Photons from Pb+Pb and S+Au collisions at ultrarelativistic energies

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The effects of the variation of vector meson masses and decay widths on photon production from hot and dense strongly interacting matter formed after S+Au collisions at CERN Super Proton Synchrotron (SPS) energies are considered. It has been shown that the photon spectra measured by the WA80 Collaboration cannot distinguish between the formation of quark matter and hadronic matter in the initial state. The photon yield in Pb+Pb collisions at CERN SPS and BNL Relativistic Heavy Ion Collider energies is estimated. [S0556-2813(99)01711-2]

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I. INTRODUCTION

Nucleus-nucleus collisions at ultrarelativistic energies offer a unique opportunity to create and study a new state of strongly interacting matter called quark gluon plasma (QGP). Photons and dileptons can probe the entire volume of the plasma without almost any interaction and as such are better markers of space-time history of the evolving matter [1]. However, apart from QGP, photons can originate from the primary interactions among the partons of the colliding nuclei, which dominate the high momentum region of the spectra, and these photons could be evaluated reliably by applying perturbative QCD (pQCD). At smaller values of the transverse momentum, meson decays (mainly π^0 and also η) dominate the spectrum. Due to their long lifetime π^0 decays into two photons outside the hot zone and photons originating from this decay can be reconstructed through invariant mass analysis. But there is no method by which the thermal photons from hadronic reactions and decays within the hot zone of the thermalized system can be identified experimentally. In an ideal scenario where all the photons from π^0 decays are reconstructed and the photons from hard QCD processes are identified and subtracted, then only thermal photons will remain in the data.

Irrespective of whether QGP is formed or not, hadronic matter (HM) formed in ultrarelativistic heavy ion collisions (URHIC) is expected to be in a highly excited state of very high temperature and/or density. Thus it is of primary importance to understand the change in hadronic properties, e.g., mass, lifetime etc. at finite temperature and density. One of the most important aspects, spontaneously broken chiral symmetry, a property of hadrons in their ground state, is expected to be restored at high temperature, which should manifest itself in the thermal shift of vector meson masses. Changes in the hadronic properties could be probed most efficiently by studying the thermal spectrum of real and virtual (dilepton pairs) photons. The thermal photon yield from S+Au collisions has been studied by many authors [2–5] without taking medium effects into account. In this work we evaluate the transverse momentum distribution of photons emitted from a strongly interacting system with initial conditions expected to be realized at CERN Super Proton Synchrotron (SPS) energies for Pb+Pb and S+Au collisions, taking in-medium effects on hadronic properties into account. The motivation of this work is to study the shift in the photon spectra due to medium effects on hadrons relative to the case where these effects are neglected and to see whether this shift could be identified by using experimental data presently available. The transverse expansion [1] has been neglected because the *relative change* in the spectra as mentioned above will hardly be affected due to such effects.

The paper is organized as follows. In Sec. II we discuss the photon emission rate from QGP and hot hadronic matter. Section III is devoted to a discussion of the medium effects on the hadronic masses and decay widths. The space-time evolution of the hot and dense matter is addressed in Sec. IV. In Sec. V we present results and discussions.

II. PHOTON EMISSION

In a phase transition scenario, thermal photons originate both from QGP and hadronic phase as the latter is realized when the temperature of the system reduces to the critical temperature (T_c) due to expansion. However, if the system does not go through a phase transition, then obviously, the thermal photons will originate from hadronic interactions only. We have studied the thermal photon spectra from both the scenarios.

The thermal emission rate of real photons can be expressed in terms of the trace of the retarded photon self-energy ($\Pi^R_{\mu\nu}$) at finite temperature [6]

$$E\frac{dR}{d^3p}=-\frac{2g^{\mu\nu}}{(2\pi)^3}\mathrm{Im}\,\Pi^R_{\mu\nu}\frac{1}{e^{E/T}-1}, \tag{1}$$

where $g_{\mu\nu}$ is the metric tensor and T is the temperature of the thermal medium. In the quark matter (QM) the lowest order contribution to the trace of the imaginary part of the retarded self-energy $\mathrm{Im}\Pi^R_{\mu\nu}(p)$ comes from the two loop diagrams and corresponds to the QCD Compton and annihilation processes, the total rate for which is given by [7]

$$E\frac{dR}{d^3p}=\frac{5}{9}\,\frac{\alpha\alpha_s}{2\pi^2}T^2\left(1+\frac{\mu_q^2}{\pi^2T^2}\right)\exp(-E/T)\ln\left(\frac{0.2317E}{4\pi\alpha_sT}\right), \tag{2}$$

where α is the fine structure constant, $\alpha_s = 6\pi/(33 - 2n_f)\ln(8T/T_c)$ [8] is the strong coupling constant and μ_q is the chemical potential of the quark.

In the hadronic matter (HM) an exhaustive set of hadronic reactions and vector meson decays involving π,ρ,ω, and η mesons have been considered. It is well known [9] that the reactions $\pi\rho\to\pi\gamma$, $\pi\pi\to\rho\gamma$, $\pi\pi\to\eta\gamma$, $\pi\eta\to\pi\gamma$, and the decays $\rho\to\pi\pi\gamma$ and $\omega\to\pi\gamma$ are the most important channels for photon production from hadronic matter in the energy regime of our interest. The rates for these processes could be evaluated from the imaginary part of the two loop photon self-energy involving various mesons. Recently it has been shown [10] that the role of intermediary a_1 in the photon producing reactions is less important than thought earlier [11,12]. In the present work we have neglected a_1 in the intermediate state.

To evaluate the photon emission rate from a hadronic gas we model the system as consisting of π,ρ,ω, and η. The relevant vertices for the reactions $\pi\pi\to\rho\gamma$ and $\pi\rho\to\pi\gamma$ and the decay $\rho\to\pi\pi\gamma$ are obtained from the following Lagrangian:

$$\mathcal{L} = -g_{\rho\pi\pi}\vec{\rho}^{\mu}\cdot(\vec{\pi}\times\partial_\mu\vec{\pi}) - eJ^\mu A_\mu + \frac{e}{2}F^{\mu\nu}(\vec{\rho}_\mu\times\vec{\rho}_\nu)_3, \tag{3}$$

where $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$, is the Maxwell field tensor and J^μ is the hadronic part of the electromagnetic current given by

$$J^\mu = (\vec{\rho}_\nu\times\vec{B}^{\nu\mu})_3 + [\vec{\pi}\times(\partial^\mu\vec{\pi} + g_{\rho\pi\pi}\vec{\pi}\times\vec{\rho}^{\mu})]_3, \tag{4}$$

with $\vec{B}_{\mu\nu} = \partial_\mu\vec{\rho}_\nu - \partial_\nu\vec{\rho}_\mu - g_{\rho\pi\pi}(\vec{\rho}_\mu\times\vec{\rho}_\nu)$. The invariant amplitudes for all these reactions have been listed in the appendix of Ref. [13].

For the sake of completeness we have also considered the photon production due to the reactions $\pi\eta\to\pi\gamma$, $\pi\pi\to\eta\gamma$ and the decay $\omega\to\pi\gamma$ using the following interaction:

$$\mathcal{L} = \frac{g_{\rho\rho\eta}}{m_\eta}\epsilon_{\mu\nu\alpha\beta}\partial^\mu\rho^\nu\partial^\alpha\rho^\beta\eta + \frac{g_{\omega\rho\pi}}{m_\pi}\epsilon_{\mu\nu\alpha\beta}\partial^\mu\omega^\nu\partial^\alpha\rho^\beta\pi + \frac{em_\rho^2}{g_{\rho\pi\pi}}A_\mu\rho^\mu. \tag{5}$$

The last term in the above Lagrangian is written down on the basis of vector meson dominance (VMD) [14]. The invariant amplitudes for these reactions are also given in Refs. [13,15].

The emission rate of a photon of energy E and momentum $\vec{p}$ from a thermal system at a temperature T is given by

$$E\frac{dR}{d^3p} = \frac{\mathcal{N}}{16(2\pi)^7 E}\int_{(m_1+m_2)^2}^{\infty} ds \int_{t_{\min}}^{t_{\max}} dt |\mathcal{M}|^2 \times \int dE_1 \int dE_2 \frac{f(E_1)f(E_2)[1+f(E_3)]}{\sqrt{aE_2^2 + 2bE_2 + c}}, \tag{6}$$

where $\mathcal{M}$ is the invariant amplitude for photon production and

$$a = -(s+t-m_2^2-m_3^2)^2,$$

$$b = E_1(s+t-m_2^2-m_3^2)(m_2^2-t) + E[(s+t-m_2^2-m_3^2)\times(s-m_1^2-m_2^2) - 2m_1^2(m_2^2-t)],$$

$$c = -E_1^2(m_2^2-t)^2 - 2E_1E[2m_2^2(s+t-m_2^2-m_3^2) - (m_2^2-t)(s-m_1^2-m_2^2)] - E^2[(s-m_1^2-m_2^2)^2 - 4m_1^2m_2^2] - (s+t-m_2^2-m_3^2)(m_2^2-t)(s-m_1^2-m_2^2) + m_2^2(s+t-m_2^2-m_3^2)^2 + m_1^2(m_2^2-t)^2,$$

$$E_{1\min} = \frac{(s+t-m_2^2-m_3^2)}{4E} + \frac{Em_1^2}{s+t-m_2^2-m_3^2},$$

$$E_{2\min} = \frac{Em_2^2}{m_2^2-t} + \frac{m_2^2-t}{4E},$$

$$E_{2\max} = -\frac{b}{a} + \frac{\sqrt{b^2-ac}}{a}.$$

The photon production rate from HM cannot be expressed in a closed form as in Eq. (2) due to the complexities arising from the nature of the hadronic interactions and reaction kinematics.

III. MEDIUM EFFECTS

To study the medium effects on the transverse momentum distribution of photons from URHIC we need two more ingredients. First, we require the variation of masses and decay widths with temperature, because the invariant matrix element for photon production suffers in-medium modifications through the temperature dependent masses and widths of the participants. As the hadronic masses and decay widths enter directly in the count rates of electromagnetically interacting particles, the finite temperature and density effects in the cross sections, particularly in the hadronic matter, are very important in URHIC.

At nonzero temperature and density the pole of the propagator gets shifted due to interactions with real and virtual excitations present in the system. Such a modification can be studied through the Dyson-Schwinger equation. In the following we calculate the effective nucleon mass in the relativistic Hartree approximation (RHA) using Walecka model for which the interaction Lagrangian density is given by [16,17]

$$\mathcal{L}_I = -g_v\bar{\psi}\gamma_\mu\psi\omega^\mu + g_s\bar{\psi}\sigma\psi. \tag{7}$$

The effective mass is obtained as

$$M^*=M-\frac{4g_s^2}{m_s^2}\int\frac{d^3k}{(2\pi)^3}\frac{M^*}{E^*}[f_{FD}(\mu^*,T)+\overline{f}_{FD}(\mu^*,T)]$$
$$+\frac{g_s^2}{m_s^2}\frac{1}{\pi^2}\bigg[M^{*3}\ln\left(\frac{M^*}{M}\right)-M^2(M^*-M)$$
$$-\frac{5}{2}M(M^*-M)^2-\frac{11}{6}(M^*-M)^3\bigg], \tag{8}$$

where

$$f_{FD}(\mu^*,T)=\frac{1}{\exp[(E^*-\mu^*)/T]+1},$$

$$\overline{f}_{FD}(\mu^*,T)=\frac{1}{\exp[(E^*+\mu^*)/T]+1},$$

$$E^*=\sqrt{\mathbf{k}^2+M^{*2}},$$

$$\mu^*=\mu-\left(\frac{g_v^2}{m_v^2}\right)n_B.$$

Here, n_B is the baryon density of the medium and is given by

$$n_B=\frac{4}{(2\pi)^3}\int d^3\mathbf{k}[f_{FD}(\mu^*,T)-\overline{f}_{FD}(\mu^*,T)]. \tag{9}$$

The effective mass of the vector meson (rho/omega) is then determined using the following interaction Lagrangian:

$$\mathcal{L}_{VNN}=g_{VNN}\left(\overline{N}\gamma_\mu\tau^a N V_a^\mu-\frac{\kappa_V}{2M}\overline{N}\sigma_{\mu\nu}\tau^a N\partial^\nu V_a^\mu\right), \tag{10}$$

where $V_a^\mu=\{\omega^\mu,\vec{\rho}^\mu\}$, M is the free nucleon mass, N is the nucleon field and $\tau_a=\{1,\vec{\tau}\}$.

The real part of the vector meson self-energy due to $N\overline{N}$ polarization is responsible for mass shifting and the imaginary part of the same due to $\pi\pi$ polarization gives the decay width of the vector meson in the medium. The details of the calculations can be found in our previous work [15,18] and we do not reproduce them here. However, from the results of those calculations the variation of nucleon, rho, and omega masses and the decay width of rho with temperature at zero baryon density can be parametrized as

$$m_N^*/m_N=1-0.0264(T/T_c)^{8.94}, \tag{11}$$

$$m_\rho^*/m_\rho=1-0.1268(T/T_c)^{5.24}, \tag{12}$$

$$m_\omega^*/m_\omega=1-0.0438(T/T_c)^{7.09}, \tag{13}$$

$$\Gamma_\rho^*/\Gamma_\rho=1+0.6644(T/T_c)^4-0.625(T/T_c)^5, \tag{14}$$

where an asterisk indicates effective mass in the medium and $T_c=0.16$ GeV. In the rho width we have included the Bose enhancement effects [15]. Note that in our calculation the nucleon, rho, and omega masses decrease differently; we do not observe any universal scaling [19]. Effects of vector meson mass variation on the photon spectra has recently been studied by Song *et al.* [20], where, they have assumed a profile for the vector meson mass variation without calculating it within the framework of any hadronic model.

IV. EVOLUTION DYNAMICS

The observed photon spectrum originating from an expanding QGP or hadronic matter is obtained by convoluting the static (fixed temperature) rate, as given by Eq. (1), with expansion dynamics. Therefore, the second ingredient required for our calculations is the description of the system undergoing rapid expansion from its initial formation stage to the final freeze-out stage. In this work we use Bjorken-like [21] hydrodynamical model for the isentropic expansion of the matter in $(1+1)$ dimension. For the QGP sector we use a simple bag model equation of state (EOS) with two flavor degrees of freedom. The temperature in the QGP phase evolves according to Bjorken scaling law $T^3\tau=T_i^3\tau_i$.

In the hadronic phase we have to be more careful about the presence of heavier particles and their change in masses due to finite temperature effects. The hadronic phase consists of $\pi,\rho,\omega,\ \eta$, and a_1 mesons and nucleons. The nucleons and heavier mesons may play an important role in the EOS in a scenario where mass of the hadrons decreases with temperature.

The energy density and pressure for such a system of mesons and nucleons is given by

$$\epsilon_H=\sum_{i=\text{mesons}}\frac{g_i}{(2\pi)^3}\int d^3pE_if_{BE}(E_i,T)$$
$$+\frac{g_N}{(2\pi)^3}\int d^3pE_Nf_{FD}(E_N,T,\mu^*) \tag{15}$$

and

$$P_H=\sum_{i=\text{mesons}}\frac{g_i}{(2\pi)^3}\int d^3p\frac{p^2}{3E_i}f_{BE}(E_i,T)$$
$$+\frac{g_N}{(2\pi)^3}\int d^3p\frac{p^2}{3E_N}f_{FD}(E_N,T,\mu^*), \tag{16}$$

where the sum is over all the mesons under consideration and N stands for nucleons and $E_i=\sqrt{p^2+m_i^2}$. The entropy density is given by

$$s_H=\frac{\epsilon_H+P_H-\mu^*n_B}{T}\equiv 4a_{\text{eff}}(T,n_B)T^3$$
$$=4\frac{\pi^2}{90}g_{\text{eff}}[m^*(T,n_B),T,n_B]T^3, \tag{17}$$

where g_{eff} is the effective statistical degeneracy.

Thus, we can visualize the effect of finite mass of the hadrons through an effective degeneracy $g_{\rm eff}[m^*(T,n_B),T,n_B]$ of the hadronic gas. The variation of temperature from its initial value T_i to final value T_f (freeze-out temperature) with proper time (τ) is governed by the conservation of entropy and baryon number

$$s\tau = s_i\tau_i,$$
$$n_B\tau = n_B^i\tau_i. \tag{18}$$

The initial temperature of the system is obtained by solving the following equation self-consistently:

$$\frac{dN_\pi}{dy} = \frac{45\zeta(3)}{2\pi^4}\pi R_A^2 4a_{\rm eff}T_i^3\tau_i, \tag{19}$$

where dN_π/dy is the total pion multiplicity, R_A is the radius of the system, τ_i is the initial thermalization time, and $a_{\rm eff} = (\pi^2/90)g_{\rm eff}$. The change in the expansion dynamics, as well as the value of the initial temperature due to medium effects, enters the calculation of the photon emission rate through the effective statistical degeneracy.

V. RESULTS AND DISCUSSION

We consider Pb+Pb collisions at CERN SPS energies. If we assume that the matter is formed in the QGP phase with two flavors (u and d), then $g_k=37$. Taking $dN_\pi/dy=600$ as measured by the NA49 Collaboration [22] for Pb+Pb collisions, we obtain $T_i=180$ MeV for $\tau_i=1$ fm/c [21]. The system takes a time $\tau_Q=T_i^3\tau_i/T_c^3$ to achieve the critical temperature of phase transition ($T_c=160$ MeV, see Ref. [23]). In a first order phase transition scenario the system remains in the mixed phase up to a time $\tau_H=r\tau_Q$, i.e., T remains at T_c for an interval $\tau_H-\tau_Q$, where r is the ratio of the statistical degeneracy in QGP to hadronic phase. At τ_H the system is fully converted to hadronic matter and remains in this phase up to a proper time τ_f when the freeze-out temperature T_f is attained. We have taken $T_f=130$ MeV [24] in our calculations.

In Fig. 1 we depict the variation of effective degeneracy as a function of temperature with (solid) and without (dashed) medium effects on the hadronic masses. We observe that for $T>140$ MeV the effective degeneracy becomes larger due to the reduction in temperature dependent masses compared to the free hadronic masses. Physically this means that the number of hadrons in a thermal bath at a temperature T is more when in-medium mass reduction is taken into account. Equation (19) then implies that for a given pion multiplicity the initial temperature of the system will be lower (higher) when medium effects on hadronic masses are considered (ignored). This is clearly demonstrated in Fig. 2 where we show the variation of temperature with proper time for different initial conditions. The dotted line indicates the scenario where QGP is formed initially at $T_i=180$ MeV and cools down according to Bjorken law up to a temperature T_c at which a phase transition takes place; it remains constant at T_c up to a time $\tau_H=8.4$ fm/c after which the temperature decreases as $T=0.241/\tau^{0.19}$ to a temperature T_f. If the system is considered to be formed in the hadronic phase then the initial temperature is obtained as $T_i=230$ MeV (270 MeV) when in-medium effects on the hadronic masses are taken into account (ignored), the corresponding cooling law being $T=0.230/\tau^{0.169}$ ($T=0.266/\tau^{0.2157}$). These are displayed in Fig. 2 by solid and dashed lines, respectively. The above parametrizations of the cooling law in the hadronic phase have been obtained by solving Eq. (18) self-consistently. With finite initial baryon density, $n_B^i=2n_B^0$ (n_B^0 is the normal nuclear matter density) the cooling laws are modified to $T=0.222/\tau^{0.172}$ and $T=0.219/\tau^{0.174}$ in a ''hadronic scenario'' (matter formed in the hadronic phase) and ''QGP scenario'' (matter formed in the QGP phase), respectively (not shown in Fig. 2). Having obtained the finite temperature effects on hadronic properties and the cooling law we are ready to evaluate the photon spectra from a (1+1) dimensionally expanding system. The transverse momentum distribution of photons in a first order

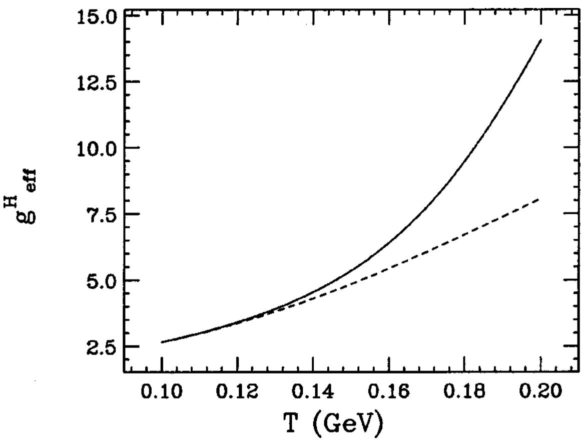

FIG. 1. The solid (dashed) line indicates the variation of effective degeneracy at zero baryon density as a function of temperature with (without) medium effects on the hadronic masses.

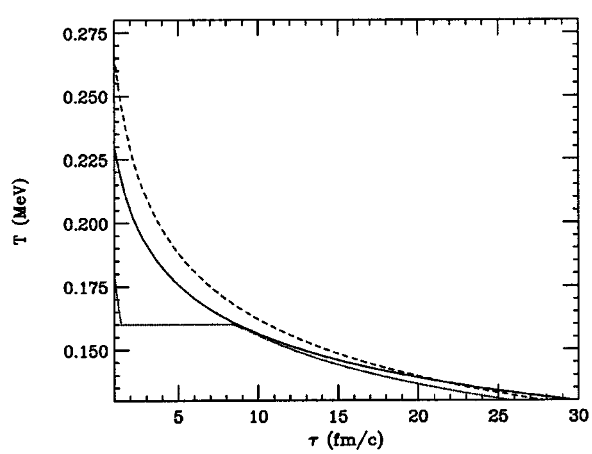

FIG. 2. Variation of temperature with proper time. The dotted line indicates the cooling law in a first order phase transition scenario. The solid (dashed) line represents temperature variation in a ''hadronic scenario'' with (without) medium effects on the hadronic masses at zero baryon density.

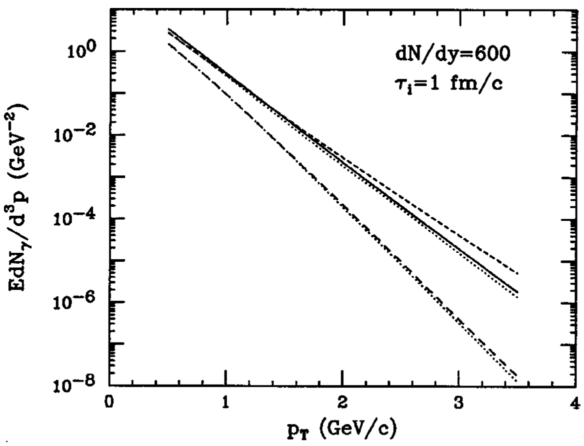

FIG. 3. Total thermal photon yield in Pb+Pb central collisions at 158 GeV per nucleon at CERN SPS. The long-dash line shows the results when the system is formed in the QGP phase with initial temperature $T_i = 180$ MeV at $\tau_i = 1$ fm/c. The critical temperature for phase transition is taken as 160 MeV. The solid (short-dashed) line indicates photon spectra when hadronic matter formed in the initial state at $T_i = 230$ MeV ($T_i = 270$ MeV) at $\tau_i = 1$ fm/c with (without) medium effects on hadronic masses and decay widths. The upper (lower) dotted line represents the photon spectra with initial baryon density $n_B^i = 2n_B^0$ in a ''hadronic'' (''QGP'') scenario.

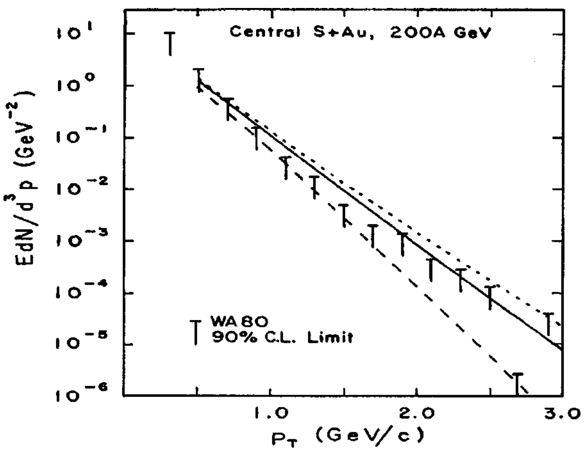

FIG. 4. Total thermal photon yield in S+Au central collisions at 200 GeV per nucleon at CERN SPS. The long-dashed line shows the results when the system is formed in the QGP phase with initial temperature $T_i = 190$ MeV at $\tau_i = 1.2$ fm/c. The critical temperature for phase transition is taken as 160 MeV. The solid (short-dashed) line indicates photon spectra when hadronic matter formed in the initial state at $T_i = 230$ MeV ($T_i = 270$ MeV) at $\tau_i = 1.2$ fm/c with (without) medium effects on hadronic masses and decay widths.

phase transition scenario is given by

$$E\frac{dN}{d^3p} = \pi R_A^2 \int \Bigg[\left(E\frac{dR}{d^3p}\right)_{\rm QGP} \Theta(\epsilon - \epsilon_Q) + \Bigg[\left(E\frac{dR}{d^3p}\right)_{\rm QGP} \frac{\epsilon - \epsilon_H}{\epsilon_Q - \epsilon_H} + \left(E\frac{dR}{d^3p}\right)_H \frac{\epsilon_Q - \epsilon}{\epsilon_Q - \epsilon_H}\Bigg] \times \Theta(\epsilon_Q - \epsilon)\Theta(\epsilon - \epsilon_H) + \left(E\frac{dR}{d^3p}\right)_H \Theta(\epsilon_H - \epsilon)\Bigg] \times \tau d\tau d\eta, \tag{20}$$

where ϵ_Q (ϵ_H) is the energy density in the QGP (hadronic) phase at T_c, η is the space time rapidity, R_A is the radius of the nuclei, and the Θ functions are introduced to get the contribution from individual phases. In Fig. 3 we present our results of the transverse momentum distribution of photons produced from Pb+Pb collisions at 158 GeV per nucleon at CERN SPS energies. The transverse momentum distribution of photons originating from the ''hadronic scenario'' with (solid line) and without (short-dashed line) medium modifications of vector mesons outshine the photons from the ''QGP scenario'' (indicated by long-dashed line) for the entire range of p_T. The upper (lower) dotted line indicates the photon spectra from ''hadronic'' (''QGP'') scenario when the initial baryon density is twice the normal nuclear matter density. The reduction in the hadronic mass due to finite baryon density effects is more drastic in the Brown-Rho scaling scenario [19] than in the present model. Therefore, the finite density effects on hadronic properties could be visible through electromagnetic signals in the Brown-Rho scaling scenario. We observe that photons from ''hadronic scenario'' with medium effects on vector mesons shine less brightly than the case without medium effects for $p_T > 2$ GeV.

Before going further we would like to note that in the ''hadronic scenario'' with medium effects the initial temperature is lower (230 MeV) compared to the case when medium effects on hadronic masses are ignored ($T_i = 270$ MeV). A lower initial temperature will result in a lower photon emission rate from the thermal system. On the other hand it has been shown in our earlier works [13,15] that the photon spectra at a fixed temperature get enhanced due to the medium effects. These two competitive effects determine the space-time integrated photon spectra, which is measured experimentally. In the present calculation the enhancement in the photon emission due to the higher initial temperature in the free mass scenario (where the static rate is smaller) overwhelms the enhancement of the rate due to negative shift in the vector meson masses (where initial temperatue is smaller), similar to the results obtained in Ref. [20] in a ''hadronic scenario.''

In Fig. 4 we compare thermal photon spectra with the upper bound of WA80 Collaboration [25]. The experimental data stands for S+Au collisions at 200 GeV per nucleon at the SPS. In this case the pion multiplicity, $dN_\pi/dy = 225$. Our calculation shows that the maximum number of photons originate from the ''hadronic scenario'' when the medium effects on vector mesons are ignored. For such a scenario the photon spectra has just crossed the upper bound of the WA80 data and more likely such a scenario is not realized in these collisions. This is in line with the analysis of the preliminary WA80 data of Ref. [3].

It should be noted for completeness that as a first approximation, the temperature variation of the degeneracy factor was not considered in Ref. [3] leading to quantitative differences in the theoretical predictions between the present work and Ref. [3]. Photons from ''hadronic scenario'' with medium modifications of vector meson properties outshine those from the ''QGP scenario'' for the entire p_T range. Considering the experimental uncertainty, no definitive conclusion t can be drawn in favor of any particular scenario.

For the Relativistic Heavy Ion Collider (RHIC) a scenario of a pure hot hadronic system within the format of the model used here, appears to be unrealistic. The initial temperature considering bare hadronic masses turns out to be $\sim$340 MeV whereas for the other extreme case of massless hadrons it is $\sim$290 MeV. With temperature dependent masses the initial temperature will lie somewhere between these two values. For such high temperatures, clearly a hot dense hadronic system cannot be a reality; the hadrons would have melted away even for lower temperatures. Thus, for RHIC we have treated the case of a QGP initial state. The baryonic chemical potential has been taken as zero for the central region and the finite temperature effects on the hadronic masses and decay widths [15] have been taken into account. The sensitivity of photon spectra on the critical temperature is demonstrated in Fig. 5 for RHIC energies. We observe that at high p_T the photon emission rate is insensitive to T_c because most of the thermal photon in this region originate from the very early hot stage of the evolution. Since the low p_T thermal photons are produced in the hadronic and mixed phase, there is an enhancement in the photon spectra for higher value of T_c in this p_T domain.

In summary, we have estimated the photon spectra from Pb+Pb and S+Au collisions at 158 GeV and 200 GeV per nucleon, respectively, with different initial conditions. In case of Pb+Pb collisions photons from the hadronic scenario dominate over the photons from the QGP scenario for the entire p_T domain. The photon yield in S+Au collisions is compared with the experimental data. We find that the photon spectra evaluated with free masses seems to exceed the experimental upper limit. However, the photon spectra obtained by assuming hadronic matter (with in-medium effects or otherwise) in the initial state outshines the spectra evaluated in a first order phase transition scenario. Considering the experimental uncertainty, it is not possible to state which one of the two is compatible with the data. Experimental data with better statistics could possibly distinguish among various scenarios. The sensitivity of the photon spectra on the critical temperature is also presented for RHIC energies.

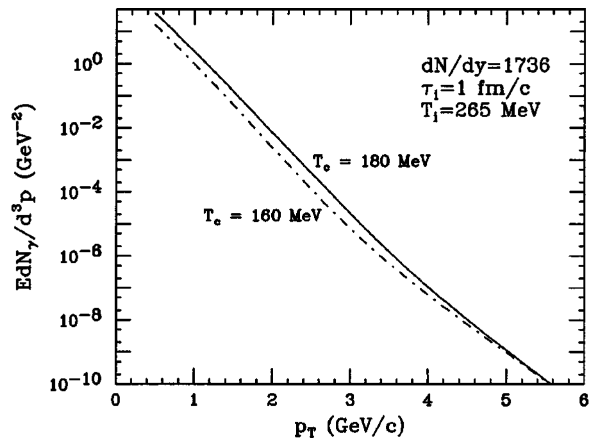

FIG. 5. Total thermal photon yield in Pb+Pb central collisions at RHIC energies with medium effects for two values of T_c.

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