ALICE ITS3 Test Device Characterisation

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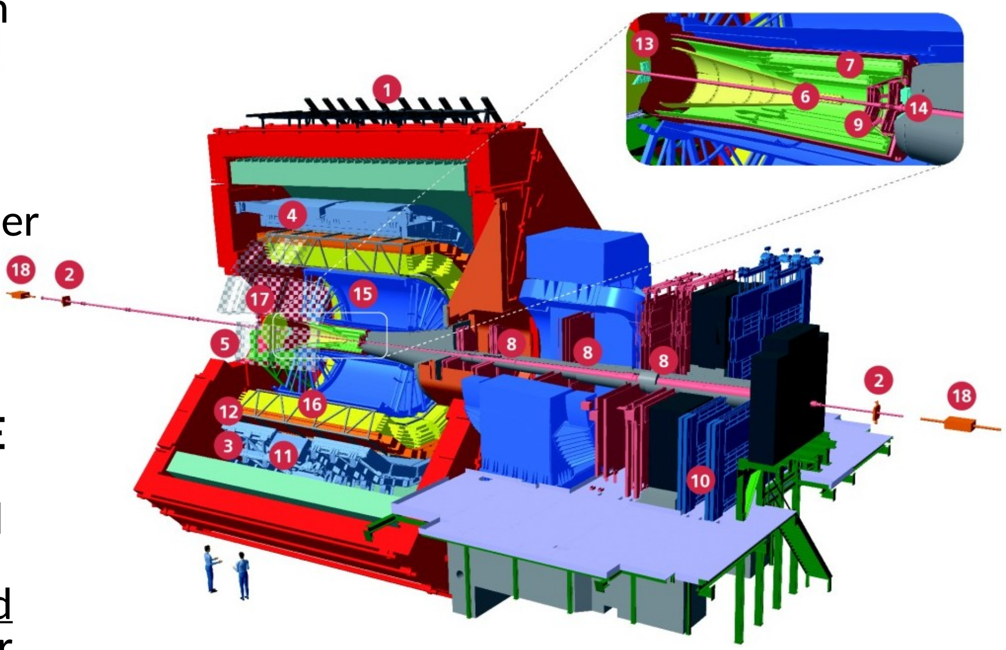
on behalf of the ALICE Collaboration

A first glance at ALICE

Run 3 is ongoing: pp and Pb-Pb up to 13.6 TeV, started in 2022.

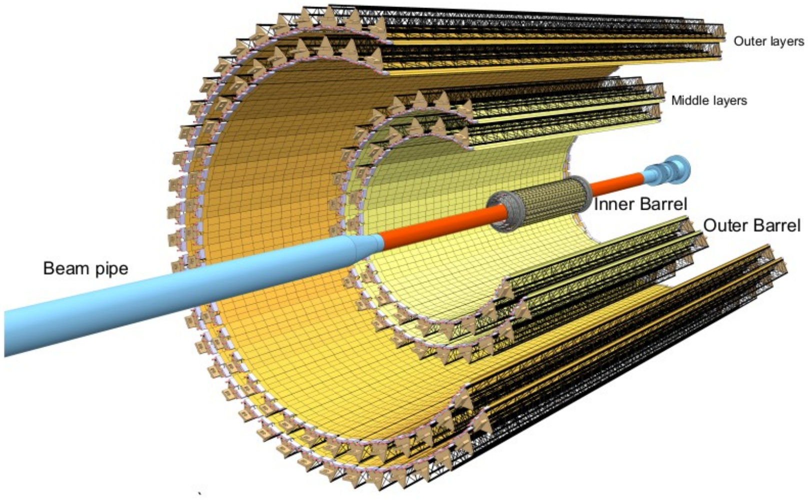
Within ALICE detector, the Inner Tracking System (ITS) and Time Projection Chamber (TPC) contribute to particle track and decay vertex reconstruction.

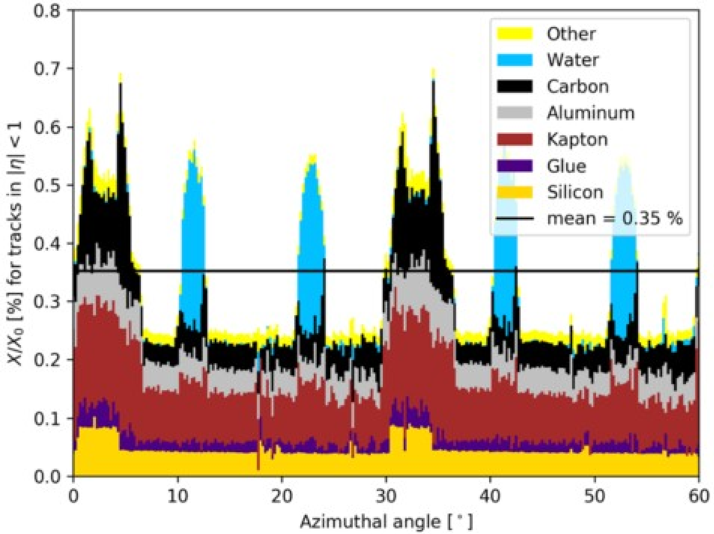
A **first upgrade of the ALICE ITS** from Run 1&2 (ITS1) **to Run 3 (ITS2)** was completed **during LS2 (2019-2022)**: compared to ITS1, <u>improved spatial resolution and higher granularity</u> have been achieved with ITS2.



① **ACORDE** | ALICE Cosmic Rays Detector
② **AD** | ALICE Diffractive Detector
③ **DCal** | Di-jet Calorimeter
④ **EMCal** | Electromagnetic Calorimeter
⑤ **HMPID** | High Momentum Particle Identification Detector
⑥ **ITS-IB** | Inner Tracking System - Inner Barrel
⑦ **ITS-OB** | Inner Tracking System - Outer Barrel
⑧ **MCH** | Muon Tracking Chambers
⑨ **MFT** | Muon Forward Tracker
⑩ **MID** | Muon Identifier
⑪ **PHOS / CPV** | Photon Spectrometer
⑫ **TOF** | Time Of Flight
⑬ **T0+A** | Tzero + A
⑭ **T0+C** | Tzero + C
⑮ **TPC** | Time Projection Chamber
⑯ **TRD** | Transition Radiation Detector
⑰ **V0+** | Vzero + Detector
⑱ **ZDC** | Zero Degree Calorimeter

ALICE ITS2: the state-of-the-art



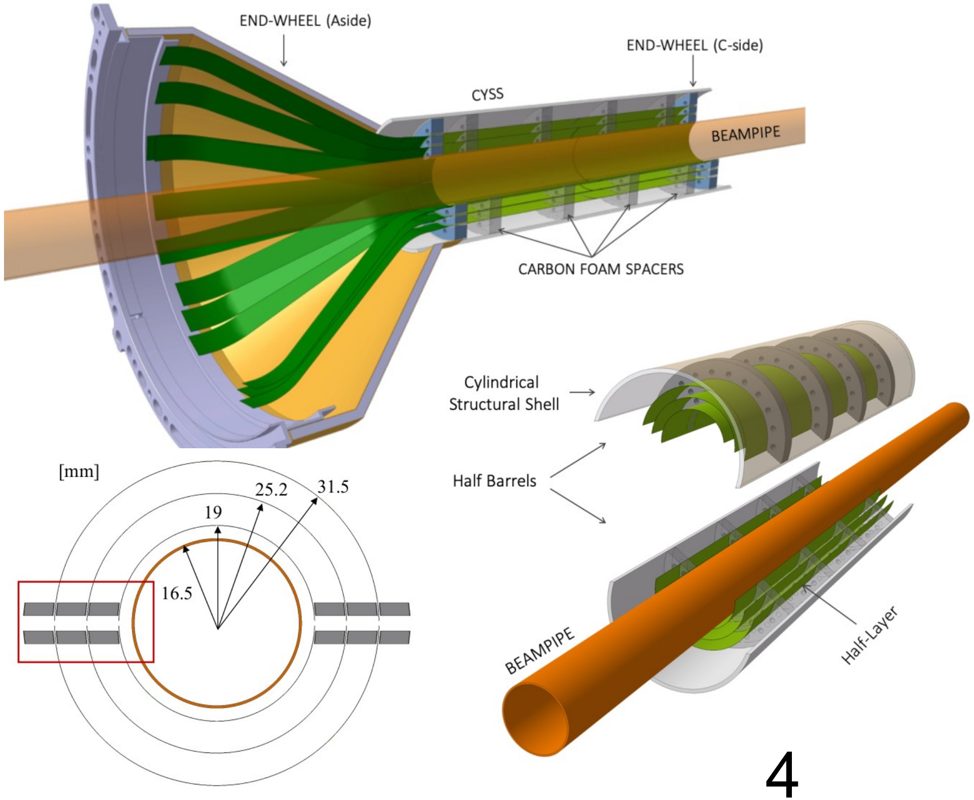


- **7 layers**, that are modular, divided in staves, and built **of ALPIDE MAPS 180 nm**;
- **Innermost 3 layers (Inner Barrel, IB)** had their **material budget reduced to 0.36% X_0 per layer** (*X_0 being one radiation length*), thanks to the integrated readout circuitry;
- However, a significant fraction of ITS2 material budget is still taken by non-silicon components, adding background and inhibiting its tracking performances.

The ALICE ITS3 Project

A **second upgrade to ITS3** is scheduled for **LS3 (expected 2026-2028)**:

- Only the 3 ITS2 IB layers will be replaced, **ITS3 layers will be made of 6 stitched, flexible, truly half-cylyndrical half-layers**;
- **Material budget** will be decreased to an **average** of **0.09% X_0 per layer,** <u>beampipe and layer radii will be smaller than ITS2</u>;
- **TPSCo 65 nm** technology will be employed: **denser circuits**, wafer diameter up to 300 mm.



ITS3 sensor requirements

- **Detection efficiency:** > 99%;
- **Spatial resolution:** ≤ 5 µm;
- **Fake hit rate:** < 0.1 $\text{pixel}^{-1}\,\text{s}^{-1}$;
- **Power dissipation density (active area):** < 40 mW cm^{-2};
- **Radiation load:** 10 kGy TID + 10^{13} 1 MeV $n_{eq}\,\text{cm}^{-2}$ NIEL.

ITS3 sensor characterisation strategy: MLR1

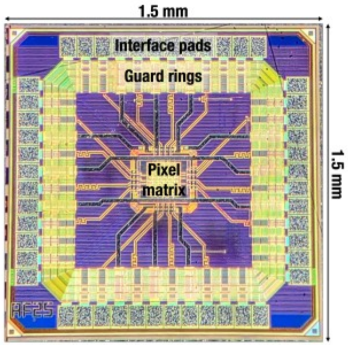
Multi-Layer Reticle 1 (MLR1, 2021):
small test devices (1.5×1.5 mm^2 pixel matrices) for TPSCo 65 nm technology validation

- ***Analog Pixel Test Structures (APTS):***
  → **10-25 µm pixels**, w/o low dose n-type implant (process modification);
  → **analog readout, 4×4 readout matrix** (6×6 total);
  → source-follower (APTS-SF) or opamp (APTS-OA) output buffer.

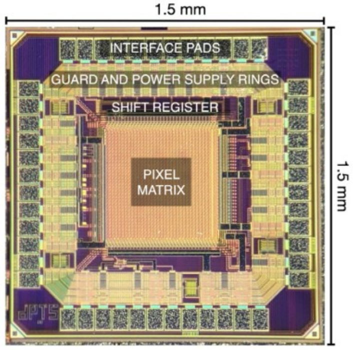
- ***Digital Pixel Test Structures (DPTS):***
  → **32×32 pixel matrix, 15 µm pixel pitch**, modified with gaps;
  → **digital readout**, time-encoded signal amplitude and position.

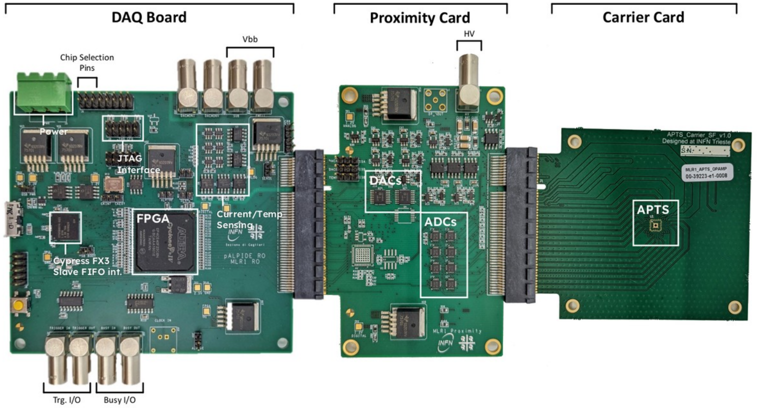
- ***Circuit Exploratoire 65 nm (CE65):***
  → **3 submatrices, rolling shutter readout**;
  → Different output buffers (amplifier and source-follower).

APTS



DPTS



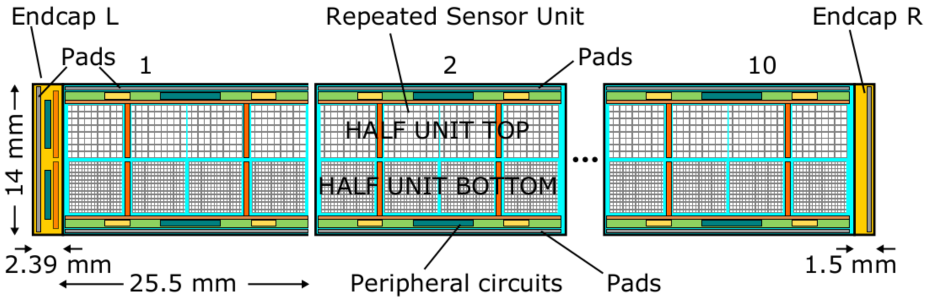


ITS3 sensor characterisation strategy: ER1

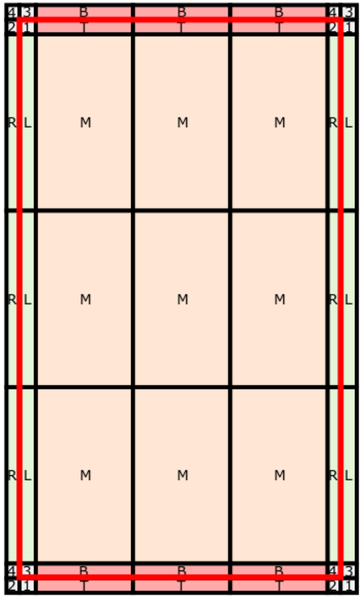
Engineering Run 1 (ER1, 2022):
large-scale stitched sensors for yield and stitching assessment. **By stitching technique, small-scale sensor units can be connected (already at wafer production stage)** into large-scale devices, ready for dicing.

- ***MOnolithic Stitched Sensors (MOSS):***
  → 259×14 mm², **10 independently powered and read-out Repeated Sensor Units (RSU) of 8 pixel matrices each**;
  → Each RSU is **divided in two half-units** (top and bottom) of different pixel pitch (22.5 and 18 μm) and circuit density.

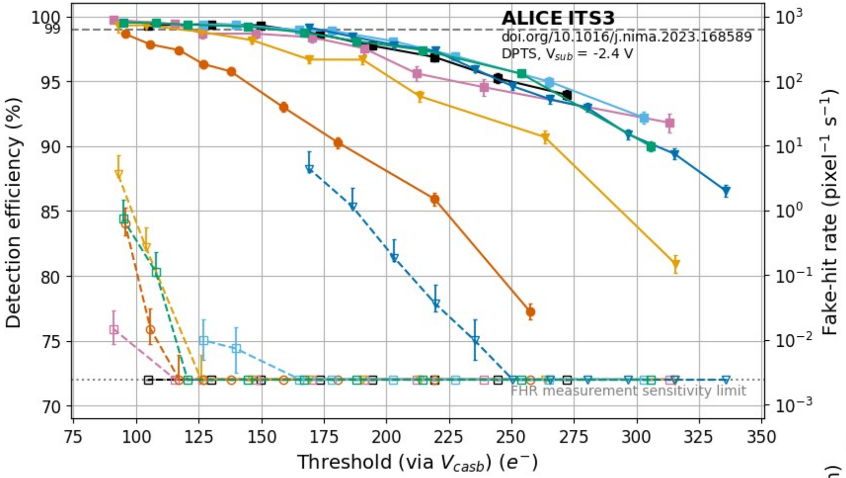
- ***MOnolithic Stiched sensor with Timing prototype (MOST):***
  → 259×2.5 mm², **10 stitched matrices divided in 4 sub-matrices each**;
  → All pixels are read-out by a **shared wafer-scale asynchronous readout**.



MOSS structure (left) and stitched chip pattern (right, letters and numbers refer to sub-units)



Small scale sensor characterisation results

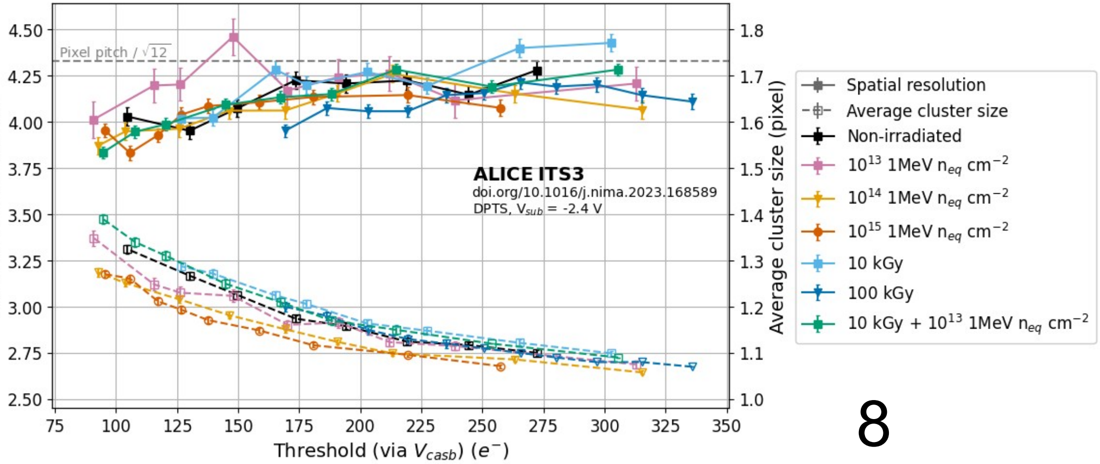


DPTS test beam:

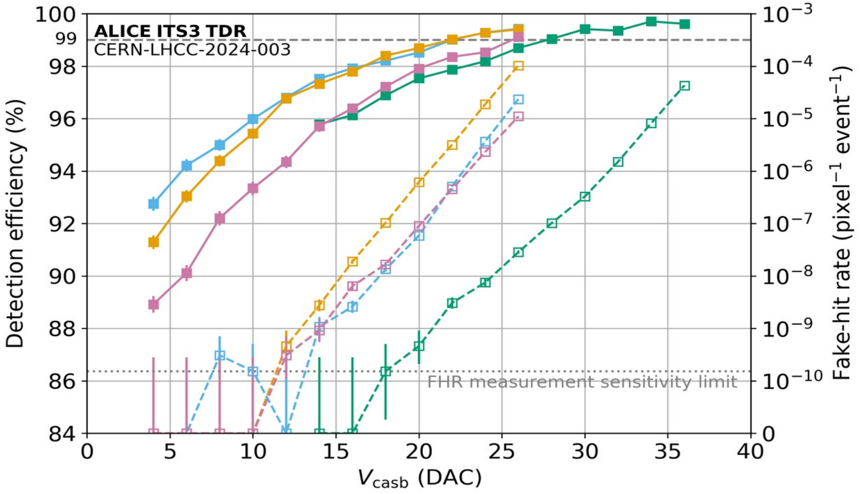
- Efficiency > 99% and FHR well below 0.1 pixel^{-1} s^{-1};
- Spatial resolution < 5 µm;
- Power consumption ~16 mW cm^{-2} (varying bias current).

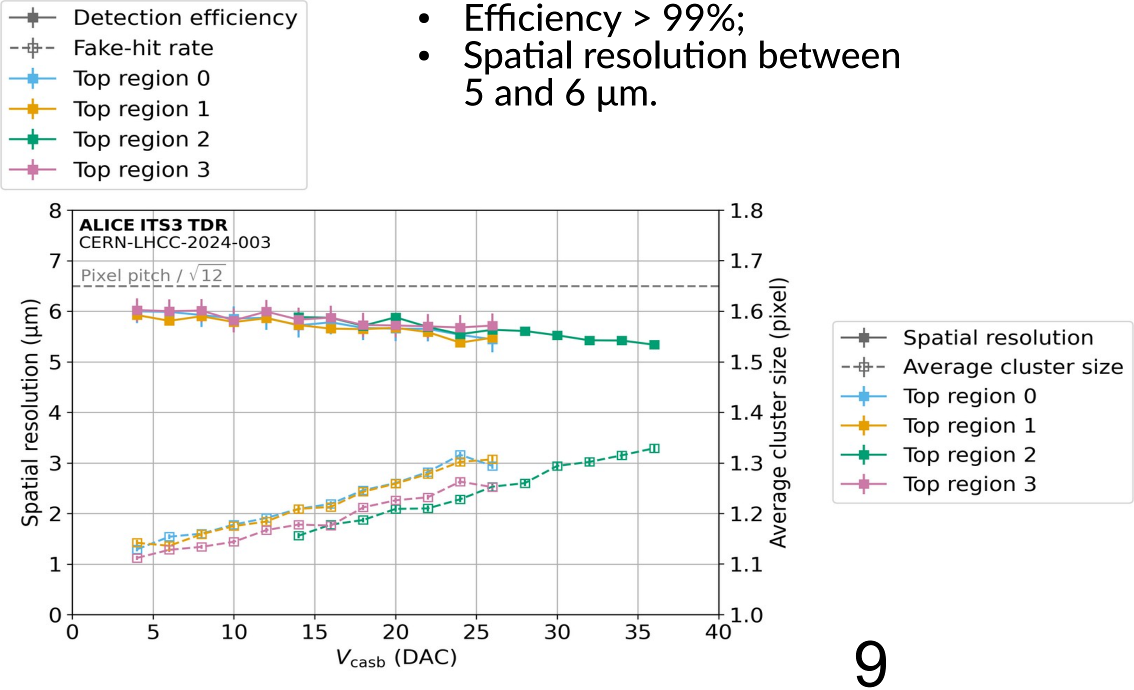
Different levels of irradiation tested:

- High efficiency up to 10^{14} 1 MeV n_{eq} cm^{-2};
- Efficiency and resolution requirements are met at 10 kGy TID + 10^{13} 1 MeV n_{eq} cm^{-2}.



Wafer scale sensor characterisation results





MOSS test beams:

- Efficiency > 99%;
- Spatial resolution between 5 and 6 µm.

Findings from MOSS test beam measurements are mostly **consistent with small scale device results, but with a sensor size of 26 cm, one order of magnitude larger!**

Conclusions

- ITS3 will replace the current 3 ITS2 IB layers with flexible, truly cylindrical, stitched TPSCo 65 nm sensors, leading to a dramatic decrease of material budget (0.09% X_0 per layer);
- Expected improvement in ITS tracking performance, thanks to reduced material budget and smaller L0 radius, but also larger radiation load;
- ITS3 test device characterisation validated the TPSCo 65 nm technology for the second ALICE ITS upgrade, showing a detection efficiency > 99%, spatial resolution ~5 µm or better, up to radiation loads of 10 kGy TID + 10^{13} 1 MeV n_{eq} cm^{-2} NIEL (or even an order of magnitude larger NIEL).

Thank you for your attention!