Charmonium Suppression at RHIC and LHC Energies in a Unified Model

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Introduction

The physical picture of quarkonium dissociation in a thermal medium has undergone theoretical and experimental refinements over the last decade. Heavy quarkonia (J/ψ, Υ etc.) suppression is considered as the most classical observable of QGP formation in heavy ion collision experiments. This is because the heavy mass scale ($m = 3.1$ GeV for J/ψ and $m = 9.2$ GeV for Υ) of these systems makes their theoretical treatment simpler. On the other side, decay of heavy quarkonia via dileptonic channel leads to relatively clean signal which can be precisely measured experimentally. All these experimental observations suggest that the charmonium suppression in QCD plasma is not the result of a single mechanism, but is a complex interplay of various physical processes. In this article we present a unified model which includes most of the dissociation as well as production (recombination) processes to finally calculate the survival probability of J/ψ in QGP medium. We have constructed this model based on the kinetic theory approach whose original ingredients were given by Thews et al. [1].

Model Description

The abundance of charm quark, anti-quark and their bound states i.e, charmonia states (J/ψ, χ_c, $\psi^{'}$ etc.) is governed by a simple master equation involving two reactions: the formation reaction and the dissociation reaction. Thus the time evolution of the number of bound charmonium state in the deconfined region can be written as [1]:

$$\frac{dN_{J/\psi}}{d\tau} = \Gamma_{F,nl} N_c \; N_{\bar{c}} \; [V(\tau)]^{-1} - \Gamma_{D,nl} N_{J/\psi}. \quad (1)$$

In the above equation, $\Gamma_{D,nl}$ and $\Gamma_{F,nl}$ are the dissociation width and recombination reactivity, respectively. N_c, $N_{\bar{c}}$ and $N_{J/\psi}$ are the numbers of produced charm, anti-charm and J/ψ, respectively. One can obtain the analytical solution of Eq.(1) as follows [1]:

$$\begin{aligned} N_{J/\psi}(\tau_f, b) &= \epsilon(\tau_f)[N_{J/\psi}(\tau_0, b) \quad (2) \\ &+ N_{c\bar{c}}^2 \int_{\tau_0}^{\tau_f} \Gamma_{F,nl}[V(\tau)\epsilon(\tau)]^{-1} d\tau], \end{aligned}$$

where τ_0 is the initial thermalization time of the QGP and τ_f is the life time of the QGP. $N_{J/\psi}(\tau_0, b)$ is the initial multiplicity and $N_{J/\psi}(\tau_f, b)$ is the finally survived number of J/ψ meson. $\epsilon(\tau_f)$ and $\epsilon(\tau)$ are the suppression factors and can be calculated as:

$$\epsilon(\tau_f) = \exp\left[-\int_{\tau_0}^{\tau_f} \Gamma_{D,nl} \; d\tau\right]. \quad (3)$$

For $\epsilon(\tau)$ we have to change the highest limit of integration. We have defined $\Gamma_{D,nl}$ as the net sum of collisional damping reaction rate ($\Gamma_{damp,nl}$) and gluonic dissociation reaction rate ($\Gamma_{gd,nl}$) of charmonia in QGP, given as [2]

$$\Gamma_{D,nl} = \Gamma_{gd,nl} + \Gamma_{damp,nl}. \quad (4)$$

$\Gamma_{damp,nl}$ accounts for collisional damping by the QGP partons and is given by;

$$\Gamma_{damp,nl} = \int [g_{nl}(r)^{\dagger} \; [Im(V)] \; g_{nl}(r)] dr, \quad (5)$$

here, $g_{nl}(r)$ is charmonia wave function. Corresponding to different values of n and l, we

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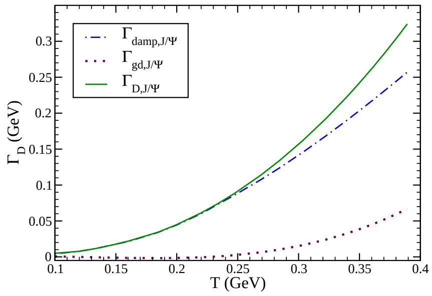

FIG. 1: (Color online) Variation of total dissociation width with temperature along with its components i.e., gluonic dissociation width and width due to collisional damping.

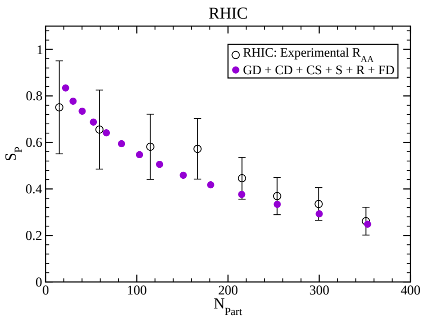

FIG. 2: (Color online) Variation of survival probability S_p of J/ψ with number of participants (N_{part}) at RHIC energy.

have obtained the wave functions for $1S(J/\psi)$, $1P(\chi_c)$ and $2S(\psi^{'})$ by solving the Schrödinger equation. The $\Gamma_{gd,nl}$ can be written as:

$$\Gamma_{gd,nl} = \frac{g_d}{2\pi^2}\int_0^\infty \frac{dp_g\, p_g^2 \sigma_{d,nl}(E_g)}{e^{E_g/T}-1} \quad (6)$$

where $g_d = 16$ is the number of gluonic degrees of freedom. The recombination reactivity, $\Gamma_{F,nl}$ is calculated by taking the thermal average of product of recombination cross section and initial relative velocity between c and $\bar{c}$, $< \sigma_{f,nl}\, v_{rel} >_{p_c}$ at temperature T as follows [3];

$$\Gamma_{F,nl} = \frac{\int\int dp_c\, dp_{\bar{c}}\, p_c^2\, p_{\bar{c}}^2\, f_c\, f_{\bar{c}}\, \sigma_{f,nl}\, v_{rel}}{\int\int dp_c\, dp_{\bar{c}}\, p_c^2\, p_{\bar{c}}^2\, f_c\, f_{\bar{c}}}, \quad (7)$$

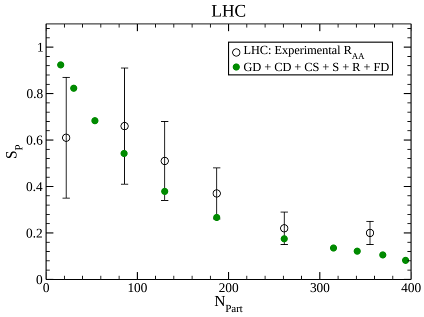

FIG. 3: (Color online) Same as Fig. 2 but at LHC energy.

where, p_c and $p_{\bar{c}}$ are momentum of charm and anti-charm quark, respectively. The $f_{c,\bar{c}}$ is the modified Fermi-Dirac distribution function of charm and anticharm quark. $E_{c,\bar{c}} = \sqrt{p_{c,\bar{c}}^2 + m_{c,\bar{c}}^2}$ is the energy of charm and anticharm quark in medium with mass, $m_{c,\bar{c}} = 1.3$ GeV and $\lambda_{c,\bar{c}}$ is their respective fugacity term [3].

Results and Discussions

In Fig. 2 and 3, we have used GD for gluonic dissociation, CD for collisional damping, CS for colour screening, S for shadowing as a CNM effect, FD for the feed-down correction and R for the regeneration via recombination of c and $\bar{c}$ quarks.

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