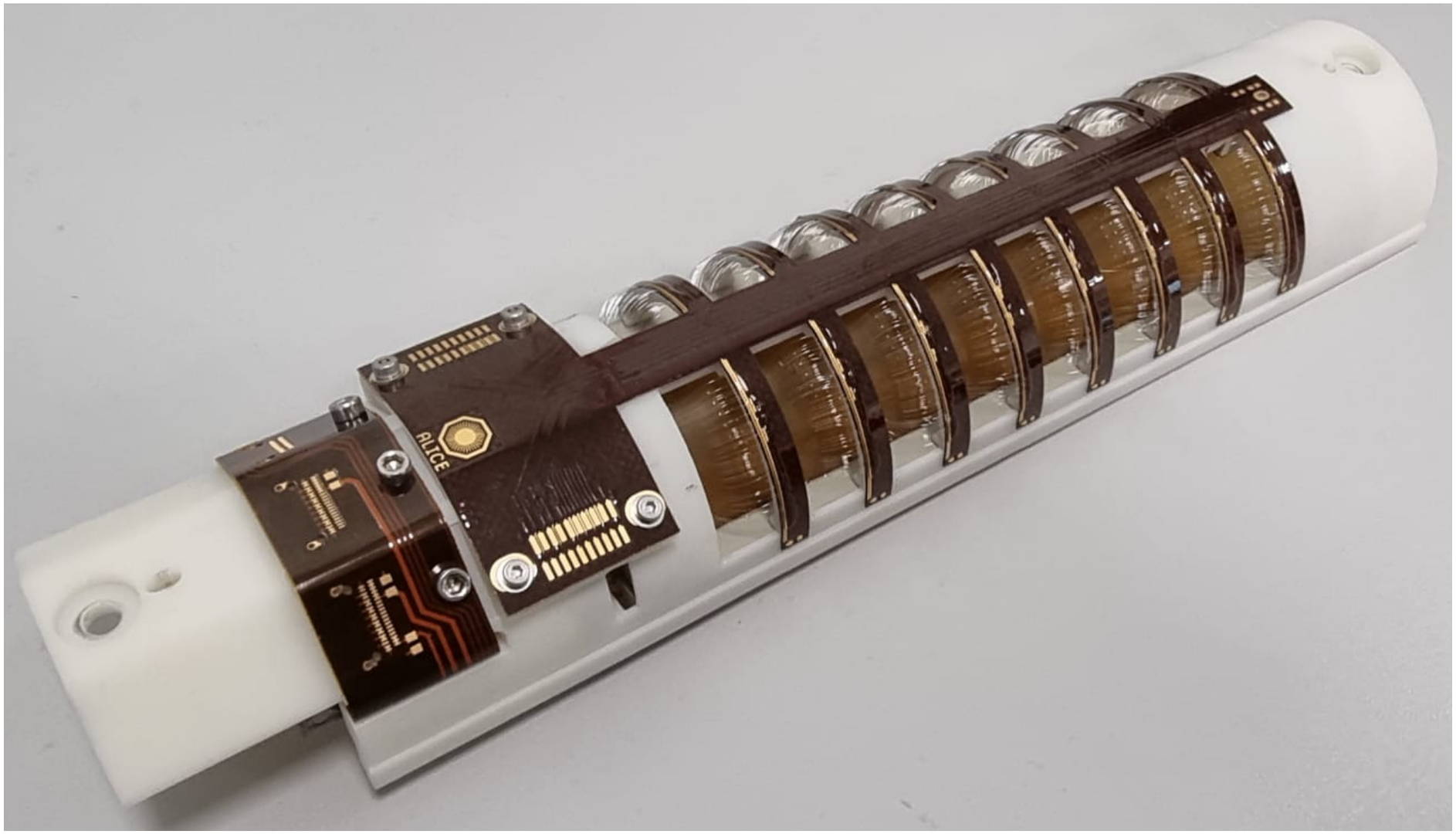
R&D activities on bending and interconnection with MAPS

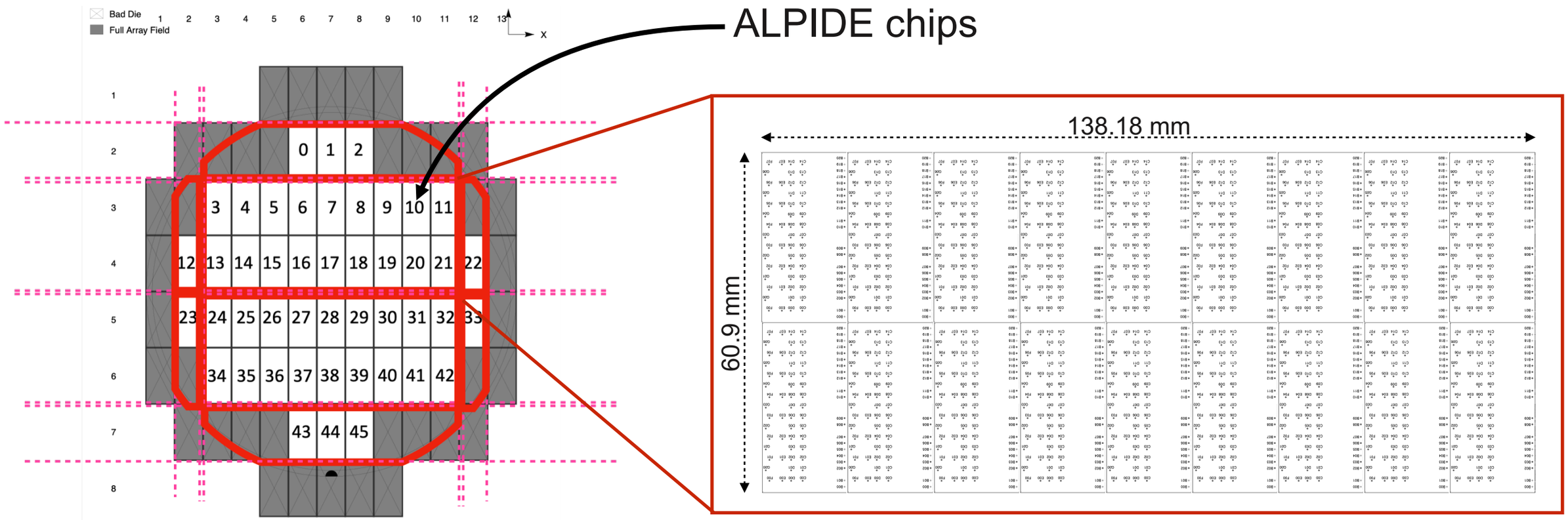


- Super-ALPIDE project
- FPC for final detector
- MLR1 bending tool
- MAPS foil

Project motivations and goals

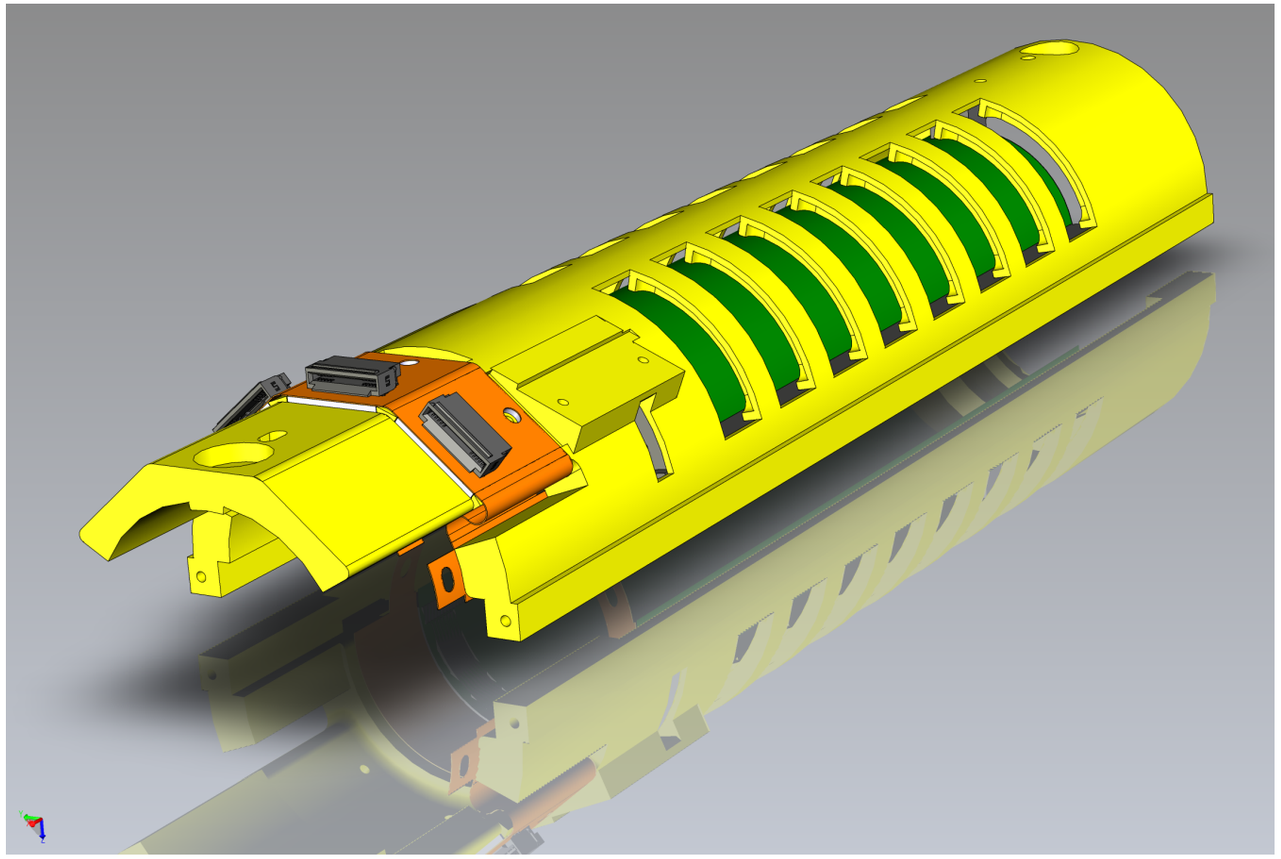
Proof of concept for large dimension bent silicon sensor detector

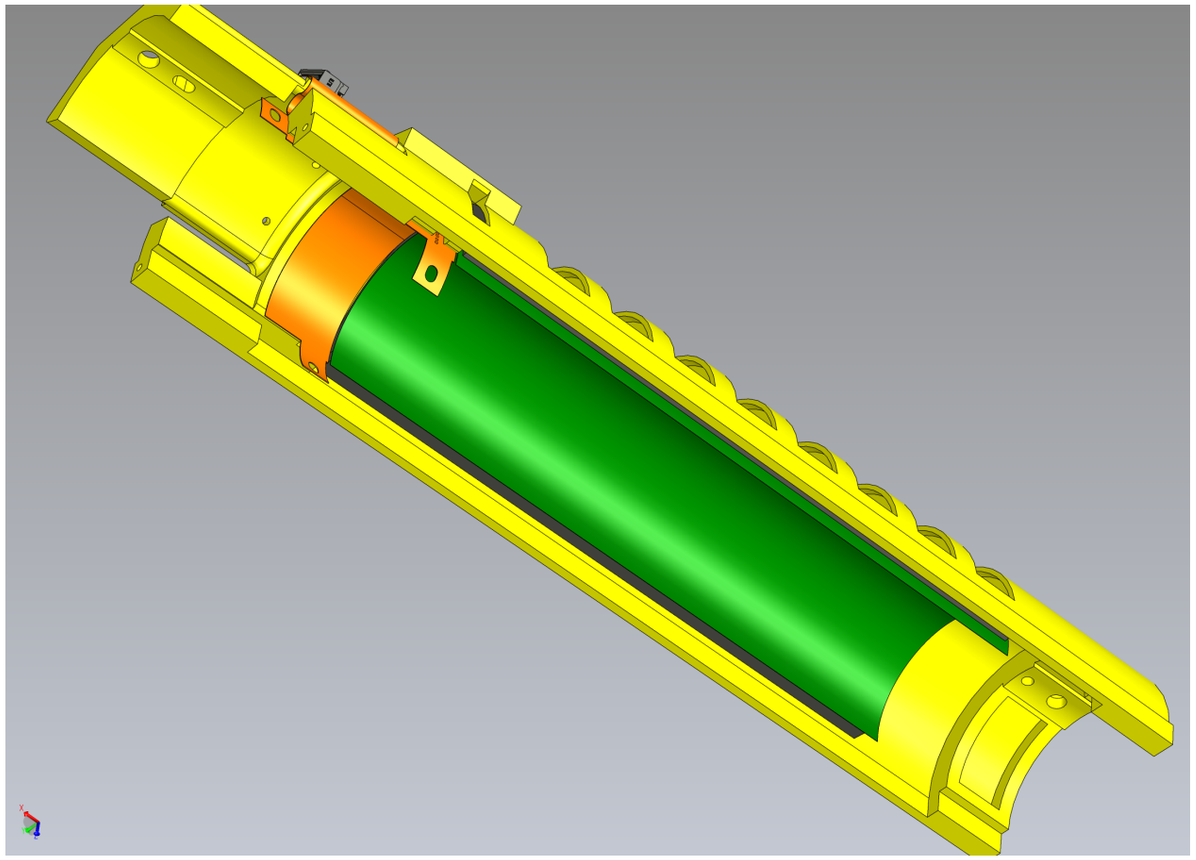
- while waiting for large-dimension ITS3 sensors
- learn how to handle large dimension chips
- explore wire-bonding interconnection to flex (for data/control/powering) and encapsulation
- explore edge-flex solutions towards final detector

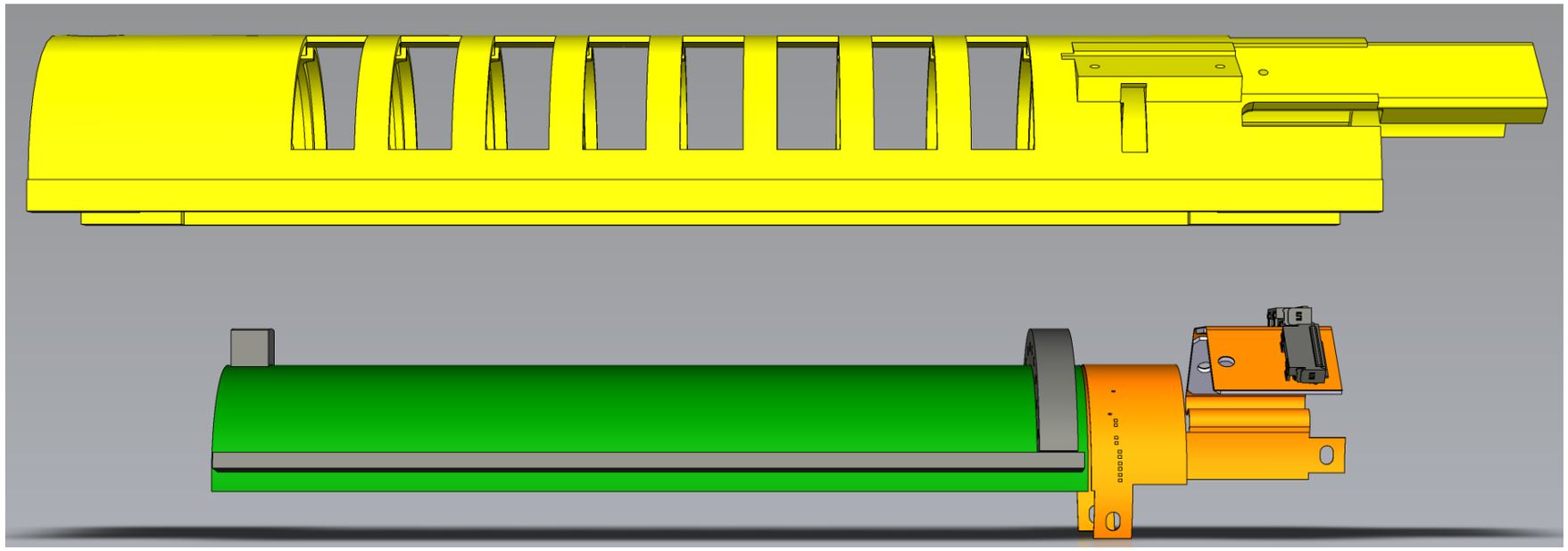


18 ALPIDE chips, as in 2 Inner Barrel ITS2 staves, but different chip orientation

Project motivations and goals







Five main components
- super-ALPIDE
- support structures
- exoskeleton
- edge-FPC
- exo-FPC (not shown)

Assembly procedure

(A) Silicon (chip) bending
(B) Interconnection to the edge-FPC
(C) Support structures alignment/gluing
(D) Exoskeleton and exo-FPC positioning/gluing/interconnection

- **Super-ALPIDE project**
- FPC for final detector
- MLR1 bending tool
- MAPS foil

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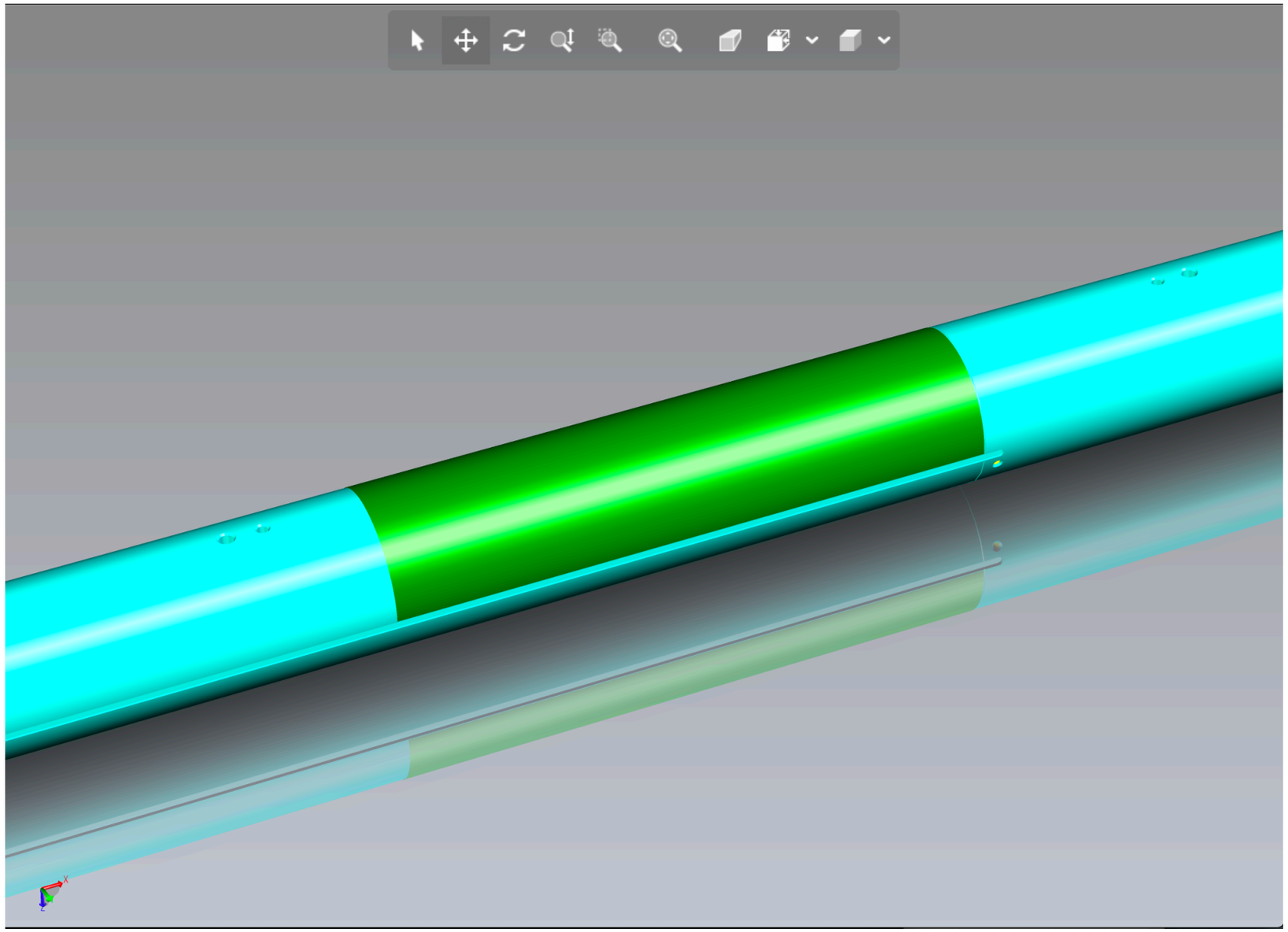
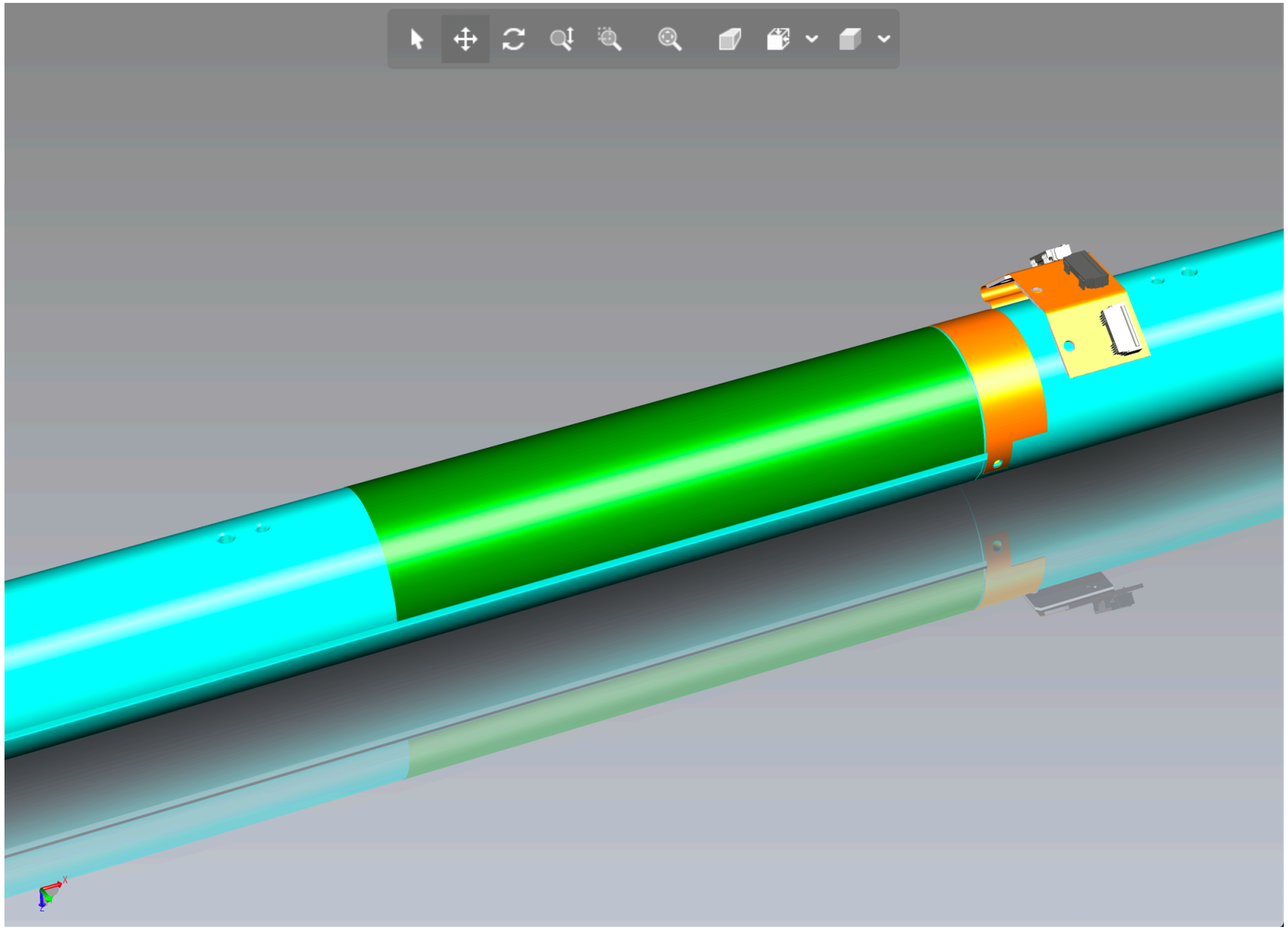


- Same tools and procedure developed for final detector assembly

Assembly procedure

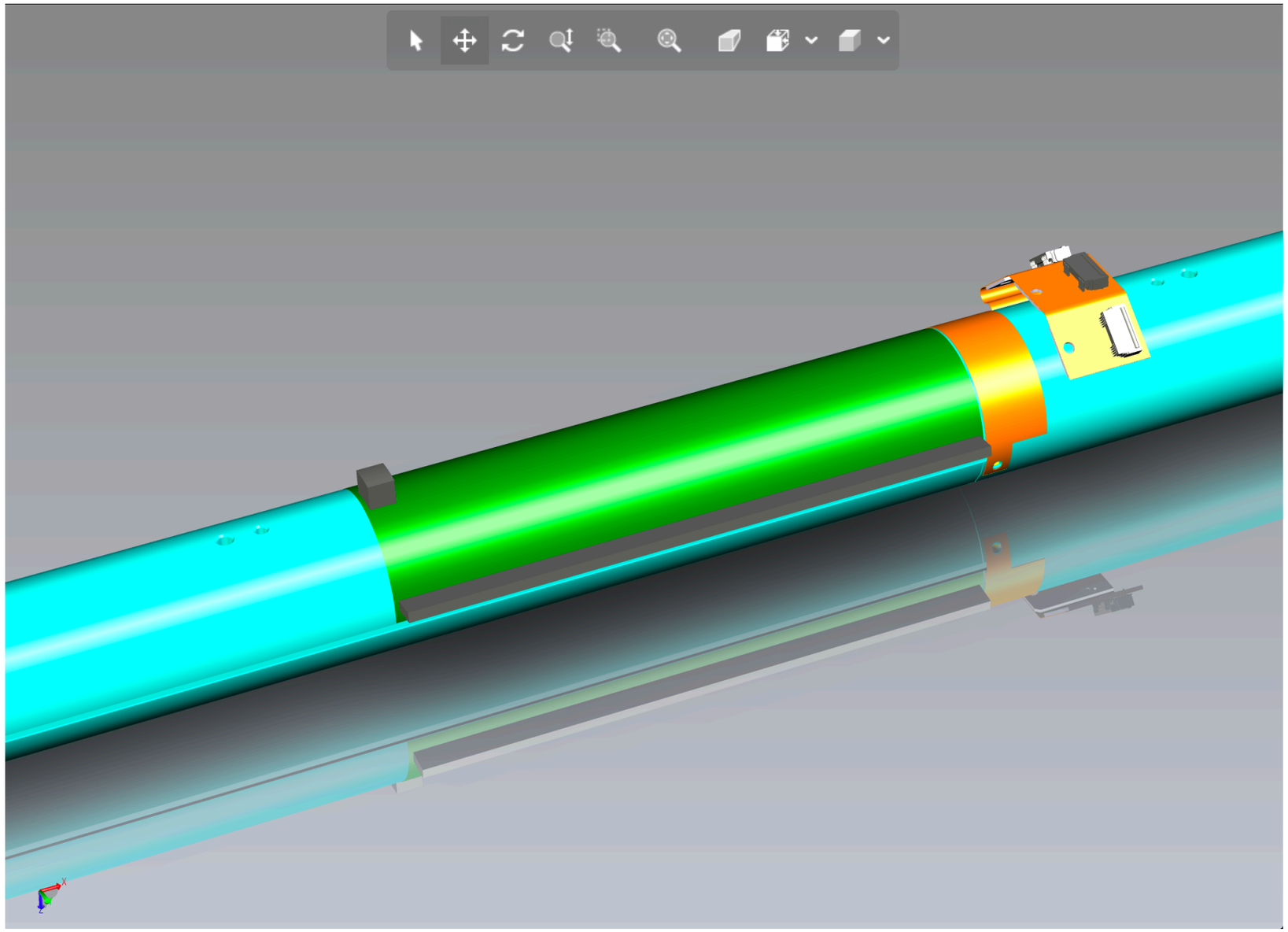
(A) Silicon (chip) bending
(B) Interconnection to the edge-FPC
(C) Support structures alignment/gluing
(D) Exoskeleton and exo-FPC positioning/gluing/interconnection



- Very first experience for the bent flex to power/control/stream the sensors
- Same connectors as ITS2-IB
- Connected to the external most two sensors

Assembly procedure

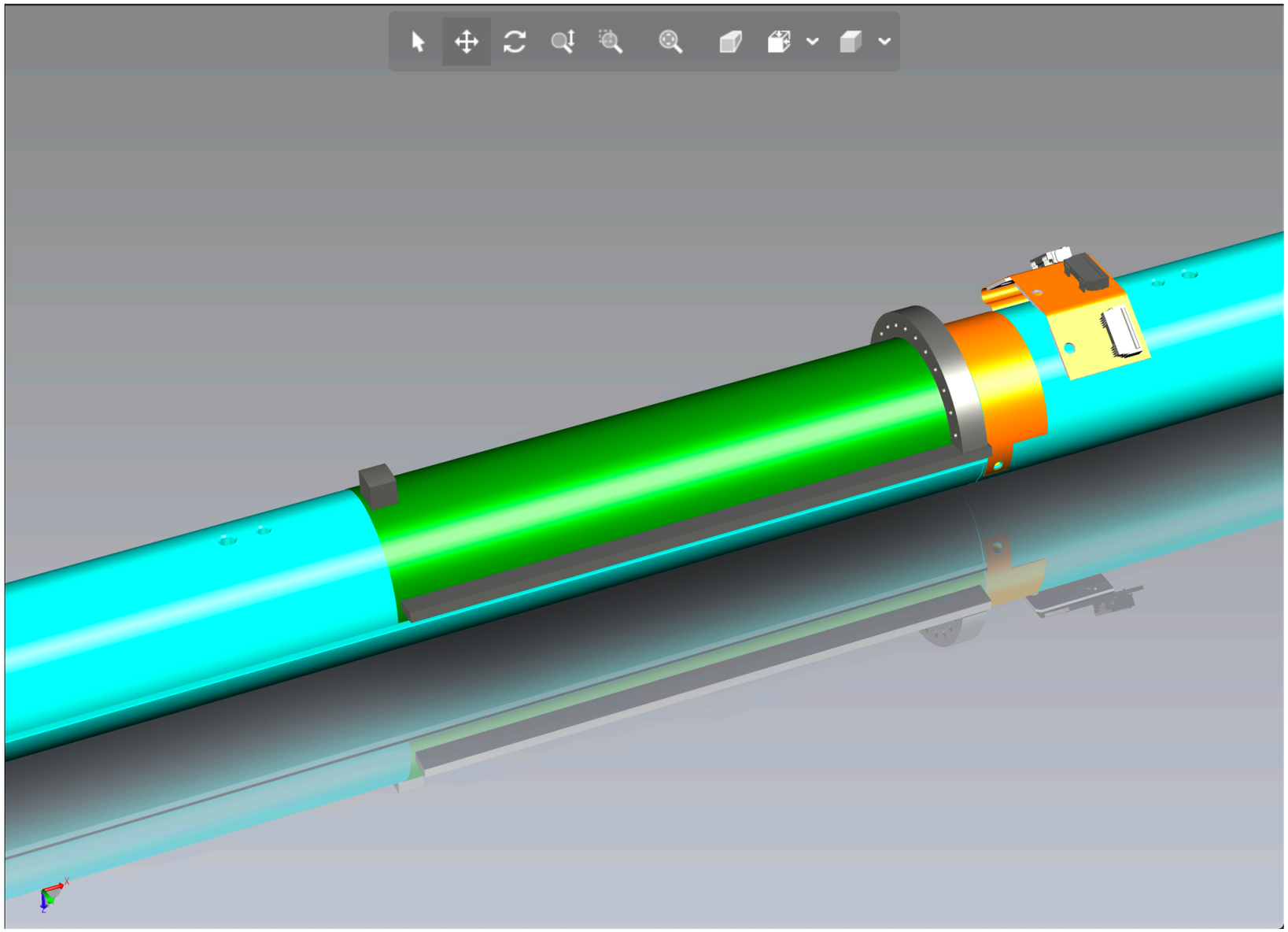
(A) Silicon (chip) bending
(B) Interconnection to the edge-FPC
(C) Support structures alignment/gluing
(D) Exoskeleton and exo-FPC positioning/gluing/interconnection



- Same shape, dimensions and material (carbon foam) of the final detector (L0)
- Same alignment/gluing tools

Assembly procedure

(A) Silicon (chip) bending
(B) Interconnection to the edge-FPC
(C) Support structures alignment/gluing
(D) Exoskeleton and exo-FPC positioning/gluing/interconnection



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Assembly procedure

(A) Silicon (chip) bending
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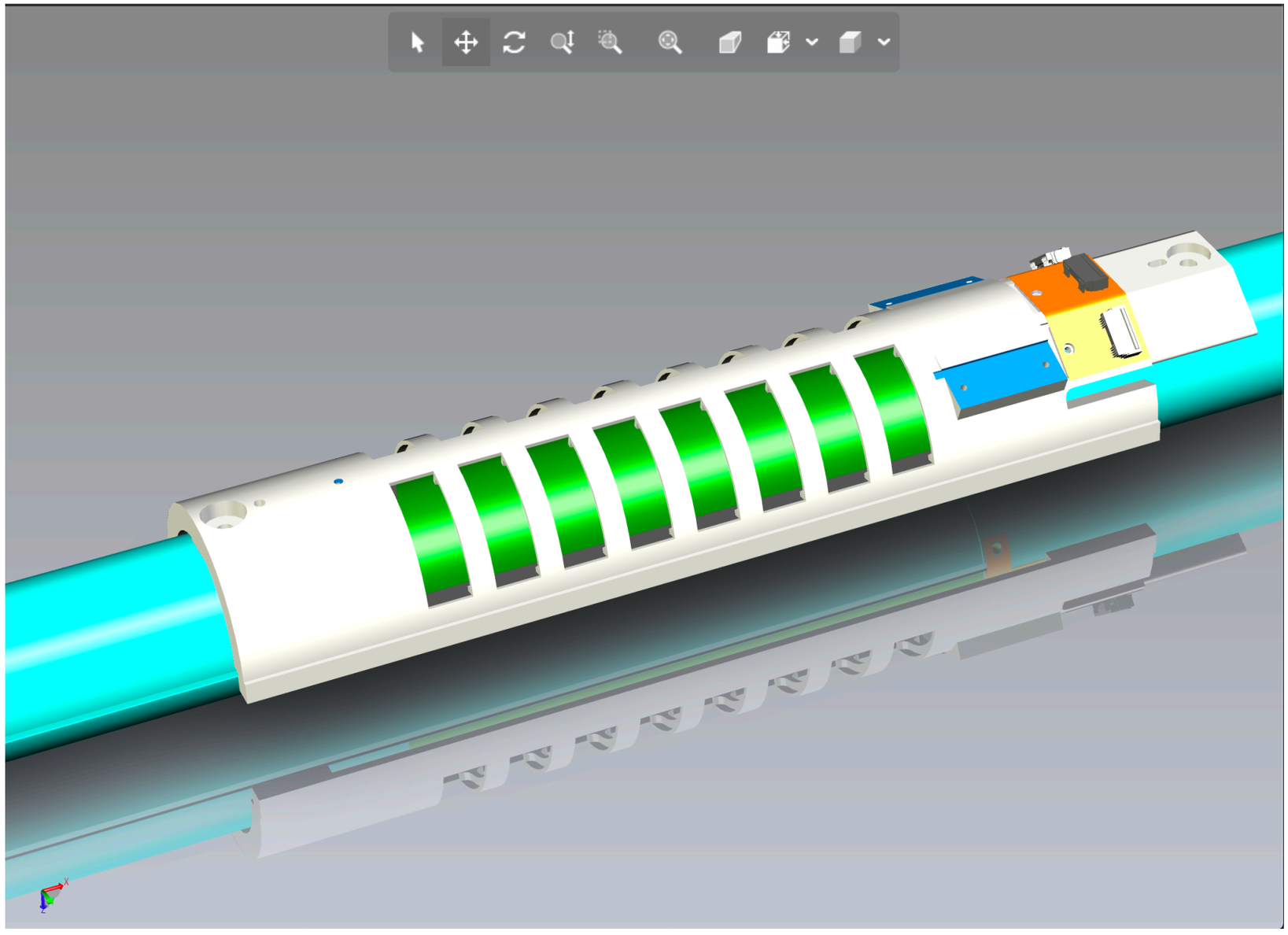
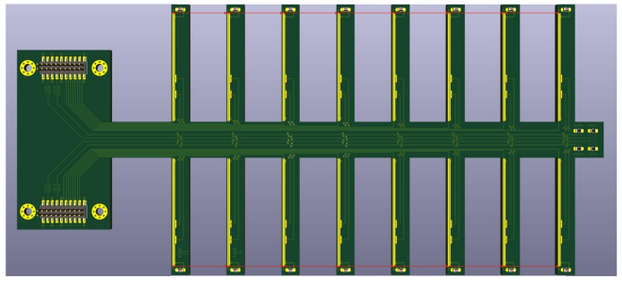


- Needed to access the remaining chips in the super-ALPIDE matrix
- 3D-printed (1 mm thick)
- 7.5 mm distance between sensor pads and exo-FPC pads
- Wire-bonding through windows
- NOT foreseen in the final detector



Assembly procedure

(A) Silicon (chip) bending
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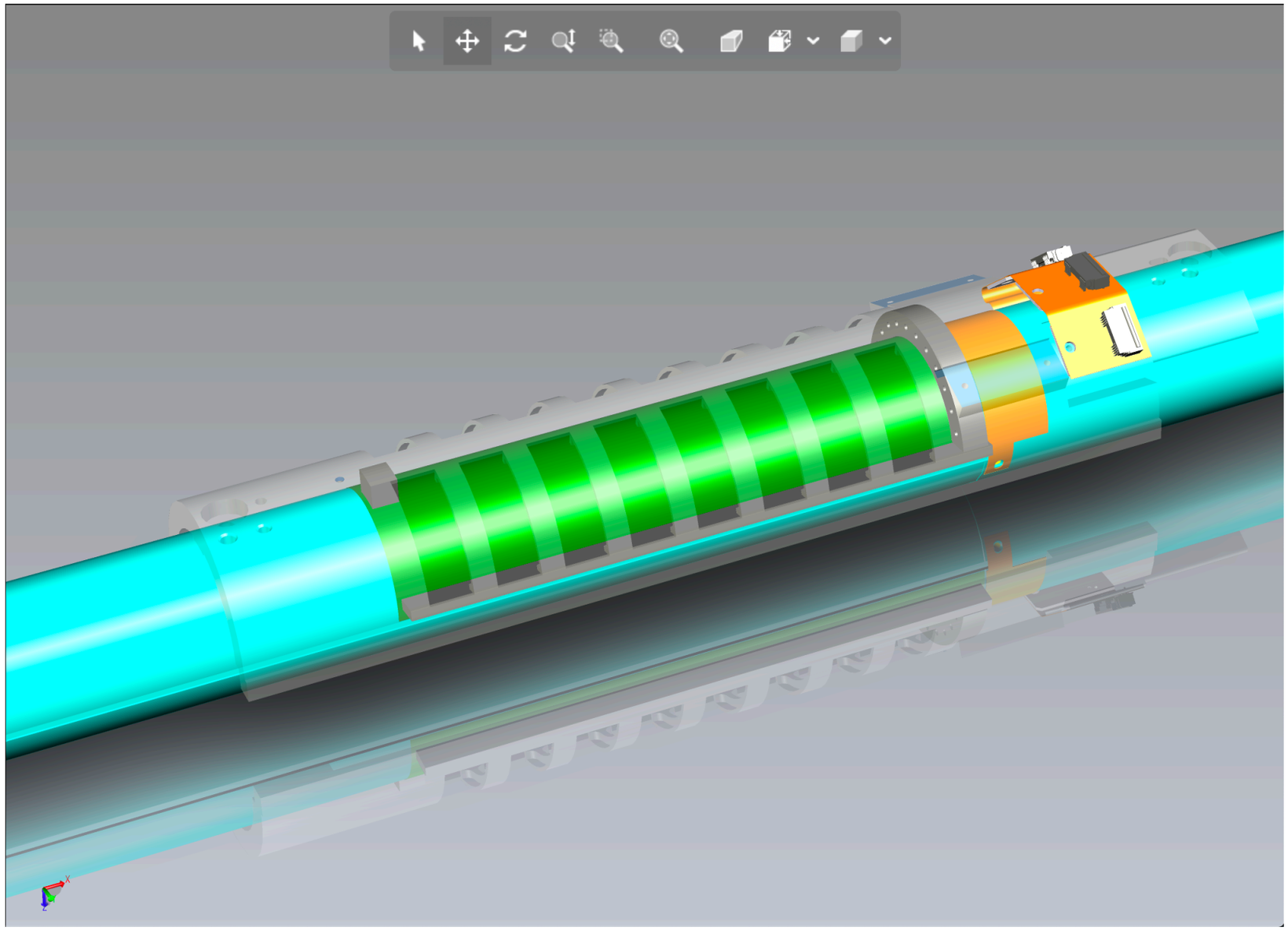

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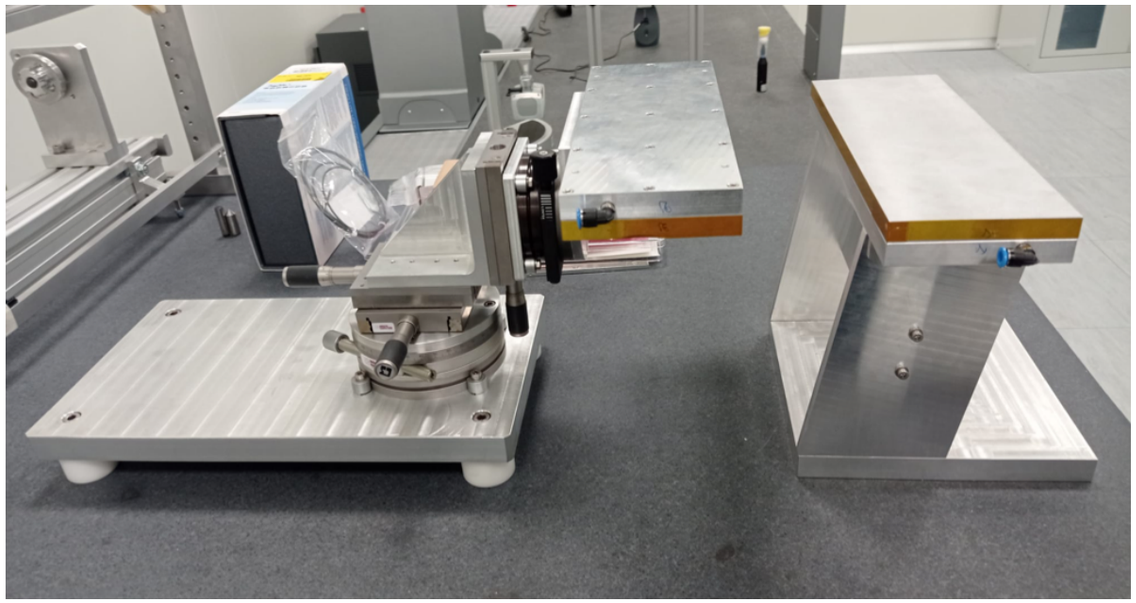
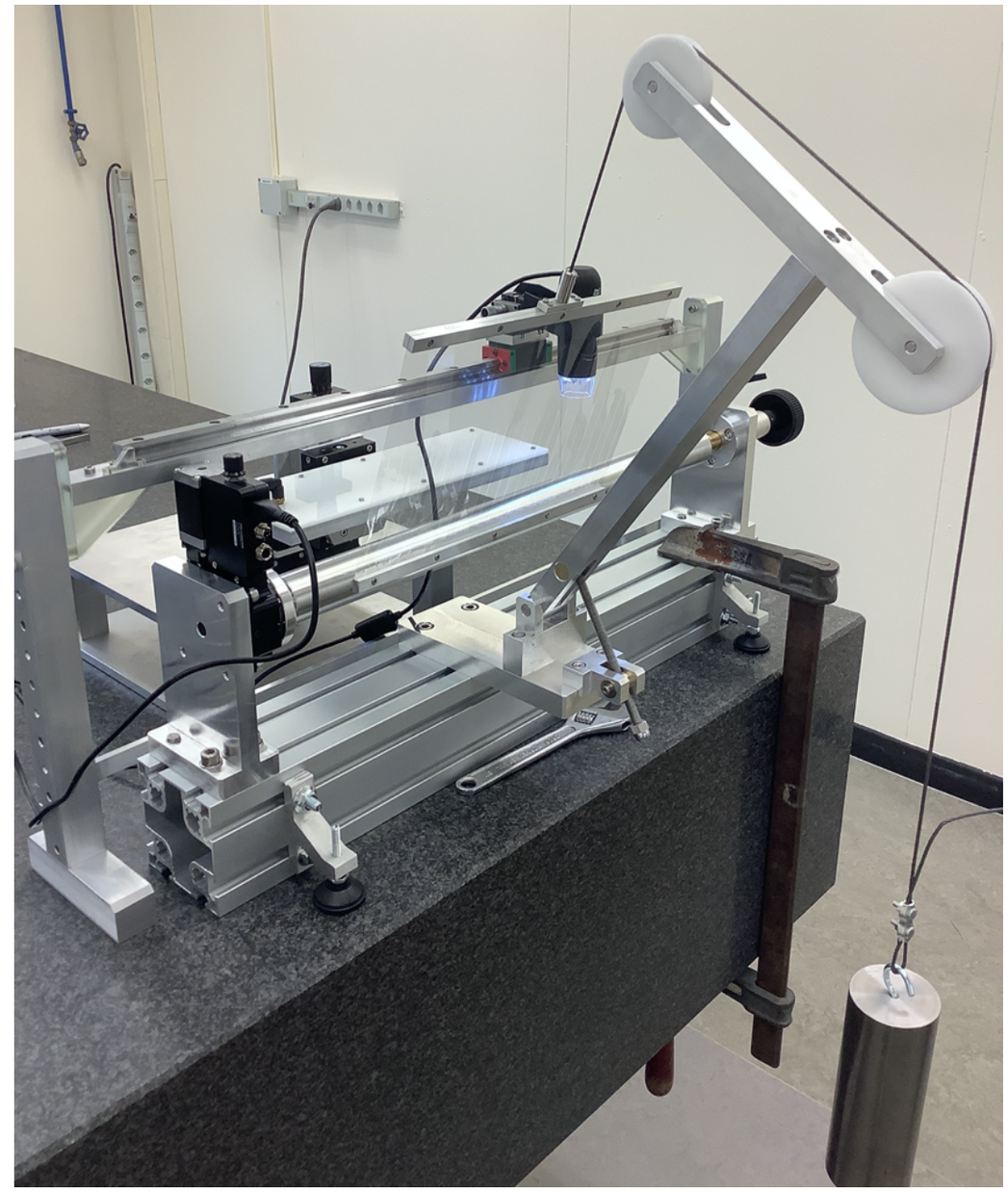
Assembly procedure

(A) Silicon (chip) bending procedure and tools



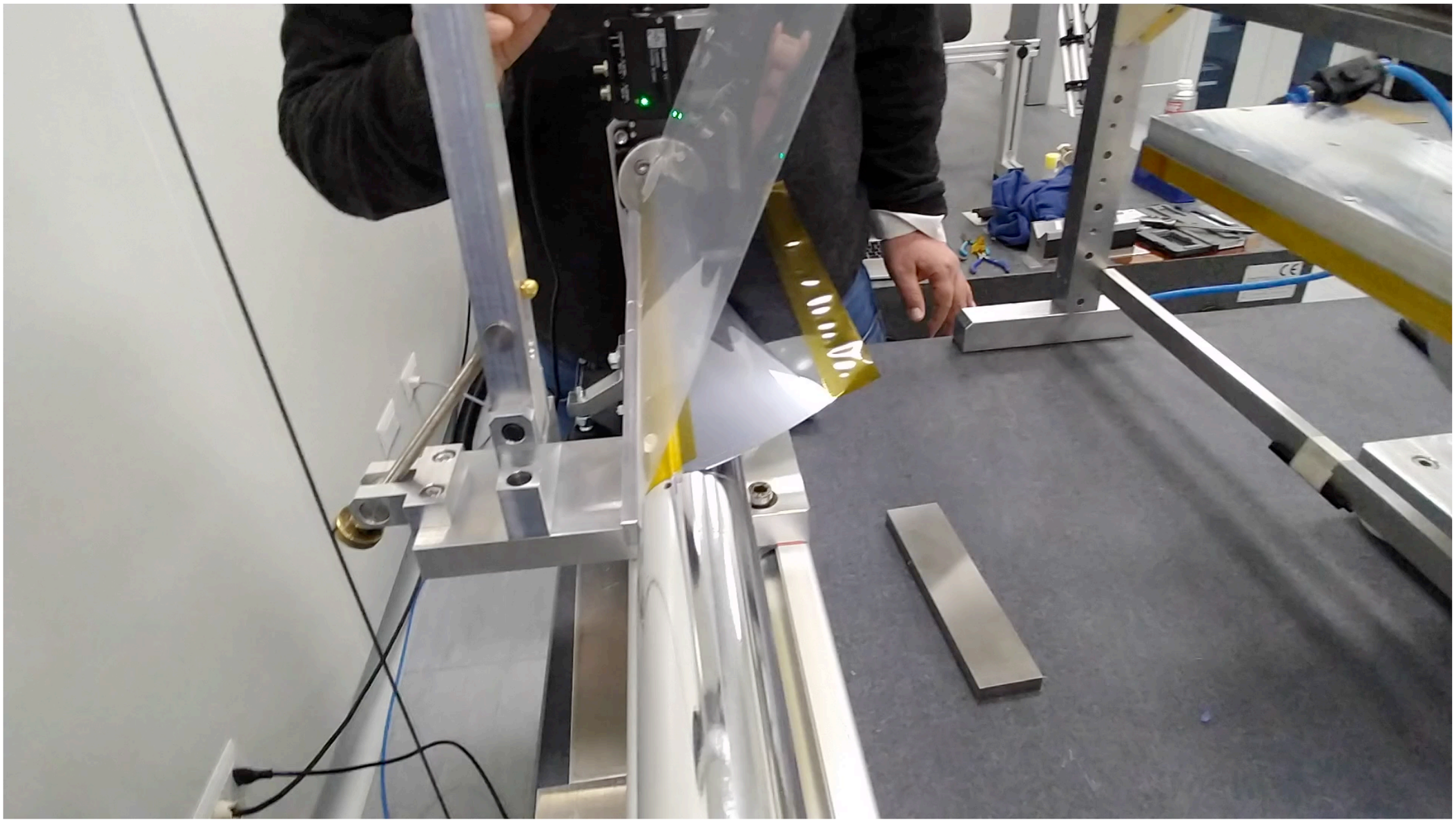
Vacuum tools to handle and align large-size silicon piece



Bending tool equipped with: cylindrical mandrel, rotary motor, arm with weight to tension mylar foil, camera for alignment

Assembly procedure

(A) Silicon (chip) bending procedure and tools



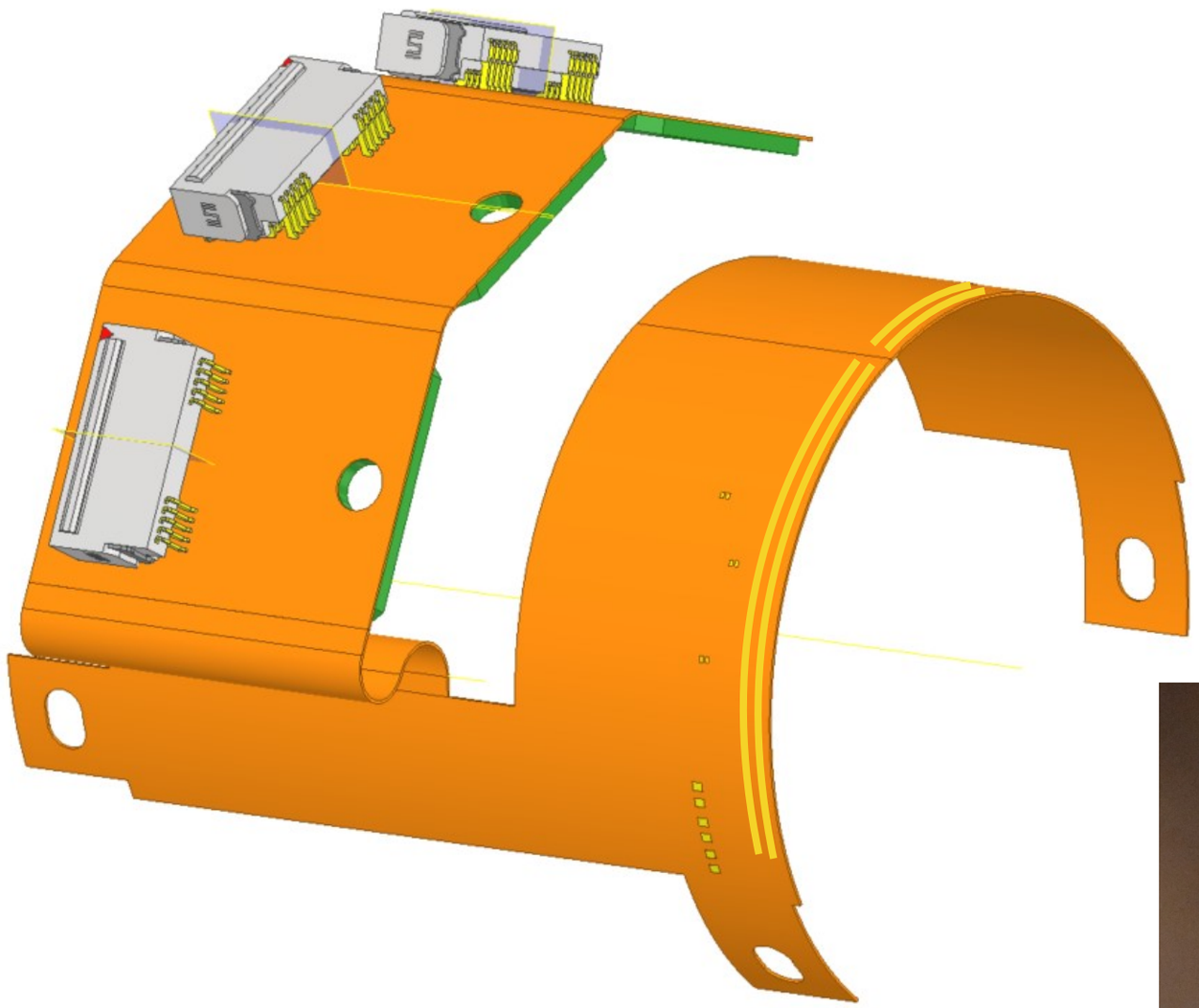
Assembly procedure

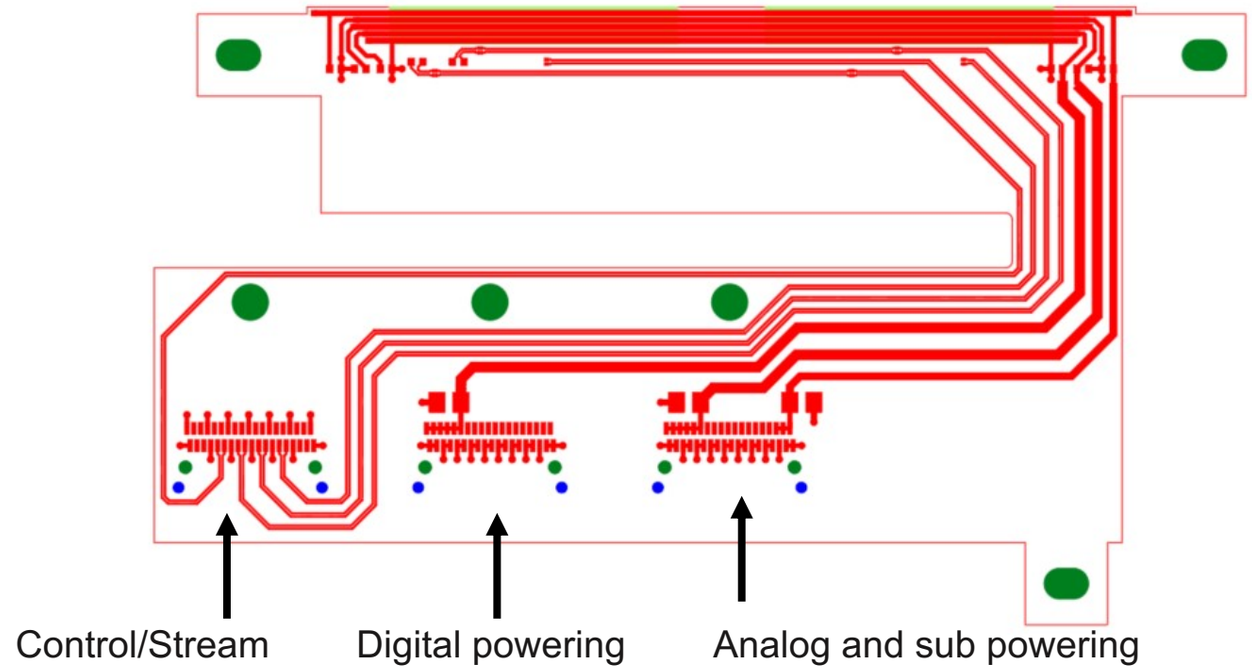
(A) Silicon (chip) bending procedure and tools

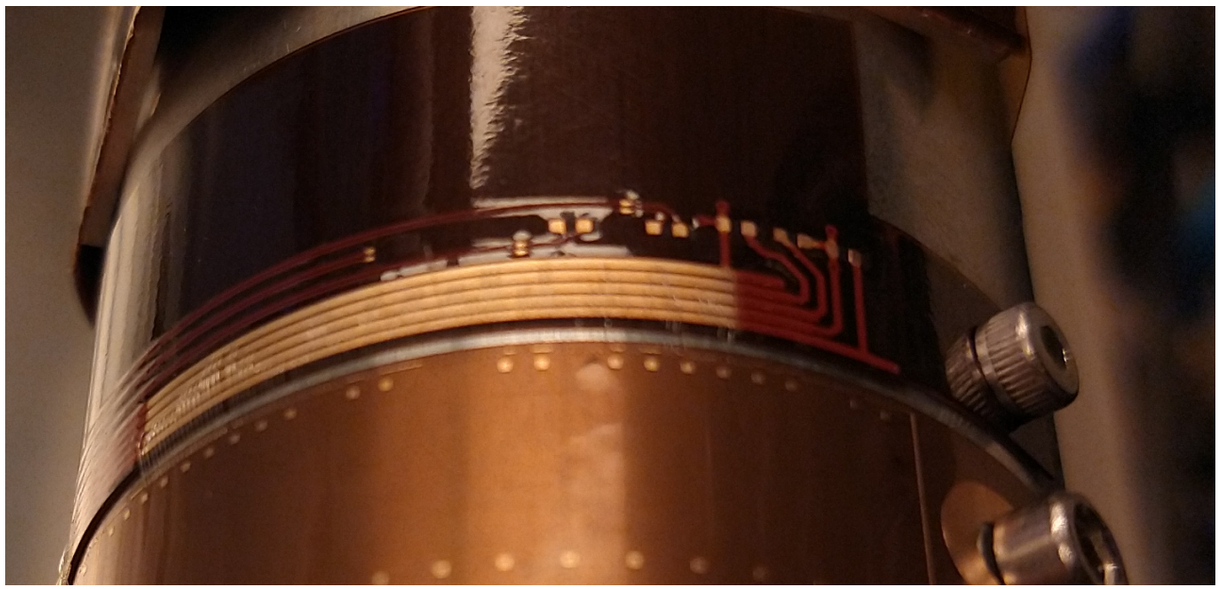
Bent silicon piece kept in position with Kapton adhesive tape

Assembly procedure

(B) Interconnection to the edge-FPC

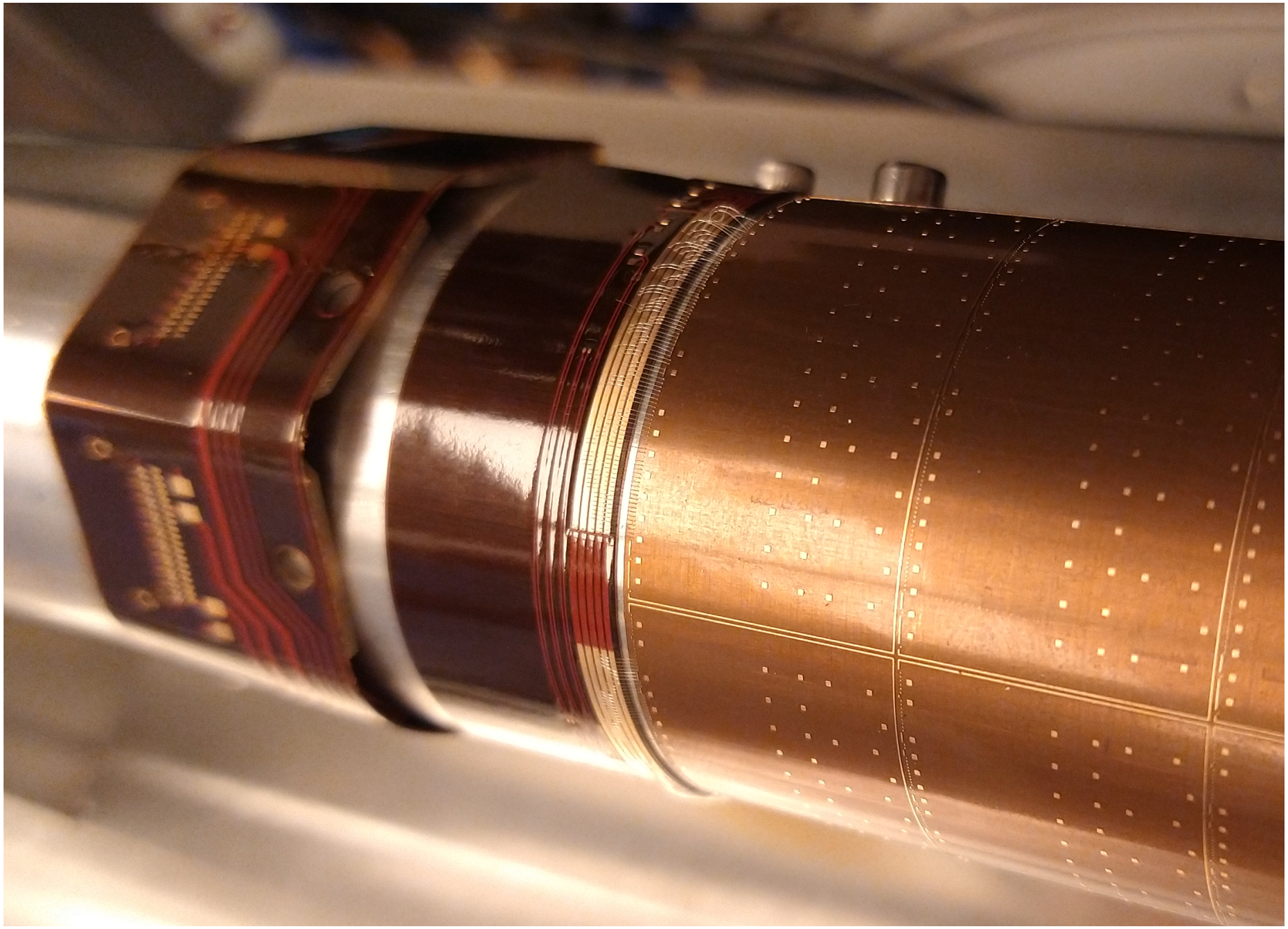


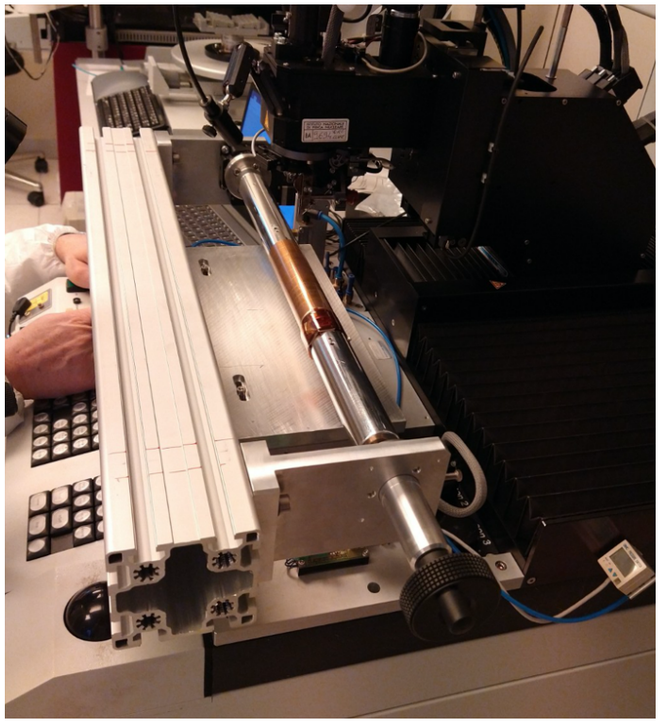




Assembly procedure

(B) Interconnection to the edge-FPC

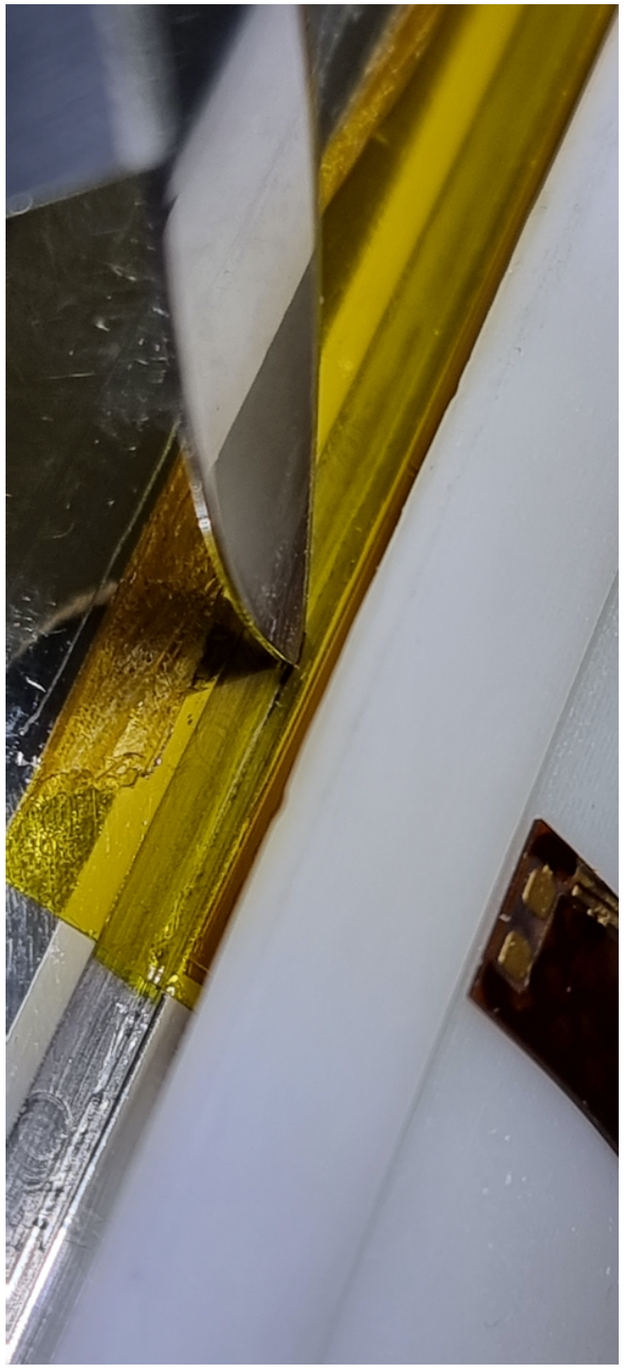




Assembly procedure

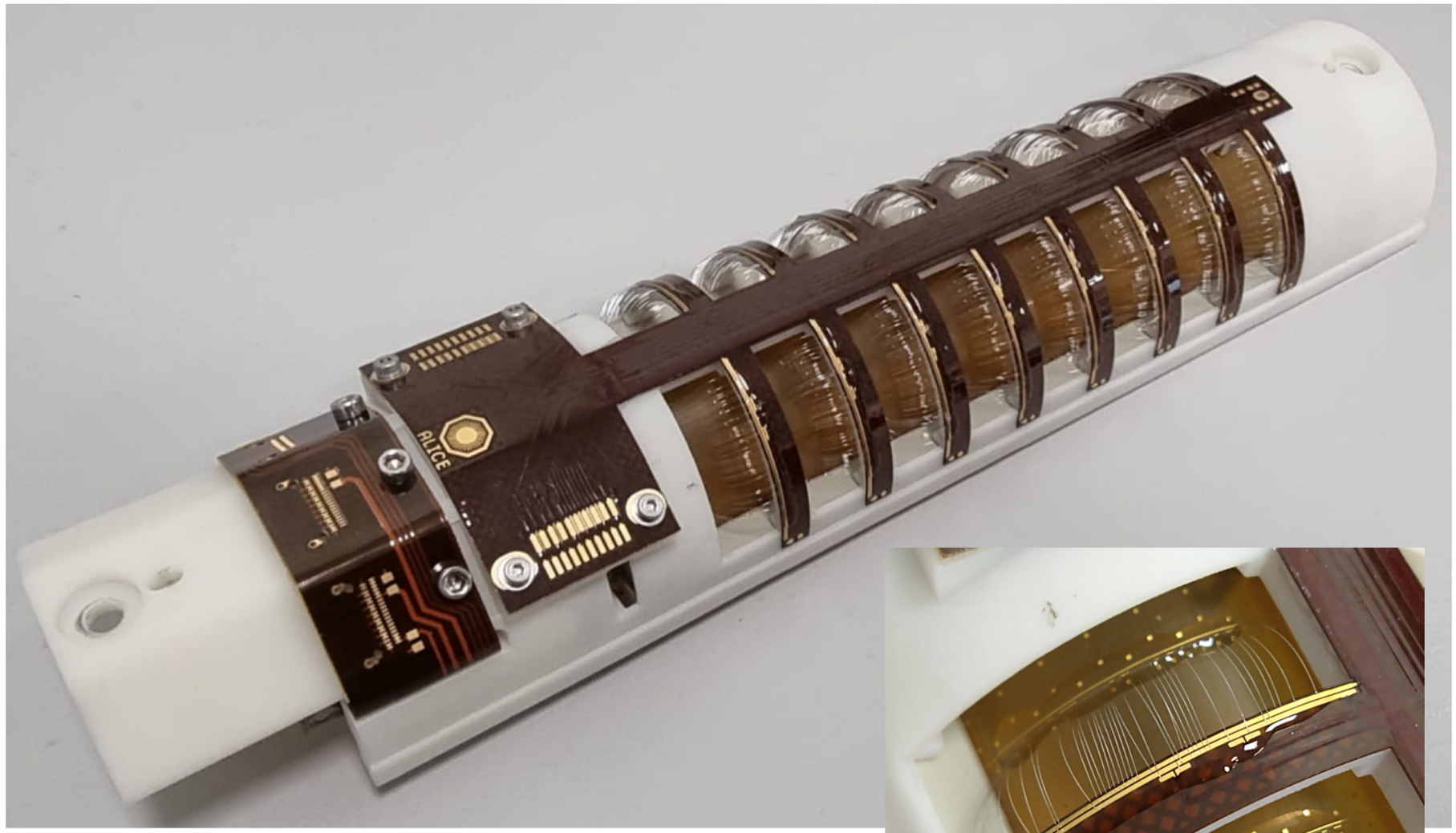
Adhesive tape cut tool

Precision and controlled cut close to the edge of the silicon

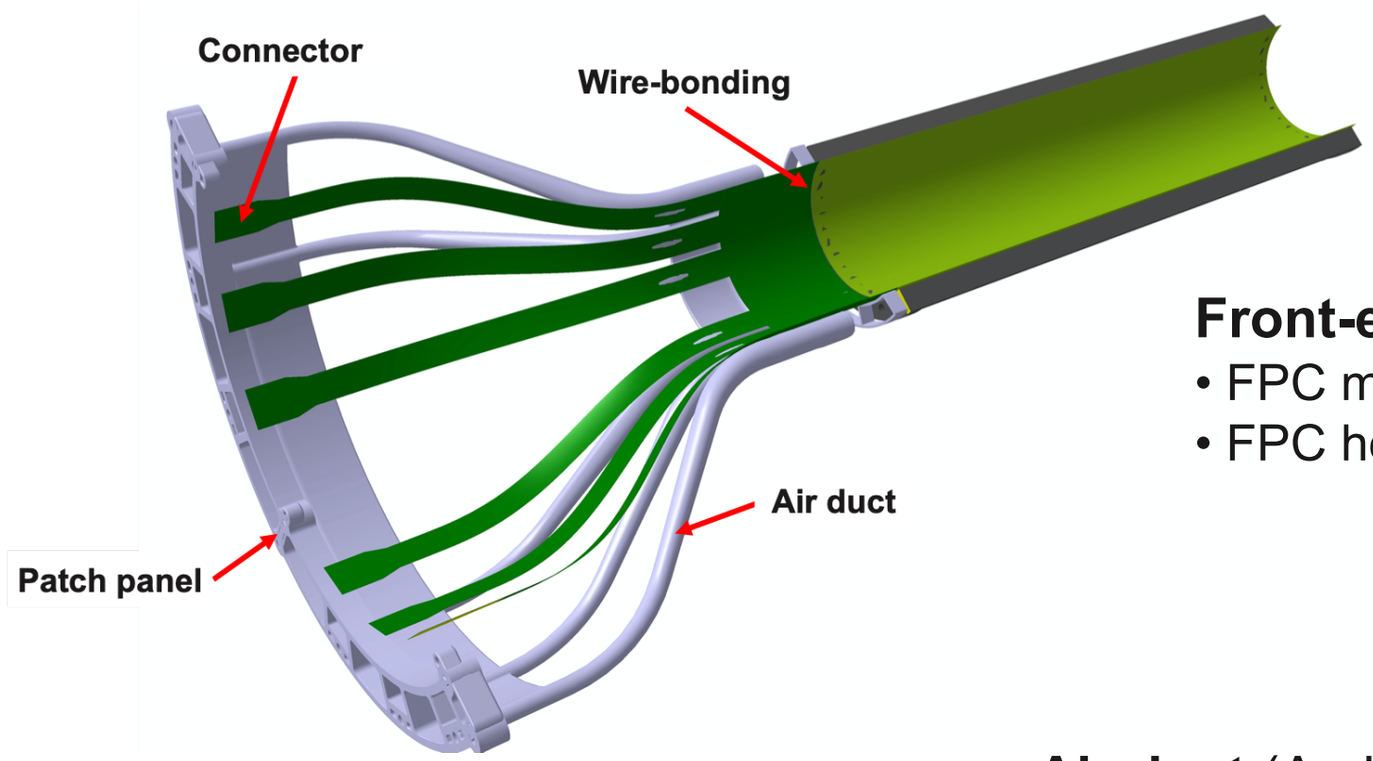


Assembly procedure

Assembly with dummy sensor

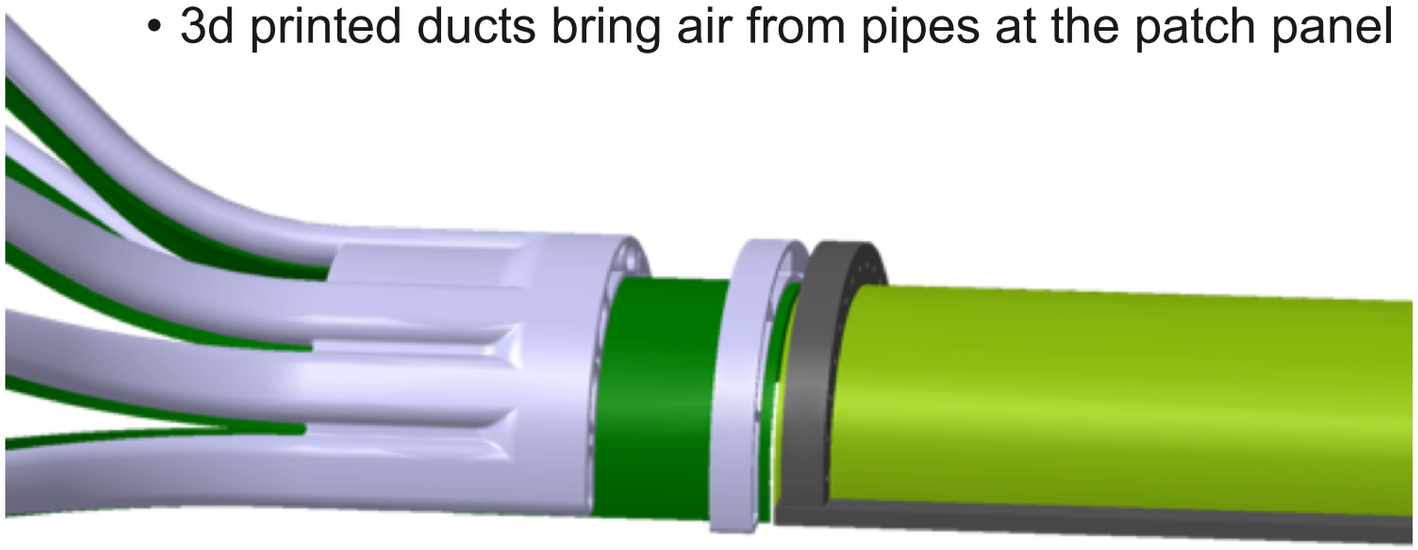


Flex and cooling pipes - First ideas



Front-end flex (A-side)
- FPC metal stack layers under definition
- FPC holding on mandrel under study

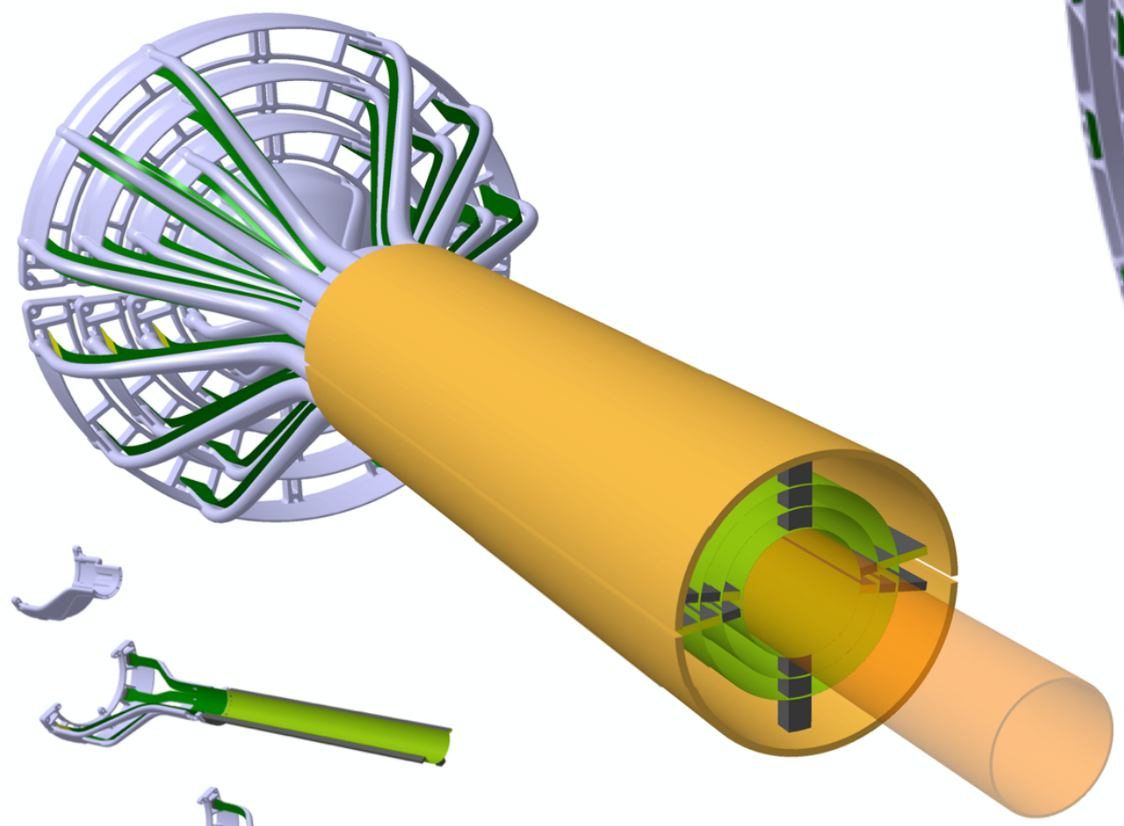
Air duct (A-side)
- Air distribution shall arrive close to the sensor edge
- 3d printed ducts bring air from pipes at the patch panel

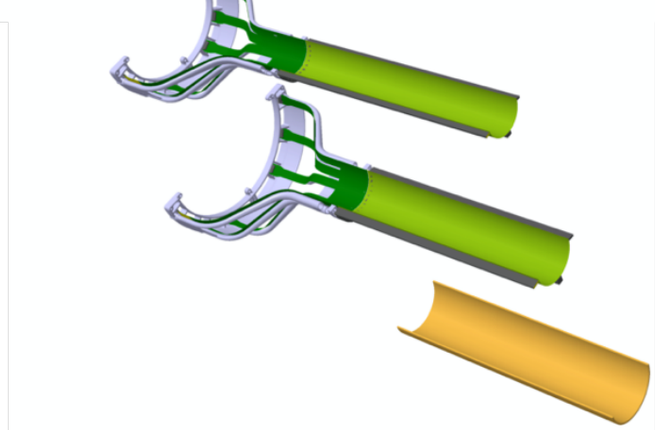


UNDER DEVELOPMENT!

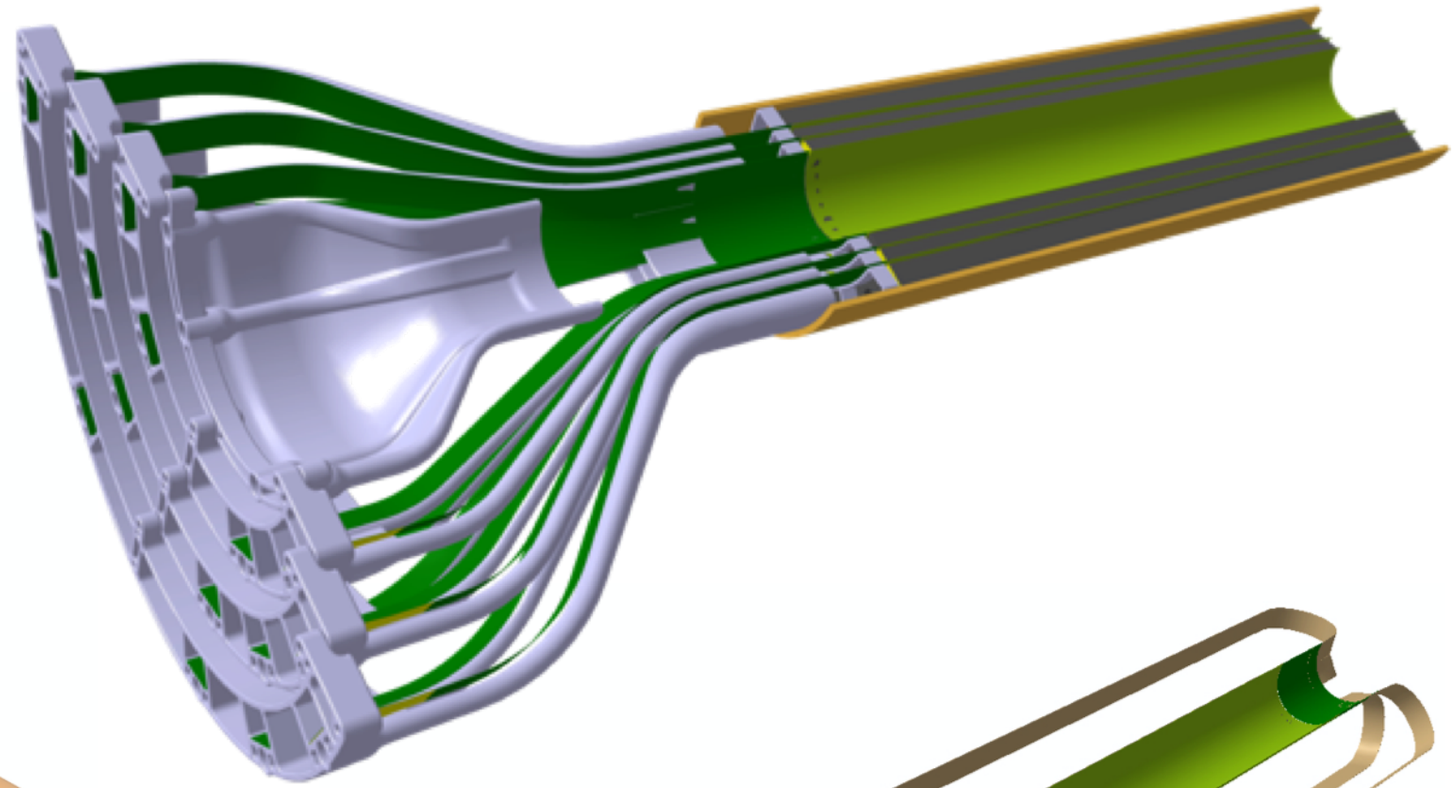
One side design

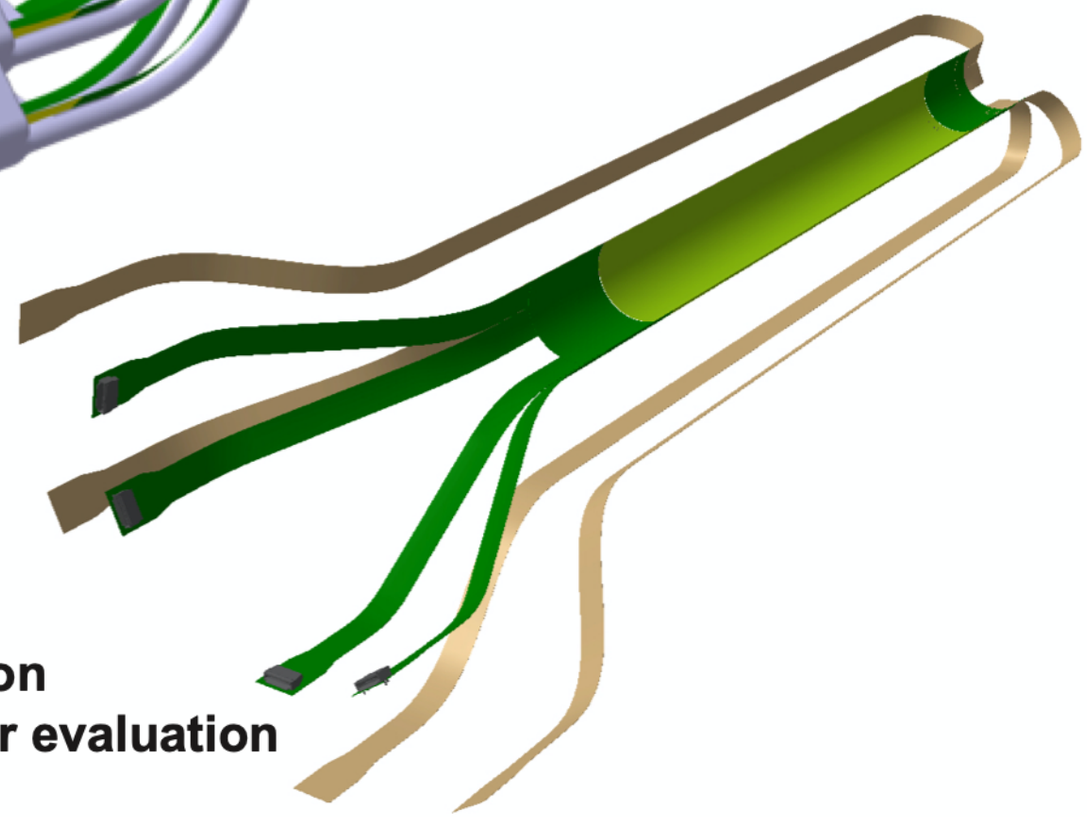
Flex and cooling pipes - First ideas





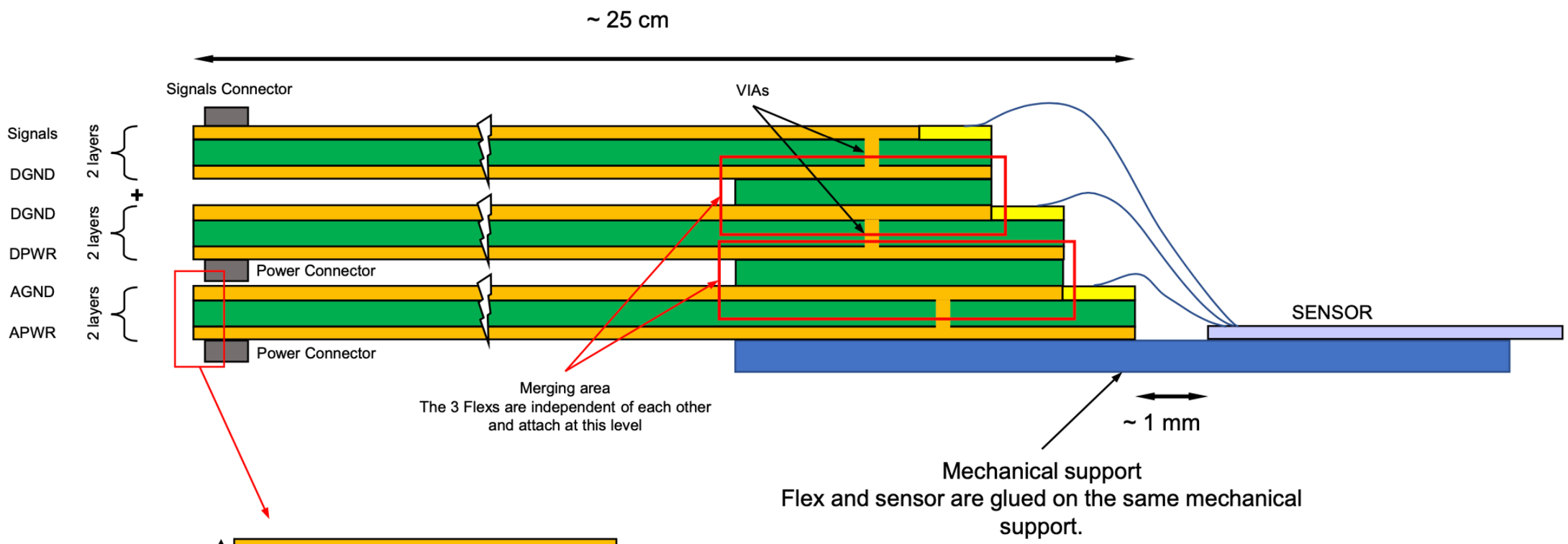
Multi-layer assembly

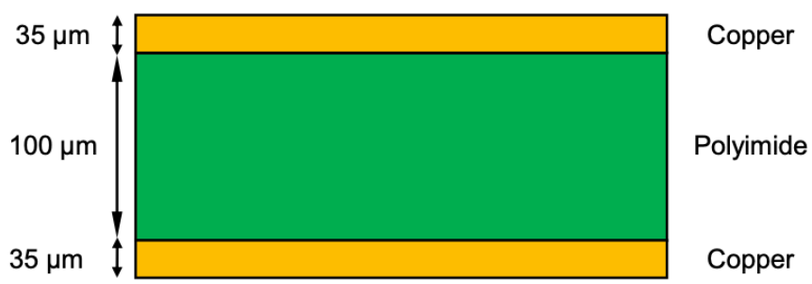


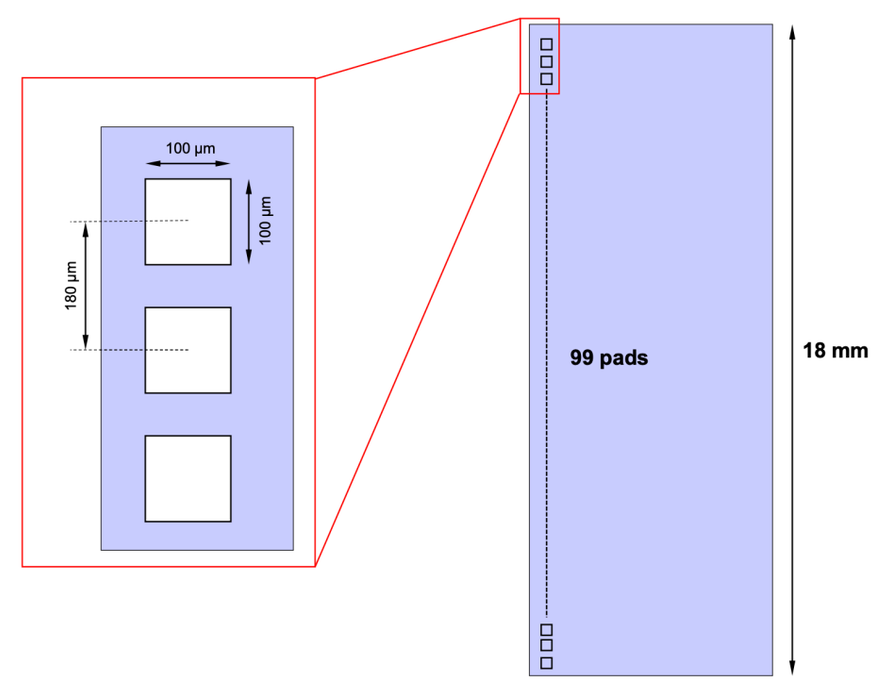


Front-end flex on both-side under evaluation

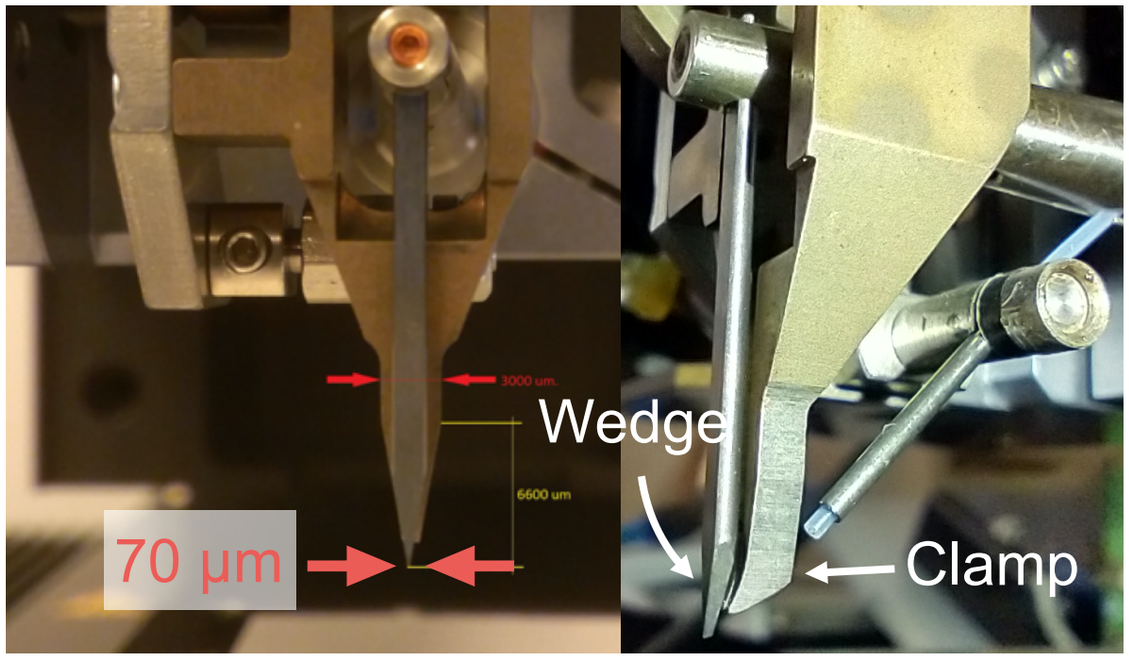
Flex and cooling pipes - First ideas



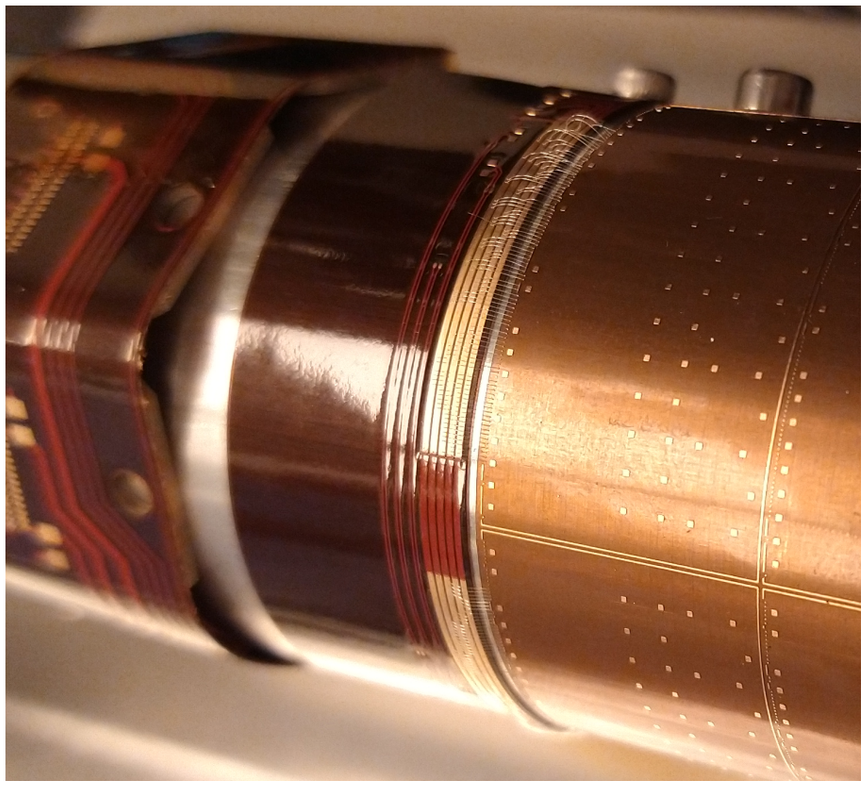




Wire-bonding performance study



- The limit to the bonding density (distance between two adjacent bonding feet) is given by the width of the wedge and clamp.
- Usual wedge thickness 100 µm → In Bari 70 µm (modified for the ITS2 assembly)
- Wire thickness: 25 µm

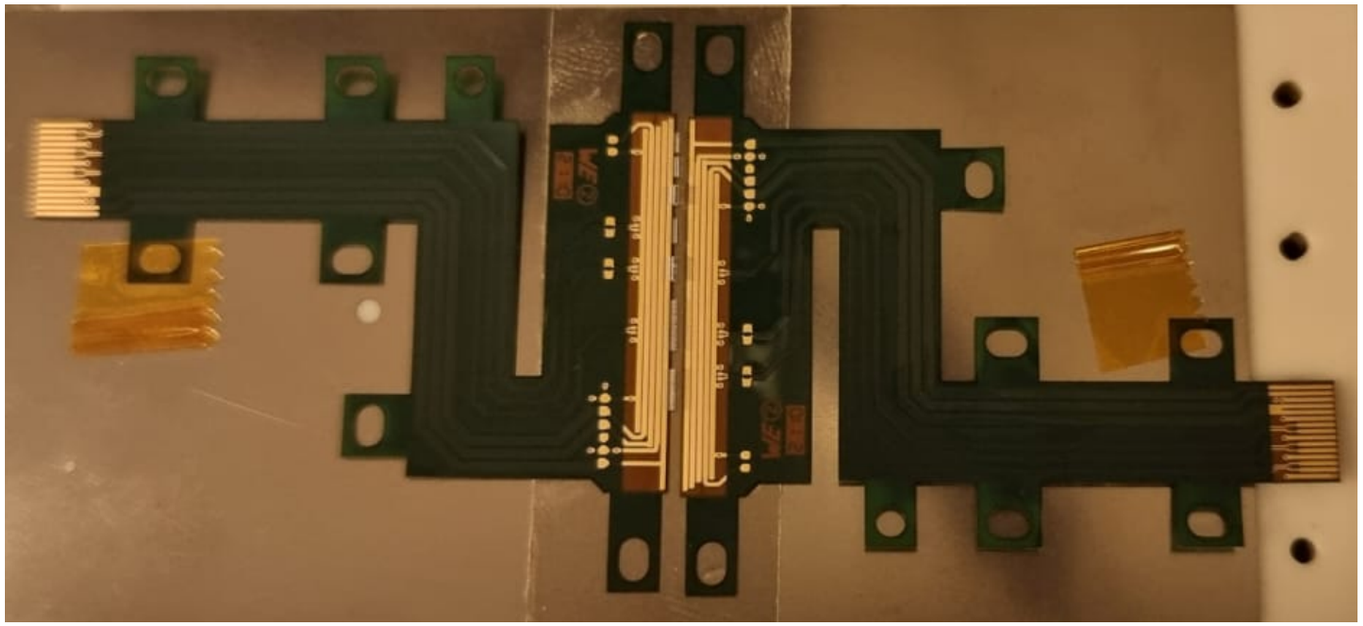


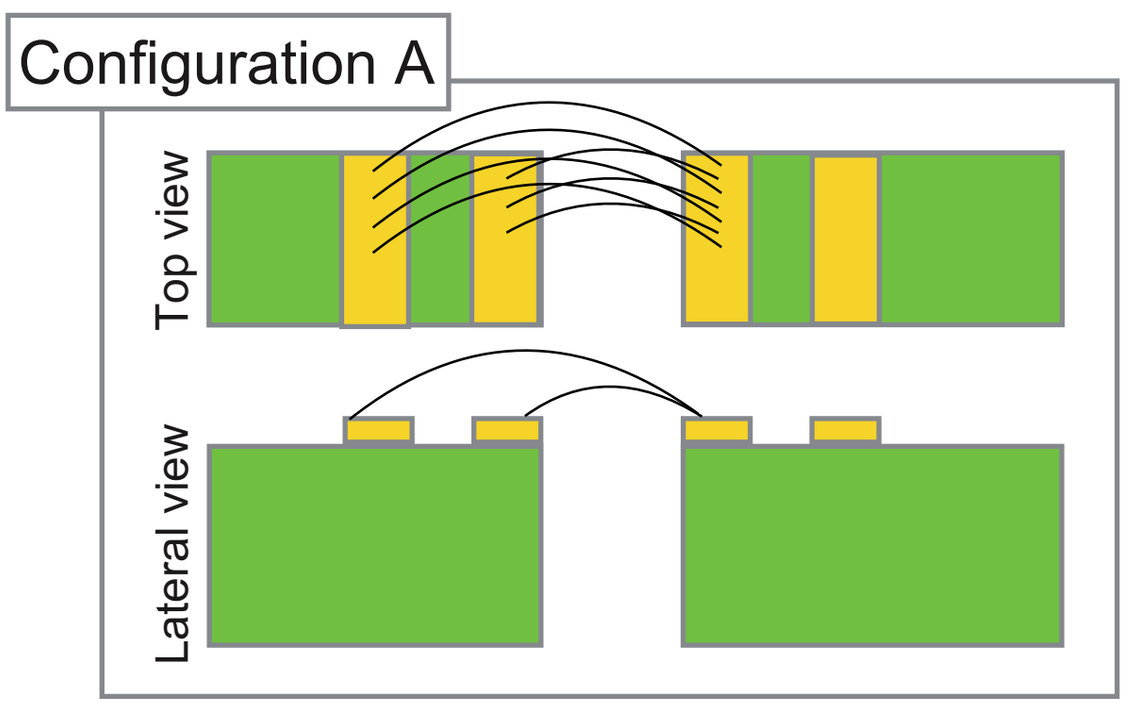
SUPER-ALPIDE edge-FPC

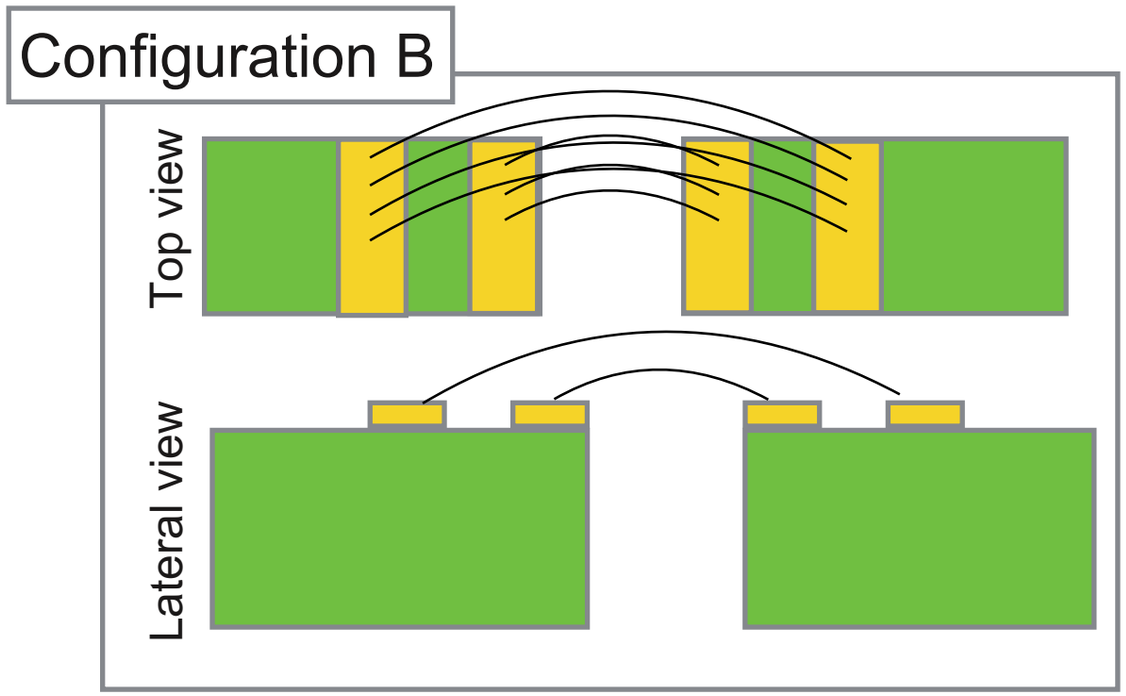
- Wires length spans between ~1 mm and ~5 mm
  - Distance between ALPIDE mini-pads and FPC border: ~1 mm
  - Distances between FPC border and long pads: ~30 µm - 4 mm
- ALPIDE mini-pads dimensions: ~90 µm x 90 µm
- Inter-pad distance, in the denser regions: ~220 µm

Wire-bonding performance study

- Setup: two single-ALPIDE FPC one facing the other, with a gap similar of ~500 μm
- Two bonding configurations:
  - A) “Deferred” : for two adjacent wires, one foot is on the same long-pad while the other is on a different long-pad
  - B) “Alternating” : for two adjacent wires, both feet are on two different long-pads
- Two inter-pad distances explored:
  - ~100 μm
  - ~80 μm

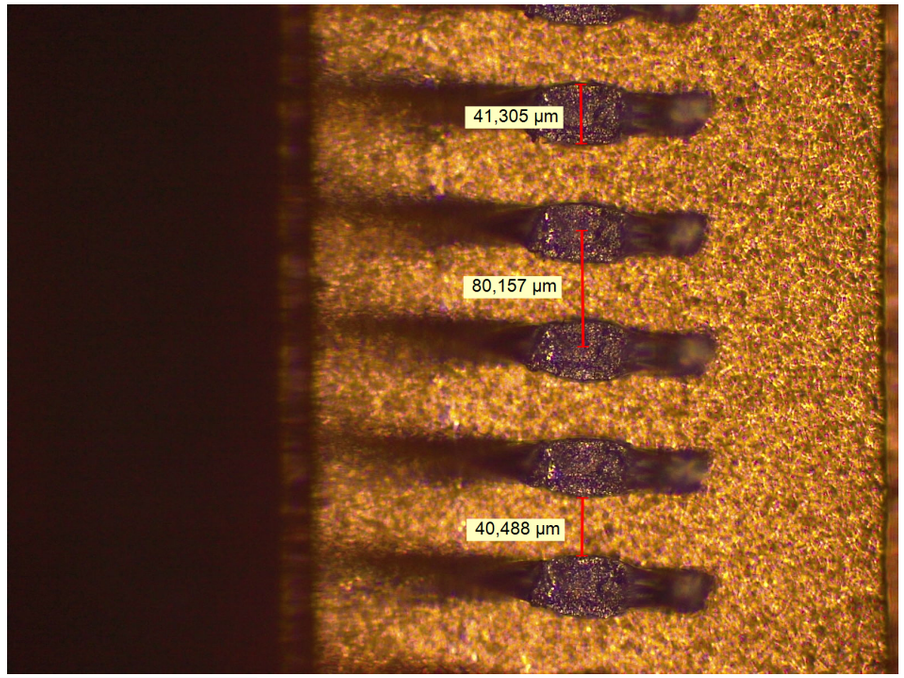




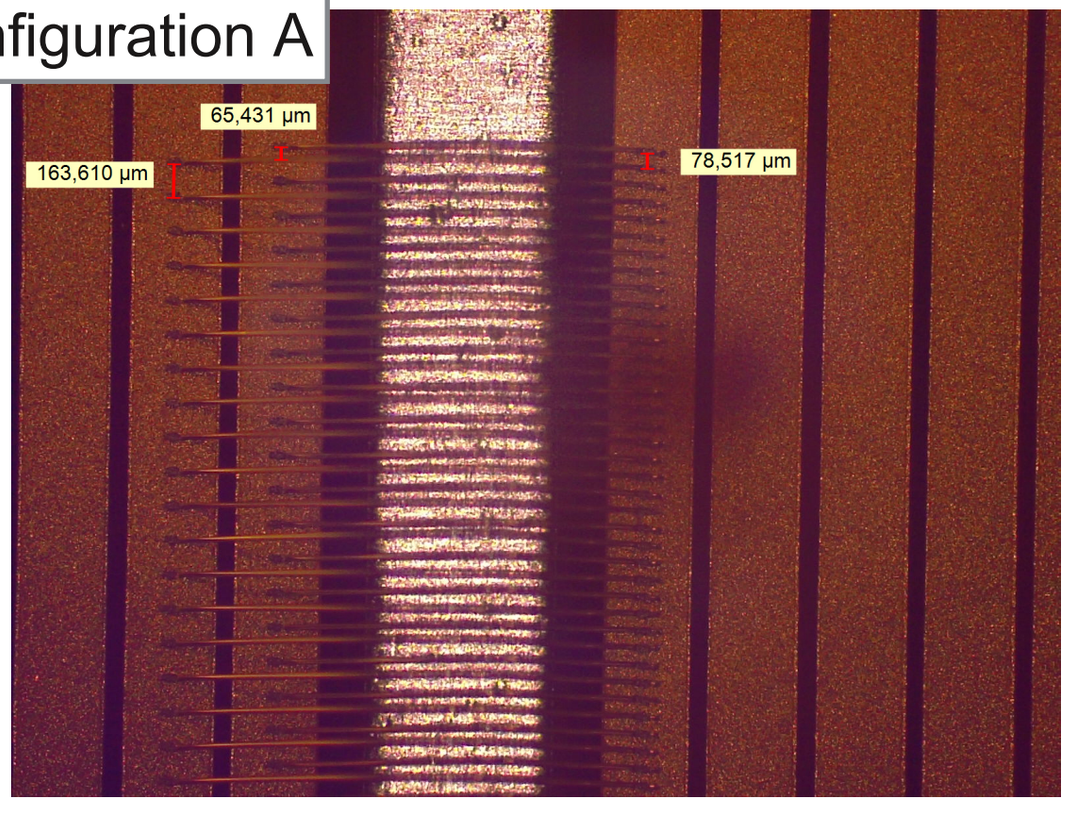


Wire-bonding performance study

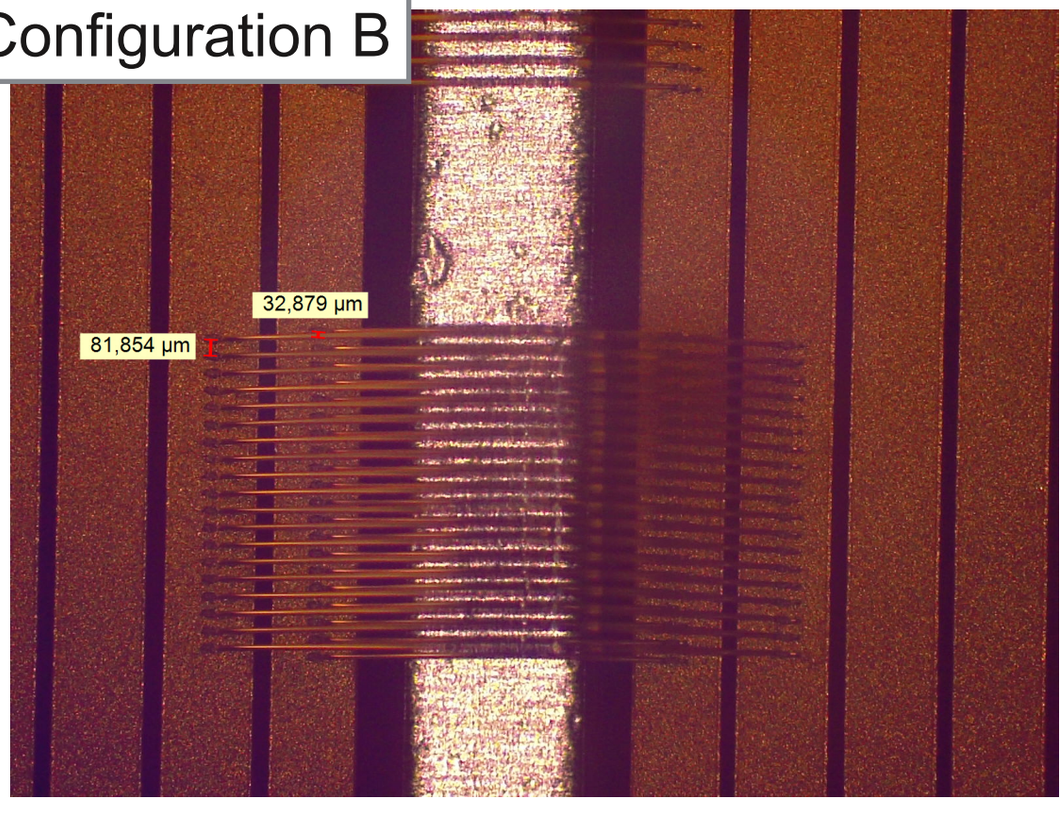
- With a wire thickness of 25 µm, a foot width of ~40 µm is expected → minimal pad dimension ~80 µm
- ~80 µm inter-pad distance achievable
- **Configuration B** bring to wire distance of **~40 µm**



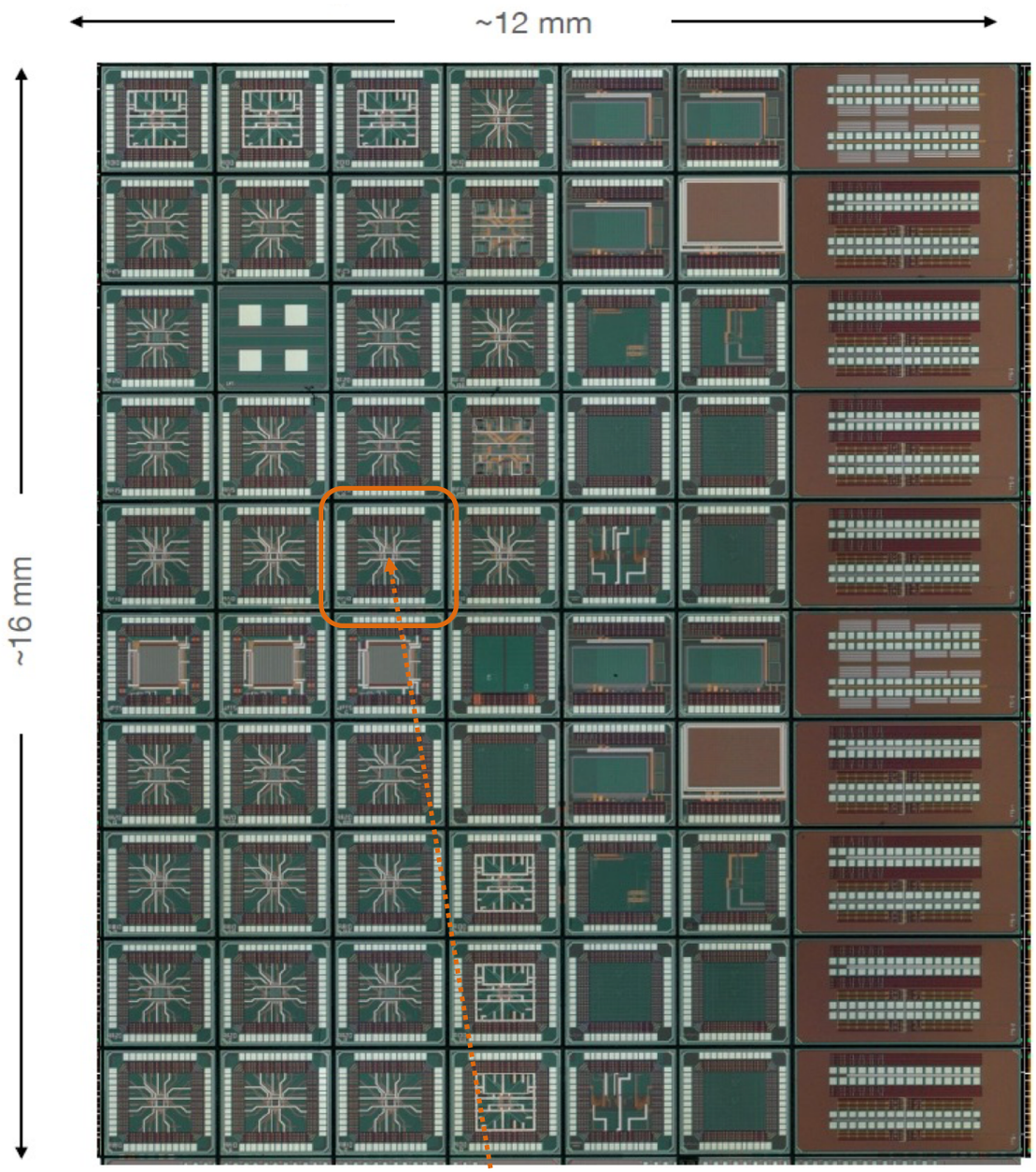
Configuration A



Configuration B

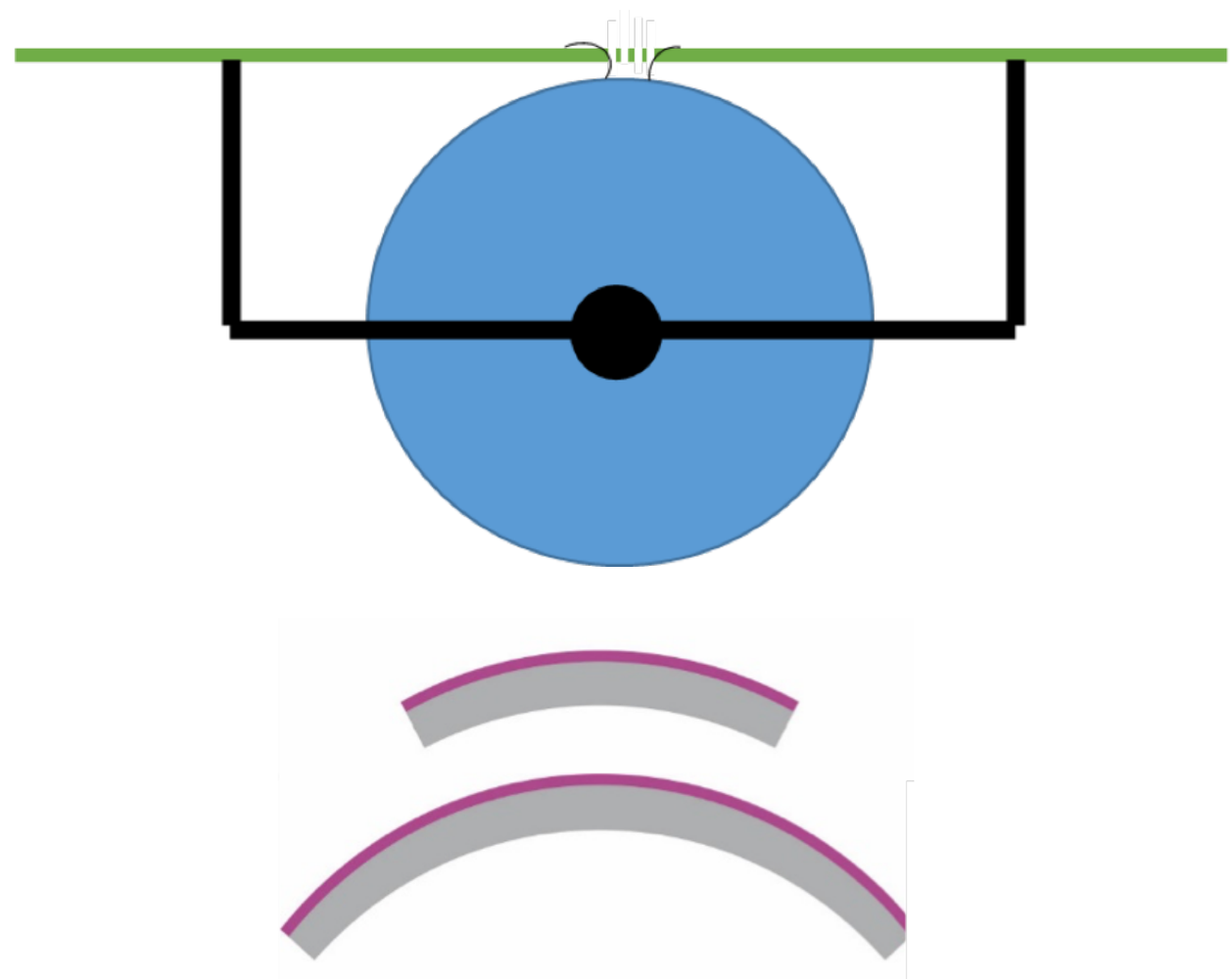


Bent MLR1 test structure characterisation



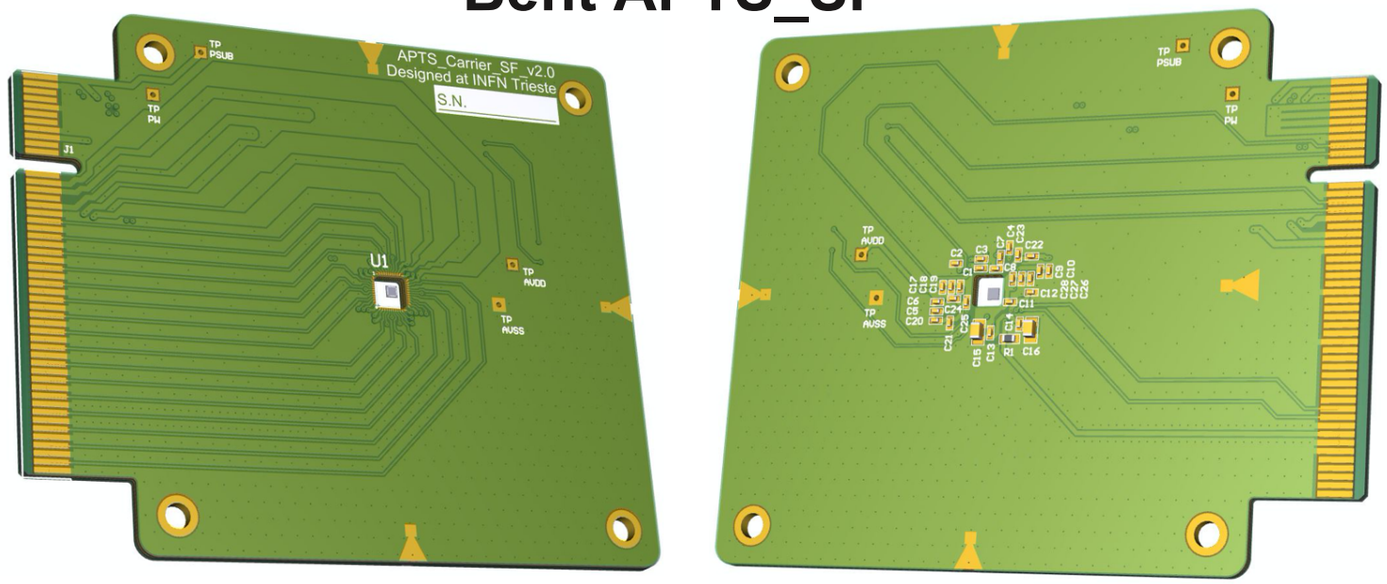
Single test structure to be tested

Bent chip support tool

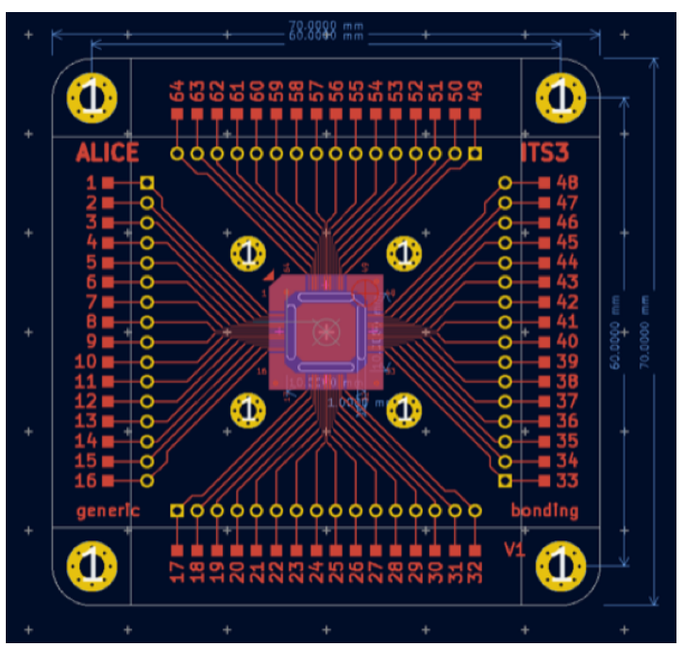


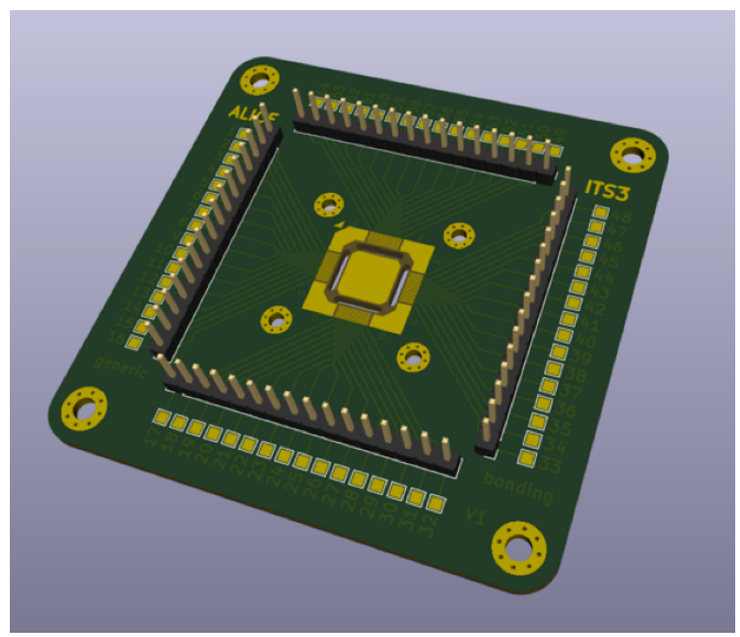
Bent MLR1 test structure characterisation

Bent APTS_SF

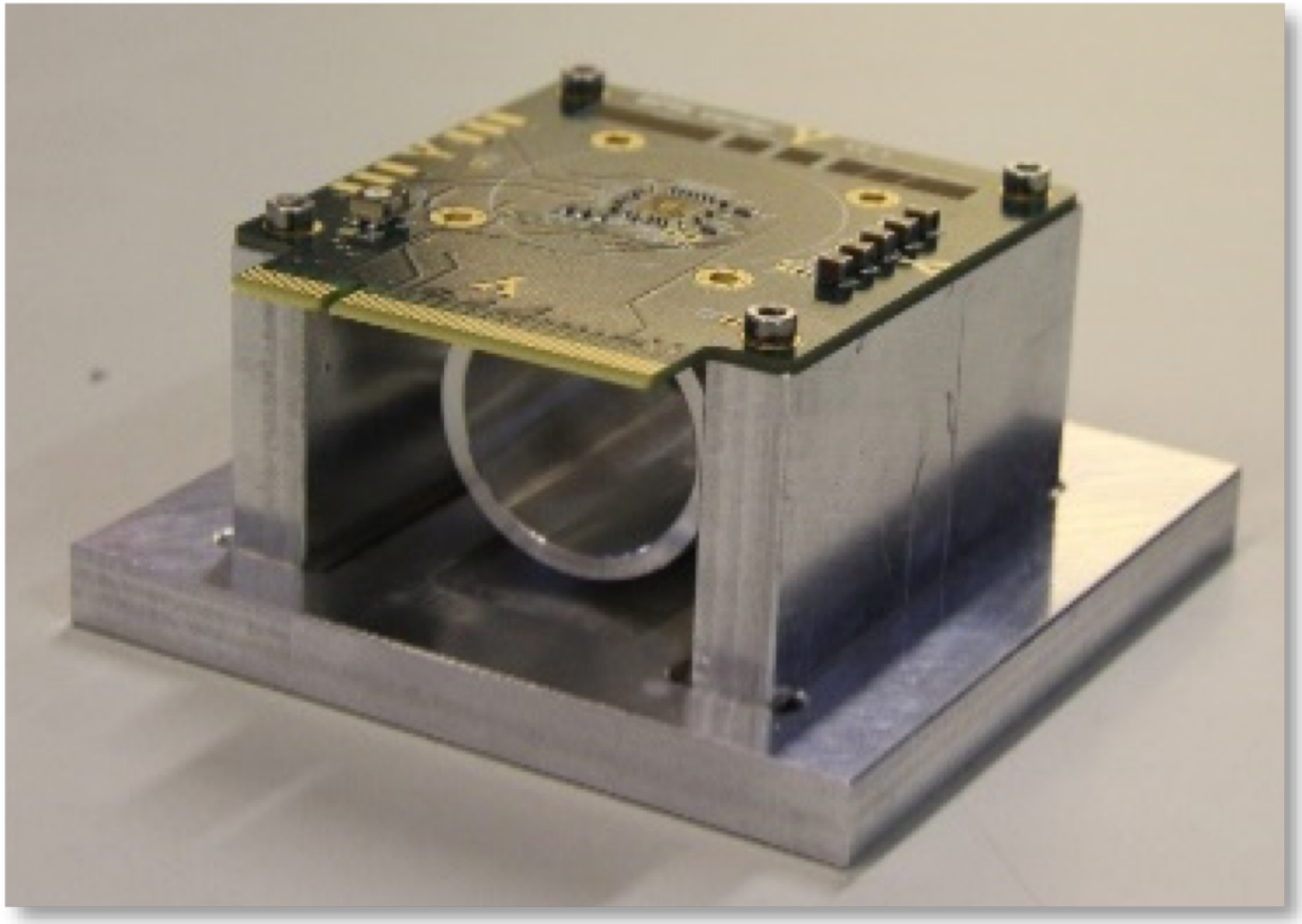


Bent Transistor TS





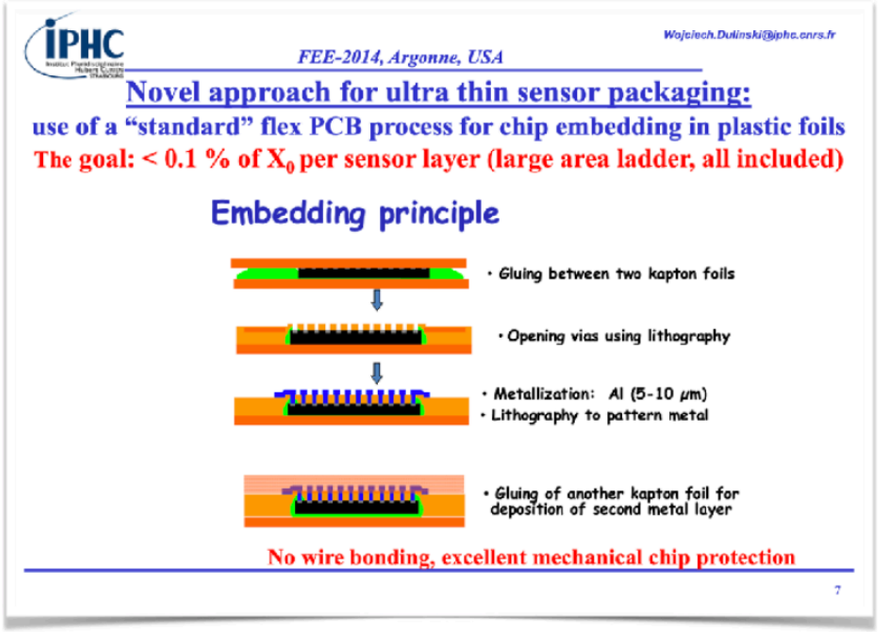
Bent MLR1 test structure characterisation

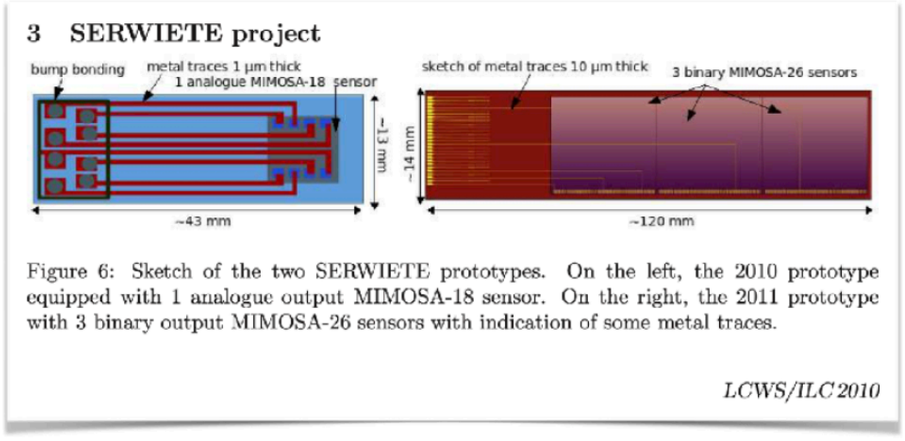


Embedded silicon

Idea
and history

- I learned about a similar technique *(and forgot about it in-between)*, at FEE2014 (Argonne): https://indico.cern.ch/event/276611/contributions/622863/attachments/502969/694527/dulinski_FEE-2014.pdf
- This actually followed the SERWIETE idea: https://arxiv.org/abs/1006.5424
- To my knowledge it was not followed up much further, and had two difficulties:
  - redistribution layer on the chips was necessary since the chips had small pads
  - It required on Al metallisation (good for material budget, bad for using standard techniques)



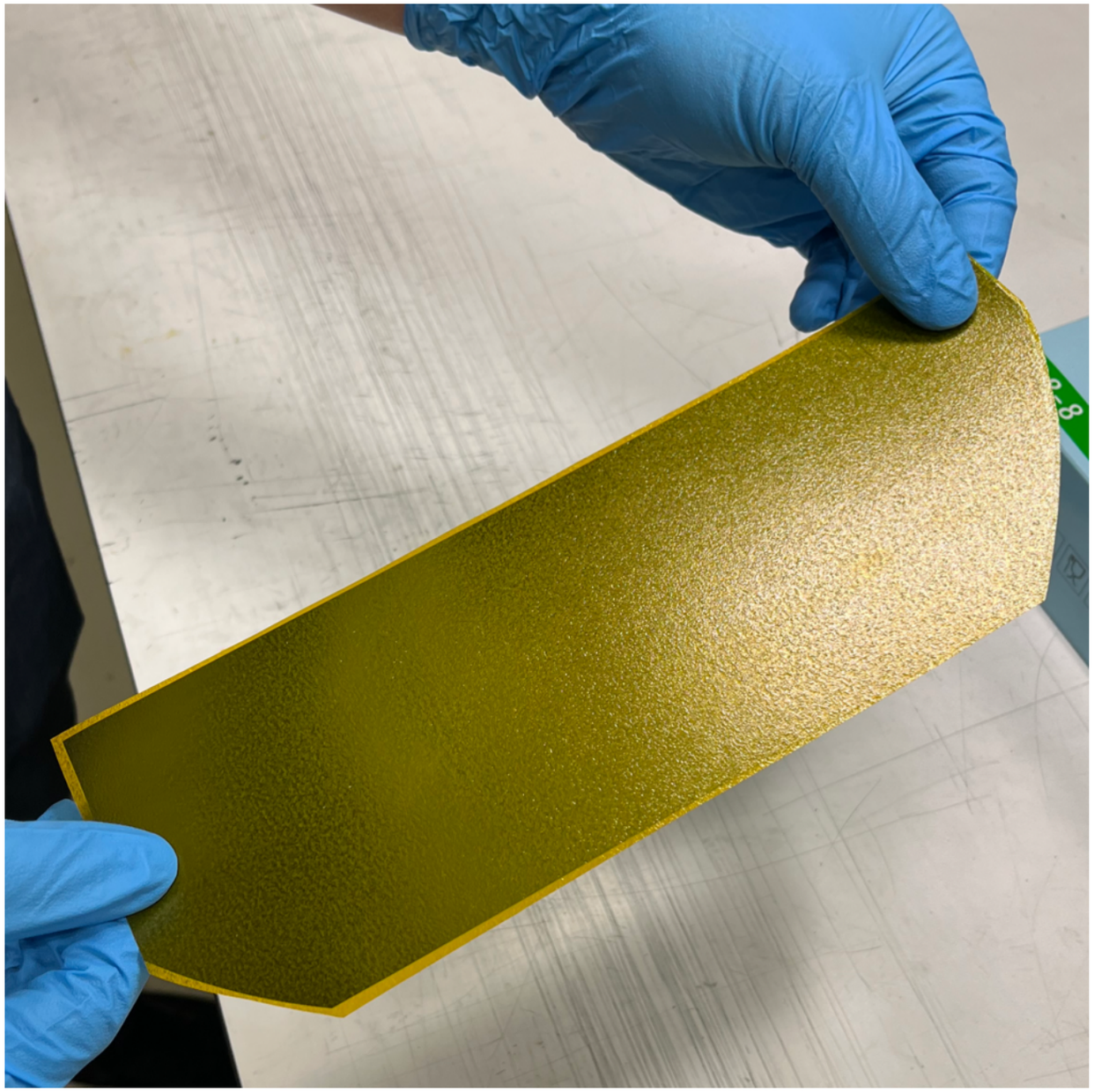


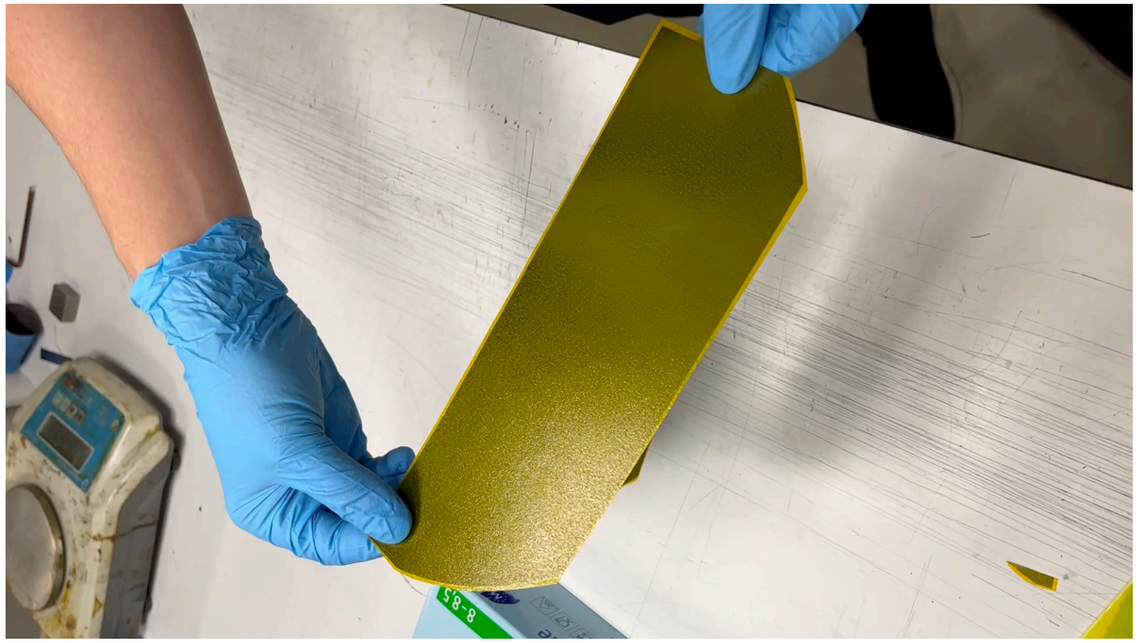
Magnus Mager (CERN) | ITS3 WP4 | 28.04.2022 | 2

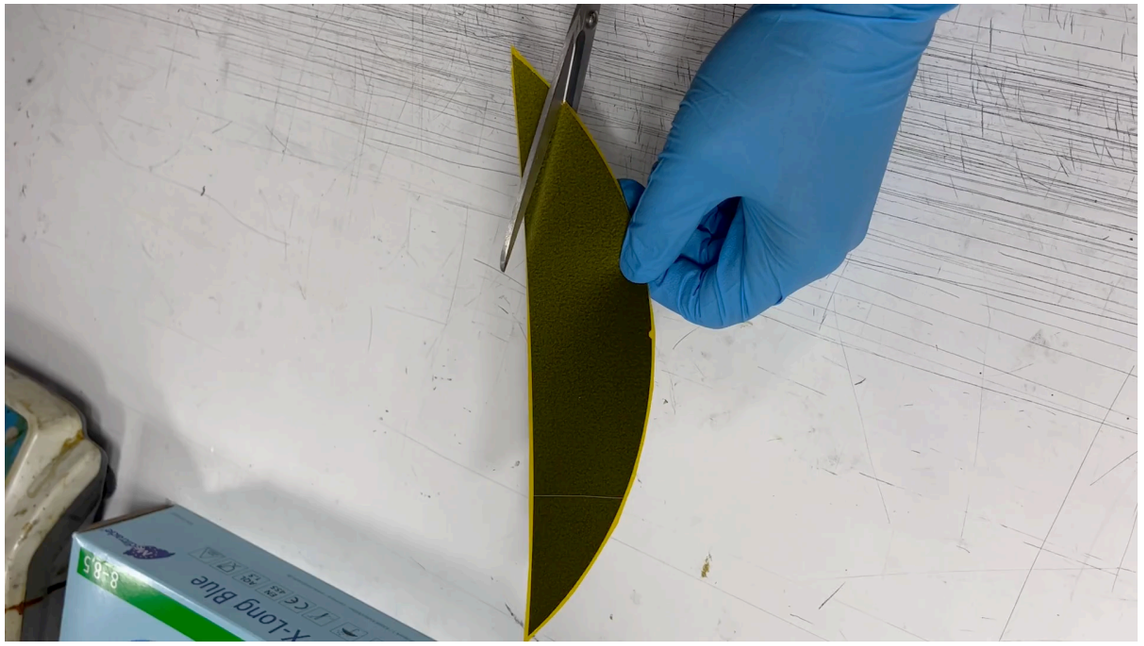
arXiv:2205.12669v1

- Super-ALPIDE project
- FPC for final detector
- MLR1 bending tool
- **MAPS foil**

Embedded silicon





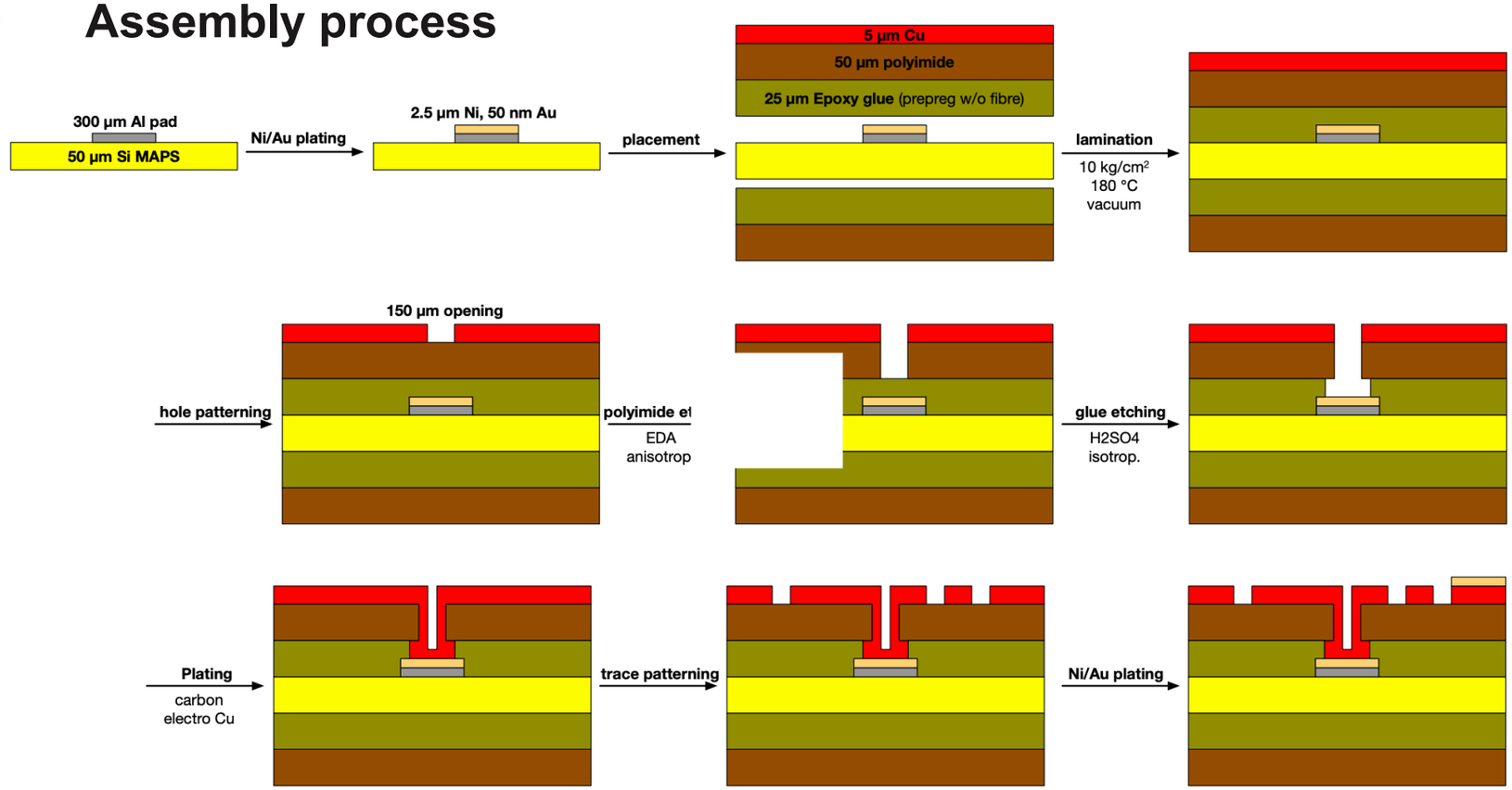


arXiv:2205.12669v1

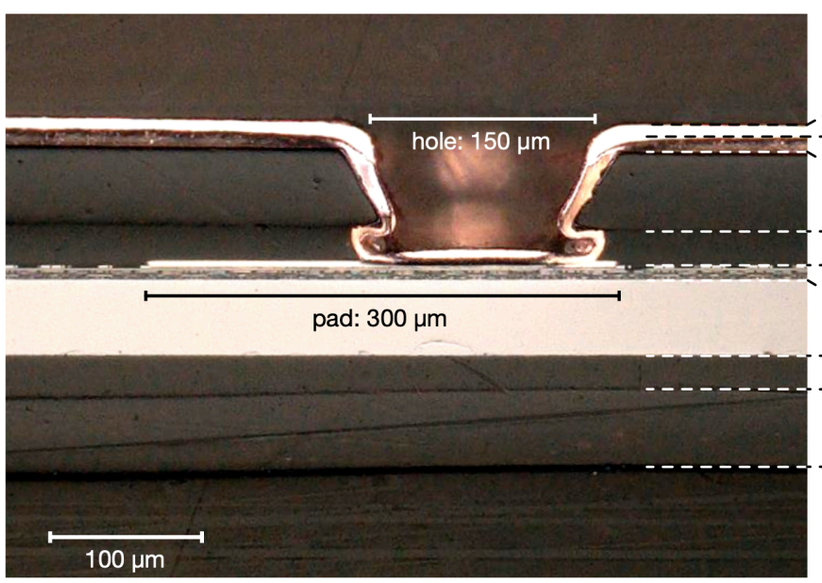
- Super-ALPIDE project
- FPC for final detector
- MLR1 bending tool
- **MAPS foil**

Embedded MAPS

Assembly process



Cross-section through one interconnection

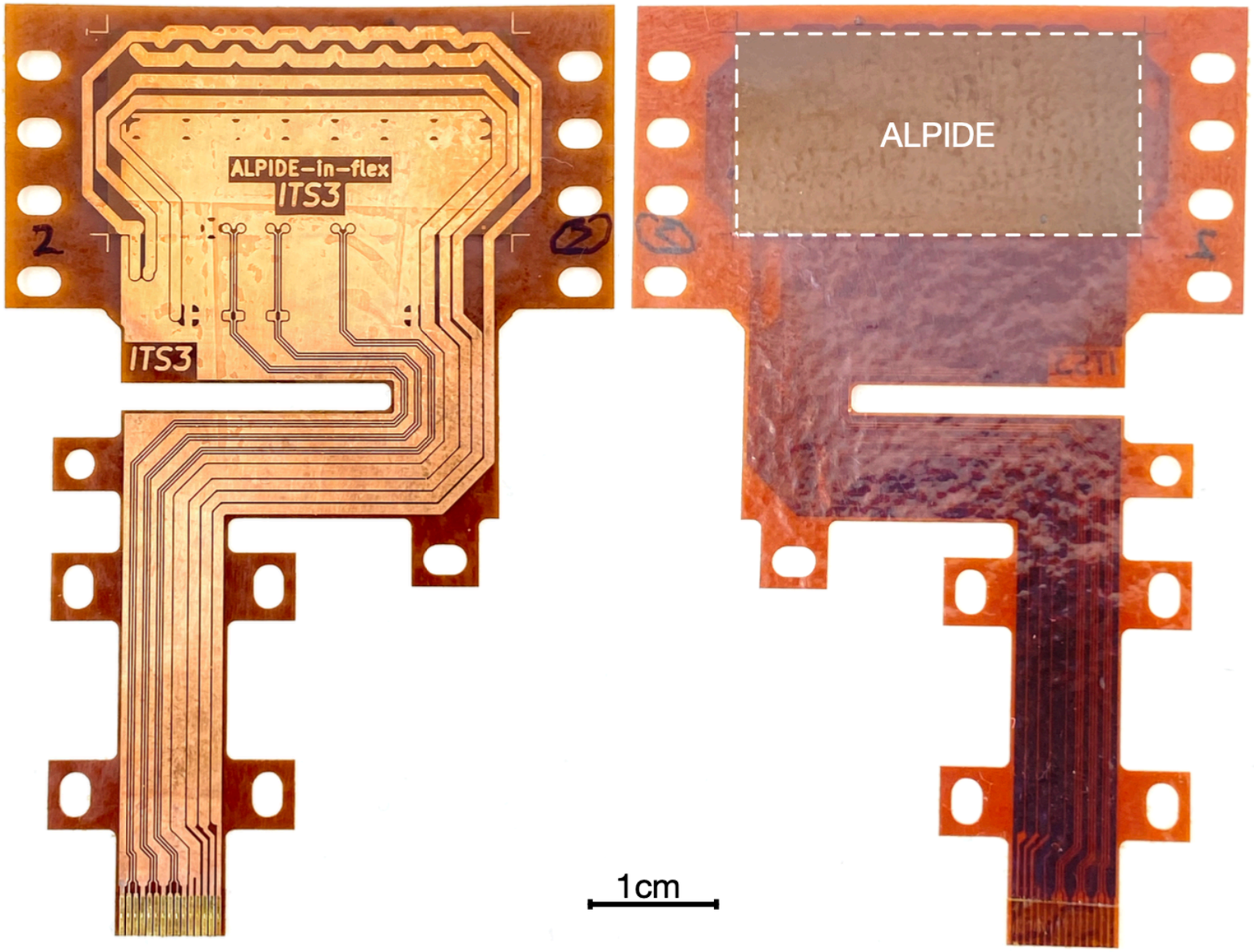


part	thickness	radiation length
Cu plating	13 µm	(0.06%)
Cu gladding	5 µm	(0.07%)
Polyimide	45 µm	0.02%
glue	25 µm	0.01%
metal stack	10 µm	0.01%
silicon	45 µm	0.05%
glue	25 µm	0.01%
Polyimide	45 µm	0.02%
total:	**213 µm**	**0.11%** (+ 0.13% Cu)

arXiv:2205.12669v1

- Super-ALPIDE project
- FPC for final detector
- MLR1 bending tool
- **MAPS foil**

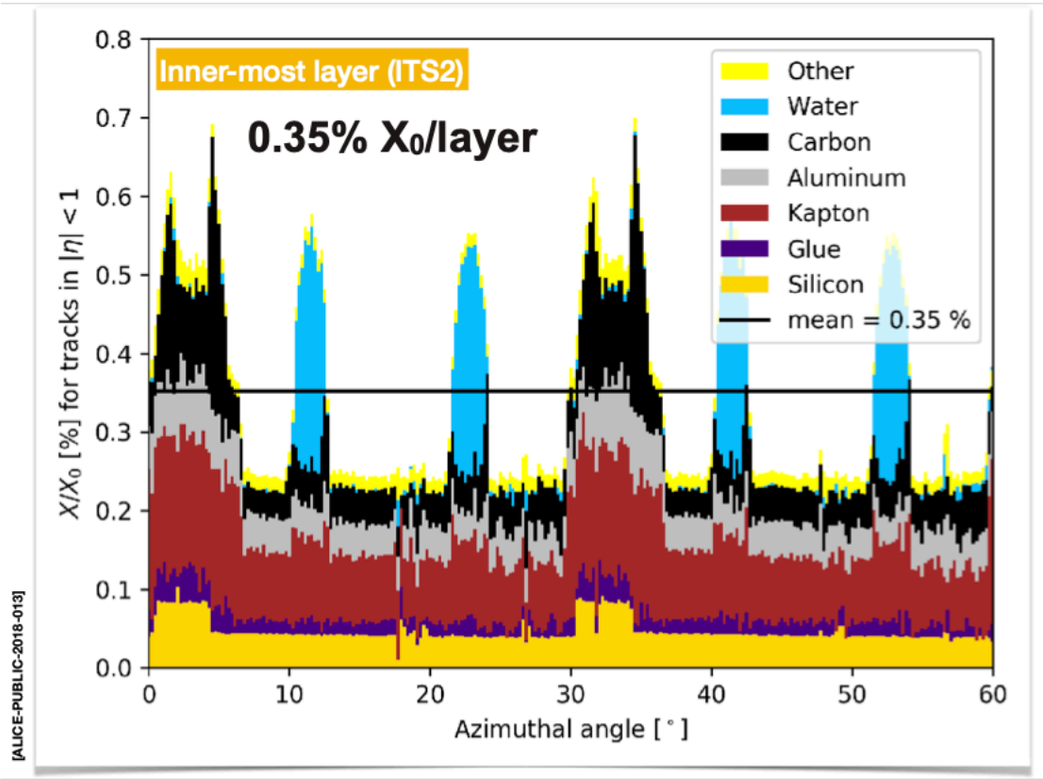
Embedded MAPS



- **Super-ALPIDE project**
  - ✓ **First working object will be assembled before August**
- **FPC for final detector**
  - ✓ **Constraints and first ideas under definition**
- **MLR1 bending tool**
  - ✓ **Ready to be used**
- **MAPS foil**
  - ✓ **Interesting development for future detectors**

BACKUP

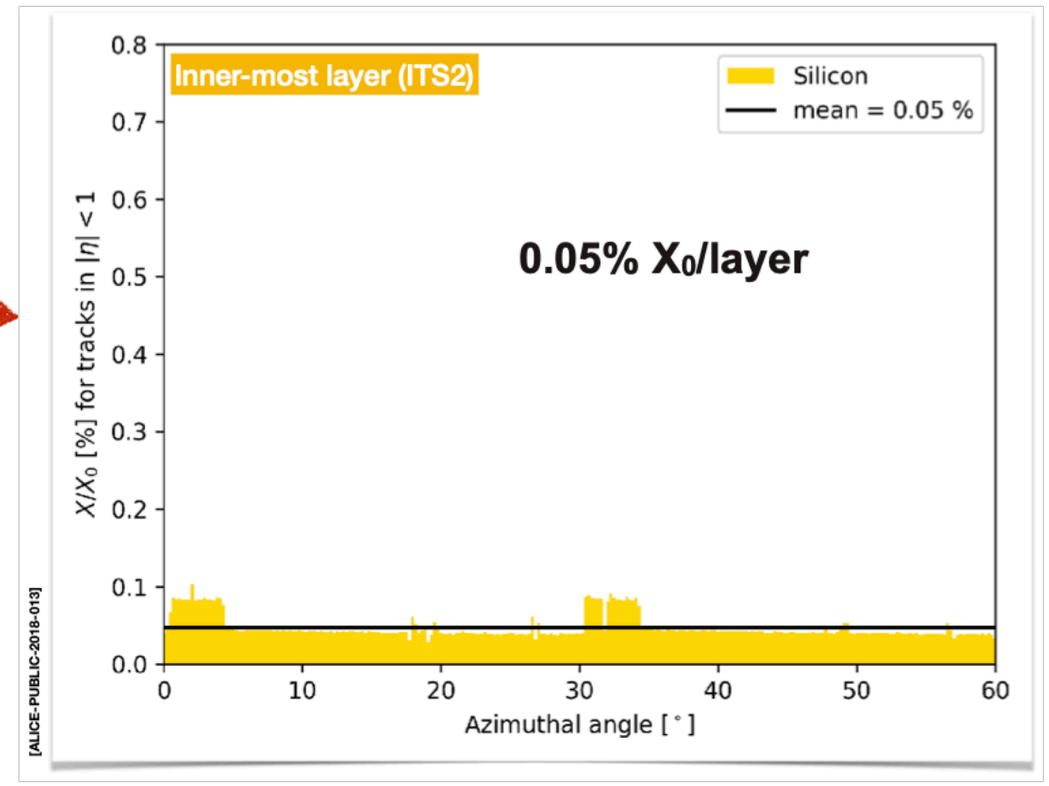
BACKUP



Observations

» Silicon makes only about 15% of total material

» Irregularities due to support/cooling and overlap



Improvements

» *Removal of water cooling*

→ **possible** if power consumption stays below 20 mW/cm²

→ move to (low flow) air cooling system

» *Removal circuit board* (power+data)

→ **possible** if integrated on chip

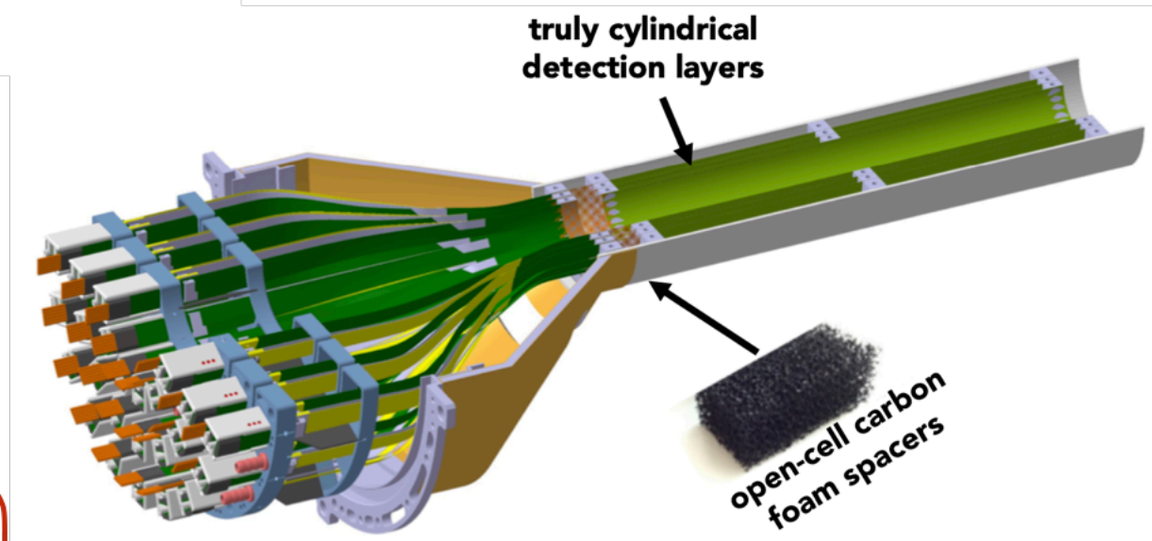
» *Removal of mechanical support*

→ **benefit** from increased stiffness by rolling Si wafers

BACKUP

Key ingredients

» Wafer-scale chips (up to ~28x10 cm), fabricated using stitching
» Sensor thickness 20-40 μm
» Chips bent in cylindrical shape at target radii
» Si MAPS sensor based on 65 nm technology
» Carbon foam structures
» Smaller beam pipe diameter and wall thickness (0.14% X_0)



The whole detector will comprise six chips (current ITS IB: 432) and barely anything else!

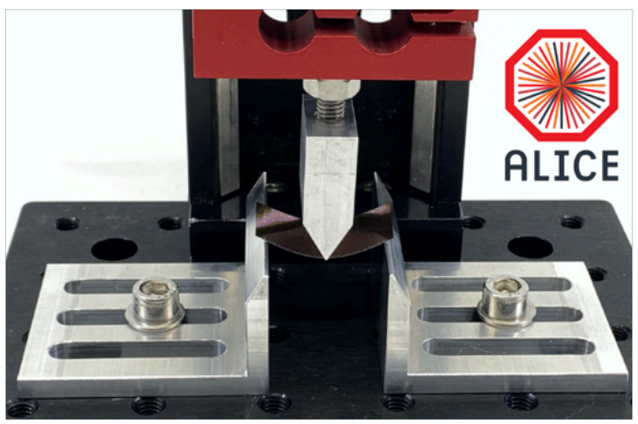
Beam pipe inner/outer radius (mm)	16.0/16.5		
IB Layer Parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length of sensitive area (mm)	300.0		
Pseudo-rapidity coverage	±2.5	±2.3	±2.0
Active-area (cm²)	610	816	1016
Pixel sensor dimension (mm²)	280 x 56.5	280 x 75.5	280 x 94
Number of sensors per layer	2		
Pixel size (μm²)	O (10 x 10)		

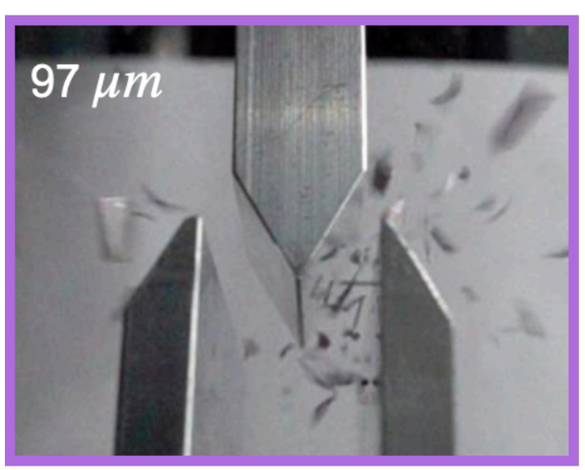
Key benefits

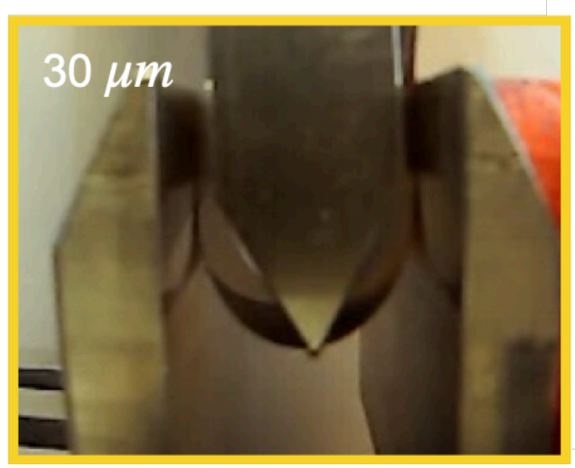
» Extremely low material budget: 0.02-0.04% X_0
» Homogeneous material distribution: negligible systematic error from material distribution

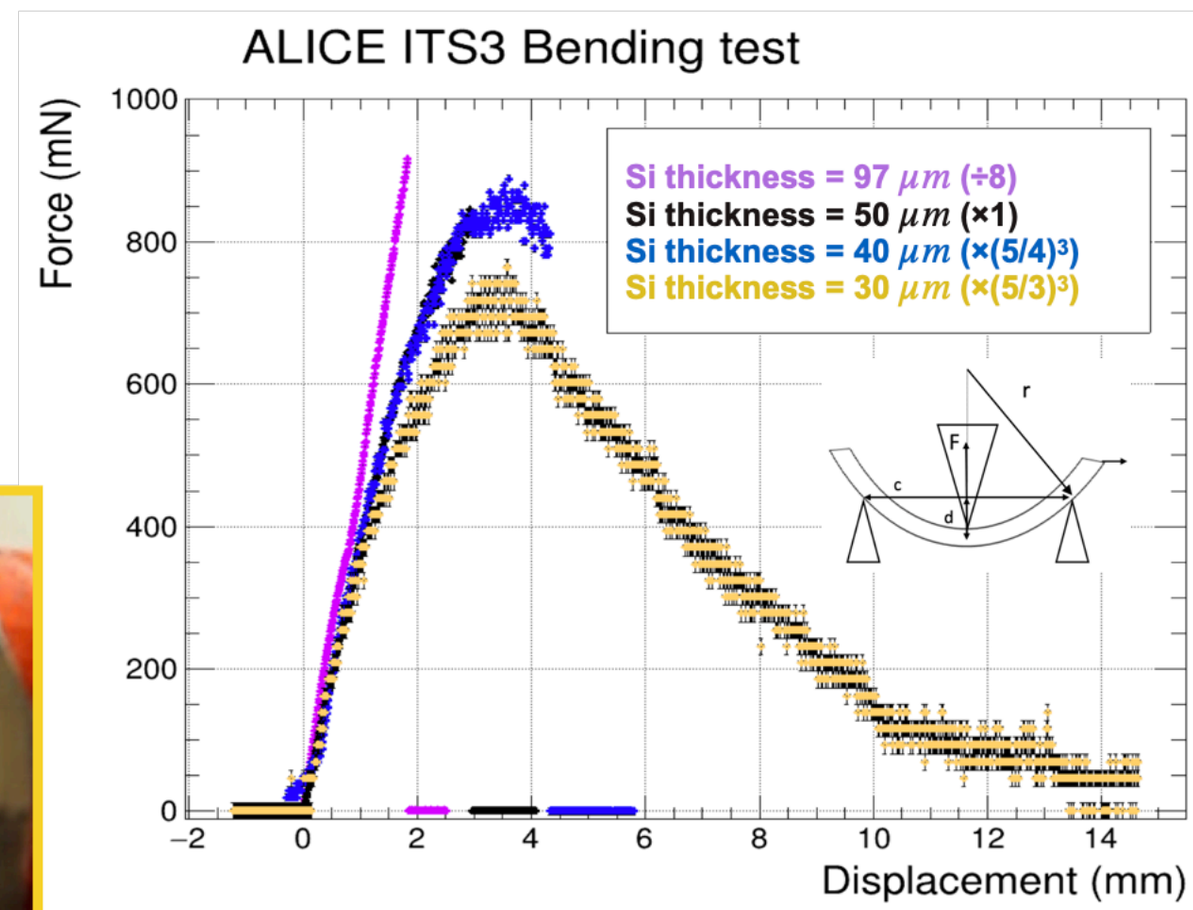
BACKUP

» MAPS at thickness used in current detectors (~50 μm) are quite flexible
» Large benefit from going even a bit thinner: the bending force scales with thickness to the third power
» The breaking point moves to smaller bending radii when going thinner
» Project goal thicknesses and desired bending radii are in a “not breaking” regime





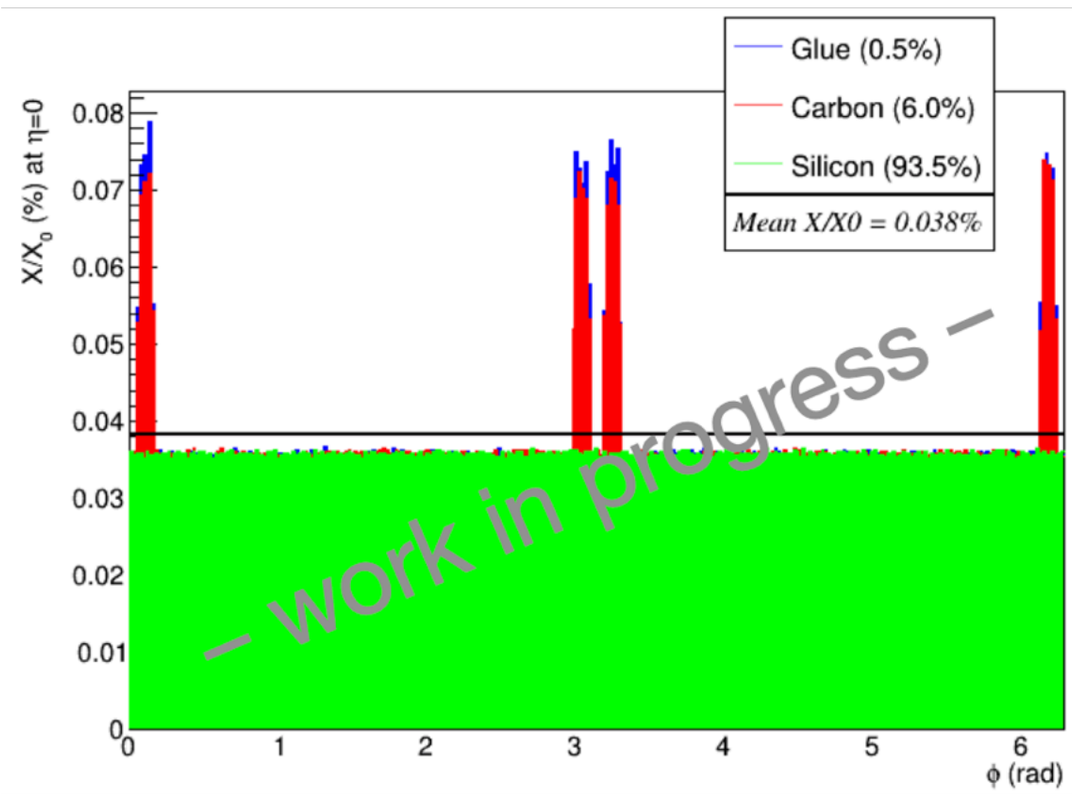


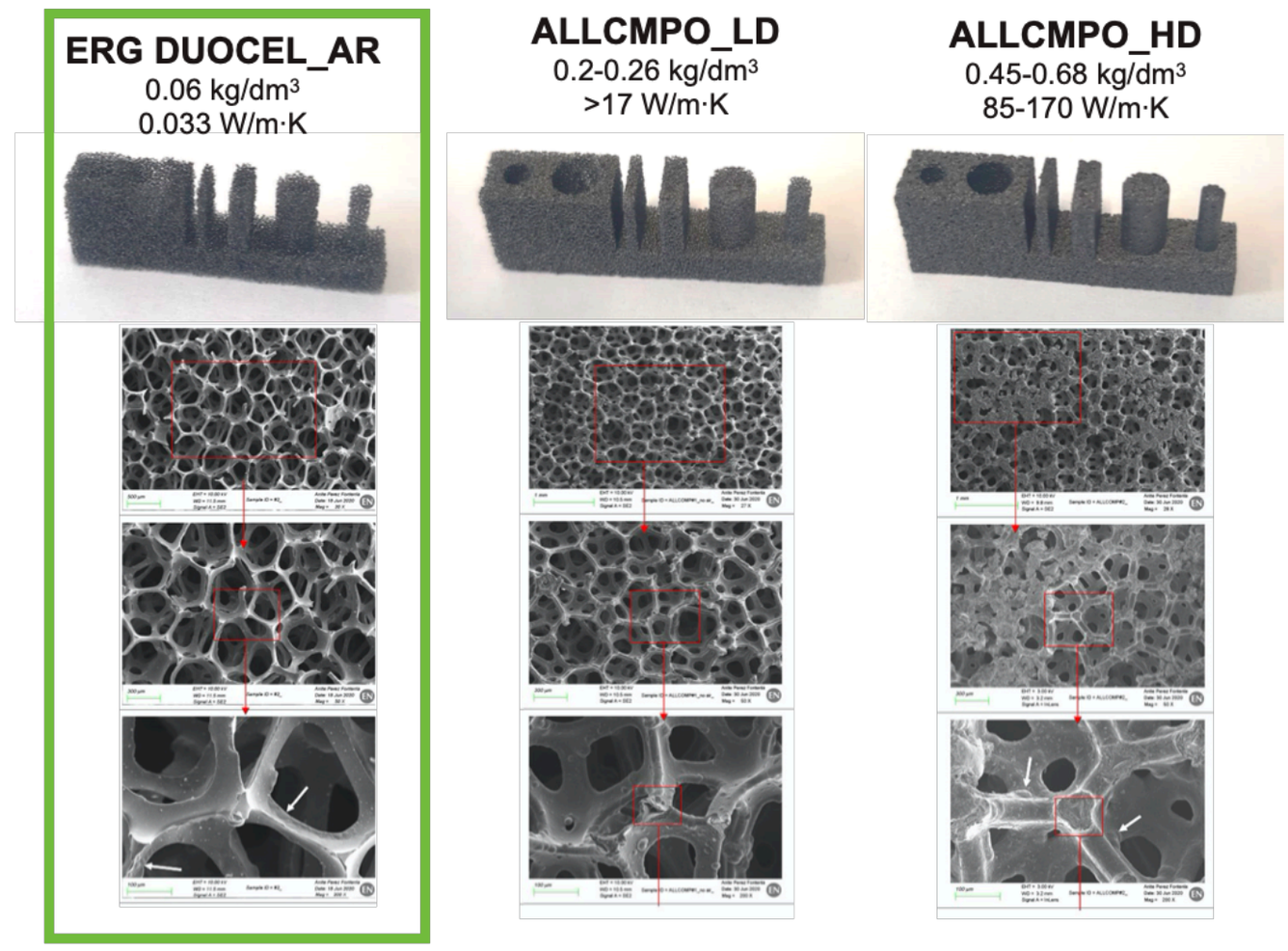


BACKUP

» Different foams characterised for machinability and thermal properties

» Baseline is ERG DUOCEL_AR, which also features the largest radiation length

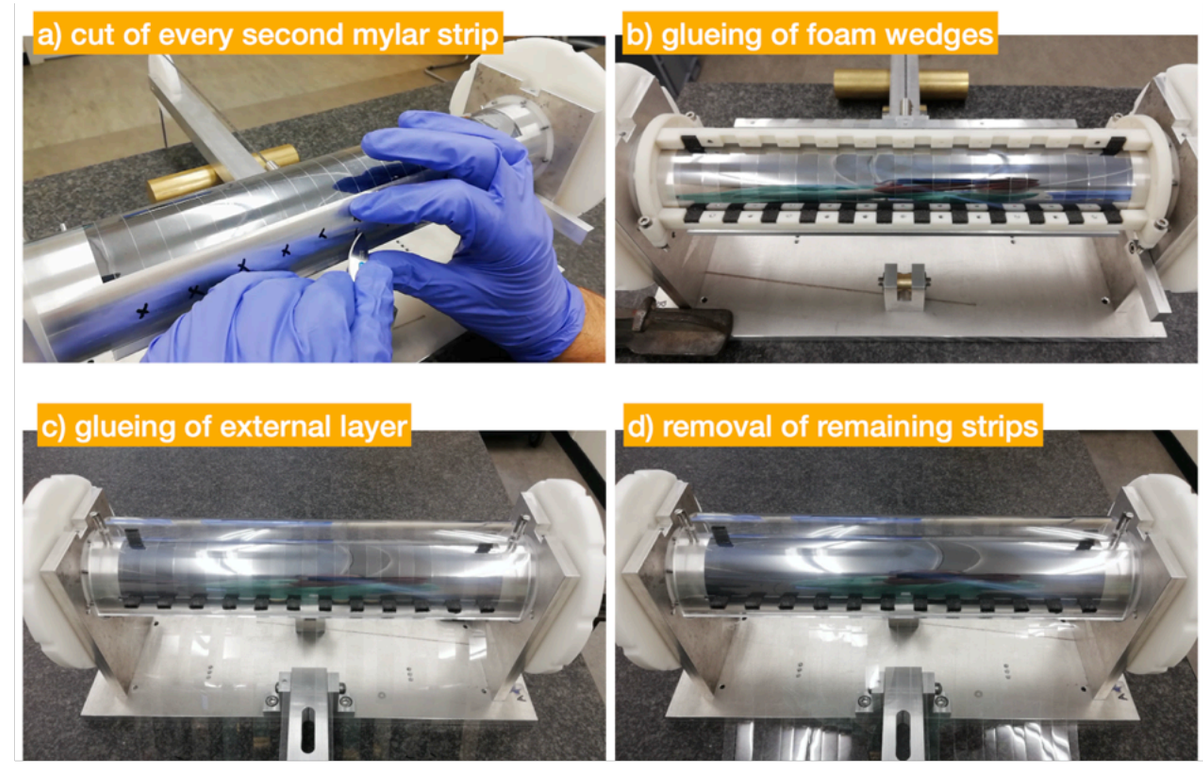


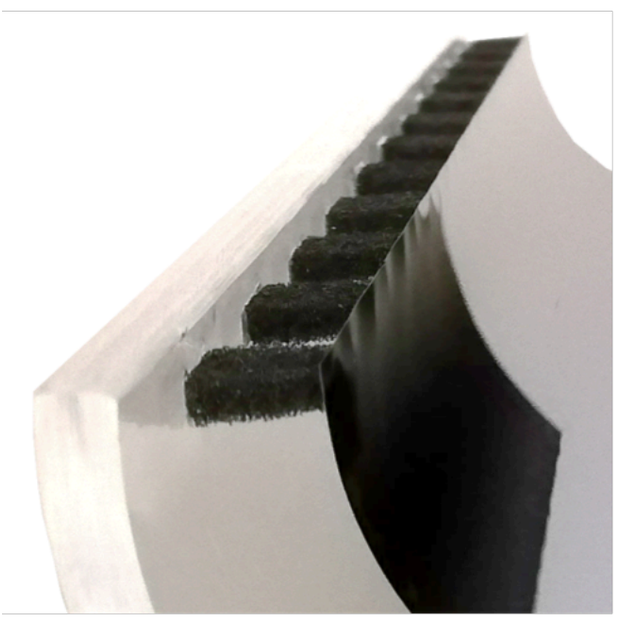


BACKUP

» Different options under study (including vacuum clamping)

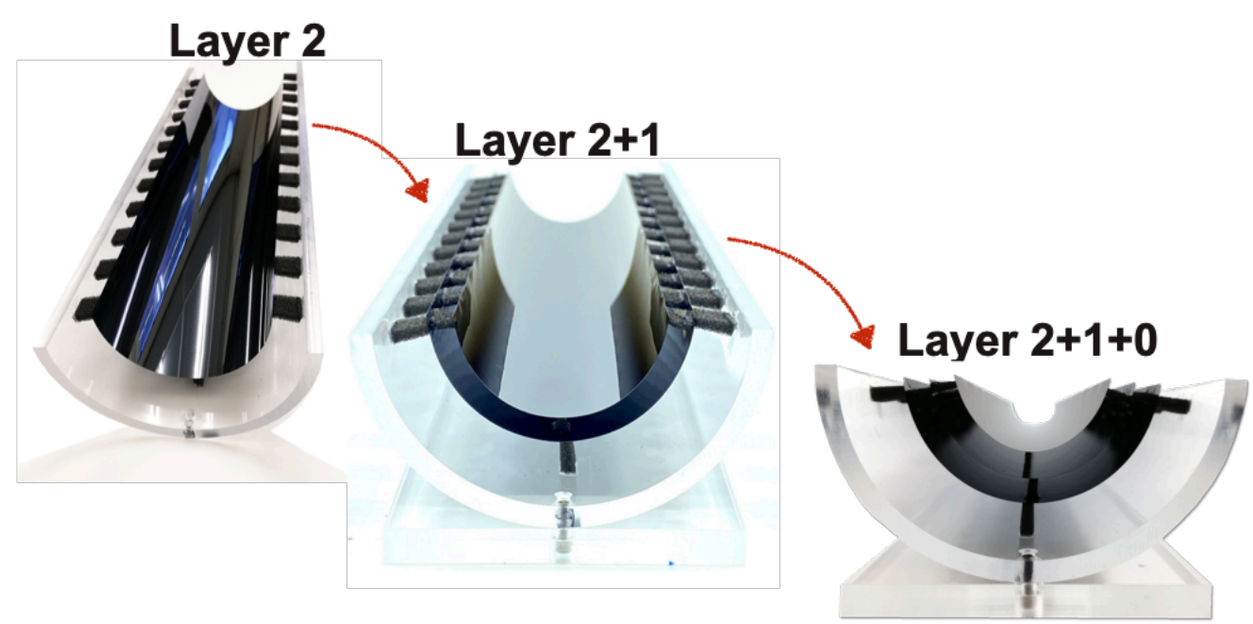
» Currently working solution based on segmented mylar foil



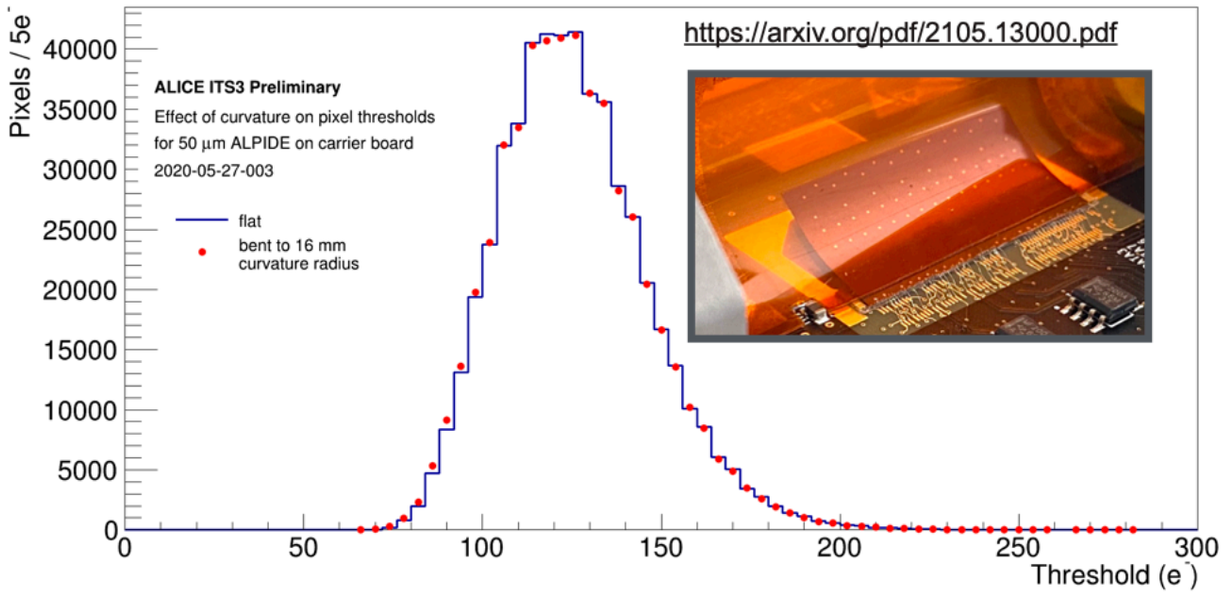


footprint effect
+ bending between wedges

Carbon foam wedges
+ fleece (to reduce glue)

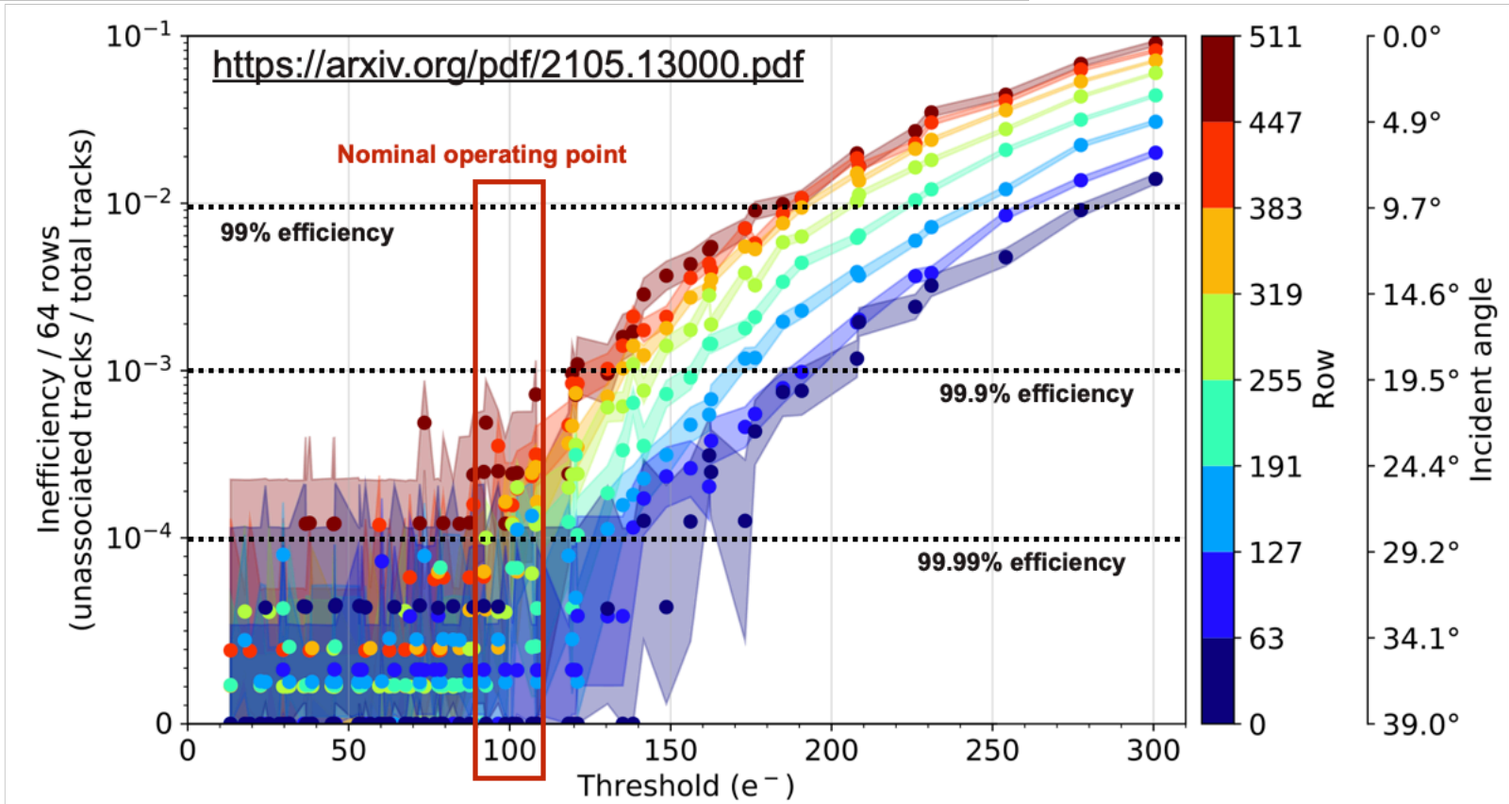


BACKUP

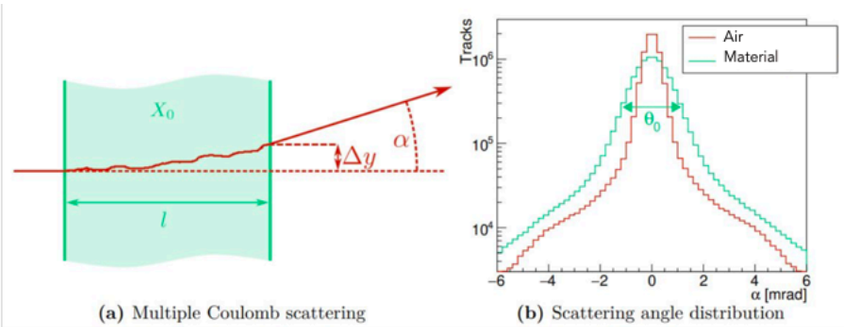


» Laboratory and test beam measurements (Jun 2020) allow to conclude that **chip performance doesn't change after bending**

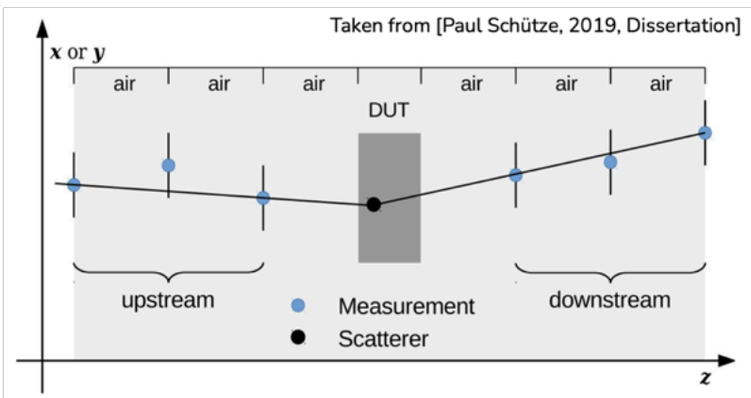
- Pixel matrix threshold distribution does not change when sensor is bent
- Efficiency above 99.9% at a threshold of 100 e^- (normal operating point)

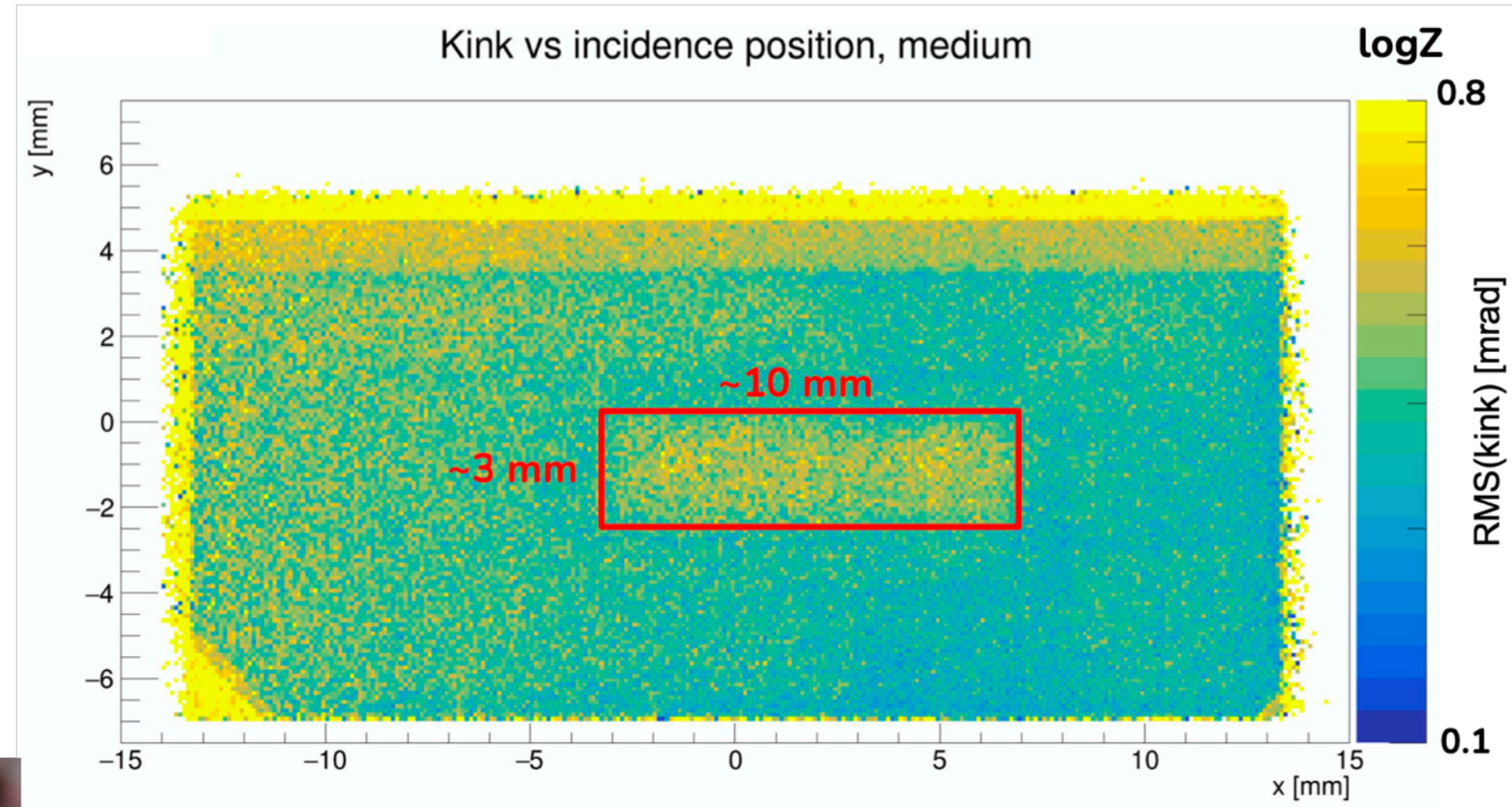


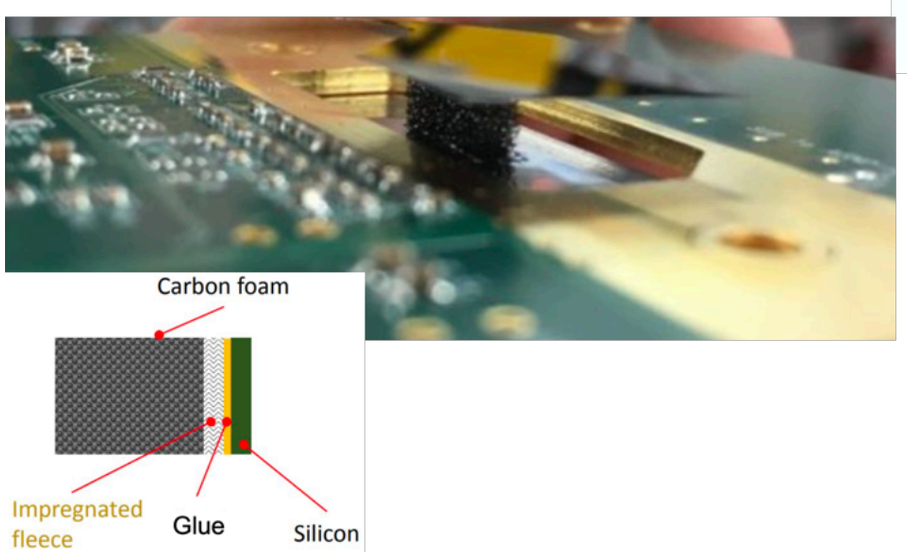
BACKUP



(a) Multiple Coulomb scattering (b) Scattering angle distribution



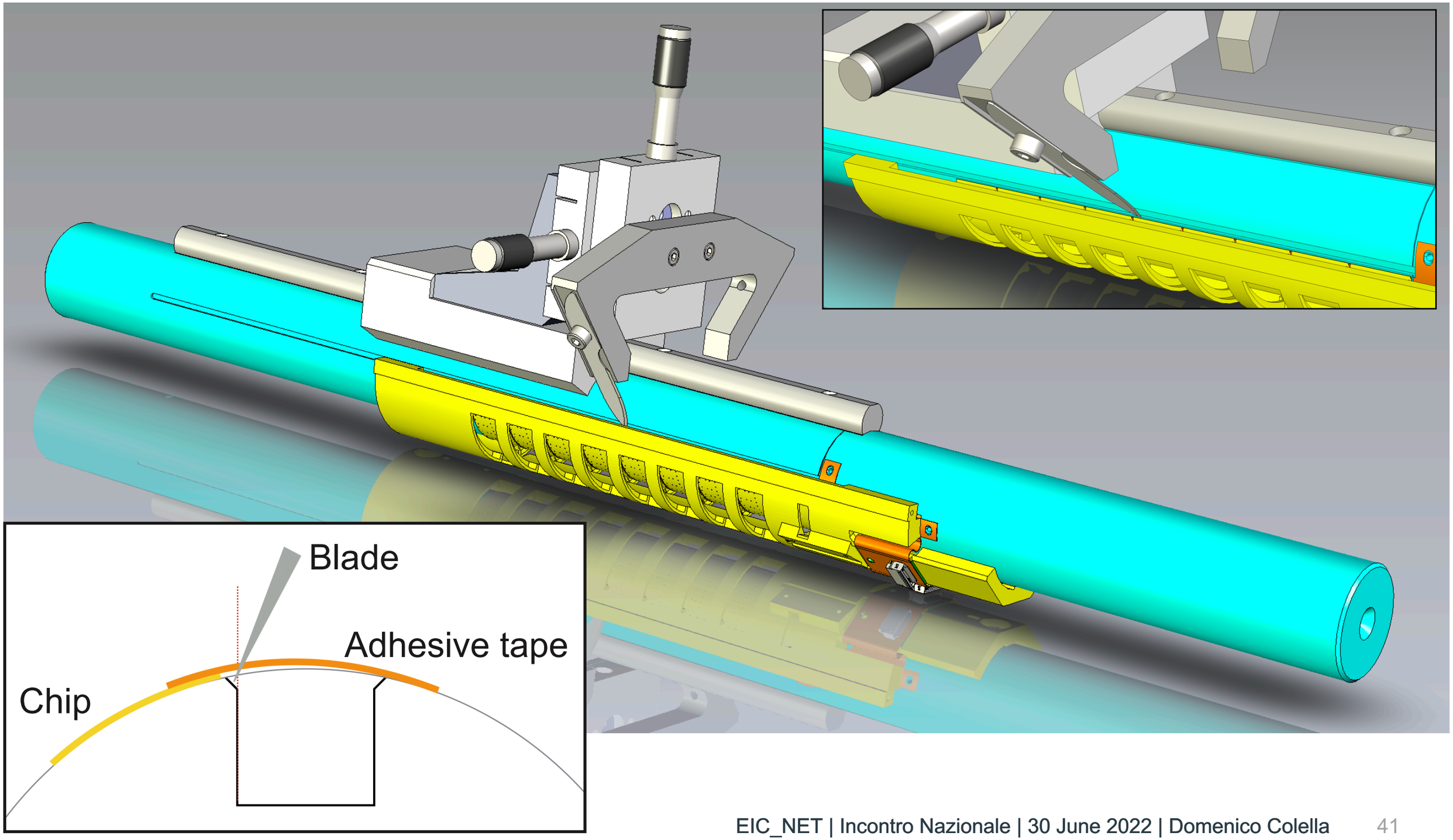




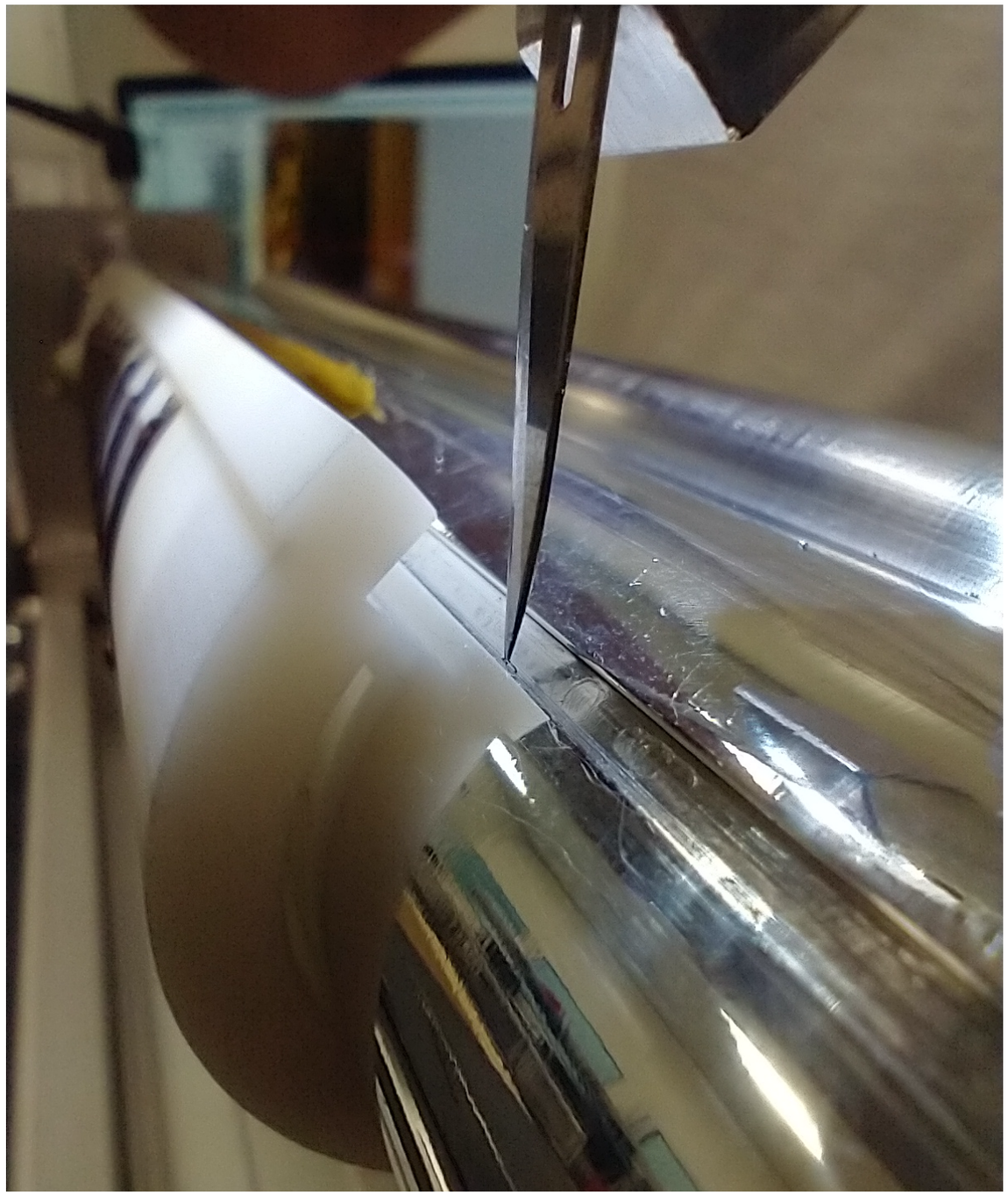
» Analysis of the kink angle distributions at the position of a scatterer

» Material budget image: represents the widths of the scattering angle distribution of all particles traversing a given bin

Cutting tool (for the adhesive tape)



Cutting tool (for the adhesive tape)



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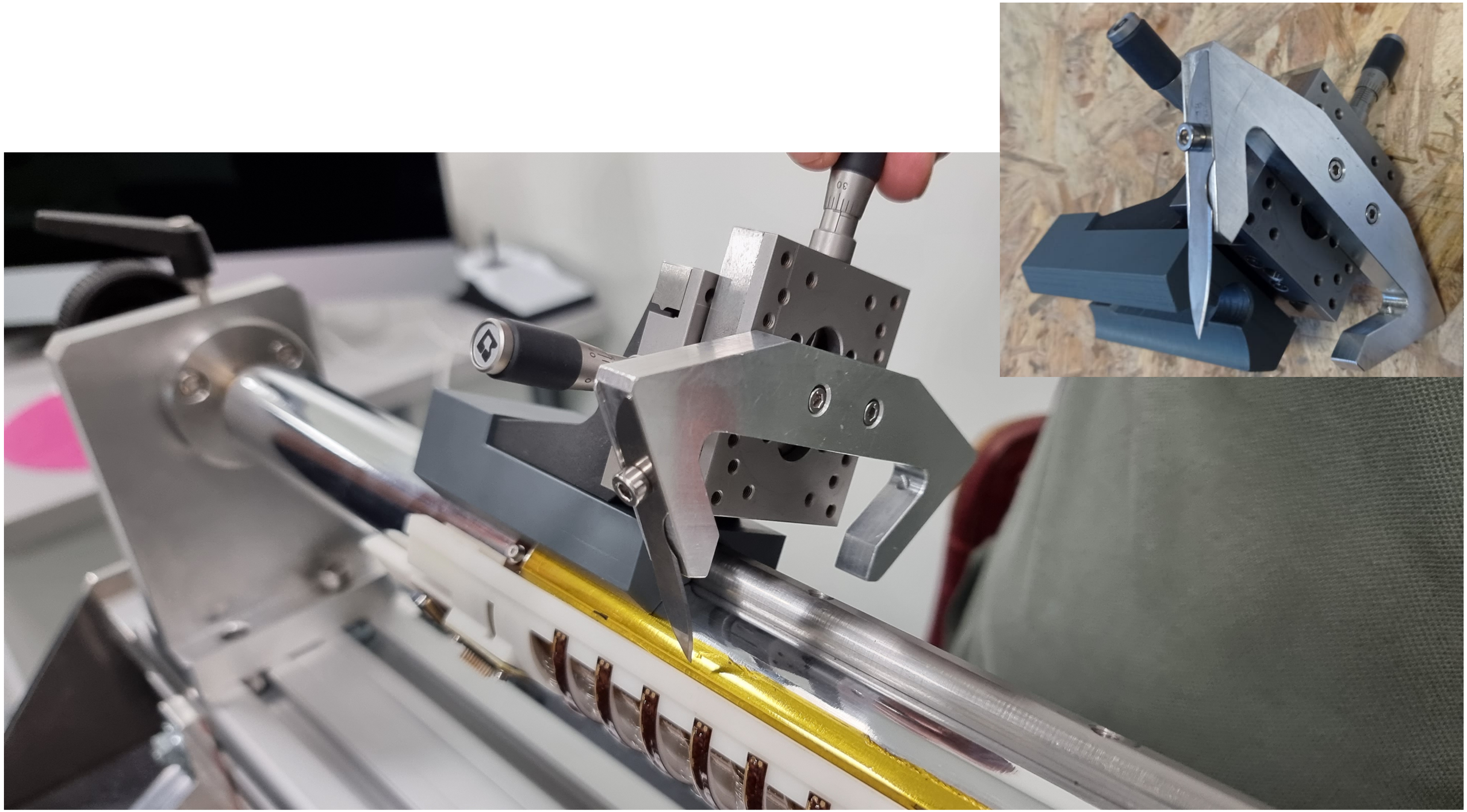
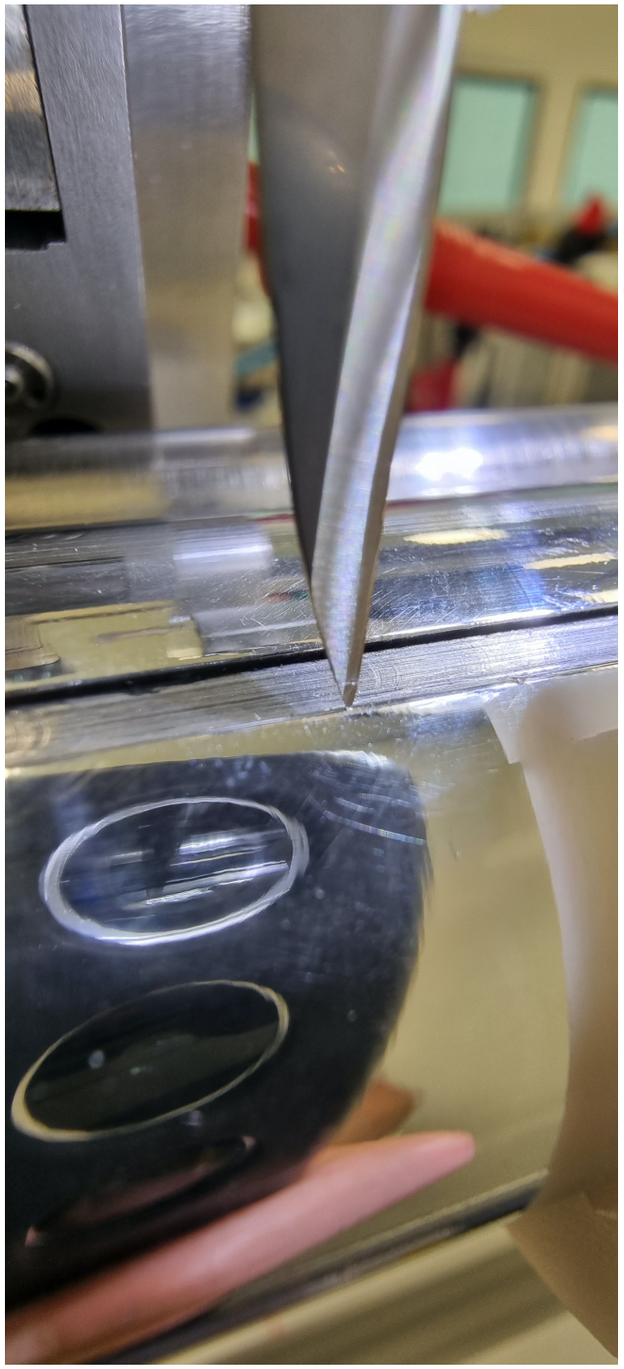
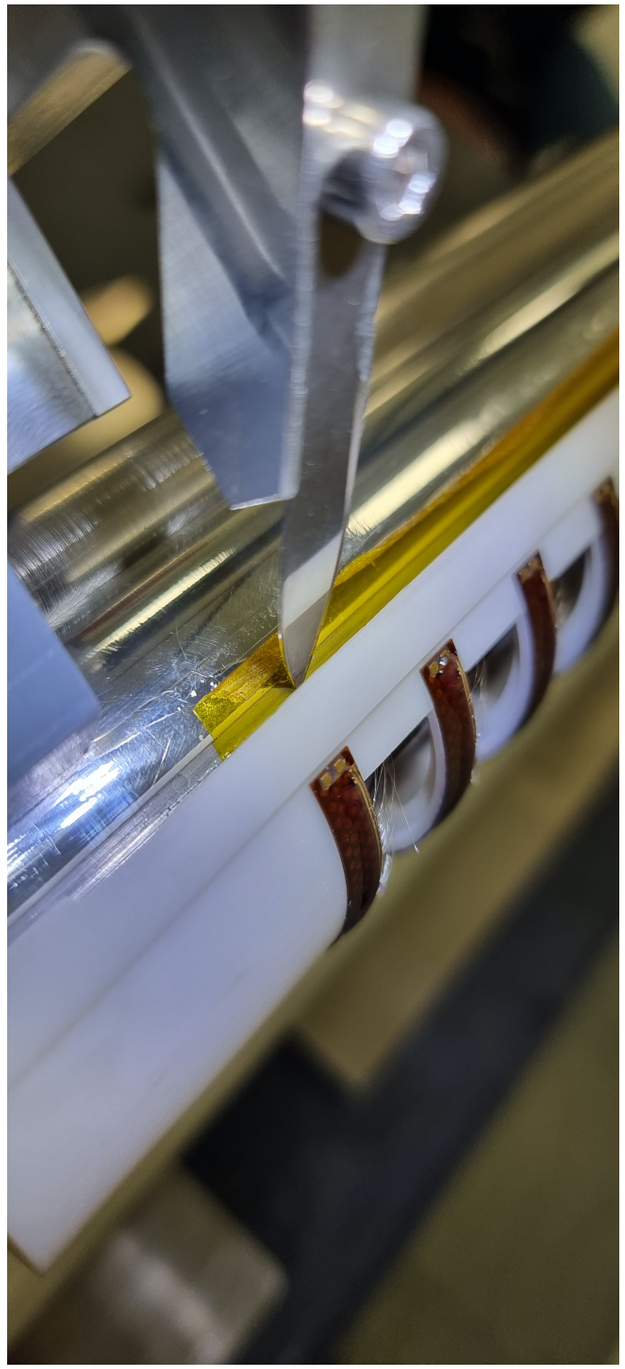
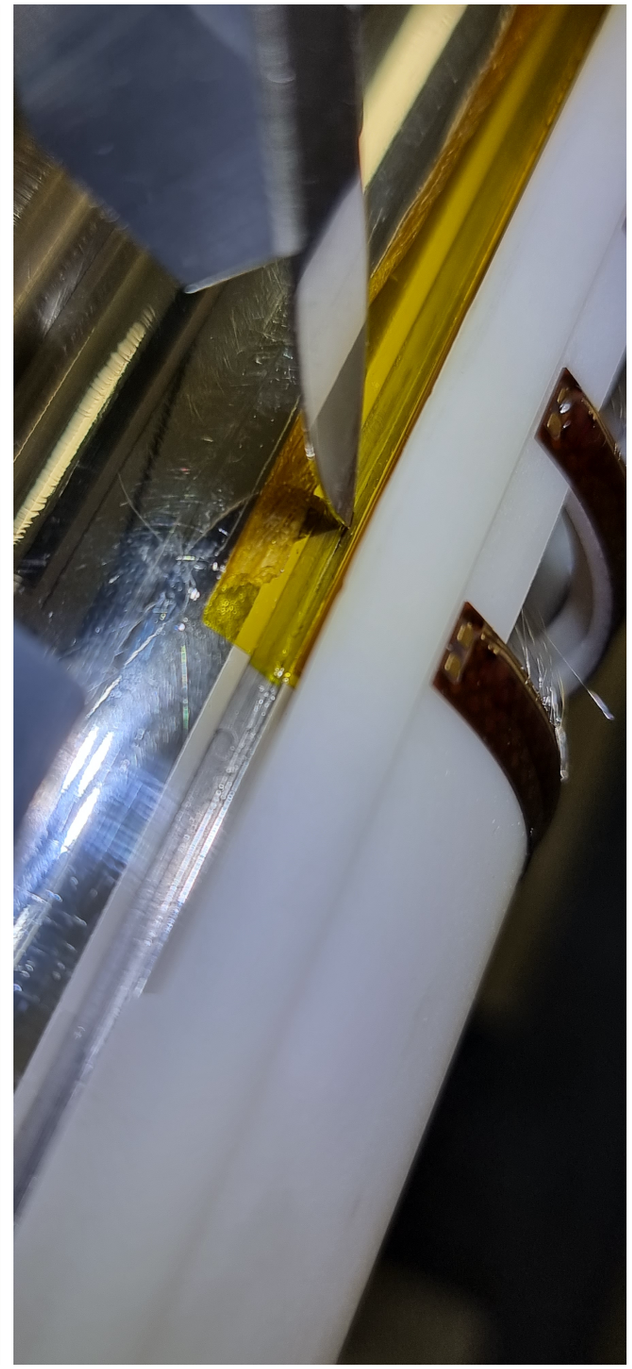
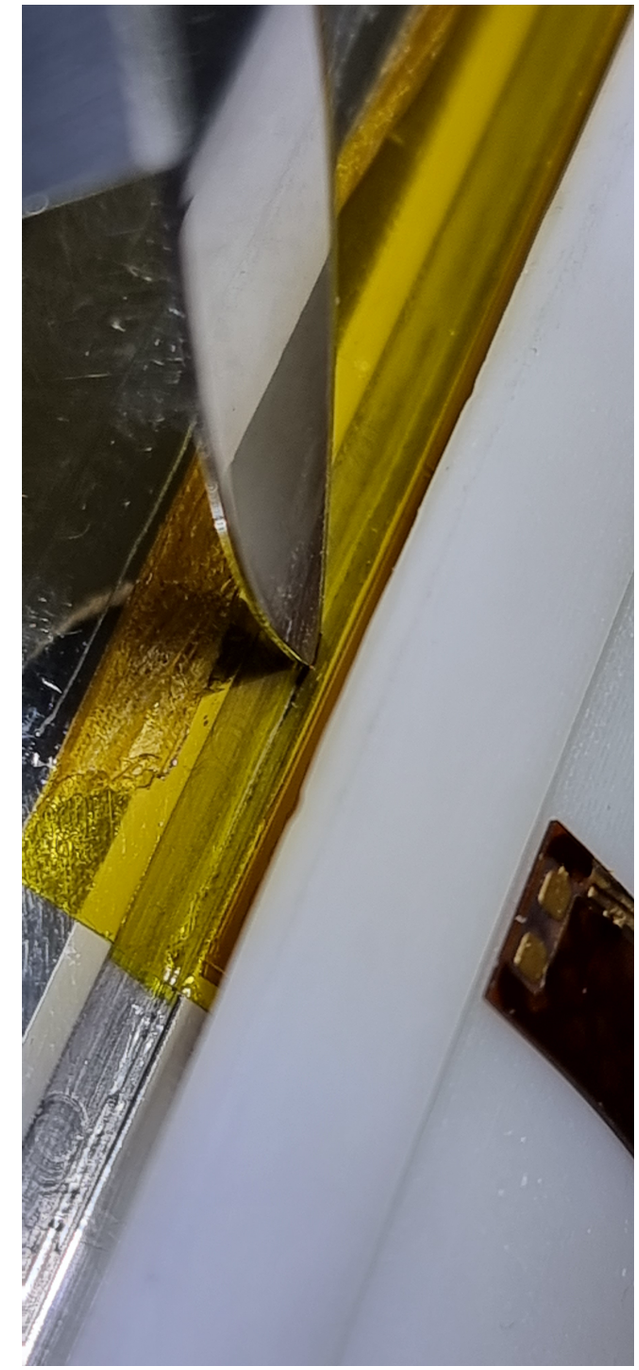
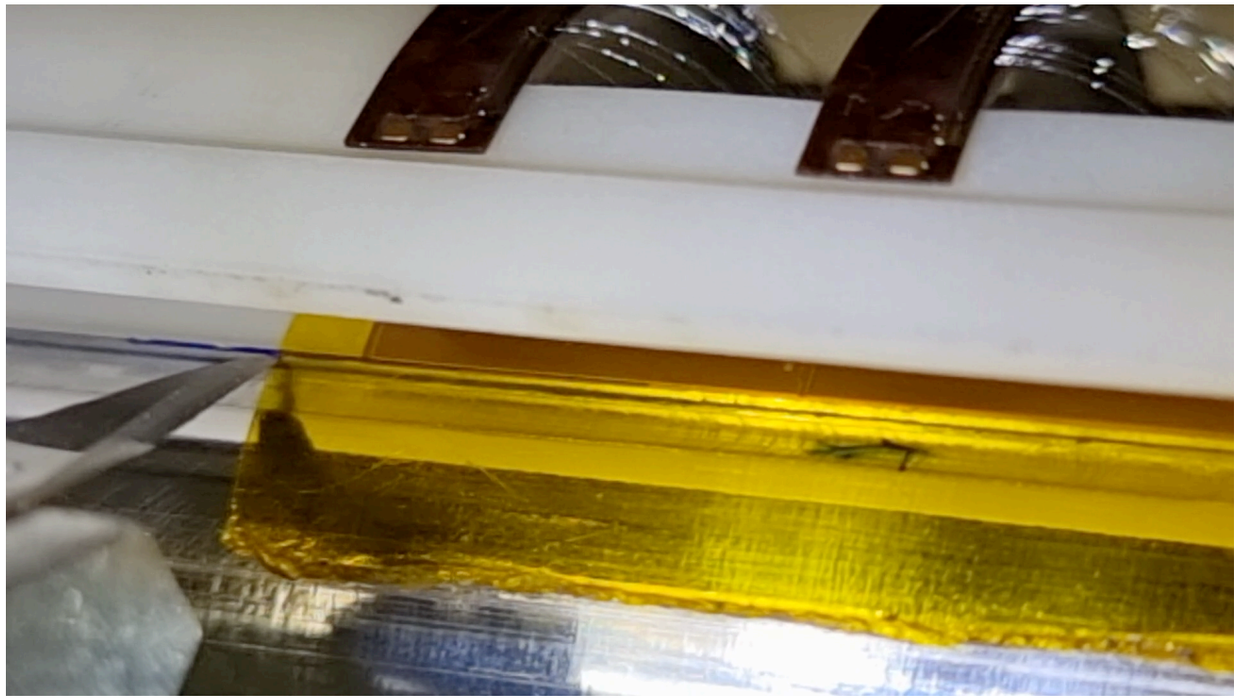
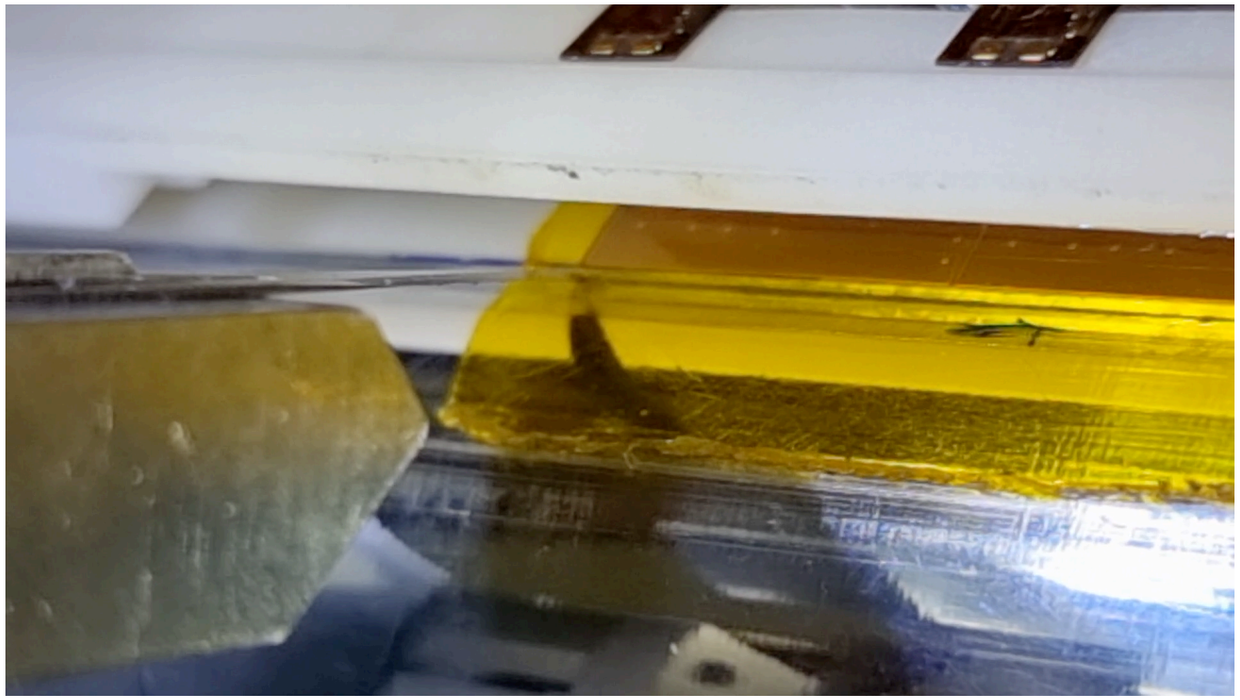


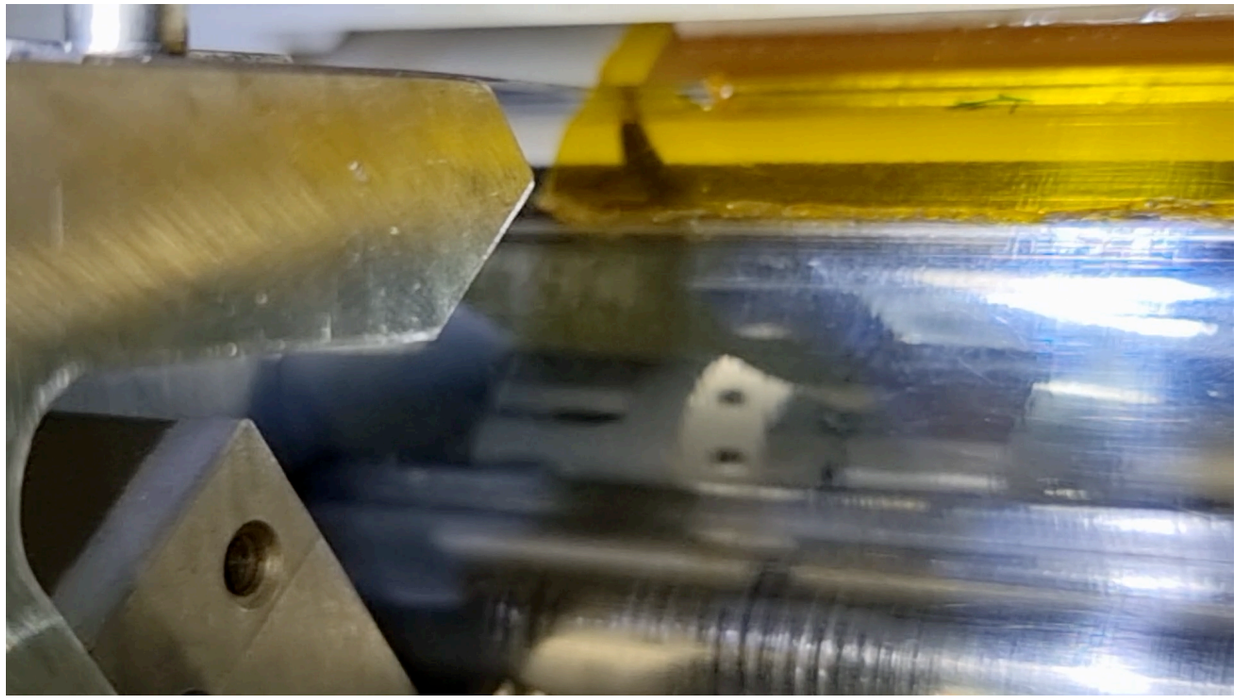
Cutting tool (for the adhesive tape)

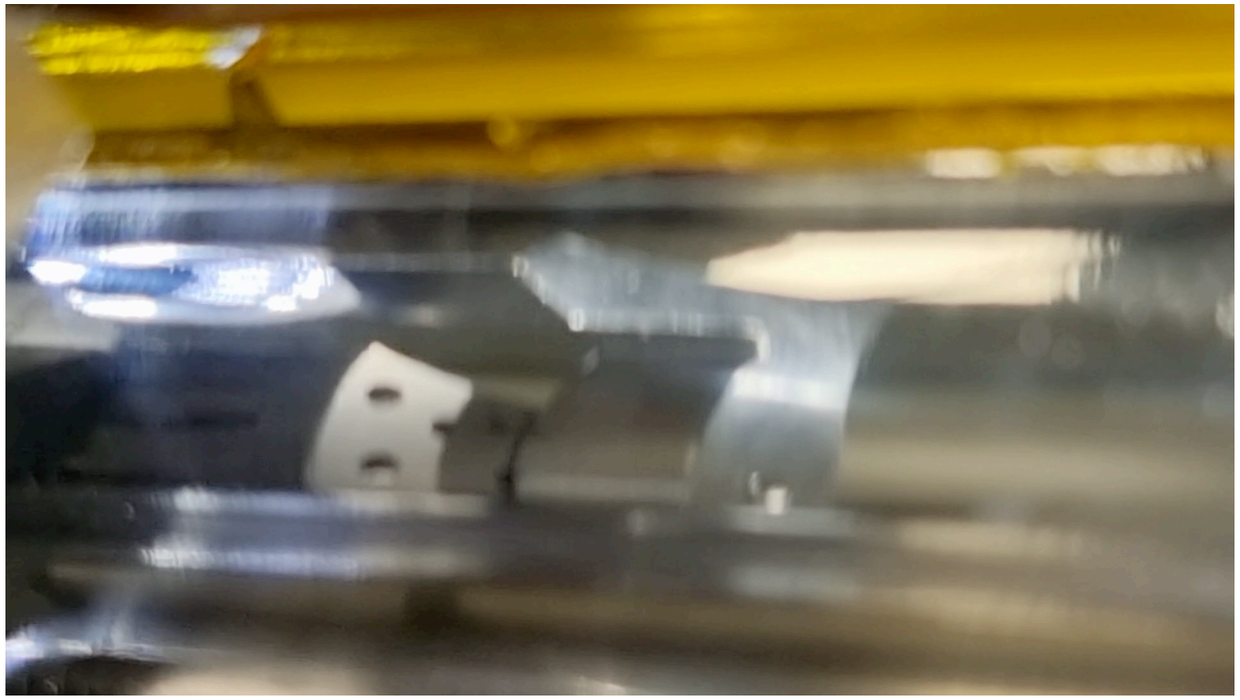





Cutting tool (for the adhesive tape)



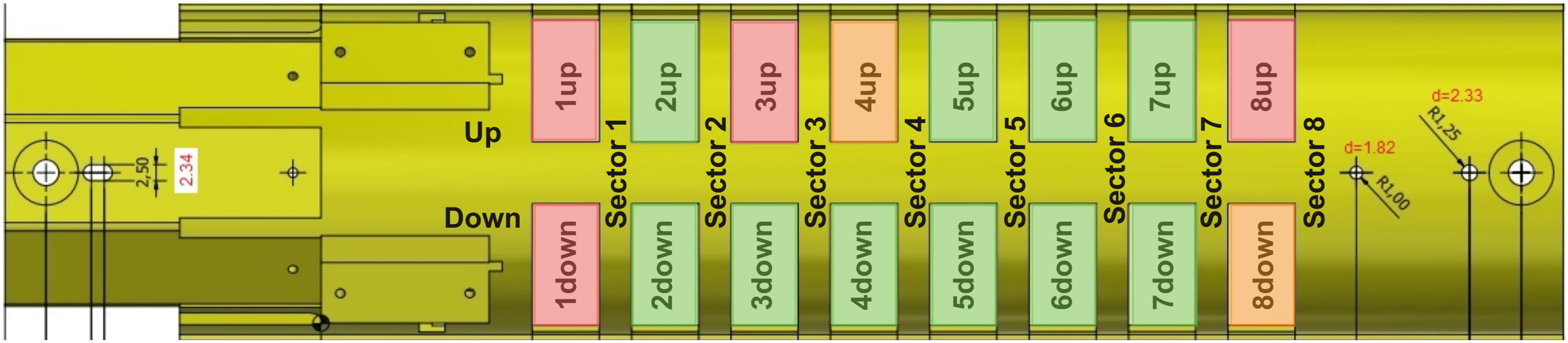


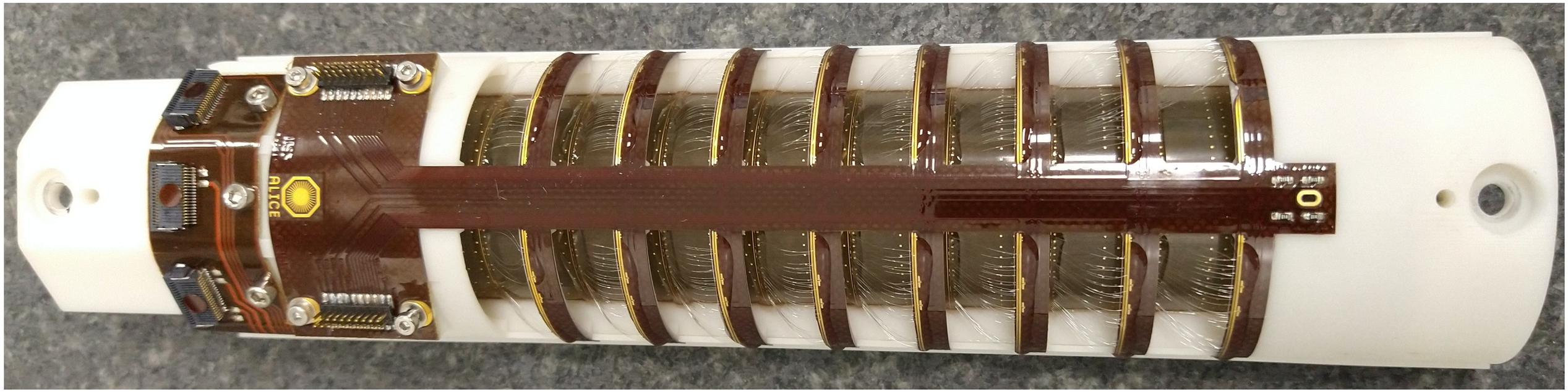


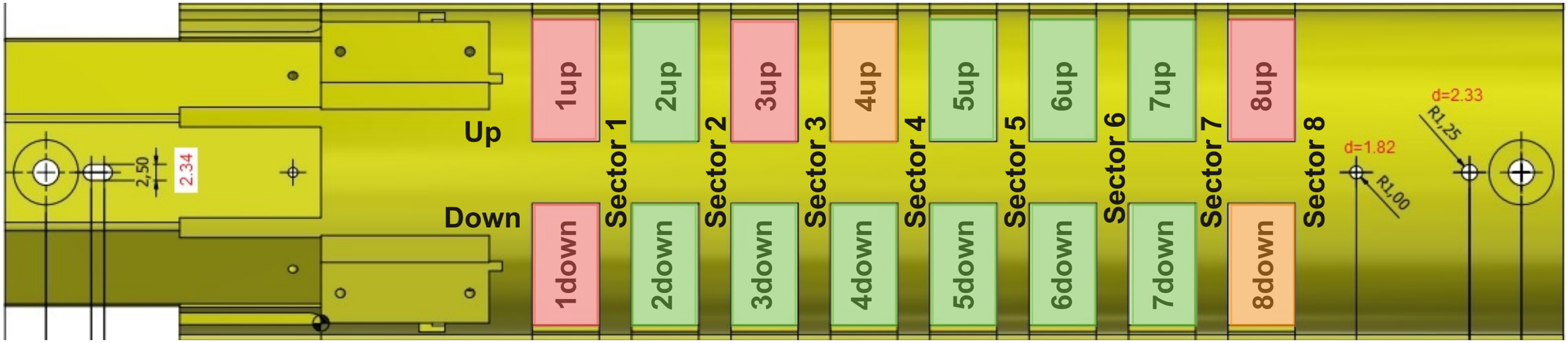


Super-ALPIDE mockup assembly V3

First report given in WP4 on May 26 : https://indico.cern.ch/event/1165136/


Up
Down
1up
2up
3up
4up
5up
6up
7up
8up
1down
2down
3down
4down
5down
6down
7down
8down
Sector 1
Sector 2
Sector 3
Sector 4
Sector 5
Sector 6
Sector 7
Sector 8
2,50
2.34
d=1.82
R1,00
d=2.33
R1,25


ALICE



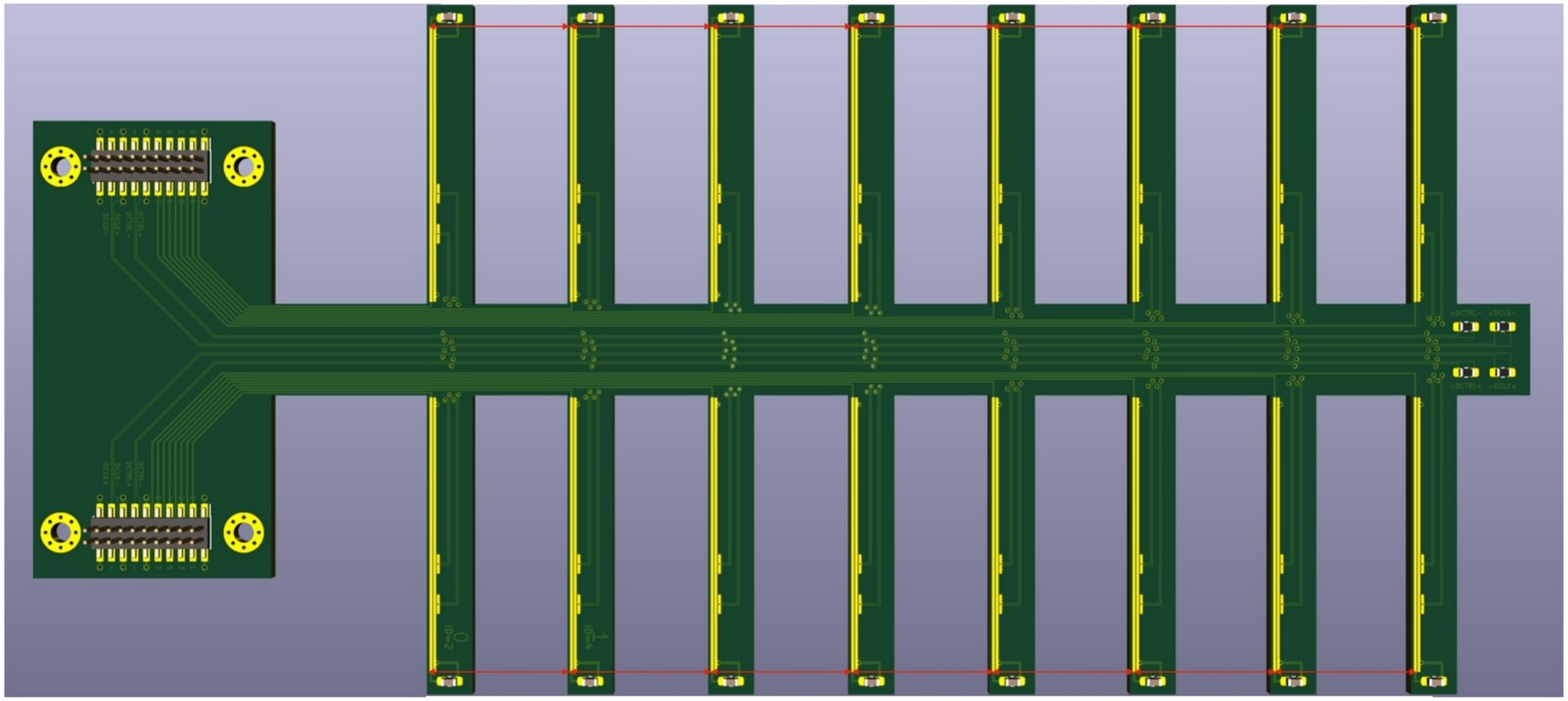
		1UP	2UP	3UP	4UP	5UP	6UP	7UP	8UP	1DOWN	2DOWN	3DOWN	4DOWN	5DOWN	6DOWN	7DOWN	8DOWN
PAD	FAILURES	24	4	17	17	2	2	3	3	22	3	3	3	3	3	3	4
A	HEIGHT				7252	7266	7275	7246	7212	7177	7230	7169	7161	7176	7205	7269	7333
17	DVSSS	X	X	X	X	X	X	X	X								
18	DVDD	X	X	X	X	X	X	X	X	X							
19	PWELL	X	X					X	X								
23	DVSS	X															
24	DVDD				X					X							
26	POR_DIS_N	X		X													
27	AVSS	X		X	X												
28	AVDD	X	X	X	X					X							
29	DCTRL_P	X															
30	DCTRL_N	X															
31	DVSS			X	X					X							
32	DVDD				X												
33	SUB				X					X							
34	AVSS			X	X					X							
35	AVDD	X		X	X					X							
38	DVSS			X						X							
39	DCLK_P									X							
40	DCLK_N									X							
41	DVDD	X			X					X							
42	PWELL			X	X					X							
43	DVSS	X		X	X					X							
44	DVDD	X		X	X					X							
45	AVSS									X							
46	AVDD	X		X	X					X							
47	CHIPID[3]																X
48	PVSS	X								X							
49	PVDD	X			X					X							
50	PVSS			X	X					X							
51	PVDD	X															
54	DVDD	X															
55	CHIPID[2]																
56	DVSS			X													
58	AVSS																
59	AVDD																
60	DVSS	X		X													
61	DVDD	X															
63	DVSS																
64	DVDD	X															
65	DVSS																
66	DVDD	X															
69	DVSS			X													
70	DVDD																
71	CHIPID[1]																
74	DVSS																
75	DVDD	X															
76	DVSS																
79	DVDD	X								X	X	X	X	X	X	X	X
80	AVDD									X	X	X	X	X	X	X	X
81	AVSSS									X	X	X	X	X	X	X	X

→ For UP side covered by exoskeleton

- Sectors **1UP**, **3UP**, **4UP** and **1DOWN** similar situation → a lot of bonding failures
- Sector **8UP** → Human error
- Sector **8DOWN** → “Bad lucky”

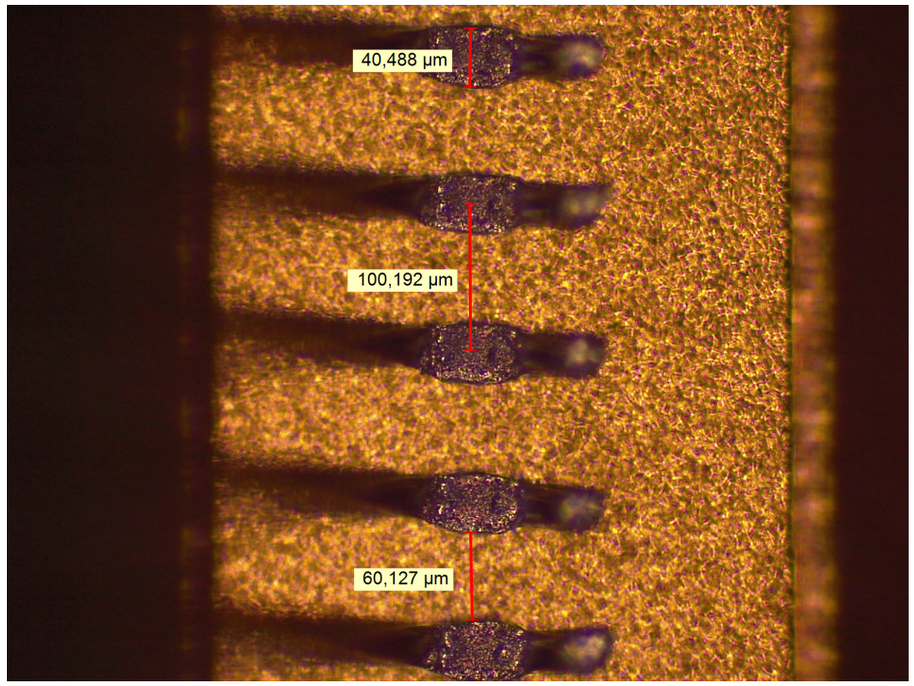
→ For DOWN side covered by exoskeleton

BACKUP

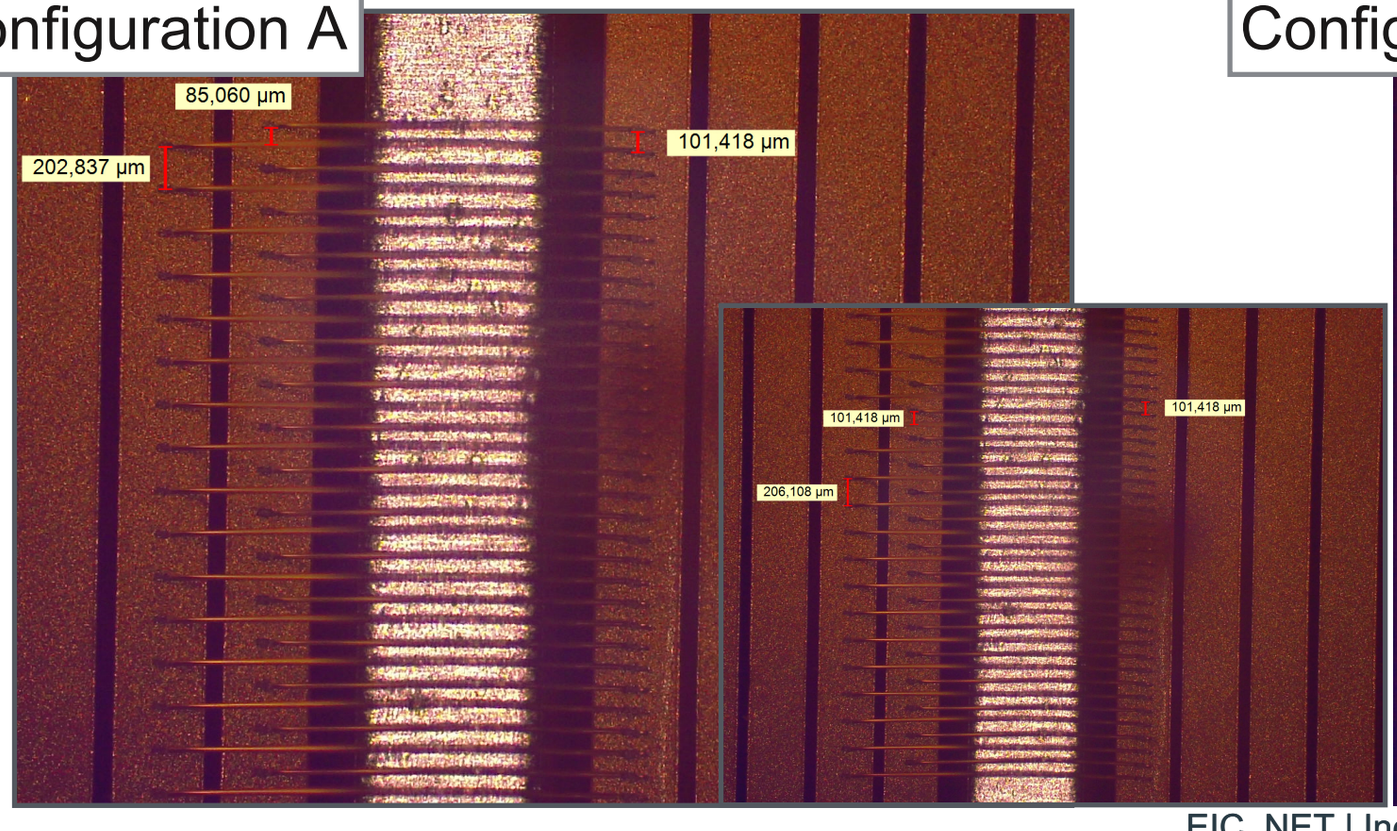
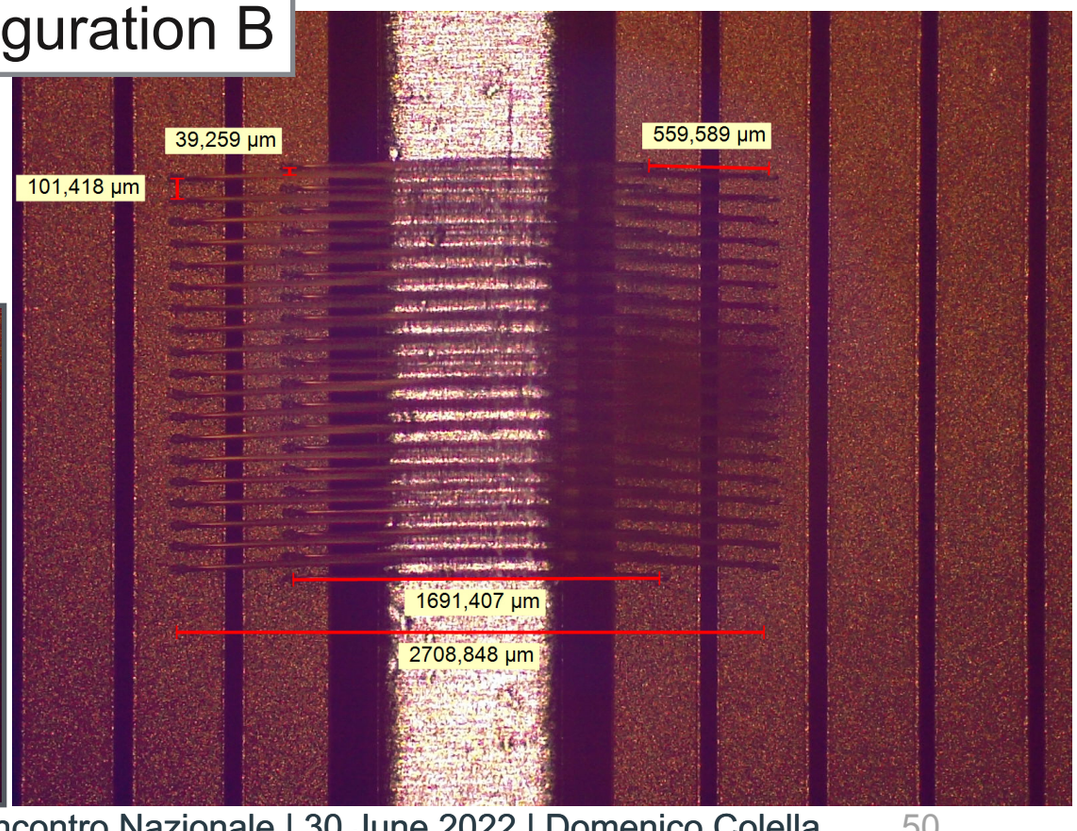


Wire-bonding performance study

- With a wire thickness of 25 µm, a foot width of ~40 µm is expected → minimal pad dimension ~80 µm
- **~100 µm inter-pad distance** can be easily achieved
- **Configuration B allow to double the bonding density**, but requires staggered pads



Configuration A



Configuration B