Mechanical Structure for EPIC TOF

15th August 2023

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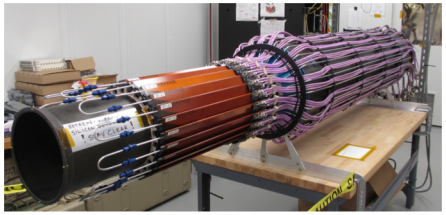
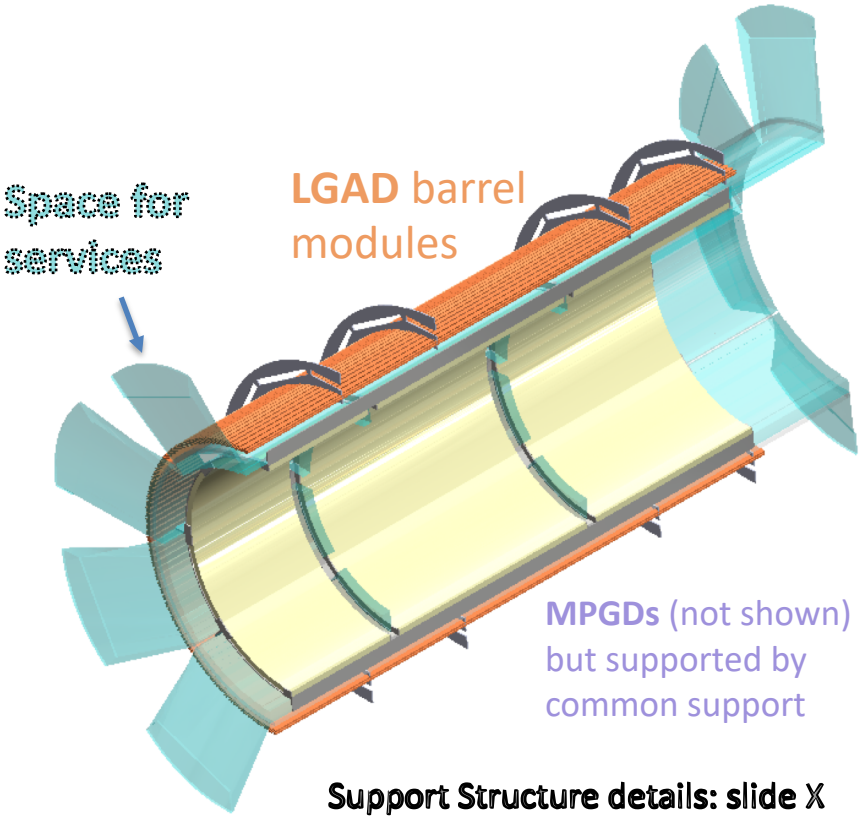
Overview: PED Request & R&D

- Current R&D activities focus on staves
  - 2023: Manufacture 2-3 more at Purdue, thermal tests & FEA at NCKU
  - 2024: R&D request for endcap low x0 techniques at Purdue
- PED request and TOF-LGAD mechanics team evolved since FY23 R&D
- Goals:
  - Includes a support structure for the barrel TOF-LGAD, see earlier slides
    - Likely a 30 or 45 degree section
  - Look at a 1st concept for cooling performance (but relies on holistic detector wide concept)
  - Lots of synergies between R&D and PED…
  - Inside of TOF
    - “Internal” MPGDs supported by barrel TOF-LGAD support – included
    - Tracker supports & services routing
  - Outside of TOF aka Integration & “Interfaces” to outside sub-detectors
    - Outer MPGD & hpDIRC support frame, some ideas and suggestions made to have a lower x0 “super” structure replacing hpDIRC

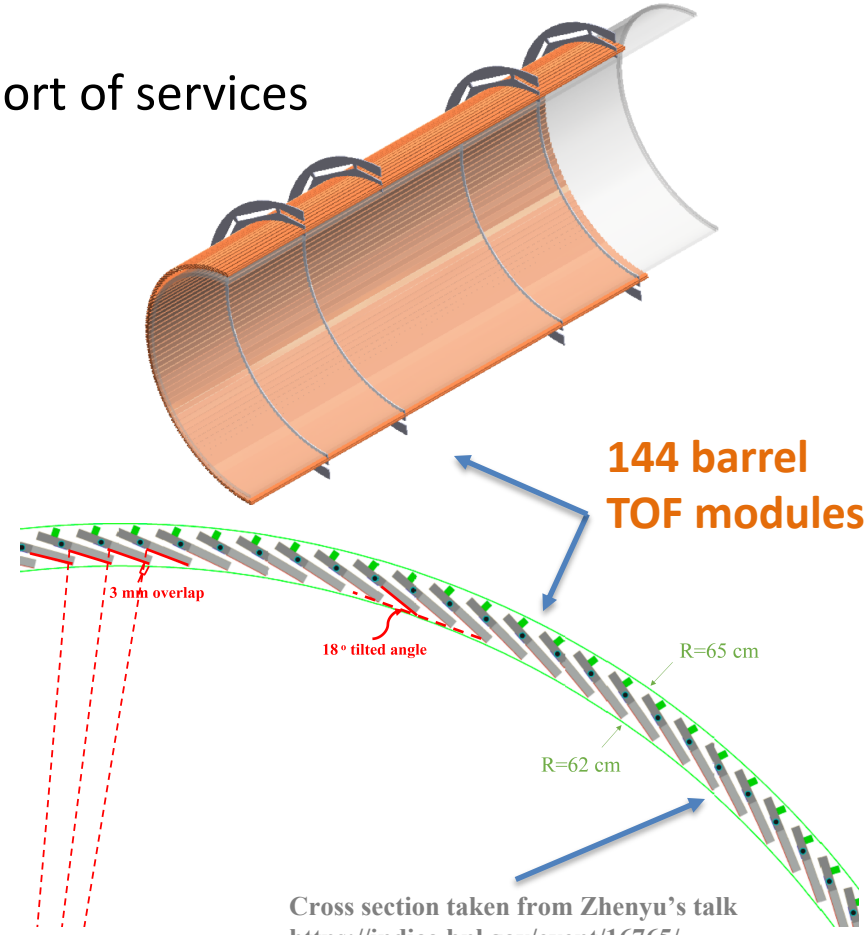
Barrel TOF



- Use similar concept of STAR IST (starting point)
- LGADs supported by “long staves”, next slide
- Common support structure
  - Barrel TOF, MPGDs, space & support of services

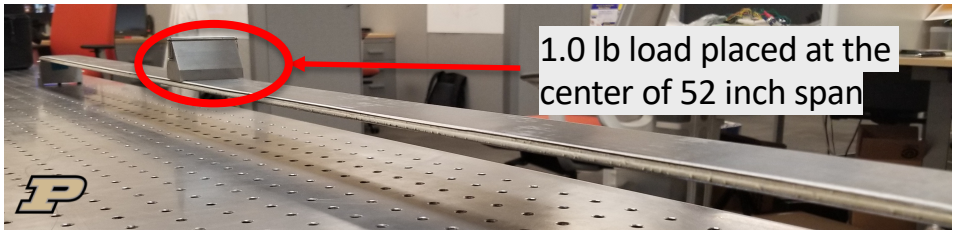


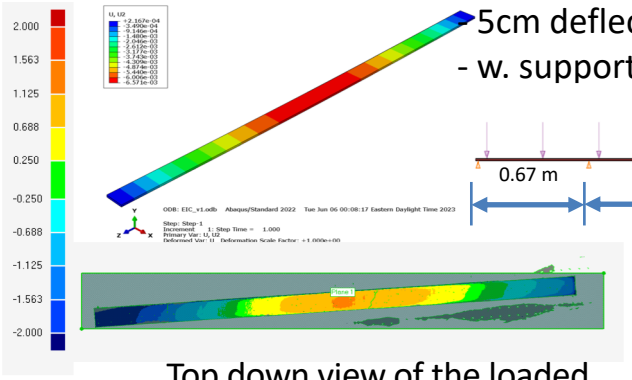
Support Structure details: slide X



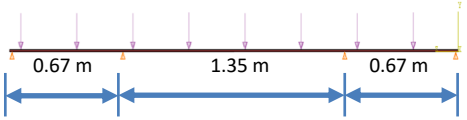
Barrel TOF

- Total of 144 barrel TOF modules
  - 9216 sensors, 18,432 ASICs, 2.4 M channels
  - Mass ~70kg and 4kW heat load
- 1st Preliminary stave structure made
  - FEA and prototype for full length
  - Deflection of 700 micron – further optimization possible





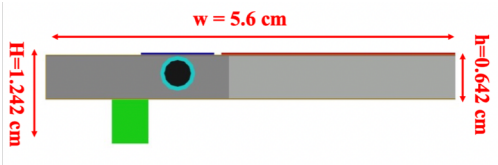
5cm deflection full length stave
- w. supports down to 700μm

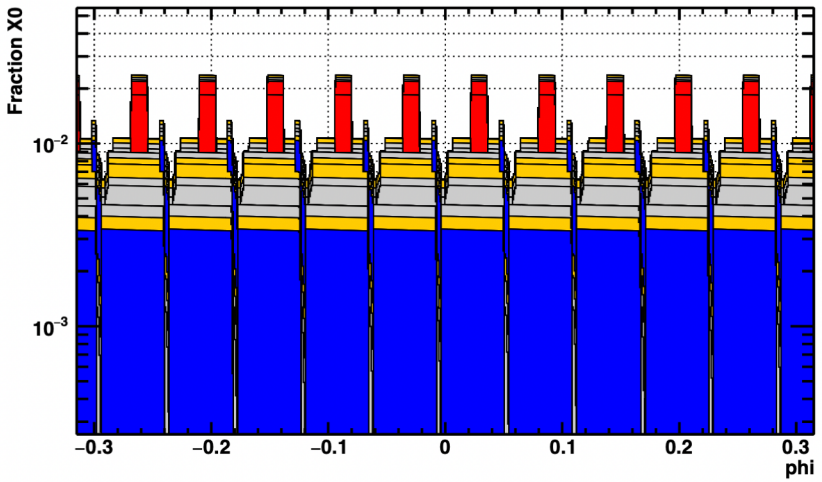


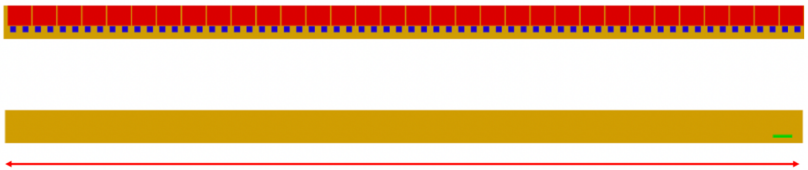
Unit: mm

Top down view of the loaded stave.

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





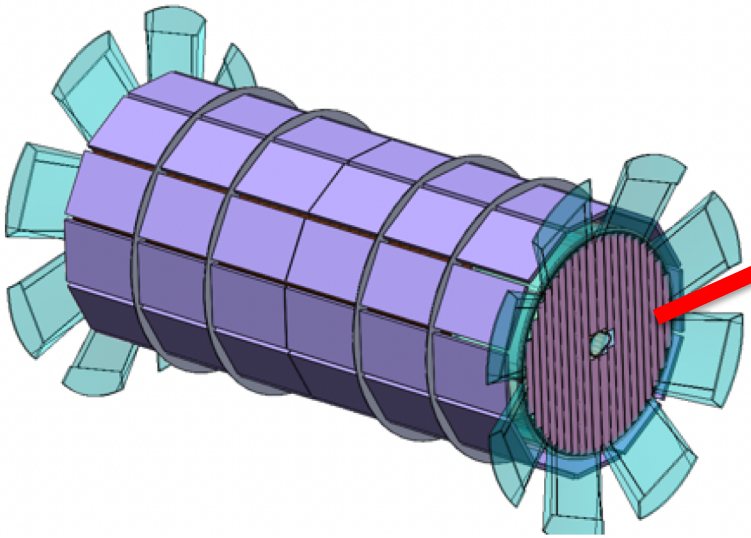


"Long stave" length ~ 2.4m

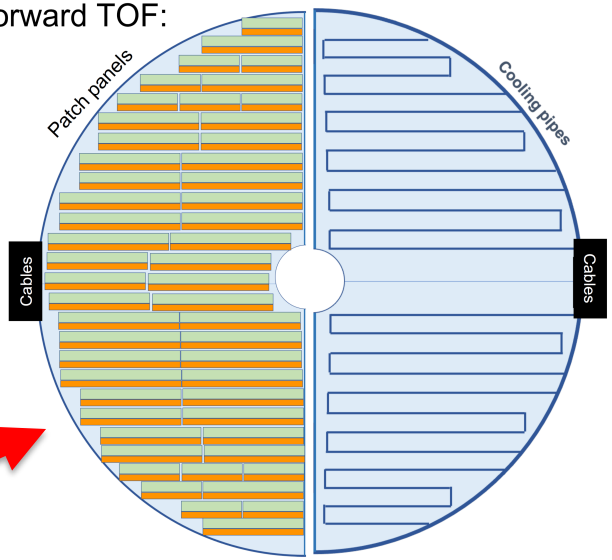
From Zhenyu's talk
https://indico.bnl.gov/event/16765/

Endcap TOF

- Endcap TOF supported by common structure supporting barrel TOF system
- Under study: Integration & access to tracking volume eased if endcap TOF moved in front of dRICH



Forward TOF:



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

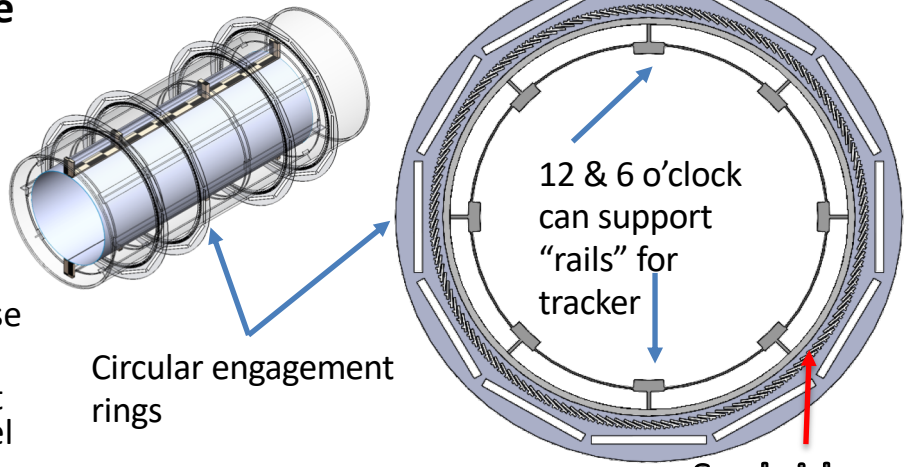
- "Clam shells" or DEEs
  - Convenient for installation/maintenance
  - Each is patched by TOF modules (one or more types) on both faces
  - No backward TOF

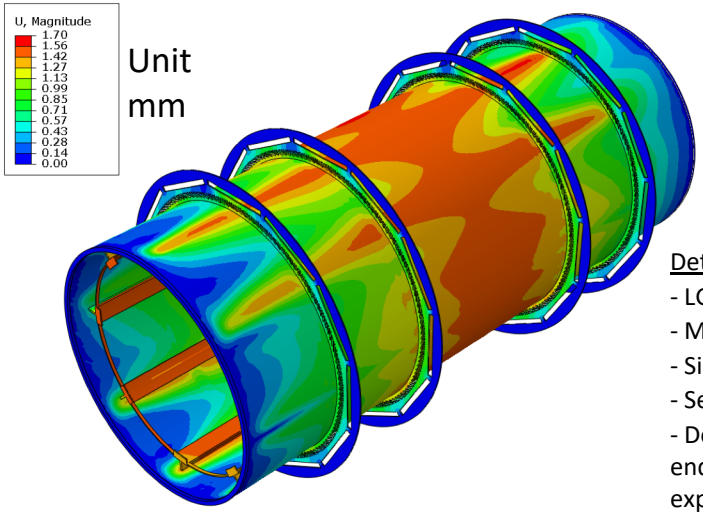
Power Budget

	Endcap TOF [kW]
Sensors	0.6
ASIC	8.5
DC-DC	3.5
lpGBT, VTRx+, SCA	0.5
Power cables	0.5
Total	13.6

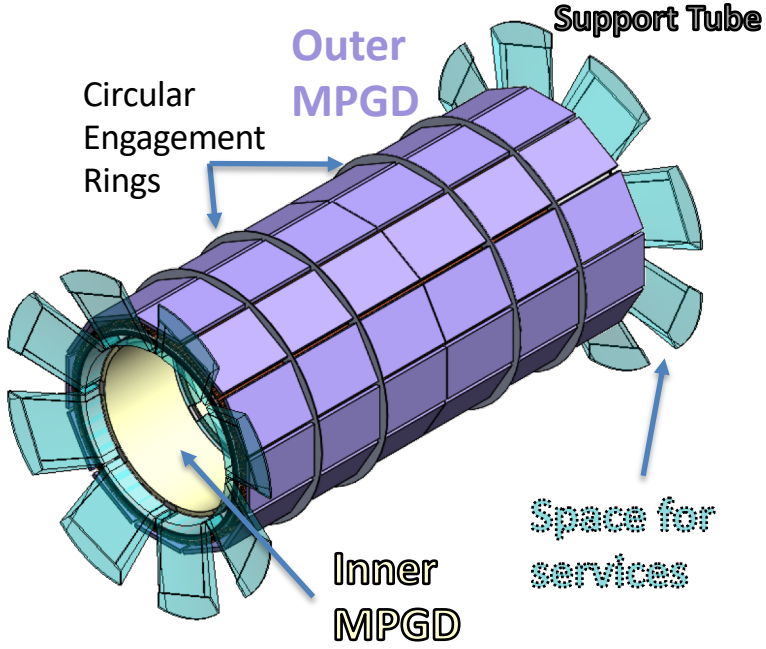
Support structure for barrel TOF

- **Concept idea of joined mechanics structure for barrel TOF, inner & outer MPGD layers, services, and even tracker**
  - 1+8+1 mm sandwich composite structure w "end-rings" to support beam pipe during installation & integration
- Integration
  - Move/Place end cap TOF closer to dRICH to ease access to inner tracking volume
  - "Rail" system (internal and external) to support half-cylinders for tracker installation after barrel TOF system is in place
- First preliminary FEAs for this design
  - 1.7mm deflection and weak regions at engagement rings – needs to be optimized!



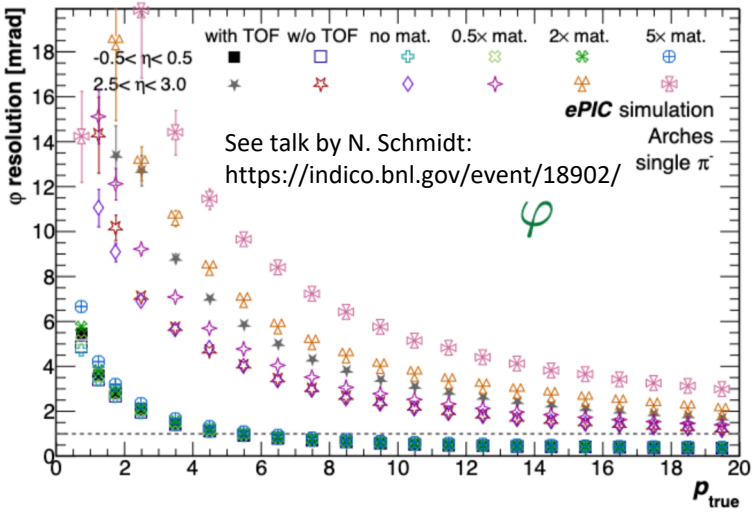


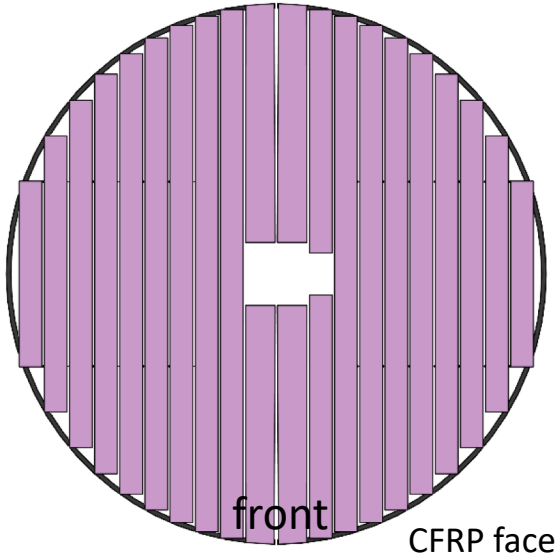
Details:
- LGADs = 70 kg
- MPGDs = 24 + 24 kg
- Silicone tracker = 10 kg
- Services (smeared) = 100 kg
- Designed engagement rings, end rings following CMS experience at Purdue

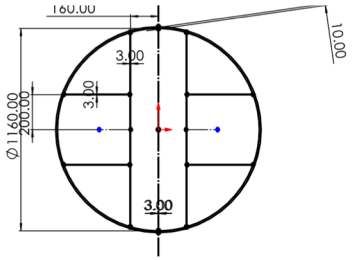


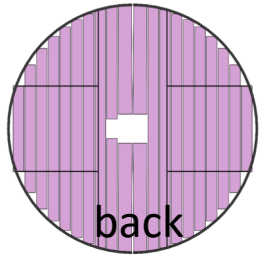
Endcap TOF

- Material budget critical for performance of dRICH
  - Heat load: 13.6 kW (Aim for 1mW / channel)
  - 5% material budget and possible to reduce to 2.5% w advanced composites
  - Detailed X_0 studies under way
- Following two design choices
  - More “traditional” composite structure with sandwich + metal thin pipes
    - Re-use “staves” or wedges
  - Cutting-edge: “no-pipe” design

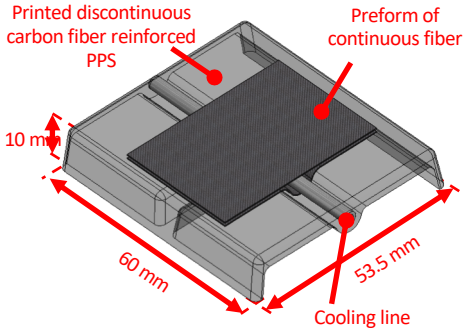


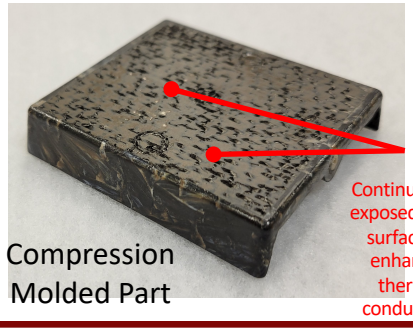






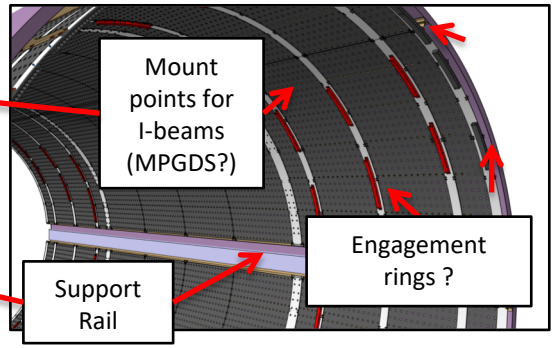
CFRP face sheets and integrated cooling stave structure



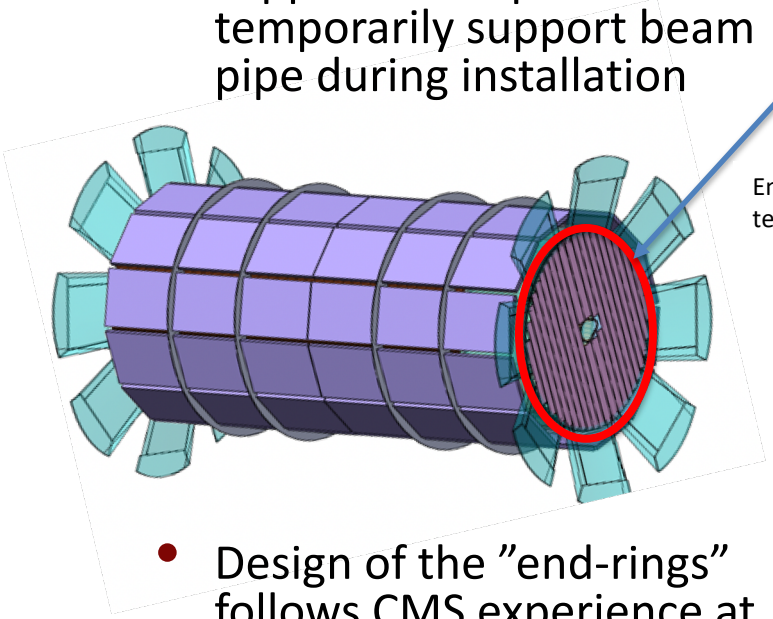


Support “super” structure

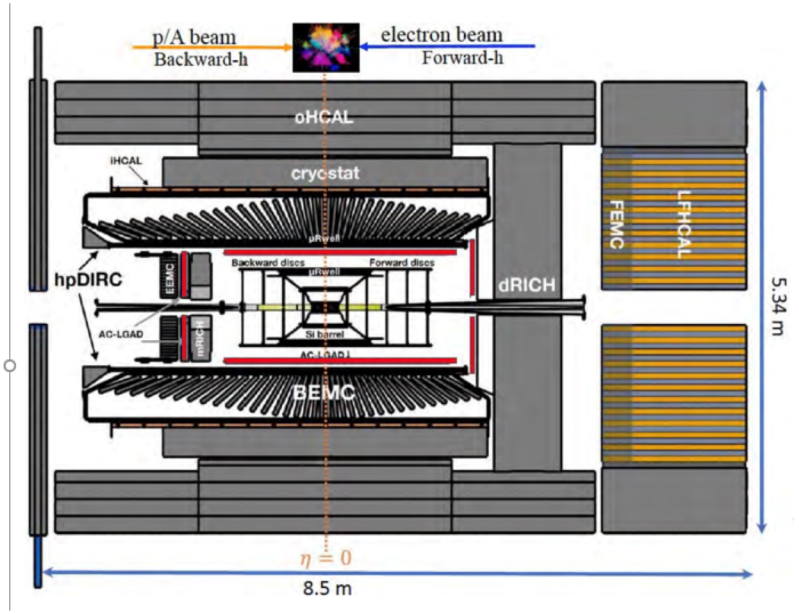
- Barrel TOF support structure allows for support of endcap TOP
  - Design for “end-rings” to support endcap TOF and temporarily support beam pipe during installation



End ring structure on either ends to temp. support beam pipe and endcap



  - Design of the ”end-rings” follows CMS experience at Purdue
  - Many options for synergies & material budget optimization



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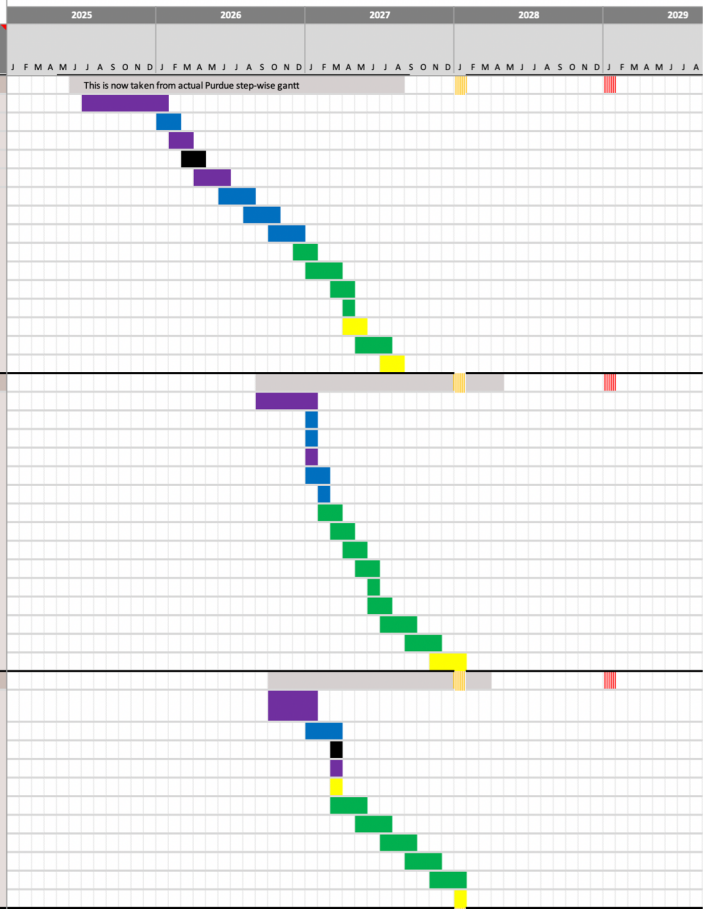
Beyond PED – Construction

Comments

- TOF support + interfaces with Purdue
- Staves & endcap joined Purdue + NCKU
- Start 01/26 and mid July for pre-production, can also start earlier
  - All done by 01/29
- PED request work to start when funds come in, realistic Oct 23 ?
- R&D work continues on the low x_0 supports through 2024

Purdue Mechanics activities
Purdue University
Andreas Jung

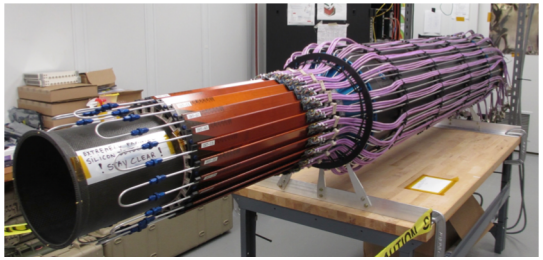
TASK DESCRIPTION	Milestone	EARLY DELIVERY (BNL)	LATE DELIVERY (BNL)	PLAN START	DURATION	PLAN END	TYPE
TOF LGAD support + interfaces (for now assume half cylinders)		**1/1/28**	**1/1/29**	7/5/25	25.5	8/5/27	
Pre-production & Prototype, earliest for final parts of supports available				7/5/25	6.0	1/5/26	P
Finalize BCs, Loads, design				1/5/26	1.0	2/5/26	B
Sched. CNC Time				2/5/26	1.0	3/5/26	P
Purchase Consumables				3/5/26	1.0	4/5/26	X
Practice Layup				4/5/26	2.0	6/5/26	P
Final prototype, final design for insertion tests				6/5/26	2.0	8/5/26	B
Final Manufacturing FEA				8/5/26	2.0	10/5/26	B
Final adjustments to manufacturing				10/5/26	2.0	12/5/26	B
3D print sub-parts				12/5/26	1.0	1/5/27	G
Tool Preparation & Machining				1/5/27	2.0	3/5/27	G
Half-cylinder layup				3/5/27	1.0	4/5/27	G
Cylinder Assembly				4/5/27	0.5	4/5/27	G
QA/QC + loading				4/5/27	1.0	5/5/27	Y
Half-cylinder layup & Assembly				5/5/27	2.0	7/5/27	G
QA/QC + loading				7/5/27	1.0	8/5/27	Y
TOF LGAD endcap (for now standard sandwich structure)		**1/1/28**	**1/1/29**	9/3/26	19.0	4/3/28	
Finalize loads/BCs				9/3/26	4.0	1/3/27	P
Current Design Review				1/3/27	0.5	1/3/27	B
Final FEA & Coolant pipe layout				1/3/27	0.5	1/3/27	B
Tool Preparation & Machining				1/3/27	0.5	1/3/27	P
Practice Layup				1/3/27	1.0	2/3/27	B
Final Manufacturing FEA				2/3/27	0.5	2/3/27	B
3D print sub-parts				2/3/27	1.0	3/3/27	G
Final adjustments to manufacturing				3/3/27	1.0	4/3/27	G
First wedge layup				4/3/27	1.0	5/3/27	G
First wedge part prep				5/3/27	1.0	6/3/27	G
Tool Preparation & Machining				6/3/27	0.5	6/3/27	G
Remaining wedges layup				6/3/27	1.0	7/3/27	G
Remaining wedges				7/3/27	2.0	9/3/27	G
Endcap assembly				9/3/27	2.0	11/3/27	G
QA/QC + loading				11/3/27	2.0	1/3/28	Y
TOF LGAD staves (cost savings via NCKU machine shop possible)		**1/1/28**	**1/1/29**	10/3/26	17.0	3/3/28	
Pre-production & Prototype, earliest for final stave available				10/3/26	3.0	1/3/27	P
Finalize design & choice				1/3/27	2.0	3/3/27	B
Purchase Consumables				3/3/27	0.5	3/3/27	X
Practice Layup				3/3/27	0.5	3/3/27	P
QA/QC				3/3/27	0.5	3/3/27	Y
Layups 1 to 72				3/3/27	2.0	5/3/27	G
Layups 72 to 144				5/3/27	2.0	7/3/27	G
Layups > 144 (spares)				7/3/27	2.0	9/3/27	G
Pipe preparation				9/3/27	2.0	11/3/27	G
Assembly/Gluing				11/3/27	2.0	1/3/28	G
QA/QC				1/3/28	0.8	1/3/28	Y

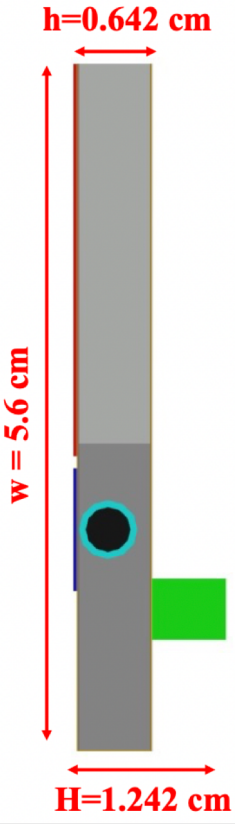


Backups

Barrel TOF

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





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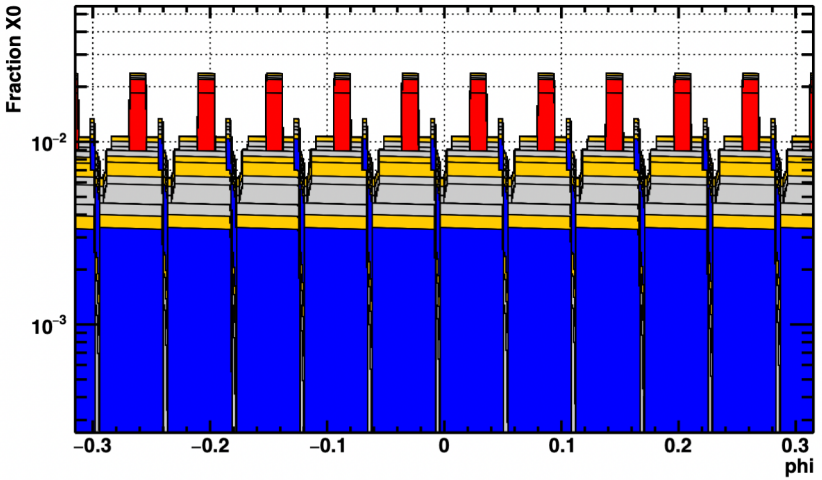
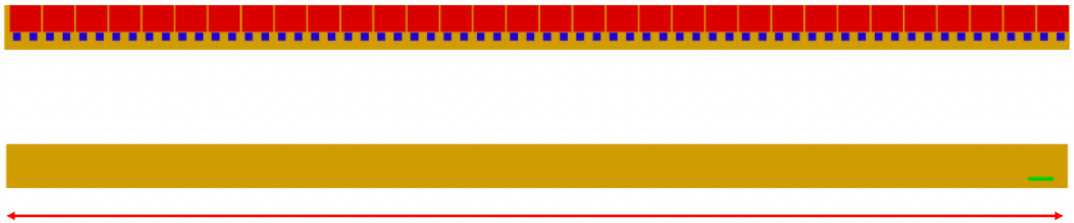
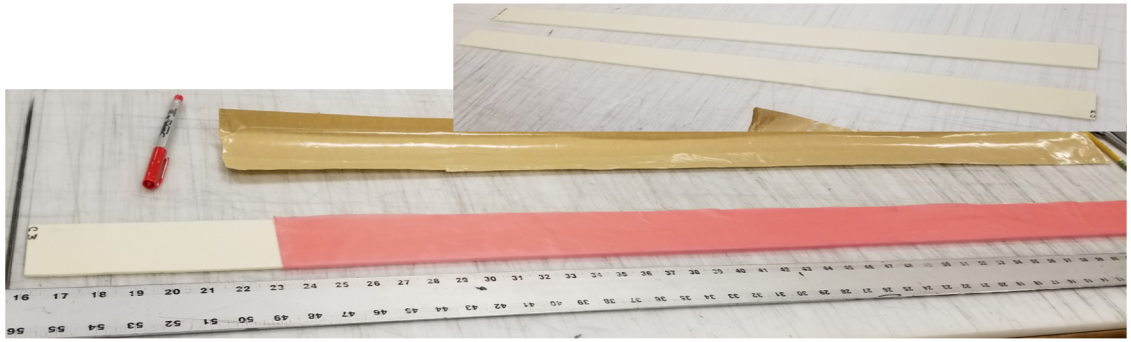




From Zhenyu's talk
https://indico.bnl.gov/event/16765/

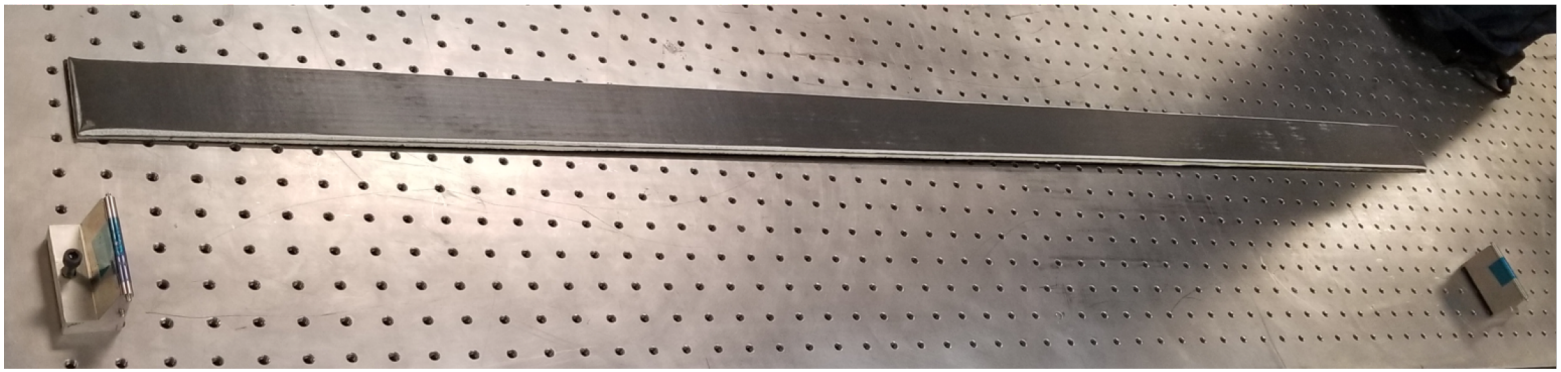
R&D progress FY23

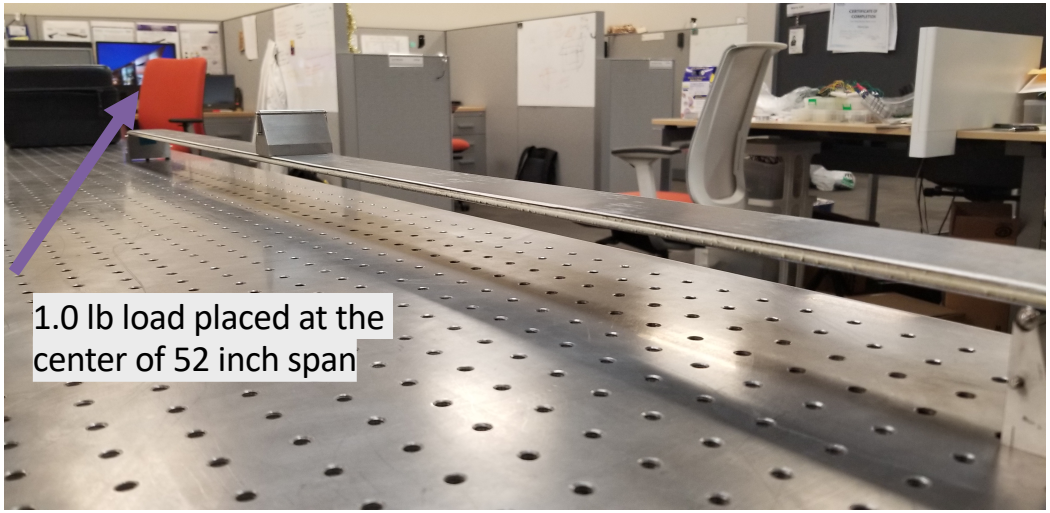
- **First limited activities started…**
- CAD model based on the STAR IST staves
- Dimensions as follows – total thickness is 6.9 mm (0.2 mm facesheet [0/90/0] + 3.25 mm foam + 3.25 mm foam + 0.2 mm facesheet [0/90/0])
- Foam material used – Airex 82.80
- Face sheet – Rockwest EHM32 / T700 – 250 F cure – UD prepreg – layup [0/90/0]

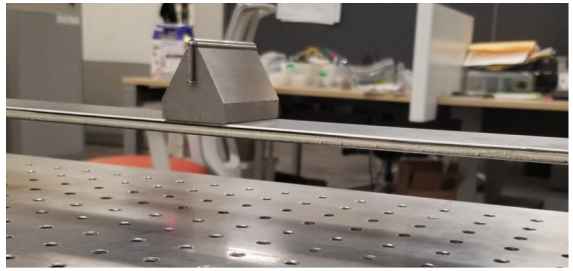


R&D progress FY23

- **Loading test w 1lb load in the center….**



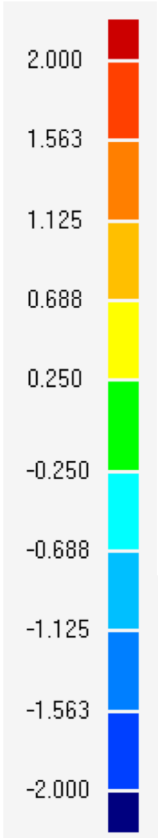




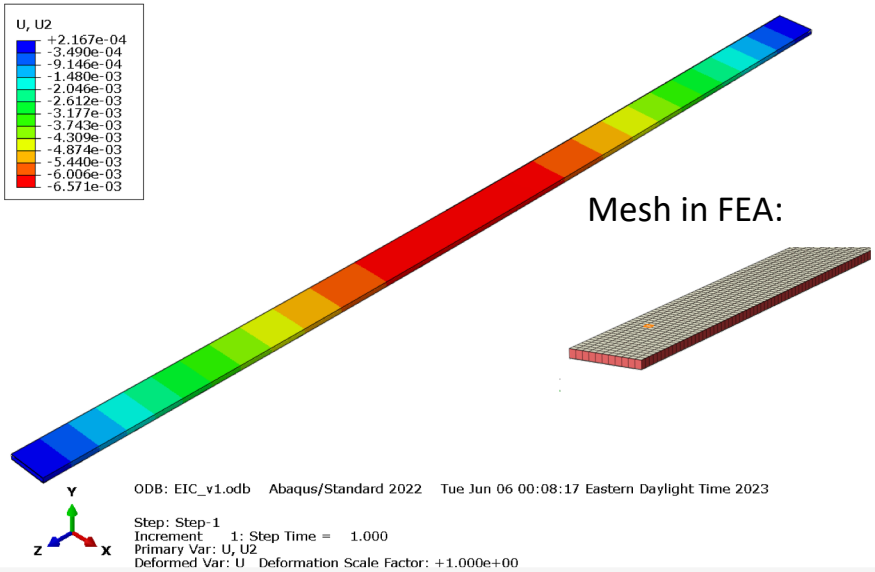
R&D progress FY23

FEA results…preliminary

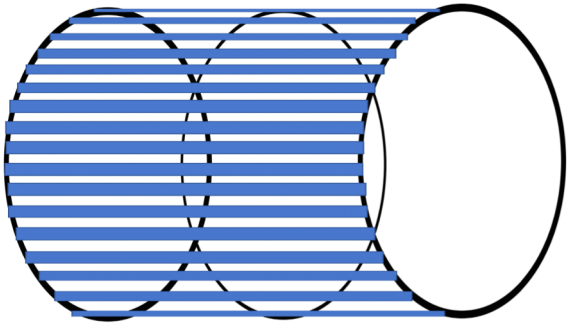
- FARO is at 6mm deflection, FEA at 2mm (longer worse, ~5cm)
  - Caveat: no pipe in it…not enough time.
- Calls for support structure which is to come – see here:

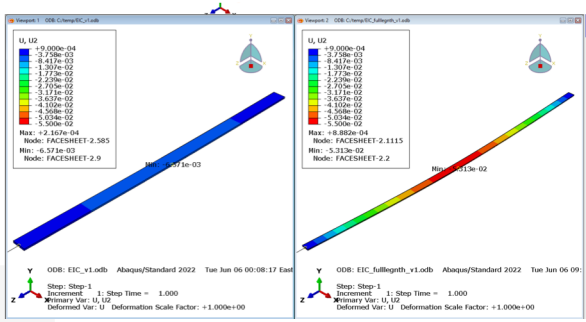


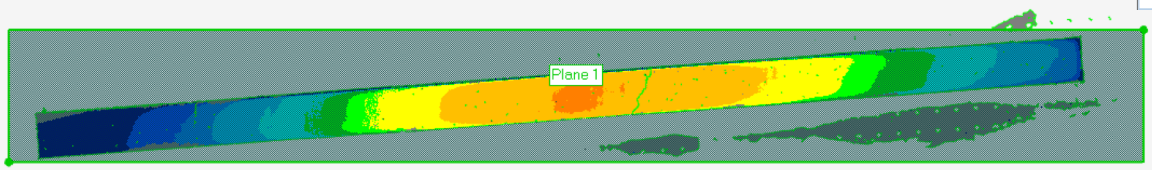
Unit: mm



Mesh in FEA:

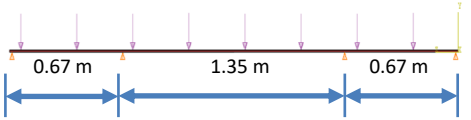






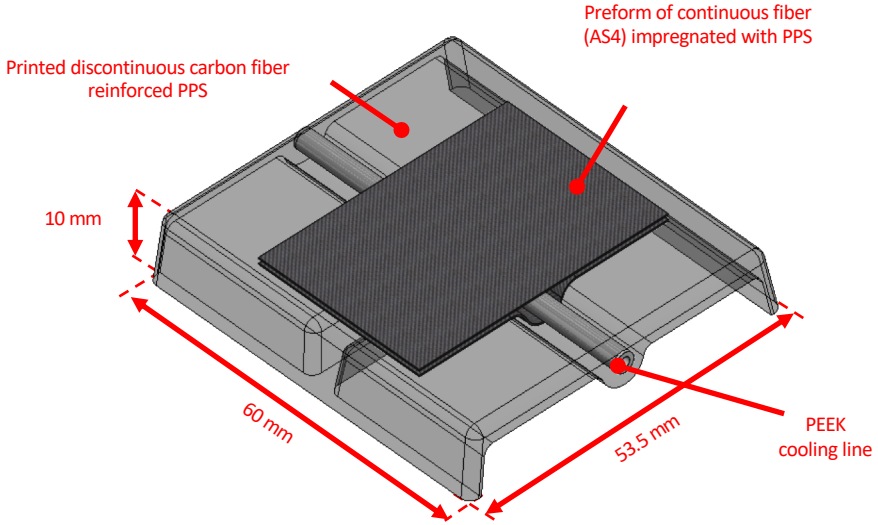
Top down view of the loaded stave.

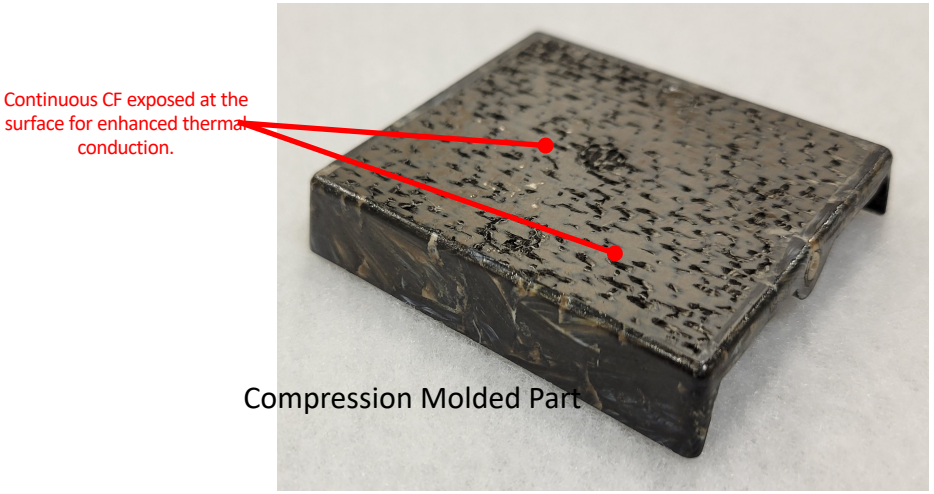
- 5cm deflection full length stave
- w. supports down to 700mu



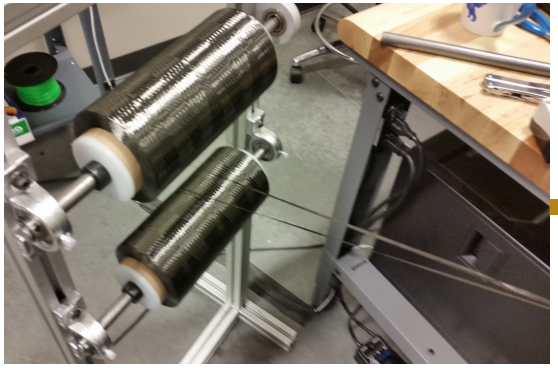
BlueSky R&D at Purdue

- Could be applicable to EIC – recent progress…

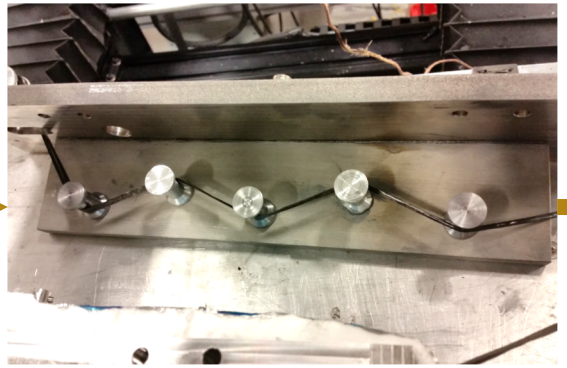




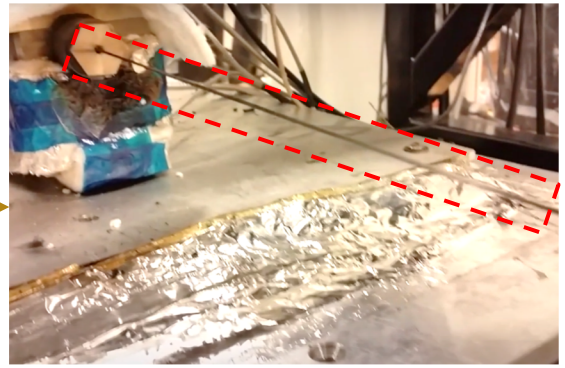
Compression Molded Part



Spools of Carbon Fiber



Interior of Impregnation Chamber

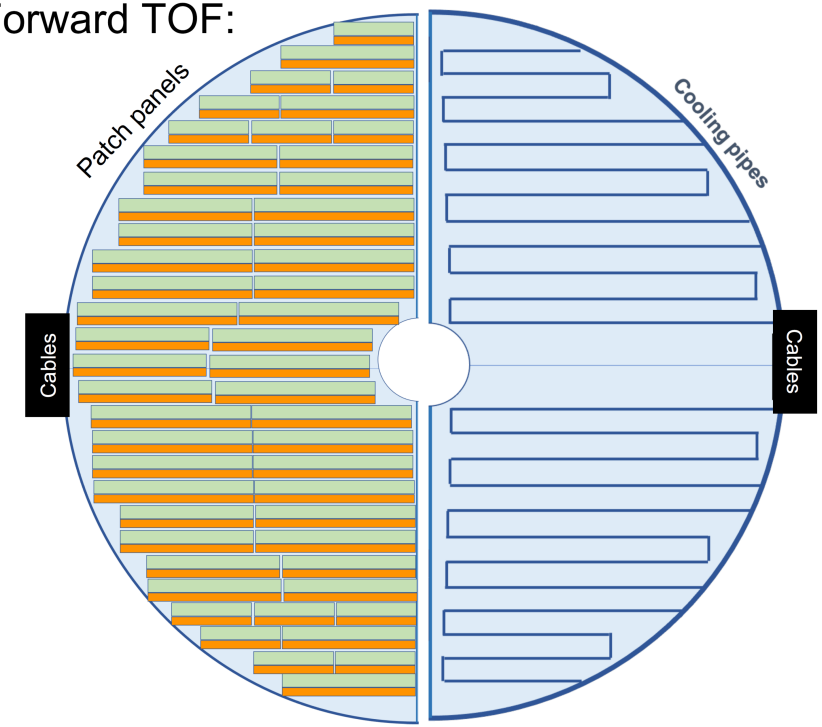


Carbon Fiber Impregnated with PPS

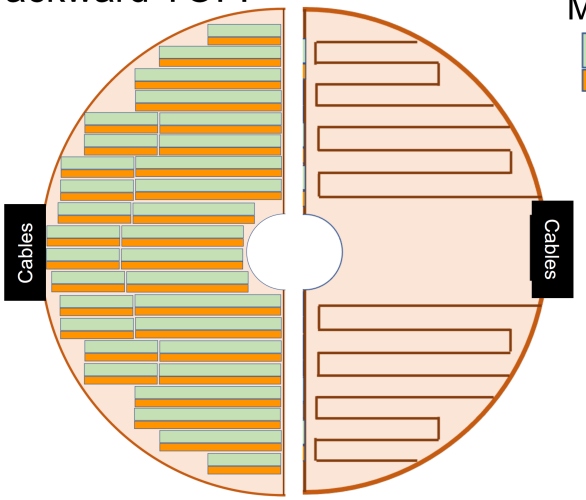
Endcap TOF

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

Forward TOF:



Backward TOF:



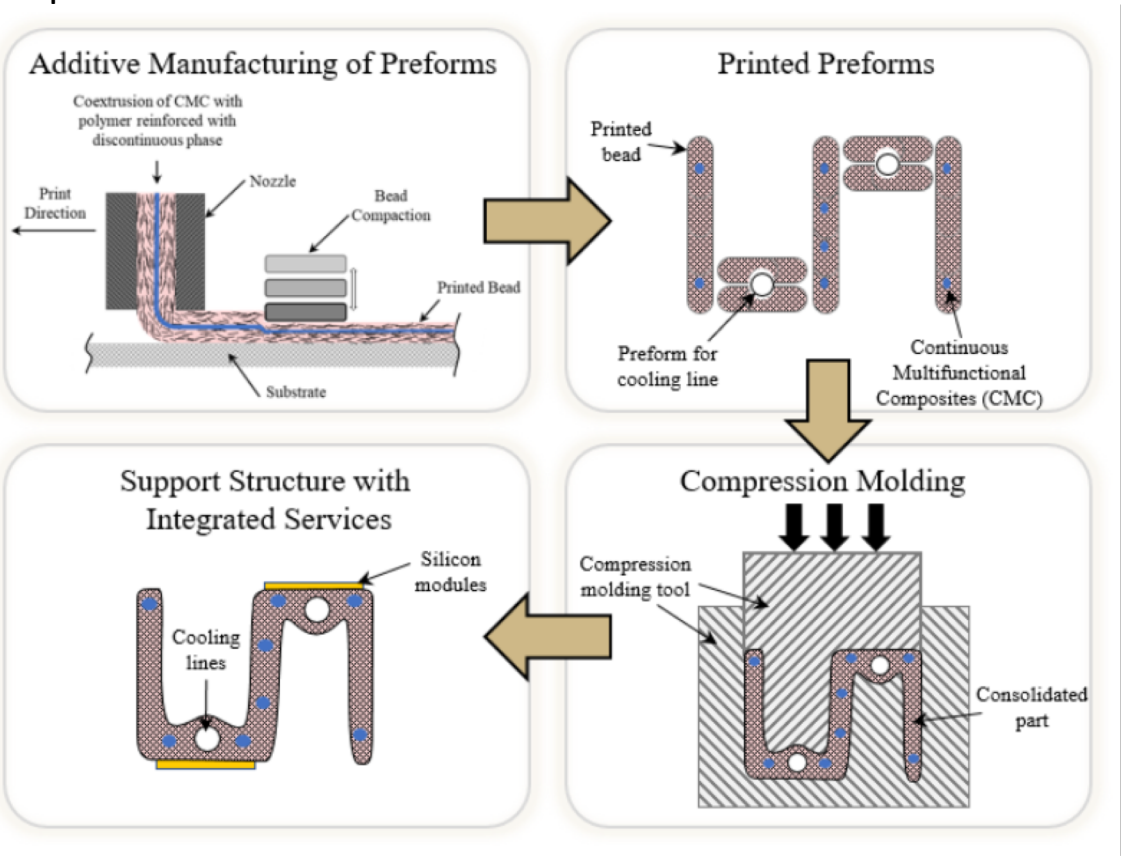
- "Clam shells" or DEEs
  - Convenient for installation/maintaenance
  - Each is patched by TOF modules (one or more types) on both faces

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)

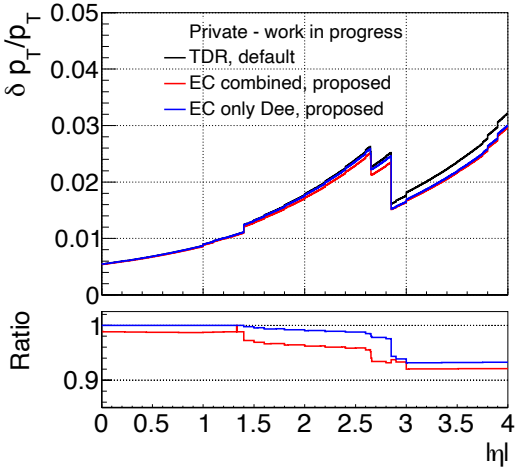
R&D for irreducible sturctres…

- Identified by DOE BRN effort
  - 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 to DOE:

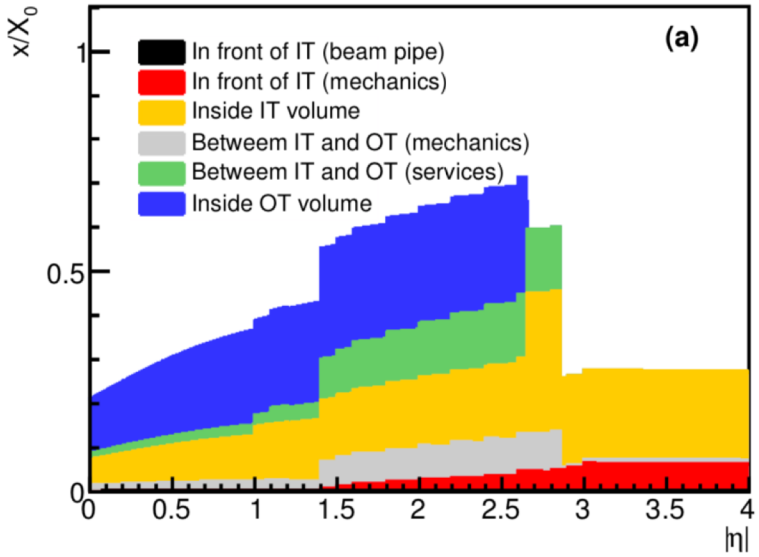


BlueSky R&D at Purdue

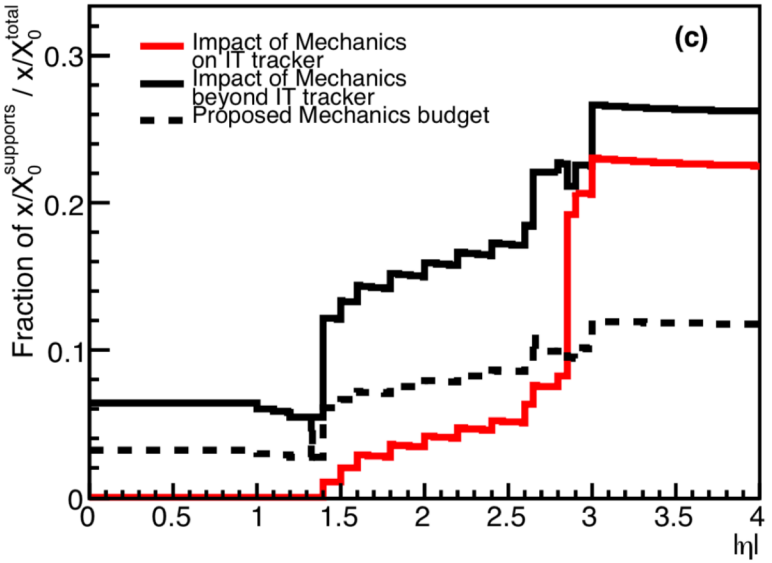
- Radiation length plot more specific to EIC (hope to get that one done till 6th)
- These techniques more easy benefit endcap detectors whereas gains are limited in barrel region
- This seems like a good fit to the needs of TOF



Example from CMS….



Aggressive design…



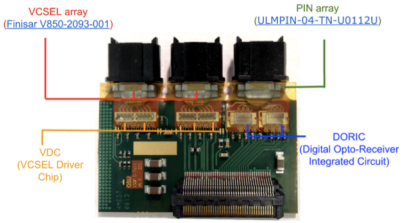
About Andreas Jung

Purdue University

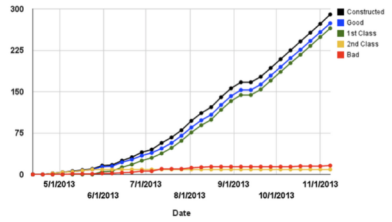
- Andreas Jung, previous experience
  - CMS IT mechanics convener (2017-2020)
    - Leading the Barrel, Forward and Extended Pixel projects
  - Mechanics leadership in CMS
    - Technical lead for the CMS BTST project, Contact for procuring all high thermal conductive CF needs in CMS and leading the related R&D at Purdue
    - Coordinating tracker mechanics projects (ITST, SC, OT, BTST) at Purdue.
  - Associated member of the Composite Manufacturing & Simulation Center at Purdue University
  - DOE Blue Sky R&D grant for irreducible tracker support structures for detectors at future colliders (FCC, ILC, muon, etc.)
  - Operation & Optimization of track trigger at H1 (HERA), and operation of silicon tracker at D0 (Tevatron)

About Yi Yang

- **2012 – 2014 (@OSU)**: Project manager for the Opto-board for inner detector

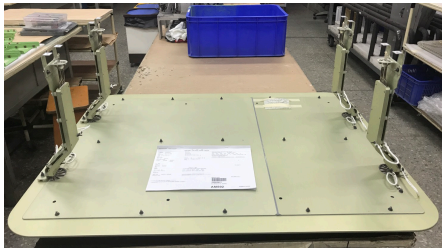


Photograph of an opto-board

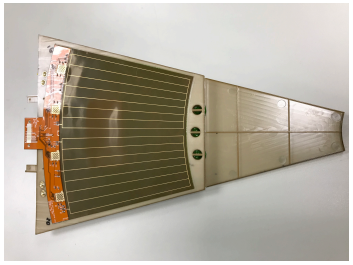


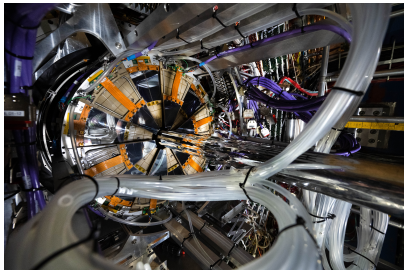
Opto-board production status

- **2015 – 2018 (@NCKU):** Project leader for the AMS-02 UTTPS radiator



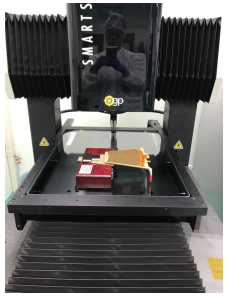
- **2018 – 2021 (@NCKU):** Deputy manager for the STAR FST, project leader for the mechanical structure for FST

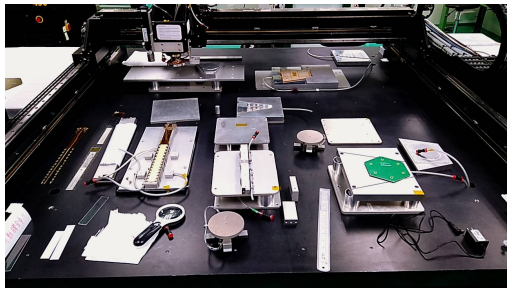
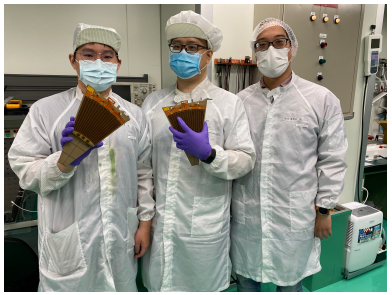




Resource from Taiwan

- **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 Aerospace Industrial Development Corporation (expert on composite material)
- **AS IoP:**
  - High precision machine shop


AIDC

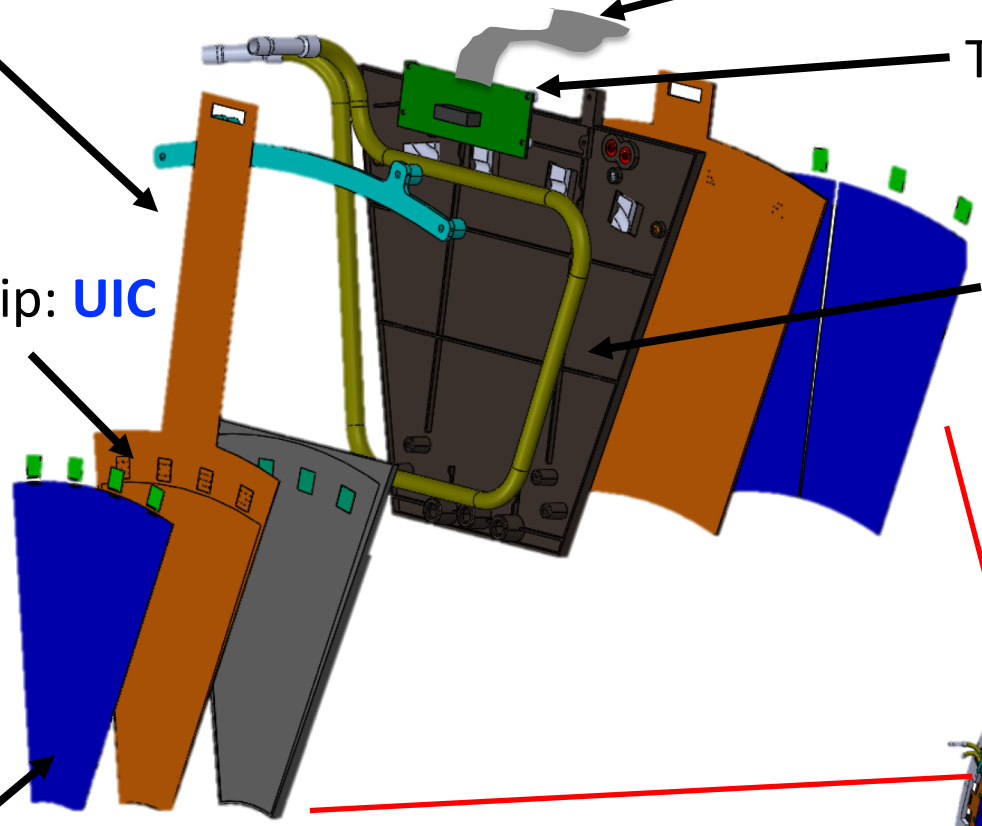
- **Three mechanical engineers from AS, NCKU and TIDC**

STAR Forward Silicon Tracker

Flexible hybrid PCB: **SDU/IU**

Inner Signal Cable: **BNL/IU**

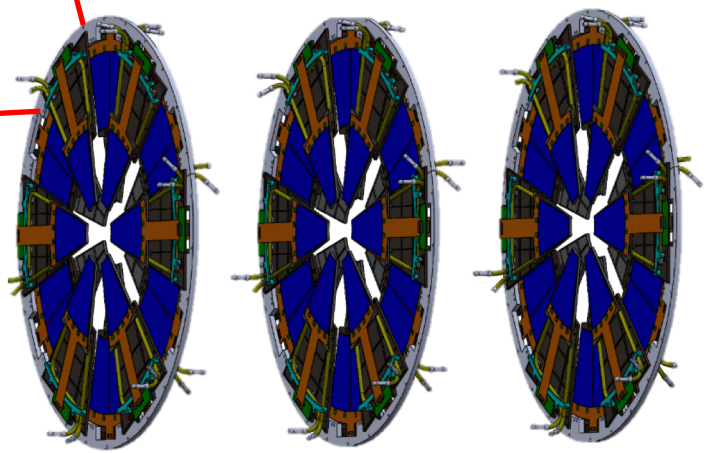
T-Board: **SDU/IU**



APV25 Chip: **UIC**

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

Supporting Structure &
Integration: **BNL**



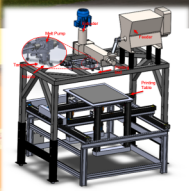
Silicon sensor: **UIC/BNL**

Cooling: **BNL/NCKU**

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

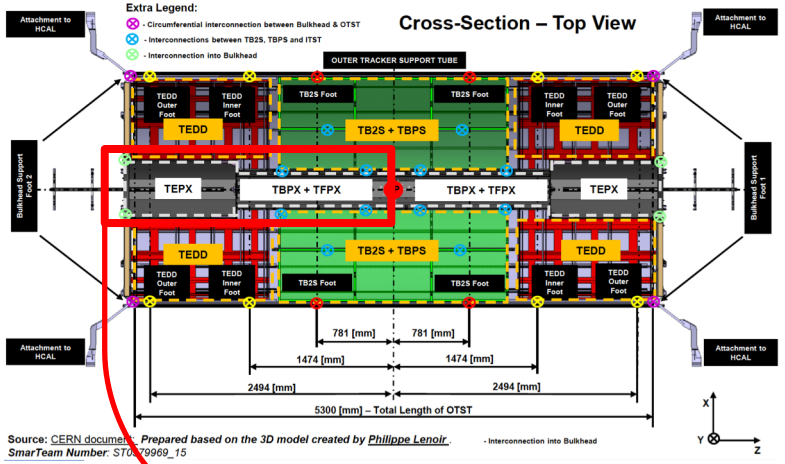
Resources from Purdue

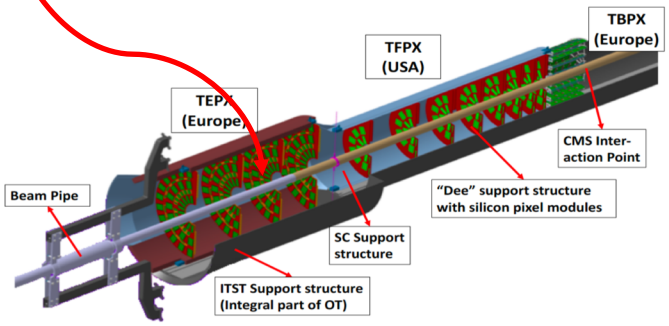
- Composite Manufacturing & Simulation Center (CMSC) at Purdue, completed in summer 2016
  - Purdue Center of Excellence across disciplines: Aeronautics, Chemical Eng, Materials Eng, Aviation Tech, Computer graphics, **and Physics**
  - A. Jung – Associated member of CMSC
- Professional composite experience:
  - 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

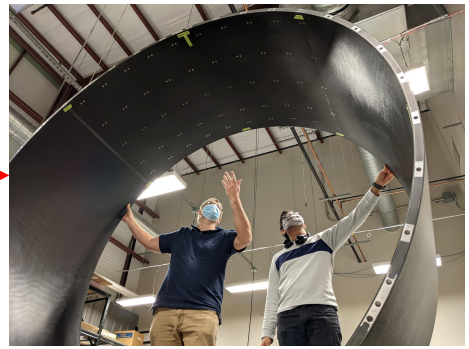


Resources from Purdue

- 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 for the OT modules assembly
  - Barrel Timing Layer Tracker Support Tube
    - Support the entire IT + OT + Timing Layer of CMS

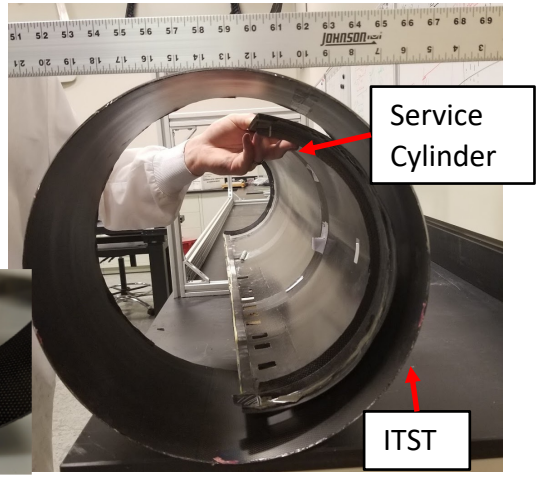


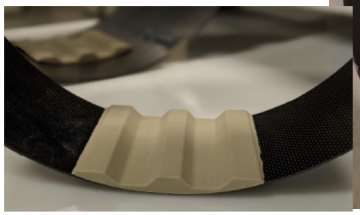


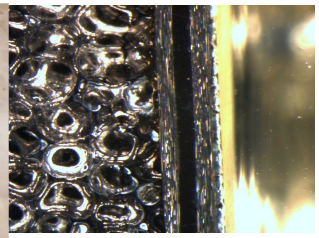


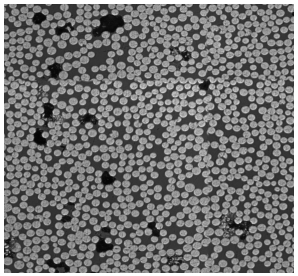
Resources from Purdue

- 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

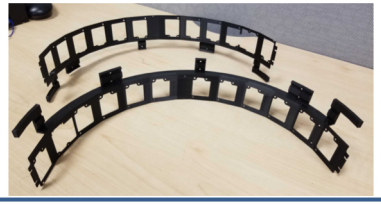


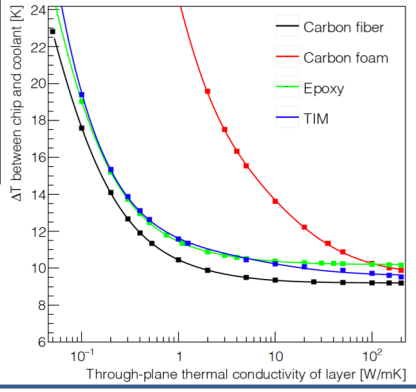


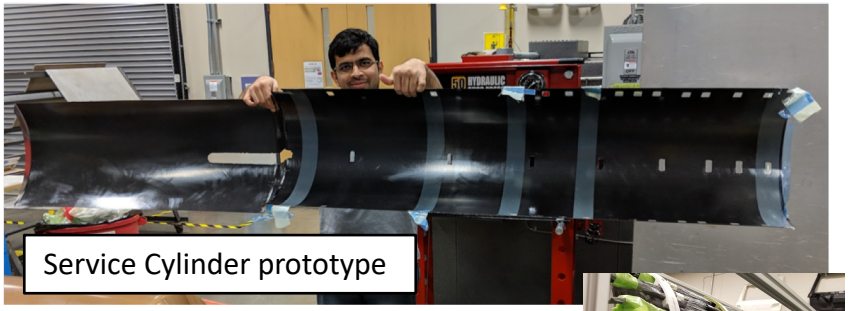


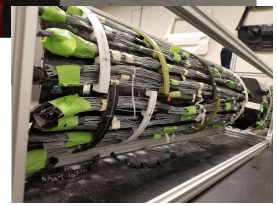


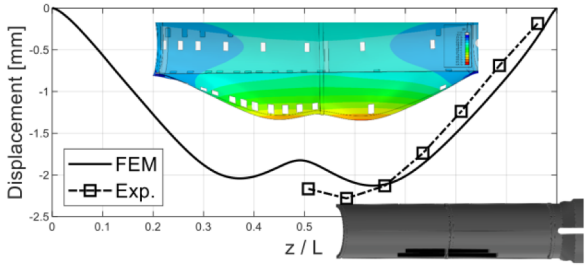
- Forward pixel dee prototype
- Co-cured samples
- Microscopies
- 3D printed mechanical supports
- Critical interfaces via FEA









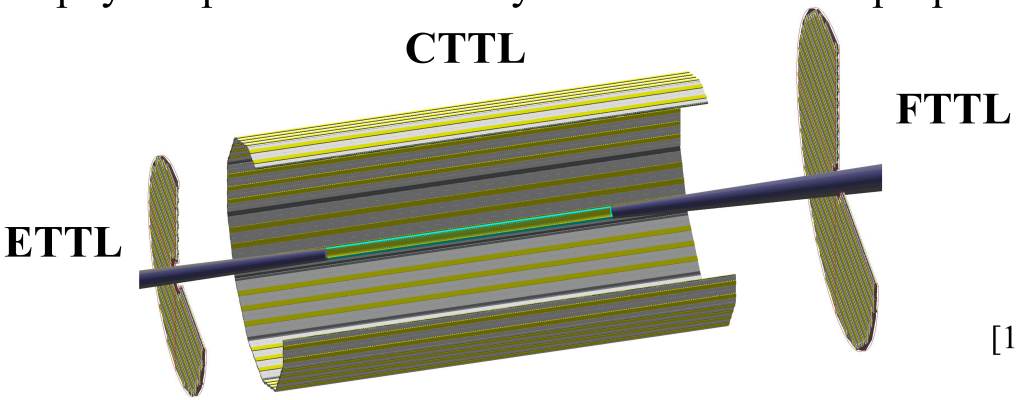


Backups

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 mm² strips**
- **Endcap: 0.5x0.5 mm² pixels (same as RPs) [1]**

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

	acceptance	Z (m)	Radius (m)	Area (m²)	Channel size (mm²)	# 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