Off-equilibrium photon production in heavy-ion collisions*

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As penetrating probes direct photons and dileptons provide insight into the hot and dense interior of matter created in heavy-ion collisions during its entire evolution. They are directly related with the electromagnetic-current correlation function in the strongly interacting medium. In this connection the most interesting signals are the p_t spectra of photons and dileptons and the invariant-mass spectra of dileptons from a thermalized medium to study the impact of the chiral phase transition in the QCD phase diagram to this current-correlation function.

However, to analyze experimental data on electromagnetic probes in heavy-ion collisions also a detailed understanding of all other "non-thermal" sources is important. In this study we investigate the contribution to the photon emission from the very early off-equilibrium state of the fireball created in heavy-ion collisions which are claimed to outshine the thermal emission from a QGP at high p_t in since here already contributions at order $\mathcal{O}(\alpha_{\text{em}})$ of the electromagnetic coupling constant, which are forbidden in thermal equilibrium due to energy-momentum conservation, occur[1, 2, 3]. However, in this approach the photon rates are plagued by spurious vacuum-to-vacuum transition contributions which can not be renormalized in a proper way [4]. As shown in [5] this problem is related to "switching on and off" the electromagnetic interaction at finite times.

Motivated by these findings we investigate a toy model with quarks and antiquarks coupled to a classical time-dependent scalar field to mimick a time-dependent quark mass to investigate the pertinent emission of photons due to a possible chiral quark-mass shift in strongly interacting matter [6]. The advantage of this model is that it is compatible with current conservation and gauge invariance.

After analytically solving the Dirac equation for the quark-field operator coupled to a classical time-dependent scalar, we calculated the one-loop photon polarization tensor in 1^{st} order perturbation theory, employing the appropriate adiabatic switching of the electromagnetic interaction a la Gell-Mann and Low. We could explicitly show that this framework eliminates the spurious vacuum-to-vacuum transition contributions and allows to write the corresponding photon-emission rate as an absolute square, ensuring the positive definiteness of the photon-number density. For the realistic case of a smooth time dependence of the external field, mimicking a dropping quark-mass scenario by effectively switching the quark mass from its constituent value of $m_{\text{c}} \simeq 0.35$ GeV to its bare value m_{b} for a duration of the off-equilibrium phase of $\tau = 1 \text{ fm}/c$, the resulting time-integrated photon-momentum spectrum decays exponentially for large momenta and thus is UV integrable, leading to a finite photon yield from the underlying off-equilibrium process. Is has also been demonstrated that, e.g., using the adiabatic switch only for $t \to -\infty$ but not for $t \to \infty$ leads to an artificial enhancement of the photon-production rate by many orders of magnitudes due to spurious vacuum-to-vacuum transition contributions that cannot be properly interpreted as observable photon numbers.

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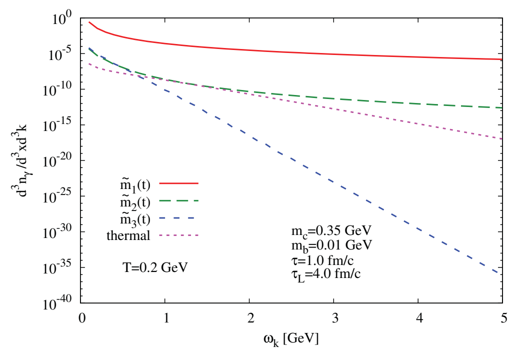

Figure 1: Comparison of the integrated off-equilibrium photon number for different mass-switching scenarios (instantaneous switch (solid line) and switching by a only 1st-order differentiable function (long-dashed line), leading implying the excitation of spurious modes and a UV divergent photon number, and a smooth switching function (short-dashed line) leading to a exponentially decreasing momentum spectrum and thus UV-finite photon-number densities with a photon spectrum from a thermalized QGP (lifetime $4 \text{ fm}/c$) at a temperature of 200 MeV.

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