Production of hard partons from soft gluonic fields^{B+G}

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We study parton-pair production from a space-time dependent chromofield via vacuum polarization by using the background field method of QCD. The processes we consider are both leading and higher order in gA but first order in the action. We derive general expressions for the corresponding probabilities. Parton production from a space-time dependent chromofield will play a crucial role in the production and equilibration of the quark-gluon plasma in ultra relativistic heavy-ion collisions at RHIC and LHC. In ultra relativistic heavy-ion collisions, when two highly Lorentz contracted nuclei pass through each other a chromofield is formed between them due to the exchange of soft gluons [1]. The chromofield so formed polarizes the QCD vacuum and produces $q\bar{q}$-pairs and gluons via a Schwinger-like mechanism [2]. As seen in numerical studies [3], the chromofield acquires a strong space-time dependence due to a combination of such effects as expansion, background acceleration, color rotation, collision and parton production. In situations like this, the parton production from a constant chromofield is not justified and one has to find the corresponding expression for a general space-time dependent chromofield.

The e^+e^- pair production from a weak space-time dependent classical field is studied by Schwinger [2]. Because of the same structure of the interaction lagrangian density the production of a $q\bar{q}$ pair is similar to the e^+e^- case except for color factors [5]. (*N.B.*: Only the real parts of the following expressions are to be taken.) Details are given in [6]:

$$\frac{dW_{q\bar{q}}}{d^4xd^3k} = \frac{g^2 m}{(2\pi)^5 k^0}\, A^a_\mu(x)\, e^{ik\cdot x}\int d^4x_2\, A^a_\nu(x_2)\, e^{-ik\cdot x_2}$$
$$(i[k^\mu(x-x_2)^\nu + (x-x_2)^\mu k^\nu + k\cdot(x-x_2)g^{\mu\nu}]$$
$$(\frac{K_0(m\sqrt{-(x-x_2)^2})m\sqrt{-(x-x_2)^2} + 2K_1(m\sqrt{-(x-x_2)^2})}{[\sqrt{-(x-x_2)^2}]^3})$$
$$-m^2 g^{\mu\nu}\frac{K_1(m\sqrt{-(x-x_2)^2})}{\sqrt{-(x-x_2)^2}}).$$

The computation of the probability for the production of gluons is not straight forward and there is no counter part to this in QED. The processes which in leading order of the action contribute to gluon pair production are evaluated following the background field method of QCD [7] which, in a gauge invariant manner incorporates a classical background field and a quantum gluonic field simultanously. The probability is obtained by spin-summing the phase-space integral over the absolute square of the amplitudes. The Feynman rules for the production of two gluons by coupling to the A-field once or twice can be read from the Lagrangian density and are given in [8, 6]. To obtain the correct physical gluon polarizations in the final state we put the sums over the polarizations of the outgoing gluons equal to the negative of the metric tensor and afterwards deduct the corresponding ghost contributions. The vertices involving two ghosts and one classical field and two ghosts and two classical fields respectively can again be read from the lagrangian density and are also found in [8, 6]. We obtain the probability per unit time and unit volume of the phase space for the production of a real gg pair from a space-time dependent classical chromofield A [6]:

$$\frac{dW_{gg}}{d^4xd^3k} = \frac{1}{(2\pi)^5 k^0}\int d^4x' e^{ik\cdot(x-x')}\frac{1}{(x-x')^2}$$
$$\{\frac{3}{4}g^2 A^{a\mu}(x)A^{a\mu'}(x')[3k_\mu k_{\mu'} - 8g_{\mu\mu'}k^\nu i\frac{(x-x')_\nu}{(x-x')^2} + 6\frac{g_{\mu\mu'}}{(x-x')^2}$$
$$+5(k_\mu i\frac{(x-x')_{\mu'}}{(x-x')^2} + k_{\mu'} i\frac{(x-x')_\mu}{(x-x')^2}) - 12\frac{(x-x')_\mu(x-x')_{\mu'}}{(x-x')^4}]$$
$$-3ig^3 A^{a\mu}(x')A^{c\lambda}(x')A^{a'\mu'}(x)f^{a'ac}K_\lambda g_{\mu\mu'}$$
$$-\frac{1}{16}g^4 A^{a\mu}(x)A^{c\lambda}(x)A^{a'\mu'}(x')A^{c'\lambda'}(x')[24g_{\mu\mu'}g_{\lambda\lambda'}f^{acx}f^{a'c'x}$$
$$+g_{\mu\lambda}g_{\mu'\lambda'}(f^{abx}f^{xcd}+f^{adx}f^{xcb})(f^{a'bx'}f^{x'c'd}+f^{a'dx'}f^{x'c'b})]\}.$$

As a simple example we choose the field to be

$$A^{a3}(t) = A_{in}e^{-|t|/t_0},\ t_0 > 0,\ a = 1, ..., 8.$$

The exponential decay of the source terms originates from the decay of the model-field. Their oscillatory behavior is due to the exponential factor,already present in the general formula.

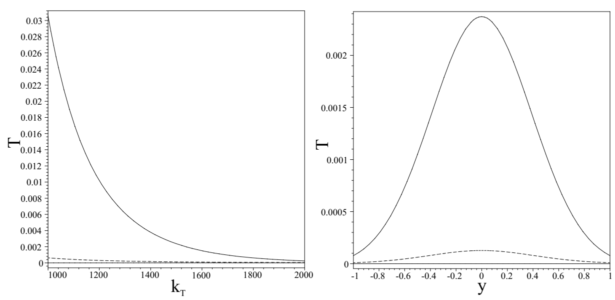

Fig. 1 Dimensionless time-integrated source terms for quarks (dash) and gluons (solid) versus transverse momentum kT in MeV and rapidity y for the parameters $\alpha_S = 0.15$, $A_{in} = 1.5GeV$, $t_0 = 0.5fm$, $k_T = 1.5GeV$, $y = 0$.

The decay behavior with the transverse momentum k_T in MeV is mostly due to the choice of the field. Only in the second contribution to the gluon source term there is already a factor $1/(k^0)^2$ present in the general formula. As the momentum structure of the general equations is mostly based on the k^0-component, the origin for the typical rapidity y behavior is mainly linked to the behavior for changing transverse momentum. For this model field, a stronger coupling, a stronger chromofield and/or a slowlier varying field emphasize dominance of the gluon-pair production over the production of $q\bar{q}$ pairs even more.

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