Hadronic Effects on Charmoium Elliptic Flows in Heavy-Ion Collisions

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Motivation

In this work, we study the possible effects of hadronic medium on charmonium elliptic flows, especially at the high p_T region. Due to the elastic collisions with the thermal hadrons, charmonium momentum will be changed, which is described via the Langevin equation.

The final elliptic flows of charmonium comes from two parts : interactions with QGP and the hadornic medium.

1) QGP($T > T_c$) $\rightarrow$ transport model

- At low p_T $\rightarrow$ regeneration mechanism
- At high p_T $\rightarrow$ primordial production

Charmonia with high p_T are produced via the primordial hard process and undergo different degrees of dissociation along different paths in the QGP.

This effect contributes $\sim$ 2% of the elliptic flow of J/Ψ in the high p_T region in semi-central Pb-Pb collisions, which is considerably lower than that obtained from experimental data.

2) hadronic medium($T < T_c$) $\rightarrow$ Langevin equation

One of the factors neglected in the theoretical studies is the charmonium diffusion in the hadronic medium.

Charmonium in QGP : transport model

- transport equation

The Boltzmann-type transport model is employed to study charmonium evolutions in the QGP [2]. The transport equation is written as :

$$\partial_t f_\Psi(t,\mathbf{x},\mathbf{p}) + \mathbf{v}_\Psi \cdot \nabla_x f_\Psi(t,\mathbf{x},\mathbf{p}) = -\alpha f_\Psi(t,\mathbf{x},\mathbf{p}) + \beta \quad (1)$$

In Eq.(1), $f_\Psi(t,\mathbf{x},\mathbf{p})$ is the charmonium density in the phase space. The second term on the left-hand side represents the free streaming of charmonium with a constant velocity. α is the charmonium dissociation rate, β is the charmonium regeneration rate.

Advantage : In this work, we will mainly focus on the charmonium elliptic flows at high p_T, where the path-length-difference effect from QGP can not explain the experimental data about charmonium elliptic flows. We temporarily neglect the regeneration process (labelled by β term) in the following calculations.

- the distributions of primordial charmonia $f_{t=0}$

The distributions of primordial charmonia in Pb-Pb collisions are obtained through a superposition of effective nucleon-nucleon collisions, according to :

$$f_{t=0}(\mathbf{x}_T,\mathbf{p}_T,y \mid \mathbf{b}) = T_A(\mathbf{x}_T+\frac{\mathbf{b}}{2})T_B(\mathbf{x}_T-\frac{\mathbf{b}}{2})\frac{d^2\sigma^{pp}_{J/\Psi}}{dy2\pi p_T dp_T}\Re_s(\mathbf{x}_T,\mathbf{p}_T,y) \quad (2)$$

In Eq.(2), $T_{A(B)}$ is the thickness function of the nucleus A(B). b is the impact parameter. $\Re_s$ is the modification factor due to the shadowing effect.

Charmonium in hadronic medium : Langevin equation

The classical Langevin equation for charmonium motion in a hadronic medium is written as :

$$\frac{d\mathbf{p}}{dt} = -\eta\mathbf{p} + \xi \quad (3)$$

In Eq.(3), $\mathbf{p}$ is the charmonium momentum, while η and ξ are the drag force and the noise from the hadronic medium, respectively.

In the hadronic medium, all the collisions between charmonia and light hadrons are parametrized in terms of the drag coefficient η and noise term ξ in the Langevin equation.

1) noise ξ and drag coefficient η

- ξ satisfies the correlation relation :

$$\langle \xi^i(t)\xi^j(t')\rangle = \kappa\delta^{ij}\delta(t-t') \quad (4)$$

Here κ is the charmonium diffusion coefficient in the momentum space, it is connected with the spatial diffusion coefficient D_s^Ψ through $\kappa = 2T^2/D_s^\Psi$ in the classical limit.

- η satisfies the correlation relation :

$$\eta \approx \frac{\kappa}{2m_\Psi T} \quad (5)$$

Here m_Ψ is the charmonium mass, and T is the local temperature of the hadronic medium. *In the above equation, only one parameter, namely D_s^Ψ for charmonium, is as yet undetermined.*

2) D_s^Ψ and geometry scale approximation

The charmonium diffusion coefficients are obtained via the geometry scale :

$$D_s^\Psi = D_s^D \times \frac{\langle r_D\rangle^2}{\langle r_\Psi\rangle^2} \quad (6)$$

In Eq.(6), D_s^D is the D meson spatial diffusion coefficient in the hadronic medium. From T-matrix and other potential model calculations [3], we take $D_s^D = 8$. Furthermore, the charge radius of the D meson is approximated to be $\langle r_D\rangle = 0.41$ fm. The radii of the charmonium ground state and excited states (χ_c,Ψ') are 0.5 and 0.72 fm.

$\Longrightarrow$ *Based on this approximation, the charmonium excited states with relatively small spatial diffusion coefficients can develop large collective flows in the hadronic medium, which will increase the elliptic flows of the prompt and inclusive J/Ψ at high p_T through the decay process $\chi_c(\Psi') \rightarrow J/\Psi X$.*

Results

- J/Ψ elliptic flows in cent.40-60%

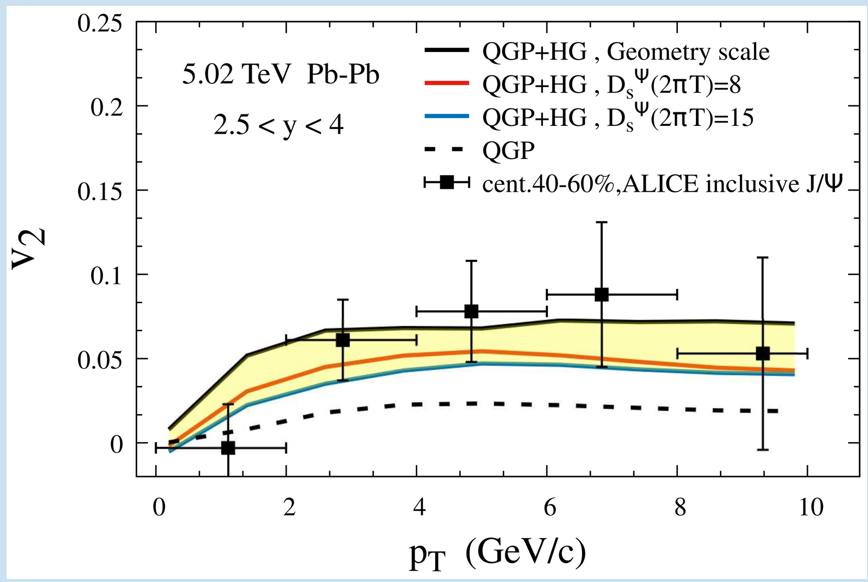

Figure 1: Elliptic flows of the primordial J/Ψ as a function of the transverse momentum in cent.40-60% in $\sqrt{s_{NN}}$ = 5.02 TeV Pb-Pb collisions.

Fig.1 shows the calculations in cent.40-60%. The hadronic effects result in an increase of $v_2^{J/\Psi}$ from $\sim$ 2% to $\sim$ 6% at $p_T \sim 6$ GeV/c when the charmonium diffusion coefficients are extracted using the geometry scale approximation, other situations with different values of the charmonium diffusion coefficient are also considered ($D_s^\Psi = 8$, 15).

- J/Ψ elliptic flows in cent.20-40%

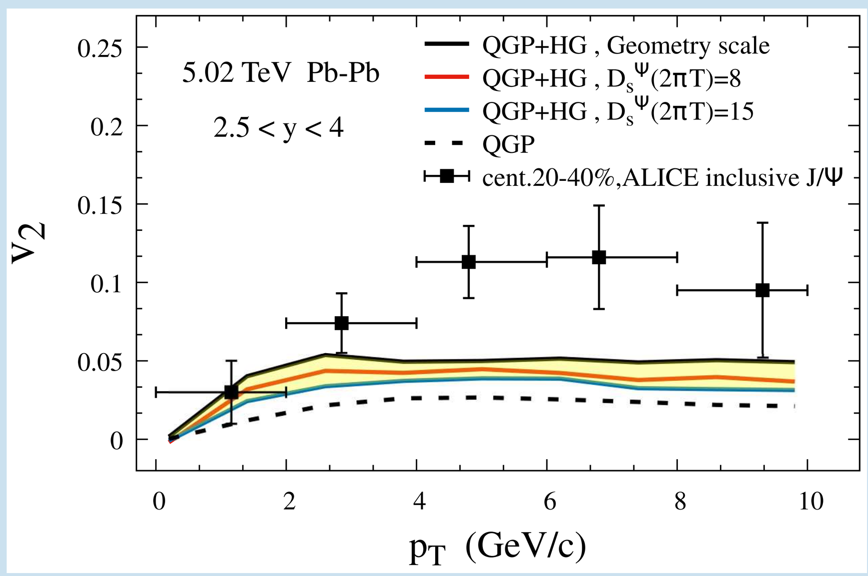

Figure 2: Elliptic flows of the primordial J/Ψ as a function of the transverse momentum in cent.20-40% in $\sqrt{s_{NN}}$ = 5.02 TeV Pb-Pb collisions.

Fig.2 shows the calculations in cent.20-40%. The hadronic effects result in an increase in the elliptic flow of the primordial J/Ψ from $\sim$ 2.5% to $\sim$ 5%.

The effect is slightly smaller than that observed in cent.40-60%. This is because a larger proportion of the charmonium excited states is dissociated in the QGP, and their contribution to the final $v_2^{J/\Psi}$ is suppressed.

Conclusions

In this work, we study the effects of hadron elastic collisions on charmonium momentum anisotropy. Different interaction strength between charmonium and the hadronic medium are considered. When the spatial diffusion coefficients in the Langevin equation are parametrized via the geometry scale approximation, the charmonium v_2 can be enhanced by $\sim$ 5% at high p_T. This contribution would be suppressed if a larger value of the diffusion coefficient was considered.

References

[1] Chen B, Jiang L, Liu Y. Hadronic Effects on Charmonium Elliptic Flows in Heavy-Ion Collisions[J]. 2020.

[2] Zhou K, Xu N, Xu Z, et al. Medium Effects on Charmonium Production at ultrarelativistic energies available at the CERN Large Haron Collider[J]. Phys.rev.c, 2014, 89(5):163-168.

[3] He M, Fries R J, Rapp R. D_s Meson as a Quantitative Probe of Diffusion and Hadronization in Nuclear Collisions[J]. Physical Review Letters, 2013, 110(11):112301.1-112301.5.

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