Dynamical transport model and freezeout concept at intermediate heavy ion reactions

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In the intermediate heavy ion collisions, intermediate mass fragments (IMFs) are copiously produced through a multifragmentation process. Isotope distribution of these IMFs, especially their widths, is mainly governed by the symmetry energy at the density and temperature of the fragment formation. In other words, the isotope distribution can be used as a probe for the density and temperature of the hot fragmenting nuclear matter through the symmetry energy.

To model the multifragmentation process, a number of different models have been developed in two distinct scenarios at this energy range. One is based on a transport model, in which nucleon propagation in a mean field and nucleon-nucleon collisions under Pauli-blocking are two main ingredients. No thermal or chemical equilibrium are assumed for IMF production. The other is based on a statistical multifragmentation under thermal and chemical equilibriums at a freezeout volume. These two modelings are quite different, but they can account reasonably well for many characteristic properties experimentally observed. In transport models, simulated events for a given reaction system show large fluctuations in space and time for the formation of IMFs. This large fluctuation causes difficulty in identifying a unique freezeout volume and time on an event by event basis. However, there are some evidences that statistical equilibrations are established before or at the time of the IMF production when the observables are averaged over many events.

In a series of our recent works [1-4], the isotopic yield ratio method has been applied to extract the density and temperature of the fragmenting source. In the present study, we apply the same method to AMD events in a wider incident energy range. AMD events are generated for central collisions (b = 0 fm) of ^{40}Ca + ^{40}Ca at 35, 50, 80, 100, 140, and 300 MeV/nucleon, using Gogny interactions having different density dependencies of the symmetry energy term, i.e., the standard Gogny interaction which has an asymptotic soft symmetry energy (g0), another with an asymptotic stiff symmetry energy (g0AS), and the other with an asymptotic superstiff symmetry energy (g0ASS). For each set of parameters, more than 10,000 events are generated up to t = 300 fm/c and IMFs are identified at that time with a coalescence technique with the radius of Rc = 5 in the phase space.

The extracted density and temperature values in the incident energy range of 35 to 300 A MeV are summarized in Fig. 1. The extracted density values (filled circles) are plotted together with the maximum density created during the collisions (open circles) in (a). The maximum density values are calculated at the origin of the center of mass system and normalized by the density of the initial nuclei at t = 0 fm/c . They increase monotonically from ρ/ρ0 ~ 1.3 at 35 MeV/nucleon to ~1.8 at 300 MeV/nucleon. On the contrary, the extracted density values for the fragmenting source distribute at ρ/ρ0 is ~0.65 to 0.7. The extracted temperature values (red dots connected by lines) in (b) [and (c)] show also more or less a constant distribution, and T0 values of 5.9 to 6.5 MeV are obtained. These flat distributions of the extracted density and temperature values indicate that IMFs are in average formed at a later stage when the hot nuclear matter reaches at a “freezeout” volume by the expansion. This freezeout volume is not assumed in any transport models, but assumed generally in statistical multifragmentation models.

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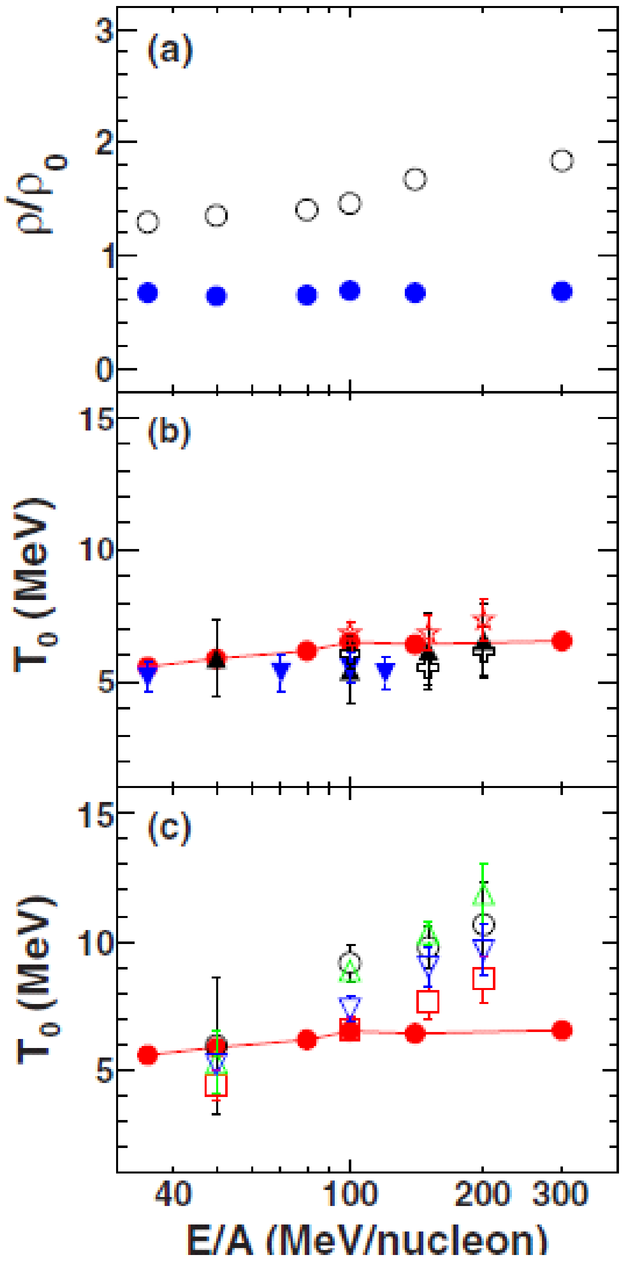

FIG. 1. (a) Extracted ρ/ρ0 values (filled circles) and the maximum ρ/ρ0 values (open circles) as a function of the incident energy. (b) Extracted T0 values from the final rounds (red dots connected by lines). Filled triangles (black) and filled inverted triangles (blue) are taken from Serfling et al. and Xi et al., respectively. Open cross and starts are the results from CLi and CC thermometer. (c) The extracted results and those of double ratio thermometers mostly related to the H and He isotopes except BeLi. Those are BeLi (black circles), Hedt (red squares), HeLi (green triangles), and tHeLiBe (blue inverted triangles).

[1] W. Lin *et al.*, Phys. Rev. C **89**, 021601(R) (2014).
[2] X. Liu *et al.*, Phys. Rev. C **90**, 014605 (2014).
[3] X. Liu *et al.*, Nucl. Phys. **A933**, 290 (2015).
[4] W. Lin *et al.*, Phys. Rev. C **90**, 044603 (2014).