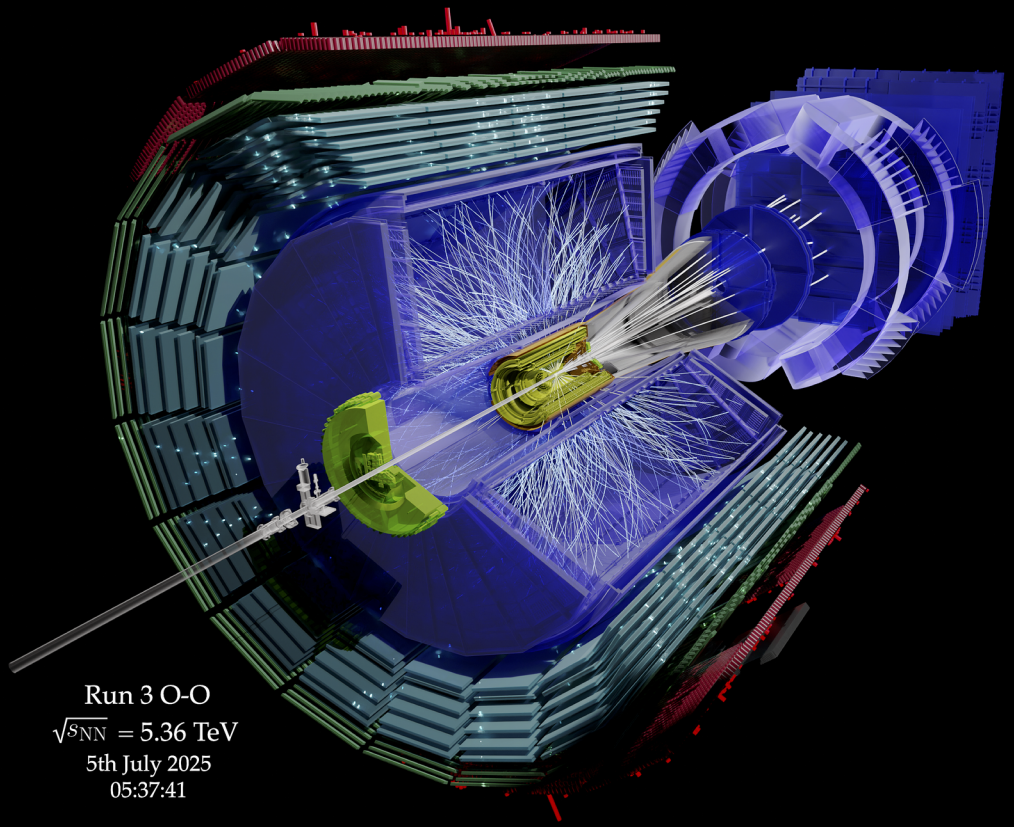
ALICE Overview from Light Ions



Romain Schotter [1],
on behalf of the ALICE Collaboration

[1]Austrian Academy of Sciences and MBI

ÖAW AUSTRIAN ACADEMY OF SCIENCES

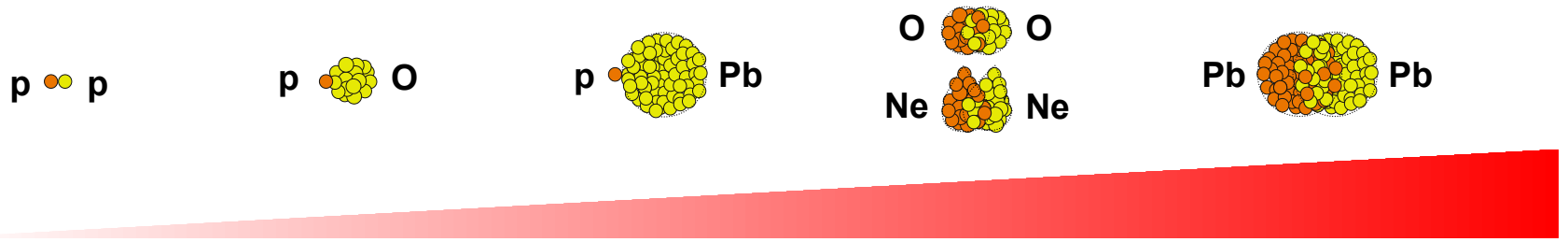
Marietta Blau Institute for Particle Physics

ExtreMe Matter Institute EMMI

Light-Ion Collisions, September 21-25, 2026

HEIDELBERG

Why light-ion collisions?



Small systems (pp, p−Pb)

- Typically used as baselines
- Collective-like signatures observed

Large systems (Pb−Pb)

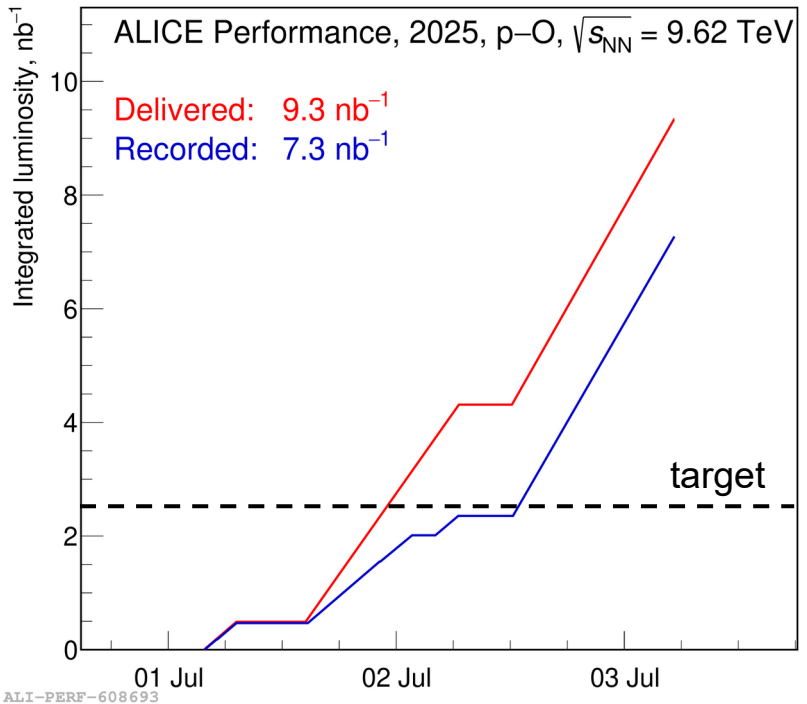
- Quark Gluon Plasma (QGP) is formed

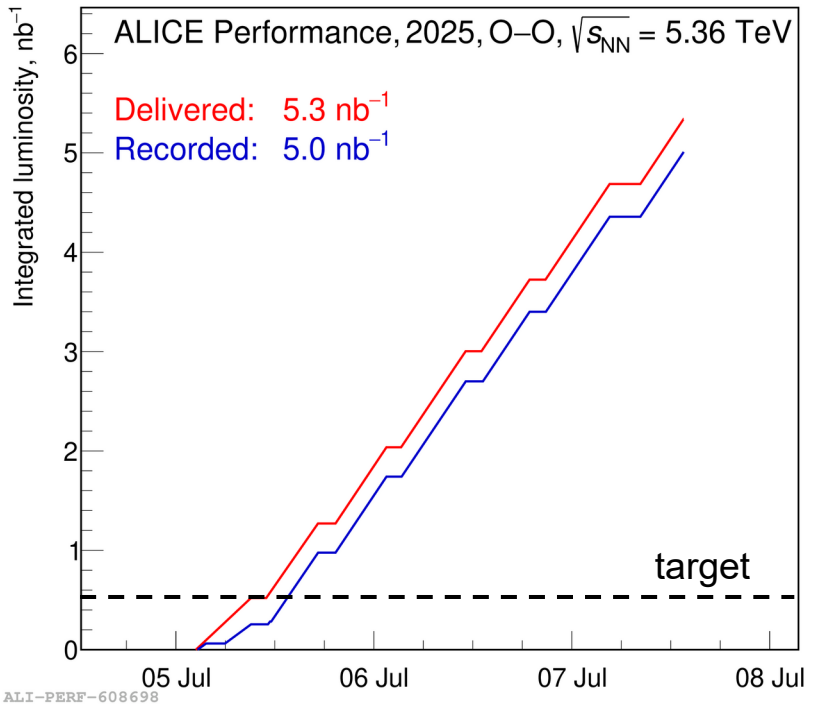
Intermediate system size, light ions (pO, OO, Ne−Ne)

- Similar multiplicities to high-mult. pp/p−Pb collisions but with a very different geometry and volume

→ **Which behaviours persist in light-ion collisions and do they have the same origin as in Pb−Pb?**

The 2025 LHC light-ion run





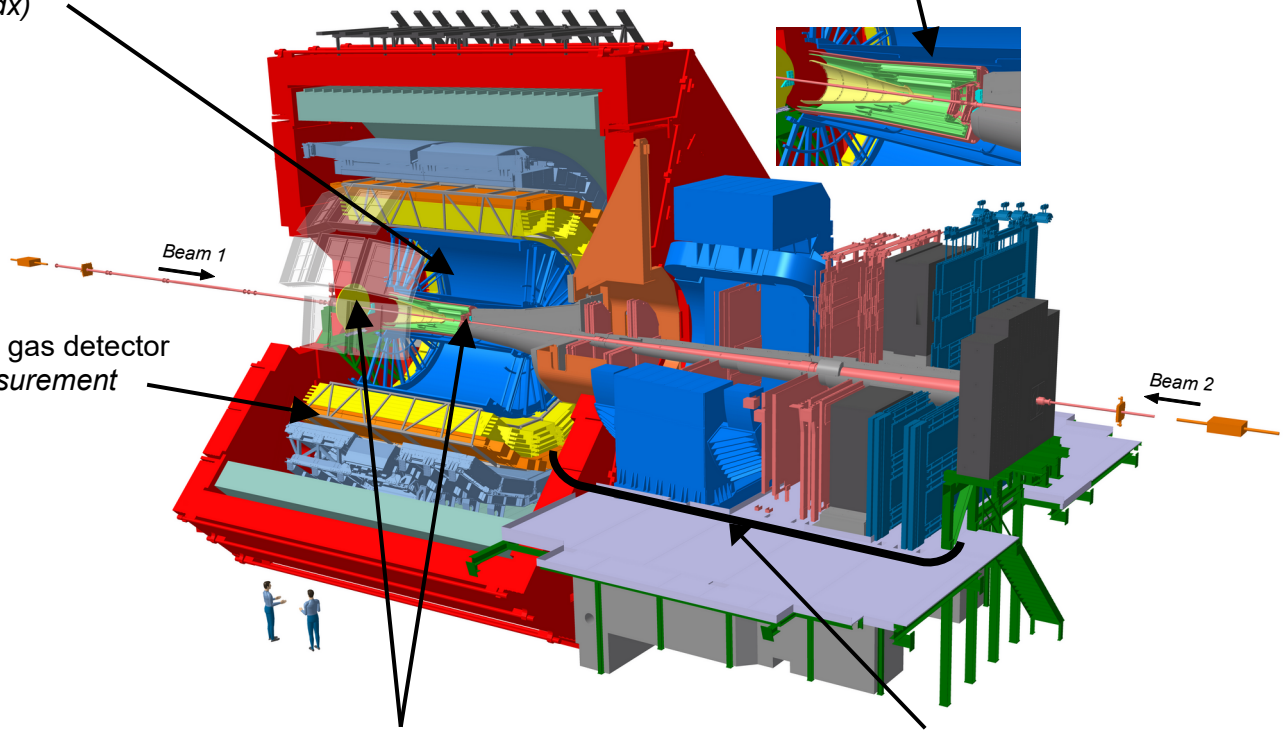
- First light-ion run at the LHC: about 10 days of data taking in July 2025
- ALICE recorded **7.3 nb^{-1} in pO**, **5.0 nb^{-1} in OO** and **0.87 nb^{-1} in Ne−Ne**

  → ~3.34 x 10^9 MB pO collisions, ~6.38 x 10^9 MB OO collisions, ~1.51 x 10^9 MB Ne−Ne collisions

The ALICE apparatus during the LHC Run 3

Inner Tracking System (ITS2), 7 layers of MAPS detectors
→ *Vertexing & Tracking*

Time Projection Chamber (TPC), gas detector
→ *Tracking & PID (dE/dx)*

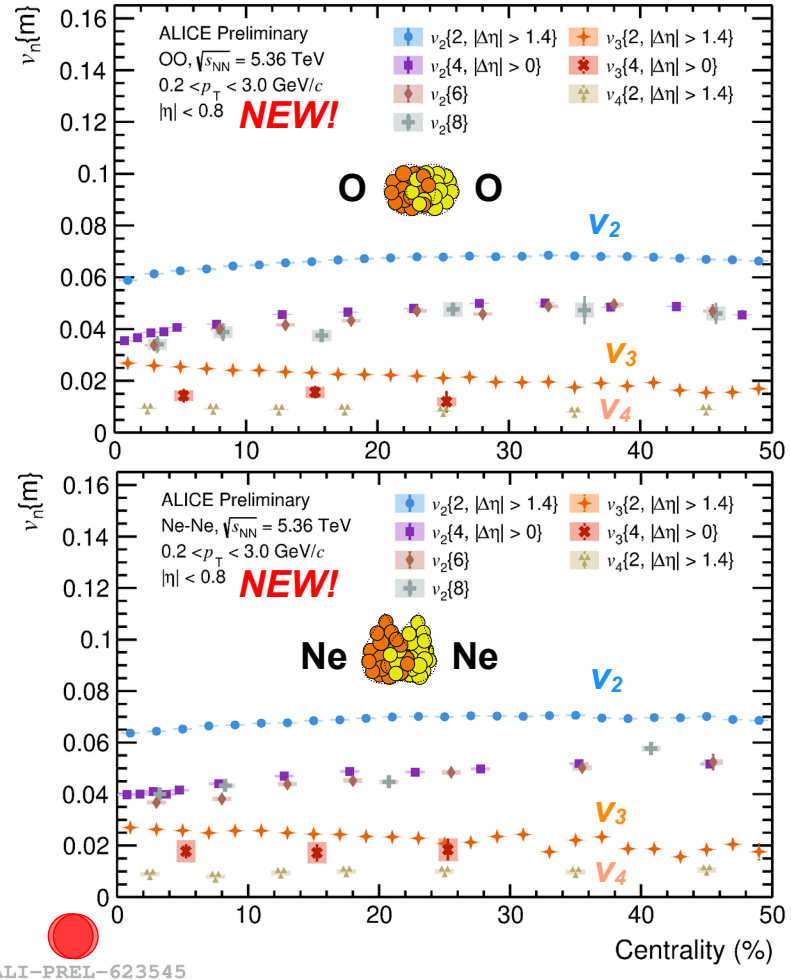


Time-Of-Flight (TOF), gas detector
→ *PID via time-of-flight measurement*

Fast Interaction Trigger (FIT), scintillator detectors (FDD, FT0, FV0)
→ *Rejection of beam-gas interaction*
→ *Multiplicity and centrality determination at forward rapidity*

Muon spectrometer, silicon, gas, scintillator detectors
→ *Muon tracking & identification*

Anisotropic flow in OO and Ne–Ne collisions



$$\frac{\mathrm{d}N}{\mathrm{d}\varphi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos(n\,(\varphi - \psi_n))$$

- Measurements of higher order harmonics and cumulants

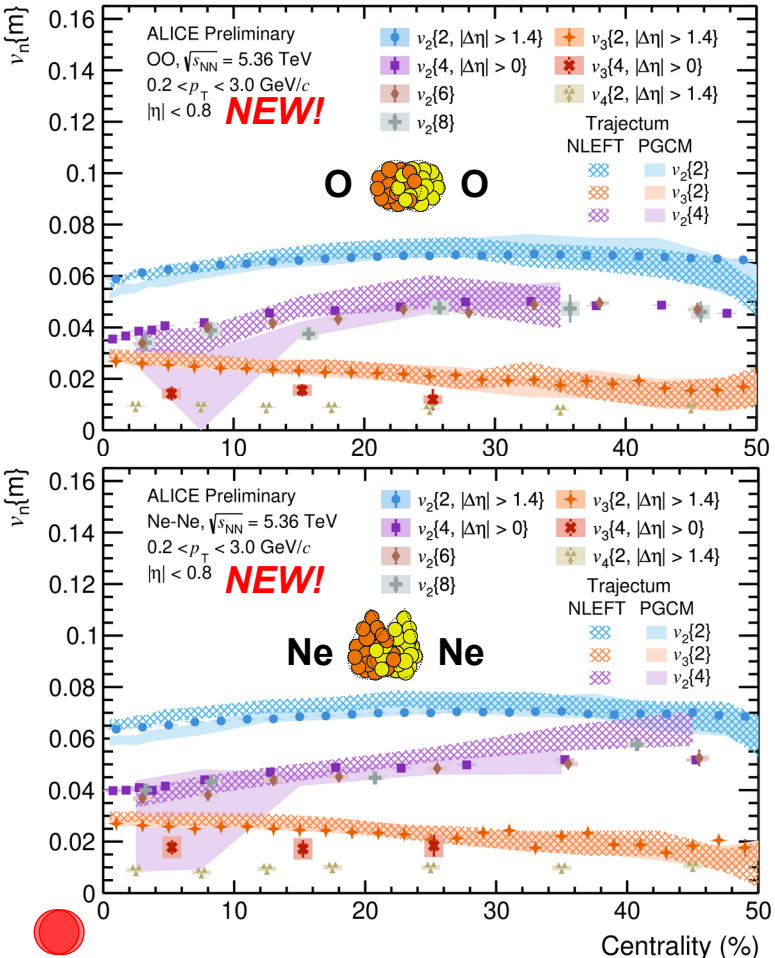
  → v_2 > v_3 > v_4 ordering

Alexian Lejeune, Wednesday 11:00

ALICE Collaboration, PRL 137, 082301

ALI-PREL-623545

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- Measurements of higher order harmonics and cumulants

  → v_2 > v_3 > v_4 ordering

  → **expected ordering from collective expansion**

- Trajectum model with realistic nuclear structure offer a good description

  → **supports emergence of hydrodynamic flow**

Alexian Lejeune, Wednesday 11:00

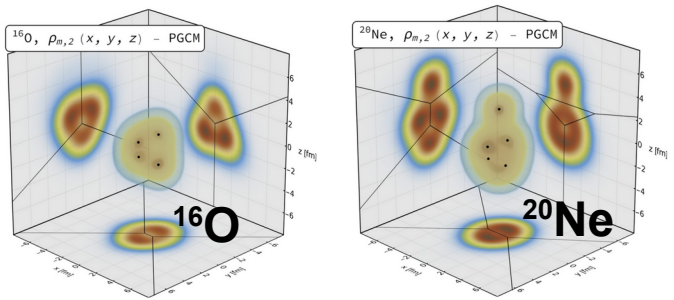
ALICE Collaboration, PRL 137, 082301

Probing the initial geometry

- **v_n (Ne−Ne/OO) ratios:** final-state effects largely cancel
  → reduce uncertainties on both data and models
  → **clean probe of the initial-state geometry**

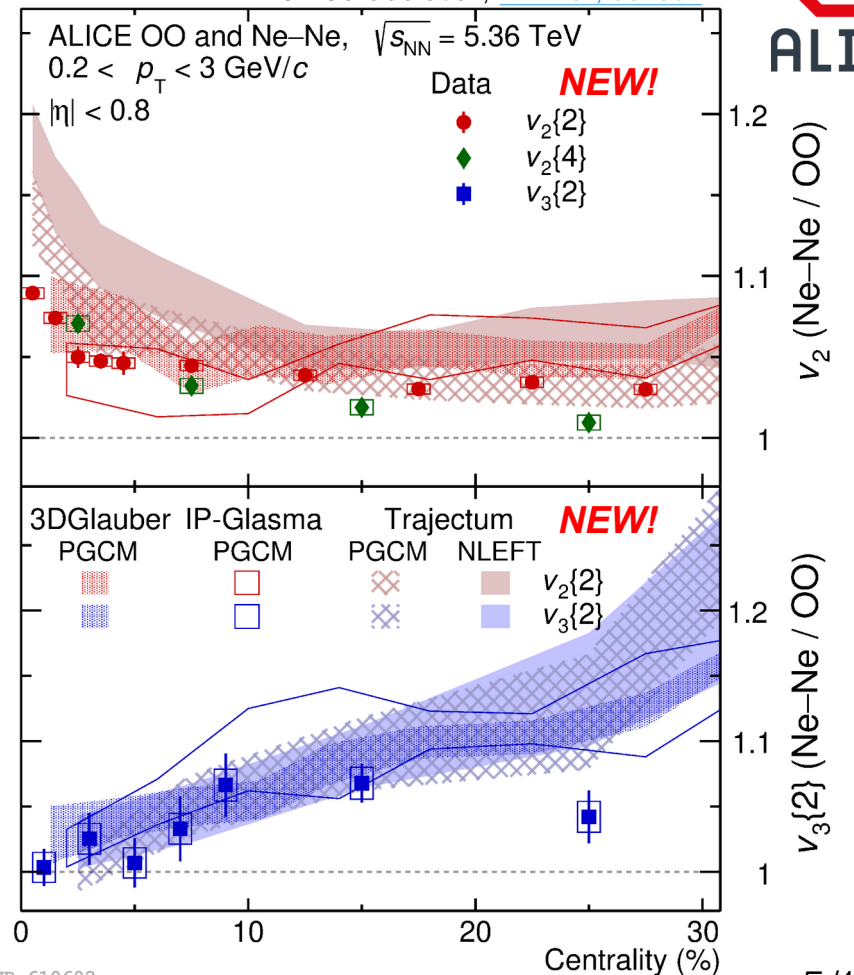
- v_2(Ne−Ne/OO) reaches ~10% in central collisions
  → **Expected from a (quadrupole-)deformed ^{20}Ne**

- v_3(Ne−Ne/OO) compatible with unity in central collisions
  → **larger ε_3 in ^{16}O → stronger octupole deformation?**

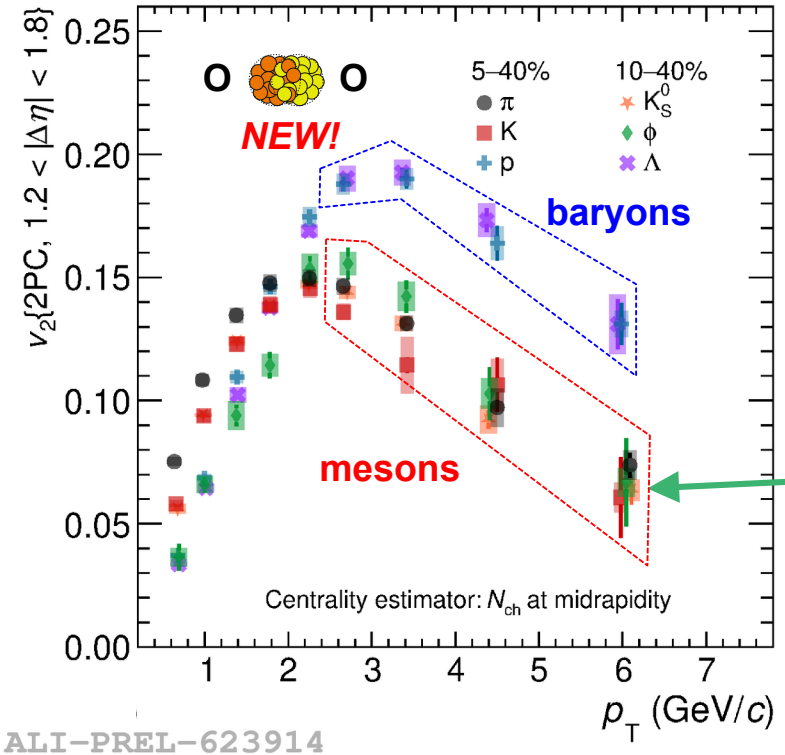


Alexian Lejeune,
Wednesday 11:00

ALICE Collaboration, PRL 137, 082301



v_2 of light-flavour hadrons in OO collisions



ALI-PREL-623914

Elliptic flow of **π, K, p, K^0_S, ϕ, Λ** in OO collisions:

- Clear **mass ordering at low p_T** consistent with collective expansion of the medium
- **Baryon-meson splitting at intermediate p_T**

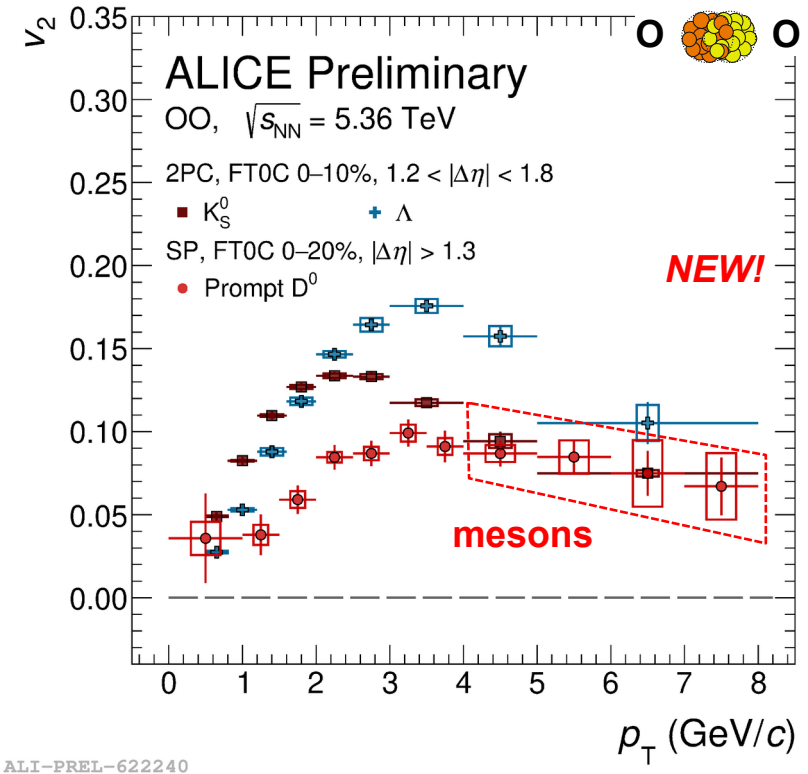
  → ϕ flows as mesons despite $M(p) \approx M(\phi) \approx M(\Lambda)$

  → splitting **driven by** quark constituents rather than **hadron mass**

Meson-like behaviour of ϕ supports hadronization via quark recombination from a collectively flowing partonic medium

→ **key signatures of partonic collectivity**

v_2 of heavy-flavour hadrons in OO collisions



Charm produced in the early stage of the collisions

→ can it thermalise through interactions with the medium?

Positive elliptic flow of D-meson in OO collisions:

- At low p_T: v_2(D) below that of light-flavour hadrons

  → inherits part of the flow from light quarks

- At intermediate/high-p_T: v_2(D) follows $v_2(K^0_S)$

  → **meson grouping** despite $M(D^0) > M(K^0_S)$

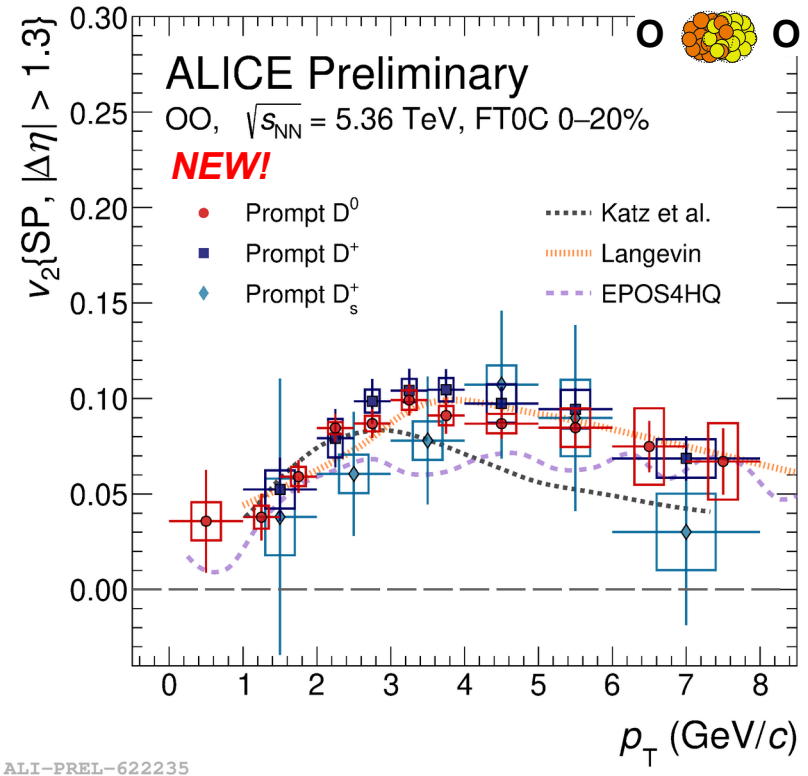
  → supports charm recombination from a flowing partonic medium

Katz et al., PRC 102 (2020) 041901

Langevin, EPJC 81 (2021) 1035

EPOS4HQ: J. Zhao et al, PRC 110 (2024) 024909

v_2 of heavy-flavour hadrons in OO collisions



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  → **meson grouping** despite $M(D^0) > M(K^0_S)$

  → supports charm recombination from a flowing partonic medium

- Measured v_2 qualitatively **described by transport models including QGP formation**

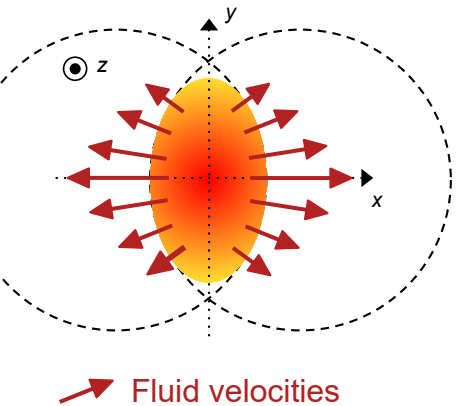
  → hints of thermalisation of charm

Katz et al., PRC 102 (2020) 041901

Langevin, EPJC 81 (2021) 1035

EPOS4HQ: J. Zhao et al, PRC 110 (2024) 024909

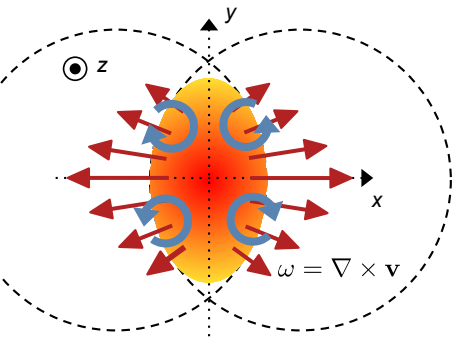
Longitudinal polarisation in OO collisions



Local asymmetries in velocity fields − driven by elliptic flow − manifest as vorticity parallel to the beam axis
→ generate Λ polarisation along the beam axis

ALICE has measured the Λ longitudinal polarization ($P_{z,s2}$) in Pb–Pb collisions in Run 2 & 3
→ do we observe similar vortical structures in light-ion collisions?

Longitudinal polarisation in OO collisions



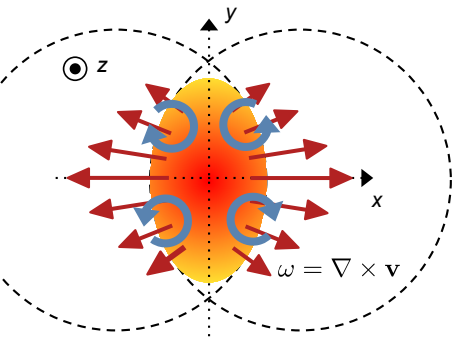
Fluid velocities

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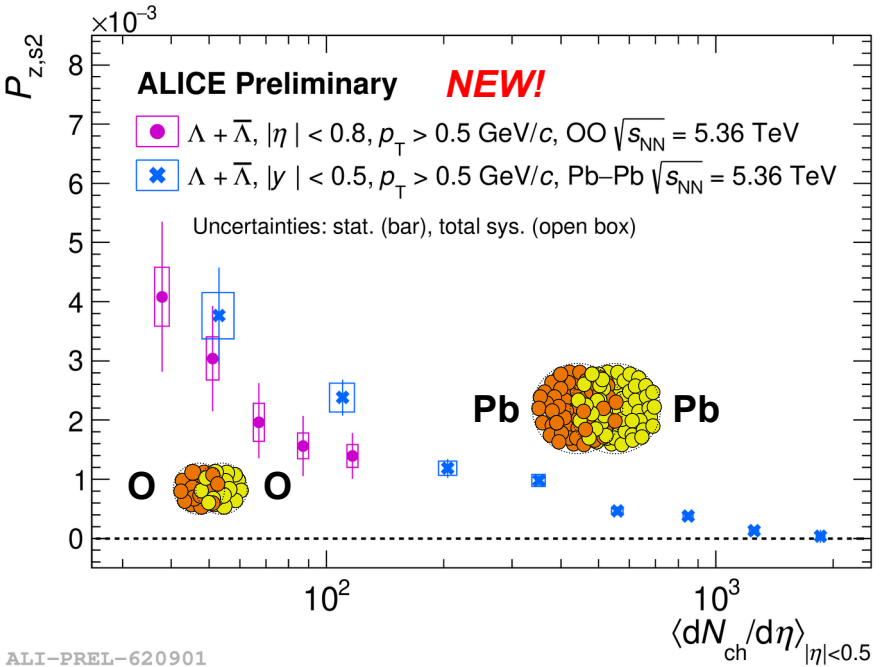
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Positive Λ longitudinal polarization is observed in OO collisions

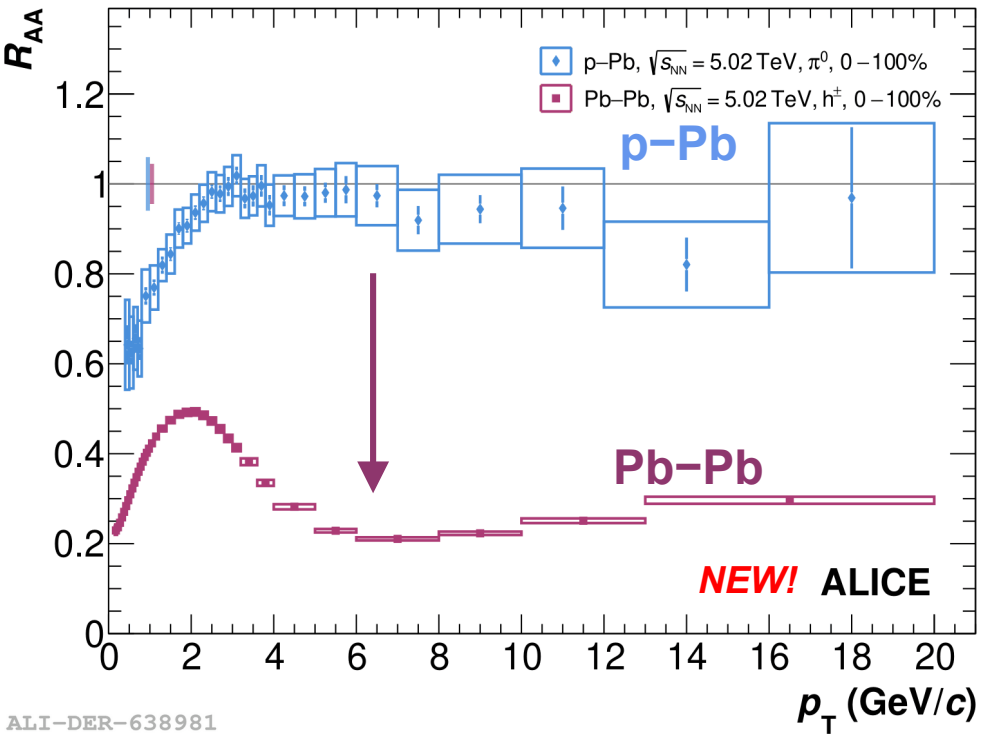
- significantly different from zero up to semi-peripheral collisions (combined significance of ~6σ)
- Similar to the one in Pb–Pb collisions at similar multiplicity values

→ help to **constrain bulk viscosity** of the medium produced in OO collisions



Observation of partonic energy loss in OO

ALICE Collaboration, arXiv:2606.19967 accepted by PRL



Nicolas Strangmann, Tuesday 11:30

- AA collisions = superposition of pp collisions for high-p_T particles? Nuclear modification factor:

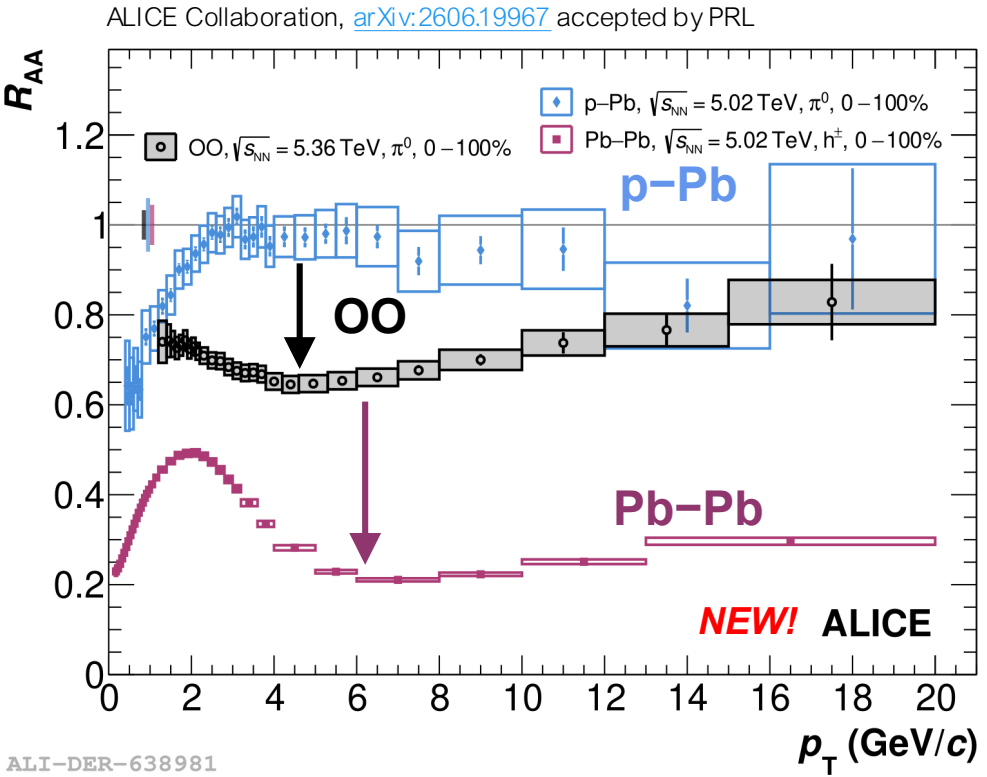
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If R_{AA} = 1, yes!

If R_{AA} < 1, particles are suppressed

- Measured to be below unity in Pb−Pb but not in p−Pb!

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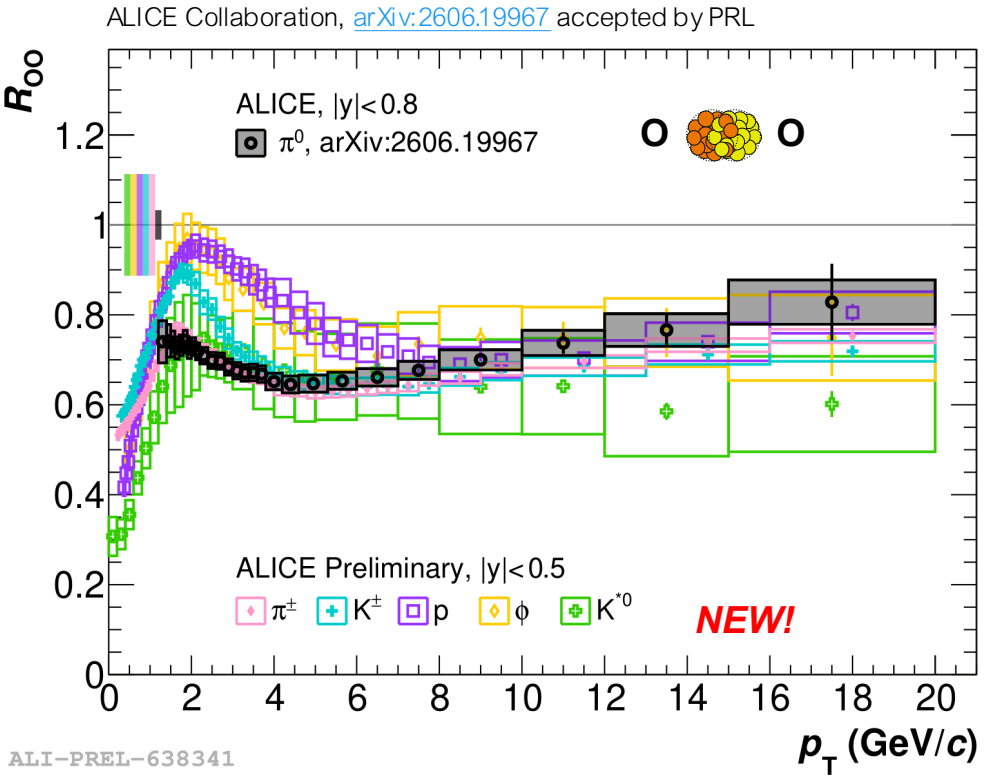
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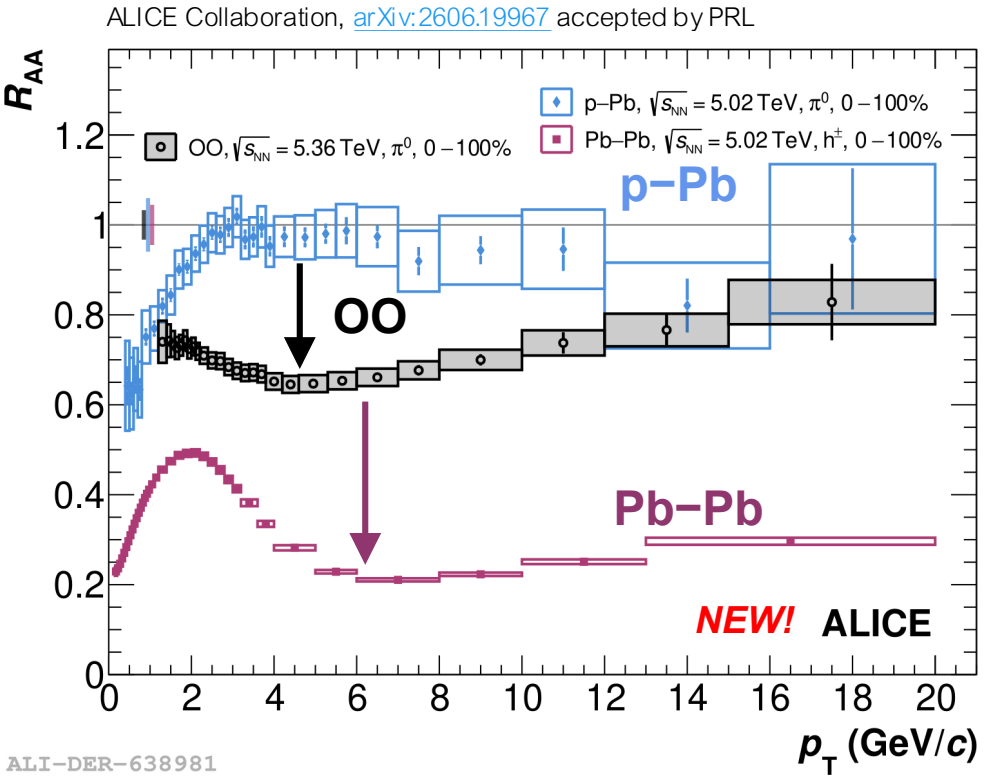
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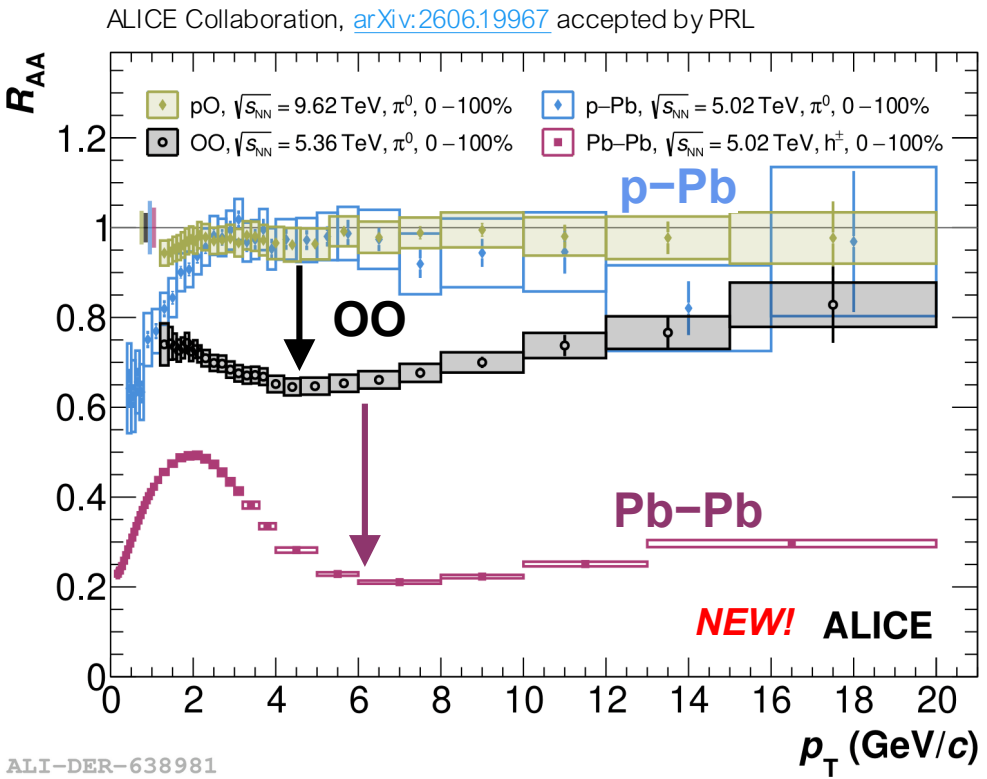
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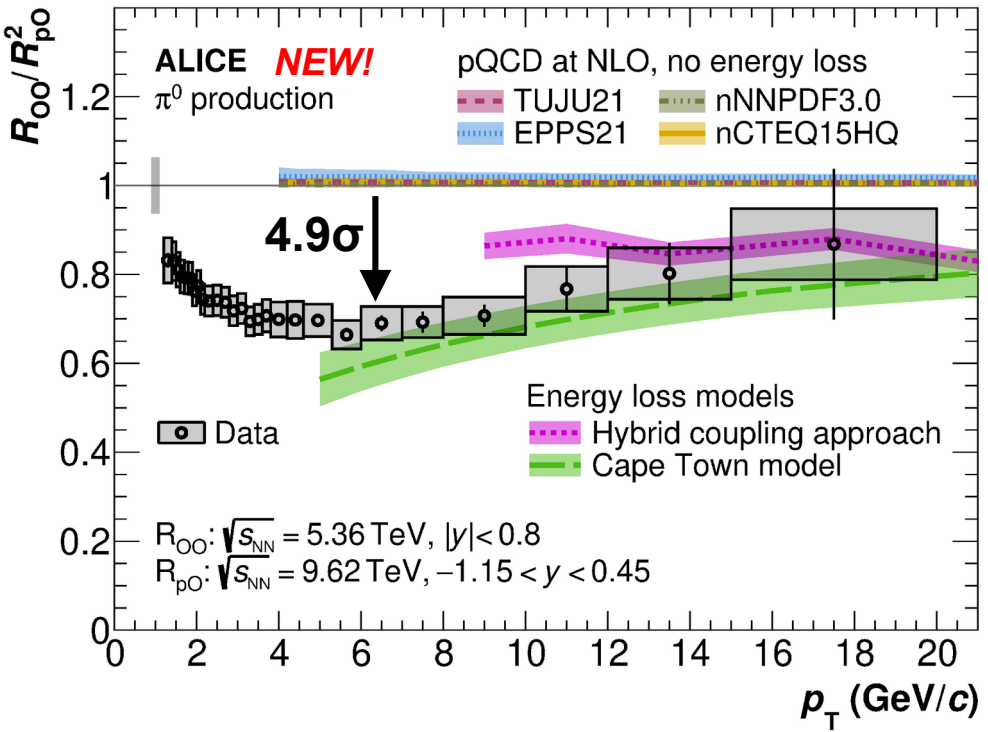
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- Origin of the effect: **partonic energy loss** or **cold nuclear matter** (CNM) **effects?**

  → **no hot-medium energy loss in pO (baseline)**

  → New variable to cancel CNM of both nuclei: R_{OO}/R_{pO}^2

  → isolate energy loss

- Observation of **partonic energy loss with a 4.9σ** in OO

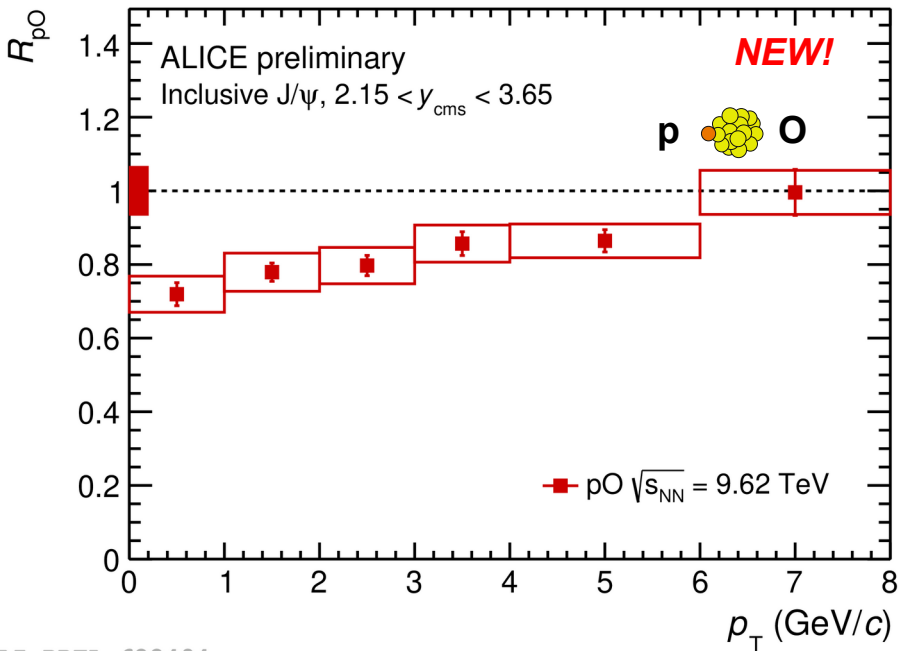
Nuclear modification factor of quarkonia

Quarkonia are sensitive to both suppression and regeneration effects in the medium

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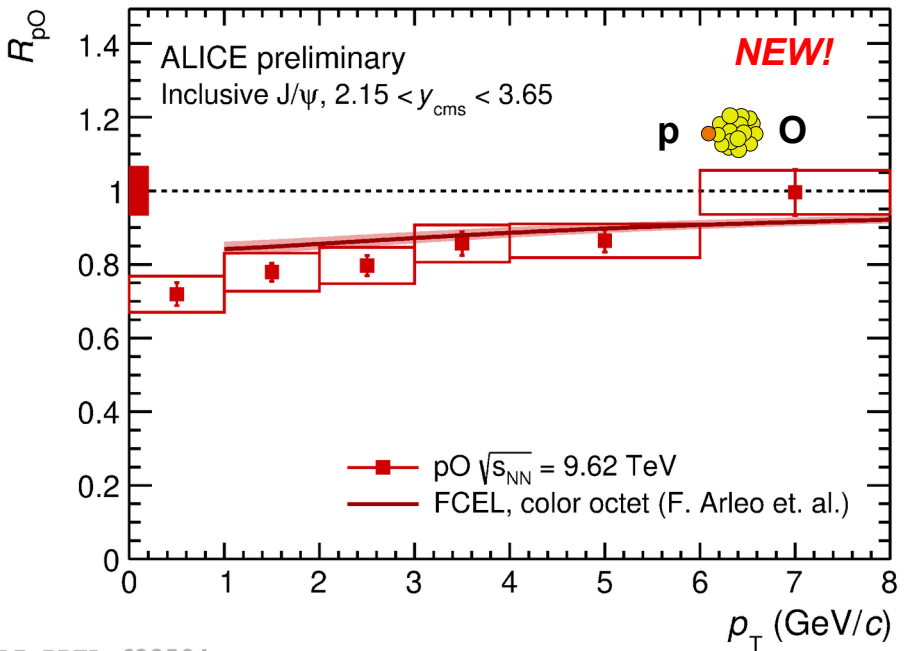
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- Fully Coherent Energy Loss (FCEL) model in agreement within uncertainties

  → coherent energy loss in cold nuclear matter is sufficient, no shadowing required

  → more models are needed to disentangle energy loss from nPDF effects



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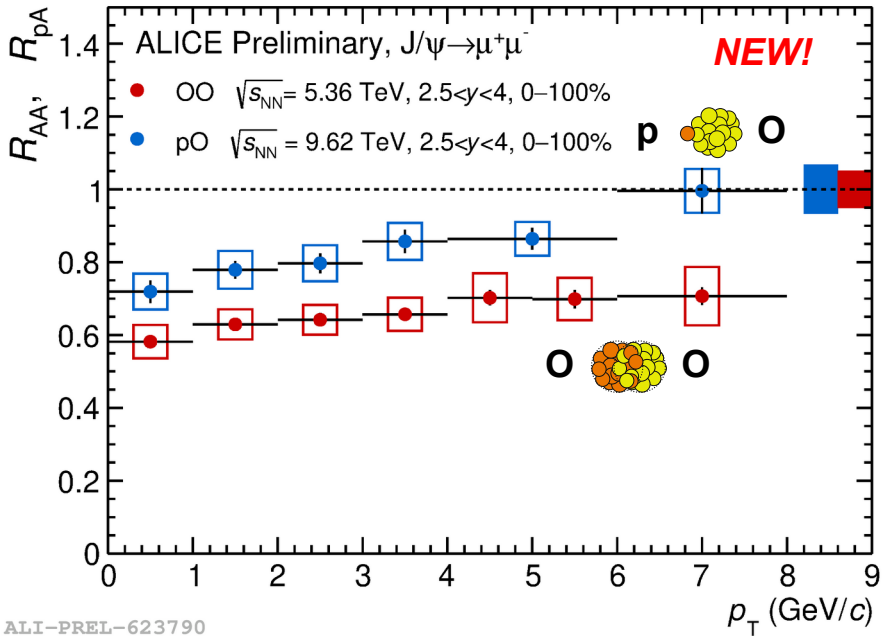
  → coherent energy loss in cold nuclear matter is sufficient, no shadowing required

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- $R_{\mathrm{OO}} < R_{\mathrm{pO}}$ for all p_{T} bins

  → **pO: mainly driven by CNM effects**

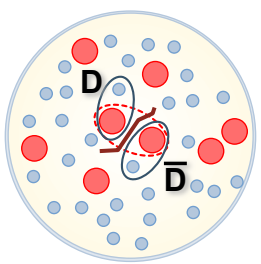
  → **OO: hot matter effects start to play a role**



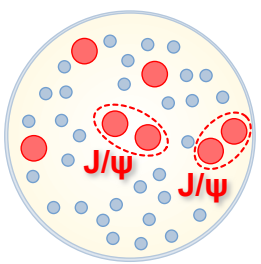
Inclusive J/ψ R_{AA} in OO collisions

- **Strong low p_T regeneration in central Pb−Pb**
- **In OO collisions: suppression with limited regeneration**

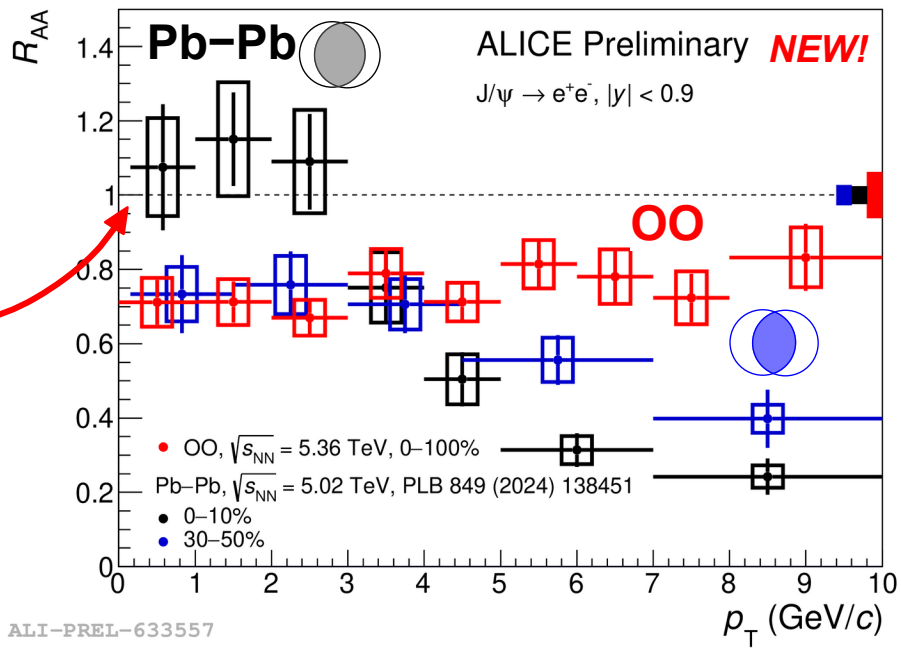
  → milder suppression at high p_T in OO than in Pb−Pb



Quarkonium **suppression**

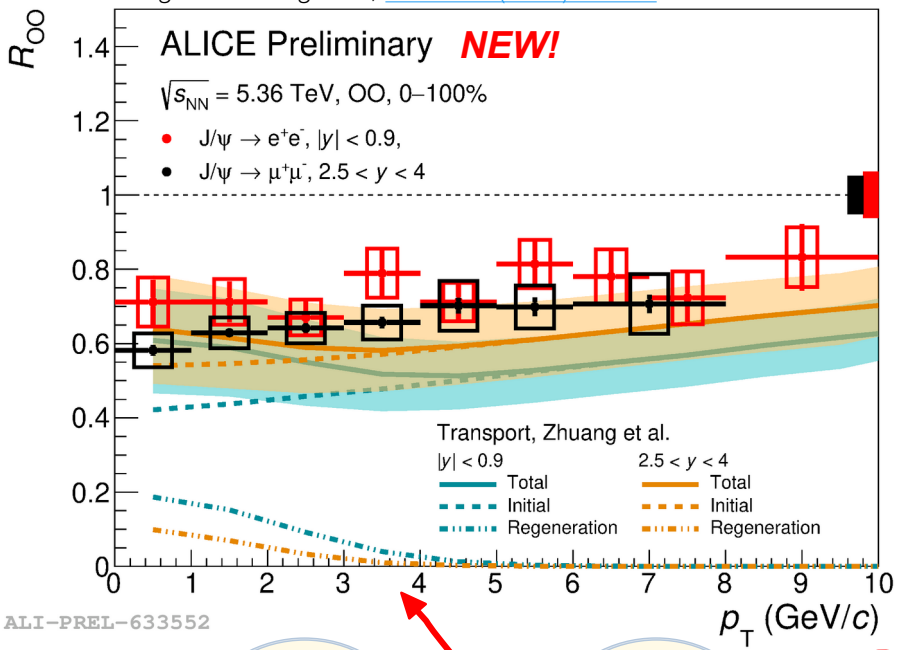


Quarkonium **regeneration**



Inclusive J/ψ R_{AA} in OO collisions

Tsinghua: Zhuang et al., PPNP 114 (2020) 103801

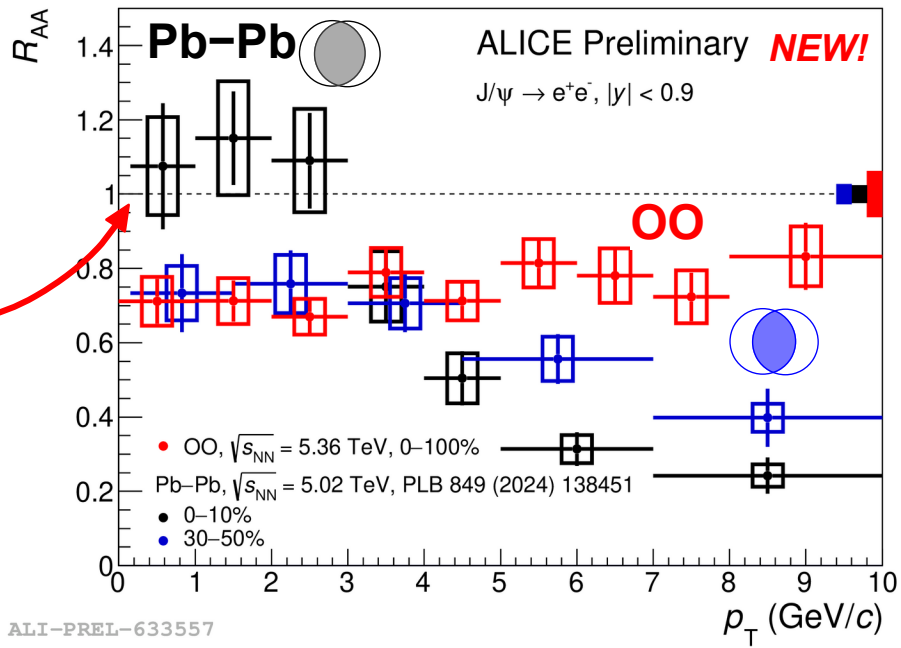


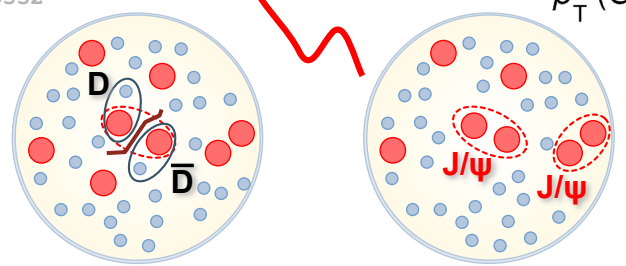
- **Strong low p_T regeneration in central Pb–Pb**
- **In OO collisions: suppression with limited regeneration**

→ milder suppression at high p_T in OO than in Pb–Pb

→ compatible with models with a QGP

→ smaller medium size?





Quarkonium **suppression**

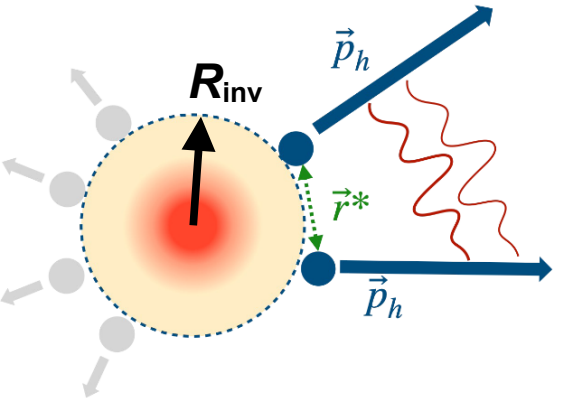
Quarkonium **regeneration**

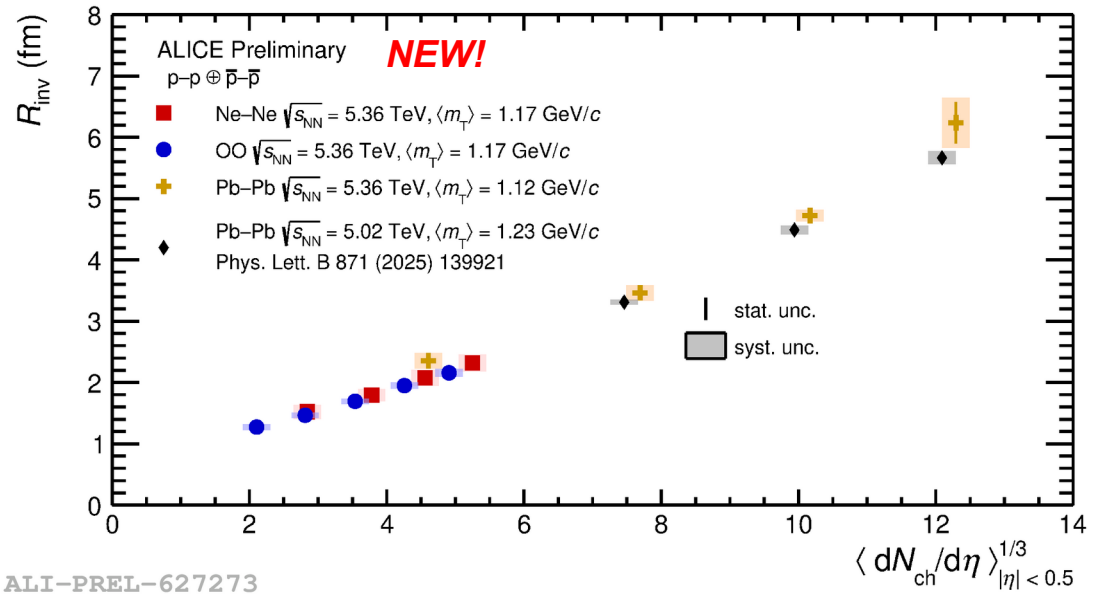
How big are OO and Ne−Ne collisions?

- **Source size can be directly measured using femtoscopy**

  → p−p + p−$\bar{p}$ correlations probe the space-time extent of the emitting source

  → source radius R_{inv} is a free parameter of the correlation function





- **R_{inv} increases smoothly with charged-particle multiplicity**

  → OO and Ne−Ne bridge the gap between small and large systems

Neelima Agrawal, Monday 15:15

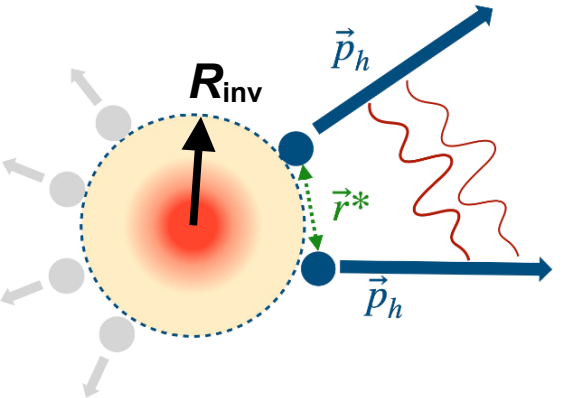
ALI-PREL-627273

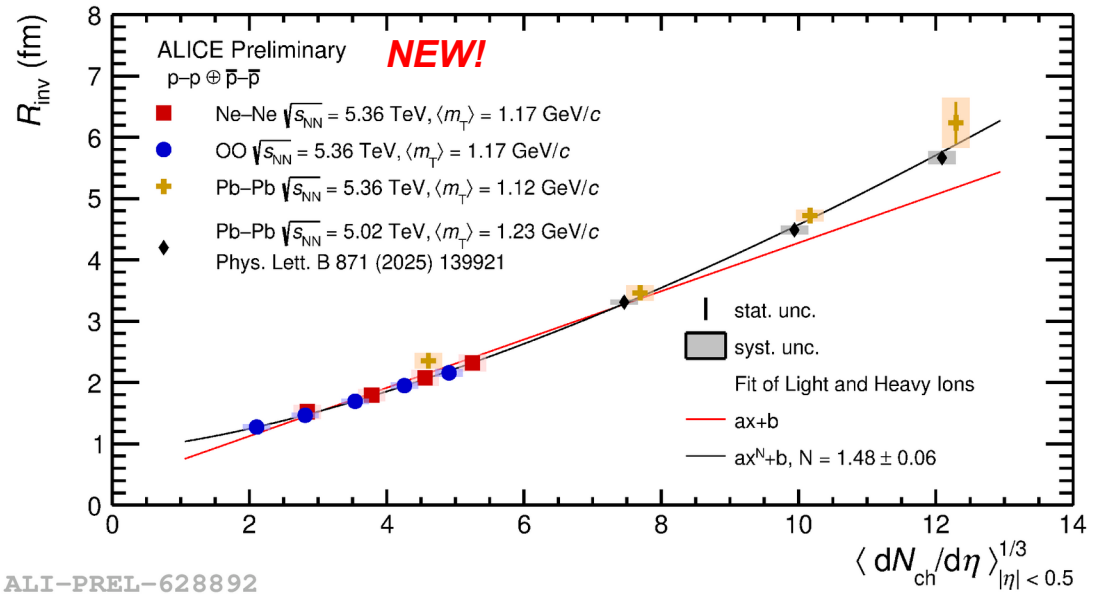
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ALI-PREL-628892

- **R_{inv} increases smoothly with charged-particle multiplicity**

  → OO and Ne−Ne bridge the gap between small and large systems

  → power law better describes light and heavy ions while linear scaling underestimates the Pb−Pb results

Common scaling of the p-p emitting source is observed from light- to heavy-ion collisions

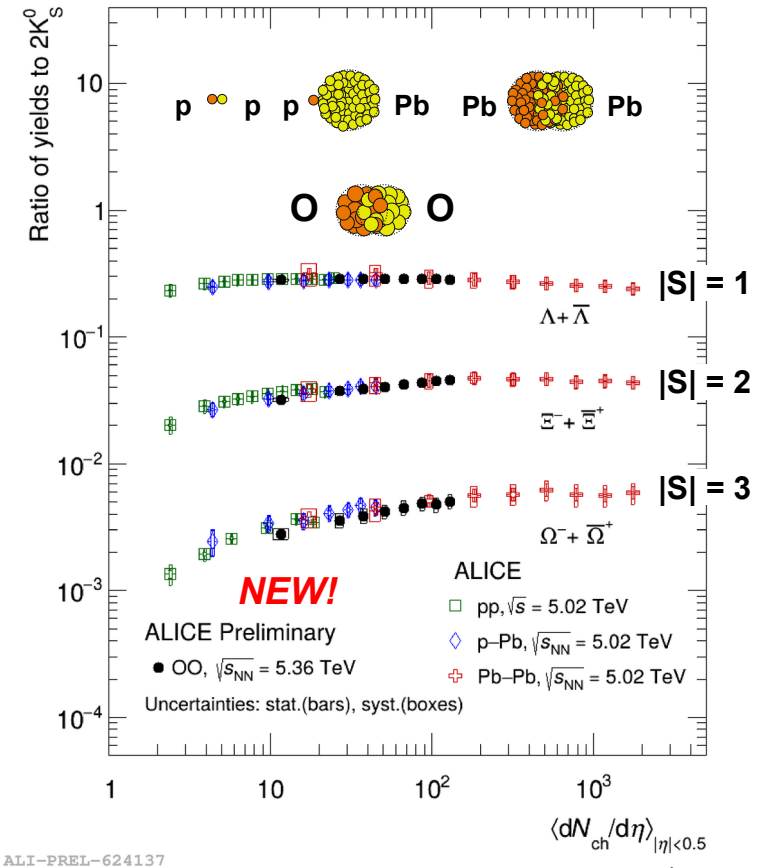
Neelima Agrawal, Monday 15:15

Does strangeness follow a common pattern?

Smooth evolution of the relative identified particle abundances with multiplicity: pp, p−Pb, OO, Pb−Pb

- Strange hadron yields are **consistent with common strangeness-driven scaling** across collision systems

  $E(K^0_S) \approx E(\Lambda) < E(\Xi^{\pm}) < E(\Omega^{\pm})$, with E = enhancement factor



Does strangeness follow a common pattern?

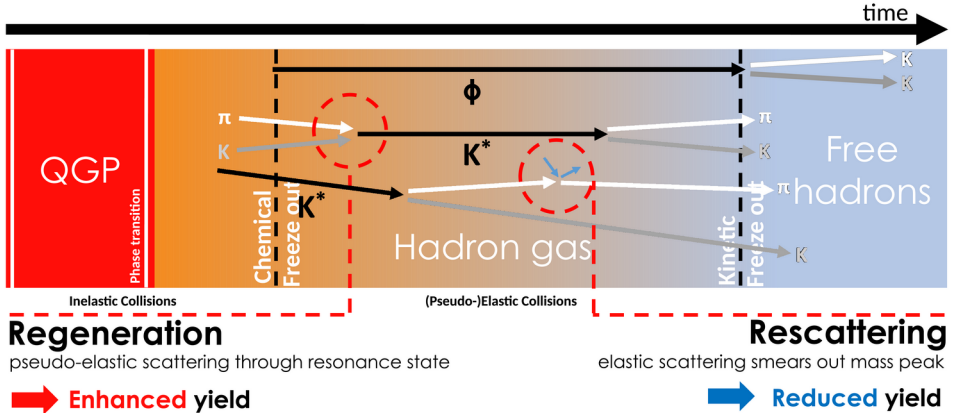
Smooth evolution of the relative identified particle abundances with multiplicity: pp, p−Pb, OO, Pb−Pb

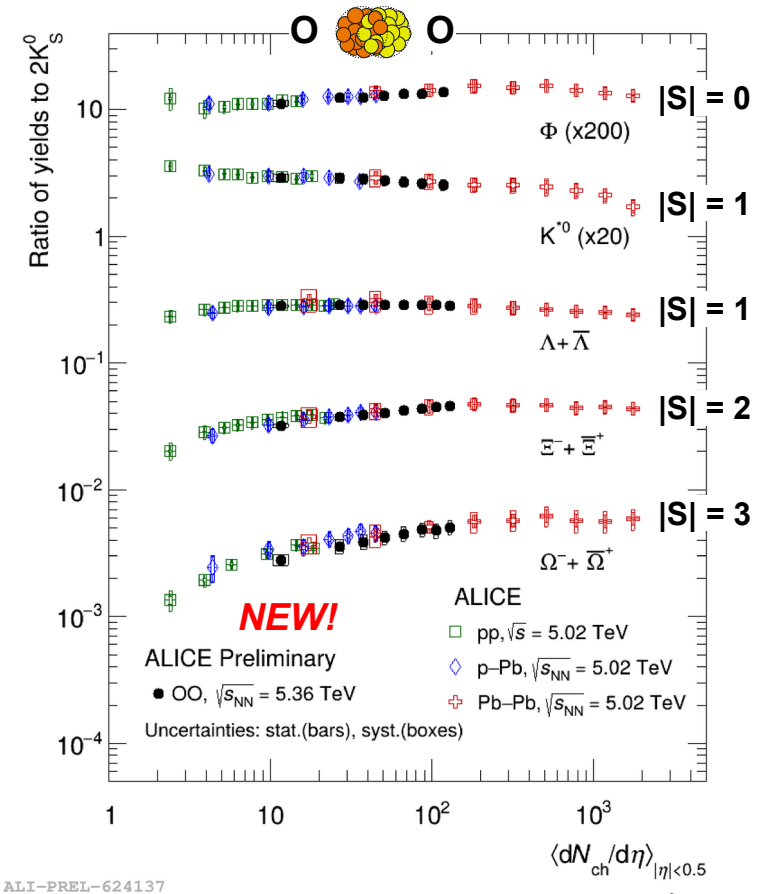
- Strange hadron yields are **consistent with common strangeness-driven scaling** across collision systems

  $E(K^0_S) \approx E(\Lambda) < E(\Xi^{\pm}) < E(\Omega^{\pm})$, with E = enhancement factor

- Decreasing trend of K^{*0}/K^0_S ratio while ϕ/K^0_S ratio stays constant

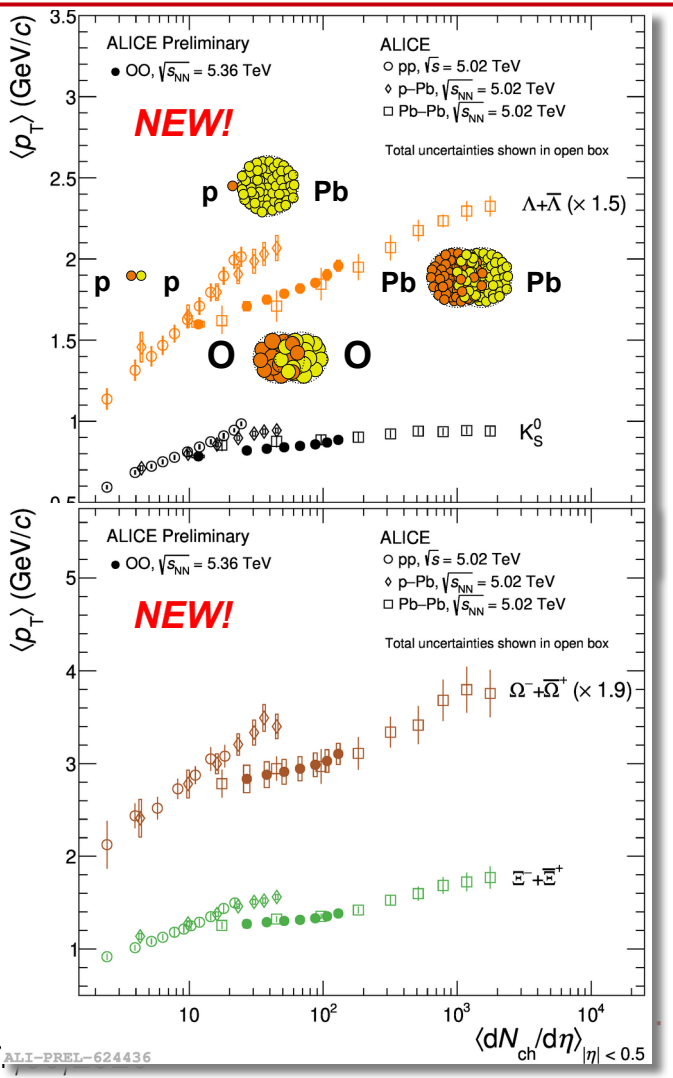
  → **short-lived K^{*0}** (~ 4 fm/*c*) **suppressed due to rescattering** while **longer-lived ϕ** (~ 46 fm/*c*) remain **unaffected**





Courtesy of Bong-Hwi Lim

Does OO expand like Pb−Pb?



Spectra get harder with increasing multiplicity

- steeper trend for hadrons with higher masses

  $M(K^0_S) < M(\Lambda) < M(\Xi) < M(\Omega)$

- At the same multiplicity, **$\langle p_T \rangle$ in pp, p−Pb lies above Pb−Pb**

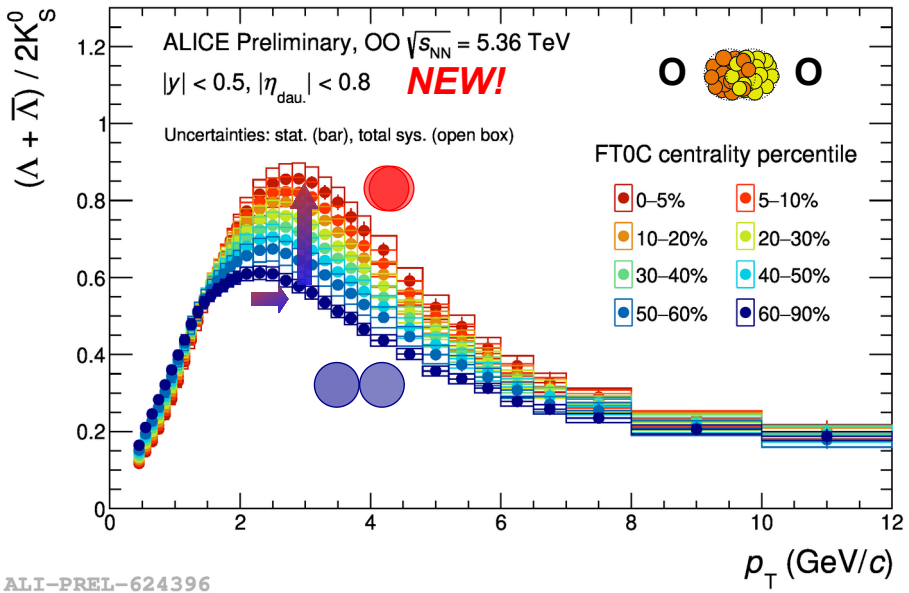
  → radial boost at fixed multiplicity is not universal

- **$\langle p_T \rangle$ in OO follows the Pb−Pb trend**

  → OO develops a boost comparable to Pb−Pb at equal multiplicity

  → **common hadrochemistry** from pp to Pb−Pb,
  with **different boost**

Do quarks hadronise differently in light ions?



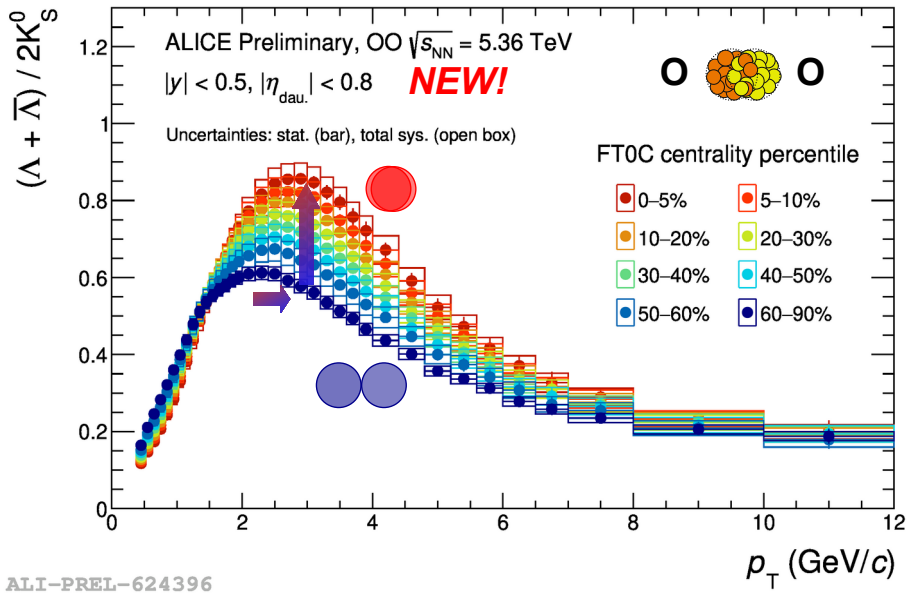
Baryon-to-meson ratio in OO collisions:

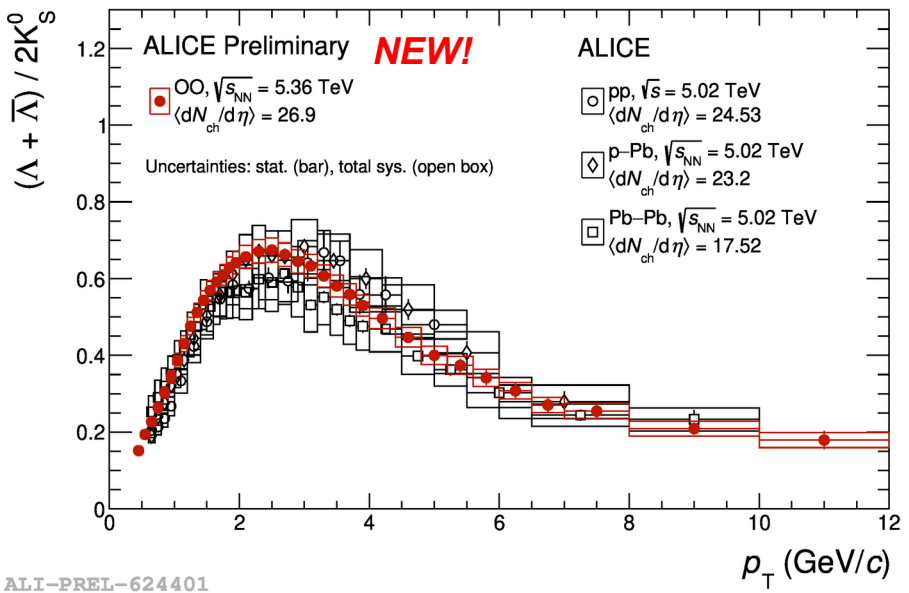
- Increases at intermediate p_T significantly from low- to high-multiplicity collisions

  → radial flow boosts baryons more efficiently than mesons

  → can be explained by coalescence inside a collectively expanding medium

Do quarks hadronise differently in light ions?





Baryon-to-meson ratio in OO collisions:

- Increases at intermediate p_T significantly from low- to high-multiplicity collisions

  → radial flow boosts baryons more efficiently than mesons

  → can be explained by coalescence inside a collectively expanding medium

- **Baryon-meson splitting has the similar magnitude as the one in pp, p−Pb, Pb−Pb** at equivalent multiplicity

What light ions have taught us

- **pO is a clean reference**

  → R_{pO} follows p−Pb, no hot-medium energy loss in pO

- **OO and Ne−Ne form a small but genuine medium**

  → collective flow described by hydrodynamics

  → Ne−Ne/OO ratios highlight nuclear structure: quadrupole-deformed ^{20}Ne, larger ε_3 ^{16}O

  → positive v_2 of light- and heavy-flavour hadrons → partonic collectivity, hints of charm thermalisation

  → partonic energy loss observed at 4.9σ

  → positive Λ longitudinal polarisation patterns as in Pb−Pb

  → enhanced strangeness production, baryon-to-meson ratio consistent across pp, p−Pb, Pb−Pb

  → source radii on a common scaling with Pb−Pb and $\langle p_T \rangle$ consistent with Pb−Pb

  BUT:

  → milder suppression than in Pb−Pb, limited quarkonium regeneration

The open question is no longer whether these signatures appear, but whether one model with the same ingredients can describe pp, pO, OO, Ne−Ne and Pb−Pb together

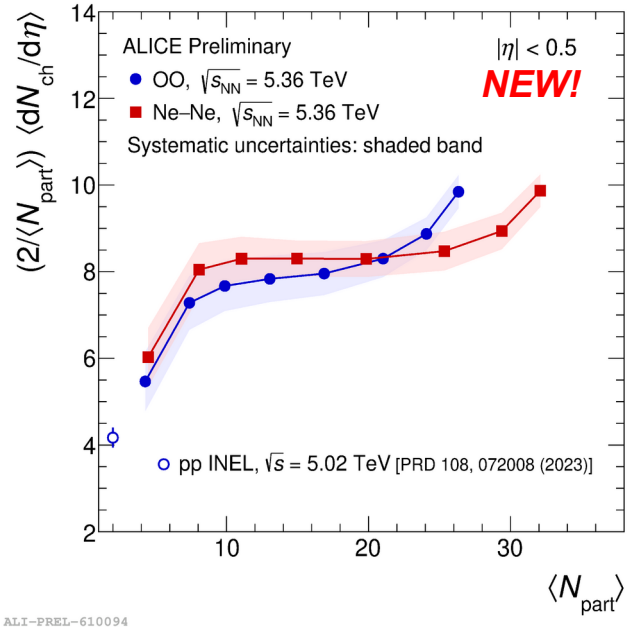
Thank you!

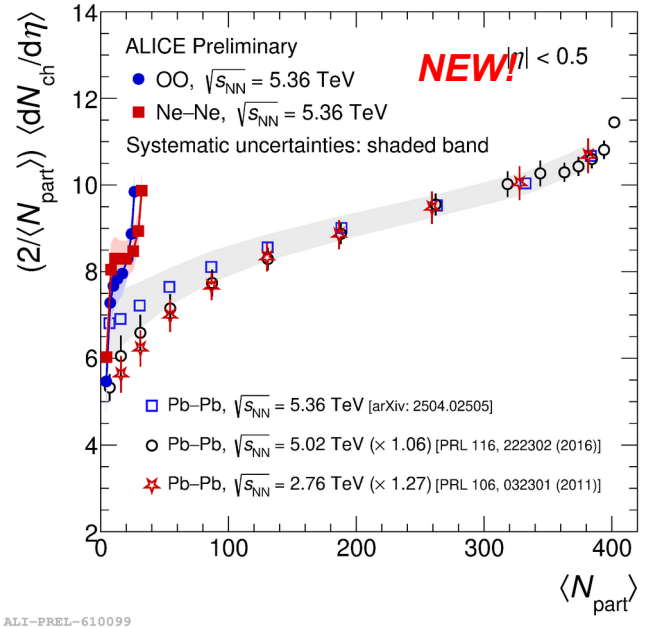
Backup slides

Midrapidity (2/<N_{part}>)<dN_{ch}/dη> in OO and Ne–Ne

- Average charged-particle multiplicity density per participant pair

  → compare **particle production "efficiency" per participant nucleon pair**





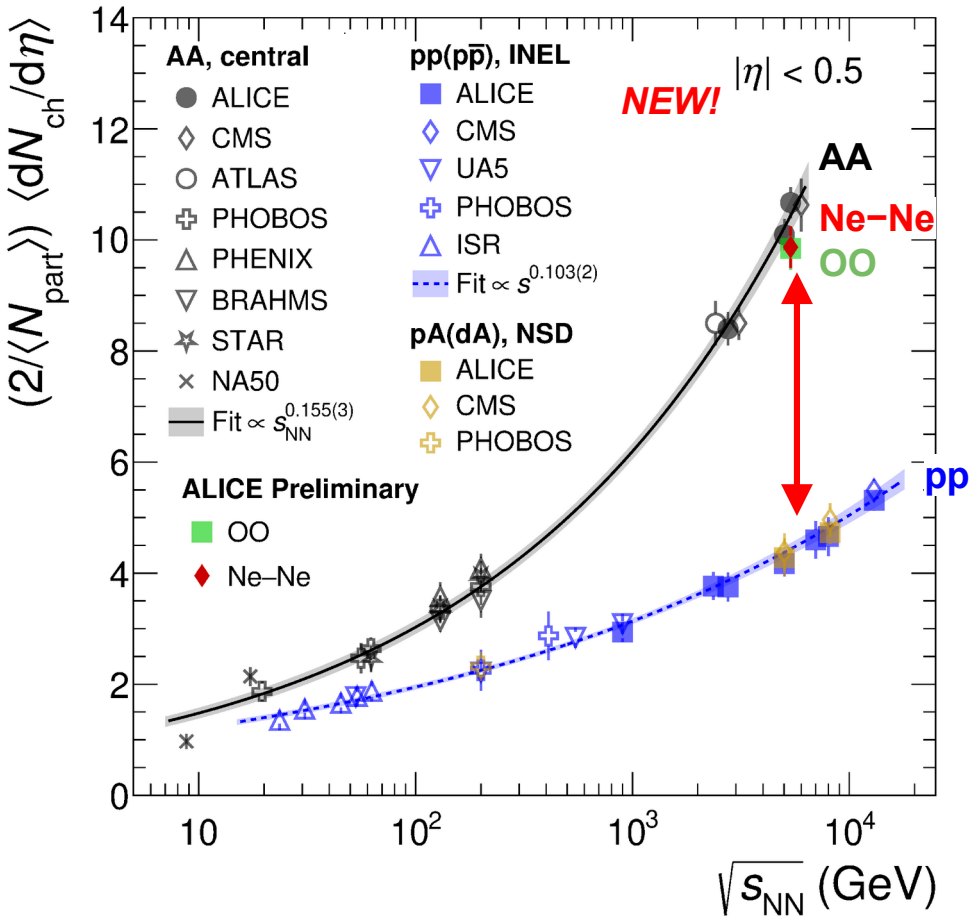
- Both **OO** and **Ne–Ne** show an **increase with respect to pp collisions**

  → Ne–Ne lies above OO as expected by the slightly larger system size

- **OO** and **Ne–Ne** have **steeper increase than heavy ions**

  → small increases in <N_{part}> lead to large changes in particle production

Midrapidity $(2/\langle N_{part}\rangle)\langle dN_{ch}/d\eta\rangle$ Vs $\sqrt{s_{NN}}$

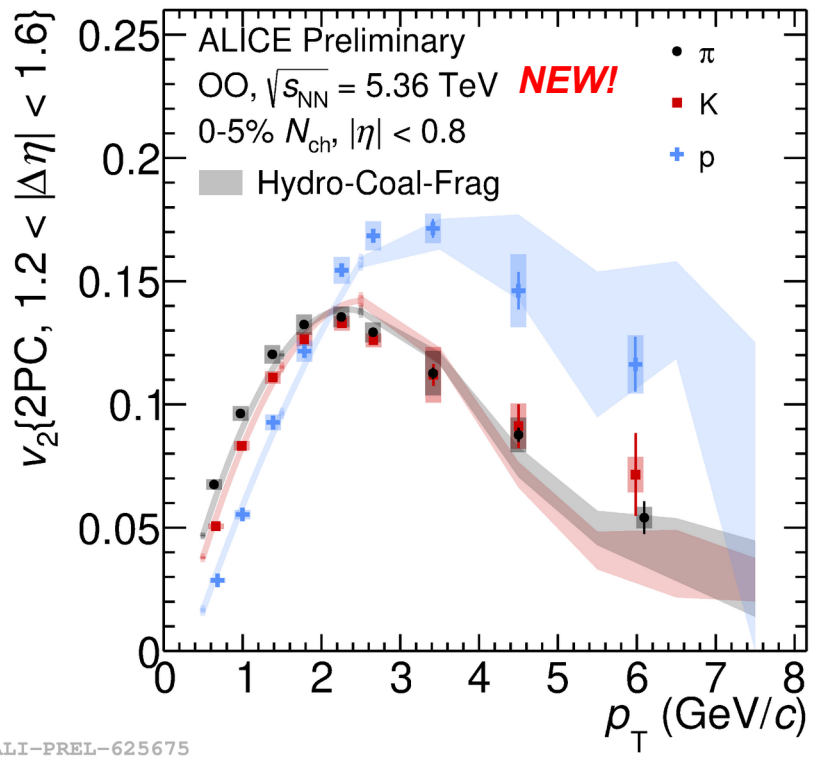


- OO and Ne−Ne points follows the AA energy-scaling trend,

  → OO is not a simple superposition of pp or pA collisions !

  → **OO behaves as the smaller AA-like system**

v_2 of light-flavour hadrons in OO collisions



Elliptic flow of **π, K, p, K^0_S, ϕ, Λ** in OO collisions:

- Clear **mass ordering at low p_T** consistent with collective expansion of the medium
- **Baryon-meson splitting at intermediate p_T**

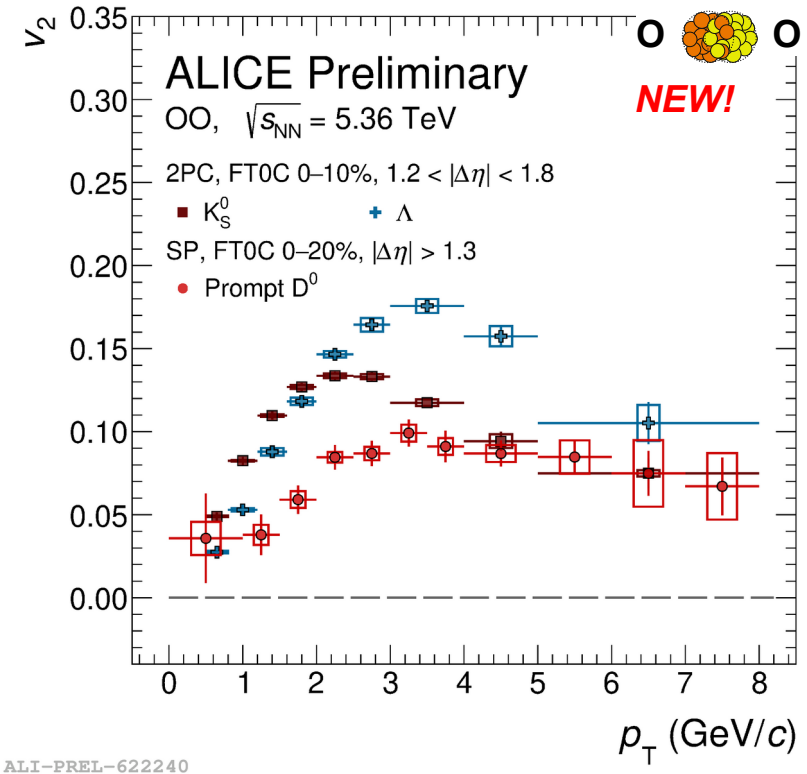
  → ϕ flows as mesons despite $M(p) \approx M(\phi) \approx M(\Lambda)$

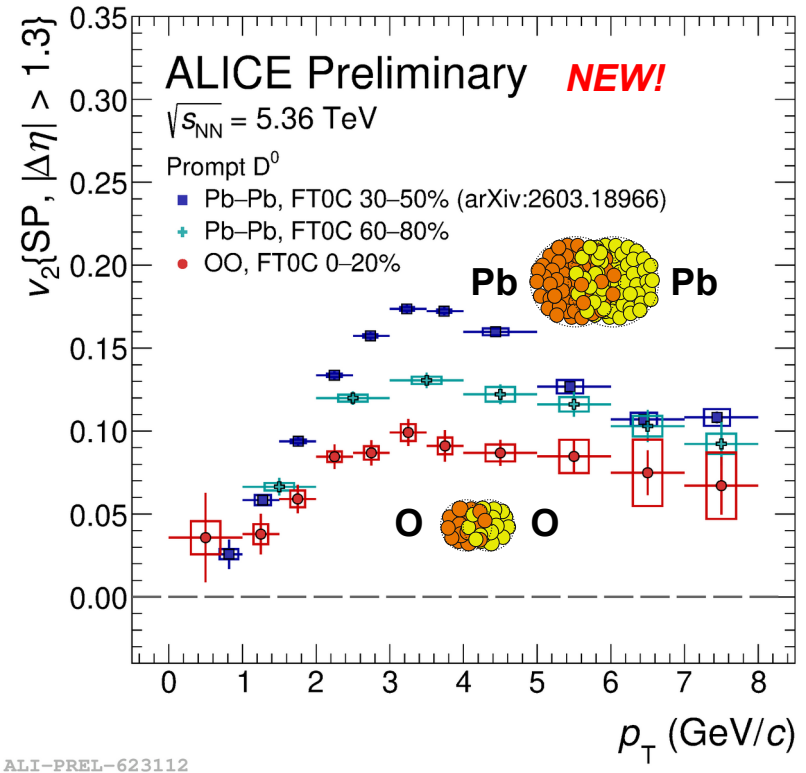
  → splitting **driven by** quark constituents rather than **hadron mass**

  Meson-like behaviour of ϕ supports hadronization via quark recombination from a collectively flowing partonic medium

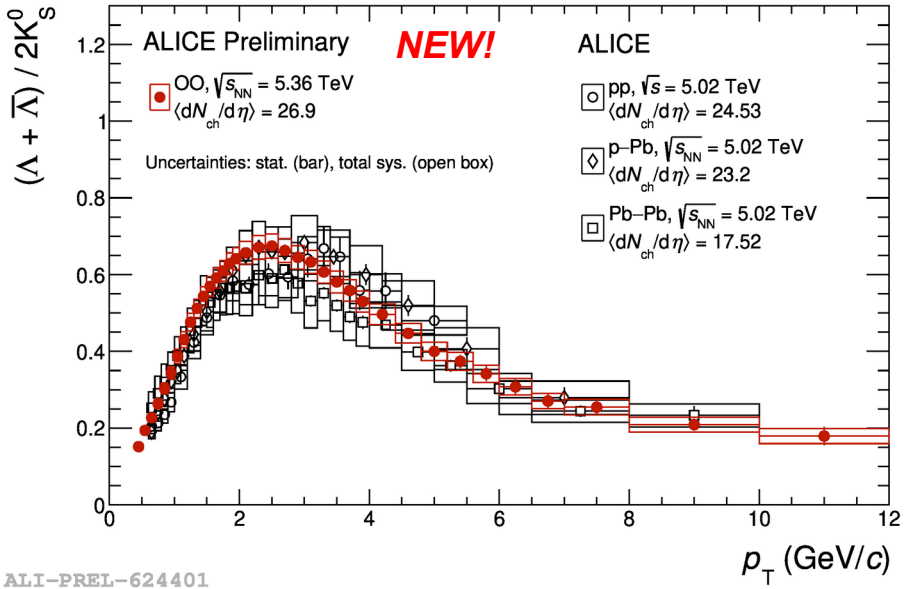
  → **key signatures of partonic collectivity**

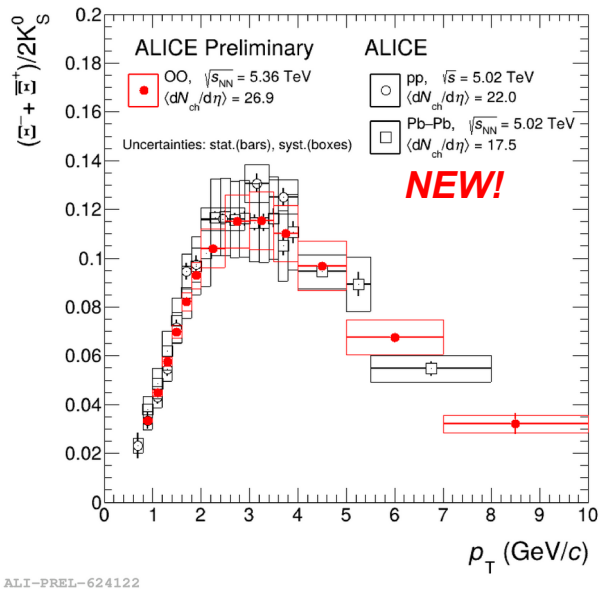
v_2 of heavy-flavour hadrons in OO collisions





Baryon-to-meson ratio in OO collisions

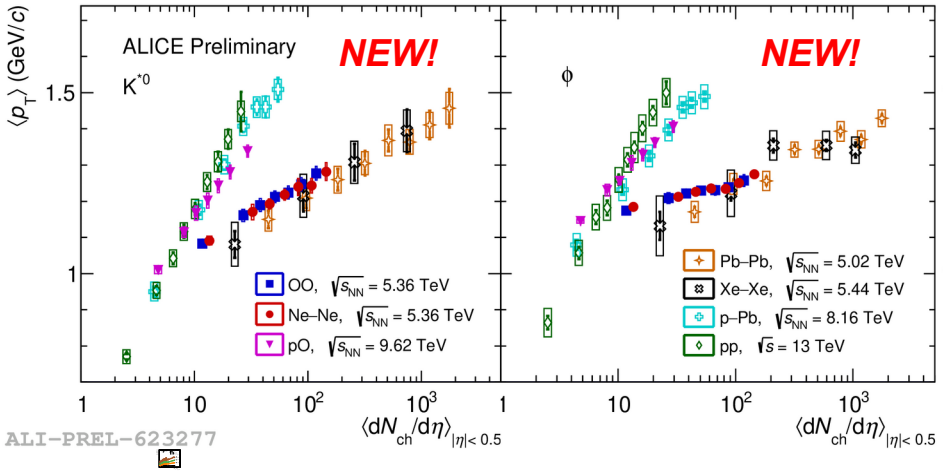




Baryon-to-meson (Λ/K^0_S, Ξ/K^0_S) **ratio in OO collisions**

- Increases at intermediate p_T
- Baryon-meson splitting has the similar magnitude as the one in pp, p−Pb, Pb−Pb at equivalent multiplicity

Strangeness production dynamics in light ions



NEW!

Spectra get harder with increasing multiplicity

- steeper trend for hadrons with higher masses

$$M(K^0_S) < M(\phi) \approx M(\Lambda) < M(\Xi) < M(\Omega)$$

→ supports the picture of **collective motion** in light-ion collisions similarly as in Pb−Pb (radial flow)

$\langle p_T \rangle$ does not connect different collision systems

- **$\langle p_T \rangle$ in pO aligns with p−Pb** measurements
- **$\langle p_T \rangle$ in OO and Ne−Ne collisions are consistent with Pb−Pb**