Transverse Photon Spectrum from QGP Fluid

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Abstract

We calculate the thermal photon distribution from the hot QCD matter produced by high energy nuclear collisions based on a hydrodynamical model, and compare it with the recent experimental data obtained by CERN WA80. Through the asymptotic value of the slope parameter of the transverse momentum distribution, we investigate the characteristic temperature of the QCD fluid.

Introduction

Since the thermal photon is considered to keep the information about the early stage of the hot matter produced by relativistic nuclear collisions, many theoretical analyses have already been done. Many groups [5] have analyzed the experimental data of CERN WA80 S+Au 200GeV/nucleon [7] so as to fit their theoretical model to the thermal photon emission data.

In this paper we analyze the photon and the hadron distribution produced by the hot QCD matter in a consistent way [1]:

1. We first choose parameters in the hydrodynamical model so as to reproduce the hadronic spectrum, i.e., the (pseudo-)rapidity distribution and the transverse momentum distribution.

2. We derive the thermal production rate of photons from a unit space-time volume based on the finite temperature field theory.

3. Accumulating the thermal production rate, over the whole space-time region covered with the particle source, which is estimated by the hydrodynamical model, we evaluate the thermal photon distribution which is to be compared with the experimental data.
Hydrodynamical Model and Hadronic Spectrum

In a previous paper [3], by making use of the following two models: I) the QGP fluid model with phase transition, II) the hot hadron gas model without phase transition, we have analyzed the pseudo-rapidity distribution of charged hadrons in S+Au 200 GeV/nucleon collision obtained by CERN WA80 [3]. Where we supposed that the fluid in the QGP phase is dominantly composed of u-, d-, s-quarks and gluons and that the fluid in the hadron phase is dominantly composed of pions and kaons.

According to the previous analysis [3], we here use the first model (the QGP fluid model with phase transition) specified by the initial temperature $T_i = 195$ MeV, the critical temperature $T_c = 160$ MeV, and the freeze-out temperature $T_f = 140$ MeV, and the second model (the hot hadron gas model without phase transition) specified by $T_i = 400$ MeV and $T_f = 140$ MeV. For these models, we obtain theoretical results of the hadronic spectrum. From Fig. 1 and Fig. 2, we observe that the both models can consistently reproduce the experimental data [3].

Figure 1: The pseudo-rapidity distribution of charged hadrons in S+Au 200 GeV/nucleon collision. Data from CERN WA80. The solid curve and the dashed curve stand for, respectively, the QGP phase transition model and the hot hadron gas model.

Figure 2: The transverse momentum distribution of neutral pions in S+Au 200 GeV/nucleon collision. Data was obtained by CERN WA80. The solid curve and the dashed curve stand for, respectively, the QGP phase transition model and the hot hadron gas model.

Thermal Production Rate of Photons

Assuming that a certain mode is dominantly excited in a local equilibrium system of the hot QCD matter and that the canonical operator of that mode obeys the quantum Langevin equation [2], we can easily derive thermal production rate semi-phenomenologically. In Fig. 3 we compare the numerical result of our semi-phenomenological production rate with another result obtained by Kapusta et al. [4, 1].

Integrating the production rate from a volume element $R(T)$ over the whole space-time volume in which the particle source exists, we obtain momentum distributions

$$k_0 \frac{d^3 N}{dk^3} = \int d^4x k'_0 \frac{d^3 R(T(x))}{dk^3} \bigg|_{k'_0 = U^\nu(x)k_\mu},$$  \hspace{1cm} (1)
which are to be compared with experimental data. Here temperature $T(x)$ and local four velocity $U^\mu(x)$ at space-time point $x$ are given by the numerical solution of the hydrodynamical model. Figure 4 shows the numerical results of Eq. (1) compared with the recent experimental data (S+Au 200 GeV/nucleon collision) obtained by CERN WA80. The solid curve and the dotted curve are, respectively, the whole thermal photon distribution given by our QGP fluid model and the contribution of the QGP phase region only. In the case of the QGP fluid with phase transition model, our result in Fig. 4 seems consistent with the experimental data of WA80. The dashed curve stands for the photon distribution given by our hot hadron gas model. The dashed curve deviates from the experimental data in both absolute value and slope.

Figure 3: The production rate as a function of temperature. The solid curve stands for our phase transition model and the dashed curve for the production rate calculated in Ref. [4]. The critical temperature $T_c = 160$ MeV.

**Effective temperature**

In order to pick up the most dominant contribution to the transverse momentum distribution, we can rewrite the thermal factor as

$$\exp\left(- \frac{k^\mu U^\mu}{T}\right) \bigg|_{\text{c.m. system}} \implies \exp\left(- \frac{k_T}{T} \frac{1-v_T}{\sqrt{1-v_T^2}} \right) = \exp\left(- \frac{k_T}{\sqrt{1 - v_L^2} \sqrt{1 + v_T^2} T} \right),$$

by which we can define the effective temperature $T_{eff}$ of the fluid at the volume element with velocity $v_L, v_T$ and temperature $T$ as,

$$T_{eff} = \sqrt{1 - \frac{v_L^2}{1 - v_T^2} \sqrt{1 + v_T^2}} T.$$

Table I shows the maximum $T_{eff}$ given by our numerical results of hydrodynamical model simulation and the slope parameter at $k_T = 20$ GeV for the above two models.
Table 1: The maximum $T_{eff}$ in our hydrodynamical simulation, and the slope parameters $T_s$ at $k_T = 20$ GeV.

| Model                                | $T$ (MeV) | $v_T$ | $v_L$ | $T_{eff}$ (MeV) | $T_s$ (MeV) |
|--------------------------------------|-----------|-------|-------|-----------------|-------------|
| QGP fluid (QGP phase)                | 157.5     | 0.53  | 0.11  | 280.8           | 273.8       |
| QGP fluid (hadron phase)             | 157.5     | 0.53  | 0.11  | 280.8           | 273.5       |
| Hot hadron gas                       | 400.0     | 0.0   | 0.0   | 400.0           | 397.0       |

Through comparison of $T_{eff}$ with the slope parameter $T_s$ in Table I, we know that the asymptotic slope parameter $T_s$ has possible origins different from each other for the above two models: The critical temperature dominates in the QGP fluid model with phase transition, while the initial temperature dominates in the hot hadron gas model without phase transition.

**Concluding Remarks**

We have derived the thermal photon distribution emitted from a hot matter produced by the high energy nuclear collisions, based on hydrodynamical model. We have observed that only the QGP fluid (with phase transition) model can consistently reproduce S+Au 200 GeV/nucleon data obtained by CERN WA80 experimental data. Furthermore we have discussed the asymptotic slope parameter of the transverse photon distribution.

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**References**

[1] T. Hirano, S. Muroya, and M. Namiki, Waseda University preprint, WU-HEP-96-13, hep-ph-9612234.

[2] M. Mizutani, S. Muroya and M. Namiki, Phys. Rev. D37(1988)3033.

[3] S. Muroya, H. Nakamura and M. Namiki, Prog. Theor. Phys. Suppl.,120(1995)209.

[4] J. Kapusta, P. Lichard and D. Seibert, Phys. Rev. D44(1991)2774.

[5] D. K. Srivastava and B. Sinha, Phys. Rev. Lett. 73(1994)2421; N. Arbex, U. Ornik, M. Plümer, A. Timmermann and R. M. Weiner, Phys. Lett. B345(1995)307; J. J. Neumann, D. Seibert and G. Fai, Phys. Rev. C51(1995)1460; A. Dumitru, U. Katscher, J. A. Maruhn, H. Stöcker, W. Greiner and D. H. Rischke, Phys. Rev. C51(1995)2166.

[6] R. Albrecht et al. : WA80, Z. Phys. C55(1992)539; M. Aggarwal et al. : WA98, Nucl. Phys. A610(1996)200c.

[7] R. Santo et al. : WA80, Nucl. Phys. A566(1994)61c; R. Albrecht et al. : WA80, Nucl. Phys. A590(1995)81c; R. Albrecht et al. : WA80, Phys. Rev. Lett. 76(1996)3506.