On the directed transverse flow and the relation between symmetric and asymmetric collisions.

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Introduction

It is now well established that the collective flow in heavy-ion collision has the ability to pin down the nuclear equation of state (EOS). A complete understanding of the fragment flow can give us knowledge about the bulk properties of nuclear matter and the relation among pressure, temperature and density of the compressed nuclear matter. Last two decade observed a vigorous developments regarding in-plane flow or sideward flow of nuclear matter. The in-plane flow is a complex many body dynamics which is highly influenced by the incident energy and the mass of colliding partners. At low incident energies, the collective flow is negative as the phenomenon of fusion, fission and dynamical cluster decay dominates the physics. At higher incident energies, repulsive nucleon-nucleon (NN) scattering take a lead and the particles are forced to move towards forward hemisphere making collective flow positive.

By now, it is evident, that the reaction dynamics driven by the symmetric colliding nuclei is different from those of the asymmetric colliding nuclei [1]. The symmetric colliding nuclei corresponds to larger participant zone, which results in larger compression and temperature as compared to asymmetric colliding nuclei. This letter present the '*directed transverse momentum* $\langle P_x^{dir} \rangle$' for the symmetric and asymmetric reactions having same isotopic content (i.e., N/Z = 1 and 1.5). The same isospin content is assumed to reduce the isospin effects and to observe the direct role of mass asymmetry.

The Model

Our calculations are carried out within the framework of isospin dependent quantum molecular dynamics (IQMD) model. The IQMD[2] is a semi-classical model which describes the heavy-ion collisions on an event by event basis. For more details, see ref.[2].
In IQMD model, the centroid of each nucleon propagates under the classical equations of motion.

$$\frac{d\vec{r_i}}{dt} = \frac{dH}{d\vec{p_i}} \; ; \; \frac{d\vec{p_i}}{dt} = -\frac{dH}{d\vec{r_i}} \; . \quad (1)$$

The H referring to the Hamiltonian reads as:

$$H = \sum_i \frac{p_i^2}{2m_i} + V_{Yukawa}^{ij} + V_{Coul}^{ij} + V_{skyrme}^{ij} + V_{symm}^{ij}. \quad (2)$$

The symmetry energy strength is found to vary with the density of the system as [3]:

$$E(\rho) = E(\rho_o)(\rho/\rho_o)^{\gamma} \quad (3)$$

The behavior of symmetry energy away from saturation density is still a topic of debate. The results obtained at supra-densities made the situation more worse. For the present study, we take $\gamma = 0.66$.

Preliminary Results

For the present analysis, we simulated the reactions of $^{58}_{28}Ni$ + $^{58}_{28}Ni$, $^{48}_{20}Ca$ + $^{48}_{20}Ca$, $^{26}_{13}Al$ + $^{65}_{30}Zn$, and $^{40}_{18}Ar$ + $^{207}_{82}Pb$, at the incident energy of 100 MeV/nucleon. We present the directed transverse momentum $\langle P_x^{dir} \rangle$ quantized along the different rapidity bins, where $\langle P_x^{dir} \rangle$ is defined as [4].

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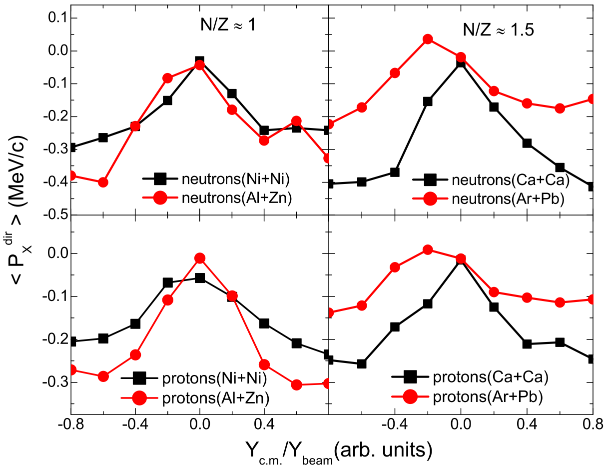

FIG. 1: $\langle P_x^{dir} \rangle$ as a function of $\frac{Y_{c.m.}}{Y_{beam}}$ for the neutrons (upper panels) and protons (lower panels). The incident energy is 100 MeV/nucleon.

$$\langle P_x^{dir} \rangle = \frac{1}{A} \sum_{i=1}^{A} sign\{y_i\} p_x(i). \qquad (4)$$

The impact parameter for analysis is b = 0.5 b_{max}, where b_{max} = 1.12 $(A_P^{1/3} + A_T^{1/3})$, A_P and A_T are the projectile and target mass respectively. We aim to correlate symmetric and asymmetric nuclear reactions with the directed transverse flow of nucleons. In fig. 1, we display the $\langle P_x^{dir} \rangle$ as a function of $Y_{red.}$, for $Y_{red.} = Y_{c.m.}/Y_{beam}$ where,

$$Y(i) \;=\; \frac{1}{2} ln \, \frac{[\; E(i) \;+\; p_z(i) \;]}{[\; E(i) \;-\; p_z(i) \;]}. \qquad (5)$$

E(i) and $p_z(i)$ are the total energy and the longitudinal momentum of the i^{th} particle respectively. The region (-0.1 $\leq \frac{Y_{c.m.}}{Y_{beam}} \leq$ 0.1) is specified as mid-rapidity region. On the other hand, $\frac{Y_{c.m}}{Y_{beam}} \neq 0$ corresponds to the spectator zone, $(\frac{Y_{c.m}}{Y_{beam}} < -0.1)$ corresponds to target like (TL) matter and $(\frac{Y_{c.m}}{Y_{beam}} > 0.1)$ corresponds to the projectile like (PL) matter.

For directed flow due to both the protons and neutrons we observed a Gaussian type behavior. The directed transverse flow remains negative through out the rapidity range except for the mid-rapidity zone (i.e. $|Y_{c.m.}/Y_{beam}| \leq 0.1$). The spectator zone (both target and projectile) with negative flow signifies the direction of particles in backward hemisphere. The present analysis is carried out at the incident energy of 100 MeV/nucleon where mean field and nucleon-nucleon (NN) scattering both plays a significant role. The effect of the asymmetric systems on the flow can be clearly observed.

The flow in asymmetric systems is more concentrated towards target zone due to the heavier target. The value of $\langle P_x^{dir} \rangle$ is more positive in case of asymmetric colliding nuclei. The significant variation of directed transverse flow in the target zone is due to the difference in the size of the target as compared to their respective projectiles in symmetric and asymmetric systems.

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