Isospin Dependence of the Nuclear Equation-of-State

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The isospin dependence of nuclear matter has recently become a subject of special interest both in connection with the structure of exotic, very asymmetric nuclei, and with astrophysical phenomena in neutron stars and supernovae. While at normal nuclear density it is largely fixed by the empirical mass formula, its density dependence is rather uncertain away from normal density. Different theoretical approaches predict very different behavior ("asy-stiff" or "asy-soft"). The most promising way to investigate this experimentally is in the study of heavy ion collisions in the energy range from the Fermi energy ($\sim$ 100 AMeV) to relativistic energies of several GeV. At low energies fragmentation is the most likely final configuration which also leads to isospin fractionation, in the sense that different fragments have different isospin content. This has recently been investigated in ref. [1]. At higher energies the high density behavior is investigated in terms of the isospin dependent flow variables, but also in particle production. This is reported here.

An appropriate way to parametrize the isospin dependence is in a Relativistic Mean Field (RMF) model in terms of meson-nucleon couplings by scalar or vector mesons in the isocalar (σ and ω) and the isovector (δ and ρ) sector. In particular the role of the δ meson has been much discussed recently [2]. In the isovector sector a similar density-dependent cancellation between ρ- and δ-fields occurs as with σ- and ω-fields. Thus heavy ion collisions are a way to determine the Lorentz structure of the symmetry energy. Here we compare two RMF models which have the same non-linear, soft EOS for symmetric nuclear matter and the same E_{sym} but with ρ and δ mesons ($NL\rho\delta$) or only with ρ mesons ($NL\rho$).

We have investigated several types of observables sensitive to the high density behavior of the isovector EOS. One are collective isospin flows, driven by the isospin pressure. An example is shown in Fig.1 for $Sn + Sn$ collisions for proton-neutron directed (transverse) flow and for elliptic flow. These variables show strong effects to the iso-EOS, however, there are no data available yet, even for less asymmetric systems. A second variable is particle production, e.g. the π^+/π^- ratios (or also the K^+/K^- ratios), which indirectly are an indication of the p/n ratios in the high density phase. A study of this has been performed in ref.[3], and preliminary data show better agreement with a stiffer iso-EOS. Finally isospin transparency has recently been introduced to determine the amount of stopping and isospin equilibration, which also depends on the iso-EOS. It can be quantified in terms of yield ratios $R_i^{AB} = Y_i^{AB}/Y_i^{BA}$ of particle i for the reactions $A+B$ and $B+A$ as a function of rapidity. E.g., at projectile rapidity ($y = +1$) one would observe $R_p^{AB} = Z_A/Z_B$ for complete transparency and $R_p^{AB} = 1$ for complete mixing, etc. In figure 2 we show such ratios for the $Ru - Zr$ system at two energies, where one does see an effect at the higher energies. We also find that the sensitivity increases when looking at ratios of yields ratios of e.g. $^3He/t$.

In summary we have demonstrated that intermediate enrgy heavy ion collisions have the potential of determining the density dependence of the isovector EOS. Comparison to existing preliminary data indicates a rather stiff behavior.

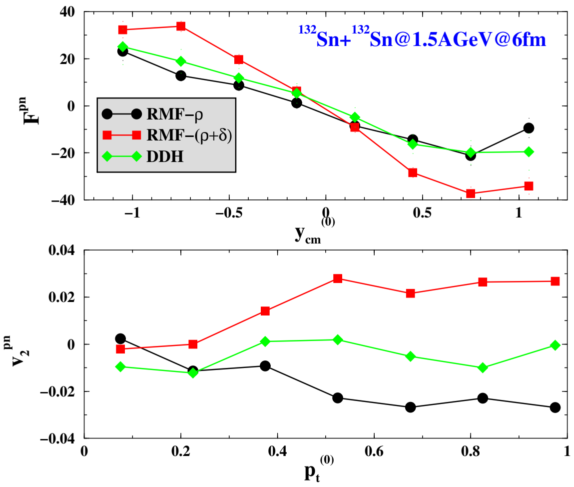

Fig. 1: Proton-neutron directed flow F^{pn} (top) and elliptic flow v_2 (bottom) at midrapidity ($|\Delta Y| < 0.3$) vs. normalized rapidity $y_{cm}^{(0)}$ and transverse momentum $p_t^{(0)}$, respectively, for $^{132}Sn(1.5AGeV) + ^{132}Sn$ semi-central reactions ($b = 6fm$).

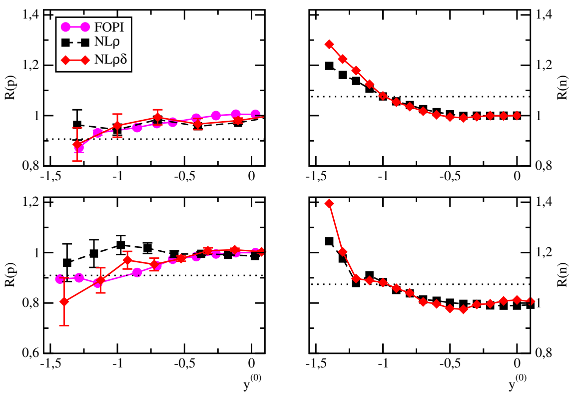

Fig. 2: Isospin yield ratios in the $Ru - Zr$ system for ρ (left) and n (right) for central collisions for 0.4 (top) and 1.5 (bottom) AGeV. Data from FOPI collaboration.

References

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