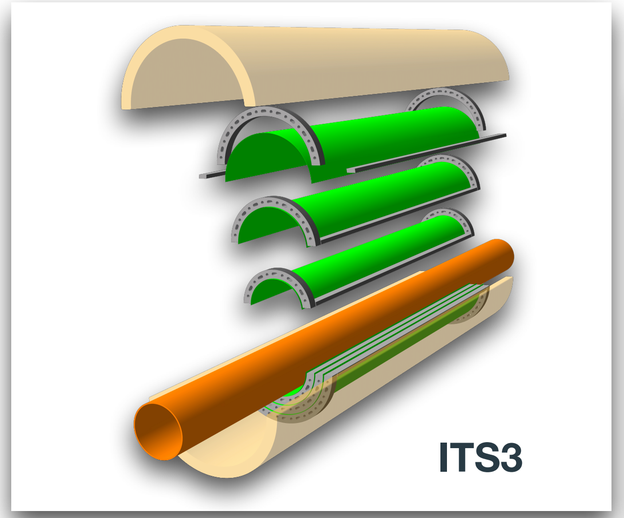
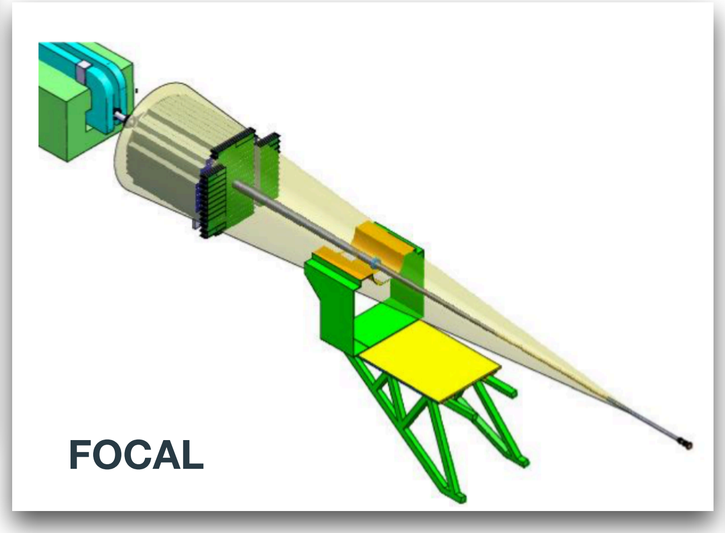
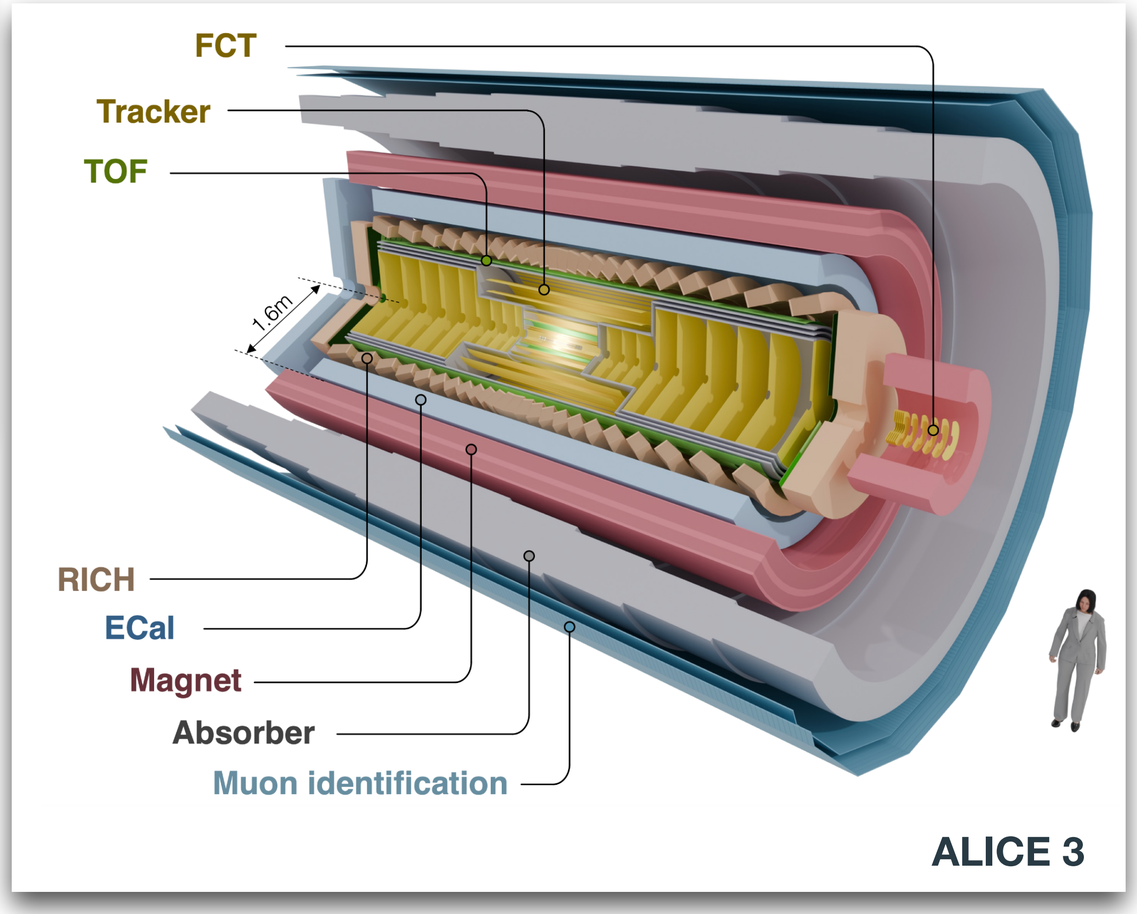


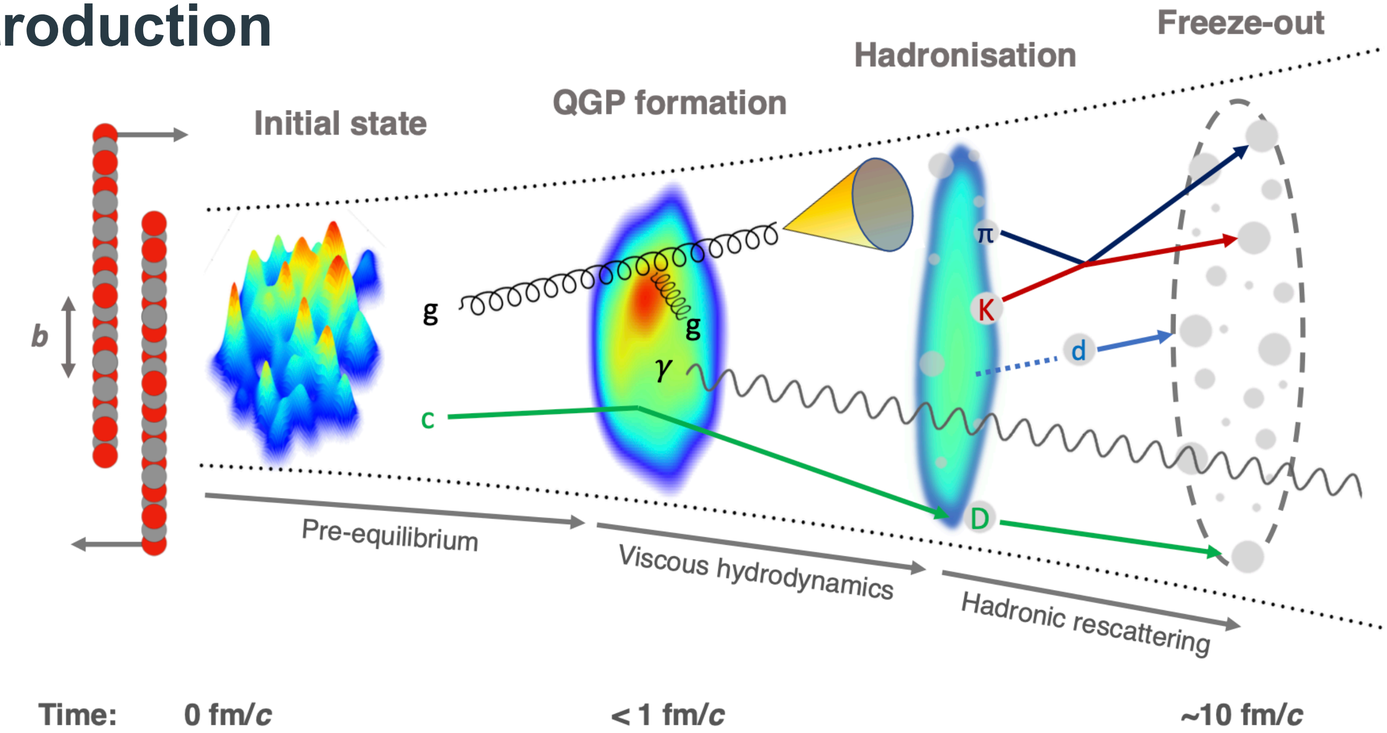



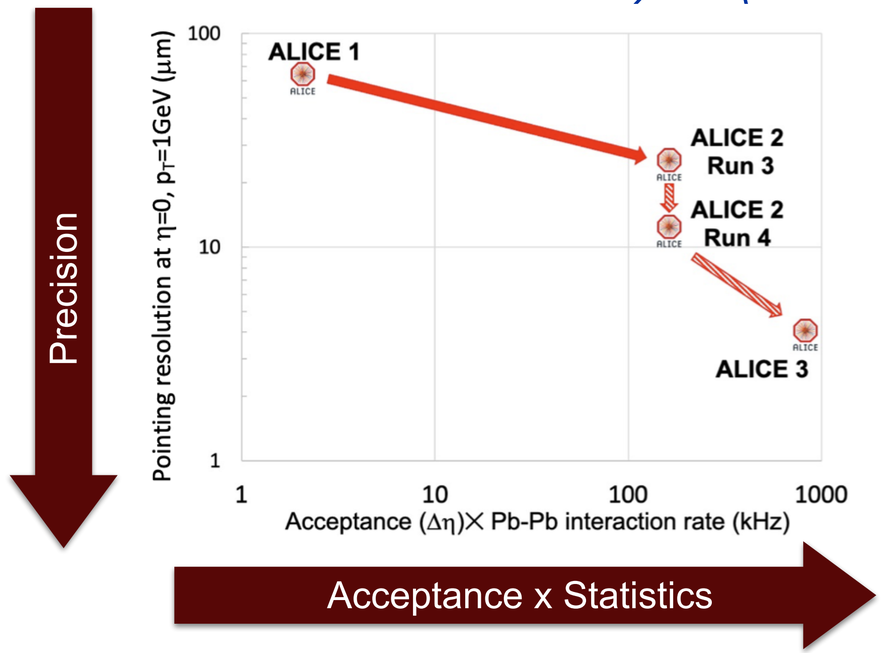

# ALICE Upgrades
## 115th ECFA Plenary

**Felix Reidt**
felix.reidt@cern.ch

on behalf of the ALICE collaboration

# Introduction



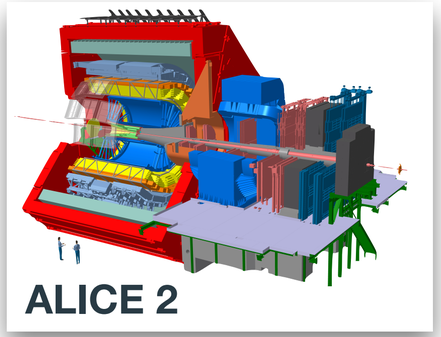

arXiv:2211.04384

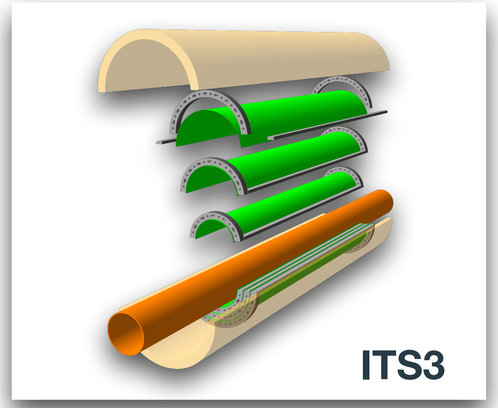
- ALICE is designed to study the quark-gluon plasma produced in heavy-ion collisions at the LHC
- Broad physics program, two key physics items driving the upgrade strategy:
  - **Heavy flavour (HF)** transport and hadronization in the medium:
    differential measurements of hadron production (suppression, enhancement, flow… ) down to vanishing $p_T$
  - **Electromagnetic radiation** from the medium: dileptons below the $J/\psi$ mass down to zero $p_T$: mapping the evolution of the collision

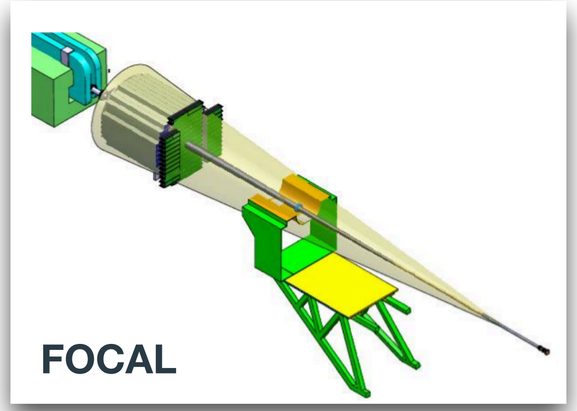
⇒ High-granularity, low-mass detector with continuous readout to access untriggerable signals with very low S/B

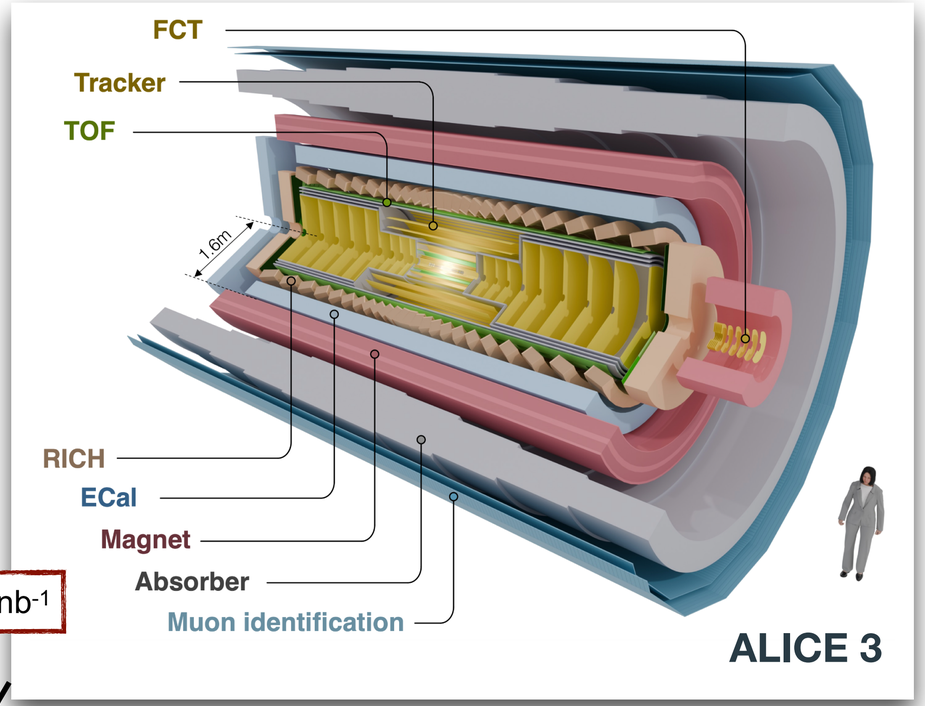
A. Kalweit - Nuclear Physics at the LHC

# ALICE Upgrade Roadmap



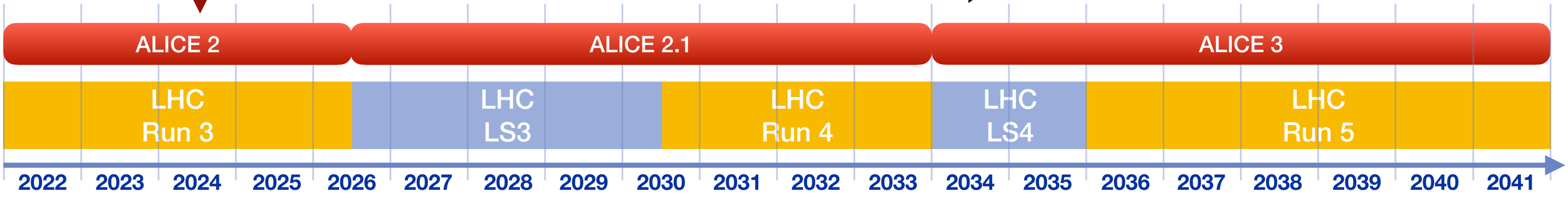




Pb-Pb: 6.2 nb$^{-1}$
O-O: 500 µb$^{-1}$

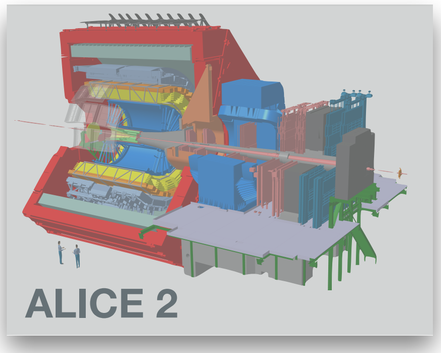
Today

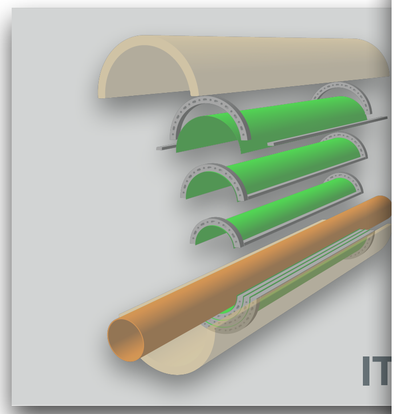
Pb-Pb: 6.8 nb$^{-1}$
p-Pb: 0.6 pb$^{-1}$

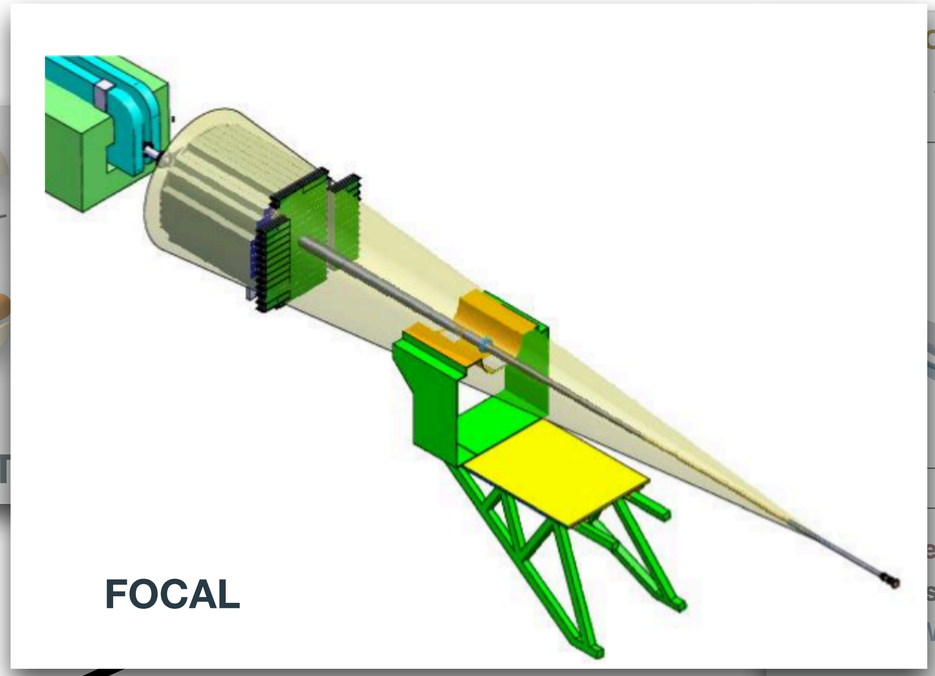
Pb-Pb: ~ 35 nb$^{-1}$

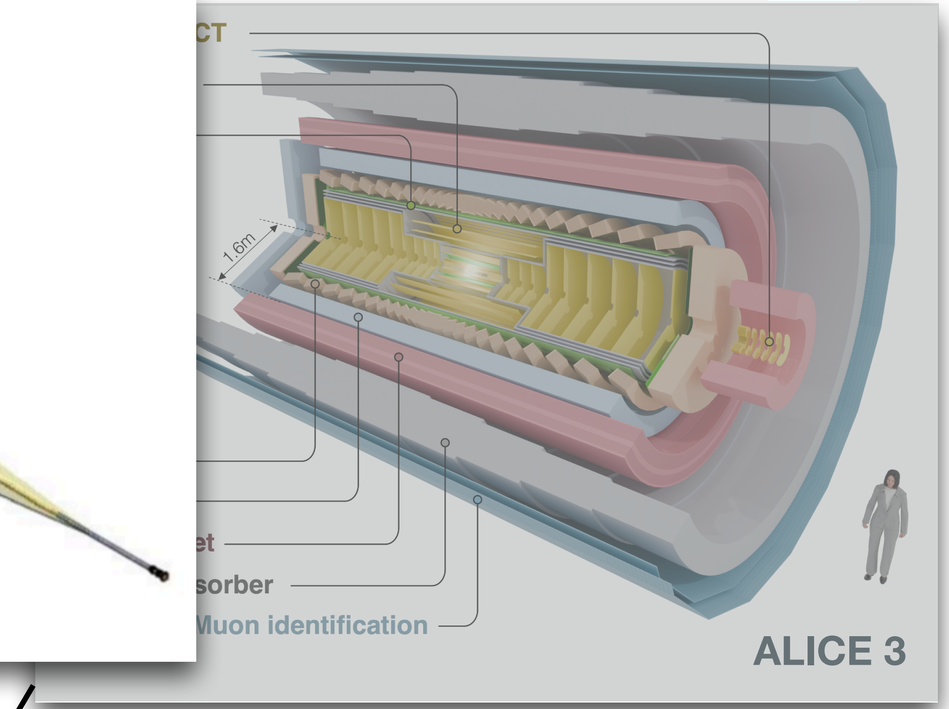


# The Forward Calorimeter (FoCal)




Today

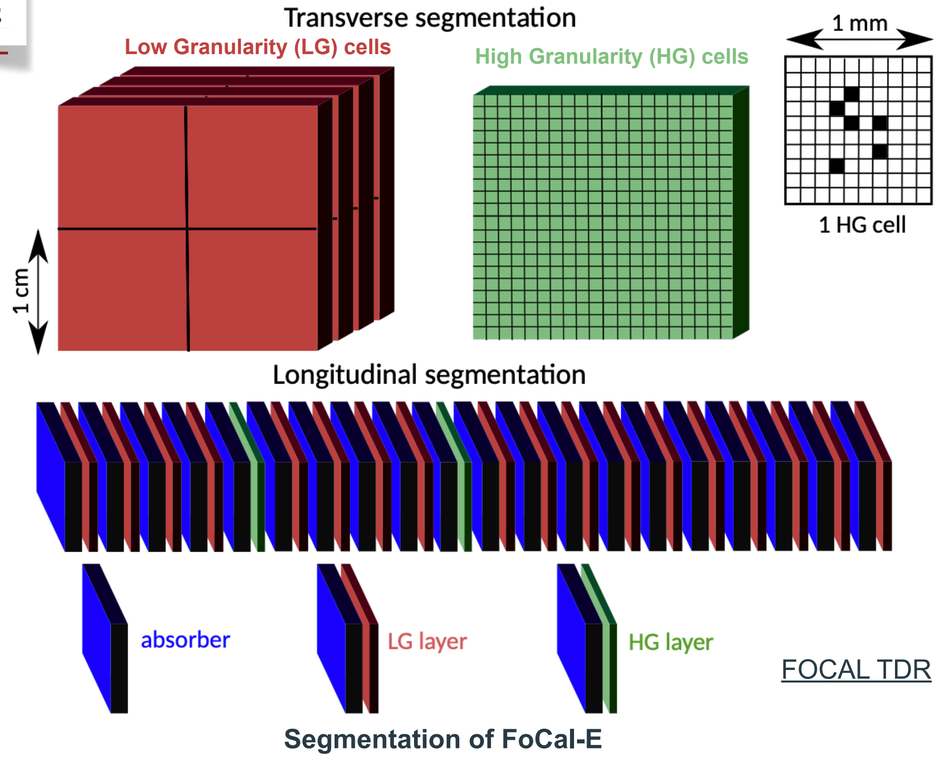
ALICE 2 | ALICE 2.1 | ALICE 3

LHC Run 3 | LHC LS3 | LHC Run 4 | LHC LS4 | LHC Run 5

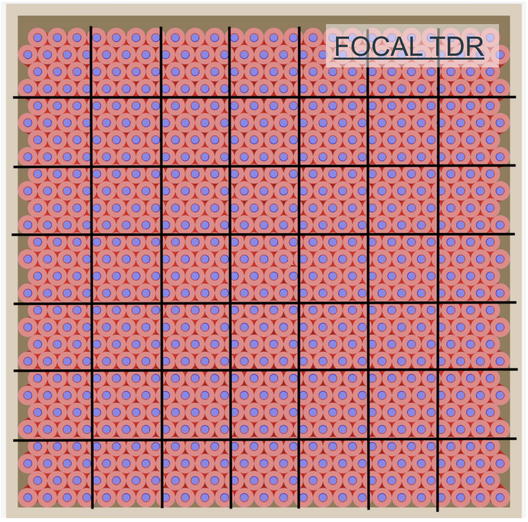
2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041

# The Forward Calorimeter (FoCal)

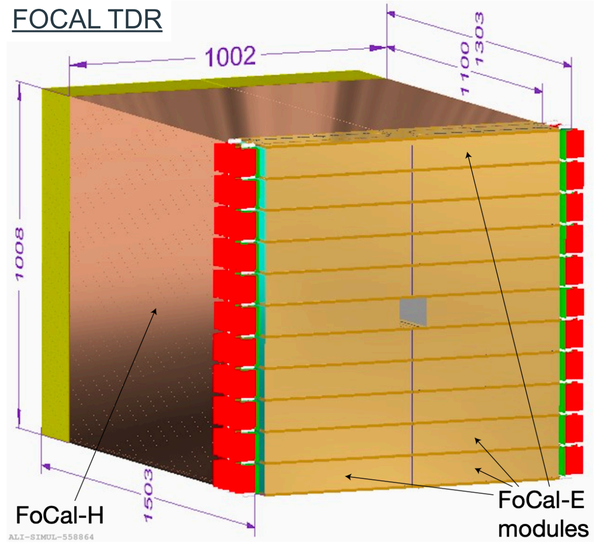
- **FoCal-E:** a compact silicon-tungsten sampling electromagnetic calorimeter with pad (1 x 1 cm$^2$) and pixel (30 x 30 μm$^2$)
  - High spatial resolution to distinguish between isolated photons and decay photon pairs
- **FoCal-H:** hadronic calorimeter constructed from copper capillary tubes filled with scintillating fibres
  - Photon isolation, energy and jet measurements
- Coverage: $3.2 < \eta < 5.6$



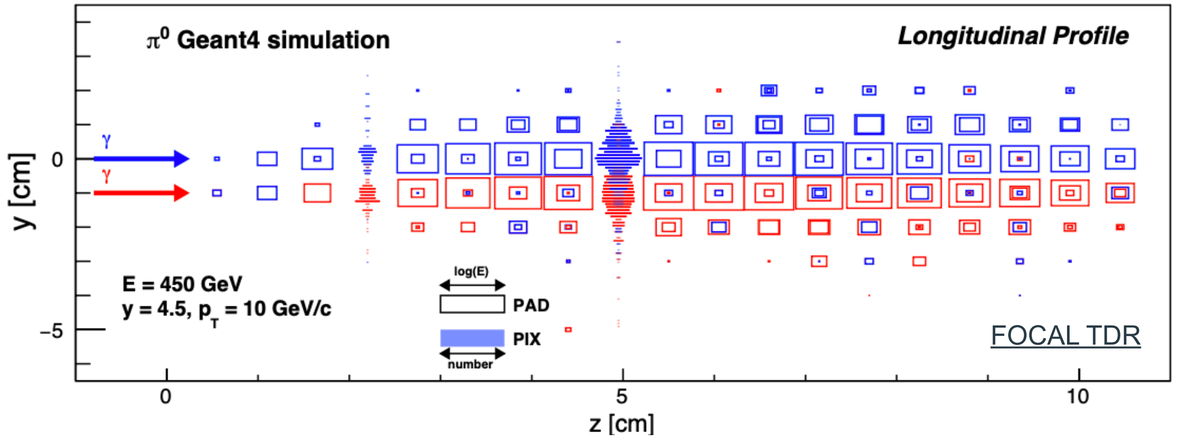

Segmentation of FoCal-E




Front view of a FoCal-H module in simulation




3d view of FoCal, dimensions in mm



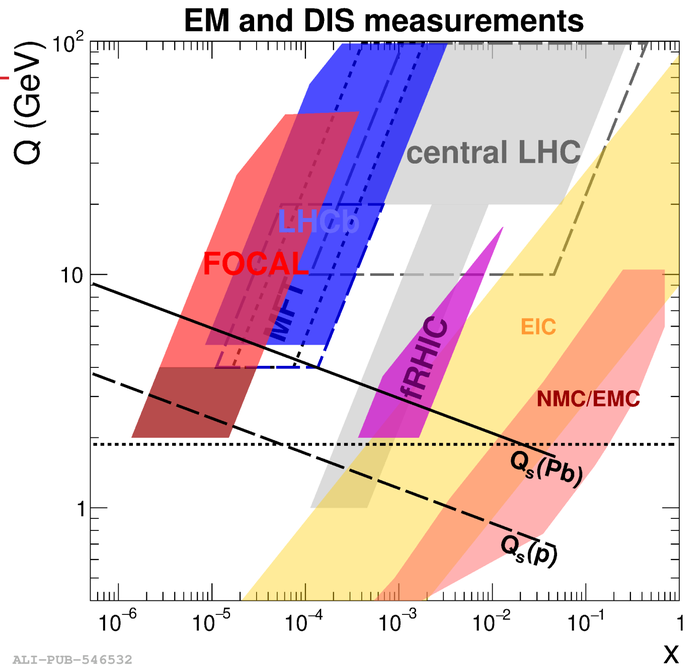

Longitudinal shower profile of two photons in FoCal-E

# FoCal — Physics Goals

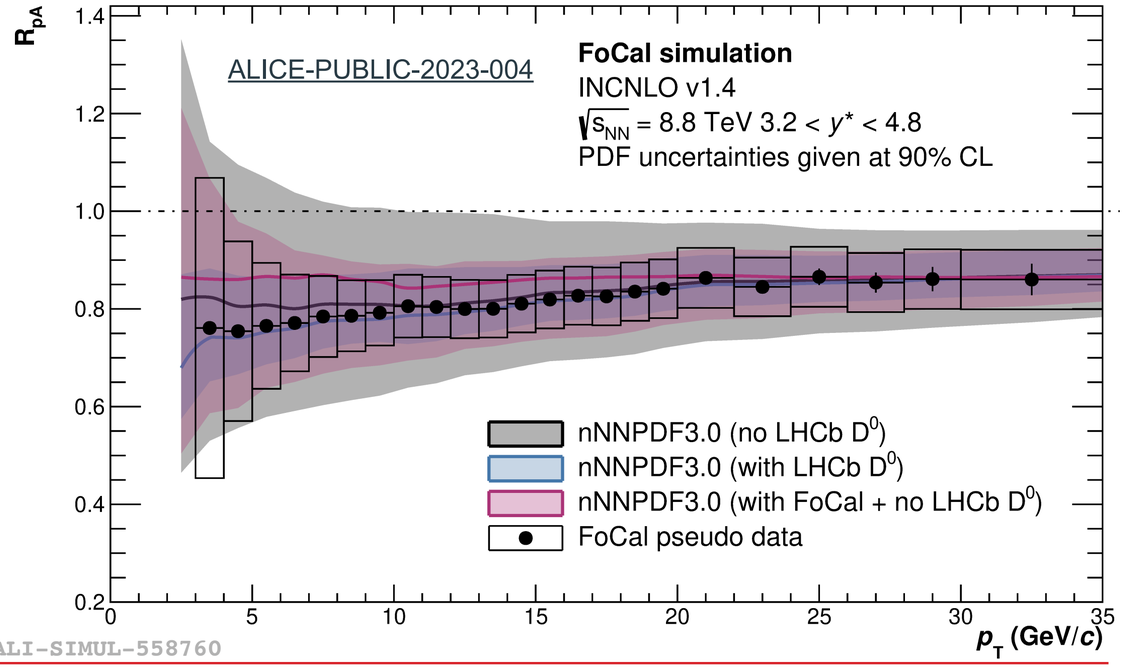
- Search for evidence of gluon saturation due to non-linear PDF evolution in QCD in nucleons and nuclei at low Bjorken-*x* down to ~$10^{-6}$
- Constrain nuclear PDFs
- Broad phase-space coverage while providing a multi-messenger approach

  ➡ Comprehensive exploration of saturation, complementary to other LHC experiments and to EIC

**Wide set of experimental observables:**
- Isolated (direct) photons
- $\pi^0$ and other neutral mesons
- Jets
- Vector mesons in UPC ($J/\psi$, $\Upsilon$,…)
- Correlations ($\gamma$-hadron, hadron-hadron, …)
- … and more

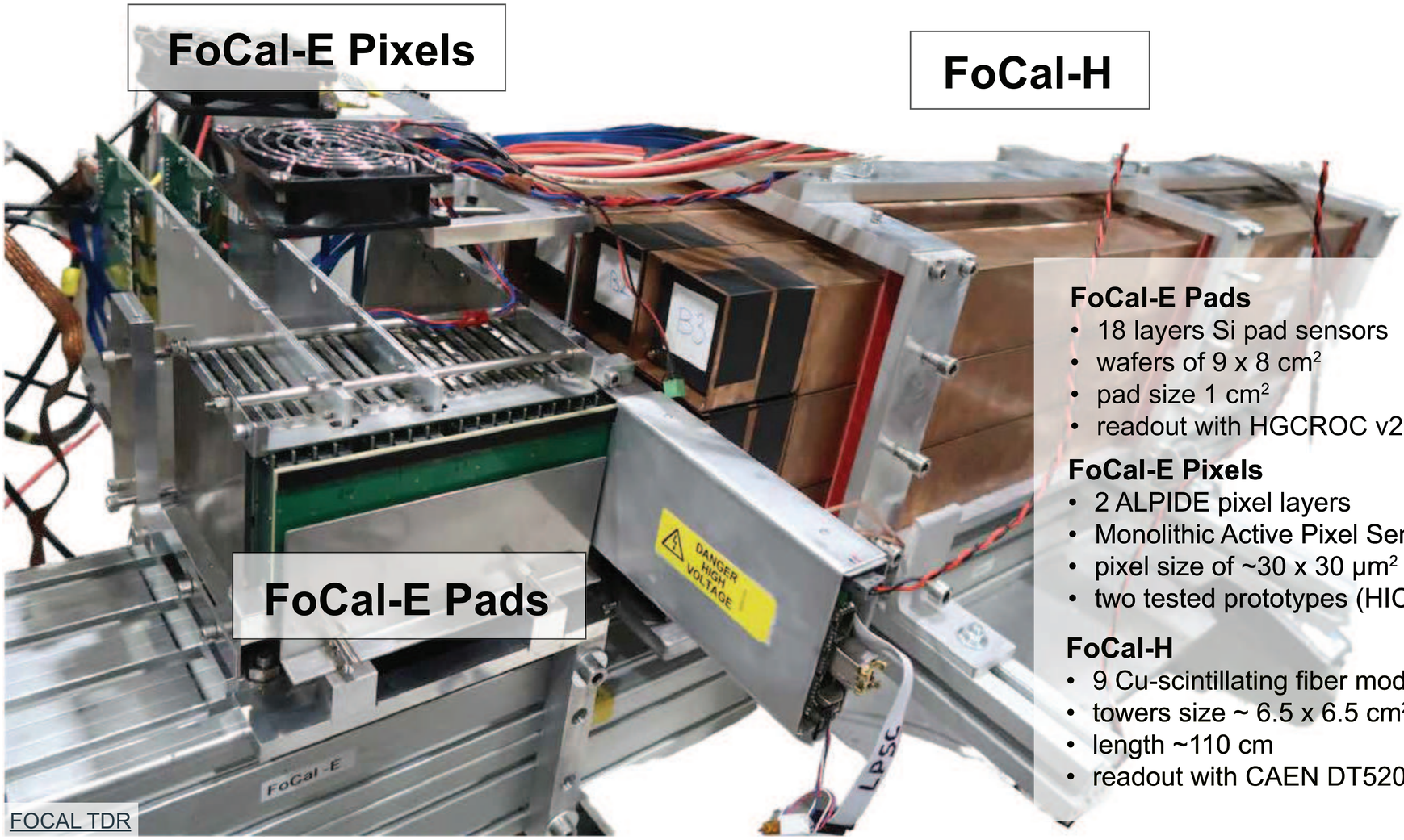



ALICE-PUBLIC-2023-001




Physics of the ALICE Forward Calorimeter upgrade: ALICE-PUBLIC-2023-001
Physics performance of the ALICE Forward Calorimeter upgrade: ALICE-PUBLIC-2023-004

# FoCal — Test Beams




FOCAL TDR

**FoCal-E Pads**
- 18 layers Si pad sensors
- wafers of 9 x 8 $cm^2$
- pad size 1 $cm^2$
- readout with HGCROC v2

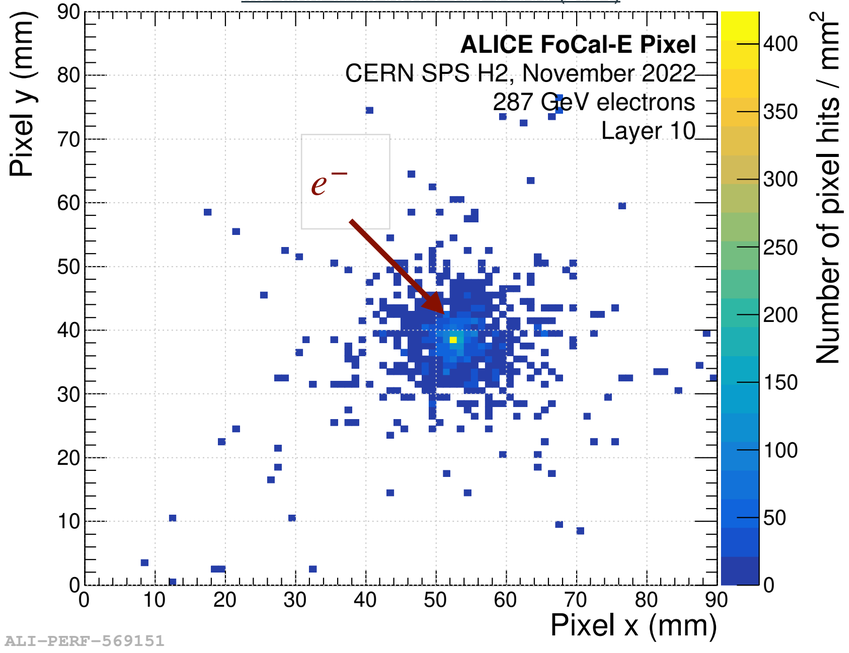
**FoCal-E Pixels**
- 2 ALPIDE pixel layers
- Monolithic Active Pixel Sensors
- pixel size of ~30 x 30 $\mu m^2$
- two tested prototypes (HIC,pCT)

**FoCal-H**
- 9 Cu-scintillating fiber modules
- towers size ~ 6.5 x 6.5 $cm^2$
- length ~110 cm
- readout with CAEN DT5202

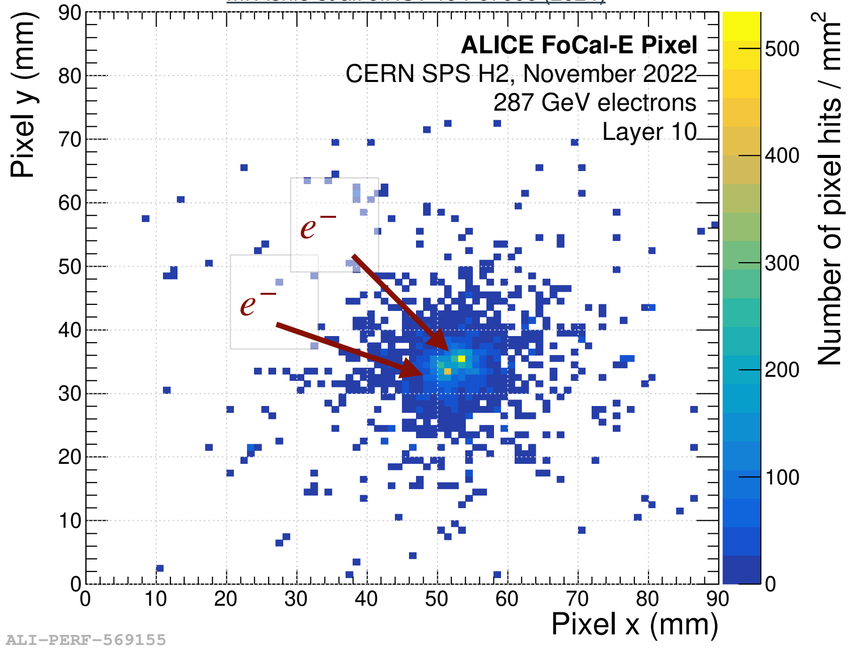
ALI-PERF-569144

# FoCal — Test Beams

M. Aehle et al. JINST 19 P07006 (2024)

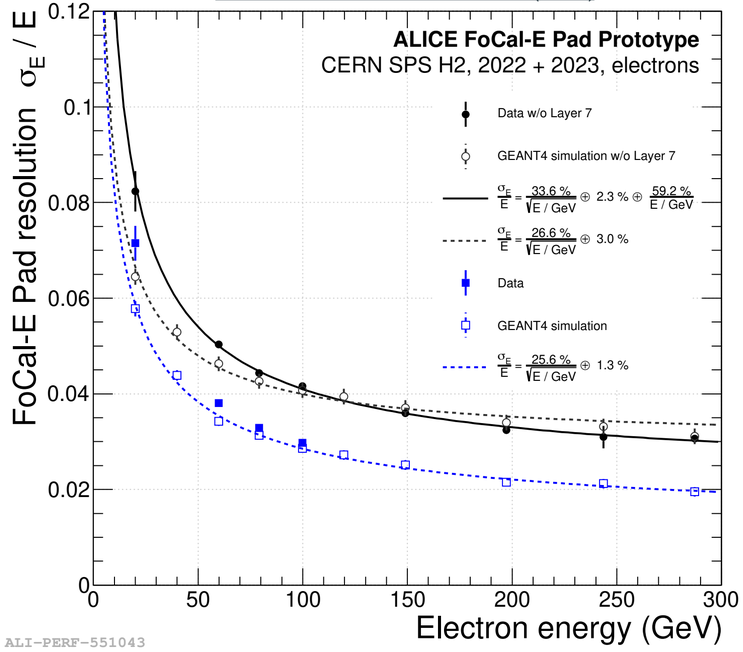



M. Aehle et al. JINST 19 P07006 (2024)



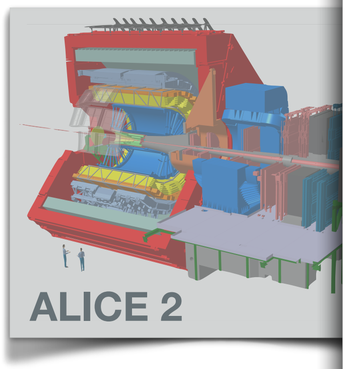

**Event display of a one-electron shower (left) and two-electron shower (right) in the 2nd pixel layer**

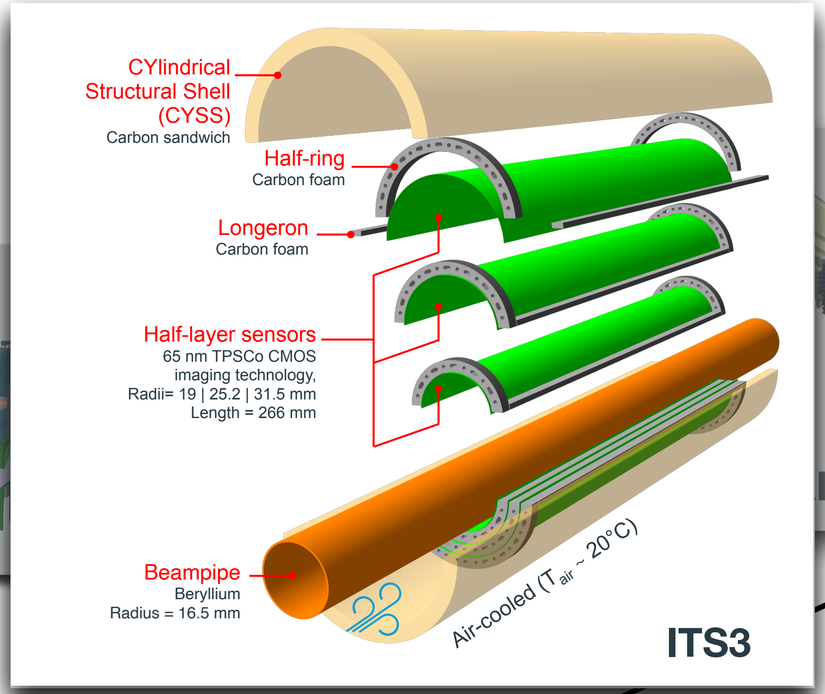
M. Aehle et al. JINST 19 P07006 (2024)

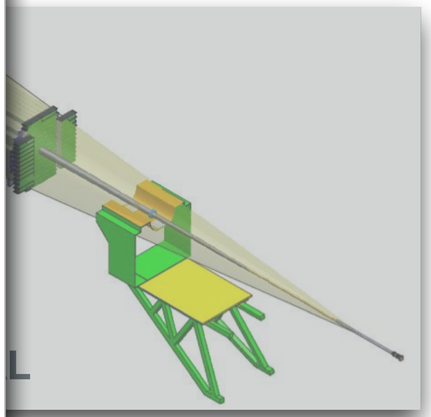


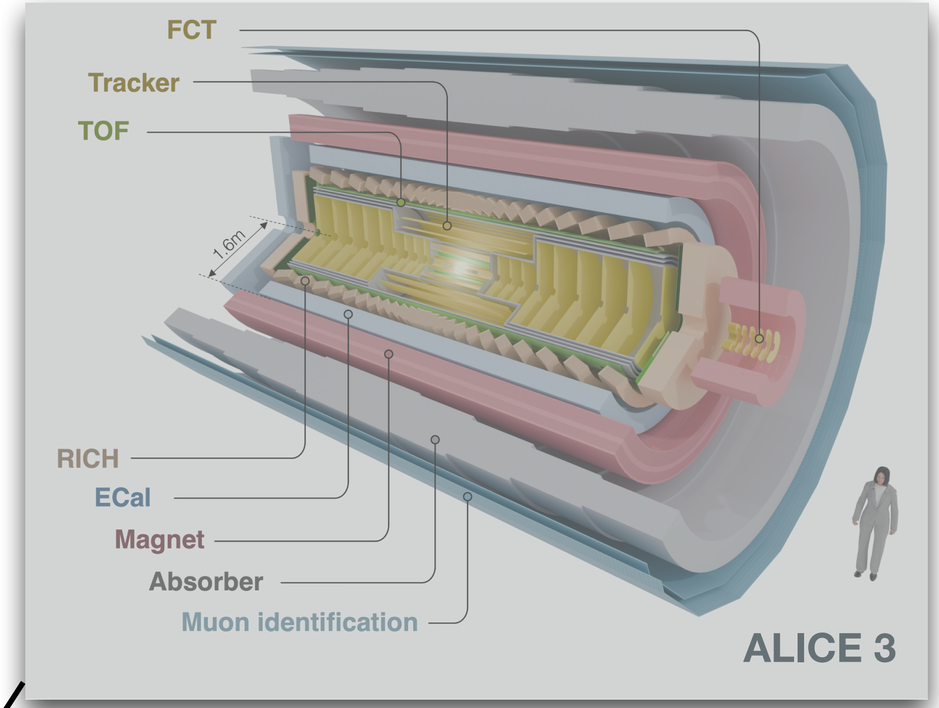

**Relative energy resolution for the FoCal-E pad layers**

# Inner Tracking System 3 (ITS3)

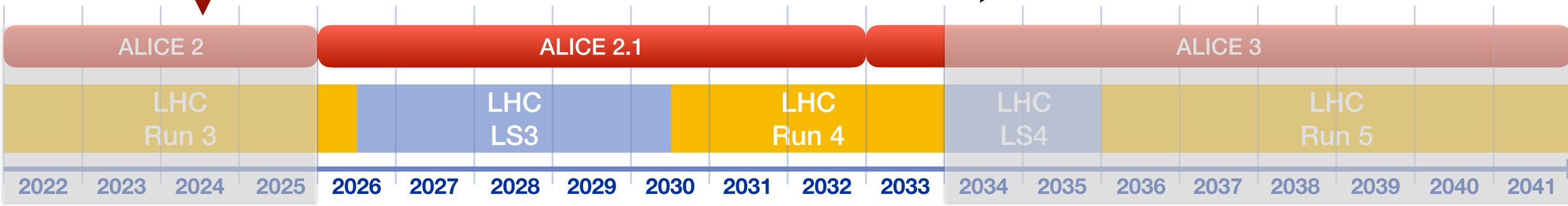


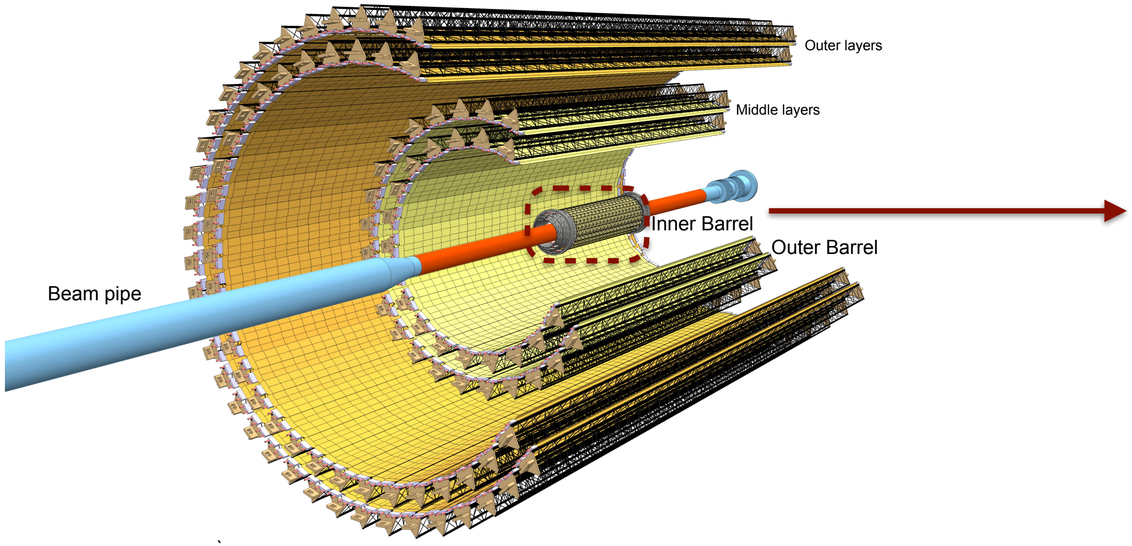



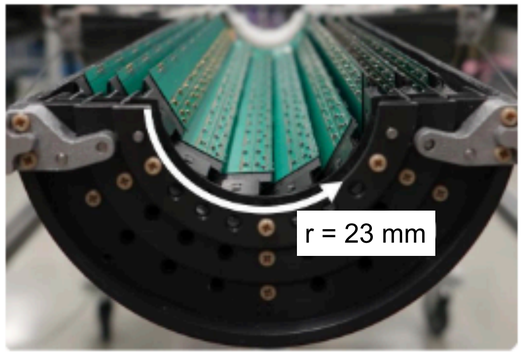



Today

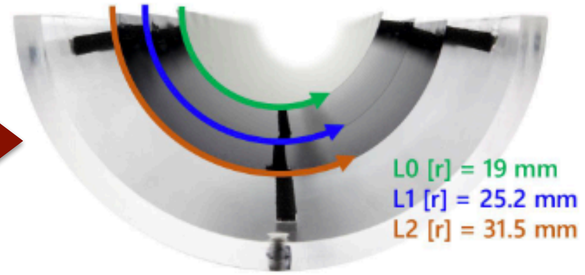


# The Inner Tracking System 3 (ITS3)



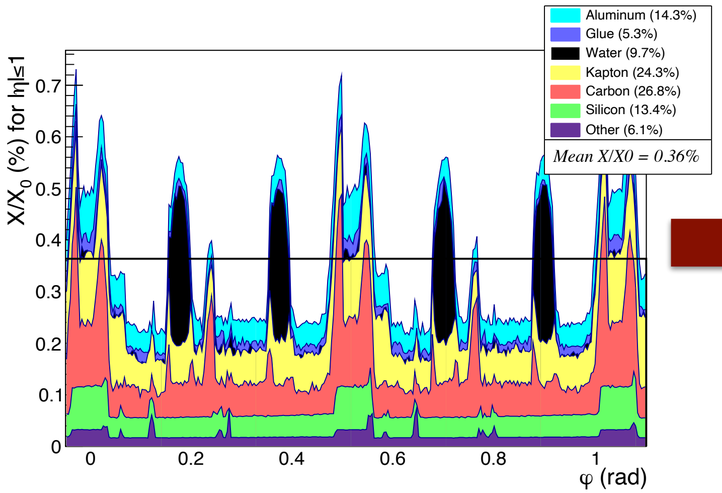




ITS2 Inner Barrel

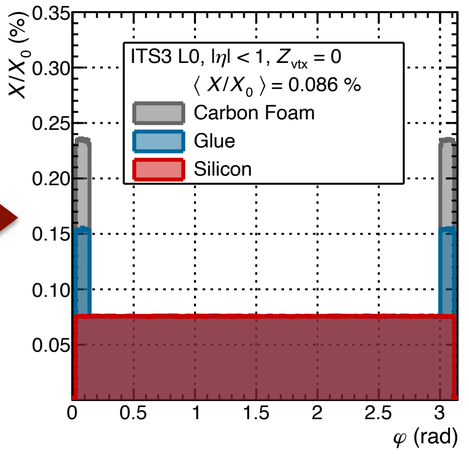



ITS3 Engineering Model 1

- Replacement of ITS2 Inner Barrel with 3 layers of curved 50 µm thick wafer-scale MAPS
- Air cooling and ultra-light mechanical supports
- Reduced average material budget of **0.09% $X_0$** instead of **0.36% $X_0$** per layer
- Smaller radius of the innermost layer: **19 mm** instead of **23 mm**



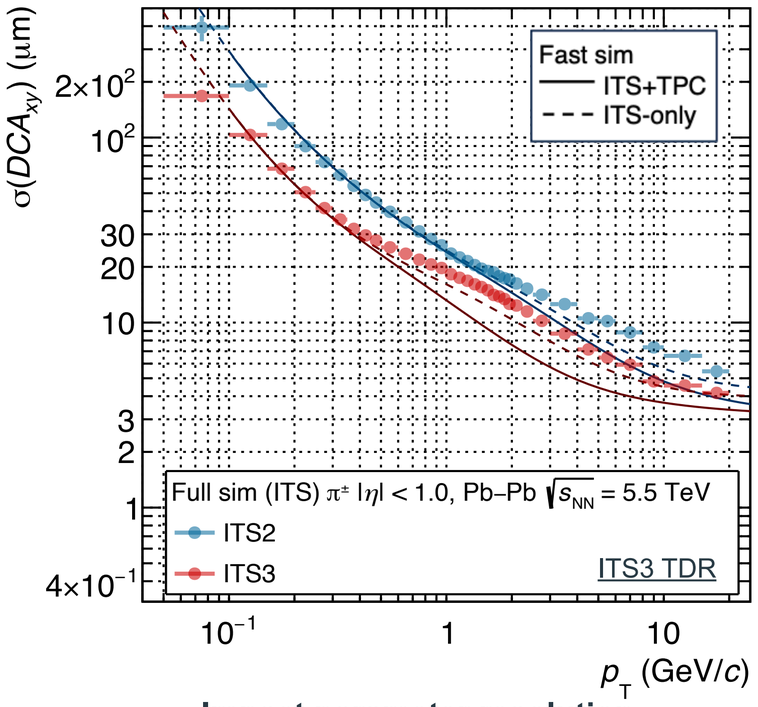

ITS2 Layer 0



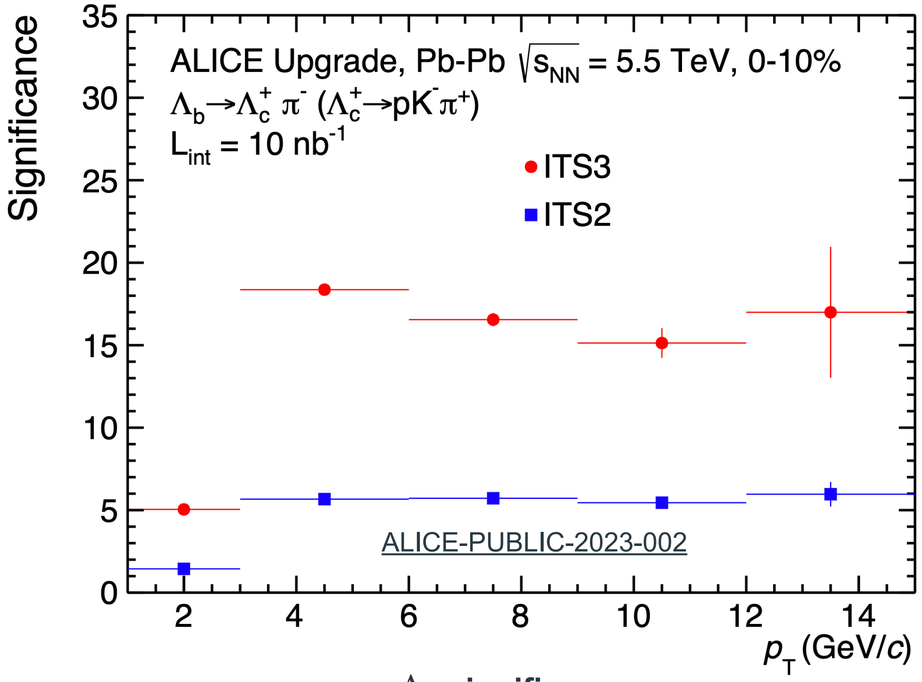

ITS3 Layer 0

**ITS3 TDR — CERN-LHCC-2024-003**

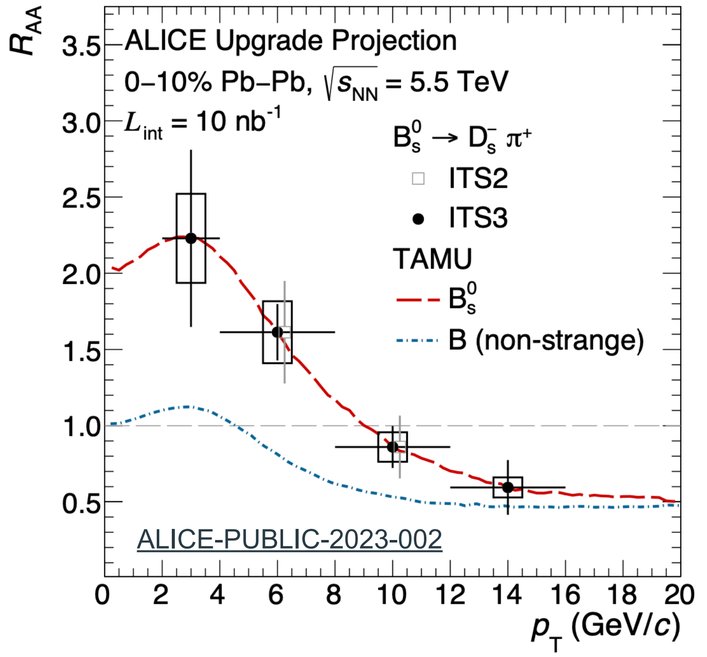
# ITS3 — Physics Impact




**Impact parameter resolution**




$\Lambda_b$ **significance**

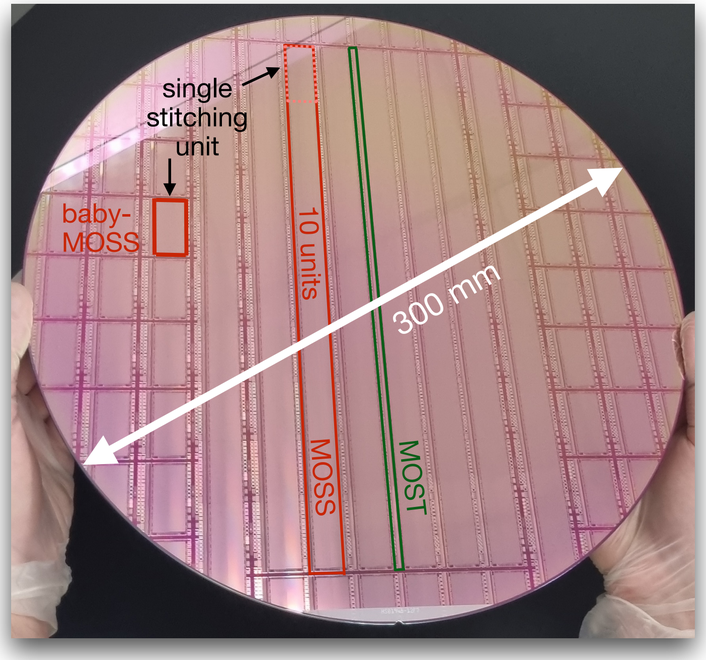



$B_s^0$ **nuclear modification factor**

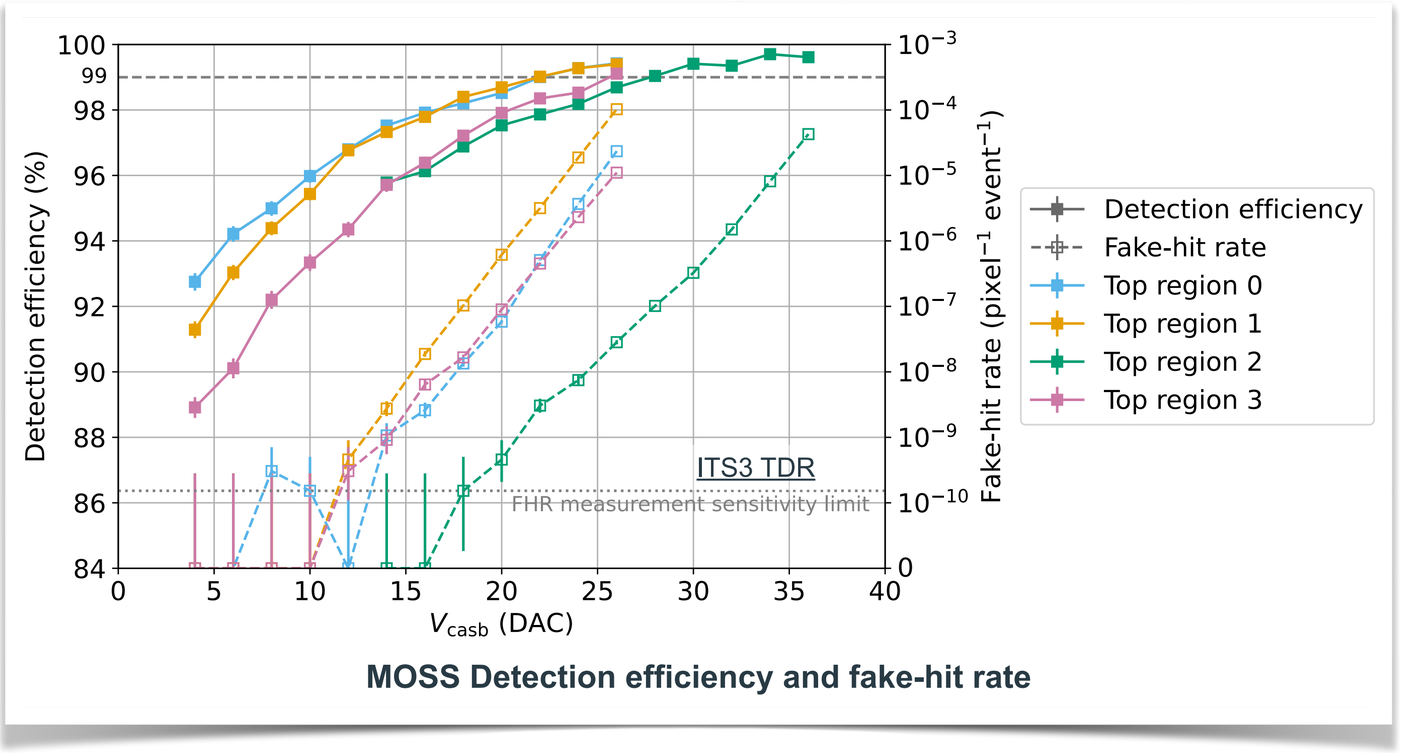
- DCA resolution improved by a about a factor of 2 → improved separation of secondary vertices
- Many fundamental observables strongly profiting or becoming in reach
  - Charmed and beauty baryons
  - Low-mass di-electrons
  - Full topological reconstruction of $B_s$

ITS3 physics performance studies:
ALICE-PUBLIC-2023-002

# ITS3 — Stitched Wafer-Scale MAPS




**Engineering Run 1 wafer with various dies**



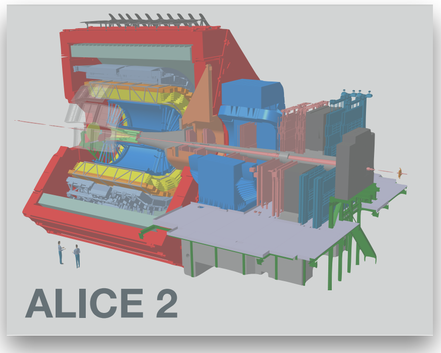

**MOSS Detection efficiency and fake-hit rate**

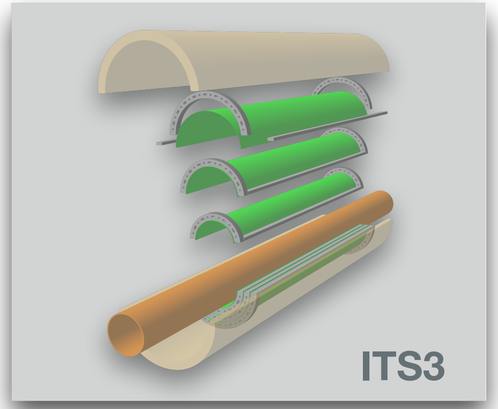
## Monolithic Stitched Sensor (MOSS)

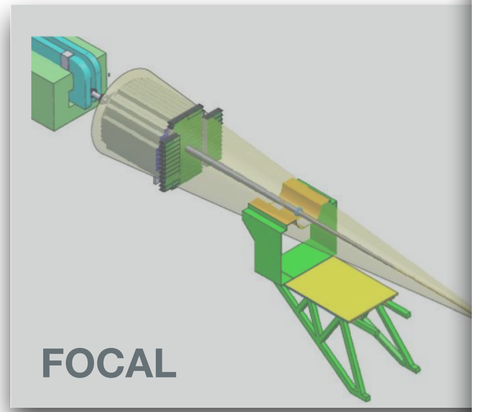
- First stitched MAPS for high-energy physics
- 10 Repeated Sensor Units (RSUs) stitched together: **259 mm x 14 mm** per **sensor**
- 2 pixel pitches (18 µm and 22.5 µm) and 5 front-end variants, a total of **6.72 MPixel** per chip
- Chip is **operational** and reaches **full efficiency**
- Yield currently studied in detail, main failure mechanism expected to be mitigated in the next submission

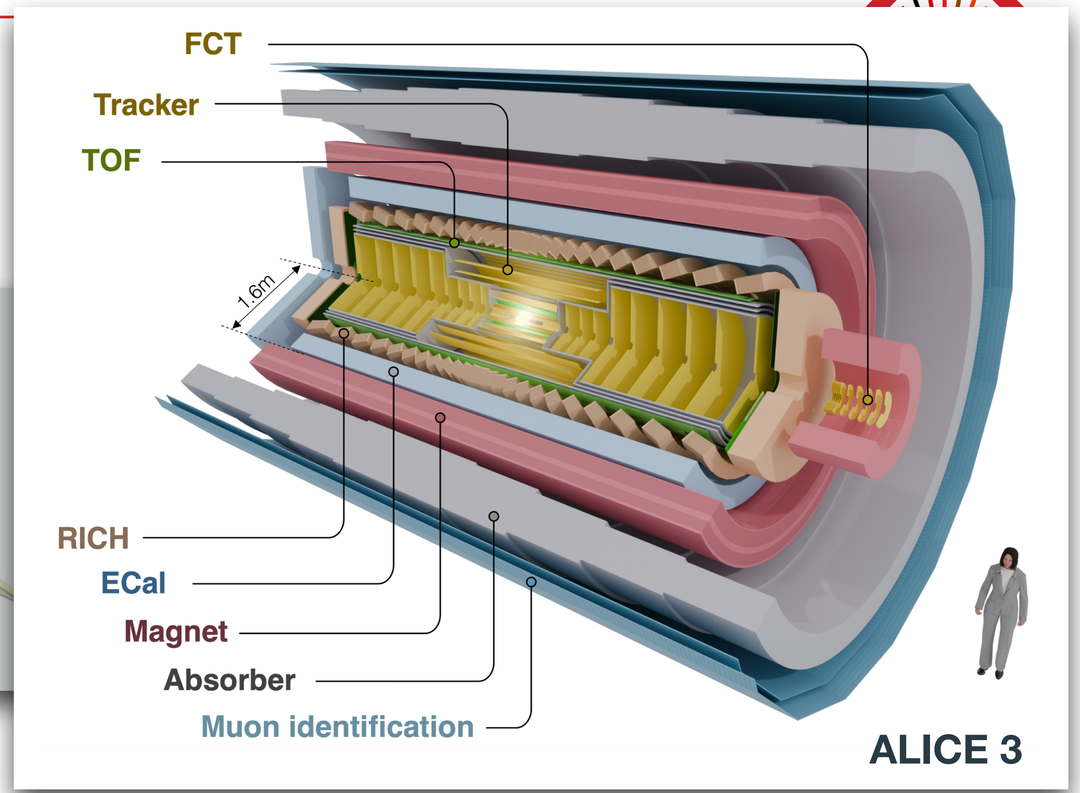
Submission for full size, fully functional prototype ‘MOSAIX’ early 2025

# ALICE 3

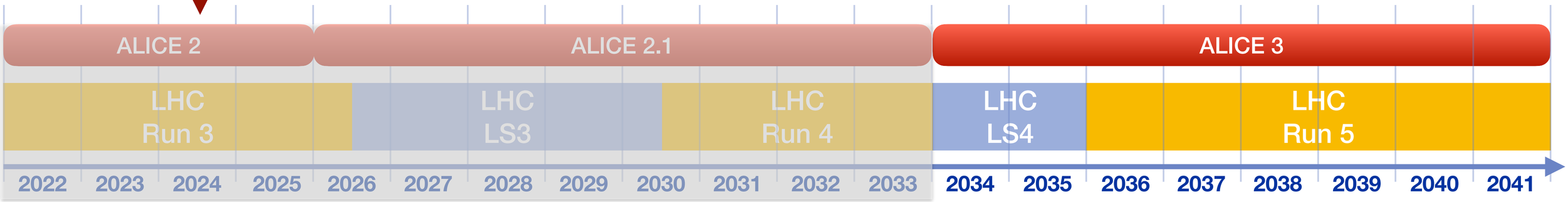


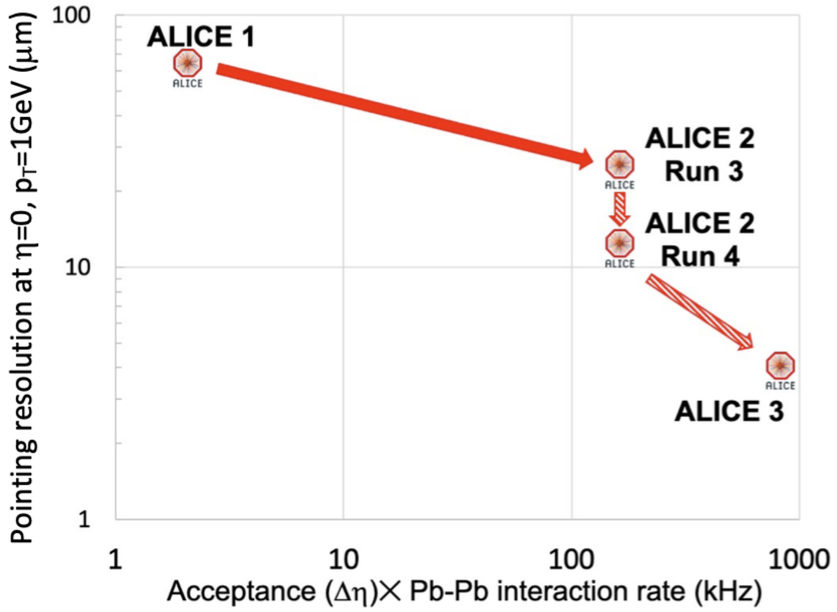

Today

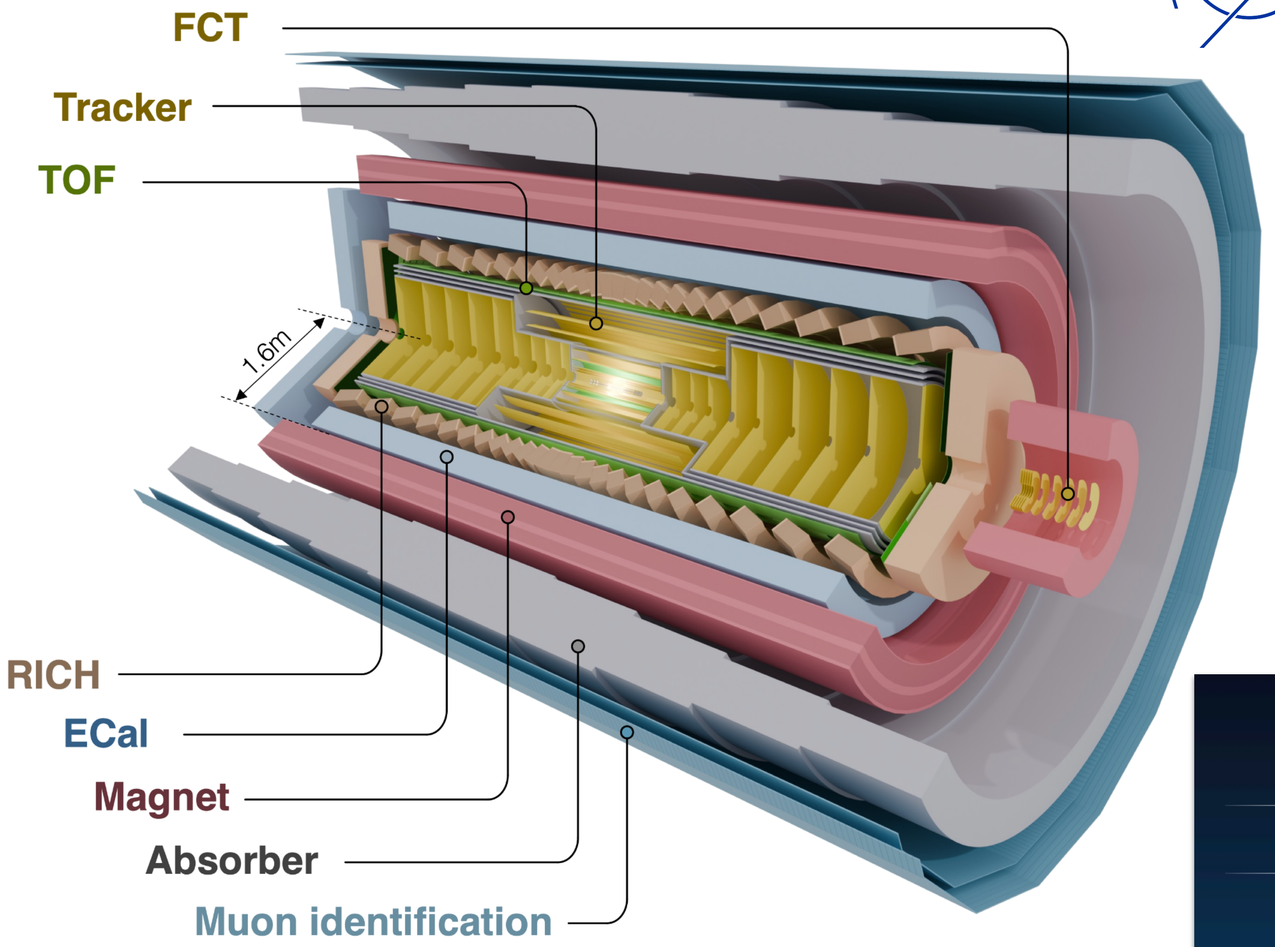


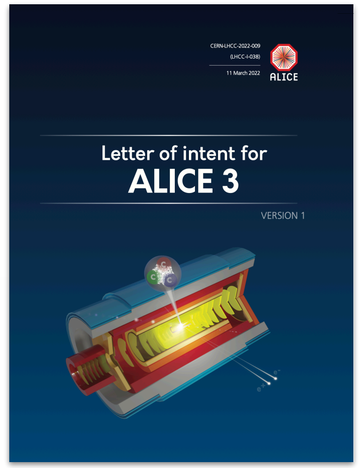
# ALICE 3 — Concept

**Novel and innovative detector concept**

- **Compact,** low-mass **all-silicon tracker**
- **Retractable vertex detector**
- Excellent **vertex reconstruction** and **PID capabilities**
- **Large acceptance**
- Super-conducting magnet system
- Continuous read-out and online processing



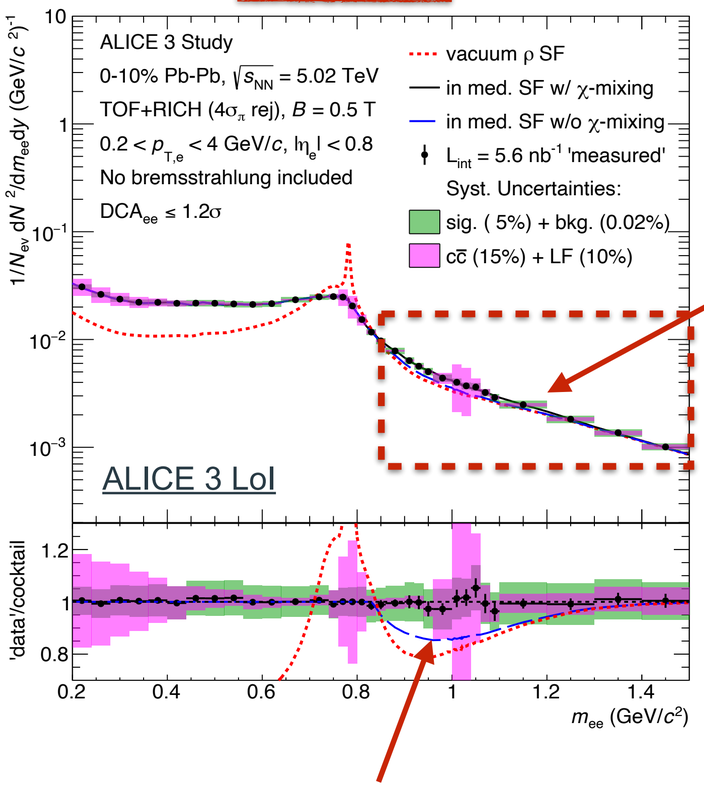

CERN-LHCC-2022-009

# ALICE 3 — Physics Case — Selected Highlights

## Dielectrons

- **High-precision measurements** of dileptons, also multi-differentially
- Understanding **time evolution** of QGP temperature (thermal dileptons) and **mechanisms** of **chiral symmetry restoration**

$m_{ee}$




Slope
→ Temperature

Without $\rho - a_1$ mixing
→ dip in thermal spectrum

# ALICE 3 — Physics Case — Selected Highlights

## Dielectrons

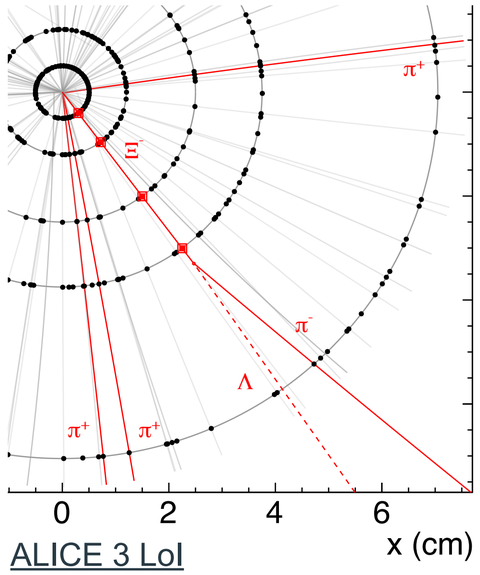
- **High-precision measurements** of dileptons, also multi-differentially
- Understanding **time evolution** of QGP temperature (thermal dileptons) and **mechanisms** of **chiral symmetry restoration**

## Hadron formation

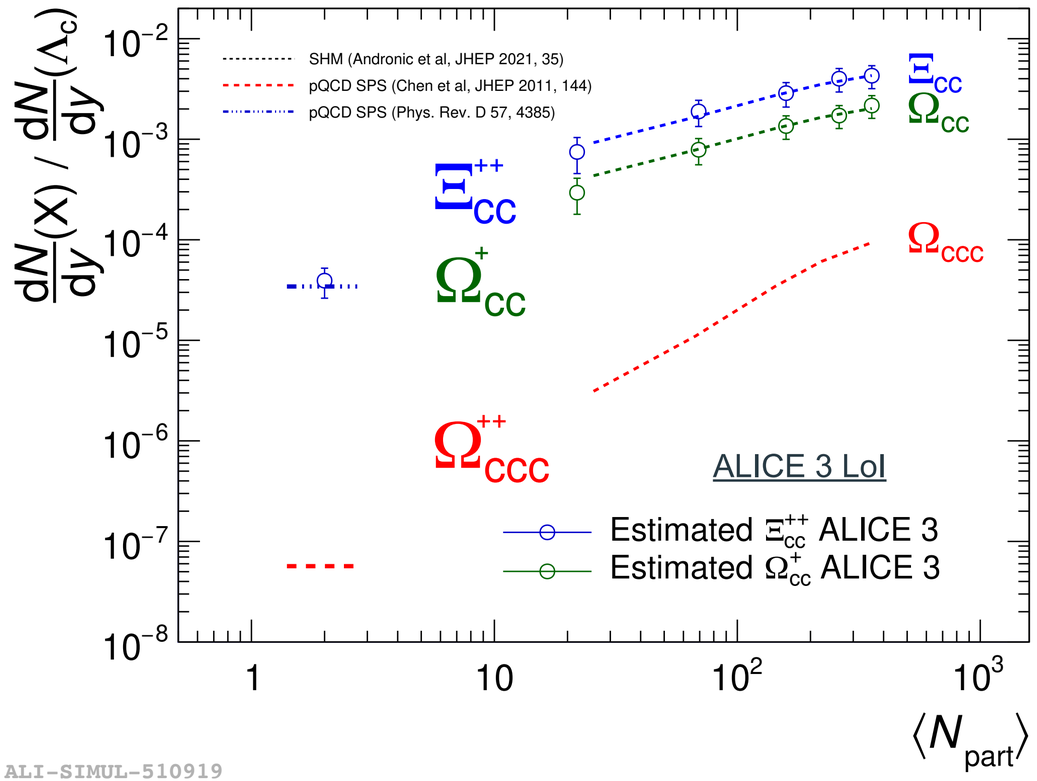
- **Multi-charm baryons** unique probe for hadron formation
  - Require **combination** of multiple **independently produced charm quarks**
- Statistical hadronisation model: **very large enhancement** (x100-1000) in Pb-Pb
  - Characteristic relation between n-charm state yields ($g_c^n$)

**Strangeness tracking**
- Track particles before their (weak) decay
- Exploiting
  - layer granularity
  - multiple decays

$$\Xi_{cc}^{++} \rightarrow \Xi_c^+ + \pi^+$$
$$\Xi_c^+ \rightarrow \Xi^- + 2\pi^+$$




ALICE 3 LoI




ALI-SIMUL-510919

# ALICE 3 — Physics Case — Selected Highlights

## Dielectrons

- **High-precision measurements** of dileptons, also multi-differentially
- Understanding **time evolution** of QGP temperature (thermal dileptons) and **mechanisms** of **chiral symmetry restoration**

## Hadron formation

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  - Require **combination** of multiple **independently produced charm quarks**
- Statistical hadronisation model: **very large enhancement** (x100-1000) in Pb-Pb
  - Characteristic relation between n-charm state yields ($g_c^n$)

## And many more:

Heavy flavour transport, exotica, nuclei,
hadron-hadron interaction potentials,
net-baryon fluctuations, ultrasoft photons, …

# ALICE 3 — Vertex Detector (VD) and Tracker

## Vertex Detector (VD)

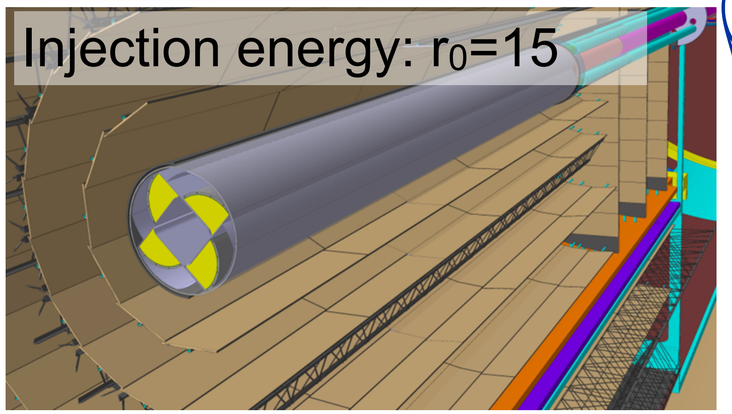
- **Retractable** as minimal radius given by required aperture:
  **$r_0$ ≈ 5 mm at top energy**, $r_0$ ≈ 15 mm at injection energy
- Material budget: **0.1% $X_0$ / layer**
- Unprecedented spatial resolution: **2.5 µm**
- 3 detection layers (barrel + disks)
- **Main R&D challenges**
  - Light-weight in-vacuum mechanics and cooling
  - Radiation hardness* ($10^{16}$ 1 MeV $n_{eq}/cm^2$ + 300 Mrad)
  - Pixel pitch of 10 µm

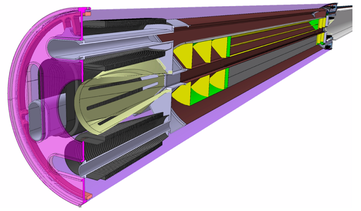
ALICE 3 R&D will build upon ITS3 experience

## Tracker (Middle Layers + Outer Tracker)

- 8 barrel layers (3.5 cm < R < 80 cm) + 2 x 9 forward disks
- Material budget: **1% $X_0$ / layer**
- Spatial resolution: 10 µm / 50 µm pixel pitch
- Low power consumption: **20 mW/cm²**
- **100 ns time resolution**
- **Main R&D challenges**
  - Module design for high yield industrial mass production
  - Low power consumption while maintaining timing performance

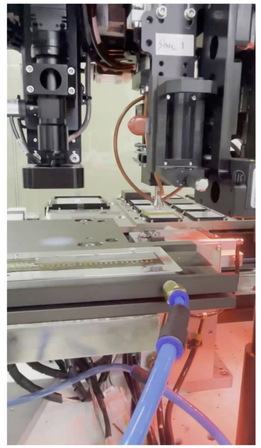
Total surface: ~ 60 m²



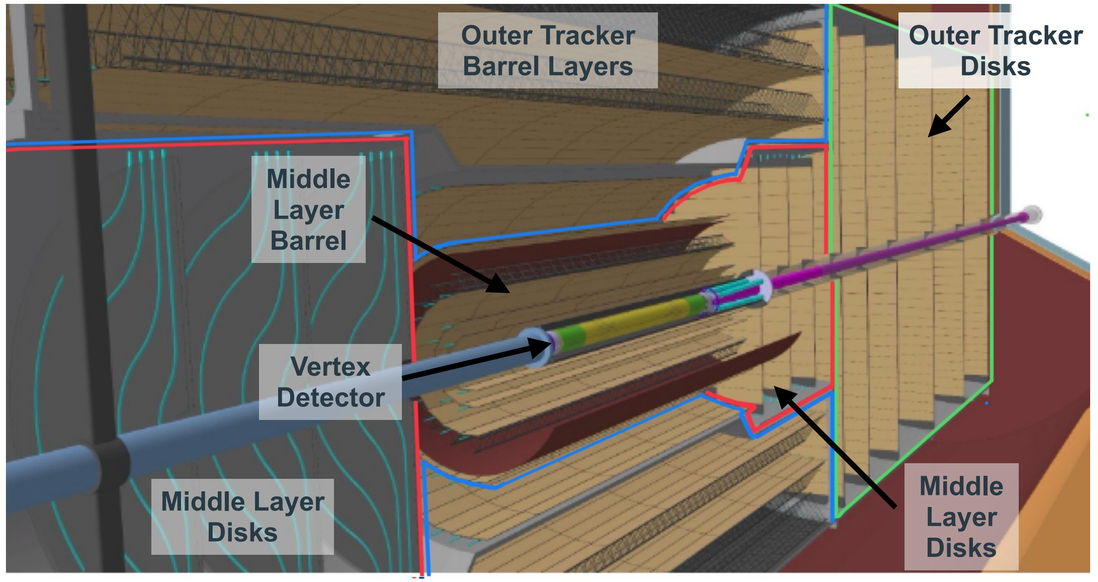



Detailed VD services integration


Lightweight Middle Layers



Automated module assembly tests




* LOI values, further simulation studies ongoing

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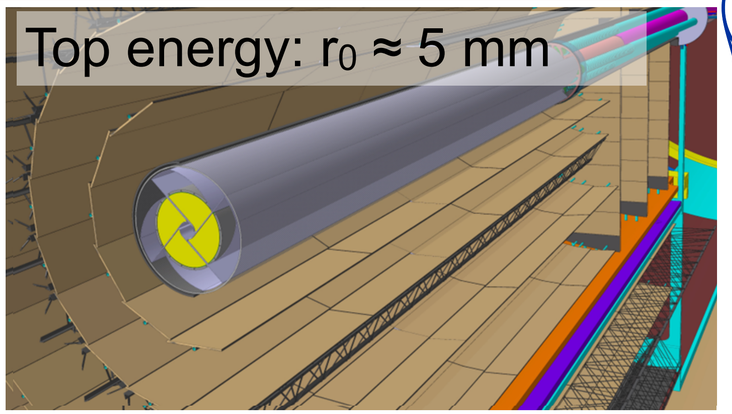


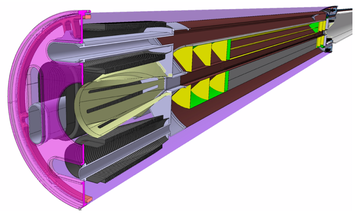

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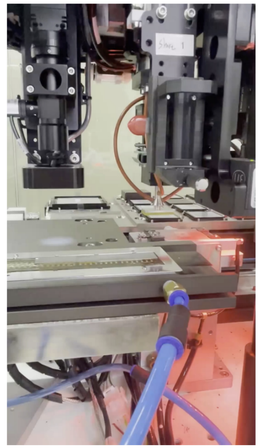

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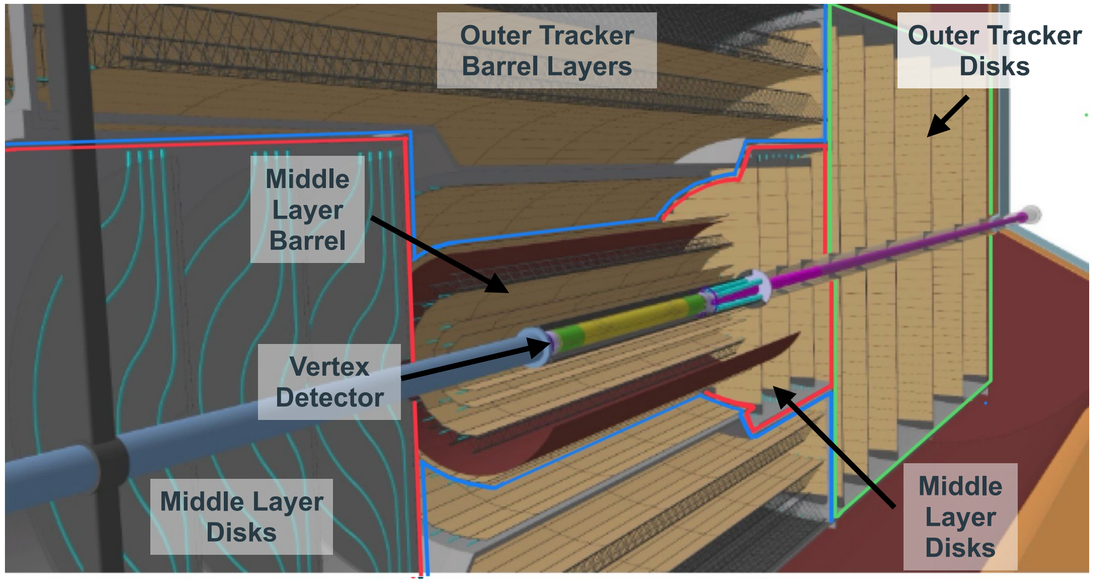



* LOI values, further simulation studies ongoing

**TOF test beam results**
F. Carnesecchi et al. Eur. Phys. J. Plus 138, 99 (2023)
F. Carnesecchi et al. Eur. Phys. J. Plus 138, 990 (2023)

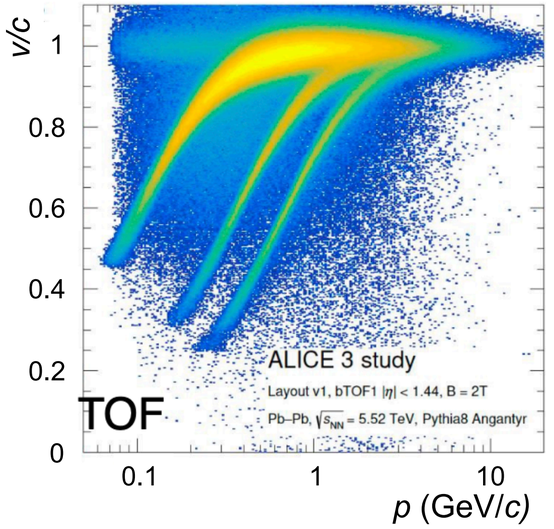
# ALICE 3 — Particle Identification

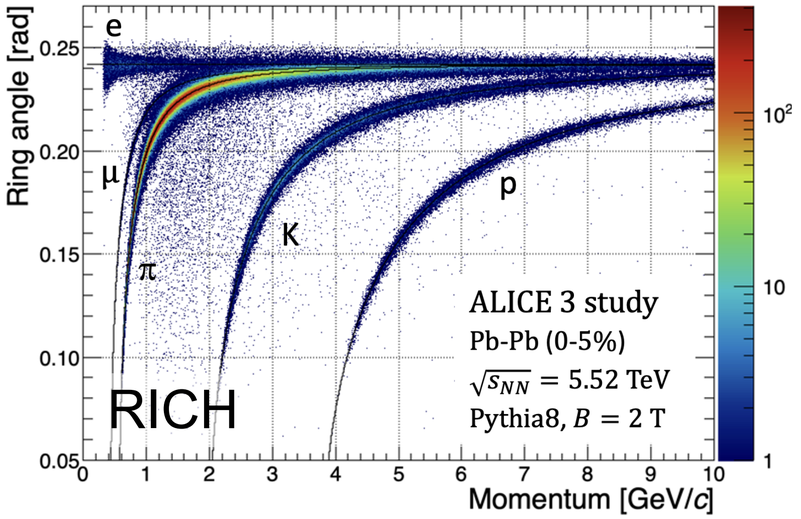
## Time of Flight

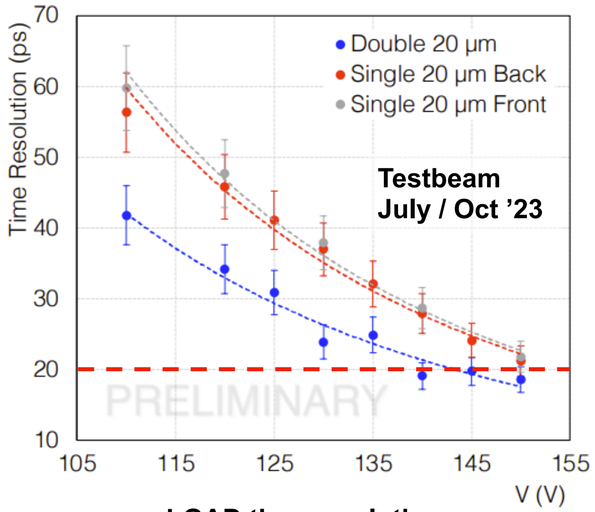
- Time resolution target: 20 ps
- Low material budget 1-3% $X_0$/layer
- Total surface: ~45 m$^2$
- **R&D streams:**
  - SiPM coated with different resins (type, thickness)
  - Single and double LGADs
  - CMOS-LGAD (ARCADIA / MADPIX)

## RICH

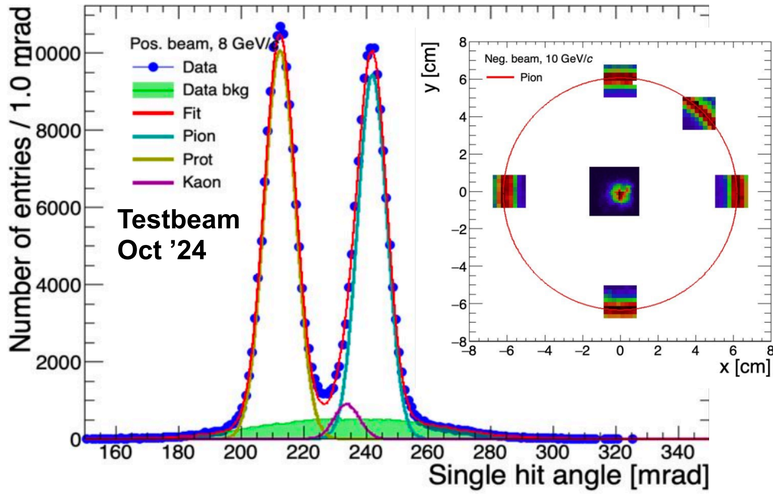
- Extending shared particle PID to higher $p_T$
- Aerogel radiator
  - n = 1.03 (barrel)
  - n = 1.006 (forward)
- Total SiPM area: ~ 35 m$^2$
- **R&D challenge:** SiPM radiation hardness



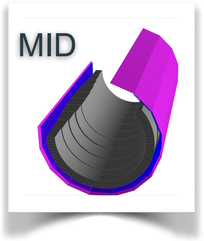




**LGAD time resolution**



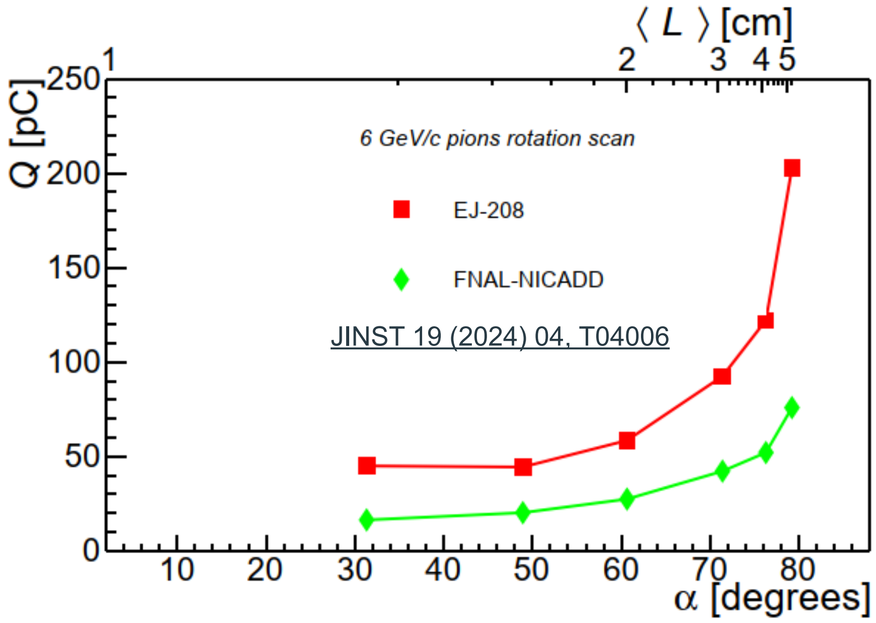

**Cherenkov angle of pions and protons:**
**5 mrad angular resolution**

# ALICE 3: Muon and Photon ID




## Muon IDentification (MID) at central rapidity

- Optimised for charmonia reconstruction down to zero $p_T$
- ~ 70 cm steel hadron absorber
- 2 layers with 5 x 5 cm$^2$ pad size
- Baseline: plastic scintillator bars w/ wave-length shifting fibres + SiPMs
- Options: RPCs or MWPCs
- Test beam results: R. Alfaro et al. JINST 19 (2024) 04, T04006



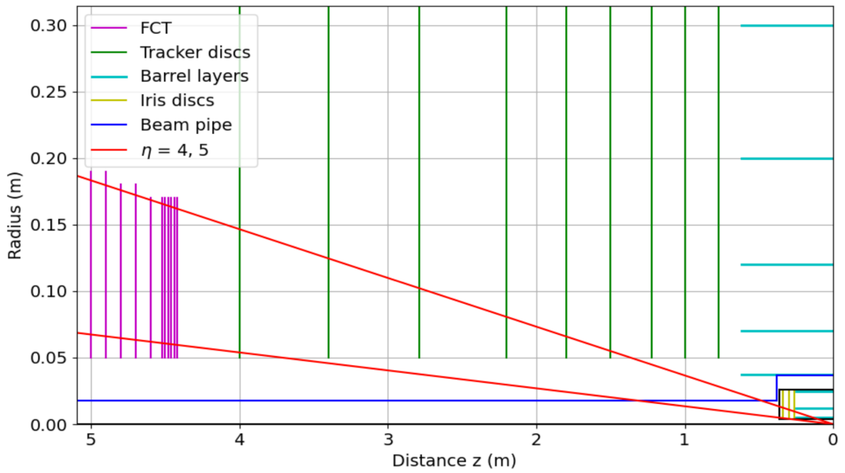

**Scintillator response to inclined tracks**

## Large acceptance Electromagnetic Cal (ECal)

- $2\pi$ coverage
- Sampling calorimeter, $O(100)$ layers of 1 mm Pb + 1.5 mm plastic scintillator
- $PbWO_4$-based high energy-resolution segment

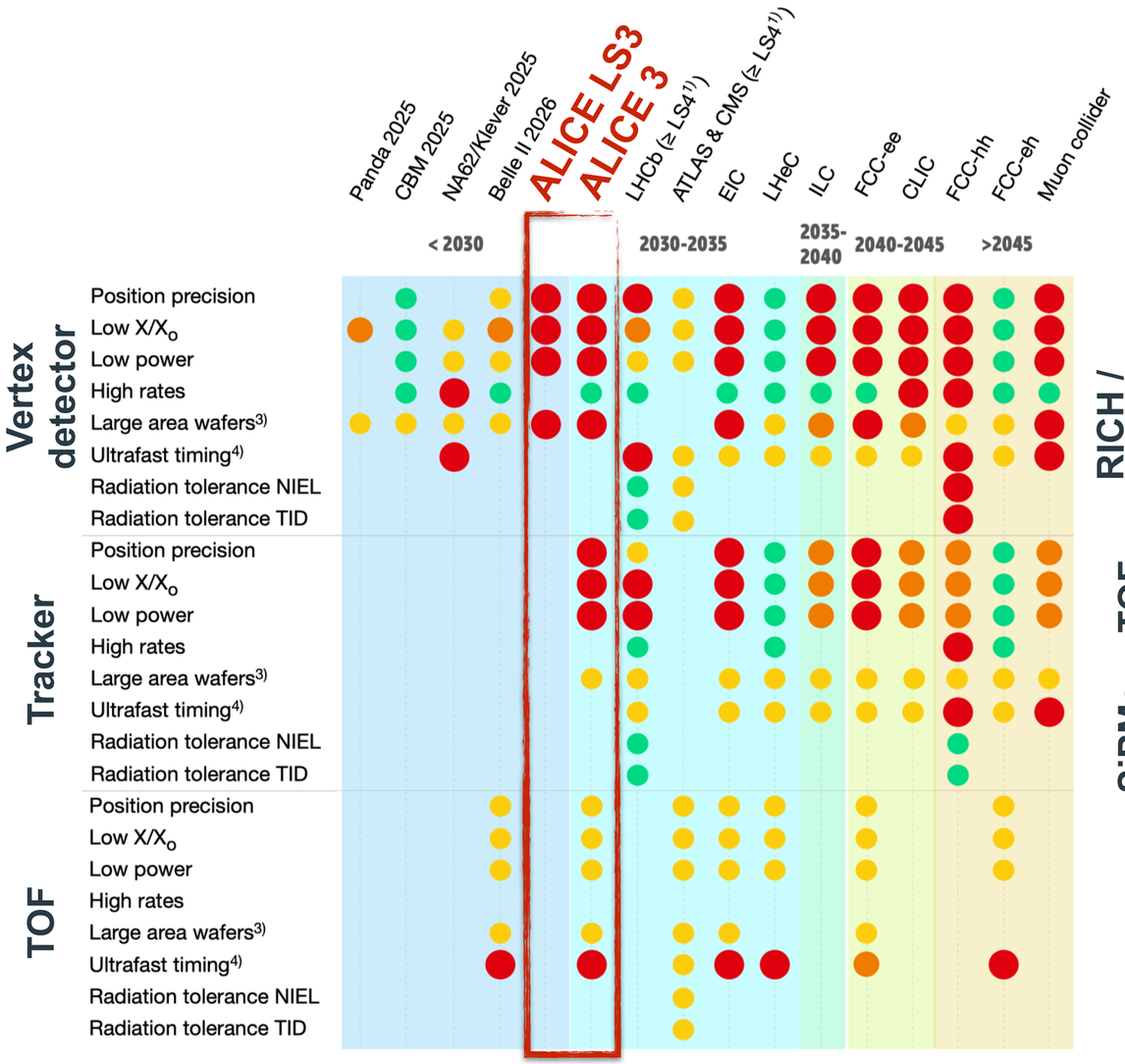
## Forward Conversion Tracker (FCT)

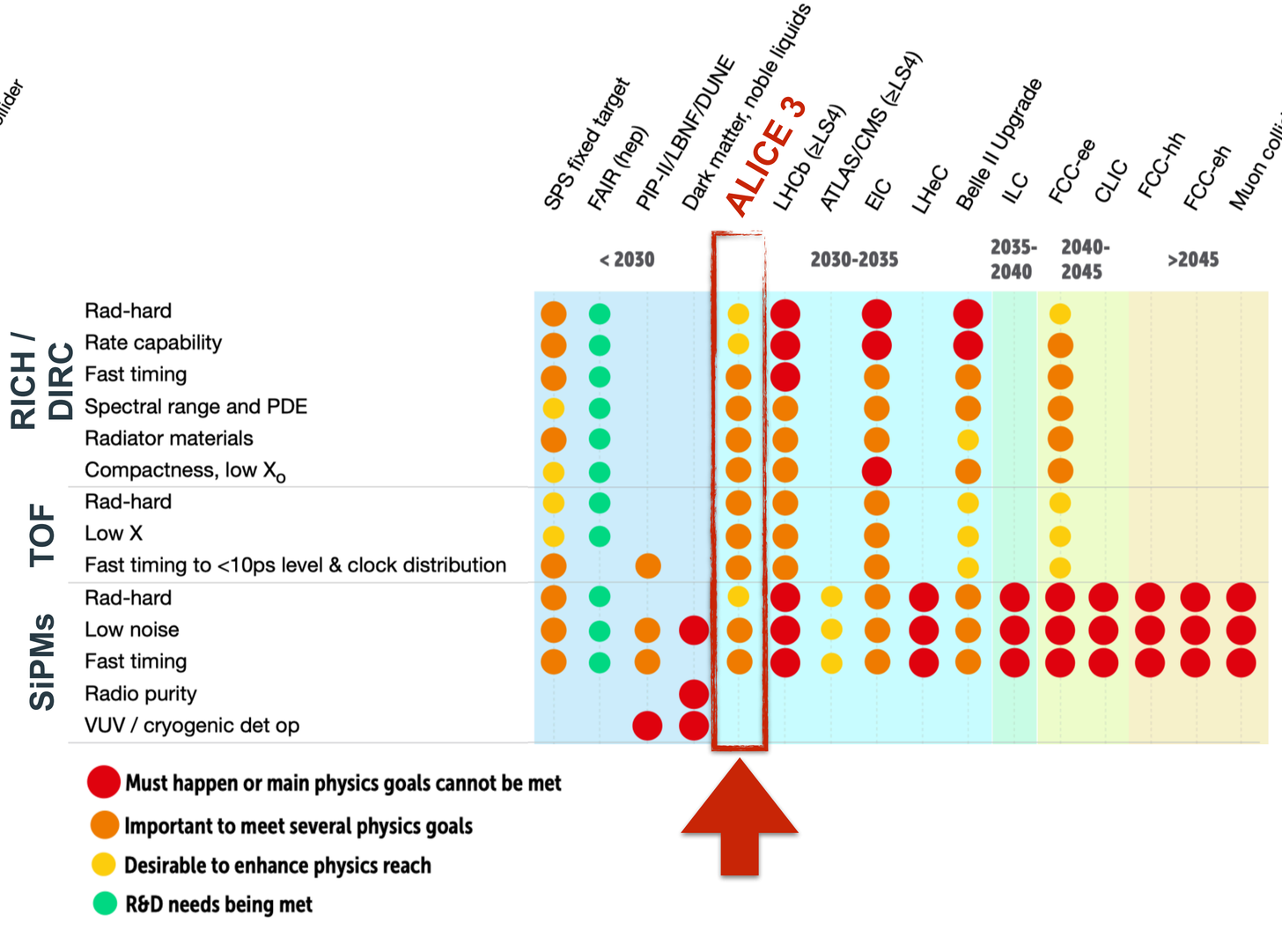
- Thin tracking disks in $4 < \eta < 5$ in a dedicated dipole magnet
- Very low $p_T$ photons (< 10 MeV/c)




**Schematic drawing of the FCT**

# ALICE 3 in light of the ECFA detector roadmap




Figures adapted from CERN-ESU-017

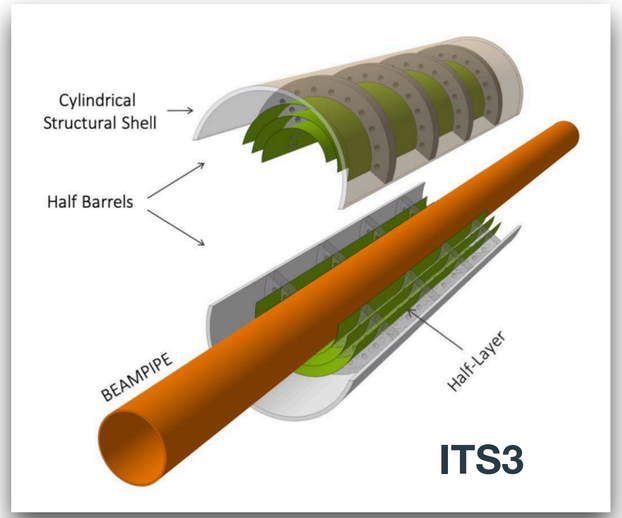
# Summary

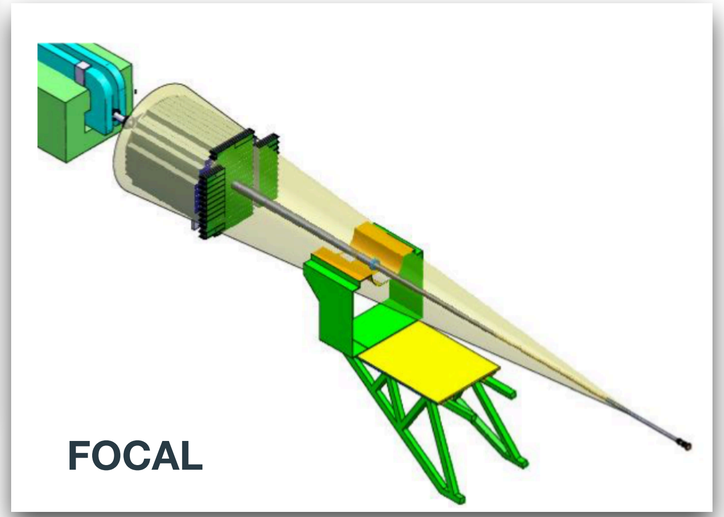
- ALICE has an ambitious upgrade program, targeting to further our understanding of the QGP and several other aspects of QCD

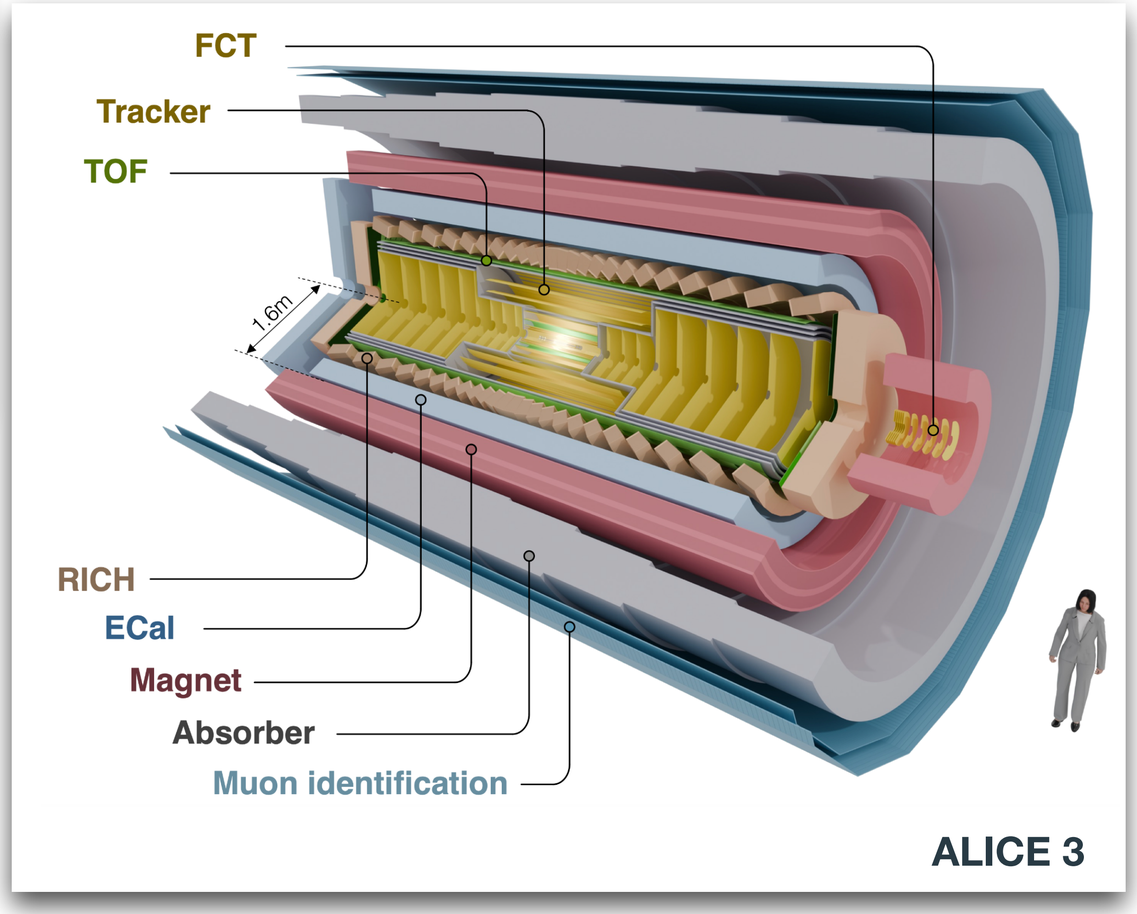
A. Kalweit - Nuclear Physics at the LHC

- **LS3 (2026-2030):** new upgrades for LHC Run 4 **approaching construction phase**
  - **FoCal**: $\gamma$, $\pi^0$, jets in the forward region to constrain the gluon nPDF at low $x$
  - **ITS3**: ultra-thin, truly cylindrical, wafer-scale MAPS: improved secondary vertex reconstruction

- **Beyond Run 4: ALICE 3** to fully exploit the HL-LHC as a heavy-ion collider until 2041
  - **Novel, silicon-based detector** concept
  - **Pioneering** several **R&D** directions with broad impact on future HEP experiments (e.g. FCC-ee)
  - Enabling precision measurements of **dileptons**, **(multi-)heavy-flavour hadrons** and **hadron correlations**



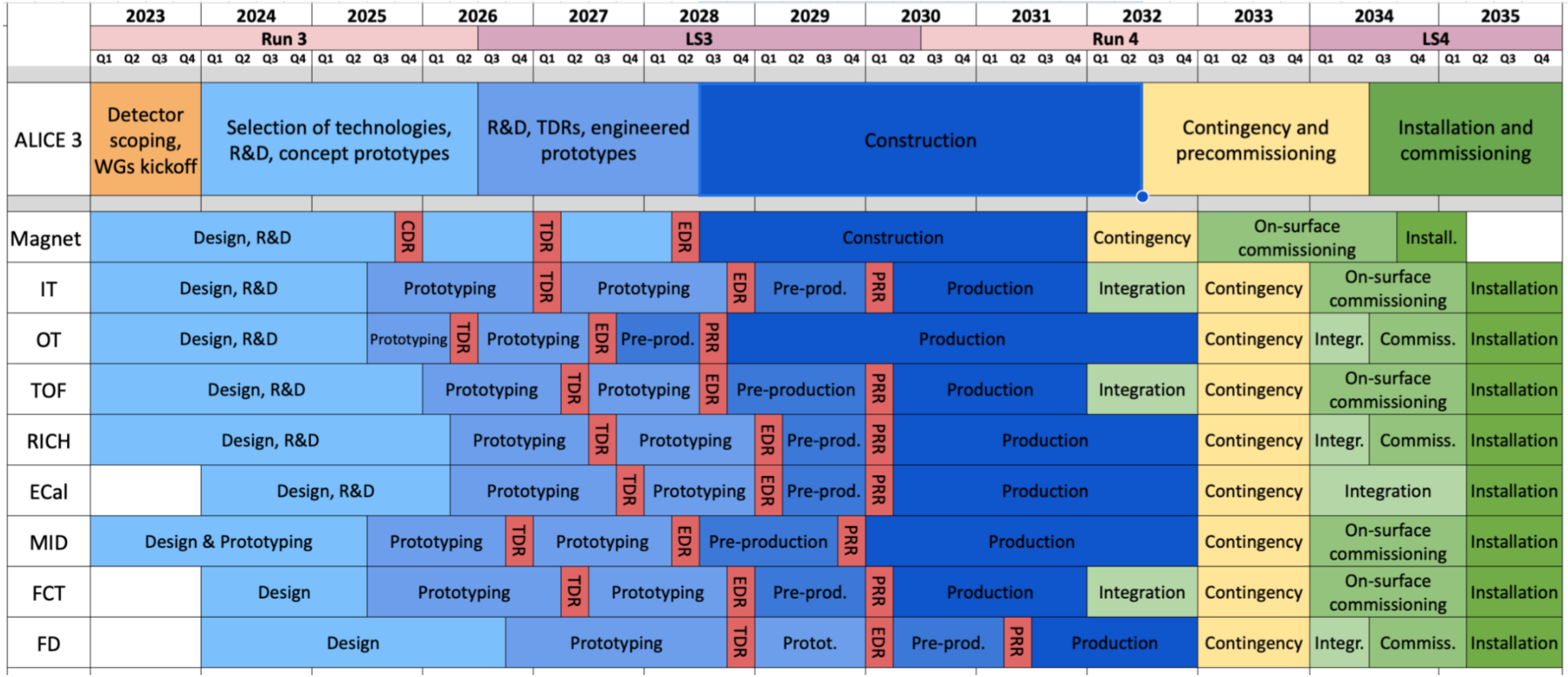




# Thank you for your attention!

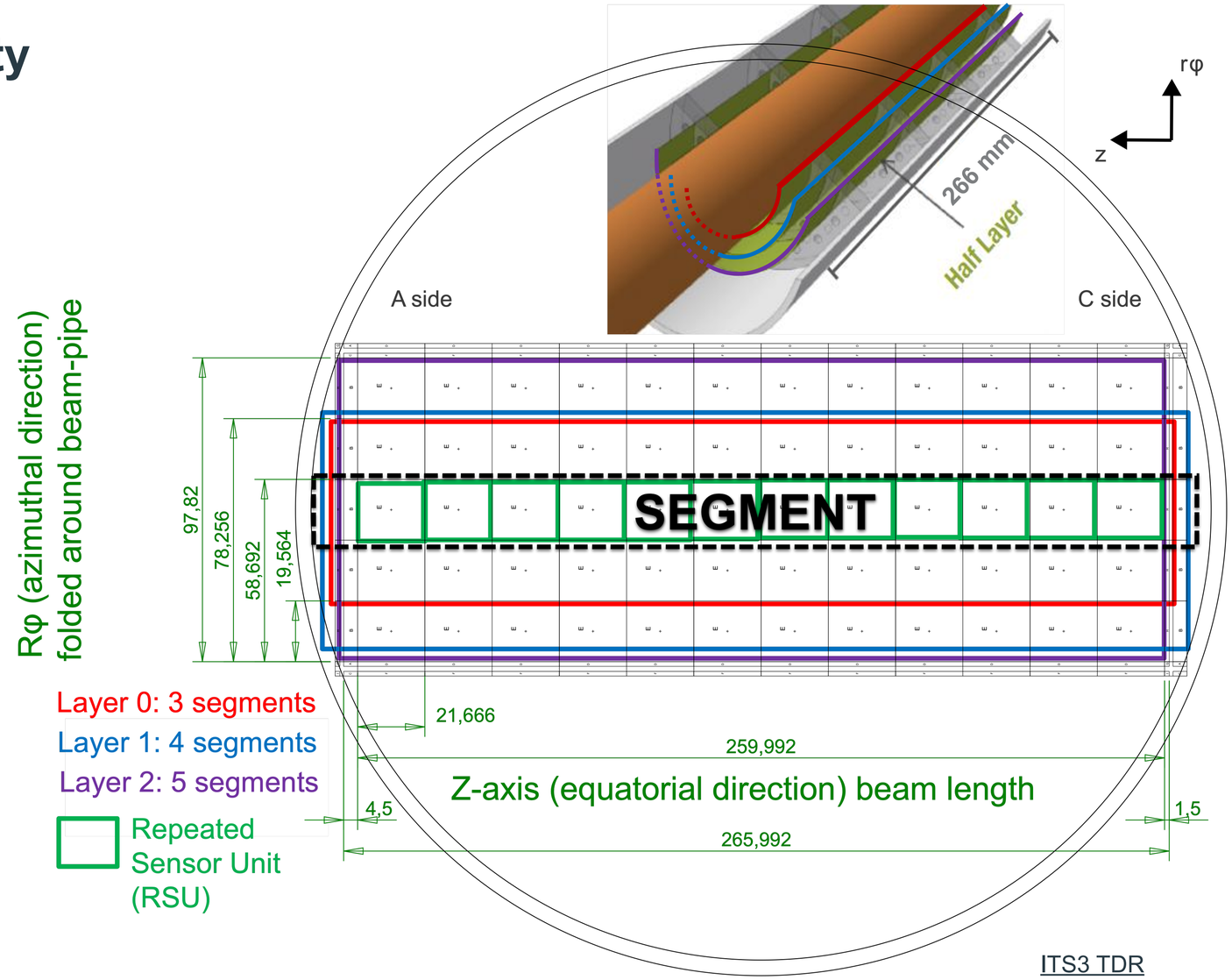
# Extra material

# ALICE 3 timeline



# ITS3 — Stitched Wafer-Scale MAPS — Next Steps

- Design of the final **full size**, **full functionality sensor** called MOSAIX is ongoing
  - Modular design:
    - Sensor divided into 5 segments (allowing to use 3, 4 or 5 segments for layers 0, 1 and 2, respectively)
    - Each segment is constituted of 12 Repeated Sensor Units (RSUs)
    - Each RSU is divided in turn into 12 fully independent tiles (powering, control and readout)
  - Interfacing from the Left End Cap (LEC) and Right End Cap (REC)
    - Powering from both sides
    - Control and readout from the LEC only
  - Yield target: >98% of pixels active
  - Submission to foundry planned for fall 2024




ITS3 TDR