Dynamical Study of Multifragmentation and Related Phenomena in Heavy-Ion Collisions

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1. Introduction & Methodology

Study of heavy-ion collisions at intermediate energies has now become important tool to investigate reaction mechanism behind collective expansion and origin of fragments. Apart from this, it also becomes possible to infer nuclear matter equation of state (EoS) [1–3].

For the present thesis work, we shall employ *quantum molecular dynamics* (QMD) model [4] to simulate the nucleus-nucleus collisions. This model is well suited to study A-particles system where nucleon-nucleon correlations become important during the collision process. The QMD approach treats the nucleons as gaussian wave packets with total nuclear wave function given as:

$$\begin{aligned} \Phi &= \prod_{i=1}^{A} \psi_i(\mathbf{r}, \mathbf{r}_i, \mathbf{p}_i, t), \\ &= \prod_{i=1}^{A} \frac{1}{(2\pi L)^{3/4}} e^{-(\mathbf{r}-\mathbf{r}_i(t))^2/4L} \cdot e^{\frac{\iota}{\hbar}\mathbf{p}_i(t)\cdot\mathbf{r}} \end{aligned} \quad (1)$$

Note that antisymmetrization is neglected here. The width of gaussian wave packet is taken to be independent of time with value $L = 1.08\ fm^2$. The total Hamiltonian of the A-particles system is given as:

$$\langle H \rangle = \sum_{i=1}^{A} \frac{\mathbf{p}_i^2}{2m_i} + V^{Sk} + V^{Col} + V^{Yuk} \quad (2)$$

The interaction potential in Eq.(2) consists of density dependent Skyrme interaction supplemented with Coulomb and Yukawa potentials.

2. Results and discussions

In the first part of thesis, we shall deal with fragment emission in central collisions studied as a function of beam energy and system mass. Central collisions are also important candidate in view of exploring collective expansion and squeeze out phenomena [3]. We have simulated the central collisions of $^{20}Ne + ^{20}Ne$, $^{40}Ar + ^{45}Sc$, $^{58}Ni + ^{58}Ni$, $^{86}Kr + ^{93}Nb$, $^{129}Xe + ^{124}Sn$, and $^{197}Au + ^{197}Au$. Our model calculations for the multiplicity of intermedi-

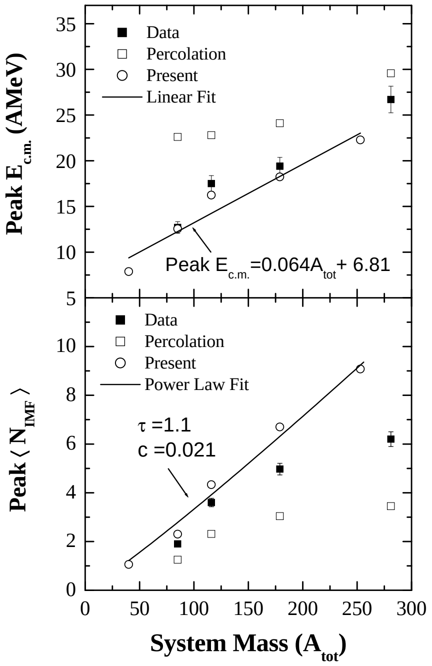

FIG. 1: Peak $E_{c.m.}$ and peak $\langle N_{IMF} \rangle$ as a function of total system mass A_{tot}. Open and solid squares depict the percolation calculations and experimental data points, respectively [5].

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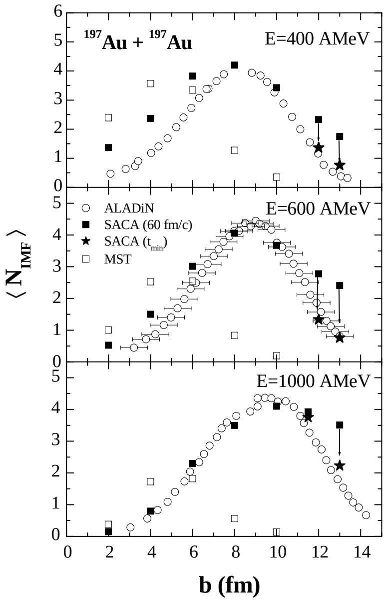

FIG. 2: The mean IMF multiplicity $\langle N_{IMF} \rangle$ vs impact parameter b for the reaction of $^{197}Au+^{197}Au$ at 400, 600 and 1000 AMeV, respectively.

ate mass fragments (IMFs) as a function of beam energy available in the center-of-mass frame agree with the experimental trends observed on MSU 4π-array set-up. We further plot the peak $E_{c.m.}$ (at which maximal emission occurs) and peak IMF multiplicity as a function of total system mass A_{tot} as shown in Fig.1. Interestingly, peak IMF multiplicity is observed to follow power law of form: cA_{tot}^{τ}, with exponent τ close to unity [6].

Next we try to understand the clusterization mechanism in spectator matter fragmentation using *simulated annealing clusterization algorithm* (SACA) advanced by Puri *et al* [7, 8]. In this approach, pre-clusters obtained with *minimum spanning tree* (MST) method are subjected to a binding energy condition [7, 8]:

$$\zeta_a = \frac{1}{N_f}\sum_{i=1}^{N_f}\left[\sqrt{\left(\mathbf{p}_i - \mathbf{P}_{N_f}^{cm}\right)^2 + m_i^2} - m_i + \frac{1}{2}\sum_{j\neq i}^{N_f} V_{ij}\left(\mathbf{r}_i, \mathbf{r}_j\right)\right] < -E_{bind}, \quad (3)$$

with $E_{bind} = 4.0$ MeV if $N_f \geq 3$, else $E_{bind} = 0$. In this equation, E_{bind} is the fragment's binding energy per nucleon, N_f is the number of nucleons in a fragment, and $P_{N_f}^{cm}$ is the center-of-mass momentum of the fragment. Using this approach, we study the spectator matter fragmentation in peripheral $^{197}Au+^{197}Au$ collisions as a function of impact parameter. The IMFs yields obtained using SACA method are then compared with conventional MST algorithm and ALADiN experimental data (See Fig.2). Remarkably, SACA calculations explain the universality feature in IMF production in the incident energy range 400-1000 AMeV quite well [8]. Earlier recognition of fragments structure (around 60 fm/c) also points towards dynamical origin of fragments. In other words, system doesn't have enough time span to undergo complete equilibration.

We shall also highlight the importance of momentum dependent interactions in probing nuclear EoS via intermediate energy heavy-ion collisions. Estimation of baryonic entropy shall also be attempted within QMD approach using composite particles yield ratios.

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