Mechanical Structures for EPIC pfRICH

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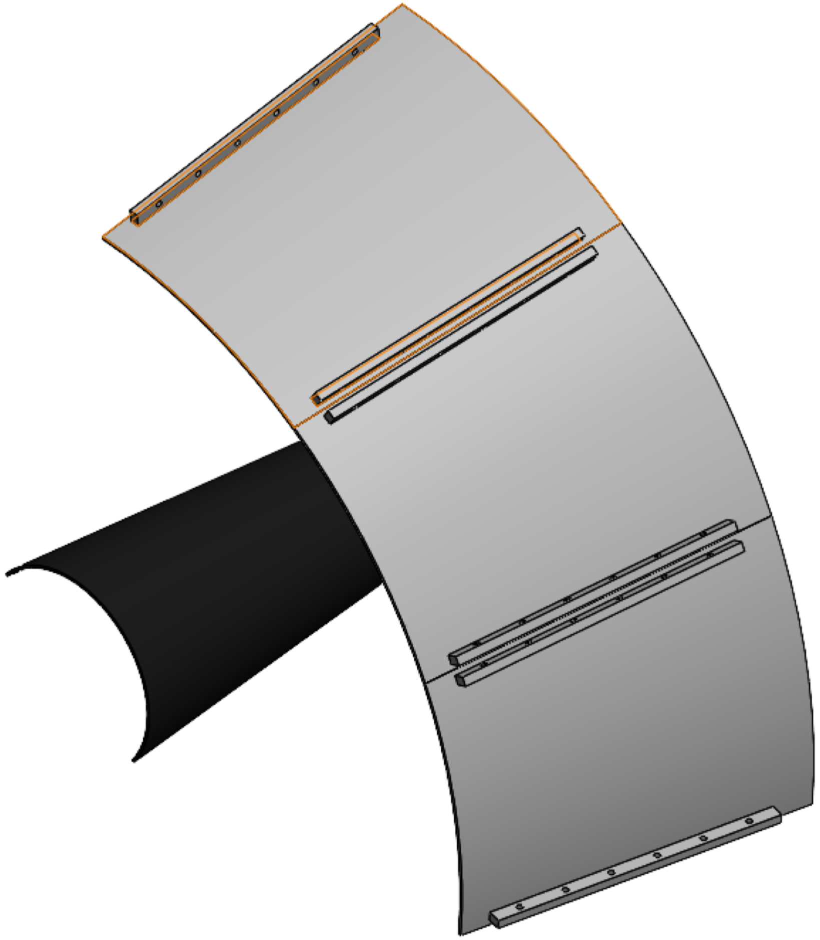
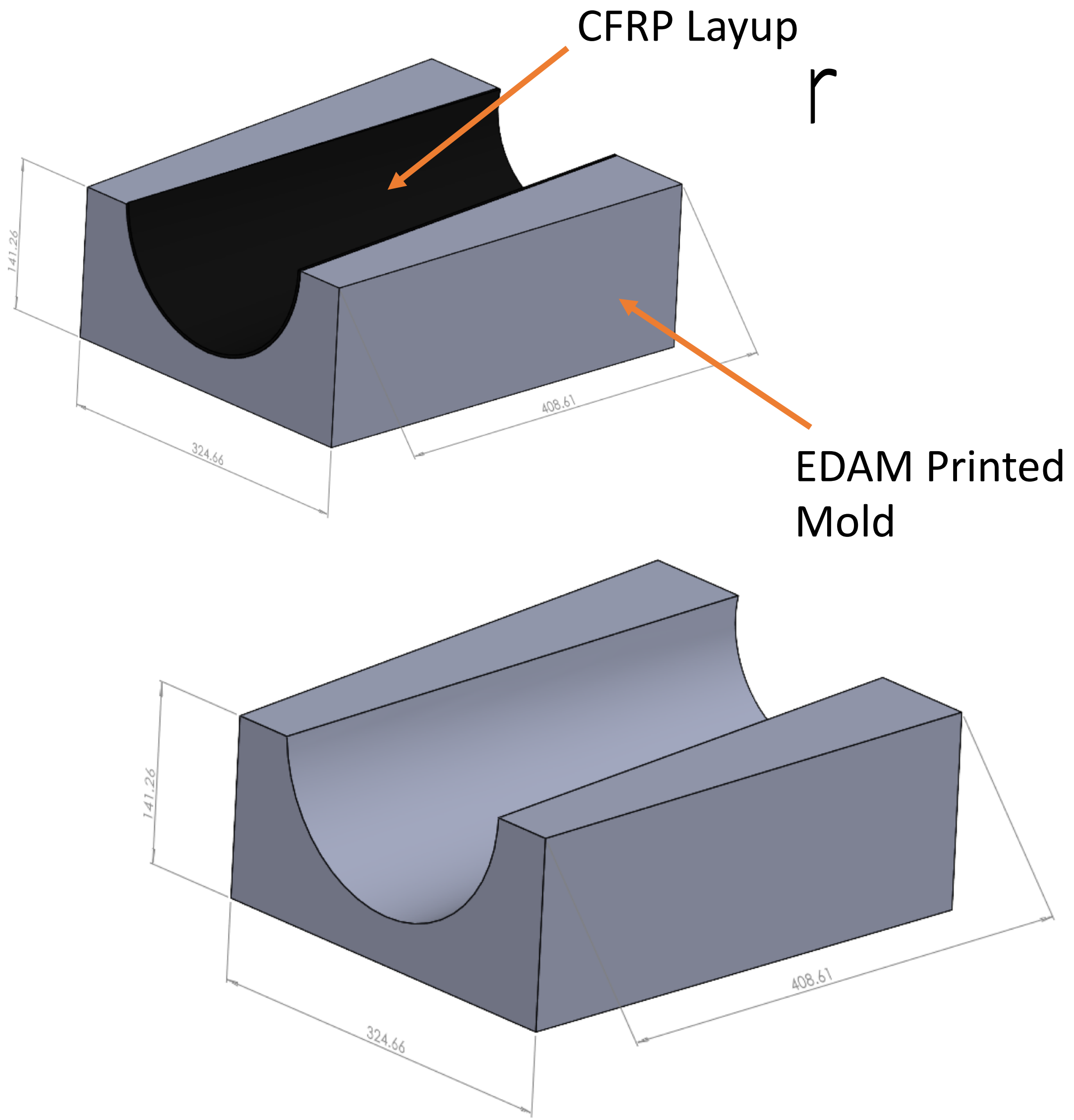
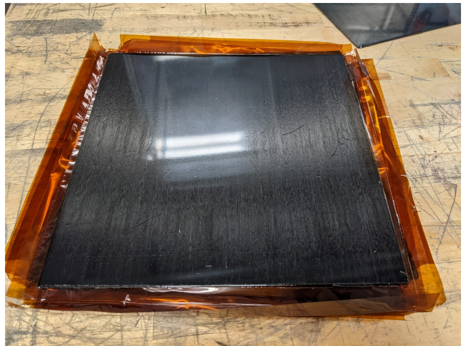
1. Mirrors

- The plan is to 3D print the tools needed for the composite layup
- Composite layup for the inner and outer mirror support structures – control surface as follows –
  - Outer surface of the inner mirror
  - Inner surface of the outer mirror



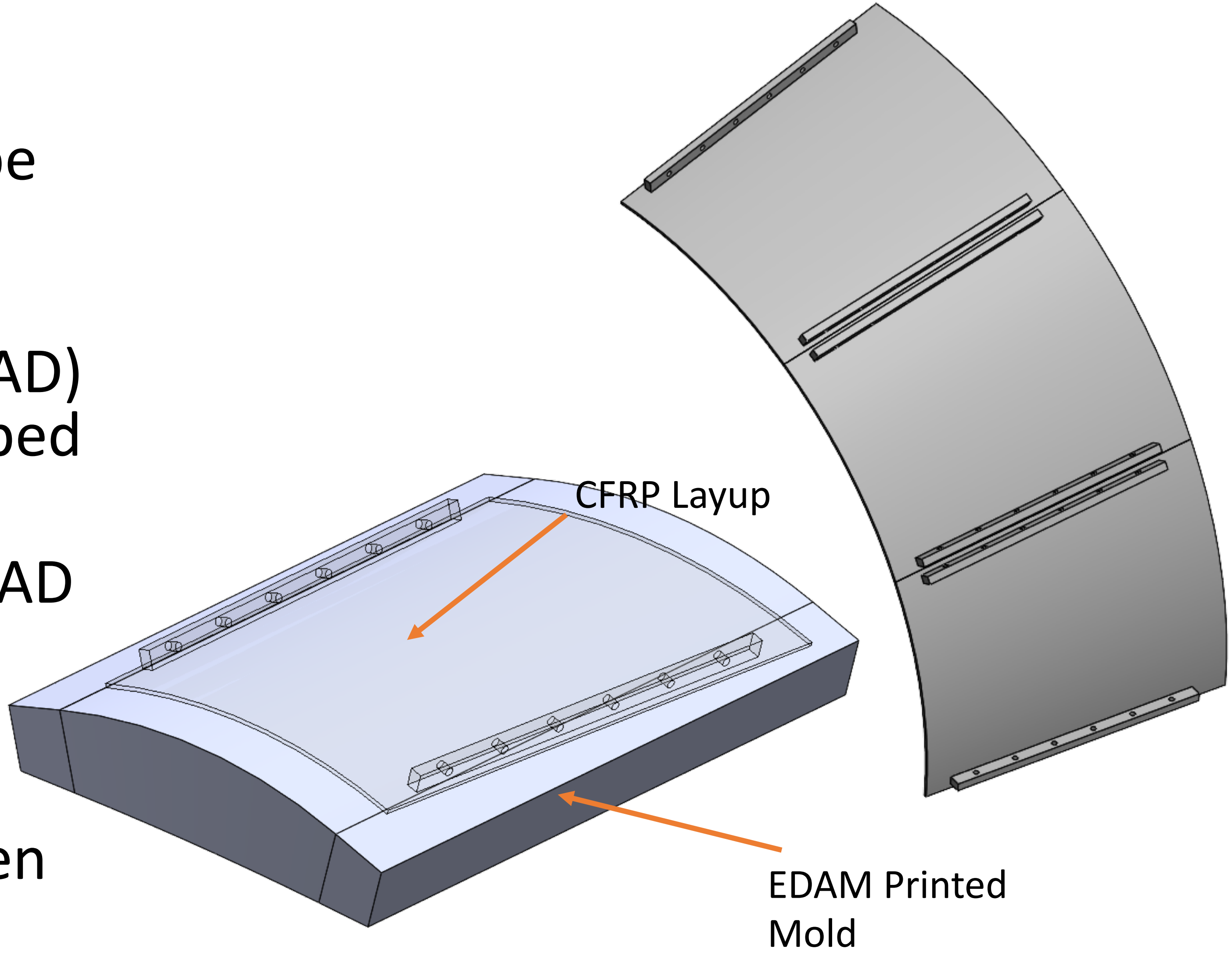


- 3D print the mold and machine after gel coating
- Received samples from Stony Brook – surface roughness measurements undergoing
- We are making (short timescale) prototypes to see what smoothness we can achieve



1.2 Outer Mirror manufacturing will be similar to inner mirror

- 3 part mirror for the prototype
- Autoclave high temp tooling with EDAM (see backup and other presentation in TOF LGAD) has been studied and developed at Purdue for many years
- Tolerances for difference to CAD and for overall “flatness” of mirror substrates is an open question
- Surface roughness – to be seen



We will send some samples to Stony Brook/ BNL soon for testing mirror deposition with different surface qualities

- Surface roughness has been thoroughly studied at CMSC Purdue – details with coating and its effect in published work

Plastic sheet – this is the surface roughness needed

CFRP laminate coated with mirror

Garam Kim, Eduardo Barocio, et al., "Enhancing surface characteristics of additively manufactured fiber reinforced thermoplastic mold using thermoset coating with ceramic particles", Surface and Coatings Technology, Volume 422, 2021, 127536, ISSN 0257-8972, https://doi.org/10.1016/j.surfcoat.2021.127536.

Abstract: A commercially available thermoset polymer liquid coating reinforced with ceramic particles was applied on the surface of an additively manufactured carbon fiber reinforced thermoplastic composites to improve its surface characteristics for composite mold application. The mold demonstrated herein was fabricated via material extrusion additive manufacturing (MEAM) and served for the fabrication of autoclave-cured laminated composite structures. Test specimens used in this investigation were additively manufactured with Polyphenylene Sulfide (PPS) reinforced with 50% by weight of carbon fiber. Following the printing process, the surface of the specimens was finished in a numerical controlled milling machine. The effect of machining parameters such as the surface speed and the chip load on the surface roughness was investigated. The machining parameters that yielded the lowest surface roughness were used to machine the specimens used in this work. Following machining, an approximately 10 μm thick coating based on a thermoset resin reinforced with ceramic particles was applied on the surface of flat specimens via the liquid spray coating technique and cured at elevated temperature. Surface characteristics relevant to molds used in composite manufacturing such as surface roughness, abrasion resistance, hardness, friction, and vacuum integrity were assessed for the coated and noncoated specimens. The results showed that the coating decreased the abrasion wear index by about 89%, decreased the vacuum loss by about 95%, and lowered the static and kinetic friction by about 40% and 38%, respectively, compared to the non-coated printed material. However, the coated surface did not improve hardness nor roughness of the surface.

Keywords: Material extrusion additive manufacturing; Polymer coating; Surface durability; Surface roughness

Samples from Stony Brook

Surface Roughness Results

Polished Mirror Surface			
Test #	Ra (μm)	Rq (μm)	Rz(μm)
1	0.01	0.012	0.062
2	0.01	0.012	0.066
3	0.01	0.013	0.08
4	0.01	0.012	0.062
5	0.01	0.013	0.072
6	0.01	0.012	0.069
7	0.011	0.014	0.072
8	0.048	0.077	0.42
9	0.01	0.013	0.077
10	0.011	0.013	0.076
AVG	**0.014**	**0.0191**	**0.1056**

ISO grade – better than N1

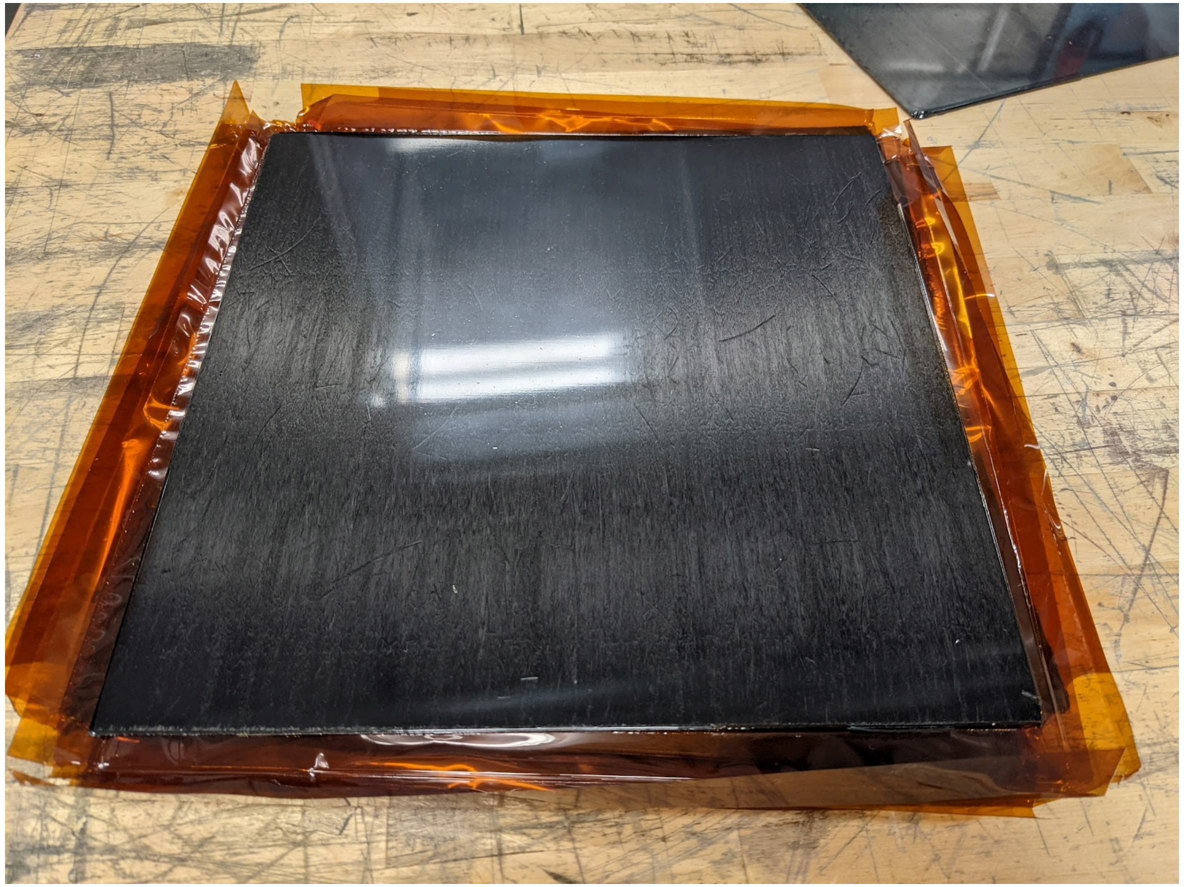
Polycarbonate Lexan Plastic Sheet			
Test #	Ra(μm)	Rq (μm)	Rz(μm)
1	0.124	0.166	0.767
2	0.37	0.55	2.657
3	0.23	0.363	1.711
4	0.238	0.299	1.239
5	0.113	0.152	0.886
6	0.116	0.143	0.618
7	0.152	0.21	0.958
8	0.141	0.178	0.698
9	0.119	0.156	0.744
10	0.105	0.131	0.599
AVG	**0.1708**	**0.2348**	**1.0877**

ISO grade number N3 – N4

Preliminary results of Purdue laminates

- 5-plies example on the right…
- Purdue layups currently:
  - Standard Al tooling: 0.4 micron (no coatings)
  - Standard glass tooling: 0.3 micron (no coatings)
- Category: roughly N4-N5

Work needed but somewhat positive we can improve on this by using aerogel to smoothen surface further

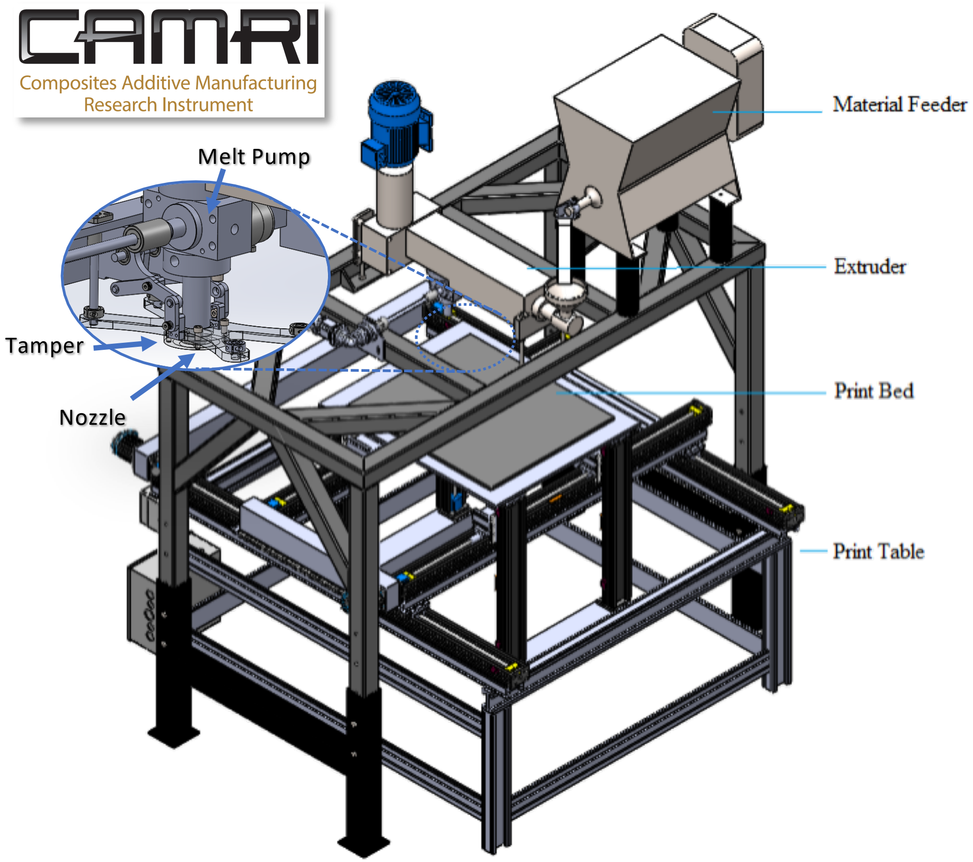


Backup – More details

Surface Roughness Definitions and read-out

Parameter	Definition	Formula
Ra	Average, or arithmetic average of profile height deviations from the mean line.	$R_a = \frac{1}{l_r}\int_0^{l_r} \lvert z(x)\rvert dx$
Rq – RMS value	Quadratic mean, or root mean square average of profile height deviations from the mean line.	$R_q = \sqrt{\frac{1}{l_r}\int_0^{l_r} z(x)^2 dx}$
Rz	Maximum peak to valley height of the profile, within a single sampling length; Average Rz value over assessment length	$R_{z_i} = R_{p_i} + R_{v_i}$; $R_z = \frac{\sum_{i=1}^{n} R_{z_i}}{n}$

Extrusion Deposition Additive Manufacturing (EDAM)



- Composite Additive Manufacturing Research Instrument (CAMRI) at Purdue
- Fixed single screw extruder configuration
- Numeric controlled print bed
- Printing highly filled thermoplastics
- Characterization/validation tool
- 20 in x 20 in x 18 in print volume

Feed Stock – CF short fiber filled
Polyphenylene sulfide (PPS) OR Polyethersulfone (PESU)

Thermwood LSAM Research Laboratory at C[illegible]SC

LSAM ADDITIVE PRINTER (10’X5’)

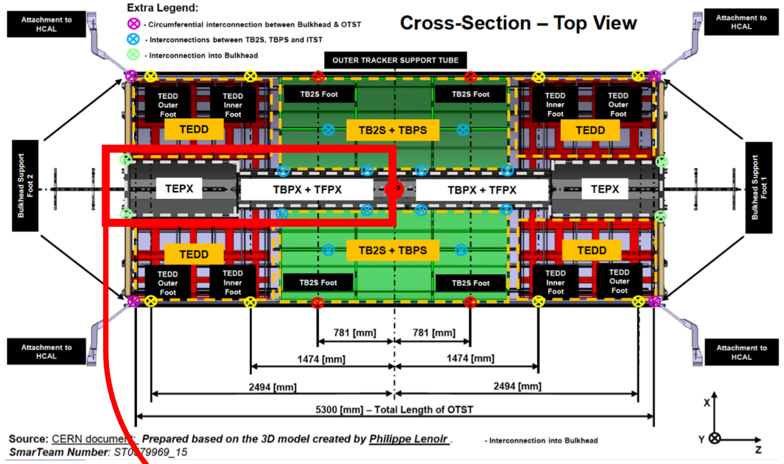
- 5 x 10 x 4 feet at print volume
- Print rates up to 200 pounds per hour
- The system has been modified to enable print temperatures of 450°C
- 5 axis LSAT – CNC milling machine

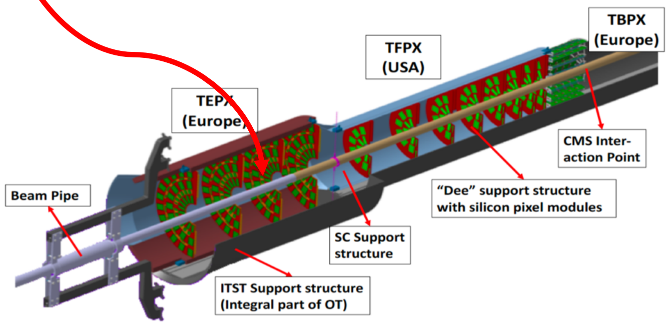
Resources at Purdue

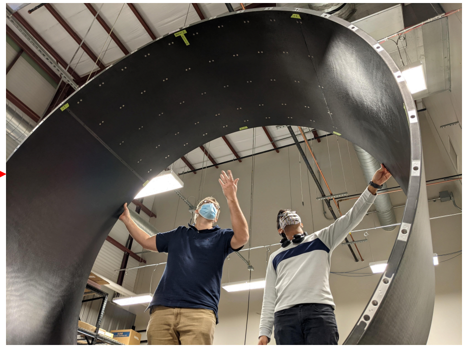
- Composite Manufacturing & Simulation Center (CMSC) at Purdue, completed in summer 2016
  - Purdue Center of Excellence across disciplines: Aeronautics, Chemical Eng, Materials Eng, Aviation Tech, Computer graphics, **and Physics**
  - A. Jung – Associated member of CMSC
- Professional composite experience: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

CMS mechanics @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

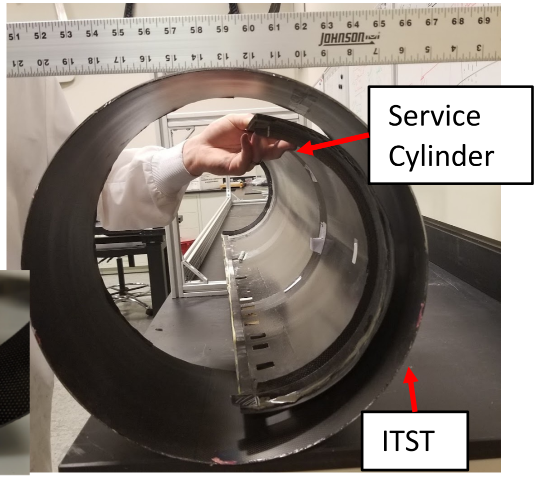


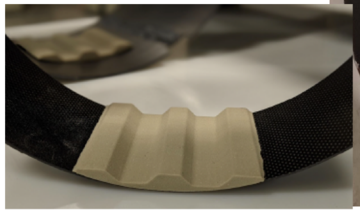


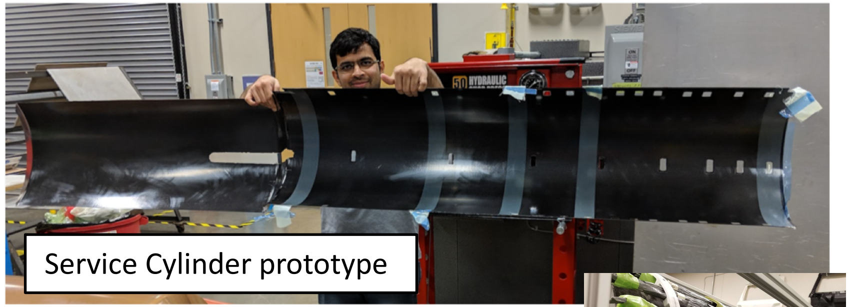


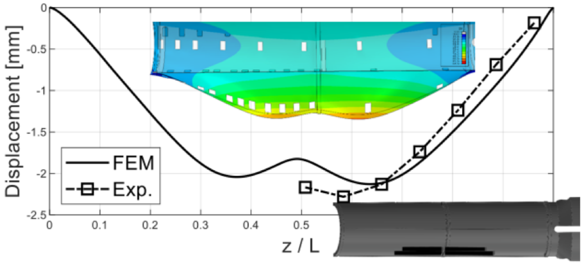
Resources @ Purdue

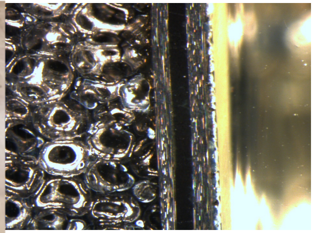
- Prototyping & Manufacturing related to ITST, SC, Dee's
  - Prototypes confronted with FEA predictions, multiple iterations
  - Prototyping and Development of additional structures for IT pixel
    - Cartridges, Portcard holders, all extensively studied for high thermal performance
    - Accompanied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

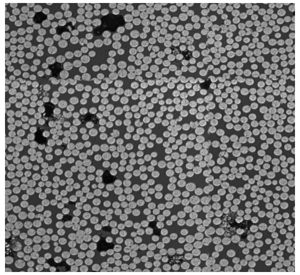




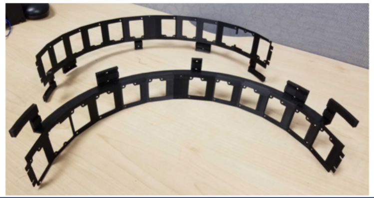


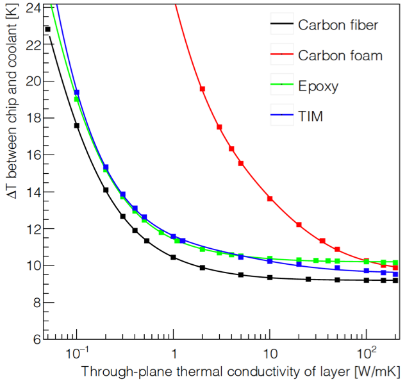






- Forward pixel dee prototype
- Co-cured samples
- Microscopies
- 3D printed mechanical supports
- Critical interfaces via FEA

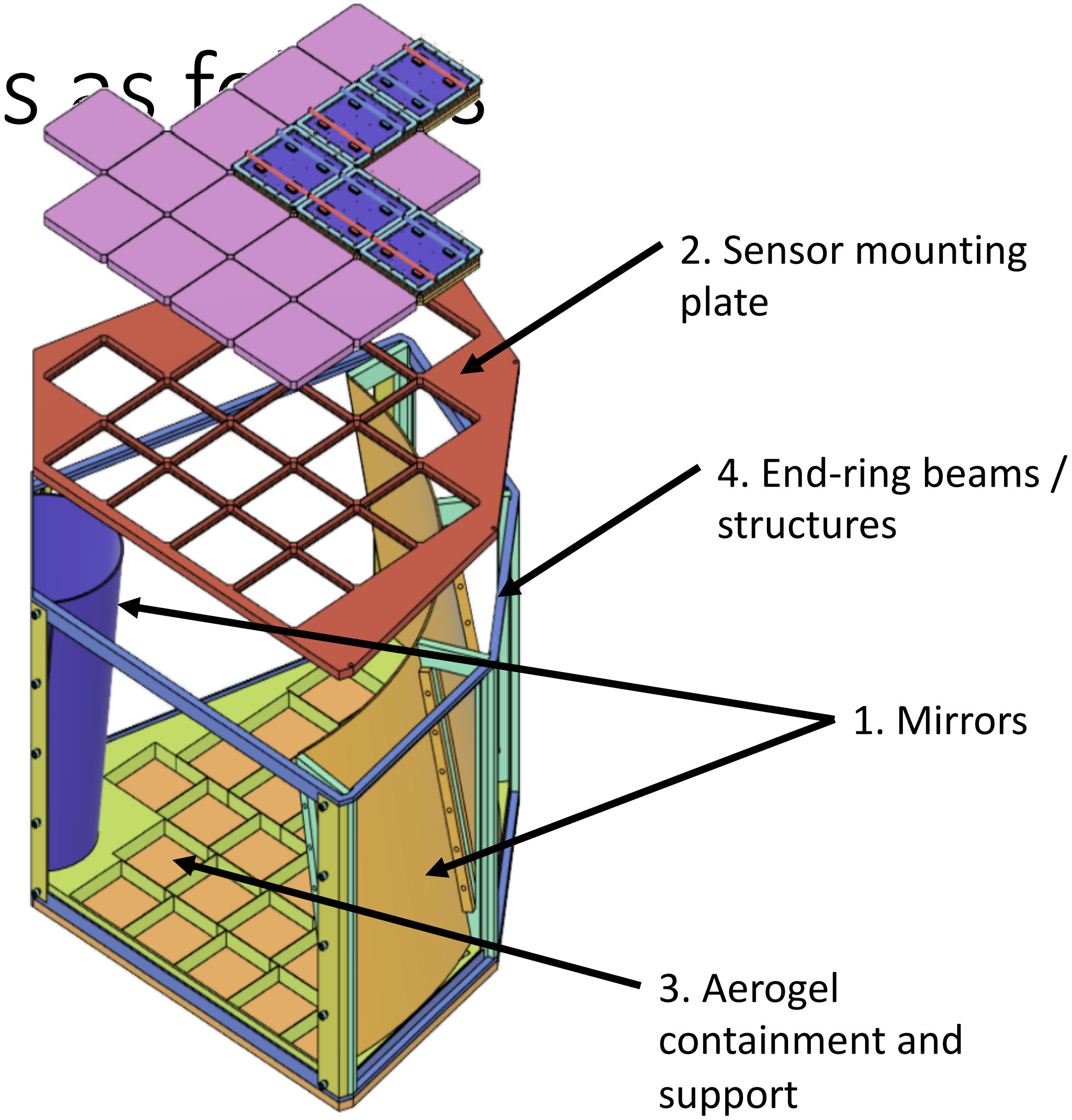




Plan is split into 4 sections as follows

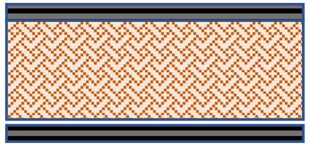
<u>Line items currently at Purdue:</u>

1. a 60 degree outer mirror sector (suffices for a test)
   1. 1/4 of the inner mirror
2. 1/4 of the rear sensor mounting plate with 17 square openings
3. 1/4 of the front plate with a bunch of aerogel pockets
   1. Sandwich + face sheets
4. the end-ring structures / beams
   1. Layup

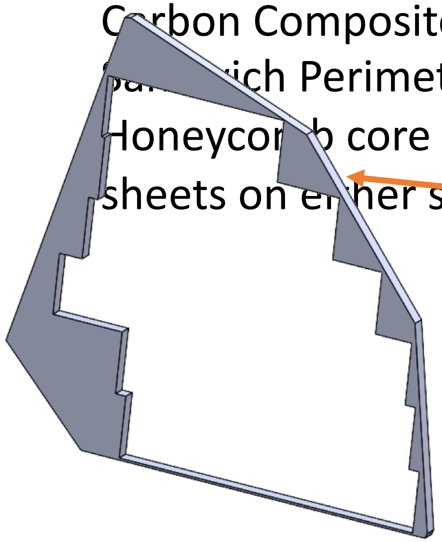


2. 1/4th rear sensor mounting plate
3. 1/4th front plate with aerogel pockets

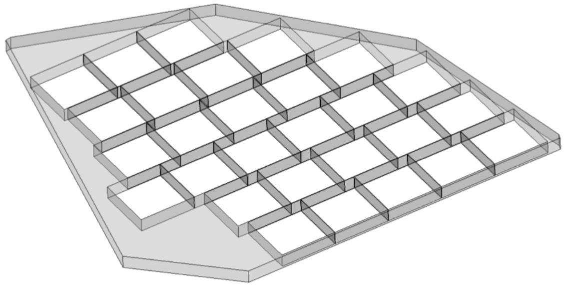
The approach for manufacturing of both will be similar so illustrating only one time

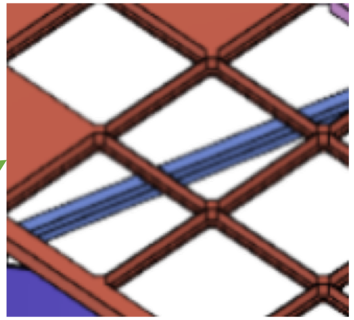


- The plates are 23 mm thick
- The perimeter will be made from a face sheet honeycomb structure to reduce mass.
- For aerogel the back sealing panel will be a simple CFRP layup cut and bonded in place
- Ribs have 2 options
    1. 3D printed using FormLabs High Temp Resin2 (known and tested to be radiation hard up to 300MRad of Co_{60} gamma radiation.) – data part of unpublished CMS work – but available to be shared upon reasonable request
    2. Made from strips of CFRP that are joined using a precision assembly jig



Carbon Composite Sandwich Perimeter with Honeycomb core and face sheets on either side

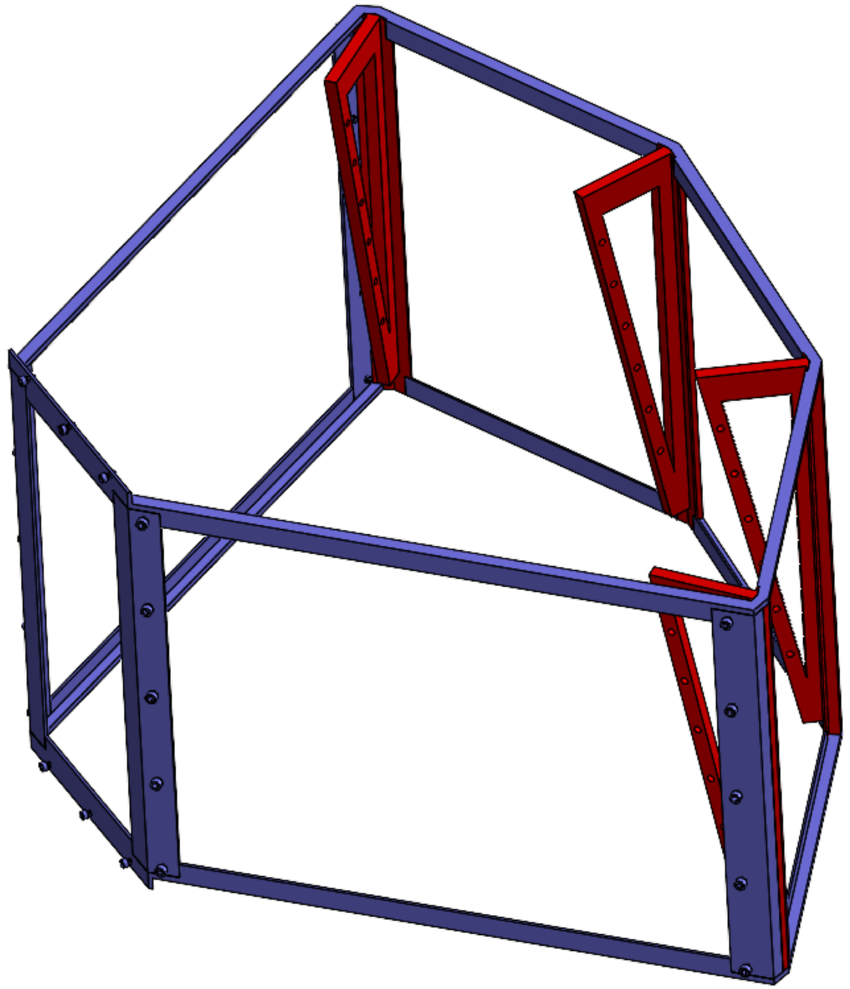




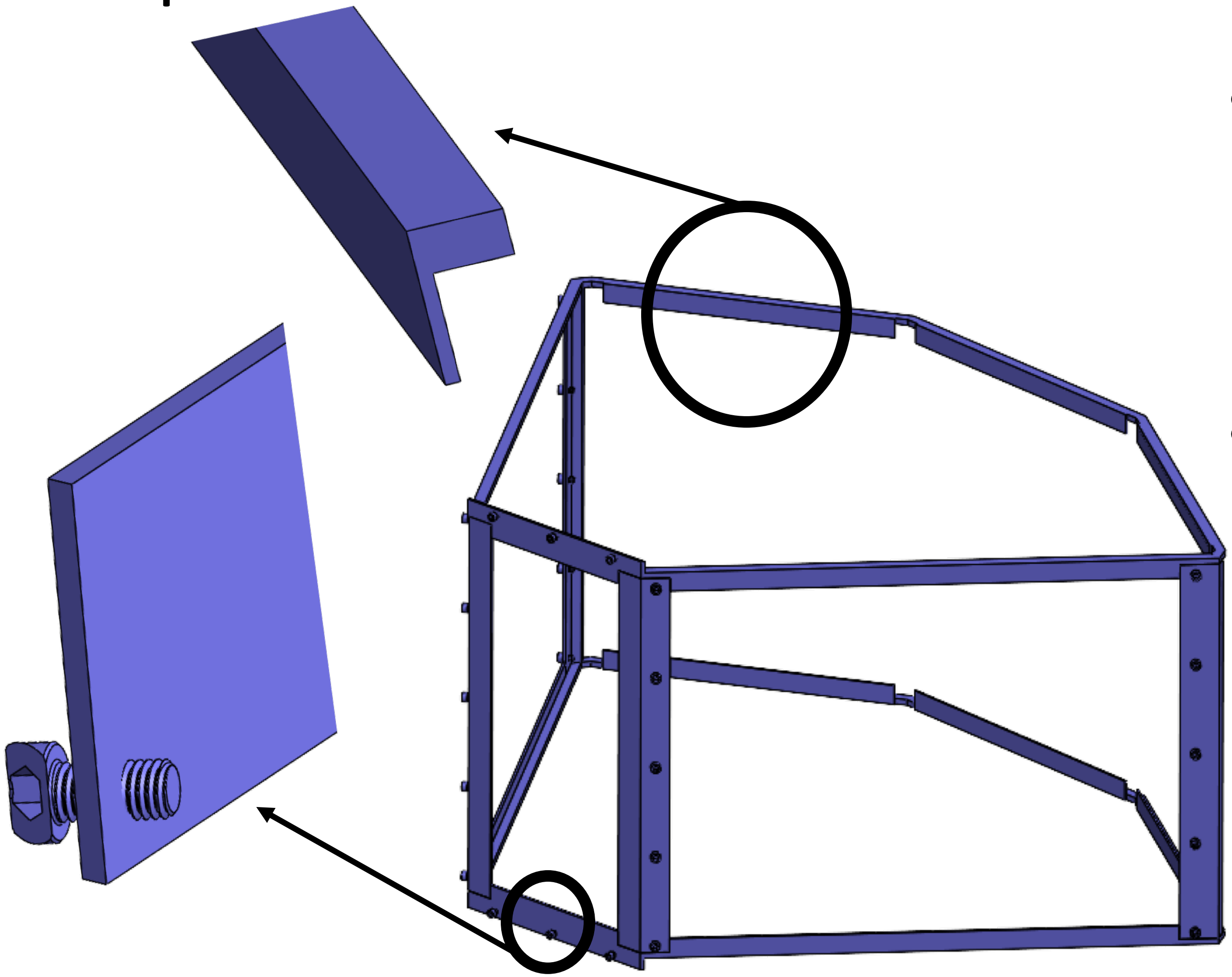
NOTE – the 'lip' needed for the sensor mounting plate can be achieved with both rib techniques

4. End ring structures / beams

- Question – Are the triangular supports that in the CAD are shown in red as a part of containment panels within Purdue manufacturing scope?
- Assumption is yes, since these integrate with the blue end ring support to form an integral part of the mechanical structure.
- All structures will be made from plain weave and uni-directional CFRP layups using multipart tools

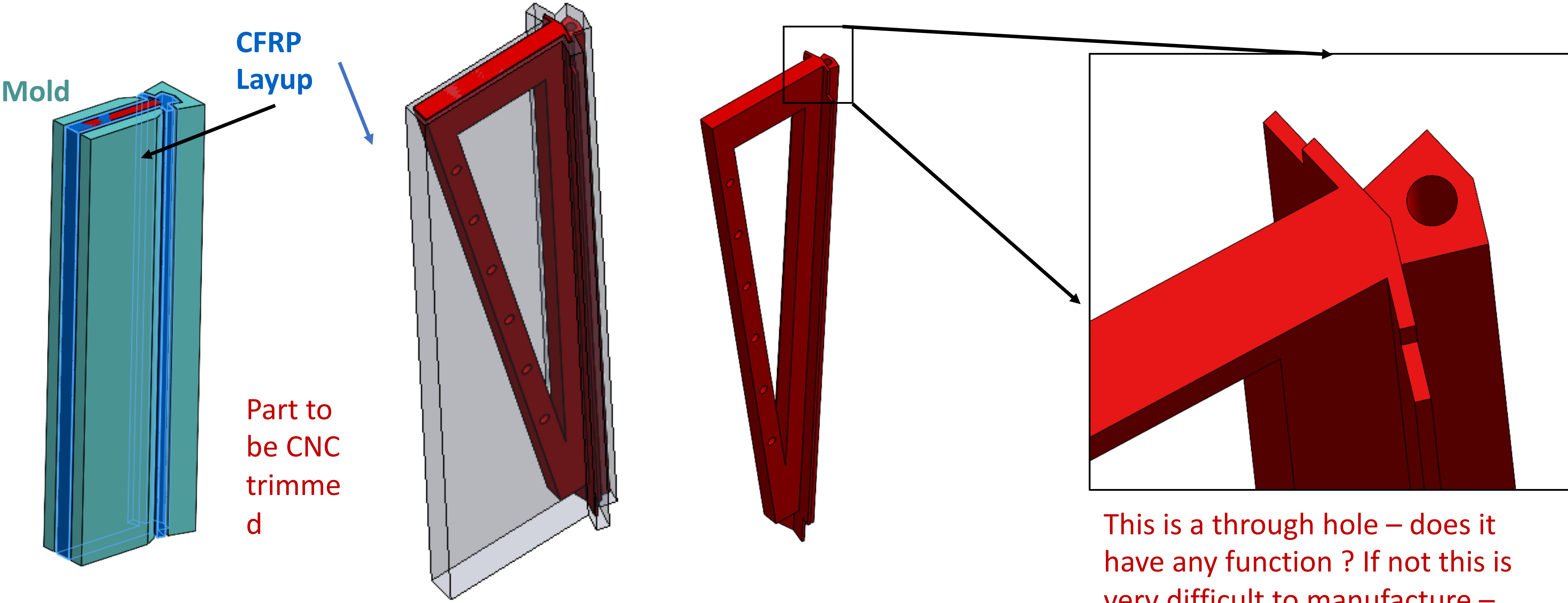


4. The other end ring structures are simple L-profiles and flat sections



- The are simple to manufacture as independent CFRP solid beams of the appropriate cross-section
- The hole locations will be CNC machined and then using an assembly jig the structure will be assembled.

To be made from 3 part layup tool and then machined to size – the rib is 0.5” thick – this will have some kind of core and face sheet structure



This is a through hole – does it have any function ? If not this is very difficult to manufacture – and will be removed