A Large Ion Collider Experiment

ALICE 3
-
Physics programme and detector R&D

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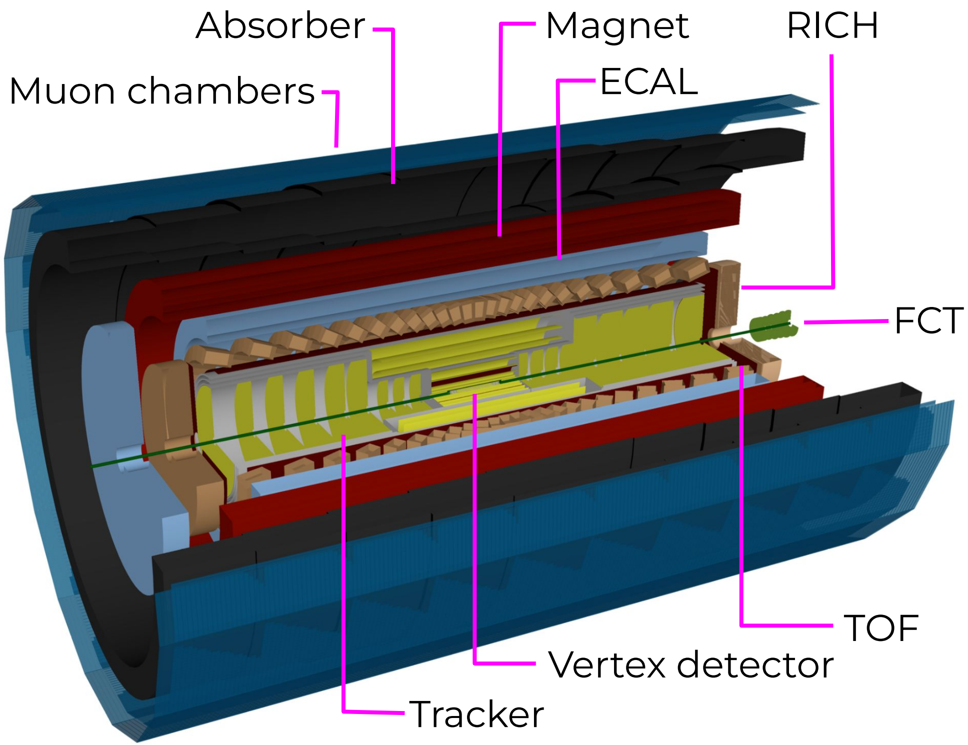
Physikalisches Institut, Ruprecht-Karls Universität, Heidelberg

ALICE 3 - A short overview of the physics program

- High-precision beauty measurements
- Multi-charm baryons, P-wave quarkonia, exotic hadrons
- $D\bar{D}$ azimuthal correlations
- QGP thermal radiation
- Chiral symmetry restoration
- Fluctuations of conserved charges
- Ultra-soft photons and tests of quantum field theories
- And more, see [Letter of Intent arXiv: 2211.02491]

New detector for LHC Runs 5&6



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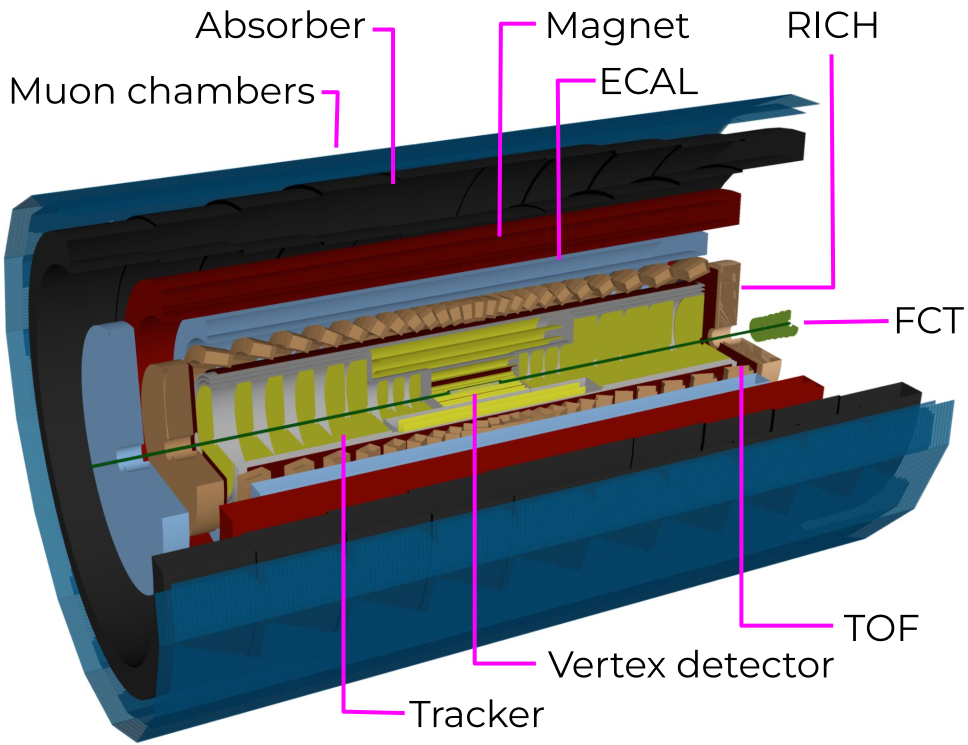


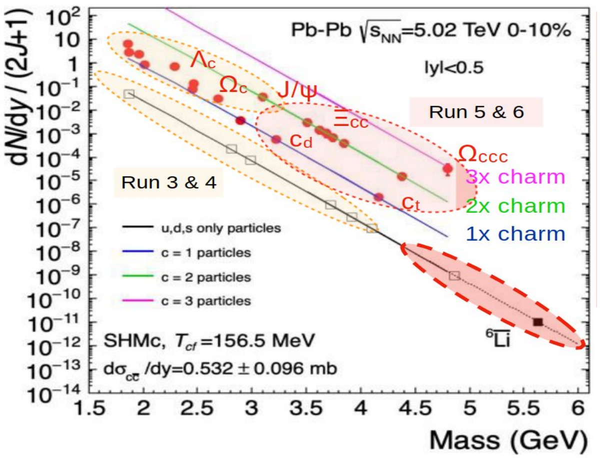
Multi-charm baryons, p-wave quarkonia and exotic hadrons

Goal: Establish connection between the thermalisation of charm quarks in the QGP and the formation of hadrons from deconfined quarks

Measurement: Measure the production of multi-heavy-flavor hadrons (like Ξ_{cc}, Ω_{cc} and ideally Ω_{ccc}) and p-wave quarkonia ($\chi_{c_{1,2}}$). Investigate dependence of the production of multi-heavy-flavor hadrons on the heavy-quark density that varies with rapidity

Method: Track all decay products, such as Ξ^- and Ω^- hyperons, before they decay further („strangeness tracking“)

Yield vs mass



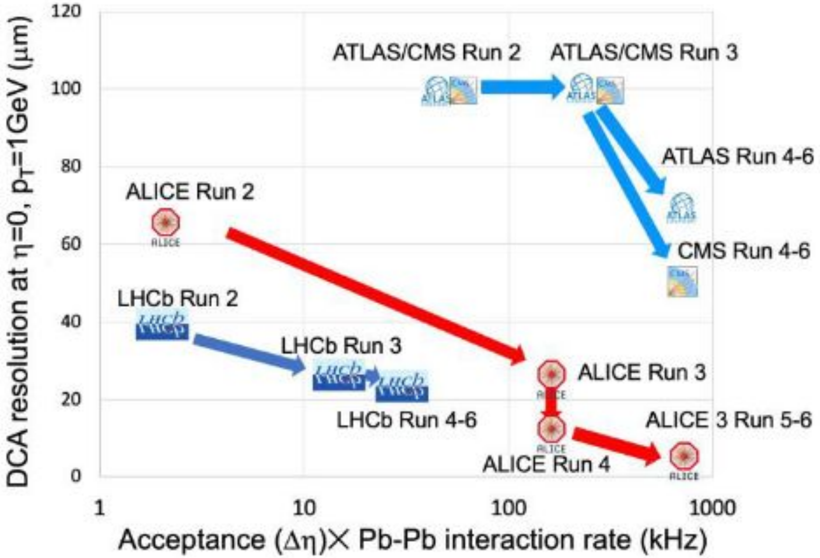
[A Andronic et al, JHEP 07 (2021) 035]

Note: Adaptations made to show capabilities of ALICE 3

Multi-charm baryons, p-wave quarkonia and exotic hadrons

Detector requirements:

- Hadron identification over a wide p_T range (few hundred MeV/*c* to a few GeV/*c*)
- Tracking close to interaction point (first layer at 5 mm)
- High readout rates (>100 kHz Pb-Pb and 24 MHz pp)
- Large acceptance ($|\eta| < 4$)



Multi-charm baryons, p-wave quarkonia and exotic hadrons

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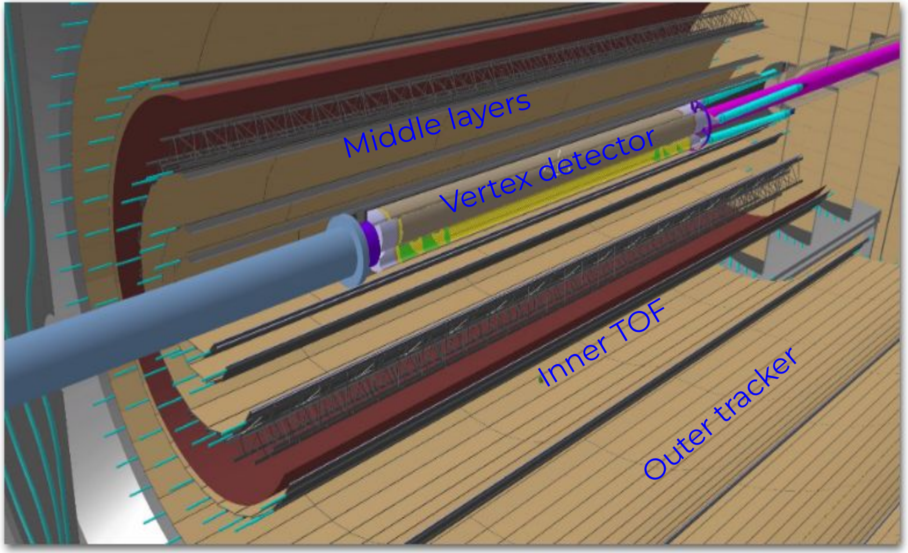
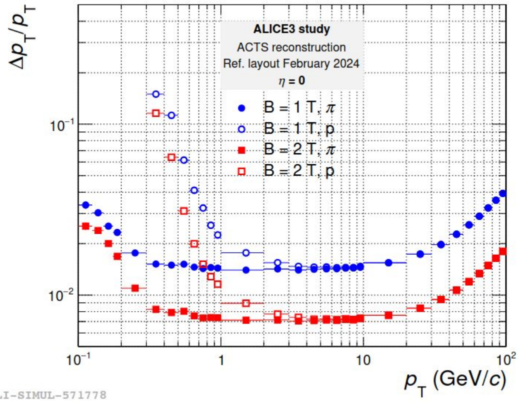
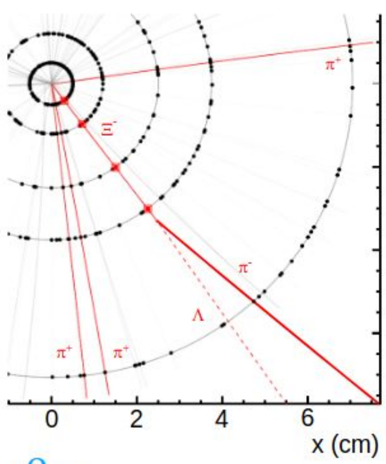




- Large coverage: $|\eta| < 4$
- Sensor pixel pitch ~ 50 μm for σPOS ≈ 10 μm
- Very low material: ~1% X_0/ layer

Strangeness tracking



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

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

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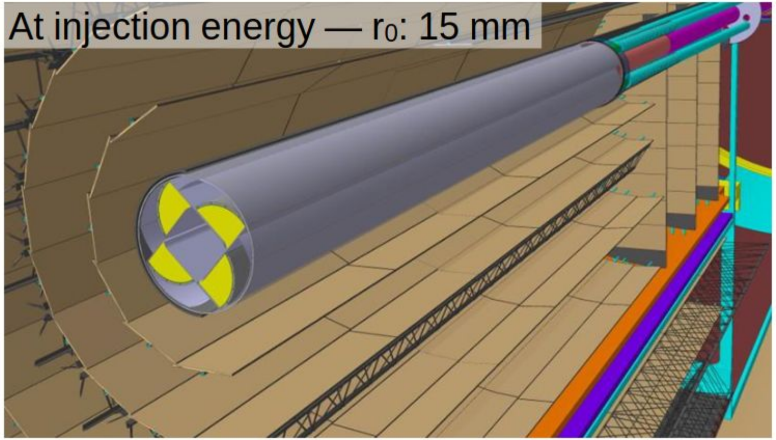
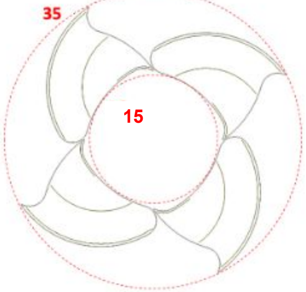
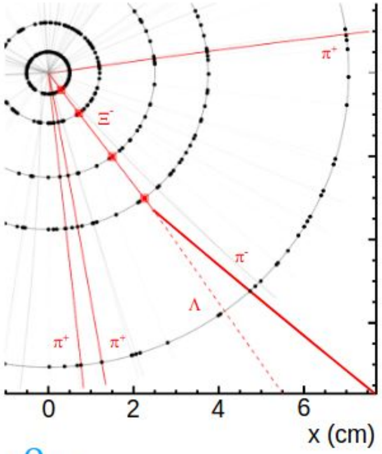




Beam injection

Stable beam

Strangeness tracking



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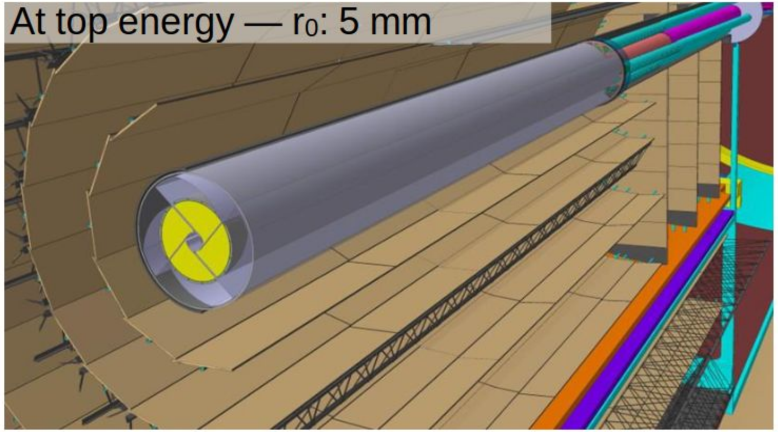
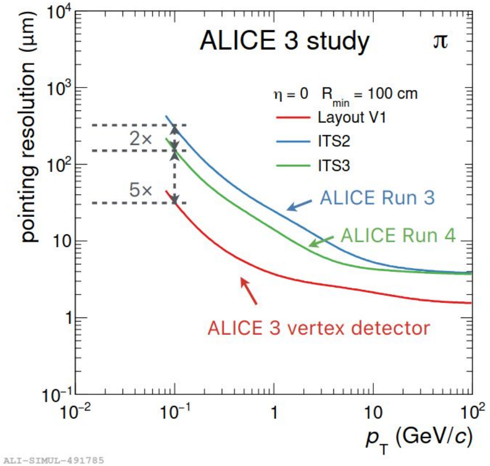
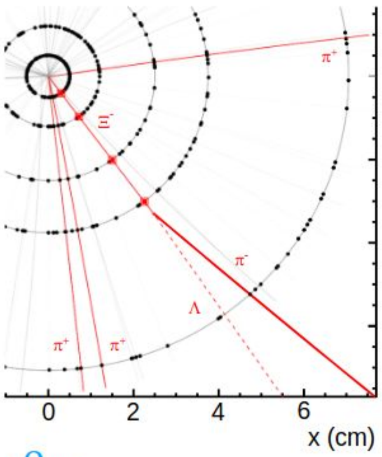




- Retractable: r_0 = 5 mm
- Material budget: 0.1% X_0 / layer
- Unprecedented spatial resolution: 2.5 μm

Strangeness tracking



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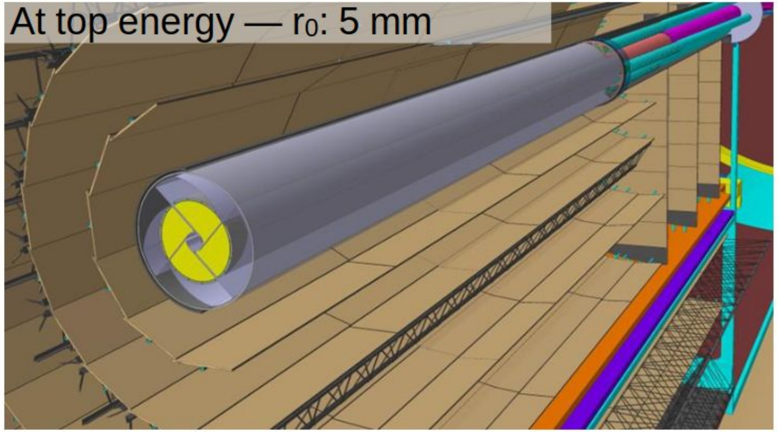
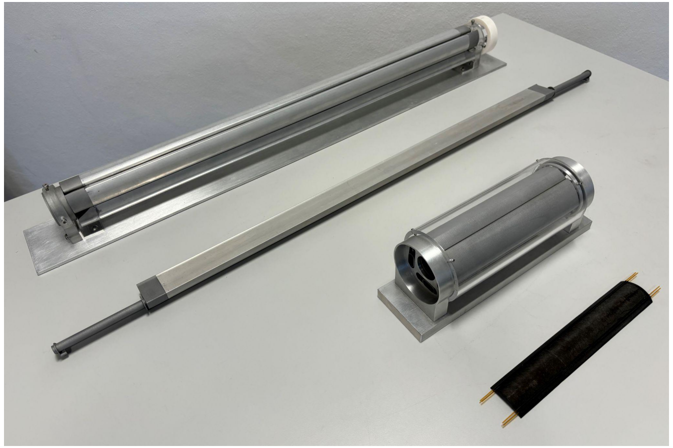
R&D for the Inner Tracker

ITS3 engineering model 2

Sensor R&D leverages on ALICE ITS3 upgrade for Run 4

For more information
Join: talk from Bong-Hwi Lim:
Design and expected performance of the ALICE ITS3 tracker upgrade (next talk)
Read: [TDR ALICE ITS3]





IRIS system:

- Full scale prototypes are being developed

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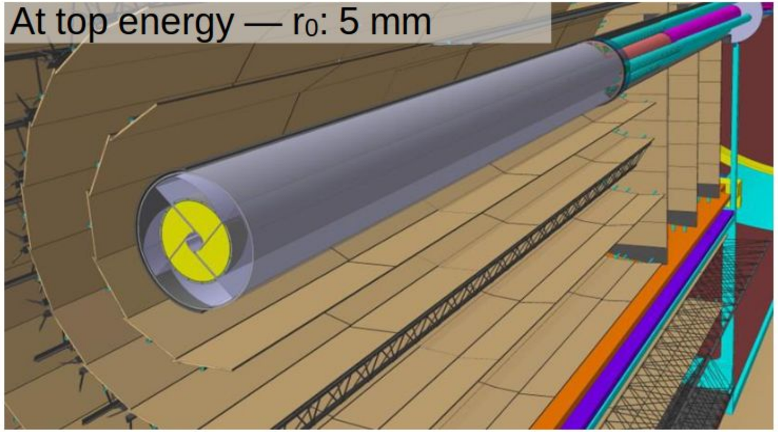

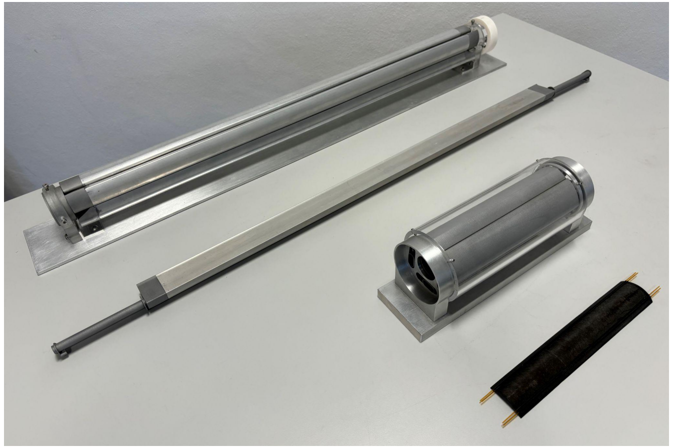

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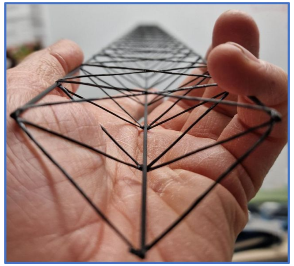
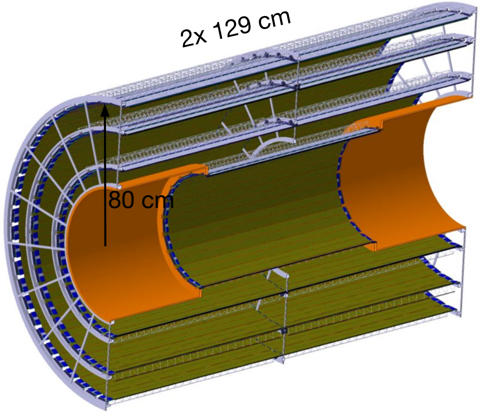
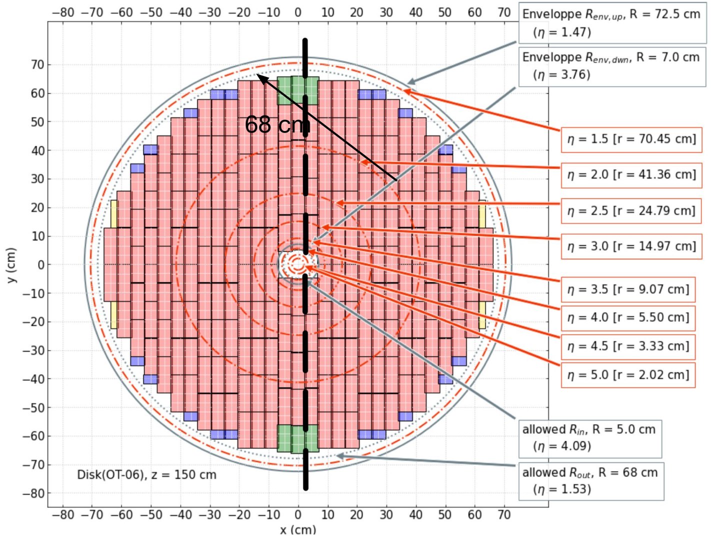
R&D for the Outer tracker





Outer tracker end caps with disks:
- "Paving" with modules
- Mechanical layout, carbon-fibre support



Outer Tracker mechanical layout and cooling concept (air or water) under study

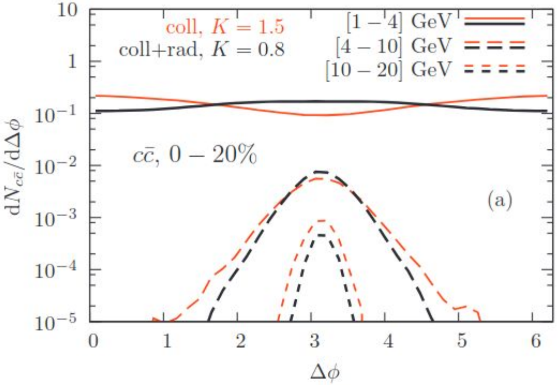
Heavy-flavor correlations

Goal: Discriminate between the different regimes of energy loss in the QGP and reveal possible charm isotropization by diffusion

Measurement: Azimuthal angular correlations between fully-reconstructed charm hadron pairs over a wide rapidity range

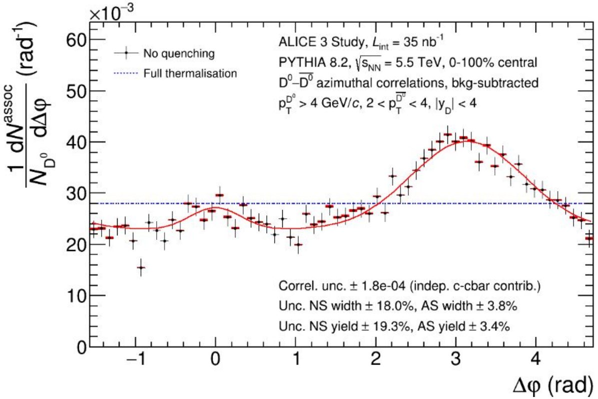
Method: Low p_T angular D^0-$\overline{D^0}$ correlations

Charm azimuthal correlations

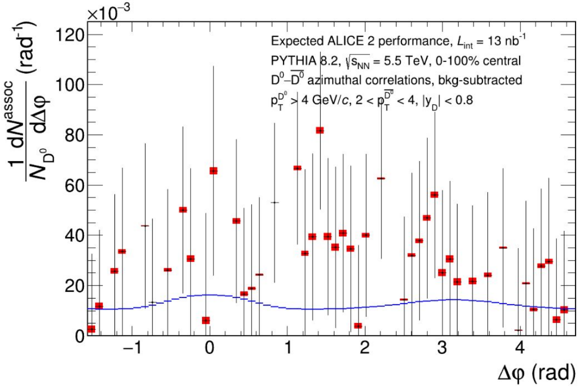


M Nahrgang et al, PRC 90, 024907

ALICE 3



Current ALICE



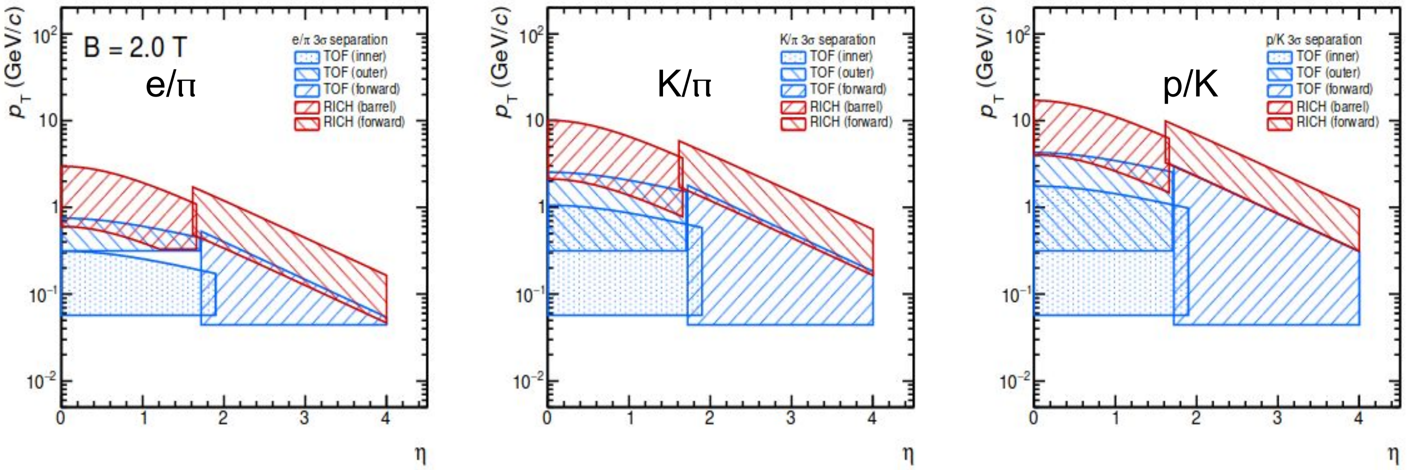
ALICE 3 LoI, arXiv:2211.02491

Heavy-flavor correlations

Detector requirements:

- Large pseudorapidity coverage
- Low p_T D^0-$\overline{D^0}$ measurements which call for excellent background reduction down to p_T = 1 GeV/c
- High statistics -> Interaction rate and read-out rate

Background reduction from the TOF (low p_T) and RICH (larger p_T) is critical to obtain pure samples of D^0.

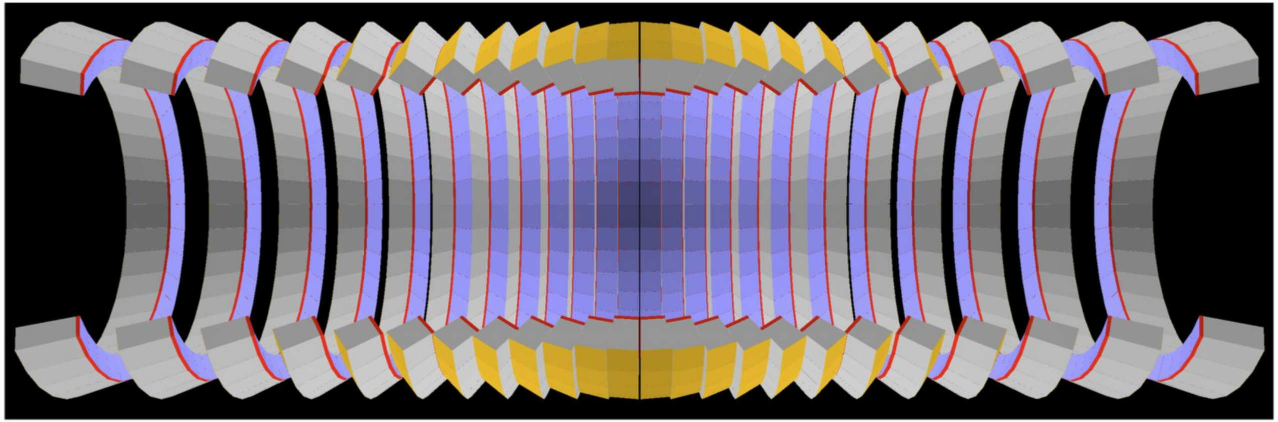


Analytical calculations of the $\eta - pT$ regions in which particles can be separated by at least 3σ for the ALICE 3 particle-identification systems embedded in a 2.0 T magnetic field.

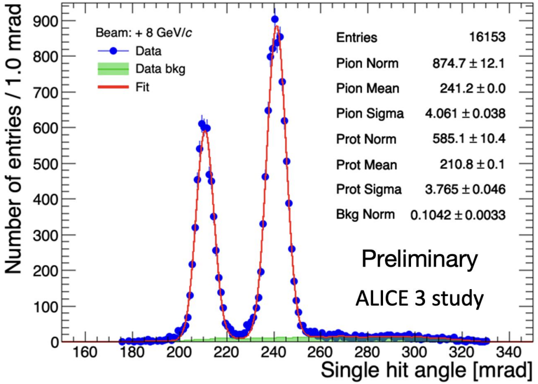
ALICE 3 LoI, arXiv:2211.02491

RICH R&D

Projective layout to minimise surface



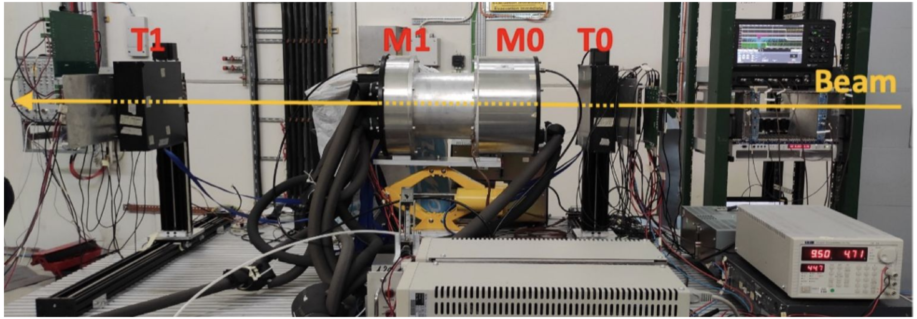
Cherenkov angle of pions and protons: 4 mrad angular resolution



Testbeam in Oct '23 at CERN PS

- Aerogel radiator by Aerogel Factory LTD (Japan)

- 8x8 SiPM matrices from HPK and FBK, various pixel sizes

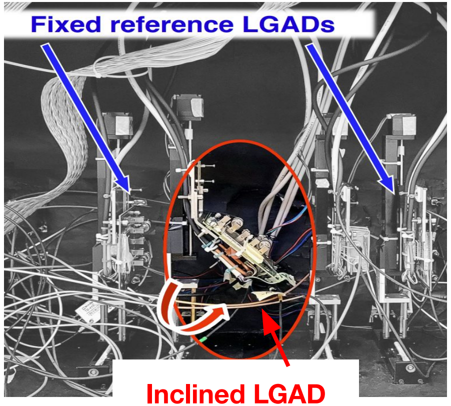


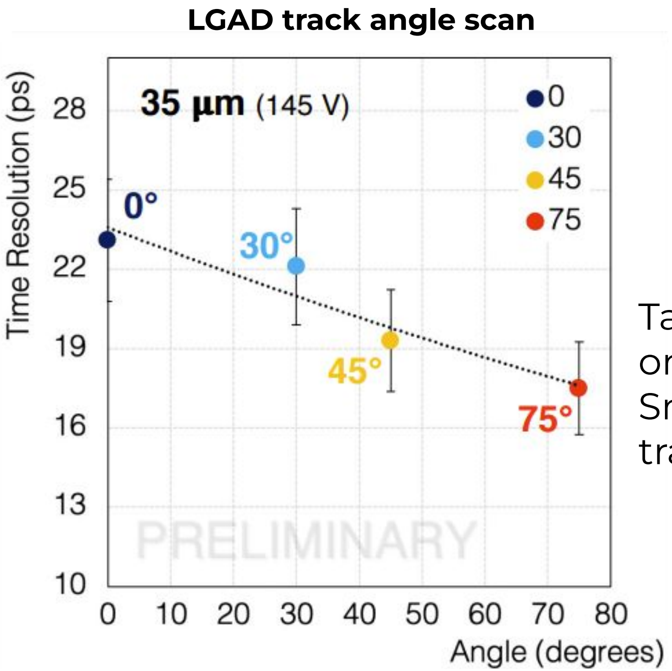
Time-of-flight R&D

Time resolution target: 20 ps

Several test beams since 2022, various sensor options:

- 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

Chiral symmetry restoration

Goal: Confirm presence of chiral symmetry restoration in the QGP at sufficiently high energies

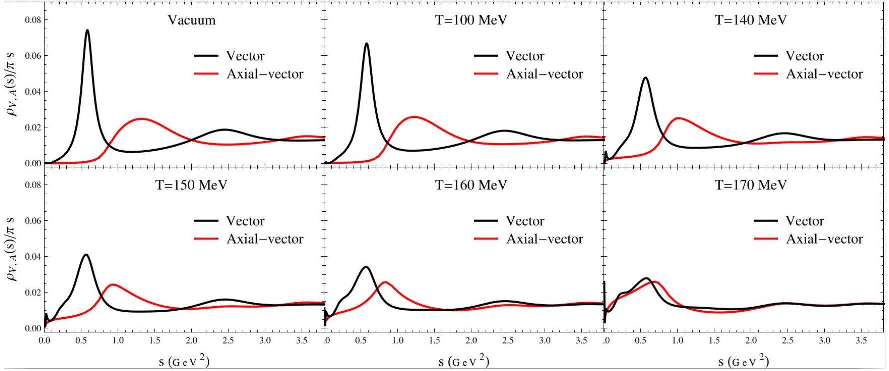
Measurement: Modification of the ρ and a1 mass spectrum in the medium because chiral symmetry breaking generates masses in QCD. Large mass difference between ρ (770 MeV) and a1 (1260 MeV) in the QCD vacuum.

Method: Measure the dilepton mass spectrum close to the ρ peak. Change of 15% is expected

Chiral symmetry restoration

When chiral symmetry is restored in QGP
the mixing of the ρ and a_1 degenerates occurs

ρ and a_1 spectral function

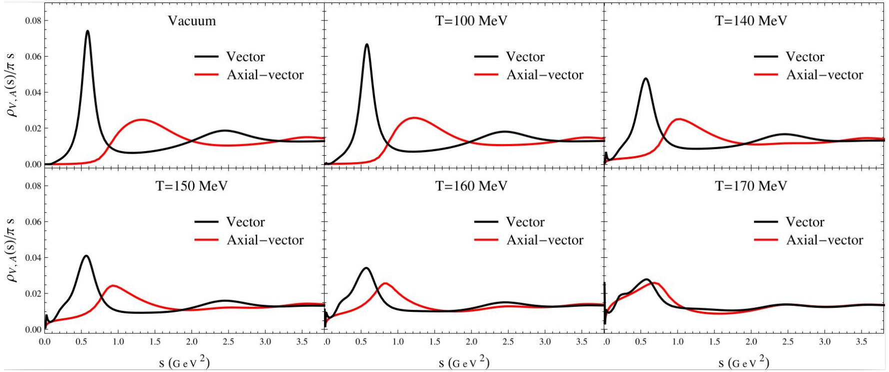


P.M. Hohler and R. Rapp, PLB 731, 103

Chiral symmetry restoration

Measure in the range between the ρ (770 MeV) and ϕ (1019 MeV) peak. This is where the 15% increases becomes visible.

ρ and a_1 spectral function



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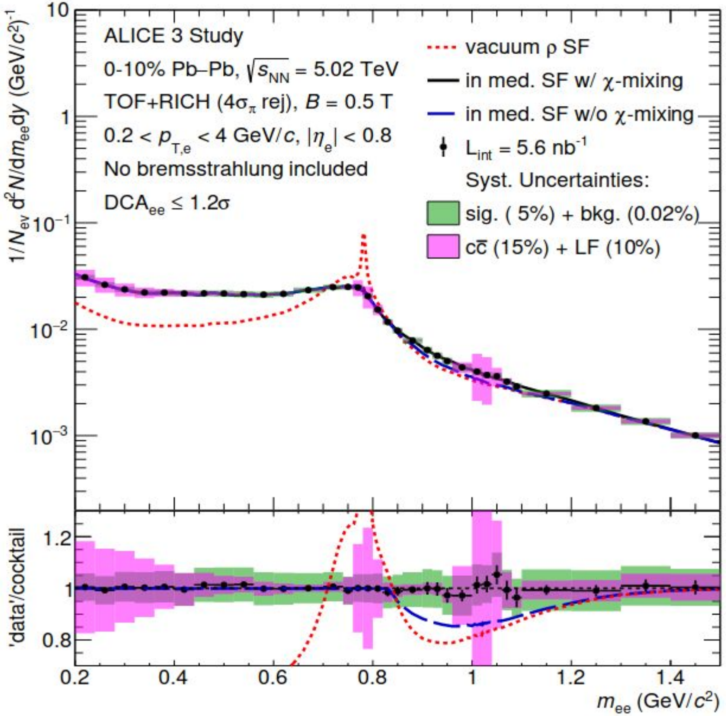


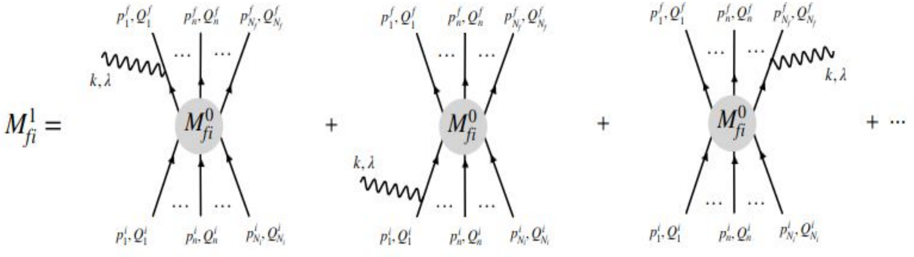
ALICE 3 LoI, arXiv:2211.02491

Ultra-soft photons and tests of quantum field theories

Goal: Conclusively verify the Low theorem, the violation of which would lead to a crisis in theory. The Low theorem can be used to test the infrared limits of quantum field theories such as QED, QCD and quantum gravity.

Measurement: Low's theorem predicts a $1/p_T$ dependence of the ultra-soft photon spectrum as a direct consequence of the conservation of electric charge.

Method: Measure the soft photon spectrum in the forward direction down to a few MeV/c via the conversion to e+e- pairs.



$$M^1_{fi} = \frac{e}{\sqrt{2\omega_k}} \sum_{n=1}^{N_i+N_f} \eta_n Q_n \frac{\epsilon^*(\boldsymbol{k},\lambda)\cdot p_n}{k\cdot p_n} M^0_{fi} + \mathcal{O}(\omega^0_k)$$

- η_n: Outgoing particle: +1, Incoming particle: -1
- Q_n: Charge
- $\epsilon^*(\boldsymbol{k},\lambda)$: Photon polarization 4-vector
- p_n: Charged particle 4-vector
- M^0_{fi}: Non-radiative charged particle production
- $\mathcal{O}(\omega^0_k)$: Higher order corrections

Ultra-soft photons and tests of quantum field theories

Detector requirements:

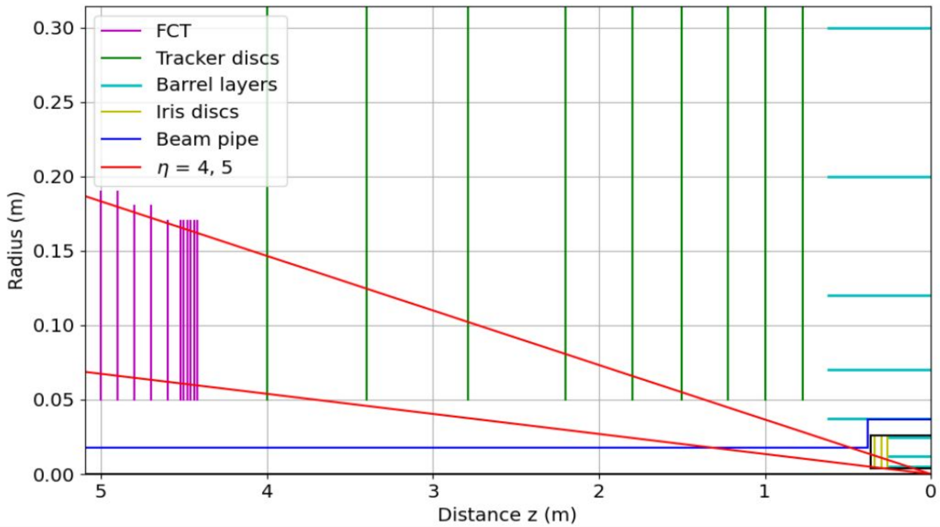
- Dedicated forward conversion tracker (FCT) with a separate dipole magnet to improve tracking in the forward direction
- Low material budget in front of the FCT
- Dedicated particle identification system behind the FCT

- 11 consecutive silicon discs with monolithic pixel trackers

- Pseudorapidity coverage: $4 < \eta < 5$

- Dipole magnet with a magnetic field of 0.25 T

- PID for e^+/e^- event veto



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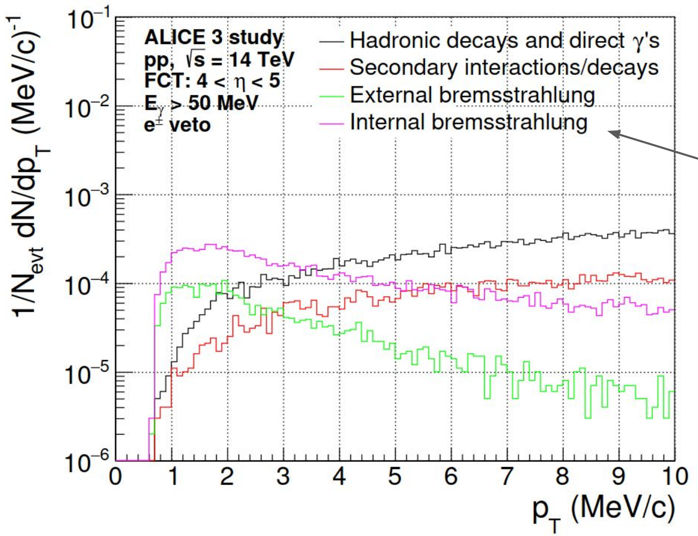


Signal with $1/p_T$

Summary

To achieve its physics goals, ALICE 3 will have

- An **unprecedented spatial and DCA resolution** from the **retractable Vertex Detector**
- **Large pseudorapidity coverage $|\eta| < 4$** thanks to the **barrel and end caps layout**
- **Very low material budget** for the all-silicon inner and outer trackers
- **High readout** capabilities 24 MHz in pp
- Comprehensive **particle identification capabilities** thanks to the RICH, TOF and MID

R&D is well on its way and the building of prototypes has started.

To learn more about the physics program of ALICE 3
I invite you to have a look at the Letter of Intent
ALICE 3 LoI, arXiv:2211.02491

Backup

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	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

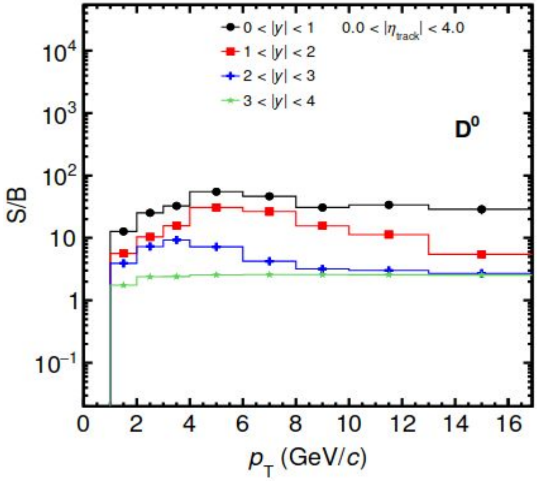
- **2023-25** : Scoping Document, selection of technologies, small-scale prototypes (~25% of R&D funds)
- **2026-27** : Large-scale engineered prototypes (~75% of R&D funds) → TDRs and MoUs
- **2028-30** : Construction and testing
- **2031-32** : Contingency and pre-commissioning
- **2033-34** : Preparation of cavern, installation
- **2035-41** : Data taking

Heavy-flavor correlations

Detector requirements:

- Large pseudorapidity coverage
- Low p_T D^0-$\overline{D^0}$ measurements which call for high selection efficiency down to p_T = 1 GeV/c
- High statistics -> Interaction rate and read-out rate

High purity for D^0 measurements.

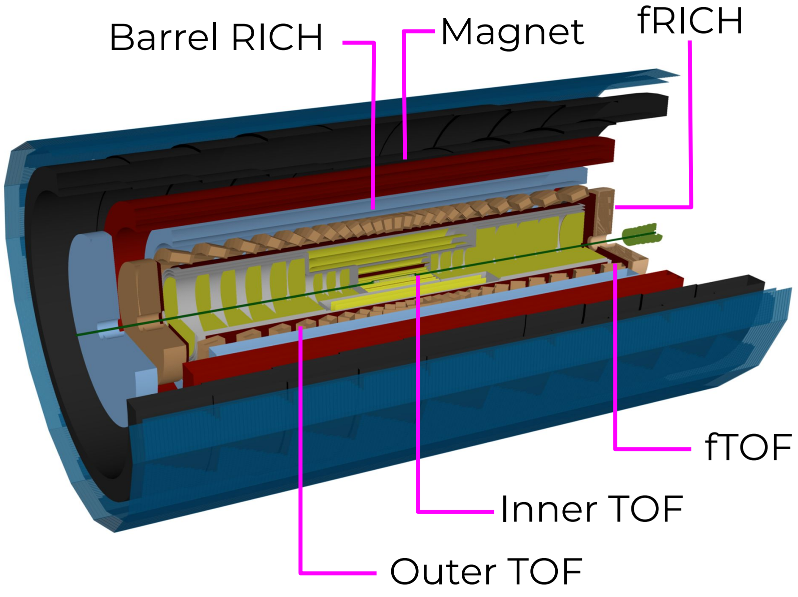


ALICE 3 LoI, arXiv:2211.02491

$$D^0 \rightarrow K^+\pi^-$$

D^0 candidate selection with IRIS and Outer tracker.

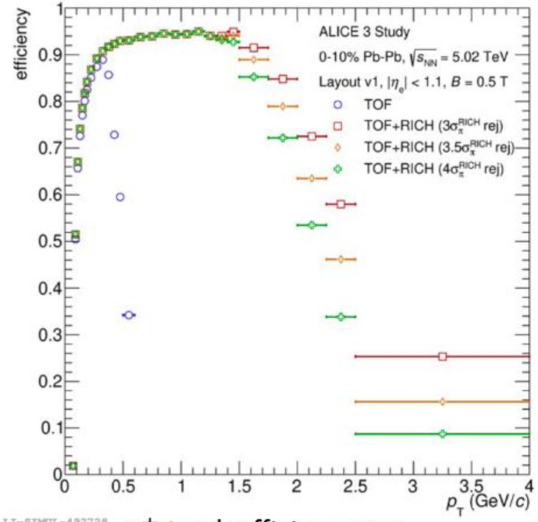
PID selection with RICH and TOF



Chiral symmetry restoration

Detector requirements:
- Electron identification
- High resolution vertexing capabilities

Electron ID



$e^{\pm}$ track efficiency vs p_T

[ALICE 3 LoI, arXiv:2211.02491](https://arxiv.org/abs/2211.02491)

Measure in the range between the ρ (770 MeV) and ϕ (1019 MeV) peak. This is where the 15% increases becomes visible.

IRIS Tracker + Outer tracker for the tracking

RICH + TOF for the electron identification

ECAL: Jet and gamma performance

ECal can measure photons with x10 larger acceptance than ALICE 2 (EMCal)

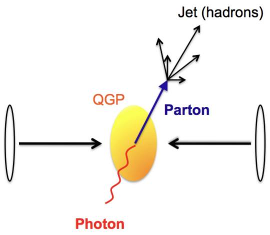
Photon can be correlated with charged-jets in |eta|<4 (exploiting ALICE 3 tracker acceptance)

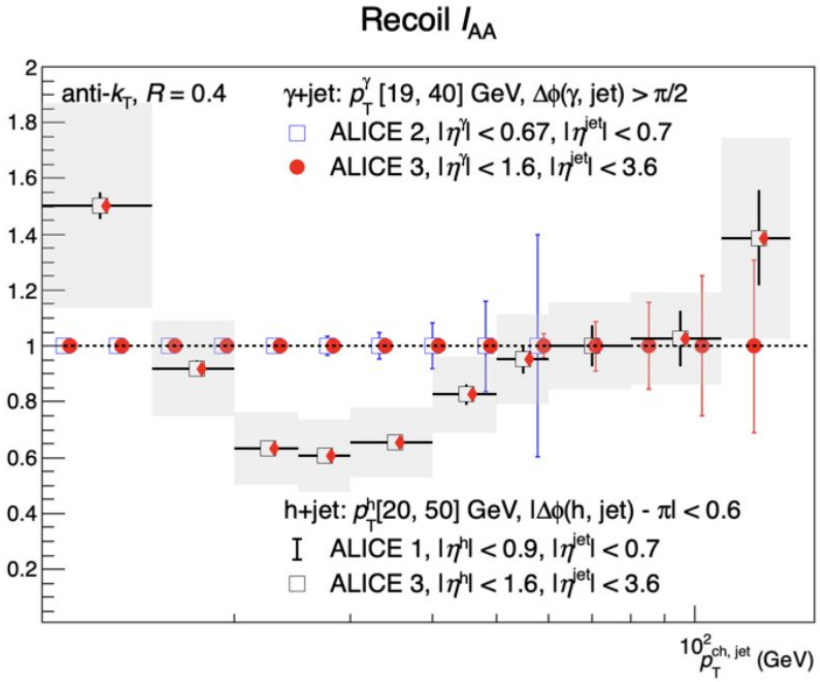
Uniqueness:

- Wrt ATLAS/CMS: low p_T
  - p_{Tjet}>10 GeV in ALICE 3 (same ALICE), vs 50 in ATLAS/CMS
  - p_{Tgamma}>10-20 GeV in ALICE 3, vs 50 in ATLAS/CMS

Wrt ALICE 2: x10 larger acceptance for the photon (EMCal vs ECal), x2 larger L_{int}, ch. jets in |eta|<3.6 vs |eta|<0.5

Projections for recoil jet R_{AA} and I_{AA}





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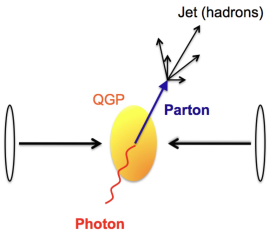
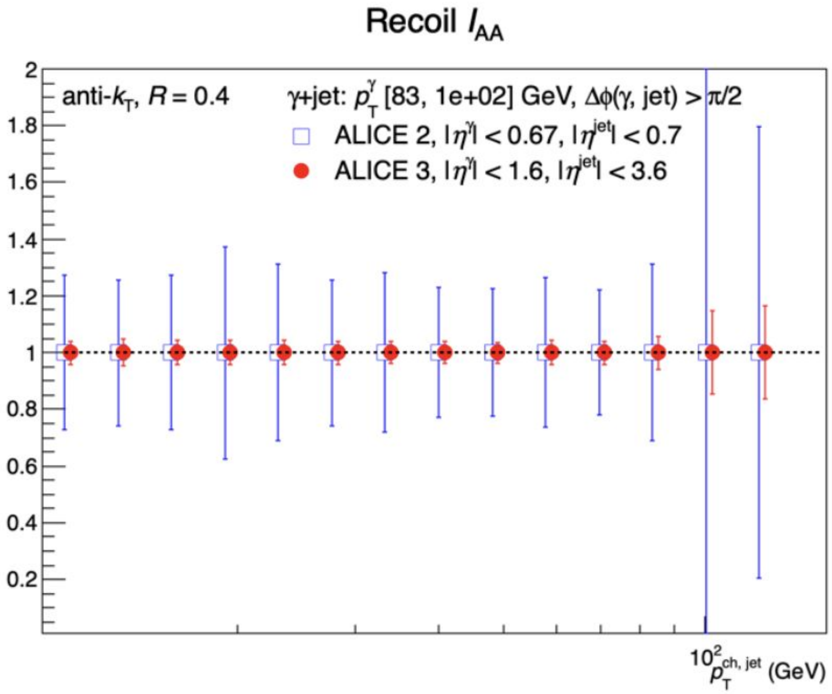
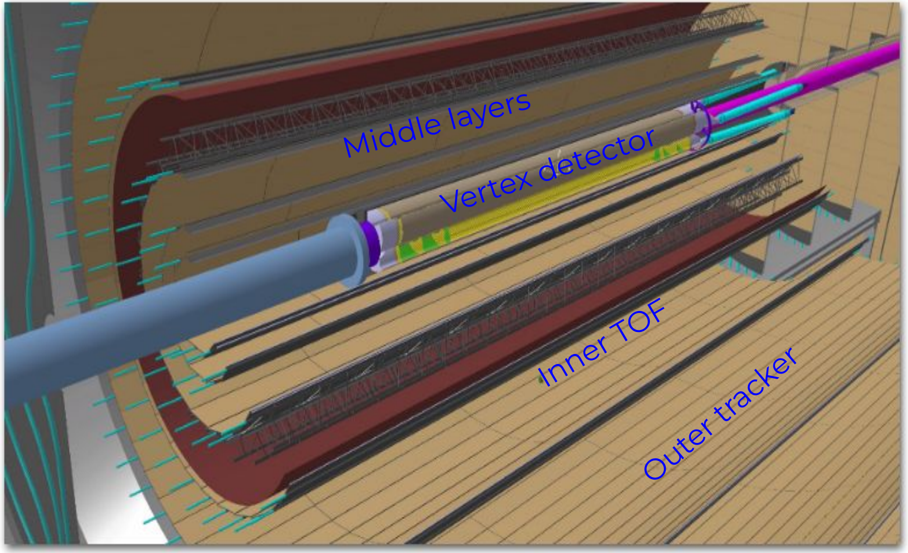


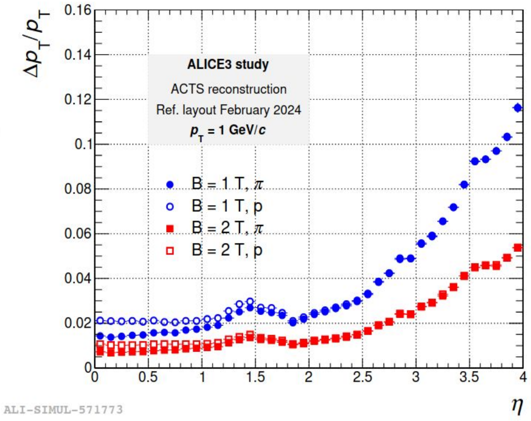


Multi-charm baryons, p-wave quarkonia and exotic hadrons

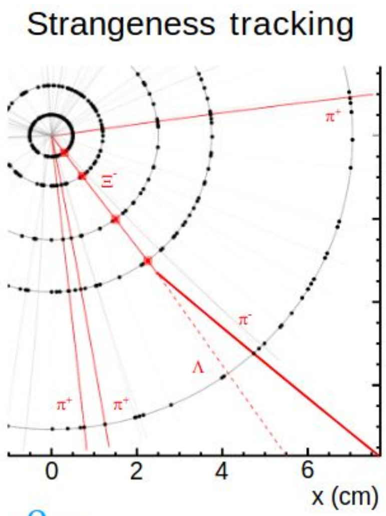
Detector requirements:

- Hadron identification over a wide p_T range (few hundred MeV/c to a few GeV/c)
- Tracking close to interaction point (5 mm)
- High readout rates (>100 kHz Pb-Pb and 24 MHz pp)
- Large acceptance (|η| < 4)





- Large coverage: |η| < 4
- Sensor pixel pitch ~ 50 µm for σPOS ≈ 10 µm
- Very low material: ~1% X_0/ layer



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

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