Impact of nuclear density on the mass splitting of the pseudoscalar D meson

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Abstract

We deduce the D meson and nucleon interactions from the QCD sum rules. Unifying the chiral SU(3) model, we study the in-medium mass splitting between pseudoscalar D^+ and D^- meson in the hot and dense asymmetric nuclear matter. The medium modified quark and gluon condensates are evaluated from the chiral SU(3) model and further plugged into the QCD sum rules to compute the in-medium mass of pseudoscalar D meson. We find that the mass of both D^+ and D^- meson increase with the medium density. We calculate the D meson mass in centroid approximation and compared it with the mass of D^+ and D^- meson. By plugging the in-medium mass of D^+ and D^- meson in the mass splitting formula, $\Delta m^*(=m^*_{D^+}-m^*_{D^-})$, we observe non-negligible splitting in the D^+ and D^- mass which increases appreciably as a function of nuclear density. The medium modified mass evaluated in this work can be used as application to study the decay width of higher charmonia states decaying into D^+D^- pairs.

Introduction

In-medium effects of pseudoscalar D meson can be used to study the J/ψ suppression [1, 2]. Various theoretical studies have been done to study the in-medium properties of pseudoscalar D mesons. For example, the in-medium mass and decay constant of D meson was studied using the method of Borel transformation [1, 2, 3, 4] and Operator Product Expansion [1, 2]. In addition to the density, temperature, and asymmetry of the medium, recently in heavy-ion collisions, the effect of the strong magnetic field was also found [2, 5]. Therefore, the study of hadrons under magnetic effects attracts the interest of many researchers [2, 5]. In this article, the scalar and vector densities with and without the effect of the magnetic field are calculated using the chiral SU(3) model and these medium effects are relayed by scalar fields to the quark and gluon condensates [2]. These condensates are further coupled with even-odd sum rules to evaluate the D meson mass.

Methodology

- **The Chiral SU(3) Model**

In the model, the density dependent light quarks $\langle\bar{q}q\rangle_{\rho_N}$ and scalar gluon condensate $\langle\frac{\alpha_s}{\pi}G^2\rangle_{\rho_N}$ can be written as [2, 6]

$$\langle\bar{d}d\rangle_{\rho_N} = \frac{1}{m_d}\left(\frac{\chi}{\chi_0}\right)^2\left[\frac{1}{2}m_\pi^2 f_\pi(\sigma-\delta)\right], \qquad (1)$$

and

$$\langle\frac{\alpha_s}{\pi}G^2\rangle_{\rho_N} = \frac{8}{9}\Bigg[(1-\xi)\chi^4 + \left(\frac{\chi}{\chi_0}\right)^2\Big(m_\pi^2 f_\pi\sigma + (\sqrt{2}m_k^2 f_k - \frac{1}{\sqrt{2}}m_\pi^2 f_\pi)\zeta\Big)\Bigg]. \qquad (2)$$

- **Even-odd QCD Sum Rules**

In this section, we derive the expression for the in-medium mass of $D^+(c\bar{d})$ and $D^-(d\bar{c})$ mesons. In QCD Sum Rules, the in-medium properties of mesons are studied using the two-point current correlation function, given by

$$\Pi(q) = i\int d^4x\, e^{iqx}\langle\Omega|\mathrm{T}\left[\mathrm{j}(x)\mathrm{j}^\dagger(0)\right]|\Omega\rangle. \qquad (3)$$

The current correlation function, $\Pi(q_0,\vec{q})$ can be expressed into an even and odd part as

$$\Pi(q_0,\vec{q}) = \Pi^e(q_0^2,\vec{q}) + q_0\Pi^o(q_0^2,\vec{q}). \qquad (4)$$

Using Borel transformation, the in-medium mass of the $D^+(m^*_+)$ and $D^-(m^*_-)$ can be written as [4, 3]

$$m^*_\pm = \Bigg[\frac{1}{4}\left(\frac{g(M,m_c)\frac{d}{d(1/M^2)}f(M,s_0,m_c,\mu) - f(M,s_0,m_c,\mu)\frac{d}{d(1/M^2)}g(M,m_c)}{f^2(M,s_0,m_c,\mu)+g(M,m_c)\frac{d}{d(1/M^2)}g(M,m_c)}\right)^2 - \frac{f(M,s_0,m_c,\mu)\frac{d}{d(1/M^2)}f(M,s_0,m_c,\mu)+\left(\frac{d}{d(1/M^2)}g(M,m_c)\right)^2}{f^2(M,s_0,m_c,\mu)+g(M,m_c)\frac{d}{d(1/M^2)}g(M,m_c)}\Bigg]^{\frac{1}{2}} \pm \frac{1}{2}\frac{g(M,m_c)\frac{d}{d(1/M^2)}f(M,s_0,m_c,\mu) - f(M,s_0,m_c,\mu)\frac{d}{d(1/M^2)}g(M,m_c)}{f^2(M,s_0,m_c,\mu)+g(M,m_c)\frac{d}{d(1/M^2)}g(M,m_c)}.$$

In the presence of magnetic field, due to Landau quantization effect, the in-medium mass of charged D meson modify as [2]

$$m^{**}_\pm = \sqrt{m^{*2}{}_\pm + |eB|} \qquad (5)$$

The mass-splitting with (**) and without (*) magnetic field effect can be written as

$$\Delta m^{**,*} = m_+^{**,*} - m_-^{**,*} \qquad (6)$$

Results and Discussions

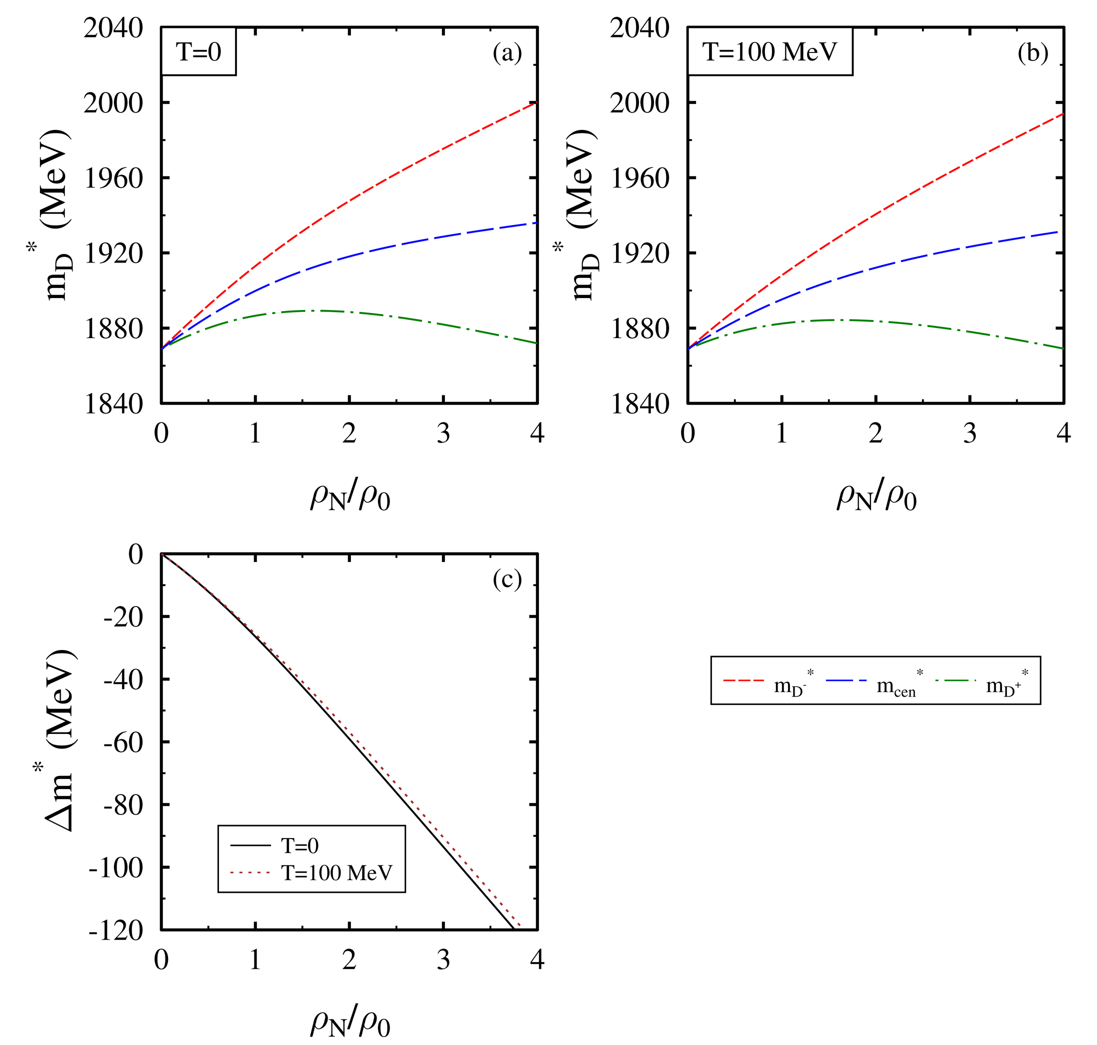

Figure 1:In-medium mass-splitting and mass of of D^+ and D^- mesons with respect to density.

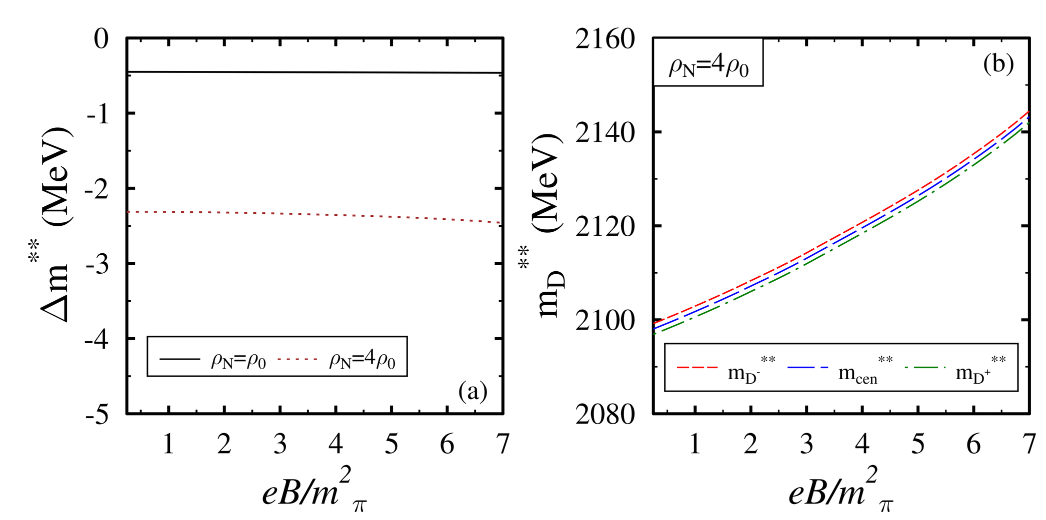

Figure 2:In-medium mass-splitting and mass of of D^+ and D^- mesons in the presence of magnetic field.

In this section, we have shown and discussed the plots of in-medium mass of pseudoscalar D meson calculated with and without the effect of a strong magnetic field. As discussed earlier, the down quark and gluon condensates are evaluated using chiral SU(3) model which are further used as input in the Even-odd Sum Rules to calculate the medium modified D meson mass. In the sum rule calculations, we use the charm quark mass m_c and continuum parameter s_0 to be 1.5 and 5.1 GeV, respectively.

The s_0 parameter is fixed to reproduce the vacuum mass of D meson. Besides, the in-medium values of quark condensates mentioned in the Eqs.(5) and (6) are taken from Ref. [4]. In the sum rules framework, we have taken the Borel parameter, M=1.21 GeV to choose the proper Borel window [3].

- We find that the mass of D^+ and D^- meson increase appreciably with increasing nuclear density.
- The in-medium mass increase with the increase in the magnetic field.
- The results obtained in the present investigation is complimentary to the work done in Ref. [1, 2]

Summary

- We find that the mass-splitting of D^+ and D^- meson mass has substantial effect of increasing nuclear density.
- The calculated in-medium mass can be utilized further to study the decay width of higher charmonia into D^+D^- pairs.

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