Dynamical and statistical nature of heavy ion reactions at 47A MeV

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In order to investigate the dynamics and thermodynamics in light ion and heavy ion collisions near the Fermi Energy, we compared the yield, energy spectra and angular distribution of products observed from different reaction systems at the same incident energy. To do this, a series of heavy ion reaction systems have been studied using a 4π detector array NIMROD at the Cyclotron Institute at Texas A&M University. The systems studied, all at an incident energy of 47A MeV, are shown in Table I.

Table I. Reaction List.

$^{1}H + ^{112}Sn$	$^{1}H + ^{124}Sn$
$^{2}H + ^{112}Sn$	$^{2}H + ^{124}Sn$
$^{3}He + ^{112}Sn$	$^{3}He + ^{124}Sn$
$^{4}He + ^{112}Sn$	$^{4}He + ^{124}Sn$
$^{10}B + ^{112}Sn$	$^{10}B + ^{124}Sn$
$^{20}Ne + ^{112}Sn$	$^{20}Ne + ^{124}Sn$
$^{40}Ar + ^{112}Sn$	$^{40}Ar + ^{124}Sn$
$^{64}Zn + ^{112}Sn$	$^{64}Zn + ^{124}Sn$

In the analysis, we separated emission resulting from nucleon-nucleon collisions from those resulting from the thermalized system using three source emission model. In order to obtain information, such as the temperature evolution, in-medium nucleon-nucleon cross sections, isospin effects, and symmetry energy for the dynamic evolution of the hot systems, particle multiplicity distributions at different velocities has been studied. Emphase has been made on the symmetry potential, including the density dependence, by comparing at different densities and different system N/Z ratios of emitting sources produced at the interaction region during the reaction process.

Several promising probes for the symmetry energy term at subnormal density have been proposed. One of these is the ratio between the yields of t and ^{3}He. This ratio has been shown as a sensitive probe for the symmetry energy using different simulation codes [1-3,5,6].

We classify events into four different groups which correspond to different collision violence using the multiplicity distribution, as shown in Fig. 1 in the case for $^{64}Zn+^{124}Sn$ reaction system. We currently focus on the most violent events in the 30% largest light particle multiplicity window.

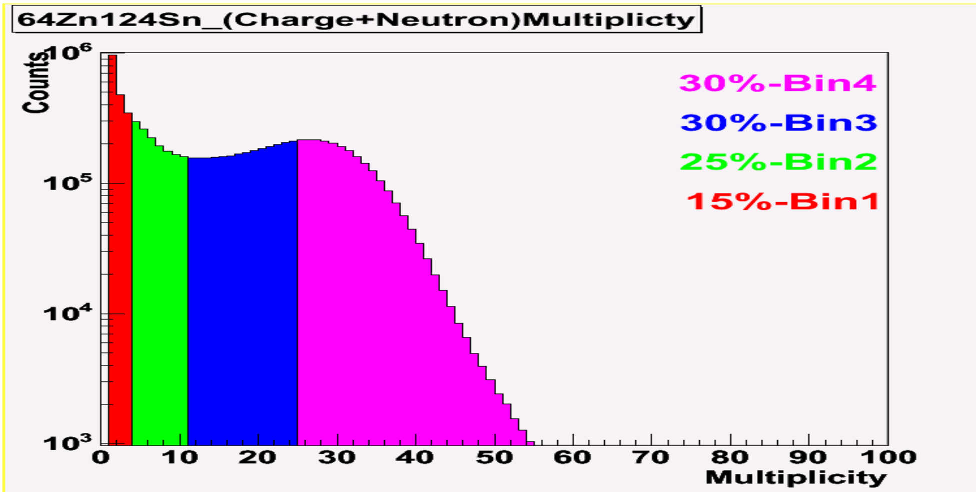

Figure 1. Multiplicity distribution of reaction system ^{64}Zn+^{124}Sn

Using those events we evaluated different observables in the invariant 2-D velocity plots for each reaction system, so that the physics quantities of interest can be studied in the different velocity regions.

In the following we show results of the evolution of t/^{3}He ratio, temperature and isoscaling parameters. In Fig.2 the t/ ^{3}He ratio is plotted for the systems ^{40}Ar+^{112}Sn and ^{40}Ar+^{124}Sn in the left and right panels, respectively. Both of the plots show that, from the low velocity region to the high velocity region, the t/^{3}He ratio is decreasing. Although the N/Z ratios of those two systems are different, the dynamic evolution of systems should be similar because of similar reaction systems and the same incident energy. The difference in the t/^{3}He ratio may, therefore, reflects the difference in the symmetry energy term [5].

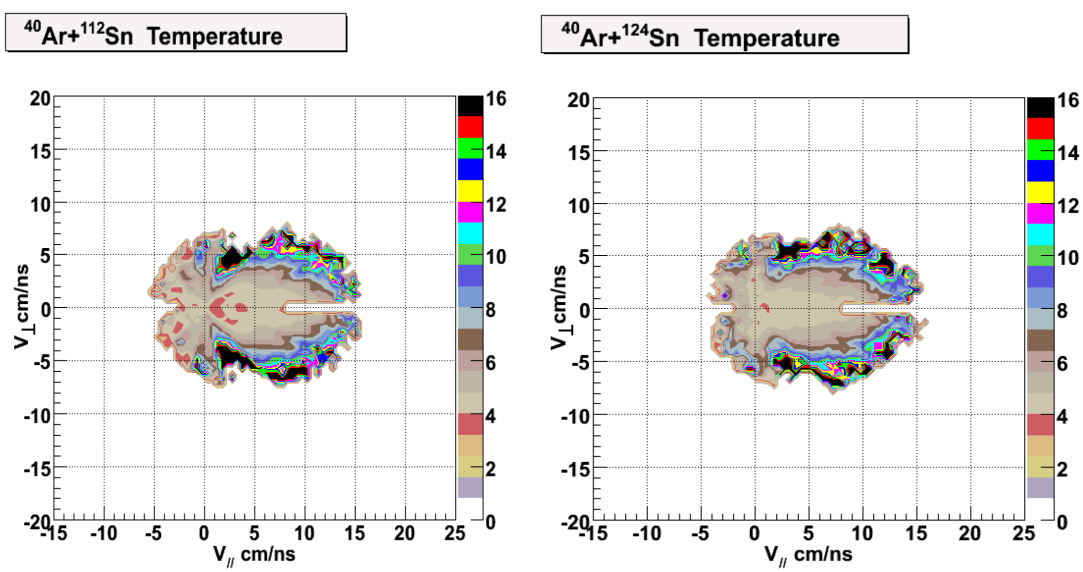

Figure 3. Temperature evolution in invariant veclotiy plot.

To characterize the temperature evolution of the system, the double isotope temperature has been calculated using the yields of d, t, ^{3}He, and ^{4}He clusters in each segment of the invariant veclocity plot. The results for the systems ^{40}Ar+^{112}Sn and ^{40}Ar+^{124}Sn are shown in Fig. 3. At the same velocity regions, the temperature in both of the systems looks very similar and increases as the velocity increases, which indicates that high velocity particles are emitted at higher temperatures and, therefore, at an early stage of the reaction.

The isoscaling parameter of the two systems was also calculated for Z = 1 and Z = 2 particles. Isotope or isotone yield ratios were fitted globally to obtain α and *β*. In Fig.4 , the isoscaling parameters α are plotted in 2-D invariant surface velocity frame [7]. Alpha values are different in the different velocity regions. The alpha values are high in low velocity regions, and gradually decrease toward high velocity regions which may reflect the N/Z ratios of different sources. The alpha parameter at a given velocity segment is related to the local temperature and symmetry energy. Further detailed study to determine the symmetry energy is now underway.

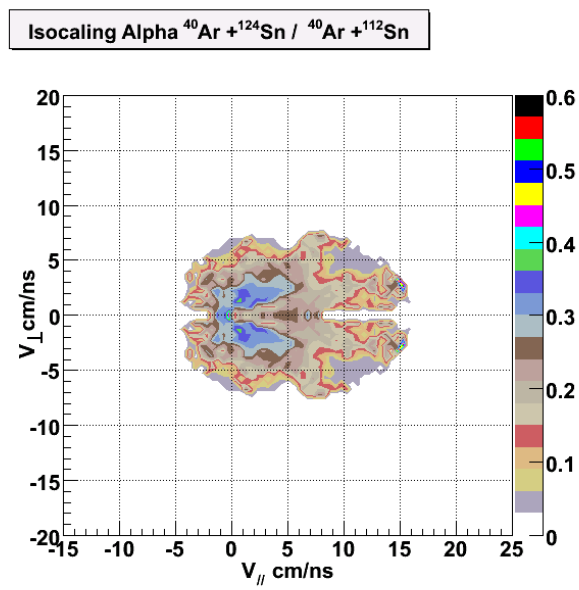

Figure 4. Alpha paramaters extracted from systems ^{40}Ar+^{112}Sn and ^{40}Ar+^{124}Sn.

We also use AMD model for better understanding of the reaction mechanics and the nature of hot nuclear matter. We conintune our analysis of symmetry free energy and density evolution in the invariant velocity frame.

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