Forward Silicon Tracker Upgrade for the STAR Detector

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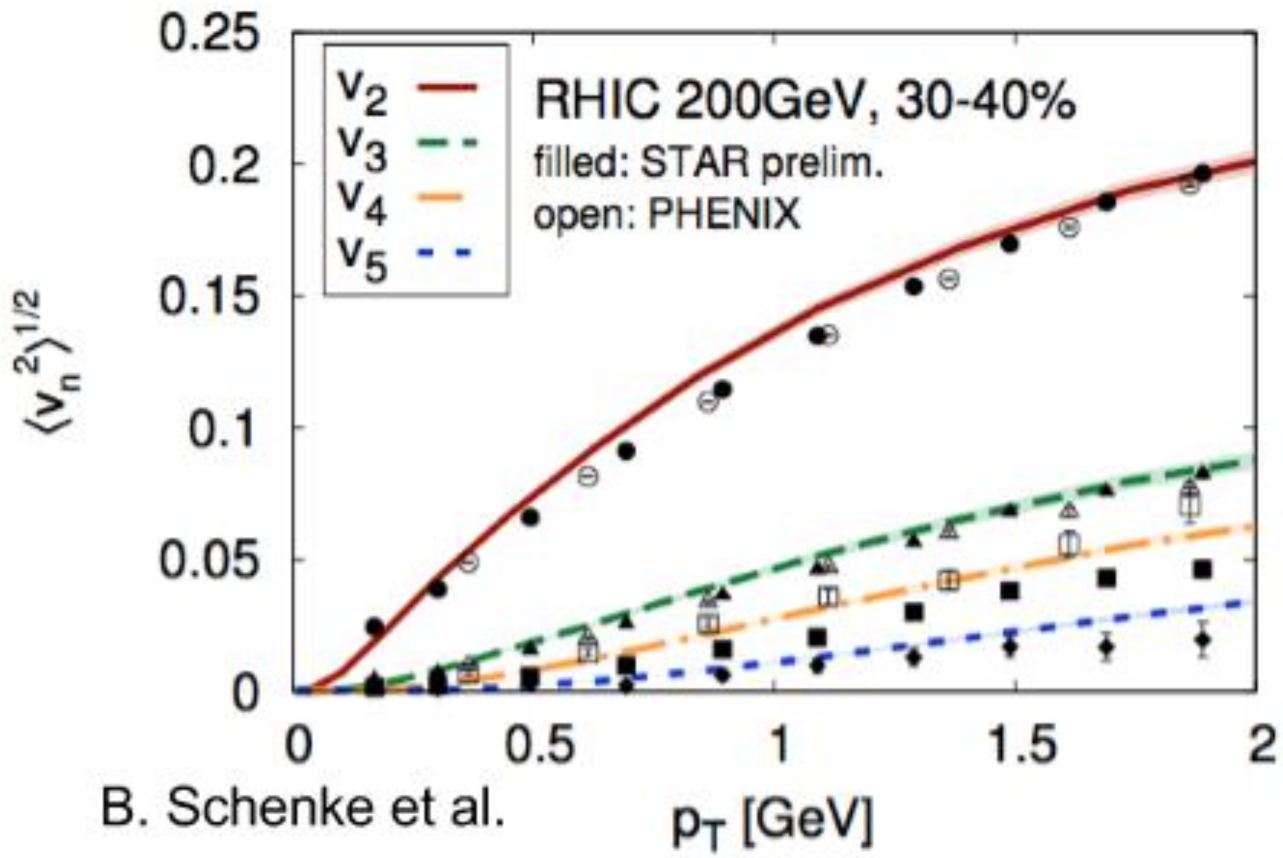
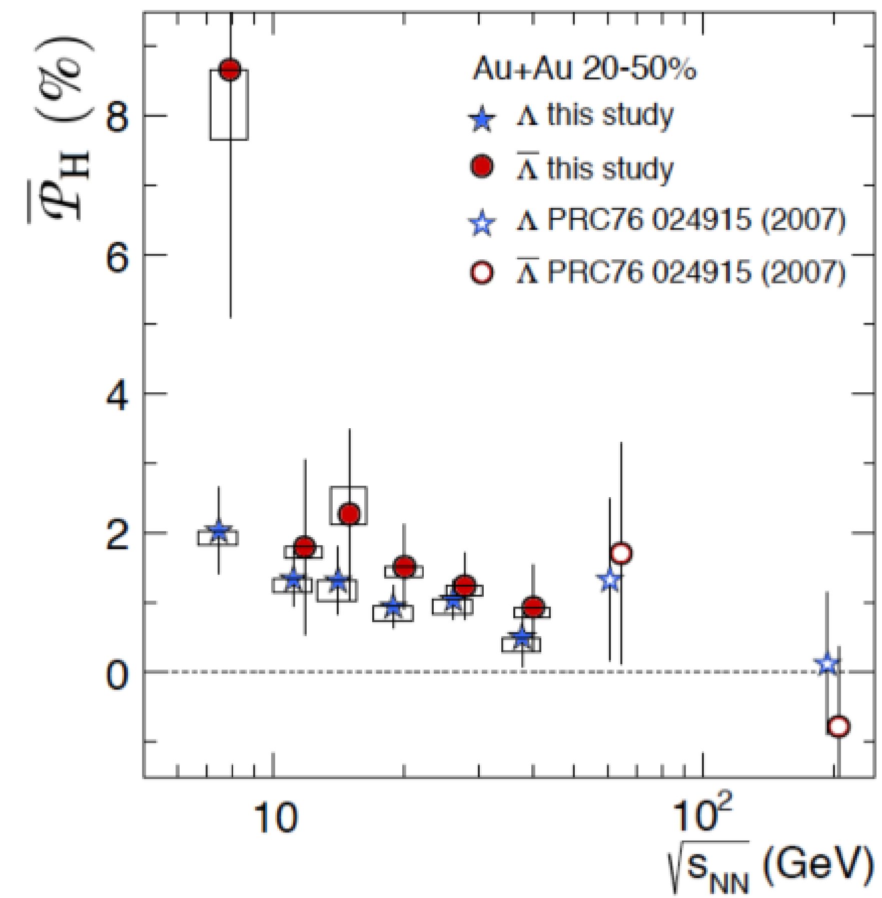
Why Forward Physics

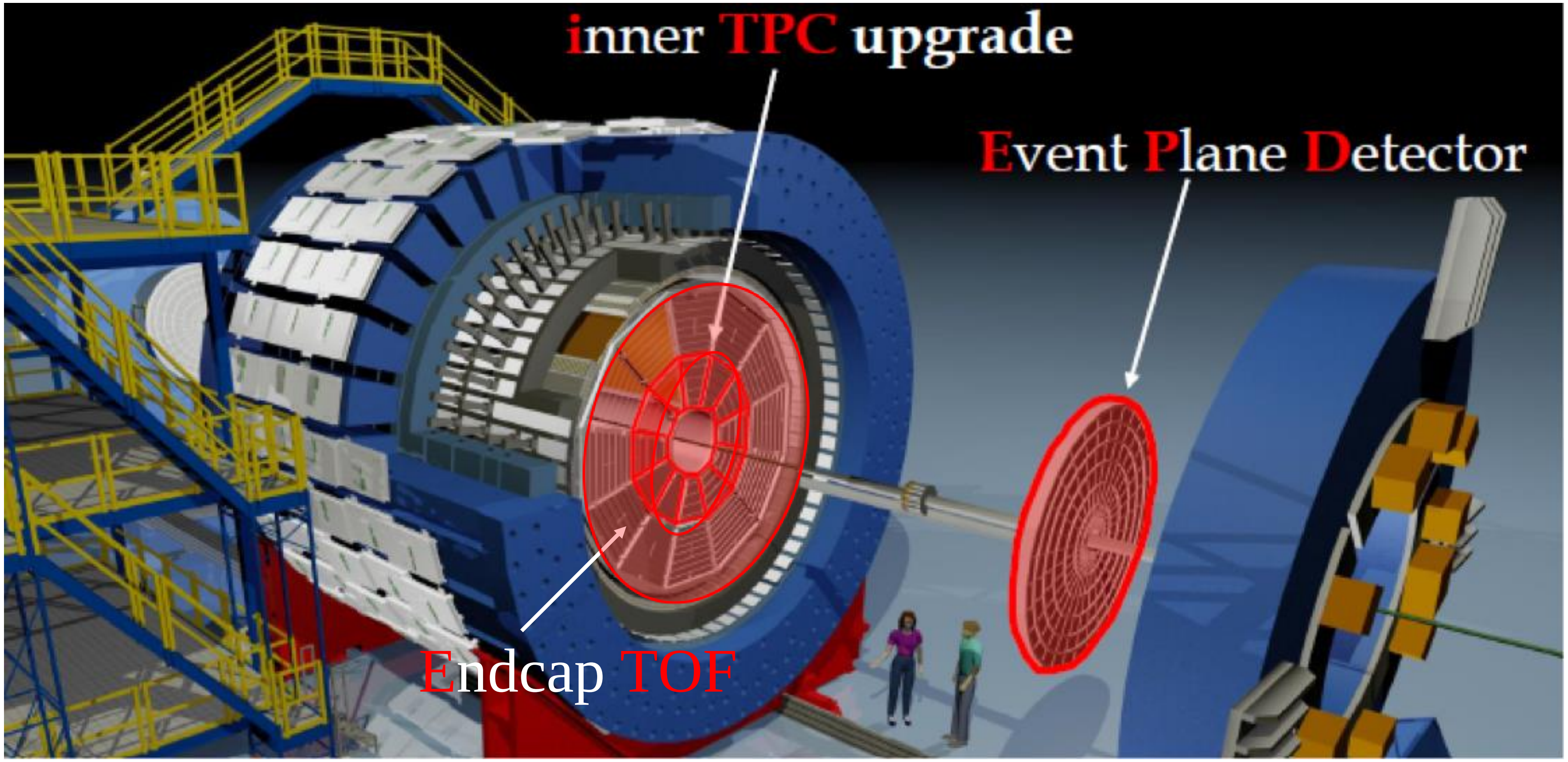




- Flow in transverse plane is well explored.
  - What about longitudinal fluctuations?
- Lambda and anti-Lambda polarized.
  - What is the rapidity dependence?

Forward upgrade is essential to the longitudinal dynamics.

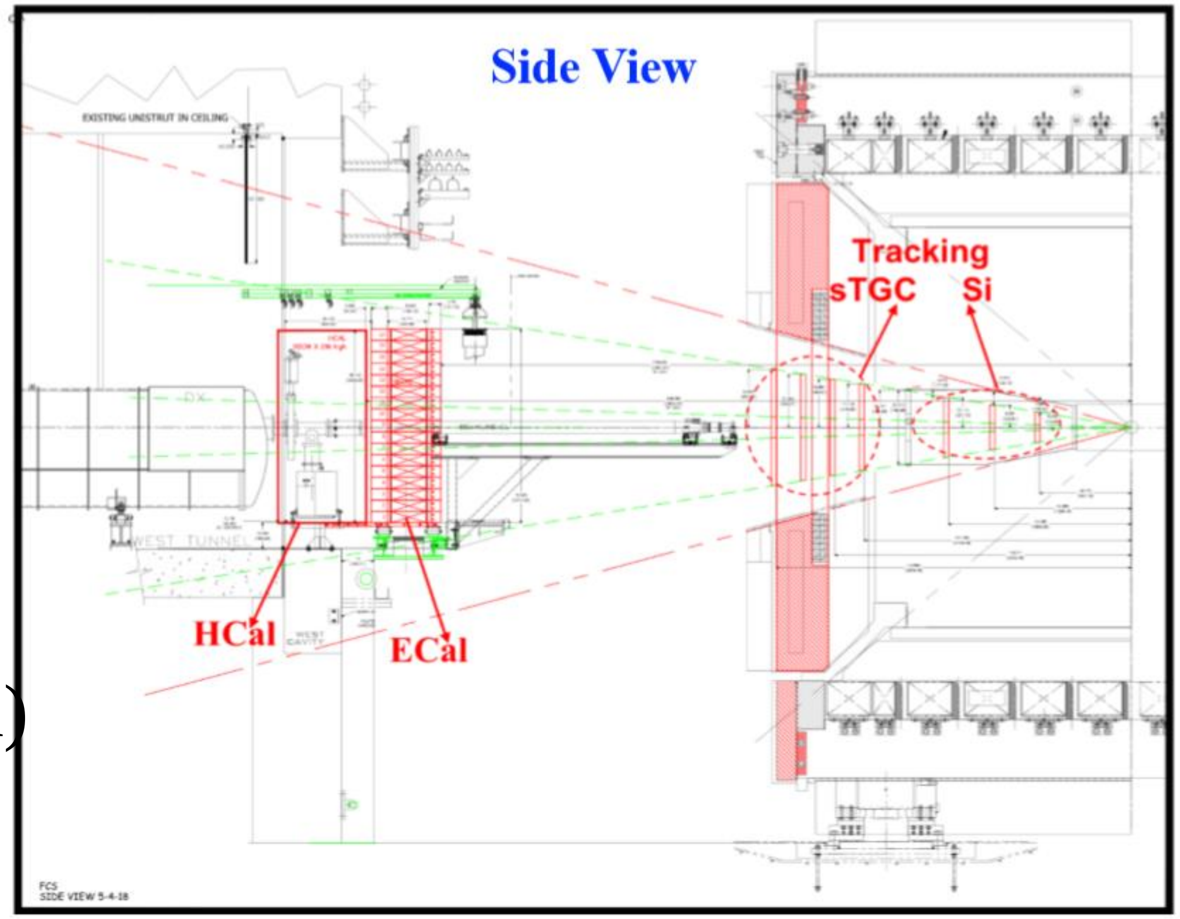
Current STAR Detector



iTPC upgrade	EPD upgrade	eTOF upgrade
Continuous pad rows Replace all inner TPC sectors	Replace Beam Beam Counter	Add CBM TOF modules and electronics (FAIR Phase 0)
$\lvert\eta\rvert < 1.5$	**$2.1 < \lvert\eta\rvert < 5.1$**	**$-1.6 < \eta < -1.1$**
$p_T > 60$ MeV/c	Better trigger & b/g reduction	Extend forward PID capability
Better dE/dx resolution Better momentum resolution	Greatly improved Event Plane info	Allows higher energy range of Fixed Target Program

Forward Upgrade

- **Calorimetry:**
  - Electromagnetic and Hadronic
- **Forward Tracking System:**
  - 4 layers of small Thin Gap Chambers
  - 3 layers of Silicon microstrip detectors
    - Fine φ segmentation and coarse in r
    - Low material budget
    - Cost effective (reuse IST DAQ system)



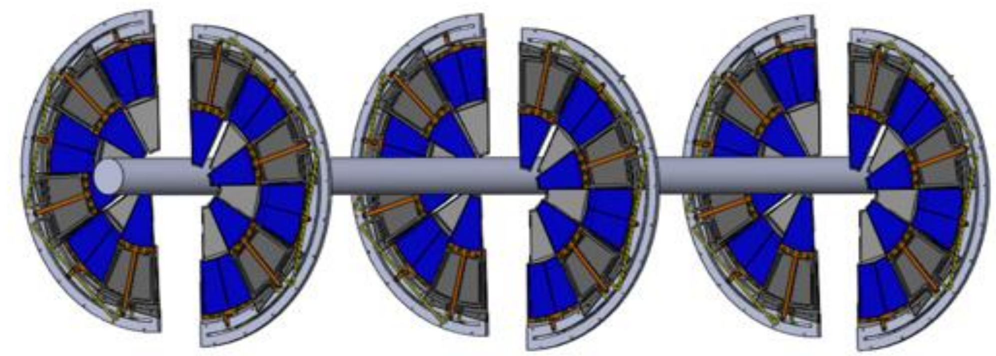
$2.5 < \eta < 4$

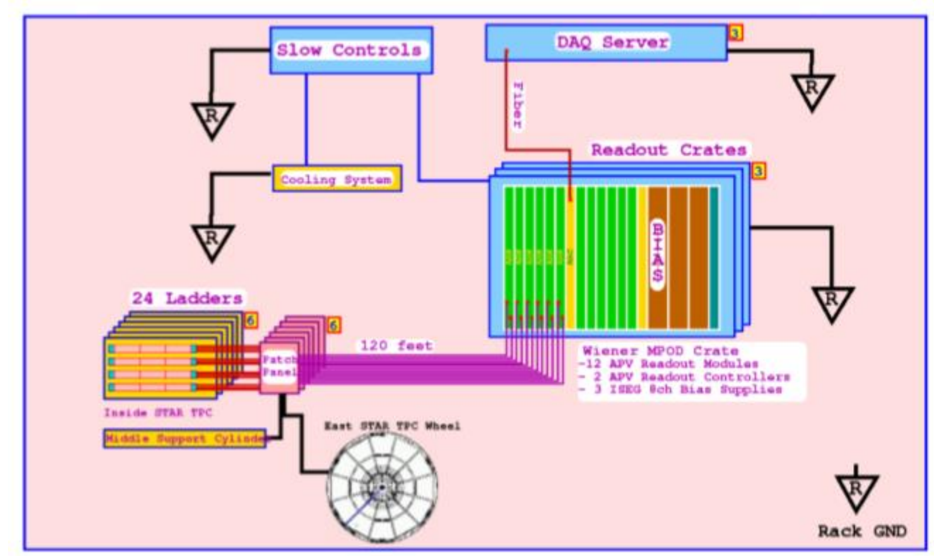
- *High tracking efficiency*
- *Charge separation*
- *Momentum measurement (20-30%)*

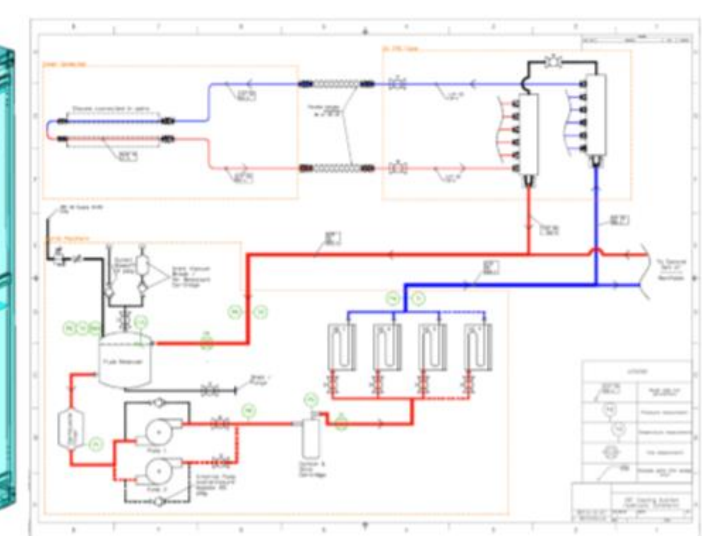
Forward Silicon Tracker

- 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, readout modules, and so on
- Cooling system
  - Cooling manifold, cooling lines
  - Rack (cooler, pumps)
- Integration
  - Supporting structure

Blue: existing   Red: new







Silicon Disk Design

- Each disk: 12 modules
- Each module split into two regions：

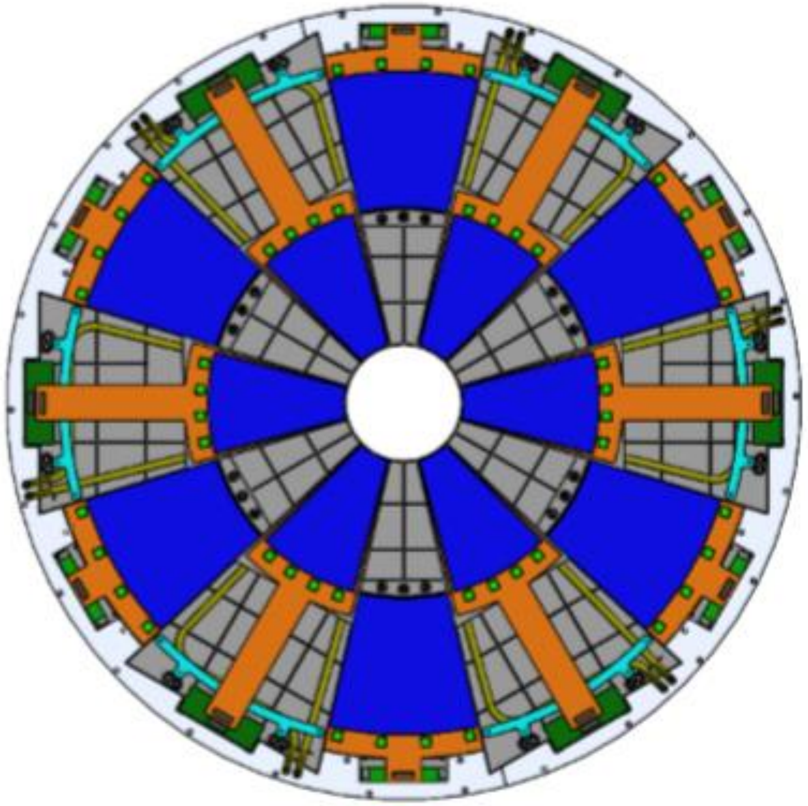
Inner region

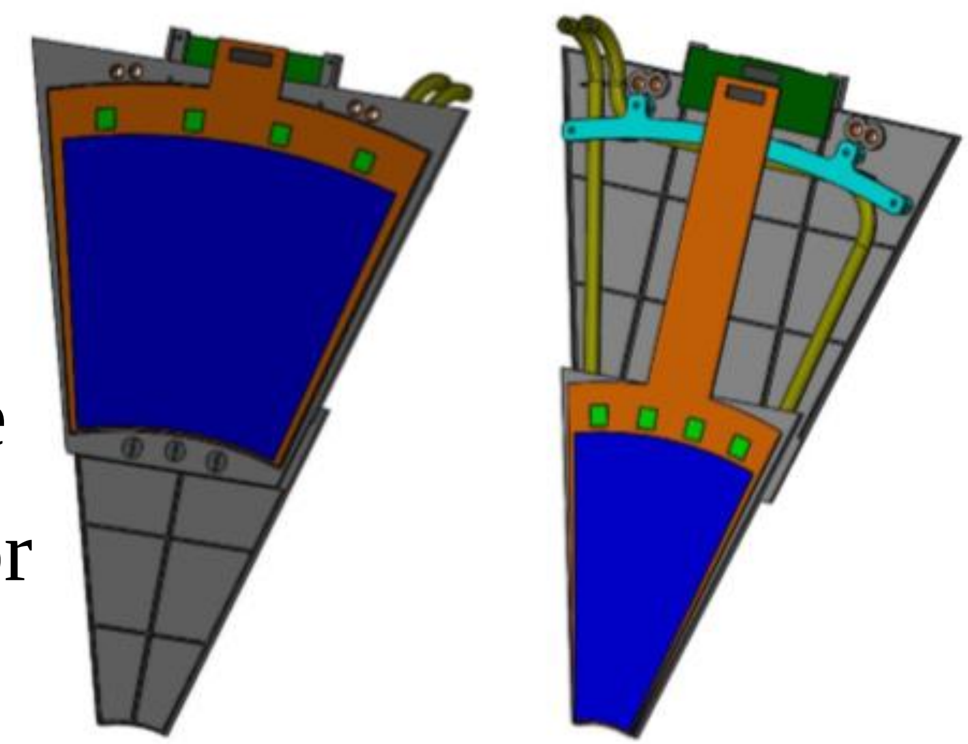
- 1 Silicon microstrip sensor: each 128 × 4 strips
- 4 APV25 chips
- 1 Kapton flexible hybrid

Outer region

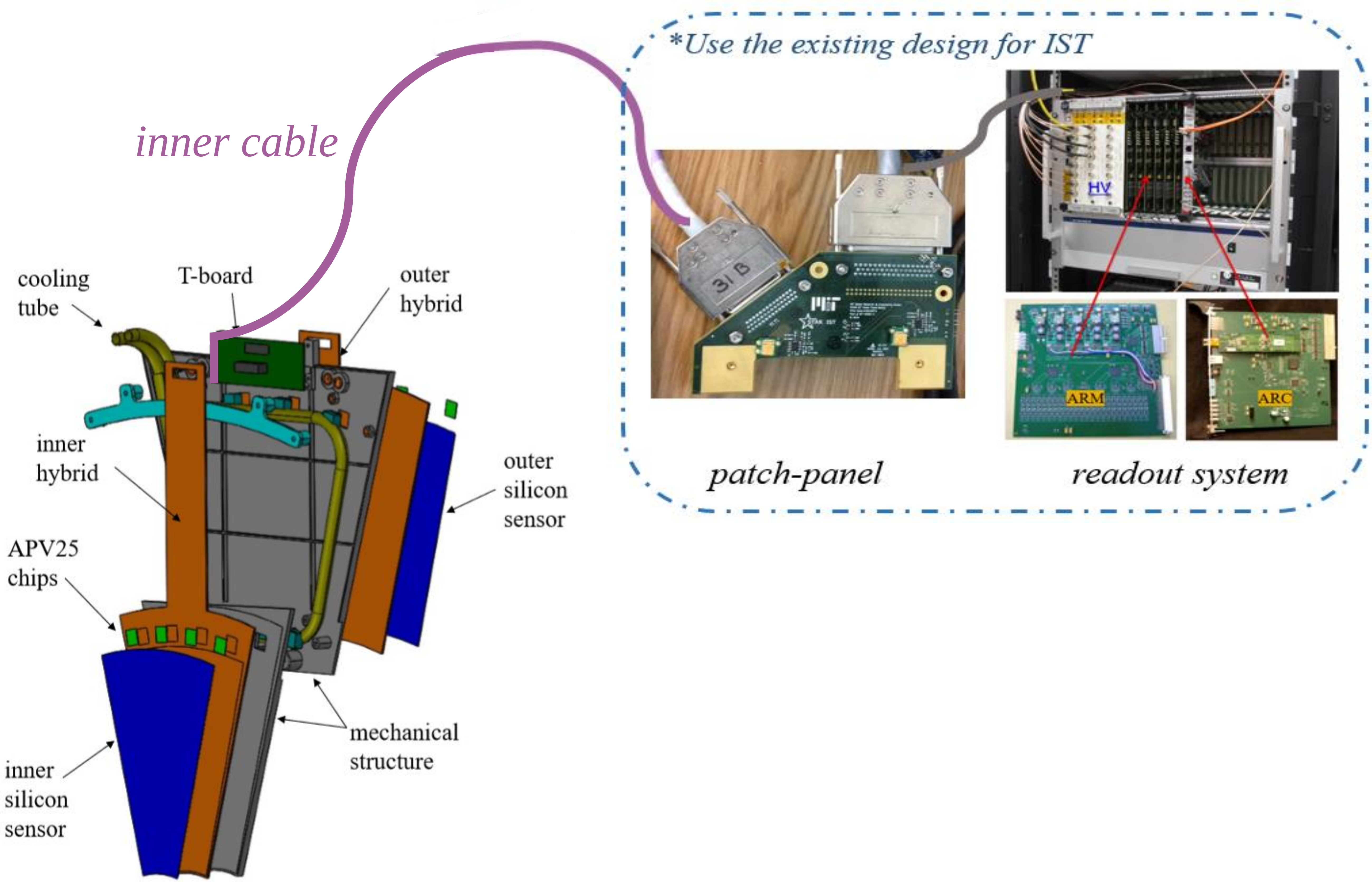
- 2 Silicon microstrip sensor: each 64 × 4 strips
- 4 APV25 chips
- 1 Kapton flexible hybrid

- Mechanical structure for each module
- Each module connect to a T-board for signal transmission



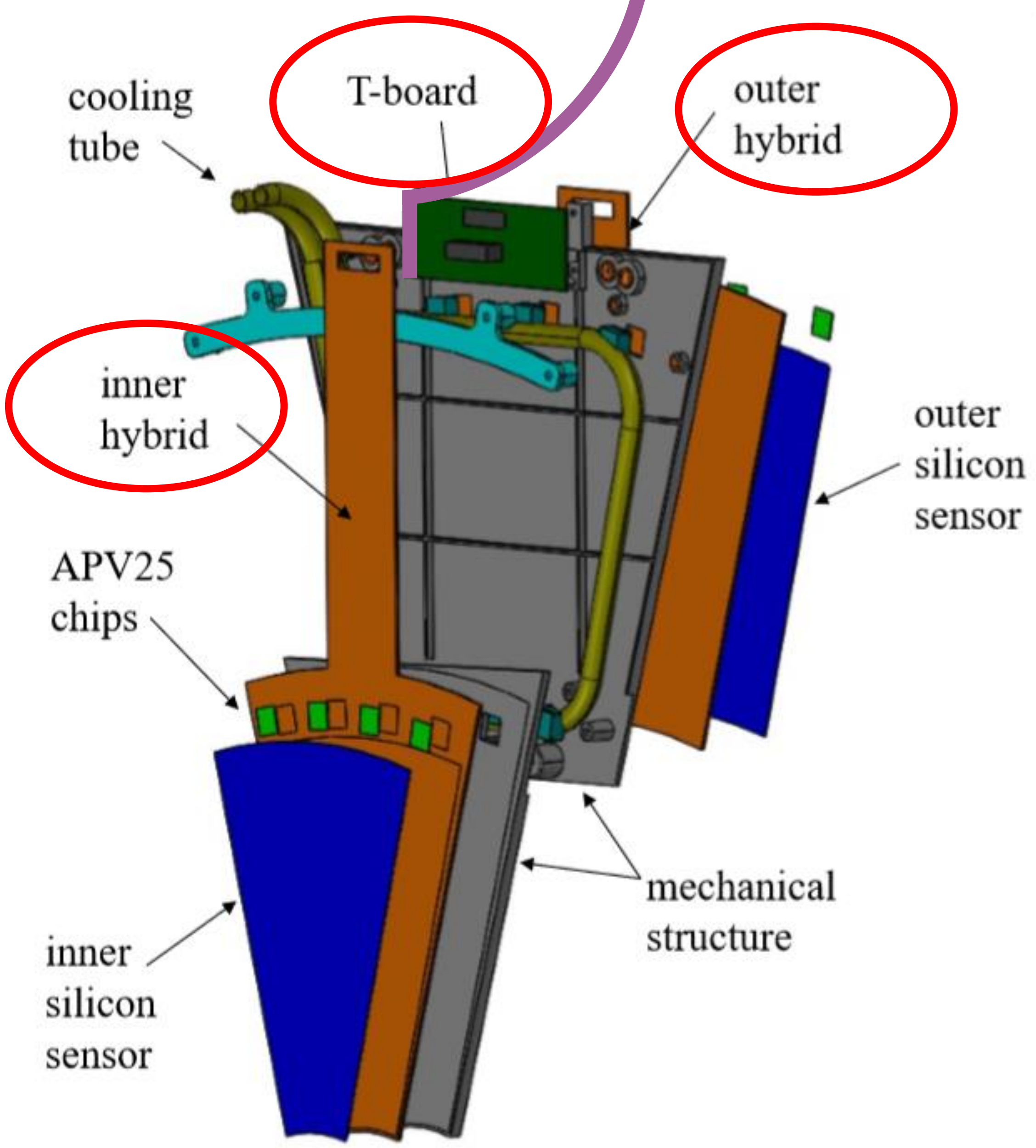


FST Module Design



FST Module Design

inner cable

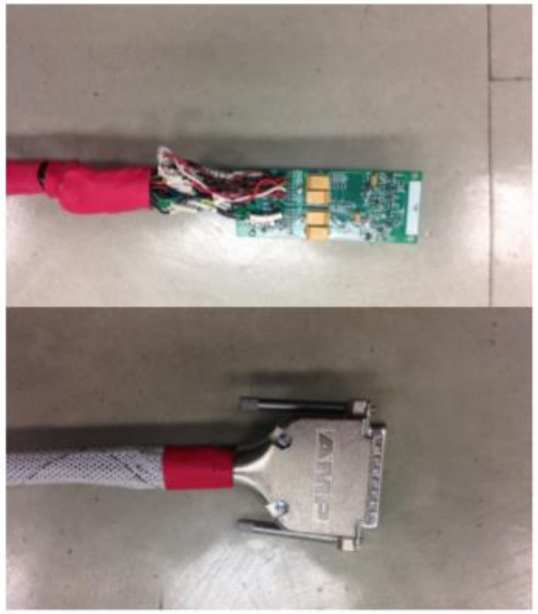


*Use the existing design for IST

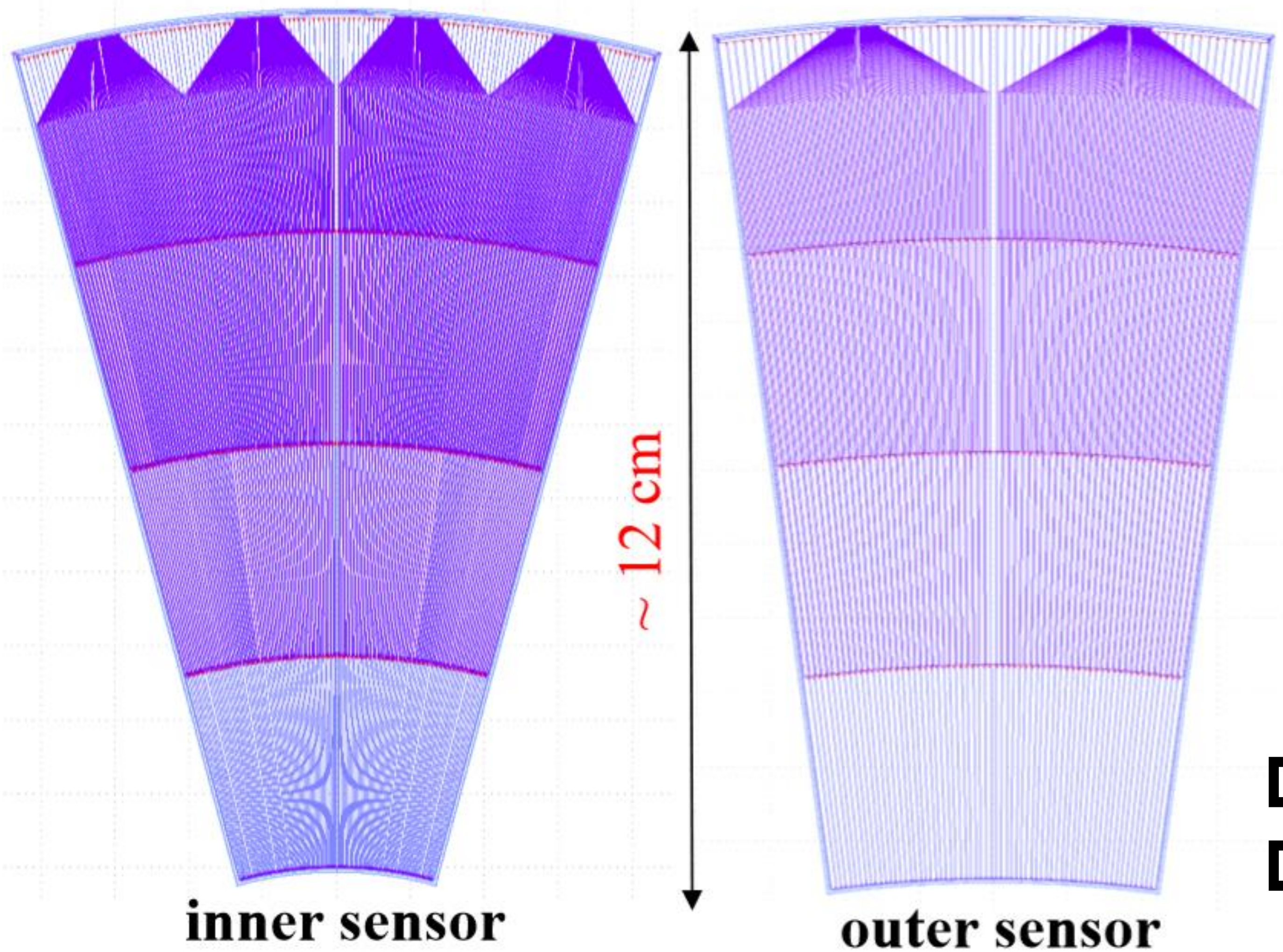
patch-panel

readout system

inner cable



Silicon Sensor



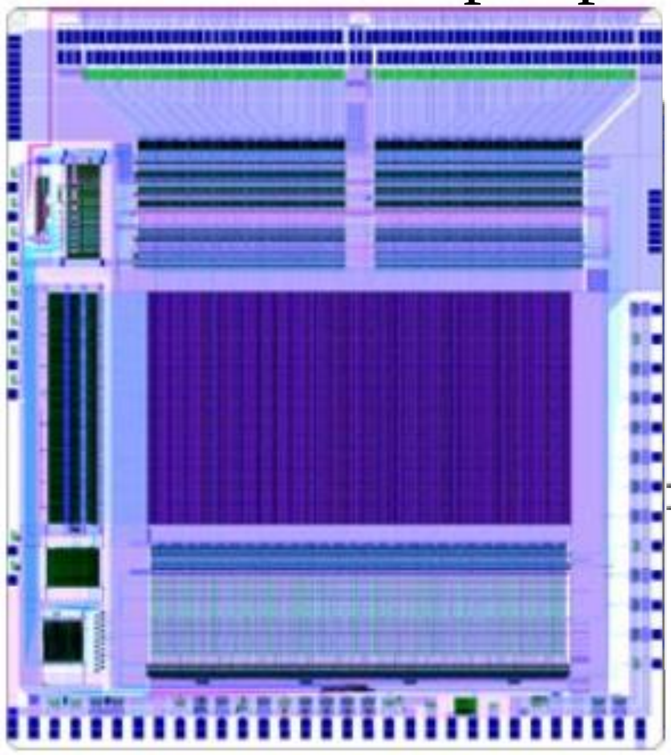
Hamamatsu Sensors

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

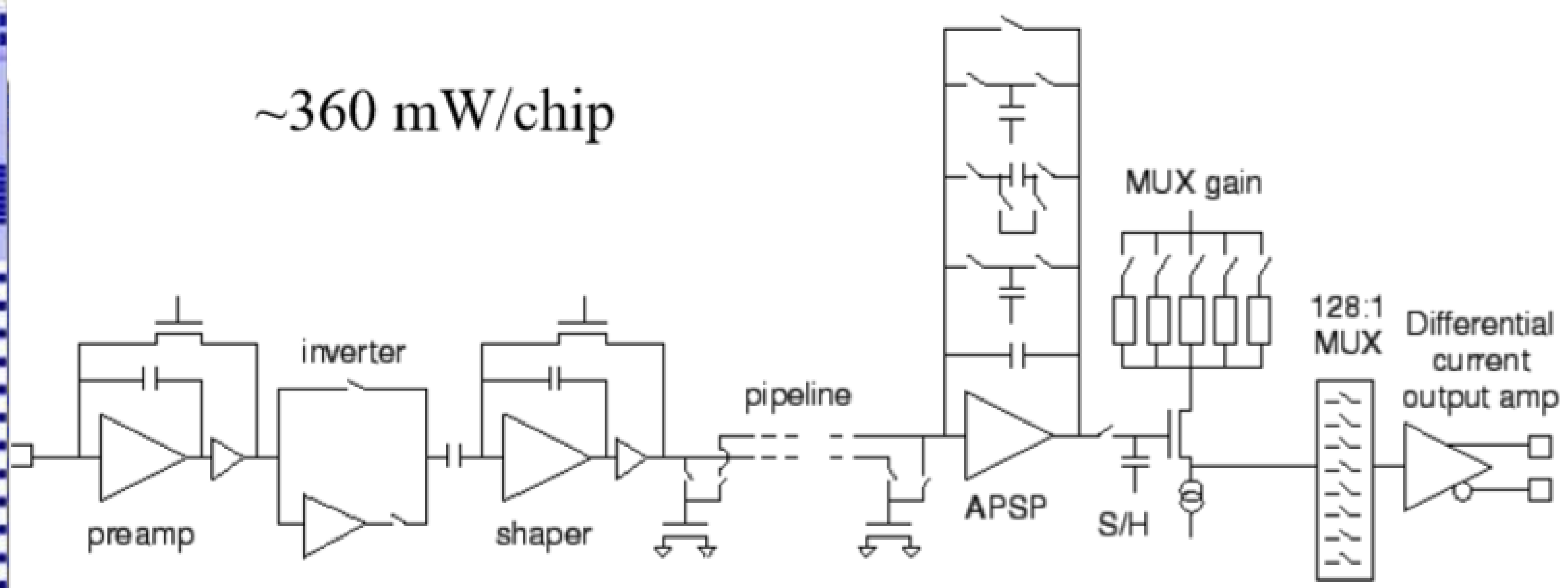
- Design completed at UIC in 2019/1
- 4 + 6 prototype sensors ordered from Hamamatsu

APV25 Chip

128 front-end input pads

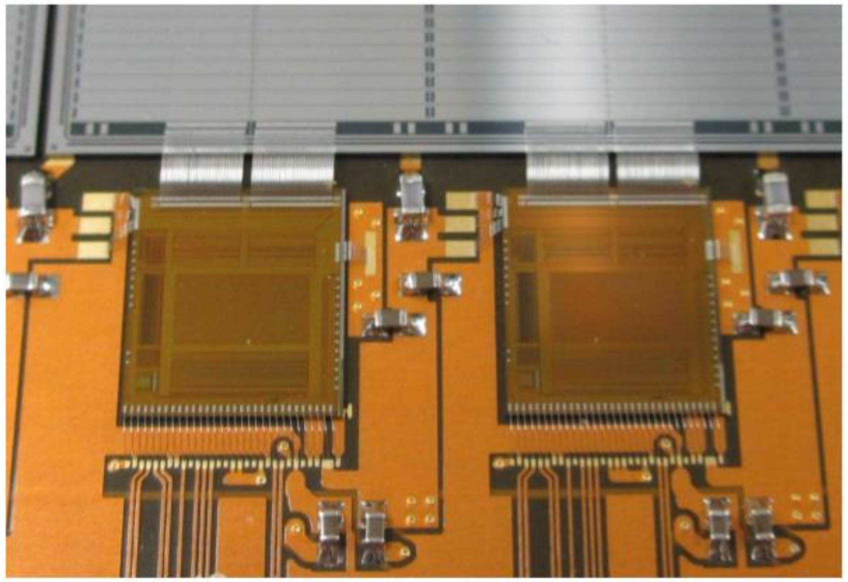


~360 mW/chip



Control and output pads

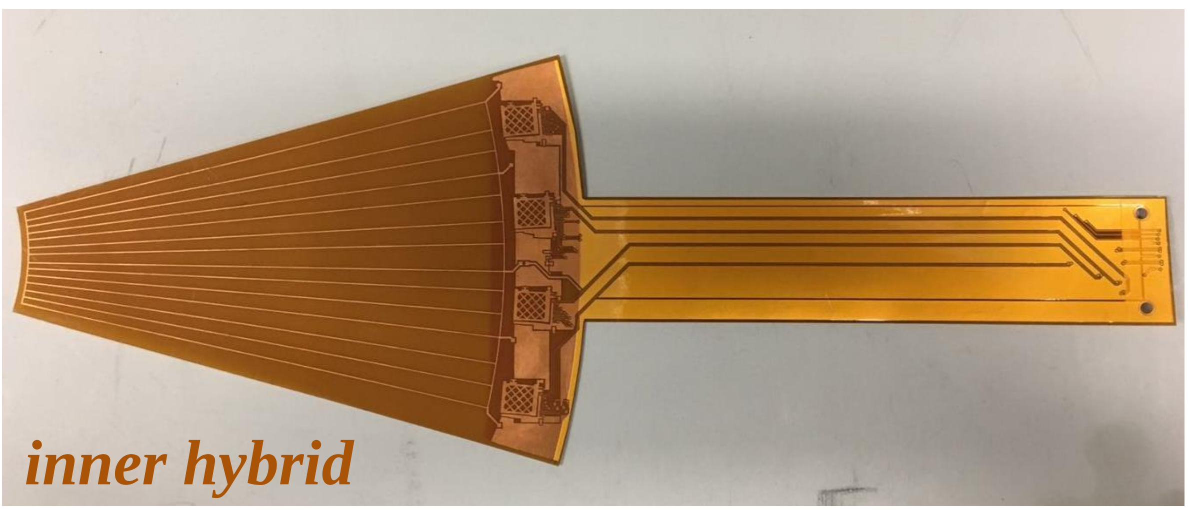
Preamplifier + shaper + 192 analog pipelines + capacitor filter + multiplexer



- Designed for CMS Silicon strip detector
- Fabricated in 0.25 μm CMOS process

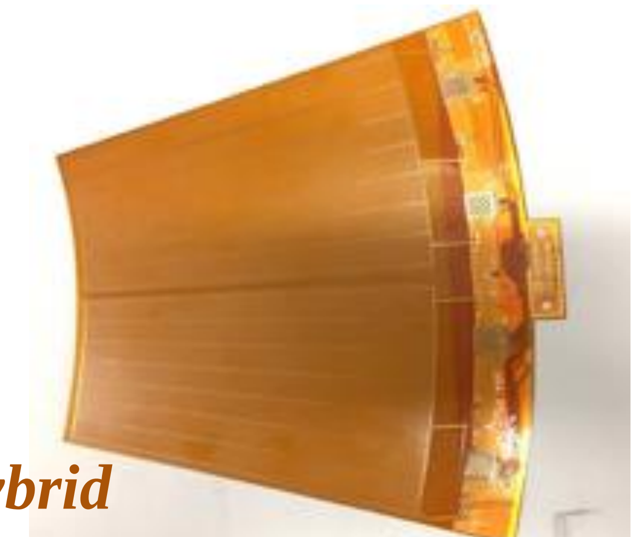
Hybrids & T-board

- 1st version design completed at SDU in 2019/2.
- 1st version hybrids & T-board received from the vendor.
- Currently, they are assembled and tested at UIC.



inner hybrid

- Phi angle: 31°
- Inner radius: 47.5 mm
- Outer radius: 185 mm
- Tail length: 135 mm

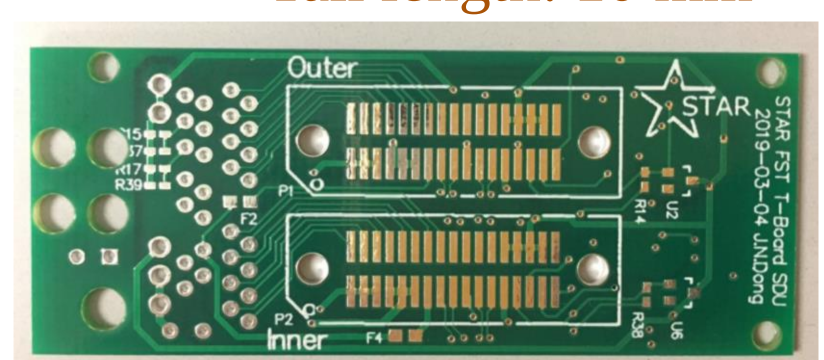


outer hybrid

- Phi angle: 31°
- Inner radius: 163 mm
- Outer radius: 300 mm
- Tail length: 10 mm

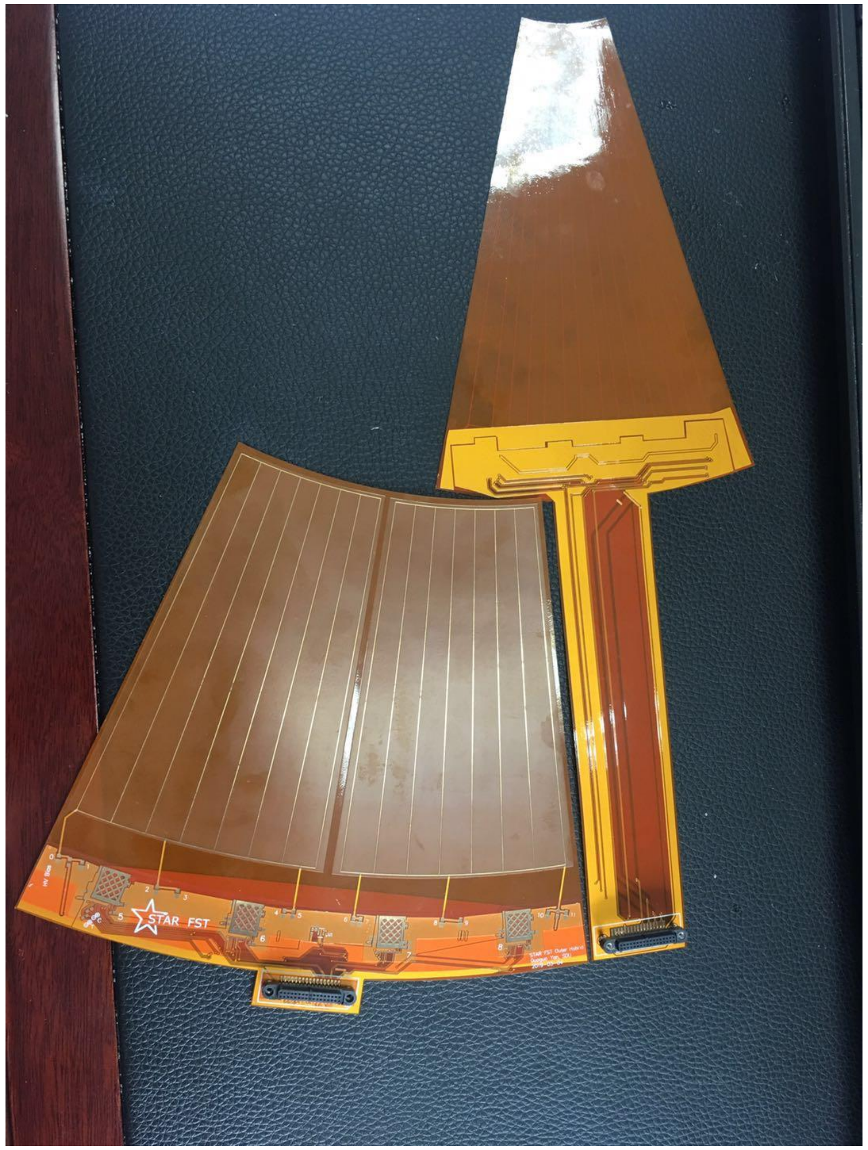
T-board

- Length: 60 mm
- Width: 24 mm



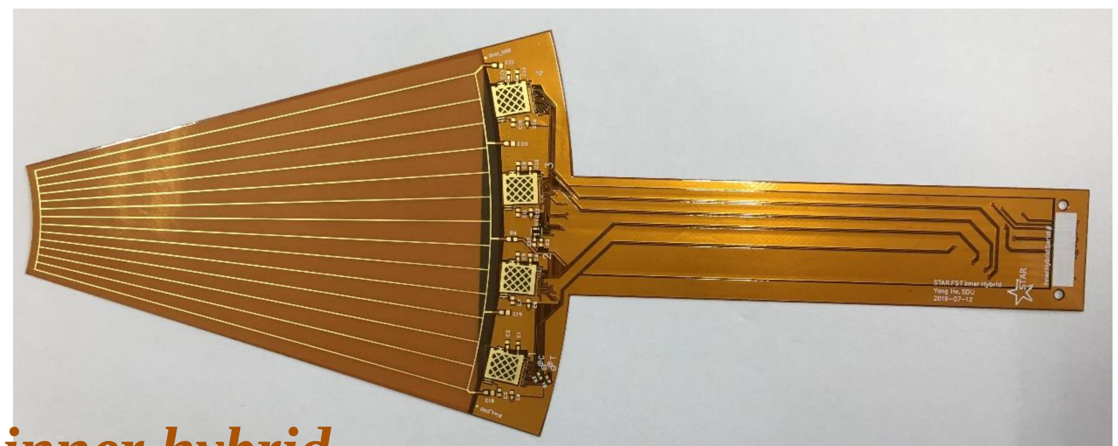
Hybrids & T-board

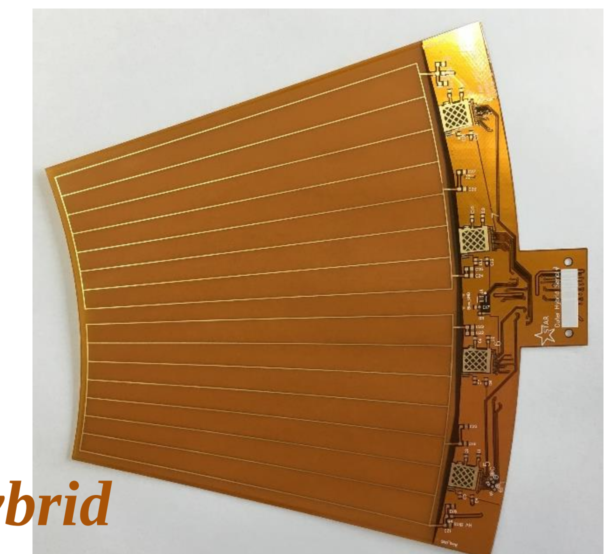
- 8 APV25 chips wire-bonded on the 1st version of hybrids and read out by 1st version T-board and test cables at UIC.
- Testing on-going



Hybrids & T-board

- 2nd version design completed at SDU in 2019/7: adjust dimensions to better fit the mechanical structure
- 2nd version hybrids & T-board just received from the vendor





inner hybrid

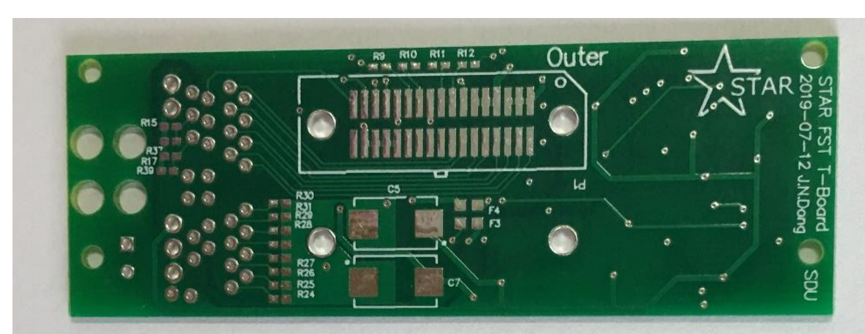
- Phi angle: 31° → 32°
- Inner radius: 47.5 mm → 49 mm
- Outer radius: 185 mm
- Tail length: 135 mm → 126 mm

outer hybrid

- Phi angle: 31° → 32°
- Inner radius: 163 mm → 164 mm
- Outer radius: 300 mm
- Tail length: 10 mm → 20 mm

T-board

- Length: 60 mm → 70 mm
- Width: 24 mm



Summary

- A 3-layer forward tracking detector based on the Silicon microstrip detector technology is designed for STAR forward upgrade.
- The FST utilized 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, in which hybrids and T-board are designed at Shandong University.
- 2nd version design of hybrids and T-boards have just been received from the vendor, and will be delivered to the collaborators to be assembled and tested soon.

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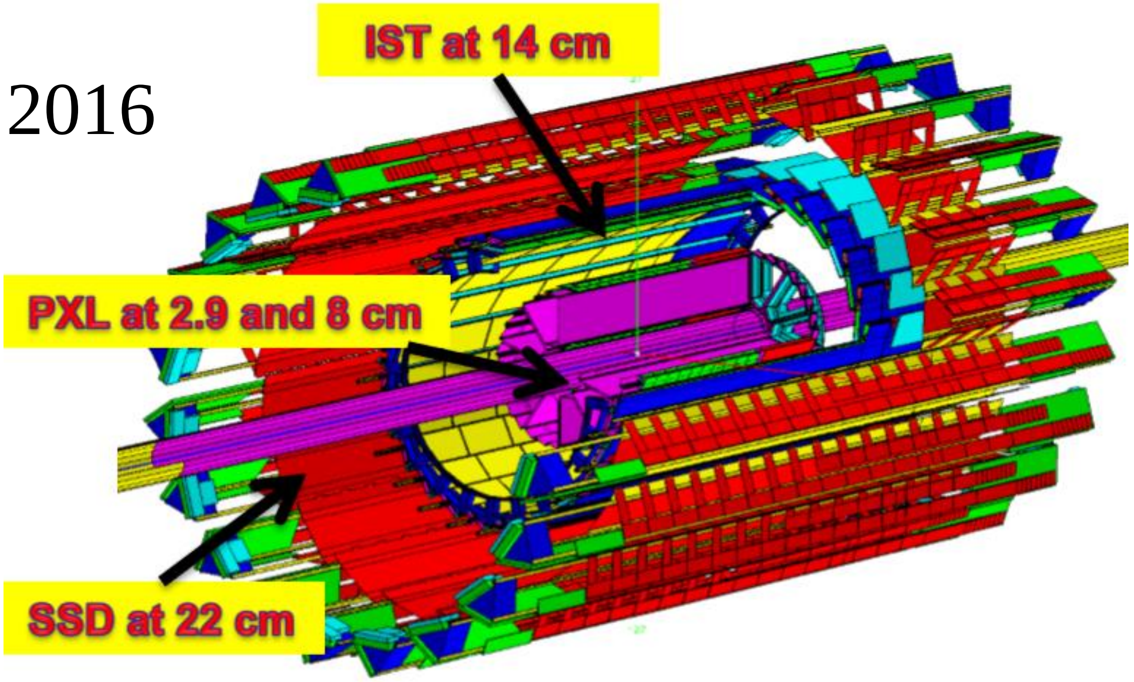
Thank you!

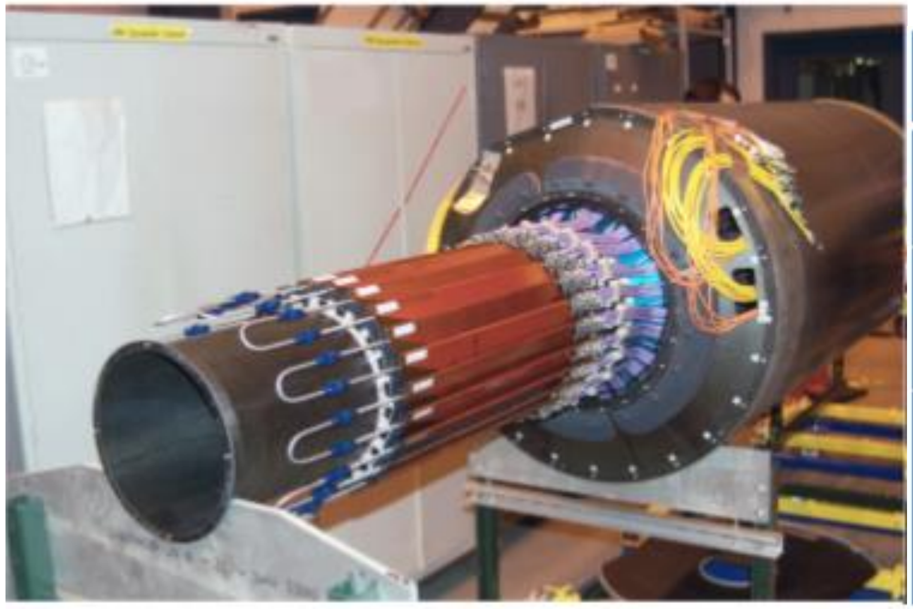
Backup

STAR IST Detector

- STAR Heavy Flavor Tracker in 2014 – 2016
- 2 layers of thin Silicon MAPS (PXL)
  - 360M pixels, each 12*12μm
- 2 layers of Si strip sensors (IST/SSD)



IST

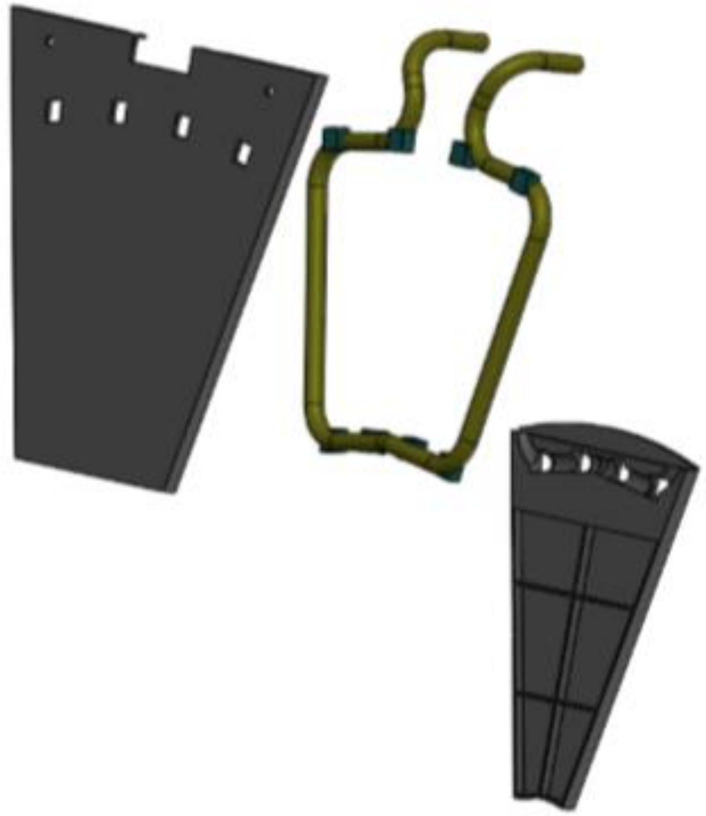


	Functional parameter	Threshold value	Optimal value	Achieved
7	IST hit efficiency and noise	> 90% from S/N better than 10:1	> 95% from S/N better than 15:1	~99% S/N 15:1-30:1
8	IST Live channels	> 85%	> 95%	>95%
10	IST Readout speed and dead time	< 5% additional dead time at 1 kHz average trigger rate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

Mechanical Structure

- 1st version design completed at NCKU 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

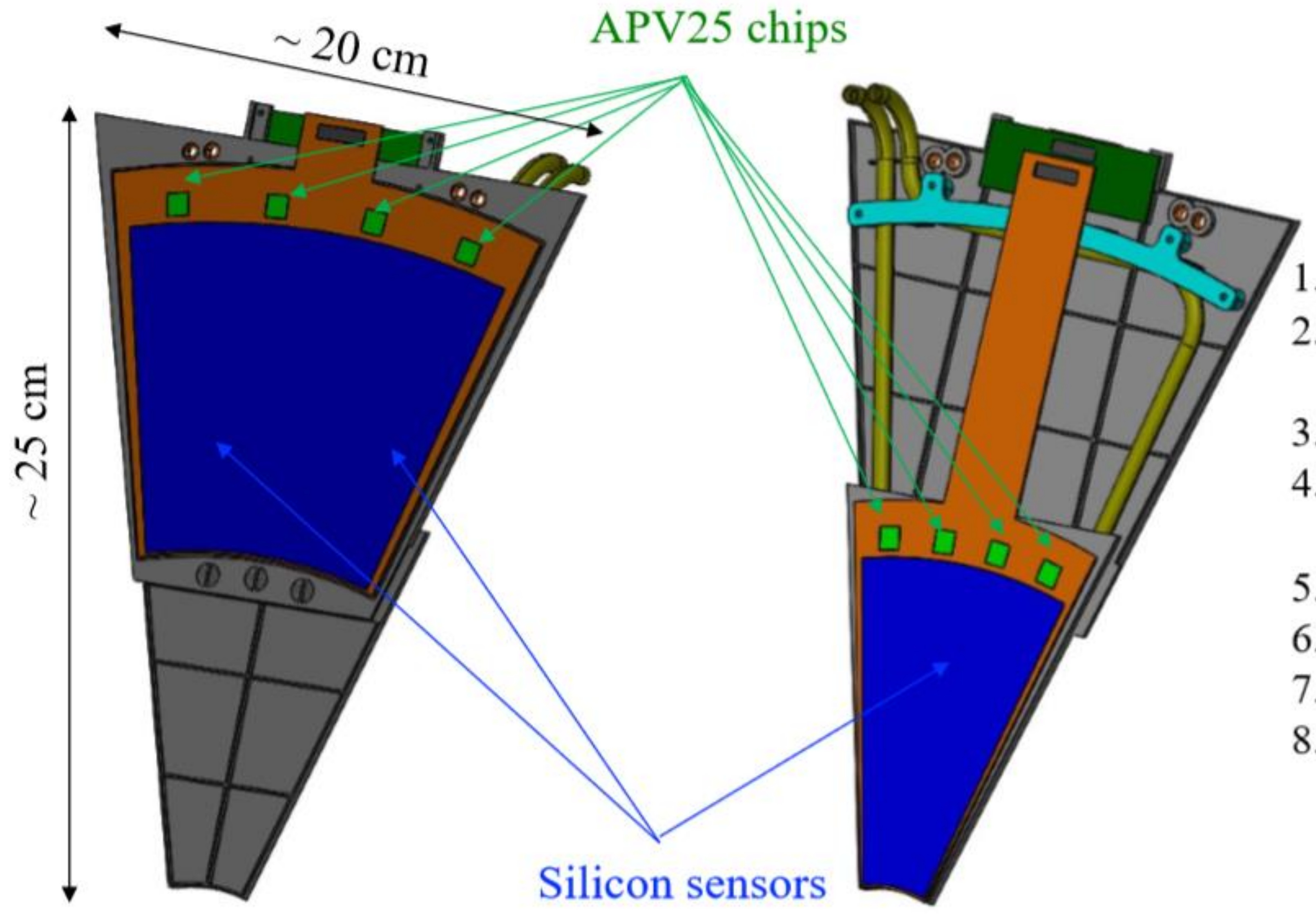
Solidwork Drawings



Photographs

Module Assembly

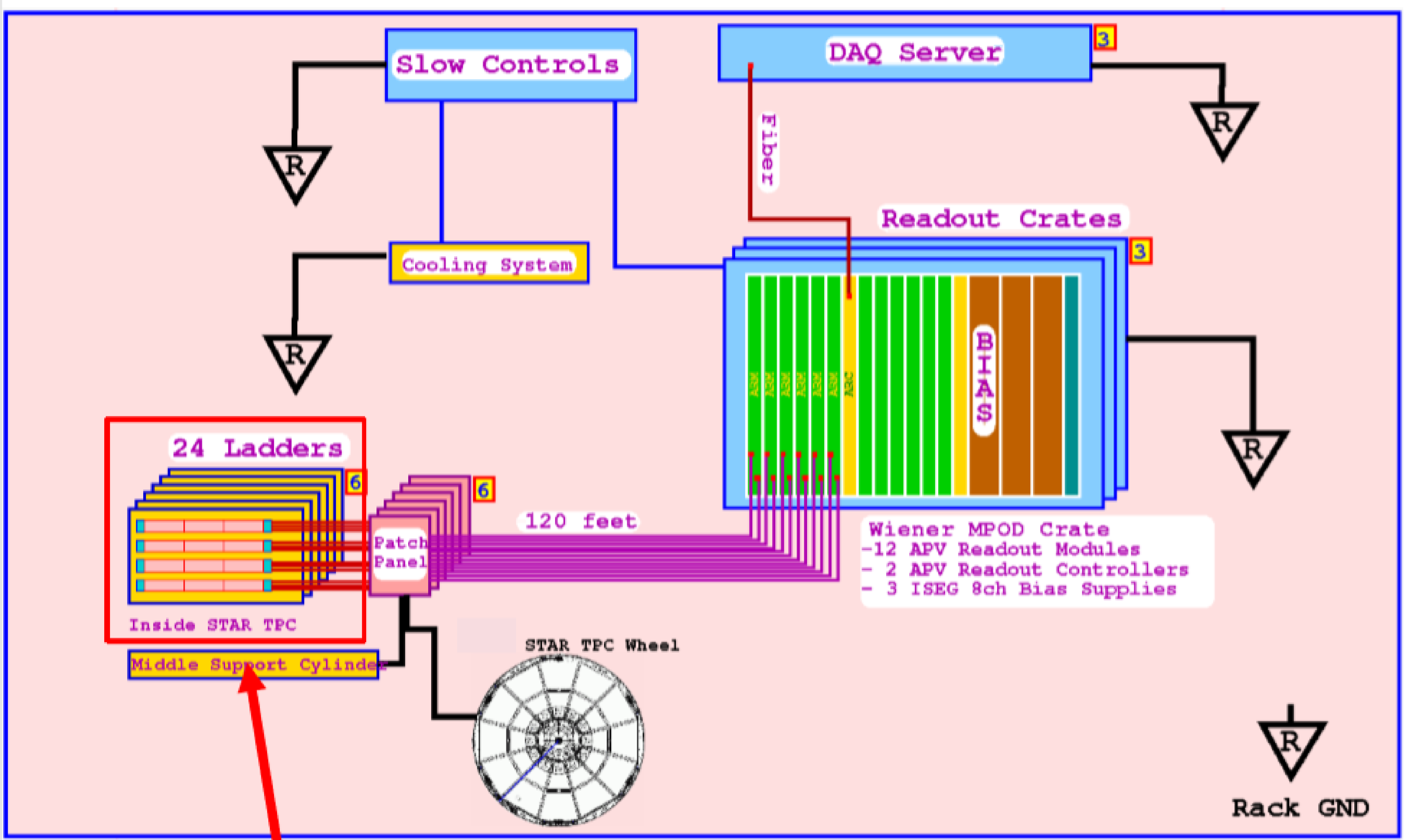
- Prototype module: 3 modules, each with 3 Silicon sensors and 8 APV25 chips
- Assembly: 2019/9 – 2019/10; Testing: 2019/11 – 2019/12
- Production module: 48 modules, each with 3 Silicon sensors and 8 APV25 chips
- Assembly: 2020/9 – 2021/2;
- Installation and testing on supporting structure: 2021/3 – 2021/4



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

DAQ System

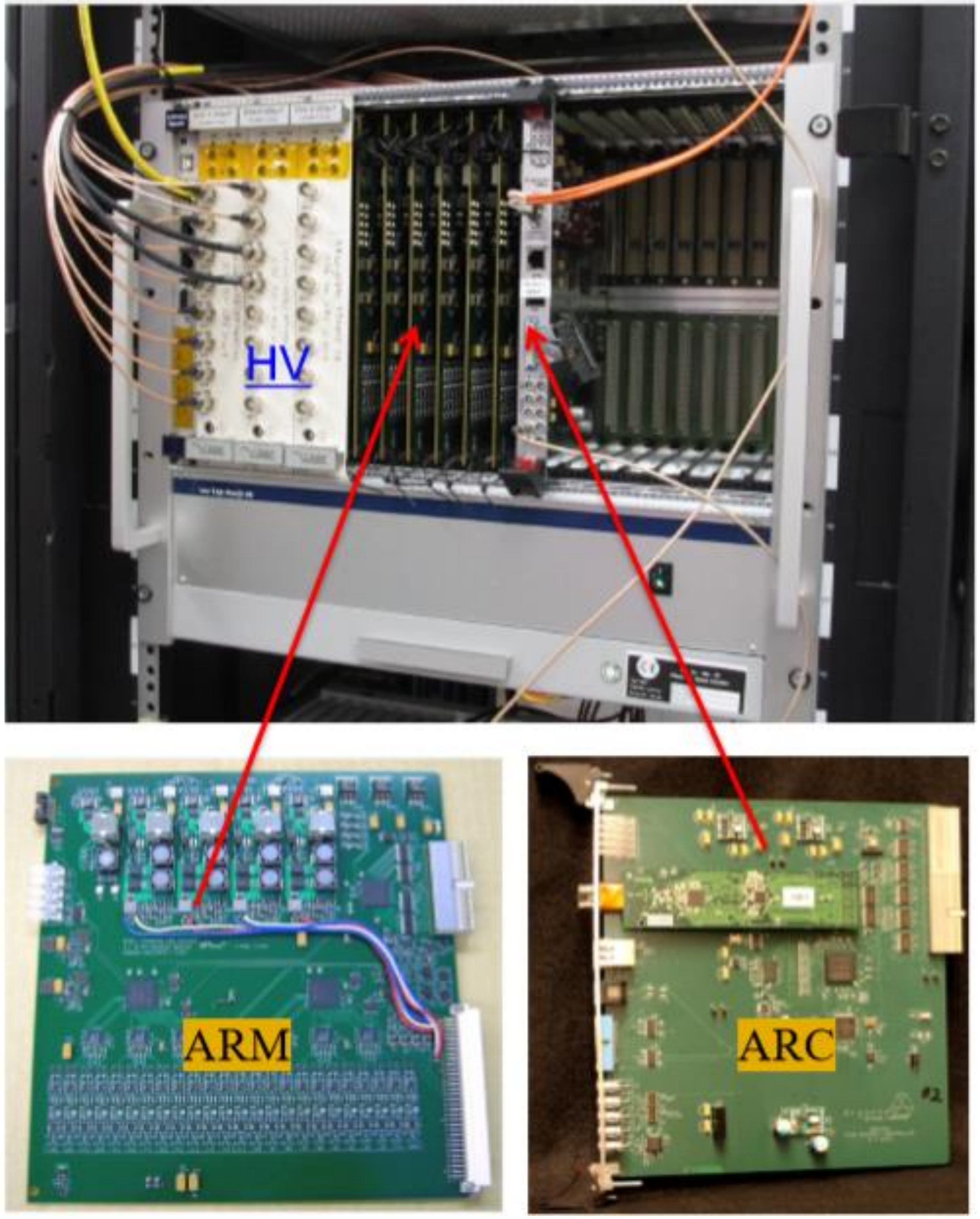


FST with new inner signal cables read out with the existing IST DAQ system

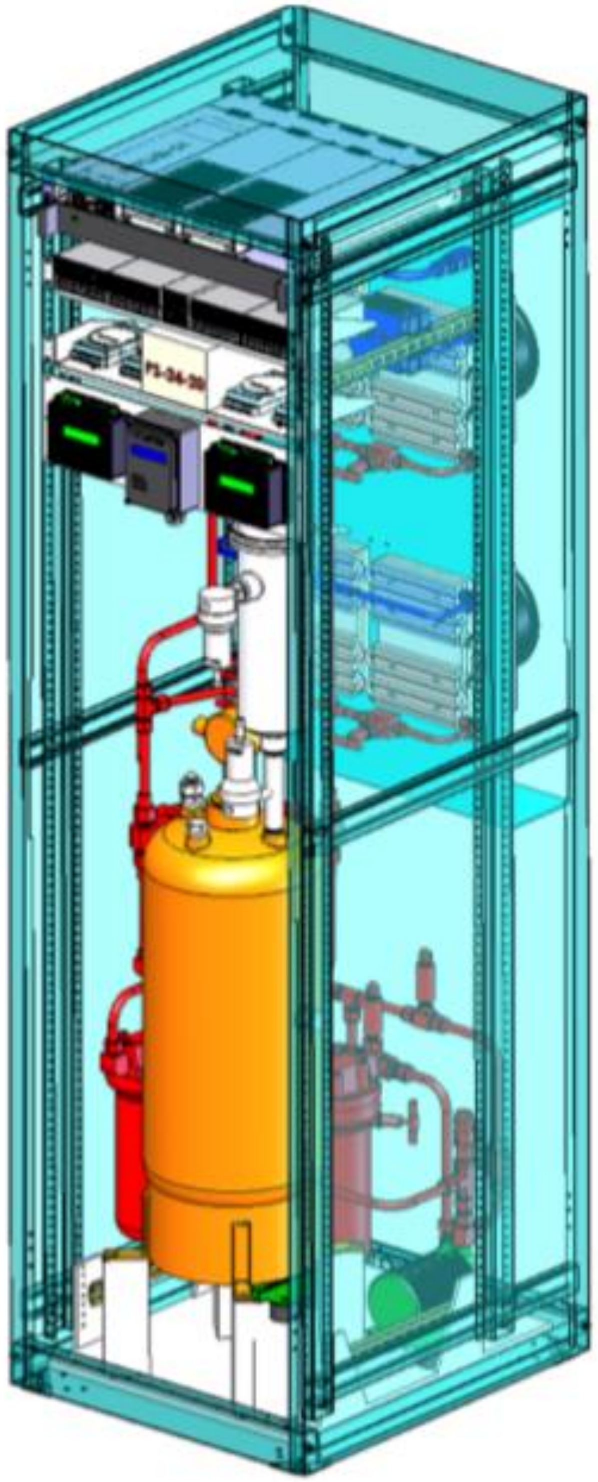
DAQ System

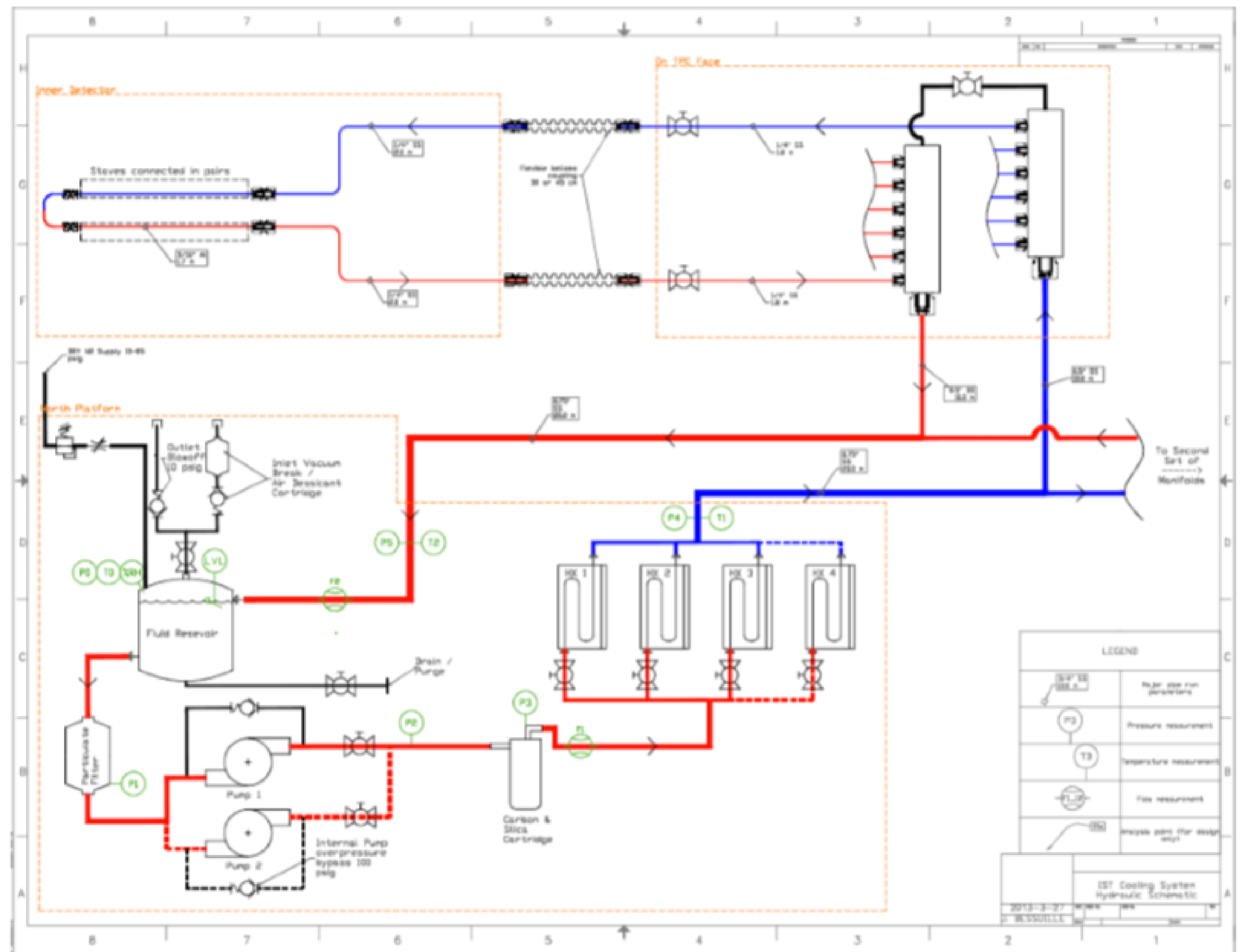
- Custom-designed DAQ system in a WIENER MPOD HV-cPCI frame
- 3 crates, 6 ARCII, 36 ARM, 36 Patch-panel boards, 72 outer signal cables from IST can be used fro FST.

- FST inner signal cable designs completed by BNL/IU
- 1st version assembled in 2019/8
- 2nd version expected in 2019/9



Cooling System





- Heat load ~ 100 W (300 W for IST)
- Coolant: 3MTM NovecTM 7200 (**$C_4F_9OC_2H_5$**)
- Sitting on STAR platform, maintenance needed

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