Mechanical Structure for EPIC TOF

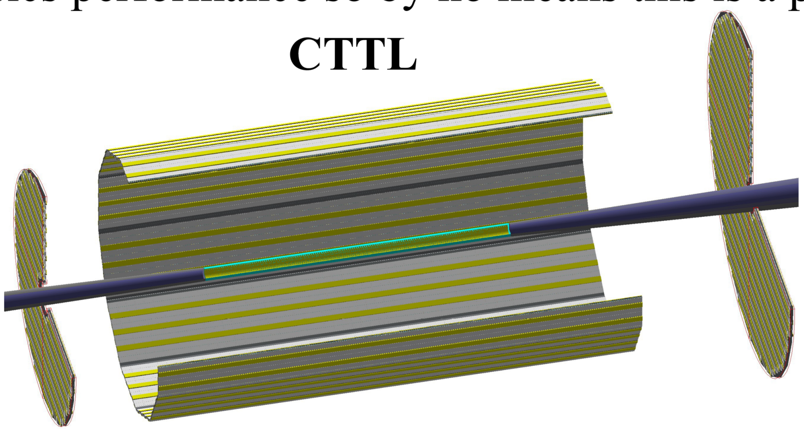
25th November 2023

Yi Yang
National Cheng Kung University

From Zhenyu's talk
https://indico.bnl.gov/event/16765/

AC-LGAD Layer for TOF PID + Tracking

- The goal is to conceive a reference layout and technical design (v0) as inputs to GD/I group to advance the detector integration (service routing etc.)
- However, there are still on-going studies to investigate the optimal channel granularity based on physics performance so by no means this is a proposal for final design.



For v0 design, we propose:

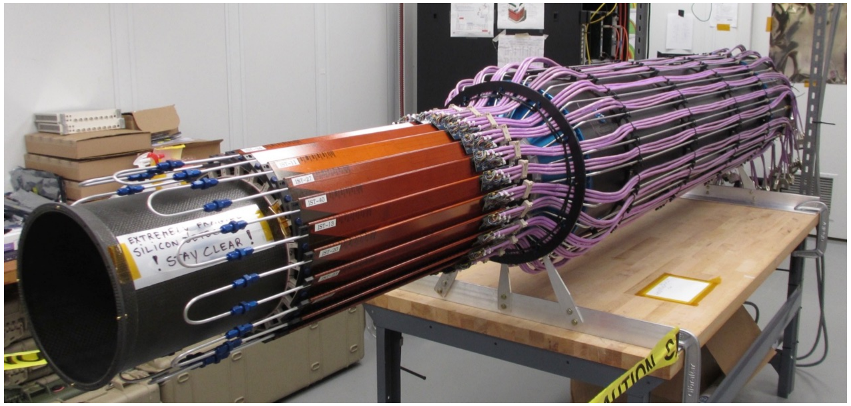
- **Barrel: 0.5x10 mm^2 strips**
- **Endcap: 0.5x0.5 mm^2 pixels (same as RPs) [1]**

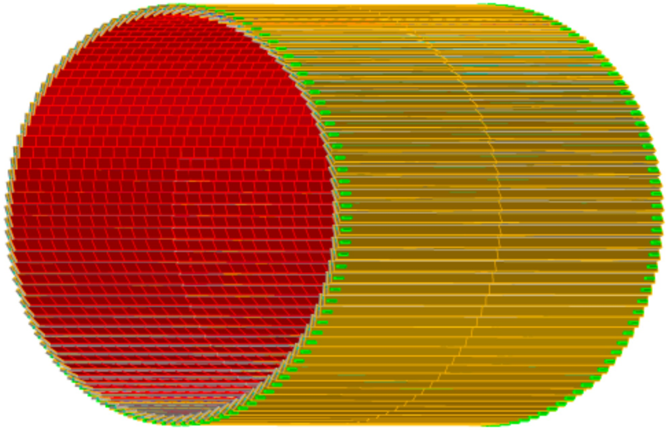
[1] Wei Li, TOF-PID WG Meeting Aug 29, 2022

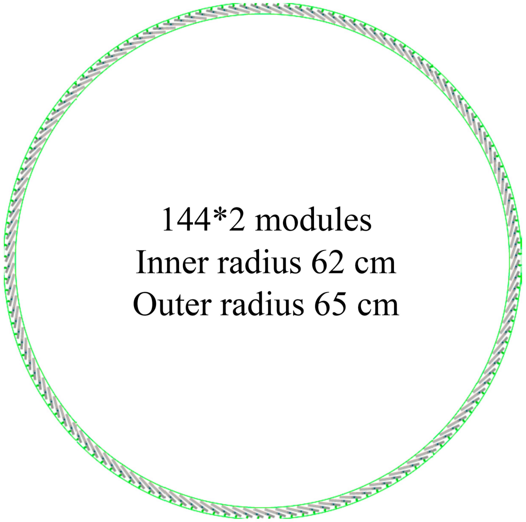
	acceptance	Z (m)	Radius (m)	Area (m^2)	Channel size (mm^2)	# of Channels
ETTL	$-3.7<\eta<-1.74$	-1.61 to -1.71	0.12 to 0.63	1.20	0.5*0.5	4.8M
CTTL	$\|\eta\|<1.4$	-1.2 to 1.5	0.625 to 0.655	10.9	0.5*10	2.4M
FTTL	$1.5<\eta<3.5$	1.555 to 1.705	0.12 to 0.85	2.22	0.5*0.5	8.8M

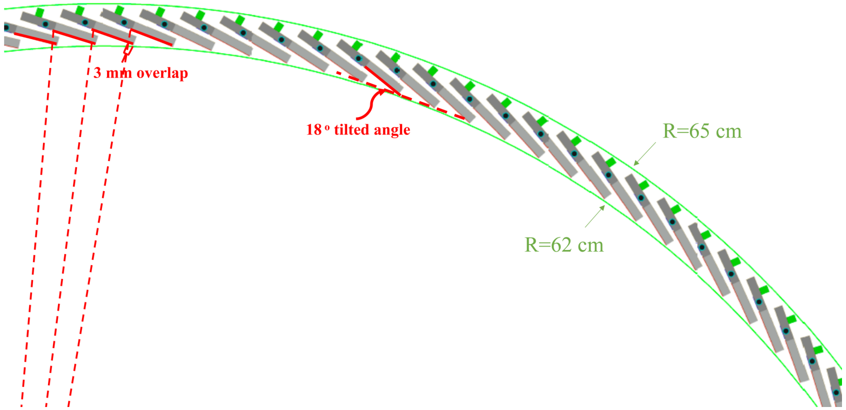
Barrel TOF

- Use the similar concept of STAR IST





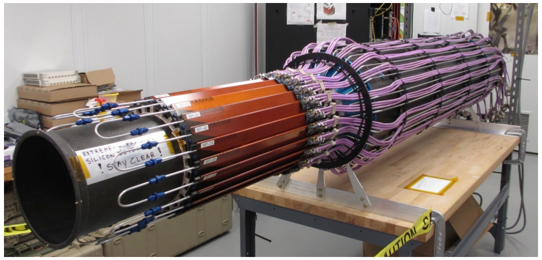


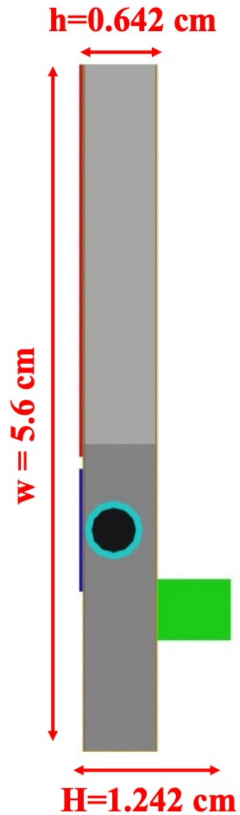


From Zhenyu's talk
https://indico.bnl.gov/event/16765/

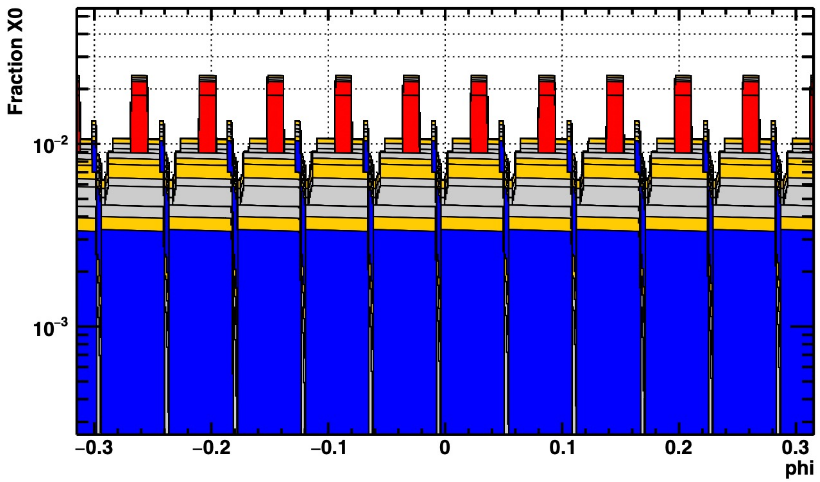
Barrel TOF

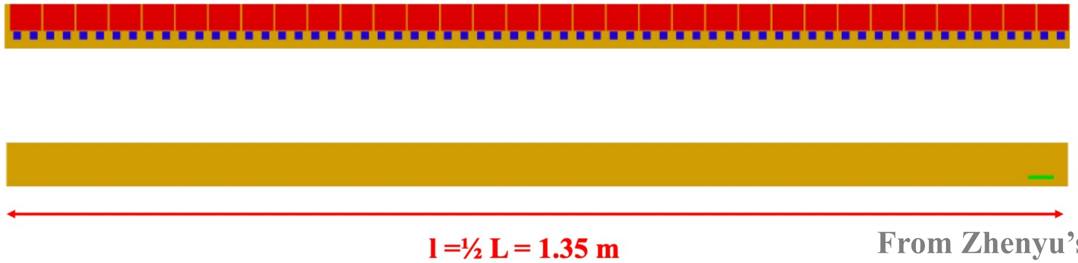
- In total 288 modules,
  - 9216 sensors, 18,432 ASICs, 2.4 M channels
  - ~70 kG, ~4 kW





- **AC-LGAD sensor**
- **Frontend ASICs**
- **Carbon foam+ Carbon honeycomb+ CF skins**
- **Al cooling tube**
- **Liquid coolant**
- **Kapton PCB**
- Connector



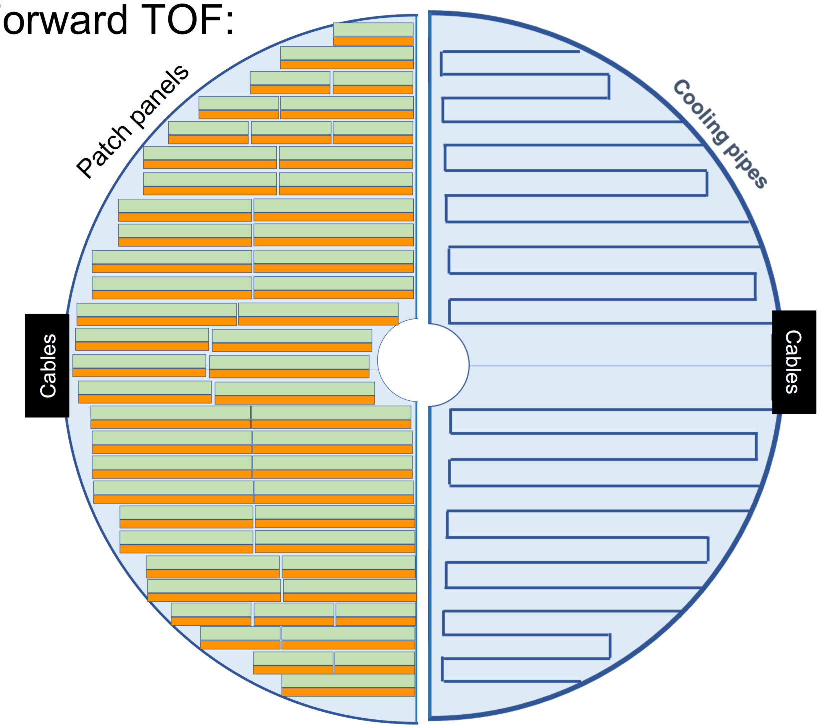


From Zhenyu's talk
https://indico.bnl.gov/event/16765/

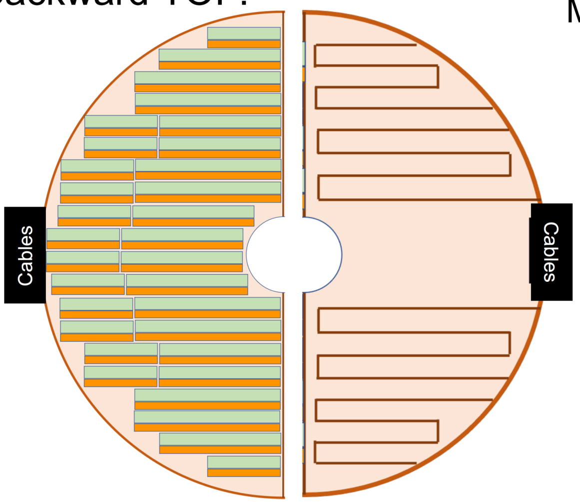
Endcap TOF

From the talk of Wei Li
https://indico.bnl.gov/event/16742/

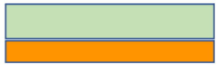
Forward TOF:



Backward TOF:



Module:



Power Budget

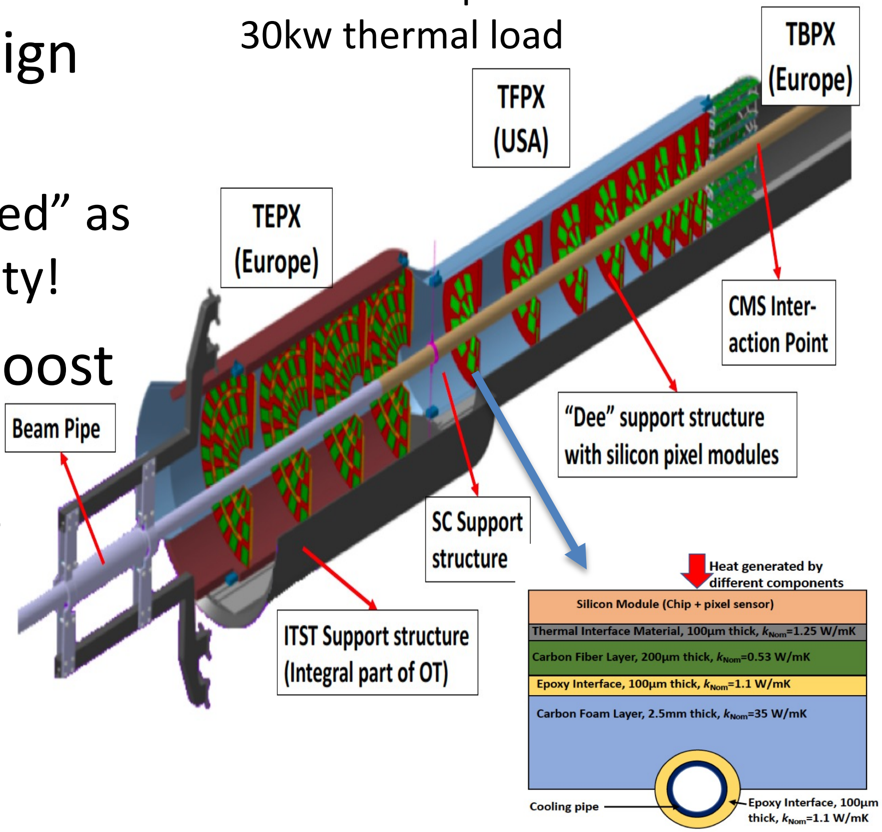
	Forward	Backward
Sensors	0.6kW	0.35kW
EPTROC	8.5kW (17kW)	4.8kW (9.6kW)
DC-DC	3.5kW	2kW
lpGBT, VTRx+, SCA	0.5kW	0.3kW
Power cables	0.5kW	0.3kW
Total	13.6kW (22.1kW)	7.75 (12.55kW)

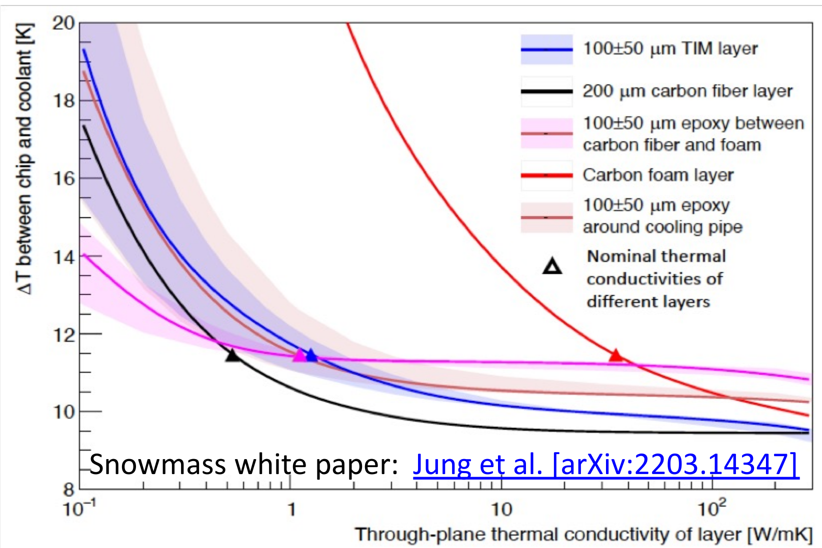
- "Clam shells" or DEEs
  - Convenient for installation/maintaenance
  - Each is patched by TOF modules (one or more types) on both faces

Mechanical Support Design

- Mechanical support structure design impacts detector performance
  - At times detector mechanics is “solved” as an after-thought – missed opportunity!
- Optimal materials & budget can boost a detectors physics performance
  - Needs timely action, well in advance

CMS IT example:
30kw thermal load





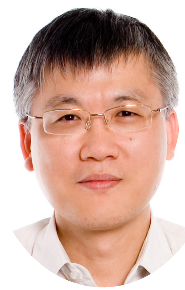
Snowmass white paper: [Jung et al. [arXiv:2203.14347]]

“Sandwich” supports pixel module:

- State-of-the art for multiple systems (inner & outer tracker, timing layers)
- Select materials depending on thermal performance needs
- Applicable to variety of detectors

AS-NCKU-Purdue Team

- Yi Yang (NCKU), Wen-Chen Chang (AS) & Po-Ju Lin (NCU)
  - Experiences with the AMS-02 UTTPS radiator and lead the project of the mechanical structure of STAR FST
  - Excellent machine shop

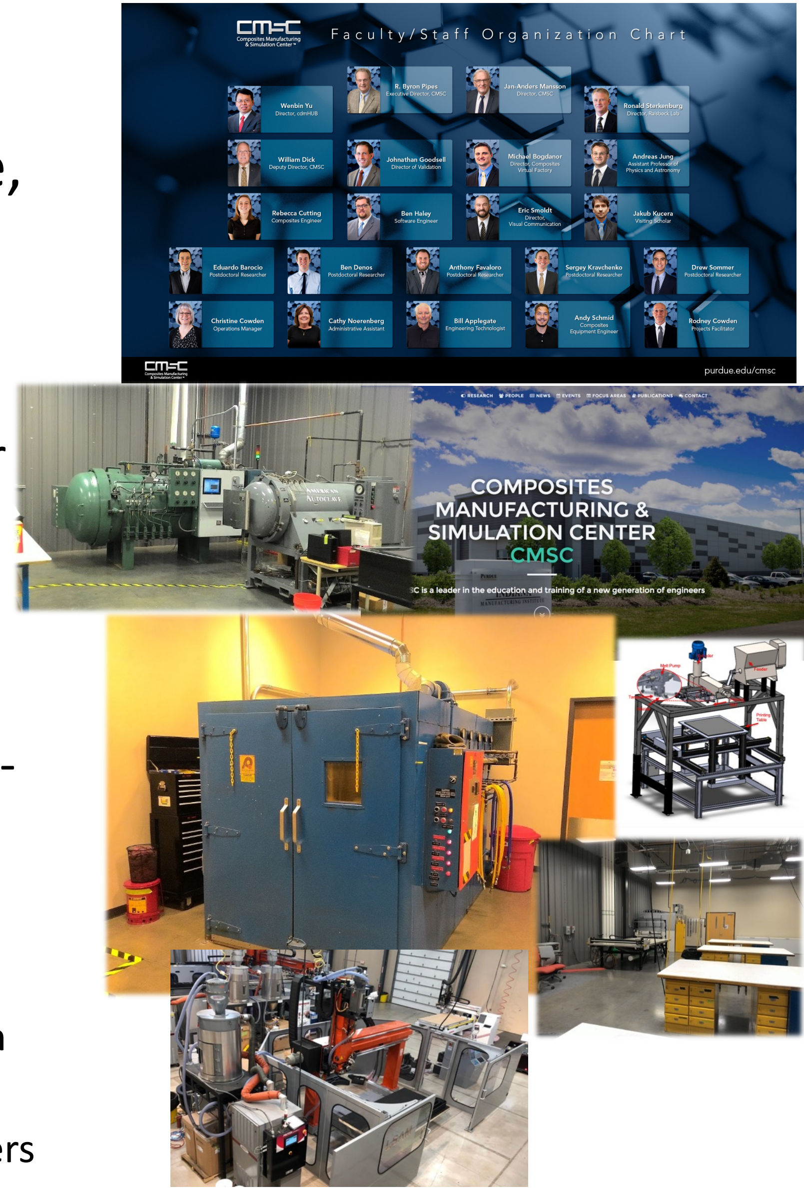




- Andreas Jung (Purdue)
  - Experienced in R&D for low mass support structures.
  - Working on the light-weight composite tracker support structures for CMS.

PURDUE UNIVERSITY

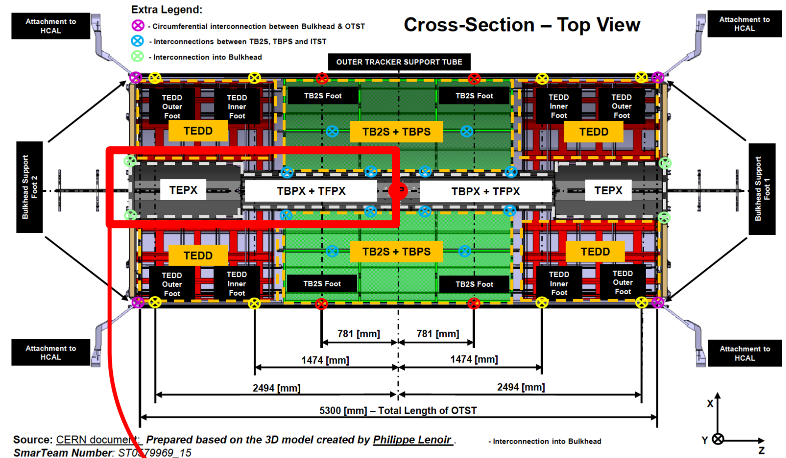
Resources from Purdue

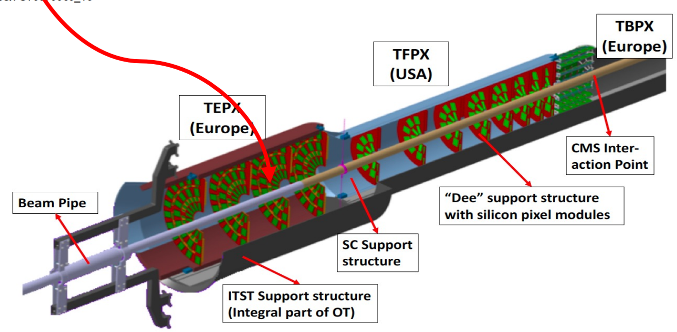
- Composite Manufacturing & Simulation Center (CMSC) at Purdue, completed in summer 2016
  - Purdue Center of Excellence across disciplines: Aeronautics, Chemical Eng, Materials Eng, Aviation Tech, Computer graphics, **and Physics**
  - A. Jung – Associated member of CMSC
- Professional composite experience:
  - Seven full-time technical staff, five post-doctoral researchers, twenty grad's
  - 35,000 sq. ft. of office and laboratory space
    - 2 large pressurized ovens, 1 larger oven with vacuum hook-ups
    - Larger ovens accessible with industry partners

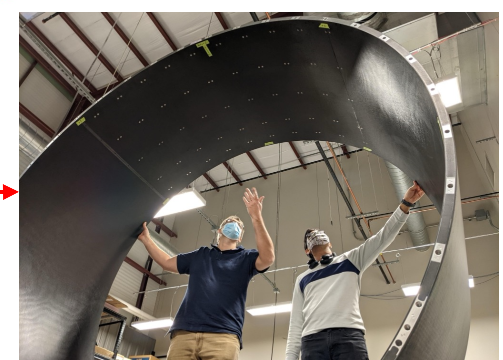


Experience from Purdue

- CMS upgrade relies on Purdue for design & manufacturing of mechanical support structures
  - Service Cylinder housing the Inner Tracker (IT)
    - 4+2 half cylinder structures with a length of 2.9m and transition region between small & large radii
    - Barrel, Forward, and Extended Pixel Detectors
  - Components for Inner Tracker pixel
    - Sandwich structures to mount pixel modules (Dee's) for the forward pixel (US project)
    - CFRP structures for the barrel pixel (European led)
  - Inner Tracker Support Tube (ITST)
    - Supports the 4 IT Service Cylinders, separates Inner Tracker and Outer Tracker volumes
    - Longitudinal stiffness for the entire Outer Tracker
  - Components for Outer Tracker (OT) modules
    - CFRP stiffeners (~3000ft^2) for the OT modules assembly
  - Barrel Timing Layer Tracker Support Tube
    - Supports the entire IT + OT + Timing Layer of CMS

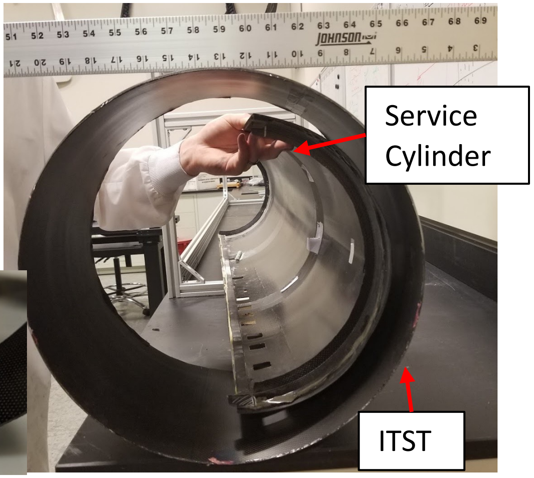


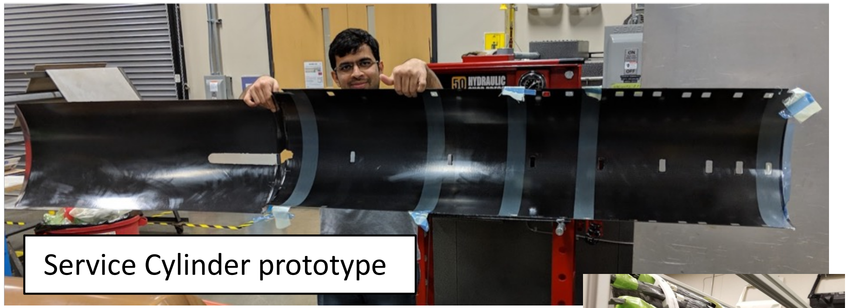


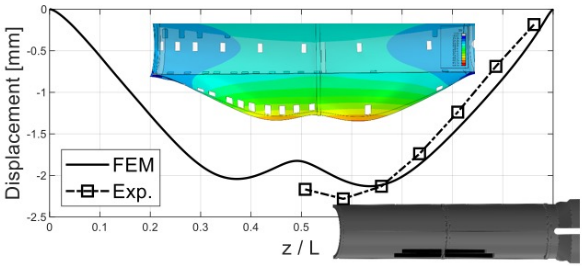


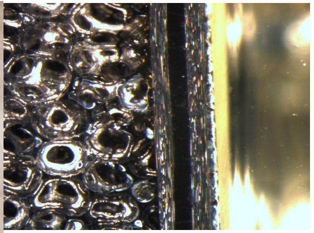
Experience from Purdue

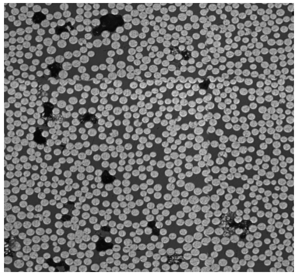
- Prototyping & Manufacturing related to ITST, SC, Dee's
  - Prototypes confronted with FEA predictions, multiple iterations
  - Prototyping and Development of additional structures for IT pixel
    - Cartridges, Portcard holders, all extensively studied for high thermal performance
    - Accompanied by irradiation campaigns: sample prep, characterization, etc.
    - Dedicated measurement of thermal conductivities
    - High thermally conductive materials for 3D printed parts



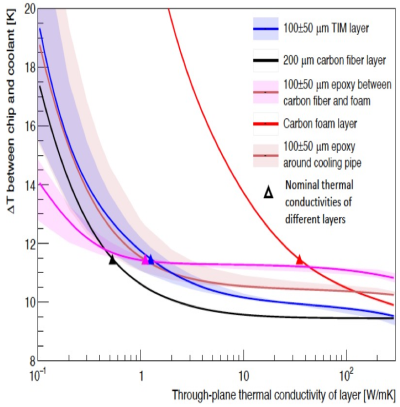






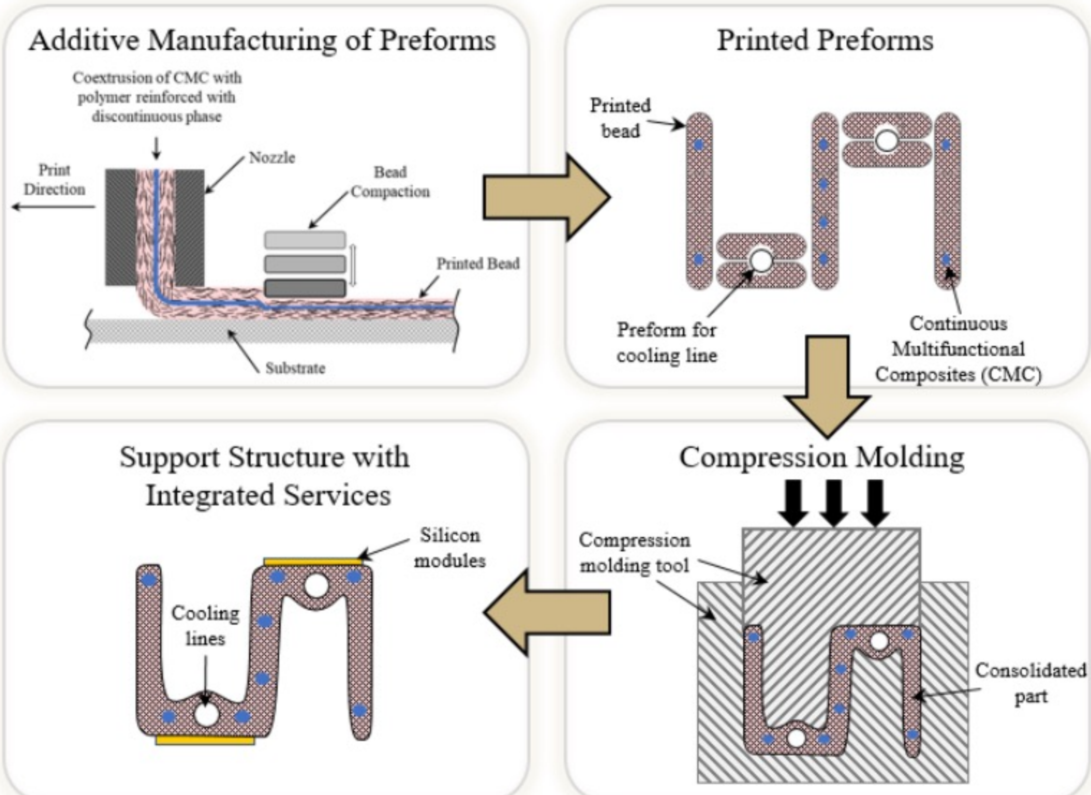


- Forward pixel dee prototype
- Co-cured samples
- Microscopies
- 3D printed mechanical supports
- Critical interfaces via FEA



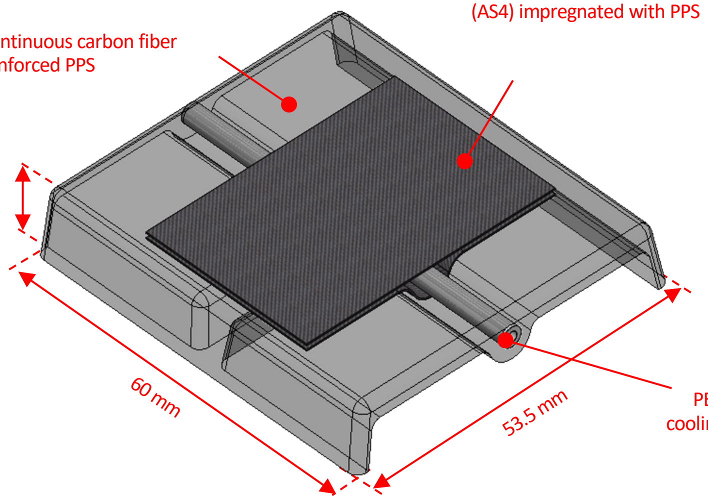
R&D for irreducible structures…

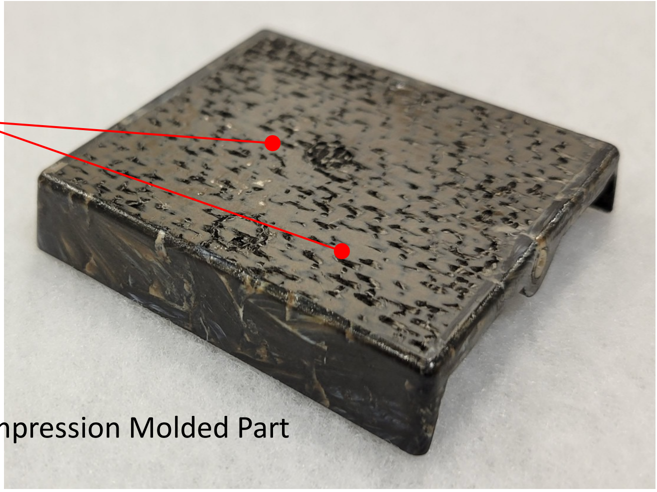
- Identified by DOE BRN effort & CPAD
  - Scaling of low-mass detector system towards irreducible support structures with integrated services. Includes: integrated services, power management, cooling, data flow, and multiplexing.
  - Purdue proposed mechanics R&D to solve detector challenges at future colliders



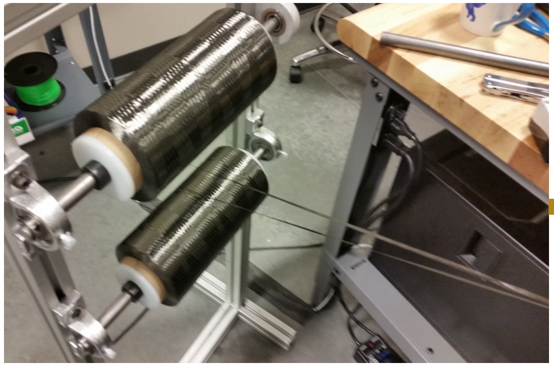
BlueSky R&D at Purdue

- Could be applicable to EIC – recent progress…

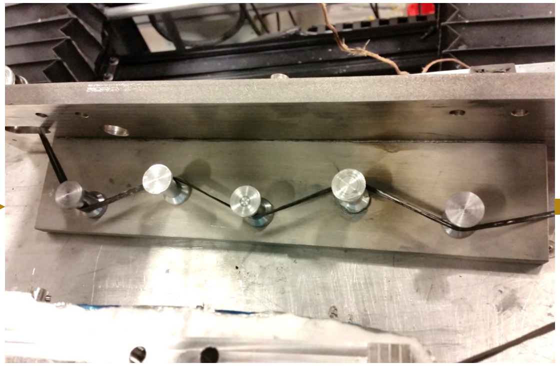




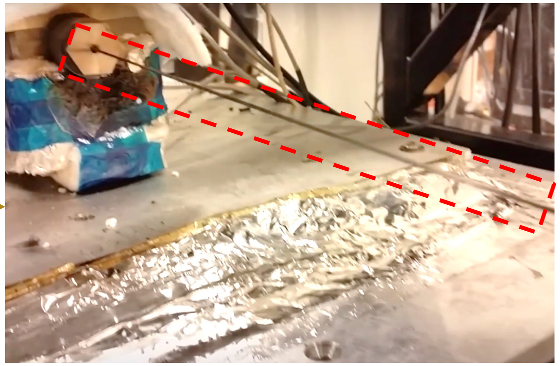
Compression Molded Part



Spools of Carbon Fiber

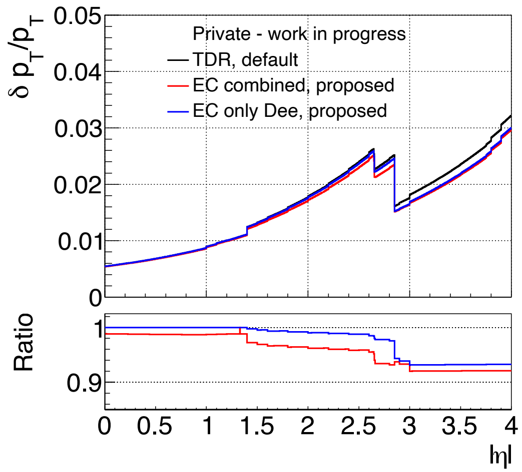


Interior of Impregnation Chamber

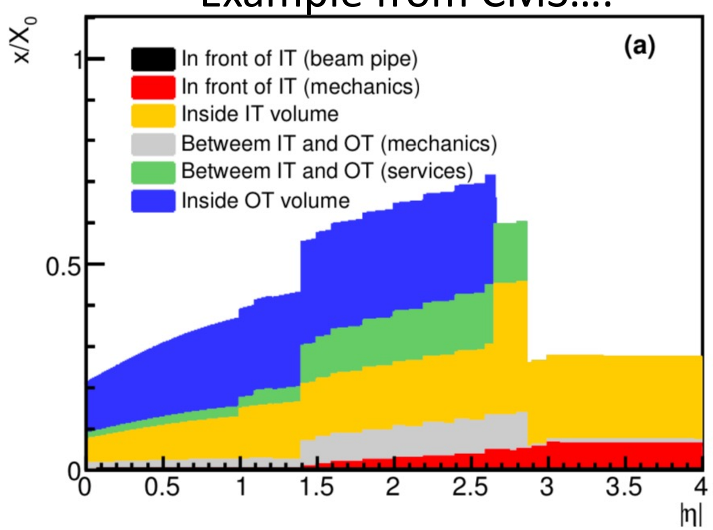


Carbon Fiber Impregnated with PPS

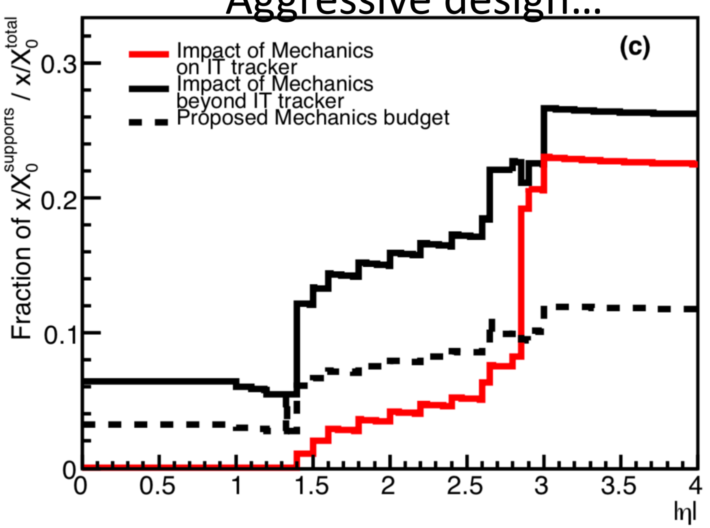
- Radiation length plot more specific to CMS but can be related to EIC conditions
  - First look during R&D phase, PED has to include this
  - Mechanics is often overlooked but impacts detector performance significantly
- These techniques more easy benefit endcap detectors whereas gains are limited in barrel region (harder)
- This seems like an excellent fit to the needs of TOF!



Example from CMS....

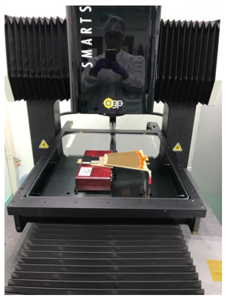
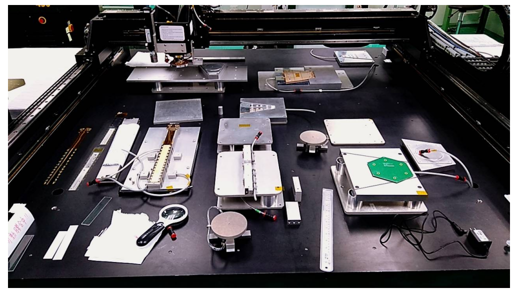
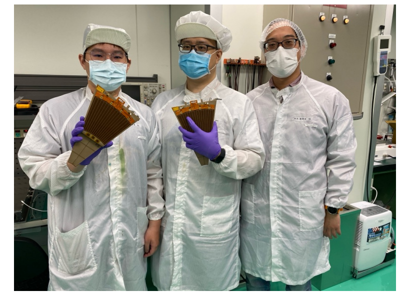


Aggressive design...

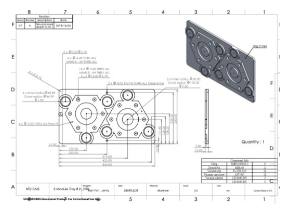


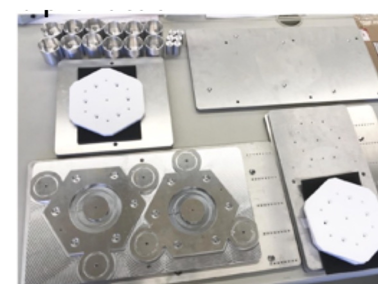
Resource from Taiwan

- **Taiwan Instrumentation and Detector Consortium (TIDC):**
  - https://tidc.phys.ntu.edu.tw/WordPress/
  - Sophisticated machines for detector assembly

- **NCKU:**
  - Strong mechanical engineering department
  - Good relationship with **A**erospace **I**ndustrial **D**evelopment **C**orporation (AIDC)
    ➔expert on composite material
- **AS IoP:**
  - High precision machine shop
  - Experienced engineers, effective production

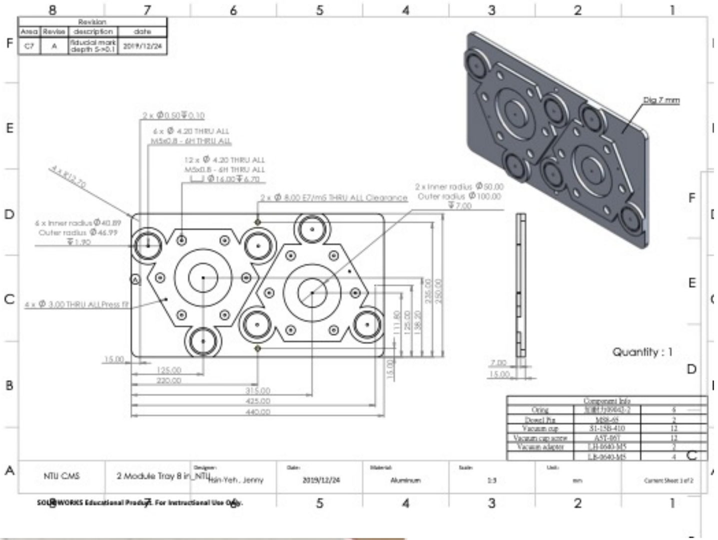


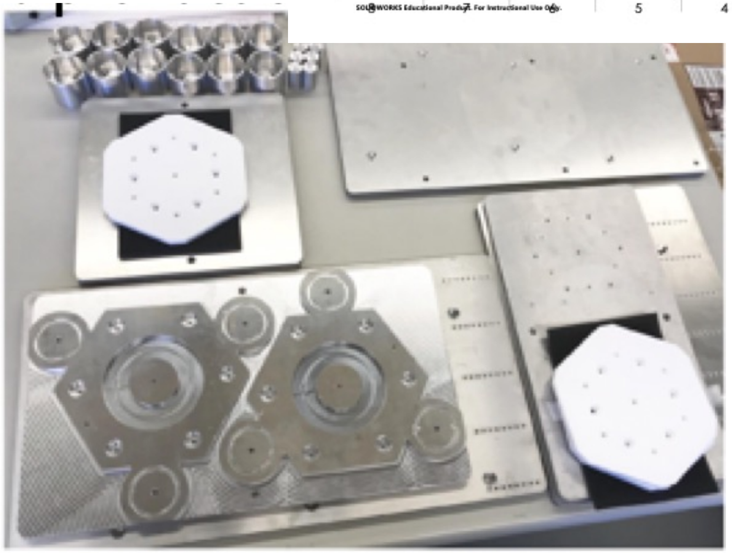



- **Three mechanical engineers from AS, NCKU and TIDC**

TIDC: High Precision Machine Shop

- Experienced engineers, effective production @ AS





STAR Forward Silicon Tracker

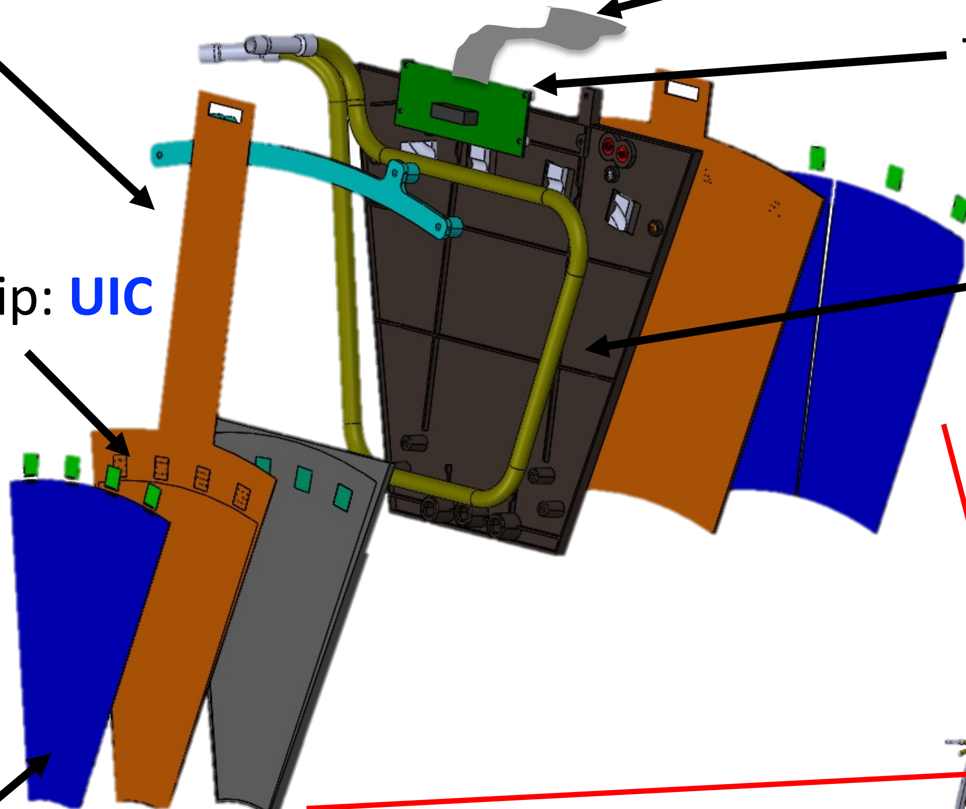
Flexible hybrid PCB: **SDU/IU**

Inner Signal Cable: **BNL/IU**

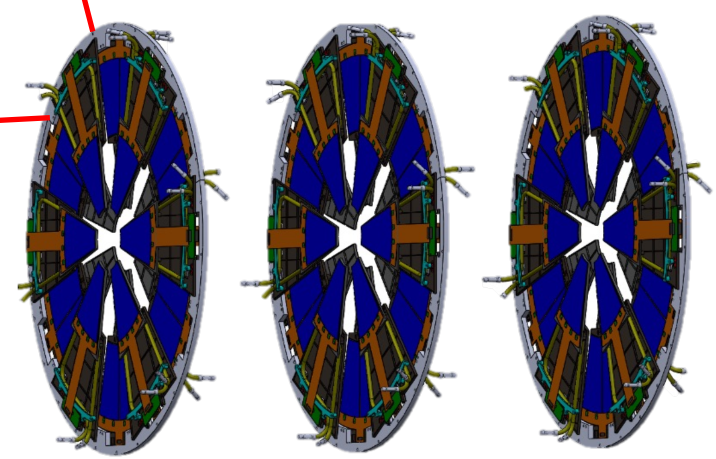
T-Board: **SDU/IU**

APV25 Chip: **UIC**

Mechanical Structure (+ cooling pipe): **NCKU/AIDC**



Supporting Structure & Integration: **BNL**



Silicon sensor: **UIC/BNL**

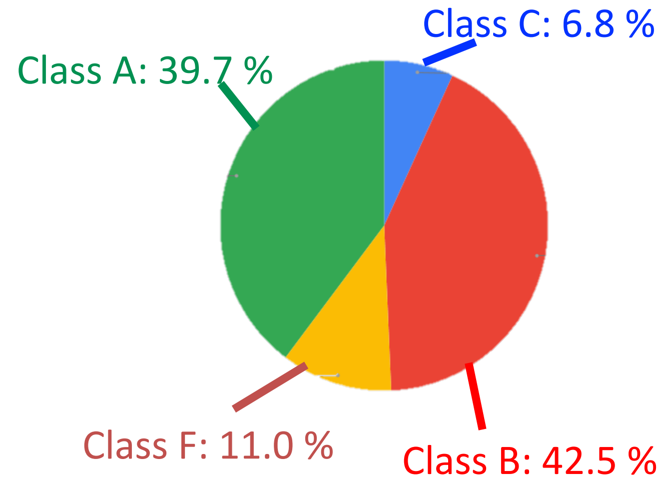
Cooling: **BNL/NCKU**

Simulation: **UIC/BNL/IISER/NCKU**

Experience from NCKU: STAR FST

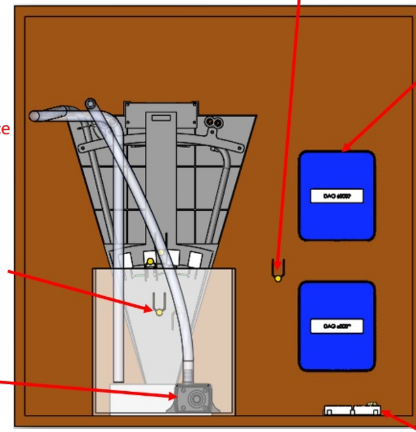
- Total 73 modules (48 needed) are produced

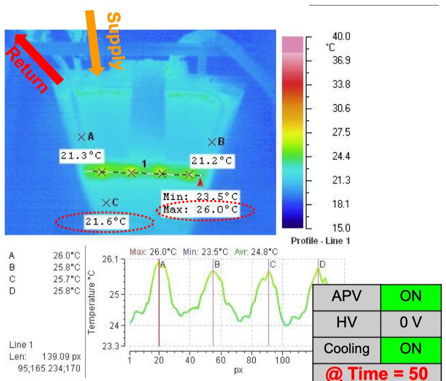
  → **Successful rate ~89%**

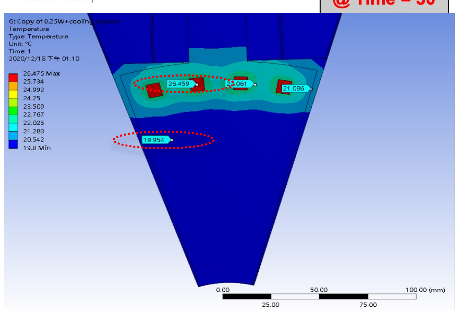


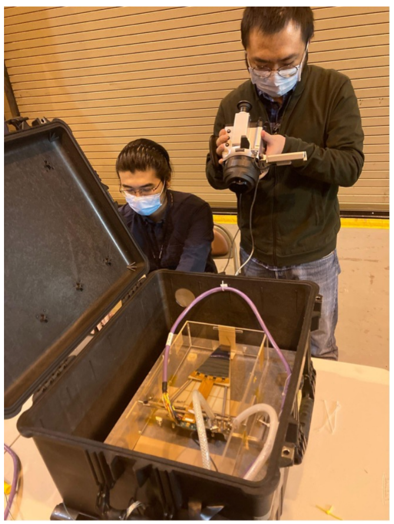
Experience from NCKU: STAR FST

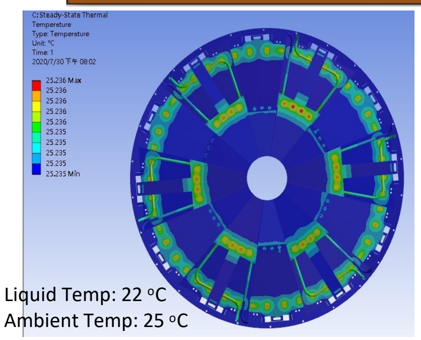
- Careful thermal analysis is performed by using single module with water cooling
- **Temperature at thermal equilibrium is less than 26 °C**
- Cooling test on FST-04
  (Dec. 21, 2020@BNL)
  - Ambient T: 19.8 °C
  - Coolant T: 22.2 °C



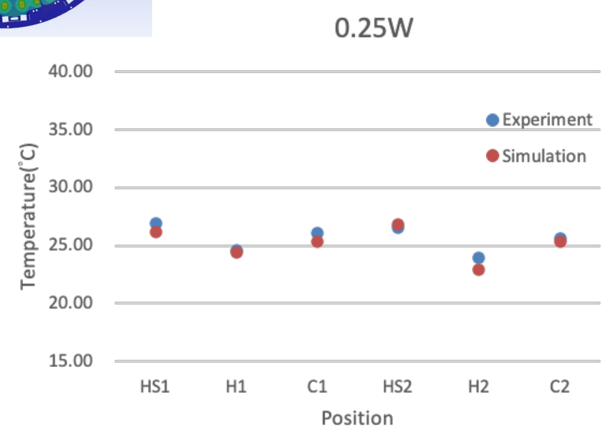








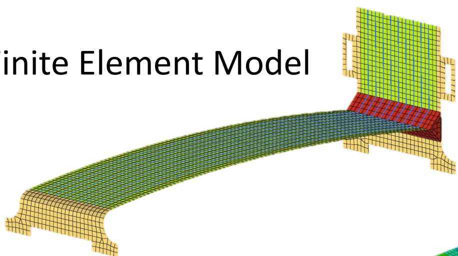
Consistent results between experiments and simulation



AMS-02 PDS Radiator in Taiwan

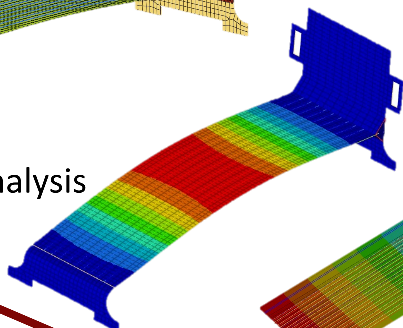
Structural design and analysis

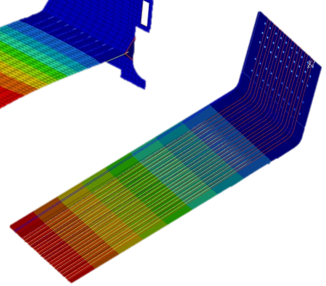
Finite Element Model



Component	Material	Weight
Heat Pipe	6063-T5	23.057 lb
Inner/Outer Skin	2024-T81	13.296 lb
Rohacell-51WF	--	3.445 lb

Modal analysis

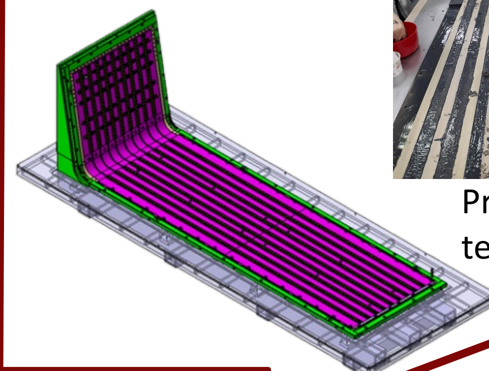


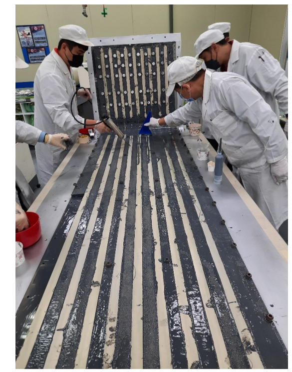


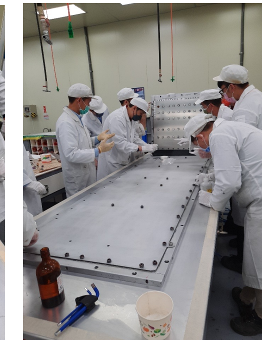
Deformation and stress

Manufacture

Jig design, manufacture procedure



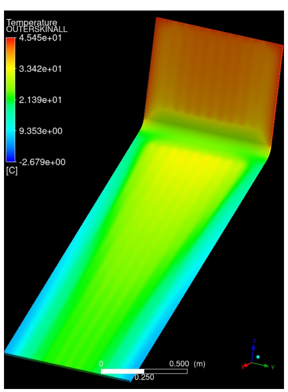


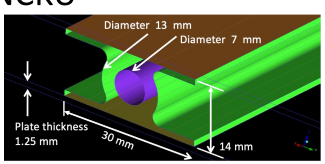


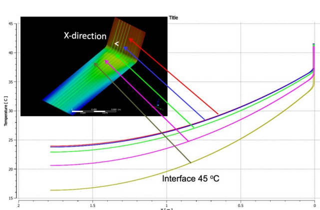
Professional assembly team

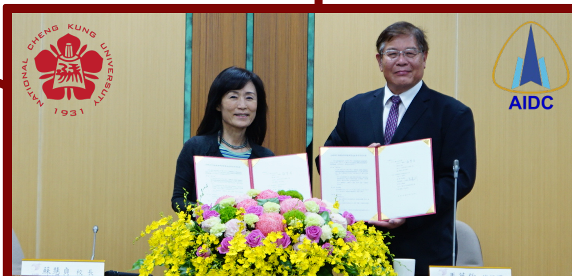
Thermal analysis

Experts and Profs. from AIDC and ME department of NCKU









NCKU and AIDC signed the agreement on PDS radiator design and manufacture (March 28, 2022)

- NCKU: management, design, fund
- AIDC: design, manufacture

> 1 M USD allocated to this project

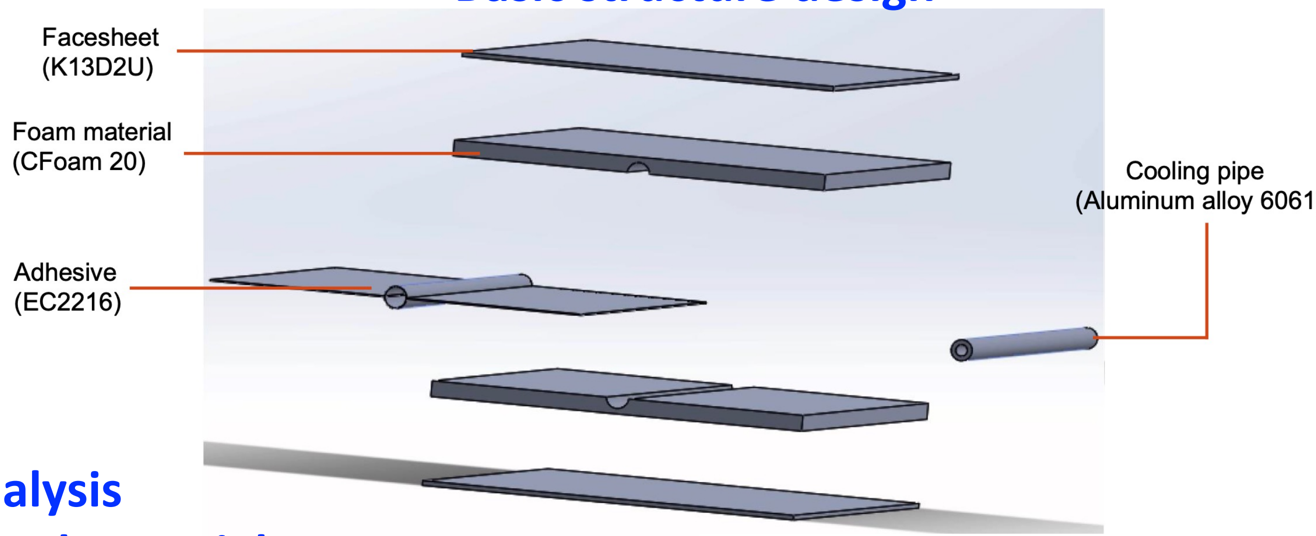
Tests

Giant thermal vacuum chamber at Taiwan Space Agency (TASA)

Operation volume: 3 meters (diameter) x 3.5 meters (length)
Ultimate pressure: 10 –7 mbar
Temperature range: 77 ° K ~ 400 ° K
Air–pumping rate: 10 –5 mbar in 4 Hours
Maximum temperature adjustment rate: 1 K/min

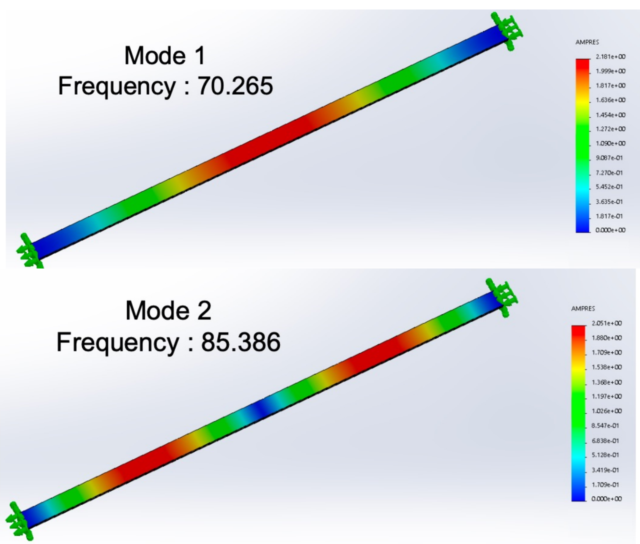
Preliminary thermal analysis @ NCKU

Basic structure design



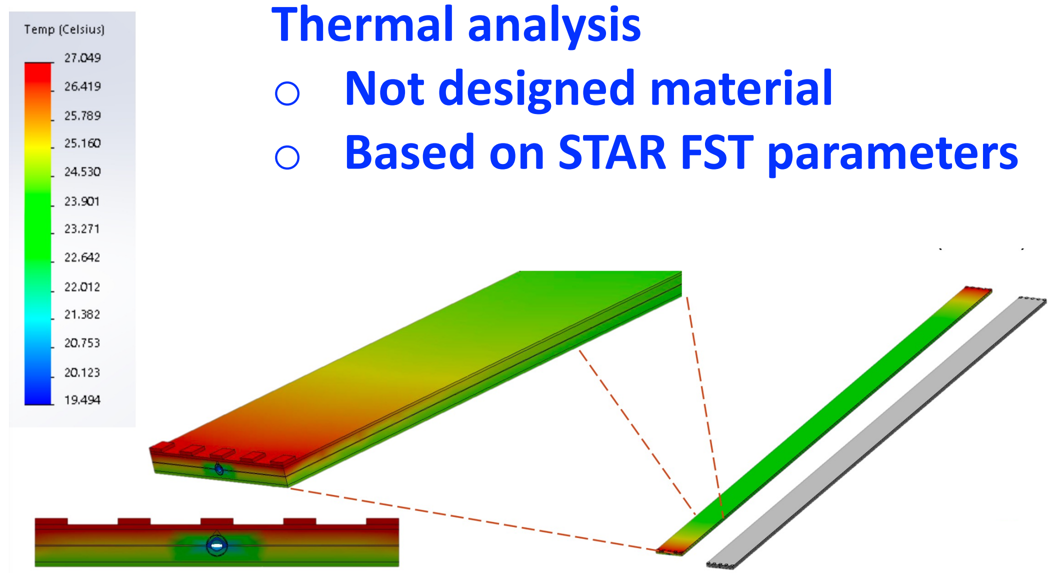
Frequency analysis

- Not designed material



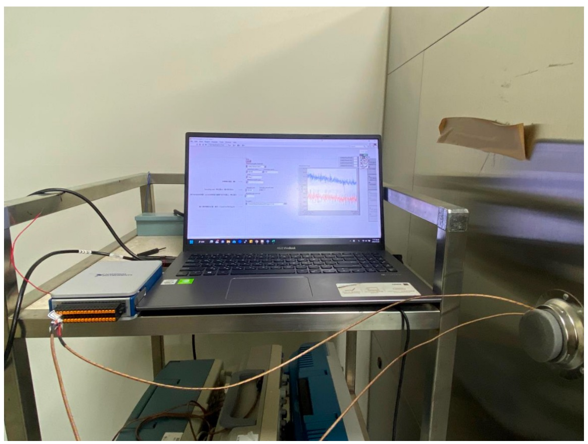
Thermal analysis

- Not designed material
- Based on STAR FST parameters



Test Facilities @ NCKU

- NCKU already has the test equipment: thermal chamber, DAS, large thermal isolation chamber



Summary

- EPIC TOF detector is the key subdetector of EPIC
- NCKU, Purdue, and AS are working together on the EPIC TOF structure
- NCKU and Purdue have excellent experience on mechanics