The hydrodynamics study on the flow vector, flow magnitude and flow angle fluctuations in Pb+Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV

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Introduction

The fluctuation of geometry in the initial states leads to anisotropic flow fluctuations of soft hadrons in the momentum space. By using two- and four-particle cumulants, one can subtract the mean flow and flow fluctuation.

However, the flow angle and magnitude also fluctuate event by event due to the fluctuation of the flow vector. Therefore, constructing four-particle correlation observables can help to study separated flow angle and flow magnitude fluctuations.

Model Setup

A (3+1)-dimensional CLVisc viscous hydrodynamic model[1] with $\mathrm{T_RENTo}$ initial condition is utilized to simulate the dynamical evolution of the QGP fireball. The equation of state comes from HotQCD Lattice results. The momentum distribution of final soft hadrons can be obtained from Cooper-Frye formula with resonance decay.

Methods of Analysis

The mean flow and flow fluctuation[2]:

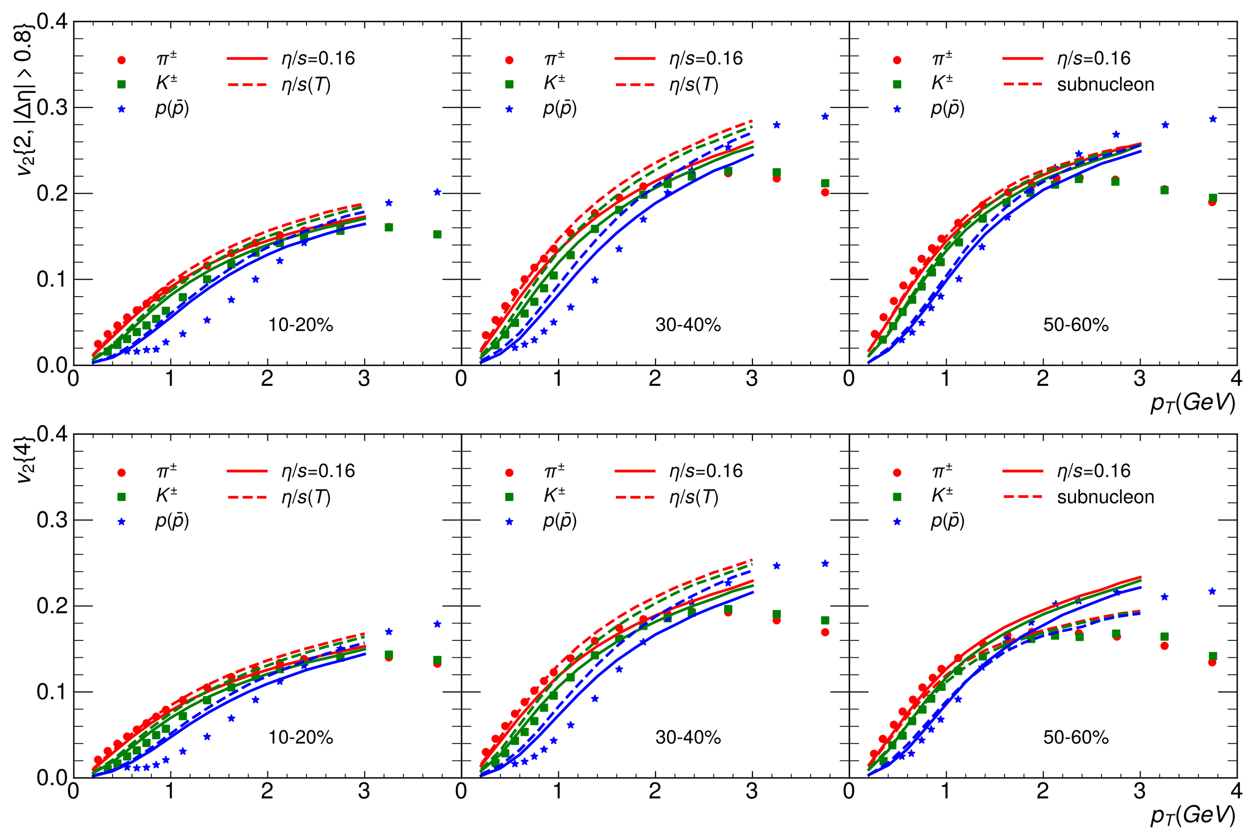
$$\begin{aligned} v_\mathrm{n}^2\{2\} &= \langle v_\mathrm{n}\rangle^2 + \sigma_{v_\mathrm{n}}^2 \\ v_\mathrm{n}^2\{4\} &\approx \langle v_\mathrm{n}\rangle^2 - \sigma_{v_\mathrm{n}}^2 \end{aligned} \implies \begin{aligned} \langle v_\mathrm{n}\rangle &\approx \sqrt{\frac{v_\mathrm{n}^2\{2\}+v_\mathrm{n}^2\{4\}}{2}} \\ \sigma_{v_\mathrm{n}} &\approx \sqrt{\frac{v_\mathrm{n}^2\{2\}-v_\mathrm{n}^2\{4\}}{2}} \\ F(v_\mathrm{n}) &= \frac{\sigma_{v_\mathrm{n}}}{\langle v_\mathrm{n}\rangle} \end{aligned}$$

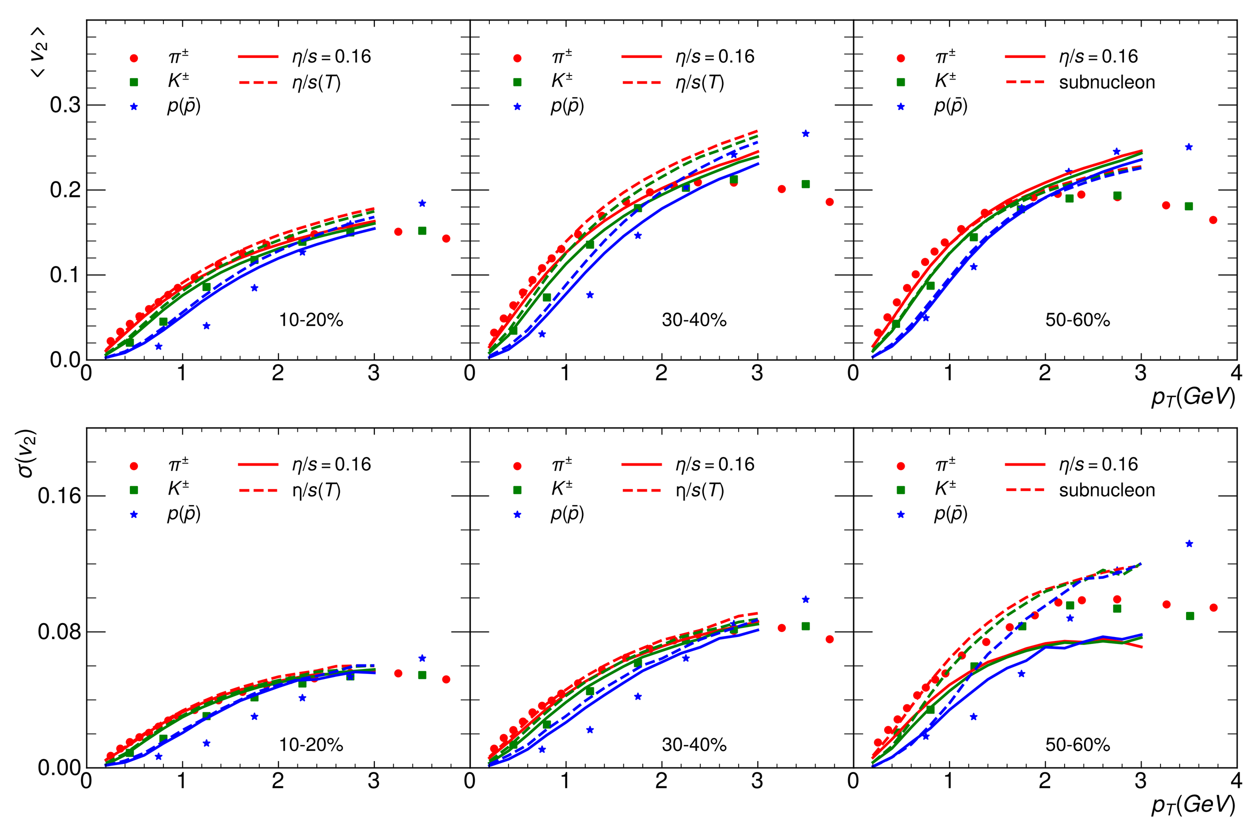
The separated flow angle fluctuation and flow magnitude fluctuation[3]:

$$\begin{aligned} A_n^f &= \frac{\langle\langle \cos n[\phi_1^a+\phi_2^a-\phi_3-\phi_4]\rangle\rangle}{\langle\langle \cos n[\phi_1^a+\phi_2-\phi_3^a-\phi_4]\rangle\rangle} \\ &= \frac{\langle v_n^2(\mathrm{p_T^a}) v_n^2 \cos 2n[\Psi_n(\mathrm{p_T^a})-\Psi_n]\rangle}{\langle v_n^2(\mathrm{p_T^a}) v_n^2\rangle} \\ &\approx \langle \cos 2n[\Psi_n(\mathrm{p_T^a})-\Psi_n]\rangle_\mathrm{w} \end{aligned}$$

$$\begin{aligned} M_n^f &= \frac{\langle\langle \cos n[\phi_1^a+\phi_2-\phi_3^a-\phi_4]\rangle\rangle}{(\langle\langle \cos n[\phi_1^a-\phi_3^a]\rangle\rangle\langle\langle \cos n[\phi_2-\phi_4]\rangle\rangle)} \Bigg/ \frac{\langle\langle \cos n[\phi_1+\phi_2-\phi_3-\phi_4]\rangle\rangle}{\langle\langle \cos n[\phi_1-\phi_2]\rangle\rangle^2} \\ &= \frac{\langle v_n^2(\mathrm{p_T^a}) v_n^2\rangle / (\langle v_n^2(\mathrm{p_T^a})\rangle\langle v_n^2\rangle)}{\langle v_n^4\rangle/\langle v_n^2\rangle^2} \end{aligned}$$

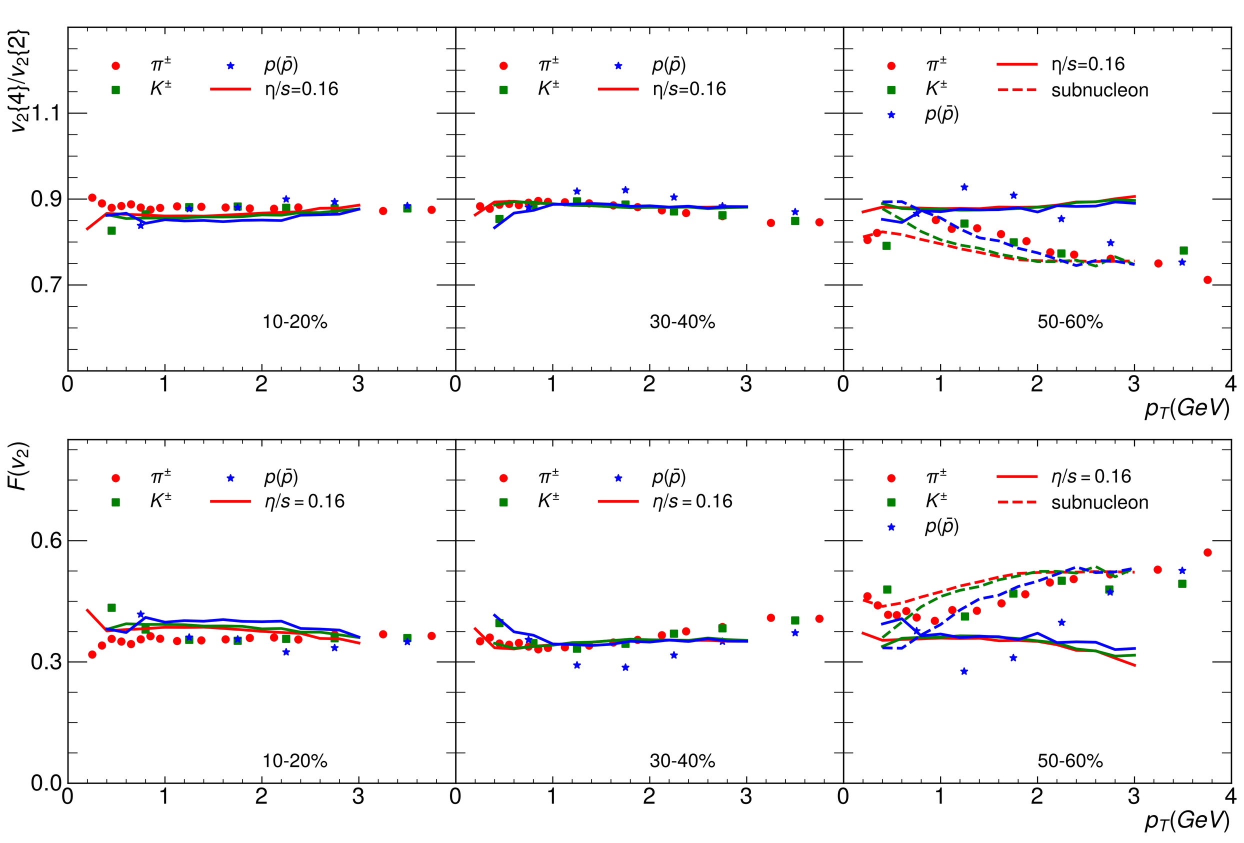
Results and Discussion

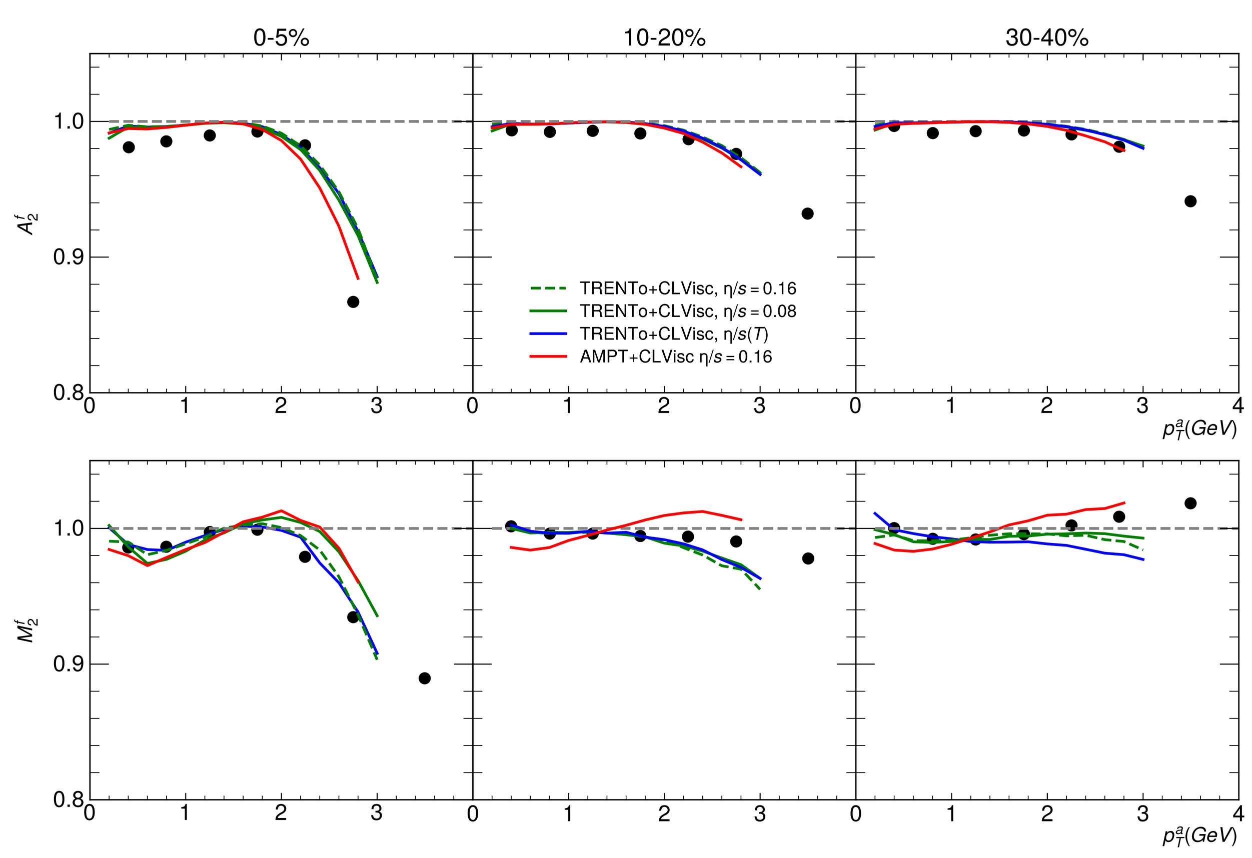




- Temperature-dependent shear viscosity $\eta/\mathrm{s(T)}$ enhances $v_2\{4\}$ and $v_2\{2\}$ at high transverse momentum and in peripheral collisions as a result of the lower shear viscosity at lower temperature in $\eta/\mathrm{s(T)}$.
- The subnucleon structure increases the $v_2\{2,|\Delta\eta|>0.8\}$and suppresses the $v_2\{4\}$ due to the effect of fluctuation.

- Specific shear viscosity has little effect on fluctuation width and a comparable effect on mean value of v_2, especially in peripheral collisions.
- The substructure of the nucleon enhances the fluctuation of various species of particles, but does not have an effect on the mean value of the elliptic flow.





- The ratios and the relative fluctuations have no dependence on particle species and transverse momentum which is consistent with the experimental results in central collisions.
- In peripheral collisions the ratios and the relative fluctuations show non-monotonic dependence on transverse momentum and particle type grouping in $1 < \mathrm{p_T} < 3$GeV, which can be qualitatively reproduced if the subnucleon structure is considered.

- CLVisc hydrodynamics framework with $\mathrm{T_RENTo}$ initial model can roughly produce the small deviation of angle fluctuations in low $\mathrm{p_T}$ and mid-central collisions as well as the large deviation in high $\mathrm{p_T}$ and central collisions.
- The angle fluctuations are larger than the magnitude fluctuations in all three centralities.
- The flow magnitude fluctuations are sensitive to the initial condition and slightly dependent on the shear viscosity except the central collision.

Reference

[1] X.-Y. Wu, G.-Y. Qin, L.-G. Pang, and X.-N. Wang, Phys. Rev. C 105, 034909 (2022), arXiv:2107.04949.

[2] ALICE, (2022). arXiv:2206.04587.

[3] ALICE, (2022). arXiv:2206.04574.