Non-equilibrium Effects in Extracting the EOS in Heavy Ion Collisions ◇

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We discuss questions involved in extracting the nuclear equation of state (EOS) from heavy ion collisions using a relativistic transport theory. The physical input in such descriptions is the nuclear mean-field. For equilibrated nuclear matter (NM) this is the desired EOS, however, due to the non-equilibrium situation particularly in the initial phase one does not really *see* the EOS in heavy-ion reactions.

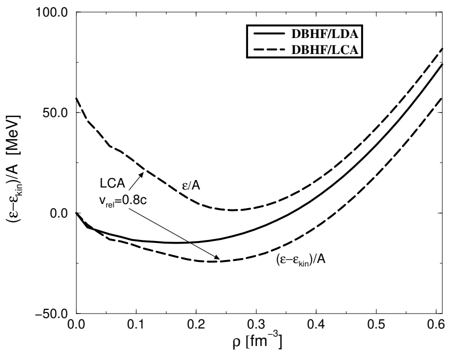

Fig. 1: Nuclear EOS from DBHF Theory in the local density (LDA, solid) and local configuration approximation (LCA, dashed). In the LCA the total energy ϵ/A and the binding energy $(\epsilon - \epsilon_{kin})/A$ are shown.

To give an answer on this non-trivial question we have developed a model which describes non-equilibrium situations by parametrizing the phase space locally by two interpenetrating NM currents with given densities and relative velocity v_{rel} (Local phase space Configuration Approximation (LCA)).The interaction between the two NM currents is taken into account in a self consistent procedure where the nuclear mean fields or self energies are taken from microscopic Dirac-Breuckner-Hartree-Fock (DBHF) calculations [2]. In the limit $v_{rel} \to 0$ this approximation yields the Local Density Approximation (LDA) with a single Fermi-sphere in momentum space. Fig 1. shows the EOS for equilibrated NM (DBHF/LDA) and for a LCA configuration (DBHF/LCA) at given v_{rel}. The later contains the kinetic energy of the relative velocity ϵ_{kin} which we substract to compare directly to the compression energy. Now a modification of the stiffness and saturation point of the non-equilibrium EOS relative to the equilibrated one are seen. The increase of the binding energy indicates a decrease of the repulsion in the LCA configuration which can be interpreted as a *softening* of the EOS in the non-equilibrium configuration. Therefore one expects important non-equilibrium effects on the reaction dynamics.

We have performed transport calculations with (without) non-equilibrium DBHF mean fields, called DBHF/LCA (DBHF/LDA) for semi-central Au+Au collisions to study observable signals of non-equilibrium effects. A very promising observable to do this is the elliptic flow v_2 which measures the anisotropy of the azimuthal flow and gives the transition of the in-plane to the out-of-plane emission of the initially formed compressed matter [4]. Negative values of v_2 corresponds to sqeeze-out and positive values to in-plane flow. Our results are summarized in fig. 2 [3]. At lower energies shadowing of spectator remnant leads to a preferential out-of-plane emission, whereas at higher energies the projectile and target spectators do not obstruct anymore the in-plane expansion of the fireball. Thus, the elliptic flow is negative at low energies and becomes positive at the highest energies [4] with a transition energy arround 4 AGeV.

Due to the early formation of the elliptic flow non-equilibrium effects will influence this observable. The effective softening of the non-equilibrium EOS (see fig. 1) leads to a considerable reduction of the squeeze-out effect and of the transition energy which is consistent with the experiments [4,5]. This also shows that the LCA approximation seems reliable to describe non-equilibrium situations of the phase space.

In conclusion, the non-equilibrium effects in heavy-ion reactions change the effective nuclear EOS, and this is observable in terms of collective flow phenomena. Our studies show that the determination of the nuclear EOS in heavy-ion reactions is non-trivial, and a reliable extraction requires the inclusion of non-equilibrium effects in transport theoretical studies of heavy-ion collisions.

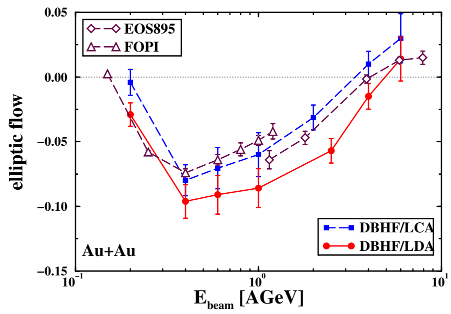

Fig. 2: Energy dependence of the elliptic flow. Calculations with DBHF mean fields in the LCA (dashed) and LDA (solid) are shown in comparison to data of the EOS [4] and FOPI [5] experiments.

References

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