Baryonic loops in the ρ self energy at finite temperature and density

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Baryons and anti-baryons have an important role to play in determining the spectral properties of ρ mesons in the medium. This applies not only in baryon-dense situations likely to be encountered in the CBM experiment but also in almost baryon-free systems such as produced at the RHIC and LHC. In the latter case baryons and anti-baryons in fact, contribute additively in the medium effects.

Most evaluations of the ρ spectral function at finite baryon density have been done at zero temperature. The ones at finite temperature are done either using a virial expansion or in a Lindhard function approach. In both these methods the contributions from distant singularities are ignored leading to inaccurate evaluation of the real part [2].

In this work, we have analysed ρ meson self-energy in baryonic matter at finite temperature considering an exhaustive set of 4-star resonances in the baryonic loops. The framework of real time thermal field theory that we use, enables us to evaluate the imaginary part of the self-energy from the branch cuts for real and positive values of energy and momentum without having to resort to analytic continuation as in the imaginary time approach.

We have used the full relativistic baryon propagator in the loop diagrams in which baryons and anti-baryons naturally appear on an equal footing. This leads to relativistically consistent expressions for the self-energy in which the additional singularities which are not considered in the Lindhard function approach are automatically included.

We have included all spin one-half and three-half 4−star resonances listed by the PDG so that R stands for the $N^*(1520)$, $N^*(1650)$, $N^*(1700)$, $\Delta(1230)$, $\Delta^*(1620)$, $\Delta^*(1720)$ as well as the $N(940)$ itself. The interaction vertices involving the ρ with the nucleon and resonances have been obtained from well known gauge invariant Lagrangians. It is essential to point out that for the spin 3/2 resonances the coupling which follows from these interactions is not quite correct owing to the fact that the free Lagrangian for the Rarita-Schwinger field has a free parameter. A symmetry is associated with a point transformation under which the free Lagrangian remains invariant up to a change in the value of the parameter. In order that the interaction also remains invariant under this transformation an additional term, contributing only in off-mass shell, is added to it.

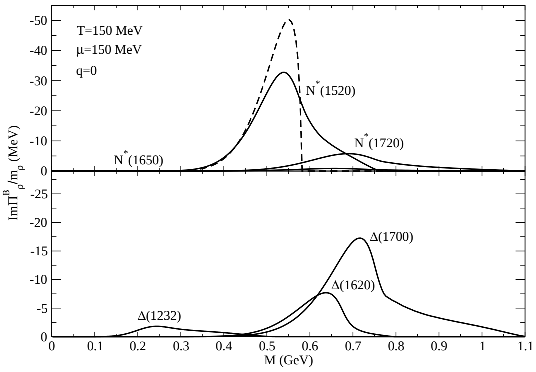

FIG. 1: Imaginary part of ρ meson self-energy showing the individual contributions for different NR loops. Left panel shows results for $\vec{q} = 0$. The dashed line shows the result evaluated in the narrow width approximation.

We present the results of numerical evaluation beginning with the imaginary part of the ρ self-energy as a function of the invariant mass $\sqrt{q^2} = M$. Shown in Fig. 1 are the contributions from the individual NR loops for a ρ meson at rest. The $NN^*(1520)$ loop makes the most significant contribution followed by the $N^*(1720)$ and $\Delta(1700)$. The correspond-

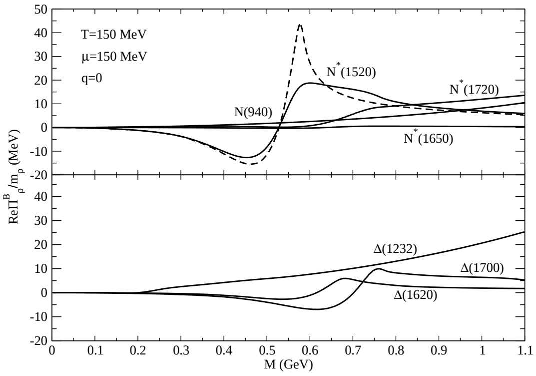

FIG. 2: Same as Fig. 1 for the real part

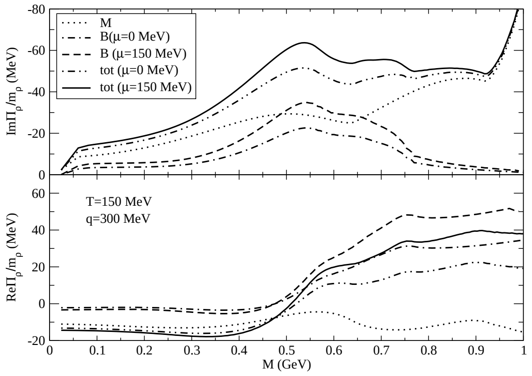

FIG. 3: The total contribution from meson and baryon loops.

ing results for the thermal contribution to the real part are shown in Fig. 2. The divergent vacuum contribution in this case is assumed to renormalize the ρ mass to its physical value. These have been folded with the spectral functions of the resonances to take into account their finite width. Shown for comparison by the dashed lines in Figs. 1 and 2 are the corresponding contributions to the real and imaginary parts coming from the $NN^*(1520)$ loop computed in the narrow width approximation. Nuclear medium at finite temperature is also substantially populated by mesons which modify the ρ propagation in the medium in a non-trivial way. This has been studied in detail in [3] for mesonic loop graphs following the same procedure as the baryonic loops tak-

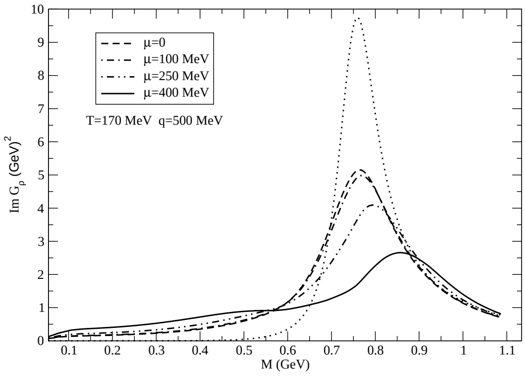

FIG. 4: The spectral function of the ρ meson for different values of the baryonic chemical potential μ

ing one internal pion line and another meson line h where $h = \pi, \omega, h_1, a_1$ using interactions from chiral perturbation theory. We plot the total contribution from the baryon and meson loops for two values of the baryonic chemical potential in Fig. 3. The small positive contribution from the baryon loops to the real part is partly compensated by the negative contributions from the meson loops. The substantial baryon contribution at vanishing baryonic chemical potential reflects the importance of anti-baryons.

We then plot in Fig. 4, the spectral function for various values of the baryonic chemical potential for a fixed temperature. For high values of μ we observe an almost flattened spectral density of the ρ, reflecting a significant modification at and below the nominal rho mass.

References

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[3] S. Ghosh, S. Sarkar and S. Mallik, Eur. Phys. J. C **70**, 251 (2010)