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Phenomenology of photon and dilepton production in relativistic nuclear collisions

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Abstract

We discuss the latest theoretical results on direct photon and dilepton production from relativistic heavy-ion collisions. While the dilepton spectra at low invariant mass show in-medium effects like collisional broadening of the vector meson spectral functions, the dilepton yield at high invariant masses (above 1.1 GeV) is dominated by QGP contributions for central heavy-ion collisions at relativistic energies. The present status of the photon v_2 "puzzle" – a large elliptic flow v_2 of the direct photons experimentally observed at RHIC and LHC energies – is also addressed. The role of hadronic and partonic sources for the photon spectra and v_2 is considered as well as the possibility to subtract the QGP signal from the experimental observables.

Keywords: Photons; Dileptons; Heavy-ion collisions

1. Introduction

Electromagnetic probes – real photons and di-lepton pairs – are of the most promising probes of the Quark–Gluon–Plasma (QGP) formed in ultra-relativistic collisions of heavy ions [1]. They also provide information about the modification of hadron properties in the dense and hot hadronic medium which can shed some light on chiral symmetry restoration (cf. [2] and references therein). The major advantages are related to the fact that dileptons and real photons are emitted from different stages of the reaction and are very little effected by final-state interactions; they provide almost undistorted information about their production channels. However, there are disadvantages, too, due to the low emission rate; the production from the hadronic corona as

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well as the existence of many production sources, which cannot be individually disentangled in experimental data. For an experimental review on the dilepton and photon measurements at SPS, RHIC and LHC energies see Ref. [3].

Since dileptons and photons are emitted over the entire history of the heavy-ion collision, from the initial hard nucleon–nucleon scatterings through the hot and dense (partonic) phase and to the hadron decays after freeze-out, it is very important to model properly the full time evolution of heavy-ion collisions. For that the dynamical models – microscopic transport or hydrodynamical approaches – have to be applied for disentangling the various sources that contribute to the final observables measured in experiments.

2. Modeling of photon/dilepton emission rates

I. The equilibrium emission rate of electromagnetic probes from thermal field theory can be expressed as [4,5]:

(1) for photons with 4-momentum $q = (q_0, \vec{q})$:

$$q_0 \frac{d^3R}{d^3q} = -\frac{g_{\mu\nu}}{(2\pi)^3} \operatorname{Im} \Pi^{\mu\nu}\big(q_0 = |\vec{q}|\big) f(q_0, T); \tag{1}$$

(2) for dilepton pairs with 4-momentum $q = (q_0, \vec{q})$, where $q = p_+ + p_-$ and $p_+ = (E_+, \vec{p}_+)$, $p_- = (E_-, \vec{p}_-)$:

$$E_+E_- \frac{d^3R}{d^3p_+ d^3p_-} = \frac{2e^2}{(2\pi)^6} \frac{1}{q^4} L_{\mu\nu} \operatorname{Im} \Pi^{\mu\nu}\big(q_0, |\vec{q}|\big) f(q_0, T). \tag{2}$$

Here the Bose distribution function is $f(q_0, T) = 1/(e^{q_0/T} - 1)$, $L_{\mu\nu}$ is the electromagnetic leptonic tensor, $\Pi^{\mu\nu}$ is the retarded photon self-energy at finite temperature T related to the electromagnetic current correlator $\Pi^{\mu\nu} \sim i \int d^4x e^{ipx} \langle [J_\mu(x), J_\nu(0)] \rangle|_T$. Using the Vector-Dominance-Model (VDM) $\operatorname{Im} \Pi^{\mu\nu}$ can be related to the in-medium ρ-meson spectral function from many-body approaches [6] which, thus, can be probed by dilepton measurements directly. The photon rates for $q_0 \to 0$ are related to the electric conductivity σ_0 which allows to probe the electric properties of the QGP [7]. We note that Eqs. (1), (2) are applicable for systems in thermal equilibrium, whereas the dynamics of heavy-ion collisions is generally of non-equilibrium nature.

II. The non-equilibrium emission rate from relativistic kinetic theory [5,8], e.g. for the process $1 + 2 \to \gamma + 3$, is

$$\begin{aligned} q_0 \frac{d^3R}{d^3q} = \int & \frac{d^3p_1}{2(2\pi)^3 E_1} \frac{d^3p_2}{2(2\pi)^3 E_2} \frac{d^3p_3}{2(2\pi)^3 E_3} (2\pi)^4 \delta^4(p_1 + p_2 - p_3 - q) |M_{if}|^2 \\ & \times \frac{f(E_1) f(E_2)(1 \pm f(E_3))}{2(2\pi)^3}, \end{aligned} \tag{3}$$

where $f(E_i)$ is the distribution function of i-particle ($i = 1, 2, 3$), which can be hadrons (mesons and baryons) or partons. M_{if} is the matrix element of the reaction which has to be evaluated on a microscopical level. For hadronic interactions One-Boson-Exchange models or chiral models are used to evaluate M_{if} on the level of Born-type diagrams. However, for a consistent consideration of such elementary process in the dense and hot hadronic environment, it is important to account