ITS3: an innovative silicon ultra-thin and flexible tracker for the ALICE Experiment

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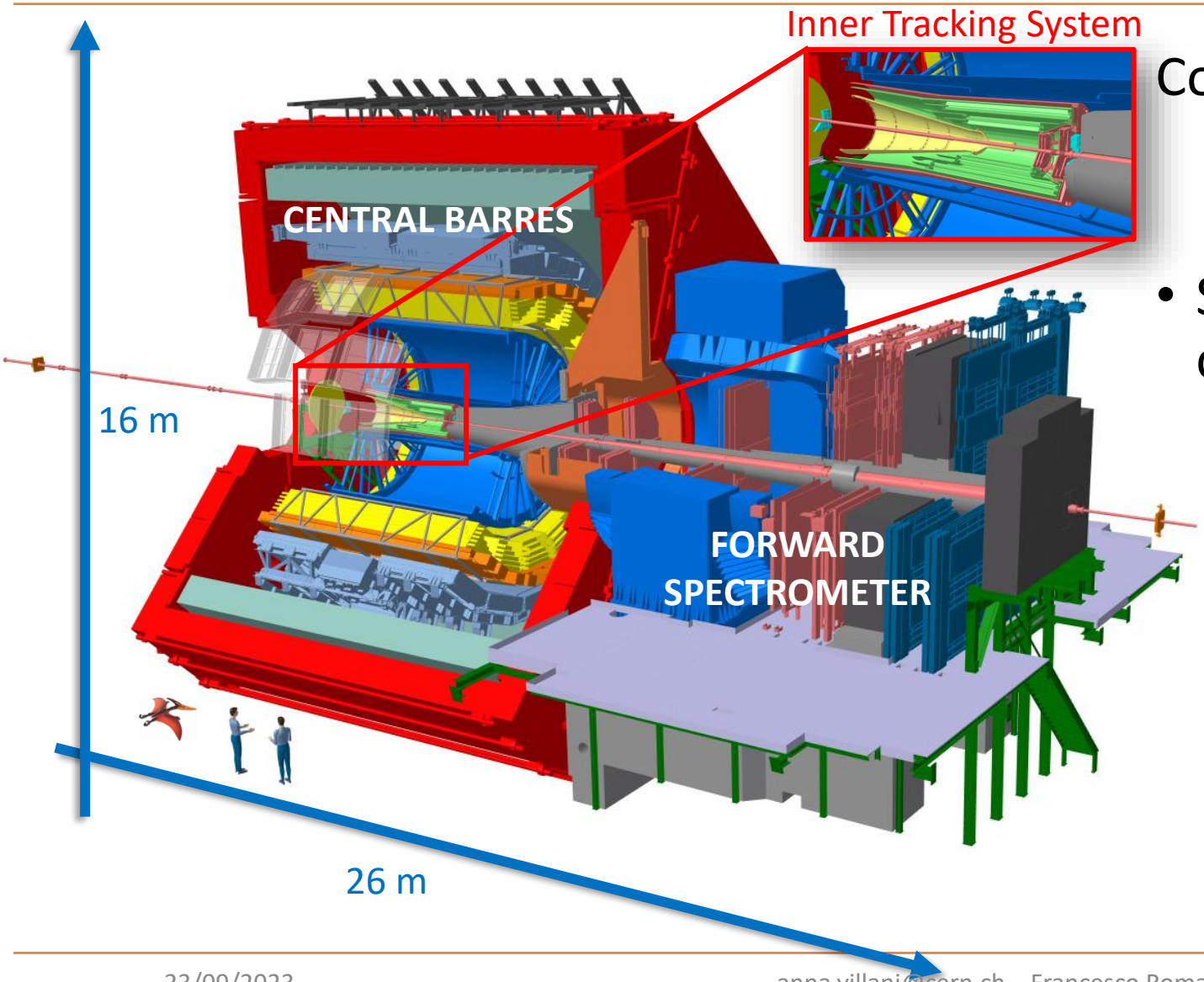
Francesco Romano School 2023, Monopoli (BA)

XXXIV International School
"Francesco Romano"
on Nuclear, Subnuclear and Astroparticle Physics

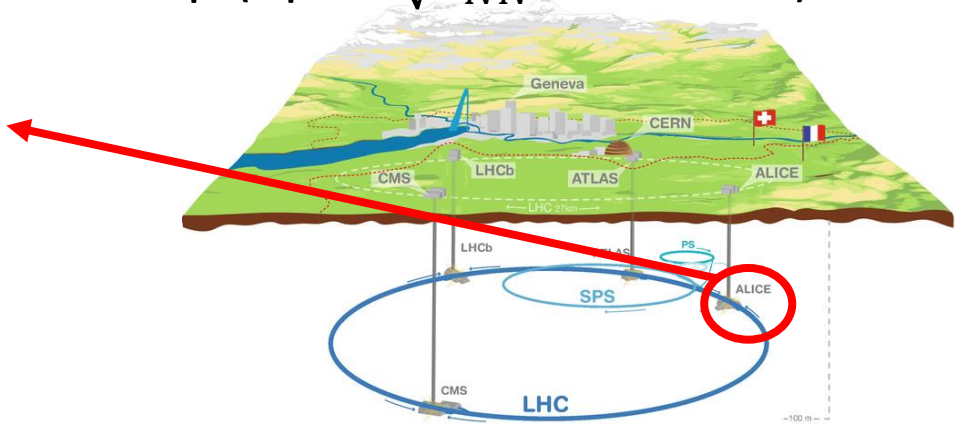
The ALICE Experiment at LHC



Composed by several detectors:

- Central barrel
- Forward muonic spectrometer

- Studies particles produced in the collisions:
  - Pb–Pb (up to $\sqrt{s_{NN}} = 5.36$ TeV)
  - pp (up to $\sqrt{s} = 13.6$ TeV)
  - Pb–p (up to $\sqrt{s_{NN}} = 8.0$ TeV)



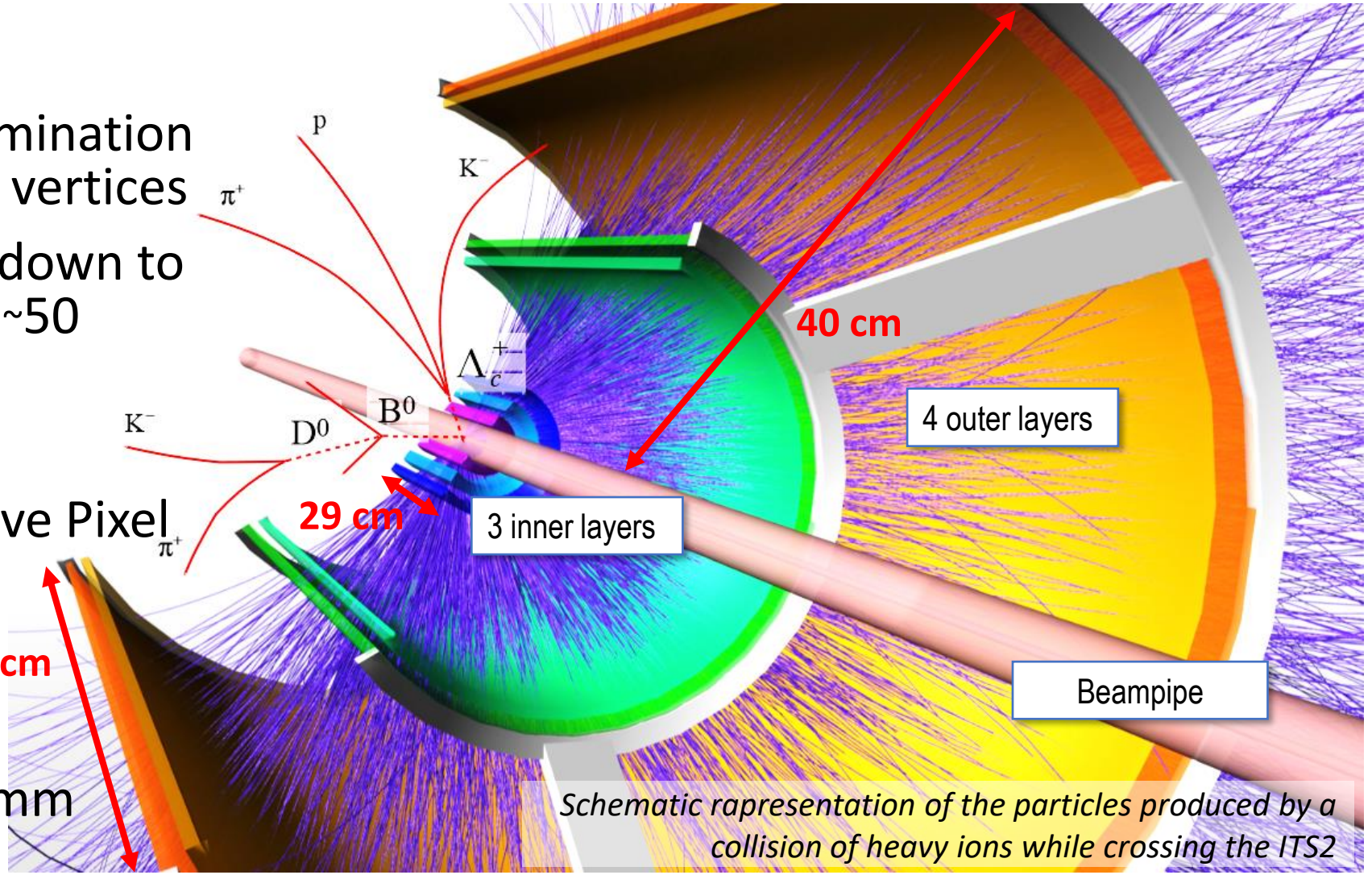
The Inner Tracking System (ITS)

ITS functions:

- Reconstruction and discrmination of primary and secondary vertices
- Charged particle tracking down to low value of momentum (~50 MeV/*c*)

ITS2 characteristics:

- **7 layers** of Monolithc Active Pixel silicon Sensor (**MAPS**)
- 10 m^2 active area
- **12.5** Gpixel
- Innermost radius of 22.4 mm

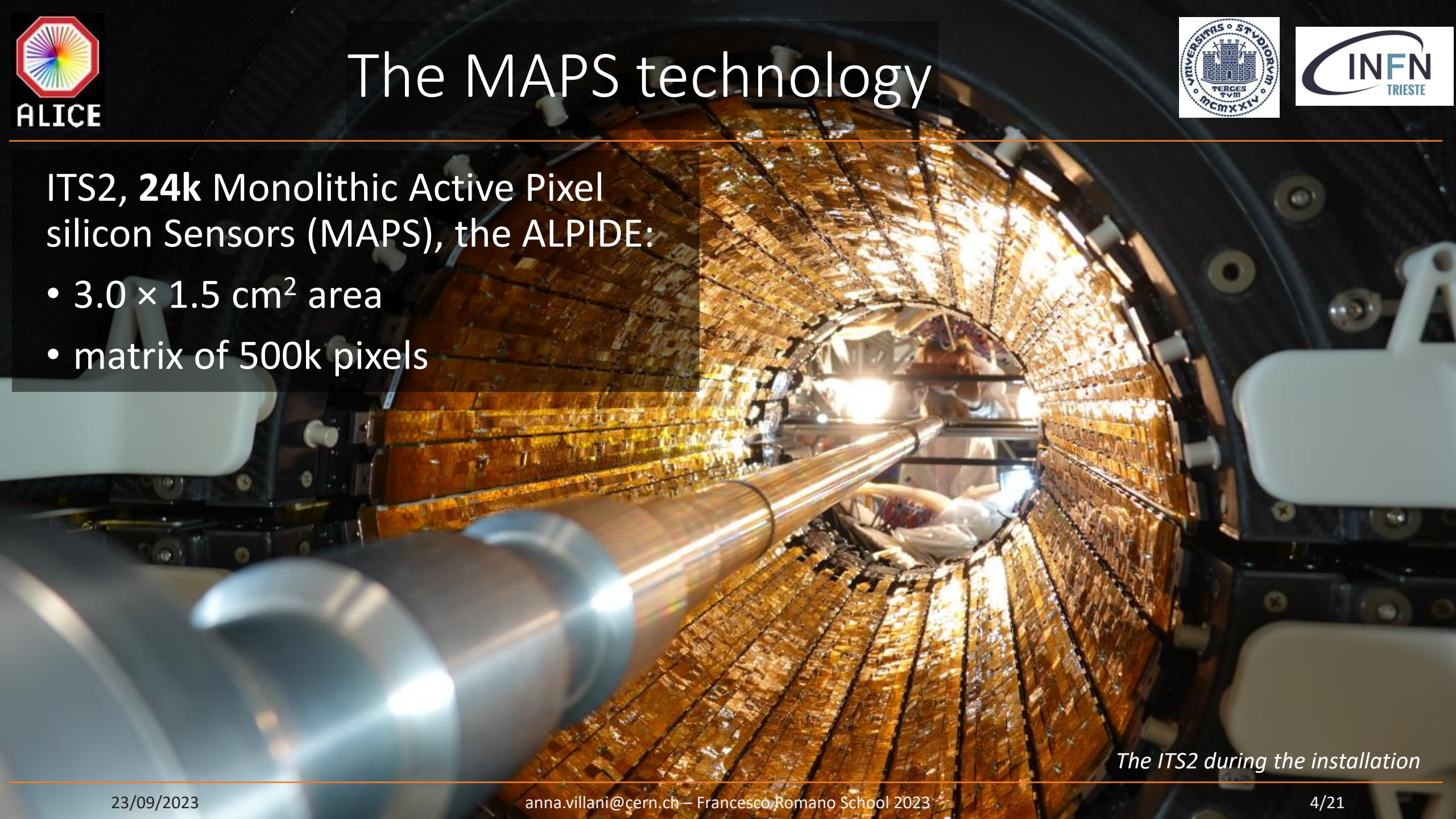


Schematic rapresentation of the particles produced by a collision of heavy ions while crossing the ITS2

The MAPS technology

ITS2, **24k** Monolithic Active Pixel silicon Sensors (MAPS), the ALPIDE:

- 3.0 × 1.5 cm^2 area
- matrix of 500k pixels



The ITS2 during the installation

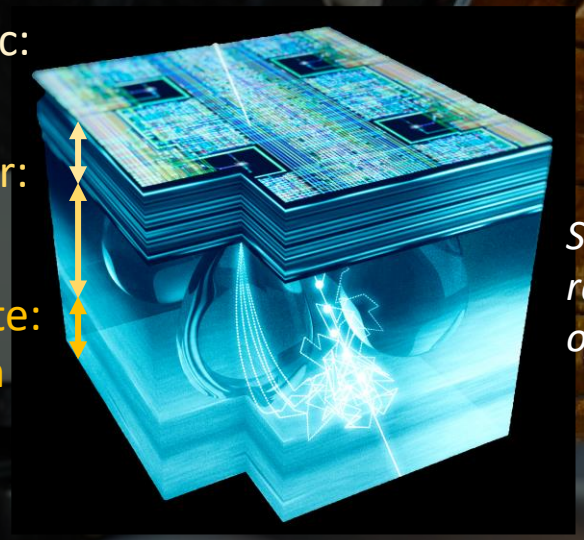
The MAPS technology

ITS2: **24k** Monolithic Active Pixel silicon Sensors (MAPS)

Read-out logic: 11 µm

Active layer: 15 µm

Substrate: 24 µm



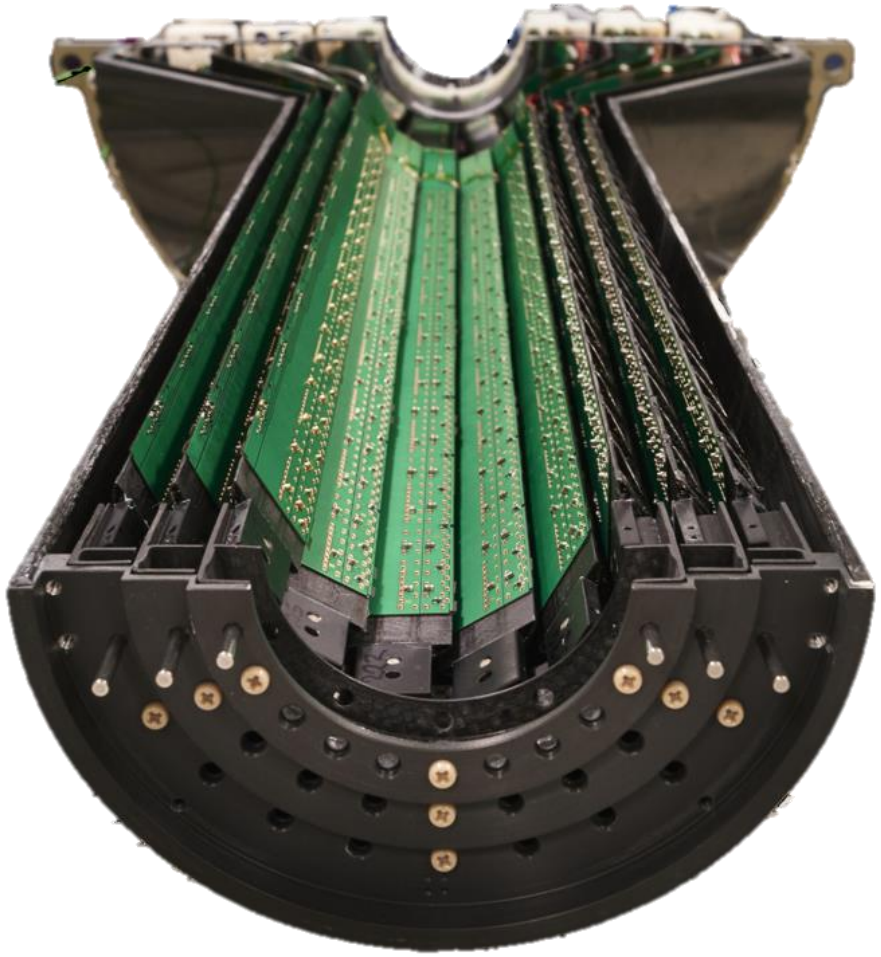
Schematic rapresentation of 4 MAPS pixels

- Read-out logic and active volume in the **same silicon crystal**
- **Complete COMS** circuitry inside the pixels
- **Low material thickness** (30-50 µm)

The ITS2 during the installation

The upgrade: towards the ITS3

Innermost layers of ITS2

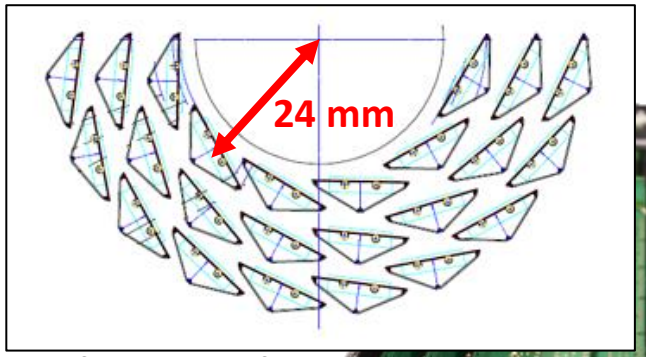


2026

Model of ITS3

The upgrade: towards the ITS3

Innermost layers of ITS2



Half-section of the three innermost layers of ITS2

2026

Model of ITS3

Half-section of the three innermost layers of the ITS3 model

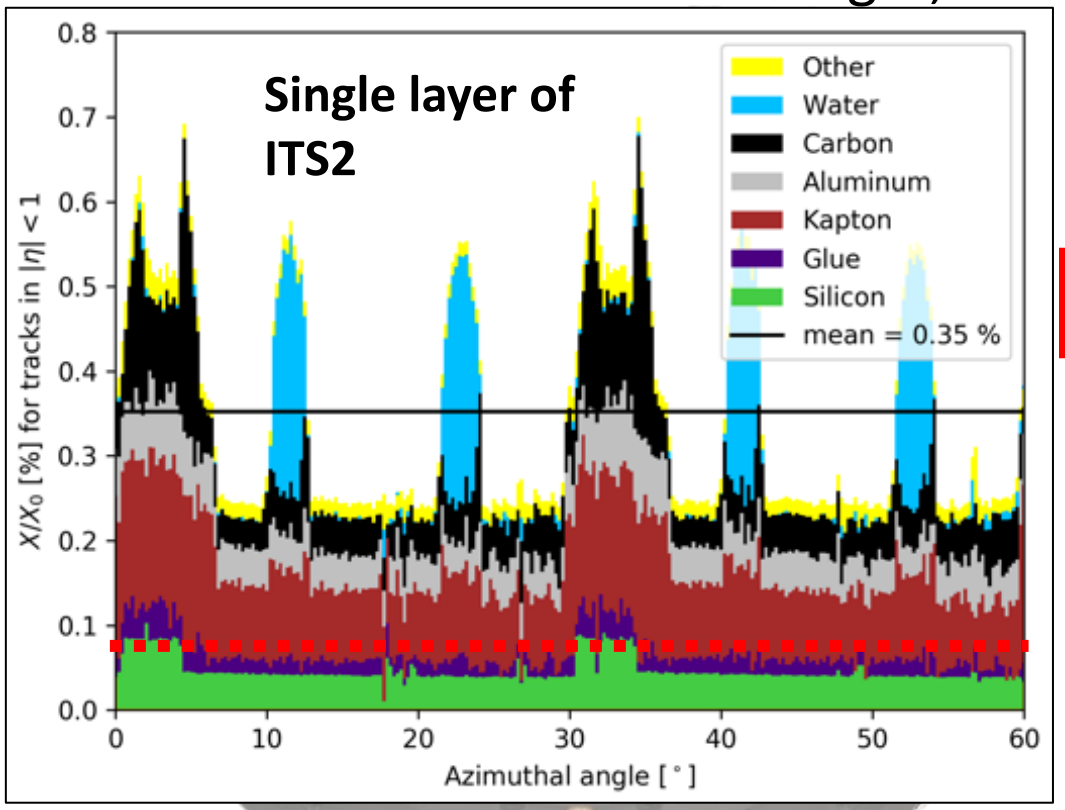
~28 cm

ITS3 characteristics:

- Rimotion of the segmented structure by using **flexible and large-area sensors**
- Reduction of the material budget introduced (0.3% → 0.05% X_0/layer) and of the distance from the interaction point (24 → 18 mm)

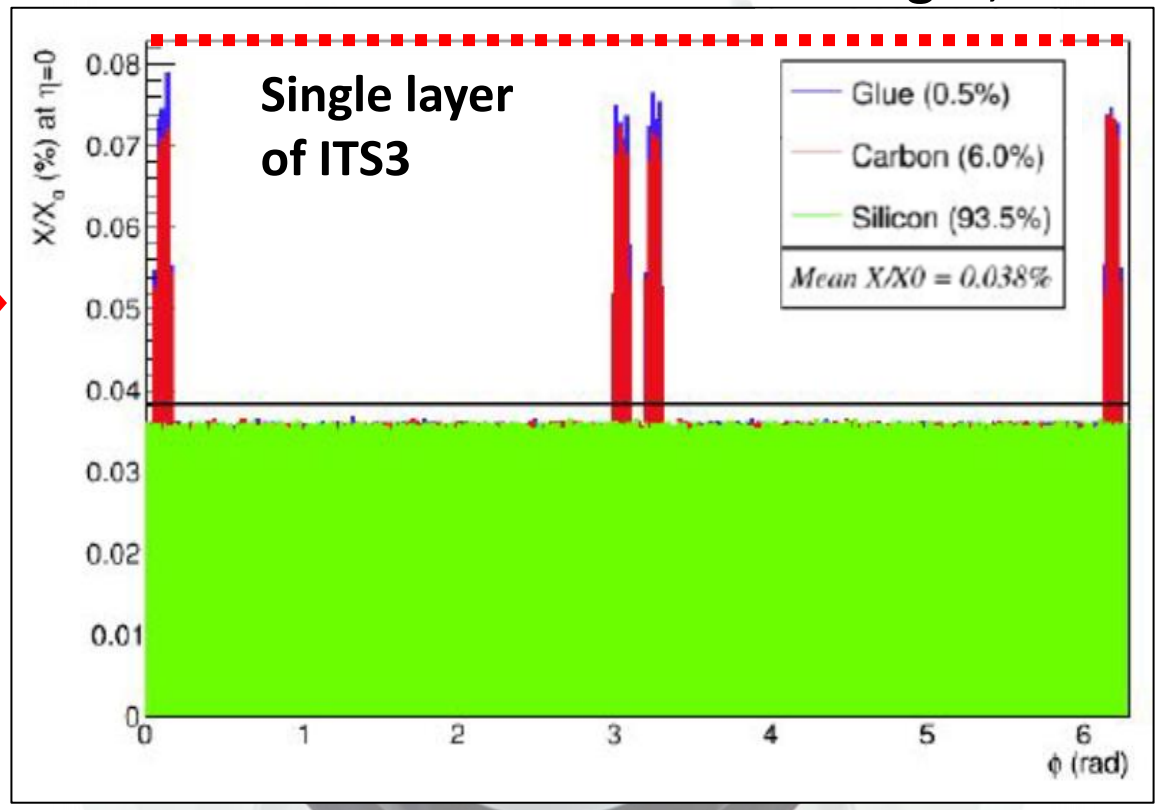
The upgrade: towards the ITS3

Contribution to the material budget, ITS2



2026

Contribution to the material budget, ITS3



ITS3: an innovative vertex detector

MAPS sensors for ITS3:

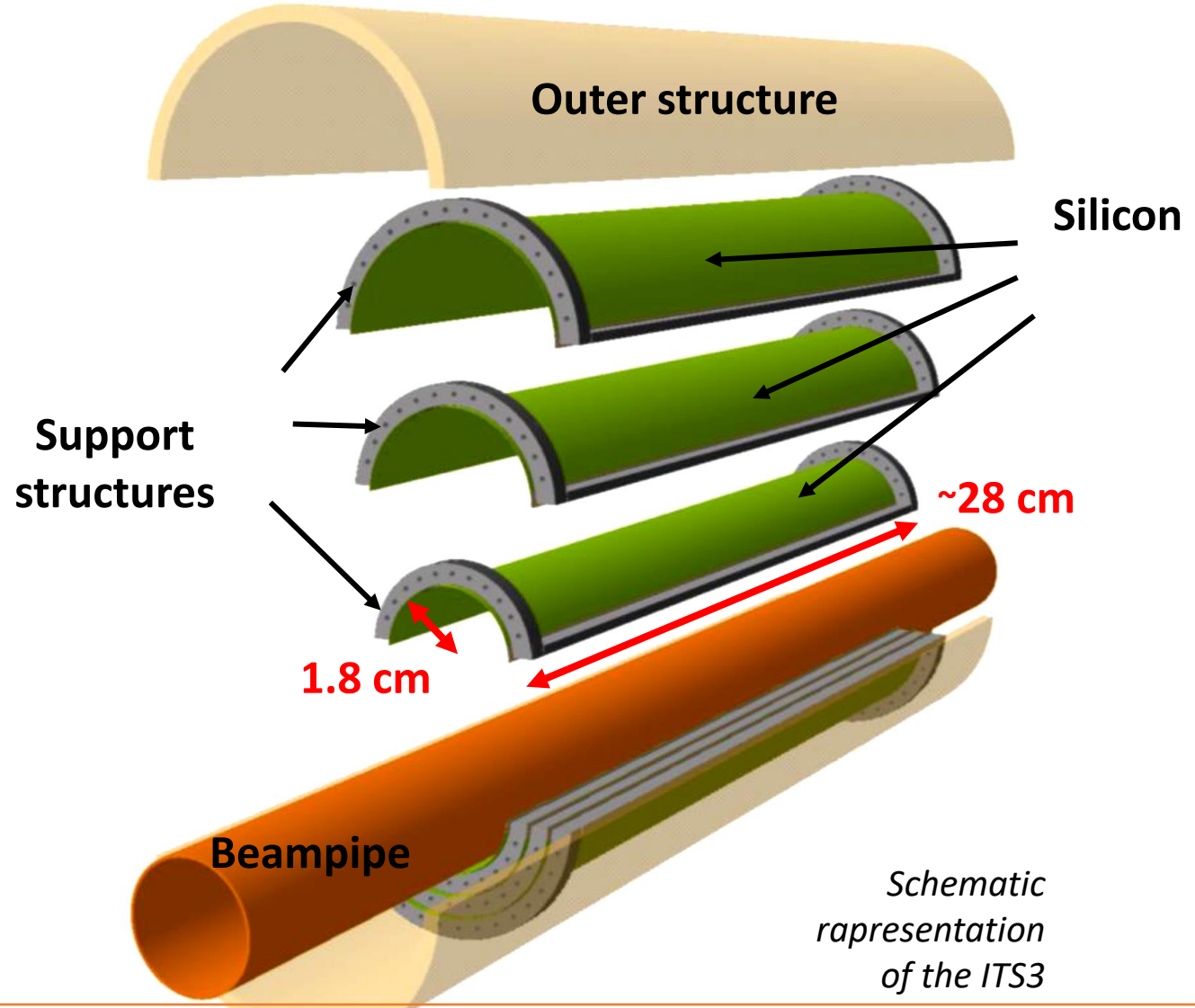
- **Large-area** (up to 28.0 × 9.4 cm^2)
- **Bent** (minimum radius 18 mm, ITS2: 22.4 mm)
- **Ultra-thin** (20-40 µm, ITS2: 50 µm)

Performance improvement:

- Tracking efficiency
- Pointing resolution (factor 2×)

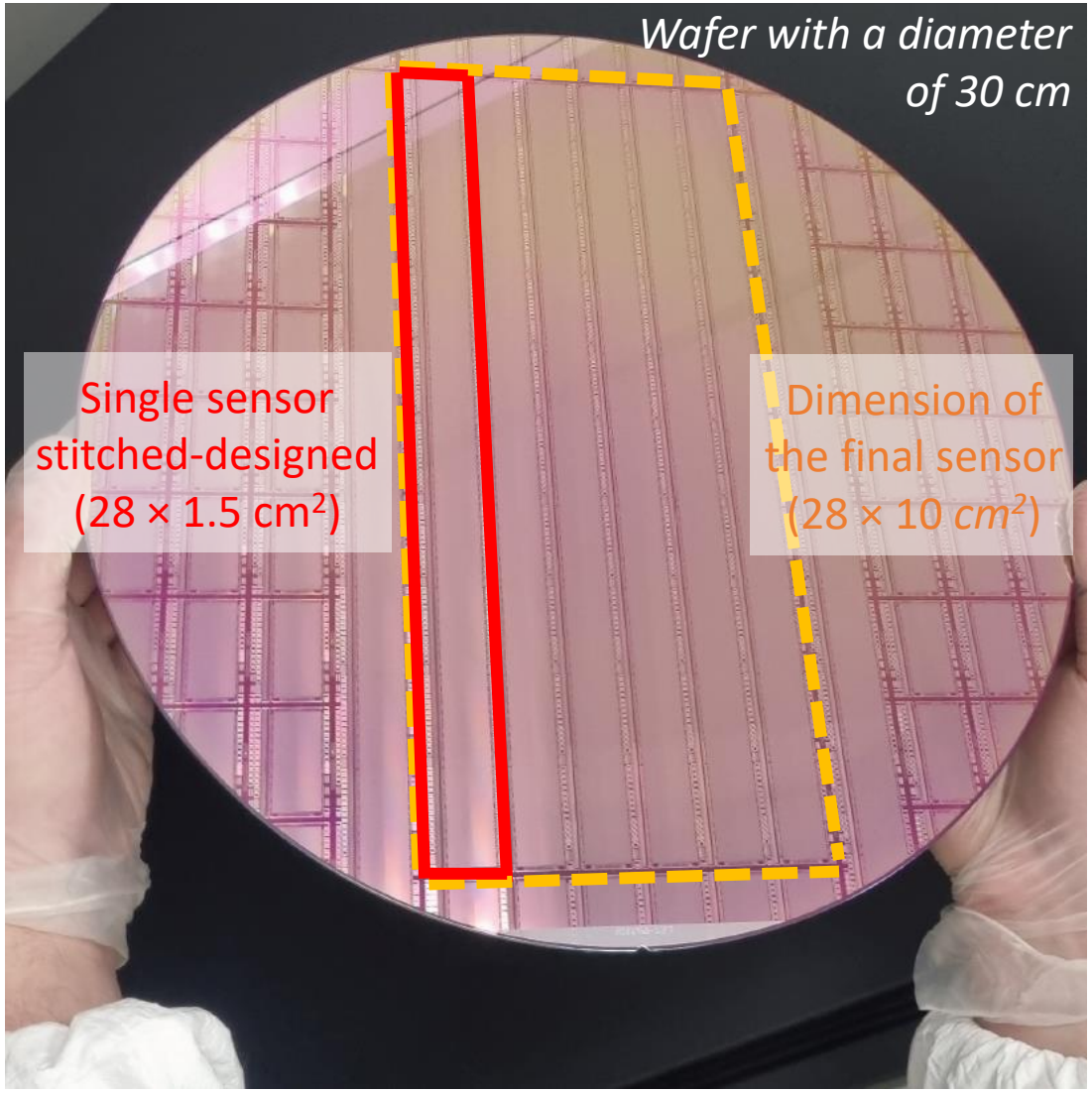
Important implications on the ALICE physics program, based on:

- Tracking down to low momentum
- Secondary vertex reconstruction

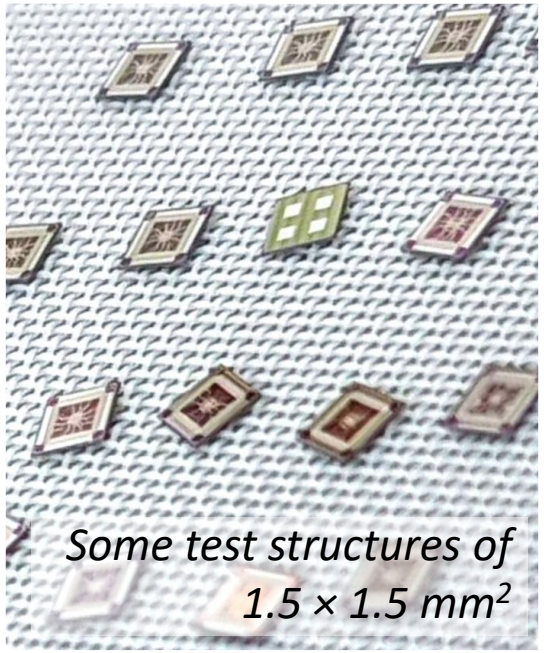


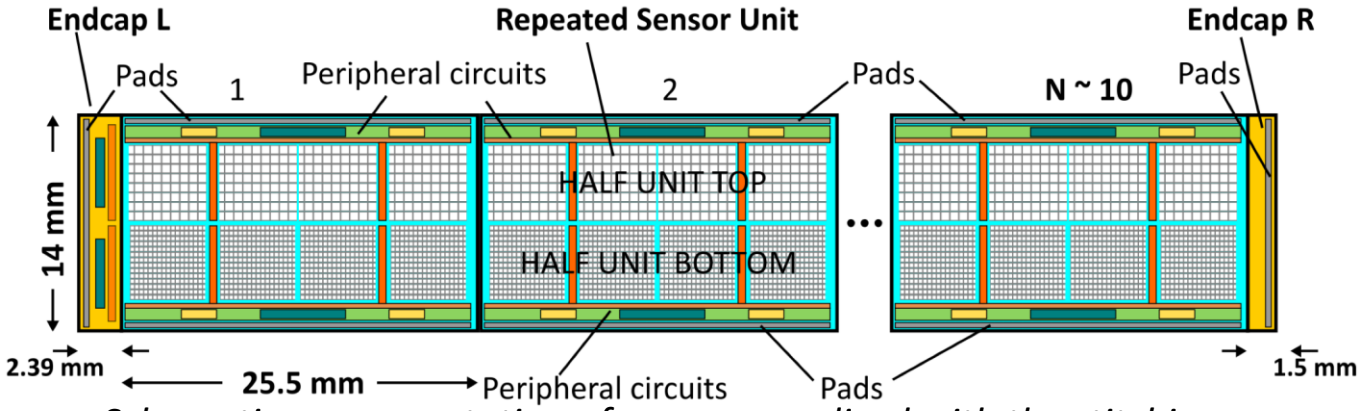
Schematic rapresentation of the ITS3

New technologies for the ITS3



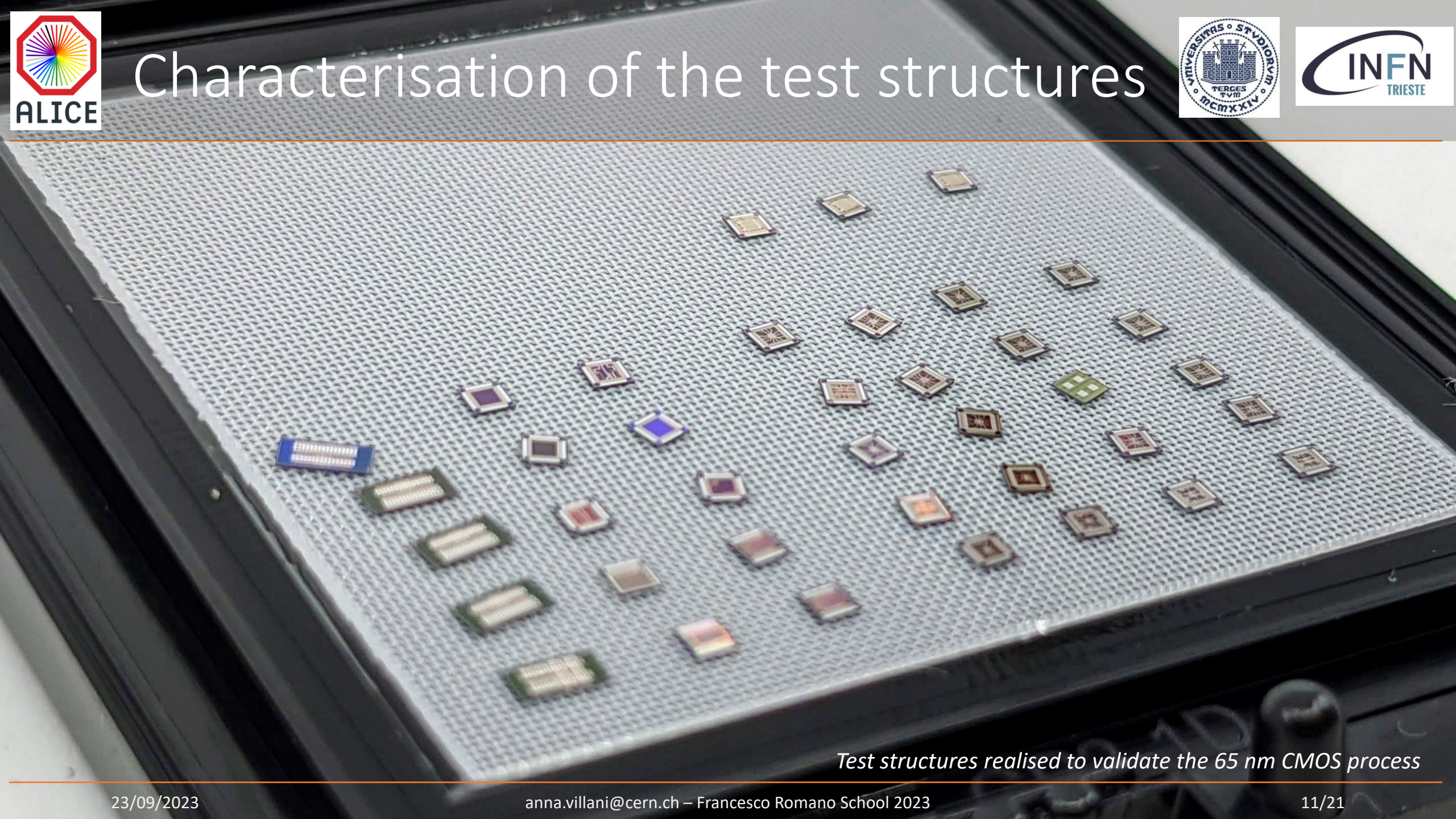
- **65 nm CMOS TPSCo process:** produced various test structures to validate its functionalities
- **Stitching:** repetition and chaining of the sensor functional unit: first stitched sensors produced and now under test


Some test structures of 1.5 × 1.5 mm²



Schematic rappresentation of a sensor realised with the stitching

Characterisation of the test structures

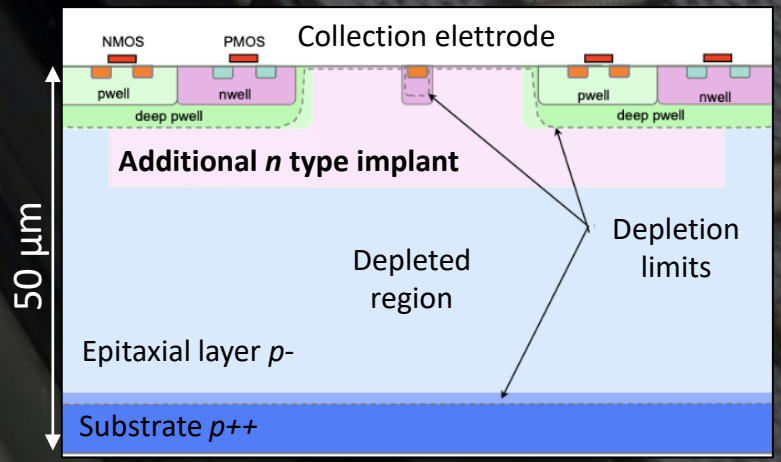


Test structures realised to validate the 65 nm CMOS process

DPTS: Digital Pixel Test Structure

Characteristics:

- 0.5 × 0.5 mm^2 matrix
- 32 × 32 pixels
- Thickness of 50 µm
- Additional *n* type implant → complete depletion, **charge collection faster, more uniform and more efficient**



Section of a MAPS pixel

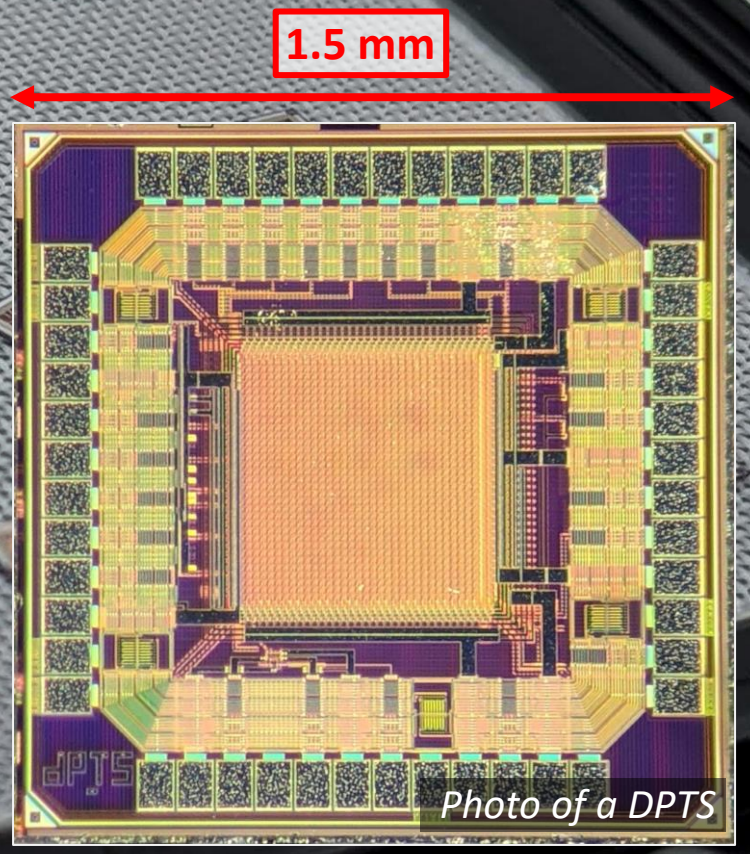
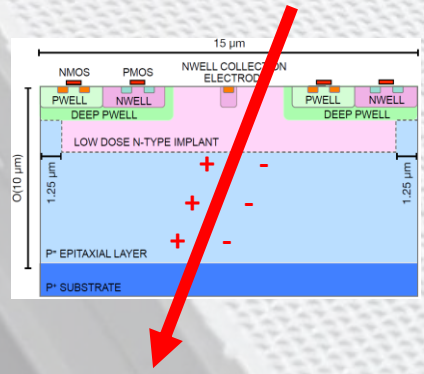


Photo of a DPTS

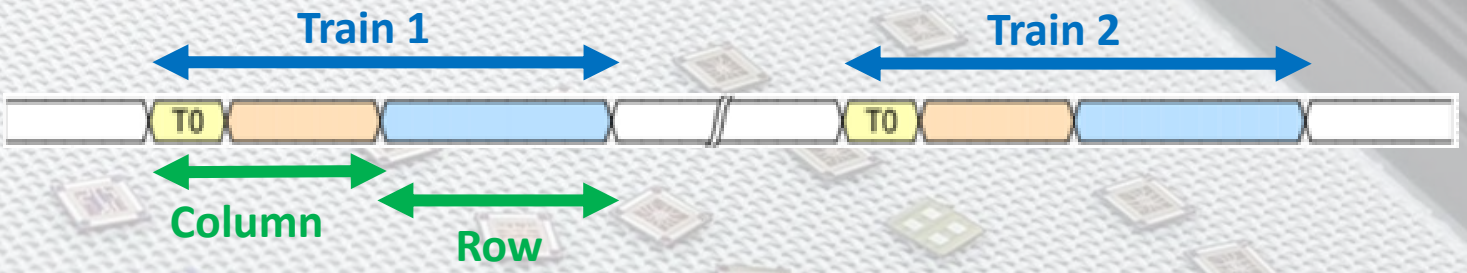
"Digital Pixel Test Structures implemented in a 65 nm CMOS process" [https://doi.org/10.1016/j.nima.2023.168589]

The output signal of the DPTS

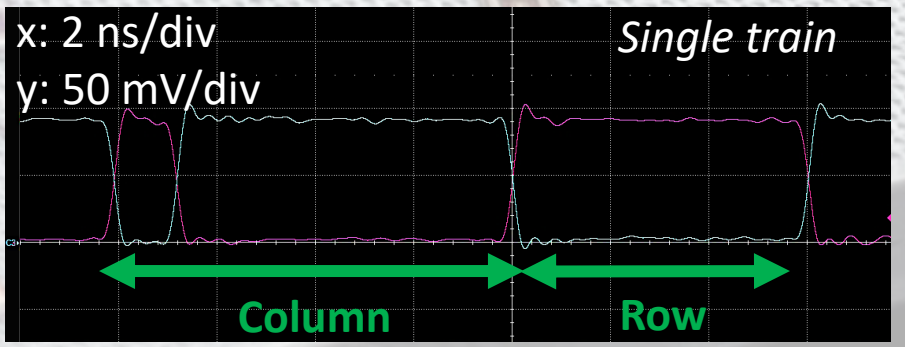
Two output signals with opposite polarity:



Output



- Time-encoded pixel position



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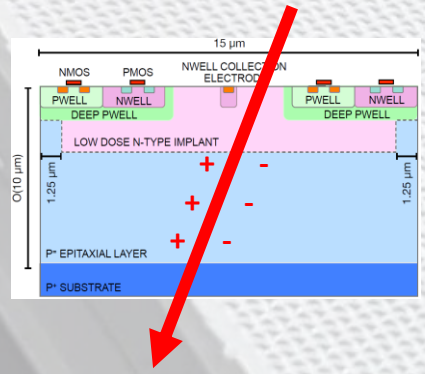
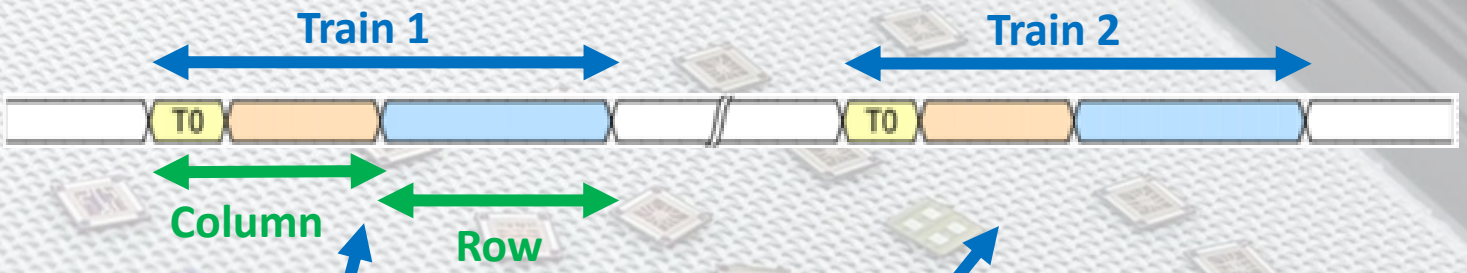
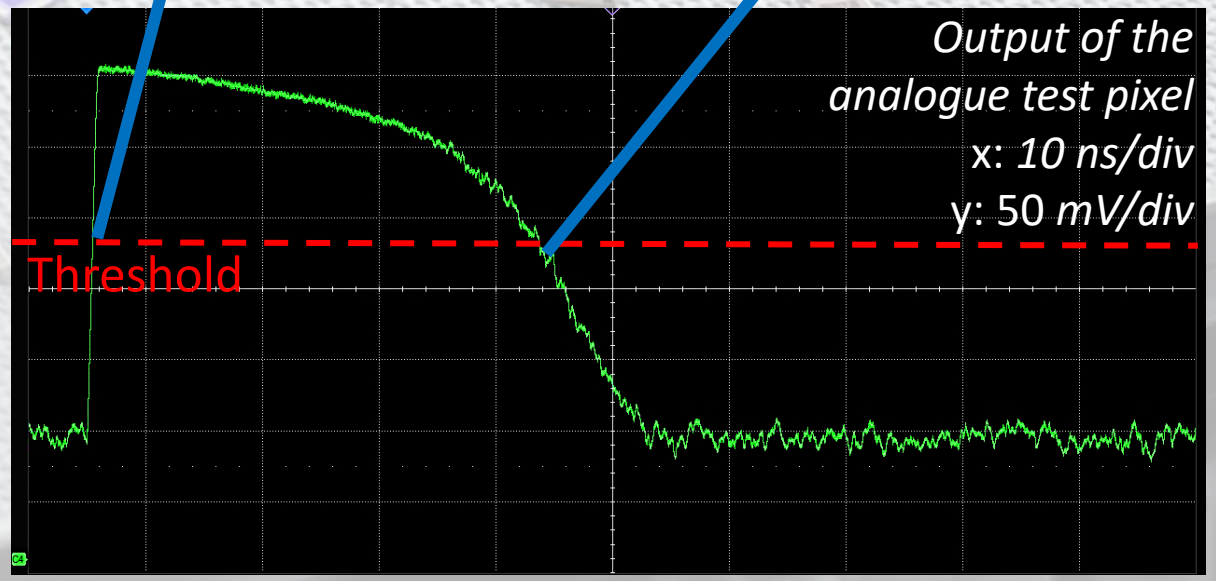


Output

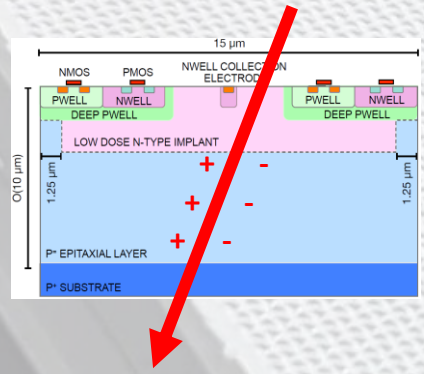


- Time-encoded pixel position

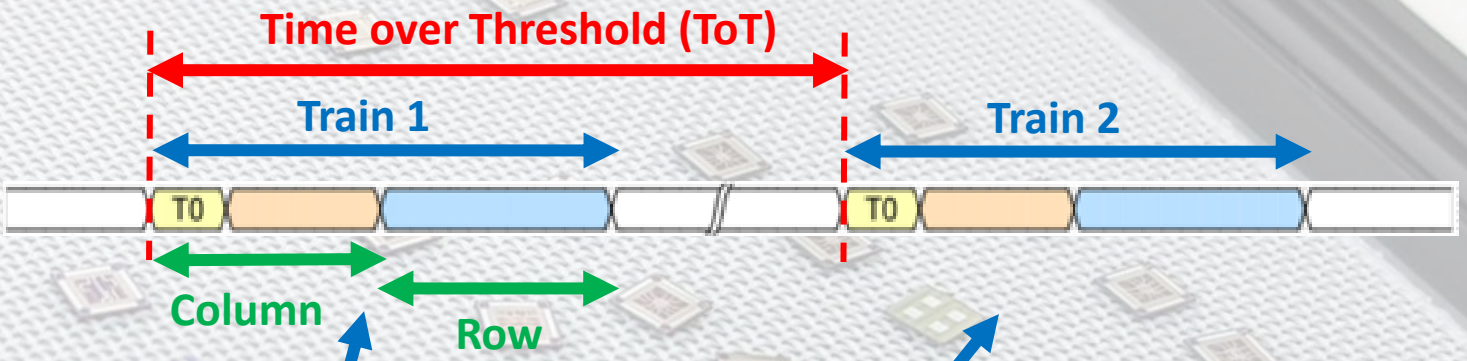


The output signal of the DPTS

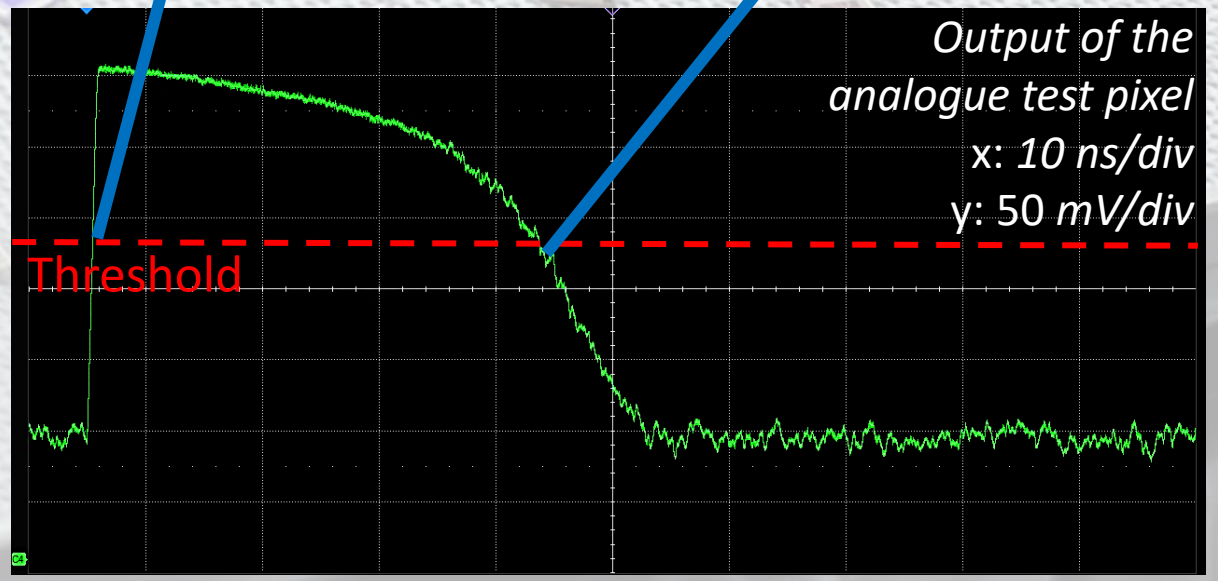
Two output signals with opposite polarity:



Output



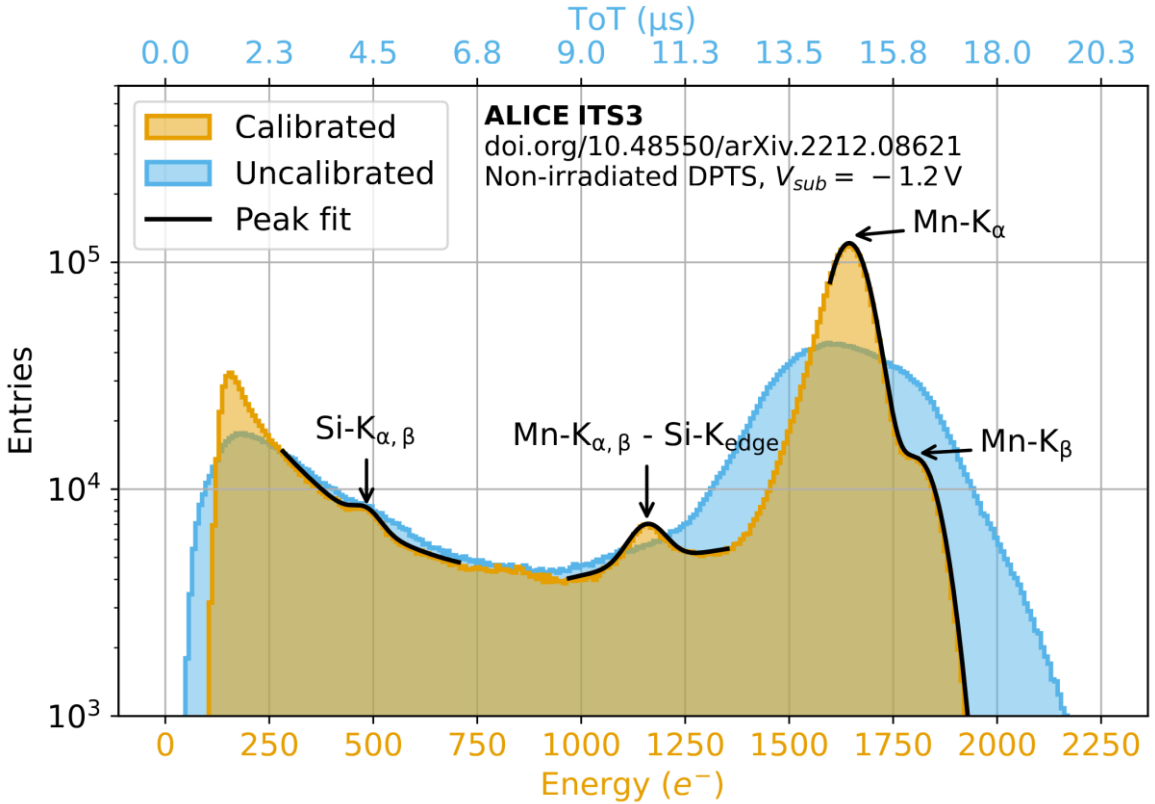
- Time-encoded pixel position
- Measurement of the time over threshold of the analogue signal → quantity correlated to the amplitude of the analogue signal

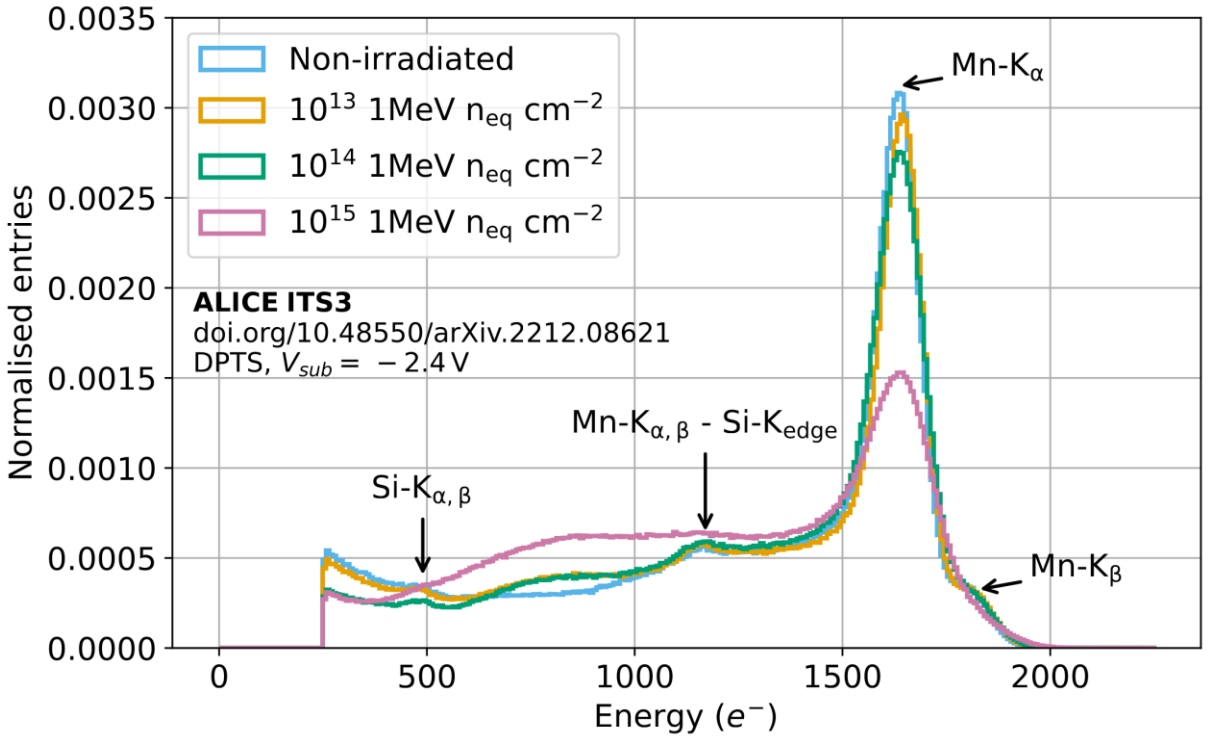


Response to a radioactive source: ^{55}Fe

Excellent energy response throught the ToT:

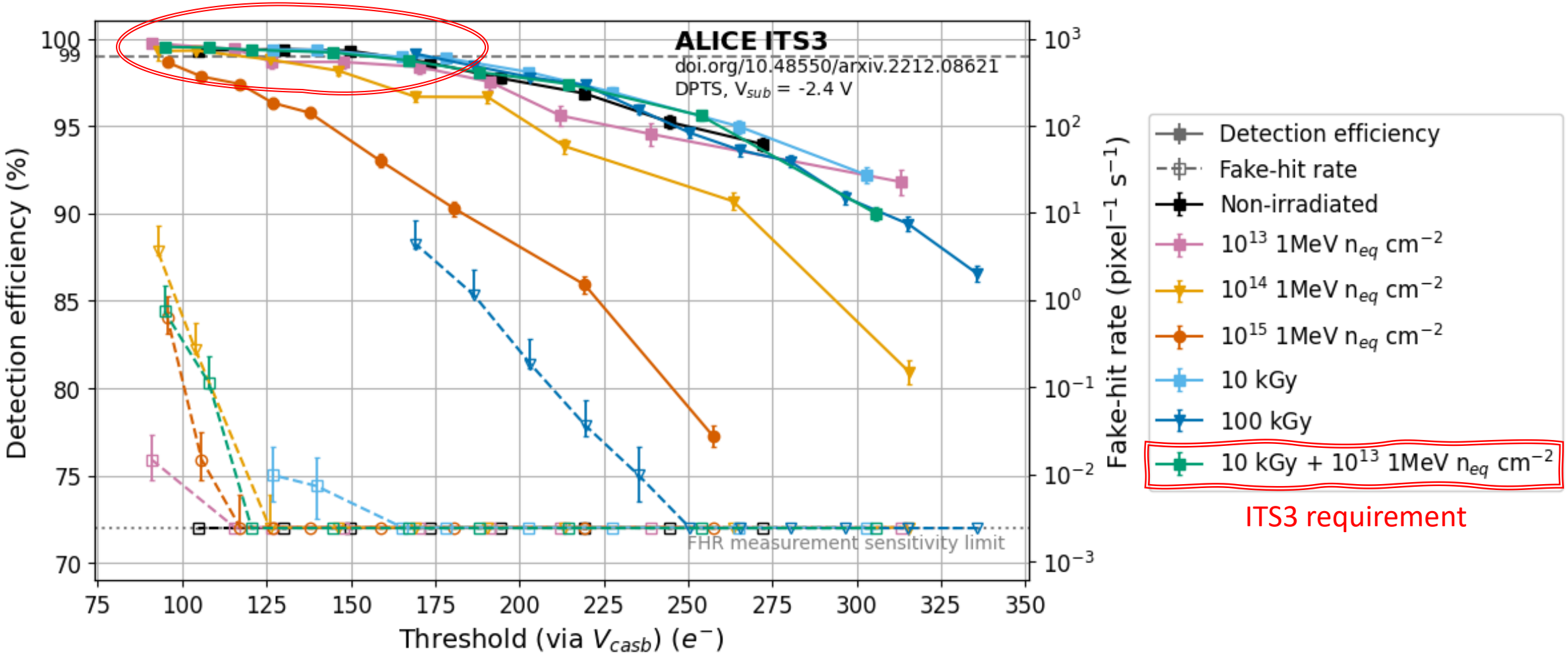
- Resolution of the ^{55}Fe spectrum even after irradiation





Detection efficiency of MIP particles

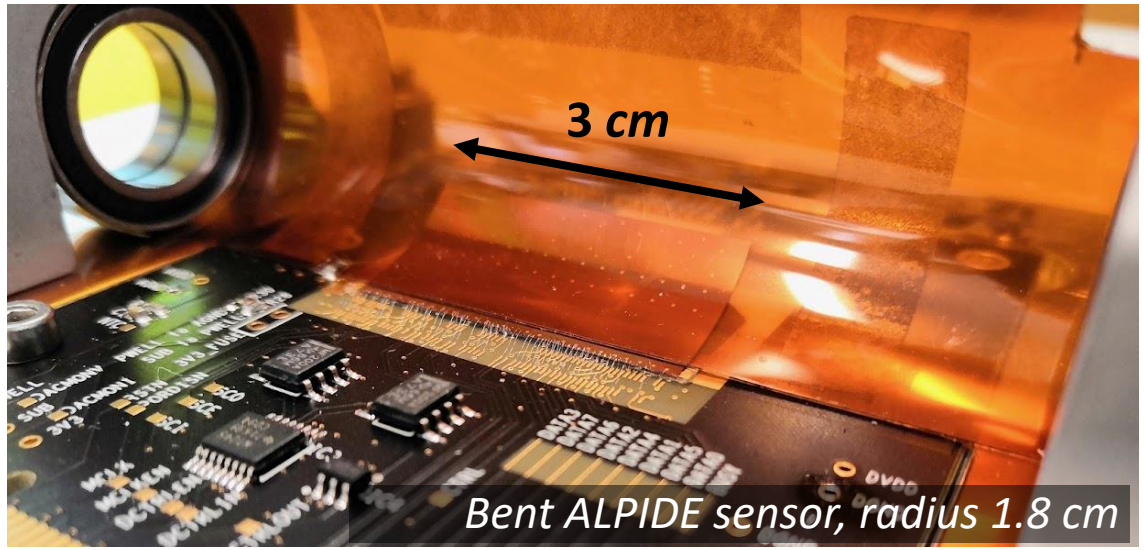
Greater than 99% in a wide range of applied theshold

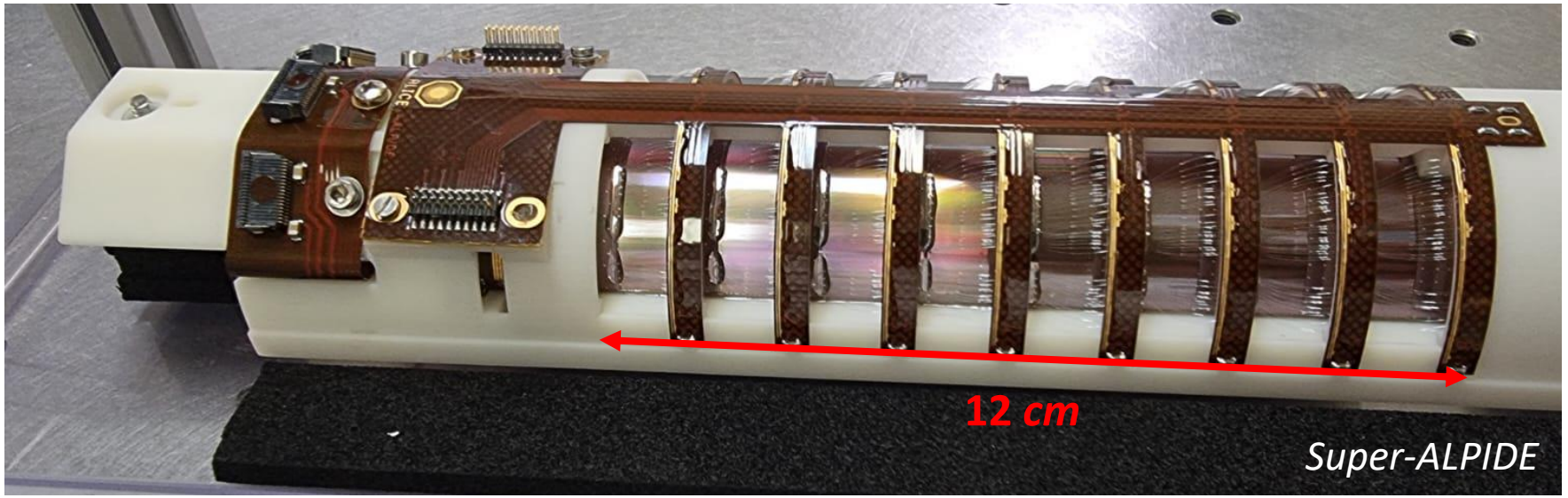


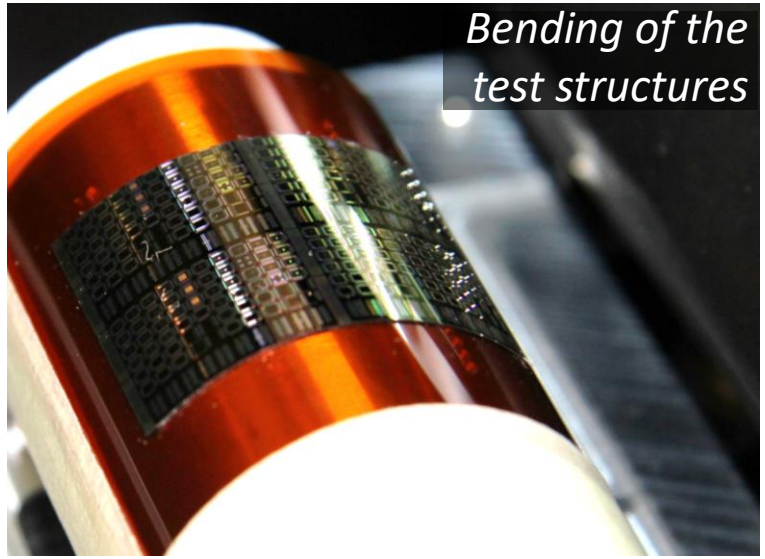
ITS3 requirement

Bending of the MAPS sensors

- **2021**: *"First demonstration of in-beam performance of bent Monolithic Active Pixel Sensors"* [doi:10.1016/j.nima.2021.166280]
- **2022-2023**: Development of a prototype for mechanics and interconnections of a single bent layer
- **2023**: Bending and characterisation of the 65 nm CMOS bent test structures







Conclusions

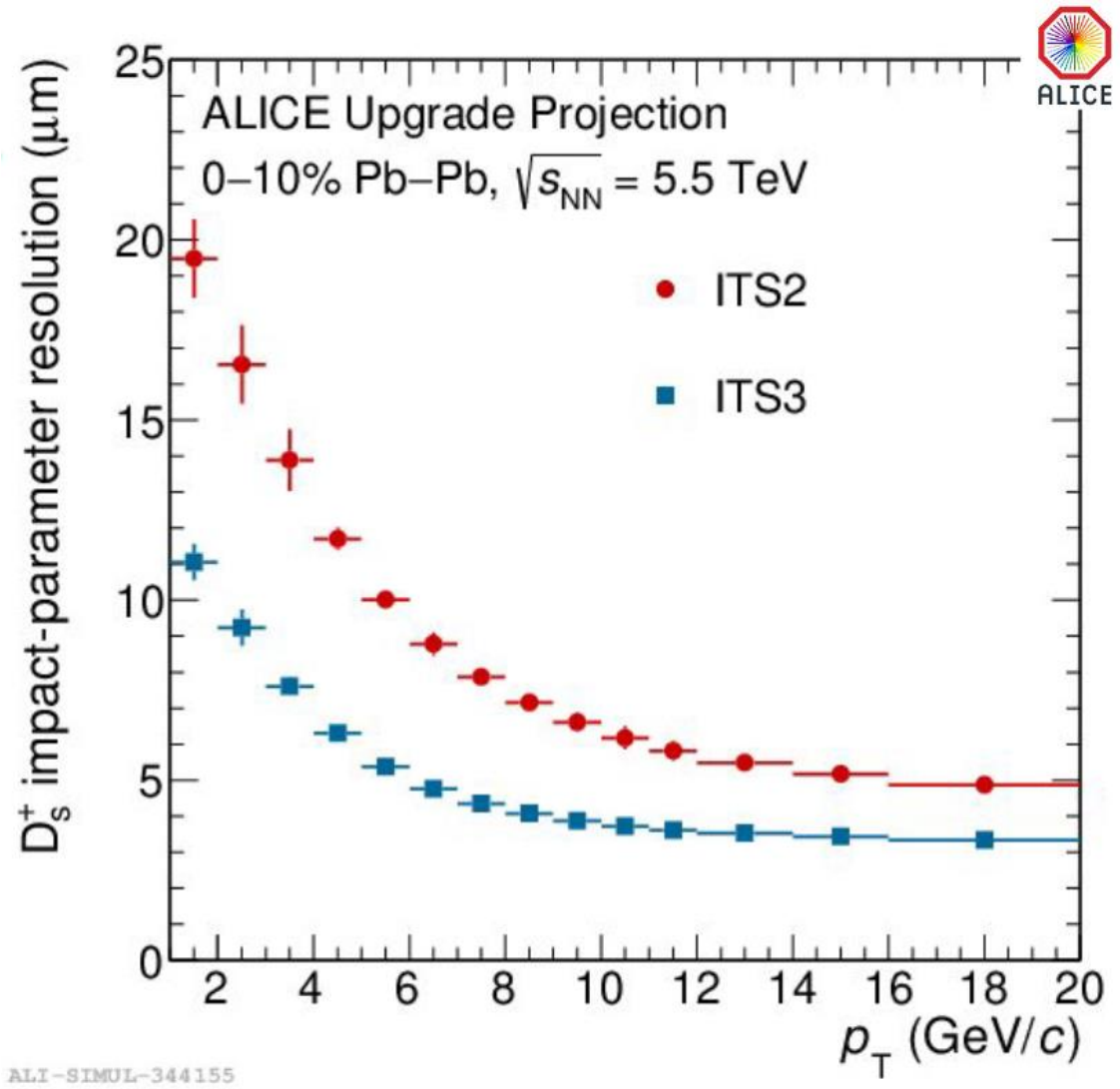
- An **innovative vertex tracker** will be installed in 2026 for the ALICE Experiment. It will be made of large-area, flexible, bent **MAPS detectors**.
- The activities towards ITS3 are going on as scheduled:
  - The **65 nm CMOS process has been validated**
  - The **radiation hardness** for both **TID** (up to 100 kGy) and **NIEL** (up to 10^{14} 1 MeV n_{eq} cm^{-2}) was verified for the first test structures
  - An **excellent response** to X-rays in terms of energetic resolution was obtained
  - **Promising results** have been obtained from the measurements with **bent sensors**
- The **ITS3** technology will be the **starting point** for the development of the new tracker for the future experiment **ALICE3**, proposed for run 5 and 6 of LHC

Thanks!

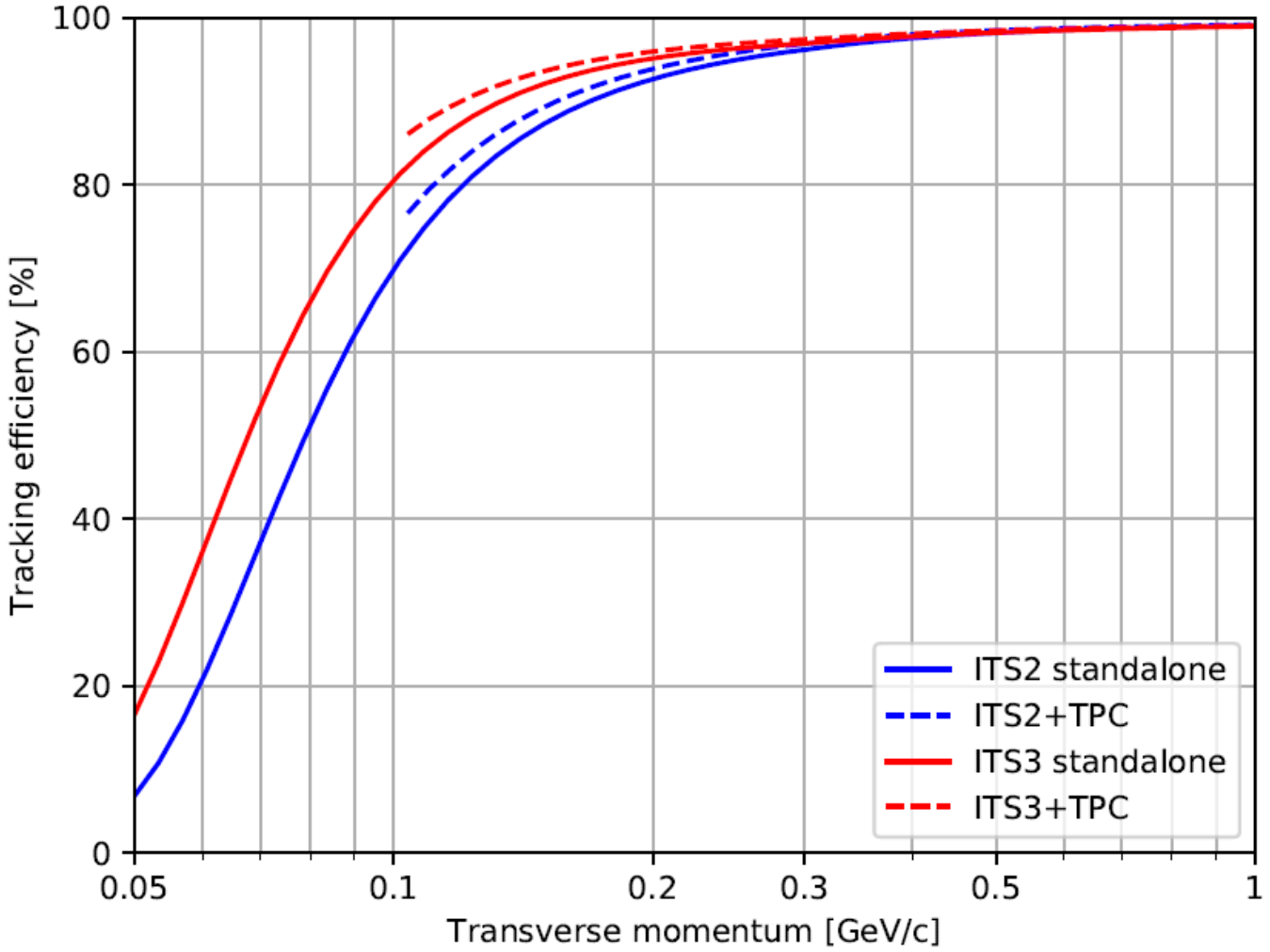
No, thanks to you

Backup

D meson


ALICE
ALICE Upgrade Projection
0–10% Pb–Pb, $\sqrt{s_{NN}}$ = 5.5 TeV
ITS2
ITS3
D_s^+ impact-parameter resolution (μm)
p_T (GeV/c)
0
5
10
15
20
25
2
4
6
8
10
12
14
16
18
20
ALI-SIMUL-344155

Tracking efficiency



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