ρ meson spectral function in weak magnetic field

Snigdha Ghosh[1],* Arghya Mukherjee[2], Mahatsab Mandal[2], Sourav Sarkar[1], and Pradip Roy[2]
[1] *Theroretical High Energy Physics Division, Variable Energy Cyclotron Centre, 1/AF Bidhannagar , Kolkata - 700064, India and*
[2] *Saha Institute of Nuclear Physics, 1/AF Bidhannagar , Kolkata - 700064, India*

Introduction

The study of strongly interacting matter in presence of magnetic field has become very important topic of research over recent years. In a non-central ultra relativistic heavy ion collision, short lived magnetic fields having strength $eB \sim 15m_\pi^2$ can be created and subsequently it can affect the evolution of the fireball. The situation is similar to that of a magnetar where the magnetic field is as strong as $eB \sim 1\ MeV^2$. It is expected that the presence of magnetic field may affect the spectral prperties of charged hadrons. In Ref.[1], pion mass and dispersion was shown to be sustantially modified for $eB \neq 0$. In the current work, we have calculated the self energy of ρ meson with $\pi\pi$ loop in presence of weak magnetic field ($eB \sim 0.1GeV^2$) using an effective lagrangian. The spectral function of ρ meson is reasonably modifed due to the effect of nonzero magnetic field.

Formalism

We take the well known phenomenological effective lagragian for the $\rho\pi\pi$ interaction as

$$\mathcal{L}_{\rho\pi\pi} = g_{\rho\pi\pi}\vec{\rho^\mu}.\left(\vec{\pi}\times\partial_\mu\vec{\pi}\right) + \frac{1}{2}g_{\rho\pi\pi}^2\left(\vec{\rho^\mu}\times\vec{\pi}\right).\left(\vec{\rho_\mu}\times\vec{\pi}\right), \quad (1)$$

and calculate the 1-loop vacuum self energy of ρ which is given by,

$$(\Pi^{\mu\nu})_{vac} = i\int\frac{d^4k}{(2\pi)^4}[N^{\mu\nu}\Delta_F(p)\Delta_F(k) + 2g_{\rho\pi\pi}^2 g^{\mu\nu}\Delta_F(k)], \quad (2)$$

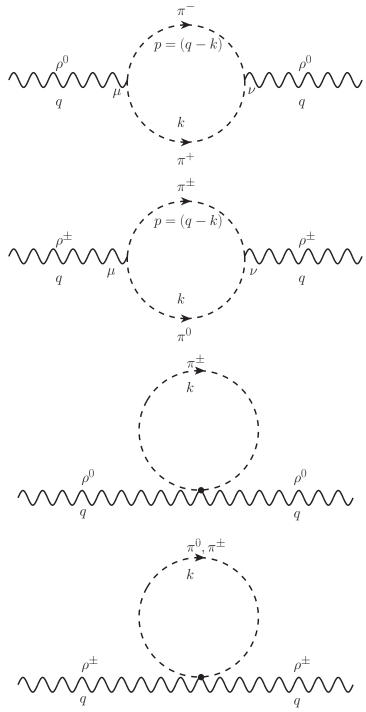

FIG. 1: Feynman diagrams for the ρ self energy

where $\Delta_F(q) = \left(\frac{-1}{q^2-m_\pi^2+i\epsilon}\right)$ is the pion vacuum propagator and the factors from vertices are contained in $N^{\mu\nu} = g_{\rho\pi\pi}^2(q^\mu - 2k^\mu)(q^\nu - 2k^\nu)$. In order to obtain the ρ self energy with nonzero magnetic field, we replace the charged pion propagators with the Schwinger proper time propagator for a charged scaler field [2][3],

$$D(q) = i\int_0^\infty \frac{ds}{\cos(eBs)} e^{is\left[q_\parallel^2 + q_\perp^2\frac{\tan(eBs)}{eBs} - m_\pi^2 + i\epsilon\right]}$$

*Electronic address: `snigdha.physics@gmail.com`

where e is the charge of the particle, B is the constant external magnetic field along z-dirrection, $q_{\parallel}^{\mu} \equiv (q^0, 0, 0, q^3)$ and $q_{\perp}^{\mu} \equiv (0, q^1, q^2, 0)$. In the weak field limit, we obtain the self energies of the ρ^0 and $\rho^{\pm}$ respectively,

$$\begin{aligned} \Pi_0^{\mu\nu} &= (\Pi^{\mu\nu})_{vac} + Aq^{\mu}q^{\nu} + Bg^{\mu\nu} + Cg_{\perp}^{\mu\nu} \\ &+ D(q^{\mu}q_{\perp}^{\nu} + q^{\nu}q_{\perp}^{\mu}) \\ \Pi_{\pm}^{\mu\nu} &= (\Pi^{\mu\nu})_{vac} + \frac{1}{2}(Aq^{\mu}q^{\nu} + Bg^{\mu\nu} + Cg_{\perp}^{\mu\nu} \\ &+ D(q^{\mu}q_{\perp}^{\nu} + q^{\nu}q_{\perp}^{\mu})), \end{aligned}$$

where, $g^{\mu\nu} = diag(1, -1, -1, -1)$ and $g_{\perp}^{\mu\nu} = diag(0, -1, -1, 0)$. The coefficients A, B, C, D are given by,

$$\begin{aligned} A &= \frac{2}{3}\frac{g_{\rho\pi\pi}^2 (QB)^2}{16\pi^2} \int_0^1 dx(1-x)^3(1-2x) \\ &\left[\left(\frac{(1-2x)(m^2 + 2q_{\perp}^2 x^2 - x^2 q^2)}{\Delta^3}\right) - \frac{2x}{\Delta^2}\right] \\ B &= \frac{1}{3}\frac{g_{\rho\pi\pi}^2 (QB)^2}{16\pi^2}[\frac{1}{m^2} - \int_0^1 dx(1-x)^3 \\ &2\left(\frac{1}{\Delta} + \frac{m^2 + 2q_{\perp}^2 x^2 - x^2 q^2}{\Delta^2}\right)] \\ C &= \frac{4}{3}\frac{g_{\rho\pi\pi}^2 (QB)^2}{16\pi^2} \int_0^1 dx \left[\frac{(1-x)^3}{\Delta}\right] \\ D &= \frac{4}{3}\frac{g_{\rho\pi\pi}^2 (QB)^2}{16\pi^2} \int_0^1 dx \left[\frac{x(1-x)^3(1-2x)}{\Delta^2}\right] \end{aligned}$$

where, $\Delta = m_{\pi}^2 - x(1-x)q^2 - i\epsilon$. Having obtained the self energy we calculate the spectral functions for the ρ^0 and $\rho^{\pm}$ using the spin averaged quantity $\Pi = -\frac{1}{3}\Pi_{\mu}^{\mu}$. The spectral function is the imaginary part of the complete propagator i.e.

$$Im\left[\frac{-1}{q^2 - m_{\rho}^2 - \Pi}\right] \quad (3)$$

Results

Now we present the numerical results of our calculation. In this work, we have taken $\vec{q} = 0$. In fig (2), we have plotted the spectral functions of ρ^0 and $\rho^{\pm}$ at different values of magnetic field. The effect of magnetic field is more on the ρ^0 as compared to $\rho^{\pm}$. This is expected

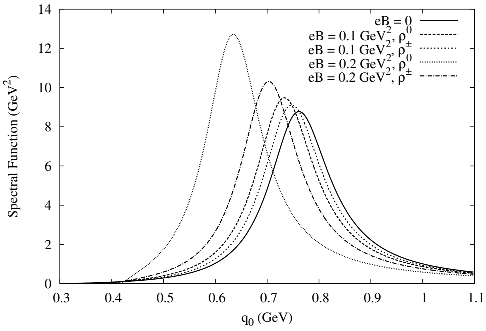

FIG. 2: Spectral Function of ρ

from fig (1), where the ρ^0 self energy diagram contains two charged particles in the internal lines, as compared to that of $\rho^{\pm}$ which contains only one charged particle. Moreover the spectral functions are shifted towards small values of q^0 and this is due to the negative contribution from the real part of self energy.

Acknowledgments

SG and AC acknowledge Department of Atomic Energy, Govt. of India for support.

References

[1] S. P. Adhya, M. Mandal, S. Biswas and P. K. Roy,Phys. Rev. D **93**, no. 7, 074033 (2016)

[2] J. S. Schwinger, Phys. Rev. **82**, 664 (1951).

[3] A. Ayala, A. Sanchez, G. Piccinelli and S. Sahu, Phys. Rev. D **71**, 023004 (2005)