Production of dileptons with intermediate masses in an expanding quark–gluon matter

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Abstract A study of dilepton spectra, in intermediate mass region (IMR), from main background sources, quark phase, and secondary processes in hadronic phase on the basis of a relativistic hydrodynamic model has been carried out. The comparison between these results indicates that in this mass region the contribution from the background sources dominates, and due to the effect of the phase boundary on the evolution of the system the contribution from the quark phase becomes more important than that from secondary processes.

Keywords Quark-gluon matter, Dilepton production, Hydrodynamic model

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1 INTRODUCTION

In recent years, both the HELIOS-3 and NA38/NA50 Collaborations have observed enhancement of the dilepton yield in the IMR (between m_ϕ and about 2.5 GeV) in central S+W and S+U collisions as compared to that in proton-induced reactions. Preliminary data from the NA50 Collaboration also show significant enhancement, i.e., in central Pb+Pb collisions.[1] There are at least three possible sources for this enhancement: the contribution from initial charmed hadronic decays and Drell-Yan mechanism, a quark-gluon matter (QGM) formed in collisions, and secondary hadronic processes. The calculations of Ref.[2] for S+W collisions at SPS energies have shown that the contribution from secondary hadronic interactions is important in the IMR. However, since it is possible for ^{197}Au + ^{197}Au collisons at RHIC energies to creat the QGM, we now study dileptons from these three sources in the IMR based on a relativistic hydrodynamic model and compared their contributions.

2 DILEPTON PRODUCTION

For the quark phase, dilepton yield from $q\bar{q}$ annihilations was calculated following Refs.[3,4]. We, in the calculation of the thermal charm quark contribution to dileptons,

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adopted the charm production cross section as given in Ref.[5], $\sigma_{c\bar{c}}(M) = \gamma_q \sigma_{q\bar{q}\to c\bar{c}}(M) + \gamma_g \sigma_{gg\to c\bar{c}}(M)$, where $\sigma_{q\bar{q}\to c\bar{c}}$ and $\sigma_{gg\to c\bar{c}}$ are, respectively, the cross sections from $q\bar{q}$ and gg reactions, and the thermal charm quark and gluon degeneracy factors are, in turn, $\gamma_q = 3 \times (2 \times 3)^2$ for three flavors and $\gamma_g = (2 \times 3)^2/2$.

For the hadronic phase, the contribution from $\pi\pi$ annihilations was also calculated according to Refs.[3,4]. Authors of Ref.[2] carried out a study of dilepton spectra from hadronic interactions in the IMR like $\pi a_1 \to l\bar{l}$, $\pi\rho \to l\bar{l}$, $\pi\omega \to l\bar{l}$, and $K\bar{K} \to l\bar{l}$, and found contributions from the processes $\pi a_1 \to l\bar{l}$ and $\pi\omega \to l\bar{l}$ to be very important. In this work we also included these two. We adopted the third approach mentioned in Ref.[2] to estimate the cross sections $\sigma_{\pi a_1} \to l\bar{l}$ from experimental cross sections of $(e^- e^+ \to \pi a_1)$ using detailed balance. By the same approach, we also obtained the cross section of the process $\pi\omega \to l\bar{l}$. In addition, $J/\psi \to l\bar{l}$ was also considered since it contributes a peak near M=3.10 GeV. Here, we take its width $\Gamma_{J/\Psi}$=0.063 MeV from the experimental value.

For the background, our calculations of the rapidity dependence of Drell-Yan pairs in the central collision were performed based on the Duke-Owens structure functions 1.1.[6] The background from the initial charmed hadronic decays was obtained via the process: $a + b \to c + \bar{c}$, then $c \to D$, $\bar{c} \to \bar{D}$, and finally $D \to X + l$ and $\bar{D} \to X + \bar{l}$, where a and b are the colliding partons. For a qualitative study, we adopted the convolution functionn $H(x_a, x_b)$ to describe the subprocess $a + b \to c + \bar{c}$, as done in Ref.[7], in which parton distributions $q(x)$, $g(x)$ and cross sections $(d\sigma/dt)_{q\bar{q}\to c\bar{c}}$ for the subprocess $q\bar{q} \to c\bar{c}$ and $(d\sigma/dt)_{gg\to c\bar{c}}$ for the subprocess $gg \to c\bar{c}$ are given in Ref.[8]. Assuming no intrinsic P_T for light quarks and using four momentum conservation to integrate over the fractions of the initial projectile and target momenta carried by interacting partons x_a and x_b, the number of charmed hadrons produced in AA collisions was calculated following the line of Ref.[7], where A was the mass number of the colliding nuclei.

3 EVOLUTION OF QGM

We have adopted the relativistic hydrodynamic equation (RHE) established in Ref.[9] to calculate the evolutions of the temperature and quark chemical potential of the QGM, where s, p, μ_b, n and T are the entropy, pressure, baryon chemical potential, baryon number and temperature of the system, respectively.

According to the assumption in Ref.[10] that the colliding nuclei are two Lorentz disks, we obtained the initial longitudinal length $z_0 = A/(\pi R_0^2 n_{b0})$ when taking the initial transverse radius $R_0 = r_0 A^{1/3}$ with r_0=1.2 fm, where n_{b0} is the initial baryon density. Authors of Ref.[10] have been satisfied with a simple model for an exploratory excursion into the problem of nucleation of plasma. To first approximation this model is consistent with the ARC cascade simulations and with direct experimental measurements. From it one can get the baryon density $2\gamma n_0$ and energy density $2\gamma^2 m_N n_0$ of the formed system if assuming the matter density within the overlap volume of the two colliding nuclei to be a constant, where n_0 is the normal nuclear matter density, m_N the nucleon mass and γ the Lorentz contract factor. Further, using the equation of state of the QGM the initial temperature T_0 and initial baryon density n_{b0} of the QGM can be obtained. In order to avoid oscillations in the numerical calculations, we implemented smoothing by multiplying the distributions which were gotten via extending the treatment as done in Ref.[9]

$$T(r,z,0) = T_0\exp\{-[(r/R_0)^N + (z/z_0)^N]\} \tag{1}$$

$$n_b(r,z,0) = n_{b0}\exp\{-[(r/R_0)^N + (z/z_0)^N]\} \tag{2}$$

where N is a free parameter. For N=10, we could obtain a nearly constant temperature and baryon density distributions in the initial fire-cylinder.

4 CALCULATED RESULTS AND DISCUSSION

We have studied central ^{197}Au + ^{197}Au collisions. Using the finite difference method for the initial value problem, the distributions of the temperature and quark chemical potential of the QGM fire-cylinder for the initial values decided from the incident energy per nucleon, E_{in}=45.00 GeV, have been calculated, which are provided for the calculation of the dilepton production. Only distributions along the z axis direction of the fire-cylinder are, respectively, shown in Figs.1 and 2. In Fig.1 curves 1 to 6 stand for, in turn, temperature distributions (and also quark chemical potential distributions in Fig.2) at t/R_0=0.00, 0.62, 1.24, 1.86, 2.48 and 3.10 fm. The calculated dilepton spectra, dN/dM^2, are shown in Fig.3. Curves 1 to 8 represent the spectra from processes $\pi\omega \to l\bar{l}$, $\pi a_1 \to l\bar{l}$, thermal $c\bar{c} \to l\bar{l}$, initial charmed hadronic decays, Drell-Yan mechanism, $q\bar{q} \to l\bar{l}$, $\pi\pi + J/\psi \to l\bar{l}$ and their total, respectively.

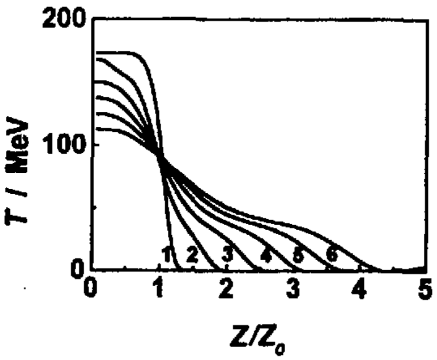

Fig.1 Calculated temperature distributions. Curves 1 to 6 are metioned in the text

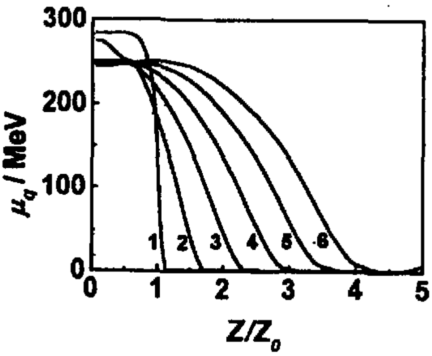

Fig.2 Quark chemical potential distributions under the same conditions metioned in the text for curves 1 to 6

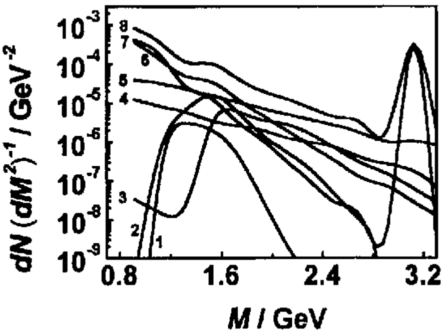

Fig.3 Dilepton spectra dN/dM^2 for the incident energy per nucleon E_{in}=45.00 GeV. Curves 1 to 8 denote, in turn, the spectra from those processes as mentioned in the text

It is seen from Fig.2 that quark chemical potentials of various local regions of the system always increase during the evolution of the system. It shows that it necessarily takes a long time for values (μ_q, T) of various local regions of the system to reach different points of the phase bound- ary at different times to make various local phase transitions. Such effects delay the evolution process of the QGM, increase the lifetime of the QGM and hence heighten the contribution of the quark phase. On the other hand, due to these effects the most local phase transitions occur at local and regions with lower temperature and higher baryon chemical potential. After the transition the temperature of the hadronic phase is still lower, thus contributions to the dilepton production from processes $\pi\pi\rightarrow l\bar{l}$, $\pi a_1\rightarrow l\bar{l}$, are $\pi\omega\rightarrow l\bar{l}$ are small compared with that from the quark phase.

In conclusion, we have calculated the production of dileptons in the IMR from background sources like initial charmed hadronic decays and Drell-Yan mechanism, quark phase, and secondary processes in hadronic phase based on a relativistic hydrodynamic model. It was found that in this mass region the contribution from the background sources dominates, and to the effect of the phase boundary on the evolution of the system the contribution from the quark phase is enhanced and becomes more important than that from secondary processes.

References

1 Abreu M C. Nucl Phys, 1996, **A610**:331
2 Li G Q, Gale C. Phys Rev, 1998, **C58**:2914
3 Kämpfer B, Pavlenko O P, Gorrenstein M I *et al.* Z Phys, 1995, **A353**:71
4 Cleymans J, Fingberg J, Redlick K. Phys Rev, 1987, **C35**:2153
5 Shor A. Phys Lett, 1988, **B215**:375
6 Owens J F. Phys Lett, 1991, **B266**:126
7 Vogt R, Jacak B V, McGaughey P L *et al.* Phys Rev, 1994, D49:3345
8 vogt R, Brodsky S J, Hoyer P. Nucl Phys, 1992, **B383**:643
9 He Z J, Zhang Jiaju, Qiu X J. Nucl Phys, 1997, **A614**:552
10 Kapusta J, Vischer A. Phys Rev, 1995, **C51**:901