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Conceptual Design for the ePIC SVT Outer Barrel Staves

Adam Huddart - Rutherford Appleton Laboratory

Georg Viehhauser, James Julian Glover, Laura Gonella, Marcello Borri, Qing Yang

Agenda

Overview

- SVT Layout
- EIC LAS → Module Assembly → OB Stave Layout

Conceptual Mechanical Design

- Stave Structure– General Overview of L4 stave

Structural and Thermal Analysis

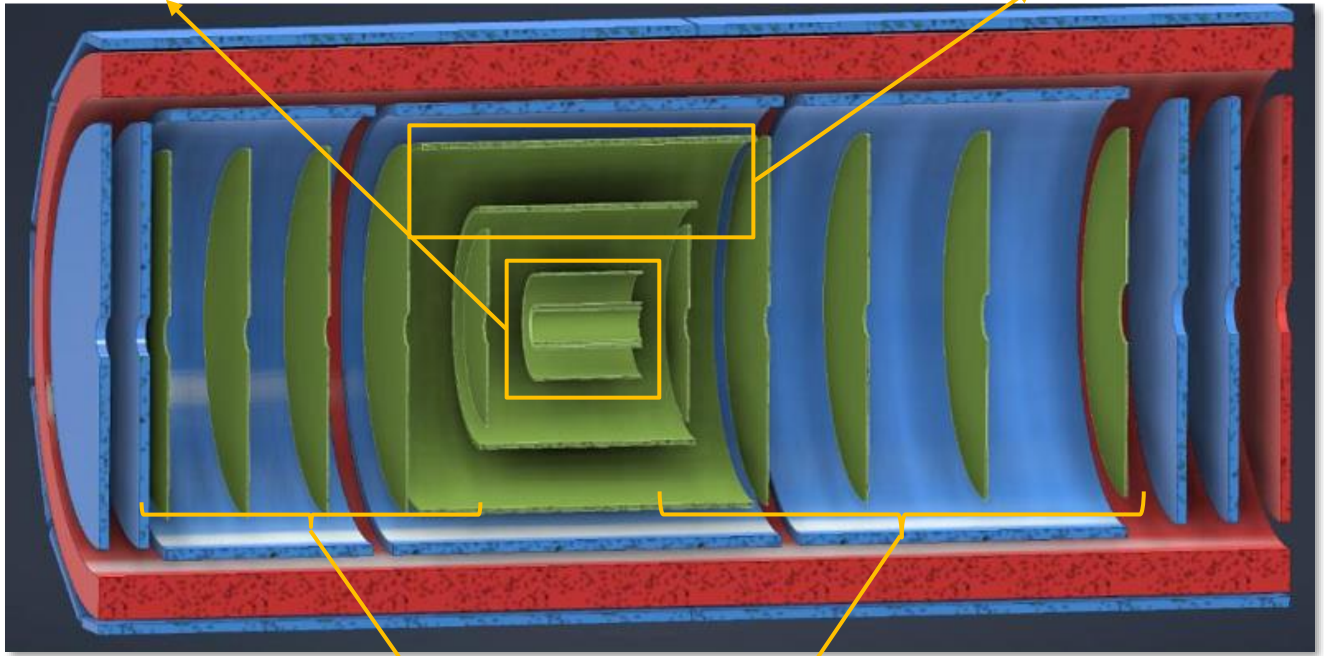
- Modal Analysis
- EIC-LAS power requirements
- Thermal Computational Fluid Dynamics

Assembly/tooling

ePIC Silicon Vertex Tracker (SVT)

Inner Barrel (IB)
3 curved layers
Same curved, wafer-scale
stitched MAPS used within ITS3

Outer Barrel (OB)
2 stave-based layers
optimised sensor for EIC.
Focus of EIC-UK WP1



SVT MPGDs ToF (fiducial volume)

Electron/Hadron Endcaps (EE, HE)
5 discs on either side of the IP

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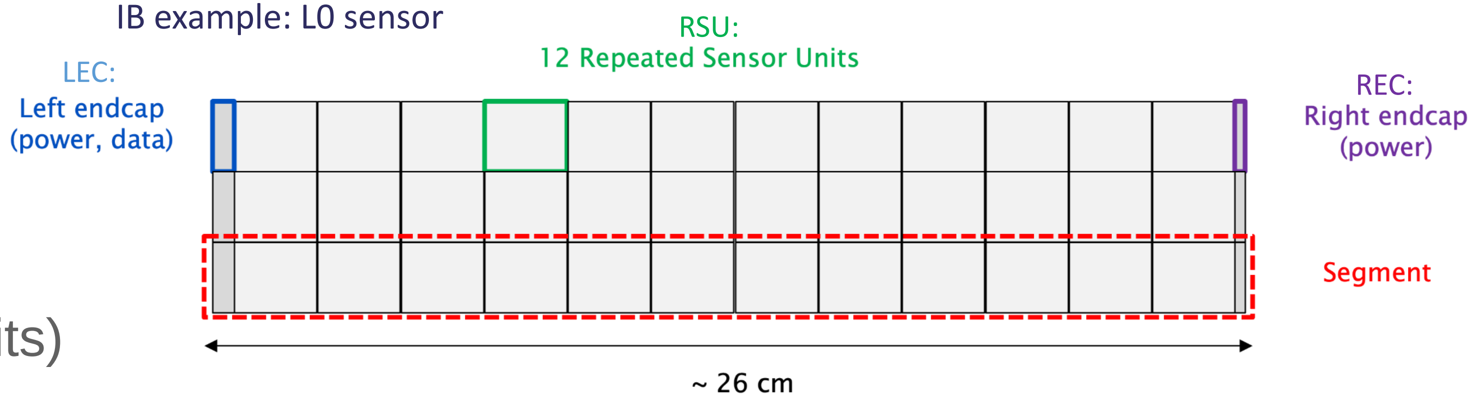
EIC-LAS Overview

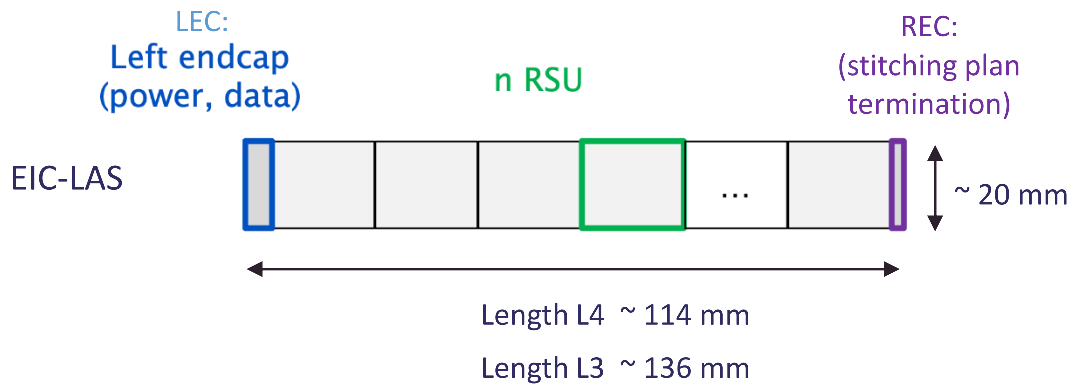
- EIC-LAS (Large Area Sensor)
- IB layers use a larger 12 RSU (Repeat Sensor Units) variant from ITS3
- L4 will use 5x1 RSU (Repeat Sensor Units)
- L3 will use 6x1 RSU

EIC optimised sensor variant to help minimise the material required due to service (data/power/control) connections and improve yield for large area coverage.

IB example: L0 sensor



OB example: L3 sensor



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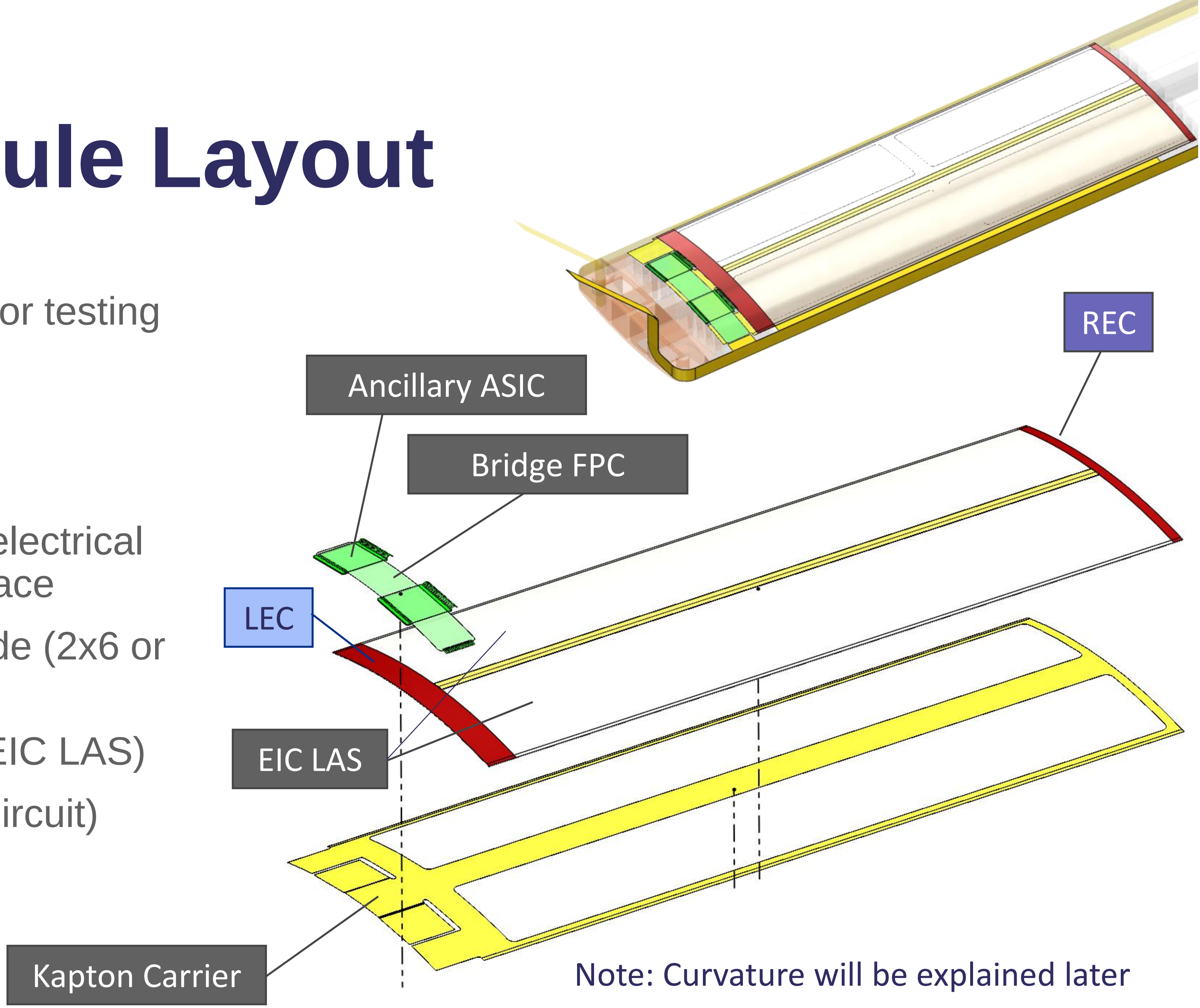
EIC-LAS Module Layout

EIS-LAS are built into a module for testing and wire bonding

Modules are comprised of:

- Kapton carrier – serves as an electrical insulation layer & bonding surface
- 2 EIC-LAS mounted side by side (2x6 or 2x5 RSU)
- Ancillary ASIC (one ASIC per EIC LAS)
- Bridge FPC (Flexible Printed Circuit)



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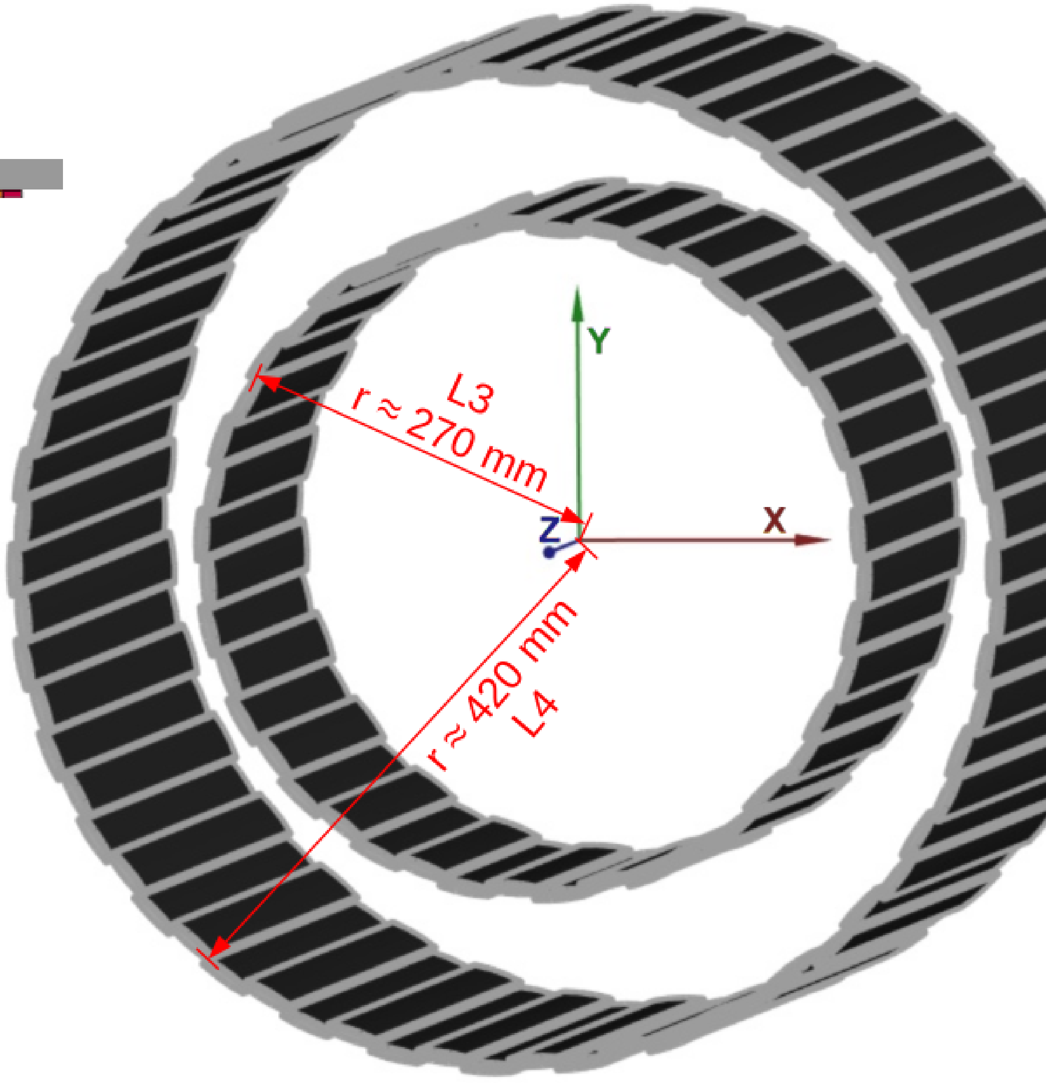
Outer Barrel Layout

OB L3 (6RSU segments)

- Modules placed in an alternating top/bottom arrangement
- Barrel layers comprised of castellated staves
  - L4 (8 x 5 RSU long EIC-LAS) at approx. 440 mm radius
  - L3 (4 x 6 RSU long EIC-LAS) @ approx. 270 mm radius



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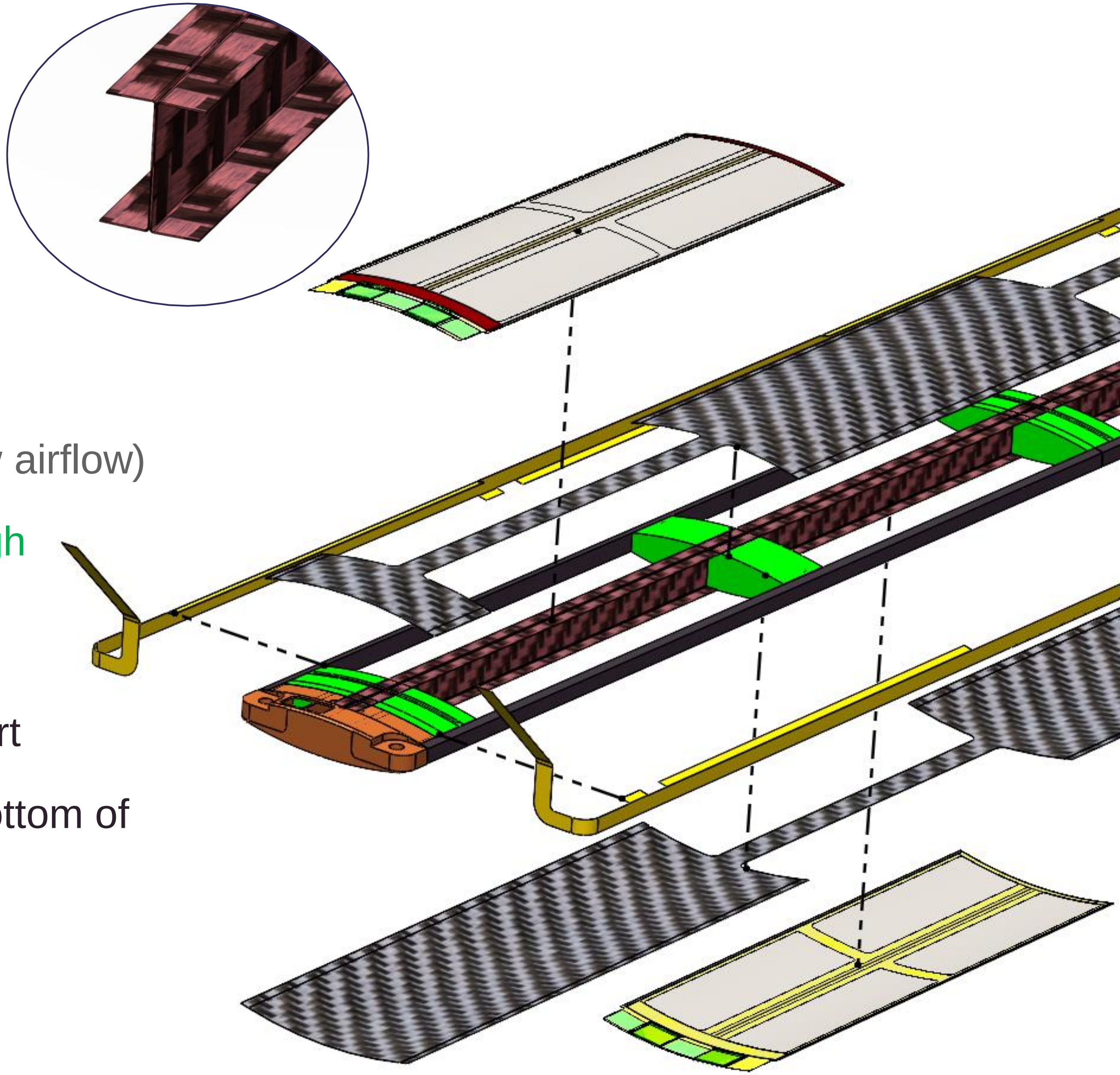
Mechanical Consideration for Stave Structures

Structural support	**First vibration mode above 100 Hz**
Radiation Length	**Target of 0.25% for L3 and 0.55% for L4**
Sensor & Ancillary Cooling	Staves will be air cooled using the internal volume of the stave structure, structure must be gas tight. **Target Delta T of 10°C across all sensors**
Mechanical & Electrical Interfaces	FPC routes power and data connections between the Support cone and the EIC-LAS, mechanical and coolant interface with support cone

Stave Structure

- Combination of carbon foams and carbon composite laminates
  - Central carbon fibre I-beam divides left and right air channels (shown in red)
  - 2 Densities of carbon foam (high porosity → allow airflow)
    - K9 used as a heatsink, in contact with the high power regions (ASIC & LEC) to aid heat dissipation
    - 3% RVC foam longerons for structural support
  - 0.1mm thick 2ply carbon fibre skins on top and bottom of the structure
- FPCs run along the longerons (shown in yellow)



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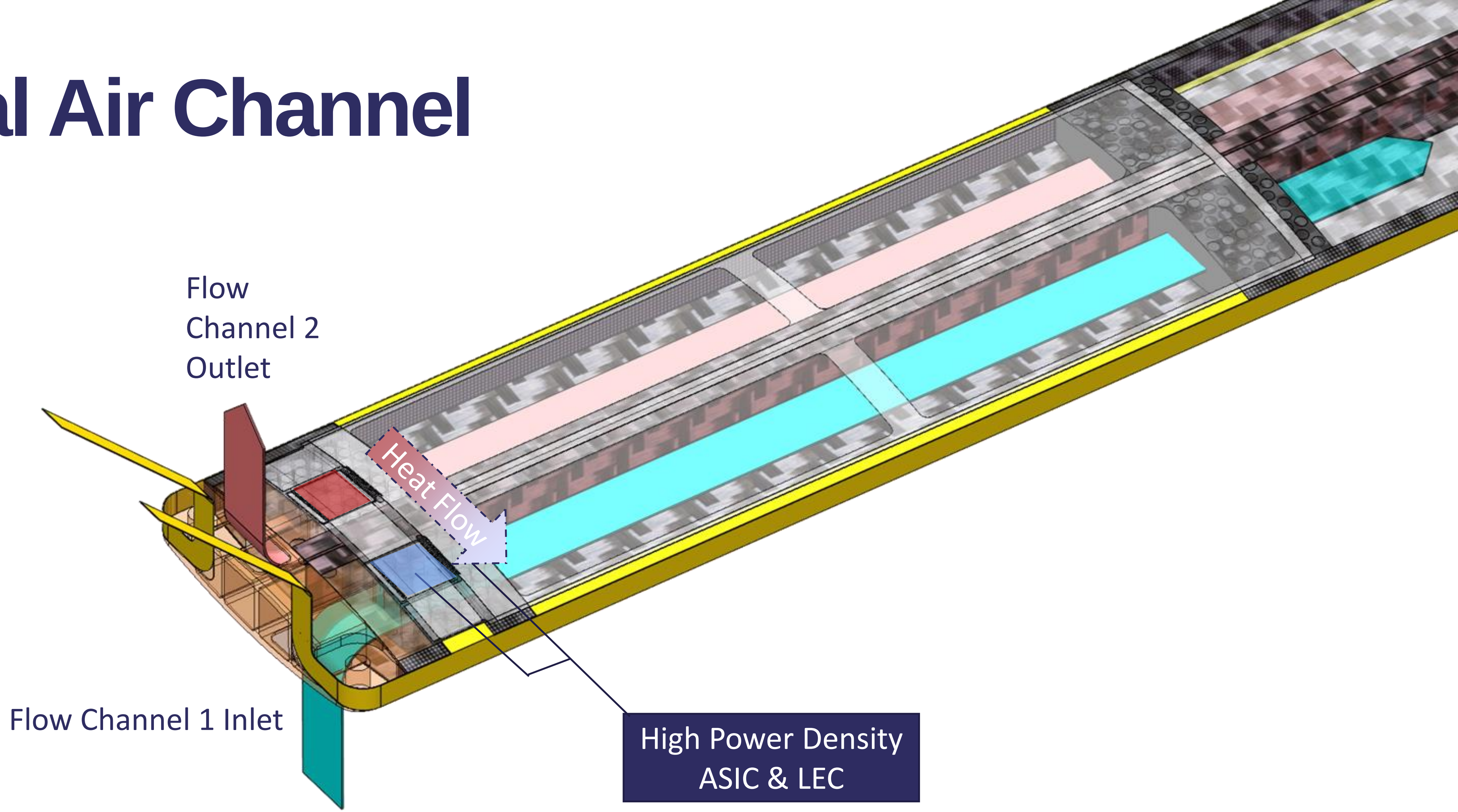
Internal Air Channel



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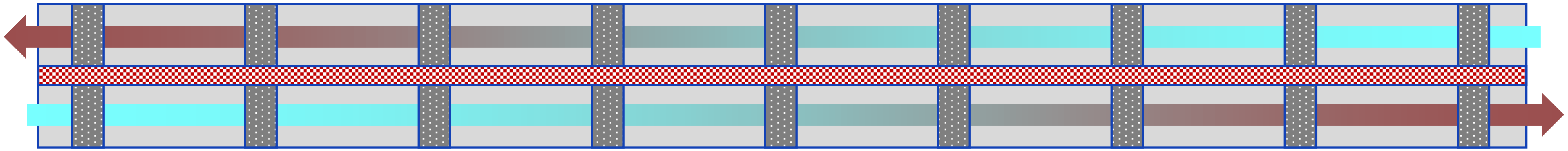

Thermal/Structural Analysis

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Structural Analysis

- First mode frequency of structure

- Deformation due to pressure – Future Work
  - Counter current flow will introduce pressure asymmetry in the stave

Material Assignment

Isotropic Elasticity

- Allcomp K9 - Cross Braces
  - 650 MPa Elastic Modulus
  - 200 kg/m^3 (known to be quite variable)
- 3% RVC Carbon Foam - Centre Spine
  - 101.84 MPa Elastic Modulus
  - 45 kg/m^3
- Kapton FPC (estimate)
  - 2.76 GPa Elastic Modulus
  - 1420 kg/m^3
- Silicon (Sensor)
  - 163 GPa Elastic Modulus
  - 2329 kg/m^3

Orthotropic Properties

- Carbon Fibre Layup
  - Young's Modulus
  - (CERN/Liverpool data for K13C2U 39% fibre volume)
    - X direction – 353 Gpa
    - Y Direction – 6 GPa
    - Z Direction – 6 Gpa
- 2 Layers 0 / +90
  - 50-micron layer thickness (100 micron total thickness)

Layer	Material	Thickness (m)	Angle (°)
(+Z)			
2	Carbon Fiber - Unidirectional X Strong	0.00005	0
1	Carbon Fiber - Unidirectional X Strong	0.00005	90
(-Z)			

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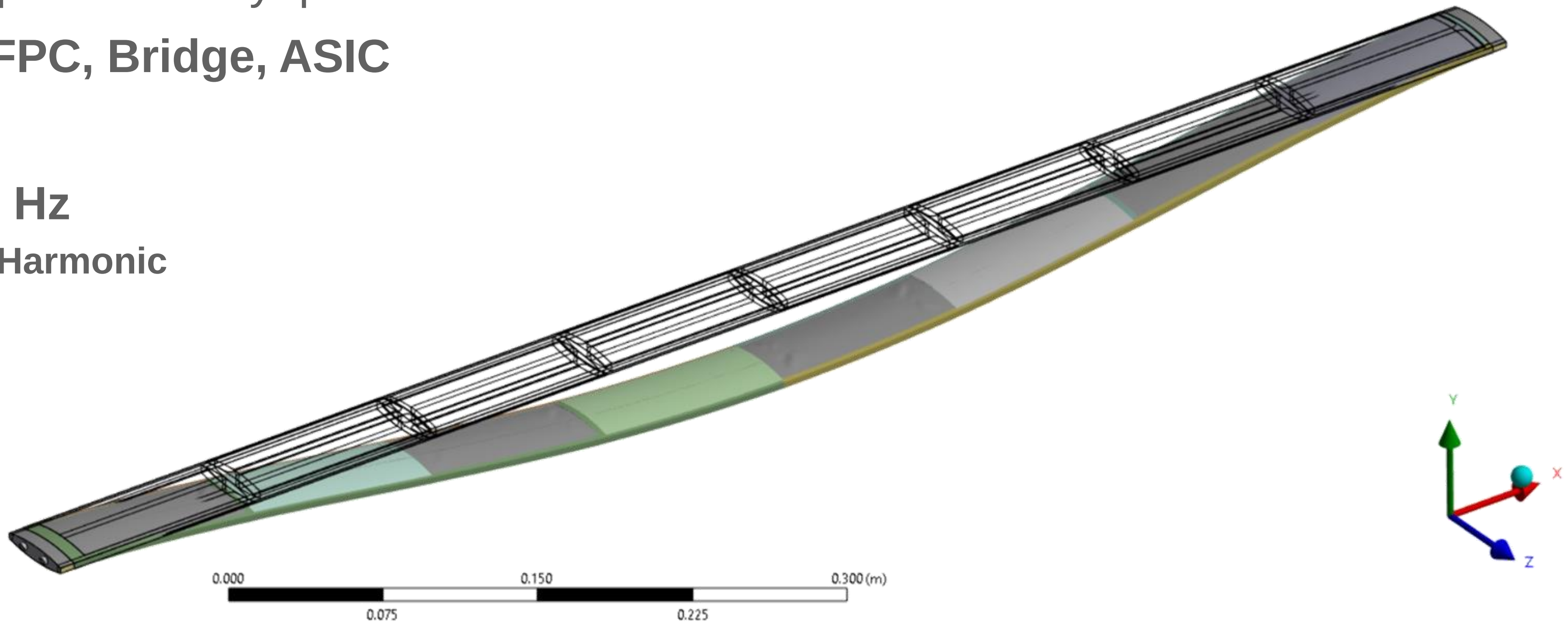
Modal Analysis of L4

- FPCs (Kapton layer), carbon skin and sensors are geometry modelled as mid plane, with 0.1 mm thick shell elements
- Carbon fibre top and bottom plates used layer section to approximate layup
- **Ignores mass of FPC, Bridge, ASIC**

- **First mode: 122.7 Hz**
  - **Y direction First Harmonic**



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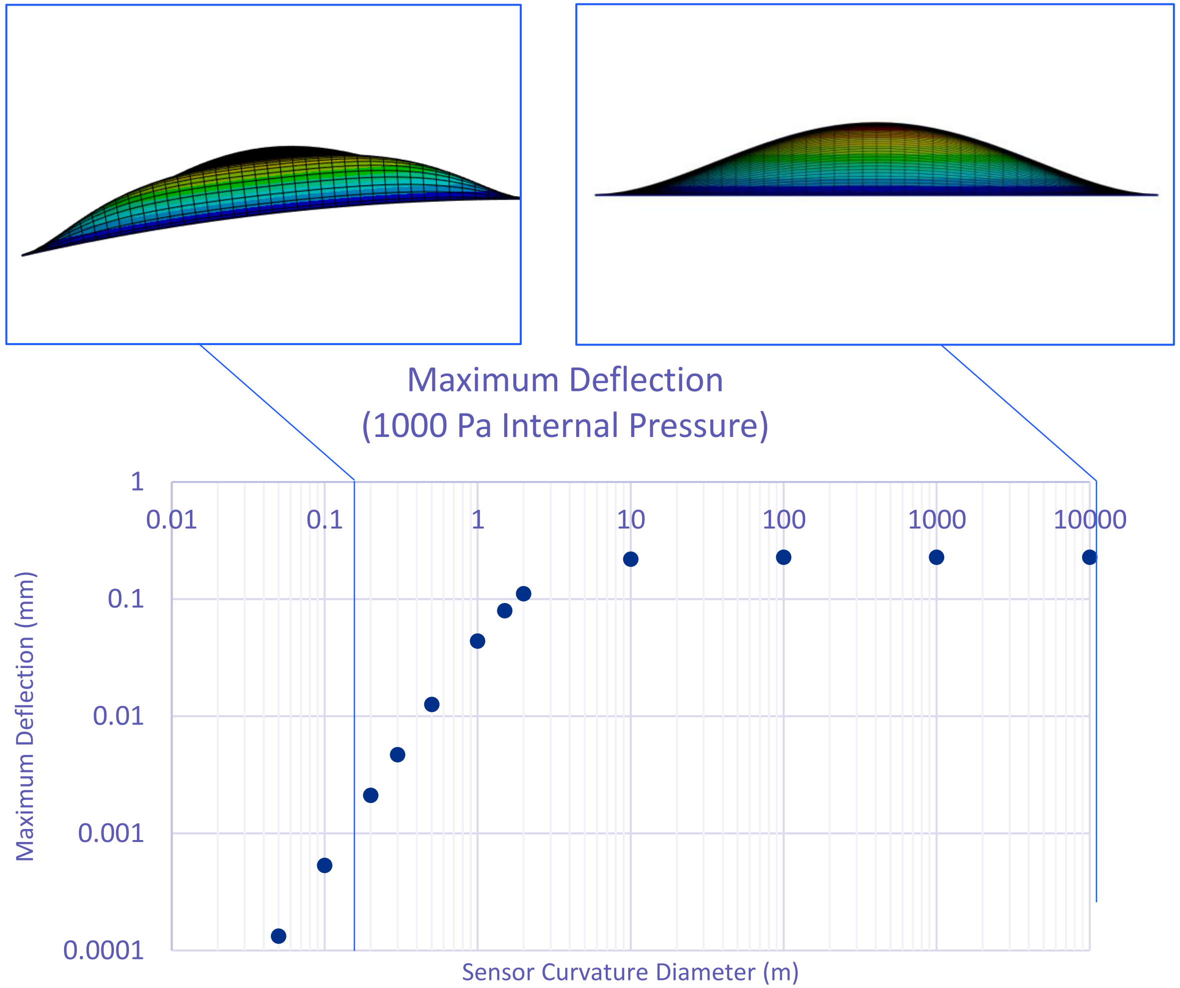
Sensor Deformation Due to Internal Pressure

- Air velocities in flow channel will be high
  - High pressure drop/high inlet pressure
- Curvature reduces deformation due to internal pressure
- Sensor/module curvature of Ø180 mm results in micron level deformation due to 1000 Pa internal pressure



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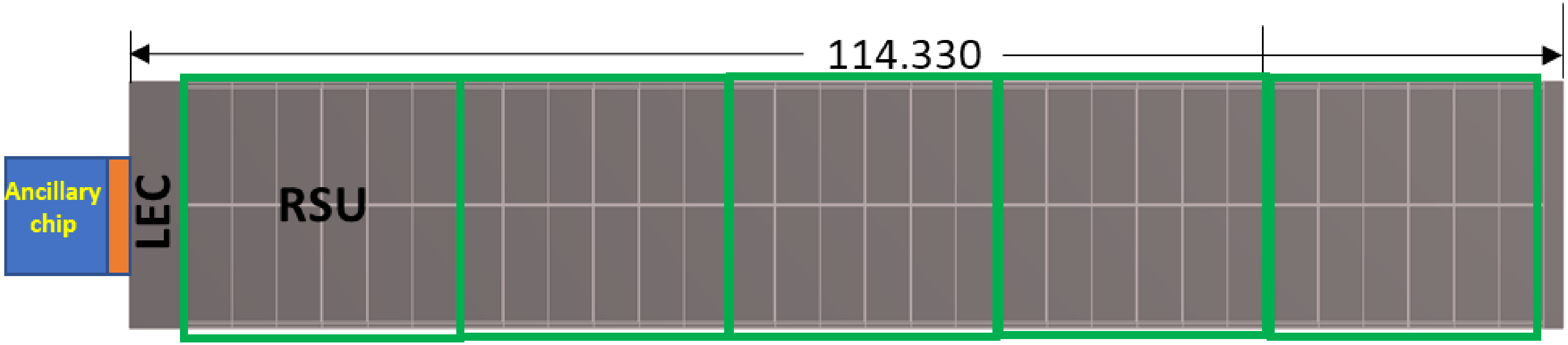
EIC-LAS Thermal Power



Ancillary chip (Si): 10mm x 10mm x 0.3mm thick
Gap (Kapton): 1mm x 10mm x 0.025mm thick
Sensor thickness: 0.04mm

Power density input at Max 25°C	[W/cm²]
LEC	0.791
active area of RSU	0.044
Pixel matrix	0.032
Biasing	0.168
Readout peripheries	0.457
Data backbone	0.719

Power density input at Max 45°C	[W/cm²]
LEC	**1.305**
active area of RSU	0.062
Pixel matrix	0.051
Biasing	0.168
Readout peripheries	0.496
Data backbone	0.719
ancillarychip	**1.521**

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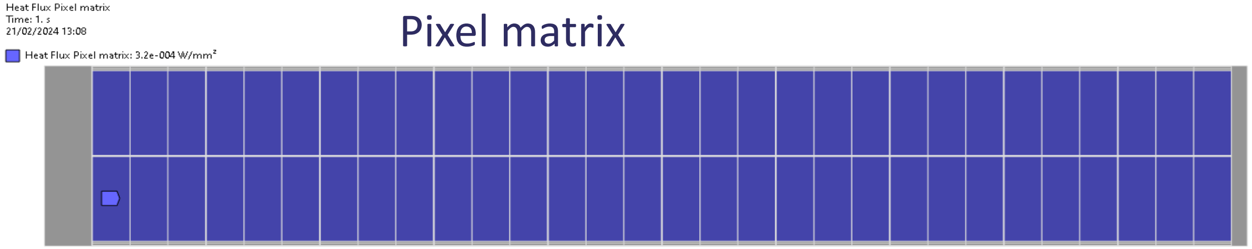
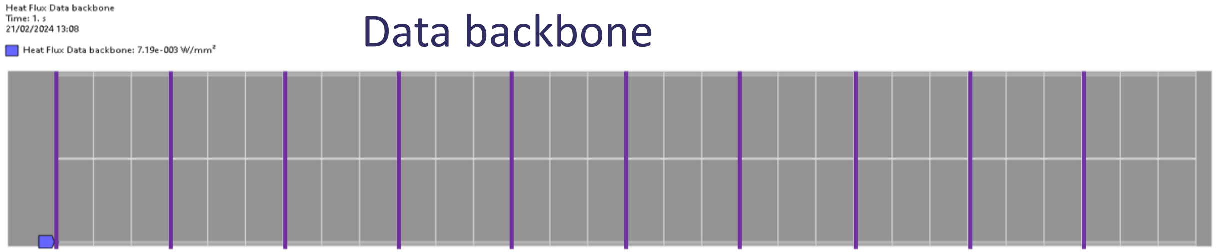
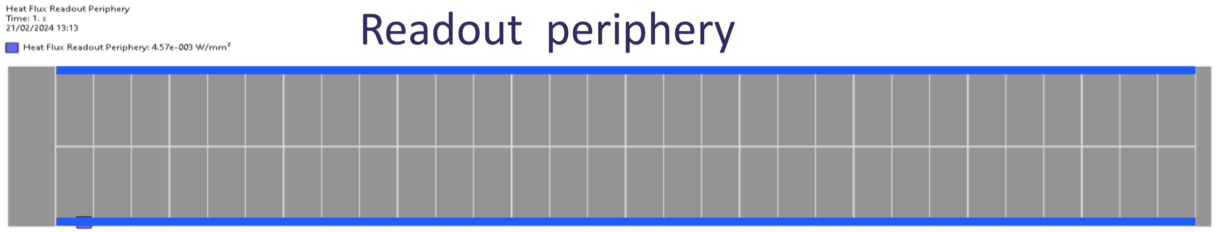
Power Density Input

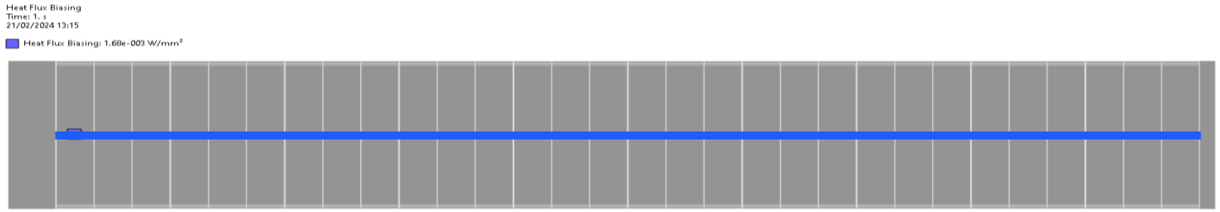
Power density input at Max 45°C	[mW/cm²]
LEC	**1305**
active area of RSU	**62**
Pixel matrix	51
Biasing	168
Readout peripheries	496
Data backbone	719

- Steady state thermal analysis
- Thermal model of sensor with known power densities mapped
- Initial reference T = 22C;
- Heat transfer coefficient values from 5 to 1000 W/m^{2}K are applied to the whole sensor surface
- From ALICE experimental data we can correlate HTC to required flow velocity in K9 foam









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Power Density Input

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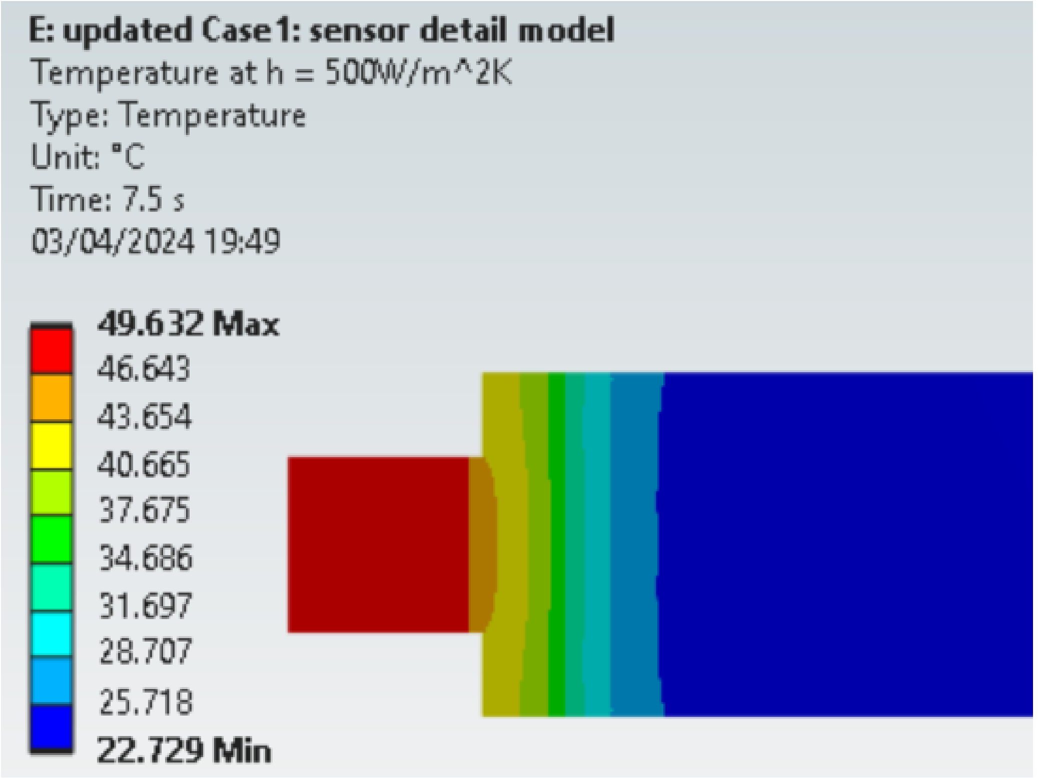
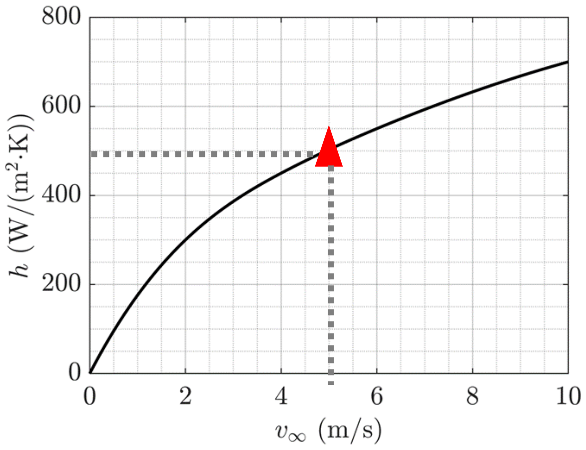


Temperature distribution of the sensor with ancillary chip, delta T = 27°C at htc = 500 W/m^2K



Reference: https://indico.cern.ch/event/1228295/contributions/5390941/

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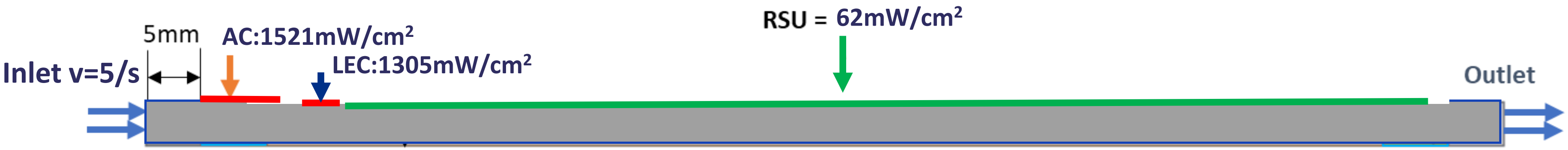
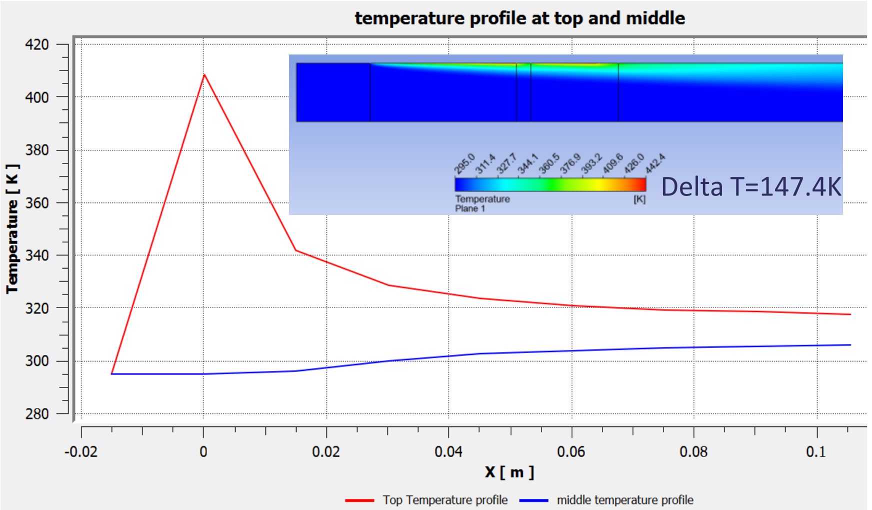
CFD 2D model (without K9 foams)

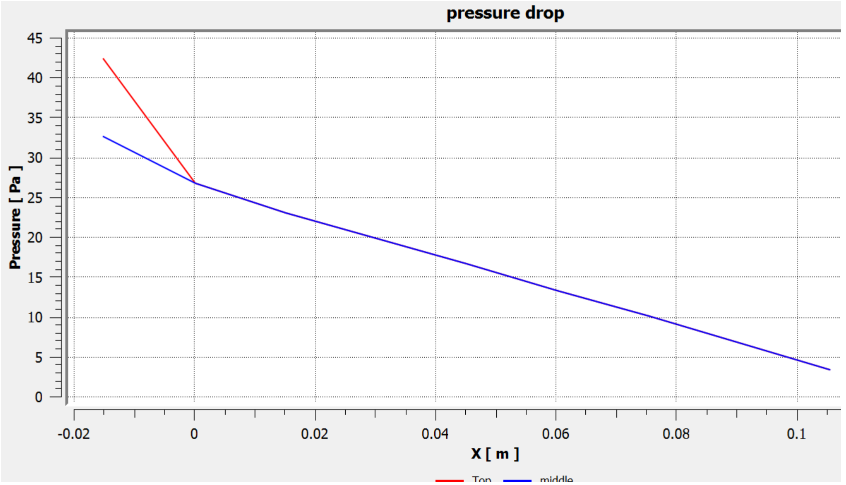
2D geometry and CFD input:

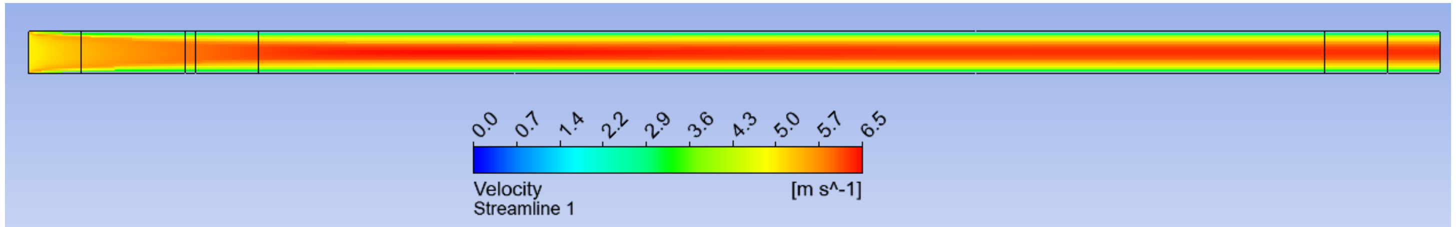


Adiabatic wall boundary conditions applied to the rest of the model

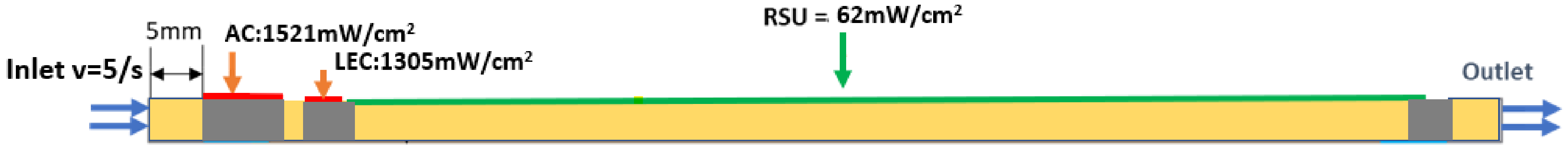


Linear pressure drop along the length





CFD 2D model (with K9 foams)



Adiabatic wall boundary conditions applied to the rest of the model

Ancillary chip foam 10mm thick;
Gap between LEC and ancillary chip: 1mm

K9 foam

Properties

Density [kg/m³]	constant
	200
Cp (Specific Heat) [J/(kg K)]	constant
	710
Thermal Conductivity [W/(m K)]	constant
	25

Setting	Current Value
Setup	
Cell Zone Conditions	
Fluid	
k9_foam1 (fluid, id=11)	
Solid Material Name	foam-k9
Porosity	0.89
Direction-2 Inertial Resistance	1259180 [m^-1]
Direction-1 Inertial Resistance	1259.18 [m^-1]
Direction-2 Viscous Resistance	412000000000 [m^-2]
Direction-1 Viscous Resistance	412000000 [m^-2]
Porous zone?	True
k9_foam2 (fluid, id=12)	
Solid Material Name	foam-k9
Porosity	0.89
Direction-2 Inertial Resistance	1259180 [m^-1]
Direction-1 Inertial Resistance	1259.18 [m^-1]
Direction-2 Viscous Resistance	412000000000 [m^-2]
Direction-1 Viscous Resistance	412000000 [m^-2]
Porous zone?	True

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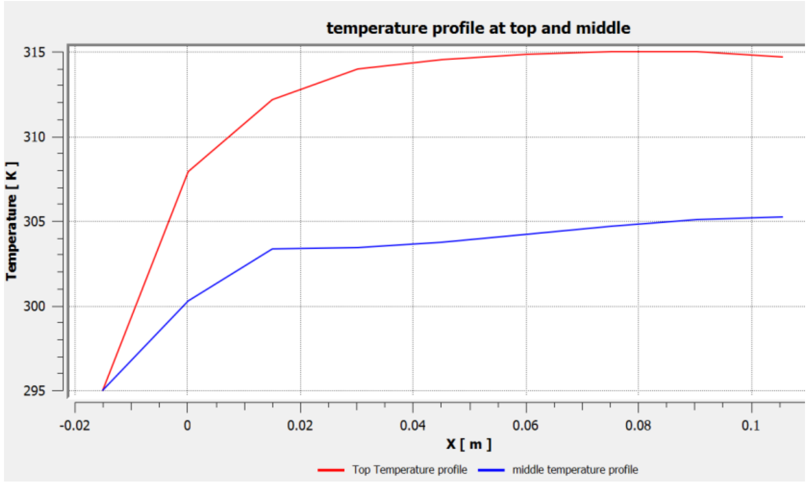
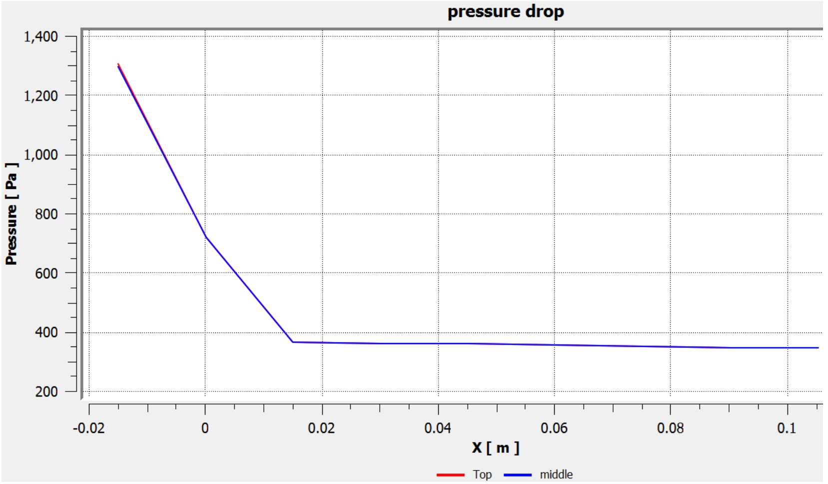
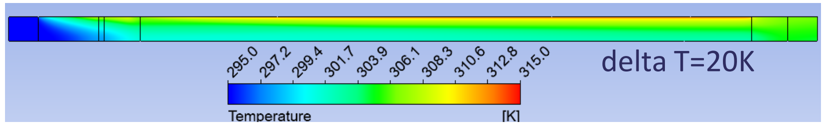
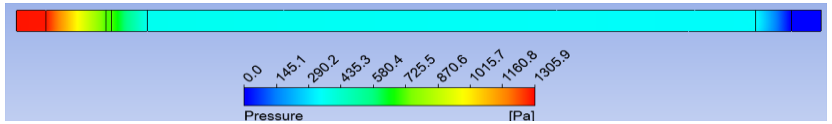
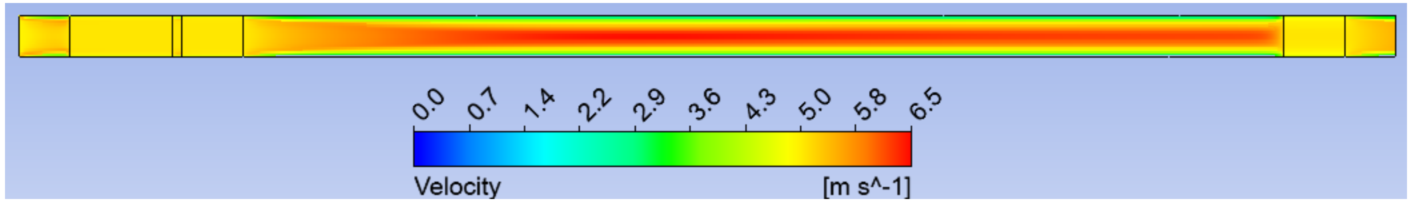
CFD 2D model (with K9 foams)











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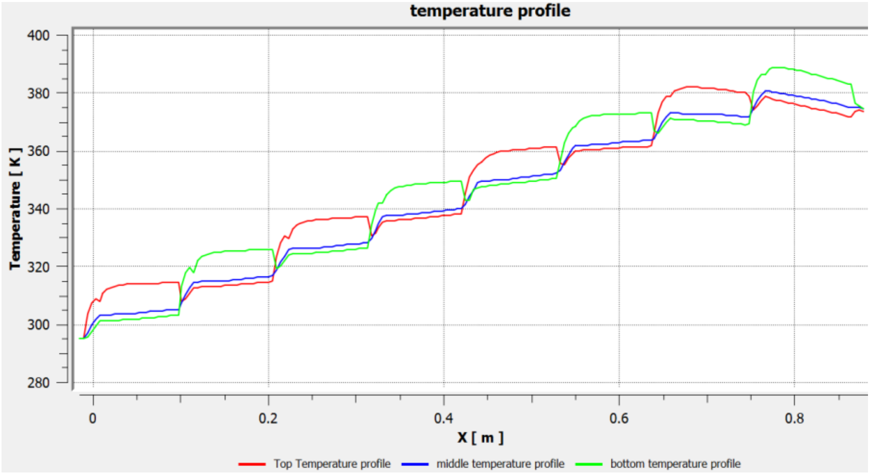
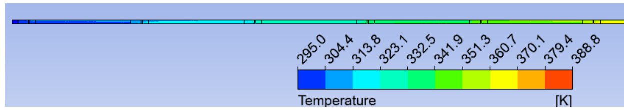
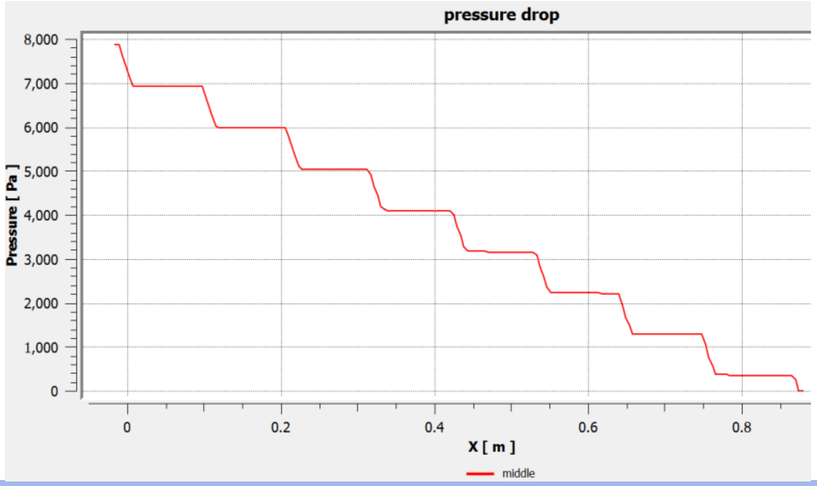
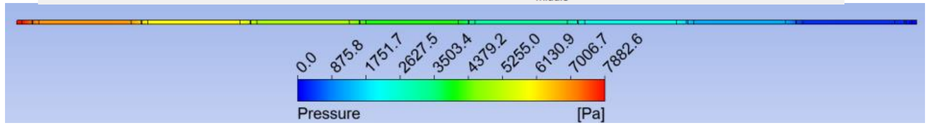
CFD 2D model L4 arrangement (5 m/s)

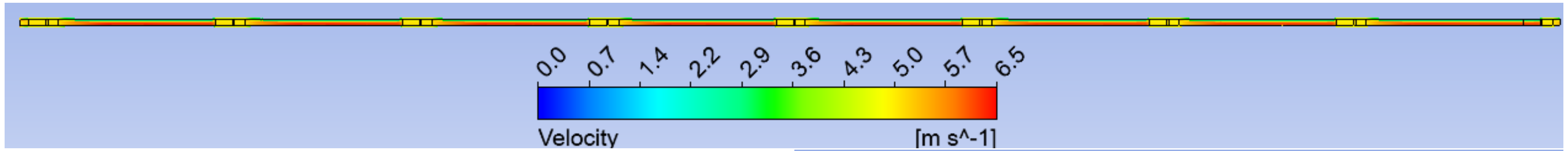




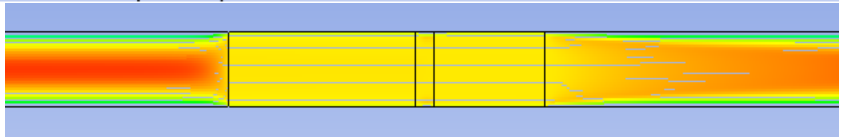
Delta T=93.8K







10mm thick foams under each Ancillary chips



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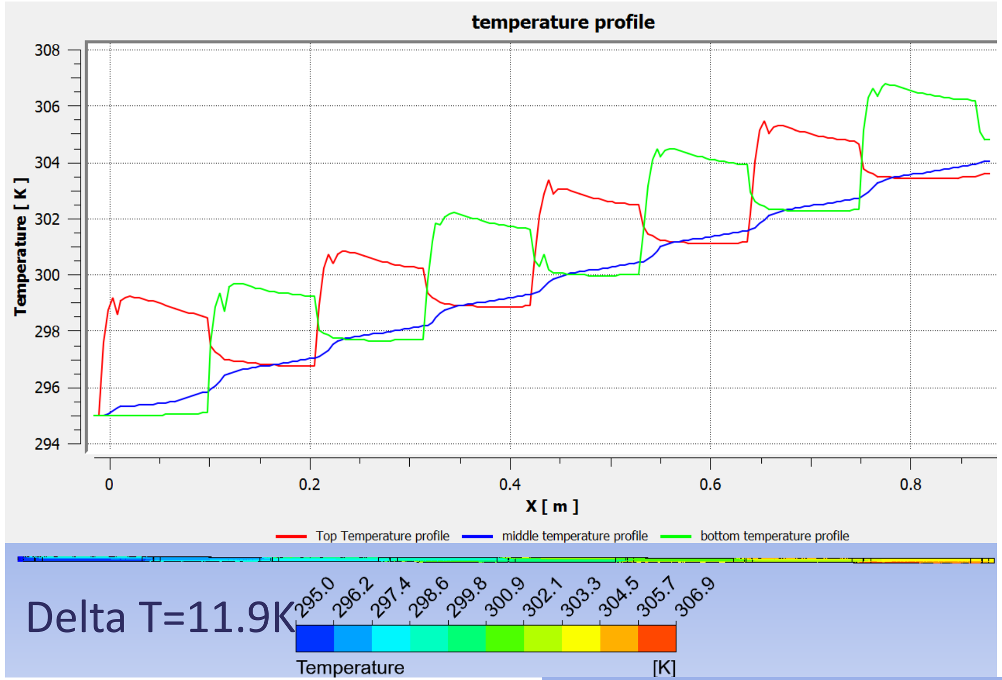
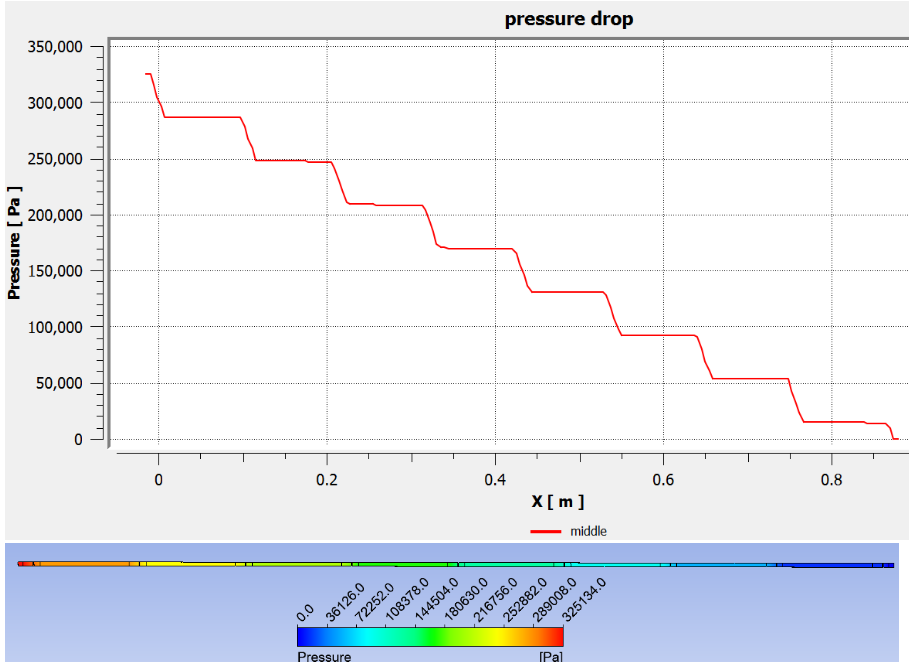
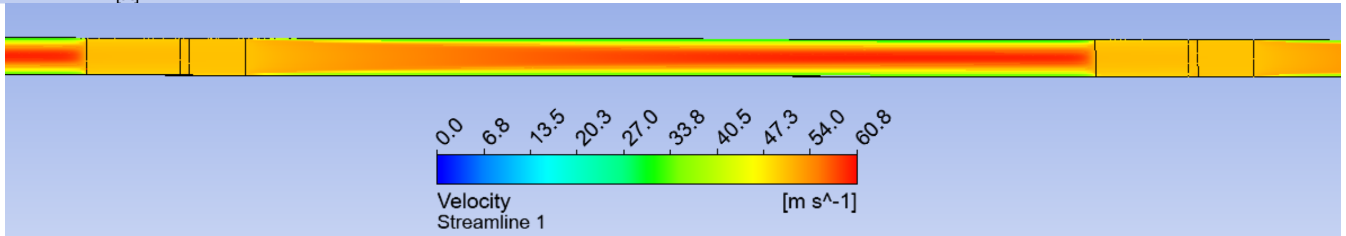
CFD 2D model L4 arrangement (50 m/s)







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50 m/s is unfeasible, but what it does give is higher thermal mass of coolant

Next Steps

- Effect of counter-current flow on temperature peaks
- 2D CFD does not capture curved profile of the stave, 3D model needed to see depth effects
- Effect of internal cross section on peak temperature

Assembly Tooling

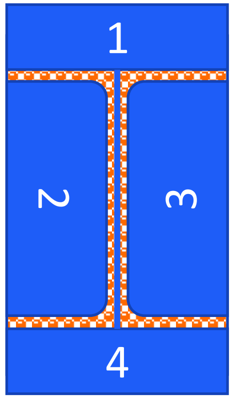
End Goal L4

Without Modules alternating top/bottom open sides

Bottom

Top

Tooling Requirements



Assembly Steps:

1. Low Temp curing of Central I beam
    - 4 part machined mould
2. Build up the carbon foam skeleton on the mould tool
3. Co-curing composite top/bottom skin to the foam and 4 FPCs
4. Building sensor modules
5. Transfer Modules onto Staves

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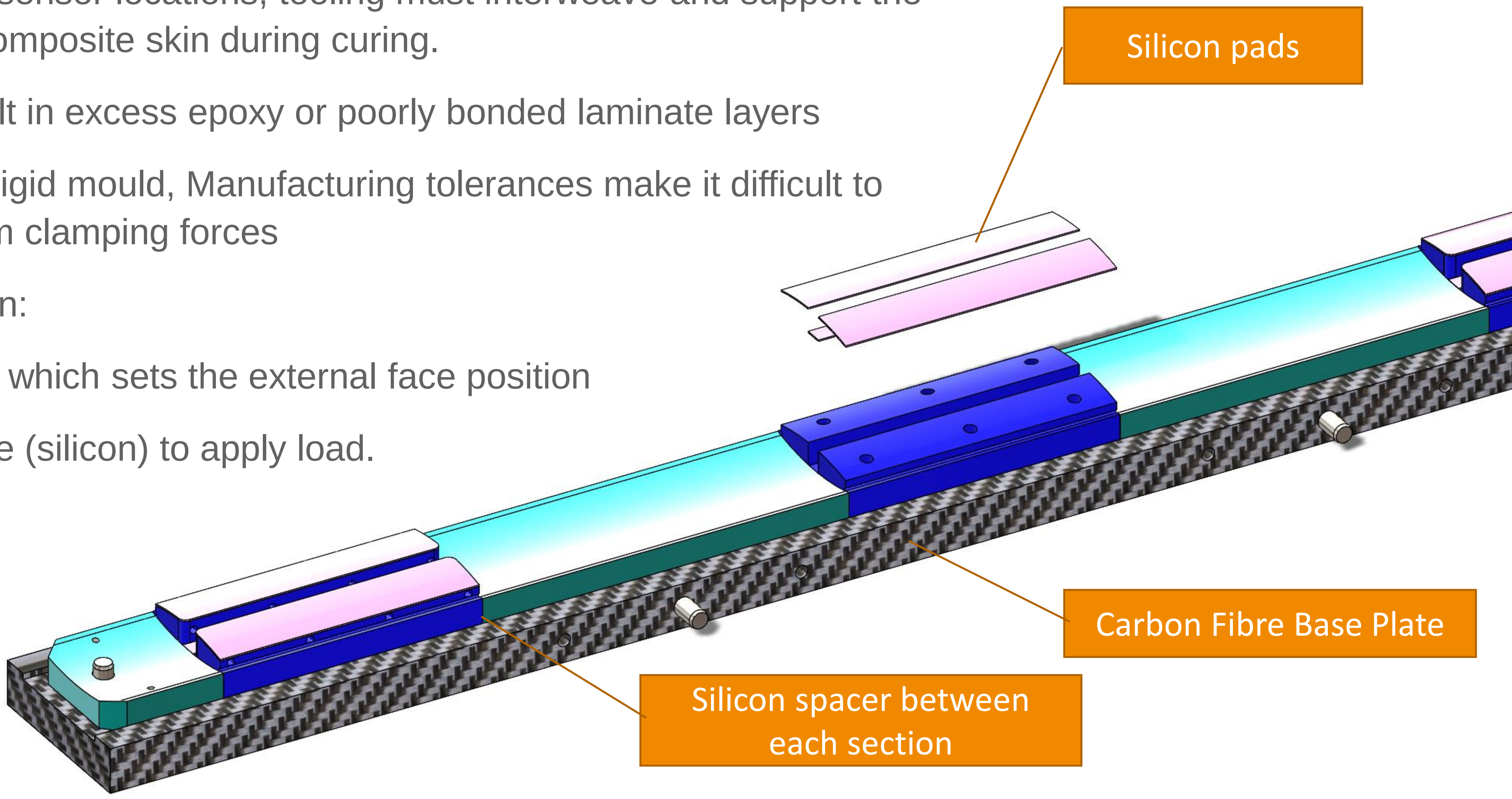
Tooling Requirements

- Due to alternating sensor locations, tooling must interweave and support the underside of the composite skin during curing.
- Any voids will result in excess epoxy or poorly bonded laminate layers
  - With a 2 part rigid mould, Manufacturing tolerances make it difficult to ensure uniform clamping forces
- To aid consolidation:
  - One rigid face which sets the external face position
  - Compliant face (silicon) to apply load.



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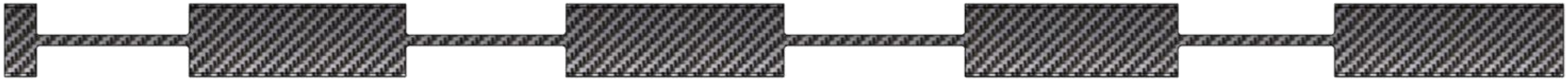
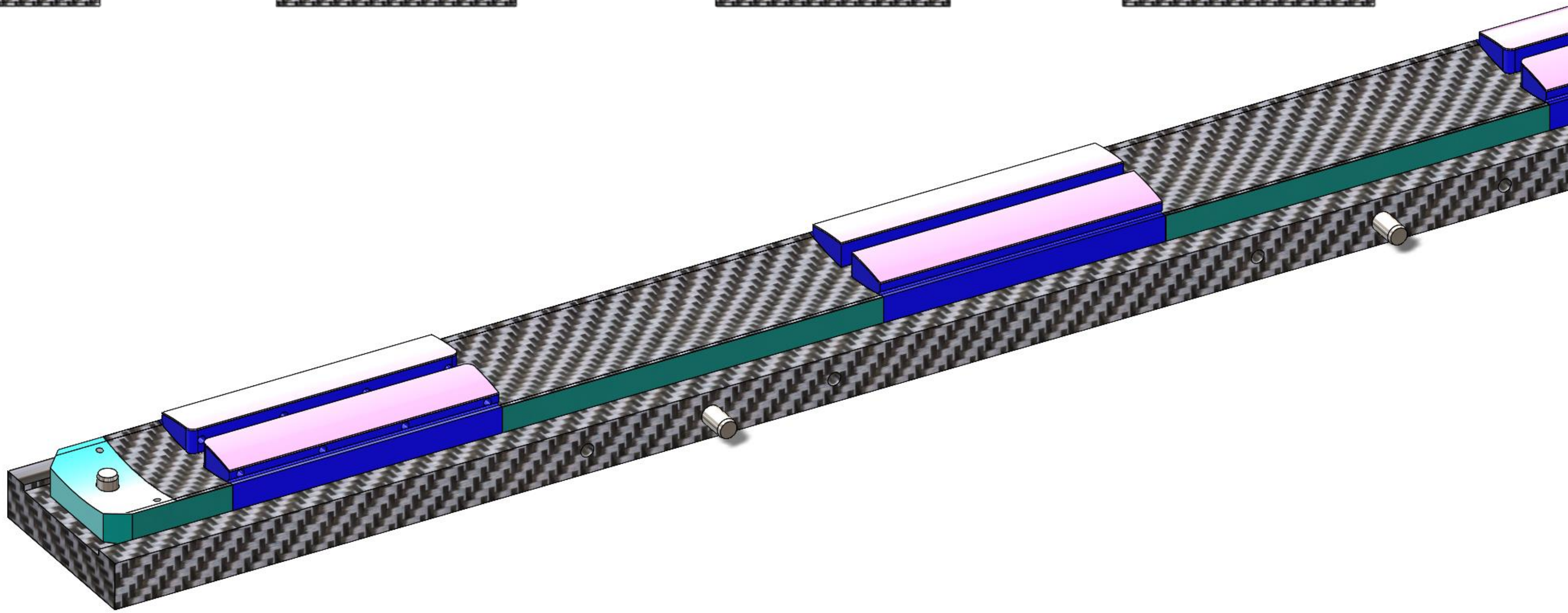
Tooling Step 1

Assembly Steps

1. Align bottom skin with mould tooling





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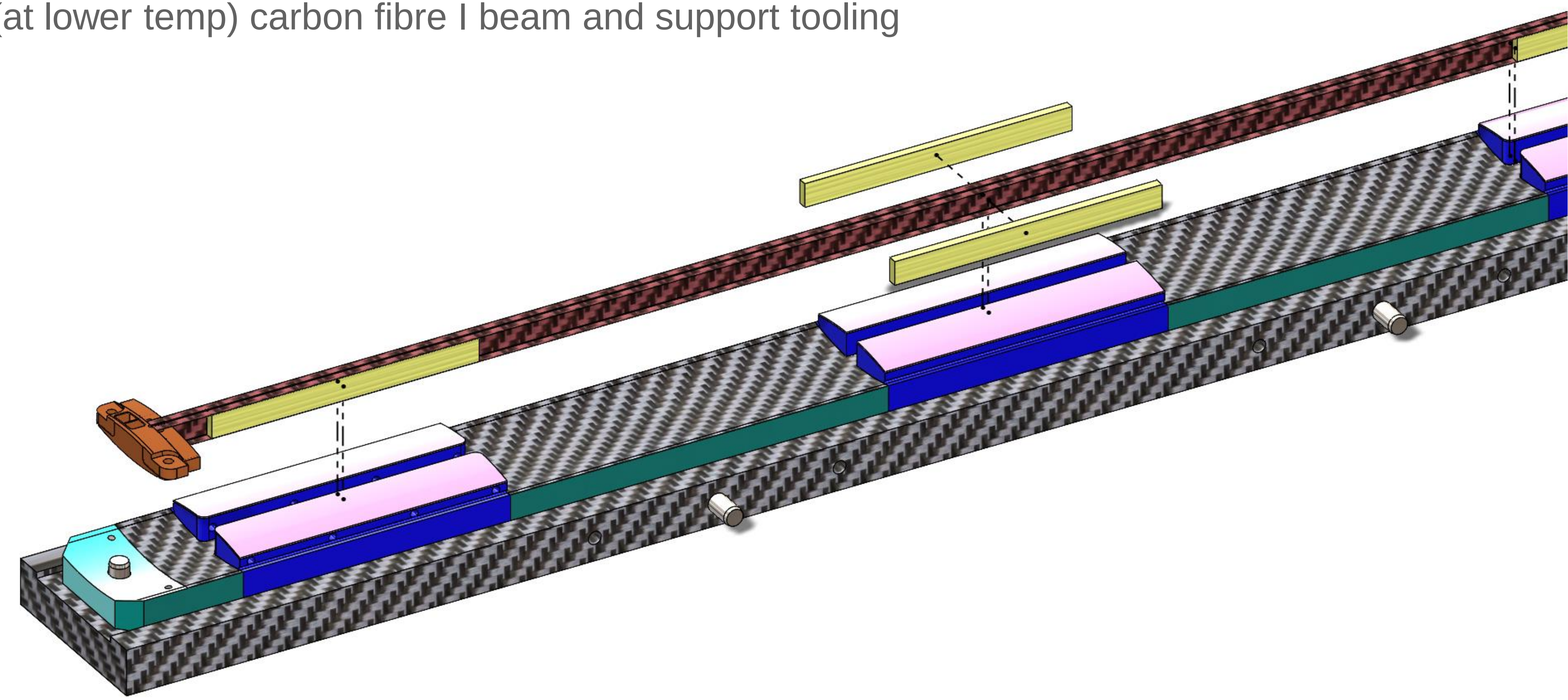
Tooling Step 2

Assembly Steps

1. Align bottom skin with mould tooling
2. Install pre-cured (at lower temp) carbon fibre I beam and support tooling



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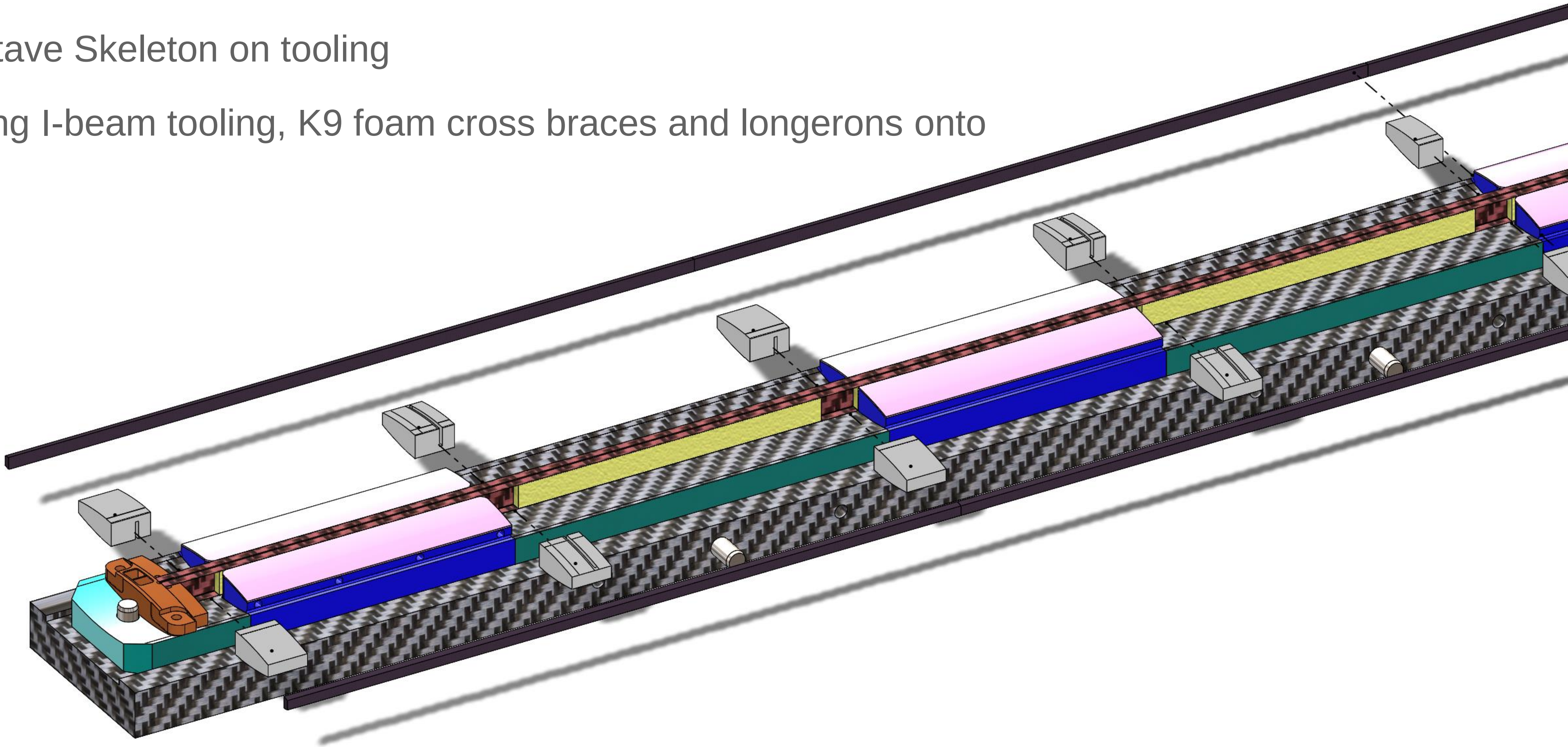
Tooling Step 3

Assembly Steps

1. Align bottom skin with mould tooling
2. Place/Build up Stave Skeleton on tooling
3. Replace remaining I-beam tooling, K9 foam cross braces and longerons onto mould



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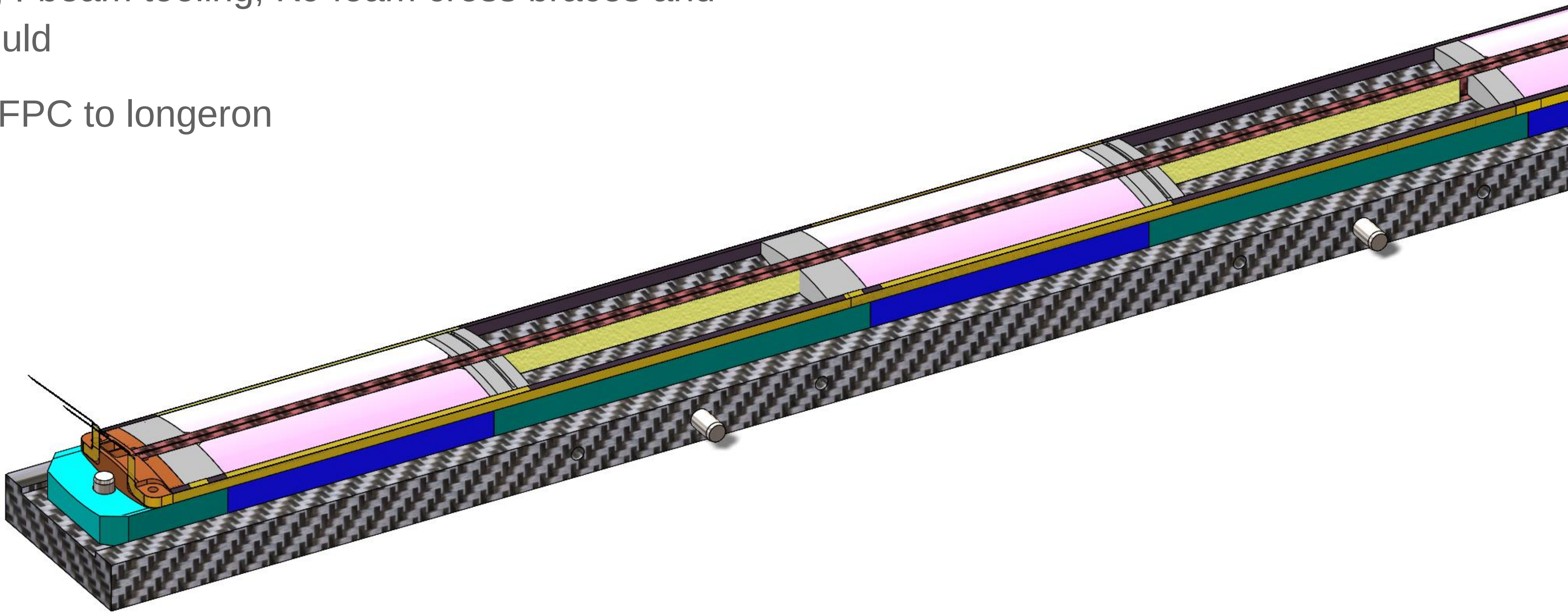
Tooling Step 4

Assembly Steps

1. Align bottom skin with mould tooling
2. Place/Build up Stave Skeleton on tooling
3. Replace remaining I-beam tooling, K9 foam cross braces and longerons onto mould
4. Adhesively mount FPC to longeron



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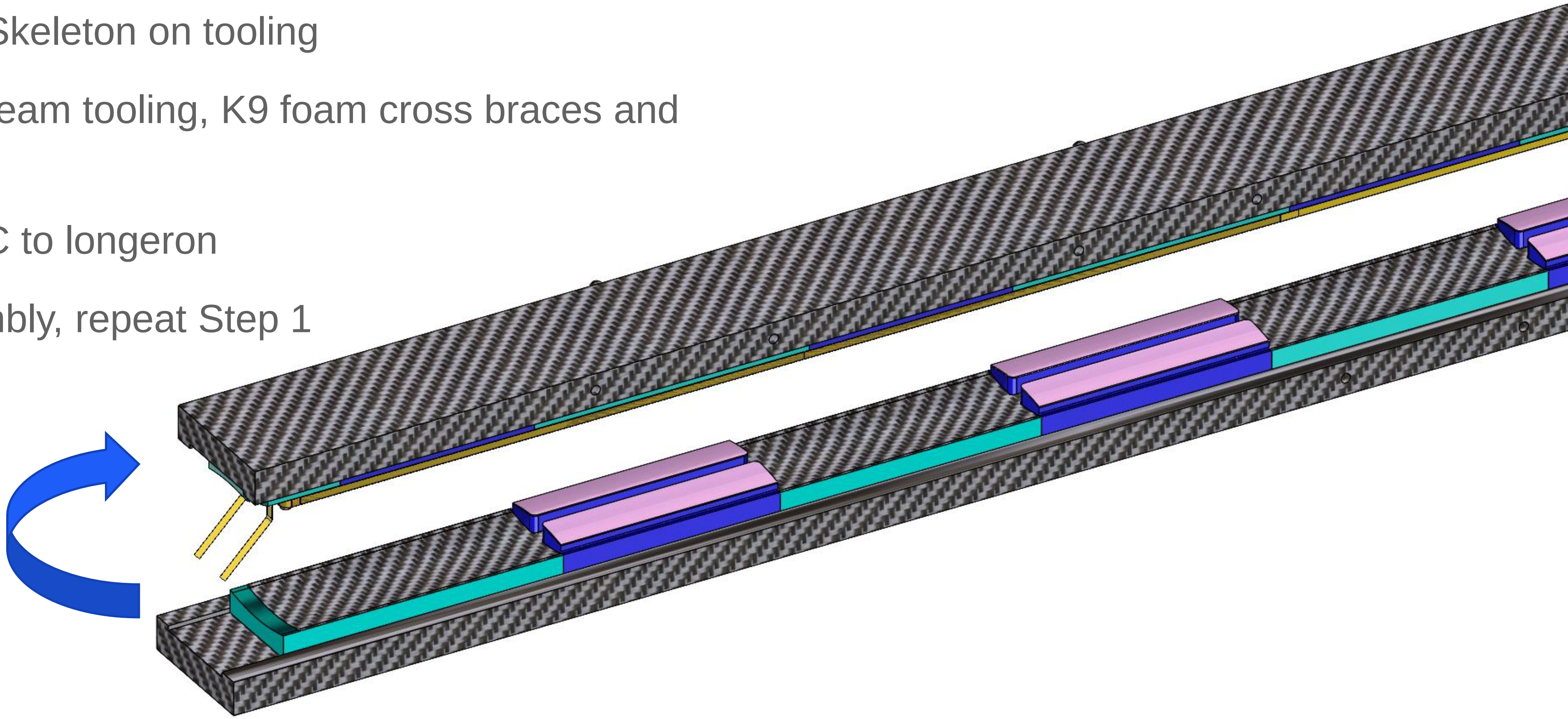
Tooling Step 5

Assembly Steps

1. Align bottom skin with mould tooling
2. Place/Build up Stave Skeleton on tooling
3. Replace remaining I-beam tooling, K9 foam cross braces and longerons onto mould
4. Adhesively mount FPC to longeron
5. Flip over mould assembly, repeat Step 1



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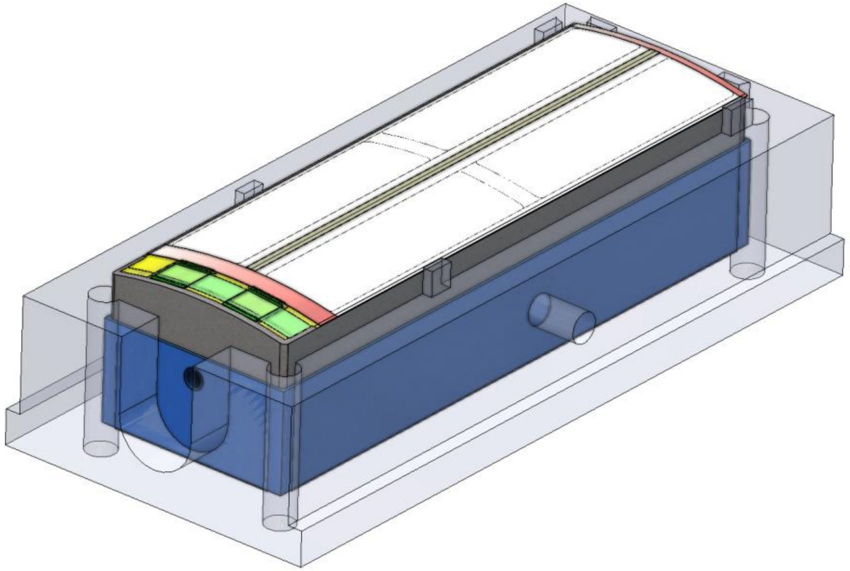
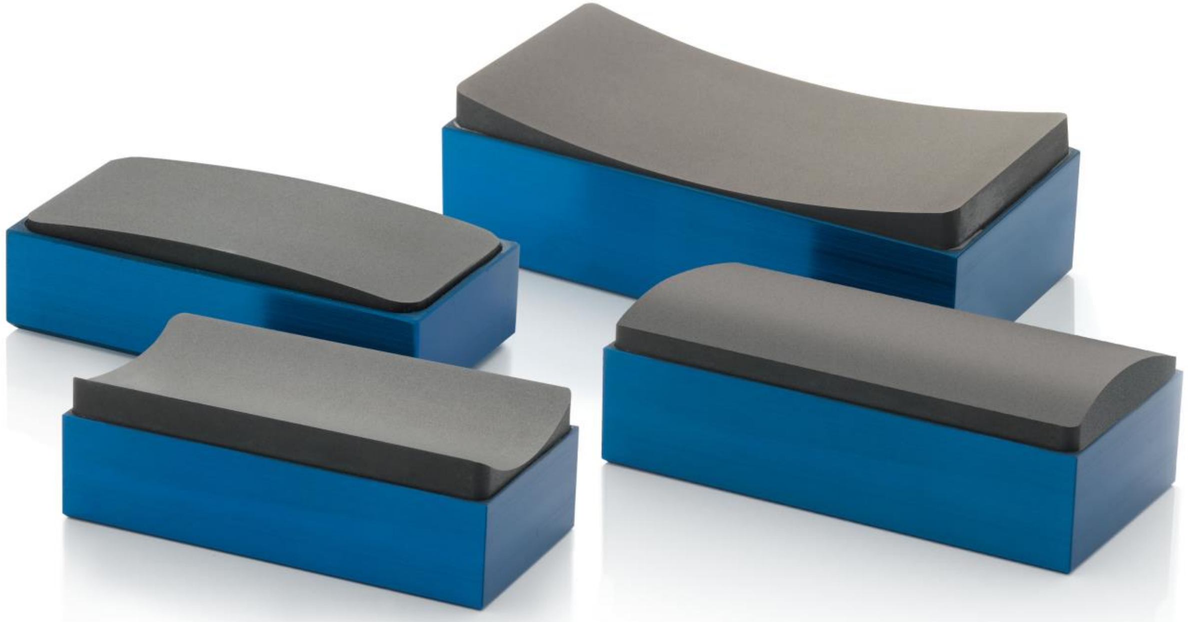
Module Assembly Tooling

Assemble and align Module Carrier, LAS, ASIC, Bridge and kapton cover strip

Machined surround to give alignment features for carrier and LAS





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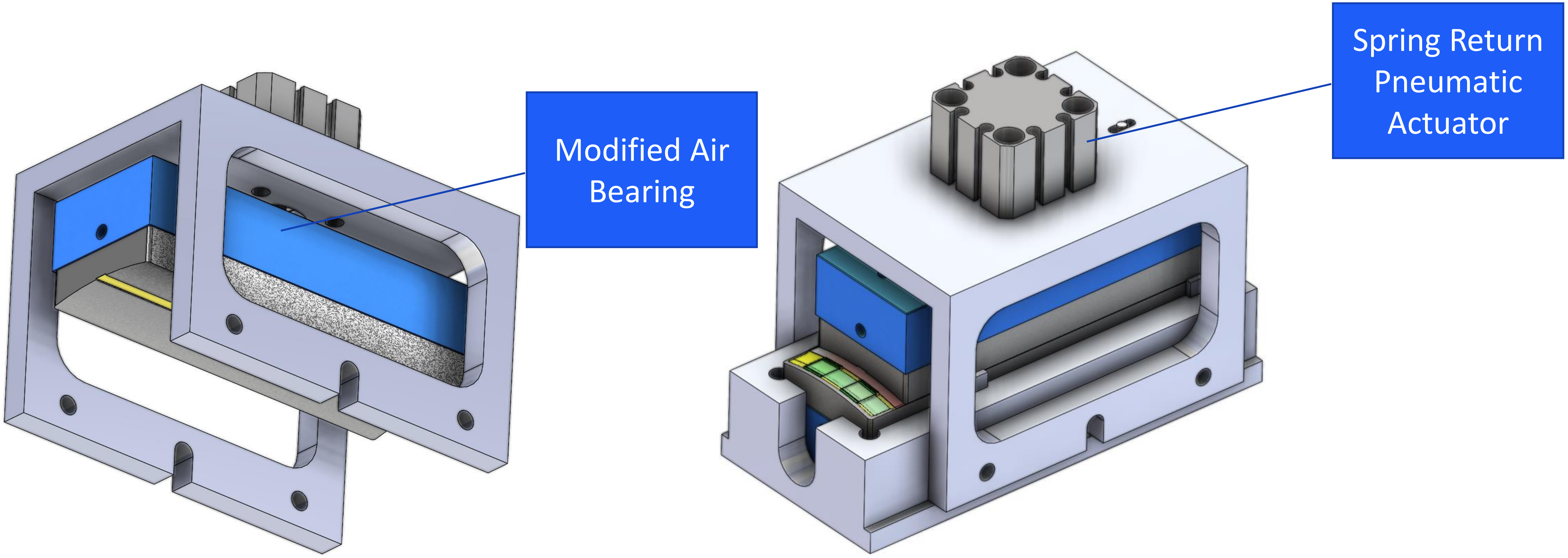
https://www.newwayairbearings.com/catalog/radial-air-bearings/

Transfer Tooling

Similar idea use porous air bearings as vacuum hold down tooling

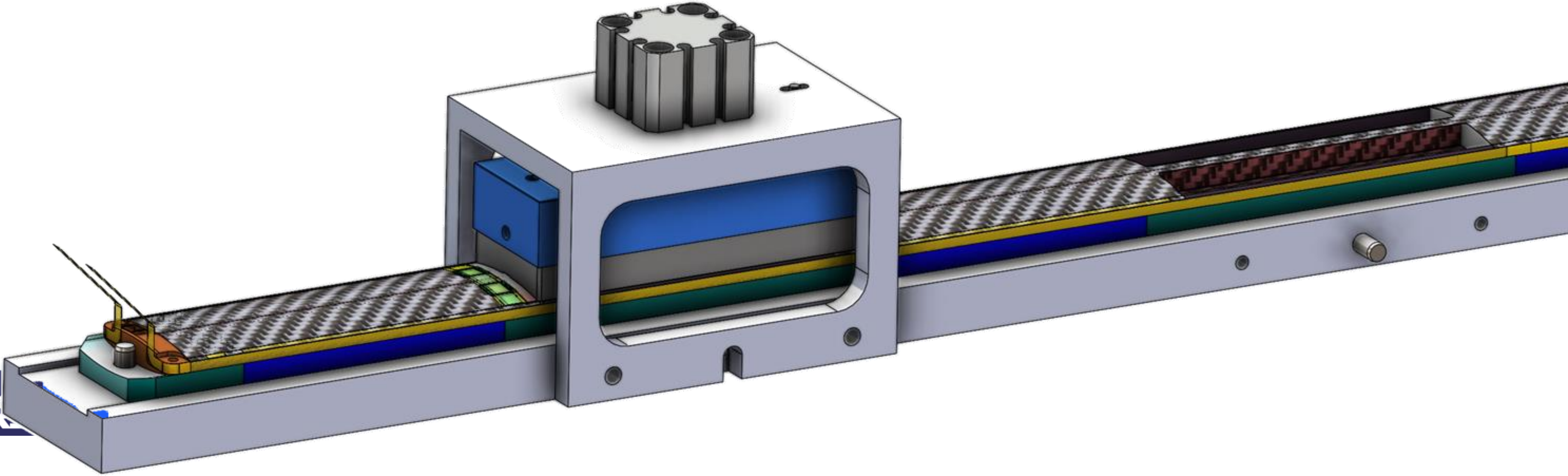
Transfer tooling would not have locating features for the Module itself but rely on matching alignment features on the Module assembly tooling and the module mounting tooling to keep alignment



Tooling Requirements

Move Stave onto a third long tooling section with vacuum hold down and cutaways around sensor and FPC/ASIC locations, adhesively mount the 4 top side modules.

Use a mirrored assembly with vacuum hold down to transfer stave and flip it over to allow 4 other modules to be mounted



Next Steps

- Prototype tooling and test manufacturing process – Summer 2024
- Experimental test setup for air cooling
  - Replicas LAS with heating elements
- Experimental test setup for structure stiffness

Questions

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Thermal Mass Model

Coolant Temperature	LEC Power Density	LEC Area	LEC Power	ASIC Power Density	ASIC Area	ASIC Power	RSU Power Density	RSU Total Area	RSU Total Power	Total Power
293.00	7910	0.00009	0.7119	15210	0.0001	1.521	44	0.00217	0.095	2.328
294.25	7910	0.00009	0.7119	15210	0.0001	1.521	44	0.00217	0.095	2.328
295.50	7910	0.00009	0.7119	15210	0.0001	1.521	44	0.00217	0.095	2.328
296.75	7910	0.00009	0.7119	15210	0.0001	1.521	44	0.00217	0.095	2.328
298.00	7910	0.00009	0.7119	15210	0.0001	1.521	44	0.00217	0.095	2.328
299.25	7910	0.00009	0.7119	15210	0.0001	1.521	44	0.00217	0.095	2.328
300.50	7910	0.00009	0.7119	15210	0.0001	1.521	44	0.00217	0.095	2.328
301.75	7910	0.00009	0.7119	15210	0.0001	1.521	44	0.00217	0.095	2.328
303.00	7910	0.00009	0.7119	15210	0.0001	1.521	44	0.00217	0.095	2.328

Flow Velocity	12.45	m/s
CSA	1.24E-04	
Density	1.2	
mDot	0.00185	kg/s
Cp	1005	J/kgK

10.00 C

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Mass & Radiation Length

ITEM NO.	PART NUMBER	Material	DENSITY(kg/m^3)	MASS(g)	QTY.	TOTAL VOLUME	TOTAL MASS (g)	X0(cm)	X/X0
1	Cross Brace	K9 Carbon Foam	200	0.41	9	1.85E-05	3.69	260.82	0.02%
2	Longerons	8% Rel Vol Aluminium Foam	216	1.66	1	7.69E-06	1.66	296.5666667	0.01%
5	Mid Brace	3% PRV Foam	45	0.10	8	1.78E-05	0.8	644	0.01%
6	Carbon Top Plate	Carbon Fibre	2000	4.14	2	4.14E-06	8.28	19.32	0.07%
7	ALICE SENSOR ASSEMBLY	Silicon	2330	0.50	8	1.70E-06	3.961072	9.37	0.06%
9	Kapton FPC - 2-4	Kapton	1420	0.85	2	1.19E-06	1.693468	28.57	0.01%
10	MirrorLongerons		216	1.66	1	7.69E-06	1.66	296.5666667	0.01%
11	Kapton FPC - 1-3	Kapton	1420	0.70	2	9.86E-07	1.4	28.57	0.01%
12	Stave End Gas Feed	Ultem	1280	0.84	1	6.56E-07	0.84	28.57	0.01%
13	Stave End Gas Feed	Ultem	1280	0.92	1	7.19E-07	0.919726	28.57	0.01%

Total Mass	**24.90**	**Total Radiation Length**	**0.21%**

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EXCLUDES CONTRIBUTIONS FROM FPC,BRIDGE FPC OR ASIC