Studying the constituent-quark scaling of elliptic flow with transverse spherocity in heavy-ion collisions at the RHIC and LHC energies

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Introduction

For decades, experiments on heavy-ion collisions have been performed extensively to produce and study the properties of the hot and dense state of the deconfined matter, called quark-gluon plasma (QGP). Due to its transient nature, different indirect probes are studied to look for the signatures of QGP in such collisions. One of the crucial signatures is the presence of collective transverse flow, mainly the elliptic flow (v_2), which is the second-order flow coefficient in the Fourier expansion of particle azimuthal distribution [1], also given as,

$$v_2 = \langle \cos[2(\phi - \psi_2)] \rangle. \quad (1)$$

Here, ϕ and ψ_2 are the azimuthal angle and second-order event plane angle, respectively. Elliptic flow is built mainly in the early partonic stages of QGP and evolves through the hadronic phase through hadronic rescattering [2]. To understand the interplay of partonic and hadronic phase in the evolution, it is necessary to study the elliptic flow for different identified particles. Another exciting aspect of the elliptic flow, which gives the most substantial evidence of deconfinement of partons, is the number of constituent-quark (NCQ) scaling. NCQ-scaling gives an insight to the hydrodynamic flow in the partonic phase and the quark coalescence during the hadronization [3].

Transverse spherocity (S_0), an event shape observable, which can separate events based on their geometrical shape, *i.e.,* jetty and isotropic events, has been introduced in heavy-ion collisions recently [4, 5]. It has been shown that v_2 is strongly anti-correlated with spherocity [4, 6]. In this work, we use the two-particle correlation method to estimate the elliptic flow coefficient for pions, kaons, and protons as a function of transverse spheorcity in heavy-ion collisions for RHIC and LHC energies using AMPT model [7, 8]. By choosing particle pairs in a certain relative pseudorapidity gap ($\Delta\eta$), we can subtract substantial nonflow effects from the estimation of v_2 [4, 8]. We also study the NCQ scaling for different event classes using spherocity, which will help us understand the interplay of jet fragmentation and quark coalescence mechanisms in particle production.

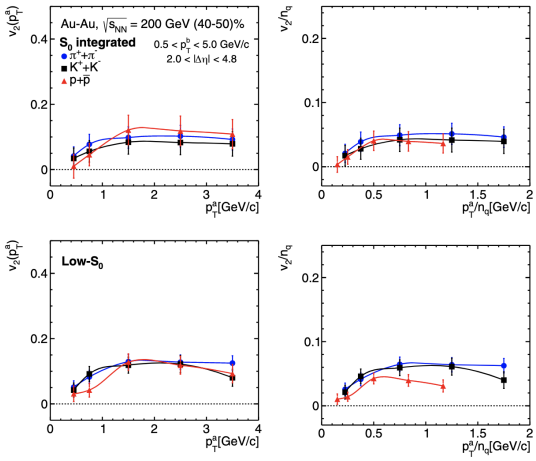

FIG. 1: (Color online) Top: Elliptic flow (v_2) vs. transverse momentum ($p_{\rm T}^a$) (left) and its NCQ scaling (right) for spherocity integrated events in 40-50% central Au-Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. Bottom: the same observables for low spherocity events. (Figure taken from Ref. [8])

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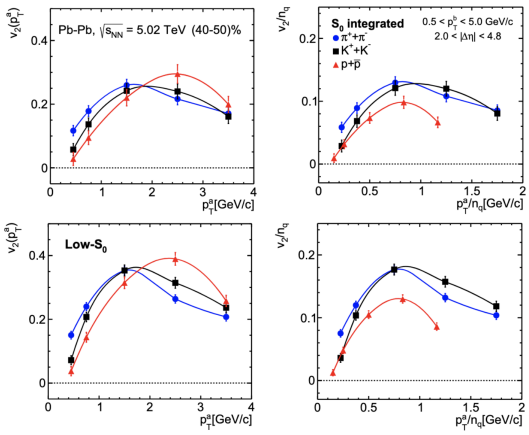

FIG. 2: (Color online) Top: Elliptic flow (v_2) vs. transverse momentum ($p_{\rm T}^a$) (left) and its NCQ scaling (right) for spherocity integrated events in 40-50% central Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. Bottom: the same observables for low spherocity events. (Figure taken from Ref. [8])

Results and Discussions

Figure 1 and 2 show the elliptic flow as a function of transverse momentum for pions, kaons, and protons in 40-50% central Au-Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV and Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV, respectively, for S_0-integrated and low-S_0 events. A clear mass hierarchy in the low-$p_{\rm T}$ region ($p_{\rm T} < 2$ GeV/c) is seen, and in the intermediate-$p_{\rm T}$, the elliptic flow for protons is higher than that of pions and kaons. The low-S_0 events contribute more to elliptic flow than S_0-integrated events for all three particle types. These results align with the results reported in Ref. [4] for all charged hadrons. The NCQ-scaling behavior for pions, kaons, and protons is also shown for S_0-integrated and low-S_0 events for RHIC and LHC energies. The low-S_0 events show a larger deviation compared to S_0-integrated events as far as the NCQ-scaling is concerned. However, the scaling holds good for Au-Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV in S_0-integrated events. This also points to the fact that spherocity can probe the scaling properties of elliptic flow in heavy-ion collisions.

Summary

This study reports the elliptic flow coefficient for pions, kaons, and protons and their NCQ-scaling behavior for various spherocity classes in RHIC and LHC energies. The study shows that low-S_0 events contribute more towards the elliptic flow for all three particle types than the S_0-integrated class. The low-S_0 events show a significant violation of the NCQ-scaling for both RHIC and LHC energies, which may be due to the dominance of fragmentation processes in the jetty kind of particle production scenario.

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