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Photons from thermalizing matter in heavy ion collisions

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Abstract

We investigate the production of direct photons in heavy ion collisions within the modified bottom–up thermalization scenario, which we show to be related to the thermalizing Glasma framework. The dynamics of the parton system up to thermalization/equilibration can be described by two momentum scales, by means of which we express the photon invariant yield excluding the prompt pQCD contribution. We derive an analytic formula, which provides an estimate of photon production from thermalizing matter for a wide range of collision systems and energies. We compare the yield with that measured in the PHENIX Au + Au run04 and the combined run07 + run10 data sets at $\sqrt{s_{NN}} = 200$ GeV. We also make theory-data comparisons for Pb + Pb at 2760 GeV and d + Au at 200 GeV collision energies. Finally, we make predictions for the direct photon invariant yield from collisions of U + U, Cu + Au, ^{3}He + Au at 200 GeV and Pb + Pb at 5020 GeV.

Keywords: Heavy ion collisions; Thermalization; Electromagnetic probes; Glasma; Quark gluon plasma

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1. Introduction

Studies of direct photons are of great importance for understanding some of the key characteristics of evolution of the matter produced in relativistic heavy ion collisions. In the context of heavy ion collisions direct photons are all the photons, which do not emerge from hadronic decays. Possibly radiated from all phases of the evolution, direct photons are excellent probes for extracting information on the medium at their space-time production points because of the weak interaction of photons with the medium.

One can obtain the direct photon yield by adding the thermal (or thermal-like) photon yield to the pQCD [1] prompt photon contribution. The hard photons at high p_T and the thermal photons at low p_T carry information on the initial hard scattering and pre-equilibrium phase as well as on the equilibrium phase of the parton system, Quark–Gluon Plasma (QGP) and hadronic gas (HG). In particular, the thermal photons are radiated from hot and dense matter [2] that can be in local (or out of local) equilibrium, and carry information about the space-time evolution of the medium.

The direct photon yield in p + p collisions is consistent with the NLO pQCD calculations [3]. These results serve as a crucial reference for photon yields in heavy ion collisions. Here, the yield at $p_T > 4$ GeV/c is found to be consistent with NLO pQCD calculations scaled by the number of binary collisions (or by the Glauber nuclear overlap function) at different centralities. However, in the low and intermediate p_T range it has been predicted that the photon yield is enhanced by thermal radiation from the QGP and HG [4]. This is in agreement with experimental observations: Although the direct photon measurements are quite challenging, especially in the low transverse momentum region, the PHENIX, STAR and ALICE collaborations have observed evidence of thermal radiation from Au + Au [5–8] and Pb + Pb collisions [9] at RHIC $\sqrt{s_{NN}} =$ 200 GeV and at LHC $\sqrt{s_{NN}} = 2760$ GeV collision energies, respectively.

There is abundant literature on direct and thermal photon studies, for example, based on the spectral function approach [10–12], Parton–Hadron–String Dynamics transport approach [13–16] as well as based on scenarios that use simulations in the framework of the elliptic-fireball expansion [17–19] and hydrodynamic simulations of the fireball evolution [20–23]. Other results can be found in [24–37]. For a recent theory overview we refer to [38].

In this work we focus on photon production in the pre-equilibrium and equilibrium stages of the parton system. Let us briefly discuss some recent theoretical results for parametric estimates of the photon production in the early time regime of the matter produced in relativistic heavy ion collisions. Refs. [39–41] give an explanation of direct photon enhancement in the intermediate p_T region based on a production mechanism of thermal photons from the thermalizing Glasma phase [42,43].[1] The Glasma [56–59] is theorized to exist based on gluon saturation (Color Glass Condensate) physics [60–67]. In [39,68], it is shown that direct photon production from the Glasma shows geometric scaling[2] at different centralities and collision energies. A parametric estimate of photon production in various stages of the bottom–up thermalization scenario [69,70] is presented in very recent studies [71]. In the bottom–up thermalization framework, a soft gluon thermal bath originates via QCD decays of A + A collision-induced primary hard gluons, the momenta of which are of the order of the saturation momentum scale.

[1] For recent studies of the thermalization process see Refs. [44–55].

[2] The geometric scaling expresses rates of particles in terms of dimensionless ratios of transverse momentum to the saturation momentum Q_s.