Study of clusters and hypernuclei production within PHSD+FRIGA model

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Abstract. We report on the results on the dynamical modelling of cluster formation with the new combined PHSD+FRIGA model at Nuclotron and NICA energies. The FRIGA clusterization algorithm, which can be applied to the transport models, is based on the simulated annealing technique to obtain the most bound configuration of fragments and nucleons. The PHSD+FRIGA model is able to predict isotope yields as well as hypernucleus production. Based on present predictions of the combined model we study the possibility to detect such clusters and hypernuclei in the BM@N and MPD/NICA detectors.

1 Introduction

Heavy-ion collisions provide the unique possibility to create and investigate hot and dense matter in the laboratory. At the initial stage of the reaction a QGP is formed, while the final stage is driven by the hadronization process and the formation of clusters. The capture of the produced hyperons by clusters of nucleons leads to the hypernuclei formation which is a very rare process at strangeness threshold energies. It is important to have the robust modelling of hypernuclei and cluster formation in order to study the detector replica and to have the possibility to optimize the experimental setup for the best efficiency.

Modelling the clusters formation is a complicated problem, and therefore in many approaches the fragment formation is simply omitted. This invalidates the prediction of single particle observables, because the cluster formation can modify the single particle spectra.

The simplest way to identify clusters is by employing coalescence or a minimum spanning tree procedure. The first needs a multitude of free parameters, whereas the second allows only for an identification at the end of the reaction which excludes any study on the physical origin [1].

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2 PHSD+FRIGA MODEL

The Parton-Hadron-String Dynamics (PHSD) [2] is a microscopic off-shell transport approach that describes the full evolution of a heavy-ion collision at relativistic energies from the initial hard scatterings and string formation through the dynamical deconfinement phase transition to the quark-gluon plasma as well as hadronization and to the subsequent interactions in the hadronic phase.

The Simulated Annealing Clusterization Algoritm (SACA) [3] and its new development and improved version "Fragment Recognition In General Application"; (FRIGA) [4] consists of the following steps: at first the algorithm takes the positions and momenta of all nucleons at time t to determine clusters within a phase space coalescence approach using the Minimum Spanning Tree technique (MST). In second step, the MST clusters and individual particles are recombined in all possible ways into fragments or left as single nucleons, such as to choose that configuration which has the highest binding energy [5]. This procedure is repeated many times (within a Metropolis procedure) and it automatically leads to the most bound configuration.

Clusters chosen that way at early times are the pre-fragments of the final state clusters, because fragments are not a random collection of nucleons at the end but the initial-final state correlations.

For our studies we use PHSD and FRIGA as one combined model: PHSD produces hadrons and stops at a certain time, which are input to the FRIGA code to determine clusters and hypernuclei. The time chosen for clustering can have a strong influence on the multiplicity of clusters.
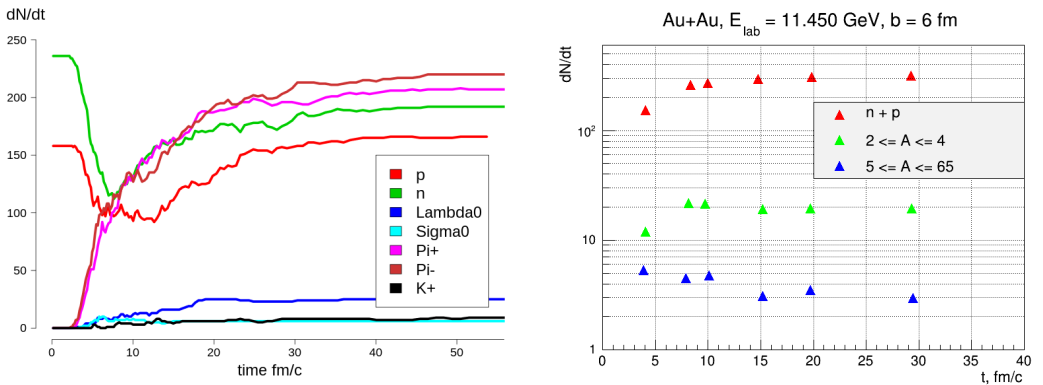
Figure 1. Time dependence of hadron (left) and fragment (right) multiplicities as predicted by the PHSD+FRIGA approach in Au+Au collisions at 11.45A GeV incident energy, 6 fm impact parameter.

Figure 1 illustrates such a time dependence in Au+Au semi-central (b=6 fm) collisions at 11.45A GeV incident energy ($\sqrt{s}$ = 5 GeV). There, the approach predicts a stabilization in the hadron and fragment yields around 15 fm/c. This earlier clusterization time as been chosen in the following for studying various fragments observables.

Figure 2 shows a comparison of PHSD+SACA predictions with AGS E-802 data [6] for central Au+Au collisions at 11.45 GeV, for the rapidity dependence of proton (left panel) and deuteron (right panel) yields. We observe there that the model reproduces well the experimental data.
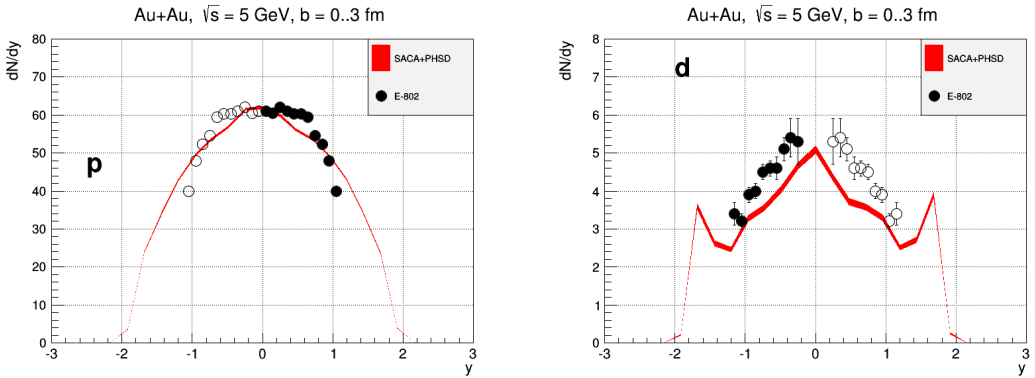
Figure 2. Yields of protons (left panel) and deuterons (right panel) as a function of rapidity (in the frame of the centre of the system) in central Au+Au collisions ($b < 3fm$) at 11.45A GeV. Red lines and black symbols show respectively the PHSD+FRIGA predictions and E-802 experimental mirrored about midrapidity (y=0) data.

3 Multi-Purpose Detector feasibility study

A new scientific program on heavy-ion physics NICA/MPD [7] has been launched at JINR (Dubna) for comprehensive exploration of the QCD phase diagram with ion species ranging from protons to Au^{79+} over the energy range $4 < \sqrt{s} < 11$ GeV. The major goal of the NICA/MPD project is the study of in-medium properties of hadrons and the nuclear matter equation of state, including a search for possible signals of deconfinement and/or chiral symmetry restoration, phase transitions and the QCD critical endpoint.

One of the tasks of the Multi-Purpose Detector [8] is to study the strangeness production. This task demands a good identification and reconstruction of heavy strange objects like hypernuclei and hyperons.

Figure 3 left panel shows the yields of hypernuclei and hyperons predicted by the PHSD+FRIGA approach in Au+Au collisions at 11.45A GeV. Preliminary results of a MPD feasibility study for hypertriton detection by the mean of reconstructed invariant mass distributions are shown on the right panel. There, the hypertriton signal is clearly viewed, with a good signal-to-background ratio of 3.3, and a detection efficiency of about 0.4%.

4 Conclusion

The PHSD+FRIGA model can produce clusters and hypernuclei and reproduce experimental data for 11.45 GeV beam energy ($\sqrt{s}$ = 5 GeV). These predictions have been already used for MPD performance studies. The new improved version of the clusterization algoritm FRIGA is still actively under development. It will be possible in a near future to obtain the fully dynamical cluster formation on each time step of the collisions.
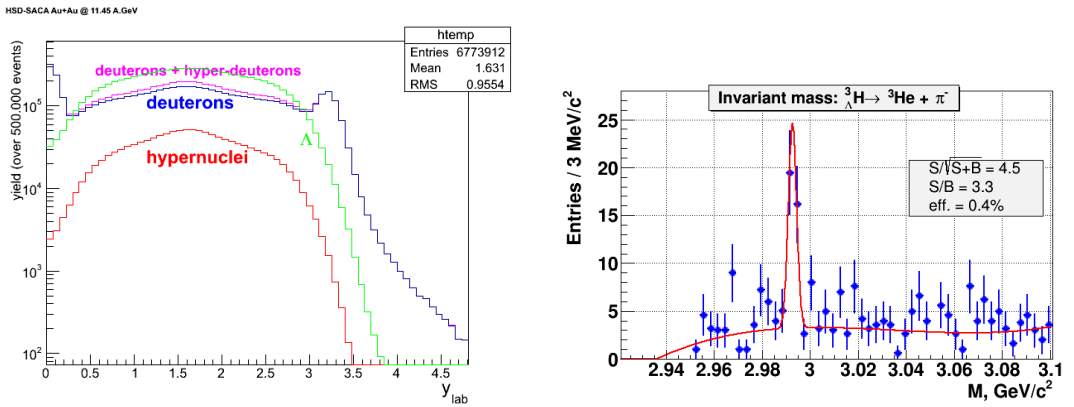
Figure 3. In Au+Au collisions at 11.45 GeV incident energy ($b < 3fm$): (left) rapidity (in the rest frame) dependence of yields of hypernuclei, deuterons and Lambda0 hyperons as predicted by PHSD+FRIGA; (right) invariant mass distribution of He3 and π^- vertexes as theoretically measured by the MPD set-up (preliminary results).

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