Towards a Consistent Transport Scheme for Particles with Mass Width[G]

Yuri Ivanov, Jörn Knoll and Dmitri N. Voskresensky
GSI Darmstadt

Over the last years it became evident that a reliable understanding of both, the dynamical and the equilibrium properties of dense systems such as nuclear -, hadronic - and deconfined quark-gluon matter can only be achieved, if one knows how to deal with particles which have a finite width in their mass spectrum. In high energy nuclear collisions resonances, like the delta resonance or rho meson, are created which have already a broad mass width Γ in vacuum exceeding the temperatures T reached in such reactions. In addition, all other constituents also aquire a collisional width Γ_{coll} which can reach values of the order of T according to standard kinetic estimates. The importance of such effects has been shown by us in the case of the production of soft real or virtual photons [1].

Yet a proper dynamical scheme in terms of a transport theory that deals with particles of broad mass width is still lacking. Rather adhoc recipes are in use that sometimes violate basic requirements as given by fundamental symmetries and conservation laws, detailed balance and the concept of thermodynamic consistency for the equilibrium situation. It turns out that the treatment of finite width particles is directly connected with genuine quantum features as space-time coherence effects. Therefore, the inclusion of such effects is beyond the scope of classical transport schemes. We have the aim to derive a generalised transport concept that at least on a certain level of approximation consistently accounts for the finite witdth of all constituents in the dense matter environment, while respecting the basic requirements mentioned above. The appropriate frame for the derivation is the real-time formalism of non-equilibrium quantum field theory, developed by Schwinger, Kadanoff, Baym and Keldysh using functional methods [2].

We use the generating functional W of the equations of motion on the real-time contour $\mathcal{C}$ in terms of an auxiliary functional $\mathrm{i}\Phi$, which has been first introduced by Luttinger and Ward [3] for equilibrium systems and later discussed by Baym [4] in the context of conserving approximations

$$\begin{aligned}\mathrm{i}W = \mathrm{i}\int_{\mathcal{C}} \mathrm{d}x \mathcal{L}^0(\phi) - \mathrm{Tr}\ln\left(1 - \odot G^0 \odot \Sigma\right)\\ -\mathrm{Tr} \odot G \odot \Sigma + \mathrm{i}\Phi\end{aligned}$$

Here $\mathcal{L}^0(\phi)$ is the free classical Lagrangian of the classical field ϕ, G^0 and G denote the free and full contour Green's fuctions, while Σ is the full contour self energy of the particles. Contrary to the perturbation theory, here the auxiliary functional Φ is given by all two particle irreducible closed diagrams in terms of *full* propagators G, *full* time dependent classical fields ϕ and bare vertices. The Φ is the generating functional for the sources $J(x)$ of the classical fields and for the self energies Σ. Thus they determine the set of coupled equations of motion for the classical fields Φ and Green's functions G (Dyson eq.)

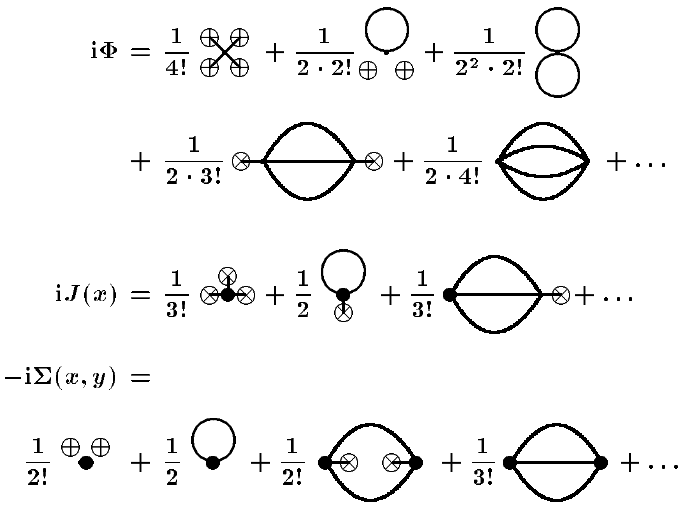
$$\begin{aligned}\phi(x) &= \phi^0(x) - \int_{\mathcal{C}} \mathrm{d}y G^0(x,y) J(y),\\ G(x,y) &= G^0(x,y) + \int_{\mathcal{C}} \mathrm{d}z \mathrm{d}z' G^0(x,z)\Sigma(z,z')G(z',y).\end{aligned}$$

Of particular interest are approximation schemes generated within a certain approximation to the functional Φ such that all source currents $J(x)$ and self energies Σ result from variational principle

$$\mathrm{i}J(x) = \frac{\delta \mathrm{i}\Phi}{\delta\phi(x)}, \qquad -\mathrm{i}\Sigma(x,y) = \frac{\delta \mathrm{i}\Phi}{\delta \mathrm{i}G(y,x)}.$$

Such approximations are called Φ-derivable approximations. They have the following distinct properties: (a) they are conserving, if Φ preserves the invariances and symmetries of the Lagrangian for the full theory; (b) lead to a consistent dynamics, and (c) are thermodynamically consistent. We proved that these properties originally shown within the imaginary time formalism with a time-dependent external perturbation also to hold in the genuine non-equilibrium case formulated in the real-time field theory.

For a ϕ^4-theory, for example, on has the following diagrams for Φ up to second order in terms of full Green's functions and bare vertices:



The $\otimes$-symbols denote the fields ϕ, small full dots define vertices which are to be integrated over, while big full dots specify the external points x or y; the first two diagrams of $\Sigma(x,y)$ give the singular $\delta(x-y)$ parts.

A closed and consistent set of coupled transport and classical field equations of motion [5] could be derived from the above set of equations of motion. Thereby we employ the gradient expansion which seems to introduce irreversibility. However we avoid the second step commonly used in the derivation of transport equations: the quasi-particle approximation. Thus we keep the mass width of the particle propagators in terms of a finite width spectral function, which accounts for all kinds of broadenings due to collisions and decays. Irreversibility is proven by a kind of H-theorem for the resulting transport equations.

Our goal is to find approximation schemes that permit the consistent implementation of finite-width and time-coherence effects into a transport simulation code.

[1] J. Knoll and D. Voskresensky, Phys. Lett. B 351 (1995) 43 and Ann. Phys. (N.Y.) 249 (1996) 532;

[2] c.f. E. M. Lifshiz and L. P. Pitaevskii, Physical Kinetics (Nauka, 1979); Pergamon press (1981);

[3] Luttinger and Ward, Phys. Rev. 118 (1960) 1417;

[4] G. Baym, Phys. Rev. 127 (1962) 1391;

[5] Y. Ivanov, J. Knoll and D. Voskresensky, to be published.