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Pseudo-critical enhancement of thermal photons in relativistic heavy-ion collisions?

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Abstract

We compute the spectra and elliptic flow of thermal photons emitted in ultrarelativistic heavy-ion collisions (URHICs) at RHIC and LHC. The thermal emission rates are taken from complete leading-order rates for the QGP and hadronic many-body calculations including baryons and antibaryons, as well as meson-exchange reactions (including Bremsstrahlung). We first update previous thermal fireball calculations by implementing a lattice-QCD based equation of state and extend them to compare to recent LHC data. We then scrutinize the space–time evolution of Au–Au collisions at RHIC by employing an ideal hydrodynamic model constrained by bulk- and multistrange-hadron spectra and elliptic flow, including a non-vanishing initial flow. We systematically compare the evolutions of temperature, radial flow, azimuthal anisotropy and four-volume, and exhibit the temperature profile of thermal photon radiation. Based on these insights, we put forward a scenario with a "pseudo-critical enhancement" of thermal emission rates, and investigate its impact on RHIC and LHC direct photon data.

Keywords: Heavy-ion collisions; QCD phase diagram; Direct photons

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1. Introduction

The thermal emission rate of photons from strongly interacting matter encodes several interesting properties of the radiating medium (see, e.g., Refs. [1–5] for reviews). Its spectral slope reflects the temperature of the system while its magnitude is related to the interaction strength of the charge carriers. In ultrarelativistic heavy-ion collisions (URHICs), the size of the interacting fireball is much smaller than the mean-free path of photons. Thus, the latter can probe the hot and dense interior of the medium. However, the observed photon spectra receive contributions from all reaction stages, i.e., primordial NN collisions, pre-equilibrium, quark–gluon plasma (QGP) and hadronic phases, plus final-state decays of short-lived resonances (these so-called "direct" photons exclude decays of long-lived hadrons, e.g., π and η). Calculations of direct-photon spectra require good control over both the microscopic emission rates and the space–time evolution of the medium. The latter not only determines the local emission temperature, but also the collective-flow field which generally imparts a net blue-shift on the radiated photons. In addition, the azimuthal asymmetry of the thermal photon spectra, v_2^γ, is of interest [6–13]: since the bulk v_2 requires several fm/c to build up, the observed value for photons helps to further constrain their emission history.

Direct-photon spectra in URHICs have been extracted in Pb–Pb ($\sqrt{s} = 0.017$ A TeV) collisions at the Super Proton Synchrotron (SPS) [14], in Au–Au ($\sqrt{s} = 0.2$ A TeV) at the Relativistic Heavy-Ion Collider (RHIC) [15], and in Pb–Pb ($\sqrt{s} = 2.76$ A TeV) at the Large Hadron Collider (LHC) [16]. At SPS, various theoretical models could approximately reproduce the measured spectra by adding thermal radiation from an equilibrated expanding fireball to a primordial component estimated from pp data [17–21]. The thermal yield prevailed over the primordial one up to transverse momenta of $q_T \approx 2$–4 GeV. However, a decomposition into contributions from QGP and hadronic radiation, which would allow for a better characterization of the origin of the signal, remains ambiguous. By subtracting the primordial component from their data, the PHENIX Collaboration extracted the "excess radiation" and determined its inverse-slope parameter ("effective temperature") in Au–Au collisions at RHIC as $T_{\text{eff}} = 221 \pm 19^{\text{stat}} \pm 19^{\text{syst}}$ MeV. Accounting for the aforementioned blue-shift effect, this result indicates that most of the radiation emanates from matter temperatures $T < 200$ MeV, challenging the notion of early QGP radiation [9]. A subsequent first measurement of the direct-photon v_2 supports this finding [22]: in the regime where thermal radiation is expected to be large, $q_T \lesssim 3$ GeV, $v_2^\gamma(q_T)$ turns out to be comparable to that of pions, which are only emitted at the end of the fireball evolution, i.e., at thermal freezeout, $T_{\text{fo}} \simeq 100$ MeV. The large v_2^γ, also found at LHC [23], thus puts rather stringent constraints on the origin of the excess photons.

In previous work [9] we have calculated thermal photon spectra at RHIC, differing from existing calculations in mainly two aspects. First, a more extensive set of hadronic thermal photon rates has been employed [19], which, in particular, includes the contributions from baryons and antibaryons (known to be important in the dilepton context [24,25]). These rates approximately match complete leading-order (LO) QGP rates around the pseudo-critical temperature, $T_{\text{pc}} \simeq 170$ MeV [26], thus rendering a near continuous emissivity across the transition region. Second, a schematic medium evolution was constructed utilizing a blast-wave type elliptic-fireball model, quantitatively fit to spectra and v_2 of bulk hadrons (π, K, p) at $T_{\text{fo}} \simeq 100$ MeV and multistrange hadrons (e.g., ϕ and Ω^-) at $T_{\text{ch}} = 170$ MeV. The implementation of this "sequential freezeout" is phenomenologically motivated [27], and, in particular, leads to a saturation of the bulk-medium v_2 close to the transition regime, after about 4–6 fm/c for central and semi-