High-D Consortium Meeting, 02.09.2022

Detection efficiency and spatial resolution of Monolithic Active Pixel Sensors bent to different radii measured with a 5.4 GeV electron beam

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ALICE detector - what the future entails

➢ ITS2 (installed in ALICE)

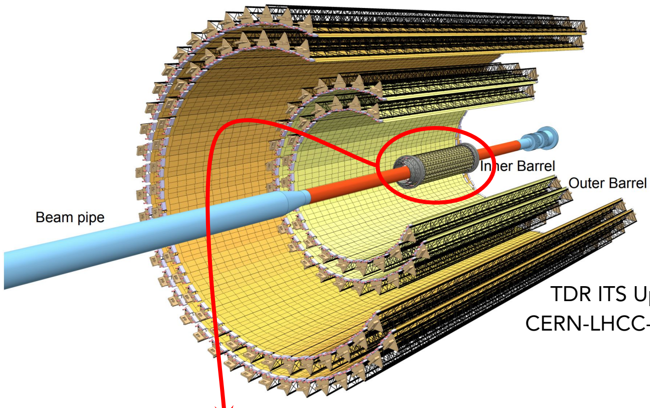
- Entirely MAPS based detector design
- Seven layers of ALPIDE sensors

➢ ITS3 (LHC LS3, 2026-2028)

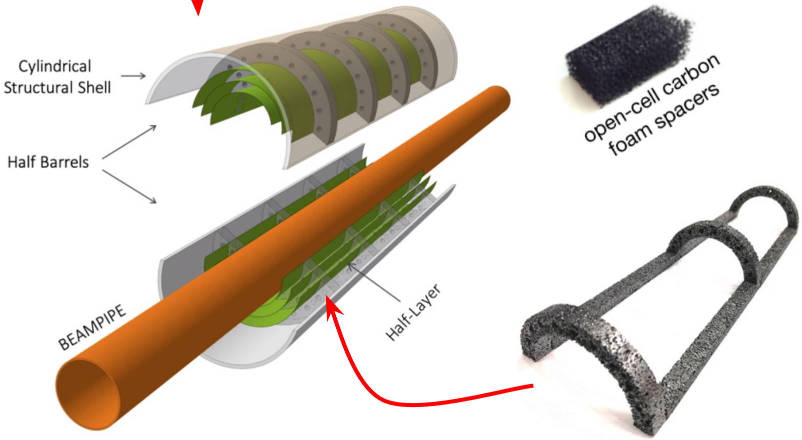
- Replaces the 3 inner layers of the ITS2
- Ultra light, wafer-scale, curved sensors in 65nm

➢ 3 fields of R&D pursued

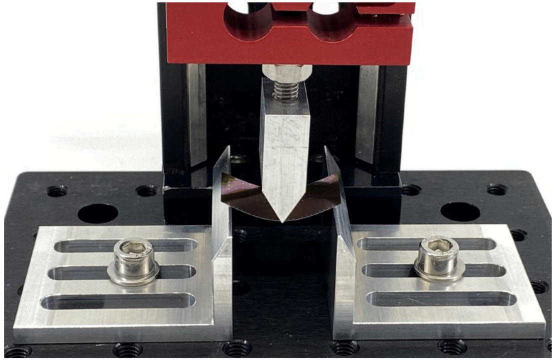
- 65 nm technology node (P. Becht)
  → testbeam results, irradiated sensors
- Wafer scale sensors
  → mechanics, wafer-scale “super-ALPIDE”
- Thin, bent sensors (this talk)
  → mechanical flexibility, testbeam results



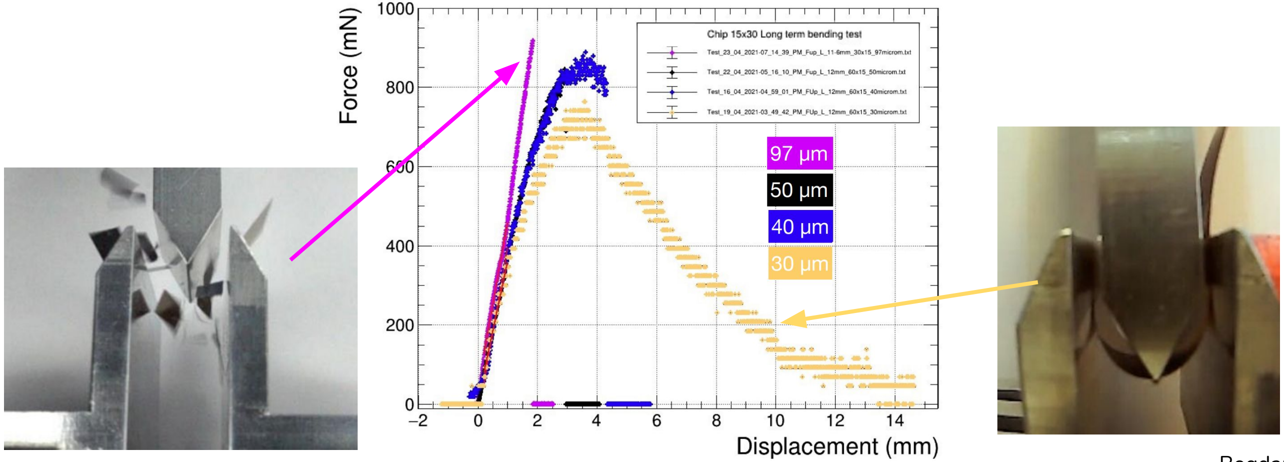
TDR ITS Upgrade
CERN-LHCC-2013-024



Silicon is flexible!

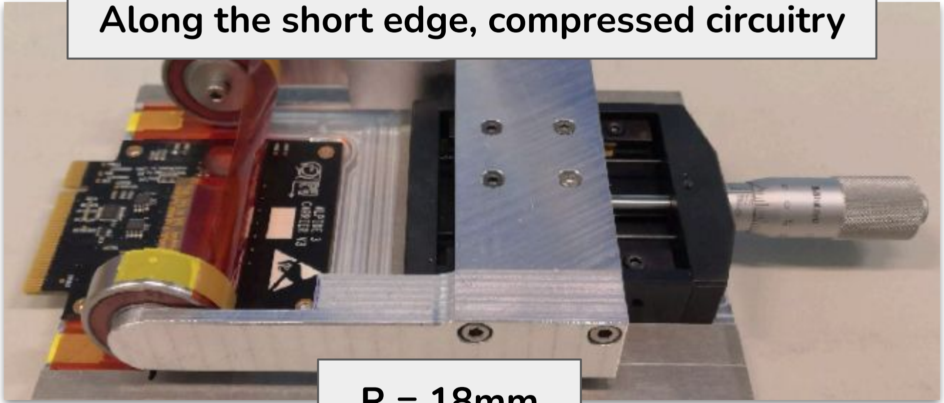


- ➢ Monolithic pixel sensors, at thicknesses used in current experiments, are already quite flexible
- ➢ Bending force scales as (thickness)$^{-3}$
  → large benefit from thinner sensors
- ➢ Target values for thickness (20–40µm) and bending radii (down to 18mm) are feasible

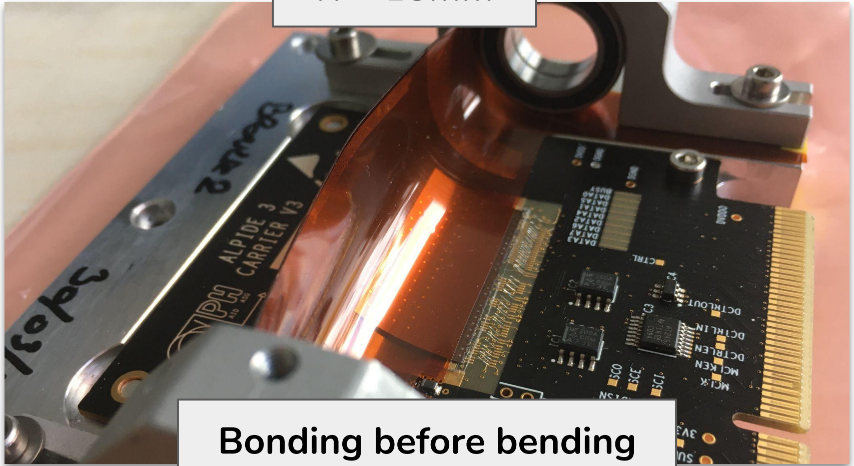


Bending ALPIDEs

Along the short edge, compressed circuitry

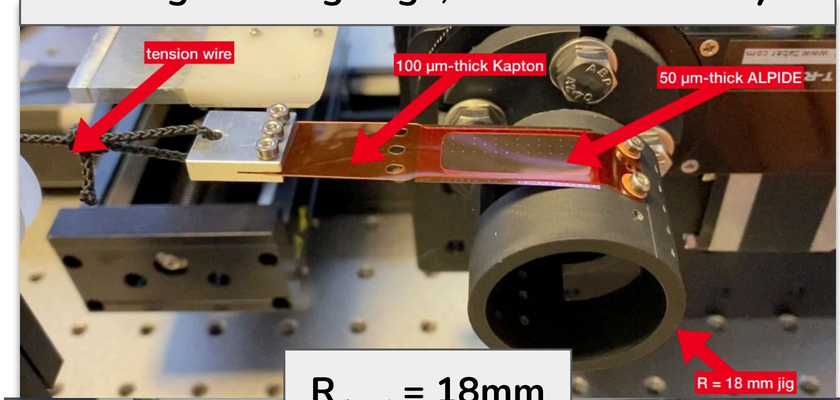


R = 18mm

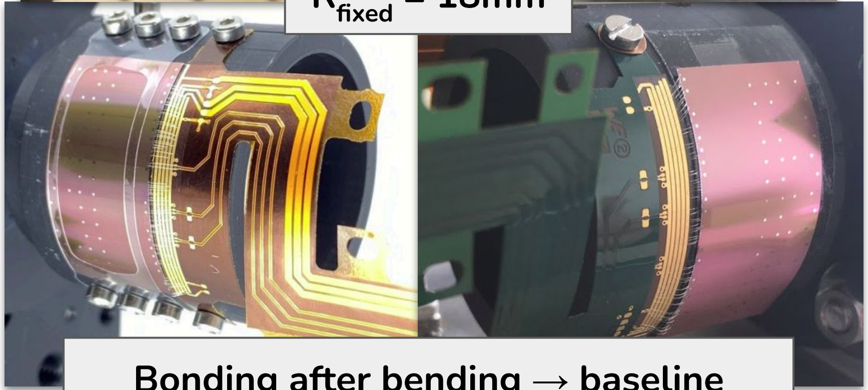


Bonding before bending

Along the long edge, stretched circuitry

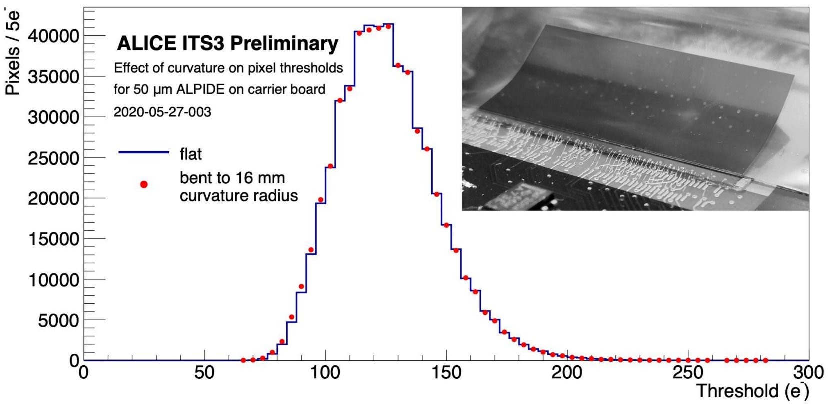


R_{fixed} = 18mm

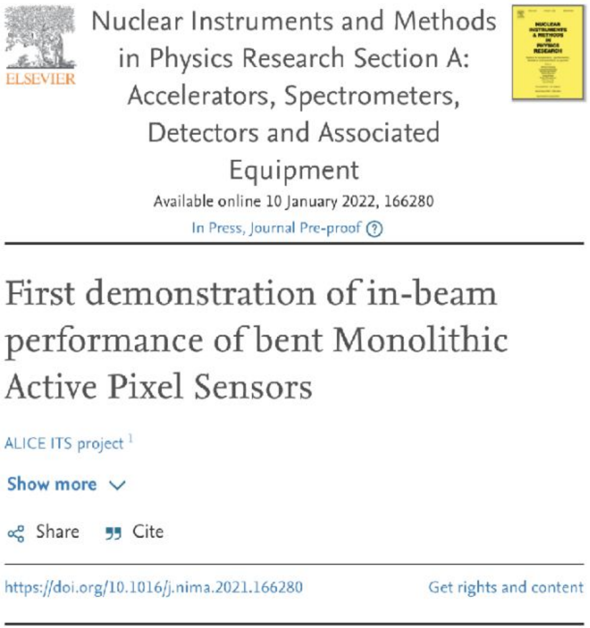


Bonding after bending → baseline

Bending ALPIDEs – electrical characterization



- ➢ Electrical performance of the chip is unchanged with respect to the flat state
- ➢ Threshold and noise levels unaffected
- ➢ No variation in the number of dead pixels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Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Available online 10 January 2022, 166280

In Press, Journal Pre-proof

First demonstration of in-beam performance of bent Monolithic Active Pixel Sensors

ALICE ITS project [1]

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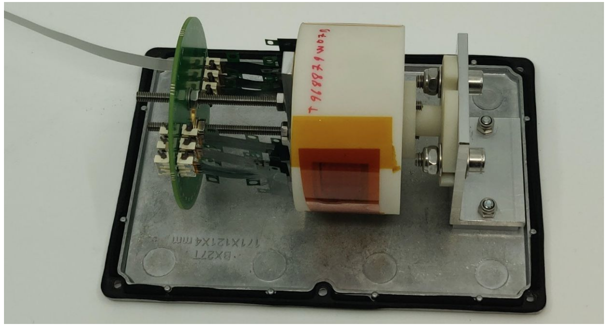
Bending ALPIDEs

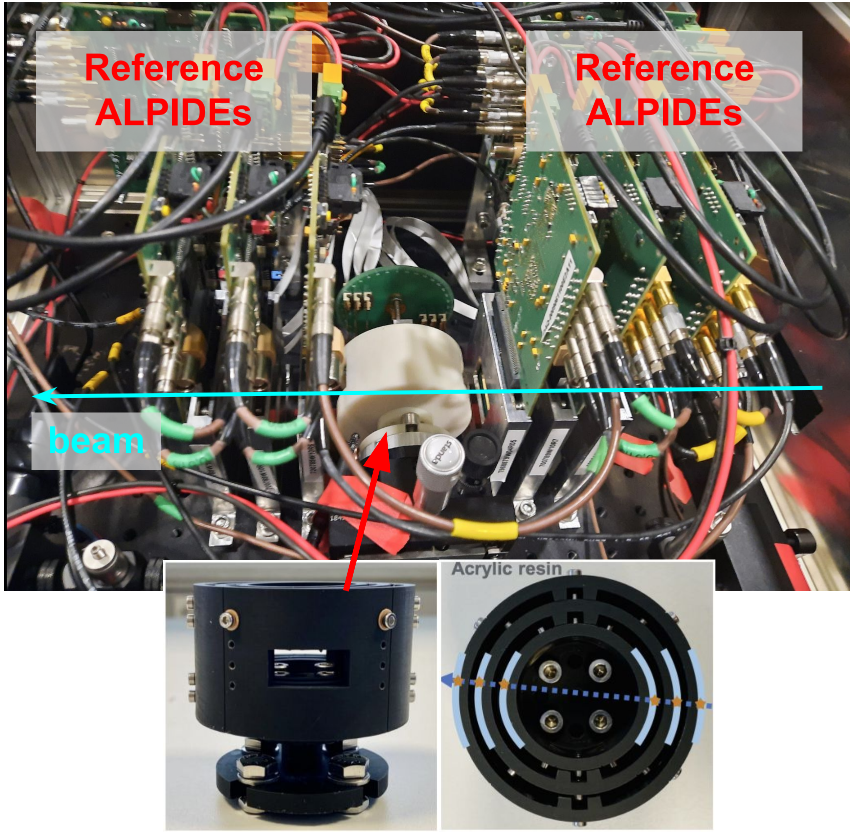
- 3D-printed jigs
  → more rigid construction
  → better control of the geometry (radius)
  → allows stacking
- Sensors bent along the long side → periphery bent
- Connection to DAQ board done via FPC (flexible-printed-cable)
- Sensors bonded after bending
- Multiple radii (18, 24, 30 mm), corresponding to the ITS3 layers



µITS3

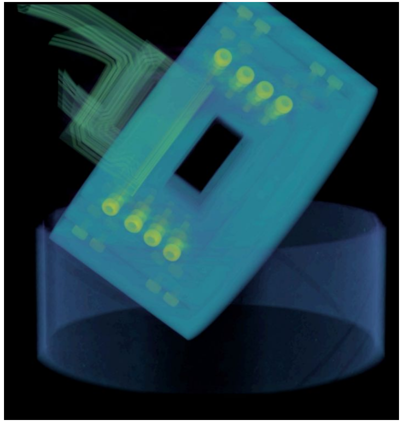
➢ Probably one of the smallest beam telescopes ever built
➢ Six bent ALPIDE sensors
➢ Opening window with no extra material

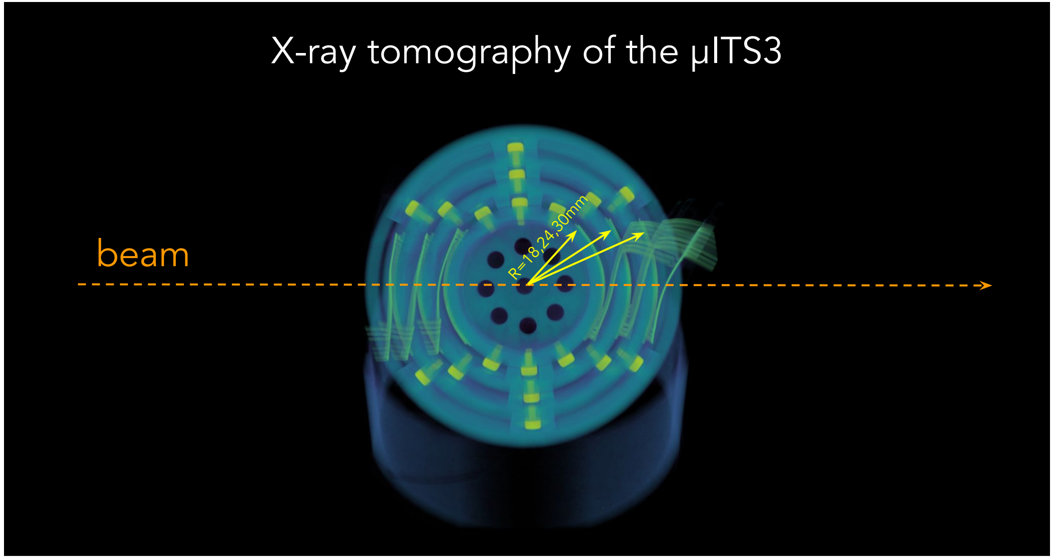
➢ Flat ALPIDEs used as reference sensors
➢ Scintillator-coincidence trigger
➢ Tested with electrons at 5.4 GeV (DESY II)



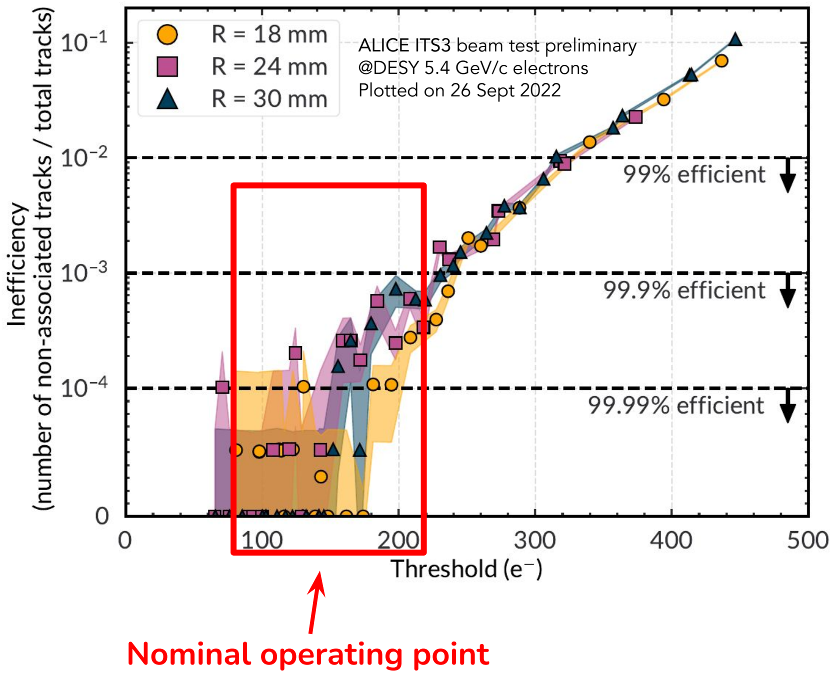
µITS3

- ➢ Mimics the ITS3
  → same bending radii (18, 24, 30mm)
- ➢ Beam (ROI) window: Si-only



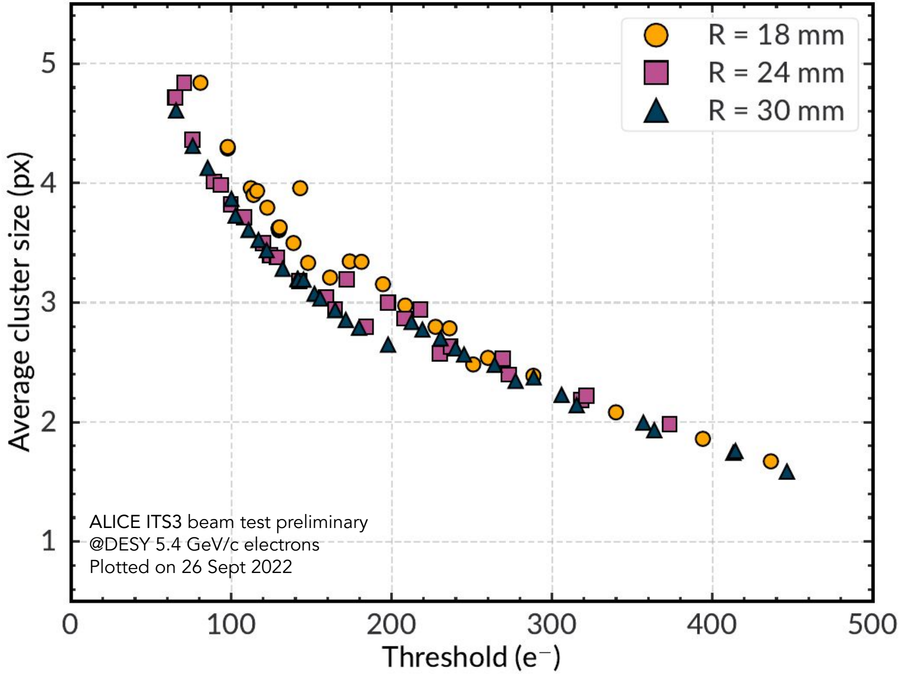


Detection efficiency of bent sensors



- Linear-logarithmic plot of the inefficiency as a function of pixel threshold for the three radii
- No dependence on the bending radii of the sensors, regardless of the operating point
- In the nominal region of operation of the ALPIDE sensors (100 – 200 e^-) an efficiency better than 99.9% is achieved

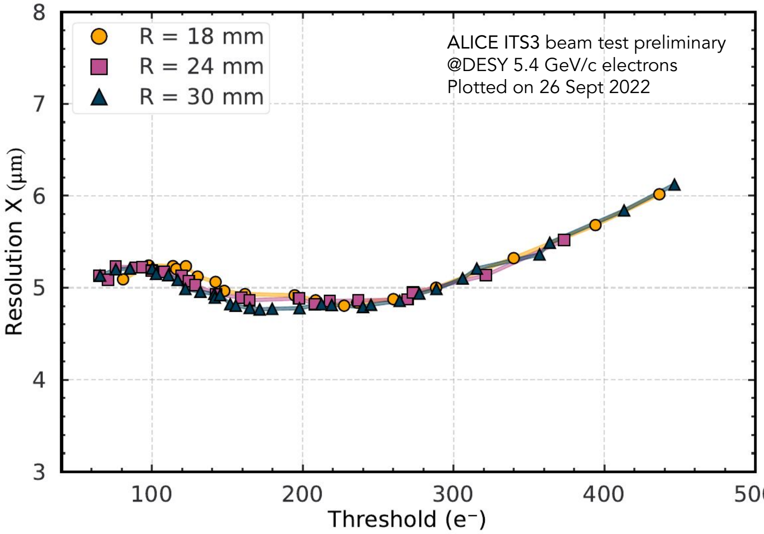
Cluster size behavior

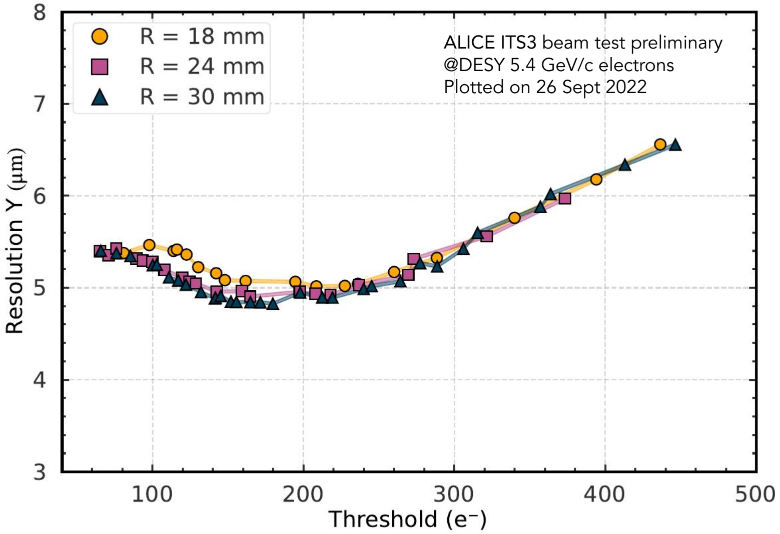


- ➢ Cluster size is decreasing with increasing threshold
- ➢ No remarkable dependence on the bending radius can be observed
- ➢ For the nominal operating thresholds an average cluster size of around 2.5–3.5 pixels is obtained → charge sharing will improve position resolution

- ➢ The small step observed around a threshold of 200 e^- is caused by a change of the decoupling filters in different data taking periods

Position resolution of bent sensors





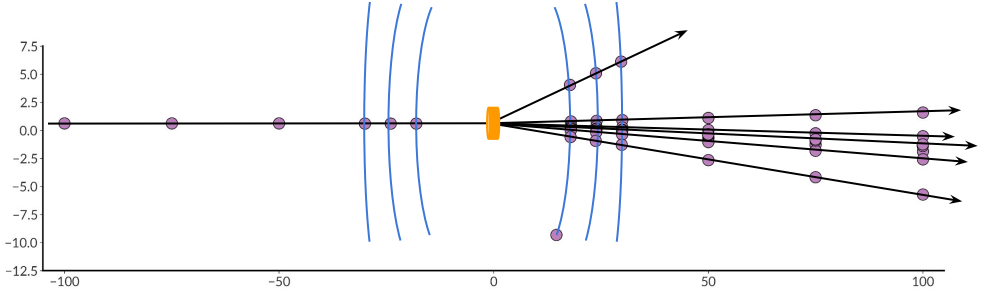
- ➢ Spatial resolution in the bending direction (x; left plot) and perpendicular to it (y; right plot)
- ➢ No significant dependence on the bending radius is observed
- ➢ Optimal resolution is observed for an average cluster size of 2-3 pixels
- ➢ Results consistent with ALPIDEs in a flat state

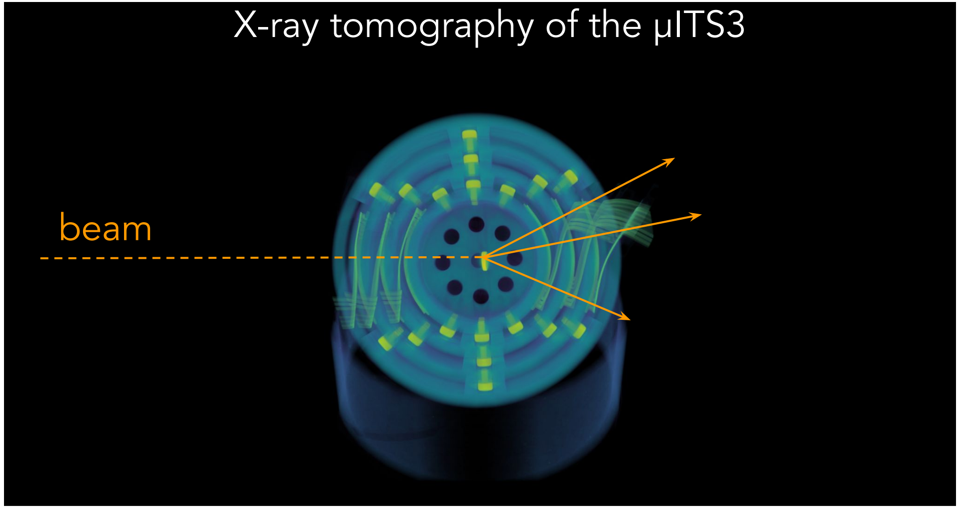
Summary and teaser

- ➢ Based on 300mm wafer scale, ultra-thin bent MAPS → ITS3 will push the technology even further, approaching a massless detector

- ➢ 50μm-thick ALPIDE sensors bent to ITS3 target radii (18, 24, 30mm) are proven to perform exceptionally well
  → unchanged performance in terms of detection efficiency and spatial resolution

- ➢ Cu target (1.2mm)
- ➢ SPS beam: 120 GeV
  → p/π – Cu collisions





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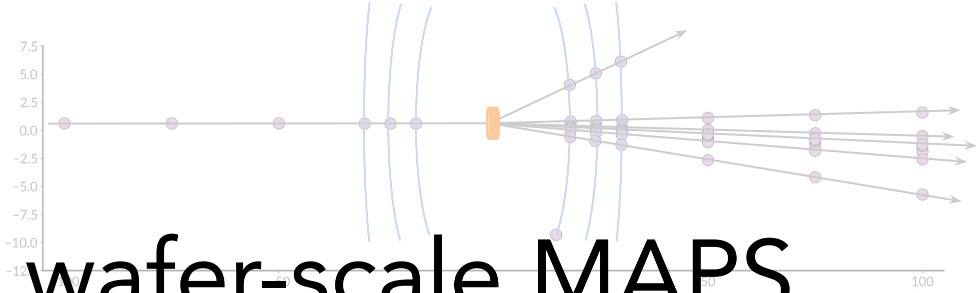

- Cu target (1.2mm)
- SPS beam: 120 GeV → p/π – Cu collisions

X-ray tomography of the µITS3

Ultra-thin, bent, wafer-scale MAPS
are becoming a reality!
For ALICE ITS3, *and beyond!*