Spectral properties of nucleon in hot nuclear matter

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The collision of heavy nuclei at ultrarelativistic energies is expected to produce a thermal medium of strongly interacting degrees of freedom. Such a system can provide us with an opportunity to investigate particle propagation through strongly interacting media. However, only the vector mesons, particularly the ρ, can at present be studied directly by detecting dileptons, into which they decay in the hot, dense media. The media created by these collisions consist, in general, not only of mesons, but also of nucleons. Thus the effects of both mesons and nucleons on the vector meson spectral functions have been extensively studied in the literature. For a more complete picture, the self-energy of nucleon itself need be investigated.

In this work, we find the one loop corrections to the nucleon propagator at finite temperature and nucleon chemical potential in the real time formulation of the thermal field theory. In this formalism the propagator and self-energy assumes the form of a 2×2 matrix. However, this can be diagonalised in terms of a self energy function which in turn can be expressed in terms of the 11-component. We have considered $\pi - N$ and $\pi - \Delta$ loops for which the self-energy is given in terms of the 11-component of the propagators by [1]

$$\Sigma^{11}(q) = i \int \frac{d^4k}{(2\pi)^4} R(q,k) D^{11}(k) E^{11}(q-k) \ . \tag{1}$$

The interaction vertices have been obtained from chiral perturbation theory which is the low energy effective theory of QCD. The appropriate field variable for pion in the effective theory is the $SU(2)$ valued matrix field $u(x)$ related to $\phi(x)$ by $u(x) = \exp(i\vec{\tau}\cdot\vec{\phi}/2F_\pi)$, where $F_\pi = 93$ MeV, the so-called pion decay constant. The effective Lagrangians are

$$\mathcal{L}_{\pi NN} = \frac{1}{2} g_A \overline{\psi} \not{u} \gamma_5 \psi \tag{2}$$

$$\mathcal{L}_{\pi N\Delta} = \frac{g_\Delta}{\sqrt{2}} \overline{\psi}_a (u^\mu)^c_b \Delta^{abd}_\mu \epsilon_{cd} + h.c. \tag{3}$$

where $u_\mu = i(u^\dagger \partial_\mu u - u \partial_\mu u^\dagger)$, $a, b \cdots = 1, 2$ and $\epsilon_{12} = -\epsilon_{21} = 1$, etc. The coupling constants g_A and g_Δ are to be determined phenomenologically. As is well-known, such a model requires form factors at the vertices, which we take in the Lorentz invariant form as

$$F(p,k) = \frac{\Lambda^2}{\Lambda^2 + (p\cdot k/m_N)^2 - k^2} \tag{4}$$

where p and k are the four-momenta of nucleon and pion at the vertices and Λ is essentially a cut-off on these momenta. This model is then checked with experimental data on πN scattering. The pion-nucleon partial wave f in the P_{33} channel may be written in the form

$$f(E) \sim \frac{1}{E^2 - m_\Delta^2 + i m_\Delta \Gamma(E)} \tag{5}$$

where $\Gamma(E)$ is the the decay width of $\Delta \to N + \pi$. We take the resonance parameters at the pole position, $m_\Delta = 1210$ MeV and $\Gamma(m_\Delta) = 100$ MeV. Taking $g_\Delta = 2.2$ and $\Lambda = 400$ MeV, we can achieve reasonable agreement with the phase shift δ_{33} computed

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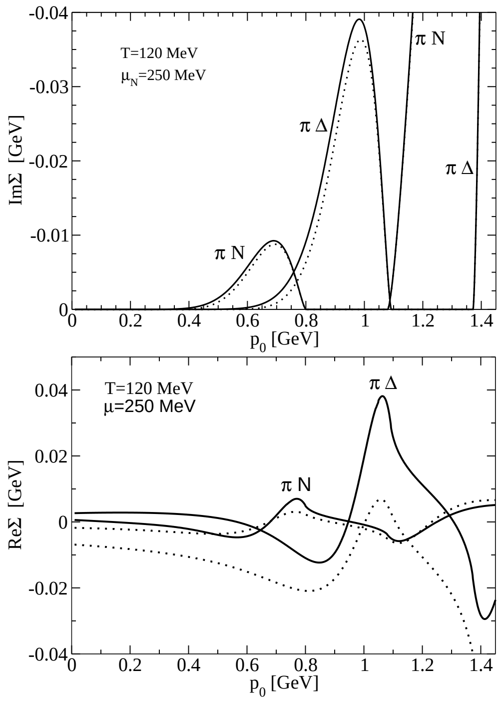

FIG. 1: Imaginary (upper panel) and real (lower panel) parts of self-energy from πN and $\pi\Delta$ loops. Solid curves represent the results of our calculation (relativistic, including unitary cuts). Dotted curves result from non-relativistic approximation.

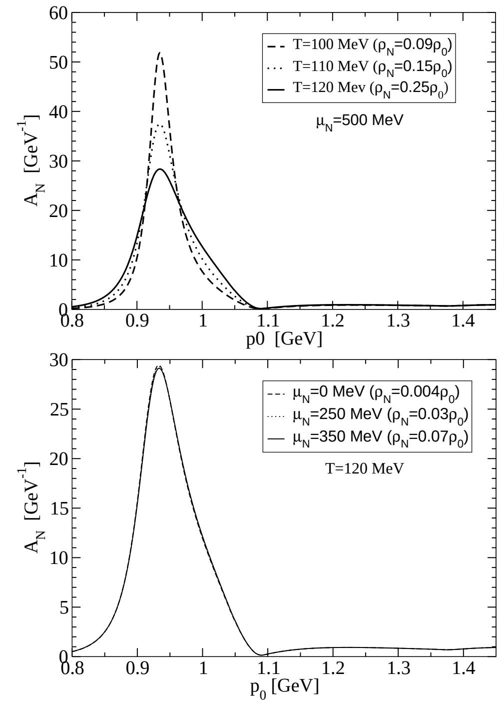

FIG. 2: Nucleon spectral function at different temperatures for a fixed chemical potential (upper panel) and at different chemical potentials for a fixed temperature (lower panel)

from the above equation with experimental data. Also we take $g_A = 1.26$ and the same form factor at the πNN vertex.

Using these values and interaction vertices the real and imaginary parts of the self energy are evaluated from Eq.(1). The imaginary part of self energy can be expressed in term of four different delta functions These delta-functions in the different terms control the regions of non-vanishing imaginary parts of self energy, which define the position of the branch cuts. In the positive invariant mass space the regions of unitary cut and Landau cut are $p_0 \geq (m+m_\pi)$ and $0 \leq p_0 \leq (m-m_\pi)$ which can be clearly seen in fig. 1.

The spectral function of nucleon is obtained from the Dyson equation, giving the complete propagator in terms of the free propagator and self-energy and in the limit of $\boldsymbol{q} = 0$, the expression of spectral function which is the imaginary part of the complete propagator is given by

$$A_N(q_0) = \frac{-\mathrm{Im}\Sigma}{(q_0 - m_N - \mathrm{Re}\Sigma)^2 + (\mathrm{Im}\Sigma)^2} \quad (6)$$

In fig. 2 we show the nucleon spectral function at different values of T and μ, which are realised in heavy-ion collisions. As expected, the height of the peak decreases with rise of temperature, while it remains about the same within the interval of chemical potential considered here.

References

[1] S. Ghosh, S. Sarkar and S. Mallik, Phys. Rev. C (in press) [arXiv:1004.2162]