Geometry of vanishing flow: effect of symmetry energy and isospin-dependent nucleon-nucleon cross-section

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Introduction

Heavy-ion collisions have been used to investigate the properties of hot and dense nuclear matter for the past three decades. Various observables like collective transverse in-plane flow [1-3], multifragmentation and particle production have been proposed in this direction to study the properties of nuclear matter like nuclear equation of state and in medium nucleon-nucleon cross-section. Out of these observables, collective flow has been found to be one of the most sensitive towards the above mentioned properties as well as entrance channel parameters like incident energies, impact parameter and colliding systems. Collective transverse in-plane flow increases with impact parameter, reaches maximum at semi-central collisions and then again starts decreasing at peripheral collisions. The value of impact parameter where collective flow vanishes (crosses zero) is called geometry of vanishing flow (GVF). GVF has been found to be sensitive to mass of the colliding systems and follows power law behaviour with system size. In [4], system size dependence of GVF has been found to be sensitive to in-medium nucleon-nucleon cross-section and is insensitive to equation of state and momentum-dependent interactions. Roe of isospin degree of freedom has been studied on collective flow and energy of vanishing flow due to the availability of RIB facilities. In the present paper, we studied the sensitivity of GVF towards isospin degree of freedom through the symmetry energy and isospin dependence of nucleon-nucleon cross-section. We use *isospin quantum molecular dynamics* (IQMD) model [5].

The Model

The IQMD model treats different charge states of nucleons, pions and deltas explicitly. The isospin degree of freedom enters into the calculations via symmetry potential, cross sections and Coulomb potential. The nucleons of target and projectile interact by two- and three-body Skyrme forces, Yukawa potential and Coulomb interactions. A symmetry potential between protons and neutrons corresponding to the Bethe-Weizsacker mass formula has also been included. The hadrons propagate using Hamilton's equations of motion. For the density dependence of nucleon optical potential, standard Skyrme-type parametrization is employed. We use soft equation of state along with standard isospin and energy-dependent nucleon-nucleon cross section.

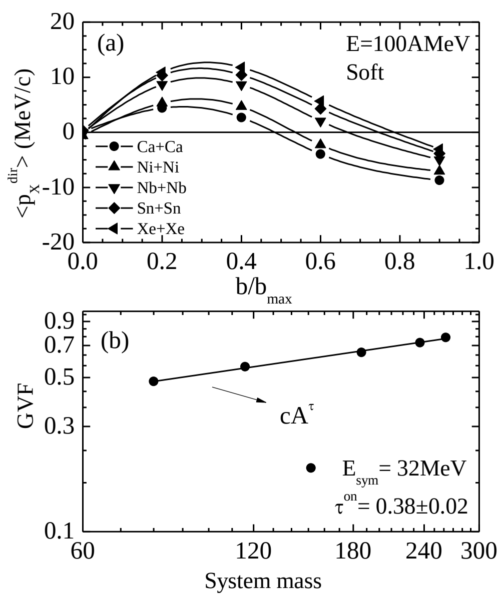

Fig. 1 $\langle p_x^{dir} \rangle$ (MeV/c) as a function of reduced impact parameter b/b_{max} for different systems using soft equation of state (upper panel) and geometry of vanishing flow (GVF) as a function of system mass (bottom panel).

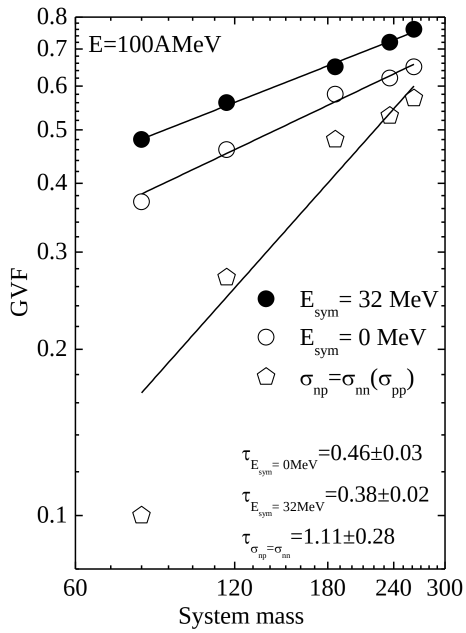

Fig. 2 The geometry of vanishing flow (GVF) as a function of system mass for zero strength of symmetry energy and isospin independent nn cross section.

Results and discussion

In fig. 1 (a), we display the impact parameter dependence of $<p_x^{dir}>$ for ^{40}Ca+ ^{40}Ca (circles), ^{58}Ni+ ^{58}Ni (up triangles), ^{93}Nb+ ^{93}Nb (down triangles), ^{118}Sn+ ^{118}Sn (pentagons) and ^{131}Xe+ ^{131}Xe (left triangles). From figure, we see that for all the systems $<p_x^{dir}>$ rises as we move from perfectly central collisions, reaches maximum at semi-central collisions, then decreases, crosses zero and become negative at peripheral collisions due to the dominance of mean field potential and absence of nucleon-nucleon (nn) collisions. In fig 1 (b), we display the system size dependence of GVF. From figure, we see that GVF increases with system size and follows a power law behaviour with system size. The power law factor τ = 0.38±0.02.

To see the role of isospin degree of freedom through symmetry energy and nn cross section, firstly, we make the strength of symmetry energy zero (to see the role of symmetry energy, open circles) and then to see the role of isospin dependence of nn cross-section, we make the nn cross-section isospin independent (open pentagons). The results are displayed in fig. 2. From figure, we see that GVF decreases when we exclude the symmetry energy. This is due to the fact that symmetry energy being repulsive in nature enhances the flow. When we make its strength zero, the flow decreases and vanishes at smaller impact parameter. We also see that power law factor τ now becomes 0.46±0.03. When we make the cross-section isospin independent, GVF decreases throughout the mass range. The np cross-section is three times as that of pp or nn cross-section. So, the net magnitude of nn cross-section decreases when we make the cross-section isospin independent. So, again flow decreases and GVF also decreases. We also see that decrease in GVF is more for lighter systems as compared to the heavier masses due to the dominant role of coulomb potential than nn cross-section in heavier systems. Thus the power law factor changes drastically (almost three times) and becomes 1.11±0.28. Thus GVF can act as a better probe to study the isospin effects due to isospin dependence of nucleon-nucleon cross-section.

References

[1] W. Scheid, H. Muller and W. Greiner, Phys. Rev. Lett. **32**, 741 (1974).
[2] H. A. Gustafsson *et al.*, Phys. Rev. Lett. **52**, 1590 (1984).
[3] K. G. Doss *et al.*, Phys. Rev. Lett. **57**, 302 (1986).
[4] R. Chugh and A. D. Sood, Parmana J. Phys. **76,** 1 (2011).
[5] C. Hartnack *et al.*, Eur. Phys. J. A**1**, 151(1998); R. K. Puri *et a*l., Nucl. Phys. A**575**, 733 (1994); *ibid.* J. Comp. Phys. **162** 245 (2000); E. Lehmann and R. K. Puri, Phys. Rev.C **51**, 2113(1995).