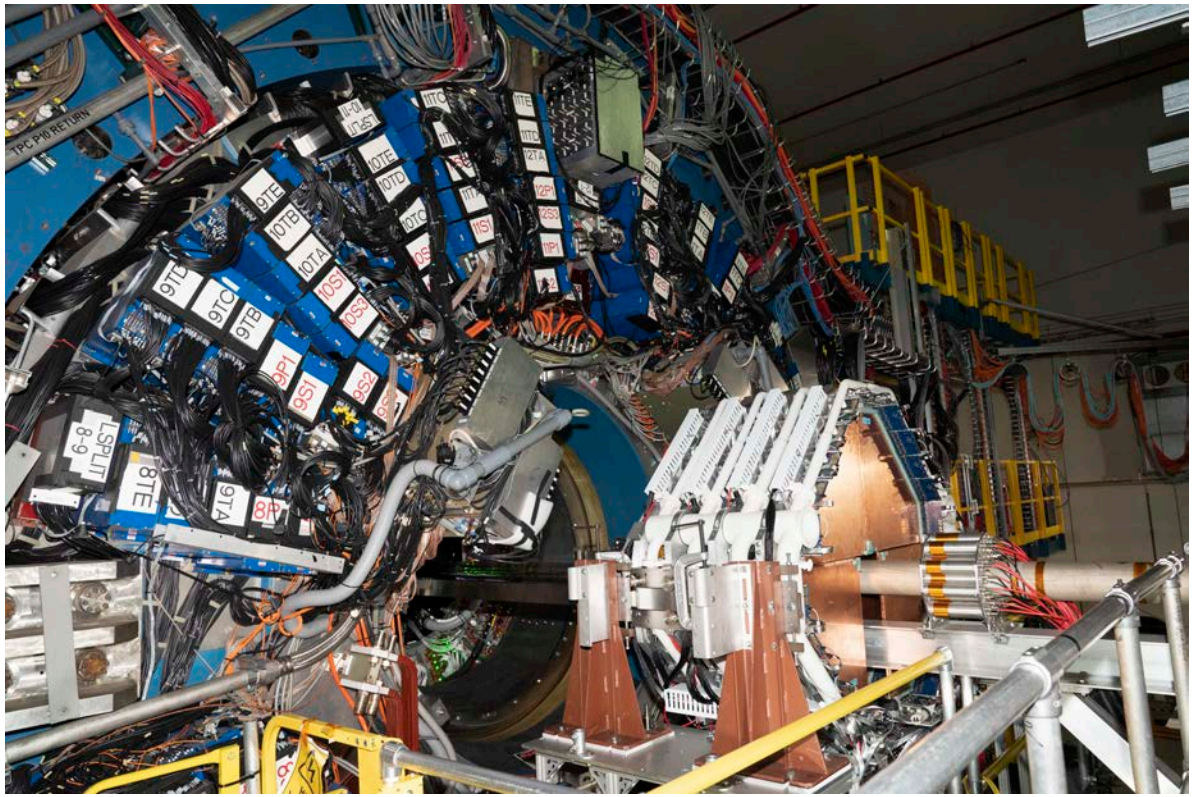
第十届全国先进气体探测器研讨会

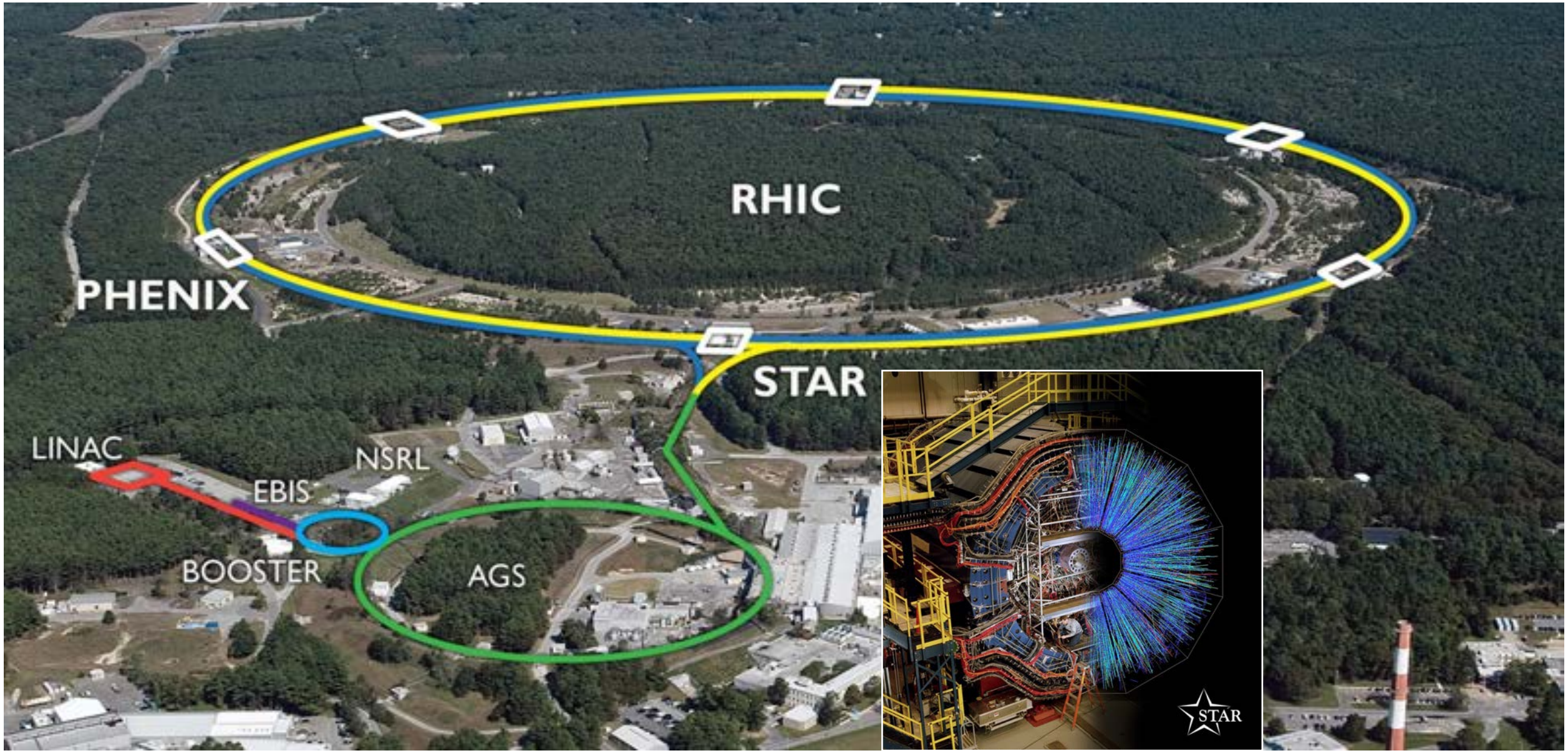
RHIC-STAR实验近期探测器升级



杨 驰

山东大学

相对论重离子对撞机RHIC上的STAR实验



位于美国布鲁克海文国家实验室(BNL)的相对论重离子对撞机（RHIC）上的STAR探测器

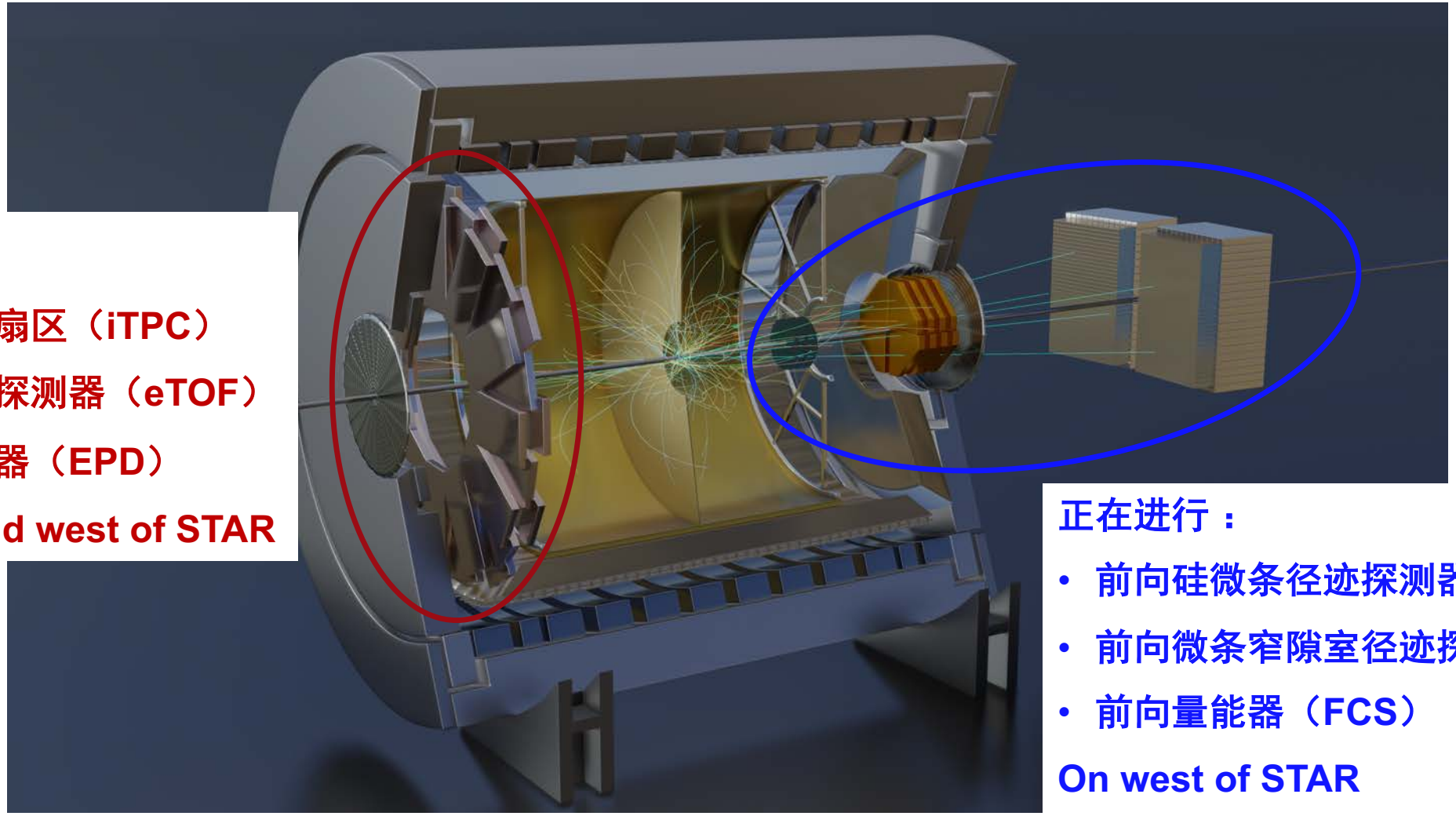
STAR近期探测器升级

束流能量扫描二期计划:

- RHIC run 2019-2021
- QCD 相图、临界点、手征相变等

冷核QCD、热核QCD物理：

- RHIC run 2022+
- QCD物质特性、核子内部结构



已完成：

- ✓ **时间投影室内扇区（iTPC）**
- ✓ **端盖飞行时间探测器（eTOF）**
- ✓ **事例平面探测器（EPD）**

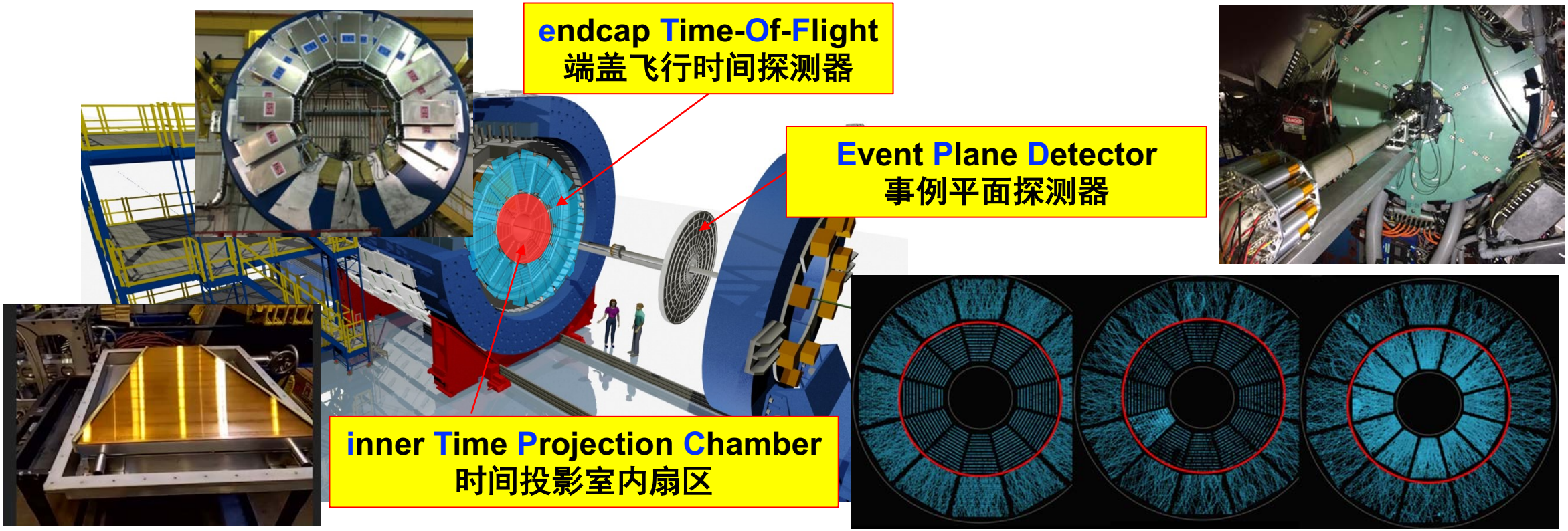
On both east and west of STAR

正在进行：

- **前向硅微条径迹探测器（FST）**
- **前向微条窄隙室径迹探测器（FTT）**
- **前向量能器（FCS）**

On west of STAR

已经完成的探测器升级



iTPC upgrade	EPD upgrade	eTOF upgrade
|η|<1.5	**2.1<|η|<5.1**	**-1.6<η<-1.1**
p_T >60 MeV/c	Better trigger & b/g reduction	Extend forward PID capability
Better dE/dx resolution Better momentum resolution	Greatly improved Event Plane info (esp. 1st-order EP)	Allows higher energy range of Fixed Target program
Fully operational in 2019	**Fully operational in 2018**	**Fully operational in 2019**

前向快度区物理测量需求

Observables:

- ✓ Inclusive and di-jets
- ✓ Hadrons in jets
- ✓ Lambda's
- ✓ Correlations mid-forward & forward-forward rapidity

Requirements from Physics:

- ✓ Good e/h separation
- ✓ Hadrons, photon, π^0 identification

Detector	pp and pA	AA
ECal	~10%/√E	~20%/√E
HCal	~50%/√E+10%	---
Tracking	charge separation photon suppression	$0.2<p_T<2$ GeV/c with 20-30% $1/p_T$

Forward-rapidity 2.8< η <4.2

A+A

Beam:
Full Energy AuAu (2023/25)

Physics Topics:

- Temperature dependence of viscosity through flow harmonics up to η ~4
- Longitudinal decorrelation up to η ~4
- Strong rapidity dependence in Global Lambda Polarization

p+A, p+p

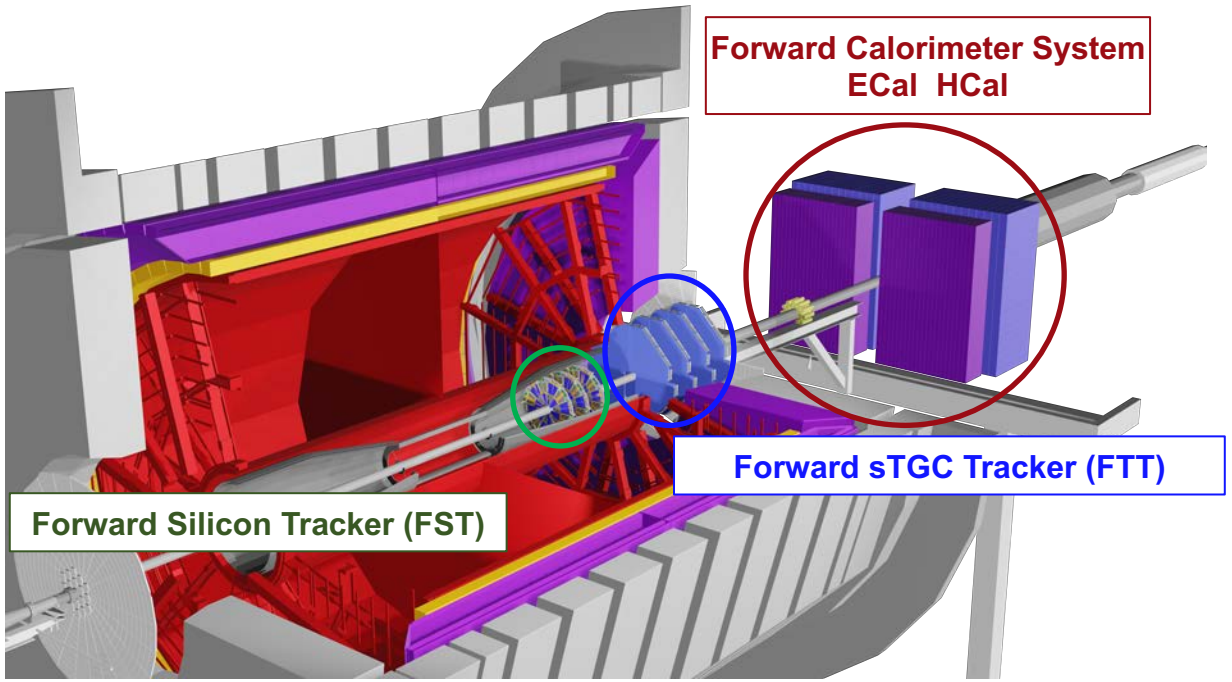
Beam:
500 GeV: p+p
200 GeV: p+p and p+A

Physics Topics:

- TMD measurements at high x
  - o transversity → tensor charge
  - o Sivers through DY, direct **γ** and tagged jets
- Gluon PDFs for nuclei
  - ➢ R_{pA} for direct photons & DY, and hadrons
- Test of Saturation predictions through di-hadrons, **γ** -Jets, di-jets

FY2022: 500 GeV polarized pp run
All other data taking in parallel to sPHENIX data taking campaign

前向快度区的新探测器



FST, 3 Silicon disks: at 146, 160, and 173 cm from IP

Built on successful experience with STAR IST

- Single-sided double-metal mini-strip sensors
  - ✓ Granularity: fine in f and coarse in R
  - ✓ Si from Hamamatsu
- Frontend chips: APV25-S1 → IST all in hand
- Reuse IST DAQ system and cooling system

FCS: 7 m from the IP

ECal: reuse PHENIX SHASHLYK 1496 Ch.

- Lateral tower Size 5.5 x 5.5 x 33 cm^3 （$18X_0$ ）

HCal: Fe/Sc (20mm/3 mm) sandwich 520 Ch.

- Lateral tower size 10 x 10 cm^2, ~ 4.5λ
- ✓ in close collaboration with EIC R&D

Preshower:

- Existing EPD, with additional splitter

FTT, 4 sTGC disks:

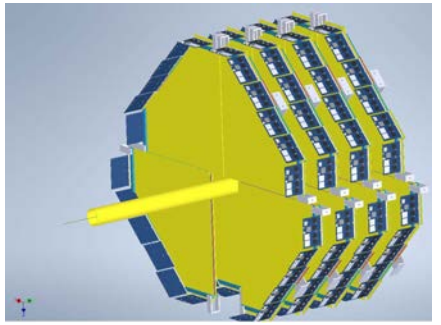
at 307, 325, 343 and 361 cm from IP

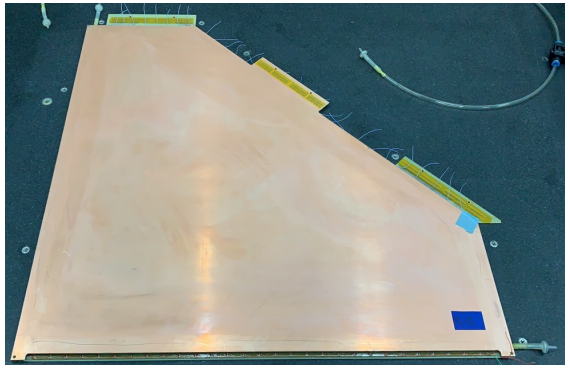
- location inside Magnet pole tip opening
  - ✓ inhomogeneous magnetic field
- 4 quadrants double sided sTGC → 1 disk
  - ✓ sTGC technique developed by ATLAS
- Position resolution: ~200 um
- Readout: based on VMM-chips

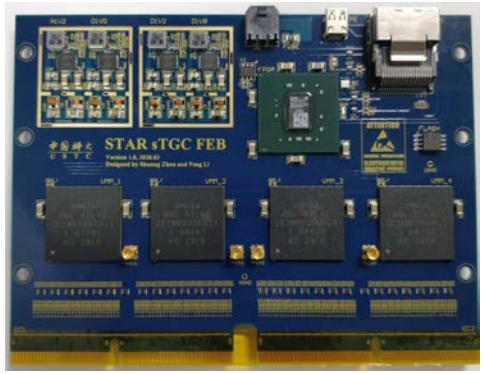
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0648

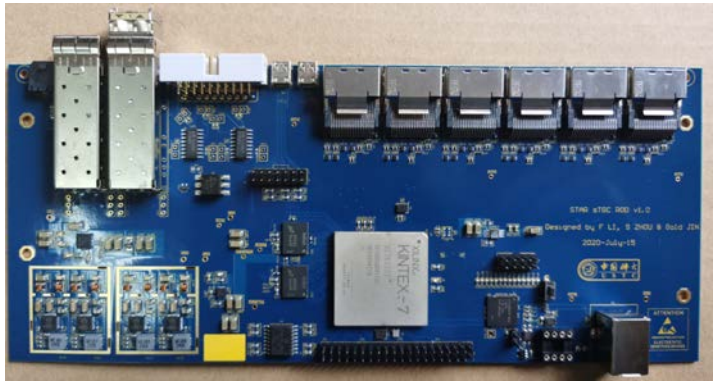
前向sTGC径迹探测器（Forward sTGC Tracker）升级

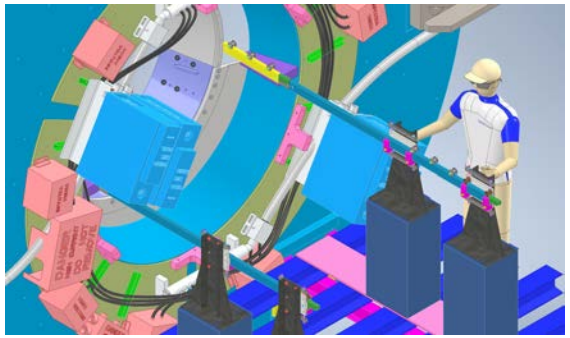
- **Four layers, 16 (+4) modules (山大)**
  - Module R&D
  - Mass production
  - Quality and performance tests
- **96 (+12) FEB + 16 (+2) ROD (中科大)**
  - Electronics R&D
  - Mass production and test
- **DAQ system (BNL)**
  - Electronics Integration
- **Integrations (BNL)**
  - Support structure
  - Gas system
  - Installation, interlocks
- **Software (BNL+山大)**
  - Simulator
  - Cluster finder

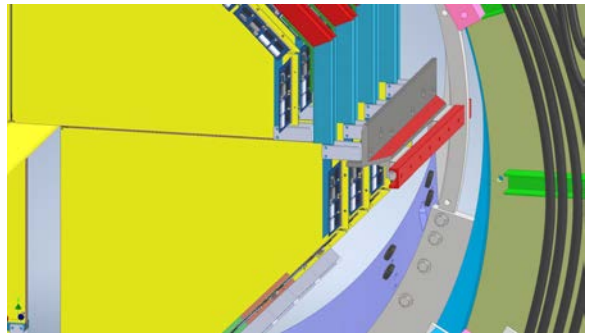










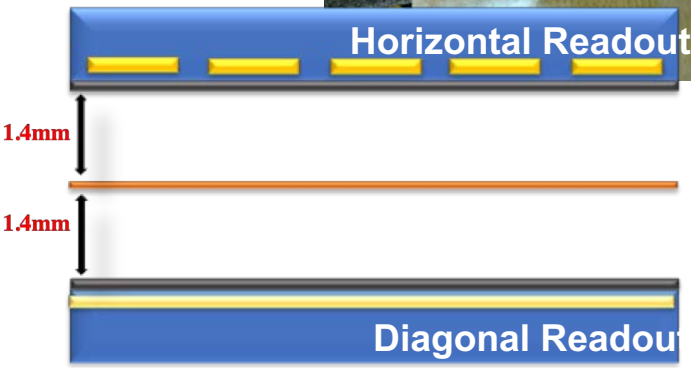


Small-strip Thin Gap Chamber（sTGC）:
Originally designed by ATLAS and used in ATLAS NSW upgrade

电子学部分详见李颖杰报告，15:36-15:54, Oct. 22nd

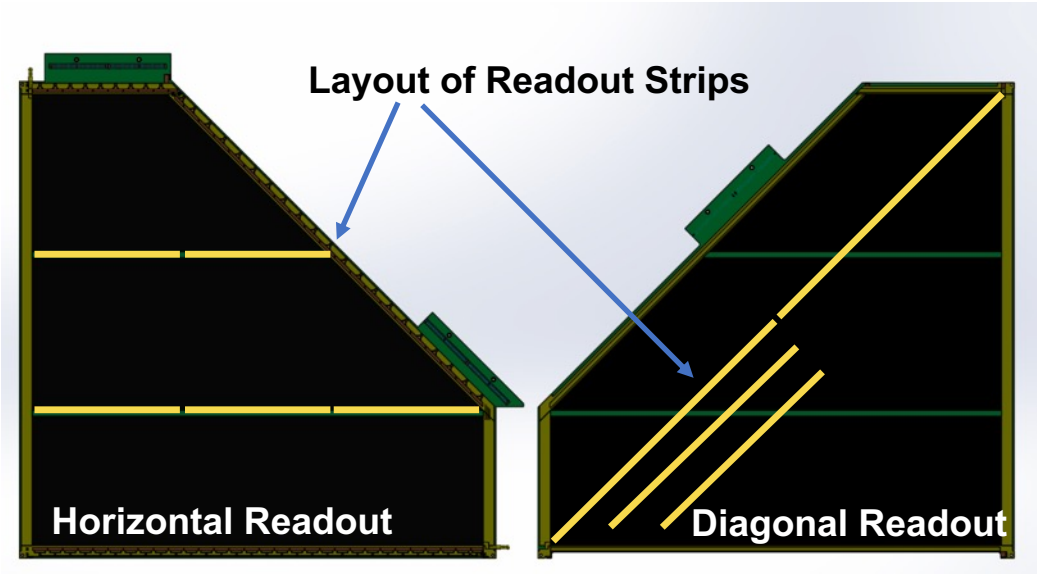
前向sTGC径迹探测器（Forward sTGC Tracker）升级

首次探测器和电子学联调。
At SDU Lab in Sep.2020.



sTGC chamber sideview layout

Anode:
50 um gold-plated tungsten wire
1.8 mm wire pitch
350g wire tension
Cathode: graphite (200kohm/2.5cm^2)



STAR FTT研制团队

Brookhaven National Laboratory
山东大学
中国科学技术大学

Management:

Chi Yang (Project Manager), Prashanth Shanmuganathan (Deputy Project Manager)

Module:

Changyu Li, Yingying Shi, Qinghua Xu, ***Chi Yang***, Qian Yang, + Local engineers

Electronics:

Ge Jin, ***Feng Li***, Peng Miao, Lijuan Ruan, Zebo Tang, Shuang Zhou, Yingjie Li

DAQ:

Timothy Camarda, ***Tonko Ljubicic***

Integration:

Felix Archampong, Michael Capotosto, Alexei Lebedev, ***Rahul Sharma***, Prashanth Shanmuganathan, John Scheblein, David Tlusty, STSG + Students + ……

Software and simulation:

James Daniel Brandenburg, Zhenyu Chen, Zhen Wang

Supported by DOE, NSFC and SDU.

STAR FTT原型机研制

From 2018 till now:

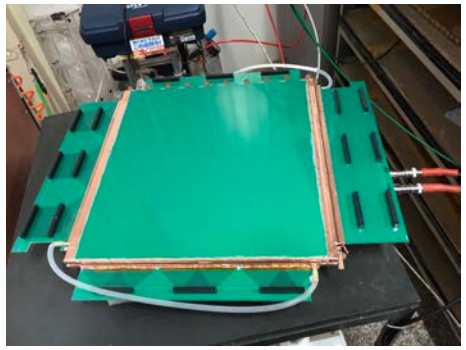
- ✓ Three versions of module prototypes
- ✓ Three versions of electronics prototype

Integrations & DAQ: **BNL**

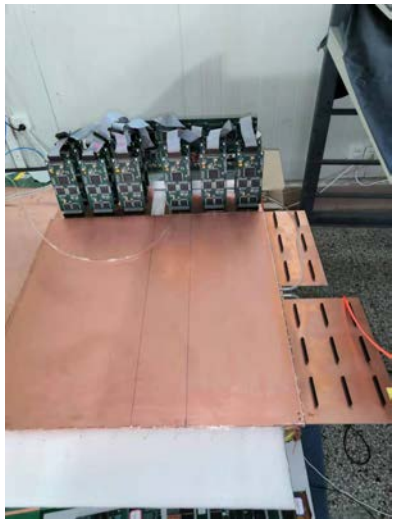
Commissioning & software: **BNL, SDU**

Detector	Produced	Shipped	Installed
1st prototype	Oct.2018	Jan.2019	Jun.2019
2nd prototype	Jan.2019	Jul.2020	May 2021
3rd prototype	Oct.2020	N/A	N/A
Final module	*Jun. 2021*	*Jun.2021*	*Oct.2021*

30 x 30 cm^2 prototype

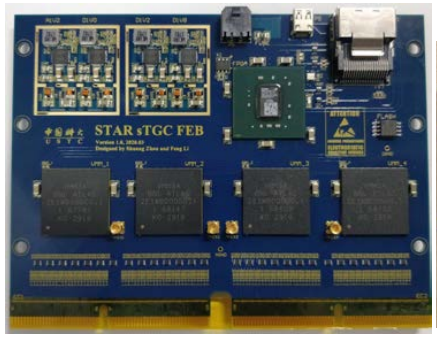


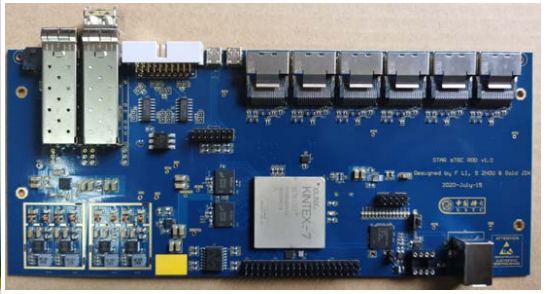
60 x 60 cm^2 prototype



Module Production: **SDU**

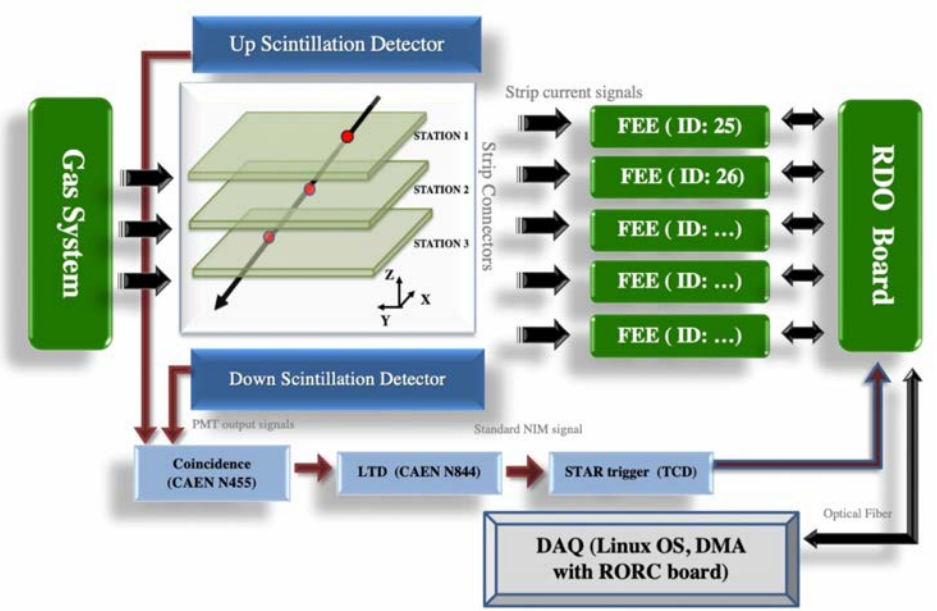
55 x 55 cm^2 pentagon

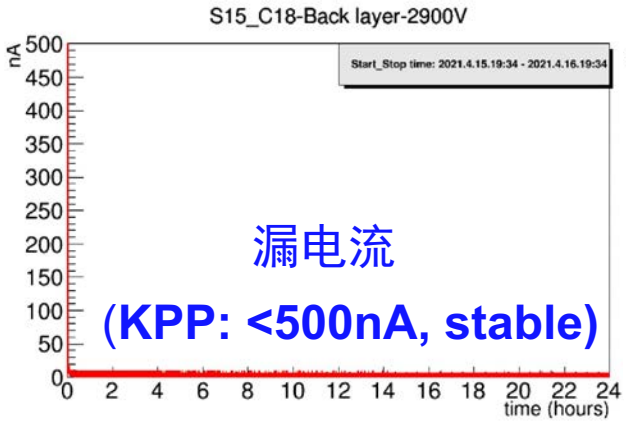




Electronics: **USTC**

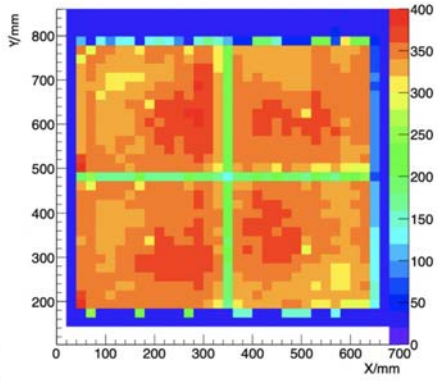
Forward sTGC Tracker – 原型机性能

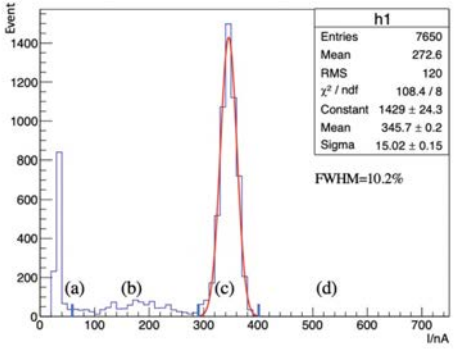




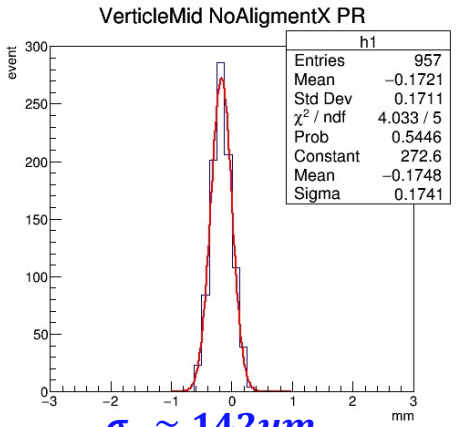
漏电流

(KPP: <500nA, stable)

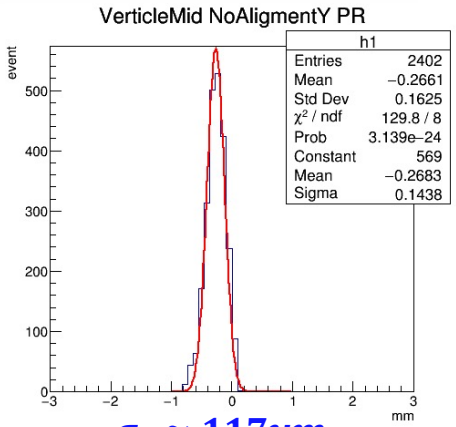




X射线漏电流扫描



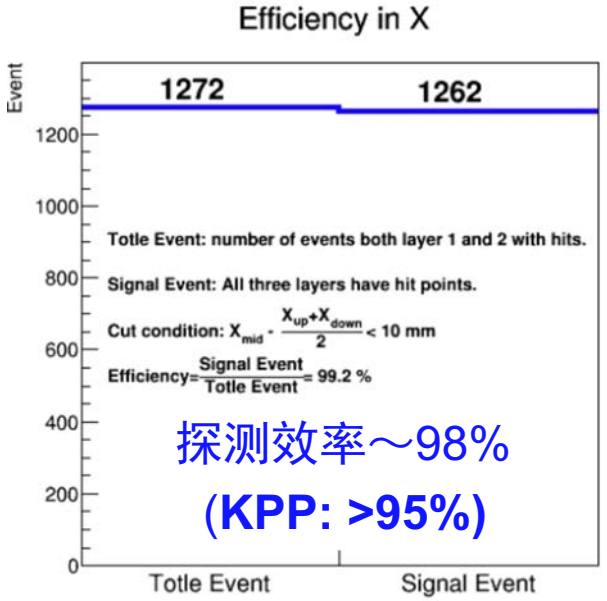
$\sigma_x \approx 142um$



$\sigma_y \approx 117um$

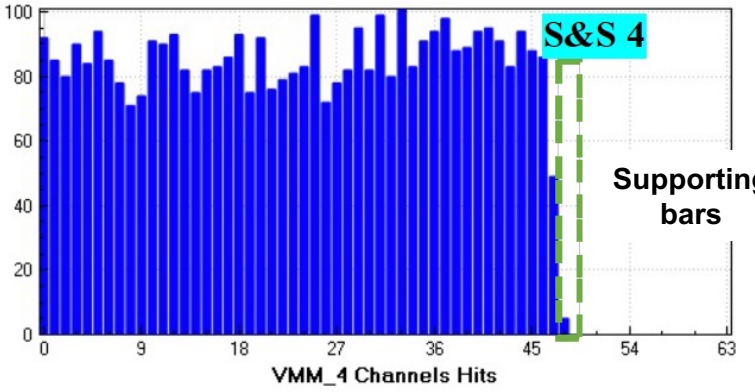
位置分辨

(KPP: <200um)



探测效率～98%

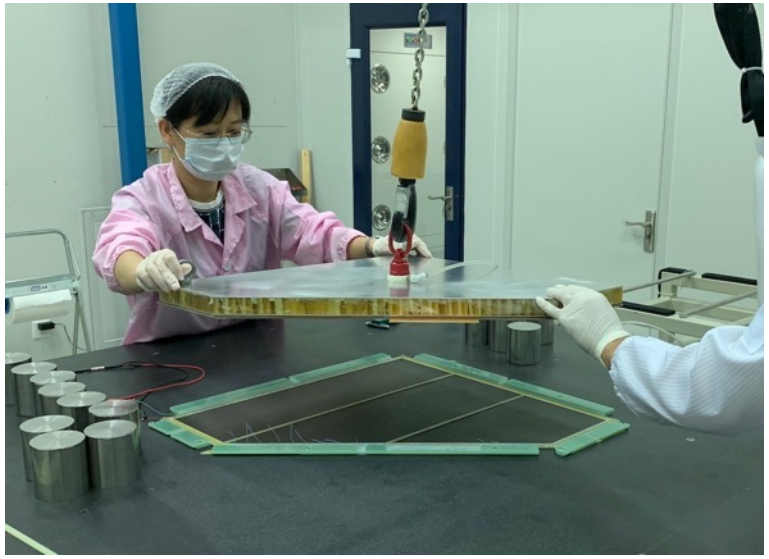
(KPP: >95%)



通道响应

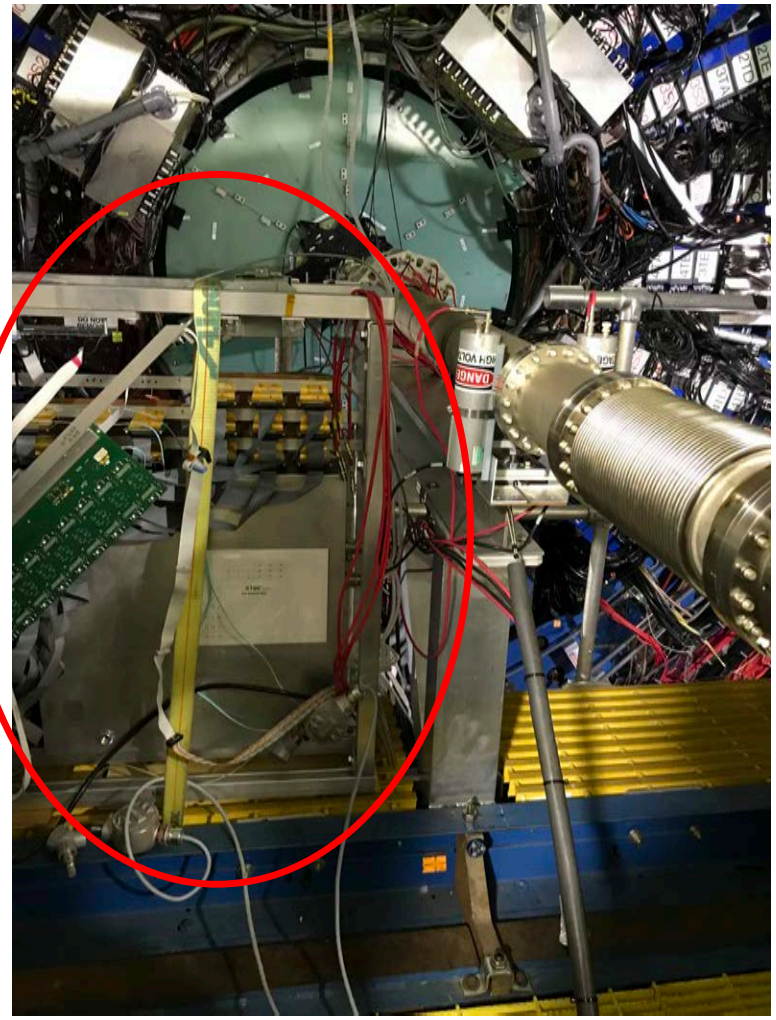
(KPP: >98%)

Production, Testing and Commissioning



sTGC module production at SDU

sTGC module test at SDU

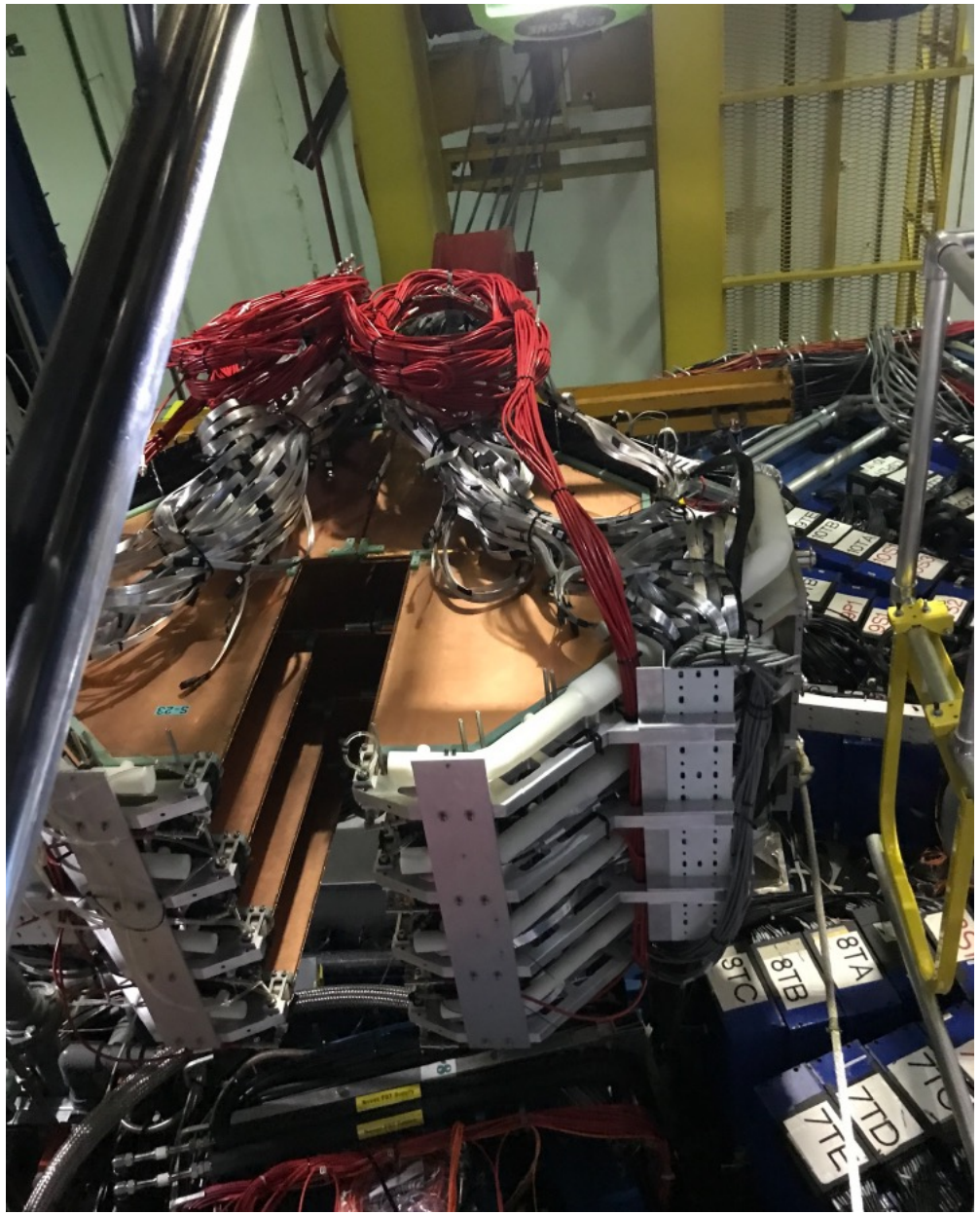


2nd prototype installed at STAR in Run21

Mass production:

- March. 9th – Jun. 8th, 2021
- 25 modules produced
- 23/25 passed QA

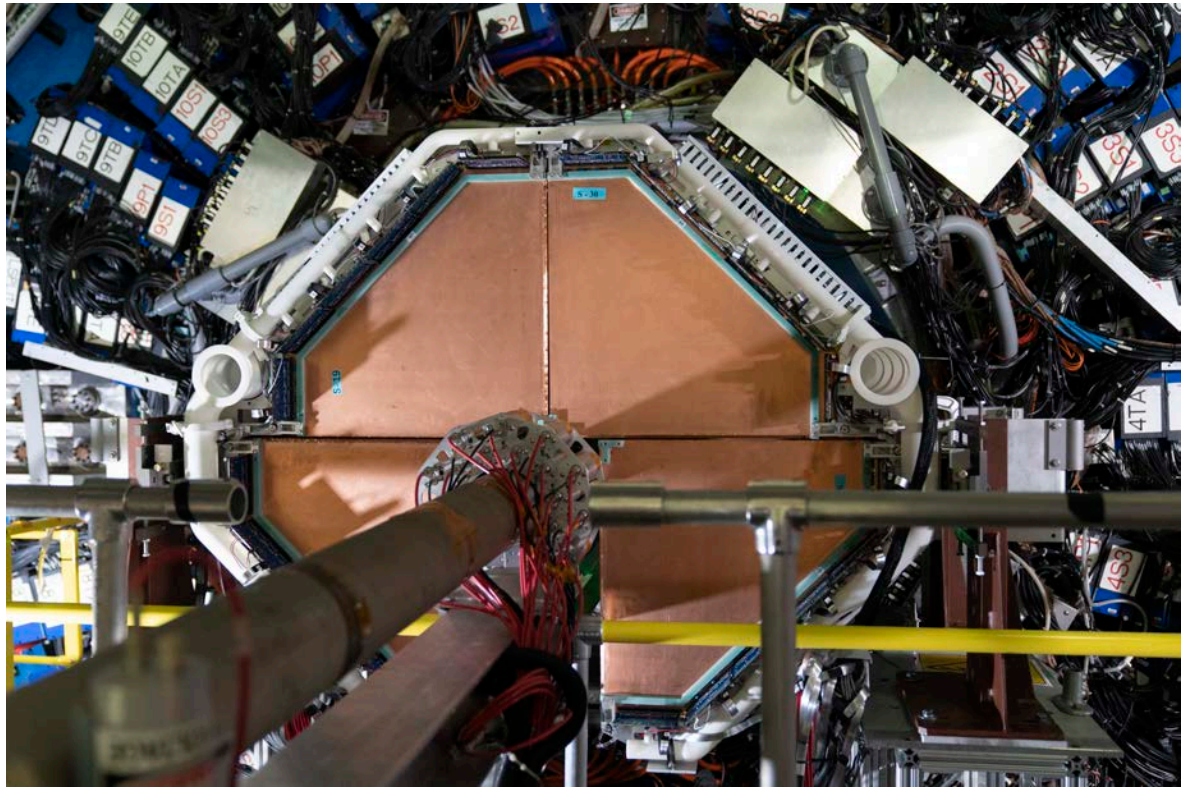
FTT安装在STAR



Critical Lift: successfully done on Oct. 14th 2021

Pushed into the pole tip: Oct. 19th 2021

非常靠近束流管，安装难度及风险大。



STAR前向快度区探测器升级参与单位

sTGC

BROOKHAVEN NATIONAL LABORATORY

Silicon

UIC UNIVERSITY OF ILLINOIS AT CHICAGO

INDIANA UNIVERSITY

BROOKHAVEN NATIONAL LABORATORY

ECal

KENTUCKY

VALPARAISO UNIVERSITY

ABILENE CHRISTIAN UNIVERSITY

HCal

UCLA

TEXAS A&M UNIVERSITY

INDIANA UNIVERSITY

VALPARAISO UNIVERSITY

RUTGERS

ABILENE CHRISTIAN UNIVERSITY

OHIO STATE

DAQ

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

Integration

BROOKHAVEN NATIONAL LABORATORY

Calibration

RIVERSIDE

TEMPLE UNIVERSITY

Slow Controls

VALPARAISO UNIVERSITY

ABILENE CHRISTIAN UNIVERSITY

Creighton UNIVERSITY

Efficient and professional collaborating within STAR collaboration!

从RHIC到EIC

RHIC-STAR近期探测器升级提供的机遇:

EIC装置探测技术的部分预研究

HCal+SiPM readout same as EIC-fHCal (joint STAR EIC R&D)

Silicon technique for EIC tracker

sTGC technique for EIC trigger/tracker

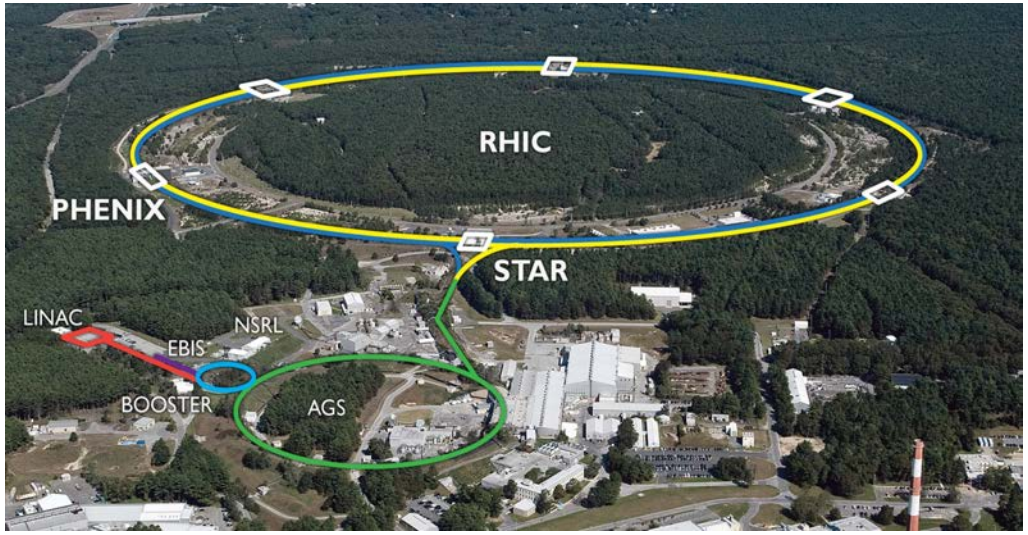
部分EIC物理的预研

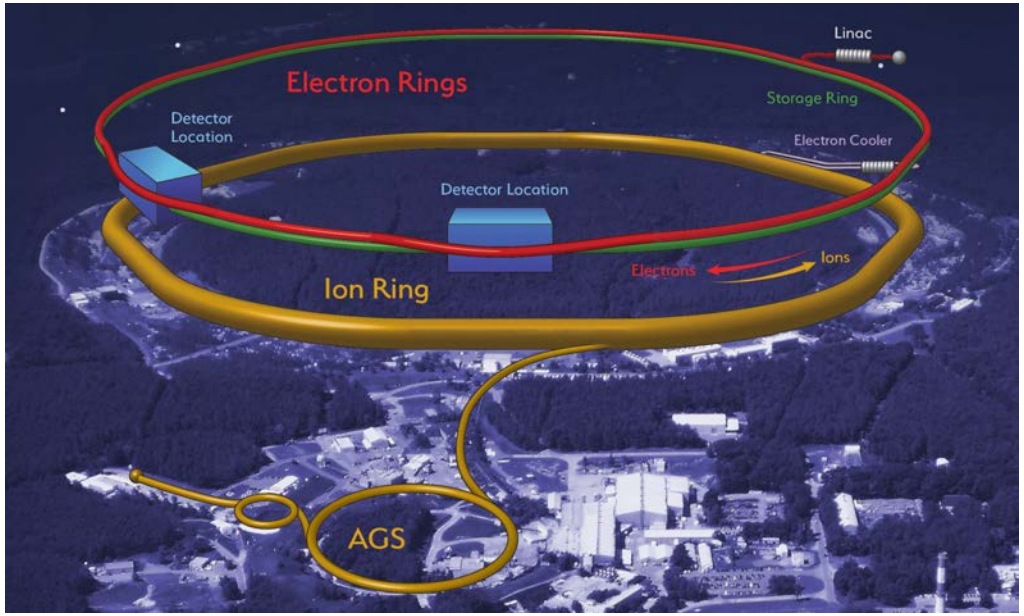
Inform the physics program

Quantify experimental requirements

人才培养

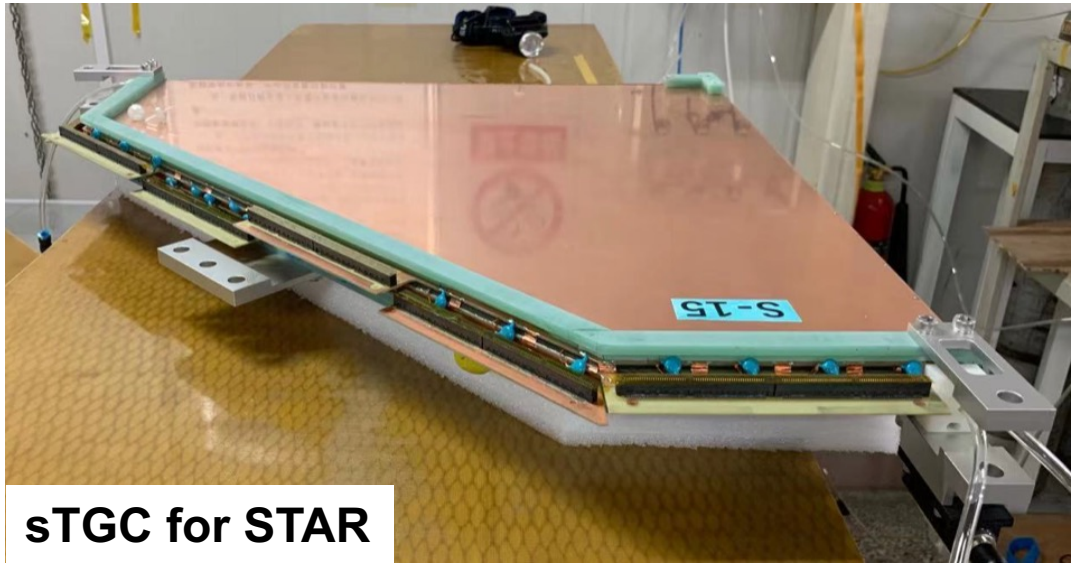
Several tens of the graduate/undergraduate students involved





Summary and Outlook

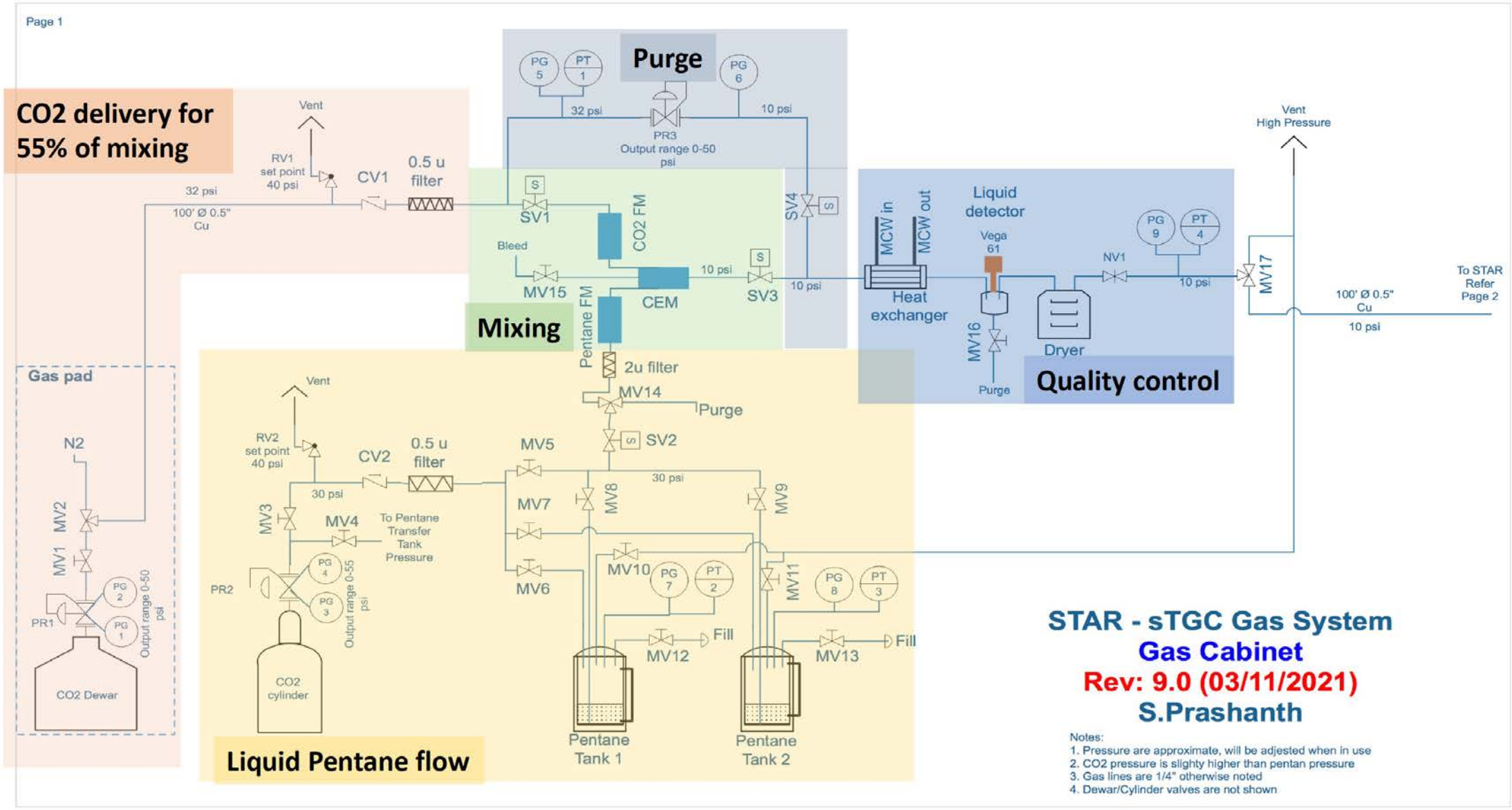
- STAR中国组在RHIC-STAR近期的前向快度区探测器升级中做出了突出贡献。
- 主导的前向sTGC探测器的模块研制及电子学研制均已圆满完成，探测器系统已经成功的整体安装到STAR上。
- 目前， STAR前向探测器升级已经完成全部安装任务，正在进行调试，准备11月开始进行取数。
- STAR前向升级为RHIC和未来的EIC装置之间架设了“桥梁” 。



sTGC for STAR

Backup

N-Pentane+CO_2 Gas Mixing System -- Backup

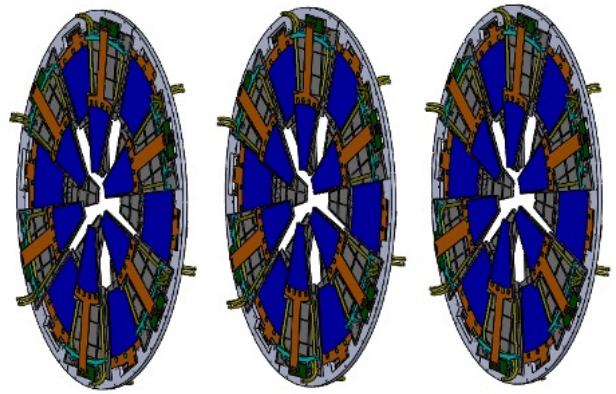


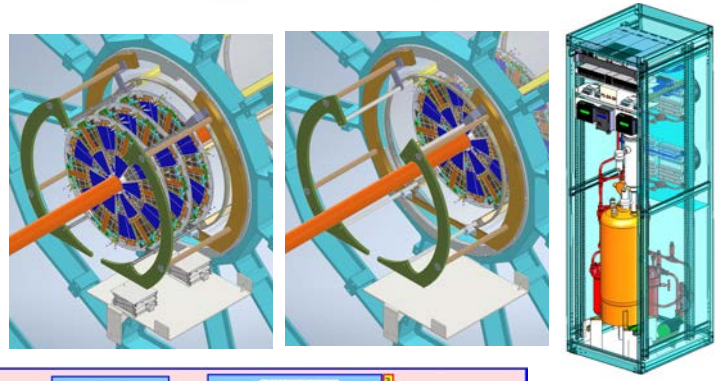
Forward Silicon Tracker, fSTAR

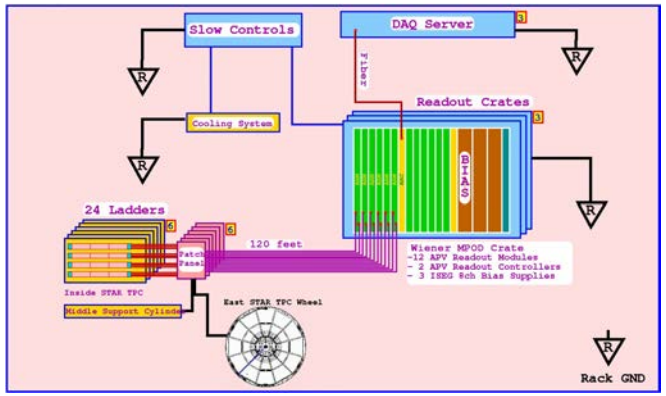
- Three disks, 36(+12) modules (NCKU/UIC)
  - Mechanical structure (NCKU)
  - Flexible hybrid (SDU/IU)
  - Silicon strip sensors (UIC/BNL)
  - APV25 frontend chips* (UIC)

    * in-hand and probe-tested
- Integration (BNL)
  - Mechanical supporting structure
  - Installation tooling
- Cooling system (BNL/NCKU)
  - Cooling lines
  - Cooling manifold
  - Rack (cooler, pumps)
- DAQ system (BNL/IU/SDU)
  - Inner signal cables
  - Outer signal cables, patch panel boards, readout modules, readout controllers, crates

Blue: existing Red: new







Forward Silicon Tracker, Module Design

Each module splits into two regions

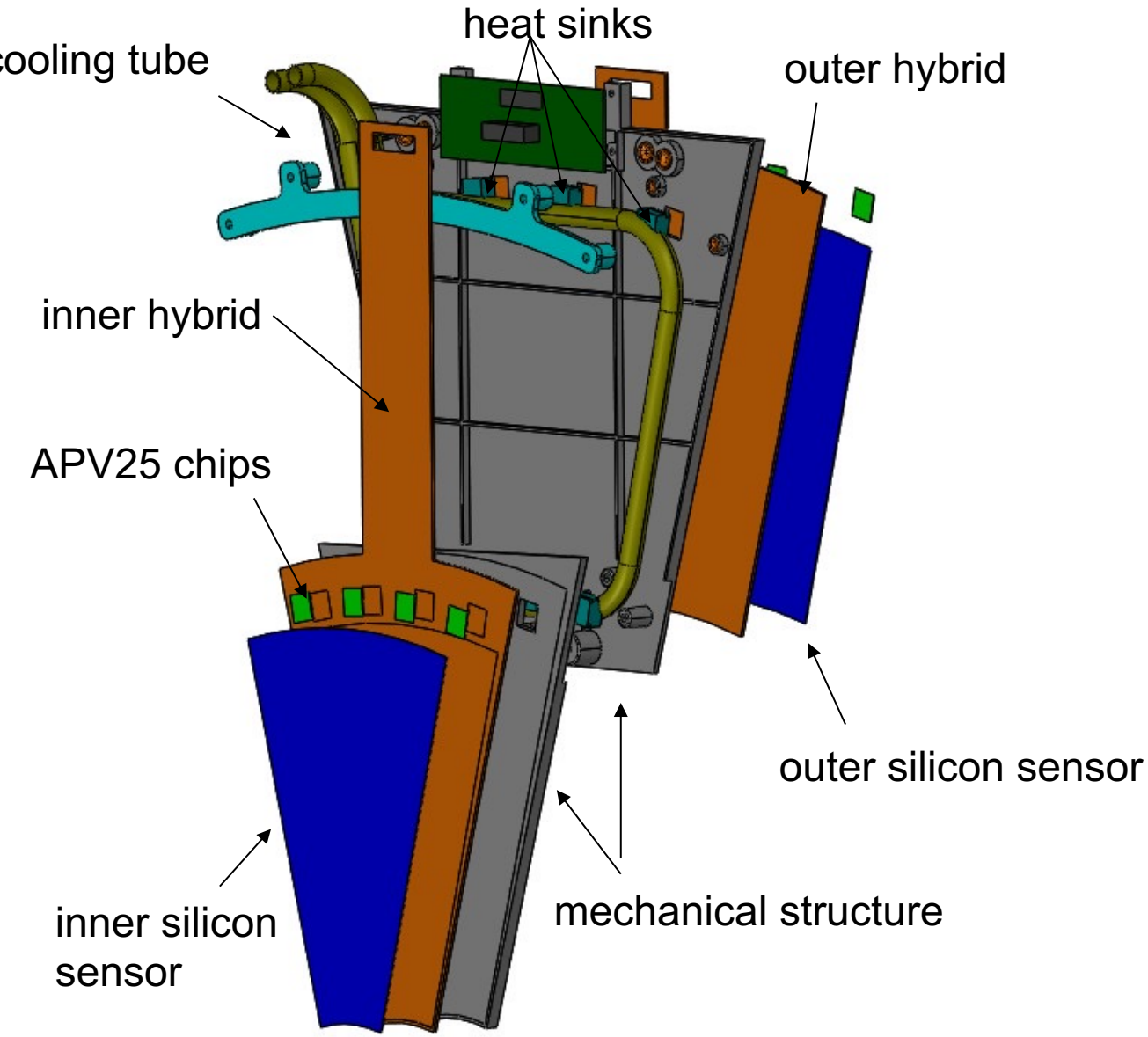
- ✓ Inner-radius region: 5<R<16.5 cm
  - 1 Kapton flexible hybrid
  - 1 Si sensor: 128 × 4 **(**$\phi \times R$) strips
  - 4 APV chips
- ✓ Outer-radius region: 16.5<R<28 cm
  - 1 Kapton flexible hybrid
  - 2 Si sensors: 128 × 4 **(**$\phi \times R$) strips
  - 4 APV chips
- ✓ material budget: ~1.5% X_0 per disk

Mechanical structure is made of

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

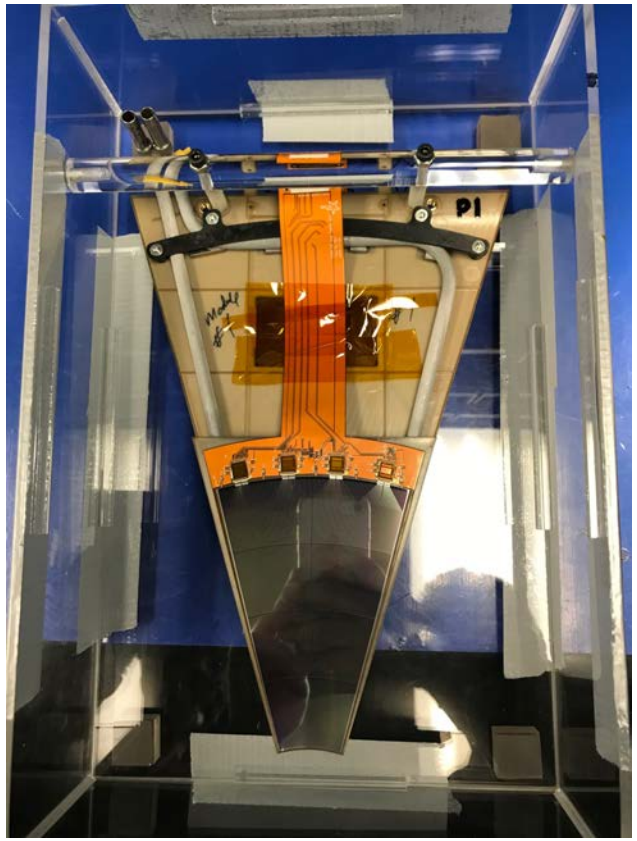
Module assembly is done at two sites

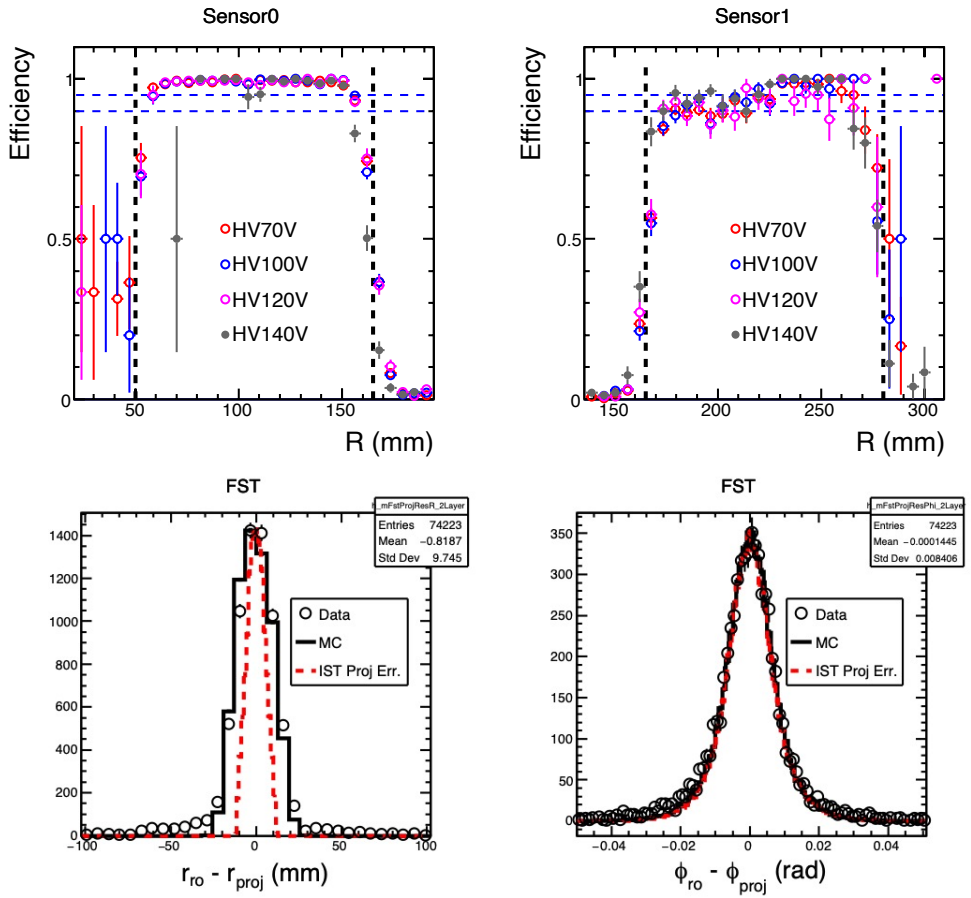
- ✓ TiDC (NCKU): gluing inner/outer hybrids and mechanical structures together
- ✓ FNAL (UIC): mount/wire-bond AVPs and Silicon sensors on hybrids

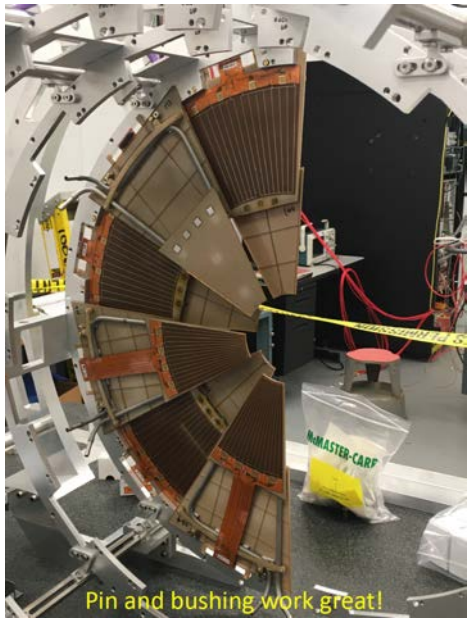


Forward Silicon Tracker – Prototype Module Performance

T-Board production at SDU







Pre-Installation at BNL

Performance of two fully assembled prototype modules evaluated with cosmic ray:

- ✓ **All channels can be read out (KPP: > 85%)**
- ✓ **Efficiency higher than 90% (KPP: > 90%)**

Key **P**erformance **P**arameter

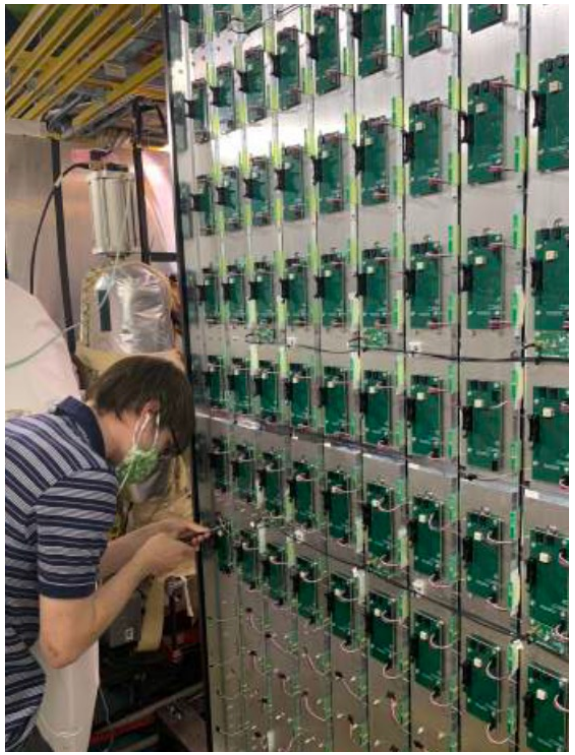
Installed on STAR in Sep. 2021.
In commissioning.

Forward Calorimeter System, fSTAR

FCS Requirements

Detector	pp and pA	AA
ECal	~10%/√E	~20%/√E
HCal	~50%/√E+10%	---

Module Installation



DEP installation

Forward Calorimeter System (FCS)

- ✓ ECal – 1496 channels ~ 8 tons
- ✓ HCal – 520 channels ~ 30 tons
- ✓ SiPM Readout Bias ~ 67V
- ✓ New digitizers + Trigger FPGA = DEP boards
- ✓ Total of 48+18+12 = 78 DEP boards
- ✓ 3 DEP-IO boards for triggering

https://www.bnl.gov/newsroom/news.php?a=217681

FCS fully operational in Run21.
Works great out of box!