Testbeam performance results of bent ALPIDE Monolithic Active Pixel Sensors in view of the ALICE Inner Tracking System 3

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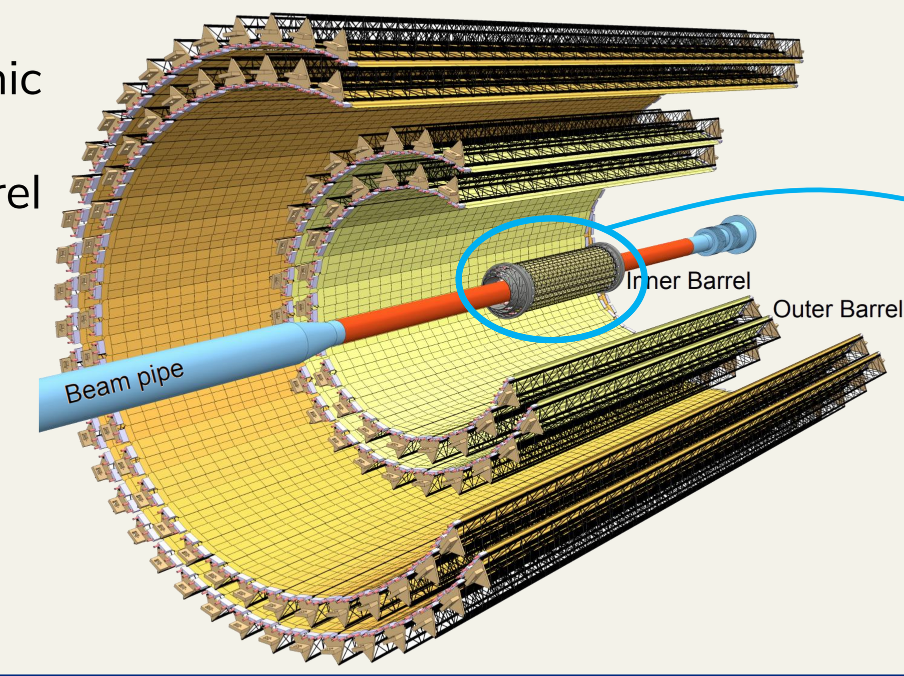
Paving the way towards the golden age of massless detectors

The ALICE experiment at CERN is planning the construction of a novel ultra-light vertex detector during the next LHC LS3 (2025-2027). The new design features highly-integrated ultra-thin (20-40μm) curved sensors, held in place by spacers made of open-cell carbon foam, inserted between layers to define their relative radial position. First encouraging results with bent monolithic pixel sensors show that the chips remain unaffected by the bending in terms of detection efficiency and spatial resolution.

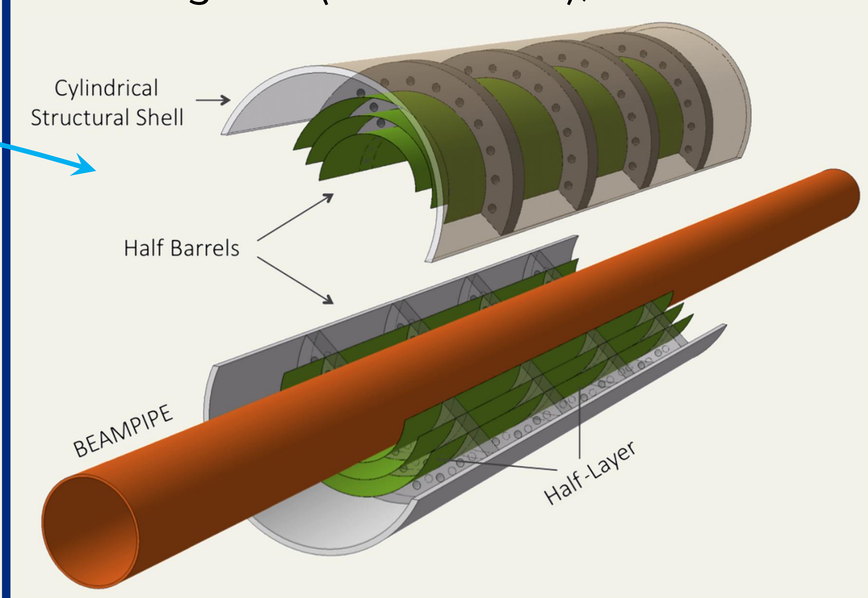
ALICE ITS2

- New tracker entirely based on Monolithic Active Pixel Sensors (MAPS) [1]
- 3 layer Inner Barrel + 4 layer Outer Barrel → 12.5 Gigapixel active area detector
- Custom sensor design → **ALPIDE**
- Low power consumption (40 mW/cm^2)
- Excellent detection efficiency (≫99%)
- Spatial resolution ~5 μm
- Fake-hit rate ≪ 10^{-6} per pixel per event



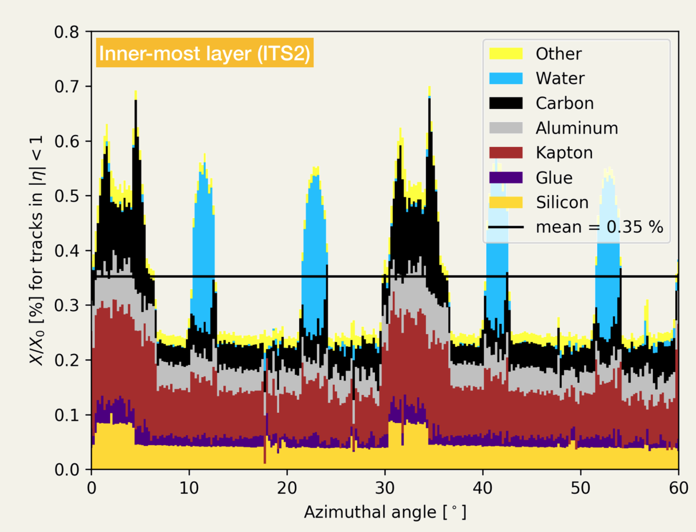
ALICE ITS3

- During LS3 (2025-2027), the Inner Barrel of ITS2 will be replaced → ITS3 project [2,3]



Beam pipe inner/outer radius (mm)	16 / 16.5		
Layer parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18	24	30
Length of active area (mm)	300		
Pixel sensor dimension (mm^2)	280 × 56.5	280 × 75.5	280 × 94.0
Sensors per layer	2		
Pixel size (μm^2)	$\mathcal{O}(10 \times 10)$		

ITS2 Inner Barrel
432 ALPIDE sensors + services



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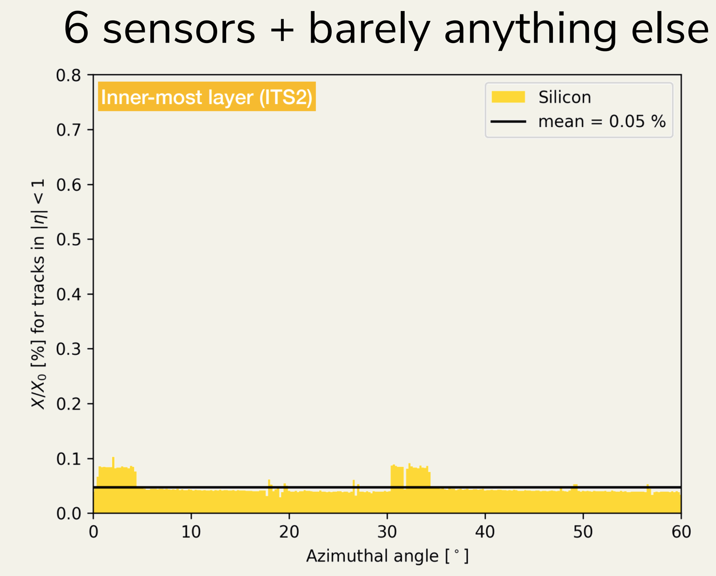
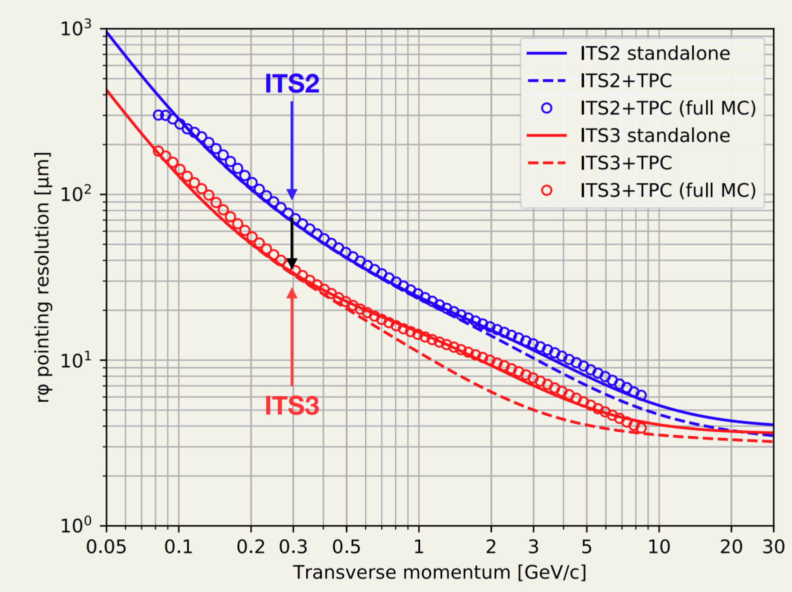
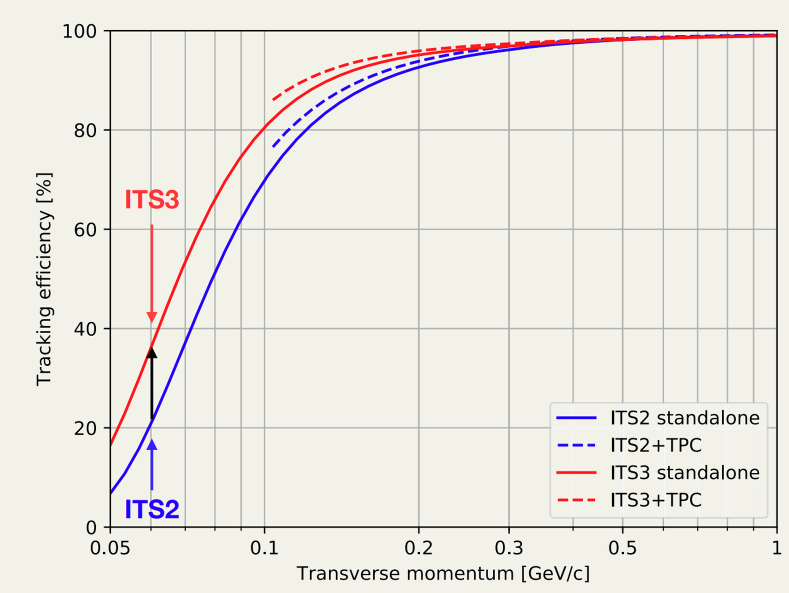
ITS3 Inner Barrel
6 sensors + barely anything else



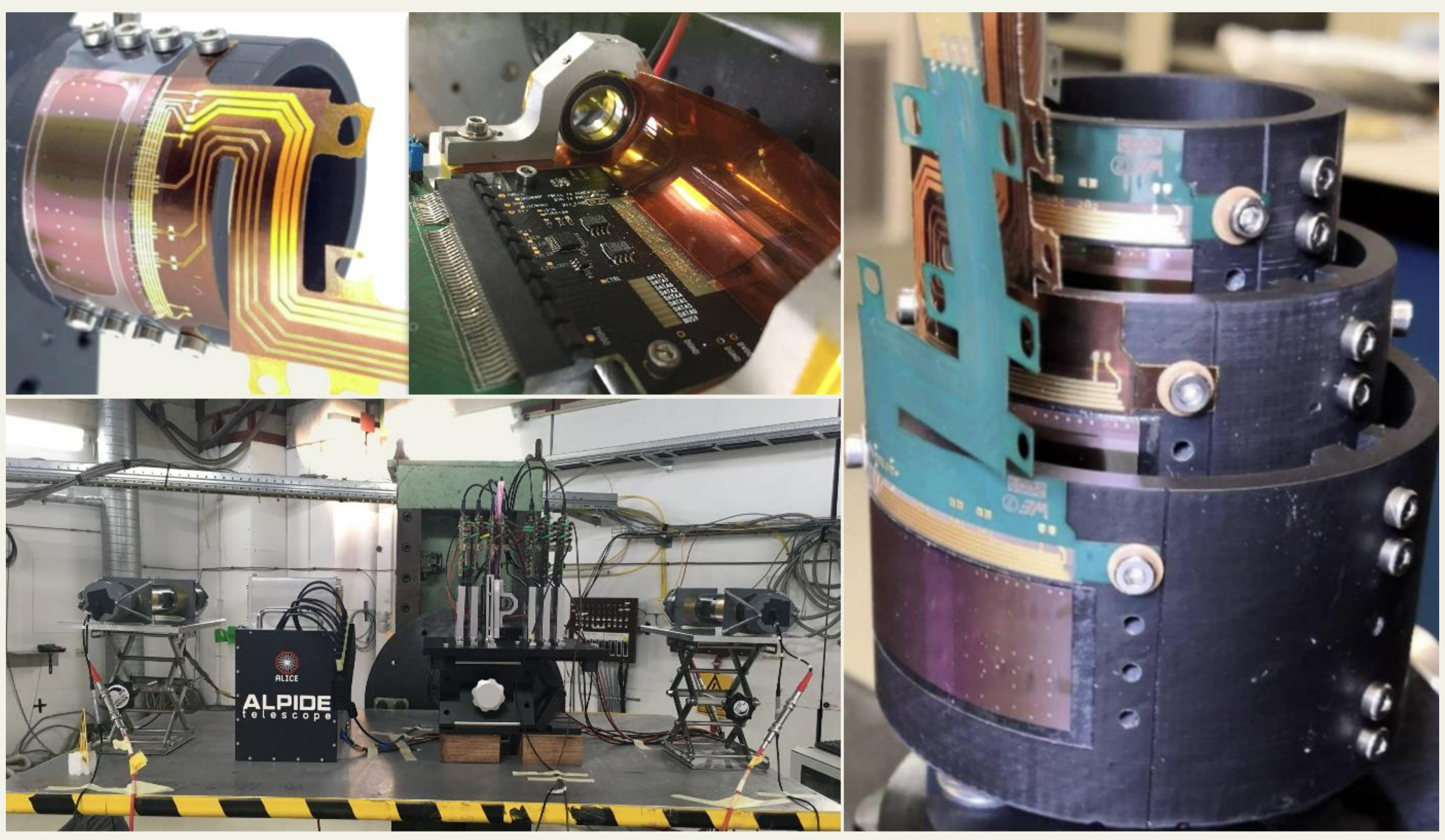


Significant improvement of tracking precision and efficiency at low momenta



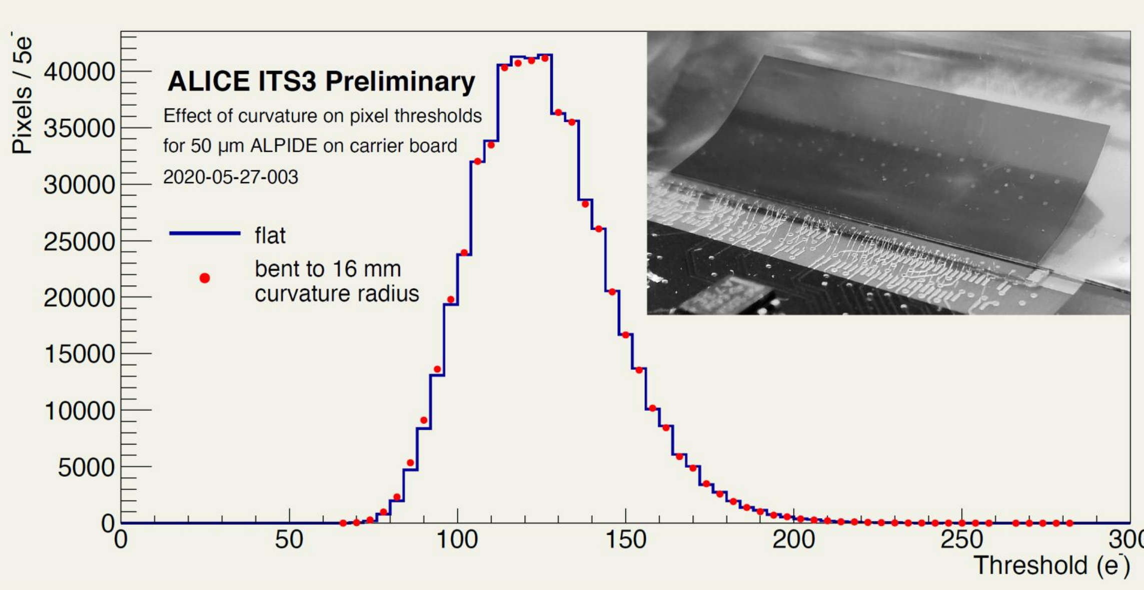
Assessing the performance of ALPIDE sensors at testbeams

Longitudinally bent — Laterally bent — Multiple planes (μITS3)

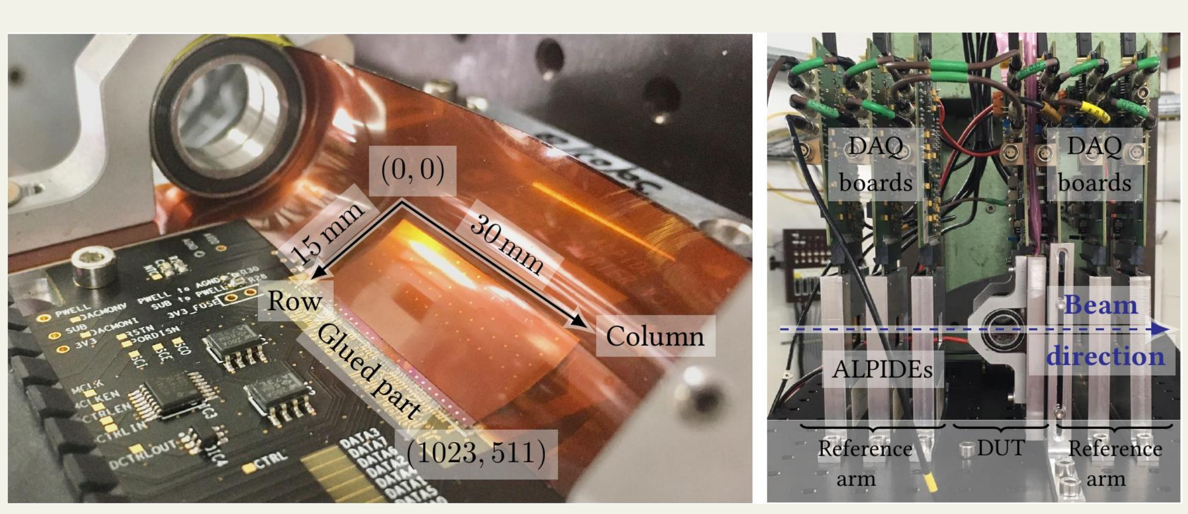


Testbeams with bent ALPIDE sensors

Curved ALPIDE testing

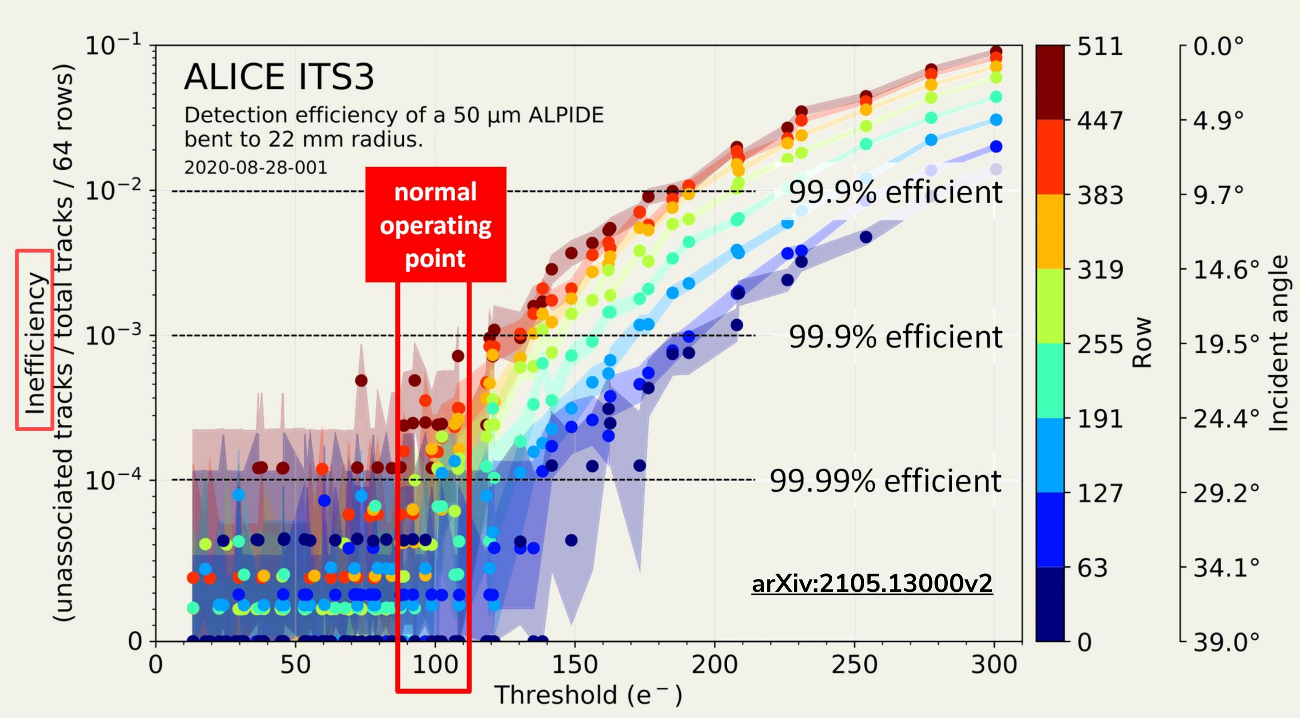


- 50 μm-thin ALPIDE bent along long/short direction
- Radii down to 18 mm successfully achieved
- Electrical performance remains unchanged



Tracking performance

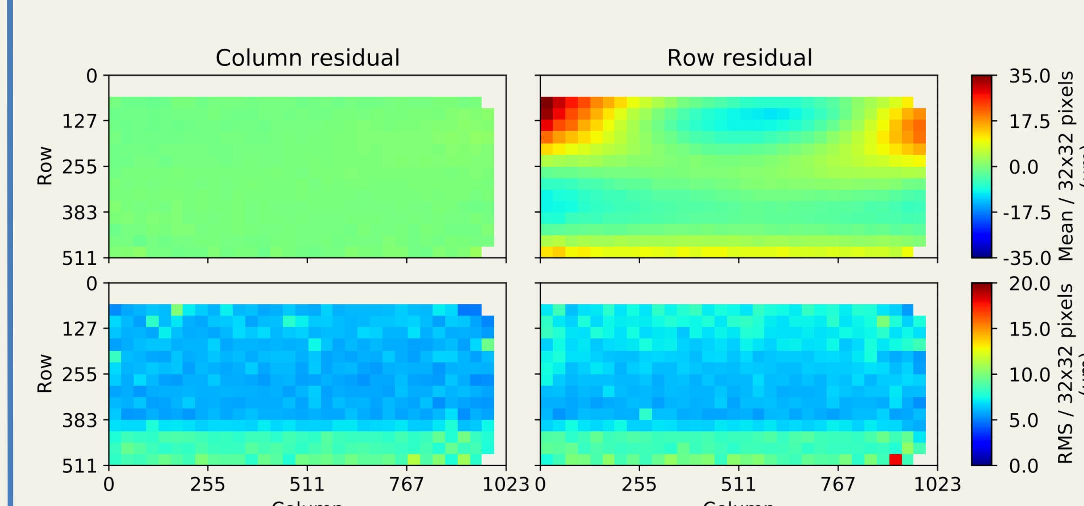
- Shape of bent chip approximated by a purely cylindrical segment (curvature measured through metrological surveys)
- Shown below: inefficiency as a function of threshold for different rows and incident angles on a semi-logarithmic plot



- Efficiency above 99.9% at a threshold of 100 e⁻ (normal operating point of ALPIDE) [4]
- The efficiency increases with larger beam incident angles (decreasing sensor row number) → charge sharing

Spatial resolution

- Shown below: Mean and RMS of the residuals in the column and row directions
- A systematic effect of magnitude up to 35 μm can be observed in the row residual mean (prominent in the unattached corners of the DUT and along the edge glued to the PCB)
- RMS of both residuals for row > 400 increases, compatible with the position of the carrier card → increase of multiple scattering
- Increase of the row residual RMS with decreasing row number → trend compatible with a cluster size increase at larger incident angles



Conclusion and Outlook

- Feasibility of bent MAPS demonstrated for the first time
- 50 μm-thick ALPIDE chips show no sign of deterioration during operation; detection efficiencies exceed 99.9%
- Important milestone in the R&D for ALICE ITS3 → new class of detectors with ideal geometries at reach

Acknowledgements

- The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)
- The data has been analyzed using the Corryvreckan framework D. Dannheim et al., J. Instr. 16 **P03008** (2021)
- I acknowledge support by the HighRR research training group [GRK 2058]

References

[1] The ALICE Collaboration: ***Technical Design Report for the Upgrade of the ALICE Inner Tracking System***, J. Phys. **G 41** 1-181(2014)
[2] The ALICE Collaboration, **Letter of Intent for an ALICE ITS Upgrade in LS3**, Tech. Rep. CERN-LHCC-2019-018. LHCC-I-034, CERN, Geneva (2019)
[3] D. Colella, **ALICE ITS3 the first truly cylindrical inner tracker**, PSD12
[4] ALICE ITS project: **First demonstration of in-beam performance of bent Monolithic Active Pixel Sensors,** Nucl. Instrum. Meth. A 1028 (2022)