Are Isospin sensitive fragments sensitive towards binding energy clusterization algorithm ?

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Introduction

With the availability of radioactive beam facilities, isospin physics has attracted the whole of the nuclear community in last decade. In the efforts to reproduce the experimental data, many secondary algorithms coupled with dynamical models have been developed to study the nuclei near the drip line[1,2,3], but very few for nuclei away from drip line[3-7].

The most commonly and widely used algorithm depends on the spatial and momentum coordinates of the nucleons, is known as minimum spanning tree (MST) algorithm[3]. According to this method, two nucleons undergo the cluster formation if the relative distance ($|R_i$-$R_j|$) and relative momentum ($|P_i$-$P_j|$) between the nucleons is less than 3.5-4 fm and 250-268 MeV/c, respectively. MST method is further extended to isospin-dependent MST, in which the cut on the momentum space is kept same, but the cut on the spatial coordinates is constraint on the basis of type of particles. The distance between the different kind of particles is taken as follow: $|R_i^p$-$R_j^p|$=3 fm, $|R_i^n$-$R_j^p|$=$|R_i^n$-$R_j^n|$=6 fm[8].

Since the MST method only depends on the constraints from position and momentum, it seems to be worried about the stability of fragments due to the formation of artificial weakly bound fragments. To avoid from this problem, more complicated methods like Stimulated Annealing Clusterization Algorithm (SACA)[7], Early Cluster Recognization Algorithm (ECRA)[7] were also developed. In its simpler form, an average binding energy cut of 4 MeV/nucleon [9] can be applied. This method was found to be as simple as MST and found to reproduce the experimental data just like the complicated methods SACA and ECRA etc. The extensive studies with different clusterization methods are done for the yield of different kind of fragments[2,3,8,9], while flow parameters are poorly known with this type of methods[1,6,10].

The main problem with the study in the literature is that isospin physics with directed and elliptic flow is either studied from the nucleon phase space or by using the simple MST method. It is worth mentioning that one can not guarantee about the stability of fragments formed with simple MST method. Due to the worry about the stability of fragments, it is the prime need of the present time to study the importance of Isospin physics from directed and elliptic flow with the stable fragments.

In the present study, first the stable fragments are formed by applying the binding energy cut on the pre-clusters formed with the simple MST method. Afterward, the sensitivity of the isospin sensitive fragments n, p, ^{3}H and ^{3}He directed flow is studied from low towards the high incident energy with the variation in isospin asymmetry of the reaction systems.

Methodology

This method is a modified version of the normal MST and old MSTB method. The difference between old MSTB and this MSTB is the addition of energy from momentum dependent interactions as well as symmetry energy. The procedure is as follow: the phase space obtained from IQMD is analyzed with simple MST method and pre-clusters are sort out. Since we are not aware about the stability of pre-clusters formed at this stage, the pre-clusters formed from the simple MST are now subjected to the binding energy condition as follow:

$$\frac{1}{N_f}\sum_{\alpha=1}^{N_f}\left[\sqrt{\left(\mathbf{p}_\alpha-\mathbf{P}_{N_f}\right)^2+m_\alpha^2}-m_\alpha+\frac{1}{2}\sum_{\beta\neq\alpha}^{N_f}V_{\alpha\beta}\right]<-E_{Bind}.$$

Here, we take E_{bind} = 4.0 MeV/nucleon if $N_f \geq 3$ and E_{bind} = 0 otherwise. In this equation, N_f is the number of nucleons in a fragment, P_{Nf} is the average momentum of the nucleons bound in the fragment.

Results and Discussions

We have simulated several thousands of events for the reactions of $^{112}Sn+^{112}Sn$ and $^{124}Sn+^{124}Sn$ between the incident energy 50 and 600 MeV/nucleon for the nearly central collisions using the dynamical model coupled with MST and MSTB algorithms. The soft momentum dependent equation of state with soft symmetry energy and isospin-energy dependent cross sections is employed.

The method used to study the directed transverse in-plane flow P_x^{dir} is as follow :

$$\langle P_x^{\mathrm{dir}} \rangle = \frac{1}{A} \sum_{i}^{A} \mathrm{sign}\{Y(i)\} P_x(i),$$

where Y(i) is the rapidity distribution and P_x (i) is the transverse momentum of the i^{th} particle in x-direction. This P_x^{dir} is defined over entire rapidity region and therefore expected to present an easier way of measuring the in-plane flow.

In Fig. 1 , the isospin asymmetry dependence of flow quantity P_x^{dir} is plotted for isobaric pairs n, p with MST and MSTB algorithm from 50 to 600 MeV/nucleon. In Fig.1, with increase in the incident energy, isospin asymmetry dependence of directed flow for n, p is found to affect more by the method of clusterization in comparison with the type of particles. In all panels, protons (neutrons) have more (less) positive directed flow with MST as well as MSTB method. This is due to the contribution of Coulomb interactions in protons production. The directed flow of protons as well as neutrons becomes more positive with MSTB over MST towards the high incident energy. This is true because of more and more unstable fragments with MST towards the high incident energy. The MSTB breaks the unstable fragments into free particles and hence dominance of collisions. Moreover, higher positive flow of neutrons towards the high incident energy can act as a tool for isospin dependent cross section. Furthermore, these findings suggest a shift in the balance energy with different kind of fragments.

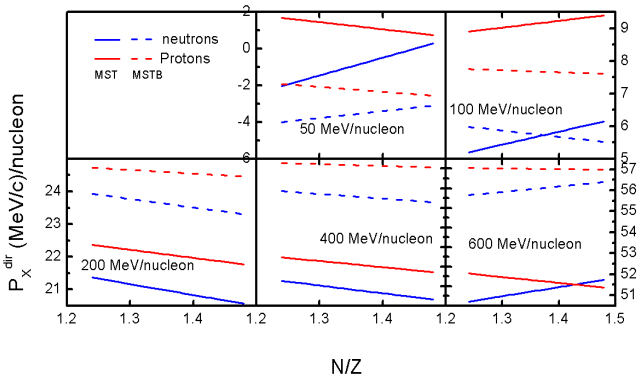

Fig. 1 Isospin asymmetry dependence of directed flow for isobaric pair neutrons -protons with MST and MSTB method. The different panels are at different incident energy ranging from 50 to 600 MeV/nucleon.

The dependence of the directed flow of isobaric pair ^3H-^3He on the MSTB in comparison to n-p with the increase of incident energy as well as isospin of the reaction systems is in progress. This can be proven as a robust approach for understanding the high density behavior of isospin physics or symmetry energy.

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