A Theoretical Study on Diphotons within a Quasi-Particle Treatment at Finite Chemical Potential

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Introduction

It is challenging to fully understand the properties of Quark-Gluon Plasma (QGP). Experiments at Large Hadron Collider (LHC) and Relativistic Heavy-Ion Collider (RHIC) use heavy-ion collisions to study its characteristics [1, 2]. Multiple indirect signatures such as strangeness enhancement, droplet creation, electromagnetic radiations and equation of state can be used to inspect the properties of QGP. Out of these, electromagnetic radiations are the most favourable since such radiations can propagate freely with rare interactions within the QGP and hadronic medium [3, 4]. In particular, we choose to study diphoton production as a measure to probe the exotic system of QGP since it allows invariant mass identification and we study the diphoton emission from the lowest order process via quark-antiquark annihilation ($q\bar{q} \rightarrow \gamma\gamma$).

It has been concluded that there is a possibility that a chemical potential μ could exist within the QGP phase [5]. It is, therefore, important to examine this effect while calculating diphoton production to get a better estimate of the nature of QGP and hadronic system. We choose the quark-antiquark annihilation process in the context of a quasi-particle model since quark-antiquark annihilation is considered here as one of the fundamental processes in QGP and it has higher rate of production of particles in QGP phase.

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Model Description and Diphoton Emission

A quasi-particle model entails a dependency of quark mass on temperature T. Besides this, we consider the influence of a small chemical potential μ [6, 7]. Then, the quark mass equation becomes [8]:

$$m^2_{quark}(T, \mu) = \gamma_q(g^2(k)) \left(T^2 + \frac{\mu^2}{\pi^2} \right) \quad (1)$$

Here, γ_q and $g(k)$ are parameters of QGP flow and running couple constant of QCD respectively. k and μ are momentum and chemical potential terms, as usual. Here, $k = (\frac{\gamma N^{1/3} T^2 \lambda^2}{2})^{1/4}$, where $N = \frac{16\pi}{(33-n_f)}$. Reynold's Number γ explains hydrodynamical attributes of QGP flow. The strong coupling constant α_s is related to $g^2(k)$: $g^2(k) = 4\pi\alpha_s$. In this, $g(k)$ is defined as:

$$g^2(k) = \frac{1}{3} \frac{48\pi}{(33 - 2n_f)} \frac{1}{ln(1 + k^2/\lambda^2)} \quad (2)$$

Here, n_f is equal to 2 (flavor number) and λ is the scale parameter of QCD ($= 150 MeV$).

Now, we consider the basic process of quark-antiquark annihilation in QGP medium:

$$q + \bar{q} \rightarrow \gamma + \gamma \quad (3)$$

Within the finite temperature field concept, Haglin used resummation methods to analyze the production of pair of photons. Because of the fact that a change in medium has occured,

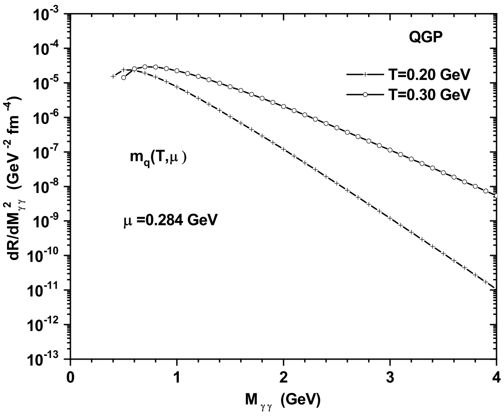

FIG. 1: Diphoton production rate displayed in QGP at temperatures T = 0.2 GeV and T = 0.3 GeV, with μ fixed at 0.284 GeV in a quark-antiquark annihilation scenario.

screening effects are also taken into consideration. The mass-dependence on the rate of diphoton production is given as [9, 10]:

$$\frac{dR}{dM^2} = \frac{1}{4\pi^3} \sum_f e_f^4 \alpha^2 N_c \left[\frac{\pi M T^3}{2}\right]^{1/2} \times e^{-M/T} e^{2\mu/T} \ln\left(\frac{2\pi}{3}\frac{cM^2}{m_q^2}\right) \quad (4)$$

Here, M is the mass of the diphoton, N_c is the colour number, c is 0.042 (const.) and α is the fine structure constant.

We have not considered the pions contribution in this work although the contribution of pions are important in amplifying the fraction of diphotons coming from HG (Hadron Gas). Finally, we produce the diphoton production rate using quasi-particle treatment at finite chemical potential.

Results

In Figure 1, we show the obtained diphoton production rate within the exotic QGP medium. We have shown the trends at T=0.2 GeV and T=0.3 GeV, keeping the chemical potential fixed at $\mu = 0.284 GeV$. We observe that the production rate keeps decreasing as the invariant mass increases. Besides this, we see an overall increase in the diphoton production rate as the temperature is increased. This indicates that diphoton production rate shows dominancy not only at higher temperatures but also produce enhancement at finite chemical potential using quark mass. The current results of diphotons are enhanced at finite chemical potential as comparison to the results of diphotons at zero chemical potential in QGP phase [9, 10].

Conclusion

Studying diphoton rates enables us to understand the ongoing physical processes of quark gluon plasma. Chemical Potential effects are considered to account for the asymmetry between quarks and anti-quarks. Such theoretical studies contribute to insights into further investigations, such as the ones at LHC/RHIC.

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