

1 - 2 In-medium Nucleon-nucleon Cross Section in Nuclear Matter*

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In-medium nucleon-nucleon (NN) cross sections at various densities and isospin asymmetries are investigated systematically in the framework of the Brueckner-Hartree-Fock approach. The calculations are based on the exact treatment of the center-of-mass momentum instead of the total momentum approximation employed in previous works^[1]. Using the G matrix, the total nucleon-nucleon elastic scattering cross section in asymmetric nuclear matter can be expressed as

$$\sigma = \frac{M^{*2}}{16\pi^2\hbar^4} \sum_{S,J} \sum_{L',L} [1 - (-1)^{S+L+T}]^2 \frac{2J+1}{4\pi} |G_{L'L}^{SJ}|^2. \quad (1)$$

For convenience in application, analytical formulas embodying the medium correction to free NN cross section with parameters calibrated to the calculated results have been provided. Using these formulas, the transverse and elliptic flows of emitted nucleons in heavy-ion collisions are studied within the isospin-dependent Boltzmann-Uehling-Uhlenbeck (IBUU) transport model. We find the medium effect of the cross section from the G matrix contributes to the transverse and elliptic flows oppositely to and obviously smaller than that from the effective mass. In addition, the present microscopic in-medium cross sections can significantly revise the predictions of the transverse and elliptic flows compared to the in-medium cross sections previously adopted in transport models for heavy-ion collisions.

In Fig. 1 shows the transverse and elliptic flows in semicentral $^{132}\text{Sn} + ^{124}\text{Sn}$ collisions at $E/A = 270$ MeV, respectively. The analytical formulas for nn, pp, and np medium correction factors are sufficiently accurate for the numerical simulation of HICs. Moreover, the discrepancy between the results from σ_{BHF} and from σ_{free} is much larger than that between the results from σ_{BHF}^* and from σ_{free}^* , which confirms that the medium effect from the effective mass strongly overwhelms that from the G matrix^[2]. Furthermore, the medium effect of the cross section from the G matrix provides an opposite contribution to the transverse and elliptic flows compared with the medium effect from the effective mass.

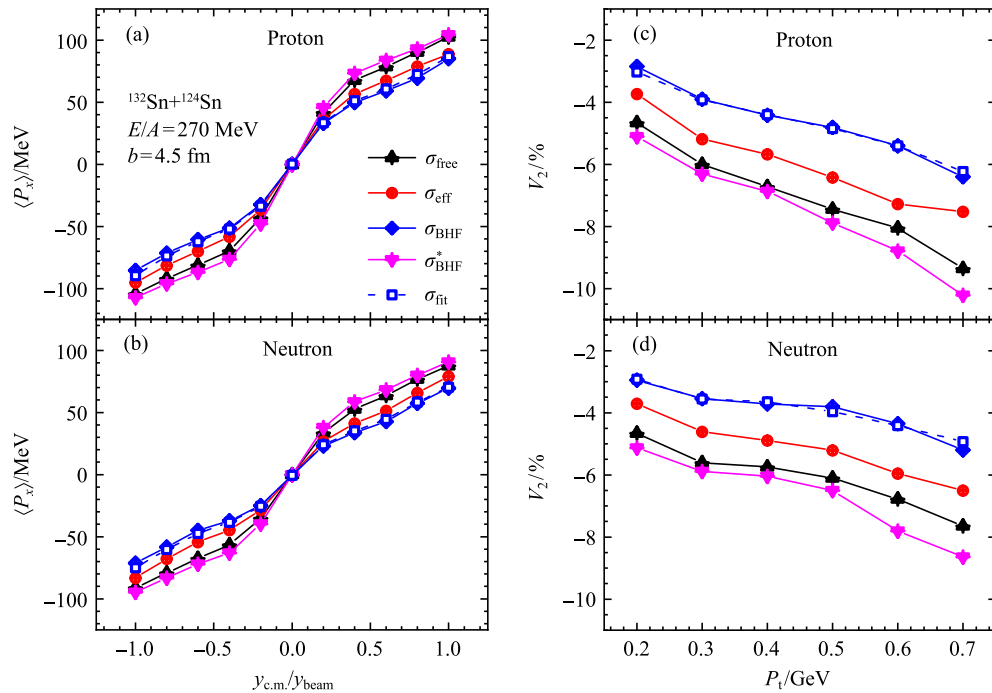


Fig. 1 (color online) Proton [panels (a) and (c)] and neutron [panels (b) and (d)] transverse (left panels) and elliptic (right panels) flows in the semi-central reaction of $^{132}\text{Sn} + ^{124}\text{Sn}$ at 270 MeV/nucleon. Left panels: Proton (a) and neutron (b) transverse flows as a function of rapidity. Right panels: Proton (c) and neutron (d) elliptic flows as a function of the transverse momentum.

References

- [1] X. L. Shang, J. M. Dong, W. Zuo, et al., Phys. Rev. C, 103(2021)034316.
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1 - 3 Probing the Incompressibility of Dense Hadronic Matter near the QCD Phase Transition in Relativistic Heavy-ion Collisions*

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Based on the extended hadronic transport model, we investigate the incompressibility of dense hadronic matter formed in relativistic Au + Au heavy-ion collisions at $\sqrt{S_{NN}} = 3$ GeV. By comparing various experimental observables, such as proton directed flow, production yields of strange hadrons ϕ , K^- as well as their ratio ϕ/K^- and proton high-order cumulants with our model calculations, we find that hadronic interactions play a dominant role in these collisions, consistent with experimental observations measure results. Our calculations also reveal that the incompressibility of hadronic matter exhibits variations across different density regions. Specifically, it appears to become stiffer from saturation density up to a certain baryon density, after which it turn to a softer regime before reaching the hadron-quark phase transition^[1].

The slope of nucleon directed flow in semi-central heavy-ion collisions is a valuable measure of the stiffness of nuclear matter generated by the interactions of participant nucleons from the target and projectile nuclei. It serves as a significant probe for investigating the EoS and the QCD phase transition. The recent experimental observation of particle directed and elliptic flows in 10% ~ 40% centrality for Au + Au collisions at $\sqrt{S_{NN}} = 3$ GeV at the Relativistic Heavy Ion Collider (RHIC) provides compelling evidence that predominantly hadronic matter is formed in these collisions and the QCD critical region.

Figure 1 depicts the proton directed flow v_1 as a function of rapidity, simulated using the AMPT-HC hadronic transport model with different incompressibilities in the mean-field option. The theoretical calculations are compared with experimental data^[2], revealing that a higher incompressibility value is required to match the observed results. Consequently, the proton directed flow v_1 provides evidence for a large incompressibility of dense hadronic matter formed in Au + Au collisions at $\sqrt{S_{NN}} = 3$ GeV at RHIC. Specifically, an incompressibility coefficient around $k \sim 300$ MeV appears to provide a satisfactory fit to the stiffness of the produced hadronic matter in these collisions. In contrast, the analysis of the nucleon directed flow with quark transport suggests that predominantly hadronic matter is indeed generated in such collisions.

Strange mesons are excellent probes of the dense nuclear matter created in heavy-ion collisions because they are hardly affected by final state interactions. In our study of Au + Au collisions at $\sqrt{S_{NN}} = 3$ GeV, we used the AMPT-HC model with different incompressibilities in the mean-field option to calculate the production of ϕ , K^- , and their ratio ϕ/K^- . Our calculations were compared to experimental data^[3]. The ϕ and K^- mesons mainly produced through baryon-baryon and meson-baryon or meson-meson collisions during the highly compressed stage of the collision. As the compression of the colliding nuclei increases, more ϕ and K^- mesons are produced. Comparing our results with experimental data, we find that a softer EoS or a smaller incompressibility coefficient ($75 < k < 150$ MeV) is favored. Our findings suggest that different observables yield different results for the incompressibility, indicating that the incompressibility of hadronic matter varies across different density regions(Fig. 2). Additionally, the incompressibility has a significant impact on the critical baryon density of the hadron-quark phase transition.

By analyzing the EoS of nuclear matter created in heavy-ion collisions and comparing it with experimental data, valuable insights can be gained regarding the stiffness of the EoS and the occurrence of the hadron-quark phase transition in nuclear matter. This information is crucial for mapping out the QCD phase diagram, which has significant implications for understanding the structure of neutron stars and the emission of gravitational waves, furthermore, studying QCD phase transition from Earth to space has crucial implications for understanding the early and present universe.