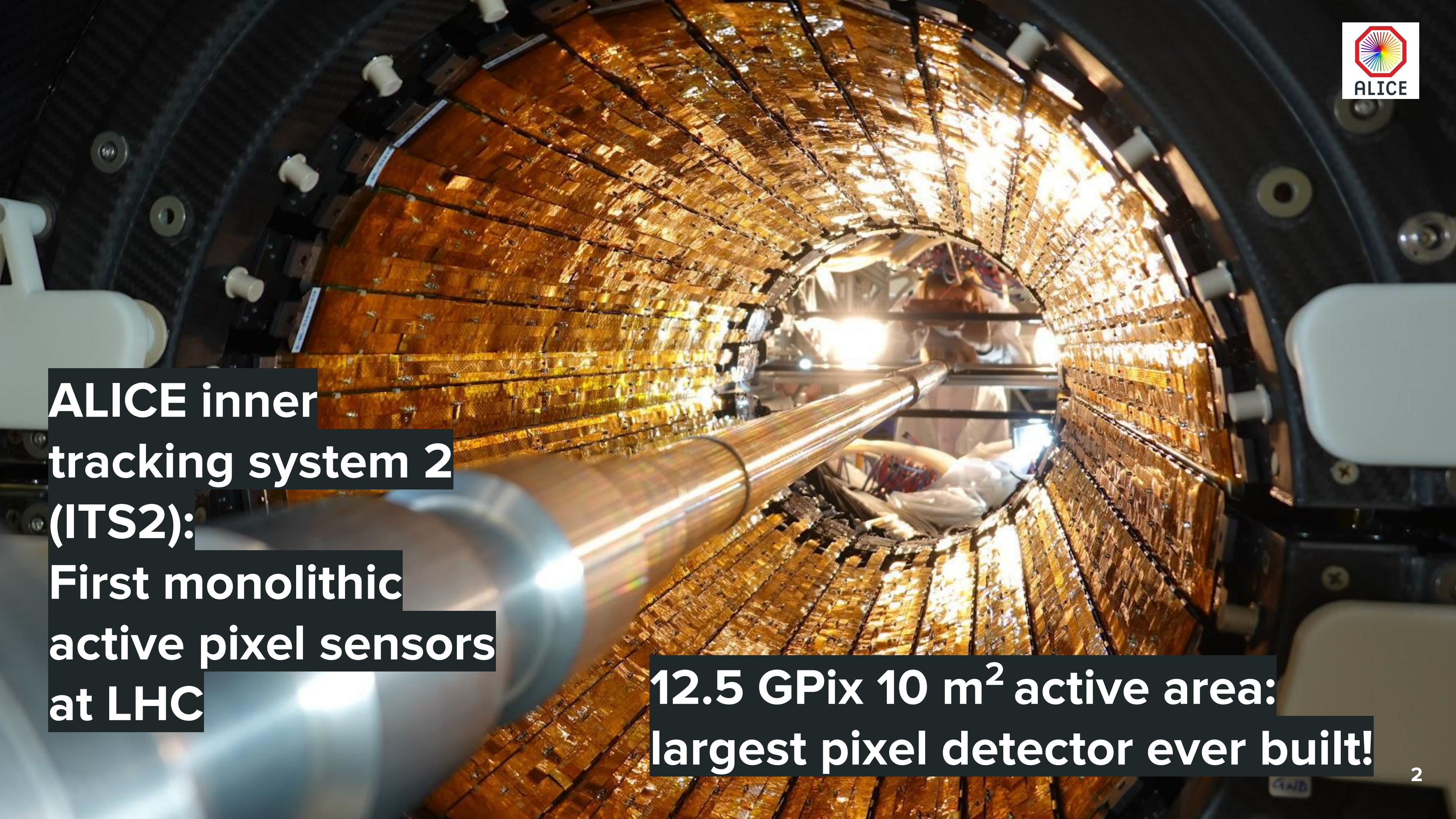
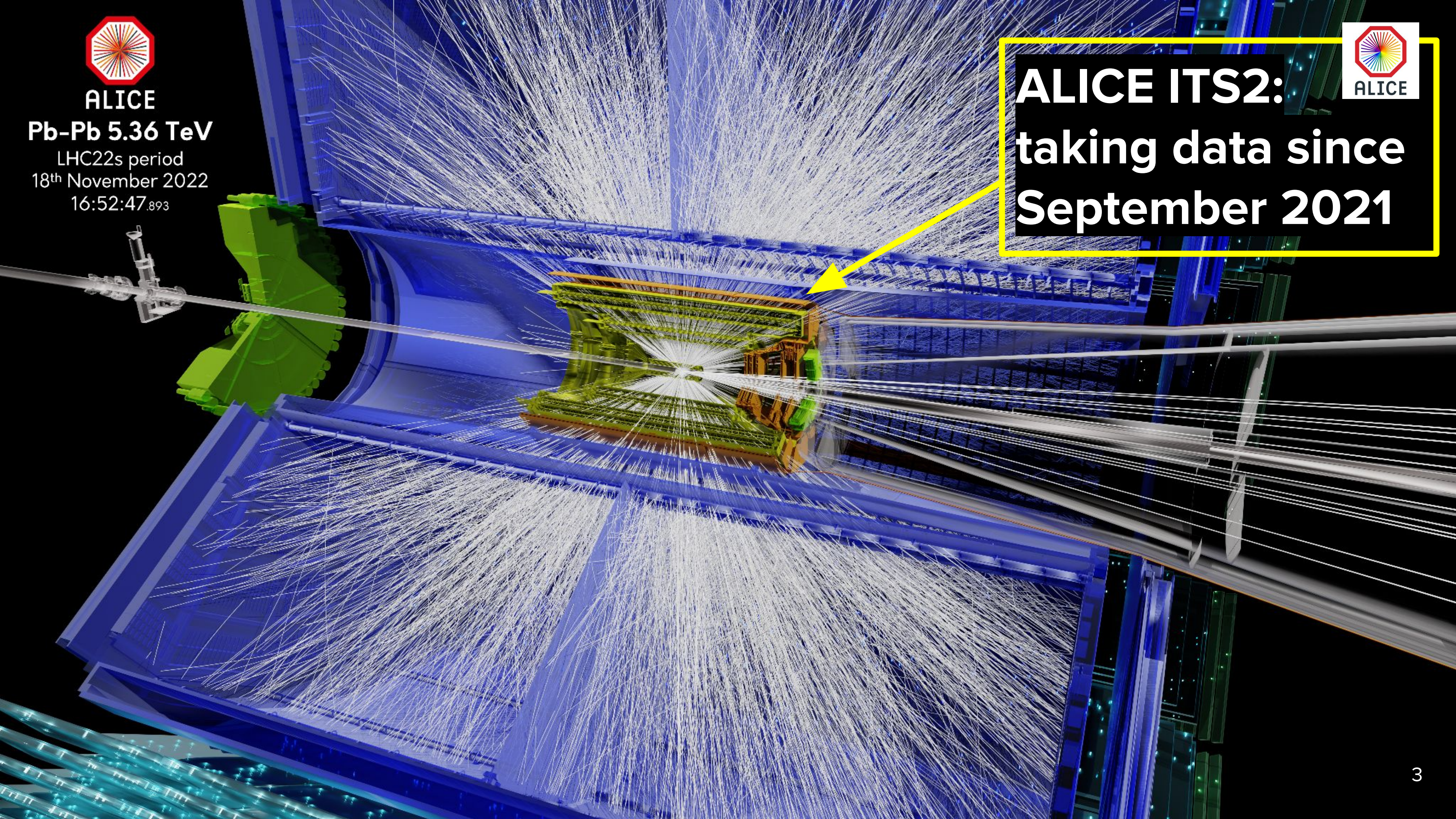
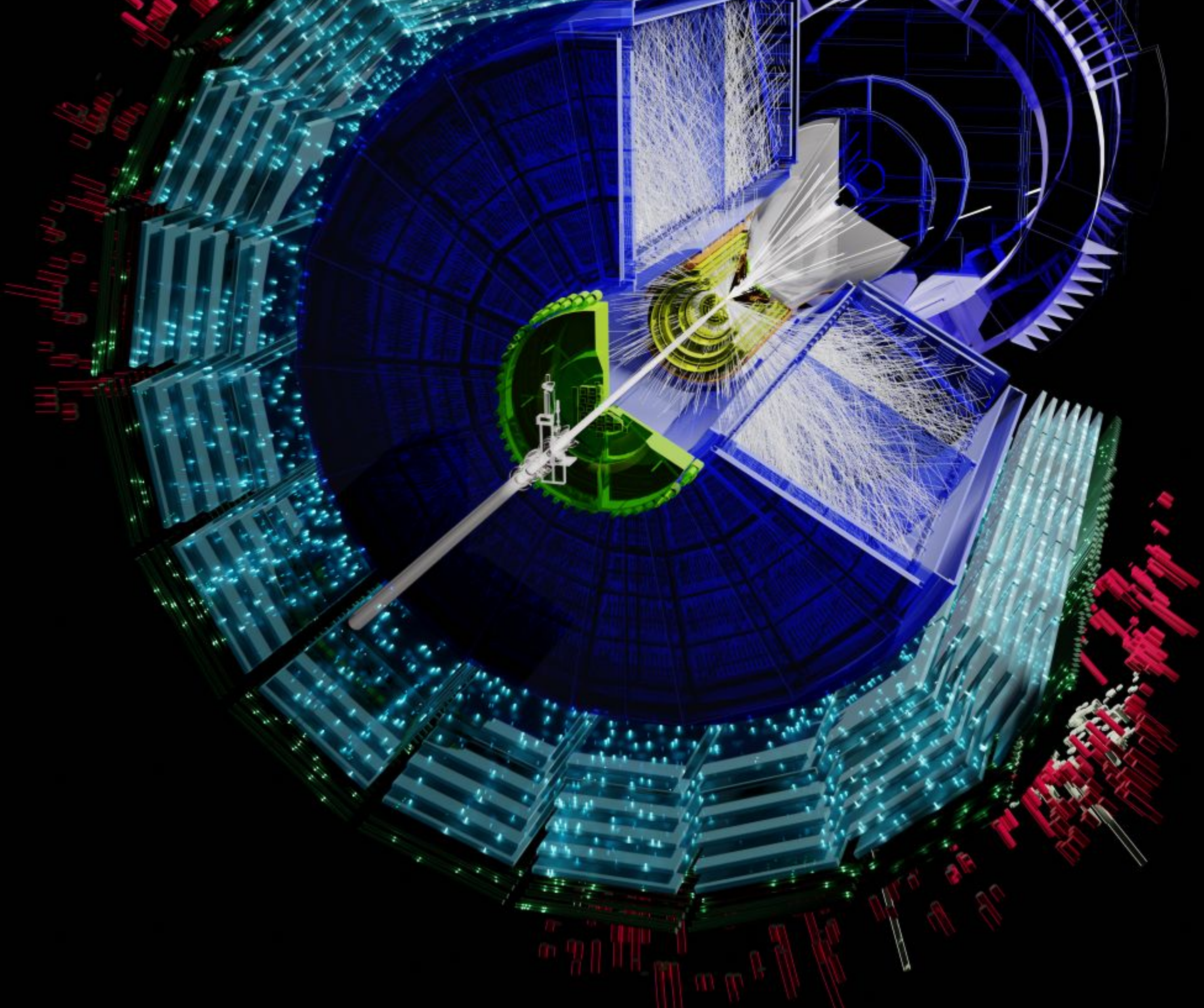
ALICE Detector R&D @Nikhef

Jory Sonneveld for the Nikhef ALICE group

jory.sonneveld@nikhef.nl


ALICE
ALICE inner tracking system 2 (ITS2):
First monolithic active pixel sensors at LHC
12.5 GPix 10 m² active area: largest pixel detector ever built!


ALICE
Pb-Pb 5.36 TeV
LHC22s period
18th November 2022
16:52:47.893
ALICE ITS2:
taking data since
September 2021
ALICE



Three inner tracker layers to be upgraded 2026-2028

ALICE

Pb-Pb 5.36 TeV

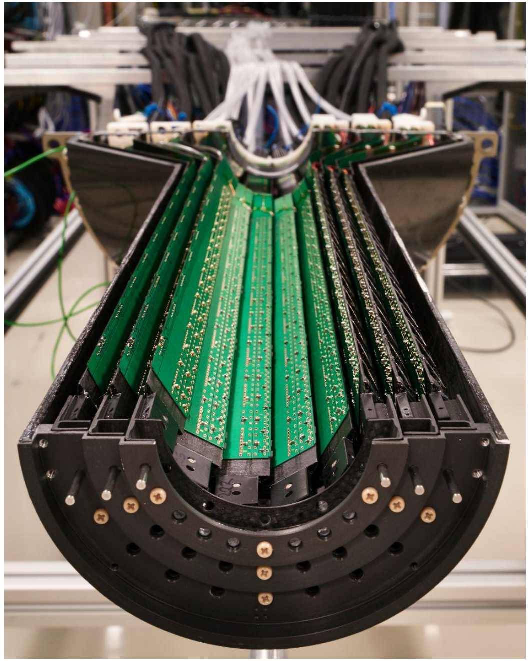
LHC22s period

18th November 2022

16:52:47.893

Future upgrade of the ALICE inner tracking system

0.36% X_0 per layer



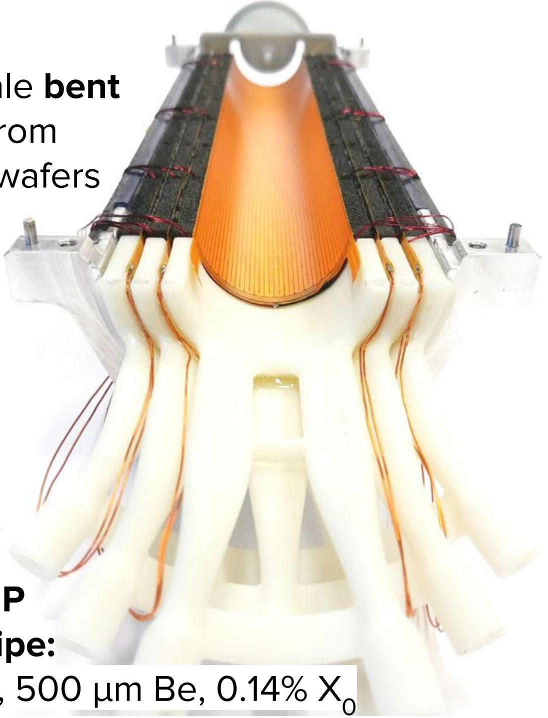
Inner three layers with 432 modules to be replaced in 2026-2028

22 mm from IP

ITS2

Very low material budget! 0.05% X_0 per layer

Stitched, wafer-scale **bent** sensors from 300 mm wafers



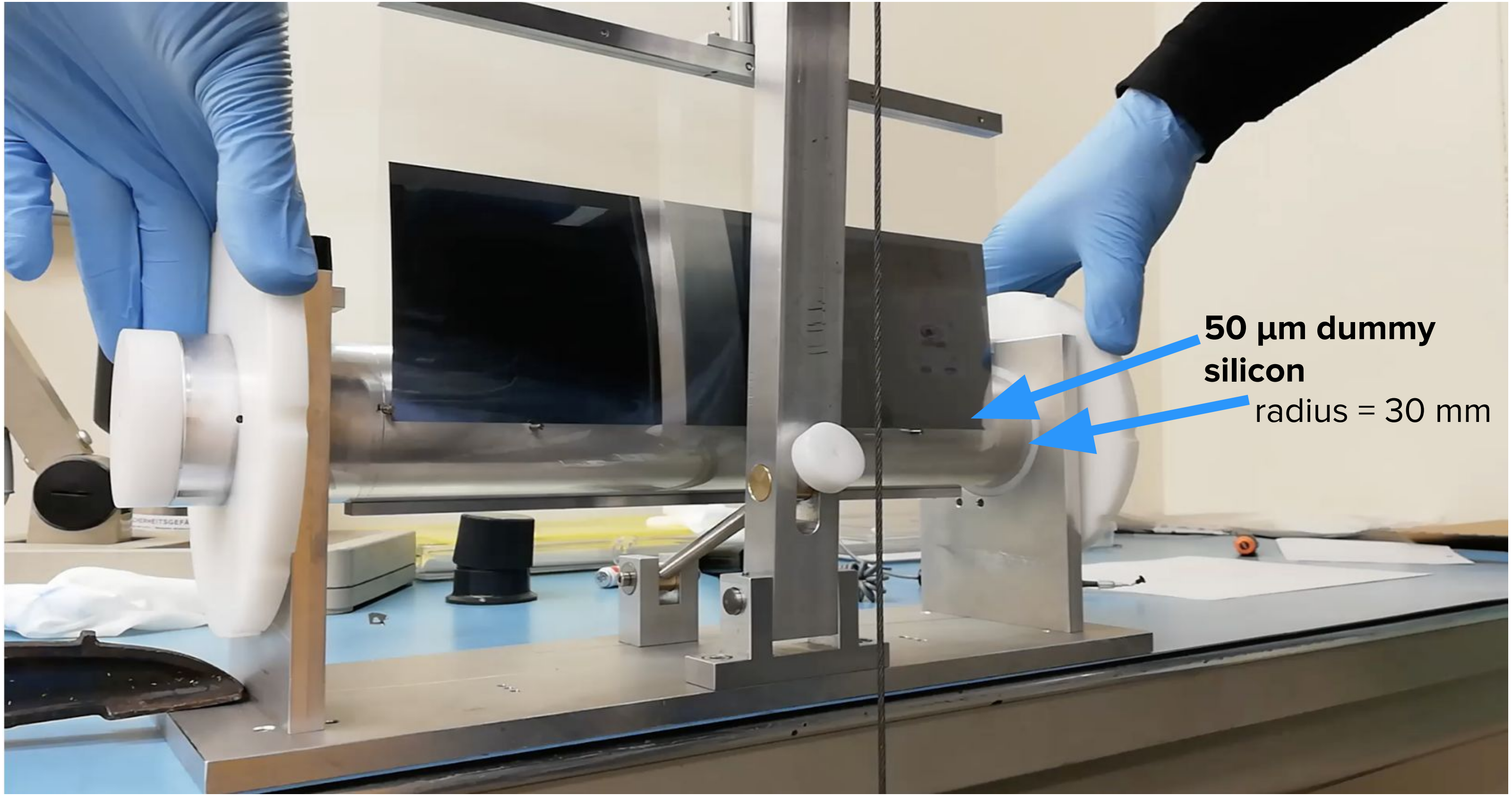
18 mm from IP

New beam pipe:

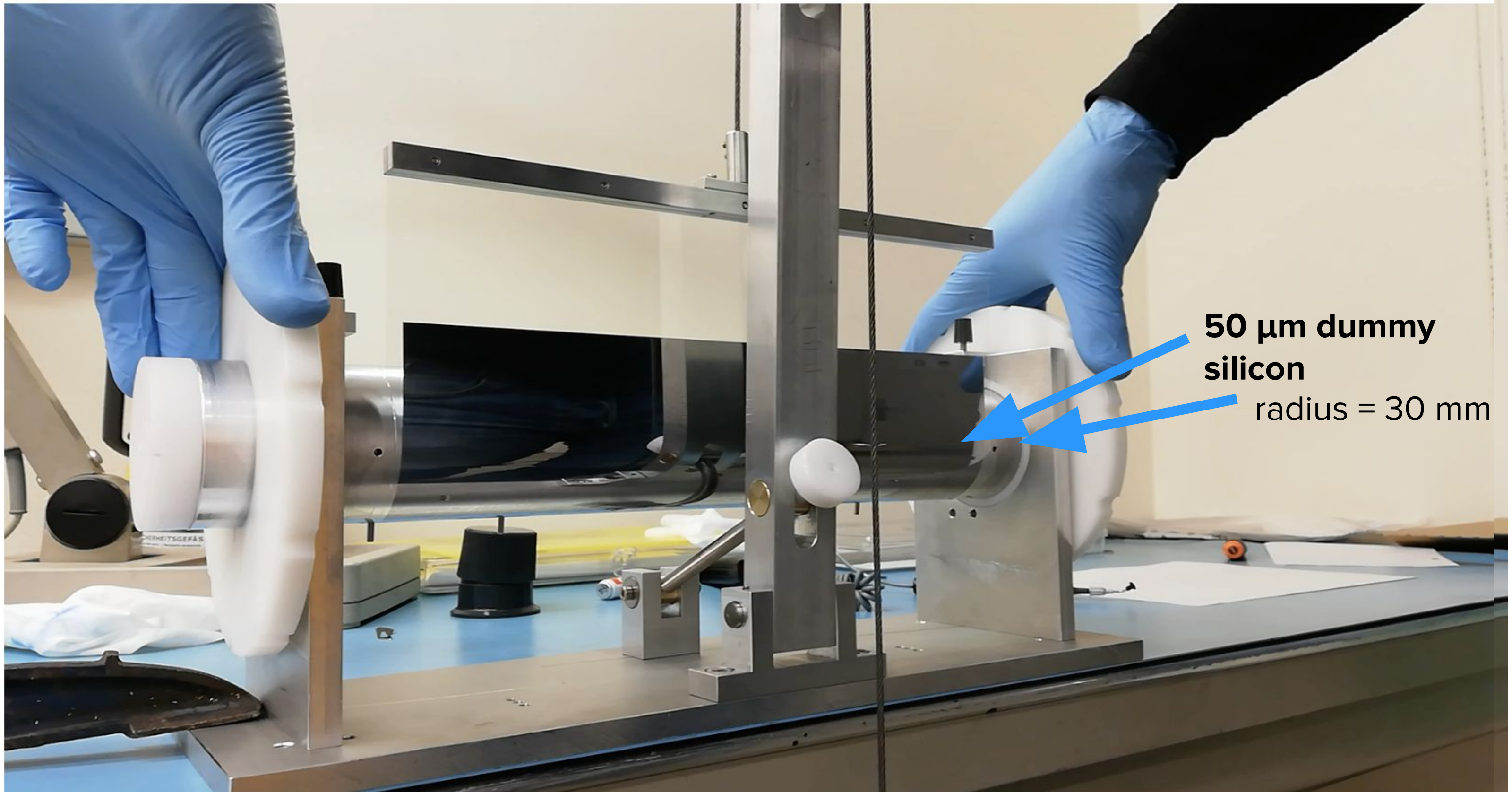
16 mm radius, 500 µm Be, 0.14% X_0

ITS3

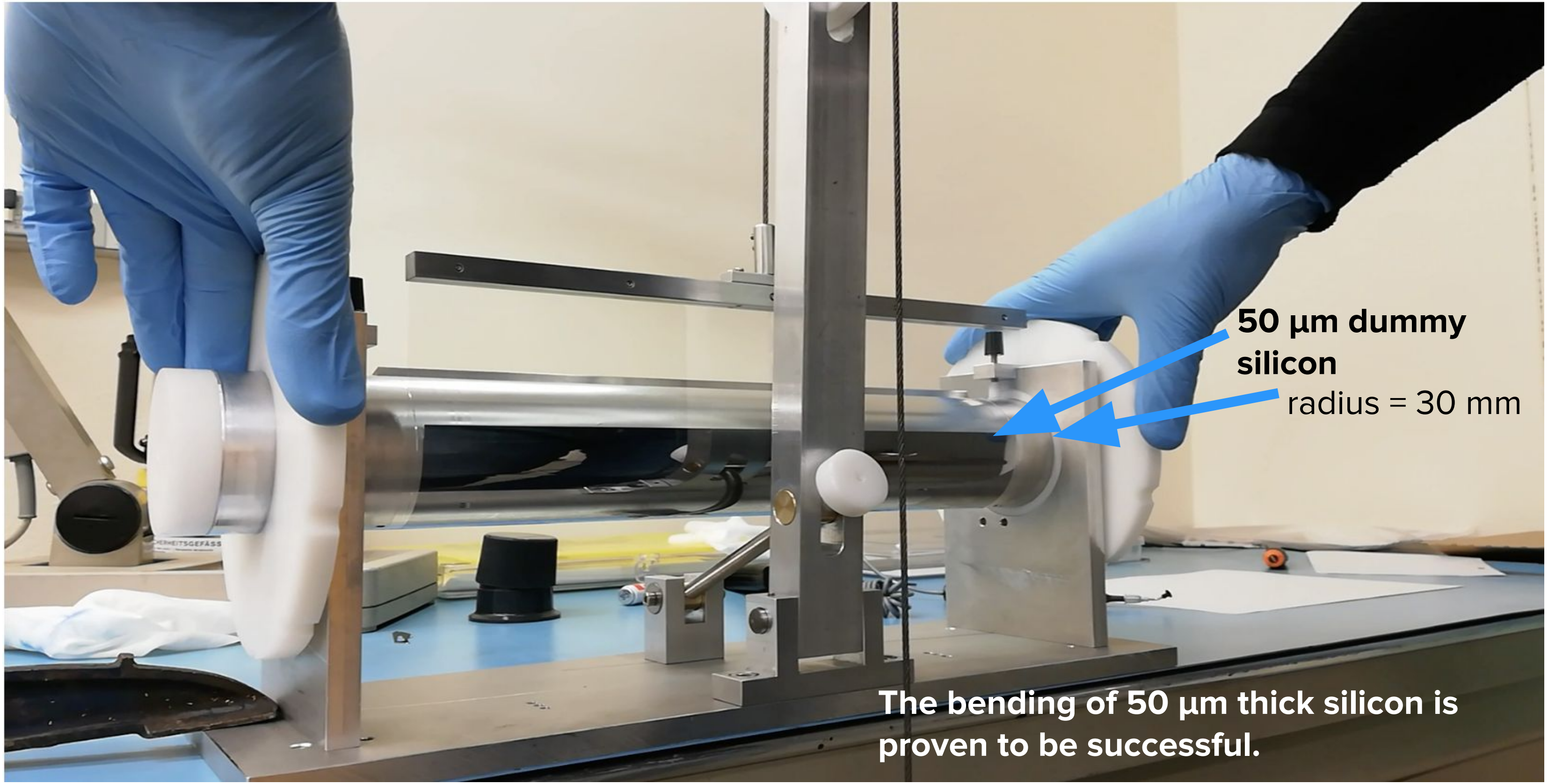
Can we bend these silicon chips?



Can we bend these silicon chips?

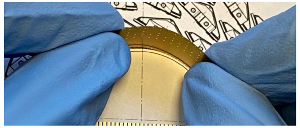


Can we bend these silicon chips?



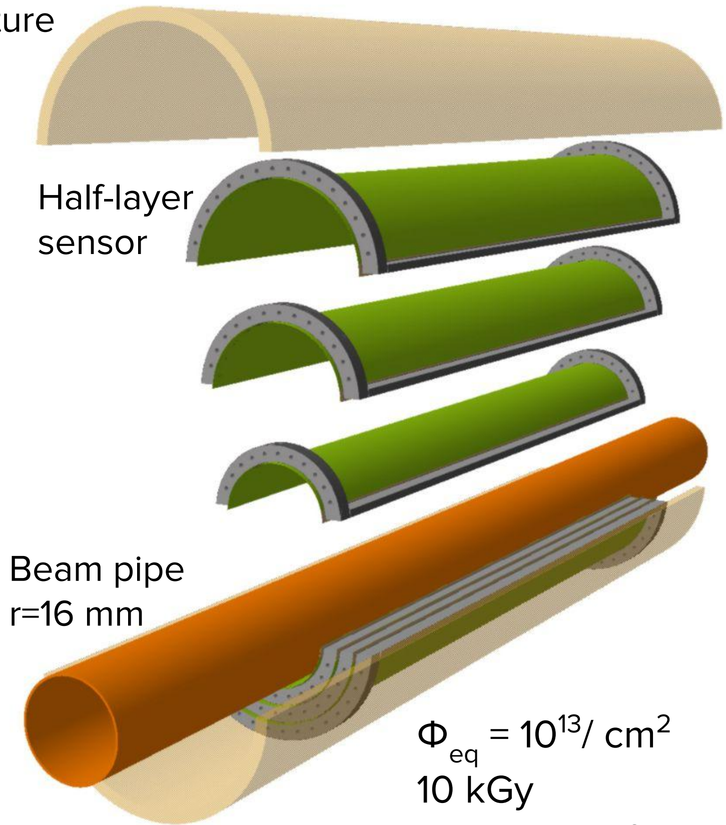
2028: ALICE ITS3 for Run 4

Each half layer is only one pixel sensor!



Stitching and **bending**

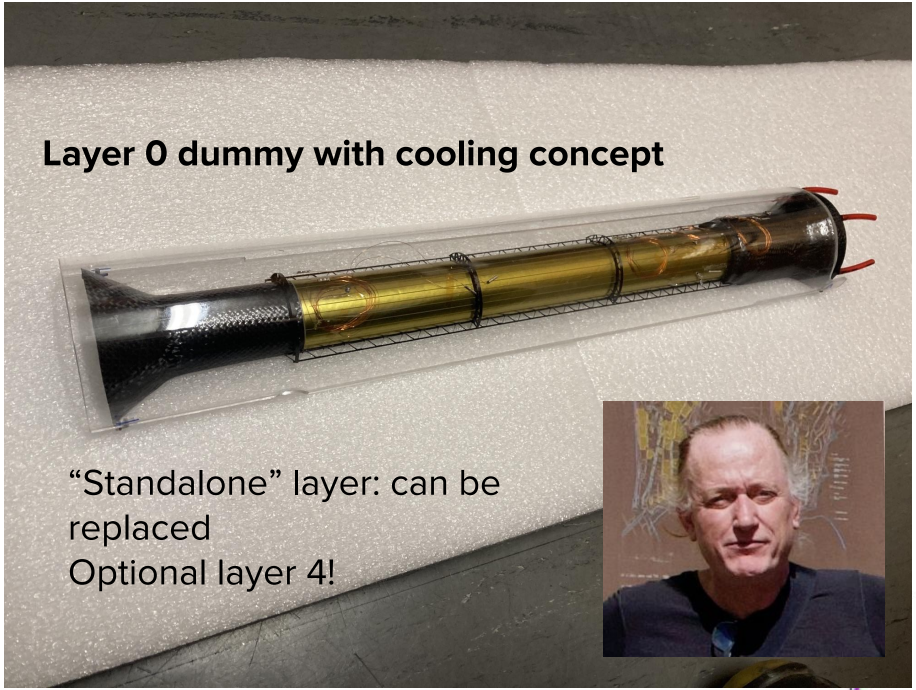
- Material: $X/X_0 \approx 0.05\%$
- **6 half-layer sensors** with 3-5 wafer-scale monolithic active pixel sensors (MAPS)
- Half layer sensor of size of 280 x 53.3 mm^2 in layer 0
- Thinned to 40-50 µm
- Mechanically held in place by carbon foam
- **Air cooling** to reduce material (now: water cooling)



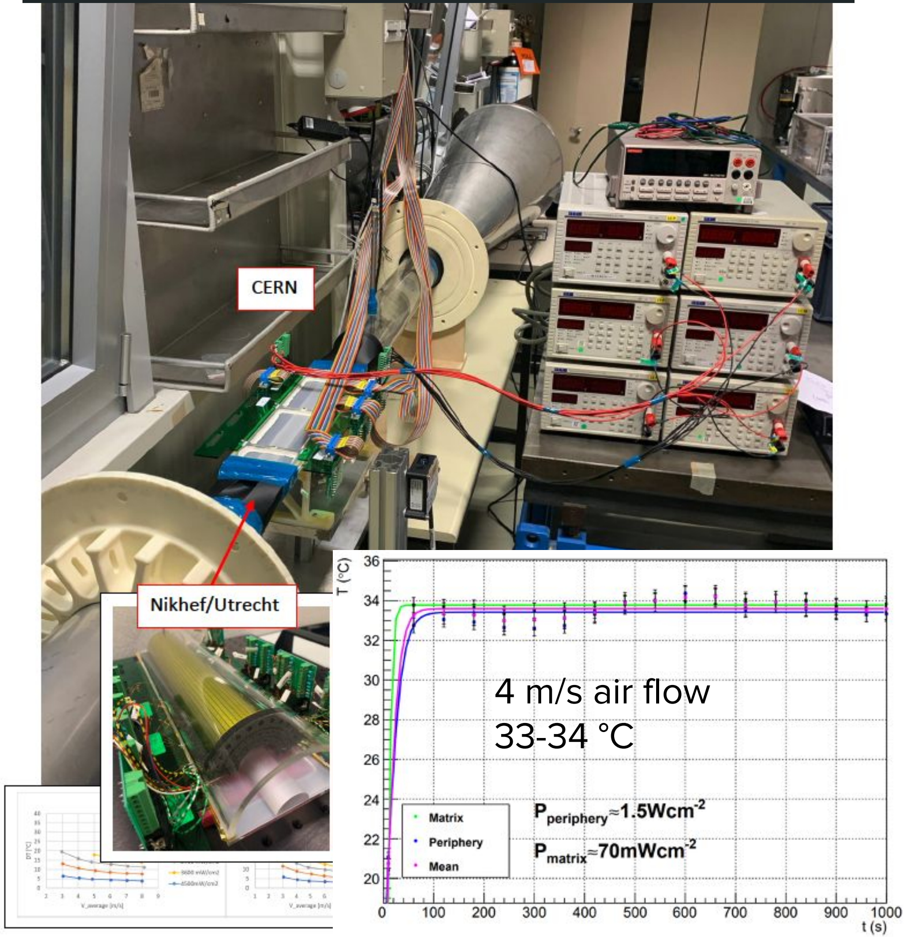
$\Phi_{eq} = 10^{13}/\ cm^2$
10 kGy
2.2 MHz/cm^2

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

ITS3 Mechanics and Cooling at Nikhef/Utrecht



Wind tunnel studies

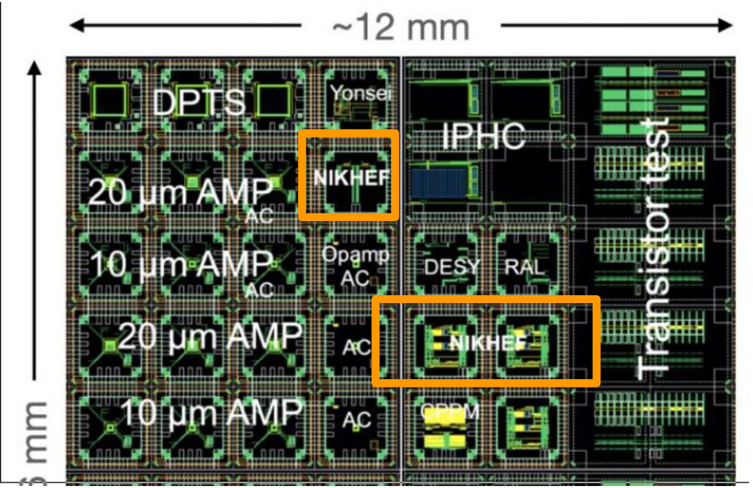


ITS3 ASIC design at Nikhef: ET

First submission 2021 multilayer reticle 1:

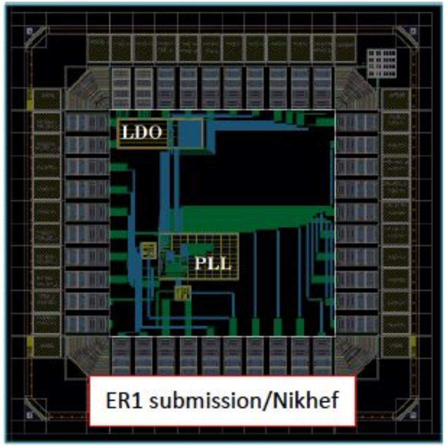
- Bandgap reference circuits
- Temperature sensor
- Voltage controlled oscillator (VCO)

A. Yelkenci *et al* 2023 *JINST* **18** C02017

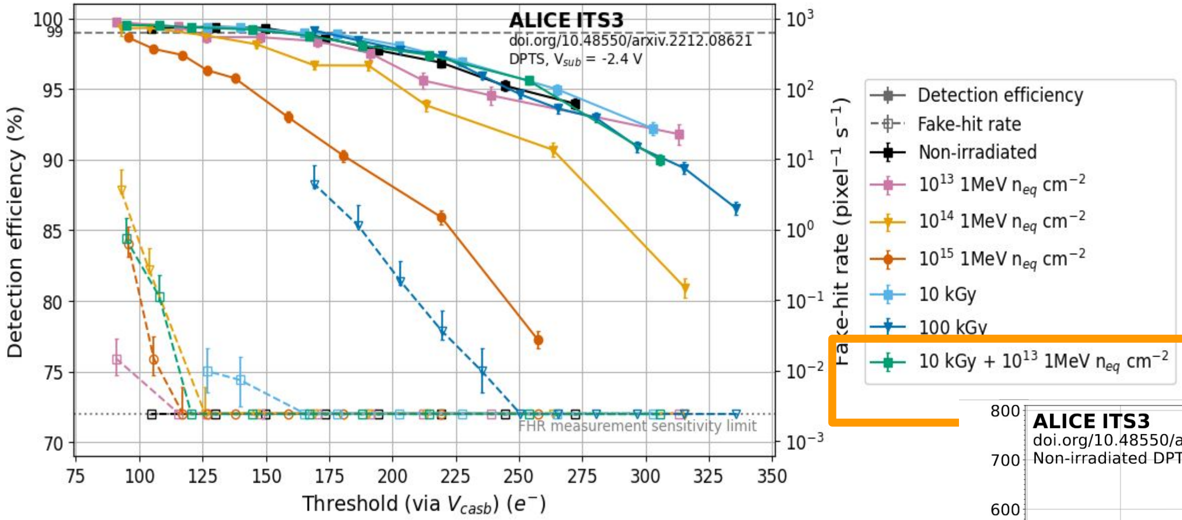


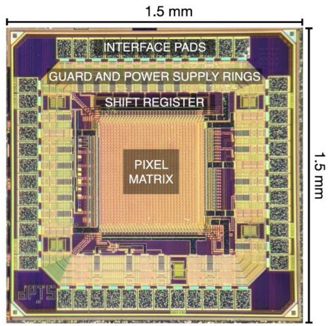
Engineering run 1: stitched sensors

- 2-stage low drop out (LDO) regulator
- phase locked loop (PLL)
- Serializer at 10.28 Gb/s



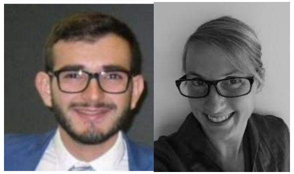
ITS3 sensor characterization: Detector R&D



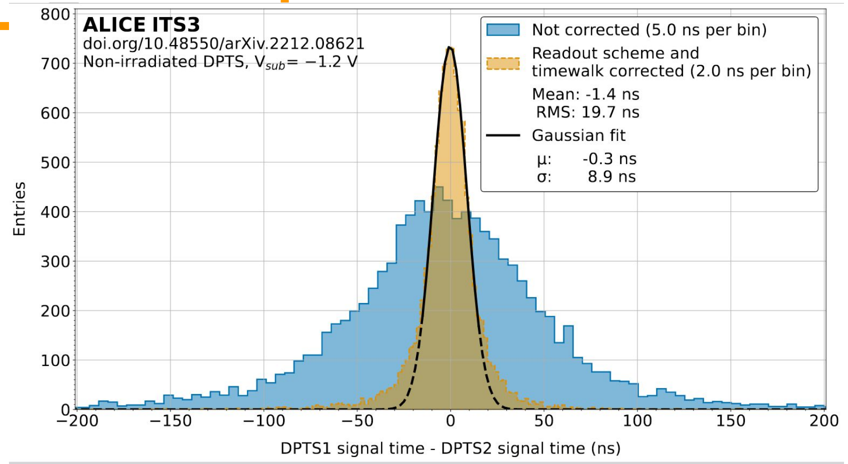


Results published in

doi:10.48550/arXiv.2212.08621

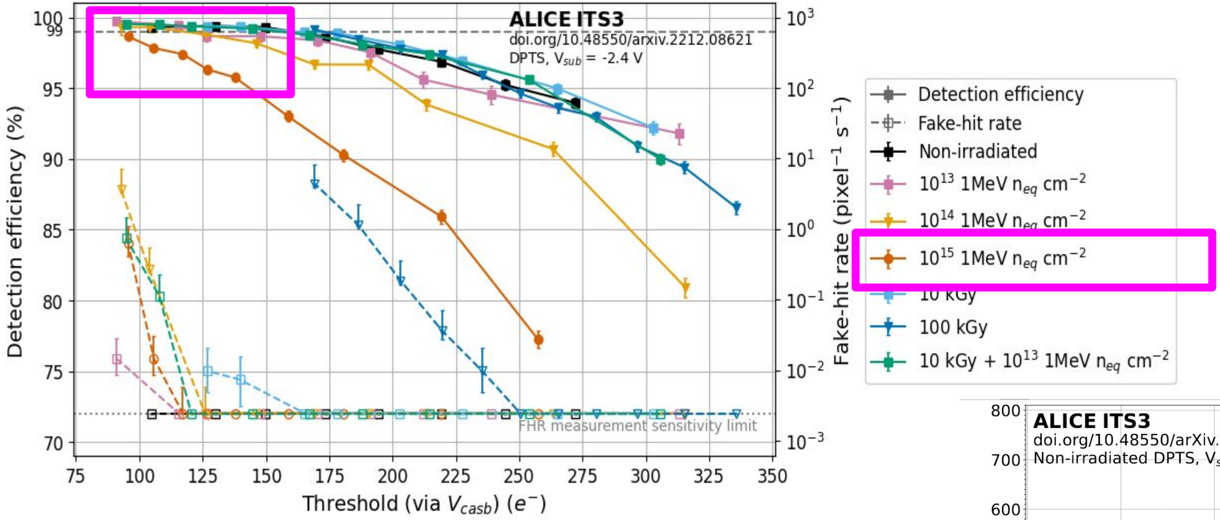


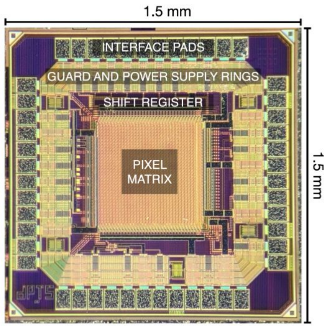
ITS3 required fluence and dose



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

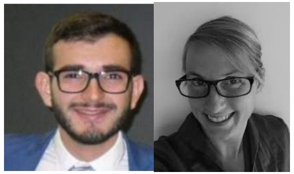
Sensor characterization: Detector R&D





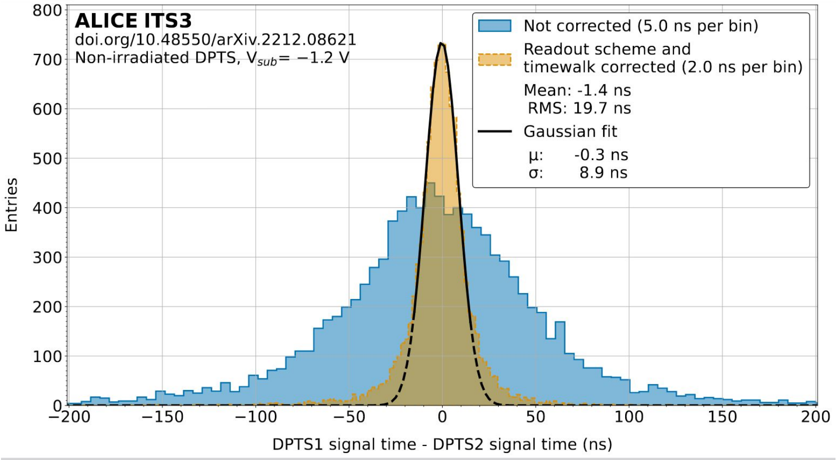
Results published in

doi:10.48550/arXiv.2212.08621



Efficient at room temperature after 100 ✕ ITS3 fluence

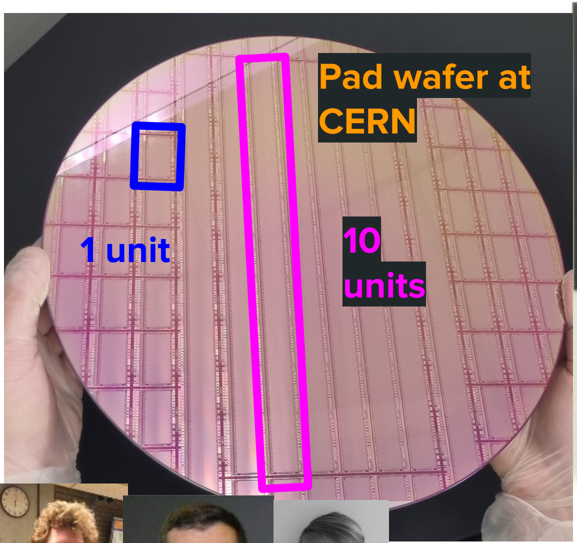
- Operated at room temperature!
- 100% efficient after ITS3 fluence
- **Sensor still operable at 99% efficiency at 20°C after Φ_{eq} = 10^{15} / cm^2**

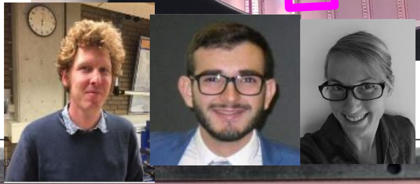


Large structures arriving soon: Nikhef preparations

ALICE

- First MAPS for high energy physics using stitching
- First full structures will come to Nikhef soon!
- “MOST”: 2.5 x 259 mm, 0.9 MPixel (18 x 18 μm^2)
- Carrier board designed at Nikhef/Utrecht
- Preparing for characterization





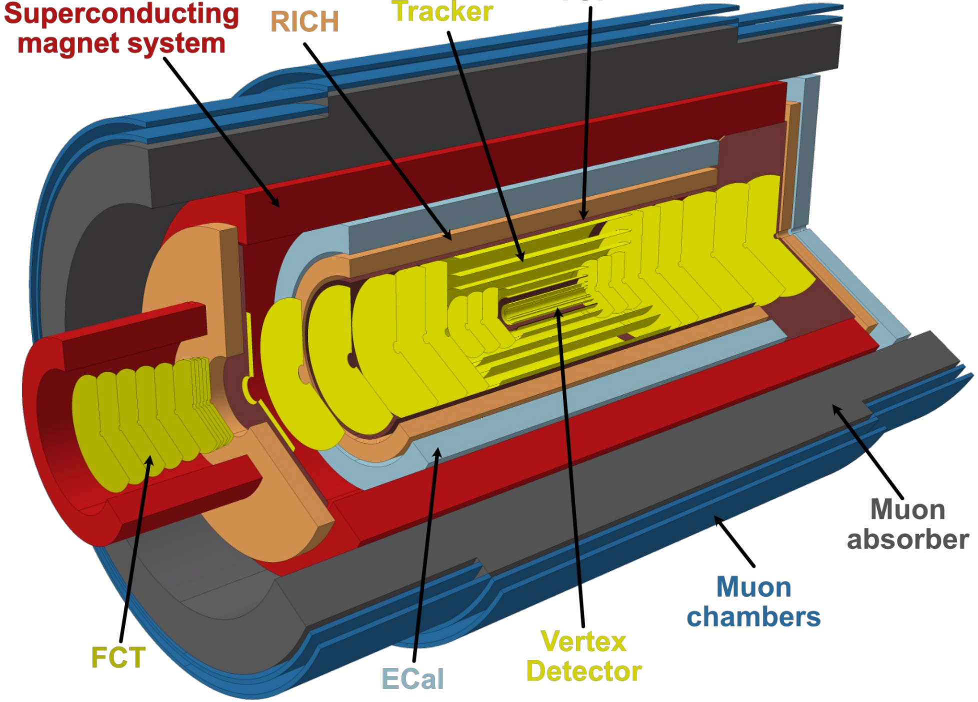
2034 and onward: ALICE3

Exciting Physics & Exciting new Technologies

Steering group members

Upgrade Coordinator	Chapter convener	Co-coordinator of the tracker chapter
		

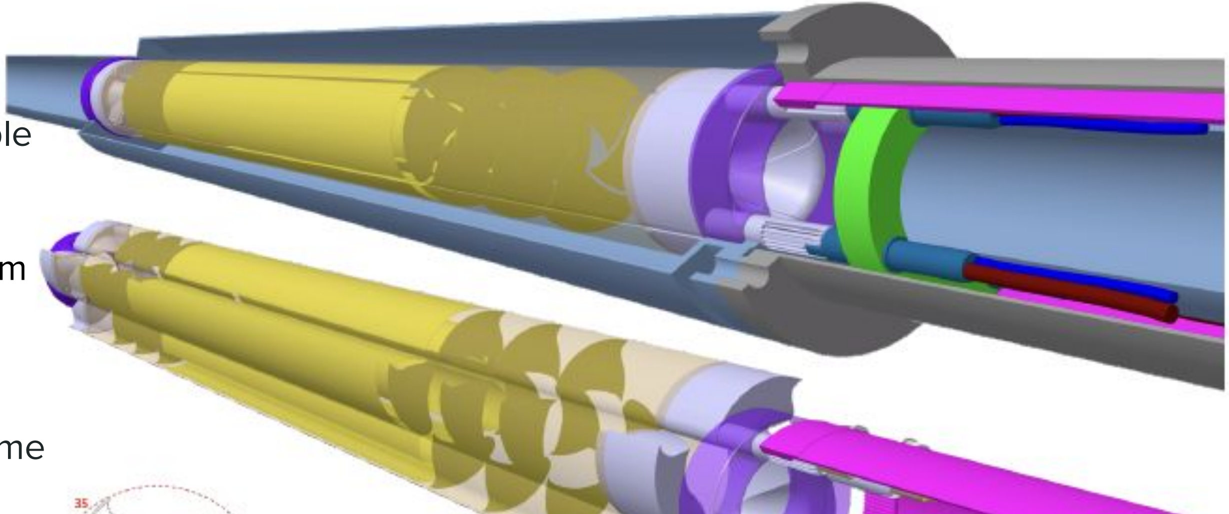
- Compact (r ≃2m, z ≃ 8m)
- Large acceptance, |η|<4, p_T > 0.02 GeV/c
- Superconducting magnet system
- Max field: B = 2 T (0.5 T runs foreseen)
- Continuous readout and online processing
- Pointing resolution ~3-4 μm and p_T resolution better than 1% @1 GeV/c
- Particle Identification (PID) in a wide range of momenta and |η|<4



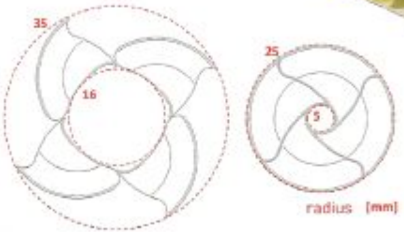
Innermost layer fluence: 1e16 / cm^2: similar to ATLAS, CMS phase 2 constraints
Innermost layer rate: 94 MHz/cm^2 and maximum power consumption: 70 mW/cm^2

ALICE3 at Nikhef: inner tracker

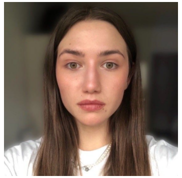
- Iris in-vacuum retractable vertex tracker at just 5 mm from beam line
- Spatial resolution 2.5 μm with 10 μm pitch pixels
- 1.5 m^2 inner barrel time-of-flight layer at 19 cm and $|\eta| < 1.75$ with time resolution of 20 ps



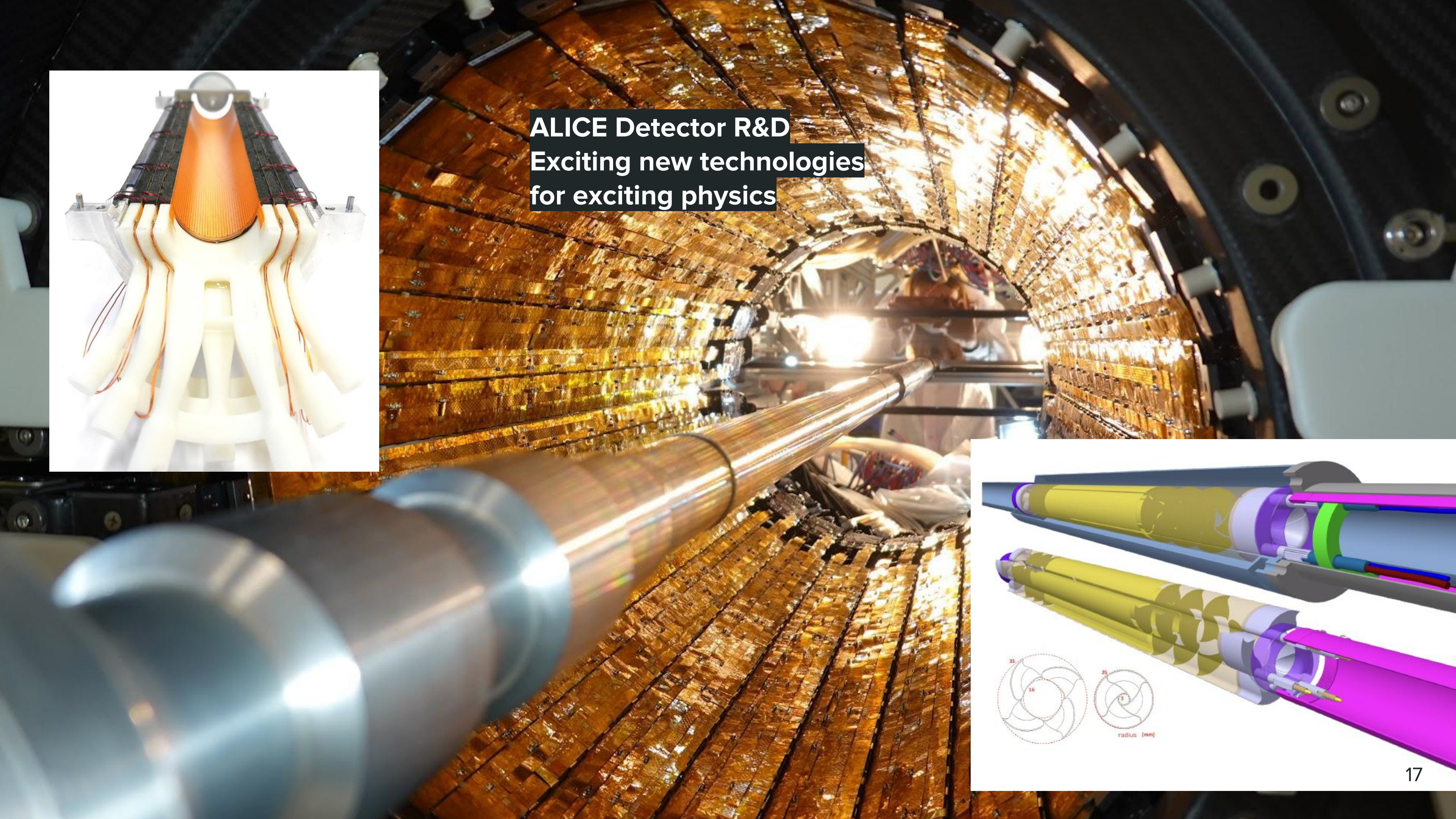
Timing: synergy with LHCb and ATLAS



Nikhef will contribute to inner tracker time of flight layer
Simulations and **timing characterization** for sensor development ongoing at Nikhef

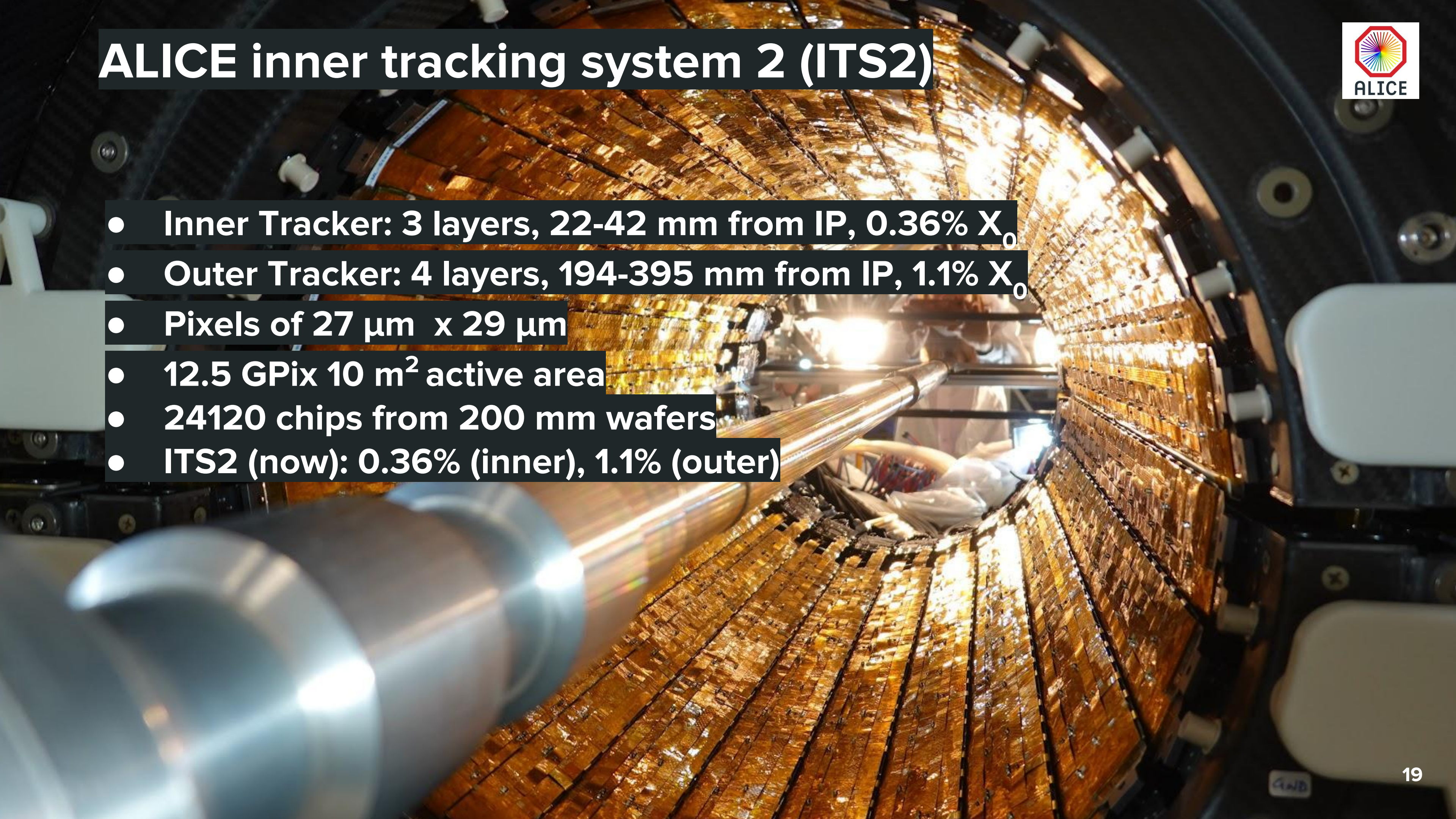



ALICE Detector R&D
Exciting new technologies for exciting physics



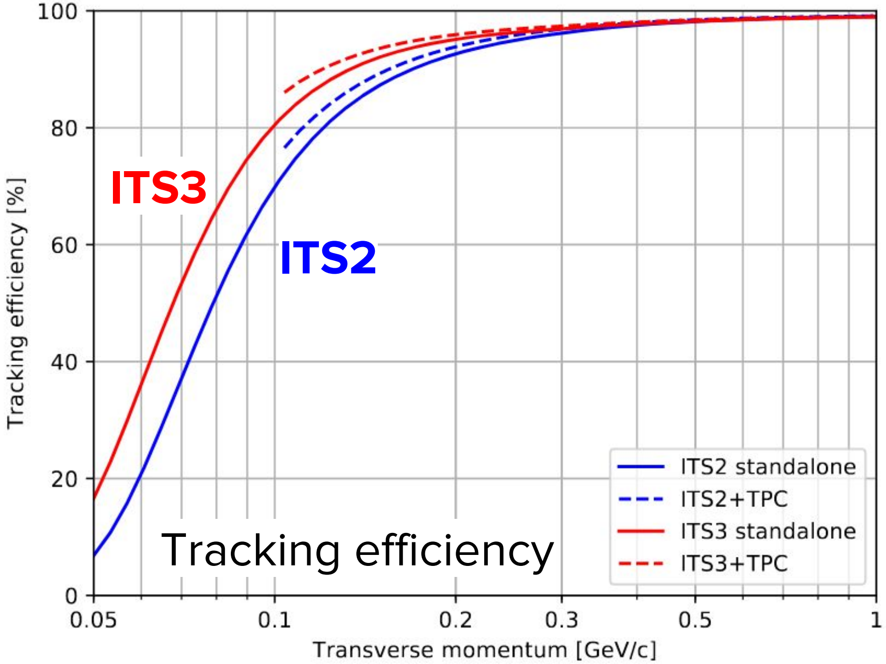
Additional material

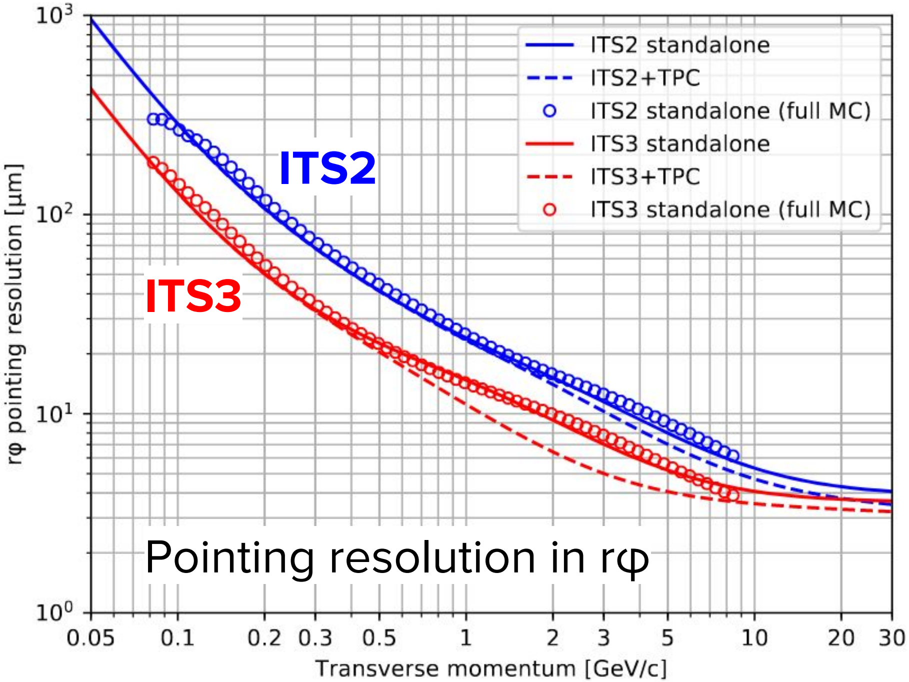
ALICE inner tracking system 2 (ITS2)



- 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
- 12.5 GPix 10 m^2 active area
- 24120 chips from 200 mm wafers
- ITS2 (now): 0.36% (inner), 1.1% (outer)

ITS3: more precise vertexing and tracking





Large improvement especially at low p_T

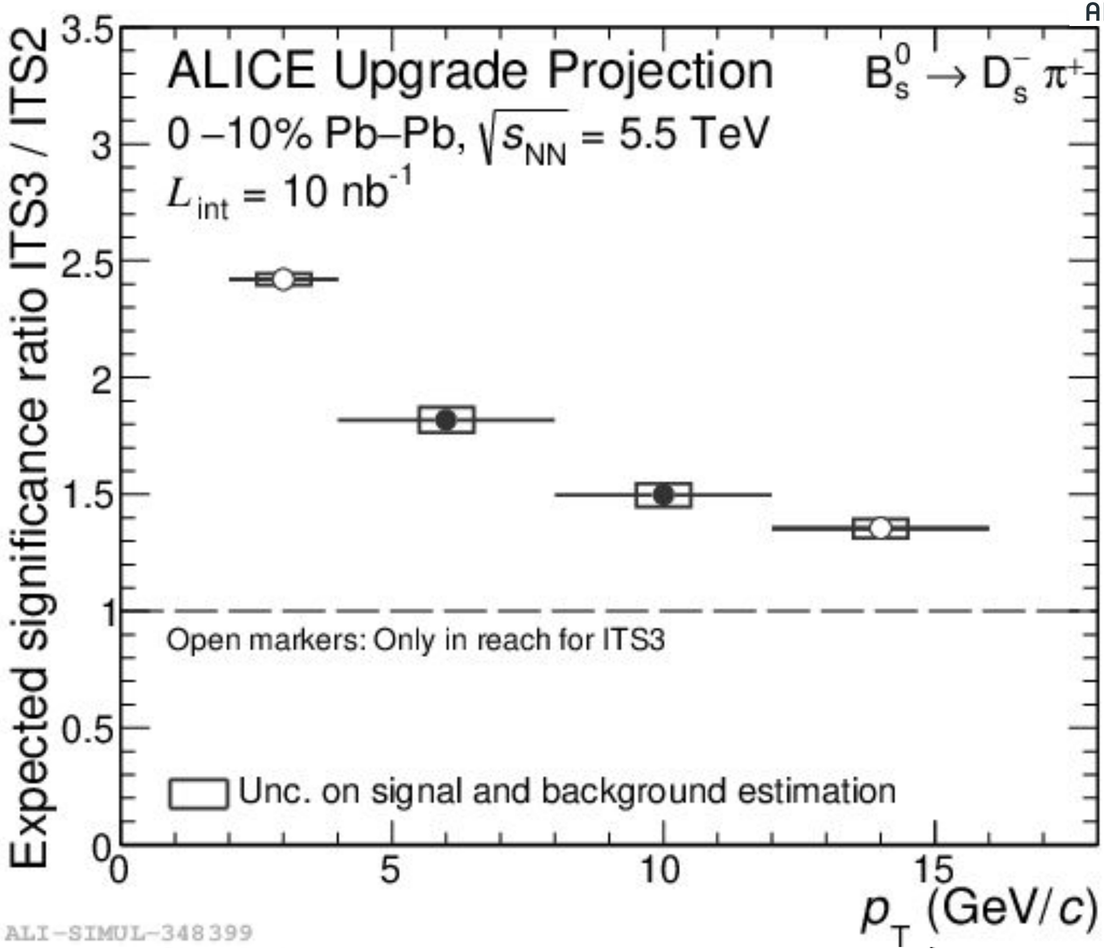
Factor 2 improvement over all momenta

ITS3 Letter of intent CERN-LHCC-2019-018

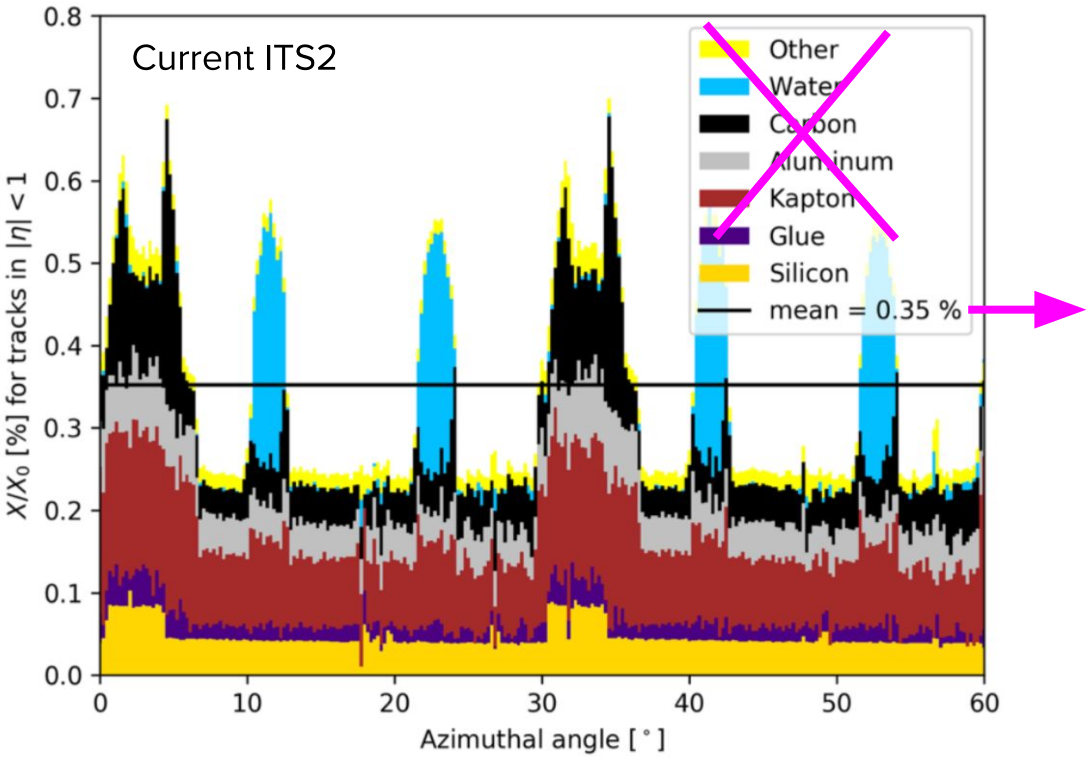
Strange beauty particles

- For studies of hadronisation in heavy ion collisions
- The Compact Muon Solenoid (CMS) Experiment made first measurement B^0_S / $B_{not\ S}$ 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!



Remove “unnecessary” material from ITS2



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

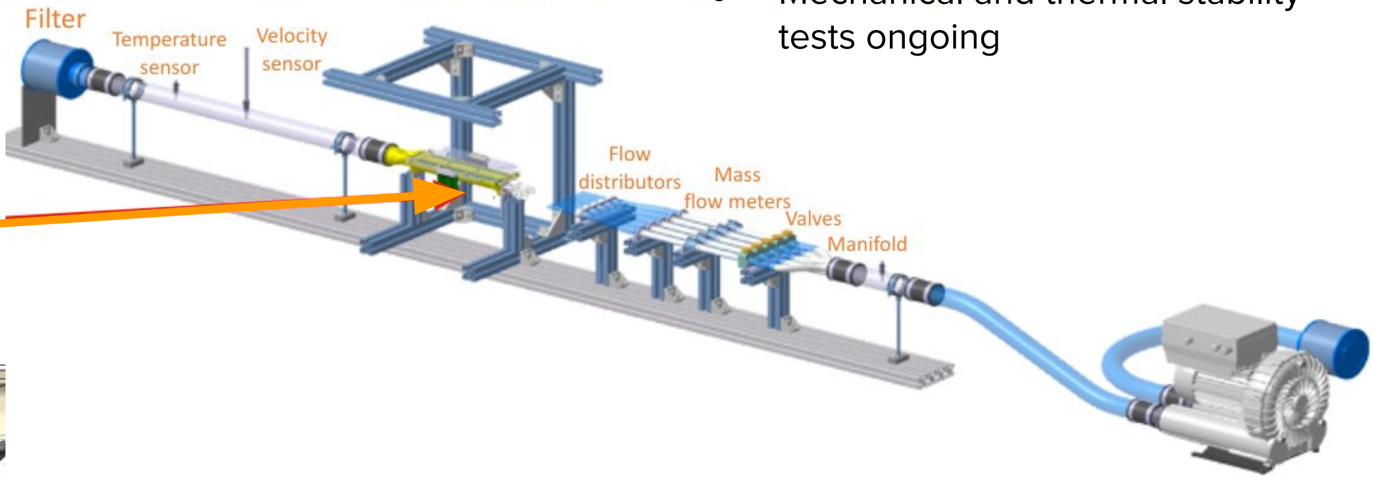
Mean 0.05% per layer

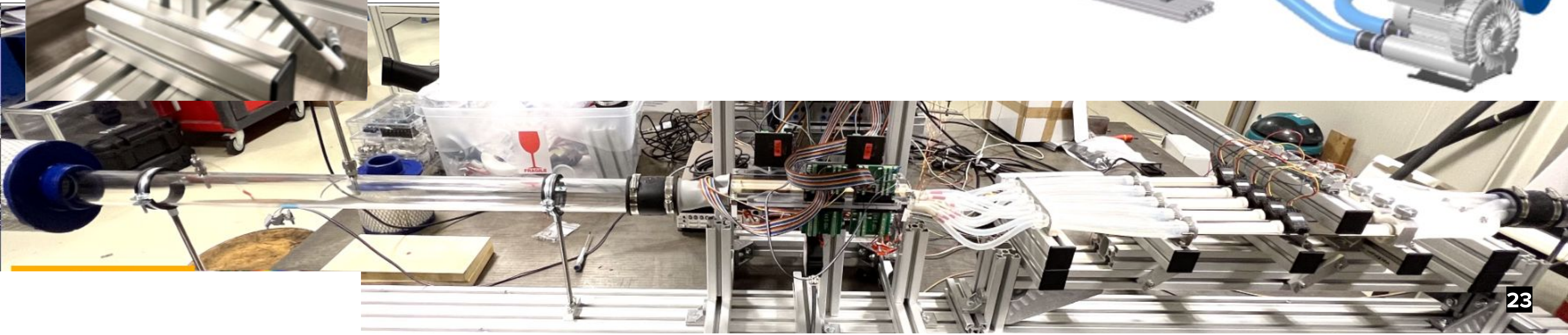
- Water cooling → replace with air cooling. Requires < 20 mW/cm^2
- Less mechanical support (carbon, glue) needed for large, bent sensors!

ITS3 Letter of intent CERN-LHCC-2019-018

Testing the air cooling

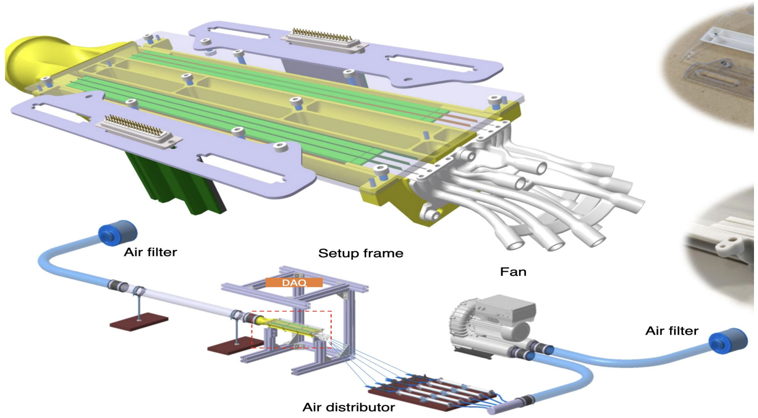
- Setup commissioned
- Mechanical and thermal stability tests ongoing

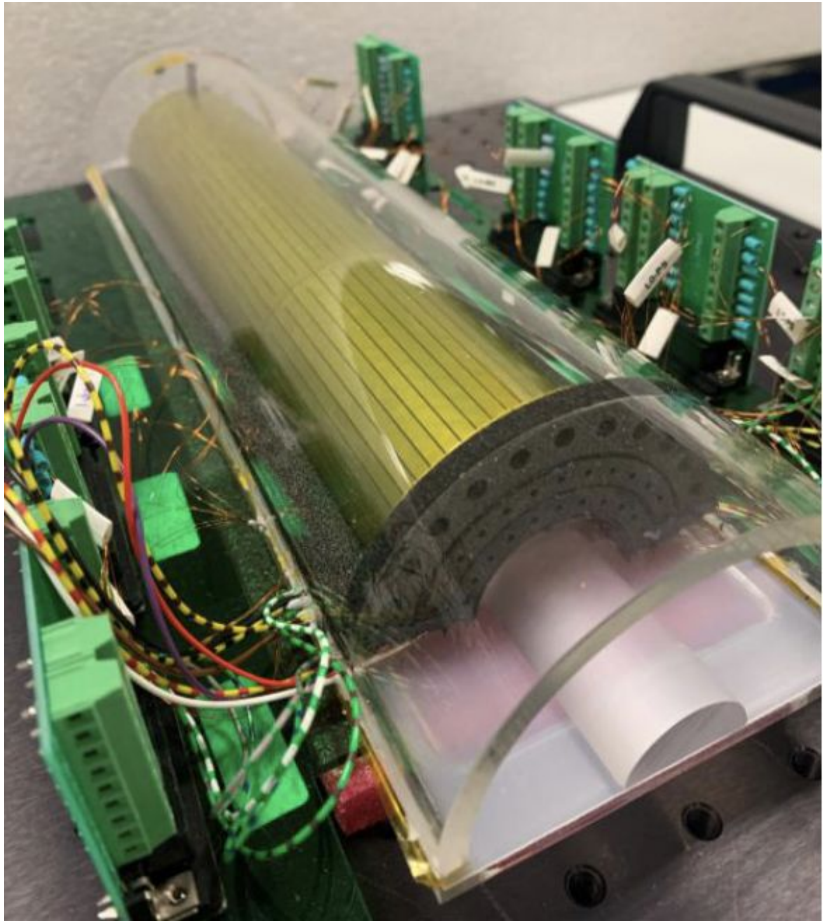




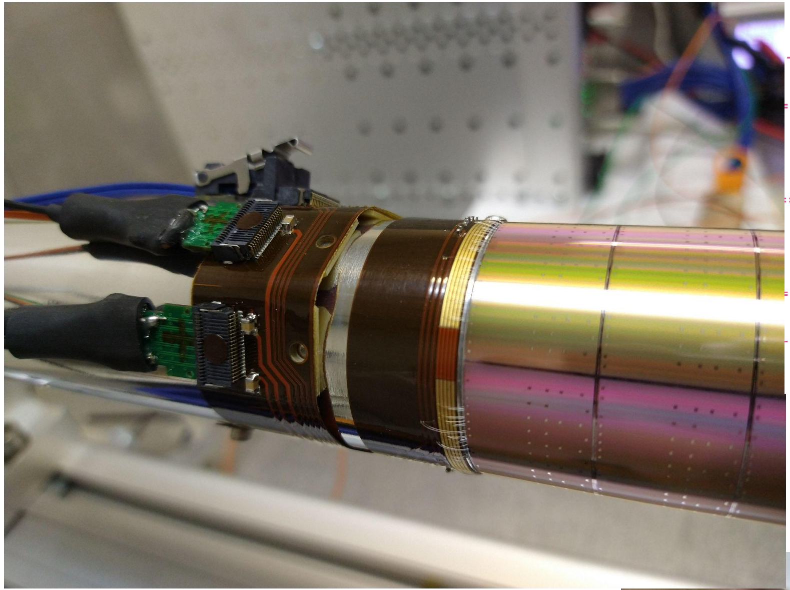
Air cooling

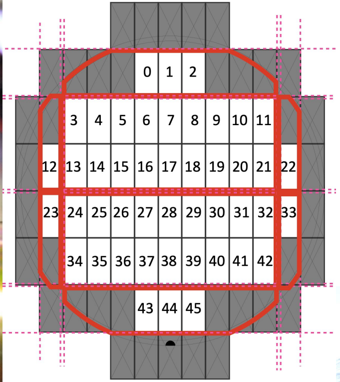
- Thermal and stability tests ongoing
- Development of models based on heating elements
- Placed in custom wind tunnel to study thermal and mechanical properties

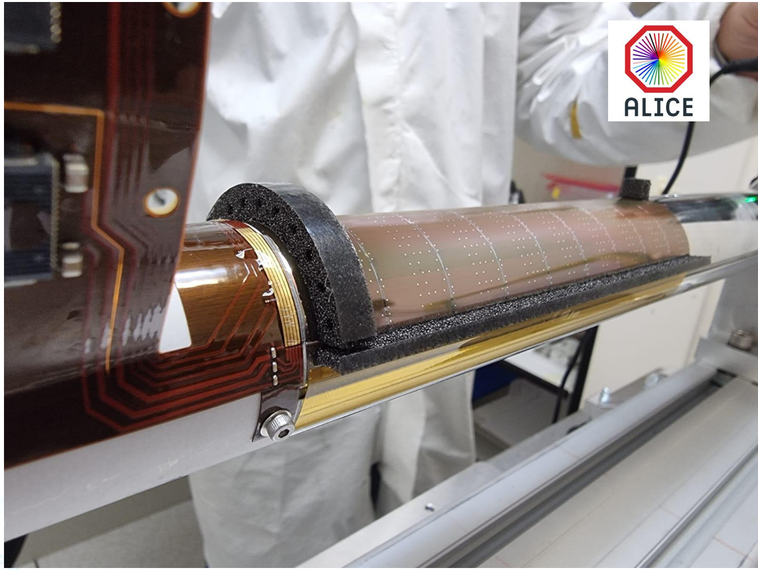


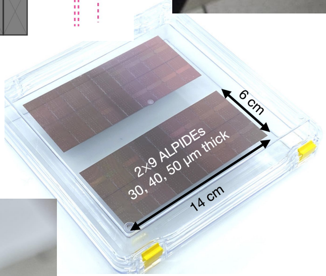


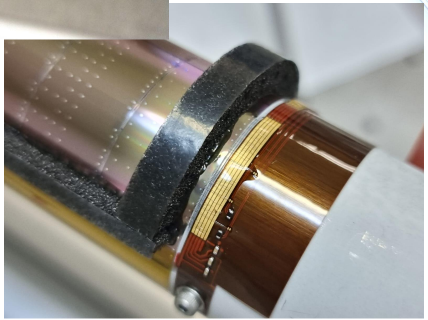
First bending with *superALPIDEs*







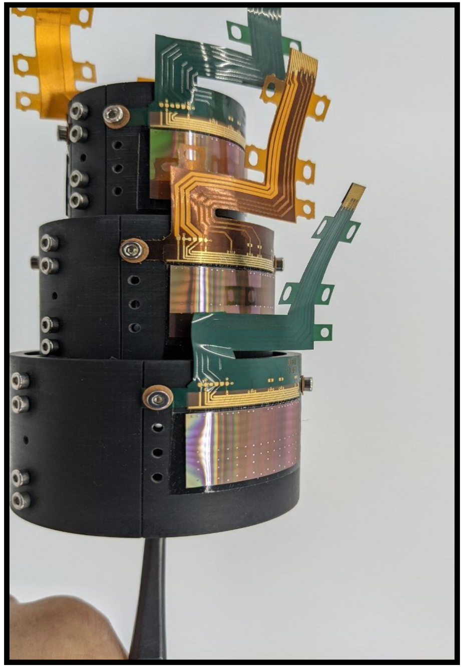


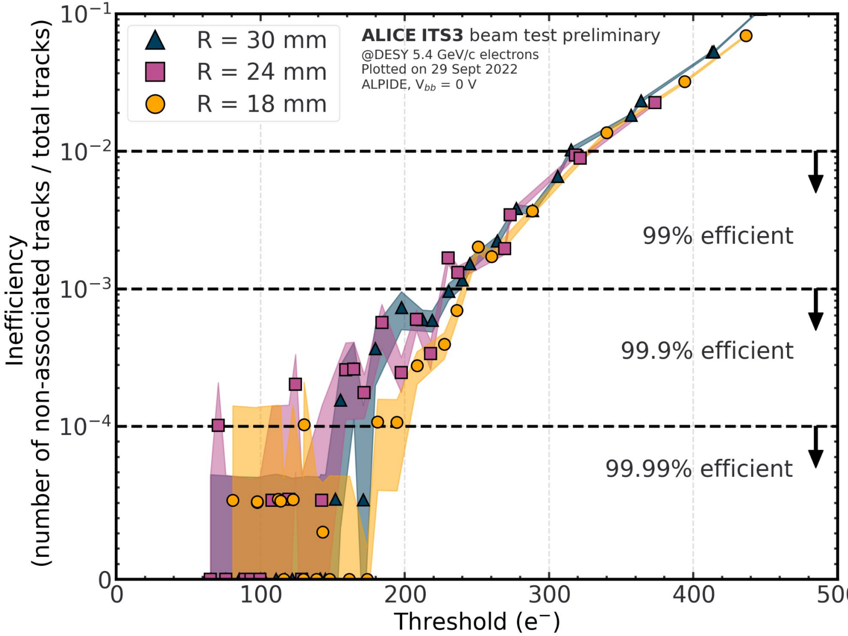


- ALPIDE: ALICE PIxel DEtector used in ITS2
- 40 µm thick sensors
- Bent to a radius of 18 mm

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

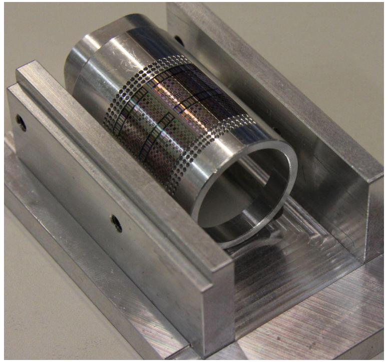




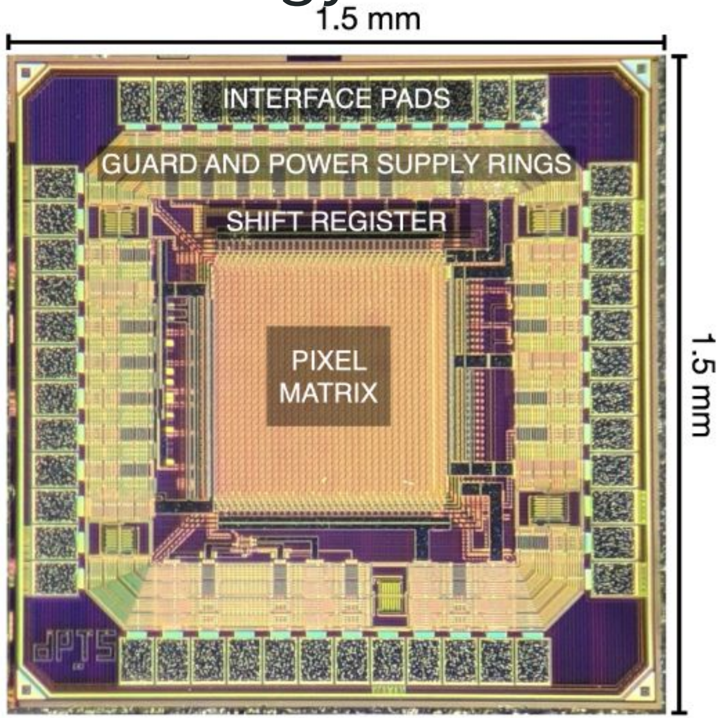
More results in doi:10.1016/j.nima.2021.166280

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

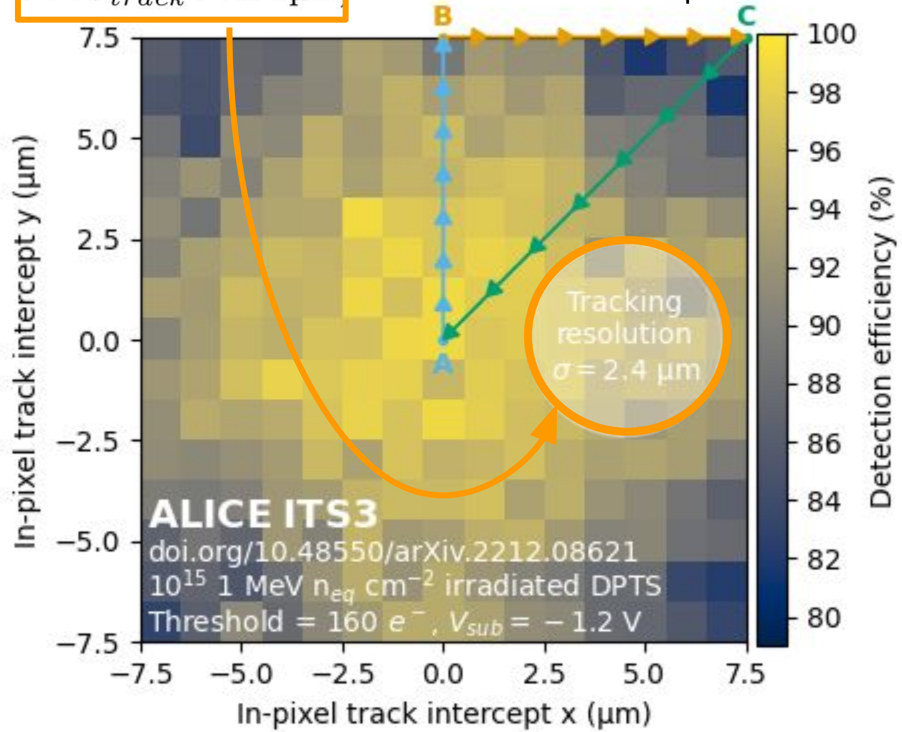
- 32 by 32 pixels with asynchronous digital readout
- 15 x 15 μm^2 pixels whose position is time encoded in the readout

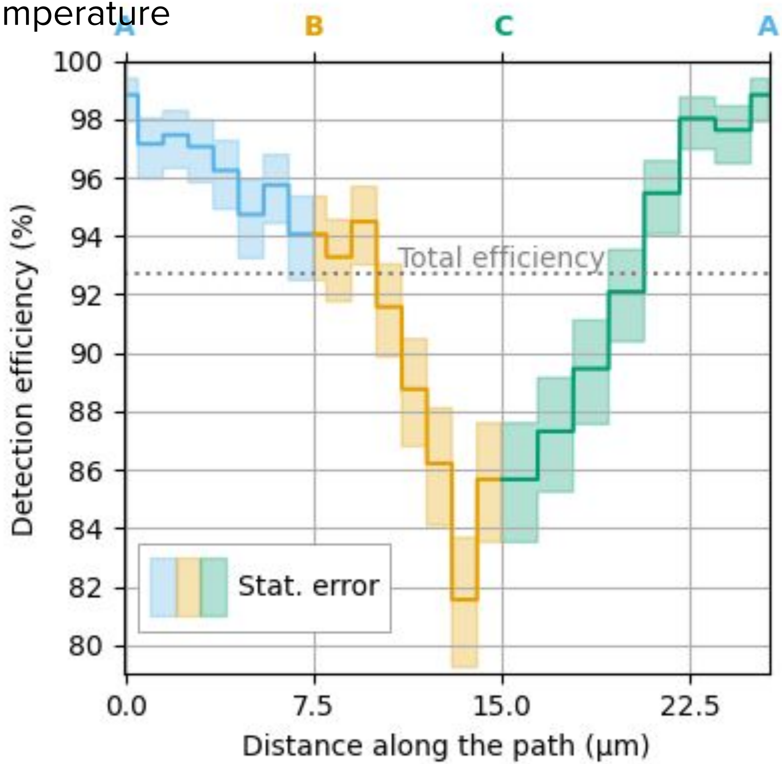
In-pixel detection efficiency after $\Phi_{eq} = 10^{15} / cm^2$

Track spatial resolution:

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

- Threshold 160 e^-
- Operated at room temperature



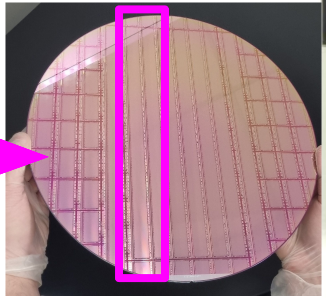


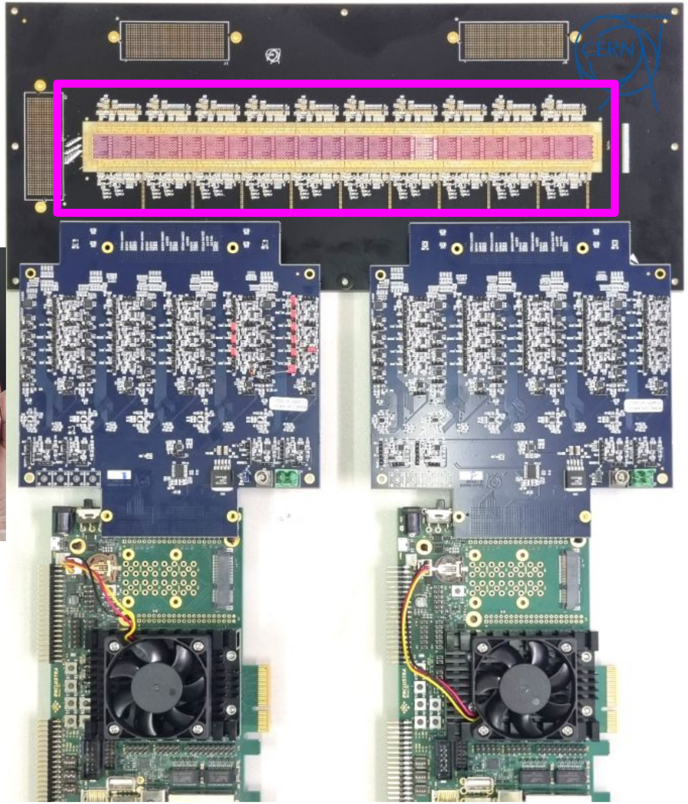
doi:10.48550/arXiv.2212.08621

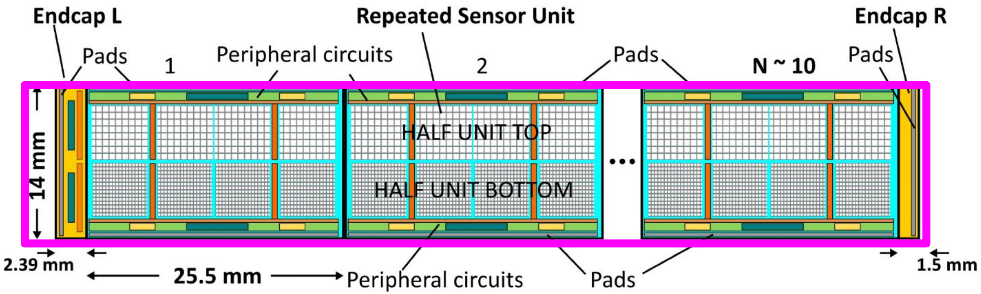
Efficiency loss as expected: occurs in corners far from collection electrode. No charge sharing.

Stitched sensor prototypes

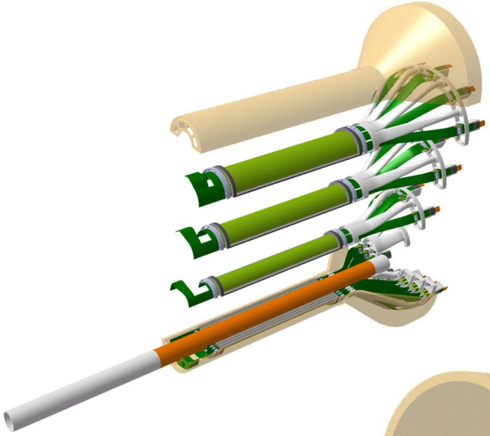
- 2 different structures, MOSS and MOST
- MOSS 14 x 259 mm^2, 6.72 MPixel structure
- MOST 2.5 x 259 mm^2, 0.9 MPixel structure
- Full structure will be 2.5 times as large
- Pixels of 22.5 x 22.5 μm^2 and 18 x 18 μm^2
- To be tested for yield and uniformity
- Pad wafer at CERN
- First full wafers arriving soon

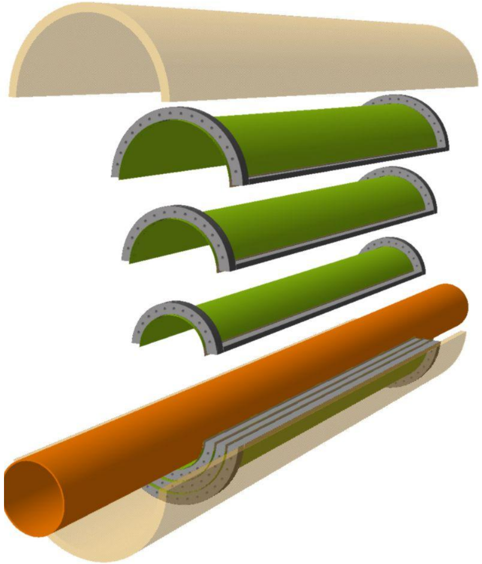






ITS3 geometry

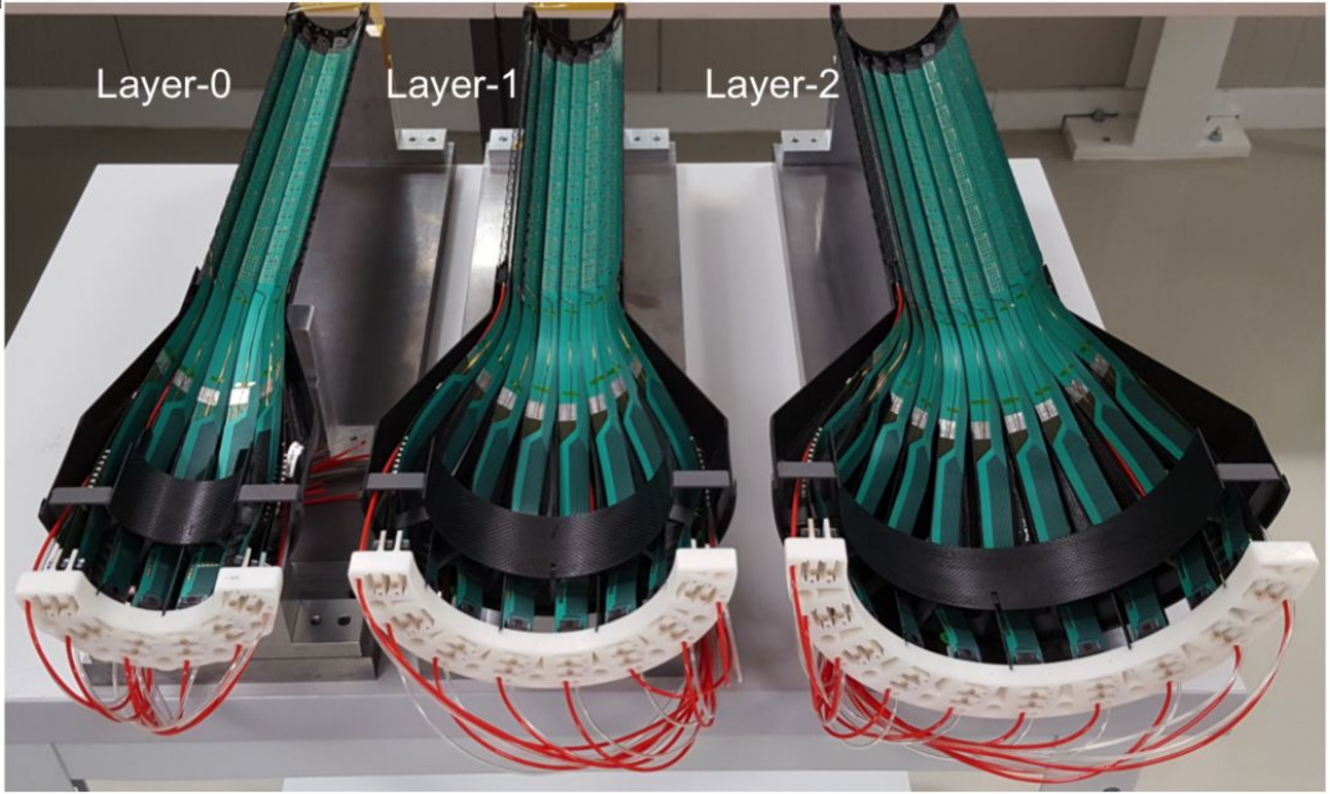




Beampipe inner/outer radius (mm)		16.0/16.5	
IB Layer parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length (sensitive area) (mm)	270	270	270
Pseudo-rapidity coverage[a]	±2.5	±2.3	±2.0
Active area (cm^2)	305	408	508
Pixel sensors dimensions (mm^2)	280×56.5	280×75.5	280×94
Number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

ITS3 Letter of intent CERN-LHCC-2019-018

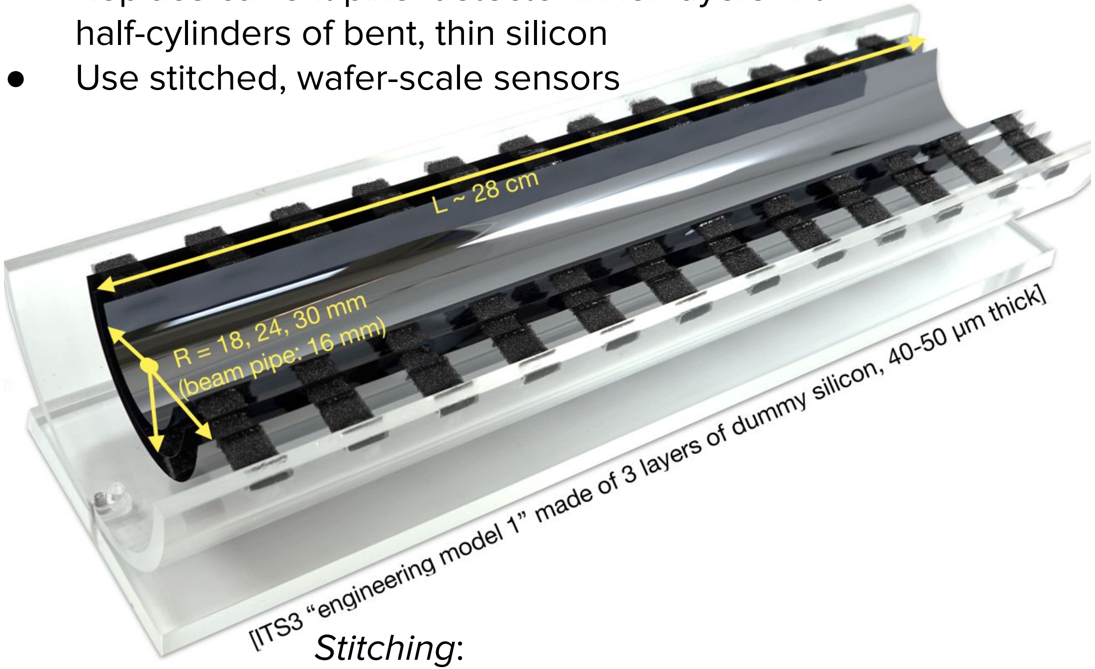
Current inner tracking system ITS2 inner three layers

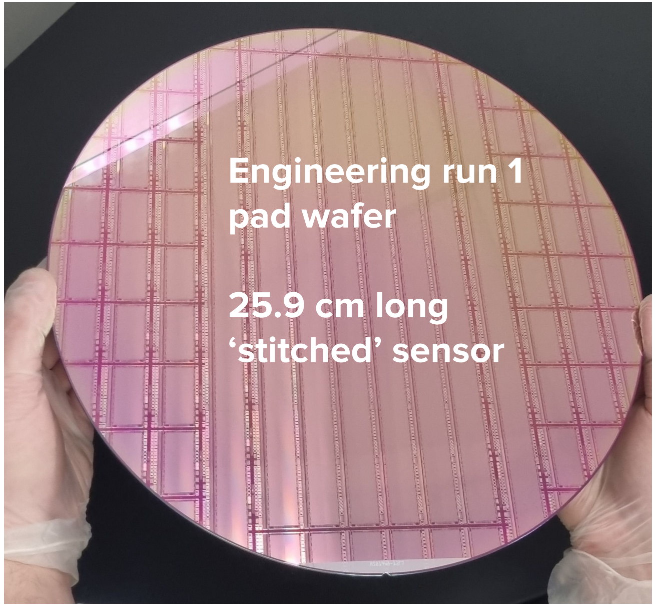


ITS3 Letter of intent CERN-LHCC-2019-018

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



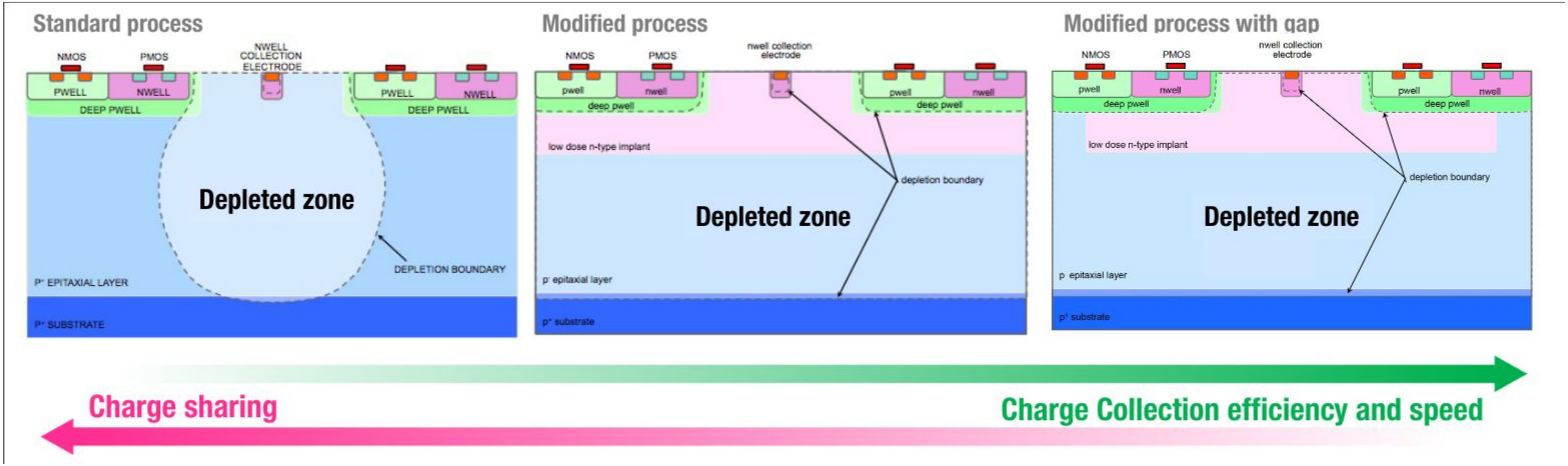


Stitching:

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

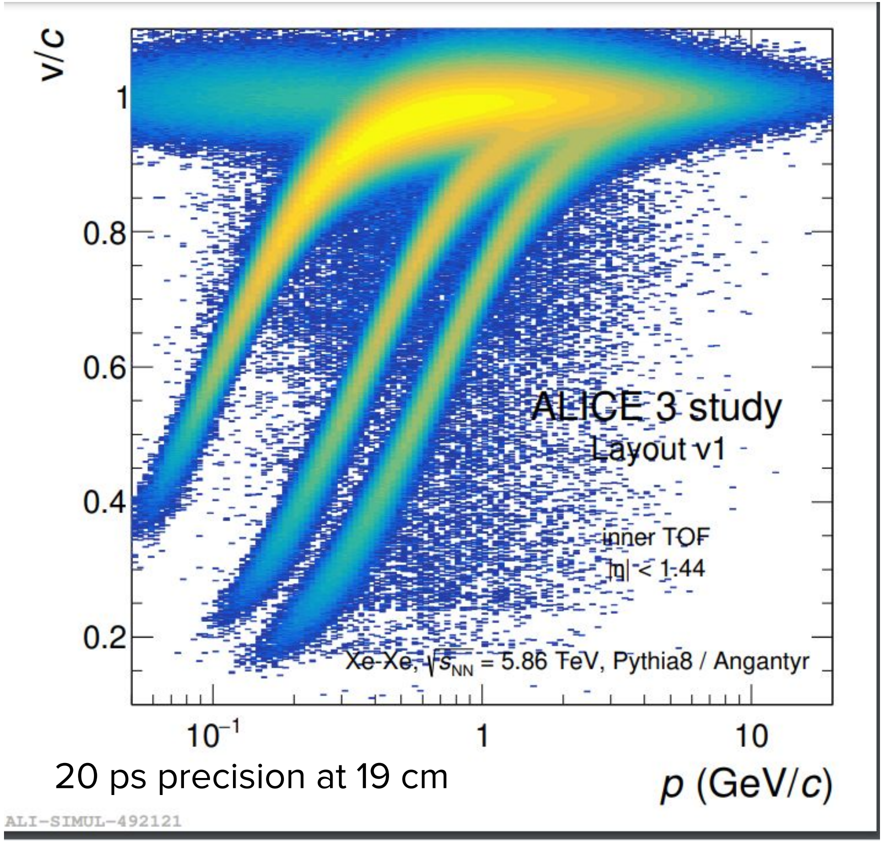
Different process modifications

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

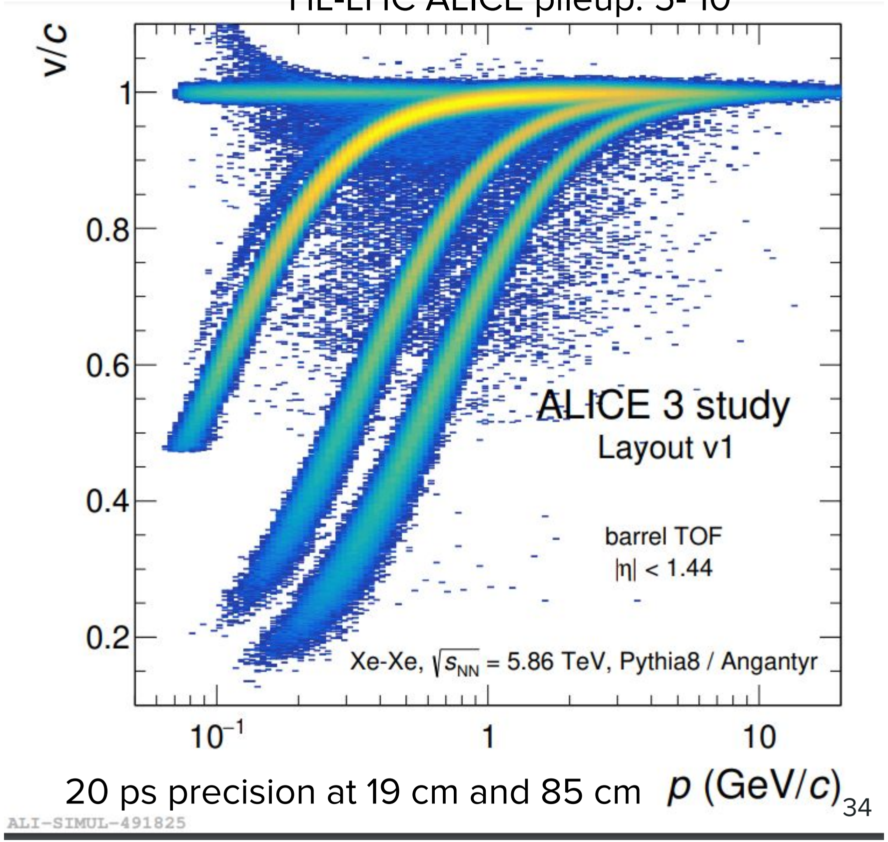


Particle identification improves with precise timing

HL-LHC ALICE pileup: 5- 10



20 ps precision at 19 cm



20 ps precision at 19 cm and 85 cm