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Quarks production in the quark–gluon plasma created in relativistic heavy ion collisions

M. Ruggieri [a,*], S. Plumari [a,b], F. Scardina [a,b], V. Greco [a,b]

[a] *Department of Physics and Astronomy, University of Catania, Via S. Sofia 64, I-95125 Catania, Italy*
[b] *INFN – Laboratori Nazionali del Sud, Via S. Sofia 62, I-95123 Catania, Italy*

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Abstract

In this article we report our results about quark production and chemical equilibration of quark–gluon plasma. Our initial condition corresponds to a classic Yang–Mills spectrum, in which only gluon degrees of freedom are considered; the initial condition is then evolved to a quark–gluon plasma by means of relativistic transport theory with inelastic processes which permit the conversion of gluons to $q\bar{q}$ pairs. We then compare our results to the ones obtained with a standard Glauber model initialization. We find that regardless of the initial condition the final stage of the system contains an abundant percentage of $q\bar{q}$ pairs; moreover spanning the possible coupling from weak to strong we find that unless the coupling is unrealistically small, both production rate and final percentage of fermions are quite large.

Keywords: Quark–gluon plasma; Relativistic transport theory

1. Introduction

In the last decade a general consensus has been reached that Ultra-relativistic heavy-ion collisions (uRHICs) at the Relativistic Heavy-Ion Collider (RHIC) and the Large Hadron Collider (LHC) create a hot and dense strongly interacting quark and gluon plasma (QGP) [1–4]. A main discovery has been that the QGP has a very small ratio of shear viscosity to density entropy, η/s,

* Corresponding author.
E-mail address: marco.ruggieri@lns.infn.it (M. Ruggieri).

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which is more than one order of magnitude smaller than the one of water [5,6], and close to the lower bound of $1/4\pi$ conjectured for systems at infinite strong coupling [7]. According to the standard picture of ultrarelativistic heavy ion collisions, before the collision the two colliding nuclei can be represented as two thin sheets of color-glass condensate [8–10] which produce, immediately after the collision, a configuration of strong longitudinal chromoelectric and chromomagnetic fields named the glasma, see [11–13] for reviews.

An interesting problem of uRHICs is the dynamical evolution of the high energy system made mainly of gluons, obtained from the decay of the glasma flux tubes, to a locally thermalized and eventually chemically equilibrated quark–gluon plasma. This problem has been discussed previously in [14] where quark–antiquark production rate is computed by means of the solution of the Dirac equation in the background of the strong initial glasma field, and in [15] by simulations based on relativistic transport theory (RTT) which is a fruitful theoretical tool to study the evolution of QGP produced in heavy ion collisions [16–22,15,23,24]. In this article we follow closely Ref. [15] and in some sense the present study is a continuation of [15]: in fact in [15] several aspects have not been investigated, in particular the role of the initial non-equilibrium distribution on $q\bar{q}$ production times and on the chemical equilibration of the QGP, as well as a study of the coupling dependence of the aforementioned quantities. These are the aspects we study in the present article.

We are interested to compute the $q\bar{q}$ production rate initializing simulations by a pure gluon plasma with the spectrum computed within the classical Yang–Mills (CYM) theory of the glasma. The evolution of the initial condition is then achieved by relativistic transport theory. The simulations with the CYM spectrum are started at $\tau_0 = 0.2$ fm$/c$, hence assuming in this time range the initial longitudinal gluon fields have decayed (the decay time is of the order of $1/Q_s$ with Q_s corresponding to the saturation scale) and to populate the transverse momentum space (in the initial glasma the fields are purely longitudinal hence the p_T-spectrum at $\tau = 0^+$ is zero). Within our approach we cannot discuss if and how quarks are produced before $\tau = \tau_0$; however we find that even neglecting the possible quark formation for $\tau < \tau_0$ the QCD inelastic processes are efficient enough to obtain a final state which consists mainly of $q\bar{q}$ pairs rather than gluons.

We also consider the problem of the chemical equilibration of the QGP. For a system of quarks and gluons thermalized at the same temperature T the equilibrium value for $R \equiv (N_q + N_{\bar{q}})/N_g$ is given by

$$R_{eq} = \frac{9}{4}\frac{m_q^2(T)K_2(m_q/T)}{m_g^2(T)K_2(m_g/T)}\ ; \tag{1}$$

for example if quarks and gluons are massless one finds easily $R_{eq} = 9/4$ at chemical equilibrium. In the case of finite masses the ratio R depends on temperature even if quasiparticle masses are temperature independent. We find that changing the initial distribution from a Glauber model to a CYM spectrum has some effect on the chemical equilibration, the effect being more relevant in the case of weak coupling.

In the present study we use the quasiparticles to identify quarks and gluons propagating in the QGP. In particular we consider the case of massless quasiparticles, which corresponds to a fluid with the perfect massless gas equation of state; the case of massive quasiparticles with temperature independent masses, corresponding to a fluid with the equation of state of an ideal massive gas. Finally we also consider the case of energy density dependent quasiparticle masses, with masses fixed by requiring the equation of state of the fluid is the one of QCD as it is measured on the lattice [25]. We consider three quark flavors in our simulations. Finally, we make use of RTT with a Boltzmann kernel type with $2 \rightarrow 2$ processes, see Eq. (3), hence neglecting