# R&D for the Forward Silicon Tracker at STAR

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National Cheng Kung University
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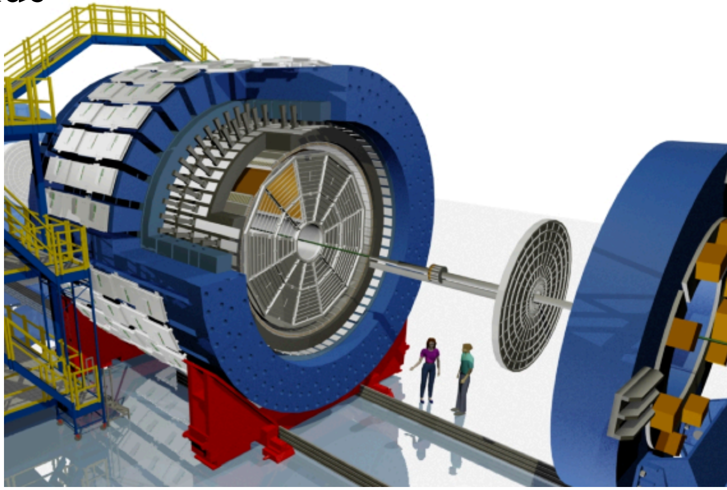
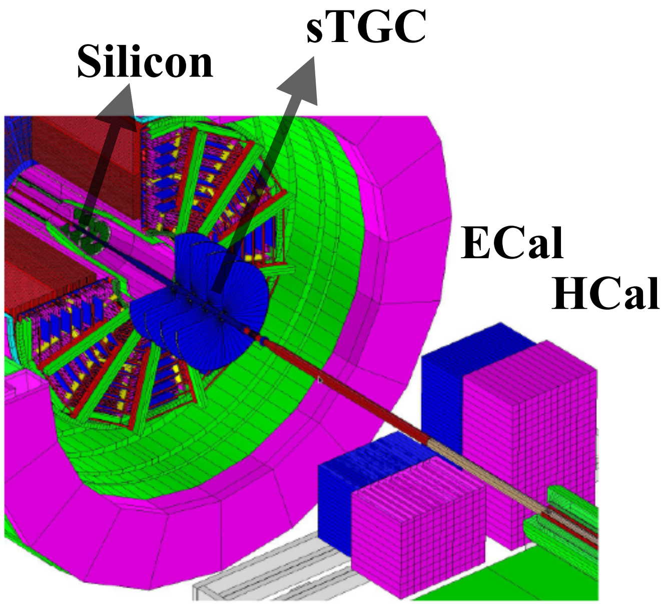
# The Forward upgrades at STAR

- Extent the STAR capability to $2.5 < \eta < 4$ on the west side

| | Year | $\sqrt{s}$ (GeV) | Delivered Luminosity | Scientific Goals | Observable | Required Upgrade |
|---|---|---|---|---|---|---|
| Potential running | 2021/22 | $p^{\uparrow}p$ @ 510 | 1.1 $fb^{-1}$ 10 weeks | TMDs at low and high x | $A_{UT}$ for Collins observables, i.e. hadron in jet modulations at $\eta > 1$ | ECal+HCal+Tracking |
| | 2021/22 | $\overrightarrow{p}\overrightarrow{p}$ @ 510 | 1.1 $fb^{-1}$ 10 weeks | $\Delta g(x)$ at small x | $A_{LL}$ for jets, di-jets, h/g-jets at $\eta > 1$ | ECal+HCal |
| In parallel with sPHENIX running | | $p^{\uparrow}p$ @ 200 | 300 $pb^{-1}$ 8 weeks | Subprocess driving the large $A_N$ at high $x_F$ and h | $A_N$ for charged hadrons and flavor enhanced jets | ECal+HCal+Tracking |
| | | $p^{\uparrow}Au$ @ 200 | 1.8 $pb^{-1}$ 8 weeks | initial state and hadronization in nuclear collisions<br>signatures for Saturation | $R_{pAu}$ direct photons and DY<br>Dihadron, g-jet, h-jet, diffraction | ECal+HCal+Tracking |
| | | $p^{\uparrow}Al$ @ 200 | 12.6 $pb^{-1}$ 8 weeks | A-dependence of nPDF,<br>A-dependence for Saturation | $R_{pAl}$: direct photons and DY<br>Dihadrons, g-jet, h-jet, diffraction | ECal+HCal+Tracking |

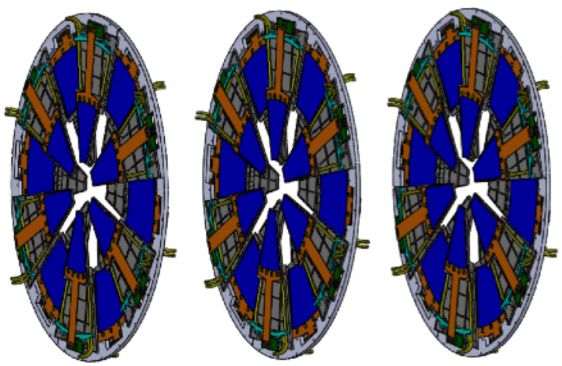


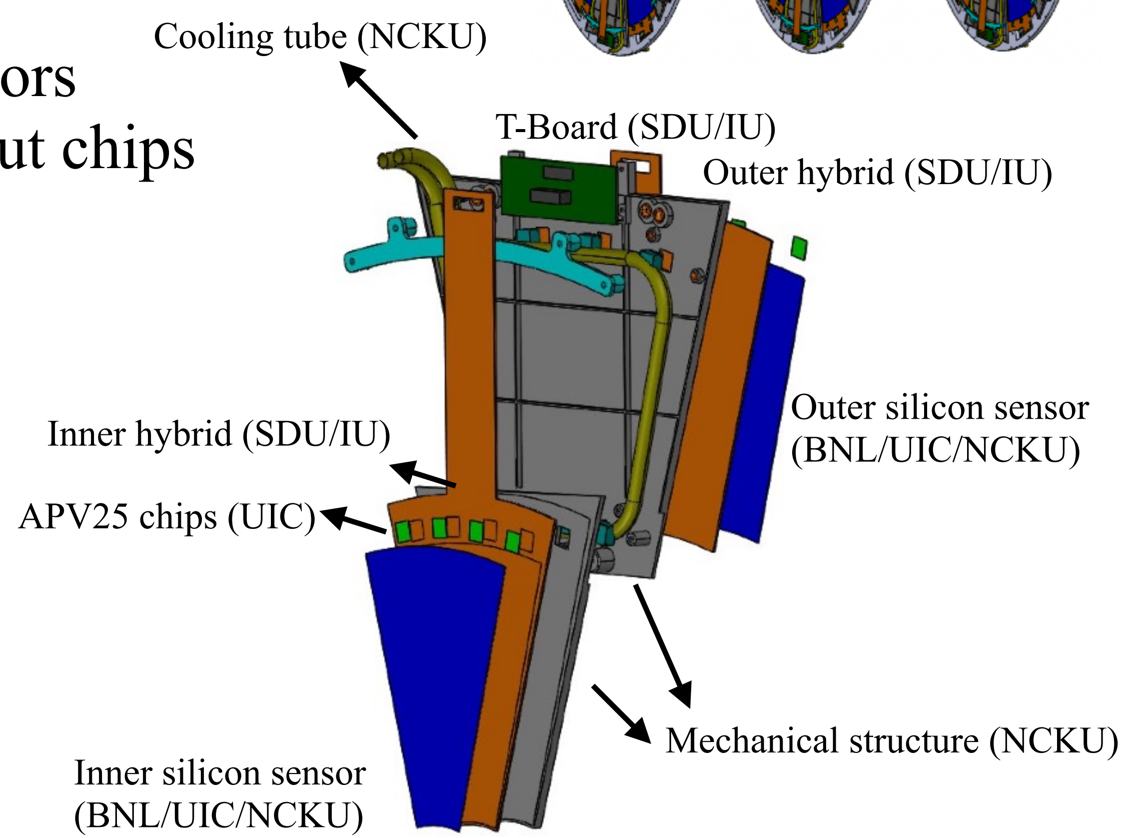
- STAR forward upgrade consist of two main systems:
  - Forward Tracking System (FTS):
    - **Forward silicon tracker (FST)**
    - small-strip Thin Gap Chamber (sTGC)
  - Forward Calorimeter System (FCS):
    - Forward preshower
    - Electromagnetic calorimeter (ECal)
    - Hadron calorimeter (HCal)
- Will run in 2021/22 with 500 GeV p+p alone, and in 2023-25 in 200 GeV p+p, p+A and A+A collisions in parallel with sPHENIX
- Lays the groundwork for future EIC physics and hardware



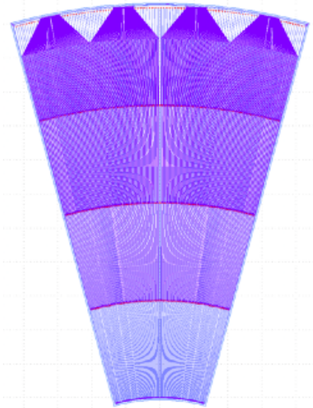
# Forward Silicon Tracker (FST)

- 3 disks covered $0 < \varphi < 2\pi$ and $2.5 < \eta < 4$
- 12 modules in each disk
- Each module is split into inner and outer parts
- Main components:
  - Silicon microstrip sensors
  - APV25 frontend readout chips
  - Flexible hybrid
  - Mechanical structure

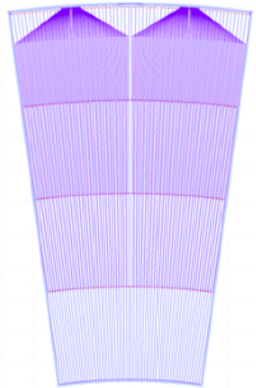




# Silicon sensor and APV25 readout chip



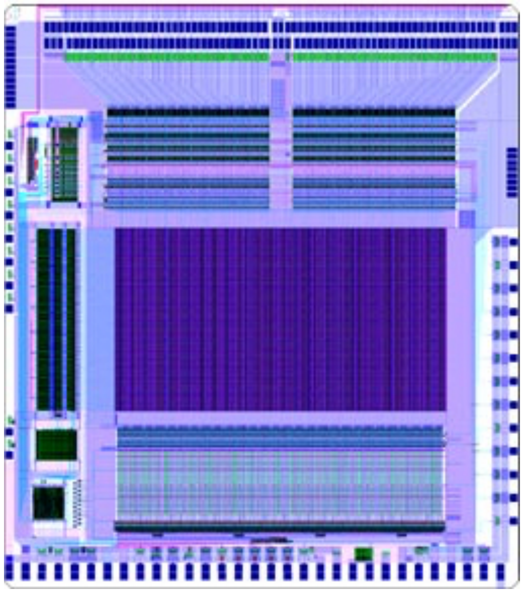
Inner sensor



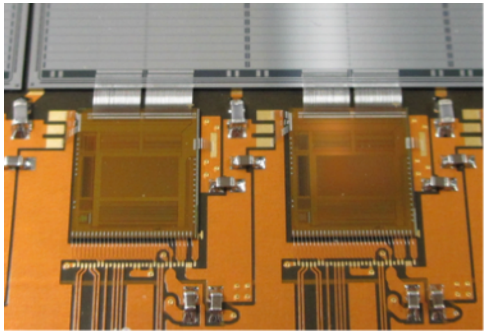
Outer sensor

## Hamamatsu Sensors

| | Inner | Outer |
|---|---|---|
| Radii (cm) | 5-16.5 | 16.5-28 |
| Angle (°) | 30 | 15 |
| # of strips (R×φ) | 4×128 | 4×64 |
| Thickness (μm) | 320 | |



128 front-end input pads

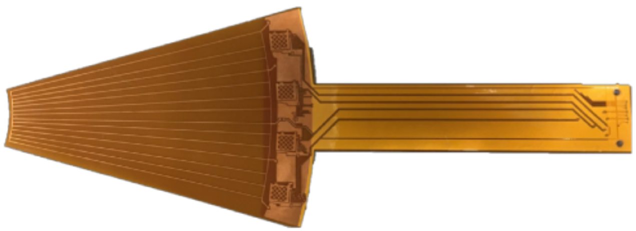


Control and output pads

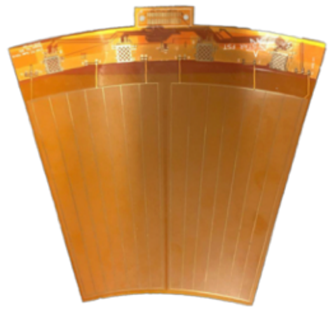
APV readout chip:

- Designed for CMS Silicon strip detector
- Fabricated in 0.25μm CMOS process
- **Used in STAR IST, and more than enough probe-tested APV25 chips in-hand for STAR Forward Silicon Tracker**

# Flexible hybrid, T-Board, and inner signal cable

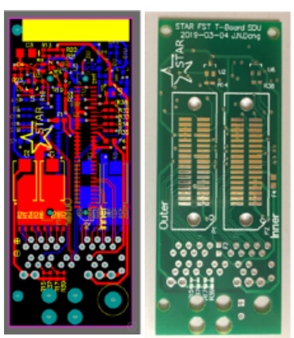


Inner hybrid



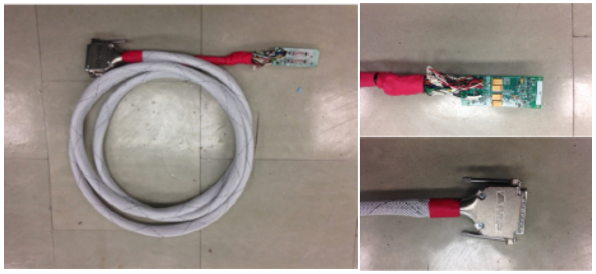
Outer hybrid

- 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 Cu layers



**T-Board**

- Design finished at SDU
- Delivery of production T-Board in 2020/3



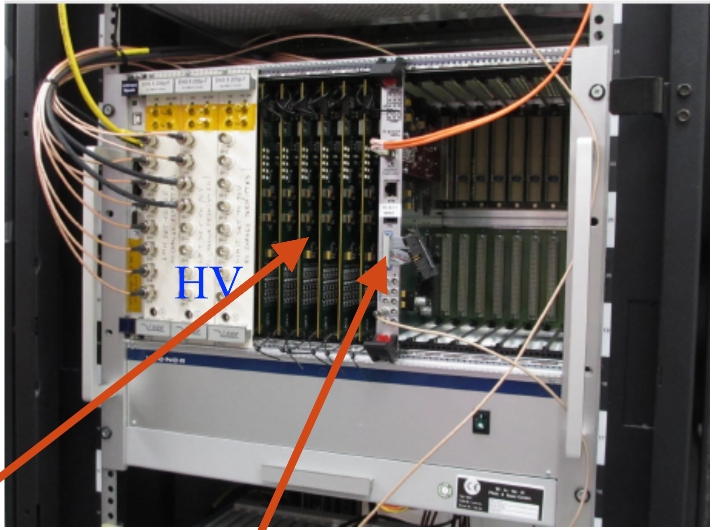
**Test inner signal cable**

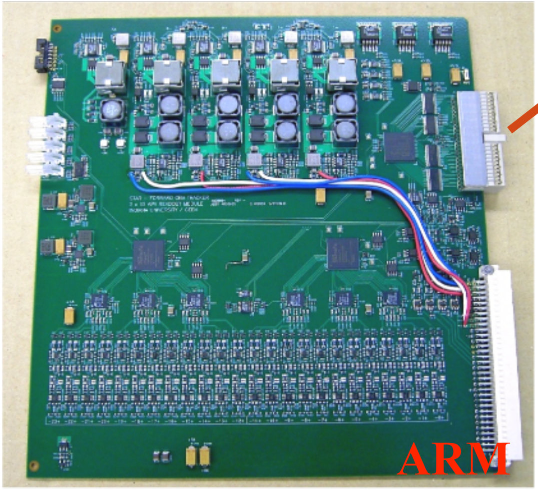
- Design finished at BNL
- Delivery of production cables in 2020/6

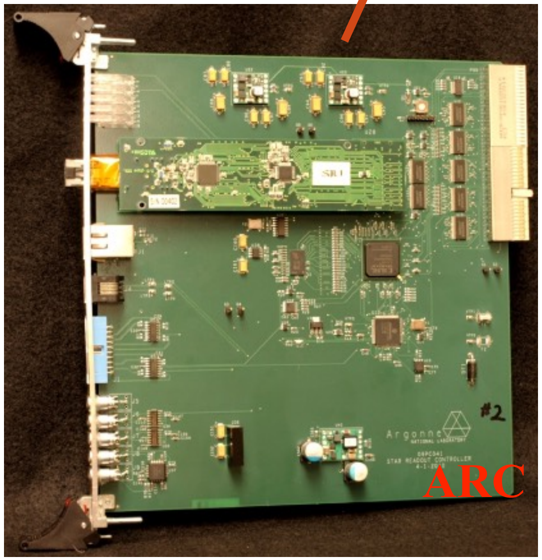
# DAQ system

Will reuse the DAQ system from IST:

- 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.
- Need new T-Board and inner signal cables for FST



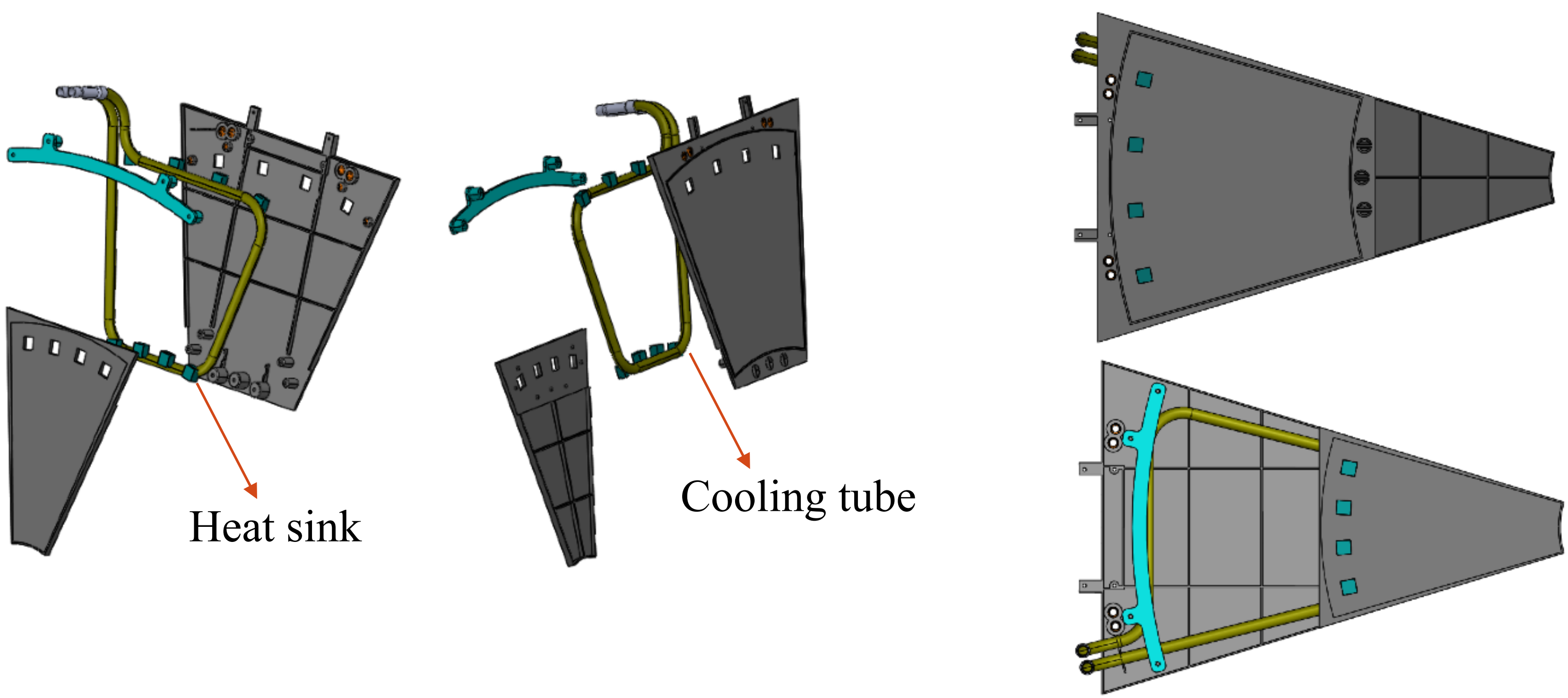



# Mechanical structure and cooling tube

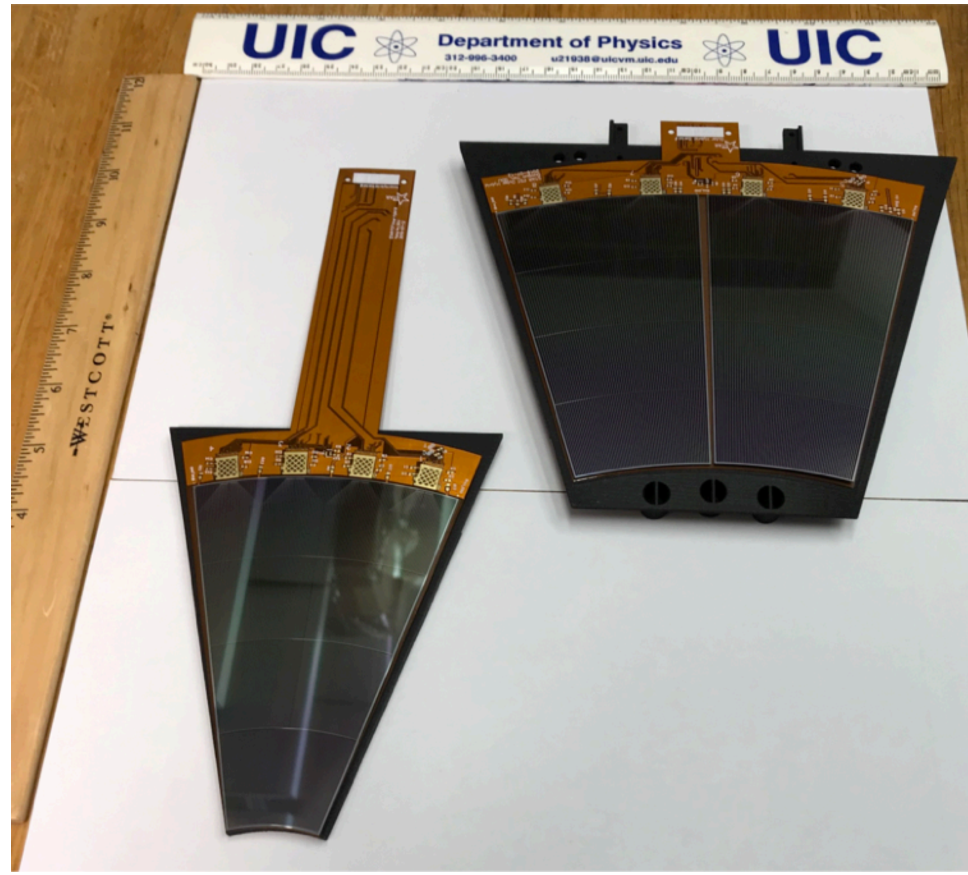
- Design, simulation, and manufacture at NCKU

| | Main structure | Heat sink | Cooling tube |
|---|---|---|---|
| Material | PEEK | Aluminum | Stainless steel |
| Thickness (mm) | 2.27 | 2.18 | 1.63 |
| Material budget ($X_0$) | 0.9% $X_0$ | 2.5% $X_0$ | 9.3% $X_0$ |



# First prototype of silicon and hybrid with 3D printed mechanical structure



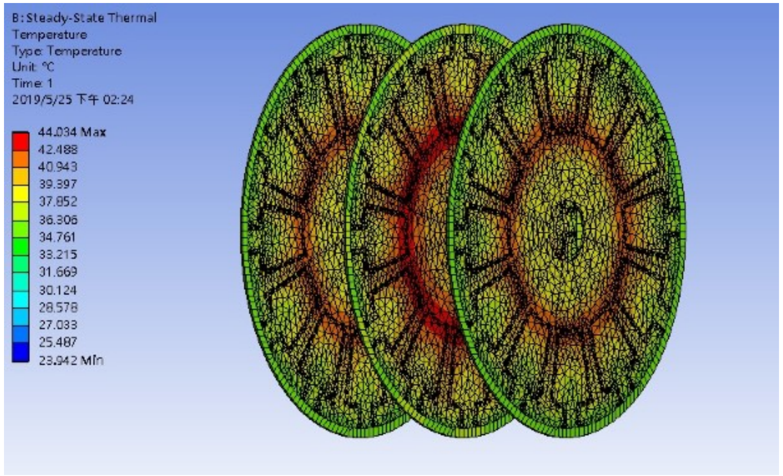


# Air cooling vs. Liquid cooling

Air cooling:

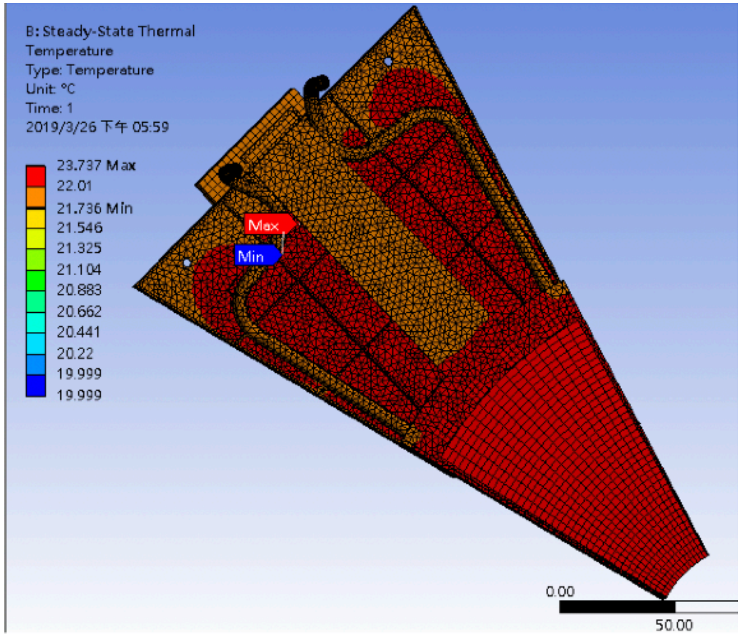
- The worst case scenario: treat the air between the silicon disks as a ”solid material” with a thermal conductivity equivalent to the nature convection
- Maximum temperature on the disk is up to ~44 °C

➜ Not good enough!




Liquid cooling (the one we will use):

- Temperature inside the tube was set to be 22 °C
- Maximum temperature on the module is ~23 °C



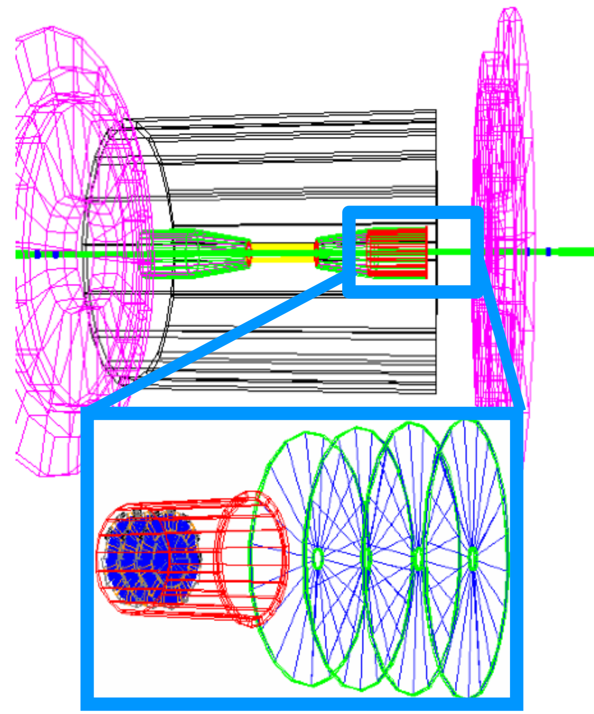
# Simulation setups

Generator → Hit simulation → Track reconstruction

**Generator**
- p+p (PYTHIA6)
  - Minumum bias
  - Primary particles
- Au+Au (HIJING)
  - Minumum bias
  - Primary particles

**Hit simulation**
- GEANT
  - Add Forward tracking system
  - Constant magnetic field
- Hit Fast simulator
  - Reconstruct realistic hit position and error

**Track reconstruction**
- Using current STAR tracking algorithm
- New tracker is under development



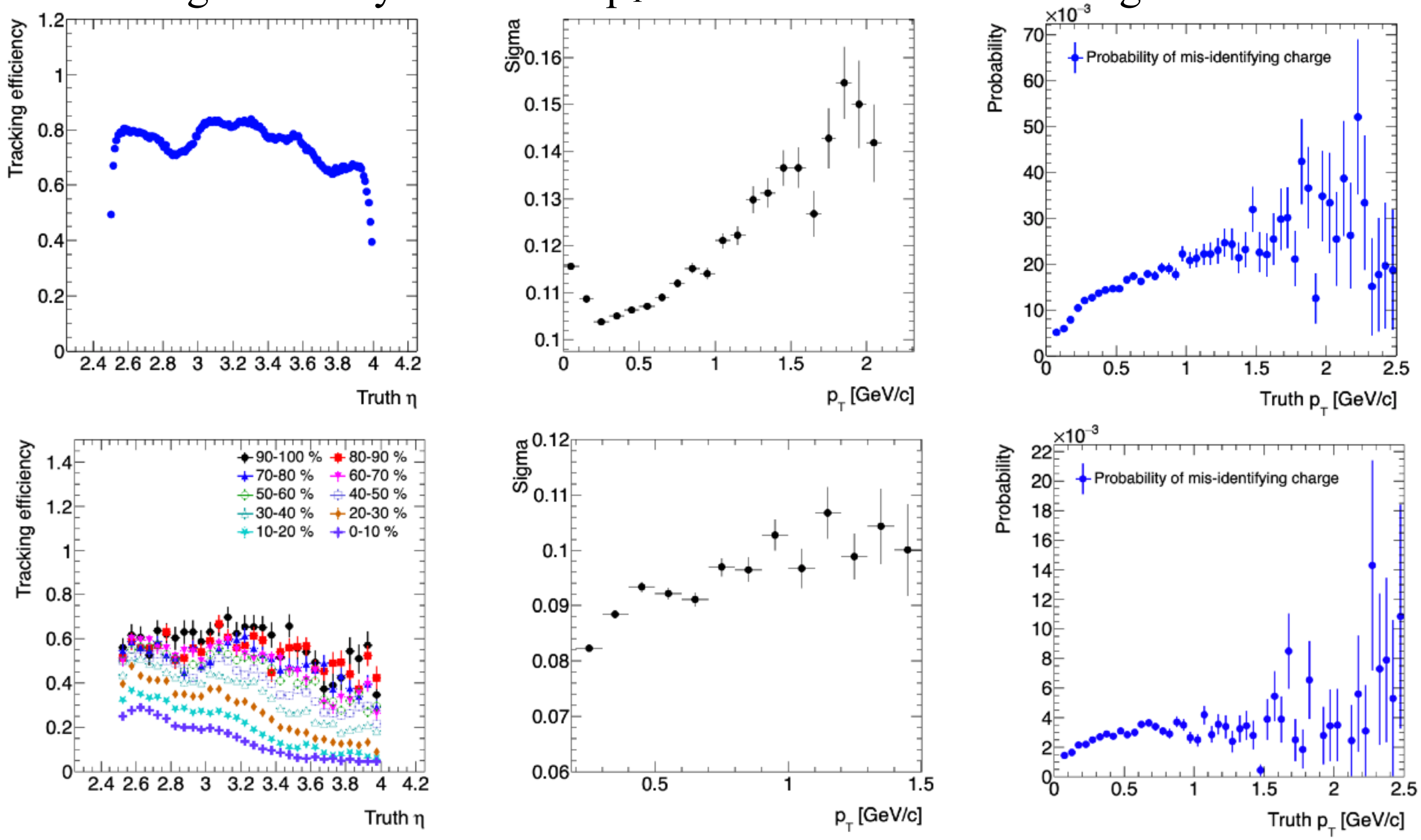
- Only silicon and mechanical structure implemented.
- Use large silicon disk as sTGC

# Tracking performance combined with sTGC

Tracking efficiency | $p_T$ resolution | Charge mis-ID rate

p+p at 510 GeV

Au+Au at 200 GeV




Very preliminary simulation study:

- Good charge distinguishing power and reasonable efficiency and $p_T$ resolution
- Stay tuned for the new tracking algorithm

# Summary

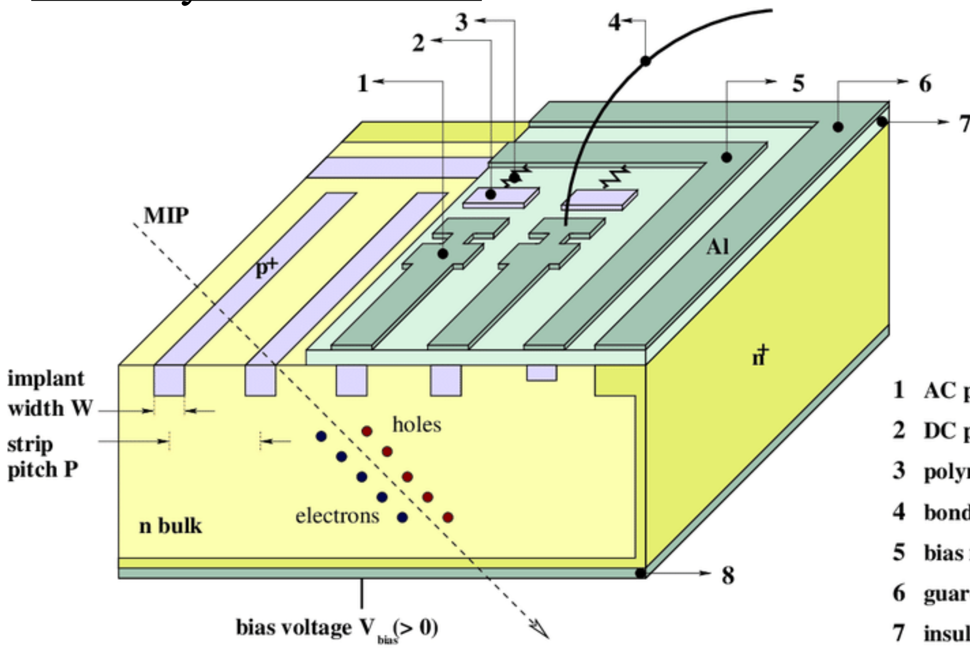
- STAR is going to extend it's capability to the forward region
- It lays the groundworks for the future EIC program
- First prototype of the silicon sensor has been tested, mechanical structure is under construction, first prototype for hybrid and T-Board are finished
- Preliminary simulation study has been done
    - Detailed GEANT modeling of FST is in progress
    - A new tracker for forward region and non-uniform magnetic field is under development

**Schedule:**
- 3 prototype modules will be assembled and tested early next year
- Whole detector is expected to be ready for data taking in Fall 2021

# 13 Backup

# Brief introduction to Silicon Strip Detectors

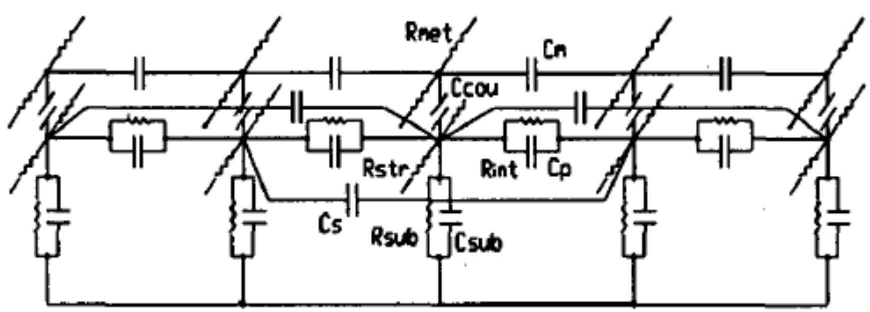
Courtesy: Markus Axer




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



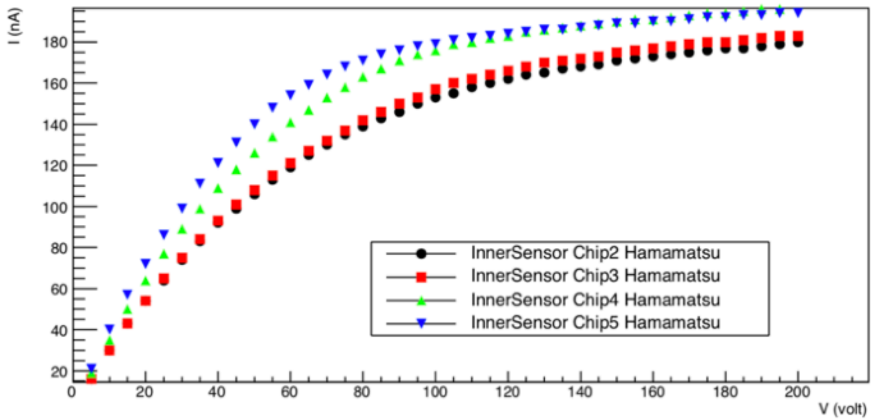

N. Bacchetta et al., 1995

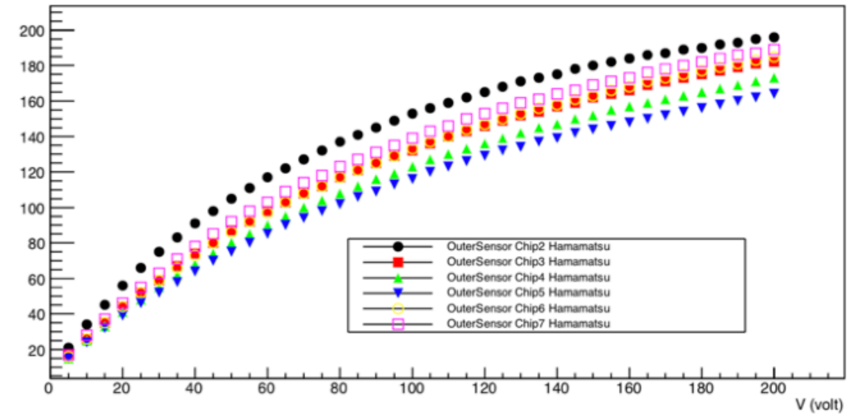
| | |
|---|---|
| Rmet | Resistance of the Al strip |
| Rstr | Resistance of the p+ implant |
| Rsub | Resistance between p+ implant and backside |
| Rint | Interstrip resistance with first neighbours |
| Ccou | Coupling capacitance |
| Csub | Substrate capacitance |
| Cp | First neighbour capacitance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

# Tests on the prototype sensors

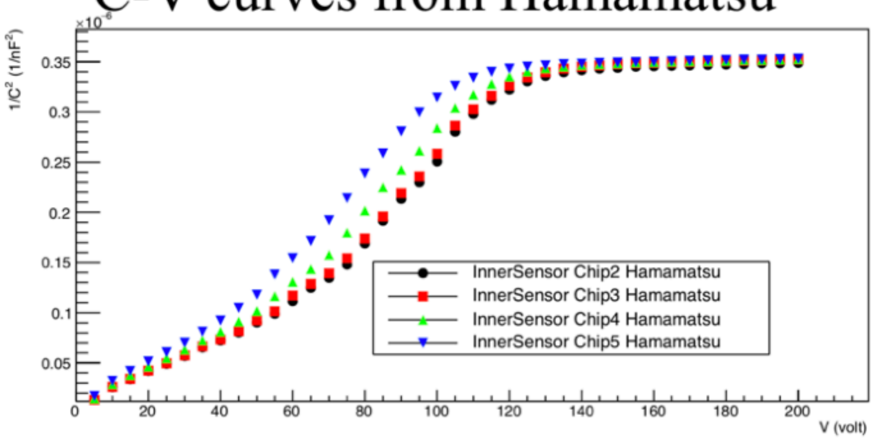
- We received 4 inner and 6 outer silicon prototype from Hamamatsu.
- Basic tests has been done at UIC

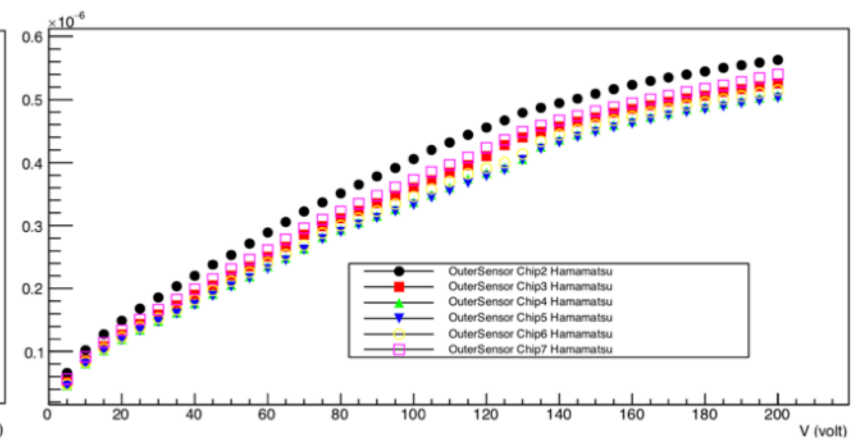
## I-V curves from Hamamatsu



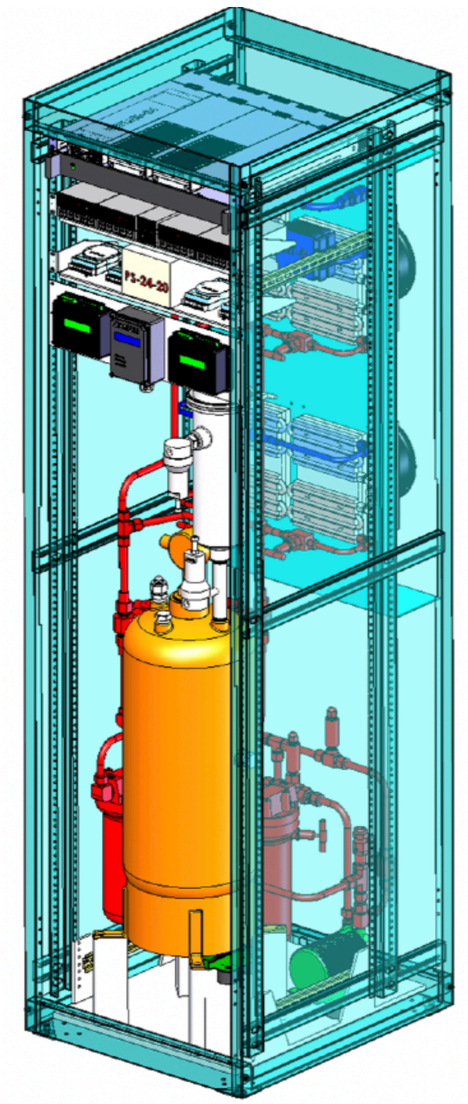



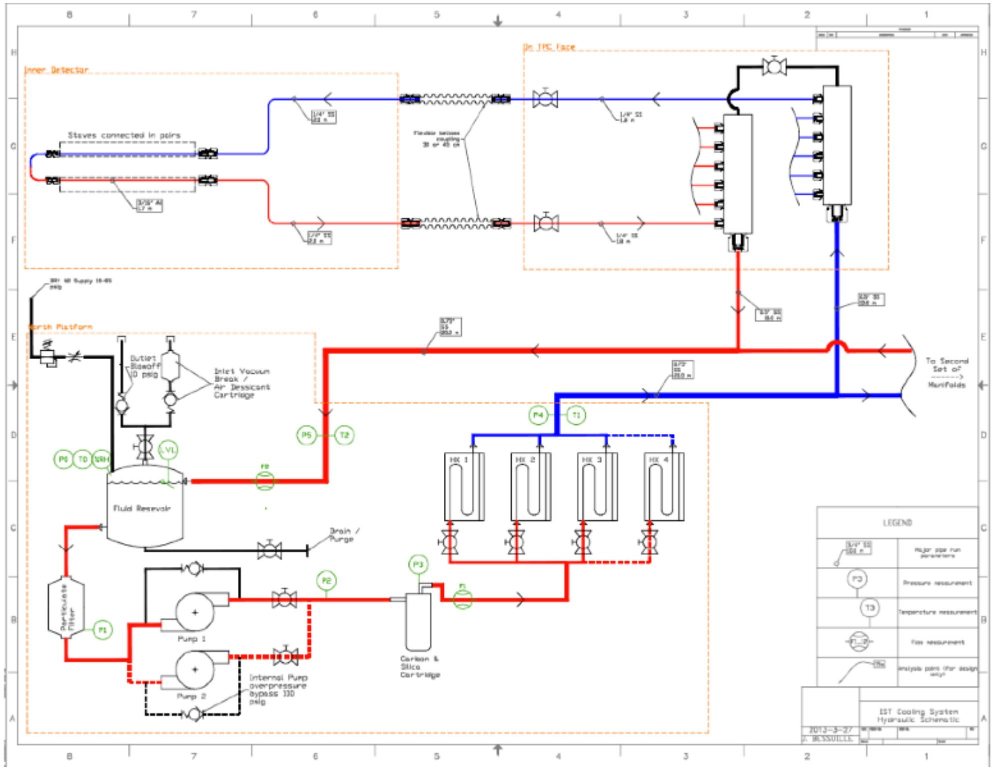

## C-V curves from Hamamatsu



# Cooling system






Will also reuse the cooling system from IST:

- Heat load ~ 100W (300W for IST)
- Coolant: 3M™ Novec™ 7200 (**$C_4F_9OC_2H_5$**)