In-medium partial decay width of decay process $\psi(4040) \rightarrow D\bar{D}$

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Introduction

The study of mesons in the hadronic medium play an essential role in the understanding of the quantum chromodynamics (QCD) phase diagram. In particular, the observation of the in-medium properties of the higher charmonium states is important to understand the phenomenon of J/ψ suppression, which is believed to be one of the famous signatures for the production of the quark-gluon plasma (QGP) in the different heavy ion collision experiments (HIC). In our previous work, we predicted the decrease in the mass of pseudoscalar D meson in the hadronic medium [1]. Further, if this drop in the mass is higher enough, then the higher charmonium states may decay to $D\bar{D}$ pairs instead of the J/ψ state, and this may also cause a decrease in the yield of J/ψ state. Therefore, to have an unambiguous understanding of the J/ψ suppression, the in-medium properties of the mesons become important. In the present work, by using $^3P_0$ model, we compute the in-medium partial decay width of the process $\psi(4040) \rightarrow D\bar{D}$. We impose the medium effects through the in-medium mass of the D meson, which we calculated using chiral SU(3) model and QCD sum rules approach [1]. The results of the present investigation may be important to understand the possible outcomes of the heavy ion collision experiments, e.g. CBM and PANDA under FAIR facility.

Methodology

We use $^3P_0$ model, in which the quark and antiquark pair is supposed to be created with the vacuum 0^{++} quantum numbers [2]. To investigate the in-medium partial decay widths of mesons mentioned above, for general decay $\psi(4040) \rightarrow D\bar{D}$, we use the helicity amplitude given in ref. [2]. We then calculate the spin matrix elements $\langle \chi^{13}_{S_D M_{S_D}} \chi^{24}_{S_{\bar{D}} M_{S_{\bar{D}}}} | \chi^{12}_{S_{\psi(4040)} M_{S_{\psi(4040)}}} \chi^{34}_{1-m} \rangle$ in terms of the Wigner's 9j symbol and the flavor matrix element $\langle \varphi^{13}_D \varphi^{24}_{\bar{D}} | \varphi^{12}_{\psi(4040)} \varphi^{34}_0 \rangle$ in terms of isospin of quarks, as done in Refs. [2]. Furthermore, using the Jacob-Wick formula [2], we transform the helicity amplitude into the partial wave amplitude:

$$\mathcal{M}^{JL}(\psi(4040) \rightarrow D\bar{D}) = \frac{\sqrt{2L+1}}{2J_{\psi(4040)}+1} \sum M_{J_D}, M_{J_{\bar{D}}} \langle L0JM_{J_{\psi(4040)}} | J_{\psi(4040)} M_{J_{\psi(4040)}} \rangle \times \left\langle J_D M_{J_D} J_{\bar{D}} M_{J_{\bar{D}}} \right| \left. J M_{J_{\psi(4040)}} \right\rangle M^{M_{J_{\psi(4040)}} M_{J_D} M_{J_{\bar{D}}}}(\vec{K}) \quad (1)$$

where $\vec{J} = \vec{J}_D + \vec{J}_{\bar{D}}$, $\vec{J}_\psi = \vec{J}_D + \vec{J}_{\bar{D}} + \vec{L}$, $M_{J_{\psi(4040)}} = M_{J_D} + M_{J_{\bar{D}}}$. Also the expression of decay width is given as

$$\Gamma = \pi^2 \frac{|\vec{K}|}{m^2_{\psi(4040)}} \sum_{JL} |\mathcal{M}^{JL}|^2, \quad (2)$$

where $|\vec{K}|$ represents the momentum of the D and $\bar{D}$ mesons in the rest mass frame of $\psi(4040)$ given as $|\vec{K}| = \frac{\sqrt{[m^2_{\psi(4040)} - (m^*_D - m^*_{\bar{D}})^2][m^2_{\psi(4040)} - (m^*_D + m^*_{\bar{D}})^2]}}{2m_{\psi(4040)}}$, and γ is the strength of the pair creation in the vacuum, and its value is taken as 6.74. By using the in-medium mass of D meson as calculated in ref. [1], we calculate the in-medium value of $\Gamma_{D\bar{D}}(\psi(4040))$.

Results and discussion

We take the masses of u, d, s and c quarks as 0.33, 0.33, 0.55 and 1.6 GeV, respectively. Further, the value of $R_{\psi(4040)}$ is chosen to be

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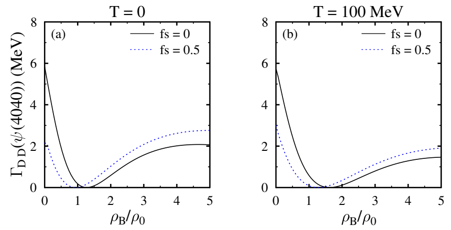

FIG. 1: (Color Online) We represent the effect of temperature and density on the partial decay width of the process $\psi(4040) \to D\bar{D}$ pairs.

3.13 GeV^{-1}. In fig. (1), we represent the variation of $\Gamma_{D\bar{D}}(\psi(4040))$, as a function of the baryonic density of the medium at finite strangeness fraction f_s and temperature T. We observe that, in nuclear medium and at T=0, the value of $\Gamma_{D\bar{D}}(\psi(4040))$ decreases as a function of the density of the medium, and become zero at ρ_B=1.2ρ_0. This happens because of the nodal structure of the simple harmonic oscillator wave function of the excited state 3^3S_1 of $\psi(4040)$ meson. Here, due to this nodal structure, the polynomial part present in the equation of the helicity amplitude of the decay ($\psi(4040) \to D\bar{D}$), cause opposite behaviour of the decay width.

TABLE I: We enlist the numerical data(in the unit of MeV) of the in-medium partial decay width of the process $\psi(4040)$ decaying to a pair of pseudoscalar D mesons, i.e. $D\bar{D}$.

		$\rho_B = \rho_0$		$\rho_B = 4\rho_0$	
	f_s	T = 0	T=100 MeV	T = 0	T=100 MeV
$\Gamma_{D\bar{D}(4040)}$	0	0.18	0.6	2	1.3
	0.5	0.007	0.09	2.6	1.7

However, beyond this nodal point, the increase in the baryonic density of the medium cause an increase in the partial decay width. This can be understood on the fact that, the mass of D meson decrease in the medium and this further enhance the decay channel for the decay $\psi(4040) \to D\bar{D}$. Furthermore, we observe that beyond the nodal point, finite strangeness fraction f_s=0.5, cause an increase in the value of $\Gamma_{D\bar{D}(\psi)}$, whereas, the finite temperature of the medium T=100 MeV, cause a decrease in the value of the above mentioned partial decay width. This can be understood on the basis that the finite strangeness fraction causes more drop in the mass of D meson, which enhances the decay channel. On the other hand, the finite temperature of the medium enhances the mass of D meson, which results in decrease in the decay width $\Gamma_{D\bar{D}}(\psi(4040))$. For the better understanding, we also represent the numerical data in table I. Moreover, the observed values of $\Gamma_{D\bar{D}}(\psi(4040))$ are just few MeVs. For the precise conclusions, the study of decay $\psi(4040) \to D\bar{D}$, and $\psi(4040) \to J/\psi + \eta$, in an isospin asymmetric hot and dense matter and their comparison will be our future goal.

Conclusion

We used $^3P_0$ model to find the in-medium partial decay width of the decay $\psi(4040) \to D\bar{D}$. The medium effects are incorporated through the in-medium mass of D mesons. We observed that finite baryonic density, strangeness fraction and temperature of the medium cause the significant change in the partial decay width $\Gamma_{D\bar{D}}(\psi(4040))$. The results of the present work may be verified from the future HIC experiments.

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References

[1] R. Chhabra and A. Kumar, Eur. Phys. J. A **53**, 105 (2017).

[2] L. Chen, D. Ye, A. Zhang, Eur. Phys. J. C **74**, 3031 (2014).