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Aspects of particle production in isospin-asymmetric matter

G. Ferini, M. Colonna, T. Gaitanos, M. Di Toro *

Laboratori Nazionali del Sud, INFN, I-95123 Catania, Italy
Physics–Astronomy Department, University of Catania, Catania, Italy

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Abstract

The production/absorption rate of particles in compressed and heated asymmetric matter is studied using a Relativistic Mean Field (RMF) transport model with an isospin-dependent collision term. Just from energy conservation in the elementary production/absorption processes we expect to see a strong dependence of the yields on the basic Lorentz structure of the isovector effective interaction, due to isospin effects on the scalar and vector self-energies of the hadrons. This will be particularly evident for the ratio of the rates of particles produced with different charges: results are shown for π^+/π^-, K^+/K^0 yields.

In order to simplify the analysis we perform RMF cascade simulations in a box with periodic boundary conditions. In this way we can better pin down all such fine relativistic effects in particle production, that could likely show up even in realistic heavy ion collisions. In fact, the box properties are tuned in order to reproduce the heated dense matter formed during a nucleus–nucleus collision in the few A GeV beam energy region.

In particular, $K^{+,0}$ production is expected to be directly related to the high density behaviour of the symmetry energy, since kaons are produced very early during the high density stage of the collision and their mean free path is rather large. We show that the K^+/K^0 ratio reflects important isospin contributions on the production rates just because of the large sensitivity around the threshold. The results are very promising for the possibility of a direct link between particle production data in exotic Heavy Ion Collisions (HIC) and the isospin-dependent part of the Equation of State (EoS) at high baryon densities.

Keywords: Asymmetric nuclear matter; Symmetry energy; Relativistic heavy ion collisions; Pion production; Subthreshold kaon production

* Corresponding author.
E-mail address: ditoro@lns.infn.it (M. Di Toro).

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1. Introduction

Recently the development of new heavy ion facilities (radioactive beams) has driven the interest on the dynamical behaviour of asymmetric matter, see the recent reviews [1,2]. Indeed, the isospin-dependent part of the EoS is of crucial importance in extrapolating structure calculations beyond the valley of stability and in astrophysical processes, such as structure and cooling of neutron stars and supernovae explosions.

Here we focus our attention on relativistic heavy ion collisions, that provide a unique terrestrial opportunity to probe the in-medium nuclear interaction in high density and high momentum regions. We will show that particle production/absorption (here pions and kaons) processes in a dense and hot neutron rich medium are nicely sensitive to the details of the relativistic structure of the effective interaction. The results appear very promising for the possibility of directly pin down from data such fundamental microscopic information.

Within a covariant picture of the nuclear mean field, for the study of asymmetric nuclear matter certainly the same considerations hold for the density behaviour of the symmetry term as in the isoscalar case. The equilibrium conditions are directly related to the Lorenz structure of the isovector effective fields in a similar way as in the isoscalar case (competition effects between attractive scalar and repulsive vector fields). However, for the description of the a_4 parameter of the Weizsäecker mass formula (in a sense equivalent to the a_1 parameter for the isoscalar part), extracted in the range from 28 to 36 MeV, there are different possibilities: (a) considering only the Lorentz vector ρ mesonic field, and (b) both, the Lorentz vector ρ (repulsive) and Lorentz scalar δ (attractive) effective fields [3,4]. The second assumption corresponds to the two strong effective σ (attractive) and ω (repulsive) mesonic fields of the isoscalar sector. In both cases one can fix the empirical value of the a_4 parameter, however, important effects at supra-normal densities appear due to the introduction of the effective δ field. In fact, the presence of an isovector scalar field is increasing the repulsive ρ-meson contribution at high baryon densities [2,4]. This is a pure relativistic effect, due to the different Lorentz properties of these fields (the vector ρ field grows with baryon density whereas the scalar δ field is suppressed by the scalar density). As a consequence, the isospin-dependent part of the EoS becomes "stiffer" when both fields are accounted for. This important feature appears in several models, see Ref. [5], where the covariant structure of the symmetry energy was investigated adopting different approaches to asymmetric nuclear matter such as Non-Linear RMF, Density-Dependent Hadronic (DDH) and Dirac–Brueckner–Hartree–Fock (DBHF) theories. Moreover, relativistic approaches to asymmetric nuclear matter naturally lead to an effective (Dirac) mass splitting between protons and neutrons due to the Lorentz scalar nature of the δ field [2–4]. This is of relevance for the dynamics of heavy ion collisions and it has recently been microscopically studied within the DBHF approach [6,7].

The study of the influence of the high density symmetry energy on the HIC dynamics has been recently started. So far one has considered collective flow observables, such as in-plane and elliptic flows [8–11] for protons and neutrons (or light isobars), isospin equilibration (or transparency) and pion production in heavy ion collisions at intermediate relativistic energies up to 1–2 A GeV [5,12,13]. However, definite conclusions have not been drawn yet due to either the lack of experimental information on some observables or the moderate dependence on the density behaviour of the symmetry energy. Comparisons with recent experimental data on isospin