Dynamical equilibration of the infinite strongly interacting parton matter

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Parton-Hadron-String Dynamics

We study the kinetic and chemical equilibration in 'infinite' parton matter within the Parton-Hadron-String-Dynamics (PHSD) transport approach [1,2], which is based on generalized transport equations on the basis of the off-shell Kadanoff-Baym equations for Green's functions in phase-space representation (in the first order gradient expansion, beyond the quasiparticle approximation). In the Kadanoff-Baym theory, the field quanta are described in terms of propagators with complex self-energies. Whereas the real part of the self-energies can be related to mean-field potentials, the imaginary parts provide information about the lifetime and/or reaction rates of time-like "particles". The basis of the partonic phase description in PHSD is the dynamical quasiparticle model (DQPM) matched to reproduce lattice QCD results – including the partonic equation of state – in thermodynamic equilibrium [3].

The Dynamical Quasiparticle Model

In the scope of the DQPM, the running coupling constant squared is

$$g^2(T/T_c) = \frac{48\pi^2}{(11N_c - 2N_f)\ln(\lambda^2(T/T_c - T_s/T)^2)}, \quad (1)$$

where the parameters $\lambda = 2.42$ and $T_s/T_c = 0.56$ were extracted from the fit to the lattice data. In (1), $N_c = 3$ stands for the number of colors, N_f denotes the number of flavors and μ_q the quark chemical potentials.

In the asymptotic high-momentum (high-temperature) regime, the functional form of the parton quasiparticle mass is chosen to coincide with the perturbative thermal mass, i.e., for gluons

$$M_g^2(T) = \frac{g^2}{6}\left(\left(N_c + \frac{1}{2}N_f\right)T^2 + \frac{N_c}{2}\sum_q \frac{\mu_q^2}{\pi^2}\right), \quad (2)$$

and for quarks

$$M_q^2(T) = \frac{N_c^2 - 1}{8N_c} g^2 \left(T^2 + \frac{\mu_q^2}{\pi^2}\right), \quad (3)$$

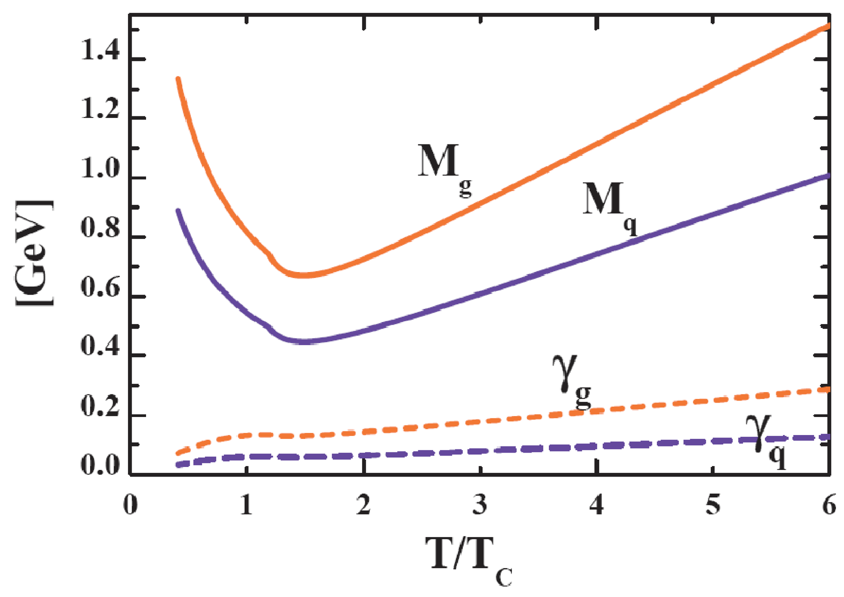
but with the coupling constant given above in (1). The effective quarks and gluons in the DQPM have finite widths, which for $\mu_q = 0$ are

$$\gamma_g(T) = \frac{1}{3}N_c\frac{g^2 T}{8\pi}\ln\left(\frac{2c}{g^2}+1\right), \quad (4)$$

$$\gamma_q(T) = \frac{1}{3}\frac{N_c^2-1}{2N_c}\frac{g^2 T}{8\pi}\ln\left(\frac{2c}{g^2}+1\right). \quad (5)$$

Note that for $\mu_q = 0$ the DQPM gives

$$M_q = \frac{2}{3}M_g, \quad \gamma_q = \frac{4}{9}\gamma_g. \quad (6)$$



In Fig.1 we show the effective gluon mass M_g and width γ_g as a function of the scaled temperature (orange lines). The blue lines show the corresponding quantities for quarks.

The parton spectral functions are no longer δ-functions in the invariant mass squared but taken as

$$\rho_j(\omega) = \frac{\gamma_j}{E}\left(\frac{1}{(\omega-E)^2+\gamma_j^2} - \frac{1}{(\omega+E)^2+\gamma_j^2}\right), \quad (7)$$

with the convention $E^2(\mathbf{p}) = \mathbf{p}^2 + M_j^2 - \gamma_j^2$, where the parameters γ_j, M_j are from the DQPM.
The spectral function is antisymmetric in ω and normalized as

$$\int_{-\infty}^{\infty}\frac{d\omega}{2\pi}\omega\rho_j(\omega,\mathbf{p}) = \int_0^{\infty}\frac{d\omega}{2\pi}2\omega\rho_j(\omega,\mathbf{p}) = 1. \quad (8)$$

Results of the dynamical simulations

The 'infinite' matter is simulated within a cubic box with periodic boundary conditions initialized at various values for the energy density. The size of the box is fixed to 9^3 fm^3. The initialization is done by populating the box with light (u,d,s) quarks, antiquarks and gluons with random space positions and the momenta distributed according to the Fermi and Bose distributions with the parameters slightly out of equilibirum.

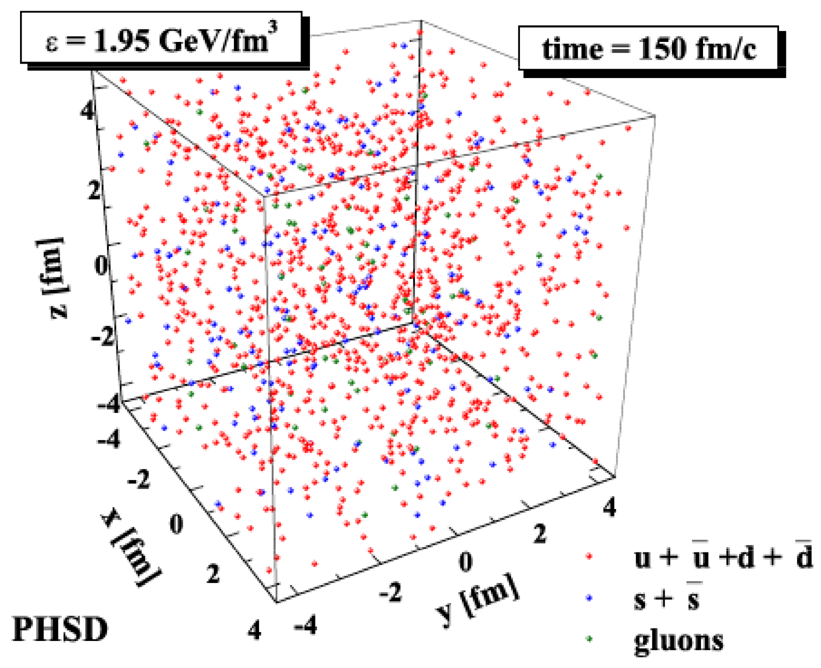
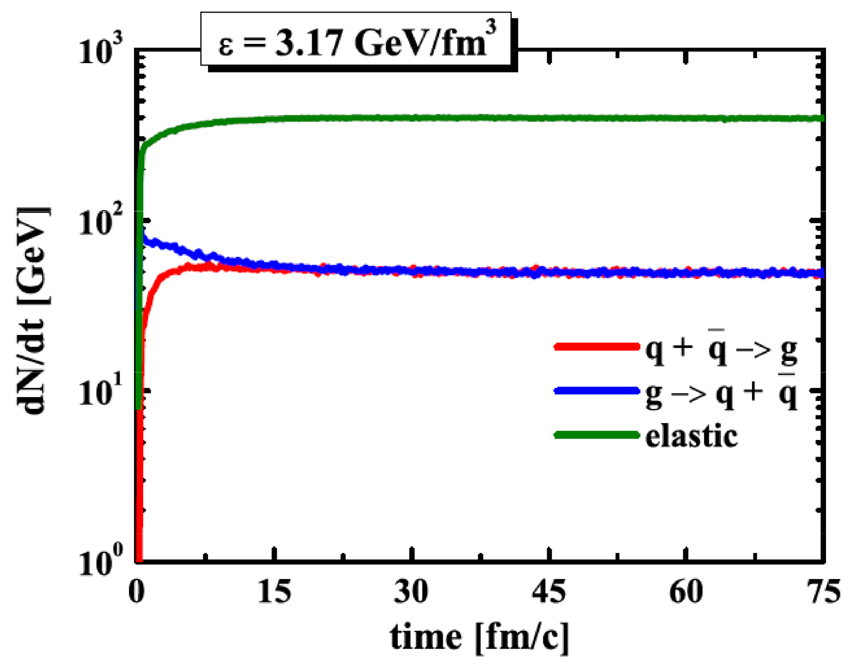
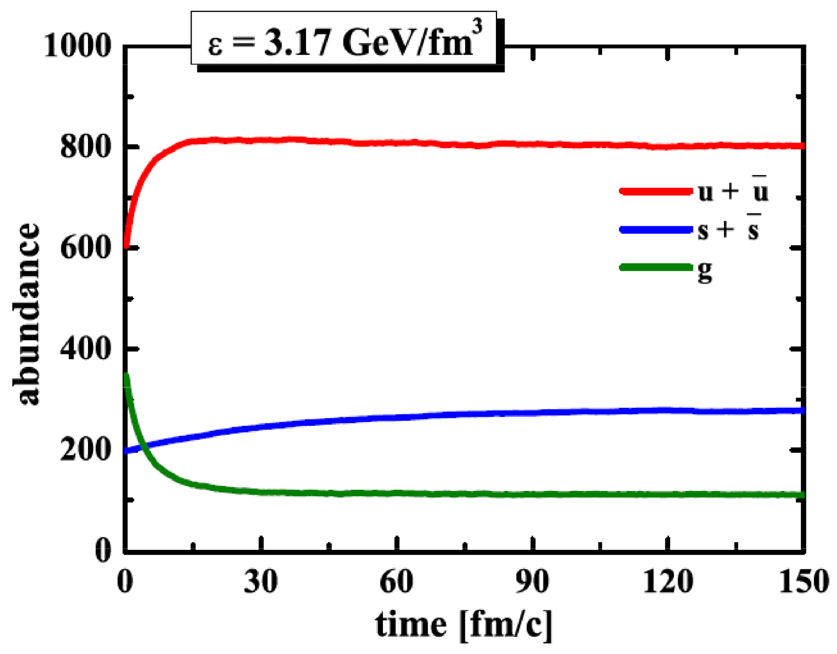


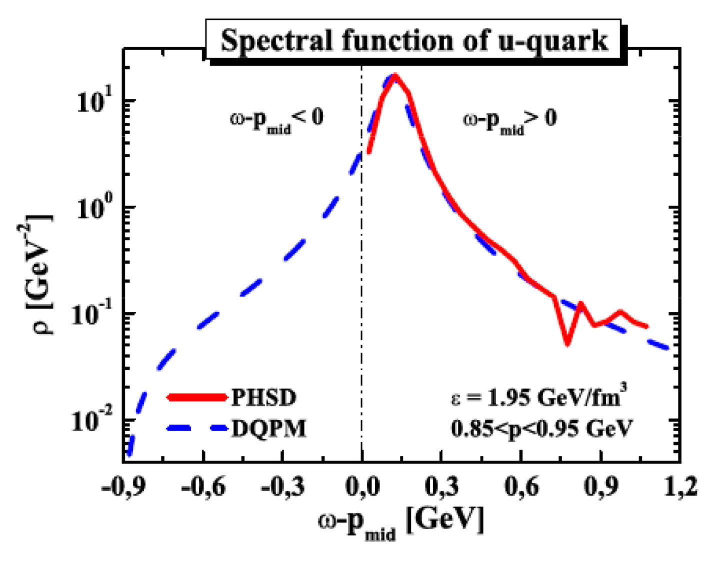
Fig.2: Snapshot of the spatial distribution of light quarks and antiquarks (red), strange quarks and antiquarks (green) and gluons (blue) after an evolution for 150 fm/c. The system has been initialized at an energy density of 1.95 GeV/fm³. At this energy density – clearly above the critical energy density – no hadrons are seen.

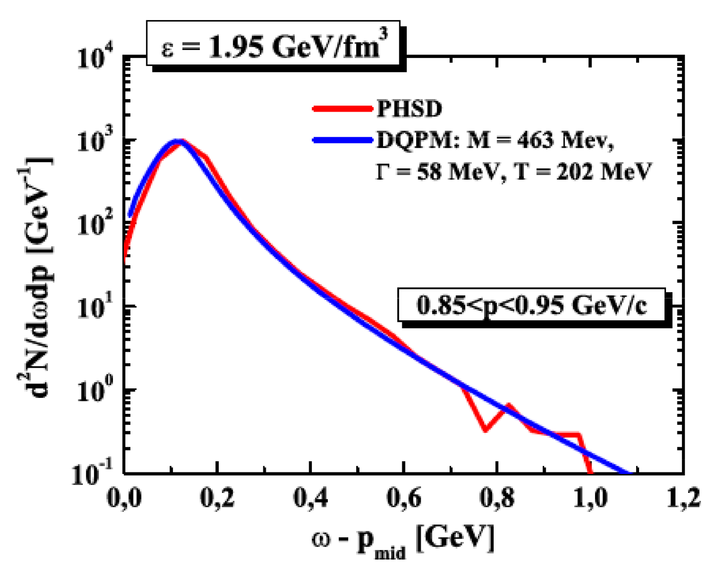
About 30-50 fm/c after initialization at an energy density of 3.17 GeV/fm³ the system achieves chemical and thermal equilibrium, since the reaction rates are practically constant and obey detailed balance for gluon splitting and quark+antiquark fusion. This is shown in Fig.3, where the reaction rates for elastic parton scattering (green), gluon splitting (blue) and flavor neutral quark+antiquark fusion (red) are presented as functions of time.





A sign of the chemical equilibrium is the stabilization of the numbers of partons of the different species. In Fig.4, we present the particle abundances as functions of time for a system, which was initialized at an energy density of 3.17 GeV/fm³ (light quarks and antiquarks – red line, strange quarks and antiquarks – blue line, and gluons – green line).





Finally, we present the spectral function of u-quarks (left plot) and the distribution of u-quarks with given energy and momentum (right plot) as functions of energy.
Both the dynamically calculated spectral function and $d^2N/d\omega dp$ of u-quarks from the PHSD simulations of the infinite partonic system (red lines) and the DQPM predictions for the respective distributions (blue lines) are shown. One can see that the DQPM is in good agreement with the dynamical calculations.

References

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