Probing the symmetry energy with the spectral pion ratio†

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Many neutron star properties, such as the proton fraction, reflect the symmetry energy contributions to the equation of state that dominate when neutron and proton densities differ strongly. To constrain these contributions at suprasaturation densities, we measure the spectra of charged pions produced by colliding rare isotope tin (Sn) beams of 270 MeV/nucleon with isotopically enriched Sn targets at RIBF.

Light charged particles, including π^- and π^+, were detected in the SπRIT time projection chamber,[1,2] placed inside the SAMURAI spectrometer.[3] Charged particles were identified by their electronic stopping powers dE/dx and magnetic rigidities.[4] We focus on the most central collisions with the highest charged particle multiplicities while retaining good statistical accuracy, corresponding to impact parameters of $b < 3$ fm.[1]

Using ratios of the charged pion spectra measured at high transverse momenta, we deduced the symmetry energy constraints of $42 < L < 117$ and $32.5 < S_0 < 38.1$ MeV. We used the dcQMD semiclassical quantum molecular dynamics model,[5] which has provided reasonable predictions of the pion multiplicities and ratios in the previous publication.[6] By interpolating the results of dcQMD calculations (typical examples are shown in Fig. 1) with various values for L and Δm^*_{np}, *i.e.* the scaled difference between neutron and proton effective masses, we fit the single ratios $SR(\pi^-/\pi^+) = [dM(\pi^-)/dp_T]/[dM(\pi^+)/dp_T]$ for both the neutron rich ^{132}Sn+^{124}Sn system and the nearly symmetric ^{108}Sn+^{112}Sn system at $p_T > 200$ MeV/c, where we could avoid complications arising from poorly determined Δ baryon potentials. The results suggest a representative symmetry pressure of $P_{sym} = 12 \pm 10$ MeV/fm^3 at $\rho/\rho_0 = 1.5$. These L values are smaller than the values $L = 206 \pm 37$ and $S_0 = 38.3 \pm 4.7$ MeV [7] extracted from a new measurement of the neutron skin thickness of ^{208}Pb,[8] but close to the values $70 < L < 101$ and $33.5 < S_0 < 36.4$ MeV[9] extracted from charge exchange reactions and elastic scattering.

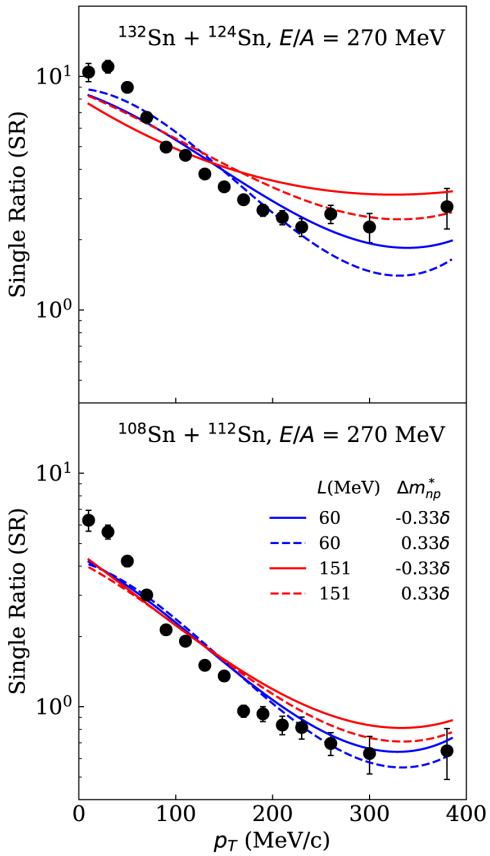

Fig. 1. Single pion spectral ratios for ^{132}Sn + ^{124}Sn (top) and ^{108}Sn + ^{112}Sn (bottom) reactions. The curves are dcQMD predictions from different L and Δm^*_{np} values listed in the bottom panel. Taken from the published article.†

† Condensed from the article in Phys. Pev. Lett. **126**, 162701 (2021)

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