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Investigating the correlations of flow harmonics in 2.76A TeV Pb–Pb collisions

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Abstract. This proceeding briefly summarizes our recent investigations on the correlations of flow harmonics in 2.76A TeV Pb–Pb collisions with viscous hydrodynamics `VISH2+1`. We calculated both the symmetric cumulants $SC^v(m,n)$ and the normalized symmetric cumulants $NSC^v(m,n)$, and found v_2 and v_4, v_2 and v_5, v_3 and v_5 are correlated, v_2 and v_3, v_3 and v_4 are anti-correlated. We also found $NSC^v(3,2)$ are insensitive to the QGP viscosity, which are mainly determined by the initial conditions.

1. Introduction

The ultra-relativistic heavy-ion collision programs at RHIC and LHC have been utilized to produce extreme conditions to create and study the strongly interacting Quark-Gluon Plasma (QGP), a deconfined state of quarks and gluons. One of the observables to probe the properties of the hot QCD matter is the azimuthal anisotropy in the momentum distribution of produced particles. The anisotropic flow coefficients V_n are generally defined through a Fourier decomposition of the emitted particle distribution as a function of the azimuthal angle φ, $P(\varphi) = \frac{1}{2\pi}\sum_{n=-\infty}^{+\infty} \overrightarrow{V_n}\, e^{-in\varphi}$ where $\overrightarrow{V_n} = v_n\, e^{in\Psi_n}$. The v_n is the n-th order anisotropic flow harmonics and Ψ_n is the symmetry plane angle. Recently, the correlations between different order $\overrightarrow{V_m}$ and $\overrightarrow{V_n}$ have been investigated both theoretically and experimentally, which not only focus on the correlations of the orientations of different flow-vector Ψ_n [1, 2, 3, 4, 5] but also on the correlations of the magnitudes of different flow-vector v_n [6, 7, 8, 9, 10, 11].

In this proceeding, we will briefly review our recent investigations on the correlations of flow harmonics in 2.76A TeV Pb–Pb collisions using the event-by-event viscous hydrodynamics `VISH2+1` with different initial conditions and the the value of shear viscosity [11].

2. Setup of the calculation

The `VISH2+1` is a (2+1)-d viscous hydrodynamic model to describe the fluid expansion of the QGP with longitudinal boost-invariance [12, 13]. In the following calculations, we use an equation of state (EoS) `s95p-PCE` [14], which matches the partially chemical equilibrium hadron resonance gas at low temperature and the lattice QCD data at high temperature. Three different initial conditions, `MC-Glauber`, `MC-KLN` [15, 16], and `AMPT` [17], are used in our calculations to study the influence of initial conditions on the correlations of flow harmonics. To explore the sensitivity of the QGP shear viscosity, we choose two values of η/s, the specific shear viscosity, for each initial condition. More specifically, η/s = 0.08 and 0.20, for the `MC-Glauber` and `MC-KLN` initial conditions, and η/s =0.08 and 0.16 for the `AMPT` initial conditions were utilised. The hydrodynamic output is converted to final hadron distributions along the freeze-out surface at the temperature $T_{dec} = 120$ MeV via the Cooper-Frye prescription [18, 19]. The initial time of hydrodynamic evolution τ_0 and the normalization factors of the initial entropy density profiles have been tuned to fit the 0-5% centrality data of $dN/d\eta$ and $p_{\rm T}$ spectra of π, K, and p [20]. The bulk viscosity, net baryon density, and the heat conductivity are set to zero to simplify the calculations.

3. Results and discussion

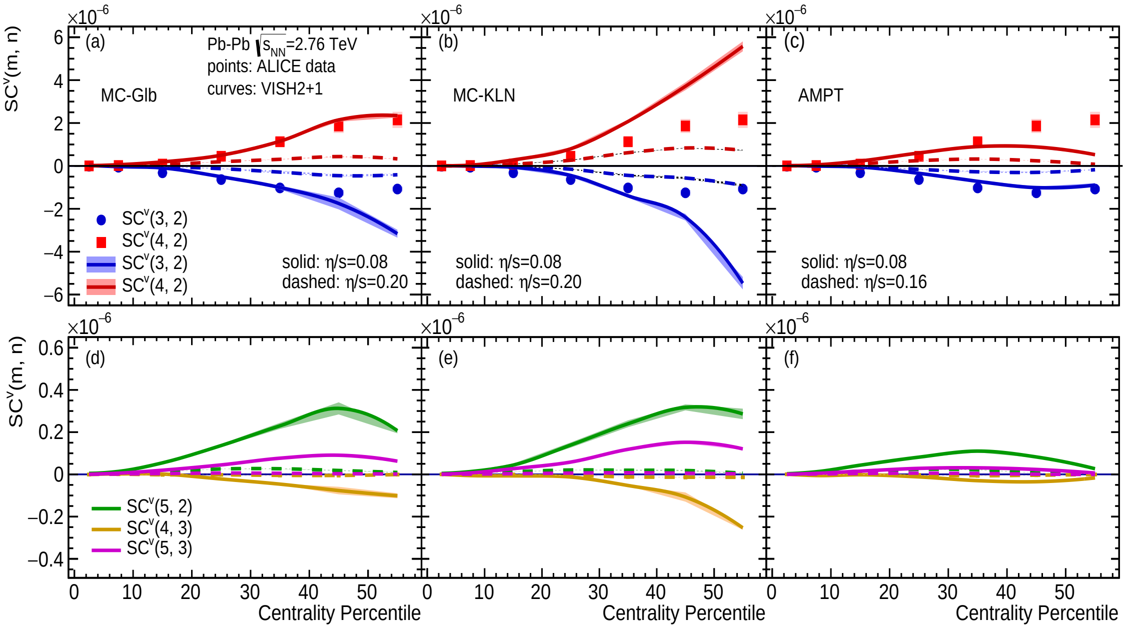

Figure 1. (Color online) Top: Symmetric cumulants $SC^v(3,2)$ and $SC^v(4,2)$ in 2.76A TeV Pb–Pb collisions. The ALICE measurements are taken from [6]. Bottom: Predicted symmetric cumulants $SC^v(5,2)$, $SC^v(5,3)$, and $SC^v(4,3)$ in 2.76A TeV Pb–Pb collisions.

Fig. 1 (top) shows the comparison between our calculations for the symmetric cumulants defined as $SC^v(m,n) = \langle v_m^2\, v_n^2 \rangle - \langle v_m^2 \rangle \langle v_n^2 \rangle$ and the ALICE measurements [6]. We find that, for these initial conditions and different values of η/s, the `VISH2+1` calculations qualitatively capture the centrality dependence of the flow correlations. In particular, even though `VISH2+1` with `AMPT` initial conditions gives good descriptions for the integrated flow v_n ($n \leq 4$) [11], it fails to quantitatively reproduce the magnitude of the measured correlations of flow harmonics. This indicates that the correlations between different flow harmonics are more sensitive to the details of hydrodynamic calculations than the individual v_n coefficients alone.

Similar to the ALICE data [6], our model gives negative $SC^v(3,2)$ and positive $SC^v(4,2)$, which suggest that v_2 and v_3 are anti-correlated, while v_2 and v_4 are correlated. The results reveal that, for a given event, the case with an elliptic flow v_2 larger than the averaged $\langle v_2 \rangle$ enhances the probability of finding a triangular flow v_3 smaller than the averaged $\langle v_3 \rangle$ and the probability of finding a quadrangular flow v_4 larger than the averaged $\langle v_4 \rangle$. The strengths of $SC^v(3,2)$ and $SC^v(4,2)$ are more suppressed with larger η/s for each initial condition, which suggests that both $SC^v(3,2)$ and $SC^v(4,2)$ are strongly influenced by the QGP viscosity. By comparing with the symmetric cumulants of the initial state, $SC^\varepsilon(m,n)$ in Ref. [11], we observe that the signs of $SC^v(3,2)$ and $SC^v(4,2)$ are determined by the signs of $SC^\varepsilon(3,2)$ and $SC^\varepsilon(4,3)$, respectively.

Figure 1 (bottom) presents our predictions for the centrality dependent $SC^v(m,n)$ with $(m,n) = (5,2)$, $(5,3)$, and $(4,3)$. We observe that, for each initial condition, the hydrodynamical calculations gives positive values for $SC^v(5,2)$ and $SC^v(5,3)$, and negative values for $SC^v(4,3)$. This reveals that v_2 and v_5, v_3 and v_5 are correlated, while v_3 and v_4 are anti-correlated. We also notice that their correlation strengths become weaker with increasing η/s. The signs of $SC^v(5,2)$ and $SC^v(5,3)$ are consistent with their initial state correlators $SC^\varepsilon(5,2)$ and $SC^\varepsilon(5,3)$ shown in Ref. [11]. However, $SC^v(4,3)$ and $SC^\varepsilon(4,3)$ show opposite signs for the `MC-Glauber` and `AMPT` initial conditions [11]. This can be well understood from the proposed relationship of $v_4 e^{i4\Phi} = a_0 \varepsilon_4 e^{i4\Psi_4} + a_1(\varepsilon_2 e^{i2\Psi_2})^2$ [21, 22], where the ε_2^2 term makes the dominant contributions in non-central collisions [23]. As a result, the signs of $SC^v(4,3)$ are affected by the correlation between ε_2 and ε_3 and the correlation between ε_3 and ε_4 rather than the correlation between ε_3 and ε_4 alone.

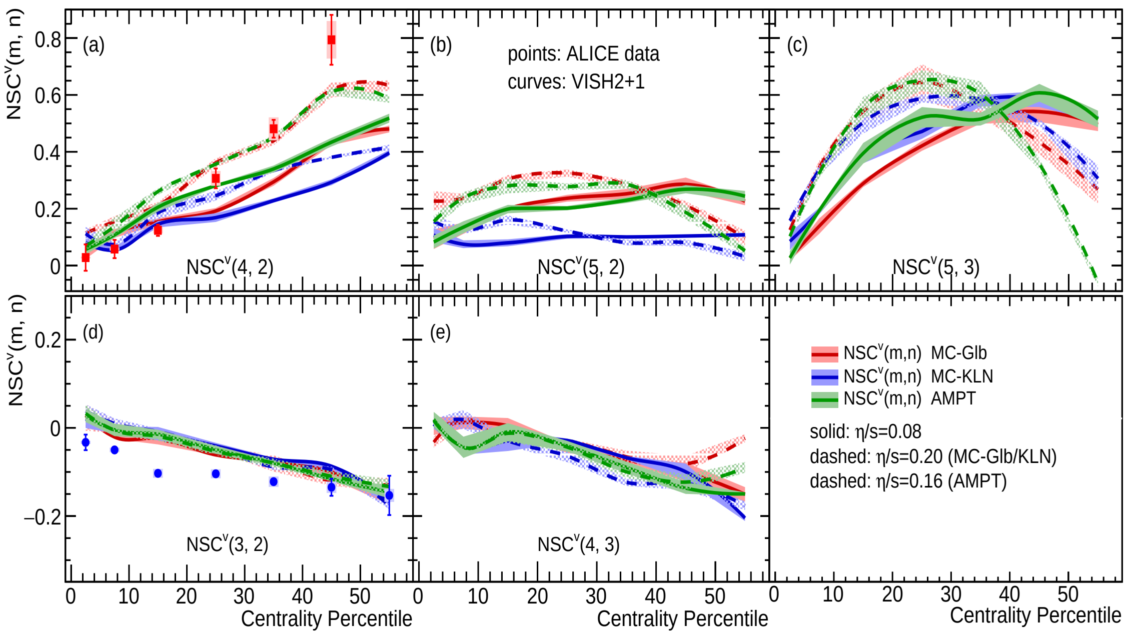

Figure 2. (Color online) Normalized symmetric cumulants $NSC^v(m,n)$ and normalized symmetric cumulants of the initial state $NSC^\varepsilon(m,n)$ in 2.76A TeV Pb–Pb collisions.

Figure 2 shows the normalized correlator of flow harmonics, which are defined as $NSC^v(m,n) = SC^v(m,n)/\langle v_m^2 \rangle \langle v_n^2 \rangle$. We find that $NSC^v(4,2)$, $NSC^v(5,2)$, and $NSC^v(5,3)$ are sensitive to both initial conditions and η/s. In Ref. [11], we found that their corresponding correlator for the initial state, $NSC^\varepsilon(m,n) = SC^\varepsilon(m,n)/\langle \varepsilon_m^2 \rangle \langle \varepsilon_n^2 \rangle$, are separated for different initial conditions. It can be seen that the NSC(4,2) captures the general centrality dependence of the measured points for `AMPT` initial conditions and $\eta/s = 0.16$ and for `MC-Glauber` initial conditions and $\eta/s = 0.2$. This indicates that the normalized symmetric cumulants can be used to constrain the QGP viscosity for different initial conditions. In addition, the $NSC^v(3,2)$

describe qualitatively the ALICE measurements fairly well regardless of the choice of initial conditions and values of η/s. Such η/s independent character of $NSC^{v}(3,2)$ can be naturally understood from the widely accepted relation $v_2 \approx k_1\varepsilon_2$ and $v_3 \approx k_2\varepsilon_3$, where k_1 and k_2 are the proportion coefficients. In Ref. [11], we also found that the $NSC^{\varepsilon}(3,2)$ from the three initial conditions used in our calculations also almost overlap from central to semi-central collisions. In contract, although the $NSC^{\varepsilon}(4,3)$ strongly depends on the initial conditions [11], the $NSC^{v}(4,3)$ almost overlap, making it insensitive to the initial conditions used in our calculation.

4. Summary

In summary, we investigated the correlations between flow harmonics in 2.76A TeV Pb–Pb collisions using the event-by-event viscous hydrodynamics `VISH2+1` with `MC-Glauber`, `MC-KLN`, and `AMPT` initial conditions. We found the symmetric cumulants $SC^{v}(m,n)$ are sensitive to both initial conditions and the QGP shear viscosity. The normalized symmetric cumulants $NSC^{v}(3,2)$ are mainly determined by the correlation in the initial state, which are insensitive to the QGP viscosity. In contrast, $NSC^{v}(4,2)$, $NSC^{v}(5,2)$, $NSC^{v}(5,3)$ are sensitive to both initial conditions and η/s. We found that the correlations of flow harmonics are more sensitive to the details of theoretical calculations than the individual flow harmonics. This could be used for further constraint the properties of the QGP.

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References

[1] G. Aad *et al.* [ATLAS Collaboration], Phys. Rev. C **90**, 024905 (2014).
[2] Z. Qiu and U. Heinz, Phys. Lett. B **717**, 261 (2012).
[3] D. Teaney and L. Yan, Nucl. Phys. A **904-905**, 365c (2013).
[4] J. Jia and D. Teaney, Eur. Phys. J. C **73**, 2558 (2013).
[5] H. Niemi, K. J. Eskola and R. Paatelainen, Phys. Rev. C **93**, 024907 (2016).
[6] J. Adam *et al.* [ALICE Collaboration], arXiv:1604.07663 [nucl-ex];
[7] G. Aad *et al.* [ATLAS Collaboration], Phys. Rev. C **92**, 034903 (2015).
[8] H. Niemi, G. S. Denicol, H. Holopainen and P. Huovinen, Phys. Rev. C **87**, 054901 (2013).
[9] G. Giacalone, L. Yan, J. Noronha-Hostler and J. Y. Ollitrault, arXiv:1605.08303 [nucl-th].
[10] J. Qian and U. Heinz, Phys. Rev. C **94**, 024910 (2016)
[11] X. Zhu, Y. Zhou, H. Xu and H. Song, arXiv:1608.05305 [nucl-th].
[12] H. Song and U. Heinz, Phys. Lett. **B658**, 279 (2008); Phys. Rev. C **77**, 064901 (2008); Phys. Rev. C **78**, 024902 (2008); H. Song, Ph.D Thesis, The Ohio State University, August 2009, arXiv:0908.3656 [nucl-th].
[13] C. Shen, Z. Qiu, H. Song, J. Bernhard, S. Bass and U. Heinz, Comput. Phys. Commun. **199**, 61 (2016).
[14] P. Huovinen and P. Petreczky, Nucl. Phys. **A837**, 26 (2010); C. Shen, U. Heinz, P. Huovinen and H. Song, Phys. Rev. C **82**, 054904 (2010).
[15] A. Adil, H. J. Drescher, A. Dumitru, A. Hayashigaki and Y. Nara, Phys. Rev. C **74** 044905 (2006); H. J. Drescher and Y. Nara, *ibid.* **76** 041903 (2007).
[16] T. Hirano and Y. Nara, Phys. Rev. C **79** 064904 (2009); and Nucl. Phys. **A830** 191c (2009).
[17] H. j. Xu, Z. Li and H. Song, Phys. Rev. C **93**, 064905 (2016).
[18] C. Shen, U. Heinz, P. Huovinen and H. Song, Phys. Rev. C **84**, 044903 (2011).
[19] H. Song, S. Bass and U. W. Heinz, Phys. Rev. C **89**, 034919 (2014); X. Zhu, F. Meng, H. Song and Y. X. Liu, Phys. Rev. C **91**, 034904 (2015).
[20] B. Abelev *et al.* [ALICE Collaboration], Phys. Rev. C **88**, 044910 (2013)
[21] F. G. Gardim, F. Grassi, M. Luzum and J. Y. Ollitrault, Phys. Rev. C **85**, 024908 (2012).
[22] D. Teaney and L. Yan, Phys. Rev. C **86**, 044908 (2012).
[23] L. Yan and J. Y. Ollitrault, Phys. Lett. B **744**, 82 (2015).