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In-medium effects on particle production in heavy ion collisions

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Abstract

The effect of possible in-medium modifications of nucleon–nucleon (NN) cross sections on particle production is investigated in heavy ion collisions (HIC) at intermediate energies. In particular, using a fully covariant relativistic transport approach, we see that the density dependence of the *inelastic* cross sections appreciably affects the pion and kaon yields and their rapidity distributions. However, the (π^-/π^+)- and (K^0/K^+)-ratios depend only moderately on the in-medium behavior of the inelastic cross sections. This is particularly true for kaon yield ratios, since kaons are more uniformly produced in high density regions. Kaon potentials are also suitably evaluated in two schemes, a chiral perturbative approach and an effective meson–quark coupling method, with consistent results showing a similar repulsive contribution for K^+ and K^0. As a consequence we expect rather reduced effects on the yield ratios. We conclude that particle ratios appear to be robust observables for probing the nuclear equation of state (EoS) at high baryon density and, particularly, its isovector sector.

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1. Introduction

The knowledge of the properties of highly compressed and heated hadronic matter is an important issue for the understanding of astrophysical processes, such as the mechanism of supernovae explosions and the physics of neutron stars [1,2]. Heavy ion collisions provide the unique opportunity to explore highly excited hadronic matter, i.e. the high density behavior of the nuclear EoS, under controlled conditions (high baryon energy densities and temperatures) in the laboratory [3]. Of particular recent interest is also the still poorly known density dependence of the isovector channel of the EoS.

Suggested observables have been the nucleon collective flows [3,4] and the distributions of produced particles such as pions and, in particular, particles with strangeness (kaons) [5,6]. Because of the rather high energy threshold ($E_{\rm lab} = 1.56$ GeV for nucleon–nucleon collisions), kaon production in HICs at energies in the range 0.8–1.8 A GeV is mainly due to secondary processes involving Δ resonances and pions (π). On the other hand, secondary processes require high baryon density. This explains why the kaon production around threshold is intimately connected to the high density stage of the nucleus–nucleus collision. Furthermore, the relatively large mean free path of positive charged (K^+) and neutral (K^0) kaons inside the hadronic environment causes hadronic matter to be transparent for kaons [7]. Therefore kaon yields and generally *strangeness ratios* have been proposed as important signals for the investigation of the high density behavior of the nuclear EoS. This idea, as firstly suggested by Aichelin and Ko [8], has been recently applied in HIC at intermediate energies in terms of strangeness ratios, e.g. the ratio of the kaon yields in Au + Au and C + C collisions [5,9]. In these studies it was found that this ratio is very sensitive to the stiffness of the nuclear EoS. Indeed comparisons with KaoS data [10] favored a soft behavior of the high density nuclear EoS, a statement which is particularly consistent with elliptic flow data of the FOPI Collaboration [11].

The idea of studying particle ratios in HICs around the kinematical threshold has been recently applied in the determination of the isovector channel of the nuclear EoS, i.e. the high density dependence of the symmetry energy $E_{\rm sym}$. It has turned out that particle ratios, such as (π^-/π^+) [12] or (K^0/K^+) [13–15], are sensitive to the stiffness of the symmetry energy and, in particular to the strength of the vector isovector field. However in medium effects on the kaon propagation have been neglected so far. Here we will test the robustness of the yield ratio against the inclusion and the variation of the corresponding kaon potentials. At the same time in Ref. [16] the role of the in-medium modifications of NN cross sections has been studied in terms of baryon and strangeness dynamics. It was found that the pion and kaon yields are sensitively influenced by the reduced effective NN cross sections for inelastic processes. Here we will see that the kaon yield ratio appears robust even with respect to the density dependence of the in-medium inelastic NN cross sections, while at variance the pion ratio seems to be more sensitive.

The collision dynamics is rather complex and involves the nuclear mean field (EoS) and binary 2-body collisions. In the presence of a nuclear medium the treatment of binary collisions represents a non-trivial problem. The NN cross sections for elastic and inelastic processes, which are the crucial physical parameters here, are experimentally accessible only in free space and not for 2-body scattering at finite baryon density. Recent microscopic studies, based on the G-matrix approach, have shown a strong decrease of the elastic NN cross section [17,18] in a hadronic medium. These in-medium effects of the elastic NN cross section considerably influence the hadronic reaction dynamics [19]. Obviously the question arises whether similar in-medium effects of the *inelastic* NN cross sections may affect the reaction dynamics and, in particular, the production of particles (pions and kaons).