Off-equilibrium photon production in heavy-ion collisions*

F. Michler[1], *H. van Hees*[1,2], *D. D. Dietrich*[1], *S. Leupold*[3], *and C. Greiner*[1]

[1]Goethe University Frankfurt, Max-von-Laue-Strasse 1, D-60438 Frankfurt, Germany; [2]FIAS, Ruth-Moufang-Strasse 1, D-60438 Frankfurt, Germany; [3]Institutionen för fysik och astronomi, Uppsala Universitet, Box 516, 75120 Uppsala, Sweden

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 $\mathcal{O}(\alpha_{\mathrm{em}})$ 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$^{\mathrm{st}}$ 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 $m_{\mathrm{c}} \simeq 0.35$ GeV to its bare value m_{b} for a duration of the off-equilibrium phase of $\tau = 1$ 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.

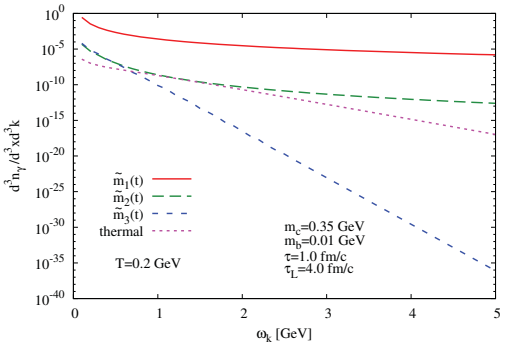

Figure 1: Comparison of the integrated off-equilibrium photon number for different mass-switching scenarios (instantaneous switch (solid line) and switching by a only 1st-order differentiable function (long-dashed line), leading implying the excitation of spurious modes and a UV divergent photon number, 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 fm/c) at a temperature of 200 MeV.

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* Work supported by HIC4FAIR/HGS-HIRe/HQM.

 doi:10.15120/GR-2014-1-THEORY-22