

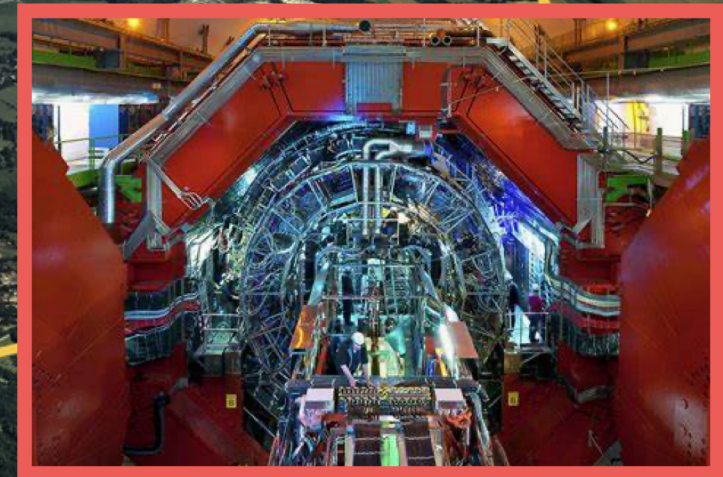
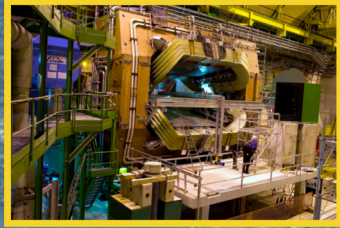
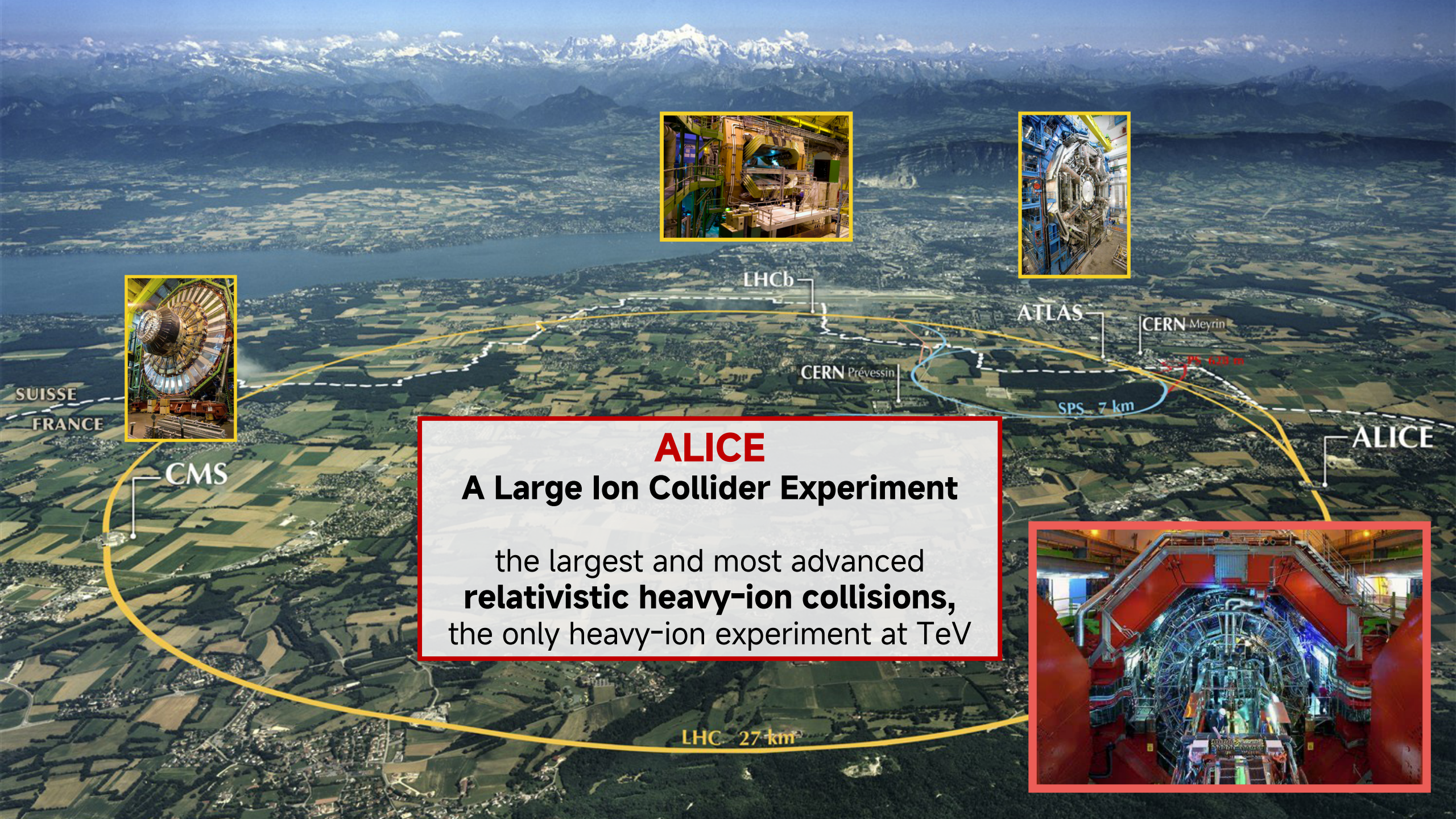
极端核物质前沿研讨会

Selected highlights of correlations and flow at LHC-ALICE

寿齐焯

复旦大学

2026.04.27 宜昌



ALICE
A Large Ion Collider Experiment
the largest and most advanced
relativistic heavy-ion collisions,
the only heavy-ion experiment at TeV

SUISSE
FRANCE

LHCb

ATLAS

CERN Meyrin

CERN Prévessin

SPS 7 km

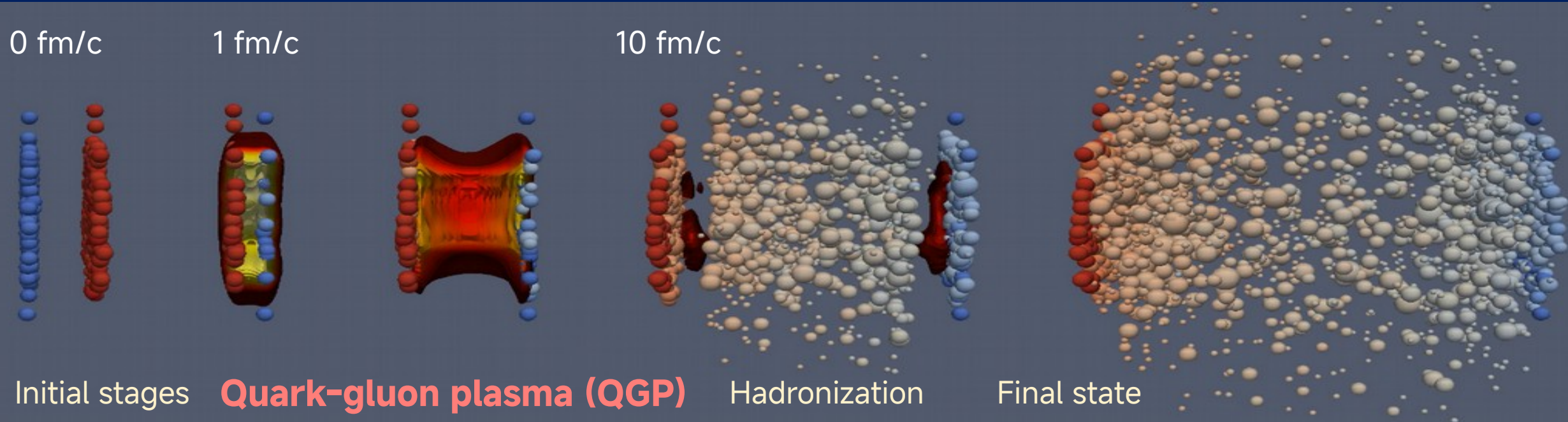
PS 6.3 km

ALICE

CMS

LHC 27 km

Evolution of relativistic heavy-ion collisions



Quark-gluon plasma (QGP)

Strongly interacting matter,
in the extremely hot and dense environment microseconds after the Big Bang

Collective motion (Collectivity)

One of the most important features and probes of the QGP

LHC Run 3 data-taking (2023–2026): high statistics

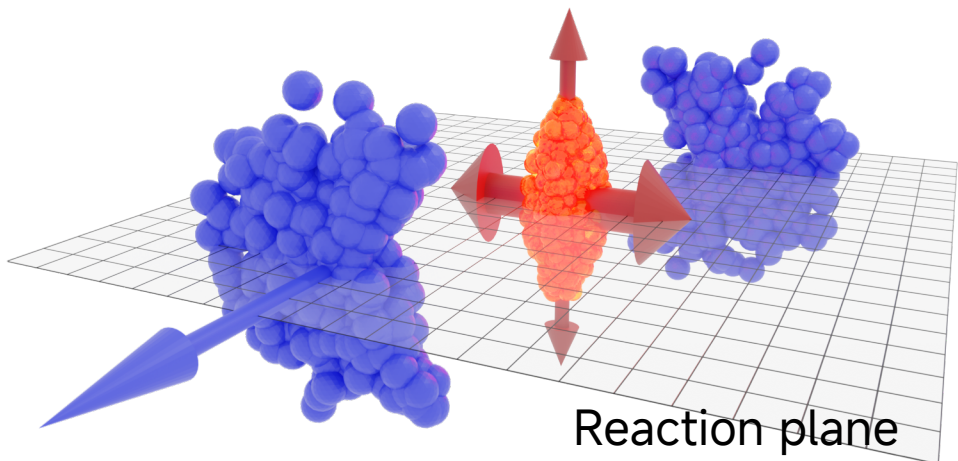
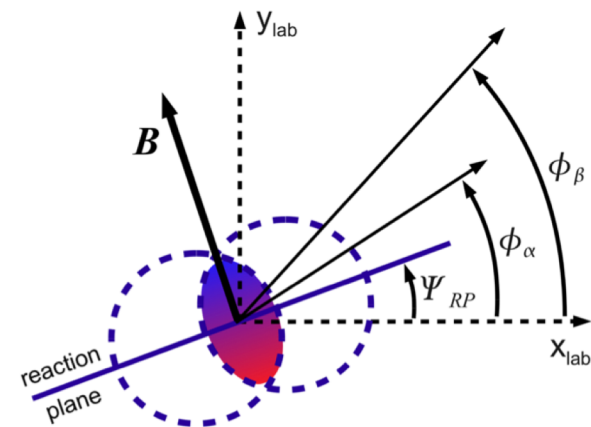
e.g. 13 nb^{-1} Pb–Pb collisions, ≈ 100 times the MB statistics of Run 2

Azimuthal correlations and anisotropic flow

Initial eccentricity + QGP evolution \rightarrow Final momentum anisotropy

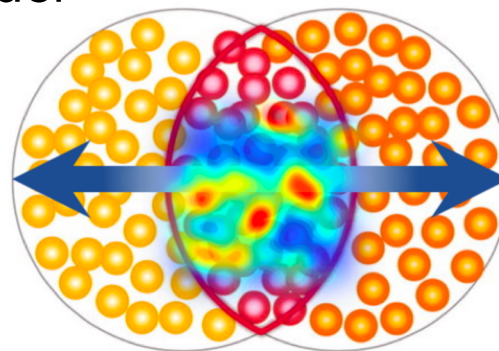
$$E \frac{d^3N}{d^3\mathbf{p}} = \frac{1}{2\pi} \frac{d^2N}{p_t dp_t dy} \left(1 + 2 \sum_{n=1}^{\infty} v_n \cos[n(\varphi - \Psi_{RP})] \right)$$

$$v_n(p_t, y) = \langle \cos[n(\varphi - \Psi_{RP})] \rangle$$



2nd order

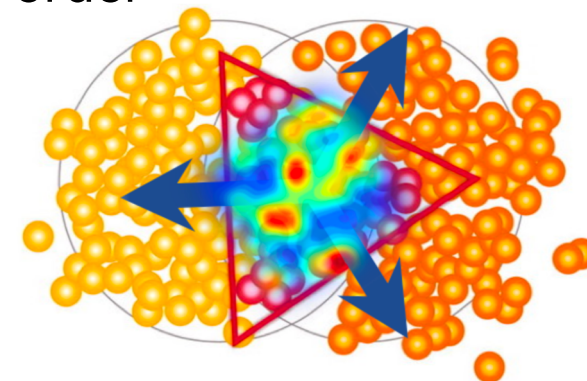
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Elliptic flow

3rd order

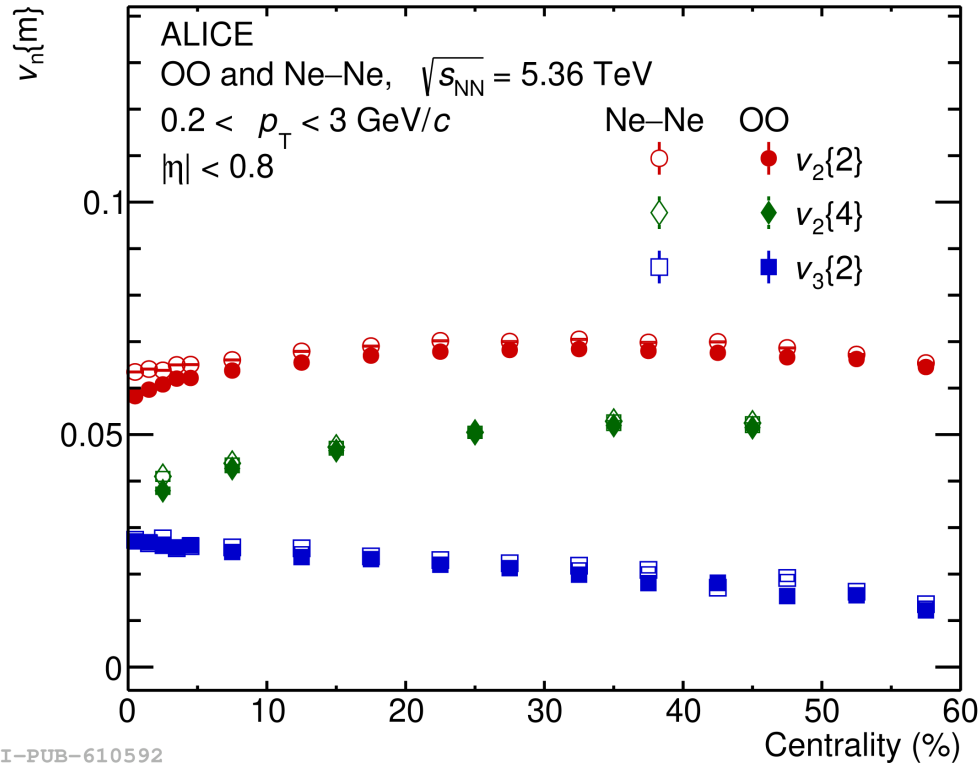
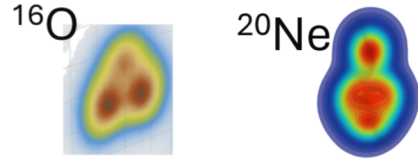
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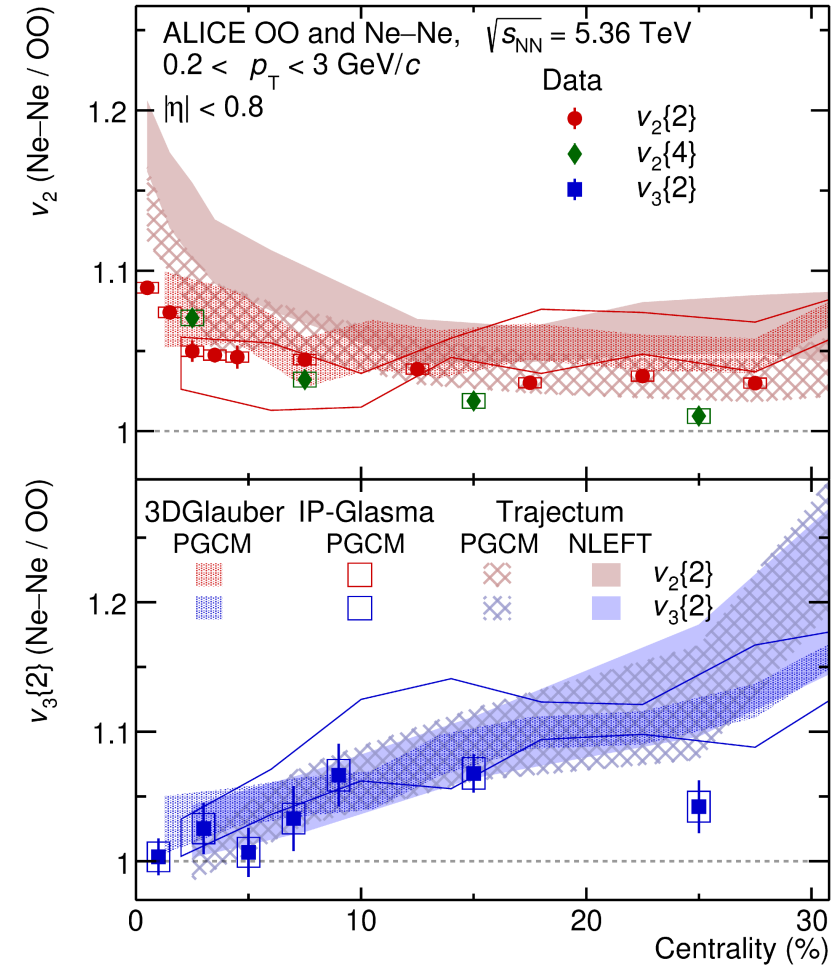
Triangular flow

Anisotropic flow in OO and Ne-Ne collisions

arXiv:2509.06428



ALI-PUB-610592



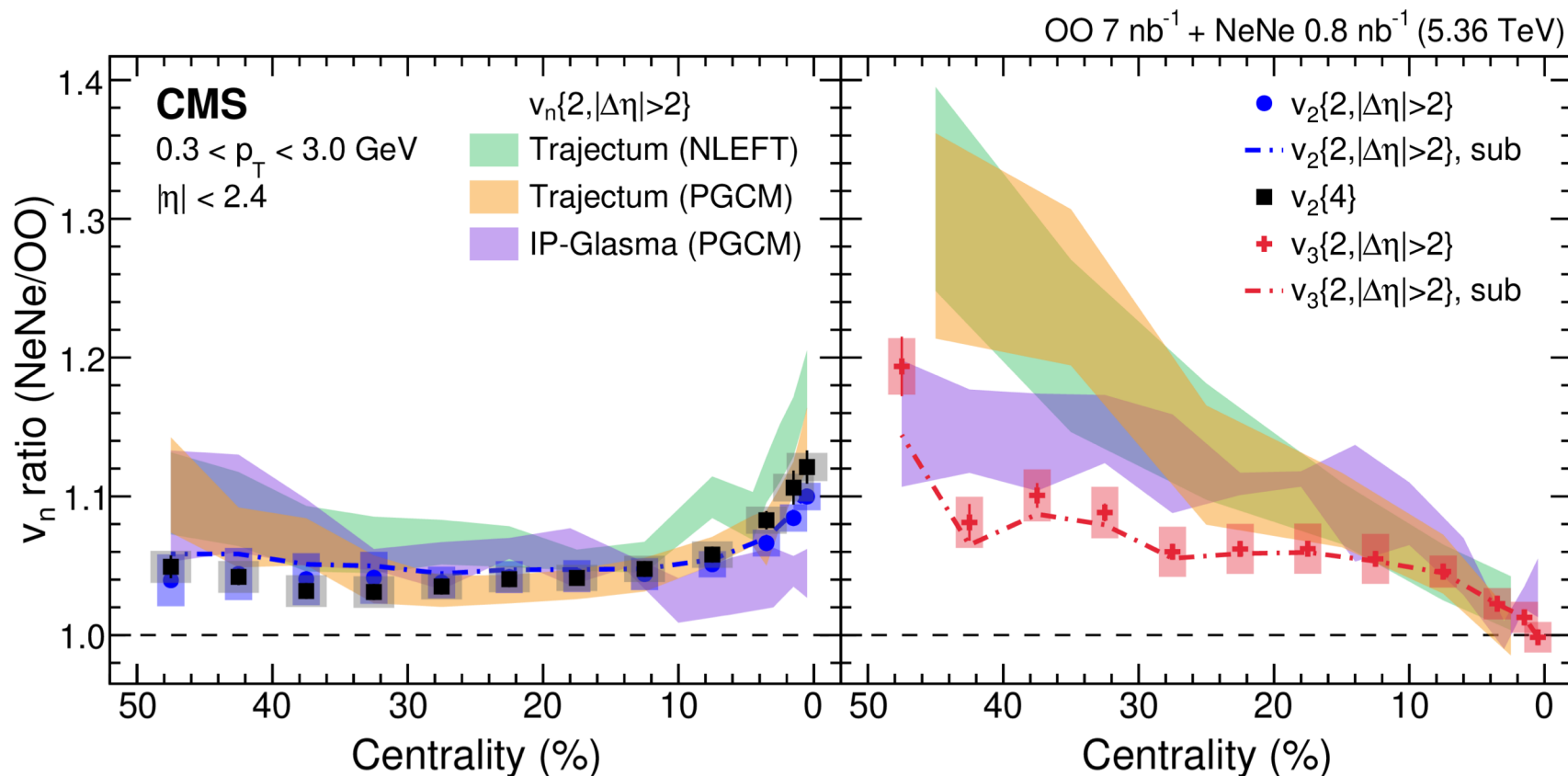
ALI-PUB-610602



Observation of hydrodynamic response to initial geometry in OO & Ne-Ne
Unique inputs to collectivity in small systems and nuclear structure

Anisotropic flow in OO and Ne-Ne collisions

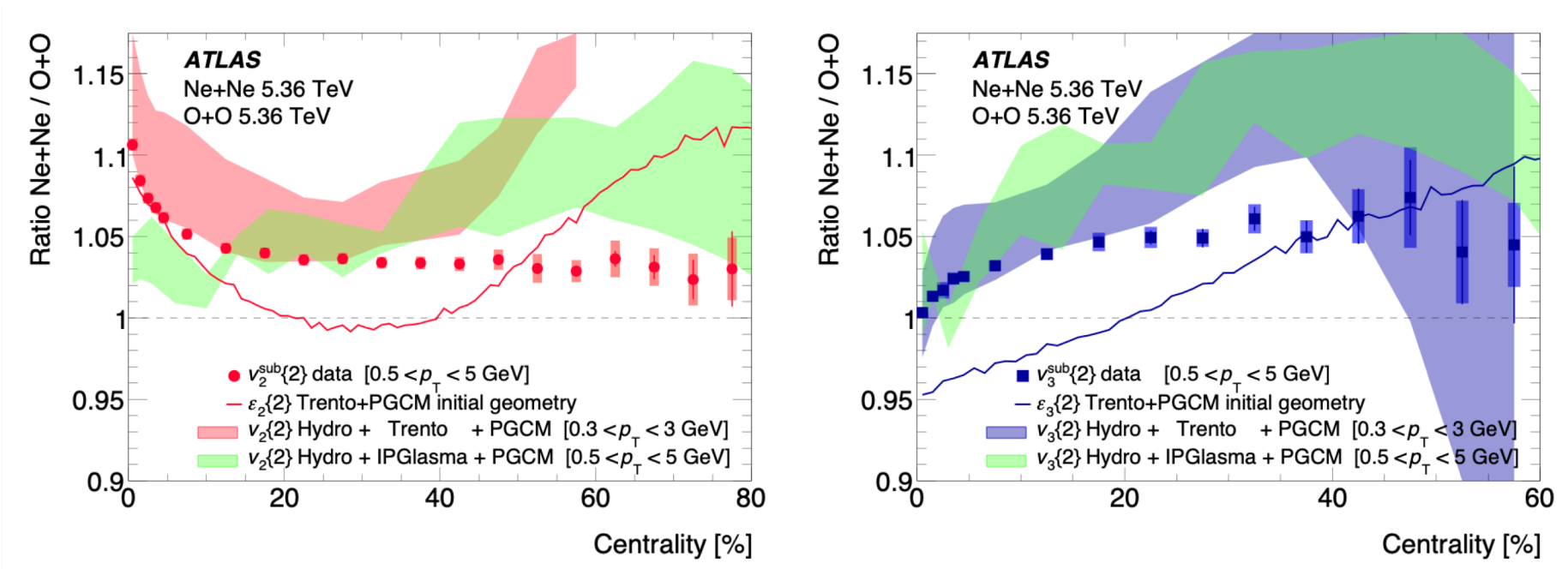
arXiv:2510.02580



Observation of hydrodynamic response to initial geometry in OO & Ne-Ne
Unique inputs to collectivity in small systems and nuclear structure

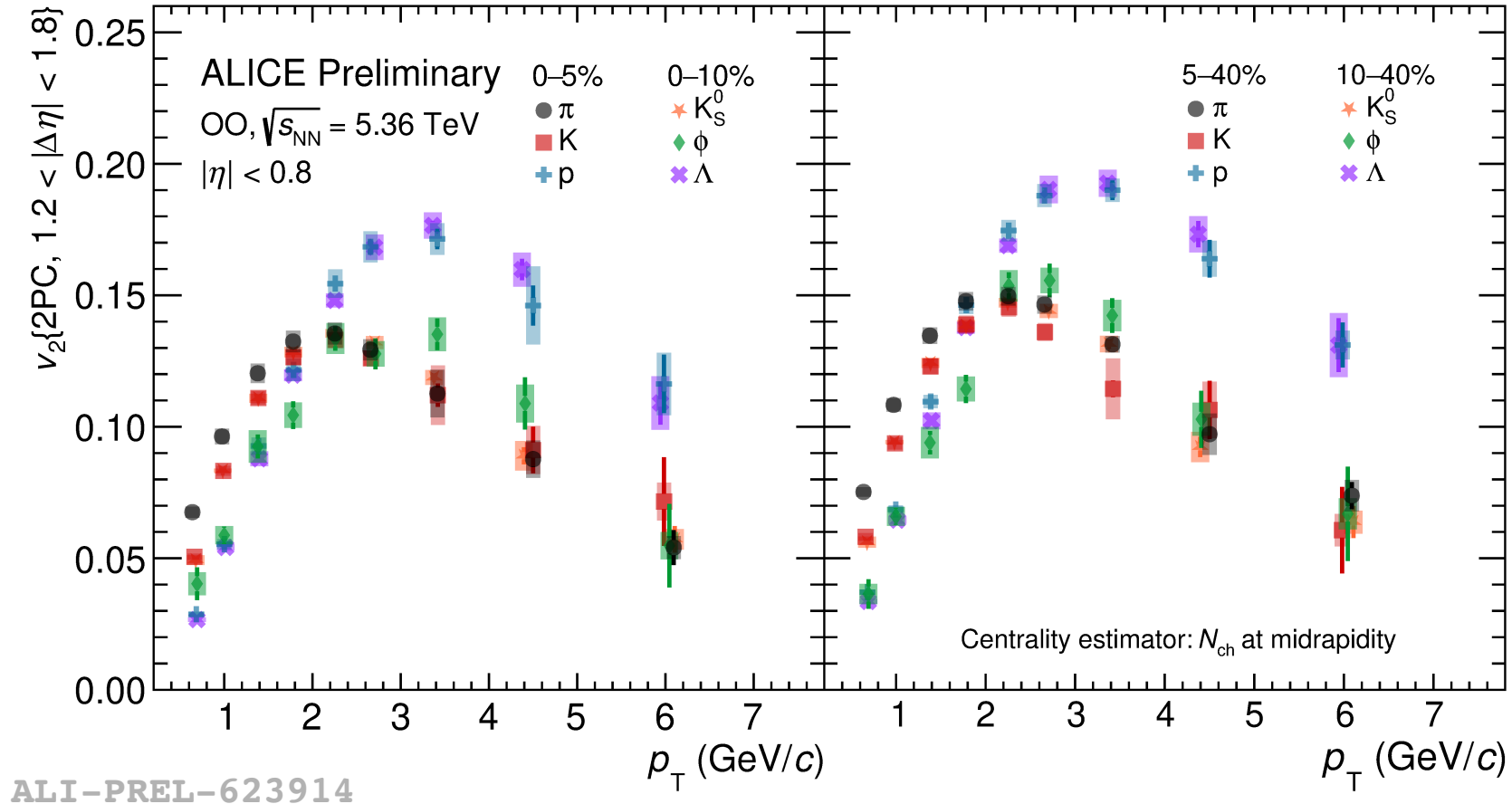
Anisotropic flow in OO and Ne-Ne collisions

arXiv:2509.05171



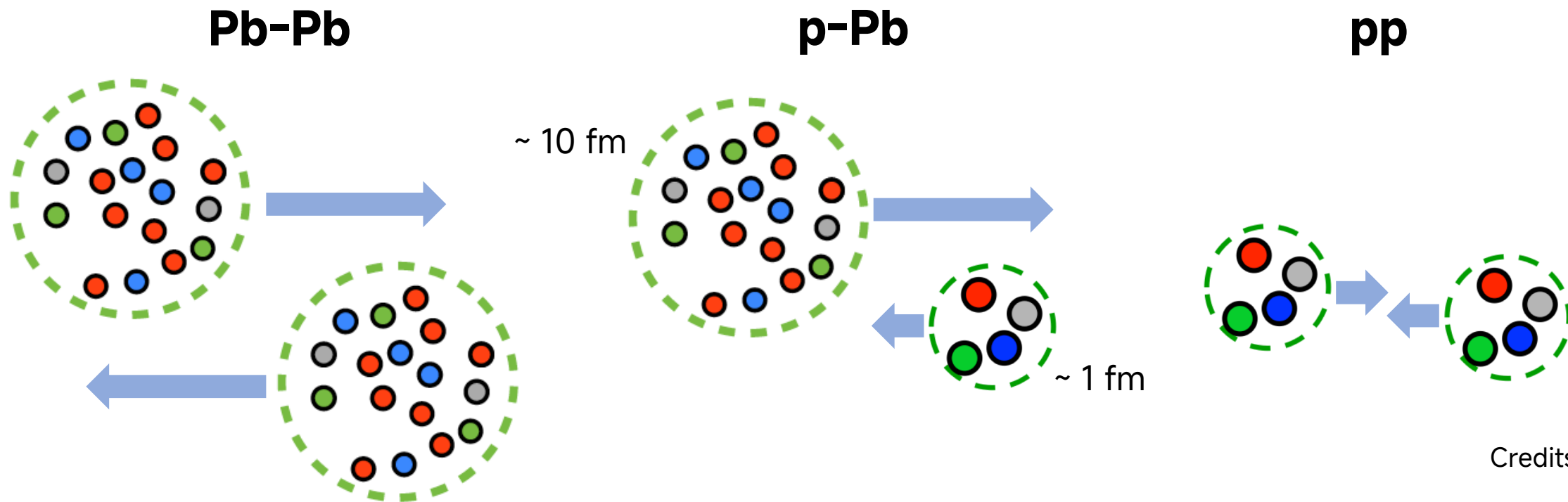
Observation of hydrodynamic response to initial geometry in OO & Ne-Ne
Unique inputs to collectivity in small systems and nuclear structure

PID v_2 in OO collisions



Mass ordering and baryon-meson grouping are observed

Collectivity in p-Pb and pp collisions

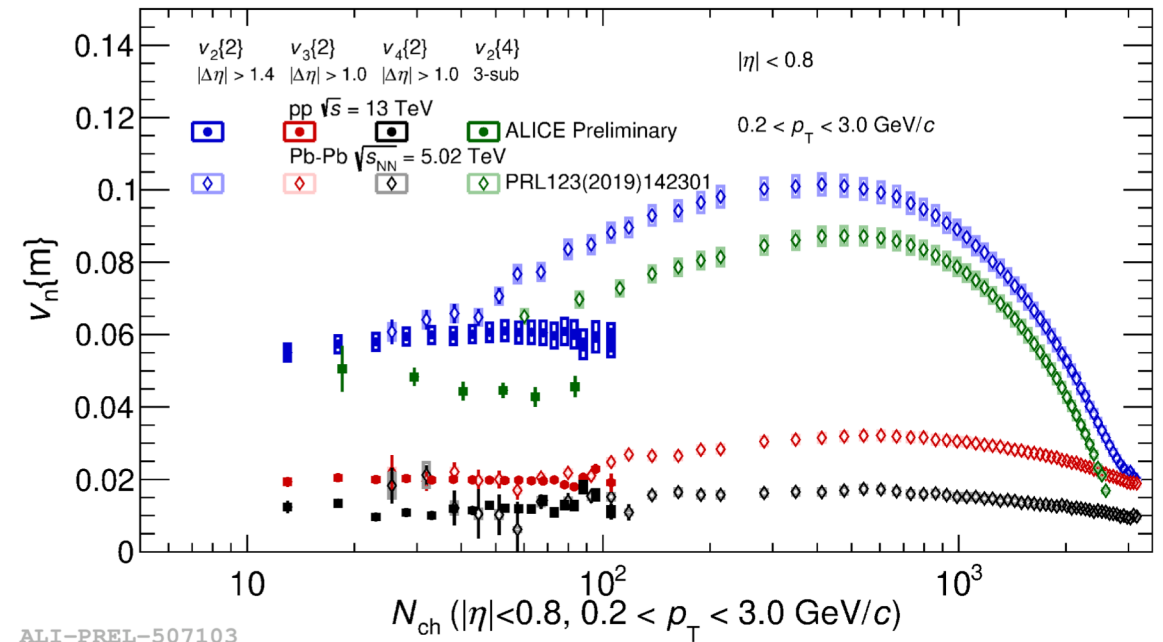
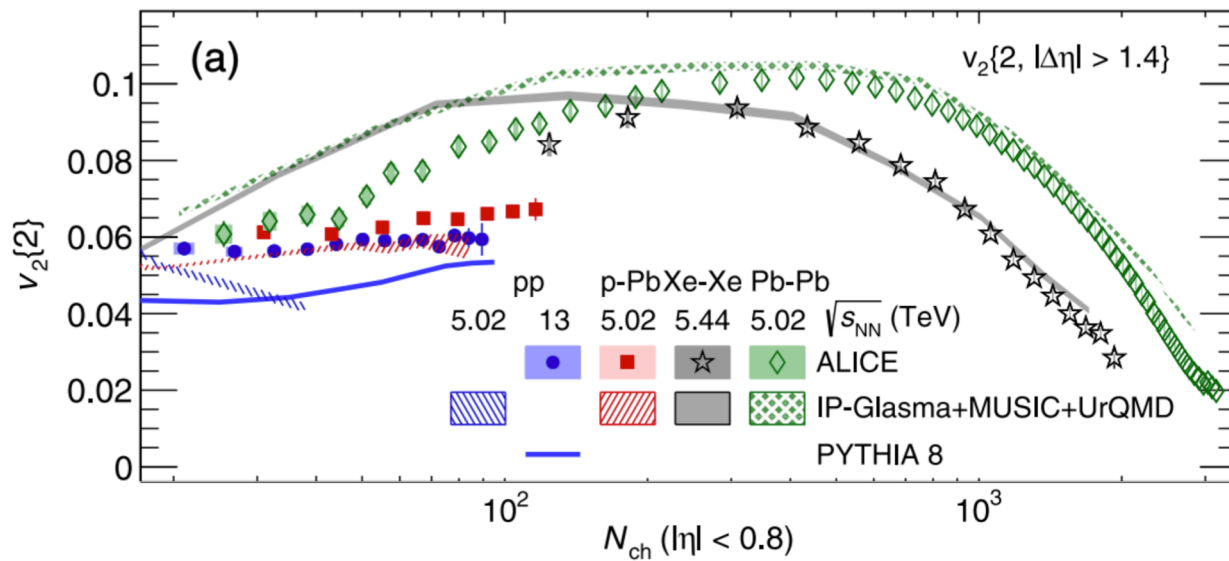


Credits to CZY

- Do we expect the collectivity in small collision systems ?
- Where is the the “smallest” (p-A, pp, ee...) and “dilutest” (lower multiplicity) limit of collectivity onset ?

Collectivity in p-Pb and pp collisions

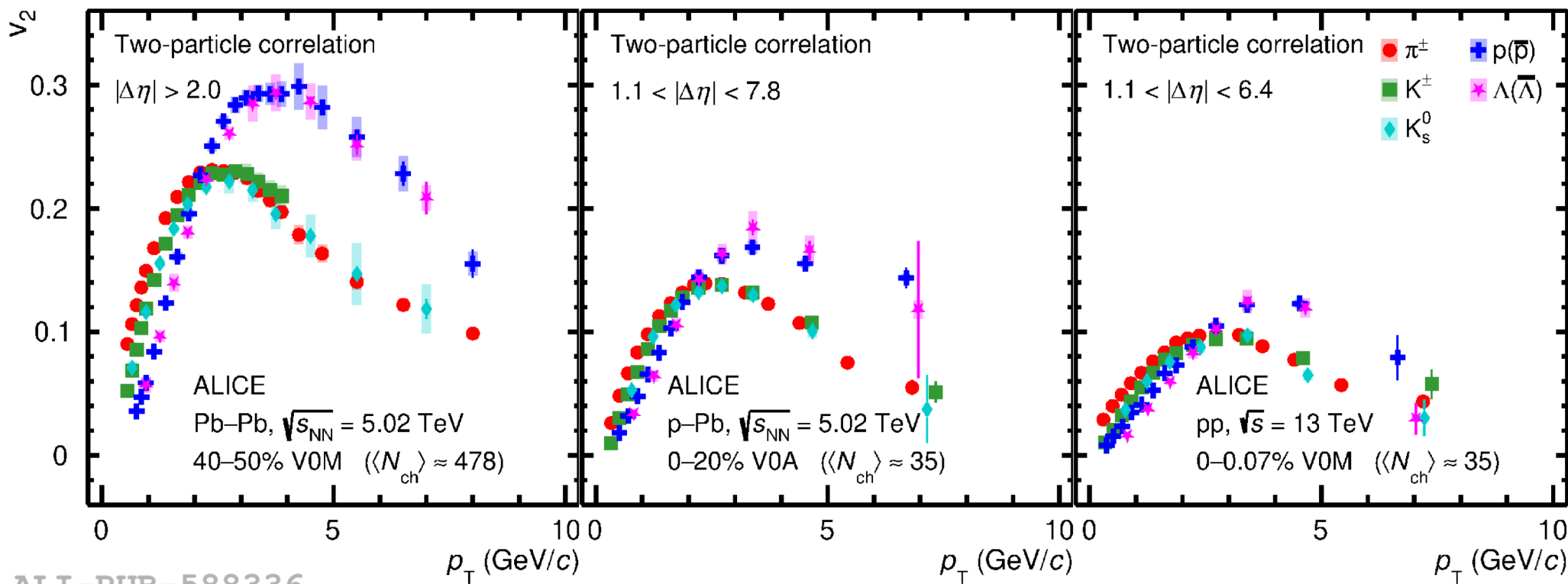
PRL 123, 142301 (2019)



The magnitudes of v_n in pp and p-Pb are similar as in Pb-Pb at low multiplicities

Elliptic flow of identified particles in small systems

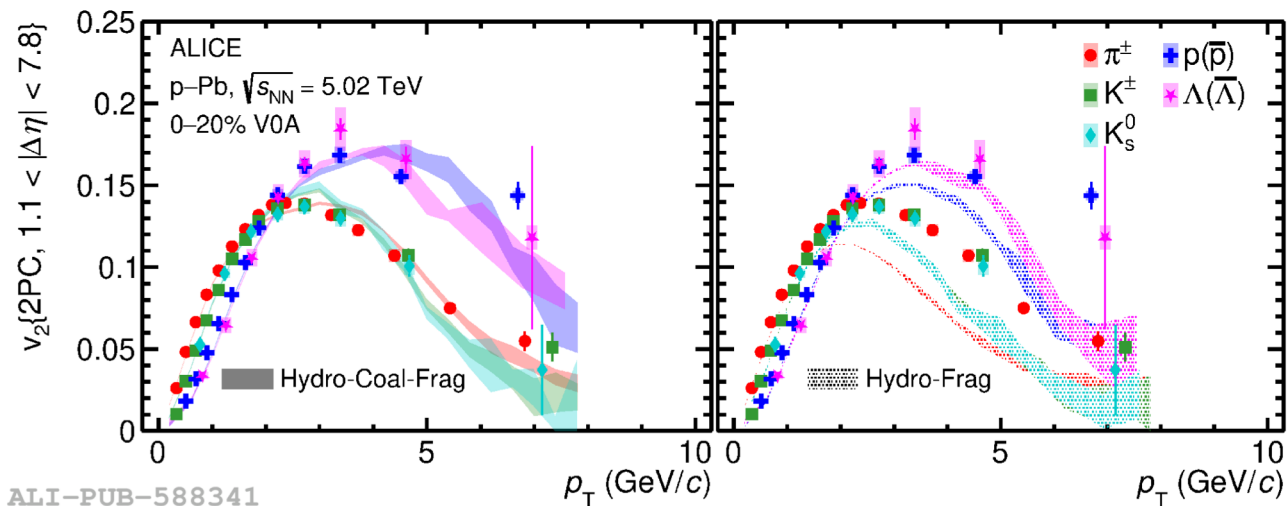
NC 17, 2585 (2026)



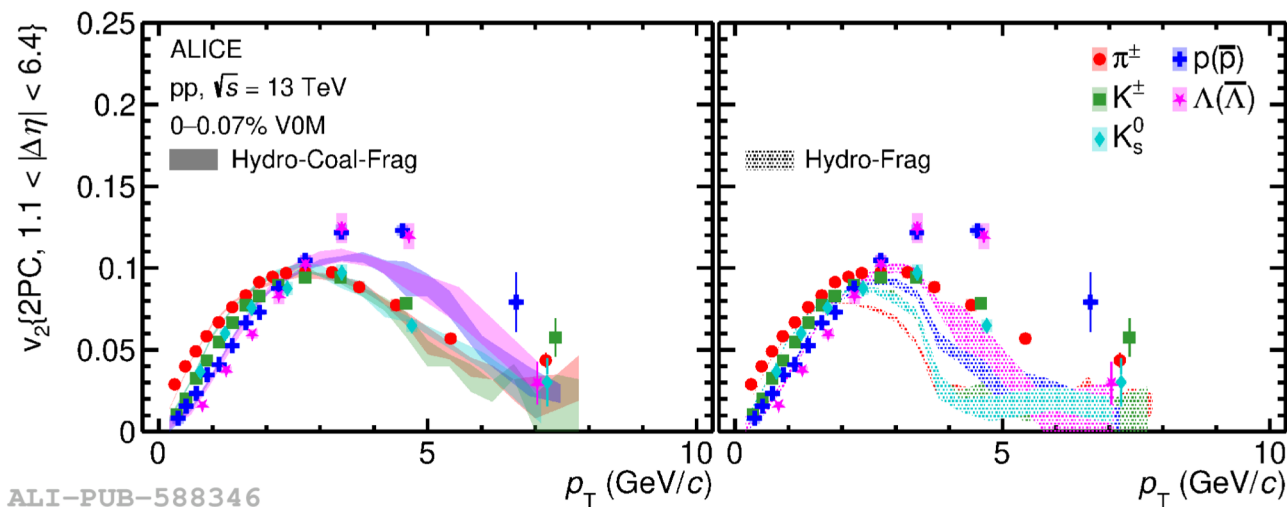
Mass ordering and baryon-meson grouping for all Pb-Pb, p-Pb and pp collisions, indicating the partonic collectivity

Elliptic flow of identified particles in small systems

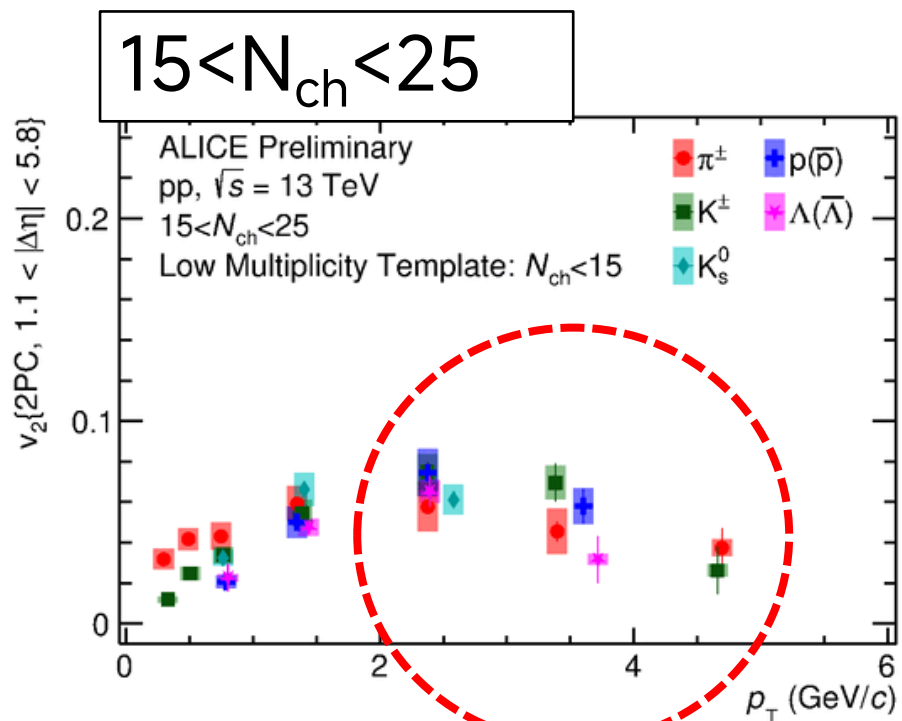
NC 17, 2585 (2026)



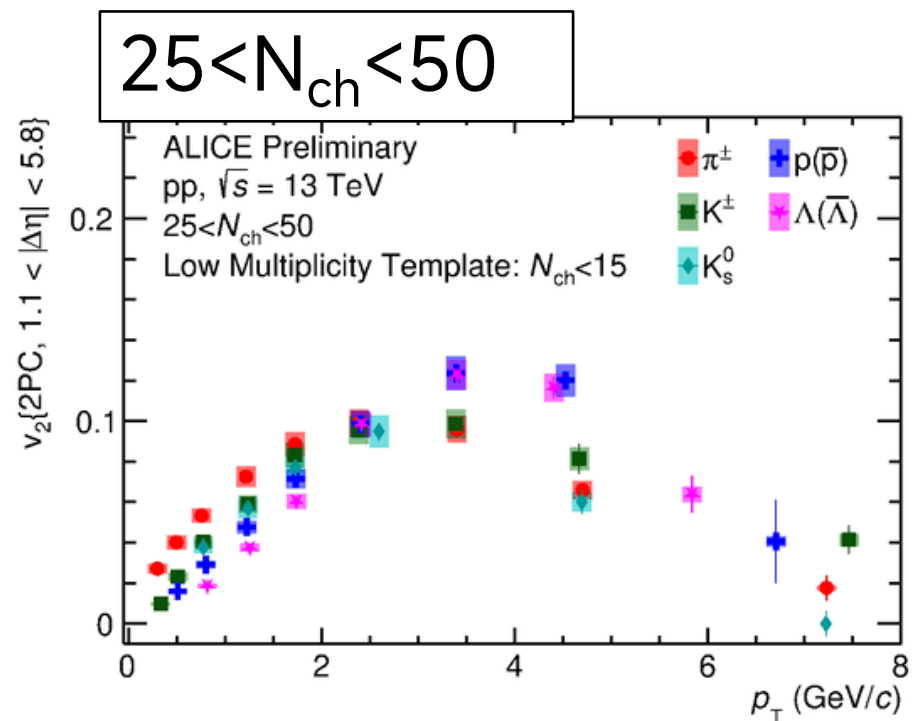
Evidence of hadronization via
coalescence of flowing quarks
in small systems



Elliptic flow of identified particles in small systems



ALI-PREL-573045



ALI-PREL-573050

Where is the the “smallest” and “dilutest” limit of collectivity onset ?

Parameterizing the shape of nuclei

nucleon density described by **Woods-Saxon profile**

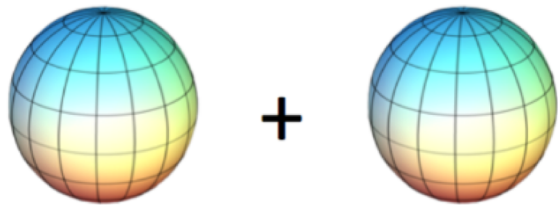
$$\rho(r, \theta, \phi) = \frac{\rho_0}{1 + e^{[r-R(\theta, \phi)]/a_0}},$$

$$R(\theta, \phi) = R_0(1 + \beta_2[\cos \gamma Y_{2,0} + \sin \gamma Y_{2,2}] + \beta_3 \sum_{m=-3}^3 \alpha_{3,m} Y_{3,m} + \beta_4 \sum_{m=-4}^4 \alpha_{4,m} Y_{4,m})$$

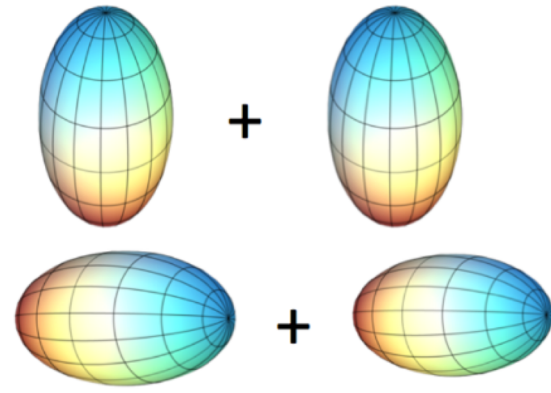
β_2 : overall deformation parameter

a_0 : diffuseness parameter

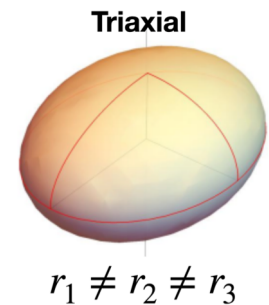
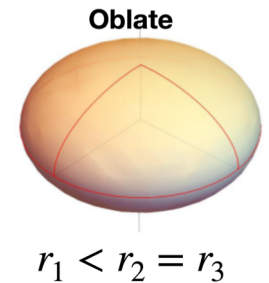
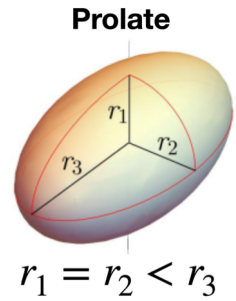
γ : triaxiality parameter



RHIC: Au+Au (relatively)
LHC: Pb+Pb (double magic nucleus)

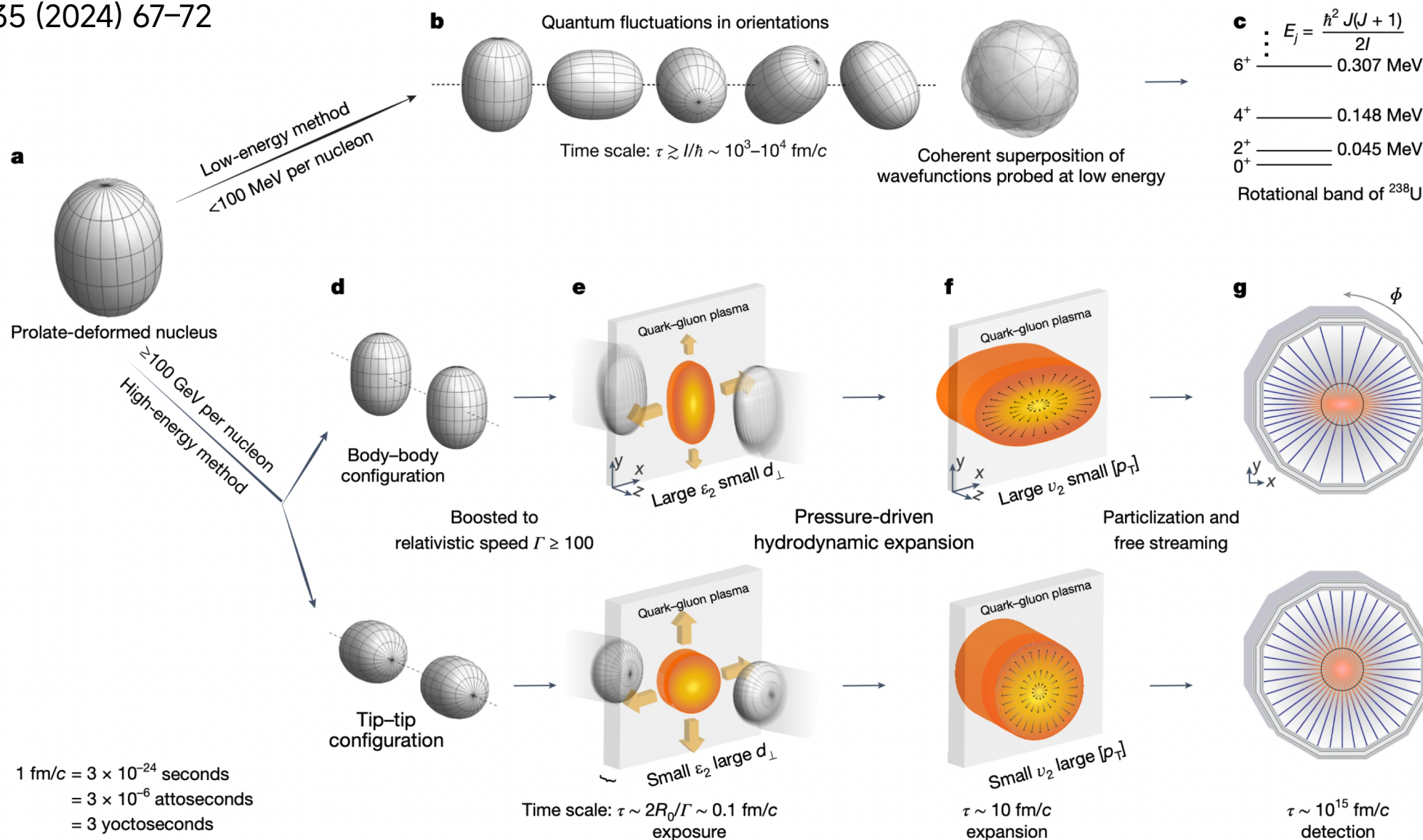


RHIC: U+U (Ru, Zr)
LHC: Xe+Xe



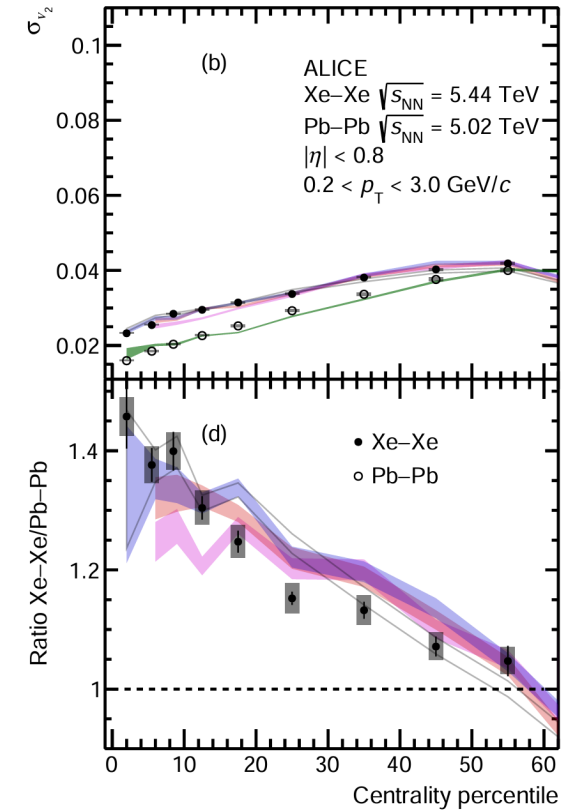
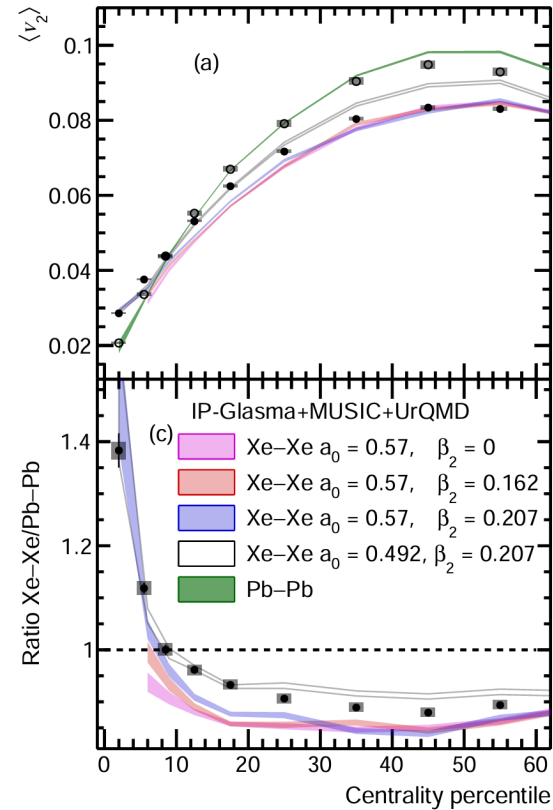
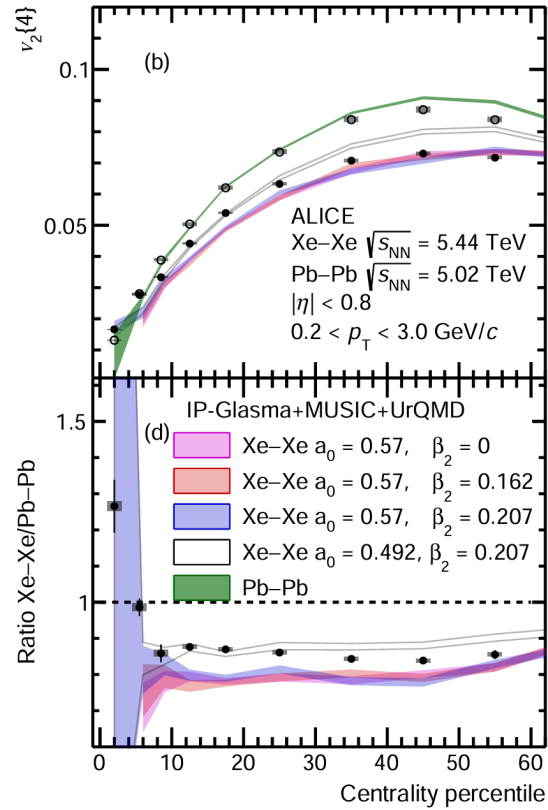
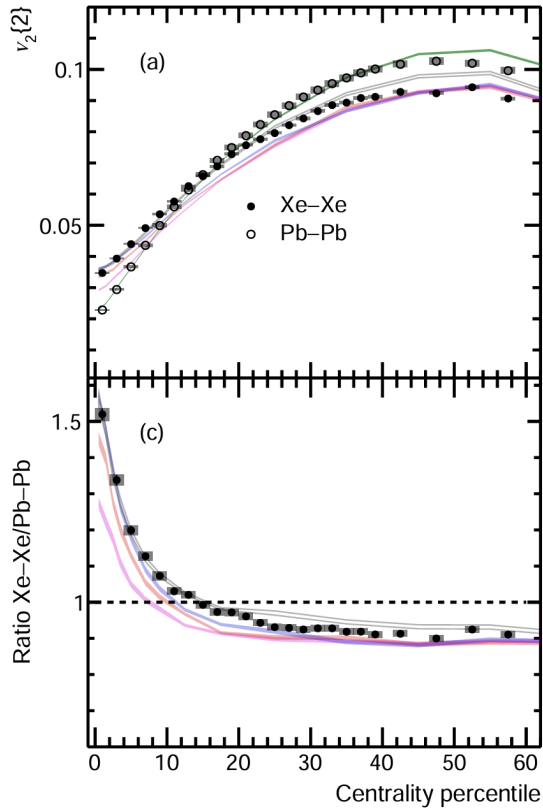
Imagining the nuclear structure

Nature 635 (2024) 67–72



Measurement of Xe at LHC-ALICE

PLB 869, 139855 (2025)



$$v_n\{2\} \equiv \sqrt{c_n\{2\}}$$

$$v_n\{4\} \equiv \sqrt[4]{-c_n\{4\}}$$

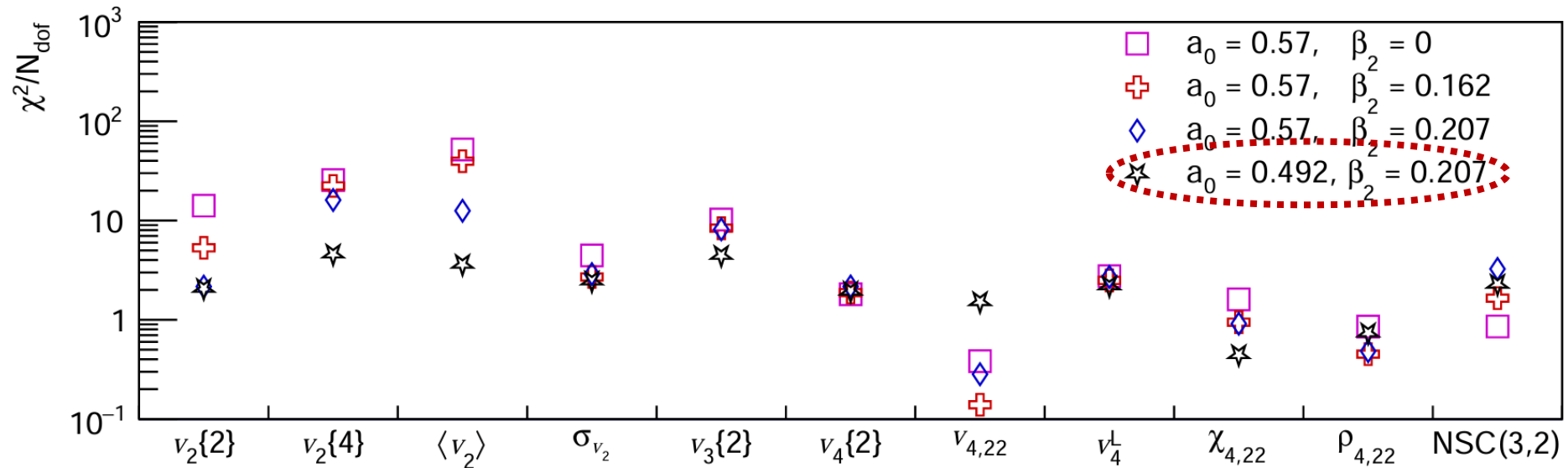
$$v_n\{2\}^2 \approx \langle v_n \rangle^2 + \sigma_{v_n}^2$$

$$v_n\{4\}^2 \approx \langle v_n \rangle^2 - \sigma_{v_n}^2$$

Measurement of Xe at LHC-ALICE

PLB 869, 139855 (2025)

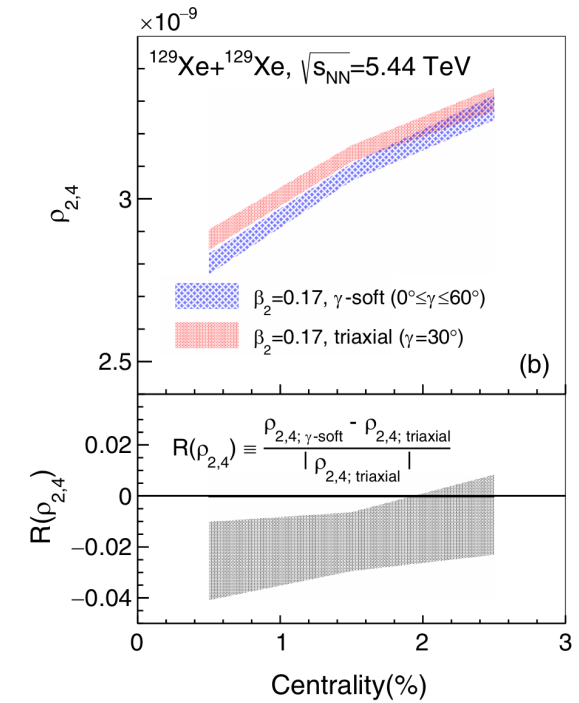
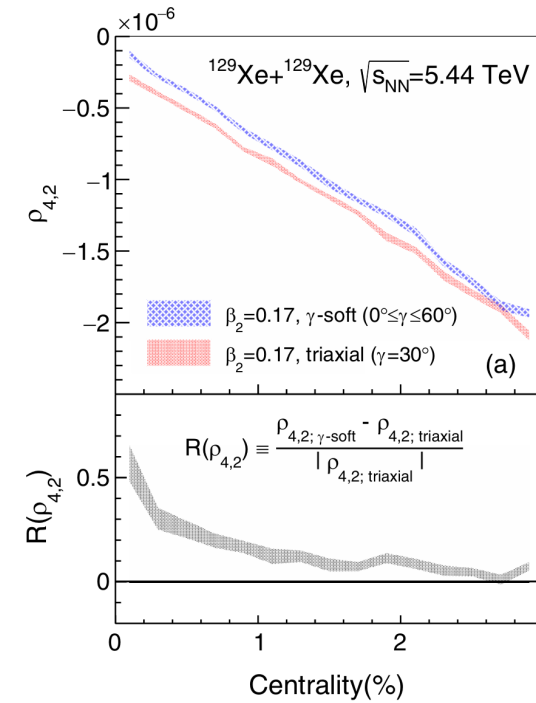
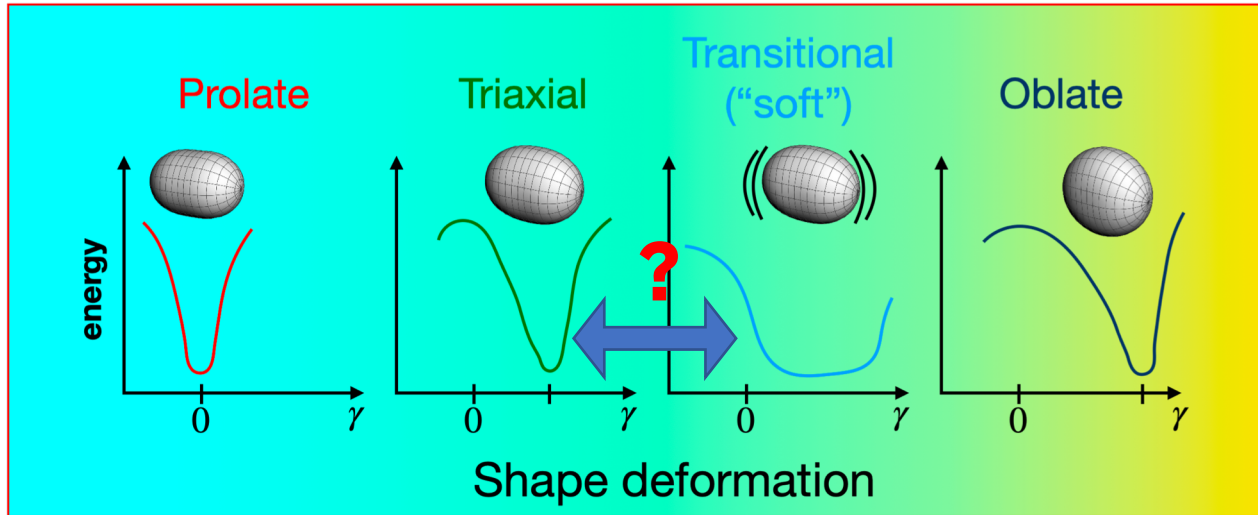
$$\chi^2/N_{\text{dof}} = \frac{1}{N_{\text{dof}}} \sum \frac{(y_i - f_i)^2}{\sigma_i^2}$$



Data favor $a \approx 0.492$ and $\beta_2 \approx 0.207$

Testing γ -soft of Xe at LHC-ALICE

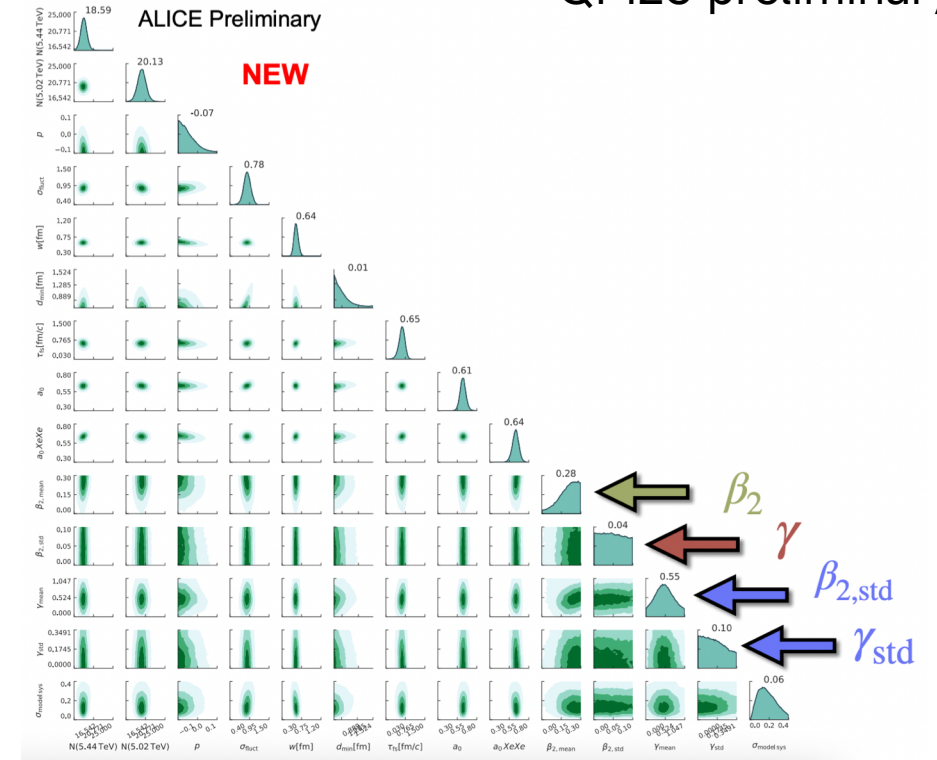
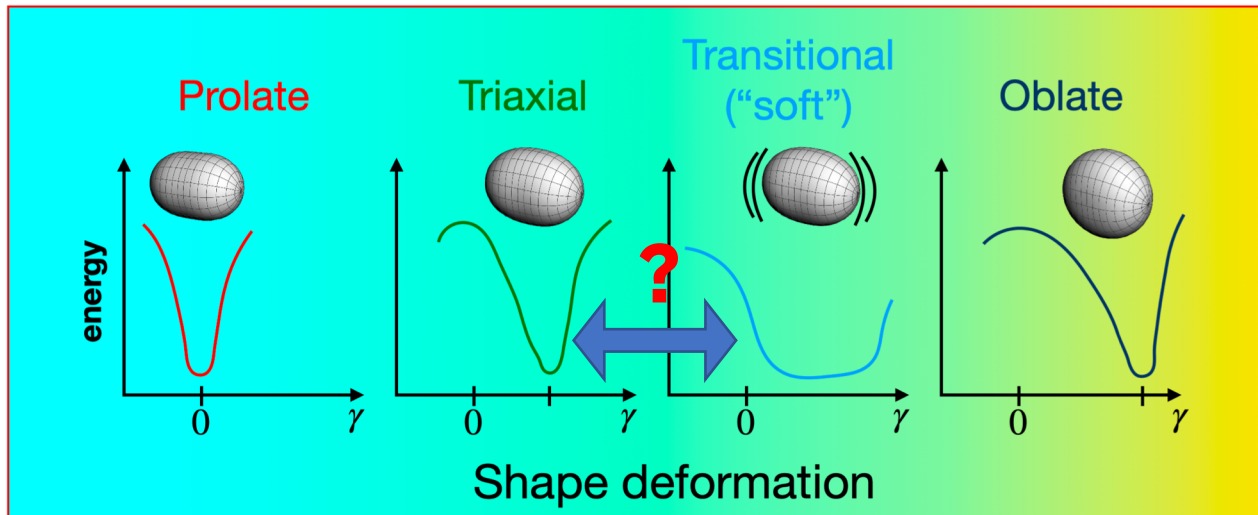
PRL 133, 192301 (2024)



6-particle cumulant needed

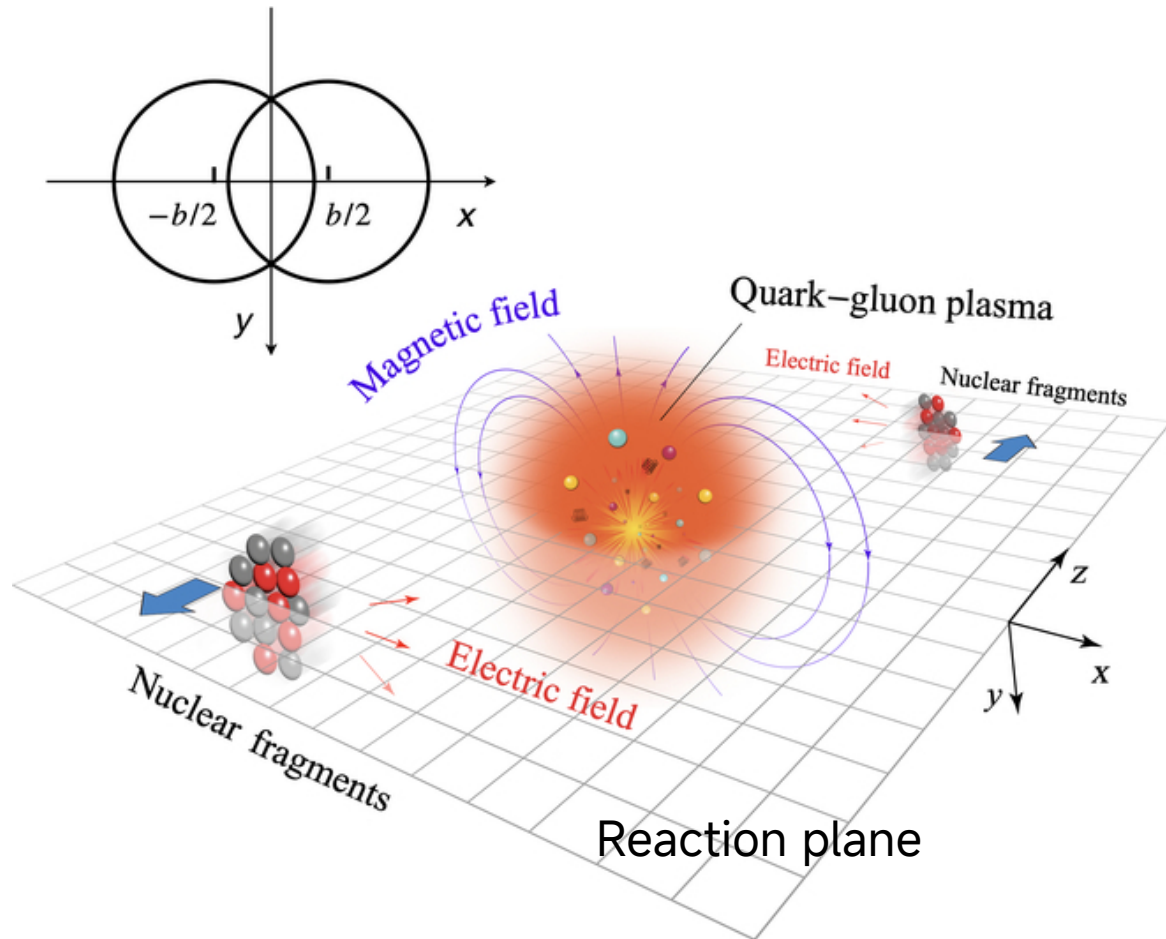
Testing γ -soft of Xe at LHC-ALICE

QM25 preliminary



Comprehensive Bayesian analysis to simultaneously pin down all parameters of Xe
 The extracted γ value with a narrow σ indicates weak/no γ -soft effect.
→ Xe has a rigid, triaxial deformation

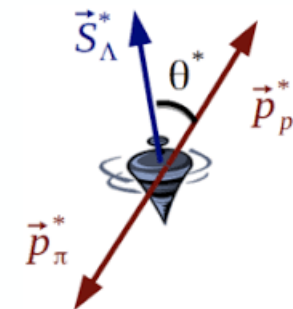
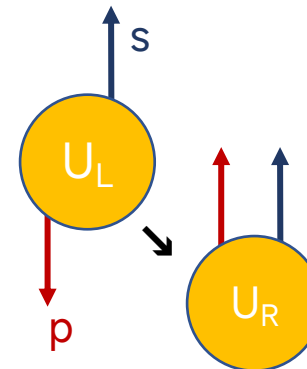
Collective effects under strong magnetic and vortical fields



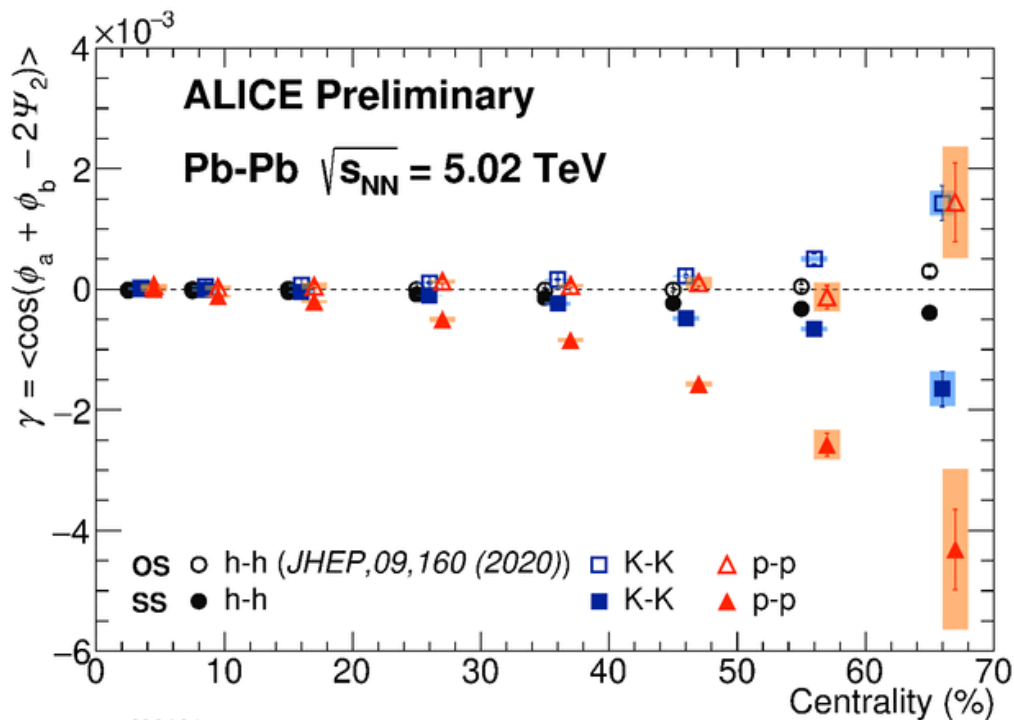
$$B \approx 10^{18} - 10^{19} \text{ Gauss}$$

$$\omega \approx 10^{21} \text{ s}^{-1}$$

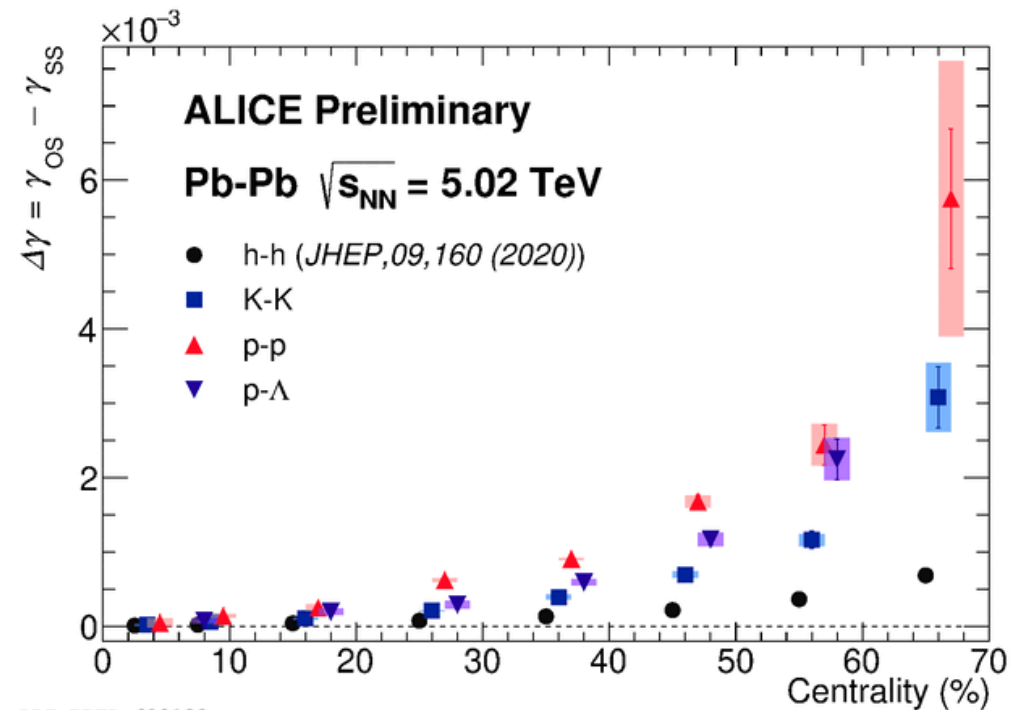
- **Anomalous chiral effects**
Search for the CP violations in the strong interactions and disentangle the background mechanisms
- **Polarization phenomena**
Reveal how global/local polarization observables respond to the QGP collectivity



Charge dependent azimuthal correlations



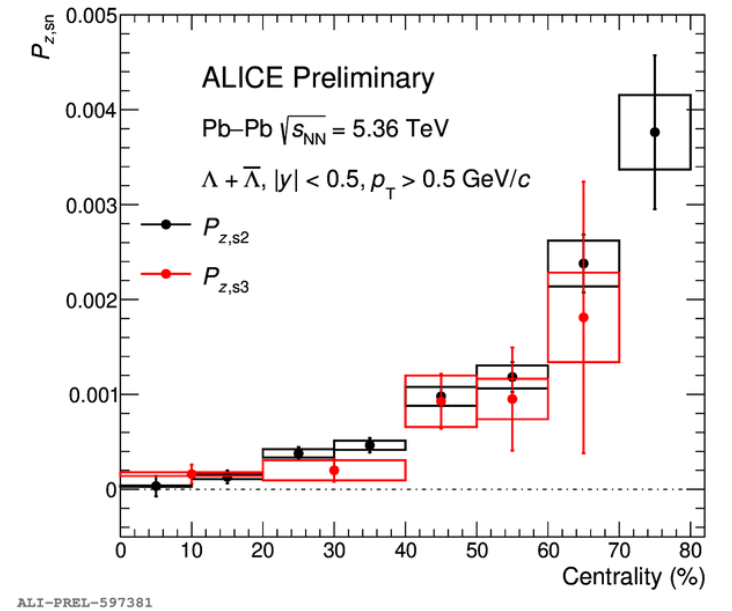
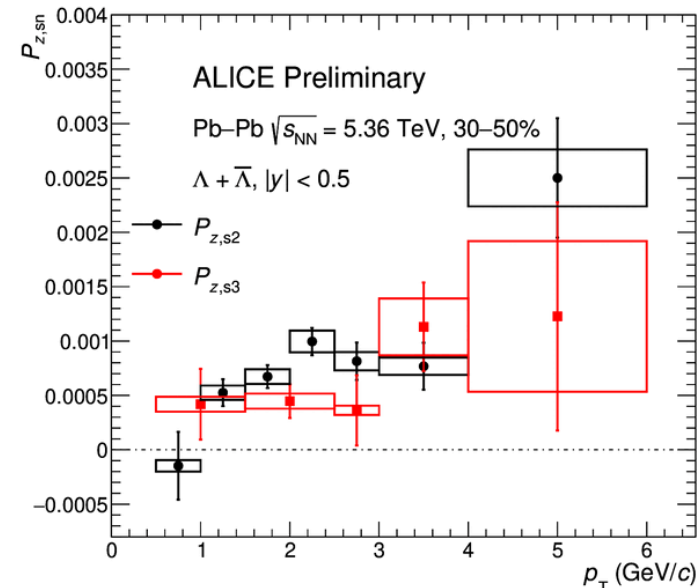
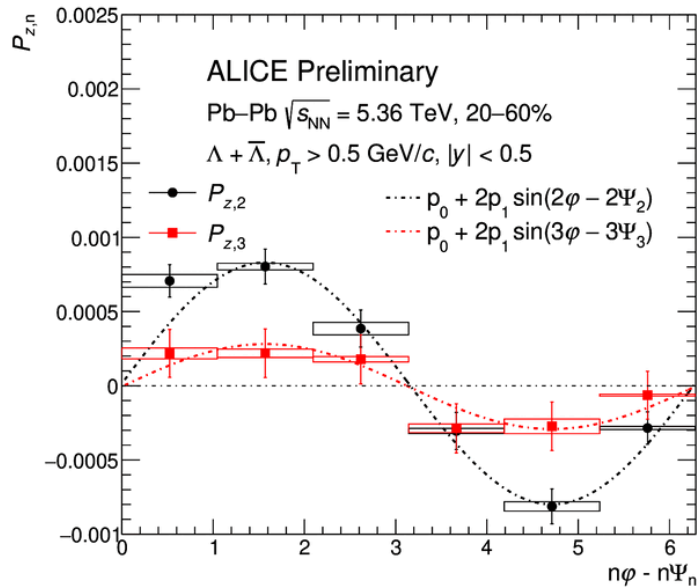
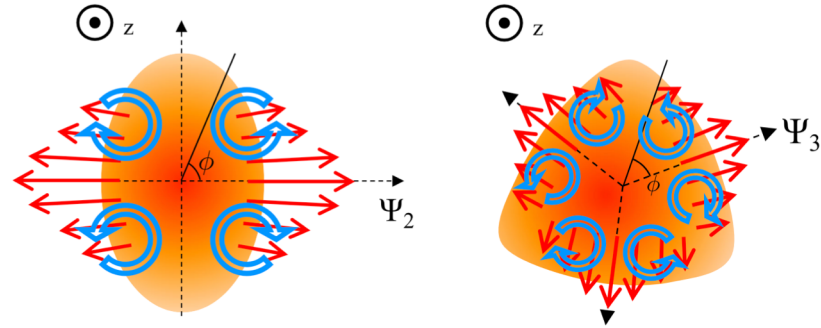
ALI-PREL-600121



ALI-PREL-600132

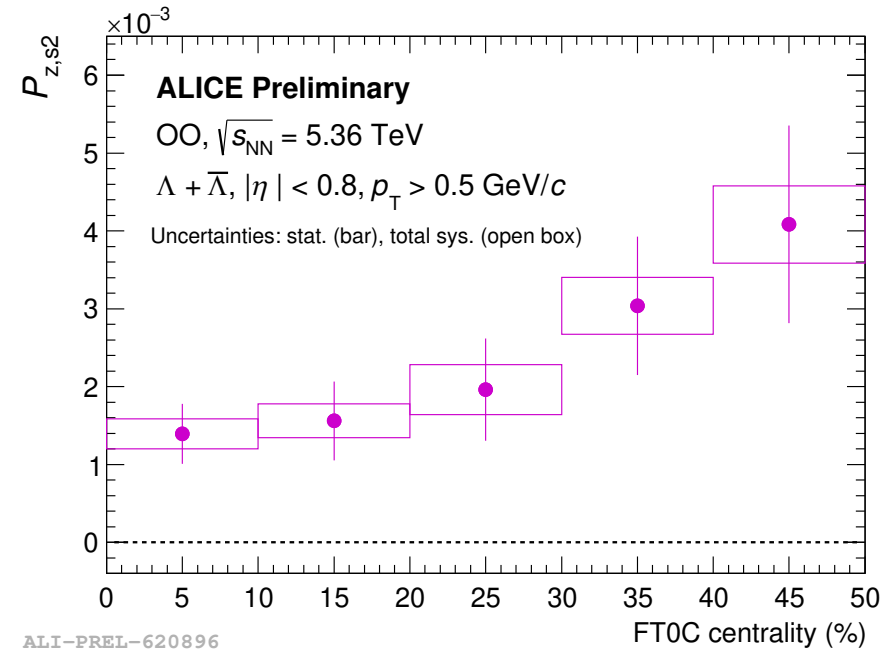
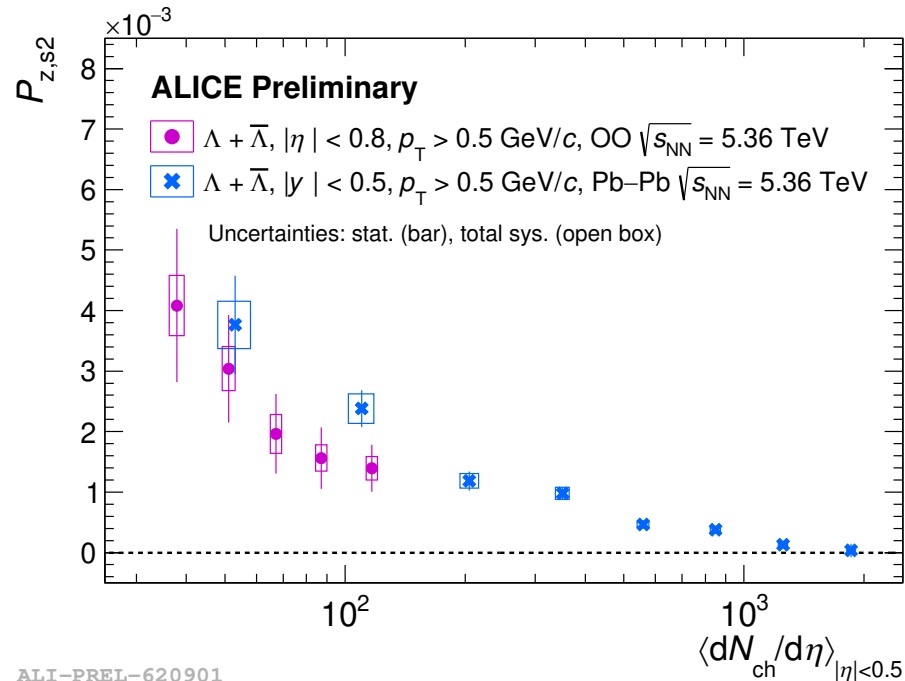
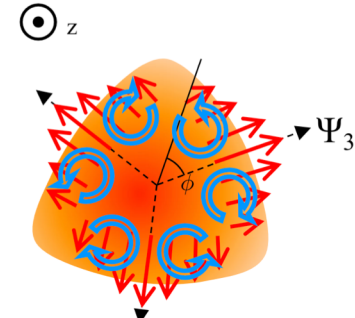
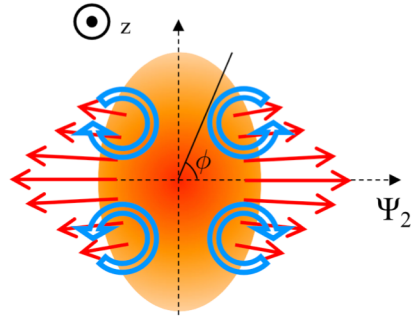
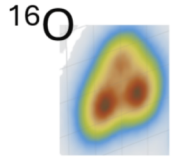
Significant separations are observed for K and p
 $\Delta\gamma$ follow p-p > p- Λ > K-K > h-h
 indicating various global/local charge conservations

Hyperon local polarization at ALICE



Second and third order local polarization are clearly observed with Run 3 data

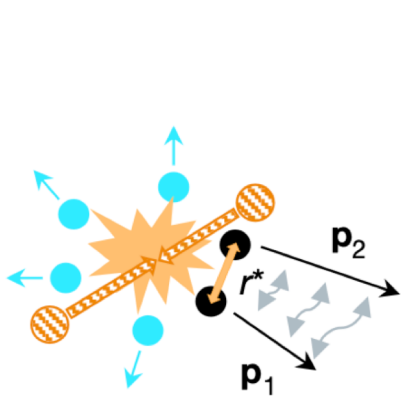
Hyperon local polarization at ALICE



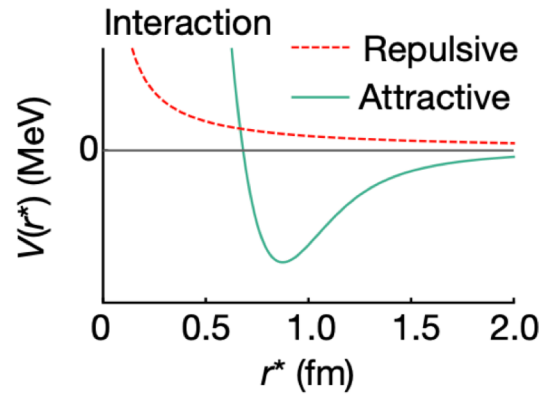
Second and third order local polarization are clearly observed with Run 3 data

Momentum correlations (Femtoscscopy)

Annu. Rev. Nucl. Part. Sci. 71, 377 (2021)



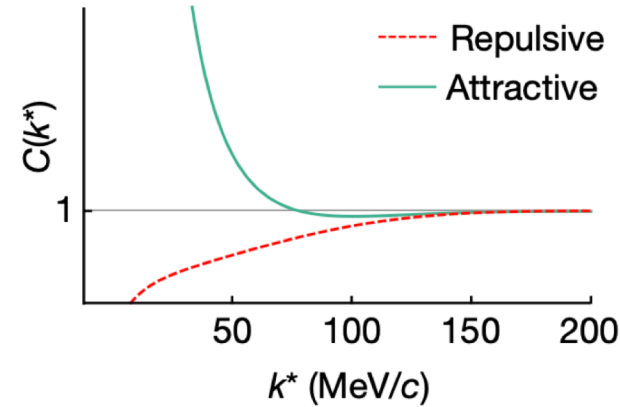
Emission source $S(r^*)$



Schrödinger equation

Two-particle wavefunction

$$|\psi(\mathbf{k}^*, \mathbf{r}^*)|$$



Correlation function

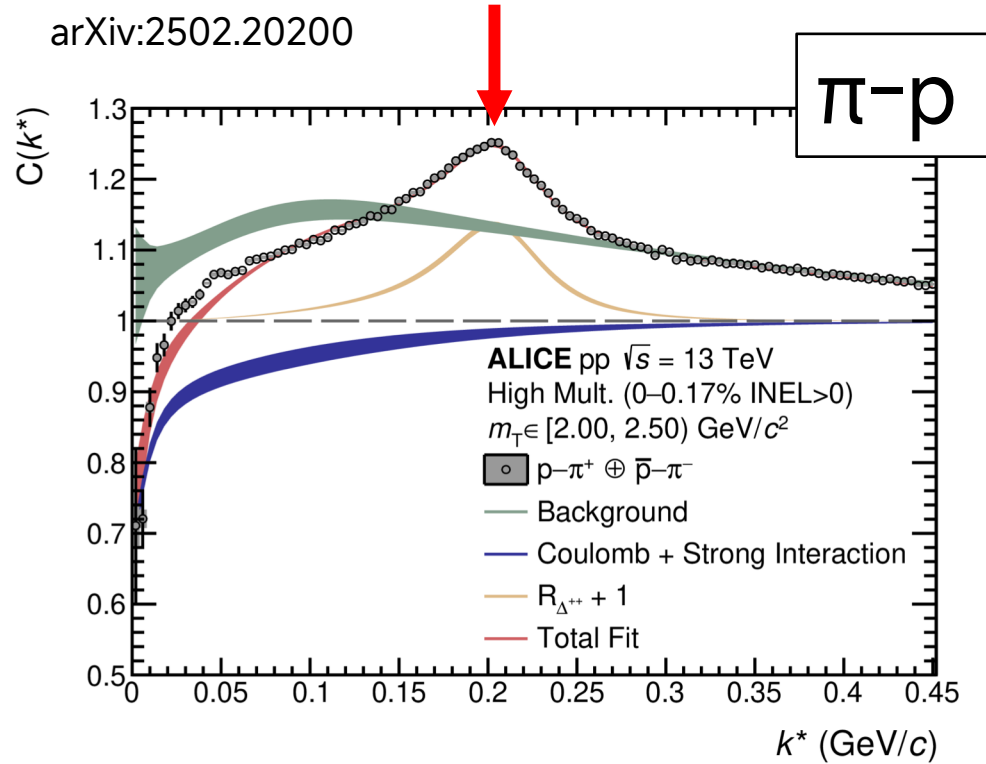
$$C(k^*, r^*) = \int S(r^*) |\psi(\mathbf{k}^*, \mathbf{r}^*)|^2 d^3r^* = \xi(k^*) \frac{N_{\text{same}}(k^*)}{N_{\text{mixed}}(k^*)}$$

What experiments measure

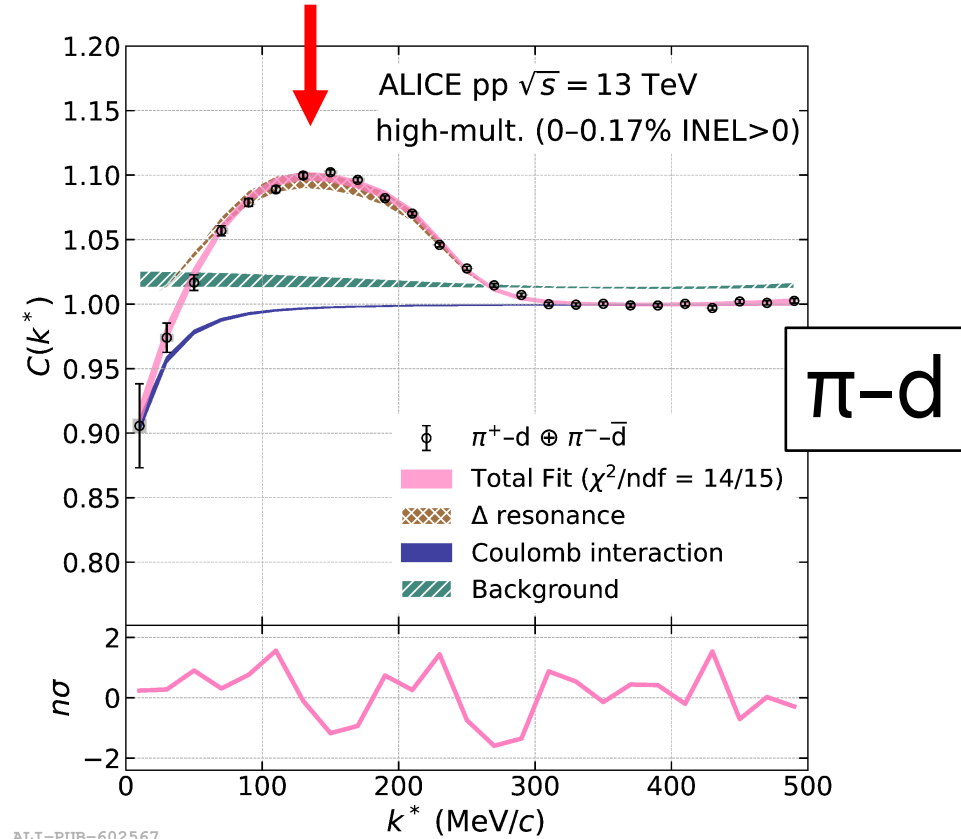
$$k^* = |\mathbf{p}_2^* - \mathbf{p}_1^*|/2 \text{ in the pair rest frame}$$

π -nuclei femto correlation

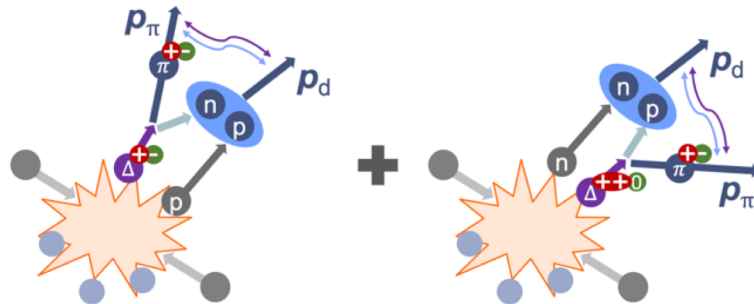
Nature 648, 306 (2025)



ALI-PUB-590167



ALI-PUB-602567

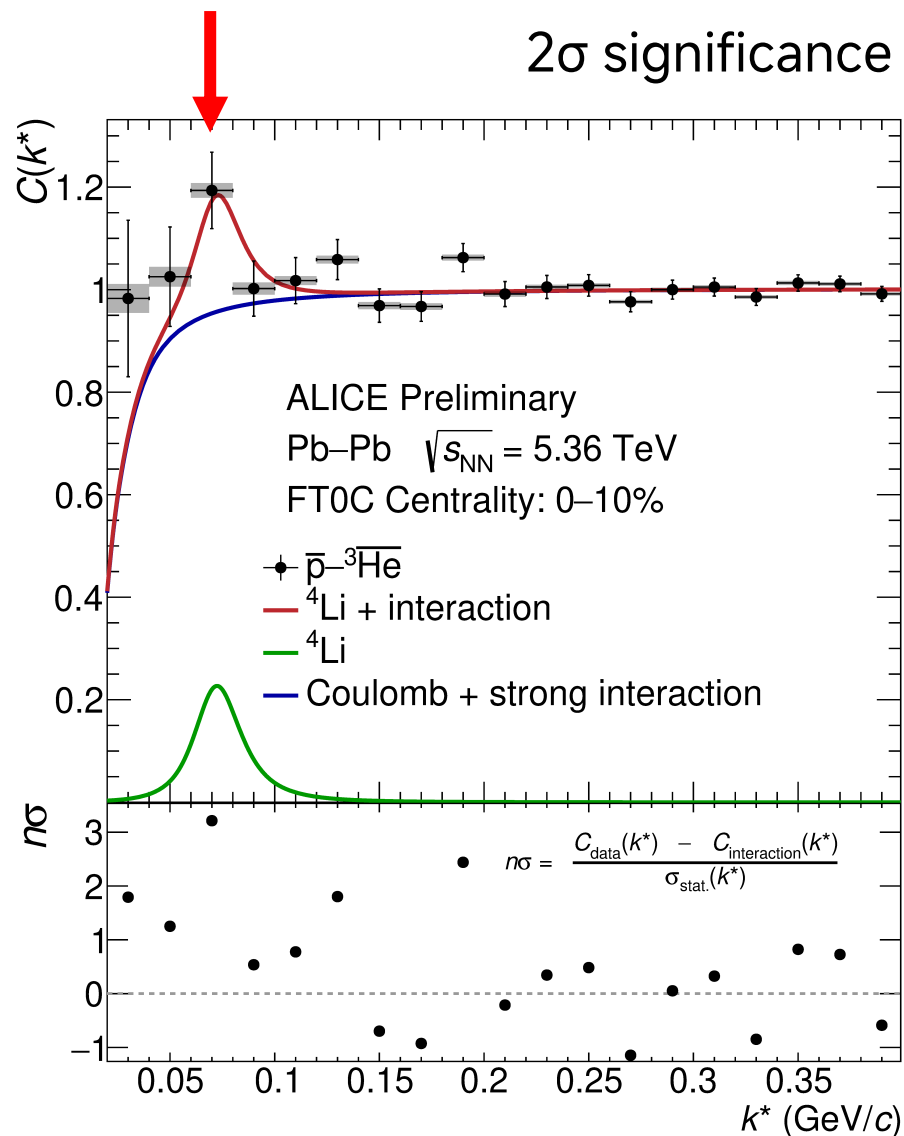


NC 15, 1 (2024)

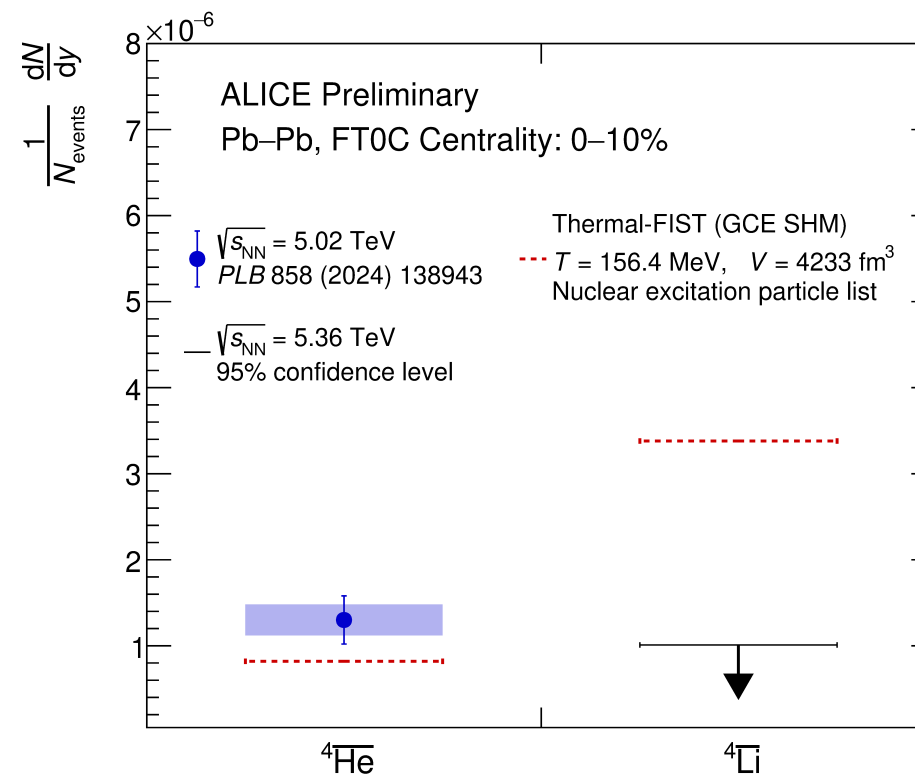
π -catalyzed process: $\pi n p \rightarrow \pi d$

${}^4\text{Li} \rightarrow \text{p}-{}^3\text{He}$ femto correlation in Pb-Pb

2σ significance (Z) to reject the null hypothesis



ALI-PREL-621440



ALI-PREL-621471

Summary

- CF is one of the most essential branches in the QGP physics
- Highlight results across azimuthal correlations, flow, femtoscopy are presented
- Chinese members have made and will keep on making big contributions

Thank you for your attention!

我仰望星空，
它是那样寥廓而深邃；
那无穷的真理，
让我苦苦地求索、追随。

我仰望星空，
它是那样庄严而圣洁；
那凛然的正义，
让我充满热爱、感到敬畏。

我仰望星空，
它是那样自由而宁静；
那博大的胸怀，
让我的心灵栖息、依偎。

我仰望星空，
它是那样壮丽而光辉；
那永恒的炽热，
让我心中燃起希望的烈焰、响起春雷。

2007年9月4日，温家宝总理在人民日报文艺副刊发表《仰望星空》一诗。

“一个民族有一些关注天空的人，他们才有希望；
一个民族只是关心脚下的事情，那是没有未来的。”