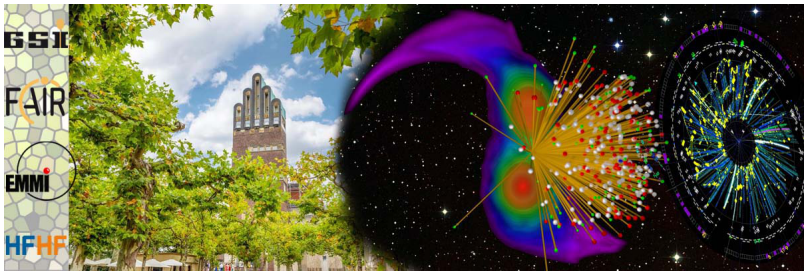


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# Extracting the high-density symmetry energy with pion and subthreshold hyperon production in heavy-ion collisions

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Within the framework of the quantum molecular dynamics transport model, the pion production and constraint of the high-density symmetry energy in heavy-ion collisions near threshold energy have been thoroughly investigated. The energy conservation in the decay of resonances and reabsorption of pions in nuclear medium are taken into account. The isospin and momentum dependent hyperon-nucleon potential and the threshold energy correction on the hyperon elementary cross section are included in the model. The density profile of pion production, energy conservation and pion potential are analyzed by the model. The isospin diffusion in the low-density region ($0.2\rho_0$ - $0.8\rho_0$) and high-density region ($1.2\rho_0$ - $1.8\rho_0$) is investigated by analyzing the neutron/proton and $\pi^-/\pi^+$ ratios in the isotopic reactions of $^{132}$Sn + $^{124}$Sn and $^{108}$Sn + $^{112}$Sn at the incident energy of 270 MeV/nucleon, in which the symmetry energy manifests the opposite contribution. The controversial conclusion of the $\pi^-/\pi^+$ ratio for constraining the high-density symmetry energy by different transport models is clarified. A soft symmetry energy with the slope parameter of $L(\rho_0) = 42 \pm 25$ MeV by using the standard error analysis within the range of $1\sigma$ is obtained by analyzing the experimental data from the S$\pi$RIT collaboration. The high-density symmetry energy is dependent on the isospin ratios $\Sigma^-/\Sigma^+$ and $\Xi^-/\Xi^0$, in particular in the domain of high kinetic energies. The isospin diffusion in heavy-ion collisions influences the neutron/proton ratio in the high-density region. The $\Sigma^-/\Sigma^+$ ratio depends on the stiffness of symmetry energy, in particular at the beam energy below the threshold value ($E_{th}$=1.58 GeV), i.e., the kinetic energy spectra of the single ratios, excitation functions and energy spectra of the double ratios in the isotopic reactions of $^{108}$Sn + $^{112}$Sn, $^{112}$Sn + $^{112}$Sn, $^{124}$Sn + $^{124}$Sn and $^{132}$Sn + $^{124}$Sn. The double strangeness ratio $\Xi^-/\Xi^0$ weakly depends on the symmetry energy because of the hyperon-hyperon collision mainly contributing the $\Xi$ production below the threshold energy ($E_{th}$ = 3.72 GeV).

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