J/ψ meson in hot and dense nuclear medium

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Introduction

Understanding of QCD phase diagram for wide range of baryonic density and temperature is the major goal of the Heavy Ion Collision experiments and of many theoreticians working in a field of Hadron Physics. Further the study of in-medium hadrons in nuclear medium is important to understand the possible outcomes of HIC experiments. In particular, the in-medium study of J/ψ state, has importance, as decrease in the yield of J/ψ state is considered as an important signature of the production of quark gluon plasma in heavy ion collision experiments. In the present paper, we observe the effect of pseudoscalar D meson loop contribution, on the shift in mass of J/ψ state. The in-medium mass of J/ψ state is observed using the second order QCD-Stark effect. The medium effects are incorporated using the gluon condensates, which is further calculated using the chiral SU(3) model in terms of dilaton field χ. The results of the present work will be helpful for the understanding of the possible outcomes of HIC experiments like CBM and PANDA under FAIR facility at GSI Germany.

Methodology

From the second order QCD-Stark effect, and the chiral SU(3) model, the shift in mass of the J/ψ state can be represented in terms of the dilaton field (χ), as [1, 2]

$$\Delta' m_{J/\psi} = \frac{4}{81}(1-d)\int dk^2 \left|\frac{\partial\psi(q)}{\partial q}\right|^2 \times \frac{k}{k^2/m_c + (2m_c - m_{J/\psi})}(\chi^4 - \chi_0^4), \quad (1)$$

here, m_c and m_ψ are the masses of charm quark and J/ψ state, respectively. $\psi(q)$ is the wave function of the charmonium state in the momentum space. Using the Guassian wave function for J/ψ state [2], and using the in-medium dilaton field χ(as calculated in chiral SU(3) model [2]), we obtain the shift in mass of J/ψ state. Furthermore, from the non-gauged Lagrangian density for $J/\psi - D$ vertices, we derive the expression of self energy for D meson loop contribution, as [3]

$$\Sigma_{DD}(m^2_{J/\psi}) = \frac{-g^2_{J/\psi DD}}{3\pi^2}\int dq \frac{q^4}{(q^2+m_D^2)^{1/2}} \left(\frac{q^2}{(q^2+m_D^2)^2 - m_\psi^2/4}\right) F_{DD}(q^2), \quad (2)$$

where $F_{DD}(q^2)$ is the vetex form factor, which is taken as dipole form factor in the present work [3]. Also the bare mass is calculated as from the vacuum values of mass of J/ψ and D meson as,

$$m^2_{J/\psi} = (m^0_{J/\psi})^2 + \Sigma(k^2 = m^2_{J/\psi}), \quad (3)$$

where, $m^0_{J/\psi}$ is the bare mass and $\Sigma(k^2 = m^2_{J/\psi})$ is the total J/ψ self-energy obtained from the contribution from DD loop. Moreover, to calculcate the in-medium mass of J/ψ state, we fix the bare mass and solve the in-medium self energy using the in-medium mass of D meson, calculated using QCD sum rule and chiral SU(3) model [4]. Finally, the shift in mass of J/ψ meson is observed as

$$\Delta'' m_{J/\psi} = m^*_{J/\psi} - m_{J/\psi}. \quad (4)$$

Here, $m^*_{J/\psi}$ denotes the in-medium mass of J/ψ state. Finally, the total mass shift is given by $\Delta m_{J/\psi} = \Delta' m_{J/\psi} + \Delta'' m_{J/\psi}$.

Results and Discussion

In this section, we will discuss various results of the present work. We take vacuum

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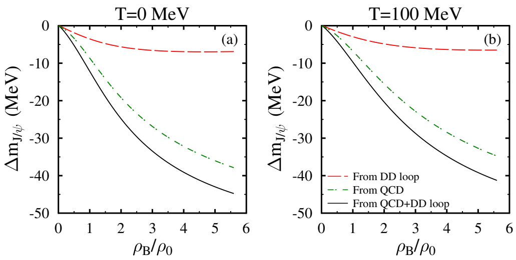

FIG. 1: (Color online) We represent the shift in the mass of J/ψ meson as a function of baryonic density of the medium, calculated using second order QCD-Stark effect and loop contribution of D meson. These values are compared for two values of temperature, i.e., $T = 0$ and $T = 100$ MeV.

mass of D and J/ψ mesons as 1867 and 3096 MeV, respectively. Further, we choose the coupling constant as $g_{J/\psi DD}$=7.66 [3]. From fig. 1, we observe a decrease in the mass of J/ψ state as a function of baryonic density. For example, at baryonic density ρ_B=ρ_0 and temperature, T=0 the shift in mass of J/ψ state is observed as -8.3 MeV, in symmetric nuclear medium. Here, D meson loop contribution further give a drop of -3.5 MeV, which enhance the drop of shift to -11.7 MeV. Likewise, at $\rho_B = 4\rho_0$, the total shift is observed as -39.1 MeV, with the contribution of -32.2 MeV from the second order QCD-Stark effect and -6.9 MeV from the D meson loop. On the other hand, finite temperature of the medium cause increase in the mass of J/ψ state. For example, at $\rho_B = \rho_0(4\rho_0)$ and temperature $T = 100$ the magnitude of the shift in mass calculated using the pseudoscalar D meson loop contribution observed to be -2.9(-6.3) MeV. This drop in the magnitude of shift in mass give the total drop of -9.67(-34.7) MeV. This can be understood on the basis of increase in the mass of D meson as a function of temperature of the medium discussed in [4]. Now we compare the results of the present investigation with literature. In [1], using second-order Stark effect, computed shift in mass of J/ψ state was -8 MeV, at baryonic density $\rho_B = \rho_0$ and temperature $T = 0$ in symmetric nuclear medium. In [5], authors used QCD sum rules and obtain J/ψ mass shift of about -7 MeV at baryonic density $\rho_B = \rho_0$. In Ref. [6] above shift was observed to be -4 MeV, at nuclear saturation density, using the OPE expansion upto dimension six in QCD sum rules. In-medium mass of J/ψ meson may be helpful, to understand the J/ψ suppression, observed in NA50 collaboration at 158 GeV/nucleon in Pb-Pb collisions. The drop in the mass of J/ψ state is not as great as observed for D meson [4]. Therefore, there is also a finite possibility of J/ψ states to decay to $D\bar{D}$ pairs and hence, the suppression of J/ψ state may occur in hadronic medium also.

Conclusion

We observe negative shift in mass of J/ψ states using second order QCD-Stark effect along with chiral SU(3) model. Further, we observe explicitly, the pseudoscalar D meson loop contribution on the shift in mass of J/ψ state. We notice that D meson loop contribution enhance the drop of J/ψ state, approximately by 2-5 MeV. The results of the present investigation, may be verified from the future HIC experiments like CBM and PANDA under FAIR facility.

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