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D AND $\overline{D}$ MESONS IN HOT AND DENSE MATTER

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Abstract

The D and $\overline{D}$ mesons are studied in hot dense matter within a self-consistent coupled-channel approach taking, as bare interaction, a broken SU(4) s-wave Tomozawa-Weinberg interaction supplemented by an attractive isoscalar-scalar term. The in-medium solution at finite temperature incorporates Pauli blocking effects, baryon mean-field bindings, and π and open-charm meson self-energies. In the DN sector, the Λ_c and Σ_c resonances remain close to their free-space position while acquiring a remarkable width. As a result, the D meson spectral density shows a single pronounced peak close to the free mass that broadens with increasing density specially towards lower energies. The low-density theorem is not a good approximation for the repulsive $\overline{D}$ self-energy close to saturation density. We discuss the implications for the J/Ψ suppression at CBM (FAIR).

The future CBM (Compressed Baryon Matter) experiment of the FAIR project at GSI aims at investigating, among others, the possible modifications of the properties of open (D and $\overline{D}$) and hidden (e.g. J/Ψ) charmed mesons in a hot and dense baryonic environment.

The in-medium modification of the $D(\overline{D})$ mesons may explain the J/Ψ suppression [1] in an hadronic environment, based on the mass reduction of $D(\overline{D})$ in the nuclear medium [2]. However, a coupled-channel meson-baryon scattering in nuclear medium is needed due to the strong coupling among the DN and other meson-baryon channels [3–6]. In the present article, we pursue a coupled-channel study on the spectral properties of D and $\overline{D}$ mesons in

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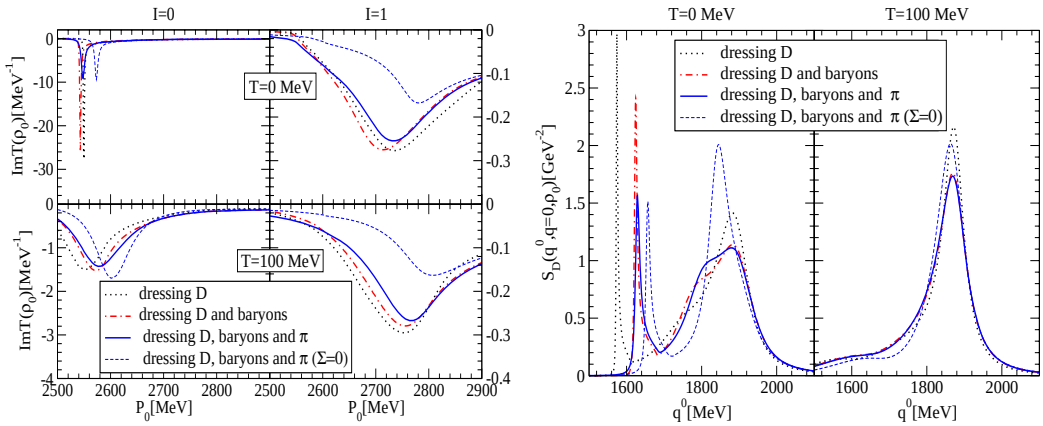

Figure 1: Λ_c and Σ_c resonances, and the D meson spectral function

nuclear matter at finite temperatures by extending the result of Ref. [3] in order to examine the possible implications in the J/Ψ suppresion at FAIR. The D and $\overline{D}$ self-energies at finite temperature are obtained by performing a self-consistent coupled-channel calculation taking, as bare interaction, a type of broken SU(4) s-wave Tomozawa-Weinberg (TW) interaction supplemented by an attractive isoscalar-scalar term (Σ_{DN}). The multi-channel transition matrix T is solved using a cutoff regularization, which is fixed by reproducing the position and the width of the $I = 0$ $\Lambda_c(2593)$ resonance while a new resonance in $I = 1$ channel $\Sigma_c(2880)$ is generated [3].

The in-medium solution at finite temperature incorporates Pauli blocking effects, baryon mean-field bindings via a temperature-dependent $\sigma-\omega$ model, and π and open-charm meson self-energies in the intermediate propagators (see [7]). The in-medium self-energy and corresponding spectral density are obtained self-consistently summing T_{DN} over the nucleon Fermi distribution.

The behavior of the $I = 0$ Λ_c and $I = 1$ Σ_c resonances in hot dense matter is shown in the l.h.s. of Fig. 1 for three different self-consistent calculations: (i) including only the self-consistent dressing of the D meson, (ii) adding the mean-field binding of baryons (MFB) and (iii) including MFB and the pion self-energy (PD). The thick lines correspond to model A (viz. $\Sigma_{DN} \neq 0$) while the thin-dashed lines refer to Case (iii) within model B ($\Sigma_{DN} = 0$).

Medium effects at $T = 0$ lower the position of the Λ_c and Σ_c resonances with respect to their free values, in particular with the inclusion of MFB. Their width values, which increase due to $\tilde{Y}_c N \to \pi N \Lambda_c, \pi N \Sigma_c$ processes, differ according to the phase space available. The PD induces a small effect in the resonances because of charm-exchange channels being suppressed, while models A and B are qualitatively similar. Finite temperature results in the

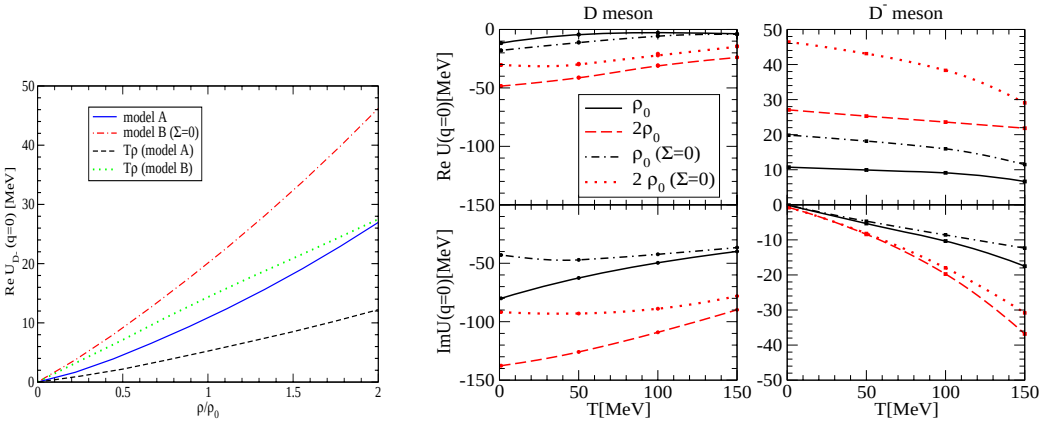

Figure 2: $\overline{D}$ mass shift as well as $T\rho$, and the D and $\overline{D}$ potentials.

reduction of the Pauli blocking effects due to the smearing of the Fermi surface with temperature. Both resonances move up in energy closer to their free position while they are smoothen out, as in [5].

In the r.h.s of Fig. 1 we display the D meson spectral function for (i) to (iii) (thick lines) for model A and case (iii) for model B (thin line). At $T = 0$ the spectral function presents two peaks: $\tilde{\Lambda}_c N^{-1}$ excitation at a lower energy whereas the second one at higher energy is the quasi(D)-particle peak mixed with the $\tilde{\Sigma}_c N^{-1}$ state. Once MFB is included, the lower peak built up by the $\tilde{\Lambda}_c N^{-1}$ mode goes up by about 50 MeV relative to (i) since the meson requires to carry more energy to compensate for the attraction felt by the nucleon. The same characteristic feature is seen for the $\tilde{\Sigma}_c N^{-1}$ configuration that mixes with the quasiparticle peak. The PD does not alter much the position of $\tilde{\Lambda}_c N^{-1}$ excitation or the quasiparticle peak. For model B ((iii) only), the absence of the Σ_{DN} term moves the $\tilde{\Lambda}_c N^{-1}$ excitation closer to the quasiparticle peak, while the latter fully mixes with the $\tilde{\Sigma}_c N^{-1}$ excitation. When finite temperature effects are included, those structures get diluted with increasing temperature while the quasiparticle peak gets closer to its free value and it becomes narrower, because the self-energy receives contributions from higher momentum DN pairs where the interaction is weaker.

In the $\overline{D}N$ sector, the scattering lengths for model A (B) are $a^{I=0} = 0.61$ (0) fm and $a^{I=1} = -0.26$ (-0.29) fm. While our repulsive $I = 1$ is in good agreement with [6], the finite value for the $I = 0$ scattering length found in this latter reference is in contrast to the zero value found here for model B due to the vanishing $I = 0$ coupling coefficient of the corresponding pure TW $\overline{D}N$ interaction. Our results are, however, consistent with a recent calculation [8]. For model A, we obtain a non-zero value of the $I = 0$ scat-

tering length, due to the magnitude of the Σ_{DN} term. As seen in the l.h.s of Fig. 2, the $\overline{D}$ mass shift in cold nuclear matter is repulsive and, in spite of the absence of resonances close to threshold, the low-density approximation or $T\rho$ breaks down at relatively low densities.

Finally, in the r.h.s of Fig. 2 we compare the D and $\overline{D}$ optical potentials. For model A (B) at $T = 0$, we obtain an attractive potential of -12 (-18) MeV for D meson while the repulsion for $\overline{D}$ is 11 (20) MeV. A similar shift in the mass for D mesons is obtained in Ref. [5]. The temperature dependence of the repulsive real part of the $\overline{D}$ optical potential is very weak, while the imaginary part increases steadily due to the increase of collisional width. The picture is somewhat different for the D meson due to the overlap of the quasiparticle peak with the $\tilde{\Sigma}_c N^{-1}$ mode. The $\tilde{\Sigma}_c N^{-1}$ mode also alters the effect of the Σ_{DN} term on the potential.

With regard to the J/Ψ suppression, the in-medium $\overline{D}$ mass is seen to increase by about $10 - 20$ MeV whereas the tail of the quasiparticle peak of the D spectral function extends to lower "mass" due to the thermally spread $\tilde{Y}_c N^{-1}$. But it is unlikely that this lower tail extends as far down by 600 MeV with sufficient strength. So the only way for the J/Ψ suppression to take place is by cutting its supply from the excited charmonia: $\chi_{c\ell}(1P)$ or Ψ' by their hadronic collisions, which appears fairly likely kinematically even at finite temperature in the present study.

References

[1] T. Matsui and H. Satz, *Phys. Lett.* **B178**, 416 (1986).

[2] K. Tsushima, D. H. Lu, A. W. Thomas, K. Saito and R. H. Landau, *Phys. Rev.* **C59**, 2824 (1999); A. Sibirtsev, K. Tsushima and A. W. Thomas, *Eur. Phys. J.* **A6**, 351 (1999); A. Hayashigaki, *Phys. Lett.* **B487**, 96 (2000); A. Mishra, E. L. Bratkovskaya, J. Schaffner-Bielich, S. Schramm and H. Stöcker, *Phys. Rev.* **C70**, 044904 (2004).

[3] T. Mizutani and A. Ramos, *Phys. Rev* **C74**, 065201 (2006).

[4] L. Tolos, J. Schaffner-Bielich and A. Mishra, *Phys. Rev.* **C70**, 025203 (2004).

[5] L. Tolos, J. Schaffner-Bielich and H. Stöcker, *Phys. Lett.* **B635**, 85 (2006).

[6] M. F. M. Lutz and C. L. Korpa, *Phys. Lett.* **B633**, 43 (2006).

[7] L. Tolos, A. Ramos and T. Mizutani, *Phys. Rev.* **C77**, 015207 (2008).

[8] J. Haidenbauer, G. Krein, U. G. Meissner and A. Sibirtsev, *Eur. Phys. J.* **A33**, 107 (2007).