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Evolution and photons of a chemically equilibrating quark–gluon plasma at finite baryon density

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Abstract
We study the evolution of a chemically equilibrating quark–gluon plasma in a (3+1)-dimensional spacetime at finite baryon density and its photon production. We find that the photon production is a strongly decreasing function of the ratio of quark chemical potential to temperature.

1. Introduction

Photon production as a signature of the formation of the quark–gluon plasma (QGP) in relativistic heavy ion collisions has been studied by many researchers [1, 2]. Authors of [1] have studied the photon production in a QGP at finite temperature. Traxler, Vija and Thoma have computed the photon production rate of a QGP at finite quark chemical potential for a given temperature (also a given energy density) [2]. Authors of [3, 4] have studied the photon production in a chemically equilibrating and longitudinally expanding baryon-free QGP system. Authors of [5] have computed photons from a chemically equilibrating and longitudinally expanding QGP system at finite baryon density. However, in calculations of photons and dileptons the evolutions of the chemically equilibrating QGP system are almost described as a longitudinal scaling expansion [4–9]. In order to improve the description of the evolution, some authors have discussed the transverse expansion, and superimposed the transverse expansion on longitudinal expansion to study the effect of the evolution of the system on the production [10].

For comparison with the experiment it is necessary to study the photon production in a QGP system with full evolution. In this work, we study the photon production in a chemically equilibrating QGP system with (3+1)-dimensional hydrodynamic expansion at finite baryon density to reveal the effects of the quark chemical potential and evolution on the production. The expansion of the QGP system is governed by conservation laws of the energy–momentum and baryon number, as well as entropy increase. From these, based on the parton distribution function in a chemically equilibrating QGP system at finite baryon density, we derive a set

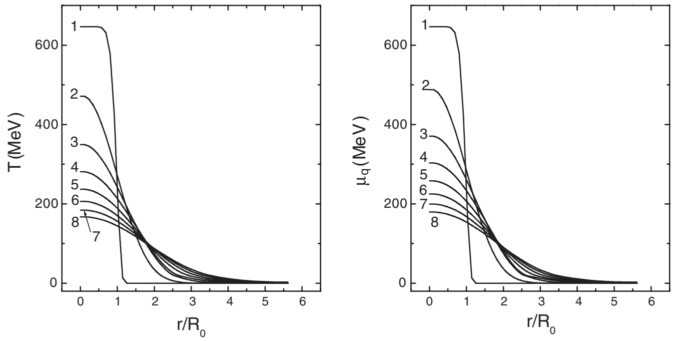

Figure 1. The calculated distributions of temperature T and quark chemical potential μ_q of the QGP system along the r direction at $z = 0$ for initial values $\tau_0 = 0.25$, $\lambda_{g0} = 0.34$, $\lambda_{q0} = 0.068$, $\lambda_{s0} = 0.034$ and $\mu_{q0}/T_0 = 1$ at the initial energy density $\epsilon = 61.4$ GeV fm^{-3}. Curves 1–8 denote, in turn, the distributions of the temperature T, quark chemical potential μ_q and fugacities λ_g and λ_q at evolution times $t = 0.25$, 0.35, 0.45, 0.55, 0.65, 0.75, 0.85 and 0.95 fm.

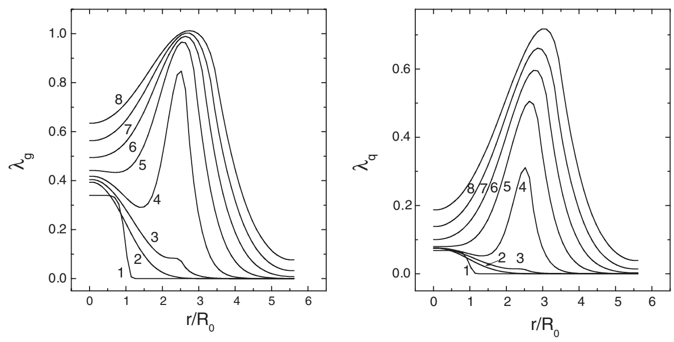

Figure 2. The calculated distributions of fugacities λ_g and λ_q of the QGP system along the r direction at $z = 0$ for initial values as given in figure 1. Curves 1 to 8 denote, in turn, the distributions of the temperature T, quark chemical potential μ_q and fugacities λ_g and λ_q at evolution times $t = 0.25$, 0.35, 0.45, 0.55, 0.65, 0.75, 0.85 and 0.95 fm.

of relativistic hydrodynamic equations (RHE) in a (3+1)-dimensional spacetime. Further considering the reactions leading to chemical equilibrium: $gg \rightleftharpoons ggg$, $gg \rightleftharpoons q\bar{q}$, $gg \rightleftharpoons s\bar{s}$ and $q\bar{q} \rightleftharpoons s\bar{s}$, we get a set of master equations describing the evolutions of gluon, quark and s quark densities. Combining the RHE together with the master equations, finally, we gain a set of coupled relaxation equations. Then we compute the photon production rate from annihilation $q\bar{q} \to g\gamma$, Compton ($qg \to q\gamma$ and $\bar{q}g \to \bar{q}\gamma$) scatterings, near-collinear bremsstrahlung and inelastic pair annihilation [13, 14] processes in the QGP system.

2. Calculated results

Here, we focus on discussing Au^{197}+Au^{197} central collisions. With the help of [6, 9, 15] we take initial values: $\tau_0 = 0.25$ fm, $\lambda_{g0} = 0.34$, $\lambda_{q0} = 0.068$ and $\lambda_{s0} = 0.034$ at initial energy density $\epsilon_0 = 61.4$ GeV fm^{-3}. We have shown the calculated distributions of the temperature T, quark chemical potential μ_q, fugacities λ_g and λ_q along the r direction at $z = 0$ for $\mu_{q0}/T_0 = 1$ in figures 1 and 2. We find that the evolution of the present model is much faster than

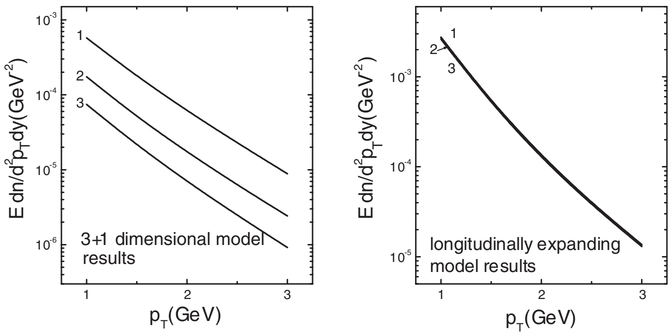

Figure 3. The calculated total photon spectra from $q\bar{q} \to g\gamma, qg \to q\gamma, \bar{q}g \to \bar{q}\gamma$, inelastic pair annihilation and bremsstrahlung processes for those initial values given in figure 1. The total spectra calculated by the present model is shown in the left panel, and by the longitudinally expanding model in the right panel. Curves 1–3 are, respectively, the calculated photon spectra for initial ratios $\mu_{q0}/T_0 = 0.1$, 0.5 and 1.

the one of the one-dimensional model (see [8, 16]). We have calculated the photon yield due to the $q\bar{q} \to g\gamma, qg \to q\gamma, \bar{q}g \to \bar{q}\gamma$, bremsstrahlung and inelastic pair annihilation processes on the basis of the evolutions for initial ratios $\mu_{q0}/T_0 = 0.1$, 0.5 and 1 [17] (see the left panel of figure 3). Since with increase of the initial quark chemical potential the anti-quark density goes down, the yield for the processes $q\bar{q} \to g\gamma, \bar{q}g \to \bar{q}\gamma$ and inelastic pair annihilation necessarily decreases. Especially, for a given initial energy density, with increase of the initial quark chemical potential the initial temperature of the system will obviously go down to cause the decrease of the yield. Thus, with increasing the initial quark chemical potential the photon yield for $qg \to q\gamma$ and bremsstrahlung processes also goes down; moreover, the decrease of the yield for the processes $q\bar{q} \to g\gamma, \bar{q}g \to \bar{q}\gamma$ and inelastic pair annihilation becomes even faster. For comparison with the calculated photon yield by the longitudinal scaling expansion model [5, 8], we also calculated the photon yield for the same four reaction processes and initial conditions as mentioned above (see the right panel of figure 3). We find that the calculated photon yield by the present model is less than that by the longitudinally expanding model by about one order of magnitude because the evolution of present model is even faster due to the presence of the transverse flow besides the longitudinal flow. Comparing with the results of [14], we also note that the result is less than that calculated by the transverse expansion model by about two orders of magnitude due to the effect of the chemical potential on the yield besides those reasons mentioned above.

3. Summary

Based on the evolution of the QGP system in a (3+1)-dimensional spacetime, we have computed the photon yield of the QGP system. We find that with increasing the ratio of quark chemical potential to temperature, the total photon yield is strongly suppressed. Especially, since in the present evolution model there exists the transverse flow besides the longitudinal flow, which leads to the quick cooling of the system, the photon yield becomes much lower than those calculated by the longitudinally expanding QGP model. This prediction of photon suppression is important for experiments at the RHIC.

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