ITS3: A truly cylindrical inner tracker for ALICE

Jory Sonneveld on behalf of the ALICE collaboration

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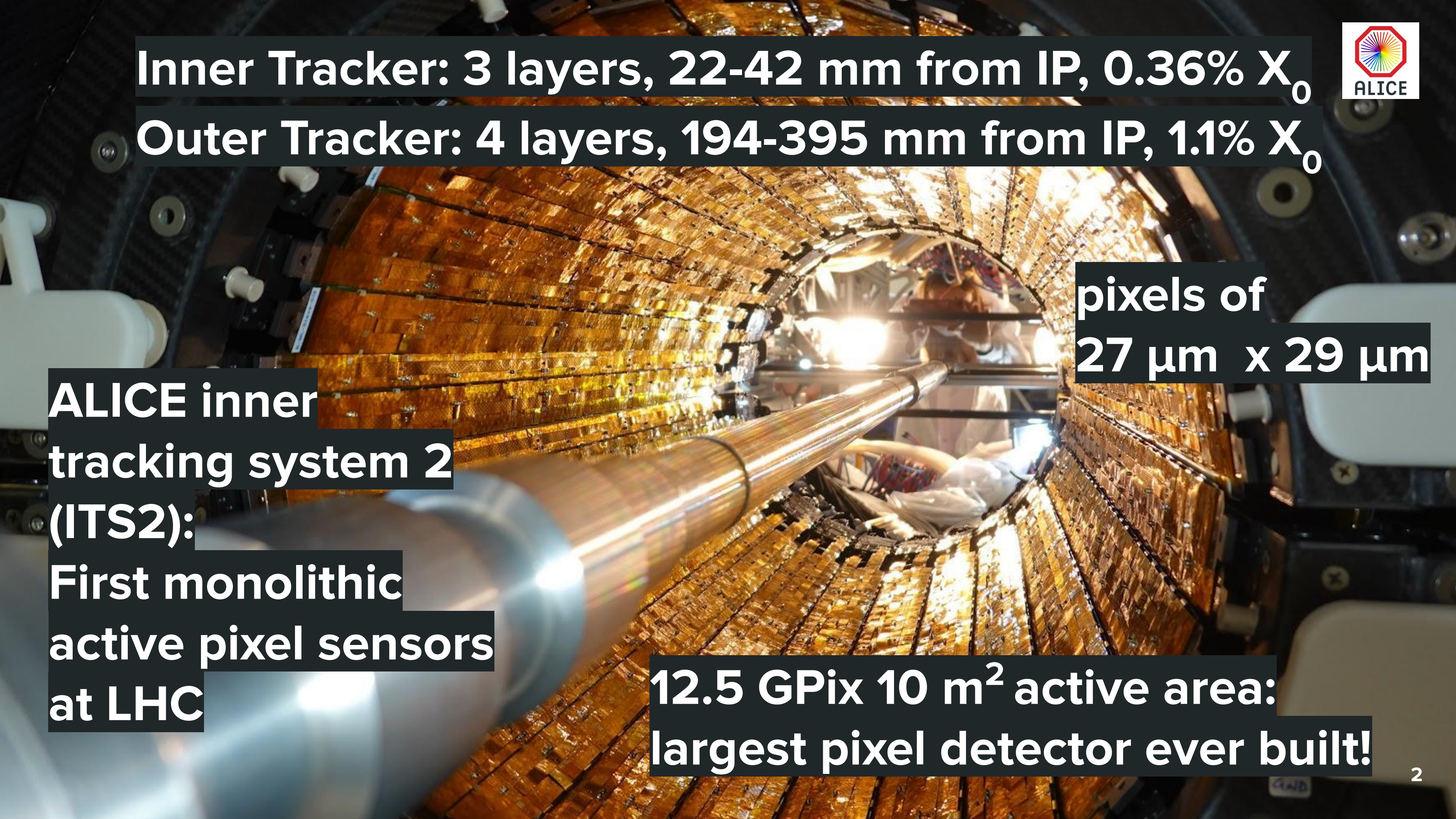


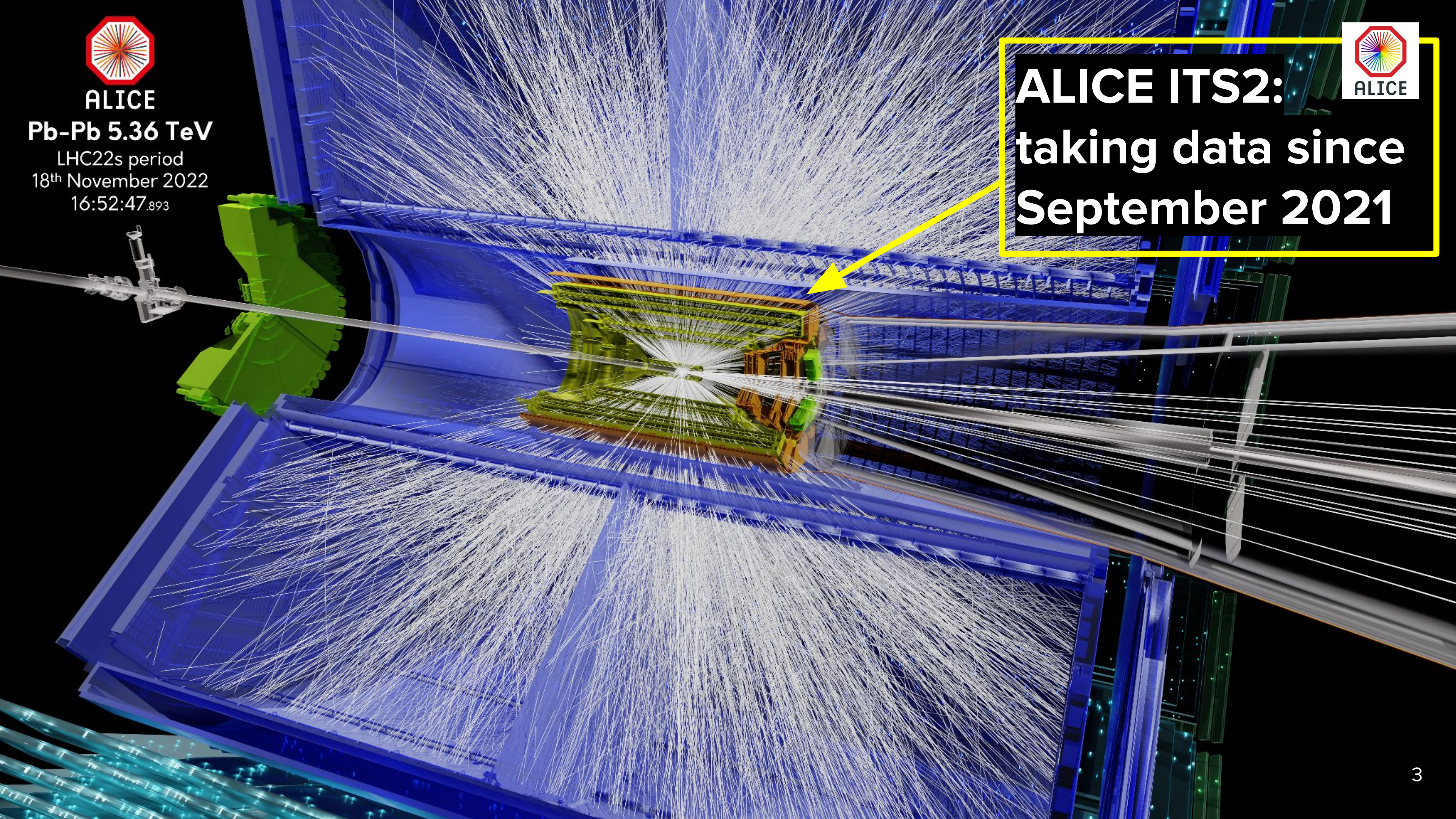
Inner Tracker: 3 layers, 22-42 mm from IP, 0.36% X_0

Outer Tracker: 4 layers, 194-395 mm from IP, 1.1% X_0

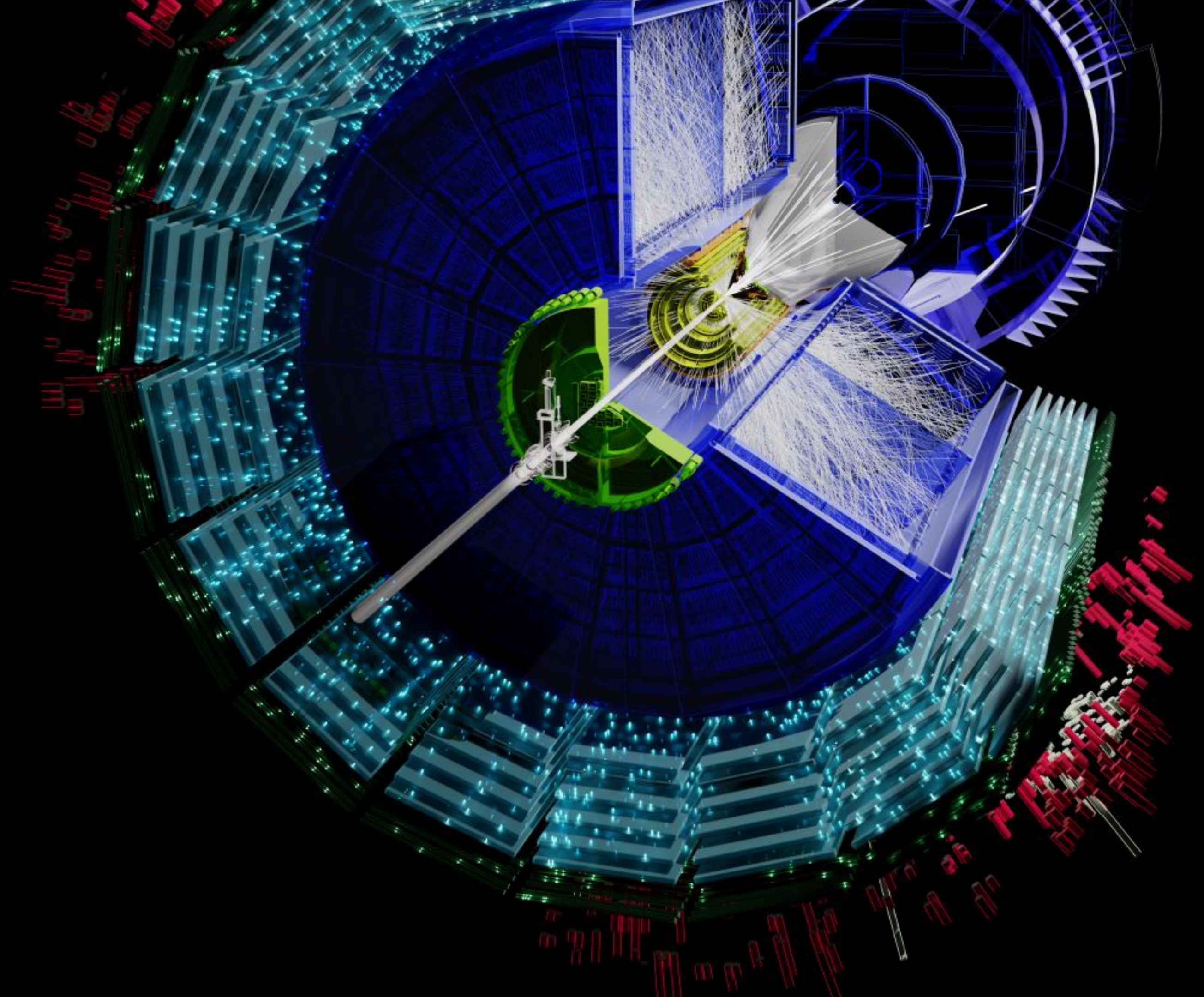
pixels of
27 µm x 29 µm

ALICE inner tracking system 2 (ITS2): First monolithic active pixel sensors at LHC

12.5 GPix 10 m^2 active area: largest pixel detector ever built!



ALICE ITS2: taking data since September 2021



ALICE

Pb-Pb 5.36 TeV

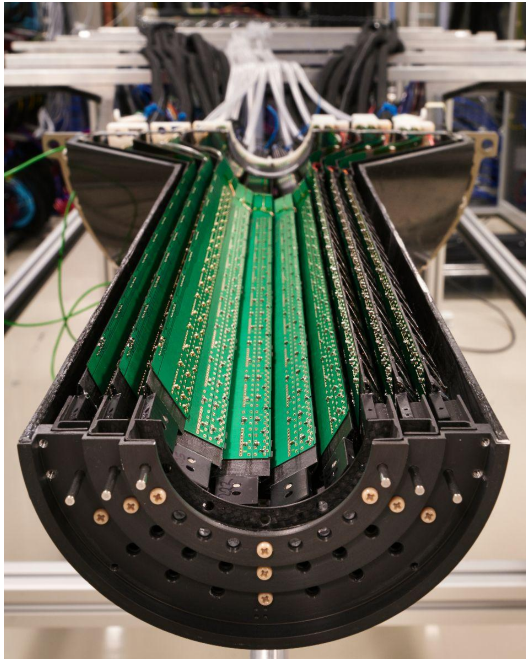
LHC22s period

18th November 2022

16:52:47.893

Future upgrade of the ALICE inner tracking system

0.36% X_0 per layer



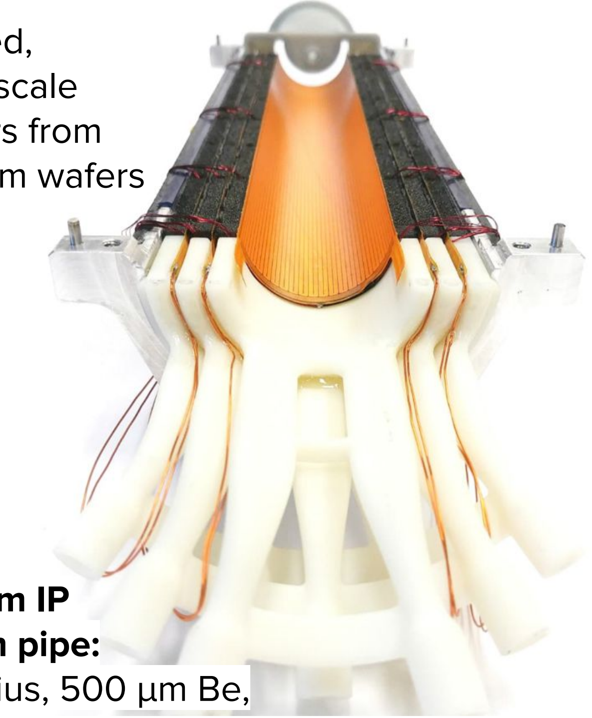
24120 chips from 200 mm wafers

22 mm from IP

ITS2

Very low material budget! 0.05% X_0 per layer

Stitched, wafer-scale sensors from 300 mm wafers



18 mm from IP

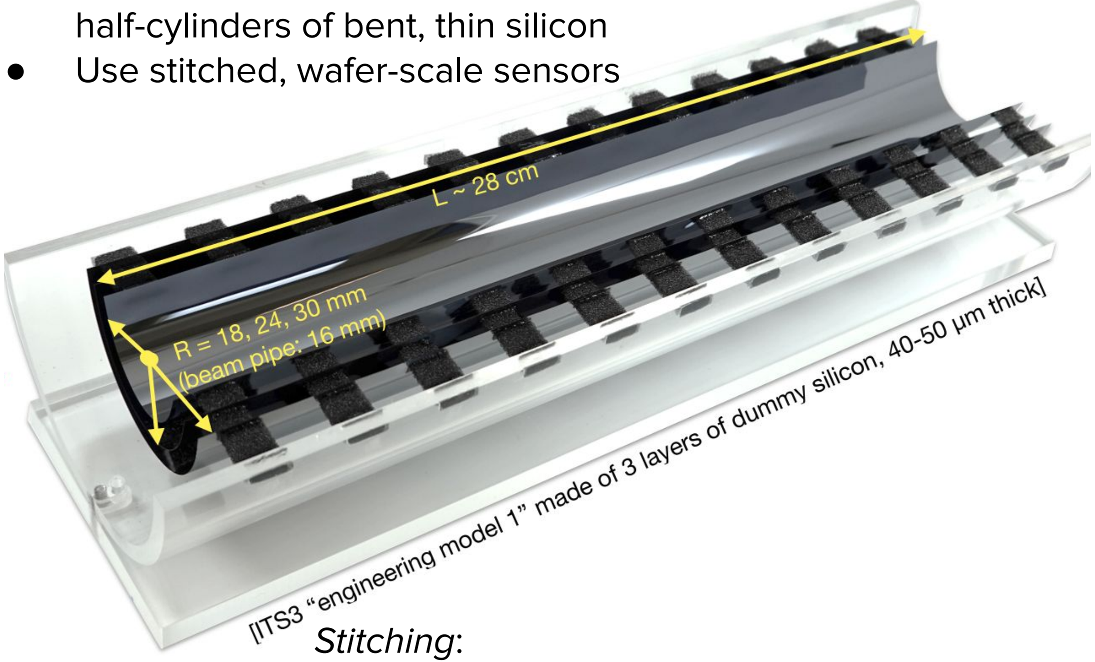
New beam pipe:

16 mm radius, 500 µm Be, 0.14% X_0

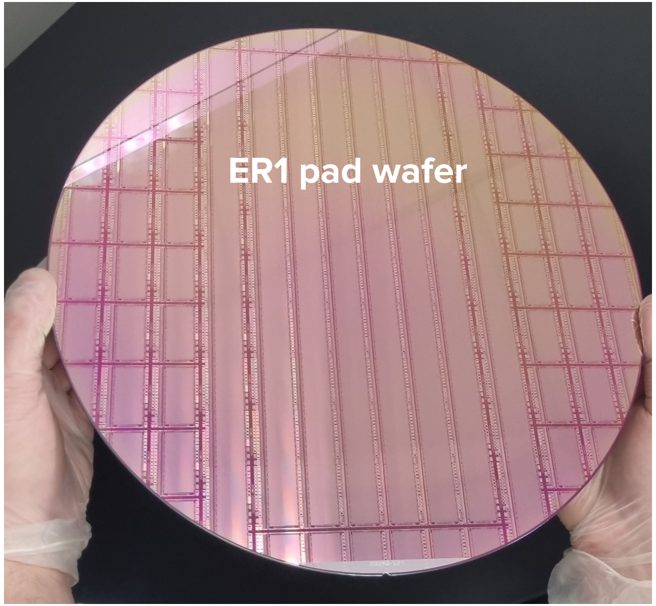
ITS3

ITS3: three new, ultralight, truly cylindrical layers

- Replace current pixel detector inner layers with half-cylinders of bent, thin silicon
- Use stitched, wafer-scale sensors



[ITS3 "engineering model 1" made of 3 layers of dummy silicon, 40-50 µm thick]



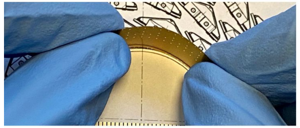
Pad wafer in engineering run 1 (ER1) using stitching: 25.9 cm long sensor

Stitching:

- put design blocks together during processing of silicon
- Can make chip larger than the field of view of the lithographic equipment

ALICE ITS3 for Run 4

Each half layer is one single pixel sensor!

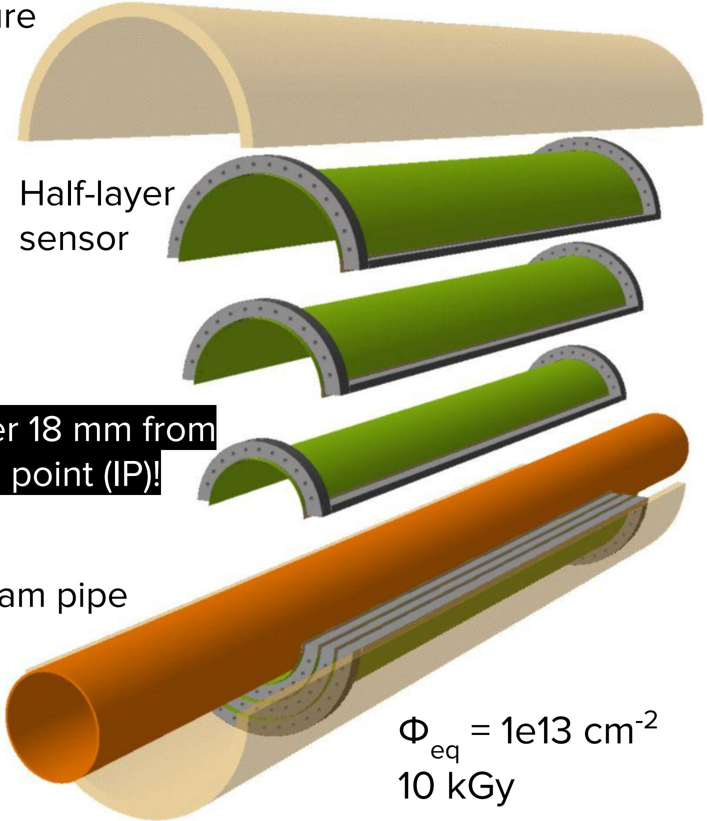


Stitching and **bending**

- Material: $X/X_0 \approx 0.05\%$

  ITS2 (now): 0.36% (inner), 1.1% (outer)

- 6 half-layer sensors with 3-5 wafer-scale monolithic active pixel sensors (MAPS)
- Half layer sensor of size of 280 x 53.3 mm^2 in layer 0
- Thinned to 40-50 µm
- Mechanically held in place by carbon foam



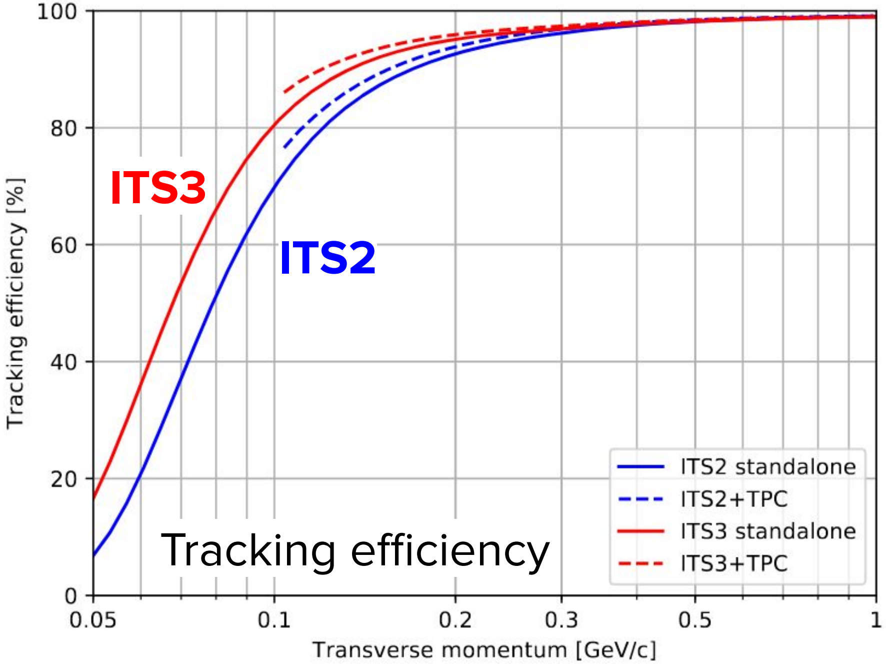
Innermost layer 18 mm from the interaction point (IP)!

Φ_{eq} = 1e13 cm^{-2}
10 kGy

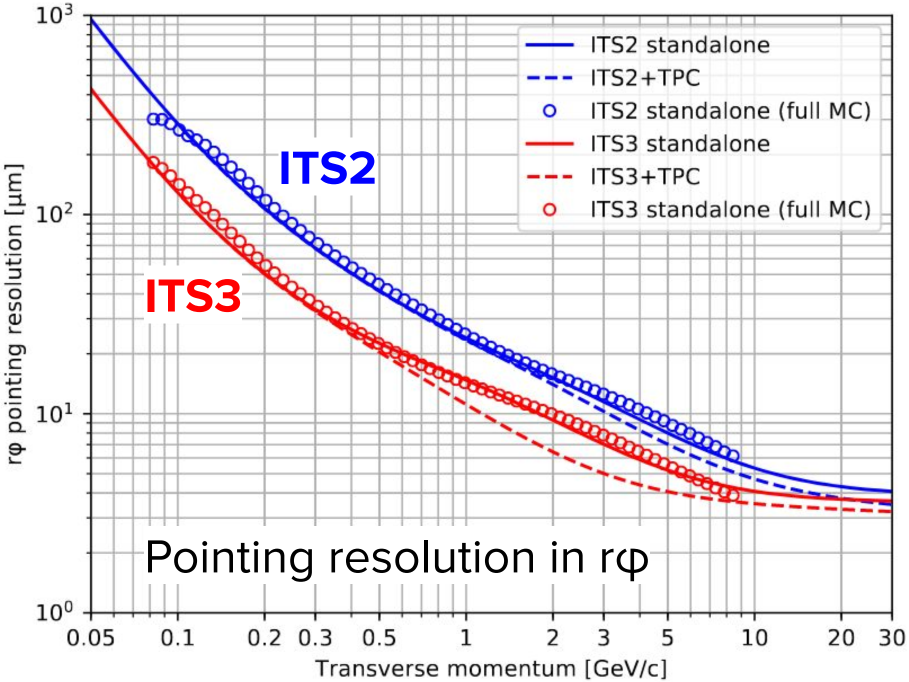
ALICE upgrades LS2 arXiv:2302.01238 ITS3 Letter of intent CERN-LHCC-2019-018

Improved measurements with more precise vertexing and tracking

ITS3: more precise vertexing and tracking



Large improvement especially at low p_T



Factor 2 improvement over all momenta

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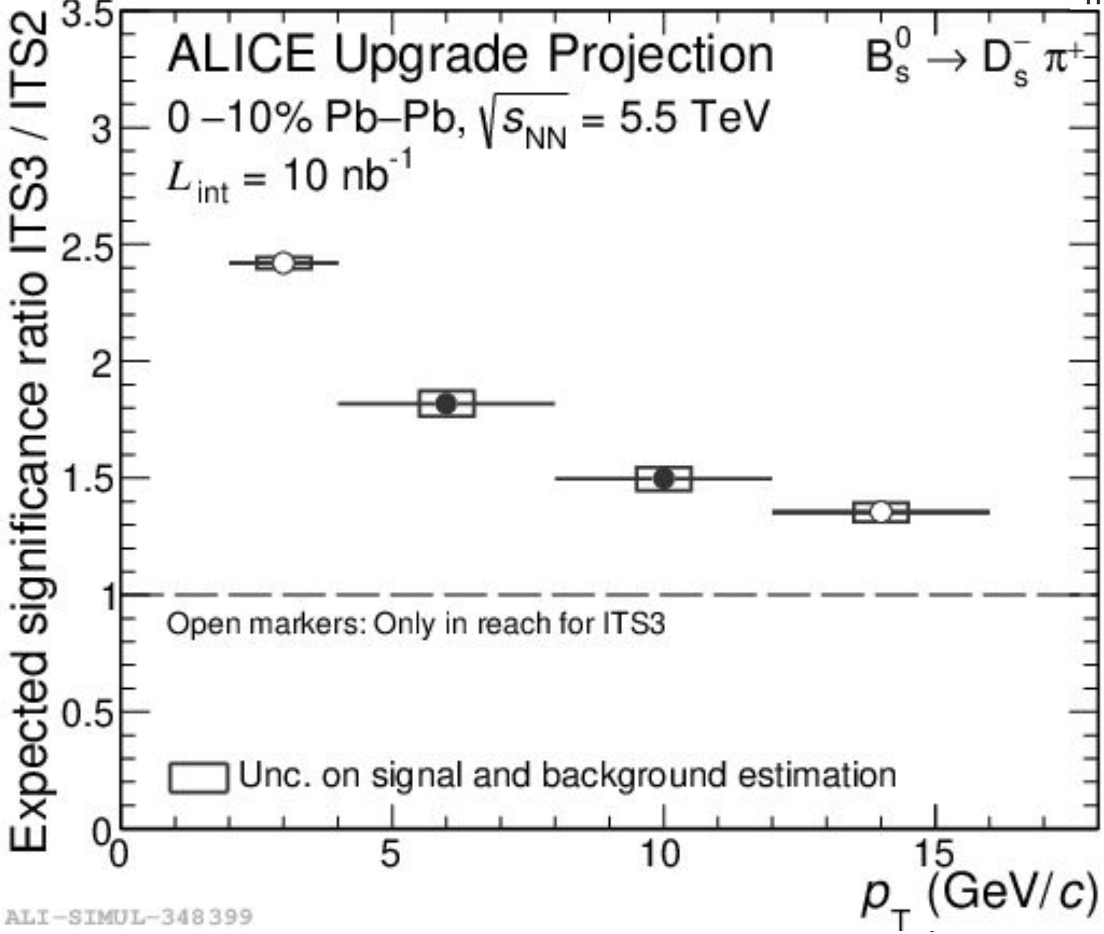
Strange beauty particles

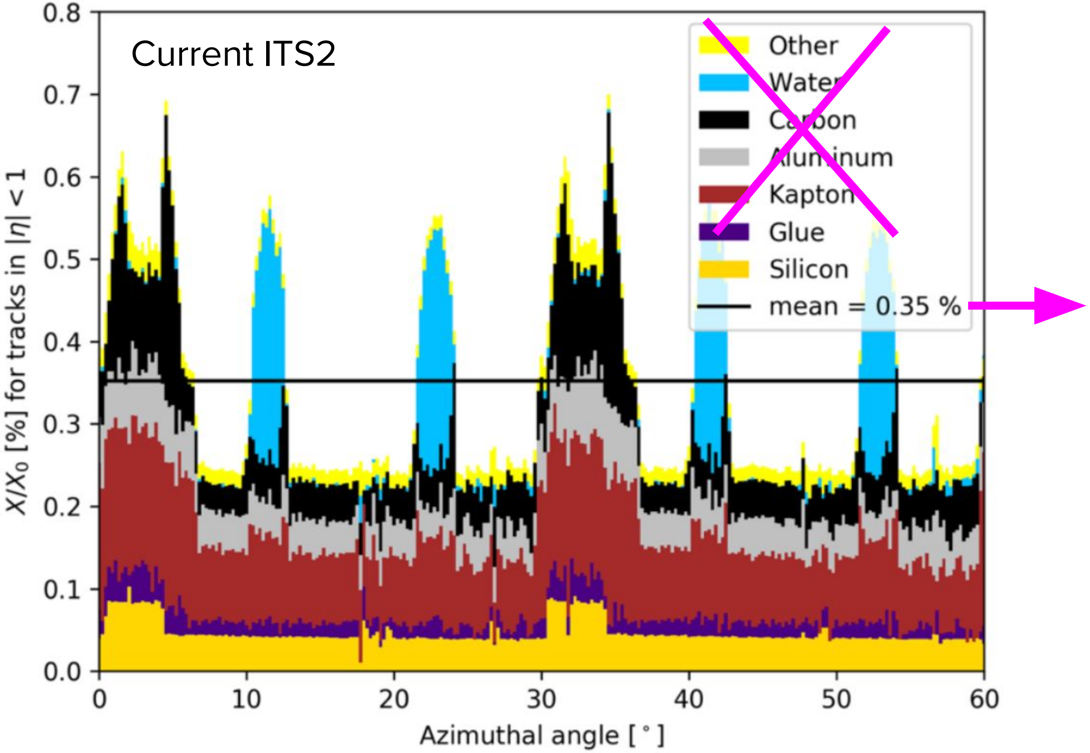
- For studies of hadronisation in heavy ion collisions
- The Compact Muon Solenoid (CMS) Experiment made first measurement B^0_S / $B_{\text{not S}}$ in Pb Pb collisions vs pp collisions – with large uncertainties
- ALICE also measured this
- Both see an enhancement, but no significant observation
- Large improvement with ITS3
- ITS3 can extend measurement to lower p_T

This all thanks to a close proximity to IP and a very low material budget!



Where did all the material go?

Remove “unnecessary” material from ITS2



- Circuit board (kapton, aluminum): not required if power and data are integrated into the silicon

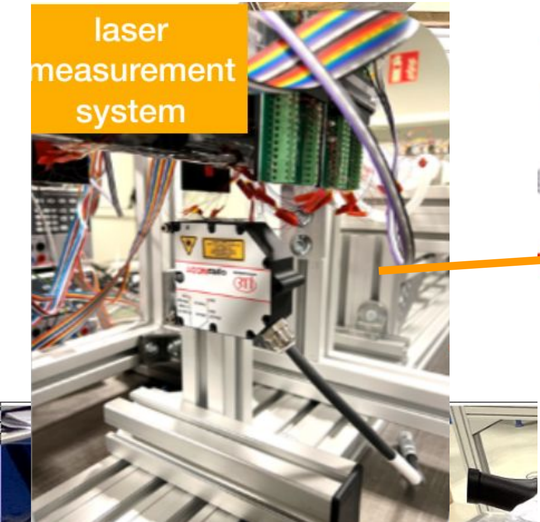
Mean 0.05% per layer

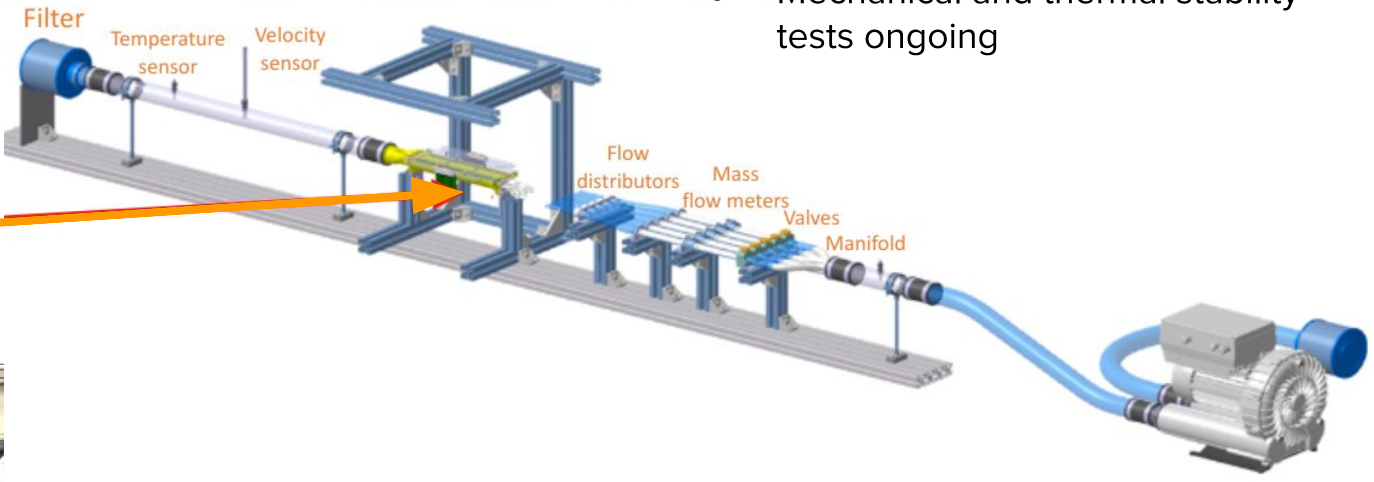
- Water cooling → replace with air cooling. Requires < 20 mW/cm^2
- Less mechanical support (carbon, glue) needed for large, bent sensors!

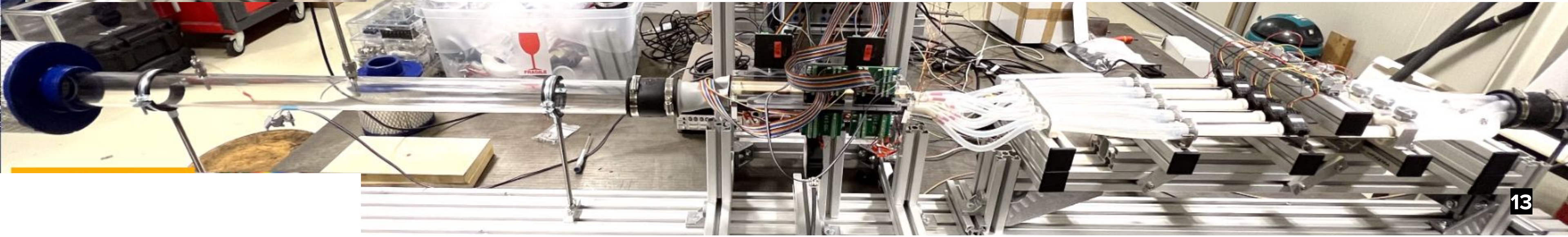
ITS3 Letter of intent CERN-LHCC-2019-018

Testing the air cooling

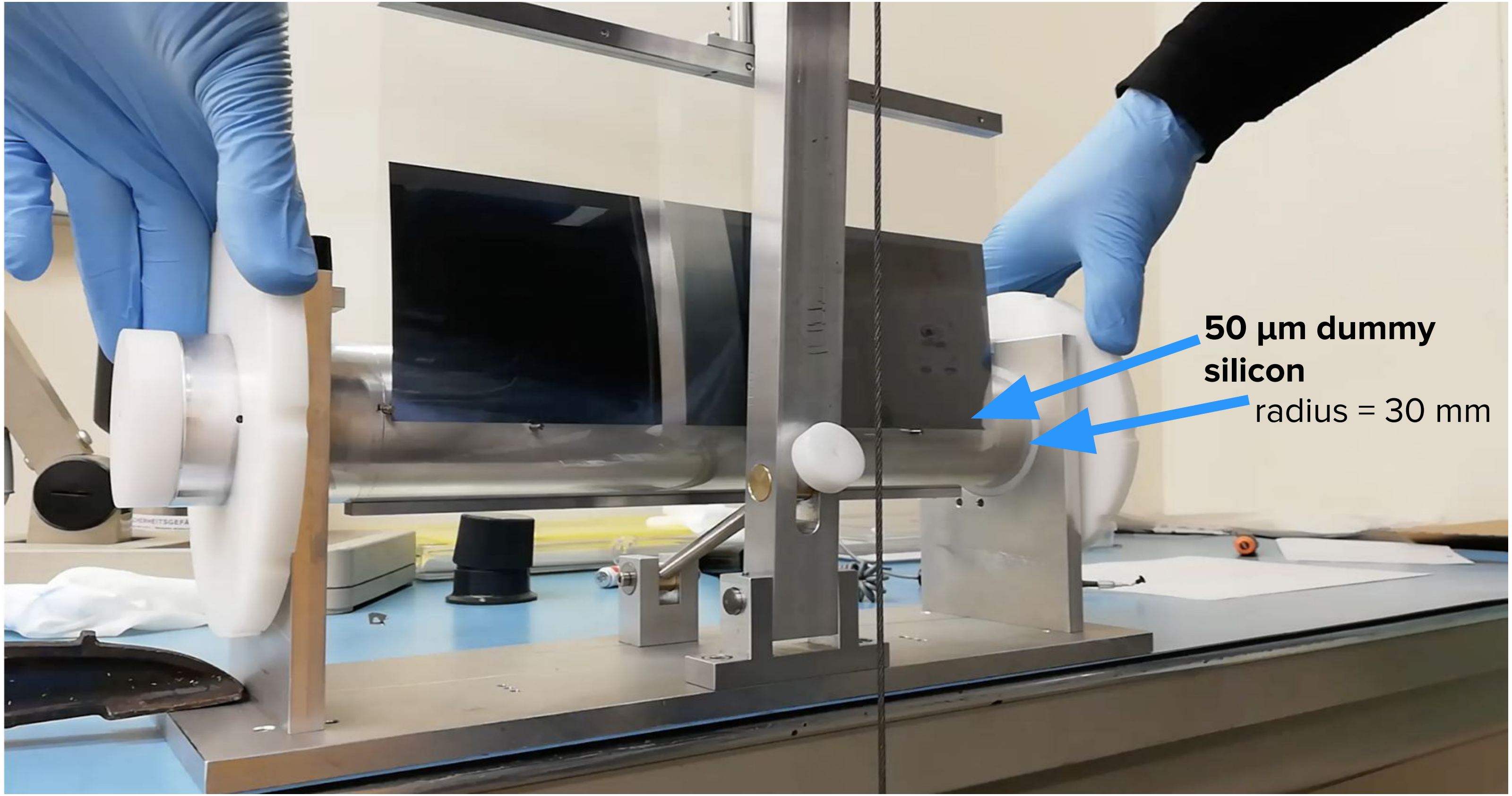
- Setup commissioned
- Mechanical and thermal stability tests ongoing







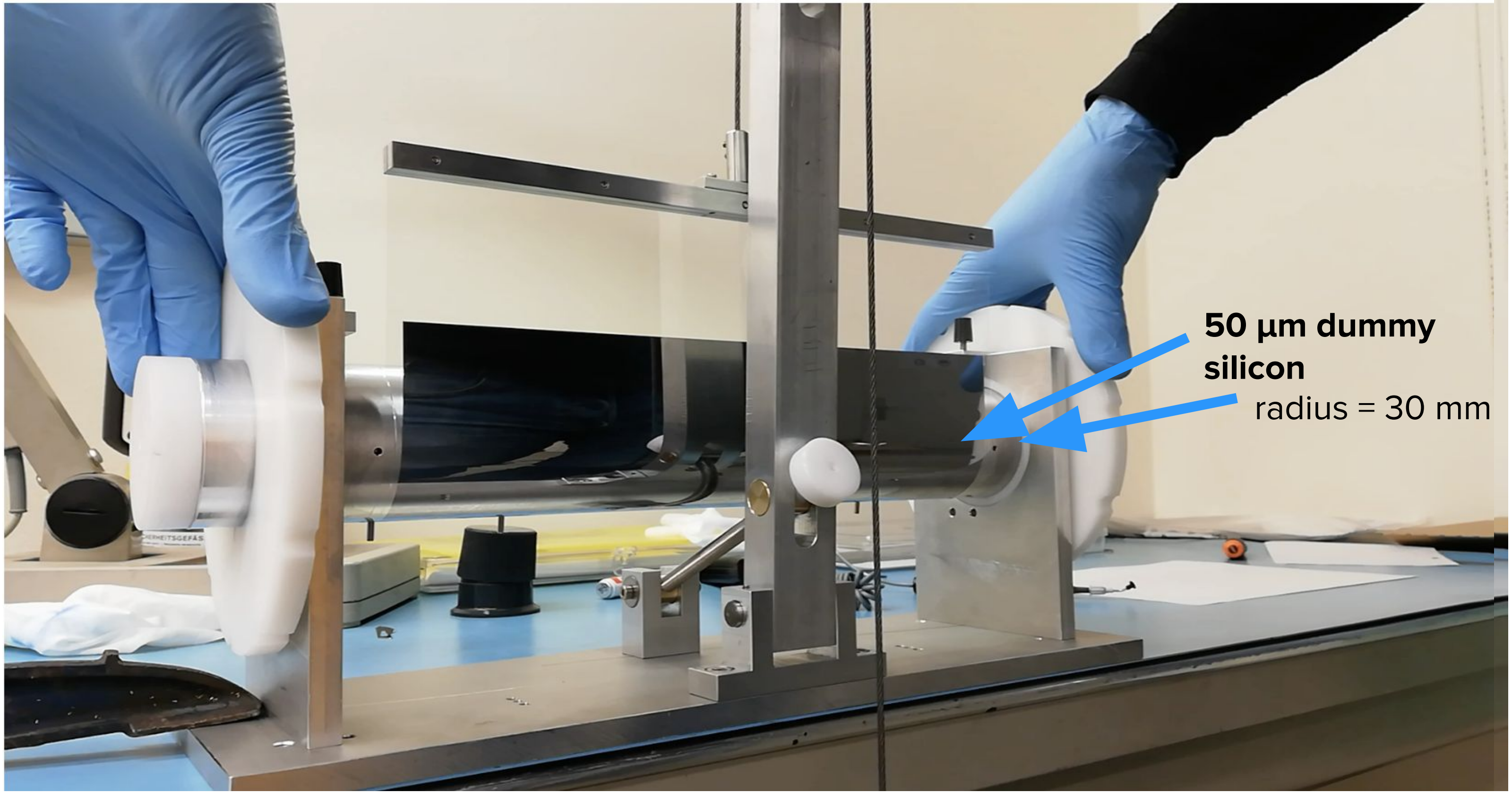
Silicon flexibility and bending



50 µm dummy silicon

radius = 30 mm

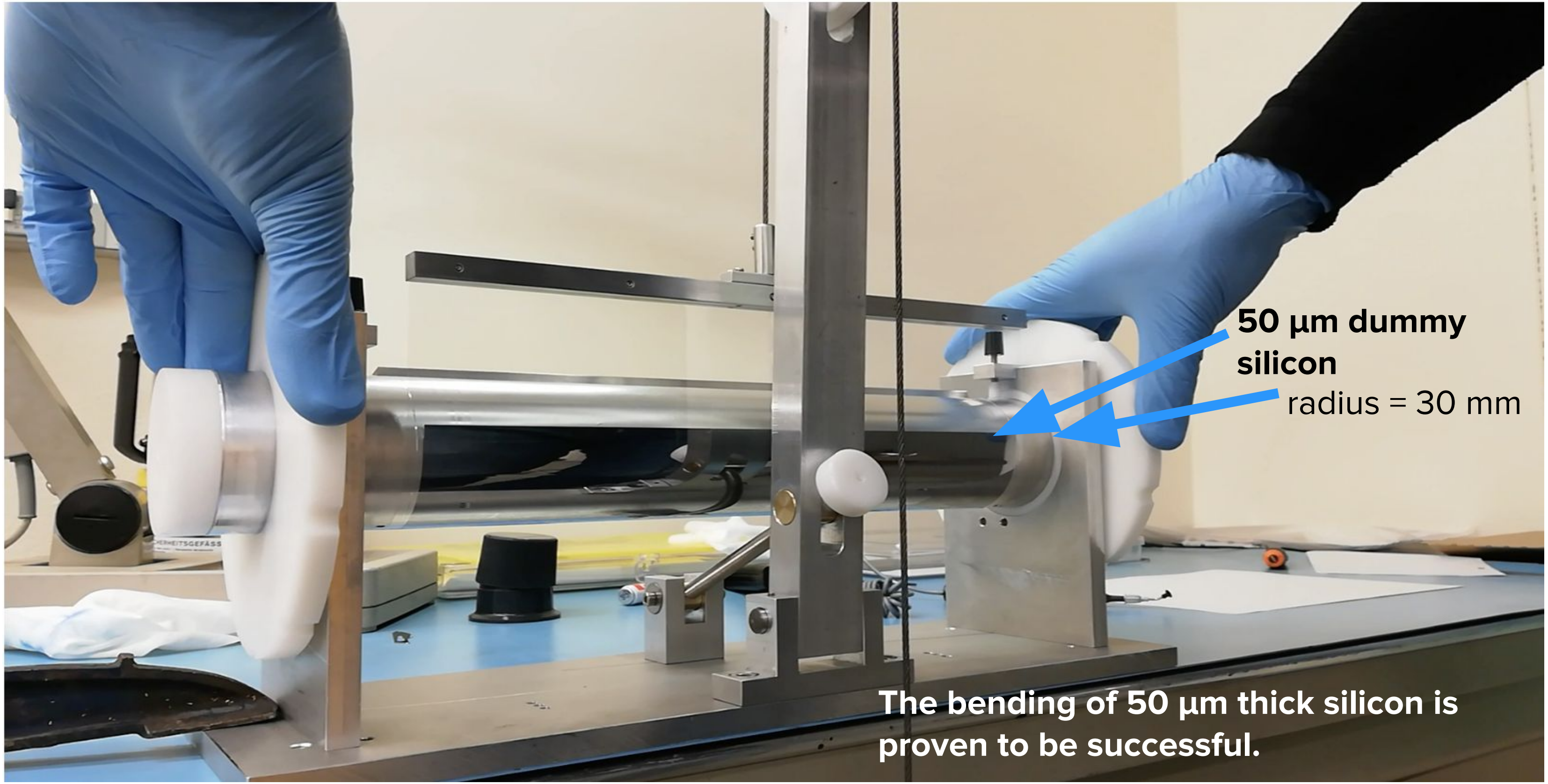
Silicon flexibility and bending



50 µm dummy silicon

radius = 30 mm

Silicon flexibility and bending

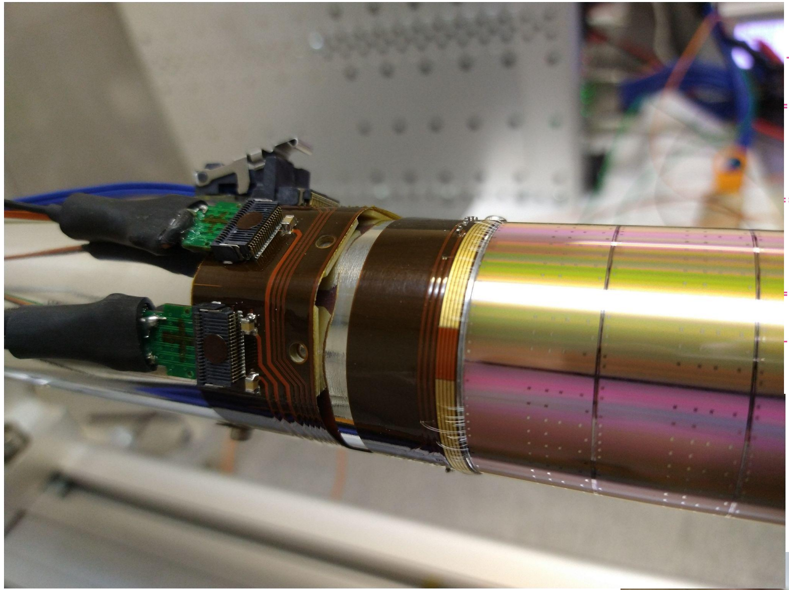


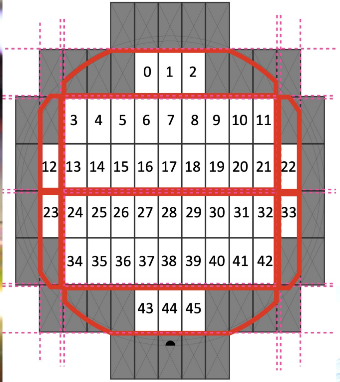
50 μm dummy silicon

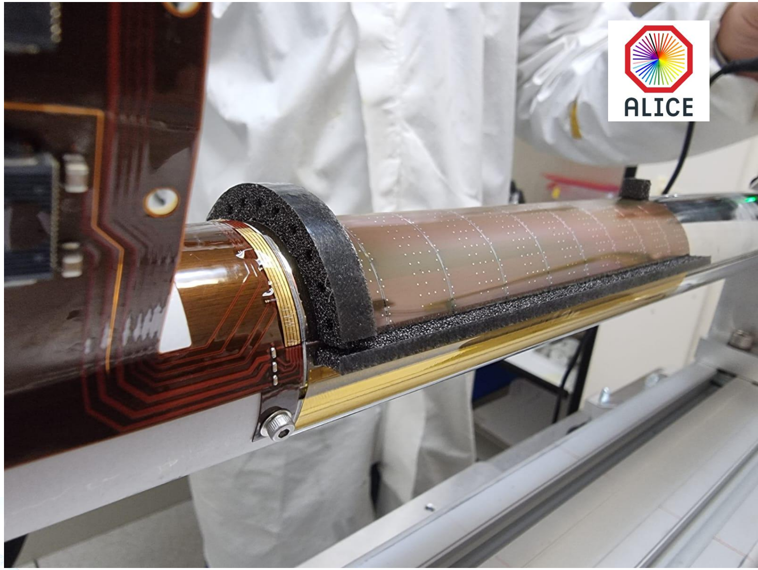
radius = 30 mm

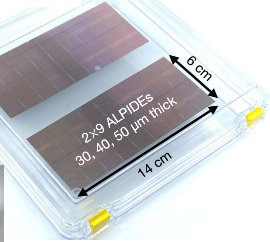
The bending of 50 μm thick silicon is proven to be successful.

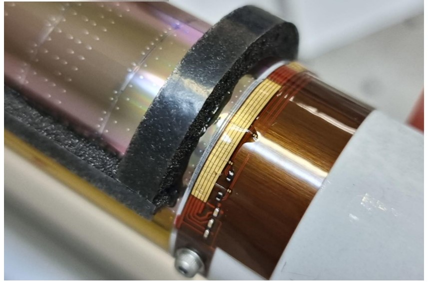
First bending with *superALPIDEs*







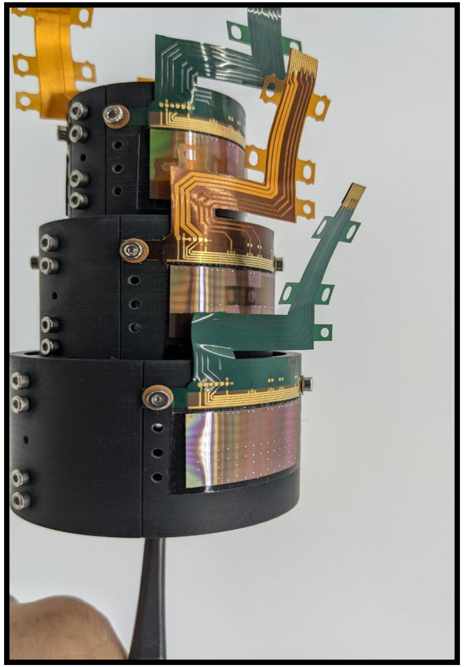


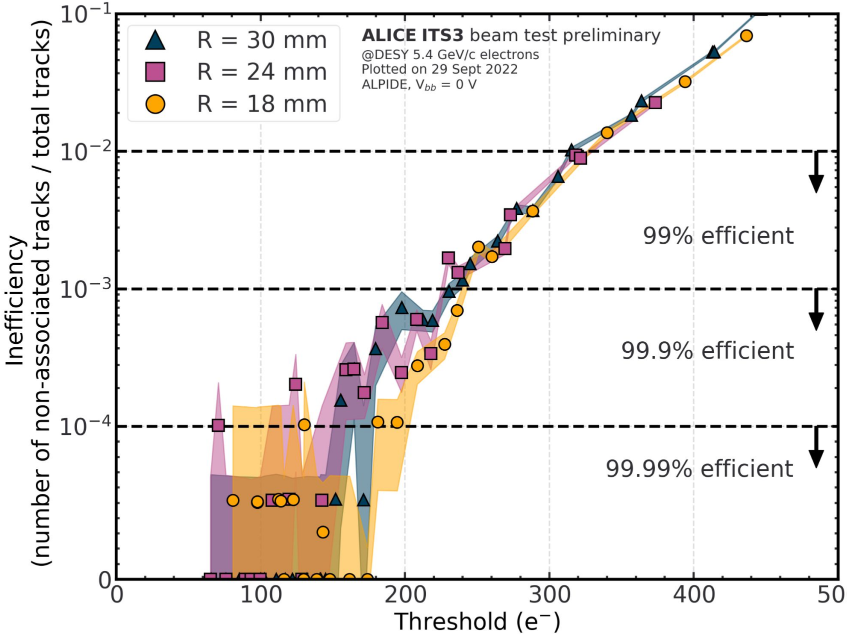


- ALPIDE: ALICE PIxel DEtector used in ITS2
- 40 µm thick sensors
- Bent to a radius of 18 mm

Beam test studies with bent sensors

- Bending silicon wafers and functional ALPIDEs is now routine
- Full mock-up of the final ITS3: “µITS3” bent to ITS3 radii tested
- Spatial resolution uniform among different radii
- Efficiency and resolution consistent with flat ALPIDEs



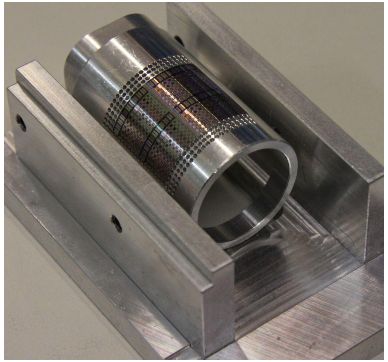


More results in doi:10.1016/j.nima.2021.166280

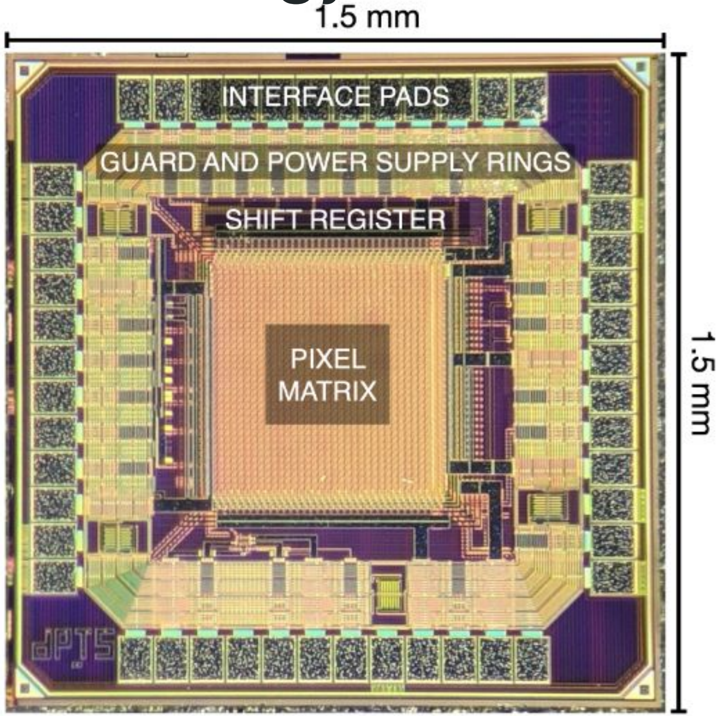
Sensor R&D

Characterization of new 65 nm technology for ITS3

- Several submissions, prototype of final wafer-scale chip expected 2024
- Now investigating many different small prototypes from a multi-layer reticle to qualify 65 nm technology
- One such prototype is a digital pixel test structure that acts as a technology demonstrator
- Results published: doi:10.48550/arXiv.2212.08621



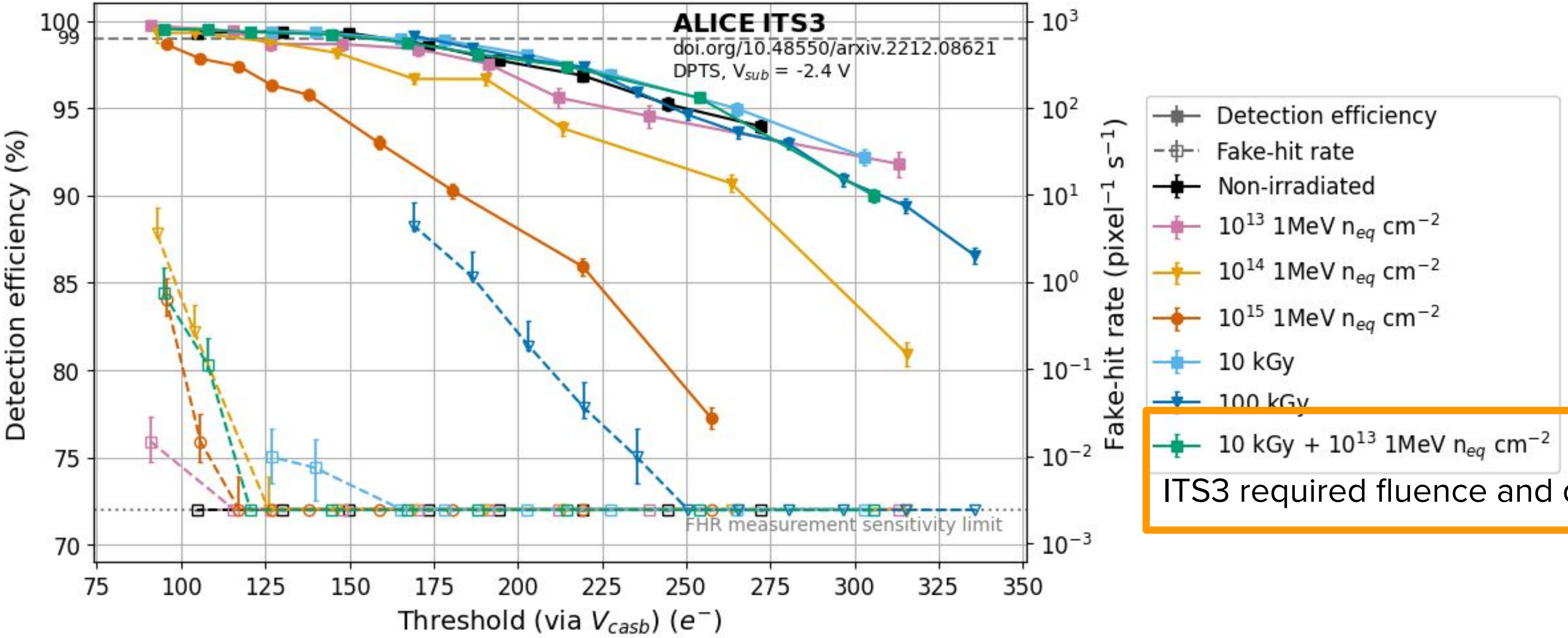
First chips bent to 18 mm radius and successfully tested with Fe-55 source



doi:10.48550/arXiv.2212.08621

- 32 by 32 pixels with asynchronous digital readout
- 15 x 15 μm^2 pixels whose position is time encoded in the readout

Digital pixel test structure efficient after irradiation

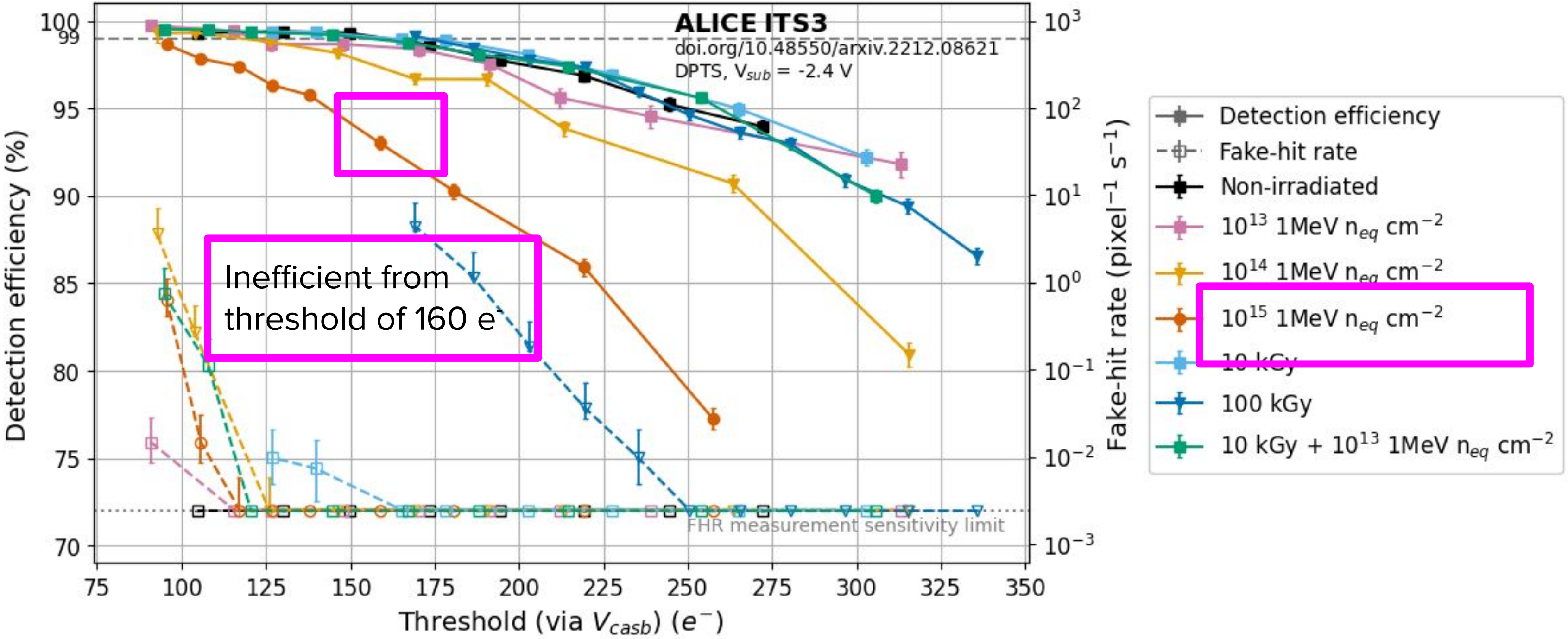


ITS3 required fluence and dose

- Operated at room temperature!
- 100% efficient after ITS3 fluence
- Sensor still operable at 99% efficiency at 20°C after Φ_{eq} = 10^{15} / cm^2

doi:10.48550/arXiv.2212.08621

Digital pixel test structure efficient after irradiation



Inefficient from threshold of 160 e$^-$

- Operated at room temperature!
- 100% efficient after ITS3 fluence
- Sensor still operable at 99% efficiency at 20°C after Φ_{eq} = 10^{15} / cm^2

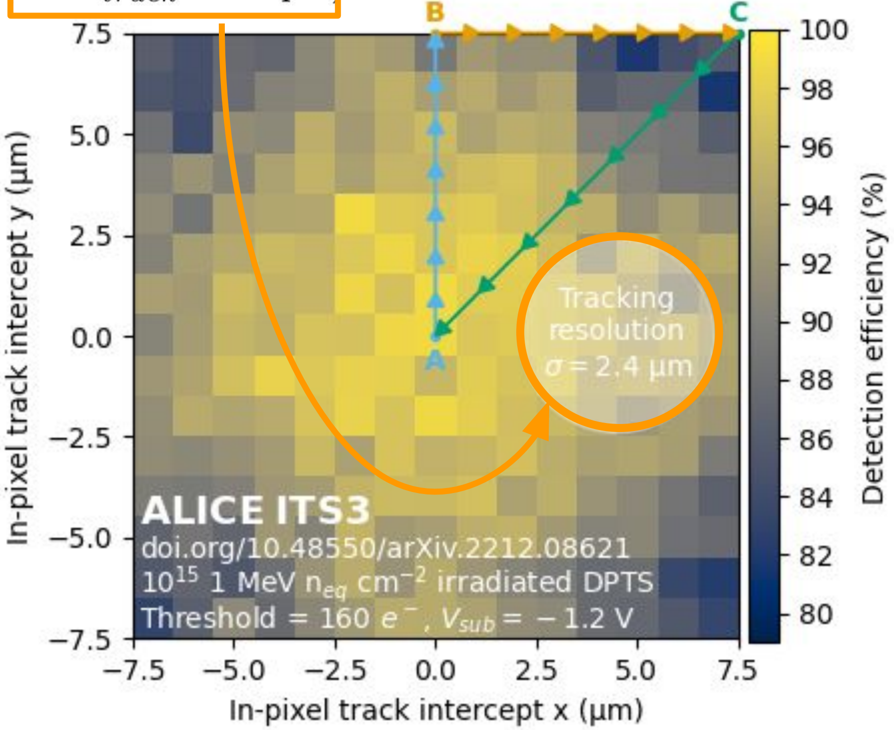
doi:10.48550/arXiv.2212.08621

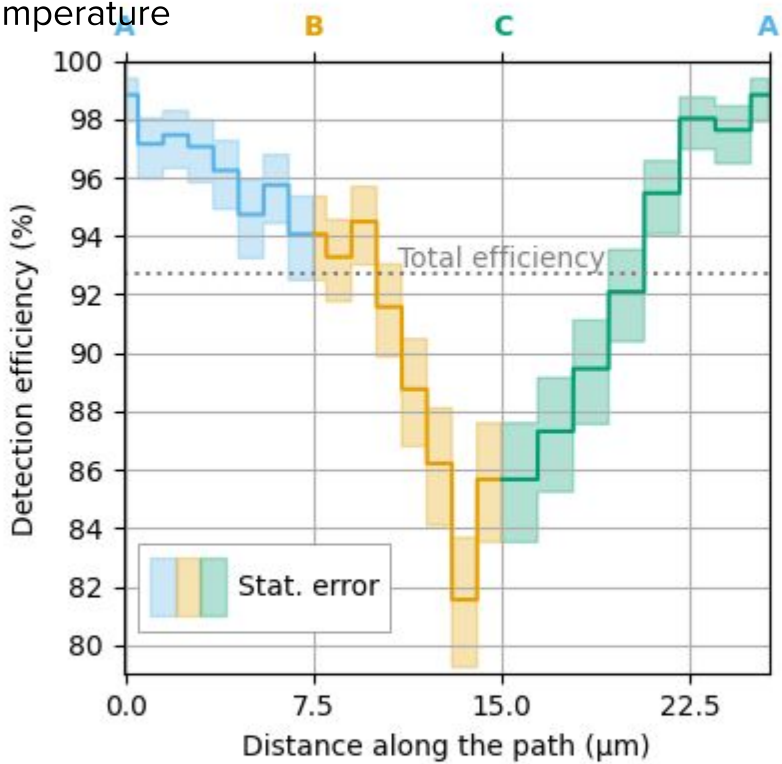
In-pixel detection efficiency after $\Phi_{eq} = 10^{15} / cm^2$

Track spatial resolution:

$r = \sigma_{track} = 2.4\,\mu\text{m}$

- Threshold 160 e^-
- Operated at room temperature



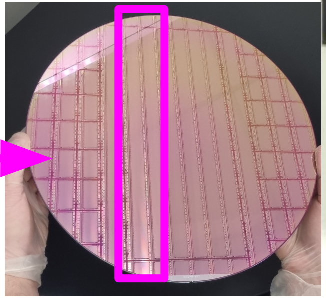


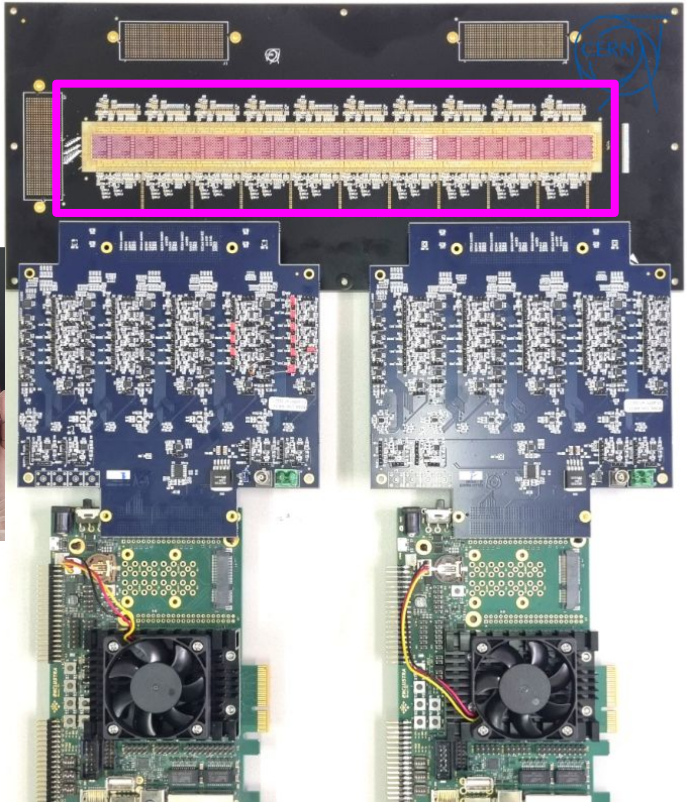
doi:10.48550/arXiv.2212.08621

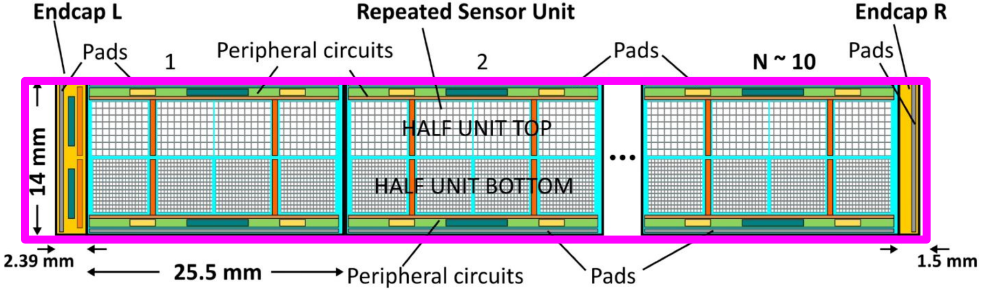
Efficiency loss as expected: occurs in corners far from collection electrode. No charge sharing.

Stitched sensor prototypes

- 2 different structures, MOSS and MOST
- 14 x 259 mm^2, 6.72 MPixel structure
- Full structure will be 2.5 times as large
- Pixels of 22.5 x 22.5 μm^2 and 18 x 18 μm^2
- To be tested for yield and uniformity
- Pad wafer at CERN
- First full wafers arriving soon

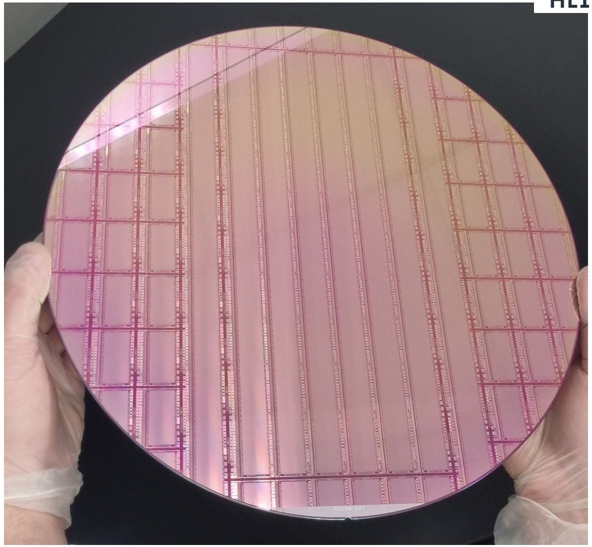


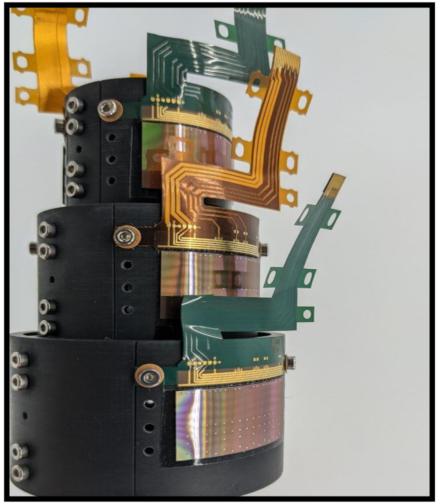




Summary and outlook

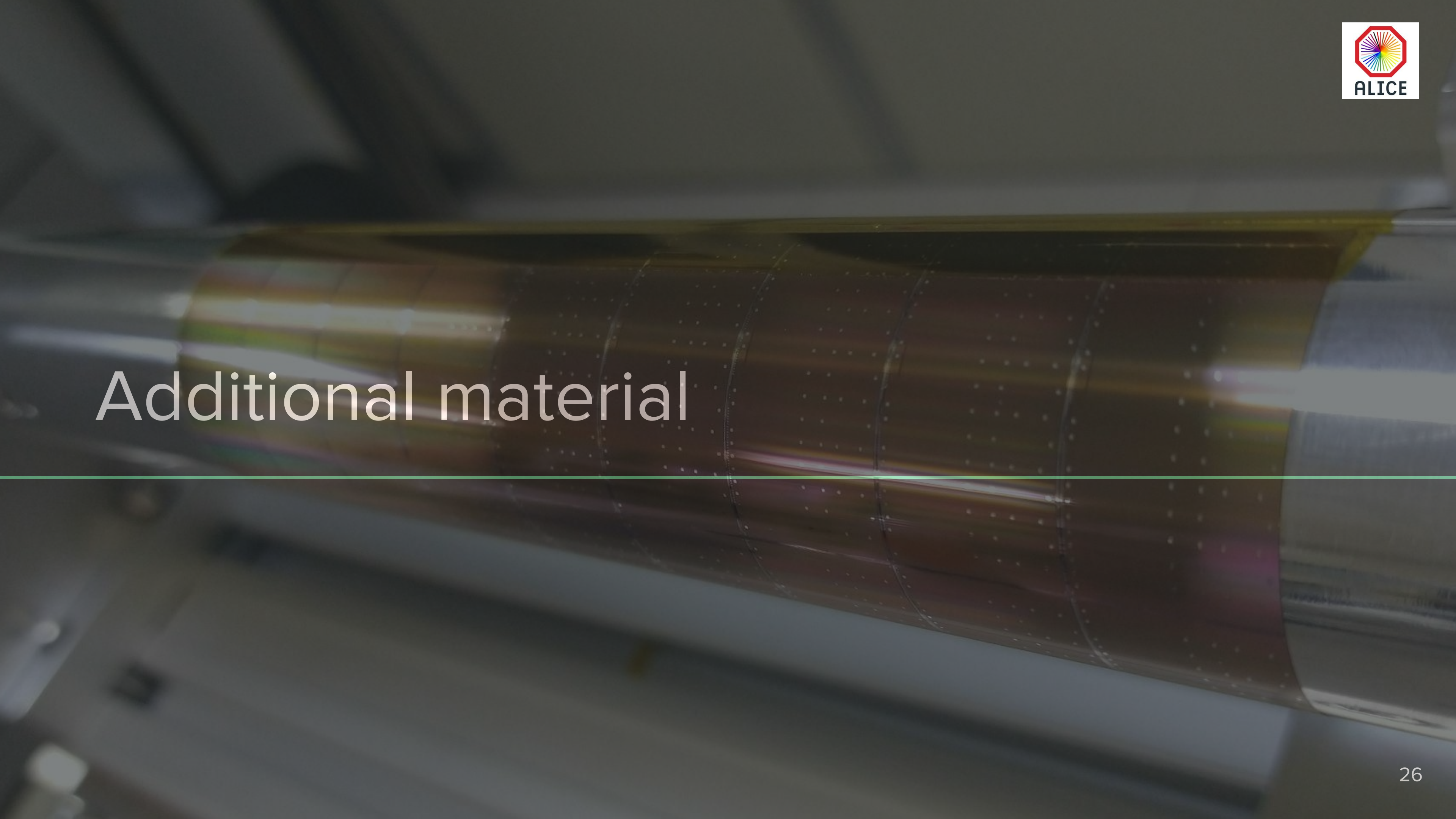
- Installation of new inner layers for ALICE inner tracking system 3 (ITS3) for LHC Run 4 in 2028
- Aim for truly cylindrical wafer-scale monolithic active pixel sensors
- Silicon flexibility and bending proved with routine bending tests
- Full mockup of ITS3 efficient when bent to ITS3 target radii





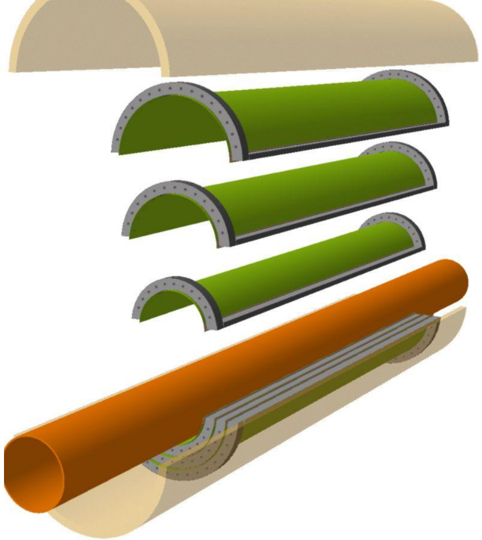
- Sensor prototypes reach 100% detection efficiency at room temperature at ALICE ITS3 fluence requirement of $\Phi_{eq} = 10^{13}$ / cm^2
- Sensor still operable at room temperature after $\Phi_{eq} = 10^{15}$ / cm^2
- First stitched sensors on their way and to be tested soon
- ITS3 R&D will pave the way to thin, low-power sensors that could be used in ALICE 3 (see talk by Alessandro Grelli in this session)

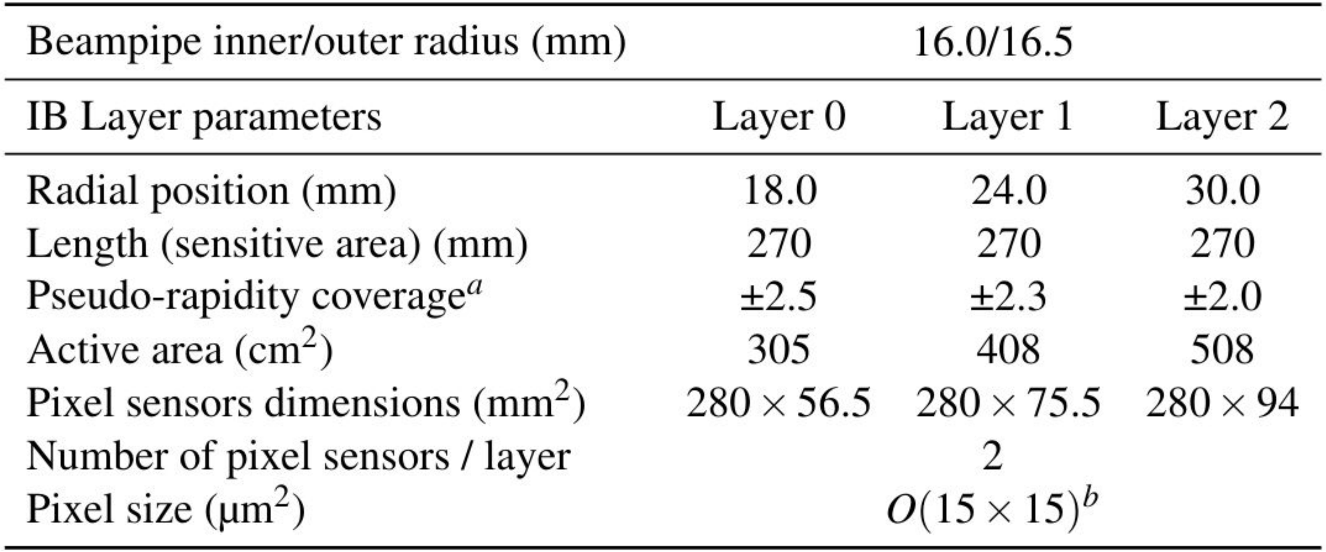
ITS3 is a successful R&D project that will enable a wealth of new precision measurements.



Additional material

ITS3 geometry



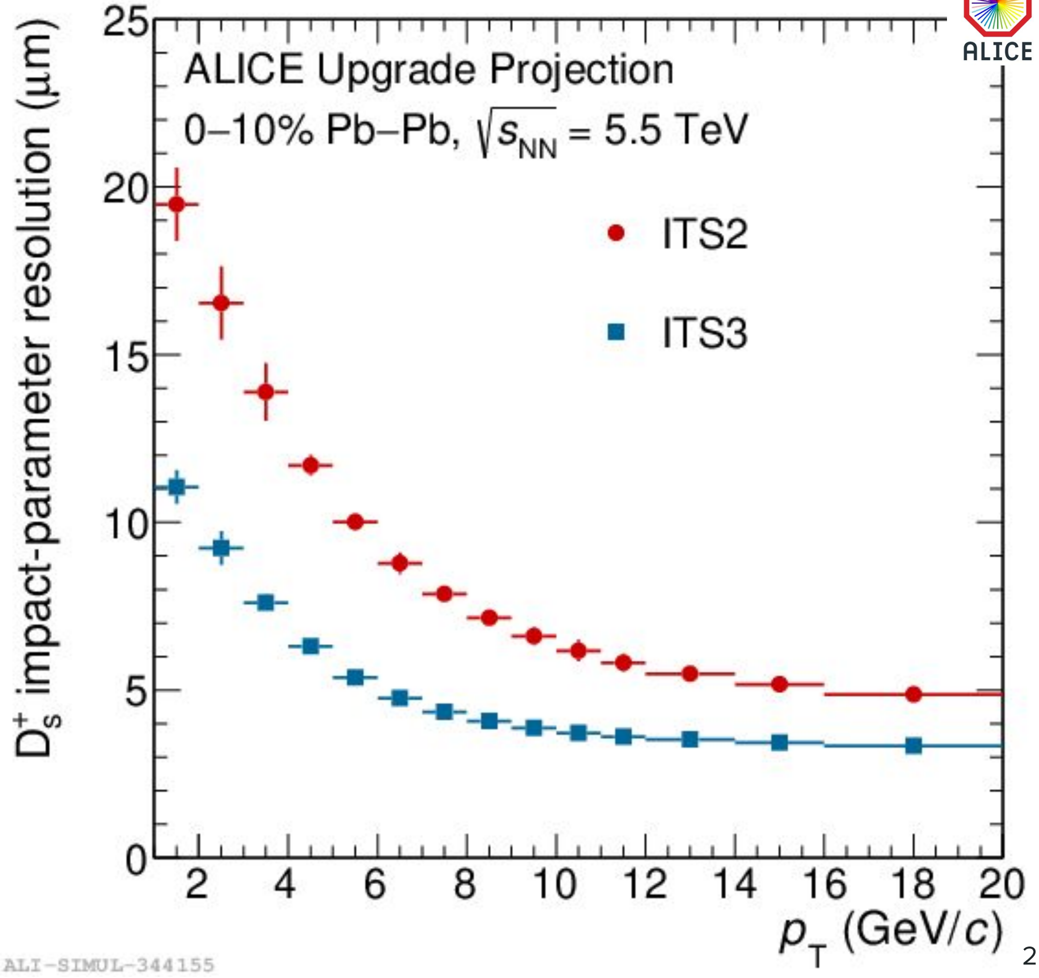


Beampipe inner/outer radius (mm)	16.0/16.5		
IB Layer parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length (sensitive area) (mm)	270	270	270
Pseudo-rapidity coverage[a]	±2.5	±2.3	±2.0
Active area (cm^2)	305	408	508
Pixel sensors dimensions (mm^2)	280×56.5	280×75.5	280×94
Number of pixel sensors / layer	2		
Pixel size (μm^2)	$O(15 \times 15)^b$		

ITS3 Letter of intent CERN-LHCC-2019-018

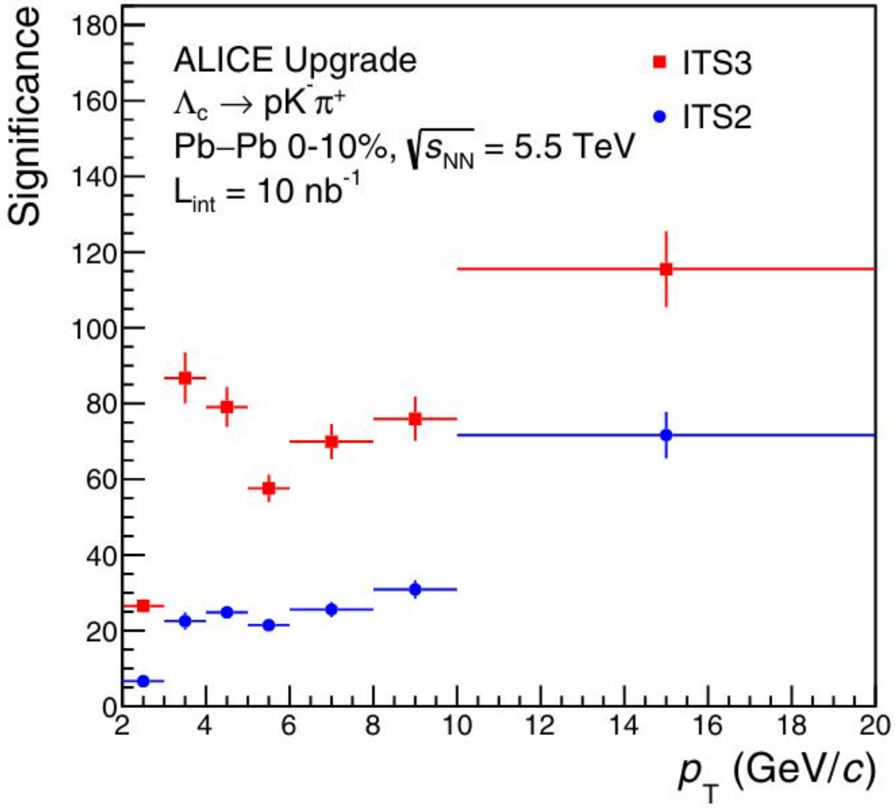
Non-prompt D mesons

- Highly sensitive to beauty-strange hadron production in quark gluon plasma
- Br(B^0_s → D^+_s + X) = (93 ± 25)%
- Higher background rejection resulting from improved track spatial resolution

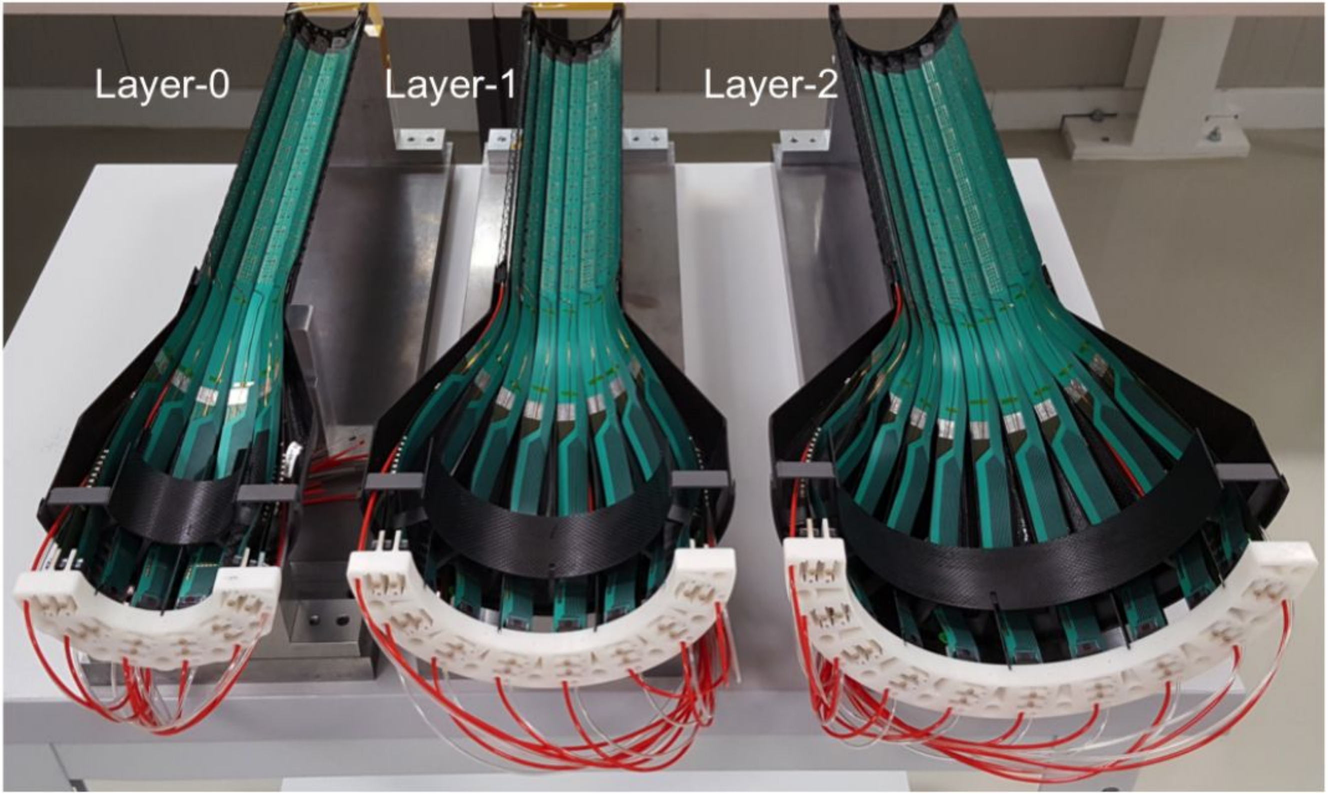


Better reconstruction of short-lived hadrons in ITS3

- Short lifetime:
  $c\tau(\Lambda^+_c)$ ~ 59 µm
  twice smaller than D^0 meson
- Decay tracks displaced O(10) µm from IP
- Significance of Λ_c in pion decay channel more than doubles in ITS3 for low momenta



Current inner tracking system ITS2 inner three layers



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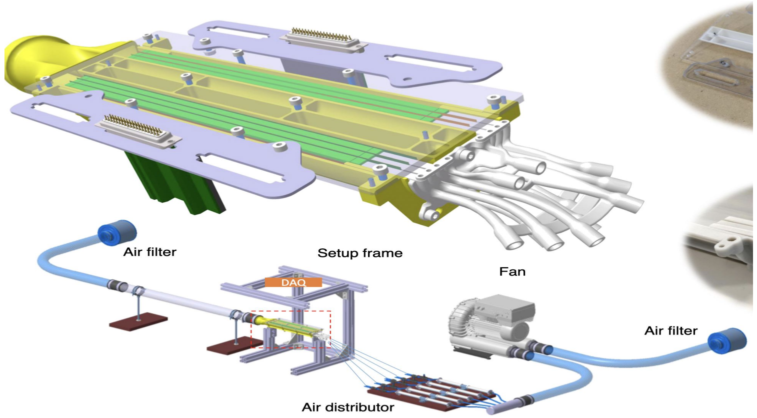
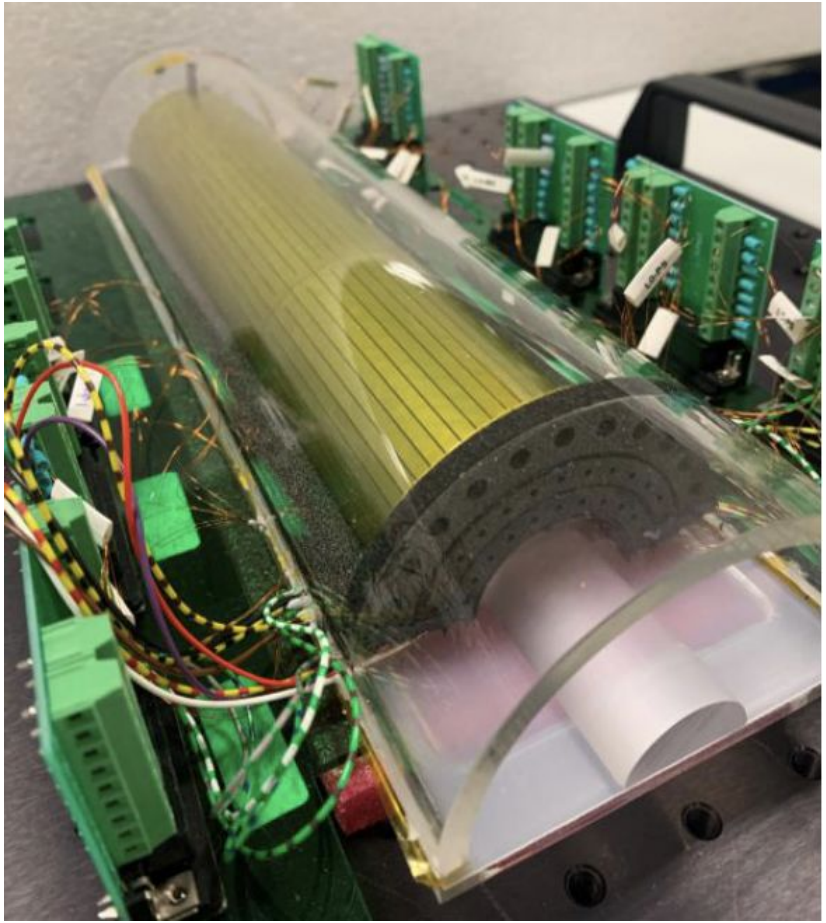
Air cooling

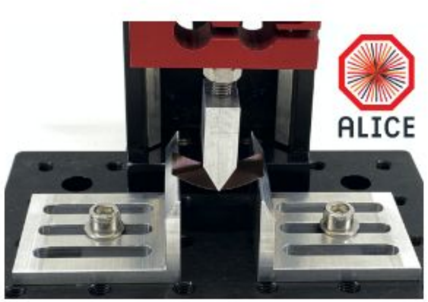
- Thermal and stability tests ongoing
- Development of models based on heating elements
- Placed in custom wind tunnel to study thermal and mechanical properties

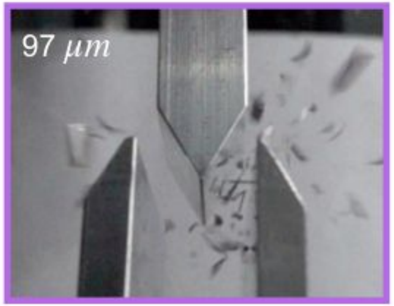


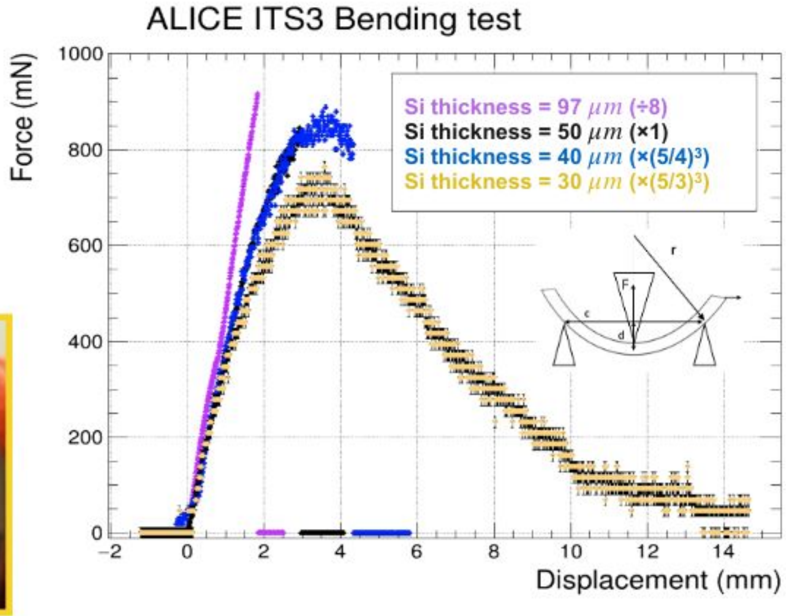


Bending tests

- Breaking point goes moves to smaller bending radii for thinner integrated sensors
- Bending force scales with the thickness to the third power

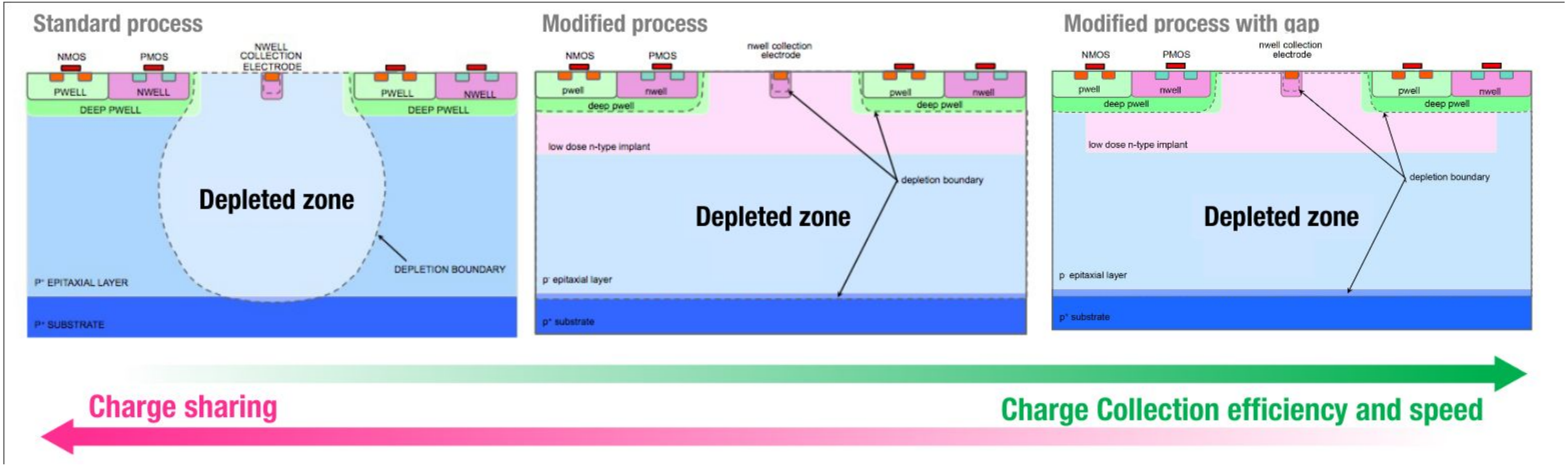






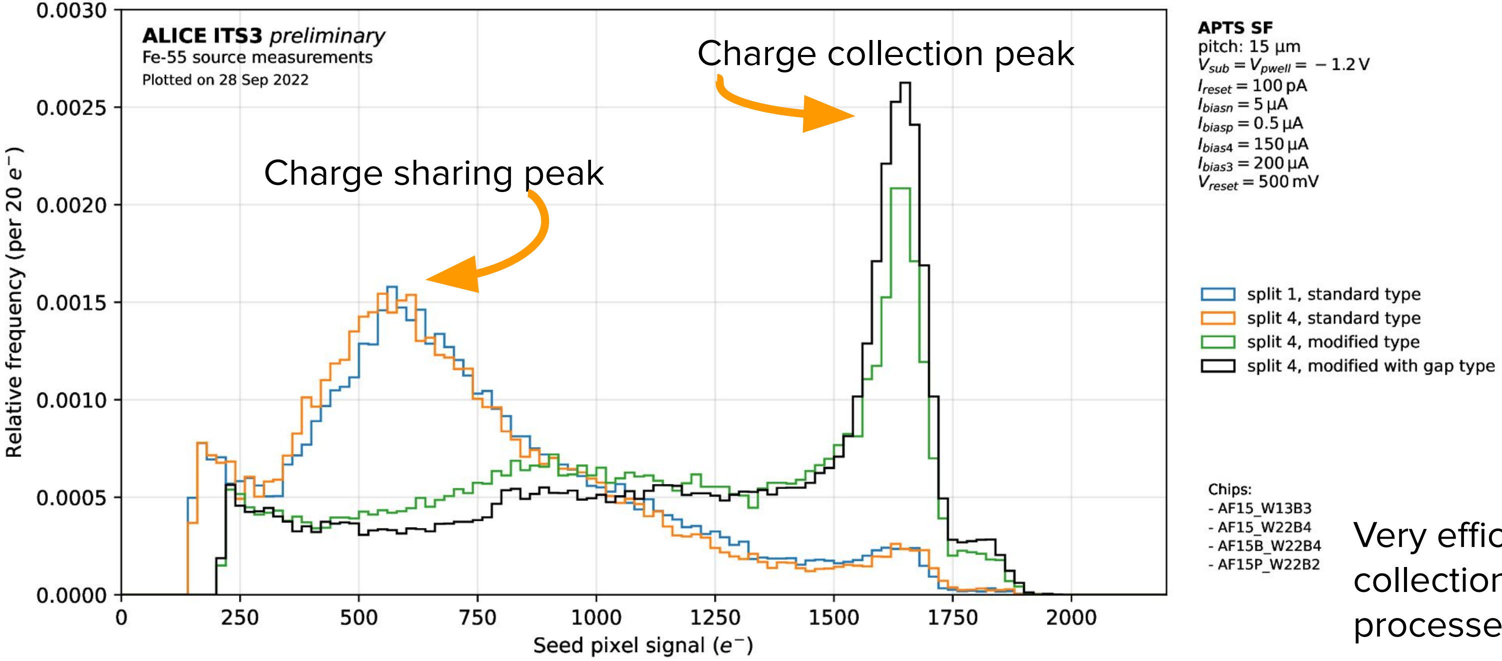
Different process modifications

- Motivated by better charge collection
- Higher speed may serve for monolithic sensors with timing functionality that could be applied in ALICE3



Analog pixel test structure results

Fe-55 results



Charge collection peak

Charge sharing peak

Very efficient charge collection for modified processes