Charmonium suppression in a baryon-rich quark-gluon plasma

Partha Pratim Bhaduri[1], *A. K. Chaudhuri[1],† and *Subhasis Chattopadhyay[1]‡
[1] Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata-700 064, INDIA

Introduction

In relativistic heavy-ion collisions, J/ψ suppression has long been identified as a potential probe to indicate the possible occurence of deconfinement phase transition to quark-gluon plasma (QGP) [1]. Till date no measurement however exists on charmonium production in heavy-ion collisions below the top SPS energy, primarily due to their extremely low production cross sections, which in turn demands extremely high beam intensities and detectotrs with large rate capability. The upcoming Compressed Baryonic Matter (CBM) experiment at FAIR [2], in GSI, Germany, for the first time, is aiming at the measurement of charmonium suppression in low energy nuclear collisions, at beam kinetic energies ranging from $E_b = 10 - 40$ A GeV. In this energy domain, highest possible baryon densities are expected to be produced at the center of the collision zone [4], which might lead to a density driven QCD phase transition of the nuclear matter to a baryon rich quark-gluon plasma. In this paper we plan to investigate the possible charmonium suppression effects induced by a baryonic plsama.

Theoretical framework

To model the suppression due to plasma screening in a partonic medium, we have developed a variant of the geometrical threshold model [5]. Debye screening mass as a function of temperature and baryon chemical potential $m_D(T, \mu_B)$, in a dynamically evolving plasma, is used to decide the fate of a particular charmonium state, implanted in the medium. For a collision at an impact parameter b, the differential survival probability, for the i^{th} charmonium state, at a transverse position $\mathbf{s}$, at time τ can be expressed as

$$S_i^{QGP}(b, \mathbf{s}, \tau) = \Theta(r_i - r_D(b, \mathbf{s}, \tau)) \qquad (1)$$

where r_i denotes the separation radius of i^{th} bound state and r_D is the in-medium screening radius. Our model requires the local T and μ_B of the fluid, as a function of collision energy and collision centrality. Recently a number of existing dynamical models based on transport or hydrodynamical equations have been employed to simulate central collisions of gold nuclei in the FAIR energy regime ($5 - 40AGeV$). For each case, central baryon density (ρ_B) and the total energy density (ϵ) are extracted as a function of time. For our present calculations we resort to the UrQMD model to get $\rho_B(t)$ and $\epsilon(t)$, extracted for a central cell of unit thickness ($\Delta z = 1$). To account for the spatial non-uniformity of the medium, we set the initial distributions of ρ_B and ϵ in the transverse plane, in proportion to the participant density ($npart(b, s)$), at a given impact parameter, according to the Glauber model. ρ_B and ϵ values so obtained, can then be simultaneously plugged in a suitable equation of state (EOS) to solve for the corresponding values of local T and μ_B. In the present paper, we use the parametric form of QGP equation of state proposed by Kapusta [3], which matches with the lattice QCD simulation at zero chemical potential and to the known properties of nuclear matter at zero temperature. In the EOS, one input parameter T_0 can be identified with T_c the pseudo-critical temperature at $\mu_B \approx 0$. The critical energy density (ϵ_c), required for deconfinement can then be estimated at $\mu_B \approx 0$. Since T_c as a function of μ_B is believed to follow a nearly constant den-

*Electronic address: partha.bhaduri@vecc.gov.in
†Electronic address: akc@vecc.gov.in
‡Electronic address: sub@vecc.gov.in

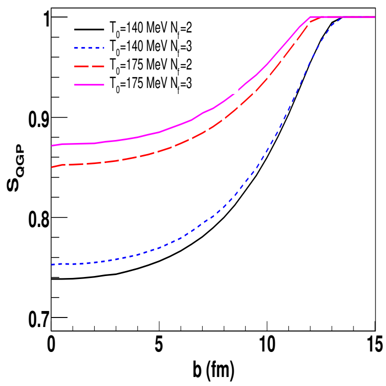

FIG. 1: Centrality dependence of total J/ψ survival probability in 30 A GeV $Au + Au$ collisions. Suppression is solely induced by a baryon rich QGP to color screening mechanism. Different curves correspond to different values of N_f and T_0 used as inputs to the QGP EOS.

sity curve, we assume ϵ_c, to remain constant with increase in μ_B.

Results and Discussions

We now have all the ingredients to calculate the centrality dependence of the J/ψ suppression pattern in a QGP medium. Inclusive survival probability can be obtained by integrating Eq. 1 over space-time. To do so we distribute J/ψ in the transverse plane, following the transverse density of binary collisions $n_{coll}(\mathbf{b}, \mathbf{s})$, as obtained in Glauber model. Debye screening remains operational on a bound state, over the time it spends inside the plasma. The lower limit of the screening time is assumed to coincide with the thermalization time of the medium (tau_{th}). Relaxation to local equilibrium cannot occur earlier than a certain time needed for the Lorentz contracted nuclei to pass through each other. Following [6], we take $\tau_{th} = (\frac{2R_A}{\gamma\beta} + \frac{\Delta z}{2\beta})$, which gives lower bound of thermalization time, where R_A denotes the nuclear radius and Δz denotes the thickness of the central cell in the longitudinal direction. In practice, it has been found that only about 60% of the observed J/ψ originate directly in hard collisions while 30% of them come from the decay of χ_c and 10% from the ψ'. Hence, the total survival probability of J/ψ becomes, S_{tot}=$0.6S_{J/\psi}+0.3S_{\chi_c}+0.1S_{\psi'}$. In Fig. 1, we have plotted the total survival probability as a function of collision centrality. In order to investigate the sensitivity of the J/ψ survival on the EOS driving the plasma evolution, curves are generated for different qurak flavors and T_0 test values. The lower value arises from the hope that T_c cannot be less than the pion rest mass. The higher value is inspired from [7]. Suppression is found to be more sensitive to the choice T_0 compared to N_f. A higher T_0 in turn results in higher critical energy density ϵ_c for deconfinement and thus results in shrinking the spatio-temporal extent of the plasma. Two different values of T_0 chosen for present illustration represent two extreme cases giving two possible boundaries of the suppression pattern. In practice, depending on the exact value of T_c, it could lie in between.

In summary, we have studied the charmonium survival probability, in a baryon rich quark-gluon plasma. Such high density plasma is believed to exist in the core of the neutron stars and expected to be formed in the low energy nuclear collisions at FAIR. Suppression pattern resulting from plasma screening is found to be sensitive to the parameters of EOS governing the plasma dynamics.

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