Role of the structural effects on the directed flow

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Introduction

Heavy-ion collisions (HIC) at intermediate energy can provide the notion about the behavior of nuclear matter at extremely different thermodynamical conditions. The directed flow plays a prominent role in extracting the information about the equation of state (EOS) and in medium nucleon-nucleon cross section of the excited nuclear matter. The directed flow (also alternatively known as in-plane-transverse flow) is studied by "*directed transverse momentum* $\langle p_x^{dir}\rangle$" which is defined as [1]

$$\langle p_x^{dir}\rangle = \frac{1}{A}\sum_{i=1}^{A} sign\{y(i)\}p_x(i), \qquad (1)$$

where $y(i)$ is the rapidity and p_x(i) is the momentum of i^{th} particle.

Directed transverse momentum $\langle p_x^{dir}\rangle$ increases with increase in incident energy and also there exist an incident energy at which it disappears that energy is known as the balance energy.

The structural effects like radius and density profile of colliding nuclei can play crucial role on the reaction dynamics at intermediate energies. Recently, Yong *et al.*, [2] studied initialization effects on the symmetry energy sensitive observables like free neutron to proton ratio (n/p), π^+/π^- ratio, and neutron to proton differential flow F_x^{n-p} in the context of IBUU model. A lot of theoretical and experimental efforts has been made to calculate the directed flow and its disappearance for systems ranging between ^{12}C + ^{12}C and ^{197}Au + ^{197}Au. There was always found a large discrepancy between the experimental and the theoretical calculated balance energies for lighter systems like^{12}C + ^{12}C [3]. It is also well known that structural effects affect the lighter system largely as compared to heavier systems. So here we aim to investigate the structural effects on the directed flow of ^{12}C + ^{12}C and ^{197}Au + ^{197}Au systems. The present study is carried out using isospin-dependent quantum molecular dynamics model [4].

The Model

The IQMD model has been used extensively for studying the isospin effects on large number of observables. The IQMD model is a N-body theory which simulates heavy ion reaction on event by event basis, hence preserves correlation and fluctuation of the reaction. The isospin degree of freedom enters into the calculations via symmetry potential, cross sections, and Coulomb interaction. In this model, nucleons are represented by Gaussian wave packets given by,

$$\psi_i(\mathbf{r},\mathbf{p}_i(t),\mathbf{r}_i(t)) = \frac{1}{(2\pi L)^{\frac{3}{4}}} e^{[\frac{i}{\hbar}\mathbf{p}_i(t)\cdot\mathbf{r} - \frac{(\mathbf{r}-\mathbf{r_i(t)})^2}{4L}]}. \qquad (2)$$

The baryons propagate using the classical equations of motion:

$$\frac{d\vec{r_i}}{dt} = \frac{d\langle H\rangle}{d\vec{p_i}}; \quad \frac{d\vec{p_i}}{dt} = -\frac{d\langle H\rangle}{d\vec{r_i}} \qquad (3)$$

where H stands for the Hamiltonian which is given by:

$$\begin{aligned}\langle H\rangle &= \langle T\rangle + \langle V\rangle \\ &= \sum_i \frac{p_i^2}{2m_i} + \sum_i\sum_{j>i}\int f_i(\vec{r},\vec{p},t) \\ &\quad V^{ij}(\vec{r}\,',\vec{r}) f_j(\vec{r}\,',\vec{p}\,',t) d\vec{r}\, d\vec{r}\,' d\vec{p}\, d\vec{p}\,'\end{aligned} \qquad (4)$$

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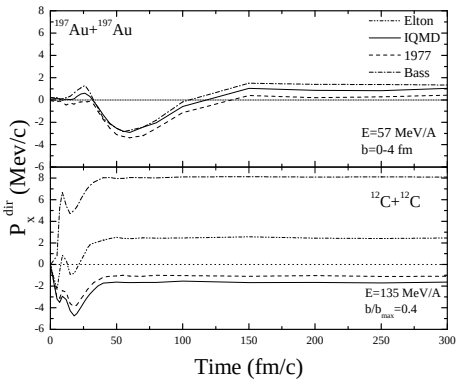

FIG. 1: The time evolution of directed transverse in-plane flow $< p_x^{dir} >$ for ^{197}Au + ^{197}Au and ^{12}C + ^{12}C for different radius parametrization. Various lines are explained in text.

The baryon potential V^{ij}, in the above relation, reads as

$$\begin{aligned} V^{ij}(\vec{r}\,' - \vec{r}) &= V^{ij}_{Sky} + V^{ij}_{Yuk} + V^{ij}_{Coul} + V^{ij}_{sym} \\ &= [t_1\delta(\vec{r}\,' - \vec{r}) + t_2\delta(\vec{r}\,' - \vec{r})\rho^{\gamma-1} \\ &\quad (\frac{\vec{r}\,' + \vec{r}}{2})] + t_3\frac{\exp(|(\vec{r}\,' - \vec{r})|/\mu)}{(|(\vec{r}\,' - \vec{r})|/\mu)} \\ &\quad + \frac{Z_i Z_j e^2}{|(\vec{r}\,' - \vec{r})|} \\ &\quad + t_4\frac{1}{\varrho_0}T_{3i}T_{3j}\delta(\vec{r_i}\,' - \vec{r_j}). \end{aligned} \quad (5)$$

Here Z_i and Z_j denote the charges of *ith* and *jth* baryon, and T_{3i} and T_{3j} are their respective T_3 components (i.e., 1/2 for protons and $-1/2$ for neutrons).

Results and discussion

We simulate the reactions of ^{12}C + ^{12}C and ^{197}Au + ^{197}Au using soft momentum dependent (SMD) equation of state and reduce isospin- and energy-dependent nucleon-nucleon (nn) cross section $\sigma = 0.8\,\sigma_{NN}{}^{free}$ at incident energy of 135 MeV/nucleon and 57 MeV/nucleon respectively.

In Fig. 1, we display the effects of different radius parametrization on time evolution of directed flow $< p_x^{dir} >$ for reactions ^{12}C+^{12}C and ^{197}Au+^{197}Au. Solid, dash, dash-dot ,dash-dot-dot lines represent the calculations performed using different radius parametrization used by IQMD [4], Blocki [5], Bass [6] and experimental value calculated for carbon by Elton [7] respectively. We can clearly see from the Fig. 1. that the structural effects like radius are more pronounced on the lighter system (^{12}C + ^{12}C) as compared to the heavier system (^{197}Au+^{197}Au). Hence the structural effects can play a very crucial role in calculating the balance energy for the lighter systems and also the balance energy calculated by taking care of the structural effects can explain the experimental data well.

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