Phase-space distributions in QGP and thermal photons†

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The discovery of collective dynamics of QCD media in the BNL Relativistic Heavy Ion Collider (RHIC) and the CERN Large Hadron Collider (LHC) implies early equilibration of low-momentum partons and materialization of a quark-gluon plasma (QGP). The azimuthal momentum anisotropy v_2 of hadrons is well-explained in the framework of hydrodynamics, but that of direct photons, whose anisotropy is inherited from the medium during thermal emission, is underestimated roughly by a factor of 2. This apparent discrepancy is recognized as a “photon puzzle”.

Thermal photon emission in the QGP phase is calculated using phase-space distribution functions. They are conventionally assumed to be ideal Fermi-Dirac and Bose-Einstein distributions, but as the lattice QCD calculations indicate, the system is a strongly interacting one and thus, non-ideal corrections have to be taken into account. The reduction of the effective degrees of freedom at high temperatures could suppress early-time photons with underdeveloped anisotropy and could enhance v_2.

I discuss the effects of the interaction corrections in the parton phase-space distributions on heavy-ion photons based on a quasi-particle parametrization, as the QGP photon emission rate is often given as a functional of distribution functions. The effective one-particle distribution can be expressed as

$$f^i_{\mathrm{eff}} = (e^{\omega_i/T} \pm 1)^{-1}, \tag{1}$$

and the partition function, in the logarithmic form as,

$$\ln Z_i = \pm V \int \frac{g_i d^3p}{(2\pi)^3} \ln\left(1 \pm e^{-\omega_i/T}\right) - \frac{V}{T}\Phi_i(T), \tag{2}$$

where $\omega_i = \sqrt{p^2+m_i^2} + W^i_{\mathrm{eff}}$ is the effective energy and Φ_i is the background contribution required for and determined by the thermodynamic consistency condition[1]. Then the standard thermodynamic relations yield the energy density and pressure as $e = (T^2/V)\sum_i(\partial \ln Z_i/\partial T)$ and $P = (1/V)\sum_i T \ln Z_i$, respectively.

Here, I determine the effective interaction contribution W^i_{eff} for the quasi-particle model to reproduce the thermodynamic quantities calculated by lattice QCD[2] assuming it is temperature dependent. For simplicity and for the lack of constraints, W_{eff} is assumed to be common for all partons.

The QGP photon emission rate is expressed as[3],

$$E\frac{dR}{d^3p} = \frac{5\alpha\alpha_s}{9\pi^2}T^2 e^{-E/T}\lambda^2\left\{\left[\log\left(\frac{4ET}{k_c^2}\right) + \frac{1}{2} - \gamma\right]\right.$$

$$\left. + \left[\log\left(\frac{4ET}{k_c^2}\right) - 1 - \gamma\right]\right\}, \tag{3}$$

where $\lambda = e^{-W_{\mathrm{eff}}/T}$ is the effective fugacity, γ is Euler's constant, and k_c is the infra-red cut-off.

I estimate thermal photon elliptic flow numerically by using the same equation of state in the quasi-particle and hydrodynamic models. A Monte Carlo Glauber model is employed to simulate the initial conditions. The elliptic flow is defined as

$$v_2^\gamma(p_T, y) = \frac{\int_0^{2\pi} d\phi_p \cos(2\phi_p - \Psi)\frac{dN^\gamma}{d\phi_p p_T dp_T dy}}{\int_0^{2\pi} d\phi_p \frac{dN^\gamma}{d\phi_p p_T dp_T dy}}. \tag{4}$$

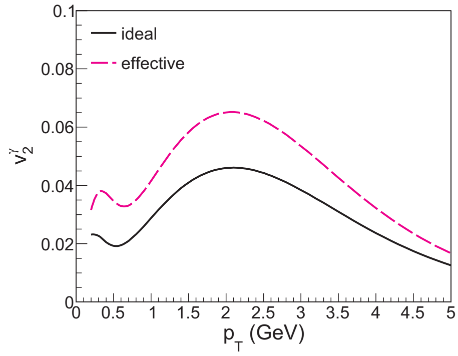

Fig. 1. (Color online) Thermal photon v_2 with ideal (solid line) and effective distributions (dashed line).

Figure 1 shows the thermal photon v_2 with ideal and effective distributions for Au-Au collisions at $\sqrt{s_{NN}} =$ 200 GeV with the impact parameter $b = 6$ fm. One can see that v_2 is enhanced in the presence of the effective interactions. This is owing to the suppression of the photons emitted from the medium with underdeveloped momentum anisotropy. This mechanism also leads to reduction in the photon yields and enhancement of higher order flow harmonics.

To conclude, effective parton distributions are constructed so that the thermal emission is consistent with the lattice QCD equation of state. The decreased degrees of freedom in the QGP phase lead to enhancement of thermal photon v_2, which contributes positively to the resolution of the photon puzzle. Future prospects include application of the effective distribution to the derivation of hydrodynamic equations.

References

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