Characterisation of small scale MLR1 devices for ALICE ITS3

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on behalf of ALICE Collaboration

Eleventh International Workshop on Semiconductor Pixel Detectors for Particles and Imaging
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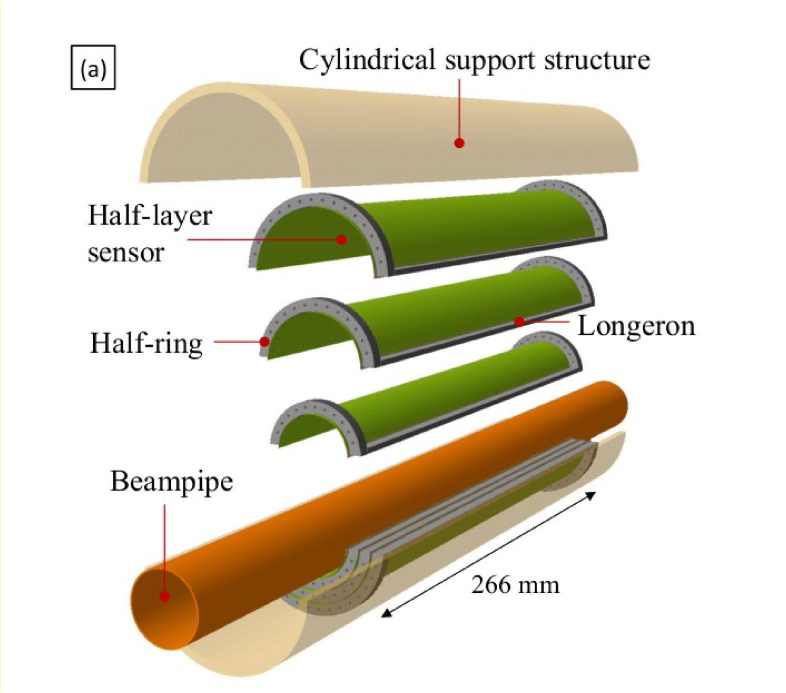
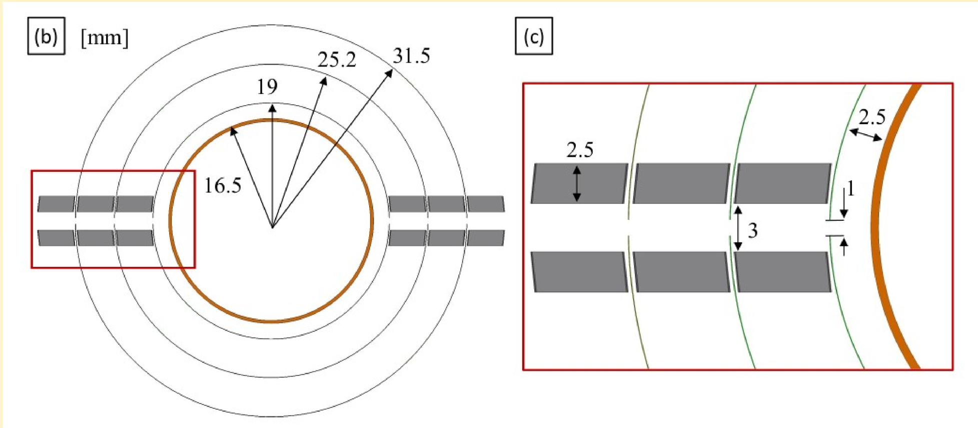


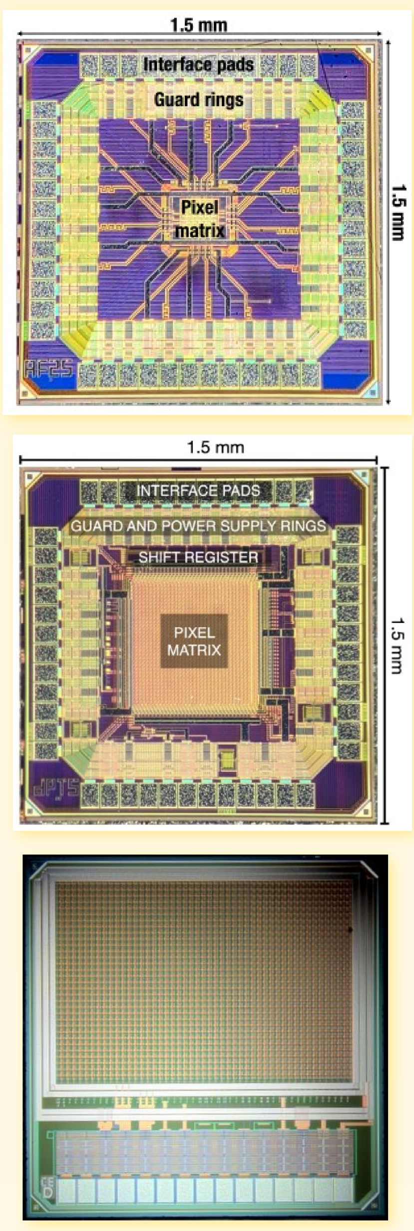
The **Inner Tracking System (ITS)** of ALICE detector, presently consisting of **7 CMOS MAPS** monolithic sensors layers (ALPIDE, i.e. ALICE PIxel DEtector), is scheduled **to be upgraded during Long Shutdown 3 (2026-2028)**. The **3 innermost layers (Inner Barrel or IB)** will be **replaced with 6 flexible and truly cylindrical half-barrels**, that will reduce the **material budget down to an average of 0.09% X₀** per layer, by removing most non-silicon contributions. **ITS3 is expected to reduce systematic uncertainties on heavy-flavored (charmed, beauty), short-lived hadron yields,** such as Λ_c^+ baryon ($c\tau$ = 60.4 μm).

ALICE ITS3:

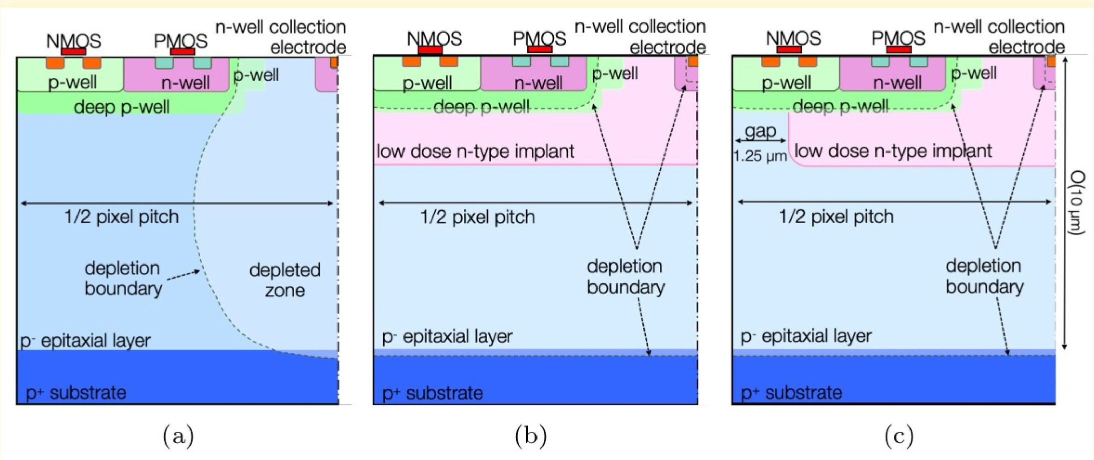
- **26 cm long sensitive area;**
- **Radius: 19 mm (L0), 25.2 (L1), 31.5 (L2);**
- **20 μm×22.5 μm pixel size;**
- **Sensor thickness ≤ 50 μm/layer;**
- **Pseudo-rapidity |η|≤ 2.5 (L0), 2.3 (L1), 2.0 (L2)**



MLR1 test structures



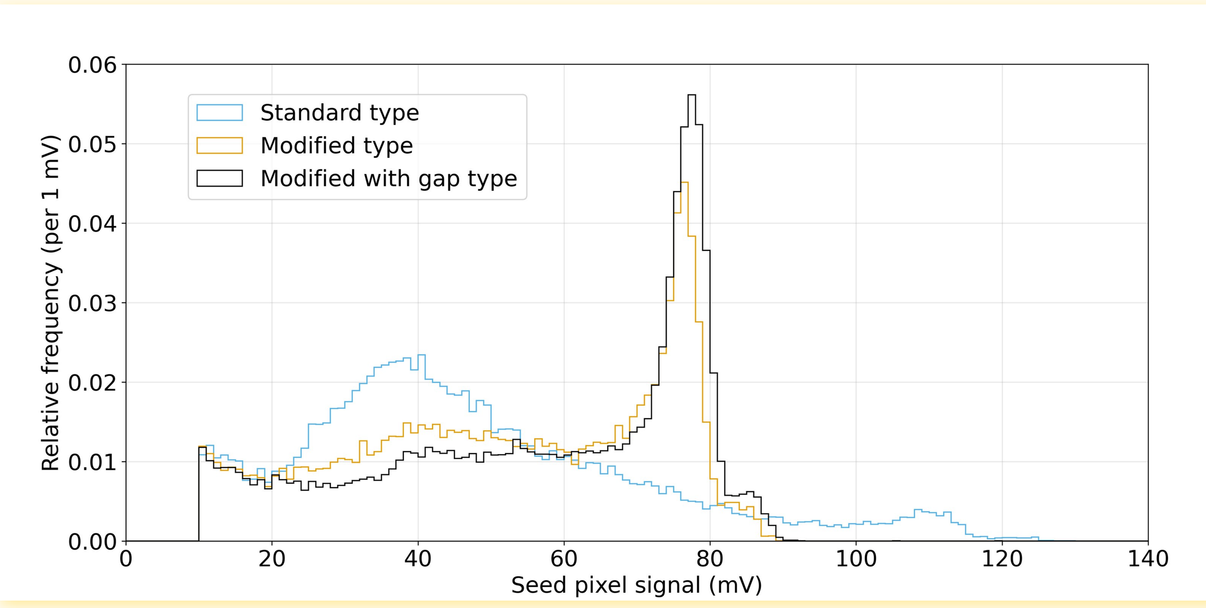
- **APTS** ***(top)*** - Analog Pixel Test Structures
  → 6×6 pixel matrix (4×4 readout matrix): **10-25 μm, standard (a), modified (b), modified with gaps (c)**;
  → Source-Follower **(APTS-SF)** or Operational Amplifier **(APTS-OA)** output buffer;
- **DPTS** ***(center)*** - Digital Pixel Test Structures
  → 32×32 pixel matrix: **15 μm, modified with gaps (c)**;
- **CE65** ***(bottom)*** - Circuit Exploratoire **65** nm
  → 64×32 pixel matrix: **15 μm (3 variants)**;
  → 48×32 pixel matrix: **25 μm (1 variant)**.



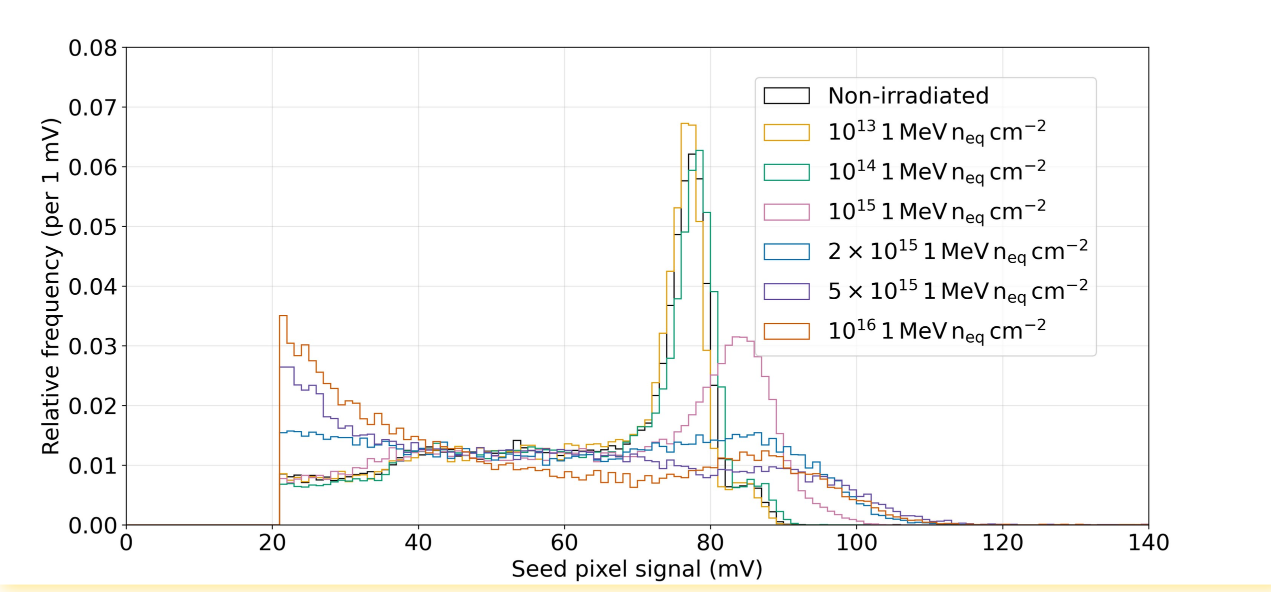
APTS-SF Tests – Laboratory measurements with ⁵⁵Fe source

⁵⁵Fe X-spectra have been acquired with chips of varying design, back-bias voltage, pixel pitch, production process (split), collection diode geometry and irradiation level (NIEL).

- → **⁵⁵Fe-K$_\alpha$ line (5.9 keV = 1640 el.)** is the **reference calibration peak**;
- → **Very small input capacitance C$_{in}$** (no larger than 6 fF);
- → **Good energy resolution,** improving to 6% with increasing back-bias;
- → **Up to ~100% charge collection efficiency** (15 μm modified chips), even at 10^{14} 1 MeV n_{eq}/cm^2 NIEL (10 times larger than ITS3 working conditions);
- → **Small average signal cluster size** (~1.5 pixels for modified chips).

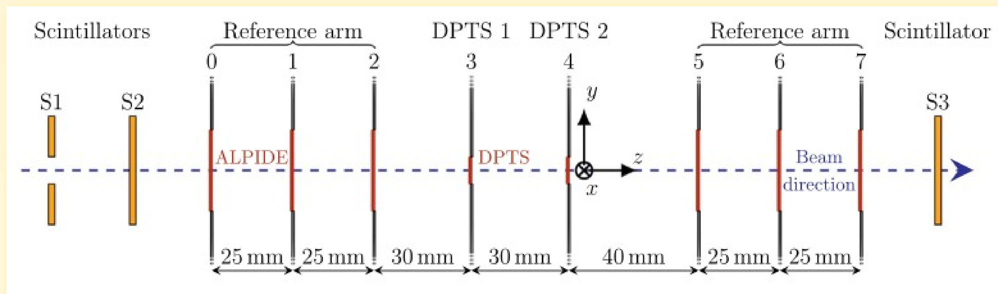


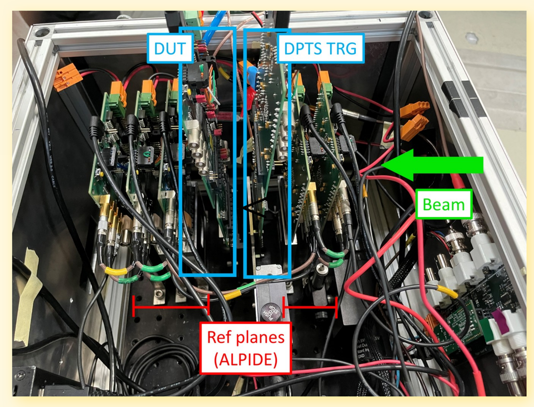
Varying design: comparison of spectra acquired by **standard, modified** and **modified with gap** devices.



Varying NIEL level: no irradiation up to 10^{16} 1 MeV n_{eq}/cm^2 NIEL **(modified with gap, 15 μm)**.

DPTS Testbeam @DESY, July 2022





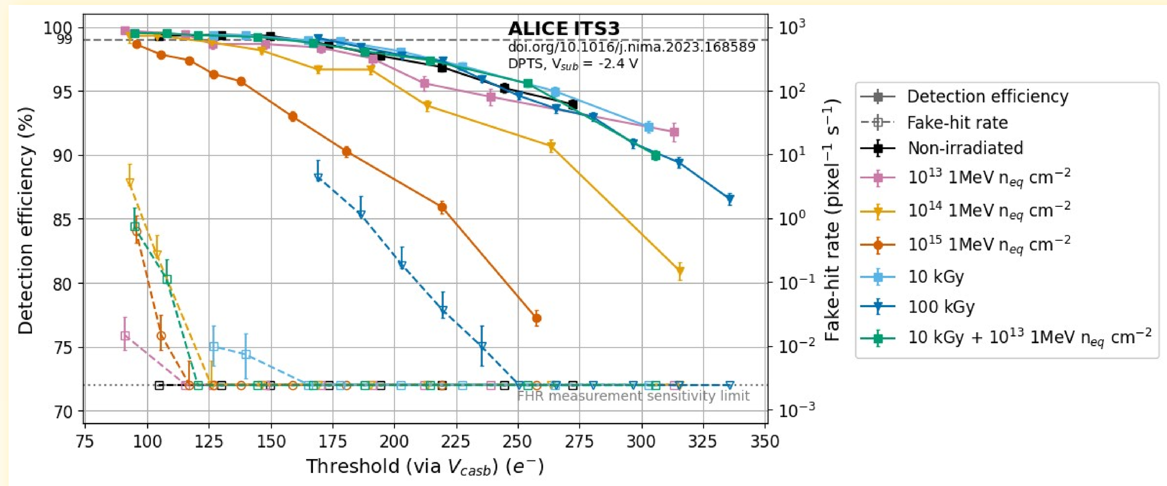
APTS and DPTS – Test beam measurements

Device Under Test **(DUT)**: targeted with **high-momentum charged particle beams**, also after **neutron or X-rays irradiation** (JSI Ljubljana, CERN PS) at different NIEL and TID levels (APTS test beam setup shown above). **Charged particle tracks were reconstructed, together with (if any) signal clusters along them.**

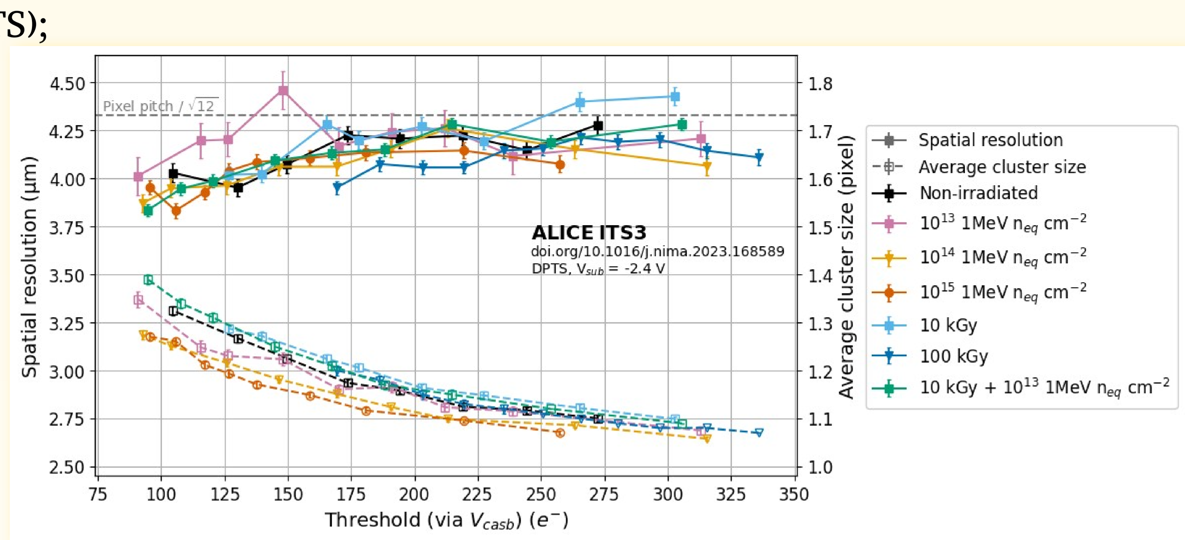
- → **Detection efficiency:** (#tracks with signal cluster)/(#tracks);
- → **Spatial resolution:** standard deviation of track-to-cluster distance on DUT;
- → **Time resolution (APTS-OA):** evaluated from the distribution of time differences between DUT signal and a reference LGAD sensor signal.

Detection efficiency, spatial and timing resolution in test beam measurements

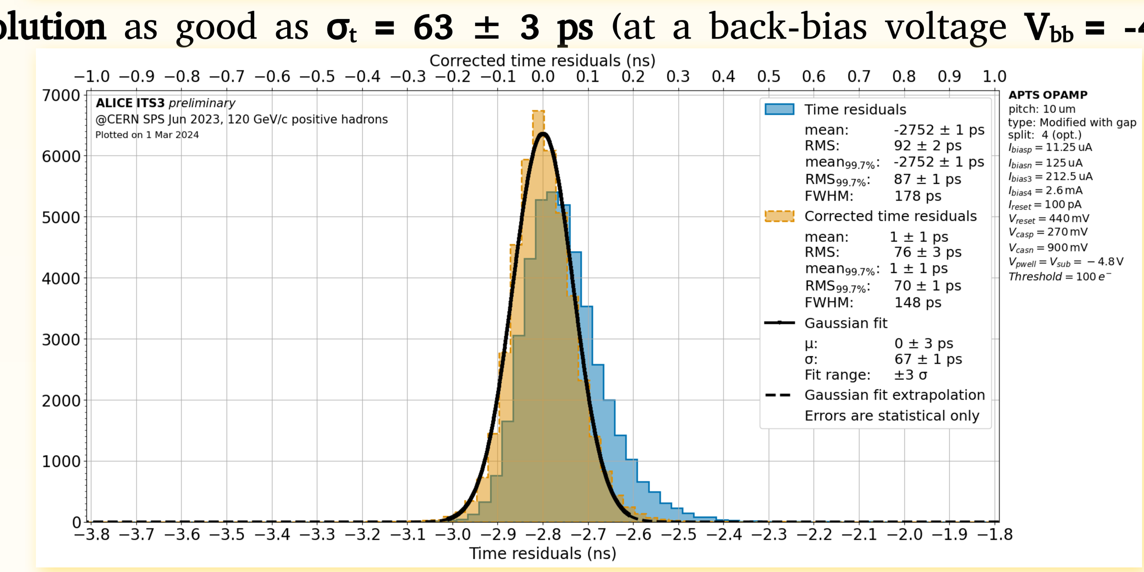
- **Detection efficiency > 99%** in ITS3 working conditions **(10 kGy TID + 10^{13} 1 MeV n_{eq}/cm^2 NIEL), FHR < 0.1 hits pixel⁻¹ s⁻¹** (DPTS);



- **Spatial resolution < 5 μm** for 15 μm (or smaller) pitches **up to ~10^{15} 1 MeV n_{eq}/cm^2** NIEL (DPTS);



- **Time resolution** as good as **σ_t = 63 ± 3 ps** (at a back-bias voltage **V_{bb} = -4.8 V**).



Conclusions

- **Modified with gaps** devices have shown **high charge collection efficiency,** even up to **10^{14} 1 MeV n_{eq}/cm^2 NIEL;**
- **Detection efficiency and spatial resolution tests have surpassed ITS3 expected goals:** 15 μm pixel devices have shown a measured **~99% efficiency** up to **10^{14} 1 MeV n_{eq}/cm^2 NIEL, spatial resolution < 5 μm. Time resolution** was estimated **~63 ps.**

- ***The ALICE Collab.*** **Technical Design Report for the ALICE Inner Tracking System 3 – ITS3. A bent wafer-scale monolithic pixel detector.** CERN-LHCC-2024-003, https://cds.cern.ch/record/2890181
- ***The ALICE Collab.*** **Upgrade of the ALICE Inner Tracking System during LS3: study of physics performance.** https://cds.cern.ch/record/2868015
- ***G. Aglieri Rinella et al.*** **Characterization of analogue Monolithic Active Pixel Sensor test structures implemented in a 65 nm CMOS imaging process.** NIMA 1069 (2024) 169896, DOI:10.1016/j.nima.2024.169896
- ***G. Aglieri Rinella et al.*** **Digital pixel test structures implemented in a 65 nm CMOS process.** NIMA 1056 (2023) 168589, DOI:10.1016/j.nima.2023.168589
- ***G. Aglieri Rinella et al.*** **Time performance of Analog Pixel Test Structures with in-chip operational amplifier implemented in 65 nm CMOS imaging process.** Submitted to NIMA, DOI:10.48550/arXiv.2407.18528