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Enhancement of Dileptons with Intermediate Masses Produced in QGP *

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Abstract The production of dileptons in the intermediate mass region in QGP has been studied on the basis of a relativistic hydrodynamic model. Due to the influence of the phase boundary on the evolution of the QGP system and the high initial temperature of the QGP produced at RHIC energies, the quark phase contribution is much more important than that from hadronic interactions and even comparable with that from background sources. It is shown that such an enhancement is a signature for the QGP formation.

Key words QGP, hydrodynamic model, dilepton enhancement

Built RHIC at the Brookhaven National Laboratory[1] and LHC being built at CERN offer the possibility to create QGP in laboratory. Dileptons as a signal for QGP formation are considered most promising because they do not suffer strong final-state interactions and are therefore expected to retain the information about the QGP.

Many authors have studied the production of dileptons in the intermediate mass region (IMR) (i.e. near 1.0 to 2.5 GeV)[2—4]. An enhancement of dileptons in the IMR has been attributed to secondary meson-meson interactions by Gale and Li[3]. While Z. Lin and X. N. Wang think that the enhancement observed by the NA50 experiment is caused by final state rescattering[4]. Since it is possible for ^{197}Au + ^{197}Au collisons at RHIC energies to creat the QGP, there are at least three possible sources for this enhancement: the QGP formed in collisions, secondary hadronic processes, and background sources like initial charmed hadronic decays and Drell-Yan pairs. In this work, for ^{197}Au + ^{197}Au central collisons at RHIC energies. we calculate dileptons from these three sources in the IMR based on a relativistic hydrodynamic model to find which should be more important if the QGP has been created in collisions at RHIC energies.

For the quark phase, dileptons from $q\bar{q}$ annihilations can be calculated following Ref.[2]. We, in the calculation of the thermal charm quark contribution to dileptons, adopt the charm production cross section as given in Refs. [5.6]. $\sigma_{c\bar{c}}(M)=\gamma_q\sigma_{q\bar{q}\text{-}c\bar{c}}(M)+\gamma_g\sigma_{gg\text{-}c\bar{c}}(M)$, where $\sigma_{q\bar{q}\text{-}c\bar{c}}$ and $\sigma_{gg\text{-}c\bar{c}}$ are cross sections from $q\bar{q}$ and gg reactions, respectively, thermal charm quark and gluon degeneracy factors are, in turn. $\gamma_q=3\times(2\times3)^2$ for three flavors and $\gamma_g=(2\times3)^2/2$.

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For the hadronic phase, the calculation of dileptons from $\pi\pi$ annihilations has been mentioned in Ref. [2], where the form factor is $F_h = \frac{1}{12} m_\rho^4 [(m_\rho^2 - M^2)^2 + m_\rho^2 \Gamma_\rho^2]^{-1}$ with $m_\rho = 0.77$ GeV and $\Gamma_\rho = 0.15$ GeV. Authors of Ref. [3] have carried out a study of the dileptons from hadronic interactions like $\pi a_1 \to l\bar{l}$, $\pi\rho \to l\bar{l}$, $\pi\omega \to l\bar{l}$, and $K\bar{K} \to l\bar{l}$ in the IMR, $\bar{y}$ and found processes $\pi a_1 \to l\bar{l}$ and $\pi\omega \to l\bar{l}$ to be significant. Thus, these two are also included in our calculation. Since an unambiguous determination of the form factor is not yet possible, we adopt the approach mentioned in Ref. [3] to estimate the cross sections $\sigma_{\pi a_1} \to l\bar{l}$ and $\sigma_{\pi\omega} \to l\bar{l}$ from experimental cross sections using detailed balance.

The background sources produced in initial collisions, such as Drell-Yan pairs and initial charmed hadronic decays, are important in the IMR. Our calculations of Drell-Yan pairs are performed based on the Duke-Owens structure functions[7]. The background from initial charmed hadronic decays is obtained via processes: $a + b \to c + \bar{c}$, then $c \to D$, $\bar{c} \to \bar{D}$, finally $D \to X + l$ and $\bar{D} \to X + \bar{l}$, where a and b are colliding partons. For a qualitative study, we adopt the description for the subprocess $a + b \to c + \bar{c}$ by the convolution function $H(x_a . x_b)$ mentioned in Refs. [8,9], in which parton distributions $q(x)$, $g(x)$ and cross sections $(d\sigma/dt)_{q\bar{q} \to c\bar{c}}$ for subprocess $\bar{c} \to \bar{D}$, and $(d\sigma/dt)_{gg \to c\bar{c}}$ for subprocess $\bar{c} \to \bar{D}$ are calculated as done in Ref. [9].

As pointed out in Ref. [10], once local thermodynamic equilibrium of the system is established, the further expansion of the system is governed by conservation laws of the energy-momentum, baryon number and entropy. Using some useful thermodynamic relations, we have obtained a set of coupled relativistic hydrodynamic equation (RHE) describing the evolution of a cylindrically symmetric QGP fire-cylinder, as seen in Ref. [11].

A rapidity density of secondary pions dN_π/dY for heavy-ion collisions at RHIC energies has been obtained in Refs. [2,12], which holds for symmetric AA collisions with $A \approx 200$ in the rapidity interval $|Y| \leqslant 4$. From it, we have easily derived the entropy density $s_0(Y)$ which is widely used at RHIC energies. To get the initial temperature from the entropy density, the effect of baryons on the entropy density should be included. Taking a parametrization for the quark chemical potential $\mu_q = bY^a T$ via using RQMD following Refs. [2, 12], one can obtain the entropy density including the influence of baryons, and finally find the initial temperature T_0 and initial baryon density n_{b0} of the QGP system.

With the origin of the cylindrical coordinates fixed to the center of the QGP system, the initial volume in this frame is a cylindrically symmetric system of transverse radius R_0 extending in the z direction from $-z_0$ to z_0. The initial condition obviously possesses a reflection symmetry with respect to $z = 0$ plane. The distributions are always cut off smoothly when the space boundary is approached. Smoothing helps to avoid oscillations in the numerical calculations. We implement smoothing by multiplying the distributions which are obtained via extending the distributions used in Ref. [13]

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

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

with the free parameter $N = 10$. Such initial baryon densities are zero in the central rapidity region since the rapidity deciding the baryon density is zero there. This result is qualitatively consistent with the original Bjorken scenario and simulation of Refs. [14,15].

For ^{197}Au + ^{197}Au central collisions at the incident energy per nucleon $E_{in} = 200.00$ GeV, the evolutions of the temperature and baryon density of the QGP fire-cylinder have been calculated. Only distributions along the diagonal $d = [\bar{r}^2 + \bar{z}^2]^{1/2}$ (from origin (0,0) to $(\bar{r}, \bar{z})$) in the fire-cylinder are, respectively, shown in Fig. 1 and 2. Where $\bar{r}$ and $\bar{z}$ are, in turn, the transverse radius and length in the z direction above $z=0$ plane at time t. Curves 1 to 6 stand for, in turn, temperature distributions in Fig. 1 (and also baryon density distributions in Fig. 2) at $t/R_0=0.00$, 1.38, 2.76, 4.14, 5.52 and 6.90 fm, where R_0 is the initial transverse radius of the fire-cylinder again.

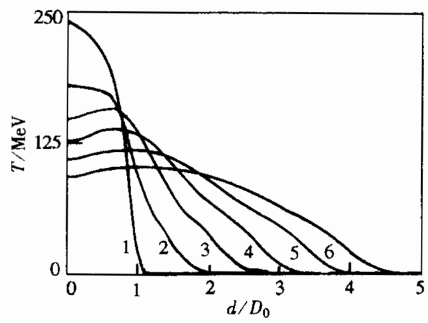

Fig. 1. The calculated temperature distributions at the incident energy per nucleon $E_{in}=200.00$GeV.

Curves 1 to 6 denote, in turn, the temperature distributions along the diagonal from origin (0,0) to ($\bar{r}$, $\bar{z}$) in ($\bar{r}$,$\bar{z}$) plane of the QGP fire-cylinder at $t/R_0=0.00$. 1.38, 2.76, 4.14, 5.52 and 6.90 fm. Where D_0 is the initial value of the diagonal d, in addition R_0, $\bar{r}$ and $\bar{z}$ have been mentioned in the text.

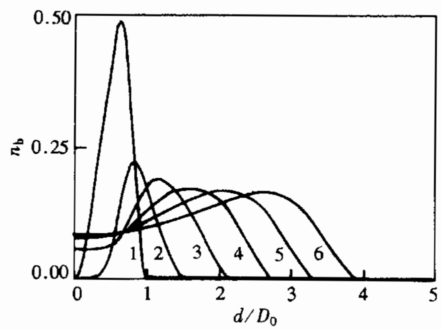

Fig. 2. The calculated baryon density distributions under the same conditions as given in Fig. 1.

Curves 1 to 6 denote, in turn, the baryon density distributions along the diagonal as mentioned in Fig. 1 at $t/R_0=0.00$, 1.38, 2.76, 4.14, 5.52 and 6.90 fm.

The calculated dilepton mass spectra dN/dM^2 are shown in Fig. 3. Curves 1 to 8 represent the dilepton spectra from processes: thermal $c\bar{c}\to l\bar{l}$, $\pi a_1\to l\bar{l}$, $\pi\omega\to l\bar{l}$, initial charmed hadronic decays. Drell-Yan pairs, $q\bar{q}\to l\bar{l}$, $\pi\pi\to l\bar{l}$ and their total, respectively. It is shown that in the IMR the contribution from the quark phase (including process $q\bar{q}$ and accompanying thermal $c\bar{c}$) is much more important than that from reactions πa_1. $\pi\omega$ and $\pi\pi$. From Fig. 1 and 2 one can see that, in the present model various local temperatures always decrease and corresponding baryon density (and also quark chemical potential) increases during the evolution of the system. 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 boundary at different times to make various local phase transitions. Such effects delay the evolution process of the QGP, increase the lifetime of the QGP and hence heighten the contribution of the quark phase. While due to these effects after the phase transition the initial temperature of the hadronic phase is lower, thus the contributions to dileptons from hadronic processes: $\pi\pi\to l\bar{l}$, $\pi a_1\to l\bar{l}$ and $\pi\omega\to l\bar{l}$ are low compared with that from the quark phase. Especially, at RHIC energies the initial temperature of the QGP system is very high, and the dilepton

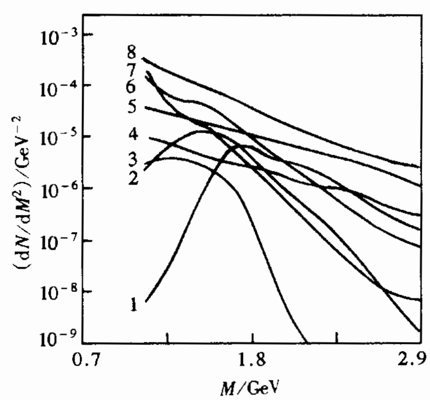

Fig. 3. The calculated dilepton mass spectra dN/dM^2 at the incident energy per nucleon $E_{in}=200.00$GeV.

Curves 1 to 8 represent, in turn, the spectra from those processes as mentioned in the text.

yield is mainly determined by the temperature, thus the contribution from the quark phase is so large that it is comparable with those from Drell-Yan pairs and initial charmed hadronic decays. as seen in Fig.3.

It is worth indicating here that in Ref.[3], under assuming only hadronic matter production in collisions, the enhancement of dileptons in the IMR produced in S + W collisions at SPS energies is due to contributions from those hadronic interactions . In this work , for ^{197}Au + ^{197}Au central collisions at RHIC energies, the calculated dilepton spectra show that if the QGP has indeed been created in collisions, the enhancement of dileptons in the IMR should be attributed to both the increase of the lifetime of the QGP due to the influence of the phase boundary on the evolution of the QGP system and very high initial temperature of the QGP system. Therefore, it is shown that if the QGP has been formed in collisions at RHIC energies, the enhancement of dileptons in the IMR is a signature indicating the QGP formation.

References

1 Ozaki S. Nucl. Phys., 1991. **A525**: 125c
2 Kämpfer B, Pavlenko O P, Gorenstein M I et al. Z. Phys., 1995, **A353**:71
3 LI G Q, Gale C. Phys. Rev., 1998, **C58**:2914; Phys. Rev. Lett., 1995, **75**:4007
4 LIN Z, WANG X N. Phys. Lett., 1998, **B444**: 245
5 Shor A. Phys. Lett., 1988, **B215**:375
6 Combridge B L. Nucl. Phys., 1979, **B151**: 429
7 Duke D W, Owens J F. Phys. Rev., 1984, **D30**: 49
8 Vogt R, Jacak B V et al. Phys. Rev., 1994, **D49**:3345
9 Vogt R, Brodsky S J, Hoyer P. Nucl. Phys., 1992, **B383**: 643
10 Baym G, Friman B L et al. Nucl. Phys., 1983, **A407**:541
11 HE Ze-Jun, ZHANG Jia-Ju, JIANG Wei-Zhou. Chin. Phys. Lett., 1999, **16**:259
12 Sorge H, Stöcker H, Griner W. Nucl. Phys., 1989, **A498**:567c
13 HE Ze-Jun, ZHANG Jia-Ju et al. Nucl. Phys., 1997, **A614**:552
14 Bjorken J D. Phys. Rev., 1983, **D27**:140
15 Bravina L V, Zabrodin E E, Gorenstein M I et al. Phys. Rev., 1999, **C60**:024904-1

产生在夸克-胶子等离子体中的中等质量双轻子的增强*

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摘要 基于一个相对论流体力学模型,在夸克-胶子等离子体中具有中等质量双轻子的产生被研究. 由于相边对夸克-胶子等离子体系统演化的影响和产生在 RHIC 能量的夸克-胶子等离子体系统有高的初始温度,夸克相的贡献变得比强子相互作用的贡献重要得多,甚至能与本底相比较. 它表明这样的增强是夸克-胶子等离子体形成的一种信号.

关键词 夸克-胶子等离子体 流体力学模型 双轻子增强

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