KnE Energy & Physics
ICPPA 2017
The 3rd International Conference on Particle Physics and Astrophysics
Volume 2018

Conference Paper

Clusters and Hypernuclei production within PHQM+FRIGA model

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Abstract

We present a new results on the dynamical modelling of cluster formation with the new combined PHQMD+FRIGA model at Nuclotron and NICA energies. The FRIGA clusterisation algorithm, which can be applied to the n-body transport approaches, is based on the simulated annealing technique to obtain the most bound configuration of fragments and nucleons. The PHQMD+FRIGA model is able to predict isotope yields as well as hyper-nucleus production.

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Received: 25 December 2017
Accepted: 2 February 2018
Published: 9 April 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICPPA Conference Committee.

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.

As we know from the data, at 3 A.GeV even in central collisions almost 20% of the baryons are bound in the clusters [1]. If we do not describe the dynamical formation of fragments we cannot properly describe the nucleon observables like $v1$, $v2$, transverse momentum spectra, and we cannot explore the new physics opportunities like hyper-nucleus formation, 1-st order phase transition, fragment formation at midrapidity (RHIC, LHC).

Modelling the clusters formation is a complicated problem, and therefore many present microscopic approaches fail to describe fragments at NICA/FAIR (and higher) energies.

2. PHQMD+FRIGA model

The simplest way to identify cluster is by the coalescence or a minimum spanning tree procedure. The first needs a multitude of free parameters, the second can be used only for an identification at the end of the reaction which excludes any study on the physical origin [2].

If one wants to identify fragments early, when the reaction still going on, one has to use momentum and the coordinate space information. This idea was launched by Dorso et al. [3] and it has been developed into the Simulated Annealing Clusterisation Algorithm (SACA) [4].

In our studies we are using "Fragment Recognition In General Application" (FRIGA) [5], an improved version of SACA, within the Parton-Hadron Quantum Molecular Dynamics (PHQMD) model, which is is a non-equilibrium microscopic transport model which describes n-body dynamics based on QMD [6] propagation with collision integrals from PHSD [7].

The "Fragment Recognition In General Application" algorithm 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. 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.

3. Model predictions

Figure 1 illustrates a good agreement of the PHQMD predictions with the existing data at SIS/FAIR/NICA energies. On the left panel the rapidity distributions are shown, while on the right panel are the invariant mass spectra.

Figure 2 shows a comparison of the PHQMD+FRIGA model predictions with the ALADIN data [8] for Au+Au collisions at 800 MeV, Z_{bound} is the sum of atomic numbers Z_i of all projectile fragments with $Z_i \geq 2$. For very peripheral reactions we expect that only the remnant is bound and no intermediate mass clusters appear, at very central collisions we expect that a fireball is created which contains essentially protons

DOI 10.18502/ken.v3i1.1774

and neutrons, so Z_{bound} is small as well as mean multiplicity of intermediate-mass fragments. In mid-central reactions we observe multi-fragmentation, means several intermediate fragments are produced together with a lot of protons. The understanding of this is a big challenge in present day heavy ion physics.

Figure 3 show the preliminary results of simulations for the NICA energies. In central collisions ($b = 0.25..2.25$ fm) we observe that only light clusters are formed. In semi-peripheral collisions ($b = 6.25..8.25$ fm) we expect the existence of heavy clusters – remnants from the spectators. In both cases there is a visible contribution of the hypernuclei production, this opens perspectives for the new physics as hyper-nucleus spectroscopy, experimental determination of L-N potential etc.

4. Conclusion

The PHQMD+FRIGA model can produce clusters and hypernuclei and reproduce experimental data for the SIS/FAIR/NICA energy range. It allows to predict the dynamical formation of fragments, to understand the proton spectra and the properties of light fragments, to understand the fragment formation in participant and spectator region, as well as the formation of hypernuclei. The new improved version of the clusterisation algorithm FRIGA is still actively under development and soon we expect the new results.

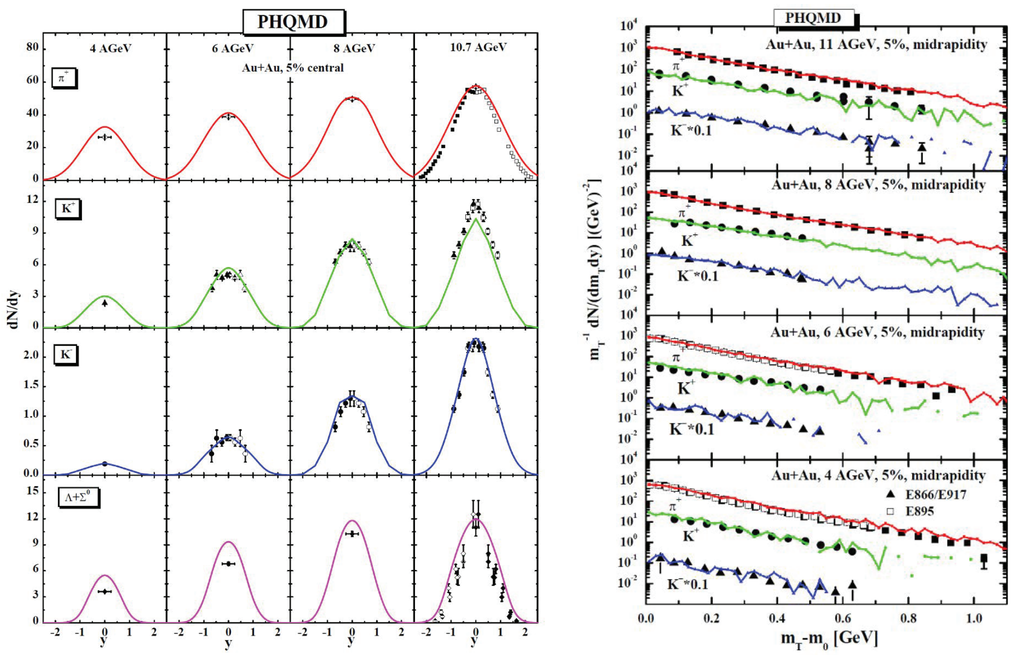

Figure 1: Left panel: particles yields as a function of rapidity; Right panel: invariant mass distribution.

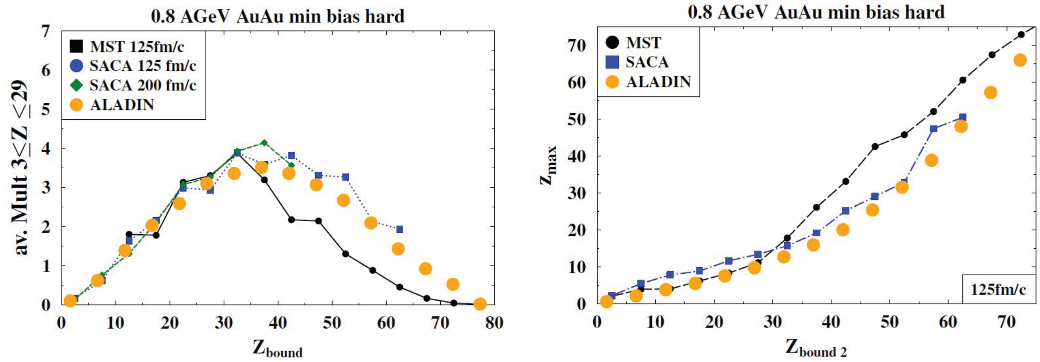

Figure 2: Left panel: mean multiplicity of intermediate-mass fragments vs Z_{bound}; Right panel: mean value of the maximum fragment charge as a function of Z_{bound}.

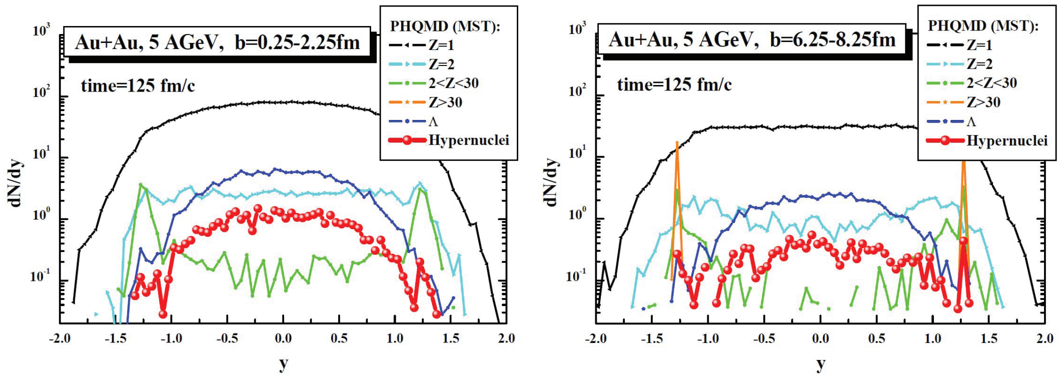

Figure 3: Rapidity distributions of different kinds of fragments for Au+Au collisions at the NICA energies (preliminary results).

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