Ellipticity of dilepton emission from a magnetized hadronic medium

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Introduction

The primary objective of modern relativistic heavy ion collision (HIC) at LHC and RHIC is to study hot and dense nuclear matter. The fireball created in HICs is very short-lived ($\sim$ few fm/c) highly restricting any possibility of direct observation and cools via rapid expansion under it own pressure gradient going through various stages of the evolution process. Hence, one has to rely on indirect observables such as electromagnetic (EM) probes (photons, dileptons). The EM probes can only participate in electromagnetic interaction and due to the large mean free path comparing with the typical size of the system, it can leave the system without further interaction carring clear informations where created. However, as the system evolvoes, hadronic phase is expected to generate from quark-gluon-plasma (QGP) via a phase transition or crossover. This phase has also significant contribution on the dilepton production in the low invariant mass region.

It is believed that very strong transient ($\sim$ few fm/c) magnetic fields of the order $\sim 10^{15-18}$ Gauss or larger might be generated in non-central HICs due to the receding spectators. However, the finite electrical conductivity of the medium ($\sim$ few MeV) can delay the decay process of the magnetic field so that non-zero magnetic field can persist even in the hadronic phase. Recently, we have studied dulepton production rate (DPR) from a thermo-magnetic hadronic medium in Ref. [1] using Vector Meson Dominance model.

In this article, we compute ellipticity of dilepton production from a thermo-magnetic hadronic medium in terms of the spectral function of rho-meson. The spectral function $\mathcal{Q}$ is evaluated from electromagnetic current correlation function using real time formalism in the scheme of finite temperature field theory.

Formalism

A. Anisotropy of Dilepton Emission

To study the anisotropy of dilepton production we consider the geometry where the beam is along the $\hat{\boldsymbol{x}}$-direction, the background constant magnetic field points in the positive $\hat{\boldsymbol{z}}$-direction without any loss of generality. Hence, the thansverse momentum of dilepton q_T makes an angle ϕ (which is called azimuthal angle) with respect to the reaction plane, i.e, x-y plane and lies in the y-z plane which is perpendicular to the beam direction. Now, the flow coefficients of dilepton (v_n) can be obtained as

$$v_n = \frac{\int_0^{2\pi} d\phi \cos(2n\phi) \frac{dN}{d^4x d^4q}}{\int_0^{2\pi} d\phi \frac{dN}{d^4x d^4q}} \qquad (1)$$

where v_1, v_2 are the corresponding directed and elliptical flows of dilepton production respectively. The normalization factor in the denominator of Eq. (1) is the total differential DPR. The calculation of DPR$=\frac{dN}{d^4xd^4q}$ from a hot magnetized hadronic medium has been discussed in subsection below.

B. Dilepton Production Rate

Following the same notation as in Ref. [1], the dilepton production per unit four-

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momentum and space-time volume d^4xd^4q can be written as

$$\frac{dN}{d^4xd^4q} = \frac{\alpha^2}{\pi^3 q^2} f_{\rm BE}(q_0) L(q^2) F_\rho^2 m_\rho^2 \mathcal{Q}(q;T,B). \tag{2}$$

where α is fine structure constant, $f_{\rm BE}(x) = (e^{x/T} - 1)^{-1}$ is Bose-Einstein distribution function, $L(q^2) = \left(1 + \frac{2m_{lep}^2}{q^2}\right)\sqrt{1 - \frac{4m_{lep}^2}{q^2}}$, m_{lep} is the leptonic mass, m_ρ is the bare mass of rho-meson, F_ρ is the coupling between rho-meson and photon fields and the thermo-magnetic spectral function of rho meson is $\mathcal{Q}(q;T,B) = -\frac{1}{3}g^{\mu\nu}{\rm Im}\ \overline{P}_{\mu\nu}$. Here the complete rho-meson propagator Im $\overline{P}_{\mu\nu}$ is the most significant component in the computation of DPR and indicates the thresholds as well as the intensity of dilepton production. We have evaluated $\overline{P}_{\mu\nu}$ by solving Dyson-Schwinger equation (Eq. 3) in terms of bare ρ-propagator $\overline{P}^{(0)}_{\mu\nu}$ and analytic self-energy function $\overline{\Pi}^{\alpha\beta}$.

$$\overline{P}_{\mu\nu} = \overline{P}^{(0)}_{\mu\nu} + \overline{P}^{(0)}_{\mu\alpha}\overline{\Pi}^{\alpha\beta}\overline{P}_{\beta\nu} \tag{3}$$

The ρ-meson self-energy is calculated in presence of constant background magnetic field (without taking any approximation on the strength of magnetic field) using the effective field theoretic Lagrangian[1]

$$\mathcal{L}_{\rm int} = -g_{\rho\pi\pi}\ (\partial_\mu \boldsymbol{\rho}_\nu)\cdot(\partial^\mu \boldsymbol{\pi} \times \partial^\nu \boldsymbol{\pi}). \tag{4}$$

where $g_{\rho\pi\pi}$ is the coupling constant of the interaction. We have used Schwinger method to obtain the pion propagator in magnetic field for the calculation of ρ meson self-energy. The analytic structure of self-energy in complex plane shows that there is a non-trivial contribution coming from Landau cut in addition to the usual Unitary cut in physical time-like kinematic domain owing to the fact that the charged pions occupy different Landau levels before and after scattering with the ρ meson. This is purely a magnetic phenomenon.

Numerical Results

The anisotropy in dilepton production rate from thermo-magnetic hadronic medium is

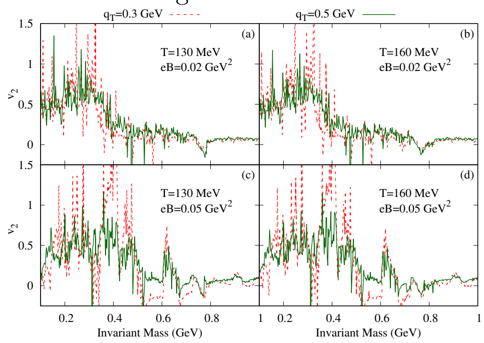

FIG. 1: (Color online) Ellipiticity of dilepton production v_2 as a function of invariant mass M for $q_T = 0.3$ and 0.5 GeV at (a) $T = 130$ MeV, $eB = 0.02$ GeV^2, (b) $T = 160$ MeV, $eB = 0.02$ GeV^2 (c) $T = 130$ MeV, $eB = 0.05$ GeV^2, (d) $T = 160$ MeV, $eB = 0.05$ GeV^2.

shown in Fig. 1(a)-(d) where we have depicted ellipticity parameter (v_2) with invariant mass (M) for various values magnetic fields ($eB = 0.02, 0.05$ GeV^2) and temperatures ($T = 130, 160$ MeV) at central rapidity ($q_x = 0$). In all the figures, the observed spikelike structure in v_2 is due to the numerous Landau level thresholds. It is also found that v_2 has a strong tendency to remain positive in low invariant mass region particularly for small eB values. This positive value of v_2 corresponds to an oblate shape of DPR and indicates larger dilepton production on the reaction plane which is perpendicular to the magnetic field. On the other hand, in high invariant mass region v_2 is highly oscillating around zero implying an isotropic nature of dilepton production.

References

[1] R. Mondal, N. Chaudhuri, S. Ghosh, S. Sarkar, P. Roy; Phys. Rev. D 107, 036017 (2023); arXiv:2301.09475.