collision is also affected by the Coulomb interaction, so π^+ production, which is mainly from proton-proton collision, is relatively less affected by the in-medium inelastic baryon-baryon scattering cross section.

Shown in Fig. 3 are the predicted elliptic flow ratios of neutron and proton $V_2^{\rm n}/V_2^{\rm p}$ with different symmetry energies as well as experimental data. Since stiffer symmetry energy/symmetry potential causes relatively more neutrons to be emitted in the direction perpendicular to the reaction plane, one sees larger values of elliptic flow ratios of neutron and proton $V_2^{\rm n}/V_2^{\rm p}$ with stiffer symmetry energies. With the nucleon-nucleon SRC in the transport model, the $V_2^{\rm n}/V_2^{\rm p}$ ratios are larger than that without the SRC. This is because the SRC of nucleon-nucleon cause neutron and proton to be correlated together, the value of $V_2^{\rm n}/V_2^{\rm p}$ ratio trends to unity. Owing to the competing effects of the SRC and the symmetry energy, for $x = 0$ case, the effects of symmetry energy on the trend of the ratio of $V_2^{\rm n}/V_2^{\rm p}$ with the SRC changes compared with that without the SRC. On the whole, the sensitivity of the observable $V_2^{\rm n}/V_2^{\rm p}$ to the symmetry enegy at FOPI-LAND experimental conditions and geometry is smaller than that of the FOPI π^-/π^+ ratio. Fig. 3 indicates the FOPI-LAND elliptic flow experimental data does not favor very soft symmetry energy ($x = 2$, 3).

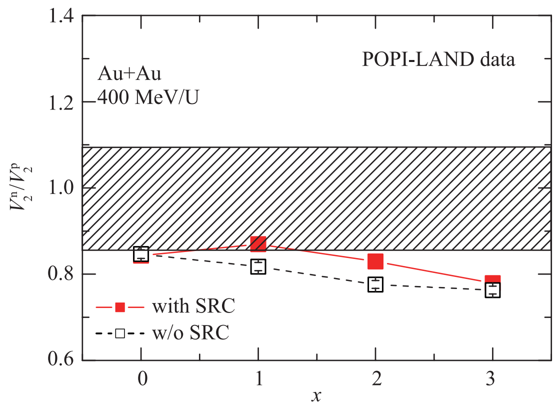

Fig. 3 (color online) The ratio of elliptic flow $V_2^{\rm n}/V_2^{\rm p}$. The effects of the SRC of nucleon-nucleon on the $V_2^{\rm n}/V_2^{\rm p}$ with same x parameters are also shown.

Combining the studies of nucleon elliptic flow and previous π^-/π^+ ratio, one may roughly obtain the symmetry energy stiffness parameter $x = 1$. It in fact corresponds a mildly soft density-dependent symmetry energy at suprasaturation densities. While the specific density region of the present constraints on the nuclear symmetry energy needs to be further studied.

Reference

[1] G. C. Yong, Phys. Rev. C, 93(2016)044610.

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1 - 7 Hollow Nuclear Matter*

Yong Gaochan

It is generally considered that an atomic nucleus is always compact. Based on the isospin-dependent Boltzmann nuclear transport model, here I show that large block nuclear matter or excited nuclear matter may both be hollow. Existence of hollow nuclear matter may have many implications in nuclear physics, astrophysics and some practical applications[1].

Fig. 1 shows the time evolution of the contour density distribution of the atomic nucleus $^{197}_{79}$Au in $X-Y$ plane with the Boltzmann nuclear transport model. The given average excitation energy (an average energy per nucleon increased relative nuclear ground state) is 5 MeV per nucleon. It is seen that as time increases a bubble steadily appears in the compact light atomic nucleus $^{197}_{79}$Au. Because the surface tension is relatively strong for relatively light atomic nucleus, to form bubble configuration in compact nucleus, one has to give excitation energy for relatively light atomic nucleus.

Shown in Fig. 2 is the $^{197}_{79}$Au + $^{197}_{79}$Au head-on collision at incident beam energy of 35 MeV/u. One can see that internally hollow nuclear matter is formed in the nucleus-nucleus collisions as time increases. And inner halo in the bubble of nuclear matter is also seen.

Internally hollow nuclear matter may have many implications in nuclear physics, astrophysics such as the physics of neutron stars, and some practical applications. Existence of internally hollow atomic nucleus may promote the developments of quantum many-body theory and nuclear theory. Increased radius of the hollow atomic nucleus may cause inner electrons of some atoms to be absorbed easily by inner nucleons. And the existence of internally hollow nuclear matter may hint the hollow configuration of neutron stars. Internally hollow superheavy or excited atomic nuclei may affect the hyperfine configuration of atomic spectrum, which is widely used in a lot of fields.

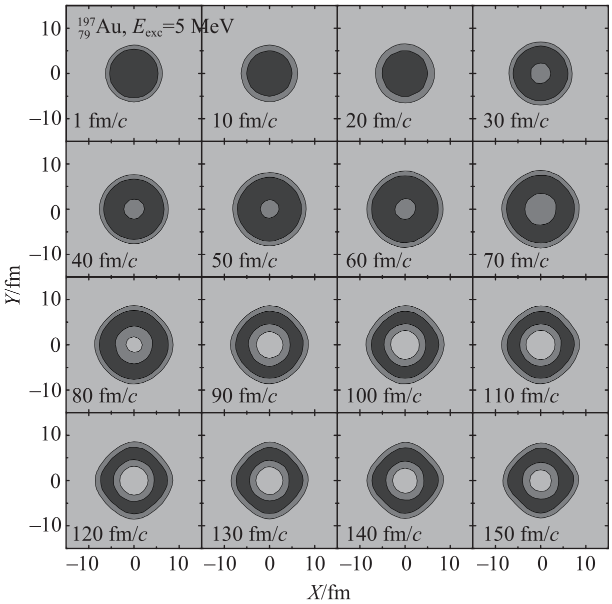

Fig. 1 Time evolution of the contour density distribution of the atomic nucleus $^{197}_{79}$Au in $X-Y$ plane with the Boltzmann nuclear transport model. The giving excitation energy is average 5 MeV per nucleon. Density becomes larger as color changes from light to dark. The bubble configuration appears after 30 fm/c in the compact nucleus $^{197}_{79}$Au.

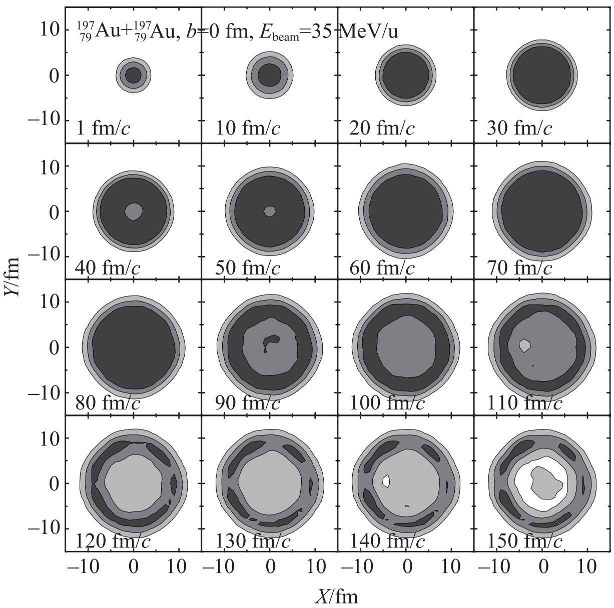

Fig. 2 Time evolution of the contour density distribution in $X-Y$ plane in the head-on $^{197}_{79}$Au + $^{197}_{79}$Au collision with the same Boltzmann nuclear transport model. The incident beam energy (in Z direction) is 35 MeV per nucleon. Density becomes larger as color changes from light to dark. The bubble configuration of the compressed nuclear matter appears after 90 fm/c.

Reference

[1] G. C. Yong, Phys. Rev. C, 93(2016)014602.

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