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D^* and B^* mesons in strange hadronic medium at finite temperature

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Abstract. We calculate the effect of density and temperature of isospin symmetric strange medium on the shift in masses and decay constants of vector D and B mesons using chiral SU(3) model and QCD sum rule approach. In the present investigation the values of quark and gluon condensates are calculated from the chiral SU(3) model and these condensates are further used as input in the QCD Sum rule framework to calculate the in-medium masses and decay constants of vector D and B mesons. These in medium properties of vector D and B mesons may be helpful to understand the experimental observables of the experiments like CBM and PANDA under FAIR project at GSI, Germany. The results which are observed in present work are also compared with the previous predictions.

1 Introduction

Medium modification of heavy mesons is important to understand the QCD phase transition and the outcomes of different heavy ion collision experiments. In-medium properties of mesons are believed to be changed from the vacuum properties due to the interactions with the medium. These modifications can effect the various observed values, e.g, if the mass reduction of D(B) meson in the medium is very large then higher charmonium (bottomonium) states can decay to these D(B) mesons instead of $J/\psi(\Upsilon)$ and hence will suppress their production. On the other hand, if masses of these mesons increase to very high value then these mesons can facilitates the production of $J/\psi(\Upsilon)$. These statements are important because suppression of $J/\psi(\Upsilon)$ is considered as an important indication of production of Quark Gluon Plasma and therefore extra care has to be taken before to make definite conclusion. Negative mass shift of these mesons predicts the attractive potential in nuclear medium which shows that the bound states of $D^*N(B^*N)$ is possible. Positive mass shift predicts repulsive potential in the medium and shows that bound states of $D^*N(B^*N)$ mesons is not possible. These predictions can be confirmed from the data of future experiments like CBM and PANDA. In present work, we investigate the medium modification of D^* and B^* mesons in hot and dense strange medium using Chiral SU(3) model and QCD sum rule. We calculate the values of condensates through Chiral SU(3) model and these act as input to the QCD sum rules which we further use to calculate the medium modification of vector D and B mesons in hadronic medium.

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2 Chiral SU(3) Model

Chiral SU(3) model is an effective theory which we can use in a regime where basic theory of QCD interaction fails. Chiral SU(3) model is based on the chiral symmetry, broken scale invariance, non realization and broken scale invariance property of chiral symmetry. From the Lagrangian density of the model, using mean field approximation, we obtain the coupled equations of motion for the scalar fields σ, ζ and scalar dilaton field χ. These coupled equations are solved to investigate the density and temperature dependence of σ, ζ and χ in hadronic medium. By introducing explicit symmetry breaking term, we can calculate the values of quark condensates $< \bar{q}q >$ in terms of these mesons [1],

$$\sum_i m_i \bar{q}_i q_i = \left(\frac{\chi}{\chi_0}\right)^2 \left(m_\pi^2 f_\pi \sigma + (\sqrt{2} m_k^2 f_k - \frac{1}{\sqrt{2}} m_\pi^2 f_\pi)\zeta\right). \tag{1}$$

Similarly, broken scale invariance term can be used to evaluate the gluon condensates and we have,

$$\left\langle \frac{\alpha_s}{\pi} G^a{}_{\mu\nu} G^{a\mu\nu} \right\rangle = \frac{8}{9}\left[(1-d)\chi^4 + \left(\frac{\chi}{\chi_0}\right)^2 \left(m_\pi^2 f_\pi \sigma + (\sqrt{2} m_k^2 f_k - \frac{1}{\sqrt{2}} m_\pi^2 f_\pi)\zeta\right)\right]. \tag{2}$$

Using equations (1) and (2) we can calculate the medium modification of quark and gluon condensates through the medium modification of scalar fields σ, ζ and scalar dilaton field χ [2].

3 QCD SUM RULE FOR VECTOR D AND B MESONS

We start with the two point correlation function, $\Pi_{\mu\nu}(q)$ which can be divided into the vacuum part, nucleon part and pion bath terms[2]. We have,

$$\Pi_{\mu\nu}(q) = \Pi^0_{\mu\nu}(q) + \frac{\rho_B}{2m_N} T^N_{\mu\nu}(q) + \Pi^{P.B.}_{\mu\nu}(q), \tag{3}$$

In Eq. (3), third term on the right, i.e, pion bath term had been used in the literature to investigate the effect of temperature on the properties of mesons. In this investigation, we ignore pion bath term and calculate the effect of temperature on the mesons through the modification of scalar σ, ζ, and scalar dilaton χ fields with temperature. As discussed in [4], correlation function $T^N_{\mu\nu}(q)$ can be related to D^*N scattering T matrix through scattering lengths. Phenomenological density can be parametrized in terms of unknown parameters a, b and c [5]. Borel transformed equation is used to solve these unknown parameters and final mass shift can be defined as [4],

$$\delta m_{D^*} = \sqrt{m^2_{D^*} + \Delta m^2_{D^*}} - m_{D^*}, \tag{4}$$

where, shift of squared mass, $\Delta m^2_{D^*}$ of mesons can be written in terms of unknown parameter a and hence scattering length a_{D^*},

$$\Delta m^2_{D^*} = \frac{\rho_B}{2m_N} \frac{a}{f^2_{D^*} m^2_{D^*}} = -\frac{\rho_B}{2m_N} 8\pi(m_N + m_{D^*}) a_{D^*}. \tag{5}$$

In this problem, we use the centroid approximation and calculate the average mass shift of particle and antiparticle instead of their mass splitting. In [3], author investigated the mass splitting by taking the even and odd part of QCD sum rule. Shift in decay constant can be written as [6],

$$\delta f_{D^\star} = \frac{1}{2 f_{D^\star} m^2_{D^\star}} \left(\frac{\rho_B}{2m_N} b - 2 f^2_{D^\star} m_{D^\star} \delta m_{D^\star}\right). \tag{6}$$

Table 1. Numerical result to indicates the effect of density ρ_B, temperature, T(in MeV) and strangeness fractions, f_s of the medium, on the decay shift(in MeV) of vector mesons

	$\delta f_{D^*}(\delta f_{B^*})$				$\delta f_{D_s^*}(\delta f_{B_s^*})$			
	$\rho_B = \rho_0$		$\rho_B = 4\rho_0$		$\rho_B = \rho_0$		$\rho_B = 4\rho_0$	
fs	T=0	T=150	T=0	T=150	T=0	T=150	T=0	T=150
0	-18(-56)	-13(-43)	-28(-104)	-23(-91)	-11(-30)	-8(-23)	-18(-53)	-15(-46)
0.3	-22(-68)	-16(-54)	-31(-108)	-24(-95)	-16(-42)	-13(-34)	-28(-76)	-24(-65)

QCD sum rule equations for vector B meson can be found by simply using mass of bottom, b, quark instead of mass of charm, c, quark in sum rule equation for vector D meson [6].

4 Results and Discussions

The values of masses, decay constants and threshold parameter s_0 of $D^*(B^*)$ mesons are 2.01(5.325), 0.270(0.195) GeV and 6.5(35) GeV^2, respectively. For $D_s^*(B_s^*)$, we use the values of masses, decay constants and threshold parameter as 2.112(5.415), $1.16 f_{D^*}(1.16 f_{B^*})$ GeV, and 7.5(38) GeV^2, respectively. Nuclear matter saturation density chosen in the present case is $0.15 fm^{-3}$. We chose the value of coupling constant $g_{D^* N \Lambda_c} \approx g_{D^* N \Sigma_c} \approx \approx g_{B^* N \Lambda_b} \approx g_{B^* N \Sigma_b}$ as 3.86 [4]. The masses of quarks, u, d, c, b used in present investigation are 0.005, 0.007, 0.095, 1.35 and 4.7 GeV, respectively. In case of mass shift the Borel window chosen for D^*, B^*, D_s^* and B_s^* are (4.5-6.5), (30-33), (5.0-7.0) and (31-34) GeV^2, respectively. For decay shift, we chose Borel window as (3.3-4.9), (26-31), (3.8-5.3) and (27-31) GeV^2, respectively [2]. We chose proper Borel window so that there is almost no variation in the shift in masses and decay constant. In Fig. 1, we plot the shift in masses and decay constants of D^*, B^*, D_s^* and B_s^* mesons as a function of square of Borel mass parameter, i.e, M^2. We observe that in nuclear medium, at zero temperature, the value of mass shift for $D^*(B^*)$, $D_s^*(B_s^*)$ meson change from -76(-367), -46(-206) to -128(-707), -76(-377) MeV, when we move from $\rho_B = \rho_0$ to $\rho_B = 4\rho_0$. This clearly indicates the much large drop of masses of $D^*(B^*)$ vector mesons, with increase in the density of the medium and therefore, this may cause $J/\psi(\Upsilon)$ suppression in heavy ion collision experiments. The negative mass shift reveals the attractive interaction in the nuclear medium and hence it may be possible to form bound states $D^*N(B^*N)$. For constant value of density and temperature of the medium, increase in the value of mass shift is observed when we move from non strange medium, i.e, $f_s = 0$ to strange medium, i.e, $f_s = 0.3$. On the other hand, shift in mass for finite temperature of medium, $T = 150$ MeV is less as compared to the zero temperature values, $T = 0$ and therefore, temperature decrease the magnitude of the shift in masses of vector mesons. Table 1 shows the shift in decay constant of $D^*(B^*)$ and $D_s^*(B_s^*)$ mesons for baryonic density, ρ_0 and $4\rho_0$ and temperature, T = 0 and 150 MeV. The results are plotted for strangeness fractions, $f_s = 0$ and $f_s = 0.3$. The magnitude of the shift in decay constants of vector mesons increase with the increase in the density of the medium for constant value of strangeness fraction, f_s and temperature, T. Similarly, for constant value of density, ρ_B and temperature, T, with increase in the strangeness fraction, f_s, of the medium, the decay shift increase. The values of masses and decay constants depend on the values of quark and gluon condensates and these condensates are proportional to the scalar fields, σ and ζ. Therefore, the medium modification of masses and decay constants of vector D and B mesons are due to the medium modification of scalar fields, σ and ζ [2].

Medium modification of heavy vector mesons had also been studied in [1, 4, 6]. Using QCD sum rules the values of mass shift for D^* and B^* in [4] were -71 and -380 MeV, respectively. In [6] by including the leading order term in the QCD sum rules, author studied the shift in masses(decay con-

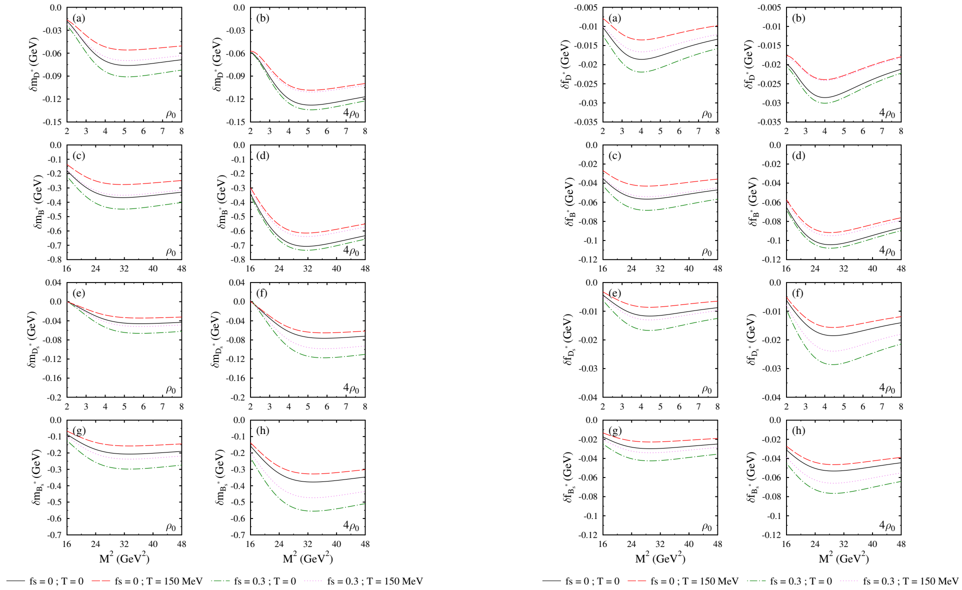

Figure 1. We plot the mass shift (left) and shift in decay constant (right) of D^*, B^*, D_s^* and B_s^* meson as a function of Borel mass parameter M^2. We show the result at temperature $T = 0$ and $T = 150$ MeV. For each value of temperature results are shown for strangeness fractions, $f_s = 0$ and 0.3.

stants) of vector D and B mesons as -70(-16) and -340(-55) MeV, whereas, including next to leading order term observation changed to -102(-26) and -687(-111) MeV, respectively. We can compare these values with our calculated values -76(-18) and -367(-56) MeV, respectively, at nuclear saturation density, zero temperature and in non-strange medium. Using self consistent coupled channel approach authors in [7] observed the positive values of mass shift, which indicates the repulsive interaction in the medium. In our present work, the negative values of shift indicates the attractive interaction in the nuclear medium and this indicates the possibility of bound states $D^*N(B^*N)$. Further, decrease in the masses of D and B meson can suppress J/ψ (Υ) production in heavy ion collision experiments.

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