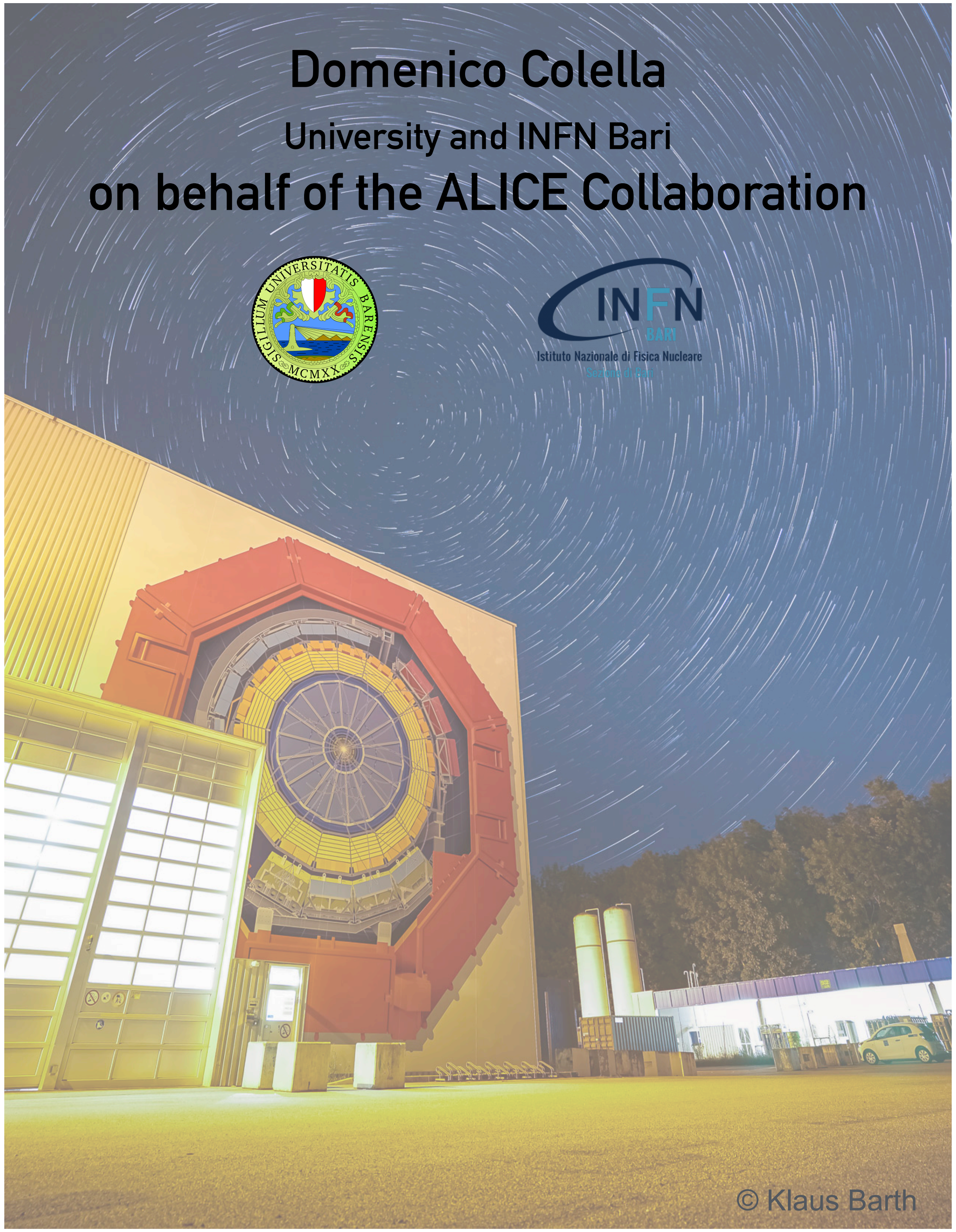
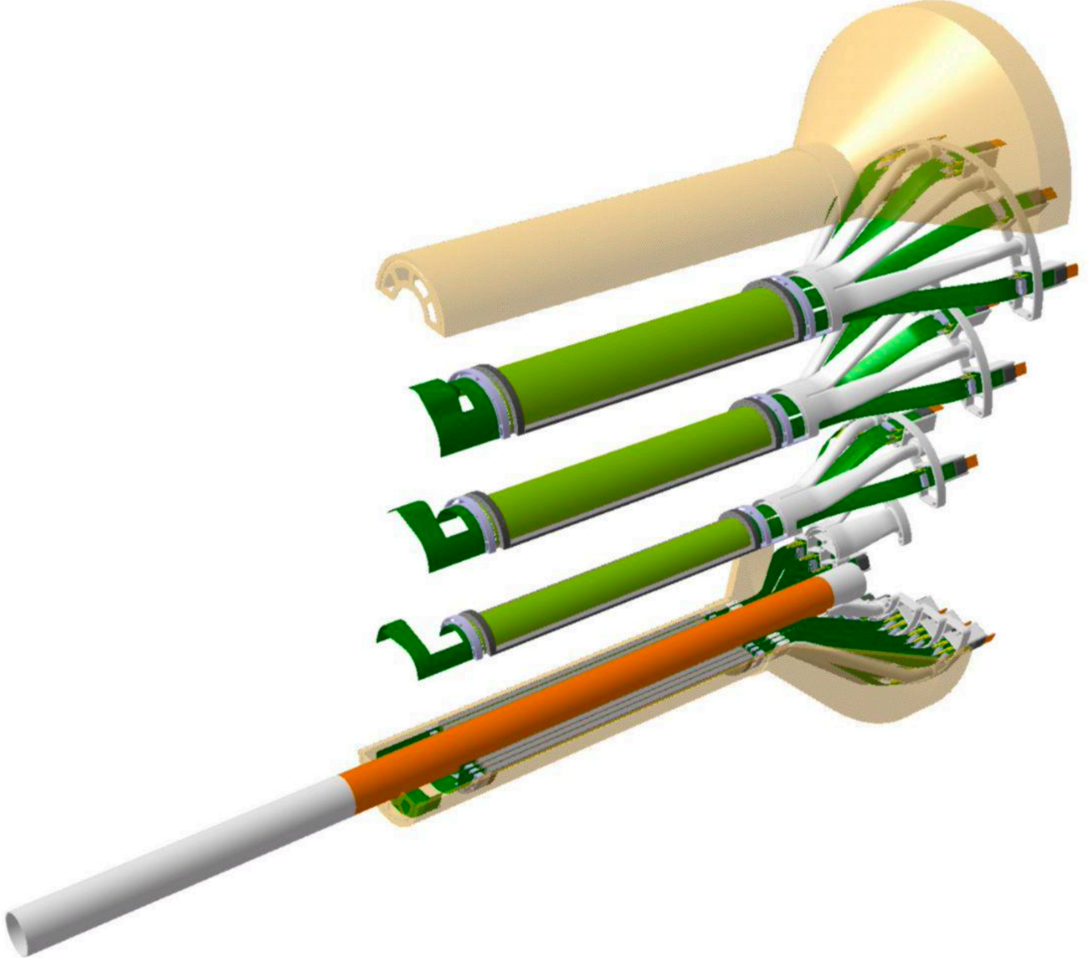
Domenico Colella
University and INFN Bari
on behalf of the ALICE Collaboration

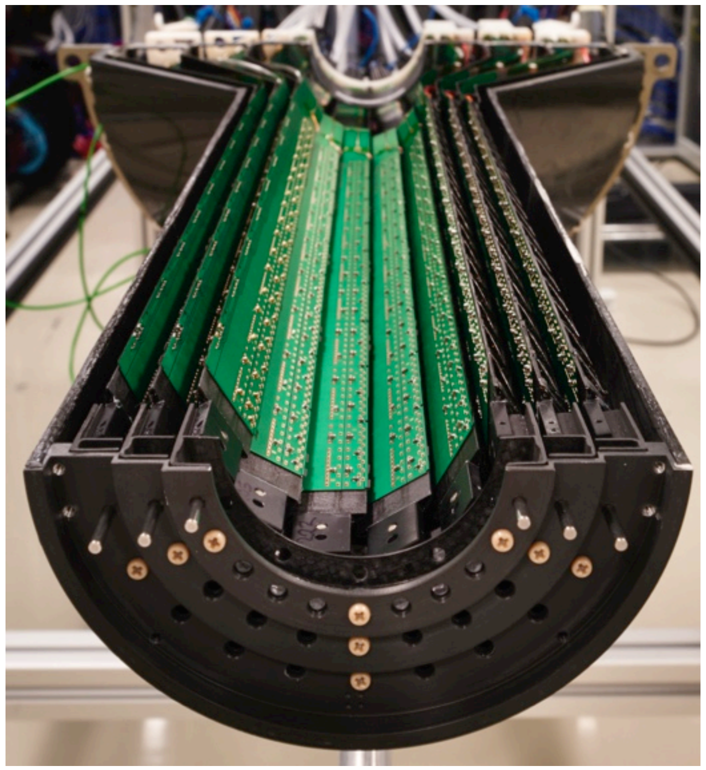


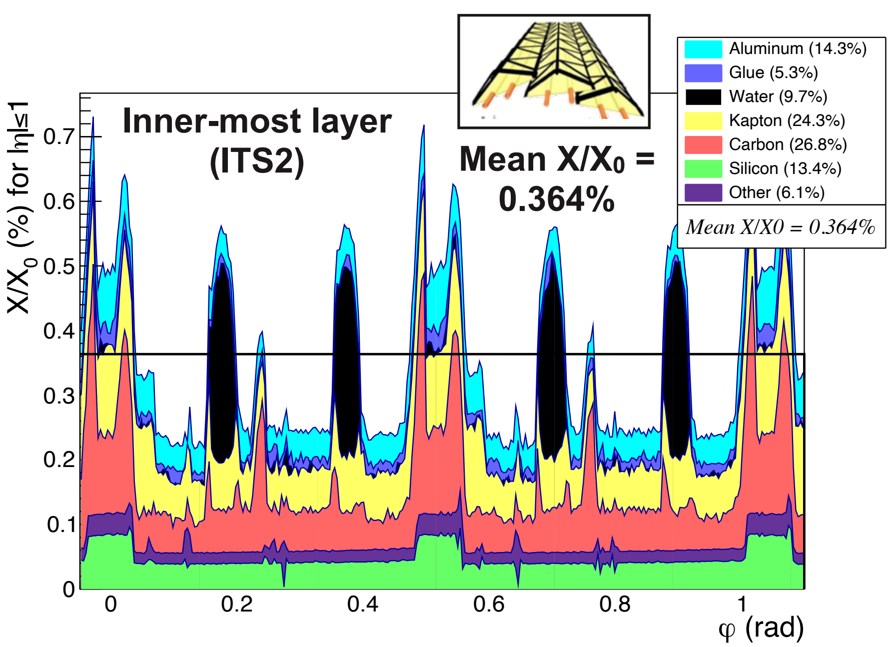
ALICE ITS3
how to integrate a large dimension MAPS sensor in a bent configuration detector



ITS3 detector concept

ITS2-IB





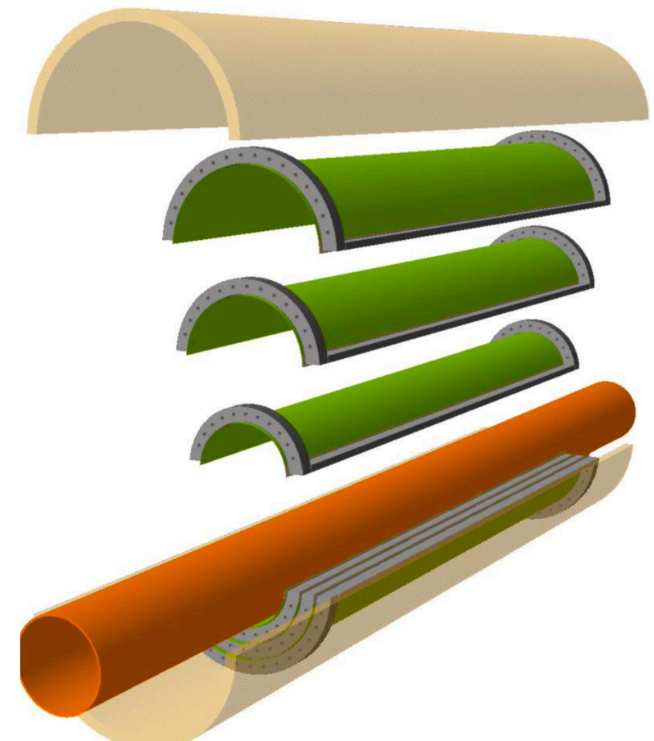
Required improvements

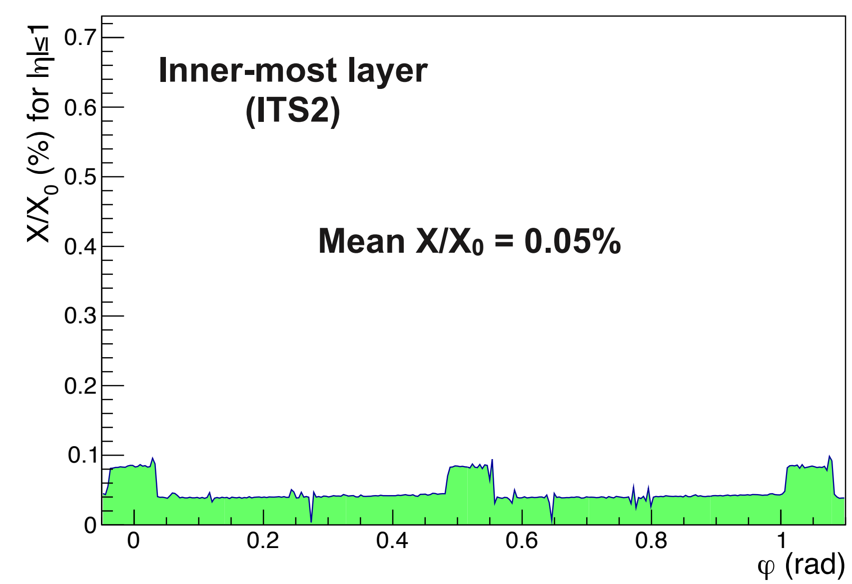
» *Removal of water cooling*
→ low flow air cooling

» *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

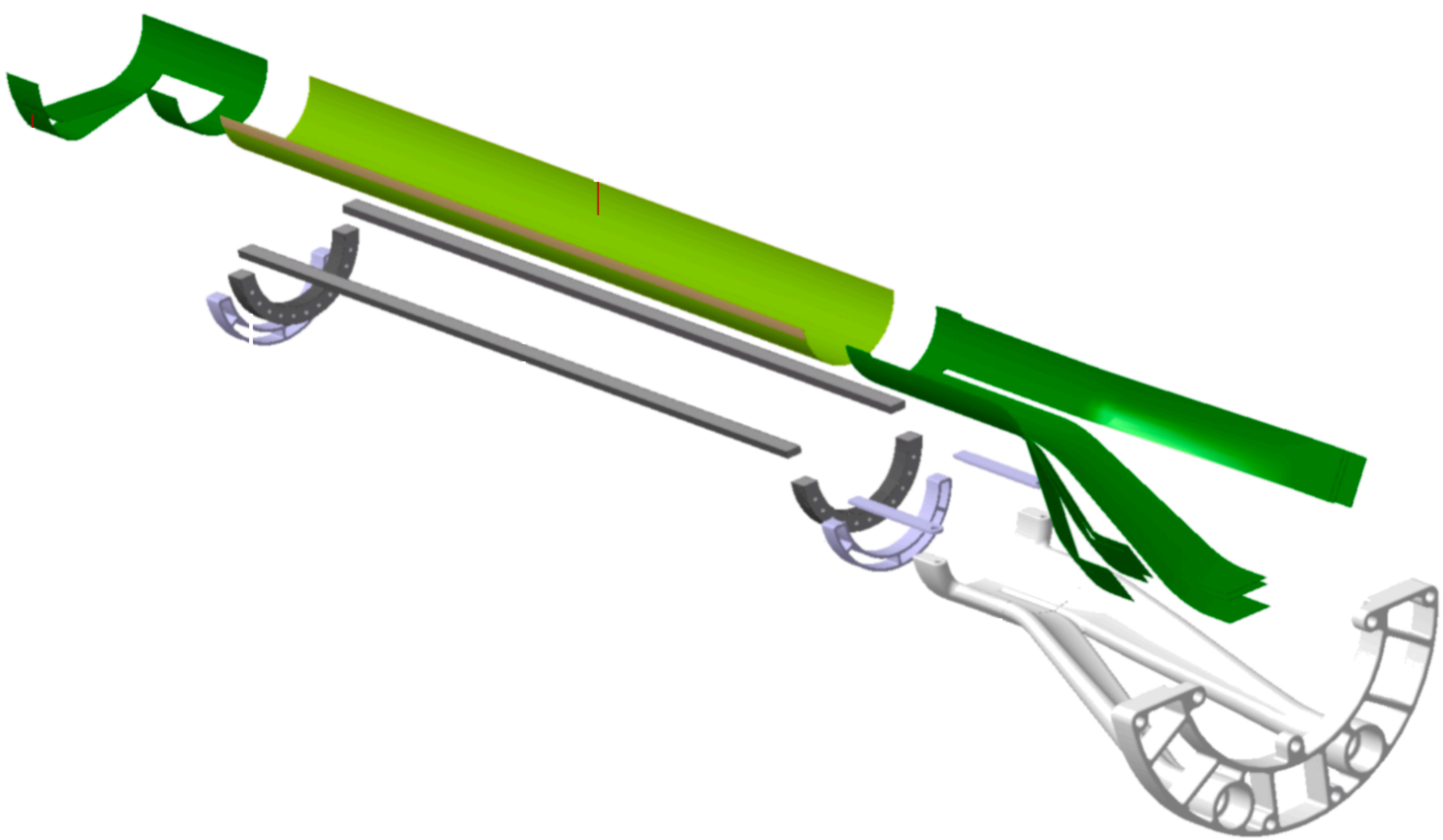




ITS3 detector concept

Key ingredients

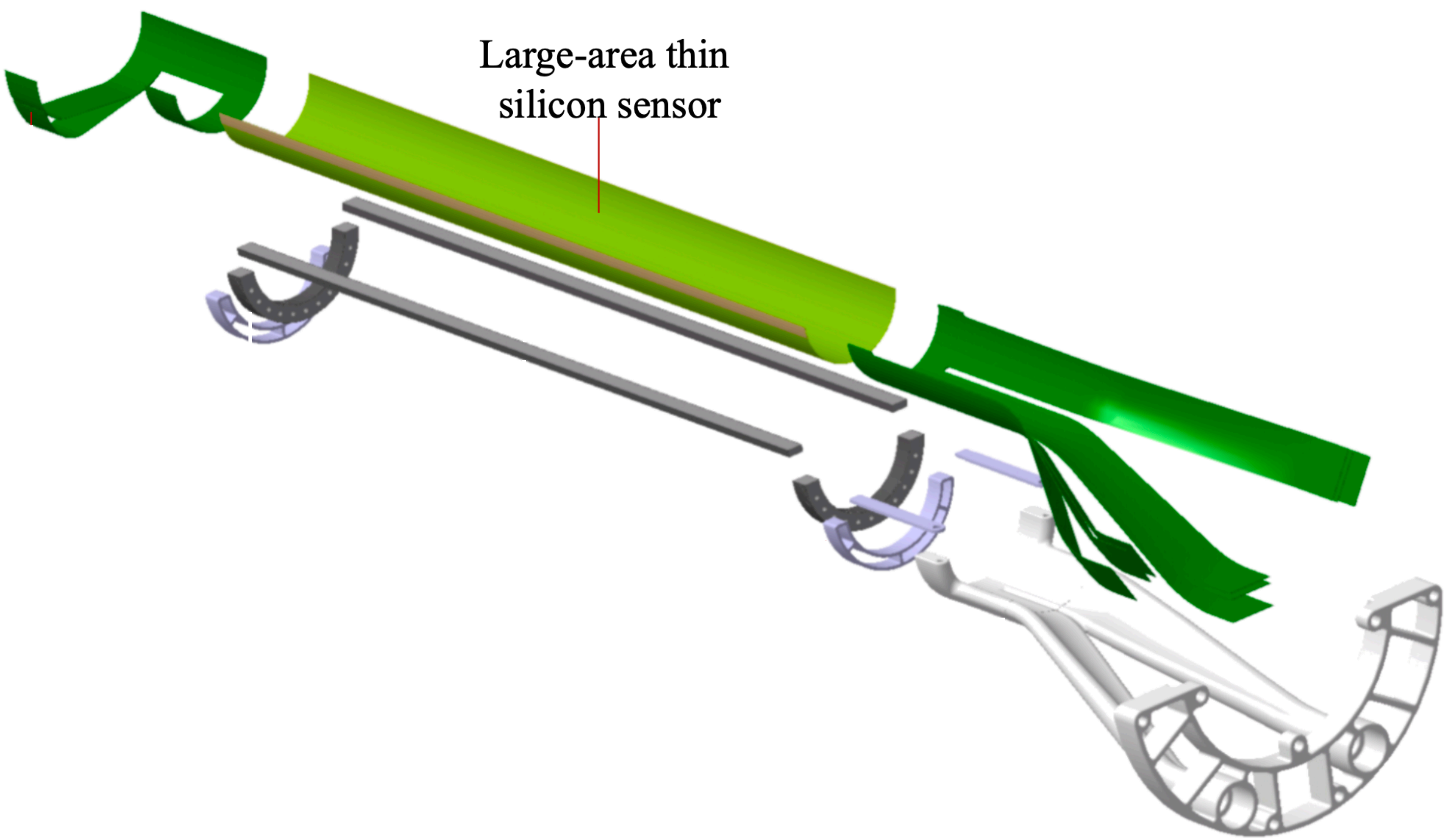
» Wafer-scale chips (up to ~28x10 cm), fabricated using stitching
» Si MAPS sensor based on 65 nm technology
» Sensor thickness ≤ 50 µm
» Chips bent in cylindrical shape at target radii
» Ultra light carbon foam structures
» Air cooling



ITS3 detector concept

Key ingredients

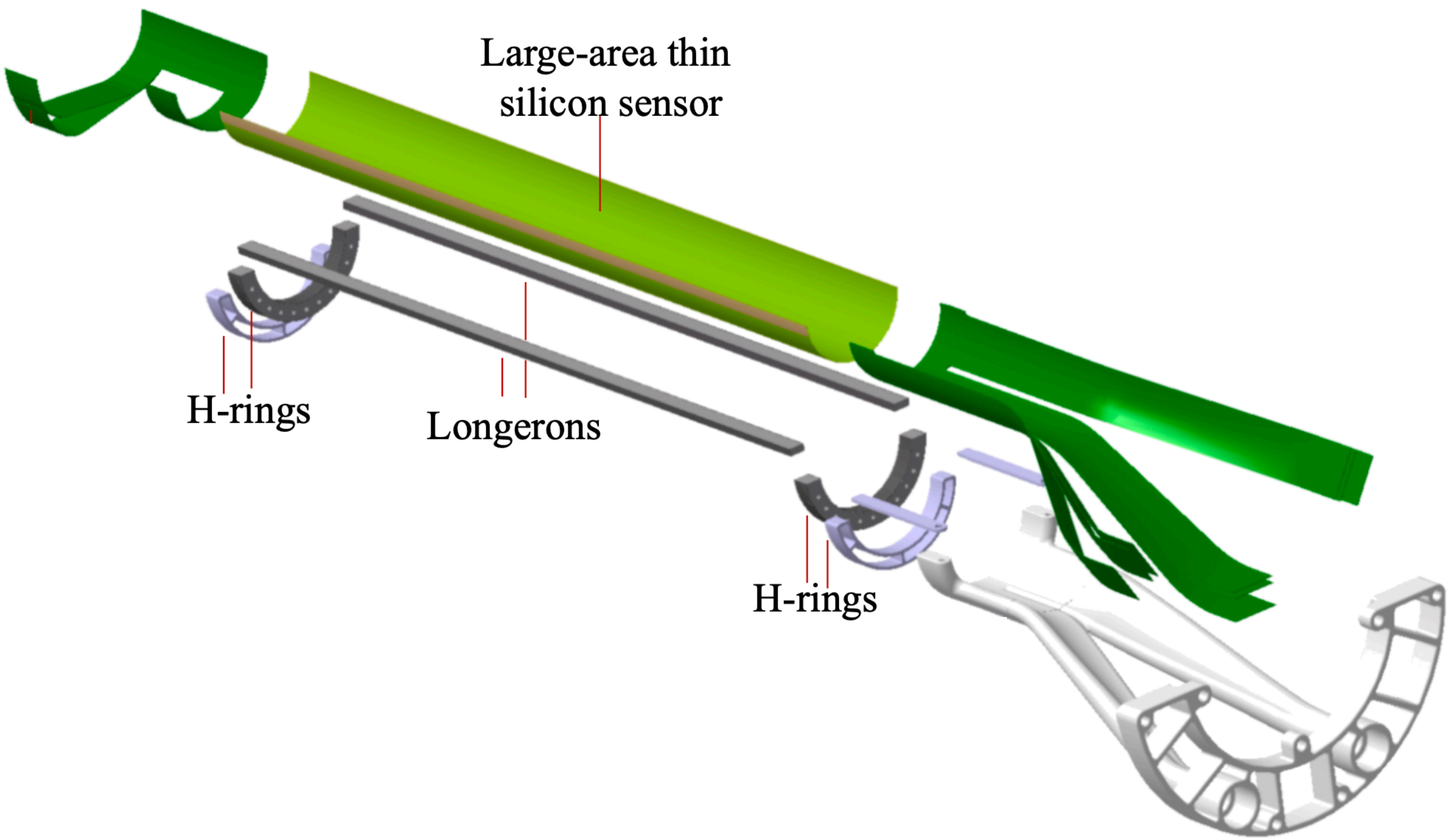
» Wafer-scale chips (up to ~28x10 cm), fabricated using stitching
» Si MAPS sensor based on 65 nm technology
» Sensor thickness ≤ 50 μm
» Chips bent in cylindrical shape at target radii
» Ultra light carbon foam structures
» Air cooling



ITS3 detector concept

Key ingredients

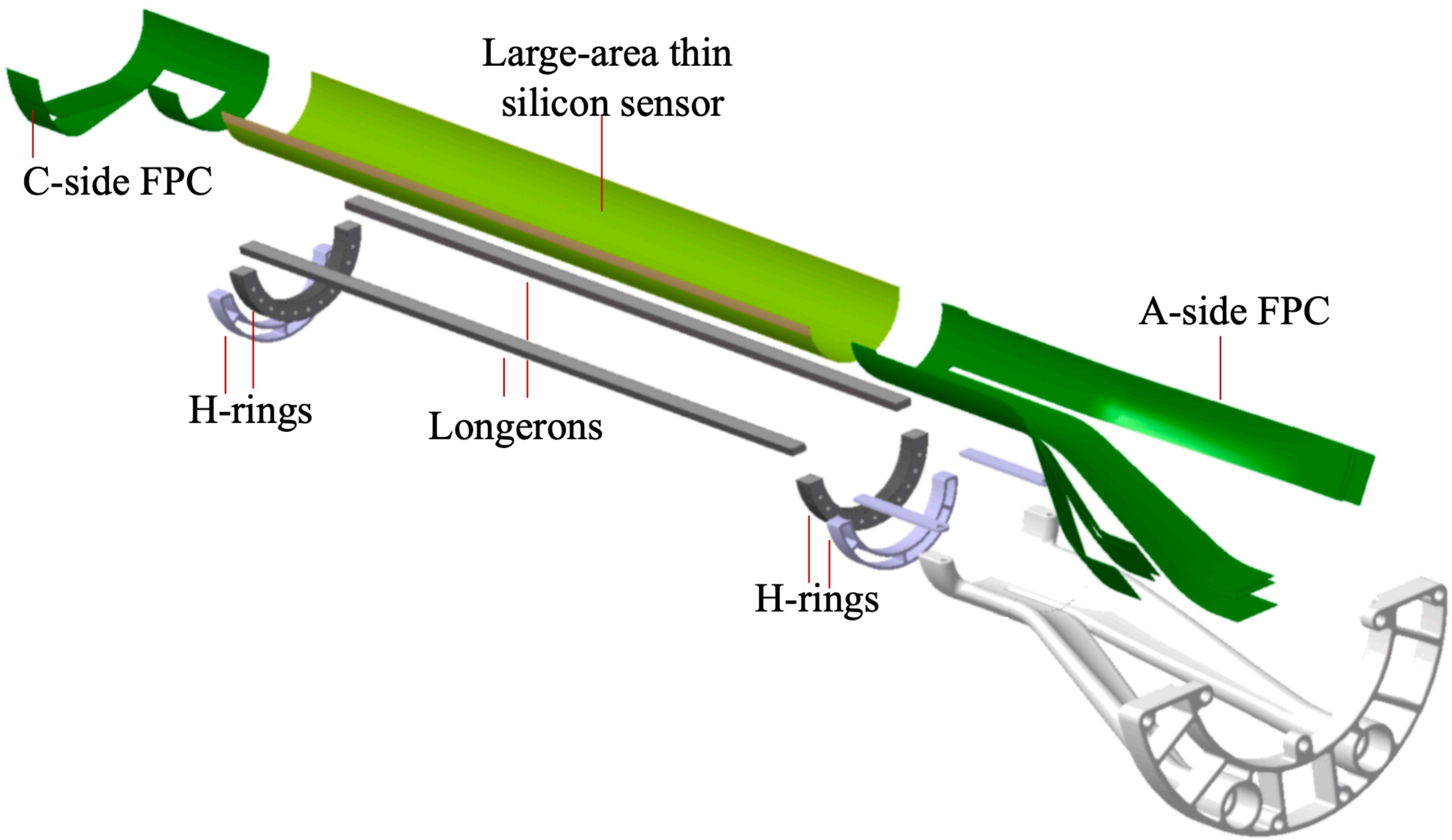
» Wafer-scale chips (up to ~28x10 cm), fabricated using stitching
» Si MAPS sensor based on 65 nm technology
» Sensor thickness ≤ 50 µm
» Chips bent in cylindrical shape at target radii
» Ultra light carbon foam structures
» Air cooling



ITS3 detector concept

Key ingredients

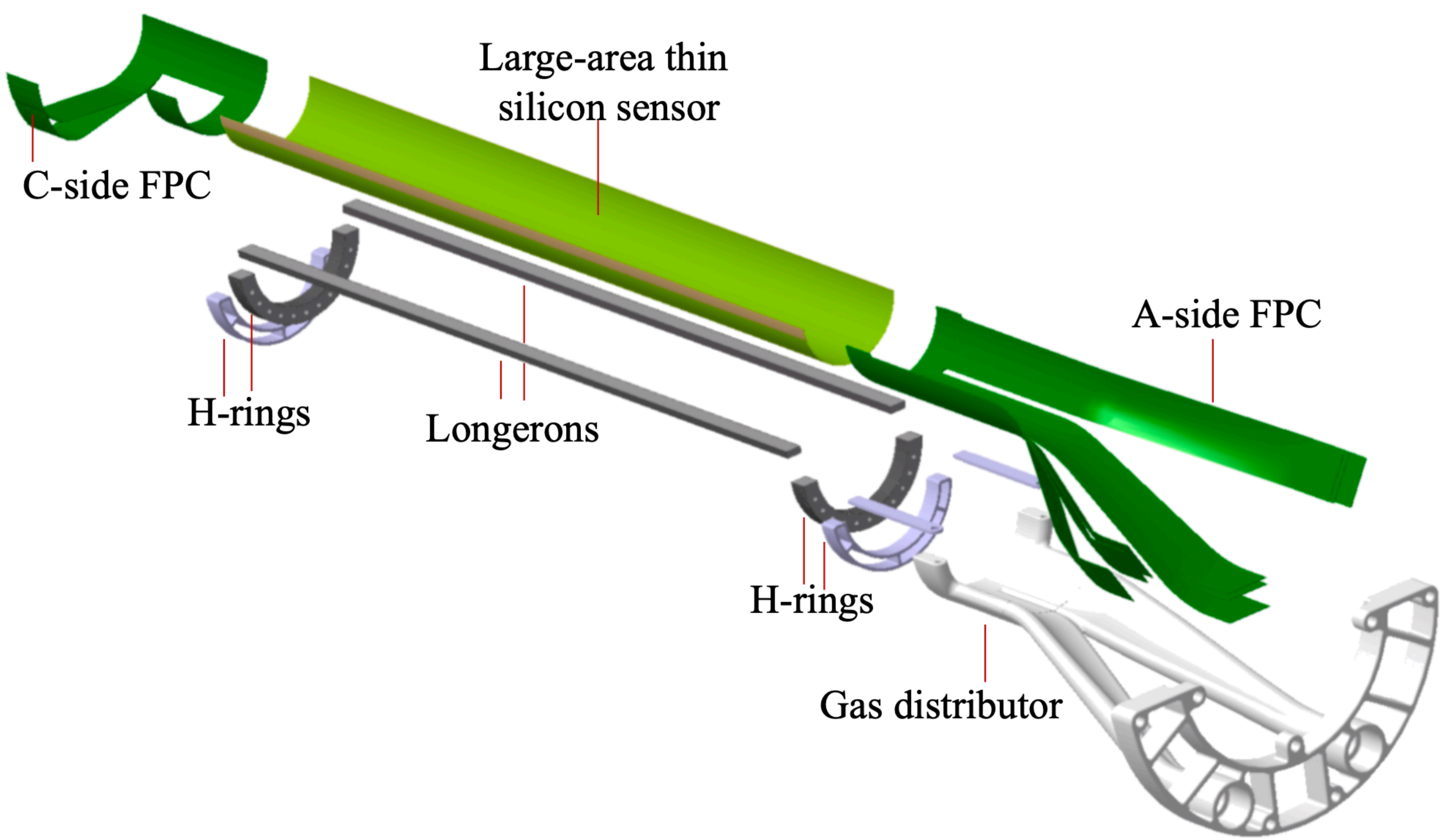
» Wafer-scale chips (up to ~28x10 cm), fabricated using stitching
» Si MAPS sensor based on 65 nm technology
» Sensor thickness ≤ 50 μm
» Chips bent in cylindrical shape at target radii
» Ultra light carbon foam structures
» Air cooling



ITS3 detector concept

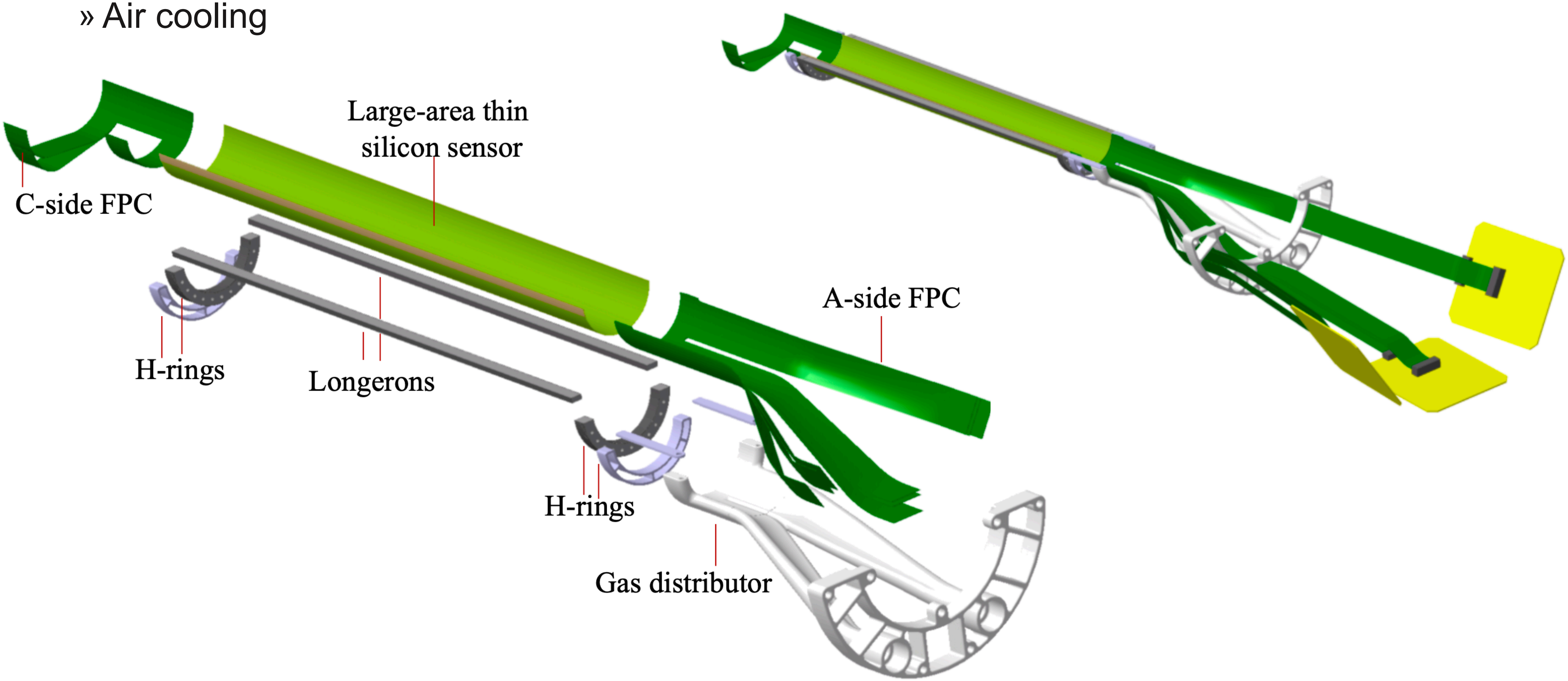
Key ingredients

» 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



ITS3 detector concept

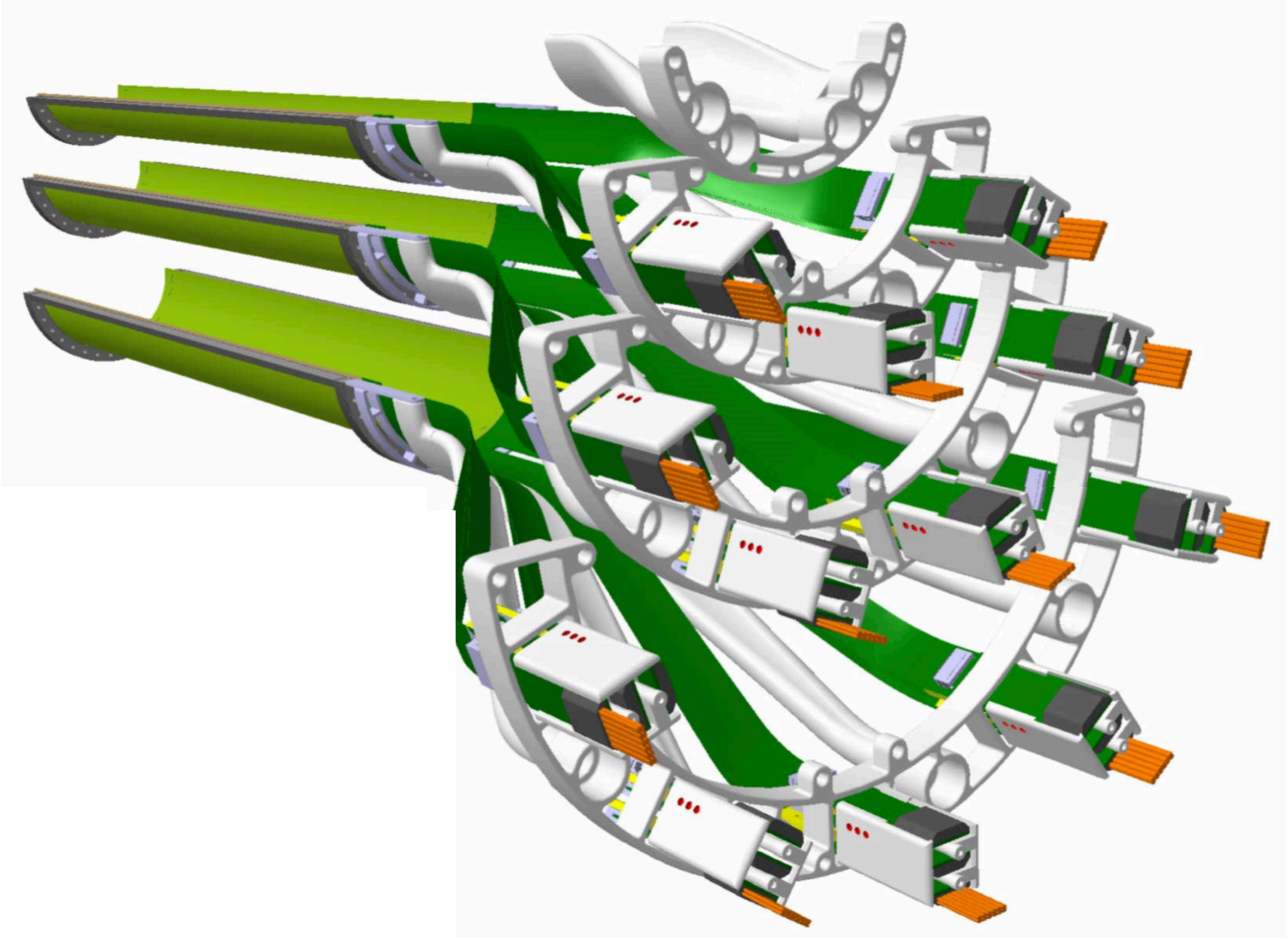
Key ingredients
» Wafer-scale chips (up to ~28x10 cm), fabricated using stitching
» Si MAPS sensor based on 65 nm technology
» Sensor thickness ≤ 50 µm
» Chips bent in cylindrical shape at target radii
» Ultra light carbon foam structures
» Air cooling



ITS3 detector concept

Key ingredients

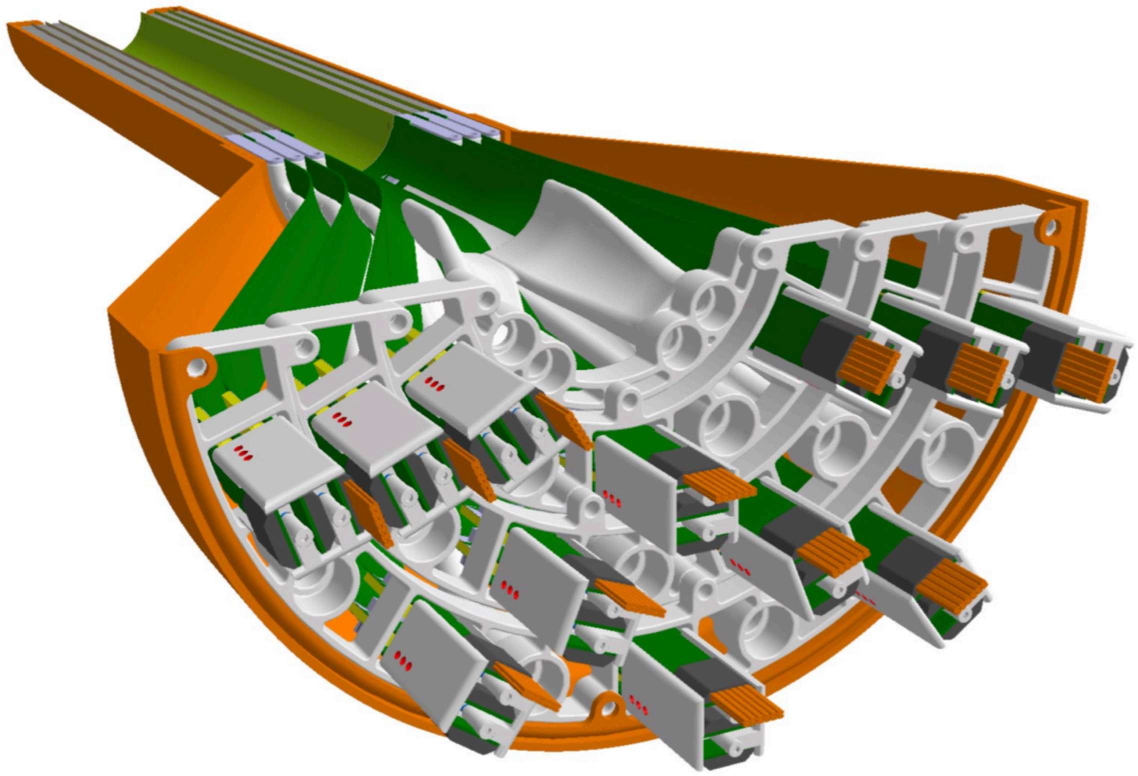
» Wafer-scale chips (up to ~28x10 cm), fabricated using stitching
» Si MAPS sensor based on 65 nm technology
» Sensor thickness ≤ 50 µm
» Chips bent in cylindrical shape at target radii
» Ultra light carbon foam structures
» Air cooling



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



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)		

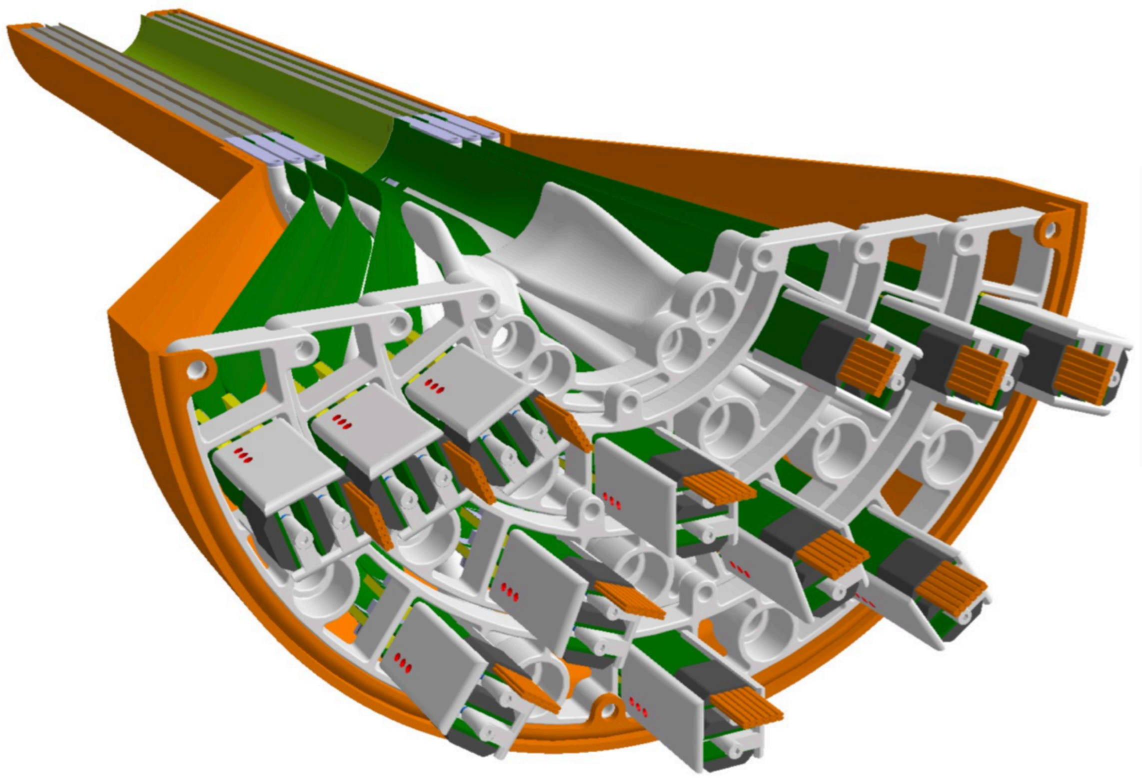
The whole detector will comprise six chips and barely anything else!

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

The ALICE Inner Tracking System Upgrade (V. Sarritzu) - Wed. 11:20 - D1 session

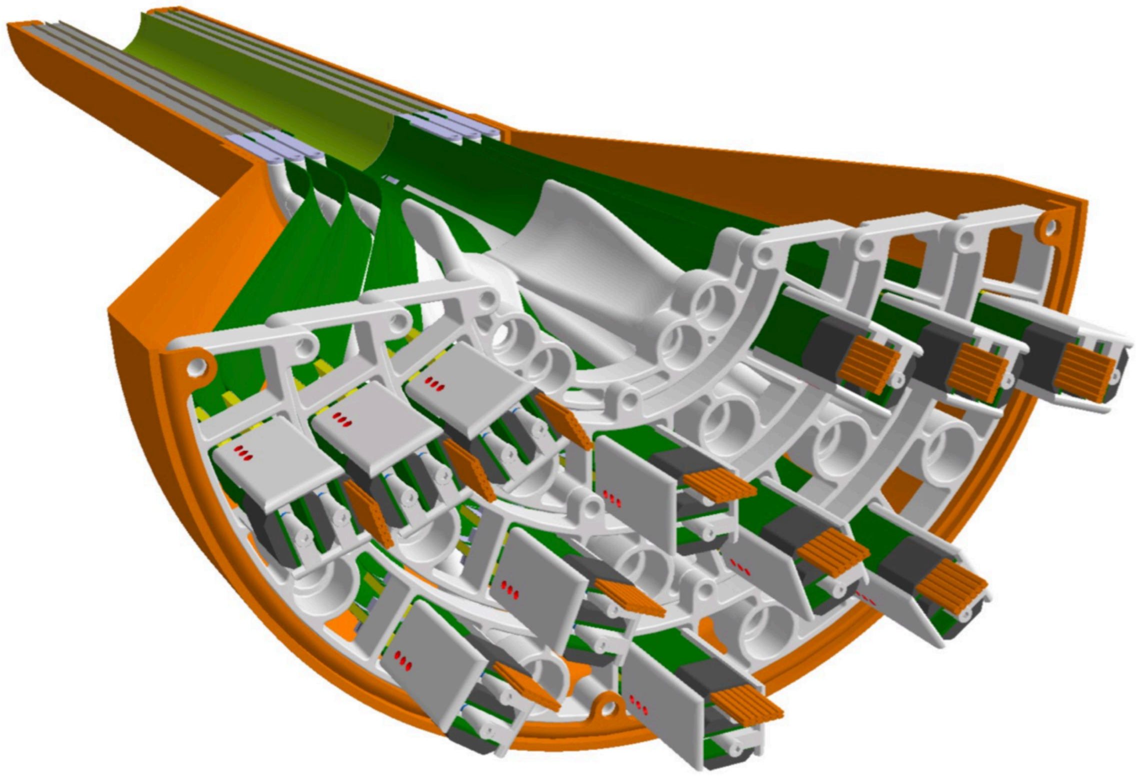


The whole detector will comprise six chips and barely anything else!

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 radi
» Ultra light carbon foam structures
» Air cooling



The ALICE Inner Tracking System Upgrade (V. Sarritzu) - Wed. 11:20 - D1 session

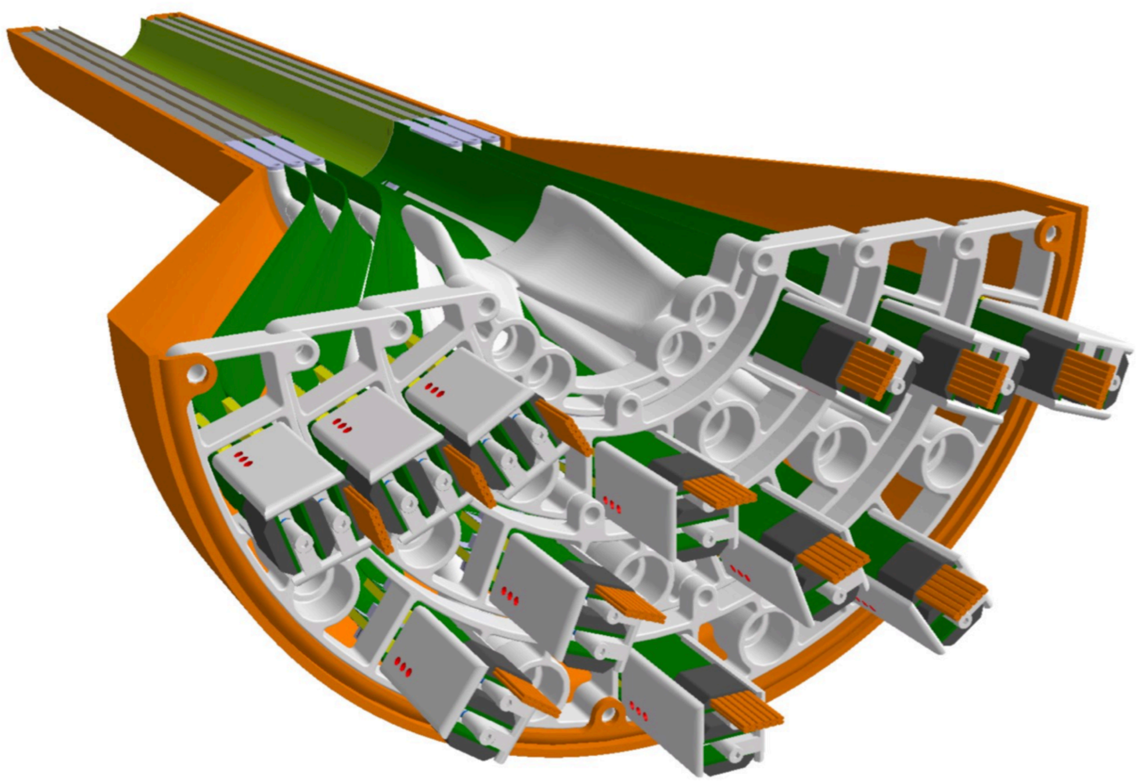
ALICE Inner Tracking System Upgrade: characterization of first chips fabricated in 65 nm CMOS technology (A. Trifirò) - Wed. 17:00 - E1 session

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

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



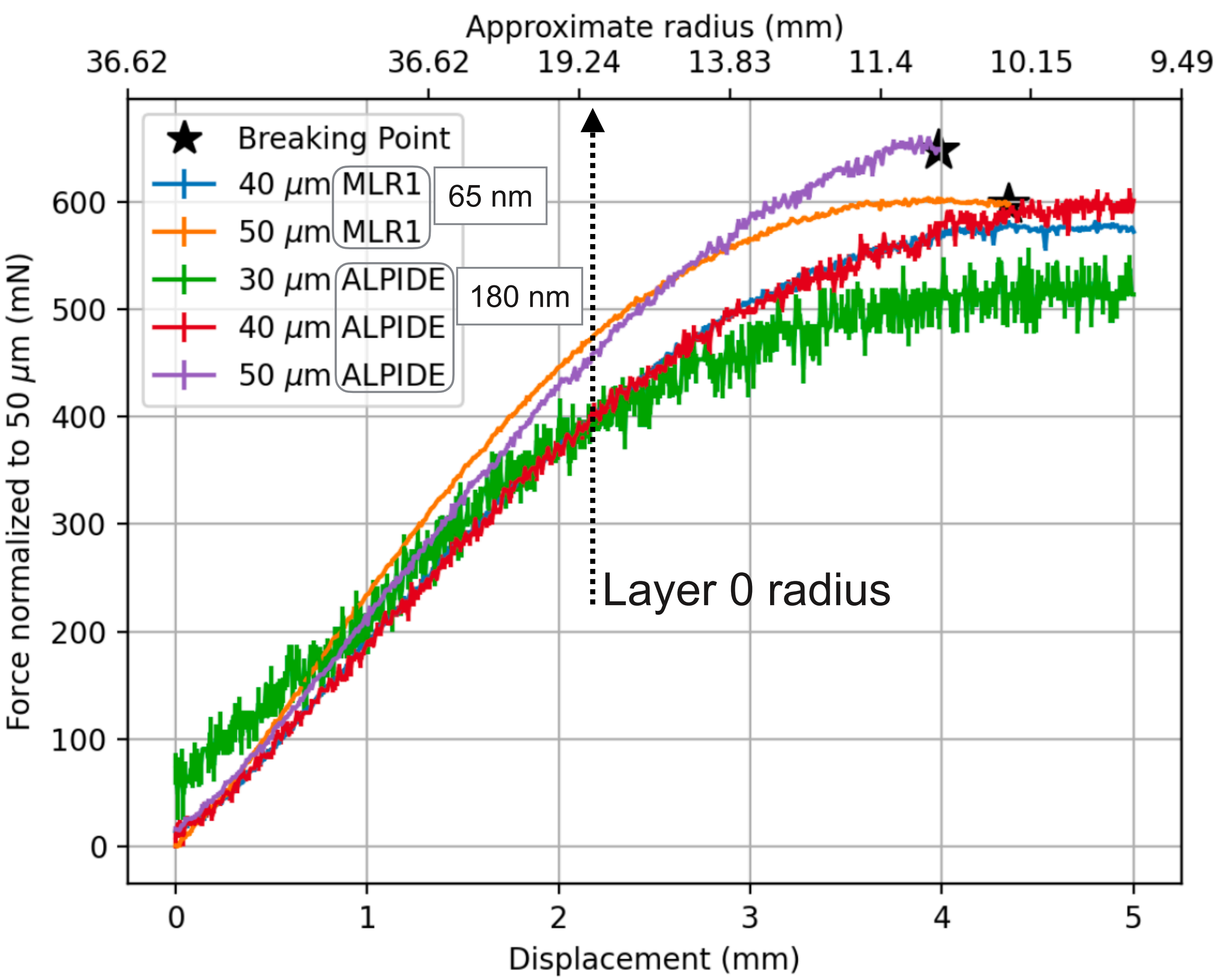
This talk content:

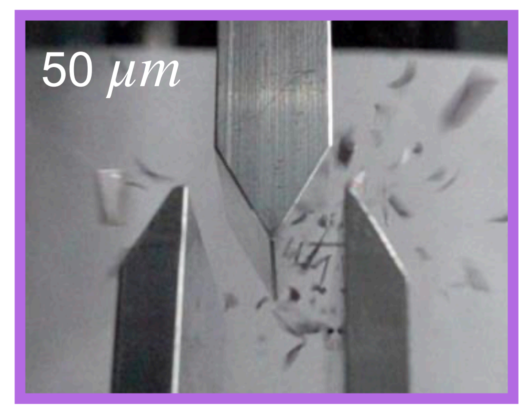
➡ Silicon bending
➡ Carbon foam properties
➡ Sensor cooling
➡ Mechanical characterization
➡ Interconnection

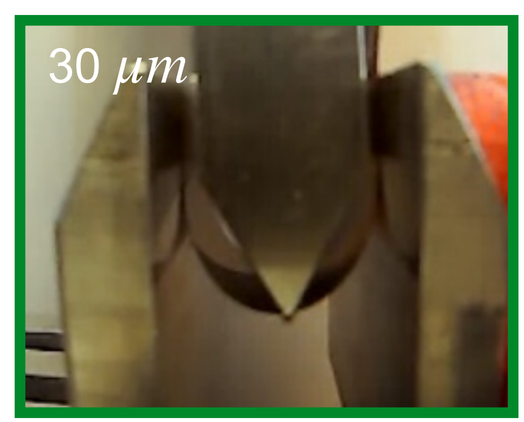
The whole detector will comprise six chips and barely anything else!

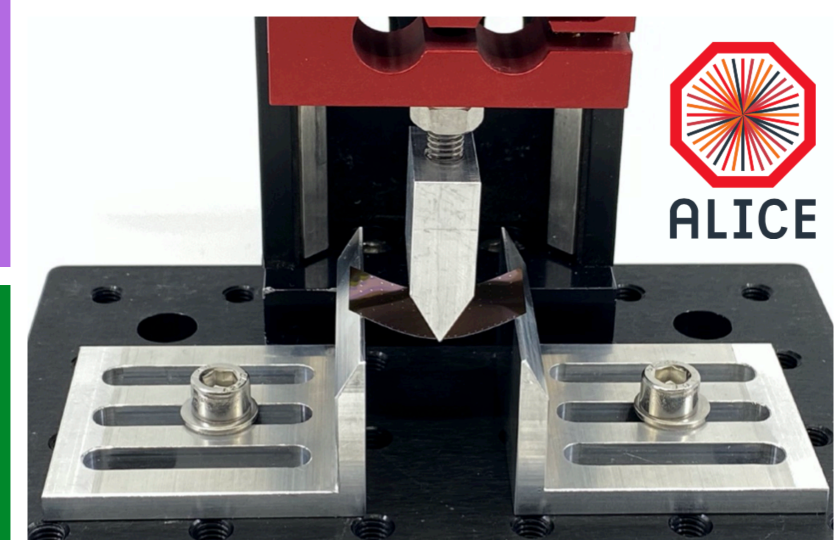
ITS3 R&D - Silicon bending

» 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**

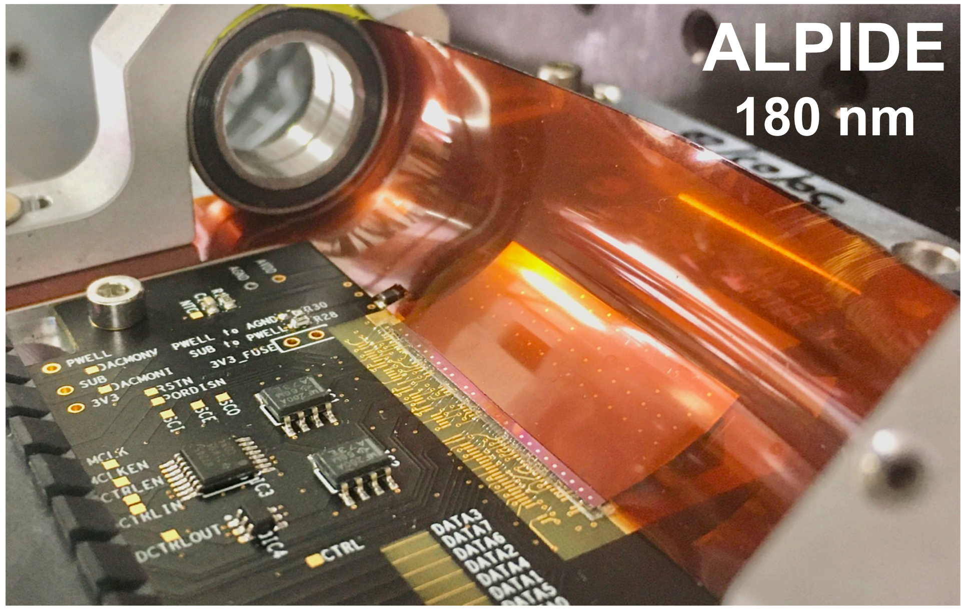




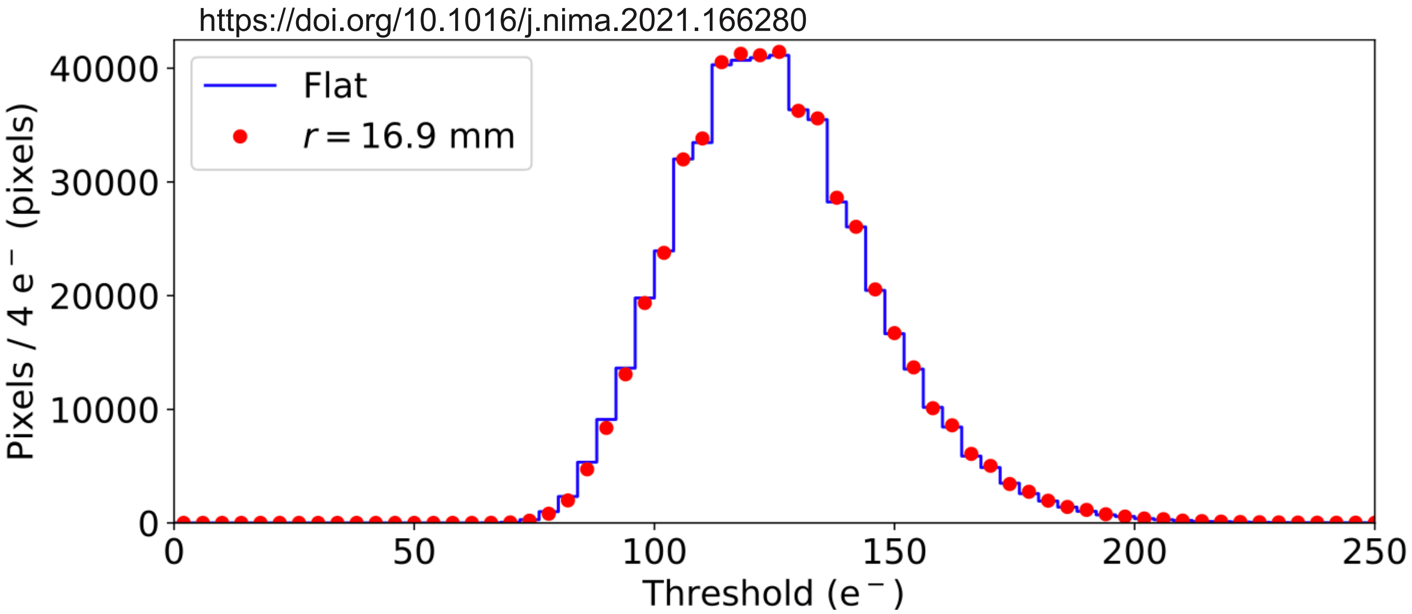


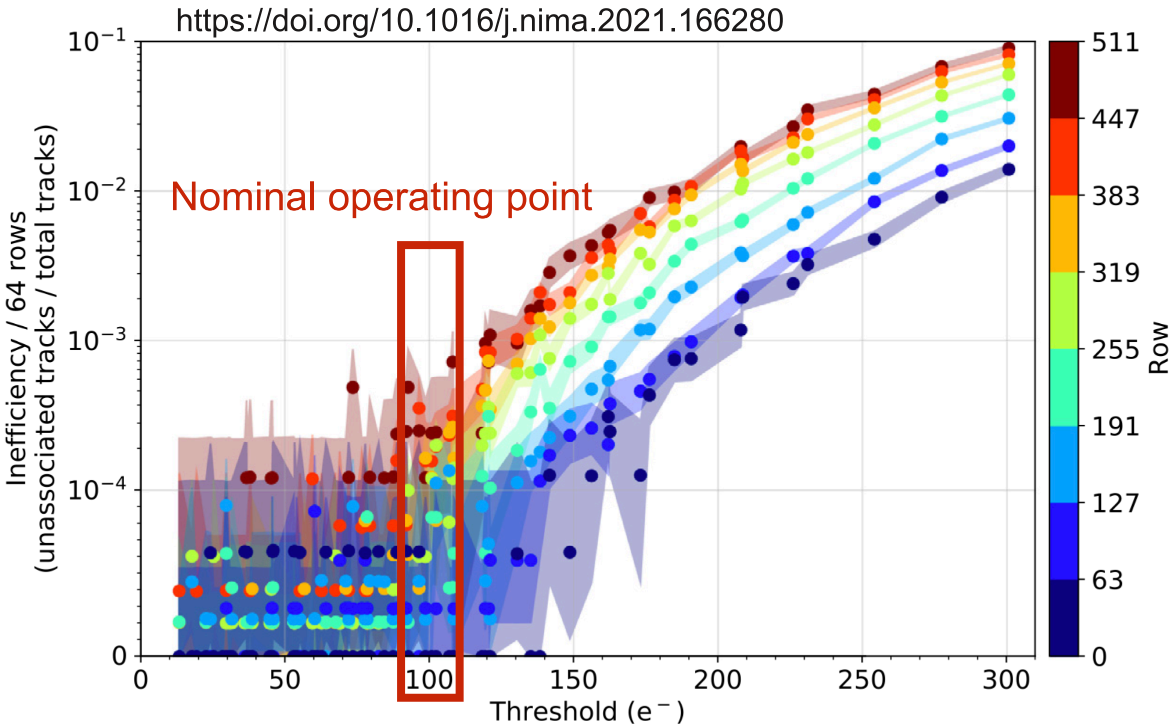


ITS3 R&D - Silicon bending



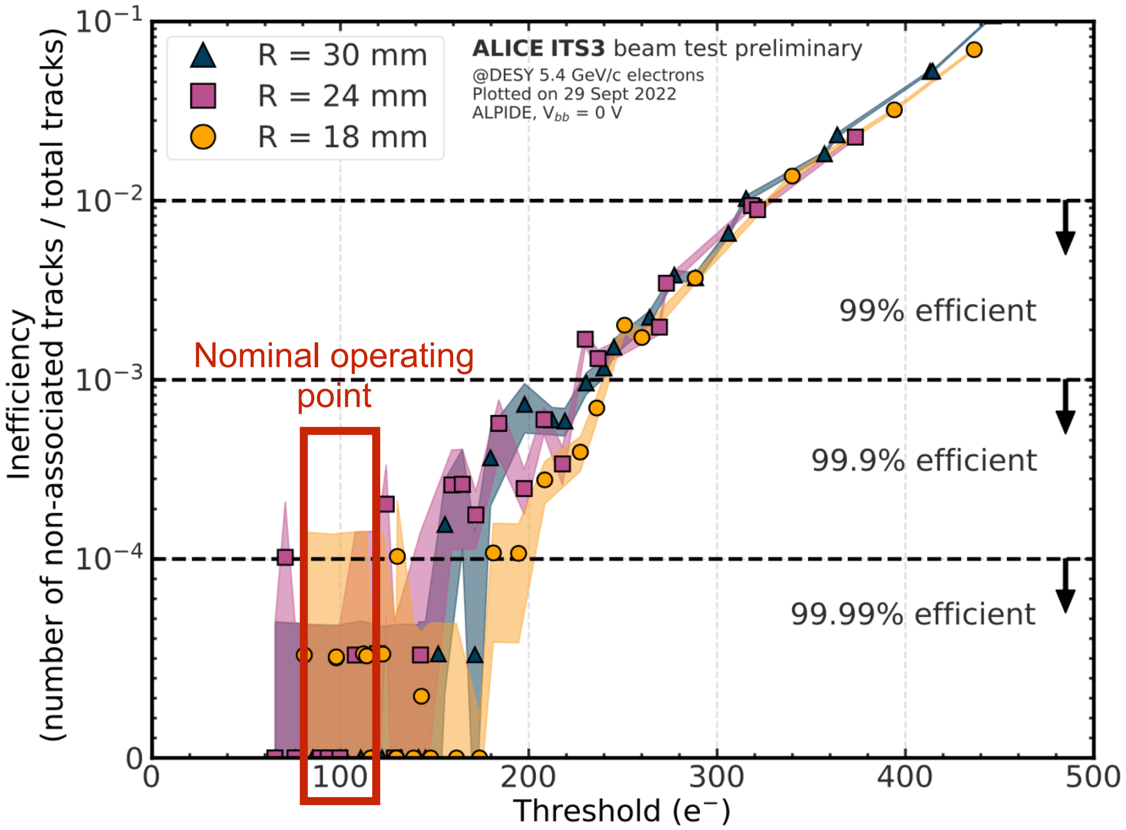
» Laboratory and test beam measurements (Jun 2020) allow to conclude that **chip (180 nm CMOS) performance doesn't change after bending**
- Pixel matrix threshold distribution does not change when sensor is bent
- Efficiency above 99.9% at a threshold of 100 e-





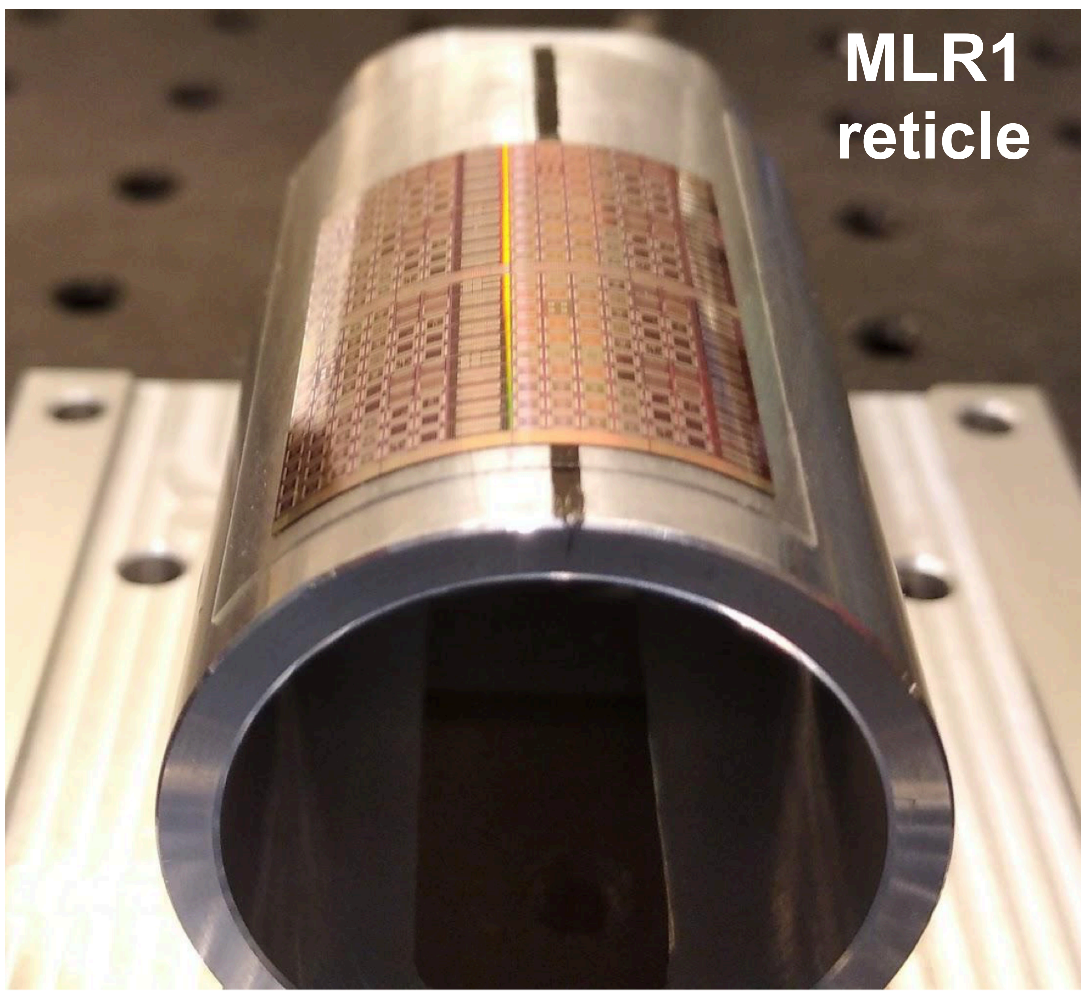
ITS3 R&D - Silicon bending

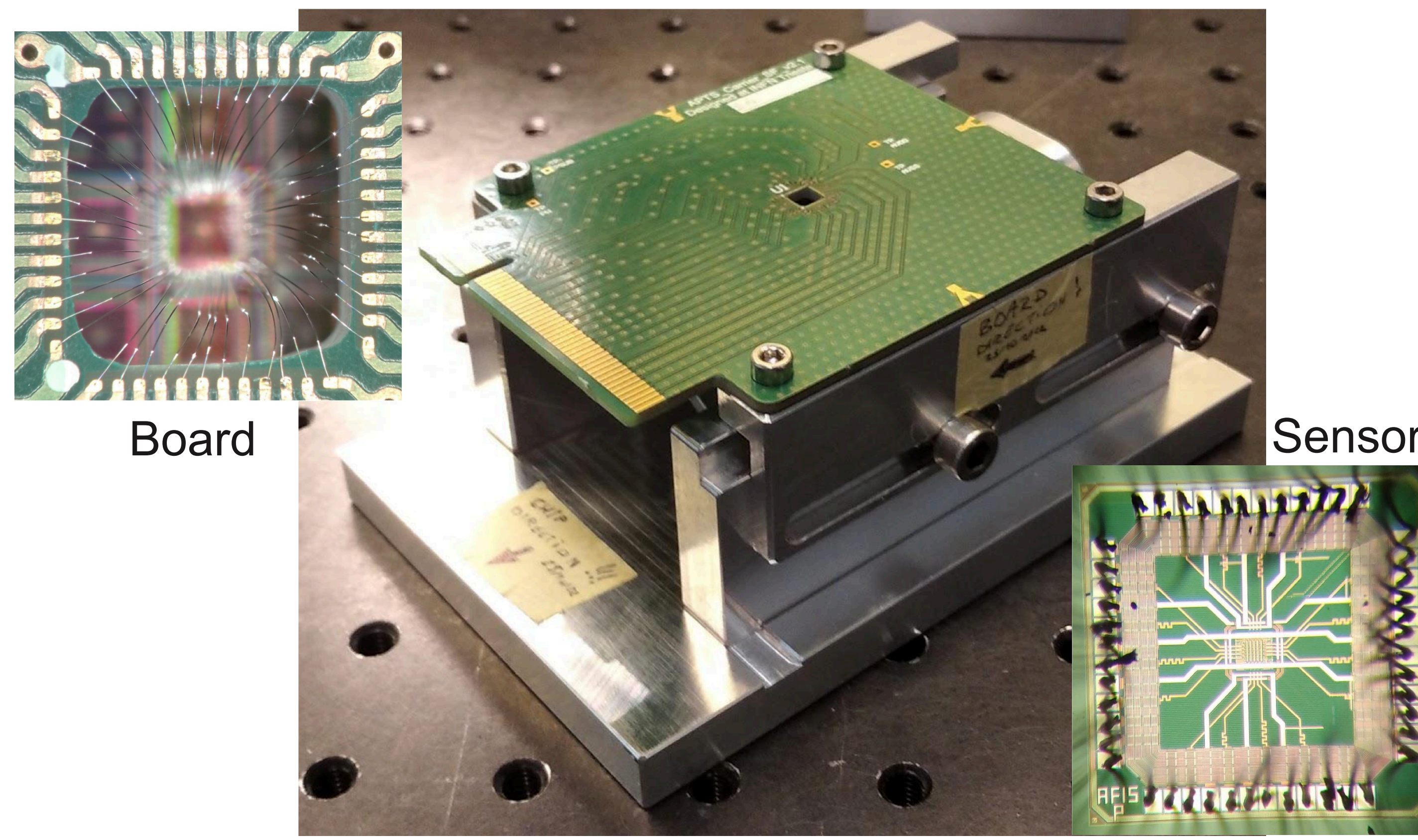
» Laboratory and test beam measurements (Jun 2020) allow to conclude that **chip (180 nm CMOS) performance doesn't change after bending**
- Pixel matrix threshold distribution does not change when sensor is bent
- Efficiency above 99.9% at a threshold of 100 e-



ITS3 R&D - Silicon bending

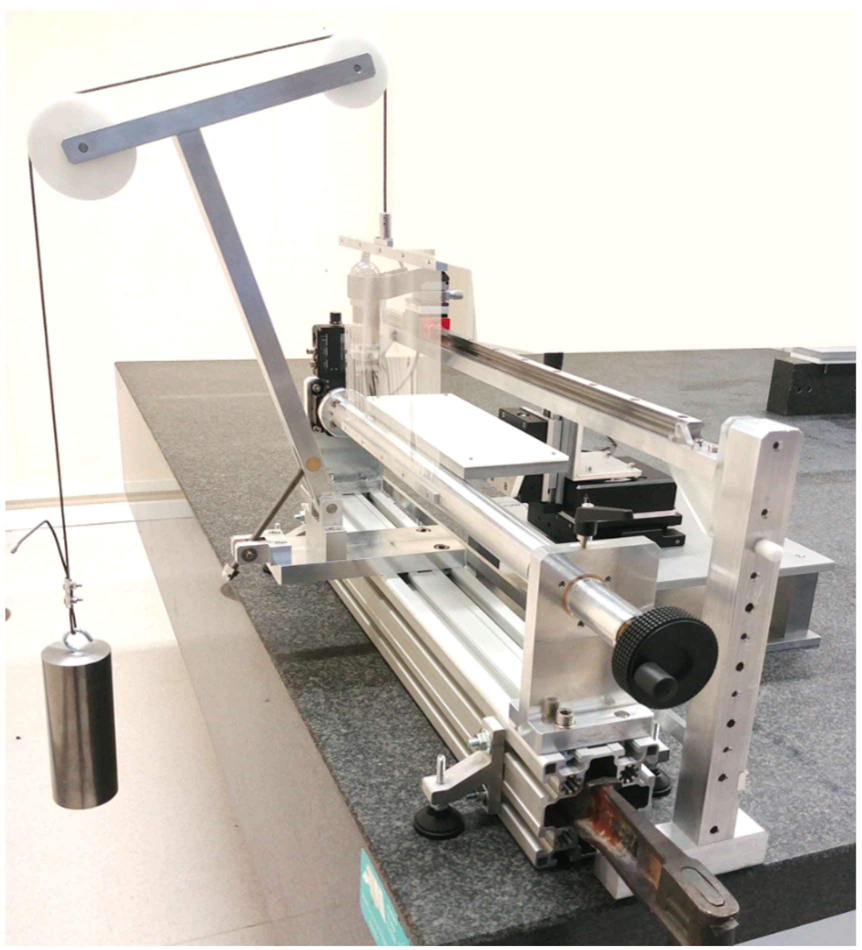
» Comparison between flat and bent MLR1 (65 nm CMOS) sensors ongoing
  - Bending procedure developed and proximity board adapted to bent configuration
  - Few samples prepared and under measurements in laboratory with ^{55}Fe source

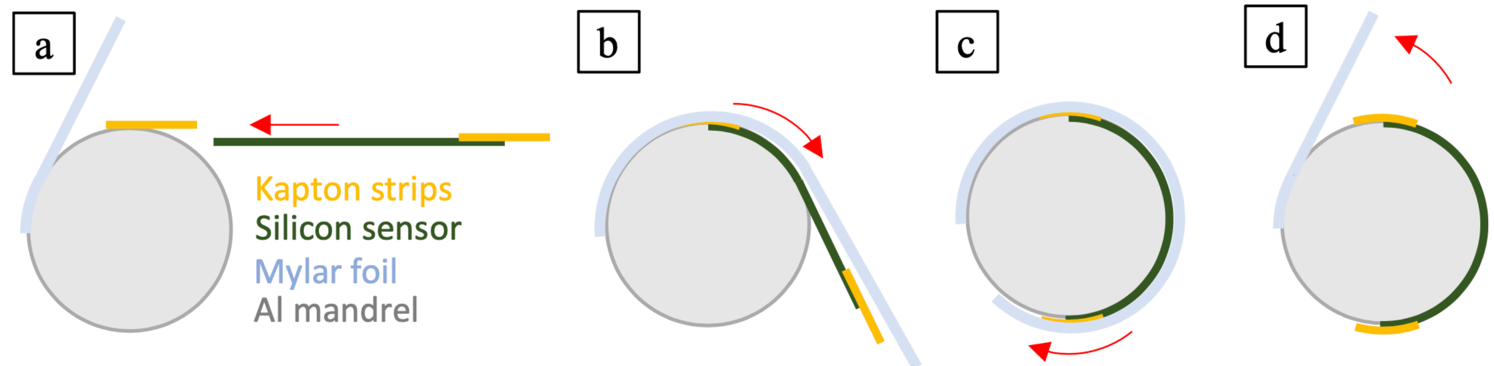


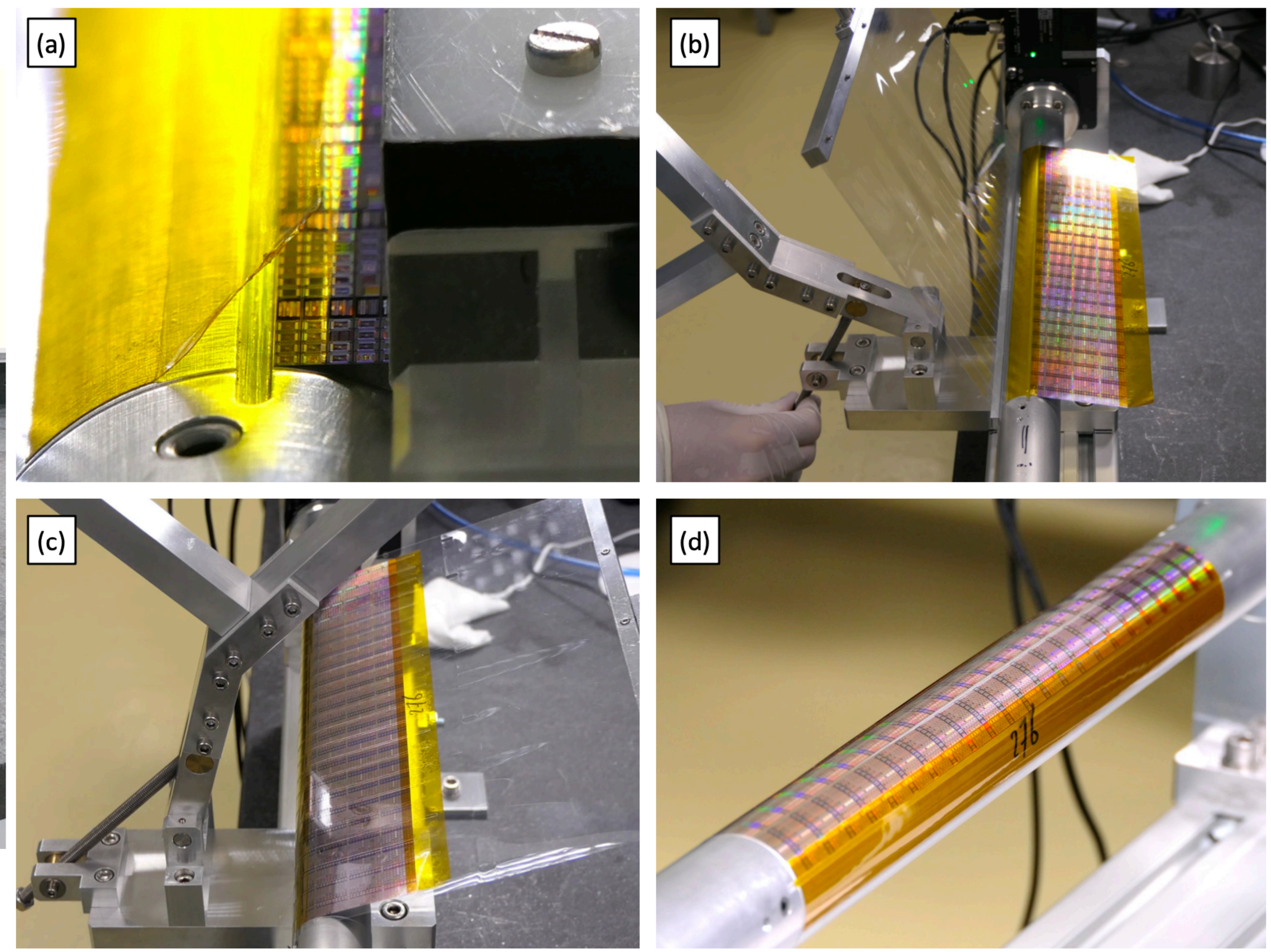


ITS3 R&D - Silicon bending

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



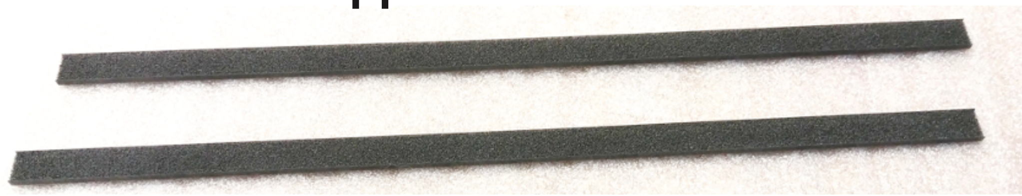




ITS3 R&D - Carbon foam properties

» Silicon sensor kept in position by:

Longerons
Support structures



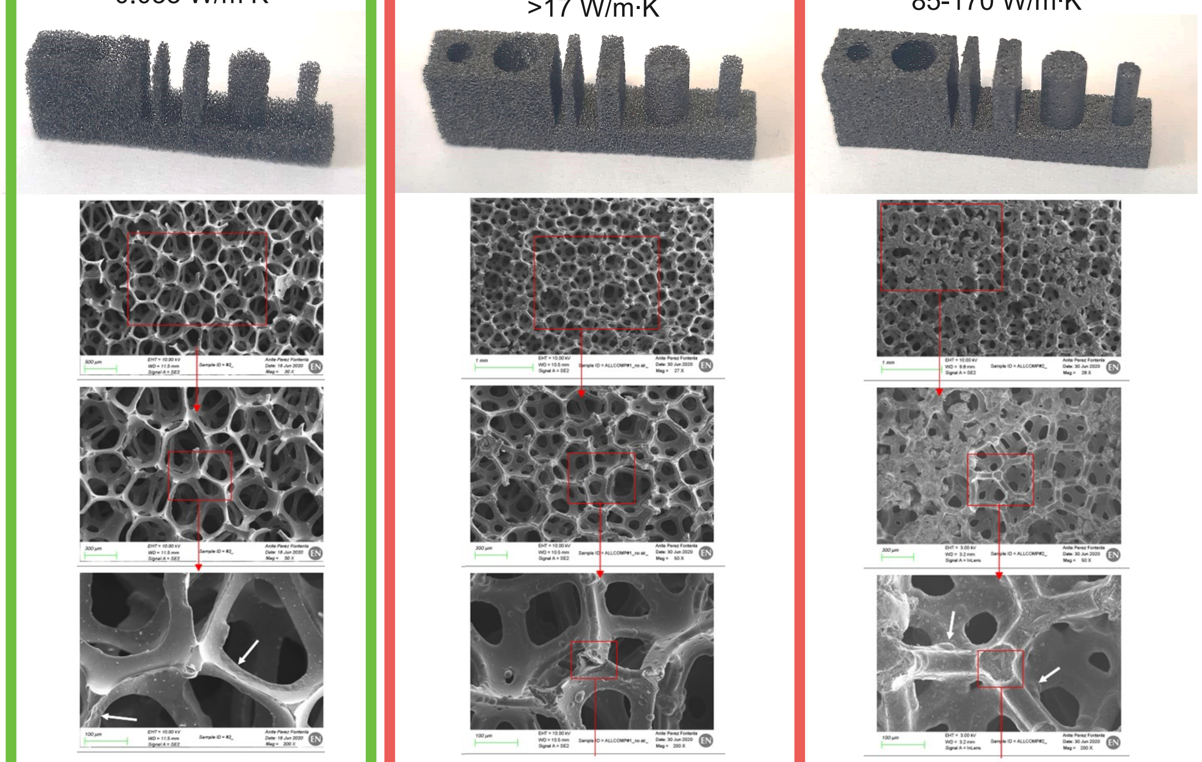
ERG Duocel (RVC)

Half-rings
Support structures and cooling radiator

ALLCOMP LD (K9)

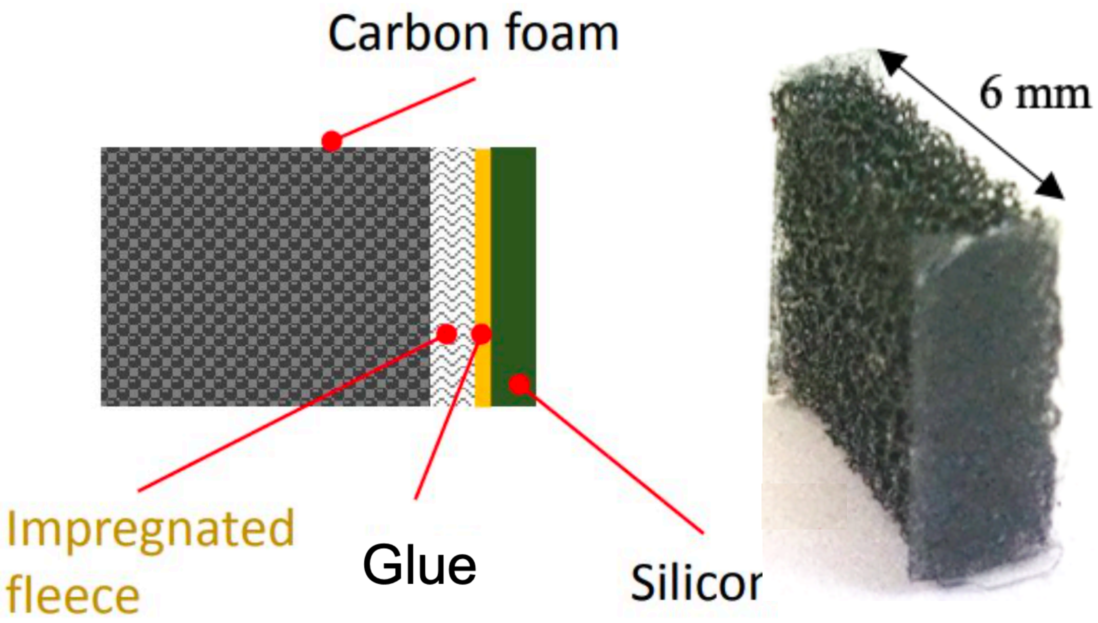
» Carbon foams characterised for machinability and thermal properties

ERG DUOCEL (RVC)	**ALLCOMP LD (K9)**	**ALLCOMP HD**
0.06 kg/dm^3	0.2-0.26 kg/dm^3	0.45-0.68 kg/dm^3
0.033 W/m·K	>17 W/m·K	85-170 W/m·K



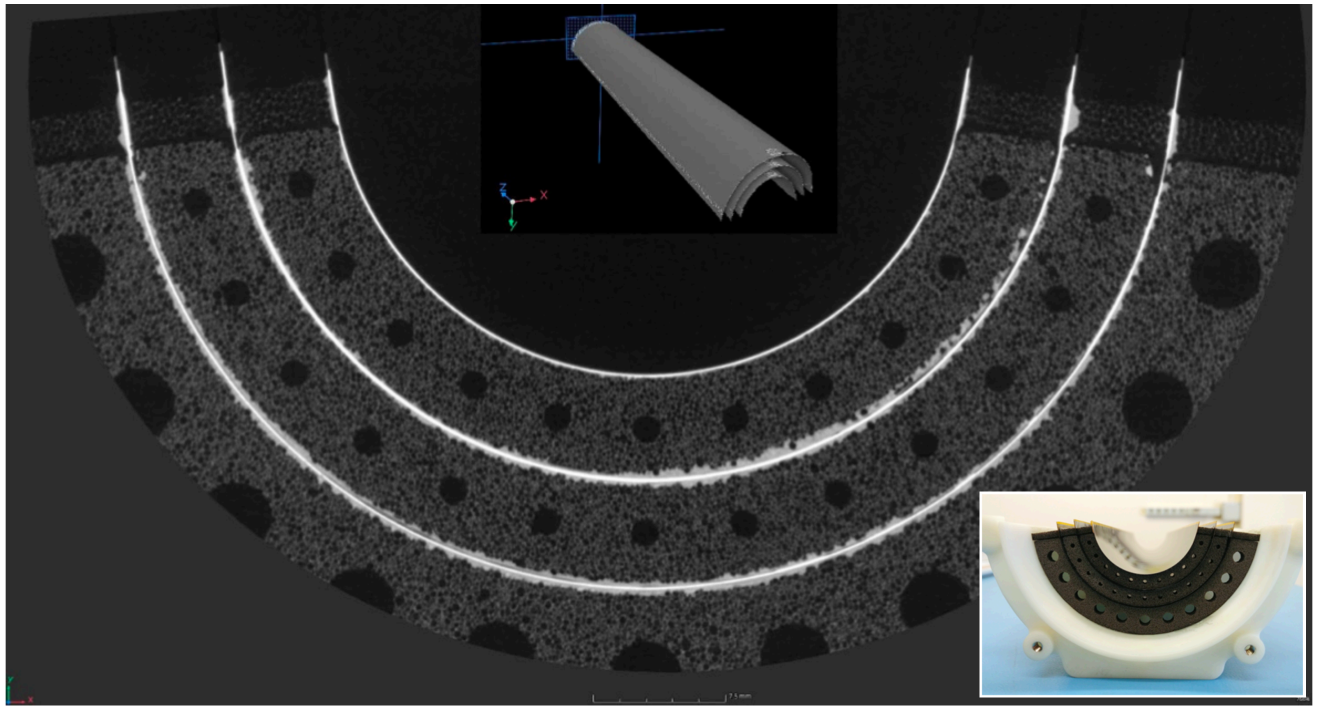
ITS3 R&D - Carbon foam properties

» 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

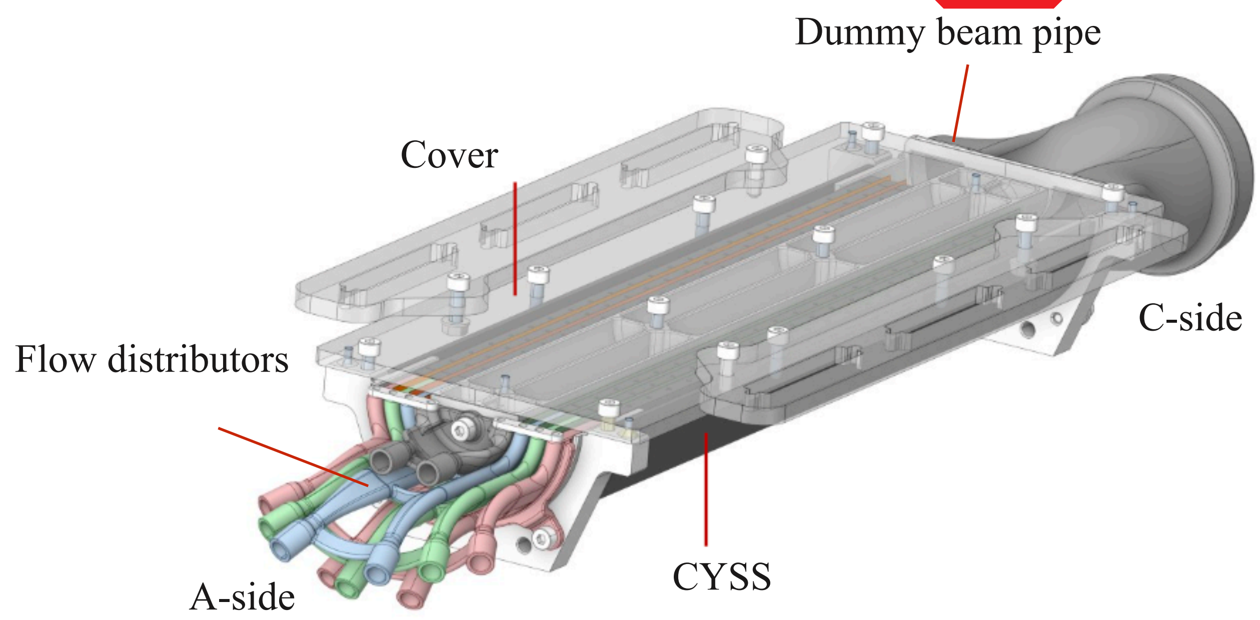
X-ray scan of Engineering Model 2 (EM2)

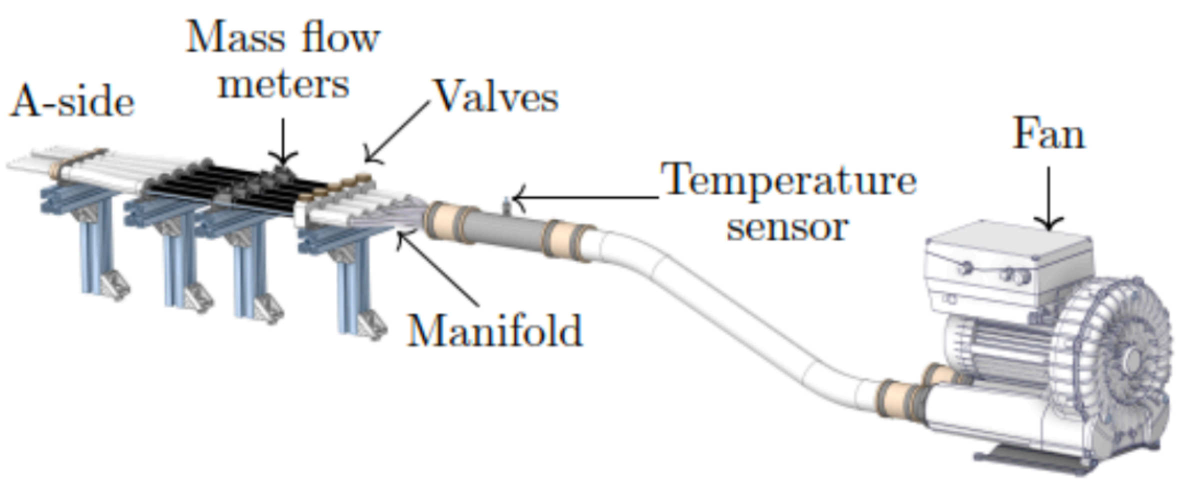


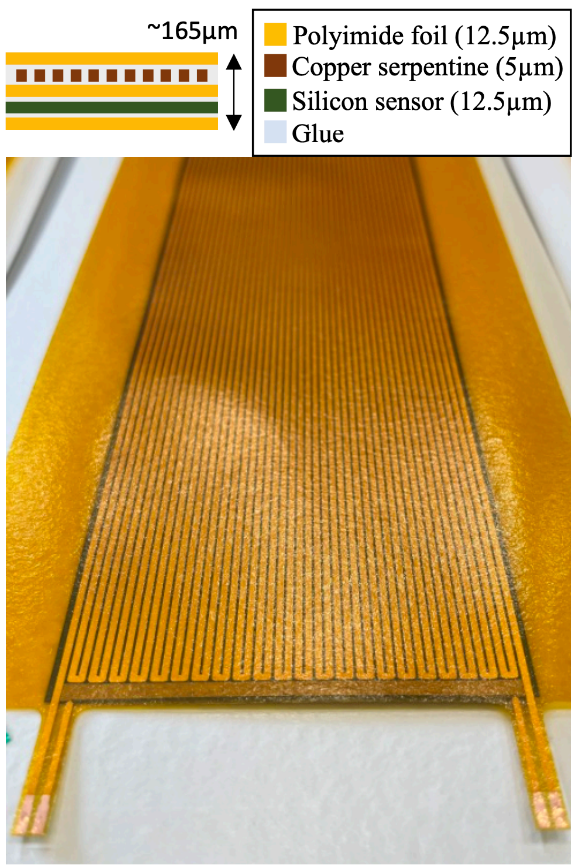
ITS3 R&D - Sensor cooling

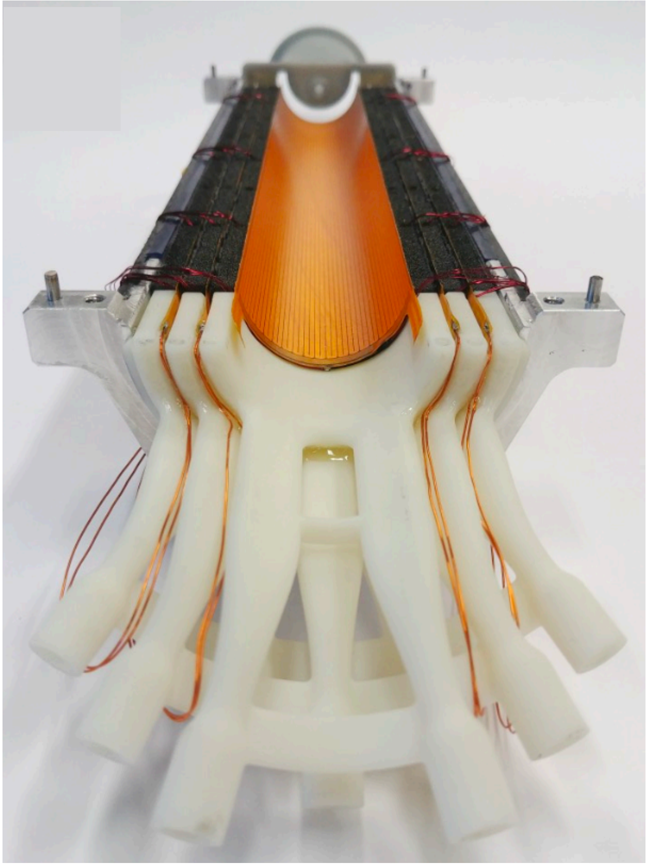
» Thermal characterization setup

- 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
- airflow from C-side to A-side





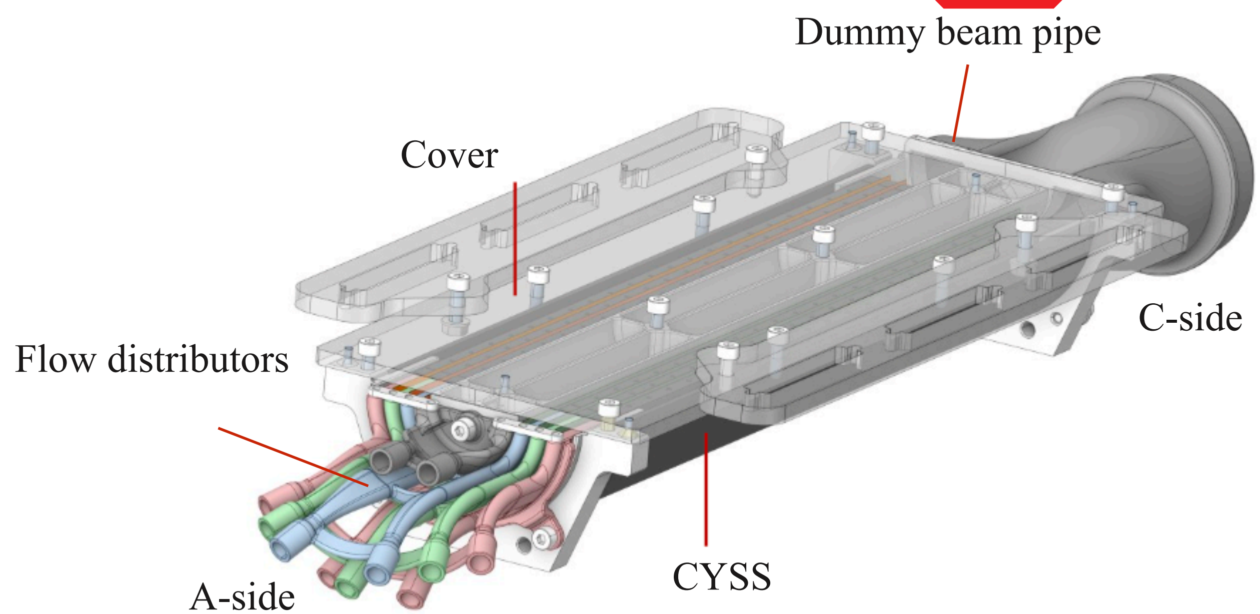


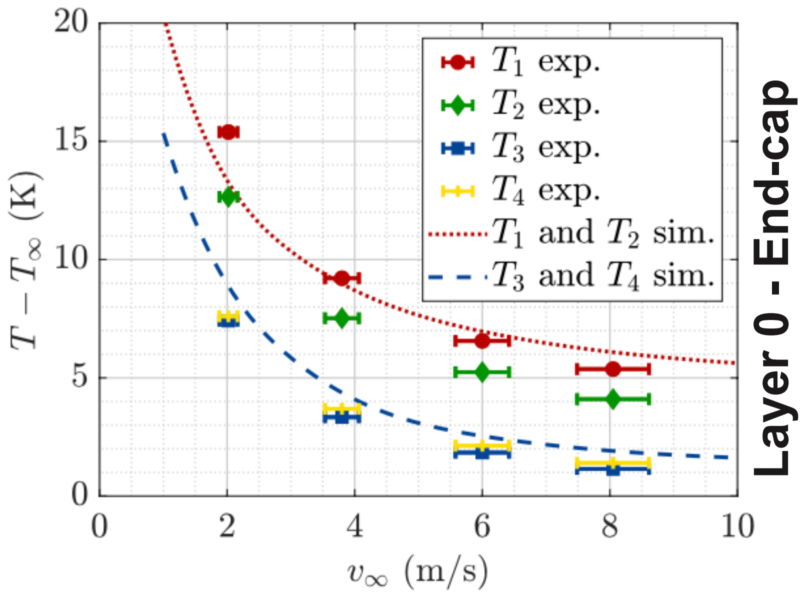


ITS3 R&D - Sensor cooling

» Thermal characterization setup

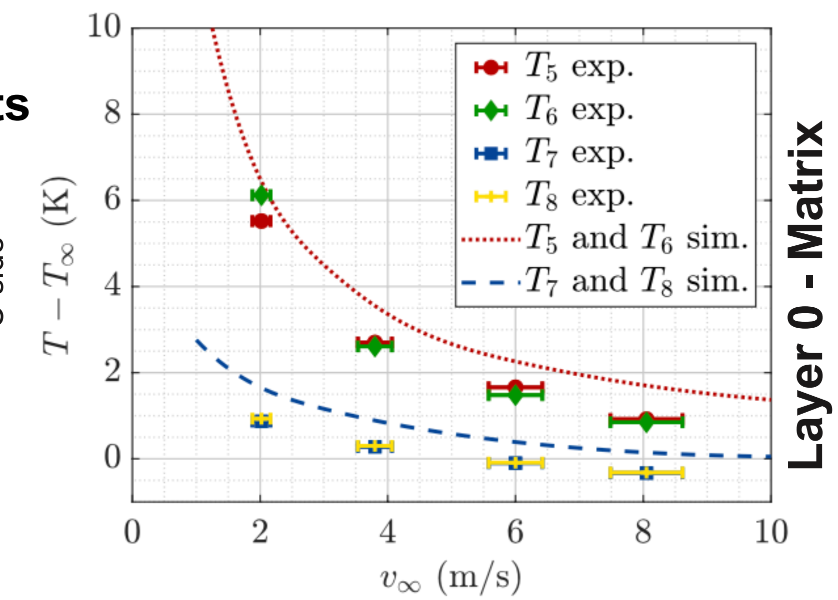
- dummy silicon equipped with copper serpentine simulating heat dissipation in matrix (25 mW/cm²) and end-cap (1000 mW/cm²) regions
- 8 PT100 temperature sensors distributed over the surface of each half-layer
- airflow from C-side to A-side





Comparison between CFD simulations and experiments

Temperature sensor position and nomenclature



» 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

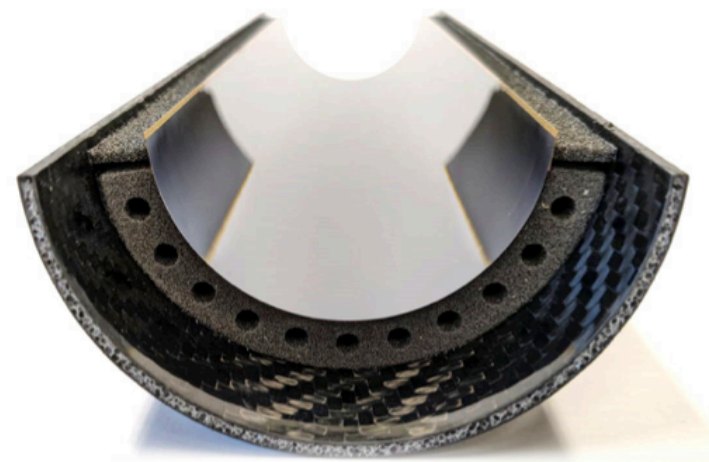
ITS3 R&D - Mechanical characterization

» 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

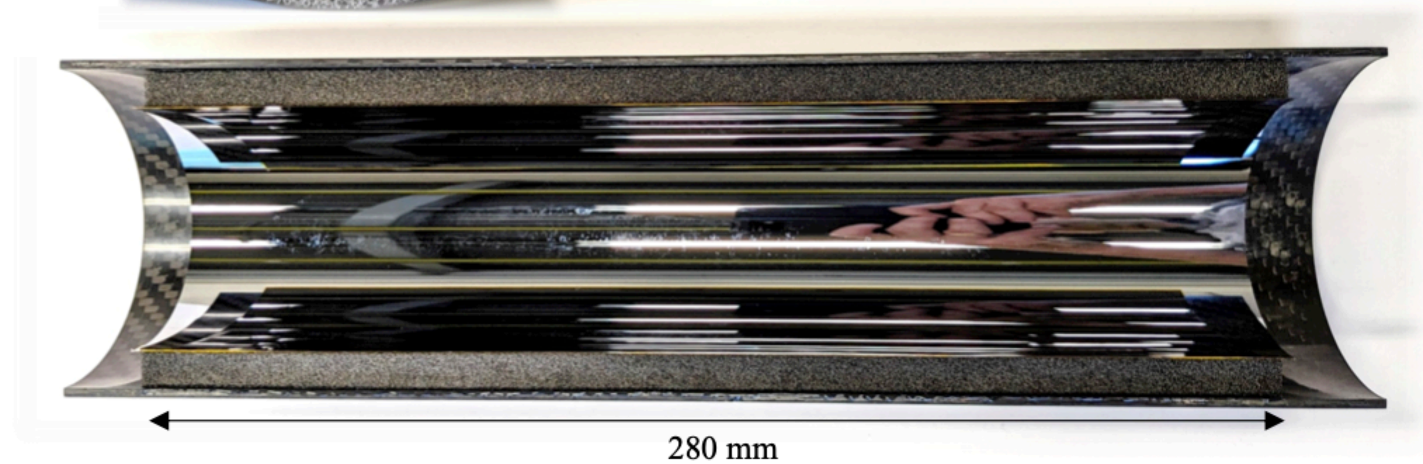
» Short-term position stability of the sensor over time affected by
- <u>thermoelastic expansion caused by short-term temperature fluctuation</u>
- airflow

» 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



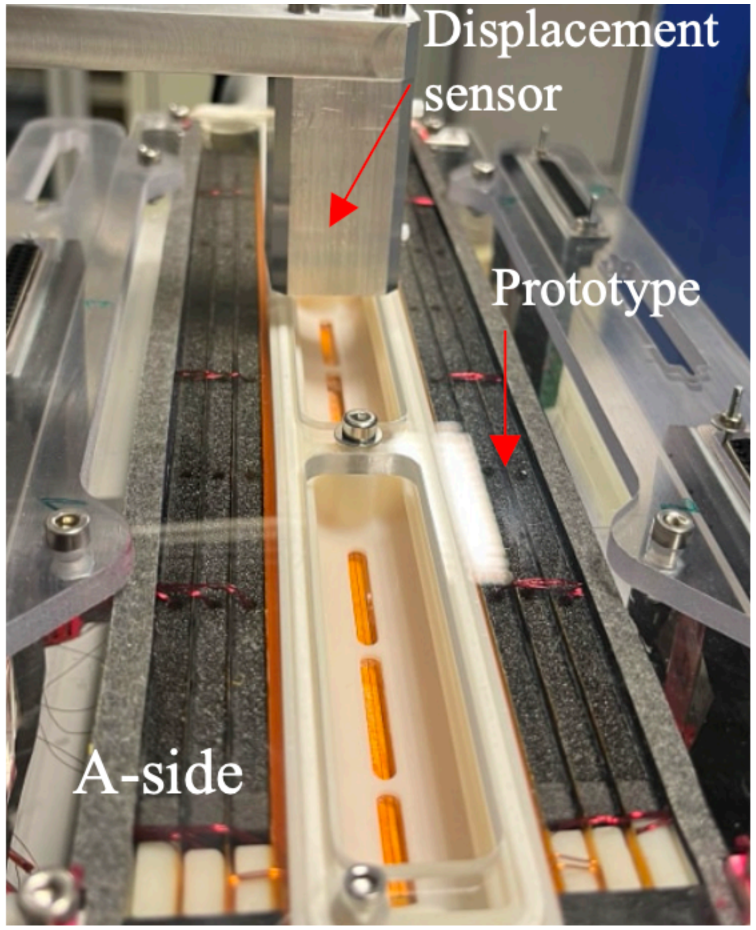
» Conclusion
- several **thermal cycles for a total of 9h → assembly unaffected**
- further tests will be performed to investigate: rapid increase of the temperature and maximum failure temperature

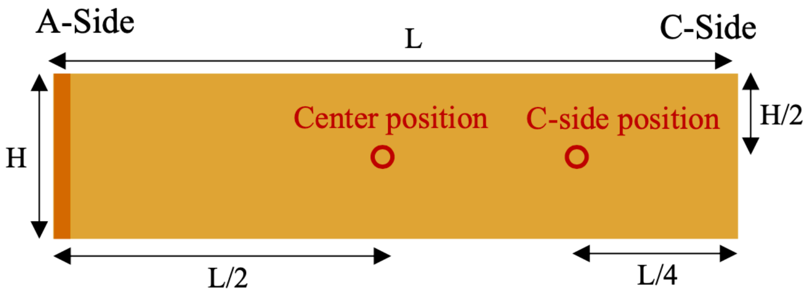
ITS3 R&D - Mechanical characterization

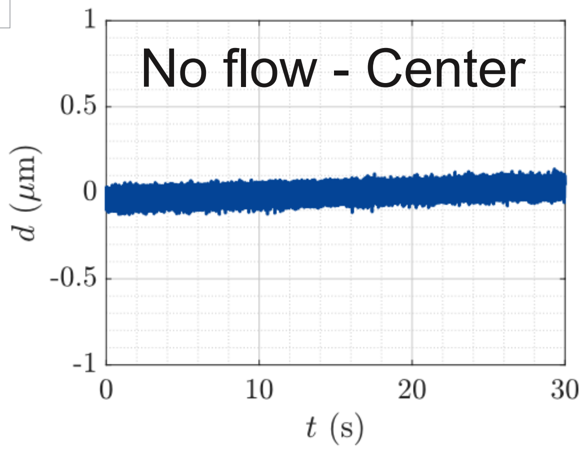
» Short-term position stability of the sensor over time affected by
- thermoelastic expansion caused by short-term temperature fluctuation
- <u>airflow</u>

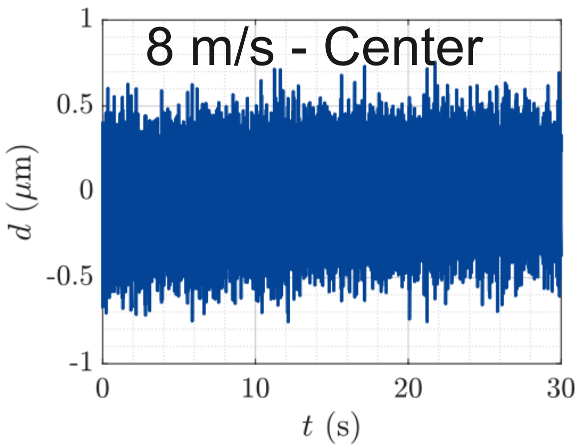
» Vibration characterization setup
- measurement of the out-of-plane vibrations of the half-layers
- confocal chromatic displacement sensors → avoids perturbation to the airflow

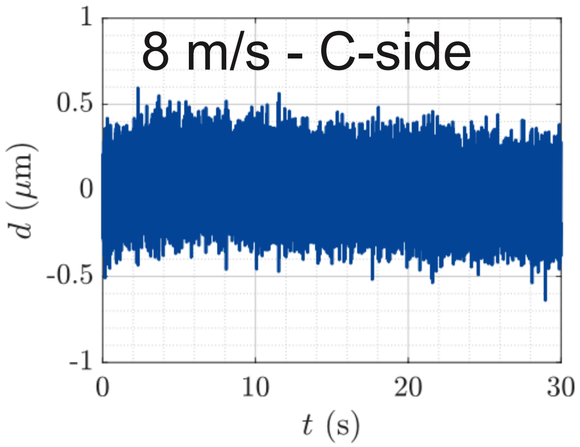
» Conclusion
- $RMS_{airflow}$ < 0.4 μm for L2 (largest sensor), smaller for L0 and L1





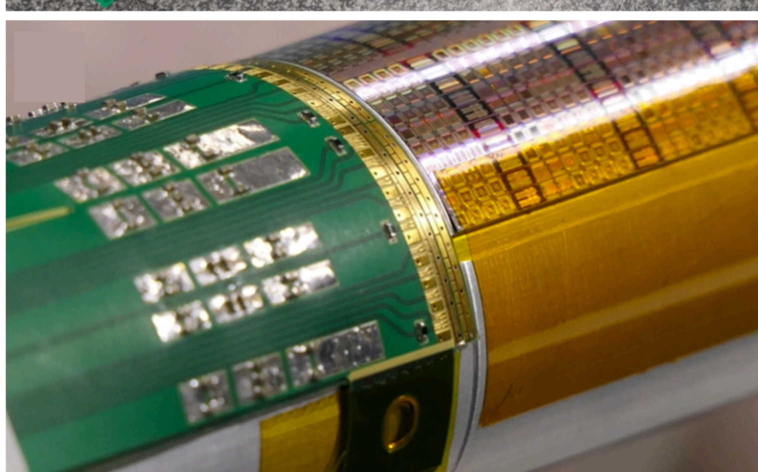


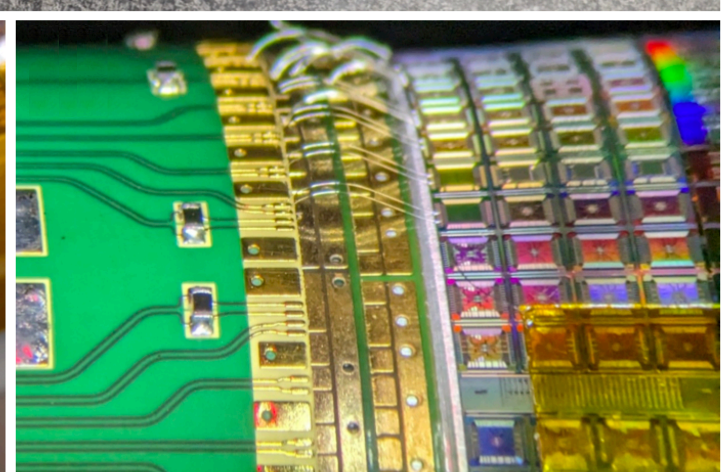


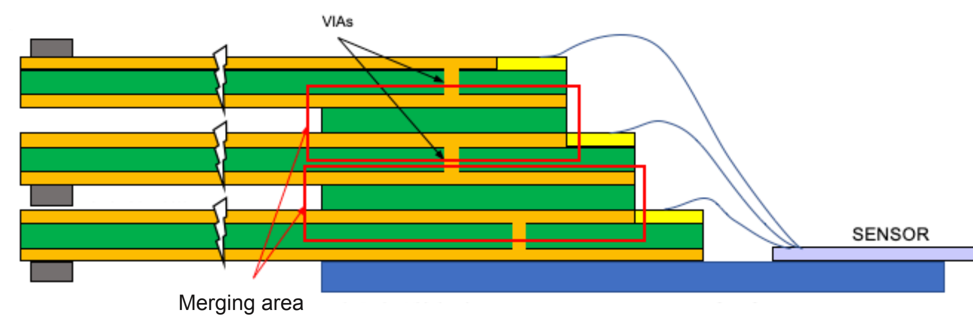


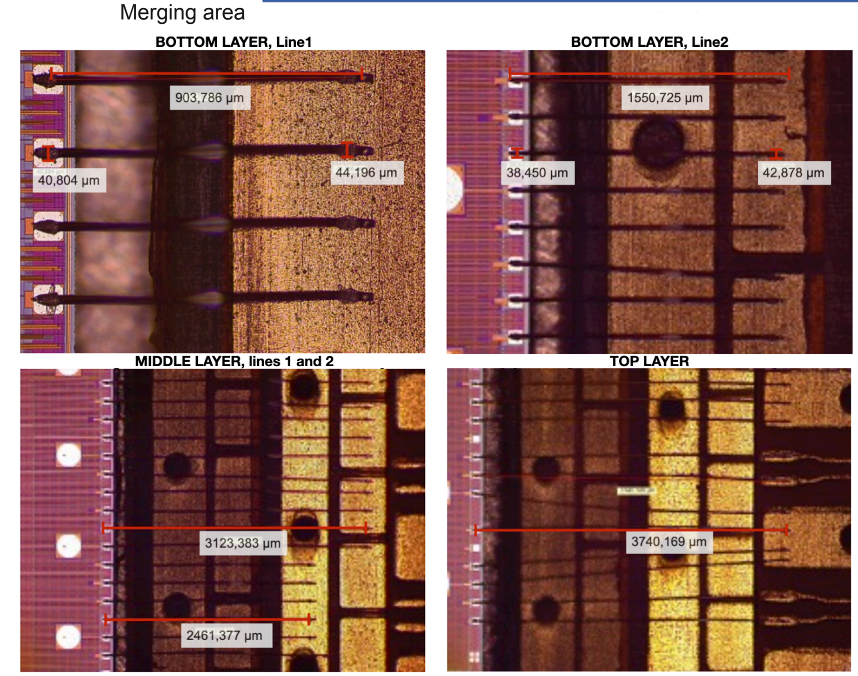
ITS3 R&D - Interconnection

» 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









SUMMARY

» ALICE proposes to build the next-generation inner tracking detector, based on **300 mm wafer-scale, ≤ 50 µm thin, bent MAPS**

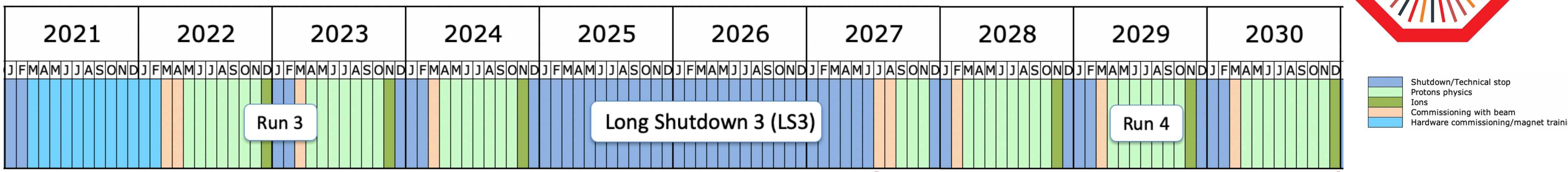
» **R&D** is making rapid progress on all fronts

- silicon bending at ITS3 bending radii → *qualified*
- bending effects on sensor performances → *absent* in 180 nm CMOS and *under study* in 65 nm CMOS
- air-cooling heat dissipation → *qualified* for 25 and 1000 mW/cm^2 (respectively in matrix and end-cap) with 8 m/s free-stream velocity
- mechanical stability → *proven* (0.4 µm vibration, thermoelastic expansion up to 36 ºC)
- wire bonding interconnection scheme → *proven*

» Final detector integration procedure under finalisation

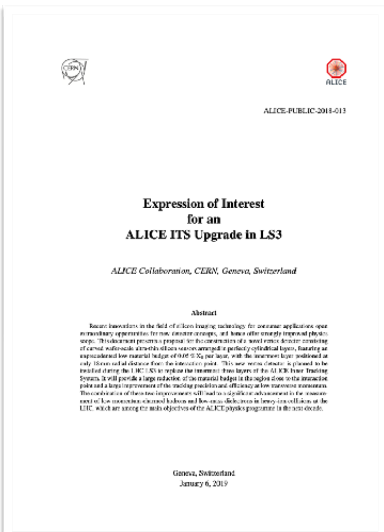
Backup

Backup



ALICE 2.1

Expression of Interest


Expression of Interest
for an
ALICE ITS Upgrade in LS3

ALICE Collaboration, CERN, Geneva, Switzerland

Abstract

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

Letter of Intent

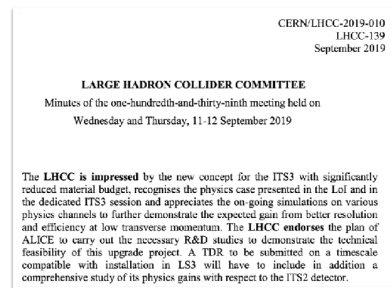

Letter of Intent
for an
ALICE ITS Upgrade in LS3

ALICE Collaboration, CERN, Geneva, Switzerland

Abstract

[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

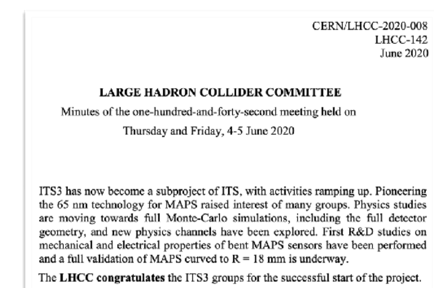
The **LHCC is impressed** by the new concept for the ITS3 with significantly reduced material budget, recognises the physics case presented in the LoI and in the dedicated ITS3 session and appreciates the on-going simulations on various physics channels to further demonstrate the expected gain from better 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

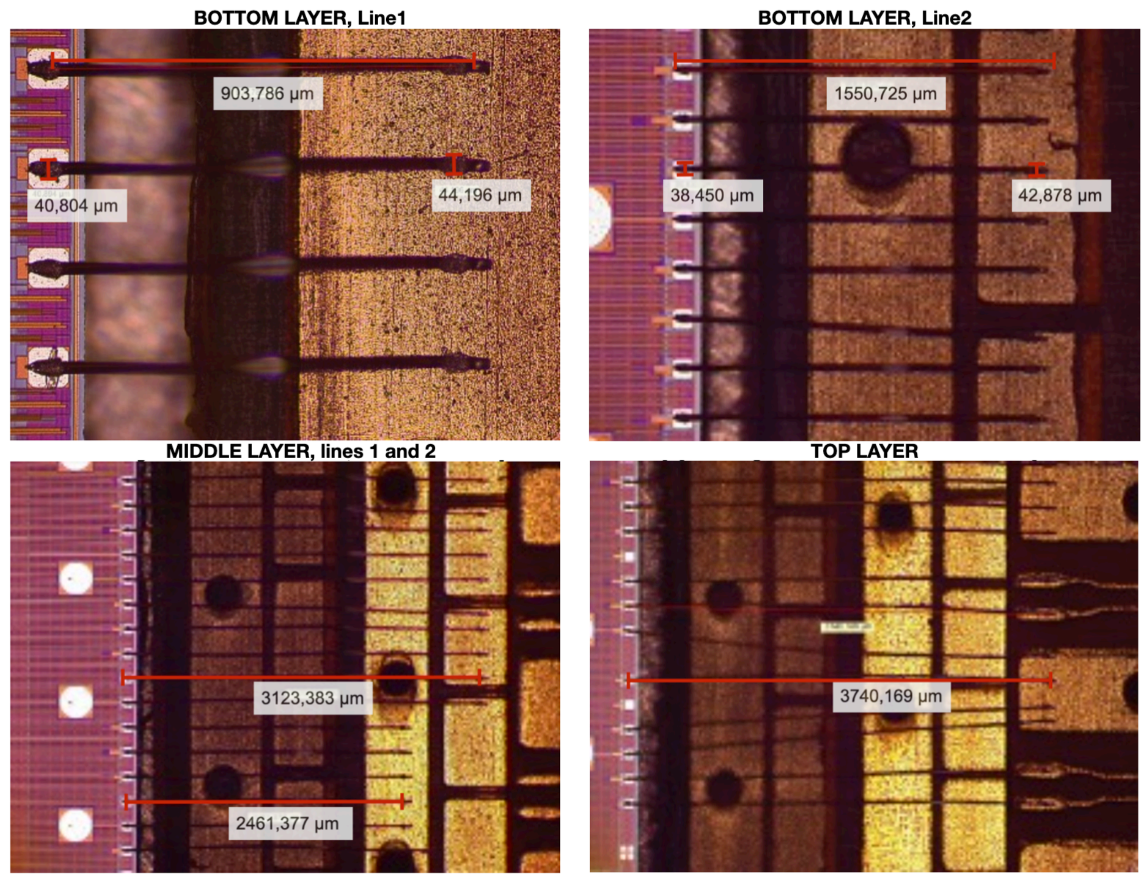
ITS3 has now become a subproject of ITS, with activities ramping up. Pioneering the 65 nm technology for MAPS raised interest of many groups. Physics studies are moving towards full Monte-Carlo simulations, including the full detector geometry, and new physics channels have been explored. First R&D studies 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

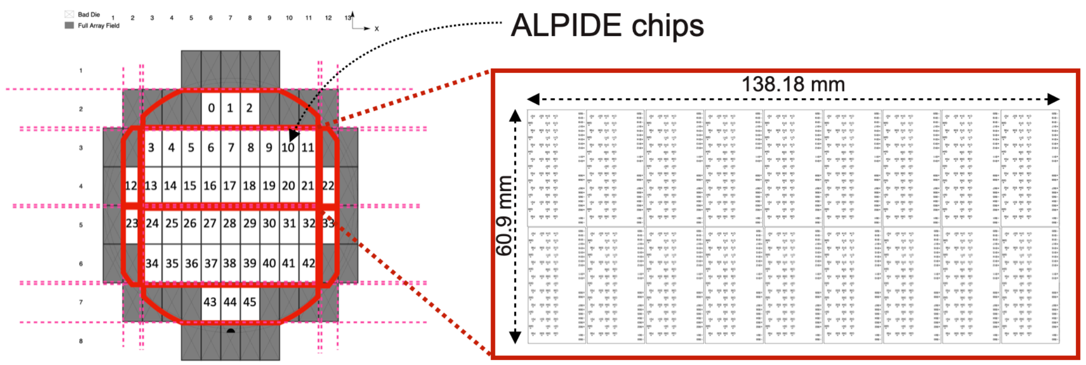


Line	BOT-L1	BOT-L2	MID-L1	MID-L2	TOP-L1
Loop height (μm)	110	220	310	360	500
Pad-pad distance (μm)	880	1520	2420	3140	3740
Wire angle on FPC ($^\circ$)	13	15	17	8	4
Wire angle on sensor ($^\circ$)	12	16	14	13	15
Pull force (g) [mean $\pm$ dispersion]	6.6$\pm$0.3	6.6$\pm$0.3	5.1$\pm$0.4	5.2$\pm$0.3	3.8$\pm$0.3
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

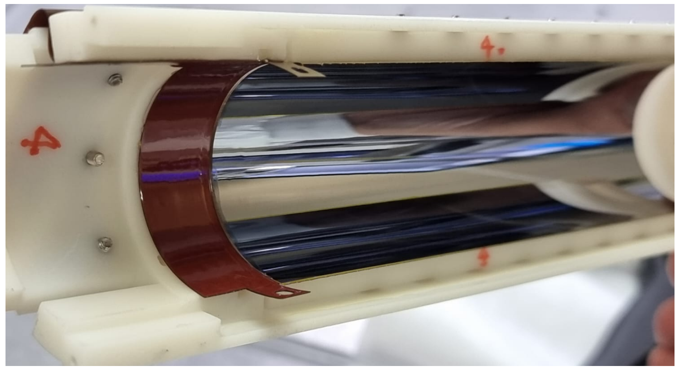
Backup - Super-ALPIDE project

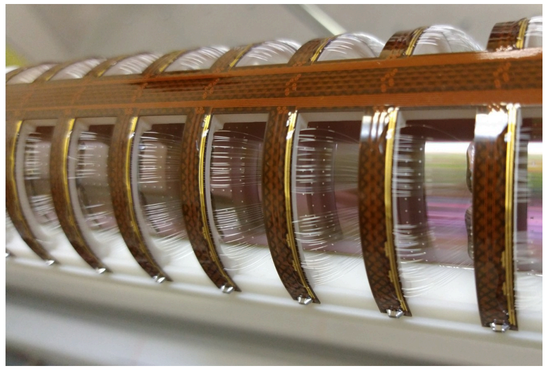
» Super-ALPIDE
- 18 not diced ALPIDE chips
- dimensions close to the ones for L0 sensor

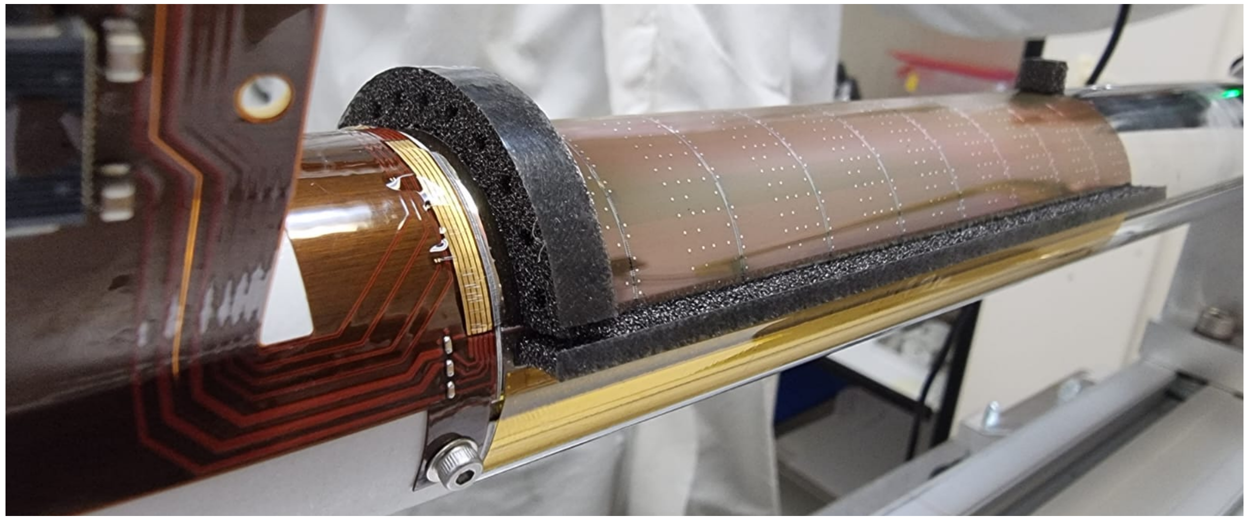
» Goals
- verify bending tools for large-size working chips
- verify mechanical support alignment tools
- develop wire-bonding over bent surface tools
- develop first bent flex prototype (for powering and data streaming)
- assemble first working large dimension bent sensor → by October 2023

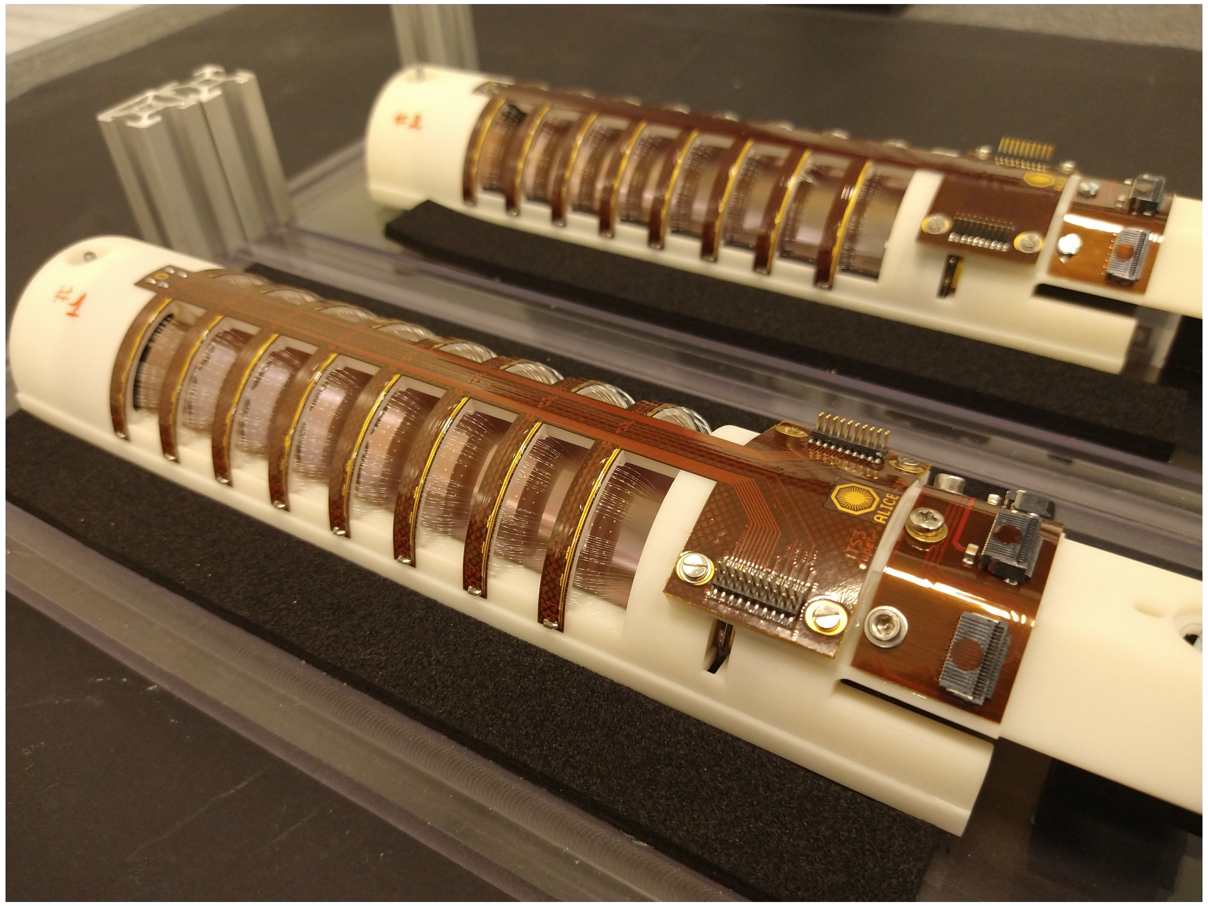


Super-ALPIDE: 18 not diced ALPIDE chips



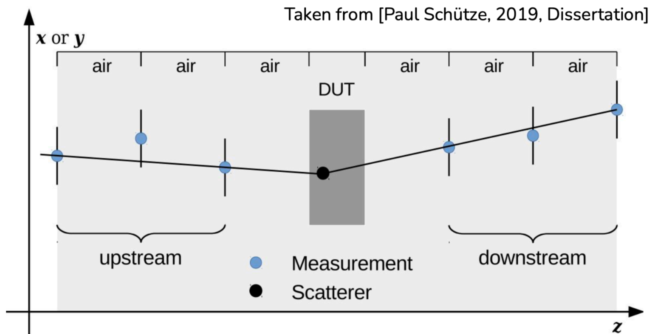


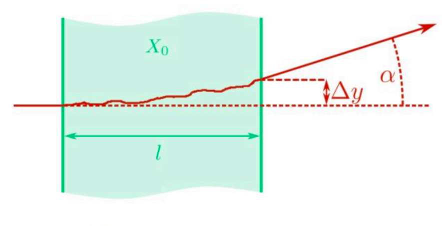




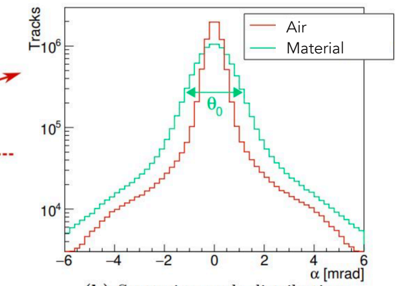
Backup - Carbon foam properties

Taken from [Paul Schütze, 2019, Dissertation]

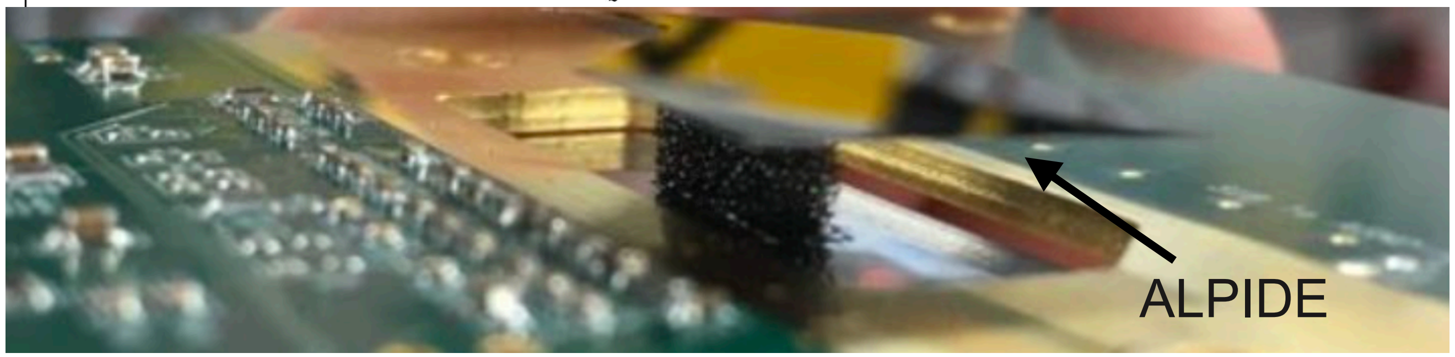




(a) Multiple Coulomb scattering



(b) Scattering angle distribution



» Carbon foam material budget study though particle deviation angle measurement