Propagation of rho meson in hot hadronic matter

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We present a unified description of the various sources modifying the propagation of the ρ in a meson gas at finite temperature. 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 new, so-called Landau cut. While the in-medium modification of the cloud of virtual particles (mostly pions) is given by the unitary cuts, the effect of collisions with surrounding particles is obtained from the Landau cuts. Thus the two sources of medium modification are automatically included in the calculation, if we retain the contribution of both the cuts. The relative importance of these cuts from different graphs depend on their thresholds, besides the couplings at the vertices of the graphs.

We consider the one loop self-energy graphs for ρ with one internal pion line and another meson which may be the pion itself or any of the heavy particles, namely ω, a_1 and h_1, up to a mass of about 1.25 GeV. The resonances are treated in the narrow width approximation. The vertices of the graphs are obtained from chiral perturbation theory. The calculations are carried out in the real time version of thermal field theory.

For the interaction vertices entering the graphs, we expand the relevant terms of the chiral Lagrangian and retain the lowest order terms to get

$$\begin{aligned}\mathcal{L}_{int} &= -\frac{2G_\rho}{m_\rho F_\pi^2}\partial_\mu\vec{\rho}_\nu\cdot\partial^\mu\vec{\pi}\times\partial^\nu\vec{\pi}\\ &+\frac{g_1}{F_\pi}\epsilon_{\mu\nu\lambda\sigma}(\partial^\nu\omega^\mu\vec{\rho}^\lambda-\omega^\mu\partial^\nu\vec{\rho}^\lambda)\cdot\partial^\sigma\vec{\pi}\\ &-\frac{g_2}{F_\pi}h_1^\mu(\partial_\mu\vec{\rho}_\nu-\partial_\nu\vec{\rho}_\mu)\cdot\partial^\nu\vec{\pi}\\ &+\frac{g_3}{F_\pi}(\partial_\mu\vec{\rho}_\nu-\partial_\nu\vec{\rho}_\mu)\cdot\vec{a}_1^\mu\times\partial^\nu\vec{\pi} \qquad (1)\end{aligned}$$

Here F_π is the pion decay constant, $F_\pi = 93$ MeV. The magnitude of other coupling constants may be determined from the observed decay rates of the particles. Thus the decay rate $\Gamma(\rho^0\to e^+e^-) = 6.9$ keV gives $F_\rho = 154$ MeV. The decay rate $\Gamma(\rho\to 2\pi) = 153$ MeV gives $G_\rho = 69$ MeV. Similarly the decay rates $\Gamma(\omega\to 3\pi) = 7.6$ MeV, $\Gamma(h_1\to\rho\pi)\simeq 360$ MeV and $\Gamma(a_1\to\rho\pi)\simeq 400$ MeV give respectively $g_1 = .87$, $g_2 = 1.0$ and $g_3 = 1.1$.

Using the above vertices and couplings we evaluate the real and imaginary parts of the $\pi\pi$, $\pi\omega$, πh_1 and πa_1 loops. The imaginary part consists of four terms [1] 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 $q^2 \geq (m_h + m_\pi)^2$, giving the unitary cut, while the second and the third are non-vanishing for $q^2 \leq (m_h - m_\pi)^2$, giving the so-called Landau cut.

We have evaluated the self energies as a function of $\sqrt{q^2}\equiv M$ 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 $q_0 = |\vec{q}|$. The $\pi\pi$ loop is distinguished by a large imaginary part of

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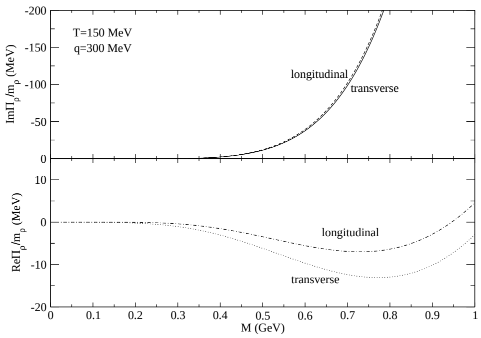

FIG. 1: The imaginary and the real parts of self-energy from $\pi\pi$ loop in upper and lower panel respectively. The longitudinal and transverse components are shown separately.

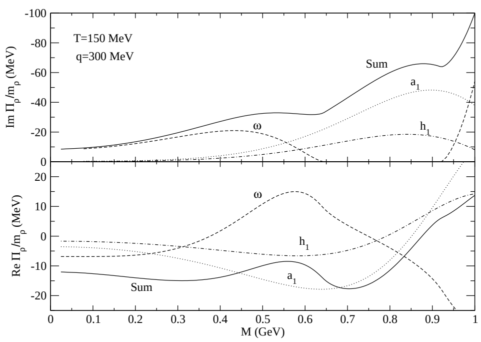

FIG. 2: The imaginary and the real parts of self-energy from different πh (where h=ω, a_1 and h_1) loops in the upper and lower panel respectively. The quantities are averaged over polarisation.

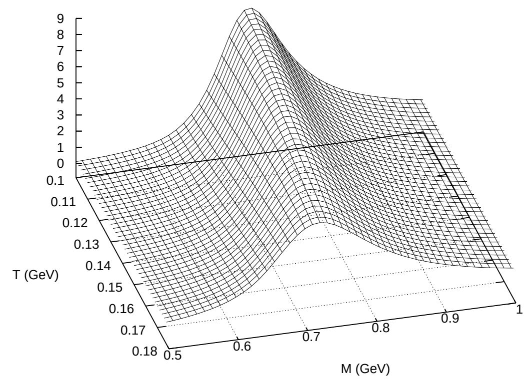

FIG. 3: The ρ spectral function averaged over the transverse and longitudinal polarizations for $\vec{q}$=300 MeV.

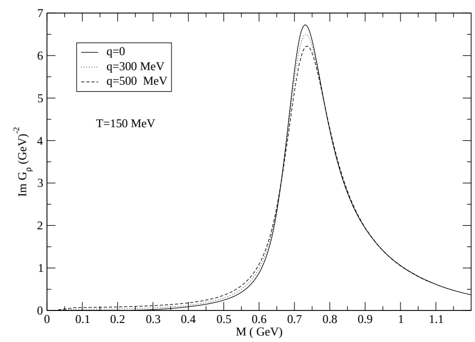

FIG. 4: ρ spectral function for different three-momenta at fixed temperature.

the self-energy, its vacuum part giving $\Gamma_\rho \equiv \mathrm{Im}\,\overline{\Pi}^{(\pi)}/m_\rho = 153$ MeV at $M = m_\rho$. Clearly it is only the unitary cut in the time-like region that gives the imaginary part. The results for this loop are shown in Fig. 1. The real and imaginary parts for the loops with heavier mesons is shown in Fig. 2. Here it is only the second part of the Landau cut ($|\vec{q}| \le q_0 \le \sqrt{(m_h - m_\pi)^2 + |\vec{q}|^2}$), which contributes to the imaginary part. The only exception is the $\pi\omega$ loop, where the unitary cut ($q_0 \ge \sqrt{(m_h + m_\pi)^2 + |\vec{q}|^2}$) also contributes, its threshold for other loops appearing outside the range of M plotted here. The $\pi\omega$ loop dominates up to about $M \sim 500$ MeV, beyond which the πa_1 loop takes over. The rising trend of the imaginary part at the upper end is due to the contribution of the unitary cut. While the imaginary parts add up, there is appreciable cancellation among the real parts of different loops.

The spectral function is plotted in Fig. 3 for a range of temperatures. We observe significant broadening at higher temperatures with almost negligible shift in the pole mass. Also, the spectral function shows very little three-momentum dependence as seen in Fig. 4.

References

[1] S. Ghosh, S. Mallik and S. Sarkar, Eur. Phys. J C (in press)[arXiv:0911.3504]