Equal-Time Formulation for Off-Shell Transport Theory

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The conventional approach to the description of heavy ion collisions is based on the Boltzmann equation with a self-consistent mean field and a collision term of the Uehling-Uhlenbeck form. The main improvements were the formulation in terms of a relativistic hadronic field theory [1] and the inclusion of some non-equilibrium effects in a Local (phase space) Configuration Approximation [2]. Only recently there has been an increasing interest in the inclusion of further quantum effects in the description of heavy ion collisions, in particular in the inclusion of the off-shell propagation of the baryons [3]. In these formulations the Kadanoff-Baym equations are solved with test particles in 8-dimensional phase space. This leads to certain problems with the initial conditions and the persistence of the off-shellness.

We have developed an alternative method by a systematic energy moment expansion of the spectral functions of finite width by formulating an equal-time theory for the one-particle Green functions [4]. These energy moments measure the spreading of the Green function in energy, e.g. the second order energy moment is a measure of the width of the spectral function. From the Kadanoff-Baym equations we obtain two hierarchies of equations for each of the two independent components of the one-particle Green function, spectral and kinetic. We discuss the compatibility of the two hierarchies of equations and the possibility of their systematic truncation. The hierarchies for the spectral Green function truncate by themselves. The lowest order truncation of the hierarchies for the kinetic Green function is a Bolzmann-like equation.

We have tested this scheme using a nonrelativistic self-interacting fermionic field. Our formulation in principle keeps all the terms in the gradients for space coordinates. We investigated the effects of higher order terms in a gradient expansion. These terms represent quantum effects and we investigated them numerically in a simple model of one-dimensional slab-on-slab collisions. The contour plots of the results of various approximations are shown in Fig.1. We find that the gradient corrections to the drift term result in a much smoother behaviour of the phase-space distribution function.

The time evolution of the width of the spectral function is presented in Fig.2. We found that it increases from the initially nonequilibrated momentum configuration, being largest for the maximum overlap of the two slabs. The width goes to zero outside of the range of the system.

We derived, in the gradient approximation, the modification in the Boltzmann equation in the next order truncation of the hierarchies with improved approximations for the collision integral, including memory effects. These are found to be controlled by a parameter related to the width of the spectral function. The equations could be applied to a realistic description of heavy ion collisions using nonrelativistic or relativistic formulations.

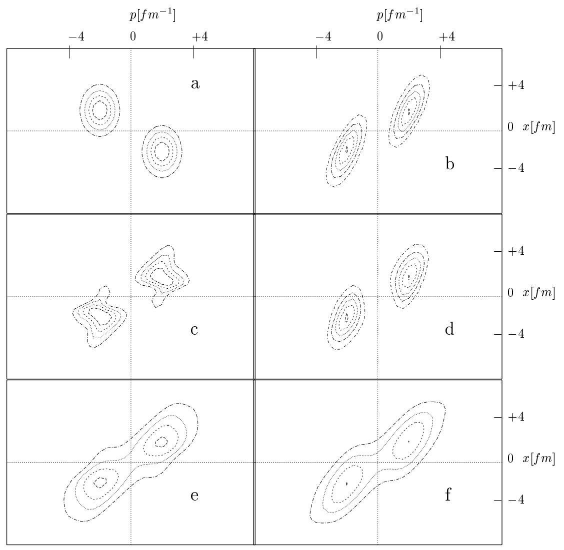

Fig. 1: Contour plots of the phase space distribution of slab-on-slab collisions at 80 MeV per nucleon. Panel (a) initial distribution. Other panels distributions (at 10 fm/c) in the following approximations: (b) free motion; (c) Vlasov approximation; (d) Vlasov plus next order gradient terms; (e) Vlasov plus collision term (i.e. BUU approximation); (f) Vlasov plus next order gradient plus collision terms.

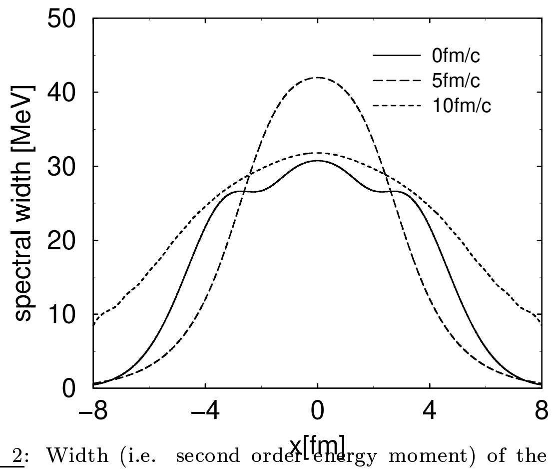

Fig. 2: Width (i.e. second order energy moment) of the spectral function at different times as a function of the coordinate of the one-dimensional model.

References

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