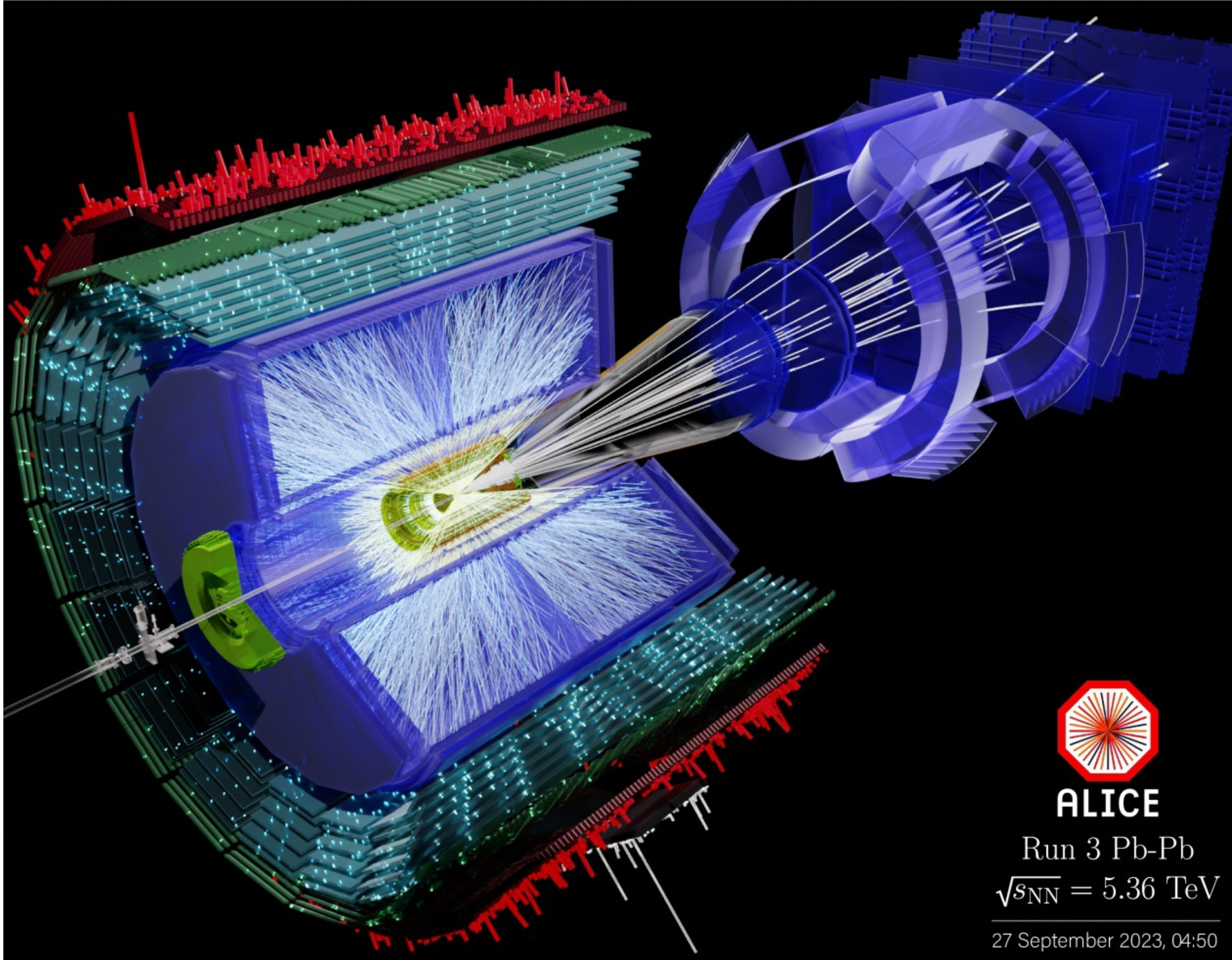
ALICE status report

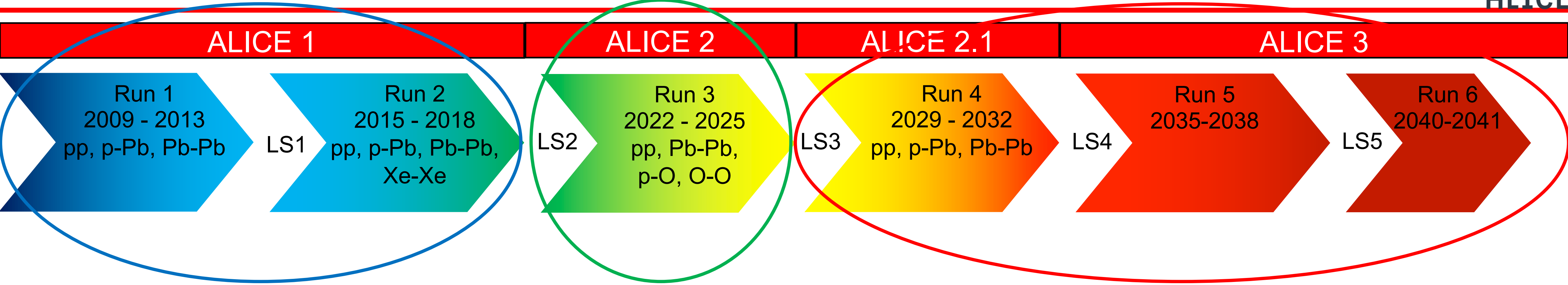
Daiki Sekihata
(Center for Nuclear Study,
the University of Tokyo)

on behalf of
ALICE Collaboration

LHCC open session
29.May.2024



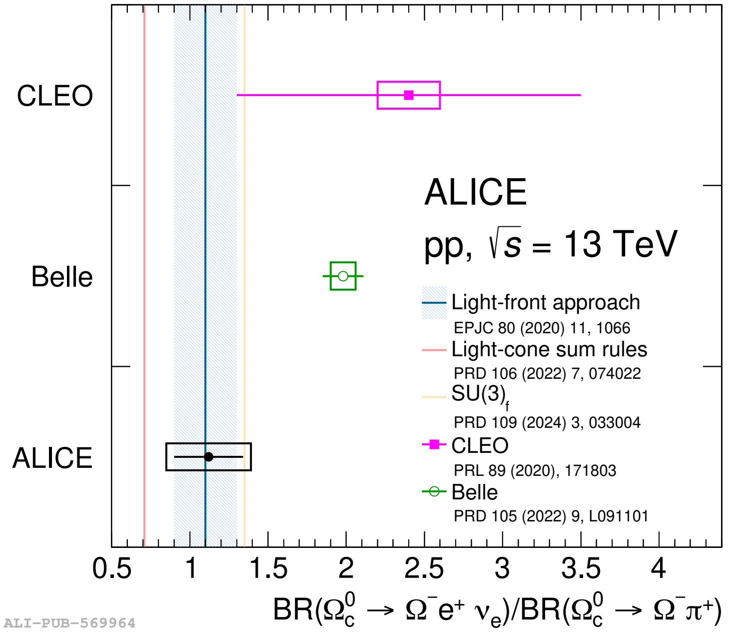
Outline

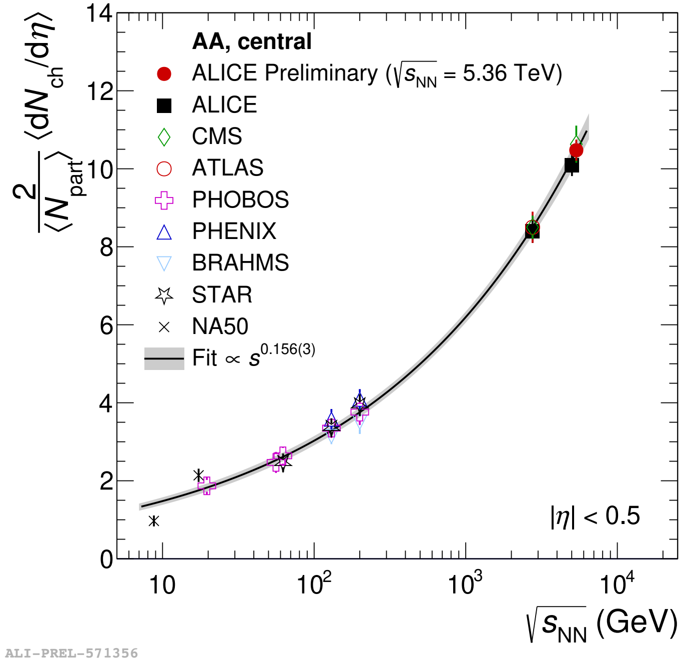


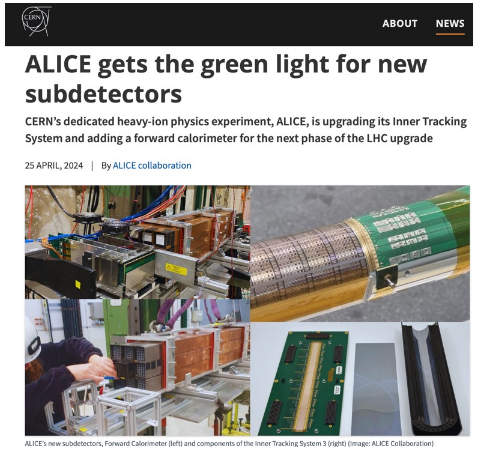
Recent physics results

First Run 3 Pb–Pb results

Upgrade projects



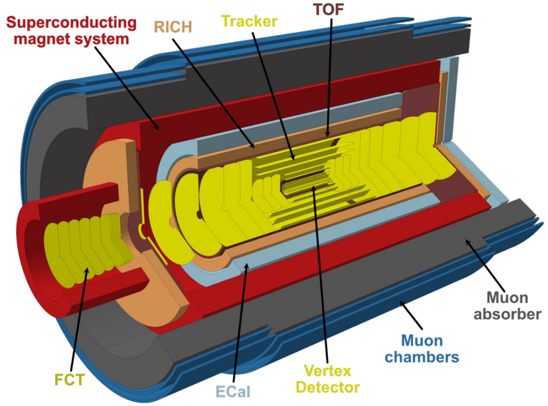




ALICE gets the green light for new subdetectors

CERN's dedicated heavy-ion physics experiment, ALICE, is upgrading its Inner Tracking System and adding a forward calorimeter for the next phase of the LHC upgrade

25 APRIL, 2024 | By ALICE collaboration



List of new publications since last LHCC

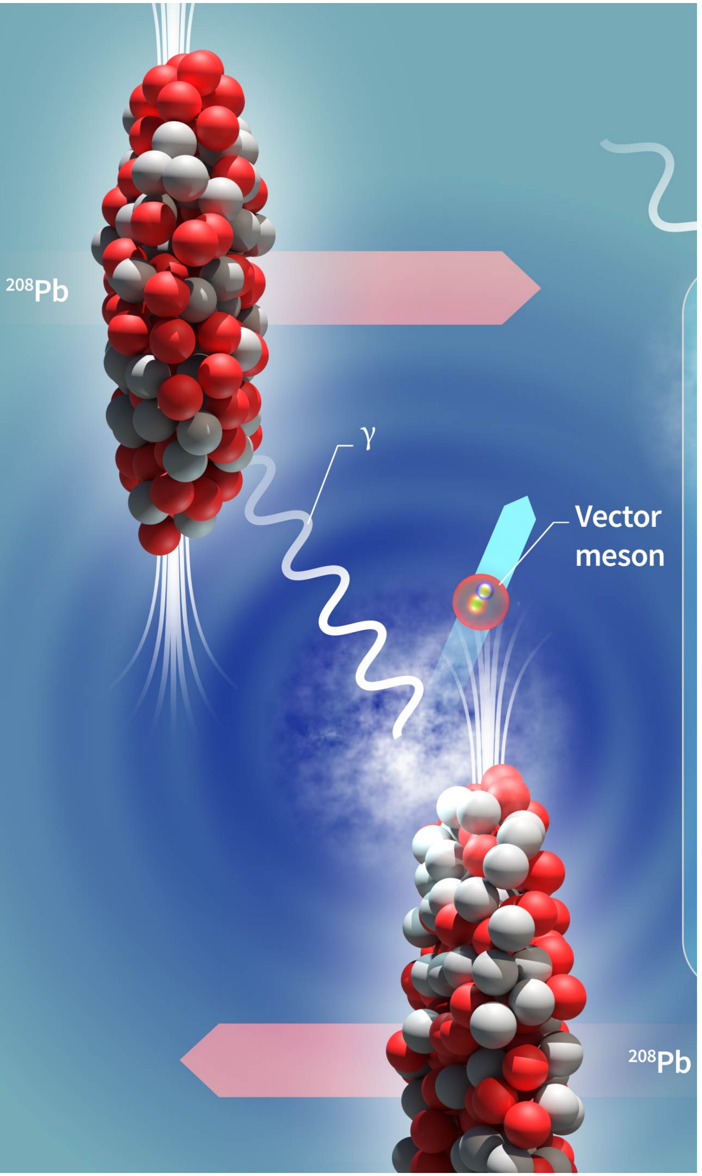
- Systematic study of flow vector decorrelation in $\sqrt{s_{NN}}$ = 5.02 TeV Pb–Pb collisions https://arxiv.org/abs/2403.15213
- Exclusive four pion photoproduction in ultraperipheral Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV https://arxiv.org/abs/2404.07542
- Measurement of Ω_c^0 baryon production and branching-fraction ratio BR($\Omega_c^0 \to \Omega^- e^+\nu_e$)/BR($\Omega_c^0 \to \Omega^- \pi^+$) in pp collisions at $\sqrt{s}$ = 13 TeV https://arxiv.org/abs/2404.17272
- Investigating strangeness enhancement in pp collisions using angular correlations http://arxiv.org/abs/2405.14511
- Measurement of the impact-parameter dependent azimuthal anisotropy in coherent ρ^0 photoproduction in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV http://arxiv.org/abs/2405.14525
- Investigating Strangeness Enhancement in Jet and Medium via ϕ(1020) production http://arxiv.org/abs/2405.14491
- Measurement of Ξ_c^0 production cross-section in p–Pb collisions at 5.02 TeV http://arxiv.org/abs/2405.14538
- Charm fragmentation fractions and $c\bar{c}$ cross section in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV http://arxiv.org/abs/2405.14571

More papers are under preparation for summer conferences (SQM, LHCP, ICHEP and HP).

- Strangeness production in p–Pb collisions in jets and medium using angular correlations
- (Anti)nuclei production and flow in Xe–Xe collisions at 5.44 TeV

Exclusive four-pion photoproduction in UPCs

https://arxiv.org/abs/2404.07542



- ALICE published $\rho^0(770)$ meson photoproduction in Pb–Pb UPCs
  - JHEP 1509 (2015) 095, Pb–Pb at 2.76 TeV
  - JHEP 06 (2020) 35, Pb–Pb at 5.02 TeV

UPC = UltraPeripheral Collision

- Not conclusive on excited states of ρ^0 due to experimental uncertainty
  - STAR at BNL and experiments at SPS, LEP : 2 resonances
  - H1 at DESY : single broad resonance

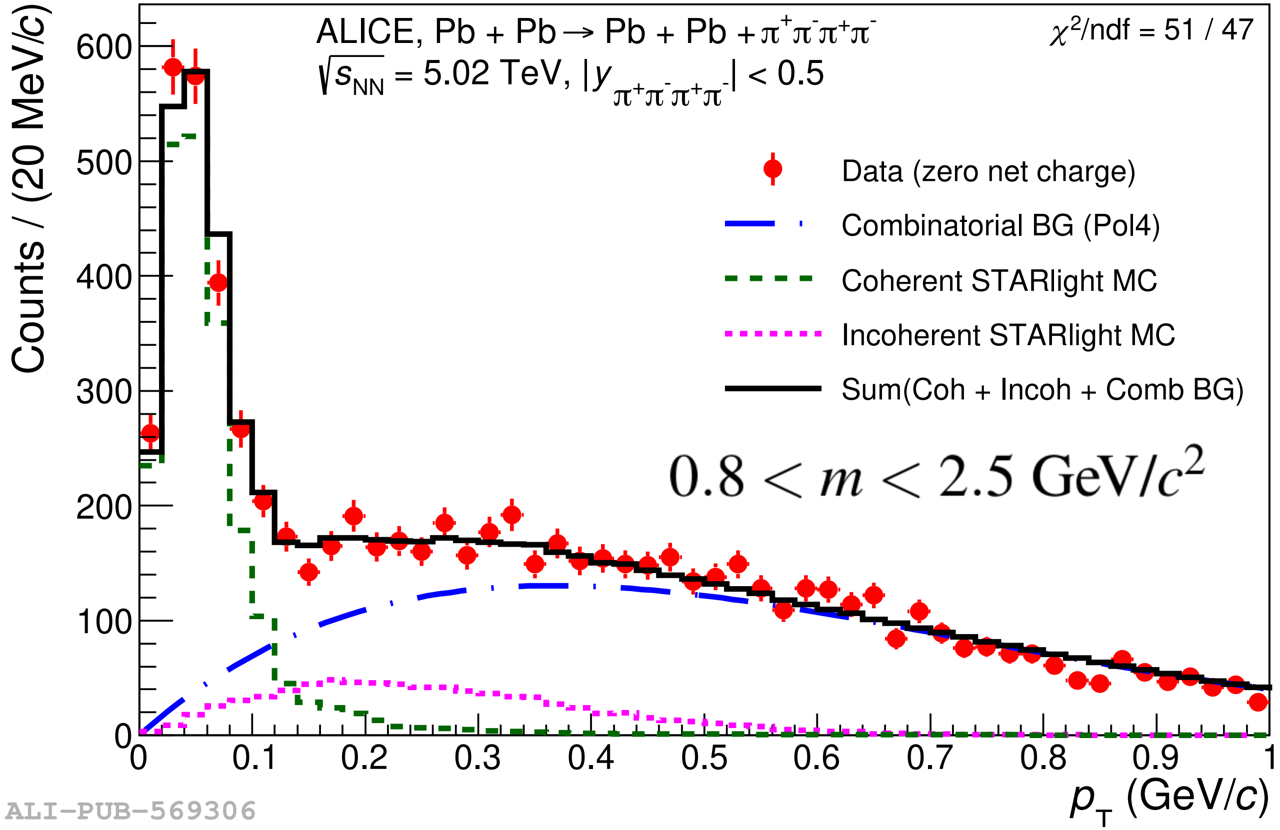
→ crucial for understanding nature of these resonances

NEW: First measurement of exclusive $\pi^+\pi^-\pi^+\pi^-$ photoproduction at the LHC

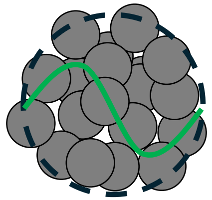
https://home.cern/news/news/physics/alice-shines-light-nucleus-probe-its-structure

Exclusive four-pion photoproduction in UPCs

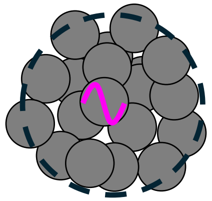
https://arxiv.org/abs/2404.07542



- Four-track events with zero net charge
- Events with non-zero net charge for combinatorial background estimation
- Raw signal counts = 1987 ± 54 (stat.)
  - template fit to data with 3 components



$\lambda_{coherent} \fallingdotseq R_{nucleus}$ ~ 10 fm
→ $\langle p_T \rangle$ ~ 50 MeV/c



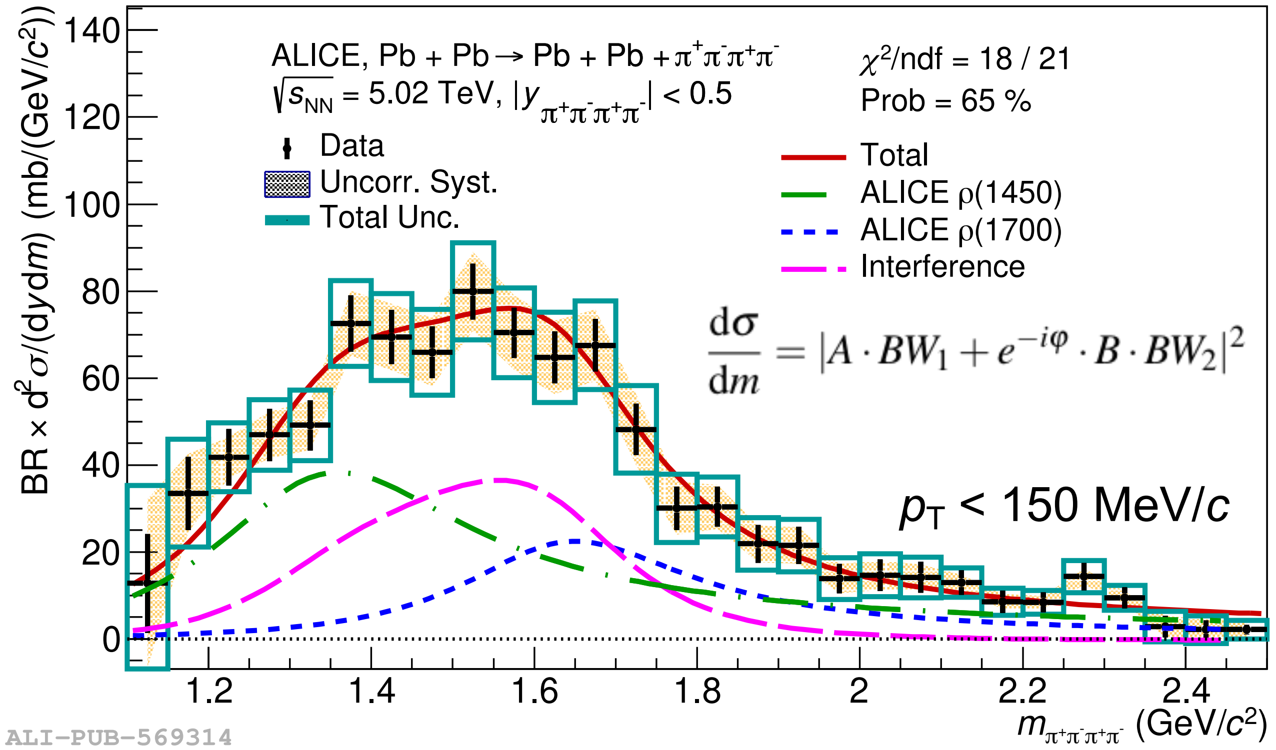
$\lambda_{incoherent} \fallingdotseq R_{nucleon}$ ~ 1 fm
→ $\langle p_T \rangle$ ~ 500 MeV/c

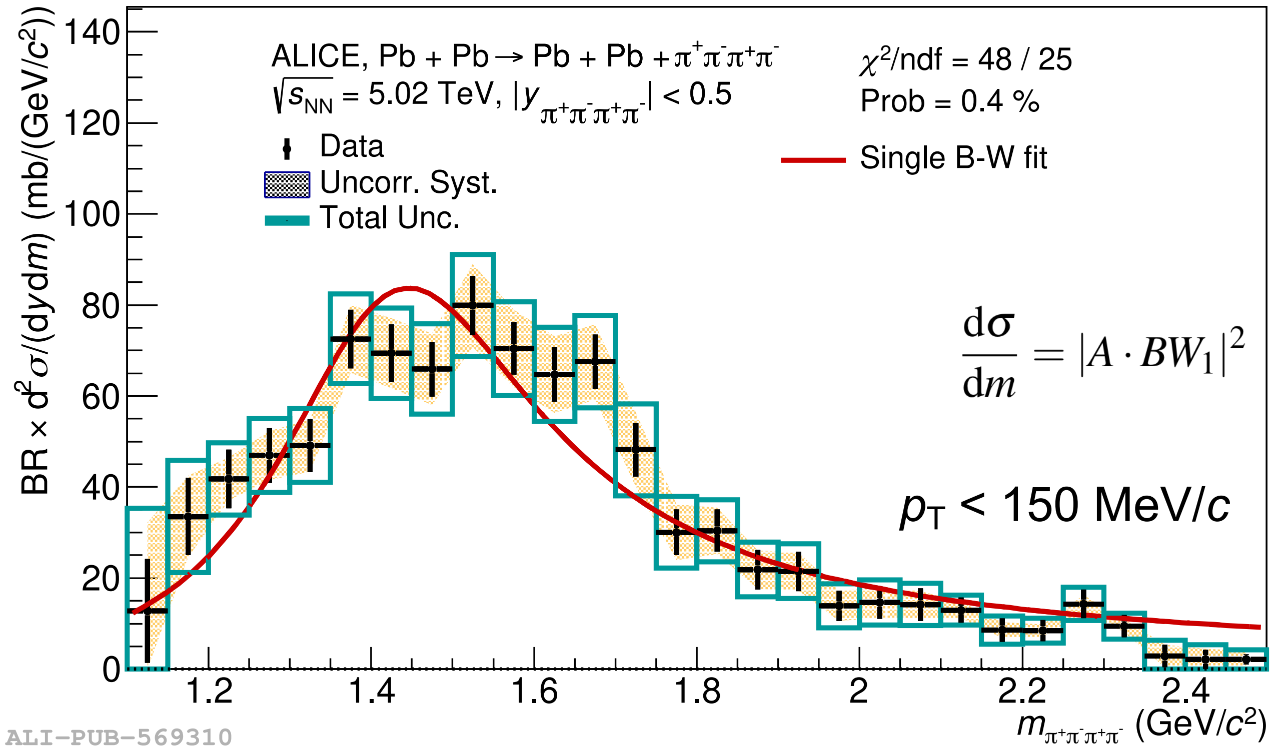
coherent : photon interacts with full nuclei
→ vector meson in p_T < 0.1 GeV/c

incoherent : photon interacts with one nucleon
→ vector meson in p_T < 1 GeV/c

Decomposition into ρ(1450) and ρ(1700)

https://arxiv.org/abs/2404.07542



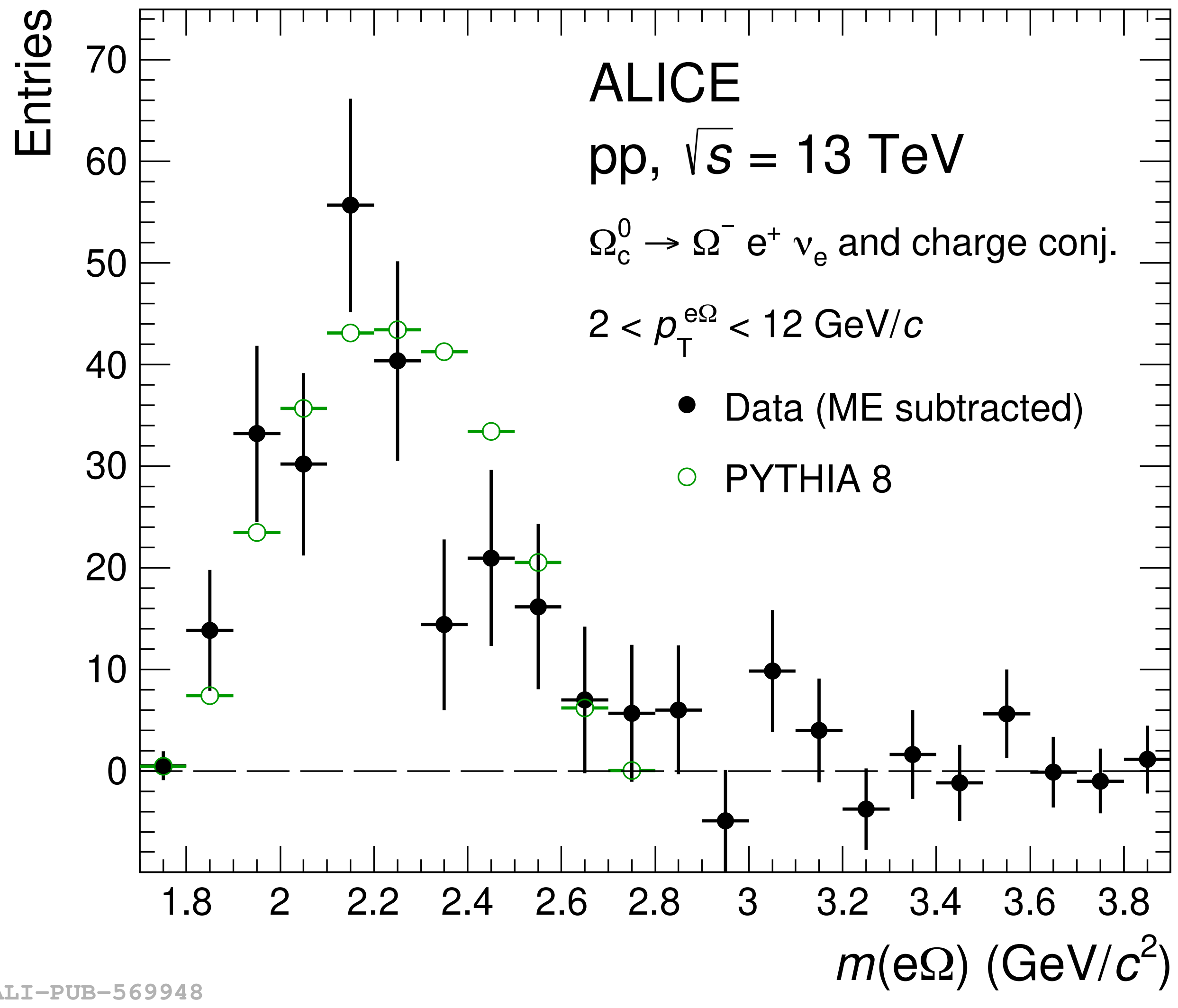


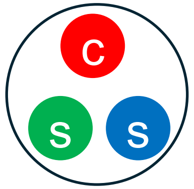
	m (MeV/c^2)	Γ (MeV/c^2)
PDG $\rho(1450)$	1465 ± 25	400 ± 60
PDG $\rho(1700)$	1720 ± 20	250 ± 100
STAR Au–Au	1540 ± 40	570 ± 60
ALICE Pb–Pb single resonance	$1463 \pm 2 \pm 15$	$448 \pm 6 \pm 14$
ALICE Pb–Pb $\rho(1450)$	$1385 \pm 14 \pm 36$	$431 \pm 36 \pm 82$
ALICE Pb–Pb $\rho(1700)$	$1663 \pm 13 \pm 22$	$357 \pm 31 \pm 49$
Mixing angle	$1.52 \pm 0.16 \pm 0.19$ (rad)	

- ALICE data favors two-resonance scenario.
- Mass positions compatible with PDG values within ~2 σ
- Mass peak widths agree with PDG values

Ω_c^0 branching-fraction ratio

https://arxiv.org/abs/2404.17272





$\Omega_c^0 \to \Omega^- \pi^+$

$\Omega_c^0 \to \Omega^- e^+ \nu_e$ New result

- Missing precise branching ratio of strange-charm baryons

$$\mathrm{BR}(\Omega_c^0 \to \Omega^- \pi^+) = (0.51^{+2.19}_{-0.31})\%$$

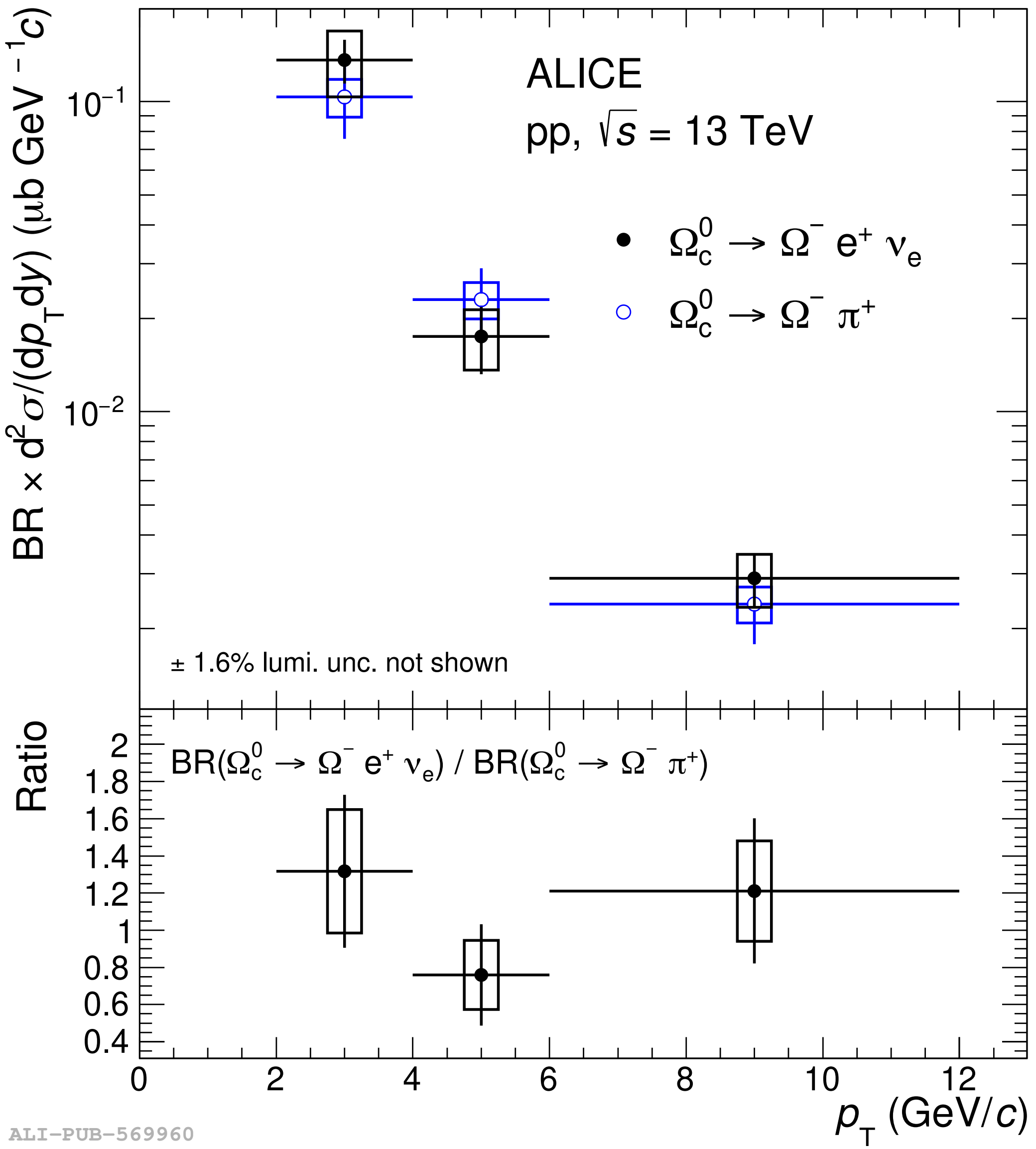
EPJC 80, 1066 (2020), theory

Large uncertainty

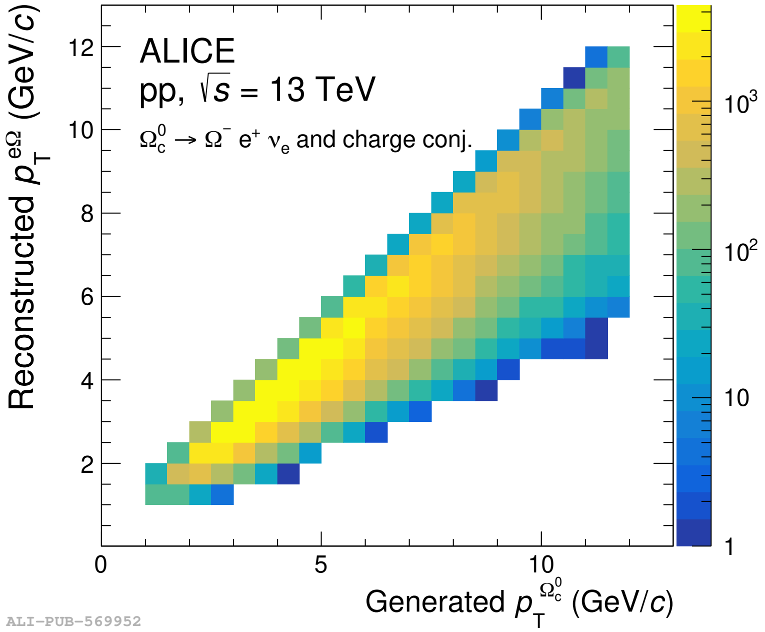
- New Ω_c^0 reconstruction via semileptonic decay
  - missing ν_e
  - signal region : $1.7 < m(e\Omega) < 2.7$ GeV/c^2
  - signal shape reproduced by PYTHIA8 simulation

BR x cross section of Ω_c^0

https://arxiv.org/abs/2404.17272



- p_T of Ω_c^0 is obtained by unfolding

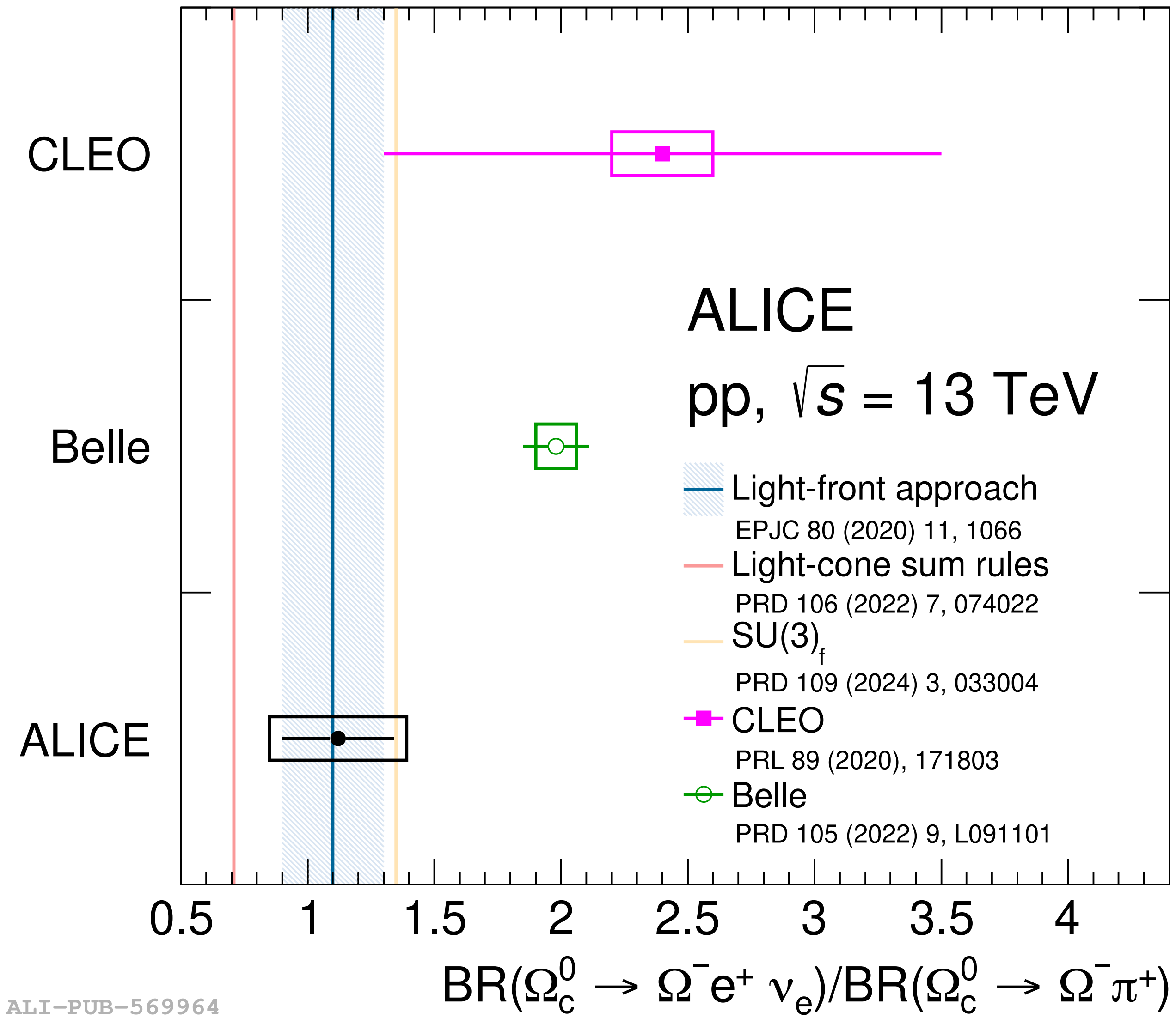


- $\Omega_c^0 \to \Omega^- \pi^+$ (hadronic channel)
  - PLB 846 (2023) 137625

- Bottom panel: Branching-fraction ratio

Constraint to Ω_c^0 branching-fraction ratio

https://arxiv.org/abs/2404.17272



- ALICE measurement in pp collisions is more precise than CLEO, but less precise than Belle.
- ALICE results compatible with
  - CLEO within 1.0 σ
  - Belle within 2.3 σ
- Further improvement expected with more data in Run 3 and 4 of the LHC.

Event-by-event flow vector fluctuation

https://arxiv.org/abs/2403.15213

$$\frac{dN}{d\varphi} \propto 1 + 2\sum_n v_n(p_T,\eta)\cos[n(\varphi - \Psi_n(p_T,\eta))]$$

$v_n(p_T, \eta)$: flow magnitude
$\Psi_n(p_T, \eta)$: flow angle

$$\vec{V}_n(p_T,\eta) = v_n(p_T,\eta)e^{in\Psi_n(p_T,\eta)}$$

Fluctuation of position of nucleon in colliding nuclei and of partonic constituents in the nucleon
→ Event-by-event flow vector fluctuation

- 4-particle correlation approach allows us to quantify flow angle and magnitude fluctuations individually.

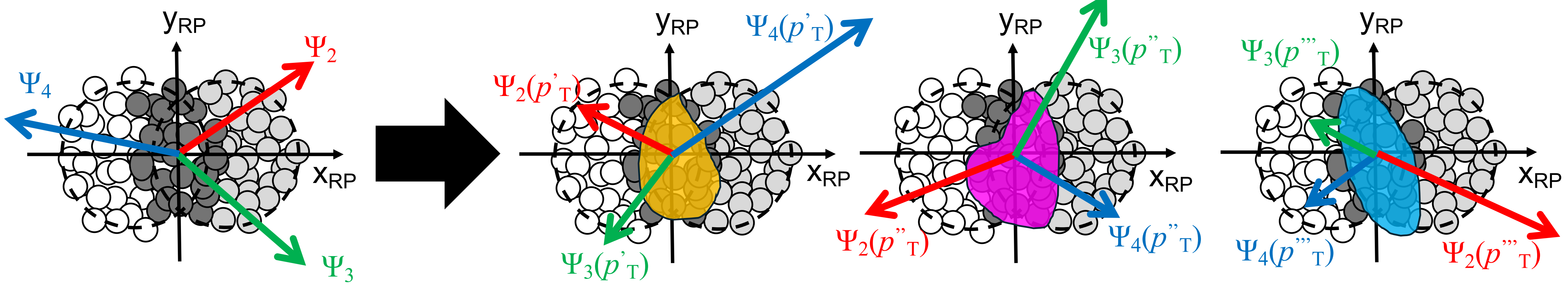
$$A_n^f \simeq \langle \cos 2n[\Psi_n(p_T) - \Psi_n] \rangle \quad M_n^f = \frac{\langle v_n^2(p_T) v_n^2 \rangle / \langle v_n^2(p_T) \rangle \langle v_n^2 \rangle}{\langle v_n^4 \rangle / \langle v_n^2 \rangle^2}$$

- if $A^f_n < 1$, flow angle fluctuation
- if $M^f_n < 1$, flow magnitude fluctuation

→ constrain initial state of heavy-ion collisions and transport coefficient of the QGP

Initial symmetry planes

p_T-dependent flow vector fluctuation



Event-by-event flow vector fluctuation

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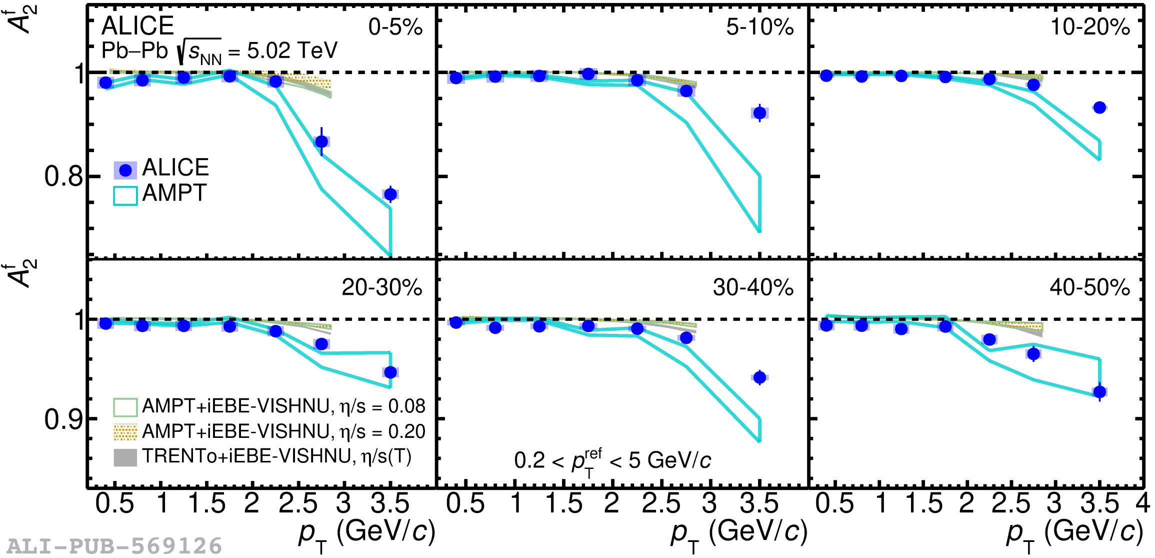
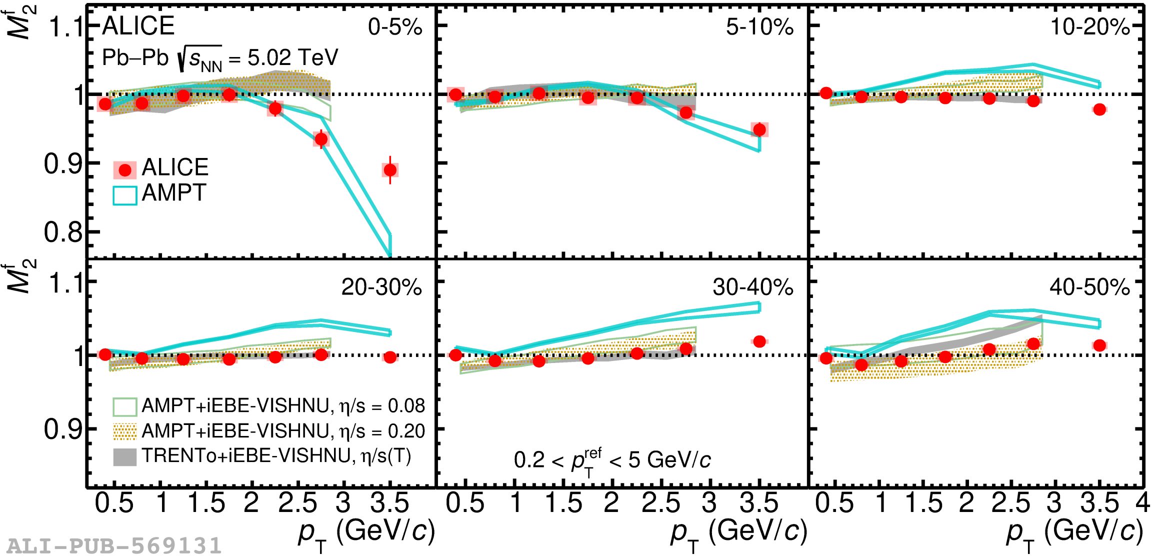
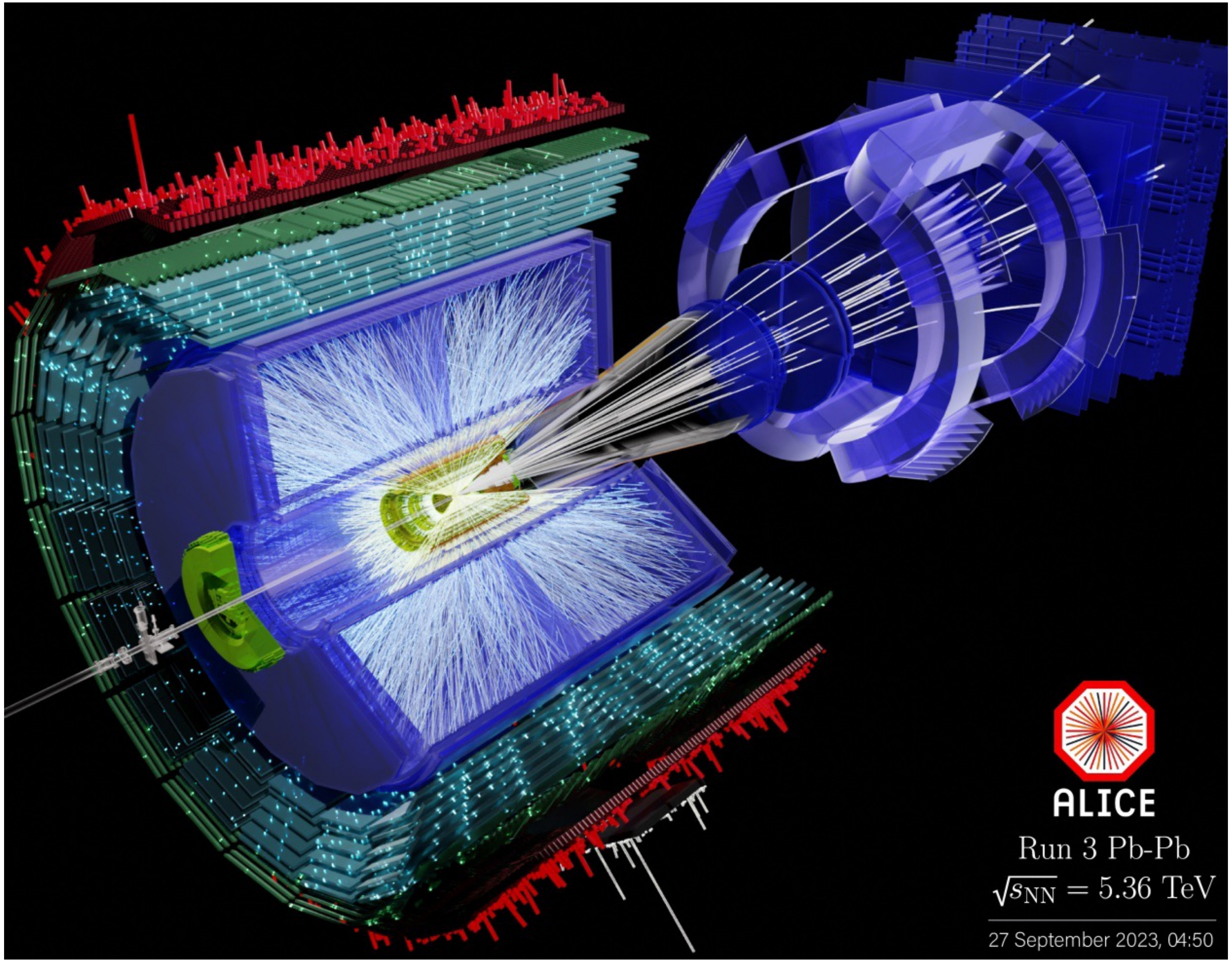




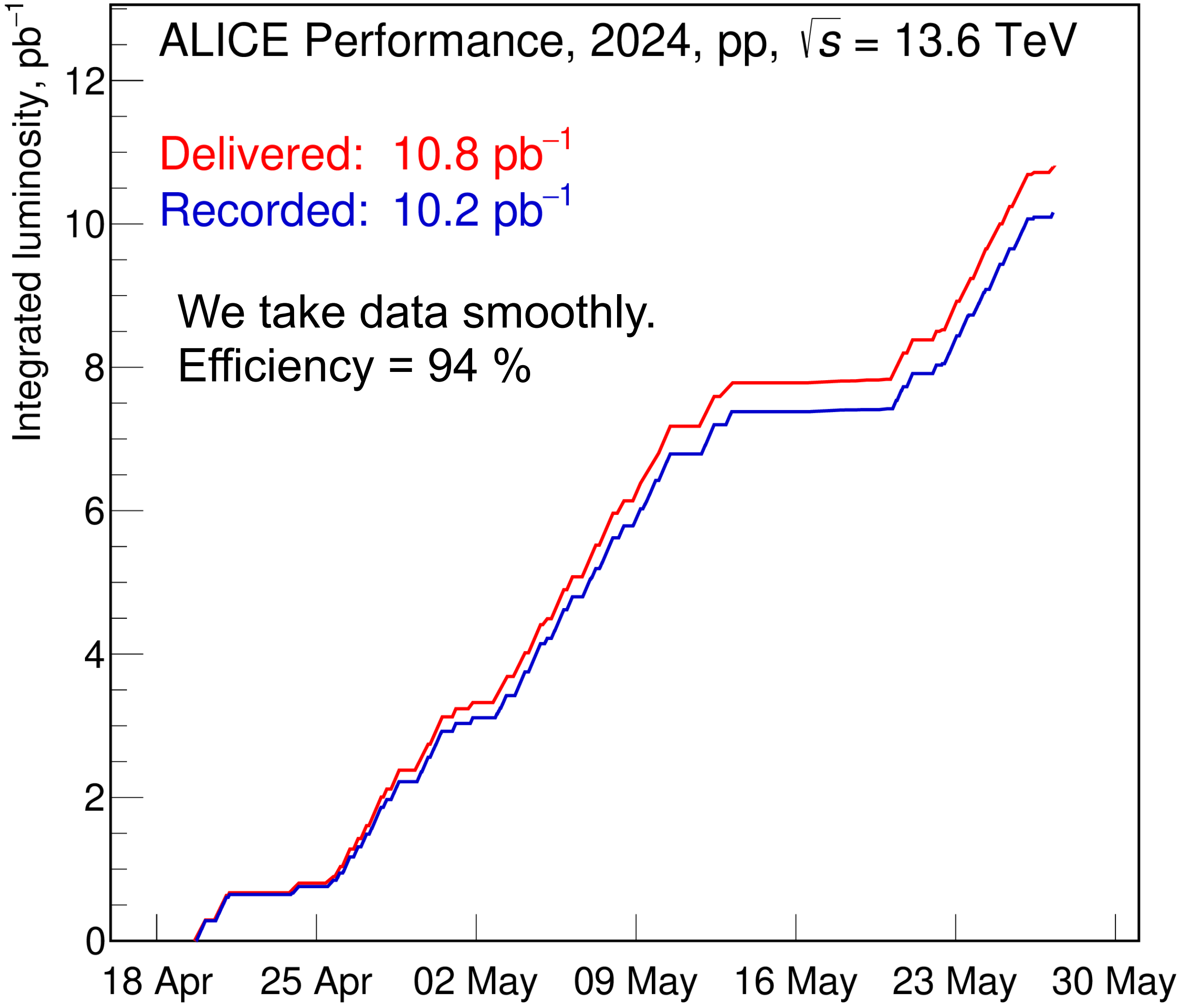
- Evidence of p_T-dependent flow angle and magnitude fluctuations at p_T > 3 GeV/c
- Max. fluctuation at high p_T in central collisions
  - As expected because of large position fluctuation
- Hydrodynamic model (iEBE-VISHNU) describes neither large flow angle nor large magnitude fluctuations at high p_T in central collisions quantitatively.

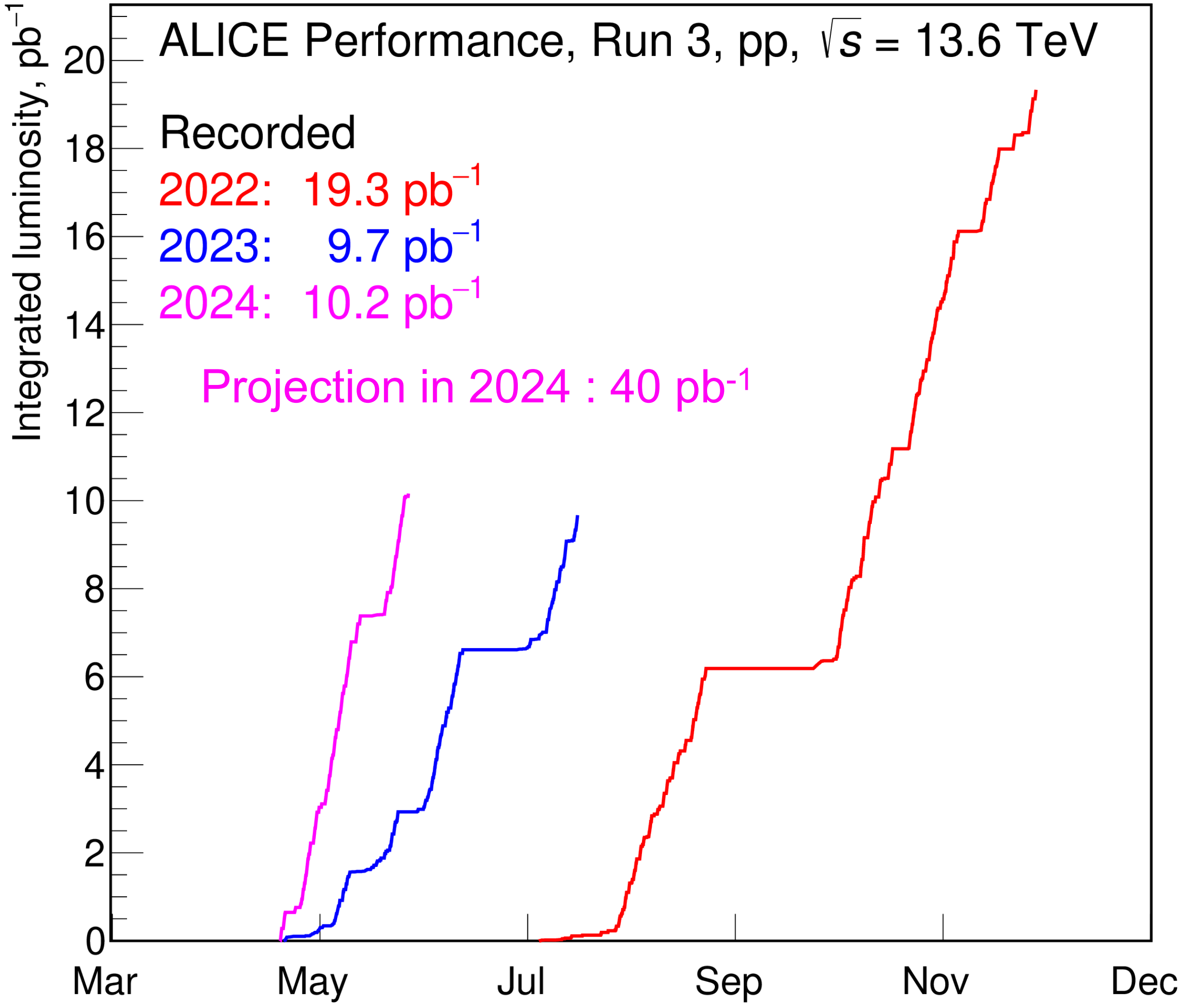
→ offer an improved understanding of the flow vector fluctuations

Run 3 results

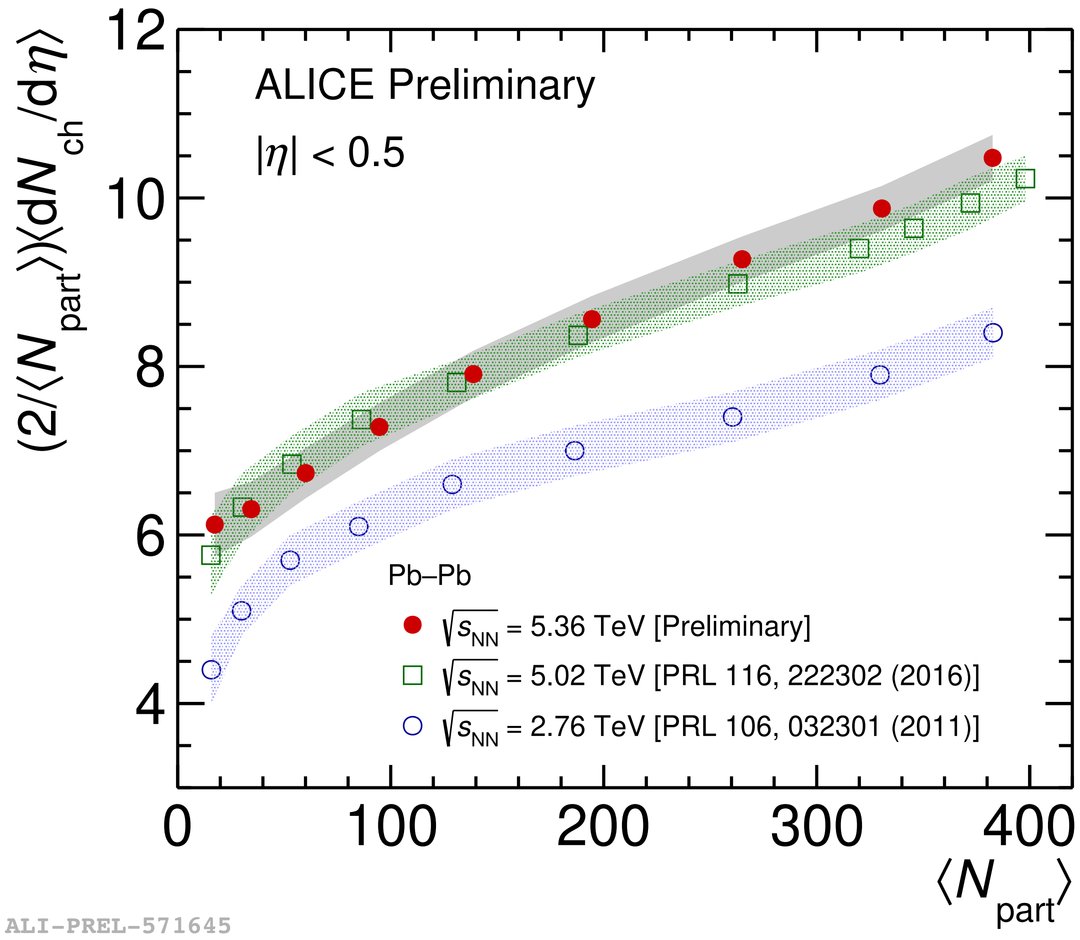


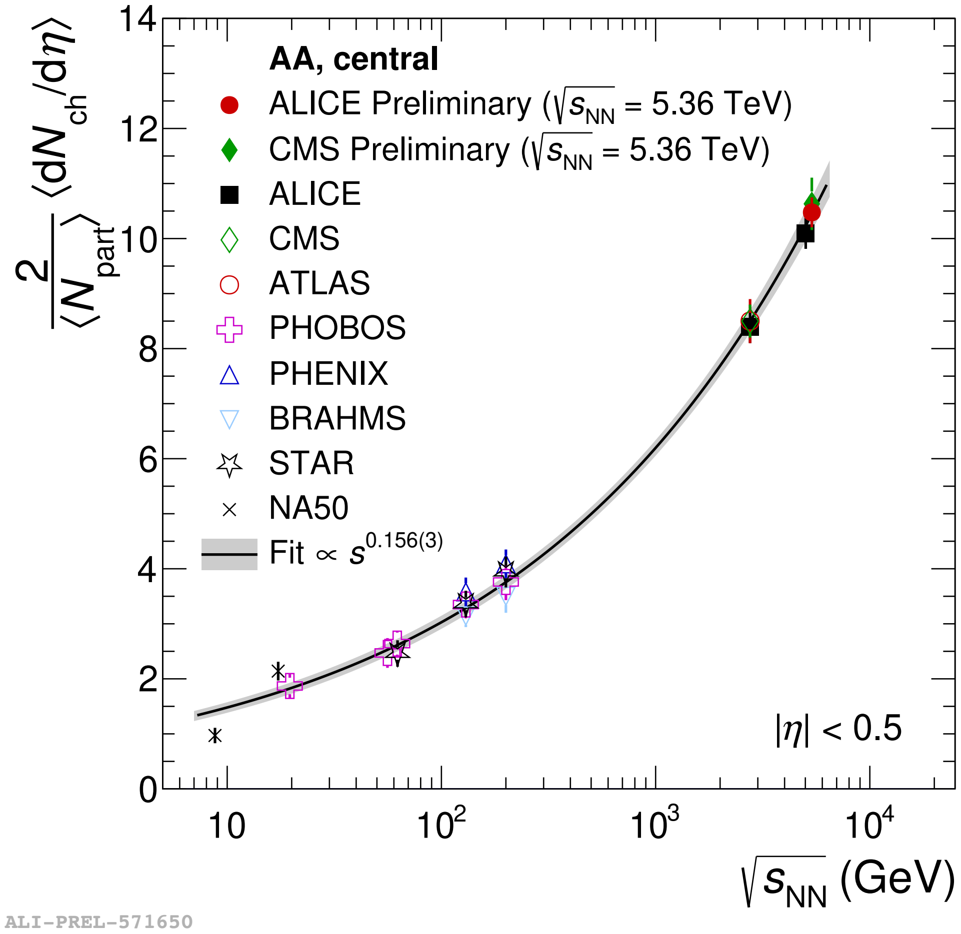
Run 3 status in 2024





Charged-particle multiplicity density in Run 3

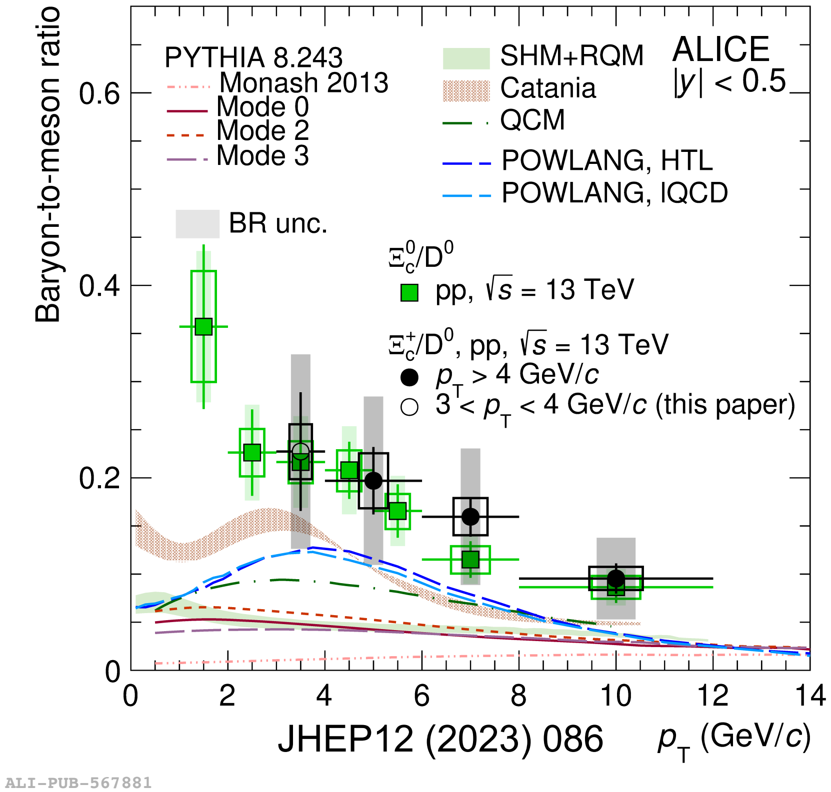


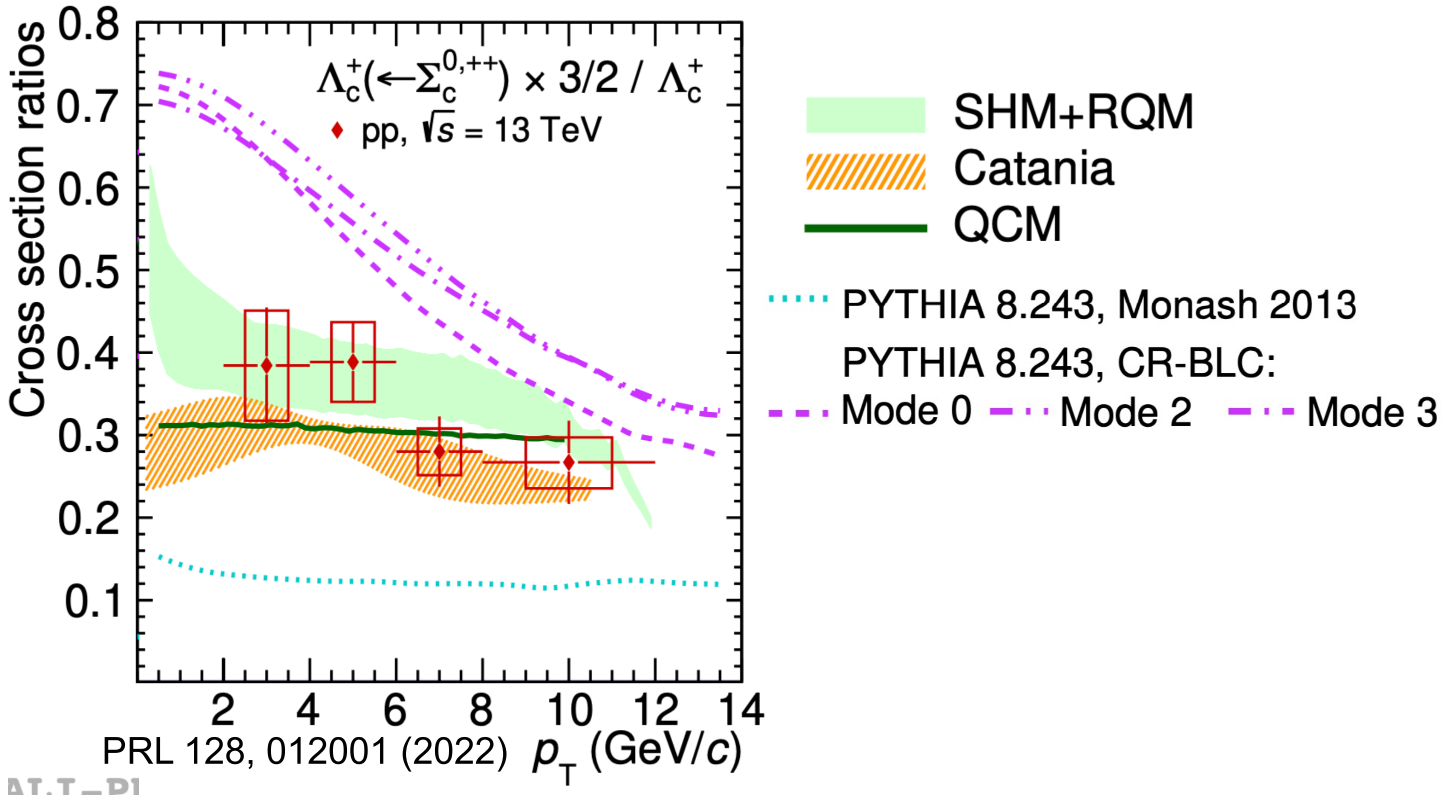


CMS data : CMS-PAS-HIN-23-007

- ALICE measured $dN_{ch}/d\eta$ in Pb–Pb at $\sqrt{s_{NN}}$ = 5.36 TeV
- Important baseline for the commissioning of the upgraded detector in Pb–Pb collisions

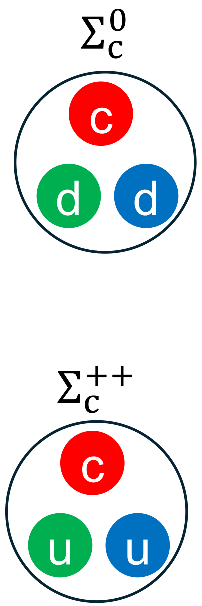
Motivation of charm baryon-to-meson ratio

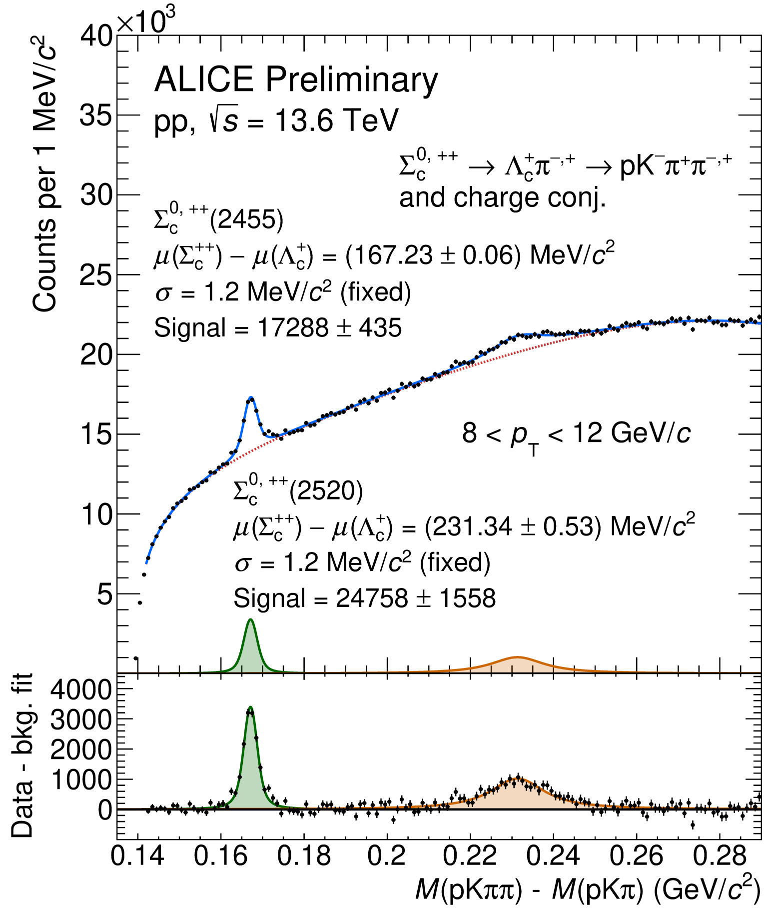




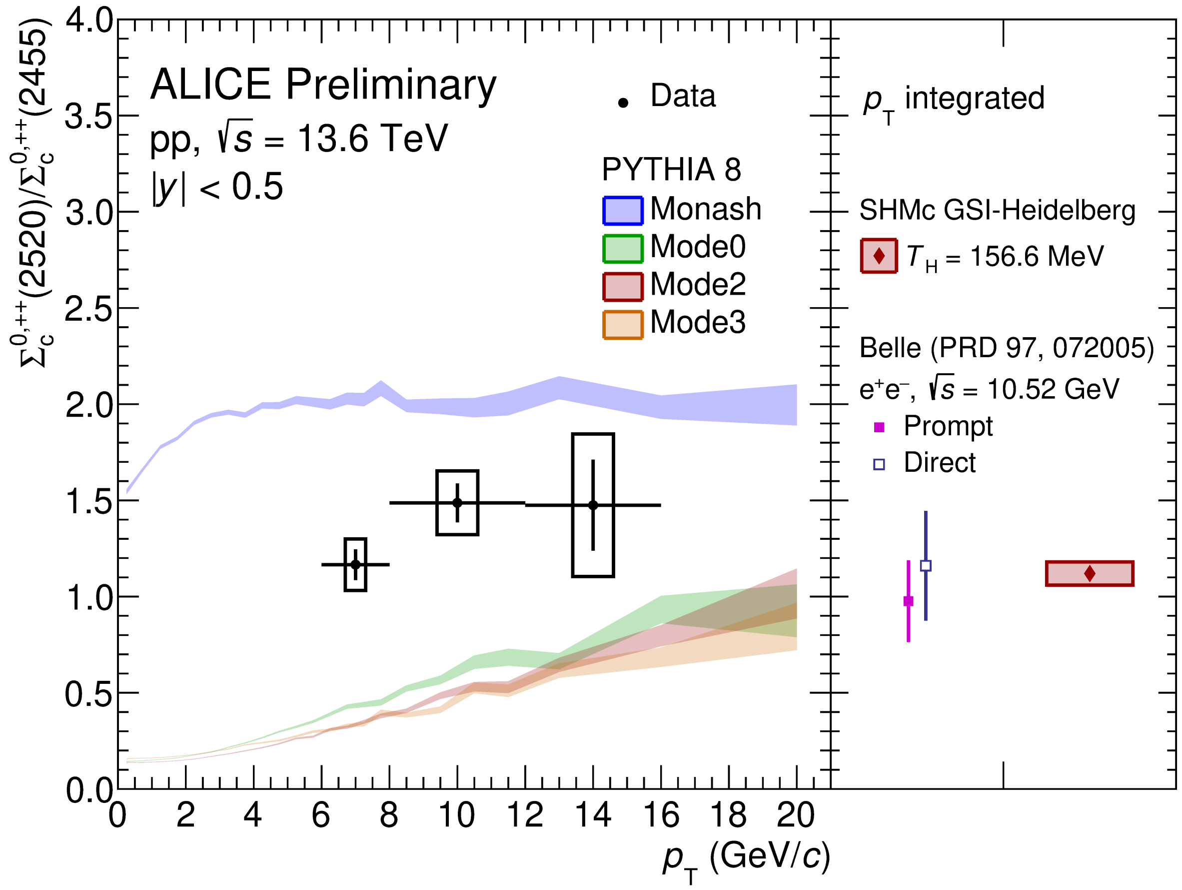
- Limited prediction power of models for charm hadronization
  - $\Xi_c^{0,+}/D^0$ ratio underestimated by models
  - $\Lambda_c^+(\leftarrow \Sigma_c^{0,++})/\Lambda_c^+$ ratio overestimated by PYTHIA with color reconnections
- Higher mass resonances could contribute to enhanced charm baryon-to-meson ratio at the LHC.
- Calculations are very difficult, but get more attention due to recent results of charm baryons at the LHC.

$\Sigma_c^{0,++}(2520)/\Sigma_c^{0,++}(2455)$ ratio in pp at $\sqrt{s}$ = 13.6 TeV





ALI-PREL-571534

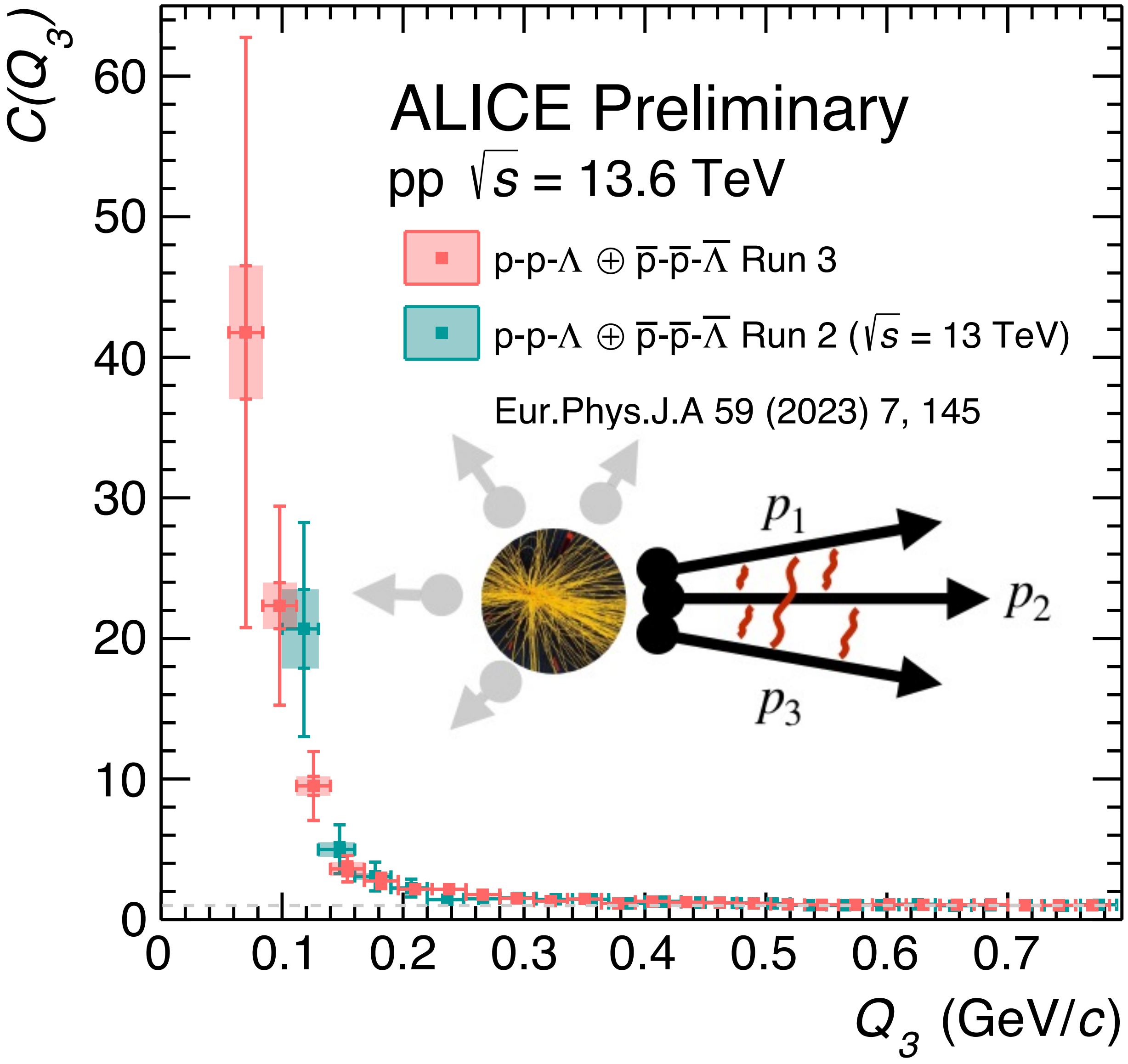


ALI-PREL-571539

500B collisions analyzed.

- First $\Sigma_c^{0,++}(2520)$ measurement at the LHC
- Further inputs to charm-hadronization models
  - PYTHIA8 Mode 0,2,3 are tuned to describe Λ_c^+/D^0 ratio, but do not describe this data.

p-p-Λ correlation function in pp at $\sqrt{s}$ = 13.6 TeV



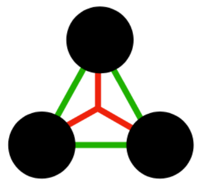
- Evidence of three-body interaction from
  - calculations: PRC 89, 014314 (2014)
  - p-d correlation: https://arxiv.org/abs/2308.16120

- Three-body correlation function is necessary to understand hyperon puzzle in neutron stars and hyper-nuclei.

- Good agreement with Run 2
  - EPJA 59 (2023) 7, 145

$$C(Q_3) = \mathcal{N} \frac{N_{\text{same}}(Q_3)}{N_{\text{mixed}}(Q_3)}$$

$$Q_3 = \sqrt{-q_{ij}^2 - q_{jk}^2 - q_{ki}^2}$$



Three-particle correlation function incorporates
- two-body interaction
- genuine three-body interaction

ALICE upgrade projects

ALICE 2	ALICE 2.1	ALICE 3

- Run 3, 2022 - 2025, pp, Pb-Pb, p-O, O-O
- LS3
- Run 4, 2029 - 2032, pp, p-Pb, Pb-Pb
- LS4
- Run 5, 2035-2038
- LS5
- Run 6, 2040-2041

ABOUT NEWS

ALICE gets the green light for new subdetectors

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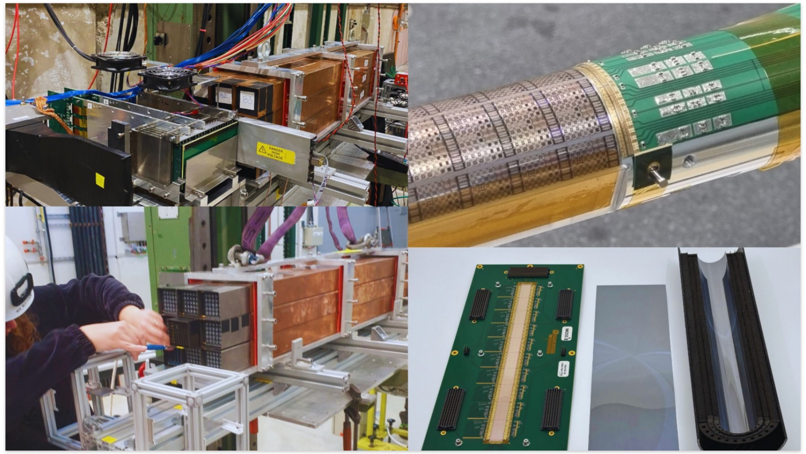
25 APRIL, 2024 | By ALICE collaboration



ALICE's new subdetectors, Forward Calorimeter (left) and components of the Inner Tracking System 3 (right) (Image: ALICE Collaboration)

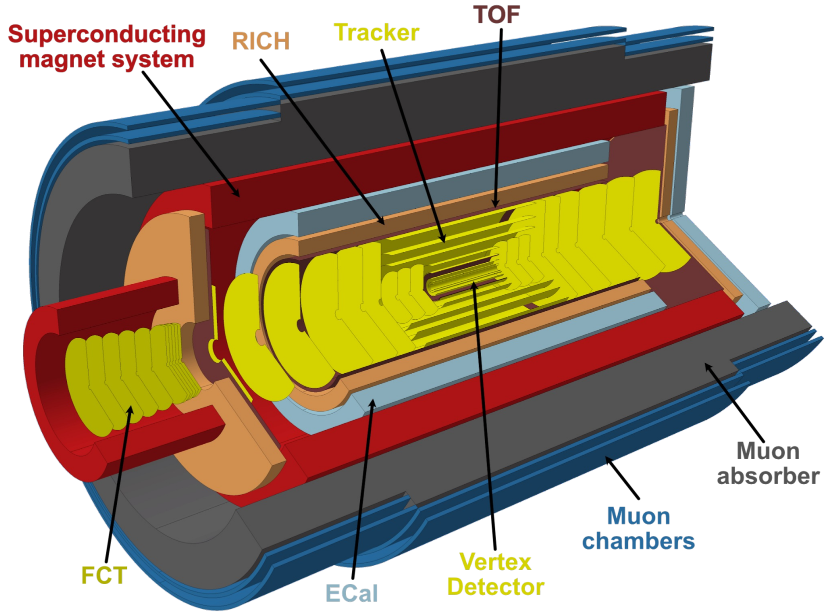
FoCal & ITS3

- TDRs completed and endorsed by Research Board in March
- FoCal TDR
- ITS3 TDR

ALICE 3

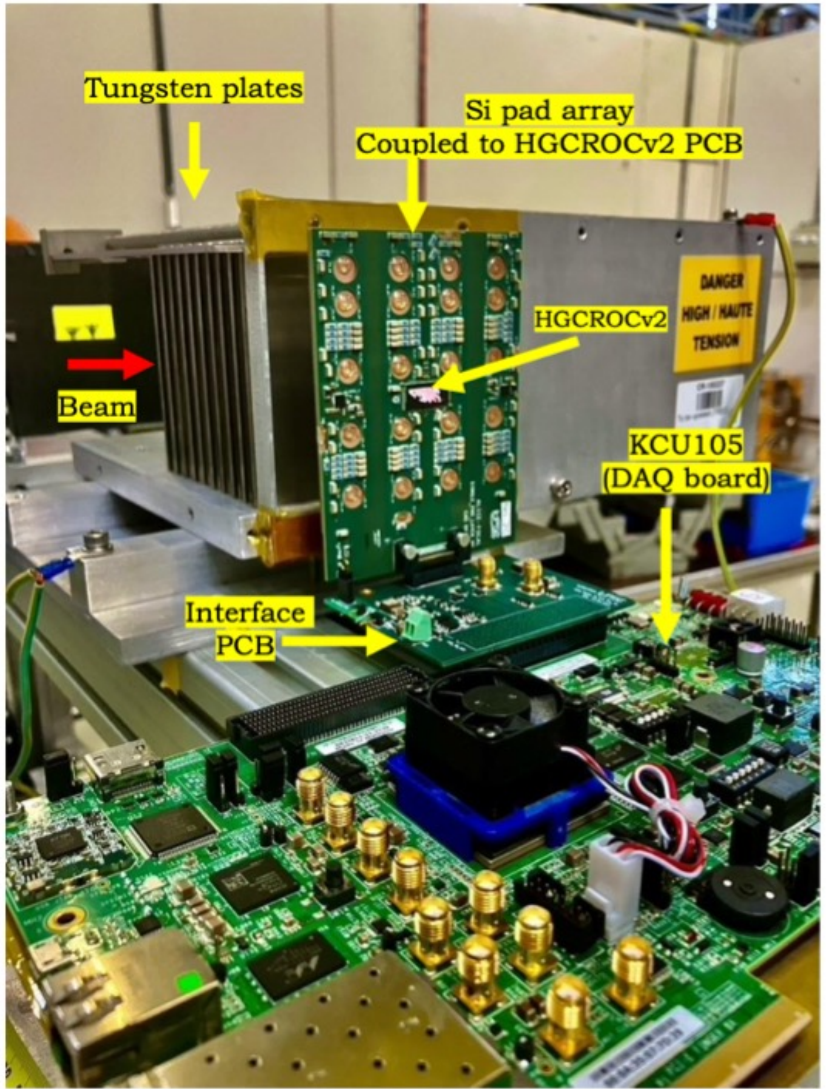
- Scoping Document close to completion
- R&D well underway, test beams of prototype sensors

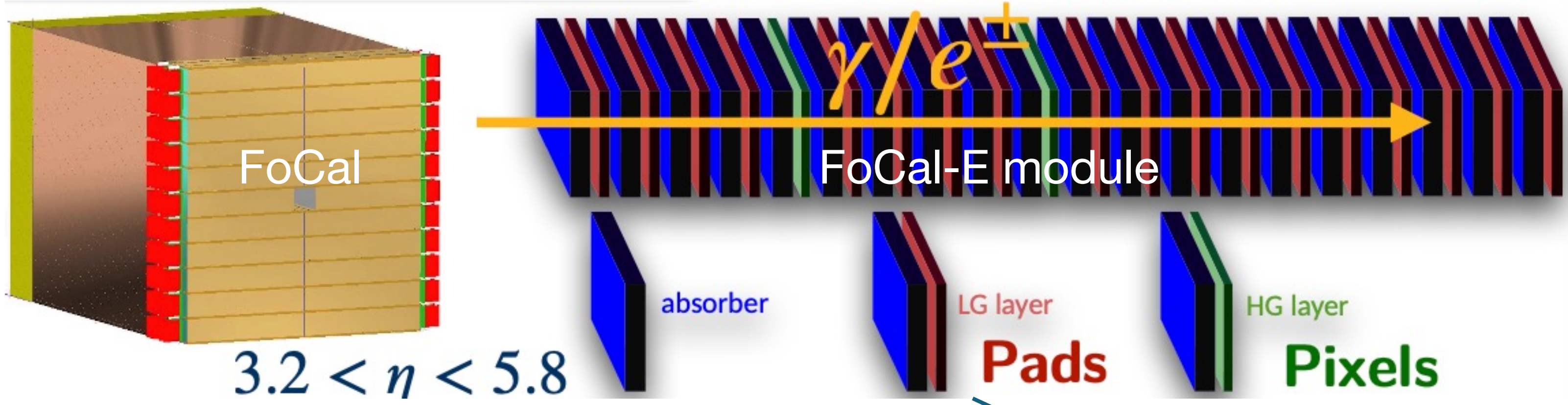
ALICE 3 LoI: CERN-LHCC-2022-009



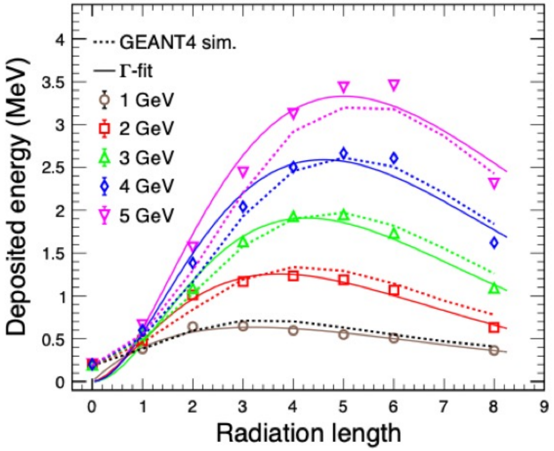
FoCal: final test beam results of n-type Si pad sensors

New test beam paper: https://arxiv.org/abs/2403.13394





- Achieved expected performance for EM shower energy and size vs N_{layers}
- Further tests with full stack in 2024



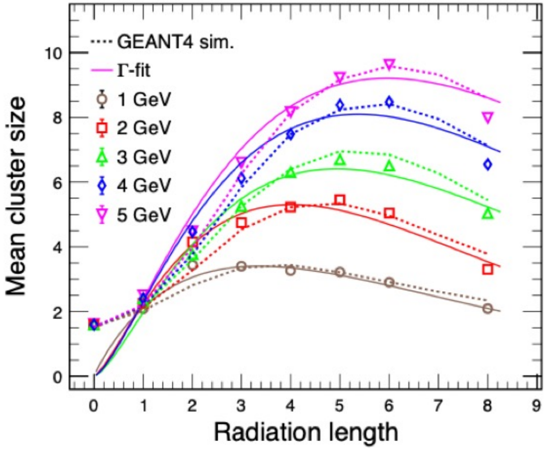
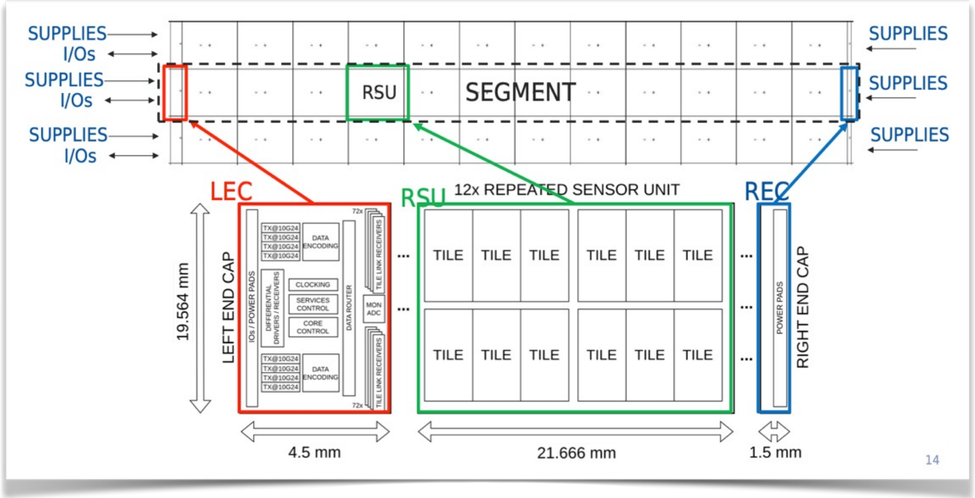


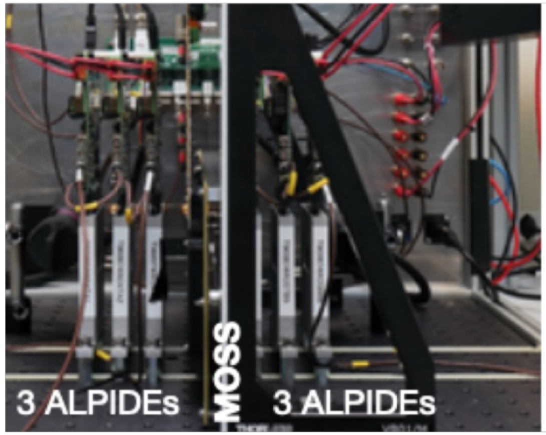
Figure 1. 8 × 9 Si pad array diced from a 6-in Si wafer.

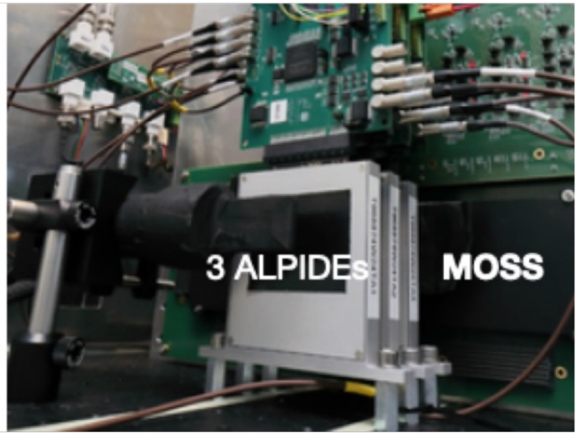
ITS3 recent highlights

✓ MOSAIX (final sensor prototype) design advancing (silicon expected early 2025)



✓ quasi continuous test beams at PS (Jul, Aug, Sep, Oct'23, Mar, May '24)

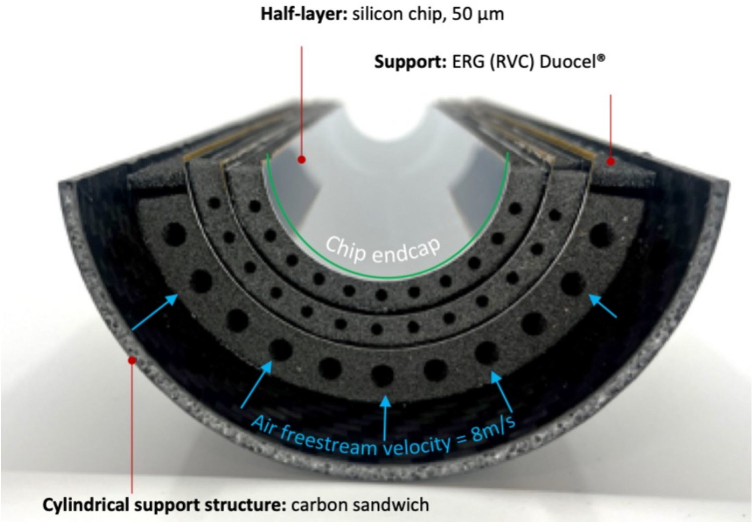


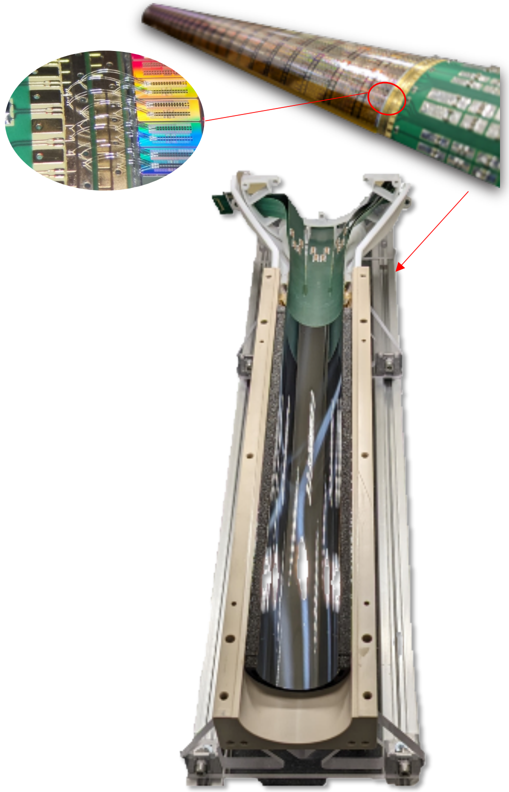


- Sensors
  - preparation of final sensor (ER2, "MOSAIX") prototype
    - design well advanced, test system being prepared

- Mechanics
  - preparation for final sensor modules
    - all jigs ready, assembly hall and cooling system under preparation

✓ three-layer assembly (final mechanics/jigs; dummy Si)





ALICE 3 detector for Runs 5-6

➡ **Novel detector concept**

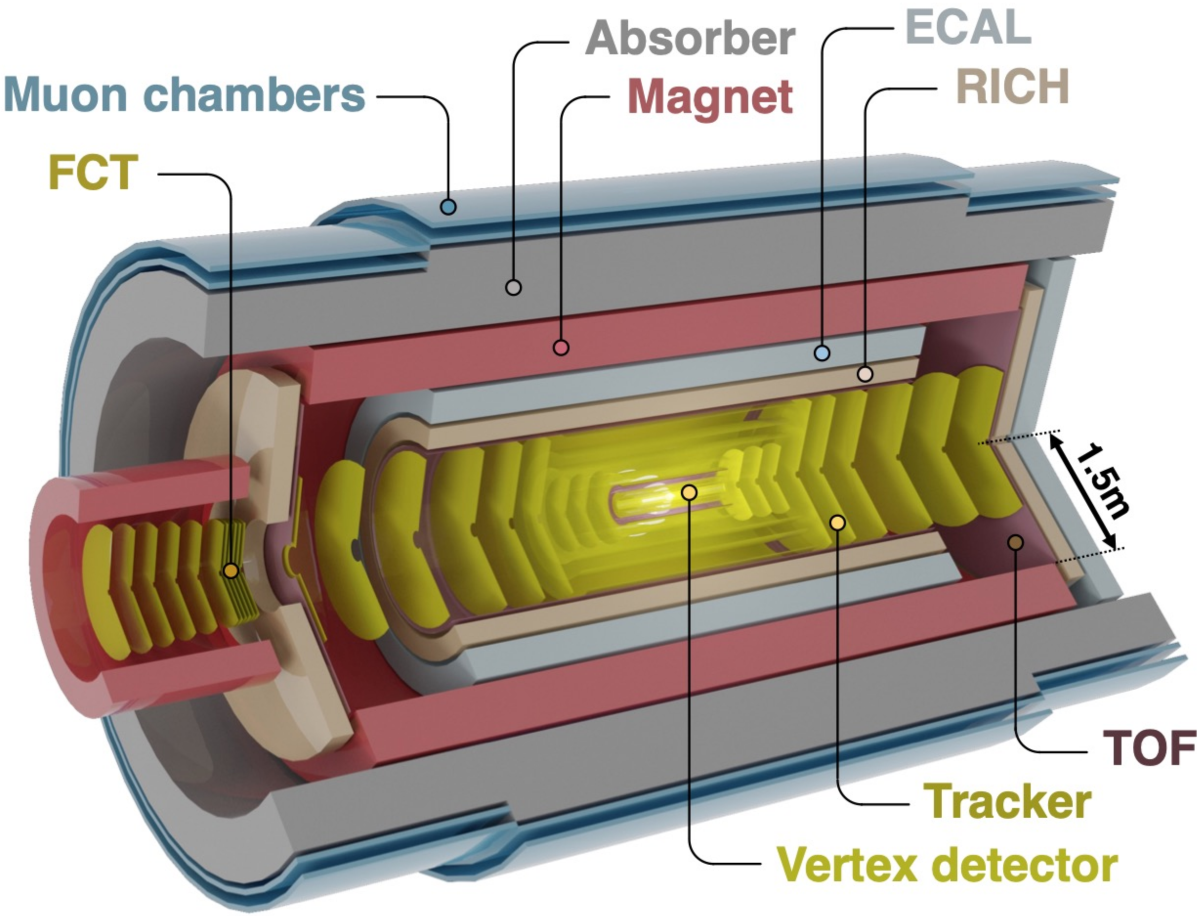
- Compact and lightweight all-silicon tracker
- Retractable vertex detector with R_{min}= 5 mm
- Extensive particle identification
- Large acceptance $|\eta| < 4$
- Superconducting solenoid, B = 2T
- Continuous read-out and online processing

➡ **Scoping Document in preparation**

- Definition of reference configuration
- Scoping options: without ECal, reduced magnetic field (1T)
- Detailed assessment of resources and schedule

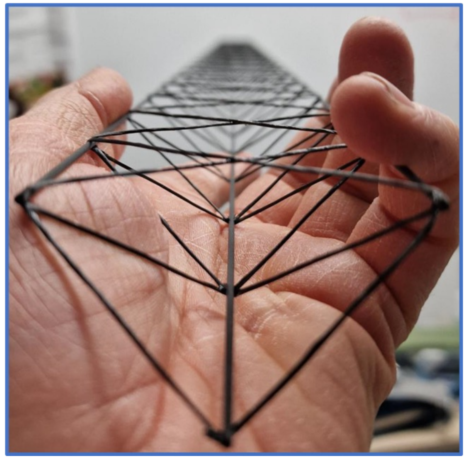
➡ **Several test beams at PS/SPS this year**

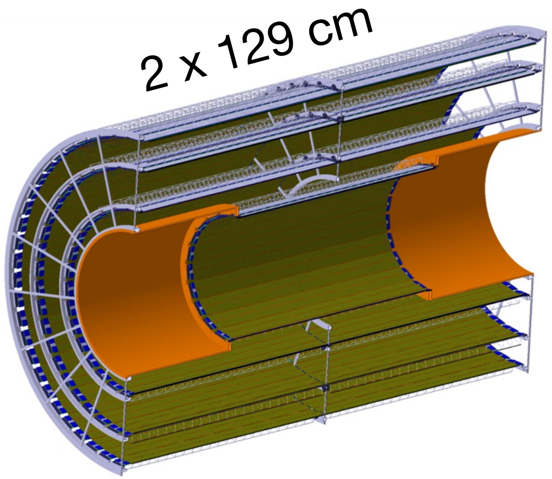
ALICE 3 LOI: https://arxiv.org/abs/2211.02491



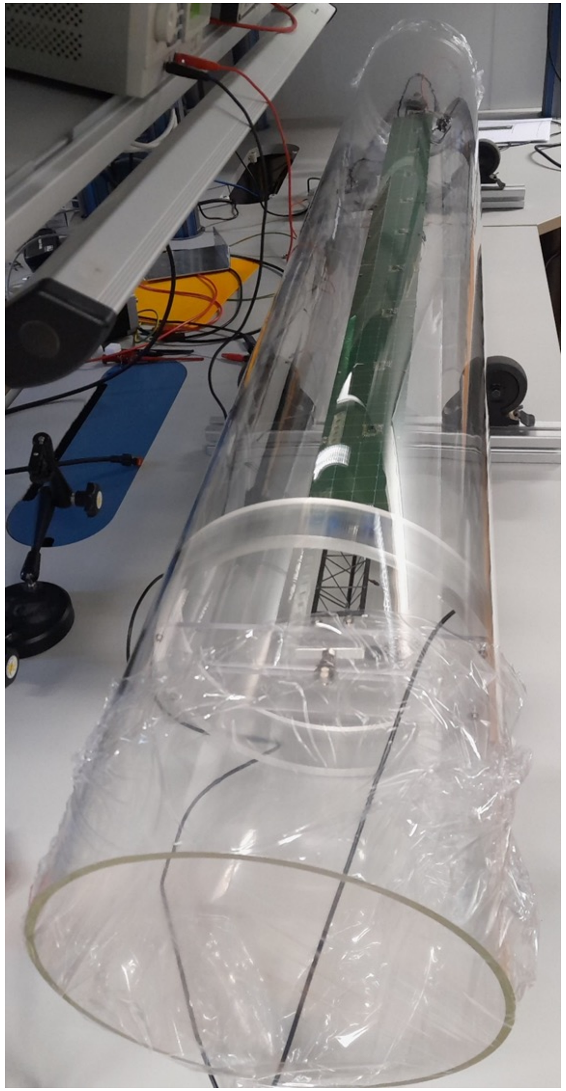
R&D for Outer Tracker

OT barrel design:
- full-scale stave model
- air and water cooling studies
- mechanical support studies

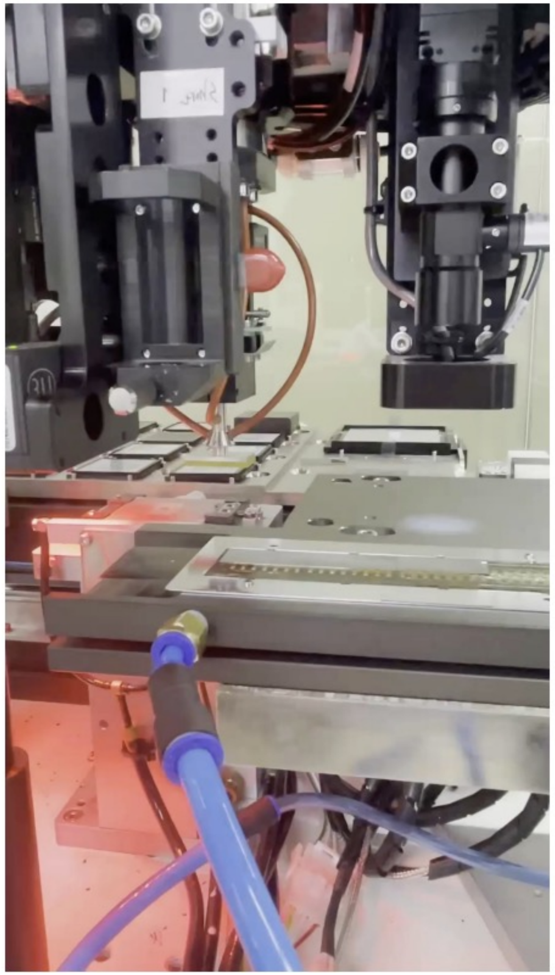




Air cooling study:

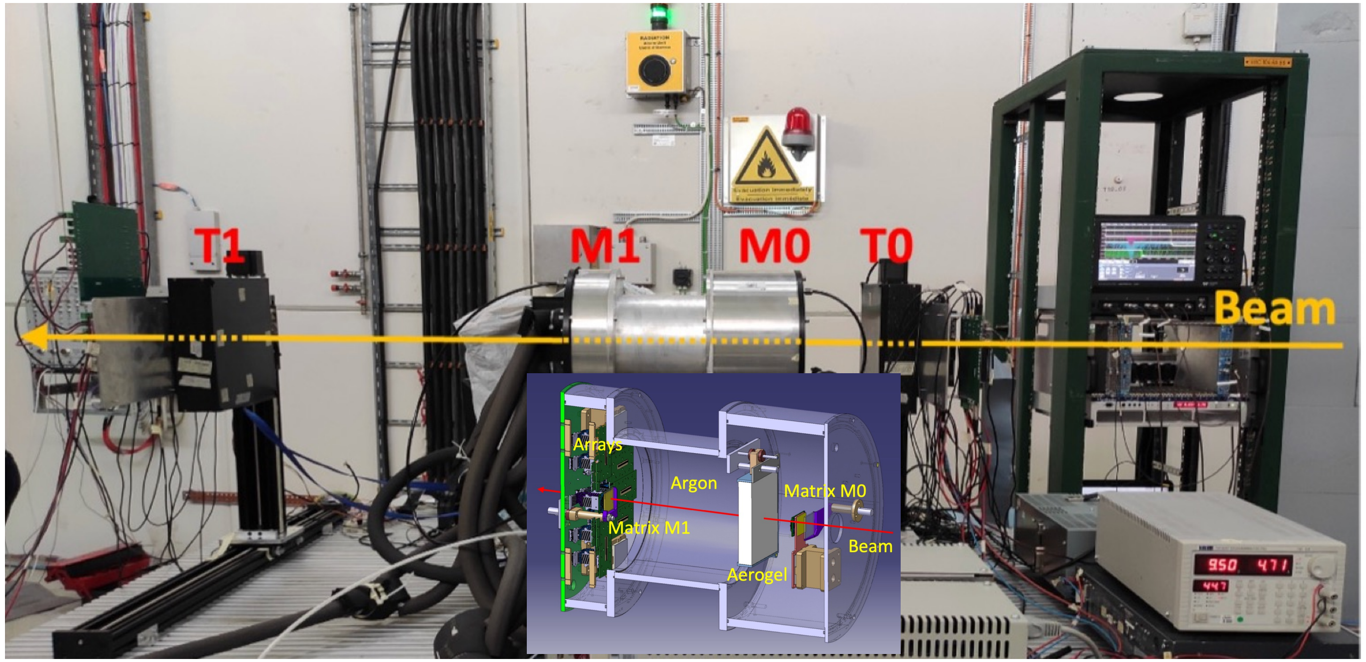


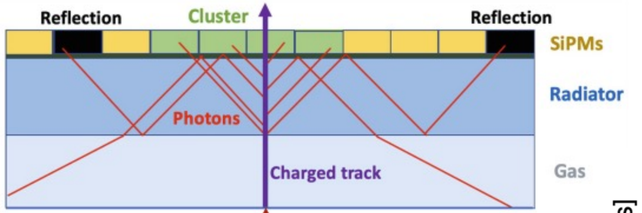
Automated module assembly:
- general-purpose die-bonder machine
- flexible printed circuit, sensor gluing and interconnections

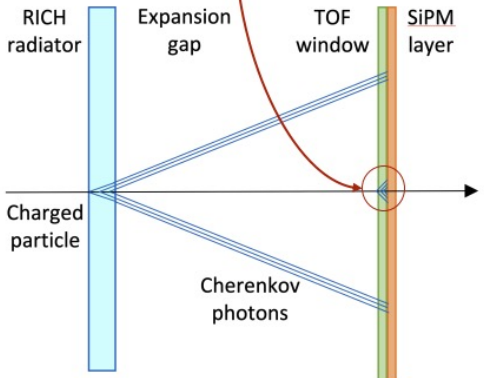


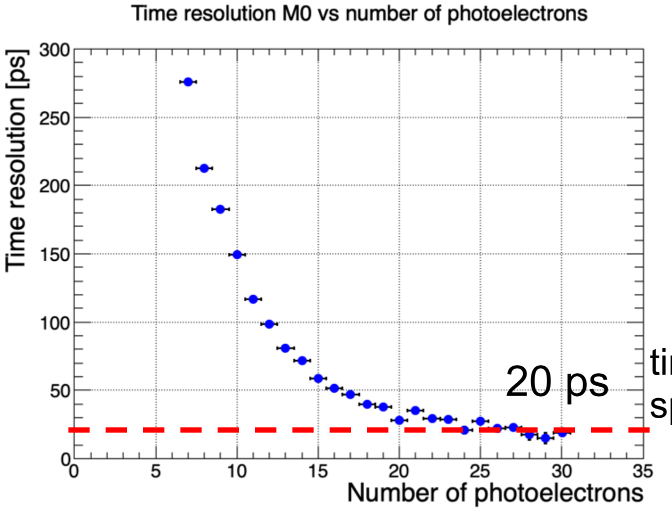
R&D for RICH detector

- Target single-photon angle resolution: 6 mrad
- **PS beam tests in Oct. 2023**
  - Aerogel
  - SiPMs from HPK and FBK, various pixel sizes
  - Radiator windows on SiPM
  (TOF + RICH integrated concept)



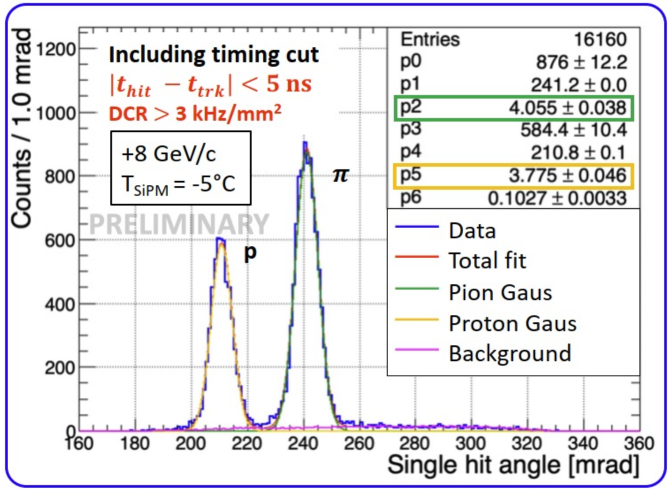






timing resolution meets specs for ALICE 3

Cherenkov angle of pions and protons:
4 mrad angular resolution



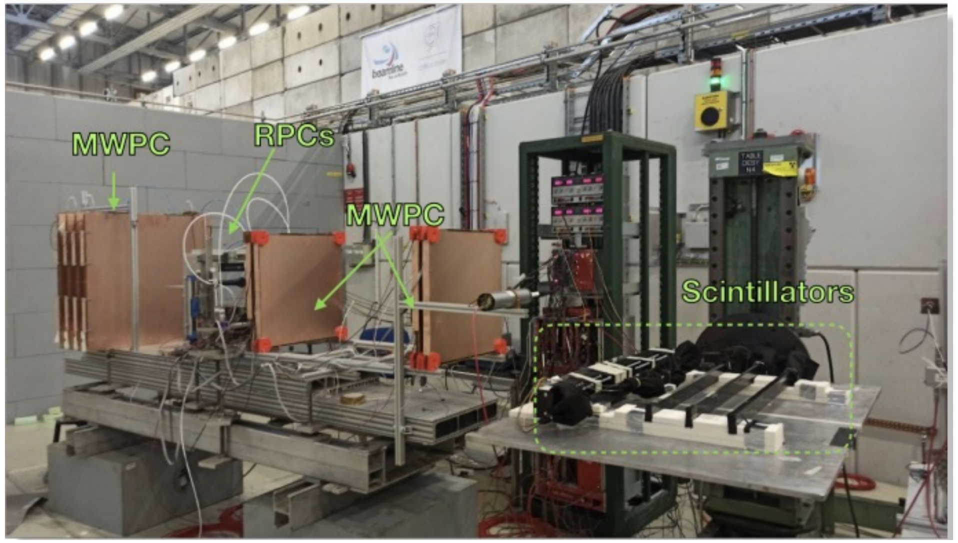
R&D for Muon Identification Detector (MID)

Beam test in July ‘23 at CERN PS

test beam paper: JINST 19 (2024) 04, T04006

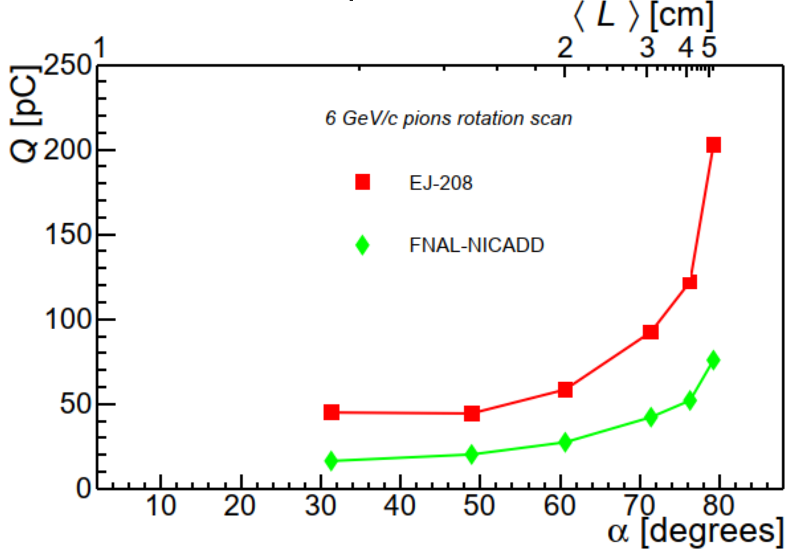
Considered technologies:

- Plastic scintillators (FNAL-NICADD, ELJEN EJ208, Protvino) + SiPM
- Multiwire proportional chambers (8 mm, 12 mm pitch)
- Resistive plate chambers

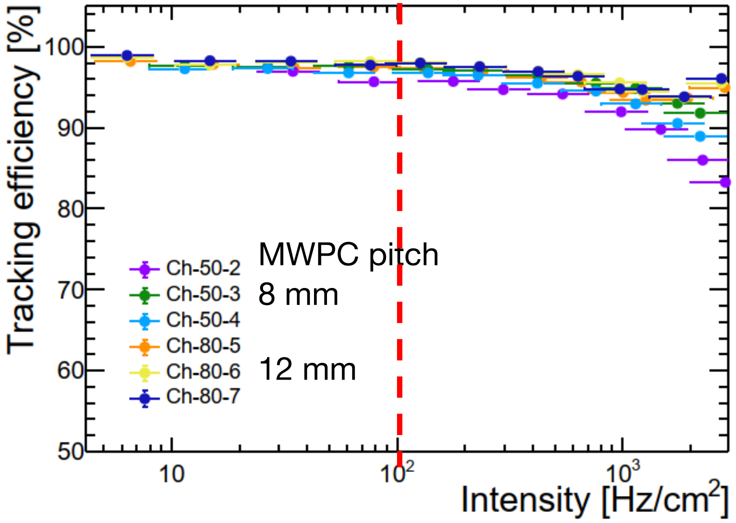


Test beam results meet target specification.

Scintillator response to inclined tracks



MWPC efficiency



Achieve 95% up to 100 Hz/cm^2,
well above the intensities at the ALICE3 MID

Conclusion

- ALICE published 8 papers since last LHCC meeting.
  - Finalizing analyses of Run 2 data

- Several new preliminary results on Run 3 data prepared for SQM, LHCP, ICHEP
  - $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$, $\Sigma_{\mathrm{c}}^{0,++}$, three-body femtoscopy, etc

- Good progress on upgrade projects
  - After completion of TDR, moving towards production for ITS3 and FoCal
  - Design studies and beam tests for R&D of future ALICE3 detectors