COLOR FLUX TUBES AND QUARK-GLUON PLASMA PRODUCTION*

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We study how the plasma production in ultrarelativistic heavy-ion collisions depends on the radius of the initial color flux tubes.

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We continue the investigations of the Quark-Gluon Plasma production in ultrarelativistic heavy ion collisions. We assume that during the collisions tubes of a very strong color field are created between the two colliding nuclei [1–6]. Such tubes can be characterized by the string tension σ and the radius r. In this letter we study, using recently proposed model [7, 8], how the plasma behaviour depends on the radius of the initial color tubes.

The initial color field can be represented in the two-dimensional space of color isotopic charge and color hypercharge [9]. Quarks and charged gluons couple to this field through the charges $\lambda\vec{\varepsilon}_i$ ($i = 1, 2, 3$) and $\lambda\vec{\eta}_{ij}$ ($i, j = 1, 2, 3,\ i \neq j$). λ is the coupling constant of strong interactions,

$$\vec{\varepsilon}_1 = (\tfrac{1}{2}, \tfrac{1}{2}\sqrt{\tfrac{1}{3}}), \quad \vec{\varepsilon}_2 = (-\tfrac{1}{2}, \tfrac{1}{2}\sqrt{\tfrac{1}{3}}), \quad \vec{\varepsilon}_3 = (0, -\sqrt{\tfrac{1}{3}}), \tag{1}$$

$$\vec{\eta}_{ij} = \vec{\varepsilon}_i - \vec{\varepsilon}_j. \tag{2}$$

The Gauss law gives

$$\vec{\mathcal{E}} A = k\lambda\vec{q}, \tag{3}$$

where $A = \pi r^2$ denotes the area of the transverse cross section of the tube, k is the number of color charges, and $\lambda\vec{q} = \lambda(q^3, q^8)$ is the color charge of a quark or a gluon.

From the definition of the string tension and Eq. (3) we get

$$\sigma = \tfrac{1}{2}(\vec{\mathcal{E}}\vec{\mathcal{E}})A = \frac{\lambda^2}{2A}\vec{q}\vec{q}. \tag{4}$$

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Substituting into Eq. (4) the quark charge $\lambda\vec{\varepsilon}_i$ (1) we obtain

$$\sigma_q = \frac{\lambda^2}{6A} \tag{5}$$

whereas replacing $\lambda\vec{q}$ by the gluon charge $\lambda\vec{\eta}_{ij}$ (2) gives

$$\sigma_g = \frac{\lambda^2}{2A}\,. \tag{6}$$

This result does not depend on the indices i, j. We conclude that the string tension of a tube spanned by gluons is three times greater than that of a quark tube [10].

The above definitions allow us to rewrite the Gauss law in the following form

$$\vec{\mathscr{E}} = \sqrt{\frac{2\sigma_g}{\pi r^2}}\, k\vec{q} = \sqrt{\frac{6\sigma_q}{\pi r^2}}\, k\vec{q}. \tag{7}$$

In this approach we have several variables which characterize an elementary tube: σ, λ, r. Having accepted the standard value $\sigma_q = 1$ GeV/fm (and consequently, $\sigma_g = 3$ GeV/fm) we obtain the relation between the coupling constant λ and the radius r:

$$\lambda^2 = 6\pi r^2\,\frac{\text{GeV}}{\text{fm}} = 30\pi r^2\,\frac{1}{\text{fm}^2}\,. \tag{8}$$

This formula together with Eqs. (5) or (6) leaves only one free parameter, i.e. r.

The formula (7) enters the Boltzmann-Vlasov equations for a Quark-Gluon Plasma as the initial condition [8]. However, it should be modified.

In the case of the high-energy collision of two nuclei the number of color charges k can be given, according to random walk hypothesis [1], by

$$k = \sqrt{\frac{dv}{d^2s}}\, A, \tag{9}$$

where dv/d^2s is the number of collisions per unit transverse area.

The exchange of color charges leads to the color field spanned by gluons therefore we take $\vec{q} = \vec{\eta}_{ij}$. (For the sake of simplicity we consider the gluons which have charges $\vec{\eta}_{12}$ so that the second component of the field vanishes $\vec{\mathscr{E}} = (\mathscr{E}^3, \mathscr{E}^8 = 0)$).

The final expression for the initial color field reads

$$\vec{\mathscr{E}} = \sqrt{2\sigma_g\,\frac{dv}{d^2s}}\,\vec{\eta}_{12}. \tag{10}$$

Now we present how the changes of r influence the plasma behaviour. At the first stage of our calculations we assume the concrete values of r and dv/d^2s. Using the expressions (8) and (10) we find λ and $\vec{\mathscr{E}}$. Afterwards we have to solve the transport equations [8] numerically.

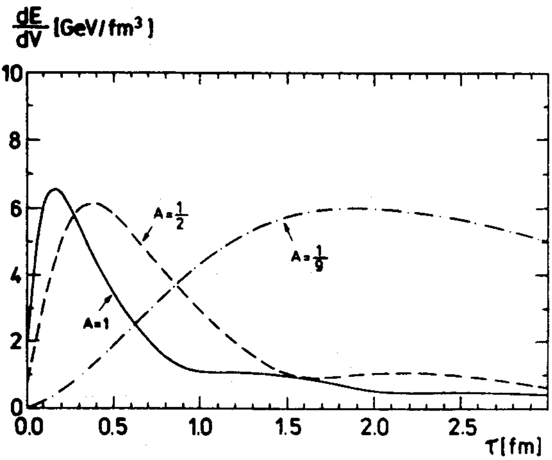

Fig. 1. Time dependence of the energy density for various choices of the transverse cross section of a tube A [fm^2]

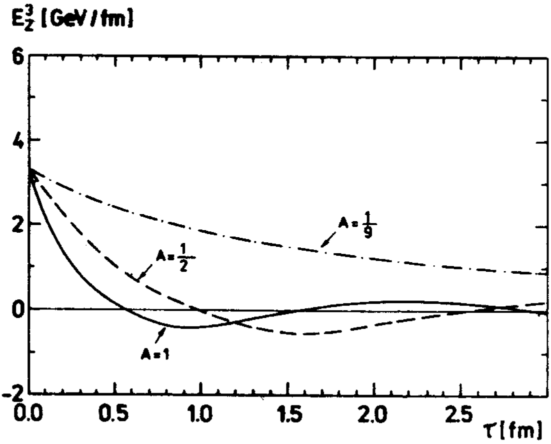

Fig. 2. Time dependence of the color field for various A [fm^2]

In Fig. 1 the energy density of quarks, antiquarks and gluons has been presented as a function of the proper time $\tau = \sqrt{t^2 - z^2}$. Three curves correspond to various choices of r: $\pi r^2 = 1, \frac{1}{2}, \frac{1}{9}$ fm^2 and dv/d^2s is taken to be 9 fm^{-2} ($\alpha_s = \lambda^2/4\pi = 2.4, 1.2, 0.3$). One can see that when the radius r decreases and dv/d^2s is constant the formation time of the plasma, defined by the maximum of the energy density, increases. However, it is interesting that the maximal energy density remains almost the same. It depends only on the value of the initial color field.

In Fig. 2 the oscillations of the color field are plotted. The period of the oscillations increases and one may suspect that for sufficiently small r they are not realizable in nature.

When r decreases all the processes are slowed down. This situation can be understood if we take into consideration Eq. (6) giving the linear dependence λ on r.

The results presented in Fig. 1 are consistent with those obtained in Ref. [4]. The plasma production timescale τ_0 [4] is determined by the initial field and the coupling constant. When the latter decreases τ_0 grows up. On the other hand the maximal energy density of the plasma remains unchanged for the same initial field.

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