Electromagnetic probes in heavy-ion collisions

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Introduction

One of the important phenomenological tool to study heavy ion collision is the electromagnetic probes. Electromagnetic probes such as photons and dileptons are especially useful probes to study the quark-gluon plasma (QGP) as they probe the earliest and hottest phase of the evolution of the QGP fireball without being affected by final-state interactions [1, 2].

Biro, Strickland and their co-workers [3, 4] studied the photon emission in a chemically equilibrating baryon free QGP system. Further a lot of research have been done in direction of photon emission at finite chemical potential [5].

In QGP phase, the photon emission occurs mostly through quark-antiquark annhilation process. Thus we focuses on photon emission with finite chemical potential at 1-loop annihilation process to reveal the effect of the quark chemical potential on photon production. The finite quark mass is defined which is computed by replacing the factor T^2 to a good accuracy of temperature as $T^2 + \mu_q^2/\pi^2$ [5, 6]. Now the quark mass is not only depends on temperature but also is a function of chemical potential which is suitably modified by Ref. [7, 8]:

$$m_q^2(T, \mu_q) = \frac{16\pi}{9N_f} \frac{\gamma_q}{\ln(1 + \frac{k^2}{\Lambda^2})} \left(T^2 + \frac{\mu_q^2}{\pi^2} \right) \quad (1)$$

where k is known as momentum with quark flavor $N_f = 3$, Λ is QCD parameter and γ_q=1/6 is the quark phenomenological parameter taken by Ref. [7, 8]. These parameters are nicely fit into the calculations. Using strong coupling constant and modified quark mass, I studied the photon emission at finite temperature and chemical potential for the quark flavor $N_f = 3$.

Photons from a QGP with finite chemical potential

Photons are interesting probe of the QGP at finite quark chemical potential and thus the area of interest lying within the hot nuclear matter. The thermal photon emission produced from the partonic medium and later hadronic phase makes a negligible contribution in the high transverse momentum range. Since photons have been proposed as a promising signature of the QGP formation in heavy-ion collisions, my emphasis is put on the photon production from a non-equilibrated QGP using finite quark chemical potential.

In this paper, I work on the photon production at finite baryon density on the basis of Jüttner distribution function considering the QCD quark-antiquark annihilation process. The photon production due to quark-antiquark annihilation process $q\bar{q} \to \gamma g$ is considered which appear at one loop level for system of quarks and gluons.

The calculation is performed at hot phase of QGP temperature $T = 0.35$ GeV for flavor 3 with the Jüttner distribution functions. Inserting the distribution funtions one can obtain the expression for photon emission rate through annihilation process at finite quark chemical potential [4, 9, 10]:

$$E\frac{dN^{Ann}}{d^3pd^4x} = \frac{2\alpha\alpha_s}{\pi^4}\lambda_q\lambda_{\bar{q}}T^2e^{-E/T}\sum_f e_f^2 \left[ln\left(\frac{4ET}{k_c^2}\right) - C_{Euler} - 1\right], \quad (2)$$

with $k_c^2 = 2m_q^2$, $C_{Euler} = 0.577216$ and fugacity for quark and gluon are taken as 0.02 and 0.09 [10].

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The total photon spectrum is calculated by integrating the rate over the space-time evolution of the fireball created in heavy-ion collision for this channel. It is expressed as [9]:

$$\frac{dn}{d^2k_T dy} = \int d^4x \left(E\frac{dn}{d^3kd^4x}\right)$$
$$= Q\int_{\tau_1}^{\tau_2} \tau d\tau \int_{-y}^{+y} dy \left(E\frac{dn}{d^3kd^4x}\right). \quad (3)$$

Where $\tau_{1,2}$ are the initial and final time, y is the rapidity of nuclei and k_T is transverse momentum, we obtain photon spectra for annihilation channel.

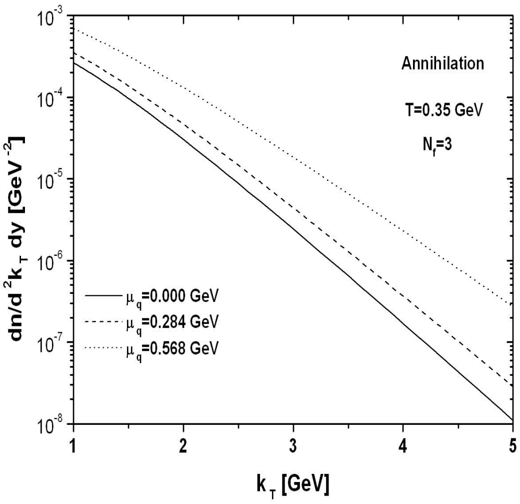

FIG. 1: The photon production through annihilation process are shown at hot phase of temperature $T = 0.35$ GeV with the variation of quark chemical potential for $N_f = 3$.

Results

In Fig. 1, the photon production rate is shown at the hot phase of temperature $T = 0.35$ GeV through the annihilation process for quark flavor $N_f = 3$. It is found that the production rate is strong increasing function of quark chemical potential μ_q. The temperature above the critical temperature is used to compute the integral of the production rate of thermal photons as a signal of photons from the QGP phase is visible just above the critical temperature T_c. The modified quark mass at finite chemical potential give the significant enhancement in the production rate and seems to be large at such hot phase of temperature as comparison to the earlier results [8].

Discussion

Here I studied one of the important production source of the electromagnetic emission from QGP at finite chemical potential in heavy-ion collision. The calculation of photon production as a function of transverse momentum incorporating the parametrization factor in the modified quark mass and coupling value give the fine and much enhanced results from the earlier results [8] i.e. without the chemical potential. The presence of quark chemical potential enhances the photons production rate in annihilation process. The output may be of importance concerning photon production as a signature for the creation of a quark-gluon plasma.

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