DREB2018 – 10th International Conference on Direct Reactions with Exotic Beams

Contribution ID: **99** Type: **Poster Contribution**

# Two novel determinations of nuclear density, temperature, symmetry energy

Nuclear symmetry energy, temperature and density at the time of the intermediate mass fragment formation are determined using two novel methods, i.e., a self-consistent method and a chemical potential method.

(1) In a self-consistent manner, the yields of primary hot fragments are experimentally reconstructed for multi-fragmentation events in the reaction system $^{64}$Zn + $^{112}$Sn at 40 MeV/nucleon. Using the reconstructed hot isotope yields and an improved method, based on the modified Fisher model, symmetry energy values relative to the apparent temperature, $a_{sym}/T$, are extracted. The extracted values are compared with those of the anti-symmetrized molecular dynamics (AMD) simulations, extracted in the same way as that for the experiment, with the Gogny interaction with three different density-dependent symmetry energy terms. $a_{sym}/T$ values change according to the density-dependent symmetry energy terms used. Using this relation, the density of the fragmenting system is extracted first. Then symmetry energy and apparent temperature are determined in a self consistent manner in the AMD model simulations. Comparing the calculated $a_{sym}/T$ values and those of the experimental values from the reconstructed yields, $\rho/\rho_0 = 0.65 \pm 0.02$, $a_{sym} = 23.1 \pm 0.6$ MeV and $T = 5.0 \pm 0.4$ MeV are evaluated for the fragmenting system experimentally observed in the reaction studied.

(2) In the chemical potential method, ratios of differential chemical potential values relative to the temperature, $(\mu_n-\mu_p)/T$, extracted from isotope yields of thirteen reaction systems at 40 MeV/nucleon are compared to those of a quantum statistical model to determine the temperature and symmetry energy values of the fragmenting system. The experimental $(\mu_n-\mu_p)/T$ values are extracted based on the Modified Fisher Model. Using the density value of $\rho/\rho_0=0.56$ from the previous analysis, the temperature and symmetry energy values of $T=4.6 \pm 0.4$ MeV and $a_{sym}=23.6 \pm 2.1$ MeV are extracted in a frame work of a quantum statistical model. These values agree well with those of the previous work, in which a self-consistent method is utilized with AMD simulations.

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