Study of fragmentation with clusterization algorithm based on temperature-dependent binding energies

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Introduction

Dynamical models such as Quantum Molecular Dynamics (QMD) and Boltzmann-Uehling-Uhlenbeck (BUU) models undergo a tremendous growth in understanding the multifragmentation phenomenon. All such dynamical models give the phase space of nucleons and one has to use the secondary algorithms to clusterize the nucleons. The most widely used algorithm to identify the fragments is based on the spatial correlations among nucleons and has been dubbed as Minimum Spanning Tree (MST) [1] method. Since MST method is based on the spatial correlations only, as a result, one was worried about the stability of the fragments. Later on, number of attempts are reported where improvements over the conventional MST method were done [1, 2]. The most prominent ones include additional constraints in the momentum space or subjecting each fragment to either constant or realistic binding energy (derived from the modified Bethe-Weizsäcker mass formula [3]) checks. The binding energy cut will filter the loosely bound fragments detected by the MST method. The above proposed binding energy checks use cold matter binding energies. At the same time, the vast and rich literature on nuclear multifragmentation clearly suggests that the fragments at freeze out stage are not cold and are excited [4]. With this in mind, we aim to see the role of temperature in governing fragmentation pattern by considering them in a thermal bath. For the respective study, fragments will undergo temperature-dependent binding energy check rather than cold matter binding energy constraint during the clusterization. The phase space is generated using Quantum Molecular Dynamics (QMD) [1]model. Brief details of the model are discussed below.

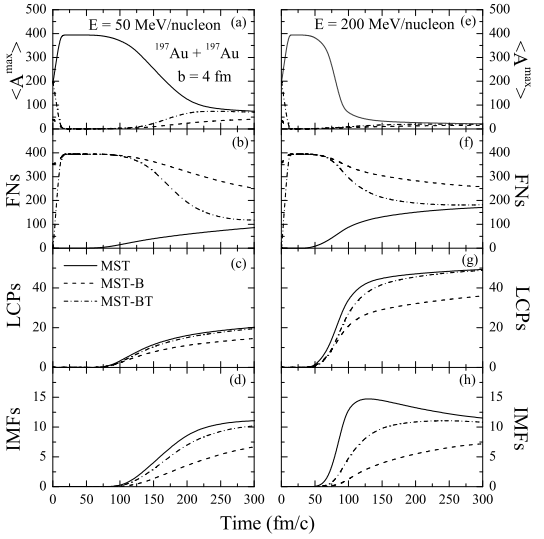

FIG. 1: The time evolution of the mean size of heaviest fragment $< A^{max} >$, multiplicities of free nucleons (FNs), light charged particles (LCPs) and intermediate mass fragments (IMFs) for the reactions of ^{197}Au+^{197}Au at 50 MeV/nucleon (left panels) and 200 MeV/nucleon (right) at an impact parameter of 4 fm.

The Model

The *quantum molecular dynamics* model is a time dependent n-body model to generate the phase space of nucleons on an event-by-event basis. Firstly, we use secondary algorithm, namely the MST method to clusterize the nucleons. We then modify the MST method by demanding each fragment to fulfill

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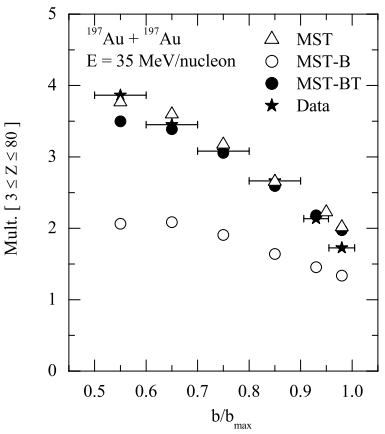

FIG. 2: The multiplicity of fragments [$3 \leq Z \leq 80$] as a function of reduced impact parameter for the reaction of ^{197}Au+^{197}Au at an incident energy of 35 MeV/nucleon. The experimental data has been extracted from Ref. [7]

the binding energy criteria:

$$\zeta_i = \sum_{i=1}^{N^f} [\frac{(\vec{p}_i - \vec{p}_{cm})^2}{2m} + \sum_{i<j}^{N^f} V_{ij}] < E_{bind}^{thermal}. \quad (1)$$

In this equation, N^f is the number of nucleons in a fragment and $\vec{p}_{cm}$ is the center-of-mass momentum of that fragment. Any fragment failing to satisfy the above constraint is treated as a bundle of free nucleons. As stated earlier, past attempts were made either by having a constant binding energy or using binding energy of the cold matter. We here rather use temperature-dependent binding energies ($E_{bind}^{thermal}$) proposed by Davidson *et al.* [5]) to identify the fragments (labelled as MST-BT). The use of binding energy at T = 0 MeV is labelled as MST-B.

Results and discussion

We simulated the reaction of ^{197}Au+^{197}Au at incident energies of 50 and 200 MeV/nucleon at an impact parameter of 4 fm using a soft equation of state and energy-dependent nucleon-nucleon cross section. In Fig. 1, we display the time evolution of the largest fragment $< A^{max} >$, multiplicities of free nucleons (FNs), light charged particles (LCPs) [$2 \leq A \leq 4$] and intermediate mass fragments (IMFs) [$5 \leq A \leq 65$] calculated using MST, MST-B and MST-BT methods. We found that MST-B gives false impression that the fragments obtained by conventional MST approach are not properly bound (as fragments are excited so use of cold binding energy is absurd), and there is a significant deviation in the results compared to the ones obtained using MST method. Very interestingly, we see that the results with MST-BT (thermal binding energy cut) method agree very well with the results of MST method. Also, significance of MST-BT lies in the fact that it can find the fragment structure much earlier in time and the fragments thus filtered are more close to the reality. Our detailed analysis for different masses, energies as well as colliding geometries clearly indicates significant role of the thermal binding energies over the cold binding energies [6]. In Fig. 2, a comparison of theoretical calculations with experimental data for the reaction of ^{197}Au + ^{197}Au at an incident energy of 35 MeV/nucleon [7] is also presented, which signifies the role of thermal binding energies over cold binding energies.

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