

第十一届中国LHC物理会议 (CLHCP2025)

Selected highlights of correlations and flow at LHC-ALICE

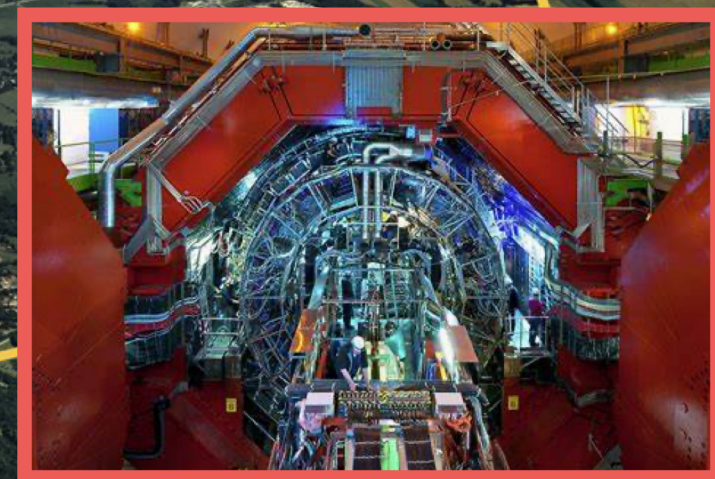
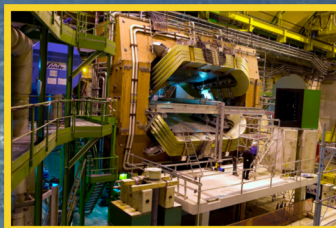
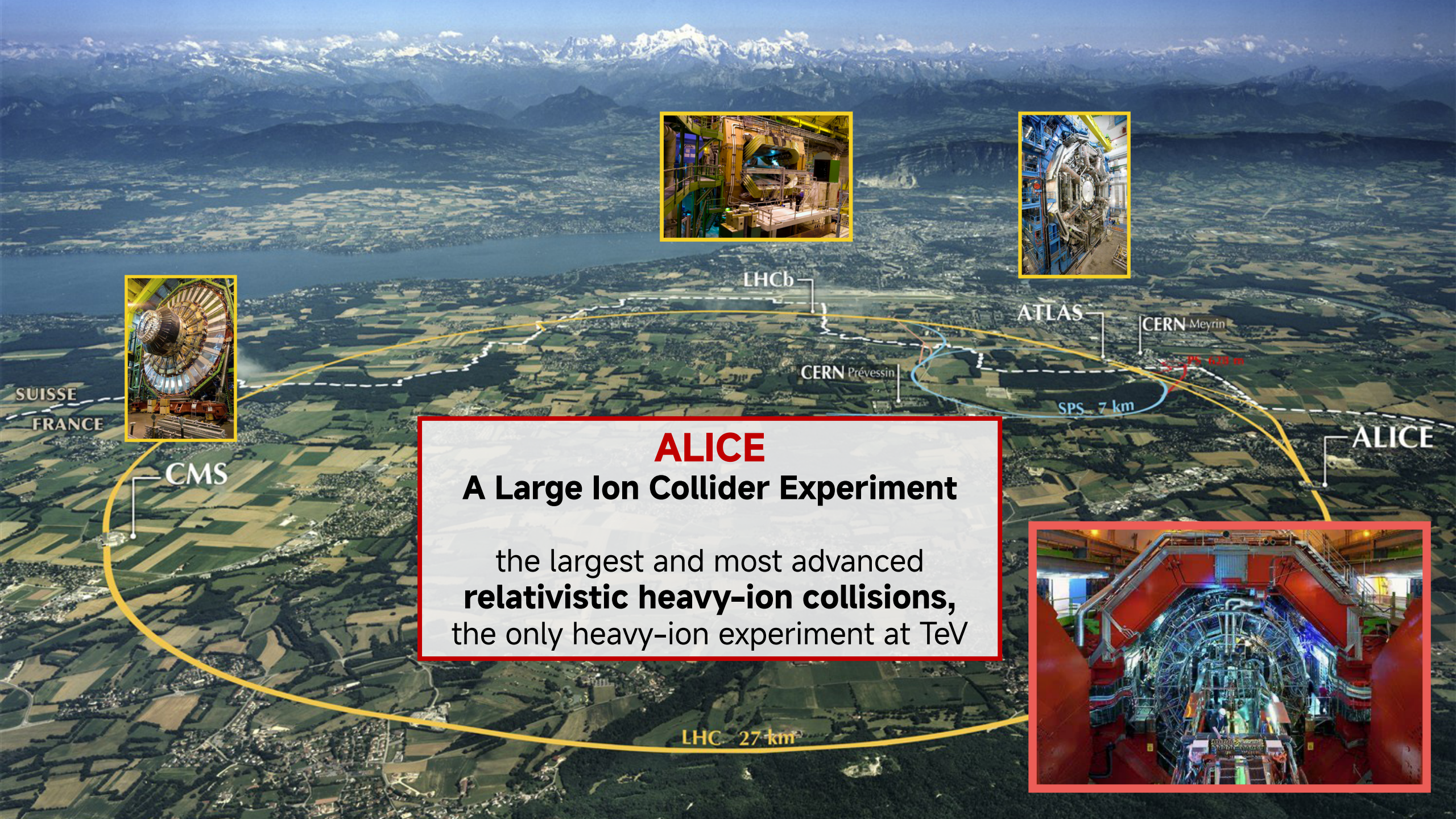
Qiye Shou 寿齐烨
Fudan University 复旦大学
2025.11.01 新乡



ALICE



復旦大學



ALICE A Large Ion Collider Experiment

the largest and most advanced
relativistic heavy-ion collisions,
the only heavy-ion experiment at TeV

LHC 27 km

LHCb

ATLAS

CERN Meyrin

CERN Prévessin

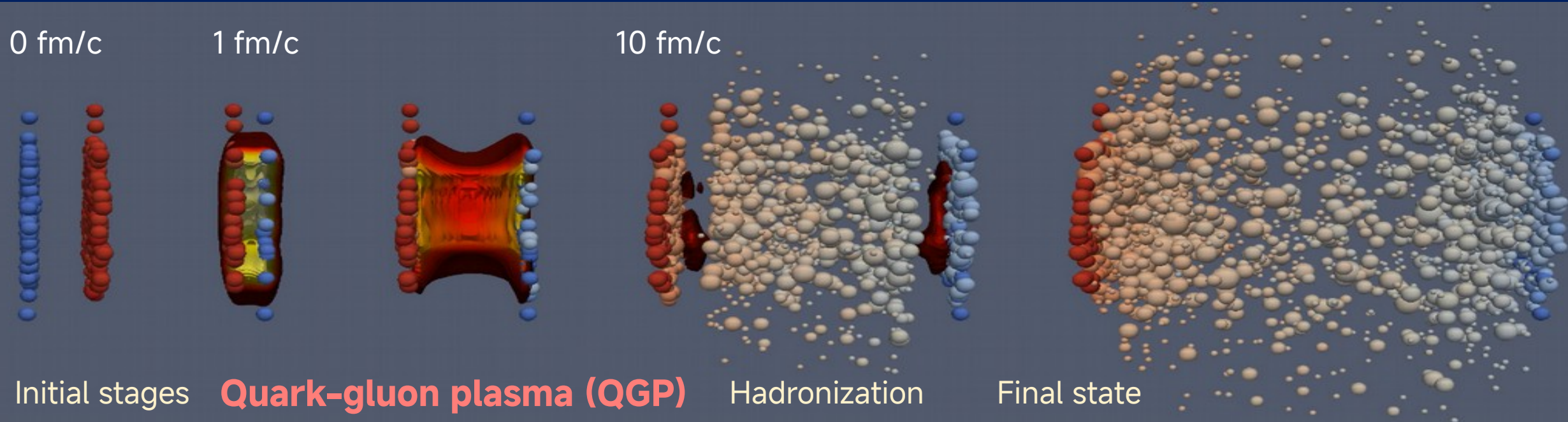
SPS 7 km

ALICE

CMS

SUISSE
FRANCE

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

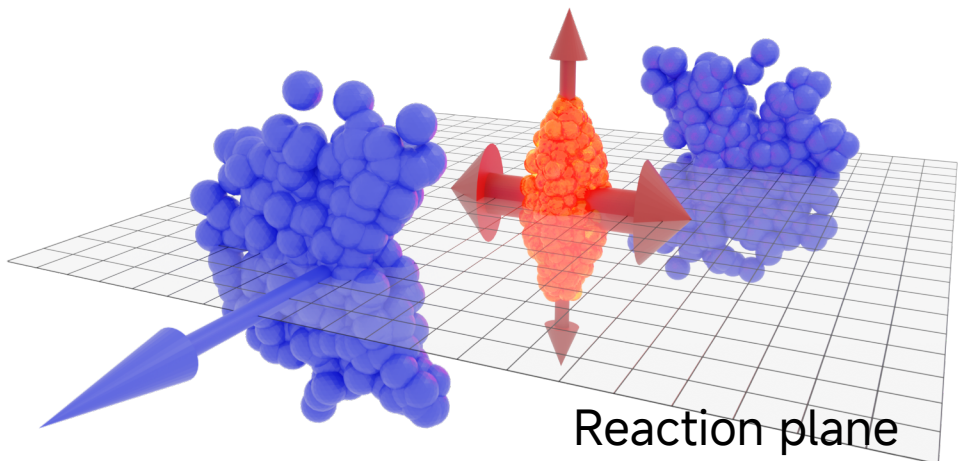
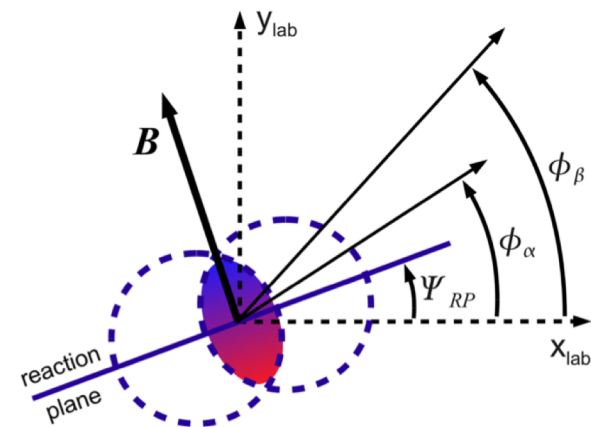
e.g. 13 nb^{-1} Pb–Pb collisions, ≈ 100 times the MB statistics of Run 2

Azimuthal correlations and anisotropic flow

Initial eccentricity + QGP evolution $\rightarrow$ Final momentum anisotropy

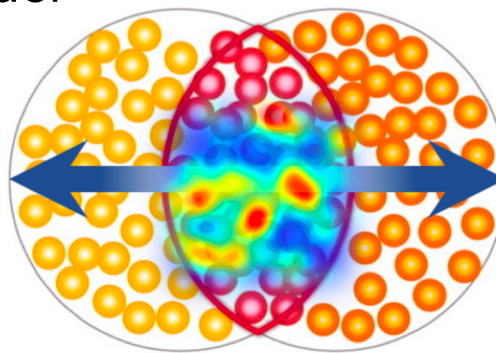
$$E \frac{d^3N}{d^3\mathbf{p}} = \frac{1}{2\pi} \frac{d^2N}{p_t dp_t dy} \left(1 + 2 \sum_{n=1}^{\infty} v_n \cos[n(\varphi - \Psi_{RP})] \right)$$

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



2nd order

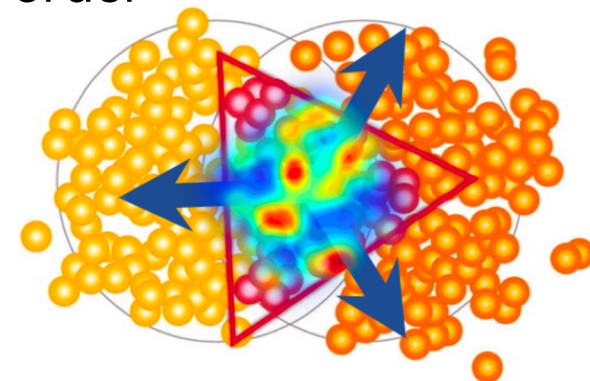
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Elliptic flow

3rd order

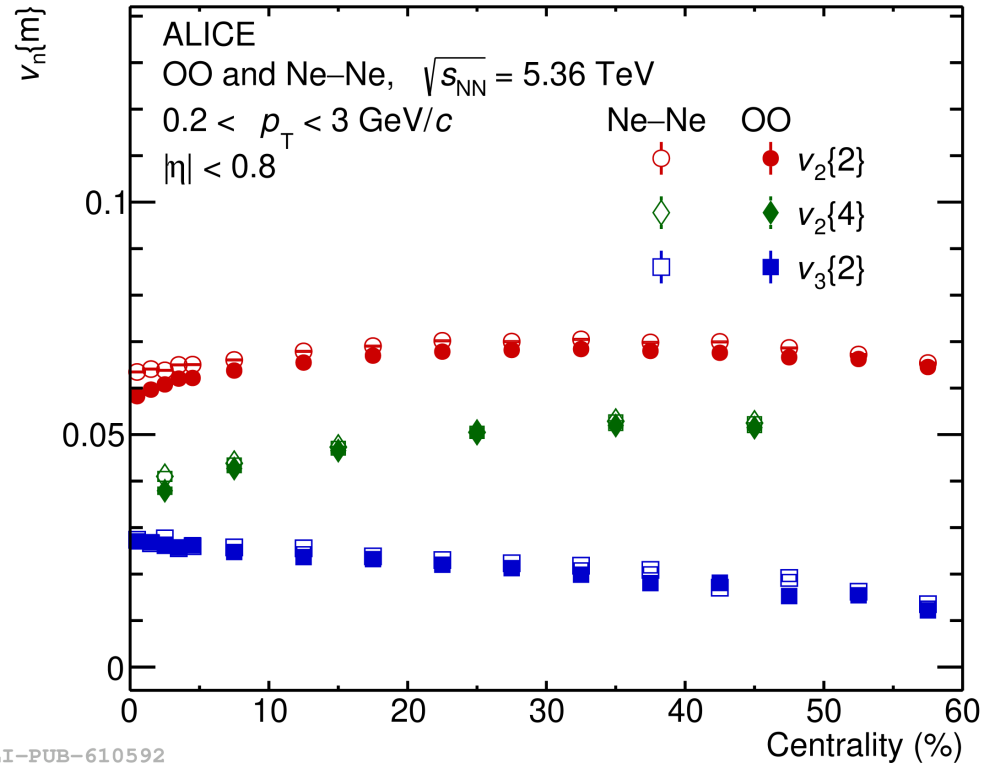
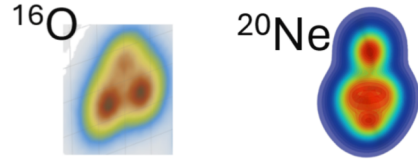
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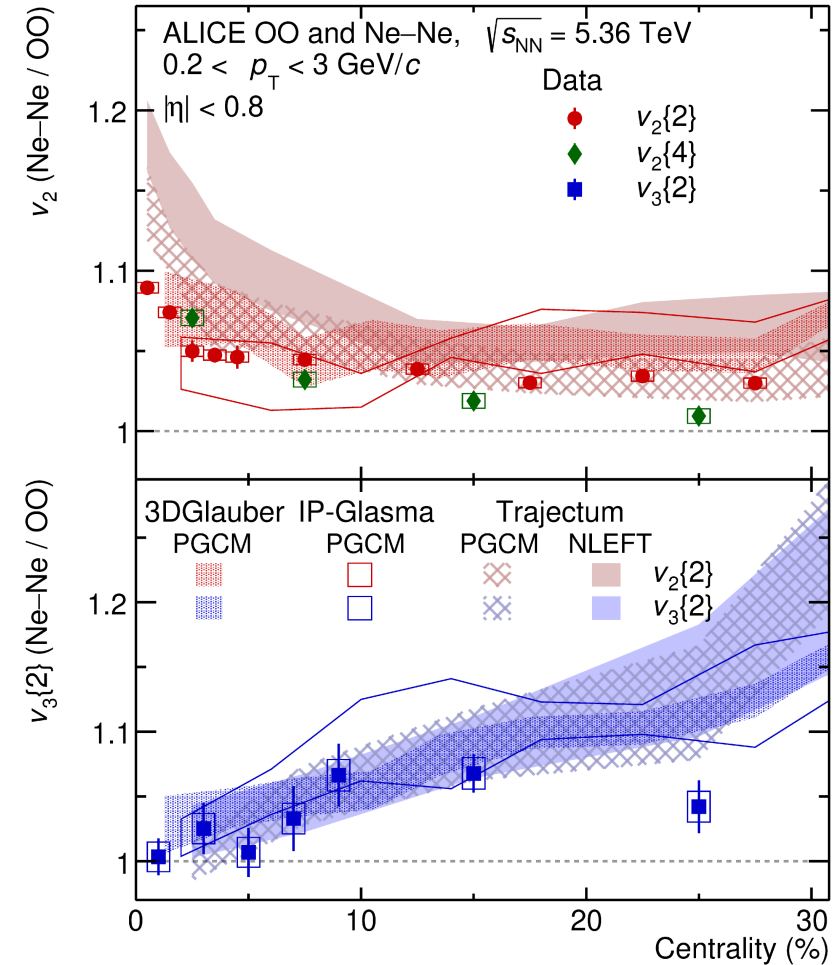
Triangular flow

Anisotropic flow in OO and Ne-Ne collisions

arXiv:2509.06428



ALI-PUB-610592



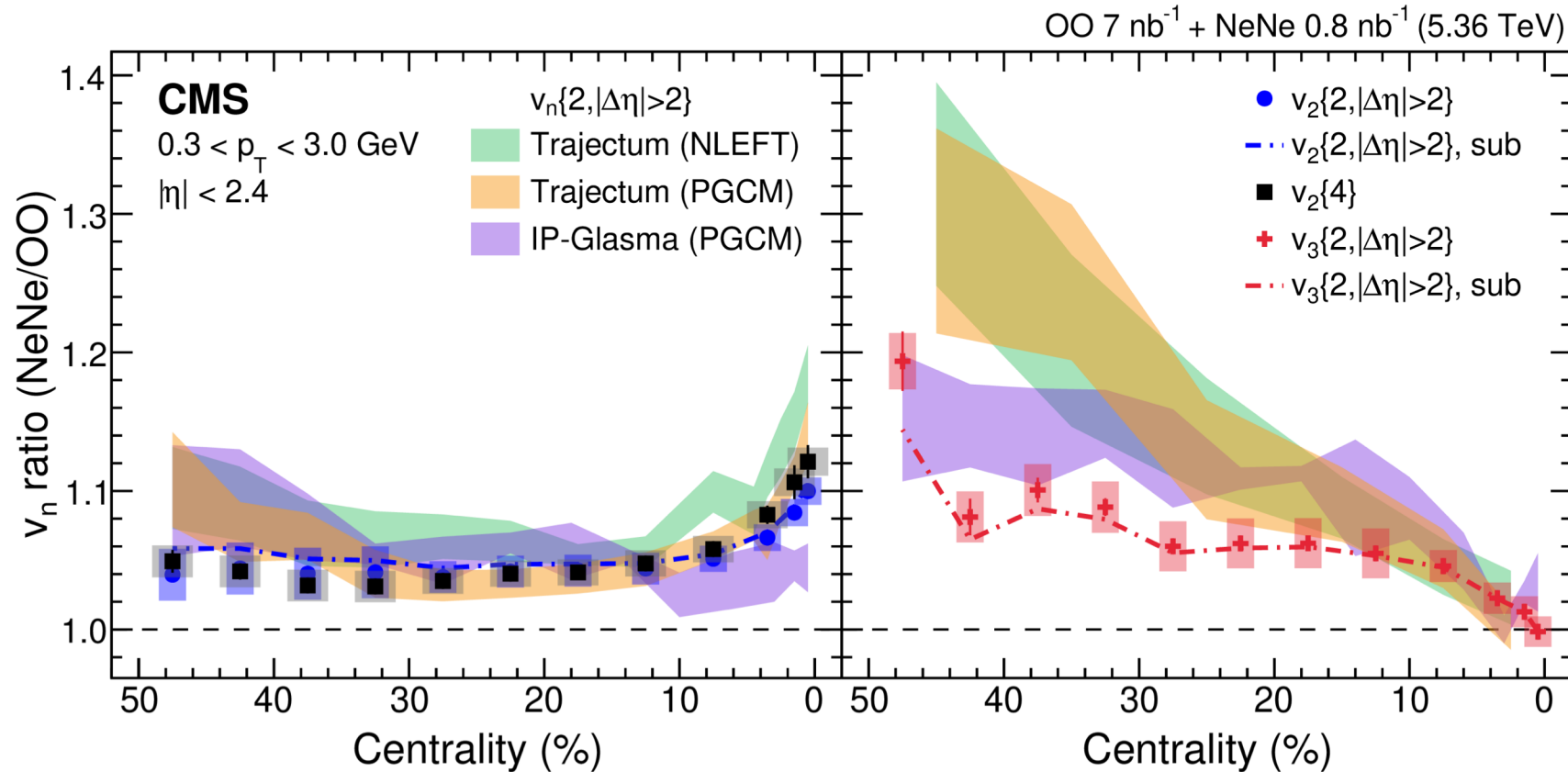
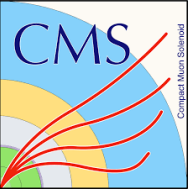
ALI-PUB-610602



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

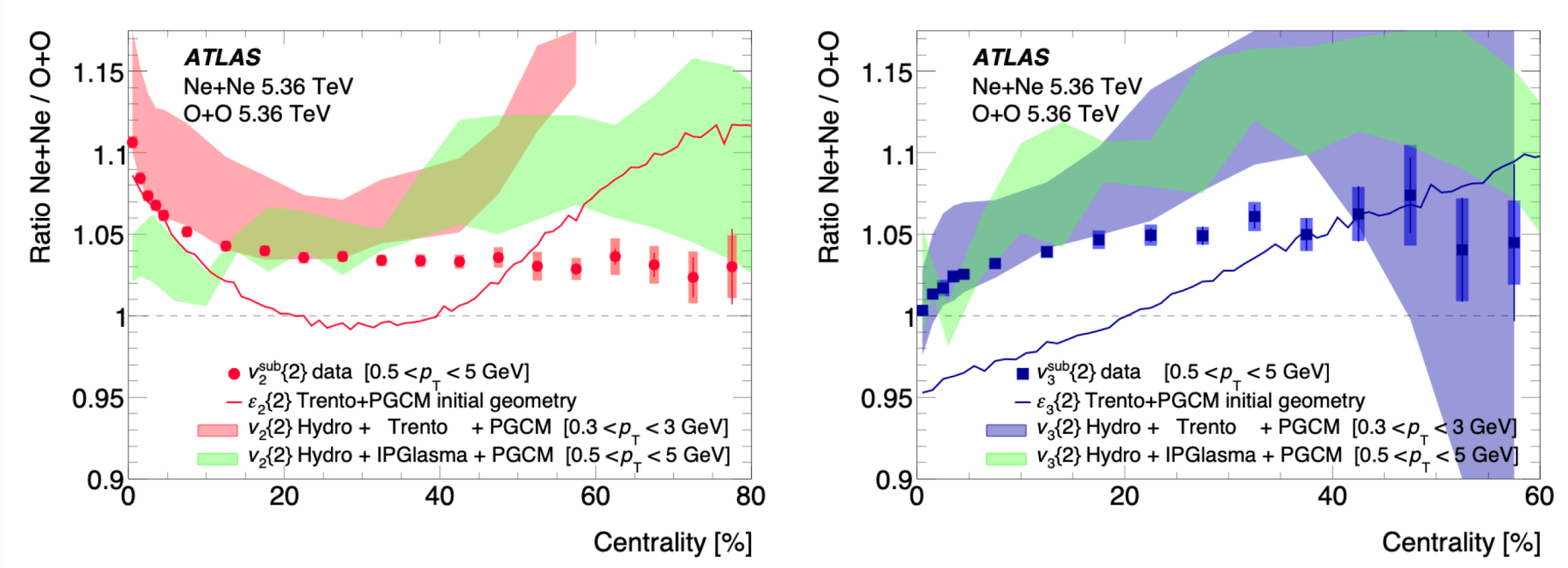
arXiv:2510.02580



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

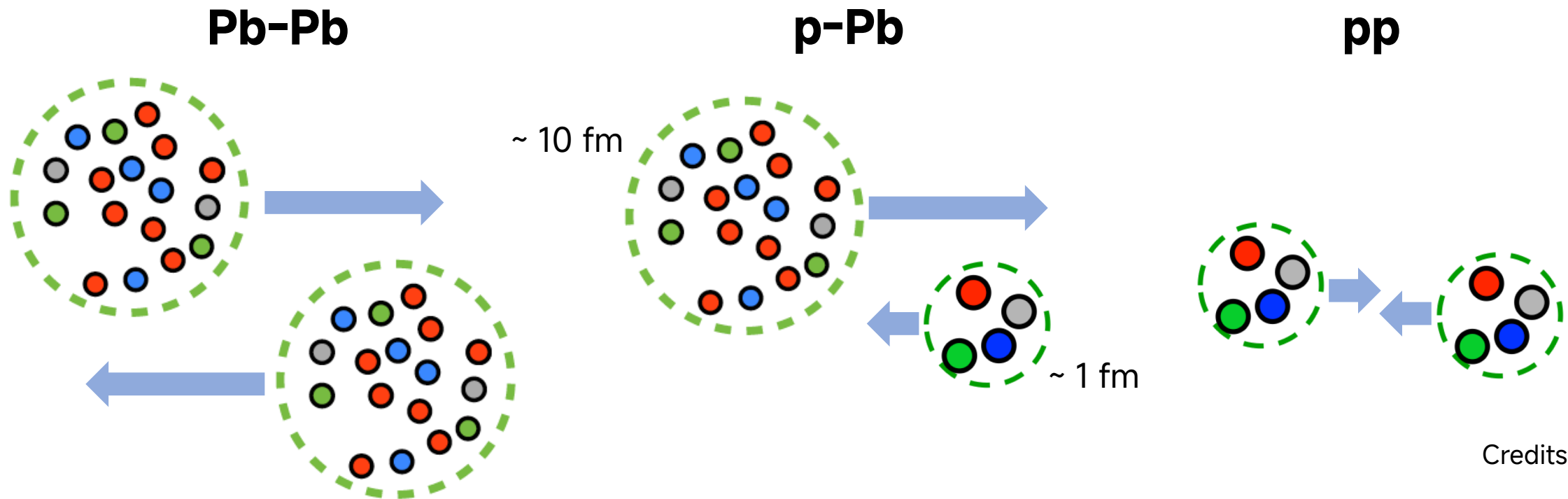
Anisotropic flow in OO and Ne-Ne collisions

arXiv:2509.05171



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

Collectivity in p-Pb and pp collisions

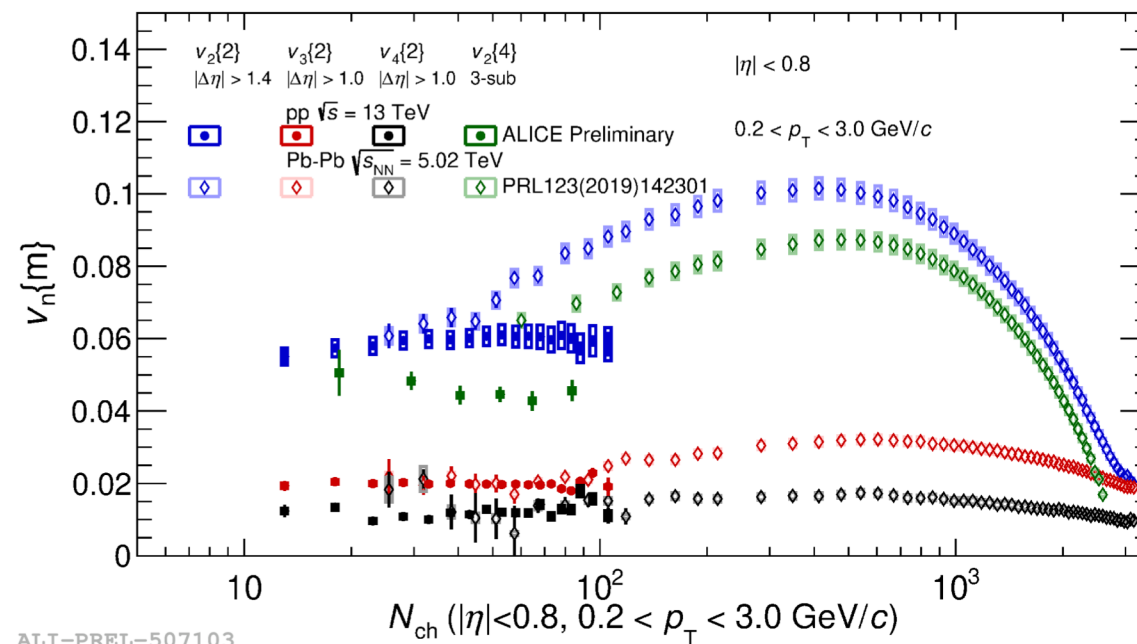
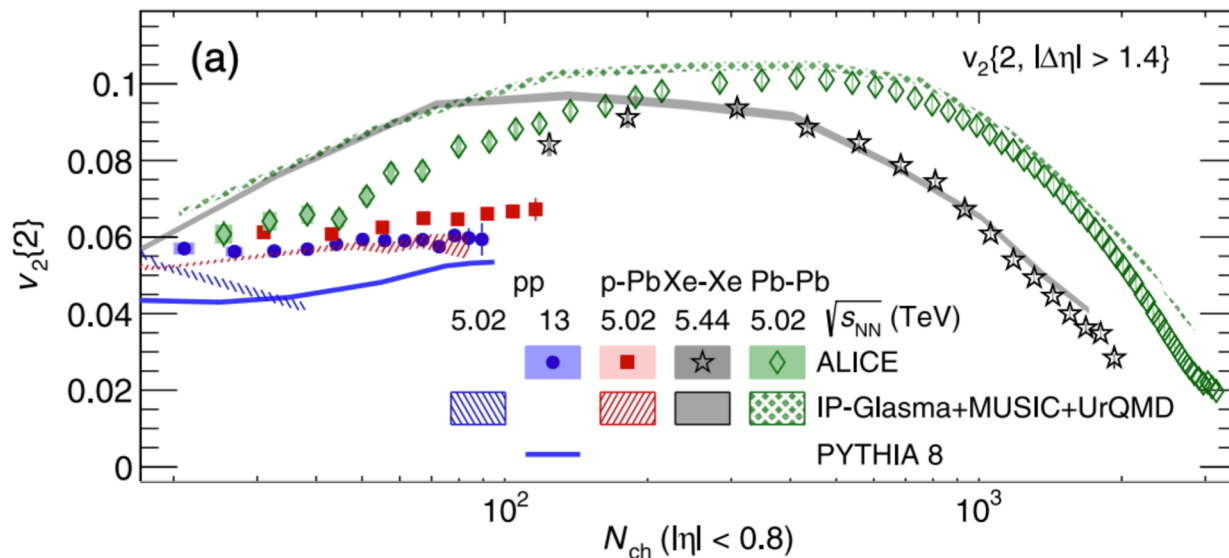


Credits to CZY

- 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)

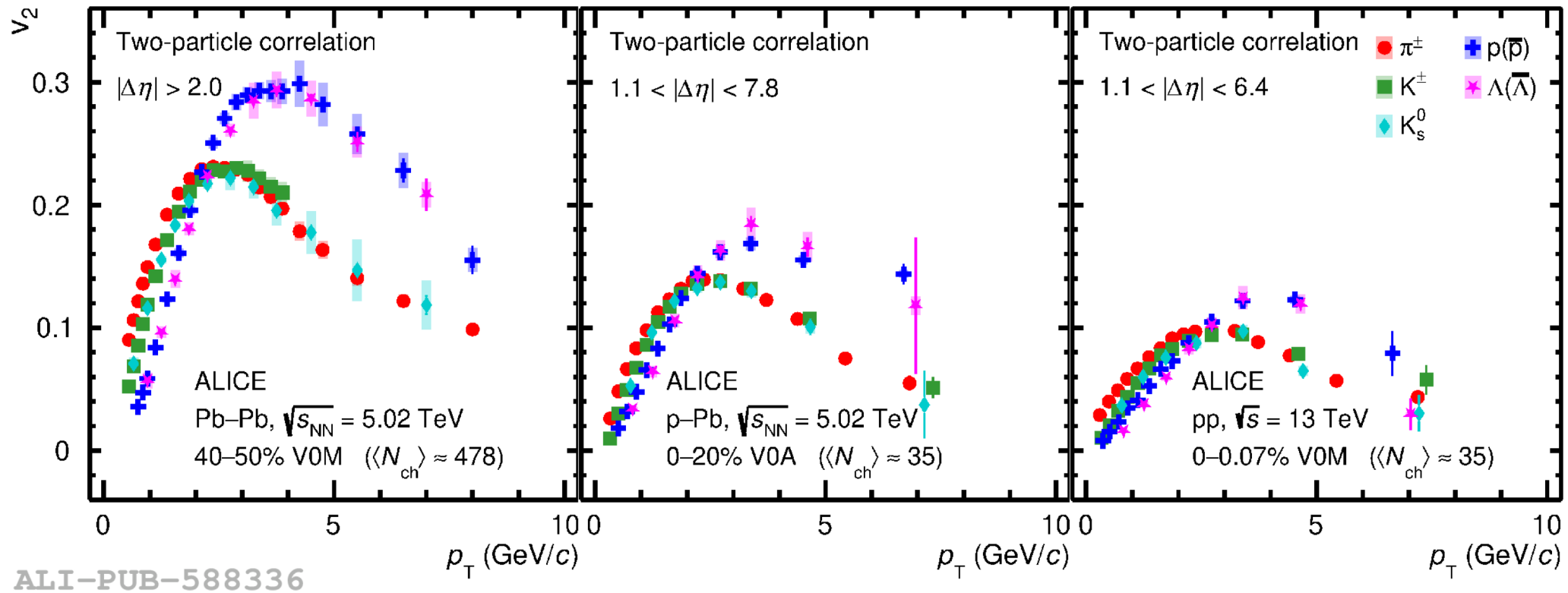


ALI-PREL-507103

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

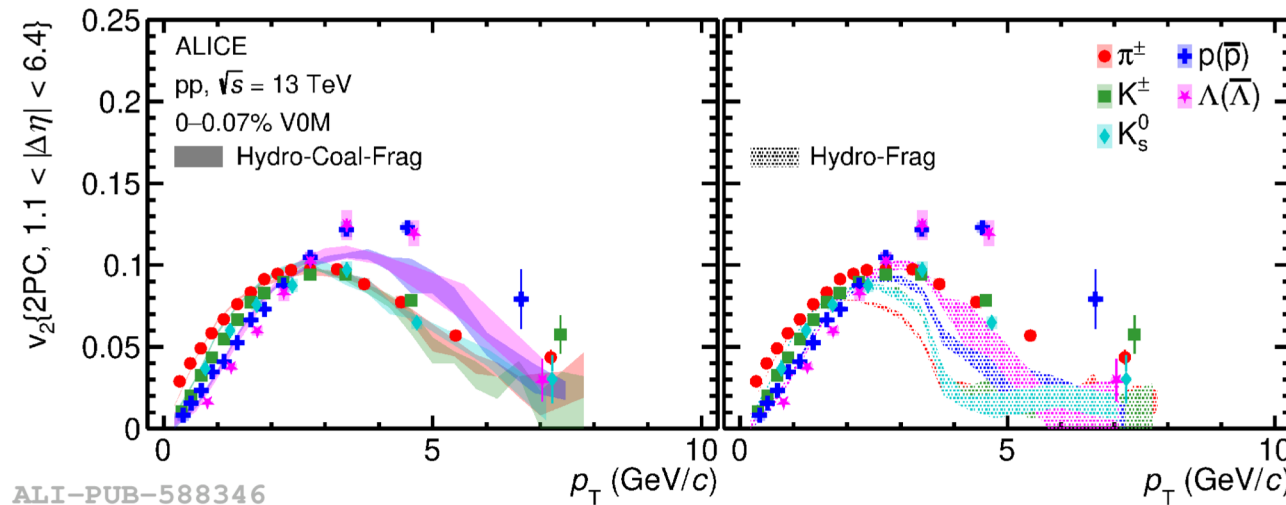
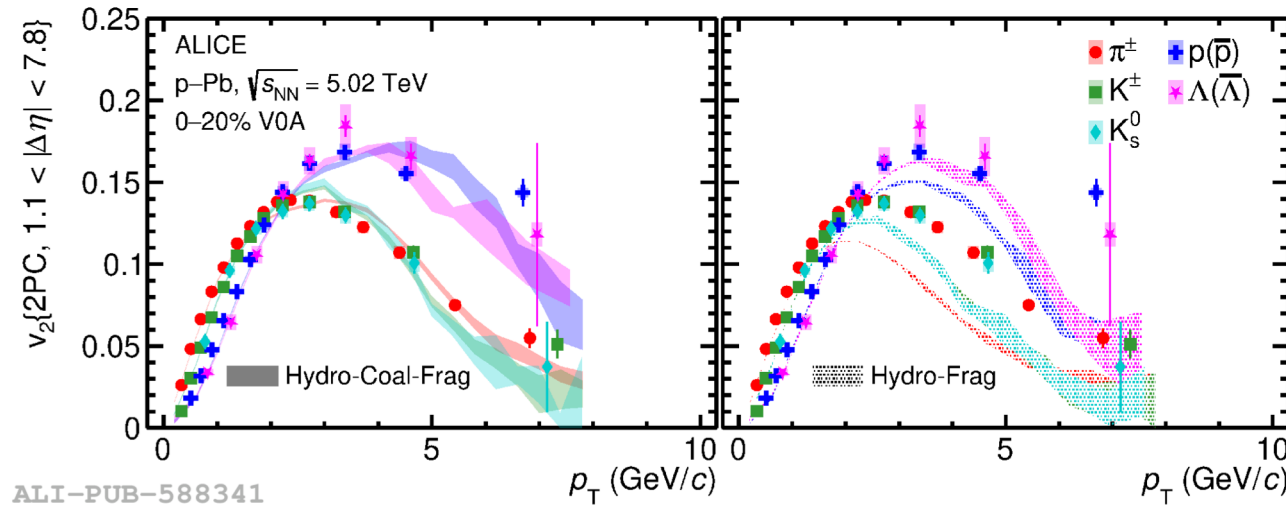
arXiv:2411.09323
Nature Commu. accepted



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

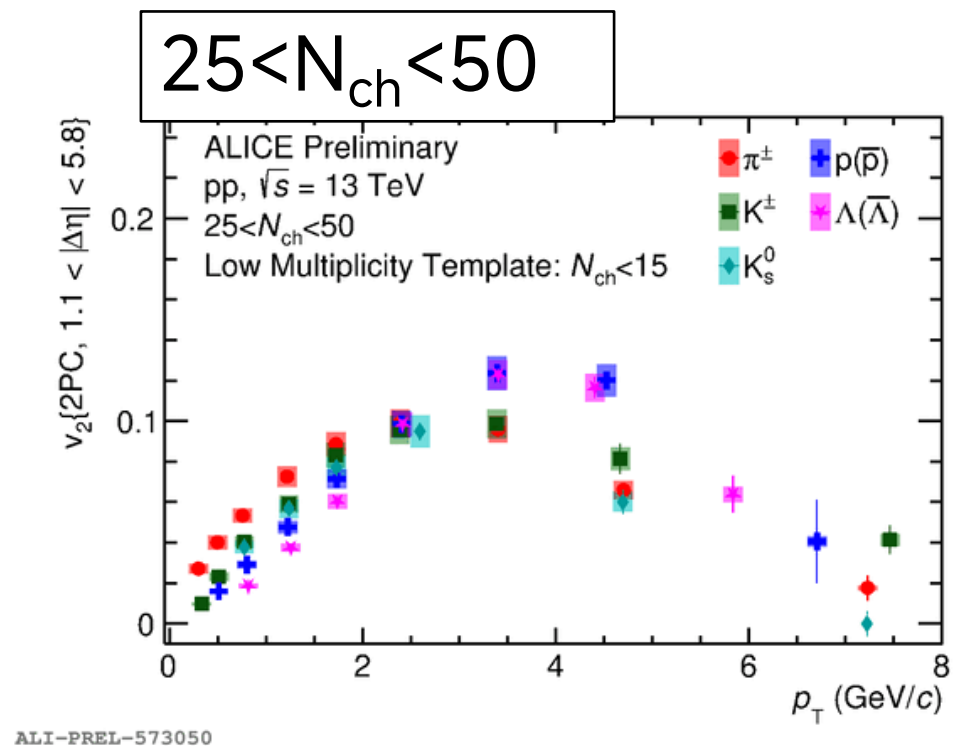
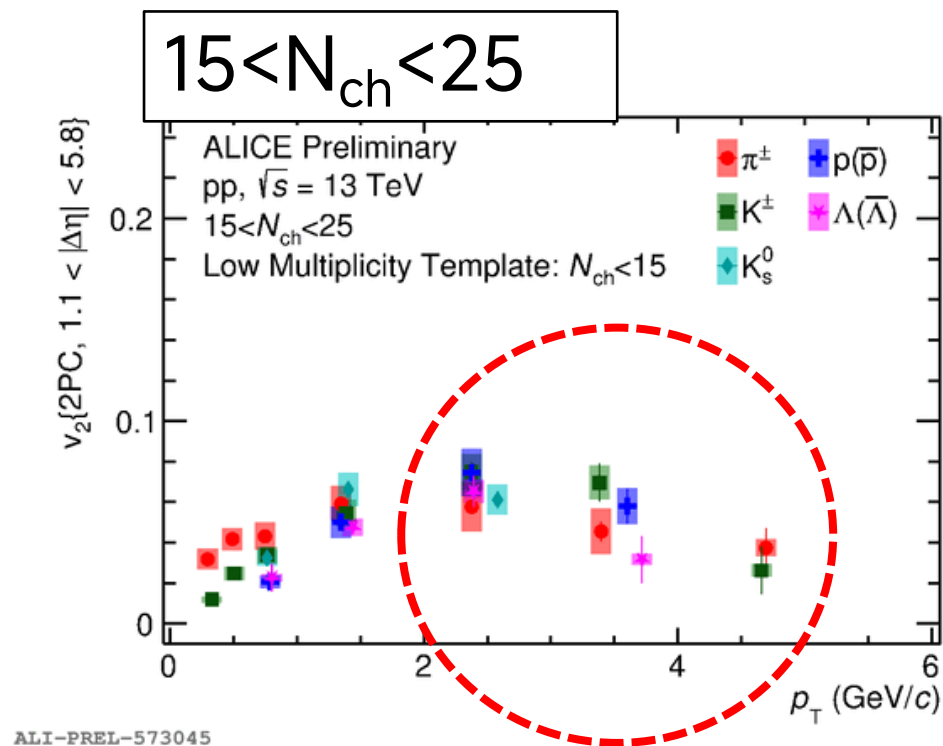
Elliptic flow of identified particles in small systems

arXiv:2411.09323
Nature Commu. accepted



Evidence of hadronization via
coalescence of flowing quarks
in small systems

Elliptic flow of identified particles in small systems



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

Parameterizing the shape of nuclei

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

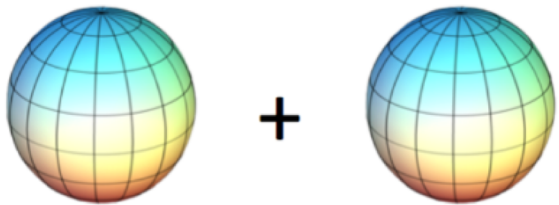
$$\rho(r, \theta, \phi) = \frac{\rho_0}{1 + e^{[r-R(\theta, \phi)]/a_0}},$$

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

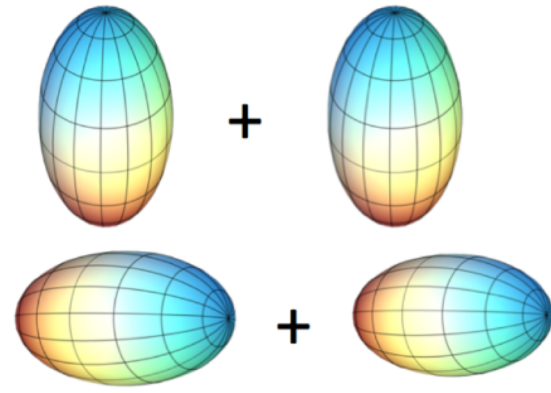
β_2 : overall deformation parameter

a_0 : diffuseness parameter

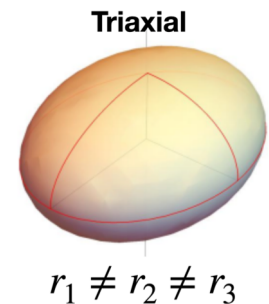
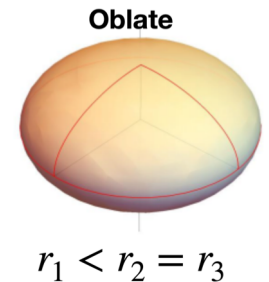
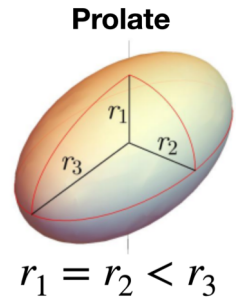
γ : triaxiality parameter



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

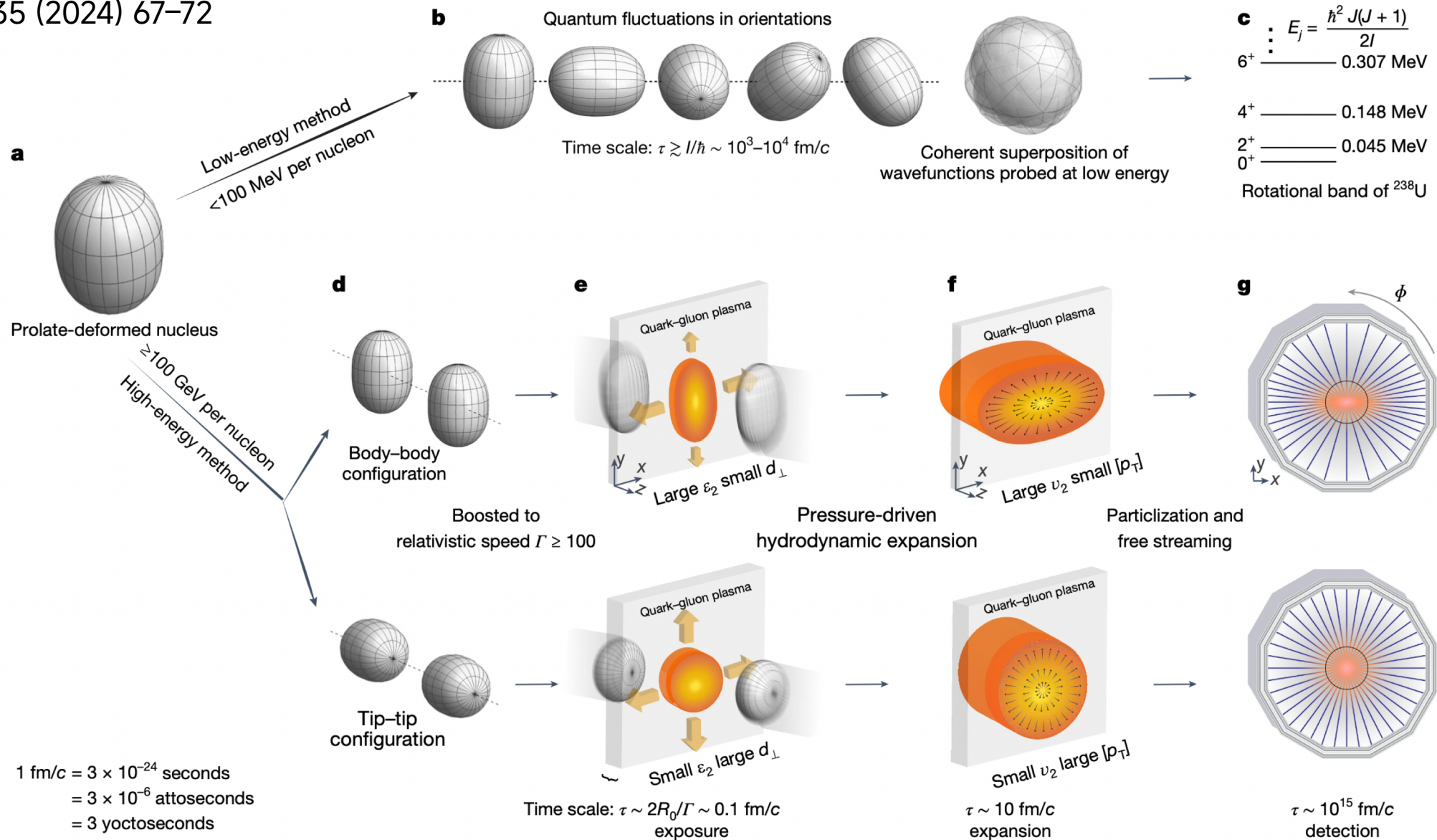


RHIC: U+U (Ru, Zr)
LHC: Xe+Xe



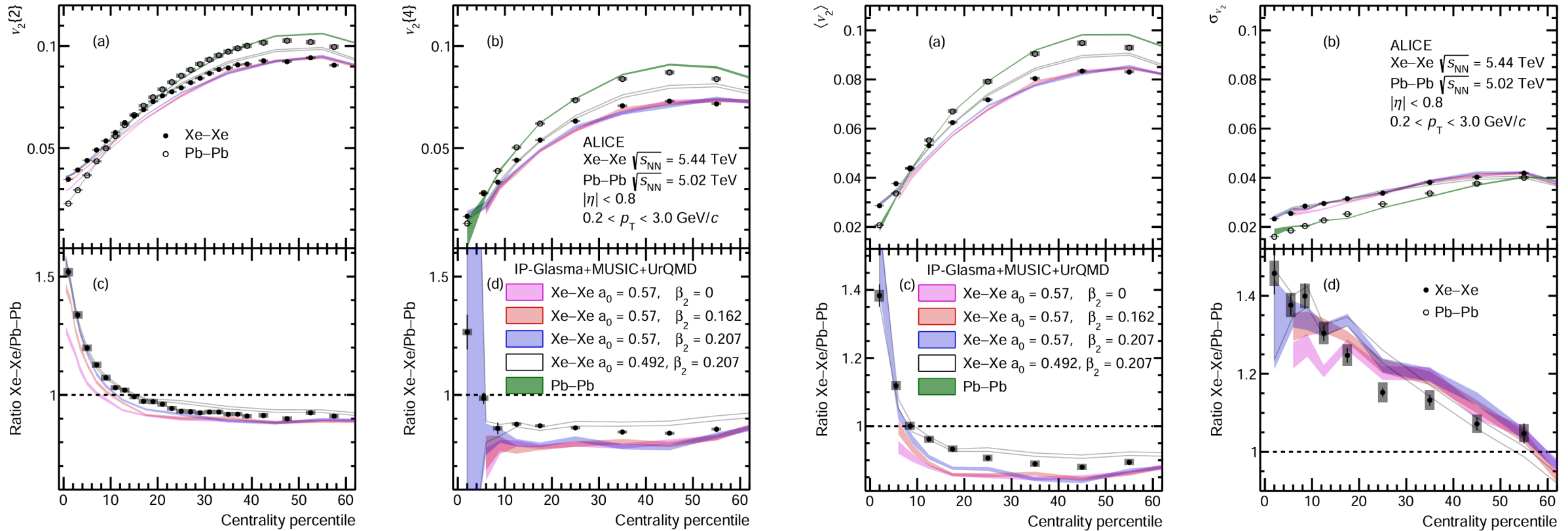
Imagining the nuclear structure

Nature 635 (2024) 67–72



Measurement of Xe at LHC-ALICE

arXiv:2409.04343



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

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

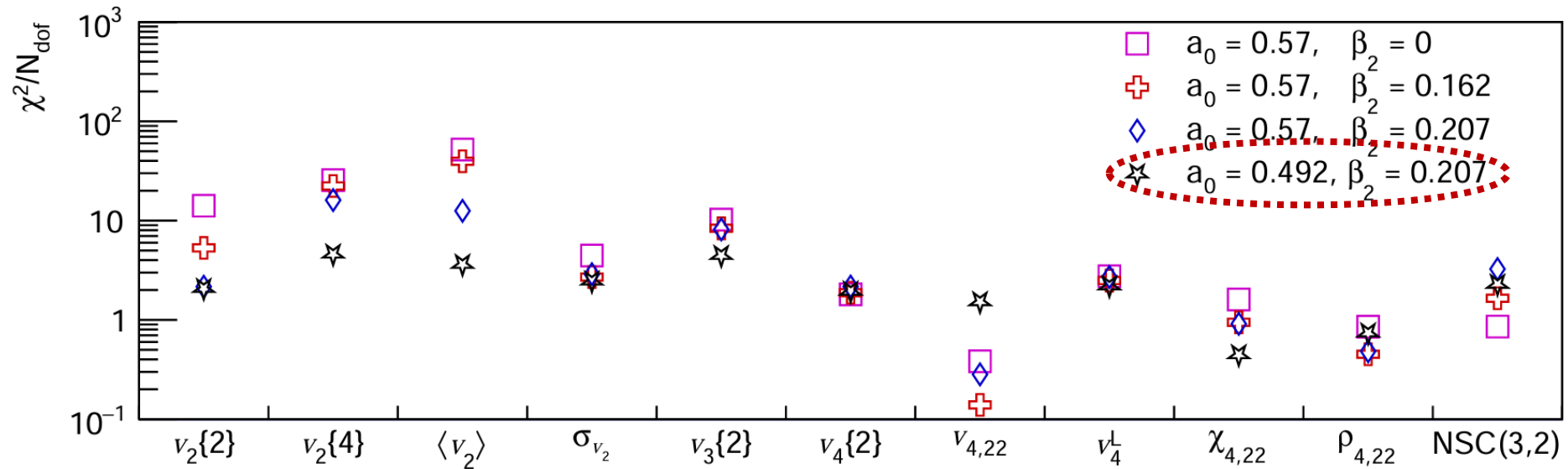
$$v_n\{2\}^2 \approx \langle v_n \rangle^2 + \sigma_{v_n}^2$$

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

Measurement of Xe at LHC-ALICE

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

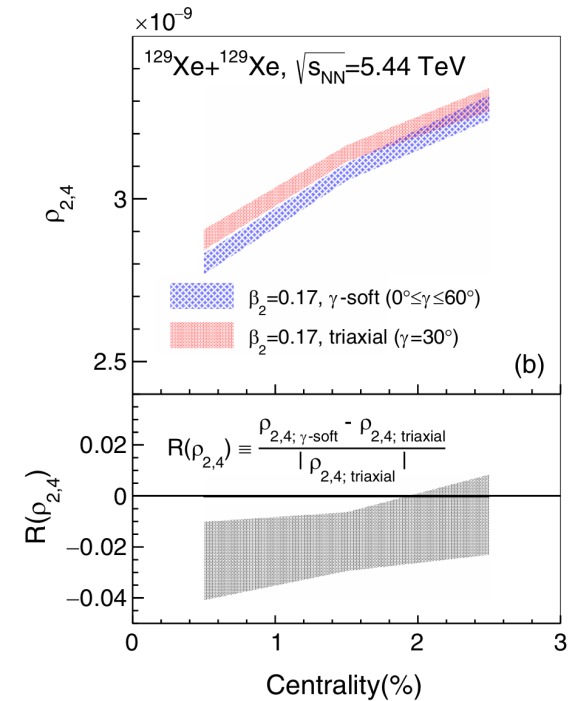
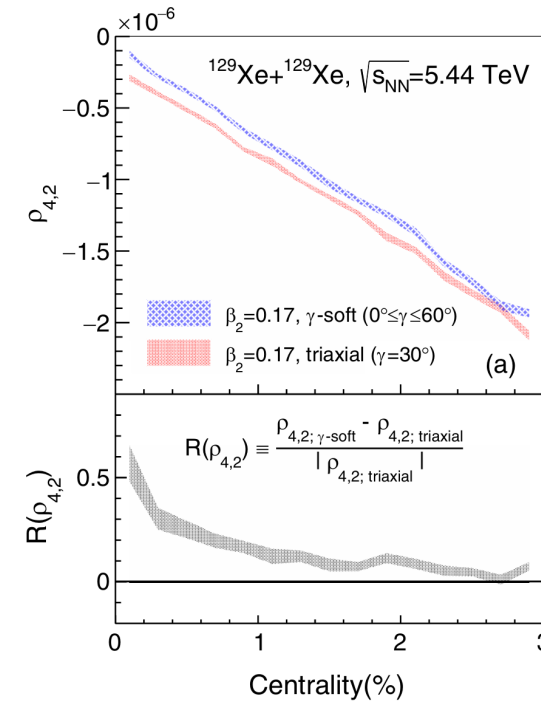
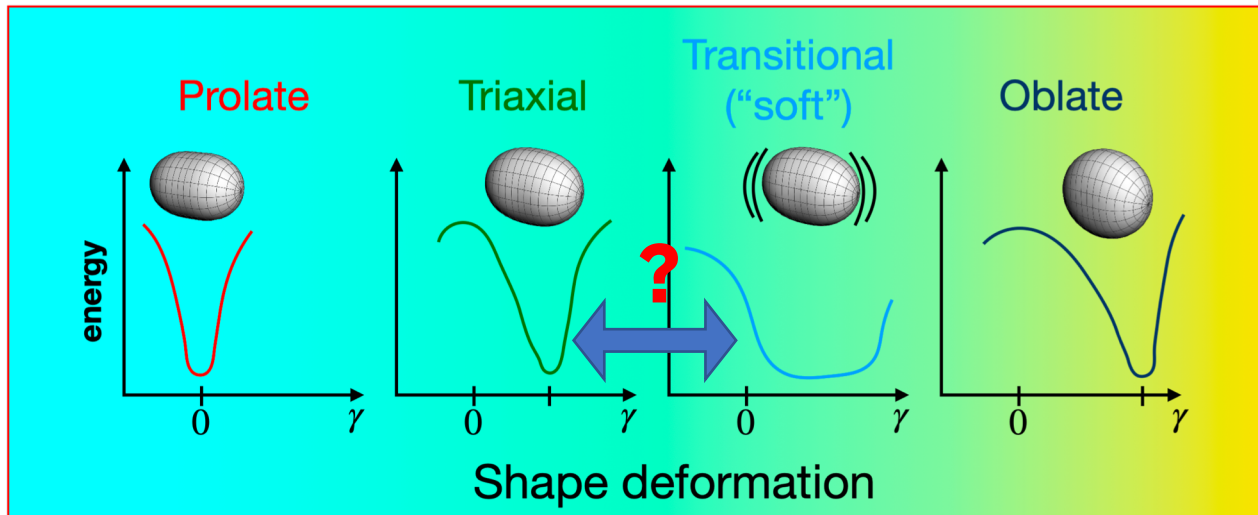
arXiv:2409.04343v1



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

Testing γ -soft of Xe at LHC-ALICE

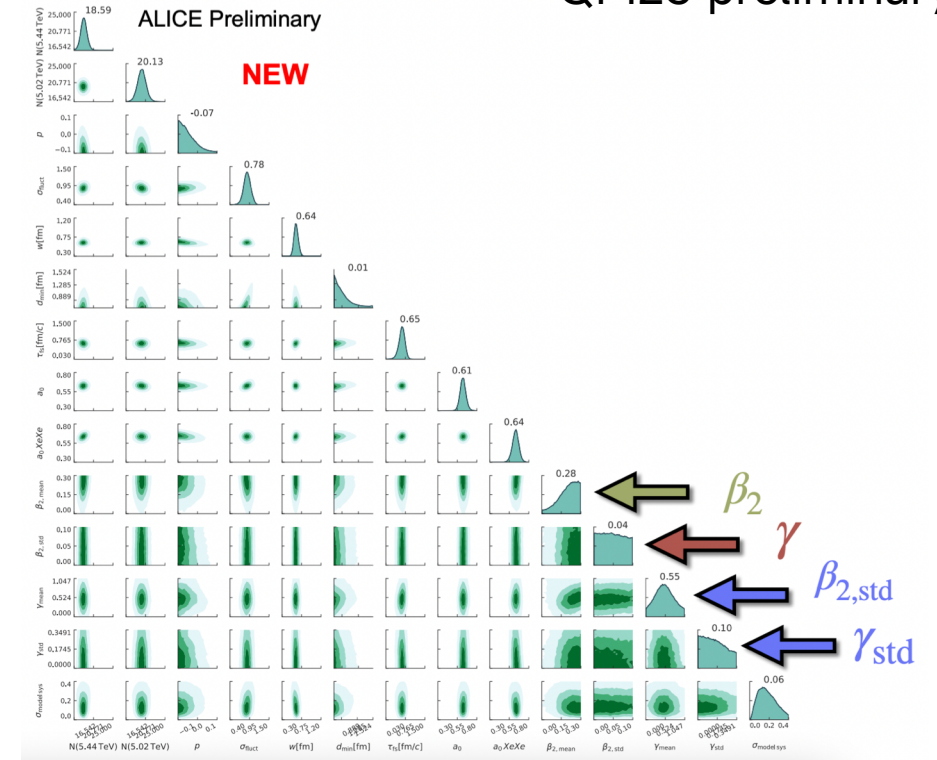
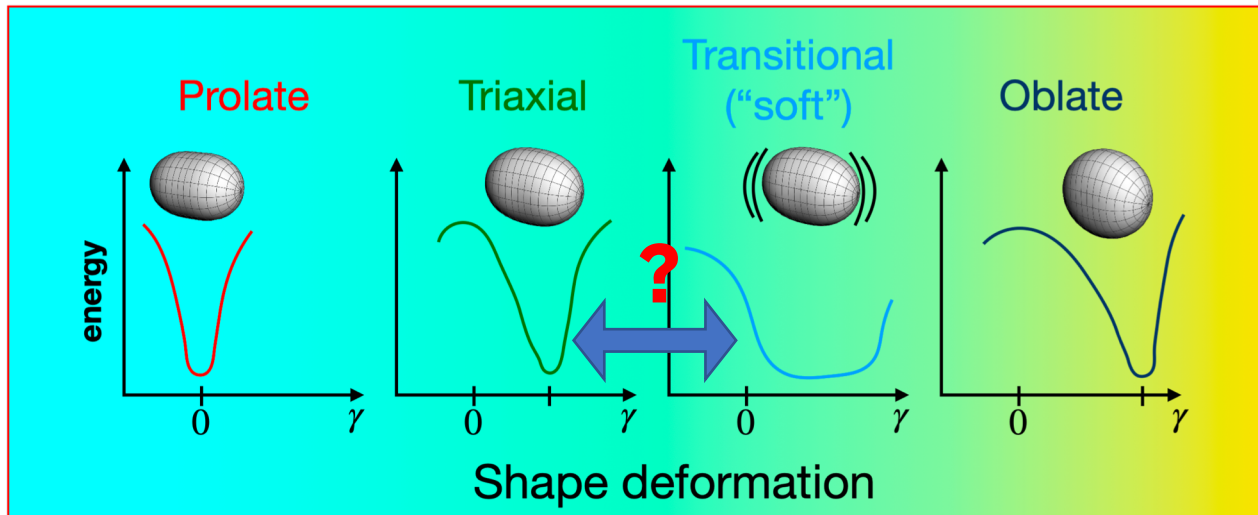
PRL 133, 192301 (2024)



6-particle cumulant needed

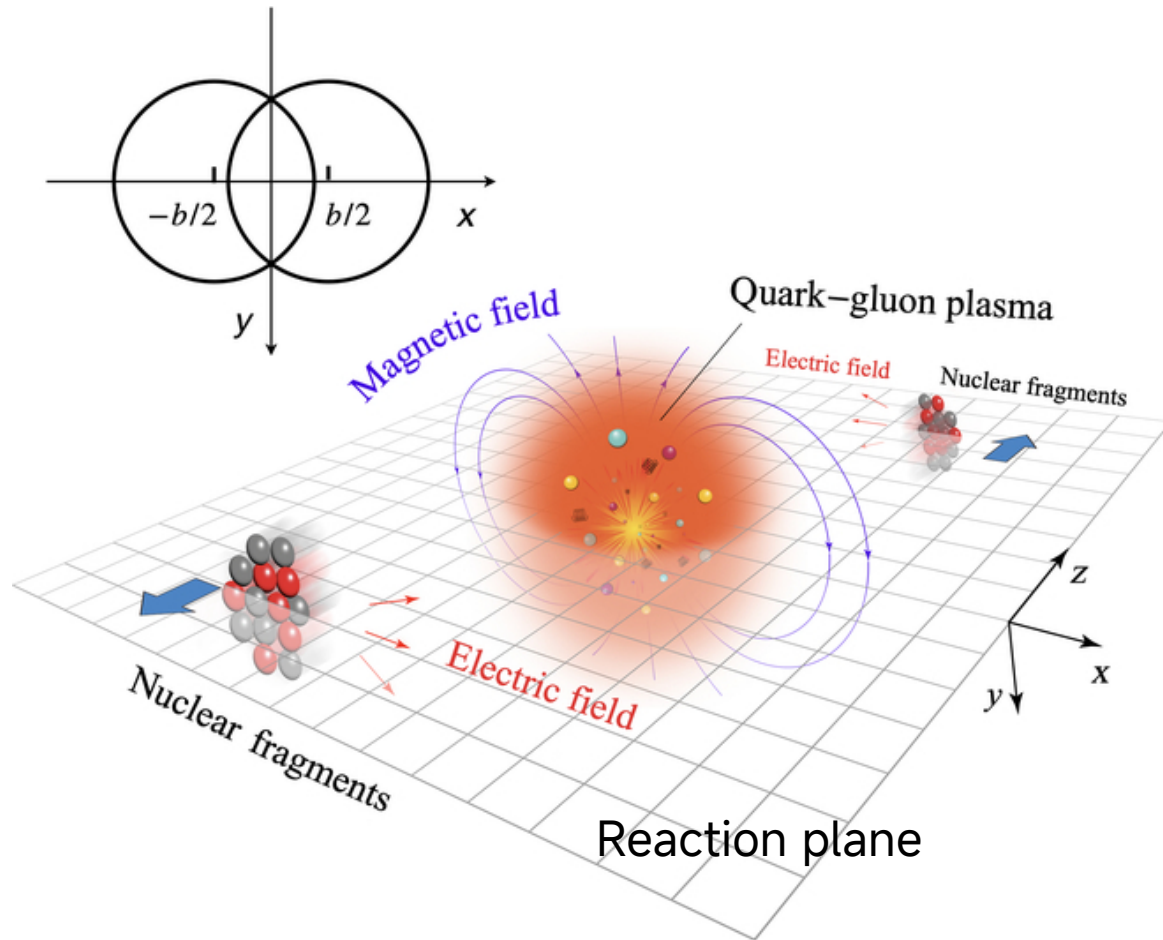
Testing γ -soft of Xe at LHC-ALICE

QM25 preliminary



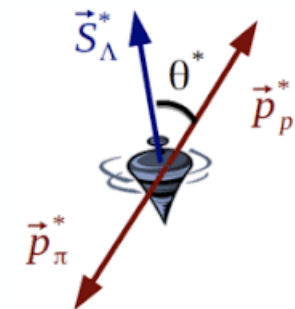
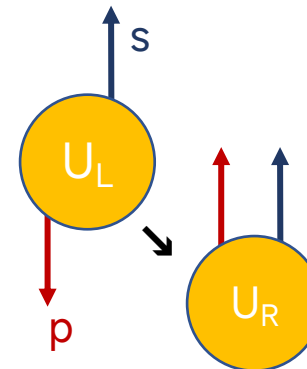
Comprehensive Bayesian analysis to simultaneously pin down all parameters of Xe
 The extracted γ value with a narrow σ indicates weak/no γ -soft effect.
→ Xe has a rigid, triaxial deformation

Collective effects under strong magnetic and vortical fields

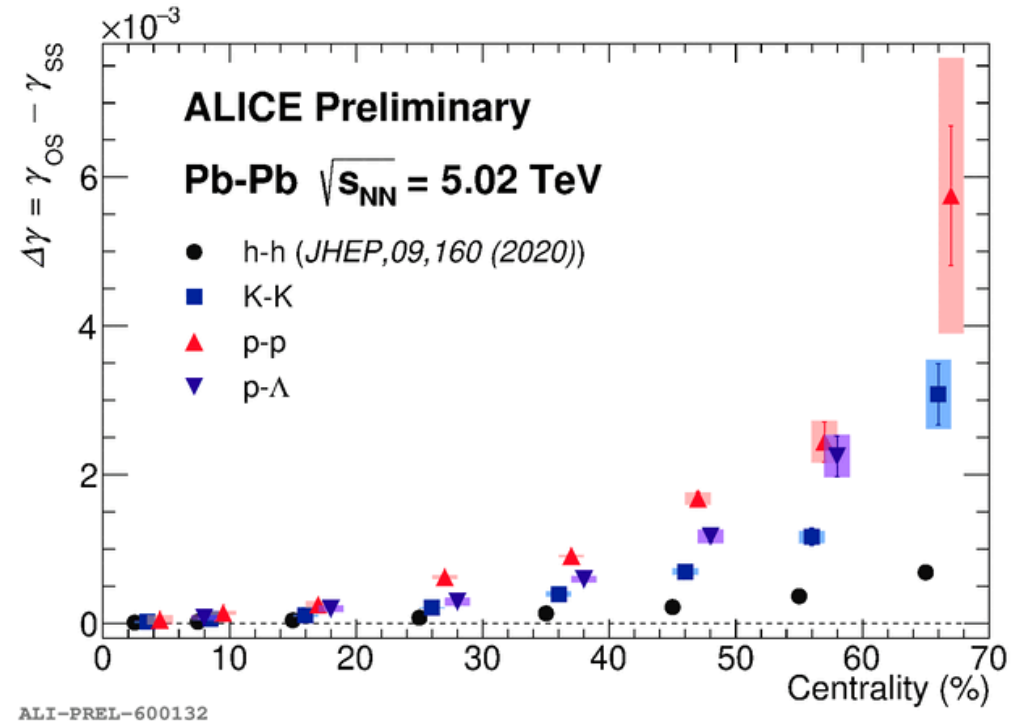
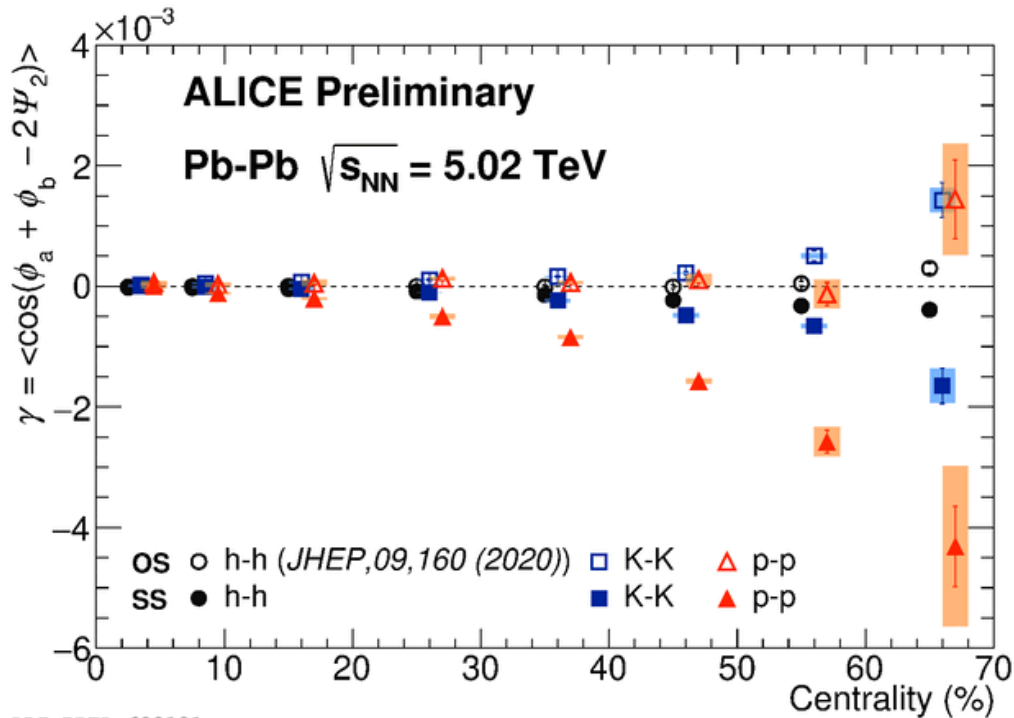


$$B \approx 10^{18} - 10^{19} \text{ Gauss}$$
$$\omega \approx 10^{21} \text{ s}^{-1}$$

- **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

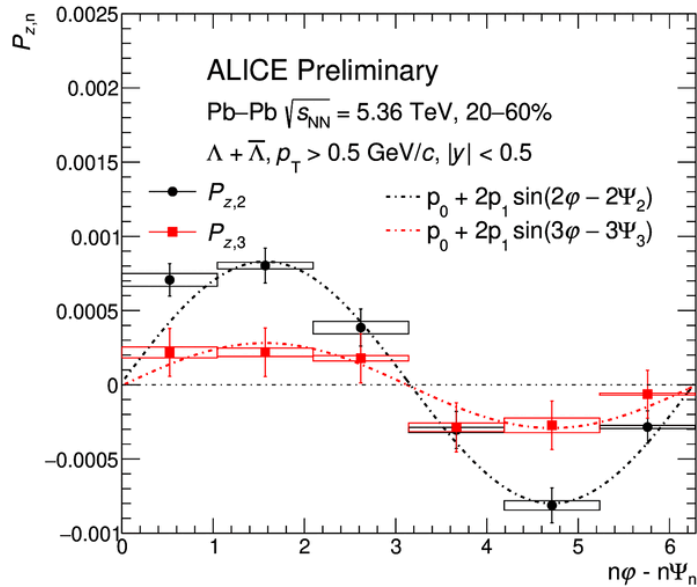
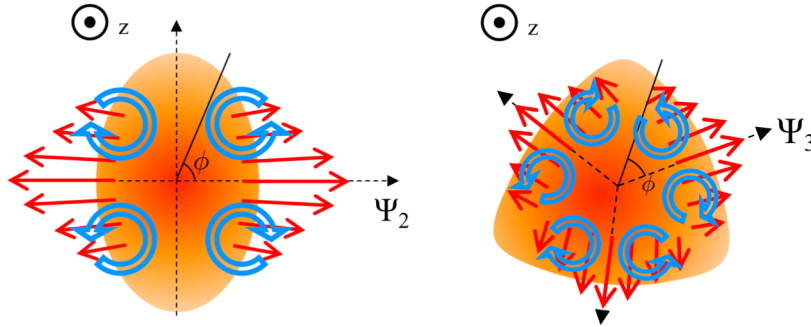


Charge dependent azimuthal correlations

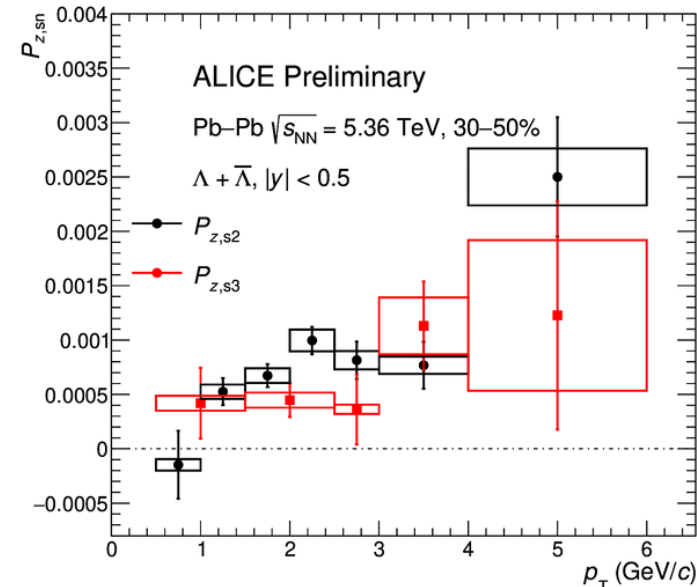


Significant separations are observed for K and p
 $\Delta\gamma$ follow $p-p > p-\Lambda > K-K > h-h$
 indicating various global/local charge conservations

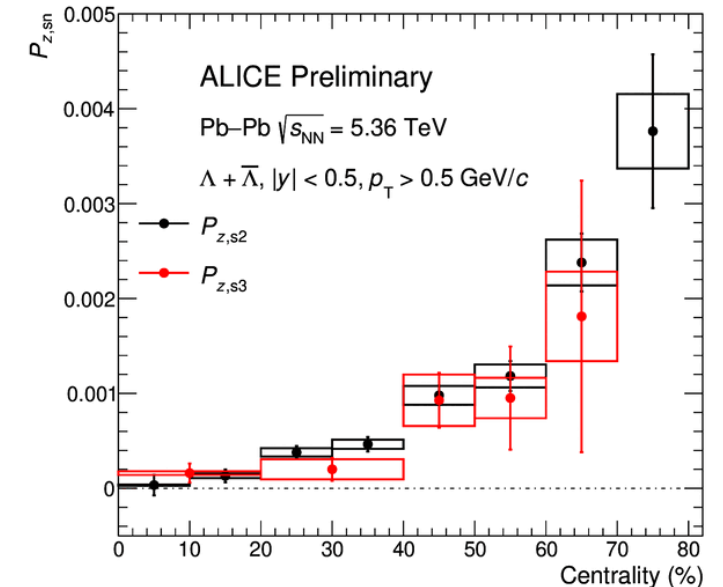
Hyperon local polarization at ALICE



ALI-PREL-597386



ALI-PREL-597376

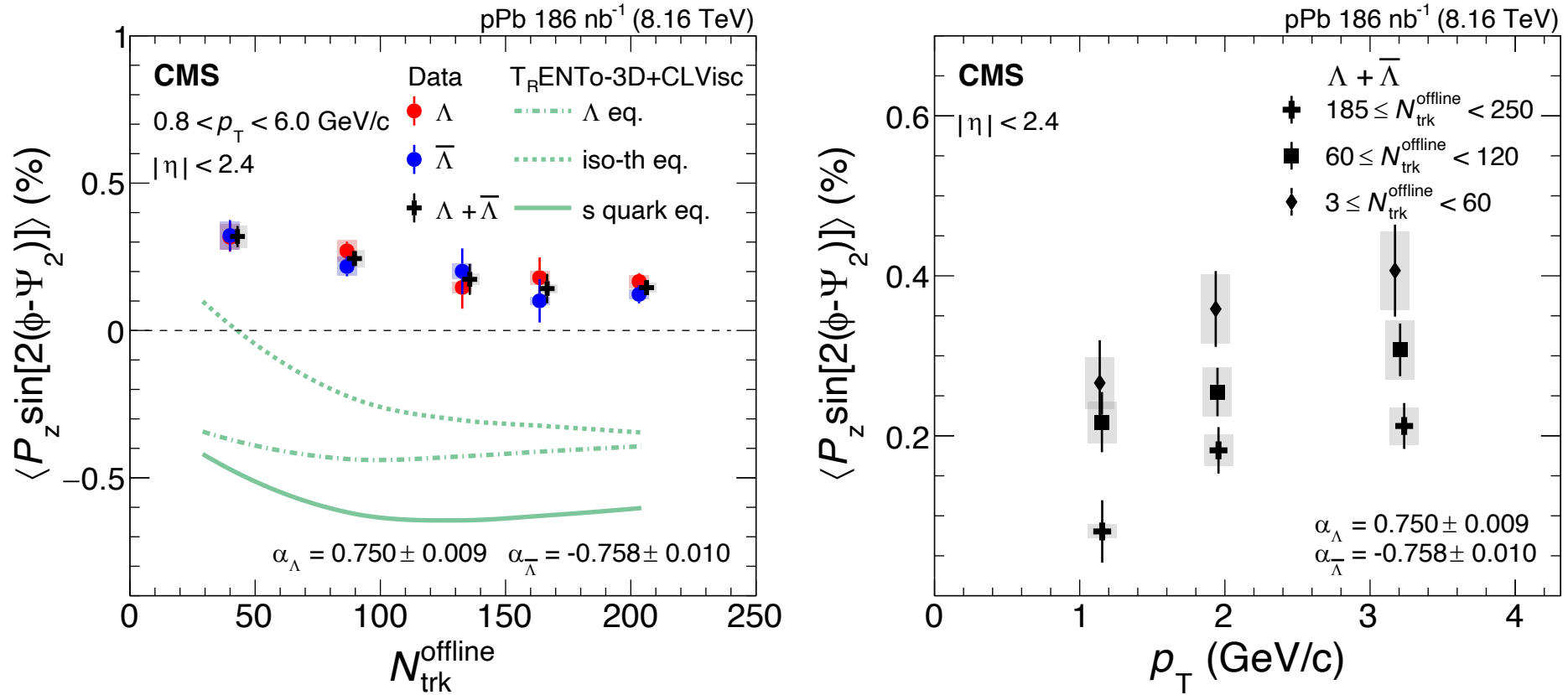
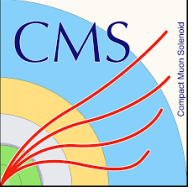


ALI-PREL-597381

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

Hyperon local polarization at CMS

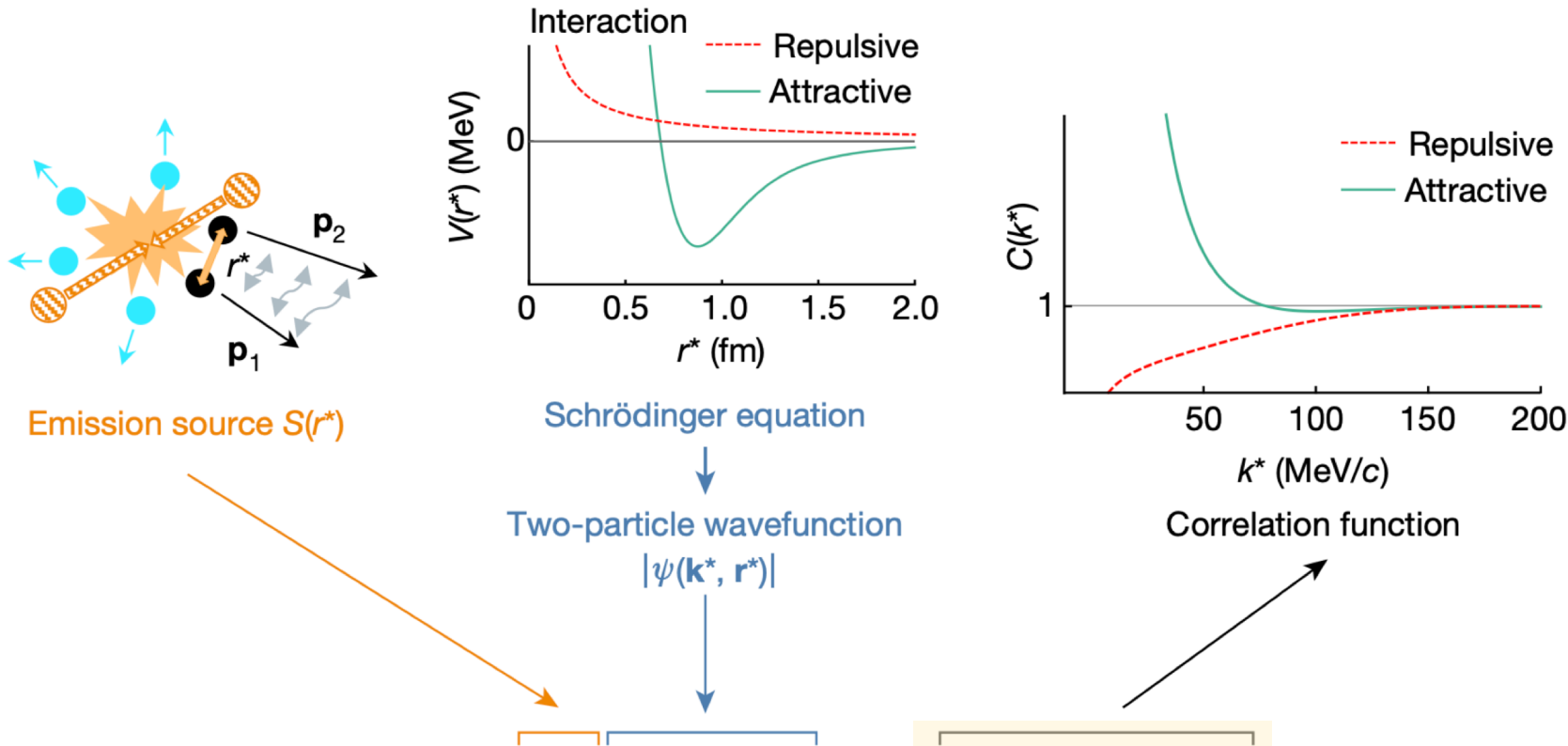
PRL 135 (2025) 132301



First observation of hyperon local polarization in small collisions
 Post challenges to theoretical framework of spin in heavy ion

Momentum correlations (Femtoscscopy)

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



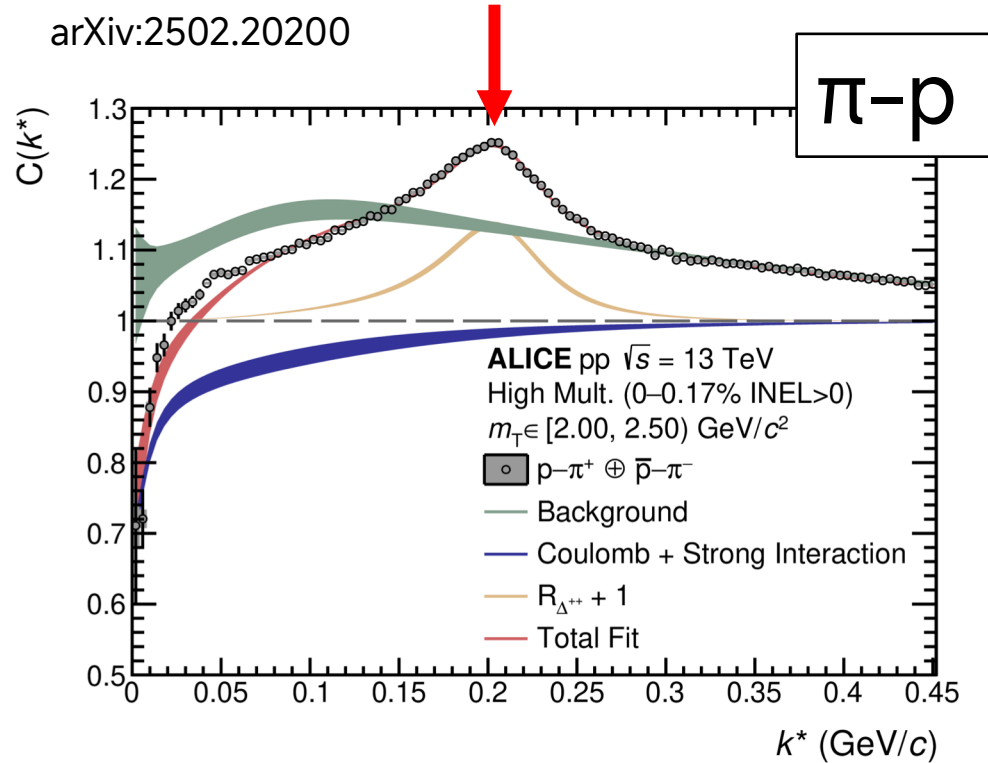
$$C(k^*, r^*) = \int S(r^*) |\psi(\mathbf{k}^*, \mathbf{r}^*)|^2 d^3r^* = \xi(k^*) \frac{N_{\text{same}}(k^*)}{N_{\text{mixed}}(k^*)}$$

What experiments measure

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

π -nuclei femto correlation

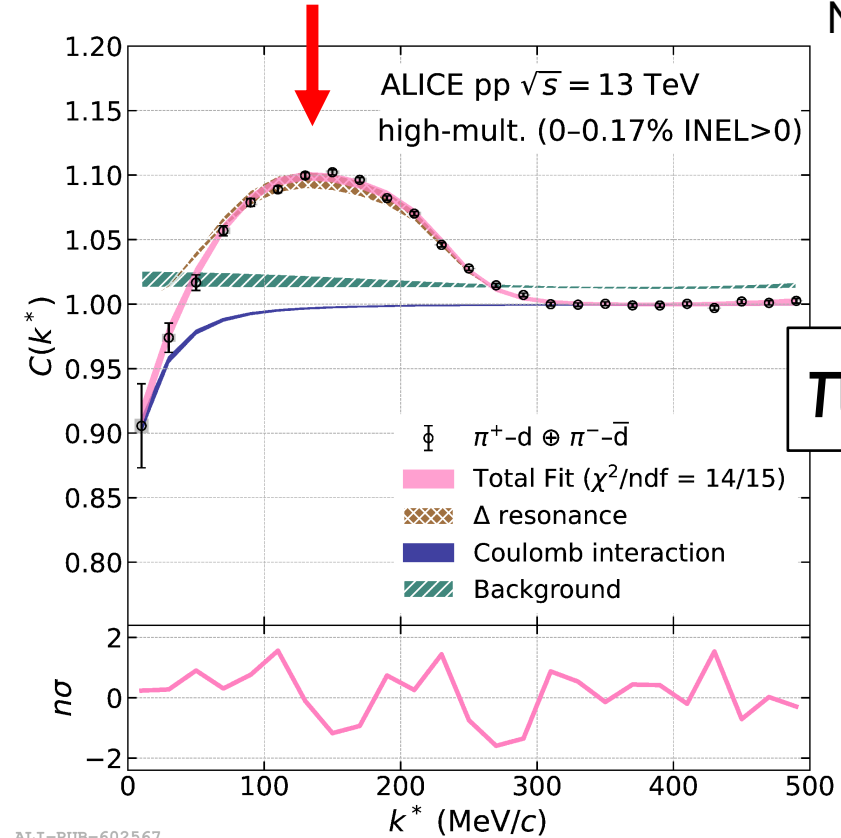
arXiv:2502.20200



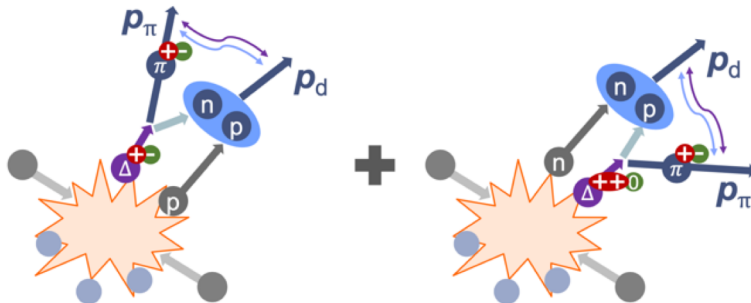
ALI-PUB-590167

arXiv:2504.02393

Nature accepted



ALI-PUB-602567



NC 15, 1 (2024)

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

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!