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Photons from quark gluon plasma and hot hadronic matter

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Abstract. The productions of real photons from quark gluon plasma and hot hadronic matter formed after the nucleus–nucleus collisions at ultra-relativistic energies are discussed. The effects of the spectral shift of the hadrons at finite temperature on the production of photons are investigated. On the basis of the present analysis it is shown that the photon spectra measured by WA98 collaboration in Pb + Pb collisions at CERN SPS energies can be explained by both QGP as well as hadronic initial states if the spectral shift of hadrons at finite temperature is taken into account. Several other works on the analysis of WA98 photon data have also been briefly discussed.

Keywords. Photons; quark gluon plasma; phase transition; spectral shift; hydrodynamics.

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1. Introduction

Calculations based on the QCD renormalization group predicts that strongly interacting systems at very high density and/or temperature are composed of weakly interacting quarks and gluons [1] due to asymptotic freedom and the Debye screening of colour charge. On the other hand, at low temperature and density the quarks and gluons are confined within the hadrons. Therefore, a phase transition is expected to take place at an intermediate value of temperature and/or density. In fact such a transition, from hadronic matter to quark gluon plasma (QGP), is actually observed in lattice QCD numerical simulations [2] at high temperature. One expects that ultra-relativistic heavy-ion collisions (URHIC) at CERN/SPS, BNL/RHIC and CERN/LHC might create conditions conducive for the formation and study of QGP [3]. Among various signatures of QGP, photons and dileptons are known to be advantageous as these signals probe the entire volume of the plasma, with little interaction and thus, are better markers of the space-time history of the evolving matter [4].

The aim of the present work is to contrast the real photon emission rate from the following two nuclear collision scenarios: (1) A + A →QGP→ mixed phase→hadronic phase or (2) A + A →hadronic phase, by taking into account the finite temperature effects on the hadronic masses and decay widths. The main sources of photons from URHIC are: (a) the decay of mesons (mainly π^0 and η), (b) thermal source, either QGP and/or the hadronic reactions and hadronic decays in the thermal medium depending on which of the scenarios (1) or (2) realized after the collisions and (c) hard scattering of the partons embedded in the nucleons of the colliding nuclei in the very early stage of the collisions. However, the transverse momentum (p_T) spectra of single photons presented by WA98 collaboration [5] does not contain the contributions from the decays of mesons. Therefore, in the present article we will consider photons from (b) and (c) only. In the scenario (1) the pre-requisite for the QGP diagnostics (by measuring photon spectra) is to estimate the photon yield from hadronic sources and hard collisions of partons in the initial stage.

In the next section we discuss the hard photon production from nucleus–nucleus collisions at SPS energies. Thermal photon emission from the QGP and hadronic matter are discussed in §3. Hadronic properties at non-zero temperature is presented in §4. Section 5 is devoted to discuss the space-time evolution and in §6 we present our results and discussions.

2. Hard QCD photons

The hard QCD photons are estimated using perturbative QCD as

$$E\,\frac{\mathrm{d}N}{\mathrm{d}^3p} = T_{AA}(b=0)\,E\,\frac{\mathrm{d}\sigma_{pp}}{\mathrm{d}^3p} \tag{1}$$

where $T_{AA}(b)$ is the nuclear thickness at impact parameter b. Its value at $b \sim 3.2$ fm corresponding to the most central event of WA98 experiment is $\sim$220/fm^2. σ_{pp} includes the pp cross-section for Compton and annihilation processes among the partons. At SPS energies one should include the effects of intrinsic k_T distribution of partons [6] (due to finite size of the nucleons). This leads to substantial enhancement in the photon spectra [7]. In practice such an effect is implemented by multiplying each of the parton distribution functions appearing in the right-hand side of the above equation by a Gaussian function of the type $f(k_\mathrm{T}) = \exp[-k_\mathrm{T}^2/\langle k_\mathrm{T}^2\rangle]/\pi\langle k_\mathrm{T}^2\rangle$ and integrating over d^2k_T. We use CTEQ5M partons [8] and $\langle k_\mathrm{T}^2\rangle = 0.9$ GeV^2 for evaluating the hard QCD photons. The energy at the centre of mass of Pb + Pb collisions at SPS is 17.3 GeV. Experimental data on hard photons does not exist at this energy. Therefore, the 'data' at $\sqrt{s} = 17.3$ GeV is obtained from the data at $\sqrt{s} = 19.4$ GeV of the E704 collaboration [33] by using the scaling relation: $E\,\mathrm{d}\sigma/\mathrm{d}^3p_\gamma\,|_{h_a+h_b\rightarrow X+\gamma} = f(x_\mathrm{T} = 2p_\mathrm{T}/\sqrt{s})/s^2$, for the hadronic process, $h_a + h_b \rightarrow X + \gamma$ [9]. However, such a scaling may be spoiled in perturbative QCD due to the momentum dependence of the strong coupling α_s and from the scaling violation of structure functions, resulting in faster decrease of the cross-section than $1/s^2$. Therefore, the data at $\sqrt{s} = 17.3$ GeV obtained by using the above scaling gives a conservative estimate of the prompt photon contributions. The photons from hard QCD processes have been used to reproduce the scaled p–p data of E704 collaboration. The higher order effects have been taken into account through a K-factor $\sim$2. Now the question is, can we say that an enhanced production in A–A collisions compared to p–p will presumably mark the presence of a thermal source? Not necessarily, because in nucleus–nucleus collisions there may be enhancement in the high p_T part of the photon spectra due to various nuclear effects, e.g., Cronin effects. However, the good news is that even if we take into account the transverse momentum broadening due to the finite size of the nucleon as well as due to the Cronin effects then we find that the theoretical yield is less than the experimental value (WA98 data) for $1.5 < p_\mathrm{T}(\mathrm{GeV}) < 2.5$ [10,11], clearly indicating the presence of thermal source. What is the nature of this thermal source which can reproduce the WA98 data? We will discuss this issue in the next section.

3. Thermal photons from QGP and hadronic matter

Since quarks are electrically charged, their interactions at the thermal bath will produce photons we are looking for. The quark–anti-quark annihilation and QCD Compton are the dominant processes for the production of photon from a thermalized system of quarks and gluons [12]. However, it has been shown [13] (see also [14,15]) that the two-loop contribution leading to bremsstrahlung and $q\bar{q}$ annihilation with scattering is of the same order as the lowest order processes. The total rate of emission (up to two loops) per unit four-volume at temperature T is given by

$$E\frac{\mathrm{d}R}{\mathrm{d}^3p} = \frac{5}{9}\,\frac{\alpha\alpha_\mathrm{s}}{2\pi^2}\,\exp(-E/T)\,\left[\ln\left(\frac{2.912E}{g^2T}\right) + 4\frac{(J_\mathrm{T}-J_L)}{\pi^3}\left\{\ln 2 + \frac{E}{3T}\right\}\right] \tag{2}$$

where $J_\mathrm{T} \simeq 4.45$ and $J_L \simeq -4.26$. The QCD coupling, g, is given by

$$\frac{g^2}{4\pi} \equiv \alpha_\mathrm{s} = \frac{6\pi}{(33-2n_\mathrm{f})\ln(\kappa T/T_\mathrm{c})} \tag{3}$$

where n_f is the number of quark flavours and $\kappa = 8$ [16]. The photon emission rate in eq. (2) is evaluated in the hard thermal loop (HTL) approximation. However, the HTL approximation is not valid at SPS energies where an initial temperature of about few hundred MeV may be realized because the HTL resummation is valid for $g \ll 1$ whereas the value of g obtained from eq. (3) is $\sim$2 at $T \sim 200$ MeV. At present it is unclear whether the rate in eq. (2) is valid for such a large value of g or not. It would be rather difficult to make any firm conclusion from the results where eq. (2) is used at SPS energies. Keeping this reservation in mind we will use eq. (2) to evaluate the photon yield from QGP. However, we will see below that within the present framework the space-time integrated photon yield from quark matter is less than that from hadronic matter due to the smaller lifetime of the QGP phase as a result of a moderate value of the initial temperature considered here. Therefore, the total thermal photon yield remains largely unaffected even in a scenario where QGP is formed in the initial state.

The photon yield from the hadronic matter (HM) (see the first reference of [12]) is evaluated from the reactions, $\pi\rho \rightarrow \pi\gamma$, $\pi\pi \rightarrow \rho\gamma$, $\pi\pi \rightarrow \eta\gamma$, $\pi\eta \rightarrow \pi\gamma$ and the decays $\rho \rightarrow \pi\pi\gamma$ and $\omega \rightarrow \pi\gamma$. We refer to ref. [17] for the invariant amplitudes of these processes. Photon production due to the process $\pi\rho \rightarrow a_1 \rightarrow \pi\gamma$ is also considered here.

4. Hadronic properties at $T \neq 0$

It has been emphasized that the hadronic properties will be modified due to its interactions with the particles in the thermal bath. As a consequence of the change in the properties of hadrons, the static photon emission rates as well as the equation of state (EOS) of the evolving matter will also change in a non-trivial way [18]. Broadly two kinds of medium modifications of hadrons are expected: (i) shift in the pole of the spectral function without any broadening and (ii) broadening of the spectral function but pole does not shift. In

[18] the effects of spectral changes of hadrons on the electromagnetic probes is studied in detail. It was observed that the gauged linear and non-linear sigma models and the model with hidden local symmetry do not show any appreciable effect on photon emissions. In the Walecka model, the universal scaling hypothesis for the hadronic masses (except pseudo-scalar) has been seen to enhance photon emission.

Both (i) and (ii) can reproduce the enhancement of the dilepton yield in the low invariant mass region. However, the photon yield is largely unaffected by (ii) since the spectral function is smeared out. Therefore, a simultaneous measurement of single photon and lepton pairs is important to shed light on the in-medium effects of hadrons. According to the universal scaling scenario [19] the in-medium quantities (denoted by $*$) at finite T is parameterized as

$$\frac{m_V^*}{m_V} = \frac{f_V^*}{f_V} = \frac{\omega_0^*}{\omega_0} = \left(1 - \frac{T^2}{T_c^2}\right)^{\lambda}, \tag{4}$$

where V stands for vector mesons, f_V is the coupling between the vector meson field and the electromagnetic current and ω_0 is the continuum threshold. Mass of the nucleon varies with temperature as in eq. (4). It is to be noted that there is no definite reason to believe that all the in-medium dynamical quantities are dictated by a single exponent λ. This is the simplest possible ansatz. The effective mass of a_1 is estimated by the Weinberg's sum rules [20].

In the QHD model [21] the effective masses of nucleon, ρ and ω mesons can be parameterized in the following forms:

$$M_N^* = M_N \left[1 - 0.0264 \left(\frac{T\,(\mathrm{GeV})}{0.16}\right)^{8.94}\right], \tag{5}$$

$$m_\rho^* = m_\rho \left[1 - 0.127 \left(\frac{T\,(\mathrm{GeV})}{0.16}\right)^{5.24}\right],$$

$$m_\omega^* = m_\omega \left[1 - 0.0438 \left(\frac{T\,(\mathrm{GeV})}{0.16}\right)^{7.09}\right]. \tag{6}$$

In (ii) the change of the width of the ρ meson with temperature is parameterized as

$$\Gamma_\rho^* = \Gamma_\rho / (1 - T^2/T_c^2) \tag{7}$$

and the mass remains constant to its vacuum value. The results for scenarios (i) and (ii) will be compared with a scenario (iii) where both the masses and widths of the hadrons remain fixed to their vacuum values.

5. Space-time evolution

It is assumed here that the produced matter reaches a state of thermodynamic equilibrium after a proper time ∼1 fm/c [22]. In case a deconfined matter is produced, it evolves in space and time till freeze-out undergoing a phase transition to hadronic matter in the process. The (3+1)-dimensional hydrodynamic equations have been solved numerically by the relativistic version of the flux-corrected transport algorithm [23], assuming boost invariance in the longitudinal direction and cylindrical symmetry in the transverse plane. The initial temperature $T_{\rm i}$ can be related to the multiplicity of the event, $\mathrm{d}N/\mathrm{d}y$, by virtue of the isentropic expansion as [24],

$$\frac{\mathrm{d}N}{\mathrm{d}y} = \frac{45\zeta(3)}{2\pi^4}\pi R_A^2 4a_k T_{\rm i}^3\tau_{\rm i} \tag{8}$$

where R_A is the initial radius of the system, $\tau_{\rm i}$ is the initial thermalization time and $a_k = (\pi^2/90)g_k$; g_k being the effective degeneracy for the phase k (QGP or hadronic matter). The bag model EOS is used for the QGP phase. $g_{\rm H}(T)$, the statistical degeneracy of the hadronic phase, composed of π, ρ, ω, η, a_1 and nucleons is a temperature dependent quantity in this case and plays a crucial role in the EOS [18]. As a consequence the square of sound velocity, $c_s^{-2} = [(T/g_{\rm H})(\mathrm{d}g_{\rm H}/\mathrm{d}T)+3] < 1/3$, for the hadronic phase, indicating non-vanishing interactions among the constituents (see also [25]). The hydrodynamic equations have been solved with initial energy density, $\varepsilon(\tau_{\rm i}, r)$ [23], obtained from $T_{\rm i}$ through the EOS. We use the following relation for the initial velocity profile which has been successfully used to study transverse momentum spectra of hadrons [26,27],

$$v_r = v_0\left(\frac{r}{R_A}\right)^{\delta}. \tag{9}$$

Here we took $\delta = 1$ and the sensitivity of the results on v_0 will be shown. It is observed that the results do not change substantially with reasonable variation of the parameter δ for a given value of v_0.

The space-time integration can also be performed by taking the temperature profile from the transport model as [28,29]

$$T(\tau) = (T_{\rm i} - T_\infty)\mathrm{e}^{-\tau/\tau_0} + T_\infty \tag{10}$$

where $\tau_0 = 8$ fm/c and $T_\infty = 120$ MeV.

6. Results and discussions

In figure 1 the effective masses of vector mesons is plotted as a function of temperature for universal scaling and QHD model calculations. In QHD the ρ and ω masses show different behaviour due to their different coupling strengths with the nucleons in the thermal bath. In figure 2, we show the photon emission rate from hadronic matter at a temperature $T = 180$ MeV. The solid and dashed lines correspond to cases (i) and (iii) respectively. The case with large collisional broadening shows no deviation from (iii). The increased photon yield at large energy E is caused by the enhancement in the Boltzmann factor due to the reduction in meson (particularly ρ) masses. The thermal photon yield with hadronic mass variation due to Walecka model or Brown–Rho scaling [19] ($\lambda = 1/6$ in eq. (4)) will lie between the solid and dashed curves in figure 2. It is clearly observed that the contributions from the decays of baryonic resonances ($N(1520), N(1535), N(1440), \Delta(1232),$ and $\Delta(1620)$) are small (dotted line). The values of the decay widths, $R \to N\gamma$, where R and N denote the baryonic resonances and the nucleon respectively, are taken from the particle data book.

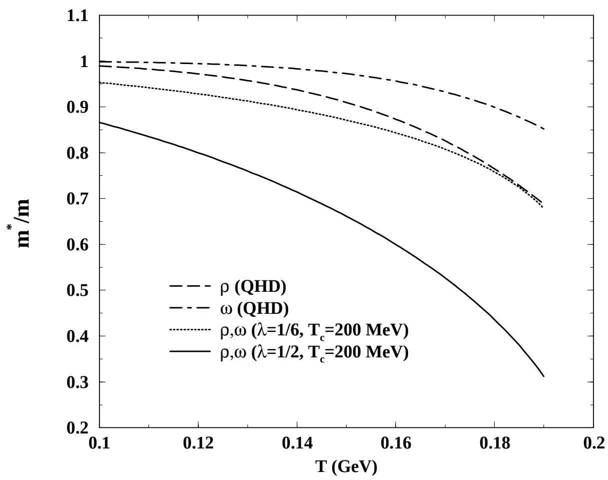

Figure 1. Variation of vector meson masses as a function of temperature in QHD model and universal scaling scenario.

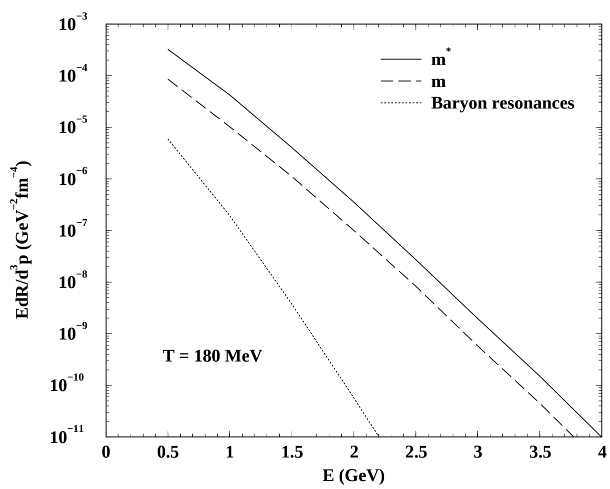

Figure 2. Photon spectra at $T = 180$ MeV. Solid (dashed) line indicates result when hadronic masses vary according to eq. (4) (fixed at vacuum values). Dotted line shows photon spectra from the decays of baryonic resonances.

We need the equation of state and the initial condition to solve the hydrodynamic equations. The effects of the temperature dependent hadronic masses have been taken into account in the EOS through the effective statistical degeneracy [18]. In figure 3 the temperature dependence obtained for different hadronic interactions is compared with the lattice QCD calculations [2]. The universal scaling scenario seems to reproduce the lattice data reasonably well.

For central collisions of Pb nuclei at 158 A·GeV at the CERN-SPS, we assume that QGP is produced at $\tau_i = 1$ fm/c which expands and undergoes a first-order phase transi-

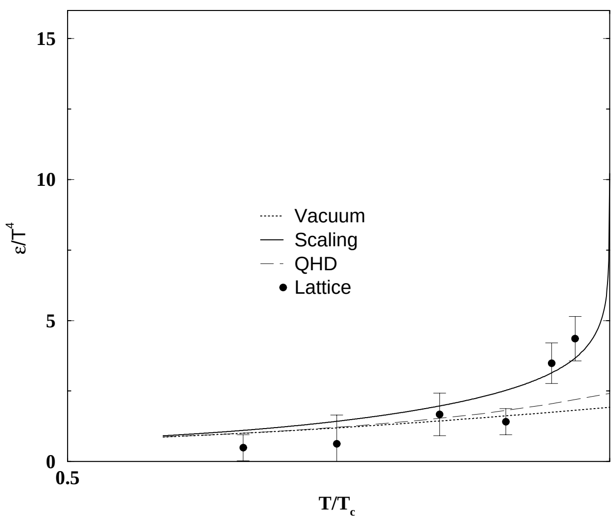

Figure 3. The energy density ε in the unit of T^4 for the equation of state used in the present work is plotted as function of temperature T in the unit of the critical temperature, T_c. The filled circle denotes the lattice results [2].

tion to hadronic matter at $T_\mathrm{c} = 160$ MeV. Taking $\mathrm{d}N/\mathrm{d}y = 700$ and $g_k = g_{\mathrm{QGP}} = 37$ for a two-flavour QGP, the initial temperature T_i comes out as 196 MeV. In a first-order phase transition one has a mixed phase of coexisting QGP and hadronic matter which persists till the phase transition is over. Thereafter the hadronic matter expands, cools and freezes out at a temperature T_f and radial velocity v_r^f. The sum total of the photon yields from the QGP phase, the mixed phase and the hadronic phase constitute the thermal yield [30]. The values of $(T_\mathrm{f}, v_\mathrm{r}^\mathrm{f})$ should in principle be obtained from the analysis of hadronic spectra. In the present work the value of T_f is taken as 120 MeV which reproduces the hadron spectra [31] of NA49 collaboration [32]. The sensitivity of the results on the value of v_0 will be demonstrated hereafter.

In the case of QGP formation the *thermal photons* contain contributions from quark matter (QM $\equiv$ QGP + QGP part of mixed phase) and hadronic matter (HM $\equiv$ hadronic part of mixed phase + hadronic phase). In figure 4, results for the total photon emission is shown for three different values of the initial transverse velocity with medium effects as in case (i). All the three curves represent the sum of the thermal and the prompt photon contribution which includes possible finite k_T effects of the parton distributions. The latter, shown separately by the dot–dashed line also explains the scaled *pp* data from E704 experiment [33]. We observe that the photon spectra for the initial velocity profile given by eq. (9) with $v_0 = 0.3$ explains the WA98 data reasonably well. It is found that a substantial fraction of the photons come from mixed and hadronic phases (hadronic masses vary with temperature according to eq. (4) with $\lambda = 1/2$). The contributions from the QGP phase is small because of the small lifetime of the QGP (~ 1 fm/c). Therefore, the results shown in this figure is largely independent of the uncertainties (mentioned above) involved in the photon emission rates from QGP.

The above statement together with the uncertainty of the critical temperature T_c [2] poses the following question: Is the existence of the QGP phase essential to reproduce the WA98

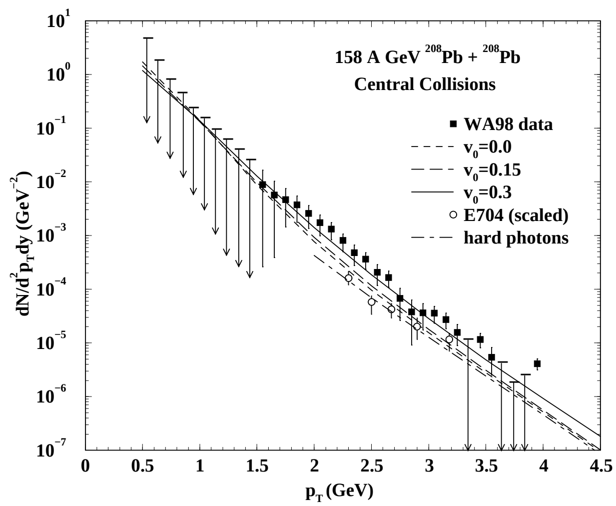

Figure 4. Total photon yield in Pb + Pb collisions at 158 A·GeV at CERN-SPS. The theoretical calculations contain hard QCD and thermal photons. The system is formed in the QGP phase with initial temperature $T_\mathrm{i} = 196$ MeV.

data? To study this problem, we have considered two possibilities: (i) pure hadronic model without medium-modifications and (ii) pure hadronic model with scaling hypothesis according to eq. (4) (for $\lambda = 1/2$). In the former case, T_i is found to be ∼250 MeV for $\tau_i = 1$ fm/c and $\mathrm{d}N/\mathrm{d}y = 700$, which appears to be too high for the hadrons to survive. Therefore, we exclude this possibility here. On the other hand, the second case with an assumption of $T_\mathrm{i} = T_\mathrm{c}$ (which is just for simplicity) leads to T_i ∼205 MeV, at $\tau_\mathrm{i} = 1$ fm/c, which is not unrealistic. In this case, the hadronic system expands and cools and ultimately freezes out at $T_\mathrm{f} = 120$ MeV. The masses of the vector mesons increase with reduction in temperature (due to expansion) according to eq. (4). The results of this scenario for three values of the initial radial velocity including the prompt photon contribution are shown in figure 5. The experimental data are well-reproduced for vanishing initial transverse velocity also. Therefore, the results shown in figures 4 and 5 indicate that a simple hadronic model is inadequate. Either substantial modifications of hadrons in the thermal bath or the formation of QGP in the initial stages is necessary to reproduce the data. It is rather difficult to distinguish between the two at present.

In figure 6 we compare the results of hydrodynamic and transport calculations. Within the framework of the transport model the data is well-reproduced when the hadronic masses are allowed to vary (scenario i) according to eq. (4) ($\lambda = 1/2$, long dashed line). As mentioned before, the photon spectra is insensitive to the change in width (scenario ii). In the scenario (ii) the experimentally observed 'excess' photon in the region $1.5 \leq p_\mathrm{T}$ (GeV) ≤ 2.5 (dotted line) is not reproduced. The change in the width of the vector mesons (ρ in particular) has very little effects on the p_T spectra of photons due to the following reasons. The density of an unstable particle in a thermal bath can be written as [34]

$$\frac{\mathrm{d}N}{\mathrm{d}^3k\,\mathrm{d}^3x\,\mathrm{d}s} = \frac{g}{(2\pi)^3}\mathrm{e}^{-\sqrt{k^2+s}/T}\,P(s) \tag{11}$$

where g is the statistical degeneracy of the particle and $P(s)$ is the spectral function,

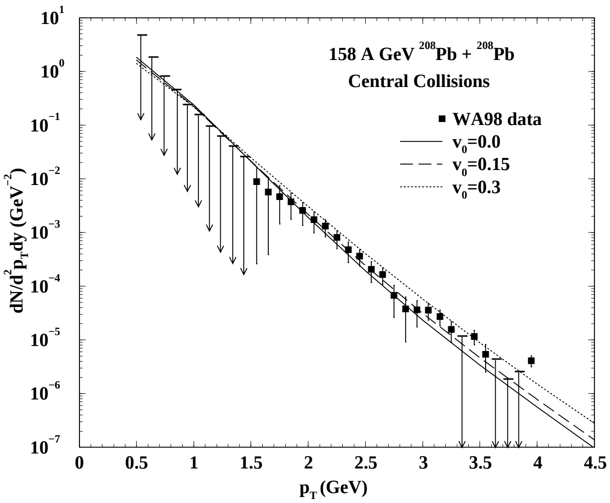

Figure 5. Same as figure 4 with hadronic initial state at $T_\mathrm{i} = 200$ MeV.

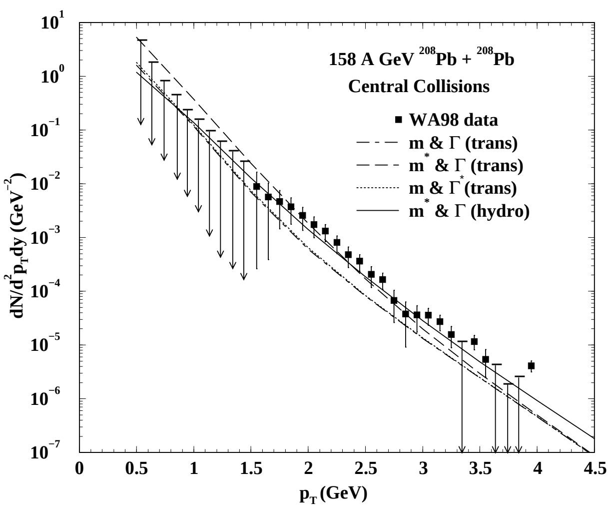

Figure 6. Same as figure 5. Results for hydrodynamic and transport (indicated by 'trans') model calculations are compared.

$$P(s) = \frac{1}{\pi} \frac{\mathrm{Im}\,\Pi}{(s - m_\rho^2 - \mathrm{Re}\,\Pi)^2 + (\mathrm{Im}\,\Pi)^2}. \tag{12}$$

$\mathrm{Im}\,\Pi$ ($\mathrm{Re}\,\Pi$) is the imaginary (real) part of the (trace of) ρ self energy. Equations (11) and (12) indicate that the density of particles in a thermal bath is given by the Boltzmann distribution weighted by the Breit–Wigner function, which gets maximum weight from the value of $s = m_\rho^2 + \mathrm{Re}\,\Pi$, the contribution from either side of the maximum being averaged out. Therefore, the results become sensitive to the effective mass, $s = m_\rho^{2*} = m_\rho^2 + \mathrm{Re}\,\Pi$ and not to the width of the spectral distribution. The dash–dotted line indicates results with

Table 1. The initial temperature obtained in the present analysis is compared with the values obtained by other authors [14,35–38].

[35]	[37]	[14]	[38]	[36]	Present
T_i	T_i	T_i	T_i	T_i	T_i
335	210	220	200–230	213–255	200

vacuum masses and widths. In the case of transport model calculations (dashed line) there is excess photons at the low p_T region compared to the hydrodynamic model (solid line) due to the following reason. We find that the variation of temperature with time (cooling law) in eq. (10) is slower than the one obtained by solving hydrodynamic equations. As a consequence the thermal system has a longer lifetime than the former case, allowing the system to emit photons for a longer time. In the case of hydrodynamics this is compensated by the transverse kick experienced by the photon at large p_T due to radial velocity of the expanding matter.

It is widely believed that the photon spectra can be very useful for the estimation of the initial temperature. In table 1, we show the initial temperature obtained by several authors [14,35–38] by analyzing the WA98 photon spectra. In [37] the thermal photon spectra was parameterized as $E\,\mathrm{d}N/\mathrm{d}^3p = V_4 F(E, T_{\mathrm{eff}}, v_0)$, similar to the parameterization one uses to study the thermal hadronic spectra. A value of $T_{\mathrm{eff}} = 170$ MeV and $v_0 = 0.3$ can reproduce the WA98 data if the prompt photon contribution is normalized to reproduce the data for $p_T > 2$ GeV. As T_{eff} is the average value of the temperature ($T_i > T_{\mathrm{eff}} > T_f$) in this analysis, one may expect an initial temperature ∼200 MeV. In [38] the hard photon contribution has been used to normalize the scaled *p–p* data at $\sqrt{s} = 19$ GeV and the thermal photon spectra was evaluated for both QGP and hadronic initial state assuming a non-zero radial velocity of the QGP/hadronic fluid. Steffen and Thoma [14] have demonstrated that the value of the statistical degeneracy (g_h) in the hadronic phase (and hence the lifetime of the mixed phase) is crucial for the description of WA98 data. An initial temperature ∼220 MeV with $T_c = 170$ MeV and $g_h = 8$ can reproduce the data in this case. In [35] and [14] the static photon emission rate from QGP is similar, then why the value of T_i is so different? Apparently the main reason is the difference in the lifetime of the mixed phase between the two cases. In [14] the lifetime of the mixed phase is large (small hadronic degeneracy) compared to that of ref. [35], hence allowing the mixed phase to emit photon for a longer time interval in the former case. In [14] the contributions from the QGP phase due to smaller initial temperature (compared to [35]) is compensated by a larger contributions from the mixed phase. Huovinen *et al* [36] have studied in detail the effects of various EOS, boost invariant and non-invariant hydrodynamic flow on the photon spectra. Thermal photon with values of T_i ∼213–255 MeV (depending on the EOS and evolution scenario) + hard QCD photon can reproduce the data well in their case. We would like to mention here that the (thermal) photon emission rate used in [36] is full order of α_s results obtained in [39].

In order to reproduce the WA98 photon data, either a substantial reduction in vector meson masses or the formation of QGP in the initial stage with T_i ∼200 MeV is necessary. A simple hadronic model is appeared to be ruled out by the experimental data.

In spite of the encouraging situation mentioned, a firm conclusion about the formation of the QGP at SPS necessitates a closer look at some pertinent but unsettled issues. A pre-requisite for the detection of the QGP by studying the photon spectra is to subtract contribution from the initial hard processes. Therefore, it is extremely important to know quantitatively the contribution from the hard processes. Again, the assumption of complete thermodynamic equilibrium for quarks and gluons may not be entirely realistic for SPS energies; lack of chemical equilibrium of quarks will further reduce the thermal yield from QGP. We have assumed $\tau_{\rm i} = 1$ fm/c at SPS energies, which may be considered as the lower limit of this quantity, because the transit time (the time taken by the nuclei to pass through each other in the CM system) is $\sim$1 fm/c at SPS energies and the thermal system is assumed to be formed after this time has elapsed. In the present work, when QGP initial state is considered, we have assumed a first-order phase transition with bag model EOS for the QGP for its simplicity, although it is not in complete agreement with the lattice QCD simulations [2]. However, it is difficult to distinguish different EOS with the current resolution of the photon data [36]. As mentioned before, there are uncertainties in the value of $T_{\rm c}$ [2], a value of $T_{\rm c}$ $\sim$200 MeV may be considered as an upper limit. Moreover, the photon emission rate from QGP given by eq. (2), evaluated in refs [12,13] by resumming the hard thermal loops is strictly valid for $g \ll 1$ whereas the value of g obtained from eq. (3) is $\sim$2 at T $\sim$200 MeV. At present it is not clear whether the rate in eq. (2) is valid for such a large value of g or not. New method is required to evaluate the photon emission rate from QCD plasma. HTL approximation is not valid at SPS energies and it may not be valid even at LHC energies. Evaluation of the spectral function from lattice QCD [40] will be very useful in this context.

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