The ITS3 detector and its physics potential for the LHC Run 4

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CEPC2025
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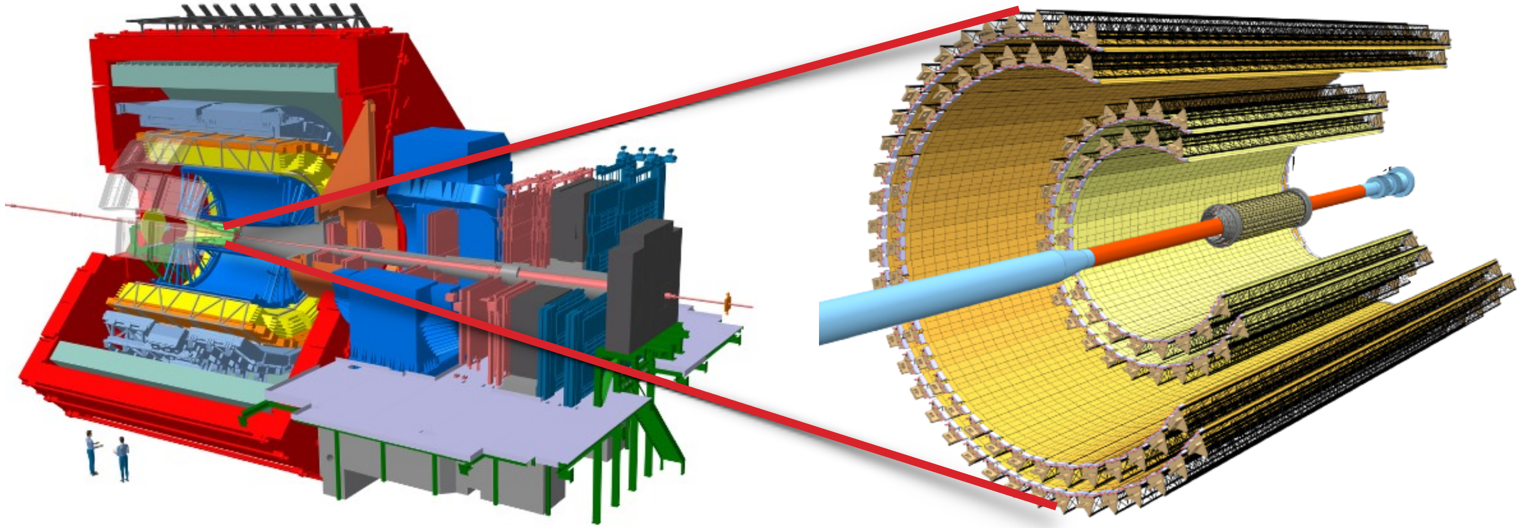
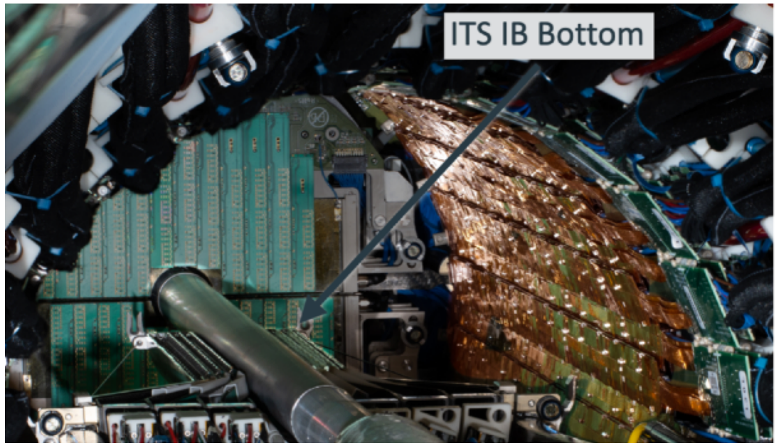
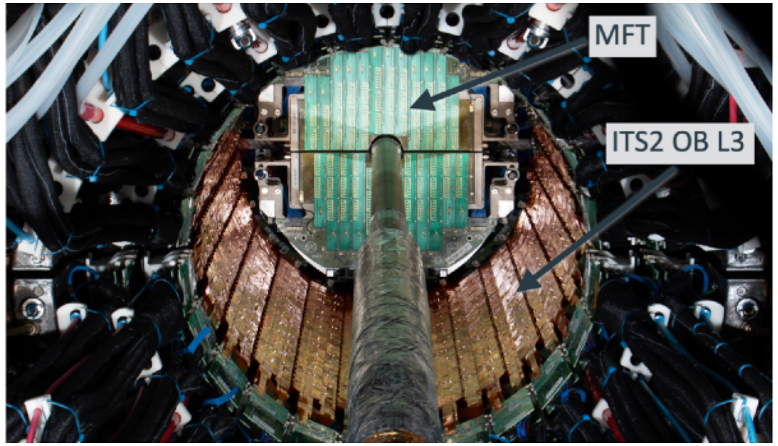
ALICE Inner Tracking System in Run 3 (ITS2)







7 Layers:

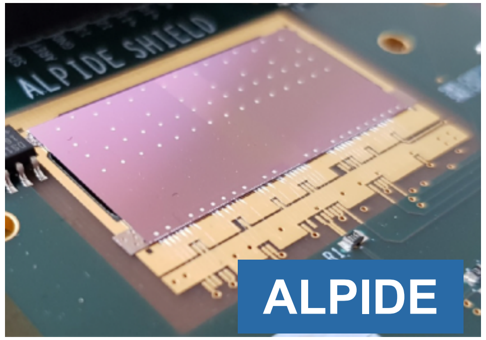
➡ 3 inner barrel (IB) and 4 outer barrel (OB)

Large active area and granularity

➡ $10 m^2$ active silicon area, 12.5×10^9 pixels

Built with ALPIDE chips

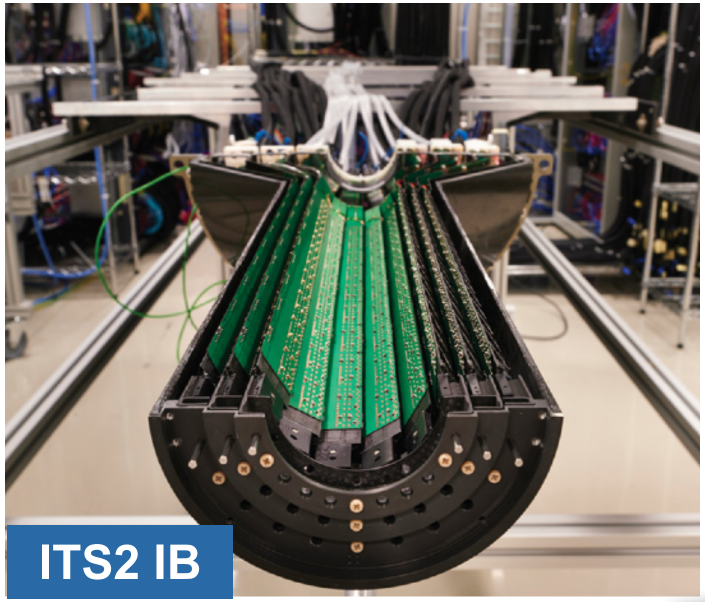
➡ 180nm CMOS MAPS, $15 \times 30\ mm^2$, 512×1024 pixels

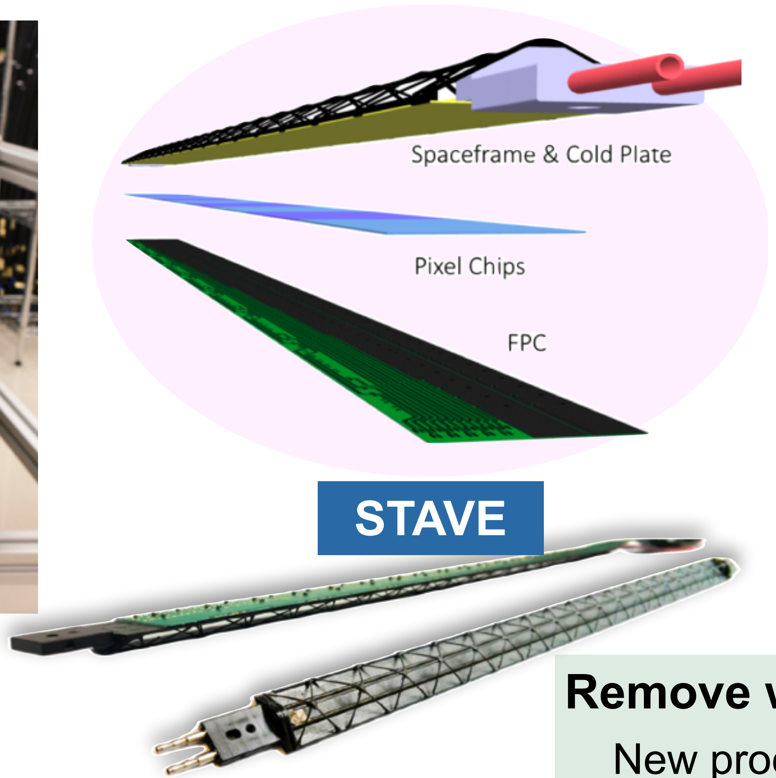


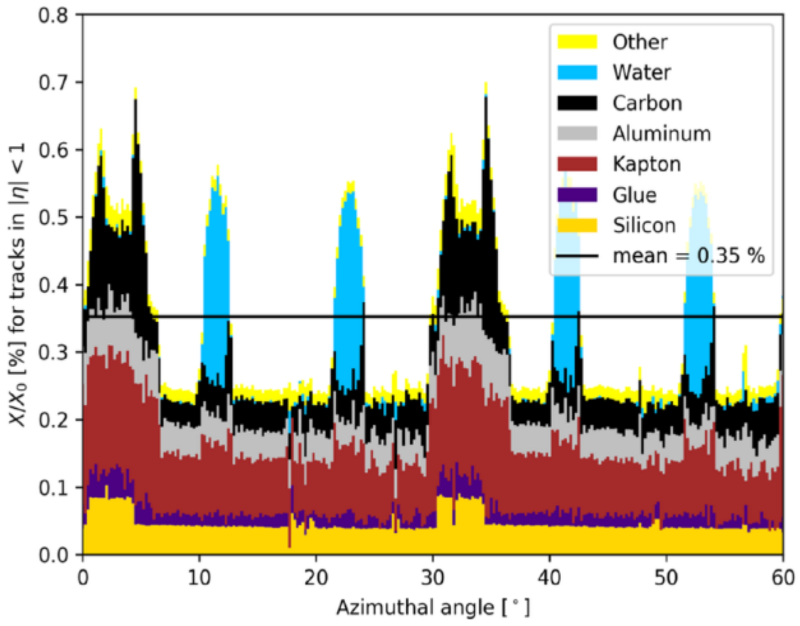
* M. Mager, for ALICE Collab, NIM-A 824, 434 (2016) * F. Reidt, for ALICE Collab, NIM-A 1005, 121793 (2021)

LHC LS2			LHC RUN3				LHC LS3				LHC RUN4			
2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033

How to improve ITS2?







Non-sensitive material

➡ Silicon has 1/7 of total material budget

Non-uniformly distributed material

➡ Stave overlapping, support and water cooling structure

Unable to be closer to the interaction point

➡ Mechanical constraints

Remove water cooling

New process chip (with lower power consumption) required to introduce air cooling

Remove the circuit board

New technology required to integrate data, control and power distribution on a single chip

Remove of mechanical support

New mechanical structure design required

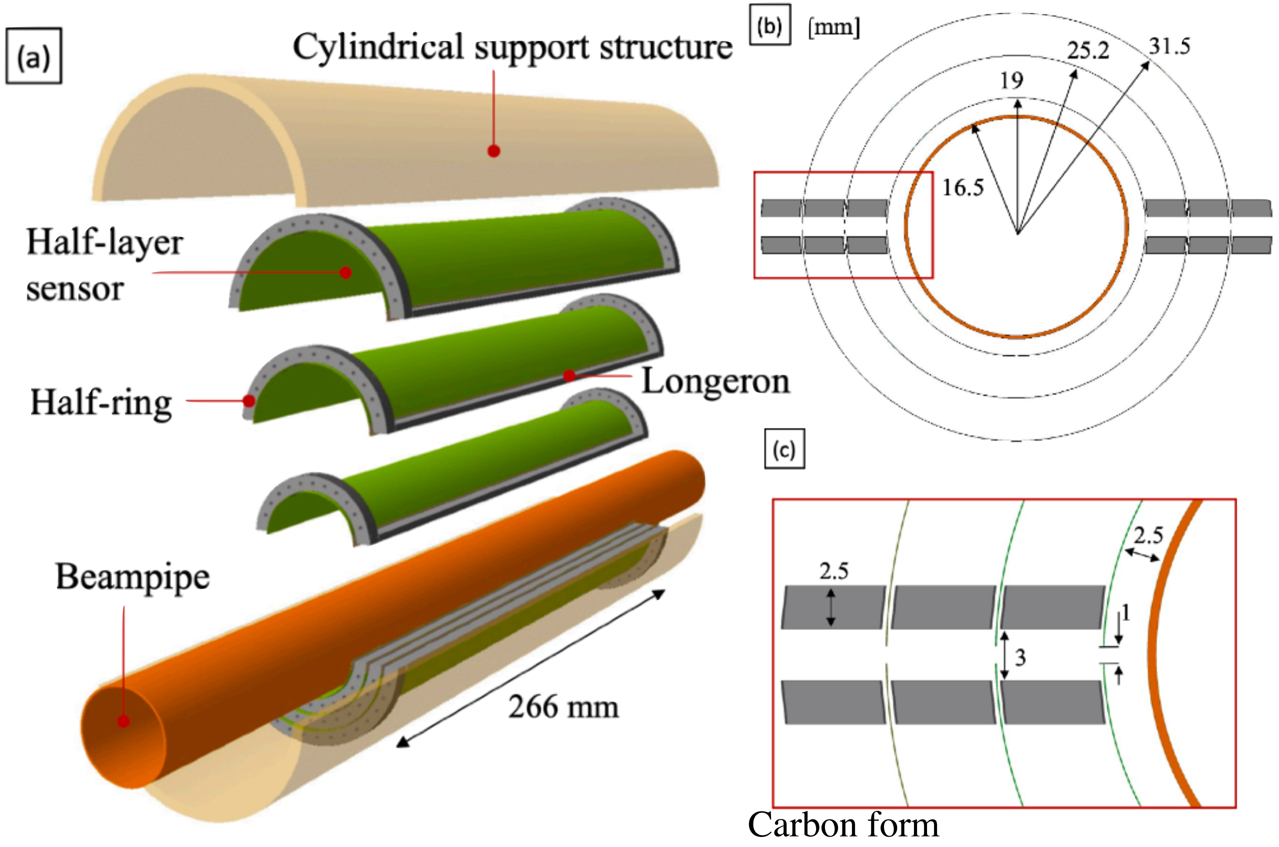
ITS3: replacement of ITS2 inner barrel

Bent wafer-scale sensor ASIC

- ➡ 65 nm CMOS MAPS
- ➡ Fabricated with stitching
- ➡ Power density < 40 mW/cm^2

3 layers with 6 sensors

Air cooling between layers



Key benefit

Lower material budget

- ➡ 0.35% X_0 → 0.09% X_0 per layer

Uniformly distributed material

Closer to interaction point

- ➡ Beampipe: 18.2 mm → 16.0 mm
- ➡ Layer 0 position: ~24 mm → 19.0 mm

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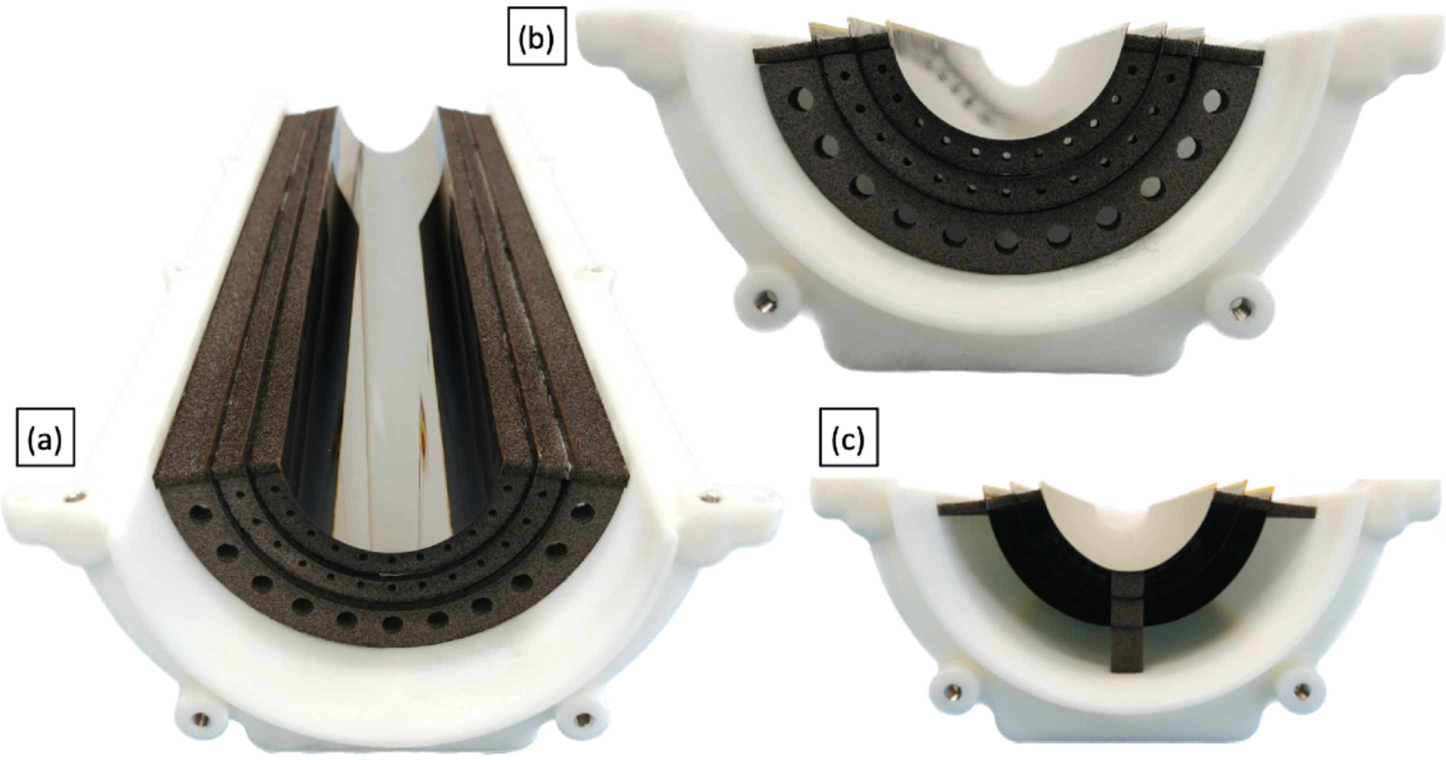

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Material budget comparison between ITS2 IB and ITS3

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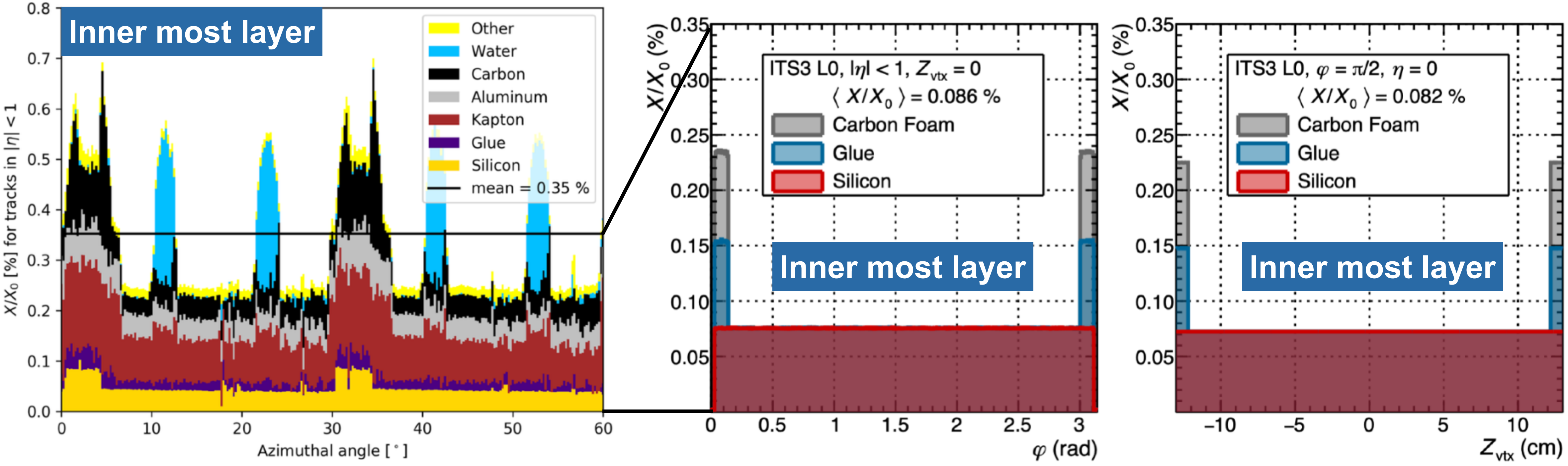


ITS2 IB

Various non-sensitive material

Silicon has 1/7 of total material budget.

Non-uniformly distributed material

Stave overlapping, support and water cooling structure.

ITS3

Few of non-sensitive material

Sillicon dominates.

Uniformly distributed material

Only some lightweight carbon foam and glue distributed on the edge of the sensitive area.

Chip development roadmap

MLR1 (Multi-reticle Layer Run 1)

- **First 65nm process MAPS**
- APTS, DPTS, CE65
- Successfully qualified the 65nm process for ITS3

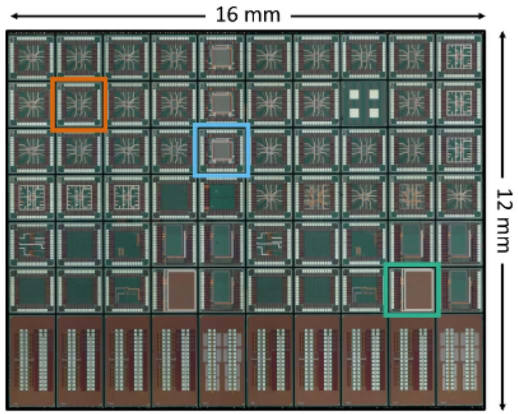
ER1 (Engineering Run 1)

- **First stitched MAPS**
- MOSS, MOST
- Successfully qualified the large scale sensor design

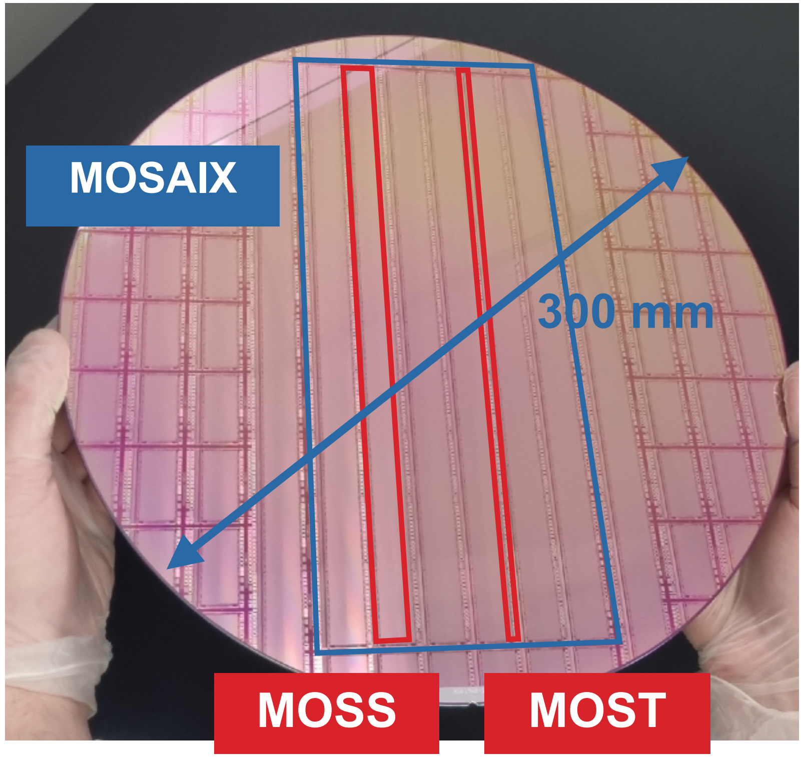
ER2 (Engineering Run 2)

- **Full-scale, fully functional prototype**
- MOSAIX (in production)

ER3 ITS3 sensor production



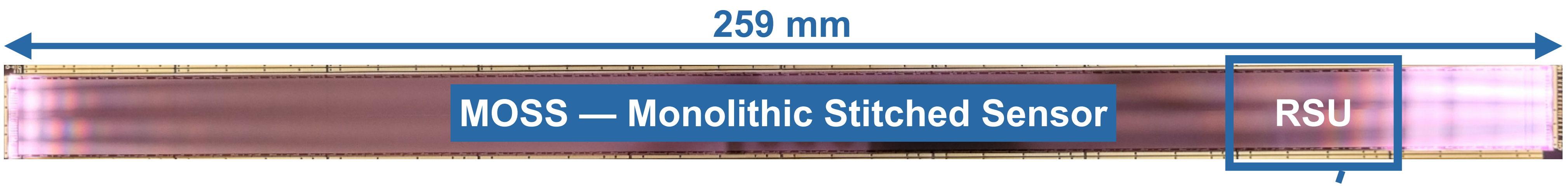
APTS
Analogue Pixel Test Structure
DPS
Digital Pixel Test Structure
CE65
Circuit Exploratoire 65 nm



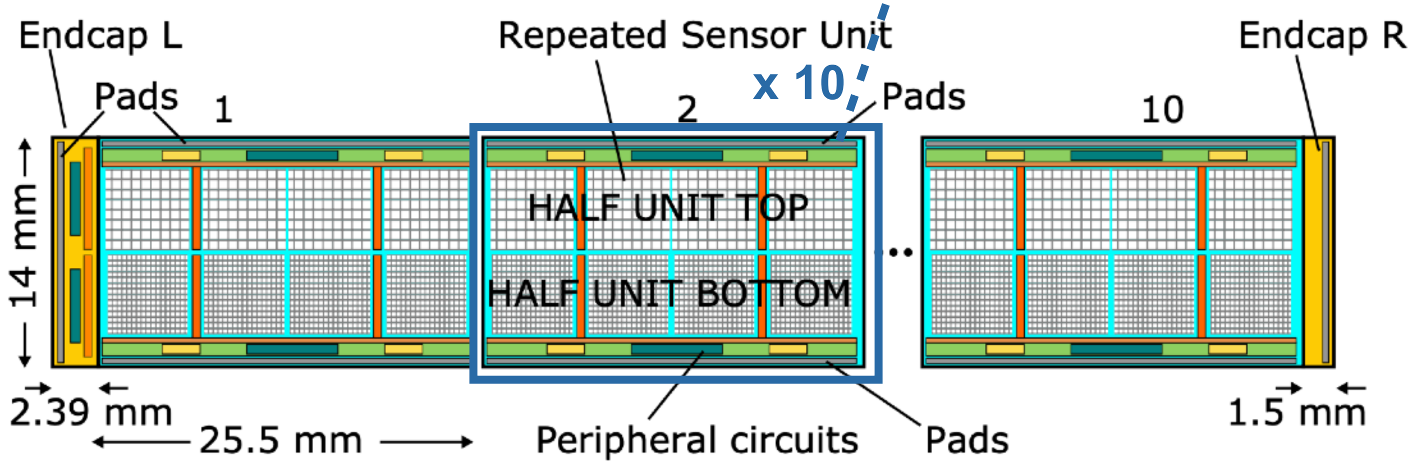
MOSS
Monolithic Stitched Sensor
MOST
Monolithic Stitched Sensor Timing

MOSAIX
Monolithic Stitched Active pixel

MOSS (ER1)



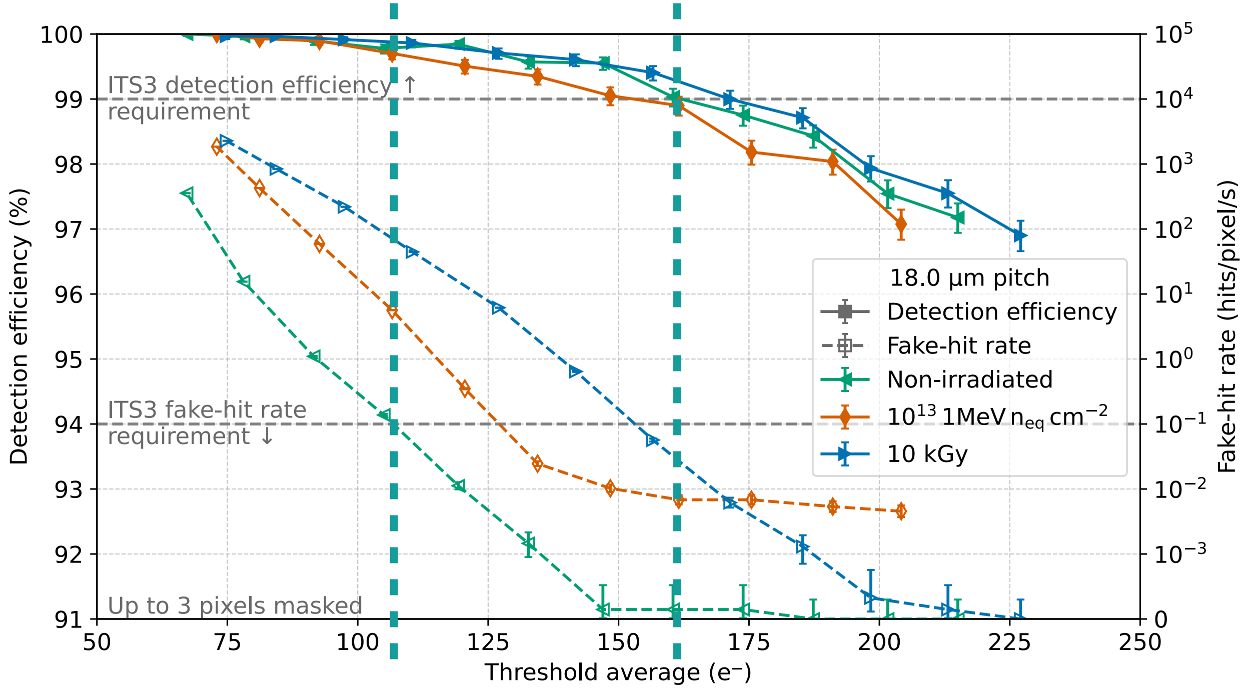
- **First stitched chips!**
  - **Full module on a single chip**
  - **Wafer-scale** (14 x 259 mm), **6.72 million pixels**
- MOSS is segmented into 10 repeated sensor units (RSU)
  - RSUs are divided into top and bottom half units with different pitches



	Pixel matrix	Pixel size
Matrices on the top	256 × 256	22.5 μm
Matrices on the bottom	320 × 320	18 μm

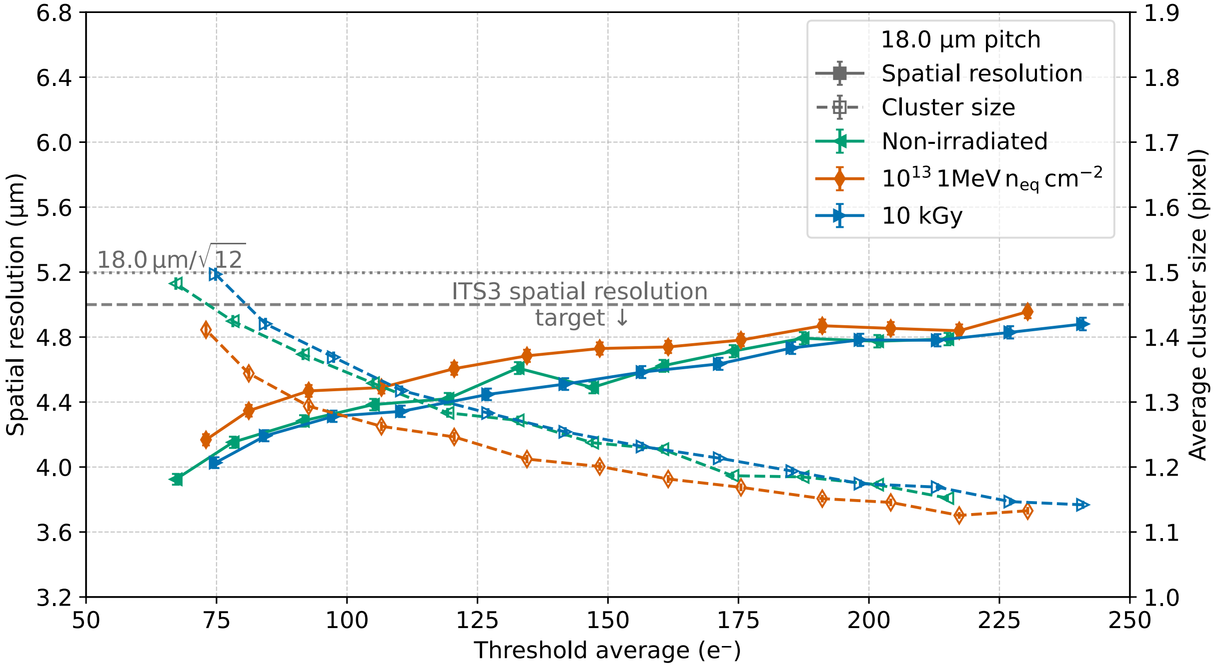
Non-irradiated MOSS performance

Detection Efficiency & Fake-Hit Rate vs Threshold



Operational Margin

Spatial Resolution & Cluster Size vs Threshold



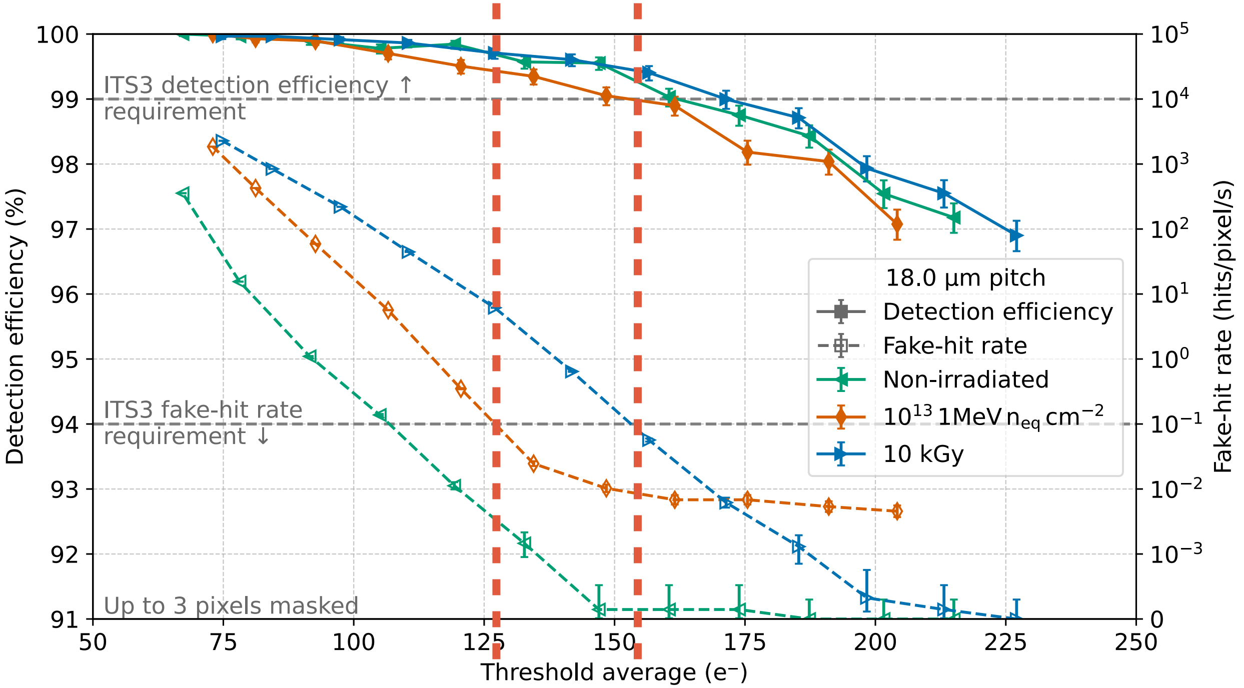
* O. Abdelrahman, et al, arXiv:2510.11463 (2015)

ITS3 requirement: Efficiency > 99%, FHR < 0.1 (hits/pixel/s)

Efficiency, spatial resolution, and radiation hardness meet the requirements of ITS3

MOSS performance with 10^{13} 1MeV n_{eq} cm^{-2} NEIL

Detection Efficiency & Fake-Hit Rate vs Threshold



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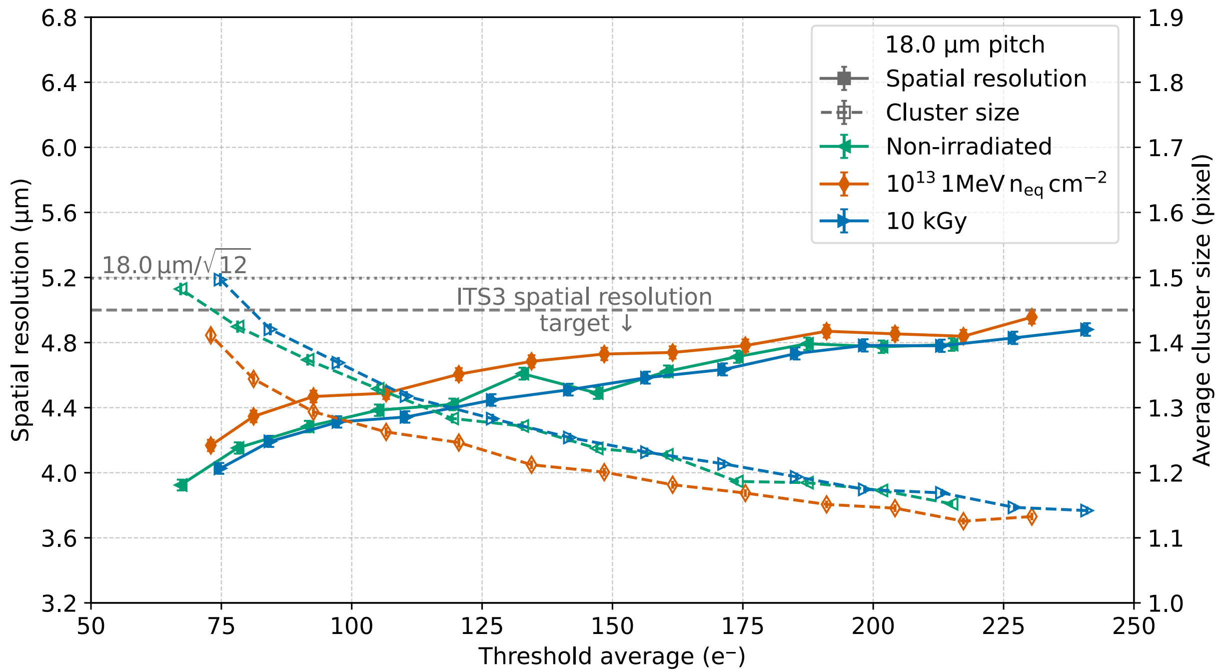

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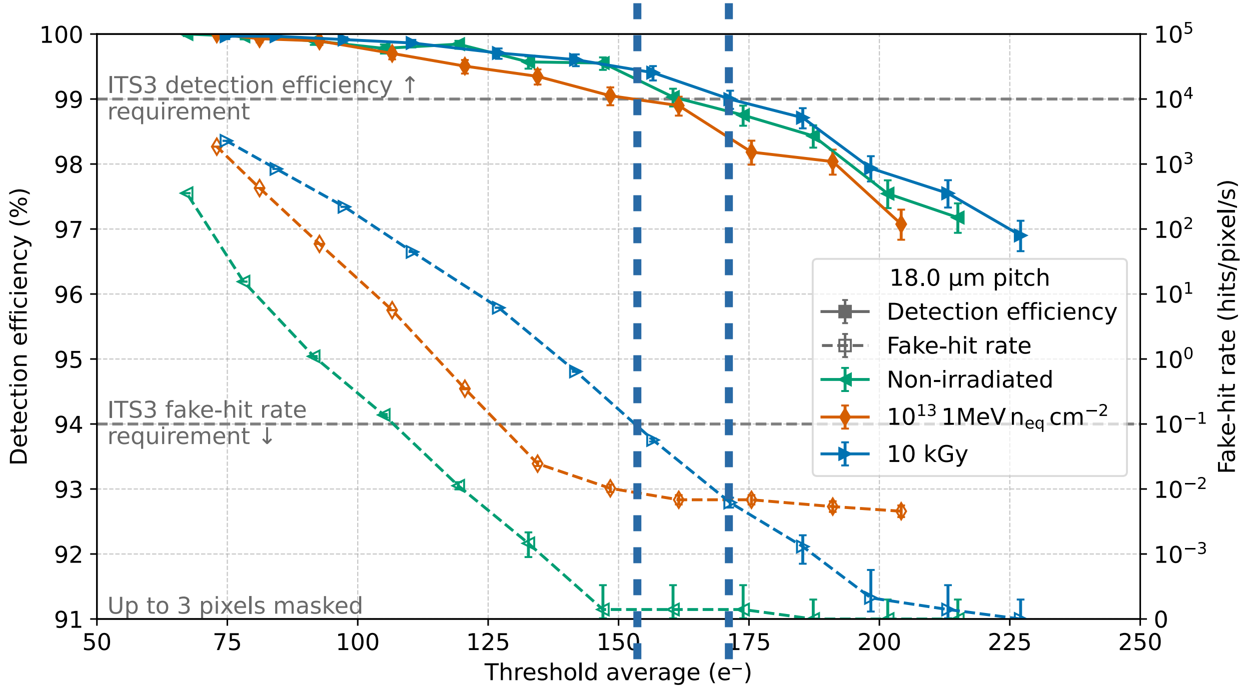
MOSS performance with 10kGy TID

Detection Efficiency & Fake-Hit Rate vs Threshold



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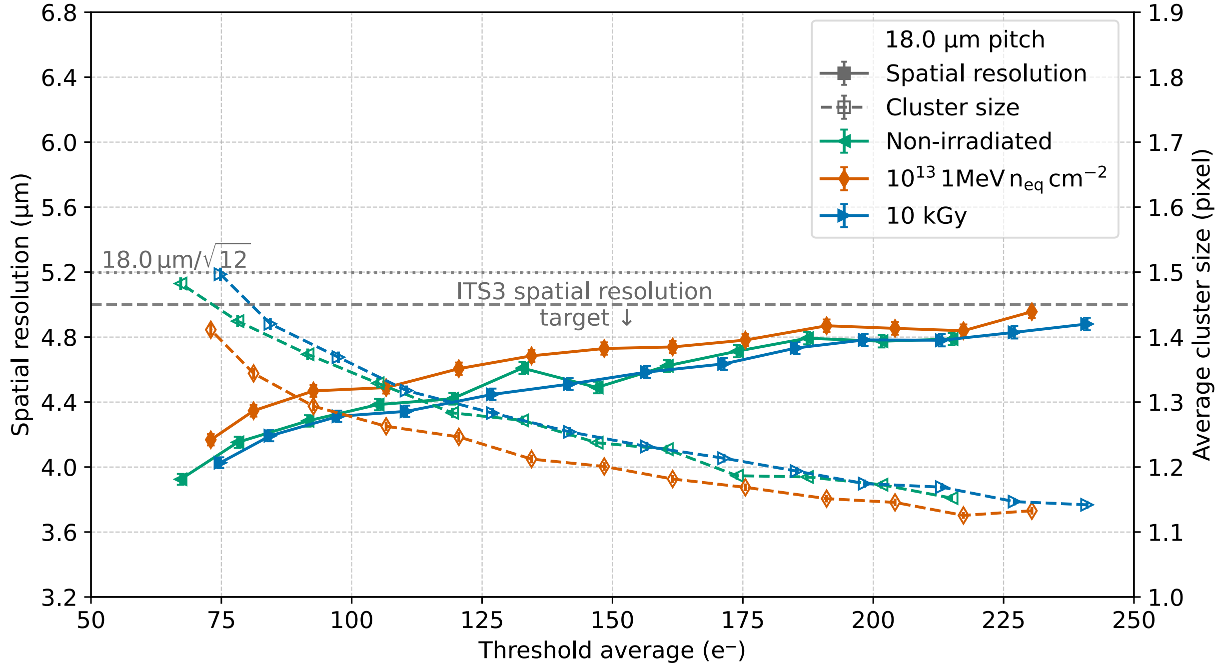

Operational Margin
TID 10kGy

* O. Abdelrahman, et al, arXiv:2510.11463 (2015)

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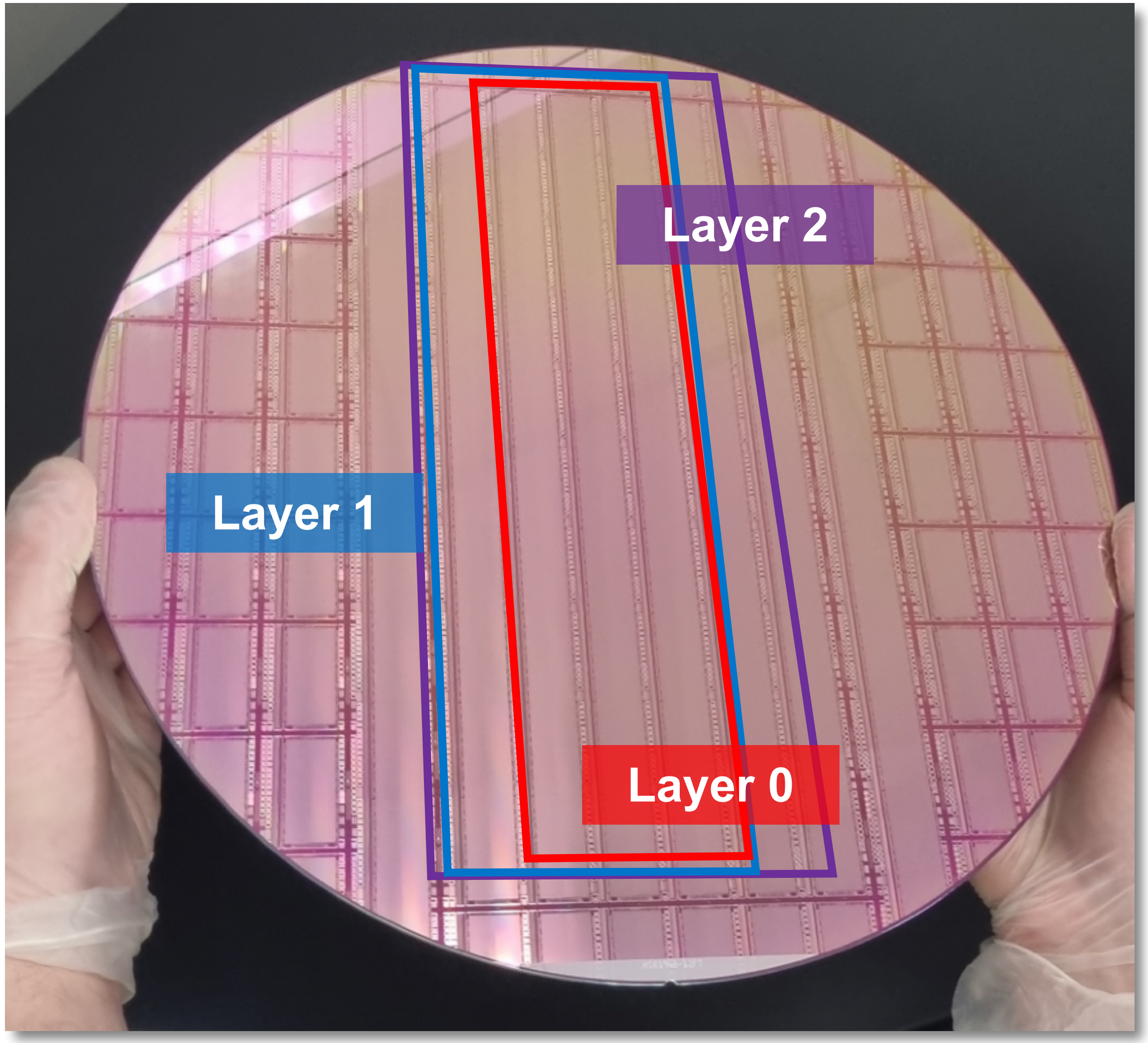
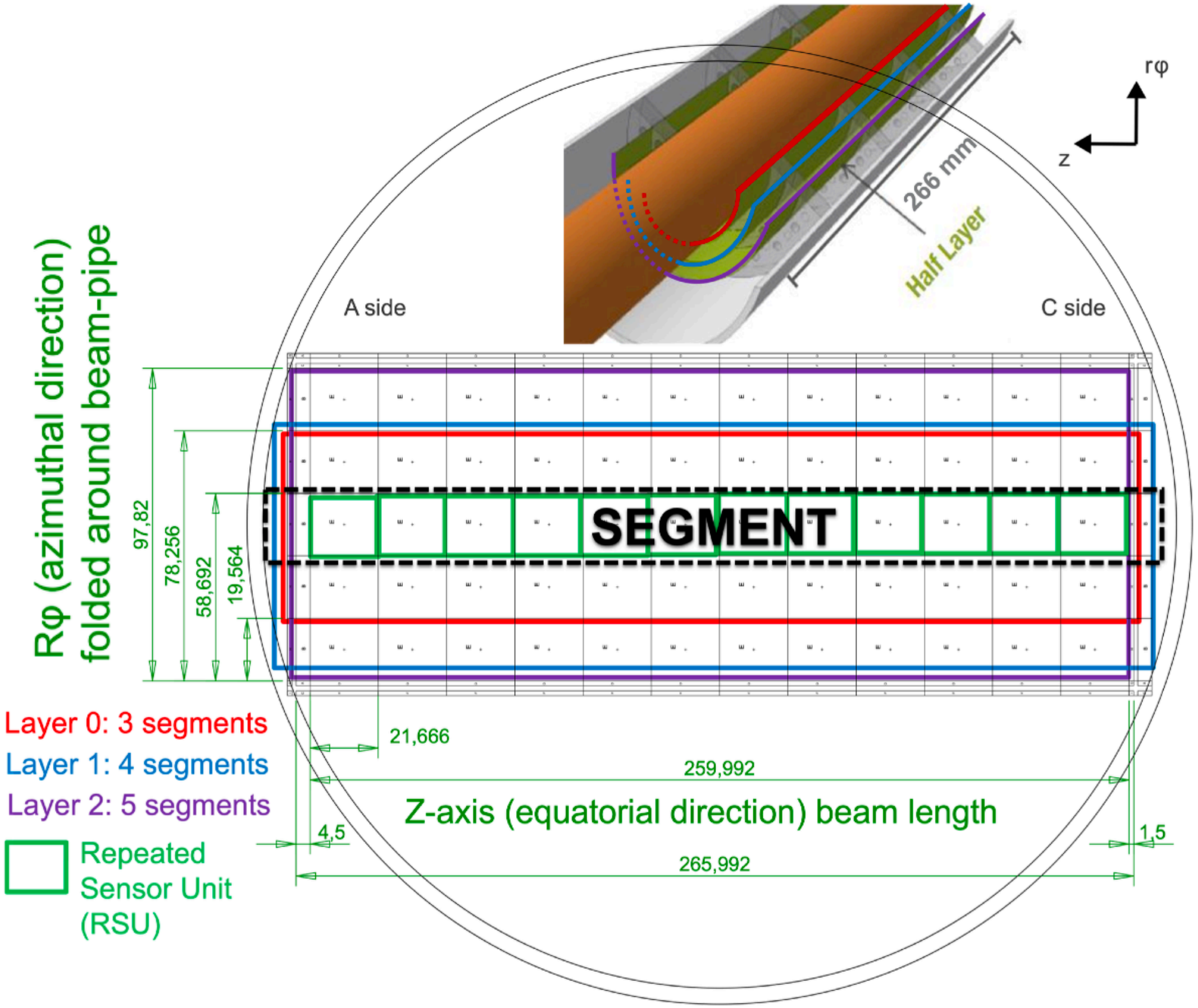
Final Chip Design





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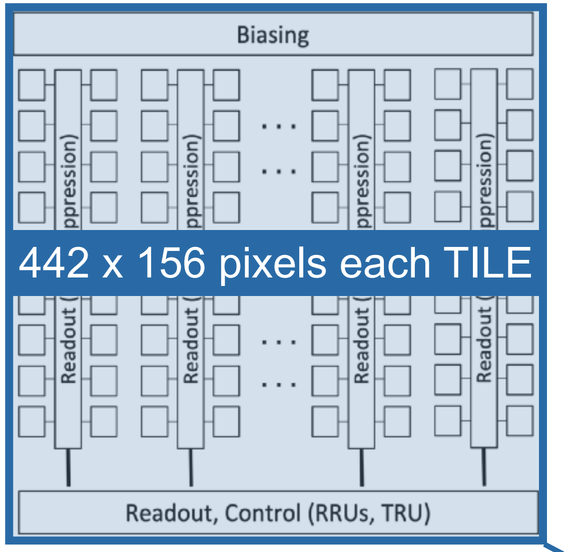
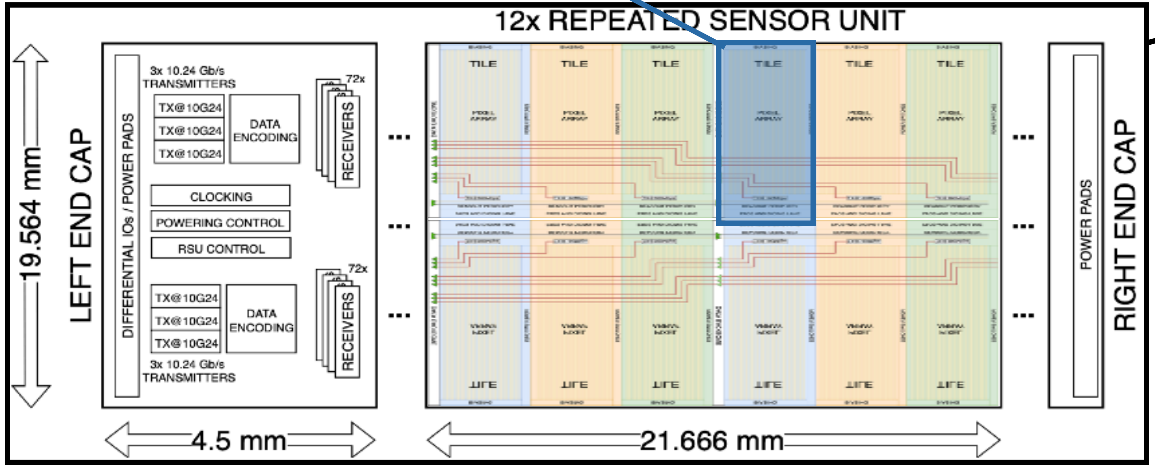
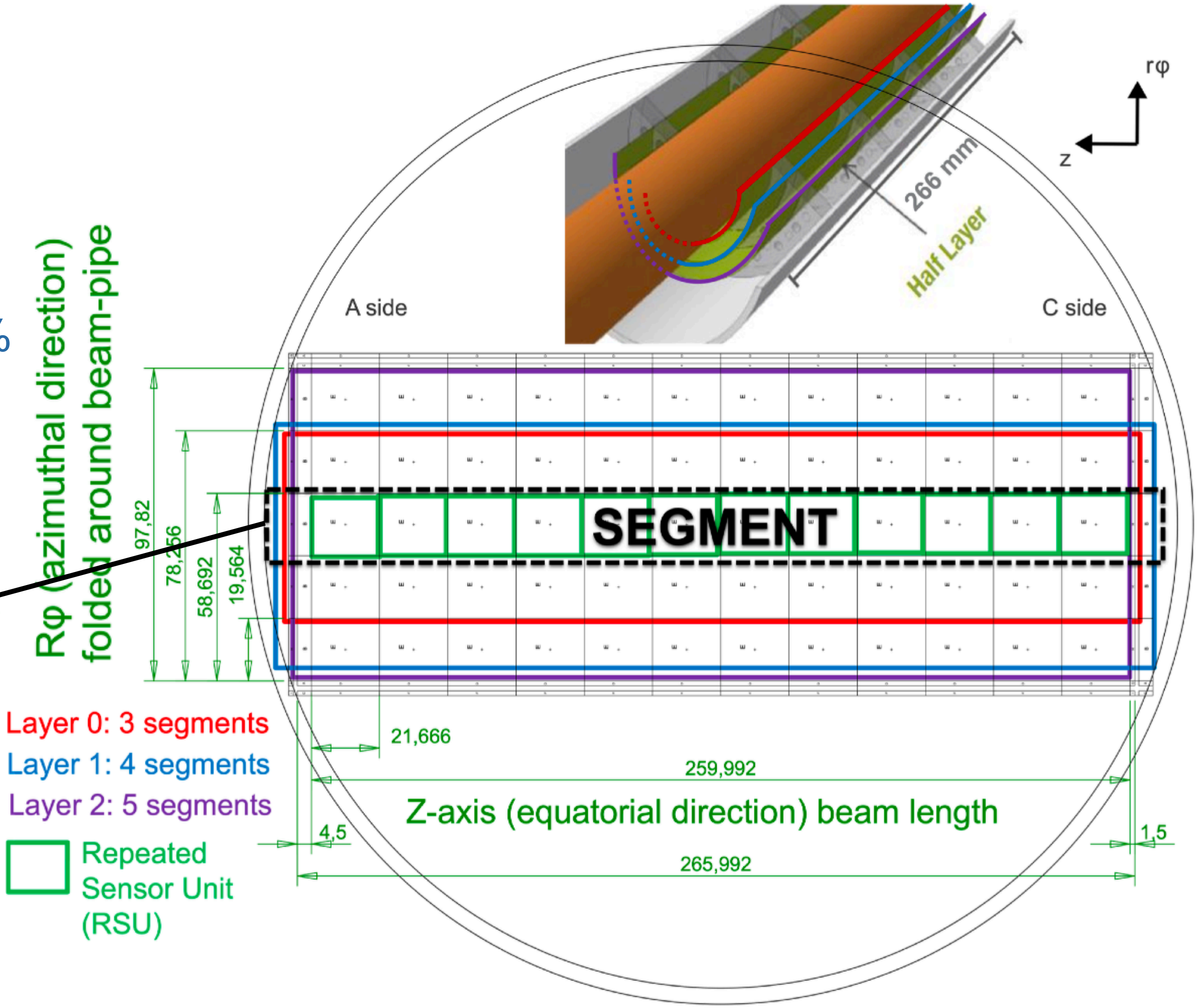


Power consumption:

40 mW/cm^2

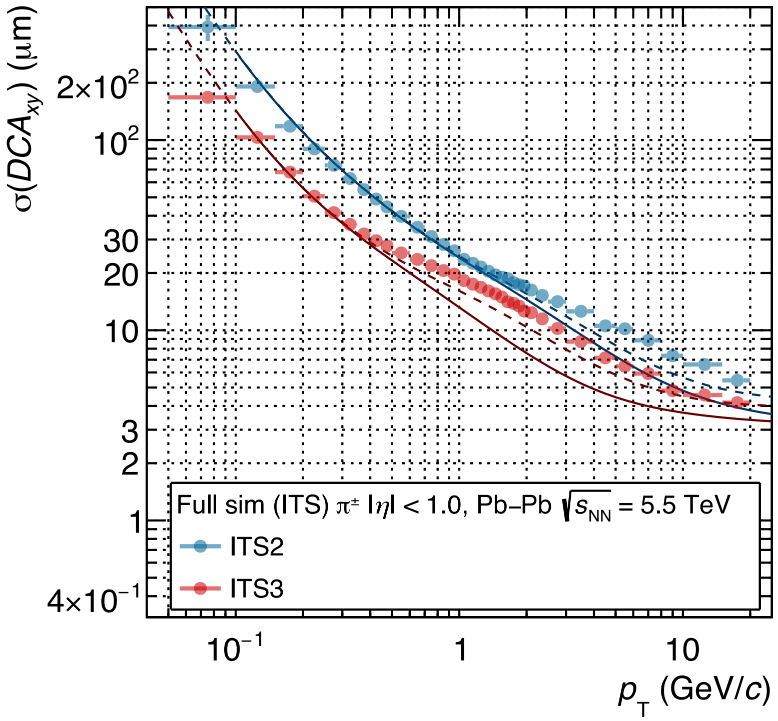
Total ITS3 Fill factor: ~93%

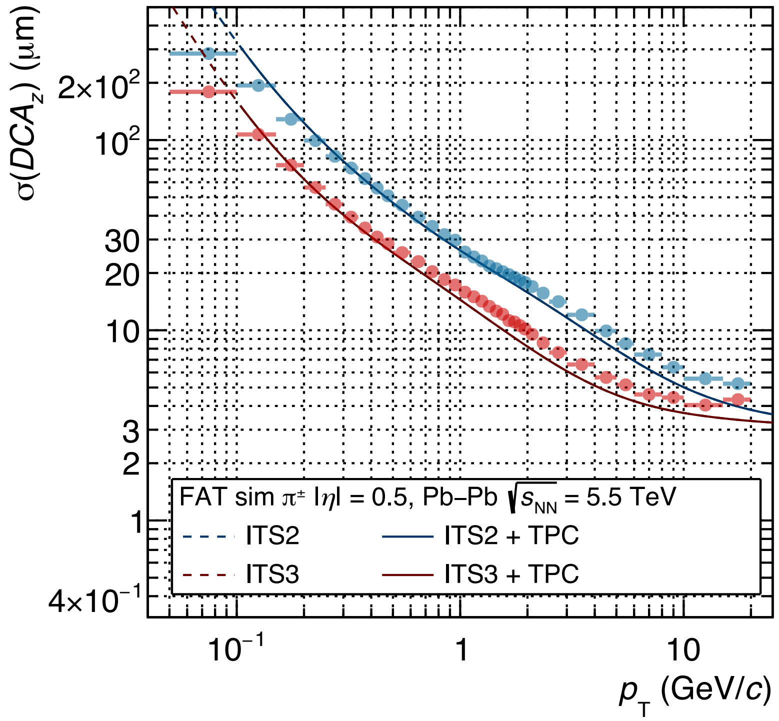




Silicon back by end of 2025 and the testing system is under the development

Physics performance — Single track in Pb-Pb collisions





- Detailed description of geometry and material applied.
- Two simulation methods used
  - Full simulation
  - Fast simulation (FAT)

- ITS-only: Full sim and FAT results in good agreement for DCAxy and DCAz
  - Residual difference related to the material description (more accurate in full sim) or to tracking model
- Bump trend on DCAxy in $0.5 < p_T < 4$ GeV/c
  - Due to p_T resolution, significantly calibrated by the introduction of TPC

A twofold improvement in spatial resolution compared to ITS2

Physics performance — Heavy flavour hadron reconstruction

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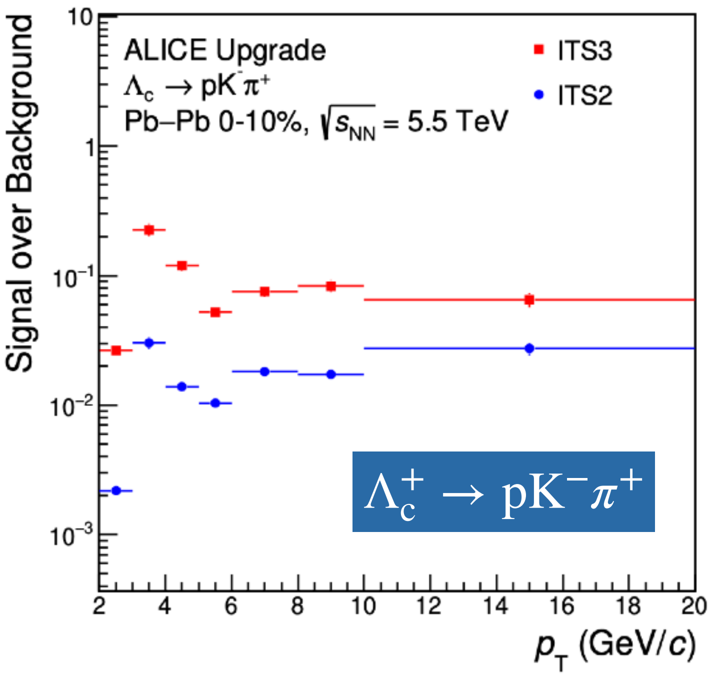
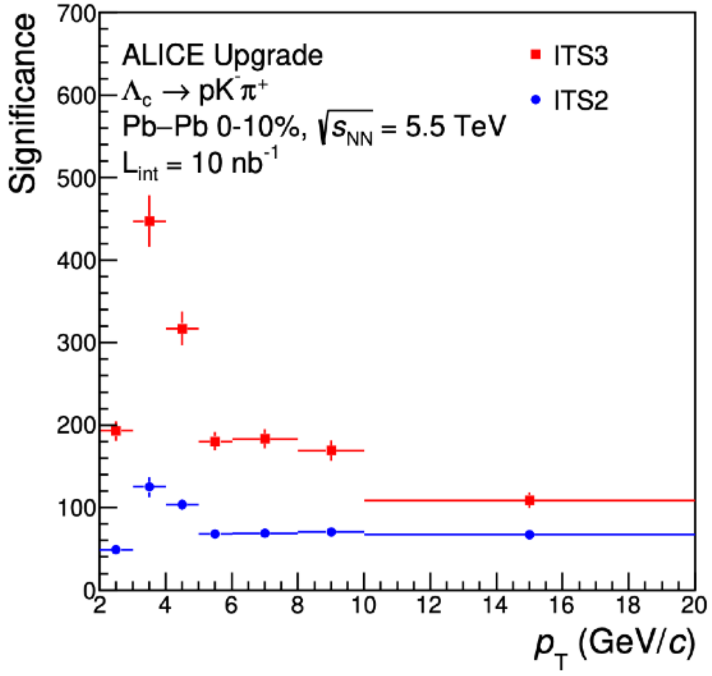
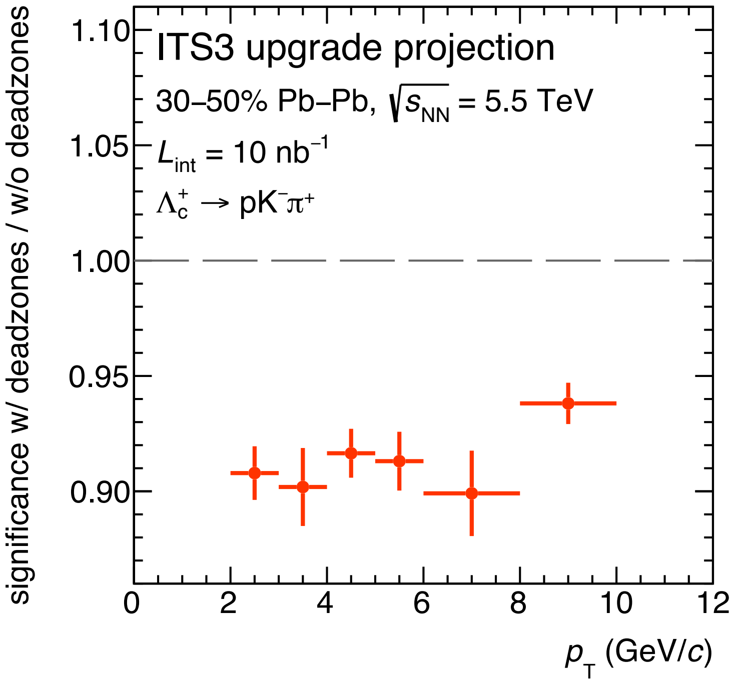






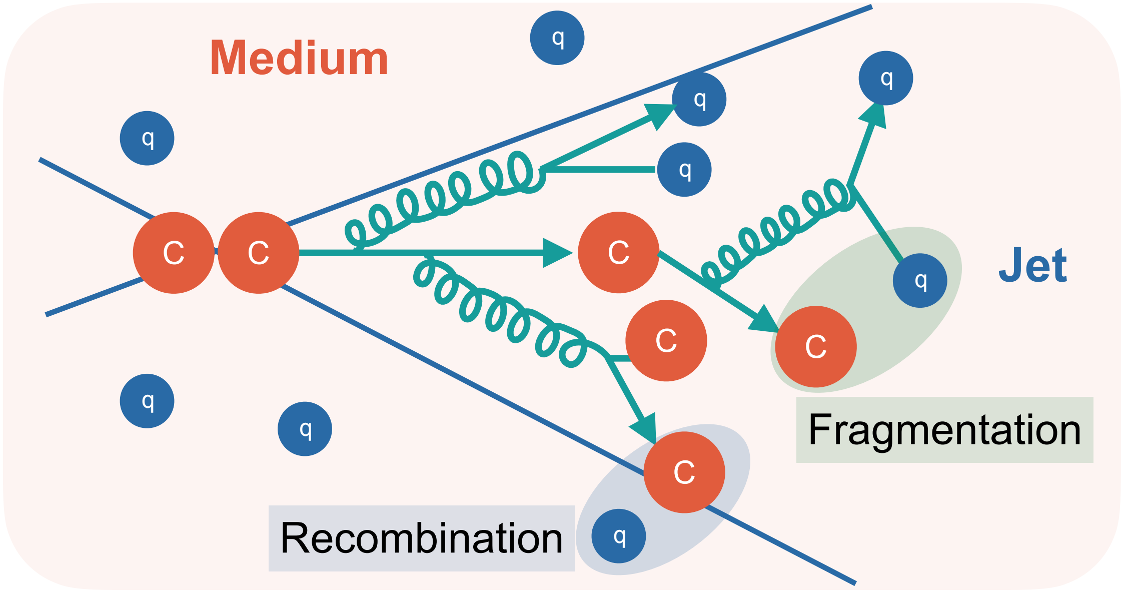
- Λ_c^+ reconstruction as an example
- Nice benchmark to evaluate the improvement
  - ➡ Large 3-prong combinatorial background
  - ➡ Measurement of primary and decay vertices can benefit from ITS upgrades.

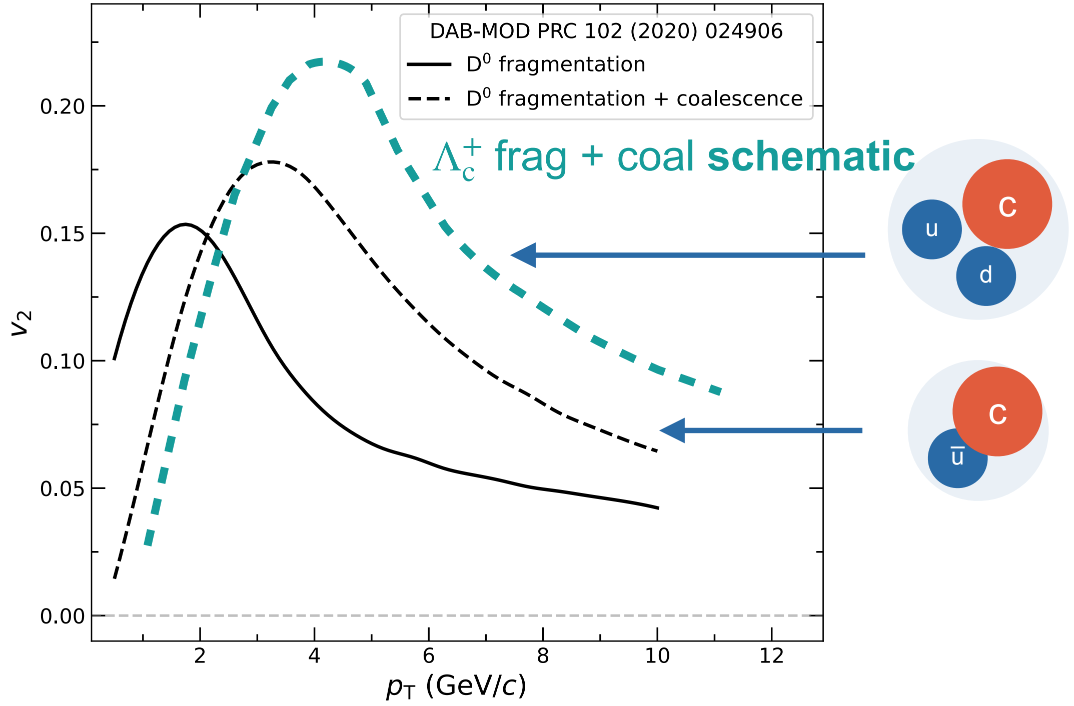
Public Note on ITS3 Physics Performance ALICE-PUBLIC-2023-002

- A factor of ~10 for the improvement on the S/B
- A factor of ~4 for the improvement on the significance
- Impact of deadzones negligible compared to the improvement between ITS2 and ITS3

*Signal and background yields estimated in an invariant-mass interval of ±3σ around the Λ_c^+ mass

Physics reach — Heavy flavour collectivity





Heavy-quark hadronization from the medium

Fragmentation $D_{q \to h}(z_q, Q^2)$

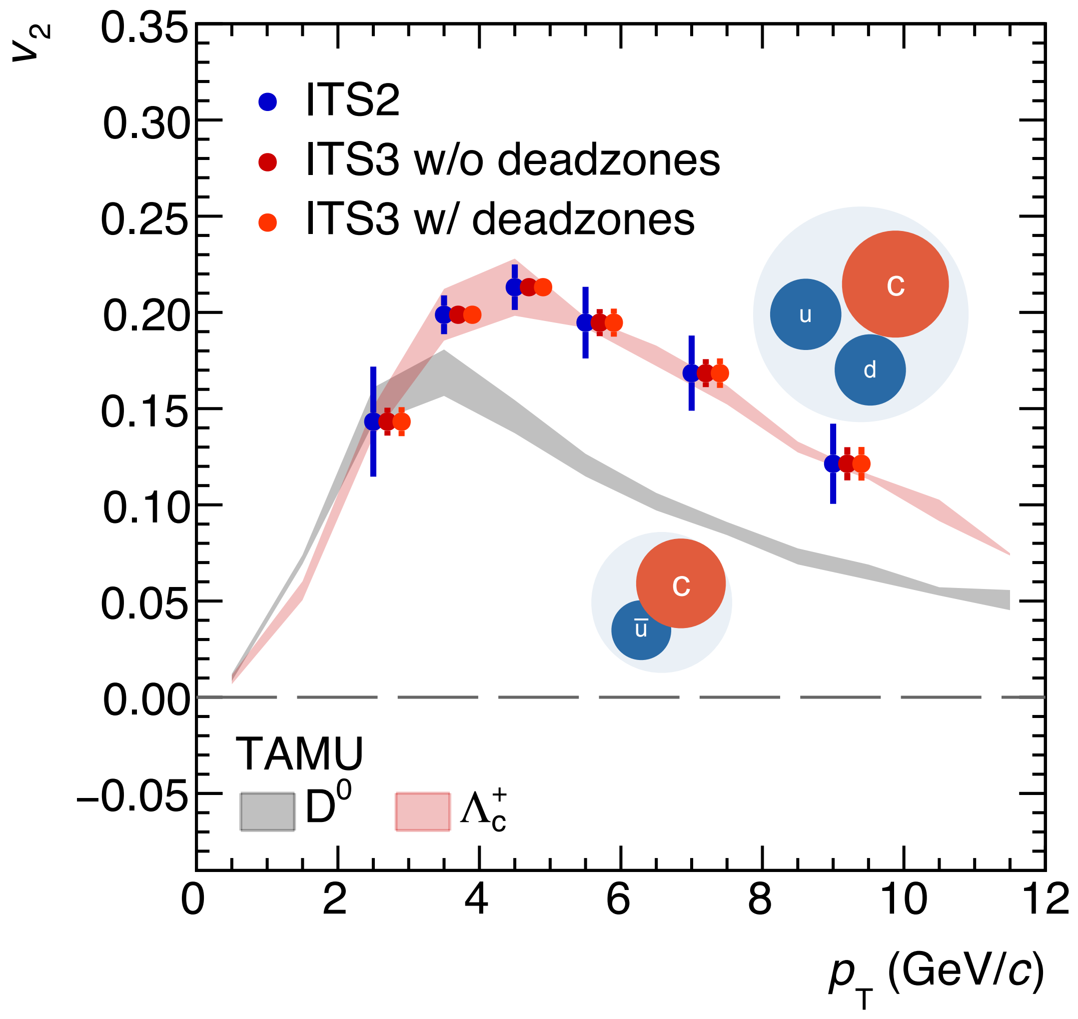
A fraction of the parton momentum z_q is taken by the hadron

Recombination/coalescence

Partons close in phase space can recombine

- Recombination of c-quarks with the medium light quarks could cause charm hadrons to partly inherit the flow of light quarks.
- Λ_c^+ (udc) has one more light quark than D^0, may inherit more "collective" characteristics of light quarks.

Physics reach — Heavy flavour collectivity



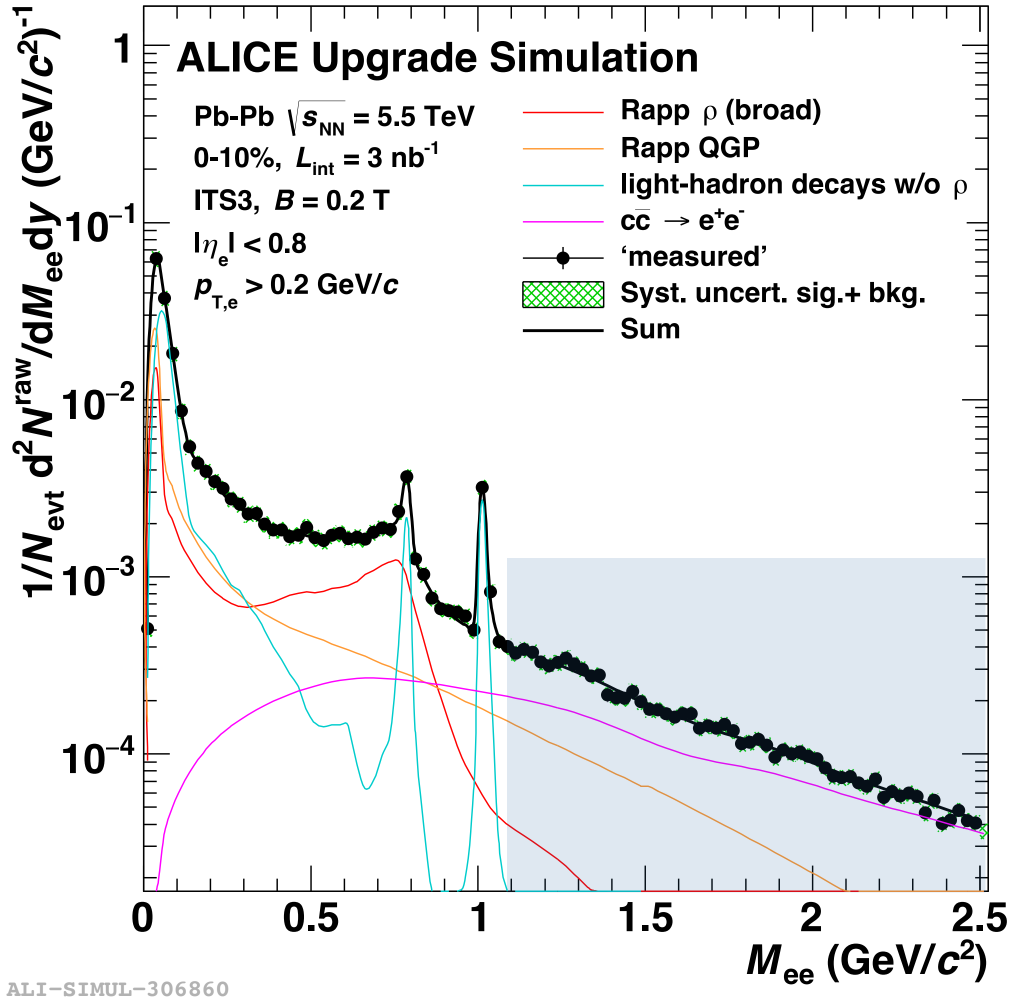
Expected to get a difference $\Delta v_2 \approx 0.03$ between D^0 and Λ_c^+ by TAMU Model*

* M. He and R. Rapp, PRL 124, 042301 (2020)

- Up to a factor of 4 reduction of the statistical uncertainty
- Impact of deadzones in ITS3 is negligible

Able to constrain the modelling of charm diffusion and hadronization in the QGP

Physics reach — Thermal dielectron measurement



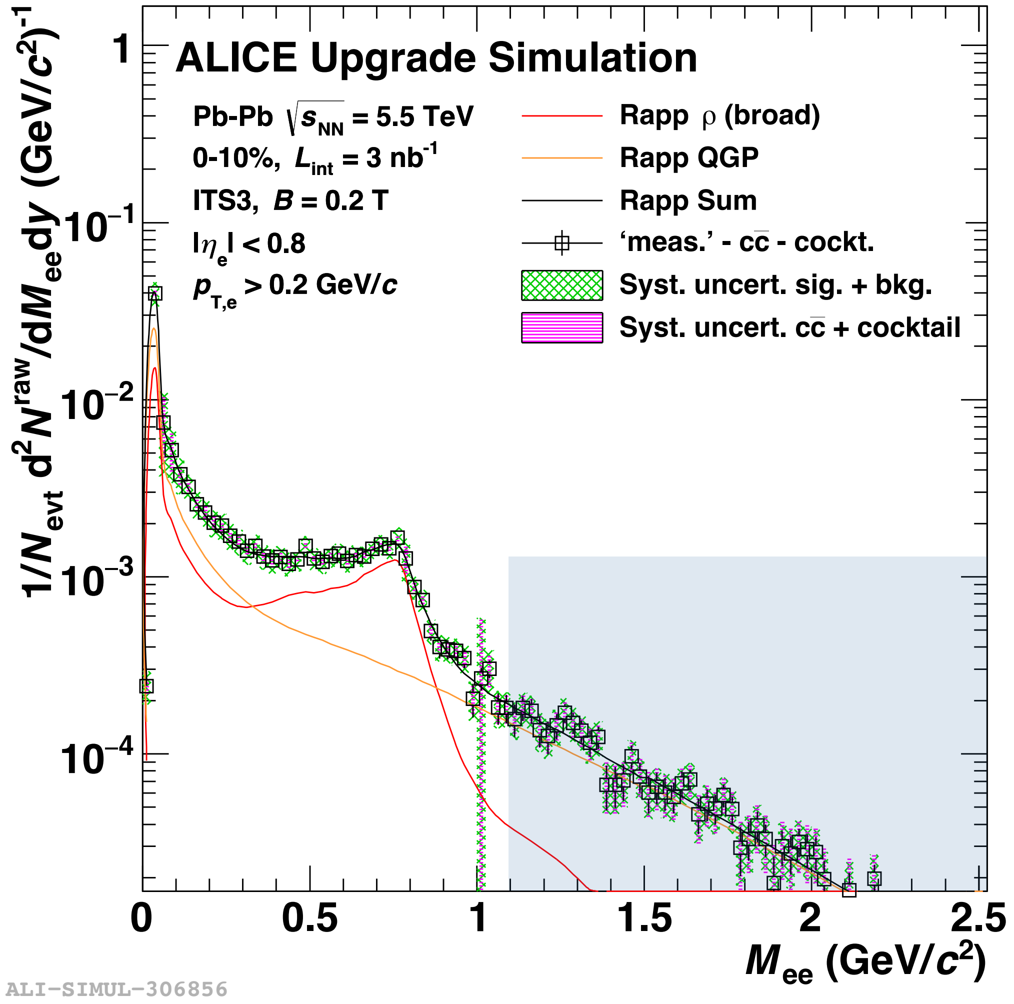
Complex invariant mass spectrum of e^+e^- pairs

- ➡ Light-flavour hadron decays
- ➡ Heavy-flavour hadron decays (suppressed using DCA to primary vertex)
- ➡ Thermal radiations:
  - ➡ from hadron gas
  - ➡ from QGP

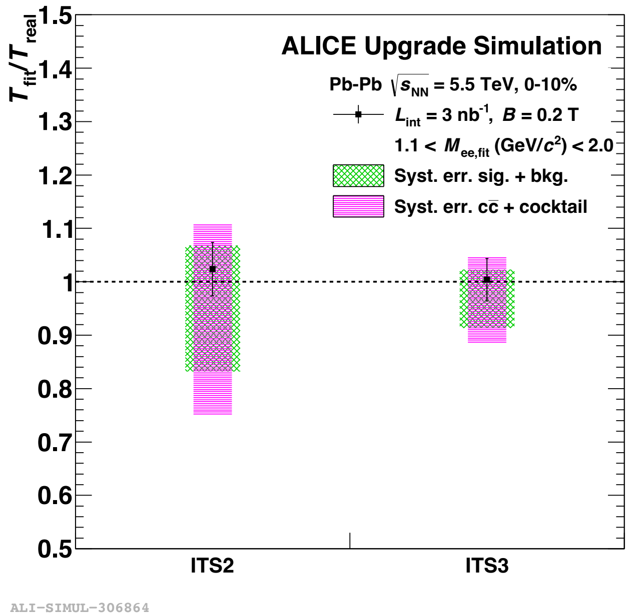
In the region where M_{ee} > 1.1GeV/c^2

- The $c\bar{c} \rightarrow e^+e^-$ process and the thermal radiations from QGP dominate
- Suitable for extracting the QGP temperature

Physics reach — Thermal dielectron measurement



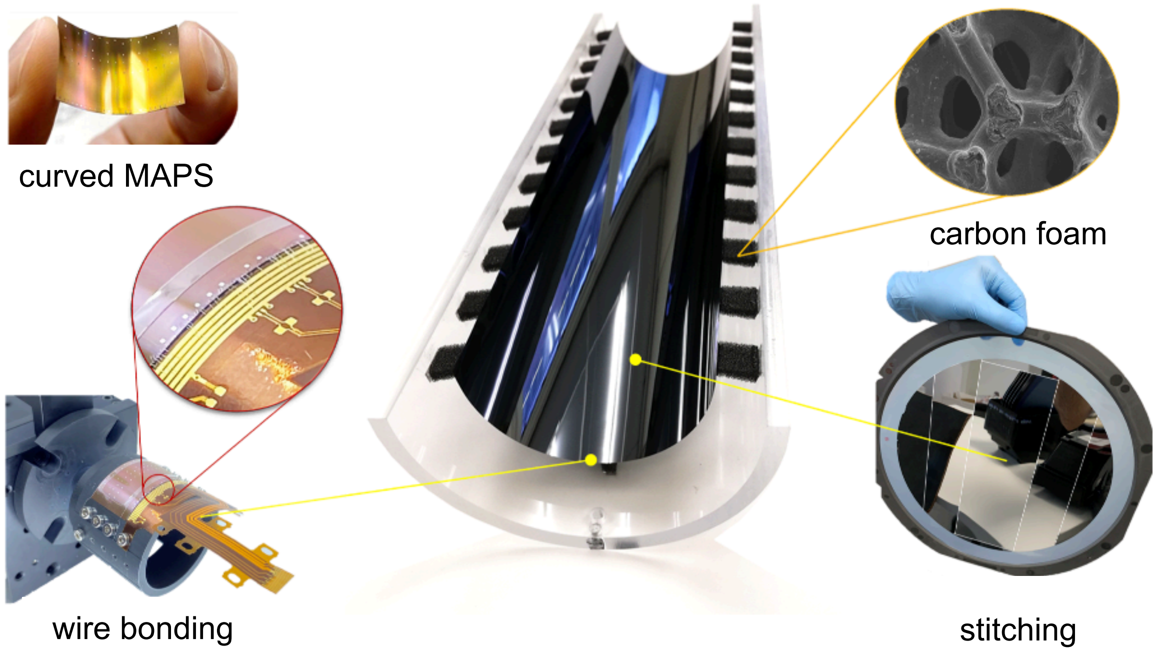
- Less material results in fewer electrons from photon conversions.
- Enhanced low-p_T electron tracking improves photon conversion reconstruction efficiency, reducing the combinatorial background.
- Improved DCA resolution suppresses contributions from heavy-flavour hadron decays.



The systematic uncertainty with ITS3 reduced by a factor of 2 compared to ITS2

Summary and outlook

- **ITS3 — a bent wafer-scale monolithic pixel detector**
- **ITS3 project is on track for installation in LS3**
- **A twofold improvement in spatial resolution wrt. ITS2**
  - ➡ a significant improvement in the reconstruction of heavy flavour hadrons
- **The following analysis significantly benefit from ITS3**
  - ➡ heavy flavour collectivity
  - ➡ thermal dielectron measurement
  - ➡ and many more analyses…



Thanks!