Spectral properties of charmed mesons at finite temperature

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We present a thermal field theoretical description of D and D^* meson propagation in hot hadronic matter containing π, K and η mesons in thermal equilibrium. We consider the one-loop self-energy function and find all the branch cuts and the associated discontinuities. In addition to the unitary cut, present already in the vacuum amplitude, the thermal amplitude generates a new, so-called Landau cut. Thus different conventional sources of medium modification are automatically included in the calculation, if we retain the contribution of both the cuts. For calculating the self-energy of D meson, We have taken four different loops with one heavy-light internal D^* line and another light pseudoscalar internal line, namely π^+, π^0, η. Replacing the D^* internal line by D we get the self-energy of D^* meson for the $D\pi$ loop.

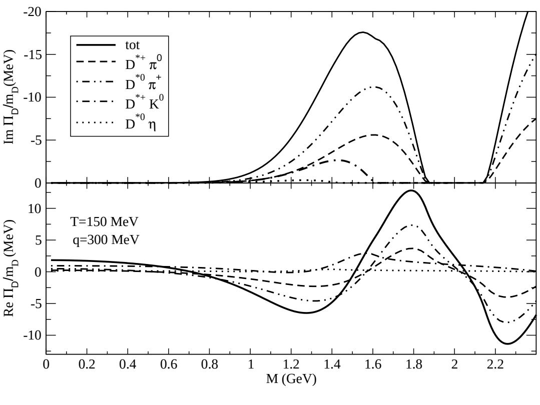

FIG. 1: Imaginary and real part of self-energy of D for different $D^*\Phi$ loops in the upper and lower panel respectively.

The imaginary part of the self-energy diagram consists of four terms each containing a δ-function defining the regions in which these terms are non-vanishing. They give rise to cuts in the self-energy function. Thus, the first and the fourth terms are non-vanishing for $q^2 \geq (m_p+m_k)^2$, giving the unitary cut, while the second and the third are non-vanishing for $q^2 \leq (m_p - m_k)^2$, giving the so-called Landau cut (see Ref. [1] for details). Here m_k and m_p denote the masses of the light pseudoscalar and heavy-light vector mesons respectively. The calculations are carried out in the real time version of thermal field theory. The vertices appearing in the calculation of the one-loop self-energy may be obtained from the covariant formalism of chiral perturbation theory. The relevant terms of the chiral Lagrangian at lowest order is given by

$$\begin{aligned}\mathcal{L}_{D^+P^*\Phi} &= \\ &-i\frac{g}{F_0}[\sqrt{2}(D^+\partial^\mu\pi^-\overline{D}^{*0}_\mu - D^-\partial^\mu\pi^+D^{*0}_\mu) \\ &+ (D^-\partial^\mu\pi^0D^{*+}_\mu - D^+\partial^\mu\pi^0D^{*-}_\mu) \\ &+ \frac{1}{\sqrt{3}}(D^+\partial^\mu\eta D^{*-}_\mu - D^-\partial^\mu\eta D^{*+}_\mu) \\ &+\sqrt{2}(D^+\partial^\mu K^0 D^{*-}_{s\mu} - D^+\partial^\mu\overline{K}^0 D^{*+}_{s\mu})] \quad (1)\end{aligned}$$

Here F_0 is the pion decay constant in the chiral limit, $F_0 = 93MeV$. The value of the coupling constant g is fixed by reproducing experimental the $D^{*+} \to D^0\pi^+$ decay width.

We have evaluated the self energies as a function of $\sqrt{q^2} = M$ at fixed values of the three-momentum $\vec{q}$ and temperature T. It thus suffices to calculate the self-energies in the time-like region, for positive values of q_0 starting from $q_0 = |\vec{q}|$.

Fig (1) and Fig (2) show the imaginary and real parts of D and D^* mesons respectively. The thermal contribution to the imaginary

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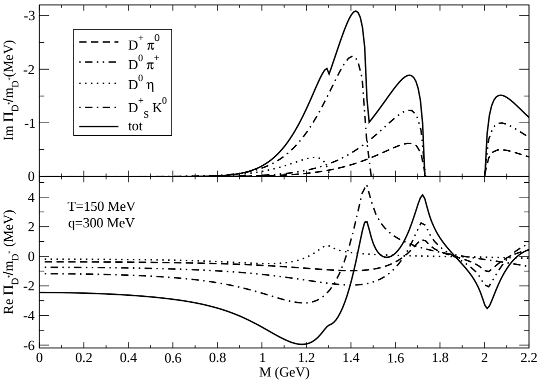

FIG. 2: Imaginary and real part of self-energy of D^* for different $D\Phi$ loops in the upper and lower panel respectively.

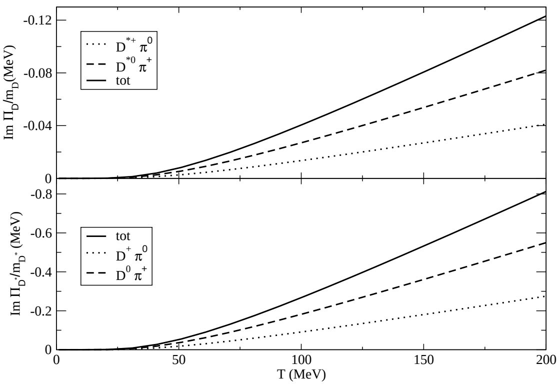

FIG. 3: In medium width enhancement vs temperature for D and D^* in the upper and lower panel respectively. The contributions coming from different loops also shown separately.

part leads to an enhancement in the width and that of the real part produces a shift in the pole position. From the upper panel of both curves, we can see a clear distinction between the two branches of $\Pi(q^0, \vec{q})$. One observes a region in between the Landau and unitary cuts, where the imaginary part of the self-energy is exactly zero. We also see a negligible in-medium mass shift from the lower panels of these figures.

The imaginary parts evaluated at the pole positions of the D and D^* are plotted in Fig (3) as a function of temperature. We observe that in hadronic matter the D and D^* mesons may acquire at most a width enhancement of approximately 100 keV.

The spectral modification of the D and D^* mesons which comes from the Landau cut and is basically a result of collisional broadening, can lead to a substantial contribution to J/ψ suppression through its dissociation in hadronic matter. The J/ψ can in fact decay sub-threshold into the $D\overline{D}$ and $D^*\overline{D}$ channels, resulting in a finite dissociation width in these otherwise closed modes. The later is calculated by folding the J/ψ decay width with the spectral function of the D and D^* mesons and its variation with temperature is shown in Fig (4). This estimate compares well with existing results in the literature.

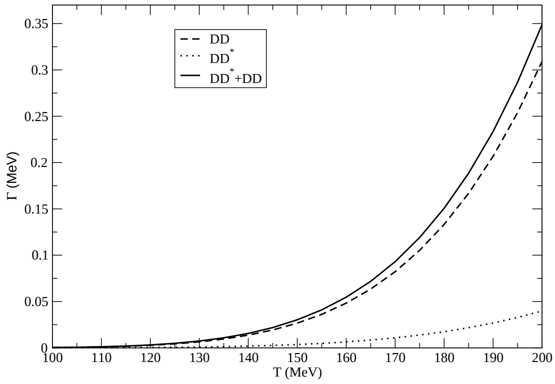

FIG. 4: In medium collision rate vs. temperature for J/ψ for $D\overline{D}$ (dashed line), $D^*\overline{D}$ (dotted line) channels and their sum (solid line). The dotted line contains contributions from both $D^*\overline{D}$ and $D\overline{D}^*$ channels.

References

[1] S. Ghosh, S. Mallik, S. Sarkar, Eur. Phys. J. **C70**, 251 (2010).