Characterising the initial conditions and probing the nuclear structure with multi-particle correlations techniques at the LHC

Emil Gorm Nielsen on behalf of the ALICE Collaboration

Niels Bohr Institute, University of Copenhagen

Initial state estimators

Mean transverse momentum: The mean transverse momentum, $[p_{\mathrm{T}}]$, is linearly correlated with the initial energy, E_i, and inversely correlated with the size of the system R [1].

$$[p_{\mathrm{T}}] \propto E_i, \quad [p_{\mathrm{T}}] \propto \frac{1}{R}$$

Anisotropic flow: The anisotropic flow, v_n ($n \leq 3$), is proportional to the initial eccentricity [2].

$$v_n \propto \epsilon_n$$

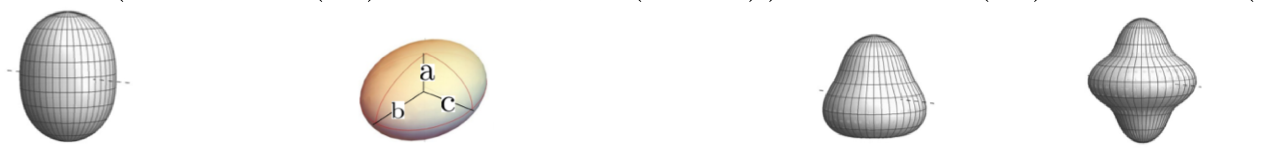
Correlations of v_n and mean transverse momentum correlations probe the correlations of **size** and **shape** in the initial state.

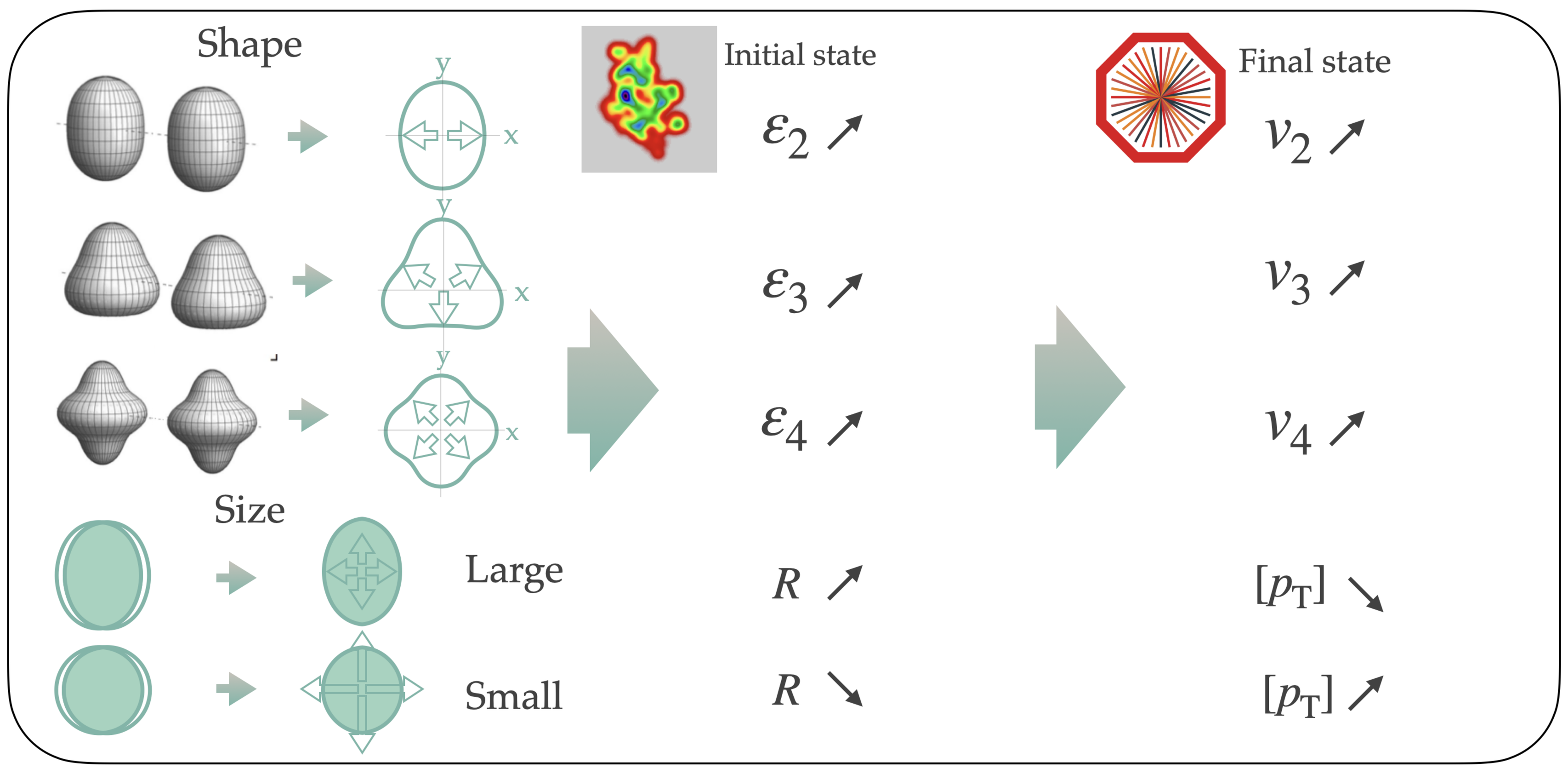
Generalised Woods-Saxon profile

$$\rho(r,\Theta,\Phi) \propto \frac{1}{1+\exp\left([r-R(\Theta,\Phi)]/a\right)}$$

Quadrupole Triaxial Octopole Hexadecapole

$$R(\Theta,\Phi) = R_0\left[1+\beta_2\left(\cos\gamma Y_{20}(\Theta)+\sin\gamma Y_{22}(\Theta,\Phi)\right)+\beta_3 Y_{30}(\Theta)+\beta_4 Y_{40}(\Theta)\right]$$





Multi-particle cumulants of v_n and $[p_{\mathrm{T}}]$

Multi-particle cumulants, $C(v_n^m,[p_{\mathrm{T}}^k])$ between v_n^m and $[p_{\mathrm{T}}^{(k)}]$.

Pearson correlation coefficient

$$\rho(v_n^m,[p_{\mathrm{T}}^{(k)}]) = \frac{C(v_n^m,[p_{\mathrm{T}}^{(k)}])}{\sqrt{\mathrm{var}(v_n^m)}\sqrt{\mathrm{var}([p_{\mathrm{T}}^{(k)}])}}$$

Normalised cumulant

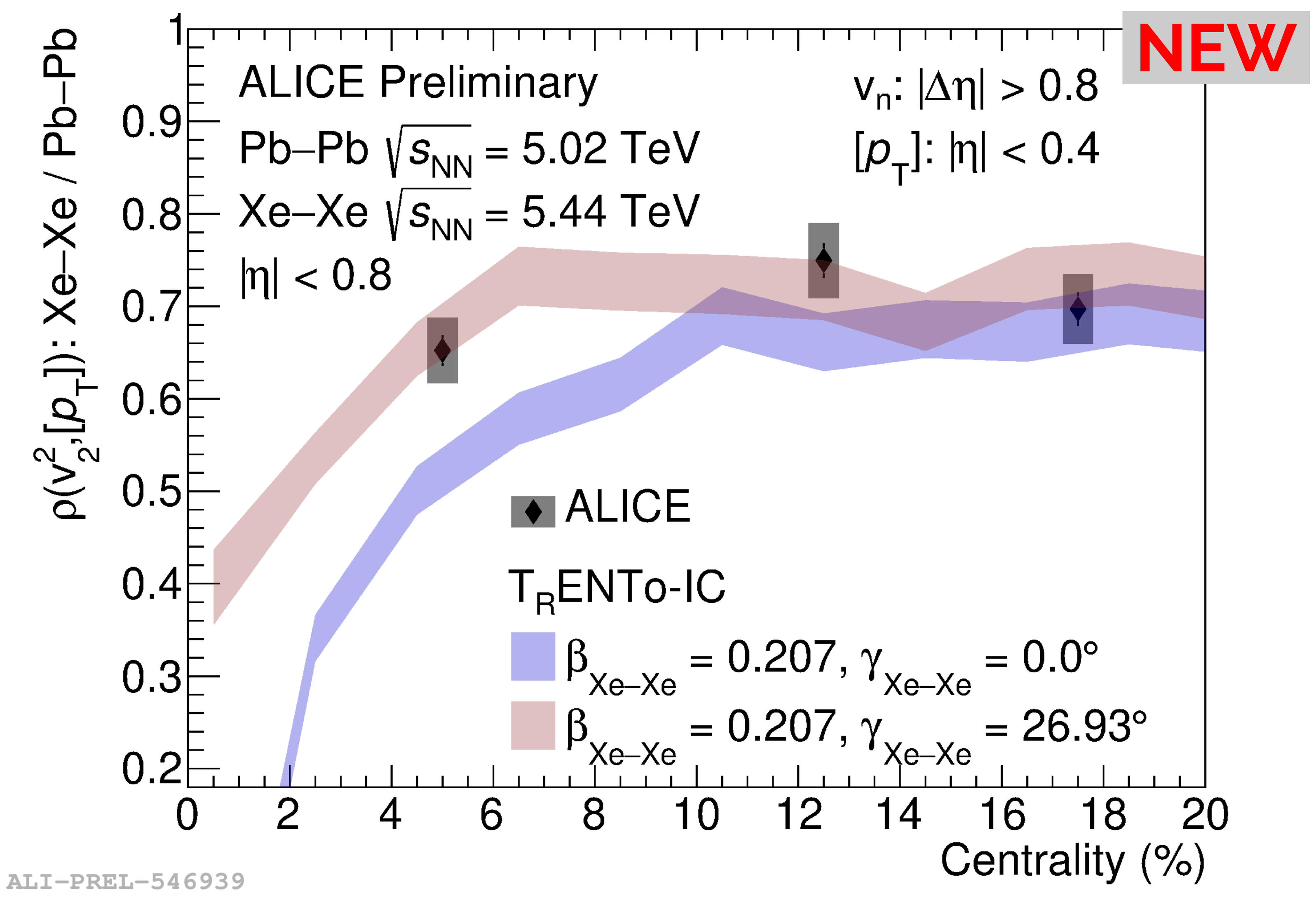
$$\mathrm{NC}(v_n^m,[p_{\mathrm{T}}^{(k)}]) = \frac{C(v_n^m,[p_{\mathrm{T}}^{(k)}])}{\langle v_n^m\rangle\langle[p_{\mathrm{T}}^{(k)}]\rangle}$$

Three-subevent method: removes auto-correlations and non-flow.

- v_n^m: two-subevent method with pseudorapidity gap $|\Delta\eta| > 0.8$.
- $[p_{\mathrm{T}}^{(k)}]$: midrapidity $|\eta| < 0.4$.

Probing the nuclear structure

- ALICE data suggests a **triaxial structure** of ^{129}Xe.



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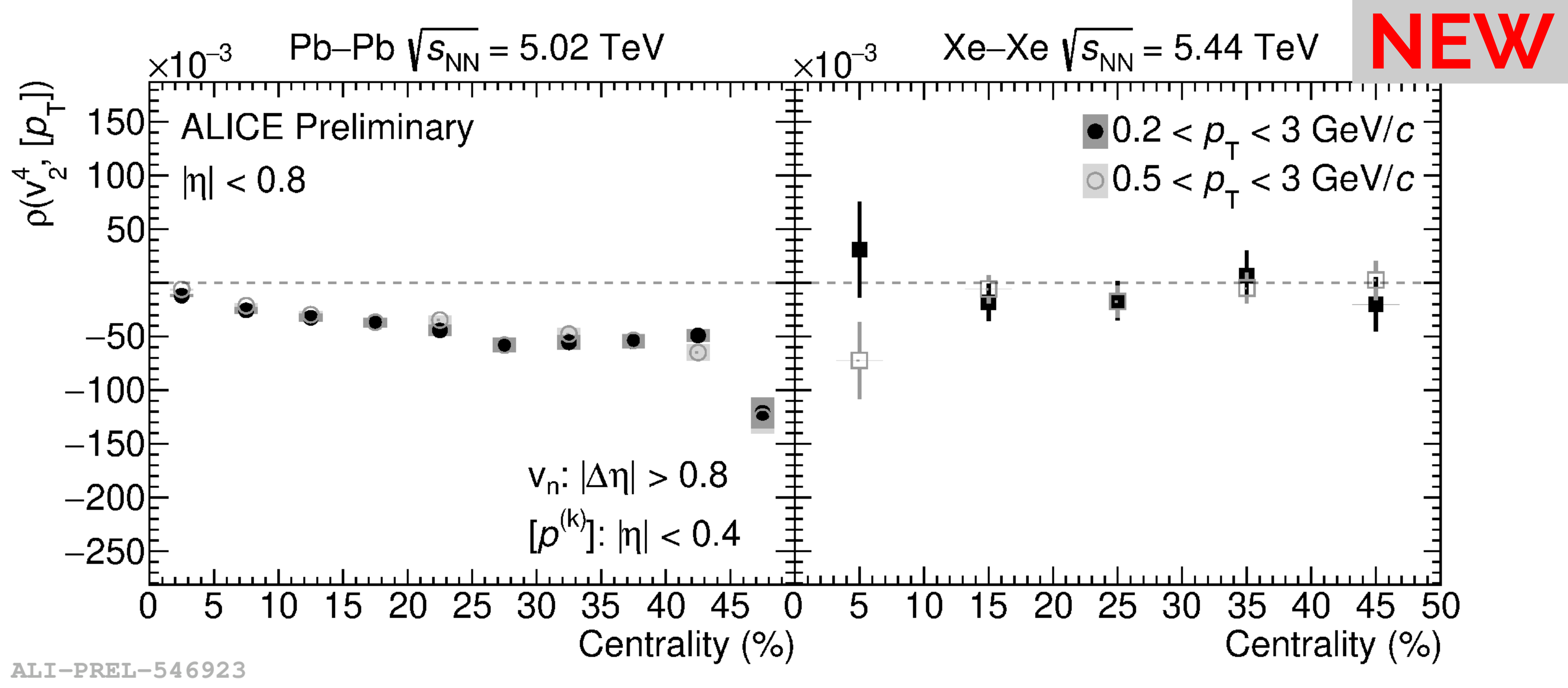
Extending to higher orders in v_n

- Negative correlation between v_2^4 and $[p_{\mathrm{T}}]$ in Pb–Pb collisions.
- Consistent with zero in Xe–Xe collisions.



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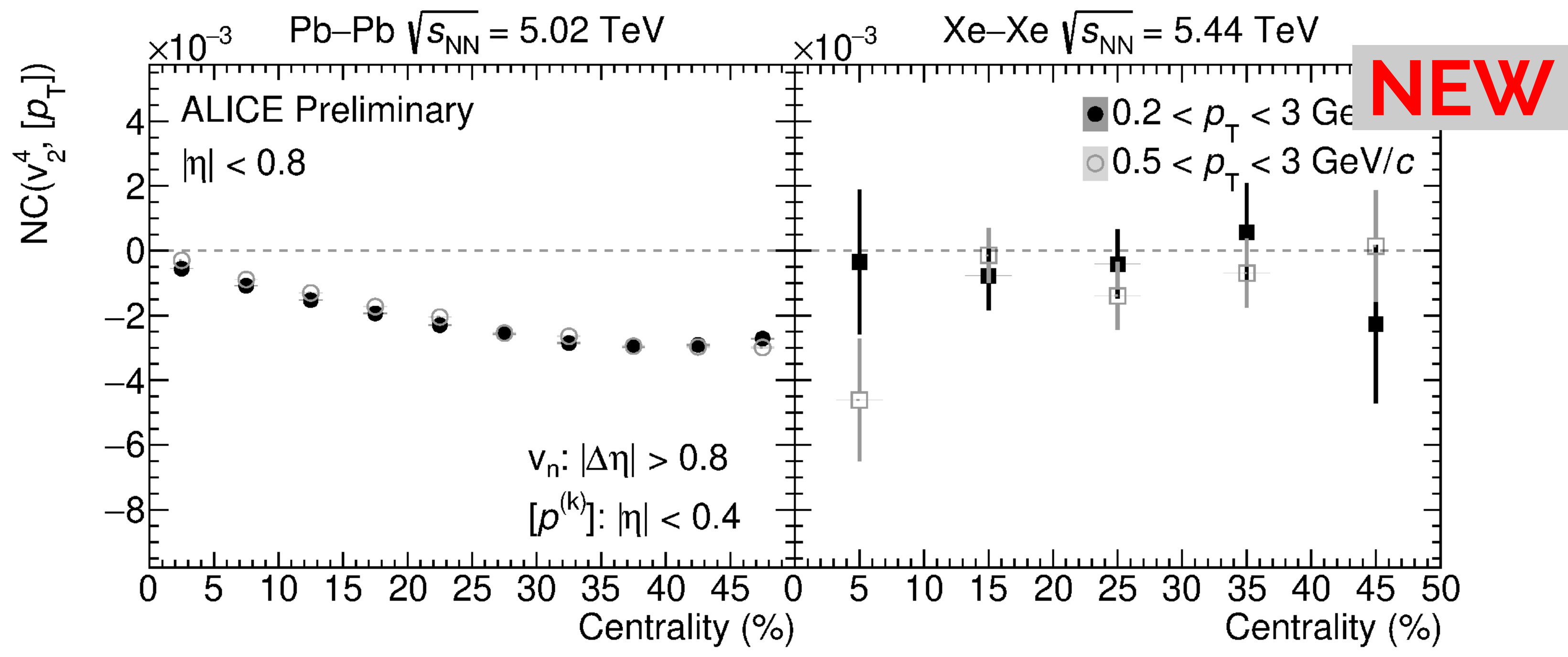

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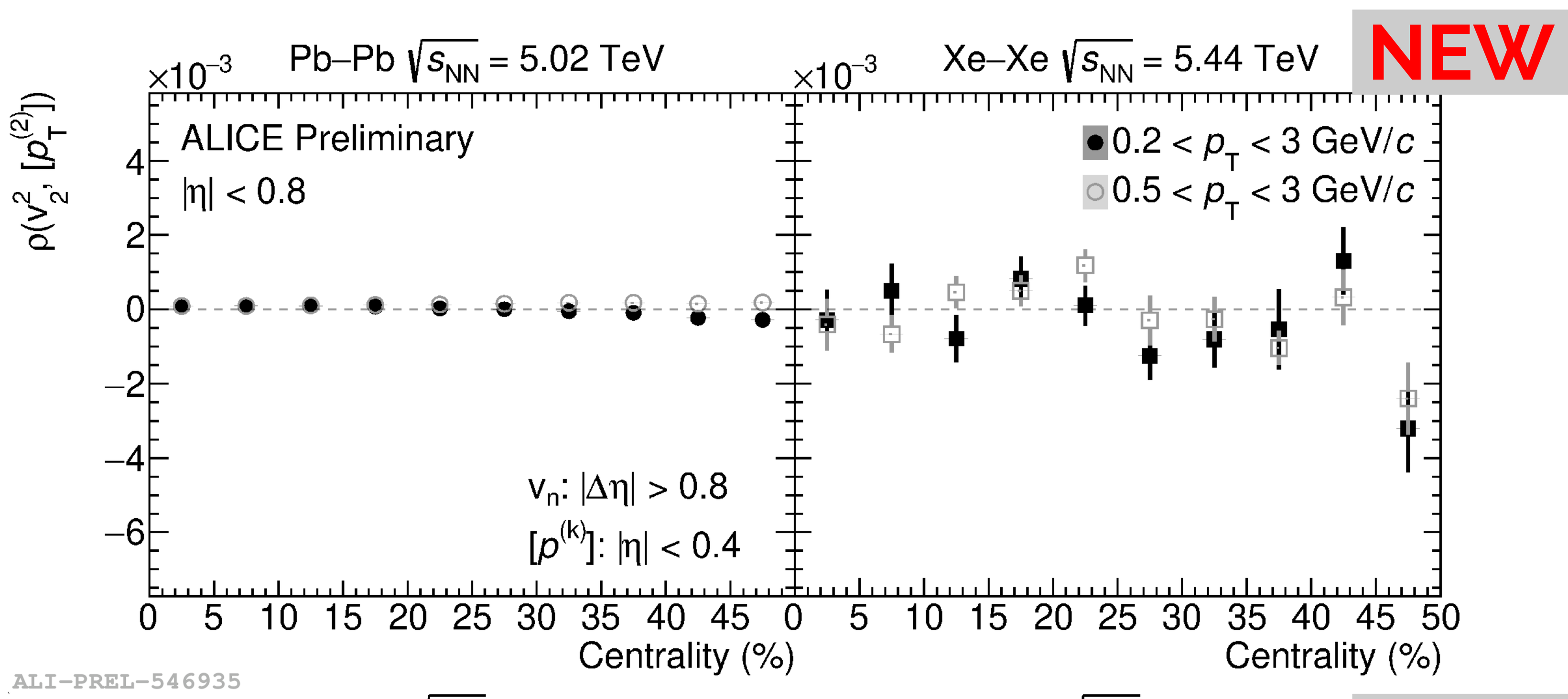
Extending to higher orders in p_{T}

- Negative or positive correlation between v_2^2 and $[p_{\mathrm{T}}^{(2)}]$ in Pb–Pb → depends on lower p_{T} cut.
- Measurements in Xe–Xe fluctuate around zero.



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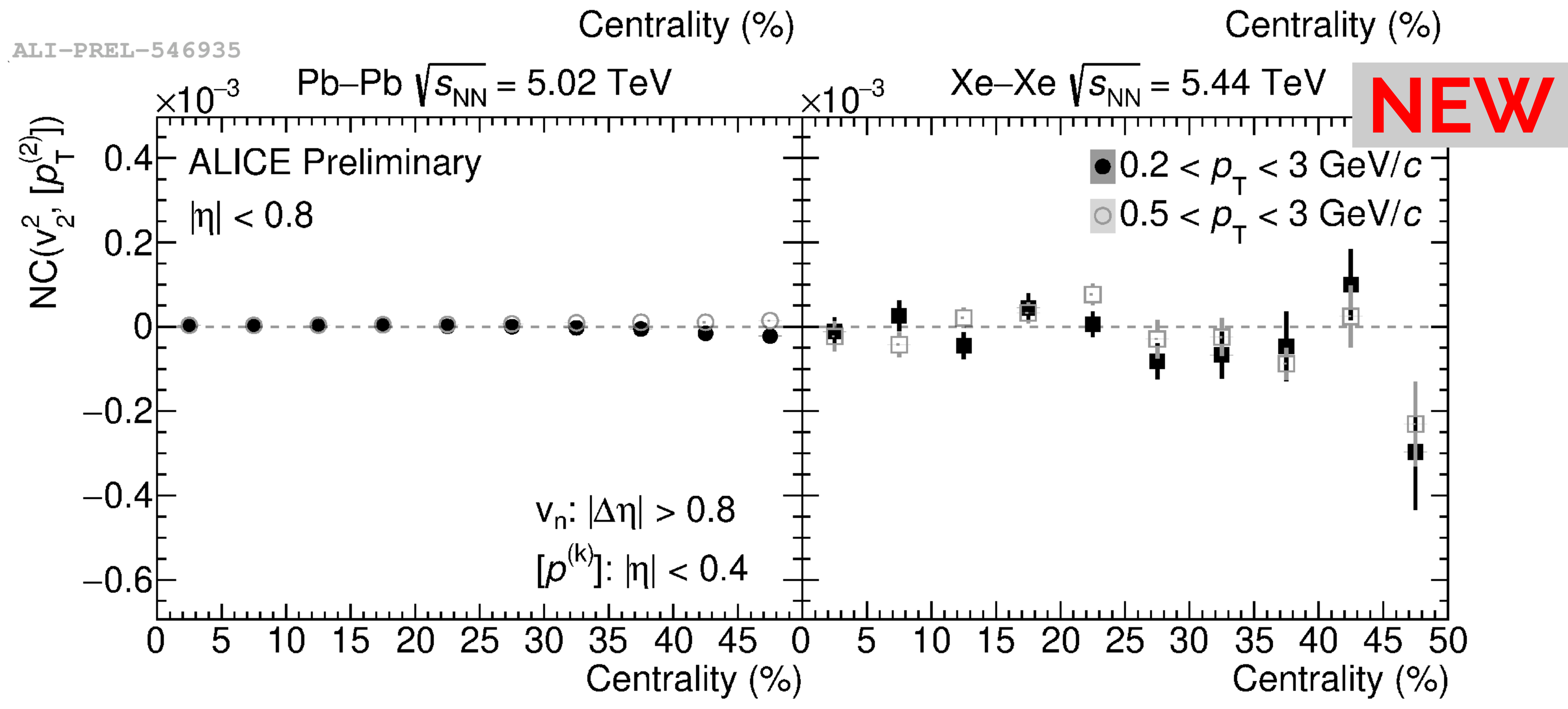

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- The full understanding of the higher-order cumulants awaits input from state-of-the-art theoretical models with different initial state structures [3].

Summary

- **Nuclear deformation:** The ratio of $\rho(v_2^2,[p_{\mathrm{T}}])$ reveals a triaxial structure of ^{129}Xe.
- **First** measurements of higher-order correlations between anisotropic flow and transverse momentum.
- **Nucleon width:** $\rho(v_n^2,[p_{\mathrm{T}}])$ highly sensitive to nucleon width ω. Higher-order may provide crucial constraints for Bayesian parameter estimation for heavy-ion models.

References

[1] Giuliano Giacalone, Fernando G. Gardim, Jacquelyn Noronha-Hostler, and Jean-Yves Ollitrault. *Phys. Rev. C*, 103(2):024909, 2021.

[2] H. Niemi, G. S. Denicol, H. Holopainen, and P. Huovinen. *Phys. Rev.*, C87(5):054901, 2013.

[3] Giuliano Giacalone, Emil Gorm Nielsen, and You Zhou. *In preparation.*