

17th Workshop of the FCPPN/L

Lyon, 29 June – 3 July 2026



ALICE



Antonio Uras
IP2I-Lyon

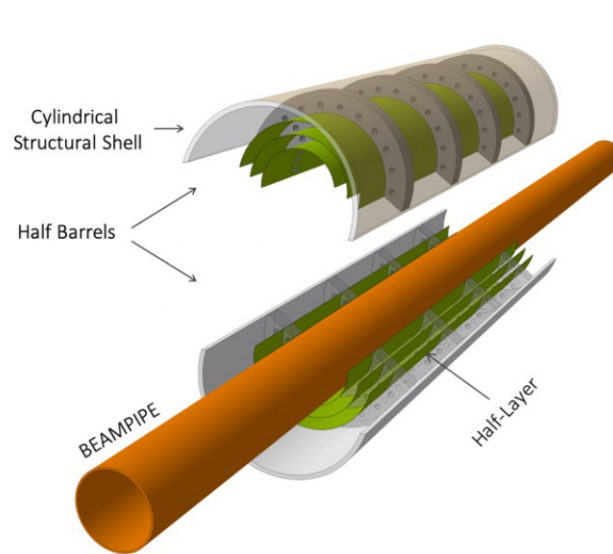
ALICE upgrades for Run 4 and Run 5



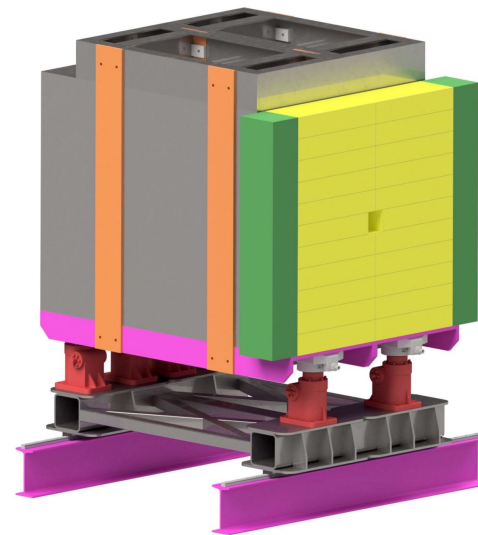
ALICE Upgrade Timeline

ITS3 & FoCal: specific upgrades in LS3 (2026-29).

TDRs approved in March 2024. Moving towards “production” phase



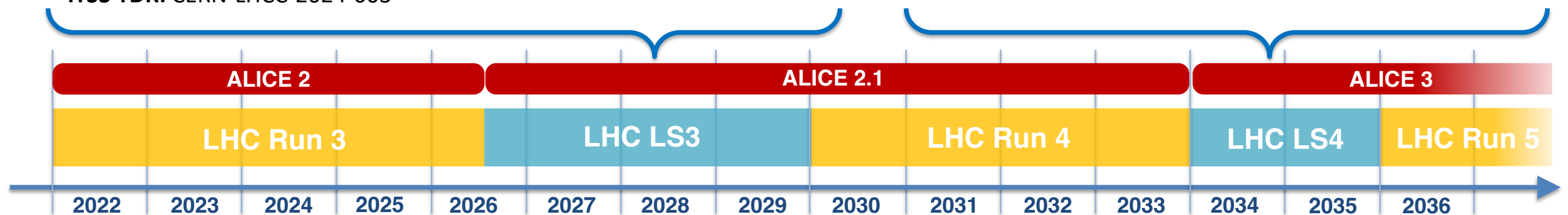
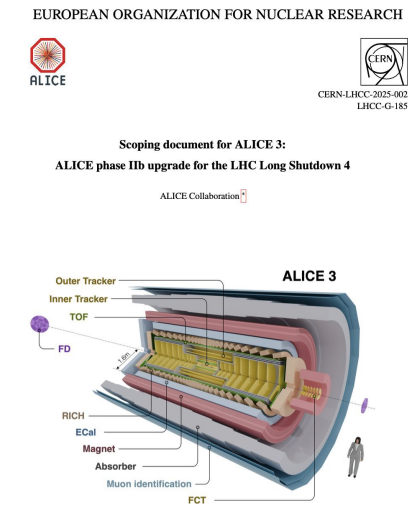
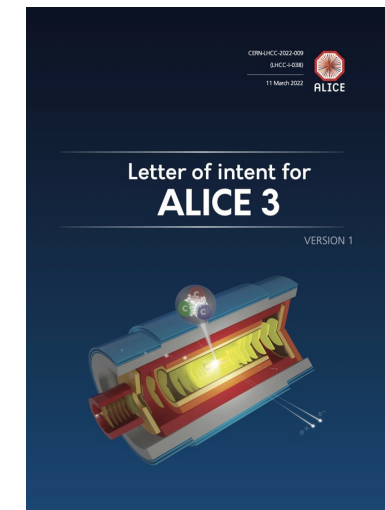
ITS3 TDR: CERN-LHCC-2024-003



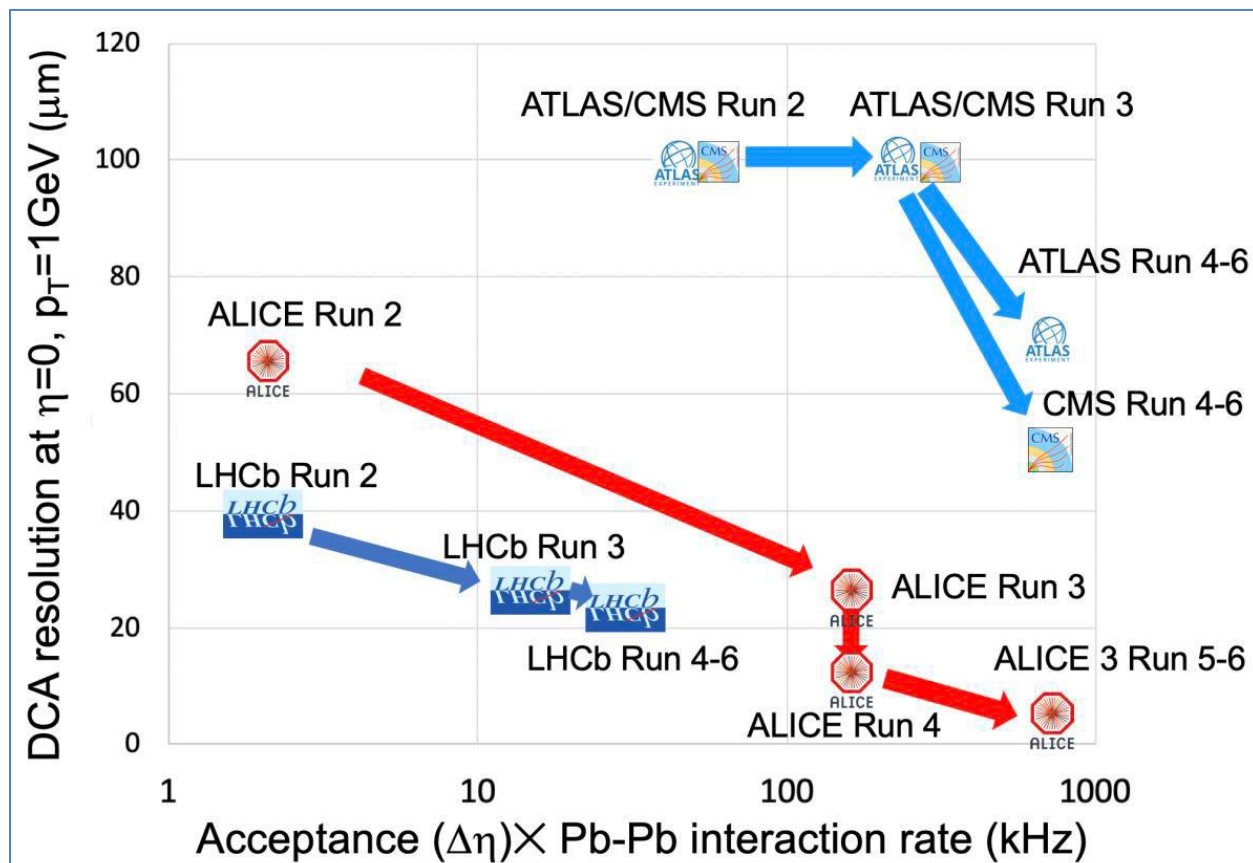
FoCal TDR: CERN-LHCC-2024-004

ALICE 3: Major upgrade in LS4 (2034-35)

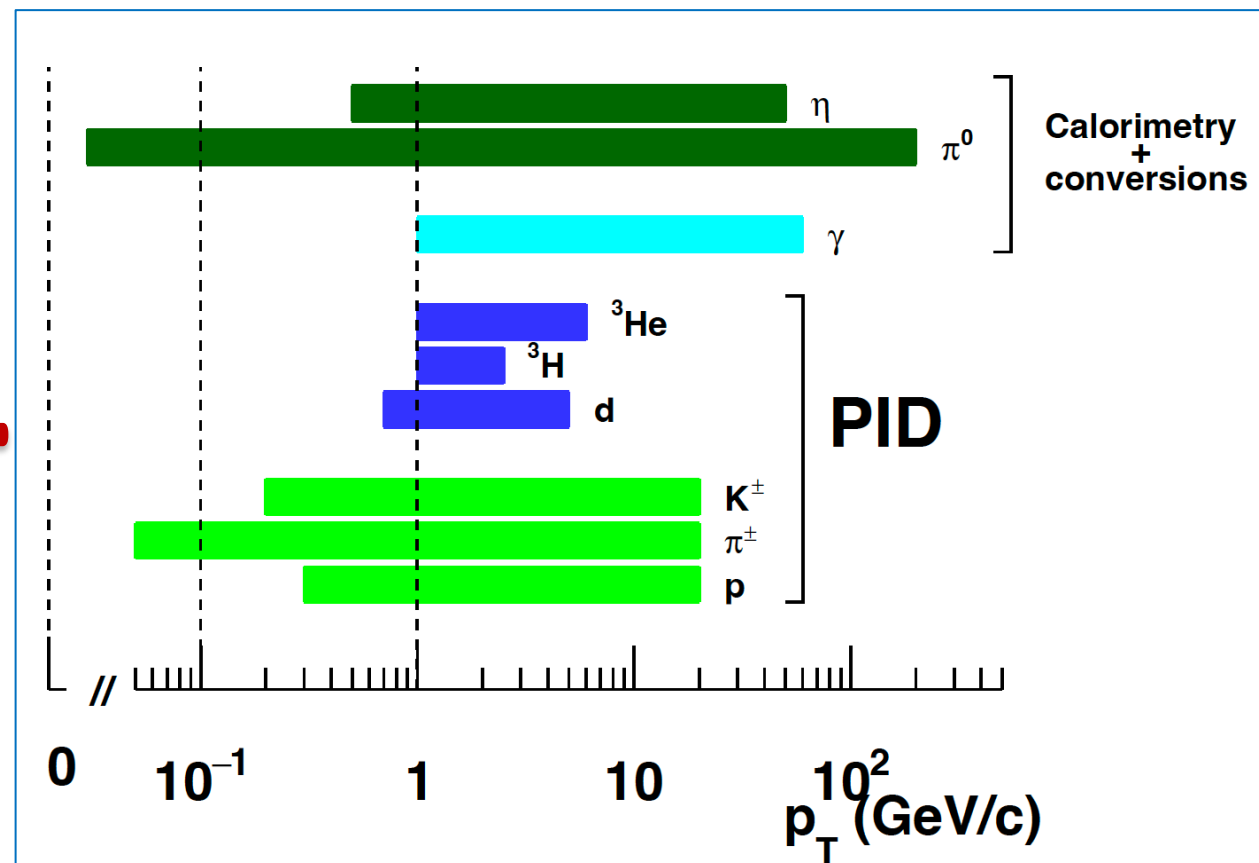
- Letter of Intent: March 2022 arXiv:2211.02491
- Scoping Document: May 2025 CERN-LHCC-2025-002



1. Evolution towards higher pointing resolution and larger effective acceptance

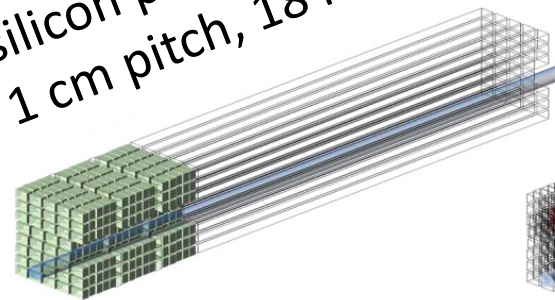


2. Maintain and enhance ALICE's unique capabilities in particle identification down to very low p_T

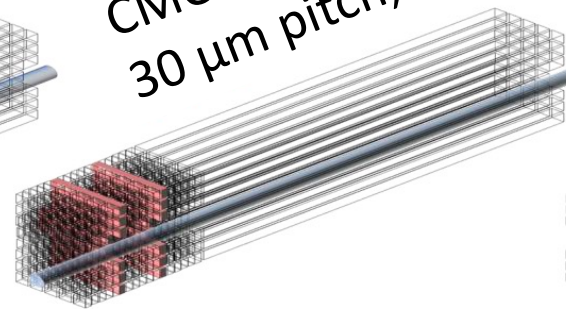


Main physics goal: measurement of forward direct photons in p-Pb collisions → access to gluon densities in Pb down $x < 10^{-5}$ and search for saturation regime of QCD

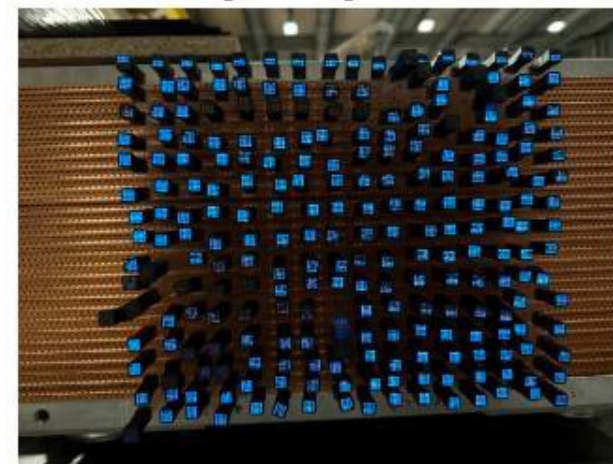
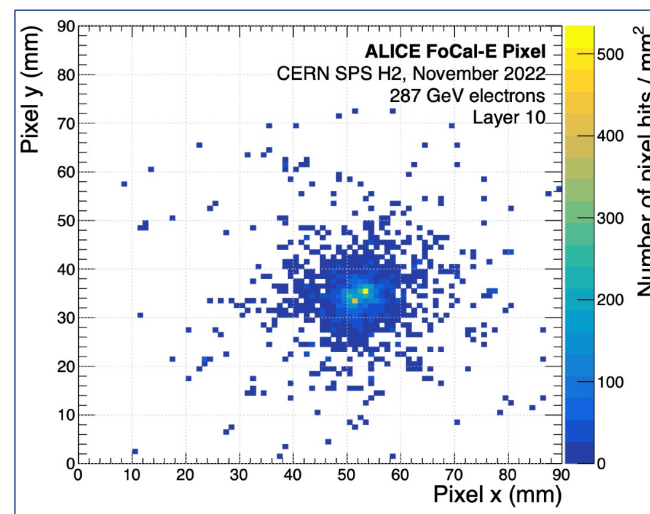
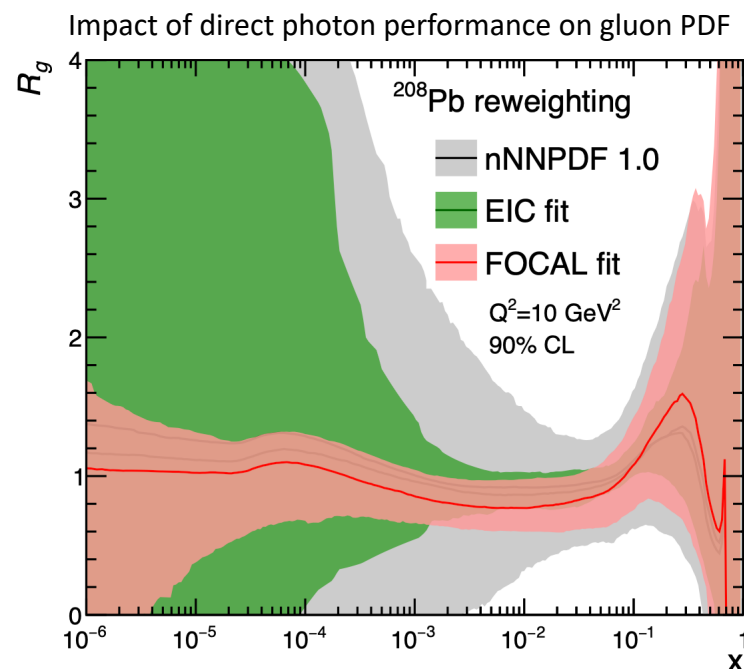
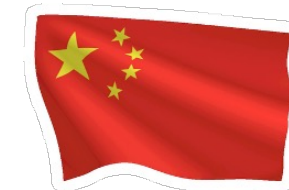
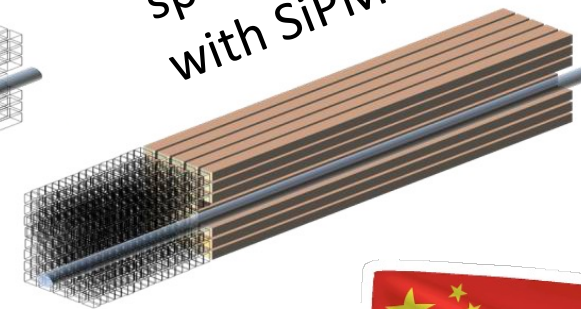
FoCal-E pads
silicon pads,
1 cm pitch, 18 layers



FoCal-E pixels
CMOS-MAPS (ALPIDE)
30 μm pitch, 2 layers



FoCal-H
spaghetti calorimeter
with SiPMs 6x6 mm²



FoCal-H:
Prototype with final design of copper grooved plates, instrumented with sci. fibres, under test using final readout

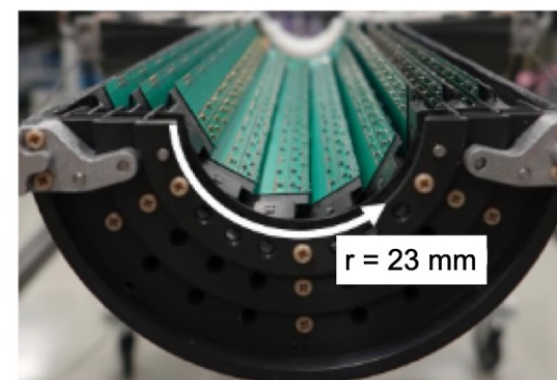
Towards Run 4: ITS3, a truly Cylindrical Inner Tracker



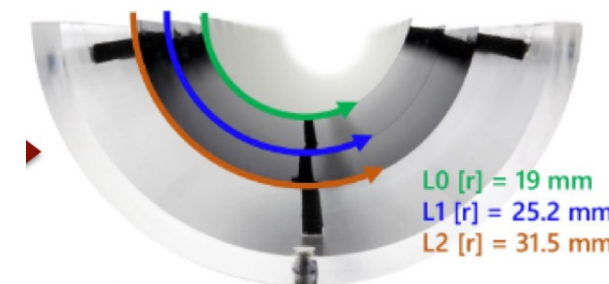
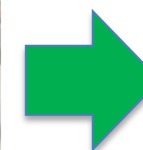
ITS3: replacing the 3 innermost layers of ITS2 with a next-generation vertex detector based on truly cylindrical layers (bent, wafer-scale CMOS sensors)



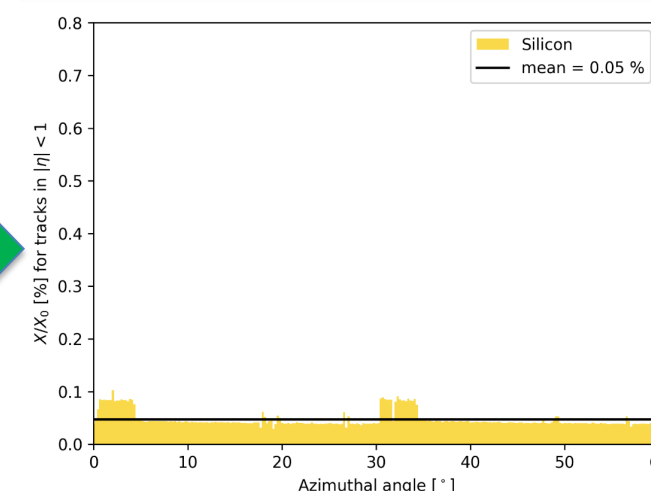
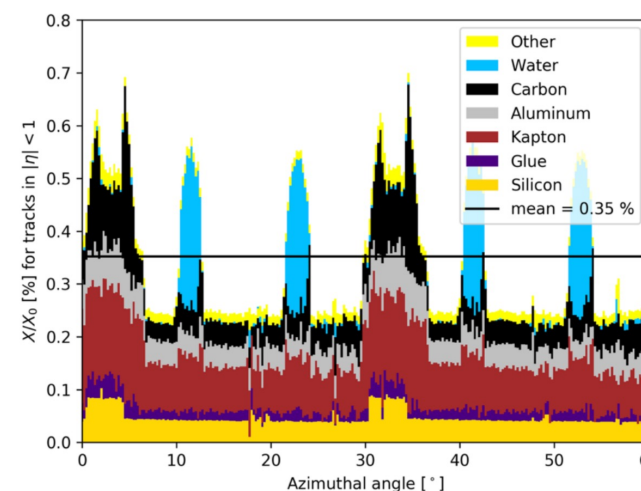
- ❖ **Pointing resolution** $\propto r_0 \cdot \sqrt{x/X_0}$
- ❖ Silicon only contributes to 15 % of the material budget for the ITS2 layers
- ❖ Pointing resolution can be improved by removing material in the first layers
 - Move from water to air cooling
 - Integrate power and data buses on chip
 - Self-supporting structure
- ❖ **Enhanced precision in the identification of HF signals, and rejection of displaced background for prompt signals (e.g. low-mass dielectrons)**



ITS2 Inner Barrel



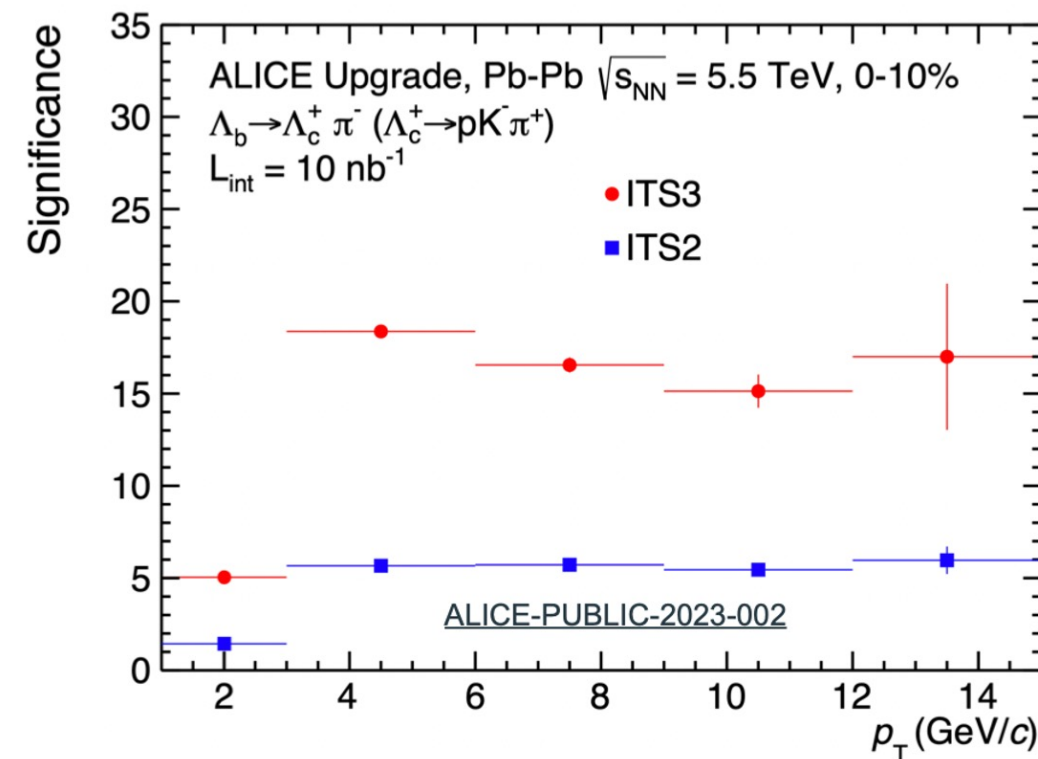
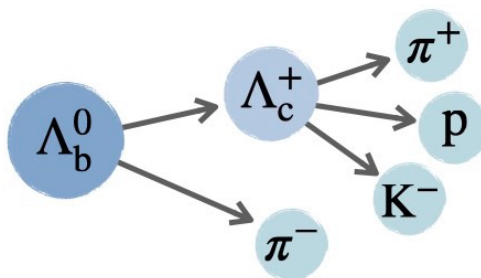
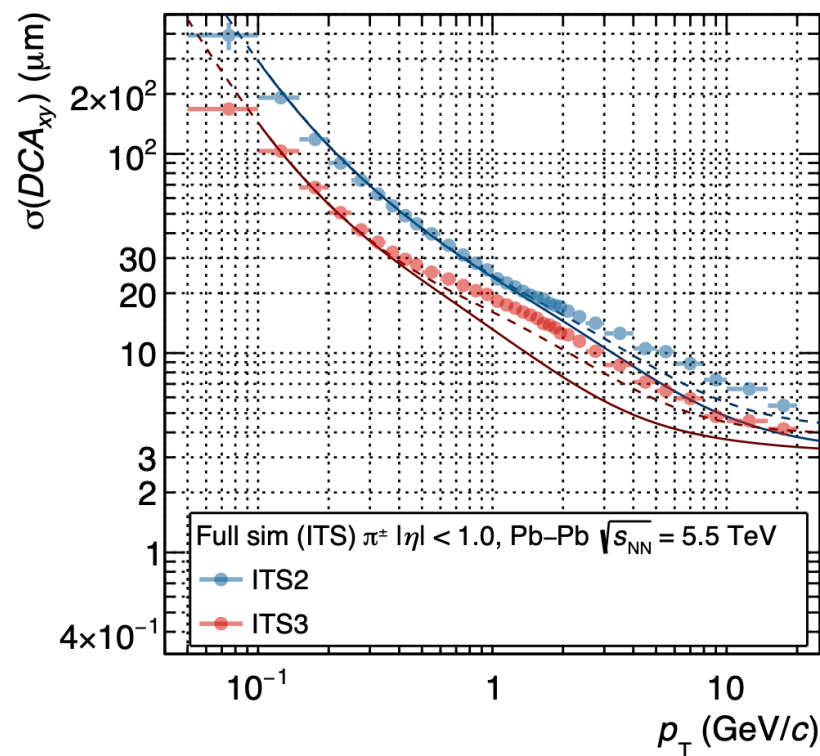
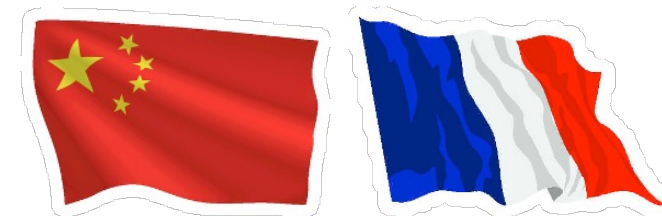
ITS3 Engineering model 1



Towards Run 4: ITS3, a truly Cylindrical Inner Tracker

ITS3 will be lighter and closer to the IP w.r.t. ITS2, improving:

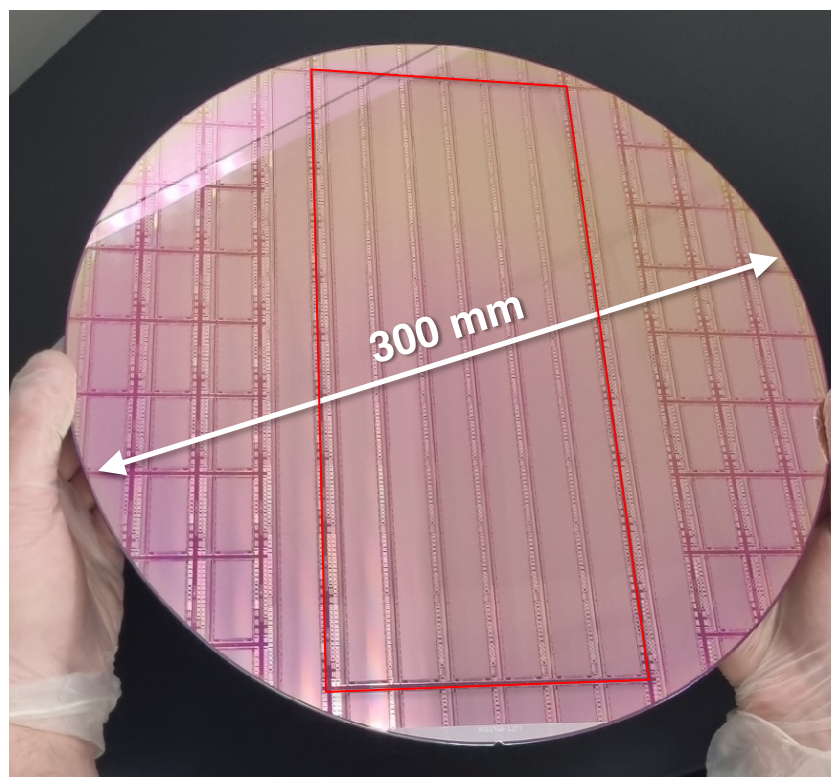
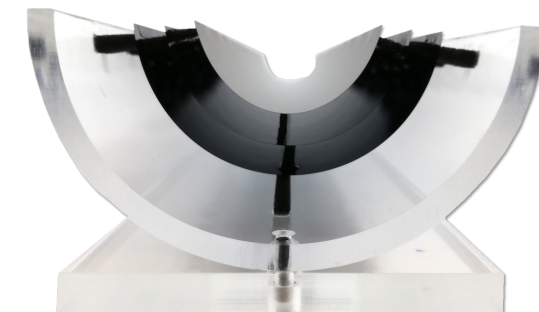
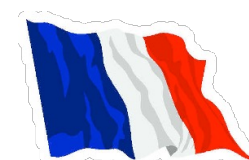
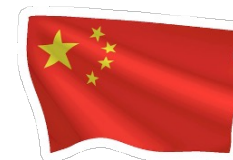
- Low- p_T reach
- Secondary vertex reconstruction
- Combinatorial background rejection: better performance for heavy-flavor and dielectron probes



Towards Run 4: ITS3, a truly Cylindrical Inner Tracker

ITS3 Concept

- 280 mm long sensor ASICs out of 300 mm long stitched wafers (2 halves × 3 layers)
- 50 μm (0.05% X_0), bent shape with $R = 19/25/31$ mm
- Carbon foam ribs to hold ASICs in place + air cooling



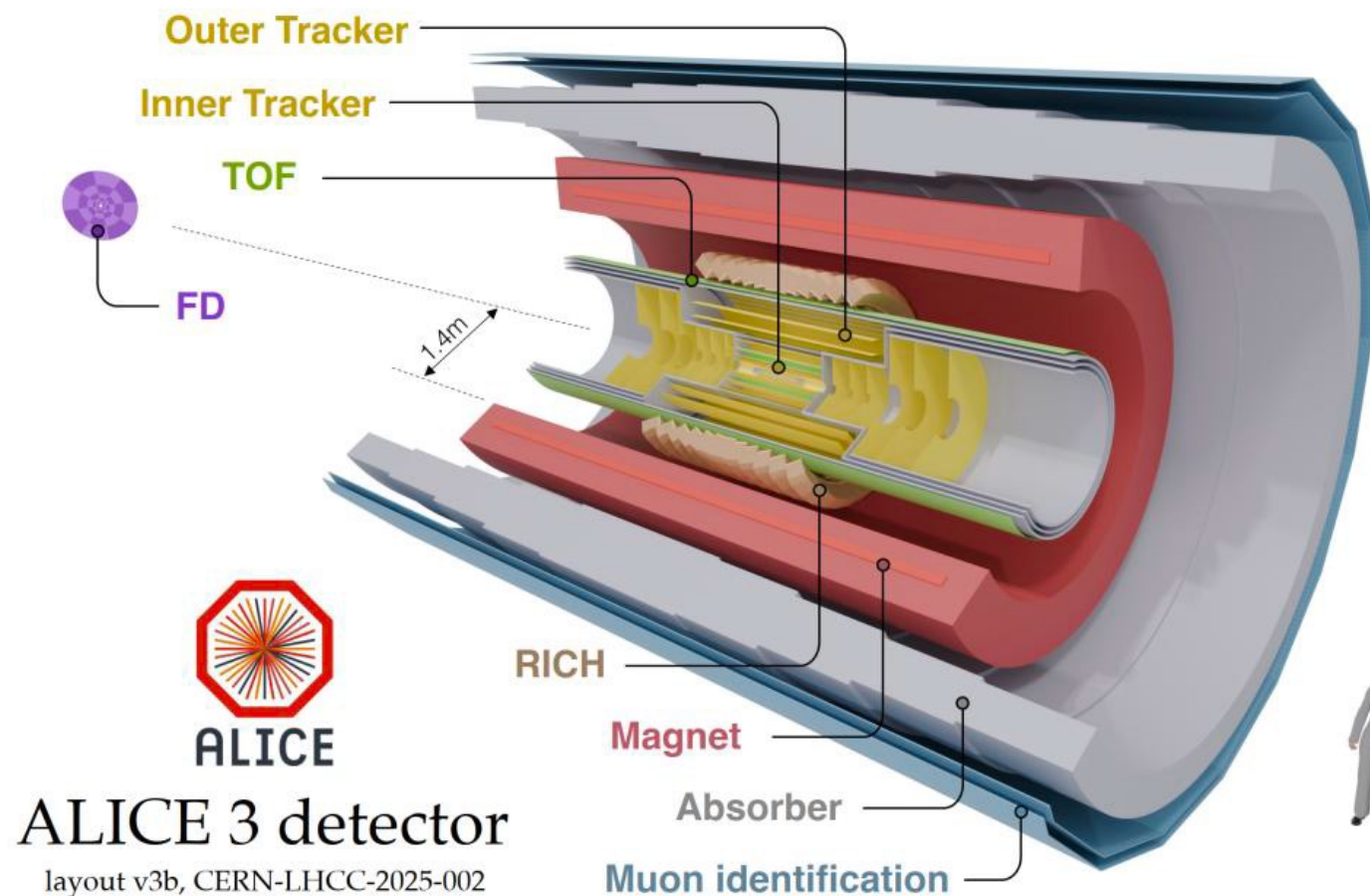
New technology with 65 nm MAPS + stitching + bending. Radiation hardness, low noise

- ❖ **First prototypes of stitched sensors and fully integrated detector modules successfully produced**
- ❖ **Operation of stitched MAPS in beam**
 - Prototypes validated successfully in beam tests
 - Target performances (efficiency > 99% & fake-hit rate < 10^{-6}) are achieved at ALICE radiation levels



ALICE 3: a new Heavy-Ion experiment for Run 5 and beyond

ALICE 3 Scoping Document: CERN-LHCC-2025-002

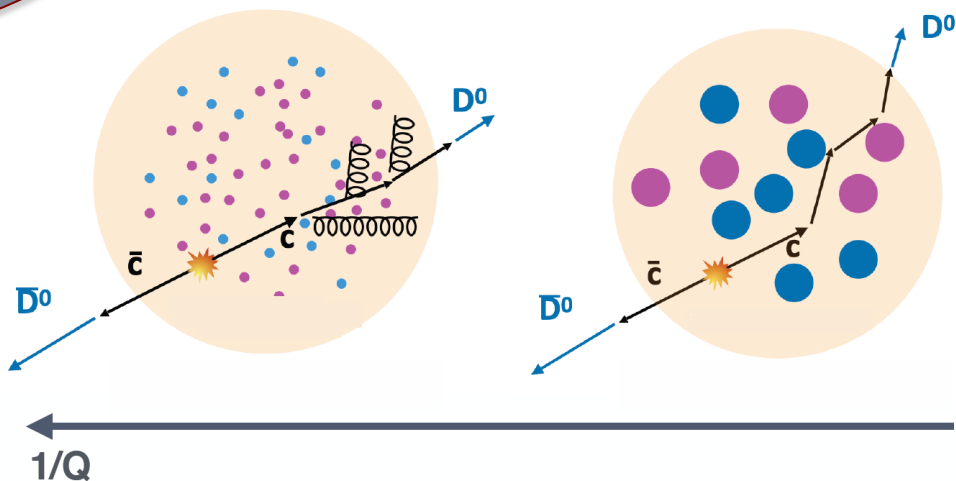


Selected physics case (LoI: CERN-LHCC-2022-009):

- Understanding thermalization and hadronization in QGP → beauty and (multi-)charm hadrons
- Access to QGP temperature vs. time → Precision measurement of dileptons
- Fundamental aspects of the QCD phase transition → chiral symmetry restoration: di-electron mass spectrum
- Laboratory for hadron physics → hadron-hadron interaction potential, exotic hadrons

- ❖ Compact and ultra-light all-silicon tracker with large acceptance and high-resolution vertex detector
- ❖ Superconducting magnet system
- ❖ Particle identification down to vanishing p_T over 5 units of pseudorapidity
- ❖ Fast readout and online processing

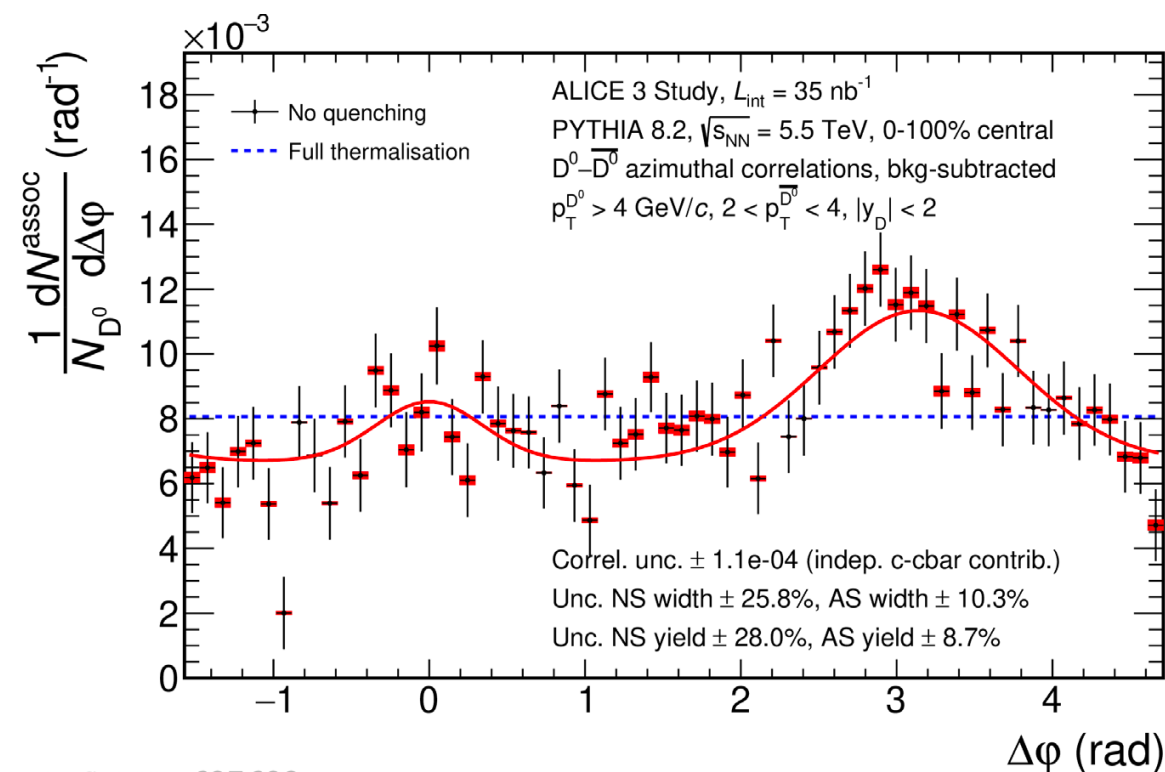
ALICE 3: HF Transport in the QGP



Goal: measure angular (de)correlations — direct probe of HF interaction with the QGP

- ❖ Very challenging measurement: need good purity, efficiency and η coverage
- ❖ Heavy-ion measurement at low p_T only possible with ALICE 3

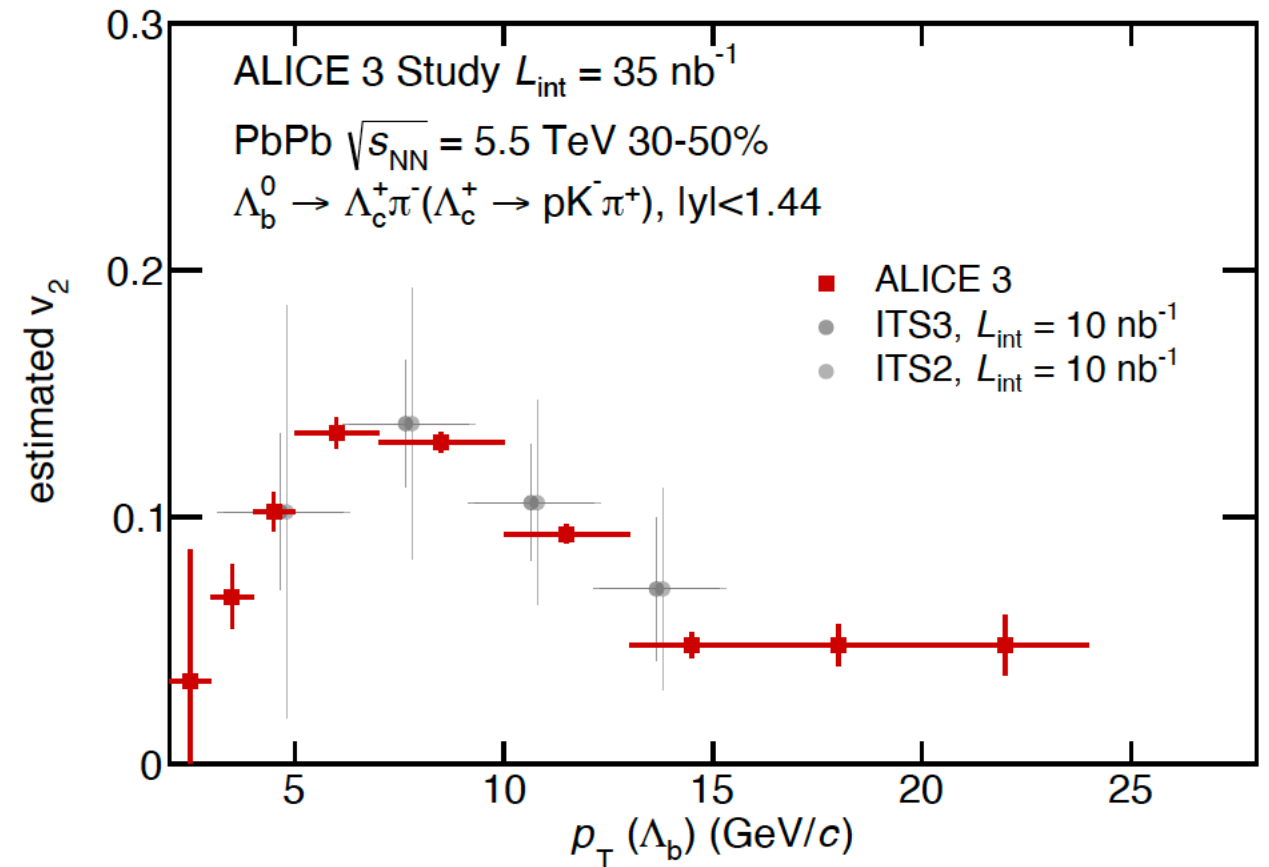
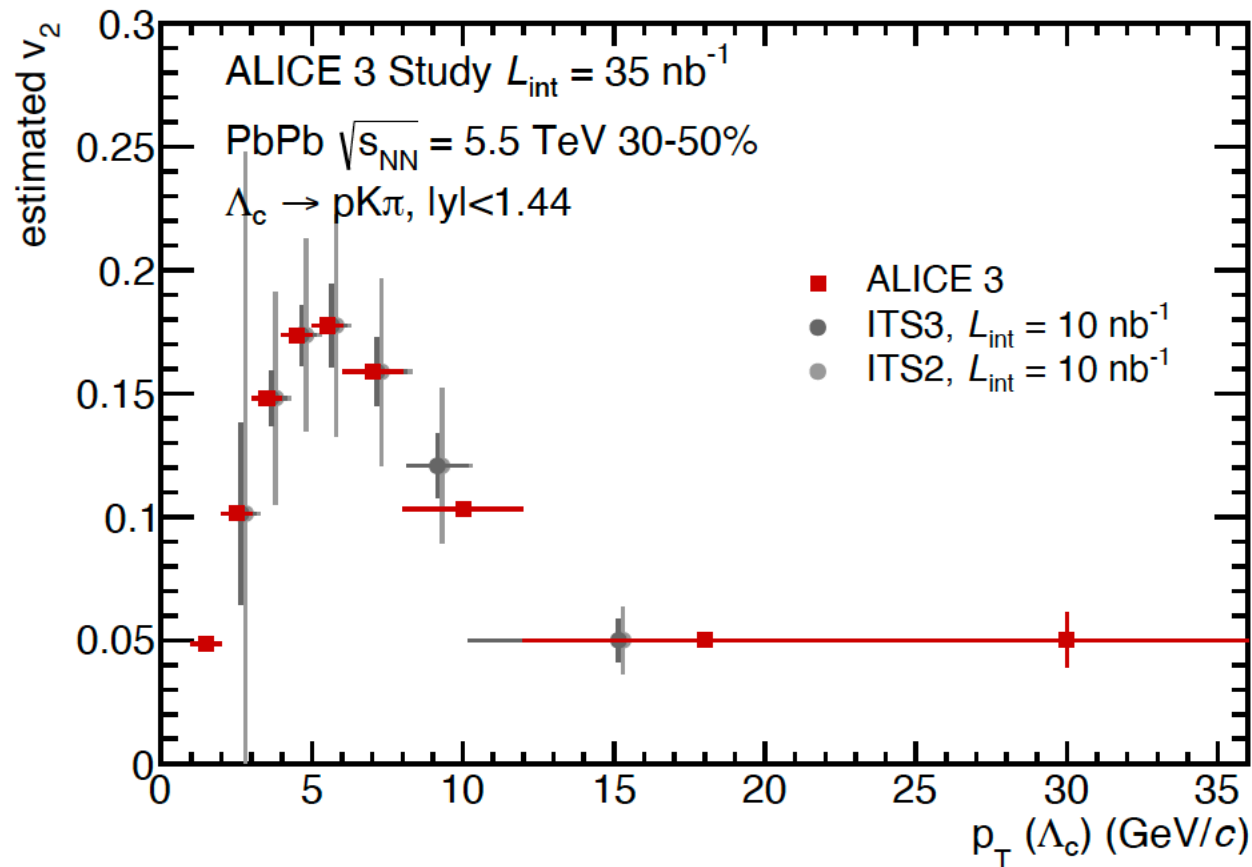
- ❖ Insight on the relative importance of the **different energy loss mechanisms** as a function of p_T
- ❖ Shed light on the quasi-particle nature of the QGP at different momentum scales
- ❖ In the limit of **full thermalisation**, the flight direction of the charm quarks would be **fully randomized**, and no remnant of the initial correlation would be visible

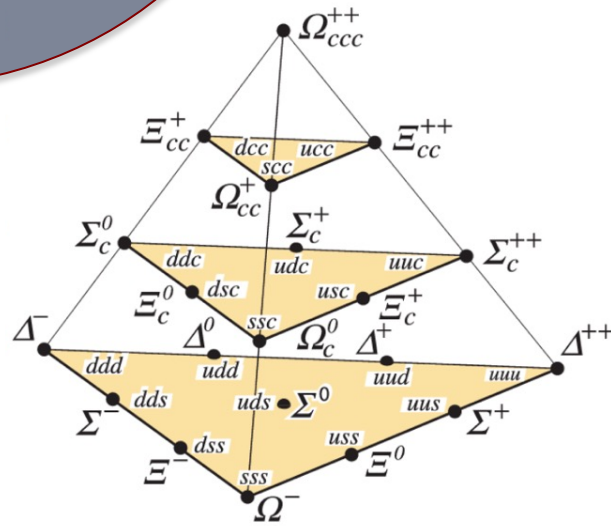


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Goal: disentangle effects of quark transport and hadronization

- Expect beauty thermalization slower than charm — does this affect hadronization?
- First measurements of Λ_b coupling to hydrodynamic flow (via v_2 parameter) in Run 3 and 4
- Need ALICE 3 performance for precision measurement





❖ Multi-charm baryons (almost pure coalescence hadrons) → **discrimination power on the role of the various hadronization mechanisms**

❖ In heavy-ion collisions at the LHC, large increase of multi-HF baryons (≈ 1000) expected via coalescence **with charm quarks from different hard scatterings ($N_c \approx 100$ in central Pb-Pb)**

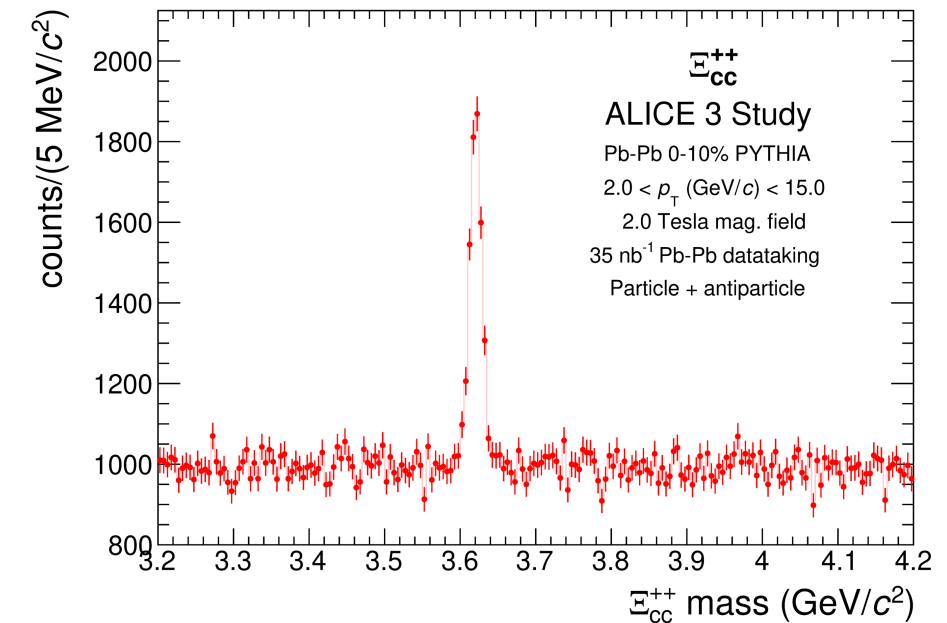
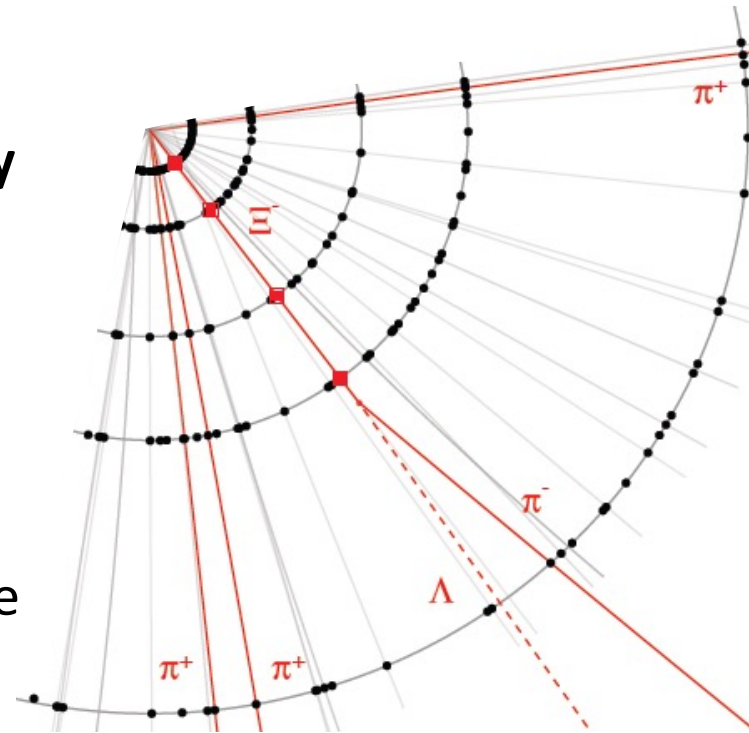
❖ Challenging reconstruction of decay cascades, e.g.

$$\Xi_{cc}^{++} \rightarrow \Xi_c^{+} + \pi^{+}$$

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

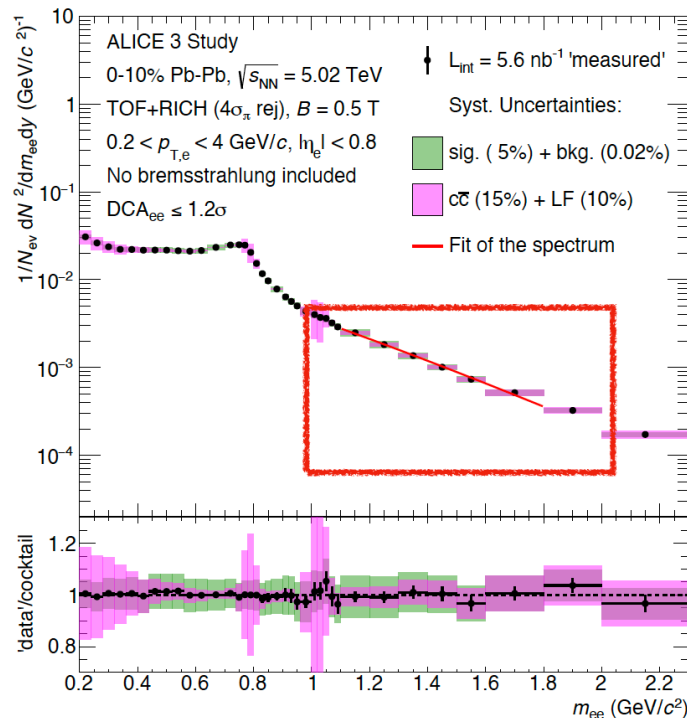


Strangeness tracking: detecting the strangeness part of the cascade in the innermost tracking layers

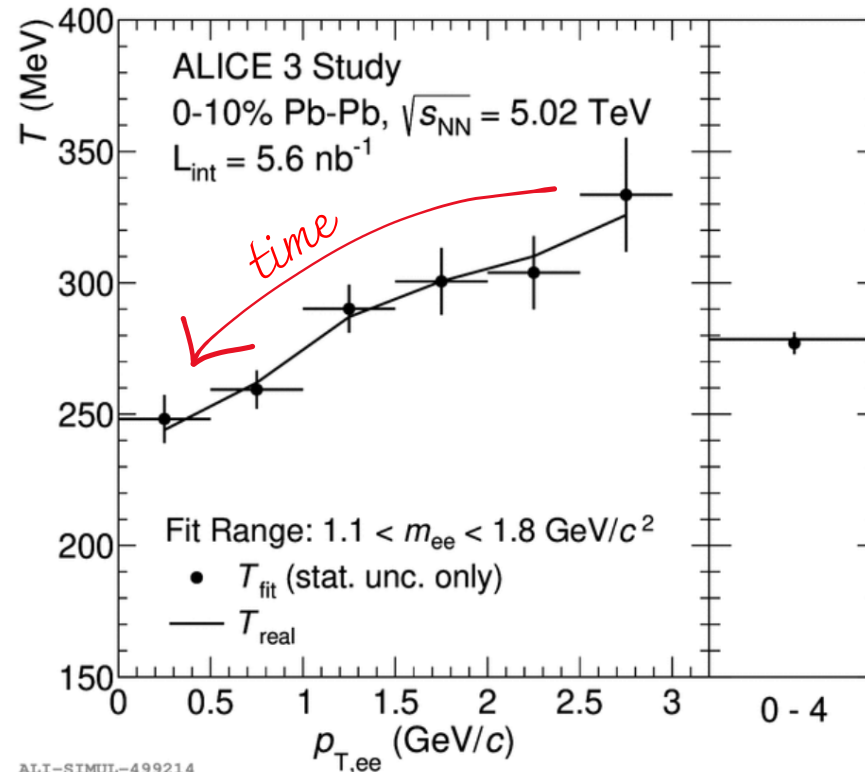


- ❖ Precision measurement of dielectrons as a function of mass and p_T
- ❖ Excellent precision for dilepton v_2 vs p_T in different mass ranges $\rightarrow$ time evolution of emission
- ❖ Improved pointing resolution $\rightarrow$ significant reduction of charm contribution and associated uncertainty: unique opportunity at the LHC

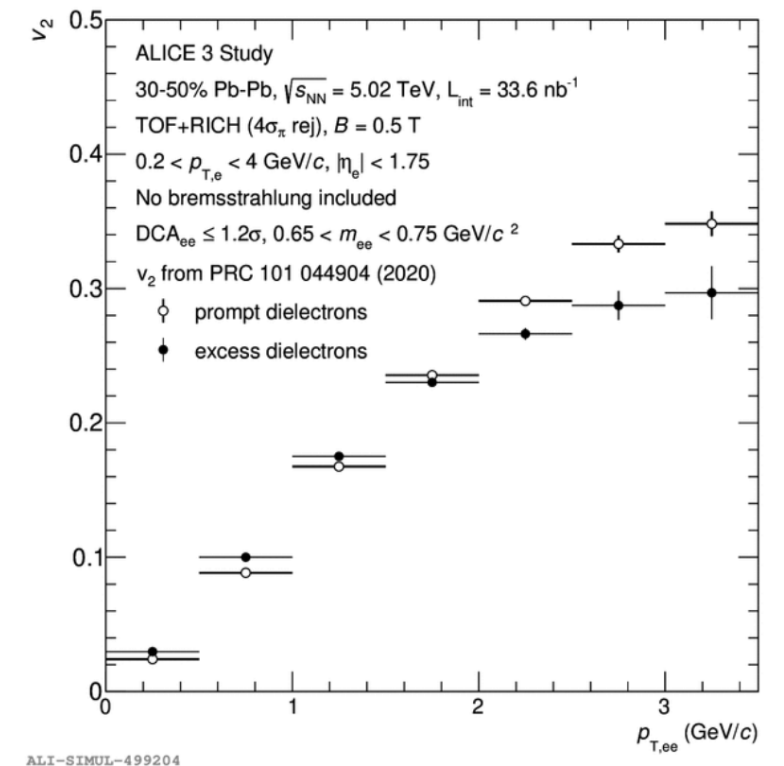
Dielectron mass distribution

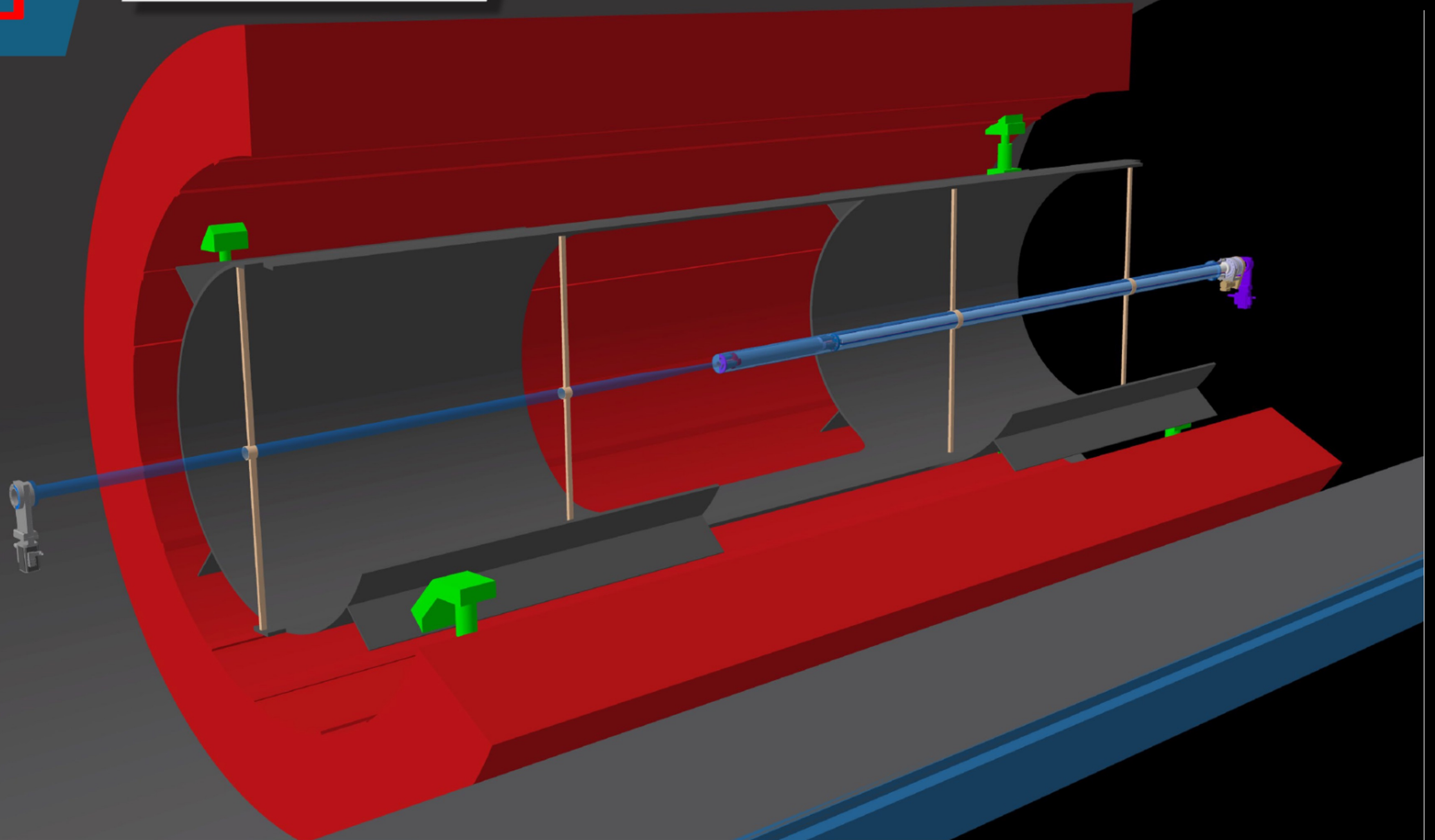


Temperature from slope (M_{ee})



Dielectron v_2

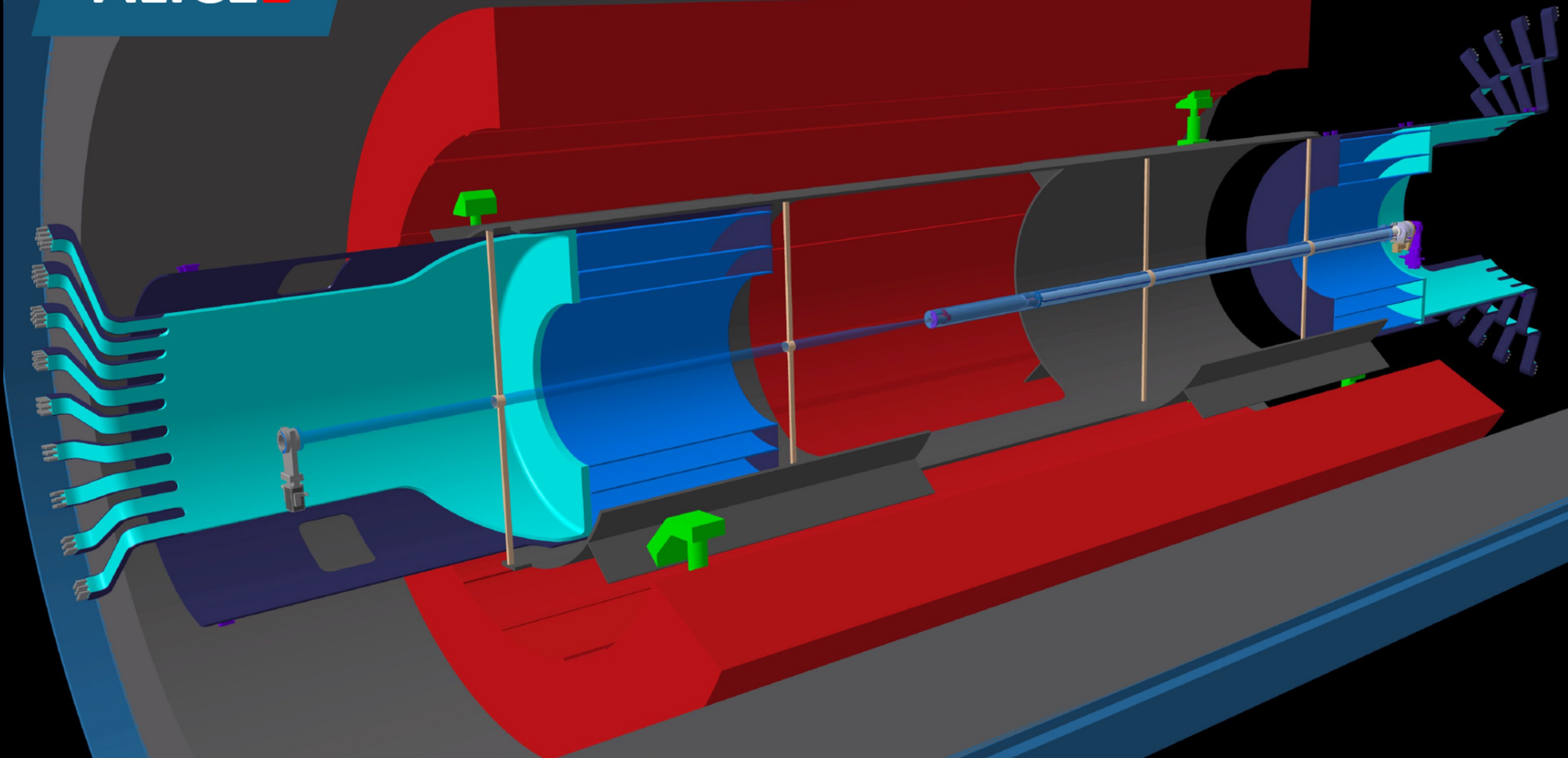




The beampipe central section, containing IRIS, is hold by the Spaceframe (same approach as ALICE2)

ALICE3

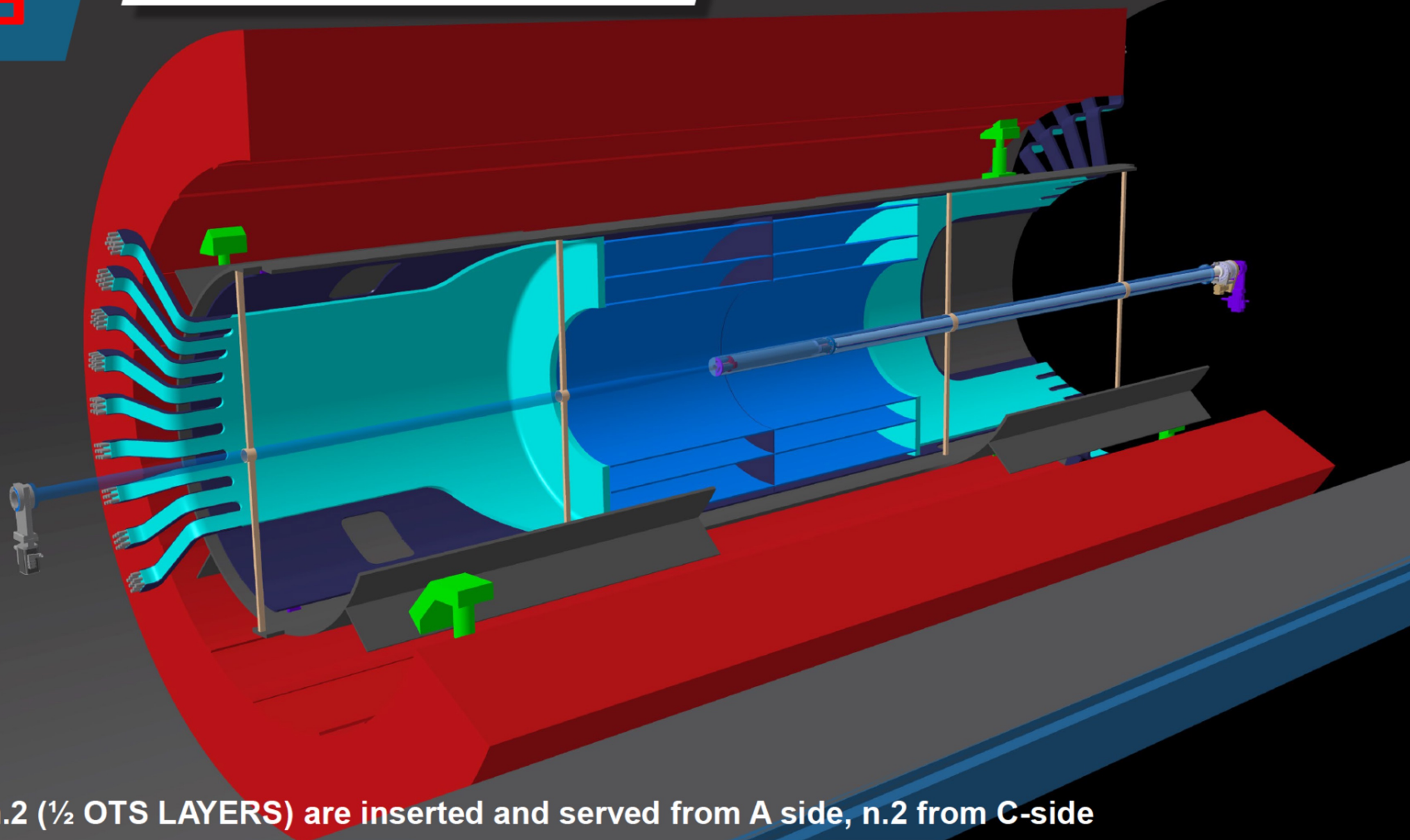
OUTER TRACKER LAYERS



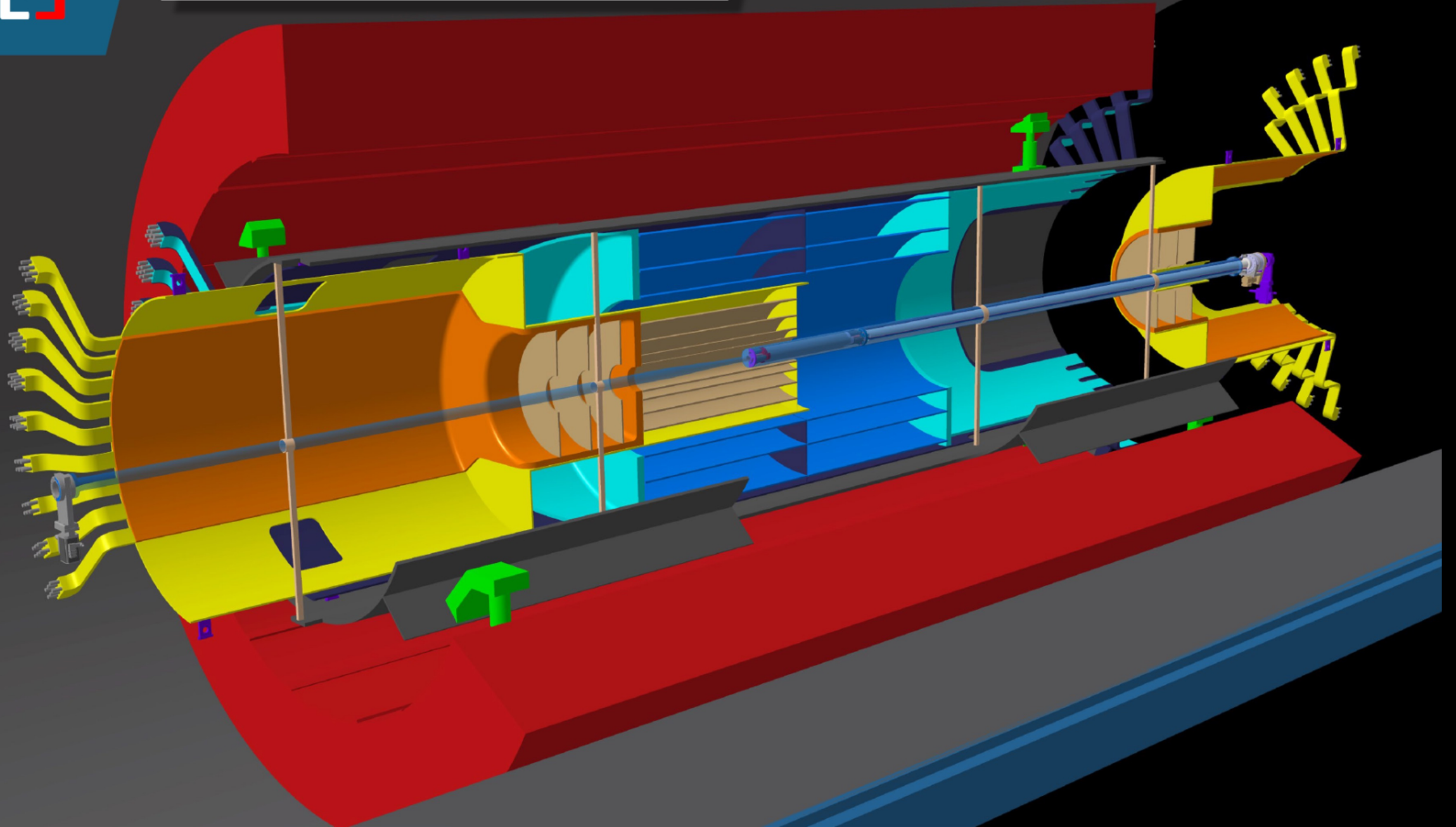
n. 2 ($1\frac{1}{2}$ OTS LAYERS) are inserted and served from A side, n. 2 from C-side

ALICE3

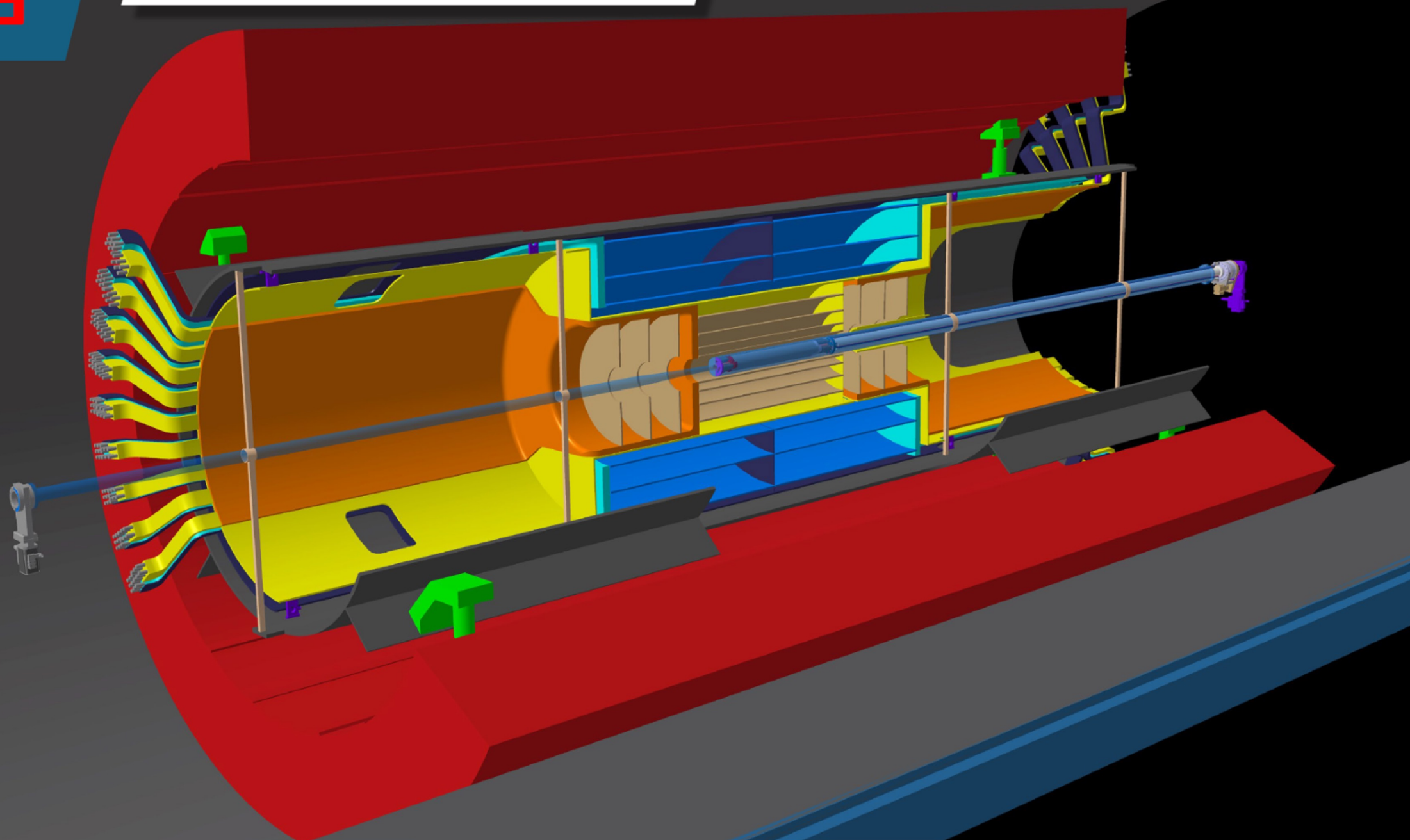
OUTER TRACKER LAYER



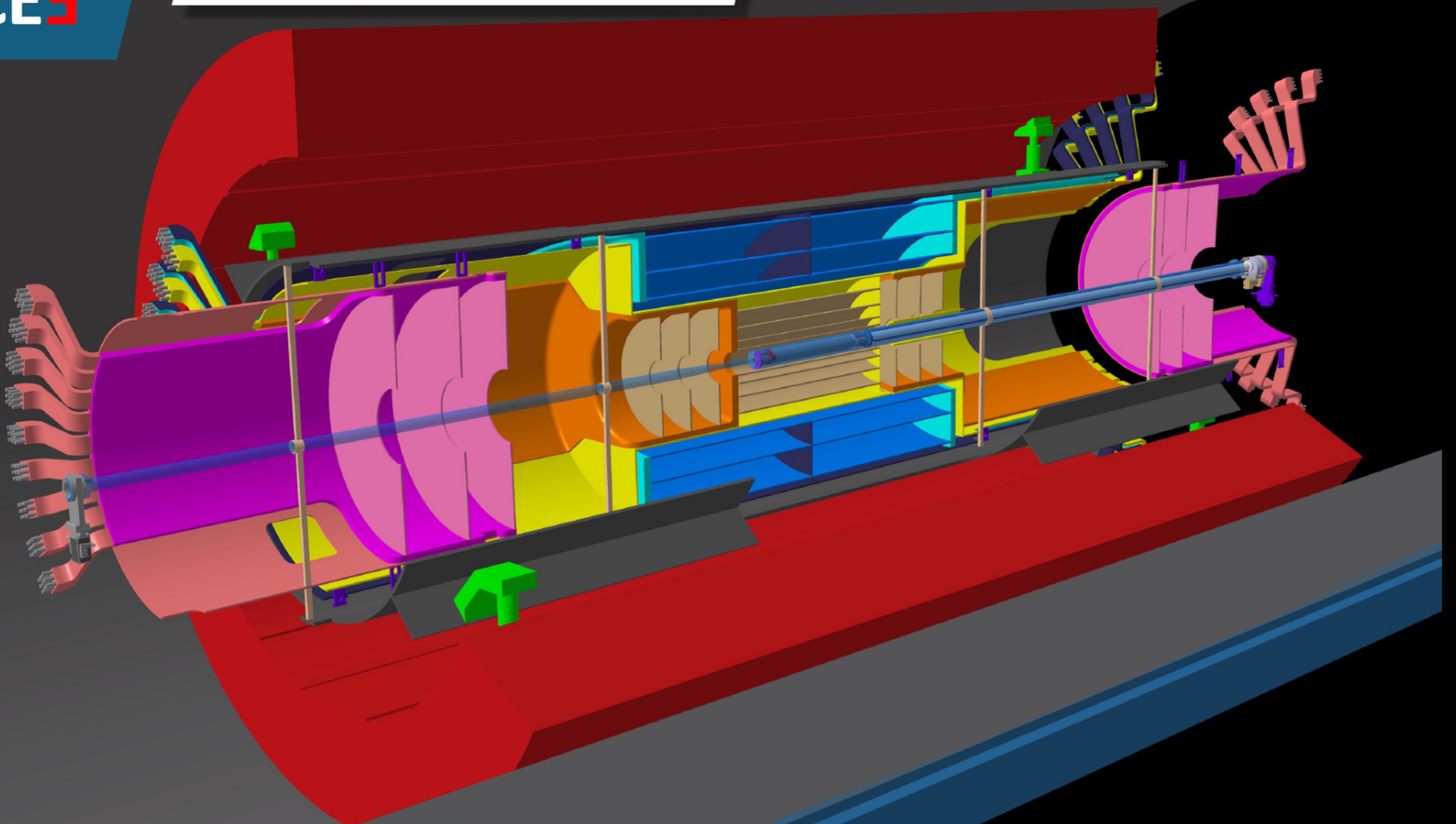
n.2 (1/2 OTS LAYERS) are inserted and served from A side, n.2 from C-side



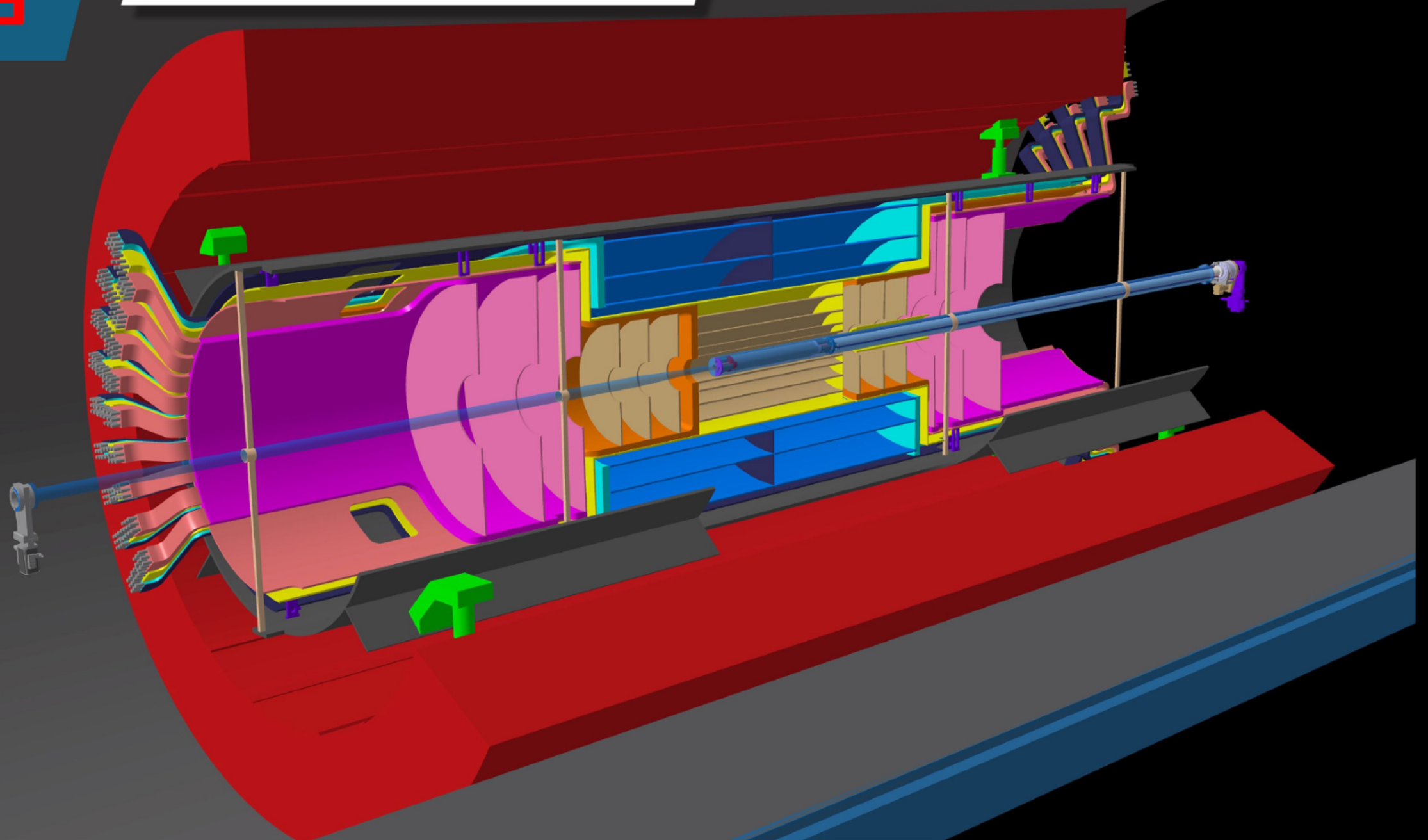
n. 2 ($\frac{1}{2}$ ITS LAYERS+ $\frac{1}{2}$ DISKS) are inserted and served from A side, n. 2 (ITS $\frac{1}{2}$ DISKS) are inserted from C-side



n.2 ($\frac{1}{2}$ ITS LAYERS+ $\frac{1}{2}$ DISKS) are inserted and served from A side, n.2 (ITS $\frac{1}{2}$ DISKS) are inserted from C-side



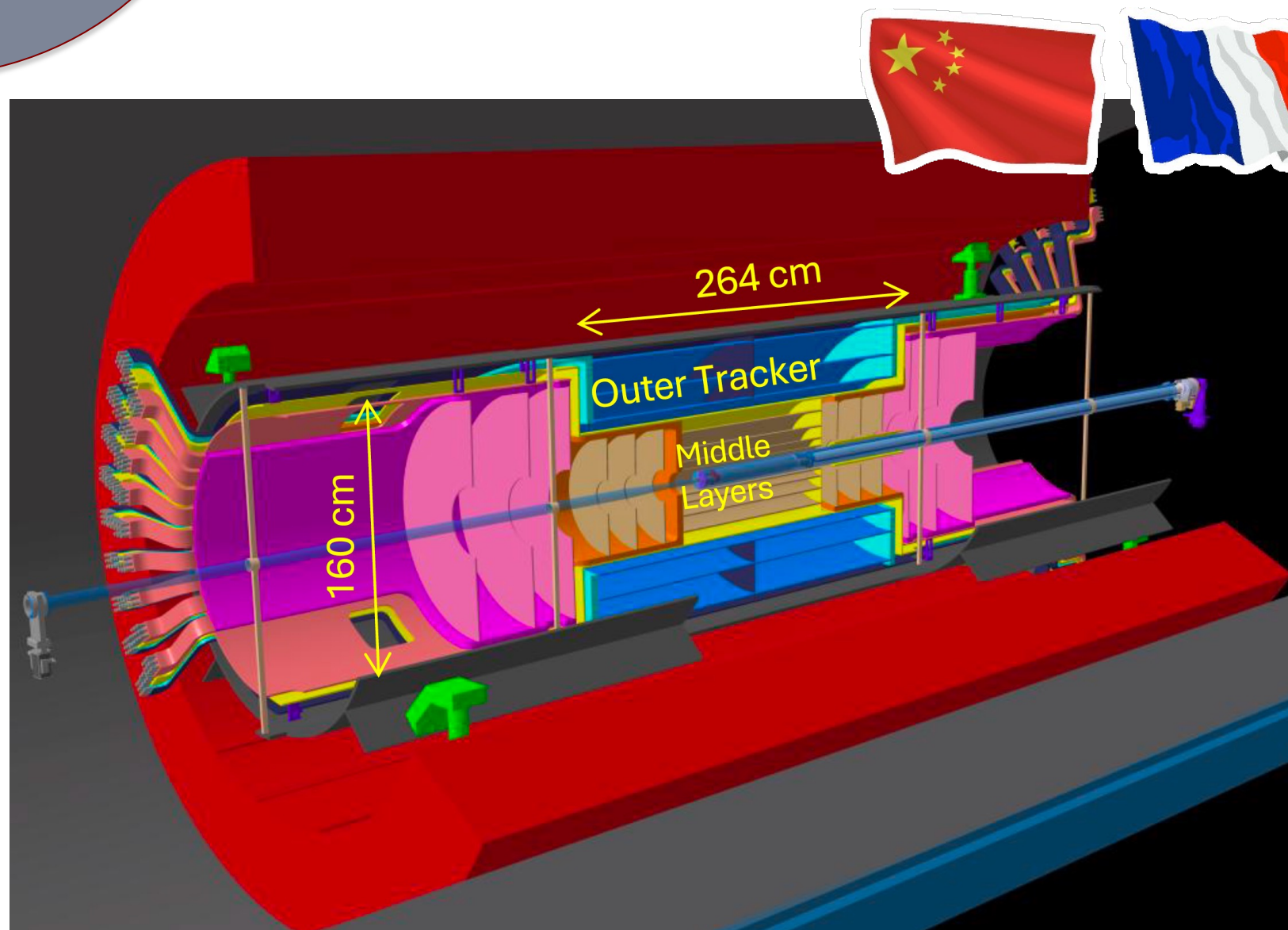
N.2 ($\frac{1}{2}$ OTS DISKS) are inserted and served from A side, 2 from C-side



n.2 ($\frac{1}{2}$ OTS DISKS) are inserted and served from A side, n.2 from C-side



ALICE3 Middle and Outer Tracker



47 m² of MAPS, $\pm 2.5 \eta$

- High spatial resolution: $\approx 10 \mu\text{m}$
- Very low material budget: $\approx 1\% X_0/\text{layer}$
- Time resolution: 100 ns, low power consumption: 20 mW/cm²
- Hit rates up to 0.5 MHz/cm²

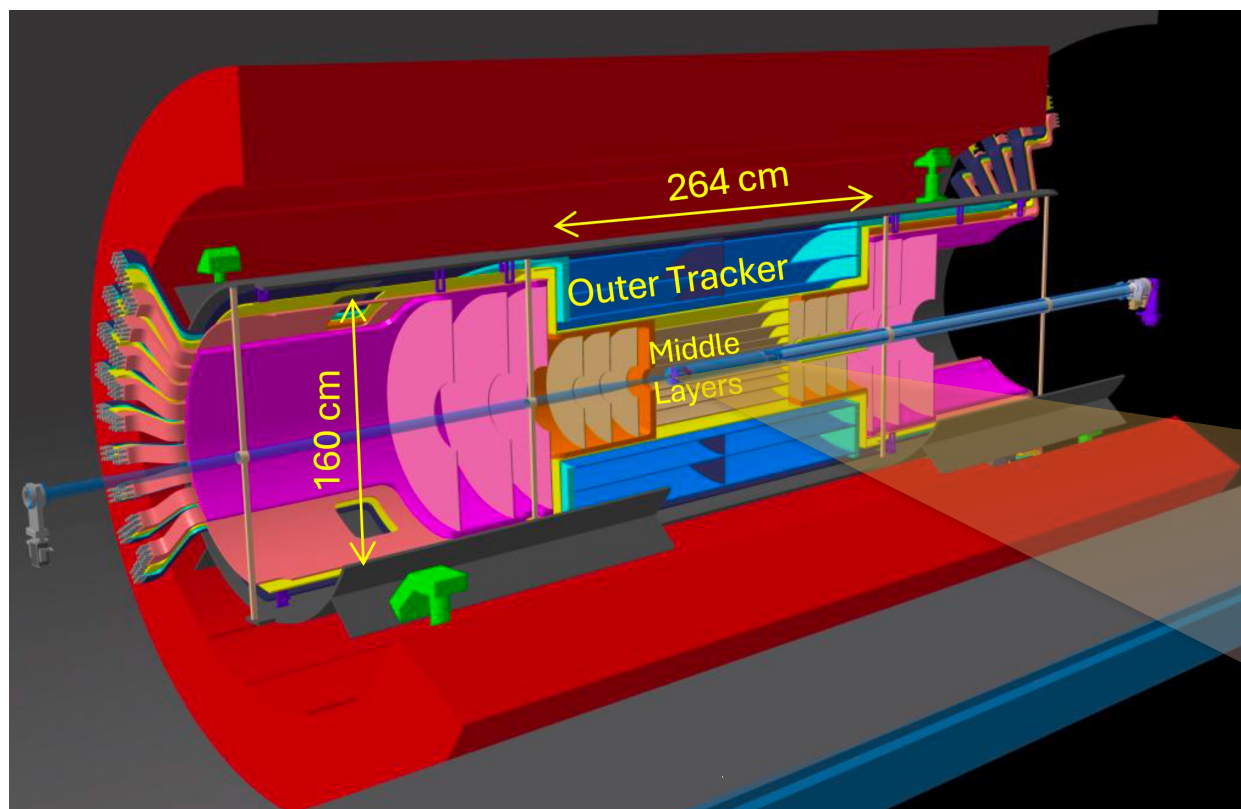
Main R&D challenge: its size

- ❖ power consumption and distribution
- ❖ module design for industrial production

Largely leverages ITS2 and ITS3

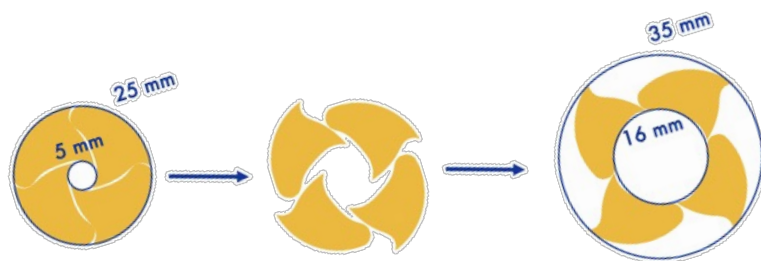
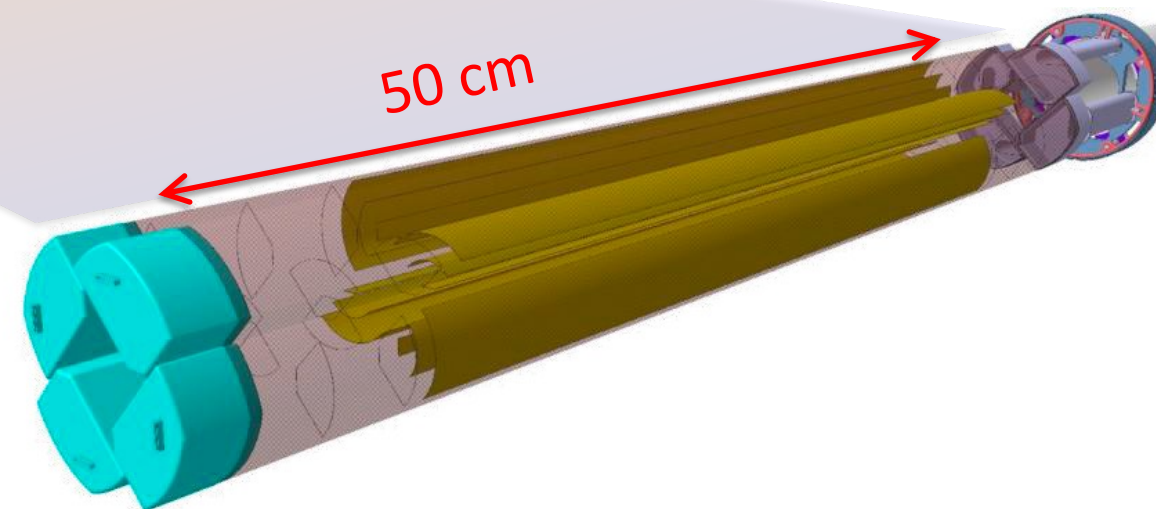


ALICE3 Vertex Detector



Wafer-scale, truly cylindrical MAPS

- Radial distance from interaction point: 5 mm (inside beampipe, retractable configuration)
- Unprecedented spatial resolution $\approx 2.5 \mu\text{m}$
- Ultra-light, material budget $\approx 0.1\% X_0/\text{layer}$
- Time resolution: 100 ns, low power: 70 mW/cm²
- Hit rates up to 94 MHz/cm²

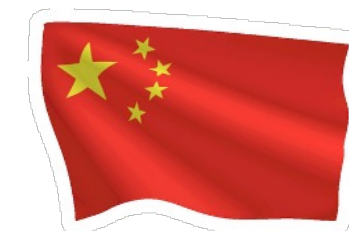
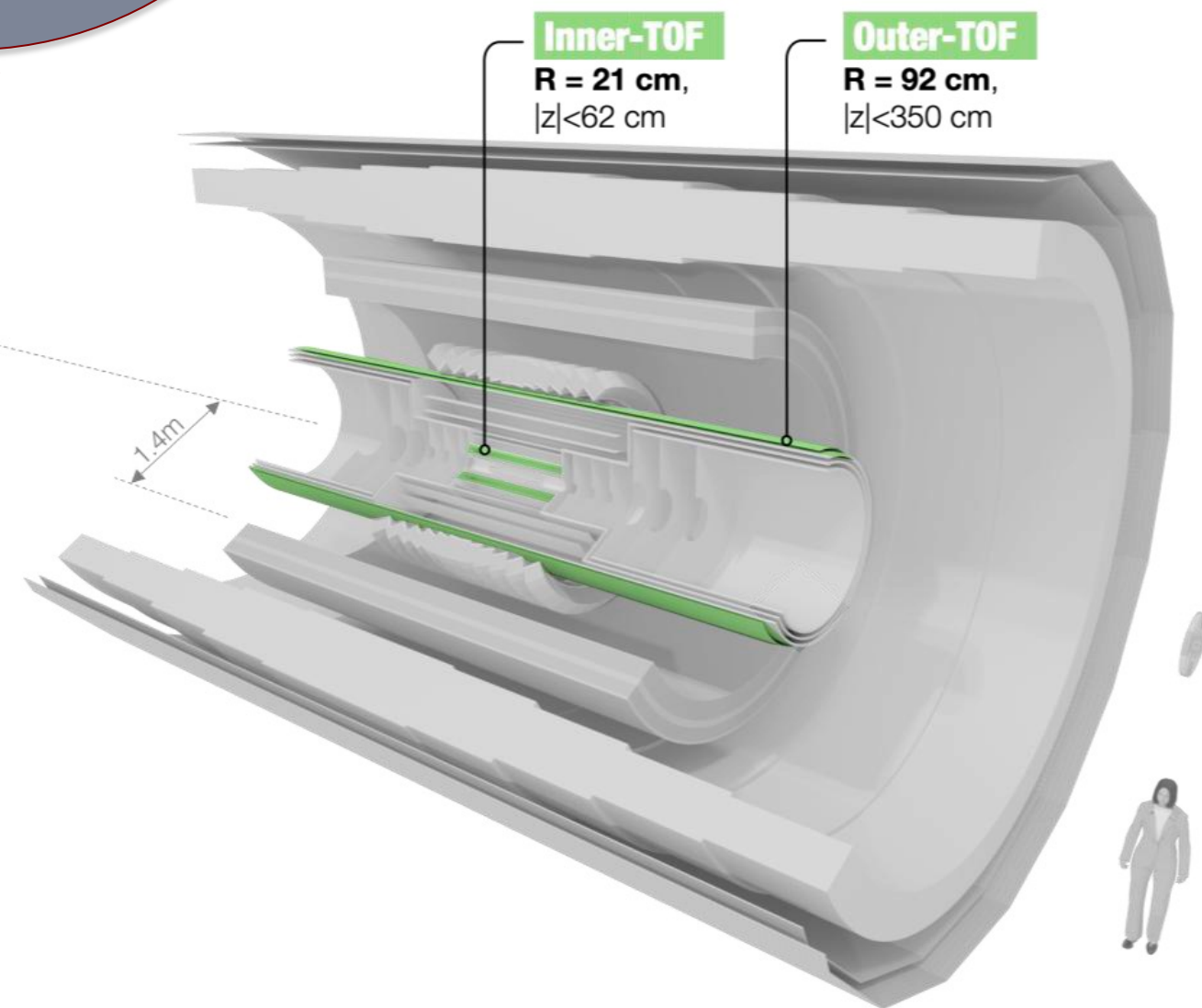


IRIS Vertex Detector
(in secondary vacuum
inside beam the pipe)



ALICE

TOF Detector



39 m² area coverage, $\pm 2.0 \eta$

- Monolithic CMOS-LGAD
- Material budget $X/X_0 \approx 1\text{-}3\%$
- Pitch: $1 \times 1 \text{ mm}^2$
- Power : 200 mW/cm^2
- **Target time resolution: 20 ps**
- Radiation load:
 - ✓ inner TOF $6.1 \cdot 10^{12} \text{ 1 MeV } n_{\text{eq}}/\text{cm}^2$
 - ✓ outer TOF $9 \cdot 10^{11} \text{ 1 MeV } n_{\text{eq}}/\text{cm}^2$

Main R&D direction: **Novel monolithic CMOS-LGAD**

- MadPix sensor prototype (LFoundry 110 nm CMOS), $250 \times 100 \text{ mm}^2$ pixel, $48 \mu\text{m}$ thick, gain 10-20 $\rightarrow \sigma_t \approx \mathbf{72 \text{ ps}}$
- New sensors from “Short-loop ER” thinned to $15 \mu\text{m}$, just delivered; expected to approach **20 ps**

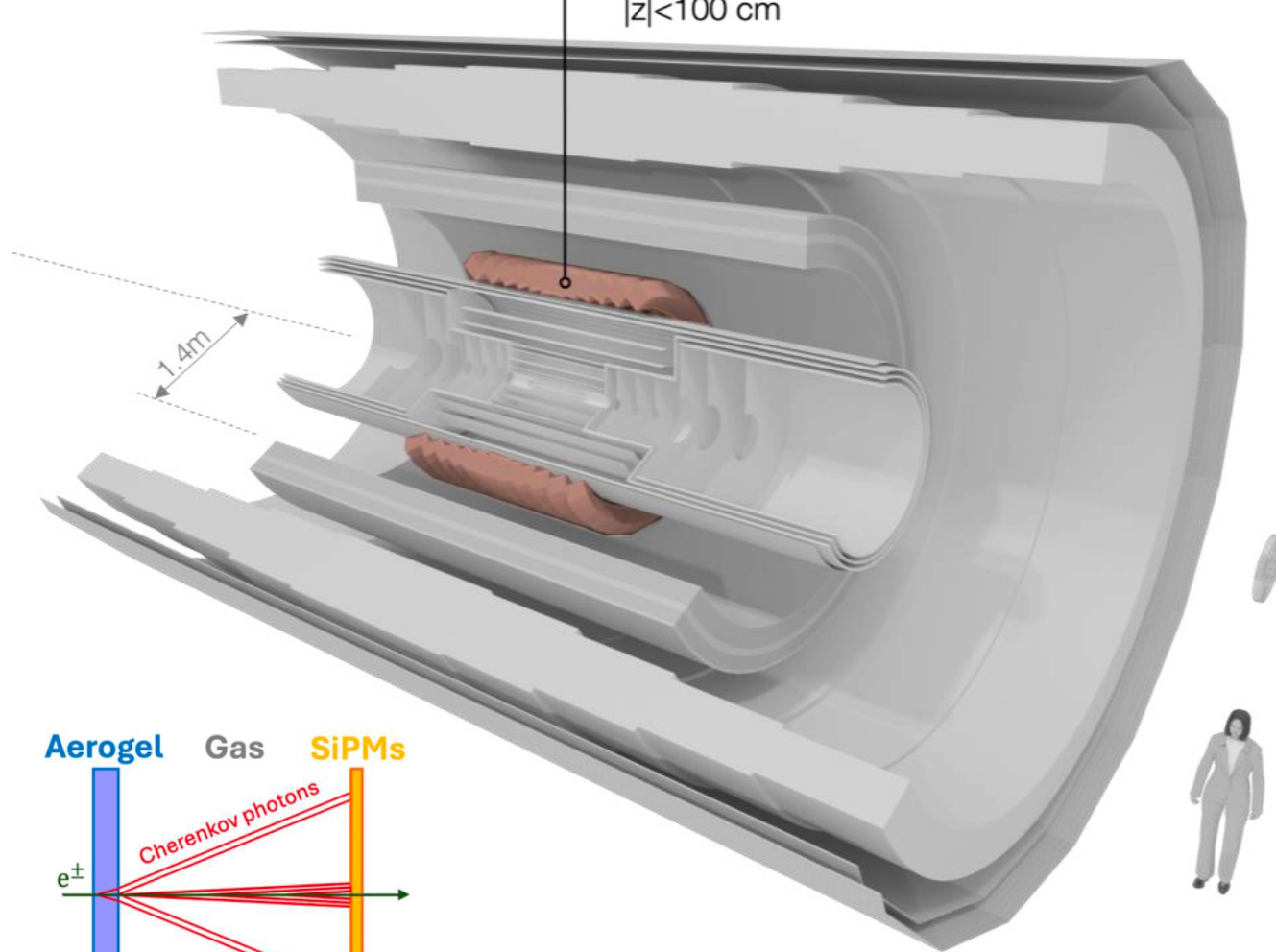


ALICE

The RICH Detector

RICH

R = 100-136 cm,
|z| < 100 cm



10.4 m² area coverage, $\pm 0.8 \eta$

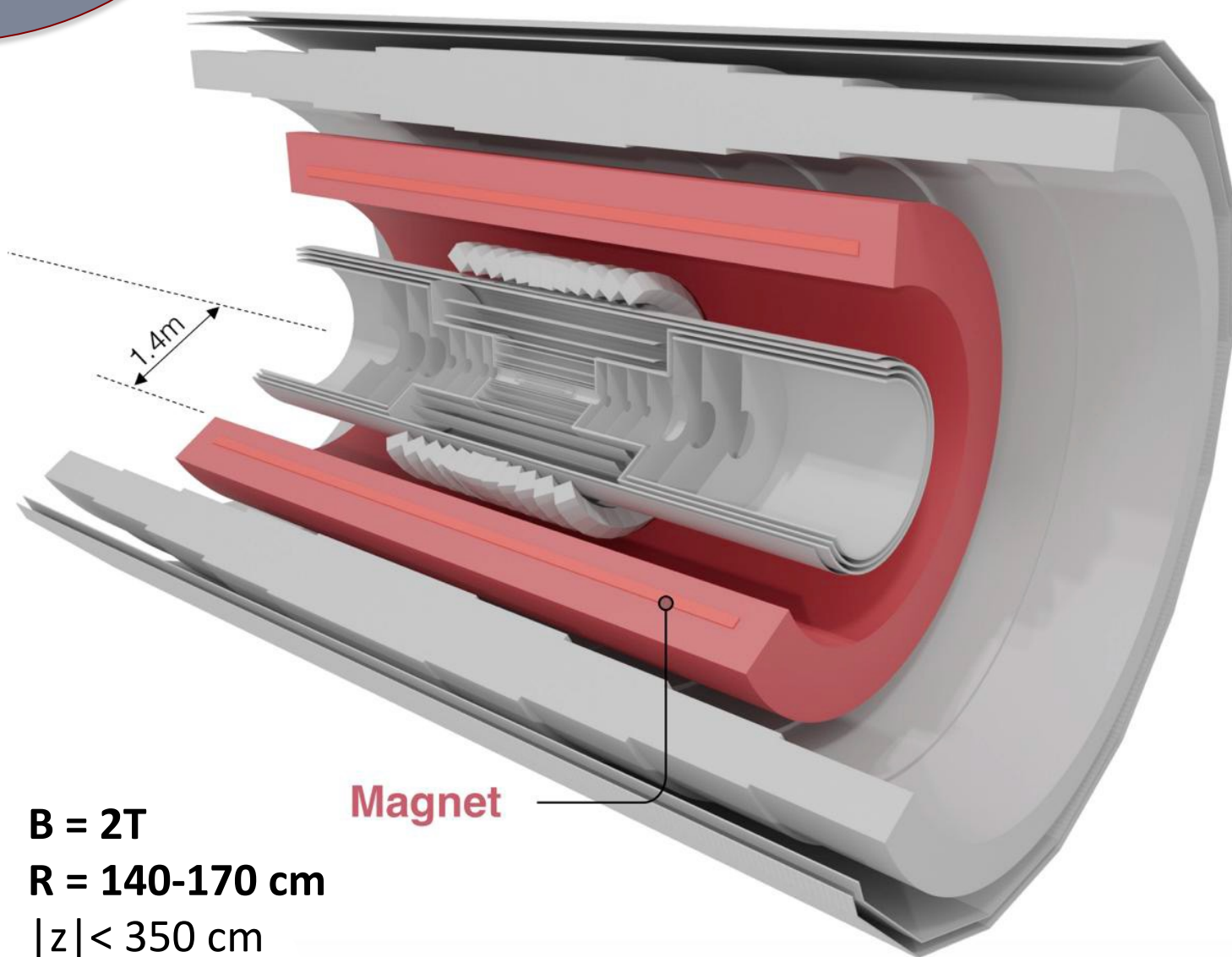
- Photo-detector: SiPM, pitch $2 \times 2 \text{ mm}^2$
- Cherenkov radiator: aerogel $n = 1.03$, gas $n = 1.006$
- Cherenkov angle resolution $\approx 1.5 \text{ mrad}$
- Time resolution $< 100 \text{ ps}$
- Radiation load: $8.3 \cdot 10^{11} \text{ 1 MeV } n_{\text{eq}}/\text{cm}^2$
- FEE ASIC: DENEb (synergy with DUNE)

Main R&D challenge

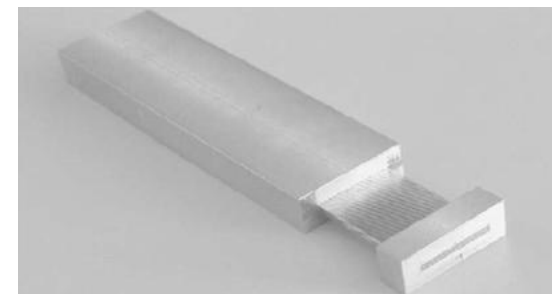
- Radiation tolerance of SiPMs (Dark Count Rate DCR $< 1 \text{ MHz/mm}^2$)



Superconducting Magnet



$B = 2\text{T}$
 $R = 140\text{-}170\text{ cm}$
 $|z| < 350\text{ cm}$

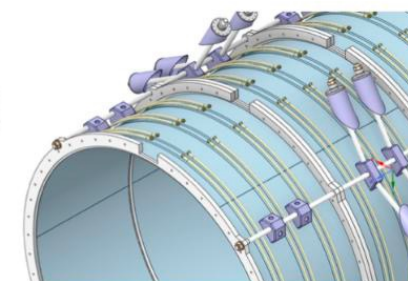


**Baseline
conductor:
Aluminum-
cladded Nb-Ti**

**CNPEM Institute (Brasil) leading the design
of the magnet** in collaboration with ALICE
Technical Coordination, CERN EP R&D
Magnet group, CEA-Saclay, and INFN Genova



Mechanical
design

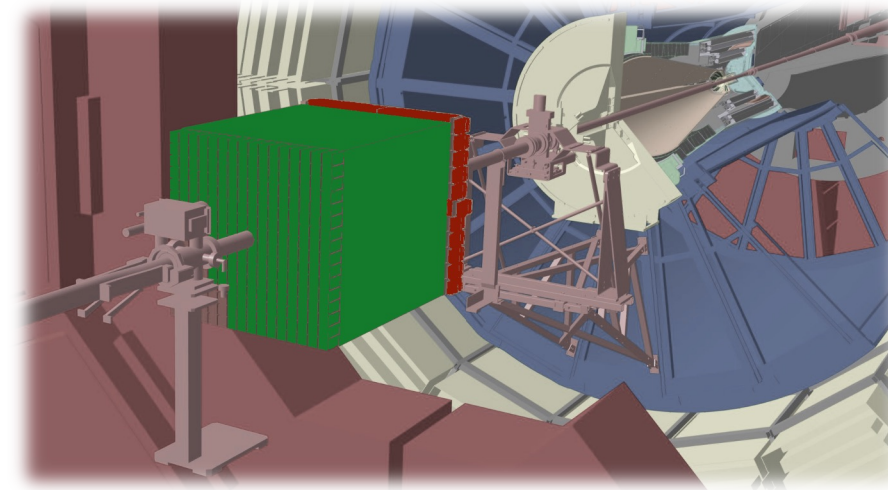
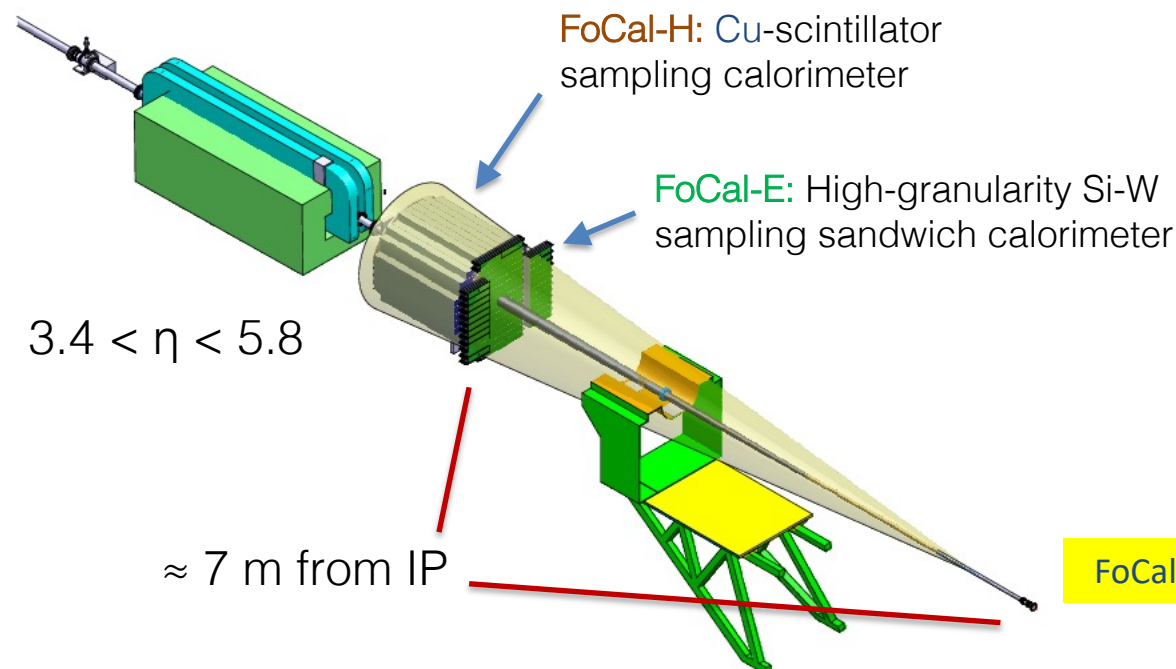


Thermosiphon design

- ❖ **The ALICE Collaboration is fully committed to exploiting the HL-LHC as a heavy-ion collider to its maximum potential, with intensive and innovative upgrade plans**
- ❖ **The LS3 and LS4 ALICE Upgrades** will enable unique new measurements and a broad physics program to address open fundamental questions in the characterization and understanding of the QGP
- ❖ **ALICE 3 R&D activities are progressing well**, and all subsystems are approaching the Technical Design Report preparation phase. **France and China actively implied in the R&D program**
- ❖ The ongoing R&D is advancing particle detector technologies in directions that largely overlap with other programs in the near and more distant future (EIC, FCC-ee)

Backup Slides

FoCal: glue at the smallest x in Run 4

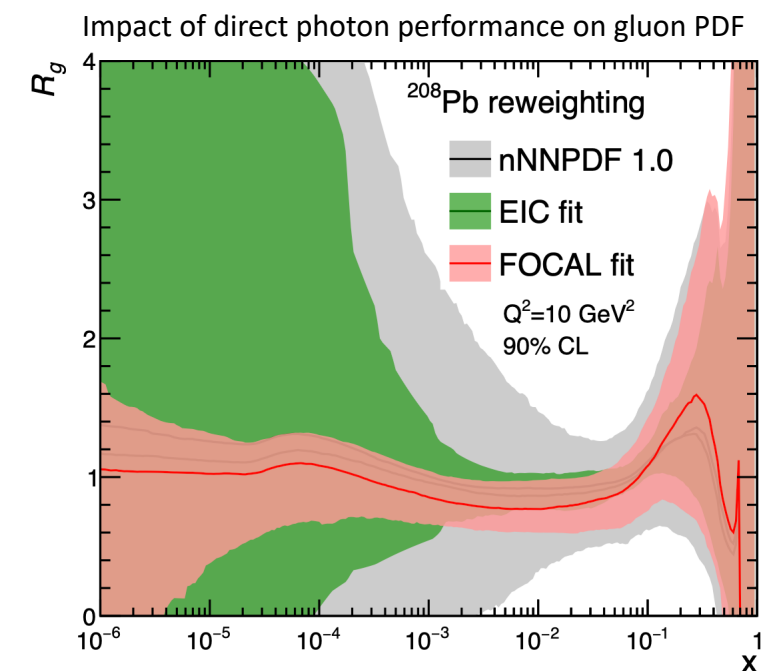


FoCal Lol: CERN-LHCC-2020-009

SOLID EDGE ACADEMIC COPY

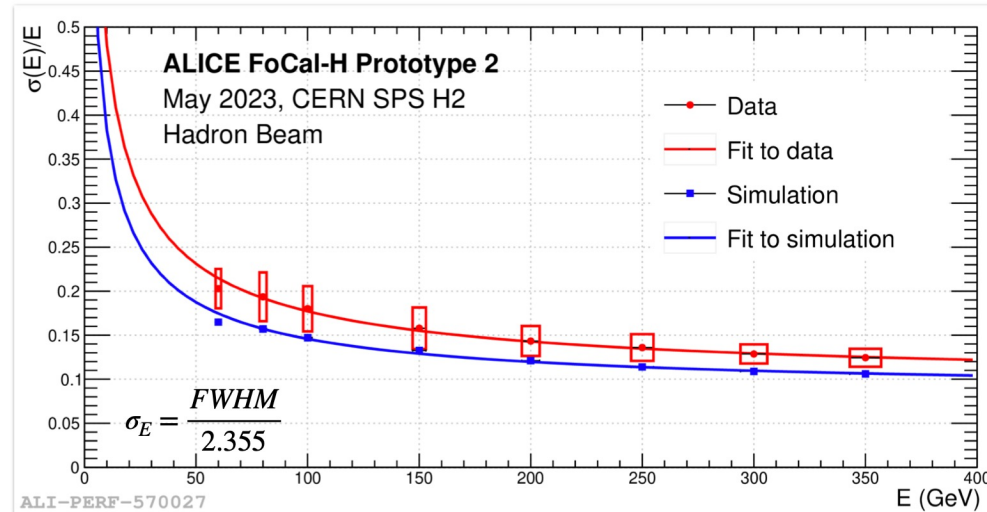
Forward physics at LHC provides an opportunity to study the low-x region

- ❖ Access to non-linear QCD mechanisms: investigate the possible onset of gluon saturation (color-glass condensate, CGC)
- ❖ Quantify and constrain modifications of gluon (n)PDFs at small-x and Q^2
- ❖ Direct photons provide a more direct access to the low-x region (10^{-5})

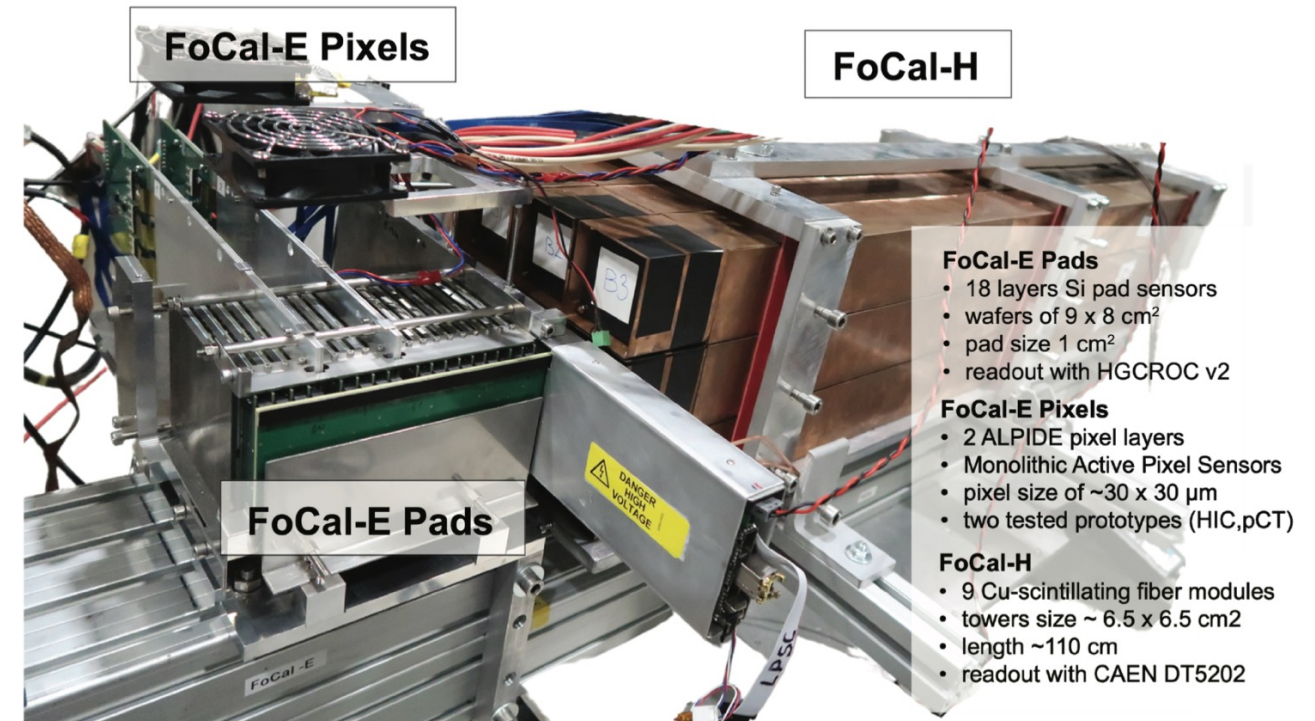
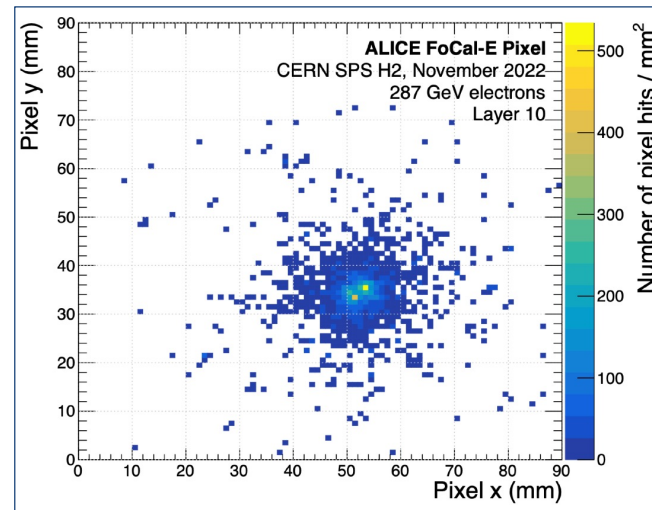
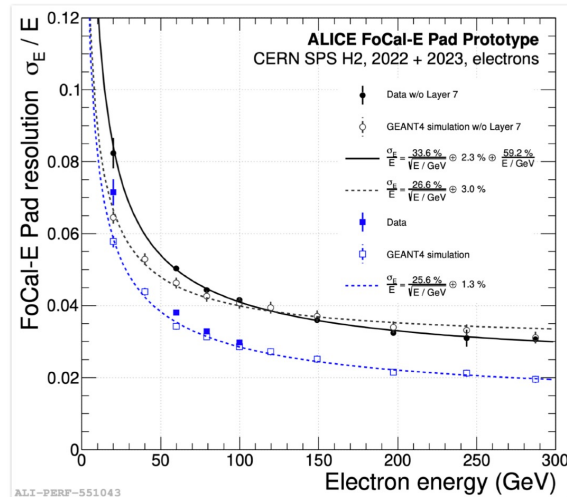


FoCal: prototype performance

FoCal-H measured resolution

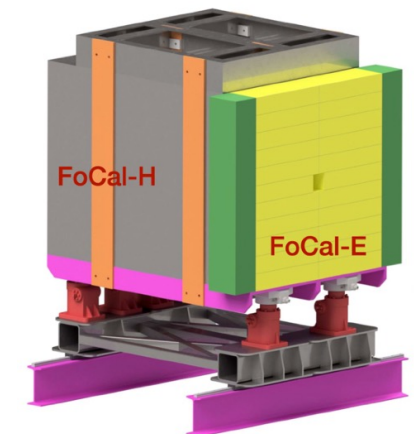


FoCal-E measured resolution



FoCal: EMCal + HCal

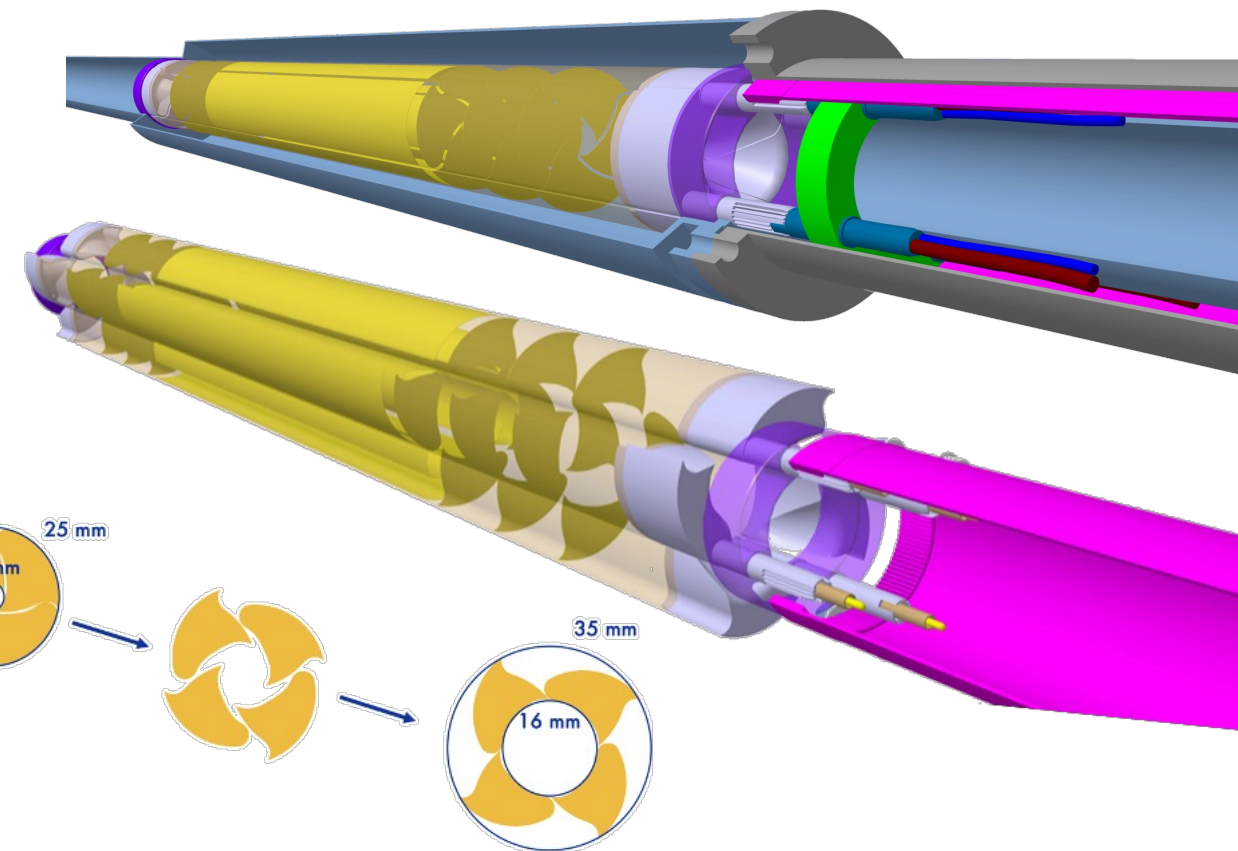
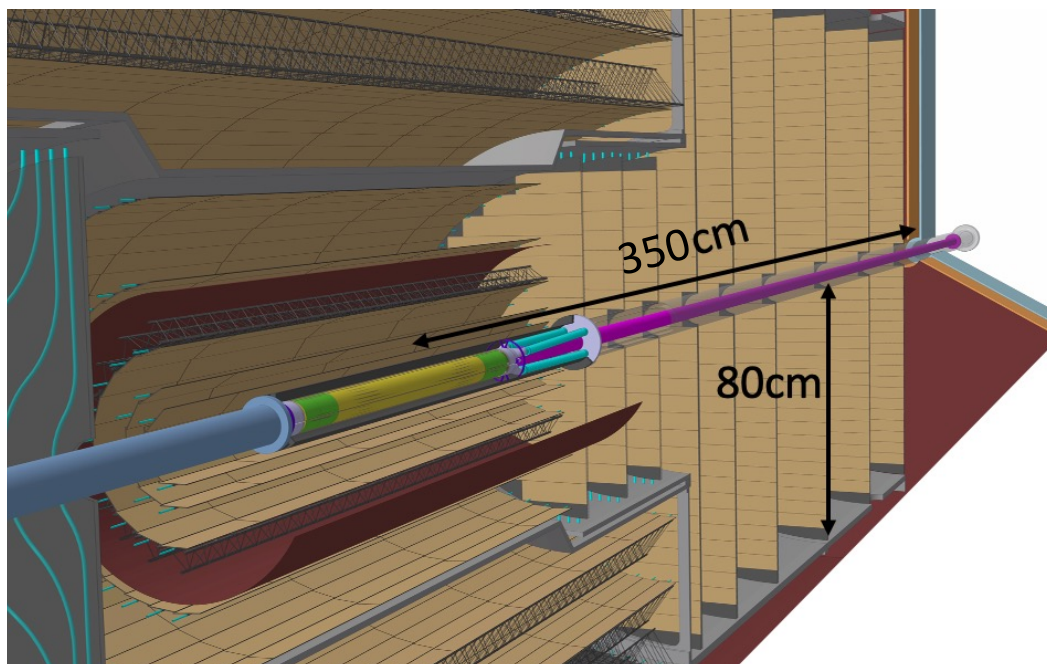
- **EMCal:** high-granularity Si-W (Si pads + Si MAPS)
- **HCal:** Cu-scintillator



ALICE 3: Vertex Detector and Outer Tracker

Vertexing layers

- Wafer-sized, bent MAPS (leveraging ITS3 activities)
- Rotary petals for secondary vacuum (thin walls to minimise material)
- R&D on mechanics, cooling, radiation tolerance



Outer Tracker

- MAPS on modules assembled on carbon-fibre cold plate
- Carbon-fibre space frame for mechanical support
- **R&D challenges** on powering scheme and industrialisation

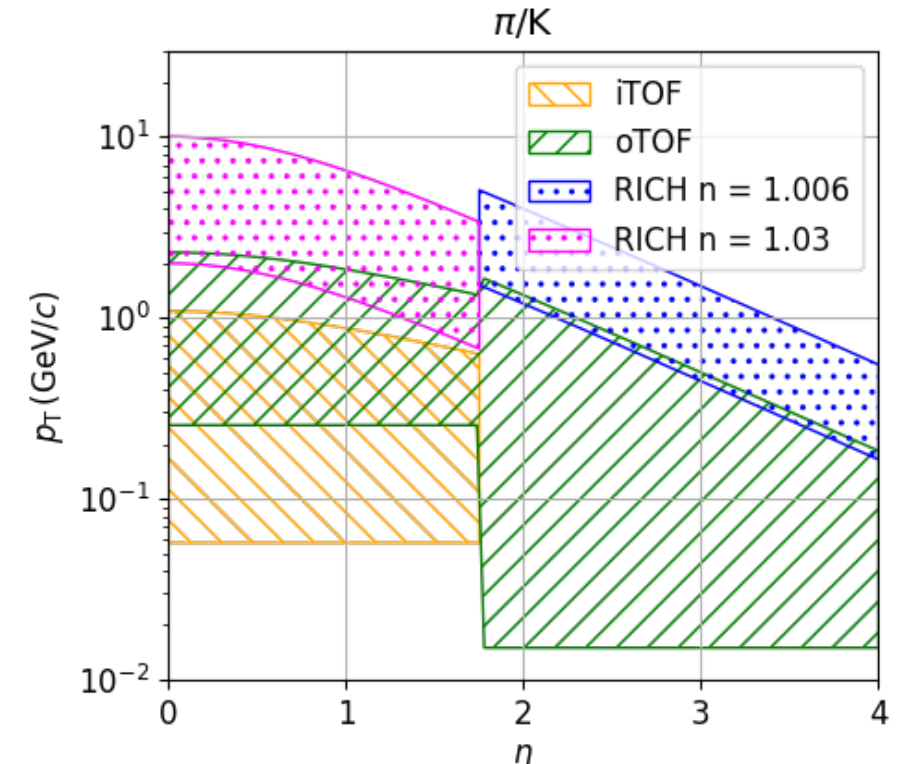
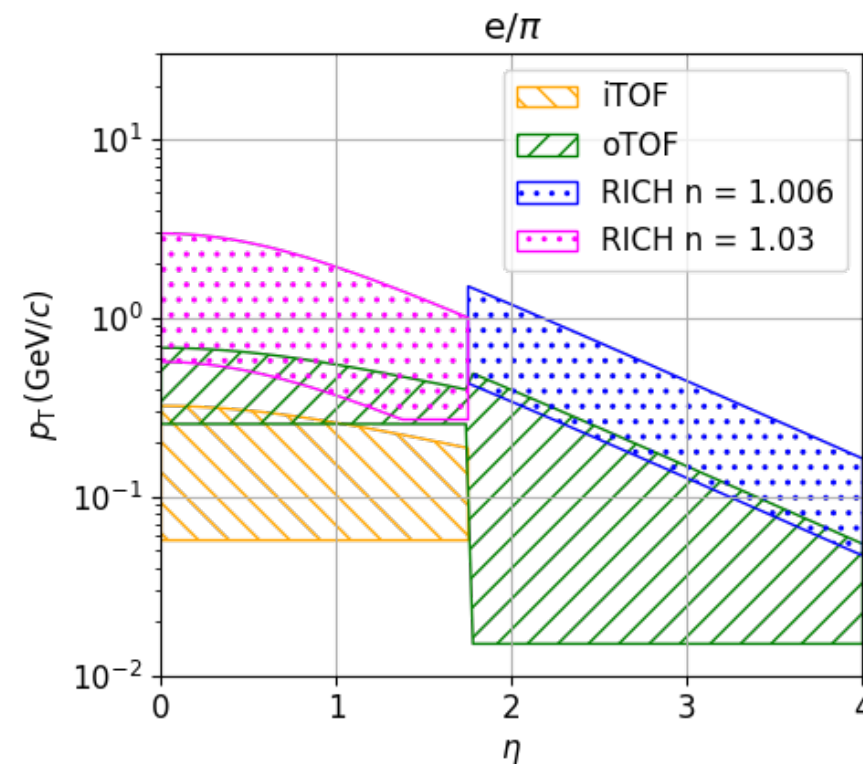
TOF detector: PID at low momenta

+ muon identifier

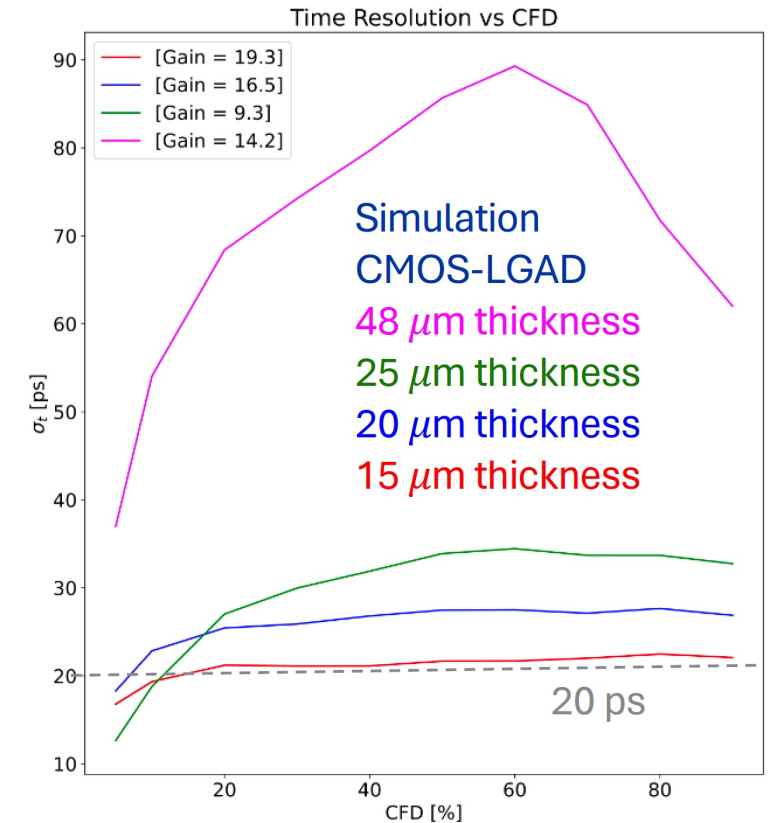
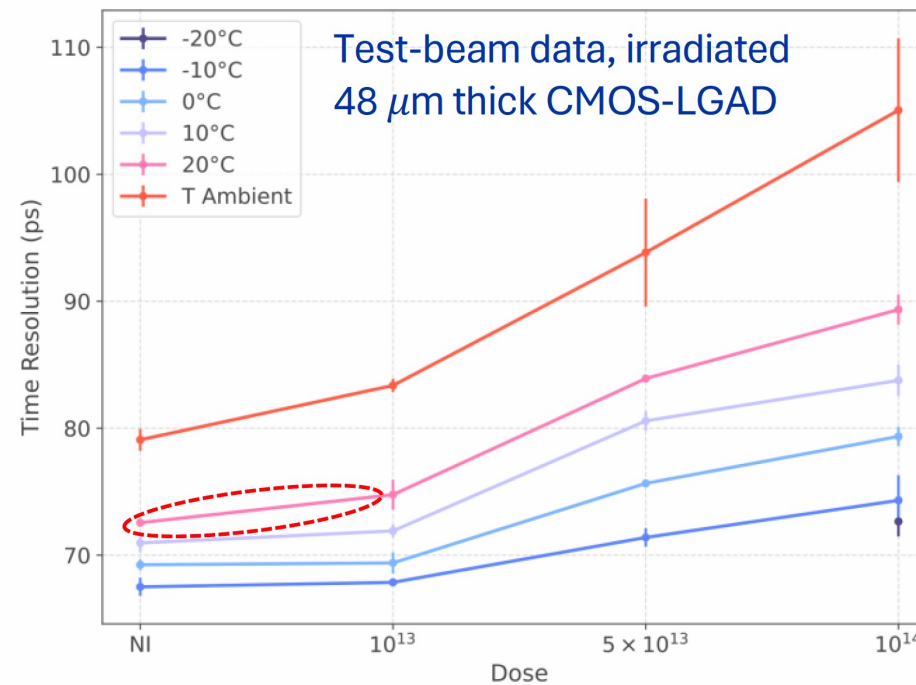
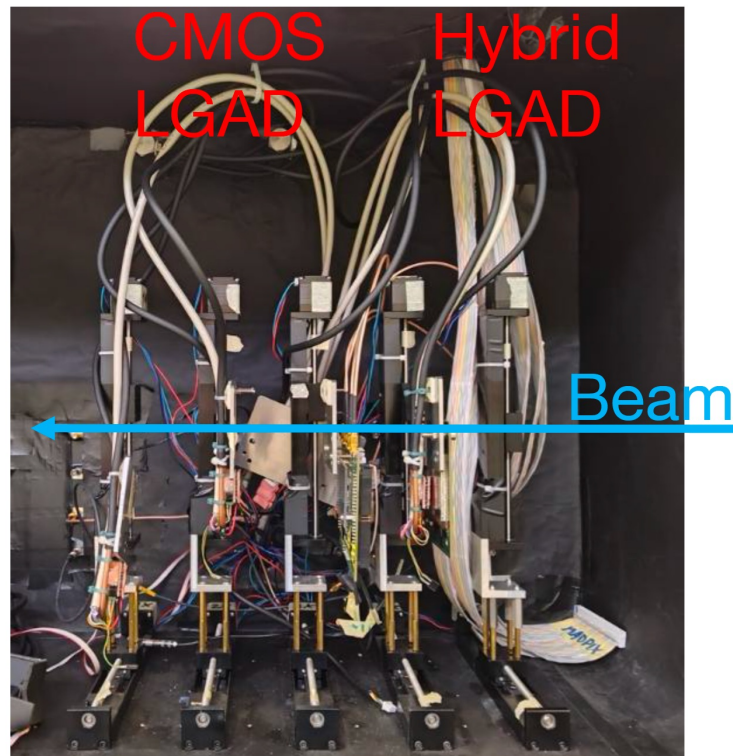
- TOF resolution ≈ 20 ps achievable with silicon timing sensors (R&D ongoing for both hybrid LGAD and CMOS LGAD options)
- Barrel TOF at $R \approx 19$ cm and $R \approx 85$ cm + forward TOF at $z \approx 370$ cm: ≈ 45 m²

RICH detector:

- Extend PID reach of outer TOF to higher p_T
- $R \approx 120$ cm, 50 ps time resolution
- Aerogel radiator + SiPM readout. Refractive index $n = 1.03$ (barrel) and 1.006 (forward)
- R&D on the choice of SiPM, radiation tolerance and cooling



- Main R&D direction: **Novel monolithic CMOS-LGAD**
 - MadPix sensor prototype(LFoundry 110 nm CMOS), 250x100 mm² pixel, 48 μm thick, gain 10-20 $\rightarrow \sigma_t \sim 72 \text{ ps}$
 - New sensors from “Short-loop ER” thinned to 15 μm , just delivered; expected to approach 20 ps



- ❖ **ALICE LS3 upgrade program under finalization: next-generation vertex detector with truly cylindrical layers (ITS3), forward calorimeter (FoCal). Significant R&D progress:**
 - Operation of bent silicon ITS3 sensors in test beams, design of components nearing completion
 - ITS3 MOSAIX sensor R&D: 2nd generation expected by the end of 2025
 - FoCal Test beams in Sept-Oct 2025: Data taking successful; analysis ongoing
 - Complete prototype under validation
- ❖ **ALICE LS4 upgrade program already well defined: ALICE 3**
→ [CERN-LHCC-2022-009](#), [CERN-LHCC-2025-002](#)
- ❖ ALICE 3 recognised by LHCC as “a unique detector at the LHC”, which “enables a compelling and unique HI physics programme in Run 5”. Also prominent in European Strategy Update symposium and physics book
- ❖ R&D in full swing: prototyping and test beams, first technology choices in the next six months



Backup Slides

- ❖ **Quarkonium Measurements beyond S-wave States**
- ❖ **Dileptons: Accessing QGP Temperature**
- ❖ **New nuclear states:** existence of bound states of a charm baryon and a nucleon without Coulomb repulsion (c-deuteron $n-\Lambda_c$ and c-triton $n-n-\Lambda_c$) sheds light on the charm-nucleon potential
- ❖ **Ultra-soft photons (down to $p_T \approx 2 \text{ MeV}/c$):** Low's theorem predictions violated in previous experiments by an excess of soft-photon production
- ❖ **Ultra-peripheral collisions:** rare single-resonance and resonance-pair production (e.g. $\rho' \rightarrow 4\pi$, $\rho-J/\psi$), light-by-light scattering
- ❖ **Net-baryon fluctuations:** baryon number conservation, baryon number susceptibility and critical behavior
- ❖ **BSM searches:** ALPs, dark photons, long-lived particles



Extreme QCD in Laboratory after Run4

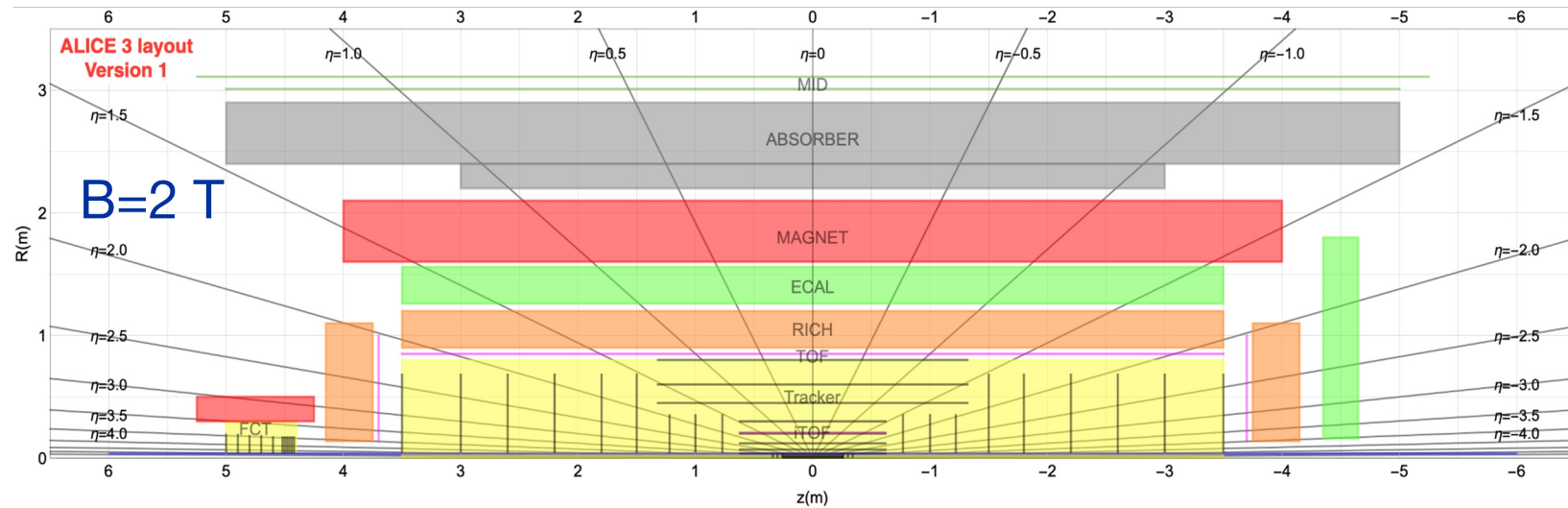
Key QGP findings in last 20 years from RHIC and LHC

- ❖ Evolves as almost perfect fluid that quenches jets
- ❖ Produces light hadrons in apparent thermal equilibrium
- ❖ Readily couples with heavy quarks
- ❖ Collective effects found in high-multiplicity events in small systems: QGP droplets or multiplicity-driven mechanisms?

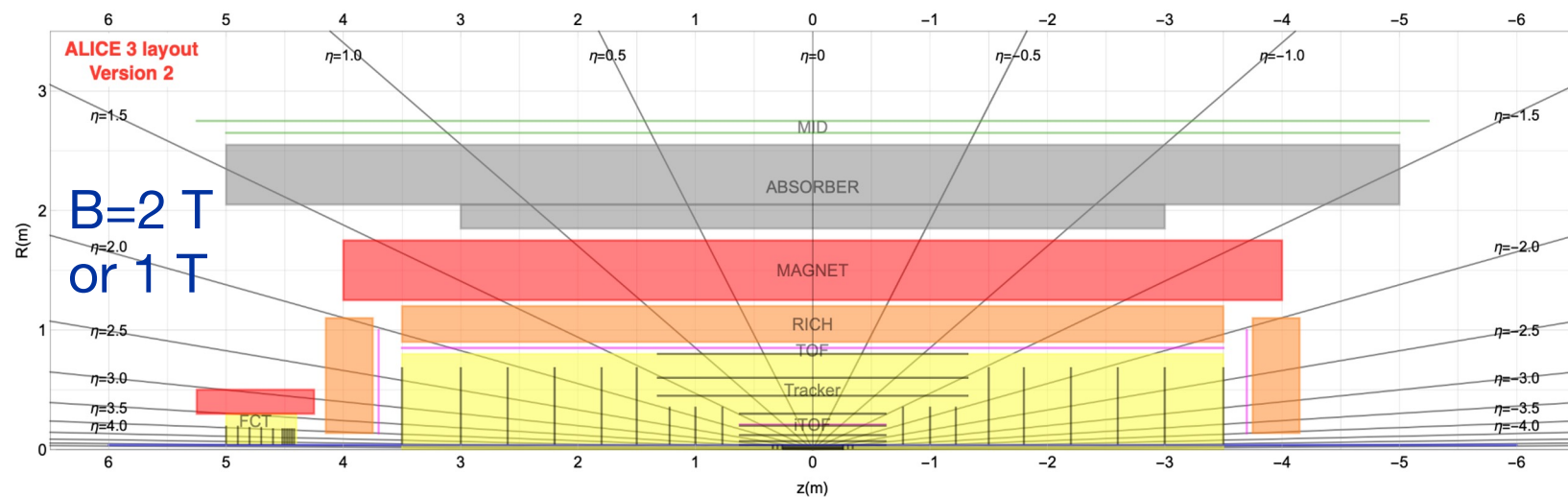
What is ALICE 3 designed to discover and explore?

- ❖ QGP temperature evolution and when “local” equilibrium achieved
- ❖ Precision measurements on heavy quark diffusion and hadronization in the QGP
- ❖ Nature of QCD phase transition at $\mu_b \approx 0$
- ❖ Rare hadron production mechanisms and hadronic interactions
- ❖ Beyond Standard Model searches...

A tale of two Setups



**Version 1
(LoI)**



**Version 2
(no ECal, smaller magnet)**

Version without ECal as de-scoped layout

Version without ECal and with reduced field (1 T) as further de-scoping

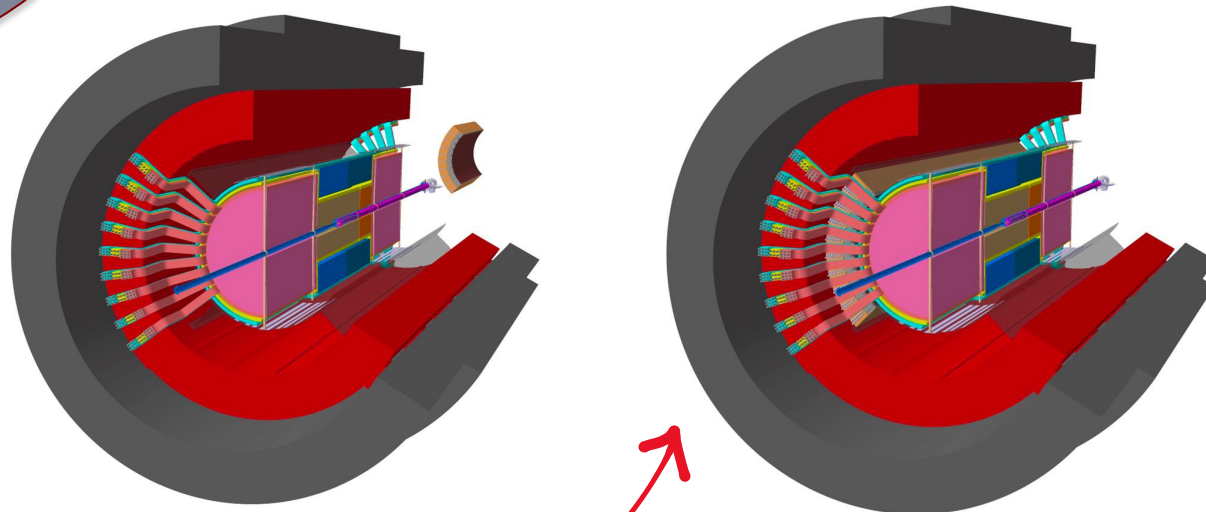
ALICE 3 Timeline

	2023				2024				2025				2026				2027				2028				2029				2030				2031				2032				2033				2034			
	Run 3								LS3								Run 4																LS4															
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4								
ALICE 3	Scoping Document, WGs kickoff				Selection of technologies, R&D, concept prototypes				R&D, TDRs, engineered prototypes				Construction								Contingency and precommissioning								Installation and commissioning																			

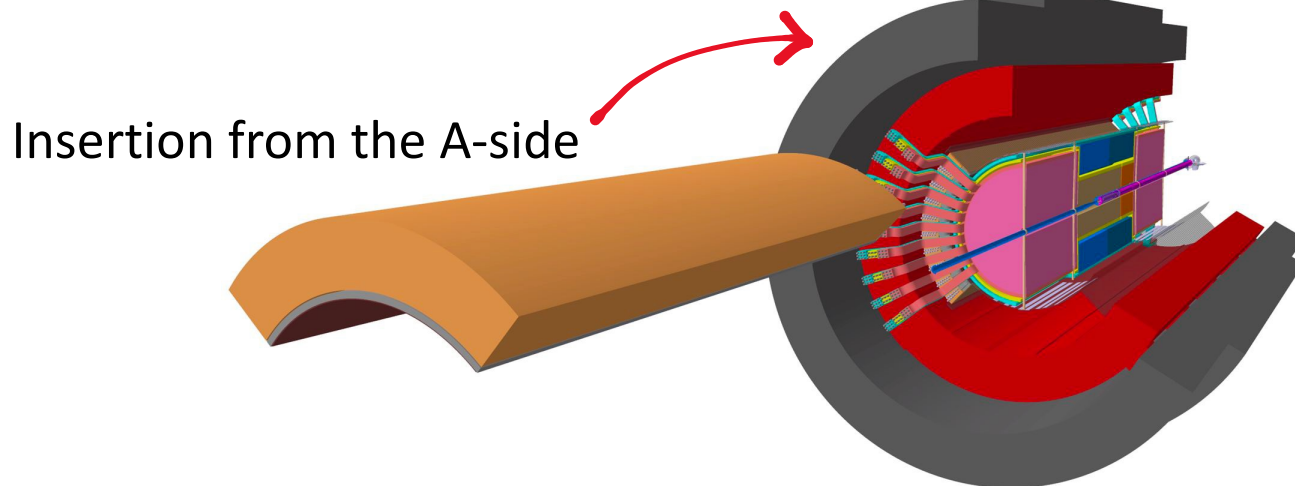
- ❖ **2023-25:** Scoping Document, selection of technologies, small-scale prototypes ($\approx 25\%$ of R&D funds)
- ❖ **2026-27:** large-scale engineered prototypes ($\approx 75\%$ of R&D funds) $\rightarrow$ TDRs and MoUs
- ❖ **2028-30:** construction and testing
- ❖ **2031-32:** contingency and pre-commissioning
- ❖ **2033-34:** preparation of cavern, installation



Layout Update: Services and Installation



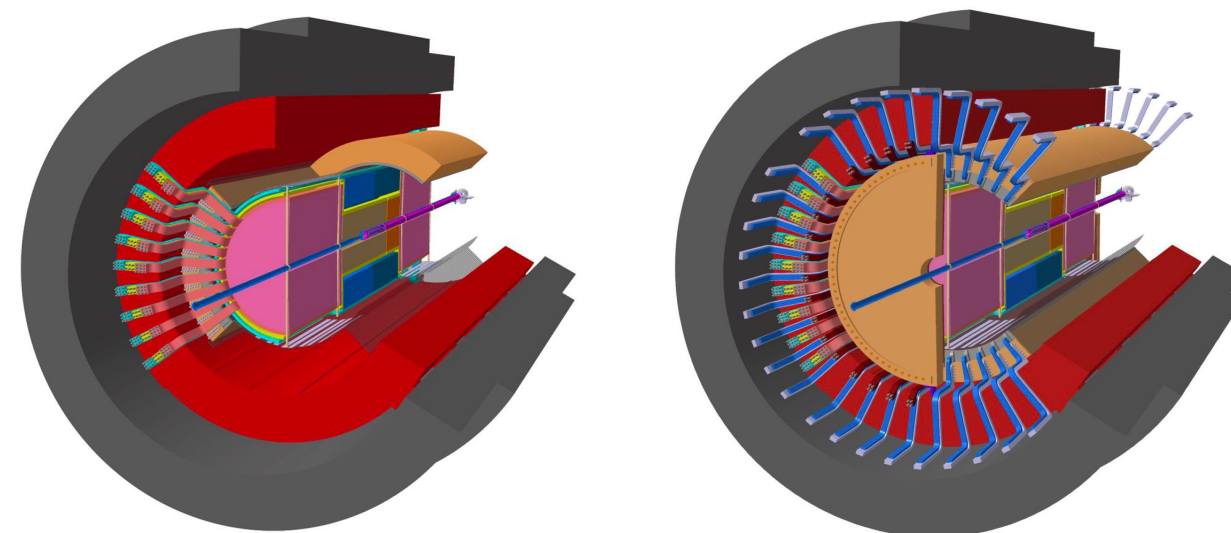
Insertion from the C-side



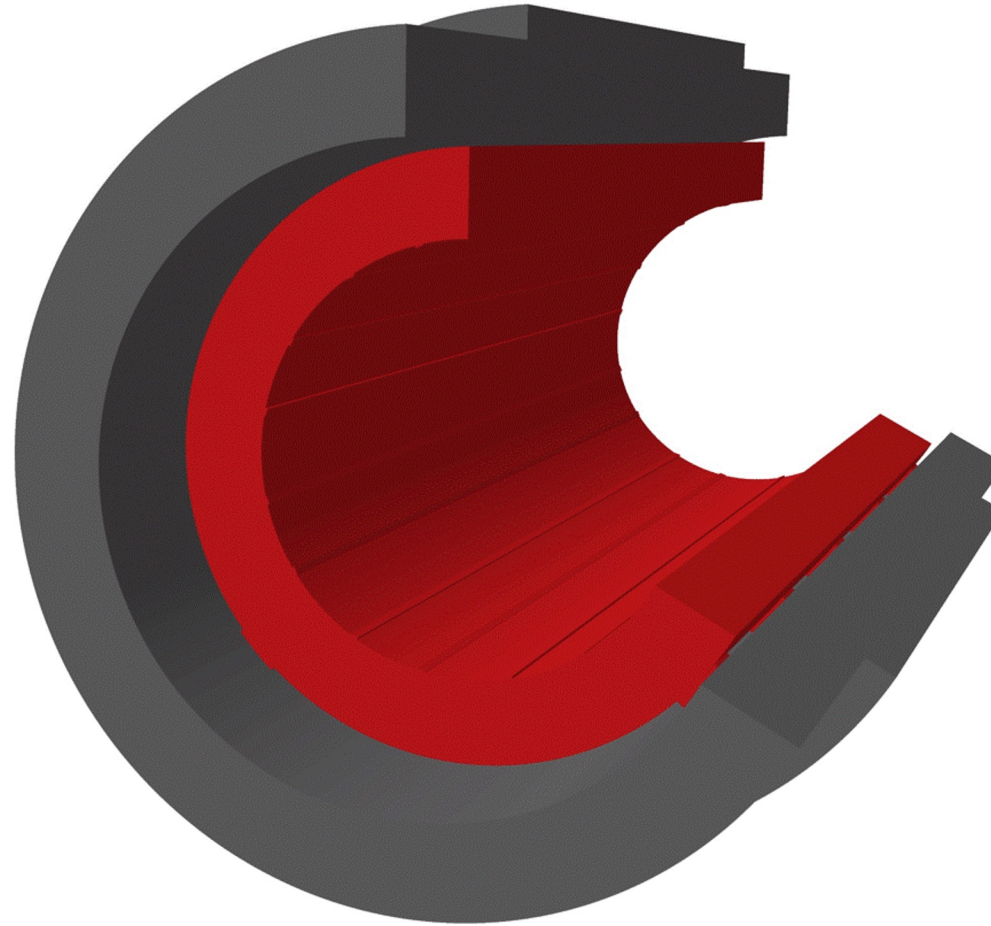
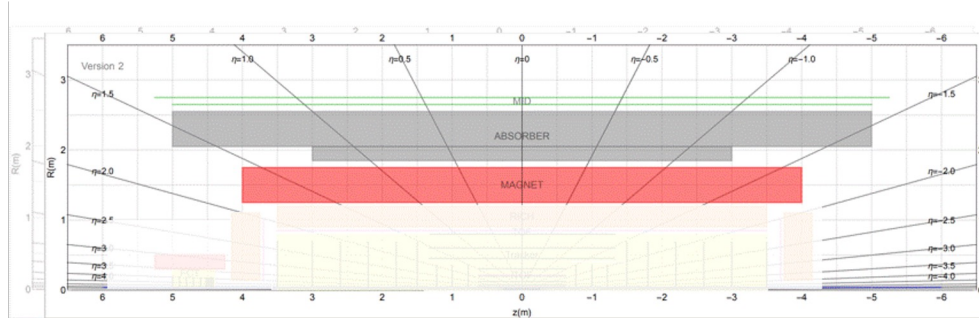
Insertion from the A-side

Study of integration scheme with alternating services enabling for modular and independent installation of OT endcaps, RICH and oTOF barrel, fRICH and fTOF endcaps

- In case of delay, any of these components can be installed during a YETS, without affecting the LHC schedule

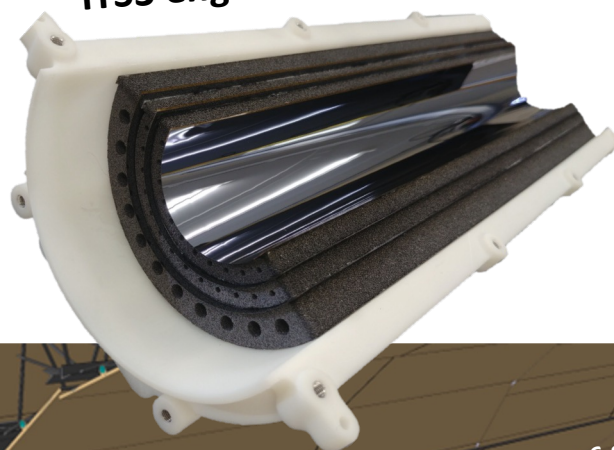


Layout Update: Services and Installation

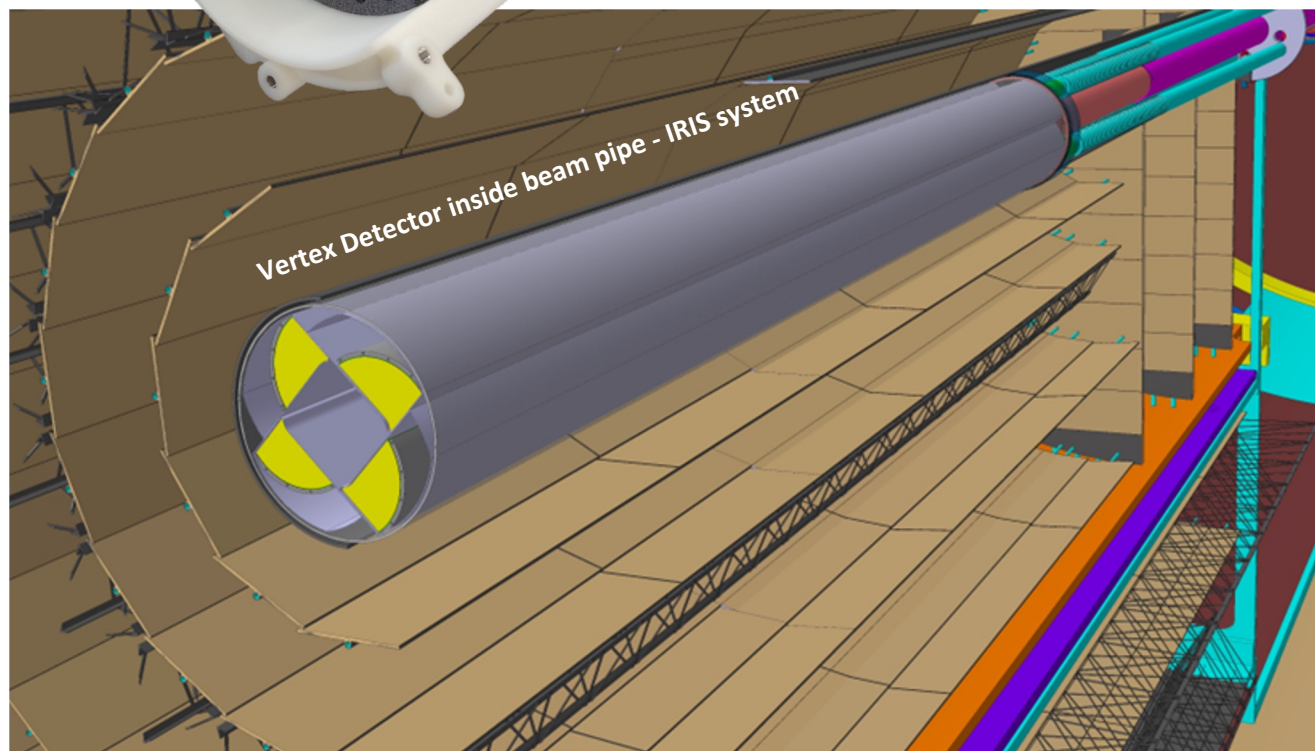


Magnet

ITS3 engineering model 2



Vertex Detector: strongly relying on ITS3 R&D (sensor design, stitching, wafer-scale bent sensor)



IRIS Breadboard model 3

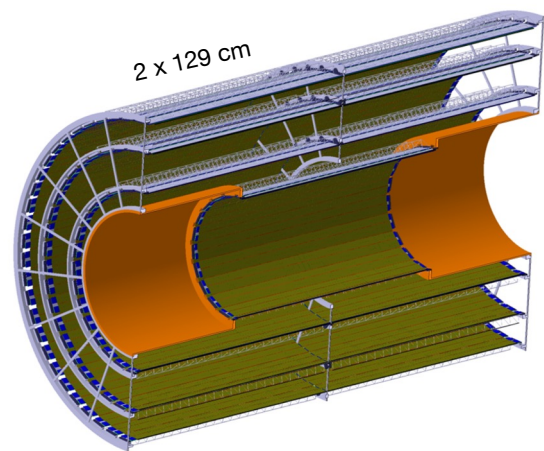
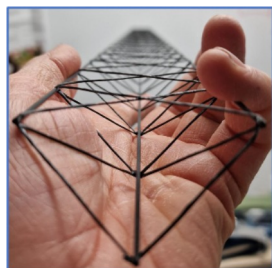


IRIS system:

- ❖ Services integration being detailed
- ❖ Study of protection between primary and secondary vacuum
- ❖ Impact of vacuum on components, wire bonding, glued parts

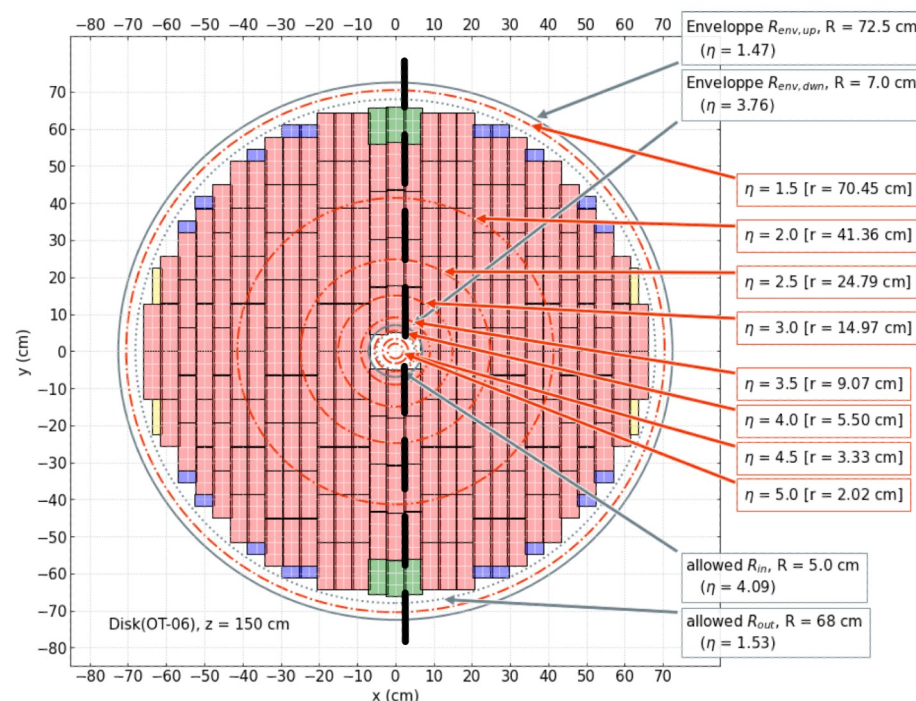
OT barrel design studies:

- ❖ Full-scale stave model
- ❖ Air and water cooling studies
- ❖ Mechanical support



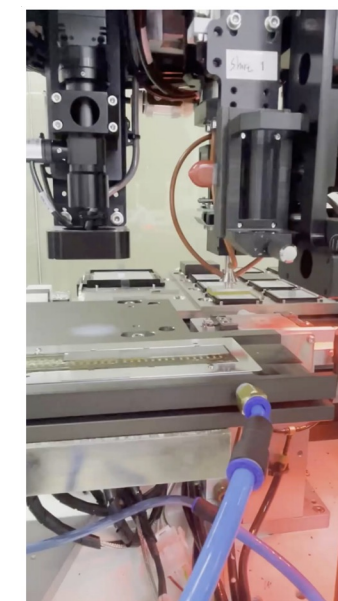
OT endcaps with disks:

- ❖ “Paving” with modules
- ❖ Mechanical layout (double-sided disks?), carbon-fibre support



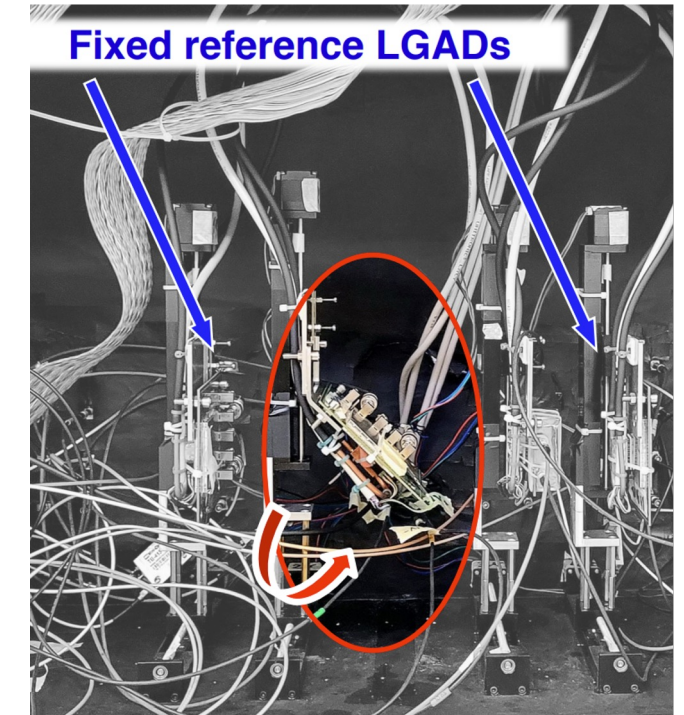
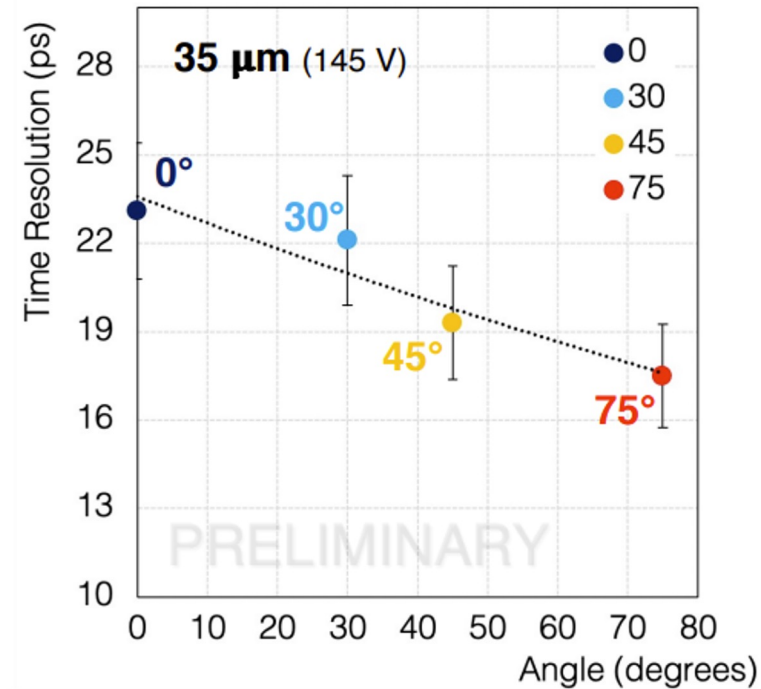
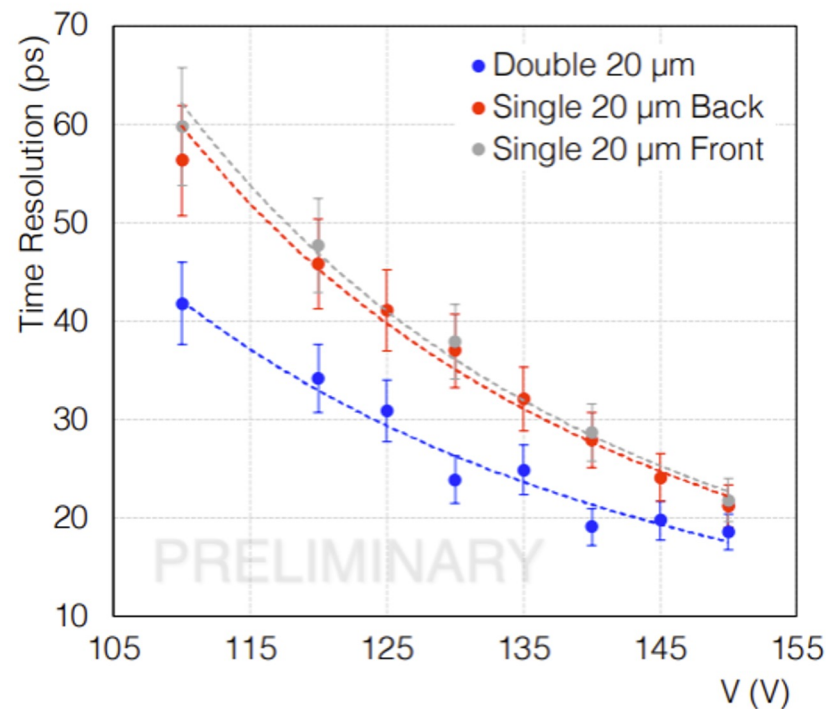
Automated module assembly:

- ❖ General-purpose die-bonder machine
- ❖ Flexible printed circuit, sensor gluing and interconnections



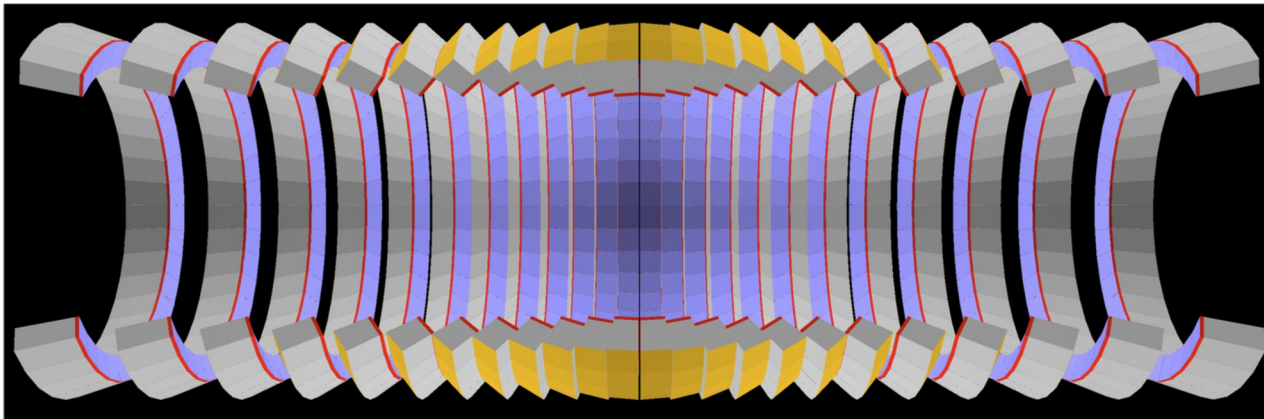
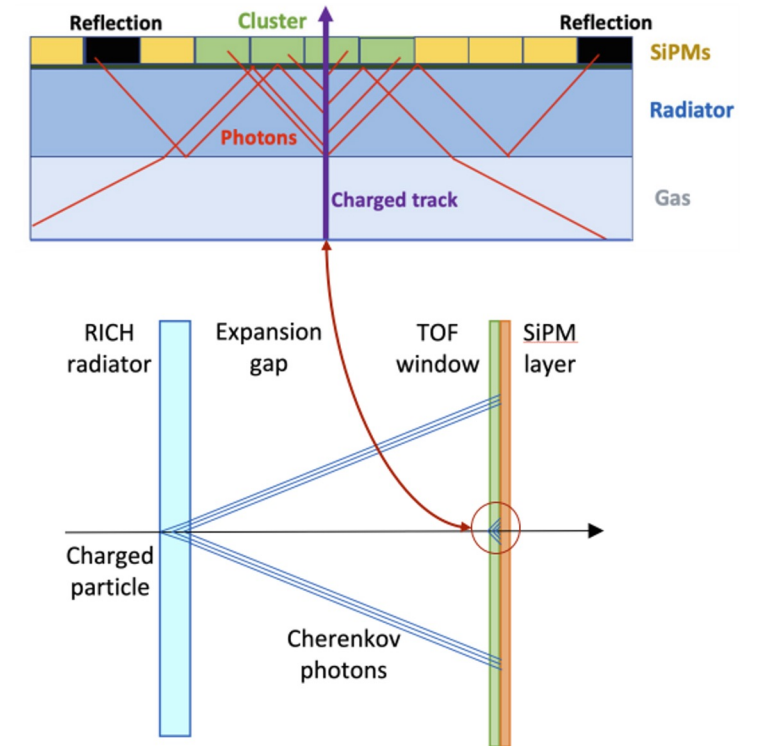
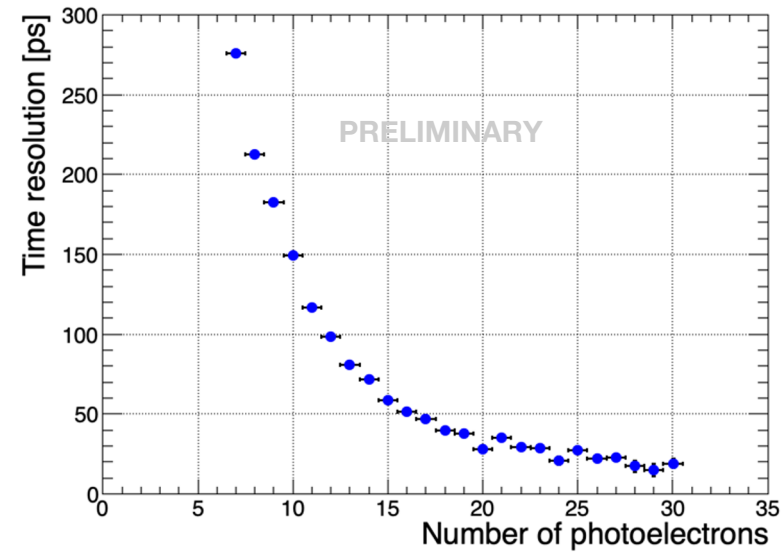
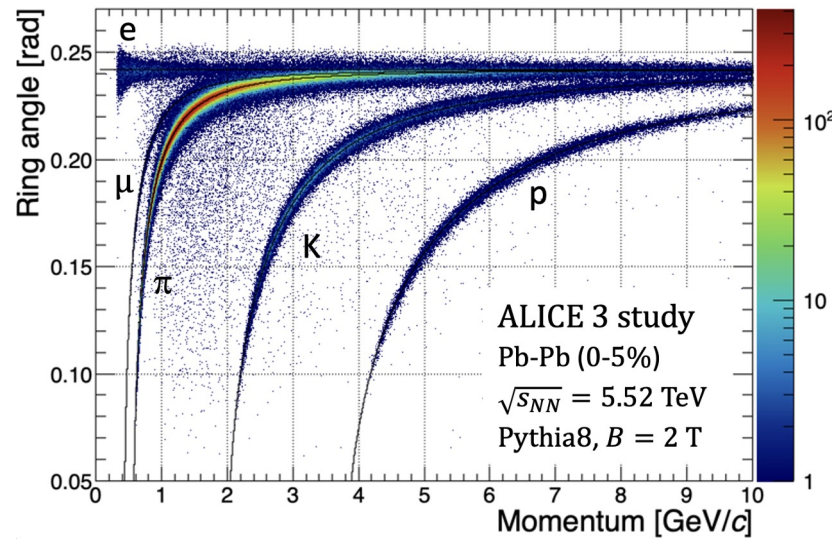
Time resolution target: 20 ps. **Testbeams in July and Oct '23:**

- ❖ SiPM coated with different resins (type, thickness)
- ❖ Single and double LGADs 20 μm , 25 μm , 35 μm thick
- ❖ 50 μm thick CMOS-LGAD (ARCADIA MAPS with gain layer) and with integrated FEE (MADPIX)



Target resolution
achieved on individual sensor

Small dependence on track
inclination



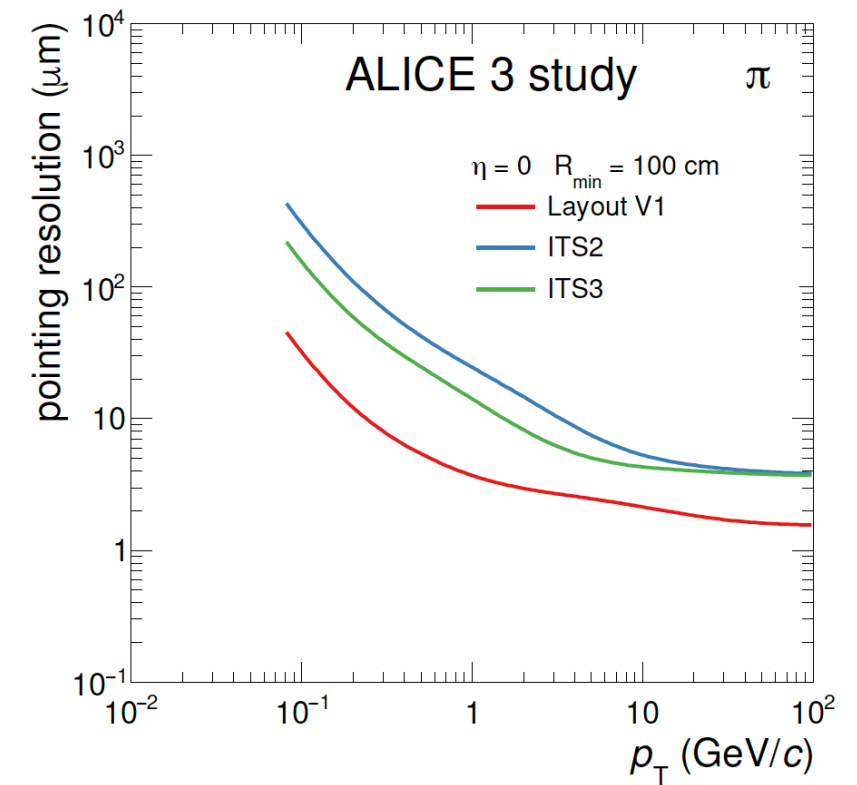
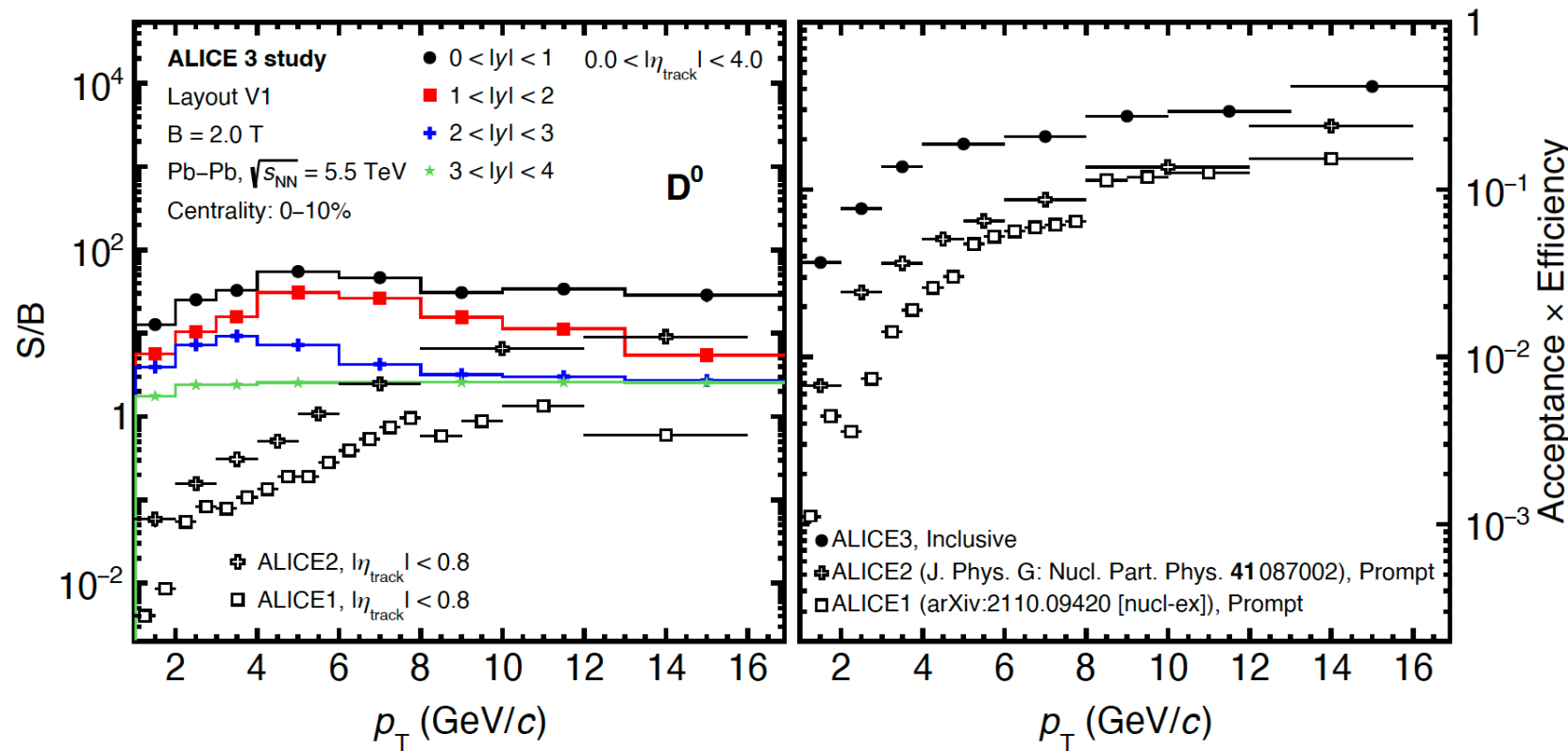
- ❖ Possible layout optimization: outer TOF layer integrated with RICH (thanks to the the generation of Cherenkov photons inside the protective layer detected by the sensor)

Heavy-Flavour Benchmark: D^0

Experimental benchmark giving access to the measurement of:

- Beauty meson and baryon v_2
- DD correlations
- Multi-charm baryons

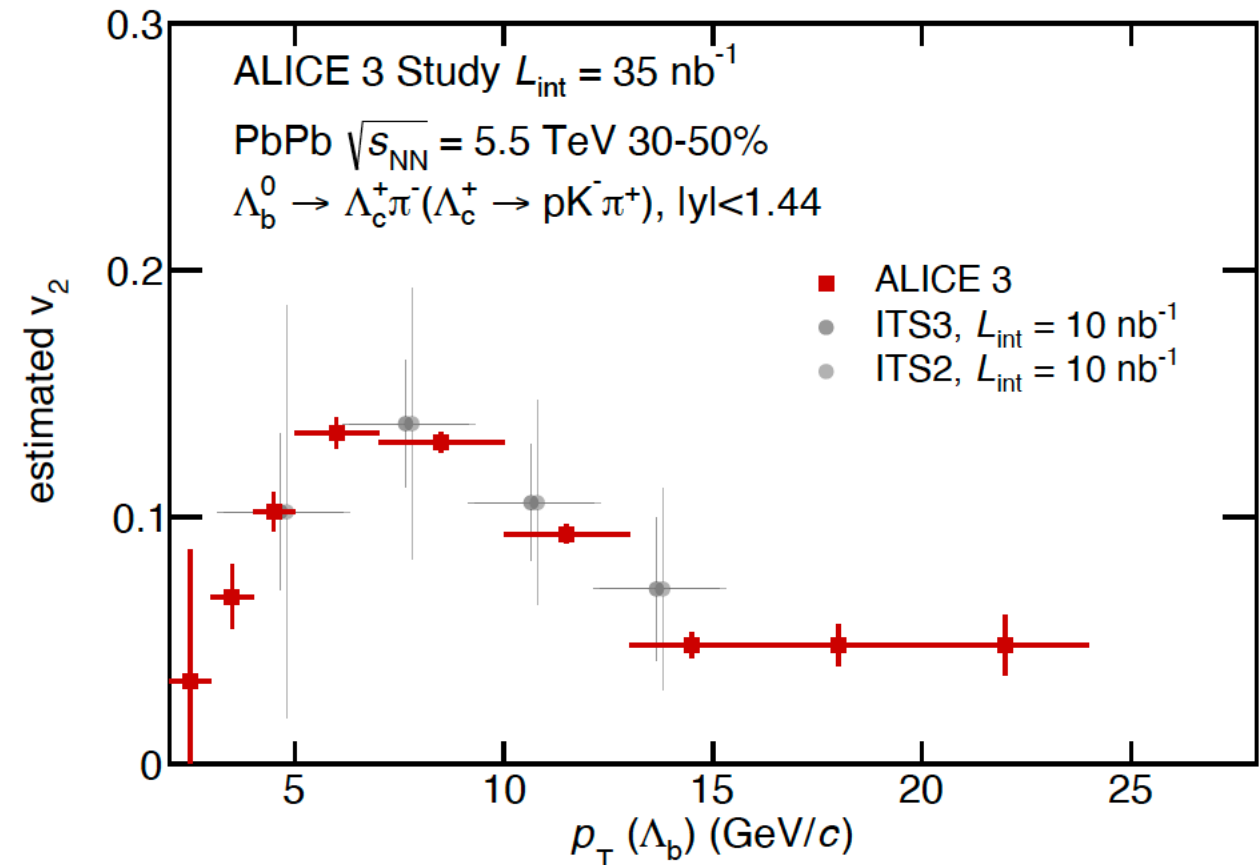
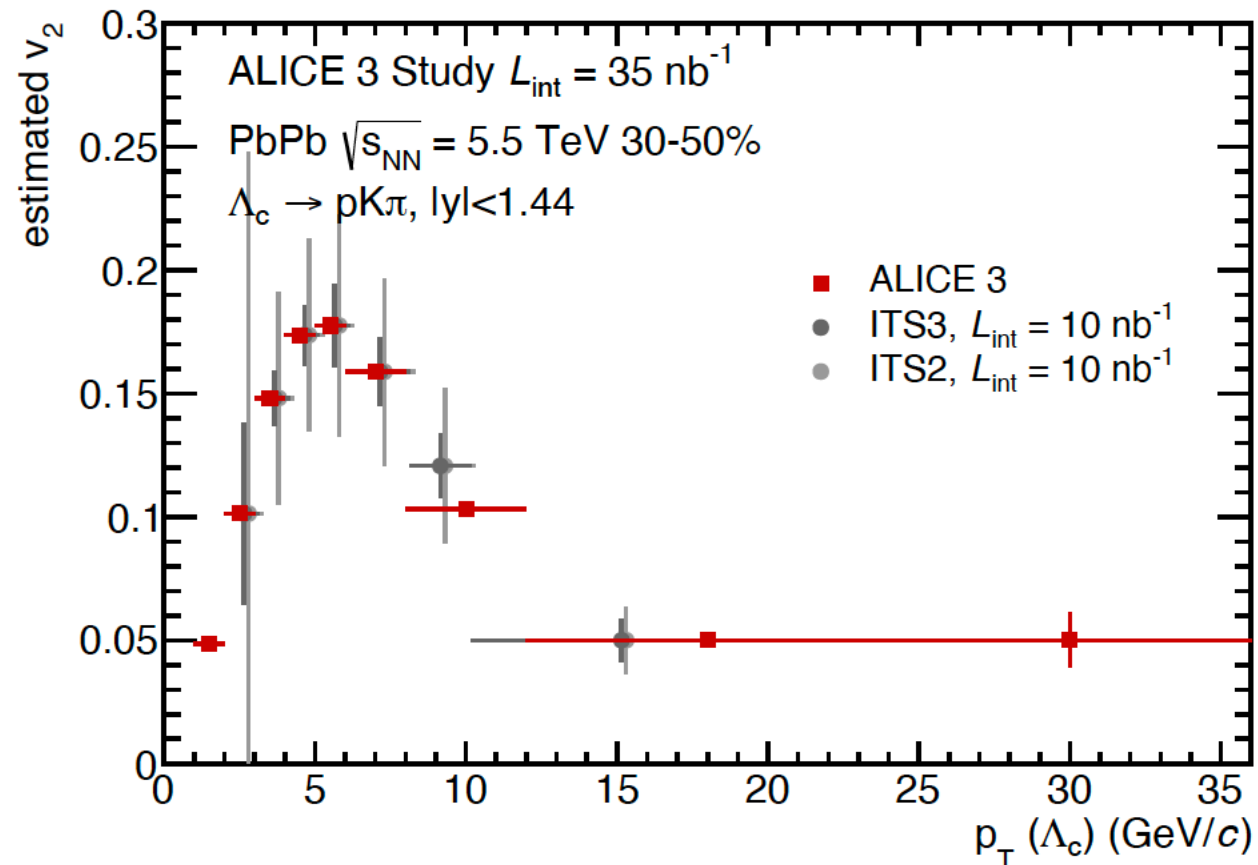
Excellent pointing resolution and PID:
large S/B and efficiency $10\text{-}20 \times$ w.r.t.
 Run 3 (i.e. ITS2) for $p_T < 4$ GeV/c



ALI-SIMUL-491785

Goal: disentangle effects of quark transport and hadronization

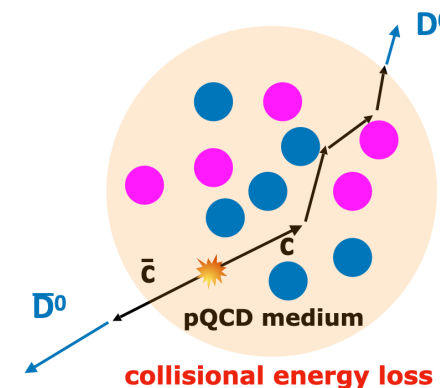
- Expect beauty thermalization slower than charm — does this affect hadronization?
- First measurements of Λ_b coupling to hydrodynamic flow (via v_2 parameter) in Run 3 and 4
- Need ALICE 3 performance for precision measurement



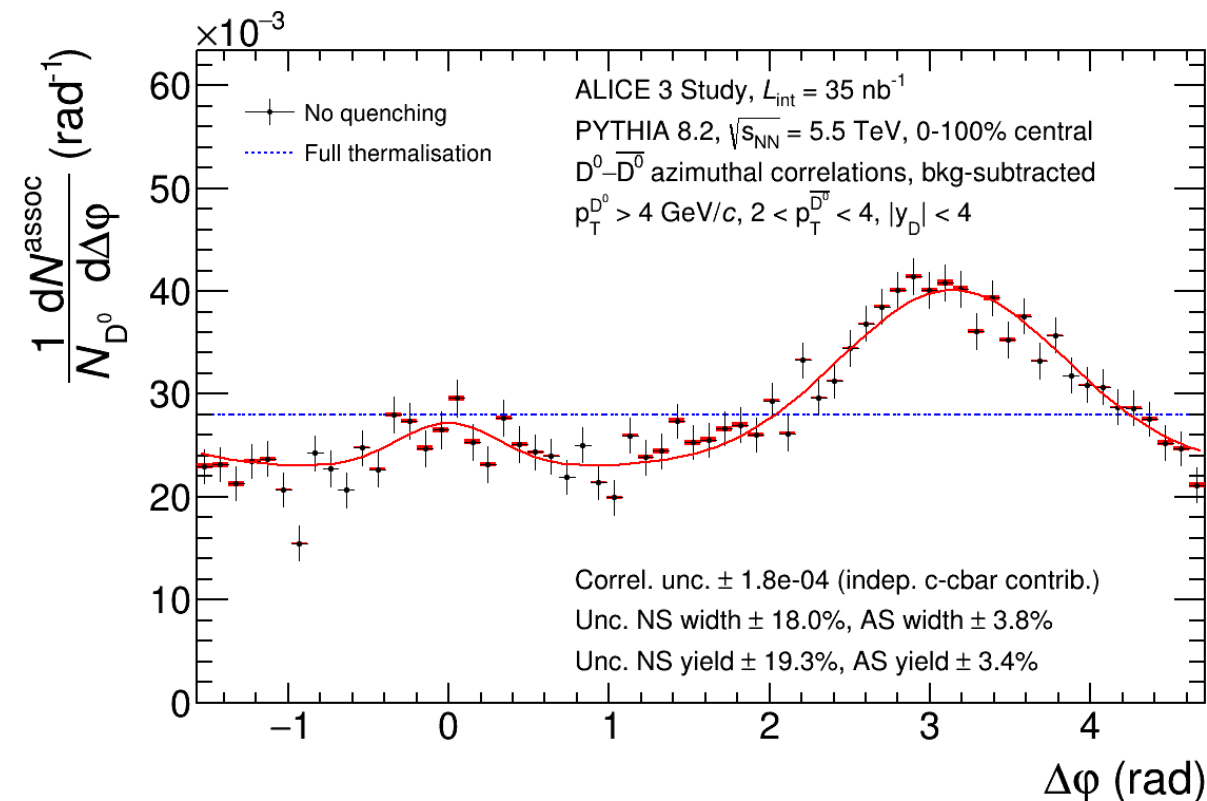
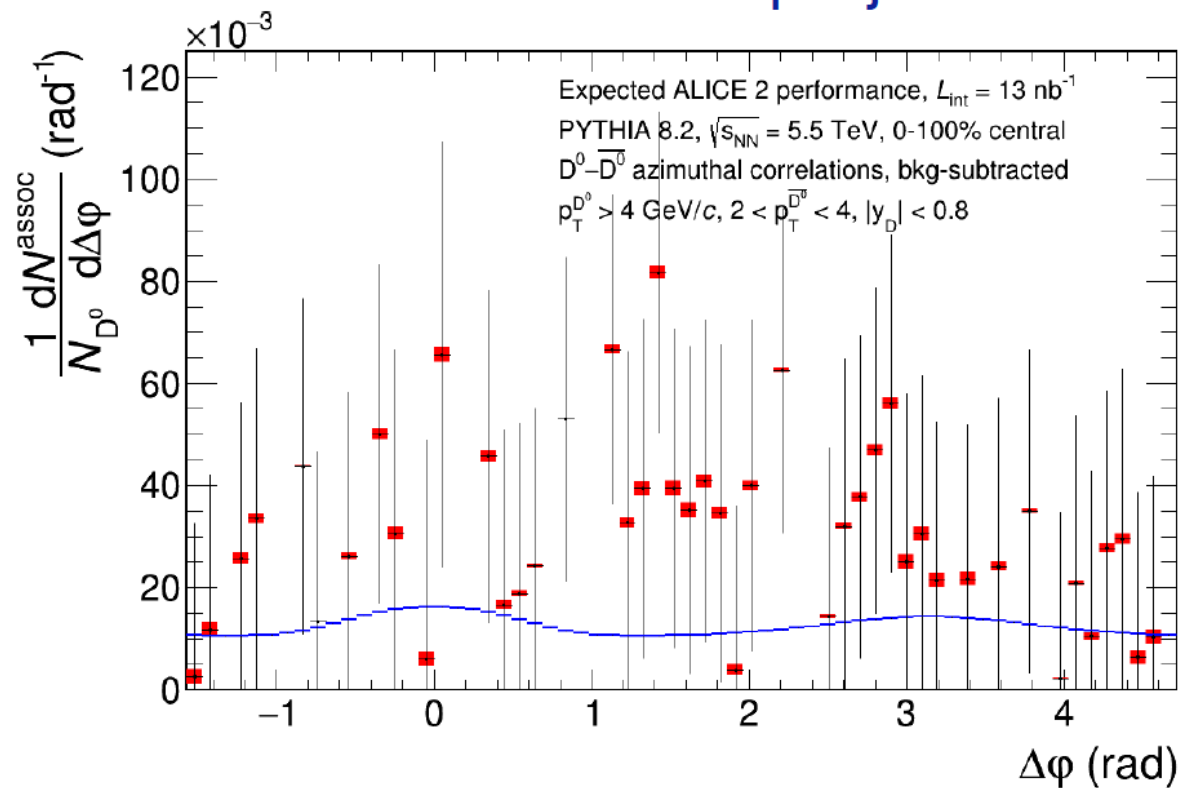
$D^0\bar{D}^0$ Azimuthal Correlations

Goal: measure angular (de)correlations — direct probe of QGP scattering

- ❖ Very challenging measurement: need good purity, efficiency and η coverage
- ❖ Heavy-ion measurement only possible with ALICE 3



ALICE Run 3&4 projection



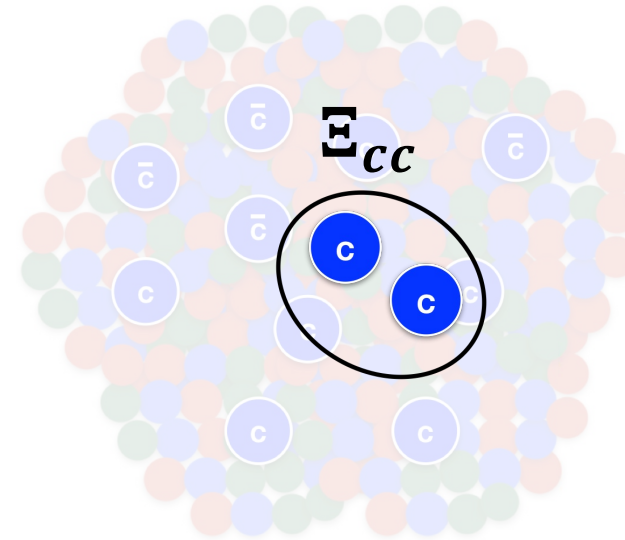
HF Hadronization Mechanisms

- ❖ In heavy-ion collisions, large increase of multi-HF baryons ($\approx \times 1000$) expected via coalescence with charm quarks from different hard scatterings ($N_{ccbar} \approx 100$ in central Pb-Pb)

Discrimination power on the role of the various hadronization mechanisms: multi-charm baryon factory (almost purely produced out of quark coalescence)

Ω_{cc} and Ω_{ccc} not yet observed. Ω_{ccc} may only be accessible in heavy-ion collisions

Challenging **reconstruction of cascade decay**, exploiting state-of-the-art vertexing and tracking



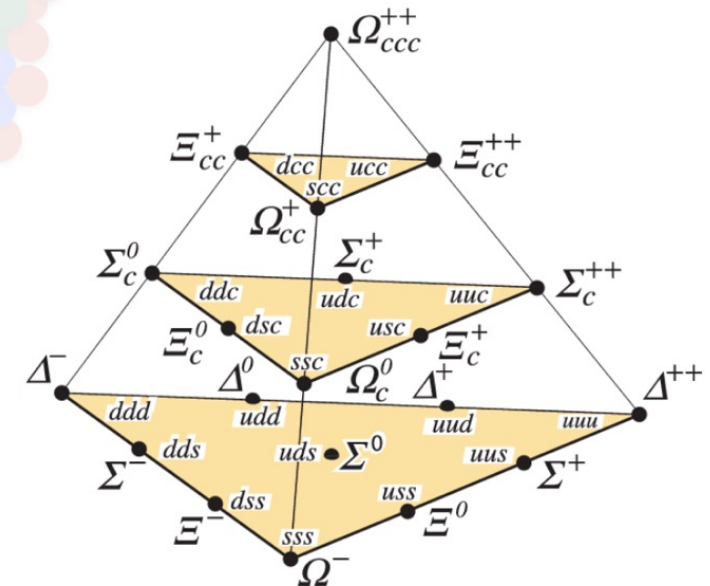
$$\Omega_{ccc}^{++} \rightarrow \Omega_{cc}^{+} + \pi^{+}$$

$$\Omega_{cc}^{+} \rightarrow \Omega_c^0 + \pi^{+}$$

$$\Omega_c^0 \rightarrow \Omega^{-} + \pi^{+}$$

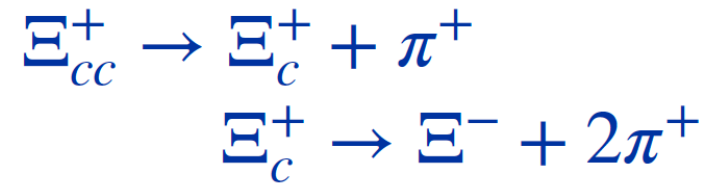
$$\Omega^{-} \rightarrow \Lambda + K^{-}$$

$$\Lambda \rightarrow p + \pi^{-}$$



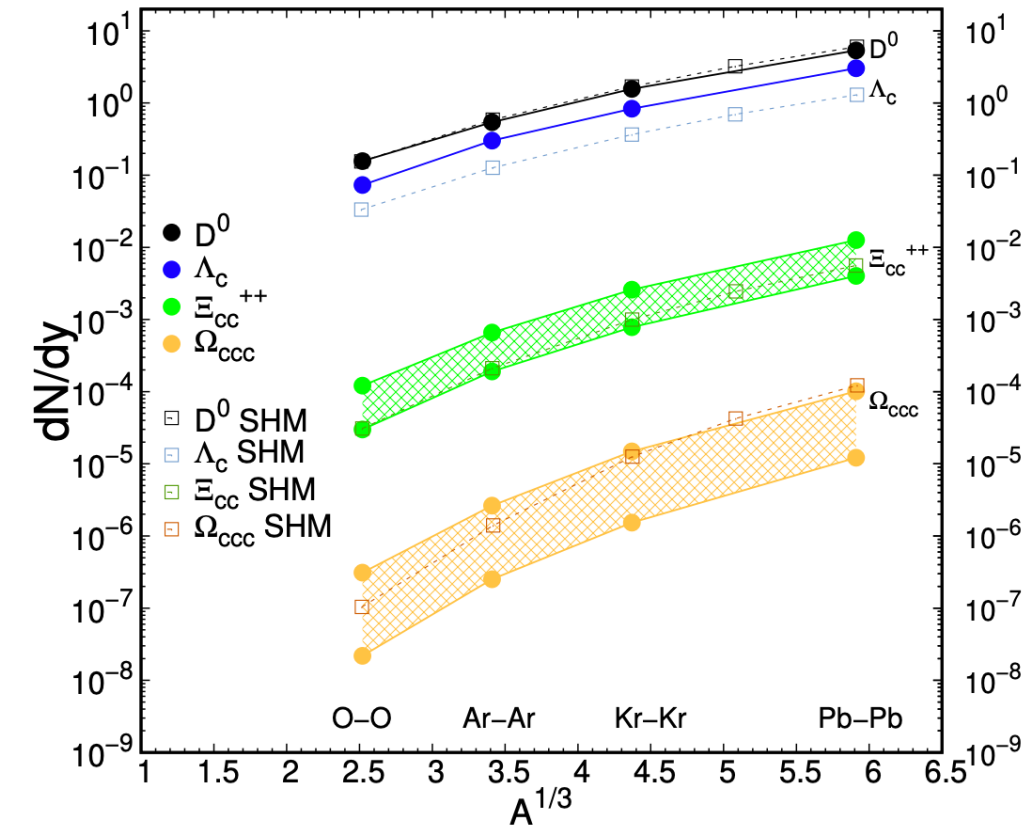
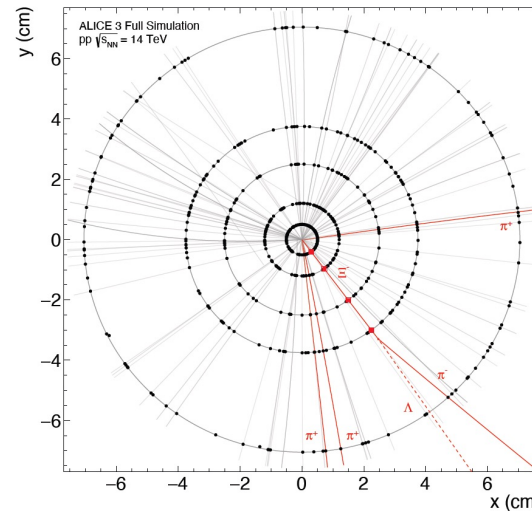
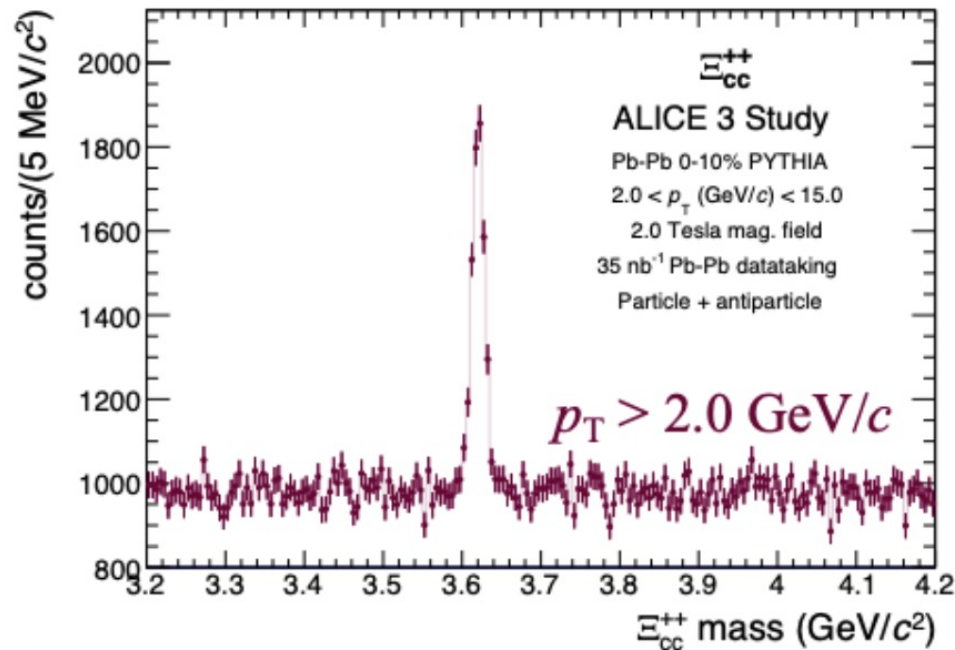
Multi-Charm Baryon Reconstruction

New technique: strangeness tracking with Ξ baryon provides high selectivity



<https://arxiv.org/abs/2305.03687>

Expected mass peak in Pb-Pb collisions

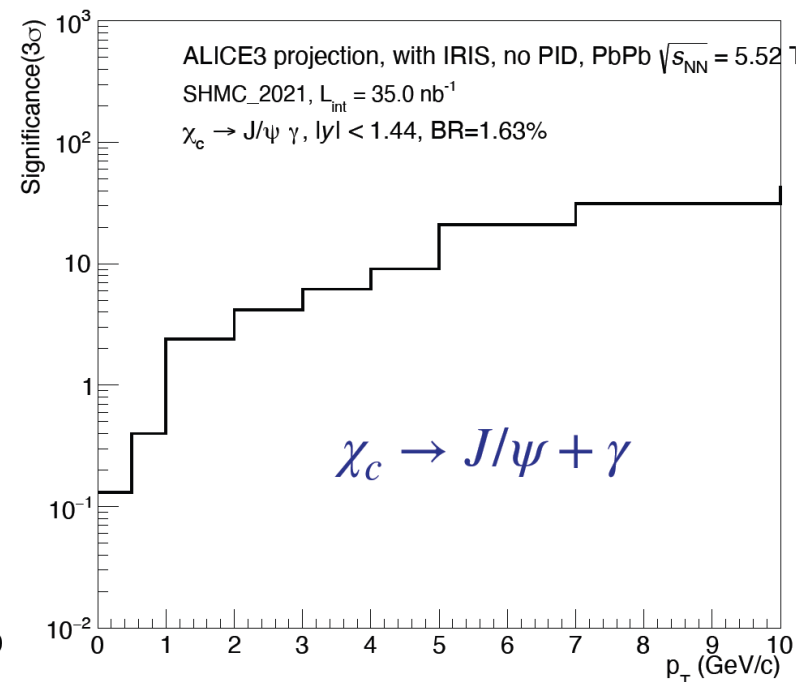
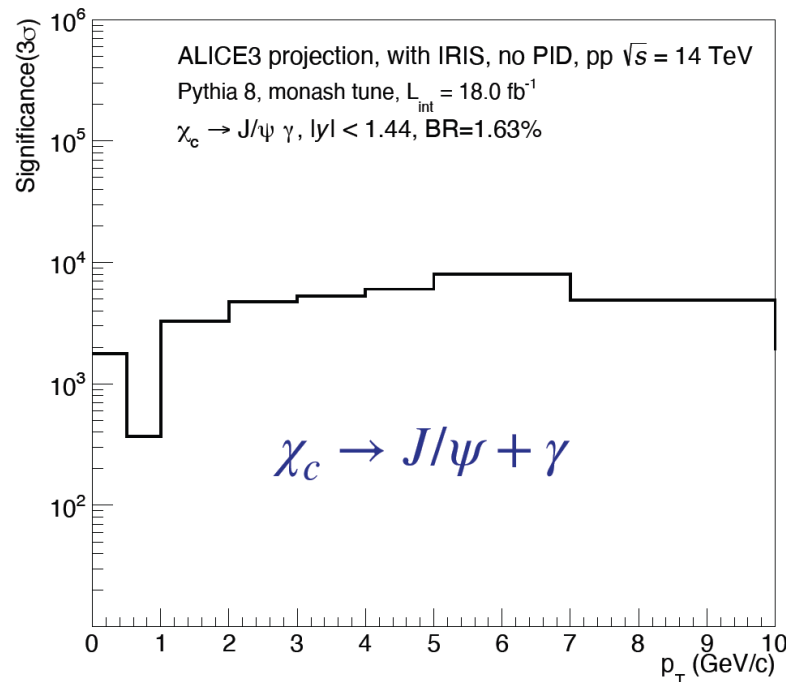


- ❖ Multi-charm baryons vs system size: unique insight in thermalization and hadronization dynamics.
- ❖ ALICE 3: unique experimental access in Pb-Pb collisions

Quarkonium Measurements beyond S-wave States

Quarkonium measurements in Heavy-Ion collisions are currently limited to S-wave states decaying into dileptons: J/ψ , $\psi(2S)$, $\Upsilon(nS)$

χ (and η) state measurements: unique tool to constrain the dynamics of bound-state interactions with the QGP, where different predictions are available from the existing approaches

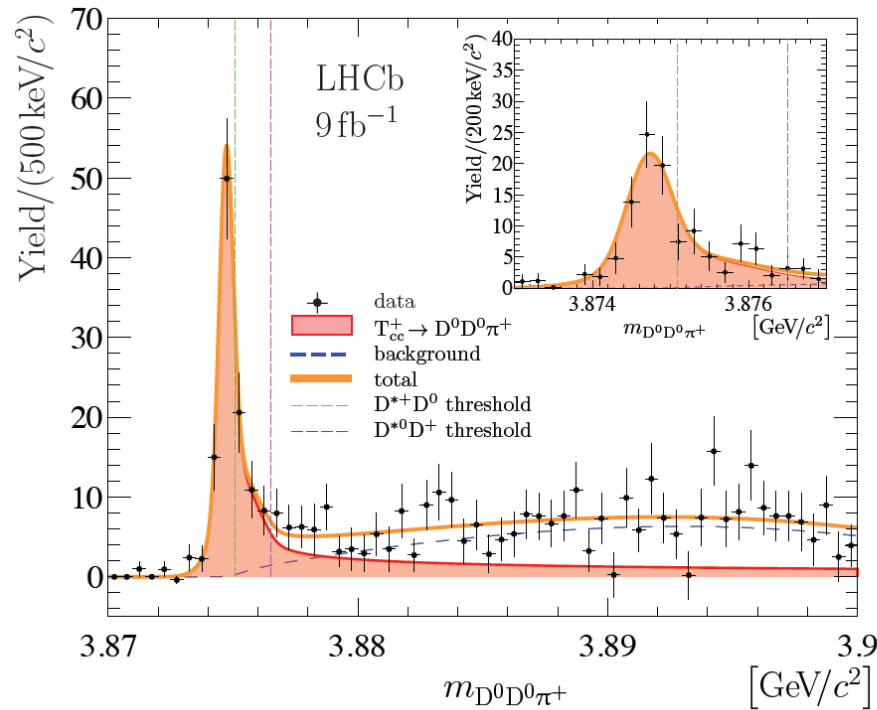


χ_c states:

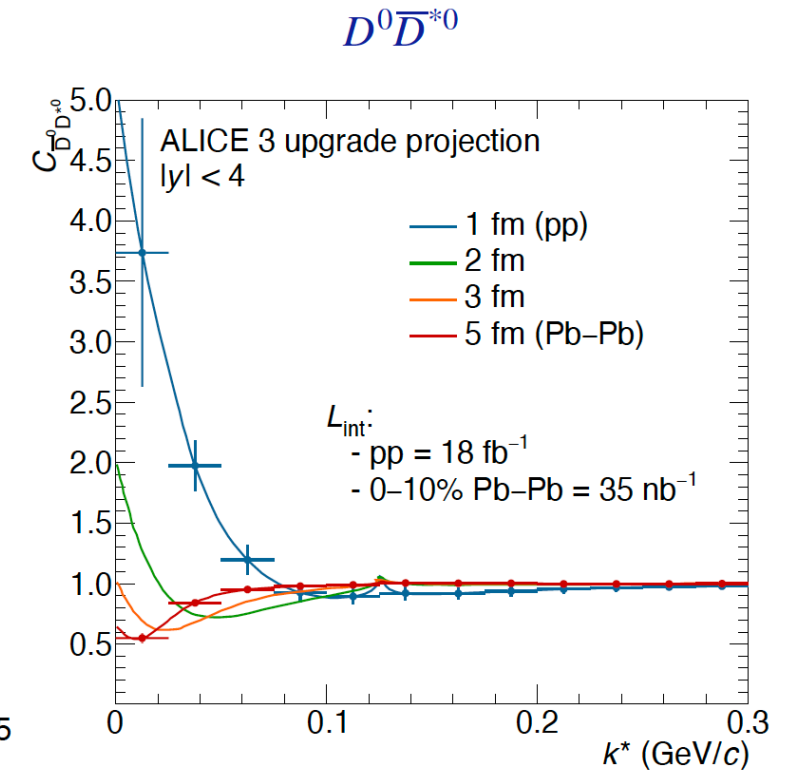
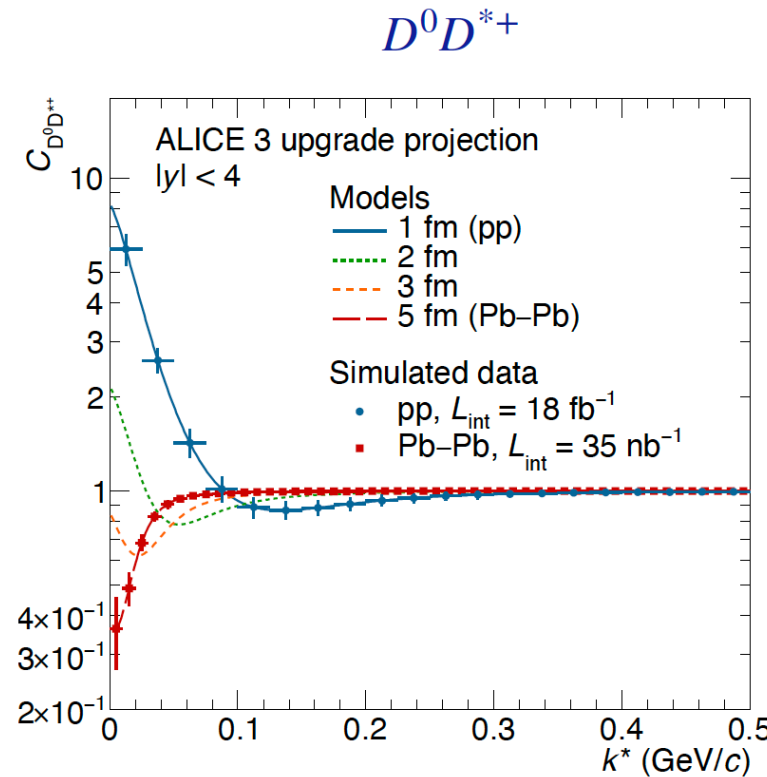
- Binding energy in between J/ψ and $\psi(2S)$
- Sizable feed-down contribution to J/ψ
- **Most promising decay mode: $\chi_c \rightarrow J/\psi \gamma$ (γ measured with calorimetry and/or pair conversion)**

DD* Momentum Correlations

- ❖ Several exotic heavy flavour states identified: loosely bound meson molecule or tightly bound tetraquark?
- ❖ Can we pin down the nature of the states other than performing direct observations?



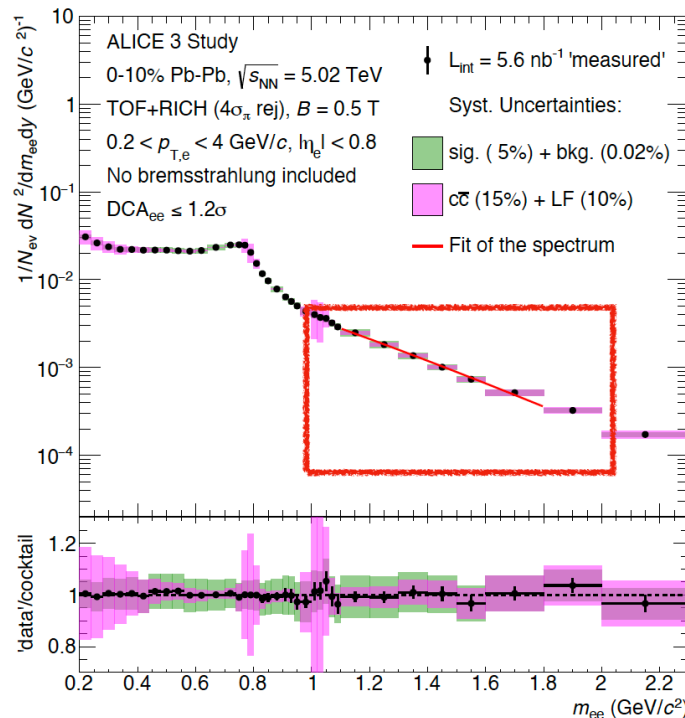
Studying binding potential with final state interactions through femtoscopic correlations



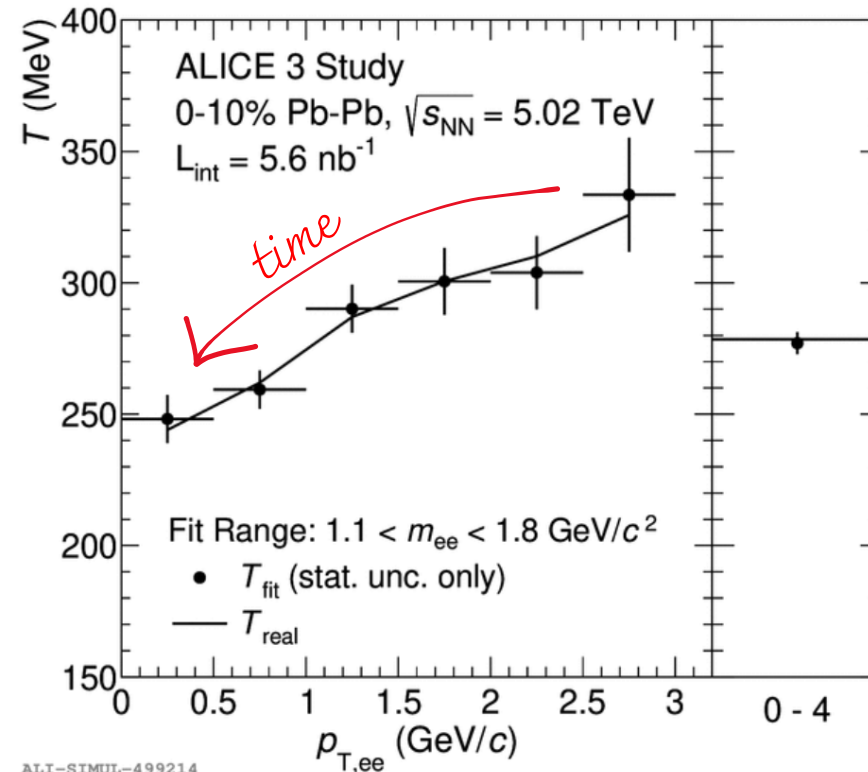
Dileptons: Insight on QGP temperature evolution

- ❖ **Improved pointing resolution** → significant reduction of charm contribution and associated uncertainty: unique opportunity at the LHC
- ❖ **Precision measurement of dielectrons as function of mass and p_T**
- ❖ Excellent precision for dilepton v_2 vs p_T in different mass ranges → time evolution of emission

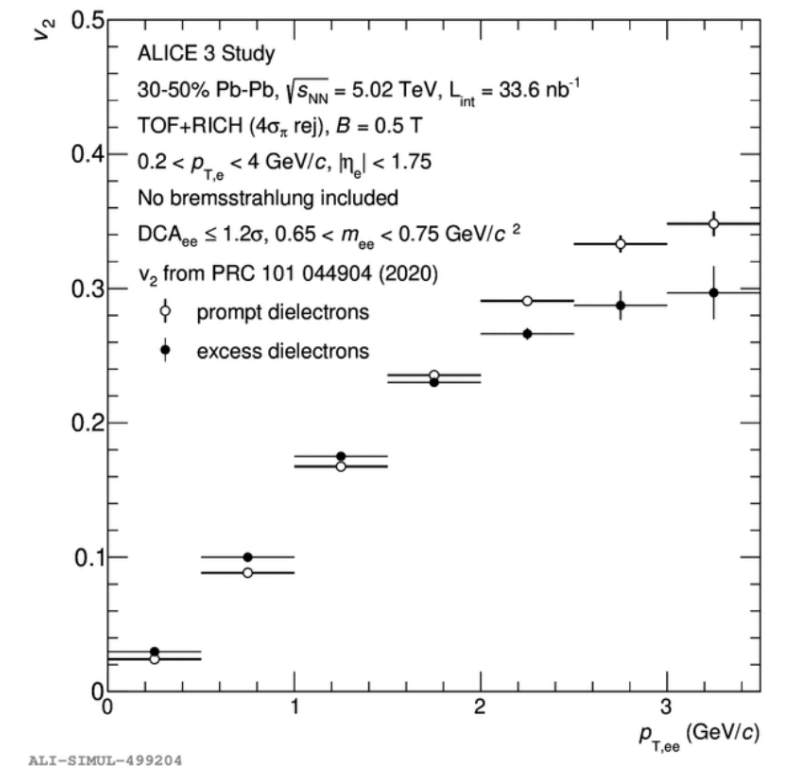
Dielectron mass distribution



Temperature from slope (M_{ee})



Dielectron v_2



Nuclear States: Charm-Deuteron

The lightest possible bound states of a charm baryon and a nucleon without Coulomb repulsion are bound states of Λ_c and a neutron: **c-deuteron and c-triton**

Their possible (non) existence is widely and controversially discussed in the literature and can shed light on the charm-nucleon potential

Most promising decay channels:

- $c_d \rightarrow d + K^- + \pi^+$
- $c_t \rightarrow t + K^- + \pi^+$

