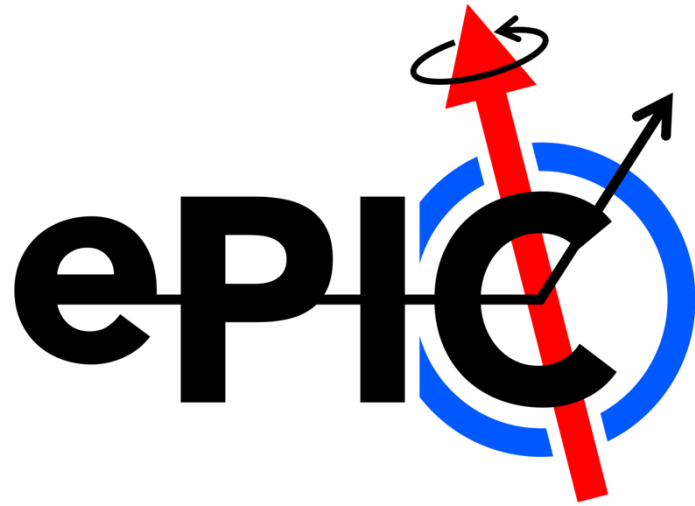
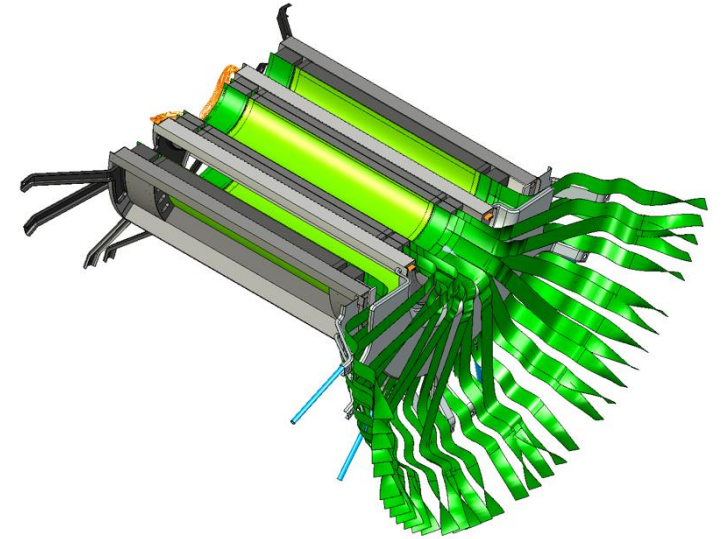




Silicon Vertex Tracker Inner Barrel



Domenico Elia
for the INFN SVT team

SVT Working Meeting - LBNL | 8 October 2026

- Introduction
- Half-barrel assembly
- Flex printed circuit
- Services integration
- Thermo-mechanical studies
- Summary and nearest planning

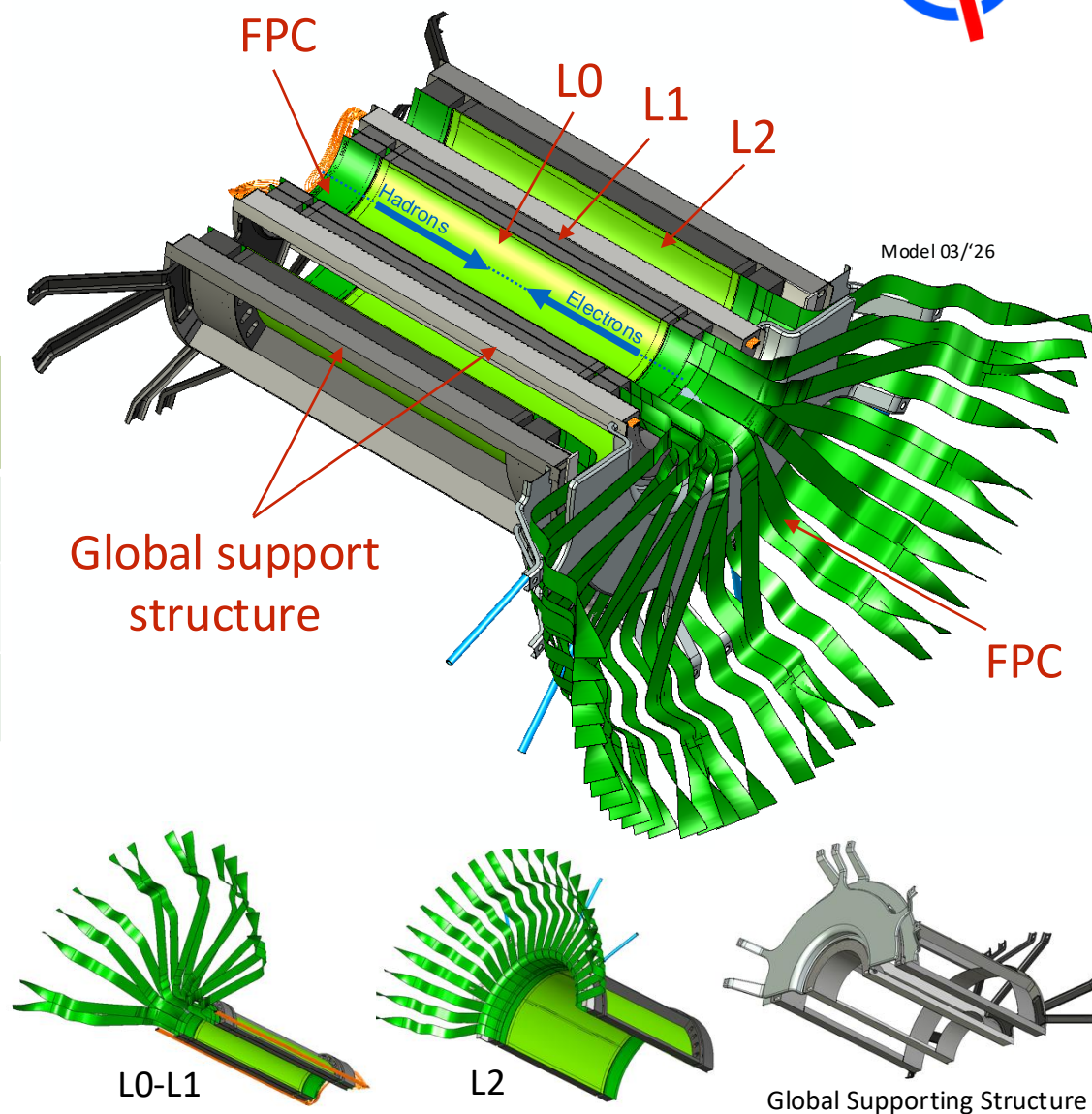
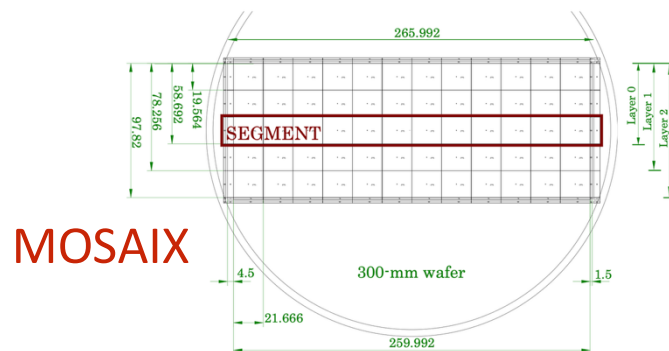
SVT Inner Barrel



Basic ingredients:

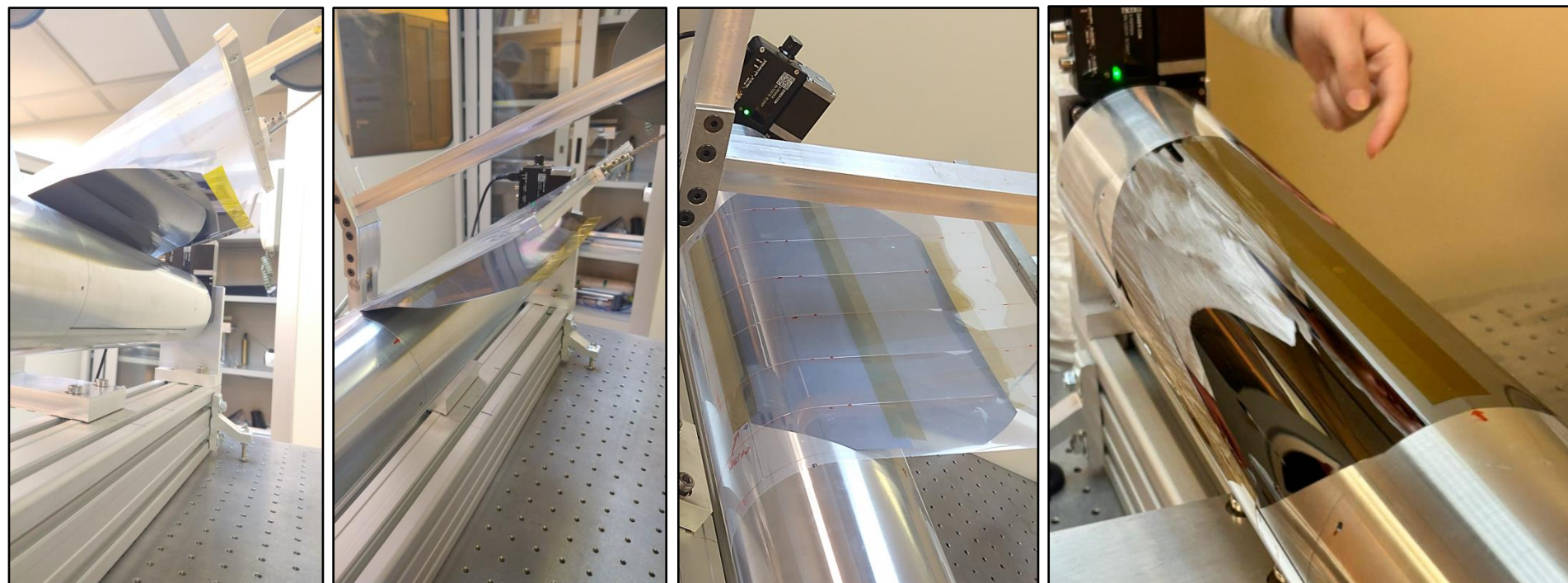
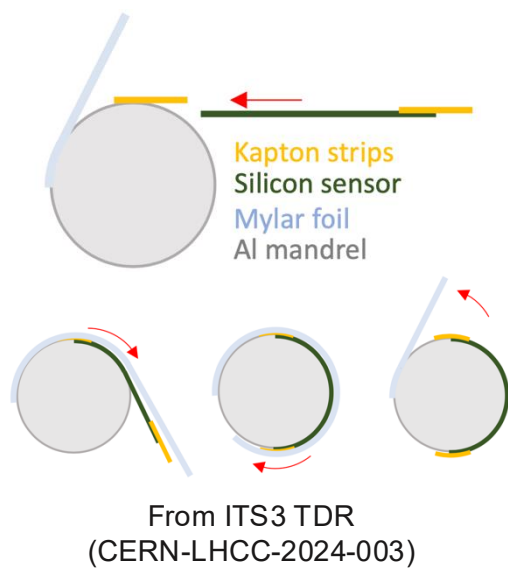
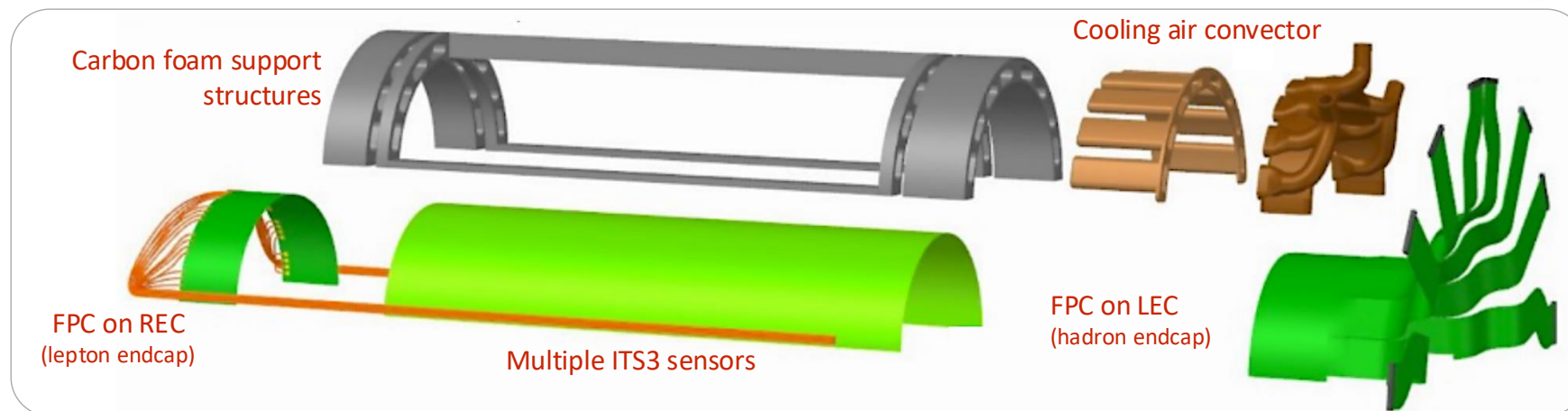
- Wafer-scale MAPS chips (ITS3 65 nm CMOS, thickness $\leq 50 \mu\text{m}$)
- Chips bent in semi-cylindrical shape at target radii
- Ultra-light carbon foam/fiber structures
- Air cooling

Half Layer	Radii (mm)	Single sensor area (mm ²)	# of sensors for a half-layer	# of segments for a half-layer
L0	38	266 x 58.7	2	6
L1	50	266 x 78.3	2	8
L2	126	266 x 97.8	4	20

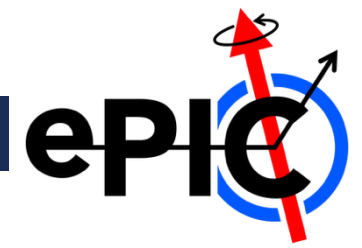


SVT Inner Barrel

Single layer components



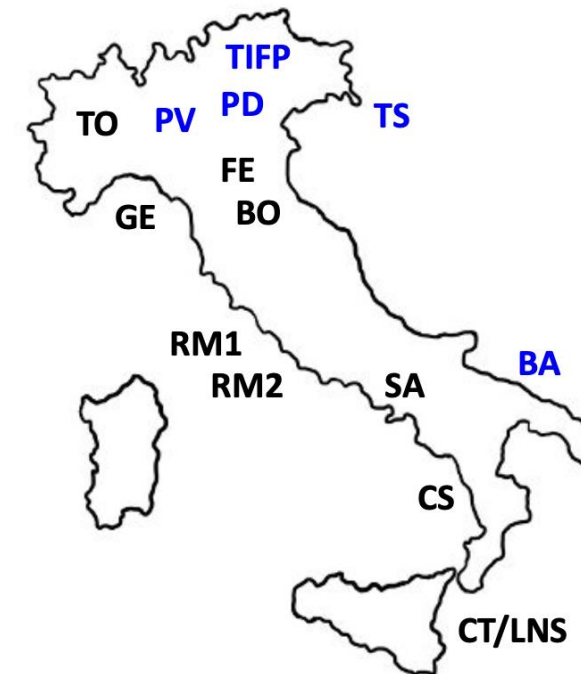
SVT Inner Barrel

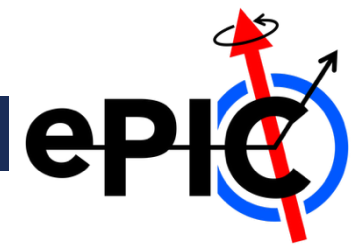


INFN team in SVT IB:

- five groups involved: Bari, Padova, Pavia, Trento (TIFPA) and Trieste (~30 people and 15 FTE)
- roles in the SVT DSC: D. Elia SVT WP4 co-convener and R. Turrisi SVT Technical Coordinator
- internal coordination: D. Colella ([2026 EICUG Award](#) @Glasgow ePIC/EICUG meeting)

	BARI	PADOVA	PAVIA	TIFPA	TRIESTE
Sensor characterization					
FPC design, characterization and production					
Global mechanical support design and production					
Layers and barrels assembly procedure and production					
Simulations: thermoelastic, vibrational and thermal load					
Cooling design and effectiveness studies					
Thermo-mechanical and vibrational stability and ageing studies					
Packaging and transport					





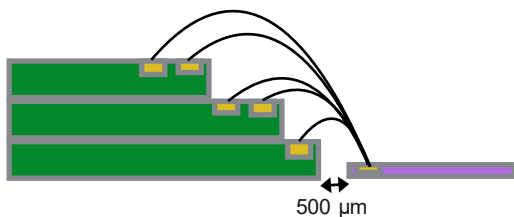
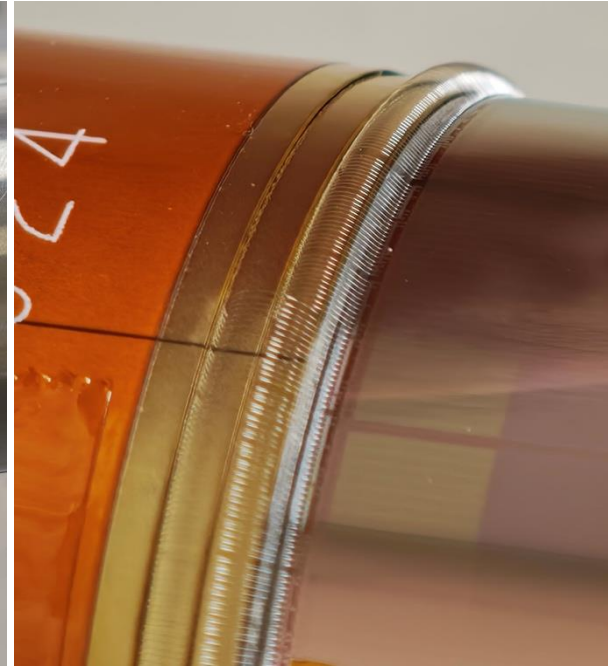
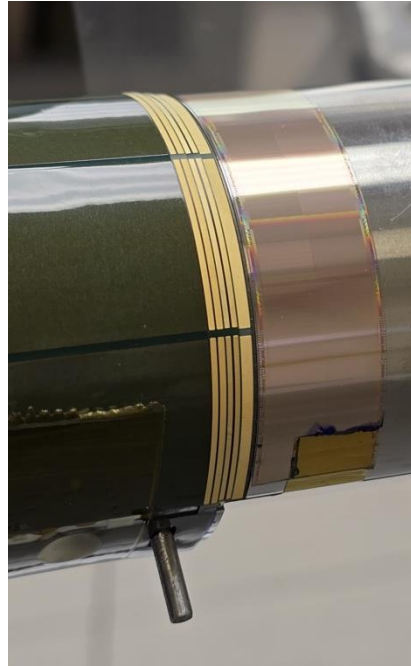
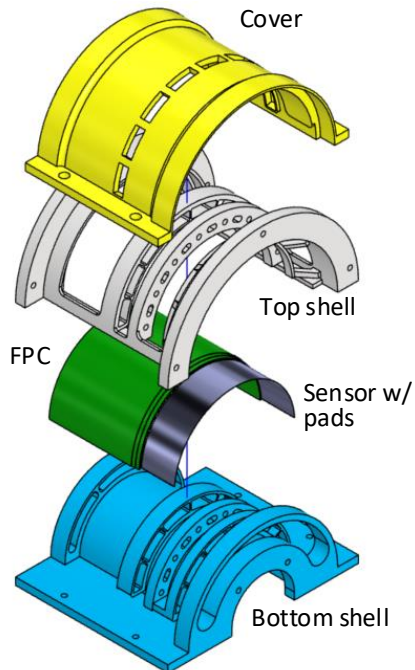
L0-L1 prototyping campaign

Prototype	Components	Goal	Delivery target date
IB-HB01 M1	- L0/L1 sensors: blank silicon pieces - LSS: 3d printed - L1COS: NOT needed, LSS self-supporting - FPC/air-ducts: NOT included	Finalize half-barrel assembly tooling and procedures	Completed in November 2025
WB-M01	- L0/L1 sensors: MOSS fraction (length to fit the ITS3 L1 radius) - LSS and L1COS: 3d printed in one single object - FPC/air-ducts: re-shaped sample of SVT FPC from Padova	Study the eventual effects of continuous air-flow over the wire-bonding	Completed in June 2026
IB-HB01 M1.2	- L0/L1 sensors: (half-mooned) blank silicon pieces - LSS: carbon foam (PocoFOAM, no fleece) - L1COS: 3d printed - FPC/air-ducts: NOT included	First assembly with carbon foam LSS + Preliminary studies in climate chamber	Completed in June 2026
IB-HB01 M2	- L0/L1 sensors: blank silicon pieces - LSS: carbon foam (ERG Duocel everywhere, w/ fleece) - L1COS: carbon fiber composite - FPC/air-ducts: NOT included	Temperature induced mechanical stress in climate chamber	Ongoing
IB-HB01 M3	- L0/L1 sensors: heaters + PT1000 sensors - LSS: carbon foam (ERG Duocel + Allcomp K9 SD, w/ fleece) - L1COS: 3d printed - FPC/air-ducts: dummy/3d printed	Air-flow cooling effectiveness in a wind tunnel	December 2026

L0-L1 prototyping campaign

WB-M01

WB-M01	- L0/L1 sensors: MOSS fraction (length to fit the ITS3 L1 radius) - LSS and L1COS: 3d printed in one single object - FPC: re-shaped sample of SVT FPC from Padova	Study the eventual effects of continuous air-flow over the wire-bonding	Completed in June 2026
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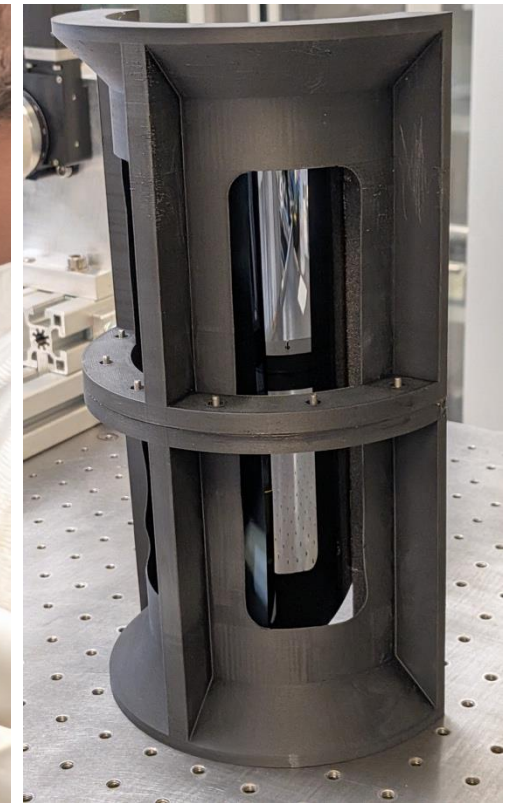
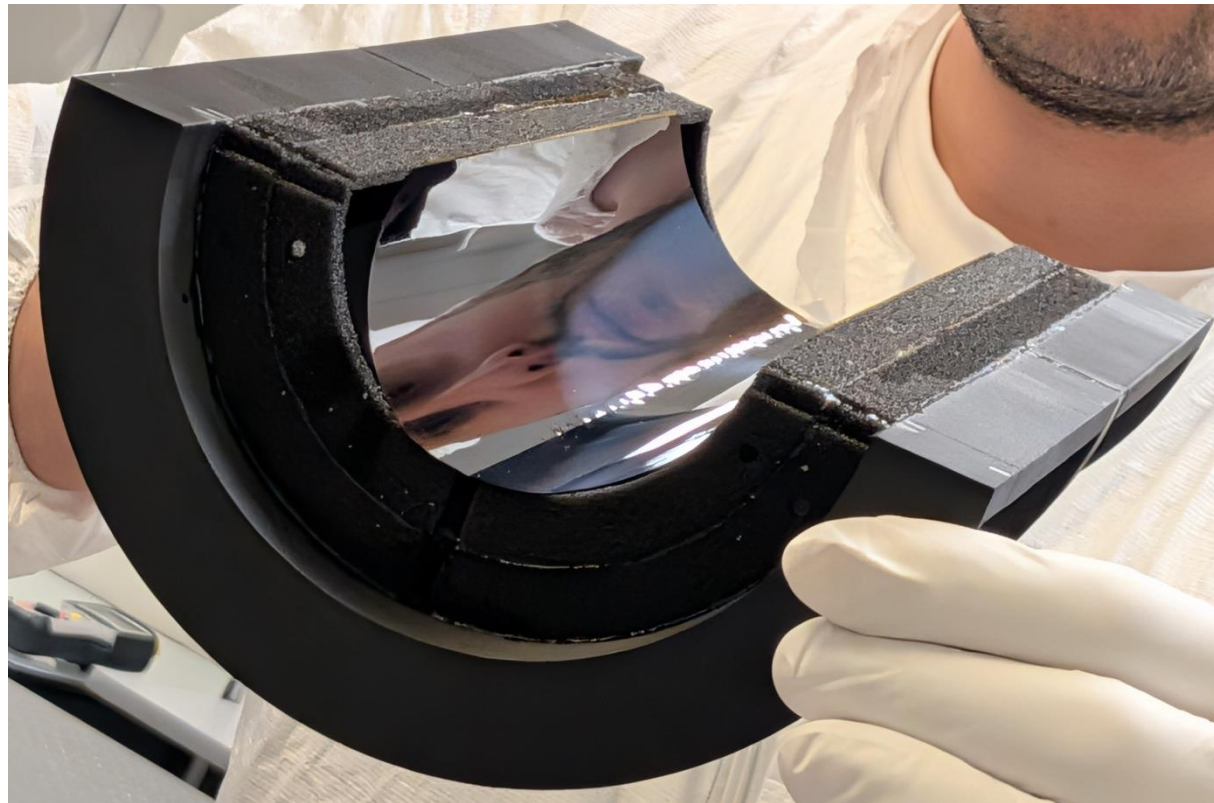


- First wire loop and soldering parameters identified
→ To be repeated with final grade pad metallization
- Two wires length: shortest and longest
- Quantitative parameter: pull-force value to be evaluated before and after continuous air-flow at target velocity → Setup for air-flow exposure to be arranged

L0-L1 prototyping campaign

IB-HB01 M1.2

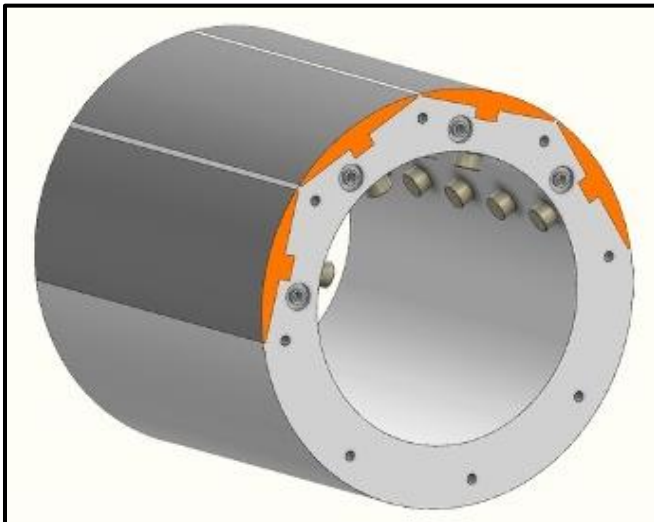
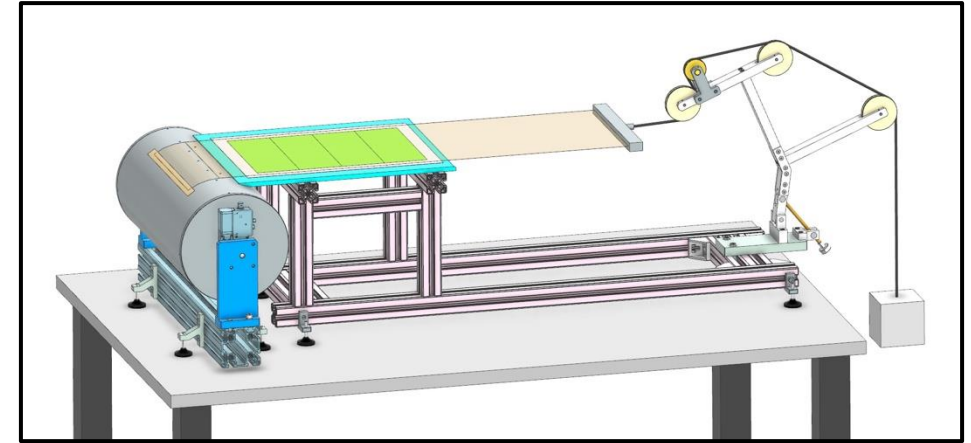
IB-HB01 M1.2	• L0/L1 sensors: (half-mooned) blank silicon pieces • LSS: carbon foam (PocoFOAM, no fleece) • L1COS: 3d printed • FPC: NOT included	First assembly with carbon foam LSS + Preliminary studies in climate chamber	Completed in June 2026
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First results from thermal cycles in the “Thermo-mechanical studies” section

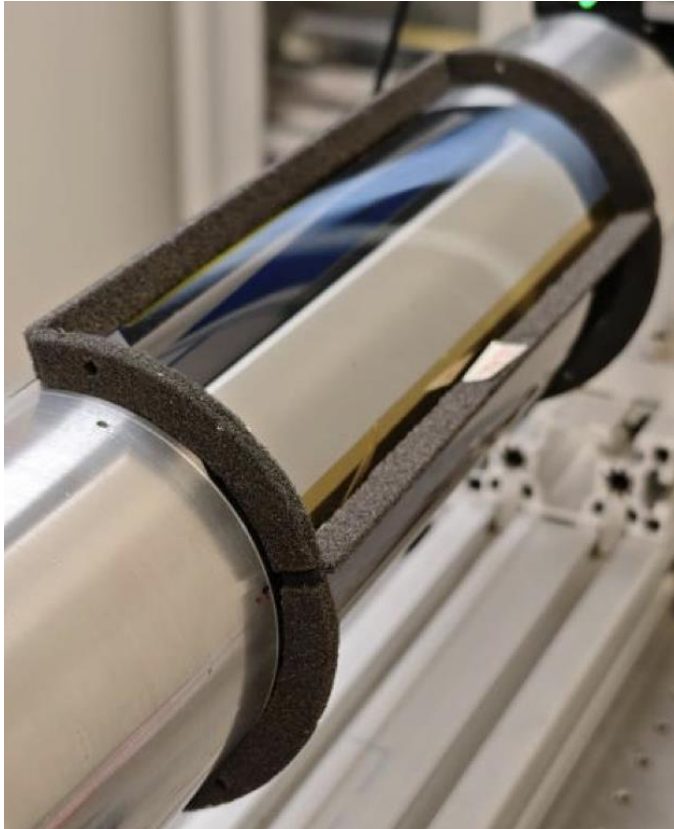
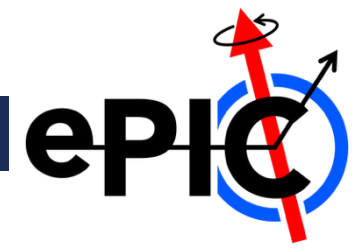
Towards L2 assembly procedure

- L2 is composed of **4 sensors** sized $\sim 266 \times 98 \text{ mm}^2$
- **First idea** for the bending procedure based on L0-L1
 - Alignment and joining of sensors (using adhesive tape) done on a flat metal/plastic sheet, than bent around the mandrel → Bending in one step
 - Criticalities emerged concerning the safety of the sensors and the procurement of really flat thin metal/plastic sheet



- A **different procedure** is under study:
 - Sensors bent one at a time, using a mandrel equipped with independent adjacent sectors made in porous aluminum (Metapor) and under vacuum
 - Procedure details still under definition: considering bending of couple of sensors to simplify and reduce potentially critical actions
 - First step: verify capability of vacuum to keep thin silicon bent
→ Mockup vacuum sector under preparation

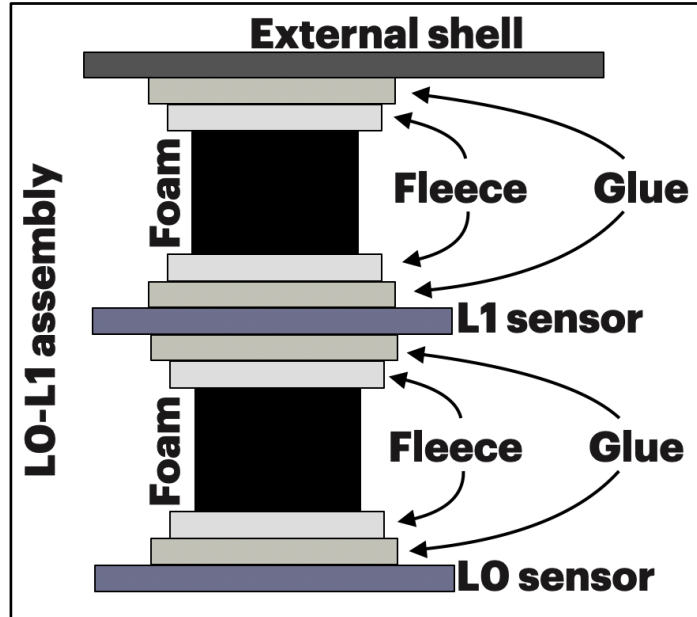
Local Support Structure



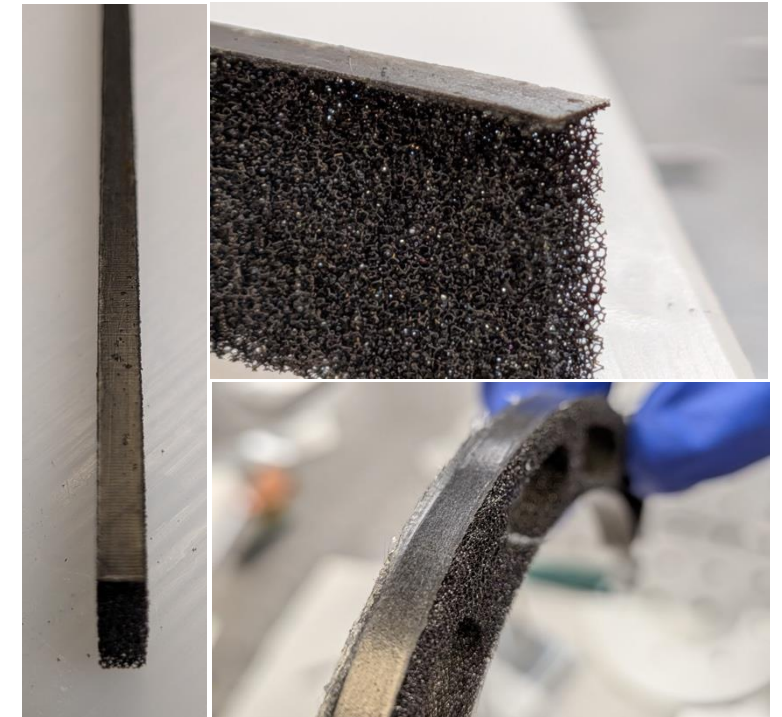
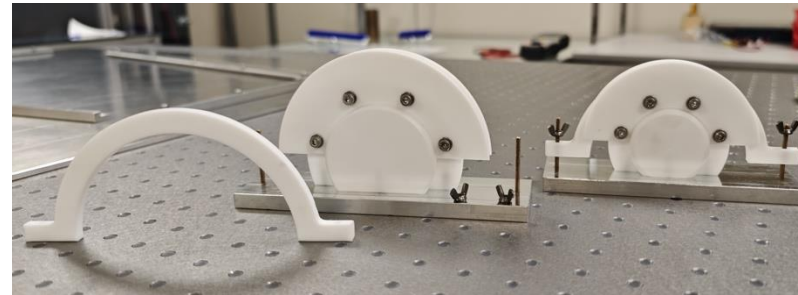
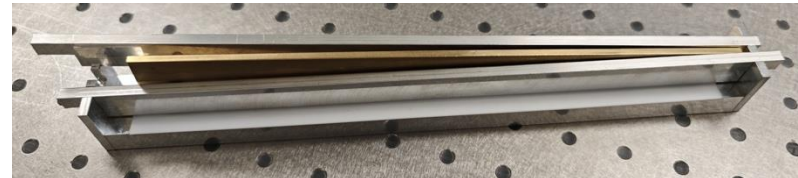
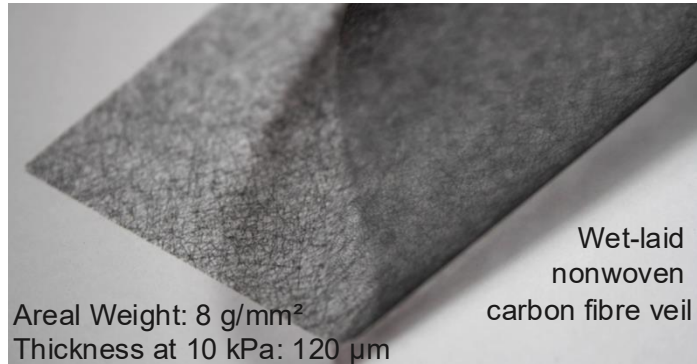
- Main functions:
 - separation elements (half-rings and longerons)
 - thermal dissipator (on the LEC side)
- Two different foams: ERG Duocel RVC and Allcomp K9
- Procurement:
 - ERG Duocel RVC → Directly from the producer
 - Allcomp K9 → Through institutes in the Collaboration also involved in ATLAS
- Shaping through laser cut:
 - Precision comparable with mechanical cut
 - Well defined procedure in place for the ERG Duocel RVC
 - Procedure to be defined/improved for Allcomp K9



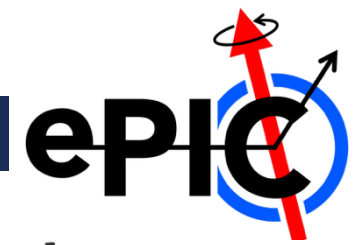
Local Support Structure



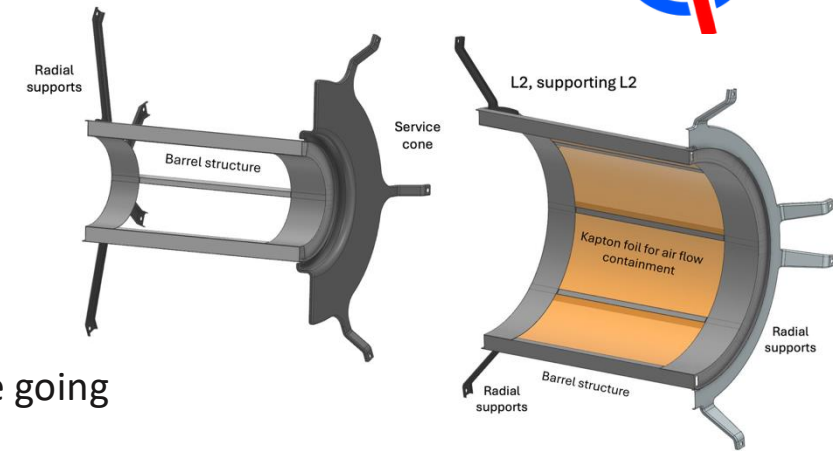
- Carbon veil glued on the interface between sensor and carbon foam for
 - Make a smoother interface
 - Control the amount of glue trapped inside the foam
- Procedure and tooling for the gluing defined
 - Soaked veil Araldite 2011, aligned to the foam and kept in position during curing



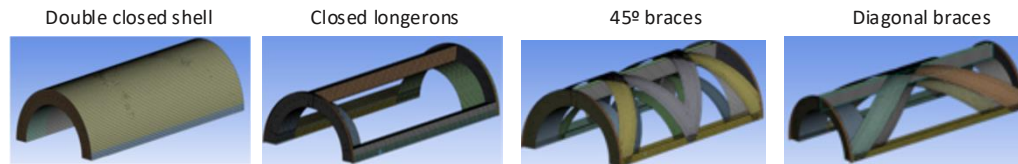
Global Supporting Structure



- SVT-IB global mechanics in advanced status of design
 - Two shells: one external to L1 and one external to L2
 - Connection to OB cone through: disks on hadron going side and radial supports on electron going side



- First sample of L1 external shell received
 - 500 μm -thick carbon fiber layer, locally reinforced in high-stress regions
 - Structure very “twisty” (design needs to be improved for final assembly, sample going to be used for L0-L1 prototypes)
 - Investigating lightest way to improve stiffness
 - Simulated many variants



- Pursuing two solutions:
 - Really thin (50 μm) double closed shell
 - Thicker open shell
- **Investigation limited by high production costs**
- Pursuing cost reduction:
 - local workshops made mould



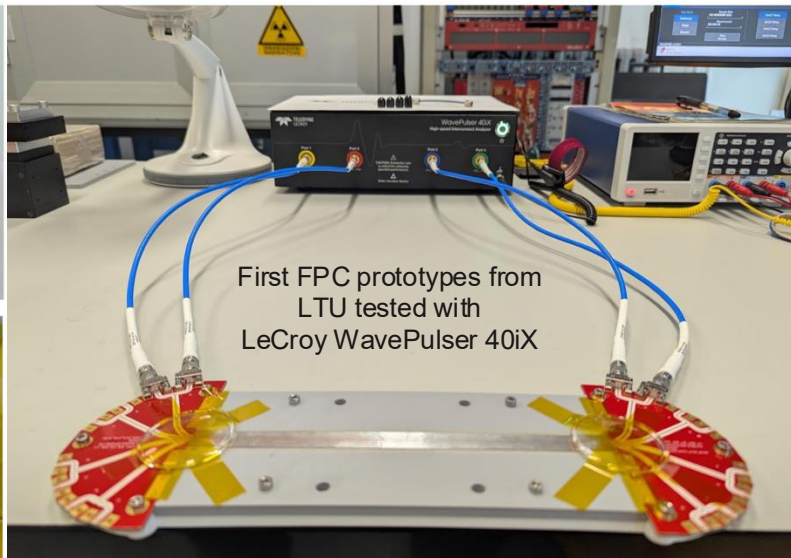
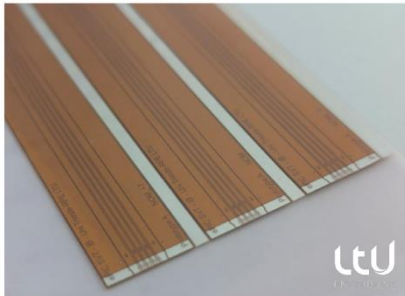
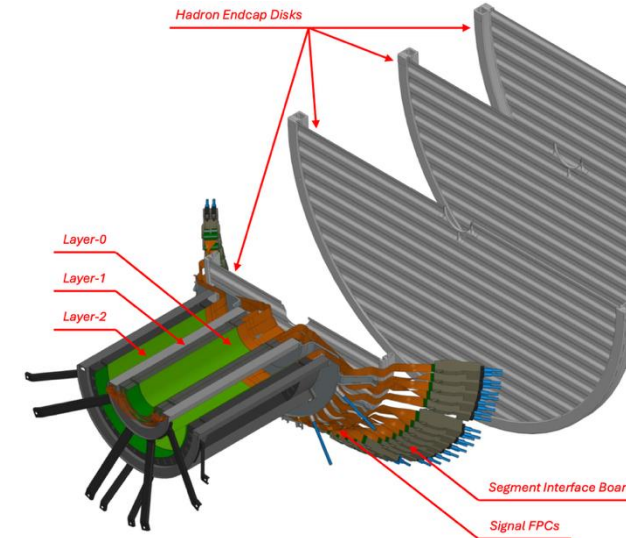
Flex printed circuit for data

MOSAIX Left End Cap (LEC)

- 8 high-speed diff. lines for data throughput (5.12 / 10.24 Gb/s)
- 8 low-speed diff. lines for sensor slow control (5 ... 160 Mb/s)

Segment Interface Board (SIB)

- VTRx+ Tx uplink for electrical-to-optical data conversion
- VTRx+ Rx downlink for sensor slow control
- SIBs location outside hadron endcap disks acceptance imply signal FPCs ~40 cm long → **Impact on signal integrity performance of high-speed differential data lines to be evaluated**



First prototypes received from LTU

- multiple-variants of two layers FPC, straight differential lines + ground plane, in “standard” aluminum-polyimide based technology, but shorter length (~20 cm) due to preliminary SIB arrangement

Preliminary characterization

- frequency domain analysis and simulations
→ Reduced eye-diagram opening at 10.24 Gb/s (see Backup)

Next steps

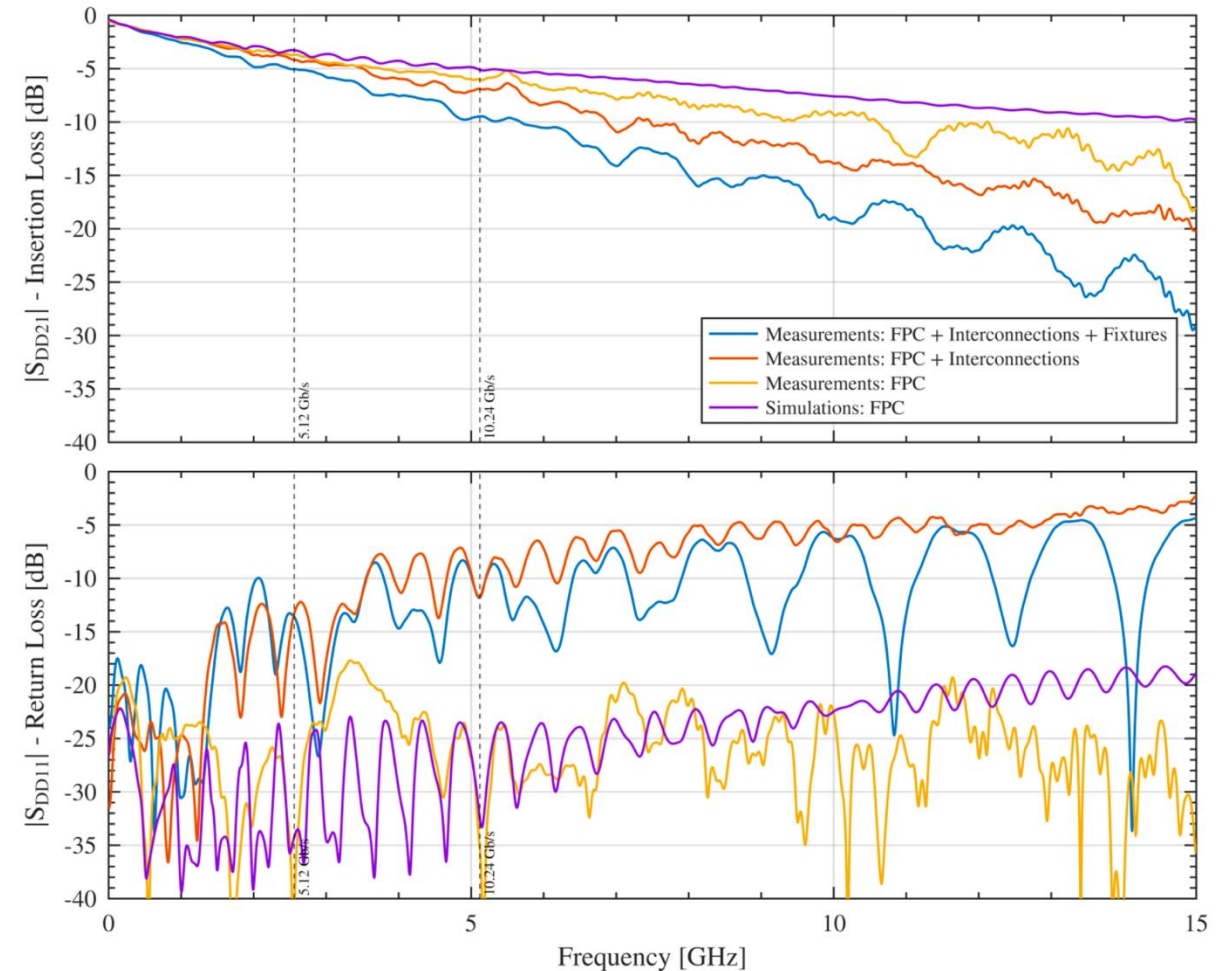
- TDR measurements with direct evaluation of eye-diagram
- Play with aluminum thickness to improve transmission
- Full ANSYS integrity simulations

Flex printed circuit for data

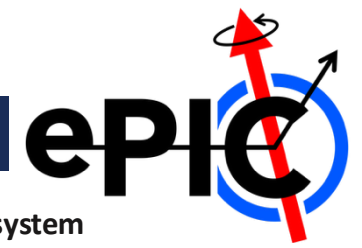
Measurements and simulation results:

- Incremental improvement in the insertion loss upon removing peripheral contributions from fixtures and interconnections (wire-bonds)
- Interconnections contribute the most to the return loss
- Reasonable agreement between measurements and ANSYS simulations at nominal frequencies

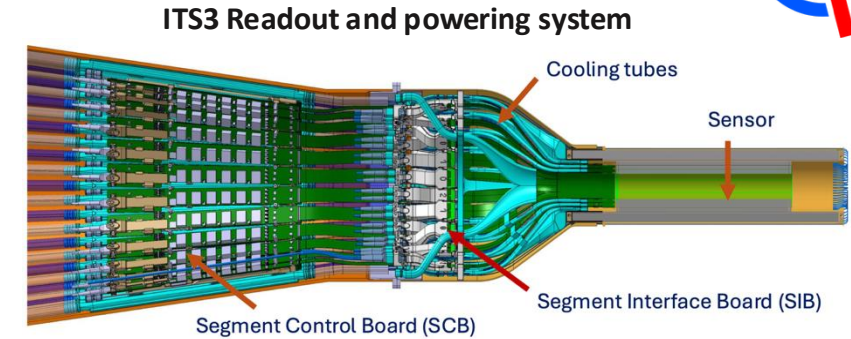
Setup	S_{DD21} [dB] 2.56 GHz	S_{DD21} [dB] 5.12 GHz
FPC + Interconnections + Fixtures	5.05	9.48
FPC + Interconnections	4.17	6.90
FPC	3.70	6.03
FPC (Simulations)	3.27	5.11



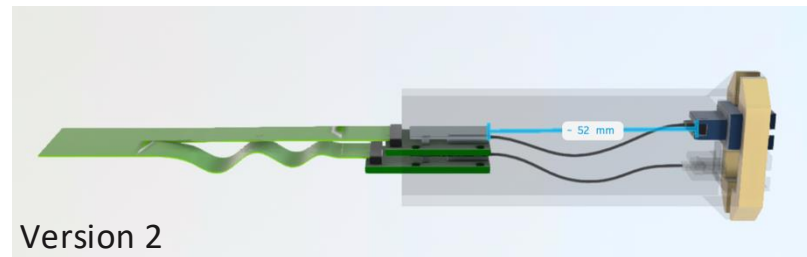
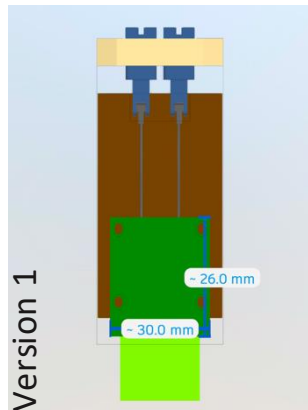
Readout and powering integration



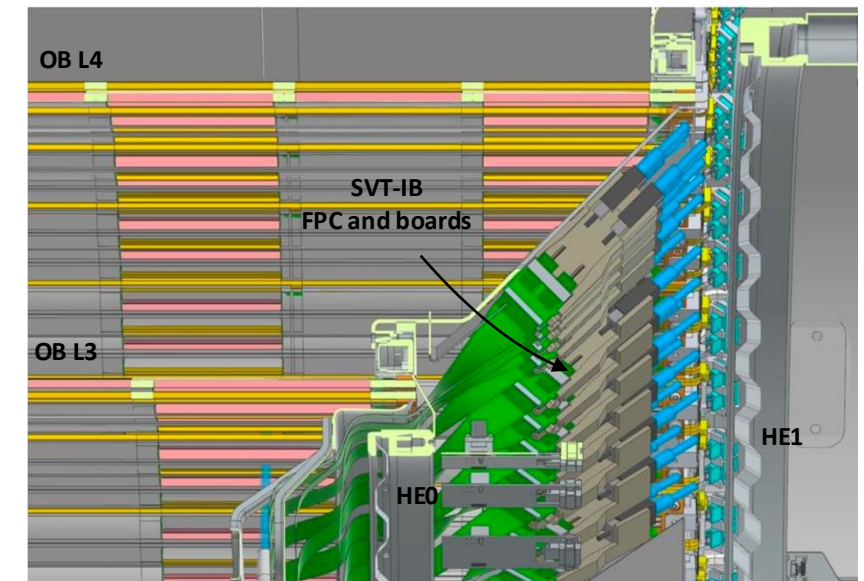
Readout and powering chains, same of the ITS3, foresee FPCs and off-detector boards (SIB/SCB)



- SIB (integrating optical transceiver) connected to sensors through FPC
 - difficult integration in the small available volume in front of disks
 - available space along the OB cone between Disk0 and Disk1
 - SIB design under optimization for SVT



- different pigtails lengths hypothesis – as an exercise
- Version 1 fits ITS3 board size and demands a twisted FPC
- Version 2 has “flat” FPC but demands a dedicated design



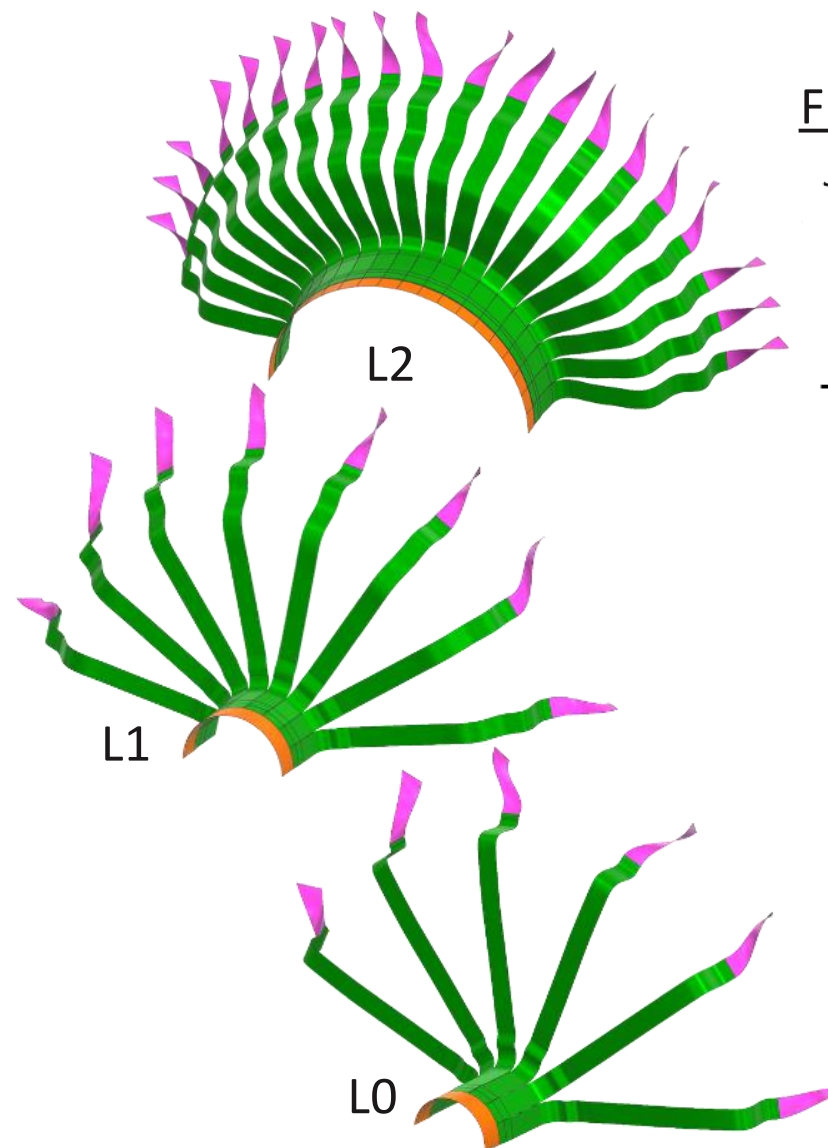
Readout and powering integration

- Recent updates:
 - SIBs mechanical layout
 - FPCs path, bending radii
 - SIBs position
 - Anchor points

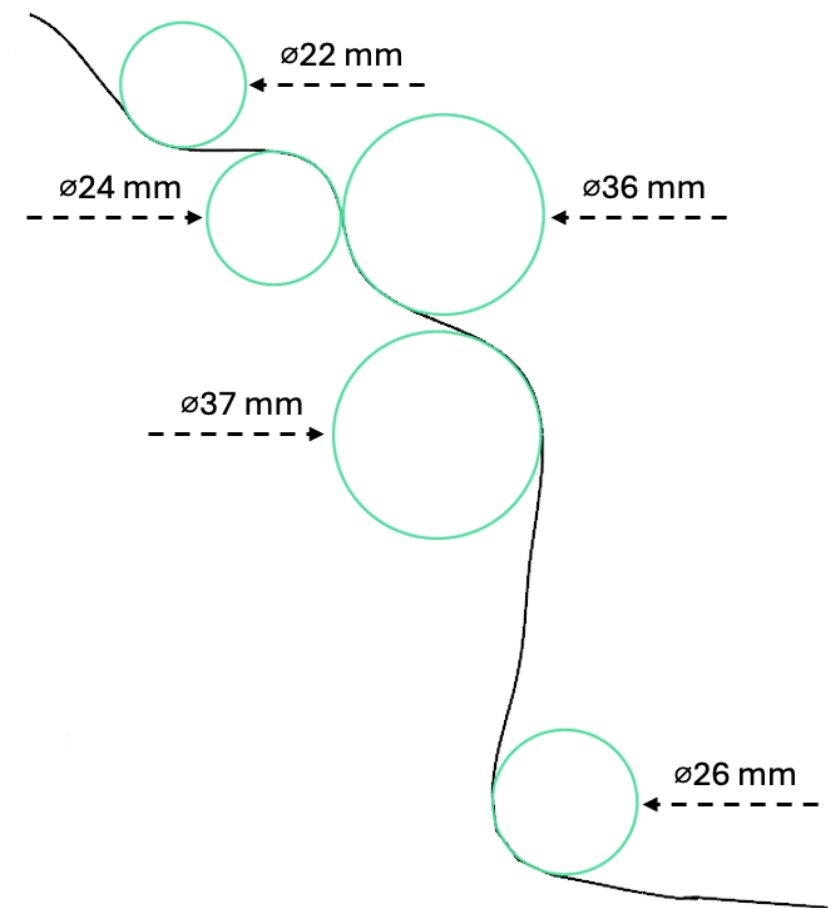
Lengths (mm)

	L0	L1	L2
	65	72	53-64
	324	296	220
	23	23	32 tbv
TOT	412	391	316

90° twist over
this distance



FPCs geometrical parameters

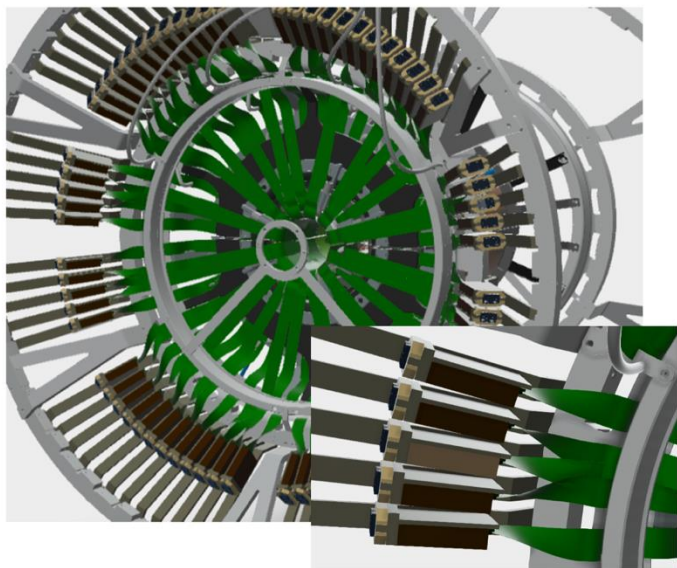


Readout and powering integration

Multiple options for SIBs mounting under consideration

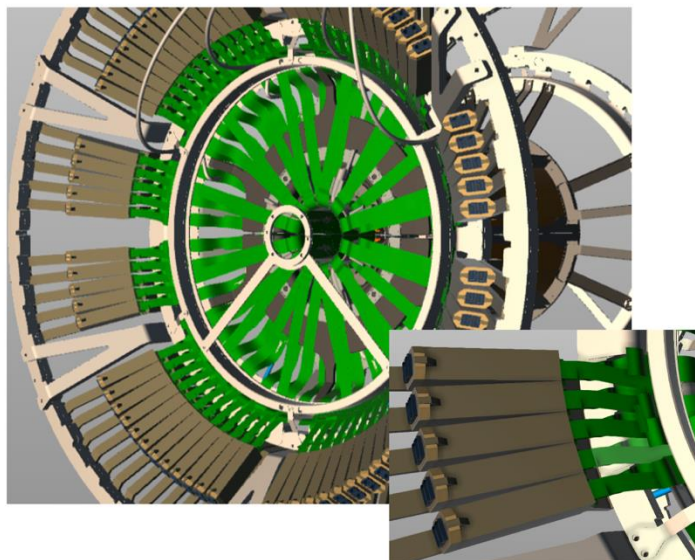
SIBs anchored on narrow side because there isn't enough space to fit when anchored on wide side.

Option "A"



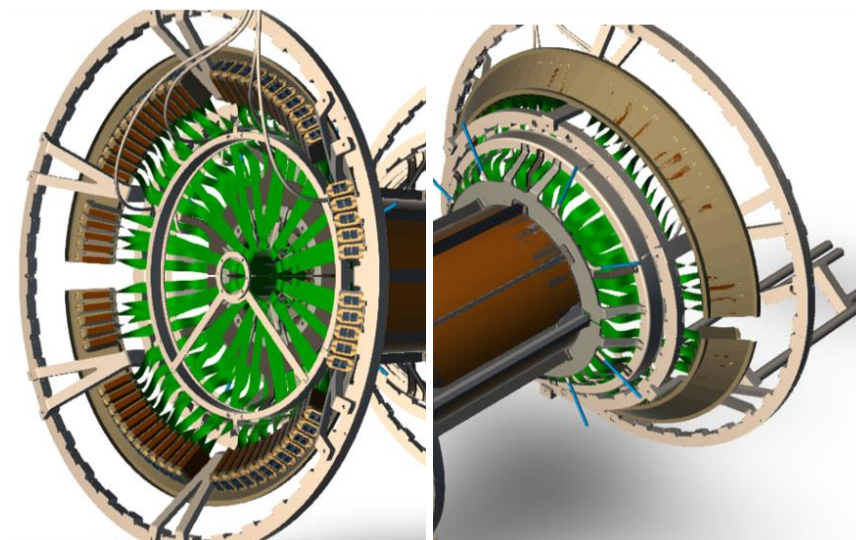
Mount SIB design v1

Option "B"



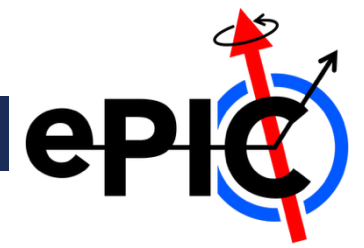
Mount SIB design v2

Option "C"



In this option two half rings support the SIB boxes (no matter the design)

Option "D" (under consideration): L2 SIBs placed on a larger circumference, at a slightly larger distance from the layer, implying ITS3-like boards and FPCs with no twist but curved design.



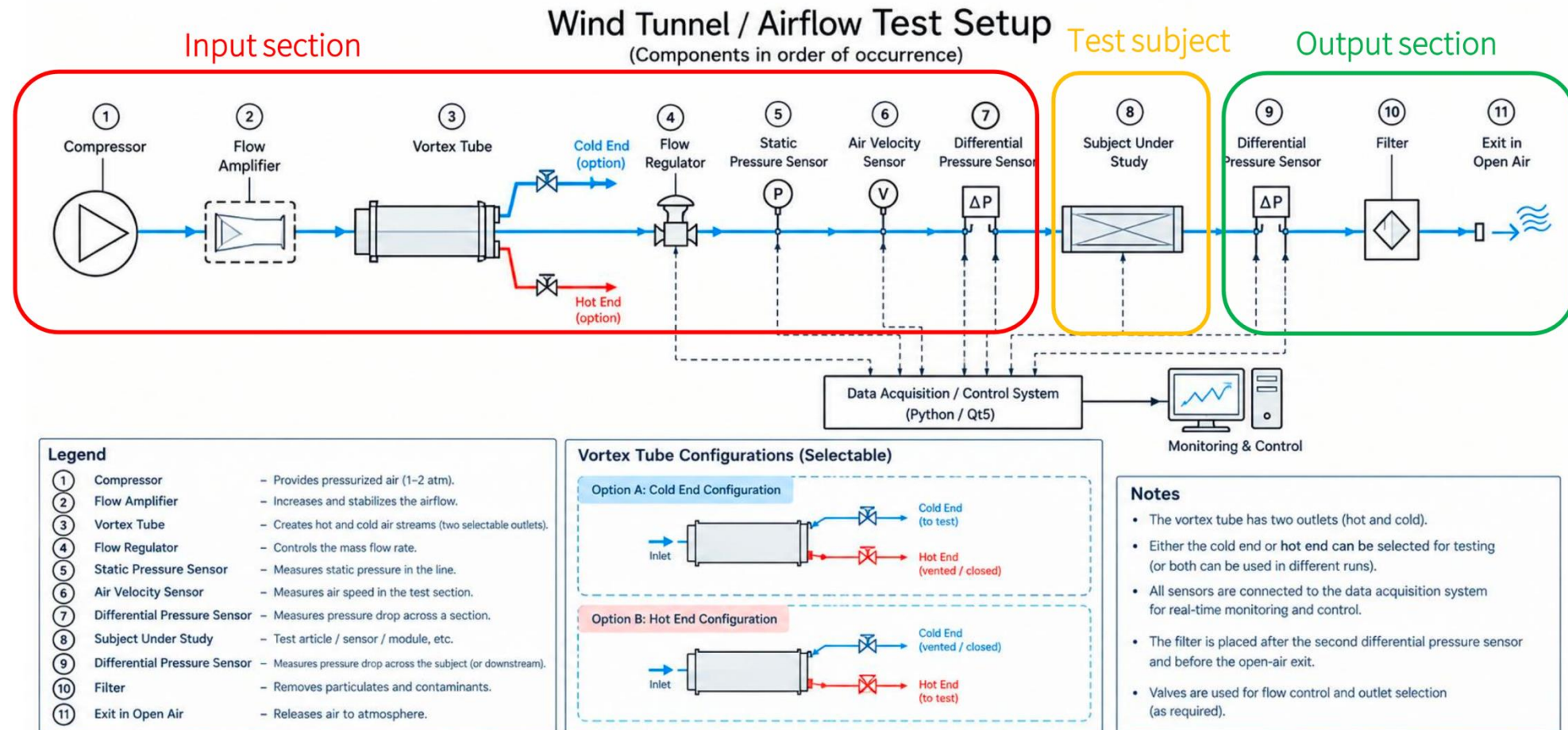
Thermo-mechanical simulations and measurements

- Collaborative effort to determine the thermo-mechanical properties of the detector
- Rich program in preparation/starting (to be completed next year):
 - Cooling effectiveness studies (simulations and measurements)
 - Baseline air-cooling setup
 - Aluminum heat sink as LEC half-ring
 - Mechanical stress induced by thermal effects (simulations and measurements)
 - Climatic chamber to simulate thermal effects applying power cycles
 - Mockup with heaters to simulate thermal effects from beam back-out
 - Mechanical stress induced by vibrations (simulations and measurements)
 - Cooling air-flow induced vibrations
 - Experimental measurements

Thermo-mechanical simulations and measurements

Cooling effectiveness studies - Baseline air-cooling setup

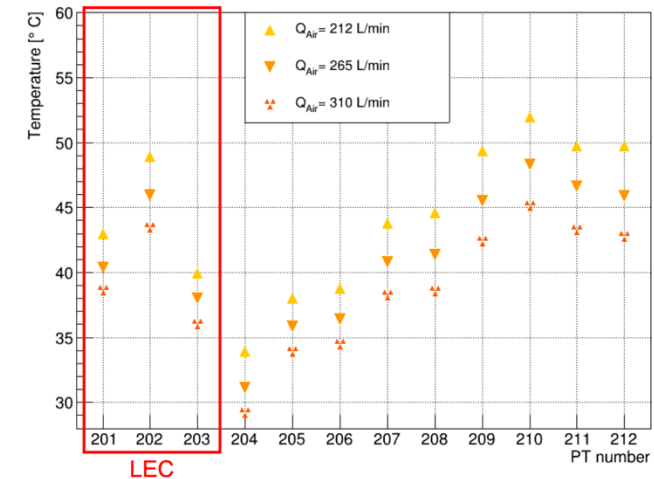
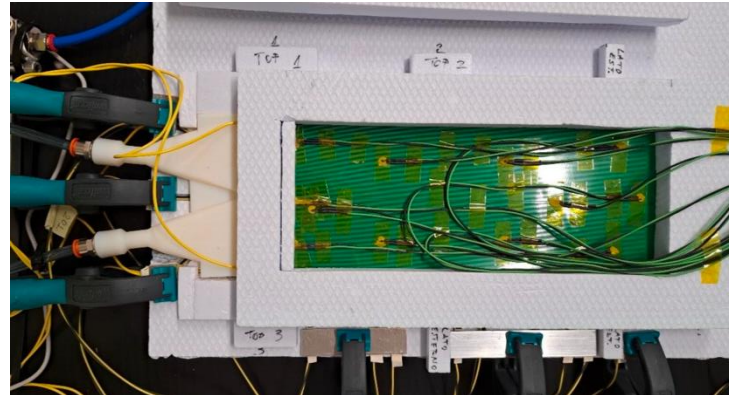
- Design finalized, procurement of the components currently under way:



Thermo-mechanical simulations and measurements

Cooling effectiveness studies - Aluminum heat sink as LEC half-ring

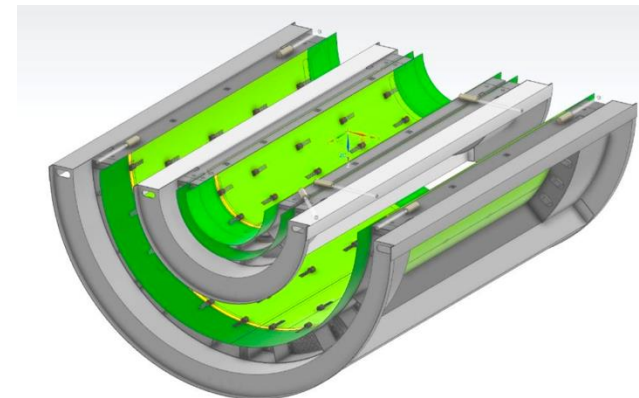
- Preliminary air-cooling test setup in flat configuration
 - L0 and L1 copper traces heaters + 12 PT1000
 - Flowmeter to measure the volumetric flow rate



Largest heat dissipation measured for the optimized heat sink

New thermal tests with the following ingredients:

- Real support prototype for L0 and L1 now available
- Dummy sensor sizes for L0, L1, L2
- Use of appropriate material like kapton or kapton + silicon
- Optimizing the air flow
- Test in wind tunnel

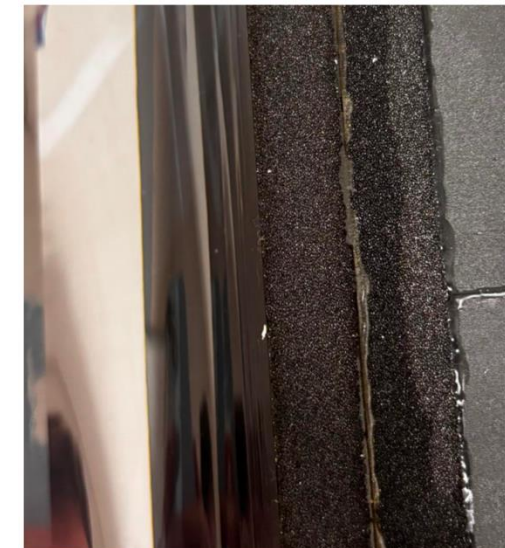
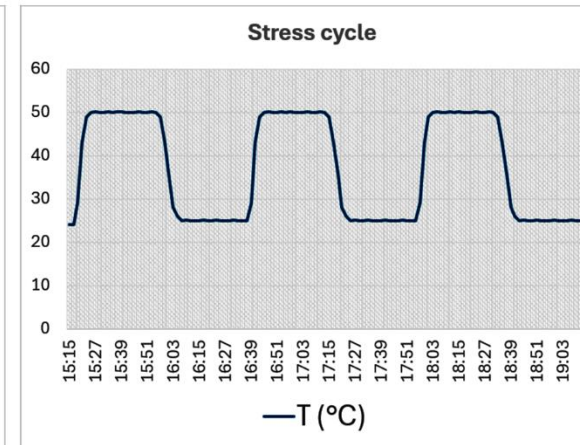
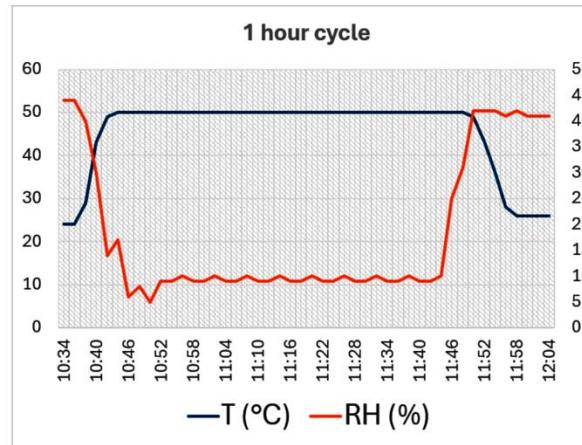
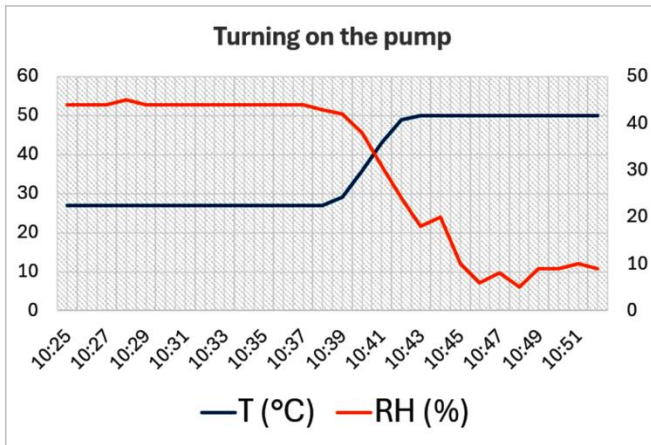


Thermo-mechanical simulations and measurements

Mechanical stress induced by thermal effects - Thermal chamber studies

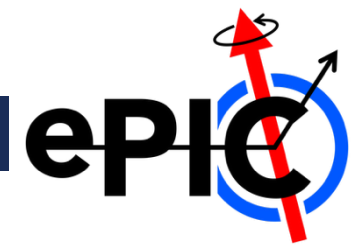
Preliminary thermal stress campaign at Pavia on M1.2:

- 1) 1 hour at 50°C, 10% RH
 - 2) 4 hours at 50 °C, 10% RH
 - 3) One night (16 hours) at 60 °C, 10% RH
 - 4) 68 hours at 50°C, 10% RH
 - 5) 3x quick cycles, heating/plateau/cooling in between 25 and 50 °c
- Fairly rapid ramp up ~5°C/min
 - Qualitative evaluation of the conditions before and after ageing
 - Picture of the kapton gluing taken with microscope also available!



No effects could be appreciated!

Thermo-mechanical simulations and measurements



Full detector model

ANSYS thermal-CFD model

- Simplified version: ITS3 geometry as reference (comparison with available analytical calculations)
- Simplified ePIC SVT-IB based on actual detector design (single sensor segment)
- Advanced ePIC SVT-IB (including all assembly details)

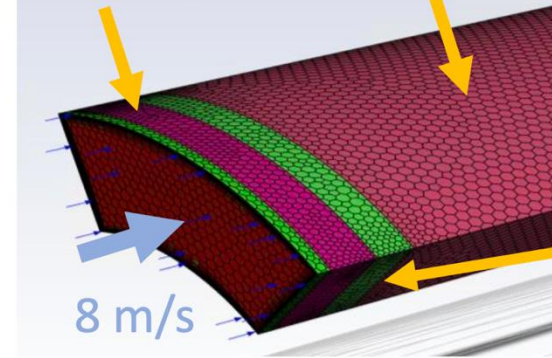
ANSYS structural model

- Preliminary for vibrational analysis

ANSYS CFD-FSI model

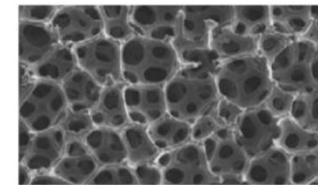
- Simplified version to evaluate the deformations

LEC Region 12 RSU Region



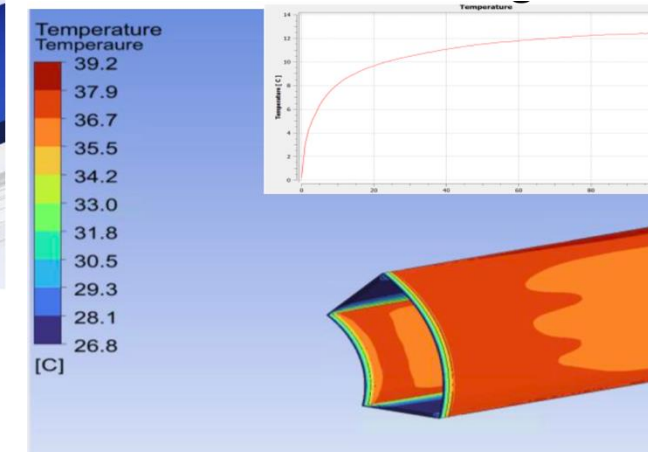
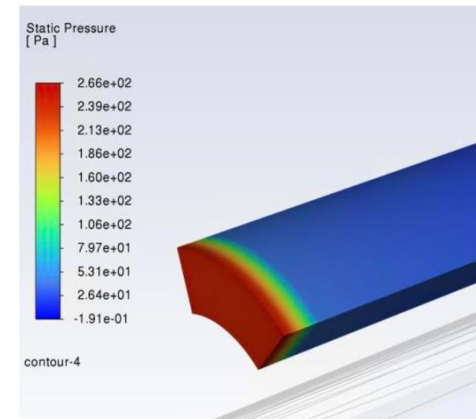
Porous K9 -

$$\bar{S} = \Phi \left(\frac{\mu}{\bar{p}} + \frac{\Phi \rho C_d}{\sqrt{\bar{p}}} |\bar{v}| \right) \bar{v} \mathbf{1}_{\Omega_f^c}.$$

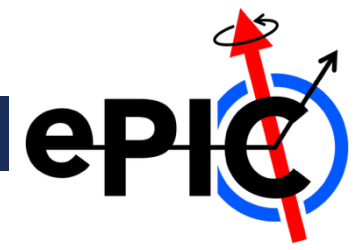


300 μm K9

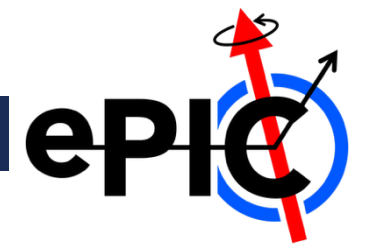
(c) $\Phi = 0.89$ (K9)



All these activities foreseen to be completed within the end of the year



- Steady progress on SVT-IB design and prototyping over the last year:
 - L0-L1 half-barrel assembly fully validated by end 2025 (M1)
 - Further improvements in tooling (e.g. for carbon fleece application) followed
 - Advancing on carbon foam procurement and local/global support structures design/production
 - First ideas towards L2 bending/assembly being refined
 - Progressing on FPC qualification, service integration and thermo-mechanical studies
- Outlook for the coming months:
 - Proceed with the L0-L1 prototyping campaign (M2 and M3)
 - Advance on studies with thermal chamber (M1.2 and M2) and cooling design (M3)
 - Implement preliminary bending/assembly procedure for L2
 - Continue effort on FPC (new prototypes in 2027) and thermo-mechanical simulations

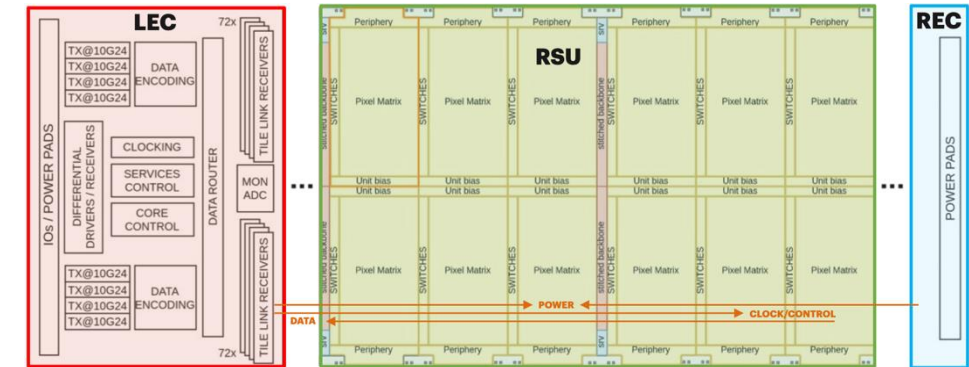


MAPS in 65 nm CMOS imaging technology.

Three main functional blocks:

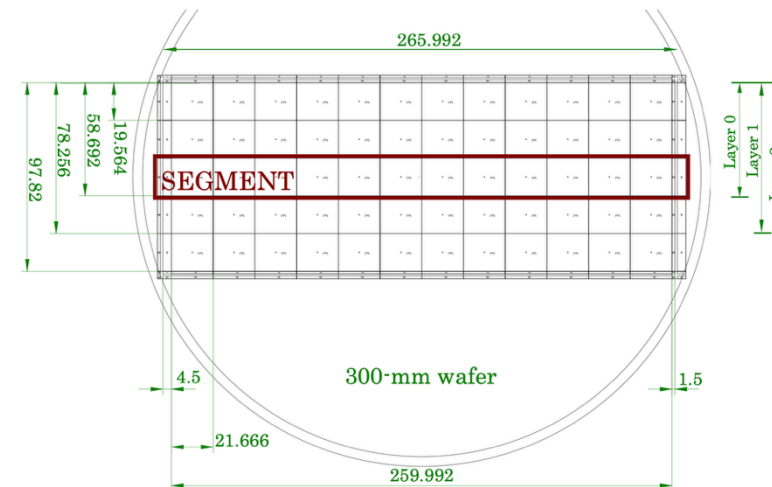
- **Repeated Sensor Units (RSUs)**: integrating 12 independent pixel ($22.8 \times 20.8 \mu\text{m}^2$) matrices and $21.67 \times 19.56 \text{ mm}^2$ in size
- **Left Endcap (LEC)**: aggregates data and transmits off-detector via eight (lpGBT-encoded) high-speed links at 10 Gb/s
- **Right Endcap (REC)**: simple block hosting the power pads and termination for the signals lines

Data, power, clock and slow control connected via a **stitching lines** running across the blocks



Same sensors as for ALICE ITS3:

- 12 RSUs
- 8 data links
- 7 slow control links
- Direct powering



Wire-bonding machine



- Wire-bonding machine used in Bari for wire-bonding over bent surfaces
 - Delvotec G4
 - In use since the time of ALICE Silicon Pixel Detector (SPD) construction
 - More than 20 years in service!
 - Producer not anymore providing assistance for reparation
 - Many repairs and adaptations done by local technicians during the years
 - Still efficient but **risky for a detector construction**
 - Delvotec G5
 - Under intense usage by CMS colleagues for module production
 - Not easily compatible with mandrel placement
- **Exploring/identifying best wedge bonding machine for multiple purposes**
 - Exchanges with Delvotec and Hesse Mechatronics
 - Requirements (under definition from different potential users, e.g. ALICE/CMS/Gr2)
 - For SVT: volume under the bonding head compatible at least with L1 mandrel

L0-L1 prototyping campaign



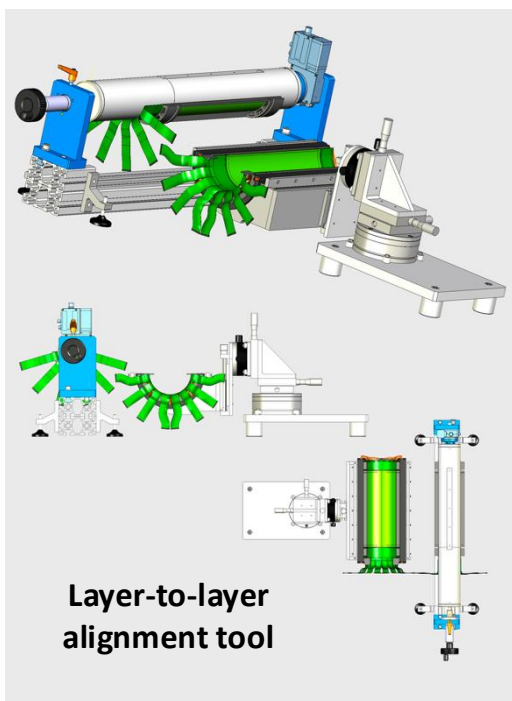
IB-HB01 M1.2

IB-HB01 M1.2

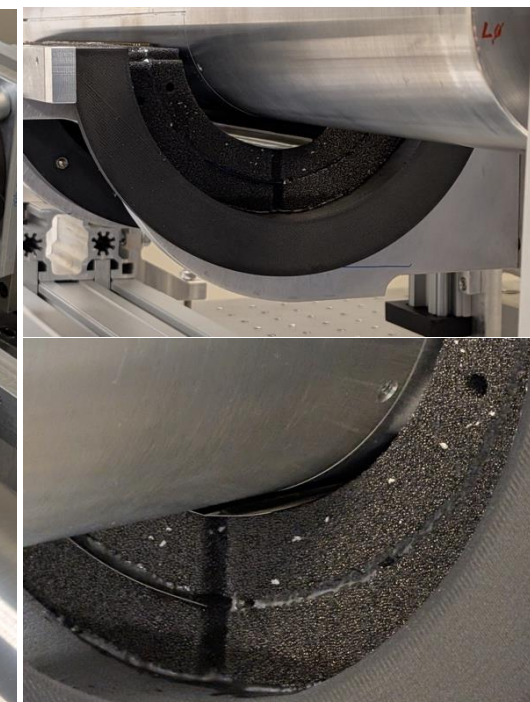
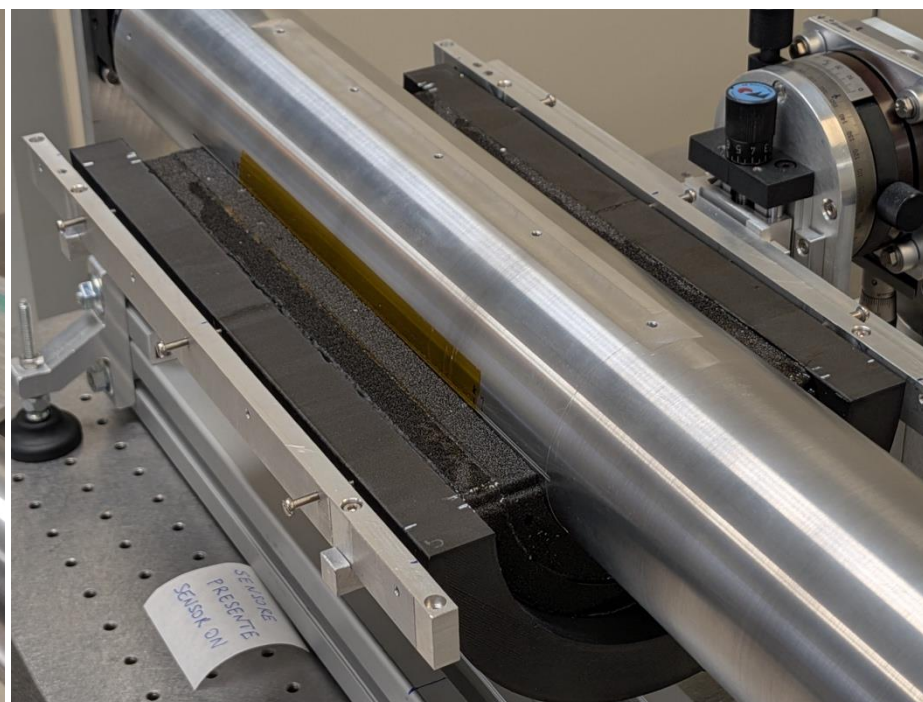
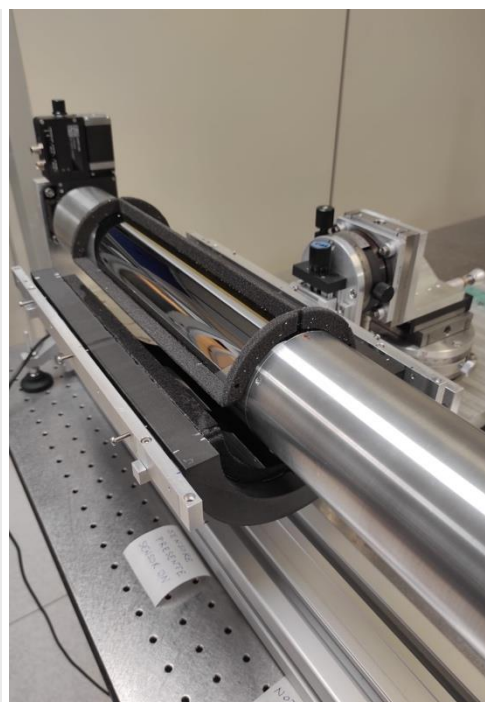
- L0/L1 sensors: (half-mooned) blank silicon pieces
- LSS: carbon foam (PocoFOAM, no fleece)
- L1COS: 3d printed
- FPC: NOT included

First assembly with carbon foam LSS +
Preliminary studies in climate chamber

Completed in June
2026

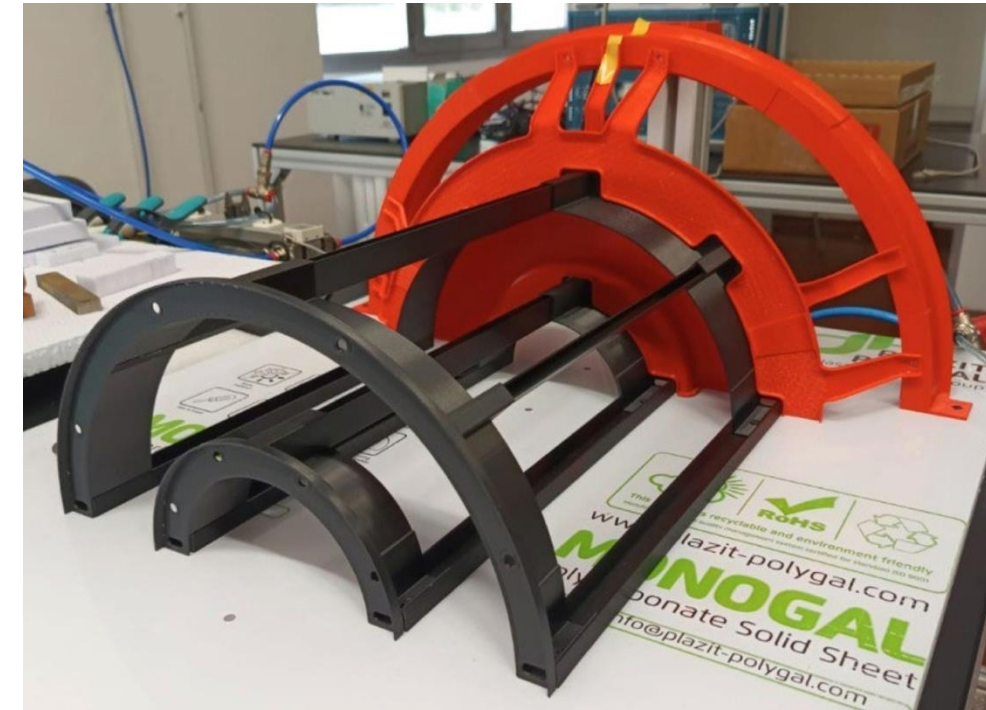
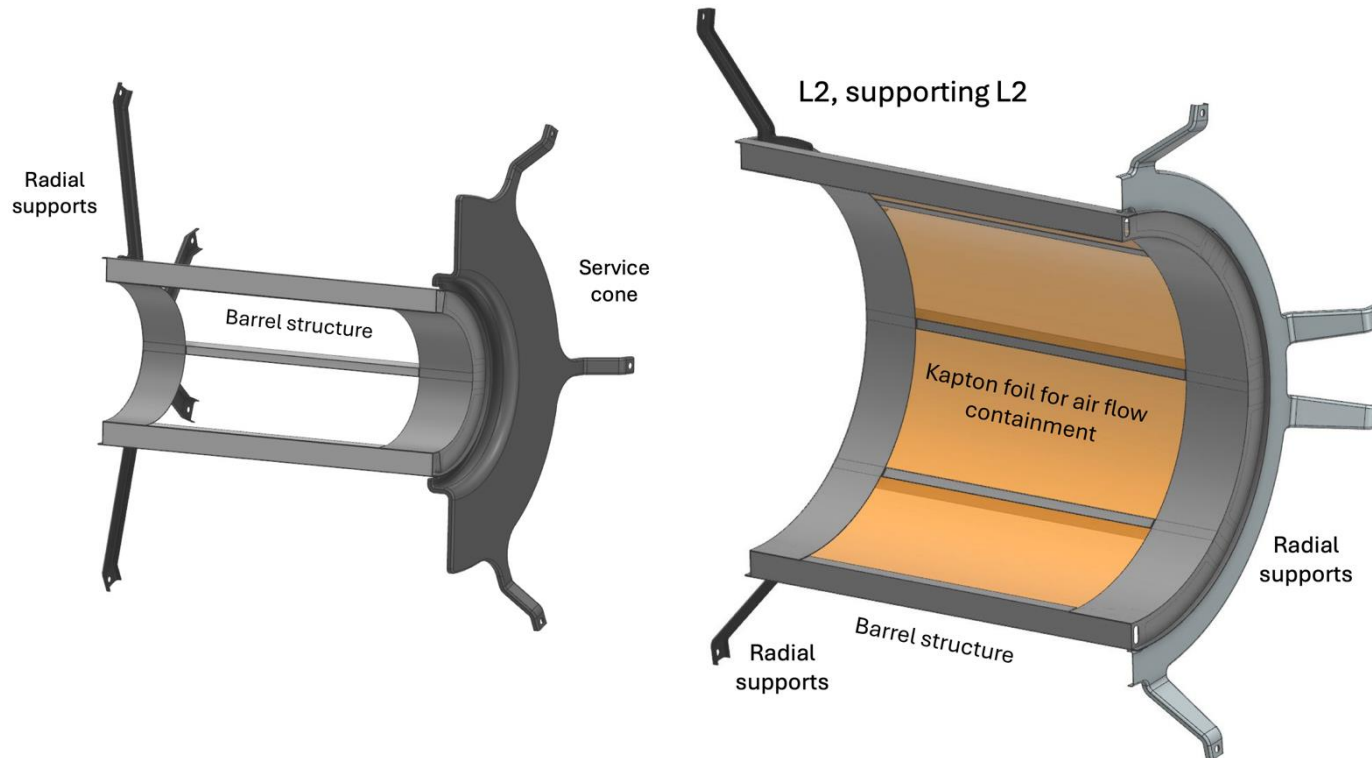


Layer-to-layer
alignment tool



First successful integration of LSS in carbon foam
First successful usage of the layer-to-layer alignment and gluing tool

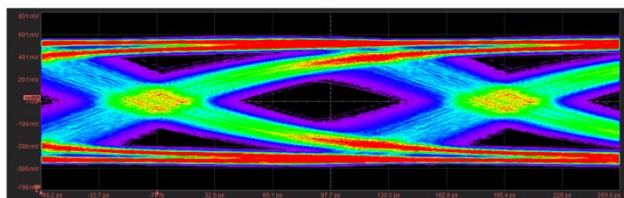
- SVT-IB global mechanics in advance status of design
 - Two shells: one external to L1 and one external to L2
 - Connection to OB cone through: disks on hadron going side and radial supports on electron going side



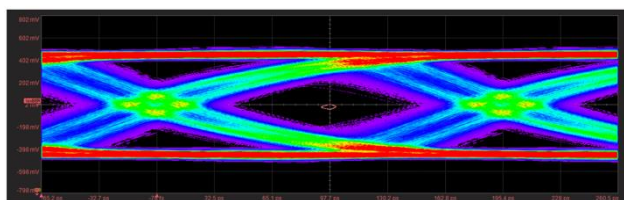
Maquette for service layout testing

EYE DIAGRAMS AT 5.12 GBPS WITH JITTER

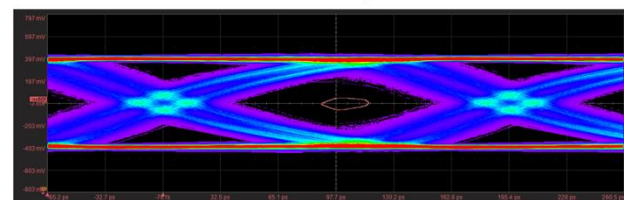
No Preemphasis



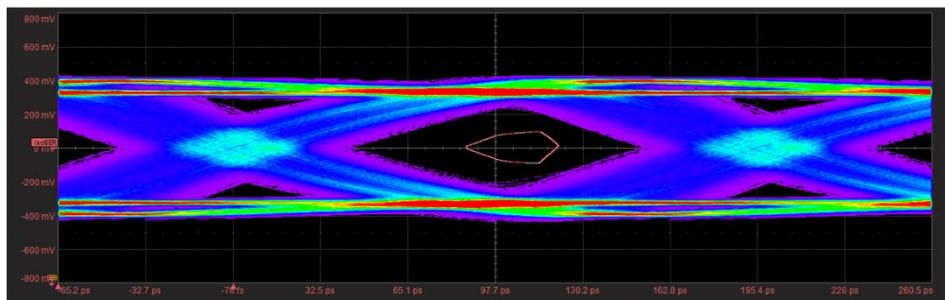
Mild Preemphasis



Moderate Preemphasis

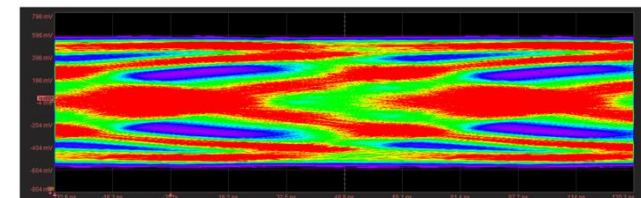


Max Preemphasis

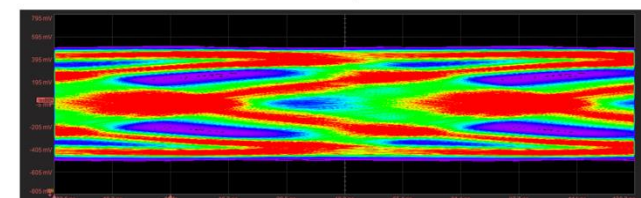


EYE DIAGRAMS AT 10.24 GBPS WITH JITTER

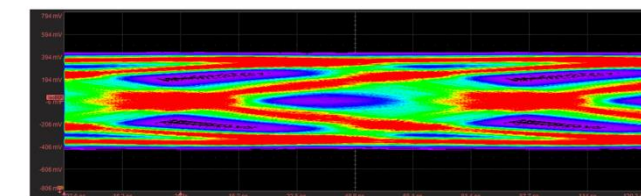
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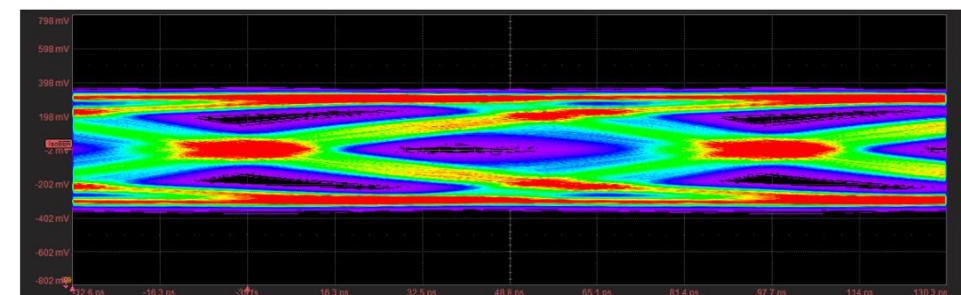
Mild Preemphasis



Moderate Preemphasis



Max Preemphasis

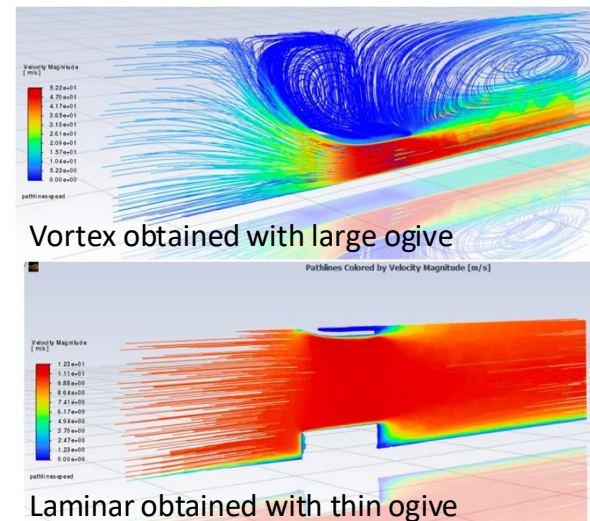
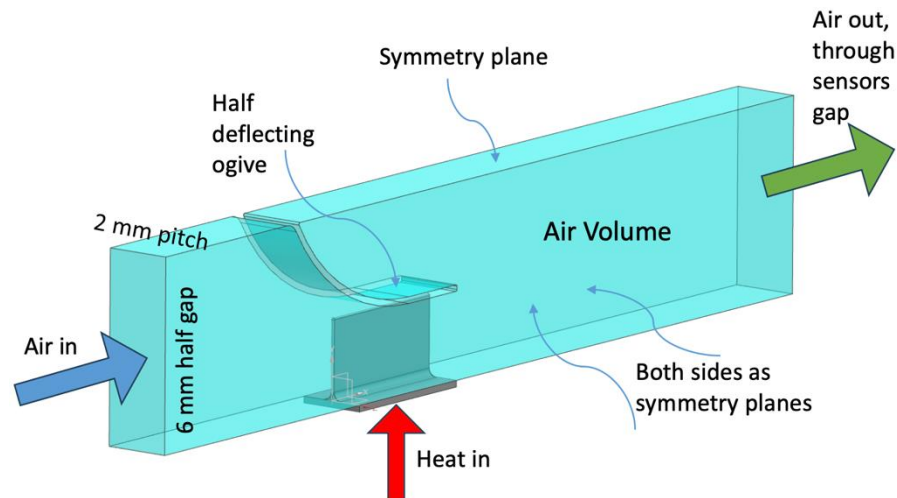
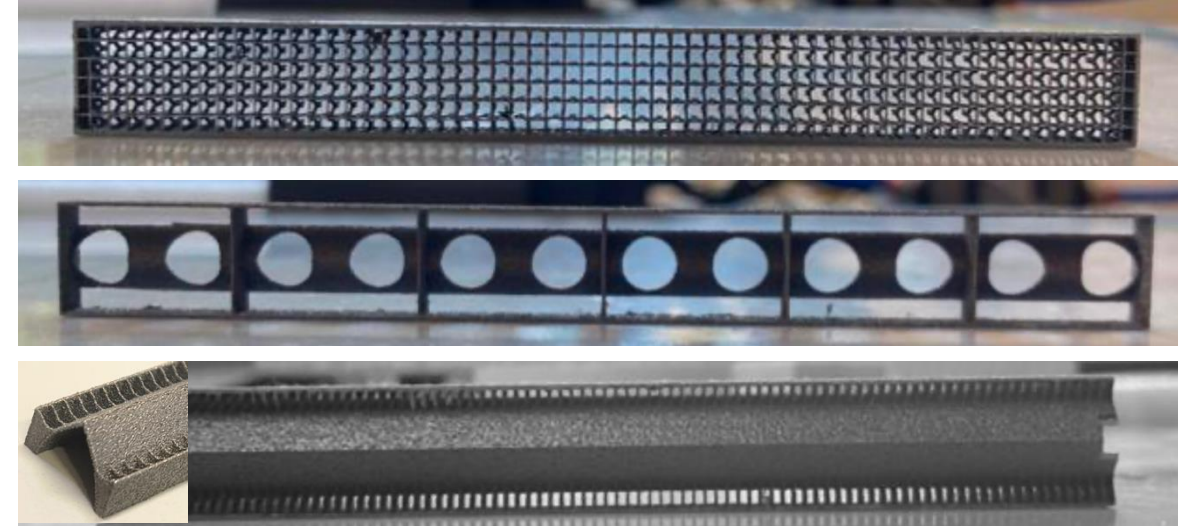


Thermo-mechanical simulations and measurements

Cooling effectiveness studies - Aluminum heat sink as LEC half-ring

Alternative to carbon foam HTC (Allcomp K9)

- Al-Si alloy with bulk thermal conductivity $\sim 140 \pm 20$ W/mK
- Equivalent density of 0.4-0.6 g/cm³, comparable with carbon foam
- Produced via additive manufacturing process



- Three shapes of the openings under test
- Shape early optimized via CFD simulations to increase heat dissipation from LEC