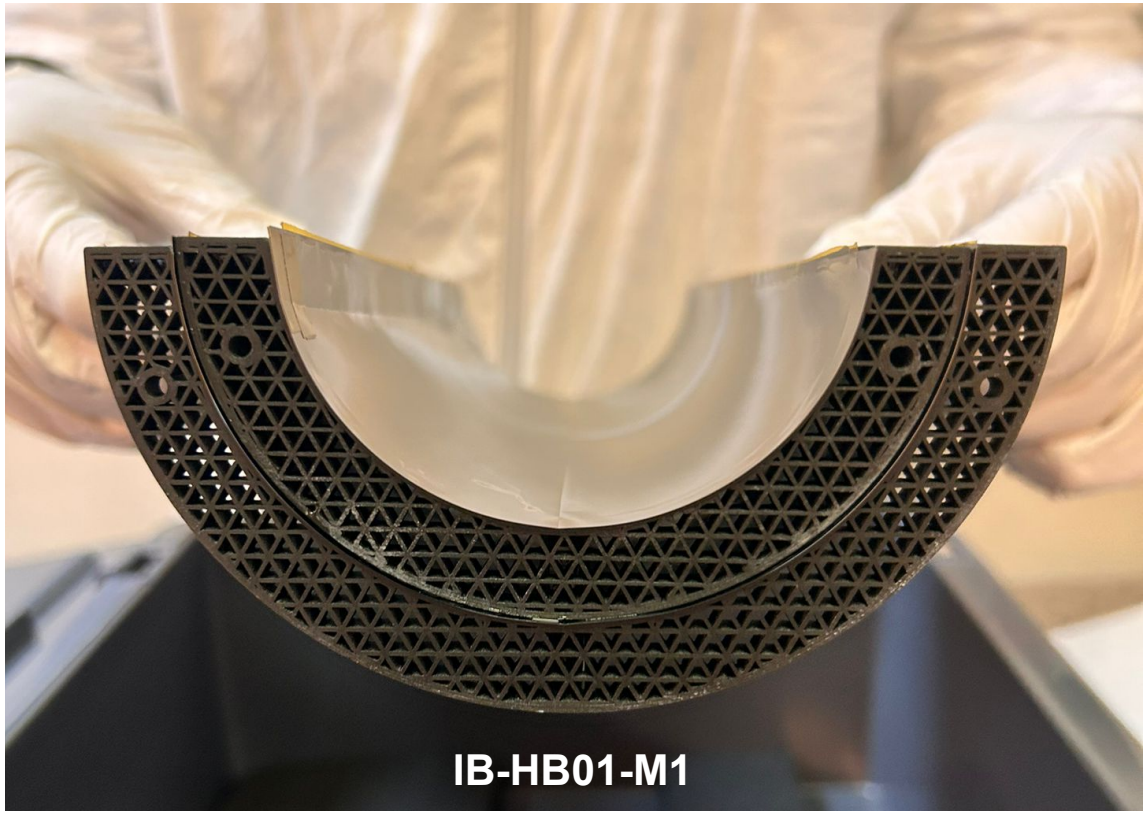


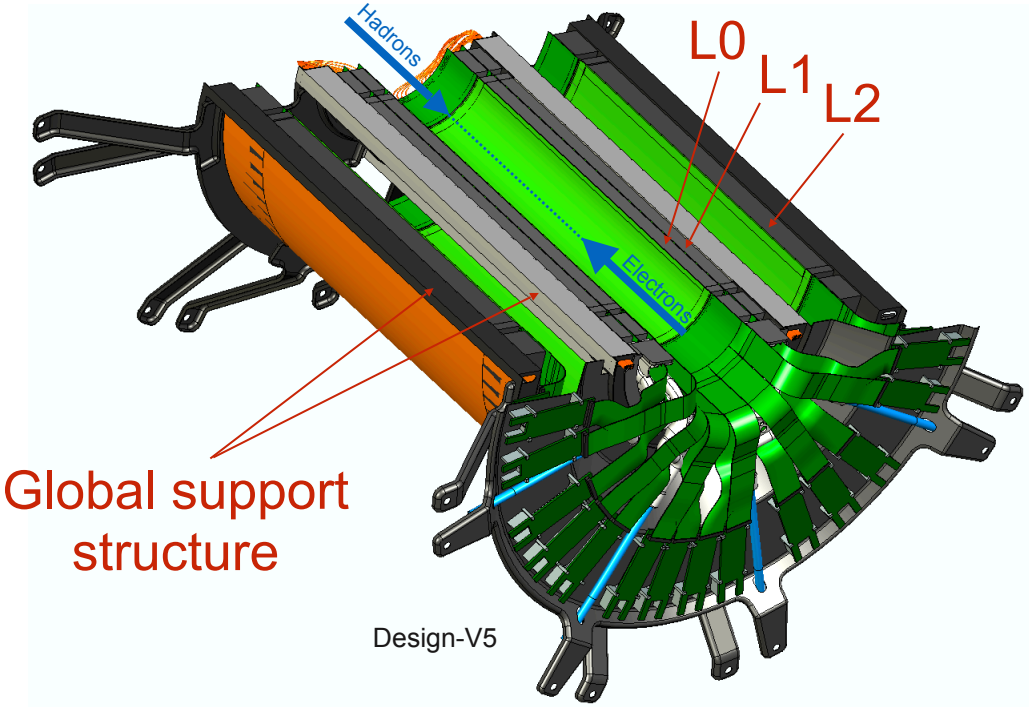
Progress on
SVT IB prototyping

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

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 (mm²)	# 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

SVT INNER BARREL

Basic ingredients:

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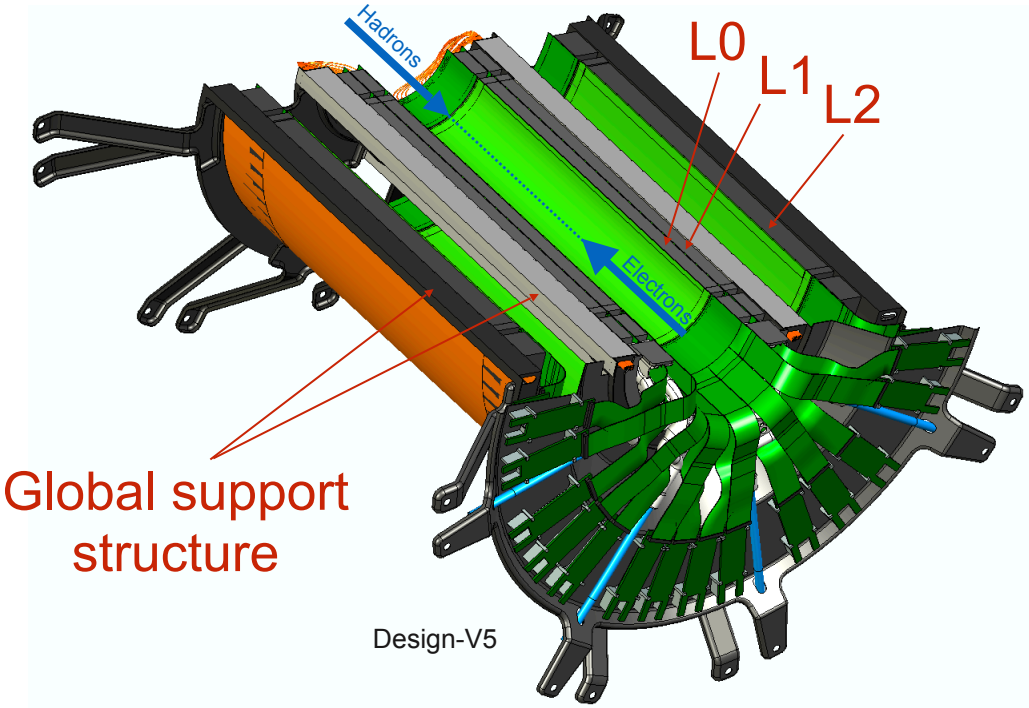
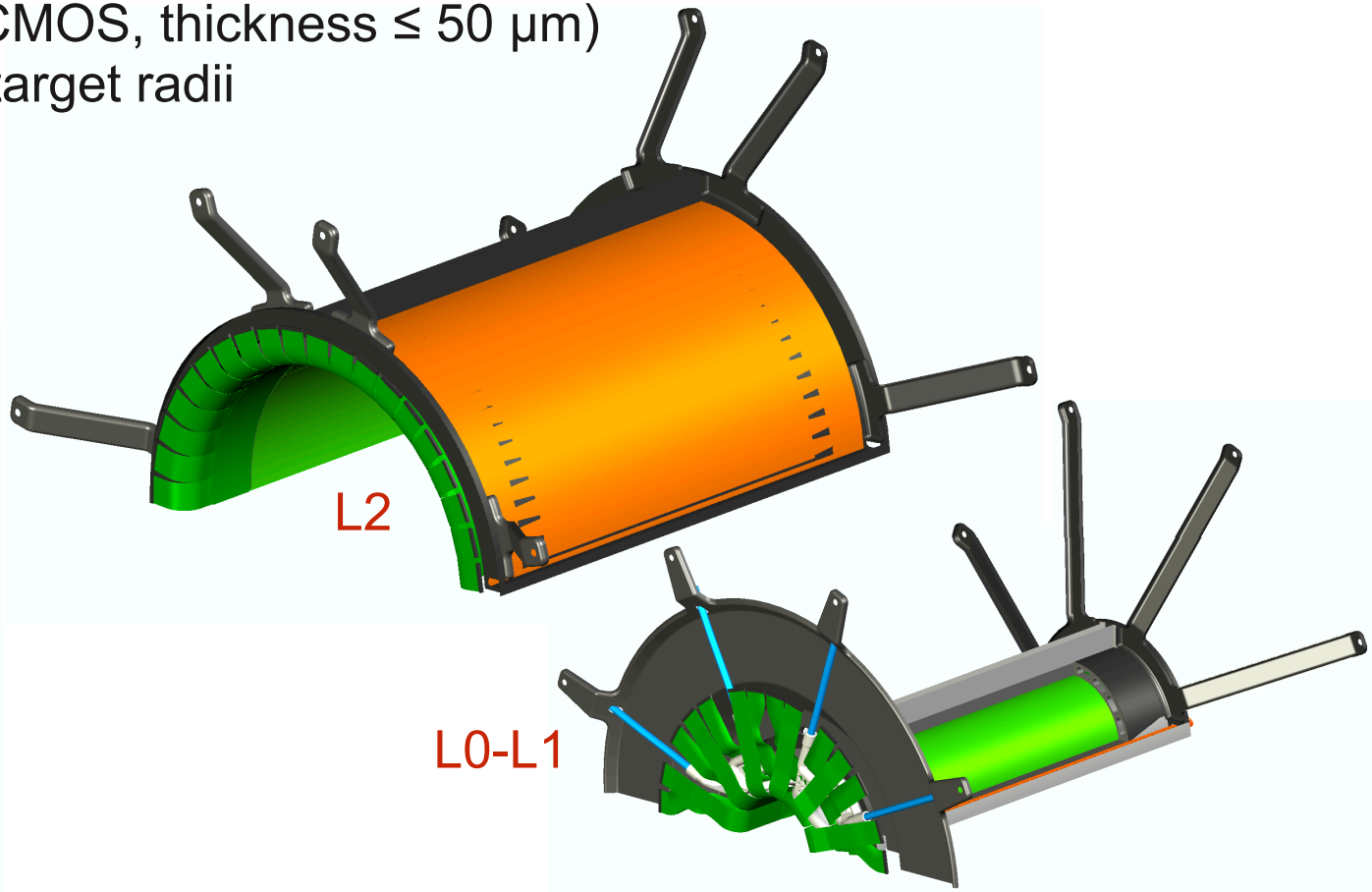




- L0-L1 half-barrel and L2 layer can be produced separately and integrated together in later stage

Progress on SVT IB prototyping

L0-L1 half-barrel assembly procedure

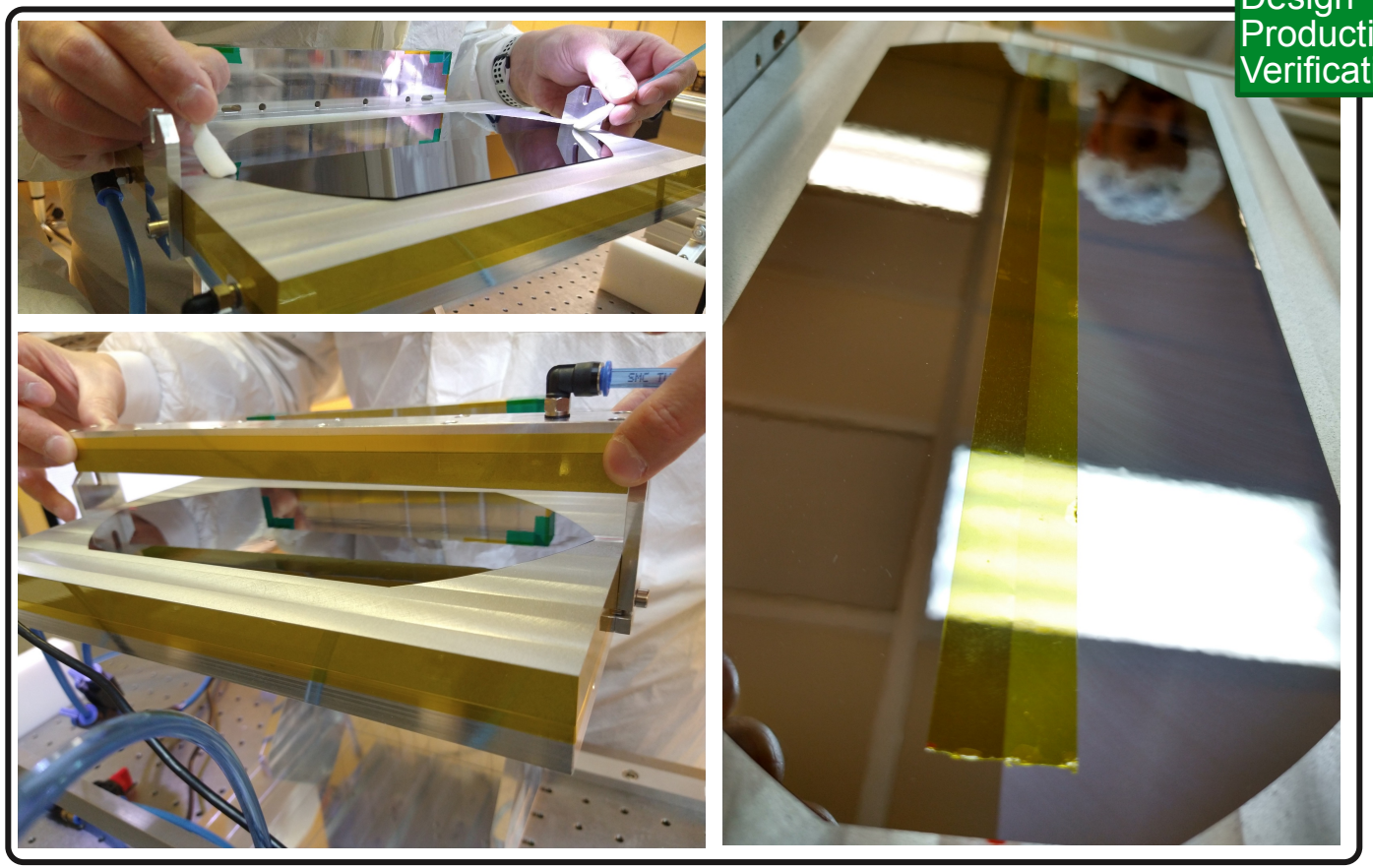
- **Sensors alignment and joining** ✓
- **Joint sensors bending** ✓
- **FPC to sensors interconnection** ↻
- **Local support structures gluing** ↻
- **Services integration in layer** ↻
- **L0-L1 half-barrel assembly** ↻

Progress on SVT IB prototyping

L0-L1 half-barrel assembly procedure

Design ☑
Production ☑
Verification ☑

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



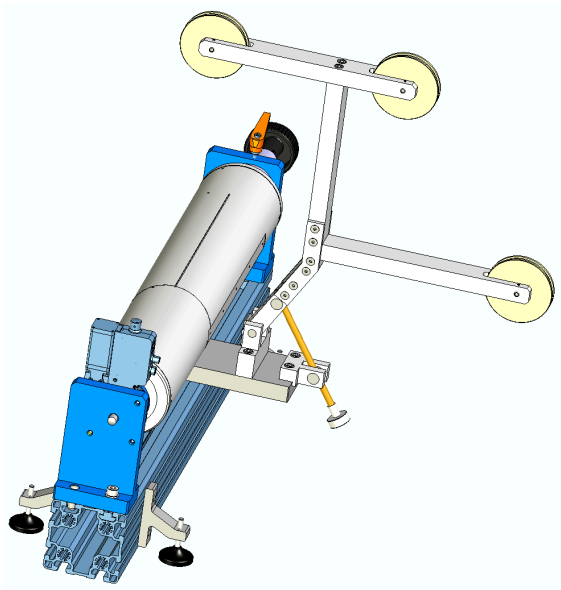
Few tens micron precision reached targeting
50 µm pitch between the two sensors

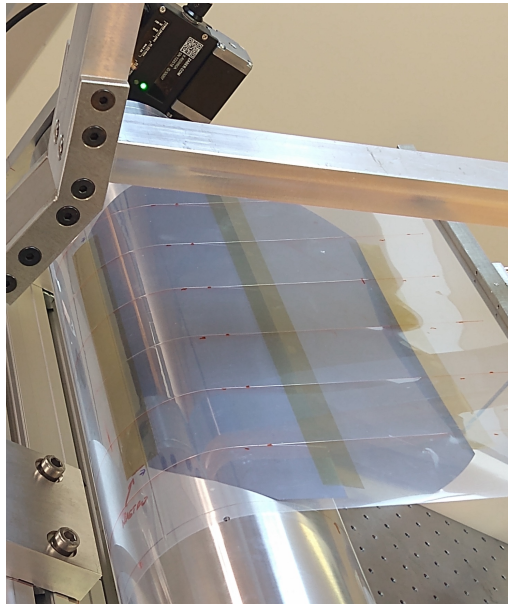
Progress on SVT IB prototyping

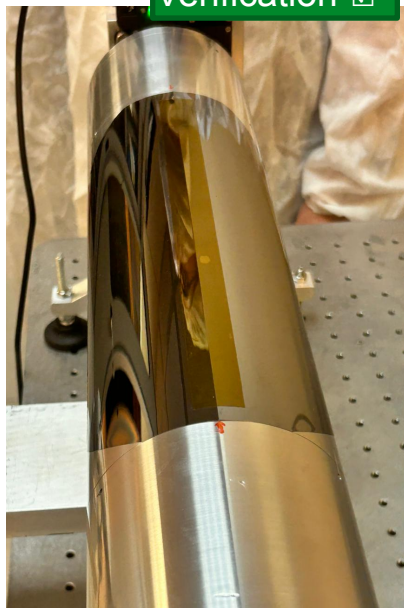
L0-L1 half-barrel assembly procedure

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

Design ☑
Production ☑
Verification ☑





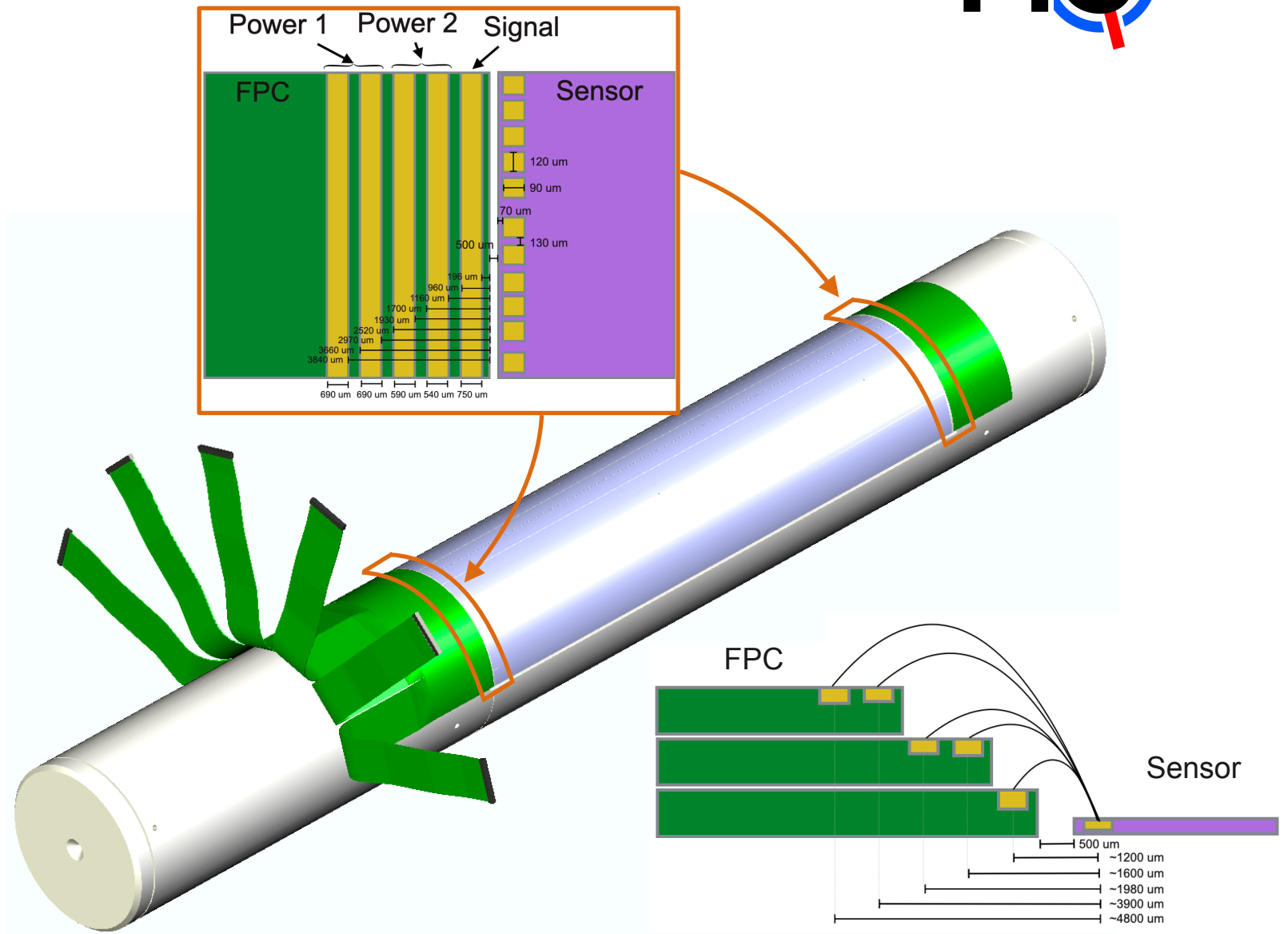


Double sensors bending mastered for L0 and L1

Progress on SVT IB prototyping

L0-L1 half-barrel assembly procedure

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

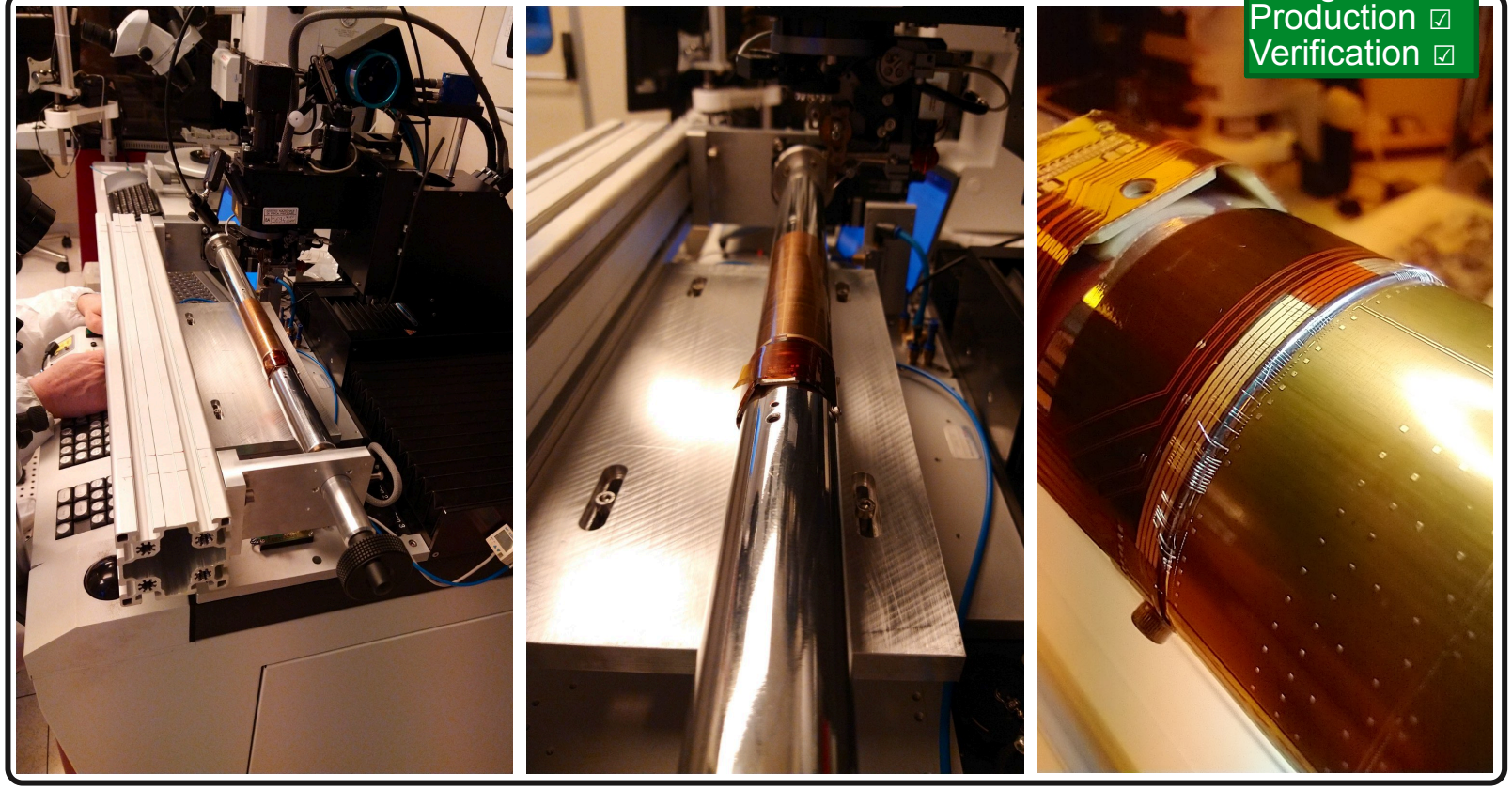


Progress on SVT IB prototyping

L0-L1 half-barrel assembly procedure

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

Design ☑
Production ☑
Verification ☑



Bending tool used to place the setup under wire-bonding machine

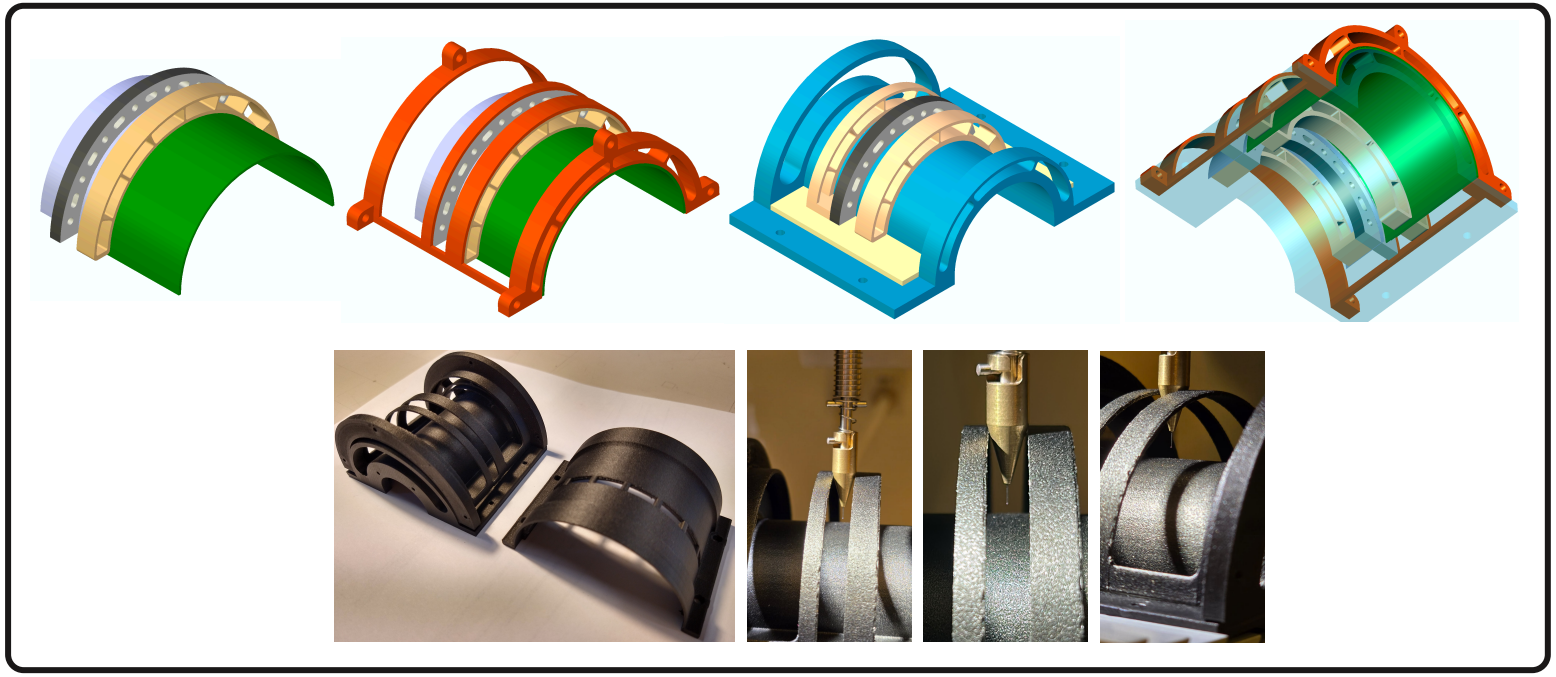
(Pictures from ITS3-SuperALPIDE exercise)

Progress on SVT IB prototyping

L0-L1 half-barrel assembly procedure

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

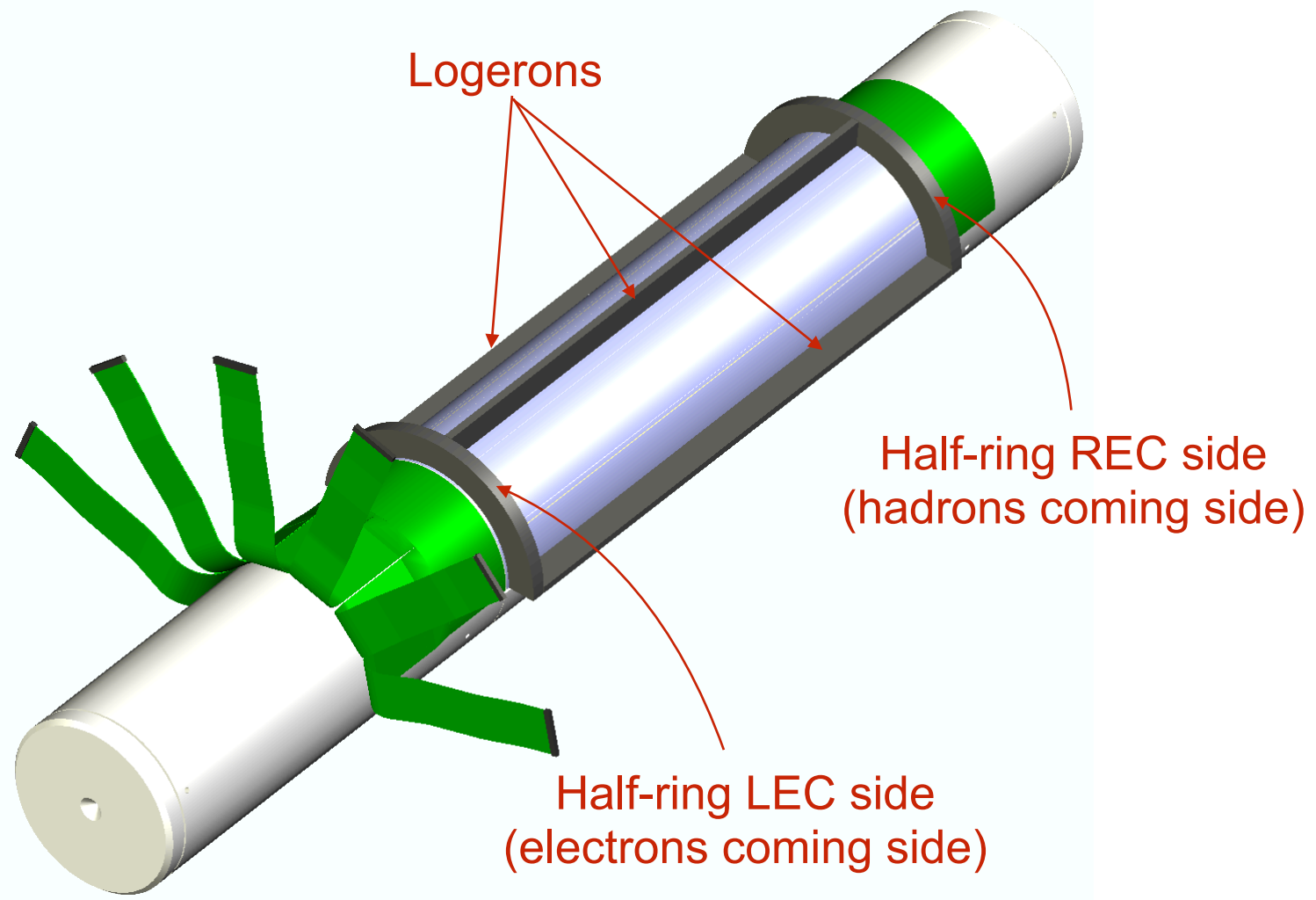
- Definition of best loop shapes and semi-automatic procedure for wire-bonding over bent surface
- Assessment of wire-bond pull-force variation following extended air-flow exposure
- Done in the context of ITS3 but valid for SVT-IB



Progress on SVT IB prototyping

L0-L1 half-barrel assembly procedure

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

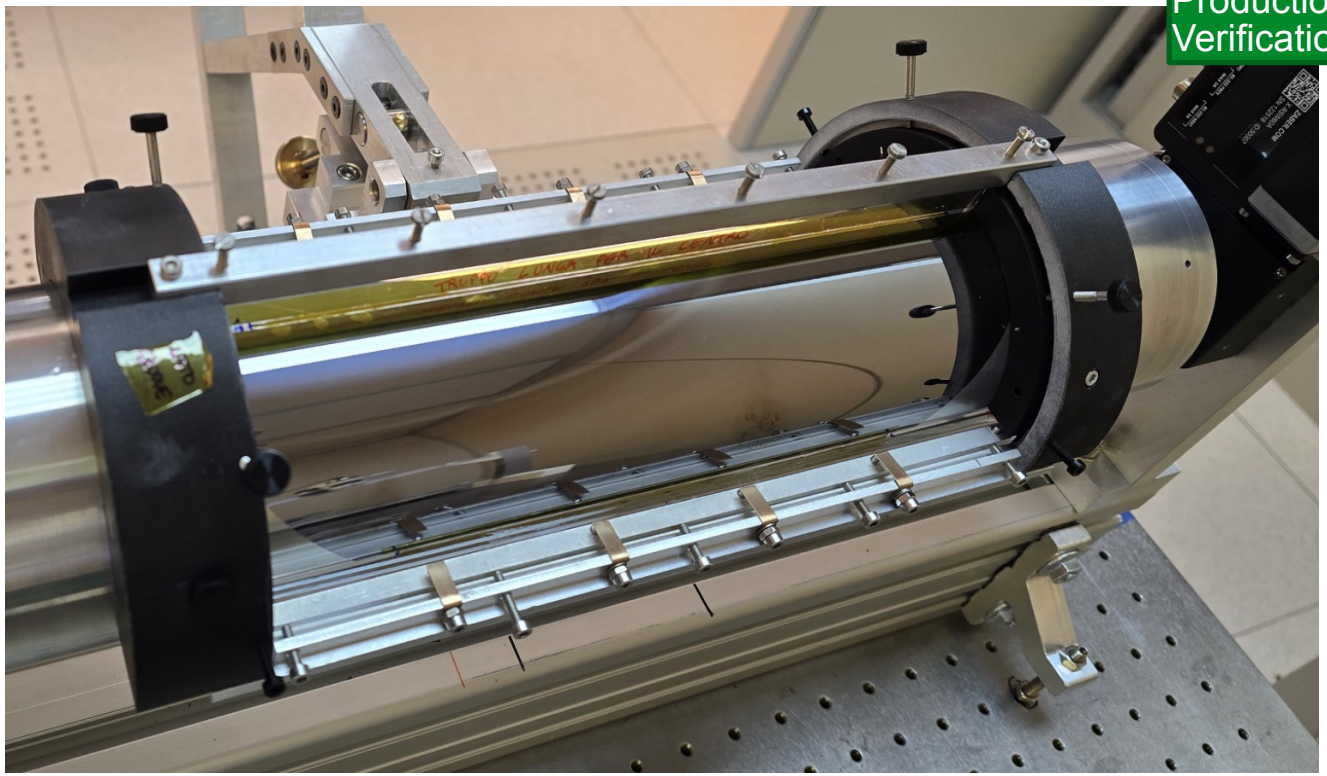


Progress on SVT IB prototyping

L0-L1 half-barrel assembly procedure

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

Design ☑
Production ☑
Verification ☑



- Proof of principle → DONE!
- Tool rapidly evolving toward final requirements

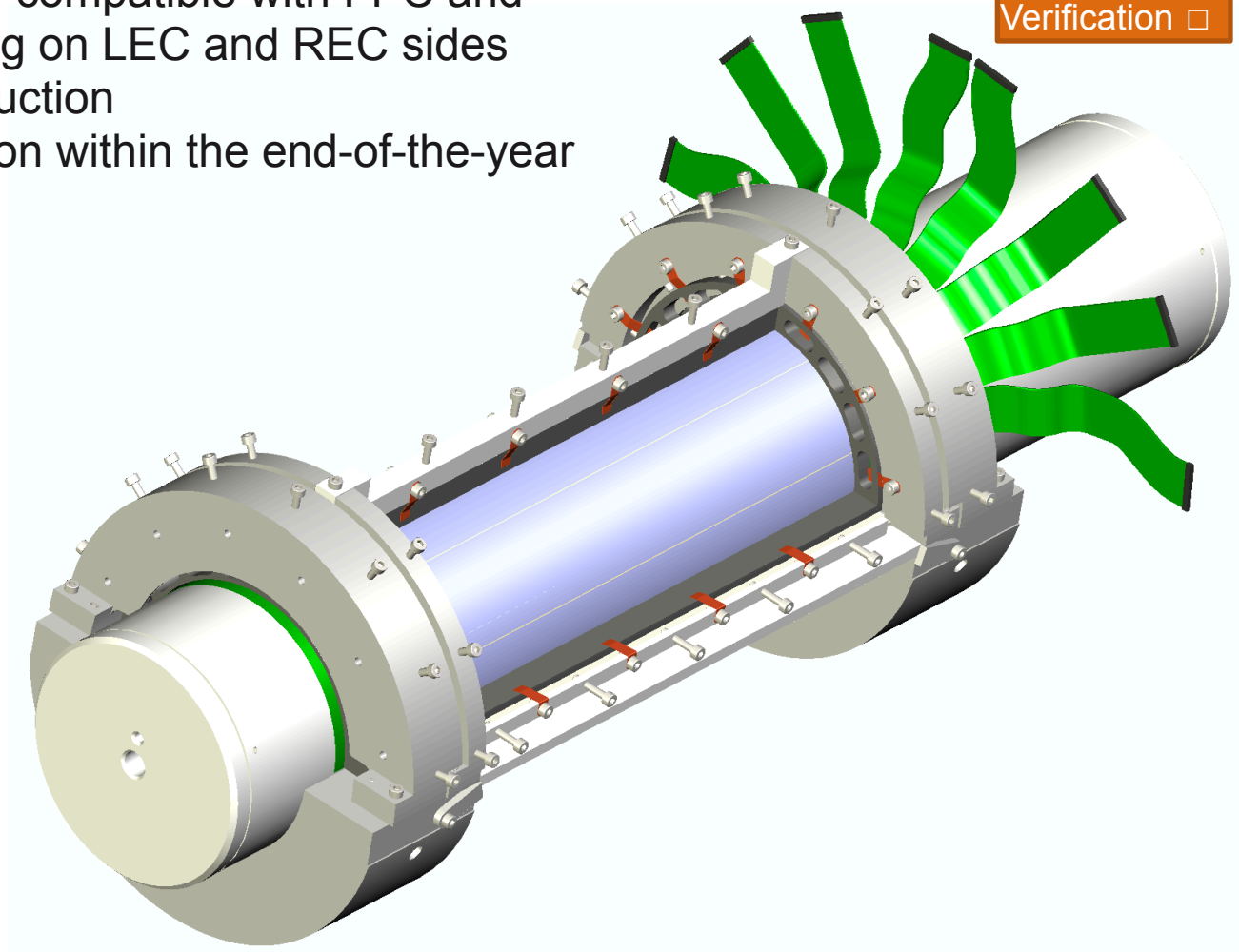
Progress on SVT IB prototyping

L0-L1 half-barrel assembly procedure

Design ☑
Production ⟳
Verification ☐

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

- New design compatible with FPC and wire-bonding on LEC and REC sides
- Under production
  → completion within the end-of-the-year



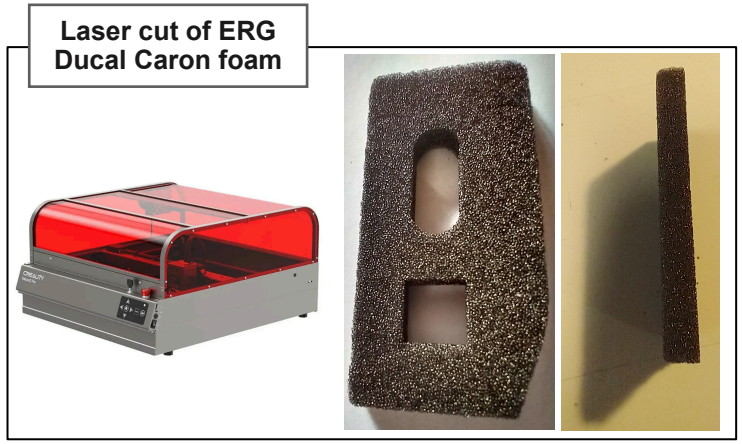
Progress on SVT IB prototyping

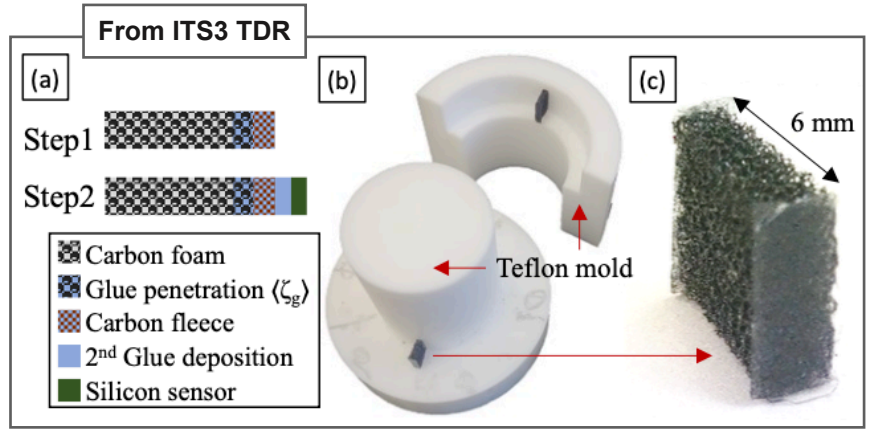
L0-L1 half-barrel assembly procedure

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

Local Support Structures in carbon foam:

- Low density (ERG Duocel) for longerons and half-ring on REC side, while high density (high heat capacity, K9 Allcomp) for half-ring on LEC side
- Alternative materials under evaluation for the half-ring on LEC:
  - C-Foam HTC (~100 W/mK)
  - Aluminum → Chiara Bonini presentation later





- Shaping currently done via mechanical cut → Alternative procedure using laser cut (requiring thin foil, up to 6 mm, for efficient cut)
- Tooling for gluing of interface between carbon foam and sensor (carbon fleece) under design

Progress on SVT IB prototyping

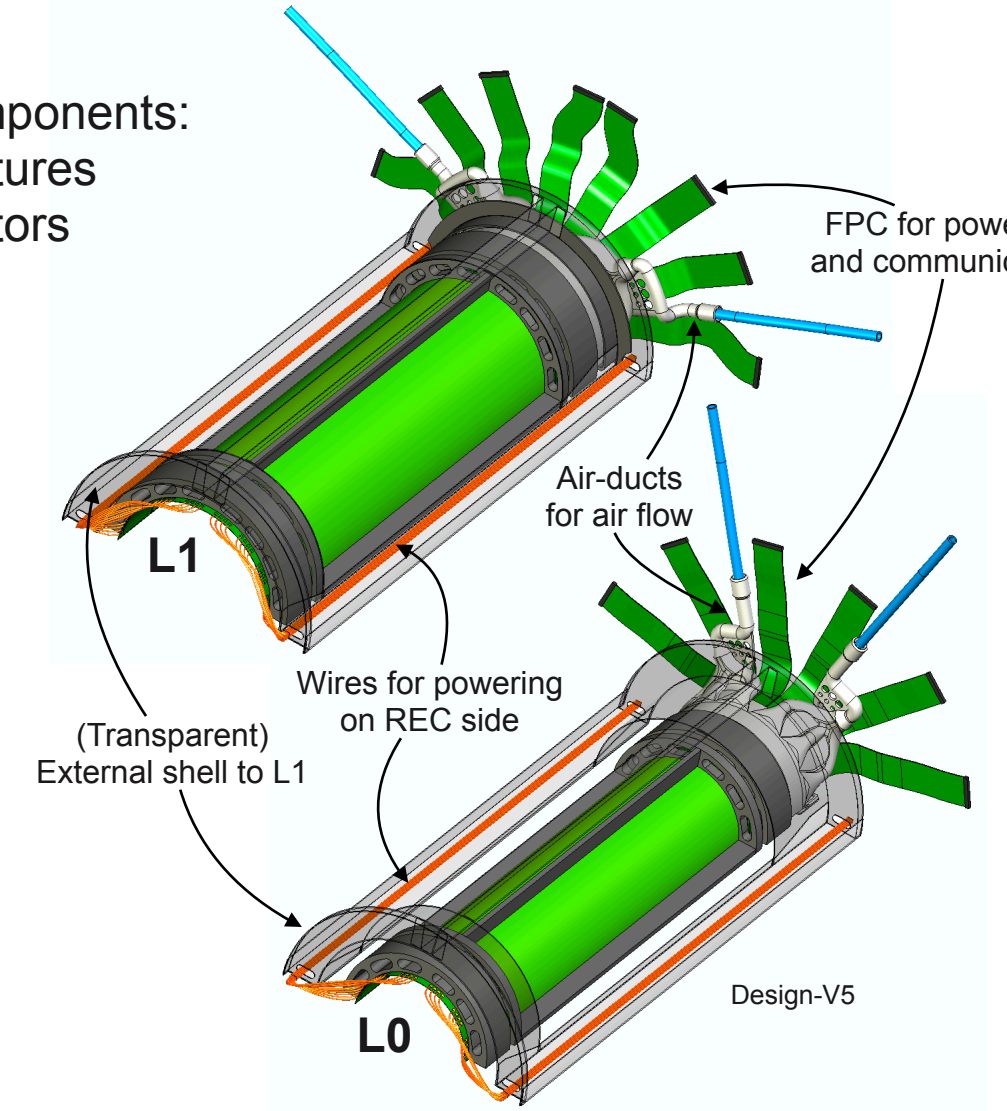
L0-L1 half-barrel assembly procedure

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

Gluing of remaining components:

- FPC supporting structures
- Air-ducts and distributors
- Powering wires

Gluing tools same used for local support structures



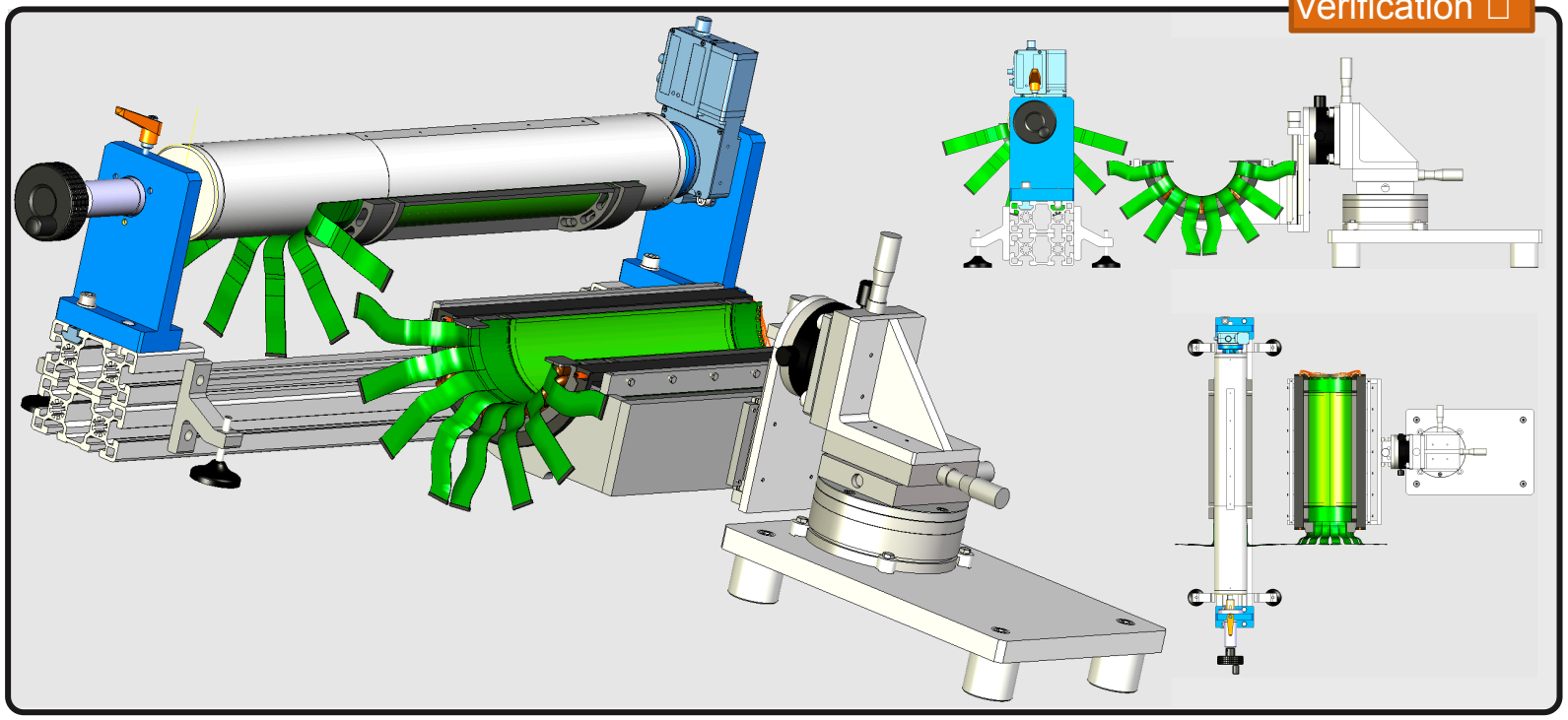
Progress on SVT IB prototyping

L0-L1 half-barrel assembly procedure

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

Layer-to-layer or layer-to-shell gluing tool

Design ☑
Production ☐
Verification ☐



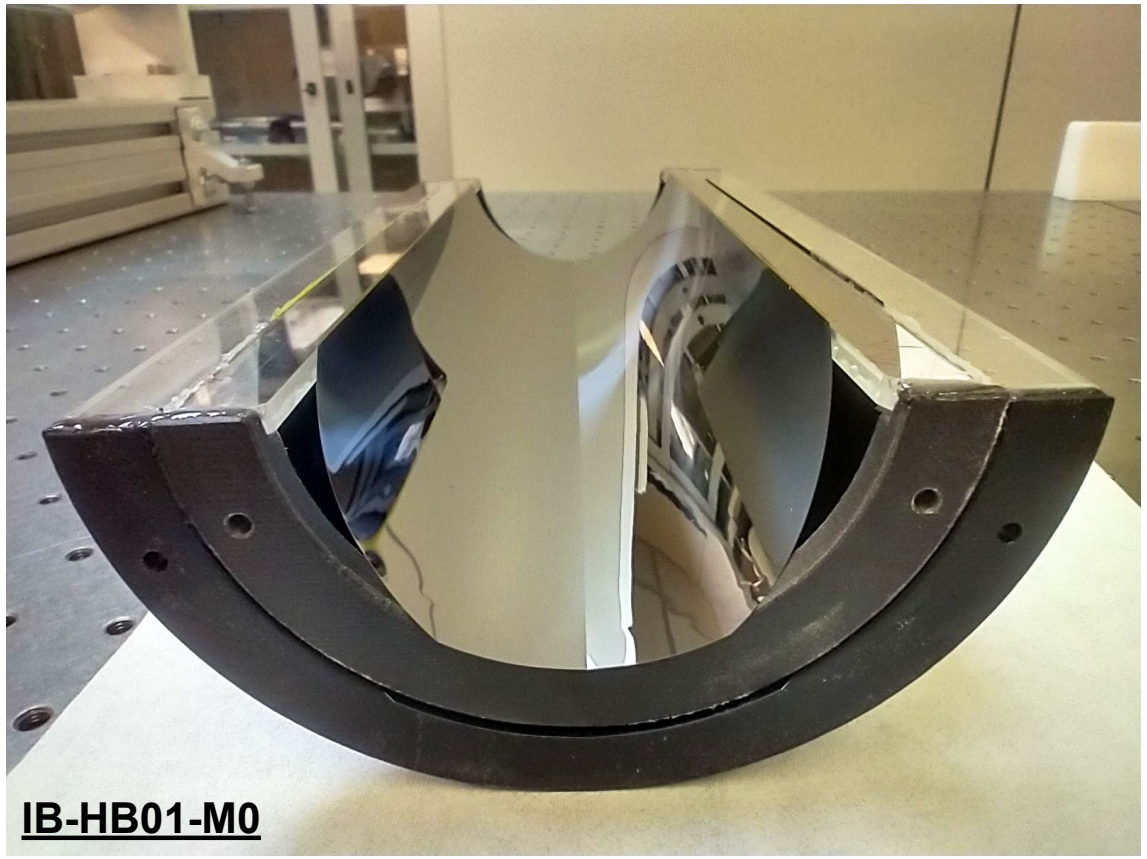
Progress on SVT IB prototyping

L0-L1 layers and half-barrel prototyping campaign

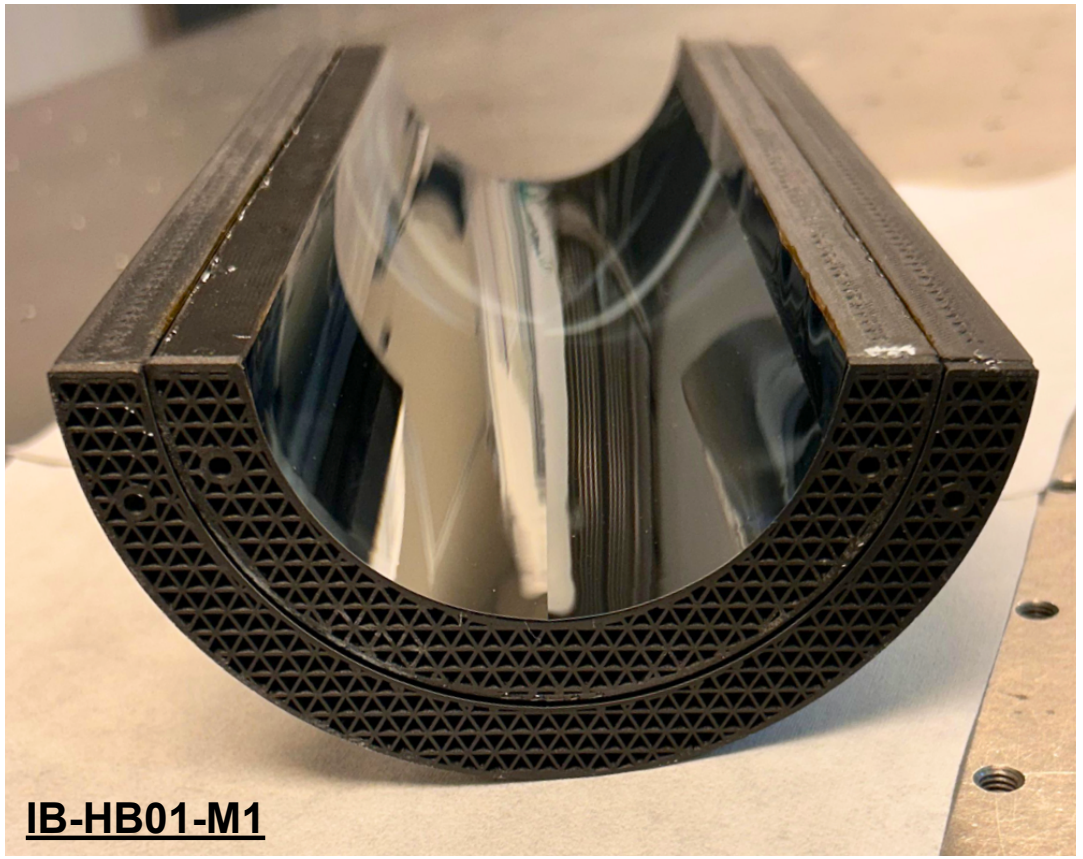
Layer	Dates	BENDING	GLUING	REMOVAL	
$L0_{V1}$	16/10/24-26/11/24	YES Silicon chipping at one edge; located under the tape, allowed for bending	YES	NO Breakage due to previous damage	
$L0_{V2.1}$	13/01/25-14/01/25	NO Breakage of one silicon edge possibly during the two sensors alignment	–	–	
$L0_{V2.2}$	16/01/25-31/01/25	YES	YES	YES	
$L0_{V3}$	24/03/25-28/03/25	YES Silicon broken already in the transport box	NO Breakage started from already present chipping	–	
$L0_{V4}$	03/04/25-10/04/25	YES	YES	YES	
$L0_{V5}$	26/05/25-03/06/25	YES	YES	YES	Used for **IB-HB01-M0**
$L0_{V7}$	08/10/25-27/10/25	YES Silicon chipping at one corner during removal from transport box → Fixed with tape, allow for bending	YES	YES	Used for **IB-HB01-M1**
$L1_{V1}$	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	Used for **IB-HB01-M0**
$L1_{V3}$	03/11/25-07/11/25	YES	YES	YES	Used for **IB-HB01-M1**

Progress on SVT IB prototyping

L0-L1 layers and half-barrel prototyping campaign



First L0-L1 bare half-barrel prototype



Second L0-L1 bare half-barrel prototype

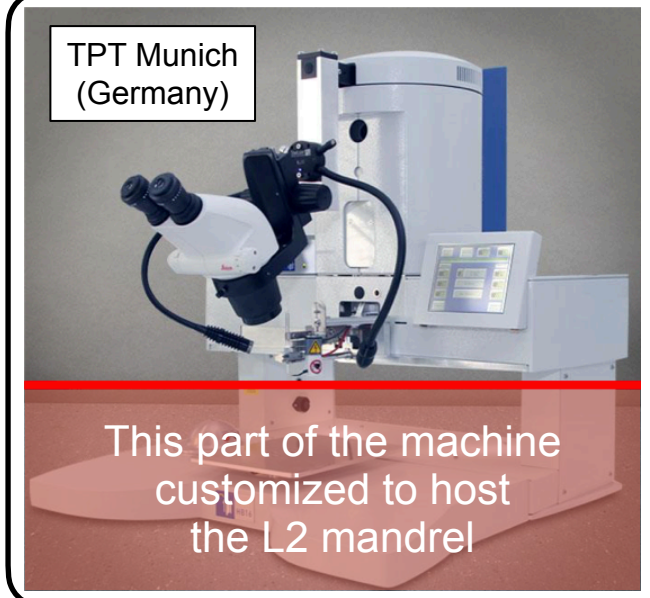
Progress on SVT IB prototyping

L2 half-layer assembly procedure

- Requested/obtained support from ePIC INFN referees and nuclear physics committee (CSN3) to take the commitment to build L2 too (funding starting from 2026 budget)
- Bari and Padova will be the construction sites, interchangeable, more dedicated to L0-L1 the former, to L2 the latter

Padova site preparation:

- Dedicated area in clean room for bending, wire-bonding, acceptance tests, etc.
- Another area dedicated to cooling tests, mock-up assembly (not requiring clean room)
- Bonding machine purchase speed-up anticipating funding from CSN3 in 2025 budget → Available before summer 2026.



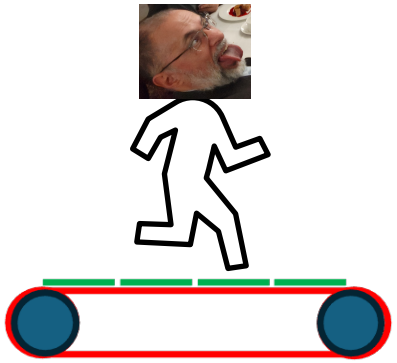
Wire wedge bonding machine

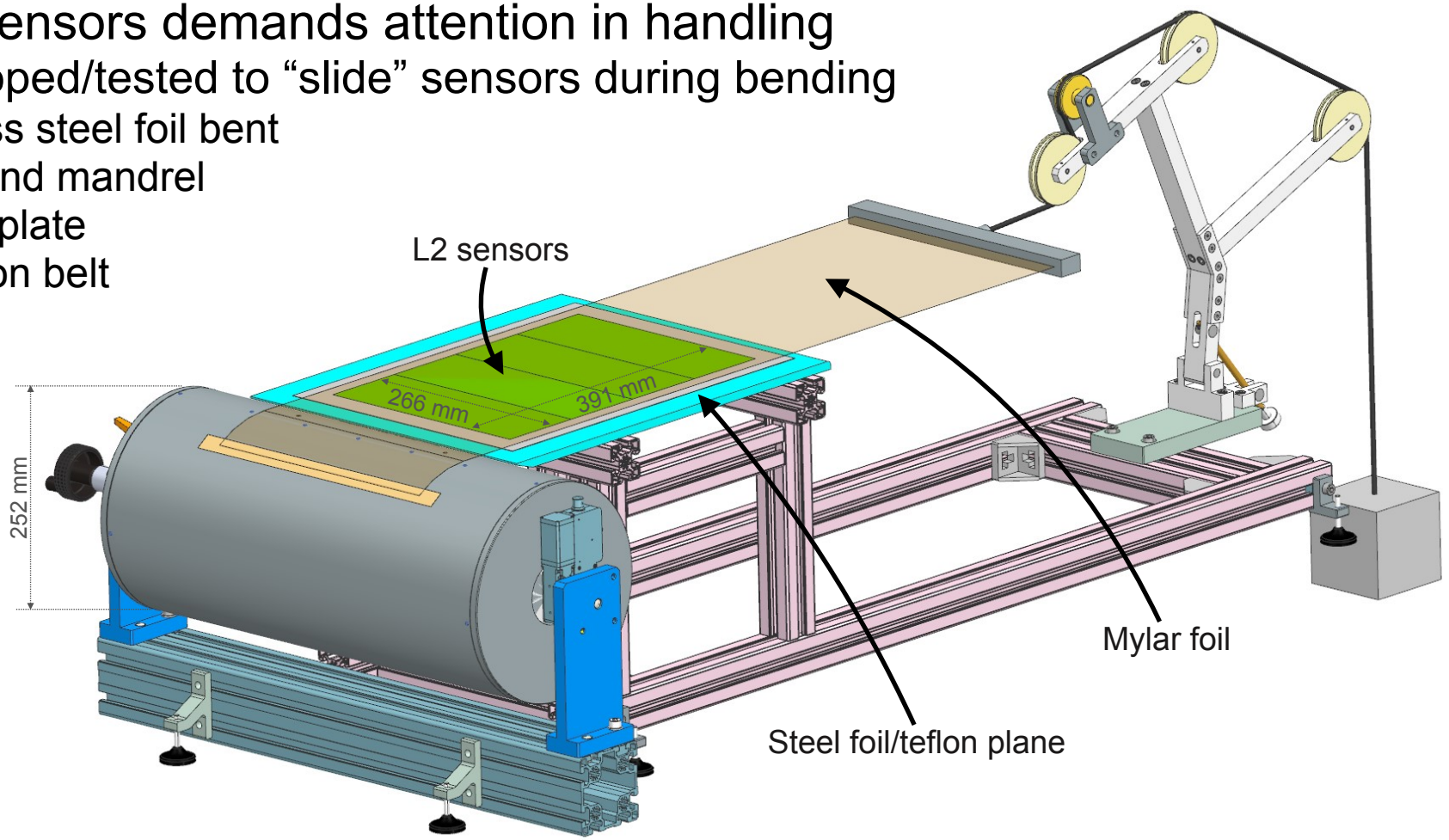
- purchase requisition completed, order out (today!)
- z, y movements will be integrated in the head (custom build)
- lower part (below red line) will be realized in Padova for custom mechanical acceptance, ‘’from pin to elephant’’
- delivery expected in 12 weeks from order

Progress on SVT IB prototyping

L2 half-layer assembly procedure

- Procedure for L2 assembly derived from L0+L1 experience
- Presence of four bigger sensors demands attention in handling
  - Few methods to be developed/tested to “slide” sensors during bending
    - Sensors stuck to a stainless steel foil bent together with sensors around mandrel
    - Sensors slipping on teflon plate
    - Sensors dragged on a teflon belt (“treadmill” method)





Progress on SVT IB prototyping

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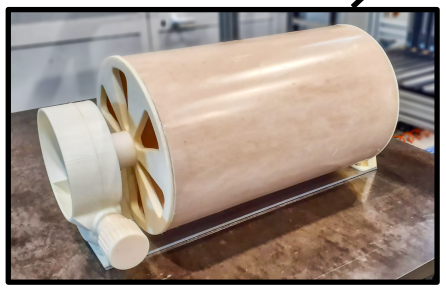
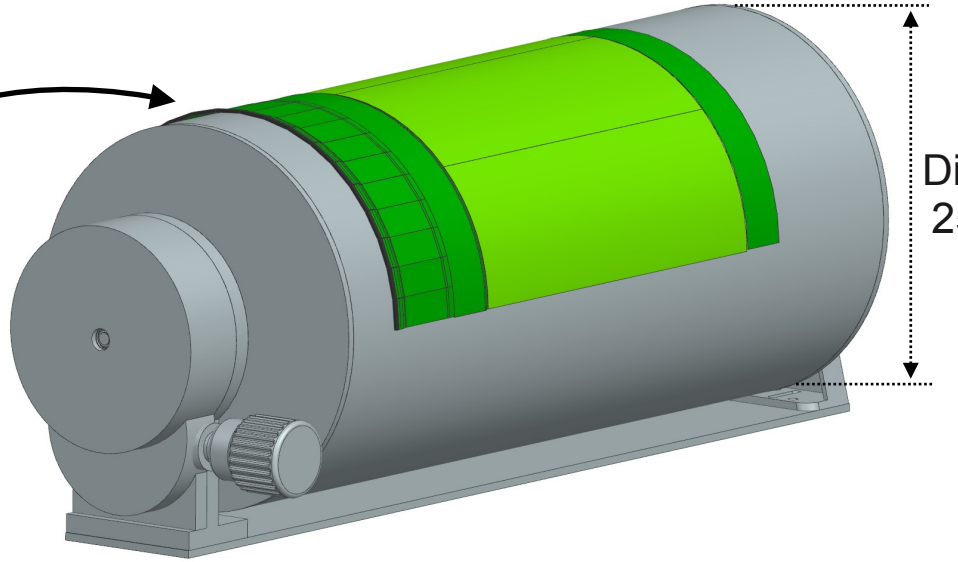
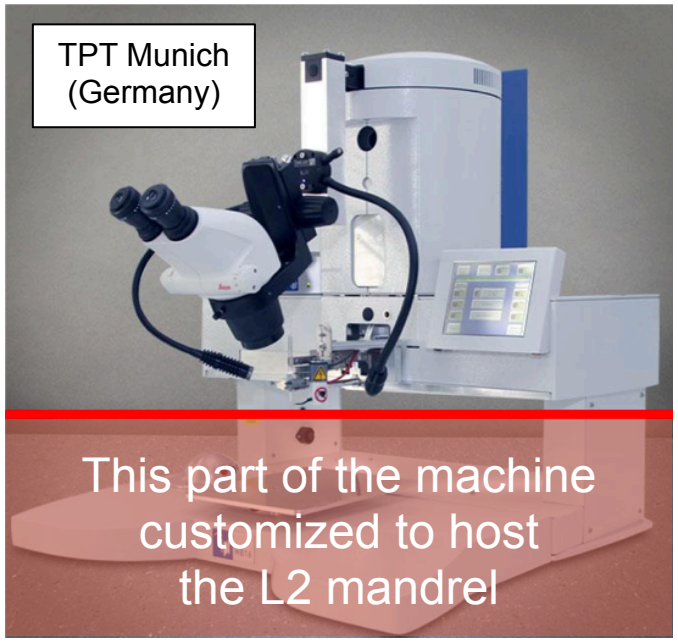


3D printed mockup existing





Progress on SVT IB prototyping

L2 half-layer assembly procedure

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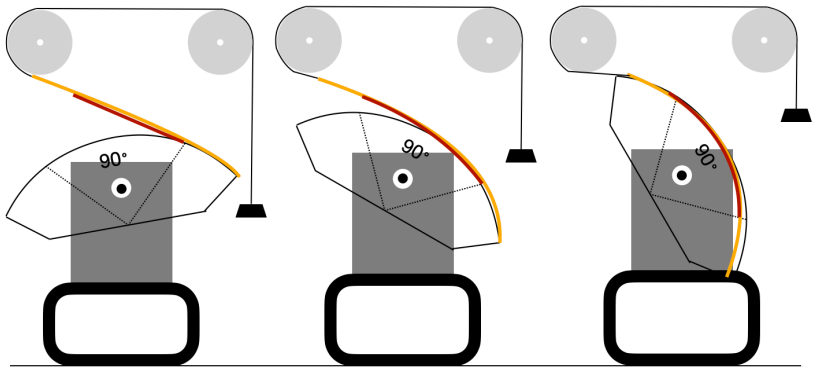


- Alternative development, based on quarter layer modules, is required in Bari, where the maximum hight available under the bonding machine is not enough to host the full L2 mandrel

Progress on SVT IB prototyping

Activities during 2026 - L0-L1 half-barrel prototyping campaign and material procurement

Prototype	Components	Goal	Target date
IB-HB01-M1	•2+2 silicon L0+L1 **naked sensors** → AVAILABLE •L0+L1 local support structures 3D printed → AVAILABLE	Finalize half-layer assembly procedure	**Completed by November 2025**
IB-HB01-M2	•2+2 silicon L0+L1 **naked sensors** → AVAILABLE •L0+L1 local support structures in carbon foam (only ERG) → RAW MATERIAL PROCURED •Outer support shell to L1 in carbon fibre → UNDER PRODUCTION	Mechanical stress studies in climate chamber	To be completed by January 2026
IB-HB01-M3	•2+2 silicon L0+L1 **sensors with heaters** → AVAILABLE •L0+L1 local support structures in carbon foam (both ERG and Allcomp) → PARTIALLY PROCURED •L0+L1 air-ducts → TO BE PRINTED •Outer support shell to L1 3D printed → TO BE PRINTED	First full integration and studies of the cooling effectiveness in wind tunnel	To be completed by March 2026
IB-HB012-M1	•2+2(+4) **ER2 pad L0+L1(+L2) sensors** •L0+L1+L2 local support structures in carbon foam (both ERG and Allcomp) •L0+L1+L2 FPCs •L0+L1+L2 air-ducts •Outer support shell to L1 and to L2 3d printed •IB global support mechanics 3d printed	• First compete integration including wire-bonding • Possible assembly of 2 HBs to allow mechanical matching	To be completed by July 2026
IB-HB012-M2	•2+2(+4) **ER2 L0+L1(+L2) sensors** •L0+L1+L2 local support structures in carbon foam (both ERG and Allcomp) •L0+L1+L2 FPCs •L0+L1+L2 air-ducts •Outer support shell to L1 and to L2 in carbon fiber •IB global support mechanics 3d printed	• Qualification model integrating actual sensors for full system (cooling, powering, DAQ, DCS) characterization	To be completed by October 2026

Progress on SVT IB prototyping

Activities during 2026 - L2 setup preparation and initial prototyping

- Design of tooling for L2 assembly → Mostly adapted from L0-L1 tools
  - Sensors alignment and joining tool
  - Bending/bonding tool
  - Local support structures gluing tool
  - L2 external shell gluing tool
- Setup for L2 bending
  - Starting with mockup parts
  - Targeting first exercise with naked silicon pieces after summer
- Setup for thermal study → More in Chiara Bonini's presentation later
  - Initially in flat configuration
  - Final detector configuration (integrated with IB-HB01-M3) in a wind tunnel, suitable also for vibrational studies / comparison with FEA simulations

Progress on SVT IB prototyping

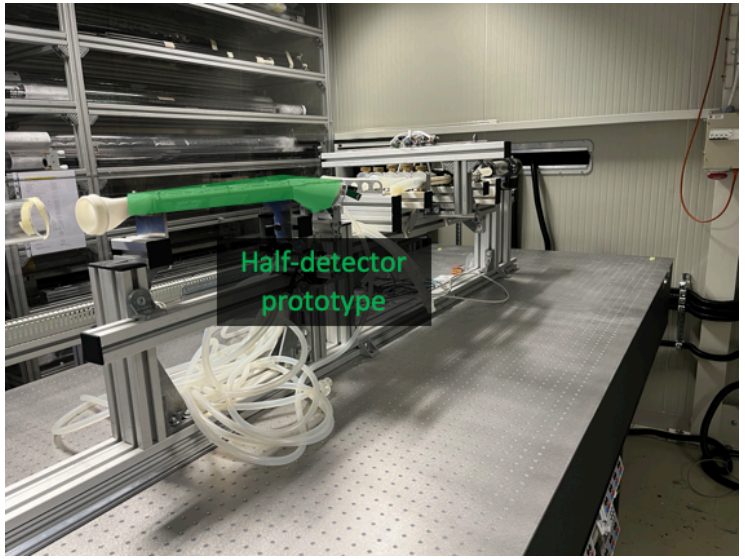
Summary

- L0-L1 assembly procedure in advanced status
  - Tooling development almost completed and production ongoing in Bari
- L2 assembly procedure at its first steps
  - Lot of effort expected in Padova in the first part of 2026
- Prototyping campaign advancing according to schedule
  - Targeting prototypes for specific measurements (mechanical stress, cooling effectiveness, aging test) until mid of 2026 (before arrival of MOSAIX sensors)
  - Final integration and verification campaign using MOSAIX sensors
- Material procurement progressing
  - Possible issue with K9 Allcomp carbon foam (for LEC cooling)
    → Proposed join procurement with larger collaborations or alternative material

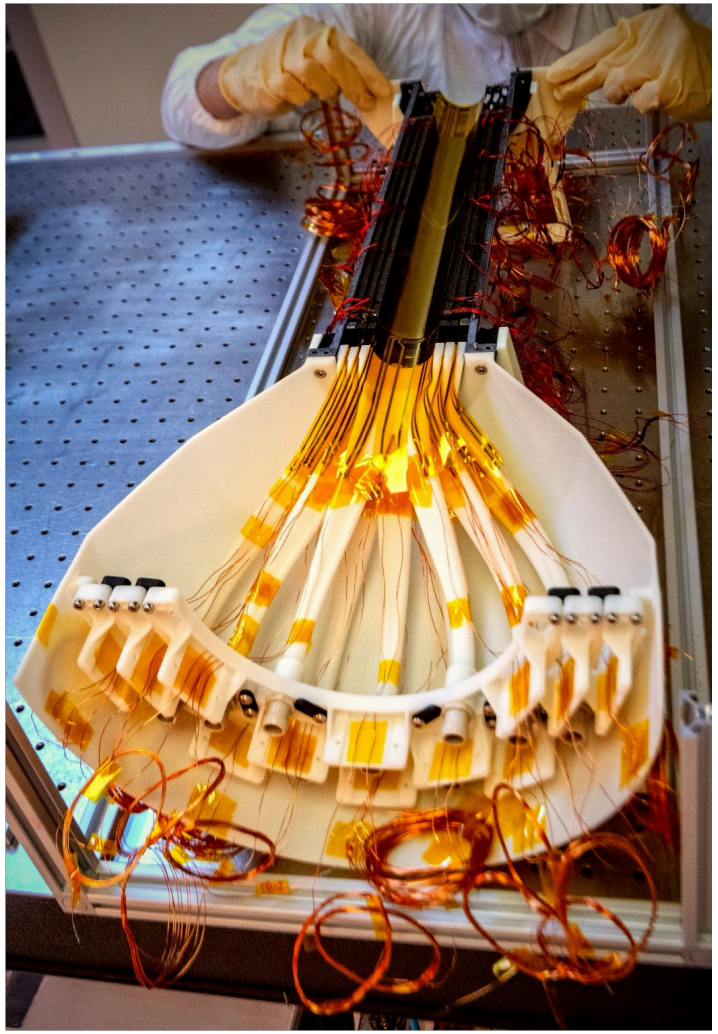
Progress on SVT IB prototyping

- 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

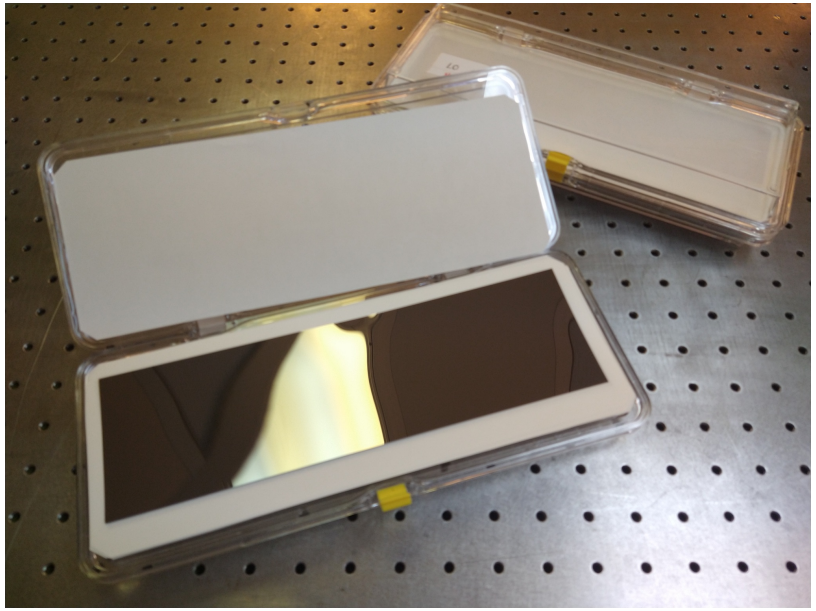


ITS3 wind tunnel @CERN

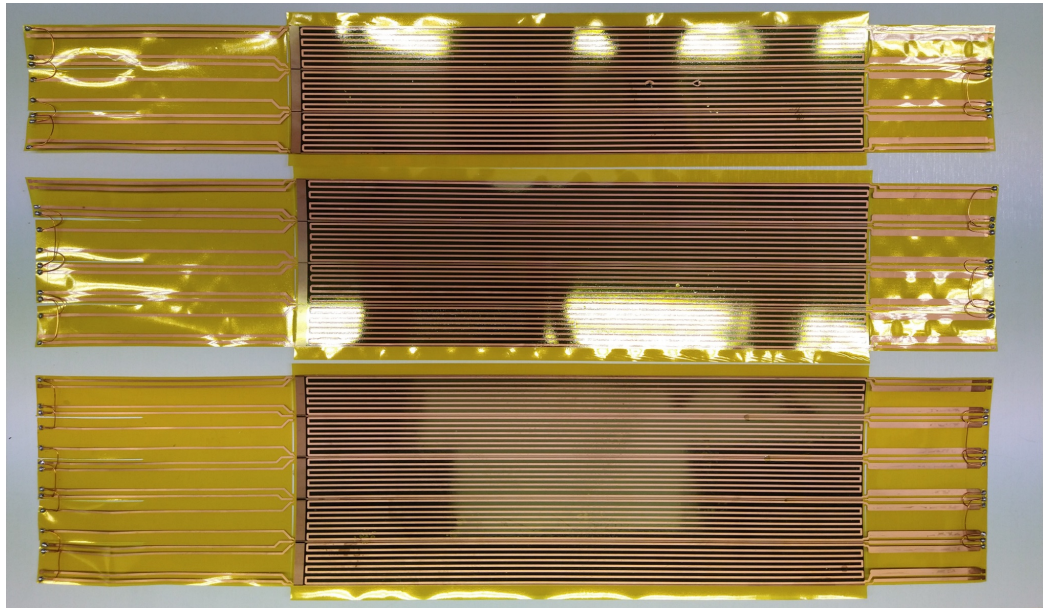

ITS3 BBM6 prototype

Progress on SVT IB prototyping

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

Progress on SVT IB prototyping

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/m^3) ● Longerons and half-ring on REC → Carbon RVC Duocel (density 45 kg/m^3, PPI 100) ● Carbon fleece: wet-laid non woven carbon fibre veil(8 g/cm^2) ● 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 → Purchasing from USA + Receiving samples from alternative producer <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)

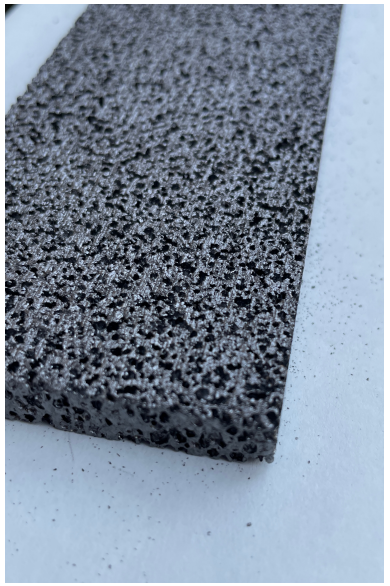
First samples of ERG Carbon RVC Duocel.
Thanks to Nikki!
Material sent to Genova for machining

Progress on SVT IB prototyping

New carbon foam from CFOAM, West Virginia (USA): HTC (stands for High Thermal Conductivity)

- easy to procure
- high thermal conductivity (to be verified, in touch with CNR and Engineering Department in Padova; a private company a true alternative)
- really dusty ☹ - need for a cleaning procedure, or painting → to be verified also under mechanical stress
- tested at CERN some time ago, will check the outcome…

		CFOAM HTC	ERG Duocel	Allcomp K9
Property	units	value	value	value
Nominal Density	g/cc	0.4 – 0.6	0.045	0.36-0.22
Compressive Strength	MPa	1.5 – 1.8	0.10-0.52	70-35 approx (resp. for the two densities)
Compressive Modulus	MPa	100 – 400		
Tensile Strength	MPa	0.9 – 1.0	0.17-0.34	
Shear Strength	MPa	1.0 – 4.0	30.3	
Coefficient of Thermal Expansion	ppm/°C	2	2.2	
Thermal Conductivity	W/m-K	106 at 0.47 g/cc	0.033-0.05	64
Maximum Operational Use Temperature	°C	400	315	
Electrical Resistivity	milliohm-cm	3 – 4	323	
Pore Volume	%	>70%	97%	
Mean Pore Size	Microns	1,200	254-5080 available	130 ppi, or 3907 micron mean size



Progress on SVT IB prototyping

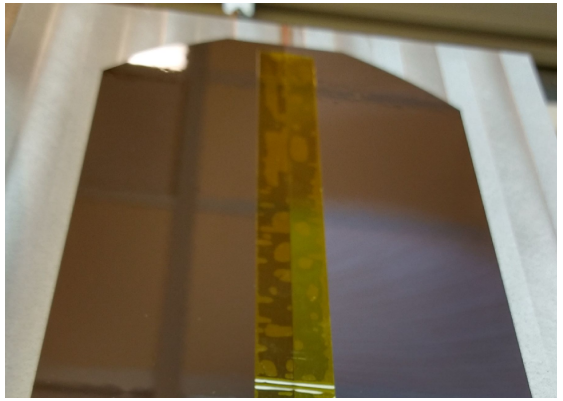
Sensors alignment and joining ☑

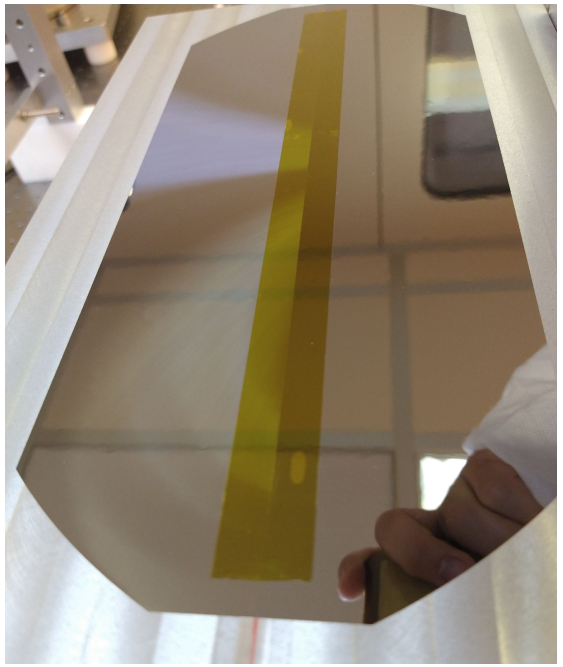
Parallelism has higher priority than pitch minimization since a large tilt can affect the success of the bondings to FPC.

#	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

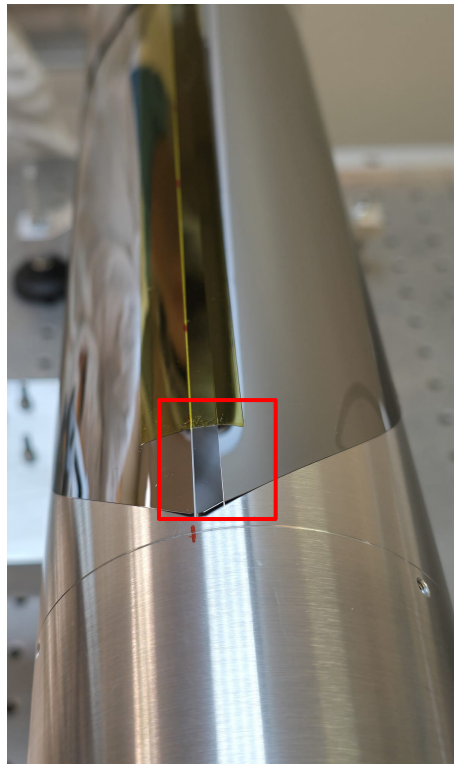




Negligible cuspids are observed after the bending

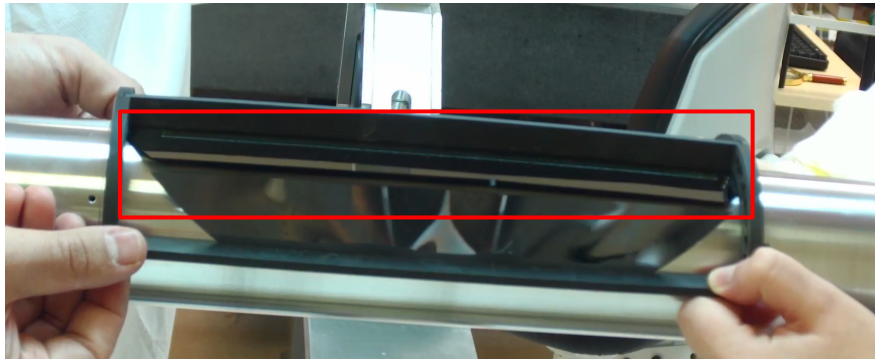
Progress on SVT IB prototyping

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 Silicon broken already in the transport box	NO Breakage started from already present chipping	–
$L0_{V4}$	03/04/25-10/04/25	YES	YES	YES
$L0_{V5}$	26/05/25-03/06/25	YES	YES	YES
$L0_{V7}$	08/10/25-27/10/25	YES Silicon chipping at one corner during removal from transport box → Fixed with tape, allow for bending	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
$L1_{V3}$	03/11/25-07/11/25	YES	YES	YES



Silicon breakage located under the tape, still allowed the bending

Final breakage during removal from mandrel



Progress on SVT IB prototyping

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$L0_{V2.2}$	16/01/25-31/01/25	YES	YES	YES
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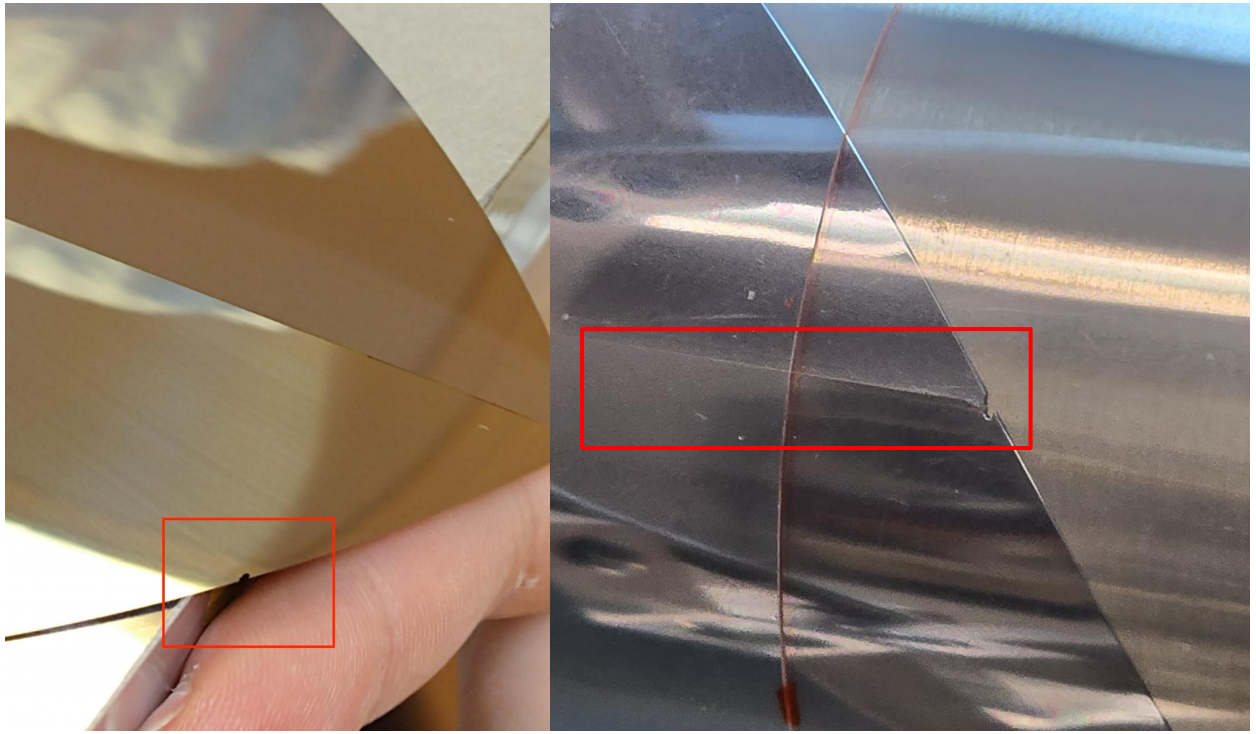
$L0_{V4}$	03/04/25-10/04/25	YES	YES	YES
$L0_{V5}$	26/05/25-03/06/25	YES	YES	YES
$L0_{V7}$	08/10/25-27/10/25	YES Silicon chipping at one corner during removal from transport box → Fixed with tape, allow for bending	YES	YES
$L1_{V1}$	28/04/25-06/05/25	YES	NO Operator error → Tools safety margins improved after failure	–
$L1_{V2}$	07/07/25-09/07/25	YES	YES	YES
$L1_{V3}$	03/11/25-07/11/25	YES	YES	YES

The edge defect caused the break during the bending



Progress on SVT IB prototyping

Layer	Dates	BENDING	GLUING	REMOVAL
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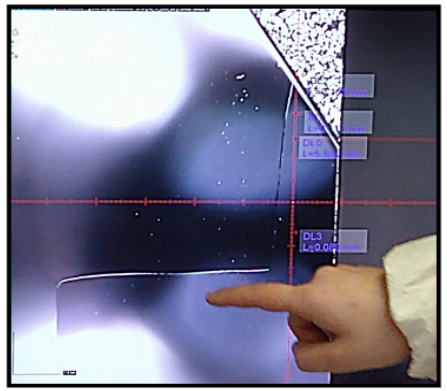
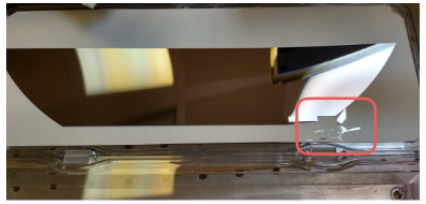
$L0_{V2.2}$	16/01/25-31/01/25	YES	YES	YES
$L0_{V3}$	24/03/25-28/03/25	YES Silicon broken already in the transport box	NO Breakage started from already present chipping	–
$L0_{V4}$	03/04/25-10/04/25	YES	YES	YES
$L0_{V5}$	26/05/25-03/06/25	YES	YES	YES
$L0_{V7}$	08/10/25-27/10/25	YES Silicon chipping at one corner during removal from transport box → Fixed with tape, allow for bending	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
$L1_{V3}$	03/11/25-07/11/25	YES	YES	YES

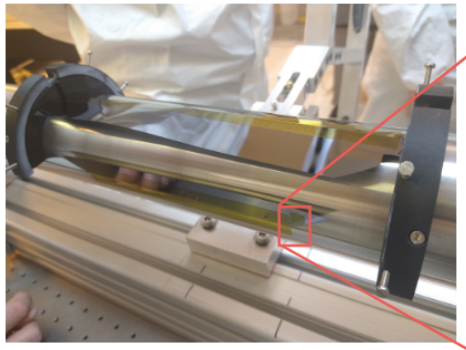


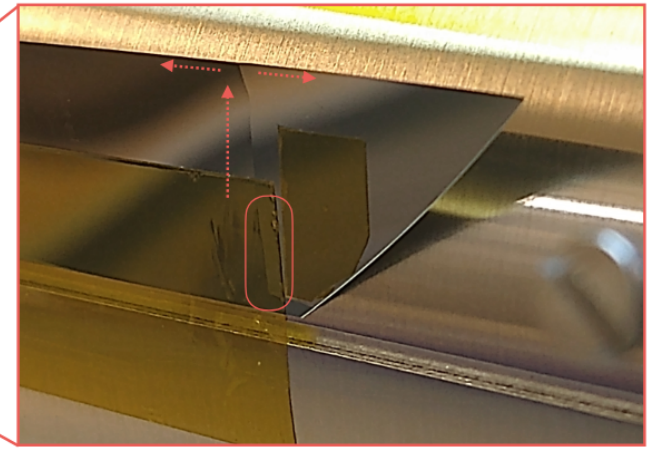
Crack stopped during bending procedures
using microscope (not easily visible by eye).



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

Progress on SVT IB prototyping

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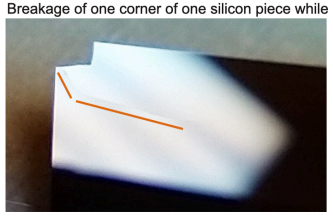
$L0_{V2.2}$	16/01/25-31/01/25	YES	YES	YES
$L0_{V3}$	24/03/25-28/03/25	YES Silicon broken already in the transport box	NO Breakage started from already present chipping	–
$L0_{V4}$	03/04/25-10/04/25	YES	YES	YES
$L0_{V5}$	26/05/25-03/06/25	YES	YES	YES
$L0_{V7}$	08/10/25-27/10/25	YES Silicon chipping at one corner during removal from transport box → Fixed with tape, allow for bending	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
$L1_{V3}$	03/11/25-07/11/25	YES	YES	YES

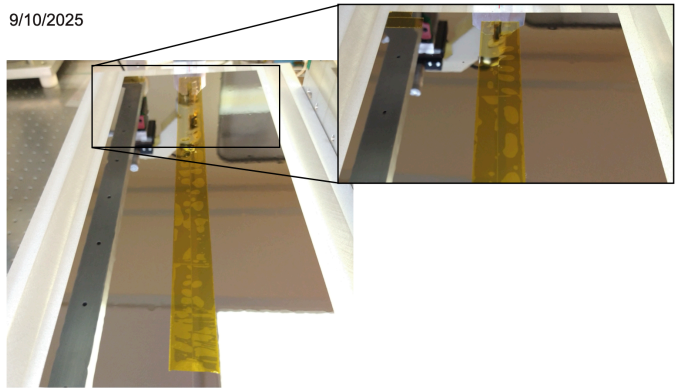
8/10/2025
Breakage of one corner of one silicon piece while picking from the box → Look for larger boxes



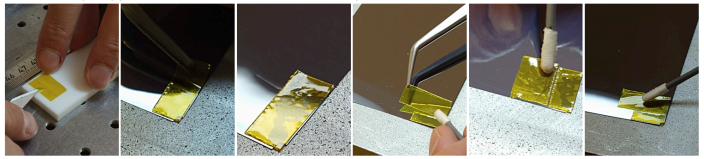
Silicon pieces temporary put aside and alignment/ joining completed with a third silicon pieces → Later decided to keep this double silicon pieces for the HBM2.

Next day, fixing broken piece and aligned/joined to the fourth silicon piece.

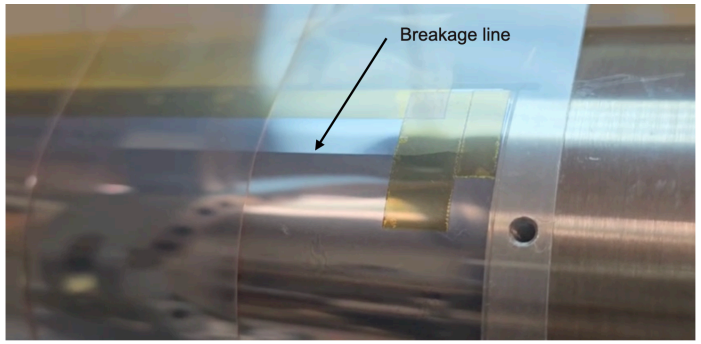
9/10/2025



9/10/2025
Adhesive tape application on both sides of the silicon piece to cover and "contain" the crack.



10/10/2025

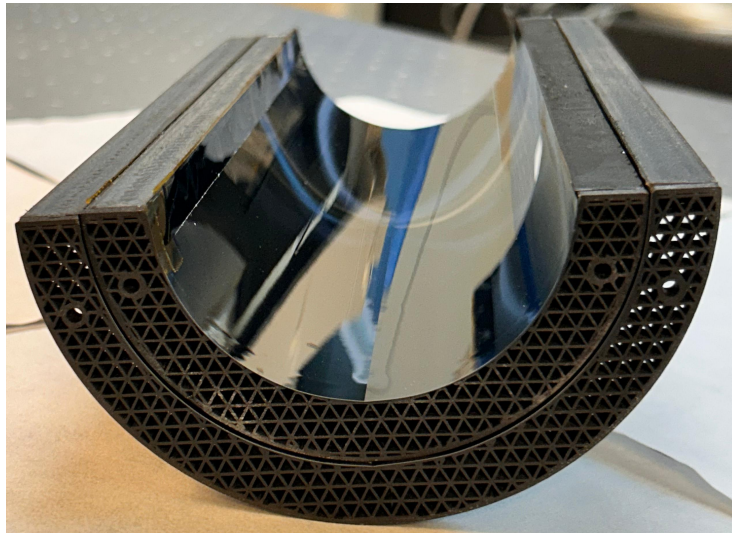
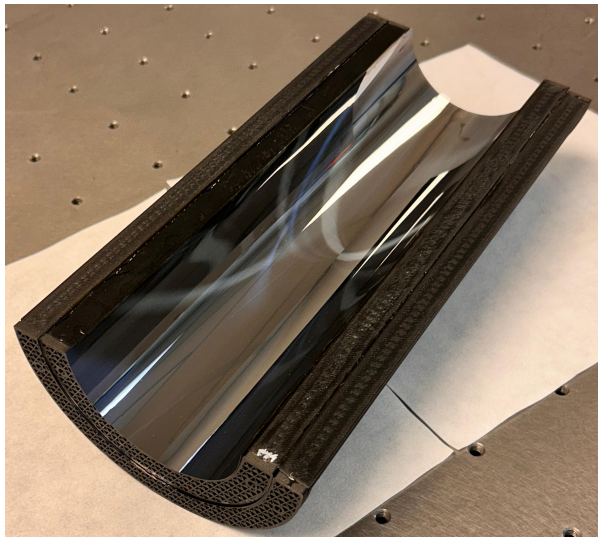
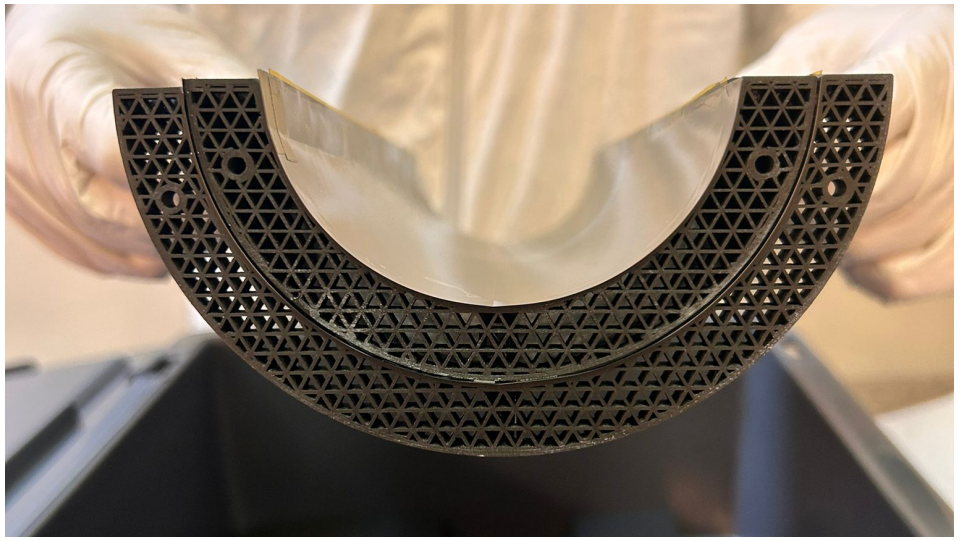
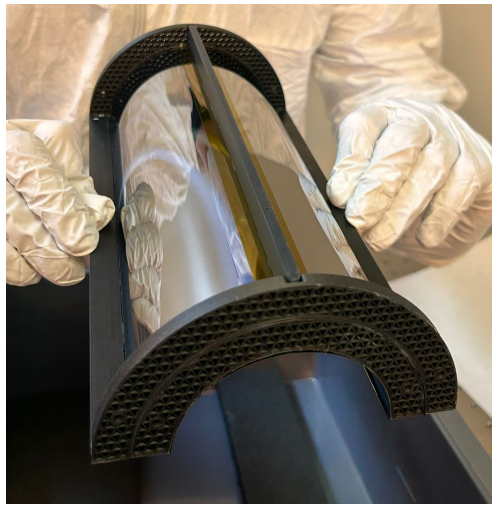


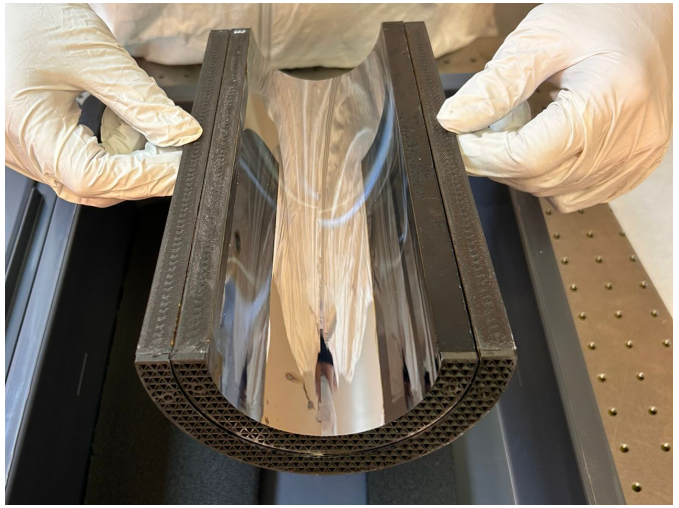
27/10/2025

L0: try to recover the broken silicon couple to complete the HBM1 assembly (without using the limited available spares).
L1: use the two available full size silicon pieces.

Progress on SVT IB prototyping

IB-HB01-M1

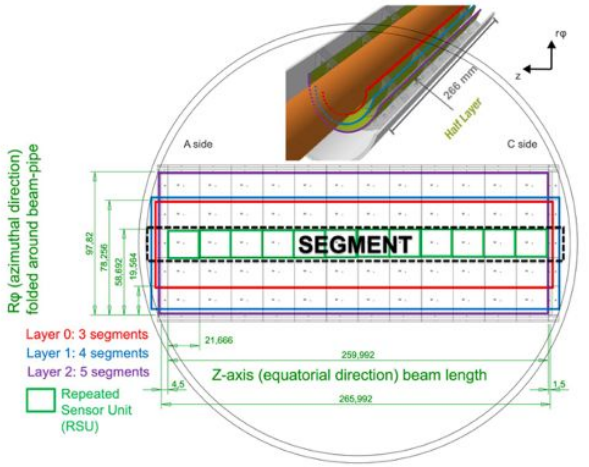


Progress on SVT IB prototyping

IB prototyping activity

Prototyping in 2026 with ER2 (pad) wafer:

- what is going to be available for SVT:
  - ✓ **24 ER2 pad wafers** (w/ pads w/o sensor)
  - ✓ **12 ER2 wafers** (w/ pads & sensor)
- IB HB prototype with ER2 pad wafers:
  - ✓ full proto (including FPCs) suited for mechanical tests
  - ✓ min required pieces (not considering failures/breakings):
    - 2 x 3 segments + 2 x 4 segments + 4 x 5 segments = **8 pad wafers**
    - ideally 2 HBs (mechanical matching tests) → 2 x 8 = **16 pad wafers** with given segments distribution
- IB HB prototype with ER2 wafers:
  - ✓ full proto (including FPCs) suited for mechanical/cooling/electrical post-assembly tests
  - ✓ suitable also for powering/DAQ/DCS development on close-to-final setup system
  - ✓ min required pieces (not considering failures/breakings and sensor yield): **8 wafers**



Domenico Elia SVT IB status and plans / Villa Mondragone, 21.1.2025 9