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Transverse spherocity dependence of azimuthal anisotropy in heavy-ion collisions at the LHC using a multi-phase transport model

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One of the event shape observables, the transverse spherocity (S_0), has been studied successfully in small collision systems such as proton-proton collisions at the LHC as a tool to separate jetty and isotropic events. It has a unique capability to distinguish events based on their geometrical shapes. In our work, we report the first implementation of transverse spherocity in heavy-ion collisions using a multi-phase transport model (AMPT). We have performed an extensive study of azimuthal anisotropy of charged particles produced in heavy-ion collisions as a function of transverse spherocity (S_0). We have followed the two-particle correlation (2PC) method to estimate the elliptic flow (v_2) in different centrality classes in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV for high-S_0, S_0-integrated and low-S_0 events. We found that transverse spherocity successfully differentiates heavy-ion collisions' event topology based on their geometrical shapes, i.e., high and low values of spherocity. The high-S_0 events have nearly zero elliptic flow, while the low-S_0 events contribute significantly to the elliptic flow of spherocity-integrated events.

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PoS(LHCP2021)227

1. Introduction

The production of a hot and dense, deconfined state of matter known as the quark-gluon plasma (QGP) has already been established in heavy-ion collisions at the Large Hadron Collider (LHC) at CERN, Switzerland, and Relativistic Heavy Ion Collider (RHIC) at BNL, USA. Recent studies at the LHC show heavy-ion-like features such as ridge-like structures [1] and strangeness enhancements [2] in *pp* collisions. To understand the system dynamics and production of jets in *pp* collisions, an event shape observable, known as the transverse spherocity (S_0), has been introduced recently at the LHC [3–7]. These studies show that transverse spherocity (S_0) has unique capabilities to distinguish events based on their geometrical shapes *i.e.* jetty and isotropic events. The study of transverse spherocity in heavy-ion collisions may reveal new and unique physics results where the formation of QGP is already known. This study in heavy-ion collisions shall also complement the current event shape approach based on flow vector analysis at the LHC [8, 9].

In this work [10], we report the first implementation of transverse spherocity in heavy-ion collisions using a multi-phase transport (AMPT) model [11]. We have performed an extensive study of azimuthal anisotropy of charged particles produced in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV as a function of transverse spherocity (S_0). We have followed the two-particle correlation (2PC) method to estimate the elliptic flow (v_2) and subtract non-flow from our calculations by following standard experimental procedures.

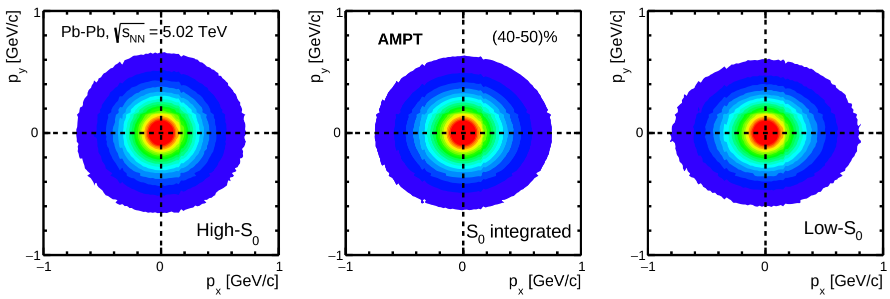

Figure 1: (Color Online) Transverse momentum space correlation ($p_{\rm y}$ vs. $p_{\rm x}$) for different spherocity classes in (40-50)% central Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV using AMPT model. (Fig. 2 [10])

Transverse spherocity (S_0) is an event property which is also a collinear and infrared safe quantity [3–5] and defined as follows,

$$S_0 = \frac{\pi^2}{4}\left(\frac{\Sigma_i\, |\vec{p}_{T_i} \times \hat{n}|}{\Sigma_i\, p_{T_i}}\right)^2. \tag{1}$$

Here, $\hat{n}(n_T, 0)$ is a unit vector known as the spherocity axis, which minimizes the ratio in Eq. 1. For jetty events $S_0 \approx 0$ and for isotropic events $S_0 \approx 1$ [7]. We have used the mid-rapidity ($|\eta| < 0.8$) spherocity distribution with $p_{\rm T} > 0.15$ GeV/c with events having at least five such tracks to meet similar conditions as in the ALICE experiment at the LHC. The low-S_0 and high-S_0 events represent the events lying in the bottom 20% and top 20% in the S_0 distributions whereas S_0-integrated events take all events into account.

Figure 1 represents the transverse momentum space correlation (p_y vs. p_x) for high-S_0, S_0-integrated and low-S_0 events in (40-50)% central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV using AMPT model. The elliptic flow in S_0-integrated events can be clearly seen from the elliptic shape of the correlation plot. This is indeed credited to the initial pressure gradient caused due to the initial almond-shaped nuclear overlap region in semi-central collisions, which is then translated to the momentum space ($p_x > p_y$) correlations. The interesting thing is that the high-S_0 events show almost spherical momentum correlation indicating the presence of nearly zero elliptic flow in such events. In contrast, the events with low-S_0 show a greater elliptical shape correlation. That indicates low-S_0 events should be more elliptic and therefore contribute more towards v_2.

2. Results and Discussions

To estimate the elliptic flow we have used the two-particle correlation method (2PC) [8, 12]. The two particle correlation function $C(\Delta\eta, \Delta\phi)$ is constructed by taking the ratios of same-event pairs $S(\Delta\eta, \Delta\phi)$ to mixed-event pairs $B(\Delta\eta, \Delta\phi)$ given by,

$$C(\Delta\eta, \Delta\phi) = \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)}. \quad (2)$$

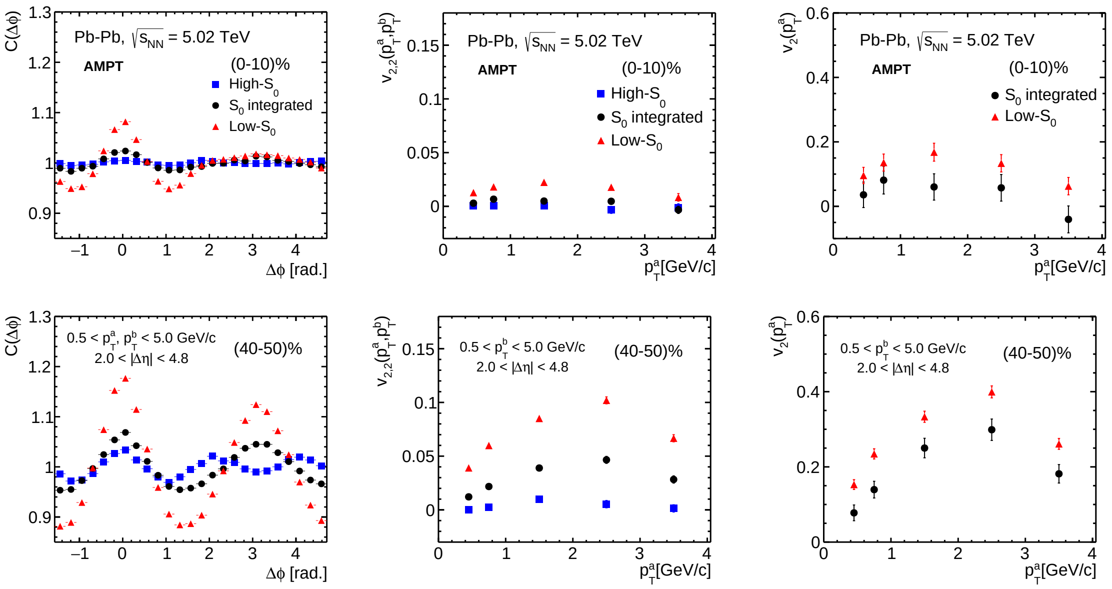

Figure 2: (Color Online) First column: One dimensional azimuthal correlation of charged particles, second column: two particle elliptic flow coefficient ($v_{2,2}(p_T^a, p_T^b)$) of charged particles as a function of p_T^a, and third column: single particle elliptic flow coefficient ($v_2(p_T^a)$) of charged particles as a function of p_T^a for low-S_0, high-S_0 and S_0-integrated events in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV for 0%–10% (top), 40%–50% (bottom) centrality classes using AMPT model. (Figs. 4-6 [10])

The one dimensional correlation function ($C(\Delta\phi)$) is then calculated by integrating all the pairs with pseudorapidity gap $2.0 < |\Delta\eta| < 4.8$. This step helps in reducing the contributions from

PoS(LHCP2021)227

non-flow effects [8]. From the $C(\Delta\phi)$ distribution, the two particle flow coefficient ($v_{2,2}(p_{\rm T}^a, p_{\rm T}^b)$) could be easily obtained as [13–15],

$$v_{n,n}(p_{\rm T}^a, p_{\rm T}^b) = \langle cos(n\Delta\phi)\rangle = \frac{\sum_{m=1}^{N} cos(n\Delta\phi_m) \times C(\Delta\phi_m)}{\sum_{m=1}^{N} C(\Delta\phi_m)}. \tag{3}$$

where, $N = 200$ is the number of $\Delta\phi$ bins in the range $-\pi/2 < \Delta\phi < 3\pi/2$. Here, $v_{n,n}$ are symmetric functions with respect to $p_{\rm T}^a$ and $p_{\rm T}^b$. The single particle flow coefficient could be obtained as,

$$v_{n,n}(p_{\rm T}^a, p_{\rm T}^b) = v_n(p_{\rm T}^a) v_n(p_{\rm T}^b). \tag{4}$$

Figure 2 first column shows that the shape and nature of the 1D azimuthal correlation vary with spherocity, and one can observe that the amplitude of the correlation is greater in low-S_0, intermediate in S_0-integrated and lower in high-S_0 events. Again, the amplitude of the correlation is larger in semi-central collisions compared to most central collisions. Figure 2 second column represents the two particle elliptic flow co-efficient $v_{2,2}(p_T^a, p_T^b)$ as a function of spherocity. Here, $v_{2,2}(p_T^a, p_T^b)$ has strong centrality dependence with showing greater values towards semi-central collisions. As far as spherocity is concerned, the high-S_0 events are found to have nearly zero elliptic flow while the low-S_0 events contribute significantly to elliptic flow of spherocity-integrated events. This is evident from the third column of Fig. 2.

3. Summary

In summary, we found that transverse spherocity successfully differentiates heavy-ion collisions' event topology based on their geometrical shapes, *i.e.* high and low values of spherocity (S_0). The high-S_0 events are found to have nearly zero elliptic flow, while the low-S_0 events contribute significantly to the elliptic flow of spherocity-integrated events. Transverse spherocity is anti-correlated to elliptic flow.

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