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On loop corrections to the dilepton rate ☆

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Abstract

Next-to-leading order analyses of the dilepton production rate from a hot QCD plasma are reviewed. In general, the photon invariant mass is taken to be in the range $\mathcal{K}^2 \sim (\pi T)^2$, permitting thereby for an interpolation between an OPE computation in a hard regime $\mathcal{K}^2 \gg (\pi T)^2$ and an LPM resummed computation in a soft regime $0 < \mathcal{K}^2 \ll (\pi T)^2$. If the computations are extended into the spacelike domain $\mathcal{K}^2 < 0$ in the future, they can also be systematically compared with lattice results at non-zero momentum.

Keywords: Thermal field theory; Quark–gluon plasma; Perturbative QCD; Lattice QCD

1. Introduction and formulation of the problem

Consider $\mu^-\mu^+$ or e^-e^+ pairs produced from a quark–gluon plasma of temperature T, with the pair having a non-zero total momentum $k \equiv |\mathbf{k}| \sim$ a few GeV with respect to the plasma rest frame, and an invariant mass

$$M \equiv \sqrt{\mathcal{K}^2} > 0, \quad \mathcal{K}^2 \equiv k_0^2 - k^2. \tag{1}$$

It is expected that non-thermal backgrounds for the production of such dileptons are in general smaller than for on-shell photons, and that dileptons may therefore offer for a good hard probe of QCD interactions at finite temperature.

The basic formulae concerning the problem can be summarized as follows. To leading order in the electromagnetic fine-structure constant α_e, the production rate reads [1–3]

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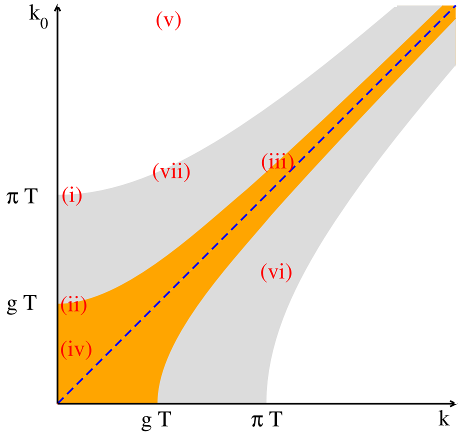


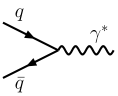
Fig. 1. Different regimes in which dilepton production rate computations have been carried out (cf. the discussion in Section 2).

$$\frac{\mathrm{d}N_{\mu^-\mu^+}}{\mathrm{d}^4\mathcal{X}\mathrm{d}^4\mathcal{K}} \stackrel{\mathcal{K}^2\ll m_Z^2}{=} -\frac{n_\mathrm{B}(k_0)}{3\pi^3\mathcal{K}^2}\theta\big(\mathcal{K}^2-4m_\mu^2\big) \times\left(1+\frac{2m_\mu^2}{\mathcal{K}^2}\right)\left(1-\frac{4m_\mu^2}{\mathcal{K}^2}\right)^{\frac{1}{2}}\alpha_e^2\sum_{i=1}^{3}Q_i^2\,\mathrm{Im}\,\Pi_\mathrm{R}. \tag{2}$$

Here n_B is the Bose distribution, Q_i the electric charge of a quark of flavour i in units of the electron charge, and $\mathrm{Im}\,\Pi_\mathrm{R}$ stands for the imaginary part of a retarded correlator (i.e. a spectral function), evaluated in an ensemble at a temperature T:

$$\mathrm{Im}\,\Pi_\mathrm{R} \equiv \int_\mathcal{X} e^{i\mathcal{K}\cdot\mathcal{X}}\left\langle\frac{1}{2}\big[\hat{\mathcal{J}}^\mu(\mathcal{X}),\hat{\mathcal{J}}_\mu(0)\big]\right\rangle_T, \qquad \hat{\mathcal{J}}^\mu \equiv \bar{\psi}\gamma^\mu\psi. \tag{3}$$

At leading order (LO) in the strong coupling α_s, the result originates from a Drell–Yan process and reads



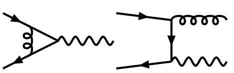
$$-\,\mathrm{Im}\,\Pi_\mathrm{R} = \frac{N_\mathrm{c}T\mathcal{K}^2}{2\pi k}\ln\left\{\frac{\cosh(\frac{k_+}{2T})}{\cosh(\frac{k_-}{2T})}\right\}, \qquad k_\pm \equiv \frac{k_0\pm k}{2} > 0. \tag{4}$$

The purpose of this note is to discuss corrections of $O(\alpha_\mathrm{s})$ to Eq. (4), for generic $k_\pm \sim \pi T$.

2. Different regimes and previous work

Let us briefly recall some of the works that have been carried out on next-to-leading order (NLO) and other types of corrections to Eq. (4). The works apply to different kinematic ranges as illustrated in Fig. 1.

(i) The NLO-result at vanishing momentum ($k = 0$) amounts to the evaluation of virtual and real corrections, i.e. graphs like



$$. \tag{5}$$