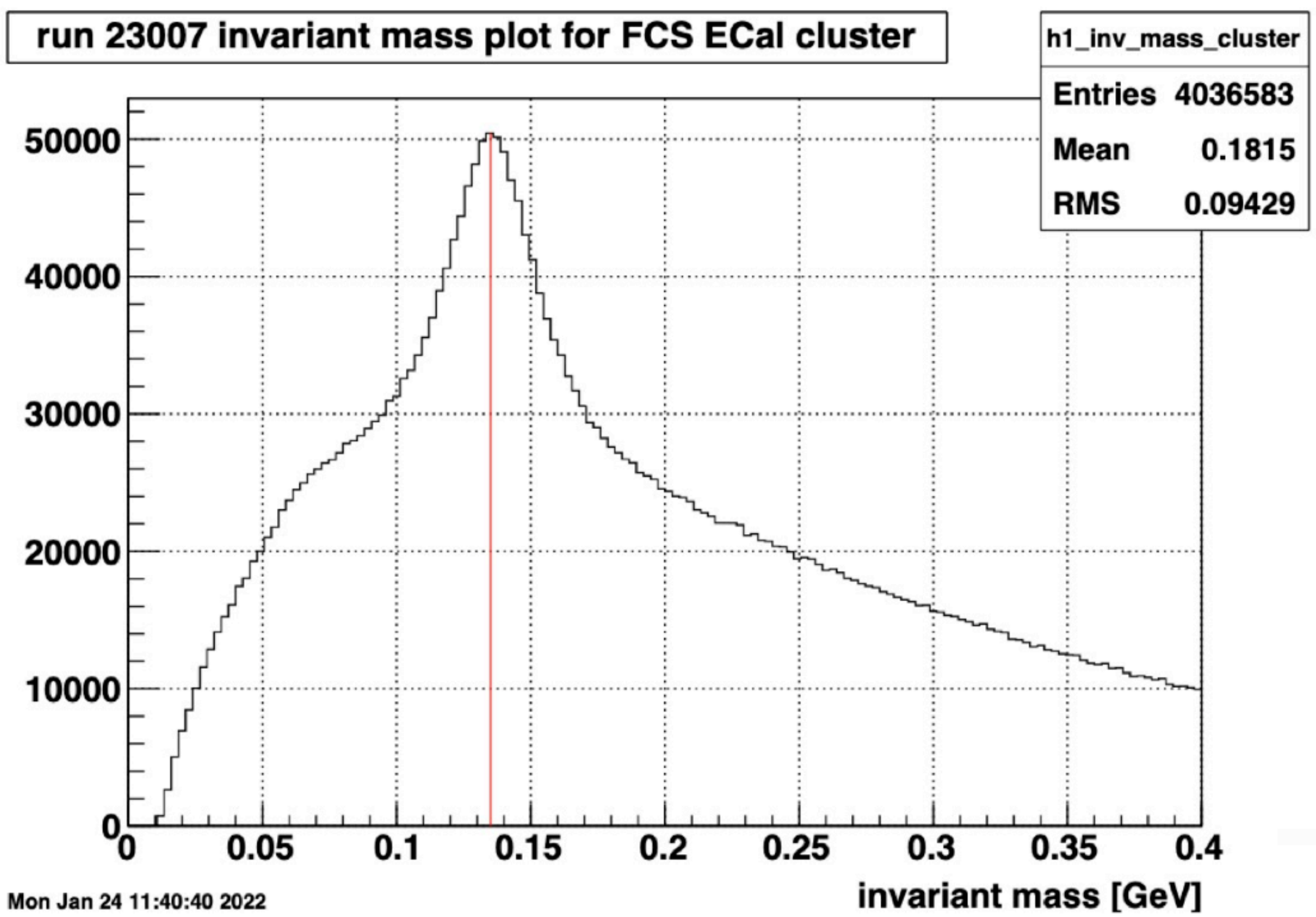
LED Test



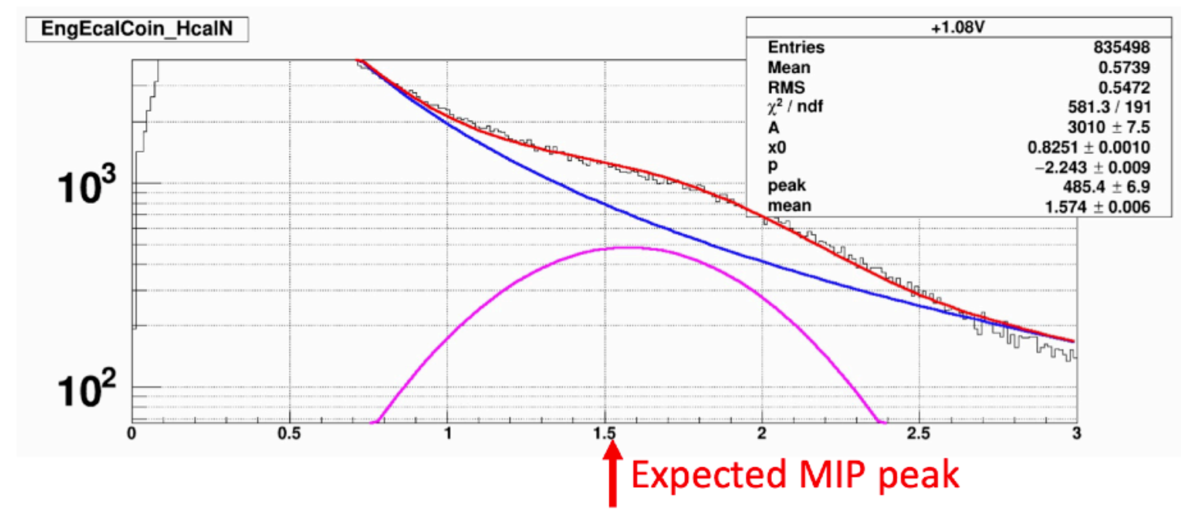


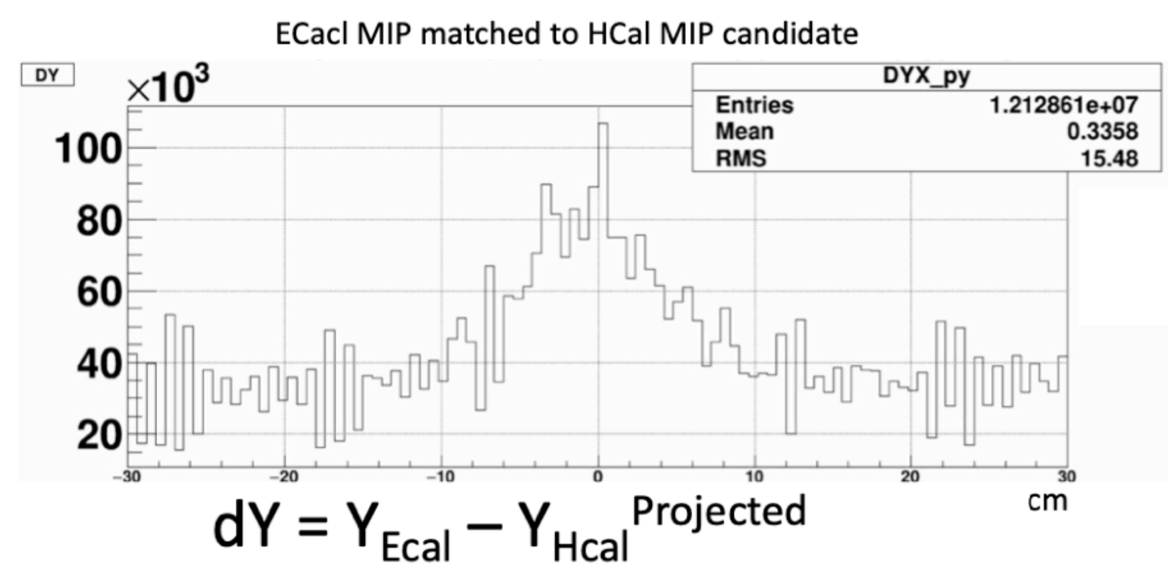
FCS Performance

π^0 reconstructed by Di-photon from ECal



MIP peak from Hcal (Matched with Ecal MIP)



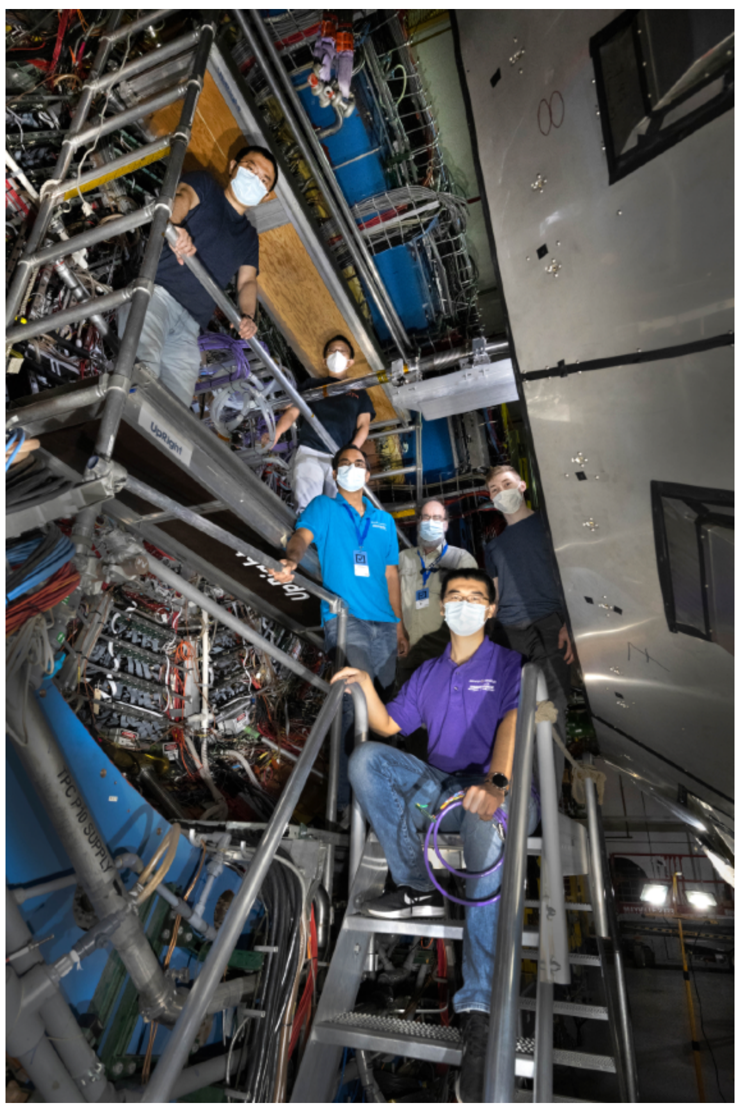


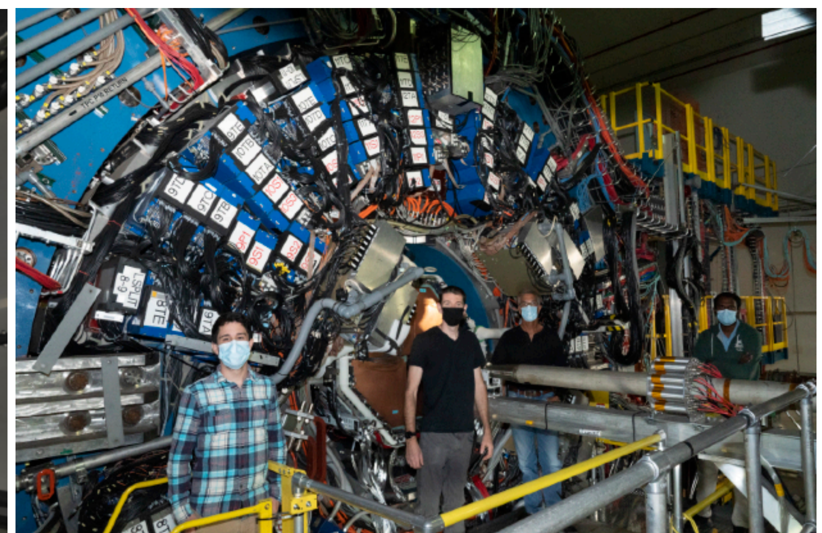
- FCS is commissioned and currently taking data at STAR run22

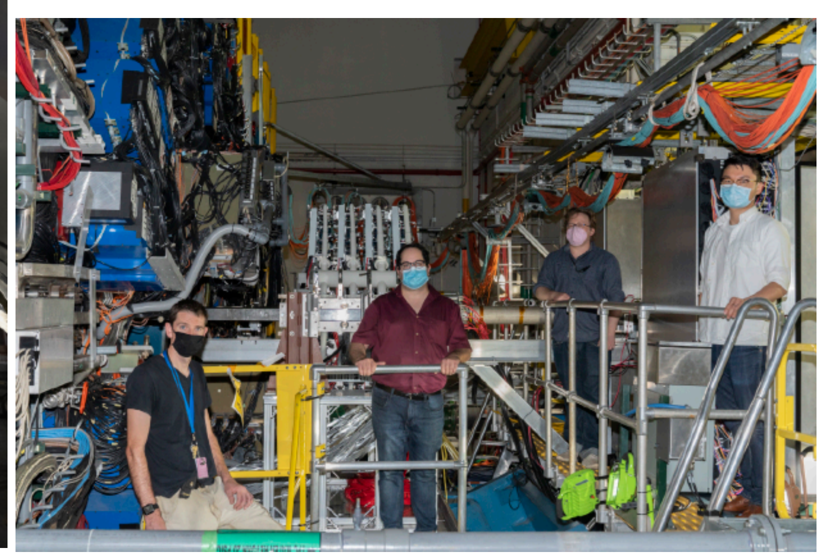
ECal MIP candidate matching HCal MIP candidate shows peak around dY=0,Vertically aligned

Summary

- Despite of COVID, all the Forward upgrade subsystems were installed on time
- All forward detectors were commissioned on time and taking data
- Many Thanks to those who are all involved to make this happen!







STAR Forward Upgrade Institutions

Dedicated manpower with large expertise for each subsystem

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
- 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