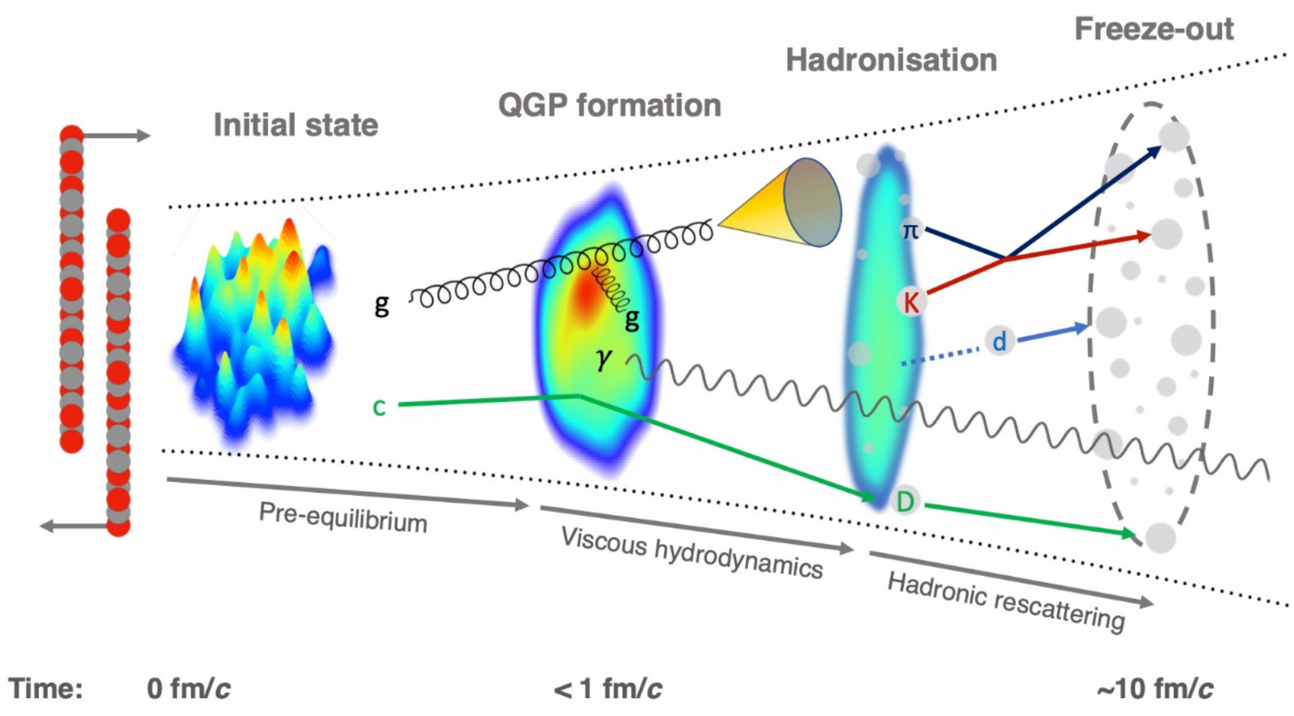
The silicon tracking system of the future ALICE 3 experiment at the LHC

Igor Altsybeev
on behalf of ALICE Collaboration

ALICE experiment: towards the Upgrade



ALICE is designed to study the quark-gluon plasma produced in heavy-ion collisions at the LHC

arXiv:2211.04384

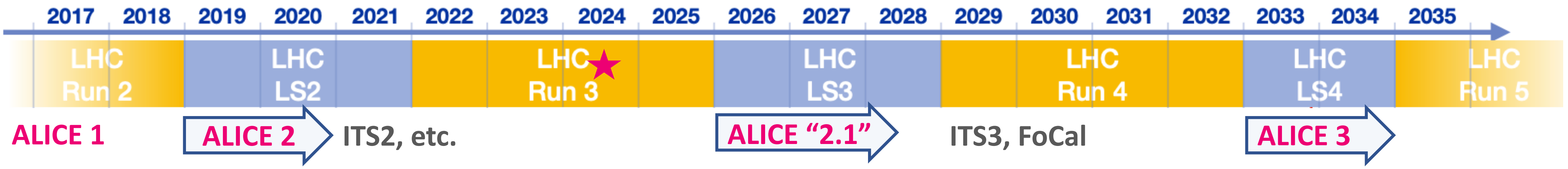
Two main physics cases driving the upgrade strategy:

- **Heavy flavour (HF)** transport and hadronization in the medium
- **Electromagnetic radiation** from the medium → dileptons

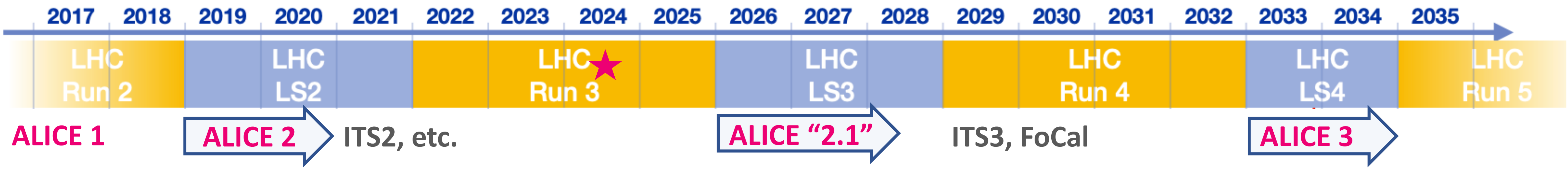
→ **High-granularity, low-mass** detector **closer to IP,** with **continuous readout** to access untriggerable signals with low S/B **down to low p_T**

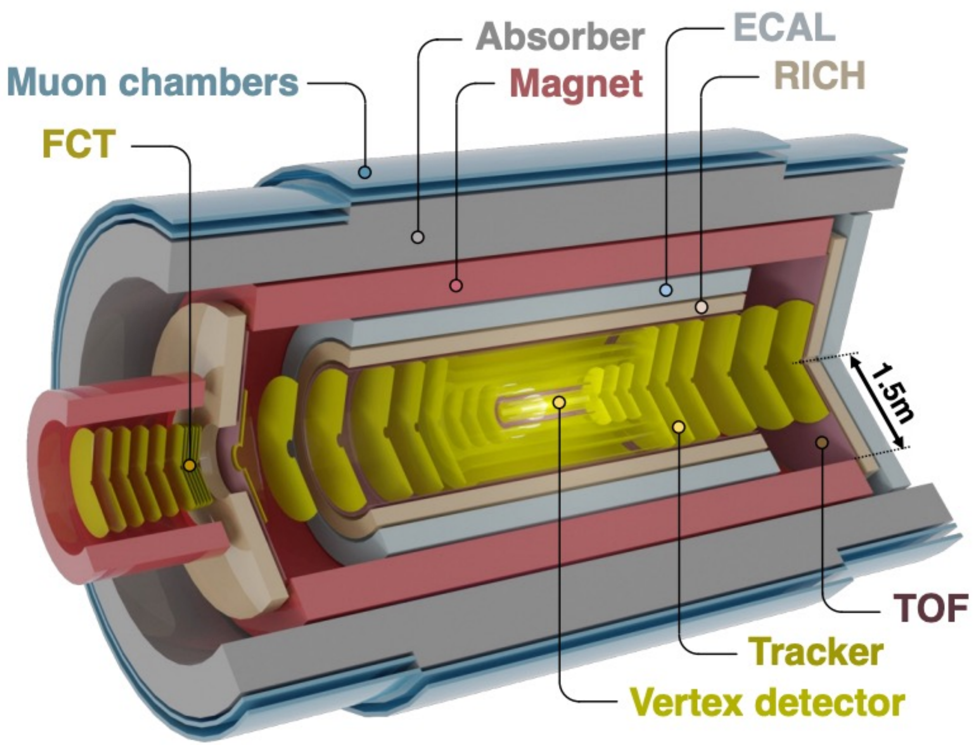
The physics program has now been broadened with many other aspects of QCD, connections to astrophysics

ALICE 3 on the Upgrades timeline



ALICE 3 on the Upgrades timeline





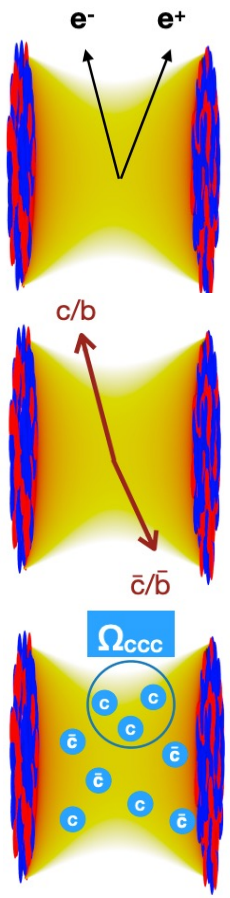
Letter of Intent: arXiv:2211.02491

Detector concept:

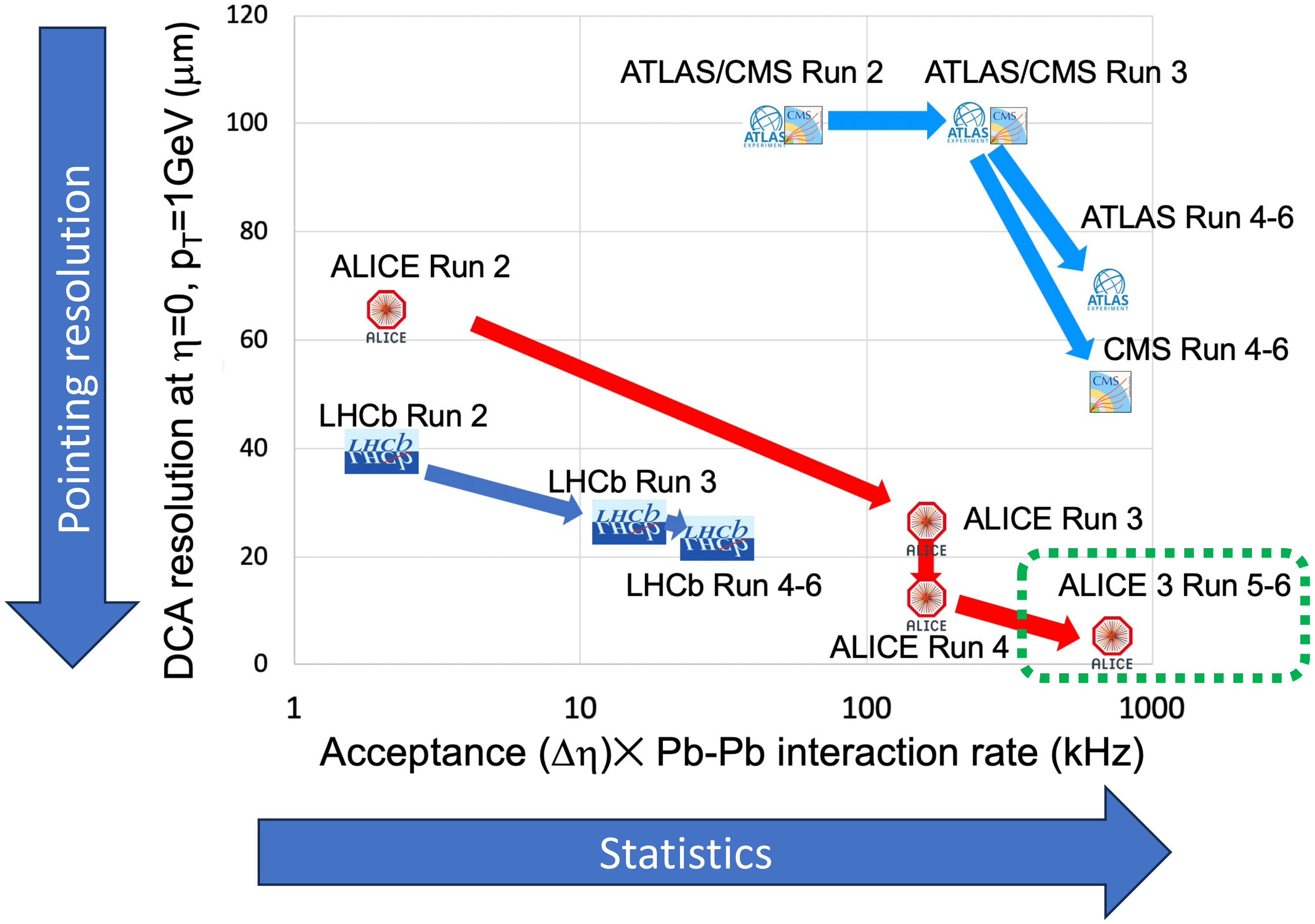
- compact **low-mass** all-silicon tracker
- excellent **vertex** reconstruction
- wide acceptance **$|\eta| < 4$**
- PID in **wide p_T range**
- high readout rate in A-A and pp

Key objectives:

- precision measurements of **dileptons**
- systematic measurements of **(multi-) heavy flavour hadrons**
- hadron long-range correlations



ALICE 3: more precise and faster



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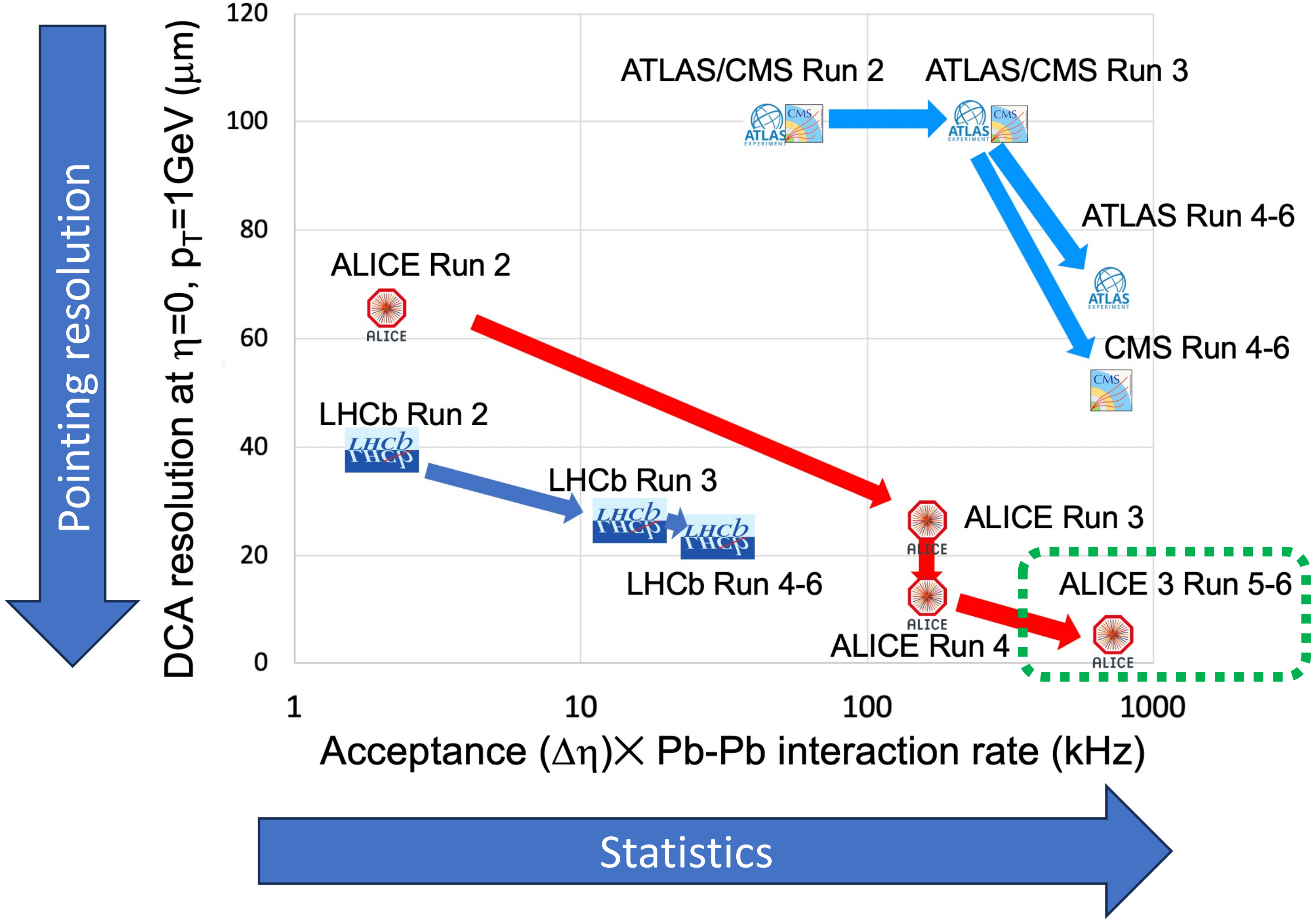
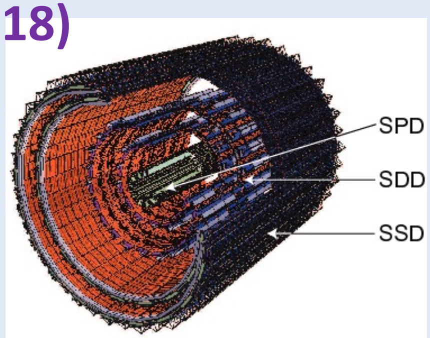
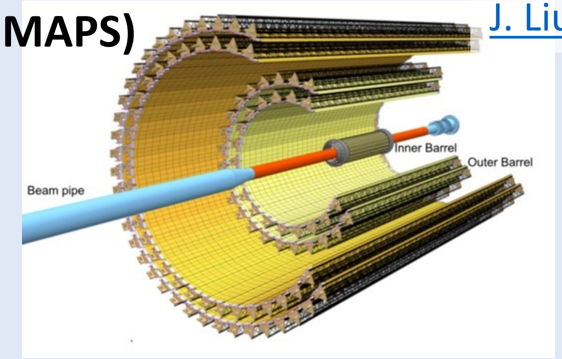


ITS1 (2010-2018)
6 layers
+ TPC



ITS2&3 (2022-2028)
7 layers **(MAPS)**
+ TPC

F. Schlepper, Thu 9.42
J. Liu, Thu 10.45



ALICE 3 tracker
11 barrel, 12 endcap layers
purely silicon → fast

Interaction rates:

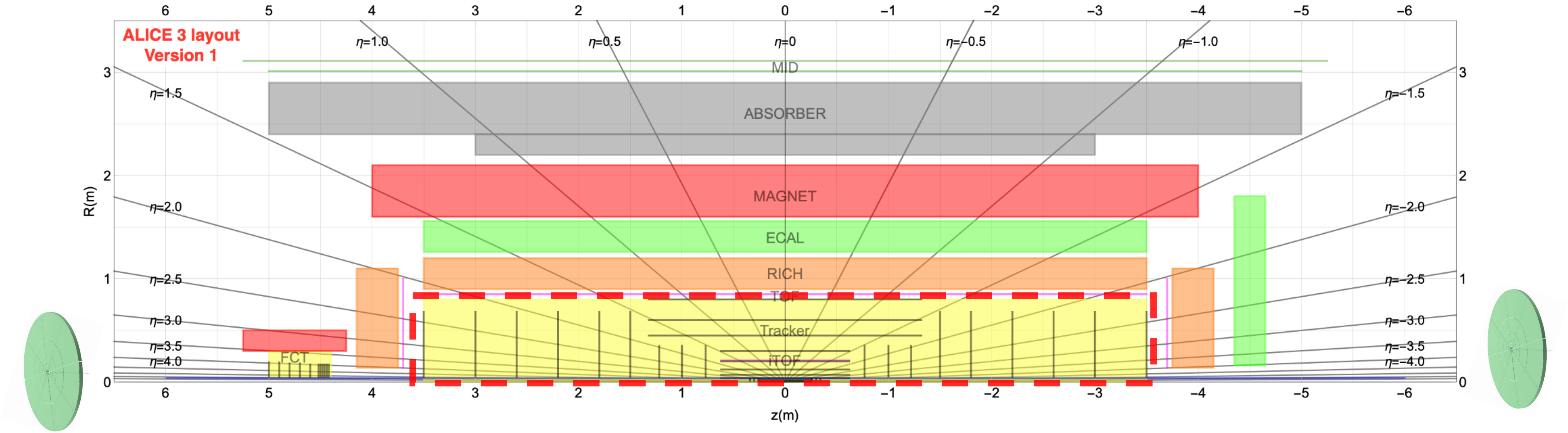
	ALICE 2	ALICE 3
pp	1 MHz	**24 MHz**
Pb-Pb	50 kHz	**100 kHz**(*)

(*) limited by the LHC projections (not detector)

ALICE 3 detector layout

ALICE

ALICE 3 LoI



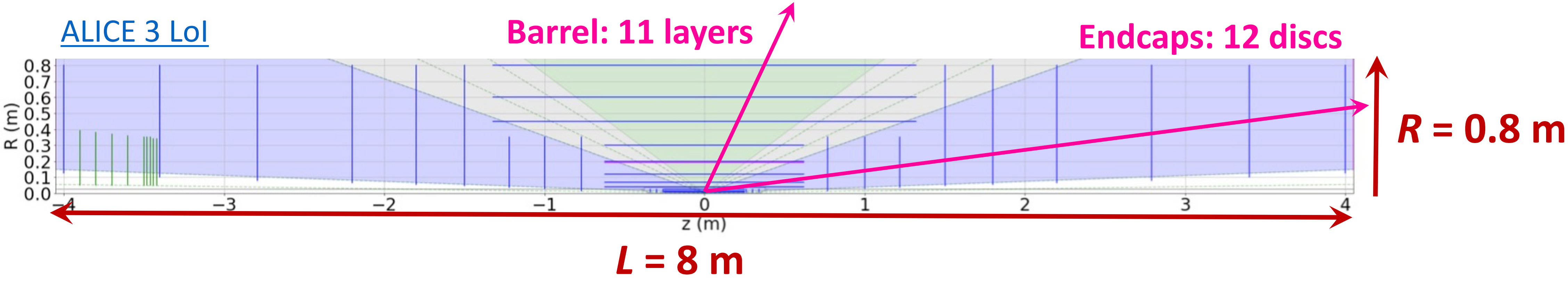
Forward Detectors
z≈17 m
$4<|\eta|<7$

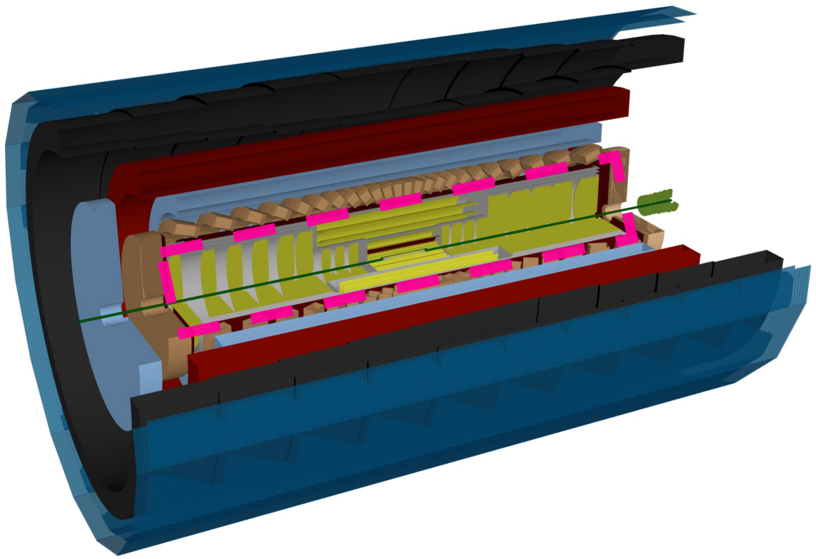
- **Silicon Tracker (monolithic active pixels)**
- PID systems: TOF, RICH, Muon ID, ECAL
- Forward scintillators
- Superconducting Solenoid 2T

ALICE 3 PID: G. Gioachin, Thu 17.36

ALICE 3 large-acceptance Silicon Tracker

ALICE 3 LoI



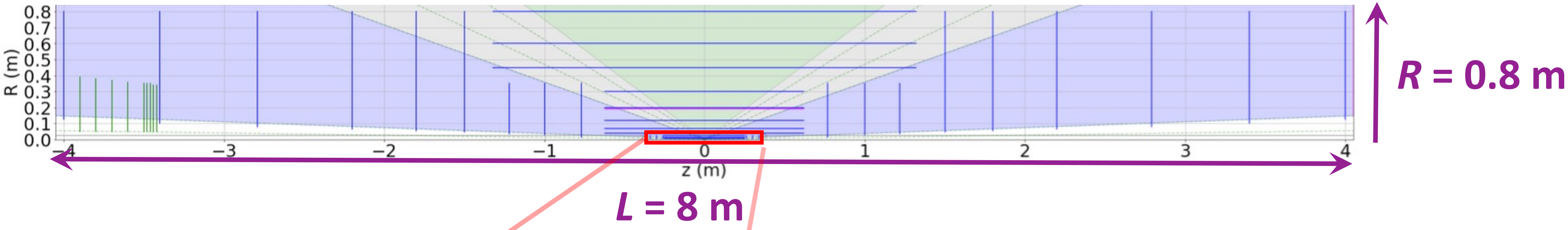


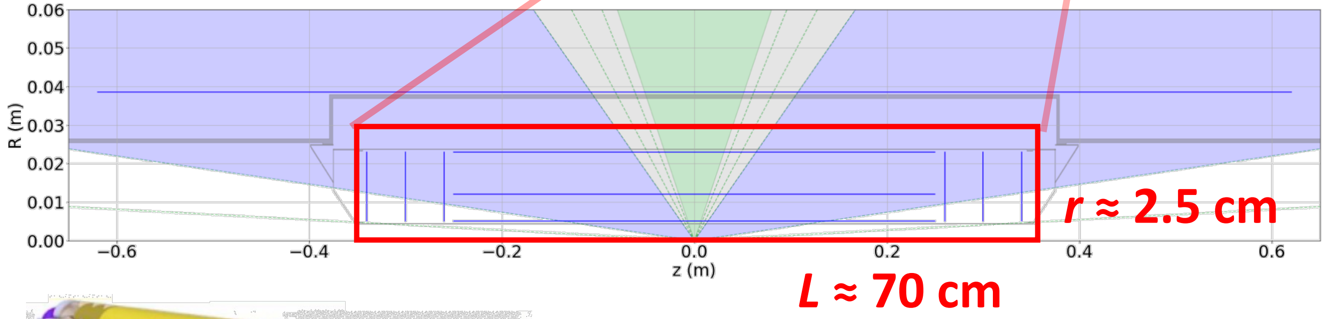
Layer	Material thickness (%X_0)	Intrinsic resolution (µm)	Barrel layers Length (±z) (cm)	Barrel layers Radius (r) (cm)	Forward discs Position ($\|z\|$) (cm)	Forward discs R_{in} (cm)	Forward discs R_{out} (cm)
0	0.1	2.5	50	0.50	26	0.50	3
1	0.1	2.5	50	1.20	30	0.50	3
2	0.1	2.5	50	2.50	34	0.50	3
3	1	10	124	3.75	77	5	35
4	1	10	124	7	100	5	35
5	1	10	124	12	122	5	35
6	1	10	124	20	150	5	80
7	1	10	124	30	180	5	80
8	1	10	264	45	220	5	80
9	1	10	264	60	279	5	80
10	1	10	264	80	340	5	80
11	1				400	5	80

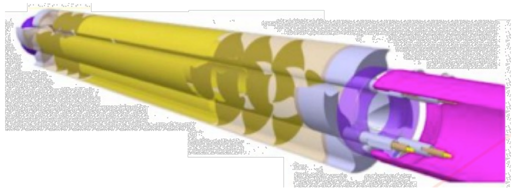
Table 8: Geometry and key specifications of the tracker.

ALICE 3 large-acceptance Silicon Tracker

ALICE 3 LoI







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ALICE 3 Vertex Detector

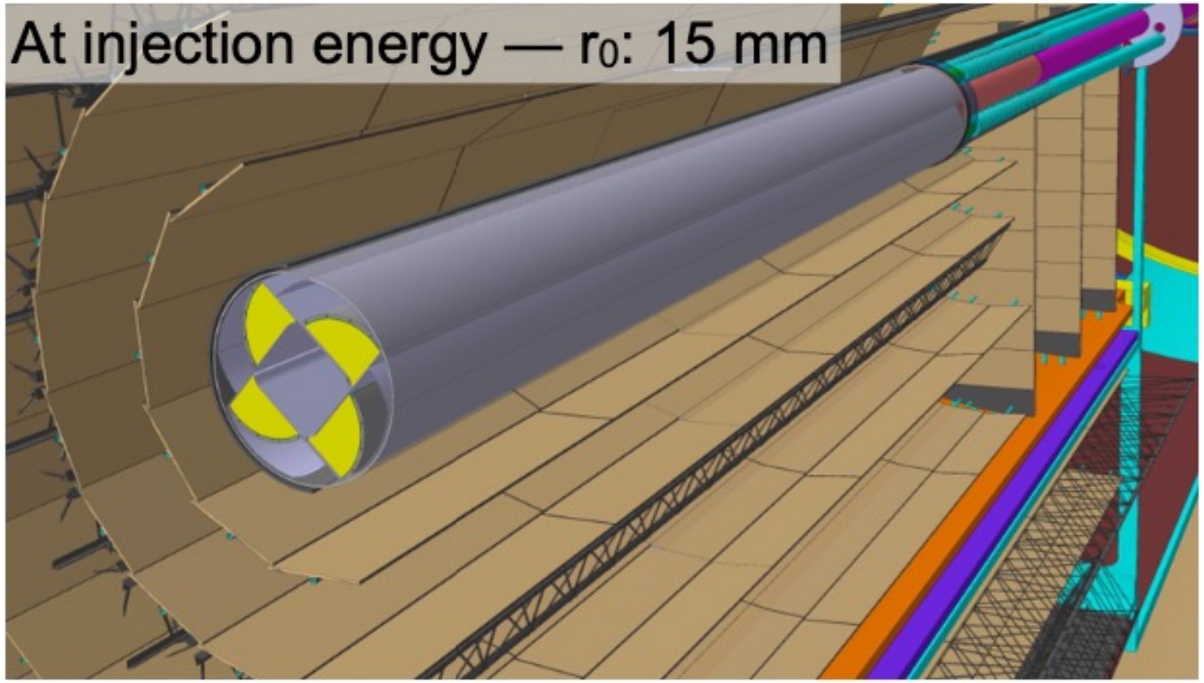
Pointing resolution $\propto r_0 \cdot \sqrt{x/X_0}$ (multiple scattering regime)

- **driven by radius and material of first layer**
- minimal radius given by required aperture:

  R ≈ 5 mm at top energy

  ***R* ≈ 15 mm at injection energy**

→ **need retractable vertex detector inside the beam pipe**



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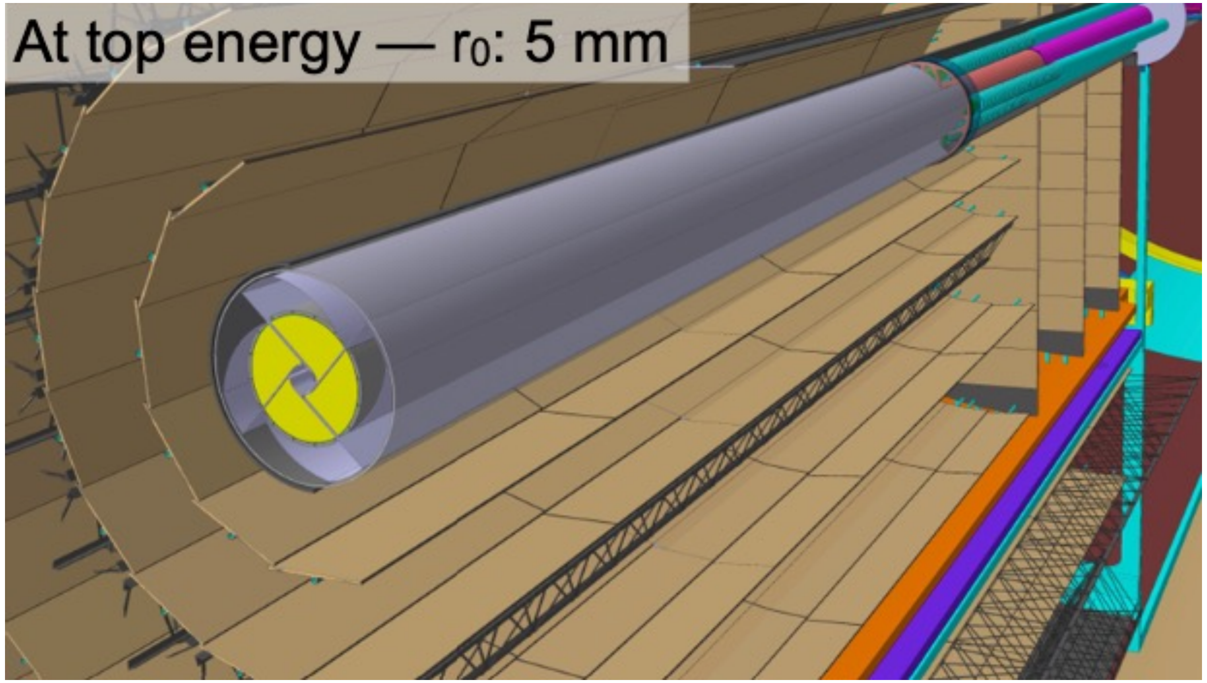

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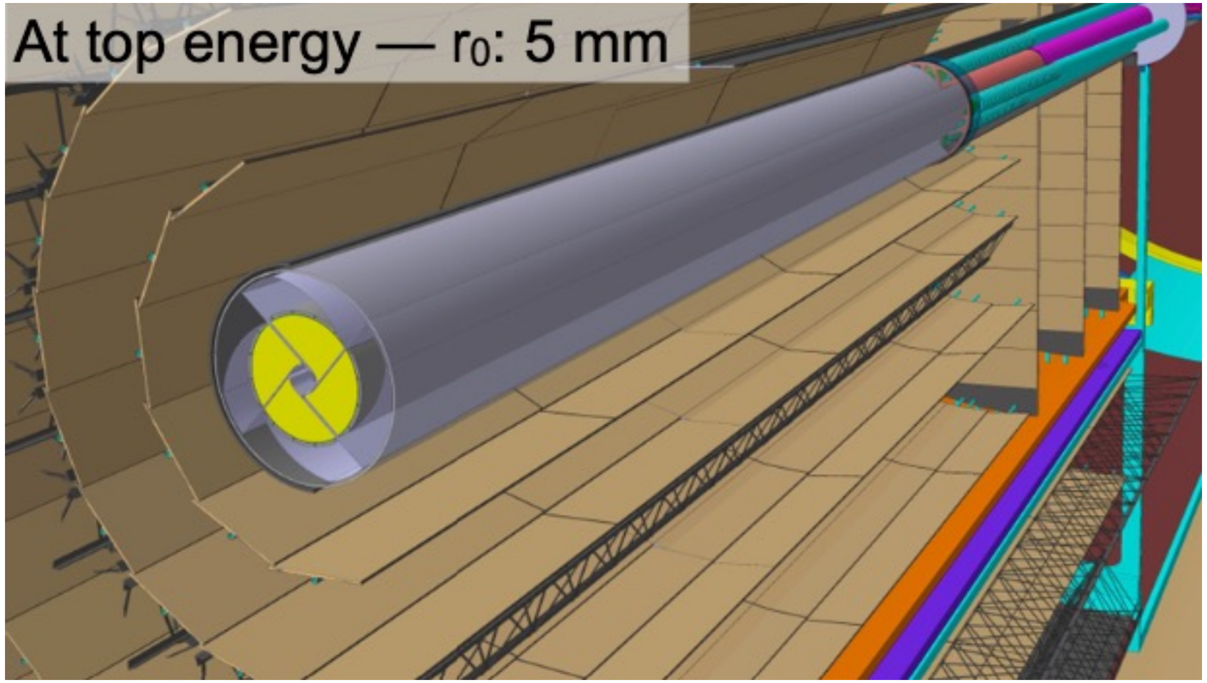
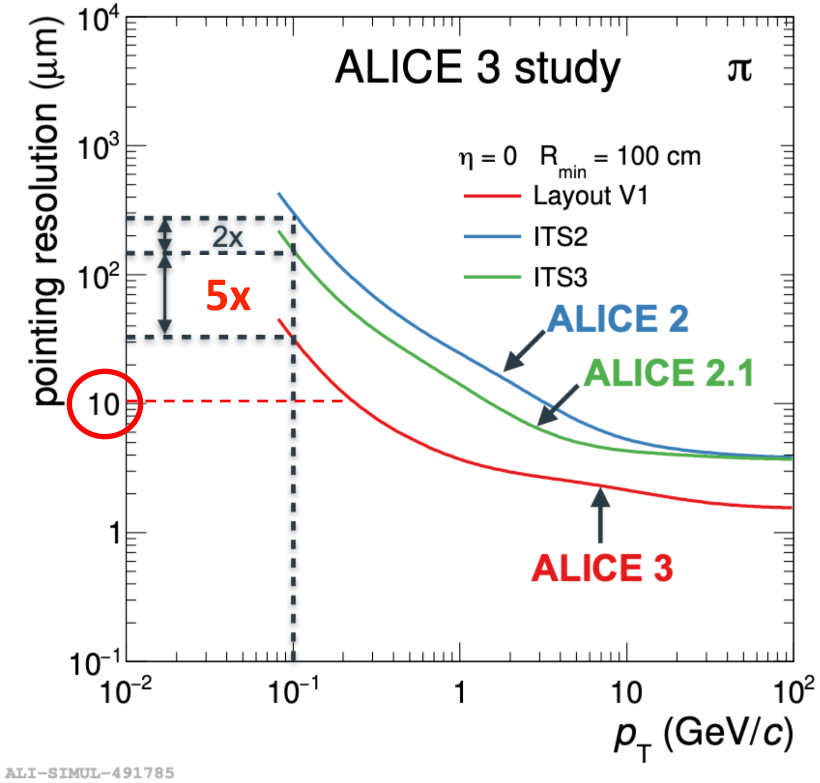


Key detector characteristics

- 3 detection layers (barrel + disks)
- Retractable: ***r*₀ = 5 mm**
- Material budget: **0.1% X0 / layer**
- Unprecedented spatial resolution of **2.5 µm**

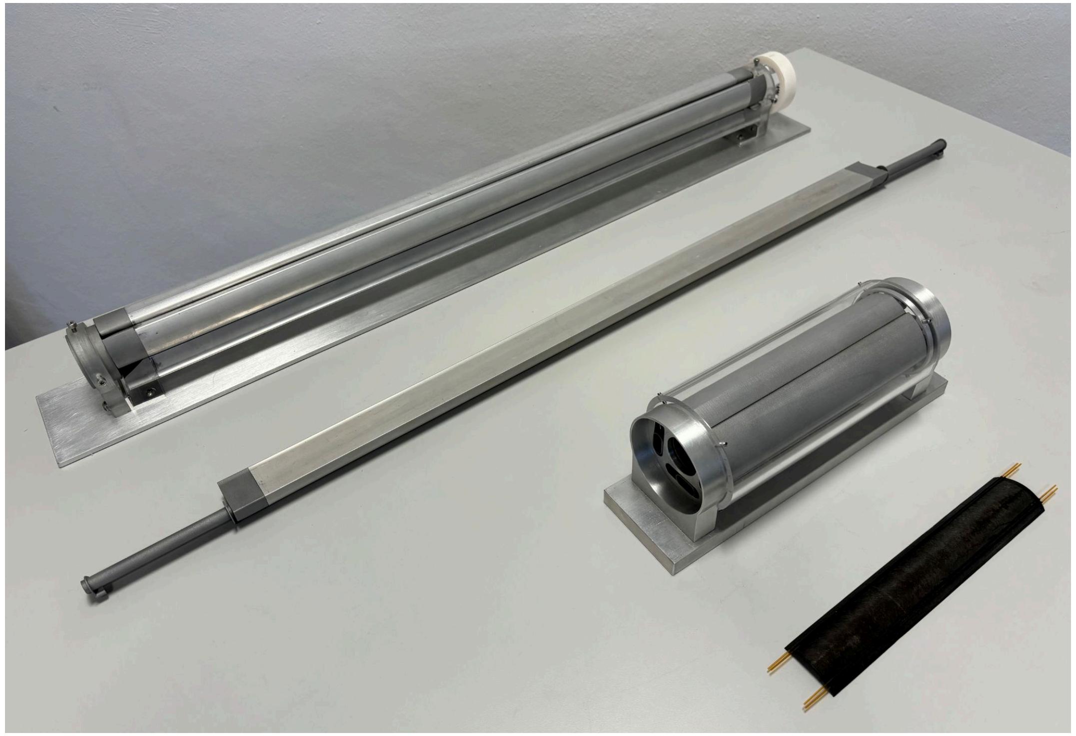


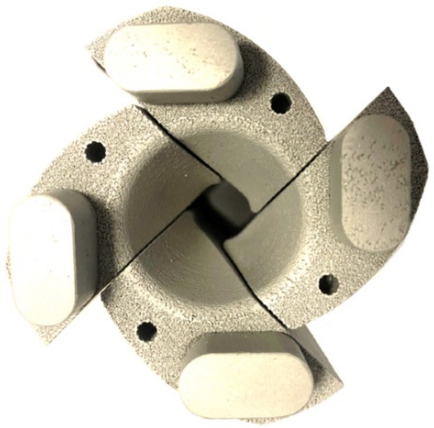
ALICE 3 Vertex Detector – **main R&D challenges**

- **Light-weight in-vacuum mechanics and cooling**
  - impact of vacuum on components, wire bonding, glued parts
  - study of protection between primary and secondary vacuum
- Relying on ITS3 R&D for sensor design, stitching, wafer-scale bent sensor
- Radiation hardness* (10^{16} 1 MeV neq/cm^2 NIEL[1] + 300 Mrad TID[2])

* LOI values, further simulation studies ongoing

- Spatial resolution 2.5 µm (pixel pitch of **10 µm**), sensors – **MAPS**

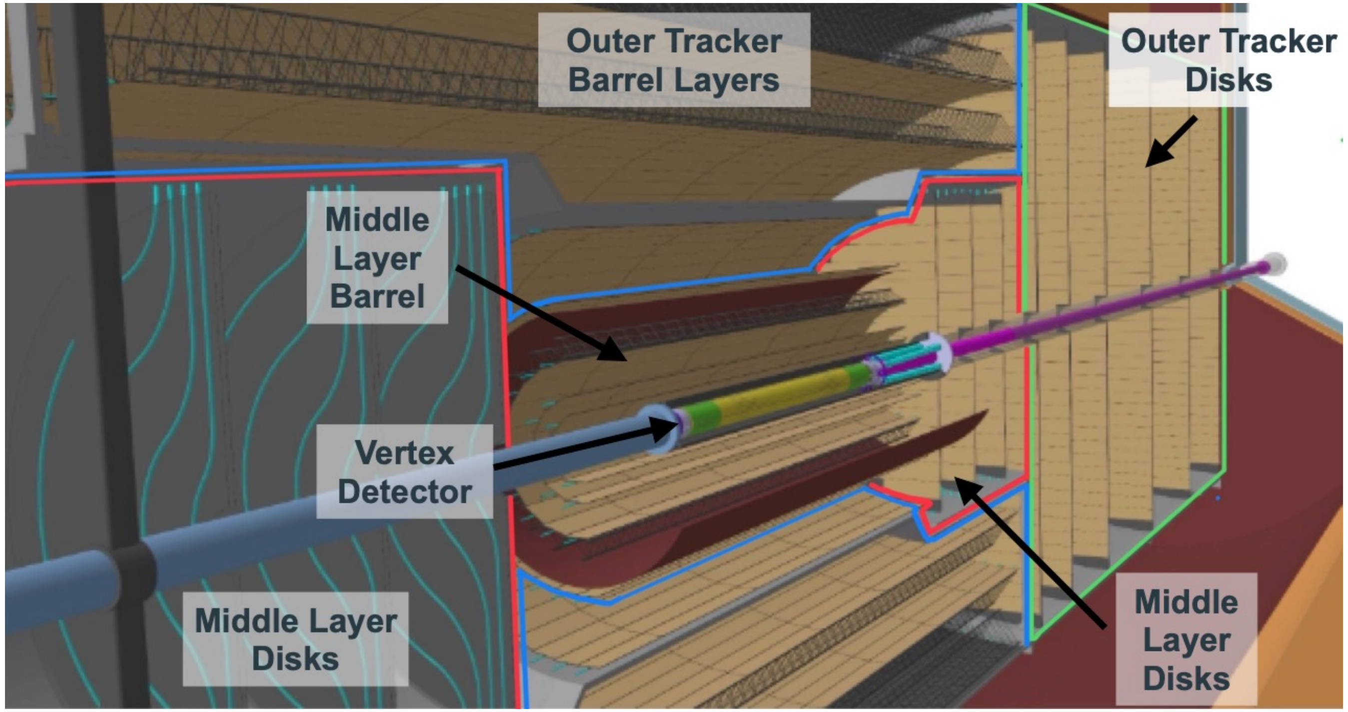




3D printed Al-Be petals
0.5 mm* thick wall
* goal is ≈ 0.15 mm

[1] NIEL – non ionising energy loss
[2] TID – total ionising dose

Middle Layers and Outer Tracker



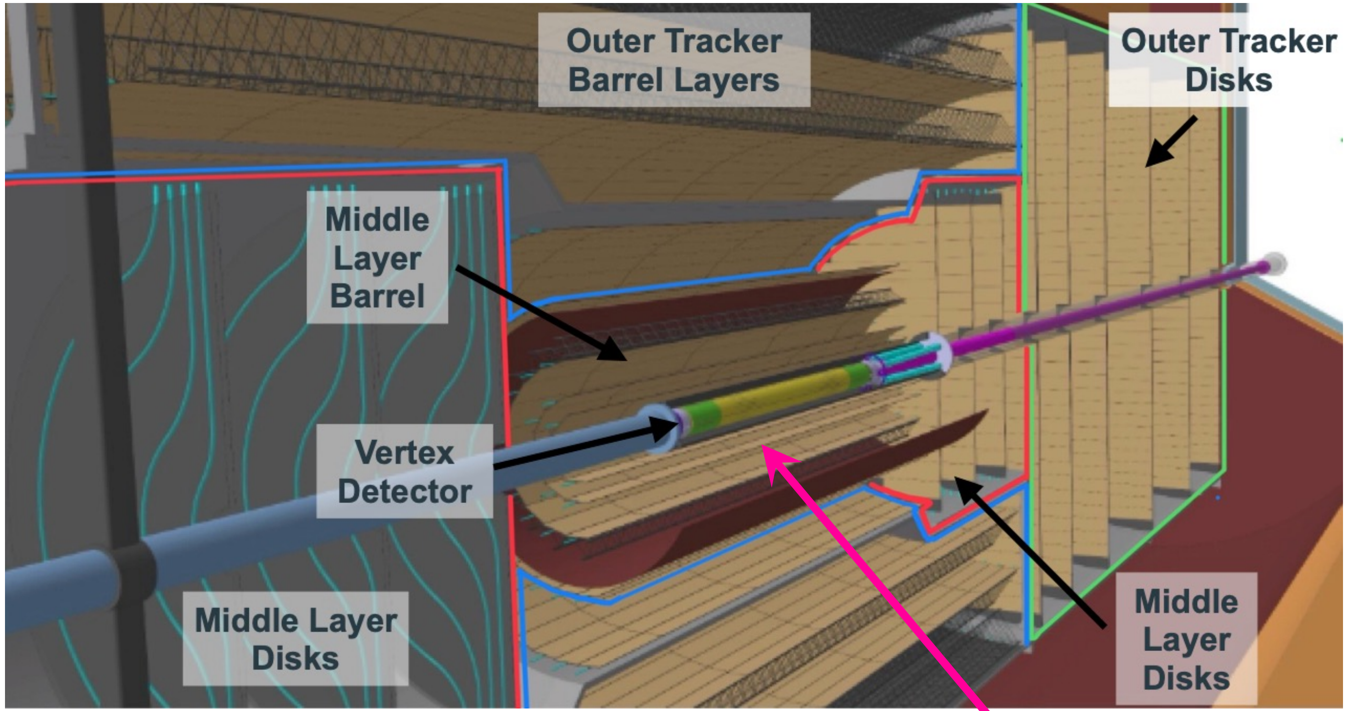
Relative p_T resolution $\propto \frac{\sqrt{x/X_0}}{B \cdot L}$
(multiple scattering regime)

- magnetic field and material budget are critical

Key detector characteristics:

- 8 barrel layers (3.5 cm < R < 80 cm)
- 2 x 9 forward disks
- Total surface **~ 60 m²**
- **Material budget: 1% X_0 / layer**
- Low power consumption: 20 mW/cm²
- **Spatial resolution 10 µm** (pixel pitch 50 µm)
- 100 ns time resolution (also for Vertex Detector)

Middle Layers and Outer Tracker



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Middle Layers:

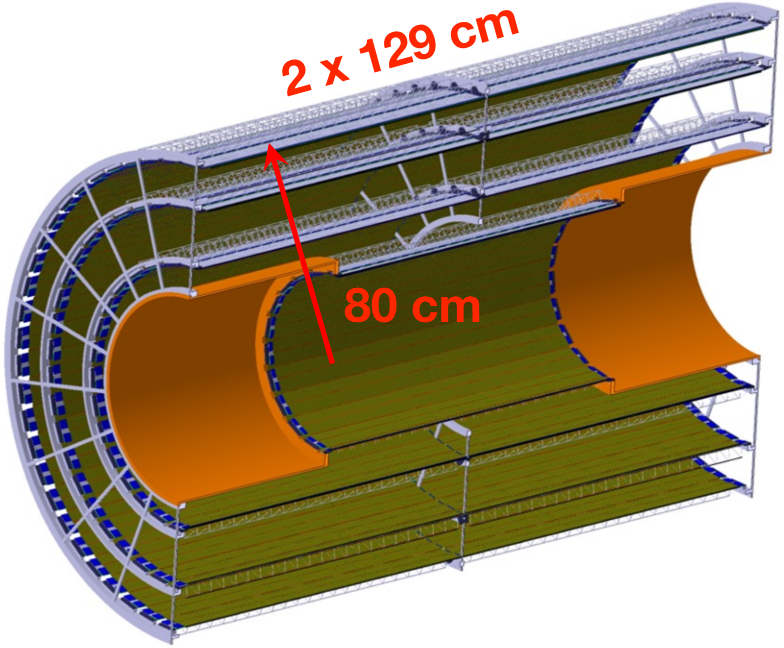
- R&D: studying various options for **ultra-light layers**, leveraging on ITS3 technology
- **benefits on tracking of soft electrons and of charged hyperons (Ξ^-, Ω^-)**

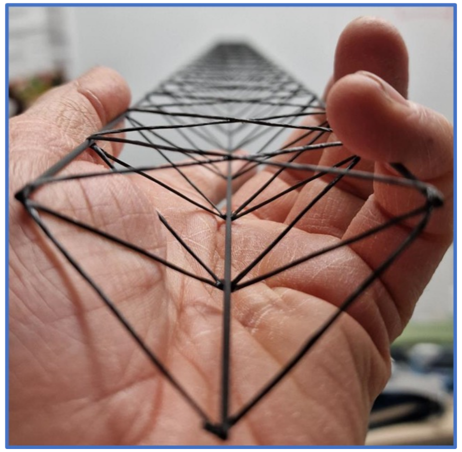
ITS3 engineering model #2

Outer Tracker – **main R&D challenges**

OT barrel design:

- 3+1 layers
- full-scale stave model
- air and water cooling studies
- mechanical support studies





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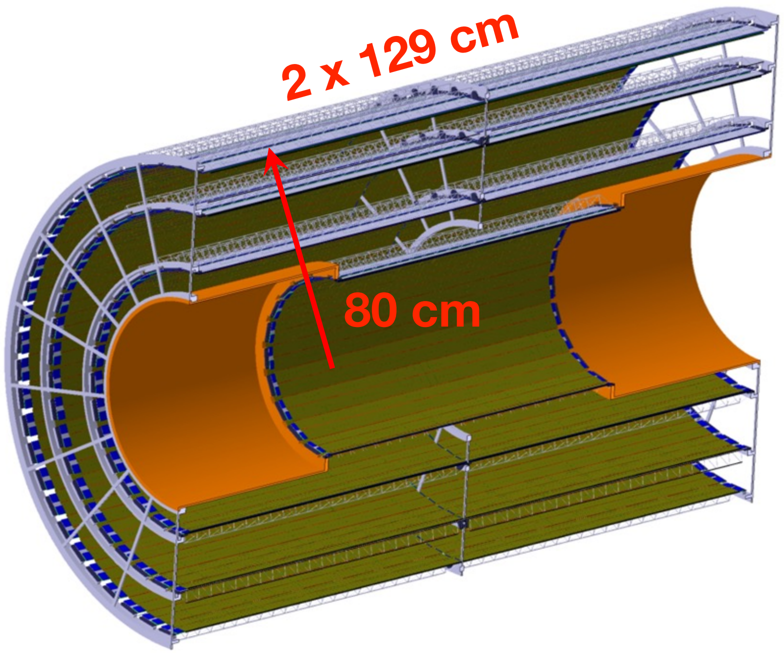
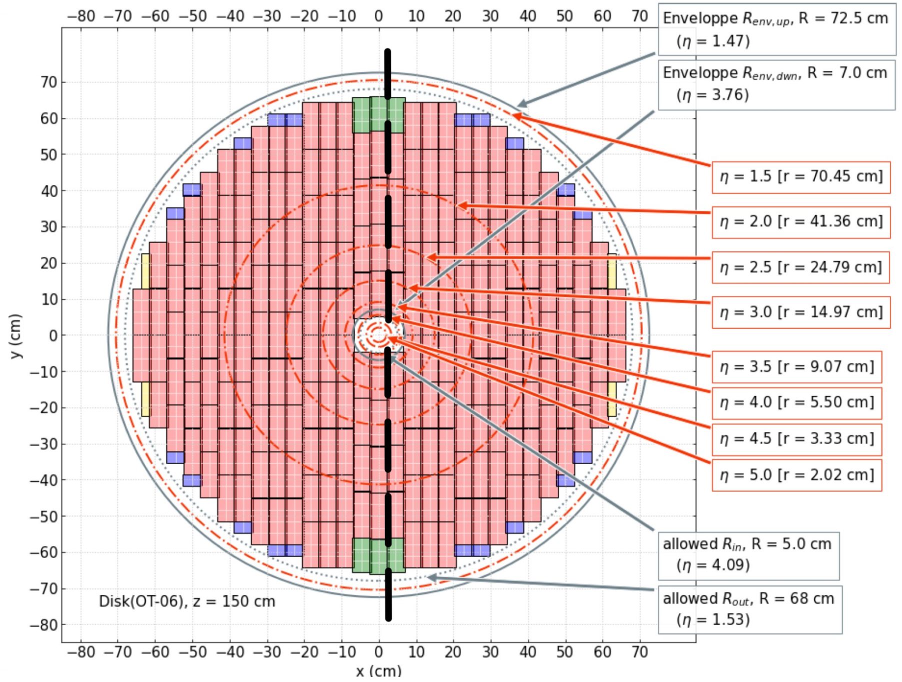
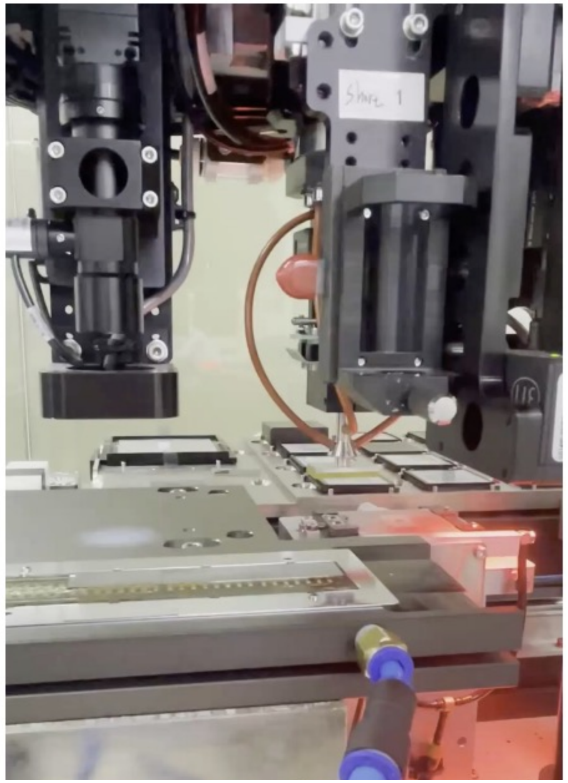


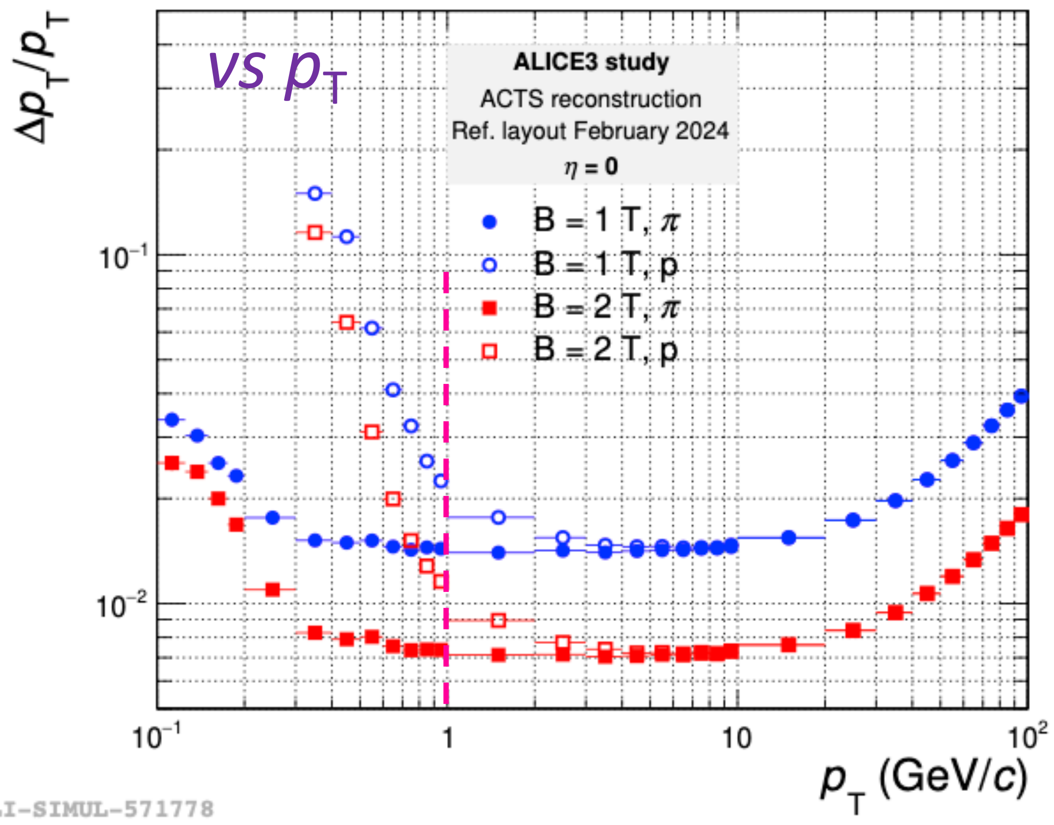
OT endcaps with disks:
- "paving" with modules
- mechanical layout (double-sided disks?), carbon-fibre support

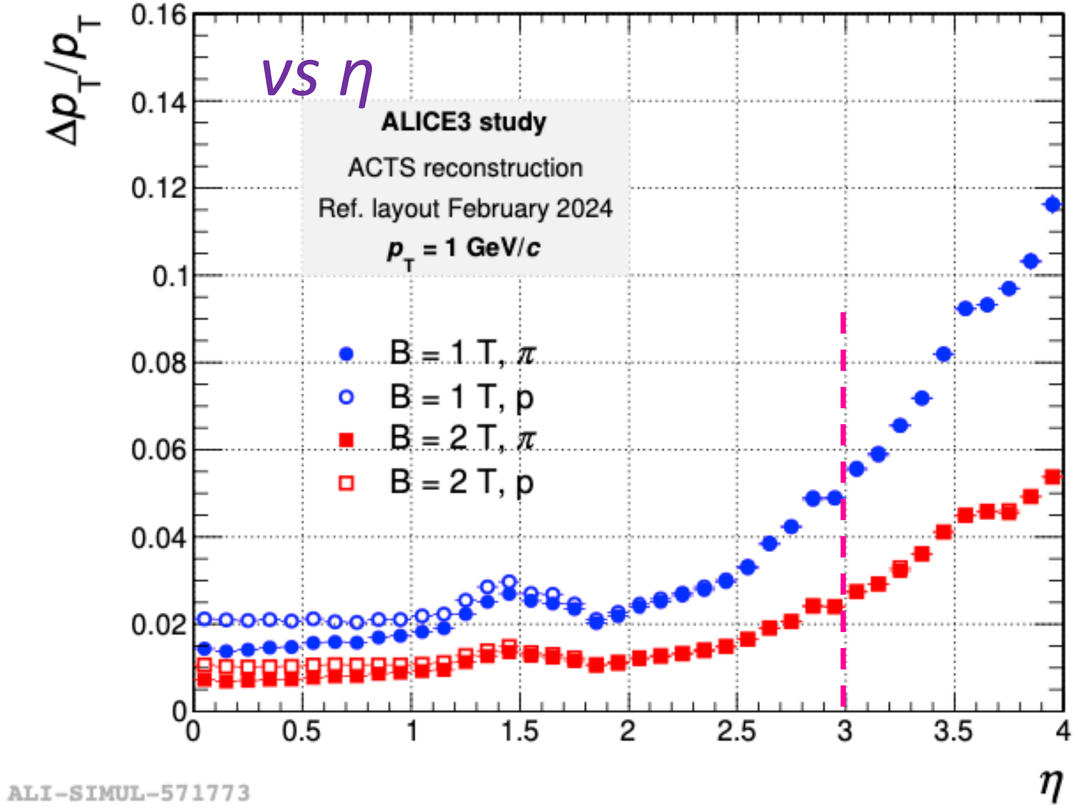


Automated module assembly:
- general-purpose die-bonder machine
- flexible printed circuit, sensor gluing and interconnections
- large area → industrialized production



Simulations & tracking: momentum resolution



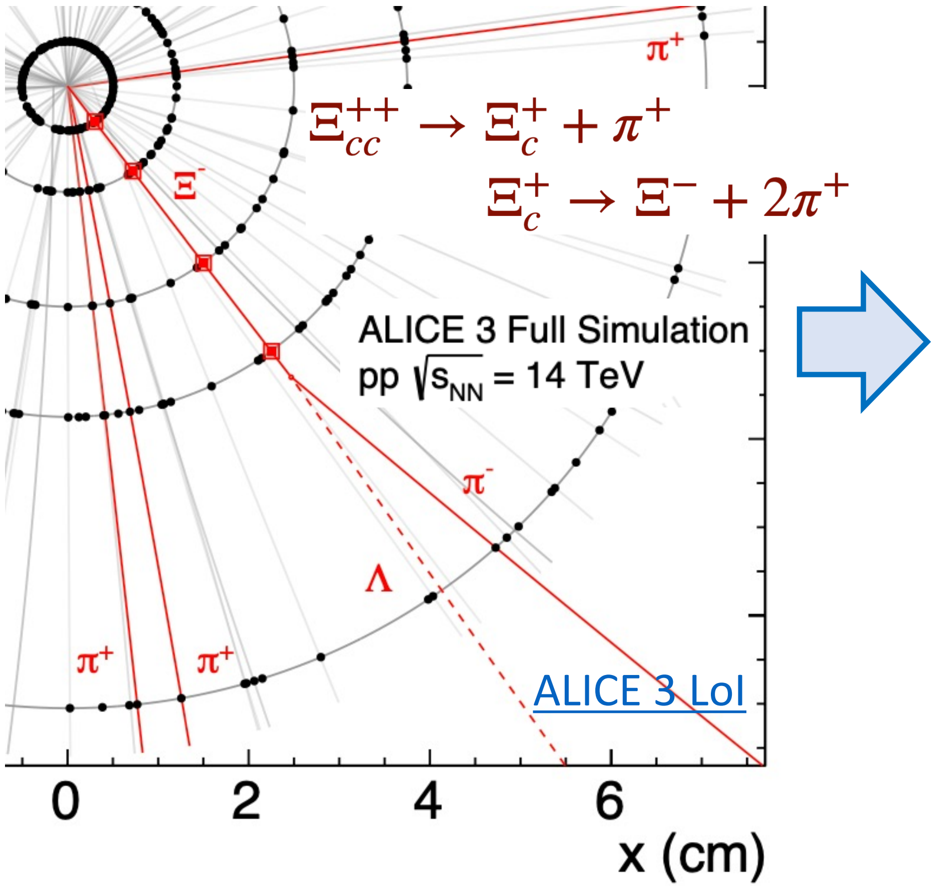


Solenoid 2T: p_T resolution for pions ≈ 0.7% at p_T ~ 1 GeV/c < 2% up to $|\eta|$ ≈ 3

A. Salzburger et. al., Comput. Software Big Sci 6, 8 (2022)

Performance: “Strangeness tracking”

Track particles before their (weak) decay
in Vertex Detector + Middle Layers:



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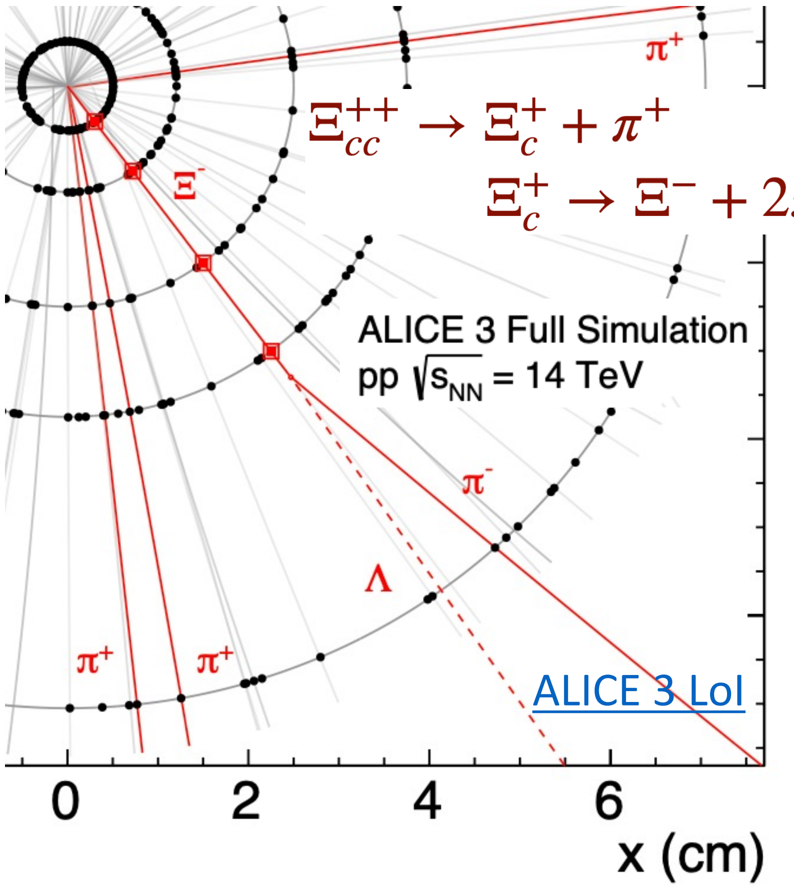
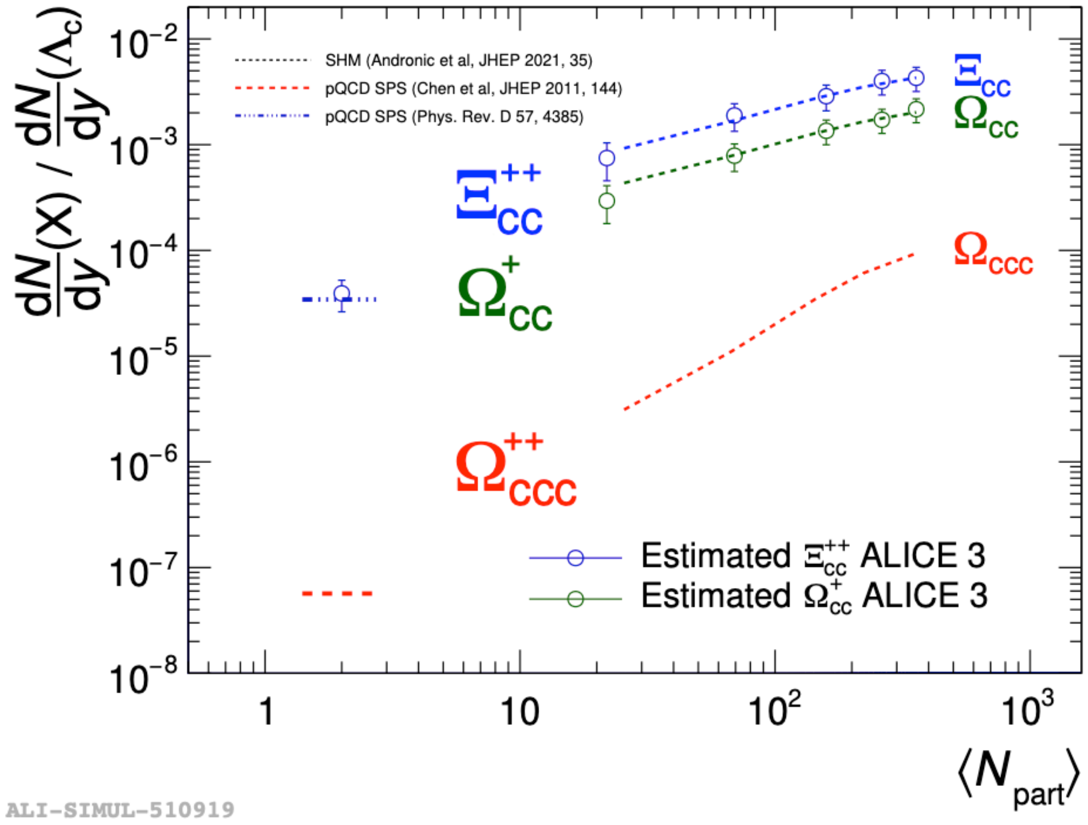
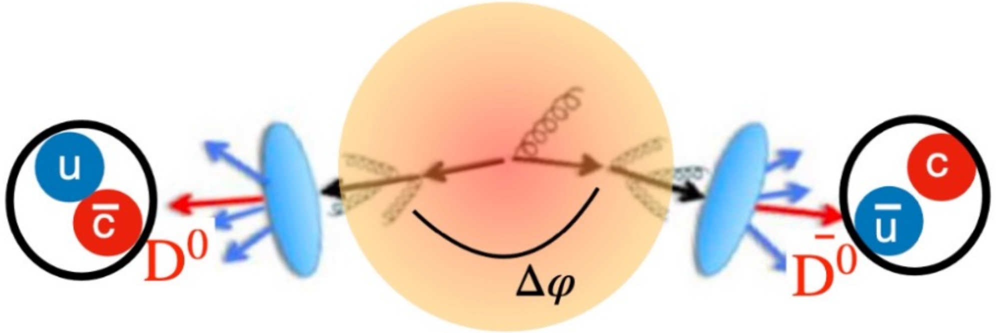


Multi-charm baryons at low p_T

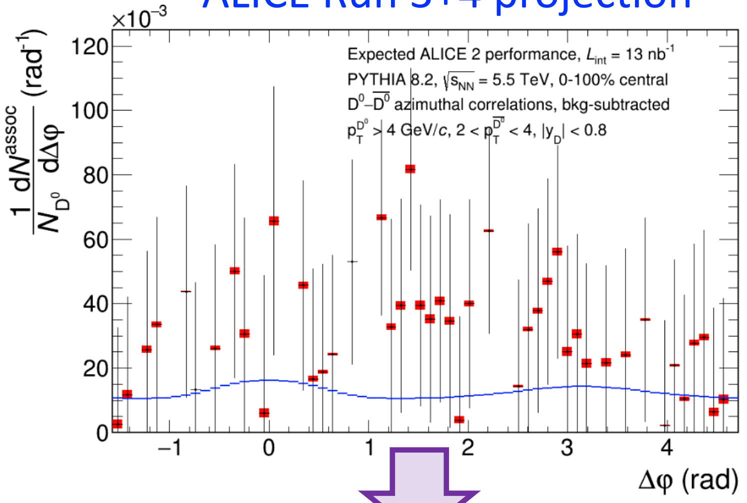
- unique probe of hadron formation
- recombination models predicts 2-3 orders of magnitude enhancement in Pb-Pb



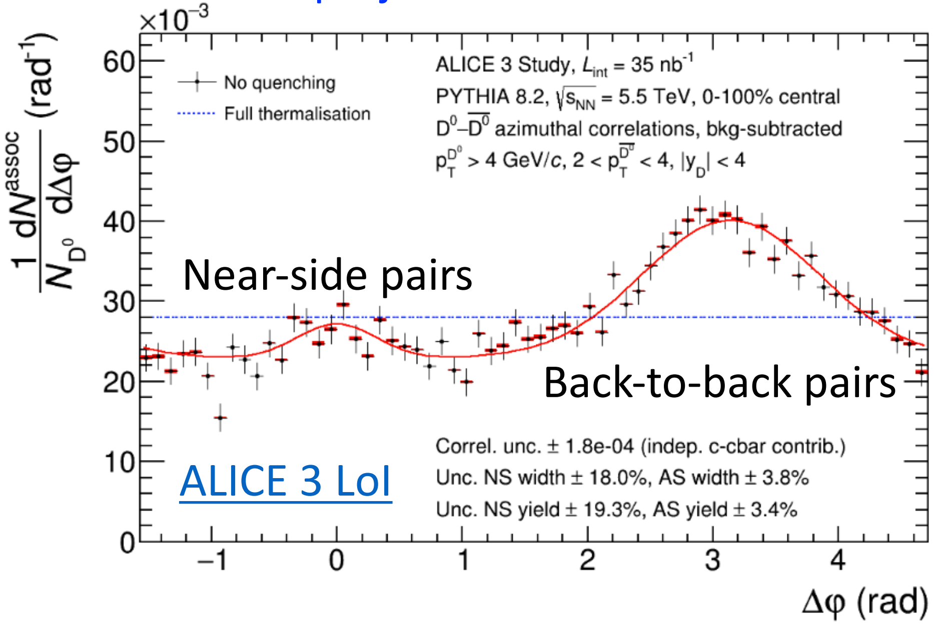
Performance: Heavy-flavour angular correlations



ALICE Run 3+4 projection

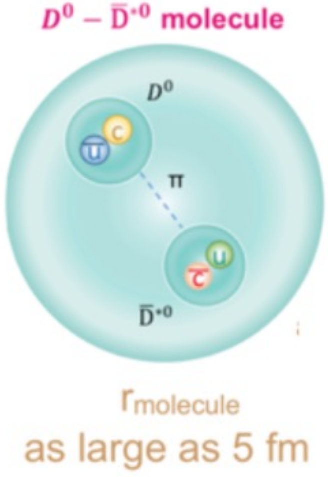


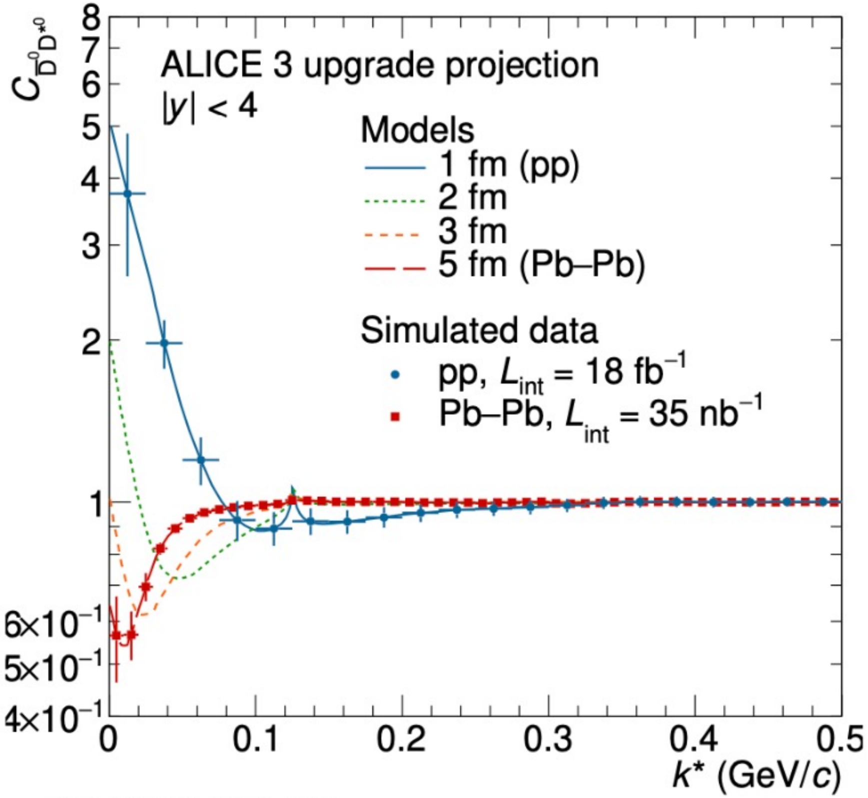
ALICE 3 projection for $D^0\overline{D^0}$ correlation



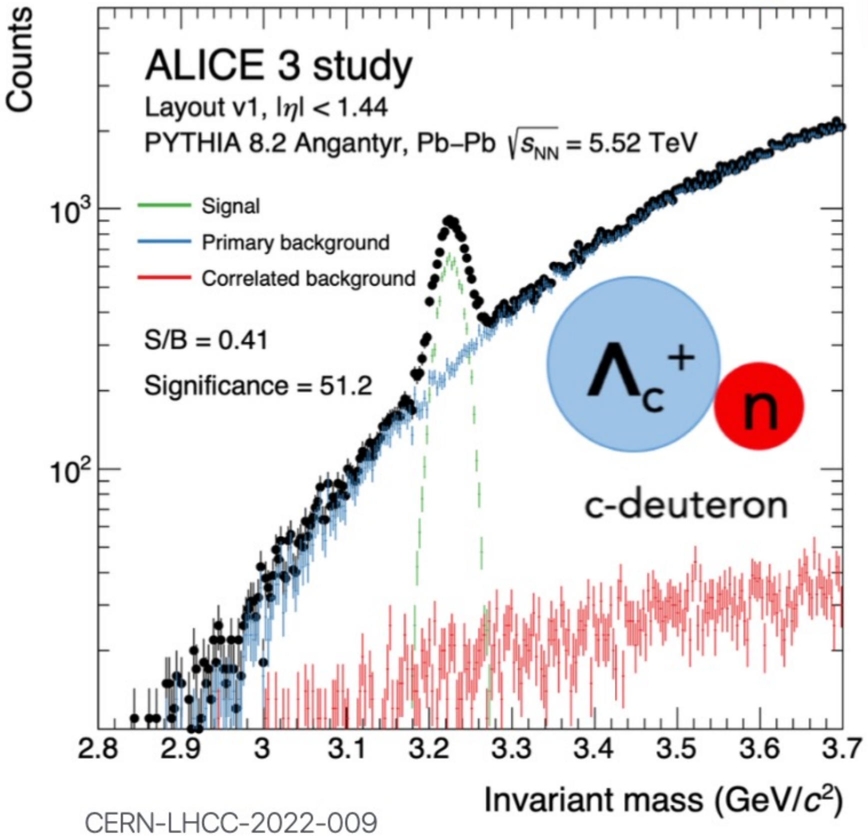
- Directly probe heavy quark transport in QGP:
  sensitive to energy loss and thermalization degree
- Advantages from large η-coverage of ALICE 3

Performance: Hadronic interactions and exotic nuclei





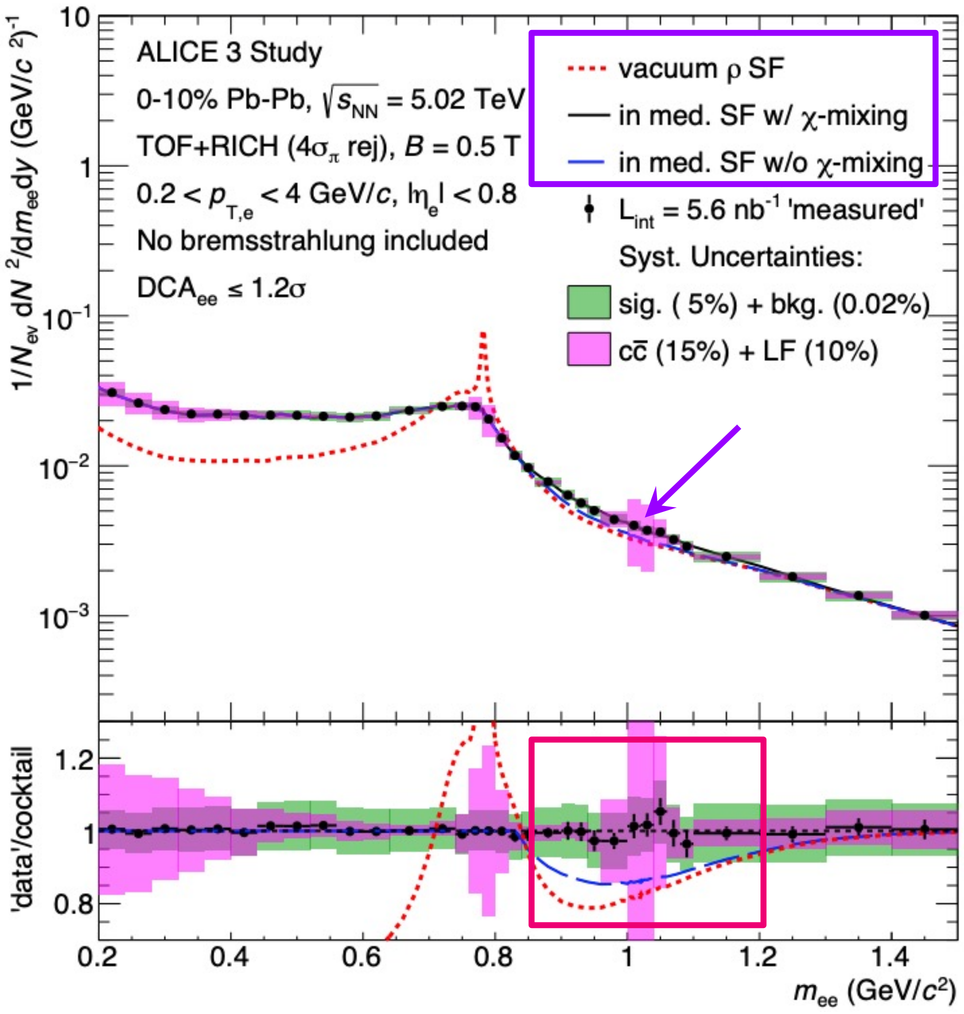
CERN-LHCC-2022-009



CERN-LHCC-2022-009

- Two-particle **D^0-$\bar{D}^{*0}$ momentum correlations** can be used to explore formation of D-D* bound states or T_{cc} particle
- Search for yet-undiscovered **c-deuteron**: reach significance of 50 for one month of Pb-Pb run

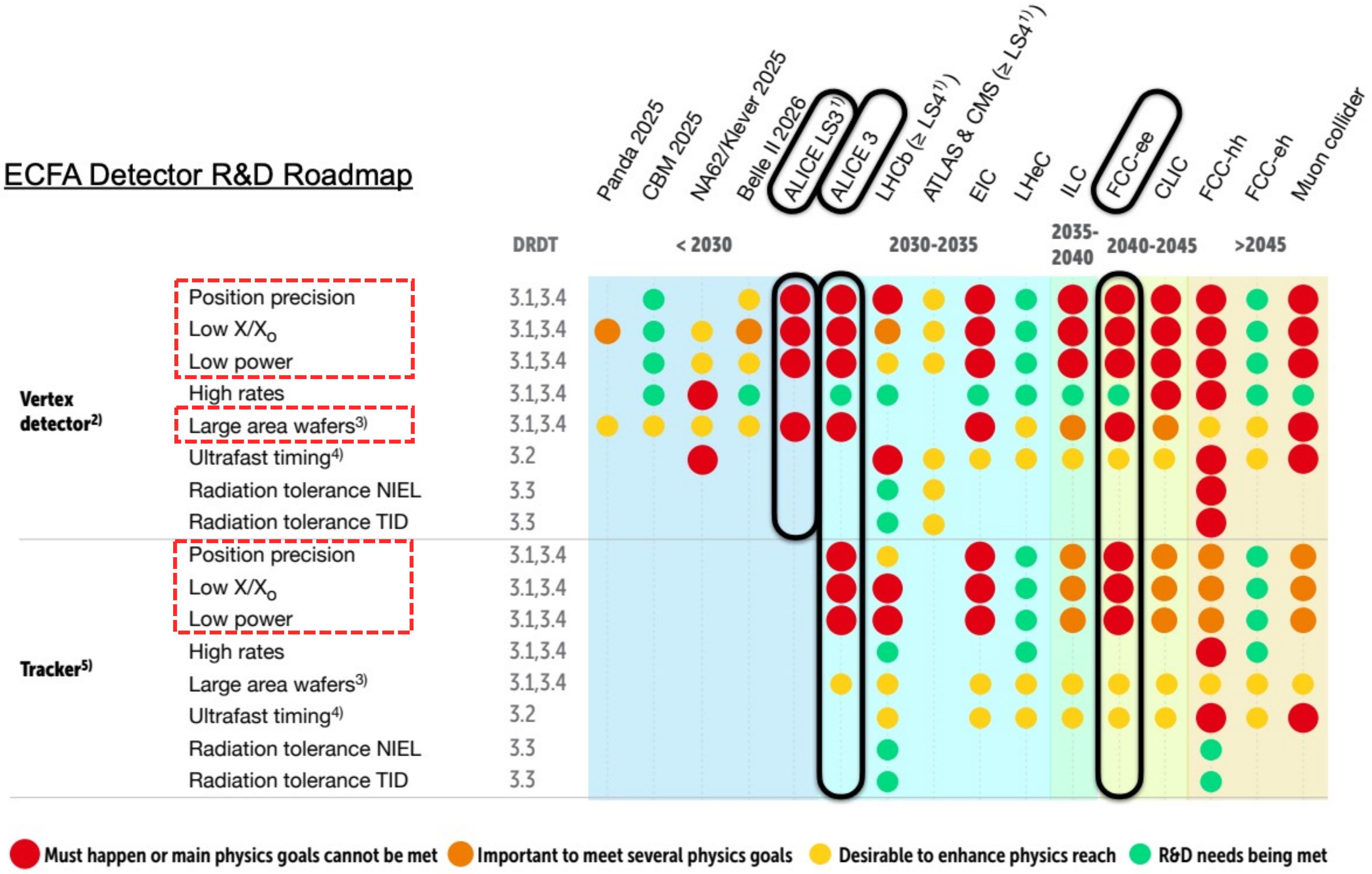
Performance: Chiral symmetry restoration with dielectrons



- Chiral symmetry breaking explains origin of 99% of visible mass in Universe
- Chiral symmetry is restored in quark-gluon plasma

Ultimate heavy-flavor background rejection, high statistics
→ Access to ρ–a_1 mixing via $\boldsymbol{m_{ee}}$ **excess spectrum**

Common challenges for ALICE and FCC-ee



Summary

- ALICE 3 will exploit the HL-LHC as a heavy-ion collider until Run 6
- Innovative (and challenging) silicon-based detector concept:

  ultra-light wide-acceptance tracker, continuous readout
- Enabling precision measurements of **dileptons, (multi-)heavy-flavour hadrons and hadron correlations**
- Pioneering several R&D directions with broad impact on future HEP experiments (e.g. FCC-ee)
- Scoping document is under preparation

Thank you for your attention!

Letter of Intent: arXiv:2211.02491