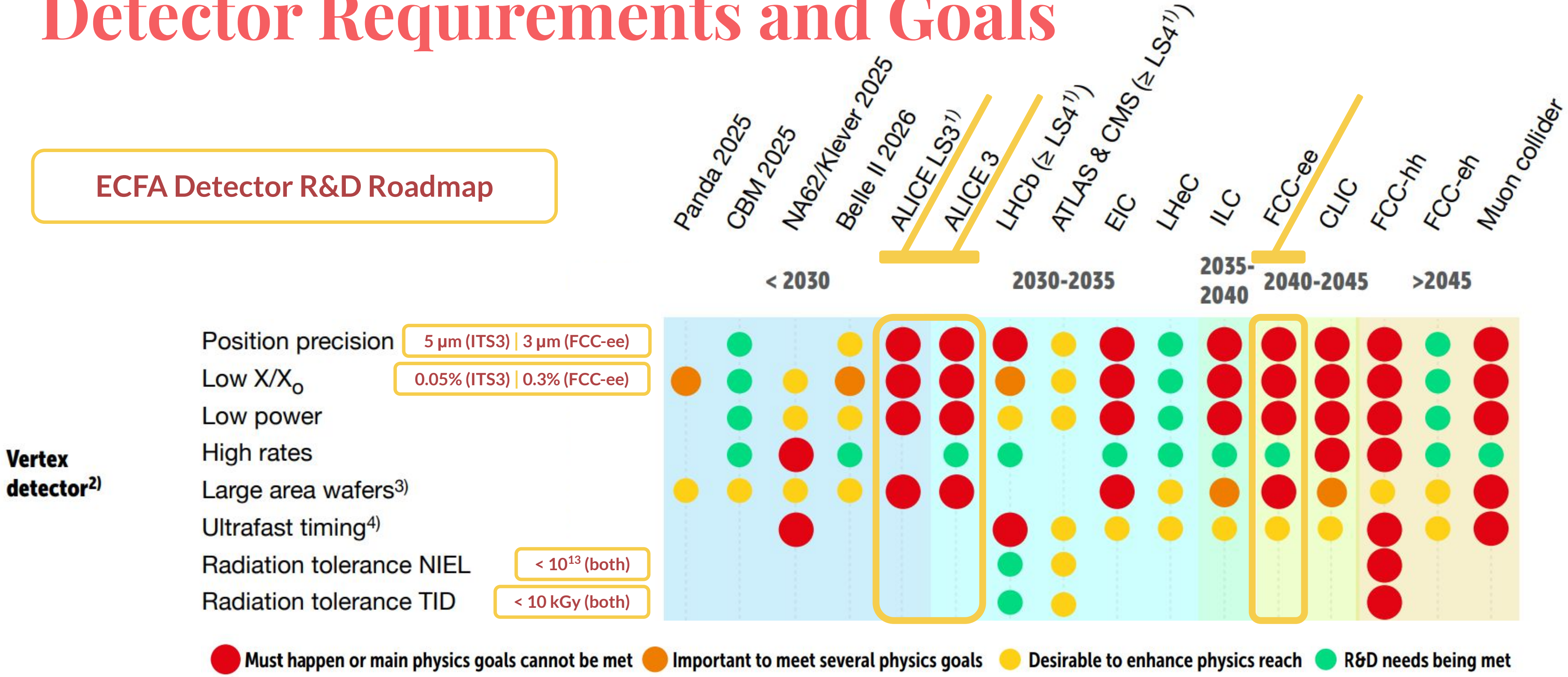
The ALICE ITS3 project and Opportunities for FCC-ee

Kunal Gautam on behalf of **ALICE**

7th FCC Physics Workshop | 30.01.2024

Detector Requirements and Goals



- Requirements for ALICE ITS3 & FCC-ee vertex detectors are congruous
- ALICE ITS3 & ALICE 3 can be a stepping stone for the FCC-ee vertex detectors

Symbiosis with Lepton Colliders

ALICE is a prototype for **lepton colliders** with similar requirements:

- Moderate radiation environment
- Low material budget and high spatial resolution is crucial
- First layer closer to the beam pipe for better IP resolution

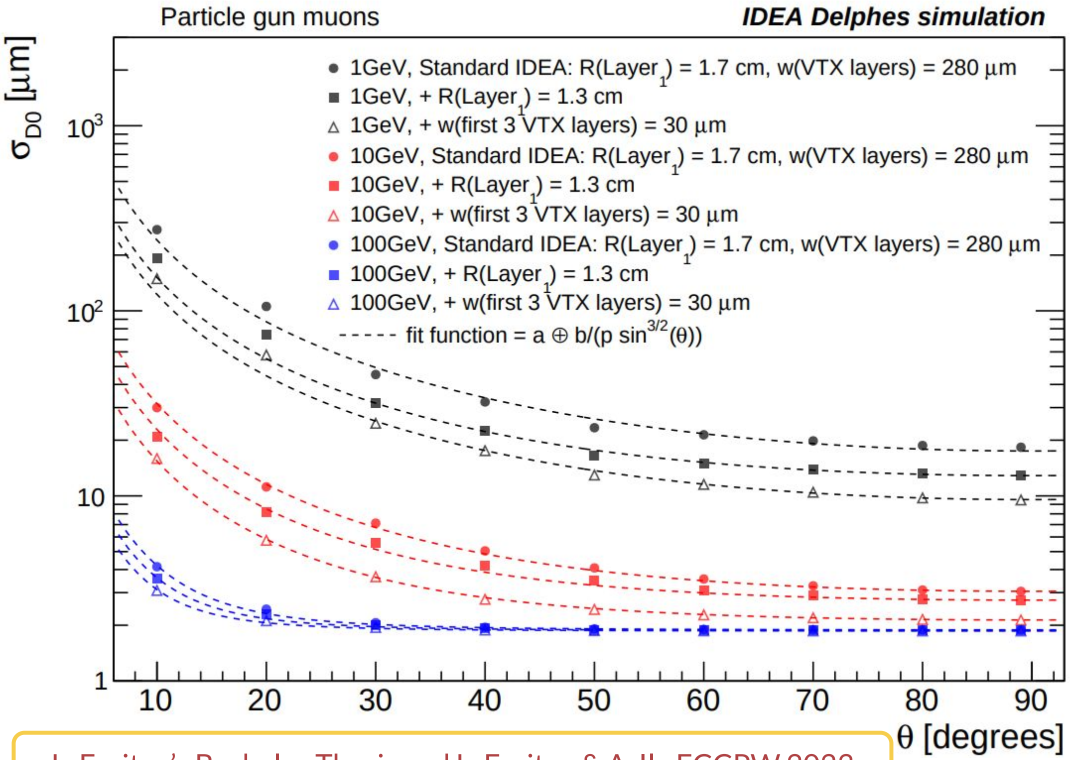
Future collider groups joined the ITS3 efforts

M. Mager FCCW2023

D. Contardo FCCW2023

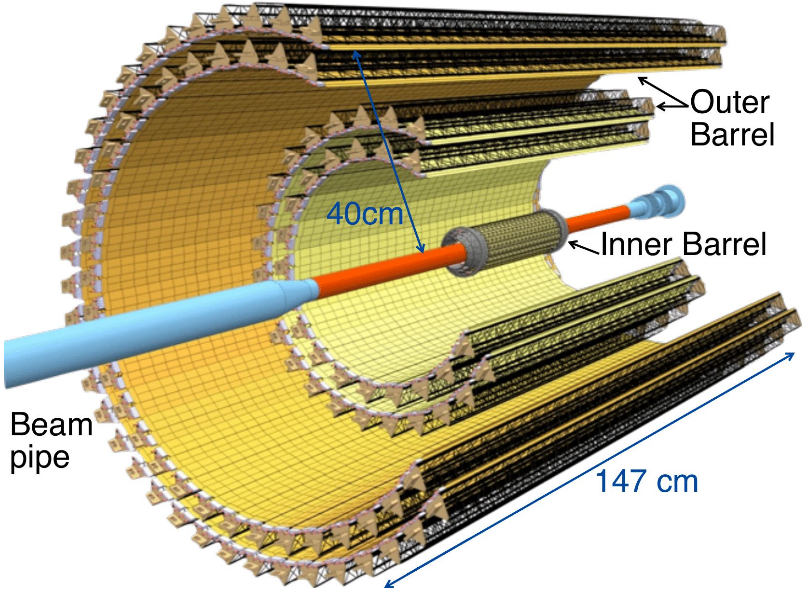
F. Palla FCCPW2024

A. Ilg FCCPW2024



L. Freitag's Bachelor Thesis and L. Freitag & A. Ilg FCCPW 2023

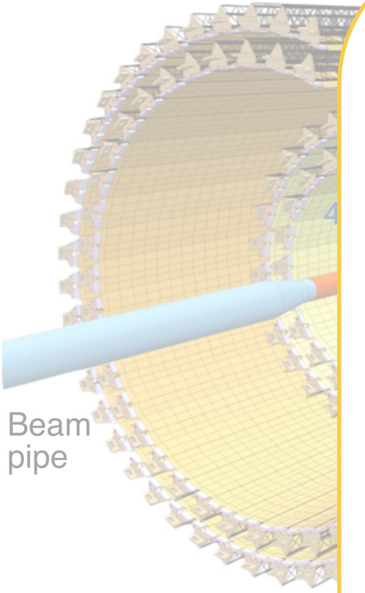
ITS2 → ITS3

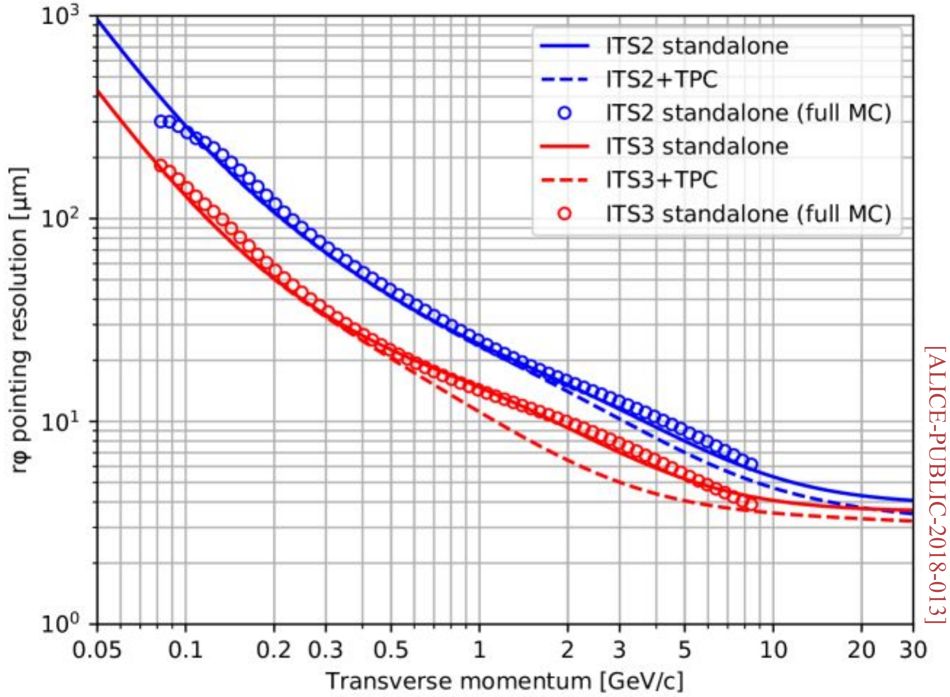


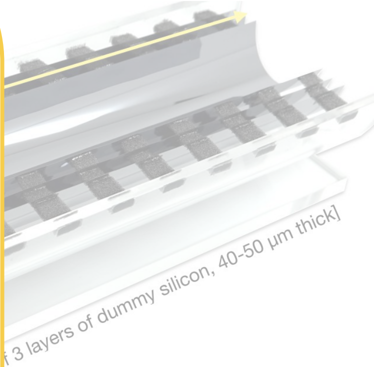
only 1/7th of the material budget

- Replacing the barrels by real half-cylinders
  - using bent, thin silicon
- Rely on stitched wafer-scale sensors
  - in 65 nm technology

ITS2 → ITS3







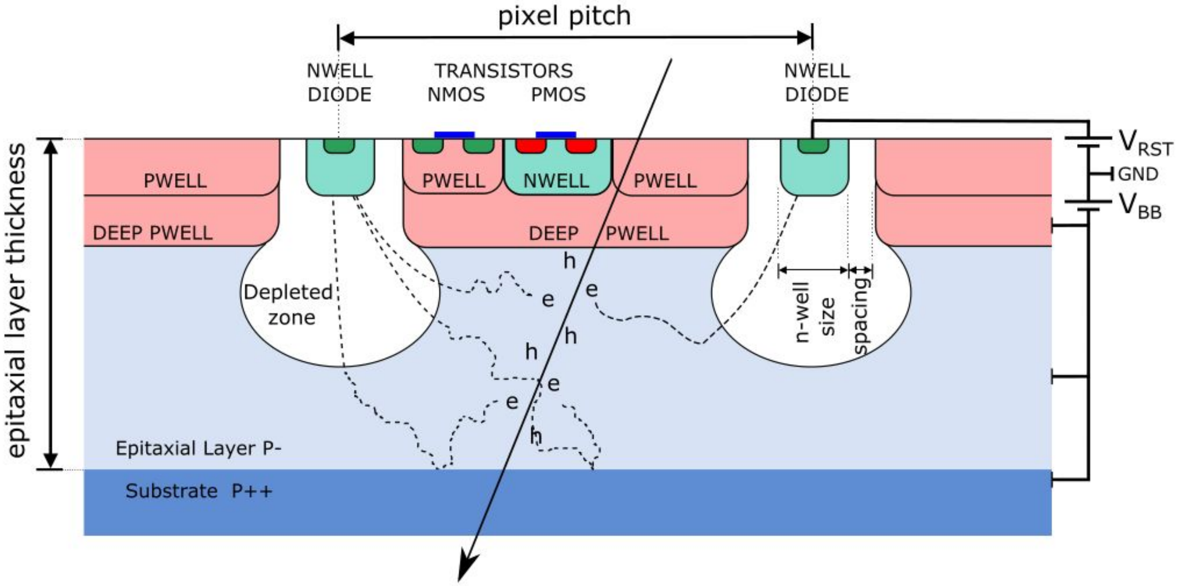
only 1/7th of the material budget

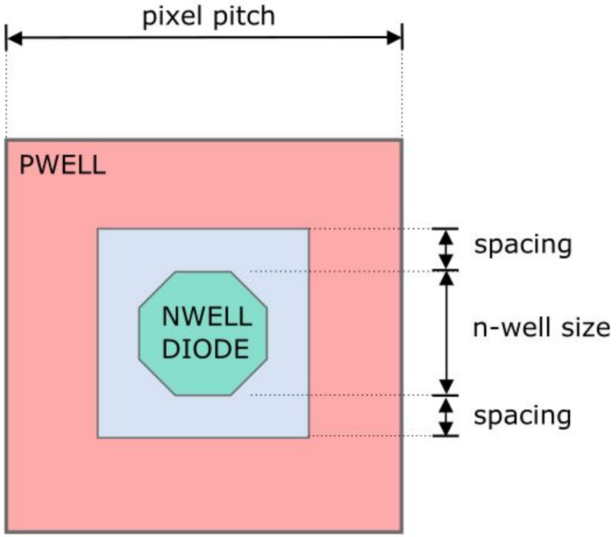
- Replacing the … ale sensors
  - using be… gy

Improvement of factor 2 over all momenta

https://doi.org/10.1016/j.nima.2020.164859

Monolithic Active Pixel Sensor (MAPS)





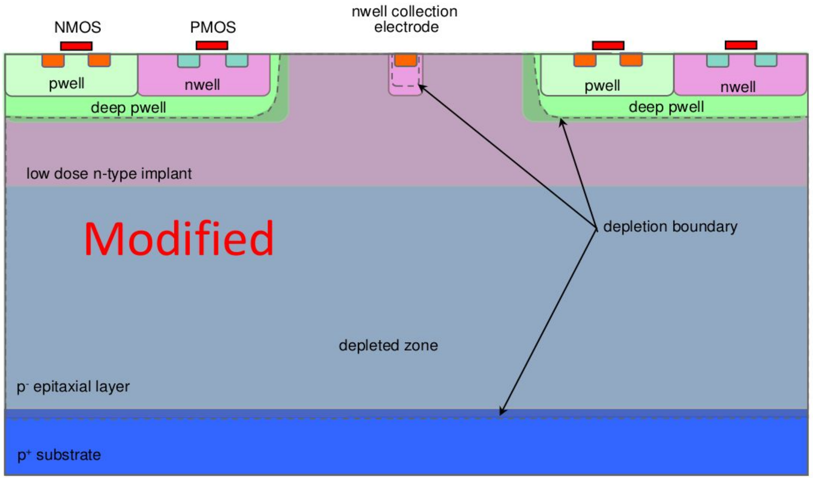
- Deep PWELL shields the CMOS circuitry from collecting charge
- Low capacitance of the small collection electrode results in lower power consumption
- Applying substrate bias increases depletion and also improves radiation tolerance
- Further modifications needed for the full depletion of the sensitive layer

http://dx.doi.org/10.1016/j.nima.2017.07.046

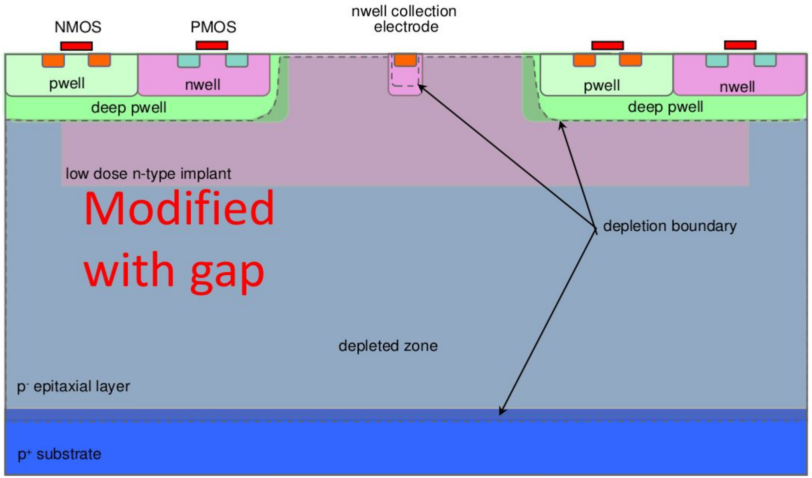
Process Modifications

TPSCo 65 nm Process

- To reach full depletion



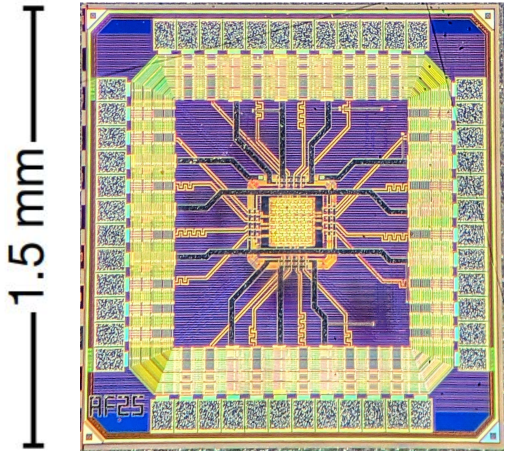
- More control over charge sharing



more charge sharing

faster charge collection

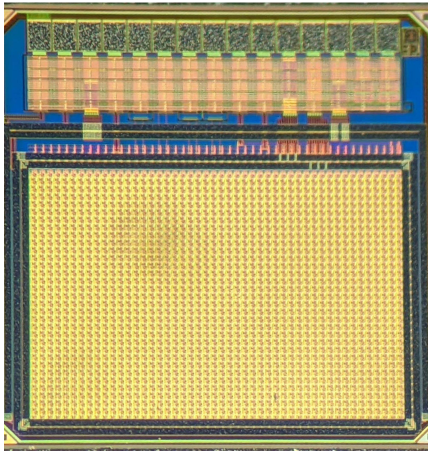
ITS3: Pixel Prototype Chips



doi.org/10.1088/1748-0221/18/01/C01065

APTS

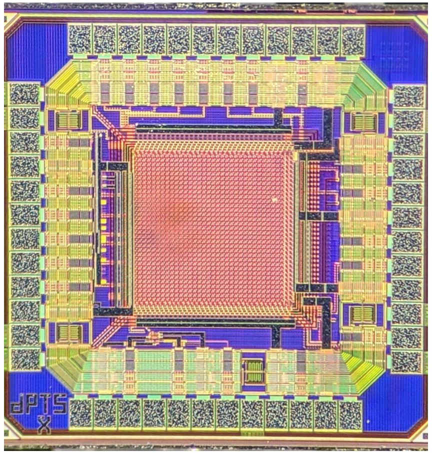
- 6x6 pixel matrix
- Direct **analog readout** of central 4x4 pixels
- Pitch: 10, 15, 20, 25 µm



doi.org/10.1016/j.nima.2022.167213

CE65

- 64x64 [v1], 48x32 [v1], 48x24 [v2] pixel matrix
- Rolling shutter **analog readout**
- Pitch: 15, 25 µm



doi.org/10.1016/j.nima.2023.168589

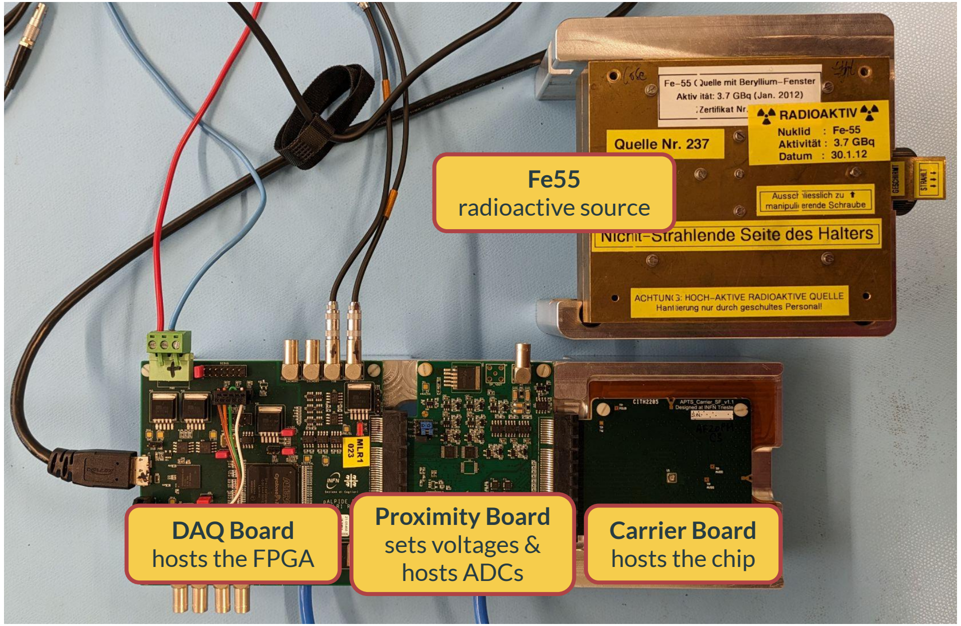
DPTS

- 32x32 pixel matrix
- Asynchronous **digital readout** with ToT
- Pitch: 15 µm

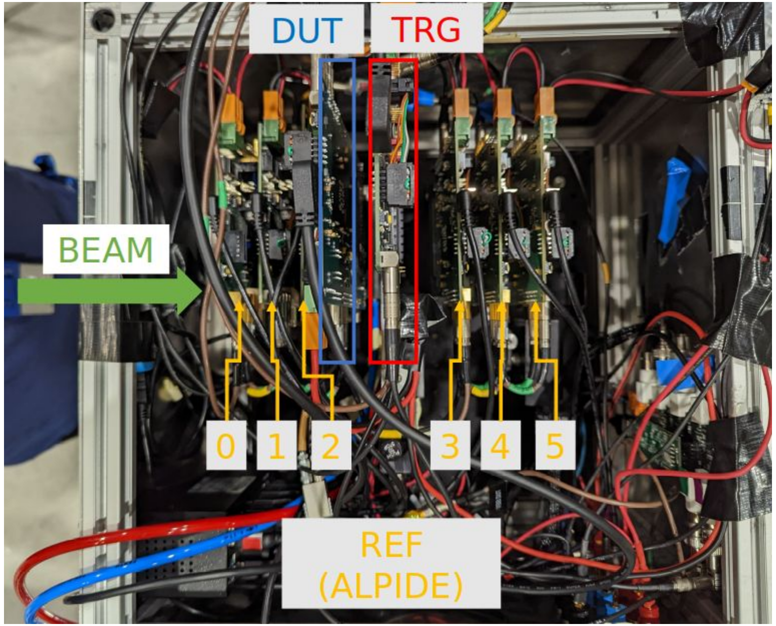
Testing Small-Scale Sensors

In Lab and at Testbeams

Measurement Setups

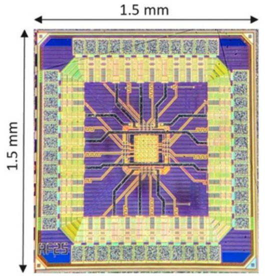


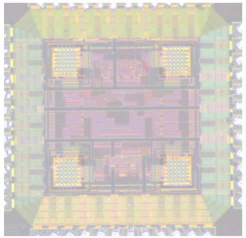
- The measurement of the **Fe55 spectrum** is used to **calibrate** the sensor readout to the collected charge at different **bias voltages**.
- Water cooling used to set a **standard temperature** during tests (16°-20°C).



- One MLR1 sensor as **DUT** at standard temperature (~16°C) and 6 **ALPIDEs** (ITS2) as reference planes.
- Tested with **120 GeV hadrons** at SPS, **10 GeV hadrons** at PS, and **0.8-5 GeV** electrons at DESY.

Charge Collection (APTS)



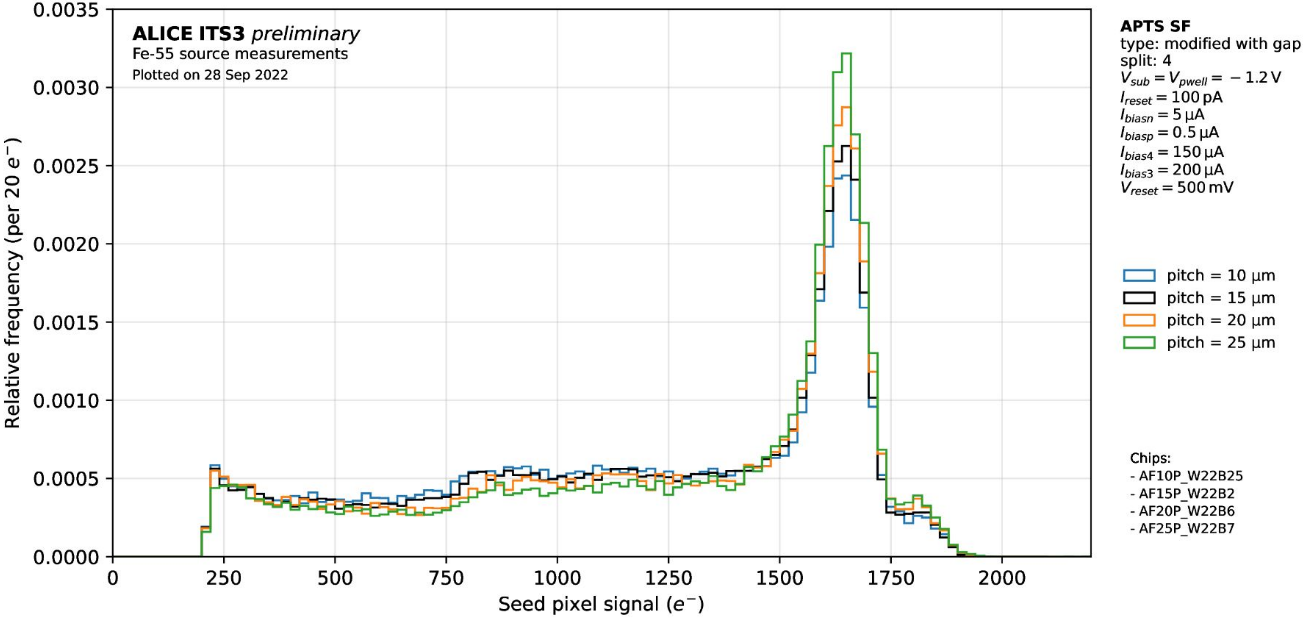


The entire generated charge is collected pointing to the near-full depletion of the sensitive layer

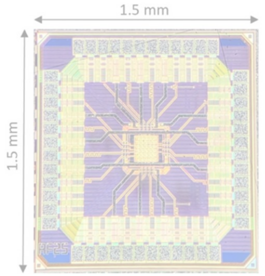
All pitches/geometries show similar results indicating efficient charge collection

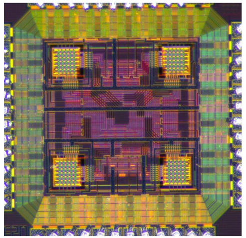
Allows to choose for the optimal pitch for the final sensor

Sensor geometry with higher capacitance leads to lower signal in mV



Charge Collection (APTS)





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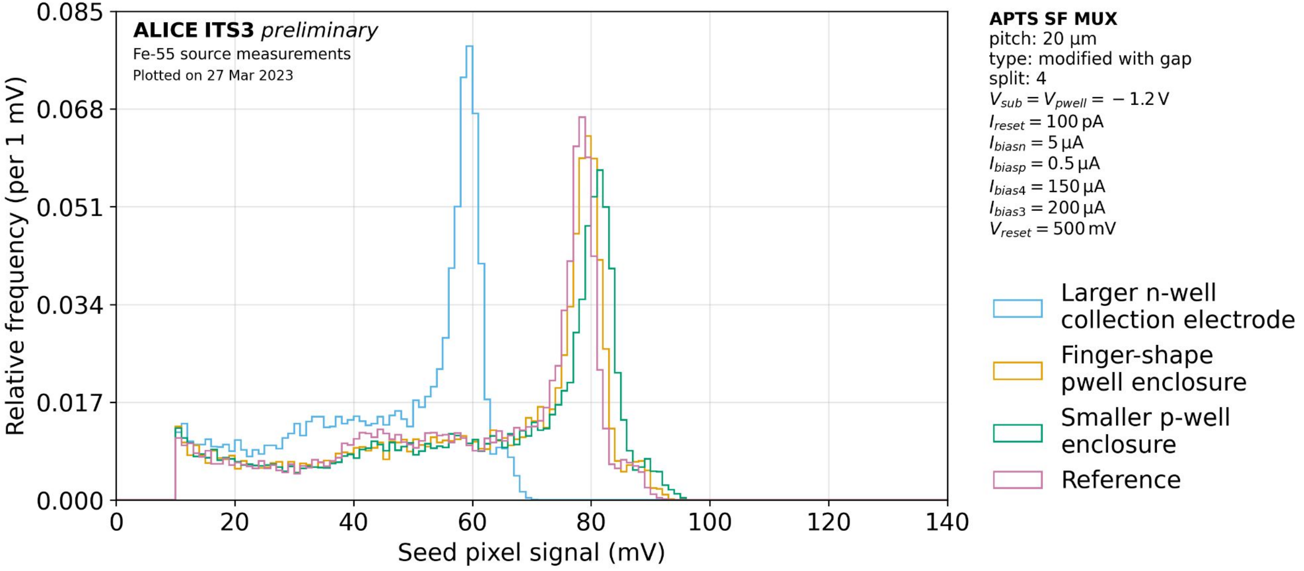
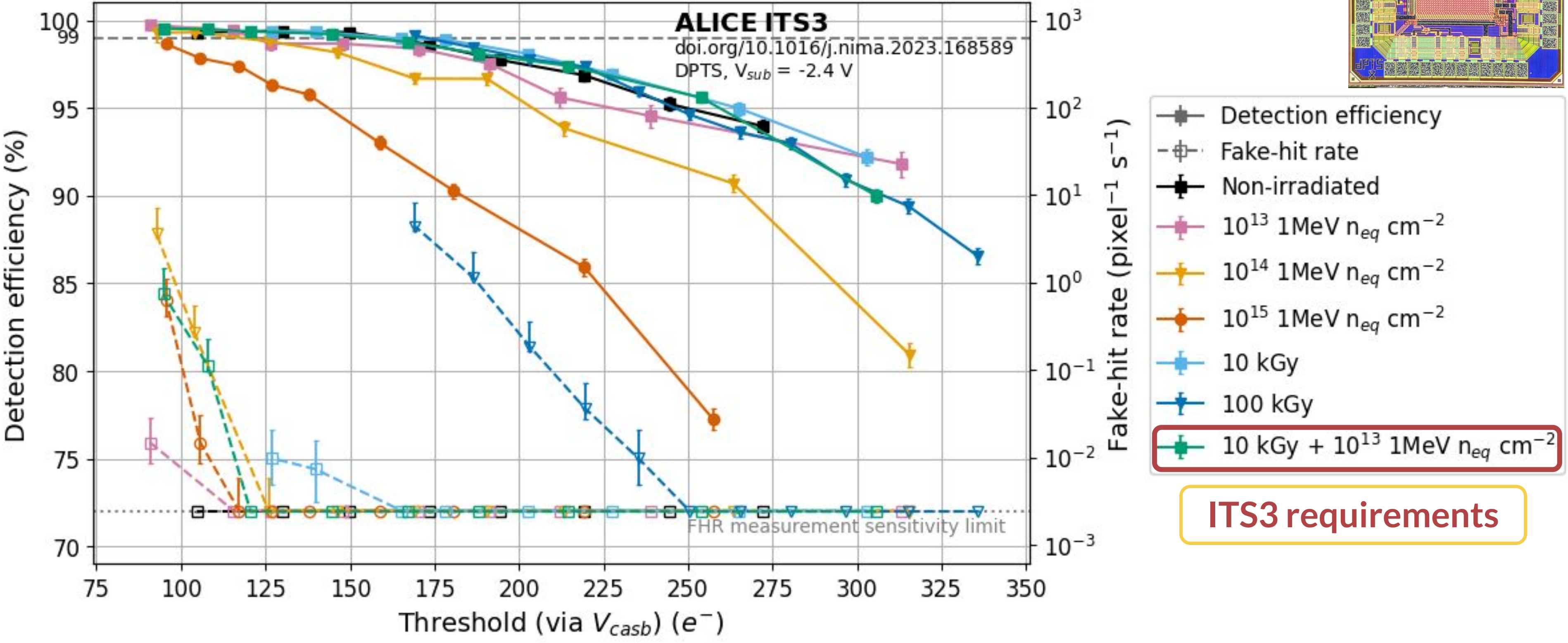
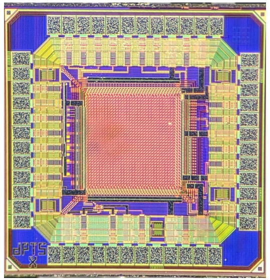


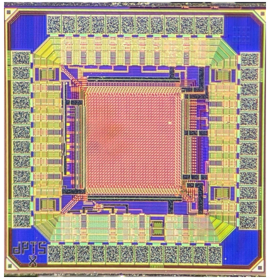
Detection Efficiency (DPTS)

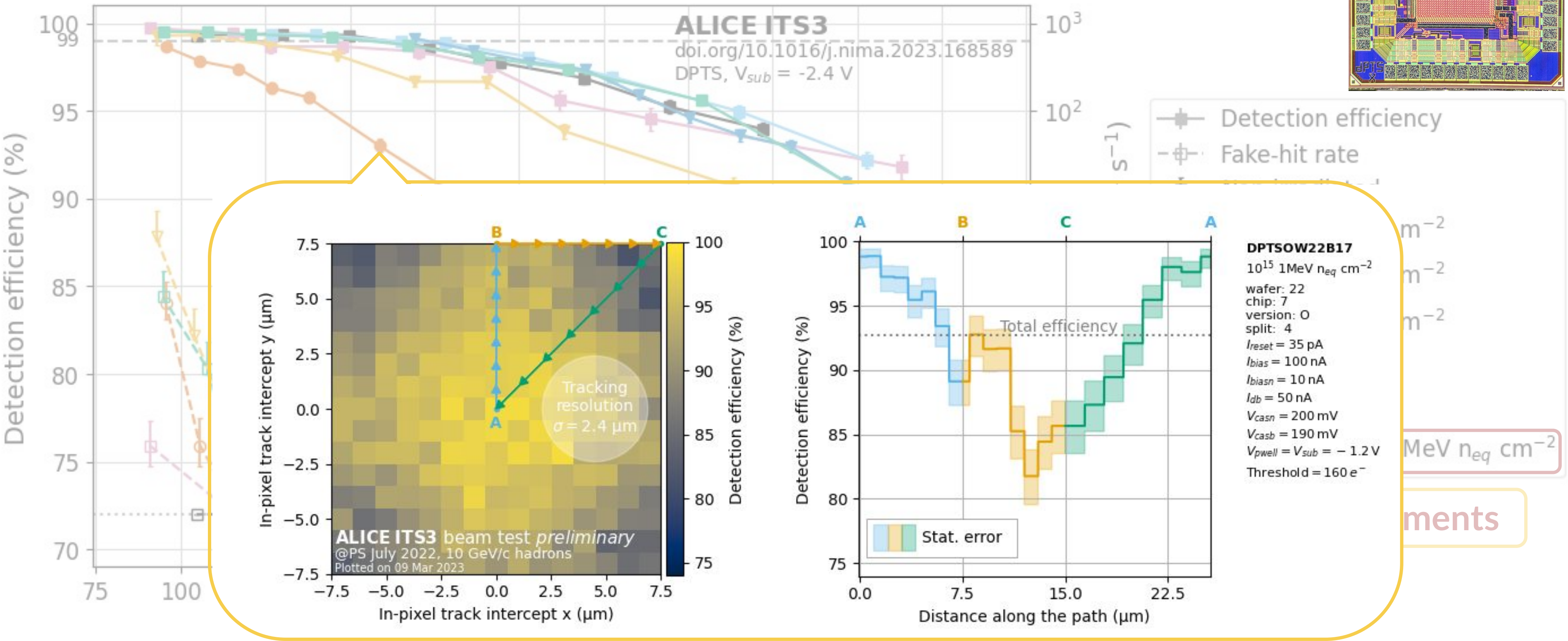




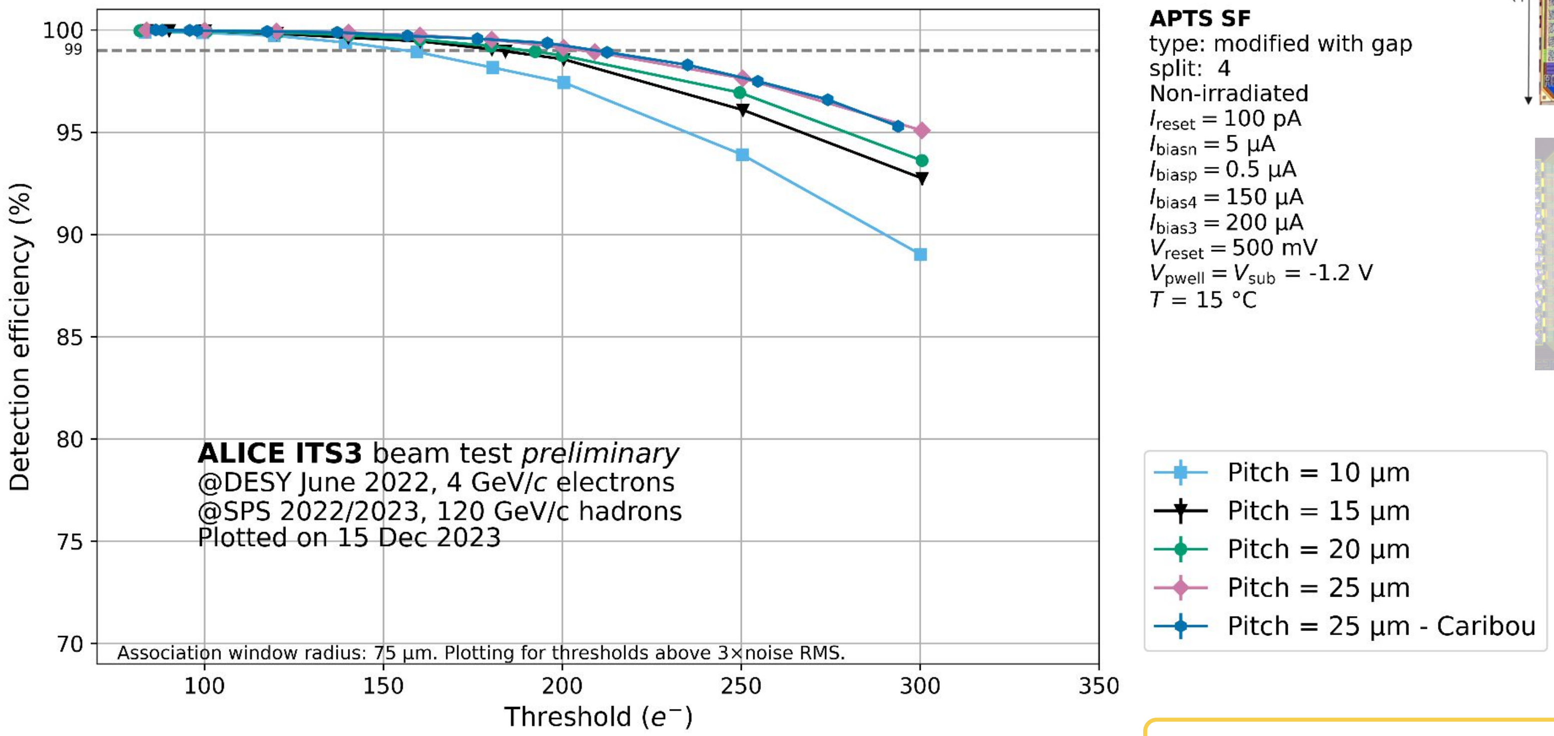
ITS3 requirements

Detection Efficiency (DPTS)

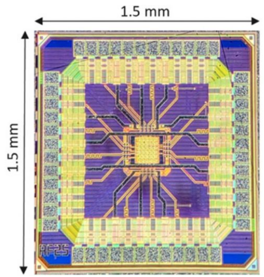


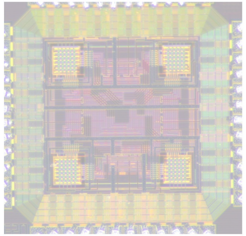


Detection Efficiency (APTS)



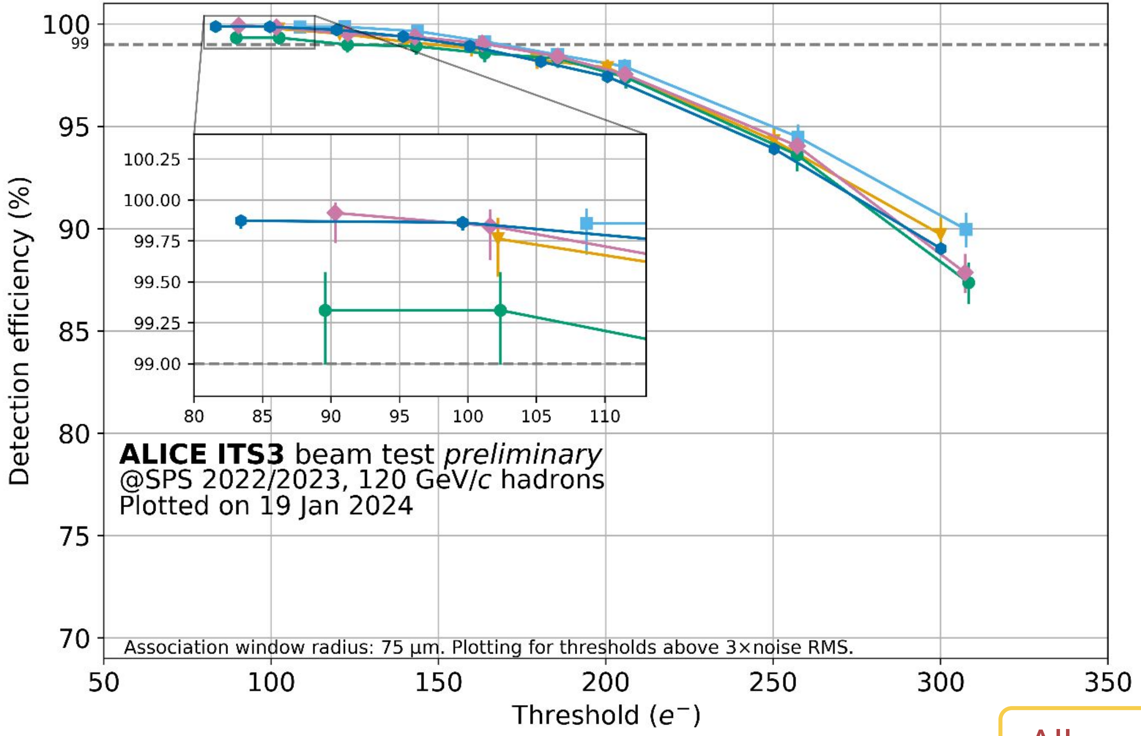
APTS SF
type: modified with gap
split: 4
Non-irradiated
I_{reset} = 100 pA
I_{biasn} = 5 µA
I_{biasp} = 0.5 µA
I_{bias4} = 150 µA
I_{bias3} = 200 µA
V_{reset} = 500 mV
V_{pwell} = V_{sub} = -1.2 V
T = 15 °C



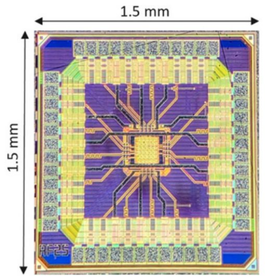


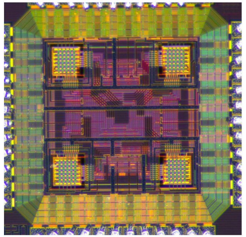
over 99% efficiency for all pitches

Detection Efficiency (APTS)



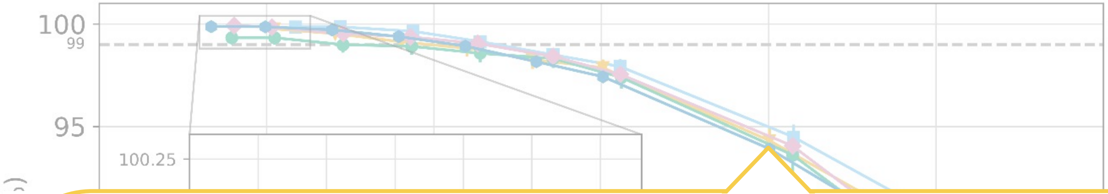
APTS SF
type: modified with gap
pitch: 10 µm
split: 4
Irradiation: None
$I_{reset} = 100$ pA
$I_{biasn} = 5$ µA
$I_{biasp} = 0.5$ µA
$I_{bias4} = 150$ µA
$I_{bias3} = 200$ µA
$V_{reset} = 500$ mV
$V_{pwell} = V_{sub} = -1.2$ V
T = 14°C



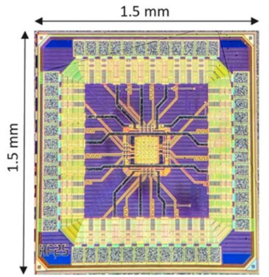


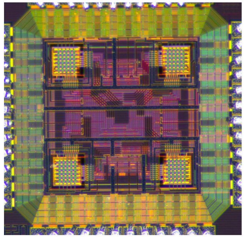
All geometries operable **over 99% efficiency**

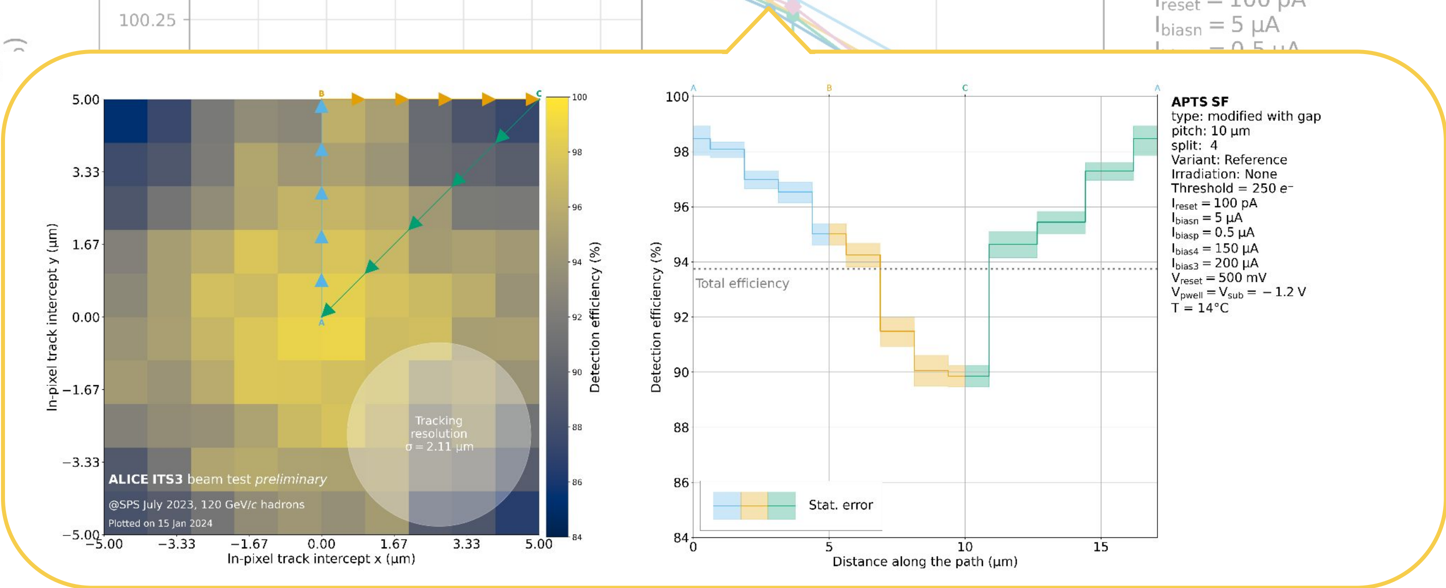
Detection Efficiency (APTS)



APTS SF
type: modified with gap
pitch: 10 µm
split: 4
Irradiation: None
I_{reset} = 100 pA
I_{biasn} = 5 µA







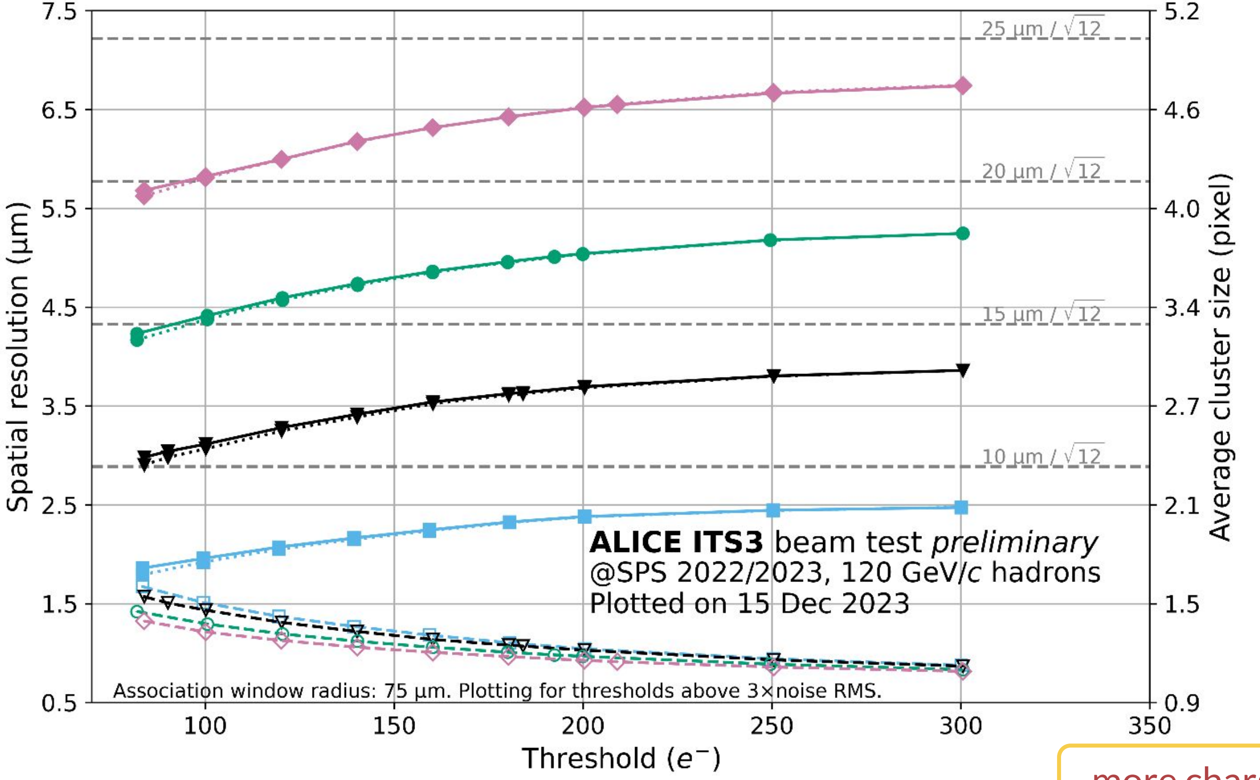
ollection electrode

WELL enclosure

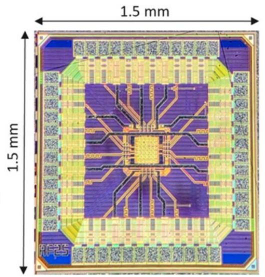
enclosure

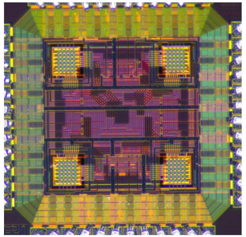
All geometries operable **over 99% efficiency**

Spatial Resolution (APTS)



APTS SF
type: modified with gap
split: 4
Non-irradiated
I_{reset} = 100 pA
I_{biasn} = 5 μA
I_{biasp} = 0.5 μA
I_{bias4} = 150 μA
I_{bias3} = 200 μA
V_{reset} = 500 mV
V_{pwell} = V_{sub} = -1.2 V
T = 15 °C





more charge sharing ⇨ improved resolution

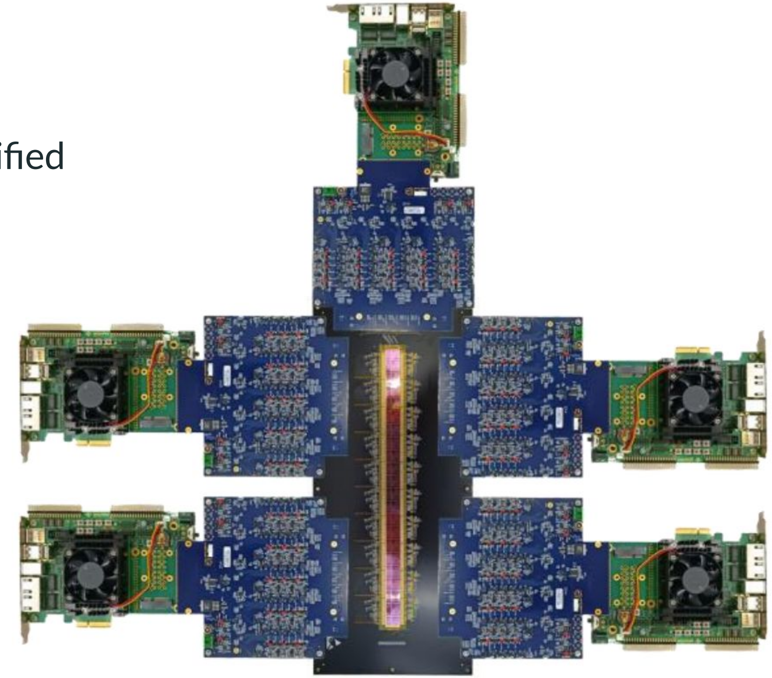
Summary & Outlook

ITS2 (now)

- 12.5 GPixel tracker based on the ALPIDE chip (180 nm technology MAPS)
- Stable, >99% functional

ITS3 (LS3)

- Bent MAPS demonstrated in testbeam, 65 nm process qualified
- Testing of stitched design started
- Assembly of wafer-scale sensors defined
- TDR now with LHCC



ALICE R&D on MAPS

- ALICE 3 with large-scale integration; 60 m^2 outer tracker
- Current and future ALICE detectors with large operational margins
- Symbiosis with the lepton collider community

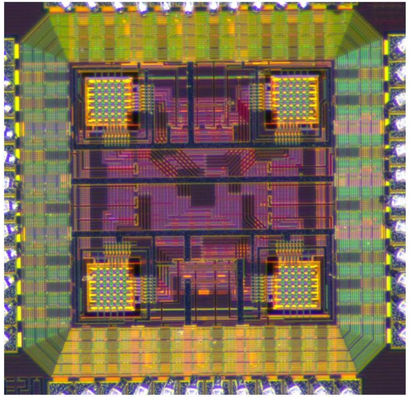
So long,

and **thanks** for all the fish

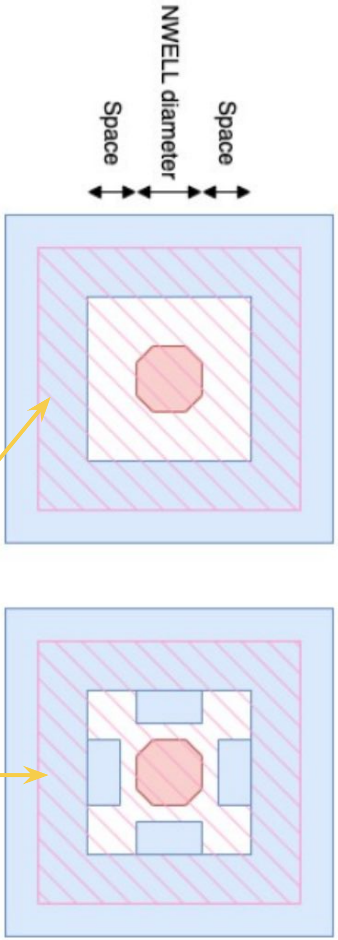
Back-up

APTS-SF Multiplexer

One out of the four sensor variants can be read out at a time by selecting an output with the 2-bit multiplexer



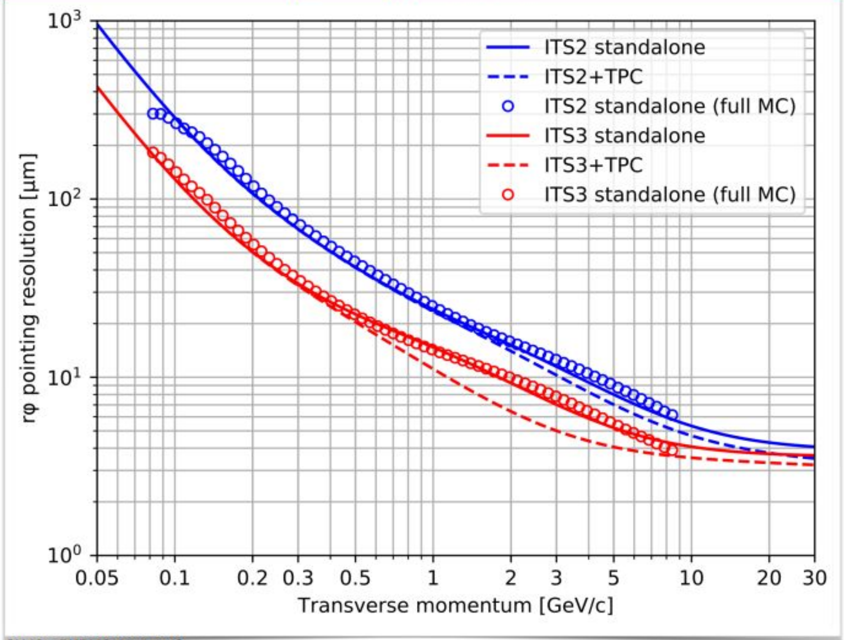
--mux	Selected Matrix	Sensor Variant
0	Left Top	Larger NWELL Collection Electrode
1	Left Bottom	Reference
2	Right Top	Finger-shaped PWELL Enclosure
3	Right Bottom	Smaller PWELL Enclosure



ALICE ITS3

Performance improvement

pointing resolution



[ALICE-PUBLIC-2018-013]

improvement of factor 2 over all momenta

- Improvement of pointing resolution by:
  - drastic reduction of **material budget** (0.3 → 0.05% X_0/layer)
  - being **closer** to the interaction point (24 → 18 mm)
  - thinner and smaller **beam pipe** (700 → 500 μm; 18 → 16 mm)
- Directly boosts the ALICE core physics program that is largely based on:
  - low momenta
  - secondary vertex reconstruction
- E.g. Λ_c S/B improves by factor 10, significance by factor 4

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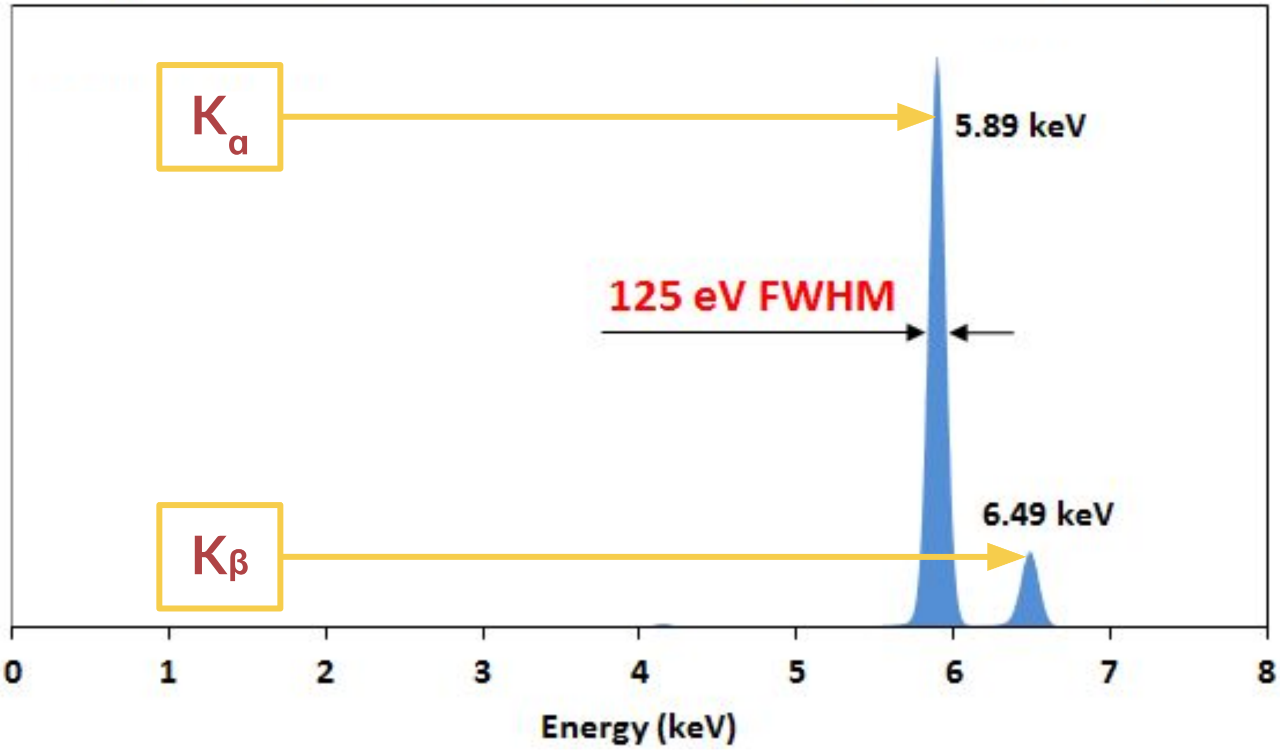
Fe55 Spectrum



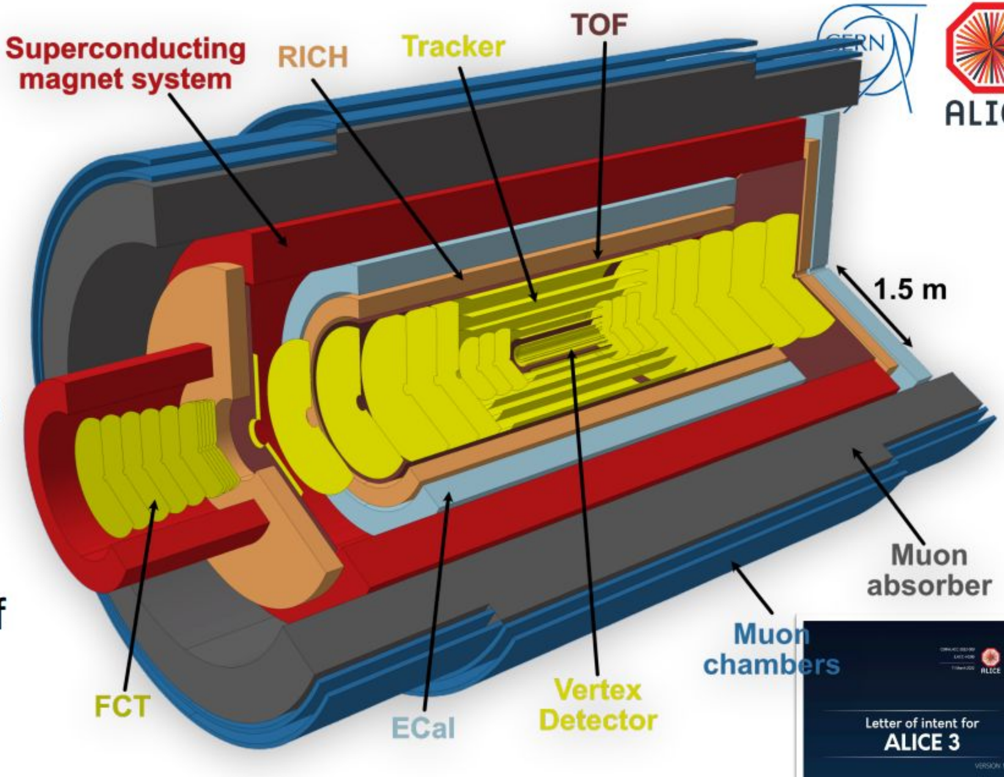
The measurement of the Fe55 spectrum is used to calibrate the sensor readout to the collected charge

- Number of electrons generated by Kα : 1640
- Number of electrons generated by Kβ : 1800

ALICE 3

LHC LS4 2033/34

- ALICE 3 is centred around a 60 m² MAPS tracker
  - innermost layers will be based on wafer-scale Silicon sensors “iris tracker”, similar to ITS3 (but in vacuum)
  - outer tracker will be based on modules like ITS2 (but order of magnitude larger)
- *This is the next big and concrete step for this technology*



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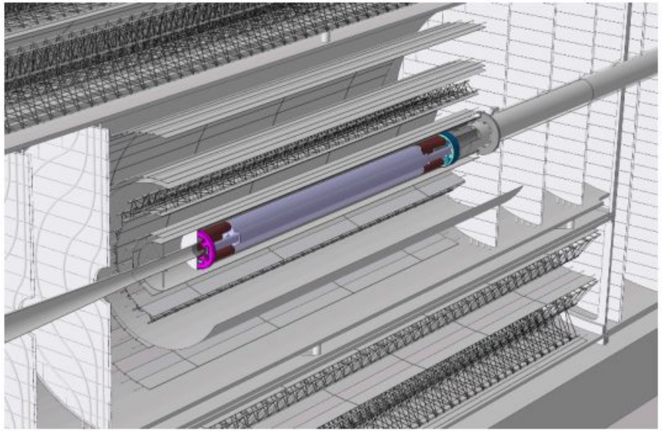
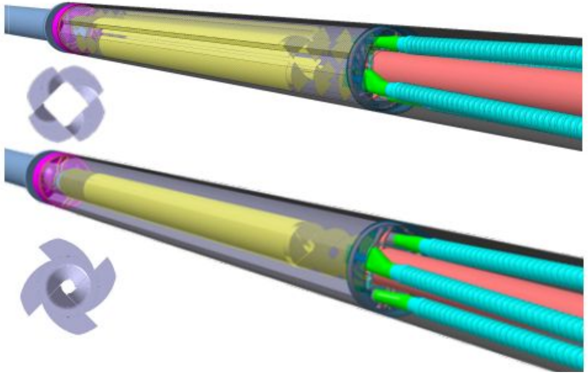
ALICE 3

vertex detector





- Based on wafer-scale, ultra-thin, curved MAPS
  - radial distance from interaction point: 5 mm (inside beampipe, retractable configuration)
  - unprecedented spatial resolution: ≈ 2.5 μm
  - … and material budget: ≈ 0.1% X_0/layer
  - at radiation levels of: ≈ 10^{16} 1MeV n_{eq}/cm^2 + 300 Mrad
  - and hit rates up to: 94 MHz/cm^2
- Unprecedented performance figures
  - largely leverages on the ITS3 developments
  - pushes improvements on a number of fronts

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