Investigation of the Nuclear Symmetry Energy by Particle Production in Heavy Ion Collisions ◇

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The properties of highly compressed and heated hadronic matter, i.e. the nuclear equation-of-state (EoS), are important for the understanding of astrophysical objects, such as supernovae explosions and neutron stars. Of particular recent interest is the experimentally and theoretically still poorly known density dependence of the symmetry energy, i.e. the isovector EoS. Heavy ion collisions (HIC) provide the opportunity to explore the nuclear EoS in the laboratory. Observables investigated have been collective flows and yields of produced particles such as pions and, in particular, particles with strangeness (kaons). Because of the high threshold ($E_{lab} = 1.56$ GeV for NN collisions), kaon production in HICs at energies around 1 $AGeV$ is mainly due to secondary processes involving Δ resonances and pions (π), which are indicative of the high density stage of the collision, inparticular because of the large mean free paths of positive (K^+) and neutral (K^0) kaons in the hadronic environment. Thus kaon yields and particularly yield *ratios* have been proposed as promising signals for the investigation of the nuclear EoS. This was recently applied for the ratio of the K^+ yields in Au+Au and C+C collisions [1], where it was found that this ratio is very sensitive to the stiffness of the nuclear EoS for *symmetric* nuclear matter. Comparisons with KaoS data favored a soft behavior of the high density nuclear EoS.

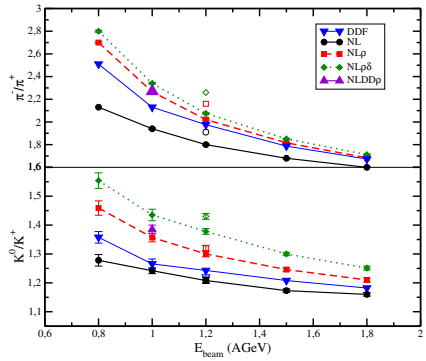

Fig. 1: π^-/π^+ and K^+/K^0 ratios as a function of the incident energy for $Au+Au$ collisions and different models for the EoS [2], which are the same in the isoscalar sector, and also agree essentially in the symmetry energy at saturation, but differ in the density behaviour. The open symbols at 1.2 $AGeV$ are for the neutron-rich $^{132}Sn + ^{124}Sn$ system. (Note the different scale for the π^-/π^+ ratios.)

Threshold effects depend on the effective in-medium masses, which are dependent on isospin for the different charge states of pions and kaons. In a relativistic field theoretical formulation of nuclear and meson fields, they depend on the isovector-scalar potential, and the available energy also depends on the isovector-vector potential. Thus it is to expected that the production of particles should also be sensitive to the *isovector* EoS. In order to minimize the uncertainties and to enhance the effects of the isovector EoS, it is advantageous to look at yield ratios, like π^-/π^+ and K^0/K^+. Of particular interest is the K^0/K^+ ratio, because kaons are a probe of the high density phase, while pion production takes place during the complete evolution of the collision.

Here heavy ion collisions are described in a relativistic transport model, where inelastic NN collisions lead to pion, Δ, and kaon production. The EoS in our investigation is specified within a non-linear relativistic mean field model, where the isovector part is parametrized via coupling to isovector scalar and vector mesons, i.e. δ and ρ fields, which leads to a stiffer isovector-EoS at high denisity [2].

Results of such calculations are presented in Fig.1 for the pion and kaon yield ratios for different isovector EoS's (the isoscalar EoS is always the same) for different incident energies [2]. It is seen that effects of the order of 15% appear for the different EoS's and that the kaon ratios are more sensitive than those for pions.

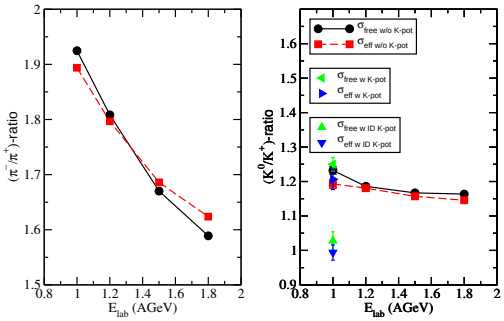

Fig. 2: Energy dependence of the π^-/π^+ (left panel) and K^0/K^+ (right panel) ratios for central ($b = 0$ fm) Au+Au reactions for in-medium modifications of the inelastic cross sections and isospin-independent and isospin-dependent (ID) kaon potentials

Since, however, the effects are not very large, we further investigated the sensitivity of these results under variations of the model ingredients [3], in particular to medium effects of the inelastic cross sections and the kaon mean fields, both of which are actively discussed but not completely under control. Results for the ratios for one particular isovector-EoS (NL) but different choices for the in-medium effects are shown in Fig. 2. It is seen that neither the pion nor the kaon rations depend strongly on such variations, with the exception of a possible isospin-dependent part of the kaon mean fields (up-down triangles), which can thus also be considered as a test of such contributions. We conclude that subthreshold strangeness production yields in relativistic intermediate HIC's are a promising and robust signature of the high-density isovector nuclear EoS.

References

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◇ work supported by BMBF grant 06ML189 and by the Greek State Scholarship Foundation (I.K.Y.)