Neutron-proton P_t-differential sideward flow as a probe for symmetry energy.

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Introduction

The energy per particle of an asymmetric nuclear matter with density ρ and an isospin asymmetry $\delta = (\rho_n - \rho_p)$, where ρ_n and ρ_p are respectively, its neutron and proton densities, is determined by a parabolic law [1], i.e.,

$$E(\rho, \delta) = E(\rho, 0) + E_{symm}(\rho)\delta^2, \qquad (1)$$

where E(ρ,0) is the energy per particle of symmetric nuclear matter and E_{symm} is the nuclear symmetry energy. The symmetry energy which is the difference of the energy per nucleon between pure neutron matter and symmetric nuclear matter is taken as 32 MeV corresponding to normal nuclear matter density i.e. $\rho = 0.16\ fm^{-3}$. This understanding does not remain valid as one goes away from the normal nuclear matter density and symmetric nuclear matter [1]. The equation given below provides us the parametrization for the density dependence of symmetry energy [1].

$$E(\rho) = E(\rho_o)(\rho/\rho_o)^\gamma \qquad (2)$$

The larger (smaller) values of the parameter γ corresponds to stiff (soft) density dependence of the symmetry energy. For the present study we take $\gamma = 0.66$. It has been reported in the literature, that the flow of particles from compressed zone are highly influenced by the symmetry energy [2]. The neutron-proton sideward flow can give us a good understanding of various nuclear matter interactions inside hot and compressed highly interacting nuclear matter. The aim of present study, is to pin down the P_t-differential sideward flow for neutrons and protons which can act as a probe for the symmetry energy.

The Model

Our calculations are carried out within the framework of isospin dependent quantum molecular dynamics (IQMD) model. The IQMD [3] is a semi-classical model which describes the heavy-ion collisions on an event by event basis. For more details, see ref.[3].
In IQMD model, the centroid of each nucleon propagates under the classical equations of motion.

$$\frac{d\vec{r_i}}{dt} = \frac{dH}{d\vec{p_i}} \ ; \ \frac{d\vec{p_i}}{dt} = -\frac{dH}{d\vec{r_i}} \ . \qquad (3)$$

The H referring to the Hamiltonian reads as:

$$H = \sum_i \frac{p_i^2}{2m_i} + V^{ij}_{Yukawa} + V^{ij}_{Coul} + V^{ij}_{skyrme} + V^{ij}_{symm}. \qquad (4)$$

Preliminary Results

For the present analysis simulations are carried out for several thousand events at the incident energy of 100 MeV/nucleon for the systems ${}^{40}_{20}Ca + {}^{40}_{20}Ca$ and ${}^{124}_{50}Sn + {}^{124}_{50}Sn$. In fig.1, we display the transverse momentum (P_t), dependence of sideward flow for neutrons and protons for both the regions, i.e., target like (TL) and projectile like (PL) region.

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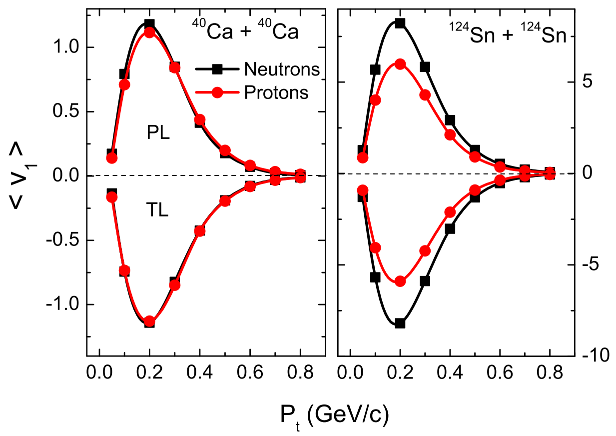

FIG. 1: Transverse momentum dependence of sideward flow v_1, for the projectile like (PL) region ($\frac{Y_{c.m}}{Y_{beam}} > 0.1$) (upper panels), and target like (TL) region ($\frac{Y_{c.m}}{Y_{beam}} < -0.1$) (lower panels).

Here, ($\frac{Y_{c.m}}{Y_{beam}} < -0.1$) corresponds to target like (TL) matter and ($\frac{Y_{c.m}}{Y_{beam}} > 0.1$) corresponds to the projectile like (PL) matter [4]. The region ($-0.1 \leq \frac{Y_{c.m.}}{Y_{beam}} \leq 0.1$) is specified as mid-rapidity region.
Here,

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

where E(i) and $p_z(i)$ are the total energy and the longitudinal momentum of the i^{th} particle respectively [4].

We observed that the peak value of v_1 is more for neutrons in both the regions (PL & TL). This signifies the larger sideward flow of neutrons around the reaction zone (or participant zone) as compared to the protons. This is due to the fact, that the symmetry energy induces pressure in the reaction system which results in larger sideward flow for neutrons. The neutrons are scattered more in sideward directions due to the symmetry energy repulsion as compared to the protons for which the symmetry energy is attractive [1].

The larger difference in the peak v_1 values for neutrons and protons in system $^{124}_{50}Sn$ + $^{124}_{50}Sn$ is due to the larger impact of symmetry energy because of larger neutron content, i.e., N/Z = 1.75. The effect of symmetry energy increases as we move away from the charge symmetric nuclear matter. This observation is of significant importance in order to probe the strength of symmetry energy as well as its density dependence. The effect of symmetry energy can also be observed in system $^{40}_{20}Ca$ + $^{40}_{20}Ca$, however, the impact is really mild.

Acknowledgement : This work has been supported by a grant from the Department of Science and Technology, Government of India [Grant No. SR/S2/HEP-0021/2010].

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