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Open-charm enhancement at FAIR?

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Abstract. We have calculated the D-meson spectral density at finite temperature within a self-consistent coupled-channel approach that generates dynamically the Λ_c (2593) resonance. We find a small mass shift for the D-meson in this hot and dense medium while the spectral density develops a sizeable width. The reduced attraction felt by the D-meson in hot and dense matter together with the large width observed have important consequences for the D-meson production in the future CBM experiment at FAIR.

1. Introduction

The future CBM experiment (Compressed Baryonic Matter) at the FAIR project (Facility for Antiproton and Ion Research) at GSI will explore matter in the region of high-baryon densities and moderature temperatures [1]. Among others, it will address the in-medium modifications of open-charm mesons. The medium modifications of D-mesons have important consequences for J/Ψ suppression [2] as well as open-charm enhancement in nucleus-nucleus collisions [3]. The J/Ψ suppression can be understood in an hadronic environment due to inelastic comover scattering and, therefore, the medium modification of the D-mesons should modify the J/Ψ absorption. On the other hand, the NA50 Collaboration [3] has observed an enhancement of dimuons in Pb+Pb collisions which was tentatively attributed to an open-charm enhancement in A+A collisions by introducting an attractive mass shift for D-mesons in the nuclear medium [4]. However, the latest results on dimuon production by NA60 [5] seem to disregard this possibility. Finally, the D-mesic nuclei, predicted by the quark-meson coupling (QMC) model [6] are the result of considering an attractive D-meson potential.

Calculations based on the QMC model [6], QCD sum-rule (QSR) [7] and chiral models [8] obtain attractive mass shifts of -50 MeV to -200 MeV at nuclear matter saturation density ρ_0, although a second analysis using QSR predicted only a splitting of D^+ and D^- masses of 60 MeV at ρ_0 [9]. In all these investigations, the D-meson spectral density in dense matter is not studied. In our previous work [10], the D-meson spectral density is obtained by including coupled-channel effects as well as the dresssing of the intermediate propagators. Thus, the attractive potential felt by the D-meson is strongly reduced or becomes slightly repulsive [10], which has been recently supported by [11]. In this paper, finite temperature effects are included in the determination of the D-meson spectral density in order to adapt our calculation to the conditions of density-temperature expected for the CBM experiment [1]. Our results indicate that the width of the D-meson is the only source of open-charm enhancement at FAIR [12].

2. Formalism

We obtain the in-medium D-meson spectral density at finite temperature taking, as bare interaction, a separable potential which parameters, coupling constant and cutoff, are determined by fixing the position and the width of the $\Lambda_c(2593)$ resonance (see [10]). Then, the in-medium DN interaction or G-matrix at finite temperature reads

$$\langle M_1B_1 \mid G(\Omega,T) \mid M_2B_2\rangle = \langle M_1B_1 \mid V \mid M_2B_2\rangle + \\ \sum_{M_3B_3} \langle M_1B_1 \mid V \mid M_3B_3\rangle \frac{F_{M_3B_3}(T)}{\Omega - E_{M_3}(T) - E_{B_3}(T) + i\eta} \langle M_3B_3 \mid G(\Omega,T) \mid M_2B_2\rangle \ , \quad (1)$$

where V is the separable potential and Ω is the starting energy. In this equation, M_i and B_i represent the possible mesons (D,π,η) and baryons (N,Λ_c,Σ_c), respectively. The function $F_{M_3B_3}(T)$ for the DN states stands for the Pauli operator, i.e $Q_{DN}(T) = 1 - n(k_N,T)$, where $n(k_N,T)$ is the nucleon Fermi distribution at the corresponding temperature. The function $F_{M_3B_3}(T)$ is $1 + n(k_\pi,T)$, with $n(k_\pi,T)$ being the Bose distribution of pions at a given temperature, for $\pi\Lambda_c$ or $\pi\Sigma_c$ states while it is unity for the other intermediate states. Furthermore, the properties of the intermediate states are also modified in the medium at finite temperature. For nucleons, we use a temperature-dependent Walecka-type $\sigma - \omega$ model with density-dependent scalar and vector coupling constants [13]. In the case of pions, the self-energy in nuclear matter at finite temperature is obtained following the Appendix of [13].

The D-meson potential at a given temperature is then calculated according to

$$U_D(k_D,E_D,T) = \int d^3k_N \; n(k_N,T) \; \langle DN \mid G_{DN\to DN}(\Omega = E_N + E_D, T) \mid DN\rangle \ . \quad (2)$$

As for the case of T=0, this is a self-consistent problem for the D-meson potential, since the in-medium DN interaction depends on the D-meson single-particle energy, which in turn depends on the D-meson potential. After achieving self-consistency for the on-shell value $U_D(k_D,E_D,T)$, we obtain the self-energy $\Pi_D(k_D,\omega,T) = 2\sqrt{m_D^2+k_D^2}\,U_D(k_D,\omega,T)$ and the corresponding spectral density is

$$S_D(k_D,\omega,T) = -\frac{1}{\pi}\mathrm{Im}\,\frac{1}{\omega^2 - m_D^2 - k_D^2 - 2\sqrt{m_D^2+k_D^2}U_D(k_D,\omega,T)} \ . \quad (3)$$

3. Results and Conclusion

In the l.h.s. of Figure 1 the D-meson spectral density at zero momentum and T=120 MeV is shown for different densities and for $\Lambda = 1$ GeV and $g^2 = 13.4$, which reproduce the position and width of the $\Lambda_c(2593)$ resonance (see [10]). The temperature is chosen in accord with the expected temperatures at FAIR. The spectral density is displayed for

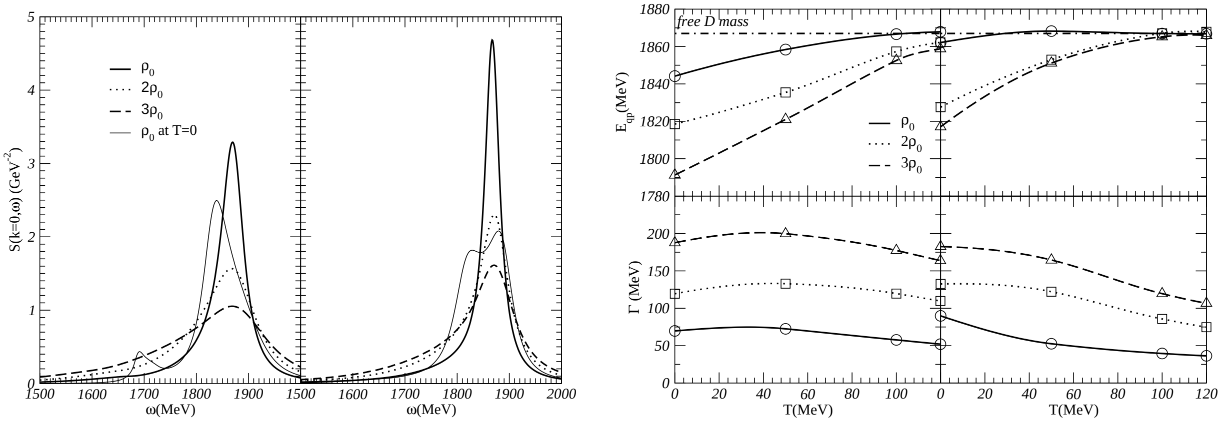

Figure 1. Left: D-meson spectral density at $k_D = 0$ and T=120 MeV as a function of energy for different densities, together with the D-meson spectral density at $k_D = 0$ and T=0 MeV for ρ_0 in the two approaches considered. Right: Quasiparticle energy and width of the D-meson spectral density at $k_D = 0$ as a function of temperature for different densities and the two approaches considered.

the two approaches considered: self-consistent calculation of the D-meson self-energy including the dressing of the nucleons in the intermediate states (left panel) and the self-consistent calculation including not only the dressing of nucleons but also the self-energy of pions (right panel). The spectral density at T=0 for nuclear matter saturation density, $\rho_0 = 0.17$ fm^{-3}, is also shown. Compared to the T=0 case, the quasiparticle peak at finite temperature stays closer to its free position for the range of densities analyzed (from ρ_0 up to $3\rho_0$). This is due to the fact the Pauli blocking is reduced with increasing temperature. Furthermore, structures present in the spectral distribution at T=0 due to the presence of the $\Lambda_c(2593)$ resonance, as reported in [10], are washed out. However, the D-meson spectral density shows a sizeable width.

Our self-consistent coupled-channel calculation is in stark contrast with previous works based on the QMC model [6], QSR rules [7] or chiral effective Lagrangians [8] which predict a strongly attractive D-nucleus potential. We find that the coupled-channel effects at zero temperature result in an important reduction of the in-medium modifications and are responsible for the considerable width of the D-meson, which was not obtained in the previous mean-field works. This effect is independent of the in-medium properties of the intermediate states, as seen in l.h.s of Figure 1. Actually, a recent study of the D-meson spectral distribution at T=0 suggests a two-mode structure with a repulsive main branch, due to the presence of a new resonance, the $\Sigma_c(2620)$ [11]. Finite temperatures effects even make the quasiparticle peak get closer to the D-meson free mass and D-mesons only show a significant width, as seen in the following.

The r.h.s of Figure 1 shows the quasiparticle energy together with the width of the D-meson spectral density at zero momentum as a function of the temperature for the previous densities and for the approaches considered before. For T=0 we observe an attractive potential of -23 MeV for ρ_0 and -76 MeV for $3\rho_0$ when D-mesons and nucleons are dressed in the intermediate states (upper left panel). For the full self-consistent calculation (upper right panel), the D-meson potential at T=0 lies between -5 MeV for ρ_0 and -48 MeV for $3\rho_0$. For higher temperatures, the quasiparticle peak gets close to the D-meson free mass, so there is almost no mass shift expected at finite temperature. On the other hand, the width of the spectral density depends weakly on the temperature. At T=120 MeV the width increases from 52 MeV to 163 MeV for ρ_0 to $3\rho_0$ for the first approach (lower left panel) and from 36 MeV at ρ_0 to 107 MeV at $3\rho_0$ for the second approach (lower right panel).

Based on the previous mean-field calculations which obtain a large D-meson mass shift, an enhancement of open-charm in A+A collisions was predicted in order to understand the enhancement of 'intermediate-mass dileptons' in Pb+Pb collisions at SPS energies [4]. According to our model, the inclusion of a considerable width of the D-meson in the medium (40-50 ρ/ρ_0 for T=120 MeV) is the only source of enhanced in-medium D-meson production, as studied for kaons in [14]. As a consequence, an off-shell transport theory to account for the D-meson production is needed. For that purpose, not only the D-meson spectral density but also in-medium D-meson cross sections are required. In our model, the cross sections at threshold are expected on the order of 1-20 mb for the range of densities studied in both approaches.

Mesons with charm content at beam energy close to threshold will be investigated by the CBM experiment [1]. Our results indicate that the mass of the D-meson is not modified but D-mesons show a considerable width in this hot and dense medium.

Acknowledgments

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