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Single photons, dileptons and hadrons from relativistic heavy ion collisions and quark-hadron phase transition

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Abstract. The production of single photons in Pb+Pb collisions at the CERN SPS as measured by the WA98 experiment is analysed. A quark gluon plasma is assumed to be formed initially, which expands, cools, hadronizes, and undergoes freeze-out. A rich hadronic equation of state is used and the transverse expansion of the interacting system is taken into account. The recent estimates of photon production in quark-matter (at two loop level) along with the dominant reactions in the hadronic matter leading to photons are used. About half of the radiated photons are seen to have a thermal origin. The same treatment and the initial conditions provide a very good description to hadronic spectra measured by several groups and the intermediate mass dileptons measured by the NA50 experiment, lending a strong support to the conclusion that quark gluon plasma has been formed in these collisions. Predictions for RHIC and LHC energies are also given.

Keywords. Quantum chromodynamics; quark-gluon plasma; relativistic heavy ion collisions; photon; dilepton; hadron; transverse momentum; phase transition; charm.

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1. Introduction

Studies of relativistic heavy ion collisions are being performed to produce quark-gluon plasma, a deconfined strongly interacting matter. This search for quark-gluon plasma which filled the early universe microseconds after the big bang and which may be present in the core of neutron stars, is one of the most notable collective efforts of the present day nuclear physics community. Its discovery will provide an important confirmation of the predictions of the statistical quantum chromodynamics (QCD) based on lattice calculations. It has been recognised for a long time [1] that electromagnetic radiations from relativistic heavy ion collisions in these experiments would be a definitive signature of the formation of a hot and dense plasma of quarks and gluons, consequent to a quark-hadron phase transition [1]. Once other signs of the quark-hadron transition, e.g., an enhanced production of strangeness, a suppression of J/ψ production, radiation of dileptons, etc., started to emerge [2], it was imperative that the more direct, yet much more difficult to isolate, signature of the hot and dense quark-gluon plasma, the single photons were identified. The WA98 experiment [3] has now reported observation of single photons in central Pb+Pb collisions at the CERN SPS. At the same time, the NA50 experiment [4] has reported excess production of dileptons in the intermediate mass range. Several groups have measured hadronic spectra from the same collisions.

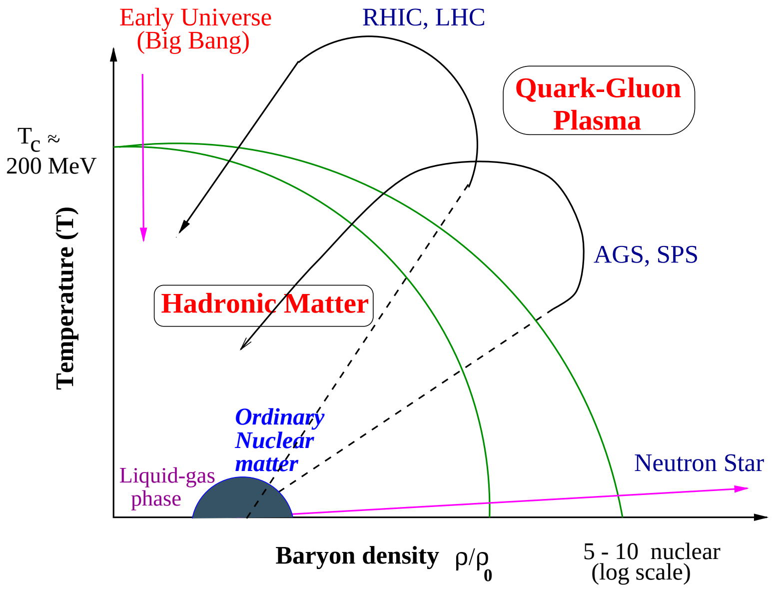

Figure 1. A schematic view of the phase diagram of hot hadronic and quark matter.

In order to put our findings in a proper perspective, let us recall that the publication of the upper limit of the production of single photons in S+Au collisions at CERN SPS by the WA80 experiment [5] was preceded and followed by several papers [6,7] exploring their connection to the quark-hadron phase transition. An early work [6], reported that the data were consistent with a scenario where a quark-gluon plasma was formed at an initial time $\tau_0 \sim 1$ fm/c, which expanded and cooled, got into a mixed phase of quarks, gluons, and hadrons, and ultimately underwent a freeze-out from a state of hadronic gas consisting of π, ρ, ω, and η mesons. On the other hand, when the initial state was assumed to consist of (the same) hadrons, the resulting large initial temperature led to a much larger production of single photons, in gross violation of the upper limit.

A reanalysis of the WA80 data on single photons was reported recently [8] which incorporated two important developments in the field during the last few years, which are worth recalling. Firstly, it was realized that the hadronic equation of state *must* be generalized to include all of the hadrons [9] (limited to $M < 2.5$ GeV, in practice). This was prompted and supported by the success of the thermal models in describing particle production in these collisions. This implied that the hadrons were in chemical equilibrium [10] at least at the time of (chemical) freeze-out. These hydrodynamical calculations have been shown to provide a very good explanation of the p_T spectra measured by the NA49 [11], NA44 [12], and WA98 [13] experiments [14].

Secondly, an evaluation of the rate of single photon production from the quark matter to the order of two-loops was reported recently by Aurenche *et al* [15,16]. This had two quite important results: (i) a substantial contribution of the bremsstrahlung ($q\,q\,(g) \rightarrow q\,q\,(g)\,\gamma$) process for all momenta in addition to the Compton ($q\,(\overline{q})\,g \rightarrow q\,(\overline{q})\,\gamma$) plus annihilation ($q\,\overline{q} \rightarrow g\,\gamma$) contributions included in the one-loop calculations available in the literature [17,18], and (ii) a large contribution by a new mechanism which corresponds to the annihilation of a quark (scattered from a quark or a gluon) by an anti-quark. These new rates were shown [19] to lead to a considerable enhancement of the production of single photons at SPS, RHIC, and LHC energies, if the initial state is approximated as an equilibrated plasma.

It was also reported [8] that when allowances were made for the above considerations, the WA80 upper limit was still consistent with a quark hadron phase transition, while a treatment without phase transition was untenable as it involved several hadrons/fm^3, at the initial time.

In the present work we show that a simultaneous interpretation of single photon, dilepton, and hadron spectra for the Pb+Pb collisions at the CERN SPS energy is possible if we assume that a quark-gluon plasma was formed in the collision.

Finally, we provide predictions for thermal photon production at RHIC and LHC energies.

2. Formulation

The rate for the production of hard photons evaluated to one loop order using the effective theory based on resummation of hard thermal loops is given by [17,18]:

$$E\frac{\mathrm{d}N}{\mathrm{d}^4x\,\mathrm{d}^3k} = \frac{1}{2\pi^2}\,\alpha\alpha_s\,\left(\sum_f e_f^2\right)\,T^2\,\mathrm{e}^{-E/T}\,\ln\left(\frac{cE}{\alpha_s T}\right), \tag{1}$$

where the constant $c \approx 0.23$. The summation runs over the flavours of the quarks and e_f is their electric charge in units of charge of the electron. The rate of production of photons due to the bremsstrahlung processes evaluated by Aurenche *et al* is given by

$$E\frac{\mathrm{d}N}{\mathrm{d}^4x\,\mathrm{d}^3k} = \frac{8}{\pi^5}\,\alpha\alpha_s\,\left(\sum_f e_f^2\right)\,\frac{T^4}{E^2} \times \mathrm{e}^{-E/T}\,(J_T - J_L)\,I(E,T), \tag{2}$$

and the expressions for J_T, J_L, and $I(E,T)$ can be found in ref. [15].

And finally the dominant contribution of the $q\overline{q}$ annihilation with scattering obtained by Aurenche *et al* is given by

$$E\frac{\mathrm{d}N}{\mathrm{d}^4x\,\mathrm{d}^3k} = \frac{8}{3\pi^5}\,\alpha\alpha_s\,\left(\sum_f e_f^2\right)\,ET\,\mathrm{e}^{-E/T}\,(J_T - J_L). \tag{3}$$

Note that all the three contributions turn out to be essentially of the order $\alpha\alpha_s$ [15]. *It has been pointed out recently* [16] *that the values of J_T and J_L given originally by Aurenche et al* [15] *are too large by a numerical factor of* 4. *We use the corrected values in the following.* A comparison of these rates is given in figure 2. It is rather interesting that the bremsstrahlung production of the soft photons, estimated within the soft photon approximation [20] are comparable to the results obtained by Aurenche *et al* in the region where the soft photon approximation is expected to be valid.

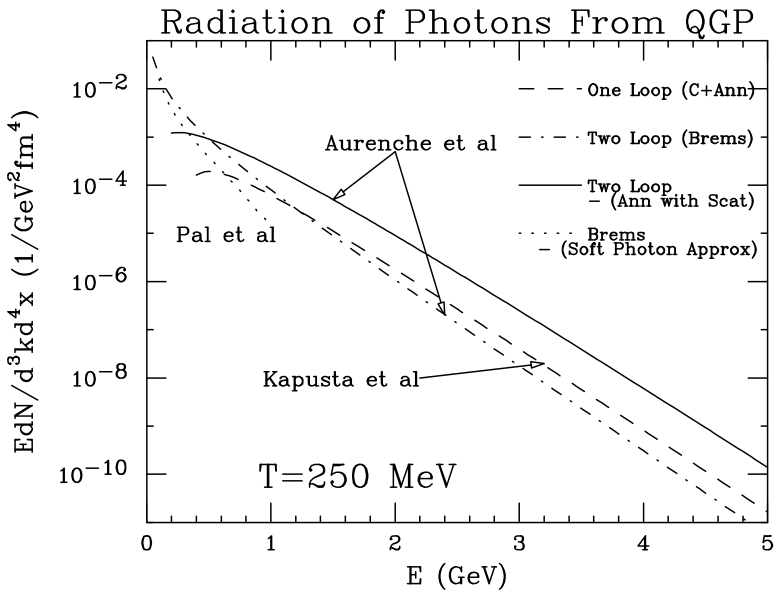

Figure 2. Rate of emission of photons from quark-gluon plasma due to various mechanisms.

We shall take the estimate of prompt photons from the work of Wong and Wang [21] which employs the NLO pQCD along with the inclusion of the effects of intrinsic partonic momenta ($\langle k_T^2 \rangle = 0.9$ GeV^2; see discussion later). We assume that a chemically and thermally equilibrated quark-gluon plasma is produced in such collisions at the time τ_0 (see later), and use the isentropy condition [22];

$$\frac{2\pi^4}{45\zeta(3)} \frac{1}{A_T} \frac{\mathrm{d}N}{\mathrm{d}y} = 4aT_0^3\tau_0 \tag{4}$$

to estimate the initial temperature, where A_T is the transverse area.

We have taken the average particle rapidity density as 750 for the 10% most central Pb+Pb collisions at the CERN SPS energy as measured in the experiment. We estimate the average number of participants for the corresponding range of impact parameters ($0 \leq b \leq 4.5$ fm) as about 380, compared to the maximum of 416 for head-on collision. We thus use a mass number of 190 to get the radius of the transverse area of the colliding system and neglect its deviations from azimuthal symmetry, for simplicity. As this deviation, measured in terms of the number of participants, is marginal ($<$ 9%) we expect the error involved to be small. We also recall that the azimuthal flow is minimal for central collisions.

We take $a = 42.25\pi^2/90$ for a plasma of massless quarks (u, d, and s) and gluons, where we have put the number of flavours as $\approx$ 2.5 to account for the mass of the strange quarks. We now use eq. (4) to estimate the (average) initial temperature, with the additional assumption of a rapid thermalization [23] so that the formation time is decided by the uncertainty relation and $\tau_0 = 1/3T_0$. This T_0 is then used to get the (average) initial energy density.

It is important to have a proper initial energy density profile as it affects the hydrodynamic developments by introducing additional gradients. We assume it to follow the so-called 'wounded-nucleon' distribution, which for central collision of identical nuclei leads to

$$\epsilon(\tau_0, r) \propto \int_{-\infty}^{\infty} \rho(\sqrt{r^2+z^2})\,\mathrm{d}z, \tag{5}$$

where ρ is the (Woods–Saxon) distribution of nucleons in a nucleus having a mass number of 190 and r is the transverse distance. This is prompted by the experimental observation that transverse energy deposited in these collisions scales with the number of participants. The normalization in the above is determined from a numerical integration so that

$$A_T\,\epsilon_0 = \int 2\pi\, r\, \epsilon(r)\ \mathrm{d}r. \tag{6}$$

We further assume that the phase transition takes place at $T = 180$ MeV and the freeze-out takes place at 120 MeV. This value of the critical temperature is motivated by the recent lattice QCD results which give values of about 170–190 MeV [25], and the thermal model analyses of hadronic ratios which suggest that the chemical freeze-out in such collisions takes place at about 170 MeV. (A recent analysis by Becattini *et al* yields a value of 181.3 ± 10.3 MeV [10] for the chemical freeze-out temperature.) The phase transition should necessarily take place at a higher temperature.

The rates for the hadronic matter have been obtained [17] from a two loop approximation of the photon self energy using a model where $\pi - \rho$ interactions have been included. The contribution of the A_1 resonance is also included according to the suggestions of Xiong *et al* [24]. The relevant hydrodynamic equations are solved using the procedure [26] discussed earlier and an integration over history of evolution is performed [9].

An integration along the freeze-out surface using the Cooper-Fry formula gives the transverse momenta of hadrons.

The dilepton spectra are similarly calculated, using rates from the QGP, for the process $q\bar{q} \to \ell\bar{\ell}$. The rates for emission of dileptons from the hadronic matter are estimated using a method brought to a high degree of sophistication by Gale and co-workers [28], where the radiation from a hadronic heat bath from a fairly exhaustive set of reactions is estimated using an effective Lagrangian. The reliability of the procedure has been established by a quantitative agreement between the rates thus obtained and those using the spectral function measured in experiments for $e^+e^- \to$ hadrons.

3. Results at CERN SPS

The results for single photon production in Pb+Pb collision at the CERN SPS measured by the WA98 experiment are shown in figure 3. The dashed curve gives the contribution of the quark-matter and the solid curve gives the sum of the contributions of the quark matter and the hadronic matter. The NLO pQCD estimates for prompt photons scaled from the results for *pp* collisions, including the effects of intrinsic momenta of partons are also given. We see that the thermal photons contribute to about 50% of the total yield of the single photons and that the sum of thermal and prompt photons provides a very good

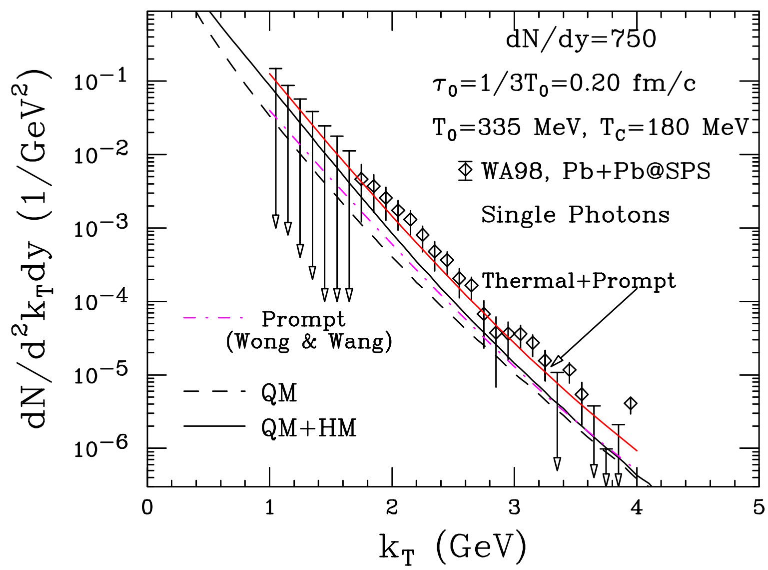

Figure 3. Single photon production in Pb+Pb collision at the CERN SPS. A chemically and thermally equilibrated quark-gluon plasma is assumed to be formed at $\tau_0 = 1/3T_0$ which expands, cools, enters into a mixed phase and undergoes freeze-out from a hadronic phase. QM stands for radiations from the quark matter in the QGP phase and the mixed phase. HM, likewise denotes the radiation from the hadronic matter in the mixed phase and the hadronic phase. Prompt photons are estimated using NLO pQCD with the inclusion of intrinsic k_T of partons (Wong and Wang [21]). The (tail) ends of the arrows denote the upper limit of the production at 90% confidence limit.

description to the data. The consequences of varying initial time (temperature) and the phase transition temperature has been discussed in ref. [27].

A very important outcome of these results (figure 3) is that a very large part of the thermal component of the single photons is seen to have its origin in the quark-matter itself! Recall that the new (and dominant) mechanism of the annihilation of quarks with scattering, suggested by Aurenche *et al*, is operative *only* if a hot and dense plasma is formed (see the detailed discussion in the Appendix in ref. [15]). Thus these results confirm the existence of this mechanism and the formation of quark gluon plasma in such collisions.

The fit to pion spectra from the WA98 experiment [13], kaon and proton spectra from the NA44 experiment [12], and the $\Lambda + \Sigma$ spectra from the NA49 experiment [11] are given in figure 4.

The production of intermediate mass dileptons measured by the NA50 experiment is shown in figure 5. We see that the sum of the thermal and Drell–Yan contributions provides a good description to the experimental data. We add that we have used the procedure described in ref. [29] to simulate the detector acceptance. We also add that the thermal production is quite similar to the production of dileptons from the decay of an ‘enhanced production of charm’ estimated by the NA50 group to ‘explain’ this excess. The corresponding fit to the p_T spectrum is shown in figure 6. It should be noted that contrary to the findings of ref. [29] most of the radiations in the present work comes from the quark

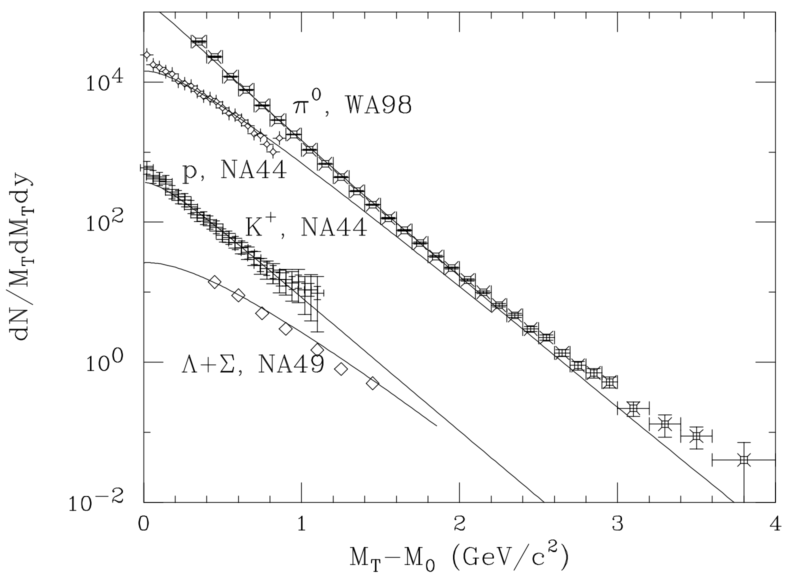

Figure 4. Transverse momentum spectra of neutral pions, protons, kaons and $\Sigma + \Lambda$ in central collisions of lead nuclei at CERN SPS.

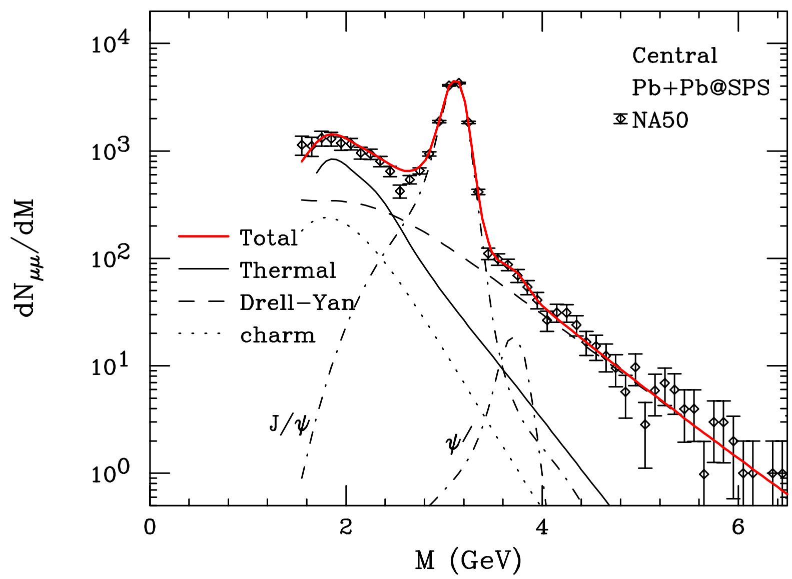

Figure 5. The invariant mass distribution of dilepton production in NA50 experiment [4].

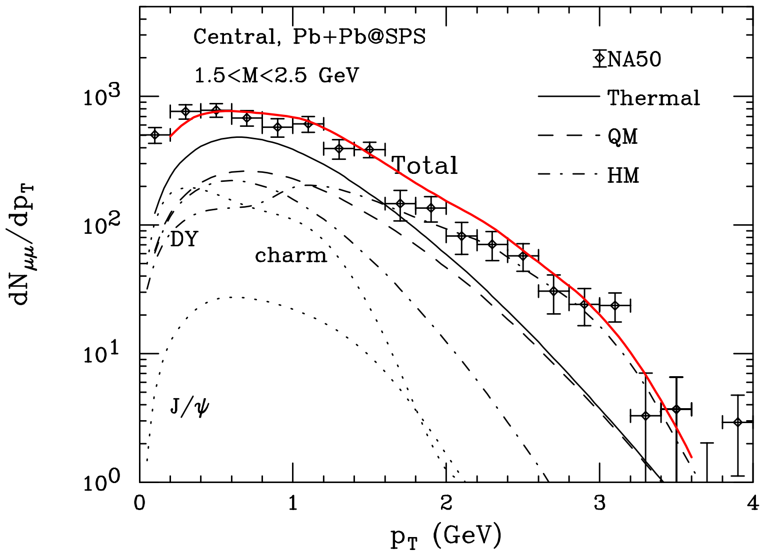

Figure 6. The p_T distribution of dileptons produced in central collision of lead nuclei.

matter itself. This difference is most likely due to the rich equation of state along with a sophisticated evolution mechanism for the plasma employed in the present work ([14]).

4. Predictions for RHIC and LHC energies

The commissioning of the relativistic heavy ion collider at Brookhaven has started a new era in search for quark-gluon plasma and understanding of relativistic heavy ion collisions. The results for single photons are expected in near future. In the following we give our predictions within the same treatment as above along with that for a more complex scenario where the QGP produced in the beginning is *not* in a state of chemical equilibrium, and it evolves towards such a state through chemical reactions of the type $gg \leftrightarrow q\bar{q}$ and gluon multiplication $gg \leftrightarrow ggg$.

Results for the case of a chemically equilibrated plasma are given in figure 7 for RHIC energies and those for the LHC energies are given in figure 8. We note two general trends. The decrease in the initial time and the subsequent increase in initial temperature (eq. (4)) increases the radiations from the quark matter at larger p_T, considerably. Secondly we note that the radiations from the quark matter outshine those from the hadronic matter for p_T up to about 0.5 GeV at RHIC energies and up to about 1 GeV at LHC energies. If we take the lowest formation times of about 0.1–0.2 fm/c then the radiations from the quark matter can really be substantial and may even out-shine those from the hadronic matter over a very large range of p_T.

It is however expected that the quark matter to be created at RHIC and LHC may be only in a state of thermal equilibrium and not in a state of chemical equilibrium, which proceeds much more slowly. Several authors have explored this in detail and we follow the treatment of ref. [30] where the initial conditions are taken from a self-screened parton

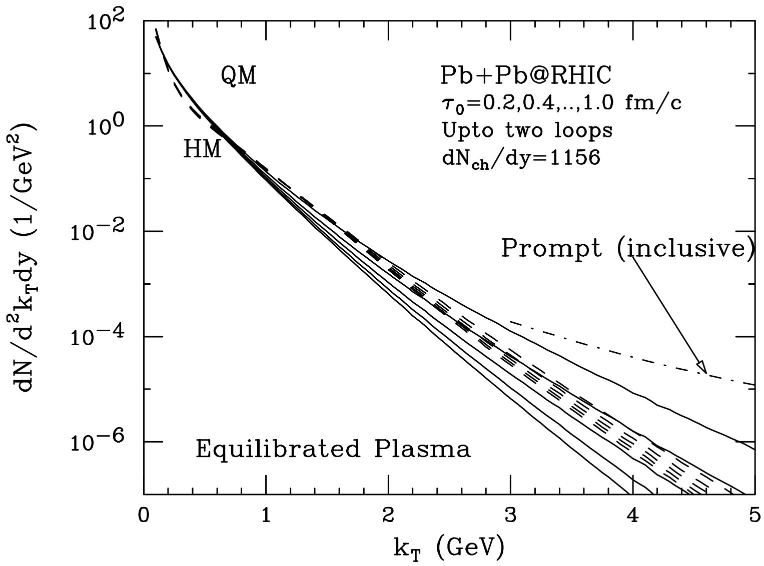

Figure 7. The production of single photons at RHIC energies. The initial time at which the plasma is formed in thermal and chemical equilibrium is changed to see when should the radiation from the quark matter outshine that from the hadronic matter.

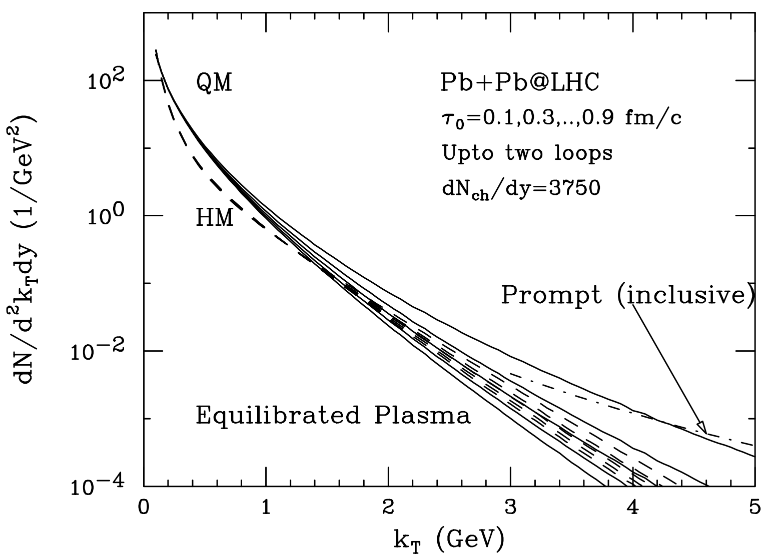

Figure 8. The production of single photons at LHC energies. The initial time at which the plasma is formed in thermal and chemical equilibrium is changed to see when should the radiation from the quark matter outshine that from the hadronic matter.

cascade model (SSPC) [31] and the evolution of the plasma proceeds hydrodynamically according to master equations controlled by the rates for the reactions mentioned earlier.

Thus the expansion of the system is described by the equation for conservation of energy and momentum of an ideal fluid:

$$\partial_\mu T^{\mu\nu} = 0 \ , \qquad T^{\mu\nu} = (\epsilon + P) u^\mu u^\nu + P g^{\mu\nu} \ , \tag{7}$$

where ϵ is the energy density and P is the pressure measured in the frame comoving with the fluid. The four-velocity vector u^μ of the fluid satisfies the constraint $u^2 = -1$. For a partially equilibrated plasma of massless particles, the equation of state can be written as [32]

$$\epsilon = 3P = \left[a_2 \lambda_g + b_2 \left(\lambda_q + \lambda_{\bar{q}}\right)\right] T^4 \ , \tag{8}$$

where $a_2 = 8\pi^2/15$, $b_2 = 7\pi^2 N_f/40$, $N_f \approx 2.5$ is the number of dynamical quark flavors, and λ_k is the fugacity for the parton species k. Here we have defined the fugacities through the relations

$$n_g = \lambda_g \tilde{n}_g, \qquad n_q = \lambda_q \tilde{n}_q, \tag{9}$$

where $\tilde{n}_k$ is the equilibrium density for the parton species k:

$$\tilde{n}_g = \frac{16}{\pi^2} \zeta(3) T^3 = a_1 T^3, \tag{10}$$

$$\tilde{n}_q = \frac{9}{2\pi^2} \zeta(3) N_f T^3 = b_1 T^3. \tag{11}$$

We further assume that $\lambda_q = \lambda_{\bar{q}}$. The equation of state (8) implies the speed of sound $c_s = 1/\sqrt{3}$.

We solve the hydrodynamic equations with the assumption that the system undergoes a boost invariant longitudinal expansion along the z-axis and a cylindrically symmetric transverse expansion [10]. It is then sufficient to solve the problem for $z = 0$, because of the assumption of boost invariance.

The master equations [32] for the dominant chemical reactions $gg \leftrightarrow ggg$ and $gg \leftrightarrow q\bar{q}$ are

$$\begin{aligned} \partial_\mu (n_g u^\mu) &= n_g (R_{2\to 3} - R_{3\to 2}) - (n_g R_{g\to q} - n_q R_{q\to g}) \ , \\ \partial_\mu (n_q u^\mu) &= \partial_\mu (n_{\bar{q}} u^\mu) = n_g R_{g\to q} - n_q R_{q\to g}, \end{aligned} \tag{12}$$

in an obvious notation.

If we assume the system to undergo a purely longitudinal boost invariant expansion, (7) reduces to the well-known relation [22]

$$\frac{\mathrm{d}\epsilon}{\mathrm{d}\tau} + \frac{\epsilon + P}{\tau} = 0, \tag{13}$$

where τ is the proper time. This equation implies

$$\epsilon \, \tau^{4/3} = \text{ const.} \tag{14}$$

and the chemical master equations reduce to [32]

$$\frac{1}{\lambda_g}\frac{\mathrm{d}\lambda_g}{\mathrm{d}\tau}+\frac{3}{T}\frac{\mathrm{d}T}{\mathrm{d}\tau}+\frac{1}{\tau}=R_3(1-\lambda_g)-2R_2\left(1-\frac{\lambda_q\lambda_{\bar{q}}}{\lambda_g^2}\right),$$
$$\frac{1}{\lambda_q}\frac{\mathrm{d}\lambda_q}{\mathrm{d}\tau}+\frac{3}{T}\frac{\mathrm{d}T}{\mathrm{d}\tau}+\frac{1}{\tau}=R_2\frac{a_1}{b_1}\left(\frac{\lambda_g}{\lambda_q}-\frac{\lambda_{\bar{q}}}{\lambda_g}\right), \tag{15}$$

which are then solved numerically for the fugacities. The rate constants R_2 and R_3 are related to the rates appearing in (12) and are given by [32]

$$R_2 \approx 0.24\, N_f\alpha_s^2\lambda_g T\, \ln(1.65/\alpha_s\lambda_g),$$
$$R_3 = 1.2\,\alpha_s^2 T(2\lambda_g-\lambda_g^2)^{1/2}, \tag{16}$$

where the colour Debye screening and the Landau–Pomeranchuk–Migdal effect suppressing the induced gluon radiation have been taken into account, explicitly. The expressions given above have been generalized for transverse expansion. The results are only mildly affected for radiations from the QGP phase as these are dominated by the contribution of the hottest stage.

We give the results for thermal photon production, up to one loop [30], and up to two loop level [33] for the scenario described above in figures 9 and 10.

5. Discussion and summary

We have presented results, which if confirmed have far reaching consequences. This calls for a careful examination of the inputs. Let us first discuss the inputs for the analysis of data at CERN SPS.

How are we to understand the use of $\tau_0 = 1/3T_0 \approx$ 0.20 fm/c here (see also [23]) against the canonical value of 1 fm/c, employed often? Firstly, within the model used, this value is *favoured* by the data [27]. Secondly, if a larger value of τ_0 is used, then an allowance should be made to supplement the predictions with an appropriate pre-equilibrium contribution. Thirdly, we note that the matter at $z = 0$ starts interacting by $t = -R/\gamma \approx -0.7$ fm/c in the present case, when the two nuclei start touching. Thus by the lapse of $\tau = 0.2$ fm/c, the matter there has been under interaction for a time ~ 1 fm/c, which may be enough for the formation of the plasma. Finally, a very important confirmation of our findings comes from the observations of Eskola *et al* [34], that a saturation of partons signaling a complete filling up of the transverse area by coloured quanta in collision of lead nuclei at SPS energies is indeed attained when the momentum transfer in partonic collisions is of the order of 1 GeV leading to a temperature $\sim$ 300 MeV at $\tau_0 \sim 0.2$ fm/c.

The assumption of a chemically equilibrated plasma is indeed a very drastic assumption, considering that the predictions at the lower transverse momenta are close to the upper limits given by the experiment? This needs to be investigated (see Neumann *et al* [7]) as also the effect of (likely) medium modification of hadron properties. The neglect of the baryo-chemical potential for the QGP is perhaps justified as the net-baryon to hadron ratio is quite small, especially in the region of the central rapidity. Finally, we may add that the photon rates used in these calculations are strictly valid only for $\alpha_s \ll 1$ and that the consequences of considering higher loops remains to be seen.

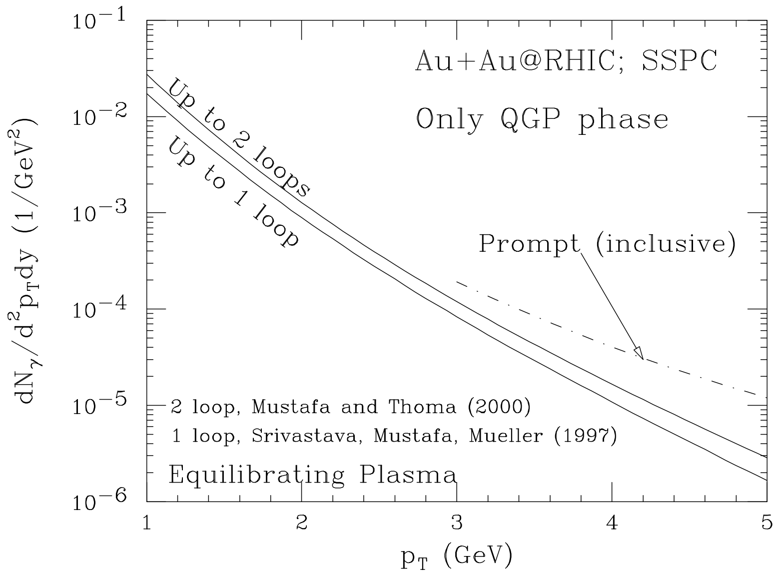

Figure 9. The production of single photons at RHIC energies, for a chemically equilibrating plasma. The initial conditions are taken from the SSPC model (table 1). The contribution from only the quark matter are shown.

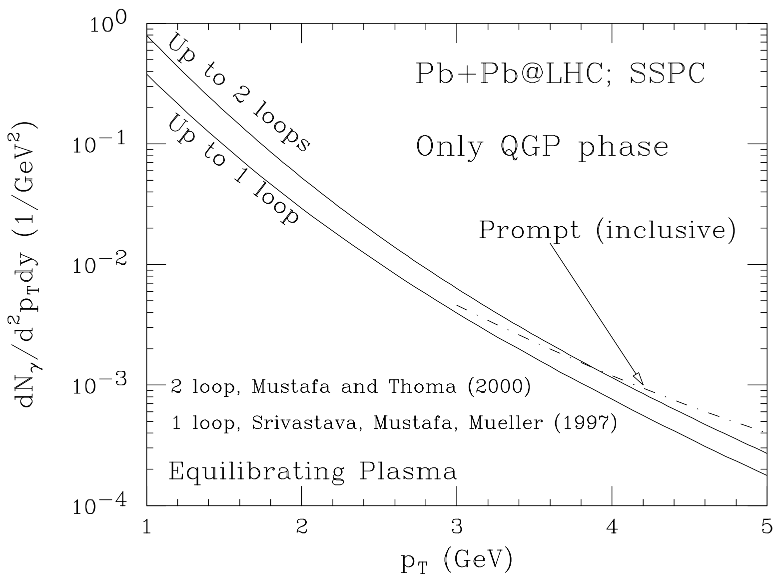

Figure 10. The production of single photons at LHC energies, for a chemically equilibrating plasma. The initial conditions are taken from the SSPC model (table 1). The contribution from only the quark matter are shown.

Table 1. Initial conditions for the hydrodynamical expansion phase in central collision of two gold nuclei at BNL RHIC and CERN LHC energies from SSPC model [31].

Energy	τ_i (fm/c)	T_i (GeV)	$\lambda_g^{(i)}$ -	$\lambda_q^{(i)}$ -	ϵ_i (GeV/fm^3)
RHIC	0.25	0.668	0.34	0.064	61.4
LHC	0.25	1.02	0.43	0.082	425

These discussions also apply to the analysis of dileptons presented in the paper. We only note that as we are interested in only intermediate mass dileptons having $M > 1$ GeV/c^2, the consequences of the modification of the hadron properties in the medium may not be large as the relevant length scale $\sim 1/M \approx 0.2$ fm is rather small. It is well-known that low-mass dileptons seem to suggest a considerable modification of the properties of the ρ meson in the relativistic heavy ion collisions at the CERN SPS energies.

We have not shown our results [14] for dilepton production for RHIC and LHC energies here. Suffice it to say that it is by now understood that a substantial background of correlated charm decay from the enhanced production of open charm at RHIC and LHC energies can completely submerge the radiation of virtual photons (dileptons) from the quark-matter (see e.g., Gavin *et al* [23]). A slight respite may be possible if the charm mesons could thermalize in the plasma due to elastic collisions with partons and radiation of gluons. This is directly related to the energy-loss suffered by heavy quarks [35,36]. Additional complications may arise due to flow experienced by D-mesons (or D-hadron scatterings), which could make the spectra of D-mesons hard, leading to a large contribution of the open charm decay at larger masses. This suggests that at RHIC and LHC energies, the measurement of open charm would provide a very important information on energy loss of heavy quarks, which will decide if the dileptons from the annihilation of quark-antiquark pair can be seen at all. Of course the open charm production, proceeding via the $gg \to c\bar{c}$ process will also provide valuable information on gluon shadowing.

No such consideration will apparently cloud the radiation of single photons. In fact there may be an additional production of photons during the early stage from the pre-equilibrium processes, which will then shed light on the approach to thermalization of the plasma.

In brief, we have seen that the first measurement of electromagnetic radiations from relativistic heavy ion collisions seem to suggest that quark gluon plasma could have been formed in the collisions involving lead nuclei at CERN SPS.

This holds out the hope of a rich display of radiation of photons from the quark matter at RHIC and LHC energies in collisions involving heavy nuclei, as much larger temperatures are likely to be attained there. The long life of the QGP phase at LHC energies will make it sensitive to such details like the transverse flow (within the QGP phase itself!), which will be of immense help in deciphering the properties of the quark matter. Additional confirmation of the evolution of the plasma could then be obtained from an interesting suggestion that the pattern of J/ψ suppression may be different for the two main processes in the plasma: the gluonic dissociation of J/ψ, and the non-formation of J/ψ due to colour Debye screening [37].

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