Influence of neutron-proton asymmetry on collective motion

Rajat Rana* and Sakshi Gautam
Department of Physics, Panjab University, Chandigarh - 1600114, INDIA

Introduction

The focus of research in intermediate energy heavy-ion collisions (HIC) is to understand the properties of dense nuclear matter and transport mechanisms. In recent decades, Isospin's degree of freedom in the nuclear equation of state (EOS) has attracted wide attention. Isospin effects are associated with nuclear EOS and are helpful to understand the properties of exotic nuclei, heavy-ion reactions, and astrophysical aspects. The role of isospin is important to constrain the neutron skin thickness of finite nuclei, neutron star radii, n-drop radii, and many more. For the last three decades, continuous efforts have been carried out to study different phenomena like nuclear multifragmentation [1], collective motion [2], nuclear stopping [3], and particle production in heavy-ion collisions which are done at intermediate energies to explore isospin dynamics. To understand the role of isospin degree of freedom in HIC, nuclear collective flow is a very prominent phenomenon. Nuclear transverse flow is given by,

$$v_1 =< cos\phi >=< \frac{p_x}{p_t} > \quad (1)$$

where $p_t = \sqrt{p_x^2 + p_y^2}$ is the transverse momentum and $p_x(p_y)$ is the momentum in *x(y)*-direction. Nuclear elliptic flow is given by second harmonic coefficient,

$$v_2 =< cos2\phi >=< \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} > . \quad (2)$$

. It is studied that the role of isospin via symmetry energy and NN cross-section is nearly the same in mass symmetric as well as mass asymmetric reactions. And from the analysis, it is concluded that there is dual sensitivity of transverse and elliptic flow towards isospin in symmetric as well as asymmetric reactions. Transverse and elliptic flows are greatly influenced by iso-scalar potential. To remove this dual sensitivity, the differential flow was put forwarded to glorify the effect of symmetry potential [4]. Differential flow utilizes isospin fractionation and collective motion constructively and is defined as :

$$F_{v_1}^{n-p}(y) = \frac{N_n(y)}{N(y)} < p_x^n(y) > - \frac{N_p(y)}{N(y)} < p_x^p(y) > \quad (3)$$

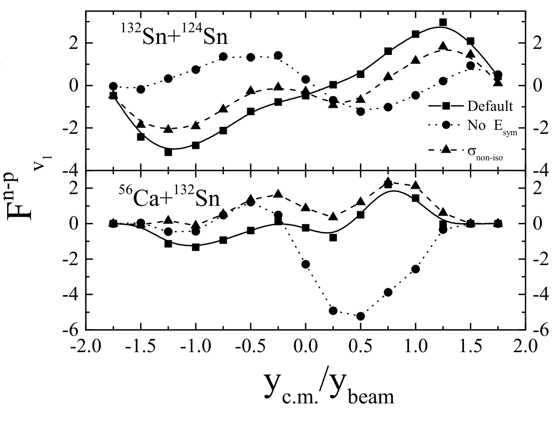

FIG. 1: The variation of differential transverse flow [$F_{v_1}^{n-p}$] with rapidity for the reactions of ^{132}Sn+^{124}Sn and ^{56}Ca+^{132}Sn at incident energy of 100 MeV/nucleon. Various symbols are explained in text. Lines are only to guide the eye.

where $N(y)$, $N_n(y)$, $N_p(y)$ are number of free nucleons, neutrons and protons at rapidity y.

*Electronic address: rajat.rana892@gmail.com

Similarly, differential elliptic flow ($F^{n-p}_{v_2}(y)$) can be defined where $p_x(y)$ in the above expression is replaced by $v_2(y)$ of protons/neutrons. Differential flow is important to extract the information of nuclear symmetry energy, this is beacuse it increases the impact of isovector potential and reduces the influence of isoscalar potential of the nuclear equation of state.

We are using the isospin-dependent quantum molecular dynamics (IQMD) model [5] for present study and a brief discussion of present study is presented in next section.

Results and discussions

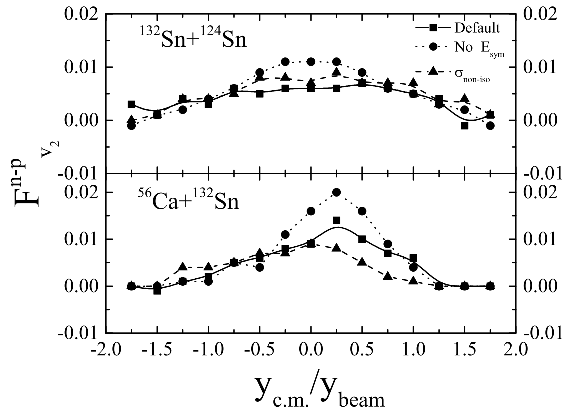

FIG. 2: The variation of differential elliptic flow [$F^{n-p}_{v_2}$] with rapidity for the reactions of ^{132}Sn+^{124}Sn and ^{56}Ca+^{132}Sn at incident energy of 100 MeV/nucleon. Various symbols are explained in text. Lines are only to guide the eye.

We simulated the reactions of ^{132}Sn+^{124}Sn (mass-symmetric) and ^{56}Ca+^{132}Sn (mass-asymmetric) collisions at beam energy of 100 MeV/nucleon for non-central collisions (b = 5 fm) using soft equation of state (EOS) with the help of IQMD model. We investigated the sensitivity and contribution of symmetry energy and isospin-dependent scattering cross-section. The results are displayed in the given Figures and to investigate and understand the role of n-p asymmetry on differential flow, the calculations are performed by neglecting the nuclear symmetry energy (circles) and with isospin independent NN cross-section (triangles). The slope of ($F^{n-p}_{v_1}(y)$) at mid-rapidity is positive for ^{132}Sn+^{124}Sn while it is negative for ^{56}Ca+^{132}Sn. This is because the lighter projectile participation in the reaction will reduce the differential flow at positive rapidities. It is noted that the differential flow is reduced when the calculations are performed without symmetry energy and isospin independent cross-section for reactions of ^{132}Sn+^{124}Sn and ^{56}Ca+^{132}Sn. But the decrease is higher in the case of without symmetry energy than isospin dependent cross-section and this shows that the stronger role of isovector potential than NN scattering effects. And it comes five times higher than the sensitivity of isospin via NN scatterings. A similar finding is observed in the case of differential elliptic flow as shown in Figure 2 and thus it is concluded that the effect of nuclear symmetry energy is more pronounced than NN scattering effects on differential flow to study charge asymmetry of systems.

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