Insight from elliptic flow of open charm mesons using quark coalescence model at RHIC and LHC energies

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Abstract. A study of elliptic flow of open charm mesons, D^0 and $D_S^{\pm}$ using quark coalescence as the mechanism of hadronization of heavy quarks will be presented. The coalescing partons are taken from a multi-phase transport model. The transverse momentum dependence of the elliptic flow parameter at mid-rapidity ($|y| < 1.0$) for minimum bias Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV (RHIC) and Pb+Pb collisions $\sqrt{s_{NN}} = 2.76$ TeV (LHC) for different values of partonic interaction cross-section and QCD coupling constant will be discussed. We have compared our calculations with the experimentally measured data at the LHC energy. We will also present the effect of specific viscosity on elliptic flow of open charm mesons within the transport model approach. Our study indicates that the elliptic flow of open charmed mesons is more sensitive to viscous properties of QGP medium compared to light hadrons.

1. Introduction

Heavy quarks are considered as an important probe to understand the properties of the Quark Gluon Plasma (QGP) created in relativistic heavy ion collisions as they are produced on a short time scale in hard partonic scatterings during the early stages of the nucleus-nucleus collision. As the probability of their thermal production is small, these are sensitive to medium dynamics. Heavy quarks decouple early in the evolution of QGP, thereby preserving the information from early stages of the system.

Elliptic flow, measured in heavy ion collisions, is the manifestation of the initial spatial anisotropy of collision geometry and the interaction among produced particles. The particle azimuthal distribution relative to reaction plane can be written in the form of Fourier series, the second coefficient of which is called the elliptic flow parameter, v_2 [1].

$$\frac{dN}{d\phi} \propto 1 + 2v_2 \cos(2(\phi - \Psi)); \qquad v_2 = \langle \cos(2(\phi - \Psi)) \rangle \tag{1}$$

where ϕ is the azimuthal angle of emitted particle and Ψ is the reaction plane. The magnitude and the conversion of geometrical eccentricity to elliptic flow depends on the dynamics and the equation of state of the medium.

This proceeding, which is about the study of elliptic of flow open charm mesons and its implications, is based on [2] and is organized in the following way. In Section 2, an introduction to the AMPT model with the prescription of the quark coalescence model used is discussed. A discussion on the elliptic flow of D-meson at RHIC (Au+Au at $\sqrt{s_{NN}} = 200$ GeV) and LHC (Pb+Pb at $\sqrt{s_{NN}} = 2.76$ TeV) energies and the effect of specific viscosity on elliptic flow of open charms is given in Section 3. We summarize in Section 4.

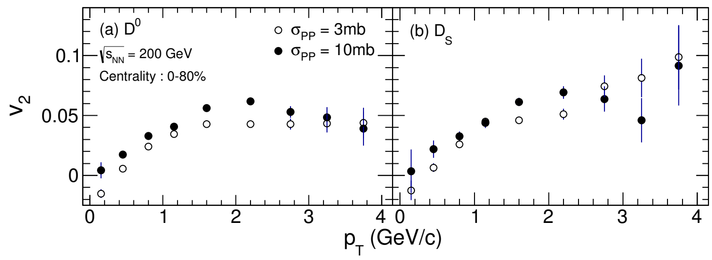

Figure 1. v_2 of D^0 and D_S as a function of p_T in 0-80% minimum bias Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV for $\sigma_{PP} = 3$ mb and 10 mb.

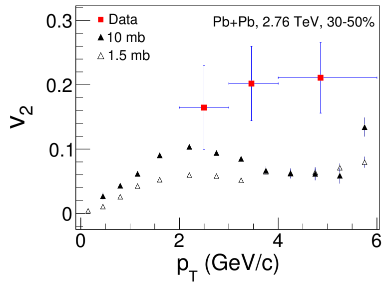

Figure 2. (Color online) Elliptic flow of D meson (average of D^0 and $D^{\pm}$) at mid-rapidity in Pb+Pb collision at $\sqrt{s_{NN}} = 2.76$ TeV for 30-50% centrality. Only statistical error is shown for ALICE data [5].

2. Quark Coalescence Mechanism

A Multi Phase Transport (AMPT) model consists of four main components: the initial conditions, partonic interactions, the conversion from the partonic to the hadronic matter, and hadronic interactions [3]. In the String melting version, a quark coalescence model is used instead to combine partons into hadrons. The dynamics of the subsequent hadronic matter is described by a hadronic cascade. However, hadronization of heavy quarks is not implemented in the string melting version of AMPT. Taking the partons from AMPT, we will implement the coalescence prescription described below to get the open charm mesons. Within the framework of the coalescence mechanism, the probability of producing a hadron from a soup of partons is determined by the overlap of the phase space distribution of partons at freeze-out with the parton Wigner phase space function inside the hadron under the assumption that the correlations between coalescing partons is weak and the binding energy of the formed hadron can be neglected. The Wigner phase space function for quarks inside a meson is obtained from its constituent quark wave function given by [4]

$$\rho^W(\mathbf{r}, \mathbf{k}) = \int \psi\left(\mathbf{r} + \frac{\mathbf{R}}{2}\right) \psi^\star\left(\mathbf{r} - \frac{\mathbf{R}}{2}\right) \exp(-i\mathbf{k} \cdot \mathbf{R}) d^3\mathbf{R} \tag{2}$$

$\mathbf{r}$ is the relative position and $\mathbf{k}$ is the relative momentum of the coalescing partons. The quark wave function is given by spherical harmonic oscillator.

3. Results and Discussions

The elliptic flow of D^0 and D_S mesons at mid-rapidity from the coalescence of heavy quarks in conjunction with AMPT model for different parton-parton interaction cross-section, σ_{PP} for

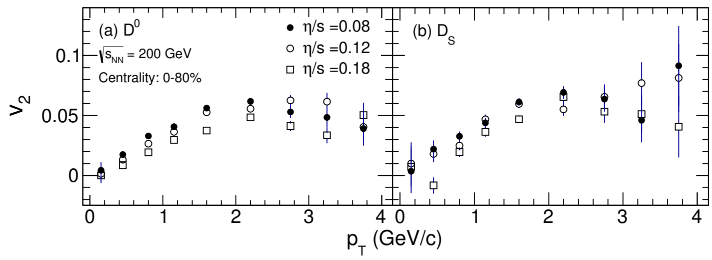

Figure 3. Elliptic flow of D^0 and D_S as a function of p_T for different specific viscous medium (η_s/s = 0.08, 0.12 and 0.18) in minimum bias Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and σ_{PP} = 10 mb.

0-80% minimum bias Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV is shown in Fig. 1. The elliptic flow of open charm meson decreases with decrease in parton parton interaction cross-section, which is similar as observed for charged hadron. Fig. 2 shows a comparison between our model calculations for v_2 of D meson (average of D^0 and $D^{\pm}$) and measured D meson v_2 at 2.76 TeV for 30-50% central collisions by the ALICE experiment [5]. Our model calculations for both 1.5 mb (which describes charged hadrons well) and 10 mb under-predict the data for D-meson v_2. It has a different trend as well at high p_T. It would be very interesting to see the behavior of data at low p_T (below 2 GeV/c).

Transport coefficients play a major role in probing the properties of the soup of quarks and gluons created in high energy heavy ion collisions. In order to study this, we compare the behavior of v_2 of open charm mesons for different values of the ratio of shear viscosity, η_s, to entropy density, s, with p_T. In the AMPT model, this can be done by tuning the QCD coupling constant, α and screening mass, μ, keeping the parton scattering cross-section, σ_{PP} fixed, where $\sigma_{PP} \approx 9\pi\alpha^2/2\mu^2$. For a system of massless quarks and gluons at temperature T, the specific viscosity is given by [6]

$$\frac{\eta_s}{s} \approx \frac{3\pi}{40\alpha_s^2} \frac{1}{\left(9 + \frac{\mu^2}{T^2}\right) \ln\left(\frac{18+\mu^2/T^2}{\mu^2/T^2}\right) - 18} \tag{3}$$

Fig. 3 shows the change in v_2 of D^0 and D_S meson due to the variation of η_s/s in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. We show that v_2 decreases with increase in specific viscosity for low transverse momentum; the trend being more pronounced for D^0. This is consistent with the interpretation that increased shear viscosity reduces transverse expansion and hence reduces v_2. The production and propagation of open charm meson in QGP medium is expected to be different from light hadrons because of their large mass. Therefore, a study of the effect of specific viscosity on v_2 for both open charm mesons and charged hadrons will be useful to probe of the QGP medium. In addition, this can give us a constraint on the specific viscosity of the relatively early time scale of the medium created in relativistic heavy ion collisions.

The ratio of v_2 for η_s/s = 0.08 and for η_s/s = 0.18 is shown as function of p_T for 10–40% central collisions in Fig. 4. The solid red and open blue circles represents the results for charged hadrons and D^0 respectively. We can see that the change in v_2 for charged hadrons is relatively small as compared to D^0. Hence, we conclude that the elliptic flow of open charm meson is more sensitive to viscous properties of the QGP medium compared to the light hadrons. The ratio of v_2 of D^0 to the v_2 of charged hadrons is independent of analysis technique used to obtain elliptic flow. This is shown for Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and Pb + Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV in Fig. 5 for different η_s/s as a function of p_T. This ratio can be calculated in data and compared to model studies to constrain specific viscosity of the medium.

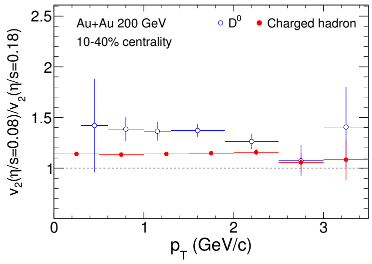

Figure 4. (Color online) Ratio between v_2 for $\eta_s/s = 0.08$ and for $\eta_s/s = 0.18$ as a function of p_T in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV for charged hadrons and D^0 for 10–40% central collisions.

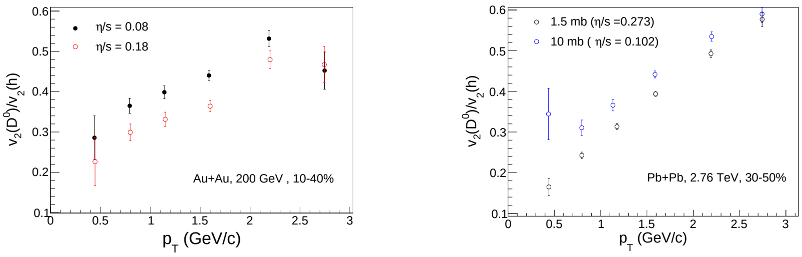

Figure 5. (Color online) Ratio between v_2 for D^0 to v_2 of charged hadrons for different η_s/s as a function of p_T in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV (left) and Pb + Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV (right)

4. Conclusion

We have studied the elliptic flow of open charm mesons as a function of p_T for heavy ion collisions at $\sqrt{s_{NN}} = 200$ GeV and 2.76 TeV within the framework of A Multi Phase Transport model by using quark coalescence as a mechanism for hadron production from heavy quarks in this model study. We have given predictions for $v_2(p_T)$ of D^0 and $D_S^{\pm}$ meson for minimum-bias Au+Au collision at RHIC for different values of partonic interaction cross-sections. We find that v_2 increases with increase in the partonic interaction cross-section. We also notice that the parameters tuned to describe charged hadron multiplicity and v_2 at 2.76 TeV fail to reproduced D meson v_2 in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for $p_T > 2$ GeV/c.

In addition, we have presented a systematic study on the effect of specific viscosity on elliptic flow within the transport model approach. We have also shown that open charmed meson are more sensitive to viscous properties of QGP medium compared to light hadrons.

References

[1] Poskanzer A M and Voloshin S A 1998 *Phys. Rev.* **C 58** 1671.
[2] Esha R, Nasim M and Huang H Z 2016 *arXiv:1603.02700.*
[3] Lin Z W and Ko C M 2002 *Phys. Rev.* **C 65** 034904; Chen L W *et al.* 2005 *Phys. Lett.* **B 605** 95; Lin Z W *et al.* 2005 *Phys. Rev.* **C 72** 064901.
[4] Chen L W and Ko C M 2006 *Phys. Rev.* **C 73** 044903; Greco V, Ko C M and Rapp R 2004 *Phys. Lett.* **B 595** 202.
[5] Abelev B *et al.* (ALICE Collaboration) 2014 *Phys. Rev.***C 90**, 034904.
[6] Xu J and Ko C M 2011 *Phys. Rev.* **C 83**, 034904.