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Directed flow of Λ from heavy-ion collisions and hyperon puzzle of neutron stars

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The hyperon puzzle is one of the primary problems in neutron star physics. Λ baryons are expected to appear in neutron star matter at $(2-4)\rho_0$ when two-body interactions based on hypernuclear data are used, but hyperons soften the equation of state (EOS) and make it difficult to explain the existence of $2M_\odot$ neutron stars. Thus Λ should feel a strong repulsive potential in dense nuclear matter. Phenomenologically, it is possible to introduce repulsion at high density by introducing, for example, ΛNN 3-body repulsion. It is also known that repulsion appears at high densities in model calculations based on the chiral effective field theory (chiral EFT) [1], but there is no experimental support of this repulsion.

Now, let us focus on the directed flow of Λ, which is considered to be sensitive to the potential at high densities. It was shown that the proton directed flow in the collision energy range $2\ \mathrm{GeV} < \sqrt{s_{NN}} < 20\ \mathrm{GeV}$ can be explained by the hadron transport model [2]. The repulsive EOS contributes positively to the slope in the early stage (compression stage), while the tilted ellipsoid contributes negatively in the late stage (expansion stage). Sum of these contributions causes the dv_1/dy sign change at $\sqrt{s_{NN}} \simeq 10\ \mathrm{GeV}$ [3]. This mechanism predicts that the Λ directed flow slope becomes negative at lower beam energies since Λ does not exist before the collision, but the data [4] show the balance energy of Λ is similar to that of proton. Then the positive contribution needs to be larger and the repulsion should be stronger for Λ.

In this work, we study the directed flow of Λ by using the transport model, JAM2-RQMDv [2] and estimate the potential of Λ at high densities. We use the Fermi momentum expansion of the potential as given in Ref. [5], and try to constrain the slope (L_Λ) and the curvature (K_Λ) parameters of the Λ potential from the v_1 slope data. We demonstrate that the Λ potential from the chiral EFT [1], which are stiffer than the naive potential, $U_\Lambda(\rho) \simeq U_N(\rho) \times 2/3$, roughly explains the data [4]. This would be the first support of the strongly repulsive Λ potential at high densities by the terrestrial experiment.

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