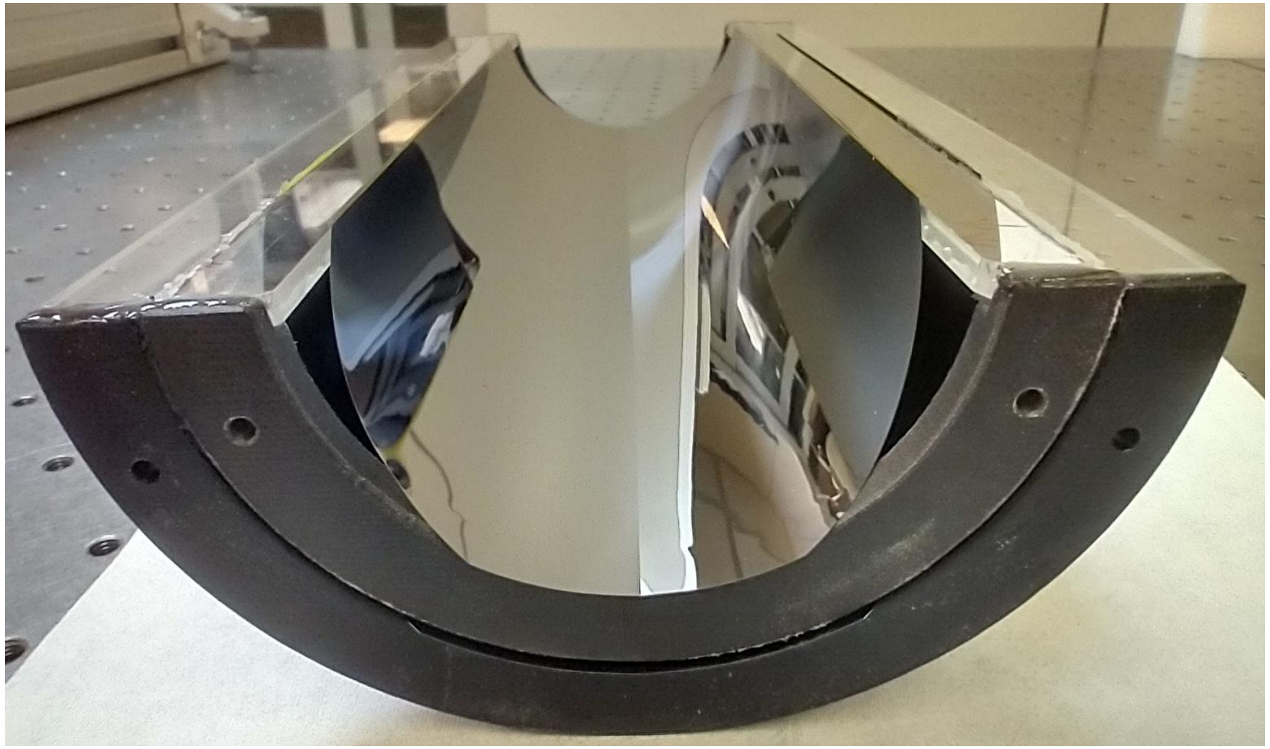


First L0-L1 bare half-barrel prototype

SVT IB
status report

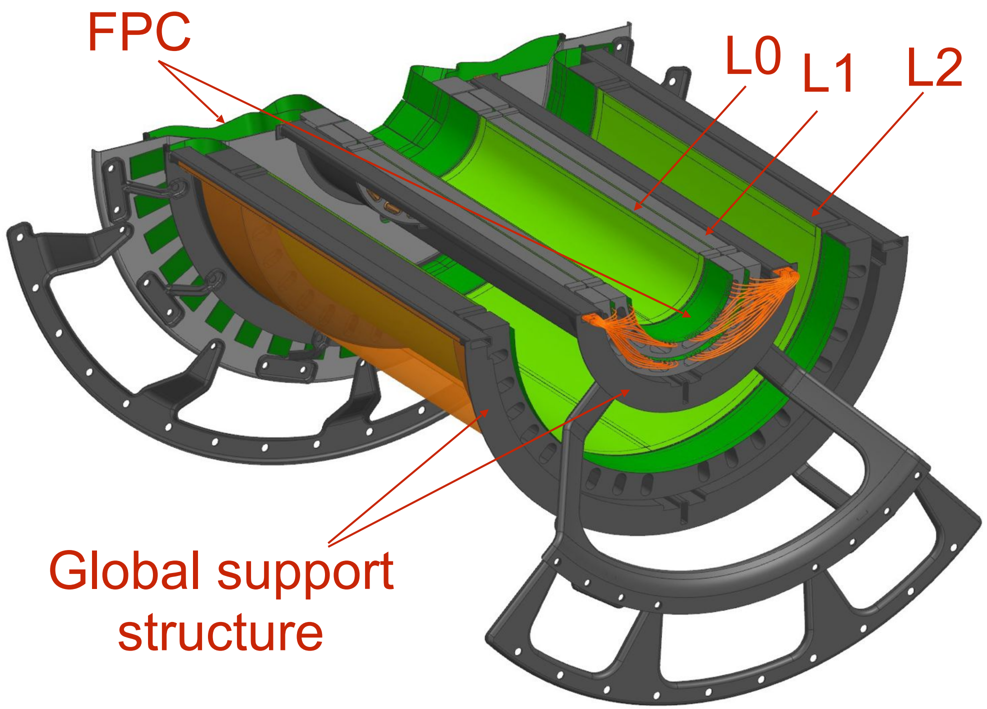
On behalf of INFN teams
(Bari, Padova, Pavia, Trento*, Trieste)

*** Trento (TIFPA) new INFN unit joining ePIC (formally after the summer) and already contributing to SVT IB activities**

SVT INNER BARREL

Basic ingredients:

- Wafer-scale MAPS chips (ITS3 65 nm CMOS, thickness ≤ 50 μm)
- Chips bent in semi-cylindrical shape at target radii
- Ultra-light carbon foam/fiber structures
- Air cooling



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

CONTENT

- Present status and future activities
  - L0-L1 assembly procedures
  - IB Global mechanics
  - IB FPC characterization
  - IB Thermo-mechanical studies

PRESENT STATUS AND FUTURE ACTIVITIES

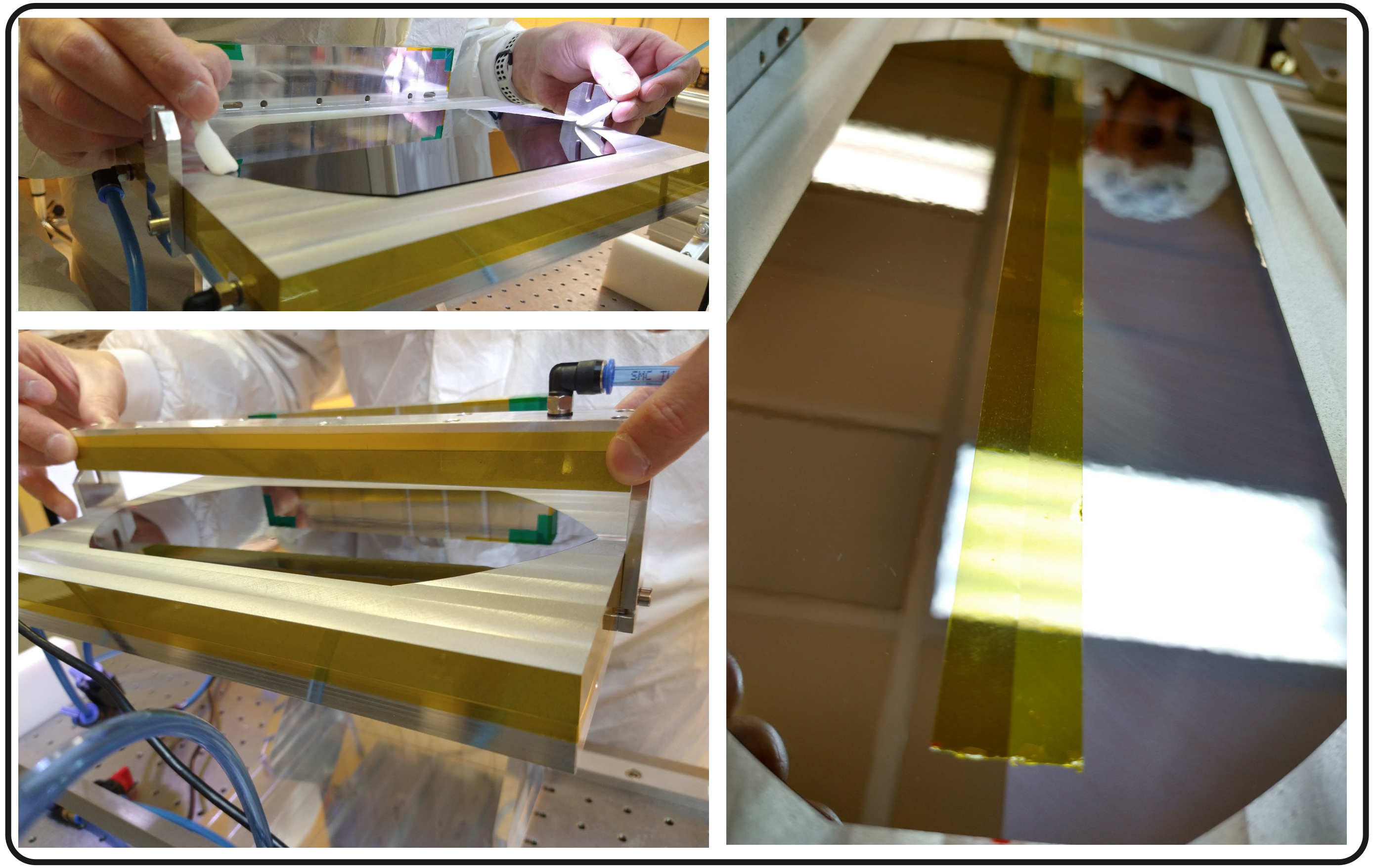
L0-L1 assembly procedure

- **Sensors alignment and joining**
- **Joint sensors bending**
- **FPC to joint sensors interconnection**
- **Local support structures gluing**
- **Services integration in layer**
- **L0-L1 half-barrel assembly**
- **L0-L1 half-barrel integration to L2**

PRESENT STATUS AND FUTURE ACTIVITIES

L0-L1 assembly procedure

- Sensors alignment and joining
- Joint sensors bending
- FPC to joint sensors interconnection
- Local support structures gluing
- Services integration in layer
- L0-L1 half-barrel assembly
- L0-L1 half-barrel integration to L2

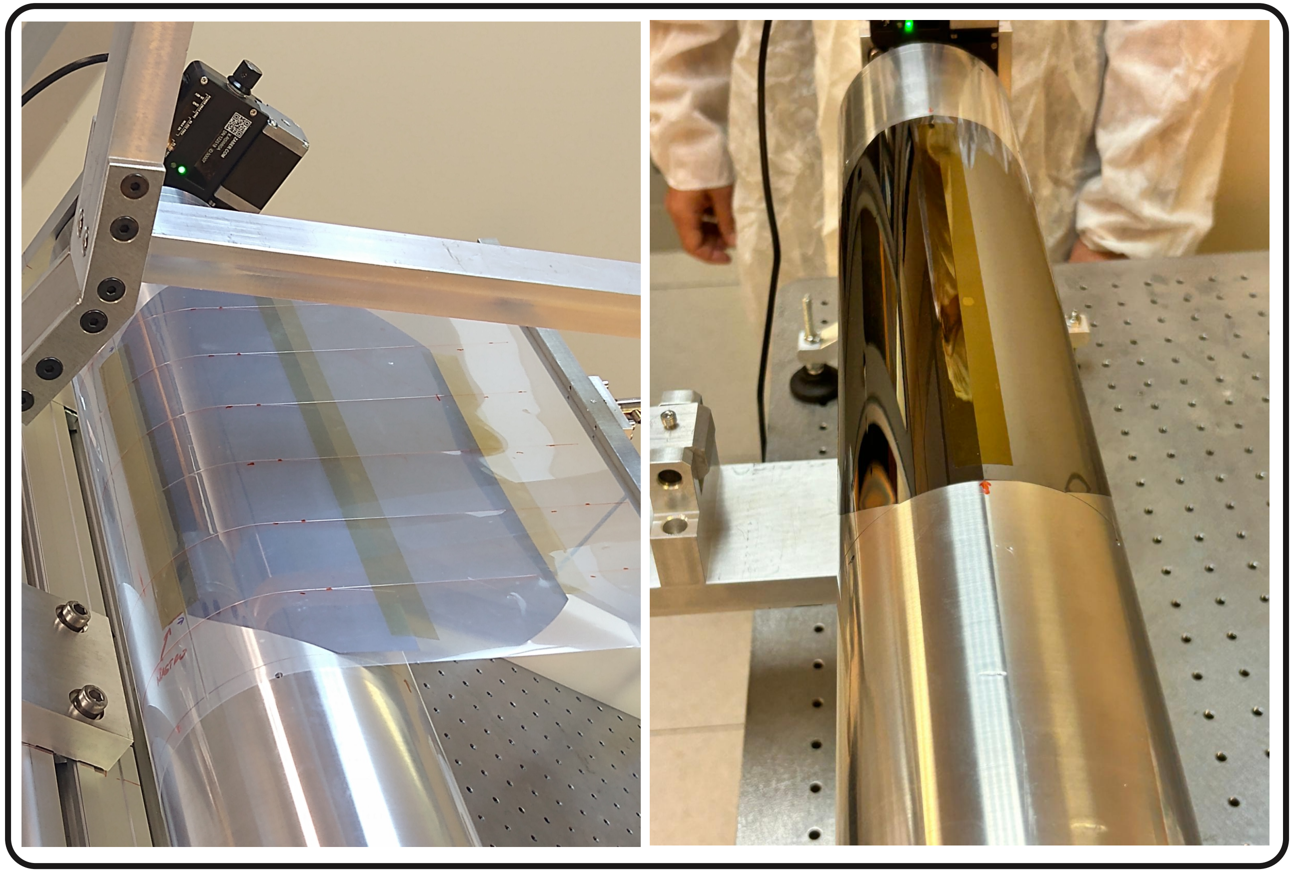


Few tens micron precision reached targeting 50 micron pitch between the two sensors

PRESENT STATUS AND FUTURE ACTIVITIES

L0-L1 assembly procedure

- Sensors alignment and joining
- **Joint sensors bending**
- FPC to joint sensors interconnection
- Local support structures gluing
- Services integration in layer
- L0-L1 half-barrel assembly
- L0-L1 half-barrel integration to L2

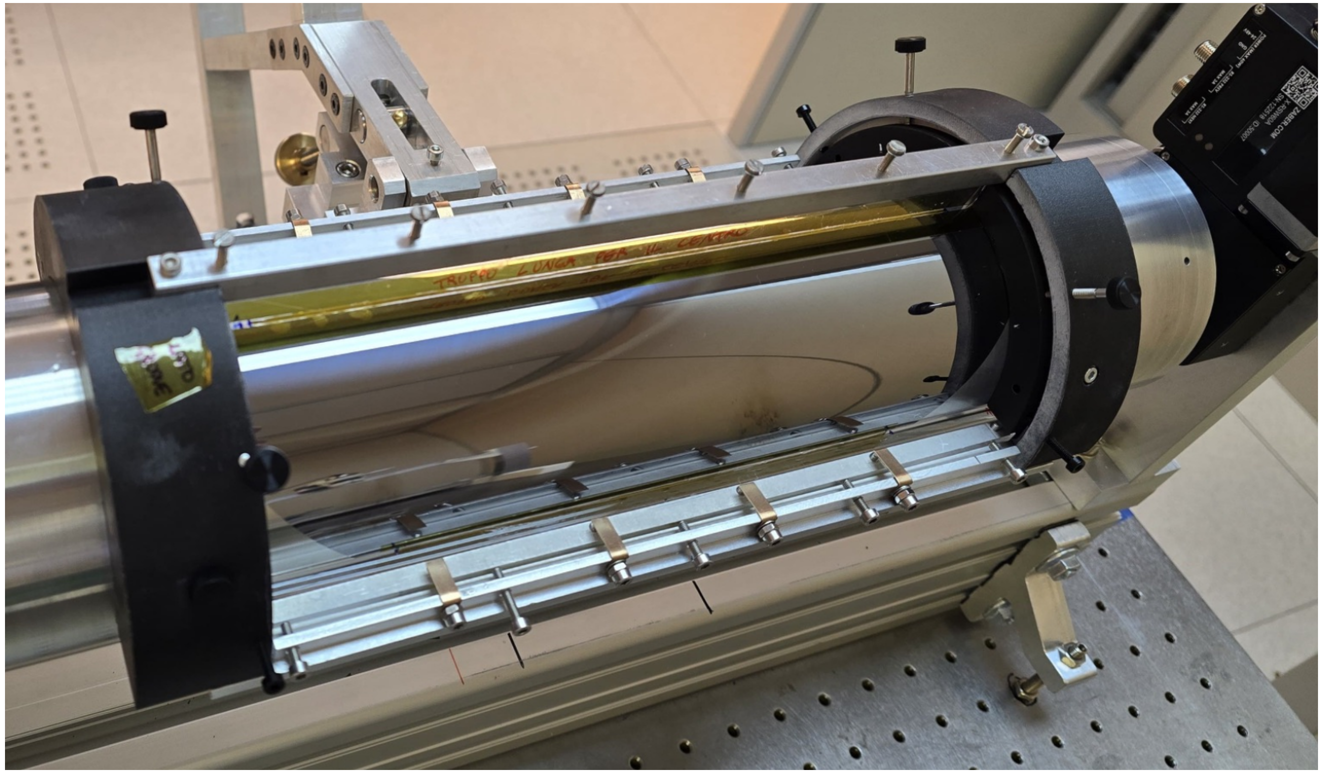


Double sensors bending mastered for L0 and L1

PRESENT STATUS AND FUTURE ACTIVITIES

L0-L1 assembly procedure

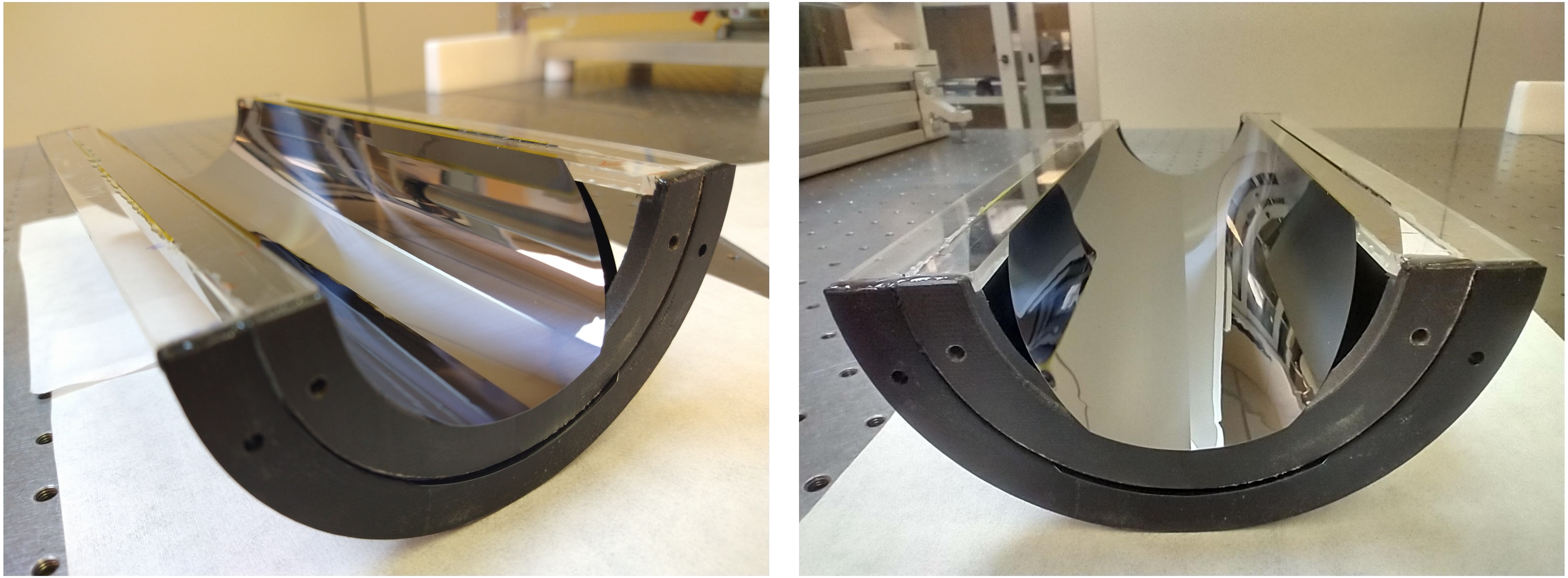
- Sensors alignment and joining
- Joint sensors bending
- FPC to joint sensors interconnection
- **Local support structures gluing**
- Services integration in layer
- L0-L1 half-barrel assembly
- L0-L1 half-barrel integration to L2



Local support gluing tools rapidly evolving toward final requirements

PRESENT STATUS AND FUTURE ACTIVITIES

L0-L1 assembly procedure



First L0-L1 bare half-barrel prototype

PRESENT STATUS AND FUTURE ACTIVITIES

L0-L1 assembly procedure - Activity summary

Layer	Dates	BENDING	GLUING	REMOVAL
L0v1	16/10/24-26/11/24	YES Silicon chipping at one edge; located under the tape, allowed for bending	YES	NO Breakage due to previous damage
L0v2.1	13/01/25-14/01/25	NO Breakage of one silicon edge possibly during the two sensors alignment	—	—
L0v2.2	16/01/25-31/01/25	YES	YES	YES
L0v3	24/03/25-28/03/25	YES	NO Silicon broken already in the transport box	—
L0v4	03/04/25-10/04/25	YES	YES	YES
L0v5	26/05/25-03/06/25	YES	YES	YES
L1v1	28/04/25-06/05/25	YES	NO Operator error → Tools safety margins improved after failure	—
L1v2	07/07/25-09/07/25	YES	YES	YES

PRESENT STATUS AND FUTURE ACTIVITIES

L0-L1 assembly procedure - Prototype campaign, material procurement

Prototype	Components	Goal
IBL01_P1 (half-layer)	• 2 naked silicon L1 sensors • L1 local support structure (3-D printed) • outer support shell (machined in PEEK)	• finalize half-layer assembly procedure
IBL01_P2 (half-barrel)	• IBL01_P1 + • 2 naked silicon L0 sensors • L0 local support structure (3-D printed)	• finalize half-barrel assembly procedure
IBL01_P3 (half-layer)	• 2 naked silicon L1 sensors • L1 local support structure (carbon foam) • outer support shell	• thermal chamber test
IBL01_P4 (half-barrel)	• IBL01_P3 + • 2 naked silicon L0 sensors • L0 local support structure (carbon foam)	• thermal chamber test
IBL01_P5 (half-barrel)	• 2+2 silicon L0+L1 **sensors with heaters from CERN** • L0+L1 local support structures (carbon foam) • outer support shell (carbon fiber, to be defined) • **air distribution inlet et outlet** (to be designed) • PT1000 sensors (to be glued on heater surface)	• wind tunnel test

➡ (IBL01_P1, IBL01_P2)
Material:
- fully available

Completed by October 25

➡ (IBL01_P3, IBL01_P4)
Material:
- Silicon pieces available
- Carbon foam under procurement
- Outer shell to be produced

Completed by November 25

➡ (IBL01_P5)
Material:
- Heaters available
- Carbon foam under procurement
- Outer shell and air-ducts to be produced

Completed by January 26

PRESENT STATUS AND FUTURE ACTIVITIES

L0-L1 assembly procedure - Prototype campaign, material procurement

Prototype	Components	Goal
IBL012_P6/7	• 2+2+4 ER2 pad wafer L0+L1+L2 sensors (x 2 HB?) • L0+L1+L2 local support structures • gloabal support mechanics (advanced design) • FPCs (advanced design) • air distribution inlet & outlet (advanced design)	• first complete IB HB prototype w/o sensors • including test of wirebonding to FPCs • final test on HB support mechanics • possibly built 2 complete HBs (to allow HB mechanical support matching test)
IBL012_P8	• 2+2+4 ER2 wafer L0+L1+L2 sensors • L0+L1+L2 local support structures • mechanics, FPCs, cooling (~final/advanced design)	• complete IB HB prototype w/ sensors • qualification model w/ bent sensors for cooling + powering/DAQ/DCS finalisation

➡ Requires ER2 pad sensors
Targeting July 26

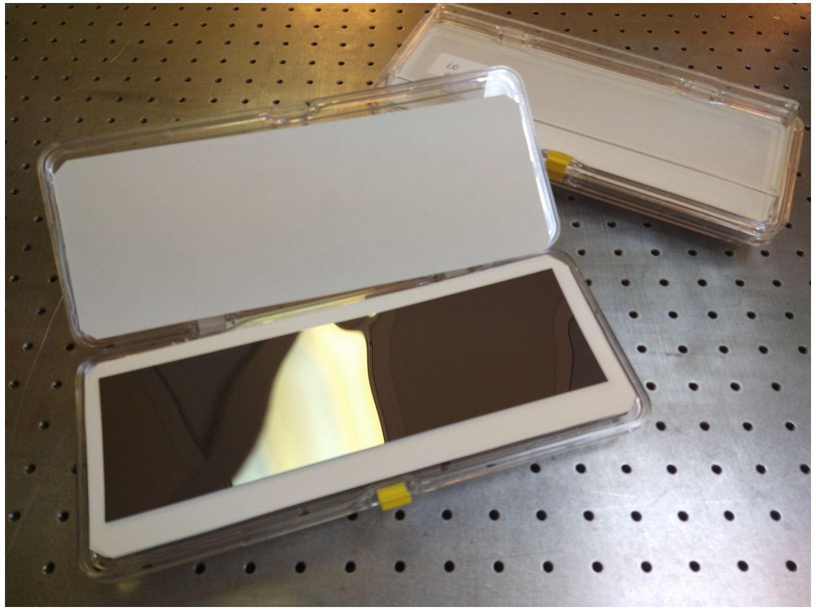
➡ Requires
- ER2 sensors
- FPC (?)
- Power/Readout system (?)

Targeting October 26

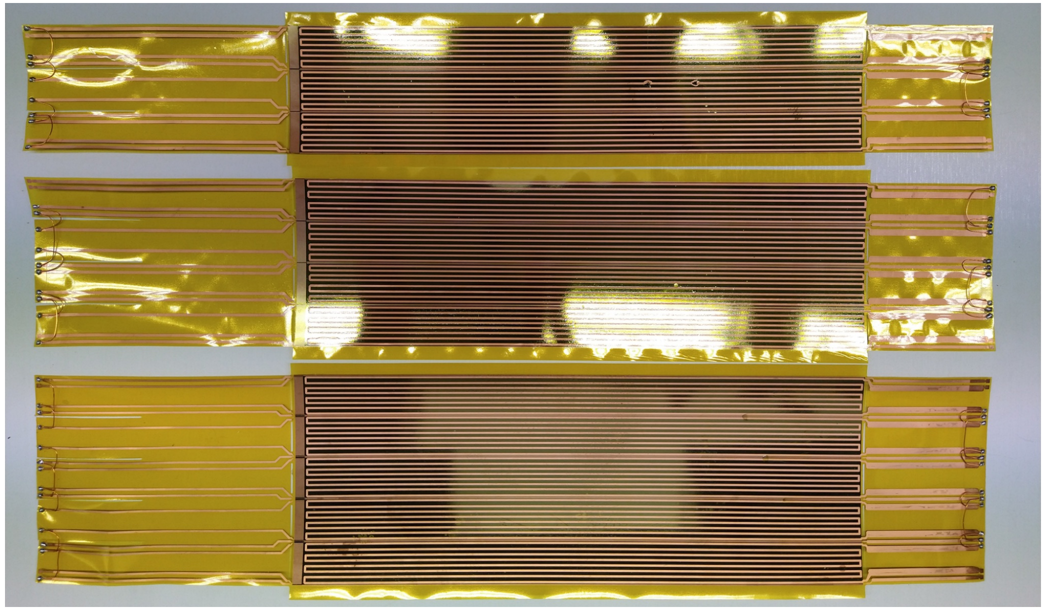
PRESENT STATUS AND FUTURE ACTIVITIES

L0-L1 assembly procedure - Prototype campaign, material procurement

Silicon pieces	4 L0 - 4 L1	AVAILABLE	Spares under procurement
Heaters	2 L0 - 2 L1	AVAILABLE	Spares: 2 L0 / 2 L1
Pad sensors	[2 L0 - 2 L1 - (4 L2)] x 2	2026	If two HB (16 pad sensors = 16 wafers) → No spares
ER2 sensors	2 L0 - 2 L1 - (4 L2)	2026	Only one half-barrel → No spares



Blank silicon pieces of exact L0 and L1 sizes



Heaters integrating blank silicon

PRESENT STATUS AND FUTURE ACTIVITIES

L0-L1 assembly procedure - Prototype campaign, material procurement

3D printed	Mixing printed and manufactured in very first exercises
Carbon fibre/foam	<u>Material for support structure elements</u> ● Half-ring on LEC → Allcomp K9 (standard density, 200-260 kg/m³) ● Longerons and half-ring on REC → Carbon RVC Duocel (density 45 kg/m³, PPI 100) ● Carbon fleece: wet-laid non woven carbon fibre veil(8 g/cm²) ● Outer shell: carbon fibre (from global structure) <u>Foam procurement</u> ● Allcomp K9 → Not easy to procure in small amount; try to associate with large request (e.g. ATLAS) ● ERG Carbon RVC Duocel → Company in USA, but possible purchasing from Europe <u>Foam shaping</u> ● Procedure details collected from CERN colleagues ● Ongoing at Genova INFN → First example completed (in POCOfoam) ● Berkley (Nikki) or U.K. (George) → Expressed availability ● Local workshop → To be identified <u>Carbon fibre production</u> ● Multiple-producers under investigation (Padova)

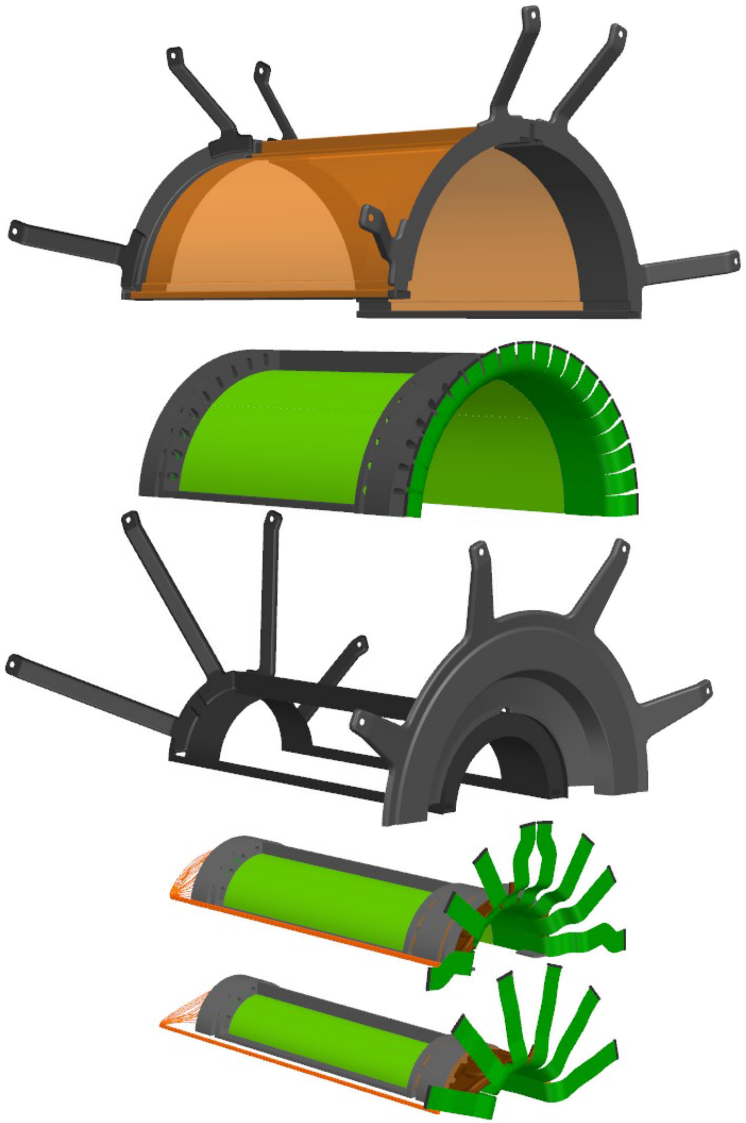
First samples of ERG Carbon RVC Duocel.
Thanks to Nikki!
Material sent to Genova for machining

PRESENT STATUS AND FUTURE ACTIVITIES

Global mechanics

- Current global support design
  - modifications subject to better definition of services
  - CFC bi-layer laminate or woven fabric configuration (depending on the part/position)

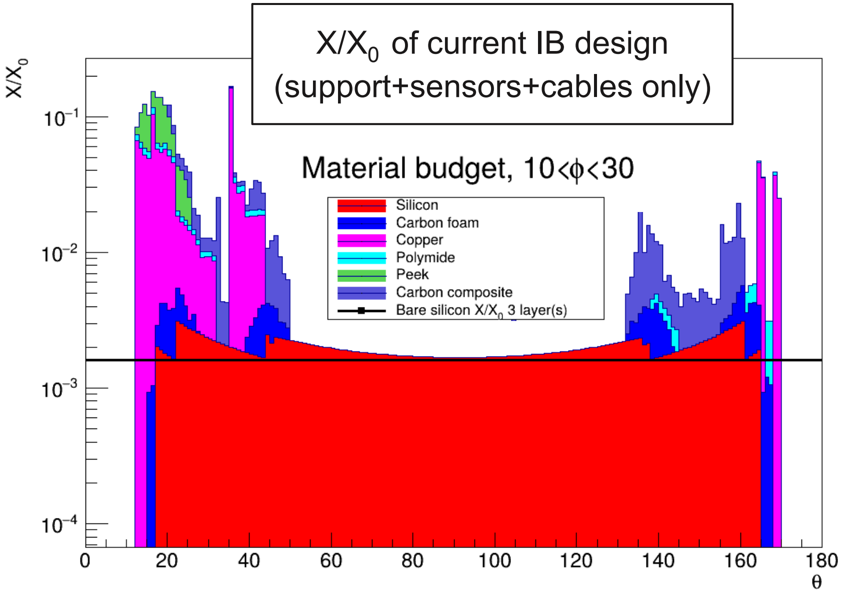
- Production status
  - three companies available for production (all in Italy)
    → already received the offers, two consistent, one much cheaper
    → few pre-production pieces will be qualified to decide
  - connected to the L0-L1 prototype campaign
    → raw versions of the L0-L1 external shell ready/ shipped to Bari for IBL01-P3&4 (October 2025) and IBL01-P5 (December 2025)
    → going to investigate (also within SVT DSC) for possible help on the preliminary production of such support structure

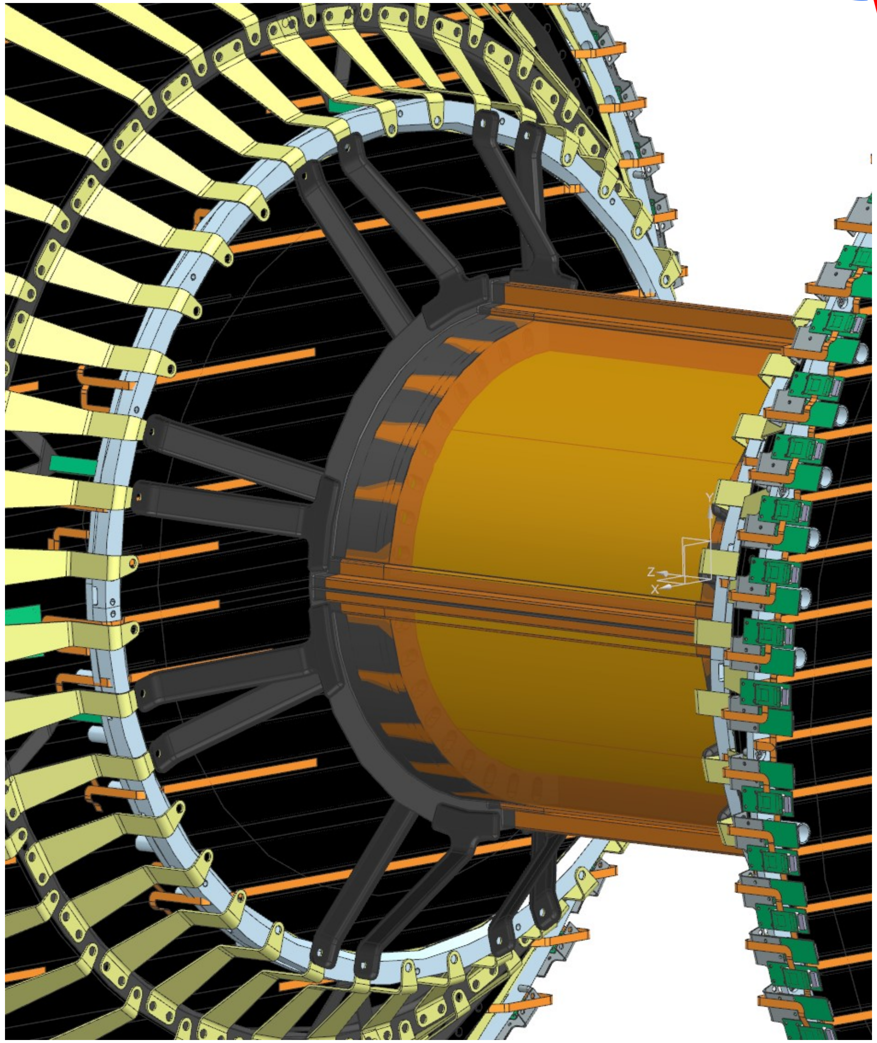


PRESENT STATUS AND FUTURE ACTIVITIES

Global mechanics

- Current global support design
  - modifications subject to better definition of services
  - CFC bi-layer laminate or woven fabric configuration (depending on the part/position)
  - current design integrated in the general detector structure (collaboration with BNL)
  - material budget always checked after updates





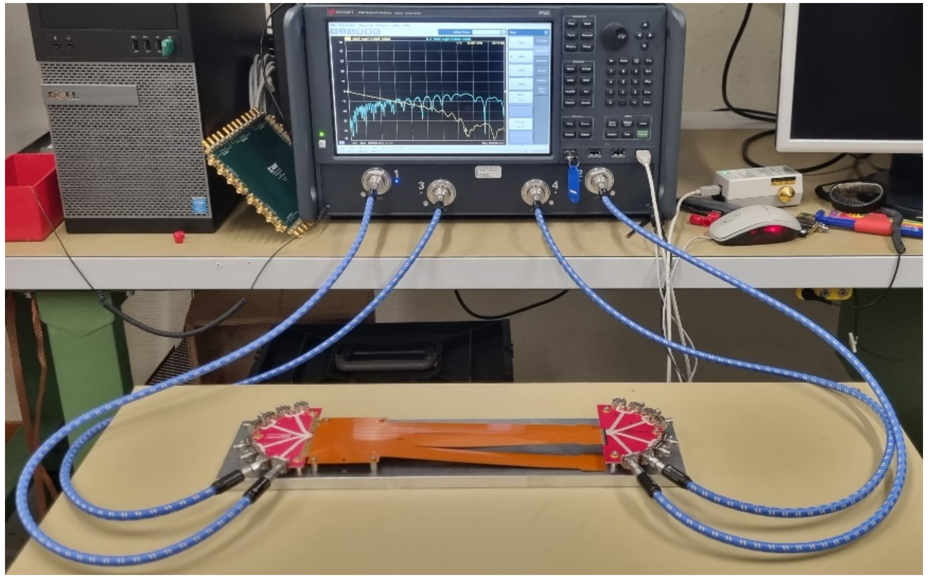
IB integration into the SVT

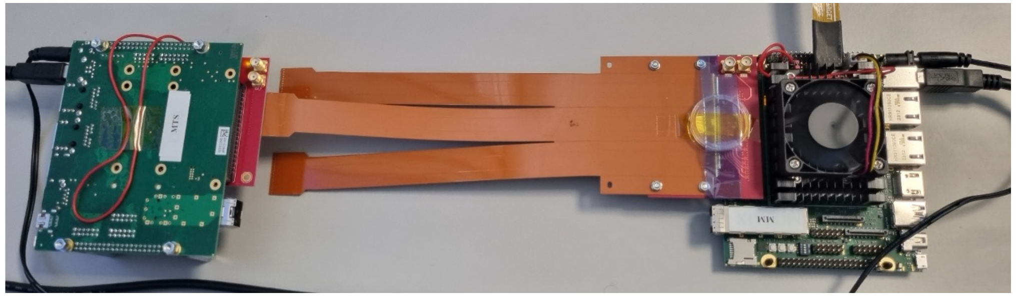
PRESENT STATUS AND FUTURE ACTIVITIES

Flexible Printed Circuit

- FPC development activities
  - Design and production of test pieces, selection of aluminium based technology
  - Development of procedures and tools for FPC bending and interconnection to the sensor
  - Qualification tests of flat and bent FPC test pieces
    - Mainly signal integrity tests of high speed links at 10.24 Gbps - S-Parameter measurement (VNA), eye diagram (High speed scope), BERT (FPGA)

- Ongoing and planned activities in 2025
  - Ongoing discussion with LTU and Daresbury for the production of simple FPC test pieces - 25 cm long, differential lines
  - Commissioning of setup and first signal integrity tests of ITS3 FPC (flat configuration)
  - FPGA boards, adapter boards and ITS3 FPC prototype acquired





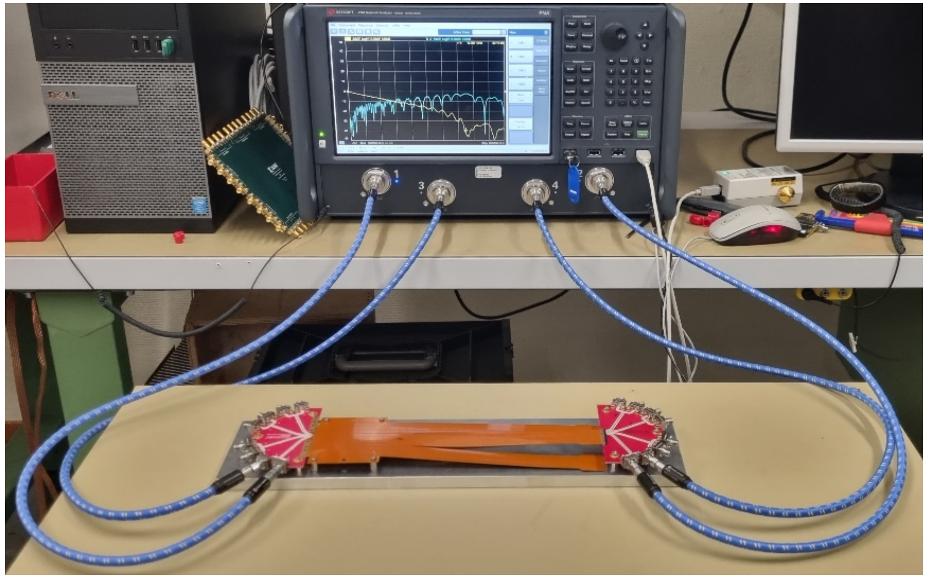
ITS3 FPC test setup and interconnections

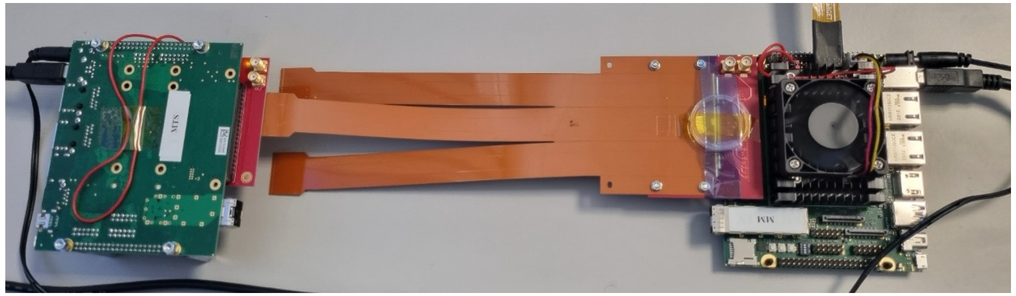
PRESENT STATUS AND FUTURE ACTIVITIES

Flexible Printed Circuit

- Activities planned for 2026
  - Ongoing discussion with LTU and Daresbury for the production of FPC test pieces based on ITS3 FPC design - three, double layer FPCs assembled together
  - Bending and bonding trials with 2025 test pieces
  - Signal integrity tests of 2025 test pieces, in flat and bent configuration
  - Signal integrity tests of 2026 test pieces, in flat configuration

- Some bottlenecks
  - Available oscilloscope not sufficient for tests of 10.24 Gbps signals (4 GHz, 40 GS/s) - looking into rental or loan possibilities of fast oscilloscope
  - 2-channel VNA available; funding requested (by ALICE INFN groups) for High-speed Interconnect Analyzer or 4-channel VNA - if approved, available in 2026





ITS3 FPC test setup and interconnections

PRESENT STATUS AND FUTURE ACTIVITIES

Thermo-mechanical studies

- Vibrational studies
  - FEA based simulations
  - Experimental measurements
- Thermal studies
  - Fluent simulations
  - Thermal expansion tests (in climatic chamber)
  - Air-flow measurements (in wind tunnel)

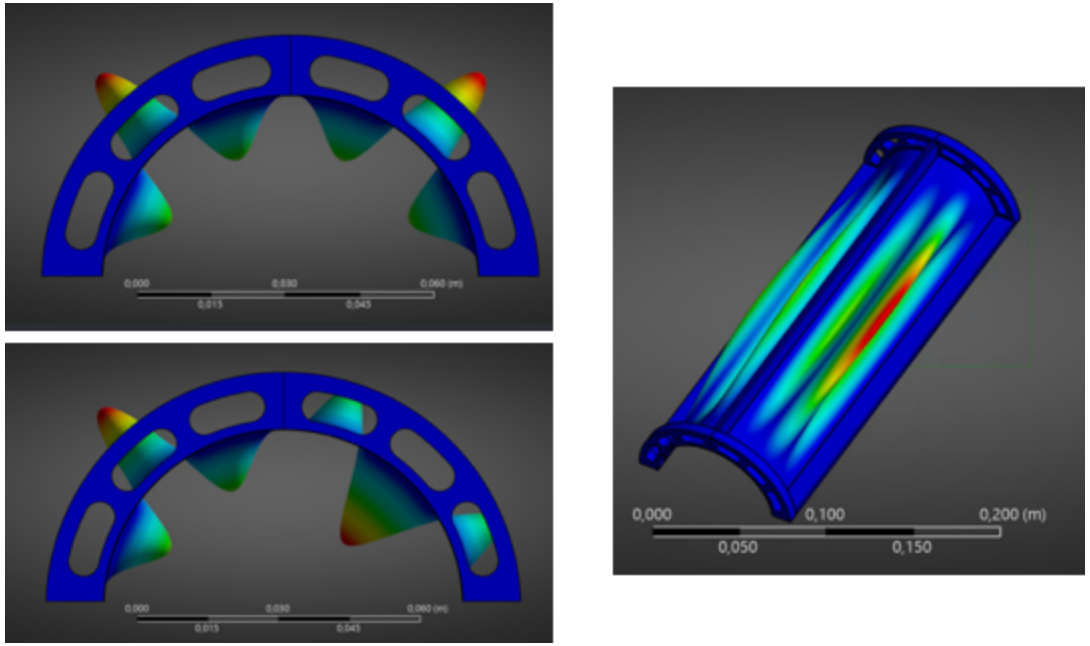
➡ To identify potential issues/failures and evaluate the short-term/long-term reliability of SVT-IB

➡ To define the operational parameters of the air-cooling system

PRESENT STATUS AND FUTURE ACTIVITIES

Thermo-mechanical studies - Vibrational studies

- **Modelling strategy developed** to analyse the vibrational behaviour of thin silicon shell structures for the SVT-IB.
- **FEM modal analysis validated** against analytical models to ensure high accuracy and reliability of the simulations.
- **First FEM random vibrational** test with PSD aerospace spectrum to assess the structural integrity and mechanical resilience of the silicon shells under severe transport conditions.



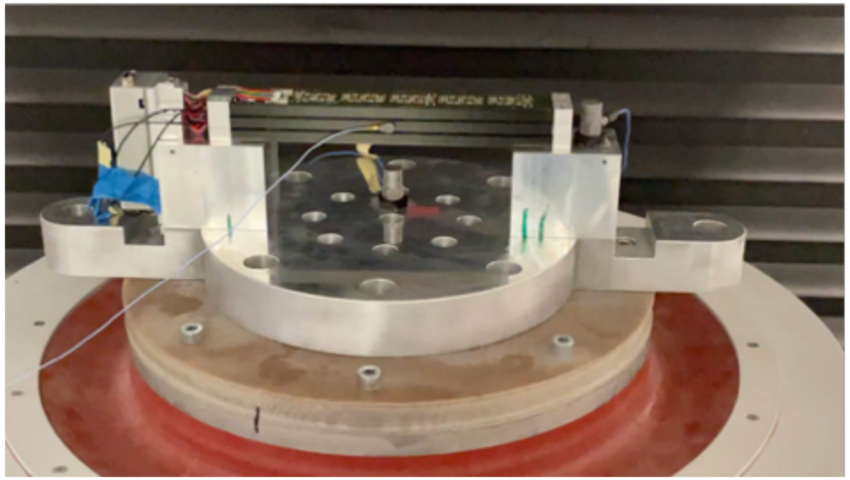
SVT DSC meeting June 24 (https://indico.bnl.gov/event/28692/) by E. Serra: https://docs.google.com/presentation/d/1T2sU62jXrhPWwts_Kt3RfQ5yjr9m1qCf/edit?usp=share_link&ouid=113048360736710244169&rtpof=true&sd=true

PRESENT STATUS AND FUTURE ACTIVITIES

Thermo-mechanical studies - Vibrational studies

- **Developing a FEM-based model of the whole SVT-IB** for estimating the displacement noise in the silicon sensors due to multiple sources of vibrations (air-flow, seismic/cultural, thermal)
- **Configuring a dedicated experimental apparatus** for performing extensive vibrational tests at PRIM facility in Trento

[Pro]M MECHATRONICS PROTOTYPING FACILITY https://promfacility.eu Trento

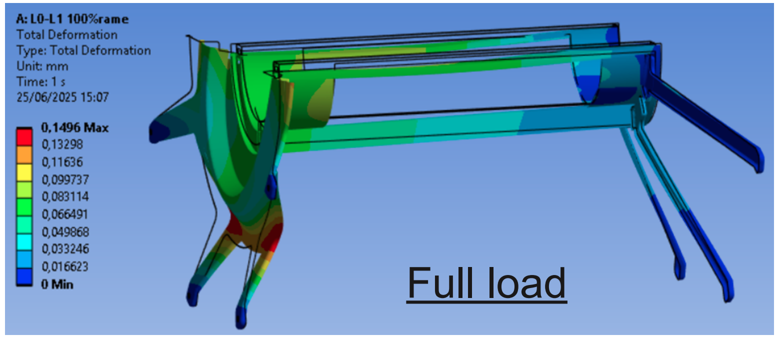


Vibrational test of ALPIDE sensors mounted on a CFRPs stave.

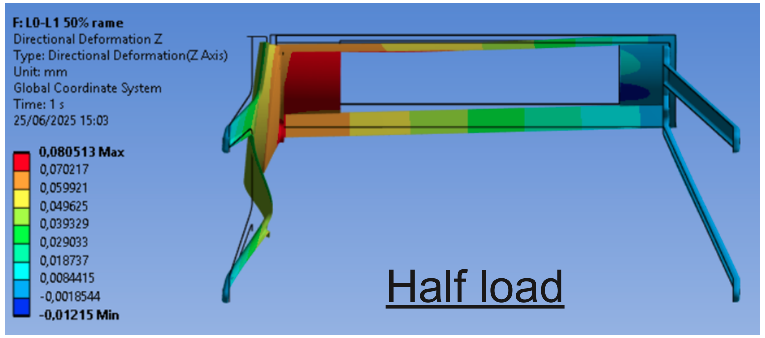
PRESENT STATUS AND FUTURE ACTIVITIES

Thermo-mechanical studies - Ansys/Fluent simulations

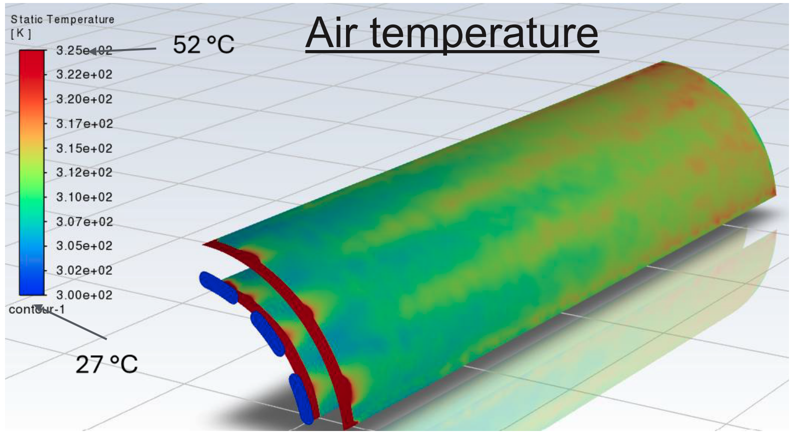
Study of support deformation with different copper quantity: full and half load.- w.i.p.!

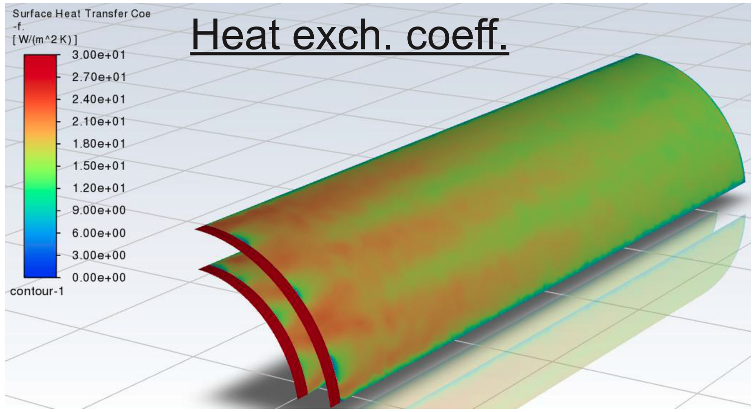


Weak points show up (bends in the supporting arms)



A small (~8 μm max.) deformation appears in the sensor region





Simulation of heat transfer between a surface emitting 40 mW/cm^2 + 8 W/cm^2 sensor + LEC and air flow @ 15 m/s.

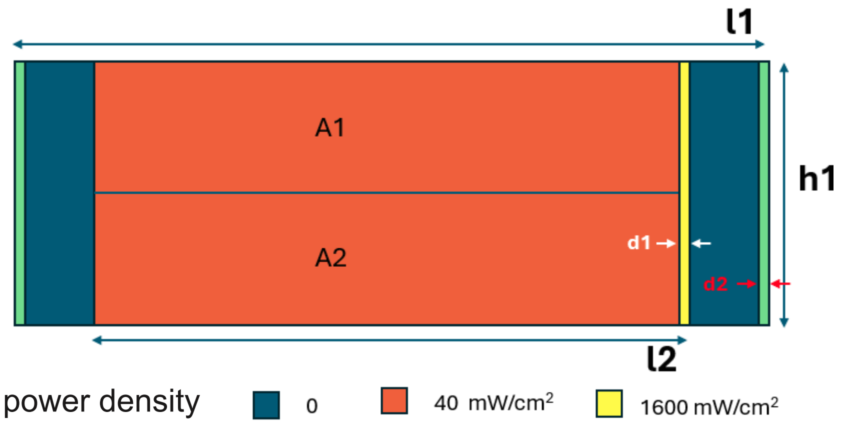
PRESENT STATUS AND FUTURE ACTIVITIES

Thermo-mechanical studies - Cooling tests (preliminary)

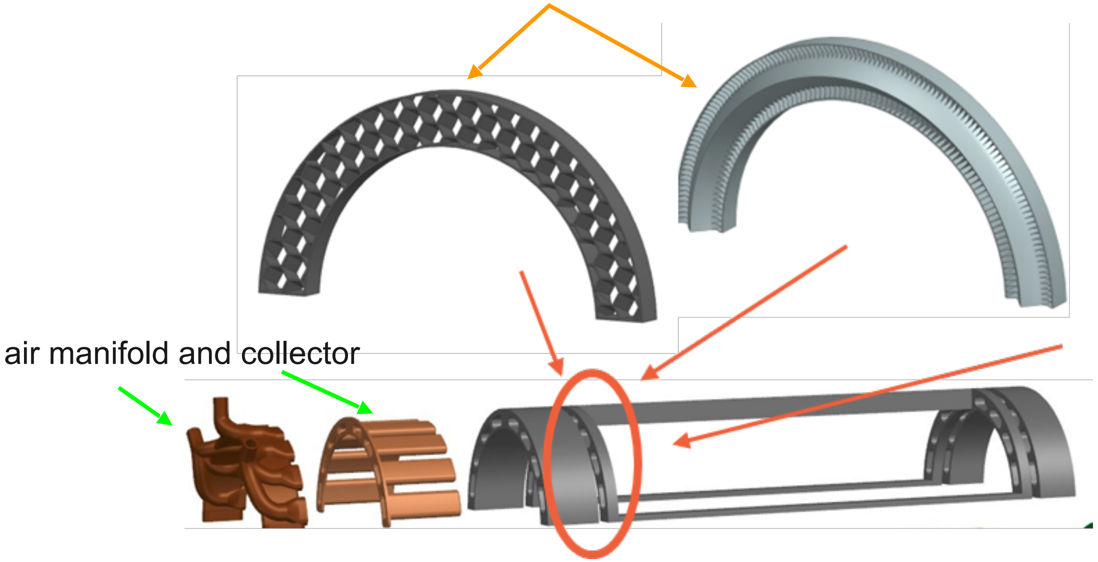
- Test of air cooling with high LEC power (1.6 W/cm^2) with alternative dissipators in aluminium 3D printed.
- Measurement of air flow (hot-wire anemometer) and temperature (IR camera and PT100). Local mechanics and global support (simplified design) 3D printed.
- Test results expected by fall 2025.

Dummy heat load, sized as two joined sensors, both L0 and L1 dummies will be built in order to simulate first 2 layers of a half barrel.

quotes (mm)
l1 = 336.5
l2 = 266
h1 = 117.5
d1 = 4.5
d2 = 5



Dissipators (2 options), 3D-printed, aluminium (but same material budget as carbon foam half-rings) for the h-side

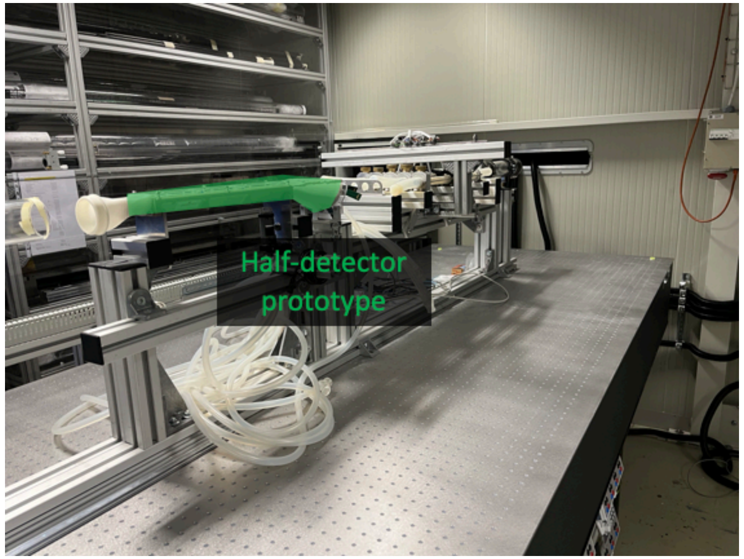


PRESENT STATUS AND FUTURE ACTIVITIES

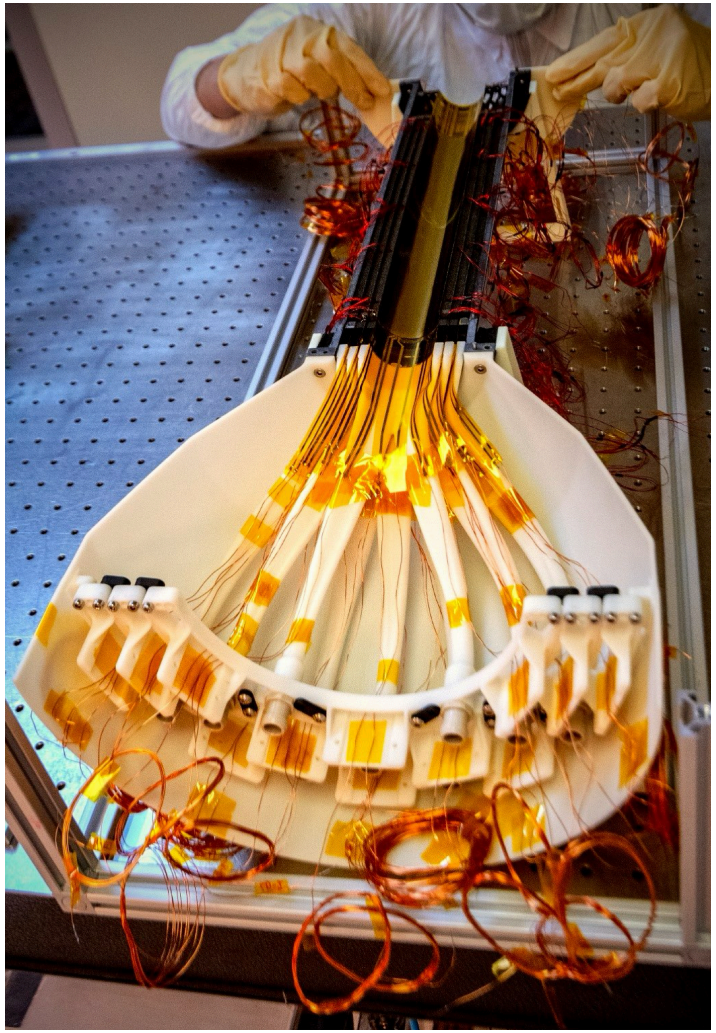
Thermo-mechanical studies - Cooling tests (advanced)

- Dedicated prototype IBL01_P5 (> January 2026)
  - L0 and L1 heaters
  - Proper carbon foam or alternatives
  - Air-ducts and temperature sensors (PT1000)

- Wind tunnel setup
  - Investigating where to assemble it
  - going to investigate (also within SVT DSC) for possible help, both for infrastructure and person-power



ITS3 wind tunnel @CERN


ITS3 BBM6 prototype

PRESENT STATUS AND FUTURE ACTIVITIES

Thermo-mechanical studies - Thermal expansion studies (in climatic chamber)

- Dedicated prototype IBL01_P3+P4
  - L0 and L1 naked silicon pieces
  - Proper carbon foam and carbon fibre external shell
- Test schedule (from ITS3 TDR) to be refined
  - Temperature: from 40°C to 10°C, in steps of 2 °C (with a 15-minute interval) and a ramp rate of 0.5°C per minute.
  - Relative humidity in the climate chamber maintained at a constant 50% during thermal cycles.
  - Testing phase, including multiple thermal cycles, should last 50 hours.
  - Subsequent thermal tests will be conducted to examine both the effect of a rapid temperature increase (ramp rate up to 10°C per minute) and determine the maximum temperature before failure.
- Scheduled after the completion of dedicated prototype in October

Model : Genviro 030LC
Temperature range : from -70 °C to +90 °C
Humidity range : from 10% to 98 %
Dimensions : 330 mm x 280 mm x 330 mm

PRESENT STATUS AND FUTURE ACTIVITIES

Summary

- L0-L1 assembly procedure
  - bare barrel procedure definition in advanced status
  - prototype campaign defined for Q4 of 2025 and 2026
  - material procurement issues on carbon foam (K9 Allcomp)
- Global mechanics: first prototype expected mid-2026
  - non-CFC prototypes for assembly/integration tests needed by late 2025
  - L0-L1 external shell production issue
- FPC activities focus on progressing test pieces development, commissioning and initial signal integrity tests
- Thermo-mechanical studies
  - First development FEA vibrational analysis completed and more detailed studies planned for the coming months
  - Thermal effect simulation in Ansys/Fluent: activity started
  - Thermal expansion studies in preparation for Q4 2025/ Q1 2026
  - Cooling tests developing now, first results during fall 2025
  - Wind tunnel tests: infrastructure and person-power issue

Back-up

PRESENT STATUS AND FUTURE ACTIVITIES

L0-L1 assembly procedure - Activity summary

Alignment btw sensors (flat)

Parallelism has higher priority than pitch minimisation since a large tilt can affect the success of the bondings to FPC.

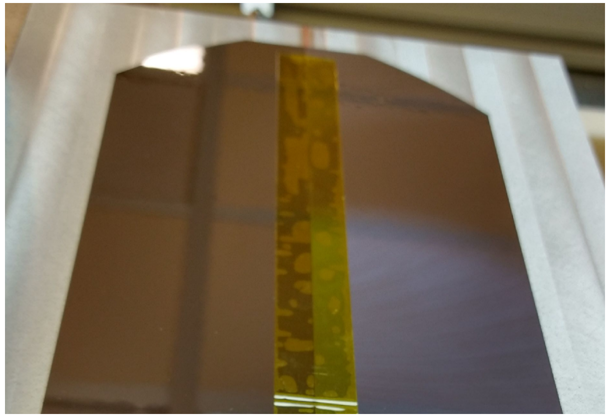
#	ID	Average pitch (µm)	Tilt angle (°)
1	**L0v1**	150	±0.021
2	**L0v2**	285	±0.008
3	**L0v3**	144	±0.006
4	**L0v4**	141	±0.002
5	**L1v1**	75.5	±0.0014
6	**L0v5**	**51.5**	±0.0004*

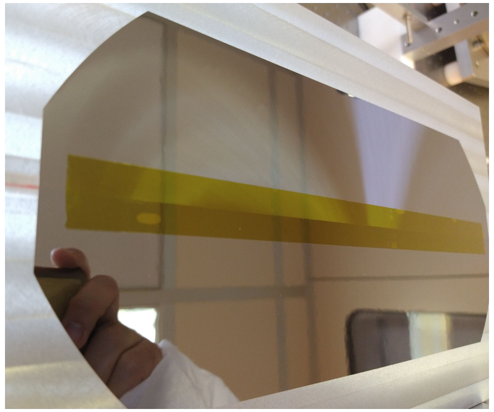
+ Offline measurements by analysing pictures
+ Design of accessories to reduce the number of attempts to reach the desired tilt and pitch.

*tilt under the resolution of dinoscope

Kapton tape

- Commercial tape: tesa® 51408 (or M3)
- Approximate length: ~250 mm (TBD)
- Tolerance: 1-2 mm of asymmetries in both the directions
- Air bubbles are minimised keeping the object rest for a night with vacuum ON



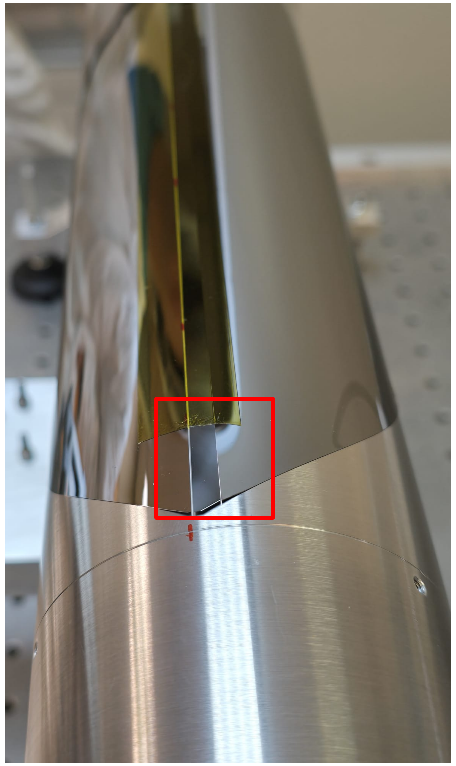


- Negligible cuspids are observed after the bending

PRESENT STATUS AND FUTURE ACTIVITIES

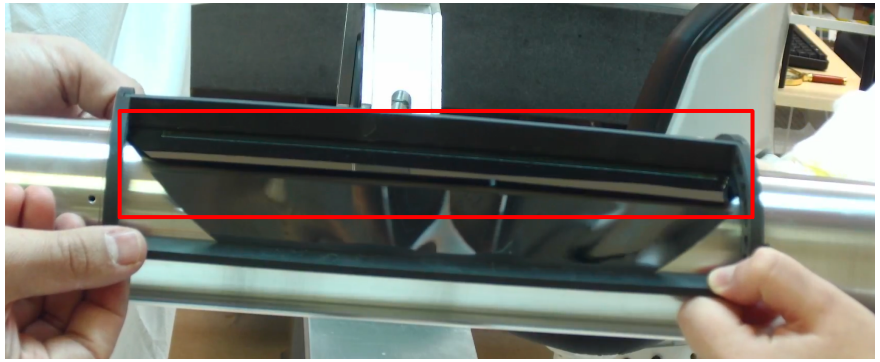
L0-L1 assembly procedure - Activity summary

Layer	Dates	BENDING	GLUING	REMOVAL
L0$_{V1}$	16/10/24-26/11/24	YES Silicon chipping at one edge; located under the tape, allowed for bending	YES	NO Breakage due to previous damage
L0$_{V2.1}$	13/01/25-14/01/25	NO Breakage of one silicon edge possibly during the two sensors alignment	–	–
L0$_{V2.2}$	16/01/25-31/01/25	YES	YES	YES
L0$_{V3}$	24/03/25-28/03/25	YES	NO Silicon broken already in the transport box	–
L0$_{V4}$	03/04/25-10/04/25	YES	YES	YES
L0$_{V5}$	26/05/25-03/06/25	YES	YES	YES
L1$_{V1}$	28/04/25-06/05/25	YES	NO Operator error → Tools safety margins improved after failure	–
L1$_{V2}$	07/07/25-09/07/25	YES	YES	YES



Silicon breakage located under the tape, still allowed the bending

Final breakage during removal from mandrel



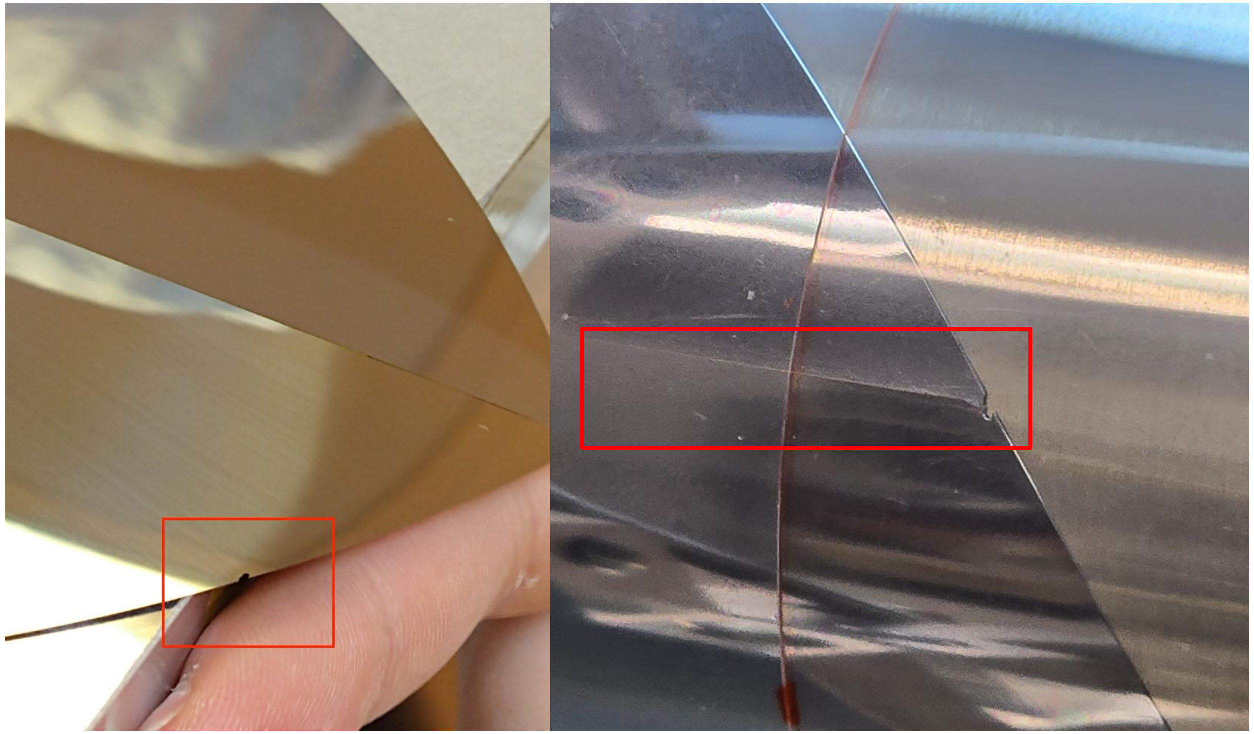
ePIC Collaboration meeting | 20-24th Jan 2025 | Bari team

PRESENT STATUS AND FUTURE ACTIVITIES

L0-L1 assembly procedure - Activity summary

Layer	Dates	BENDING	GLUING	REMOVAL
$L0_{V1}$	16/10/24-26/11/24	YES Silicon chipping at one edge; located under the tape, allowed for bending	YES	NO Breakage due to previous damage
$L0_{V2.1}$	13/01/25-14/01/25	NO Breakage of one silicon edge possibly during the two sensors alignment	—	—
$L0_{V2.2}$	16/01/25-31/01/25	YES	YES	YES
$L0_{V3}$	24/03/25-28/03/25	YES	NO Silicon broken already in the transport box	—
$L0_{V4}$	03/04/25-10/04/25	YES	YES	YES
$L0_{V5}$	26/05/25-03/06/25	YES	YES	YES
$L1_{V1}$	28/04/25-06/05/25	YES	NO Operator error → Tools safety margins improved after failure	—
$L1_{V2}$	07/07/25-09/07/25	YES	YES	YES

The edge defect caused the break during the bending

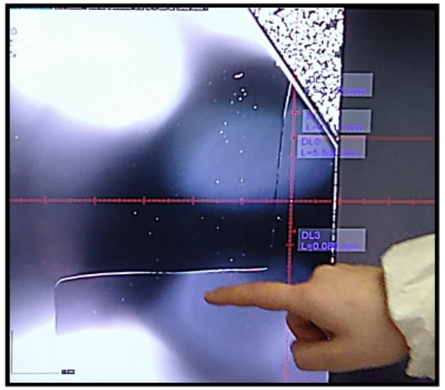


ePIC Collaboration meeting | 20-24th Jan 2025 | Bari team

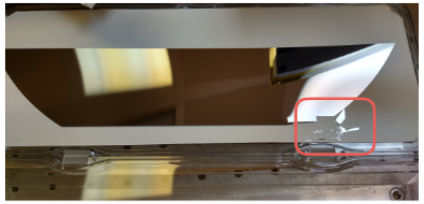
PRESENT STATUS AND FUTURE ACTIVITIES

L0-L1 assembly procedure - Activity summary

Layer	Dates	BENDING	GLUING	REMOVAL
L0V1	16/10/24-26/11/24	YES Silicon chipping at one edge; located under the tape, allowed for bending	YES	NO Breakage due to previous damage
L0V2.1	13/01/25-14/01/25	NO Breakage of one silicon edge possibly during the two sensors alignment	–	–
L0V2.2	16/01/25-31/01/25	YES	YES	YES
L0V3	24/03/25-28/03/25	YES	NO Silicon broken already in the transport box	–
L0V4	03/04/25-10/04/25	YES	YES	YES
L0V5	26/05/25-03/06/25	YES	YES	YES
L1V1	28/04/25-06/05/25	YES	NO Operator error → Tools safety margins improved after failure	–
L1V2	07/07/25-09/07/25	YES	YES	YES

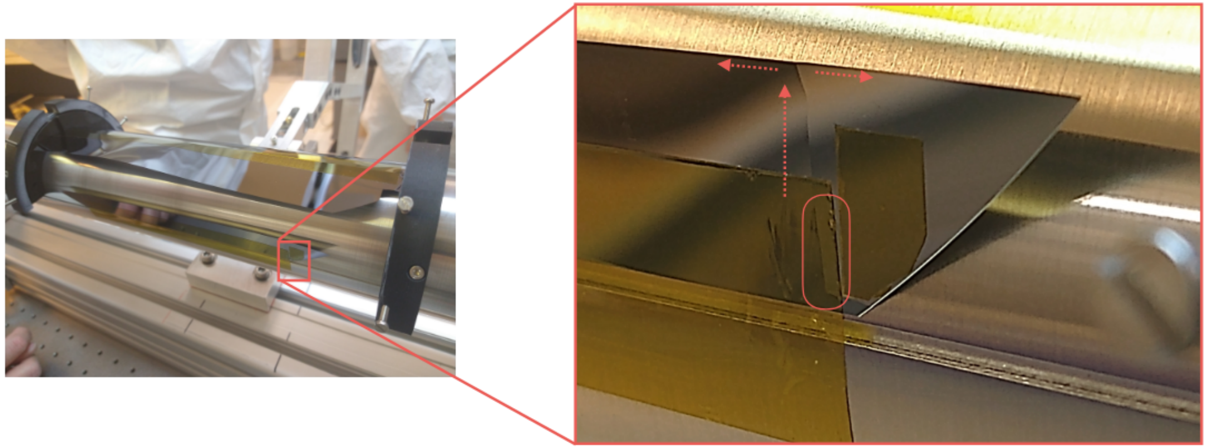


Crack stopped during bending procedures using microscope (not easily visible by eye).



Broken silicon pipe found in the same box
- Don't stack many silicons in the same box
- Visual inspection before each assembly

Discovered fracture was covered by extra kapton tape



Extra tape was not sufficient: fracture was the source of the successive break in the picture