

Non-equilibrium time evolution of Φ^4 -theory in 2+1 dimensions

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Quantum transport theory is of strong interest in the study of systems out-of-equilibrium which can be generated in present and upcoming high-energy heavy ion experiments. In this context it is important to describe the time evolution of non-equilibrium systems in a fundamental way rather than relying on widely used approximation schemes since the validity of the underlying assumptions might be questionable. Especially the quasi-particle Ansatz appears to be doubtful when considering the huge collision rates in such reactions.

First studies in this respect have been performed for non-relativistic nuclear matter [1] and the relativistic Φ^4 -theory in 1+1 dimensions [2]. We now investigate the time evolution of the real scalar Φ^4 -theory in 2+1 space-time dimensions out of equilibrium. For reasons of numerical expense we restrict ourselves to homogeneous systems in space.

The self-consistent evolution equations are derived by loop expansion of the 2PI action of the underlying quantum field theory. Taking into account contributions up to the three loop order for the action one ends up with the Kadanoff-Baym equation, which governs the time evolution of the two-point Green function $iG^<(x, y) = \langle \Phi(y) \Phi(x) \rangle$. It includes the influence of a mean field on the particle propagation - generated by the tadpole diagram - as well as of scattering processes inherent in the sunset diagram. It, furthermore, incorporates memory effects in contrast to the local time structure of Boltzmann-type evolution equations.

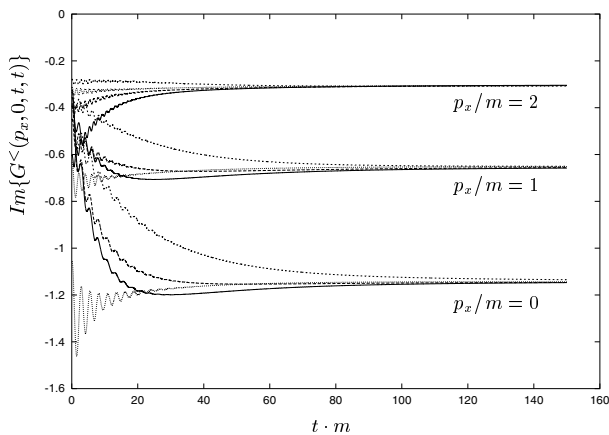


Figure 1: Time evolution of three momentum modes of the equal-time Green function $G^<(p_x, p_y = 0, t, t)$ for four different initial conditions characterized by the same energy density.

As already observed in the 1+1 dimensional case the inclusion of the mean field self energy, only, does not lead to an equilibration of arbitrary initialized momentum distributions since it only modifies the propagation of particles

by generation of an effective mass. Thermalization in 2+1 dimensions requires to take into account the collisional self energies stemming from the sunset diagram.

In Figure 1 we show a typical time evolution of various initial value problems for a coupling constant of $\lambda/m = 15$, where m is the mass of the particle. Displayed are three momentum modes of the equal time two-point function $G^<(\vec{p}, t, t)$ for four different Green function initializations (characterized by common line type) with the same energy density. In course of the - energy conserving - propagation in time all respective momentum modes approach their equilibrium value. The evolution of each momentum mode might be characterized by different timescales as already discussed for the 1+1 dimensional case in [2].

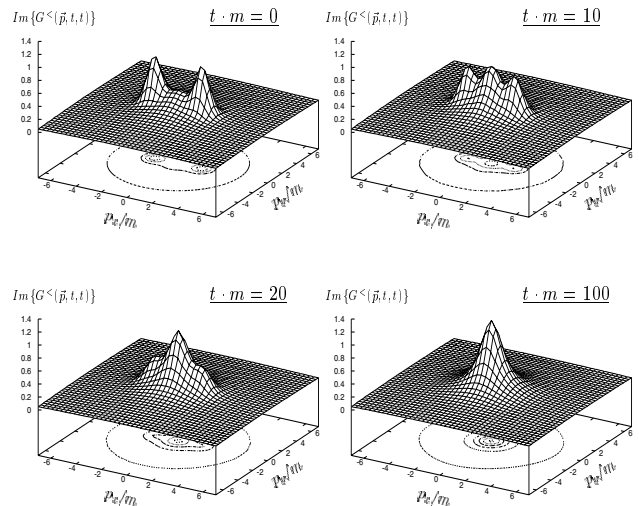


Figure 2: Non-equilibrium time evolution of the equal-time Green function $G^<(\vec{p}, t, t)$ for dimensionless times $t \cdot m = 0$ (initial), 10, 20 and 100.

The equilibration in two-dimensional momentum space is shown in Figure 2 for a coupling of $\lambda/m = 15$. Starting from an non-isotropic initial state the time propagation leads towards an isotropic final distribution.

All calculations so far have been performed within a regularization as appropriate for the momentum grid used. Further studies will need a complete renormalization prescription for the logarithmically divergent sunset self energy as addressed recently also in [3].

References

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- [3] H. van Hees, J. Knoll, Phys. Rev. D 65: 025010 (2002), hep-ph/0111193.