ITS3: The upgrade of the Inner Tracking System of the ALICE Experiment

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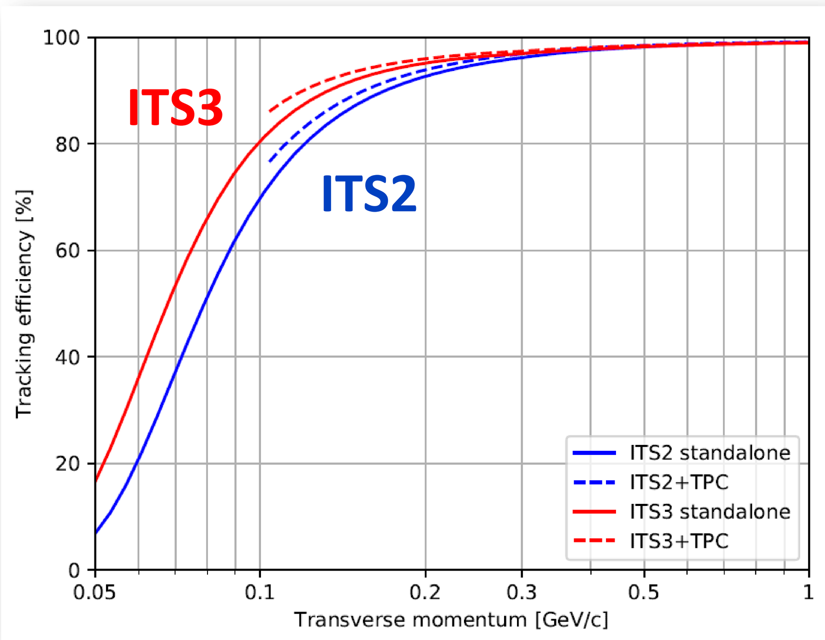
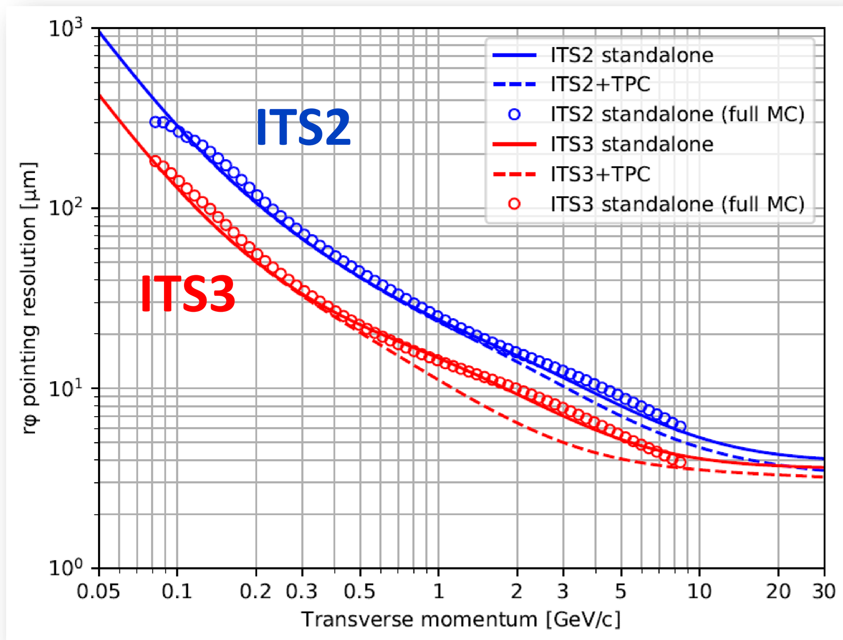
1. Physics motivation

- The innermost layers of the ALICE Inner Tracking System (ITS2) will be replaced with a **new tracker** during LHC Long Shutdown 3 (2026-2028), **the ITS3** [1].
- This upgrade will further improve **tracking efficiency** and **pointing resolution** especially for low momentum particles, thus allowing to improve the precision of **measurements in the heavy-flavour sector** and to bring **another set of fundamental observables** into reach [2].
- E.g. these measurements will be allowed:
  - $\mathbf{B_s^0}$ and $\mathbf{\Lambda_b^0}$ at low transverse momenta
  - **Non-prompt $\mathbf{D_s^+}$ and $\mathbf{\Xi_c^+}$** decays in heavy-ion collisions

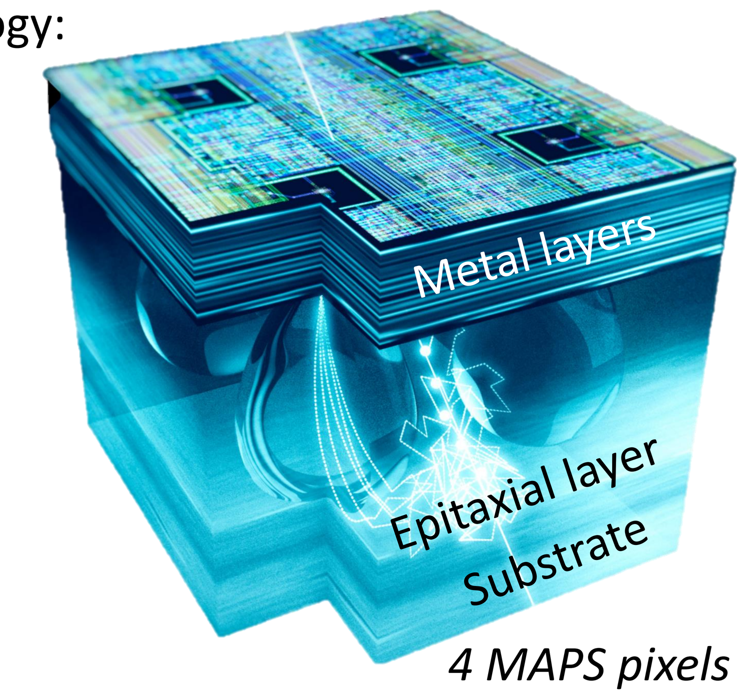




2. Monolithic Active Pixel Sensor (MAPS) technology

The ITS3 will be realized using the MAPS technology:
- Read-out logic and sensitive volume in the **same silicon crystal**
- Complete in-pixel **CMOS circuitry**
- **Ultra-thin silicon** O(≤50 μm)

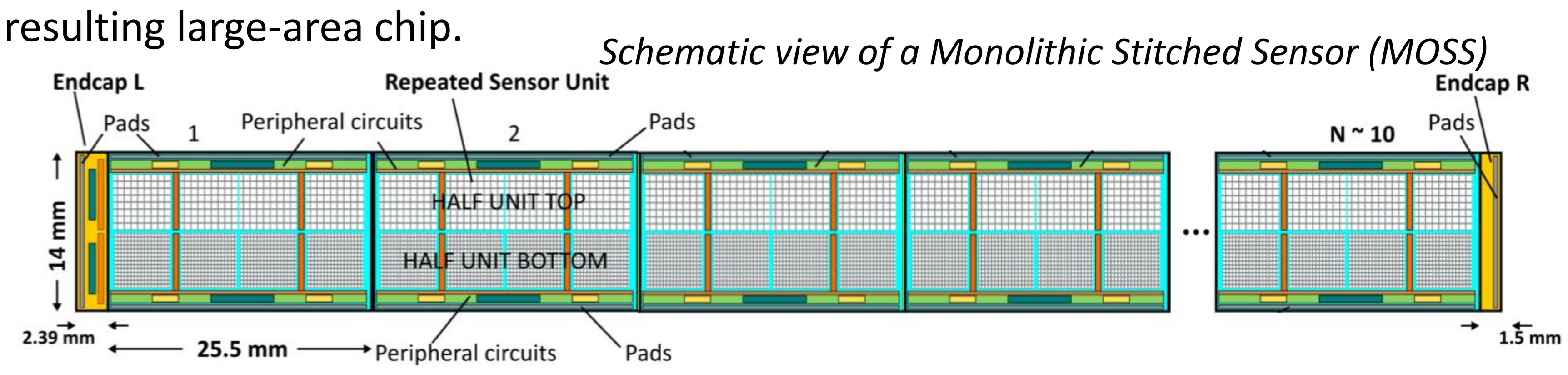
The Tower Partners Semiconductor Co. [3] **65 nm CMOS imaging process** for MAPS was chosen for the ALICE ITS3. Key advantages:
- High **radiation hardness**
- Low **power consumption**
- **5 μm** 2D spatial resolution
- **Large wafers** (Ø 300 mm)



4 MAPS pixels

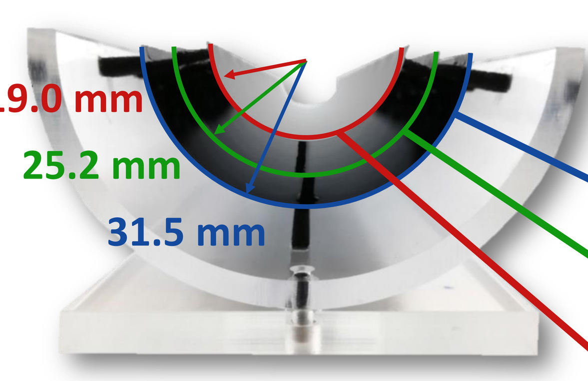
Stitching will be used: repeated identical but functionally independent units, with **in-silicon interconnections** and peripheral structures along the outer edges of the resulting large-area chip.

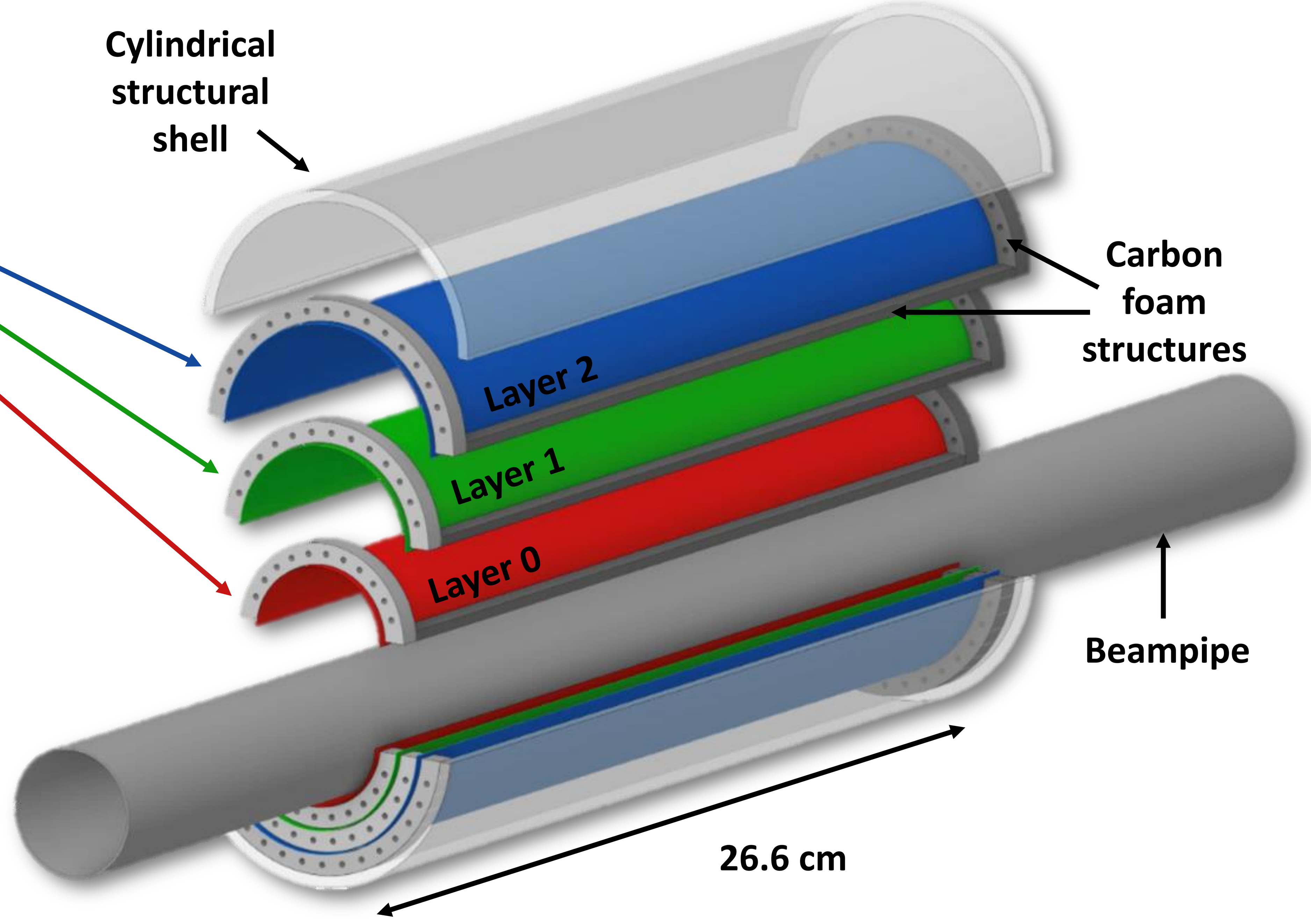
Schematic view of a Monolithic Stitched Sensor (MOSS)

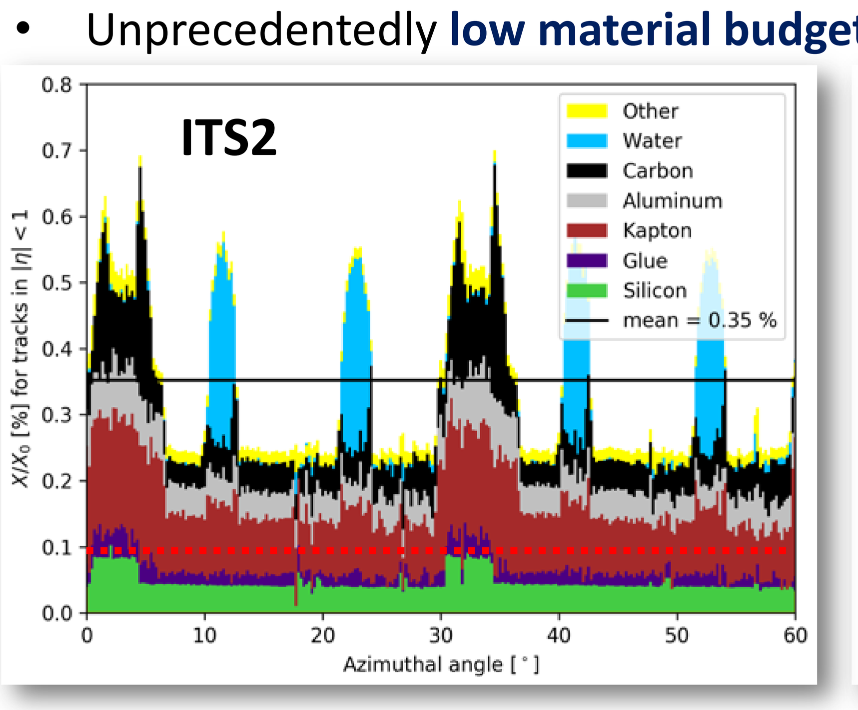


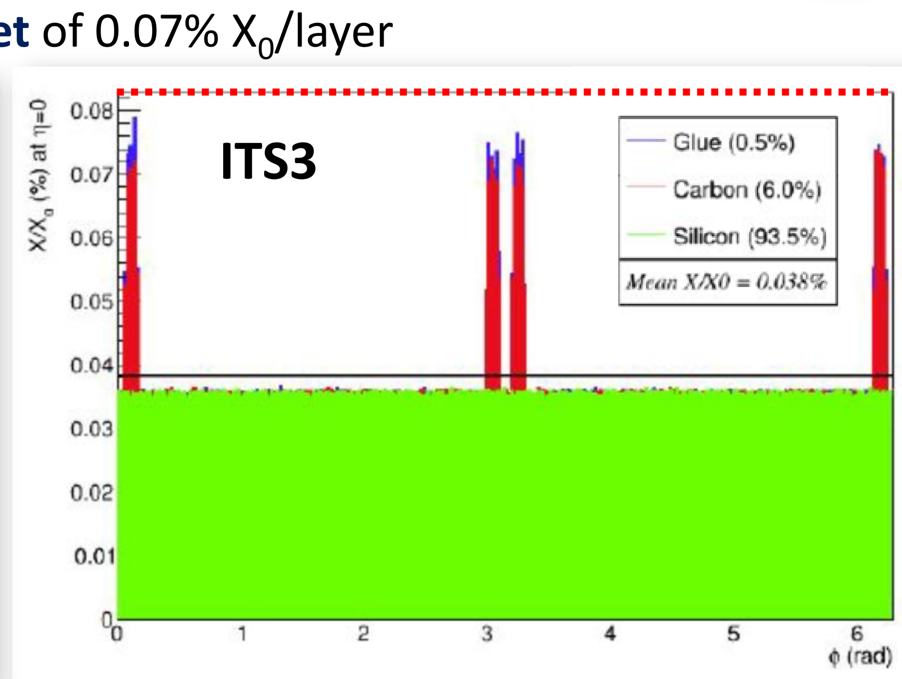
3. Detector layout

- 3 truly cylindrical **self-supporting** layers
- Each layer made by 2 **flexible MAPS** sensors which:
  - have a **large-area** O(10×26 cm^2)
  - are **ultra-thin** (≤50 μm)
- Ultra-light **carbon foam structure** keeps in position the sensors
- **Innermost layer at 19 mm** from the interaction point
- Unprecedentedly **low material budget** of 0.07% X_0/layer







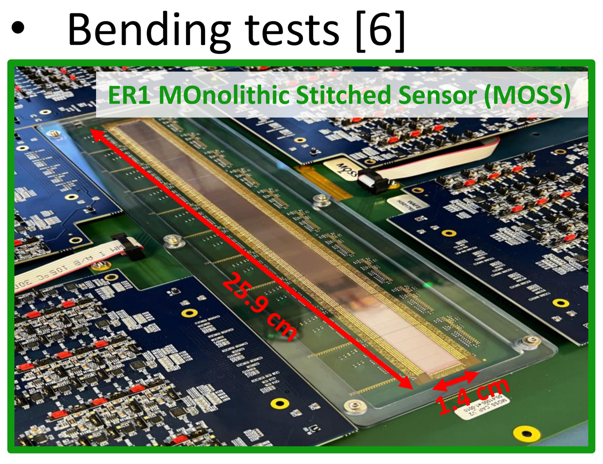


4. Sensor qualification

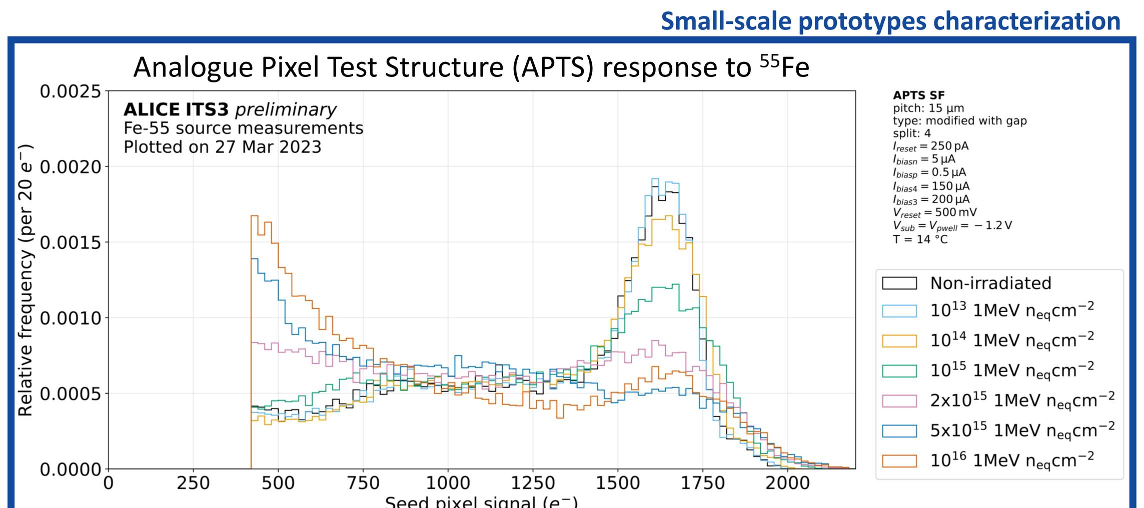
1. Characterization of the **small-scale prototypes** realized in the 65 nm technology. First production: Multiple Layer Reticle 1 - MLR1
2. Performance and production yield evaluation of the **large-area MOnolithic Stitched Sensor (MOSS)**. First production (2023): Engineering Run 1 – ER1
3. Qualification of the **ITS3 final sensor**

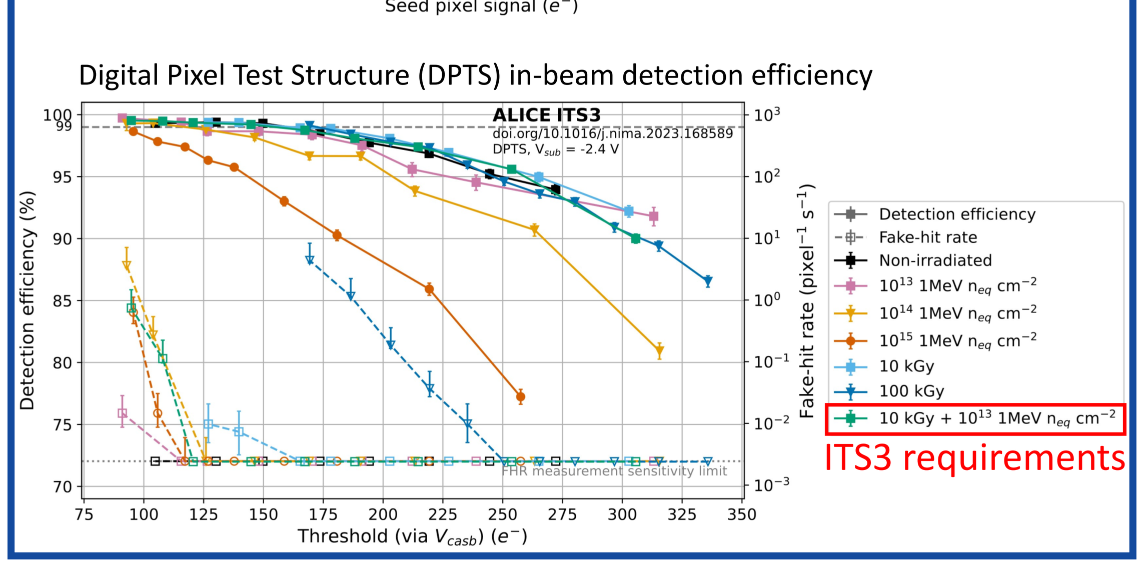
A wide campaign of test is ongoing to qualify both small-scale and large-area prototypes [4, 5].

- Laboratory measurements:
  - Definition of the **operating conditions**
  - **Response to X-rays**: ^{55}Fe source and fluorescence photons
- In-beam measurements to assess:
  - **Detection efficiency**
  - **Spatial resolution**
- Bending tests [6]



Small-scale prototypes characterization

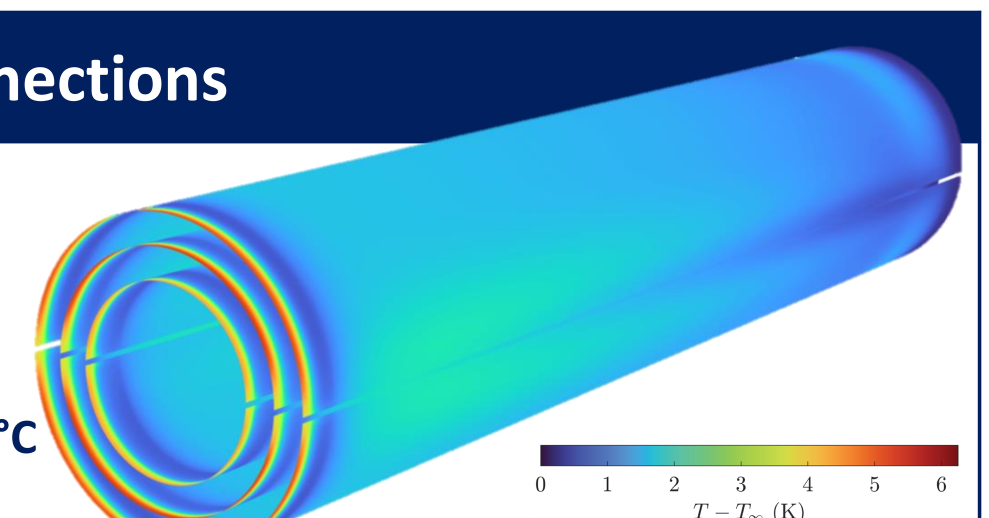




5. Air cooling and interconnections

Air cooling avoids introducing structures in the active region
→ keeps the material budget low

These requirements must be satisfied:
- Sensor **operating temperature <30°C**
- **Temperature gradient** in the matrix region **<5°C**
- Sensor **power density < 40 mW/cm²**

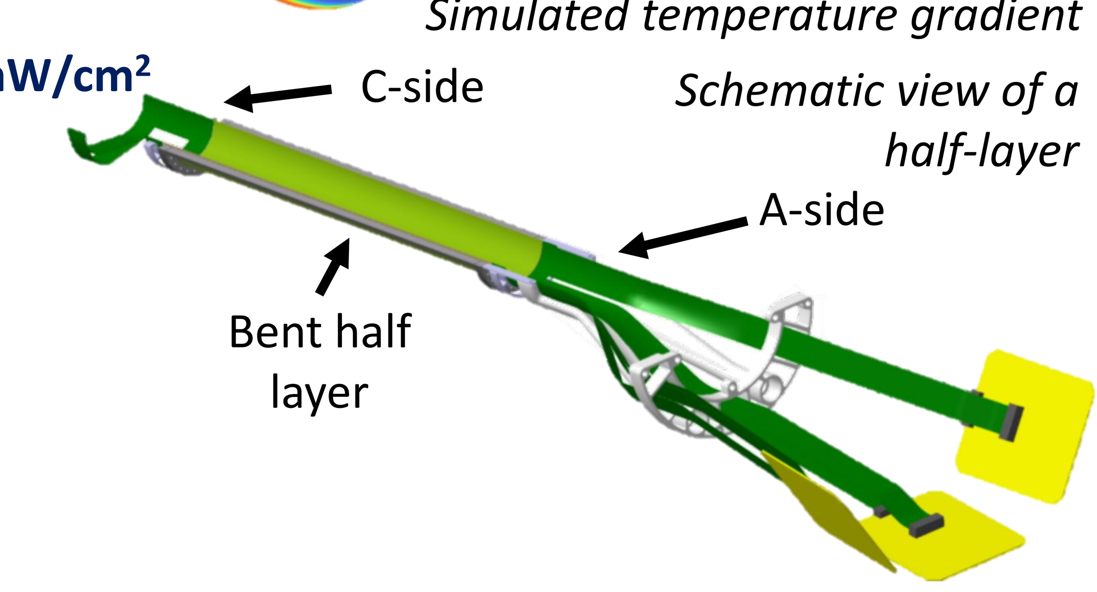


Simulated temperature gradient

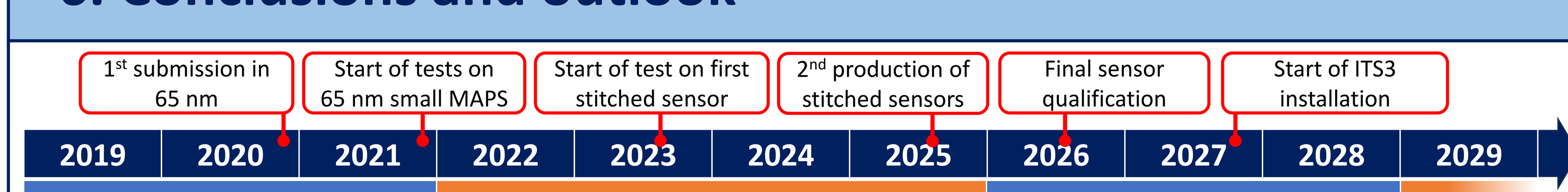
The electrical interconnections are on both sides:
- FPC for power on the C-side
- FPC for power, data and control on the A-side

Data transmission up to 10 Gb/s

Schematic view of a half-layer



6. Conclusions and outlook



- ITS3 will be installed during LS3 to be ready for LHC Run 4 (2029-2032)
- Sensor qualification on track:
  - Demonstrated operability of bent MAPS
  - Validated 65 nm CMOS process
  - Stitching qualification is ongoing
- Air cooling system and services design is completed, prototyping is ongoing

References

[1] ALICE Collaboration, Letter of Intent for an ALICE ITS Upgrade in LS3, 10.17181/CERN-LHCC-2019-018
[2] Shreyasi Acharya et al., Upgrade of the ALICE Inner Tracking System during LS3: study of physics performance, http://cds.cern.ch/record/2868015
[3] Tower Semiconductor home page, https://towersemi.com/
[4] S. Bugiel et al., Charge sensing properties of monolithic CMOS pixel sensors fabricated in a 65 nm technology, https://doi.org/10.1016/j.nima.2022.167213
[5] G. Aglieri Rinella, et al., Digital pixel test structures implemented in a 65 nm CMOS process, https://doi.org/10.1016/j.nima.2023.168589
[6] ALICE ITS3 project, First demonstration of in-beam performance of bent Monolithic Active Pixel Sensors, https://doi.org/10.1016/j.nima.2021.166280