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Isoscaling behavior studied by HIPSE model*

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Abstract The isoscaling behavior in the reaction system of ^{58,64}Ni + ^{9}Be has been studied by using the heavy-ion phase-space exploration(HIPSE) model. The extracted isoscaling parameters α and β for both heavy and light fragments for HIPSE model calculations are in good agreement with recent experimental data. The investigation shows that the parameters in the HIPSE model have some effect on the isoscaling parameter. The isoscaling parameters for hot and cold fragments have been extracted.

Key words isosacling, HIPSE, evaporation effect

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In a series of recent papers ,the scaling properties of cross-sections for fragment production with respect to the isotopic composition of the emitting systems were investigated[1—4]. More precisely ,to quantify the comparison of the isotope yields $Y(N,Z)$ obtained in reactions with different isospin asymmetry, the ratio $R_{21}=Y_2(N,Z)/Y_1(N,Z)$ is used. By convention, 2 denotes the more neutron-rich system. In multifragmentation events, such ratios are shown to obey an exponential dependence of the neutron number N or proton number Z characterized by three parameters α, β and C:

$$R_{21}(N,Z)=\frac{Y_2(N,Z)}{Y_1(N,Z)}=C\exp(\alpha N+\beta Z). \qquad (1)$$

In ground-canonical approximation, $\alpha=\Delta\mu_{\rm n}/T$ and $\beta=\Delta\mu_z/T$ where $\Delta\mu_{\rm n}$ and $\Delta\mu_z$ are the differences between the neutron and proton chemical potentials for two reactions. C is an overall normalization constant. So far, the isoscaling behavior has been studied experimentally and theoretically for different reaction mechanisms[5—7]. However, most studies focus on light particles. A few studies on the heavy projectile-like residues in deep elastic collisions and fission fragment have been reported[8]. In this paper, we concentrate our attentions on the isoscaling features for projectile-like fragments in the framework of Heavy Ion Phase Space Exploration(HIPSE) model. HIPSE parameters dependence and effect of evaporation on the isoscaling parameters will also be investigated.

The Heavy Ion Phase Space Exploration (HIPSE) model[9] mainly describes nuclear collisions in the intermediate energy range. Based on a macroscopic-microscopic "phenomenology", the model accounts for both dynamical and statical aspects of nuclear collisions. Nuclear reaction, as described by the HIPSE model, can be separated into three stages: approach of the projectile and the target, fragment formation, and the cluster propagation. At the minimal distance of approach, the participant and spectator regions are obtained using simple geometrical considerations. Nucleons outside the overlap region define the Quasi-Projectile and Quasi-Target spectators. Then two

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physical effects, direct nucleon-nucleon collision and nucleon exchange, are treated in a simple way. After these preliminary steps, clusters are formed using a coalescence algorithm and propagated. Before freeze-out is reached, the two nuclei fuse and the properties of compound system are calculated if two fragments cannot separate because their relative energy is lower than the fusion barrier. This feature leads, in general, to a large Final State Interaction (FSI). Once all the FSIs are processed, the nuclei cannot exchange particles anymore and chemical-freeze-out is reached. At this stage, the total excitation energy can be determined and shared among fragments. Then the partition is ready for the after-burner phase. The decay is achieved using the SIMON event generator[10]. There are three important parameters in the model: the percentage of nucleons transferred, $x_{\rm tr}$, between the projectile and target, the parameter $\alpha_{\rm a}$ which describes the hardness of the potential, and the percentage of nucleon-nucleon collisions in the overlap range, $x_{\rm coll}$.

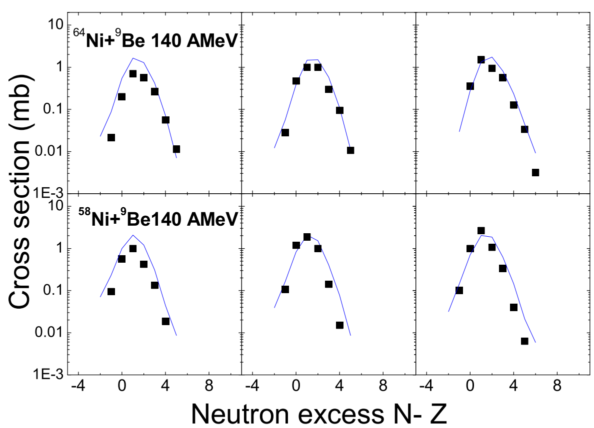

Fig. 1. Comparison of isotopic distributions between the HIPSE model and the experimental data. Fragment production cross sections of 140 MeV/nucleon ^{64}Ni+^{9}Be (upper panel) and 140 MeV/nucleon ^{58}Ni+^{9}Be (lower panel) by HIPSE model (solid line) are compared to experimental results. The squares are the experimental data taken from Ref. [11].

In order to study the isoscaling effect in projectile fragmentation, the reaction of ^{64,58}Ni $+^{9}$ Be at 140 MeV/nucleon was simulated by HIPSE model. Since HIPSE's parameters were energy dependent, using simple functions, the values of $\alpha_a = 0.55$, $x_{\rm tr} = 0.09$, $x_{\rm coll} = 0.18$ were chosen for beam energy of 140 MeV/nucleon. HIPSE model can describe the isotopic distribution well. We compare the experimental fragment production cross sections with that predicted by the HIPSE model. The comparison for $Z = 9-11$ from the reaction is shown in Fig. 1. From Fig. 1, we can see that the HIPSE model reproduce the experimental data quite well not only for shape but also for peak position.

To study the isoscaling effect, we extract the yield ratio $R_{21}(N,Z)$ obtained with HIPSE model for ^{64,58}Ni+^{9}Be system. Fig. 2 (left) shows the yield ratios of final fragments after sequential decays for selected isotopes and isotones, calculated by HIPSE model, as a function of neutron number N (upper panel) and proton number Z (lower panel). The different isotopes and isotones considered are shown by alternating filled and open symbols for triangle. From this figure we can observe that the ratio for each isotope Z or isotone N exhibits a remarkable exponential behavior.

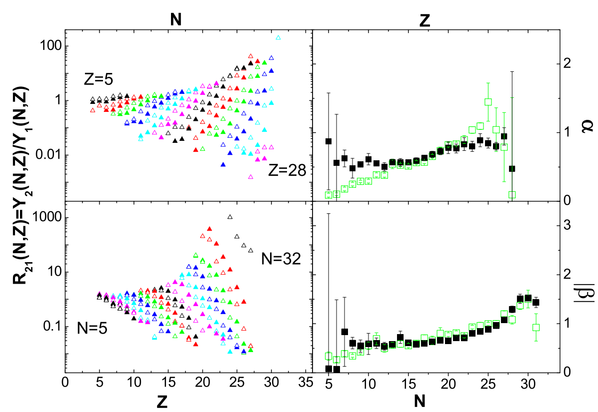

Fig. 2. Yield ratios $R_{21}(N,Z)$ for fragments from the reaction of ^{64,58}Ni $+^{9}$ Be at 140 MeV/nucleon versus N for the selected isotopes (left, upper panel) and Z for the selected isotones (left, lower panel). Different isotopes and isotones are shown by different symbols. Isoslaing parameters α as a function of Z (right, upper panel) and $|\beta|$ as a function of N (right, lower panel). Sold symbols represent the experimental results with the cross section data take from Ref. [11], open symbols present calculations by HIPSE model.

For each isotope (isotone), exponential function of the form $C\exp(\alpha N)$ $(C\exp(\beta Z)$ was fitted to the data. By fitting the calculated points, the parameters α and β are obtained for all isotopes and isotones. In Fig. 2 (right), we present the extracted slope parameters α (upper panel) and $|\beta|$ (lower panel) of the exponential fits as a function of N and Z. Using the same method, we also get isocaling parameters from experimental fragment production cross section, and present those in Fig. 2 (right). In this figure, α and $|\beta|$ from experimental data show a increasing trend with the increasing of N and Z, and the isoscaling parameters calculated by HIPSE model have the same trend. From Fig. 2 (right), we can see that the HIPSE model can reproduce the isoscaling parameters of experimental data for both projectile-like and light fragments quite well. But α of light fragments ($Z \leqslant 10$) from multifragmentation calculated by HIPSE model are lower than experiment result. This decrease of the isoscaling parameters in our calculations may be mainly attributed to the evaporation effect of the prefragment[12].

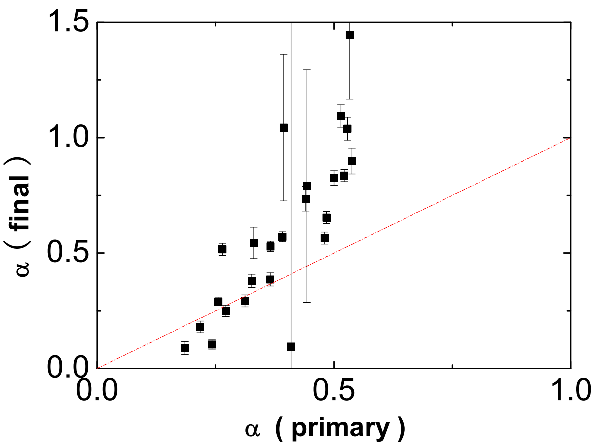

Fig. 3. Effect of sequential decays on the isoscaling parameter, α(final) and α(primary) are shown in one panel.

Generally the nuclear reaction model includes the production of primary fragment and their decays. In order to extract symmetry energy information by isoscaling of experimental data, a detailed understanding of the effects of sequential decays on the isosaling parameter α is necessary. In a recent study, the sequential decays effects are very different between statistical multifragmentation models and evaporation models[13]. The effects of sequential decays by the HIPSE model are studied in this paper. The isoscaling coefficient α was determined from the calculated fragment yields before (hot fragments) and after (cold fragments) the sequential decays. In the upper right panel of Fig. 2 α of the cold fragments calculated by HIPSE model for each element show a increasing trend with the increasing of Z. Isoscaling parameters α(final) of cold fragments and α(primary) of hot fragments are shown in Fig. 3. For the Ni+Be reaction, the parameter α(final) is similar to α(primary) within the range α(primary)$=0.1$–0.5, and larger than α(primary) while α(primary)> 0.5. As discussed in Ref. [13], this trend is different form those observed in dynamical and statistical calculations. Since in the HIPSE model the secondary deexcitation of fragments is described with SIMON code and this code is not a reasonable model to reproduced isoscling phenomena[12, 13], the difference of sequential decay effect may be mainly due to the evaporation program.

HIPSE contains many inputs as a schematic model. For most phenomenological parameters, constant value is used in all applications. However, there are still three important parameters in the model. As the values of these parameters have been adjusted by comparing the results of the calculations with experiment data[9, 12] and chosen just by a simple function in Ni+Be reaction, it is necessary to study the HIPSE parameters dependence of isoscaling parameters. By independently adjusting HIPSE parameters $\alpha_{\rm a}$, $x_{\rm tr}$ and $x_{\rm coll}$ the influence is shown in Fig. 4. All the parameters of HIPSE model have some effects on isoscaling parameter α, especially for heavy fragments, but the trends of isoscaling parameter α are not changed by adjusting HIPSE parameters.

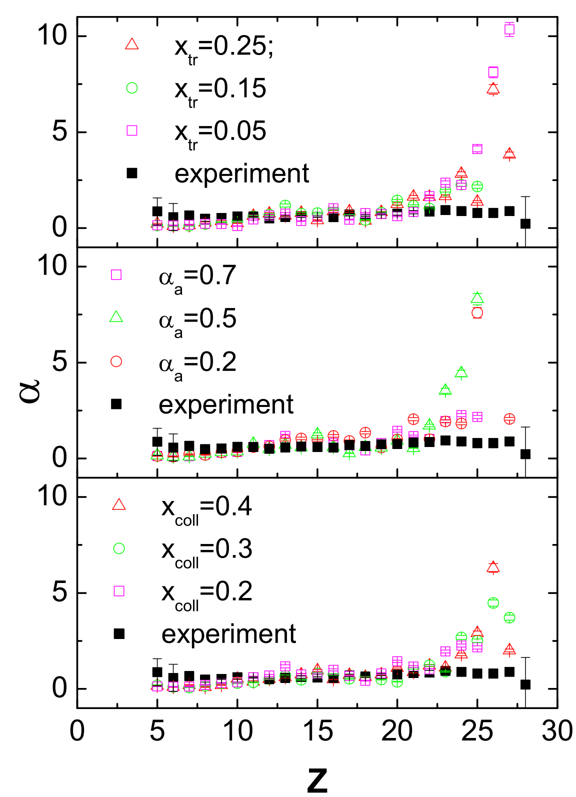

Fig. 4. HIPSE parameters dependence of isoscaling parameters. We present isoscaling coefficient α as a function of the isotope by independently adjusting HIPSE parameters $x_{\rm tr}$ (upper panel), $\alpha_{\rm a}$ (middle panel) and $x_{\rm coll}$ (lower panel). Experimental data (filled square) are shown in the figures too.

In summary, ^{64,58}Ni+^{9}Be reaction has been studied by HIPSE model. The isotopic distributions (shape and peak positions) can be described quite well by this model. The extracted isoscaling parameters from HIPSE model calculations are in good agreement with recent experimental data for both projectile-like and light fragments. Thus HIPSE model could be used to investigation the isoscaling phenomena of fragments produced in central and peripheral collisions. Sequential decays and the parameters of HIPSE model have some effects on isoscaling parameters, especially for heavy fragments; it needs careful treatment.

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