Detector mechanics and support structures

- *Activities at HL-LHC*
  - *IT structures*
- *Future requirements*
- *Conclusions*

Andreas Jung

Purdue University

Composites Manufacturing & Simulation Center

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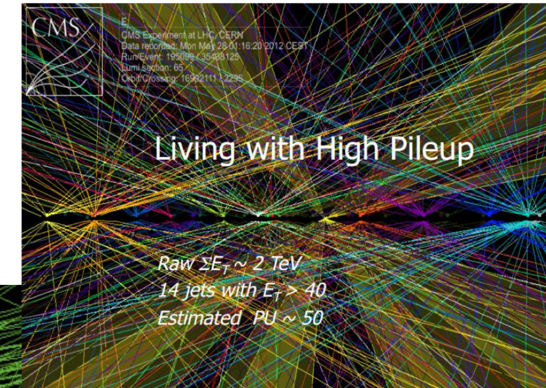
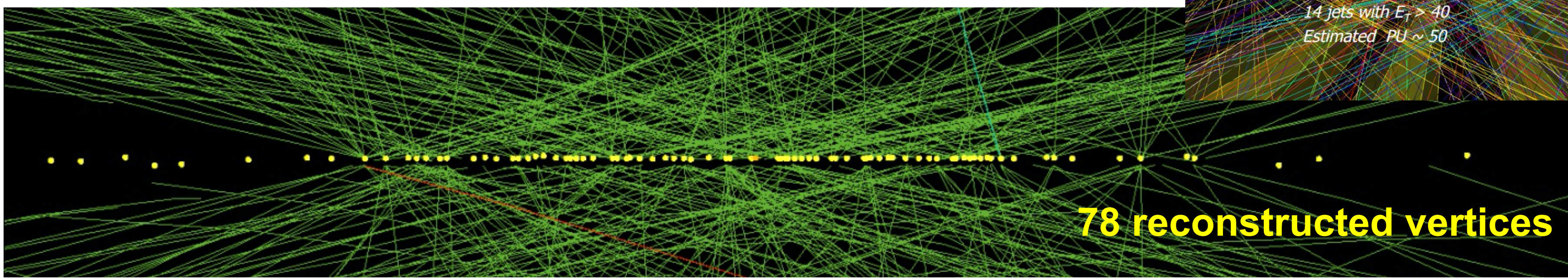
HL-HLC upgrade

High-luminosity phase of the LHC

- Instantaneous luminosities up by factor 5
- Collected data up by factor 10





<u>ATLAS+CMS exposed to significantly higher rates, radiation damage, pile-up</u>

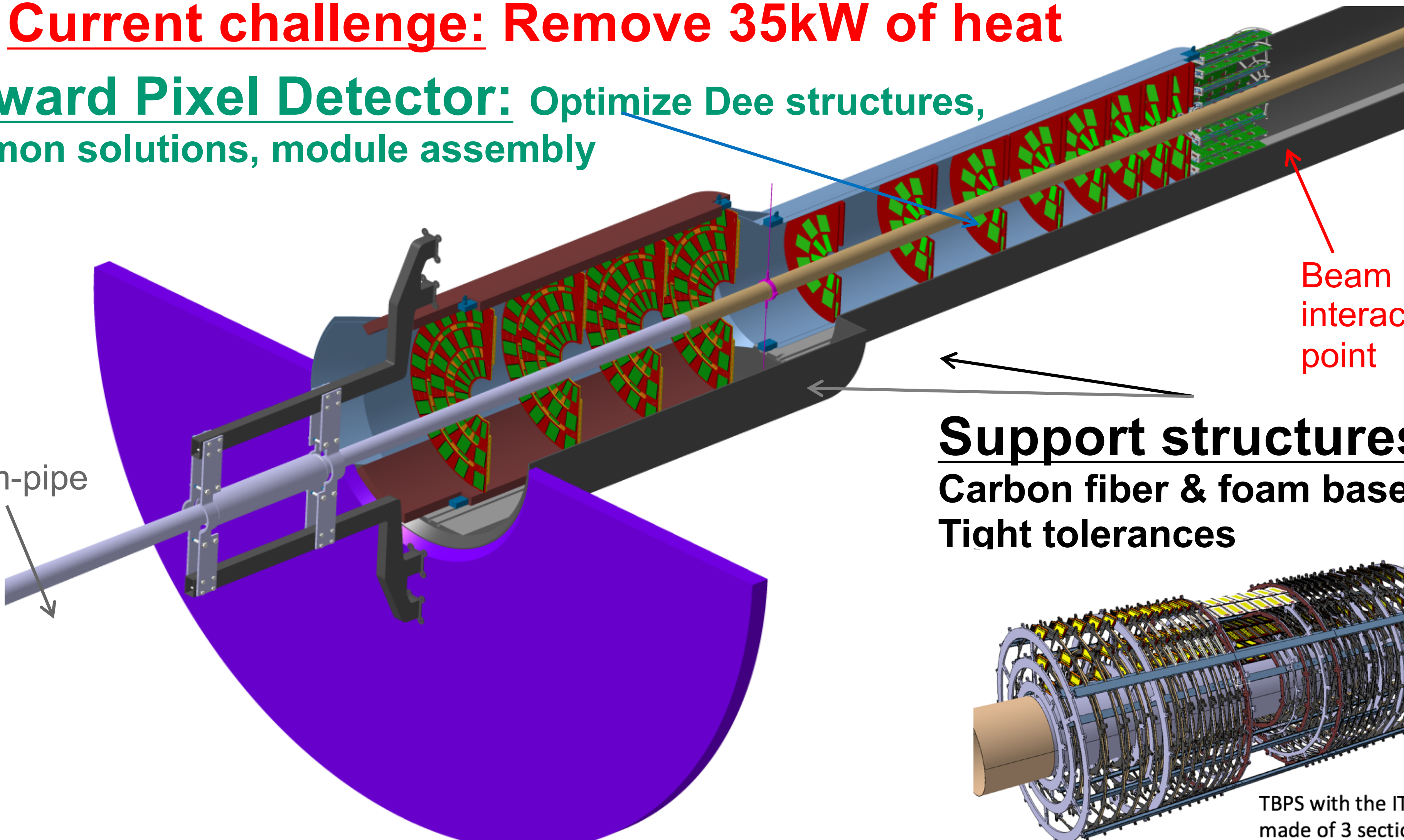
- Tracking information for the trigger system
- Higher granularity of tracking devices (→ more channels)
- Radiation-hard devices
- Reduce amount of “dead” material

The CMS Inner Tracker region

Instrumentation R&D making use of the Purdue Silicon Lab

Current challenge: Remove 35kW of heat

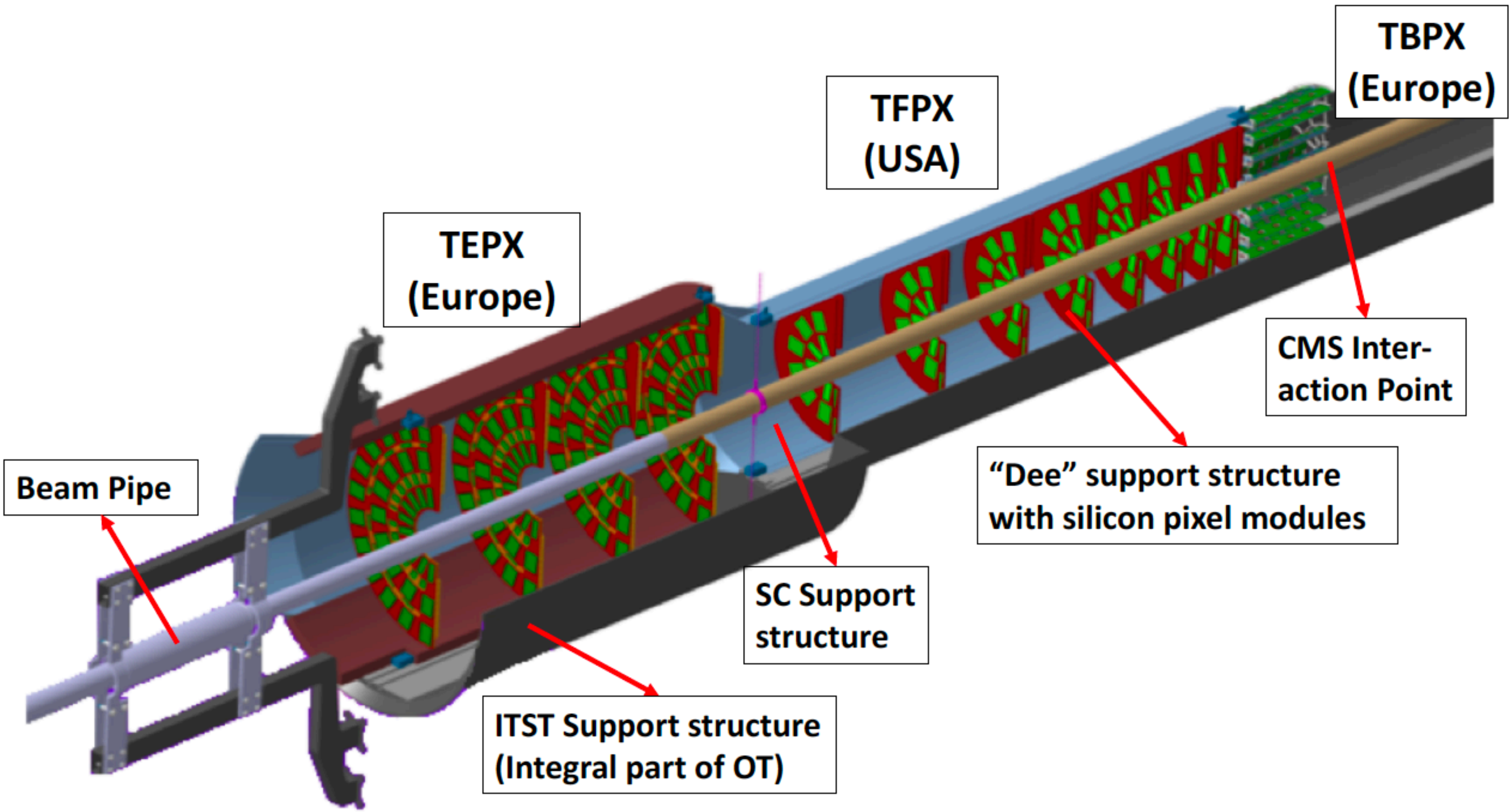
Forward Pixel Detector: **Optimize Dee structures, common solutions, module assembly**



Support structures:
Carbon fiber & foam based, Tight tolerances

TBPS with the ITST made of 3 sections.

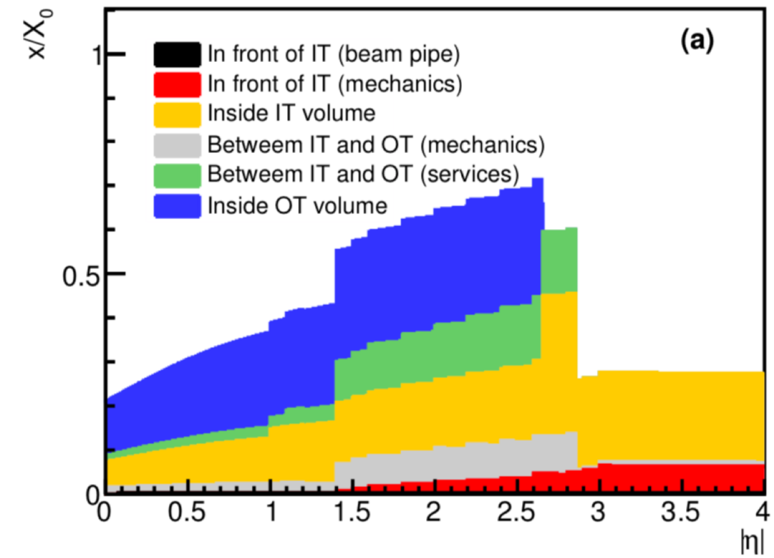
Inner Tracker region



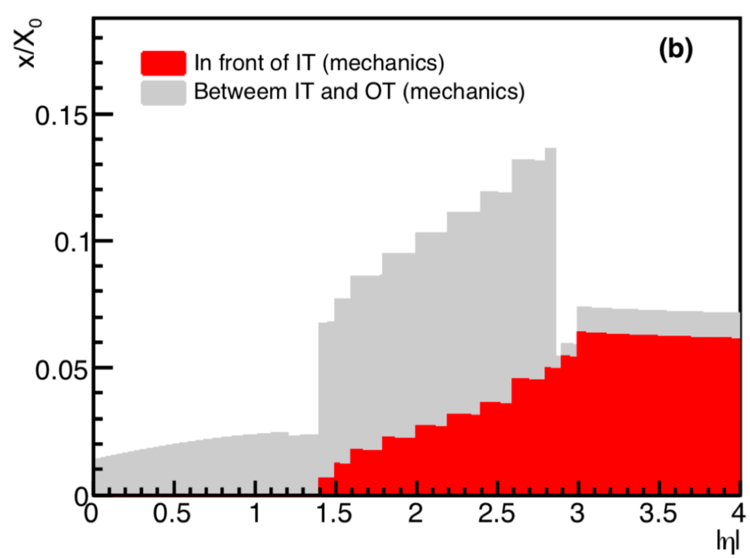
Material budgets & mechanics

Tracker of the HL-LHC is a very significant fraction of the total CMS upgrade budget

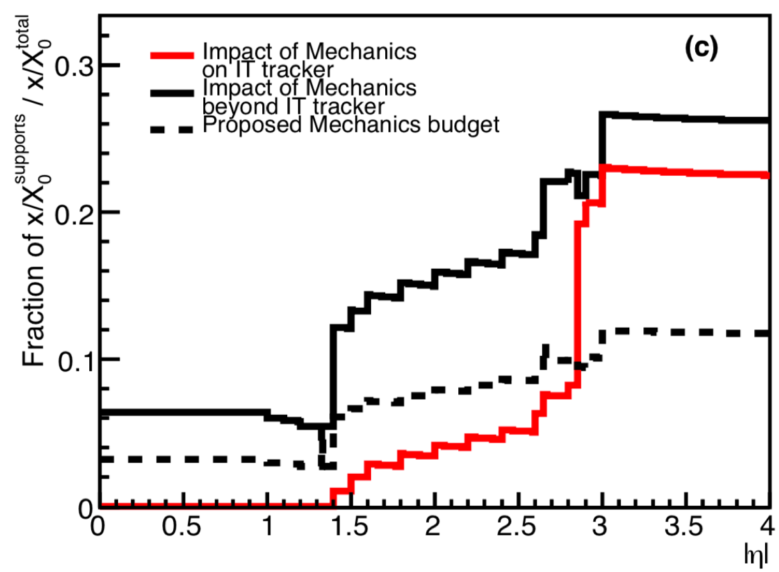
- Support & Cooling is the constrain in which Tracker is operated, e.g. thermal runaway
- Mechanics is significant fraction of the material budget
- The “only” budget that can be optimized
- But requires detailed FEA & mock-up's to understand and verify experimental measurements



Basically Dee's and support tube structures

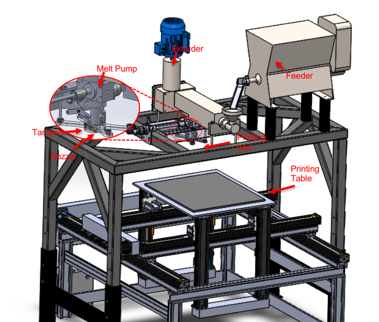


Fraction of mechanics vs entire Detector material



Completed in summer 2016:

- Composite manufacturing & simulation center, CMSC
- Aeronautics, Chemical E, Materials E, Aviation Tech, Computer graphics
- Associated member of CMSC



Main Equipment relevant for the Cylinder effort:

→ 2 large pressurized ovens, 1 larger oven with vacuum hook-ups

→ **Larger ovens accessible** with an industry partner in the area

→ Successful tour after the Mechanics Forum in May by fellow CMS members

Manufacturing techniques

Collaborating with Composite Manufacturing & Simulation Center at Purdue

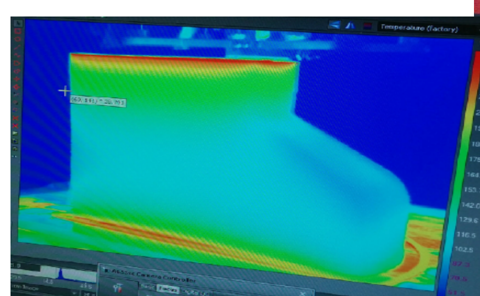
→ Large 3+3m long carbon fiber based support cylinders

→ FEAs to optimize material budget, stiffness, deformation

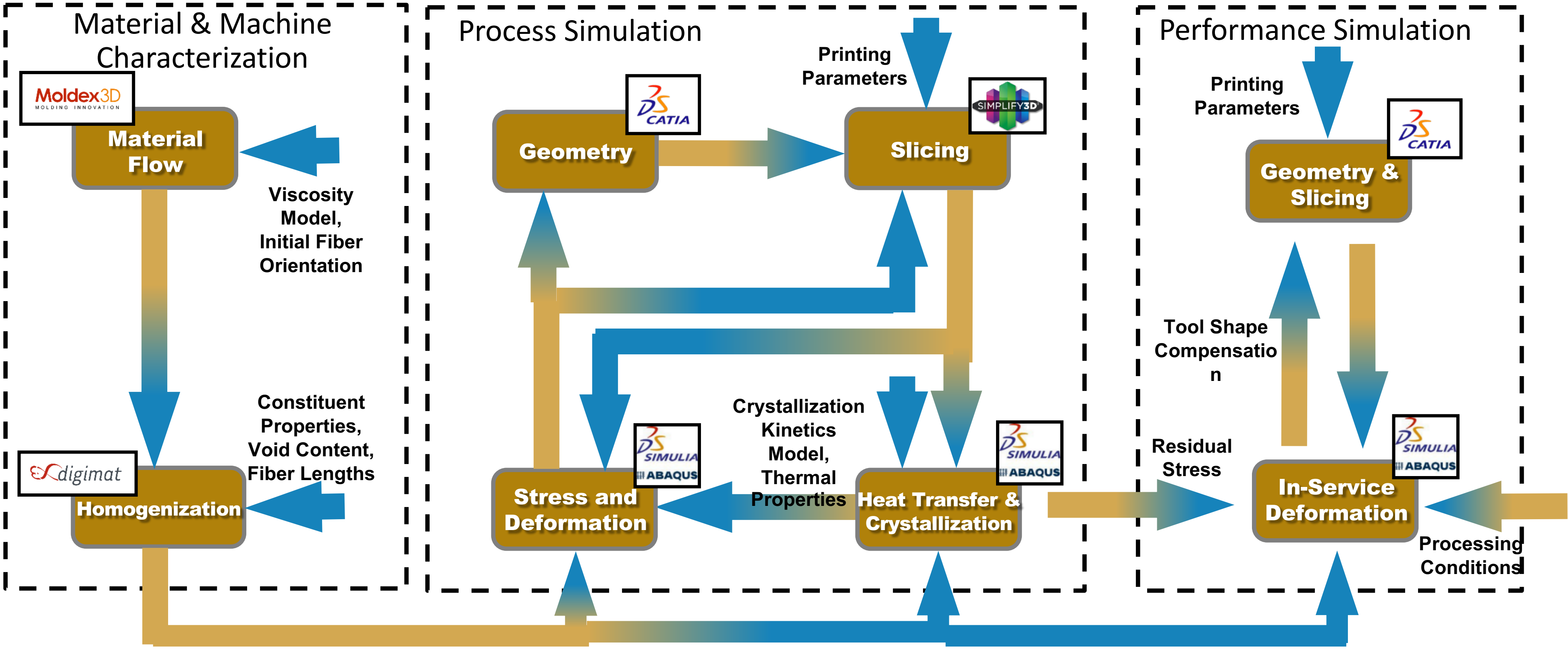
→ Accurate simulation of 3D-printed molds used for layup

→ No CTE miss match between mold and layup Material

→ Higher accuracy



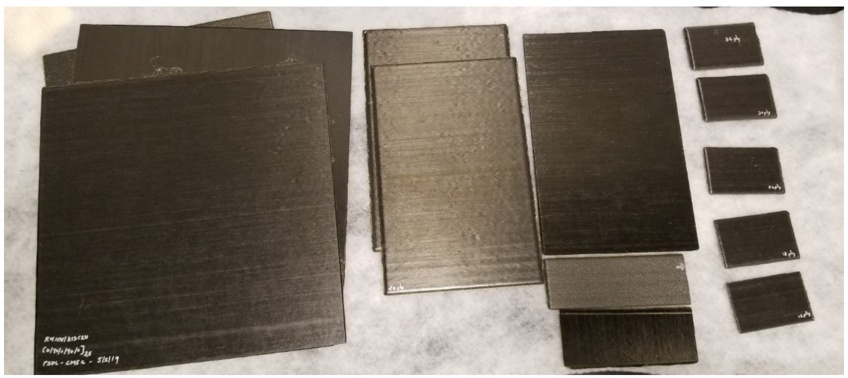
Process and Performance simulation

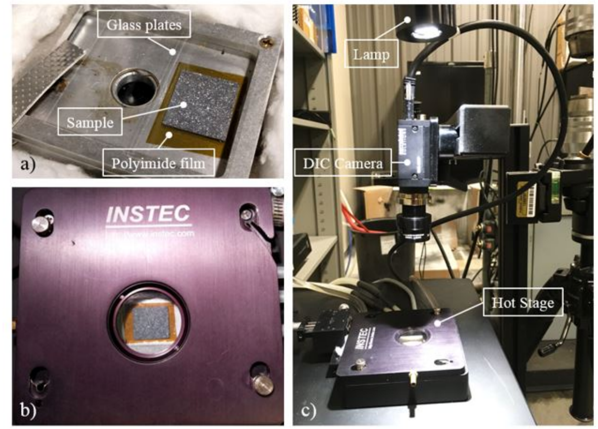


Irradiation studies…

Material Characterization and Irradiation Studies – CTE results for Sylgard and Polyurethane UR6060

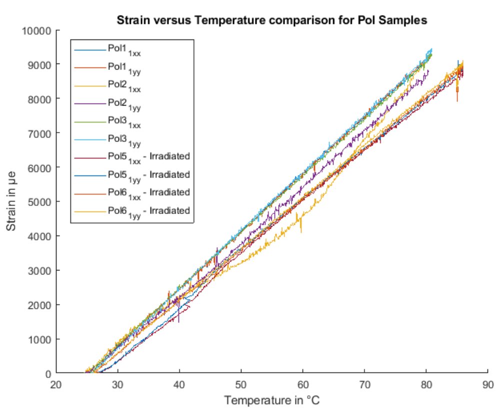
- Characterization Samples prepared for tensile testing, thermal conductivity, delamination testing and coefficient of thermal expansion for studying irradiation effects on RM1515-K13D2U carbon composite pre-preg.

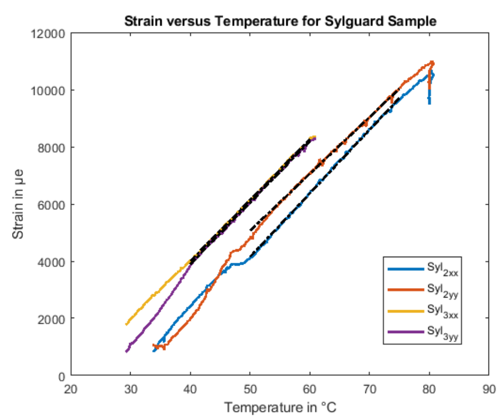


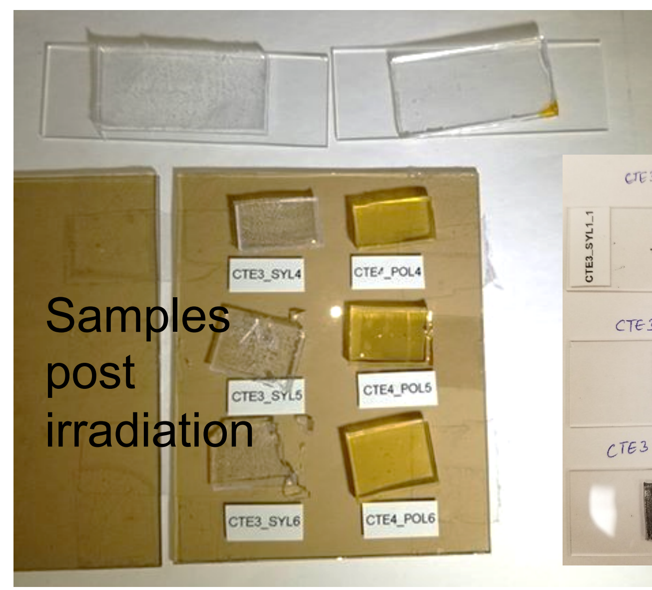


Post irradiation there was no appreciable change in the CTE for polyurethane UR6060 encapsulant. Sylgard turned glassy and brittle and could not be used for experimentation. Detailed report – CMSC-PSDL-Material Characterization Note 4 (06 May 2019)

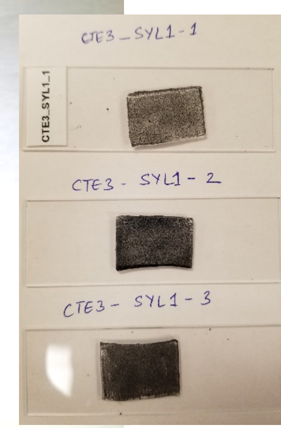
Samples before irradiation







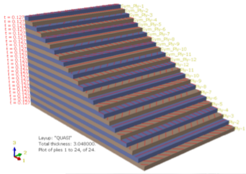
Samples post irradiation

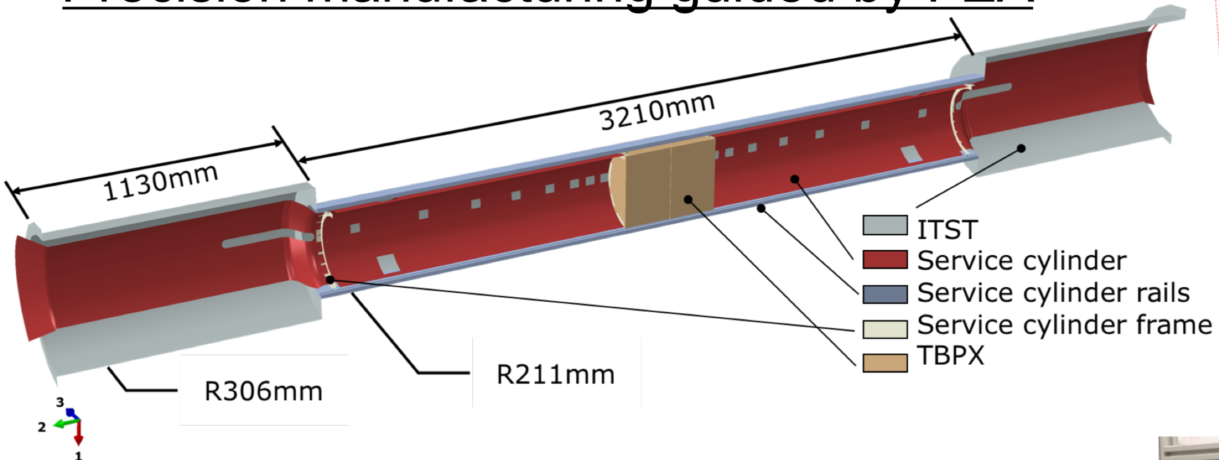


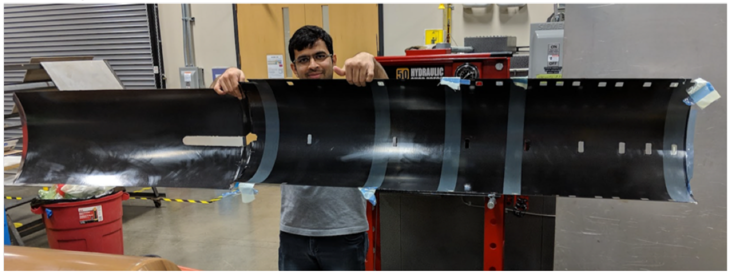
Prototypes

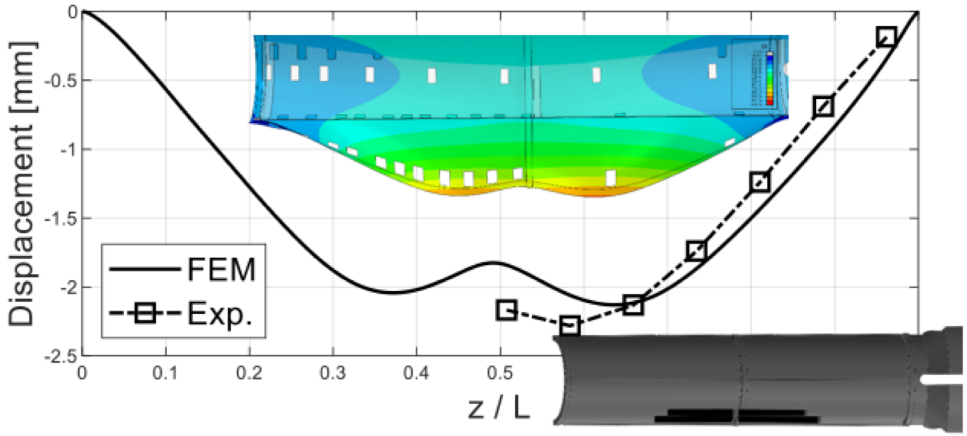
First prototype of the Service Cylinder, **sub-mm tolerances**
- Structure mass is 2.77kg
- Loaded mass is large, shows deflection more easily
- Very good agreement with the FEA

→ <u>Precision manufacturing guided by FEA</u>



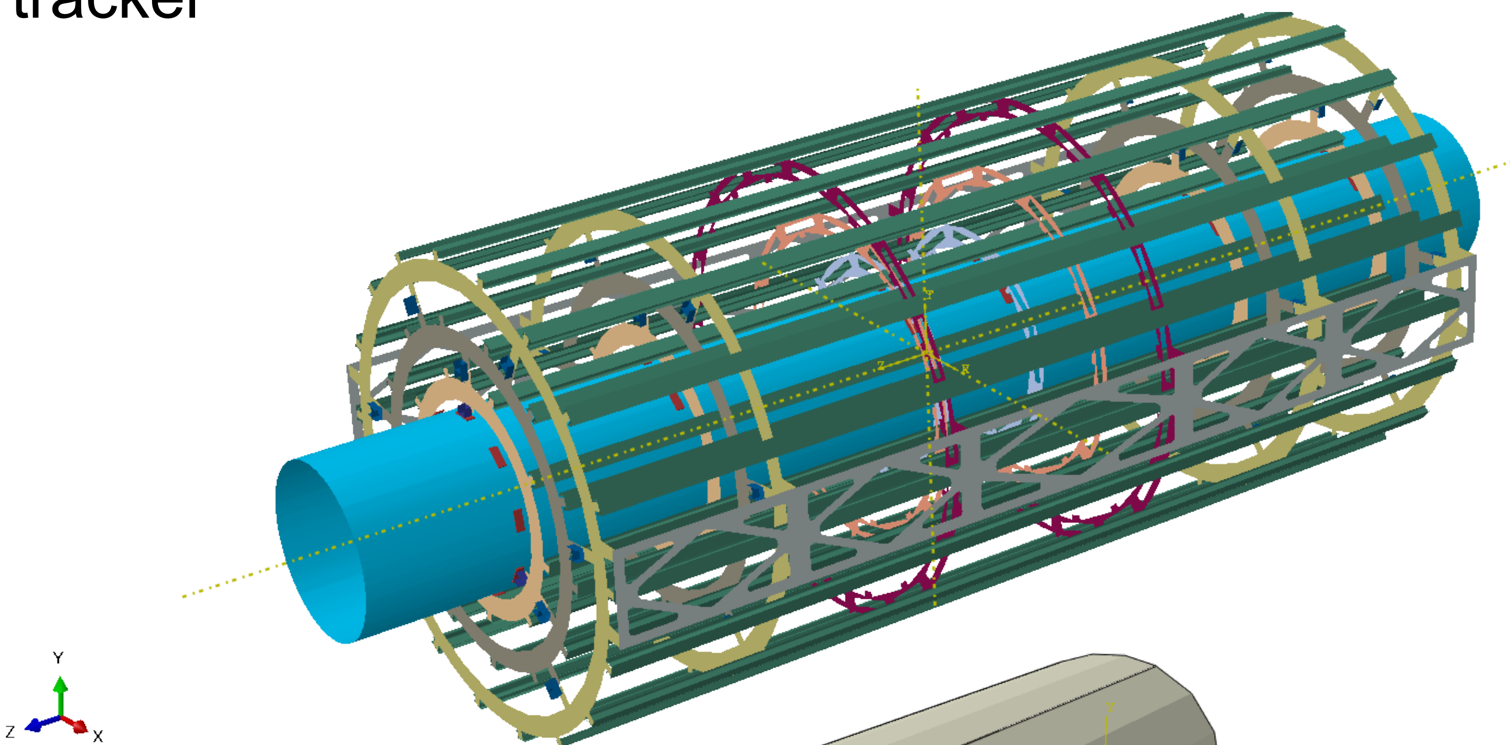


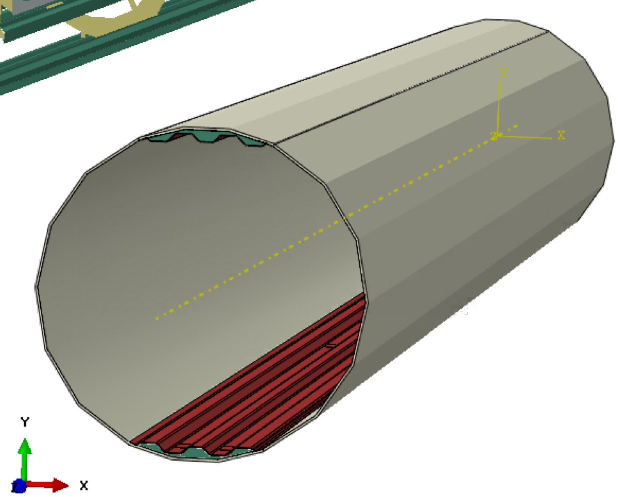


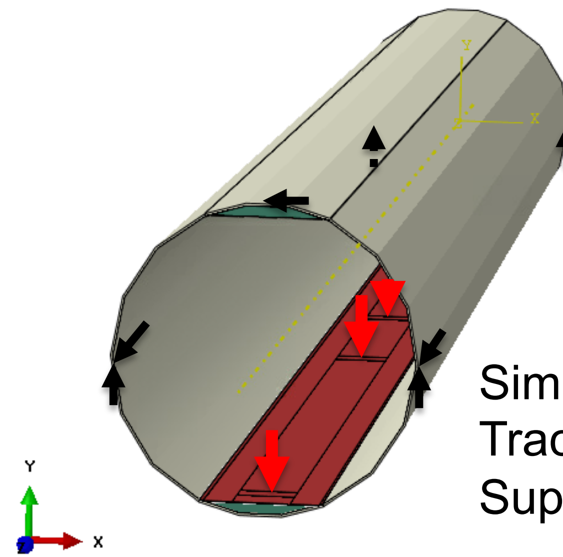


Inner + Outer Tracker region

Only full structure is up for the task of supporting the entire IT+OT tracker







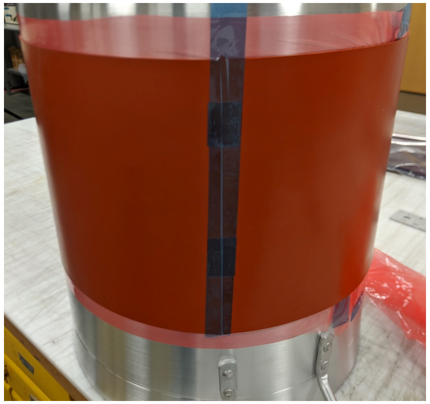
Simple Track Support

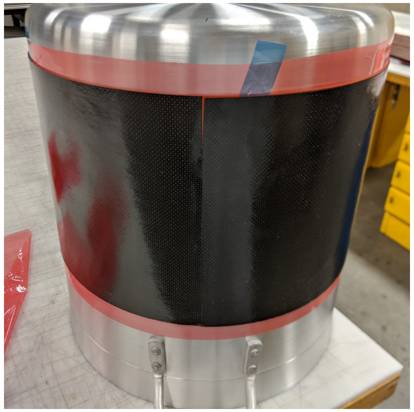
Inner Tracker region

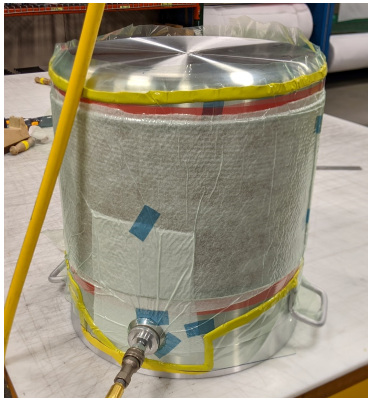
First prototype of the ITST

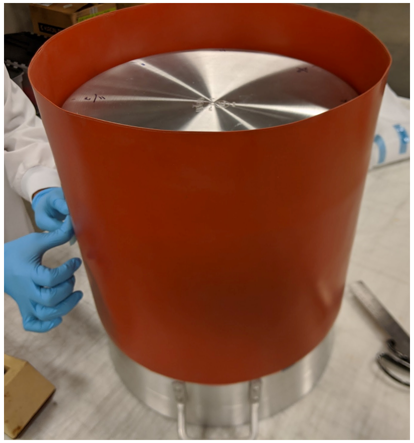
- Very good agreement with the FEA
- Small scale but first trials
- Low (low) budget, i.e. cooking pot as mold – still allows

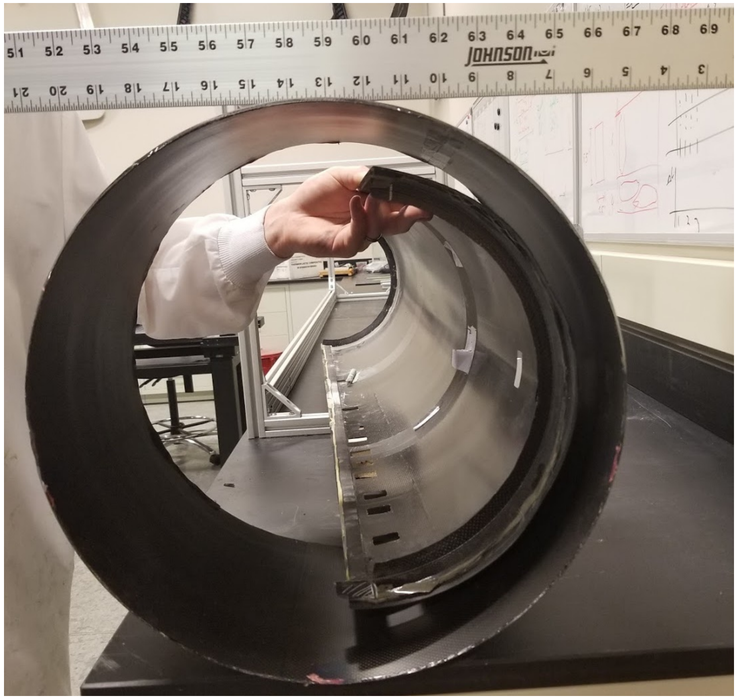
→ Precision manufacturing guided by FEA







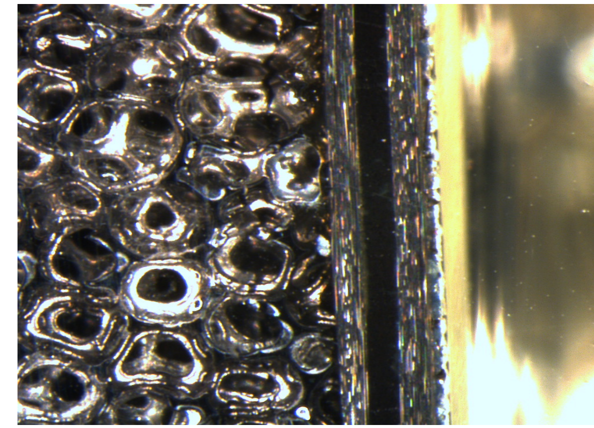




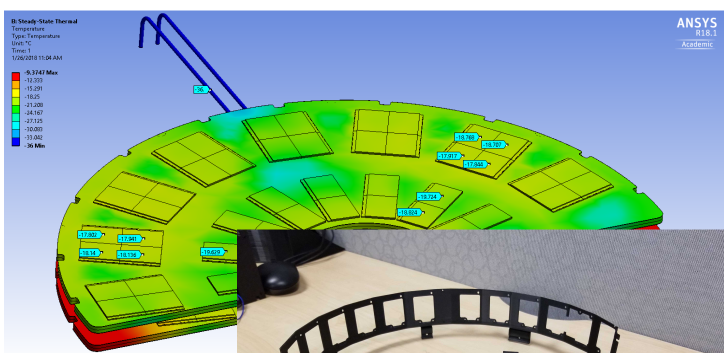
Dee support structures

→ Disc-like support structures made from Carbon Foam & Fiber
→ FEAs use TC measurements as inputs
→ Capable of cooling all ~1800 pixel modules
→ Carbon is light-weight, and strong

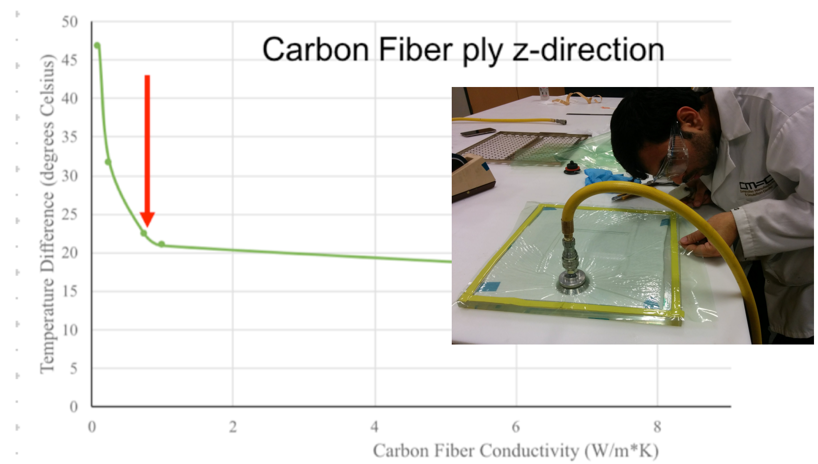
1st half dee prototype, in collaboration with Cornell University



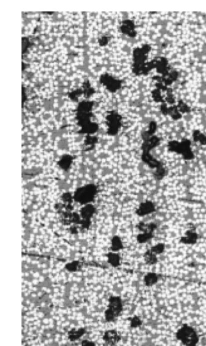
Carbon foam
3-ply skin



High TC support pieces

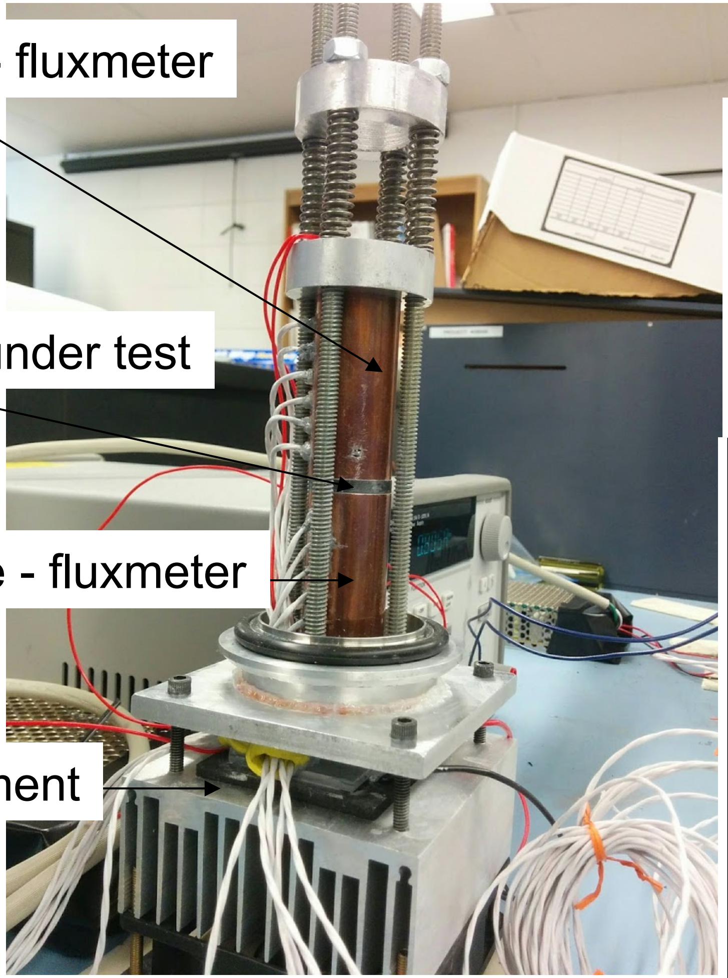


Bad laminate



TC measurement setup

→ UG student driven activities, **preliminary results!**
→ Method stable against radiative losses
→ Pressure clamp ensures good thermal contact

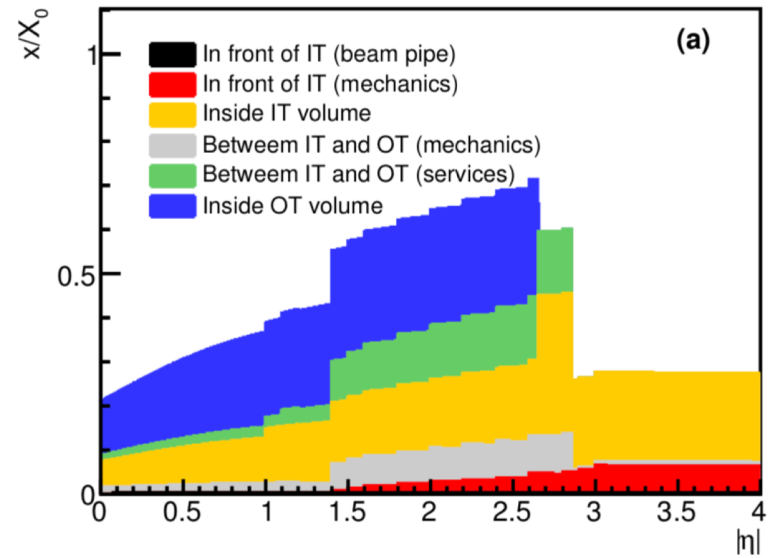


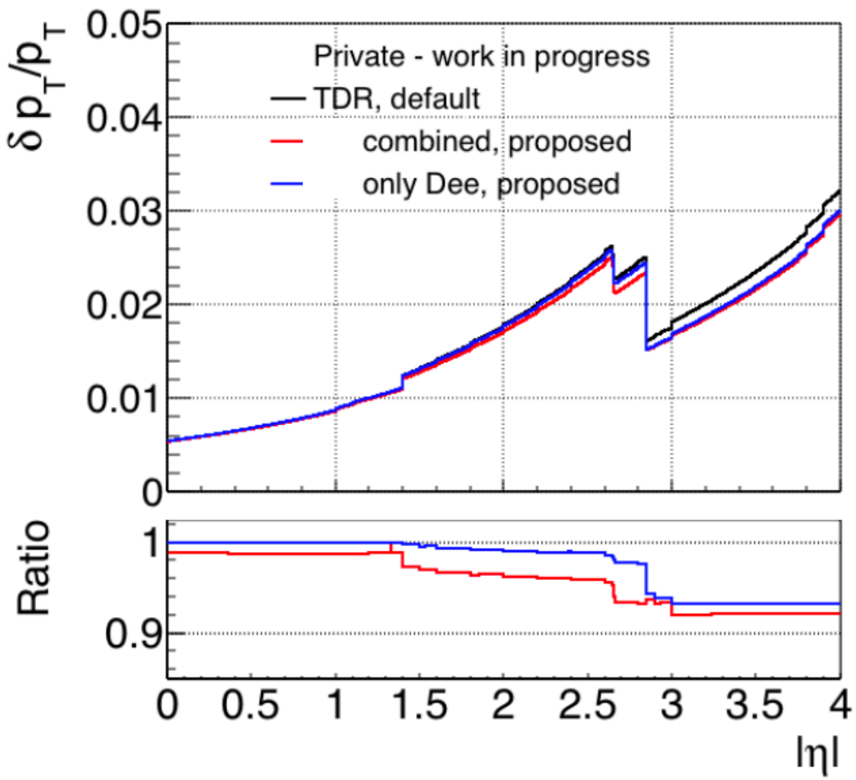
Direction	Thermal conductivity (k) [W/mK]	Interface thermal resistance of Cu-TIM-CF (R_{int}) [Km^2/W]
Calibration samples		
Copper	(426 ± 36)	$(14 \pm 3) \cdot 10^{-6}$
Aluminium	(195 ± 27)	$(21 \pm 8) \cdot 10^{-3}$
Quartz	(1.72 ± 0.19)	$(0.14 \pm 0.06) \cdot 10^{-3}$
K13C2U+EX1515 carbon fiber composite		
x-axis	(318 ± 26)	$(19 \pm 3) \cdot 10^{-6}$
y-axis	(6.3 ± 2.7)	$(0.38 \pm 0.19) \cdot 10^{-3}$
z-axis	(1.11 ± 0.12)	$(-0.05 \pm 0.12) \cdot 10^{-3}$
z-axis, cured at 20 bar	(2.20 ± 0.23)	$(0.04 \pm 0.06) \cdot 10^{-3}$
K13D2U+EX1515 carbon fiber composite		
x-axis	(387 ± 27)	$(16 \pm 2) \cdot 10^{-6}$
y-axis	(7.5 ± 3.9)	$(0.40 \pm 0.24) \cdot 10^{-3}$
z-axis	(1.45 ± 0.21)	$(0.15 \pm 0.10) \cdot 10^{-3}$

What's the benefit of all this ?

Tracker of the HL-LHC is a very significant fraction of the total CMS upgrade budget

- Can improve b-ID efficiencies by 2-3% per b-jet
- High b-jet multiplicity can be 10-15%, significant improvement

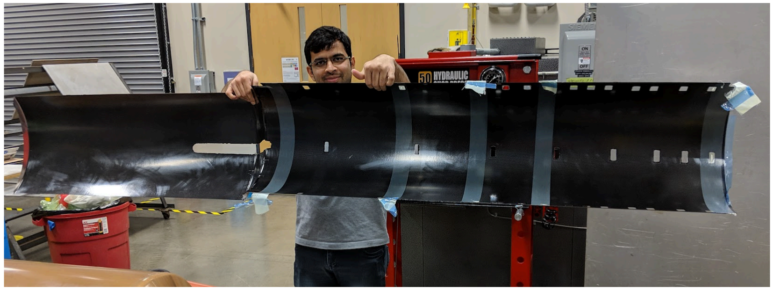




Conclusions

Detector mechanics can play a significant role in a detector's performance, improvements require:

- In-depth study of total mass
- Novel ways to reduce the total mass
- Electron-Positron machines have significantly smaller material budgets



But detector mechanics often takes a back

Personal view and experience:

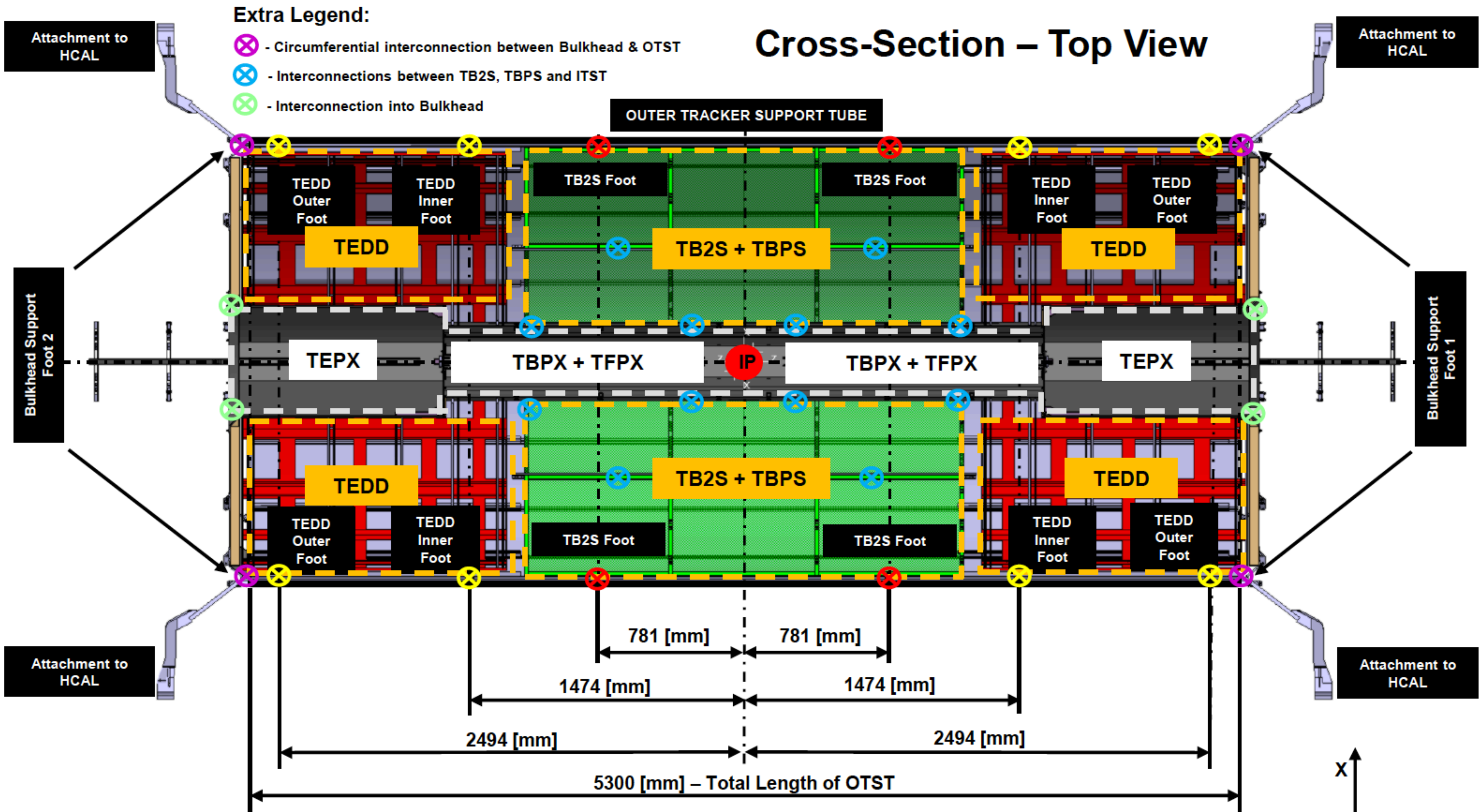
→ Need more R&D on detector mechanics at boundary of material science, engineering and physics.

→ Possibility of RD like efforts via Forum on Tracking

→ Happy to also present on RD efforts and future constrains

Backup

Conceptual design of IT support tube



Source: CERN document: ***Prepared based on the 3D model created by Philippe Lenoir*** .
SmarTeam Number: *ST0579969_15*

- Interconnection into Bulkhead

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