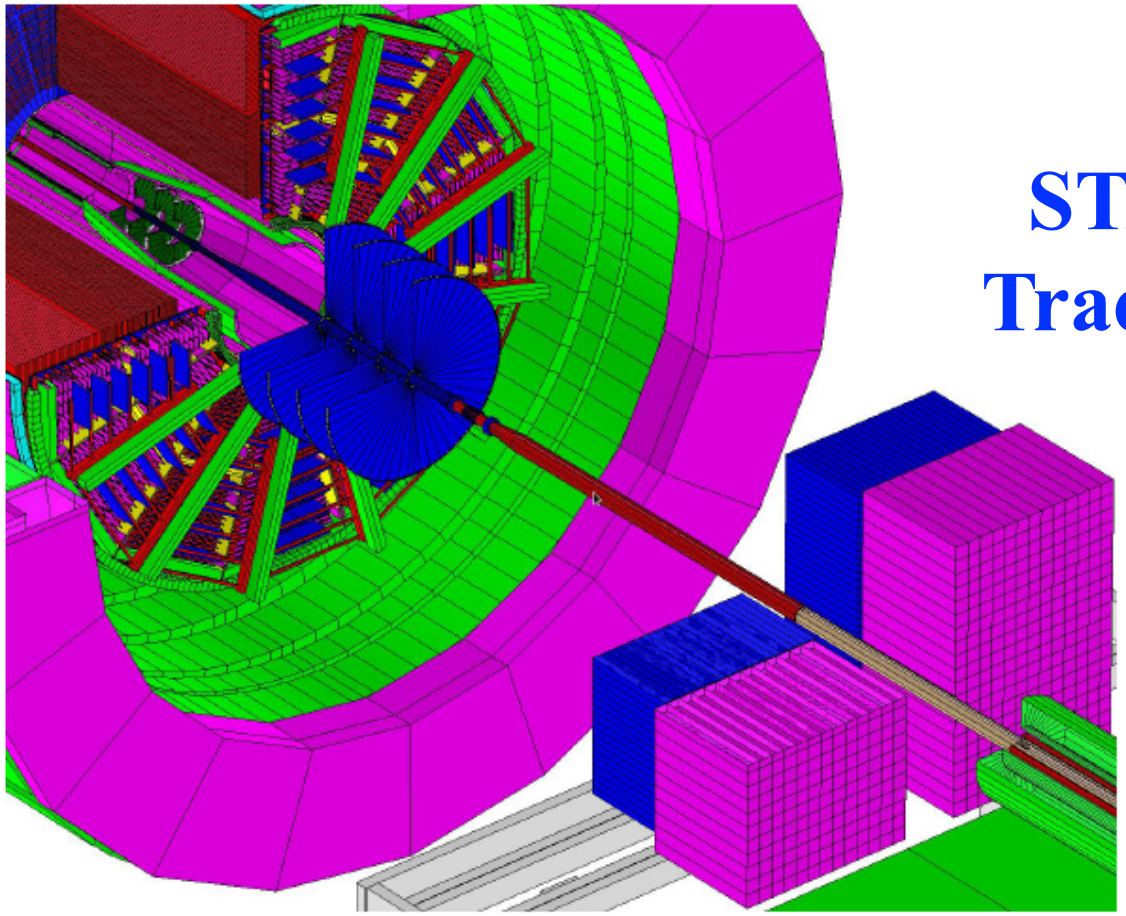
Workshop on QCD Physics & Study of the QCD Phase Diagram and New Type Topologic Effect
Shandong University, July 17-25, 2019



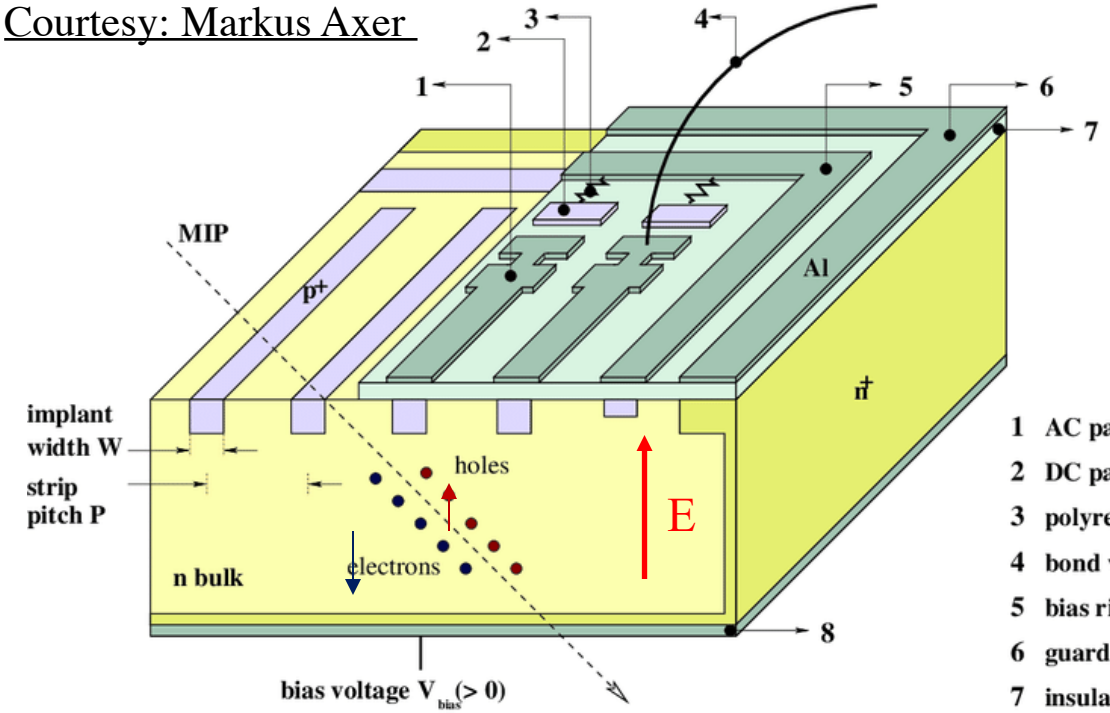
STAR Forward Silicon Tracker Upgrade Status

Zhenyu Ye
University of Illinois at Chicago

U.S. DEPARTMENT OF ENERGY | Office of Science

Brief Introduction to Silicon Strip Detectors

Courtesy: Markus Axer

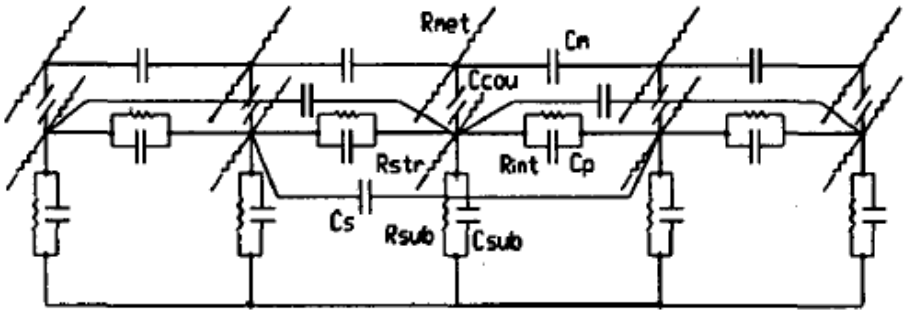


1 AC pad
2 DC pad
3 polyresistor
4 bond wire to readout
5 bias ring (ground)
6 guard ring
7 insulating layer
8 aluminium backplane (positive HV)

AC-coupled p-in-n Si strip sensor

- reverse bias of p-n junction to deplete free charges in Silicon
- ionization signal proportional to thickness: ~ 300-500 microns
- noise linearly depends on input capacitance $C_{sub}+C_p$ to FEE preamplifier: typically ~1pF/cm

- Resolution
- Efficiency
- Lifetime
- Cost



N. Bacchetta et al., 1995

Rmet	Resistance of the Al strip
Rstr	Resistance of the p+ implant
Rsub	Resistance between p+ implant and backside
Rint	Interstrip resistance with first neighbours
Ccou	Coupling capacitance
Csub	Substrate capacitance
Cp	First neighbour capacitance
Cs	Second neighbour capacitance
Cm	Intermetal capacitance

STAR Forward Silicon Tracker

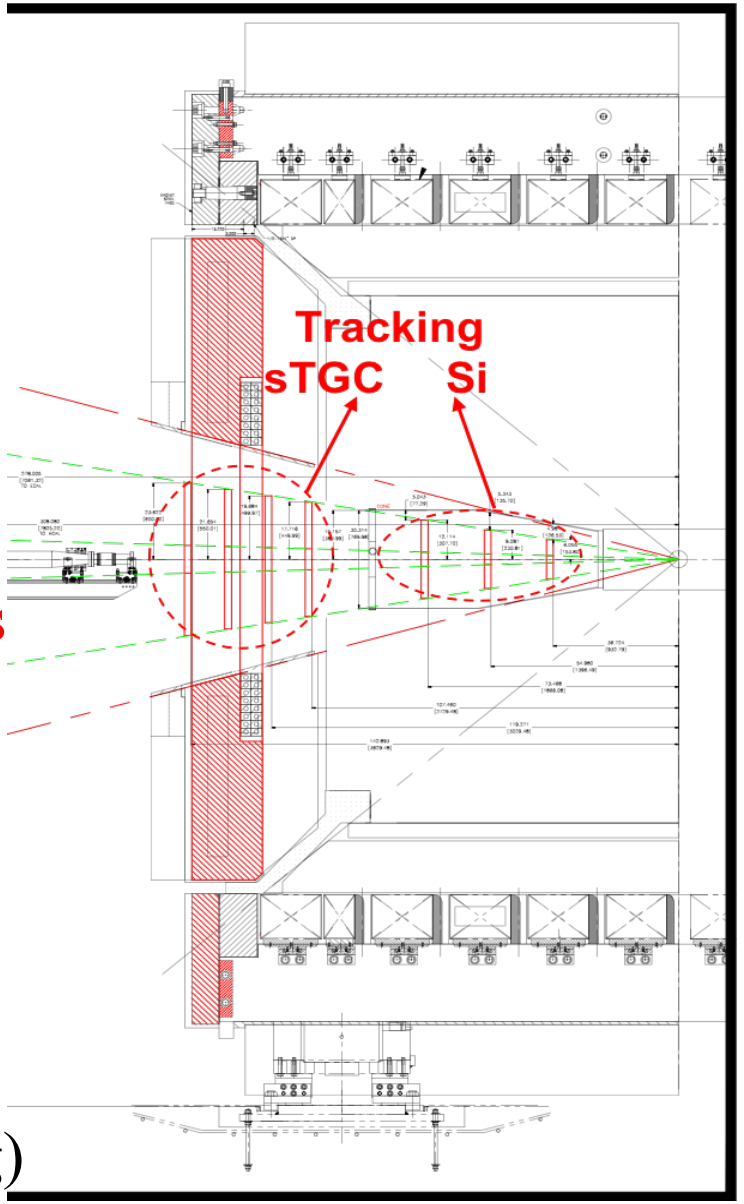
- **Forward Tracking System** provides
  - high tracking efficiency
  - charge separation
  - momentum measurement (20-30%)

  for charged particles in $2.5 < \eta < 4$ in p+p, p+Au and Au+Au collisions.

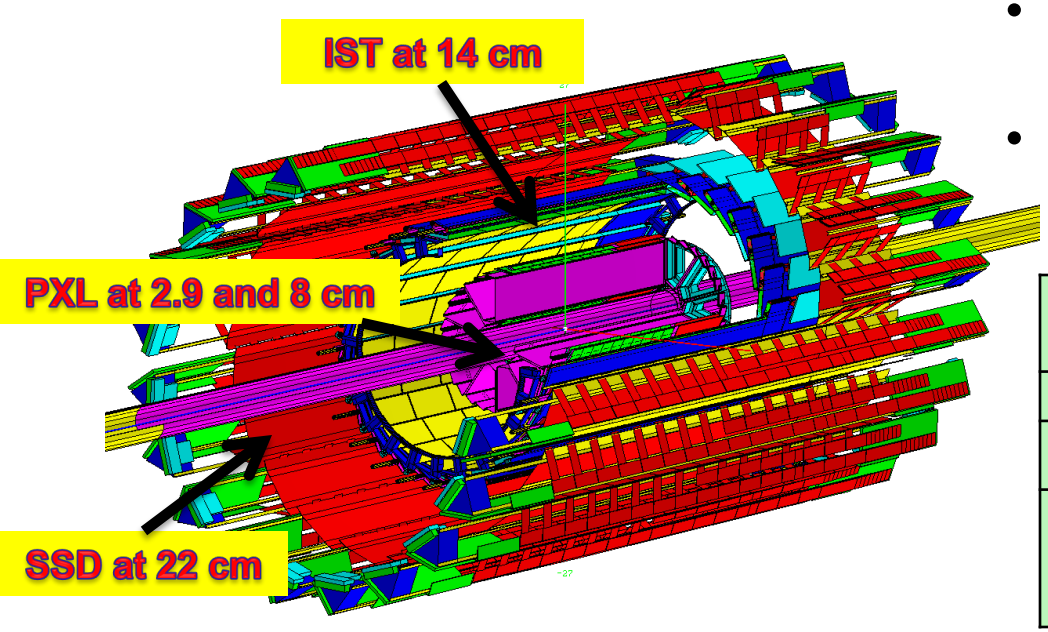
- **Forward Tracking System** includes
  - 3 layers of Silicon microstrip detectors
  - 4 layers of small Thin Gap Chambers

  inside a 0.5T solenoidal magnetic field.

- **Forward Silicon Tracker**
  - fine ϕ segmentation and coarse in r
  - low material budget
  - cost effective (reuse IST DAQ/cooling)



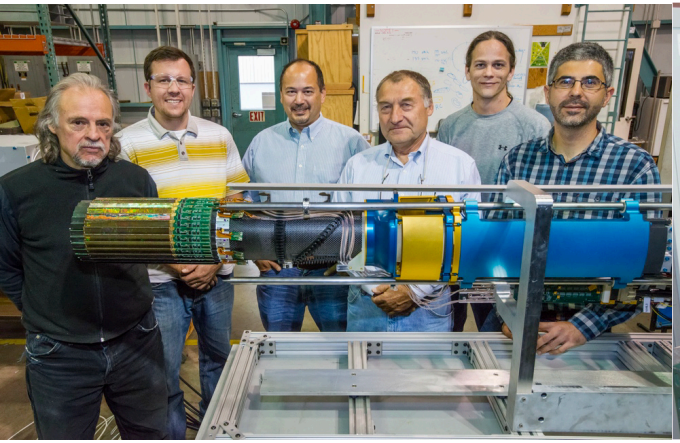
STAR Heavy Flavor Tracker in 2014-2016



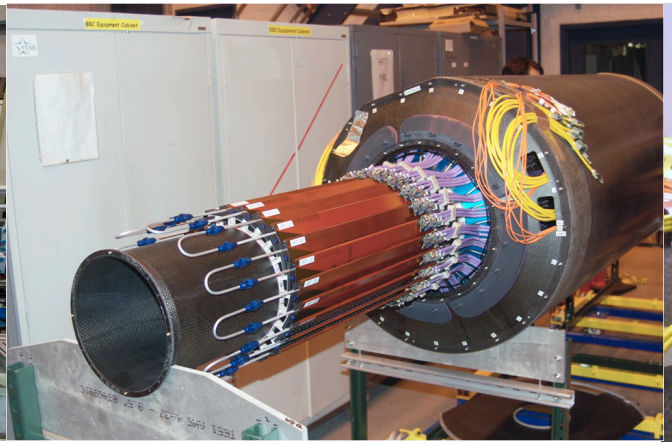
- 2 layers of thin Silicon MAPS (PXL) 360M pixels, each 12x12μm
- 2 layers of Si strip sensors (IST/SSD) fast readout, bridging TPC/PXL

Detector	Radius (cm)	Hit Resolution R/φ - Z (μm)	Radiation length
SSD	22	20 / 740	1% X_0
IST	14	170 / 1800	<1.5 %X_0
PXL	8	12 / 12	~0.6 %X_0
	2.9	12 / 12	~0.4% X_0

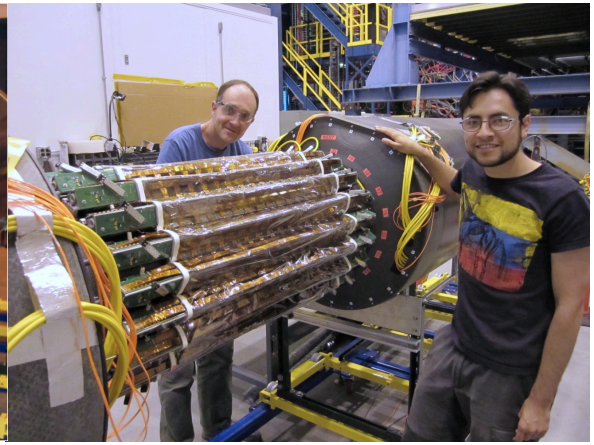
PXL



IST



SSD



IST: Conclusion

- A very successful run for IST in 2014
  - Operational with beam for more than 110 days since March 15
  - Participated in physics data taking for low/medium/high luminosity Au+Au @ 200 GeV and most of the He3+Au collisions
- Performance exceeds all of the optimal specifications

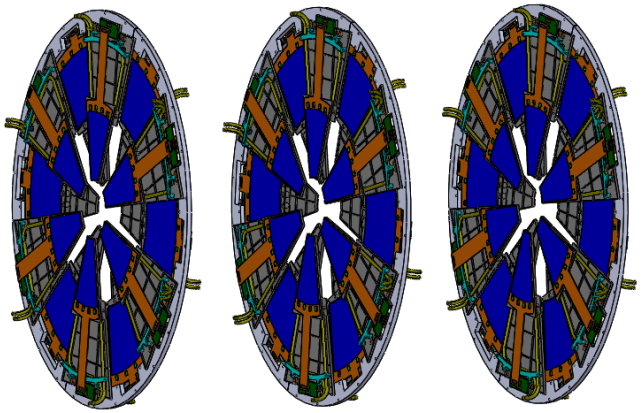
	Functional parameter	Threshold value	Optimal value	Achieved
7	IST hit efficiency and noise	> 90% from S/N better than 10:1	> 95% from S/N better than 15:1	~99% S/N 15:1-30:1
8	IST Live channels	> 85%	> 95%	>95%
10	IST Readout speed and dead time	< 5% additional dead time at 1 kHz average trigger rate and simulated occupancy	~2% additional dead time at 1kHz average trigger rate and simulated occupancy	~0%

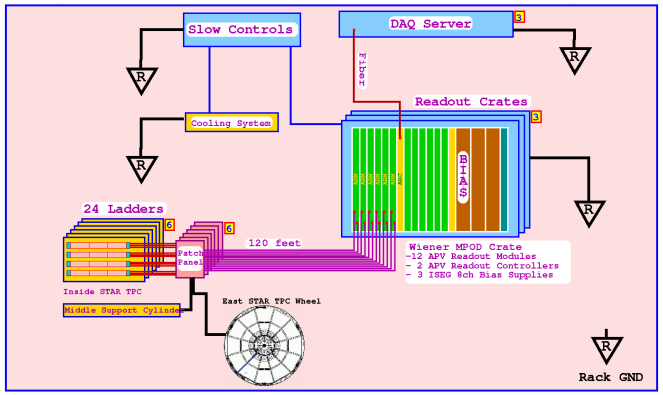
- All project deliverables are provided

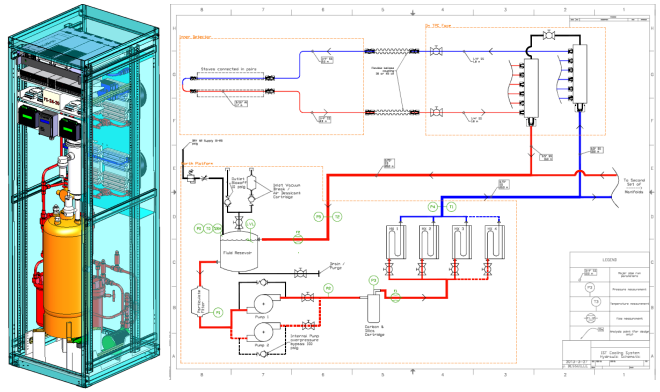
STAR Forward Silicon Tracker

- Three layers of identical Silicon disks
  - Silicon microstrip sensors
  - APV25 frontend readout chips
  - Flexible hybrid
  - Mechanical structure
- DAQ system
  - Inner signal cables
  - Outer signal cables, patch panel boards, readout modules, readout controllers, crates
- Cooling system
  - cooling manifold, cooling lines
  - rack (cooler, pumps)
- Integration
  - supporting structure

Blue: existing Red: new

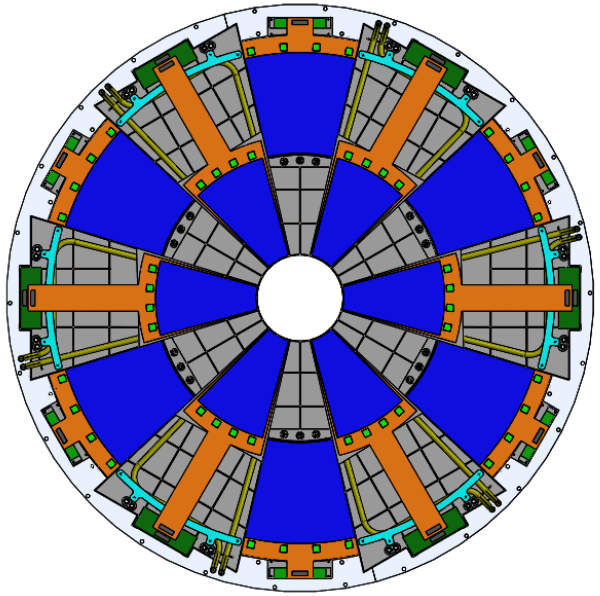


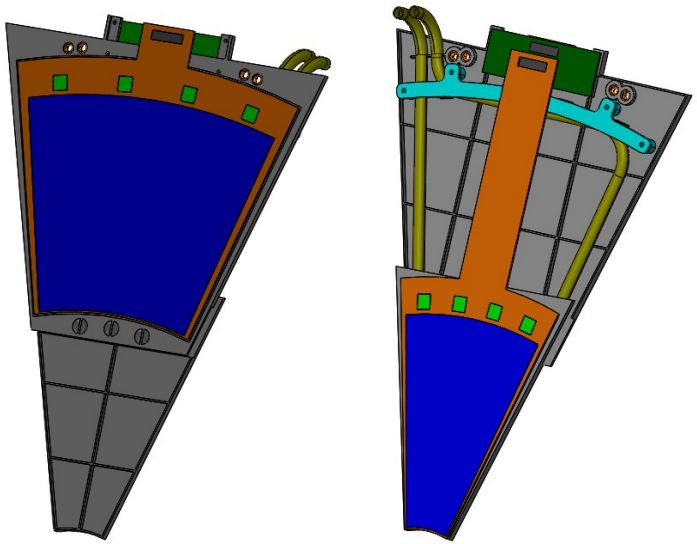




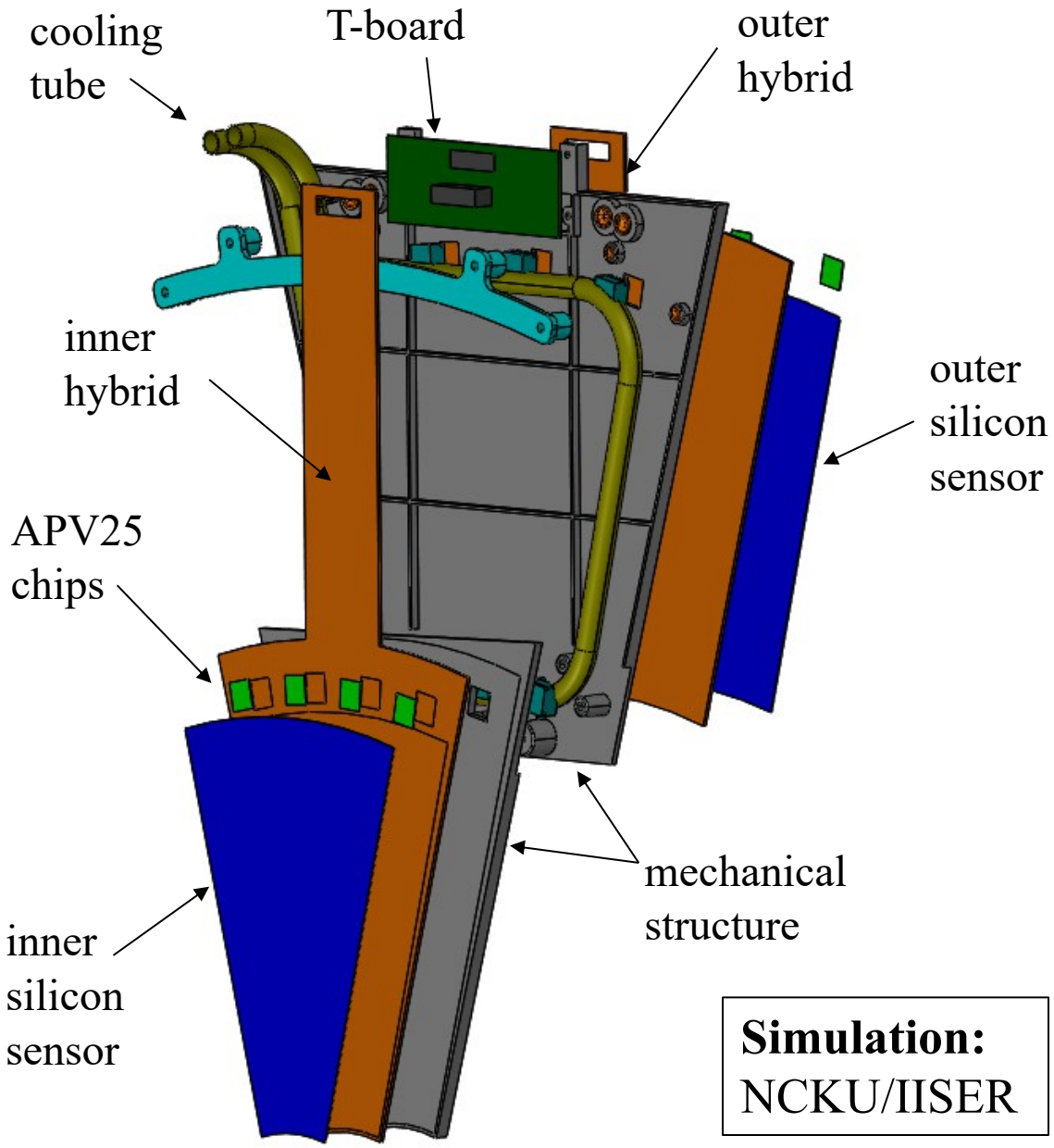
STAR Forward Silicon Tracker – Module Design

- Each disk: 12 modules, $\leq 1\%\ X_0$
- Each module split into two regions
  - **inner region (front side)**
    - 1 Silicon microstrip sensor: each 128×4 $(\phi \times r)$ strips
    - 4 APV chips
    - 1 Kapton flexible hybrid
  - **outer region (back side)**
    - 2 Silicon microstrip sensors: each 64×4 $(\phi \times r)$ strips
    - 4 APV chips
    - 1 Kapton flexible hybrid
- Mechanical structure for each module
  - Made of PEEK + Carbon Fiber, with Stainless Steel cooling pipe





STAR Forward Silicon Tracker – Module Design



Silicon sensor:
Shandong/UIC

APV25:
UIC

Hybrid, T-board:
Shandong/BNL/Indiana

Mechanical structure:
National Cheng Kung Univ.

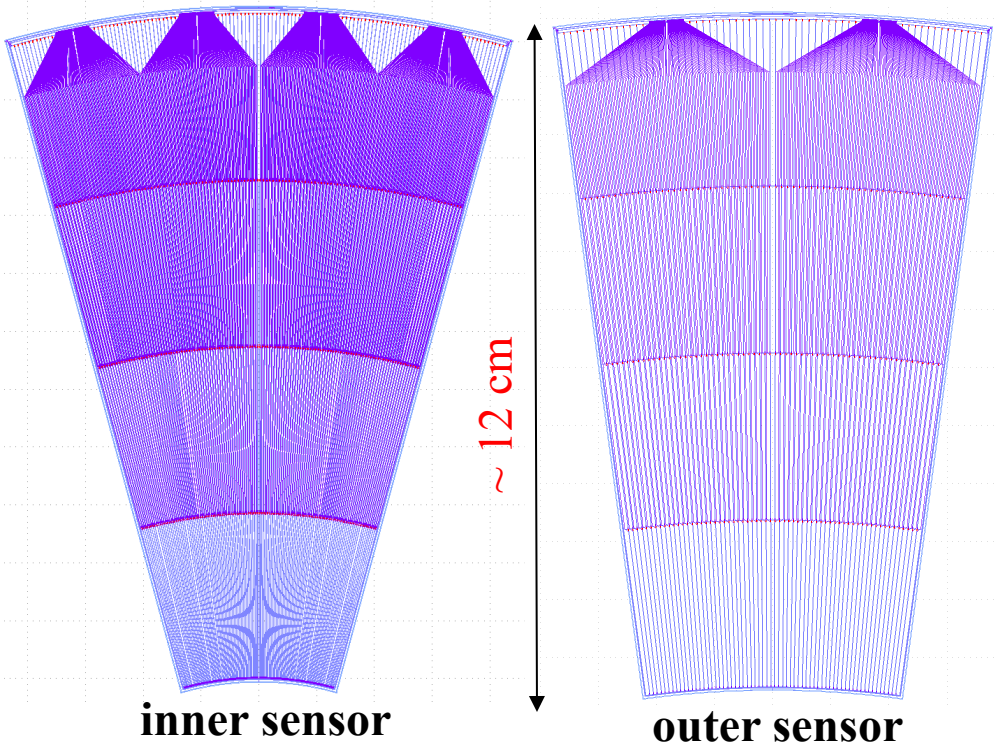
Cooling system:
BNL/NCKU

DAQ system:
BNL/Indiana

Supporting structure:
BNL

Simulation:
NCKU/IISER

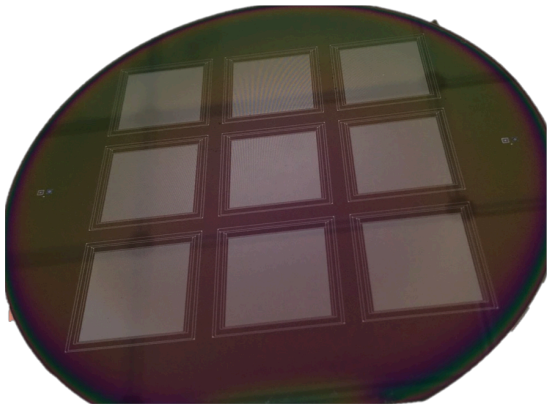
STAR Forward Silicon Tracker – Silicon Sensor

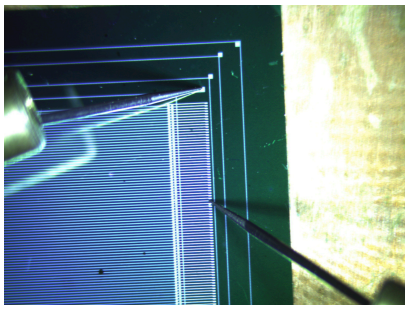


Hamamatsu Sensors

	Inner	Outer
Radii (cm)	5-16.5	16.5-28
Angle (o)	30	15
# strips (R*ϕ)	4*128	4*64
Thickness (μm)	320	

- Design completed at UIC in 2019/1
- 4+6 prototype sensors ordered in 2019/2
- Prototype sensors expected in 2019/8
- Performance tests in 2019/9-2019/12
- Delivery of production sensors in 2020/8



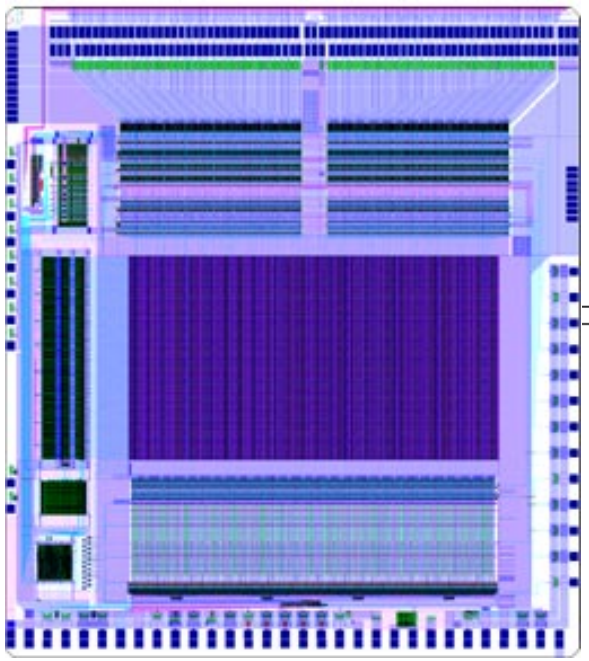


NCKU-NDL Sensors

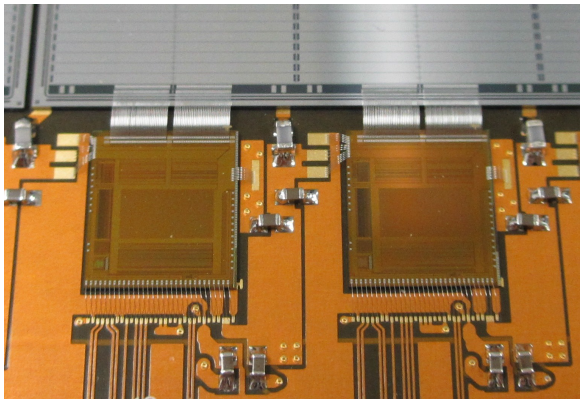
- Investigation into alternative vendors
- Design with simplified layout in 2018/7
- 1st batch received in 2019/1
- 2nd batch production ongoing

STAR Forward Silicon Tracker - APV25 Chip

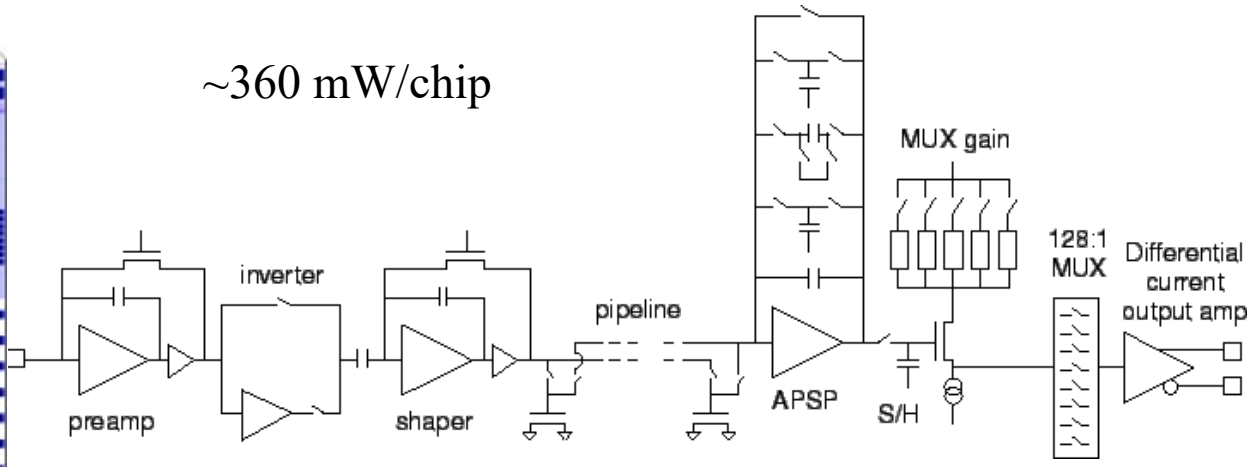
128 front-end input pads



control and output pads



~360 mW/chip



preamplifier + shaper + 192 analog pipelines + capacitor filter + multiplexer

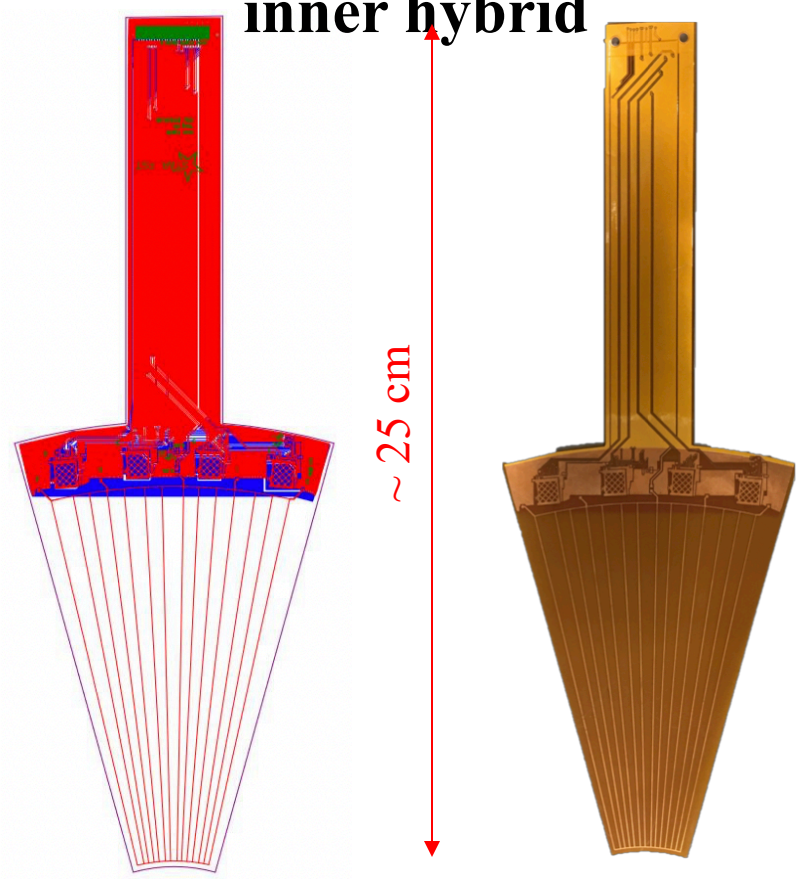
Designed for CMS Silicon strip detector

Fabricated in 0.25μm CMOS process

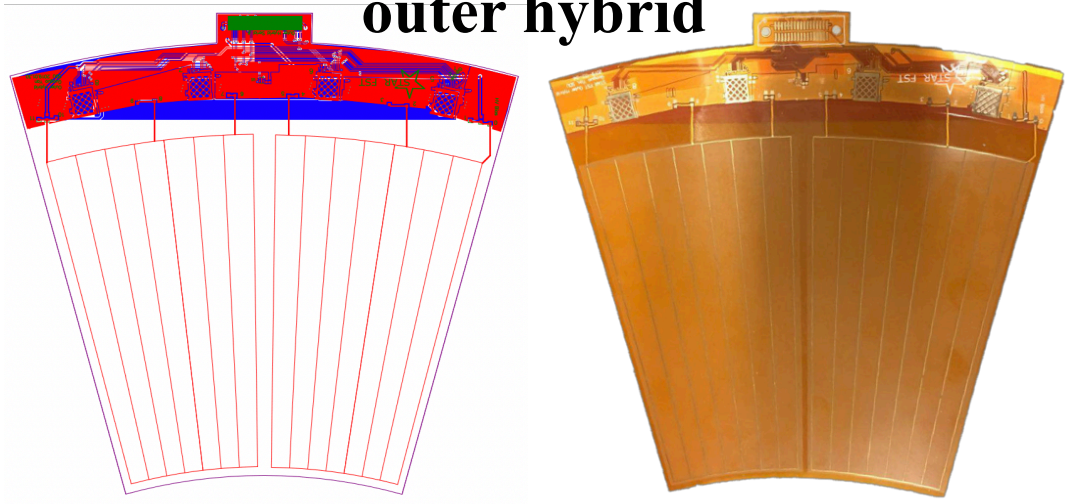
More than enough probe-tested APV25 chips in-hand for STAR Forward Silicon Tracker

STAR Forward Silicon Tracker – Flexible Hybrid

inner hybrid



outer hybrid



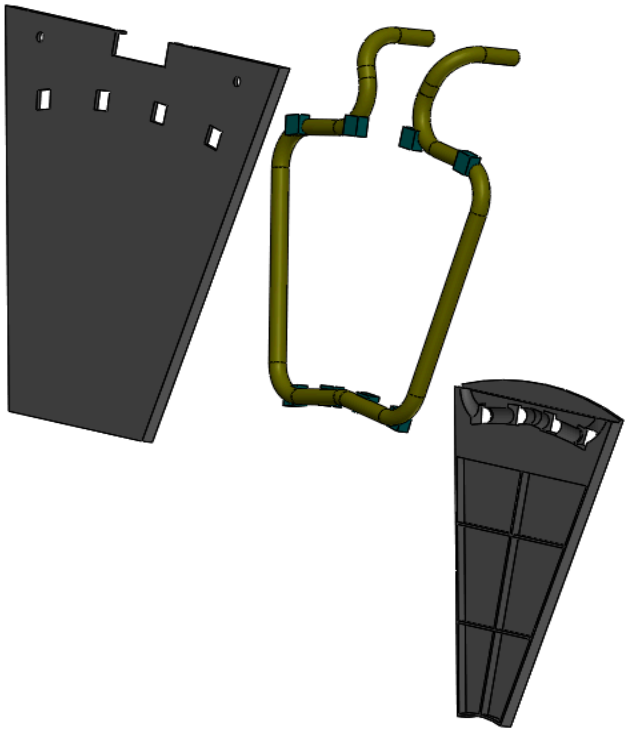
Bring power, clock, control signals to APV25 and sensor, and APV output signals to T-board

Material: 25 μm thick Kapton
+ 17.5-35 μm thick Copper layers

- 1st version design completed at SDU (Jianing Dong et al.) in 2019/2
- 1st version hybrids received from vendor in 2019/3
- 2nd version design completed at SDU in 2019/7: adjust dimensions and connector type
- 2nd version hybrids expected in 2019/8
- Delivery of production hybrids in 2020/3

STAR Forward Silicon Tracker – Mechanical Structure

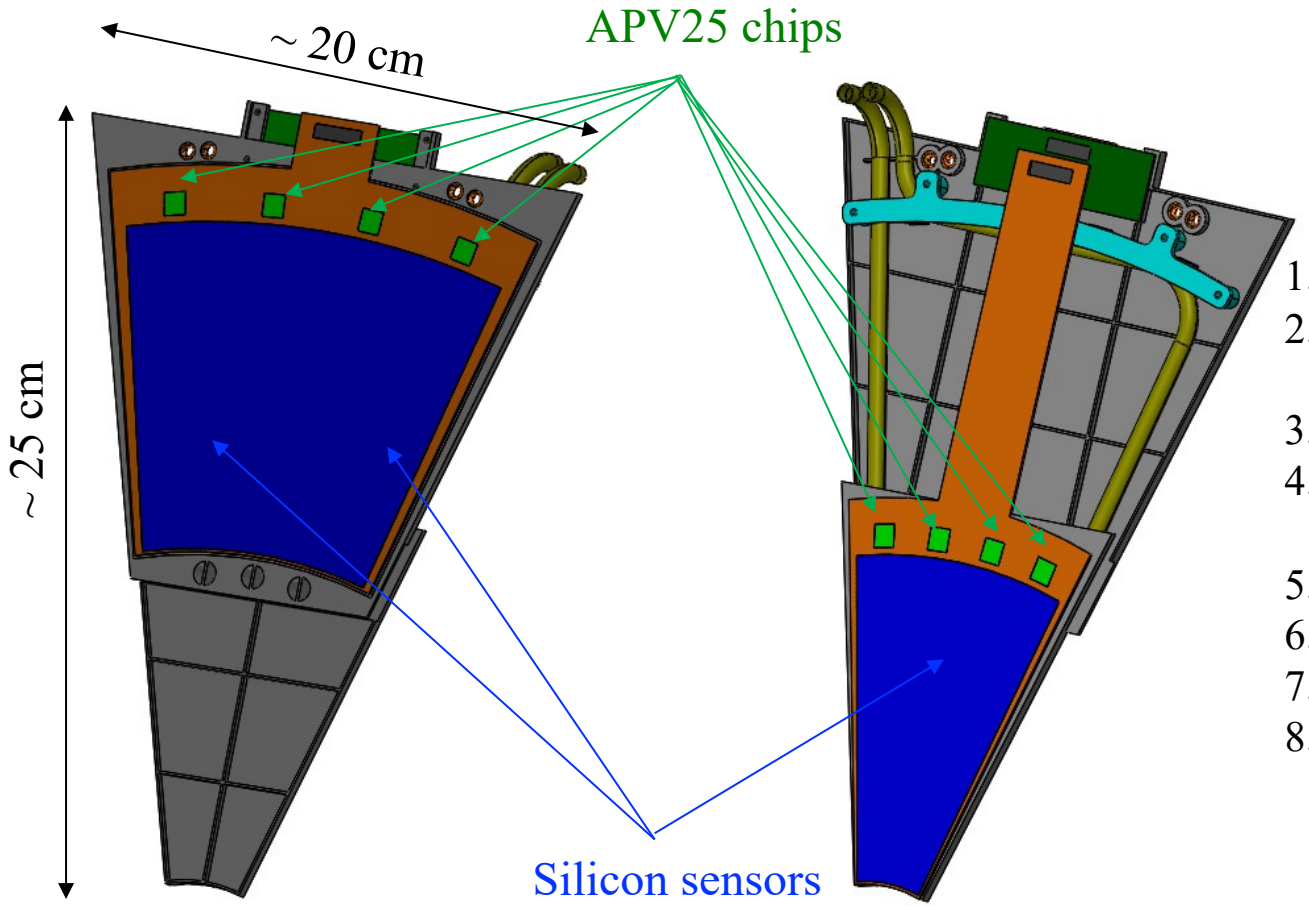
Solidwork Drawings



Photographs

- 1st version design completed at NCKU (Yi Yang et al.) in 2019/2
- 1st version structures received with uneven surface in 2019/3
- 2nd version design completed at NCKU in 2019/7: optimize material composite and thickness; adjust dimension and shape; thermal-stress simulation
- 2nd version structures expected in 2019/8
- Delivery of production mechanical structures in 2020/5

STAR Forward Silicon Tracker – Module Assembly

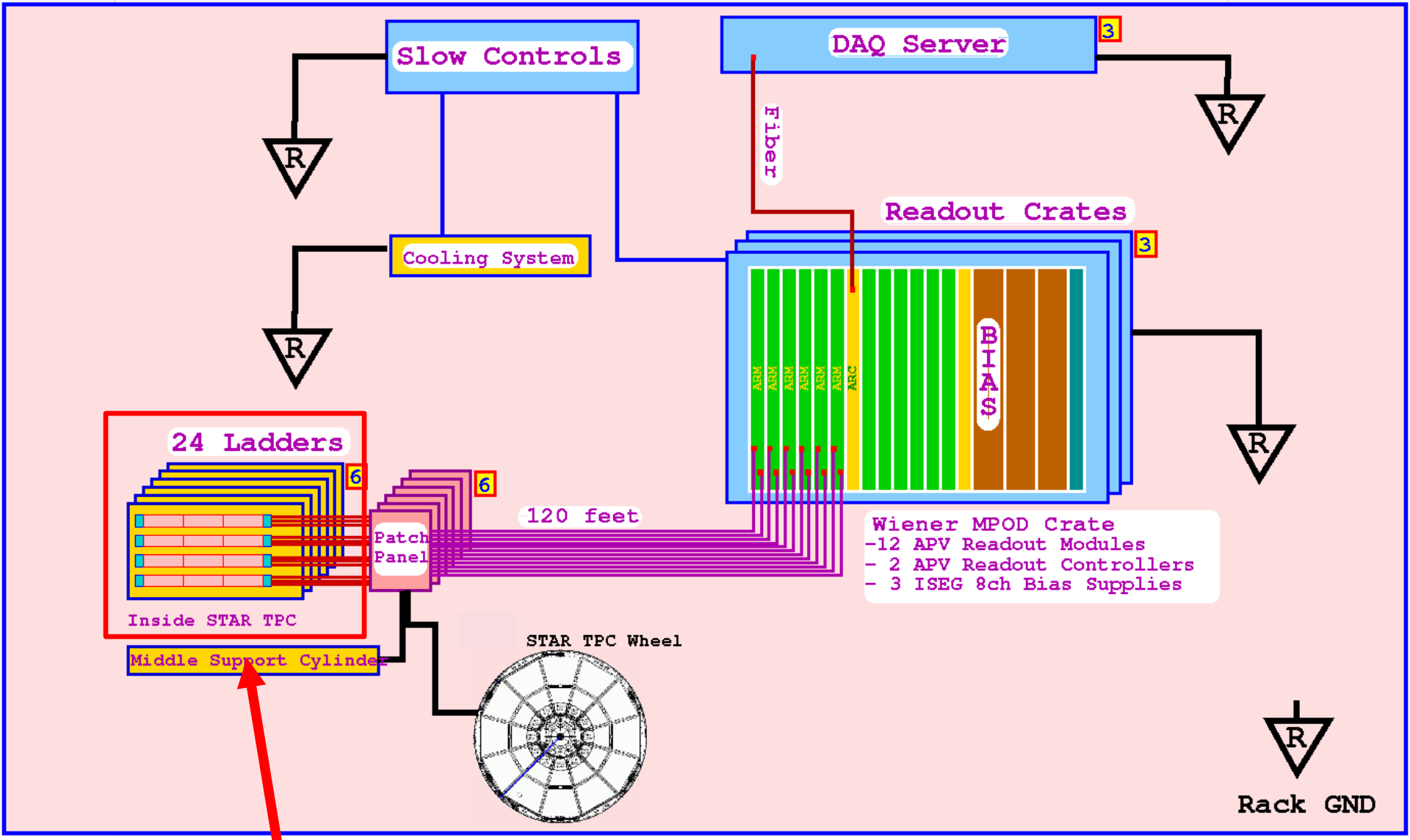


Assembly procedure

1. Hybrid wire-bonding pull test
2. Chip mounting and wire-bonding
3. Readout test
4. Sensor mounting and wire-bonding
5. Readout test
6. Encapsulation
7. Readout test
8. Survey

- **Prototype module**: 3 modules, each with 3 Silicon sensors and 8 APVs
  Assembly: 2019/9-2019/10; Testing: 2019/11-2019/12
- **Production module**: 48 modules, each with 3 Silicon sensors and 8 APVs
  Assembly: 2020/9-2021/2; Installation and testing on supporting structure: 2021/3-2021/4

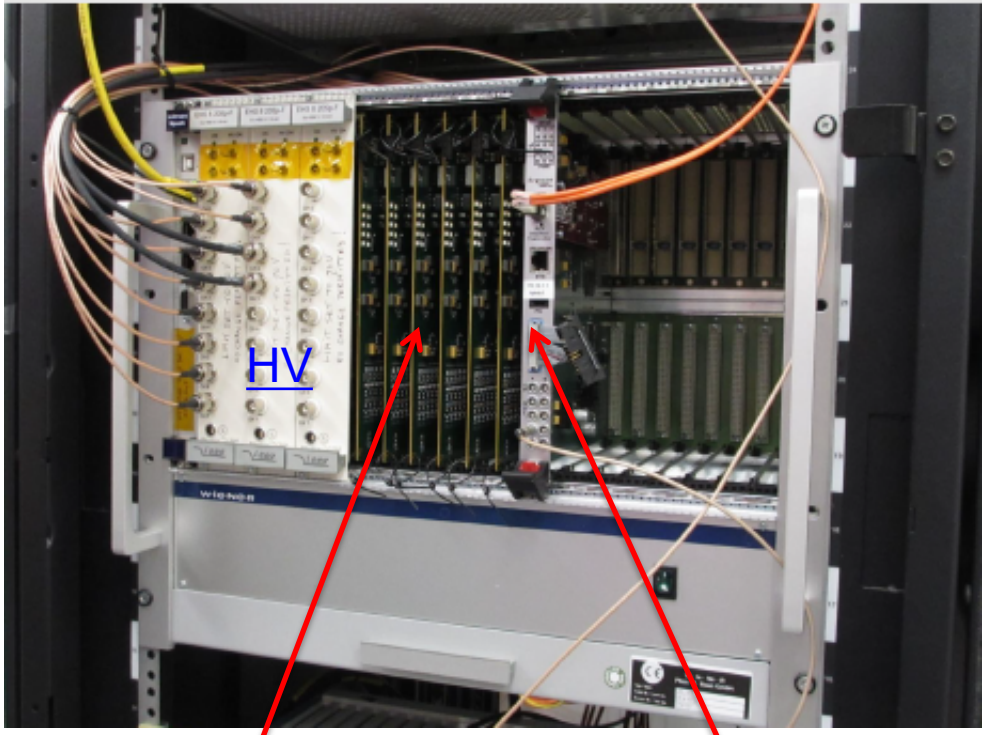
STAR Forward Silicon Tracker – DAQ System

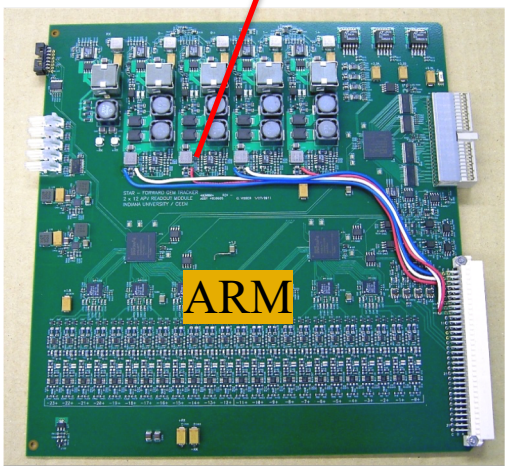


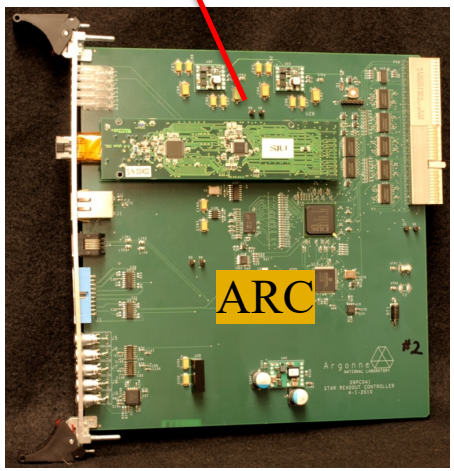
FST with new inner signal cables read out with the existing IST DAQ system

STAR Forward Silicon Tracker – DAQ System

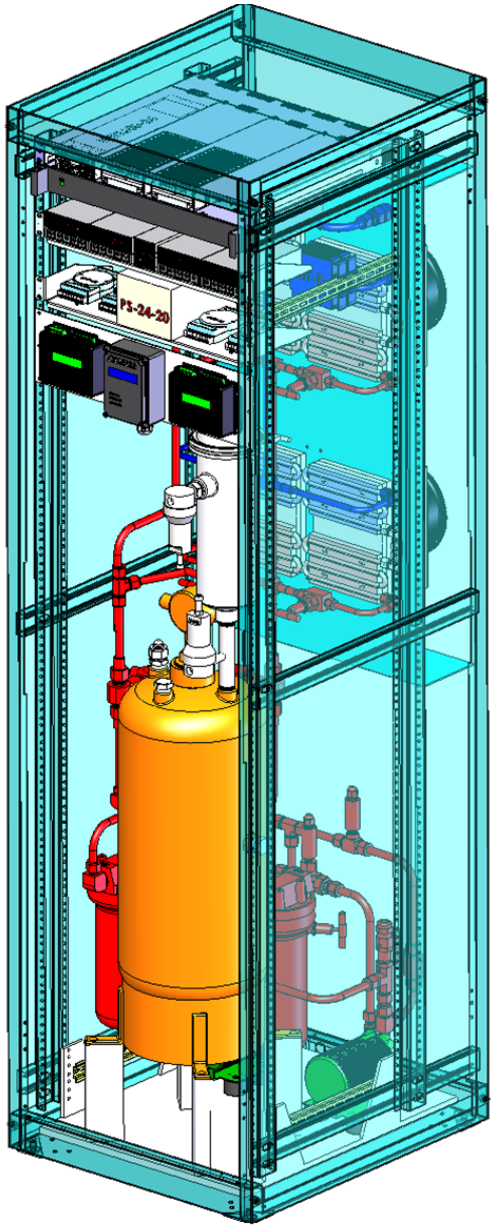
- Custom-designed DAQ system in a WIENER MPOD HV-cPCI frame
- 3 crates, 6 ARCII, 36 ARM, 36 Patch-panel boards, 72 outer signal cables from IST can be used for FST. Status verification in 2019/9
- FST T-board and inner signal cable designs completed by SDU/BNL/IU
  - 1st version assembled in 2019/8
  - 2nd version expected in 2019/9
  - Delivery of production cables and T-boards in 2020/6

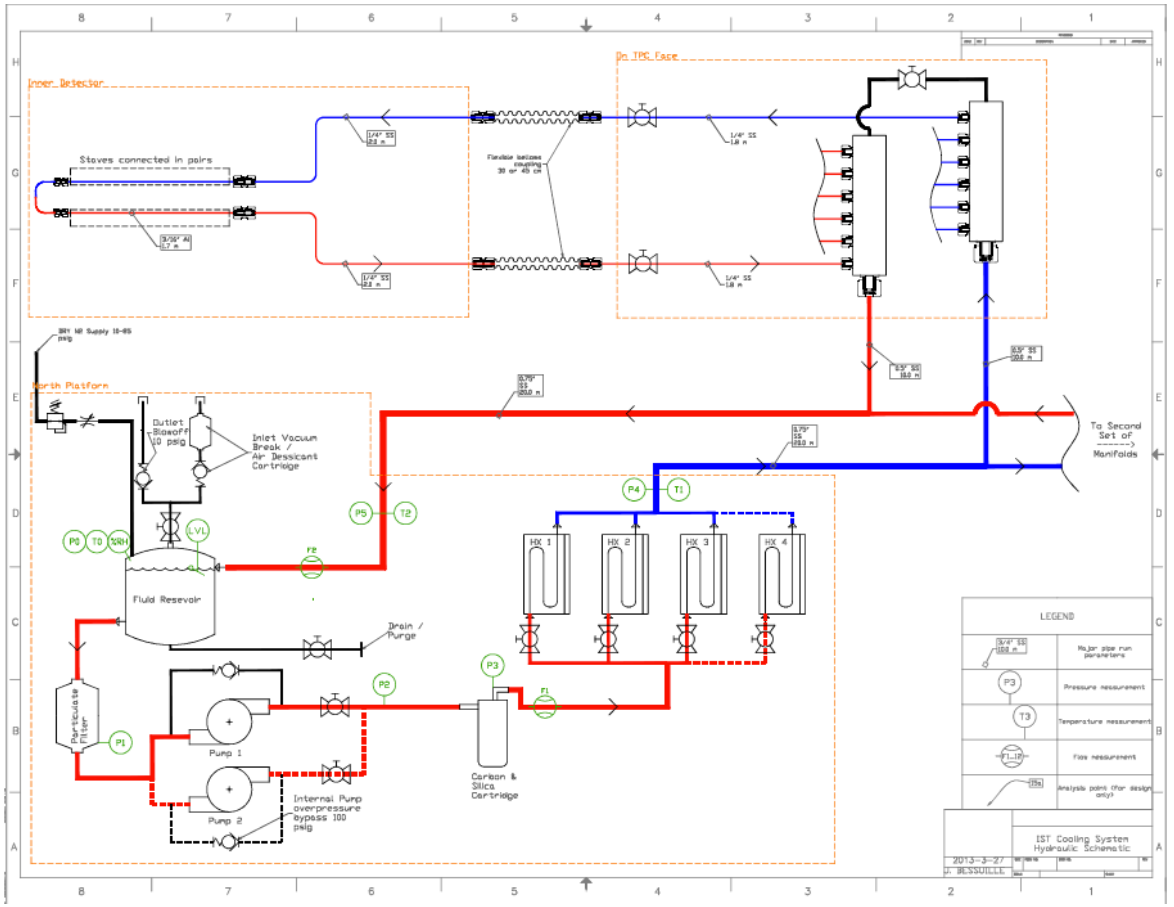






STAR Forward Silicon Tracker – Cooling System





Heat load ~ 100W (300W for IST)

Coolant: 3M^{TM} Novec^{TM} 7200 ($\mathbf{C_4F_9OC_2H_5}$)

Sitting on STAR platform, maintenance needed

STAR Forward Silicon Tracker – Milestones

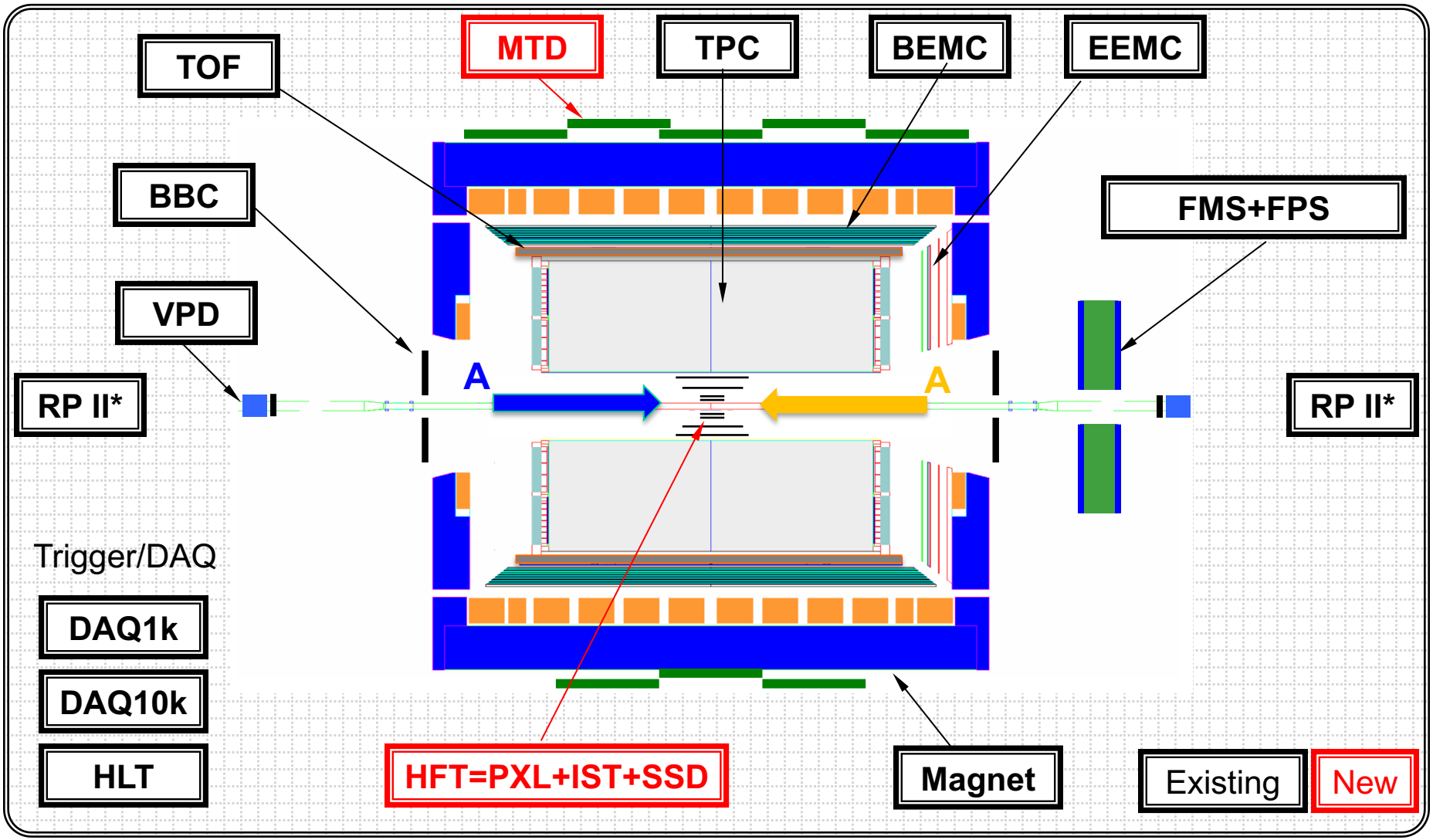
- **Prototype**
  - Mechanical structure: 1st: 3/28/2019, 2nd: 8/30/2019
  - Flexible hybrid: 1st: 3/21/2019, 2nd: 8/15/2019
  - Silicon sensor: 08/30/2019
  - Detector module assembly: 10/31/2019
  - Detector module testing: 12/31/2019
- **Production**
  - Ordering: 01/31/2020
  - 1st batch of flexible hybrid: 03/31/2020
  - 1st batch of mechanical structure: 05/31/2020
  - 1st batch of Silicon sensors: 08/31/2020
  - Detector module assembly complete: 02/28/2021
- **Supporting structure and cooling system**
  - Design 12/31/2019
  - Fabrication 05/31/2020
- **Installation**
  - Installed onto supporting structure: 04/30/2021
  - Installed into STAR: 07/15/2021
  - Ready for data taking: 08/31/2021

STAR Forward Silicon Tracker – Summary

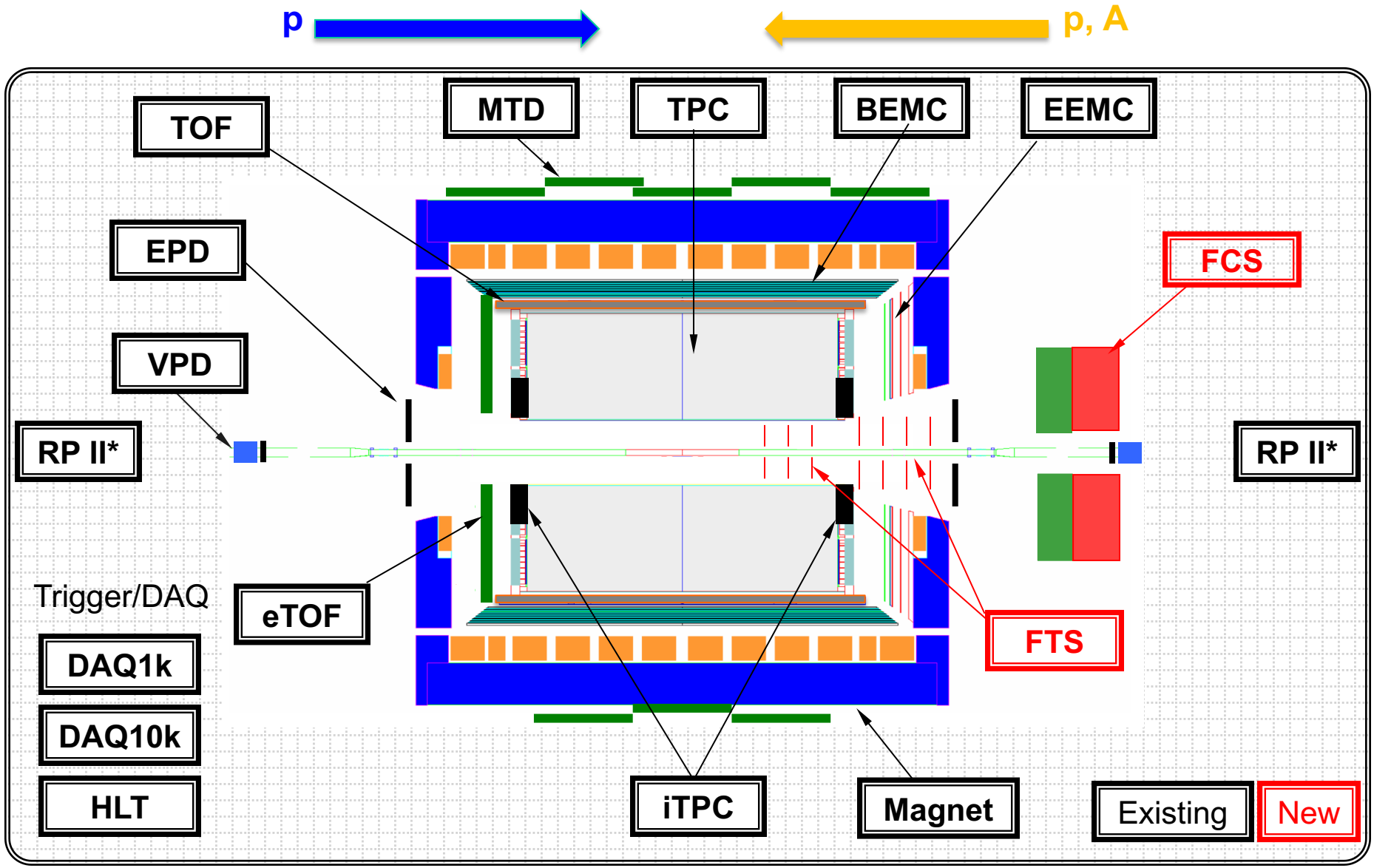
- A 3-layer forward tracking detector based on the Silicon microstrip detector technology is designed for STAR Forward upgrade.
- The FST utilizes the successful experience and infrastructure of the previous STAR Intermediate Silicon Tracker, in order to reduce cost and risk.
- The project is currently in the R&D phase to build prototype detector modules, including Silicon sensors, hybrids, mechanical structures, T-boards, inner signal cables.
- Production of the detector is expected to start in 2020 and completed in early 2021, so that it will be ready for the installation into STAR in summer 2021.

BNL, IISER, Indiana, NCKU, SDU, UIC …

STAR Experiment in 2014-2016

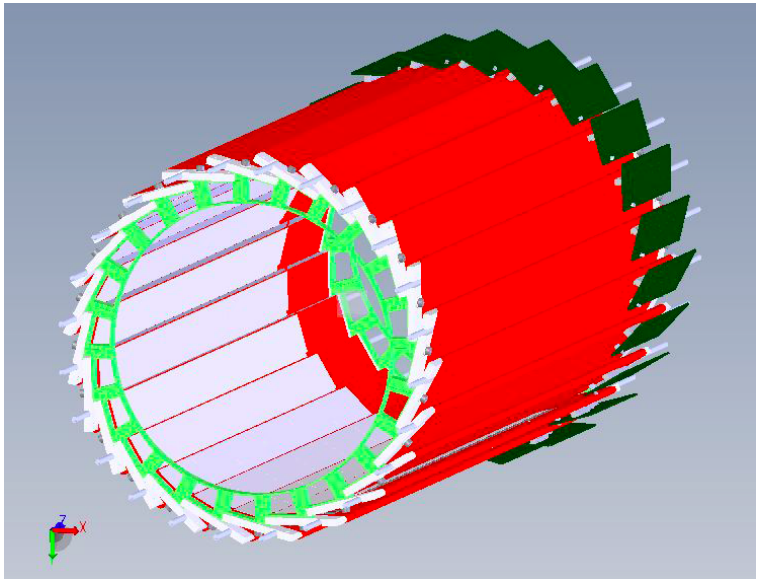


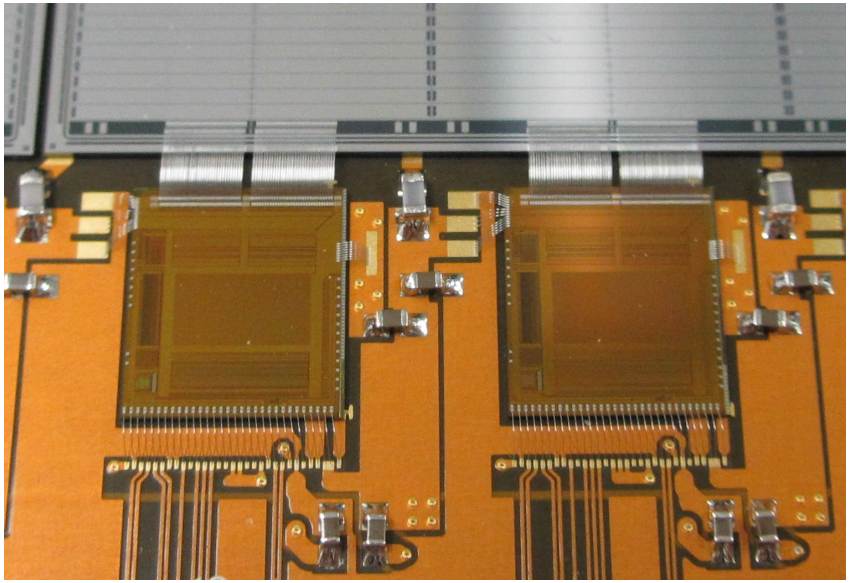
A+A @ 200 GeV - QCD in hot and dense medium, QGP dynamics and properties

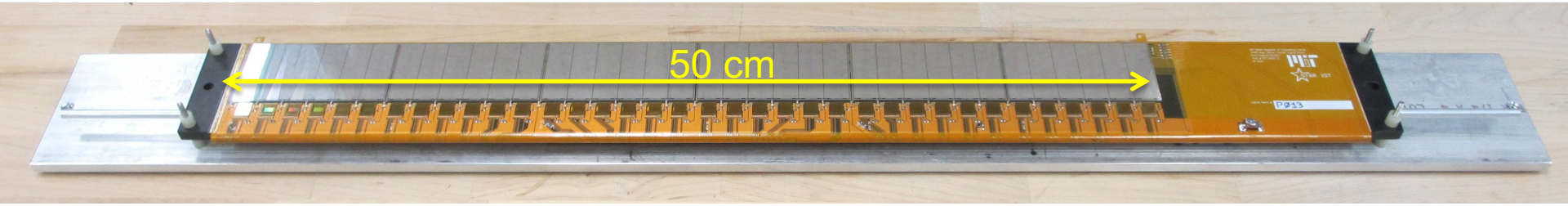


p+p/A @ 200/510 GeV - spin and partonic structures of nucleon and nuclei

STAR Intermediate Silicon Tracker

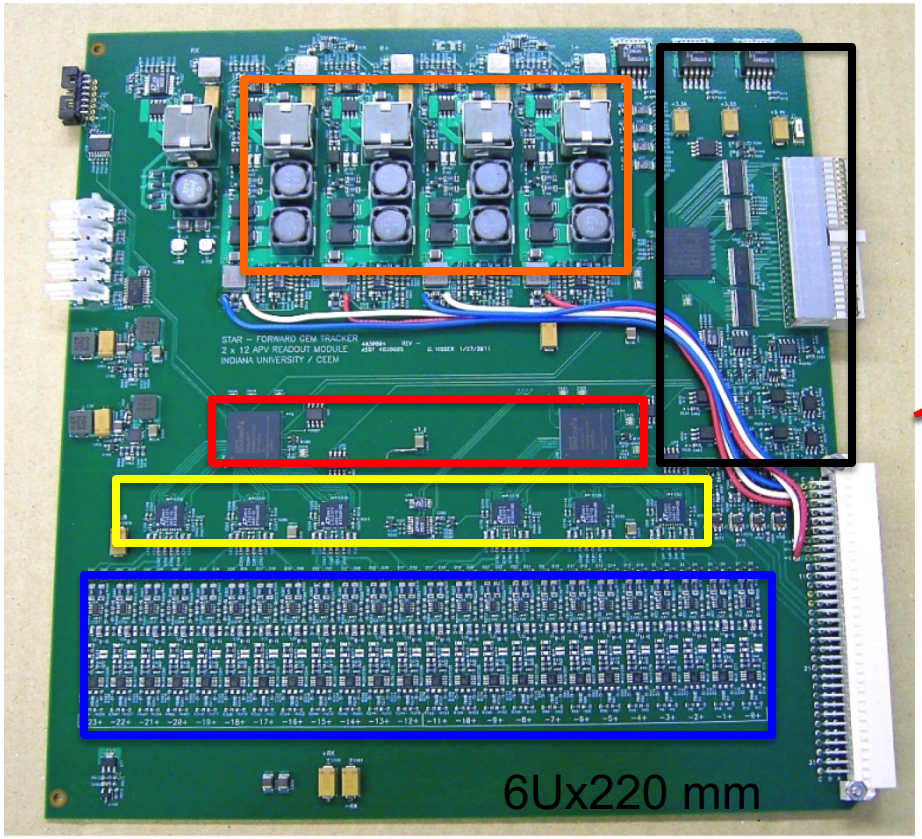


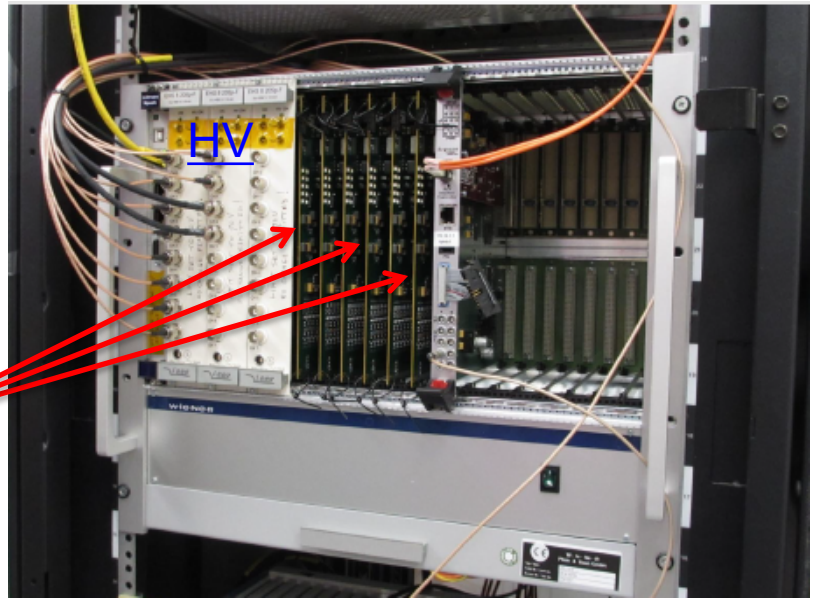




24 ladders, 144 sensors, 864 readout chips, 110,592 channels

STAR Forward Silicon Tracker – APV Readout Module





Custom-designed DAQ system in a WIENER MPOD HV-cPCI mainframe

APV/ADC clock 37.532 MHz

4 1.75V Front-end Power Suppliers

2 FPGA

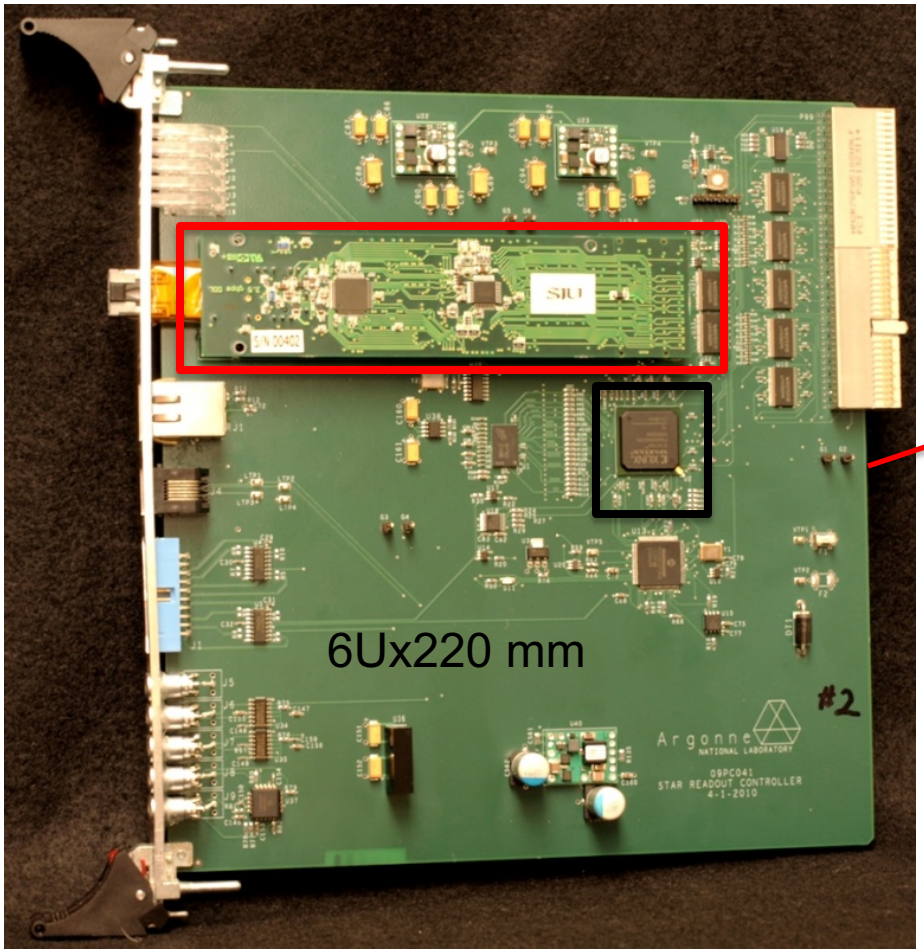
6 Quad ADC (12-bit)

24 analog receivers (= 2 sections on a ladder)

Trigger, Clock, I^2C interface

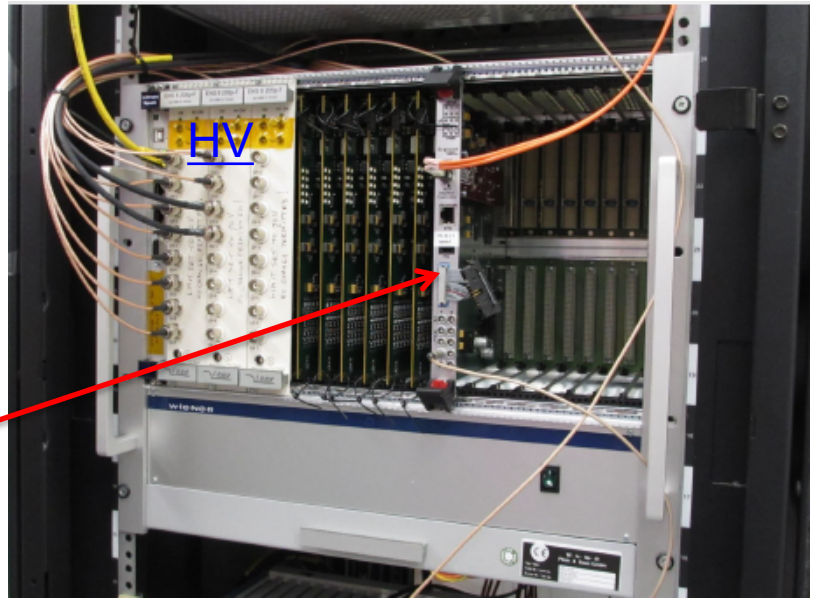
3 crates, 6 ARCII, 36 ARM for IST sitting on STAR platform

STAR Forward Silicon Tracker – APV Readout Controller



DDL Optical Data Link to DAQ-PC

FPGA

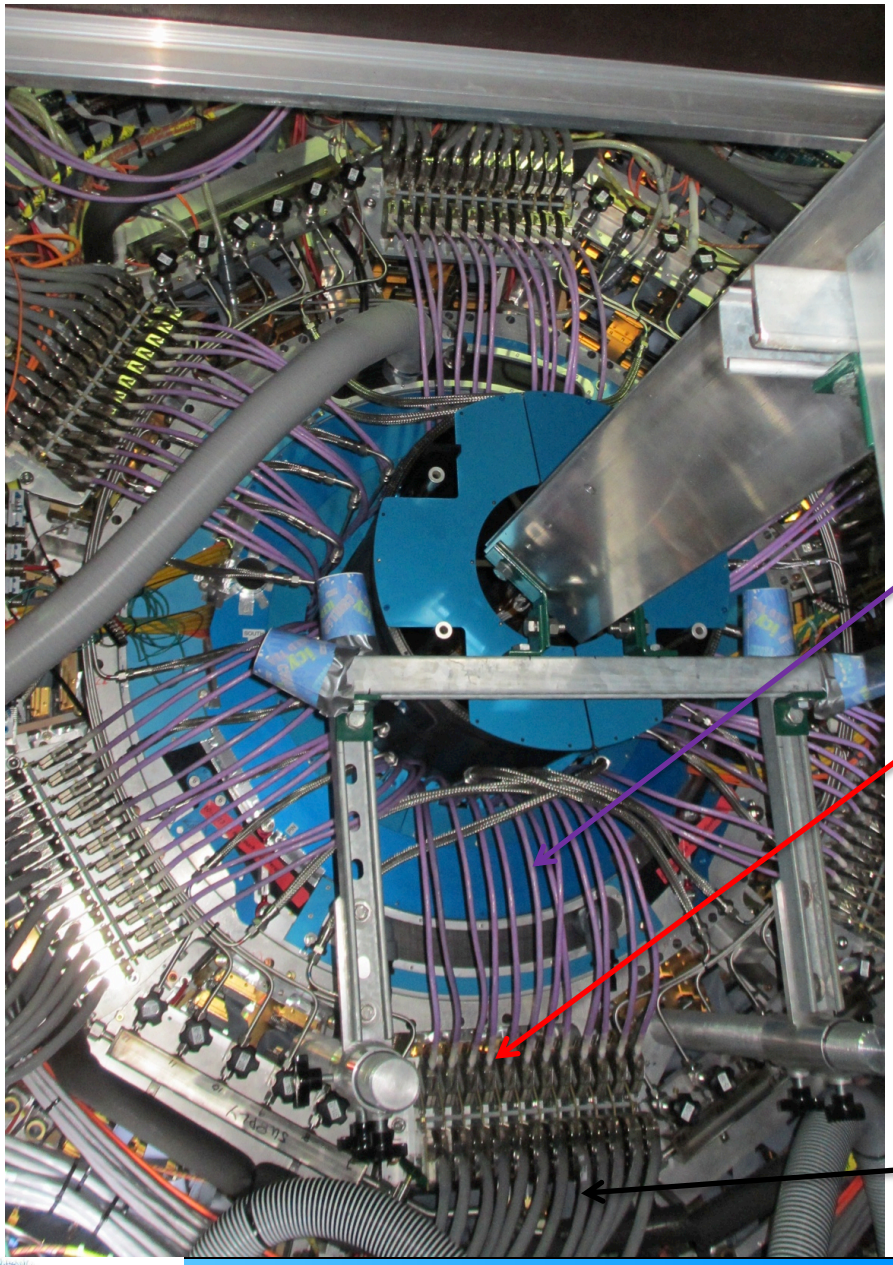


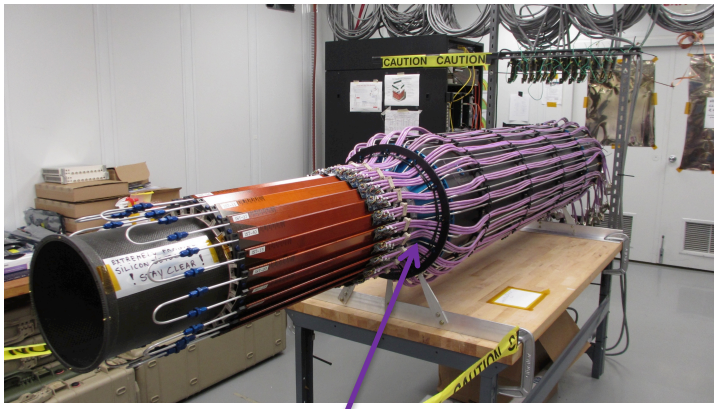
Custom-designed DAQ system in a WIENER MPOD HV-cPCI mainframe

Readout clock 33 MHz

3 crates, 6 ARCII, 36 ARM for IST sitting on STAR platform

STAR Forward Silicon Tracker – Cables, Patch Panel Boards



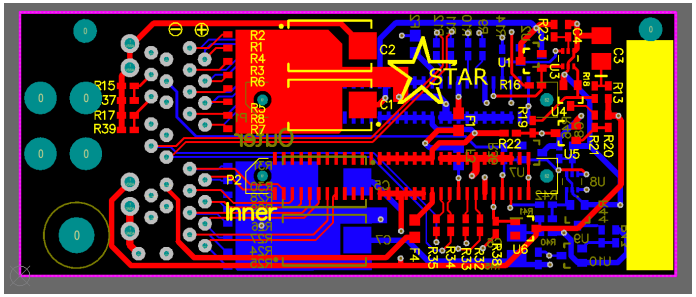


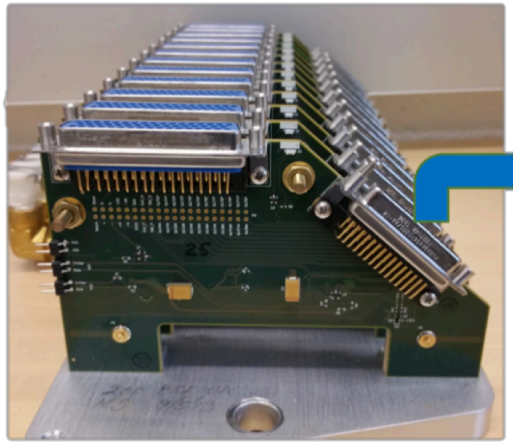
Inner signal cables

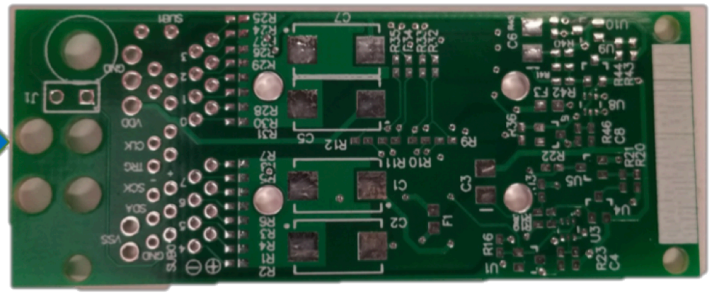
Patch Panel Boards:
interconnect between ladders and readout boards;
trigger/clock signal buffering;
APV low voltage regulators

Outer signal cables

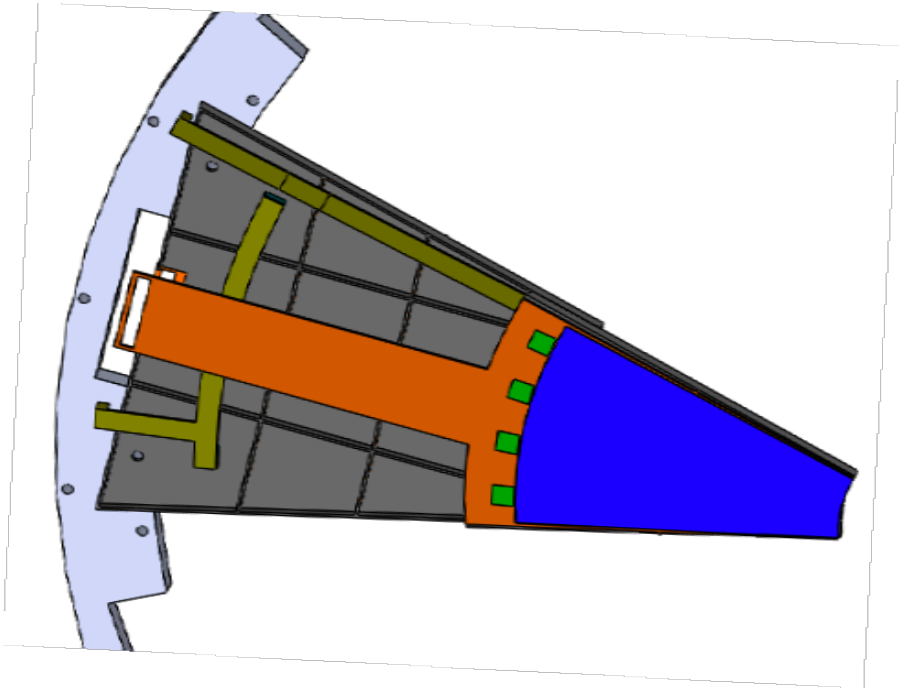
STAR Forward Silicon Tracker – T-board, Inner Signal Cable

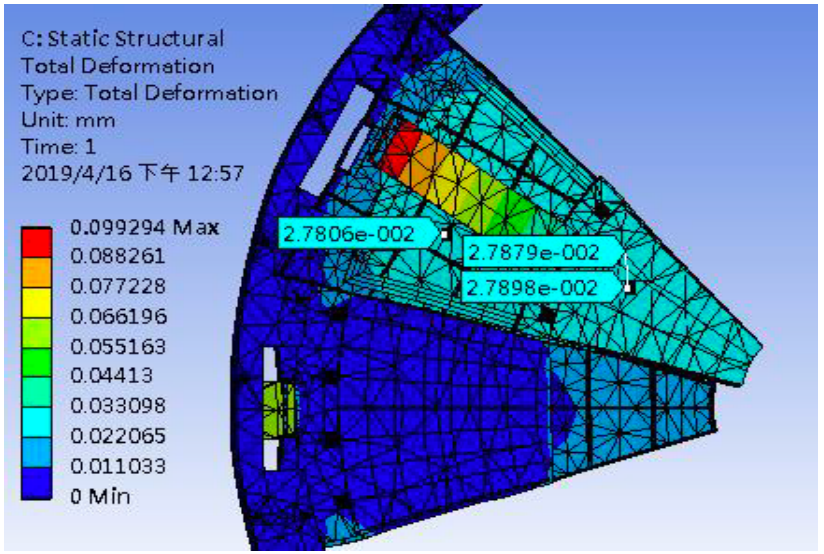


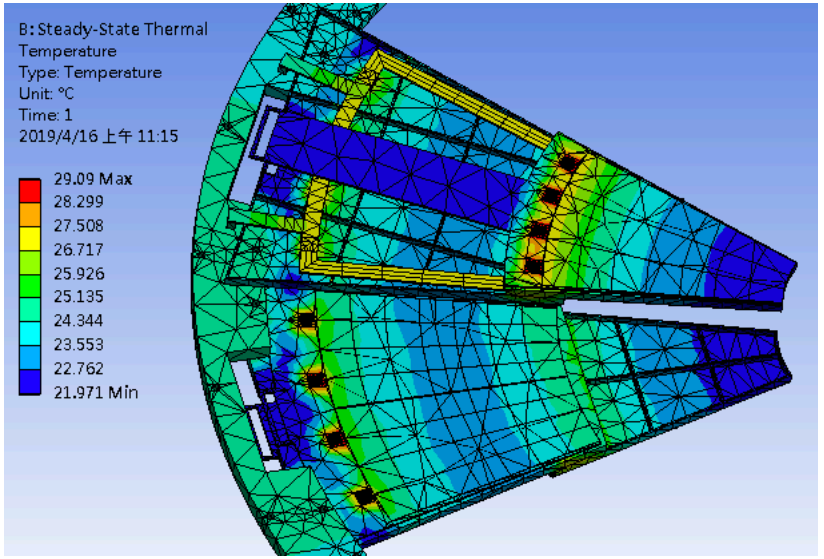




STAR Forward Silicon Tracker – Mechanical Structure







- The maximum deformation of mechanical structure, except the hybrid, is about 28 μm
- The maximum temperature is 29 degree C.

STAR Intermediate Silicon Tracker – Module Assembly

- 18 (3+15) IST ladders assembled at Fermilab/UIC in 5 (3+2) months:
  - Hybrid wire-bonding pull test
  - Chip mounting and wire-bonding
  - Readout test
  - Sensor mounting and wire-bonding
  - Readout test
  - Encapsulation
  - Readout test
  - Survey