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Transport and Statistical Simulations for the Production of Nuclei and Hypernuclei at High Energy

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Abstract. We have analysed the formation of new nuclei in heavy-ion collisions at high energies by using the hypothesis of local chemical equilibrium in expanding nuclear matter. In this study, the ultra-relativistic quantum molecular dynamics (UrQMD), the Dubna cascade model (DCM), and the statistical multifragmentation model (SMM) are applied for theoretical calculations of nuclei and hypernuclei production. The good agreement with experimental data is obtained within our hybrid approach. In future the planned experiments on FAIR and other accelerators will provided an excellent opportunity for the further progress in this field.

1 Introduction

Theoretical and experimental investigations on the description of peripheral and central heavy ion collisions are among the specific interests of studies in the literature [1–13]. In this study, it is investigated Au+Au central collisions to describe nuclei and hypernuclei formation by using hybrid models [7, 9, 10]. These models have constructed on three stages, generation of initial nucleon distribution(s), identification of clusters, and statistical decay of excited clusters, respectively. In the first stage, initial nucleon distributions are determined by using Phase space generation method (PSG) [7], Dubna cascade model (DCM) [10] and Ultra relativistic quantum molecular dynamics model (UrQMD) [9] are employed. For UrQMD model version, "cascade" as baryon generator is used. All of them account for conservation of total energy and momentum and produce nucleon momenta strongly correlated with nucleon coordinates. In the second stage, hot clusters are "identified" based of nucleon relative velocities $v_c = 0.14 - 0.22c$ via clusterization of baryons (CB). The primary selected baryon clusters present local pieces of nuclear matter in the coexistence region of the nuclear liquid-gas type phase transition, where the chemical equilibrium is established. In the third stage, SMM is employed to obtain final nuclei and hypernuclei [7, 11].

2 Comparison of Theoretical Models and Experimental Data for Light Hypernuclei

We briefly present information on hybrid model calculations and discuss our results by comparing them with experimental data. In Figure 1, we show the mass distributions of the hot clusters as a function of the mass number A after the coalescence of the initial nucleons and de-excitation of the primary source $A_0 = 197$, $Z_0 = 79$, for coalescence parameter $v_c = 0.22c$ at $\sqrt{s_{NN}}$=3 GeV. A comparison of the PSG, DCM and UrQMD models is demonstrated in Figure 1. While the DCM model produces qualitatively broader mass distributions for larger masses, all models confirm the decrease in yield evolution with increasing mass number of fragments produced.

The excitation energies of the produced hot nuclei and hypernuclei are plotted for the coalescence parameter $v_c = 0.22c$ in Figure 2. As is well known, the

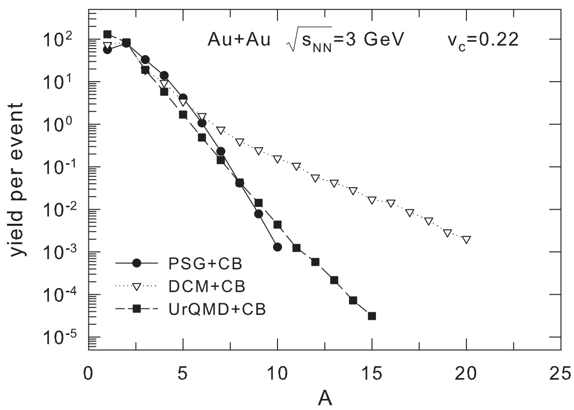

Figure 1. Mass yield per event of hot nuclei versus their masses A. The calculations are performed with the PSG, UrQMD and DCM initial nucleon generation for the initial source with $A_0 = 197$ and $Z_0 = 79$ at $\sqrt{s_{NN}}$=3 GeV and parameter $v_c = 0.22c$, afterwards CB procedure is applied for the formation of hot nuclei.

excitation energies of the nuclei fluctuate in an interval between $6-8$ MeV/nucleon, while the PSG+CB and DCM+CB model results are slightly higher of these values, the UrQMD results seem to be in the limits for smaller nuclei, these results affecting the number of nuclei and hypernuclei produced after sequential deexcitation.

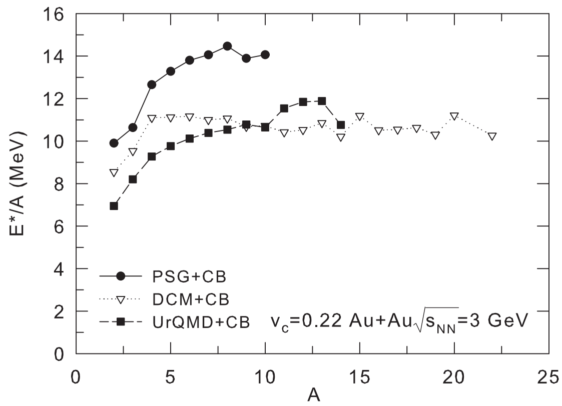

Figure 2. Average excitation energies per nucleon of hot nuclei versus their mases A. The calculations are performed with the PSG, UrQMD and DCM initial nucleon generation for the initial source with $A_0 = 197$ and $Z_0 = 79$ at $\sqrt{s_{NN}}$=3 GeV and parameter $v_c = 0.22c$, afterwards CB procedure is applied for the formation of hot nuclei.

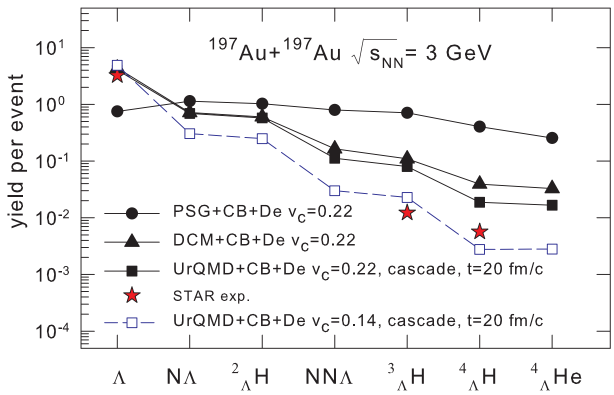

Figure 3. Comparison of our calculations with the STAR experimental data on the hypernuclei production in central Au+Au collisions at $\sqrt{s_{NN}}$=3 GeV. The parameters of the initial source are given in the figure. The initial nucleon distributions are after PSG, DCM, and UrQMD, CB and deexcitation preocedure are applied to obtain final cold yields, parameters $v_c = 0.22c$ and $0.14c$ are used in the calculations.

We present distributions of final hypernuclei produced in central Au+Au collisions at $\sqrt{s_{NN}}$=3 GeV in Figure. 3 by using PSG+CB+De, DCM+CB+De and UrQMD+CB+De model calculations and by comparing them with the STAR [12] experimental data. The PSG generation is used to describe initial nucleons, clusterization of baryons and de-excitation processes are applied to obtain final cold nuclei. Calculations are performed for the coalescence parameter $v_c = 0.22c$, and a $v_c = 0.14c$ calculation is added for the UrQMD+CB+De model to show how one can extend the description window for comparison with experiment. Λ, ${}^3_\Lambda$H and ${}^4_\Lambda$H hypernuclei values are found to be in agreement with the STAR experimental data [12].

3 Conclusion

We have demonstrated that the decomposition of the excited nuclear matter into nuclei and hypernuclei in central collisions can be naturally explained by their statistical formation at the subnuclear density when the matter expands and enters the coexistence region of the nuclear liquid-gas phase transition. We use different transport and phenomenological models to produce initial nucleons, then we determine baryons which can be selected into local equilibrized clusters, and then SMM is used to describe the final formation of nuclei and hypernuclei. In particular, it is shown that the nuclei yields obtained in STAR experiments can be successfully described by using the UrQMD model at the first reaction stage. More experimental data needed (especially, which are related to the correlations of the produced particles and nuclei), and we hope it will be available soon, after the experiments at FAIR.

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