Probing flow fluctuation through factorization-breaking coefficients in heavy-ion collision

NATIONAL SCIENCE CENTRE POLAND

Rupam Samanta, Piotr Bożek

Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Krakow, Poland

AGH

Motivation

- Asymmetry in the source distribution at the initial state $\longrightarrow$ hydrodynamic evolution of the dense medium (QGP) $\longrightarrow$ momentum anisotropy of the particles at the final state.

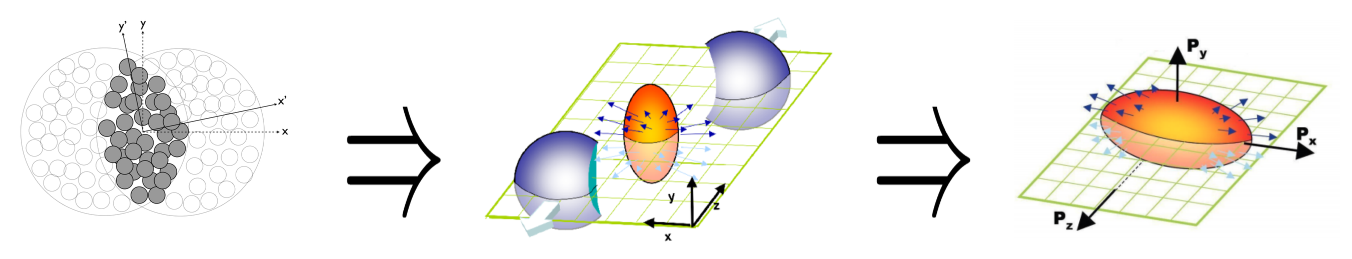

Fig. 1: Asymmetric source in initial state leading to momentum anisotropy at final state.

- The azimuthal anisotropy in momentum space is characterized by the fourier expansion,

$$\frac{dN}{dpd\phi} = \frac{dN}{2\pi dp}\left(1 + 2\sum_{n=1}^{\infty} V_n(p) e^{in\phi}\right)$$

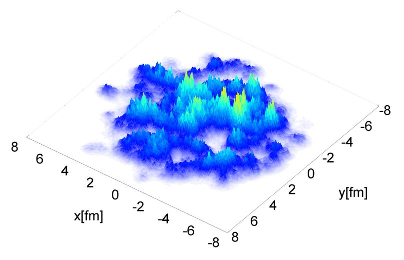

Fig. 2: Initial state fluctuation

- Harmonic flow vector,

$$V_n(p) = |V_n(p)| e^{in\Psi_n(p)} \; ; \quad |V_n(p)| \to \text{flow magnitude and } \Psi_n(p) \to \text{flow angle}$$

.

- Event-by-event fluctuation of initial state $\longrightarrow$ event-by-event fluctuation of V_n's $\longrightarrow$ **decorrelations between the flow vectors** in two momentum bins$\longrightarrow$ **includes both flow magnitude and flow angle decorrelations**.
- Could be studied in models and measured in experiments by constructing correlation coefficients between the **squares of the flow**, known as **"factorization-breaking coefficients."**

Model

- Flow magnitude and flow angle decorrelation could not be measured in the 1st moment $\longrightarrow$ correlation in 2nd moment or between the squares of the flow.
- To ease the measurement difficulty, factorization-breaking coefficients could be constructed between $V_n(p)$ (momentum dependent flow) and V_n (momentum averaged flow).
- The **flow vector square and flow magnitude square factorization coefficients** are constructed as,

$$r_{n;2}(p) = \frac{\langle V_n^2 V_n^*(p)^2\rangle}{\sqrt{\langle |V_n|^4\rangle \, \langle |V_n(p)|^4\rangle}} \quad \text{and} \quad r_n^{v_n^2}(p) = \frac{\langle |V_n|^2 |V_n(p)|^2\rangle}{\sqrt{\langle |V_n|^4\rangle \, \langle |V_n(p)|^4\rangle}}$$

- The **flow angle decorrelation** is obtained from the ratio of the flow vector and flow magnitude factorization coefficients,

$$F_n(p) = \frac{\langle V_n^2 V_n^*(p)^2\rangle}{\langle |V_n|^2 |V_n(p)|^2\rangle} = \frac{\langle |V_n|^2 |V_n(p)|^2 \cos[2n(\Psi_n - \Psi_n(p))]\rangle}{\langle |V_n|^2 |V_n(p)|^2\rangle} \simeq \frac{\langle |V_n|^4 \cos[2n(\Psi_n - \Psi_n(p))]\rangle}{\langle |V_n|^4\rangle}$$

Summary and Outlook

- Flow fluctuations $\to$ **flow decorrelation in transverse momentum (p).**
- Extraction of flow angle decorrelation $\to$ **need to measure 2nd moment of flow decorrelation between the squares of the flow.**
- One of the flows momentum dependent $V_n(p)$ and other flow momentum averaged V_n $\longrightarrow$ **experimentally preferable.**
- Flow-angle decorrelation = $\frac{(\text{Flow vec})^2 - (\text{Flow vec})^2 \text{ factorization-breaking coefficients}}{(\text{Flow mag})^2 - (\text{Flow mag})^2 \text{ factorization-breaking coefficients}}$
- We measure the angle decorrelation :

$$\frac{\langle |V_n|^4 cos[2n(\Delta\Psi)]\rangle}{\langle |V_n|^4\rangle} \neq \langle cos[2n(\Delta\Psi)]\rangle$$

- **Only the magnitude weighted flow angle decorrlation could be measured**, **the simple angle correlation (green line) gives completely different results.**

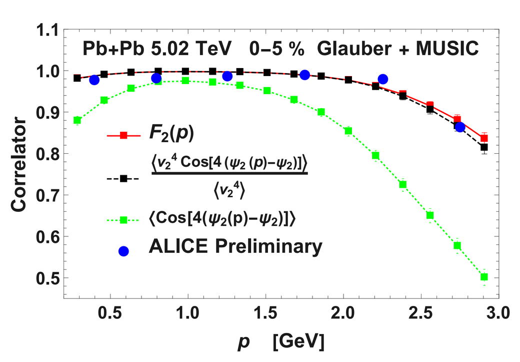

Fig. 3: Correct description of flow angle decorrelation

- Similar **correlations between mixed-flow** $\longrightarrow$ **non-linear hydro-response of the medium**$\longrightarrow$ put constraints on the models.
- Future study : momentum dependent correlations for the **deformed nuclei collisions** e.g. **U+U collision, isobar collisions** etc. $\longrightarrow$ **effect of the deformed nuclear structure on the correlation coefficients.**

Results

Factorization-breaking coefficients

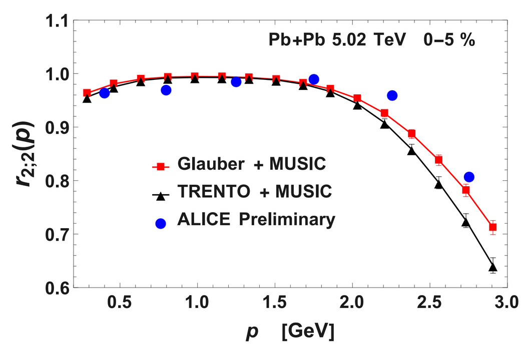

Fig. 4: Flow vector square factorization coefficient

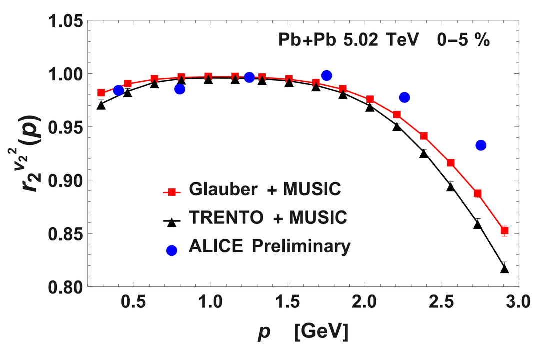

Fig. 5: Flow magnitude square factorization coefficient

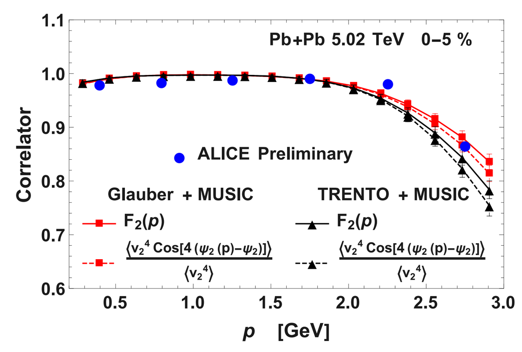

Fig. 6: Flow angle decorrelation

- For the central collision (0-5 %) **our model results reproduce the data** for the elliptic flow.
- The flow magnitude and the flow angle decorrelation both are **approximately one half** of the flow vector decorrelation:

$$[1 - r_n^{v_n^2}(p)] \simeq \tfrac{1}{2}[1 - r_{n;2}(p)]$$

- For semi-peripheral collision (30-40 %) our model results do not really reproduce the data ; the data go slightly above 1 at high p $\longrightarrow$ may indicate a significant **non-flow** contribution.

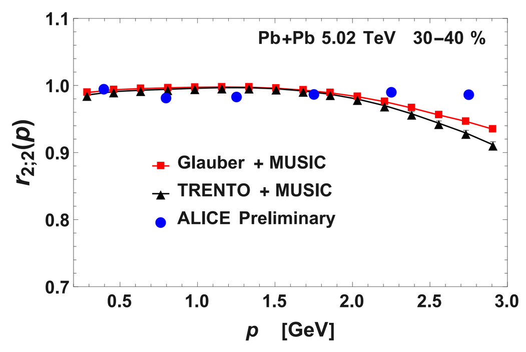

Fig. 7: Flow vector square factorization coefficient

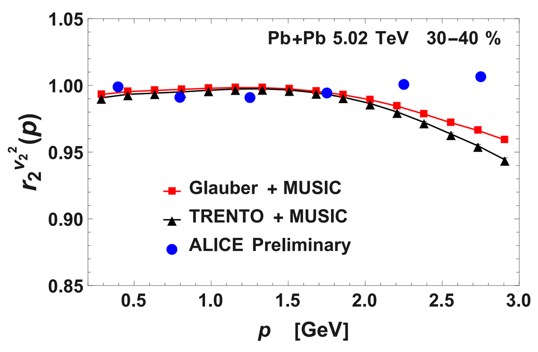

Fig. 8: Flow magnitude square factorization coefficient

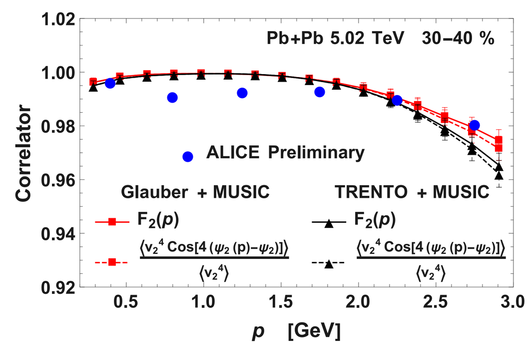

Fig. 9: Flow angle decorrelation

Mixed-flow correlations

- Similar momentum dependent correlation coefficients between the flow harmonics of different order e.g V_2^2-$V_4(p)$ and V_2V_3-$V_5(p)$ correlation:

$$\frac{\langle V_2^2 V_4^*(p)\rangle}{\sqrt{\langle |V_2|^4\rangle \, \langle |V_4(p)|^2\rangle}} \quad \text{and} \quad \frac{\langle V_2 V_3 V_5^*(p)\rangle}{\sqrt{\langle |V_2|^2 |V_3|^2\rangle \, \langle |V_5(p)|^2\rangle}}$$

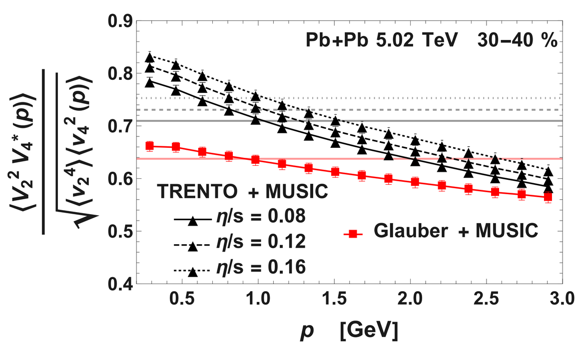

Fig. 10: V_2^2-$V_4(p)$ correlation

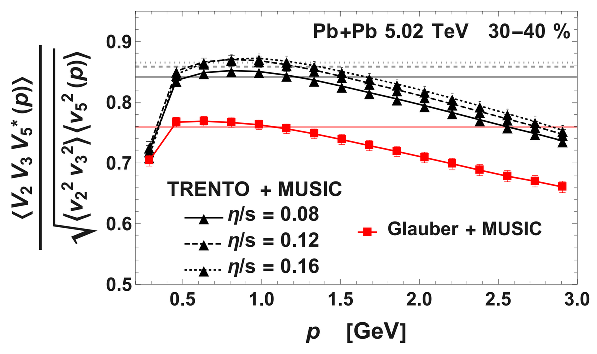

Fig. 11: V_2V_3-$V_5(p)$ correlation

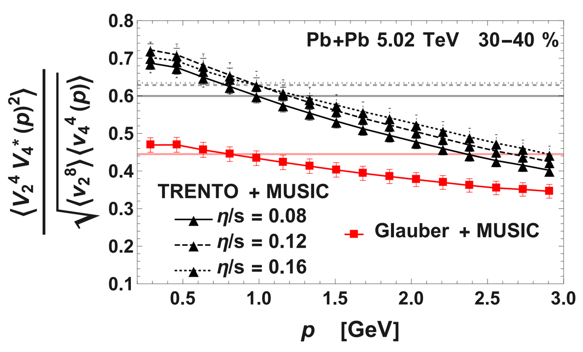

Fig. 12: (Flow vector)^4-(Flow vector)^2

- The horizontal lines denote the corresponding correlation between the momentum averaged flows e.g. $V_2^2 - V_4$ $\longrightarrow$ baseline of the plots.
- Such mixed-flow correlations provide **non-linear hydro-response of the QGP medium.**
- To measure the magnitude and angle decorrelation $\longrightarrow$ need to calculate 2nd moments: V_2^4-$V_4(p)^2$ correlations.

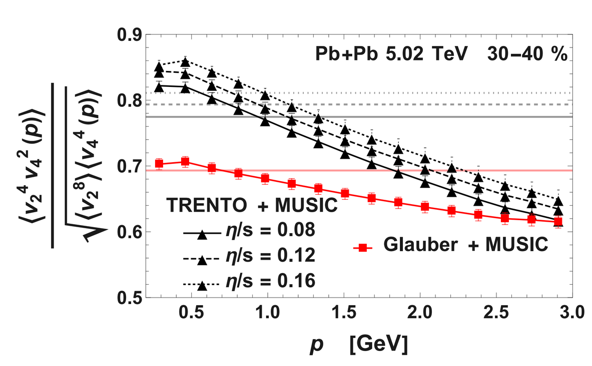

Fig. 13: (Flow magnitude)^4-(Flow magnitude)^2

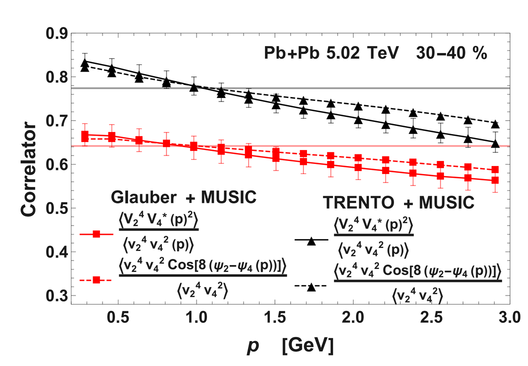

Fig. 14: V_2^4-$V_4(p)^2$ flow angle decorrelation

Acknowledgments

This research and the participation to this conference was supported by the AGH University of Science and Technology and by the Polish National Science Centre (NCN) grant: 2019/35/O/ST2/00357. We thank the organizers for successfully organizing this conference and giving us the opportunity to present our results through this poster.

References

[1] Fernando G. Gardim et al. "Breaking of factorization of two-particle correlations in hydrodynamics". In: *Phys. Rev. C* 87.3 (2013), p. 031901. arXiv: 1211.0989 [nucl-th].

[2] Ulrich Heinz, Zhi Qiu, and Chun Shen. "Fluctuating flow angles and anisotropic flow measurements". In: *Phys. Rev. C* 87.3 (2013), p. 034913. arXiv: 1302.3535 [nucl-th].

[3] Piotr Bożek. "Angle and magnitude decorrelation in the factorization breaking of collective flow". In: *Phys. Rev. C* 98.6 (2018), p. 064906. arXiv: 1808.04248 [nucl-th].

[4] Fernando G. Gardim et al. "Sensitivity of observables to coarse-graining size in heavy-ion collisions". In: *Phys. Rev. C* 97.6 (2018), p. 064919. arXiv: 1712.03912 [nucl-th].

[5] Piotr Bozek and Rupam Samanta. "Factorization breaking for higher moments of harmonic flow". In: *Phys. Rev. C* 105.3 (2022), p. 034904. arXiv: 2109.07781 [nucl-th].

[6] ALICE Collaboration. "Observation of flow angle and flow magnitude fluctuations in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV at the LHC". In: (June 2022). arXiv: 2206.04574 [nucl-ex].

[7] Niseem Magdy. "Measuring differential flow angle fluctuations in relativistic nuclear collisions". In: *Phys. Rev. C* 106.4 (2022), p. 044911. arXiv: 2207.04530 [nucl-th].