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Phenomenology of collinear photon emission from quark-gluon plasma in *AA* collisions

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The thermal photon production in AA collisions shows some inconsistency with the quark-gluon plasma (QGP) evolution supported by the results of the jet quenching analyses. The data from RHIC and LHC on jet quenching in AA collisions can be explained in the picture with radiative and collisional energy loss for the hydrodynamical QGP evolution with the QGP production time $\tau_0 \sim 0.5$ fm and the initial entropy determined from the measured hadron multiplicities [1–3]. However, theoretical predictions for the thermal photon spectrum [4] underestimate the photon spectrum measured at RHIC by PHENIX [5] in Au+Au collisions at $\sqrt{s} = 0.2\,\text{TeV}$ by a factor of ~ 3. Several mechanisms have been suggested that can increase the photon emission in AA collisions. There were suggestions that very strong magnetic field created in noncentral AA collisions can increase the photon emission due to the conformal anomaly [6] and the synchrotron radiation [7]. However, these mechanisms require too high magnitude of the magnetic field [8], that contradicts to calculations for realistic evolution of the plasma fireball [9]. In [10] it was suggested that a considerable additional contribution to the photon production may be due to the boundary bremsstrahlung resulting from interaction of escaping quarks with collective confining color field at the surface of the QGP. In [11–13] it was argued that the pre-equilibrium glasma phase also can give large contribution to the photon emission in AA collisions.

In the leading order (LO) pQCD the thermal photon emission from the QGP is due to the $2 \to 2$ processes: $q(\bar{q})g \to \gamma q(\bar{q})$ (Compton) and $q\bar{q} \to \gamma g$ (annihilation). In the pQCD picture a significant contribution to the photon emission comes also from the higher order collinear processes $q \to \gamma q$ and $q\bar{q} \to \gamma$ [14]. That turn out to be more important than the $2 \to 2$ processes at $k/T \lesssim 2$. The collinear photon radiation is due to multiple scattering of thermal quarks in the QGP (similar to the induced gluon radiation from fast partons [15, 16]). In [14] the collinear processes have been evaluated for constant QCD coupling using the thermal field theory methods within the hard thermal loop (HTL) resummation scheme. In the case of the induced gluon emission from fast partons in the QGP the results for constant and running α_s differ considerably. For running α_s the energy dependence of the radiative parton energy loss weakens [17]. The analyses of the data on the nuclear modification factor R_{AA} from RHIC and LHC [1–3, 18] show that running α_s allows to obtain a better agreement with the data. In [4] the photon emission has been addressed using the AMY [14] formulas obtained for a fixed QCD coupling constant. For accurate confronting the QGP signals from jet quenching and from photon production it would be of great interest to perform calculations of the collinear photon emission with running α_s consistent with that used in the successful jet quenching analyses. Also it would be interesting to study the sensitivity of the collinear photon emission to variation of the quark quasiparticle mass m_q. The predictions of the pQCD analysis [14], based on the HTL resummation scheme, have been obtained for the standard pQCD quark quasiparticle mass $m_q = gT/\sqrt{3}$. However, the analysis of the lattice data within a quasiparticle model [19] gives practically constant thermal quark mass $m_q \sim 300\,\text{MeV}$. In a more recent analysis [20] it was demonstrated that in a strongly coupled QGP the thermal quark mass may be much smaller than that in the pQCD HTL picture. This may increase the photon emission rate, with a very small effect on the jet quenching that is practically insensitive to the quark quasiparticle mass [15, 16]. Due to the theoretical uncertainties for the thermal quark mass, it would be interesting to study the collinear photon emission in a phenomenological picture without the HTL constraints on the quark quasiparticle mass.

We study the effect of running α_s and the role of variation of the quark quasiparticle mass on the collinear photon emission in AA collisions. We treat quark multiple scattering in the QGP in the scheme we used previously in successful jet quenching analyses [1–3, 18]. There we used the Debye mass obtained in the lat-

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tice calculations that, contrary to the HTL scheme, give nonzero magnetic screening. In our phenomenological scenario as in [1–3, 18] we use running α_s frozen at small virtualities at some value $\alpha_s^{\rm fr}$. We compare the results for this phenomenological scenario with the results for the HTL scheme with static α_s. We use the formalism of [21] based on the light-cone path integral approach [16]. The formulation given in [21] reproduces the results of the AMY [14] approach. In [14] the photon emission rate has been expressed via solution of an integral equation. In this work the photon spectrum is expressed via solution of a two-dimensional Schrödinger equation with a smooth boundary condition. In Fig. 1 we present the

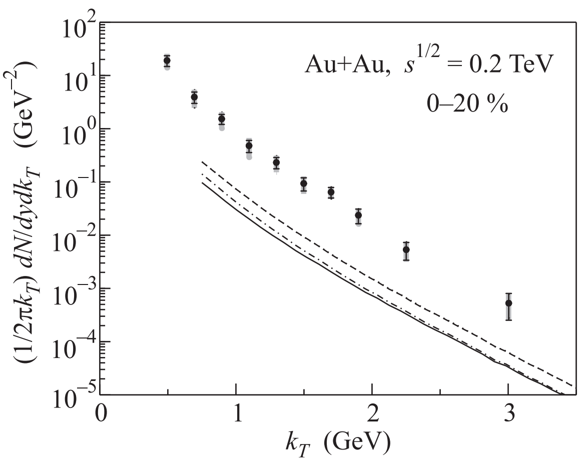

Fig. 1. The photon spectrum $(1/2\pi k_T)dN/dydk_T$ for Au+Au collisions at $\sqrt{s} = 0.2$ TeV in the $0 - 20\,\%$ centrality range. Solid: the sum of the $q \to \gamma q$ and $q\bar{q} \to \gamma$ processes for running coupling with $\alpha_s^{\rm fr} = 0.5$ for $m_q = 300$ MeV, dotted: the same as solid but for $m_q = 50$ MeV, dot-dashed: the sum of the $q \to \gamma q$ and $q\bar{q} \to \gamma$ processes for the HTL scheme for $\alpha_s = 0.3$, dashed: the sum of the collinear process with the LO $2 \to 2$ processes for the HTL scheme for $\alpha_s = 0.3$. Data points are from [5]

photon spectrum $(1/2\pi k_T)dN/dydk_T$ averaged over the azimuthal angle for Au+Au collisions at $\sqrt{s} = 0.2$ TeV in the $0-20\,\%$ centrality range. The results have been obtained for the Bjorken model of the QGP evolution without transverse expansion for the lattice equation of state from [22]. For the phenomenological scenario with running coupling we use $\alpha_s^{\rm fr} = 0.5$ supported by the jet quenching analyses [1–3]. From Fig. 1 one can see that the results for the phenomenological scenario with running coupling and $m_q = 300$ MeV are close to that for the HTL scenario with fixed coupling. Assuming that for the phenomenological scenario the relative effect of the $2 \to 2$ processes is similar to that for the HTL scenario from Fig. 1 one can conclude that for the phenomenological scenario with running α_s with a very small thermal quark mass ($m_q = 50$ MeV) the contribution of the higher order collinear processes summed with the LO $2 \to 2$ processes can explain $\sim 50\,\%$ of the experimental photon yield from PHENIX [5]. We conclude that, for the picture of the QGP evolution and for the model of multiple parton scattering in the QGP consistent with data on jet quenching, the photon emission from the QGP stage alone is not enough to fit the data on the photon production in Au+Au collisions even for the scenario with a very small thermal quark mass.

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