Studying the diffusion of charm quarks in a deconfined medium using Color String Percolation approach

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1. Introduction

Heavy quarks can play a vital role to characterize the QGP medium as they are produced relatively early in the system as compared to the lighter quarks. The relaxation time of heavy quarks can be approximated as m/T times the relaxation time of the lighter quarks. Due to their high m/T ratio, the number of heavy quarks is expected to be conserved throughout the QGP medium. Moreover, the lifetime of QGP is around 4-5 fm/c at the Relativistic Heavy Ion Collider (RHIC) and 10-12 fm/c at the Large Hadron Collider (LHC). This makes the charm and bottom quarks, which have relaxation time of 10-15 fm/c and 25-30 fm/c respectively, perfect probes to understand the QGP medium. As the charm quarks traverse the medium, they undergo brownian motion in the thermalized medium, which can be quantified by the Fokker-Plank transport equation. Due to the interactions in the medium, the momentum spectra of the charm quark get modified. This information can be extracted by evaluating drag and momentum diffusion coefficients.

2. CSPM formulation

Color String Percolation Model is a QCD-inspired model, and the thermodynamics and transport properties of hot QCD medium computed using CSPM formalism agree with lQCD results to a very good extent. With initial information of the percolation density parameter, ξ, and initial percolation temperature, we can estimate the relaxation time (τ_c), drag coefficient (γ) and the diffusion coefficient in momentum (B_0) and coordinate space ($D_{\rm s}$). Using CSPM formalism, relaxation time for charm quarks can be expressed as [1],

$$\tau_{\rm c} = \frac{M_{\rm c}}{T}\frac{L}{(1-e^{-\xi})} \tag{1}$$

where, L $\sim$ 1 fm, is the longitudinal extension of a string and $M_{\rm c}$ is the mass of the charm quark. The inverse of the relaxation time is the drag coefficient ($\gamma = 1/\tau_{\rm c}$), which incorporates the average momentum change. The transverse momentum diffusion coefficient, B_0, accounts for the broadening of the transverse momentum spectra. From Einstein's relation, the transverse momentum diffusion coefficient relates to the drag coefficient as,

$$B_0 = \gamma M_{\rm c} T = \frac{(1-e^{-\xi})T^2}{L} \tag{2}$$

Further, we introduce the diffusion in coordinate space, $D_{\rm s}$ which contains information on the dissemination of charm quarks in the medium. In other words, it can be understood as the speed of diffusion of charm particles. Following the same formalism, we can express spatial diffusion coefficient, $D_{\rm s}$, as

$$D_s = \frac{L}{(1-e^{-\xi})} \tag{3}$$

Using initial inputs from CSPM, we can compute relaxation time, drag and transverse momentum diffusion coefficient, and spatial diffusion coefficient. A detailed formulation has been shown in the ref. [1].

3. Results and Discussion

In Fig. 1, we have plotted the relaxation time of the charm quark with the temperature of the system. It tells us about the time

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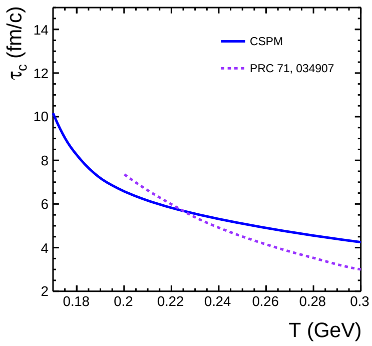

FIG. 1: (Color Online)Relaxation time of charm quarks as a function of temperature [1].

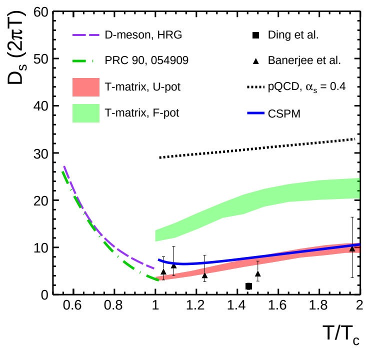

FIG. 2: Spatial diffusion coefficient D_s as a function of temperature scaled by critical temperature [1].

the charm quarks take to get thermalized in a medium. Around the critical temperature, relaxation time is about 10 fm/c. With an increase in the temperature of the system, we observe a decreasing trend in relaxation time. From this, we can conclude that in a dense system, like central heavy-ion collision, the charm quark will interact more as compared to a less dense system like in pp collision. We have also compared our result with the results from ref. [2], where the authors have taken a pQCD approach.

Finally, we have studied the variation of spatial diffusion coefficient, scaled by a factor of $2\pi T$, making it dimensionless, with T/T_c, where T_c is the critical temperature. AdS/CFT calculations suggest a minima, $D_s(2\pi T) \sim 1$, at T_c. In our results, we can observe a similar behavior of $D_s(2\pi T)$ approaching minima near T_c. Our results agree well with the lQCD results [3] along with many other theoretical studies. The observed trend gives us an idea about the interaction in the medium. At a very high temperature, $\sim 2T_c$, a higher value of D_s indicates a significant decrease in the strength of interaction, which can be understood as the partons in that temperature are assumed to be asymptotically free. As the temperature decreases, near T_c, due to the nature of strong interaction, we find a minima for D_s. Again in the hadronic phase, for D meson, there is no strong interaction due to color neutrality resulting in an increase of D_s. It is important to note that particle production dynamics can be drastically affected by the interaction that the heavy quarks undergo in the deconfined medium. It can substantially affect the production of open charm and charmonium particles.

References

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