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Disintegration of Nuclei in High Energy Reactions

N. Buyukcizmeci[1], **A.S. Botvina**[2,3], **M. Bleicher**[2,3]

[1]Department of Physics, Selcuk University., 42079 Konya, Türkiye
[2]Institute for Theoretical Physics, J.W. Goethe University, D-60438 Frankfurt am Main, Germany
[3]Helmholtz Research Academy Hesse for FAIR (HFHF), GSI Helmholtz Center, Campus Frankfurt, 60438 Frankfurt am Main, Germany

Abstract. In this study, we present our further developed model for statistical disintegration of excited systems formed in heavy ion collisions. Calculations for the mass yields, charge yields and kinetic energy per nucleon are done for Ni+Ni and Au+Au collisions at various energies and the charge yields and kinetic energies are compared with existing experimental data. We have found satisfactory agreement with the experimental data, our further step will be to investigate hypernuclei formation by using this new approach model to propose future experiments at FAIR facilities.

1 Introduction

There are a lot of investigations to describe central and peripheral heavy-ion collisions as theoretically and experimentally [1–9]. Statistical methods and hybrid models are developed to describe disintegration and multifragmentation phenomena in these collisions at different energies so far, however, new theoretical efforts are still necessary to find out unknowns about processes and phenomenology. In this study, it is investigated Ni+Ni and Au+Au central collisions to describe final fragment formation by using hybrid model constructed recently by our group [10]. Below we briefly present model description and promising results for the further discussions.

2 Description of Model

Our model has constructed on three stages: (1) generation of initial nucleon distribution(s); (2) identification of excited clusters; (3) statistical decay of excited clusters.

For (1) two algorithms, Phase Space Generation (PSG) and Hydrodynamical Generation (HYG) are employed. Both of them account for conservation of total energy and momentum and produce nucleon momenta strongly correlated with nucleon coordinates. The most noteworthy difference in their outcomes concerns the excitation energy as a function of cluster size. In (2) clusters are "identified" based of nucleon relative velocities via coalescence of baryons (CB). Different values, ranging between $0.18c$ and $0.28c$, are employed for the cut-off. Arbitrariness in cluster definition is reflected into distributions of cluster size, excitation energy and kinetic energy. For (3) Statistical Multifragmentation Model (SMM) is employed. Detailed information about model description can be found in Ref. [10].

3 Mass, Charge and Kinetic Energy Distributions of Final Nuclei

In Figure 1, we show the distributions of clusters as a function of mass number A after the coalescence of initial nucleons and de-excitation of the primary source $A_0 = 116$, $Z_0 = 56$, for $E_0 = 25A$ MeV, for the different velocity coalescence parameters $v_c = 0.18c$, $0.24c$ and $0.28c$. In Figure 1, one can compare PSG (a) and HYG (b) nucleon generation method. We see qualitatively wider mass distributions for PSG calculation confirming the yield evolution very different initial distributions.

As a second step, distribution of kinetic energies of produced final fragments versus their charge are investigated by using both PSG and HYG calculations. As can be seen in Figure 2 (a and b), one can confirm that both approach give

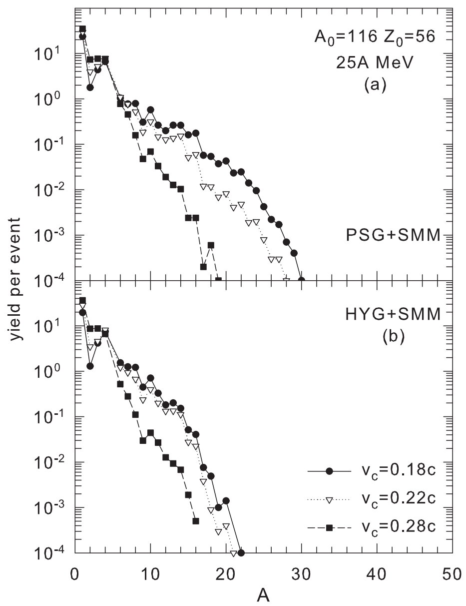

Figure 1. Yield per event of final nuclei versus their mass number A after the de-excitation of primary hot clusters at the source energy of $25A$ MeV. Composition, size of source, energy, nucleon generators (PSG and HYG), as well as coalescence parameters (v_c) are indicated in the panels.

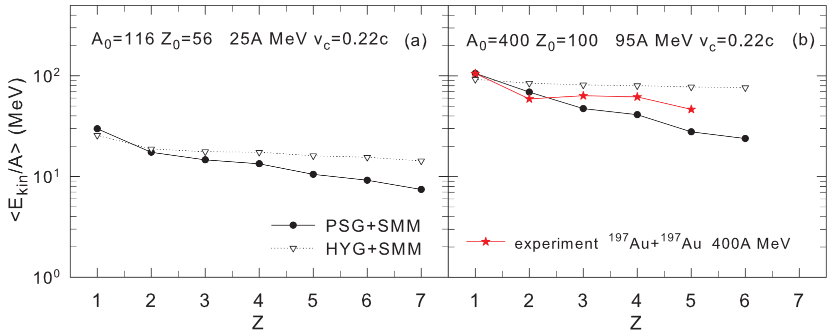

Figure 2. Average kinetic energies per nucleon of final nuclei versus their charges Z. The calculations are performed with the PSG and HYG initial nucleon generation for the initial source with $A_0 = 116$ and $Z_0 = 56$ at the initial excitation energy $25A$ MeV (a) and with $A_0 = 400$ and $Z_0 = 100$ at the initial excitation energy $95A$ MeV (b) and parameter $v_c = 0.22c$. Red stars represent experimental data [8] for Au+Au reaction at $400A$ MeV energy.

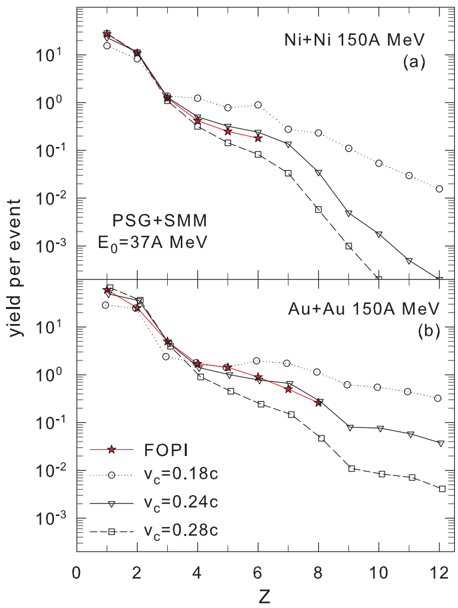

Figure 3. Comparison of our calculations with the FOPI experimental data on the nuclei production in central Ni+Ni (a) and Au+Au (b) collisions at $150A$ MeV. The parameters of the initial source are given in the figure. The nucleon distributions are after PSG, and parameters $v_c = 0.18c, 0.24c$, and $0.28c$ are used in the calculations.

similar trend for the distributions for the kinetic energy spectra of produced cold fragments. We compare experimental data [8] for Au+Au reaction at $400A$ MeV energy and PSG and HYG calculations for $A_0 = 400$ and $Z_0 = 100$ system at the initial excitation energy $95A$ MeV (b) and parameter $v_c = 0.22c$.

We present charge distributions of final nuclei produced in central Ni+Ni (a) and Au+Au (b) collisions at $150A$ MeV in Figure 3. The PSG generation is used to describe initial nucleons, coalescence of baryons and de-excitation processes are applied to get final cold nuclei. $E_0 = 37A$ MeV is taken into account for PSG calculations as the corresponding excitation energy. Coalescence parameters are taken as $v_c = 0.18c$, $0.24c$ and $0.28c$ for comparison. The excitation energies of the final nuclei fluctuates an interval in between 6–8 MeV/nucleon for $v_c = 0.18c - 0.28c$, that is why v_c parameter can be accepted as $v_c = 0.24c$ as a modest approach. In Figure 3, red stars represent the experimental data obtained by the FOPI collaboration [8] and coincidence with our calculations.

4 Conclusion

It is investigated that the localization and clustering features of nuclei in central collisions. Two different initial generation PSG and HYG are used to produce initial nucleons, coalescence of baryons follows this process and afterwards SMM is used to describe final nuclei formation. It is shown that clustering features PSG and HYG generations are more or less similar and successful, PSG generation gives agreement with experimental data. We plan to make detailed research on correlations of nuclei taking into account both generation system, afterwards one can apply those for hypernuclei formation. We believe that these kind of theoretical efforts would be promising to predict future experiments at FAIR and other facilities.

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References

[1] J.P. Bondorf, A.S. Botvina, A.S. Iljinov, I.N. Mishustin, K. Sneppen, *Phys. Rep.* **257** (1995) 133.

[2] P. Kreutz, et al., *Nucl. Phys. A* **556** (1993) 672.

[3] A.S. Botvina, et al., *Nucl. Phys. A* **584** (1995) 737.

[4] R. Ogul, et al., *Phys. Rev. C* **83** (2011) 024608.

[5] R.P. Scharenberg, et al., *Phys. Rev. C* **64** (2001) 054602.

[6] M. D'Agostino, et al., *Phys. Lett. B* **371** (1996) 175.
[7] N. Bellaize, et al., *Nucl. Phys. A* **709** (2002) 367.
[8] W. Reisdorf, et al., *Nucl. Phys. A* **848** (2010) 366.
[9] A.S. Botvina, N. Buyukcizmeci, M. Bleicher, *Phys. Rev. C* **103** (2021) 064602.
[10] A.S. Botvina, N. Buyukcizmeci, M. Bleicher, *Phys. Rev. C* **106** (2022) 014607.