The Symmetry Energy at High Baryon and Isospin Density ◇

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Particle production has been suggested as a useful tool to constrain the poorly known high density behaviour of the nuclear equation of state (EoS) [1] in relativistic heavy ion collisions (HIC) at SIS/GSI energies ($0.1-2$ AGeV). This information is crucial both to learn about the effective nuclear interaction and to get a deeper insight into many interesting astrophysical phenomena. Pion and (subthreshold) kaon productions have been extensively investigated both theoretically and experimentally, leading to the conclusion of a soft behaviour of the EoS at high densities [2]. Kaons (K^+, K^0) appear as particularly sensitive probes since they are produced in the high density phase without suffering large reabsorption effects. On the other hand, the $K^{+,0}$ production cross sections are also isospin dependent. We therefore propose the K^0/K^+ yield ratio as a good observable to constrain the high density behavior of the symmetry energy, E_{sym}, [3]. Some promising indications have been recently obtained in nuclear matter calculations [4], we present here results for realistic *open* systems, i.e. for collisions of neutron-rich heavy ions in the energy range around the kaon production threshold (1.56 $AGeV$).

The theoretical description of dynamical (HIC) and static (infinite nuclear matter, NM) nuclear systems is based on the effective field theory of the Quantumhadrodynamics [5]. A relativistic treatment naturally describes the saturation mechanism for isospin-symmetric NM (cancellation effects between an attractive scalar σ and a repulsive vector ω field) and the strong spin-orbit force. In asymmetric NM (ANM) the density behavior of the symmetry energy E_{sym} enters via vector ρ and scalar δ mesonic fields, which largely cacel each other similar as in the isoscalar sector. Due to their different Lorentz structure (competition Thus they lead to differences in the symmetry energy at high baryon densities. The inclusion of the isovector, scalar δ meson in the description of ANM yields a stiffer E_{sym} at supra-normal densities. Since finite nuclei probe only the region near saturation [6], the high density structure of the symmetry energy, which is still unkown experimentally and very controversial theoretically, can be only tested in high energetic HIC or in neutron star structure.

We have analyzed intermediate relativistic HIC in an isospin dependent covariant transport model [7] by means of meson production of pions ($\pi^{\pm,0}$) and kaons ($K^{+,0}$). At relativistic beam energies of $\sim 1-2$ AGeV the main mechanism of meson production goes through the excitation ($NN \to N\Delta, \Delta\Delta$) and reabsorption ($N\Delta \to \pi N$) of the $\Delta(1.232GeV)$ resonance. However, kaons are directly emitted from the high density phase due to strangeness conservation (with associate hyperon production) without undergoing any further secondary interaction with the hadronic environment, as is the case for the pions [4,7]. One therefore expects a higher sensitivity of the kaon yield on the symmetry energy at supra-normal densities relative to that of pions. This is nicely confirmed in Fig. 1 in terms of the π^-/π^+ (left) and K^0/K^+ (right) ratios as a function of the incident energy using different models for the symmetry energy: In the NL model only the kinetic cotribution to the symmetry potential is included. In the $NL\rho$ model the ρ meson is accounted for and in the $NL\rho\delta$ model both, the ρ and δ fields are taken into account. The symmetry energy becomes stiffer in the direction $NL \to NL\rho \to NL\rho\delta$.

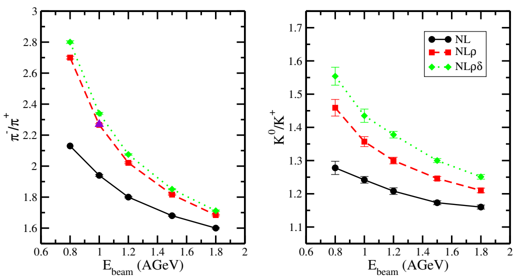

Fig. 1: π^-/π^+ (left) and K^0/K^+ (right) ratios as a function of the incident energy for central Au+Au reactions (see text).

The influence of the isospin effect is more pronounced for the kaonic than for the pionic ratio, as discussed above. The important isospin effects on the kaon ratio originate from two competing effects; *mean field (MF)* and *threshold* effects: The stiffer the symmetry energy, the more repulsive is the isospin potential for neutrons which leads to faster neutron emission. This MF effect should reduce the kaonic ratio in the direction $NL \to NL\rho \to NL\rho\delta$. However, as discussed in [4,7] the threshold conditions for kaon production, which strongly depend on the isospin part of the nuclear potential, act in opposite direction. The net effect is a substantial enhancement (reduction) of the $K^0(K^+)$ yields leading to an increase of the K^0/K^+ ratio with increasing stiffness of the symmetry energy.

Thus subthreshold strangeness production in relativistic intermediate HIC's provides a useful tool to determine the Lorentz structure of the isovector channel and the high-density isovector nuclear EoS. Further theoretical studies and future experiments with radioactive heavy ion beams will be an important issue in this direction.

References

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