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Heavy quark production in strong non-Abelian field

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In the framework of Wigner function formalism we investigated strange and charm quark-pair production in the early stage of heavy ion collisions. According to our model the particle production is initiated by an external time-dependent color field, that simulates an overlap of two colliding ions and color charge separation. The calculations were performed in an SU(2)-color model with finite current quark masses. We obtained that the production efficiency of heavy quarks is determined by the large inverse effective pulse duration of the field. We demonstrated that for short field pulses (i.e. for ultrarelativistic heavy ion collisions) the heavy quark-pair production is strongly deviates from commonly used Schwinger formula estimate, reading exponential suppression of the probability of heavy particle production $P \sim \exp(-m^2/E)$.

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1. Introduction

In the asymptotic limit of infinite energy, ultrarelativistic nucleus-nucleus collisions can be described as two colliding sheets of Colored Glass Condensate, where strong longitudinal color-electric and color-magnetic fields are created [1]. The decay of these fields produces Quark Gluon Plasma. We offered an alternative description based on a kinetic model, with continuous energy dependence [2, 3, 4, 5], investigated quark-pair production and determined particle spectra in time-dependent external U(1) and SU(2) chromo-electric fields. In this paper, we summarise the results of Ref. [5], where we have described strange, charm and bottom quark-pair production, and made a calculations of corresponding suppression factors for SU(2) gauge field.

2. The kinetic equation for the Wigner function

The equation of motion for color Wigner function W in gradient approximation can be written down in the general form as (see [3, 4, 5, 6] for details):

$$\partial_t W + \vec{V}\frac{\partial}{\partial \vec{k}} W = SW, \tag{2.1}$$

where the Wigner function W, the effective convection "velocity" $\vec{V}$ and the "source term" S are tensors in color and Dirac spaces. The objects $\vec{V}$ and S depend on an external field. The Eq. (2.1) consists of 16×8 components for SU(3)-color case and should be further simplified. We consider pure longitudinal $SU(2)$-color field with fixed color direction. In this case we obtain only 12 partial differential equations to be solved. With the known solution for the Wigner function, the momentum distributions and the integrated properties of created quarks can be determined. In Ref. [3] we described the time evolution of the quark distribution functions to obtain the longitudinal and transverse quark momentum spectra. Here we focus on the integrated particle yields, n.

In the numerical calculation we have used the following parameters: the maximal string tension $E_0 = 1$ GeV/fm; coupling constant $g = 2$; the current quark masses $m_{u,d} = 8$ MeV, $m_s = 150$ MeV, $m_c = 1200$ MeV for light, strange and charm quark, respectively. The particle production is ignited by a pulse-like field $E_z^{\diamond}(t) = E_0 \cdot \left[1 - \tanh^2(t/\tau)\right]$, which is characterized by the amplitude of the pulse E_0 and its temporal width τ.

The dependence on the pulse width is demonstrated on the left panel of Fig. 1. Charm quark-pair production is substantially enhanced in the cases of short pulse widths, and this enhancement has a maximum at $\tau \sim 0.1\sqrt{E_0}$. The ratio of number densities of heavy quark-pairs, e.g. strange to light quark-pairs (u, d-quarks) is widely known as a suppression factor γ. We have investigated the suppression factor and its dependence on the pulse widths and quark masses. On the right panel of Fig. 1 the dependence on the pulse width is displayed. The strange to light ratio has a weak dependence on the pulse width, its value is approaching slowly the asymptotic value of Schwinger limit (0.84) from below. For charm quark this Schwinger limit is negligibly small, which value is reproduced by our numerical calculation for very long pulse width. On the other hand, for short pulse widths, the relative charm production is surprisingly large, which does not follow any earlier expectation [5].

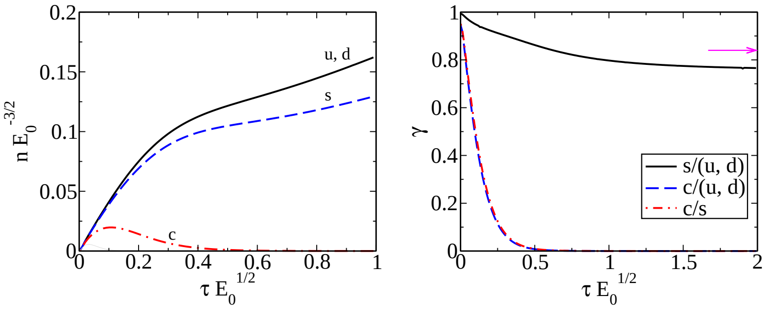

Figure 1: Left panel: the total quark-pair number densities at the final state, $n(t \gg \tau)$, as a function of pulse width τ. Right panel: the pulse width, τ, dependence of the suppression factor γ. Arrow indicates the Schwinger limit for strangeness suppression factor.

3. Conclusion

We have calculated light, strange and charm quark-pair production in time-dependent SU(2) non-Abelian field. Applying a pulse-like time evolution and investigating the influence of pulse width, we observed that light and strange quark-pairs are produced as we expected, approaching the Schwinger limit. Charm quark-pairs followed this behaviour for large pulse widths. However, for short pulses we did not see the expected charm suppression, connected to the large charm quark mass. Indeed, the large value of inverse temporal width of the pulse, overwhelming the mass of the heavy quark, $1/\tau \gg m_c$, determines the quark-pair production.

As it was concluded in Ref. [7], the particle production processes strongly deviates from calculation based on Schwinger-like estimates for constant color fields. The string tension parameter should be gradually increased to describe the data of d-Au and Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV. From our analysis we could extract the proper effective string tensions. The obtained values (see Ref. [5]) were close to the applied ones in Ref. [7].

Acknowledgments

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