# Intermediate mass dilepton production during the chemical equilibration of quark gluon plasma

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**Abstract** The production of dileptons from the chemically equilibrating quark gluon plasma in the intermediate mass region has been studied. Comparing with the calculated results based on the thermodynamic equilibrium system of quark gluon plasma, it has been found that the quark phase of the chemically equilibrating system gives rise to an even larger enhancement of the dileptons production. Therefore, such an enhancement of dilepton production may signal the formation of quark gluon plasma.

**Keywords** Quark gluon plasma, Intermediate mass dilepton, Chemically equilibrating system

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## 1 INTRODUCTION

One of the most promising efforts of all the future ultrarelativistic heavy ion collision experiments at RHIC and LHC is to detect the quark gluon plasma (QGP). The QGP, if formed, will cool by expansion till it reaches a phase boundary, then, the QGP will be transformed to the hadron phase through a phase transition. During the process of the thermal expansion, dileptons are considered one of the ideal and promising probes for the detection as they do not suffer strong final-state interactions.

In recent years, an enhancement of the dileptons yield in the intermediate mass region (IMR) in central S+W, S+U, and Pb+Pb collisions as compared to that in the proton-induced reactions has been observed[1]. In the previous works[2–5], we adopted a relativistic hydrodynamic model to describle the evolution of the thermodynamic equilibrium QGP system (TES) and found that such an enhancement of dileptons produced in $^{197}$Au+$^{197}$Au central collisions at RHIC energies can be attributed to the contribution of quark phase. However, some recent works [6–8] suggested that, because of the high initial density of quarks and gluons, the plasma may be far from the chemical equilibrium. In this work, for the above reactions, we calculated the dilepton production in the chemically equilibrating system (CES) to reveal the characteristic of the dilepton distribution via comparing with the results based on the evolution of the TES in which the chemical reactions among partons were not considered.

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## 2 CHEMICAL EQUILIBRATION AND DILEPTONS PRODUCTION

In general, chemical reactions among partons can be quite complicated because of the possibility of initial and final state gluon radiation. However, only considering the four dominant processes $gg \leftrightarrow ggg$ and $gg \leftrightarrow q\bar{q}$, as done in Ref.[10], we can obtain master equations which describe the evolution of the parton densities of the system. Under the modified Fermi-Dirac (MFD) type approximation[9], we develop a treatment for the QGP system with the finite baryon density. From the master equations[10], equations of the conservation of energy-momentum and bayron number, we can obtain a set of coupled relaxation equations which describe the evolution of the temperature $T$, quark chemical potential $\mu_q$, and the fugacity factor $\lambda_g$ for gluon, $\lambda_q$ for quark and $\lambda_{\bar{q}}(=\lambda_q$ because we assume baryon symmetric matter as Ref.[10]) for antiquark.

$$\frac{\dot{\lambda}_g}{\lambda_g}+3\frac{\dot{T}}{T}+\frac{1}{\tau}-R_3(1-\lambda_g)+2R_2(1-\frac{\lambda_q^2}{\lambda_g^2})=0 \tag{1}$$

$$\frac{\dot{\lambda}_q}{\lambda_q}+(3-\frac{\mu_q}{T})\frac{\dot{T}}{T}+\frac{\dot{\mu}_q}{T}+\frac{1}{\tau}-R_2\frac{a_1}{b_1}\frac{\lambda_g}{\lambda_q}(1-\frac{\lambda_q^2}{\lambda_g^2})e^{-\mu_q/T}=0 \tag{2}$$

$$\frac{\dot{\lambda}_q}{\lambda_q}+(3-\frac{\mu_q}{T})\frac{\dot{T}}{T}+\frac{1+e^{-2\mu_q/T}}{1-e^{-2\mu_q/T}}\frac{\dot{\mu}_q}{T}+\frac{1}{\tau}=0 \tag{3}$$

$$a_2\dot{\lambda}_g+2b_2\dot{\lambda}_q\cosh(\mu_q/T)+\frac{4}{3}A_t[3-\frac{3}{2}\frac{b_2\lambda_q}{A_t}\sinh(\mu_q/T)\frac{\mu_q}{T}]\frac{\dot{\mu}_q}{T}+2b_2\lambda_q\sinh(\mu_q/T)\frac{\dot{\mu}_q}{T}+\frac{4}{3\tau}A_t=0 \tag{4}$$

where $A_t=a_2\lambda_g+2b_2\lambda_q\cosh(\mu_q/T)$ with $a_2=8\pi^2/15$ and $b_2=N_f(7\pi^2/40)$, $N_f=2.5$ is the dynamical quark flavors, $\frac{a_1}{b_1}=\frac{64}{45}$. According to the Ref.[10], the quark production rate $R_2$ and gluon production rate $R_3$ are, in turn, written as

$$R_2\approx 0.24N_f\alpha_s^2\lambda_g T\ln\frac{1.65}{\alpha_s[\lambda_g+\cosh(\mu_q\lambda_q/2T)]} \tag{5}$$

$$R_3=1.2\alpha_s^2T(2\lambda_g-\lambda_g^2)^{1/2} \tag{6}$$

with the strong coupling constant $\alpha_s=0.3$.

The non-equilibrium fugacity factors $\lambda_i(i=g,q)$ in the above equations give the measure of the deviation of the distribution functions from the equilibrium values and the chemical equilibrium is said to be achieved when $\lambda_i\to 1$.

As well known, dilepton production rate, for the quark phase, is given by

$$\frac{dR}{d^4p}=\int\frac{d^3p_1}{(2\pi)^3}\frac{d^3p_2}{(2\pi)^3}f_q(p_1)f_{\bar{q}}(p_2)U_{q\bar{q}}\sigma_{q\bar{q}}^{l\bar{l}}\delta^4(p-p_1-p_2) \tag{7}$$

where $R=dN/dx^4$ is the total number of lepton pairs emitted per unit space-time, $U_{q\bar{q}}$ the relative velocity between quark and antiquark, $\sigma_{q\bar{q}}^{l\bar{l}}$ the cross section for the reaction $q\bar{q}\to l\bar{l}$. Adopting MFD parton distribution function [9]

$$f_{q(\bar{q})}=\frac{\lambda_{q(\bar{q})}}{e^{(p\pm\mu_q)/T}+1} \tag{8}$$

from the view point of experiments, for the system of longitudinal expansion, with the help of Ref.[11], we obtain dilepton yield dominantly from the quark phase

$$\frac{dN_{l\bar{l}}}{dM^2dY} = \frac{\alpha^2R^2}{2\pi^2}\int_{\tau_0} d\tau \int dM_\perp^2\sqrt{\frac{2\pi}{M_\perp}}\tau\lambda_q^2T^{1/2}\exp(-\frac{M_\perp}{T})F_qJ_q \tag{9}$$

where $Y, M$ are the rapidity and invariant mass of the dilepton, respectively, $F_q$=5/9 the form factor for u,d quark. The factor $J_q$ is the function of the temperature $T$ and quark chemical potential $\mu_q$, $R = r_0A^{1/3}$ with $r_0$=1.2 fm the initial radius of the fireball.

## 3 CALCULATED RESULTS AND DISCUSSIONS

For $^{197}$Au+$^{197}$Au central collision at RHIC energies, taking initial conditions from the HIJING model calculation[10], i.e., proper time $\tau_0$=0.31fm, initial temperature $T_0$=0.57 GeV, fugacity factors $\lambda_{g0}$=0.09 and $\lambda_{q0}$=0.02. For initial chemical potential $\mu_{q0}$=0.00, 0.57GeV, the time dependence of $T$,$\mu_q$ and $\lambda_g$, $\lambda_q$ have been obtained via solving the equations (1)~(4) by fourth order Runge-Kutta method, as shown in the Fig.1 and 2.

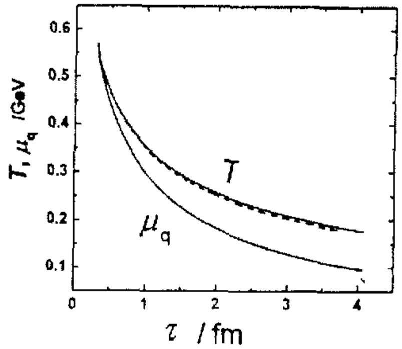


Fig.1 Solid curves show the calculated $T$ and $\mu_q$ distributions for $\mu_{q0}$=0.57 GeV at the initial conditions as mentioned in the text. The dash line shows the calculated temperature $T$ distribution for $\mu_{q0}$=0.00 GeV

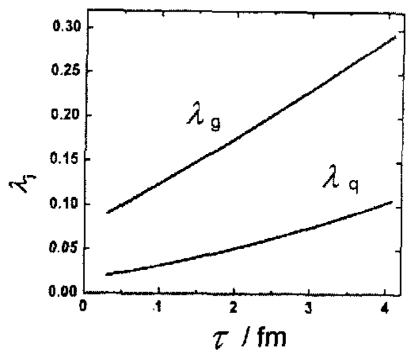


Fig.2 Calculated fugacity factors $\lambda_i (i = g, q)$ distributions for $\mu_{q0}$=0.57GeV at the same initial conditions as mentioned in the text.

Fig.1 shows that, compared to the baryon-free QGP system ($\mu_q$=0), the baryon-rich QGP system gives longer evolution time in the quark phase (4.1fm vs. 3.7fm). As shown in the Fig.2, the fugacity factors $\lambda_i (i = g, q)$ are far below 1.0. So the QGP is still far from the chemical equilibrium and even their values $(T, \mu_q)$ reach the phase boundary condition.[2]

The production of dileptons in the equilibrating QGP system has been calculated, as shown in Fig.3. In this work, in order to compare with results calculated on the basis of the evolution of the TES, we only consider the dilepton production of the quark phase because authors of Ref.[5] have shown that the contribution from the quark phase is much more important than those from hadronic interactions, making the enhancement of dileptons in the IMR. In the Fig.3, we see that the production of dileptons in the CES of QGP has a significant enhancement as compared with that in the TES though the time of non-equilibration evolution is shorter than that of TES[5]. Obviously, the high initial temperature $T_0$ and the increase of the lifetime of the quark phase as pointed out in the above paragraph are the reasons why dilepton production is enhanced.

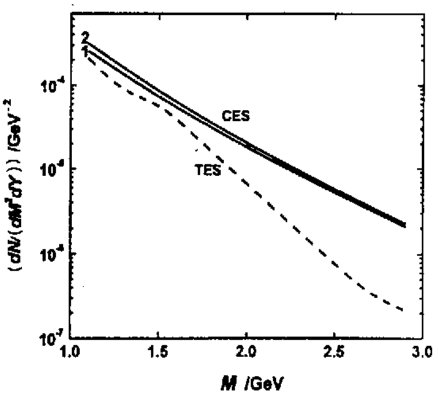


**Fig.3** Calculated dileptons production spectra $dN/(dM^2dY)$ from the CES (solid lines) and the TES (dash line). Solid lines 1,2 denote, respectively, the calculated spectra for initial chemical potentials $\mu_{q0}$=0.00GeV and 0.57GeV. Other initial conditions are the same as those in Fig.1.

In Ref.[5], it was shown that the enhancement of intermediate mass dileptons should be a possible signature for QGP formation and the contribution from the quark phase mostly gives rise to this kind of enhancement in the TES, In the present work, we have found that the enhancement of intermediate mass dilepton production only from a quark phase in the CES is much more than that of the TES. Thus, in the CES, the enhancement of intermediate mass dilepton production is also owing to the contribution of quark phase and this kind of enhancement is also a signature for QGP formation in heavy ion collision at RHIC energies.

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