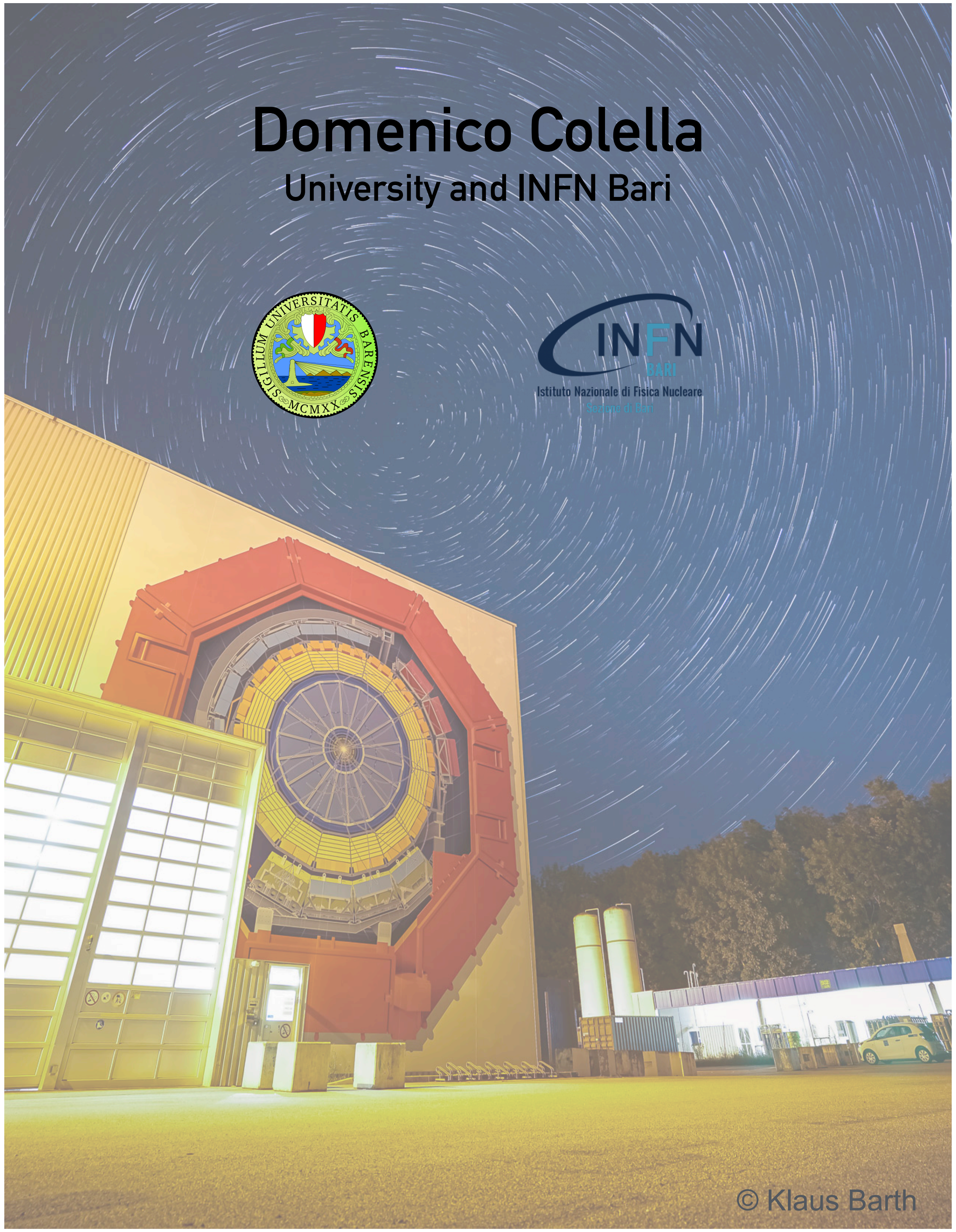
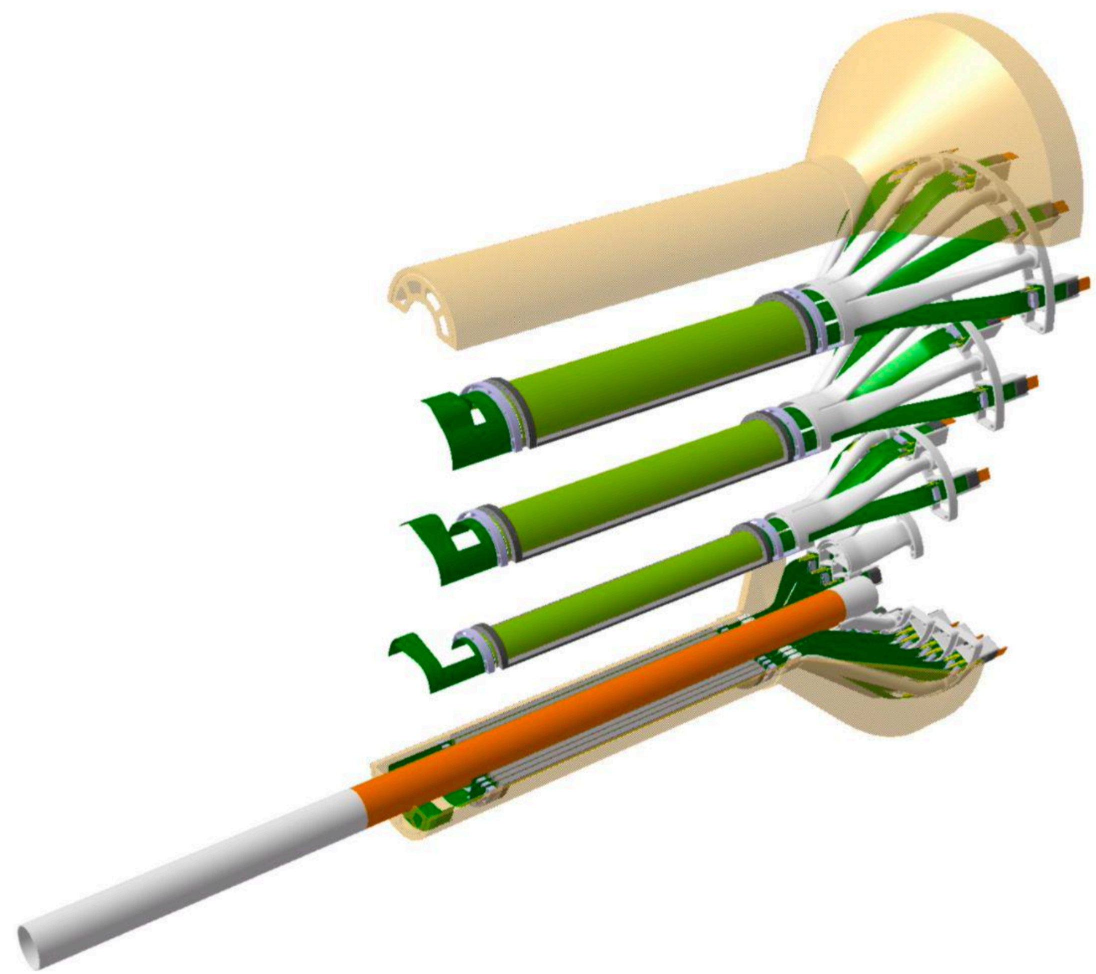
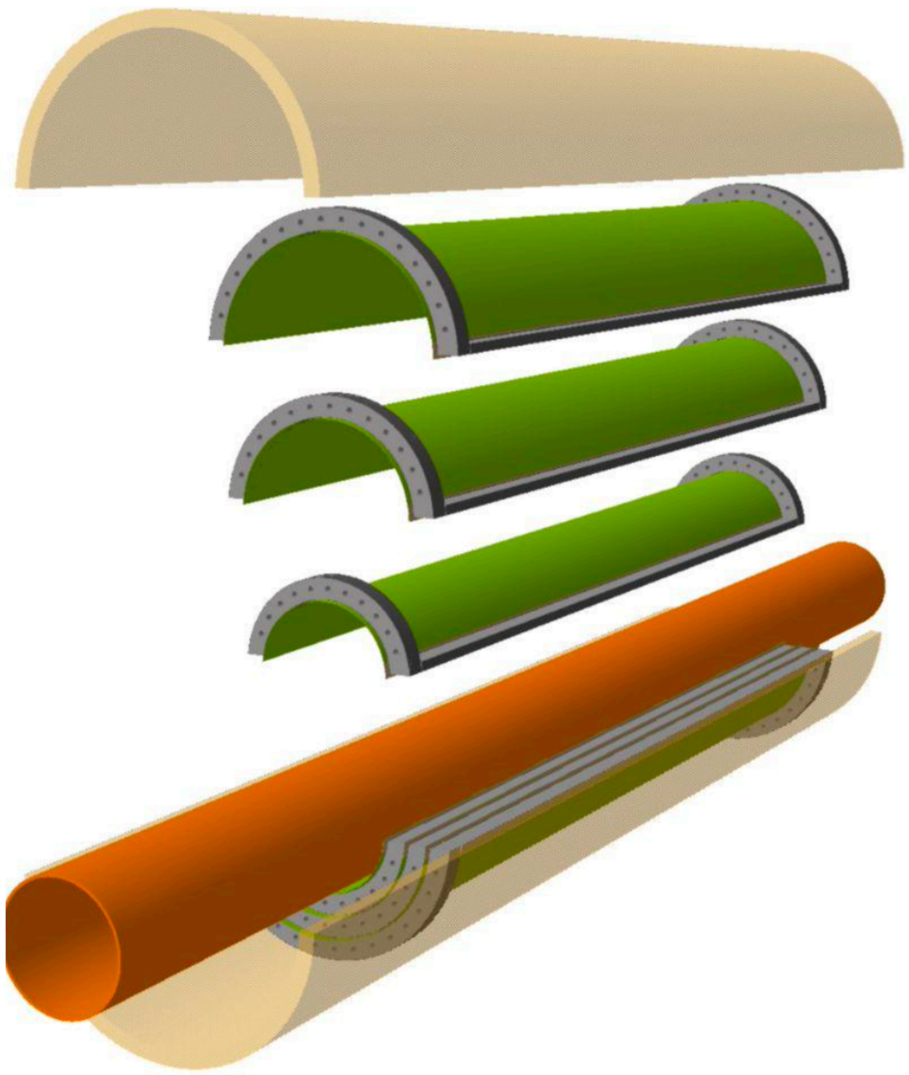
Domenico Colella
University and INFN Bari



ALICE ITS3
how to integrate a large dimension MAPS sensor in a bent configuration detector
+ ALICE3

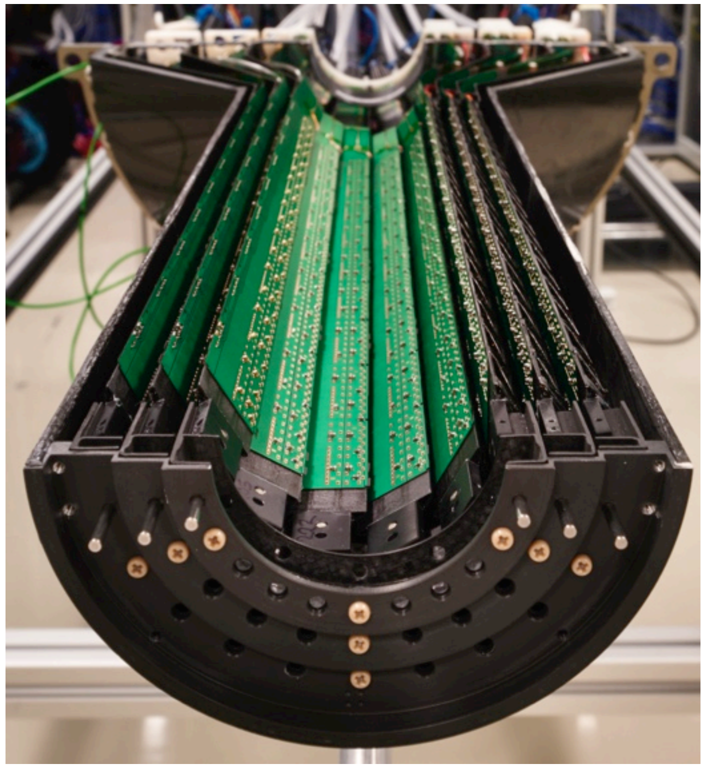


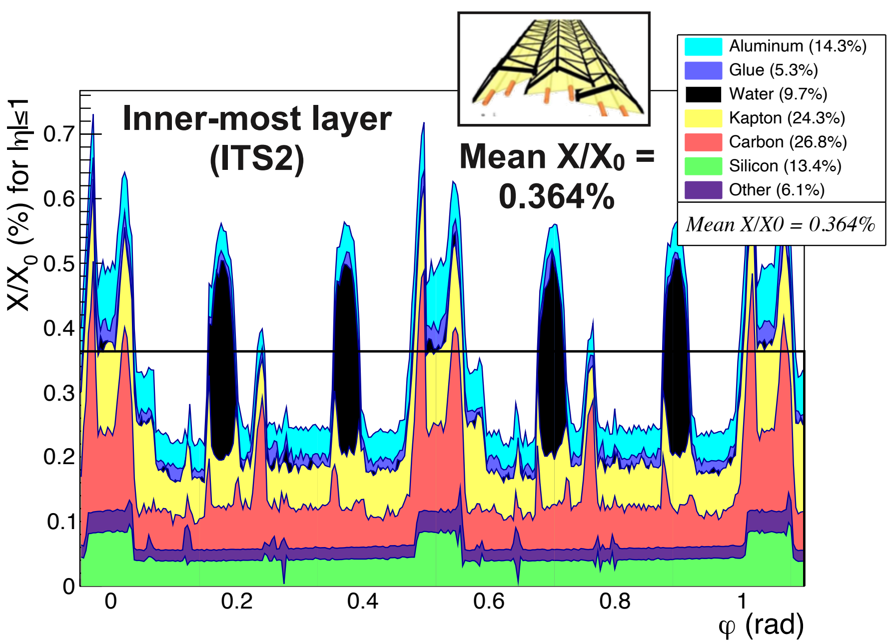
ITS3



ITS3 detector concept

ITS2-IB





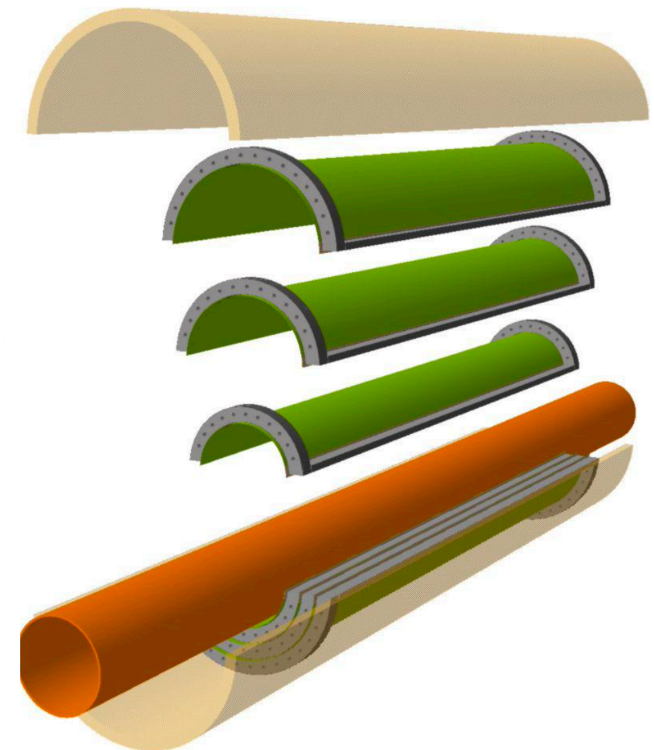
Required improvements

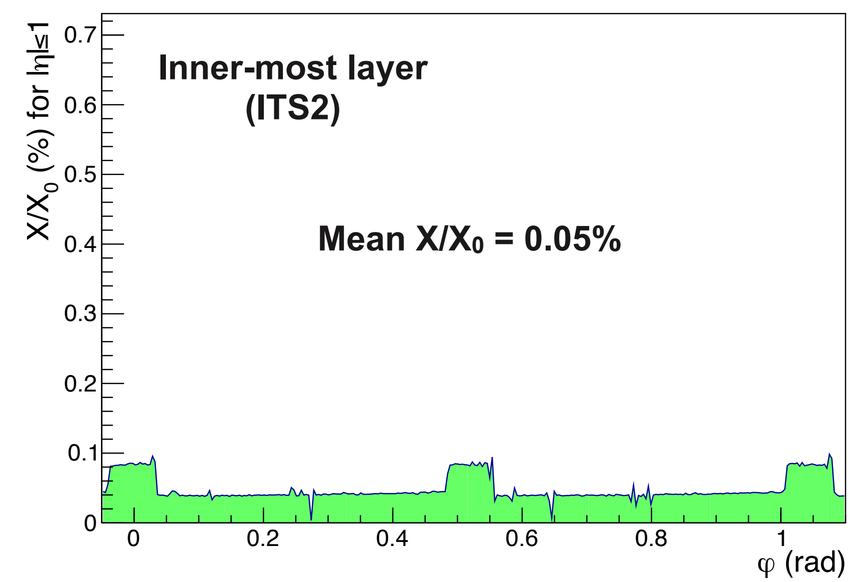
» *Removal of water cooling* → low flow air cooling

» *Removal of circuit board* from the sensitive region

» *Removal of mechanical support* from the sensitive region, profiting from increased stiffness of bent Si wafers

ITS3

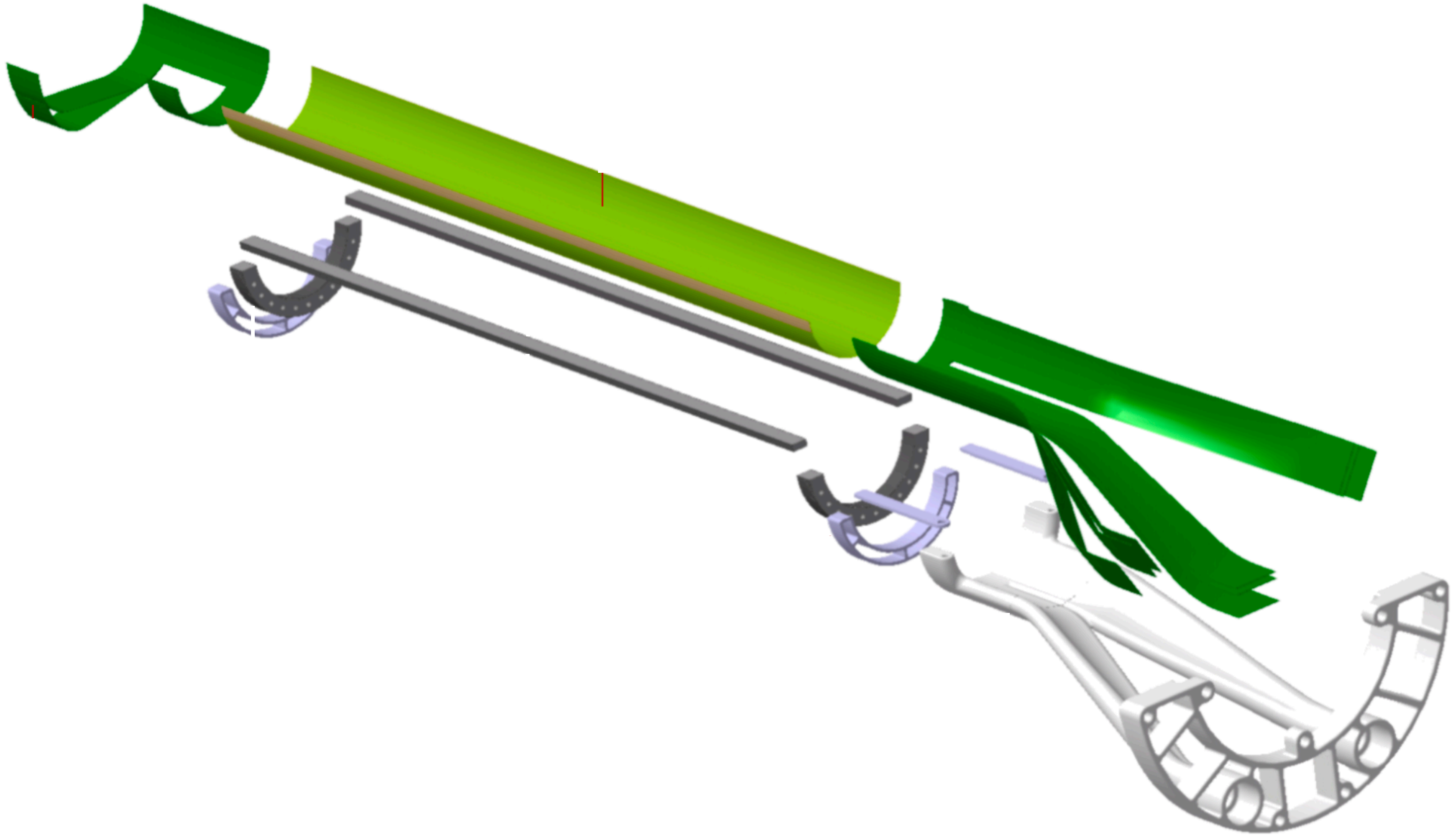




ITS3 detector concept

Key ingredients

» Wafer-scale chips (up to ~28x10 cm), fabricated using stitching
» Si MAPS sensor based on 65 nm technology
» Sensor thickness ≤ 50 μm
» Chips bent in cylindrical shape at target radii
» Ultra light carbon foam structures
» Air cooling



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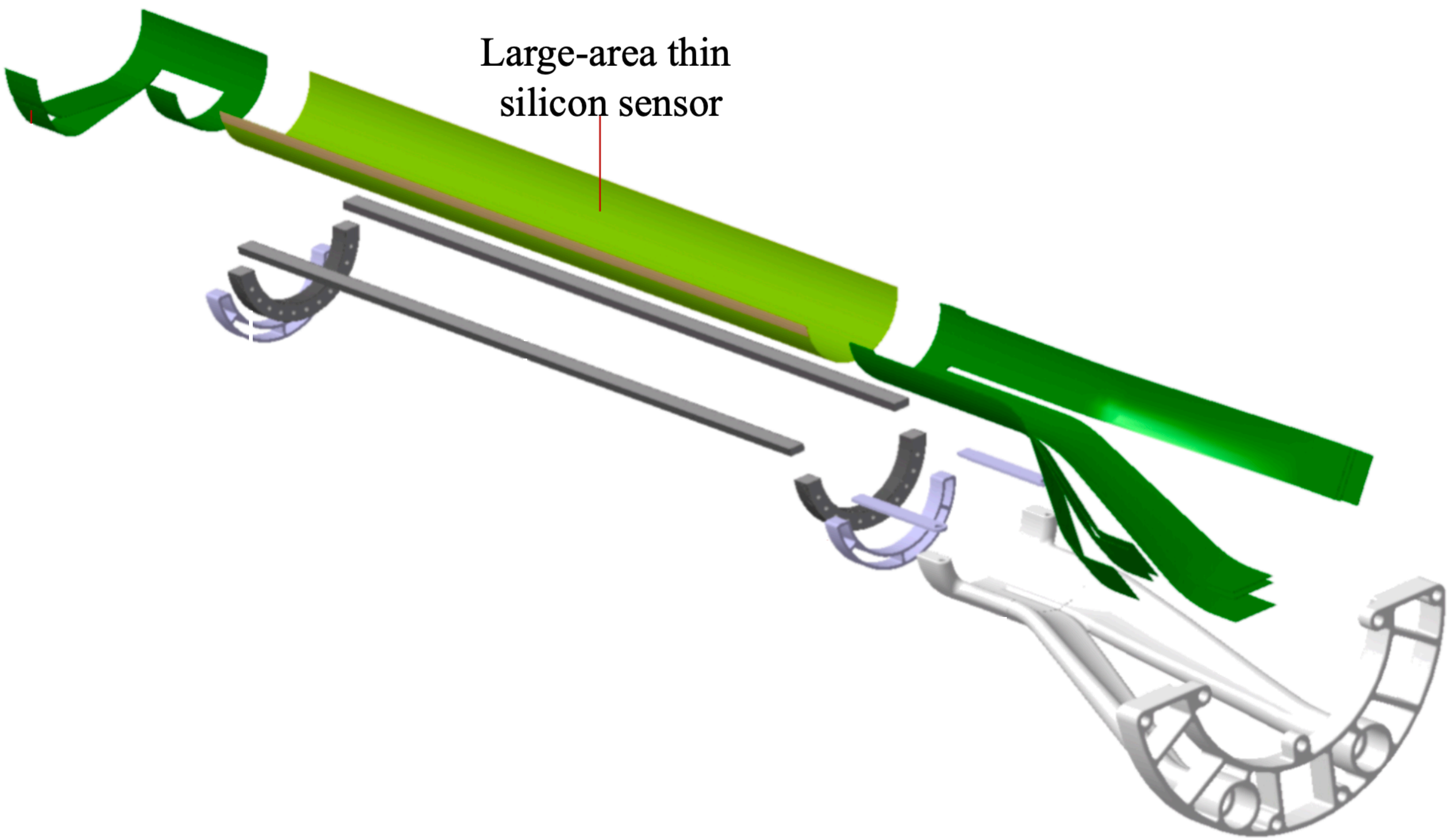

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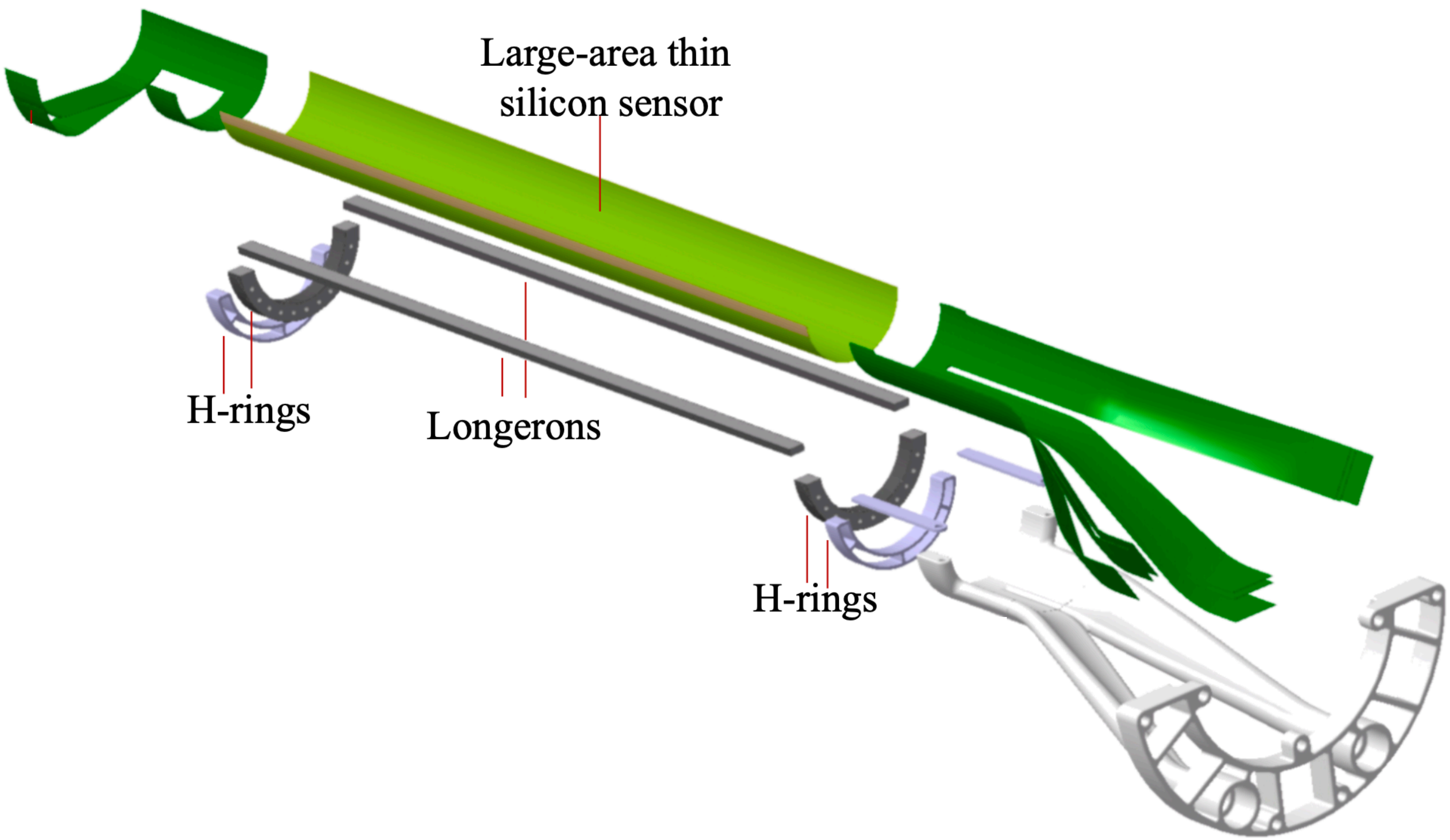

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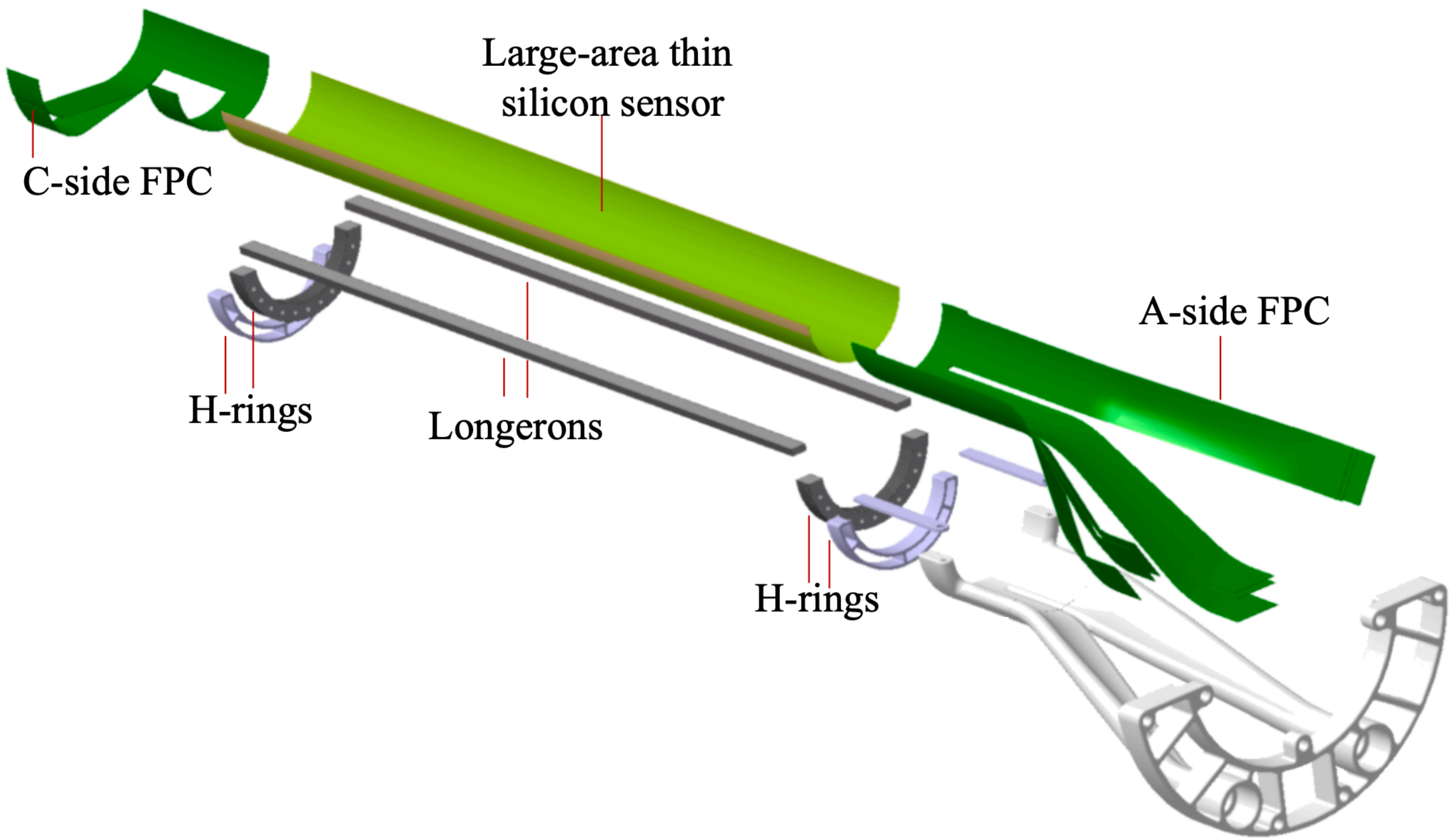

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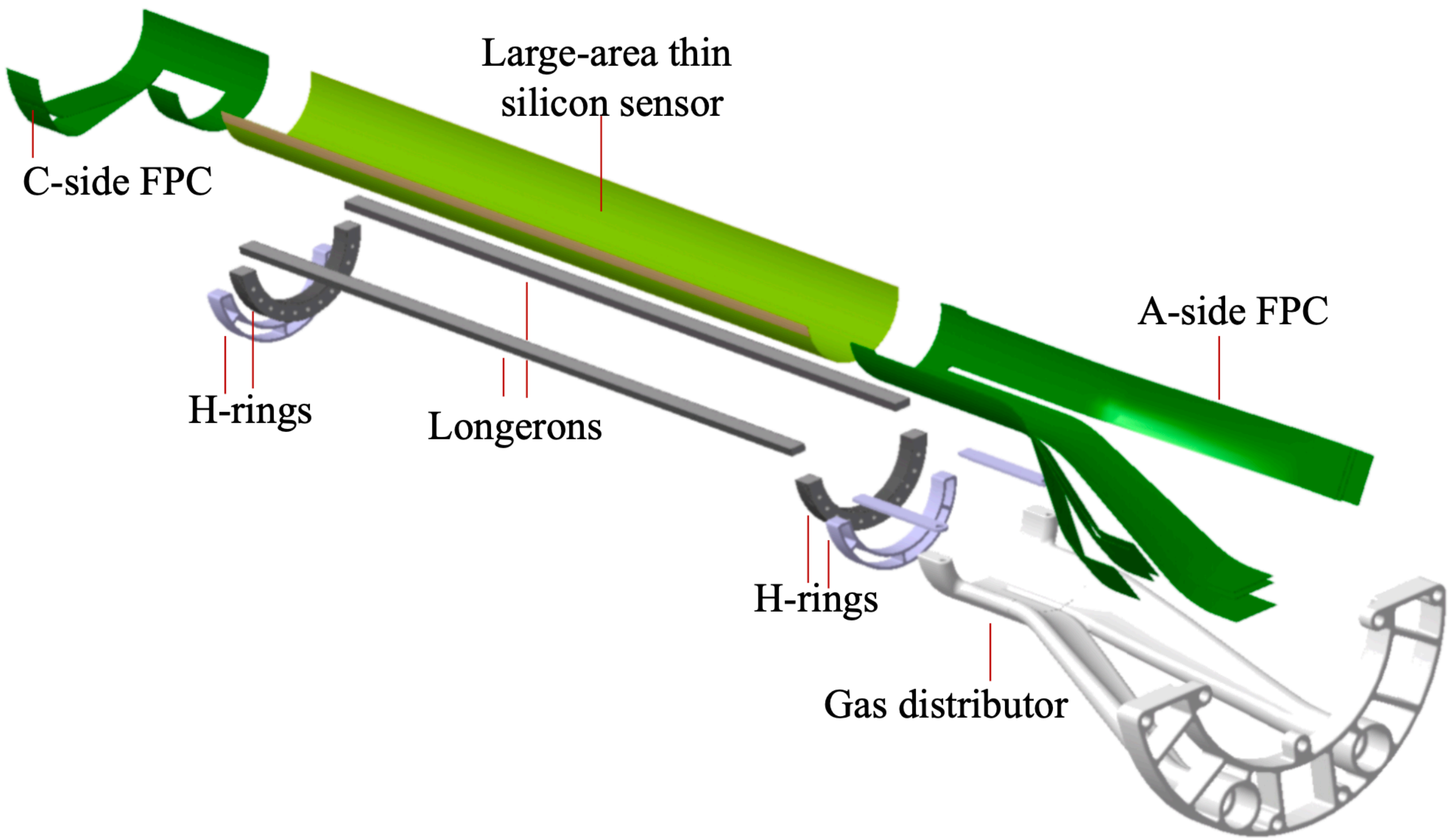

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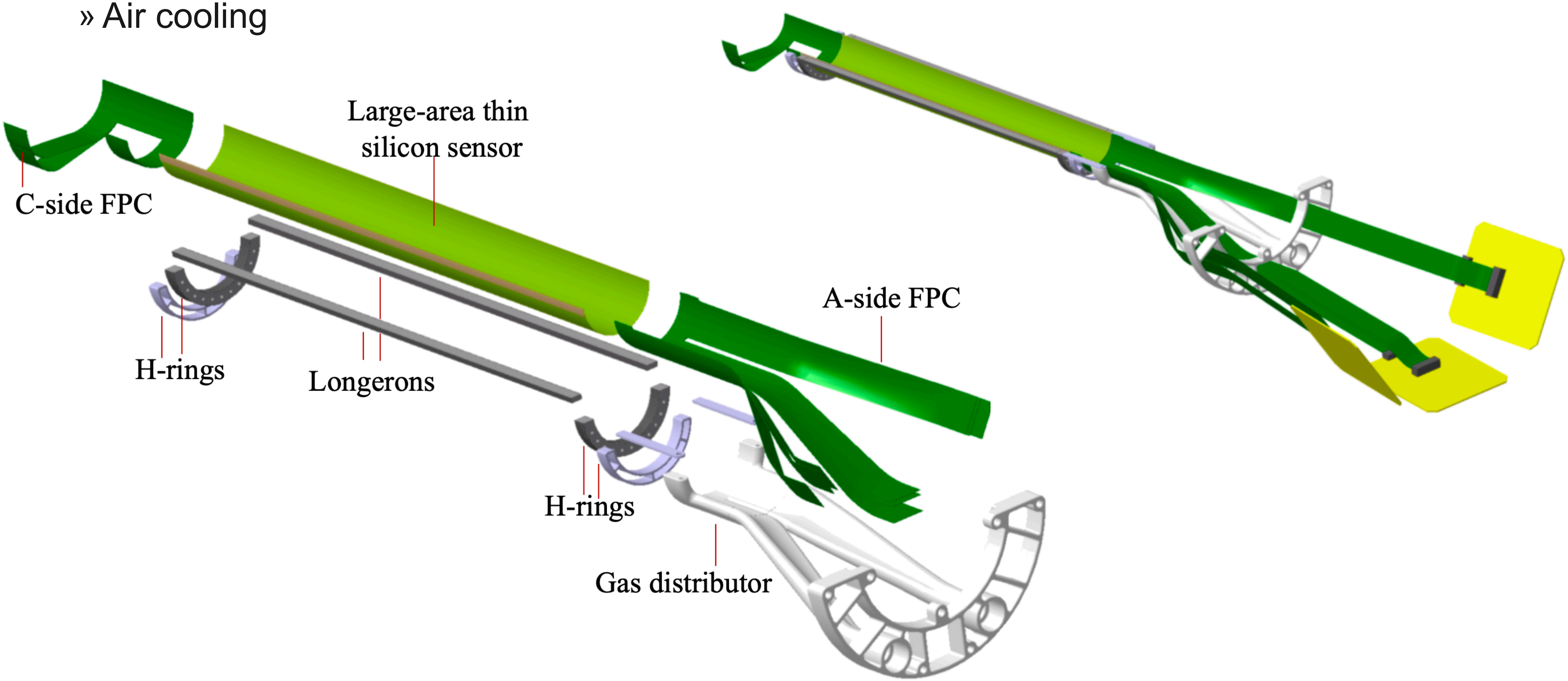

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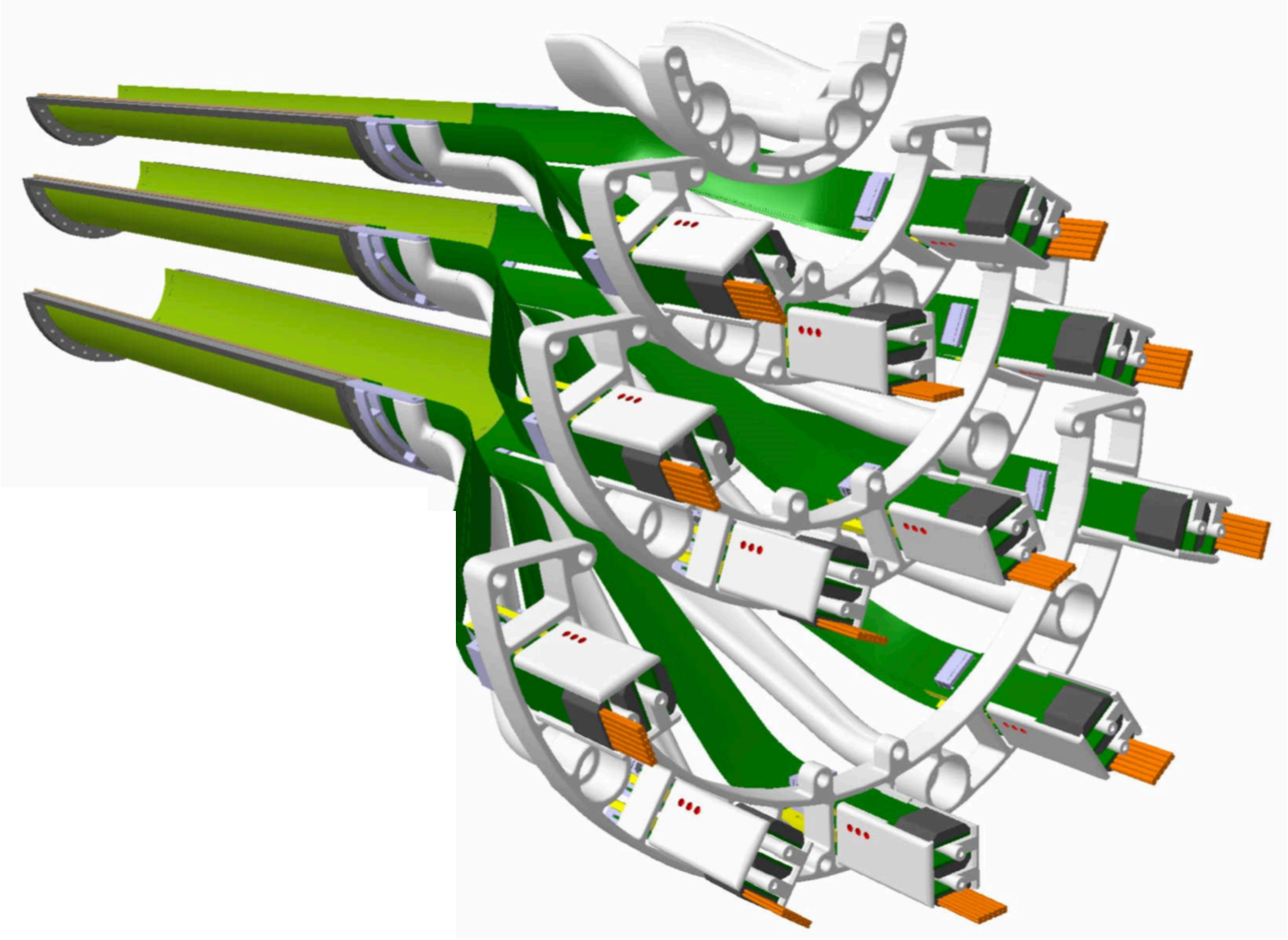

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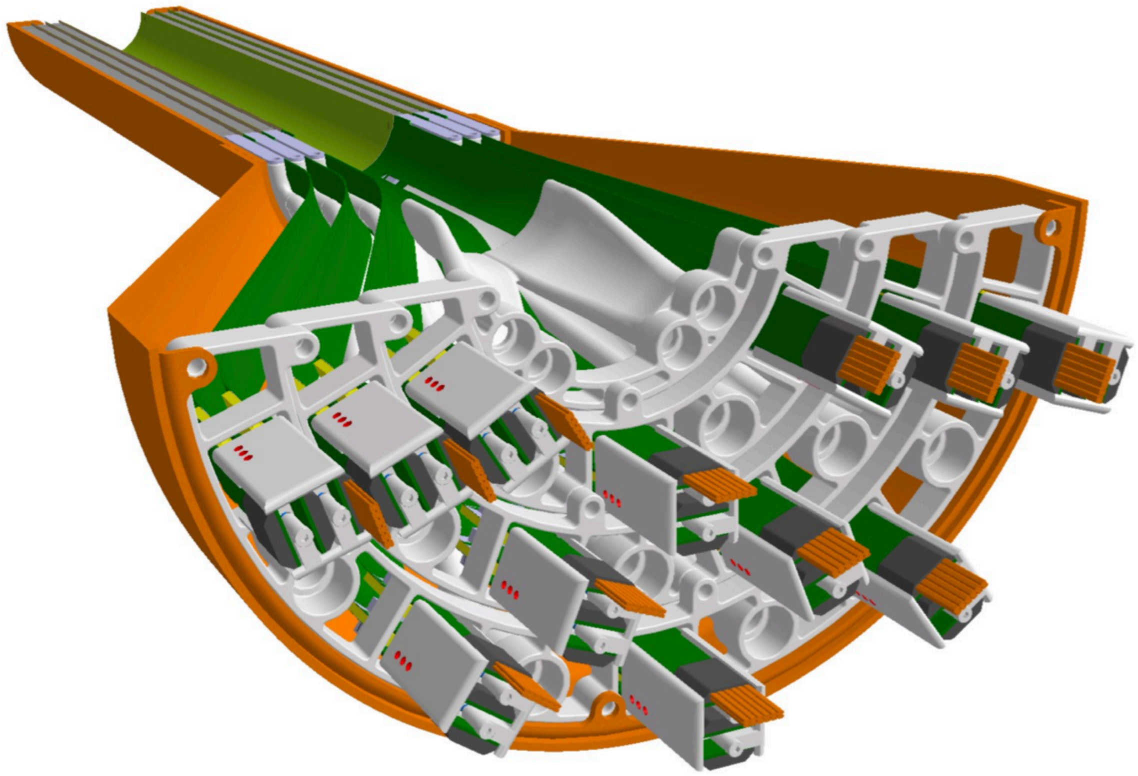

Beam pipe inner/outer radius (mm)	16.0/16.5		
IB Layer Parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length of sensitive area (mm)	280.0		
Pseudo-rapidity coverage	±2.5	±2.3	±2.0
Active-area (cm^2)	610	816	1016
Pixel sensor dimension (mm^2)	280 × 56.5	280 x 75.5	280 x 94
Number of sensors per layer	2		
Pixel size (μm^2)	O (10 x 10)		

The whole detector will comprise six chips and barely anything else!

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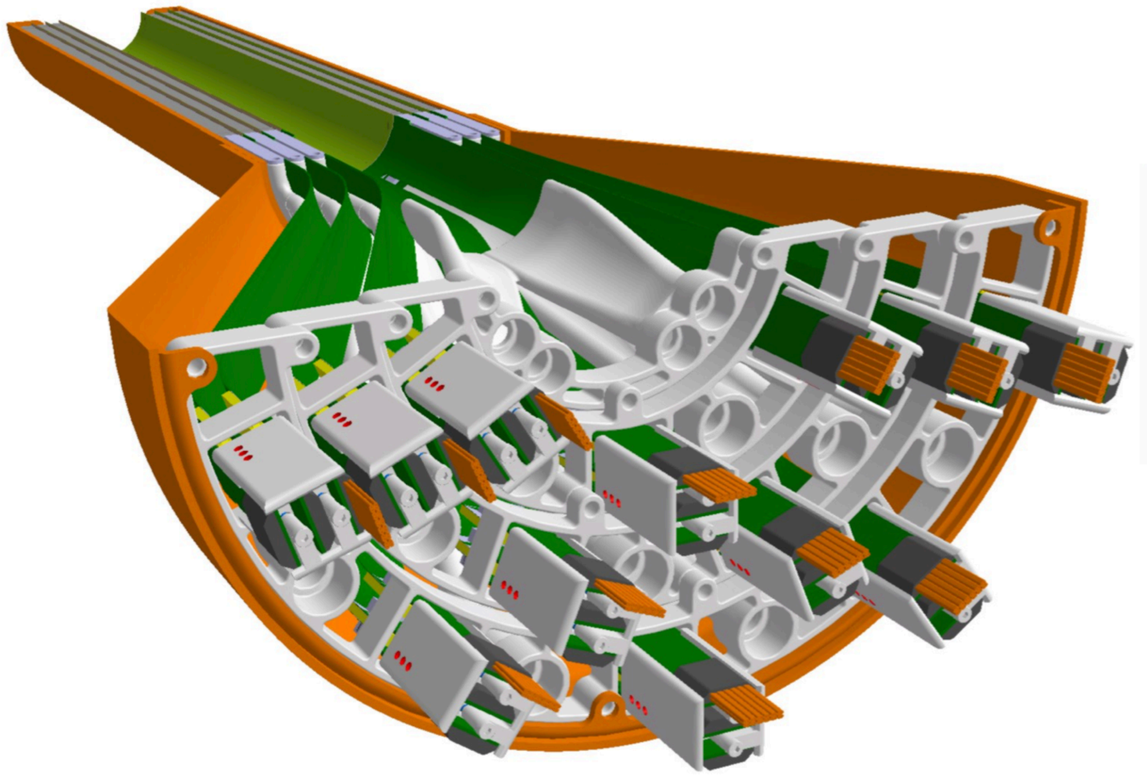


This talk content:

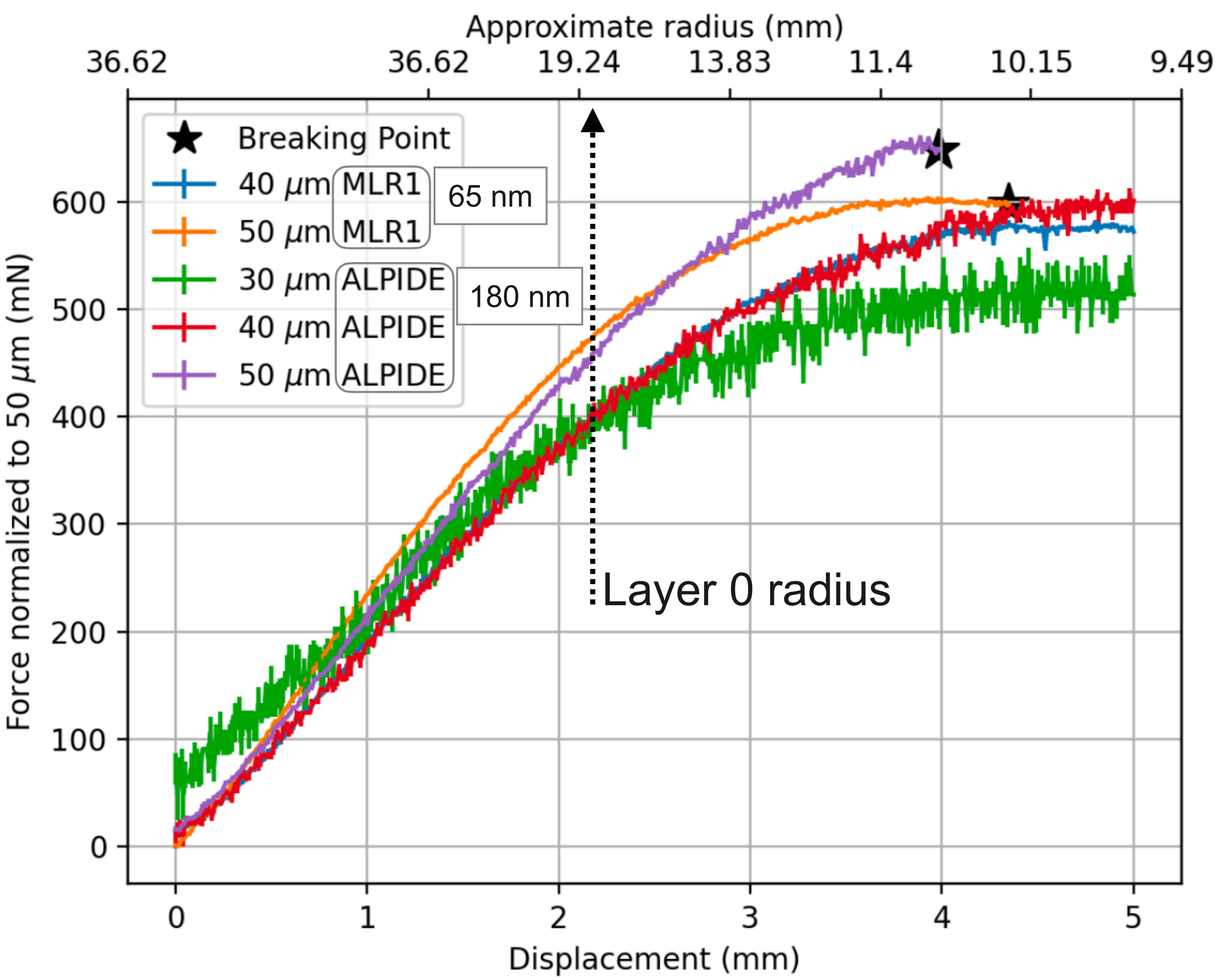
➡ Silicon bending
➡ Carbon foam properties
➡ Sensor cooling
➡ Mechanical characterization
➡ Interconnection

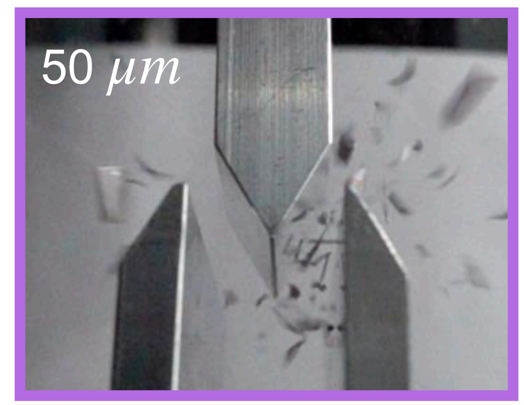
The whole detector will comprise six chips and barely anything else!

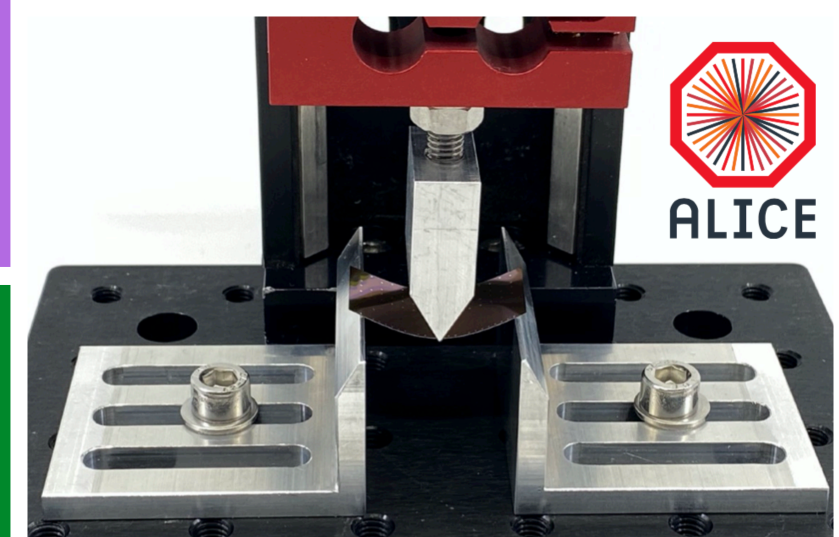
ITS3 R&D - Silicon bending

» Three points <u>bending force measurements</u>:

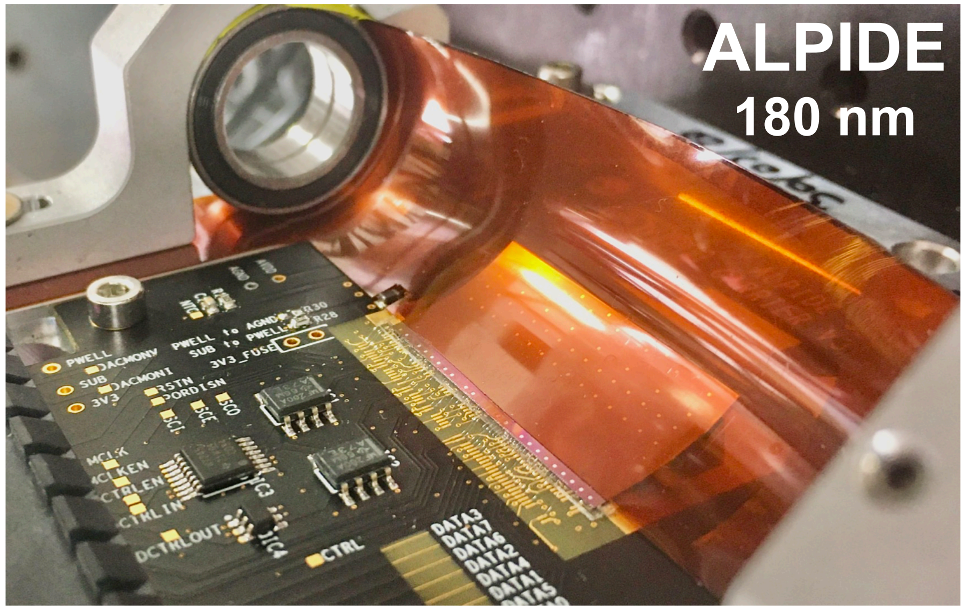
- MAPS ~50 µm thick are quite flexible
- Large benefit from going thinner
- **Project goal thicknesses and desired bending radii achievable**



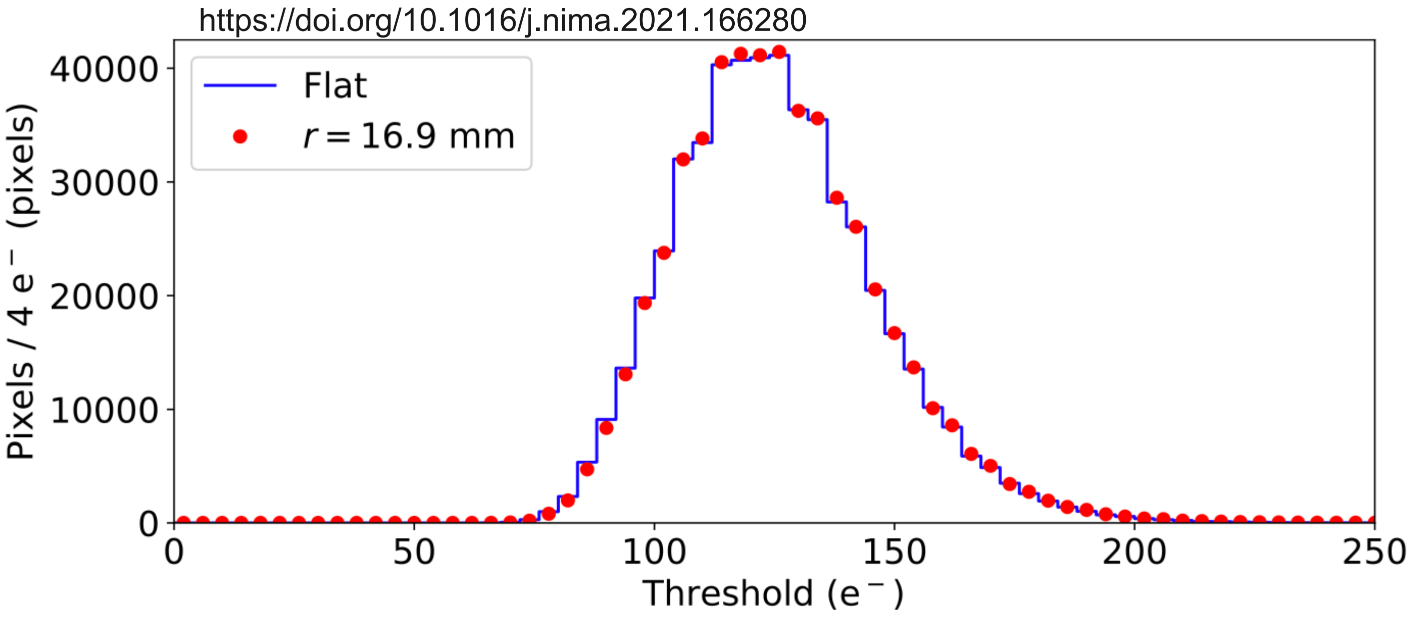


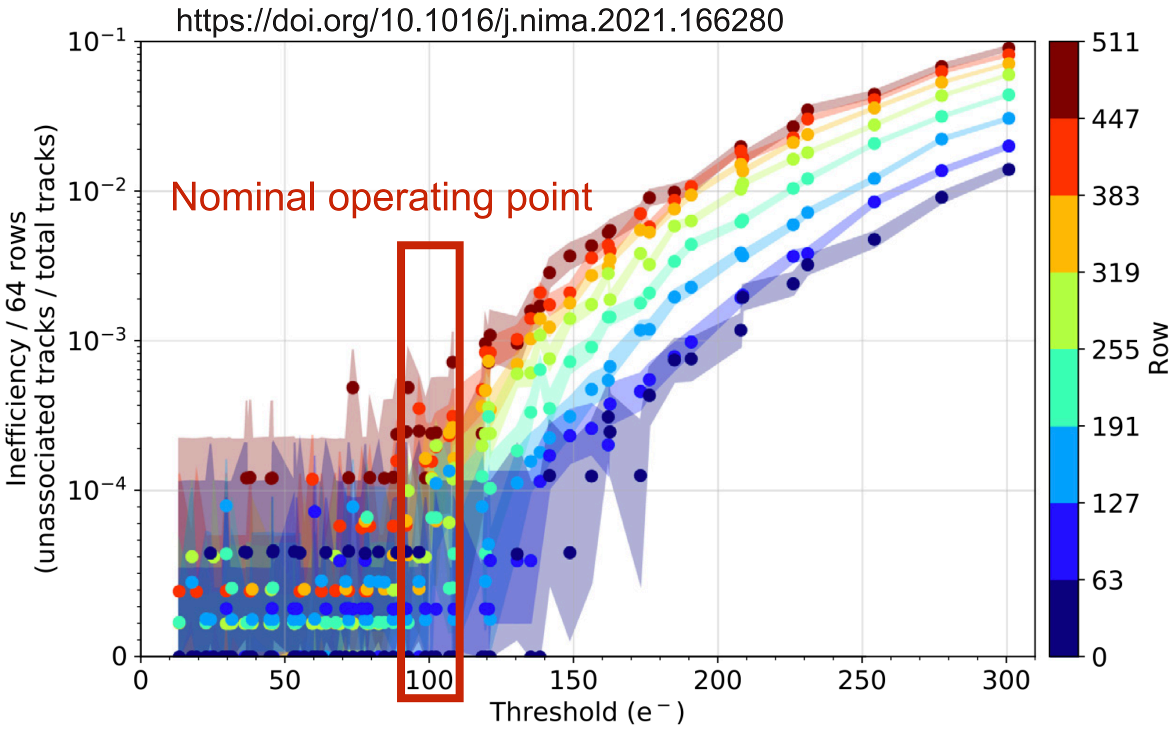


ITS3 R&D - Silicon bending



» Laboratory and test beam measurements (Jun 2020) allow to conclude that **chip (180 nm CMOS) 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⁻





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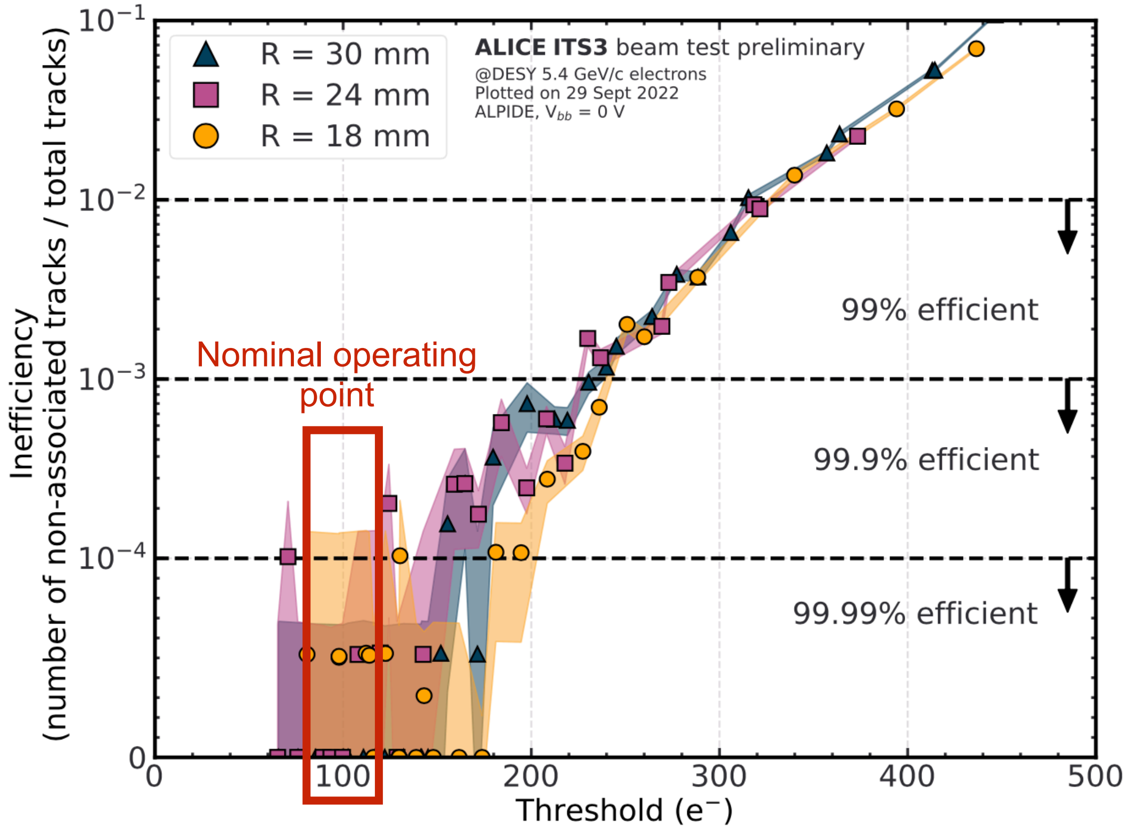
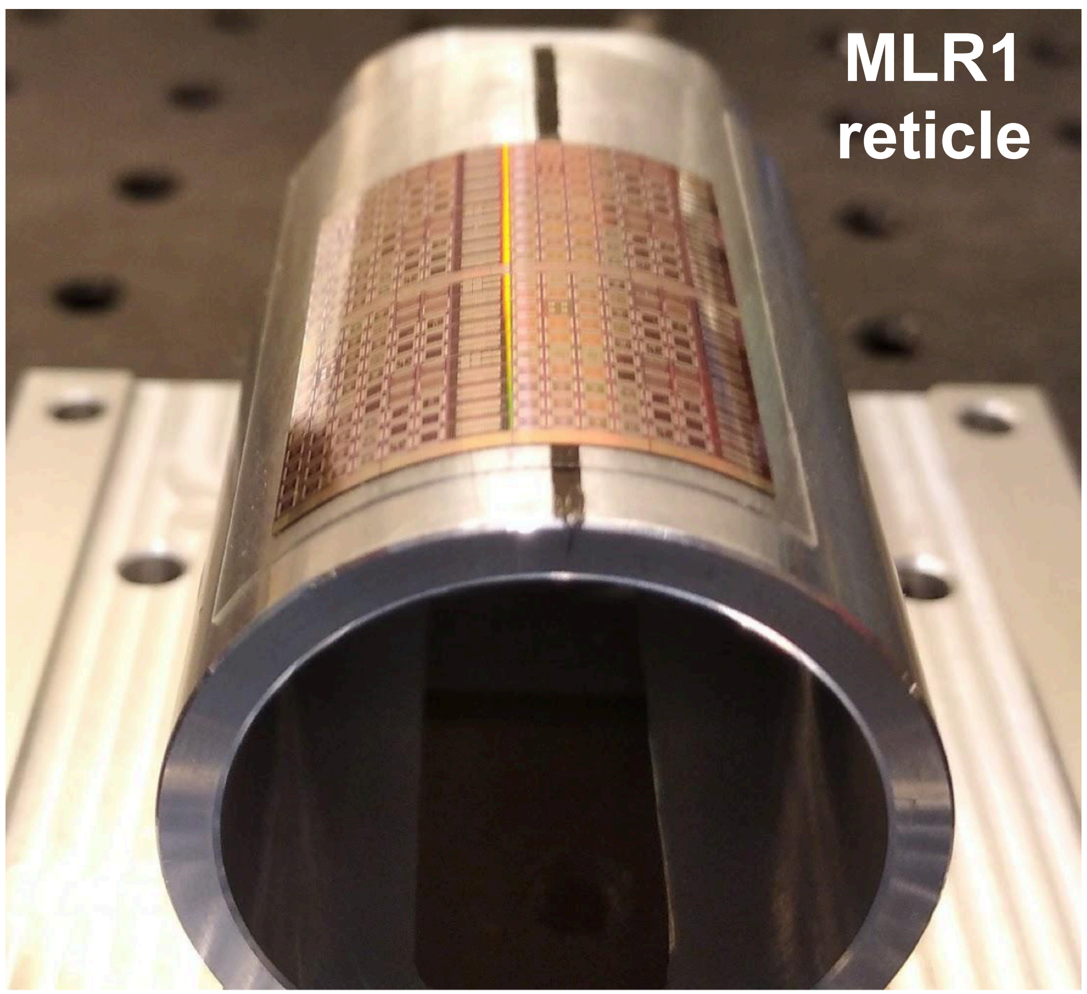
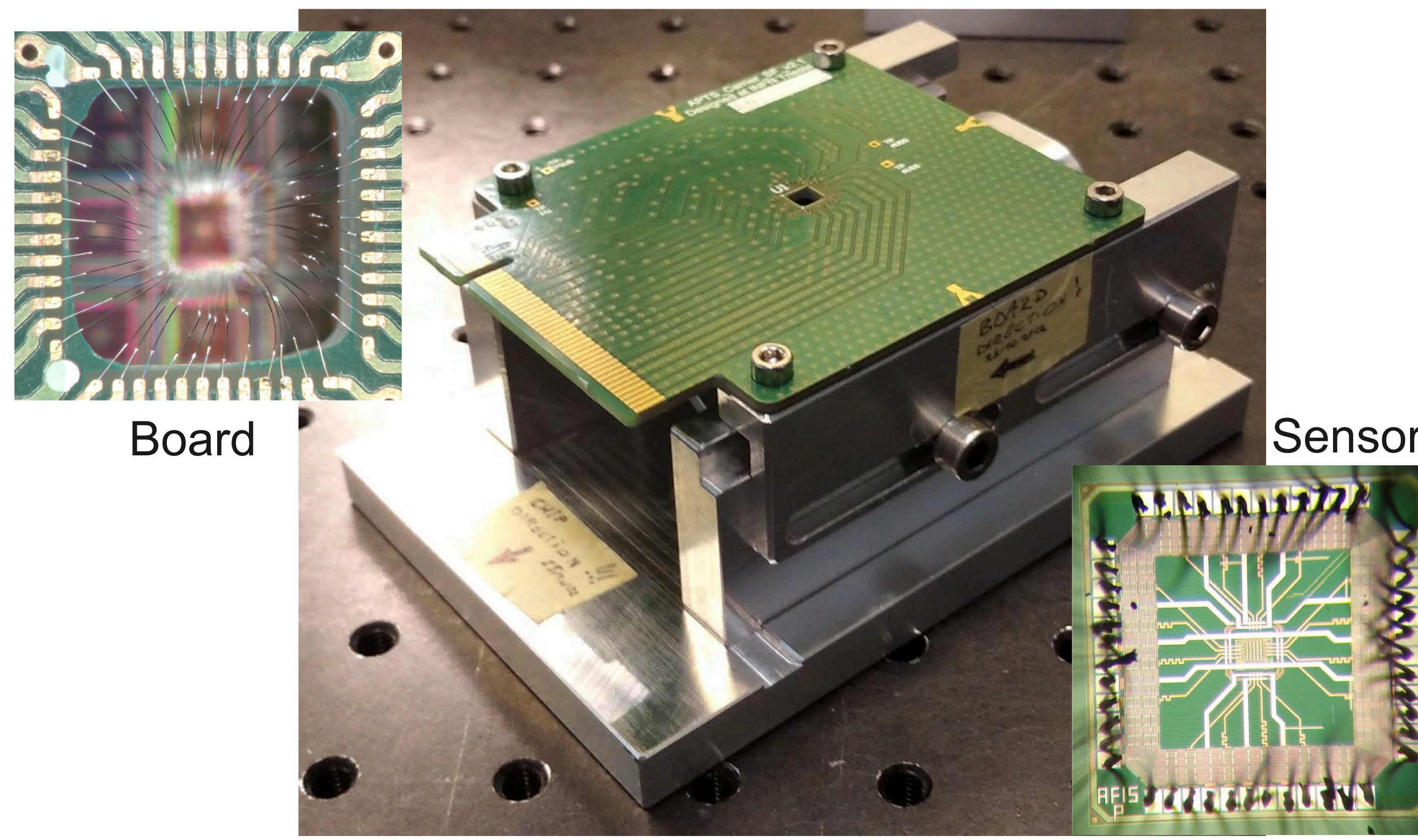


ITS3 R&D - Silicon bending

Ongoing at INFN Trieste

» Comparison between flat and bent MLR1 (65 nm CMOS) sensors ongoing
- Bending procedure developed and proximity board adapted to bent configuration
- Few samples prepared and under measurements in laboratory with ^{55}Fe source

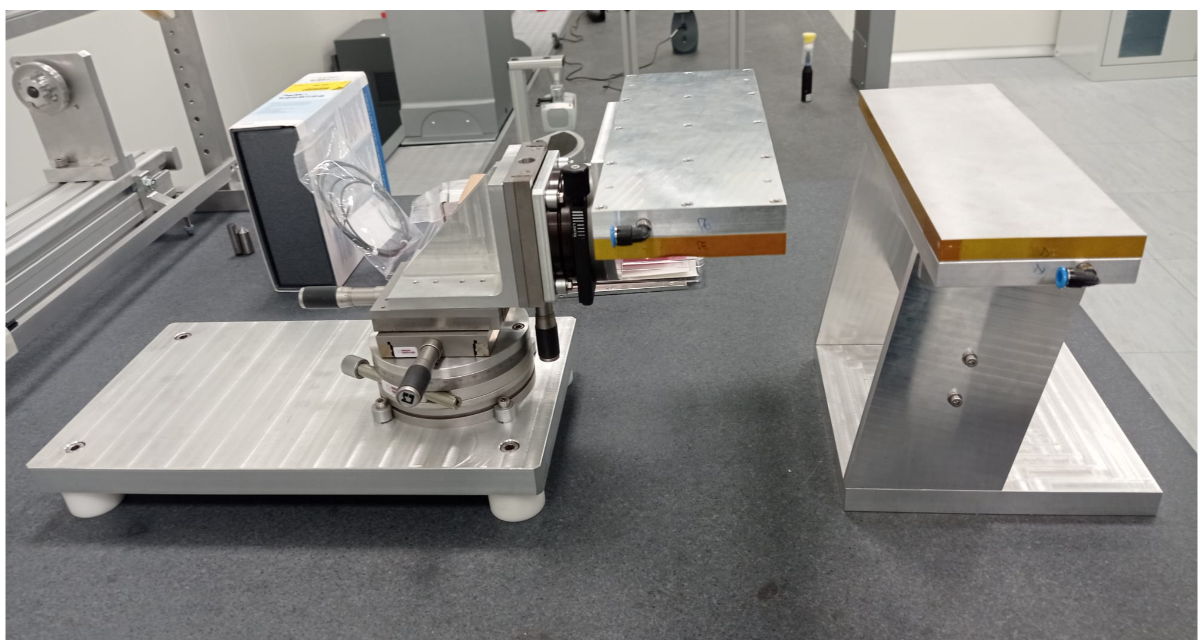




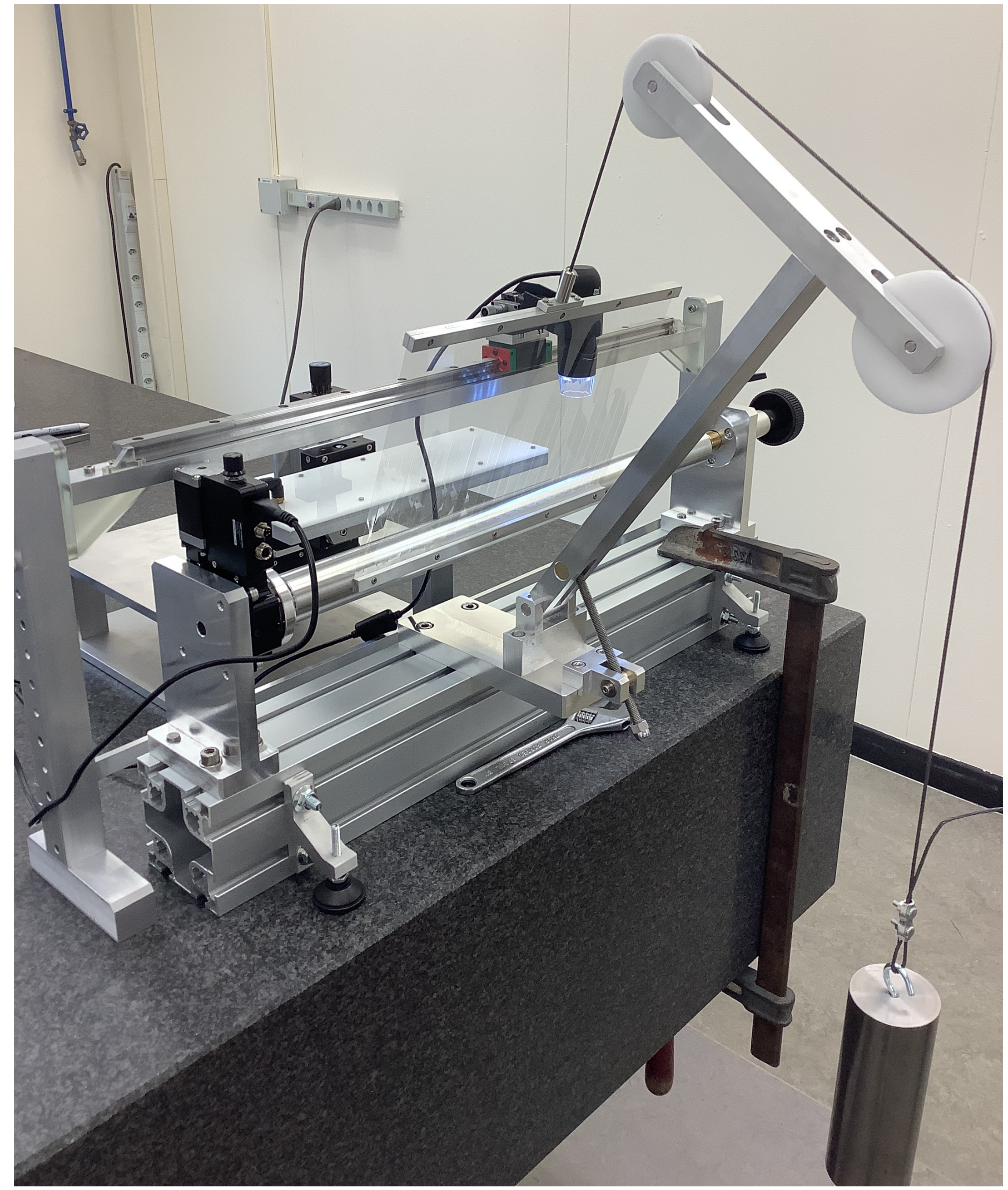
ITS3 R&D - Silicon bending

Ongoing at INFN Bari

» <u>Large dimension silicon</u> bending procedure
- Bending tool: tensioned mylar foil wrapping around cylindrical mandrel



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

ITS3 R&D - Silicon bending

Ongoing at INFN Bari

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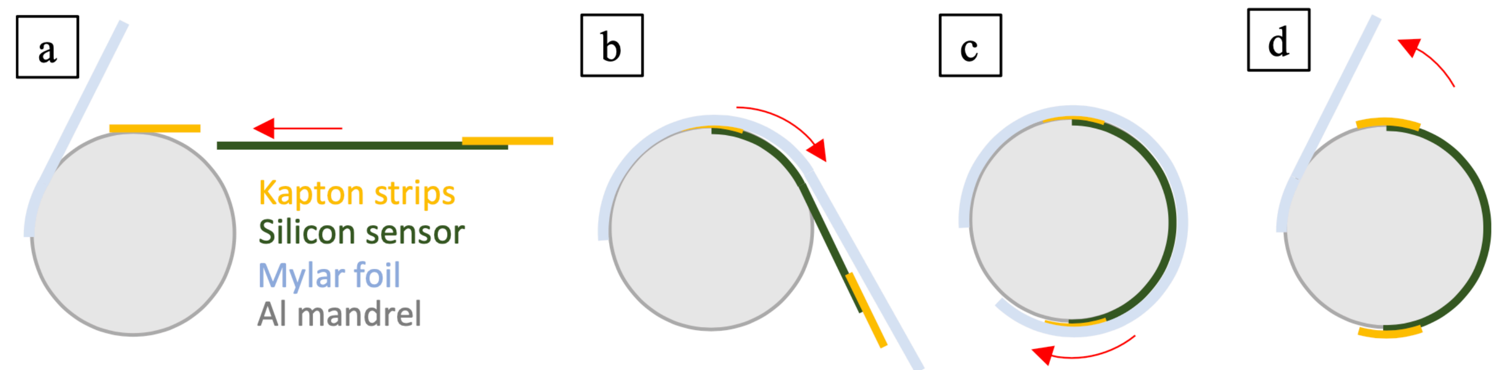

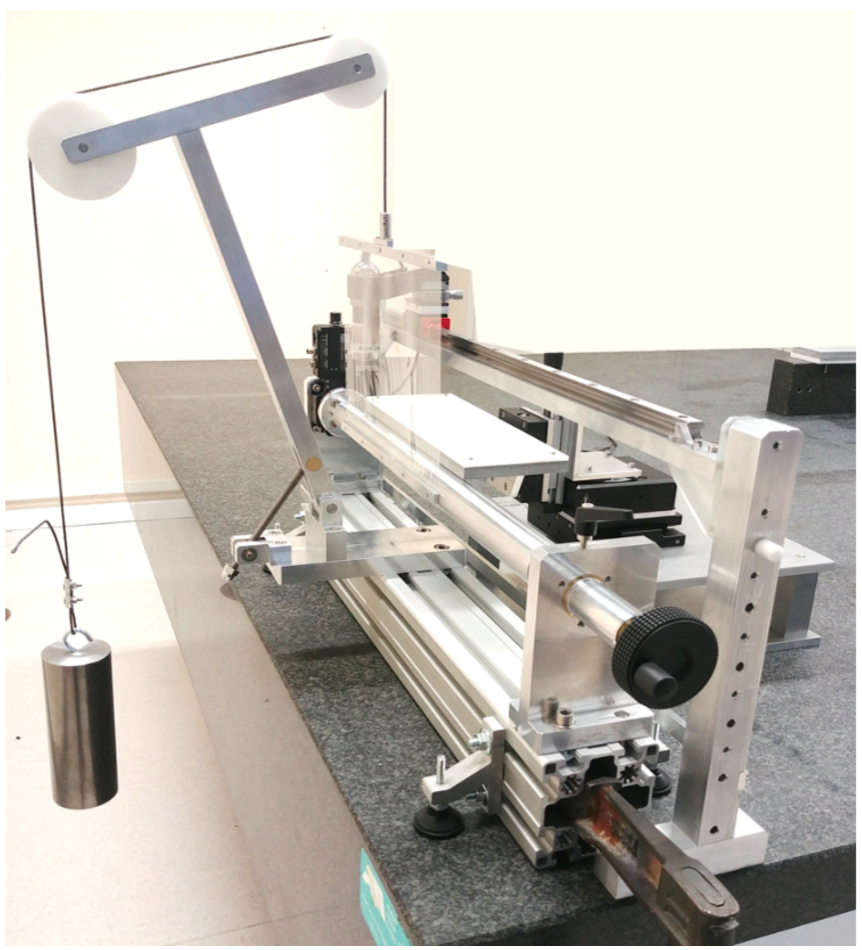

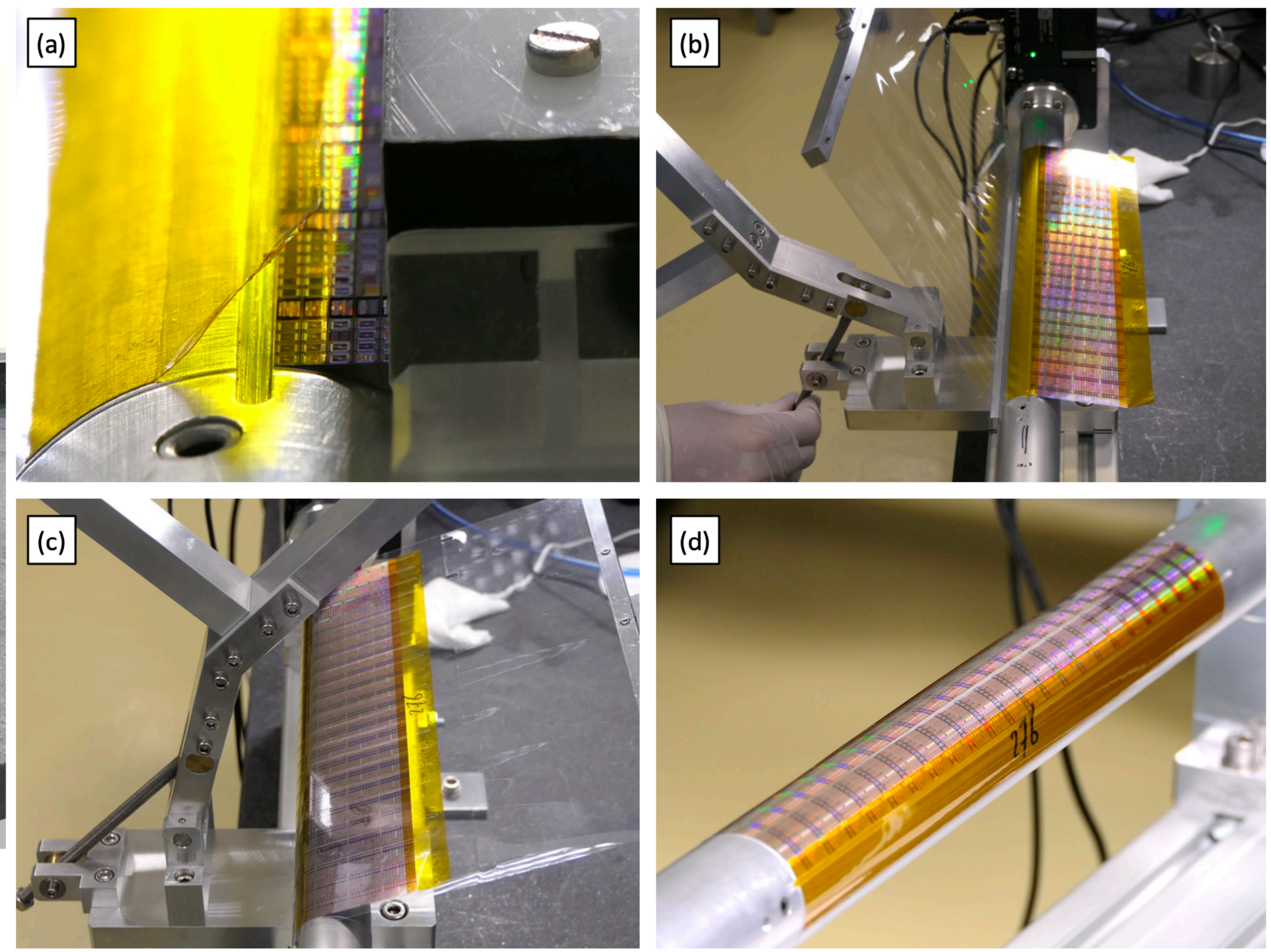

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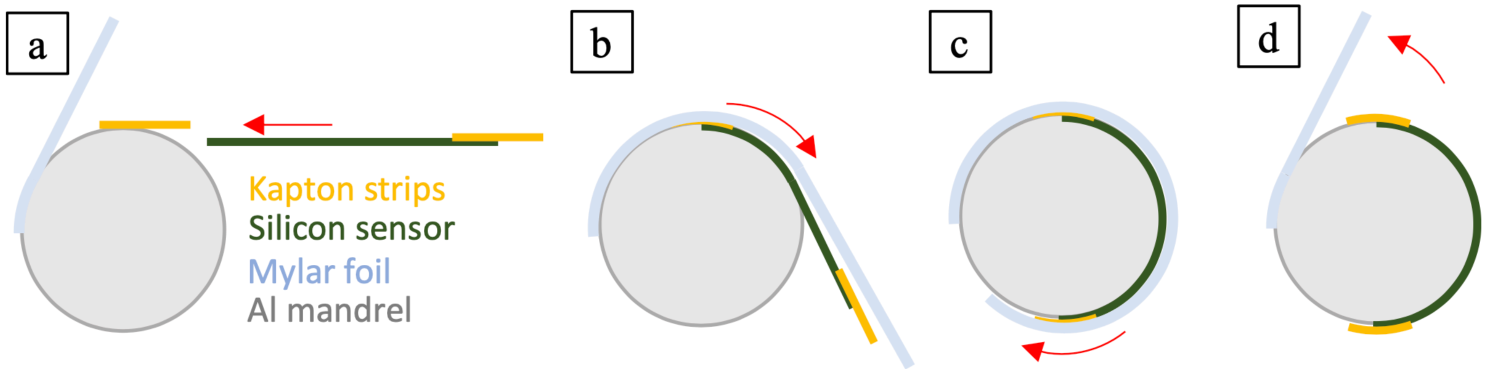
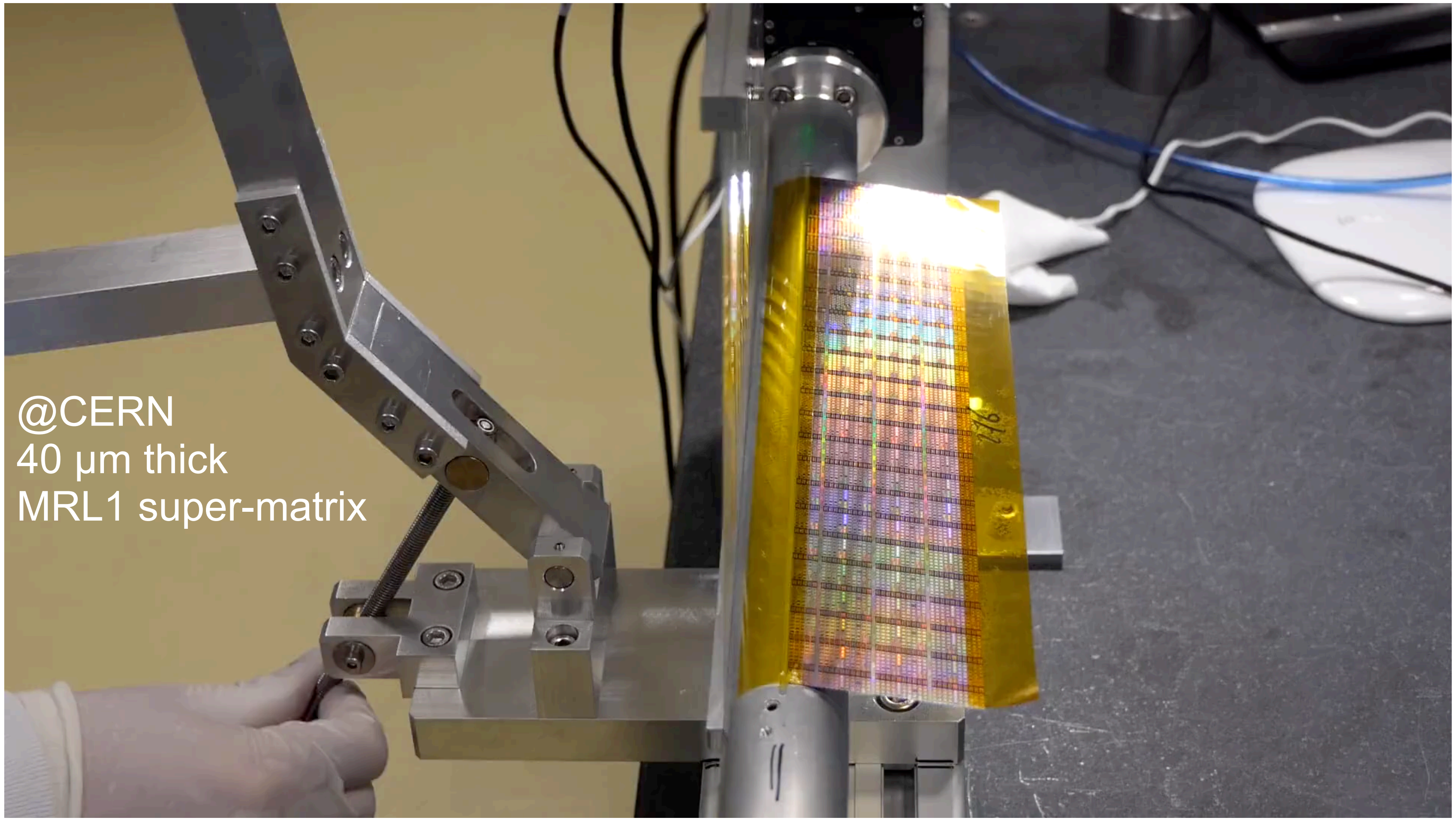
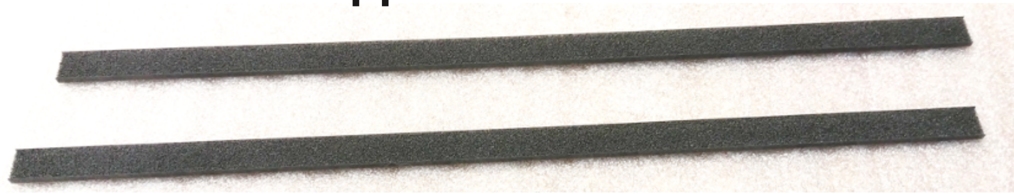




ITS3 R&D - Carbon foam properties

» Silicon sensor kept in position by:

Longerons
Support structures



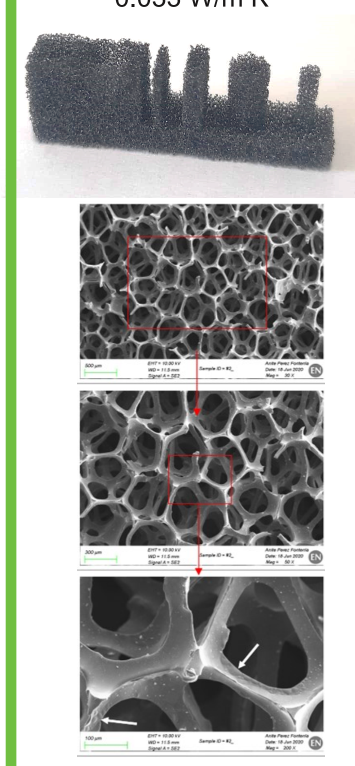
ERG Duocel (RVC)

Half-rings
Support structures and cooling radiator

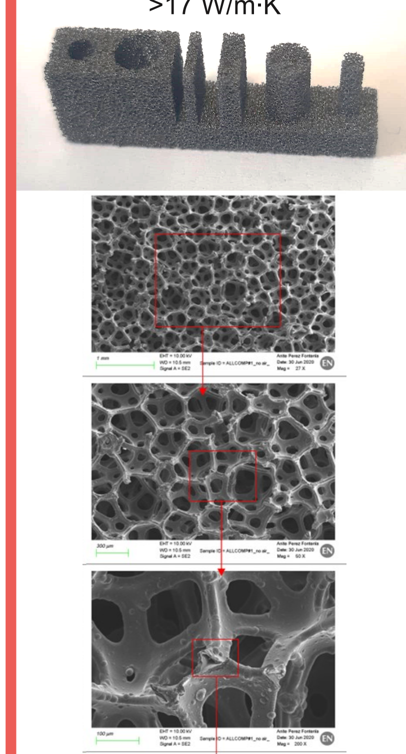
ALLCOMP LD (K9)

» Carbon foams characterised for machinability and thermal properties

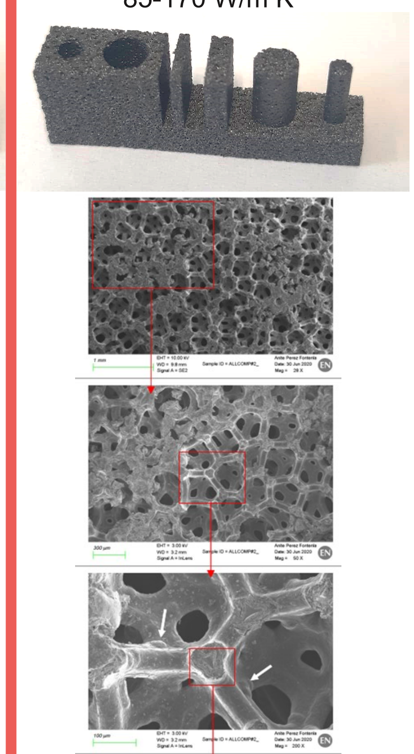
ERG DUOCEL (RVC)
0.06 kg/dm³
0.033 W/m·K



ALLCOMP LD (K9)
0.2-0.26 kg/dm³
>17 W/m·K

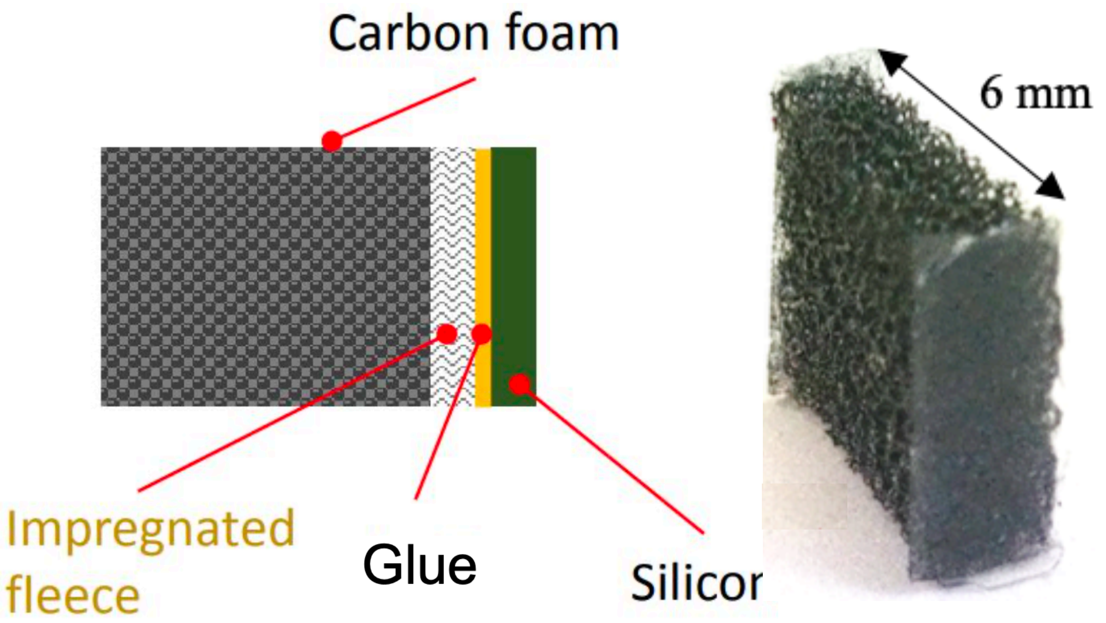


ALLCOMP HD
0.45-0.68 kg/dm³
85-170 W/m·K



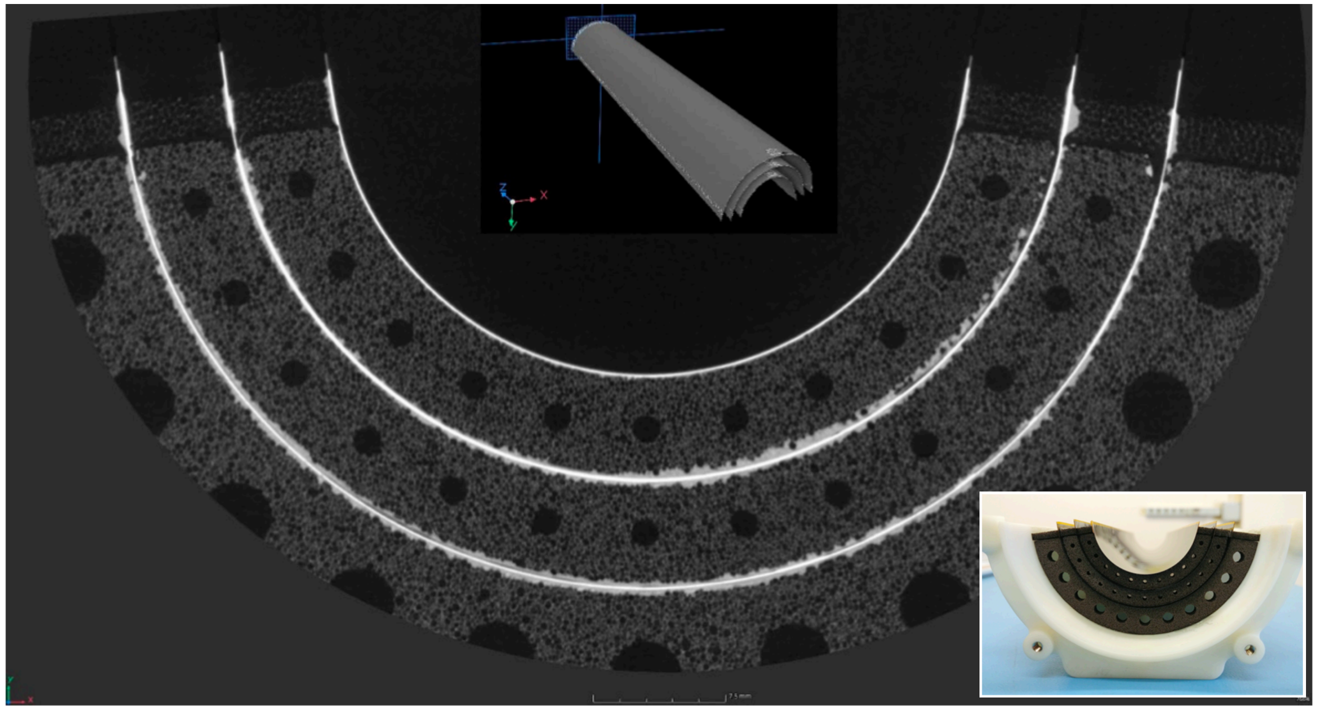
ITS3 R&D - Carbon foam properties

» Carbon fleece veil (120 µm thick) between silicon and carbon foam used to:
- Control the glue thickness
- Reduce thermal contact resistance
- Reduce carbon foam footprints on the silicon



» Cylindricity granted within 0.05 mm using the half-ring

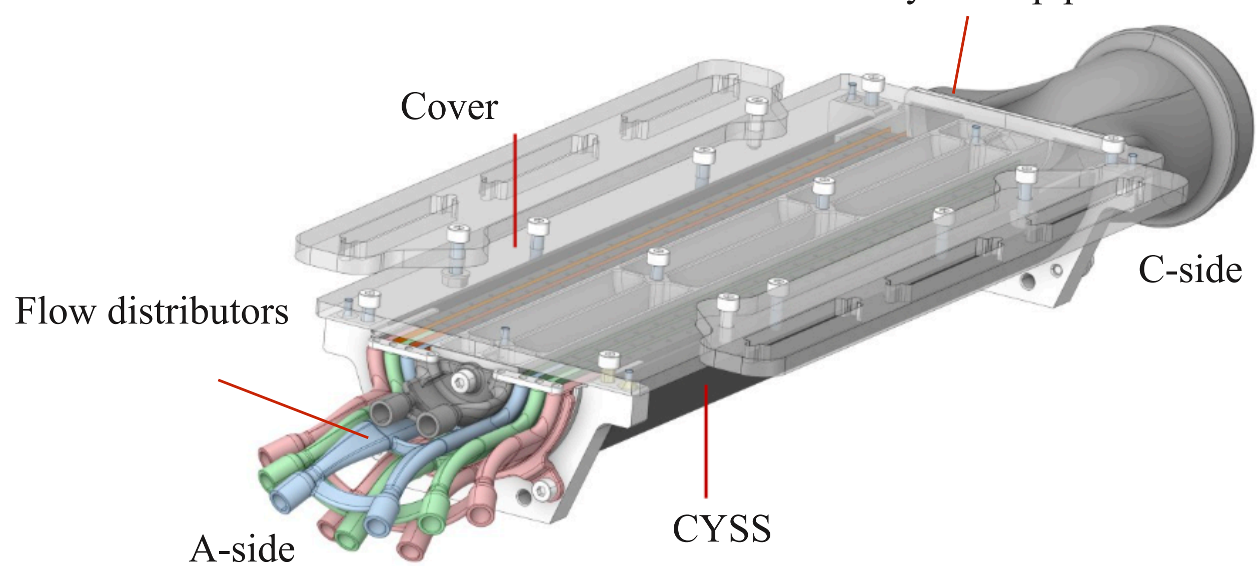
X-ray scan of Engineering Model 2 (EM2)

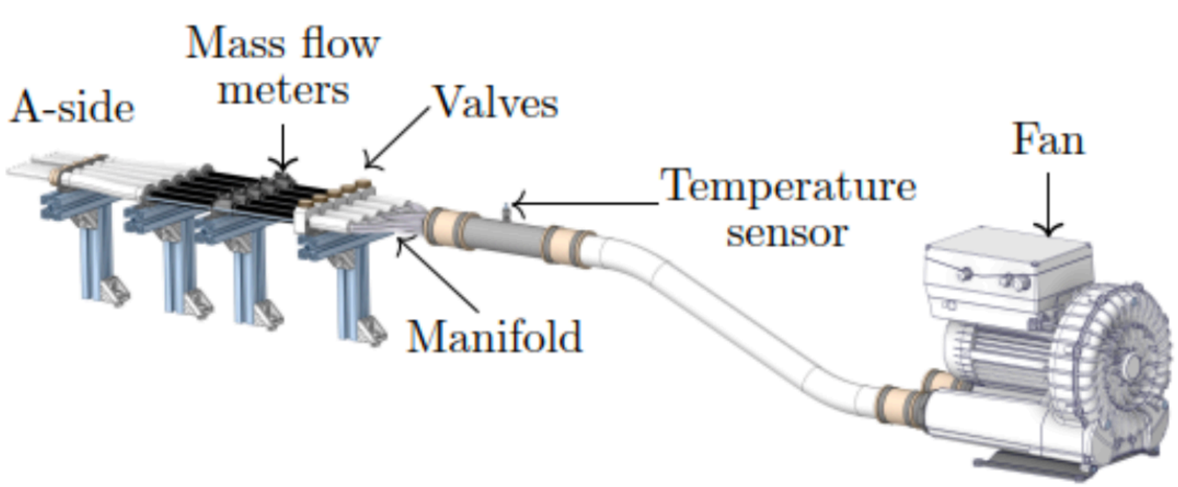


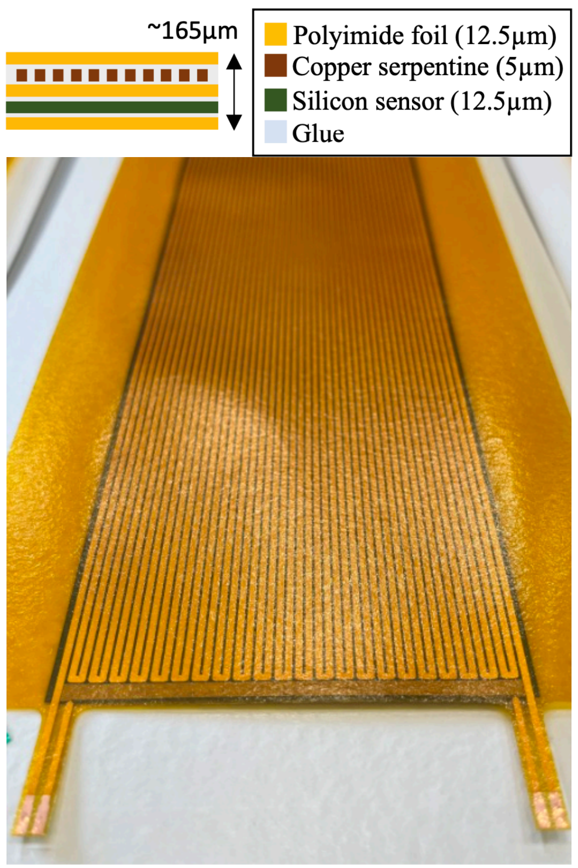
ITS3 R&D - Sensor cooling

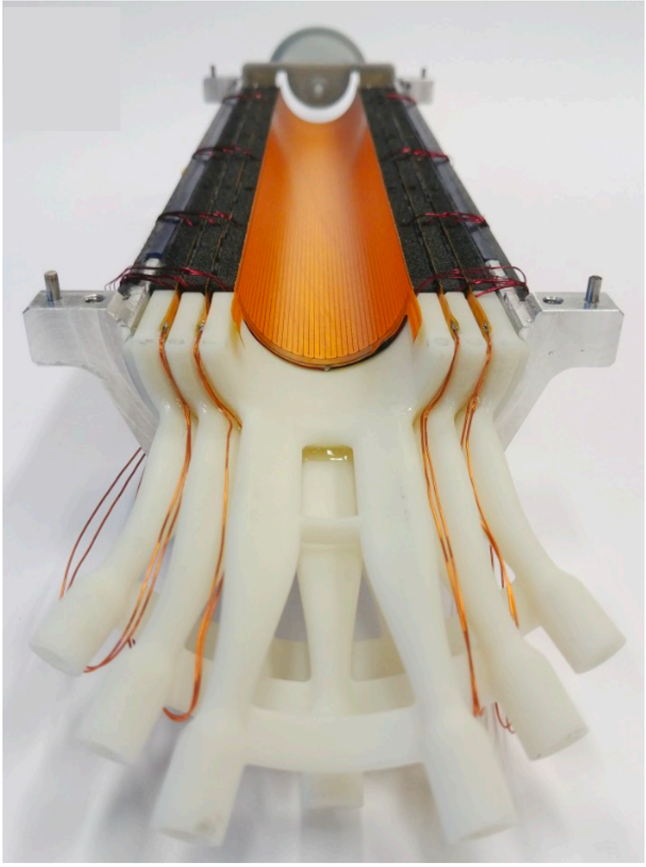
» Thermal characterization setup

- dummy silicon equipped with copper serpentine simulating heat dissipation in matrix (25 mW/cm^2) and end-cap (1000 mW/cm^2) regions
- 8 PT100 temperature sensors distributed over the surface of each half-layer
- <u>airflow</u> from A-side to C-side









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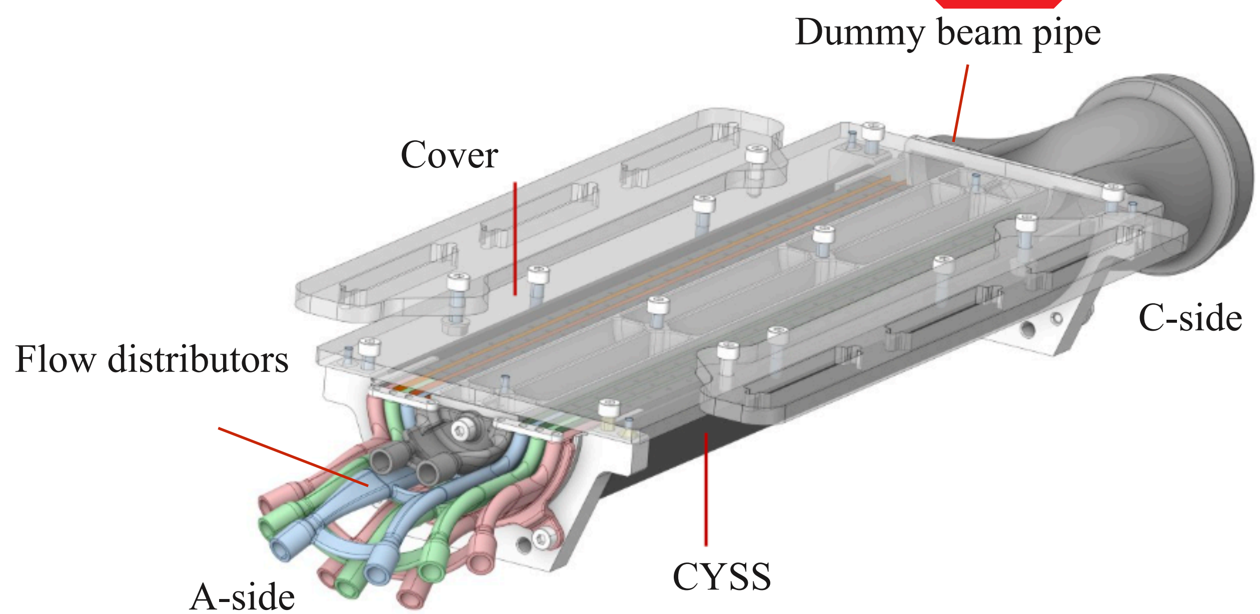
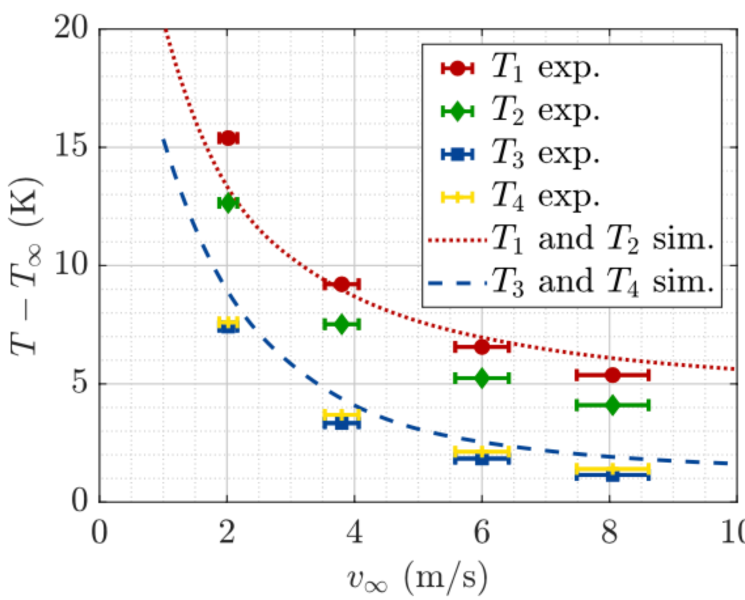
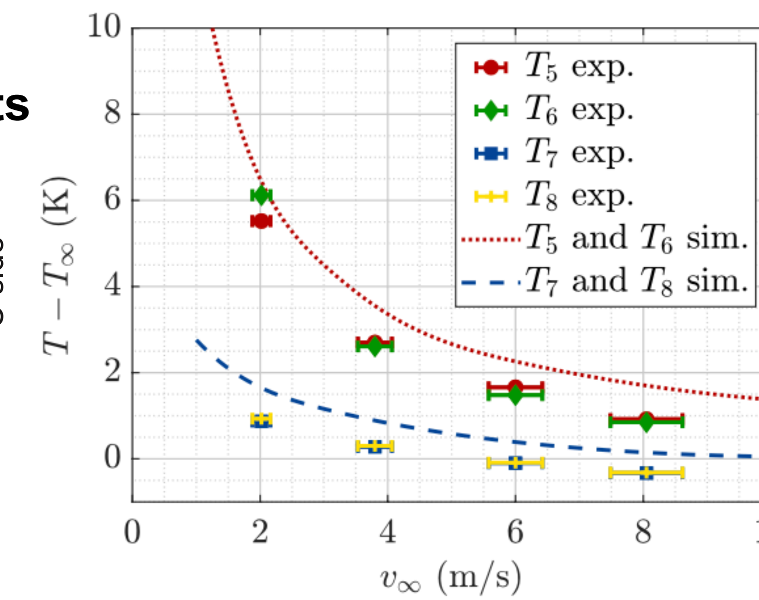




Layer 0 - End-cap

Comparison between CFD simulations and experiments

Temperature sensor position and nomenclature



Layer 0 - Matrix

» Conclusion

- **with** an average **airflow free-stream velocity** between the layers **of about 8 m/s**, the **detector can be operated** at a temperature of 5 degrees above the inlet air temperature
- temperature uniformity along the sensor can be also kept within 5 degrees

ITS3 R&D - Mechanical characterization

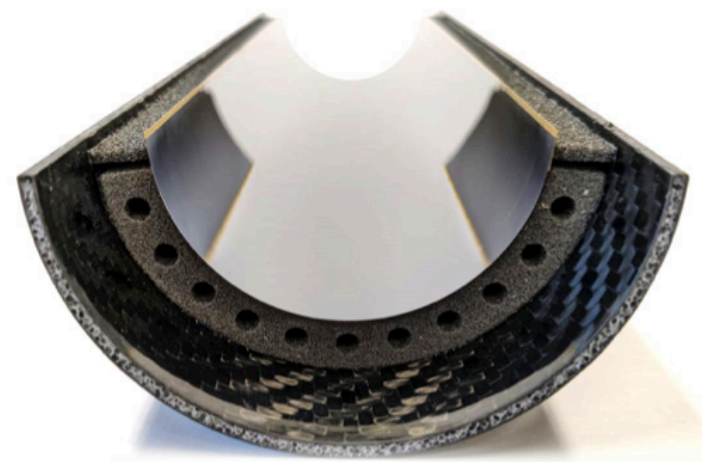
» Short-term position stability of the sensor over time affected by

- thermoelastic expansion caused by short-term temperature fluctuation
- airflow

ITS3 R&D - Mechanical characterization

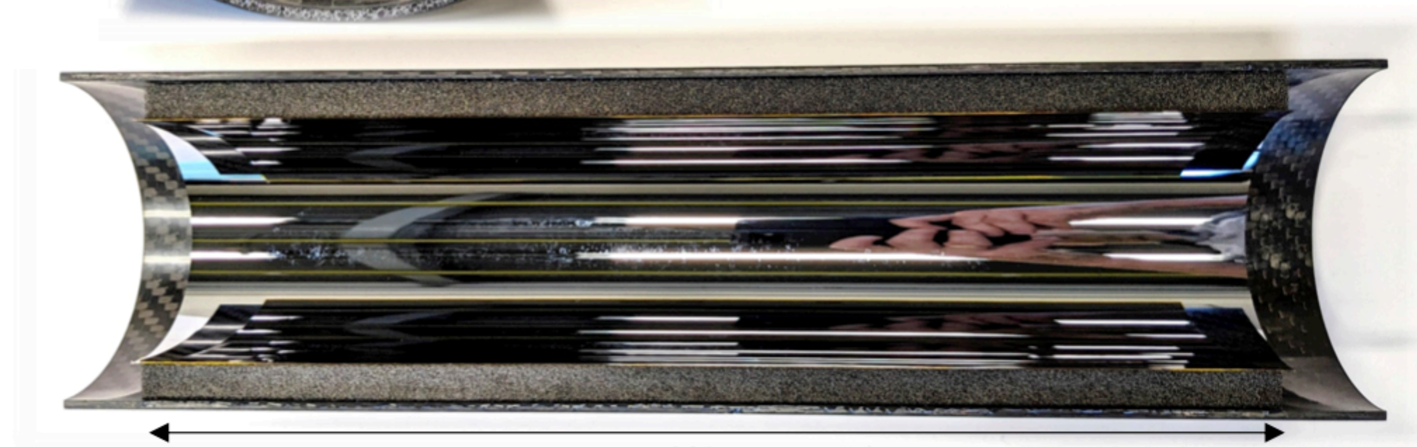
» Short-term position stability of the sensor over time affected by
- <u>thermoelastic expansion caused by short-term temperature fluctuation</u>
- airflow

» Thermoelastic expansion setup
- differential thermoplastic expansion among different components could introduce failures
- final grade material half-layer assembly in climate chamber (up to 36ºC by steps of 2 ºC)



Materials

C-side H-ring: carbon foam, ERG (RVC) Duocel®
Longerons: carbon foam, ERG (RVC) Duocel®
Half-layer 2: Blank silicon 40 μm
CYSS: carbon sandwich
A-side H-ring: carbon foam, Allcomp k9 SD

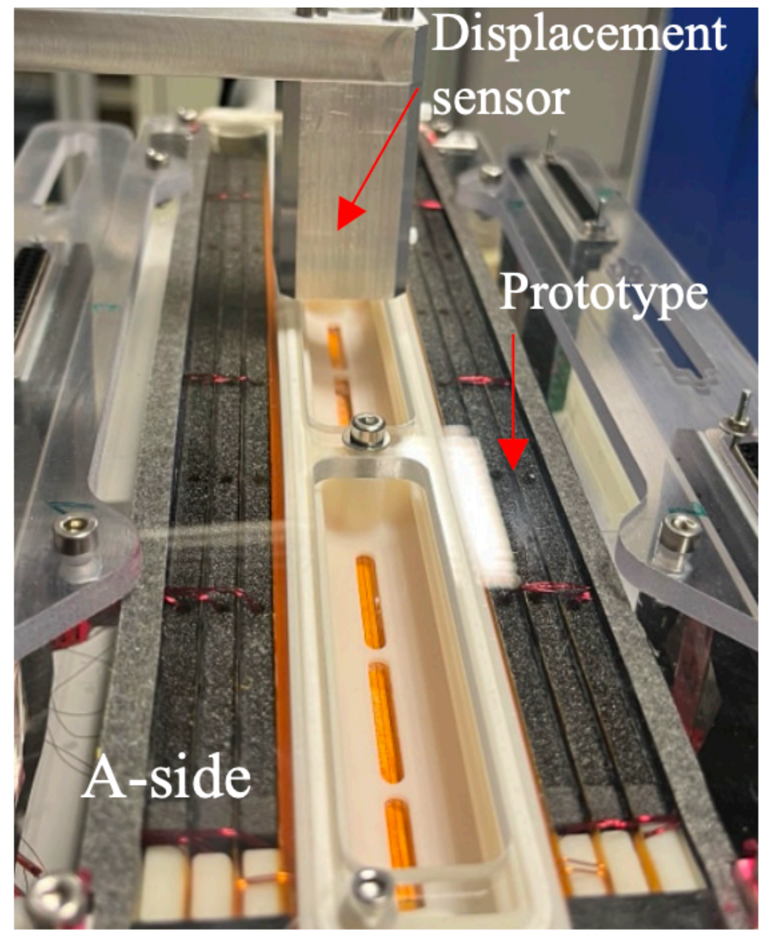


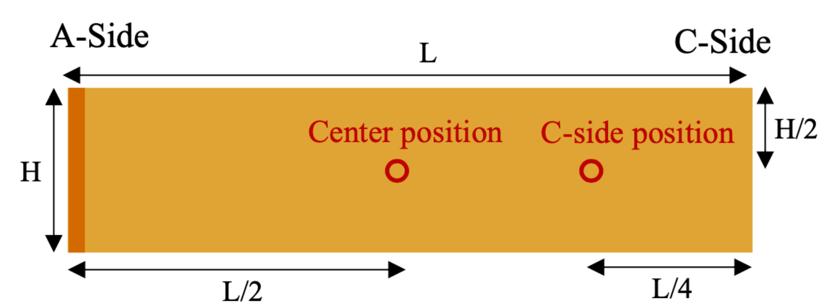
» Conclusion
- several **thermal cycles for a total of 9h → assembly unaffected**
- further tests will be performed to investigate: rapid increase of the temperature and maximum failure temperature

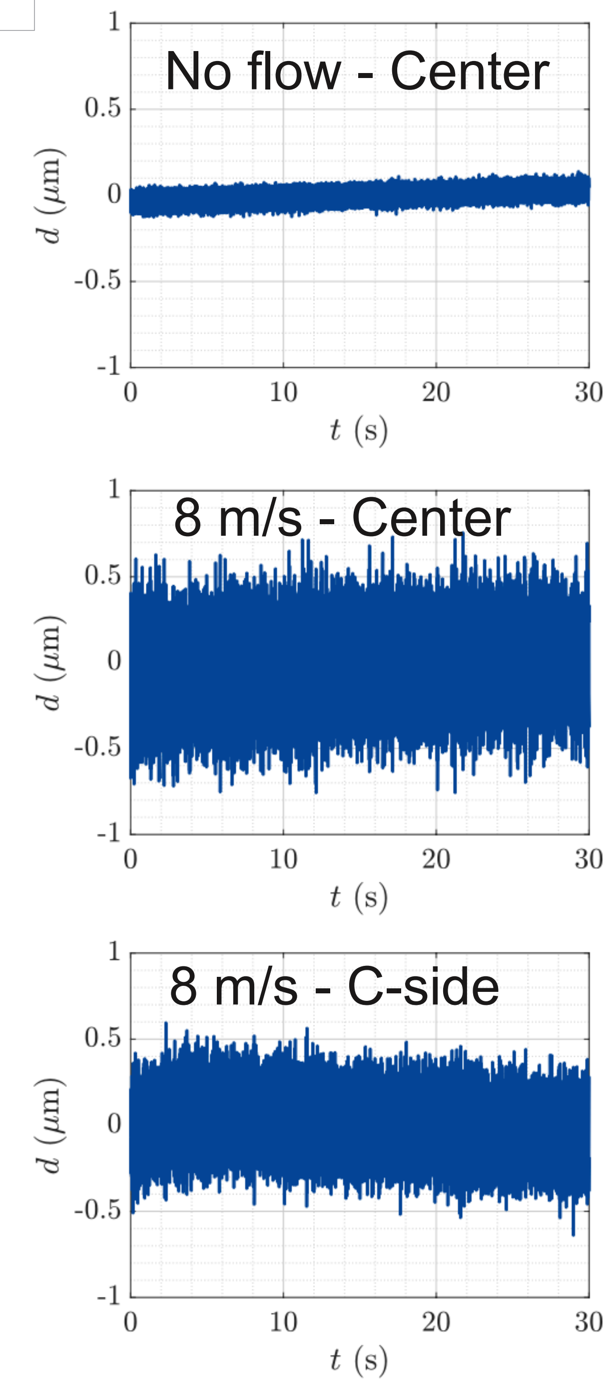
ITS3 R&D - Mechanical characterization

» Short-term position stability of the sensor over time affected by
- thermoelastic expansion caused by short-term temperature fluctuation
- <u>airflow</u>

» Vibration characterization setup
- measurement of the out-of-plane vibrations of the half-layers
- confocal chromatic displacement sensors → avoids perturbation to the airflow



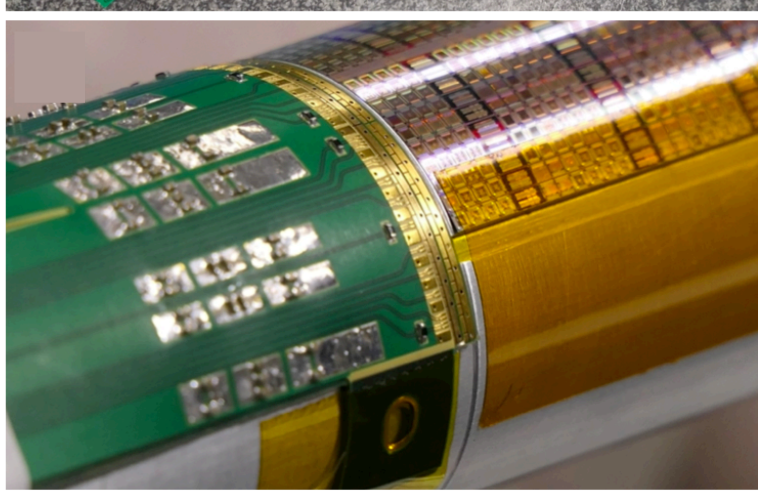


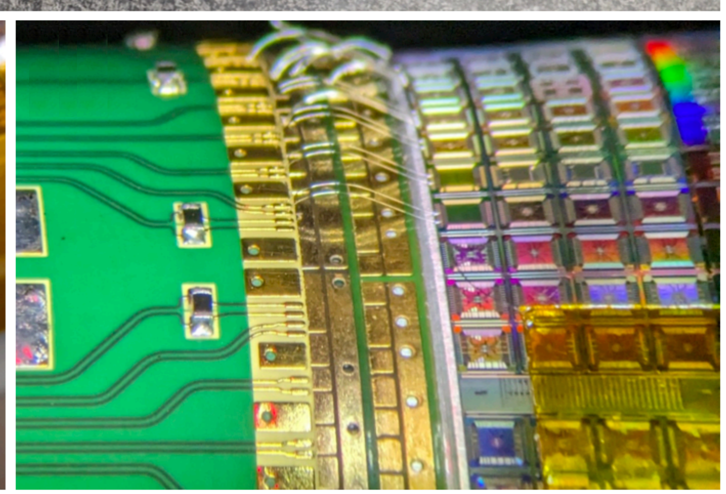


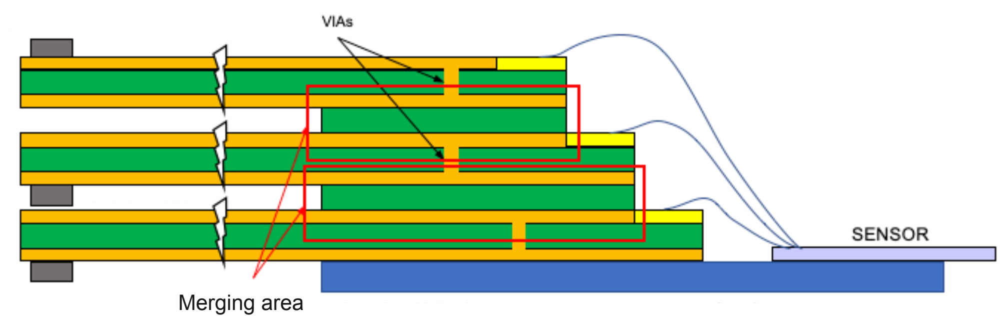
» Conclusion
- $RMS_{airflow}$ < 0.4 μm for L2 (largest sensor), smaller for L0 and L1

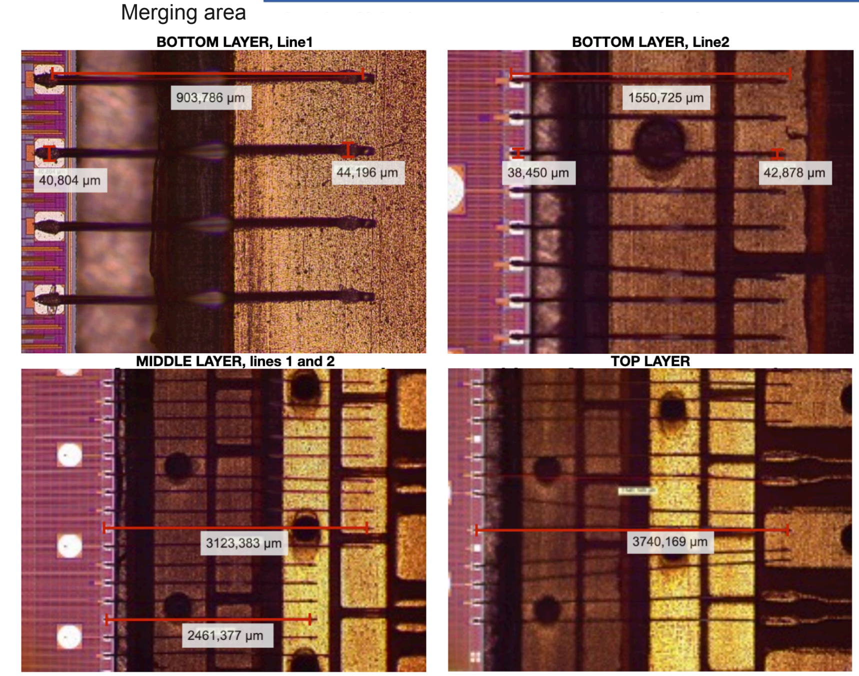
ITS3 R&D - Interconnection

» Flexible printed circuits for communication and powering
- placed outside the sensible area
- three double copper layers flex, multi-strip shaped (15-30 cm long), connected in a merging area
- **interconnected via wire-bonding** at the edge of the sensor **verified**
  - wire-bonds loops optimisation based on pull-force measurements
  - present setup (not final grade material): 6.6±0.3 g at ~900 µm pad-to-pad distance

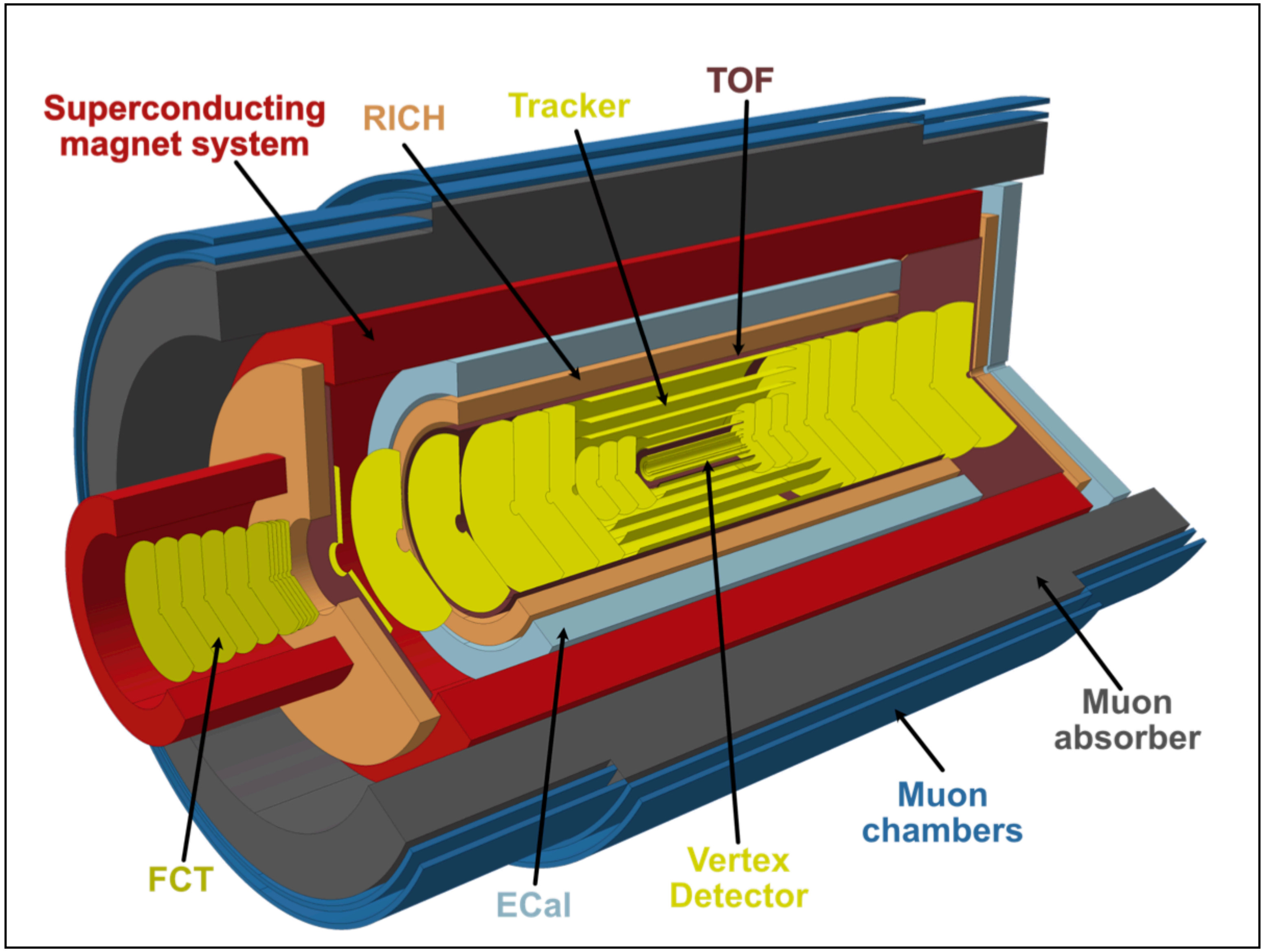








ALICE3



ALICE3: a silicon sensor based experiment

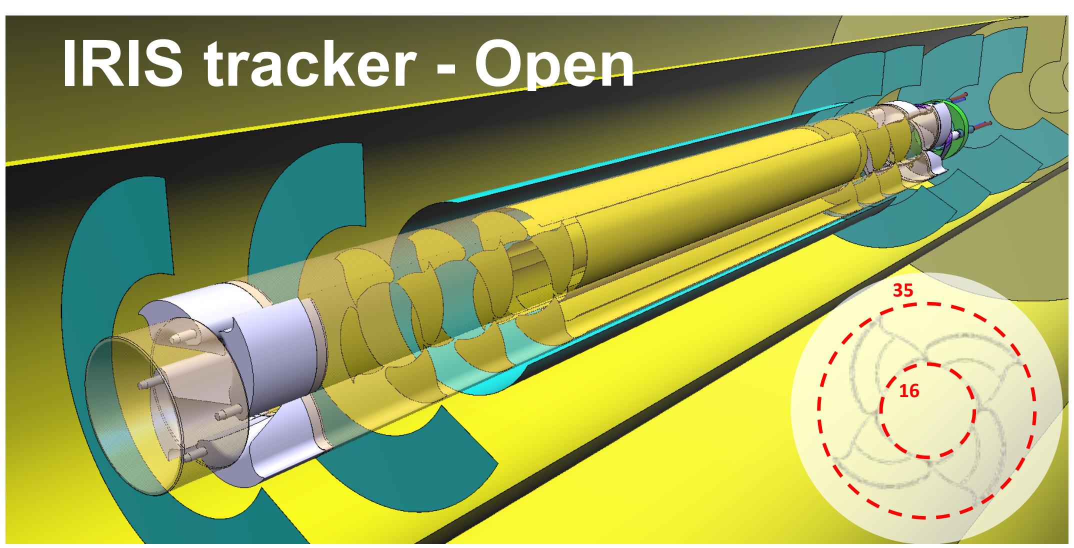
ALICE3 - IRIS

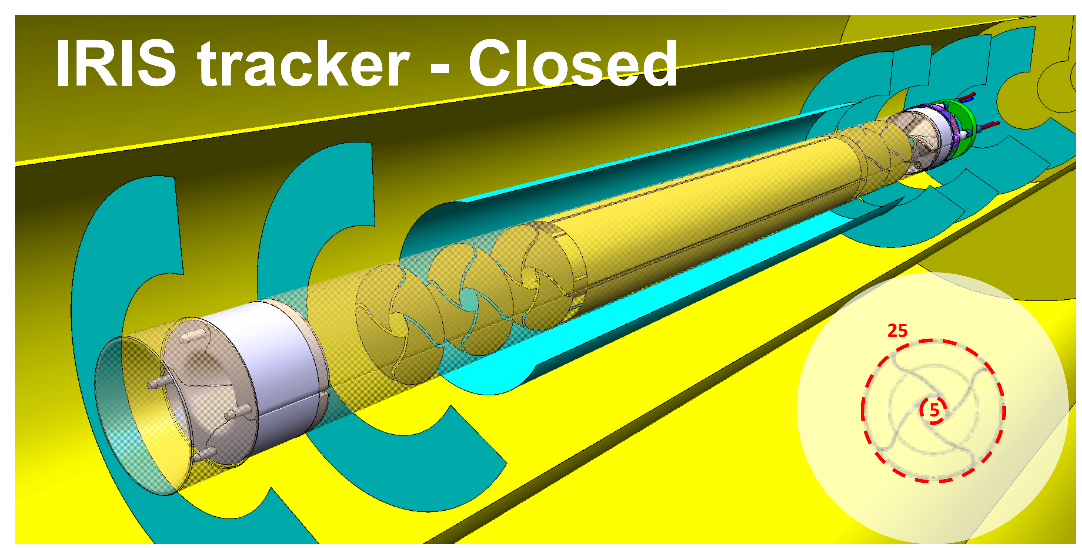
» Based on wafer-scale, ultra-thin, curved MAPS

» Basic requirements

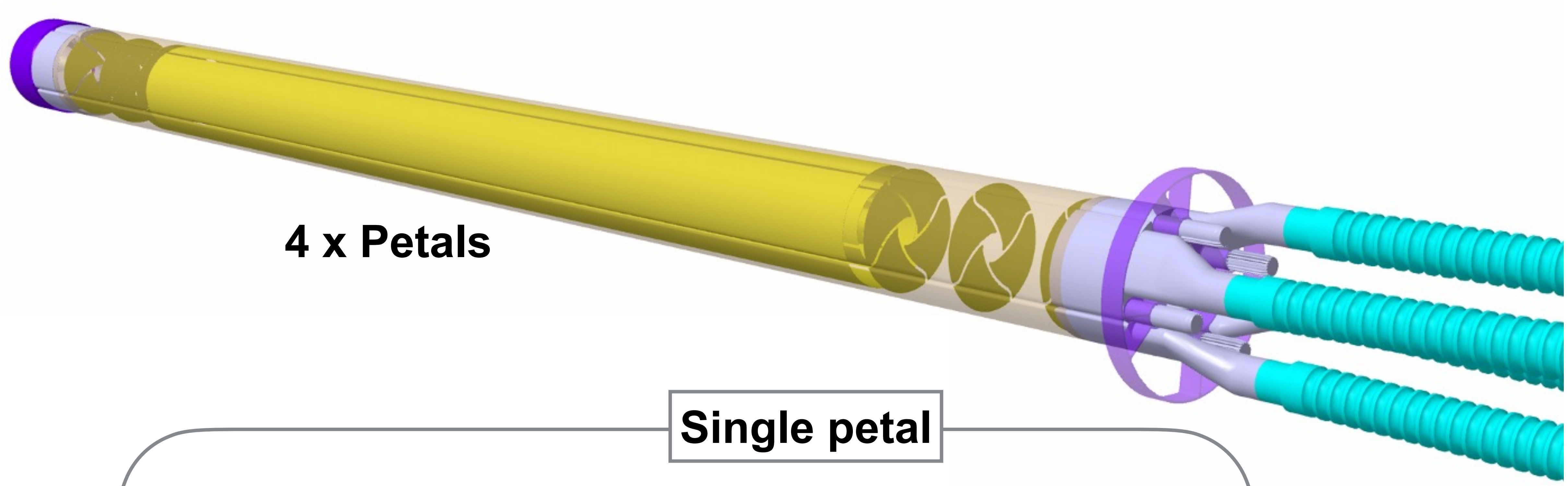
- radial distance from interaction point: 5 mm
  (inside beam pipe, retractible configuration)
- unprecedented spatial resolution: ≈ 2.5 µm
- unprecedented low material budget X/X_0 (per layer): ≲ 0.1%
- radiation tolerance: ≈ 10^{16} 1 MeV n_{eq}/cm^2 + 200 Mrad
- hit rates up to: 94 MHz/cm^2

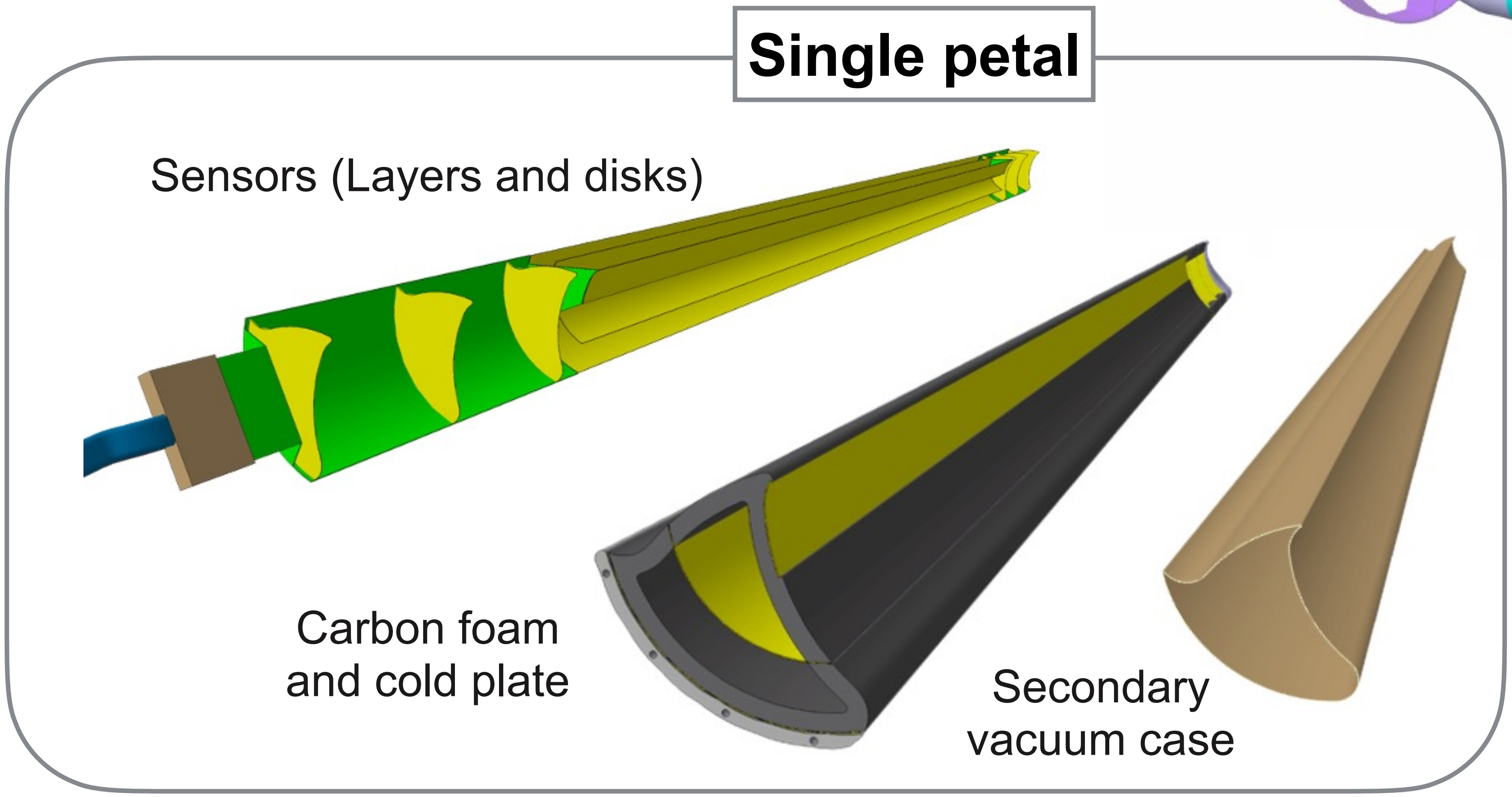
» R&D will largely leverage on the ITS3 developments and push improvements on a number of fronts



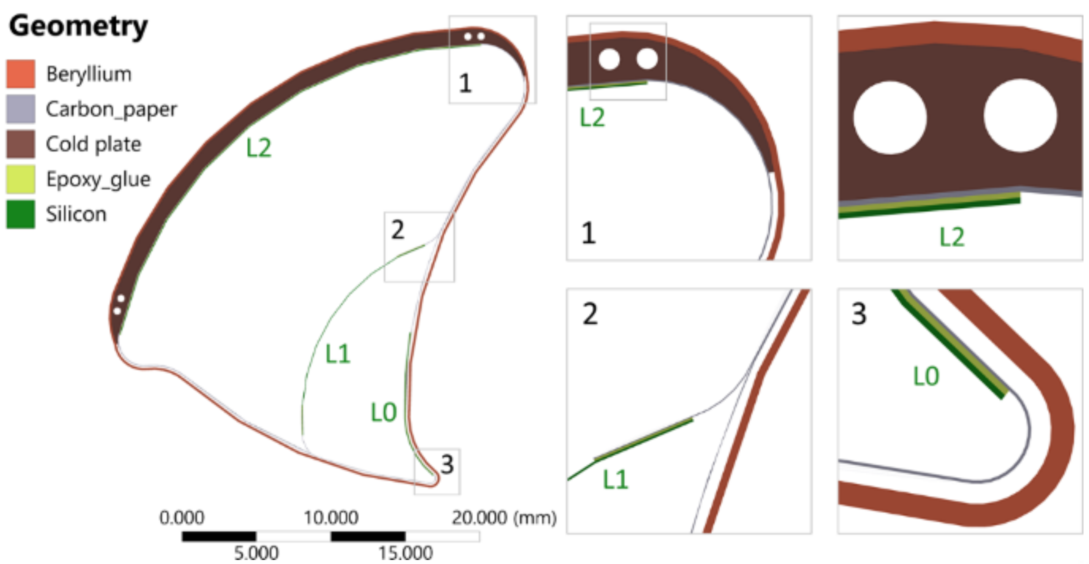


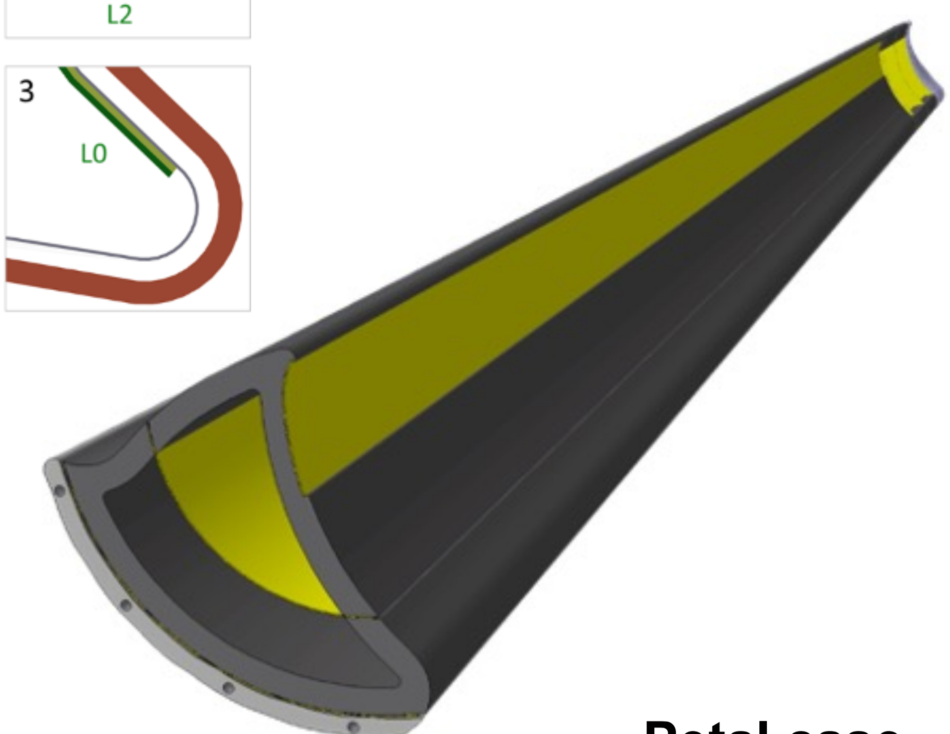
ALICE3 - IRIS

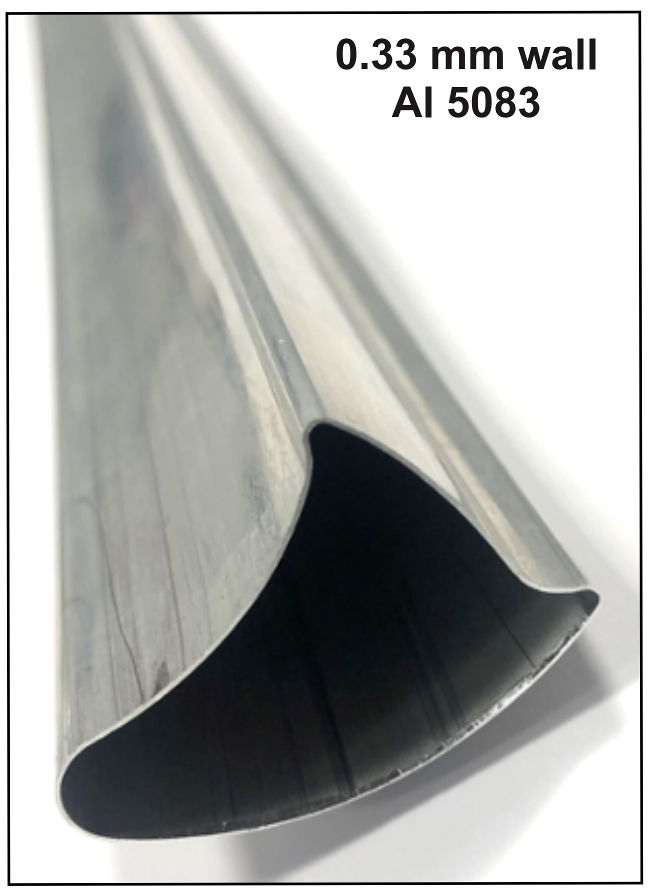

4 x Petals

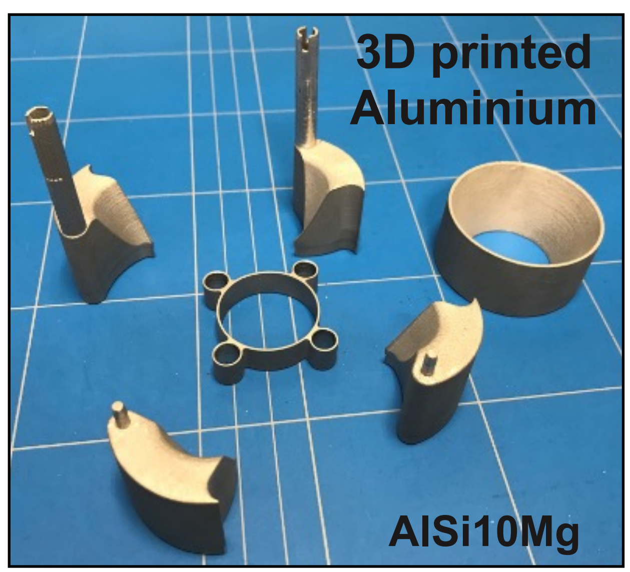

Single petal
Sensors (Layers and disks)
Carbon foam
and cold plate
Secondary
vacuum case

ALICE3 - IRIS

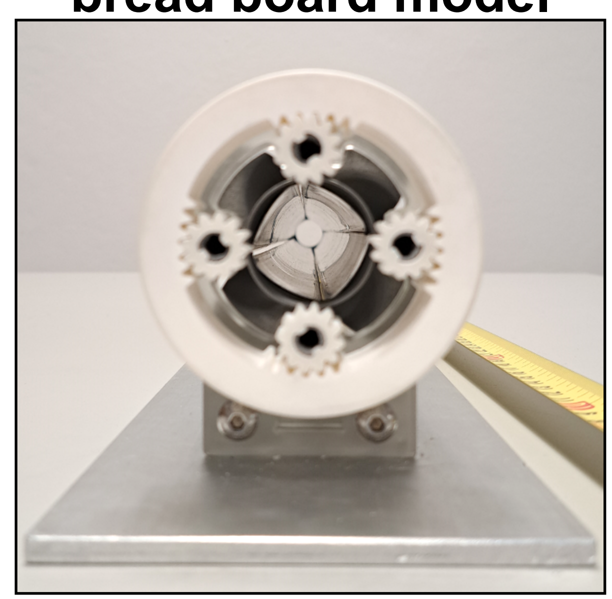


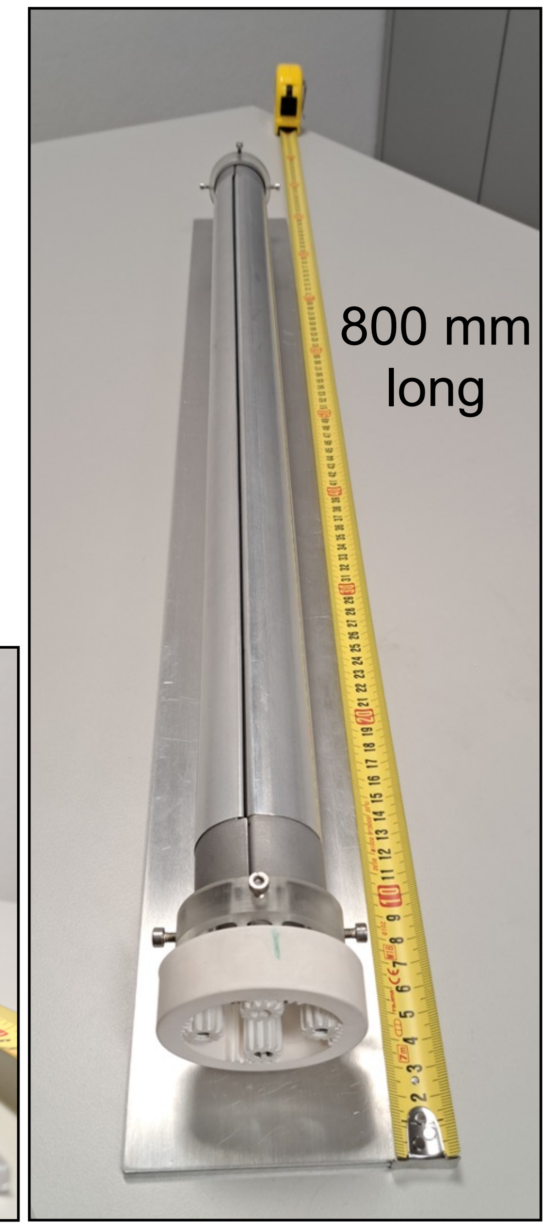






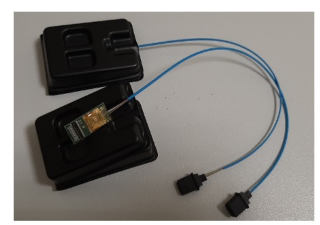
Petal case bread board model

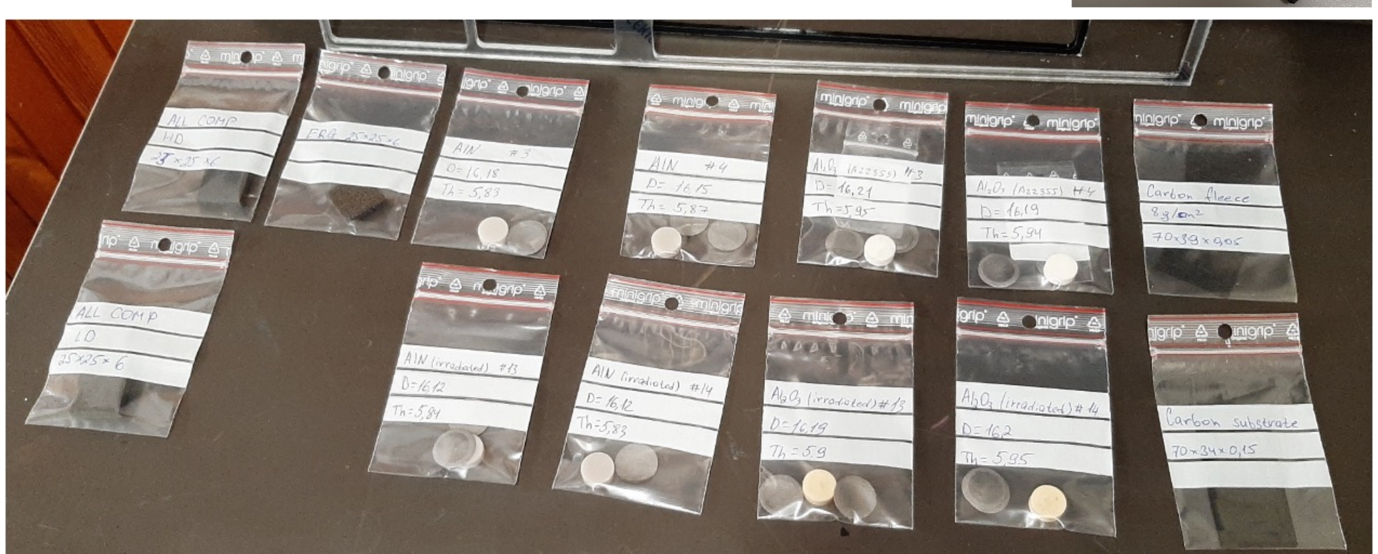


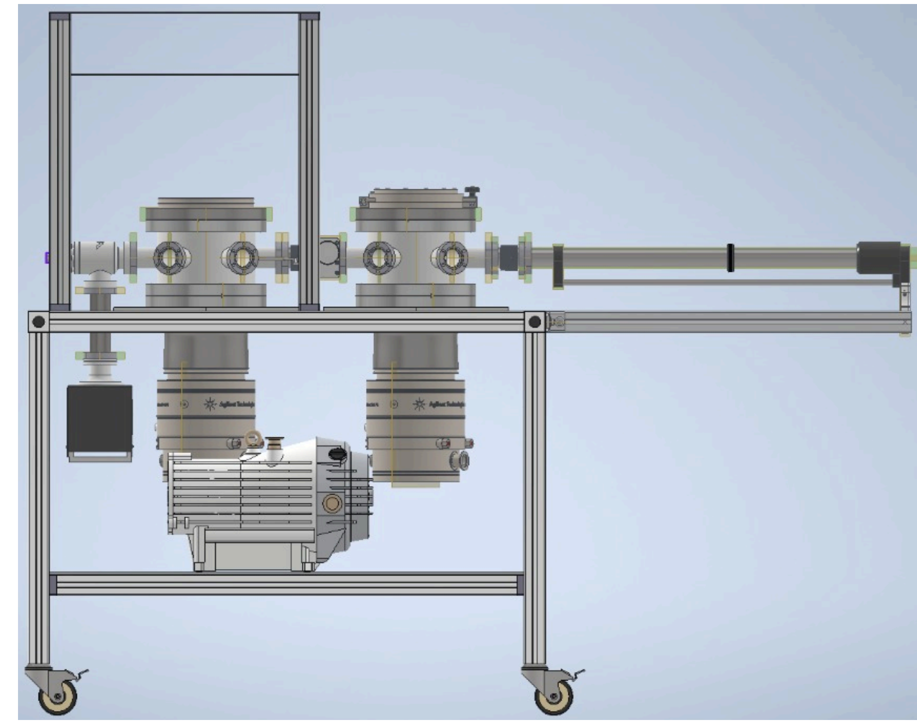


Outgassing studies at INFN Bari

- Carbon (LAYPUS) Substrate of the cold plate
- Carbon Fleece of the cold plate
- Carbon foam All comp high density
- Carbon foam All comp low density
- Carbon foam ERG duocel
- Optical Fiber with connector
- NASA Epoxy
- Si wafer
- Wire bonded Si wafer
- FPC
- 3D printed aluminium nitride (AIN) samples disks
- Al2O3 samples disk: 3D printed alumina (Al_2O_3) samples disks
- 3D printed AlSi samples disks



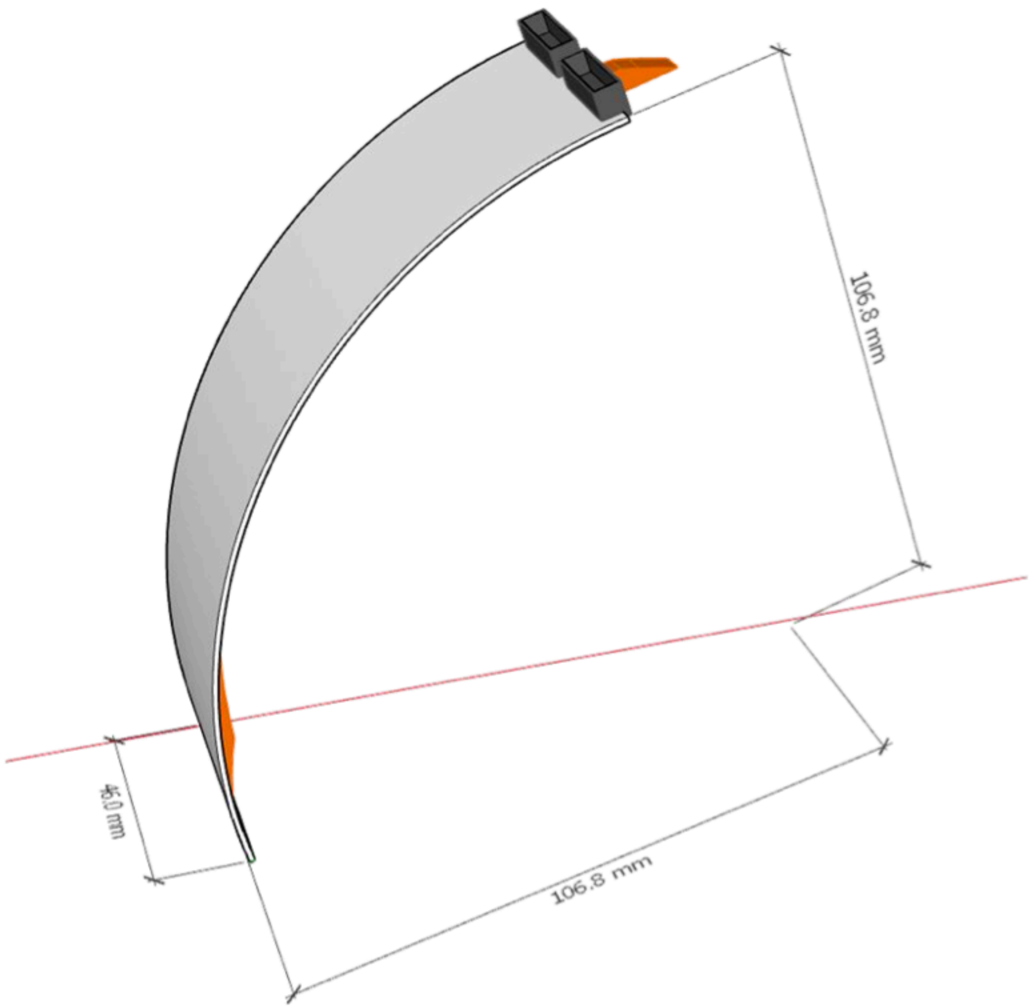




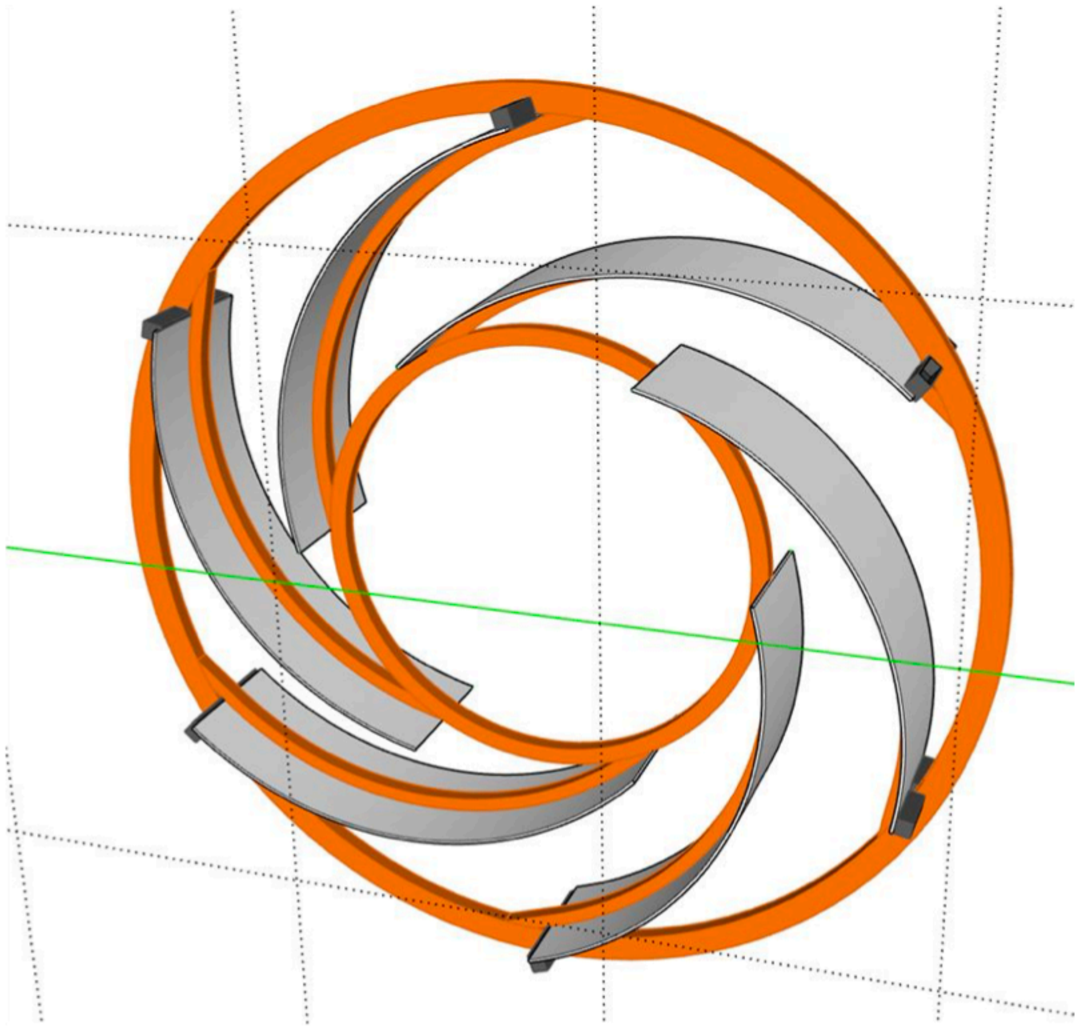
ALICE3 - MIDDLE LAYER

Prototype by INFN Padova

Modular unit - blade

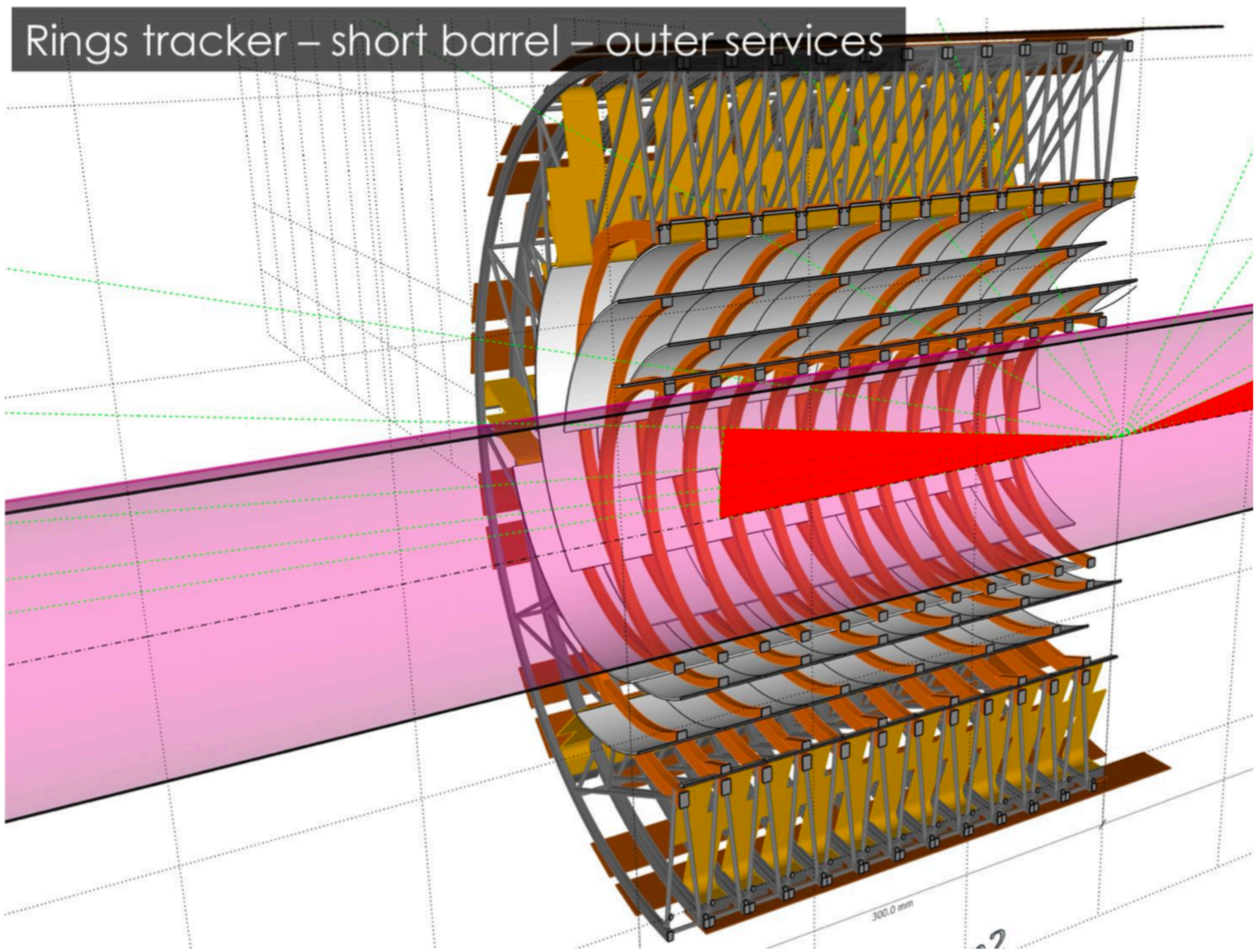


Modular unit - wheel

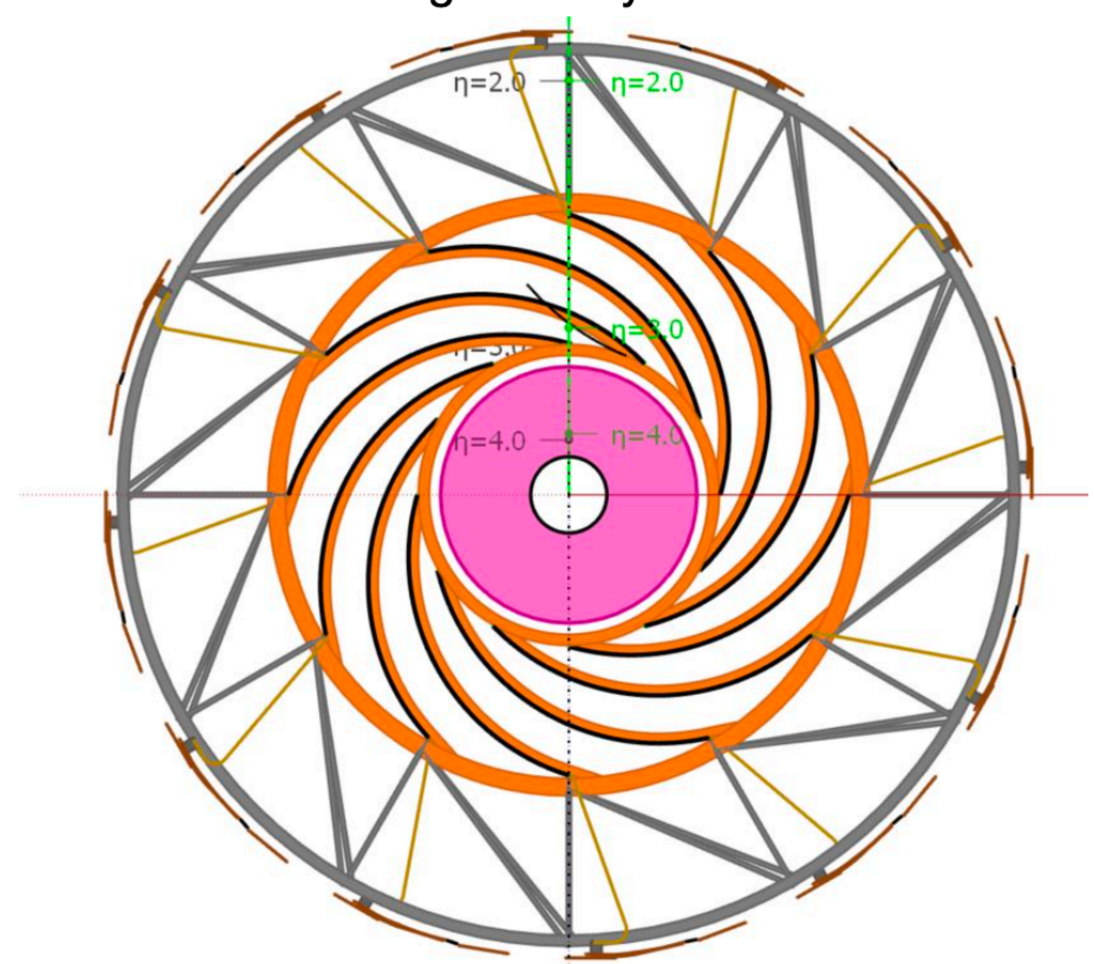


ALICE3 - MIDDLE LAYER

Prototype by INFN Padova

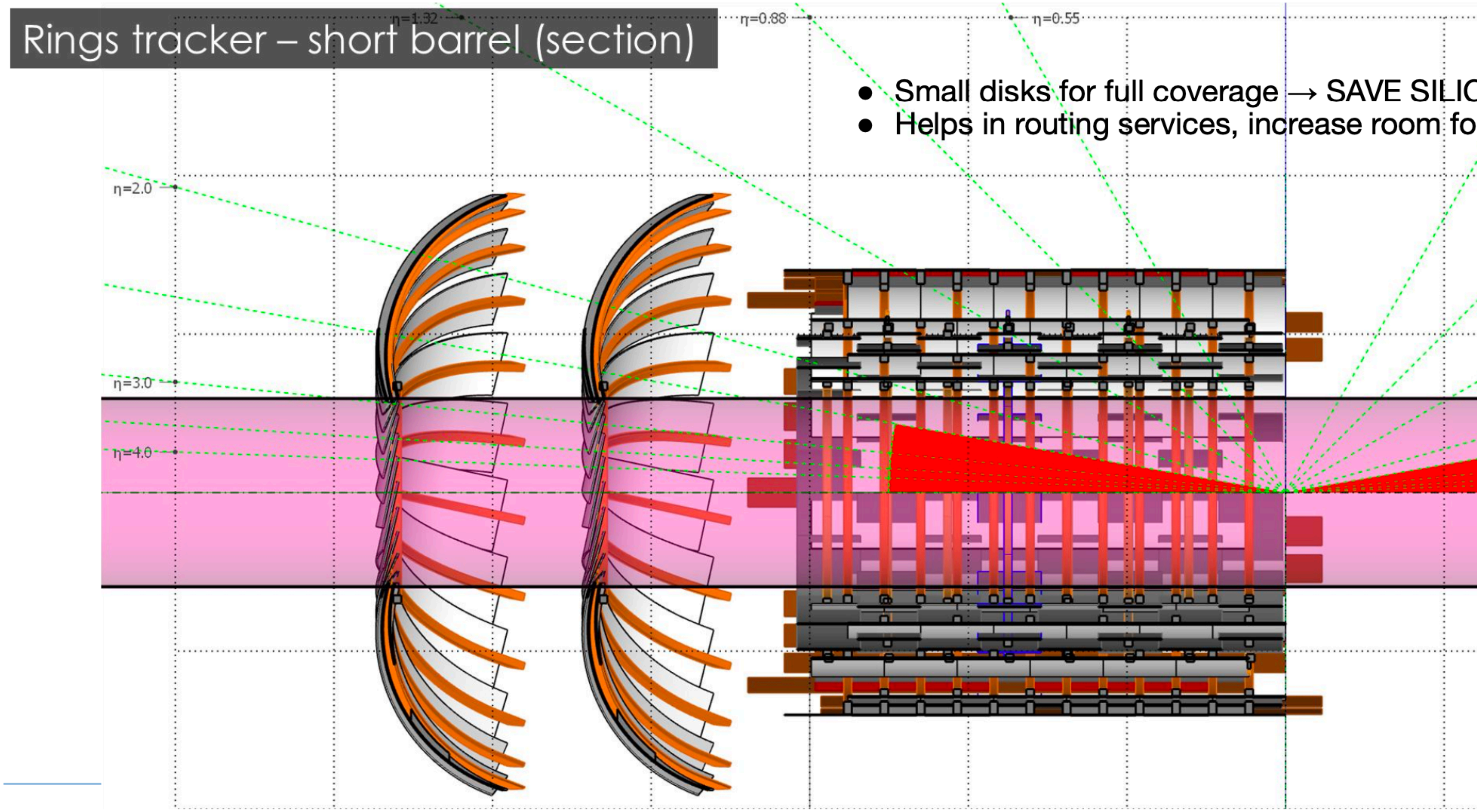


- Power from outer radii concept
- Air-cooling "friendly" structure



ALICE3 - MIDDLE LAYER

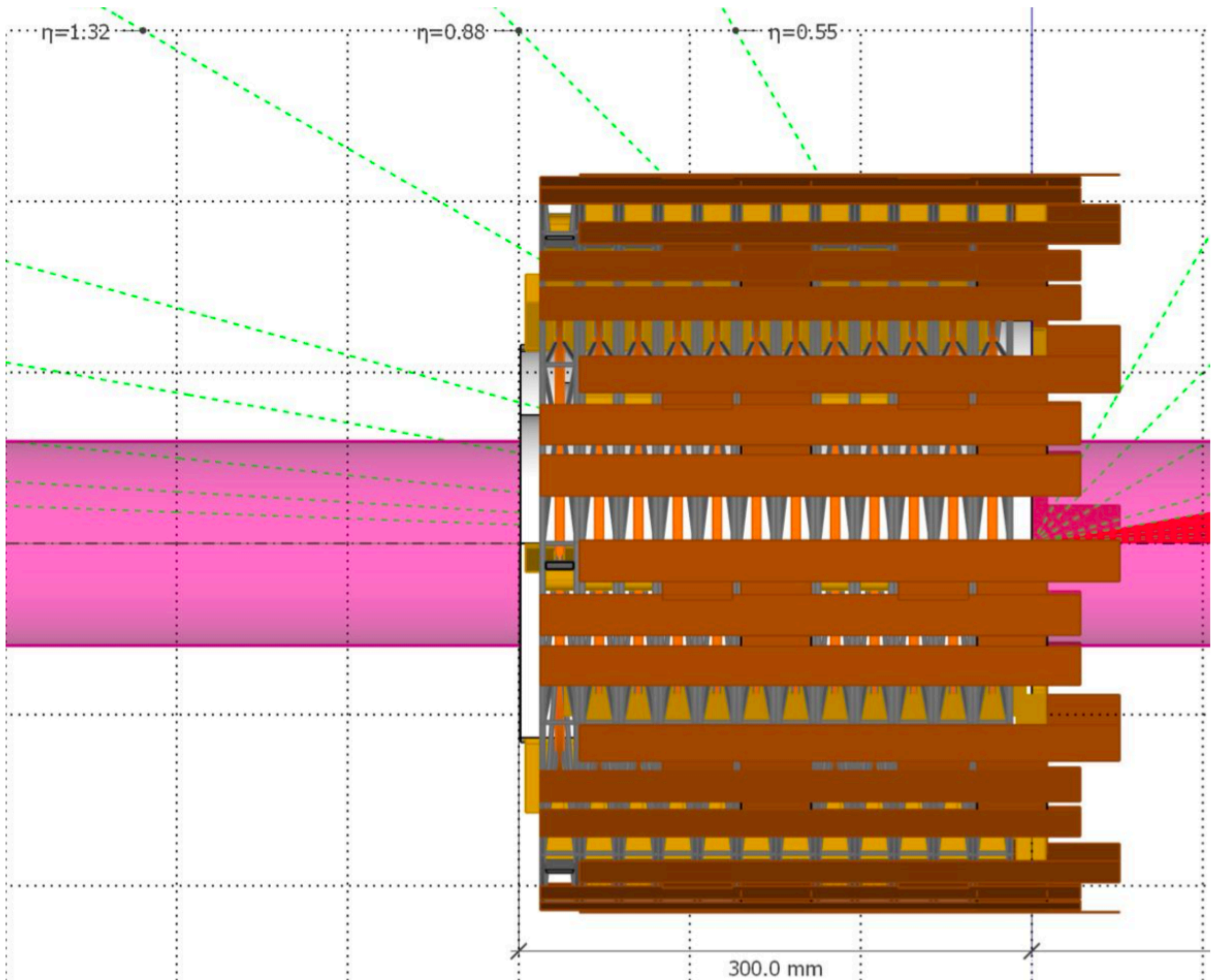
Prototype by INFN Padova



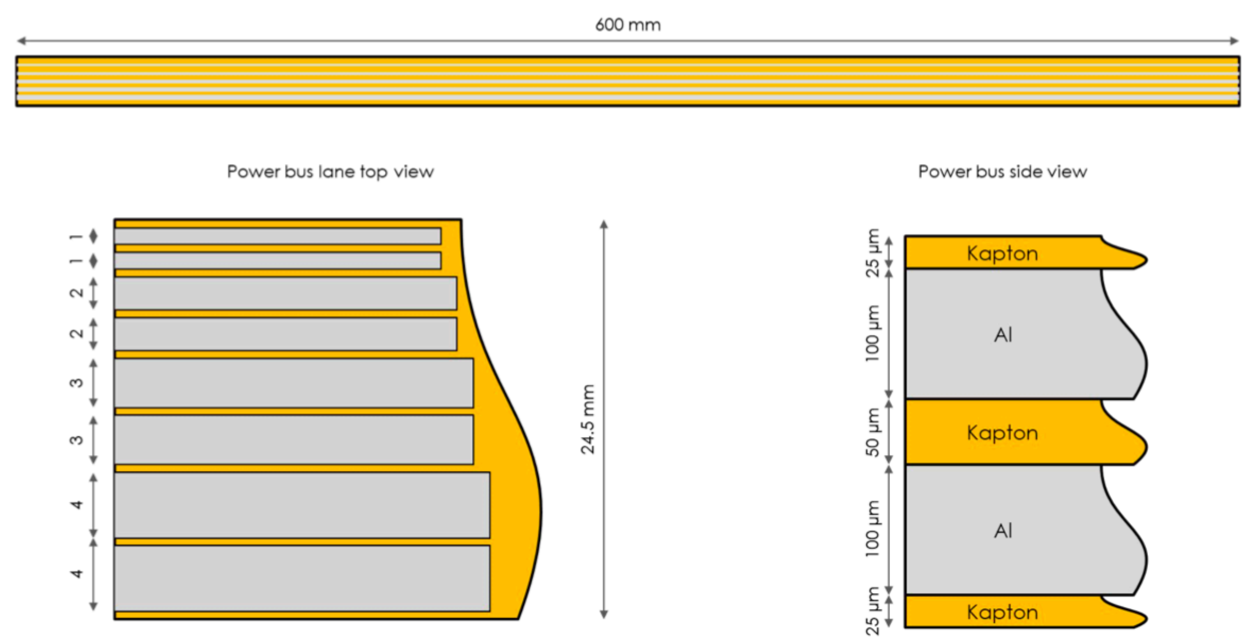
- Small disks for full coverage → SAVE SILICON!
- Helps in routing services, increase room for air-cooling

ALICE3 - MIDDLE LAYER

Prototype by INFN Padova

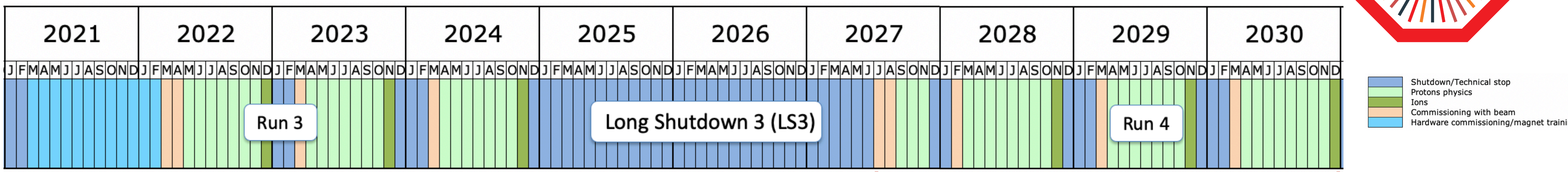


- Power bus studied for PARALLEL powering (so far)
- SERIAL powering will further reduce material (to do)



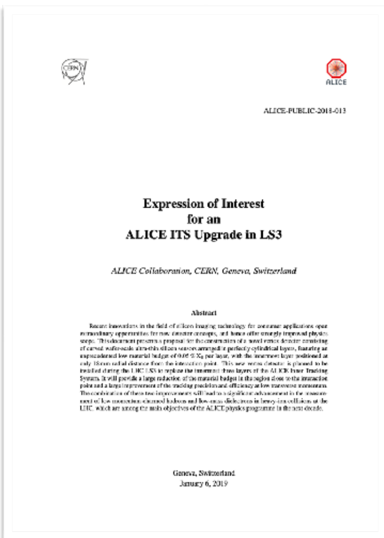
Backup

Backup



ALICE 2.1

Expression of Interest


ALICE-PUBLIC-2018-013

Expression of Interest
for an
ALICE ITS Upgrade in LS3

ALICE Collaboration, CERN, Geneva, Switzerland

Abstract

Geneva, Switzerland
January 6, 2019

[ALICE-PUBLIC-2018-013]
https://cds.cern.ch/record/2644611

Letter of Intent


Letter of Intent
for an
ALICE ITS Upgrade in LS3

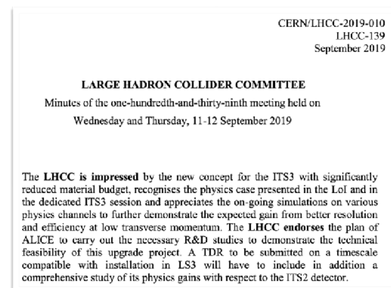
ALICE Collaboration, CERN, Geneva, Switzerland

Abstract

Geneva, Switzerland

[CERN-LHCC-2019-018 ; LHCC-I-034]
https://cds.cern.ch/record/2703140/

LHCC 139 (Sep 2019)


CERN/LHCC-2019-010
LHCC-139
September 2019

LARGE HADRON COLLIDER COMMITTEE

Minutes of the one-hundredth-and-thirty-ninth meeting held on
Wednesday and Thursday, 11-12 September 2019

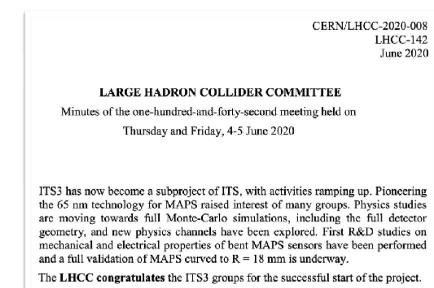
The **LHCC is impressed** by the new concept for the ITS3 with significantly reduced material budget, recognises the physics case presented in the LoI and in the dedicated ITS3 session and appreciates the on-going simulations on various physics channels to further demonstrate the expected gain from better resolution and efficiency at low transverse momentum. The **LHCC endorses** the plan of ALICE to carry out the necessary R&D studies to demonstrate the technical feasibility of this upgrade project. A TDR to be submitted on a timescale compatible with installation in LS3 will have to include in addition a comprehensive study of its physics gains with respect to the ITS2 detector.

"The LHCC is **impressed** by the new concept for the ITS3…"

Project setup (spring 2020)

- Project leaders
- Work packages conveners
- Institutes joining

LHCC 142 (Jun 2020)


CERN/LHCC-2020-008
LHCC-142
June 2020

LARGE HADRON COLLIDER COMMITTEE

Minutes of the one-hundred-and-forty-second meeting held on
Thursday and Friday, 4-5 June 2020

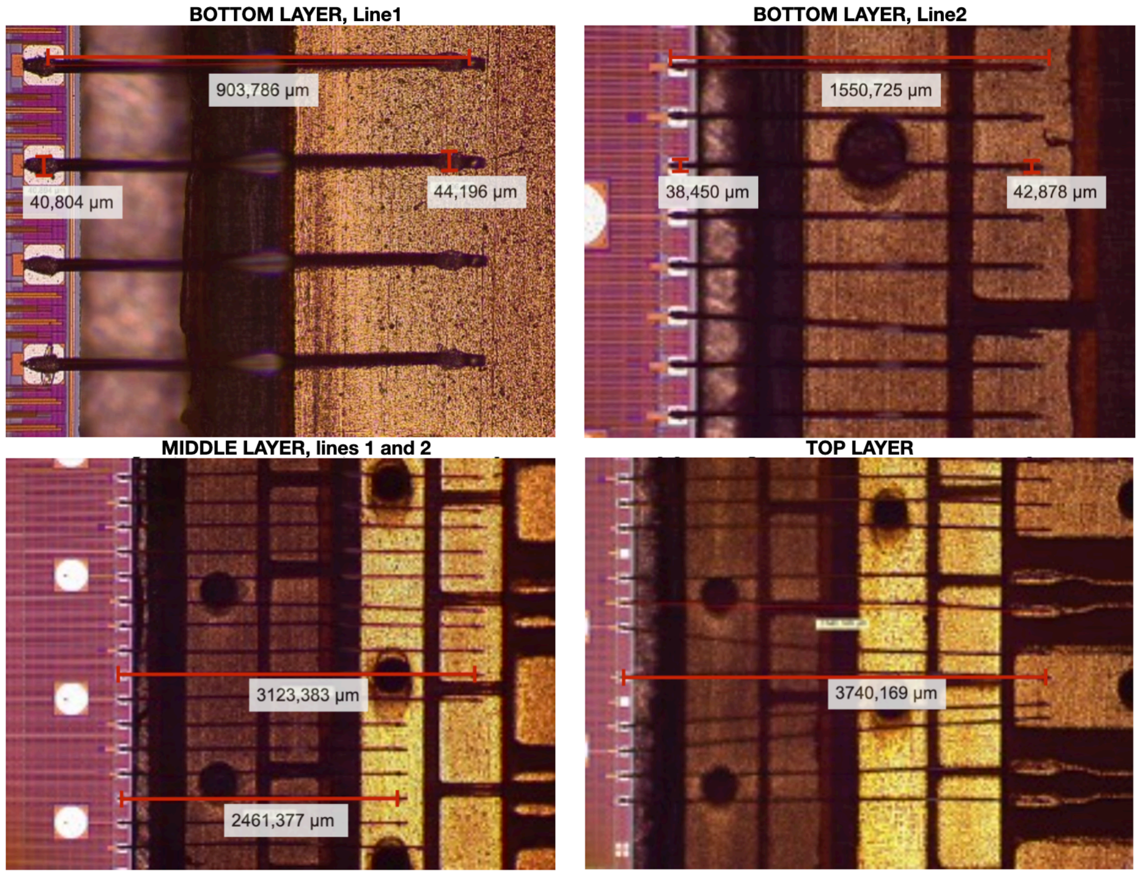
ITS3 has now become a subproject of ITS, with activities ramping up. Pioneering the 65 nm technology for MAPS raised interest of many groups. Physics studies are moving towards full Monte-Carlo simulations, including the full detector geometry, and new physics channels have been explored. First R&D studies on mechanical and electrical properties of bent MAPS sensors have been performed and a full validation of MAPS curved to R = 18 mm is underway.

The **LHCC congratulates** the ITS3 groups for the successful start of the project.

"The LHCC **congratulates** the ITS3 groups for the successful start of the project."

Oct 2018 — **Sep 2019** — **Sep 2019** — **Dec 2019** — **Spring 2020** — **Jun 2020**

Backup - Interconnection

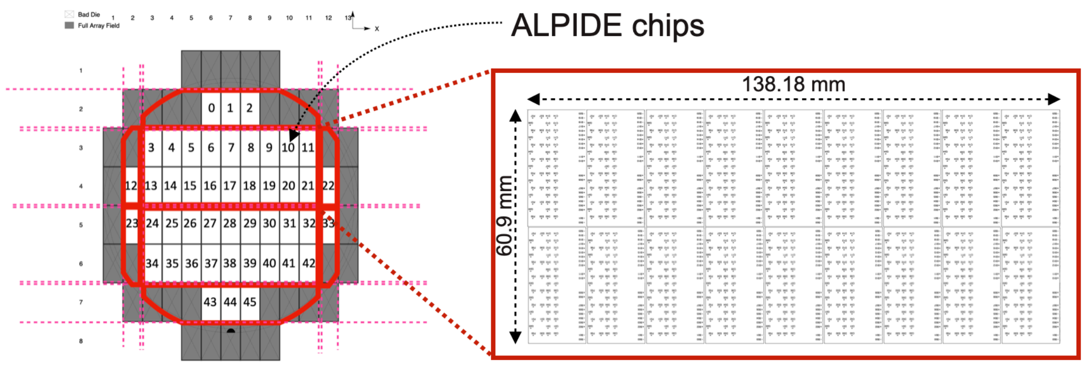


Line	BOT-L1	BOT-L2	MID-L1	MID-L2	TOP-L1
Loop height (μm)	110	220	310	360	500
Pad-pad distance (μm)	880	1520	2420	3140	3740
Wire angle on FPC (°)	13	15	17	8	4
Wire angle on sensor (°)	12	16	14	13	15
Pull force (g) [mean ± dispersion]	6.6±0.3	6.6±0.3	5.1±0.4	5.2±0.3	3.8±0.3
Pull force (g) [min - max]	5.8-7.0	6.2-7.1	4.3-5.7	4.7-5.6	3.2-4.2
Force on wire FPC side (g)	15.3	12.3	13.8	14.1	11.3
Force on wire sensor side (g)	15.2	12.4	14.1	14.4	11.6

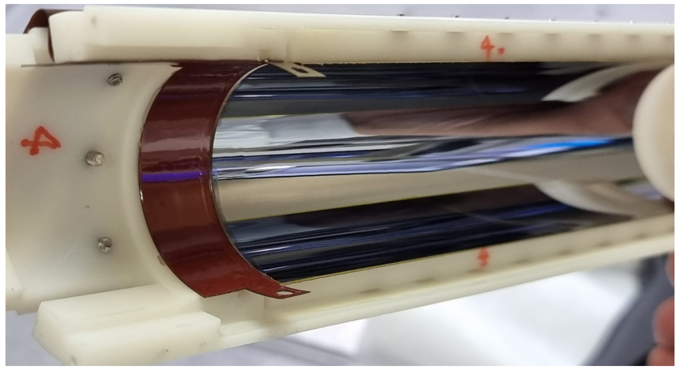
Backup - Super-ALPIDE project

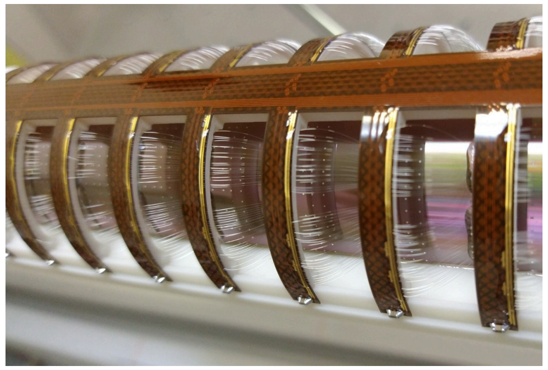
» Super-ALPIDE
- 18 not diced ALPIDE chips
- dimensions close to the ones for L0 sensor

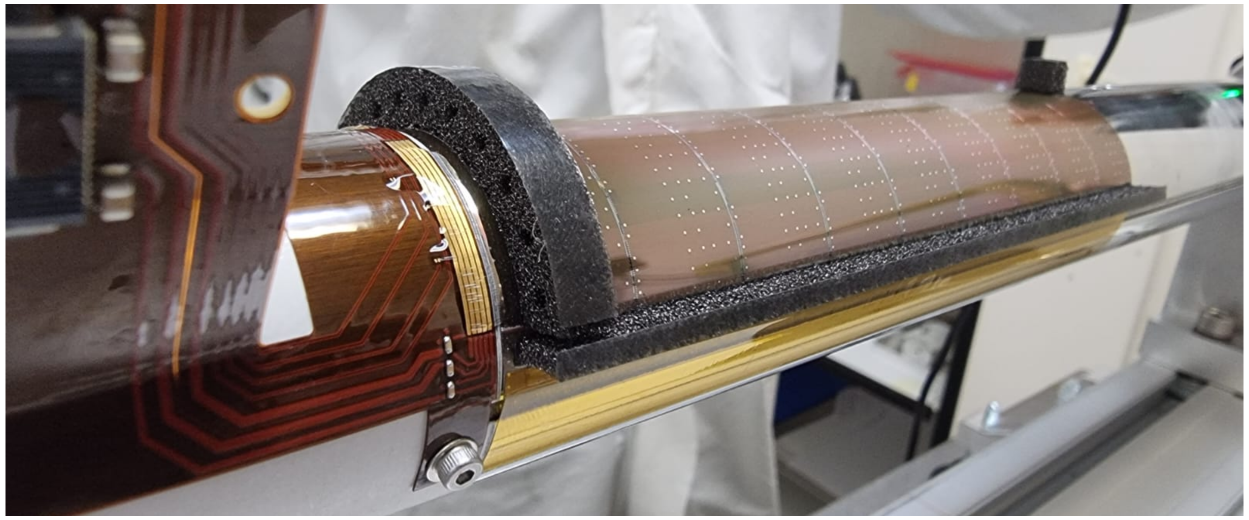
» Goals
- verify bending tools for large-size working chips
- verify mechanical support alignment tools
- develop wire-bonding over bent surface tools
- develop first bent flex prototype (for powering and data streaming)
- assemble first working large dimension bent sensor → by October 2023

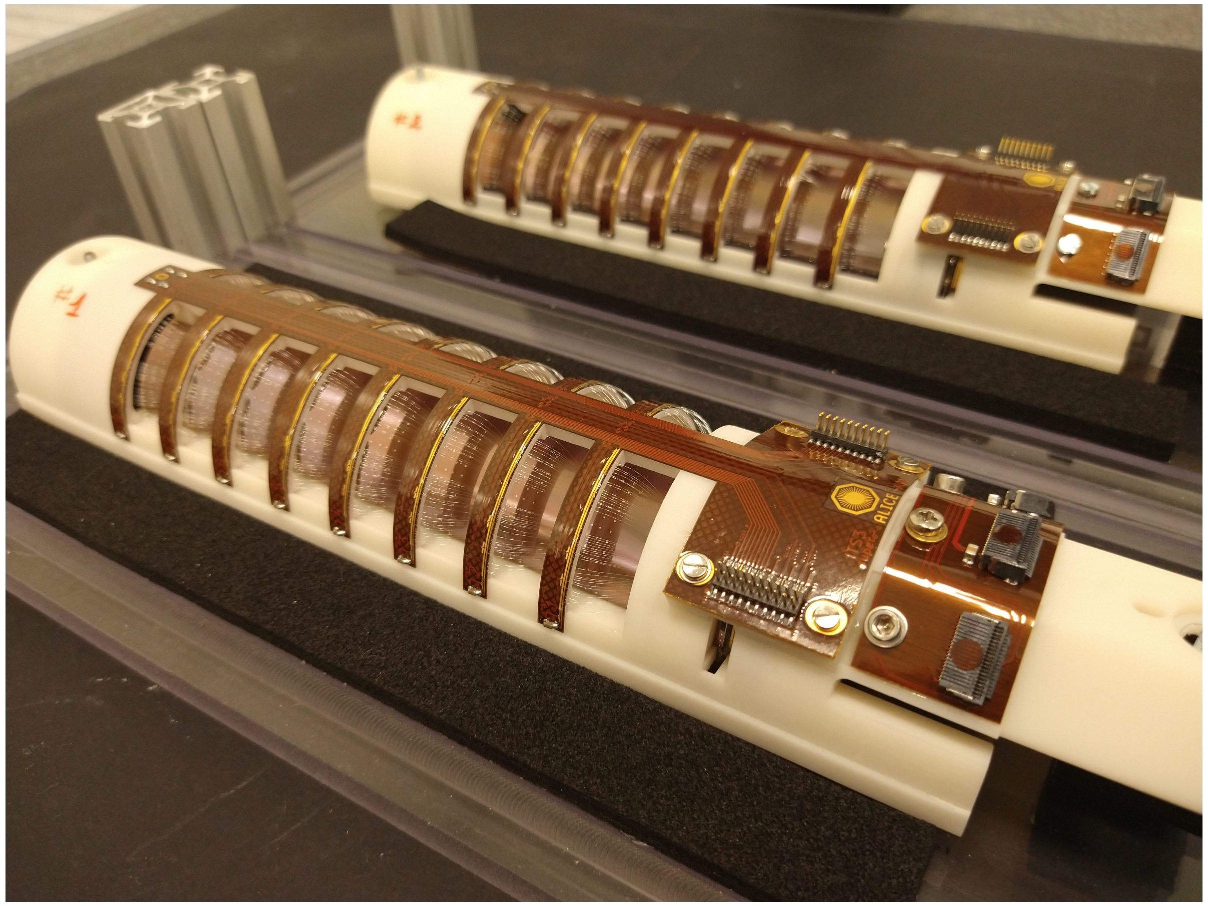


Super-ALPIDE: 18 not diced ALPIDE chips

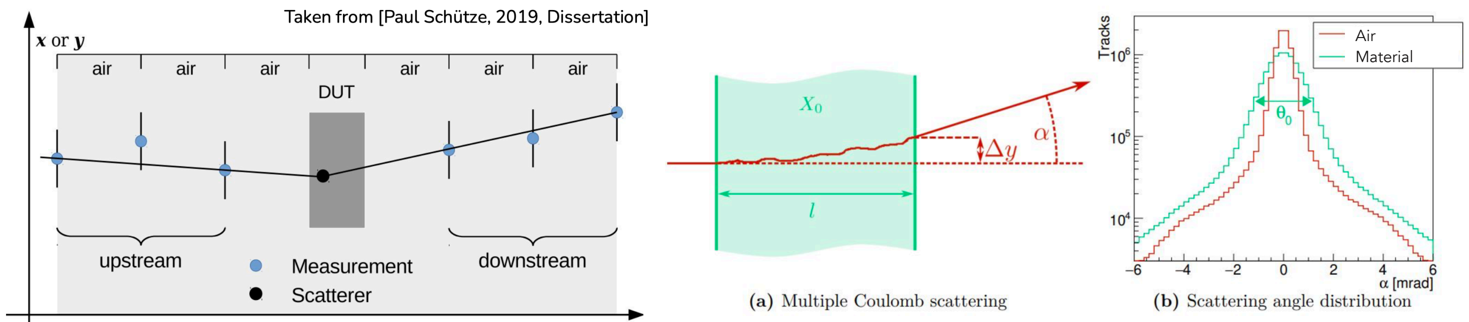


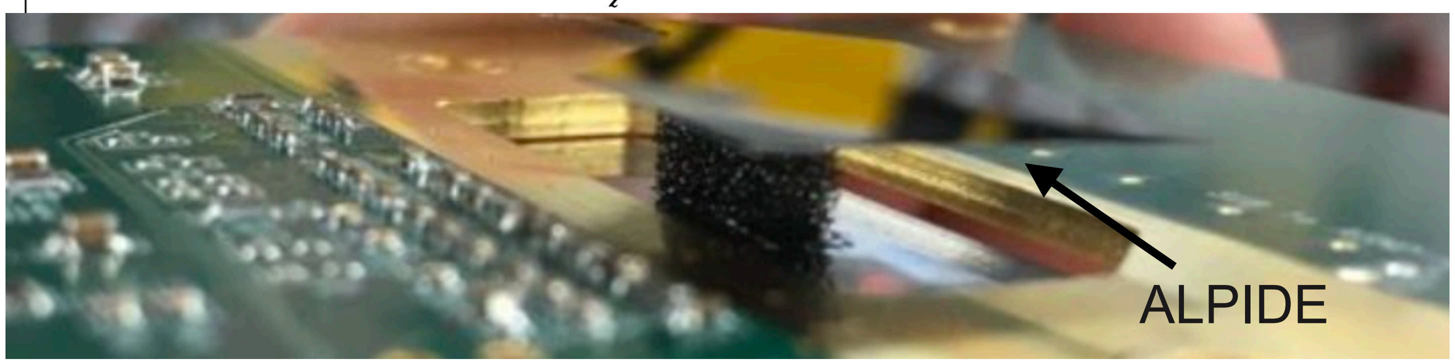




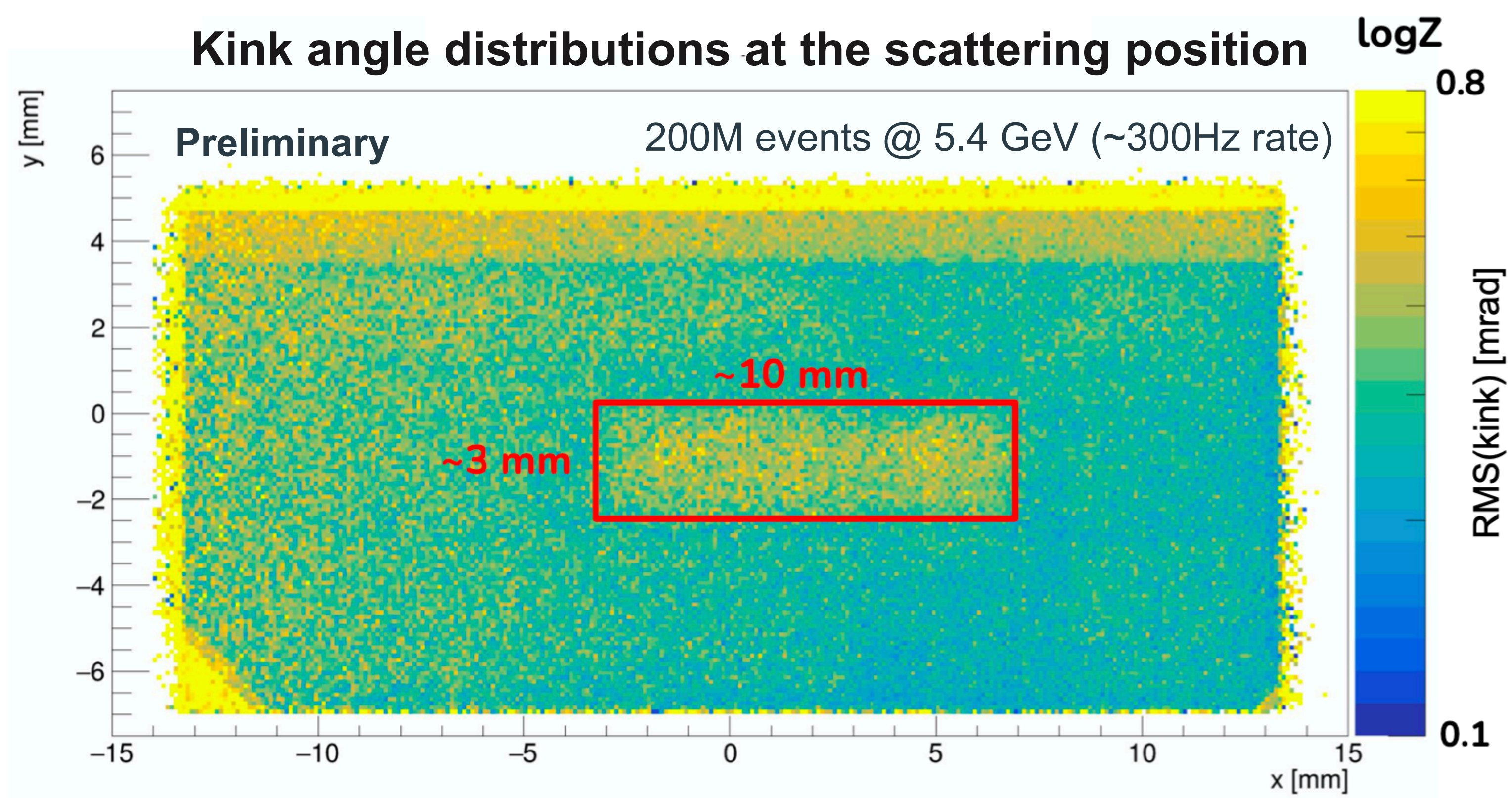


Backup - Carbon foam properties



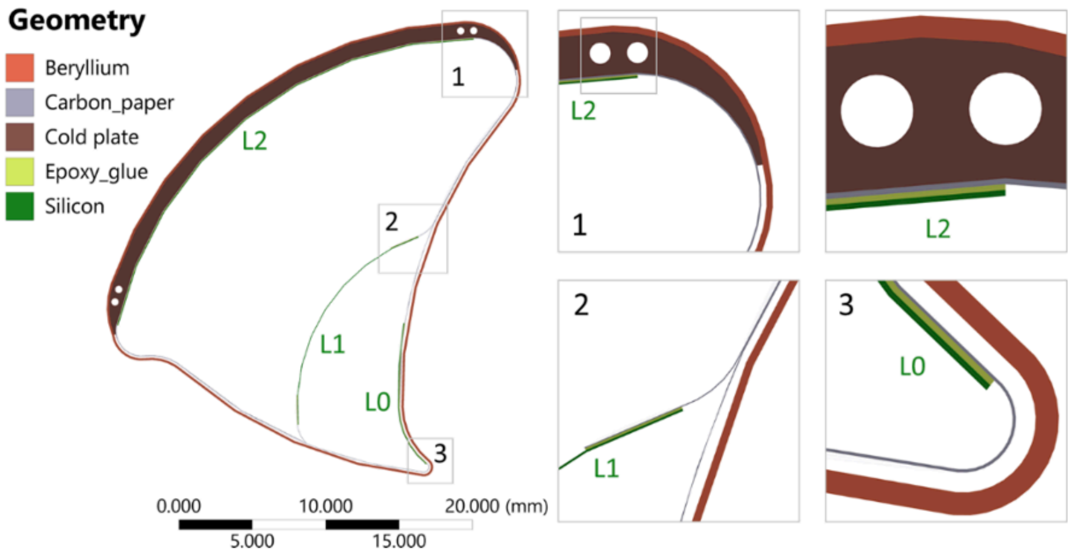


- » Carbon foam material budget study though particle deviation angle measurement



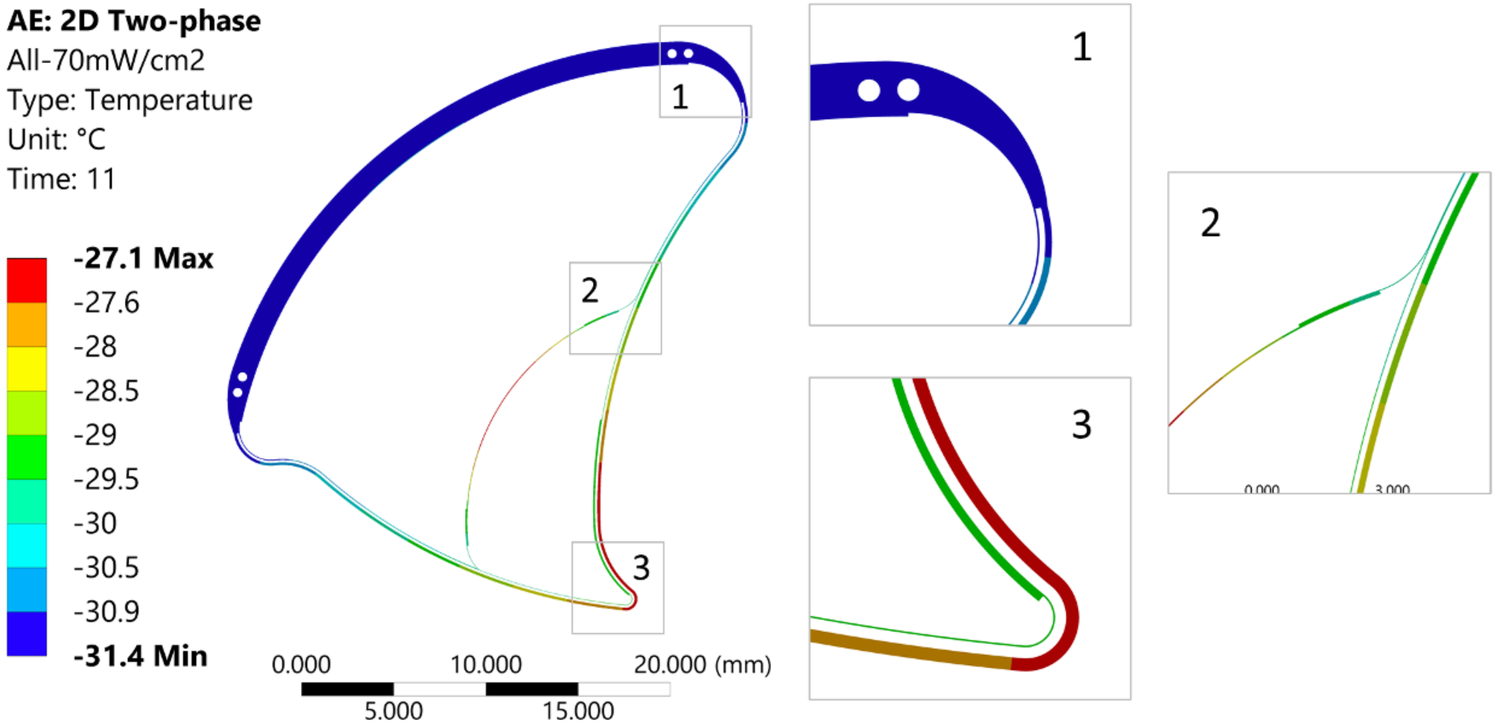
Iris tracker: Petals Cooling @~-25°C

Expected 1x10^16 1 MeV n_eq of NIEL in 50 months of operation and 6 Mrad TID. Cooling will mitigate leakage current damages that will also depend on the process and the pixel geometry, not yet defined, in addition to the NIEL radiation level. The NIEL radiation load is about the same as for ATLAS and CMS.



Design assumption for preliminary assessment

1. Two-phase evaporative CO_2
   (alternatives fluid will be considered)
2. Applied heat flux
   70mW/cm2 sensors heat flux
   100mW/cm2 beam pipe current flow (impedance)



Temperature profile

Preliminary results show that the sensors can be cooled at ~ -29C with an inlet CO_2 at -35C.

Same analysis also shows a deltaT of 1-2 degrees within the single sensor and 5 degrees between the coldest (outermost) and hottest sensor (innermost).