Transverse spherocity dependence of the global observables in heavy-ion collisions at the LHC

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Introduction

Transverse spherocity is an event-shape observable which is quite robust while separating events based on their geometrical shapes, i.e., it can successfully separate jetty events dominated by hard QCD processes from soft QCD-dominated isotropic events. For an unit vector $\hat{n}(n_T, 0)$, transverse spherocity (S_0) can be defined as [1]:

$$S_0 = \frac{\pi^2}{4}\min\Bigg(\frac{\sum_i |\vec{p_{T_i}} \times \hat{n}|}{\sum_i |\vec{p_{T_i}}|}\Bigg)^2 \qquad (1)$$

Where i runs over all the charged hadrons in the event with transverse momentum (p_T) larger than 0.15 GeV/c in the mid-rapidity region, i.e., ($|\eta| < 0.8$) [2]. Events having less than five charged particles within the defined rapidity and p_T range are rejected. The extreme limits of S_0, namely, zero and one, refer to jetty and isotropic events, respectively. In this study, we choose the highest and lowest 20% events from the S_0 distribution and refer to them as high-S_0 and low-S_0 events, respectively [2]. Transverse spherocity is proven to be quite successful in small systems like pp collisions, which are dominated by p-QCD processes. In this work, we aim to apply transverse spherocity on the global observables in heavy-ion collisions, dominated by soft-QCD processes. We study the squared speed of sound, Bjorken energy density and kinetic freeze-out parameters like kinetic freeze-out temperature and average transverse radial velocity in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV using a multi-phase transport model (AMPT) for different S_0 selections.

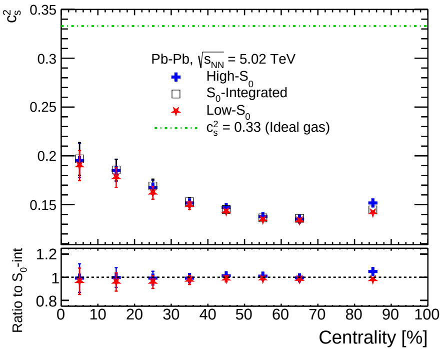

FIG. 1: Squared speed of sound (c_s^2) vs centrality for different transverse spherocity selections [2].

Results and Discussions

In the framework of Landau hydrodynamics, one can appraise the squared speed of sound (c_s^2) using the width of the pseudorapidity distribution (σ_y), extracted from the fit of a double Gaussian function, with the following relation [3]:

$$\sigma_y^2 = \frac{8}{3}\frac{c_s^2}{1 - c_s^2}\ln\left(\frac{\sqrt{s_{\rm NN}}}{2m_p}\right). \qquad (2)$$

where m_p is the mass of the proton. Figure 1 shows c_s^2 as a function of centrality for different spherocity classes. As one goes from most central to peripheral collisions, c_s^2 decreases, indicating the system gets less dense with the decrease in multiplicity. However, there is no S_0 dependence on the c_s^2, which seems familiar at first glance as S_0 is not expected to affect the energy density.

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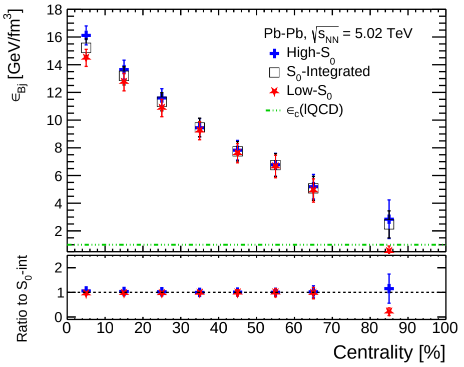

FIG. 2: Bjorken energy density as a function of centrality for high-S_0, S_0-integrated and low-S_0 classes [2].

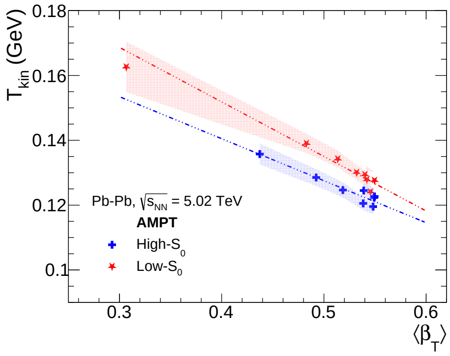

FIG. 3: Kinetic freeze-out temperature (T_{kin}) vs mean transverse radial velocity ($\langle\beta_{\mathrm{T}}\rangle$) for different spherocity classes [2].

In the Bjorken boost-invariant hydrodynamics model, the initial energy density can be estimated by the Bjorken energy density (ϵ_{Bj}) defined as [4]:

$$\epsilon_{Bj} = \frac{1}{\tau S_T}\frac{dE_T}{dy}. \quad (3)$$

Where τ is the formation time, taken to be one fm/c, S_{T} is the transverse overlap area, and E_T is the transverse energy. Figure 2 represents the Bjorken energy density as a function of centrality for different S_0 classes. The decreasing trend of ϵ_{Bj} towards peripheral collisions due to a decrease in energy deposition per unit volume is obvious from figure 2. On the other hand ϵ_{Bj} has effects from both dN/dy and $\langle m_T\rangle$, and since S_0 has opposite effects on dN/dy and $\langle m_T\rangle$, therefore, one observes no S_0 dependence on ϵ_{Bj} [2].

The transverse momentum spectra at the freeze-out are well described by the Boltzmann Gibbs Blastwave function (BGBW) [5]. One fits the BGBW to the identified particles' p_T spectra to extract the free parameters of the function, such as the kinetic freeze-out temperature (T_{kin}) and the mean transverse radial flow velocity ($\langle\beta_{\mathrm{T}}\rangle$). Figure 3 shows ($T_{\mathrm{kin}}$) vs ($\langle\beta_{\mathrm{T}}\rangle$) for different S_0 classes. Due to the domination of soft particles in high-S_0 events, particles take higher time to reach the freeze-out and their $\langle\beta_{\mathrm{T}}\rangle$ is comparatively higher. However, the case is reversed for low-S_0 events, and they possess lower $\langle\beta_{\mathrm{T}}\rangle$ and higher T_{kin} values for a given centrality.

Summary

In this work we explore the dependence of transverse spherocity on the global properties such as c_S^2, ϵ_{Bj}, T_{kin}, and $\langle\beta_{\mathrm{T}}\rangle$ in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV using AMPT. Both c_S^2 and ϵ_{Bj} do not have S_0 dependence while T_{kin}, and $\langle\beta_{\mathrm{T}}\rangle$ are found to be strongly correlated with S_0. The sensitivity of the transverse spherocity depends upon the observables under study, which may have counterbalancing effects from the medium.

References

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