WP5 Mechanics and Cooling

		achieved	need to be achieved and will be included	need to be achieved and will not be included
REQUIREMENTS DEFINITION		• STABILITY • OPERATIVE TEMPERATURE	• OVERLAP • LAYERS STAGGERING • LAYERS RADIUS • LAYERS NUMBER • POWER MAP • POWER ON C-SIDE	
LAYOUT		• 3 layers, no overlap, service A-side	• 1.5 mm Vs beampipe; 1mm Vs Halves • Change radius layers/support on beampipe • Services A and C-side	• 3+ layer, overlap, offset, radius, services sides
MATERIAL		• carbon foam, glue	• Material budget assessment and optimisation	
ASSEMBLY	silicon bending	• Engineering Model with bent dummy silicon	• Qualification Model with bent prototype sensors -->	• --> --> -->
	services at sensor edges	• Design of FPC/ Cooling ducts	• Engineering Model with dummy silicons+FPC; • + PW to C-side	• Qualification model with prototype sensors +FPC+PW C-side
COOLING		• air cooling / stability vibration-thermoelastic	• Wind tunnel test on Engineering Model with dummy silicon+heater (ongoing)	• Wind tunnel test on Qualification Model with dummy sensors
SERVICE BARREL		• reuse of ITS2 service barrel	• New service barrel design if required to fulfil different requirements	
INSTALLATION		• reuse of ITS2 installation sequence	• Design remote matching/ on-beampipe	• Barrel Mock-up to demonstrate feasibility and beam pipe interface

1 Detector Layer

1.1 Silicon layer
  - *Definition and description*

1.2 Mechanics and Cooling
  - *Definition and description*

1.3 FPC
  - *Definition and description*

1.4 Material budget
  - *Plot of L0 material budget*

2 Mechanical support structure and cooling

2.1 Design
  - *Design Requirements: non/operative temperature, stability,..*
  - *Design Specification to match requirements and boundary conditions*

2.2 Materials and production processes

2.2.1 Carbon foam
  - *Material choice and characterisation*
  - *Thermal Carbon foam, pressure drop and thermal conductivity*
  - *Structural Carbon foam*

2.2.2 Glues
  - *Material choice and characterisation*

2.2.3 Interfaces
  - *Thermal resistance and material budget characterisation and optimisation*

2.3 Thermal characterization

2.3.1 CFD analysis
  - *Thermal map of layer Vs airspeed*
  - *Air flow optimisation*

2.3.2 Wind tunnel test thermal validation
  - *BBMs layout and test results*

2.3.3 Comparison between CFD and tests

2.4 Mechanical characterisation

2.4.1 Aeroelastic analysis and test
  - *Impact of airflow on sensor stability, vibration*

2.4.2 Thermoelastic analysis and test
  - *Impact of thermal on sensor stability, thermoelastic movement*

2.5 Mechanics and cooling alternative designs

3 Flex Printed circuit

3.1 Design

3.2 xx

3.3 xxx

3.4 xxx

4 Detector assembly

4.1 Detector layout
  - *Layout and sub/assembly sequence*

4.2 Layer bending

4.2.1 Jigs and procedures

4.2.2 Layer dimensional scan (cilindricity)

4.3 Layers bonding to mechanics

4.4 Layer to FPC connection

4.5 Layers cooling ducts

4.6 Layers test and characterisation

4.7 Detector alternative layout

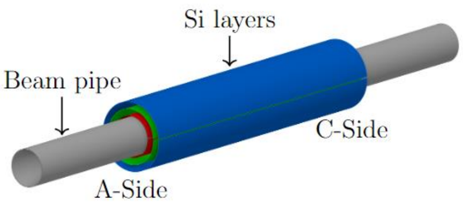
5 Global support structure, services and integration

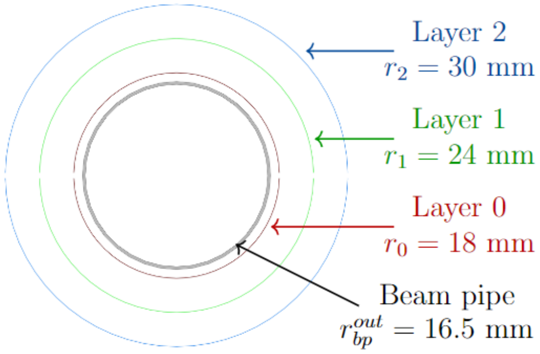
5.1 General requirements
5.2 Detector support structure
5.3 Services
5.3.1 Cooling
5.3.2 Cabling
5.3.3 Service support structure
5.4 Beam pipe
5.4.1 Beam pipe radius and wall thickness
5.4.2 Beam pipe supports
5.4.3 Beam pipe bake-out
5.5 Installation and removal
5.5.1 Sequence
5.6 Survey and mechanical alignment

1 Detector Module

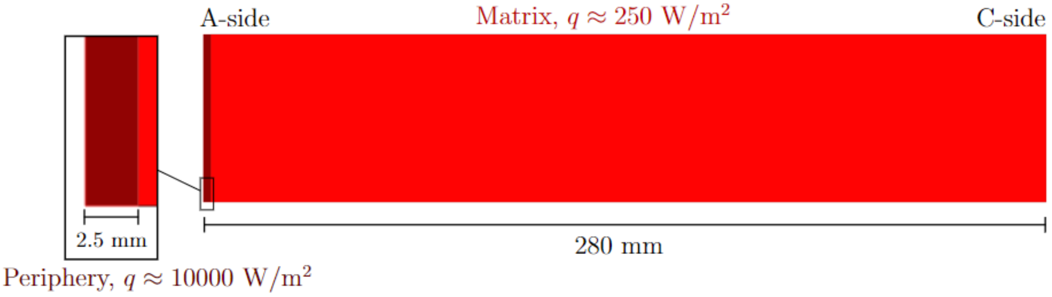
1.1 Silicon layer

The ITS3 will consist of two half barrels. Each half barrel will be based on three silicon layers that are bended into cylindrical shape.





The matrix covers almost all of the surface. Due to the wire bonding process on the A-side, there is an increased dissipation on the edge of the A-side (periphery region).



1.3 Mechanics and Cooling

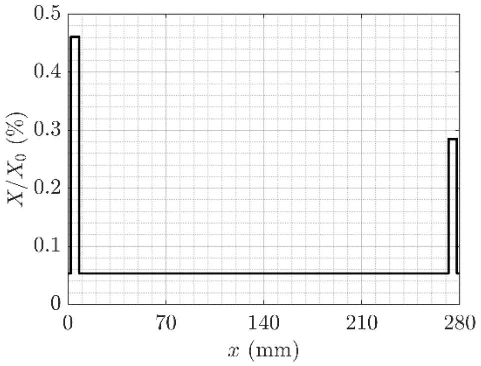
Taking into account the total dissipated heat, air cooling is chosen with a target maximum temperature increase of 10 degrees. The forced air flow is not enough to cool down the periphery region, and to increase the heat transfer rate a low-mass heat exchanger is planned to be used. Carbon (graphite) foam rings are the choice due to their high thermal conductivity and low material budget.

1.2 FPC

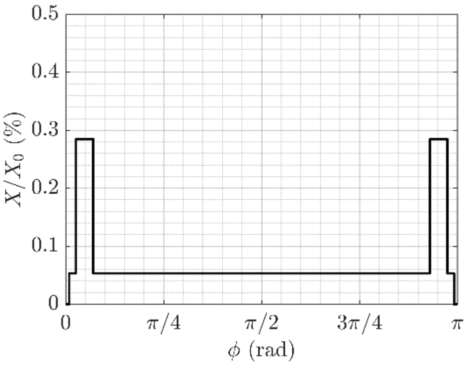
Xxxx

1.4 Material budget

The value of silicon (X_0=21.82 g/cm^2) is used to calculate the material budget of the layers, and the one of carbon (X_0=42.7 g/cm^2). The plot takes into account the glue layer that is needed for the silicon-foam interfaces. The glue that is currently used is an epoxy filled with alumina. To calculate the material budget of the glue, a standard value of an epoxy adhesive is used (X_0=43.25 g/cm^2), obtained from [1], and the radiation length of the filled glue is calculated with the formula of mixtures shown in that document, giving (X_0=23.77 g/cm^2) for the filled glue. A total glue thickness of 300 microns is considered at each of the foam-silicon interfaces.



Longitudinal direction



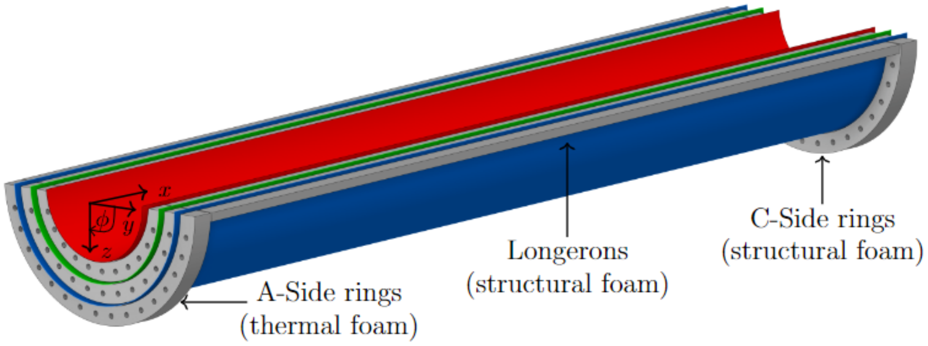
Azimuthal direction

The mean value of the material budget (X/X_0) is approximately 0.07 % in both directions.

2 Mechanical support structure and cooling

2.1 Design

The silicon layers need mechanical supports to be kept into cylindrical shape. This will be done with the addition of thermally-conductive carbon foams on the A-side (that act additionally as a radiator), and lighter and less thermally-conductive carbon foams called longerons.



The thermal interface between the carbon foam and the silicon sensor is critical. To reduce the thermal resistance, increase the mechanical resistance and reduce the amount of glue that penetrates into the foam, a carbon fleece is used at the interface. Additional details are provided in later sections.

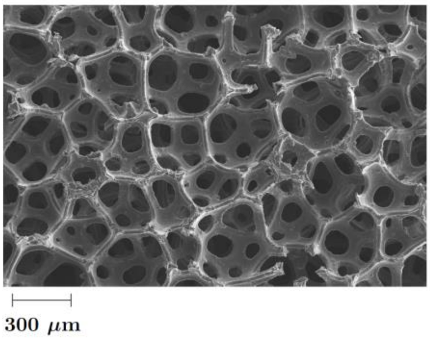
Preliminary CFD simulations have showed that a single flow distribution channel does not allow the control of the temperature distribution in the layers. To solve this issue, four separated flow channels are used.

2.2 Materials and production processes

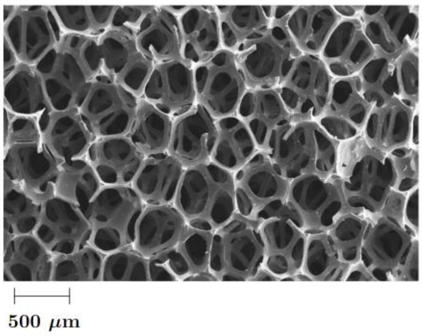
2.2.1 Carbon foam

The thermal foam selected is the K9 foam manufactured by Lockheed Martin, with a density $\rho \approx 200$ kg/m^3 and thermal conductivity $k \approx 25$ W/(m*K). The value of the thermal conductivity has been obtained from tests performed by the supplier and at CERN.

The structural foam selected is the ERG RVC 100 PPI foam, with a lower density ($\rho \approx 45$ kg/m^3). This foam has a low thermal conductivity ($k \approx 0.05$ W/(m*K)), but no thermal performance is required in the zones where this foam is used.

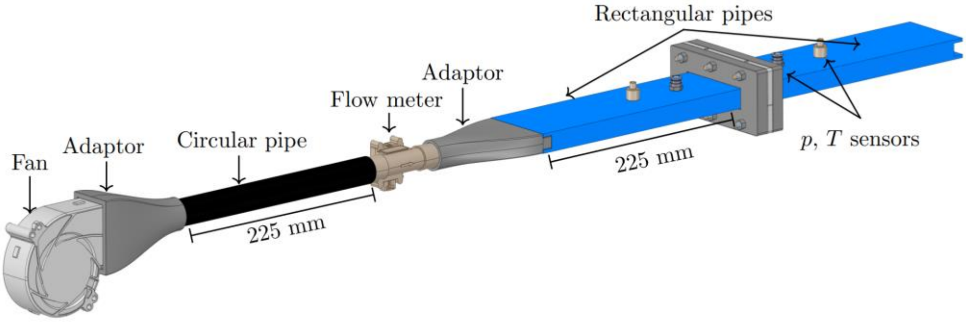


Thermal foam (K9)

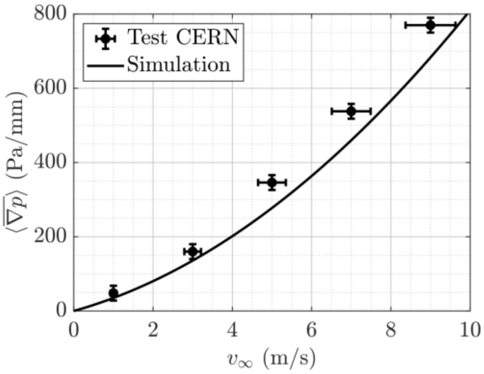


Structural foam (ERG RVC 100 PPI)

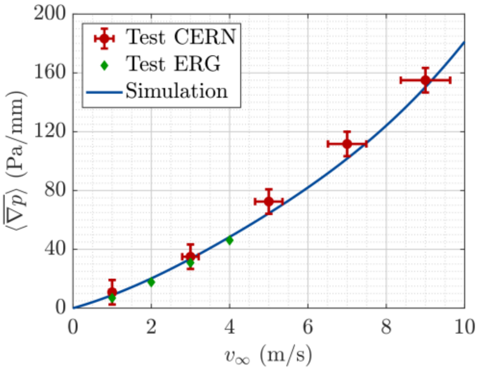
The pressure loss produced by the foams to be calculated. This value is later used in the thermal simulations of the ITS3. A computational model based on the microscopic geometry of foams has been developed, and an experimental setup has been built at CERN for testing. The experiment has a rectangular channel of 6x60 mm of section, and allows the testing of foam samples of 6x6x60 mm.



The numerical and experimental results have been compared, showing good agreement.



Thermal foam (K9)



Structural foam (ERG RVC 100 PPI)

2.2.2 Glues

A review has been done about the thermally-conductive glues (epoxy+filler) used in other experiments at CERN, and the optimum glue has been chosen in terms of the following properties:

- Viscosity: Low enough so that the glue penetrates into the foam but not too low, because in that case the material budget increases. From previous detectors, a reference in terms of viscosity is the Araldite 2011

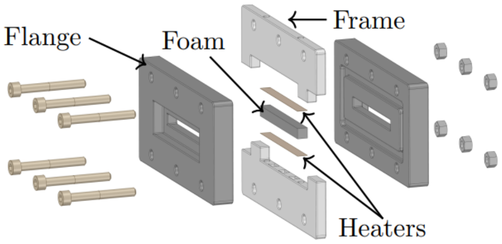
- Thermal conductivity: As high as possible.
- Radiation length: Fillers are limited to graphite, boron nitride, and alumina for material budget reasons.
- Particle size: It should be as low as possible to reduce the damage to the silicon sensors.
- Electrical conductivity: The adhesive should be an electrical insulator to contribute to the grounding and shielding tasks.
- Young modulus and ultimate shear strength
- The foam must keep the sensors into cylindrical shape. Thus, thermal gels are not taken into account.
- Coefficient of thermal expansion: It should be as closer as possible to the one corresponding to silicon ($\approx 2.5 * 10^{-6}$ K^{-1}) and carbon ($\approx 10^{-6}$ K^{-1})
- Curing temperature: Curing at higher temperatures than room temperature induce thermal stresses. Thus, the glues considered are the ones that can be cured at temperature.
- Water absorption and flammability: Water absorption should be minimized to avoid the degradation of the thermal interface, and the adhesive should meet the standard for safety of flammability UL94-V0.

Based on the previous requirements, three glues have been tested in a thermal conductivity setup built at CERN (EP-DT department), and the Epoxies 50-3150 FR has been chosen. It has spherical alumina powder of a maximum of 20 microns of diameter, a thermal conductivity tested at CERN of 0.85 W/(m*K), and a coefficient of thermal expansion of 24 $* 10^{-6}$ K^{-1}

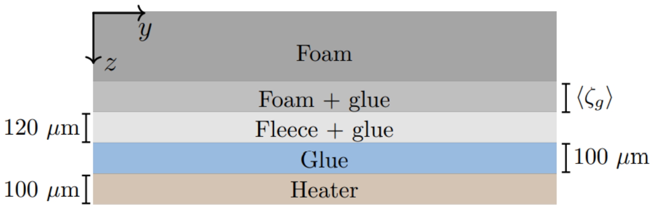
2.2.3 Interfaces

The thermal resistance of the joint between carbon foams and solid surfaces, which is expected to play a major role in the thermal performance of foams, has not been studied in depth. In this line, an initial study applied to the previously mentioned CO2 cooling systems has been performed at CERN [2]. However, the applicability to this study in other configurations with different interface materials is unclear.

Apart for measuring the pressure loss of foams, the setup mentioned before is built to represent the thermal interface between a foam and a silicon sensor in the ITS3. Previous tests performed at CERN have showed that a direct contact between the foam and the silicon sensor of 50 µm of thickness creates footprints in the sensor, which constitute a risk of deterioration of the quality of the measurements. To solve that issue, a carbon fleece of 120 µm of thickness and areal density of 8 g/m2 is added between the foam and the heater. The fleece glued to the foam provides a smoother contact, with additional contact points that lead to the reduction of the contact resistance and the increase of the shear strength of the joint. Moreover, the presence of the fleece helps the control of the thickness of the glue layer of mean thickness $\langle \zeta_g \rangle$ that penetrates into the foam. In the assembly, first the foam is glued to the fleece, and after the curing process the resulting part is glued to the heater. The thickness of the glue layer between the fleece and the heater is 100 µm.

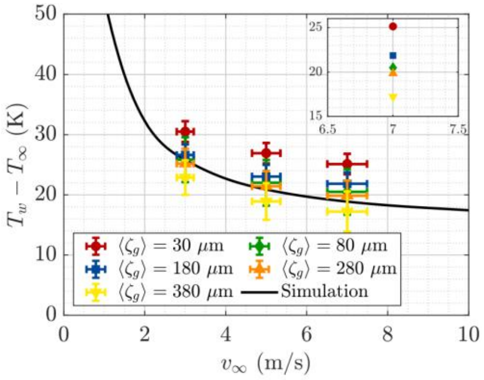


Sample assembly



Foam-heater interface

To understand the effect of the glue penetration, six samples of mean glue penetration values of $\langle \zeta_g \rangle$ = 30, 80, 130, 180, 280 and 380 µm are tested in the setup. The case of $\langle \zeta_g \rangle$ = 30 µm gives higher temperature values and is expected to be sensitive to variations in the glue thickness, therefore it is discarded for future tests. The decrease of the heater wall temperature when the glue penetration is increased is explained by the combined effect of two aspects: the decrease of the thermal resistance, and the increase of the thermal conductivity of the foam, since the glue fills the cells of the foam. It is concluded that a mean glue penetration between 80 and 180 µm provides the optimum balance between thermal performance and material budget.

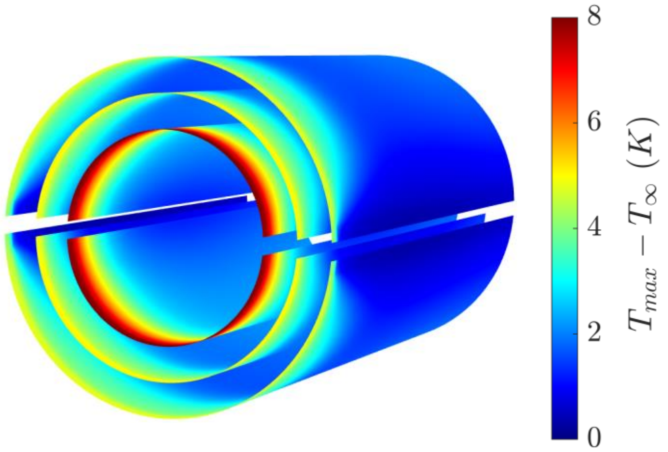


2.3 Thermal characterization

2.3.1 CFD analysis

The software Ansys Fluent is used to simulate the thermal performance of the ITS3. The simulations of the latest version of the detector are in progress.

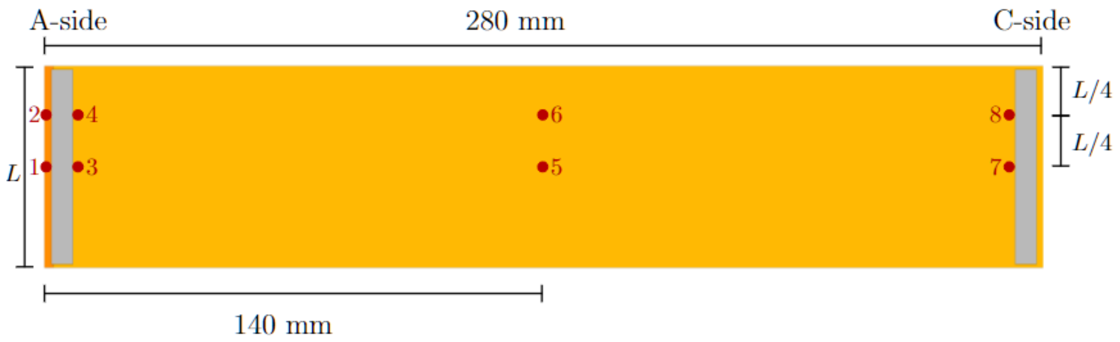
The following plot was done a few months ago with a simplified layout. The maximum temperatures are a good approximation, but I think that the temperature distributions will be more uniform.



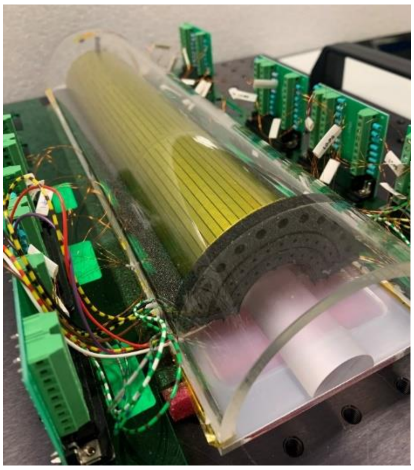
Temperature contours for v_∞*= 6 m/s,* $q_p = 2500$ *mW/cm*^{2}*,* $q_m \sim 18.75$ *mW/cm*^{2}

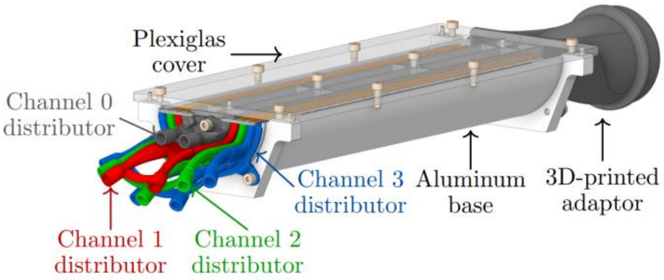
2.3.2 Wind tunnel test thermal validation

A experimental setup with the layout shown in section 2.1 has been built to validate the CFD simulations (EM3). The structure has a flow distributor for each channel that includes a mass flow meter, and the heat dissipation is simulated with integrated heaters in a silicon sensor of 50 microns. The temperature distribution is obtained from eight PT1000 sensors in each layer.



Location of the temperature sensors

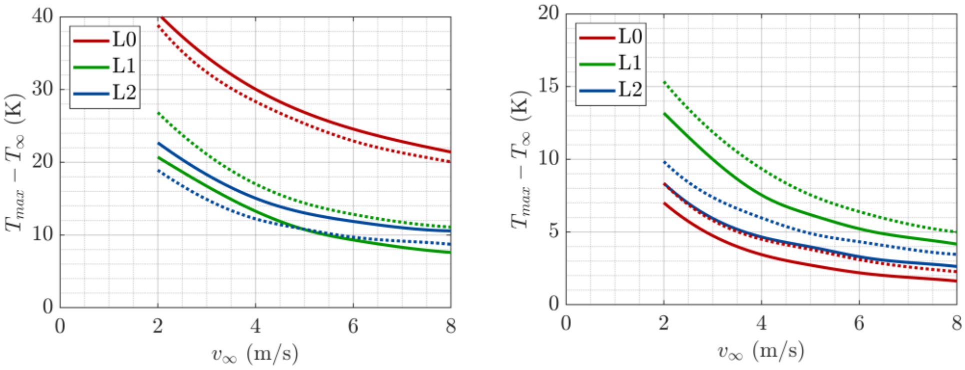




2.3.3 Comparison between CFD and tests

The EM3 has been built, and after performing a computed-tomography scan, in two weeks all of the sensors will be installed. It is expected to finish the comparison before the end of the year.

The following plots are the comparison between CFD and experiments of the BBM2 showed in previous meetings. The results are very poor, but this is due to the fact that a single flow distribution was used. Moreover, FR4 was used instead of silicon. FR4 has a very low thermal conductivity (1000 times lower than silicon).



a) Periphery, Matrix. Maximum temperature variation in each layer. Experiments (continuous lines) and simulations (dashed lines)

2.4 Mechanical characterisation

2.4.1 Aeroelastic analysis and test

Taking as a reference the anisotropic properties of silicon obtained from the literature, the natural frequencies of the structure have been computed. The L2 layer is the one with the lowest first natural frequency equal to 920Hz.

Since the displacements of the structure will be reduced, the mechanical and fluid dynamics problems can be decoupled. To obtain the vibrations of the structure, the following methodology is proposed:

1) Perform CFD simulations and compute the unsteady aerodynamic loads in the layers.
2) Obtain the forces and use them as inputs for the mechanical simulations

2.4.2 Thermoelastic analysis and test

The thermoelastic behavior can be studied by including the temperature distribution obtained from the CFD simulations.

2.5 Mechanics and cooling alternative designs

3 Flex Printed circuit

3.1 Design

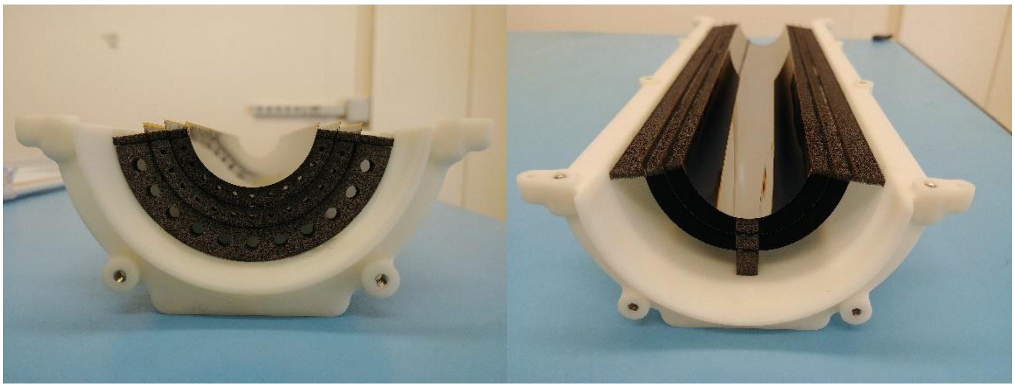
3.2 xx

3.3 xxx

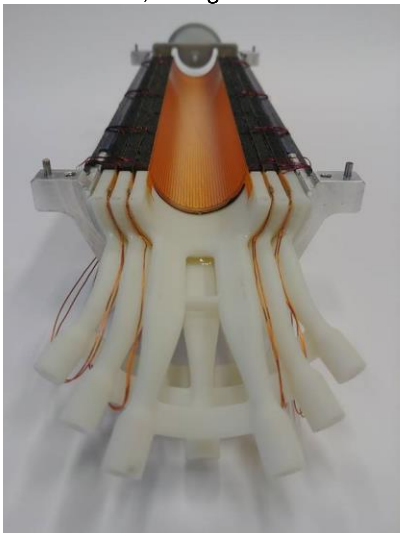
3.4 xxx

4 Detector assembly

4.1 detector layout

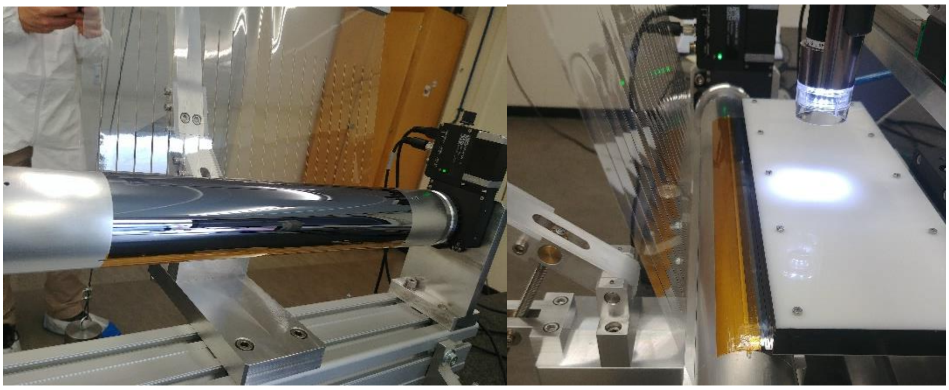


EM2 (one flow distributor, wedge on the C-side, no heaters)

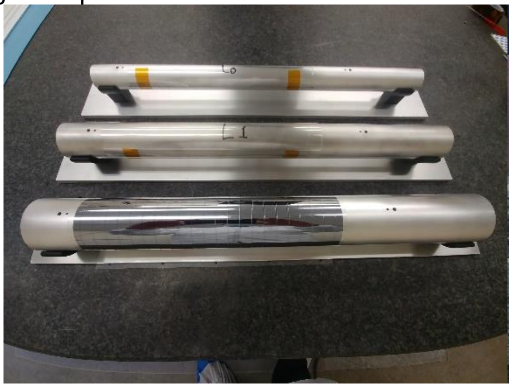


BBM3 (four flow distributors, carbon foam ring on the C-side, with heaters)

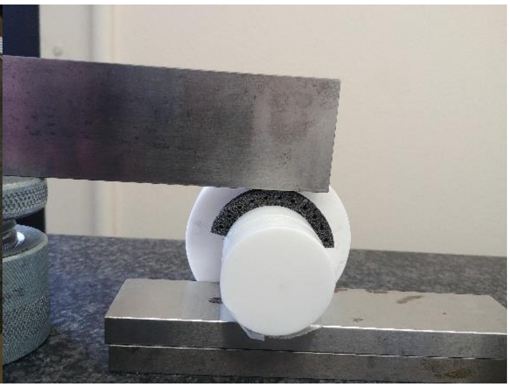
4.2 Layer bending



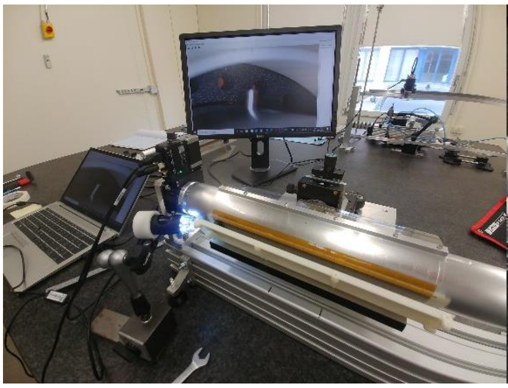
4.2.1 Jigs and procedures



Mandrels

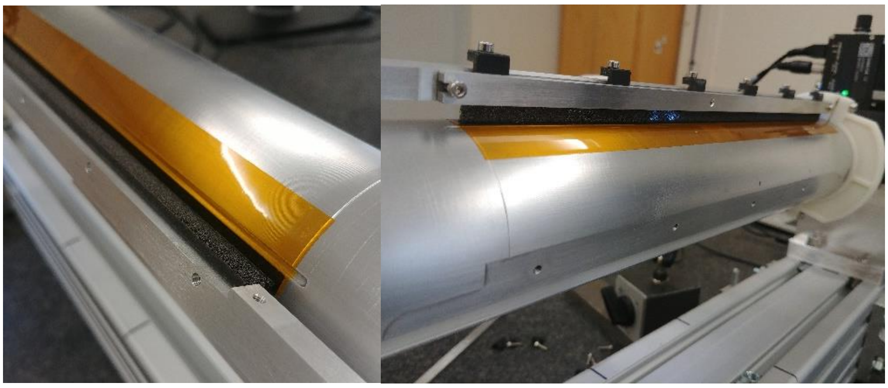


Mold for the rings



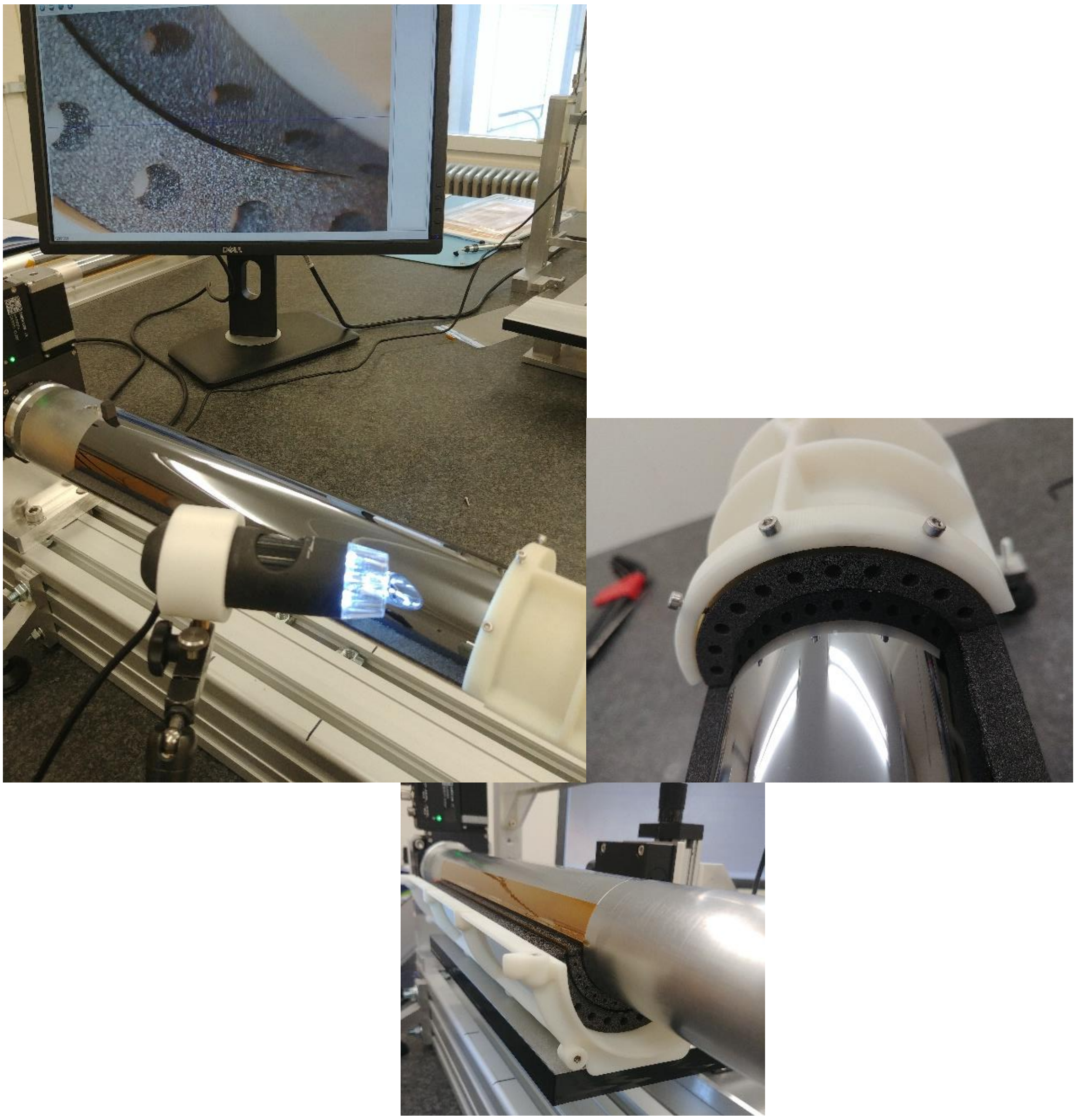
Placement of a ring

Support for gluing the longerons



Gluing of the longerons

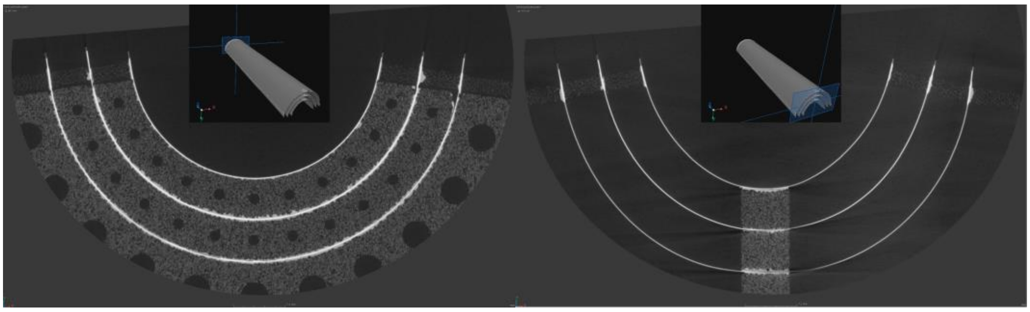
L2 assembled



Similar process for the rest of the layers

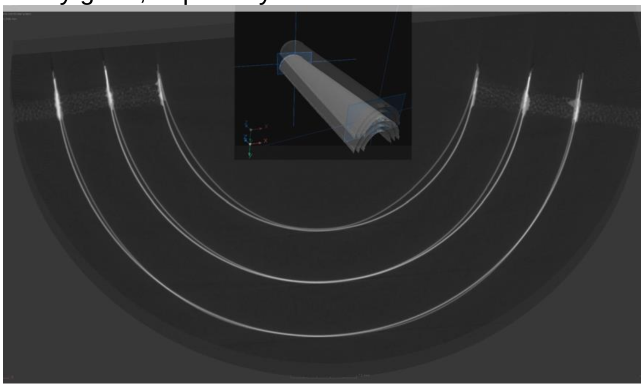
4.2.2 Layer cilindricity

A CT scan has been obtained from the EM2, which has carbon foam rings on the A-side, and wedges on the C-side



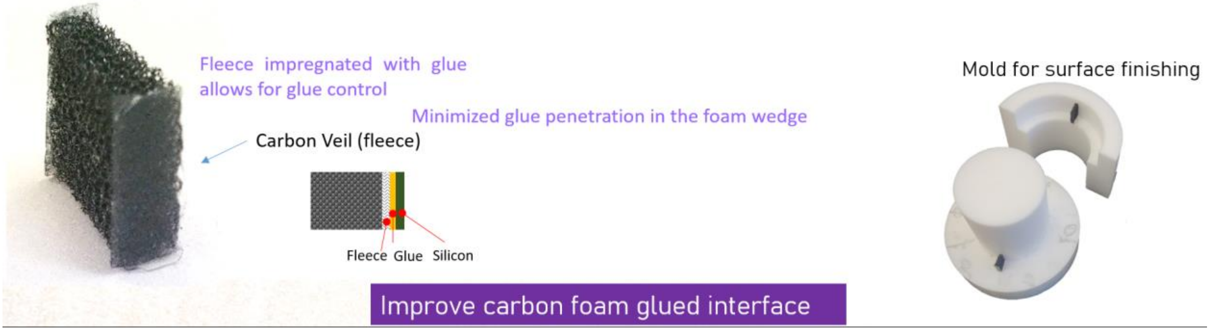
A-side *C-side*

When compared to the CAD model, the A-side shows correct values of cylindricity, while on the C-side the cylindricity is not very good, especially in the L0.



C-side. Comparison with the CAD model

4.3 Layers bonding to mechanics

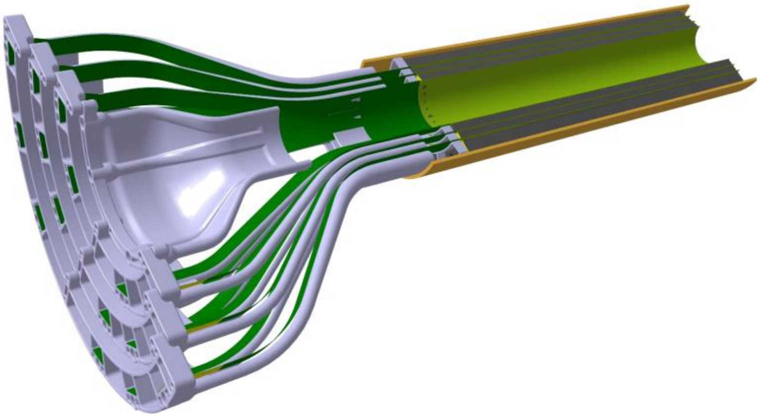


Fleece impregnated with glue allows for glue control

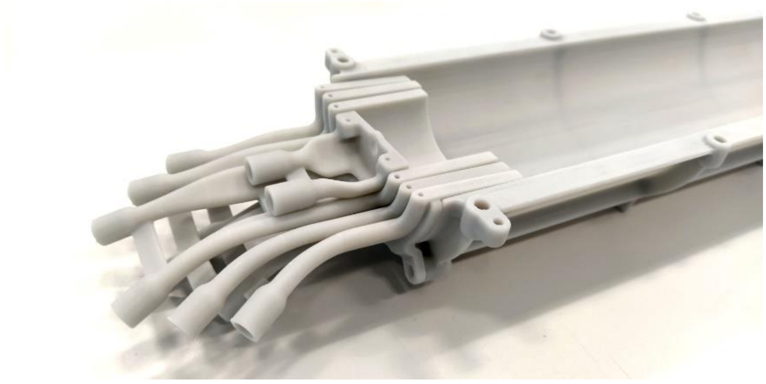
Minimized glue penetration in the foam wedge

Improve carbon foam glued interface

4.4 Layer to FPC connection



4.5 Layers cooling ducts



4.6 Layers test and characterisation

Xxx

4.7 Detector alternative layout

Xxx

5 Global support structure, services and integration

5.1 General requirements

5.2 Detector support structure

5.3 Services

5.3.1 Cooling

5.3.2 Cabling

5.3.3 Service support structure

5.4 Beam pipe

5.4.1 Beam pipe radius and wall thickness

5.4.2 Beam pipe supports

5.4.3 Beam pipe bake-out

5.5 Installation and removal

5.5.1 Sequence

5.6 Survey and mechanical alignment.