New advancements in symmetry plane correlations and multiharmonic fluctuations in heavy-ion collisions with ALICE

Marcel Lesch [1] and Cindy Mordasini [2]
on behalf of the ALICE Collaboration

[1] Technical University of Munich
[2] University of Jyväskylä

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JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

ALICE

European Research Council
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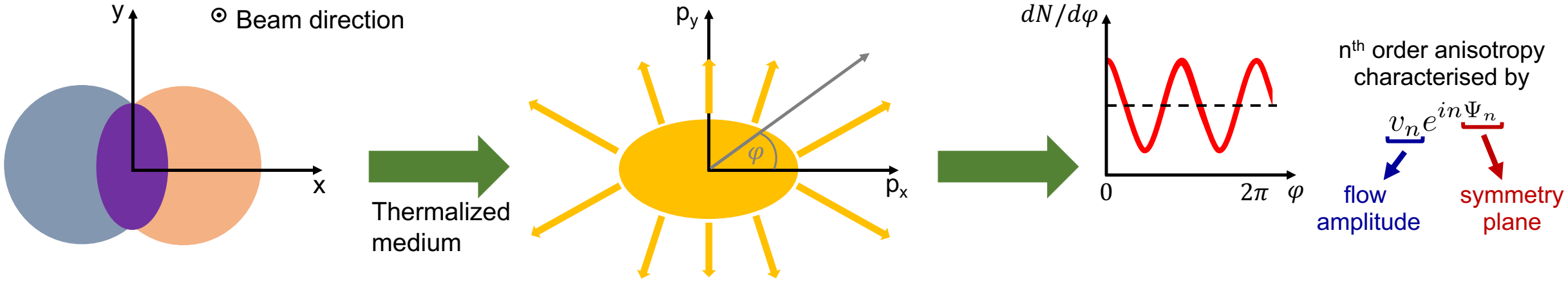
QGP studies with anisotropic flow



- Anisotropic Flow: Transition from anisotropy in coordinate space to anisotropy in momentum space via thermalized medium
- Final state anisotropies characterised by v_n and Ψ_n contain information on initial state and QGP
- Correlations between flow degrees of freedom important to improve our knowledge of the QGP

  → Such measurements present useful input for Bayesian analyses of heavy-ion collisions
- In this poster:
  - Symmetry plane correlations (SPC)
  - Asymmetric cumulants (AC) for different moments of flow amplitudes
  - Comparisons to state-of-the-art model tuning of T$_R$ENTo + iEBE-VISHNU for SPC and AC

J. E. Bernhard, J. S. Moreland, and S. A. Bass, Nature Phys. 15 no. 11, (2019) 1113–1117

Gaussian Estimator - a new experimental technique for SPC

- Previous work: **Scalar Product (SP) Method**

  STAR Collaboration. PRC 66, 034904, 2002

  R. S. Bhalerao, J.-Y. Ollitrault, S. Pal. PRC 88, 024909, 2013

- Example:

$$\langle \cos[4(\Psi_4 - \Psi_2)] \rangle_{\mathrm{SP}} = \frac{\langle v_2^2 v_4 \cos[4(\Psi_4 - \Psi_2)] \rangle}{\sqrt{\langle v_2^4 \rangle \langle v_4^2 \rangle}}$$

→ Neglects correlations between flow amplitudes v_n

- New: **Gaussian Estimator (GE)**

  A. Bilandzic, ML, S. F. Taghavi: "New estimator for symmetry plane correlations in anisotropic flow analyses", PRC 102, 024910 – 2020

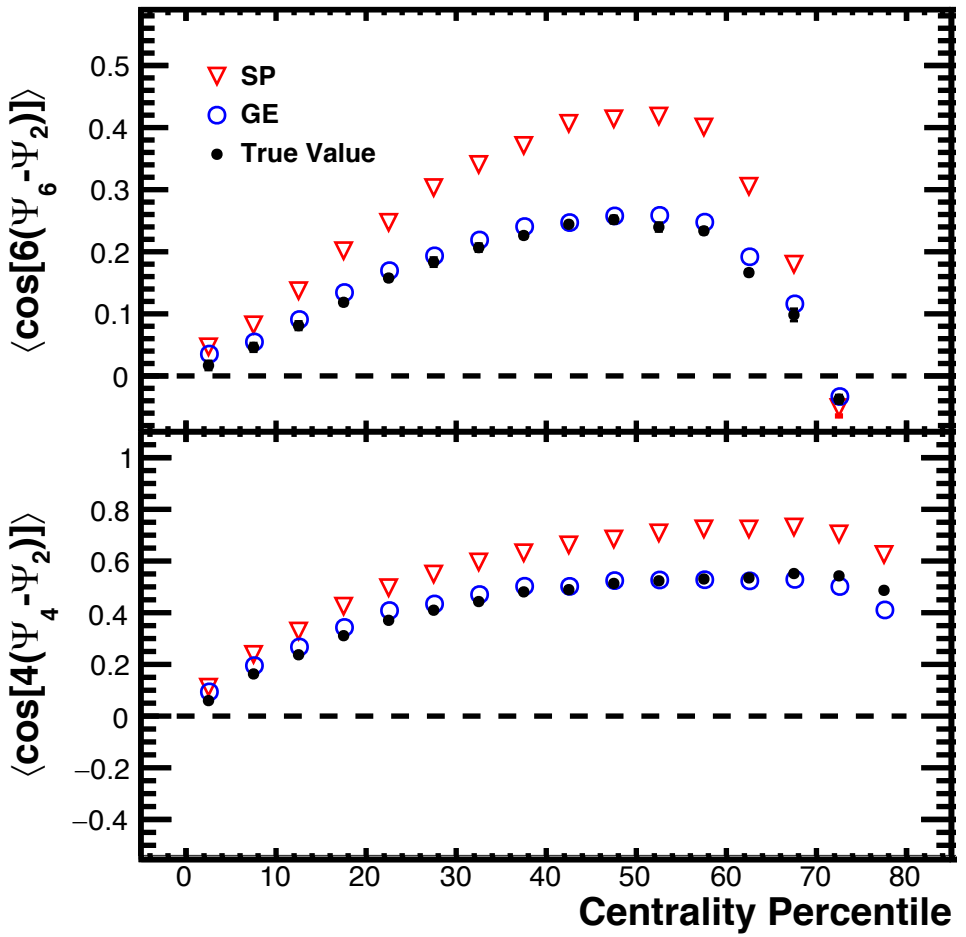
- Example:

$$\langle \cos[4(\Psi_4 - \Psi_2)] \rangle_{\mathrm{GE}} = \sqrt{\frac{\pi}{4}} \frac{\langle v_2^2 v_4 \cos[4(\Psi_4 - \Psi_2)] \rangle}{\sqrt{\langle v_2^4 v_4^2 \rangle}}$$

→ Not sensitive to correlations between flow amplitudes

→ Overcomes main bias of previous SPC estimators

Comparison of GE to SP and "true" value in iEBE-VISHNU (Pb−Pb $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV)



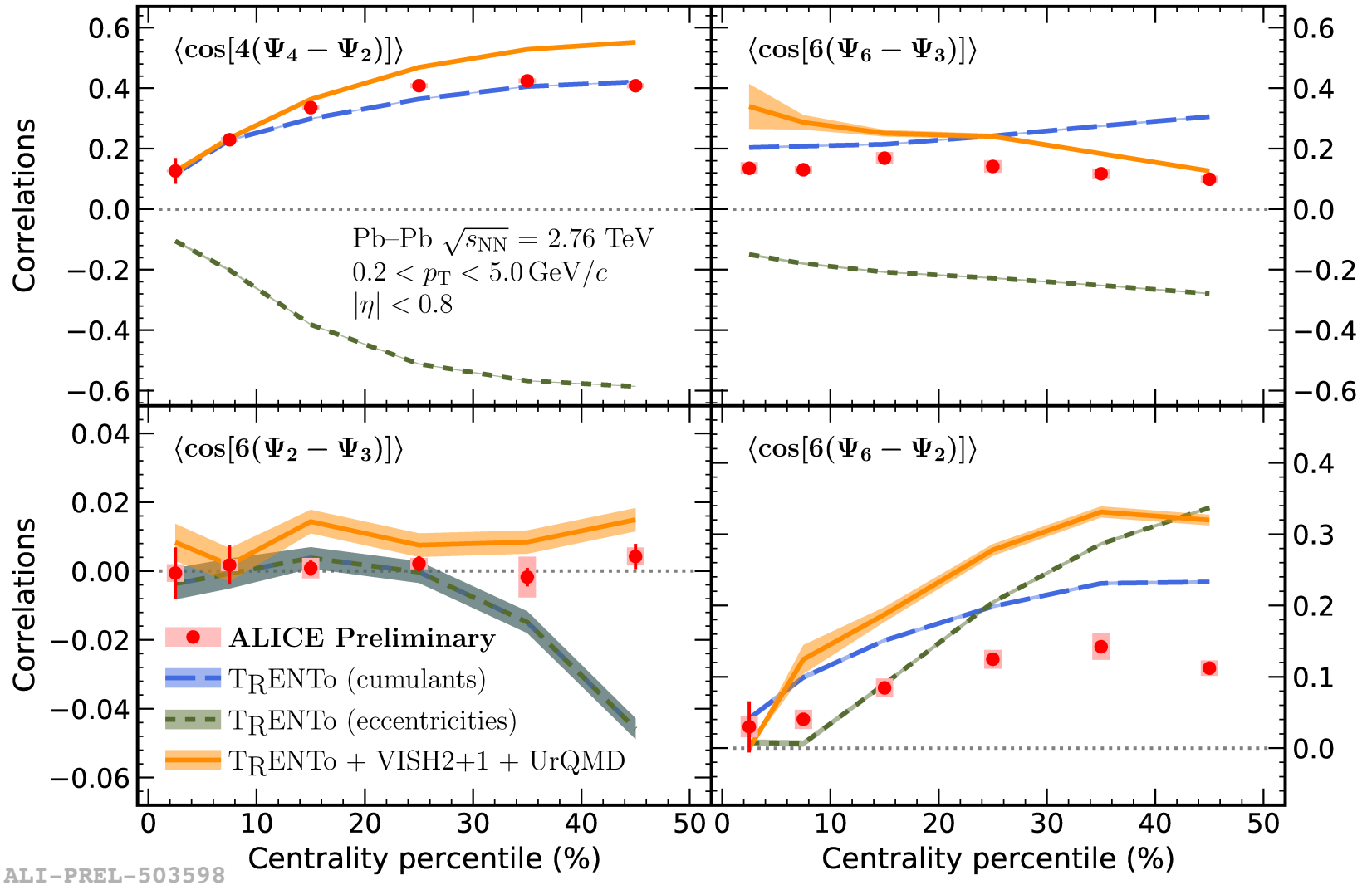
A. Bilandzic, ML, S. F. Taghavi: "New estimator for symmetry plane correlations in anisotropic flow analyses", PRC 102, 024910 – 2020

Correlations between two symmetry planes

- Measurements of SPC via GE in Pb−Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV with ALICE

New

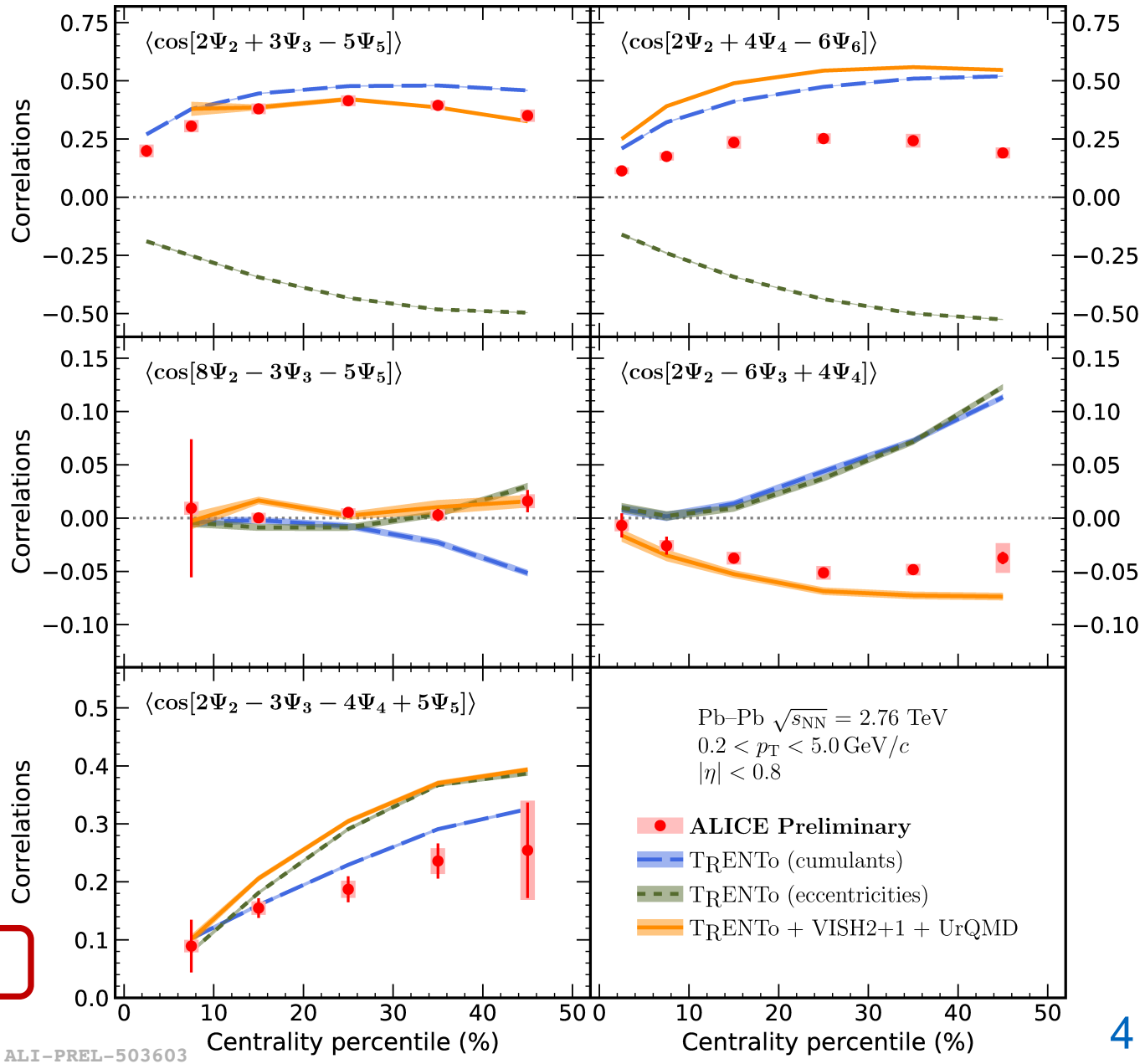
- Ψ_2 and Ψ_4 correlated in final state
  - Data only well reproduced in the linear response regime
- Ψ_2 and Ψ_3 uncorrelated in final state
  - Correlations in initial state lost/suppressed during hydro-dynamic evolution
- Large deviation of the model from data for SPC involving Ψ_6



Correlations between three and four symmetry planes

- Two combinations for Ψ_2, Ψ_3 and Ψ_5 with different final-state signals
  - Reason: contribution of different initial state correlations
- Large deviation of the model from measurements in case of Ψ_2, Ψ_4 and Ψ_6
- Negative final-state correlation for Ψ_2, Ψ_3, Ψ_4
  - Sign change during hydrodynamic evolution from initial to final state
- First experimental measurement of correlation between four symmetry planes $\Psi_2, \Psi_3, \Psi_4, \Psi_5$

New



Correlations between different moments of v_m and v_n

- Measurements of AC in Pb−Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV with ALICE

$$\mathrm{AC}_{2,1}(m,n) \equiv \langle (v_m^2)^2 v_n^2 \rangle_c = \langle v_m^4 v_n^2 \rangle_c = \langle v_m^4 v_n^2 \rangle - \langle v_m^4 \rangle \langle v_n^2 \rangle - 2\langle v_m^2 v_n^2 \rangle \langle v_m^2 \rangle + 2\langle v_m^2 \rangle^2 \langle v_n^2 \rangle$$

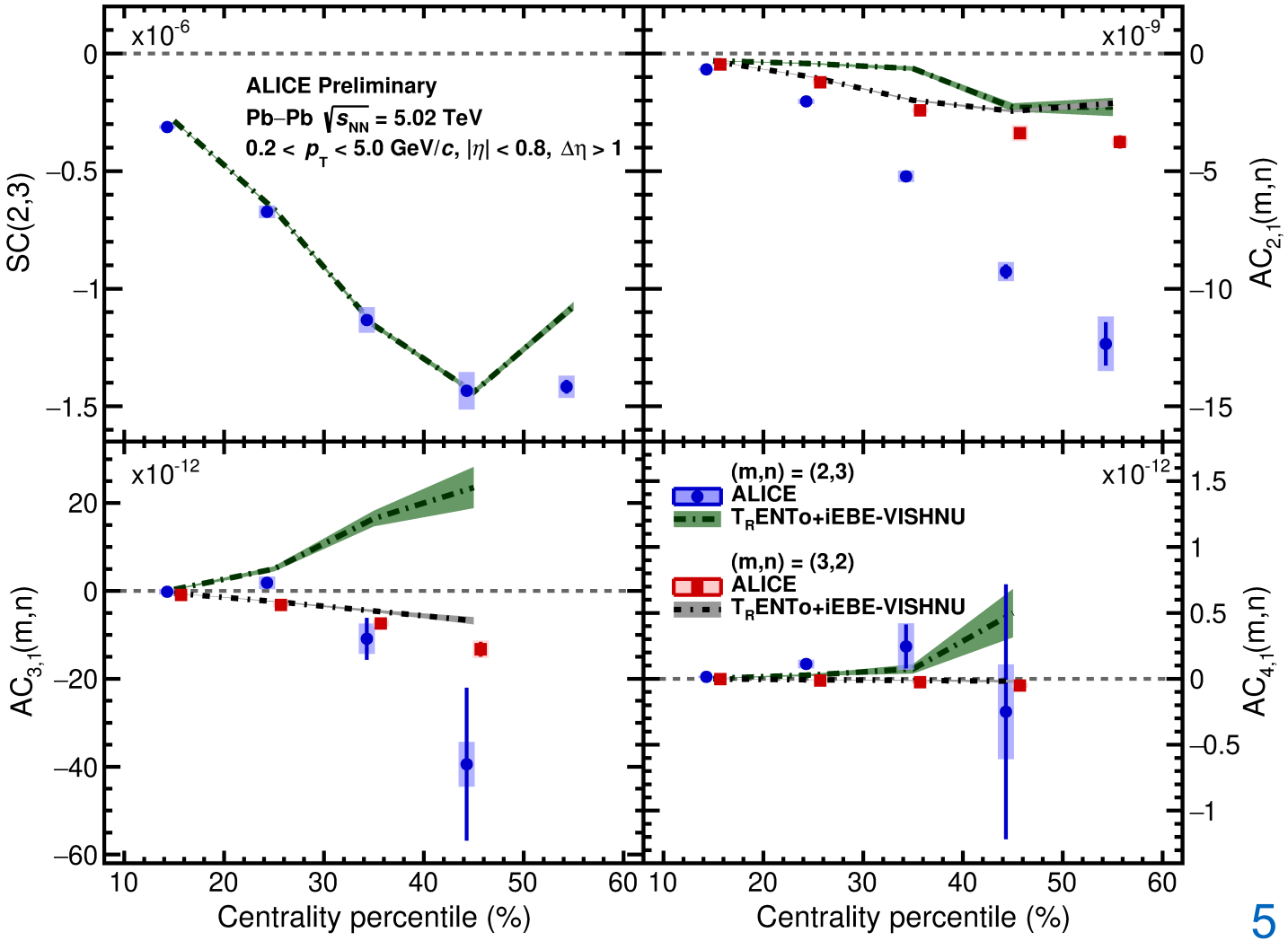
New

- General expression of $\mathrm{AC}_{a,1}$(m,n)

$$\mathrm{AC}_{a,1}(m,n) \equiv \langle (v_m^2)^a v_n^2 \rangle_c$$

A. Bilandzic, M. Lesch, CM, S.F. Taghavi, PRC **105**, 024912 (2022)

- Decreasing magnitude of $\mathrm{AC}_{a,1}$ for increasing value of index *a*
- Good agreement between the data and the model for $\mathrm{AC}_{a,1}$(3,2), not for $\mathrm{AC}_{a,1}$(2,3)
  - Potential input for Bayesian analyses
- Independent input on nonlinear response from deviation between $\mathrm{AC}_{a,1}$(2,3) and $\mathrm{AC}_{a,1}$(3,2)



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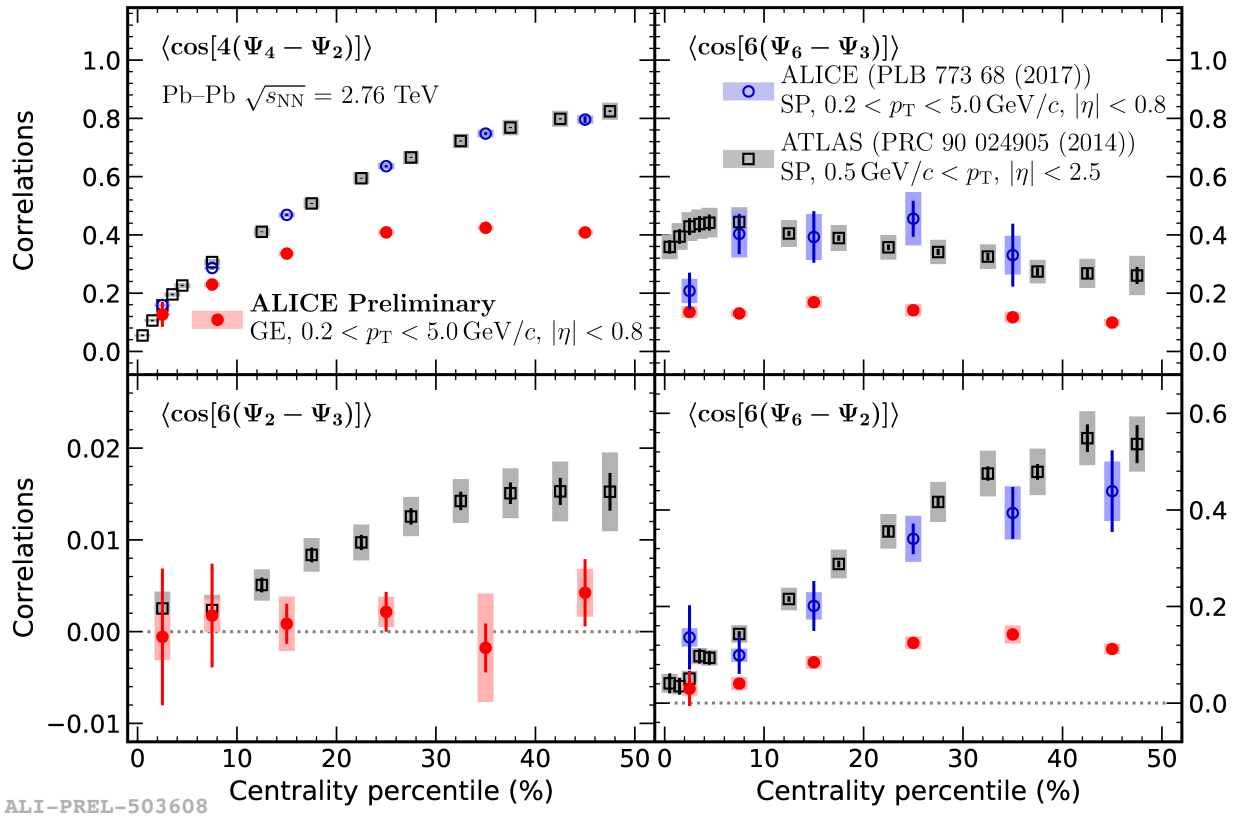
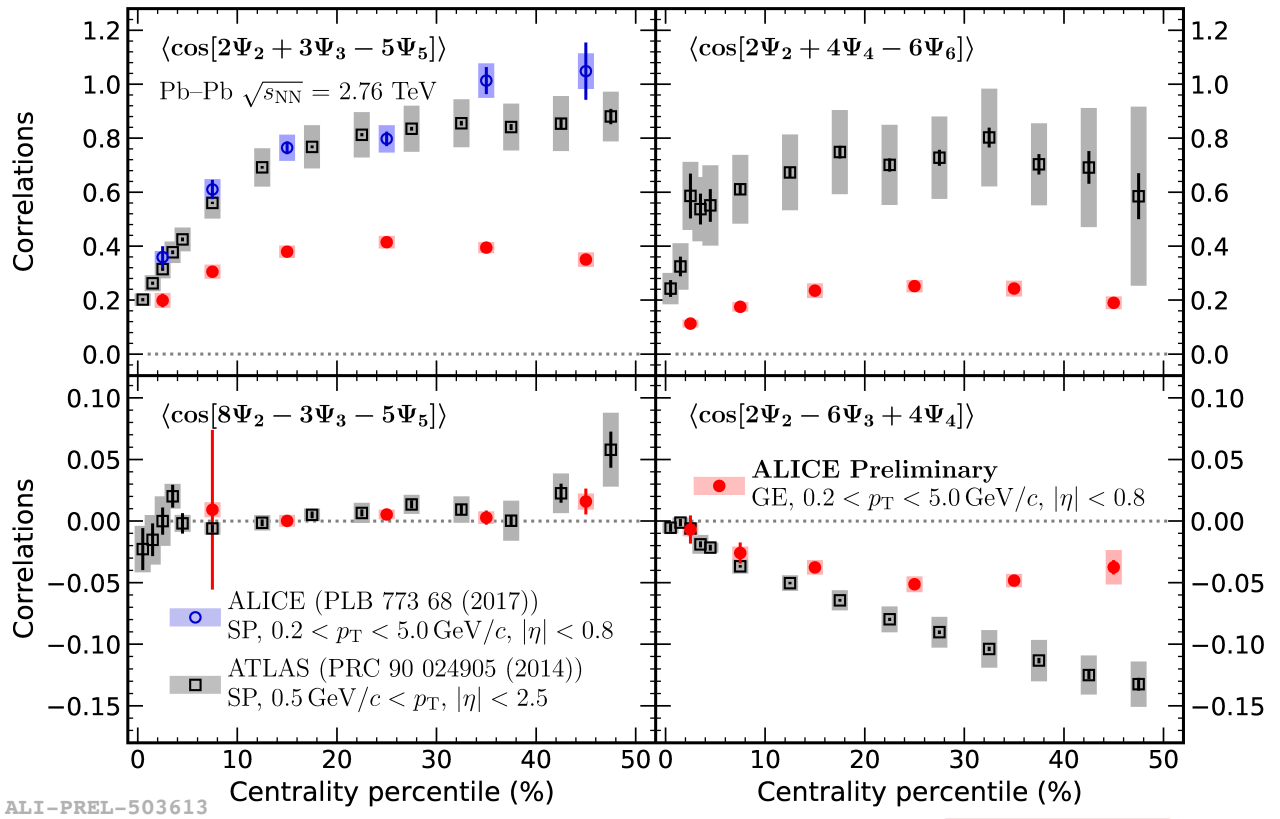
Backup

Comparison of experimental results from GE and SP





New

- Results of SPC via GE lead to significantly smaller values than SP method
  → Different interpretation of SPC signal possible, for example:
- Correlation between Ψ_2 and Ψ_3 small but non-zero in SP → correlated symmetry planes
- Result of GE compatible with zero in all centrality bins → uncorrelated symmetry planes

Correlations between different moments of v_m and v_n

- Measurement of NAC in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV with ALICE

  A. Bilandzic, M. Lesch, CM, S.F. Taghavi, PRC **105**, 024912 (2022)

$$\mathrm{NAC}_{a,1}(m,n) = \frac{\mathrm{AC}_{a,1}(m,n)}{\langle v_m^2 \rangle^a \langle v_n^2 \rangle}$$

- Normalisation removes the magnitude dependence of AC on flow amplitudes
- Good agreement of the model for $\mathrm{NAC}_{a,1}(3,2)$, not for $\mathrm{NAC}_{a,1}(2,3)$
  - Potential input for Bayesian analyses
- Independent input on nonlinear response from deviation between $\mathrm{NAC}_{a,1}(2,3)$ and $\mathrm{NAC}_{a,1}(3,2)$

New