Spectral properties of ρ meson in hot magnetized matter: Effects of (inverse) magnetic catalysis

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Introduction

In-medium spectral function and production cross-section of the light vector meson state ρ are studied accounting for the effects of the magnetized Dirac and Fermi sea of nucleons in a hot magnetized nuclear matter. The in-medium hadronic partial decay widths of $\rho \to \pi\pi$ are calculated considering the effective interaction vertices with the phenomenologically fitted coupling and the medium modified mass of the ρ meson in the hot magnetic matter. The masses are computed using the Borel transform sum rule followed by the finite energy sum rules in terms of the in-medium light scalar quark condensates (up to dimension six) and the scalar gluon condensate. The condensates are studied within the chiral $SU(3)$ model framework in terms of the medium modified scalar, isoscalars σ, ζ, isovector δ and the dilaton field χ. The effects of the magnetic field are incorporated through the magnetized Dirac sea as well as the Landau energy levels of protons and the anomalous magnetic moments (AMMs) of the nucleons in the Fermi sea of nuclear matter at finite temperature. The temperature effects are incorporated through the Fermi distribution functions in the number ($\rho_{p,n}$) and scalar ($\rho^s_{p,n}$) densities of nucleons. The effects of (inverse) magnetic catalysis due to the magnetized Dirac sea contribution at finite temperature are thus studied on the spectral functions and production cross-sections of neutral ρ meson. This may have considerable observable impacts in the invariant dilepton spectra of the light vector meson state in the relativistic heavy ion collision experiments.

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Theoretical Framework

The resonance properties (mass etc.) of the meson states under consideration are calculated within the framework of QCD Sum Rule (QCDSR). The Borel transform is applied to extract the properties of the lowest lying resonance followed by the finite energy sum rules (FESRs). In FESRs, the in-medium resonance parameters are determined in terms of the QCD condensates of dimension up to six. The effects of baryon density (ρ_B), isospin asymmetry (η), temperature (T) and magnetic fields ($|eB|$) are then incorporated into these condensates. The condensates are computed within the chiral $SU(3)$ model framework, which is based on the non-linear realization of chiral $SU(3)_L \times SU(3)_R$ symmetry and the broken-scale invariance of QCD [1]. The explicit symmetry breaking term in the model Lagrangian is compared to that in the QCD Lagrangian to relate the QCD light quark condensates ($m_q\langle\bar{q}q\rangle; q = u, d$) with the scalar fields σ, δ in the scalar meson octet and parameters of the Lagrangian.

$$m_q\langle\bar{q}q\rangle|_{q=u,d} = \frac{1}{2}m_\pi^2 f_\pi(\sigma \pm \delta)$$

The scalar gluon condensate ($\langle G^{a\mu\nu}G^a_{\mu\nu}\rangle$) is simulated by comparing the scale-invariance breaking terms in the model and QCD Lagrangians. In QCDSR the time-ordered product of the locally separated currents with the quantum numbers of the meson state is considered. Its Fourier transform is called the current-current correlator $\left[\Pi_{\mu\nu}(q) = q_\mu q_\nu R(q^2) - g_{\mu\nu}K(q^2)\right]$. The invariant correlator $R(q^2)$ is taken for both the vector and axial-vector currents [2]. Real part of $R(q^2)$ on the phenomenological side is related to its imaginary part via a dispersion relation. $ImR^{phen.}(s)$, the spectral density is parametrized in terms of hadronic resonance plus perturbative continuum. On the other representation, $ReR(s)$ is expanded via Wilson's operator product expansion (OPE) in the deep Euclidean region ($Q^2 \equiv -q^2 >> 0$),

$$R_{OPE}(q^2=-Q^2) = \left(-c_0 \ln\left(\frac{Q^2}{\mu^2}\right) + \sum_{n=1}^{3} \frac{c_n}{Q^{2n}}\right)$$

The first term in the OPE is a contribution from perturbative QCD at $\mu = 1$ GeV scale [3]. The coefficients c_i $(i = 1, 2, 3)$ of the subsequent terms contain QCD non-perturbative effects in terms of the light quark and scalar gluon condensates and some parameters from the QCD Lagrangian. The resonance properties are related to the QCD condensates as [2]

$$\int_0^{s_0} ds\ R_{res}(s) = (c_0 s_0 + c_1),$$

$$\int_0^{s_0} ds\ sR_{res}(s) = \left(\frac{c_0 s_0^2}{2} - c_2\right),$$

$$\int_0^{s_0} ds\ s^2 R_{res}(s) = \left(\frac{c_0 s_0^3}{3} + c_3\right)$$

s_0 separates the low energy resonance and the high energy continuum regions. The normalized form of the Briet-Wigner spectral function $A(M)$ and production cross-section $\sigma(M)$ (M is the invariant mass) used here are $A(M) = \frac{2}{\pi}\frac{M^2\Gamma^*}{(M^2-m^{*2})^2-M^2\Gamma^{*2}}$ and $\sigma(M) = \frac{6\pi^2\Gamma^* A(M)}{q(m^*,m_1,m_2)^2}$, respectively. Where, q is the momentum of the scattered particles in the center-of-mass frame of the produced resonance state. The decay width for the channel of $\rho \to \pi\pi$ is given by $\Gamma_{\rho\to\pi^+\pi^-} = \frac{\tilde{g}^2}{48\pi} m_\rho \left(1 - \frac{4m_\pi^2}{m_\rho^2}\right)^{3/2}$ [2]. Here, m^* and Γ^* denote the in-medium mass and decay width of ρ^0, respectively.

Results and Discussions

The classical scalar fields are solved at the given values of ρ_B, η, T and $|eB|$. The medium effects are incorporated into the scalar fields solutions via the number densities $\rho_{p,n}$ and the scalar densities $\rho^s_{p,n}$ of the nucleons in the hot magnetized nuclear matter. The effects of the magnetized Dirac sea lead to the (decrement) increment of the light quark condensates $\langle \bar{q}q \rangle$; $q = u, d$ with magnetic field, phenomena called (inverse) magnetic catalysis [4] at $T = 0, 50, 100, 150$ MeV of temperature, below the chiral phase transition. The modifications in the vacuum mass and decay width of ρ^0 state as obtained through the scalar quark and gluon condensates are reflected on the shifting of peak position and change in the width of the spectral function of ρ^0 resonance as in fig [1]. This may further modify its production cross-sections as observed in fig.[2] for different values of ρ_B, $|eB|$, and T [2].

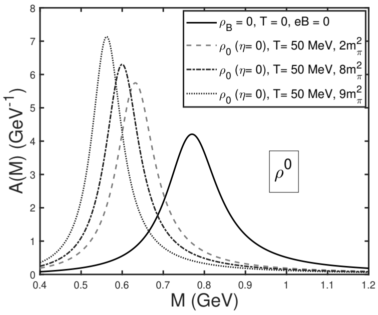

FIG. 1: $A(M)$ (GeV^{-1}) vs. M (GeV) of ρ^0 at $\rho_B = 0, \rho_0$; $\eta = 0$, $T = 50$ MeV & $|eB| = 2,\ 8,\ 9m_\pi^2$.

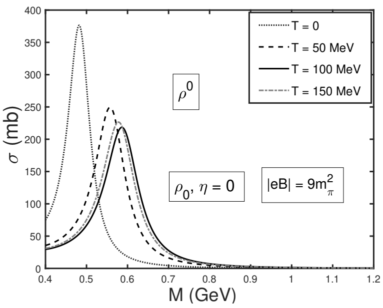

FIG. 2: σ (mb) vs. M (GeV) of ρ^0 at $\rho_B = \rho_0$, $\eta = 0$, $T = 0,\ 50,\ 100,\ 150$ MeV, $|eB| = 9m_\pi^2$.

References

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