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The width of the ω meson in dense matter *

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We obtain the width of the ω meson in dense nuclear matter by taking into account (i) the free decay of the ω into three pions, which is dominated by $\rho\pi$ mode, (ii) the processes induced by a vector-baryon interaction dominated by vector meson exchange, and (iii) the $\omega \to K\bar{K}$ mechanism in matter. The ω meson develops an important width in matter, coming from the dominant $\omega \to \rho\pi$ decay mode, with a value of 121 ± 10 MeV at normal nuclear matter density for an ω at rest. At finite momentum, the width of the ω meson increases moderately with values of 200 MeV at 600 MeV/c.

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1. Introduction

The interaction of vector mesons with nuclei has been a matter of much attention over the past decades. One of the more thoroughly investigated vector mesons is the ω meson.

From the experimental point of view, there are several investigations on the properties of the ω meson in matter with proton beams on nuclei at KEK by E325 Collaboration [1], photoproduction on nuclei by CBELSA/TAPS [2], photonuclear reactions looking for dileptons in the final state by CLAS [3] or dilepton production in p+p and p+Nb at HADES [4]. These experiments seem to point to the existence of a large width of the ω meson in the medium.

Different scenarios are present in the theoretical determination of the ω properties in matter. The obtained mass shifts range from an attraction of the order of 100-200 MeV [5, 6], through no changes in the mass [7], to a net repulsion [8]. As for the in-medium width of an ω meson at rest, the models of [5, 9] reported a value of about 40 MeV, while the width was found to be around 60 MeV in [10]. All these studies show a considerable increase of the ω width in the medium.

In this paper we study the ω width in dense matter, similary to the $\bar{K}^*$ meson [11, 12], paying a special attention to the decay of the ω into three pions via the dominant $\rho\pi$ decay mode [13].

2. Formalism: The ω self-energy in matter

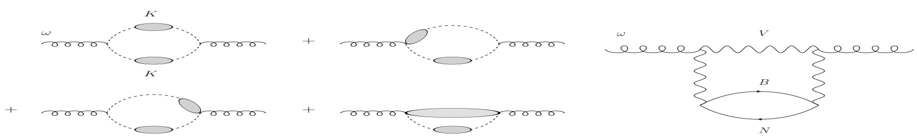

Figure 1: The ω self-energy from the $\omega \to \bar{K}K$ channel in the nuclear medium including vertex corrections (left plot) and from the s-wave ωN interaction with vector mesons and baryons (right plot).

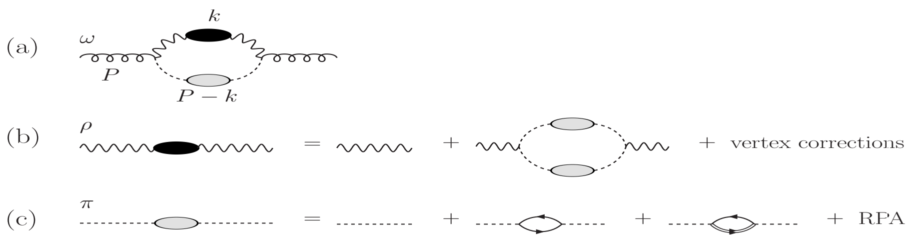

Figure 2: The ω meson self-energy from its decay into the $\rho\pi$ (a), where the ρ meson decays into two pions (b) and the π is dressed by its coupling to particle-hole and Δ-hole including short-range correlations (c).

A free ω meson decays predominantly into three pions, most of the strength associated to the $\omega \to \rho\pi$ process with the subsequent decay of the ρ meson into two pions. The ω width is small, $\Gamma_\omega^{(0)} = 8.49 \pm 0.08$ MeV, with 89.2% of this value corresponding to the 3π decay channel. This is due to the fact that the $\omega \to \rho\pi$ mechanism proceeds through the tail of the ρ-meson distribution. The situation, however, changes drastically in the nuclear medium.

First, the $\omega \to K\bar{K}$ mechanism is energetically open in matter when the medium modifications of the $\bar{K}$ and K mesons are incorporated (see left plot of Fig. 1). The $\bar{K}$ self-energy in matter is

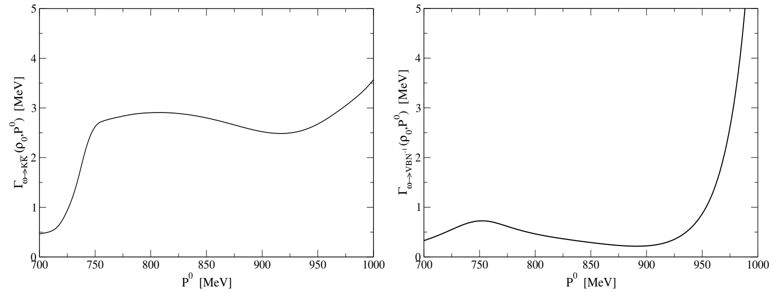

Figure 3: In-medium contribution to the width of the ω meson at zero momentum due to its coupling to $K\bar{K}$ (left plot) and the s-wave $\omega N \to VB$ interaction (right plot), at ρ_0 and as a function of the ω energy P^0.

obtained from the $\bar{K}N$ interaction within a chiral unitary approach [14, 15, 16]. For K, due to the much weaker KN interaction, we use the low-density approximation [17, 18]. Moreover, because of gauge invariance of the model, it is necessary to include vertex corrections.

Second, the ω properties are modified due to quasielastic and inelastic vector-baryon processes dominated by vector meson exchange. The contribution to the ω self-energy coming from the s-wave ωN interaction with vector mesons and baryons is depicted on the right plot of Fig. 1. The ωN interaction is constructed within the hidden gauge formalism in coupled channels [19]. The vector meson-baryon scattering amplitudes are then obtained from the coupled-channel on-shell Bethe-Salpeter equation by incorporating medium modifications on the intermediate states [13].

Finally, the most important contribution to the ω width in matter comes from its decay into $\rho\pi$ in the nuclear medium due to the increase of the phase space available as compared to the free case. The self-energy for the $\omega \to \rho\pi$ process is depicted in Fig. 2(a), where the ρ- and π-meson lines correspond to their medium propagators shown in Figs. 2(b) and (c), respectively. The pion in matter is dressed via its self-energy which is strongly dominated by the p-wave coupling to particle-hole and Δ-hole components and also contains a small repulsive s-wave contribution, as well as short-range correlations and contributions from $2p$-$2h$ excitations. For the ρ-meson we employ three different self-energy models, as we will see.

Note that in our calculation in matter we do not consider interference terms between the different physical states $\rho^+\pi^-$, $\rho^+\pi^-$ and $\rho^0\pi^0$. While in free space, we miss an important part of the free ω width, the interference terms are negligible in matter [13]. Moreover, we also need to incorporate the contribution of uncorrelated three pions. This contribution can be supplied by either introducing a contact term that provides a background to be added to the $\omega \to \rho\pi$ process, as done in Ref. [20], or by adjusting the coupling of $\omega \to \rho\pi$ to reproduce the complete free $\omega \to \pi\pi\pi$ width directly from the $\rho\pi$ mechanism. We analyze both mechanisms in the following.

3. Results: The width of the ω meson in matter

In left plot of Fig. 3 we show the in-medium ω width correction coming from its coupling to $K\bar{K}$ states in matter. At normal nuclear saturation density, $\rho_0 = 0.17\text{fm}^{-3}$, and around the free ω mass, this amounts for 2.9 MeV for an ω meson at rest. This correction to the width mainly comes from the $\omega N - KY$ processes, with $Y = \Lambda(\Sigma)$, that result from the p-wave coupling of $\bar{K}$ to YN^{-1}.

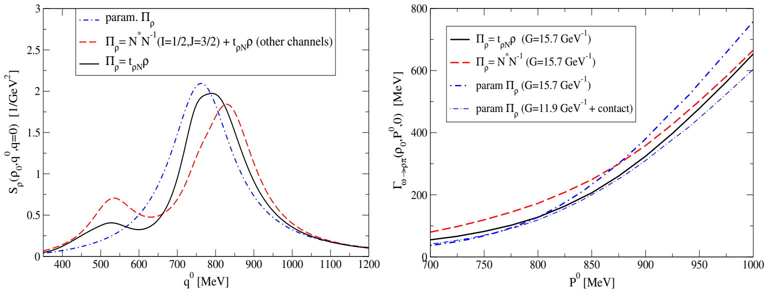

Figure 4: Left plot: The spectral function of a ρ-meson of zero momentum at ρ_0 for the three prescriptions employed in this paper. Right plot: Width of the ω meson from $\omega \to 3\pi$ at ρ_0 and $\vec{P} = 0$ as a function P^0.

We also present in the right plot of Fig. 3 the ω width correction associated to the elastic and inelastic processes from the s-wave interaction of ωN with vector mesons and baryons as a function of the ω energy. We observe that this contribution produces a very small ω width correction, about 0.5 MeV, for energies around the free ω mass and at ρ_0. The small ω width correction is associated to the $\omega N \to \omega N$ and $\omega N \to \rho N$ processes. Note that the implementation of pseudoscalar mesons, hence opening vector-baryon to pseudoscalar-baryon transitions such as $\omega N \to \pi N$, might also add some width to the ω decay in matter. For that purpose, we adopt the model independent view of Ref. [21], based on detailed balance and unitarity, and add 9 MeV to the width of the ω meson.

In the right plot of Fig. 4 we show the in-medium width of an ω meson at rest for ρ_0 as a function of the energy, from the $\omega \to 3\pi$ mechanism, which corresponds to absorption processes of the type $\omega N \to \pi\pi N$ and $\omega NN \to \pi NN$. Results are shown for three different prescriptions of the ρ spectral function, displayed on the left of Fig. 4, corresponding to using a phenomenological width (dash-dotted line); employing the $t_{\rho N \to \rho N}$ model from the coupled channel unitary model within the local hidden gauge formalism of Ref. [19] but replacing the $I = 1/2, J^P = 3/2^-$ amplitude by the $N^*(1520)N^{-1}$ contribution of Ref. [22] (dashed line); and taking the complete $t_{\rho N \to \rho N}$ amplitude from Ref. [19] (solid line). The $\omega \to \rho\pi$ coupling of $G = 15.7$ GeV^{-1} has been adjusted to reproduce the complete free $\omega \to 3\pi$ width directly from the $\rho\pi$ mechanism. The in-medium ω width increases smoothly with energy for all the ρ-dressing models employed, the phenomenological one (thick dash-dotted line) presenting a stronger dependence. In this case, results are also shown for the model that uses a contact term without adjusting the coupling $\omega \to \rho\pi$ of $G = 11.9$ GeV^{-1} (thin dash-dotted line). We observe that, up to the free ω mass, both models present a similar behavior. We conclude that the in-medium width correction at the free ω mass is 101.2 ± 10 MeV for the most complete ρ self-energy model adjusting the $\omega \to \rho\pi$ coupling (solid line), the error associated to reasonable variations in the parameters of the π meson self-energy [13].

In summary, we find [13] that the width of the ω meson at rest in nuclear matter at saturation density is $\Gamma_\omega(\rho_0, m_\omega) = 7.6$ MeV (free width)$+101.2$ MeV ($\omega N \to \pi\pi N, \omega NN \to \pi NN$)$+2.9$ MeV ($\omega N \to KY$)$+0.5$ MeV ($\omega N \to K^*Y \to \rho N$)$+9$ MeV ($\omega N \to \pi N$)$= 121 \pm 10$ MeV. We note that one could add one more MeV to account for the other free decay channels of the ω meson, $\omega \to \pi^0\gamma$ and $\omega \to \pi^+\pi^-$. With regards to the mass shift, no clear conclusion can be drawn due to the uncontrolled high-momentum components of the π and ρ propagators [13].

Our value of the width of the ω meson at rest in nuclear matter is larger than that found by other works [5, 9, 10], and similar to more recent calculations [23]. In order to compare with the experimental determination of the ω width, we need to extend our calculation to finite momentum. We find that $\Gamma_{\omega\to 3\pi}$ rises smoothly with momentum, and it can reach values of about 200 MeV at $P = 600$ MeV/c. The experimental width is quoted to be $\Gamma_\omega \approx 130-150$ MeV for an average 3-momentum of 1.1 GeV/c [2]. We obtain a good agreement within errors for 400 MeV/c and 600 MeV/c reported in Fig. 4 of Ref. [2], where our results should be more accurate.

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