Effect of neutron skin thickness on transverse flow in heavy-ion collisions

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Introduction

The availability of radioactive ion beams provide the opportunity to study the nuclei far from stability line and hence made it possible to determine the nuclear interaction radii of β-unstable nuclei. One can also study proton and neutron density distribution and neutron thickness (difference of neutron and proton root mean square radii). The neutron skin thickness is a very sensitive probe of measure of pressure difference that exists between neutrons and protons and is found to be sensitive to the symmetry energy and equation of state of nuclear matter [1]. Since neutron skin is composed of neutrons, hence it can affect the reaction dynamics and observables like collective flow and multifragmentation. In the present work, we aim to study the behavior of these observables towards different radii of initialized nuclei (initialization takes into account neutron skin). For a long time, it has been known that root mean square radius of the charge distribution increases less fast that $A^{1/3}$ [2]. In this direction, various parametrisations for radius have been proposed for past three decades. For present study, we have used the parametrisations given by Ngô and Ngô (1980), Denisov (2002) and Royer (2009). The present study is carried using isospin-dependent quantum molecular dynamics (IQMD) model, details of which can be found in Ref. [3].

Results and discussion

We simulate the reactions of ^{60}Ca + ^{60}Ca using soft equation of state. We use standard isospin- and energy-dependent nucleon-nucleon (nn) cross section $\sigma = 0.8\ \sigma_{NN}{}^{free}$. The reactions are followed till 100 fm/c for ^{60}Ca when transverse flow saturates.

The radius parametrisations according to Ngô-Ngô, Denisov and Royer are give below.

1. Ngô- Ngô(1980)

The nuclear radius R_i reads as [4]

$$R_i = \frac{NR_{ni} + ZR_{pi}}{A_i}\ \mathrm{fm}(i = 1, 2) \quad (1)$$

The equivalent sharp radius for protons and neutrons are given as

$$R_{pi} = r_{0_{pi}} A_i^{1/3}; R_{ni} = r_{0_{ni}} A_i^{1/3} \mathrm{fm}\ (i = 1, 2) \quad (2)$$

with

$$r_{0_{pi}} = 1.128;\ r_{0_{ni}} = 1.1375 + 1.875 * 10^{-4} A_i, \quad (3)$$

in fm. The above different radius formulas for the neutrons and protons take isotopic dependence into account.

2. Denisov (2002)

The effective nuclear radius R_i according to Denisov parametrisation (by taking 119 spherical and nearly spherical nuclei along β-stability line (from ^{16}O to ^{212}Po) is given as [5]

$$R_i = \quad R_{ip}\ (1 - \frac{3.413817}{R_{ip}^2}) + 1.284589 * \quad (4)$$
$$(I_i - \frac{0.4A_i}{A_i + 200})\ \mathrm{fm}\ (i = 1, 2) \quad (5)$$

where, proton radius R_{ip} is given by (8$\leq$ Z <

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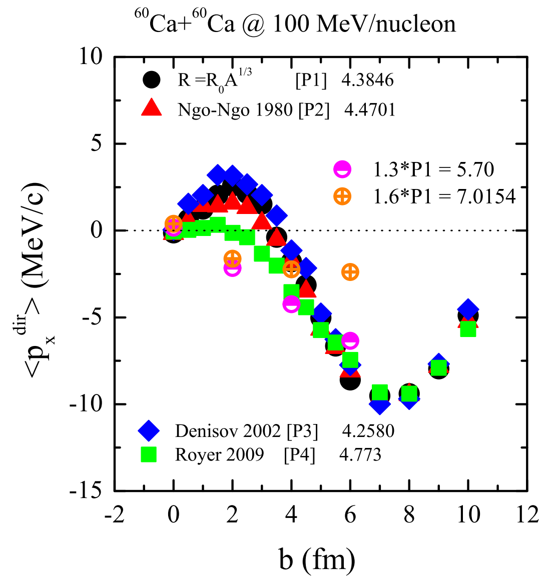

FIG. 1: The directed transverse in-plane flow $< p_x^{dir} >$ as a function of impact parameter for ^{60}Ca + ^{60}Ca for different radii of initialized nuclei. Various symbols are explained in text.

38)

$$R_{ip} = 1.240 A_i^{1/3}\{1+\frac{1.646}{A_i} - 0.191(\frac{A_i - 2Z_i}{A_i})\} \tag{6}$$

and

$$I_i = \frac{N_i - Z_i}{A_i} \ (i = 1, 2) \tag{7}$$

3. Royer (2009)

G. Royer in 2009 proposed a more precise formula for the radius given by [6]

$$R = 1.2332 A^{1/3} + 2.8961 A^{-2/3} - 0.18688 A^{1/3} I \tag{8}$$

in fm, with

$$I = \frac{N - Z}{A} \tag{9}$$

The normal radius parametrization R = R_0*$A^{1/3}$ is labelled as P1, whereas parametrizations of Ngô, Denisov and Royer are labelled as P2, P3 and P4, respectively.

In Fig. 1, we display the impact parameter dependence of $< p_x^{dir} >$ for ^{60}Ca + ^{60}Ca reactions for P1 (circles), P2 (triangles), P3 (diamonds) and P4 (squares). From figure, we see that for enhanced radius, flow decreases. Also, the change in flow occurs at central and semi-central collisions and disappears for peripheral colliding geometries. This is because of the fact that for enhanced radius of the nuclei, the density decreases and thereby lowering the effect of repulsive density-dependent forces and so flow reduces. At peripheral collisions, the effect of the different radius parametrizations disappears because of the reduction in the less overlapping region and so less density will be achieved and hence the effect of density-dependent forces will not alter much for different radius parametrizations. To further strengthen our point, we increase the radius P1 by 30% (half shaded circles) and 60% (crossed circles) and calculate the flow at b = 0, 2 ,4 and 6 fm for ^{60}Ca + ^{60}Ca. Again, we see that on increasing the radius flow decreases. This demonstrates that radius of initialized nuclei has significant effect on flow.

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