The high density symmetry energy in heavy ion collisions^B

T. Gaitanos[1,2], V. Greco[4], V. Baran[1,3], M. Di Toro[1], M. Colonna[1], and H. H. Wolter[2]

[1]LNS-Catania, [2]LMU-München, [3]NIPNE-Bukarest, [4]Texas A&M Univ.

The symmetry energy part E_{sym} of the nuclear equation of state is important for the understanding of many astrophysical phenomena. The study of finite nuclei gives information on E_{sym} around saturation, but the low and high density behavior of E_{sym} is not constrained from such studies and is also very uncertain in theoretical models. Heavy ion collisions (HIC), however, allow to study E_{sym} far from saturation. At energies somewhat above the Fermi energy the low density behaviour is explored in the fragmentation process. This was investigated extensively experimentally [1] and theoretically [2] and some indications for a stiff asymmetry behaviour were found. At relativistic energies one can investigate E_{sym} at high density in the compression phase and in differences of proton and neutron flow [3, 4]. In the latter work, about which we report here, a relativistic transport model is used based on scalar and vector meson fields both in the isoscalar (σ, ω-mesons) and in the isovector (ρ, δ-mesons) channel. We are particularly interested in the role of the δ-meson which has rarely been included in nuclear structure RMF calculations.

We investigate the dynamic effects of the symmetry energy in three different RMF models, shown in Fig. 1. These three models parametrize the isovector channel (a) by only the vector field (RMF-ρ), (b) by a vector and a scalar field (RMF-$\rho+\delta$) and (c) by a density dependent coupling (DDH) with $f_\rho(\rho)$ adjusted to a range of finite nuclei [5]. In (RMF-$\rho+\delta$) the symmetry energy results from a cancellation between the attractive δ- and the repulsive ρ-meson, where, however, the ρ-coupling is now three times larger than in (RMF-ρ) in order to reproduce the empirical saturation value of a_4. Including a δ-meson the ρ-coupling is effectively replaced by $(f_\rho - f_\delta(m^*/E_F^*)^2)$ and thus increases the symmetry energy at above-normal densities due to the larger ρ-meson coupling and the suppression of the δ-coupling.

We note the very similar behavior in Fig. 1 of the symmetry energy in the RMF-$(\rho+\delta)$ and realistic DDH models. Although the influence of the δ-meson in static finite nuclei calculations was found to be not very important [5], we expect substantial differences in dynamical situations due to the different *Lorentz* character of the isovector mesons. Fig. 2 shows results of relativistic transport calculations of the Boltzmann-type (RBUU) [6] for collisions of very asymmetric $Sn+Sn$-isotopes. What is shown is the differential proton-neutron directed and elliptic flow as a function of rapidity, resp. transverse momentum. It is seen that the flow in and, especially, perpendicular to the reaction plane is sensitively influenced by the high density behavior of the symmetry energy. The inclusion of the δ-meson (RMF-$\rho+\delta$) considerably increases the differential flows as expected from the above arguments. The difference in the Lorentz structure also becomes more relevant in dynamical situations due to the additional Lorentz γ-factor of the collective motion.

Thus intermediate energy HIC with radioactive beams are a promising tool to determine the high density symmetry energy and its relativistic structure. The isospin effects are substantially enhanced relative to static situations because of the different Lorentz structure of the fields. Collective flows are found to be sensitive to isospin effects, especially the elliptic flow. Thus, future experiments with radioactive isotopes should set stringent constraints on the high density behavior of the isovector part of the nuclear equation of state.

References

[1] H. Xu, et al., Phys. Rev. **C65** (2002) 064614

[2] V. Baran, et al., Nucl. Phys. **703** (2002) 603

[3] B.A. Li, Phys. Rev. Lett. **82** (1999) 5004.

[4] V. Greco, V. Baran, M. Colonna, M. Di Toro, T. Gaitanos, H.H. Wolter, Phys. Lett. B (2003) in press.

[5] S. Typel, H.H. Wolter, Nucl. Phys. **A656** (1999) 331.

[6] T. Gaitanos, C. Fuchs, H.H. Wolter, A. Faessler, Eur. Phys. J. **A12** (2001) 421.

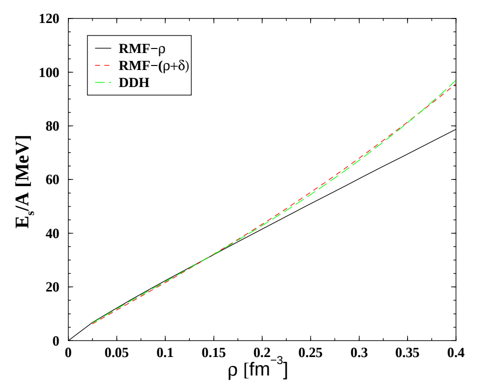

Figure 1: Symmetry energy E_{sym} vs. baryon density ρ for three different model explained in the text.

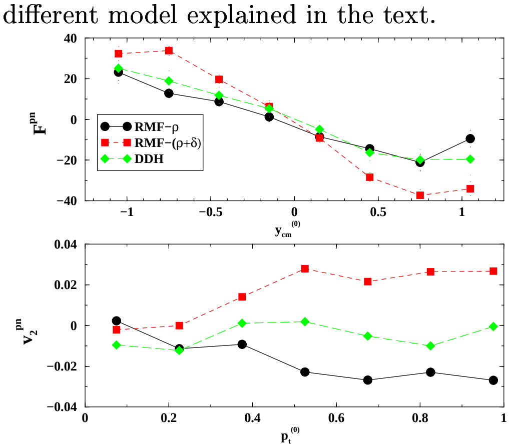

Figure 2: Proton-neutron directed flow F^{pn} (top) and elliptic flow v_2 (bottom) at midrapidity ($|\Delta Y| < 0.3$) vs. normalized rapidity $y_{cm}^{(0)}$ and transverse momentum $p_t^{(0)}$, respectively, for $^{132}Sn(1.5AGeV) + {}^{132}Sn$ semi-central reactions ($b = 6\ fm$).