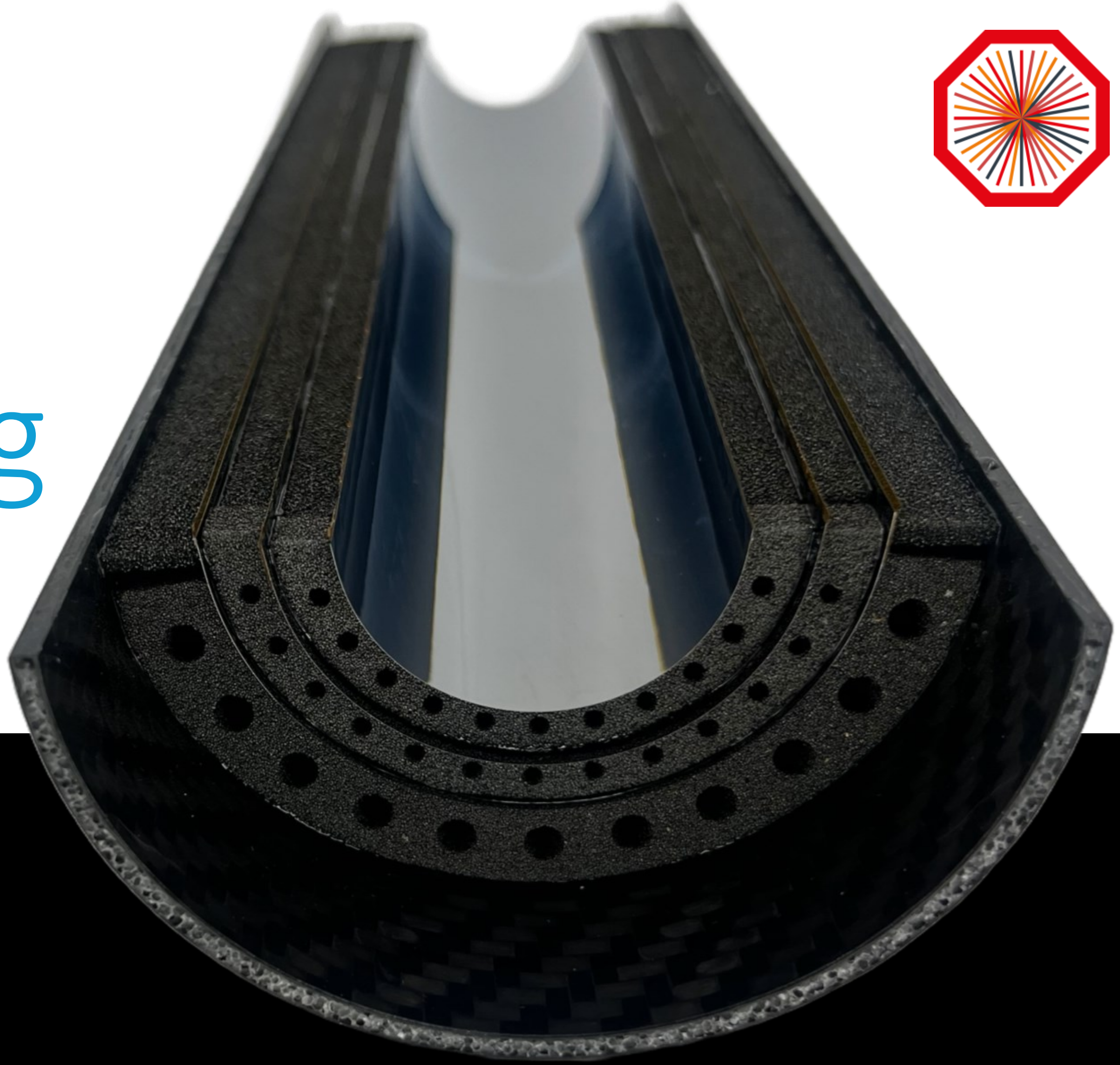
ALICE ITS3 vertex detector upgrade: mechanics & cooling overview

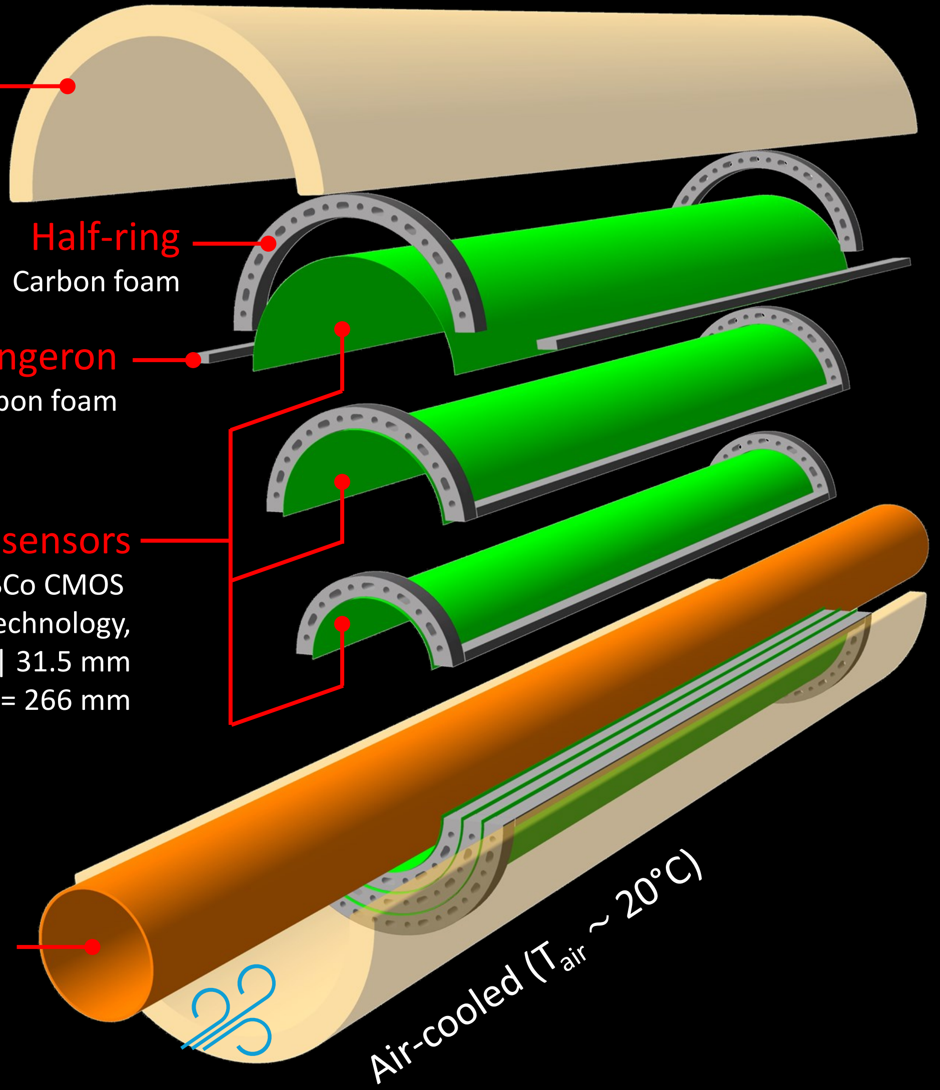


Corrado Gargiulo
on behalf of ALICE ITS3 Work Package 5

Outline

- Mechanics and Cooling
- Material budget
- Prototyping strategy
- Half-detector assembly
- Testing:
  - Cooling performance
  - Dynamic stability Vs airflow
  - Thermoelastic failure assessment
- Services

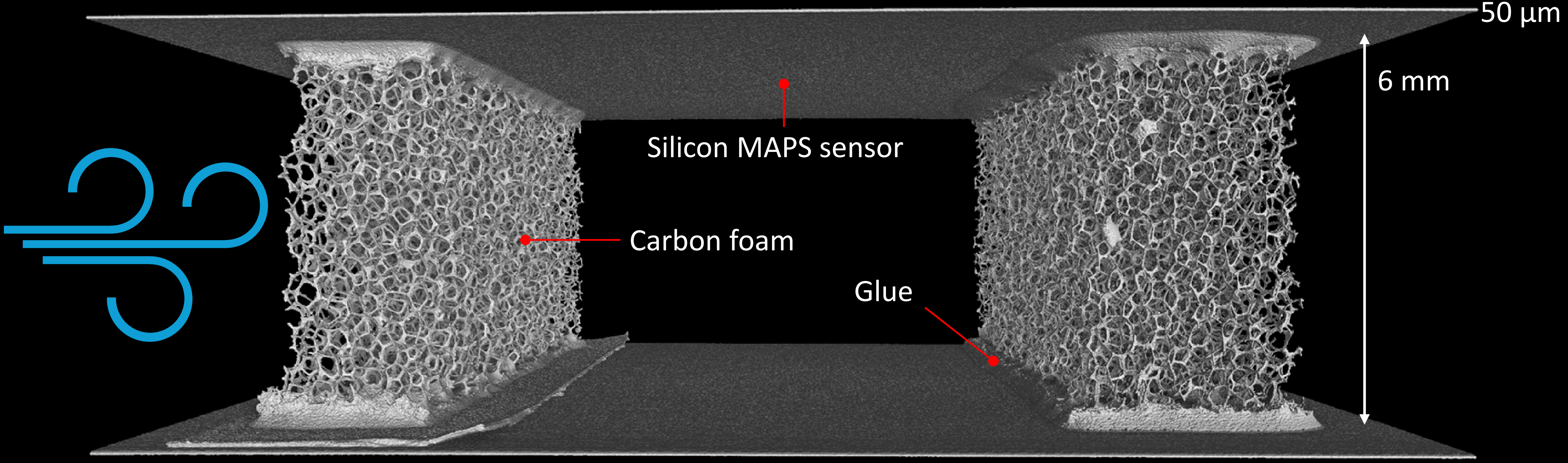
Simplified schematic of the ALICE Inner tracking system 3 (ITS3)



Mechanics and Cooling design

The limited dissipated power allows for the use of **air cooling** at ambient temperature

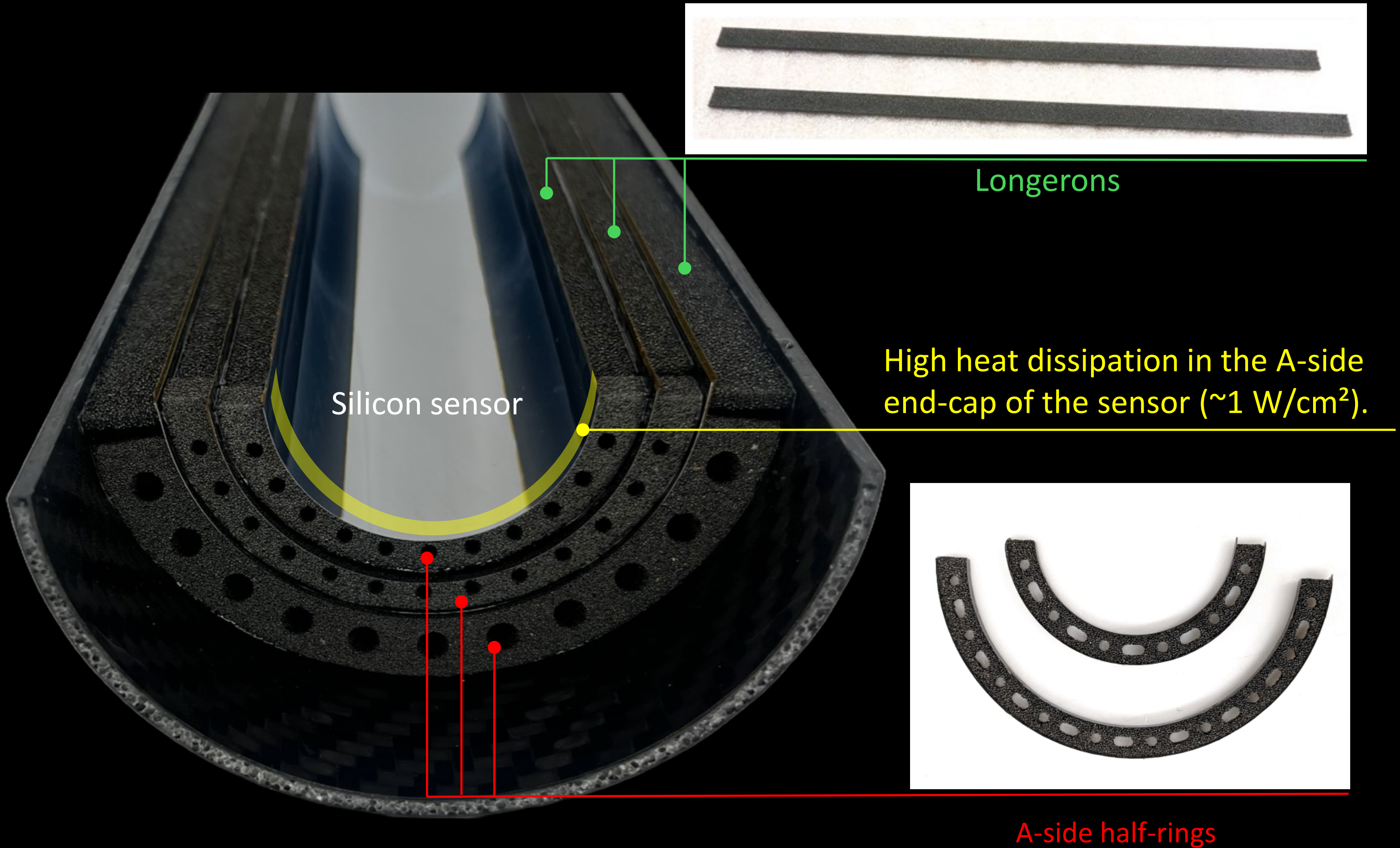
The material budget requirement (<1%) calls for an unpalpable support structure, i.e. **carbon foam** used as **support** and **radiator**



µCT scan (Voxel =11µm, @CERN EN-MME)

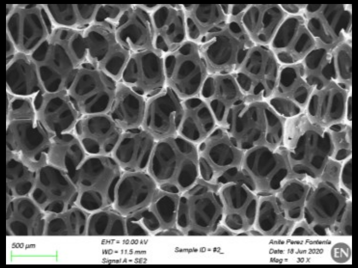
Mechanics and Cooling design

Power dissipation is concentrated at the short edge of the sensor, where carbon foam **half-rings** (radiators) are placed.
Carbon foam **longerons** along the length keep the sensor in position and provide structural stability.



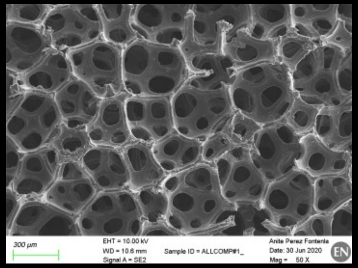
Carbon foam types

Support



ERG Duocel Carbon (RVC) Foam 100 PPI
ρ = 0.07 kg/dm3
K = 0.033 W/m·K

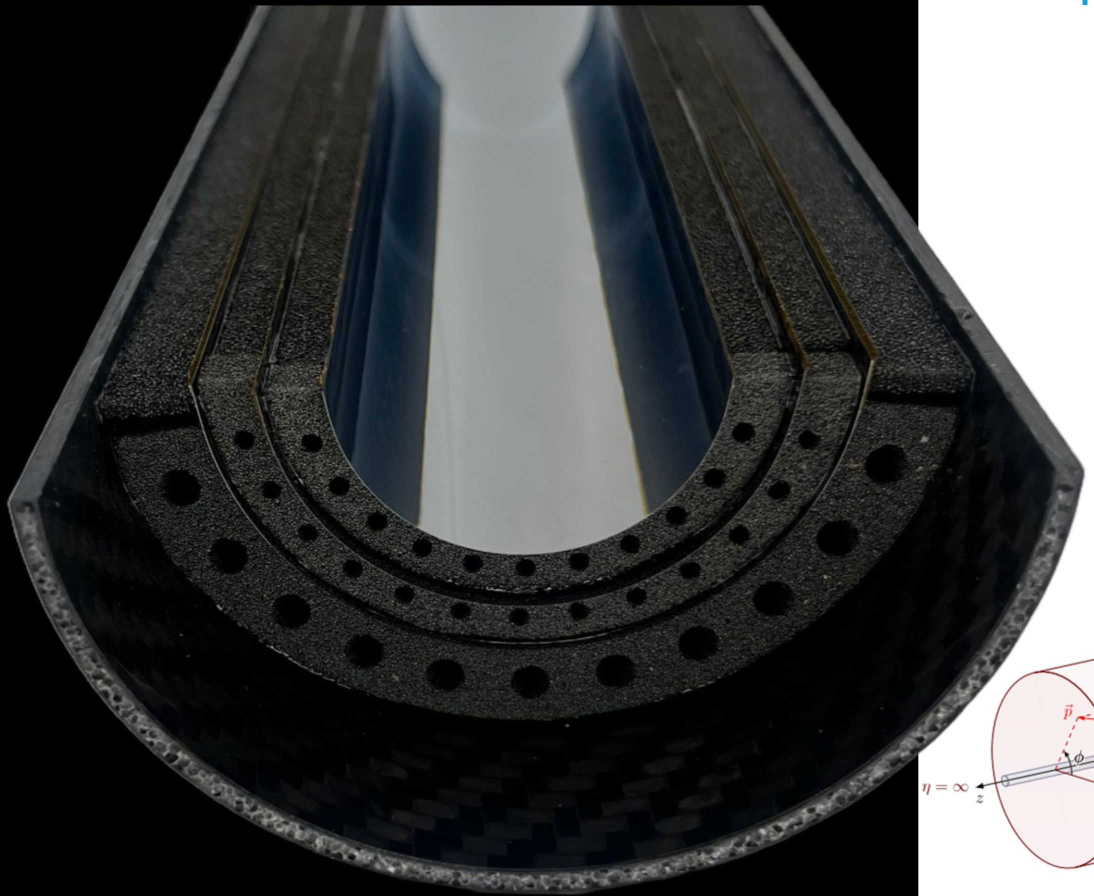
Cooling radiator



Allcomp K9 Standard Density (SD)
ρ = 0.2-0.26 kg/dm3
K = >17 W/m·K

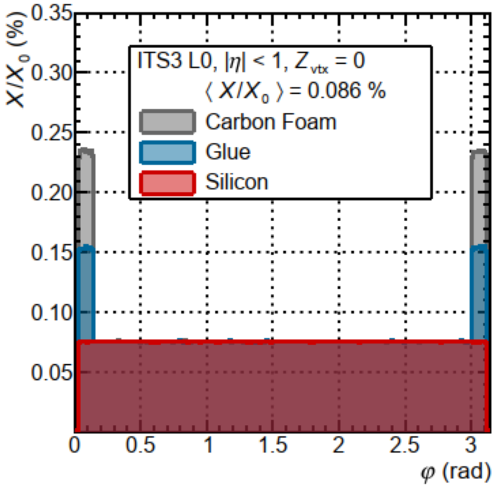
Material budget

The half-layer layout has been developed to achieve **minimum material budget,** with most of the material budget belonging to the silicon sensor itself.

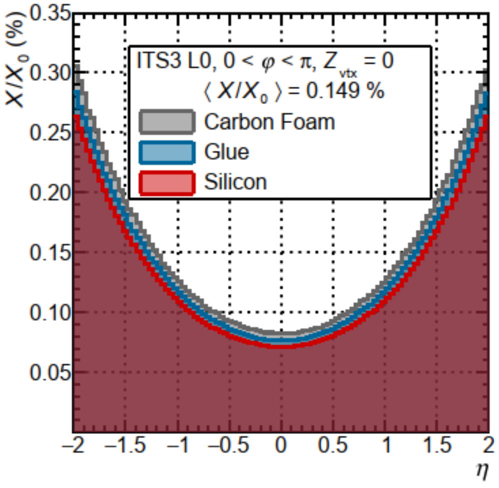


Material budget evaluation for half-layer 0

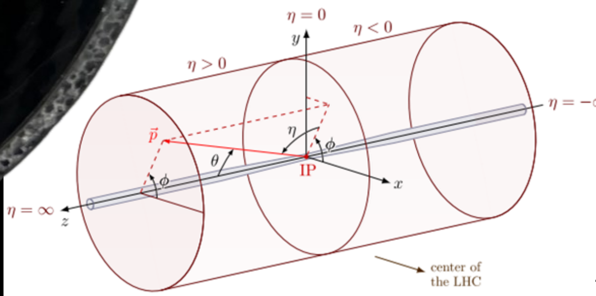
The silicon sensor itself is responsible for **0.07%** X_0 and the material budget for tracks with **|η| < 1 on average** is set at **0.09%** X_0.



Material budget for tracks of particles originating from the interaction point (Z_{vtx} = 0) as a function of φ. The material budget plotted is averaged for tracks with $|\eta| < 1$, resulting in an average material budget contribution (⟨X/X0⟩) of 0.086% for tracks with $Z_{vtx} = 0$, $|\eta| < 1$, and $0 < \varphi < \pi$.



Material budget for tracks of particles originating from $Z_{vtx} = 0$ as a function of η. The plotted material budget is averaged for tracks with $0 < \varphi < \pi$, resulting in ⟨X/X0⟩ = 0.149% for tracks with $Z_{vtx} = 0$, $|\eta| < 2$, and $0 < \varphi < \pi$.



Courtesy of ITS3 WP1

Prototyping strategy

The strategy involves prototyping assemblies with varying levels of accuracy to validate the mechanics and cooling.

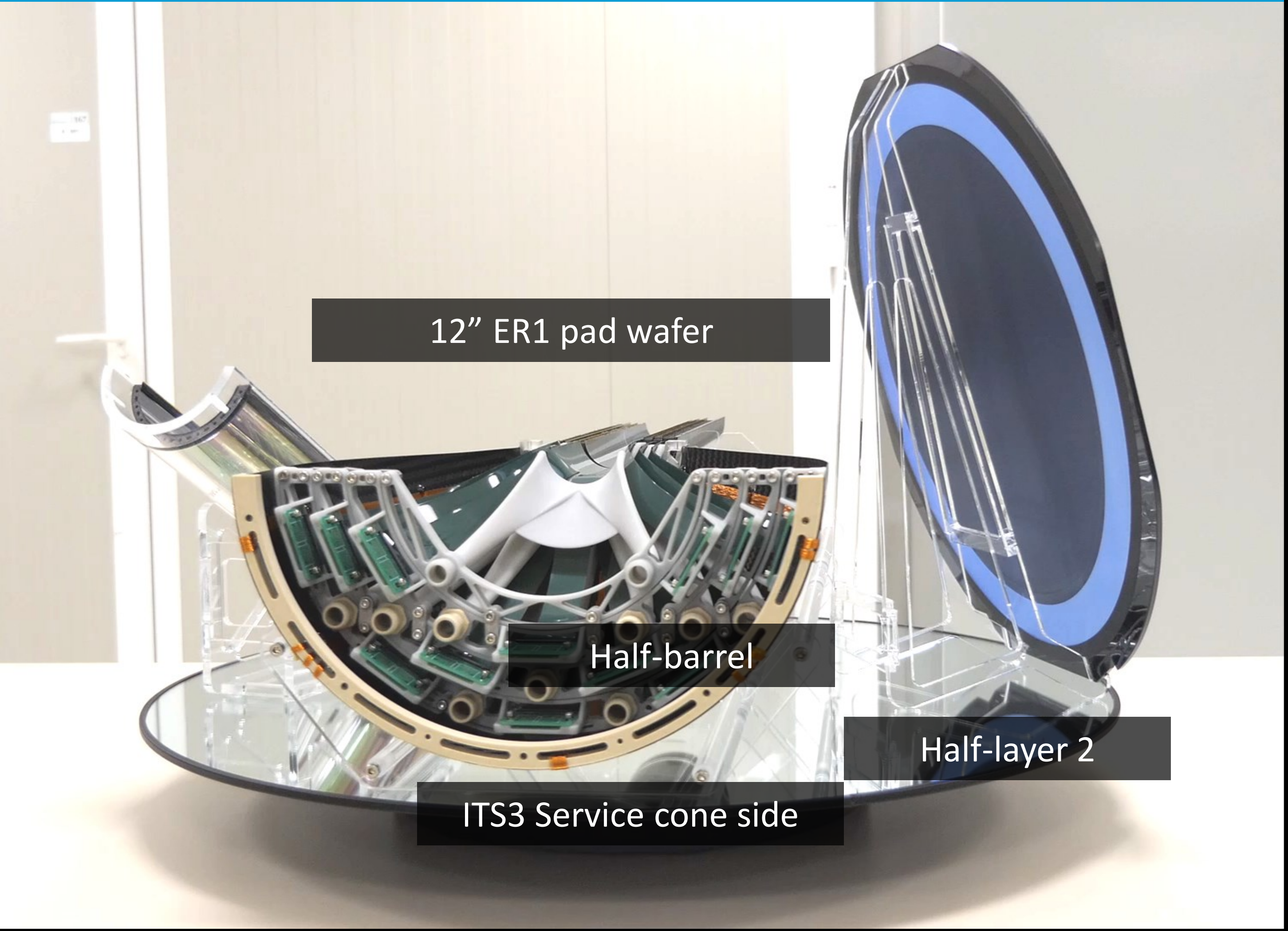
BreadBoard Models (BBMs):
Test samples and initial prototypes, partially representative of some of the final model features

Engineering Models (EMs):
Used for design development, they are a mixture of final-grade and commercial components

Qualification Models (QMs):
Final grade, fully integrated assemblies including MOSAIX sensors, used for qualification tests

Final Models (FMs):
2x final half-detectors to be integrated in the ALICE experiment + 2x half-detectors spares

ALICE ITS3 prototype



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(BBM1) (BBM2)

- Thermal testing

BBM3

- Thermal testing,
- Aeroelastic testing

BBM4

- (MLR1) wafer-size sensor integration,
- FPC-sensor wire bonding,
- Aeroelastic testing

BBM5

- Thermoelastic testing

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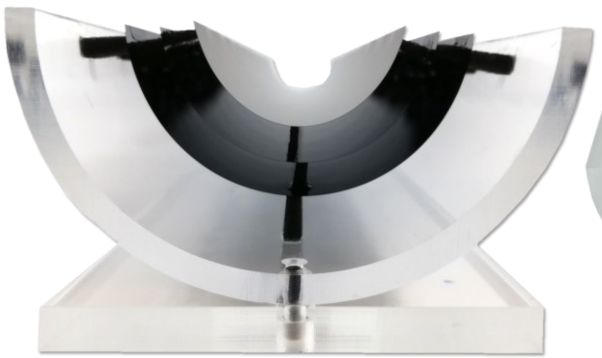
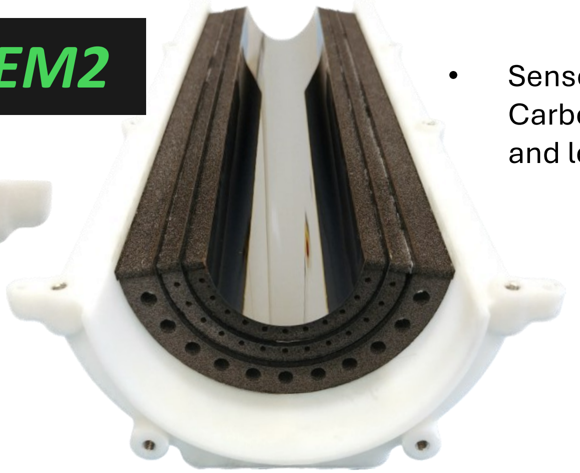
EM1



- Sensors supported by Carbon foam wedges

EM2



- Sensors supported by Carbon foam half-ring and longerons

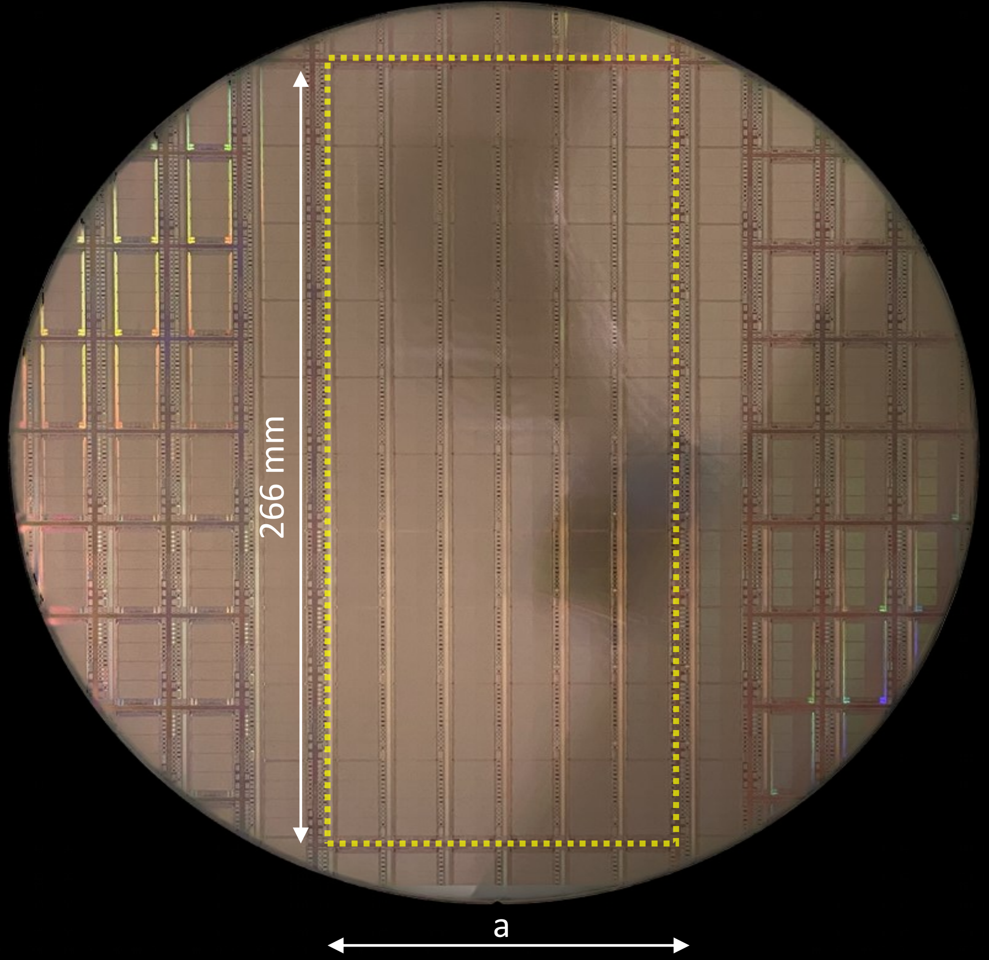
Detector assembly: Half-layer bending

ALICE ITS3 WP5

Challenge: **bending** of the wafer-size thin silicon sensor without inducing stresses or failure

12" Si wafer, 50 µm

65 nm TPSCo CMOS imaging technology,

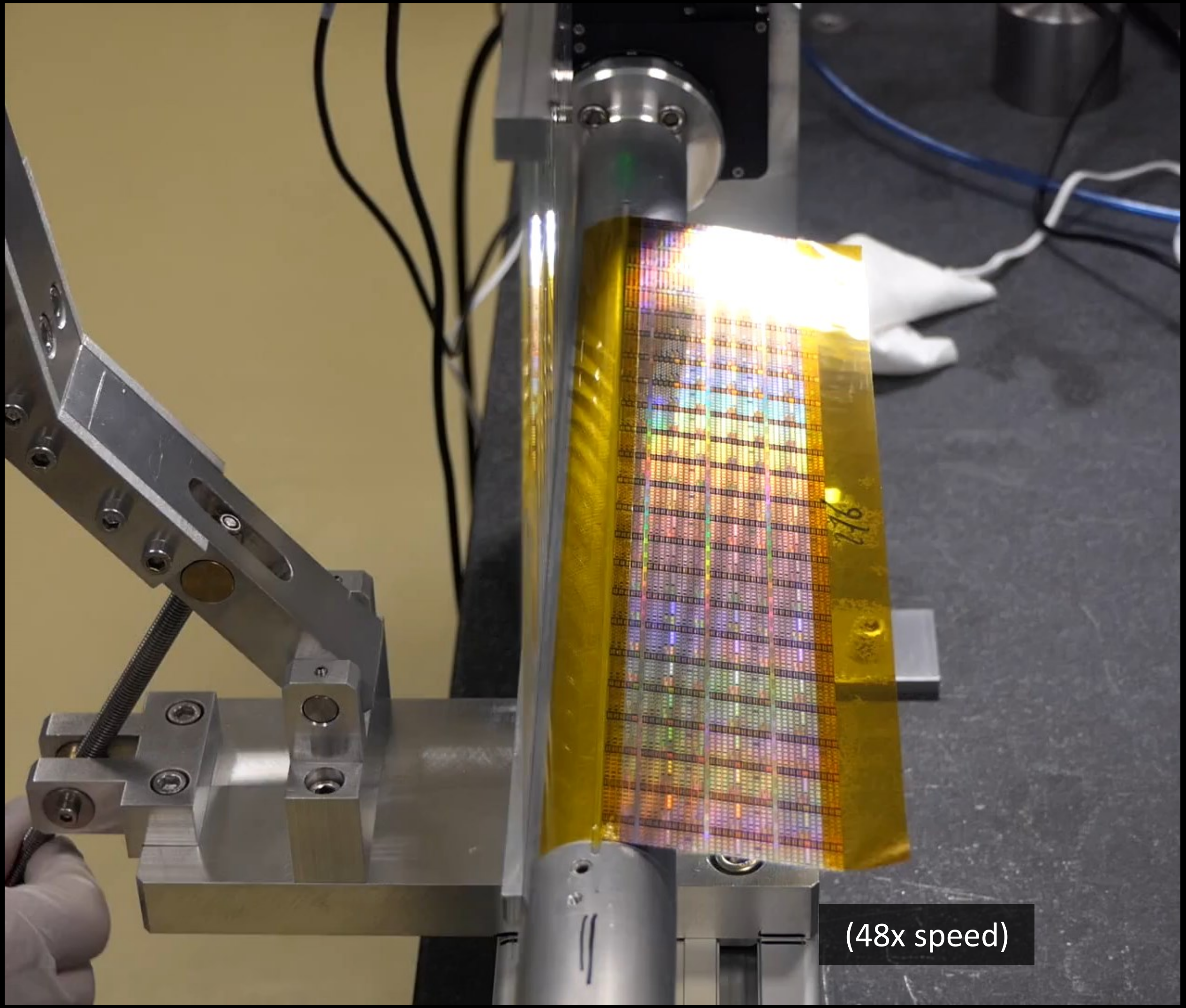


Half-layer 0 a = 58.7 mm

Half-layer 1 a = 78.3 mm

Half-layer 2 a = 97.8 mm

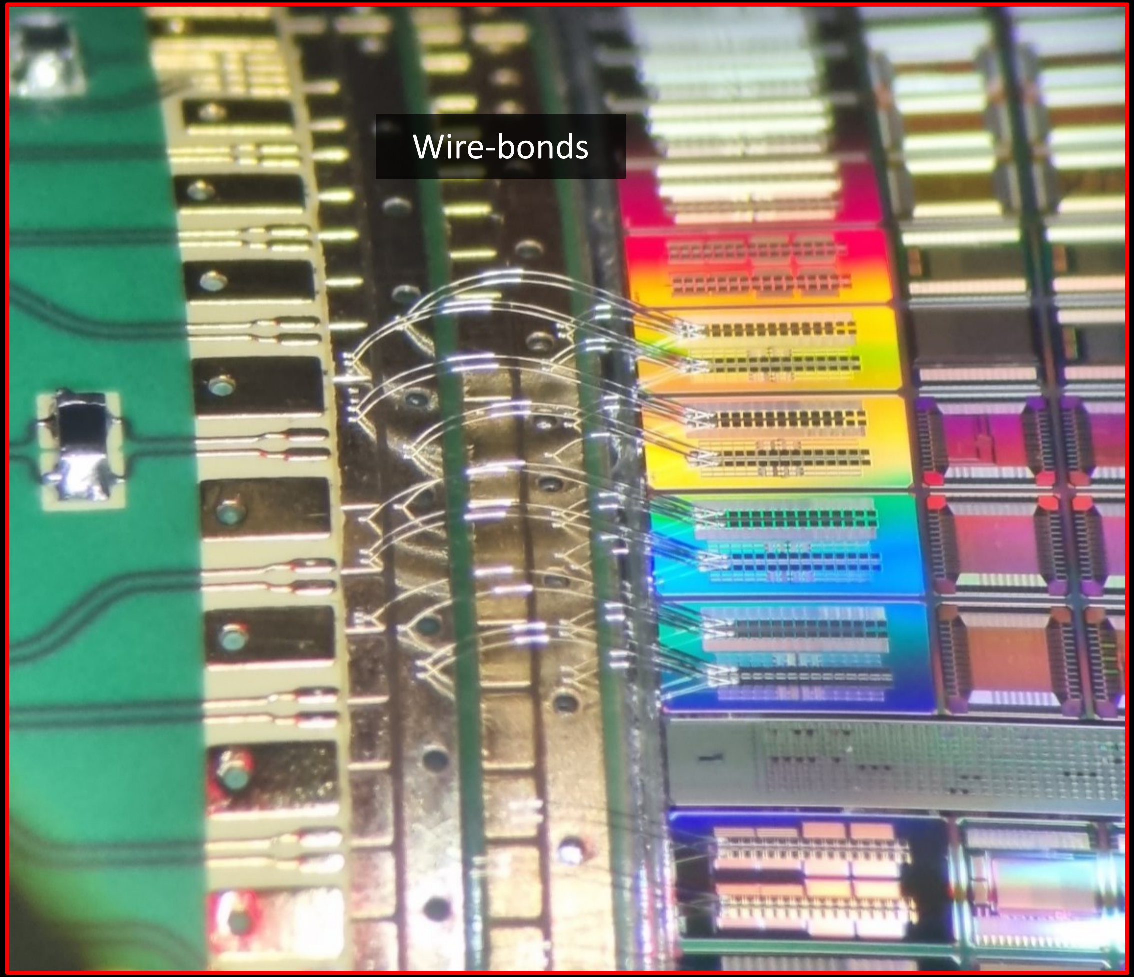
Bending procedure



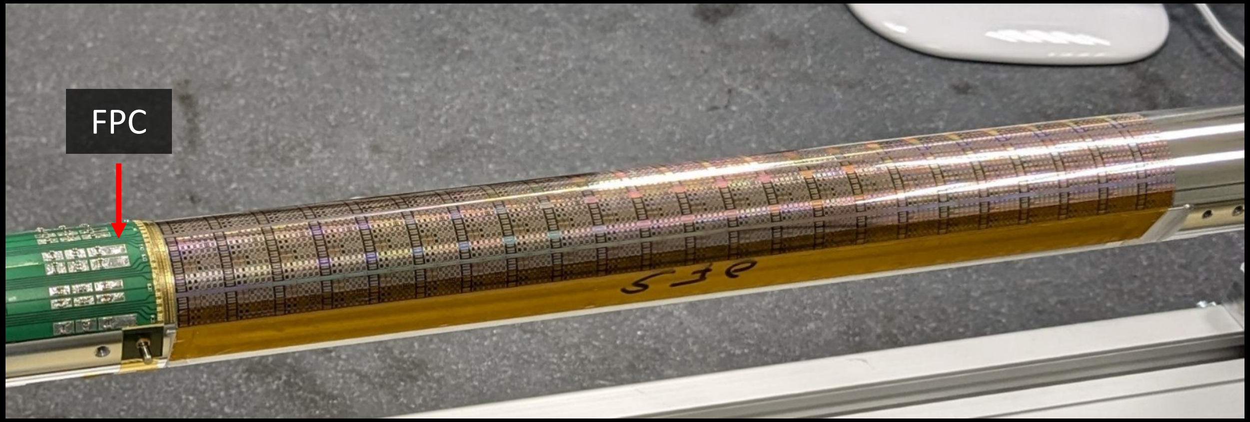
Detector assembly: Half-layer wire bonding

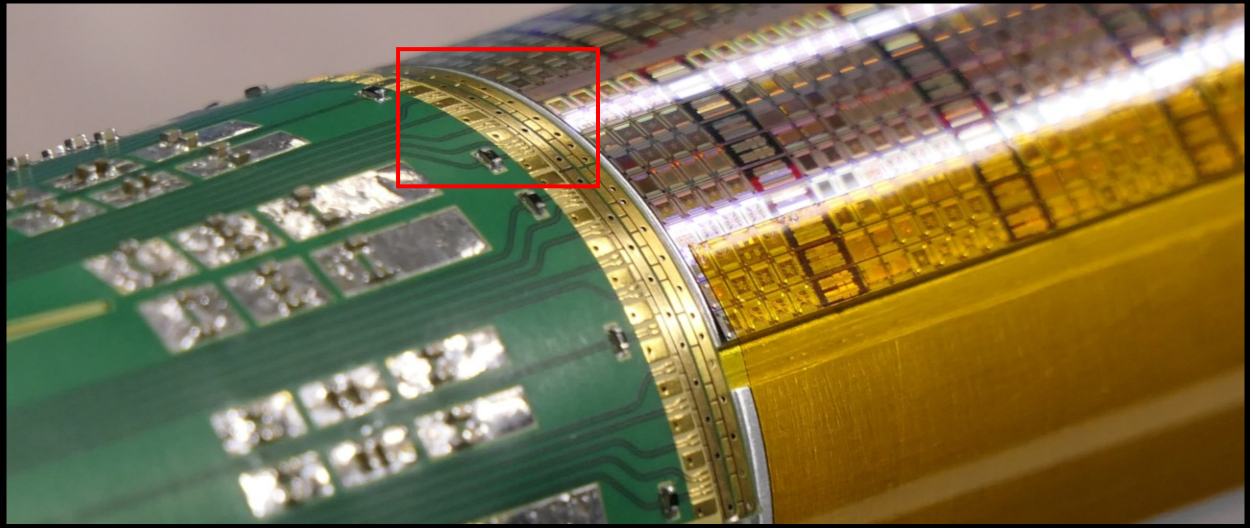
ALICE ITS3 WP5

Challenge: is the electrically connection by **wire bonds** of the **curved sensor** to the close front end electronics



Electrical interconnection





Detector assembly: carbon foam Vs silicon gluing

Challenge: **optimum glue penetration** thickness (minimum material budget Vs thermal conductivity) in the foam, and a **smooth surface finishing**, avoiding punctual stresses and footprints.

- Carbon foam
- Glue penetration ~200 µm
- Carbon fleece ~100 µm
- 2nd Glue deposition ~100 µm
- Silicon sensor

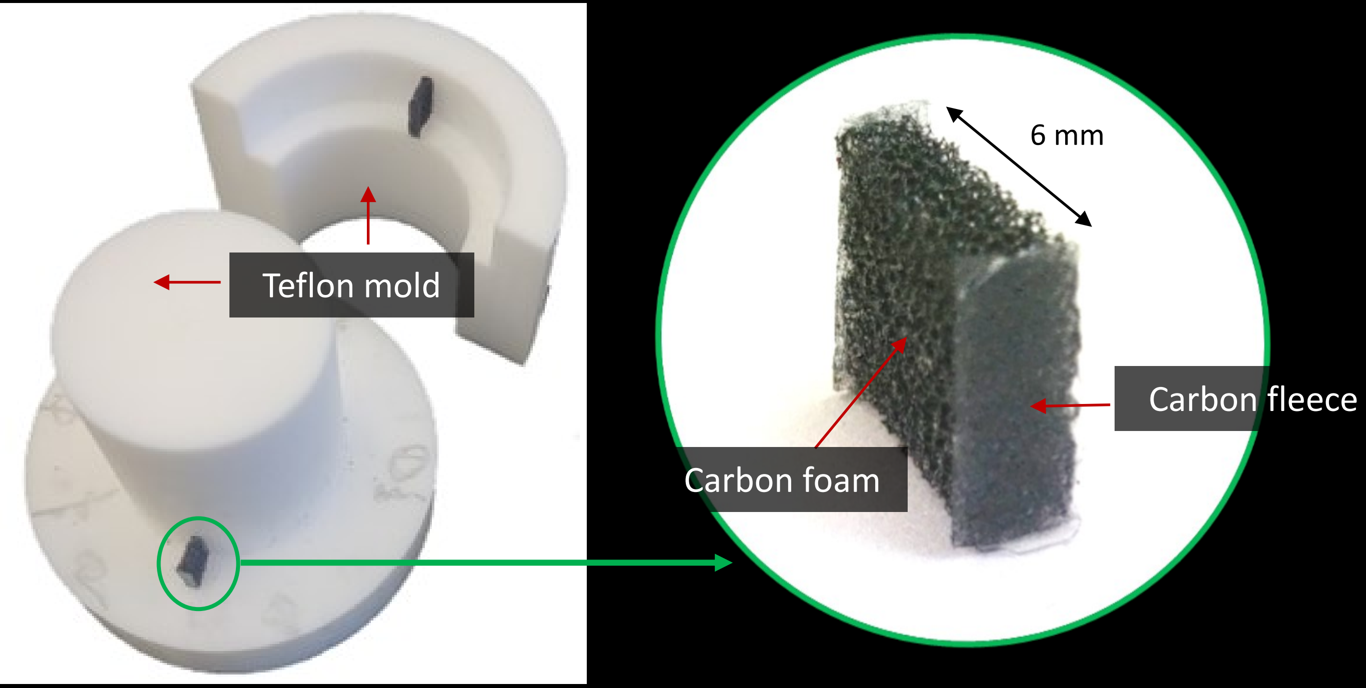
Step1 

The carbon fleece veil is glued to the carbon foam surface in contact with the sensor and cured in a Teflon mold for a smooth finish.

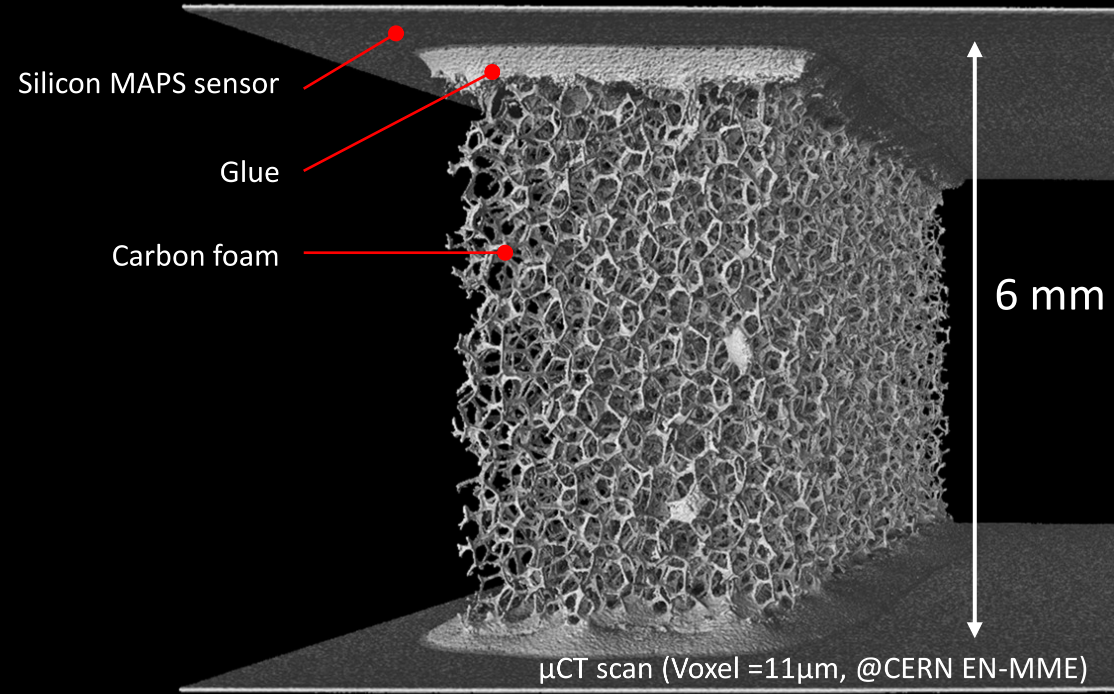
Step2 

Subsequently, the carbon foam is glued to the silicon sensor, the glue thickness is 0.1 mm.

Step1 – Smooth surface finish



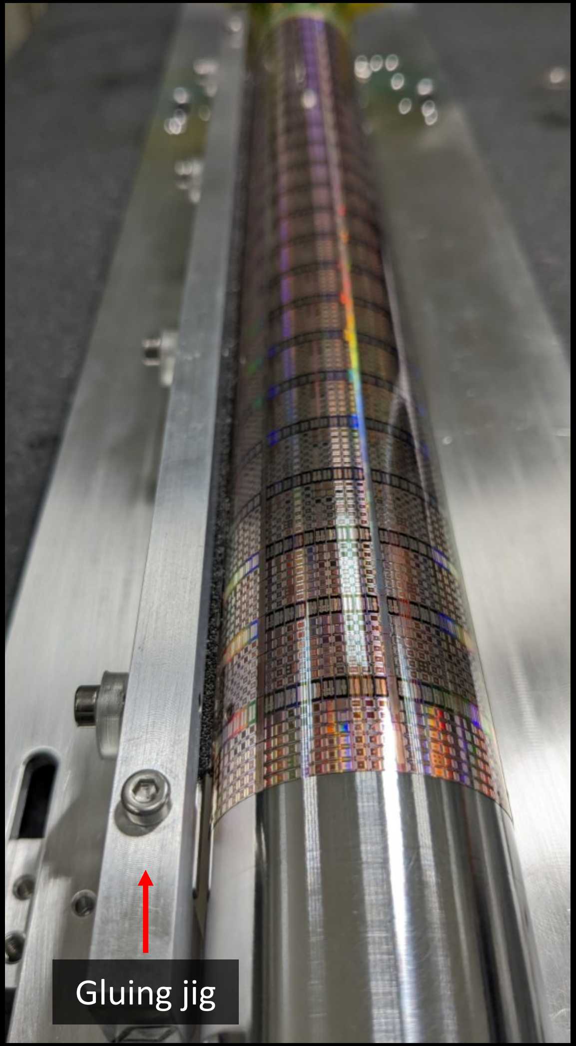
Step 2 – Gluing to Silicon

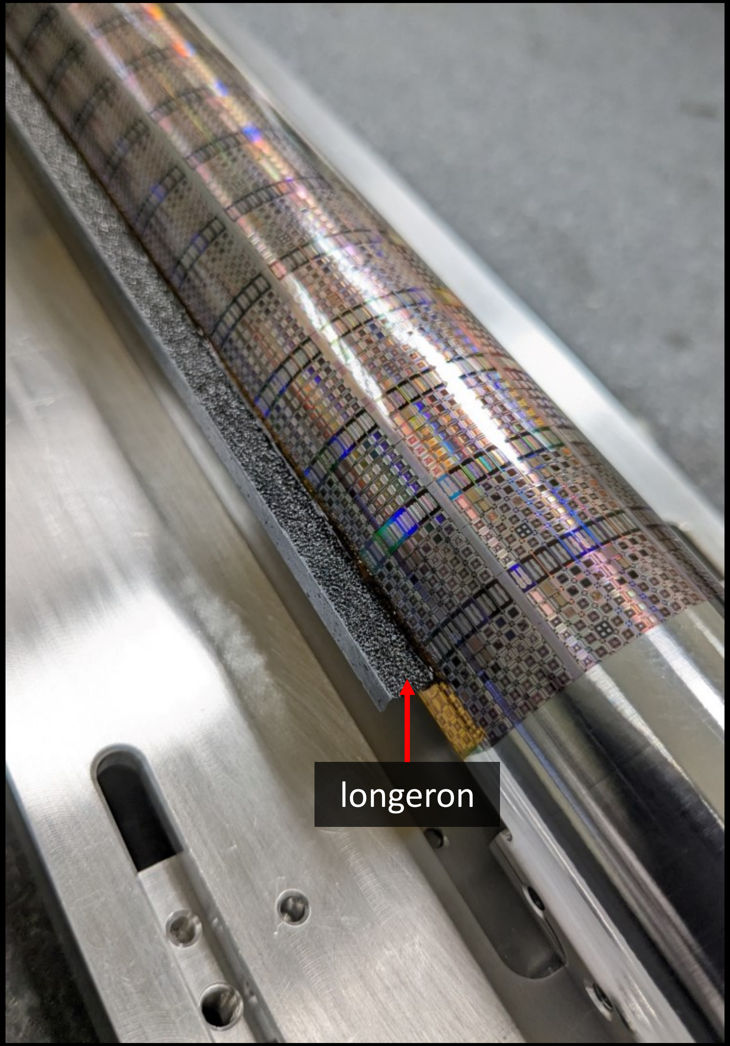


Detector assembly: Half-layer longerons

Challenge: **precise machining, positioning** and **gluing** of the carbon foam support

Gluing of the longerons





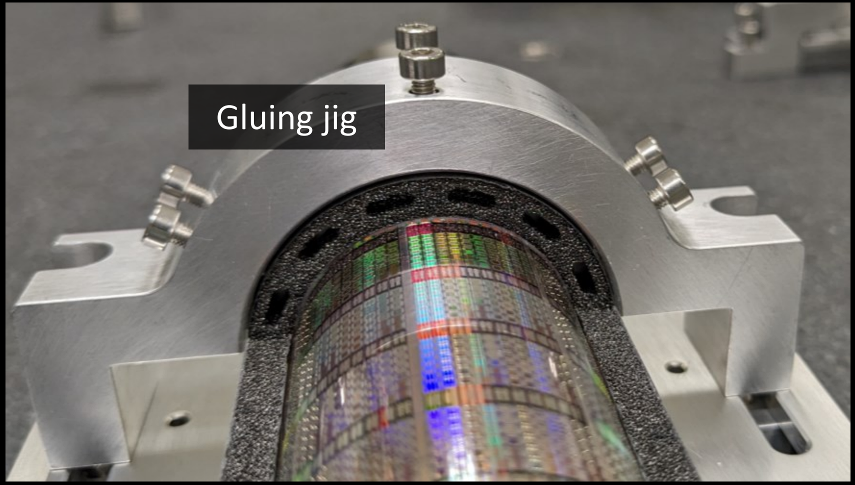
Detector assembly: Half-layer rings

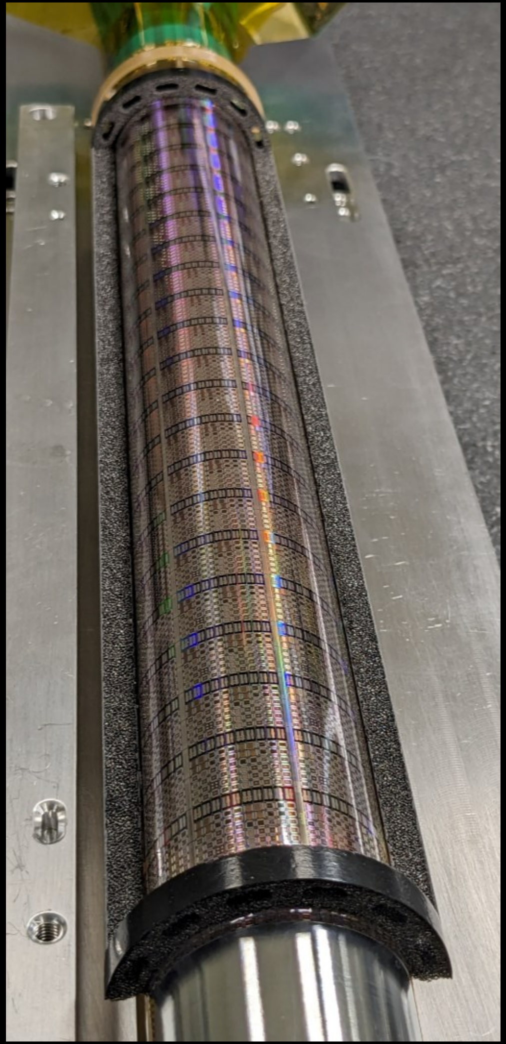
Challenge: **precise machining, positioning** and **gluing** of the carbon foam support

A-side half-rings:
Allcomp K9 SD

C-side half-rings:
ERG Duocel Carbon (RVC) foam

Gluing of the half-rings

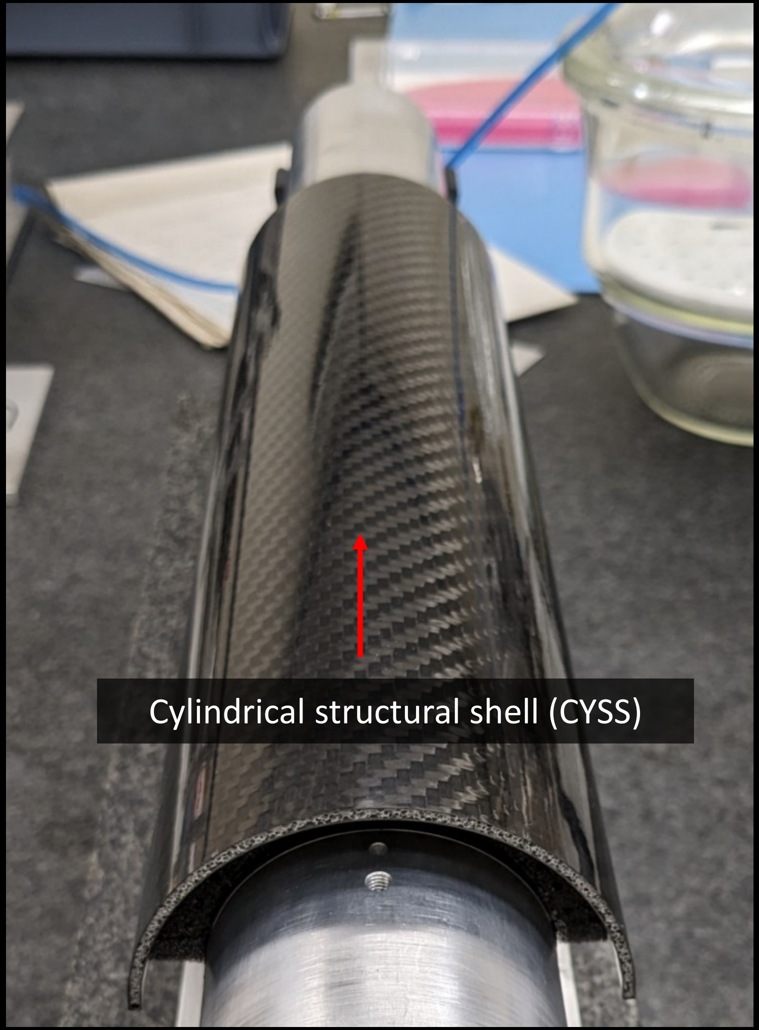




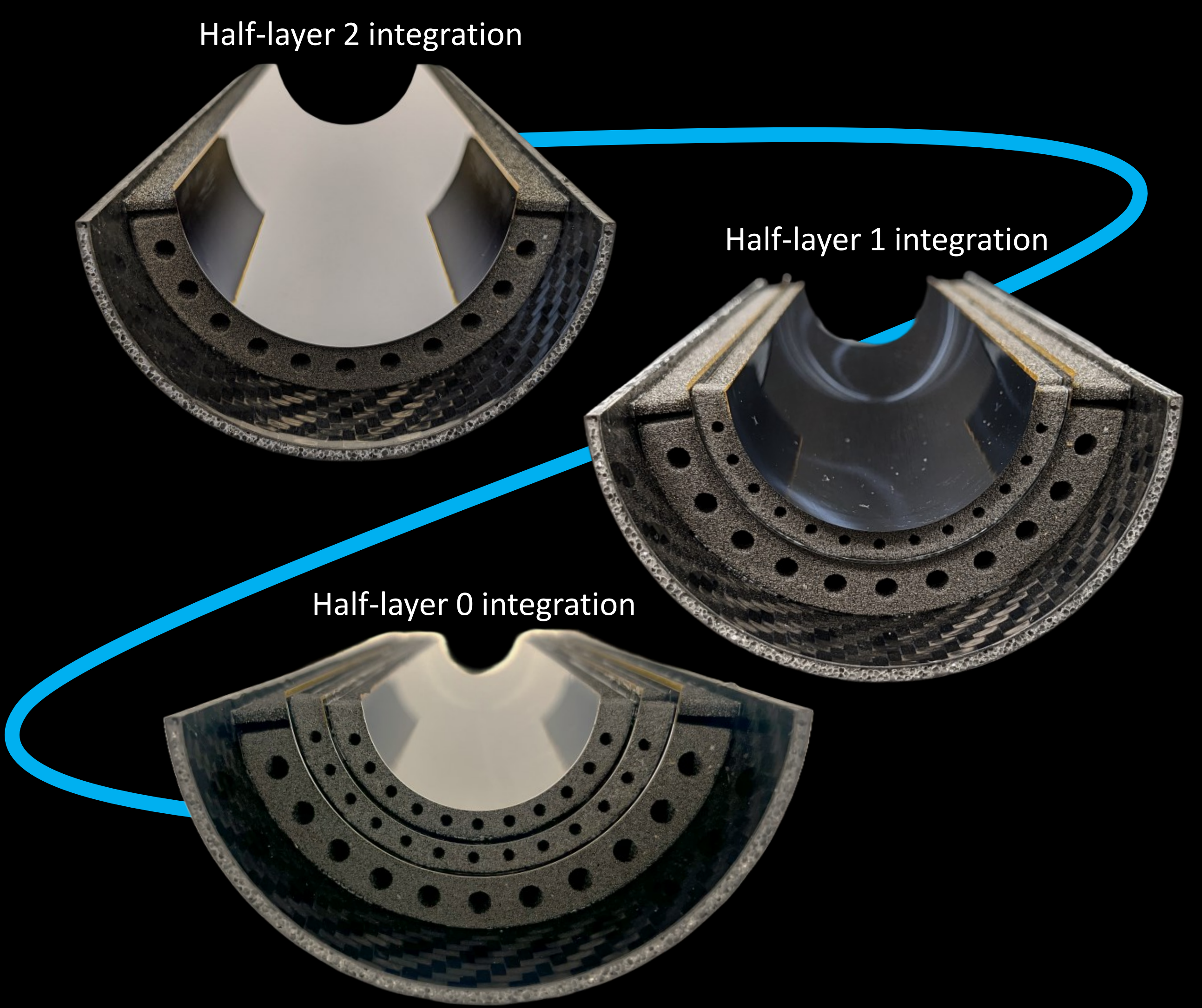
Detector assembly: Half-barrel

Challenge: minimum material budget achieved by a thin carbon cylindrical **exoskeleton** for the support to the three half-layers

H-L2 integration (Gluing deposition, alignment, curing)



Half-detector after each half-layer integration

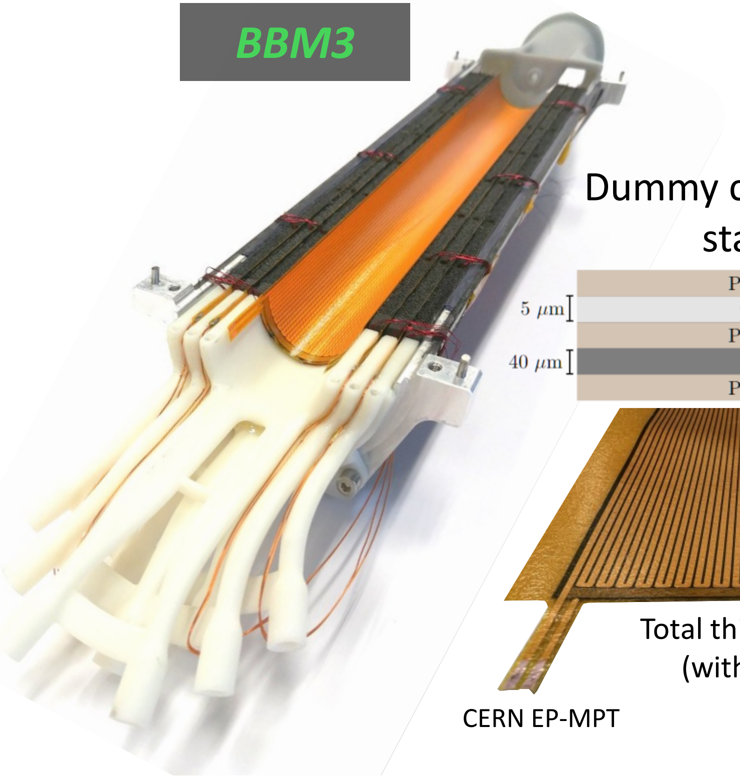


Testing: Cooling performance

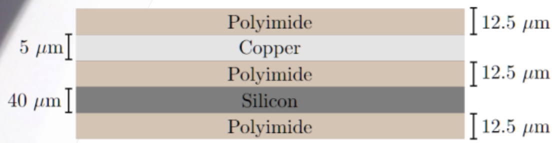
An airflow through the carbon foam radiator ring of **8m/sec** allows to keep the sensor below 25°C with an air inlet of 20°C

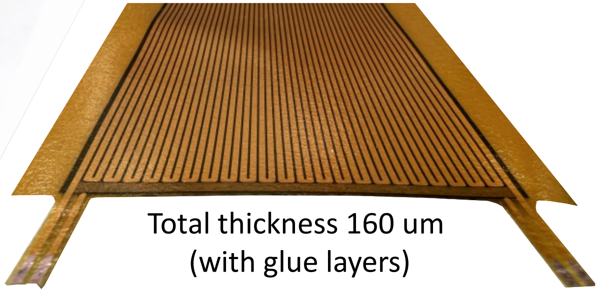
Prototype

BBM3



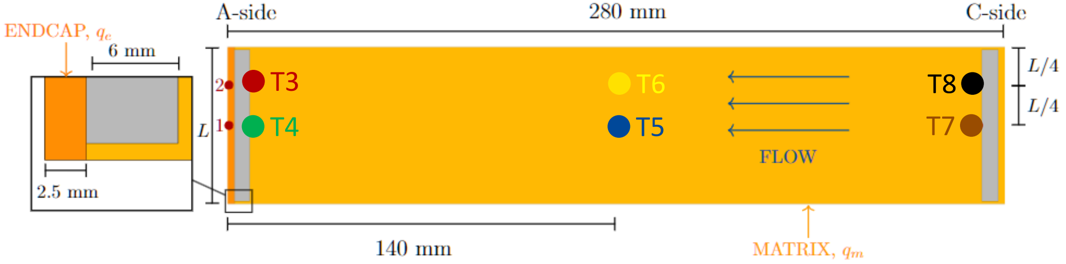
Dummy chip (heaters) stack-up





Total thickness 160 um (with glue layers)

CERN EP-MPT



Experimental results

Two zones of different power dissipation: Endcap and Active area

Same freestream velocity v_∞ in all layers, v_∞ = 8 m/s

Temperature of the inlet air $T_\infty \approx 20$ °C

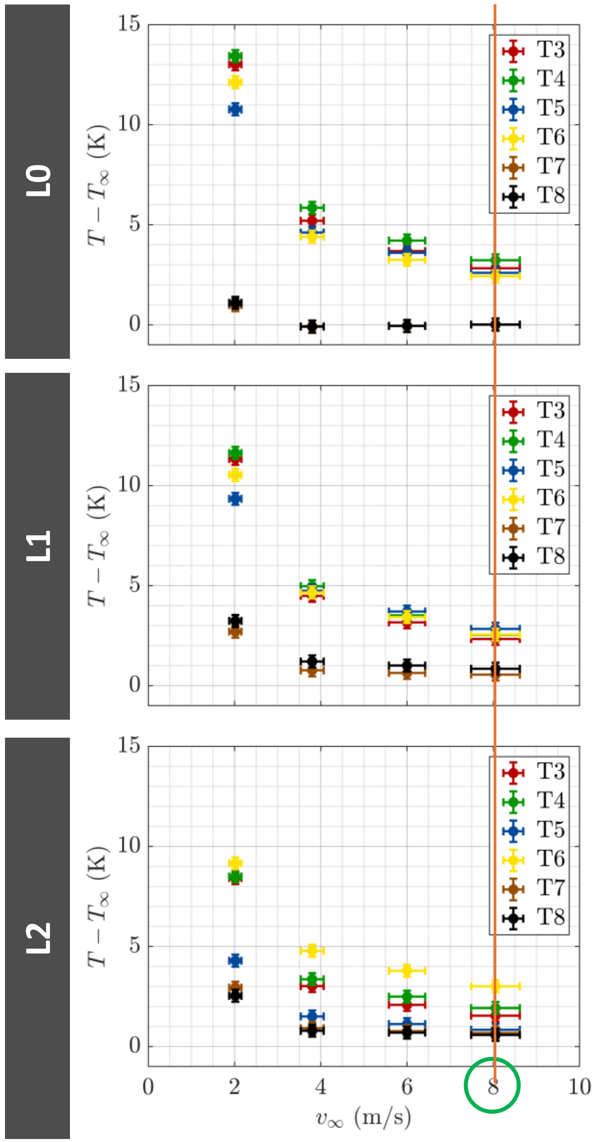
Surface power dissipation

Left End-cap: $q_e = 1000$ mW/cm^2 , uniform

Active area: $q_a = 50$ mW/cm^2 , uniform

Estimates of power consumption (TDR)

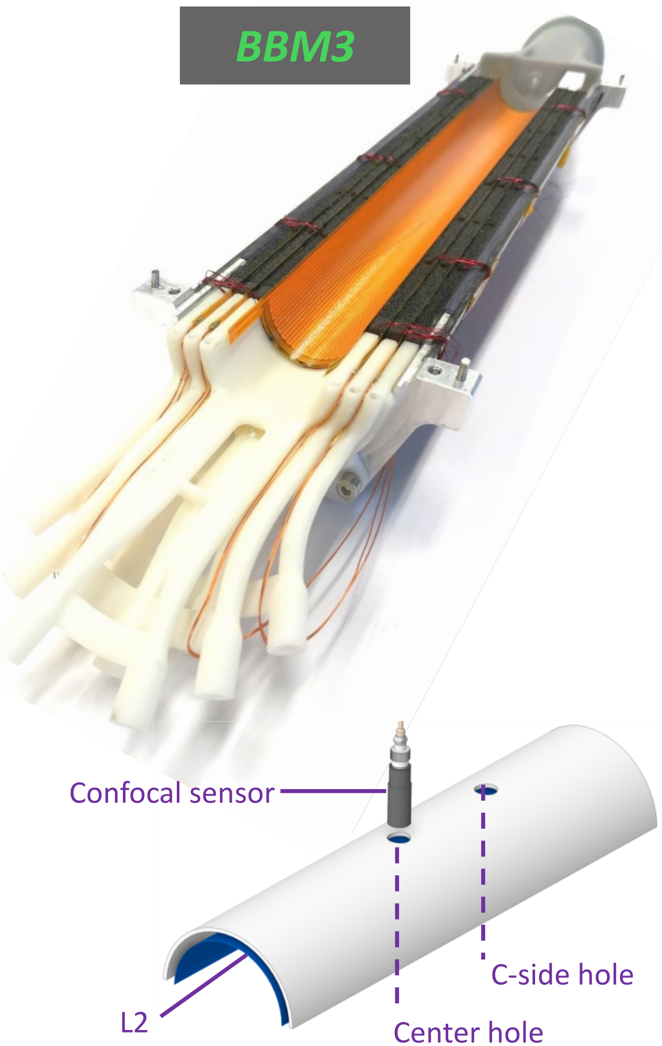
	Power density [mW cm^{-2}]		
	Expected 25 °C	Max 25 °C	Max 45 °C
Left End Cap (LEC)		791	
Active area (RSU)	28	44	62
Pixel matrix	15	32	51
Biasing	168	168	168
Readout peripheries	432	457	496
Data backbone	719	719	719



Testing: Dynamic stability Vs airflow

The experimental test results align with the simulation, showing a peak-to-peak displacement of approximately 1.1 µm.

Prototype

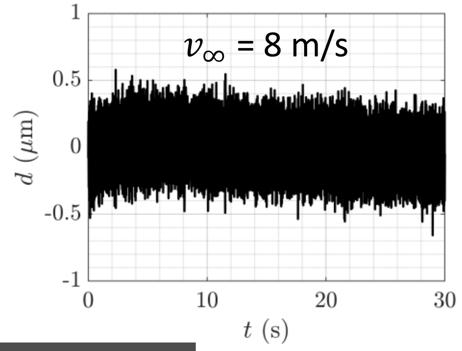


Experimental results

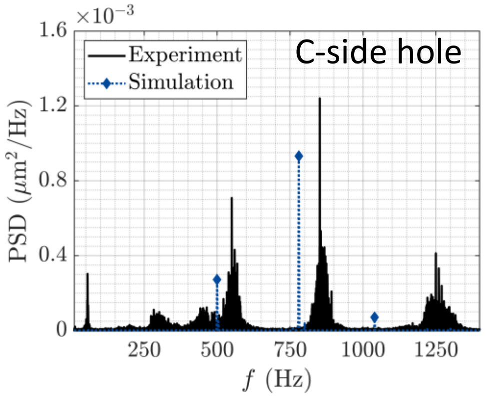
Confocal chromatic displacement sensor (at 30 kHz)
Freestream velocity v_∞ = 8 m/s

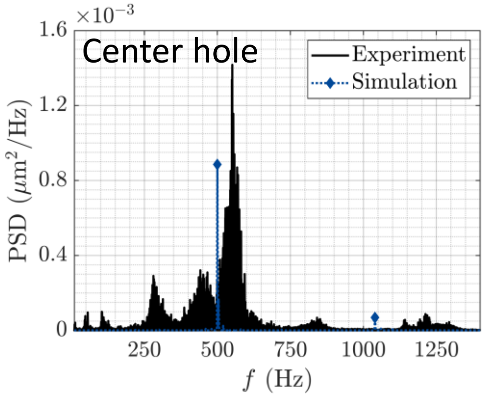
Modeling of fluid-structure interaction (FSI):
The procedure includes comprehensive fluidic dynamic analysis to evaluate the aerodynamics forces induced to the sensor by pressure fluctuations, which are utilized as input to finite element transient simulations.

Displacement Vs time
half-layer 2, center hole



Power spectral density of the displacement
for half-layer 2, v_∞ = 8 m/s

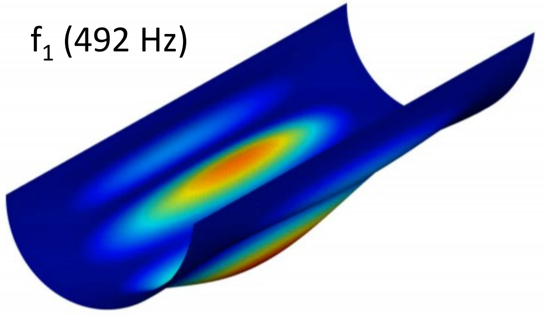




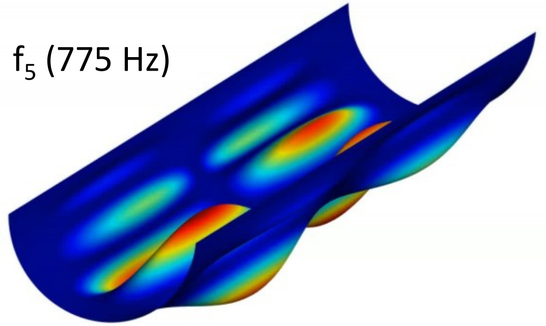
Displacement: Peak-to-peak ~ 1.1 µm, Root Mean Square < 0.4 µm

Modal analysis H-L2

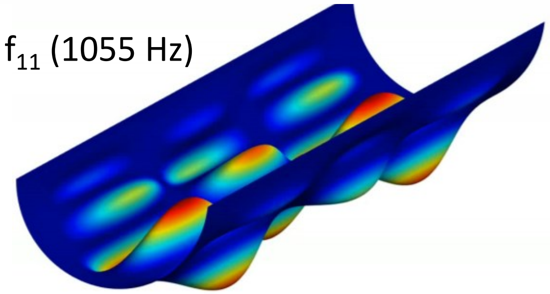
f_1 (492 Hz)



f_5 (775 Hz)



f_{11} (1055 Hz)



Testing: Thermoelastic failure assessment

ALICE ITS3 WP5

No structural damage in a range of 10÷50°C and thermal peak up to 45 °C .

Prototype

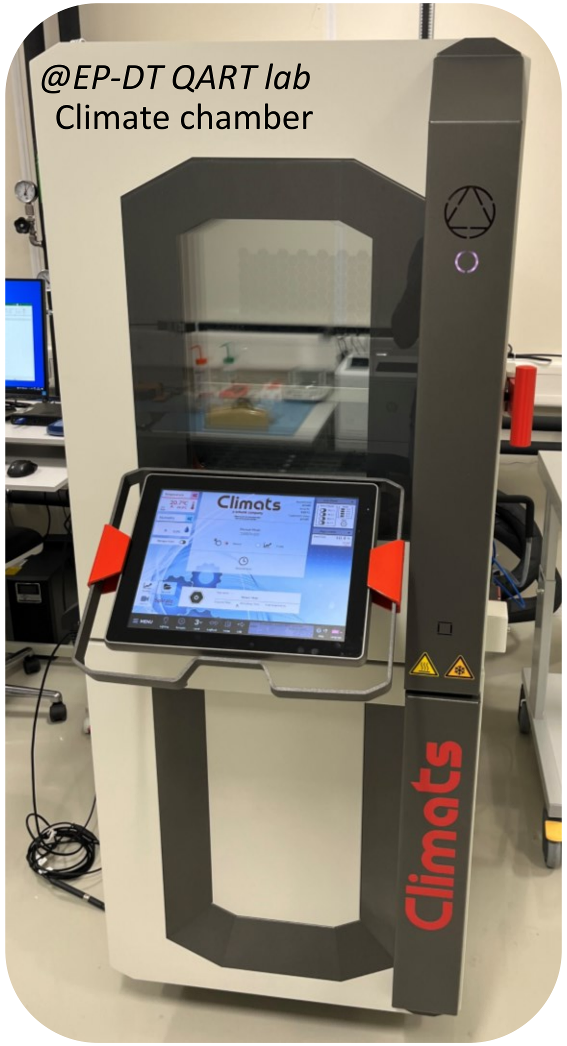
BBM5

Made of final-grade materials

Thermal cycles

Thermal cycles

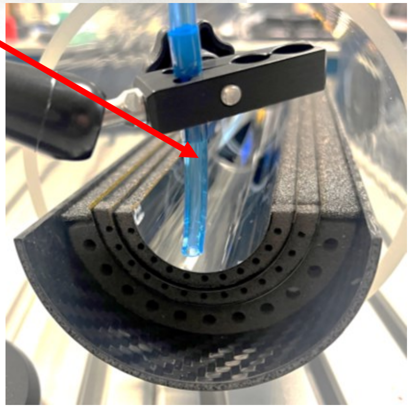
10 °C ÷ 50 °C

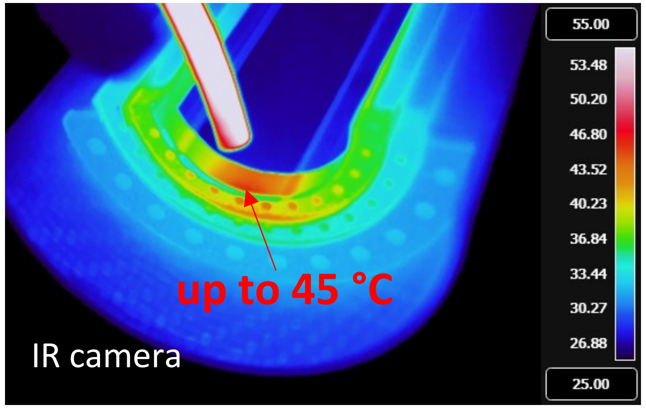


Hot-spot testing

- Localized heating to assess the effect of thermal gradient

Heat gun





Hot spot

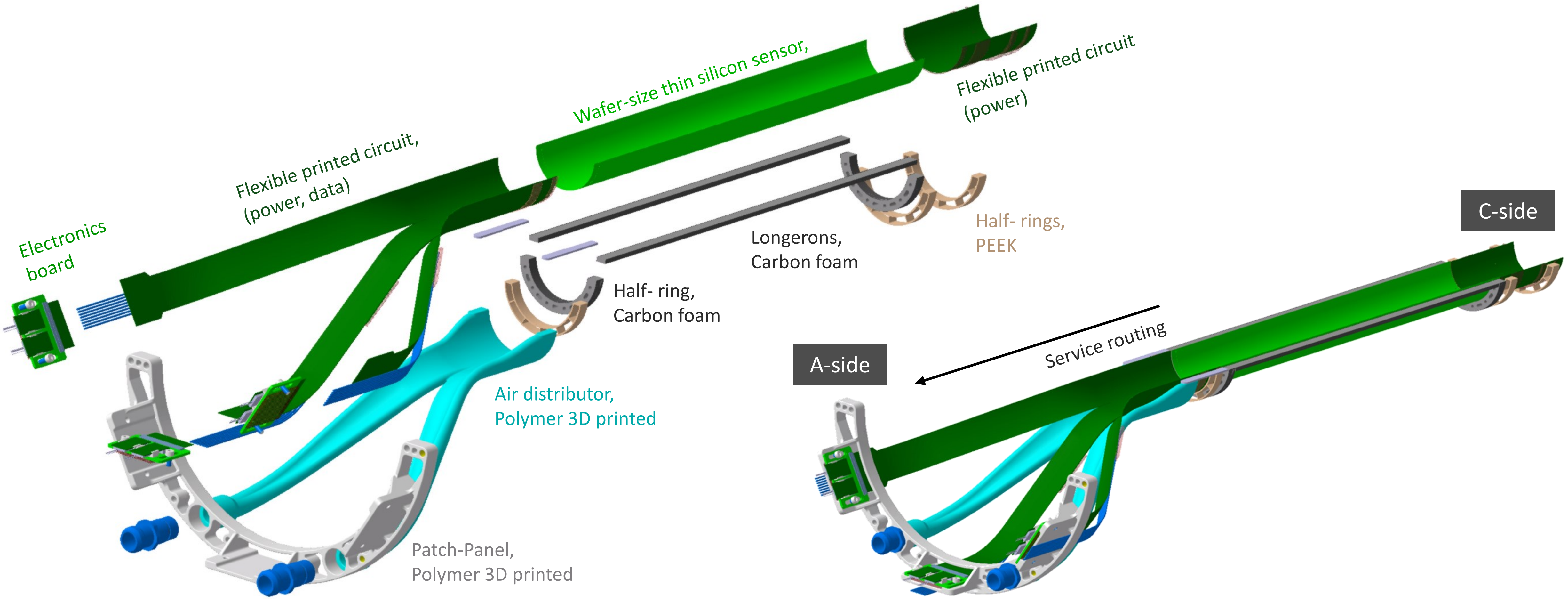
up to 45 °C

Humidity 30-40%

Services: half-layer

Challenge: integrate power/data lines and cooling ducts in minimum space, use of specific FPC design and 3d printing

CAD model of Half-layer 0: (left) Exploded view and (right) assembled view.

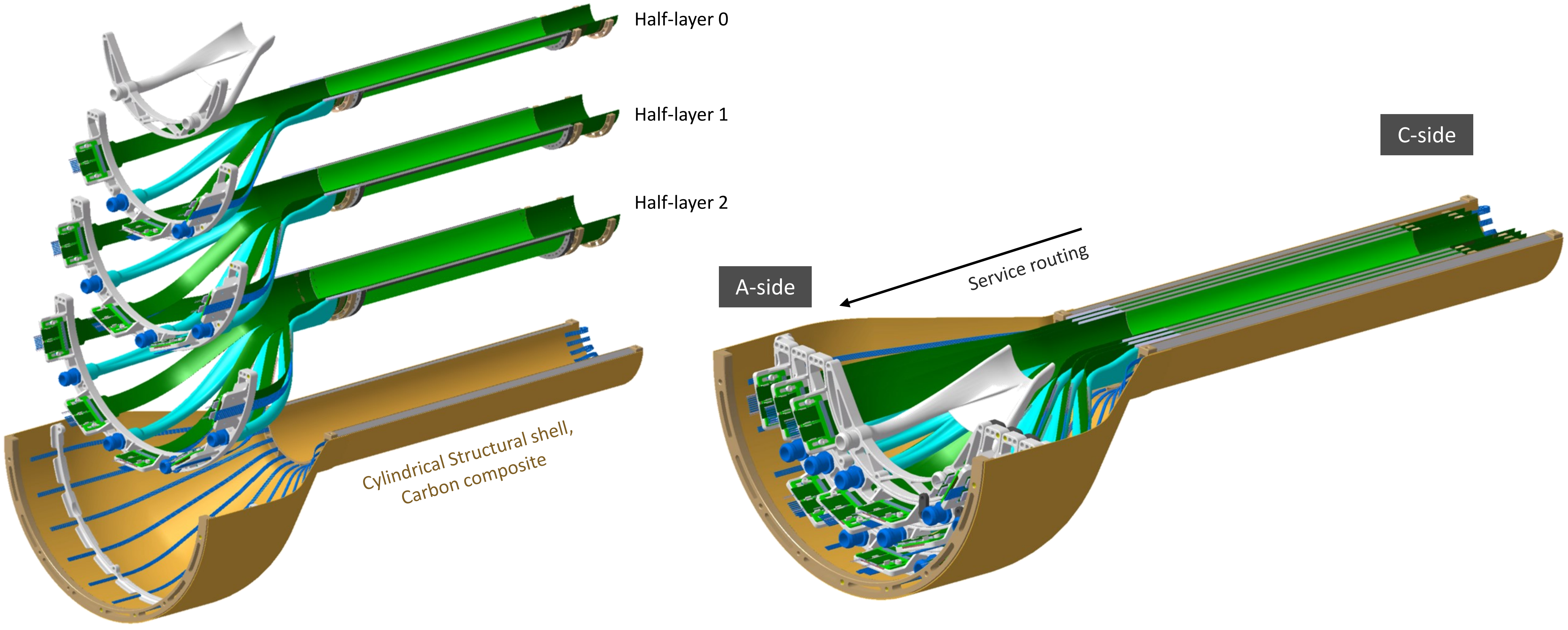


Services: half-detector

ALICE ITS3 WP5

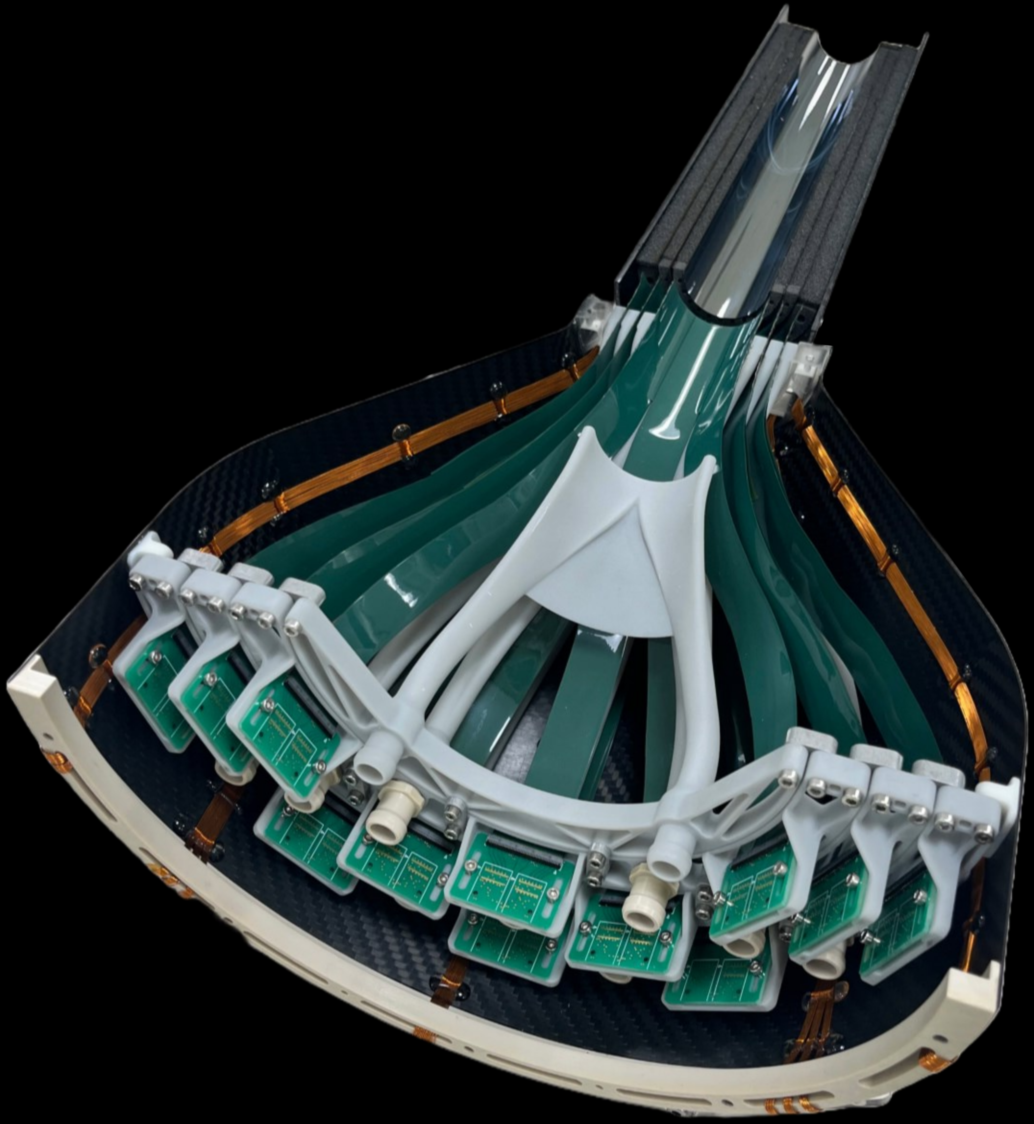
Challenge: handling and precise positioning and integration of layers and services inside the mechanical exoscheleton

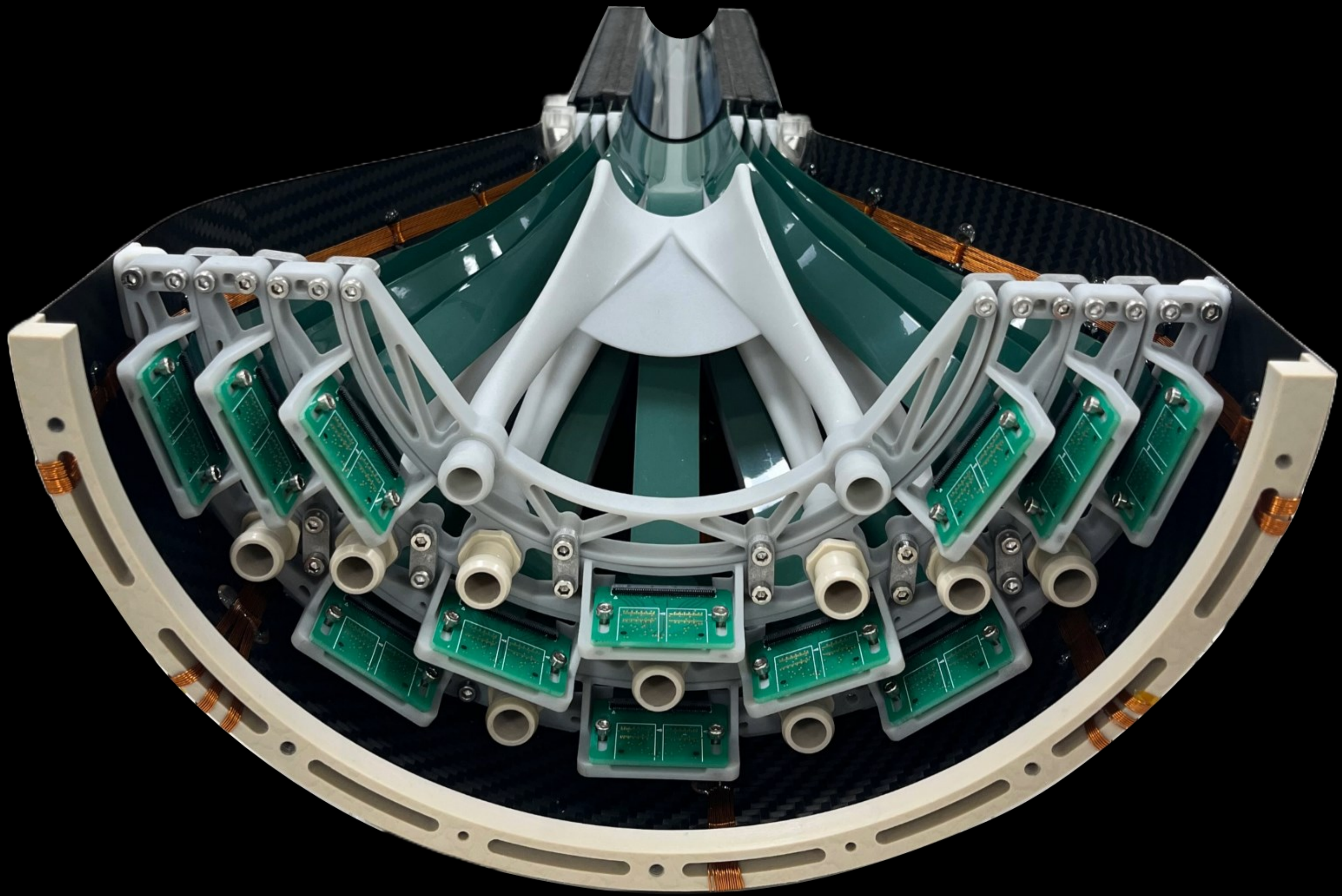
CAD model of Half-layer 0: (left) Exploded view and (right) assembled view.



Services: prototyping

The challenge here involves **finding space** for all the services and making them accessible and removable during assembly





Conclusions

- Wafer-size thin sensors successfully bent to cylindrical shape to form the detector’s layer
- Air-cooling based on carbon foam radiator developed and satisfying thermal and stability requirements
- Layer connected to front end electronics by wire bonding
- Three layers integrated in a half barrel layout
- Service design implemented
- Different models built for the design validation

- Next: build a final-quality half-barrel (QM) within 2025 to be ready for final detector assembly (FM) in 2026