Non-perturbative effects on heavy quark drag

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Introduction

Experimental heavy-ion collision (HIC) programs at Relativistic Heavy Ion Collider (RHIC) and at the Large Hadron Collider (LHC) indicate the production of a liquid-like phase of the matter, having a remarkably small value of shear viscosity to entropy density ratio, $\eta/s \approx 0.1$, where the properties of the system are governed by quarks and gluons. Such a state of matter is known as quark gluon plasma (QGP) [1]. To characterize the properties of QGP, penetrating and well calibrated probes are essential. In this context, the heavy quarks (HQs) [2], mainly charm and bottom, play a crucial role since they do not constitute the bulk part of the matter owing to their larger mass compared to the temperature created in heavy-ion collisions. Also, thermal production of heavy quarks is negligible, due to their large masses, in the QGP within the range of temperatures that can be achieved in RHIC and LHC colliding energies.

Heavy quarks interact with the plasma constituents, the light quarks, and the gluons, but their initial spectrum is too hard to come to equilibrium with the medium. Therefore, the high momentum heavy quarks spectrum carry the information of their interaction with the plasma particles during the expansion of the hot and dense fireball and on the plasma properties. Since the light quark, anti-quark and gluons are thermalized, the heavy quark interaction with the light constituents leads to a Brownian motion which can be treated with the framework of a Fokker Plank equation. Thus the interaction of the heavy quark in QGP is contained in the drag and diffusion coefficients of the heavy quark. The resulting momentum distribution of the heavy mesons which depend upon the drag and diffusion coefficients get reflected in the nuclear modification factor (R_{AA}) which is measured experimentally.

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Formalism

In the QGP phase, the Boltzmann equation for charm quark distribution function, neglecting any mean-field term, can be written as [3]:

$$\frac{\partial f_{HQ}}{\partial t} = \left[\frac{\partial f_{HQ}}{\partial t}\right]_{col}, \tag{1}$$

where f_{HQ} represents the spatially integrated non-equilibrium distribution function for heavy quark. The drag and diffusion coefficients are given as

$$A = p_i A_i/p^2 = \langle\langle 1\rangle\rangle - \frac{\langle\langle p.p\prime\rangle\rangle}{p^2} \tag{2}$$

$$B_0 = \frac{1}{4}[\langle\langle p\prime^2\rangle\rangle - \frac{\langle\langle (p.p\prime)^2\rangle\rangle}{p^2}] \tag{3}$$

The first experimental data [4] on heavy quarks suggest a strong nuclear suppression factor which can not be explained within the pQCD framework. Several attempts have been made to study the heavy quarks interaction in QGP going beyond pQCD to include the nonperturbative effects. Recently in Ref.[6], an effort to include Polyakov loop in HQ transport coefficient within matrix model of semi QGP has been made.

At high temperature, the density of colored particles like quarks and gluon are large and can be calculated using perturbative QCD. However, at low temperature, colored particles are statistically suppressed and is measured by the small value of Polyakov loop e.g., at chiral cross-over temperature $T_c \sim 170$

MeV, $\phi = 0.2$ [5]. Because of suppression of colored particles, the region near chiral cross-over is termed as semi-QGP and is chracterized by the Polyakov loop. The color dependent distribution function of quarks and gluons are defined as

$$f_a(E) = \frac{1}{e^{\beta(E-iQ_a)}+1},, \tag{4}$$

$$\tilde{f}_a(E) = \frac{1}{e^{\beta(E+iQ_a)}+1} \tag{5}$$

$$f_{ab}(E) = \frac{1}{e^{\beta(E-i(Q_a-Q_b))}-1}, \tag{6}$$

where the single and double indices are for quark/antiquark and gluon.

Results and Discussion

The temperature variation of the drag coefficient has been shown in Fig.(1) for charm quark for a given momentum (p=0.1 GeV). The temperature dependence of heavy quark drag coefficient is quite a mild for the case of Polyakov loop from PQM. However, with lattice, we obtained a quite stronger temperature dependence of heavy quark drag coefficient than the one with PQM. We notice that the drag coefficient obtained with PQM input is larger at low temperature than the one obtained with lattice inputs whereas the trend is opposite at high temperature. This is mainly because of the interplay between the Debye mass and Polyakov loop value obtained within both the models. In Fig.(2), the effect of both the bulk and the shear viscosities on drag coefficient as a function of temperature is shown. At low temperature shear viscosity dominates so drag coefficient decreases and at moderate temperature e.g., around 250 MeV bulk viscosity dominates so it increases. Again at high temperature around 320 MeV, both shear and bulk viscosities decreases the drag coefficient. For small shear and bulk viscosities i.e., $\eta/s = 0.1, \xi/s = 0.01$ (black curve), the dependence of drag on medium temperature is weak, however, it grows for larger values of viscosities e.g., $\eta/s = 0.2, \xi/s = 0.035$ (blue curve).

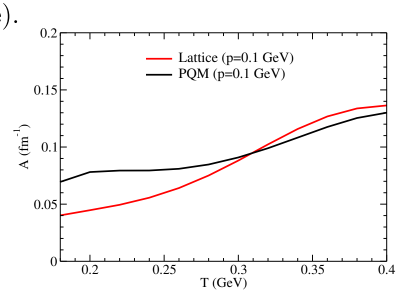

FIG. 1: Variation of drag coefficients (A) with temperature for momentum $p = 100$ MeV.

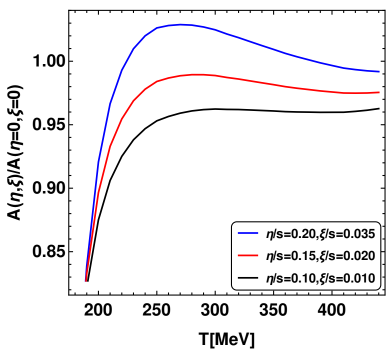

FIG. 2: $A(\eta, \xi)/A(\eta = 0, \xi = 0)$ variation with Temperatur for various values of η/s and ξ/s and $p = 1$ GeV.

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