Thermodynamically Congruous Model of Photon Pair Production

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Introduction

Out of the various methods for studying the Quark Gluon Plasma (QGP) [1, 2], electromagnetic signatures prove to be one of the best signals to probe the formation and detection of the exotic phase of matter at RHIC and LHC [3]. Due to their non-interactive nature, the photon pairs do not scatter or communicate with the surrounding matter till they reach the detector and since they are produced through various channels from the hot QGP phase to the freeze out phase, they are considered as excellent probes to study both the hadronic as well as the QGP medium [4]. Along with this, the background radiation due to the decay of hadrons and other sources also contribute crucially to the production of diphotons which can not be ignored in the study of photon pairs. Here, we focus on the theoretical study of photon pairs emitted from the hot matter. This work deals with the production rate of diphotons via quark-antiquark annihilation ($q\bar{q} \to \gamma\gamma$) process using a thermodynamically congruous model with effective quark mass.

Description of the model and the production rate of photon pairs

At vanishing value of chemical potential and the critical value of temperature around $T = 200MeV$, the interaction between the quarks and the gluons generate the thermally dependent quasi-particles. The masses can be described by their effective mass which is defined through thermal mass expression [5]. Using thermal Hamiltonian, the effective mass can be achieved by [6, 7]:

$$m_{eq}^2 = m_{cq}^2 + m_{th}^2 + \sqrt{2} m_{cq} m_{th} \tag{1}$$

Where m_{eq} on the left hand side is the effective quark mass, m_{cq} is the current mass of the quarks. The temperature dependent quark mass is described by m_{th} which has a strong temperature dependent characteristic, also depending on the coupling parameters. It can be inferred that the simple phenomenological congruous models work well with high temperature values above the critical temperature. The thermal quark mass is expressed as [5, 8]:

$$m_{th}^2 = g^2(\kappa)(\gamma_q)T^2 \tag{2}$$

The parameters used in the above equation are defined in Ref. [5].

The elementary process (lowest order) as quark-antiquark annihilation is used in this work since it shows an efficient rate of production in the QGP region. Along with this, the pionic decays are also considered. The equations are given as:

$$q + \bar{q} \to \gamma + \gamma$$
$$\pi^+ + \pi^- \to \gamma + \gamma$$
$$\pi^0 \to \gamma + \gamma$$

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By considering well opted values for the parametrization factors in the effective quark mass and by using re-summation techniques used in the work of Haglin [9], the variation of diphoton production rate with mass can be determined as [8, 9]:

$$\frac{dR}{dM^2} = \frac{3}{4\pi^3} \sum e_f^4 \alpha^2 [\frac{\pi M T^3}{2}]^{\frac{1}{2}} \times \ln\left(\frac{2\pi \times c M^2}{3 \times m_{eq}^2}\right) e^{-\frac{M}{T}} \quad (3)$$

Here, T is the temperature, colour number is $N_c = 3$ with $c \approx 0.042$. The summation is taken across the value of f. The invariant mass of diphotons is given by M whereas α is fine structure constant. The meson decay to diphotons can be expressed as [8, 9].

Finally, we show the results of photon pair production in QGP and hadronic phase with the help of effective quark mass. The results of photon pair with effective quark mass are compared to thermal quark mass in QGP phase and also with HG phase.

Results and Conclusion

Our result of diphoton production rate against the invariant mass of the diphoton using the effective quark mass, at a critical temperature ($T = 200MeV$) is shown in Fig. 1. Our result of diphotons with effective quark mass is compared with the work of Kumar et al. [8] with thermal quark mass. The comparative study has also done between two phases of matter i.e. QGP and HG. We observe a clear cut improvement of diphotons from pions in HG in low mass region and further, it get suppressed in the intermediate mass region and diphotons from $q\bar{q}$ annihilation process in QGP take lead over HG in mass range: 1 GeV $< M_{\gamma\gamma} \leq 4$ GeV. The effective quark mass shows almost same output as compared to thermal quark mass which indicates results are not diverged in the presence of effective quark mass and therefore consistent with the result of diphotons production rate. The study also helps in predicting the initial temperature if phase shift show some visible sign between HG and QGP. To this end, this is still a topic of research and may provide valuable cognizance in this field.

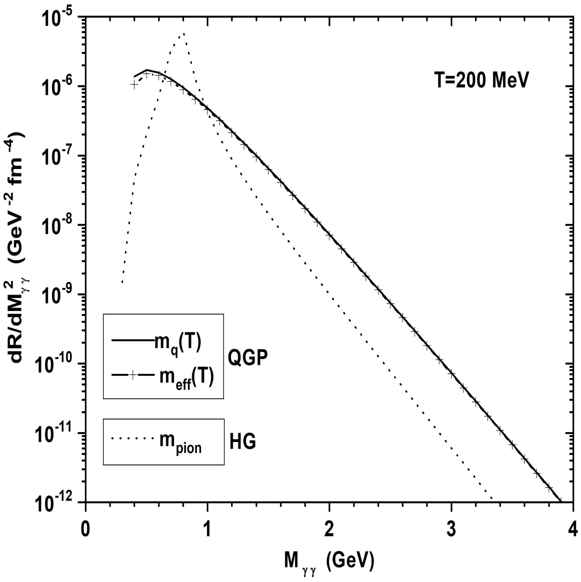

FIG. 1: Mass spectrum of diphotons at $T = 200MeV$ is shown with effective quark mass and compared with thermal quark mass in QGP phase. The diphotons production from QGP and HG is also compared.

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