# Study of Clusters and Hypernuclei production within PHSD+FRIGA model

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## I - 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.

## II – Description of the PHSD model

**Initial A+A collisions – HSD:** string formation and decay to pre-hadrons

**Fragmentation of pre-hadrons into quarks:** using the quark spectral functions from the Dynamical QuasiParticle Model (DQPM) approximation to QCD

**Partonic phase:** quarks and gluons (= „dynamical quasiparticles“) with off-shell spectral functions (width, mass) defined by DQPM

elastic and inelastic parton-parton interactions:
using the effective cross sections from the DQPM
- ✓ q + qbar (flavor neutral) <=> gluon (colored)
- ✓ gluon + gluon <=> gluon (possible due to large spectral width)
- ✓ q + qbar (color neutral) <=> hadron resonances

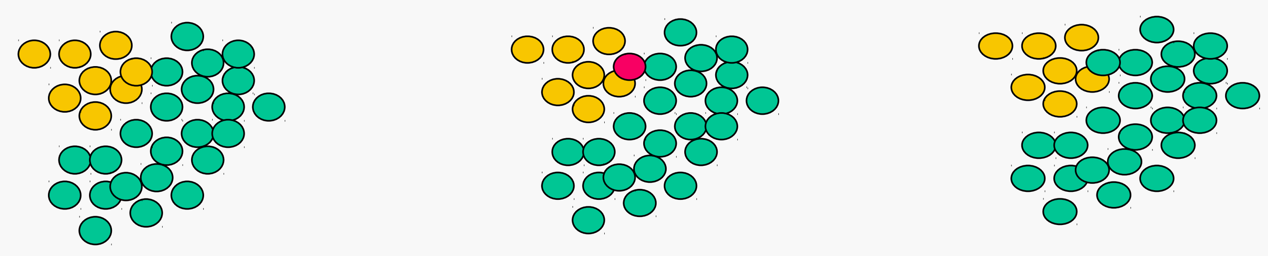
**Hadronization:** based on DQPM - massive, off-shell quarks and gluons with broad spectral functions hadronize to off-shell mesons and baryons:
gluons → q + qbar; q + qbar → meson (or string);
q + q +q → baryon (or string) (strings act as ‚doorway states‘ for hadrons)
Hadronic phase: hadron-string interactions – off-shell HSD

## III – Simulated Annealing Clusterisation Algorithm (SACA)

1) Pre-select good «candidates» for fragments according to proximity criteria: real space coalescence = Minimum Spanning Tree (MST) procedure.

2) Take randomly 1 nucleon out of one fragment

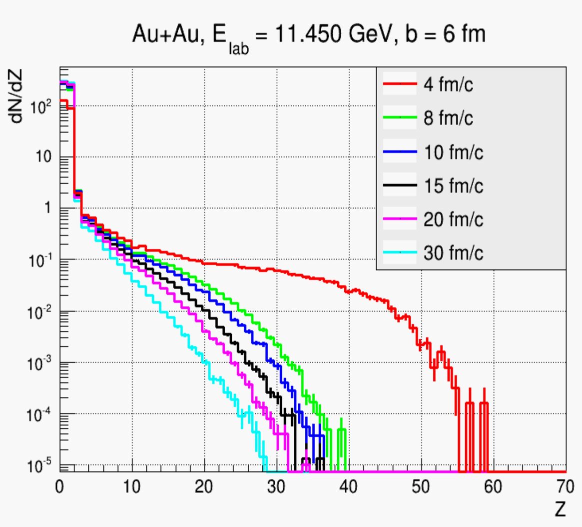
3) Add it randomly to another fragment or consider as free particle



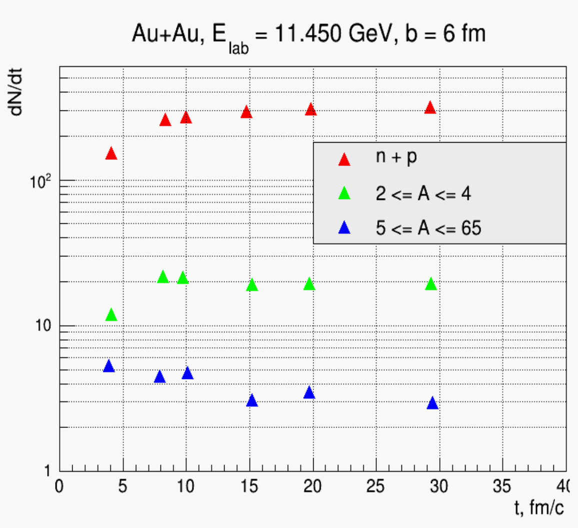
$E = E^1_{kin} + E^2_{kin} + V^1 + V^2$ $\quad$ $E' = E^{1'}_{kin} + E^{2'}_{kin} + V^{1'} + V^{2'}$

<u>If E’ < E</u> take the new configuration
<u>If E’ > E</u> take the old with a probability depending on E’-E
Repeat this procedure very many times...
It leads automatically to the most bound configuration.

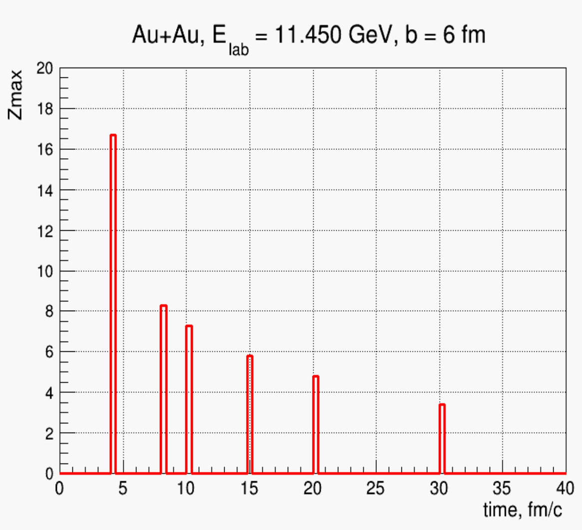
## IV – In PHSD clusters can be found, but their they are not stable because PHSD is a one body theory




Charge distribution for different times

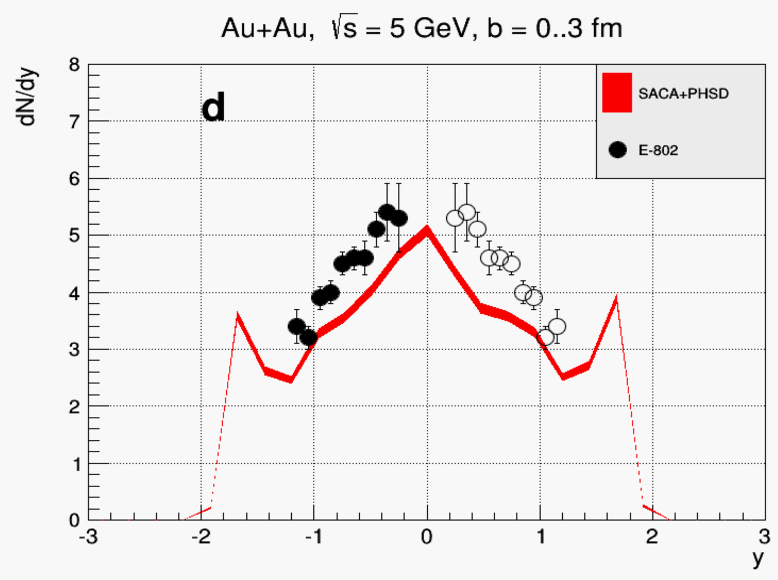



Multiplicity of different kind of particles and fragments




<Zmax> versus formation time

t = 15 fm/c has been chosen to start SACA simulations at 11.45 GeV




PHSD+FRIGA comparison with E-802 experimental data 11.45 GeV

Model reproduce experimental data dN/dy distributions for protons and deuterons.

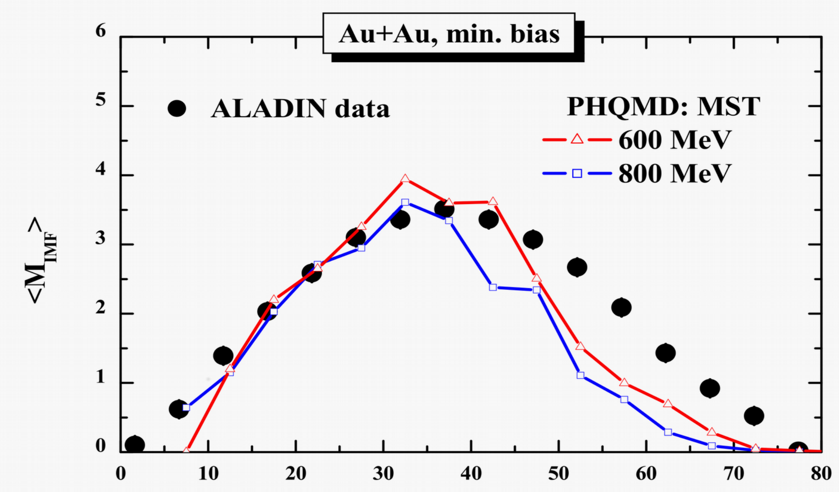
## V — Current state, fragments and nuclei formation

SACA → FRIGA (Fragment Recognition In General Application)

PHSD → PHQMD (Parton-Hadron Quantum Molecular Dynamics*, N-body approach)

FRIGA is implemented **inside** the code of the PHQMD model and has some new features like pairing and asymmetry energies as well as other structure effects

PHQMD with Minimum Spanning Tree model (MST) for clusters formation: MST finds the dynamically formed clusters at the end of the reaction

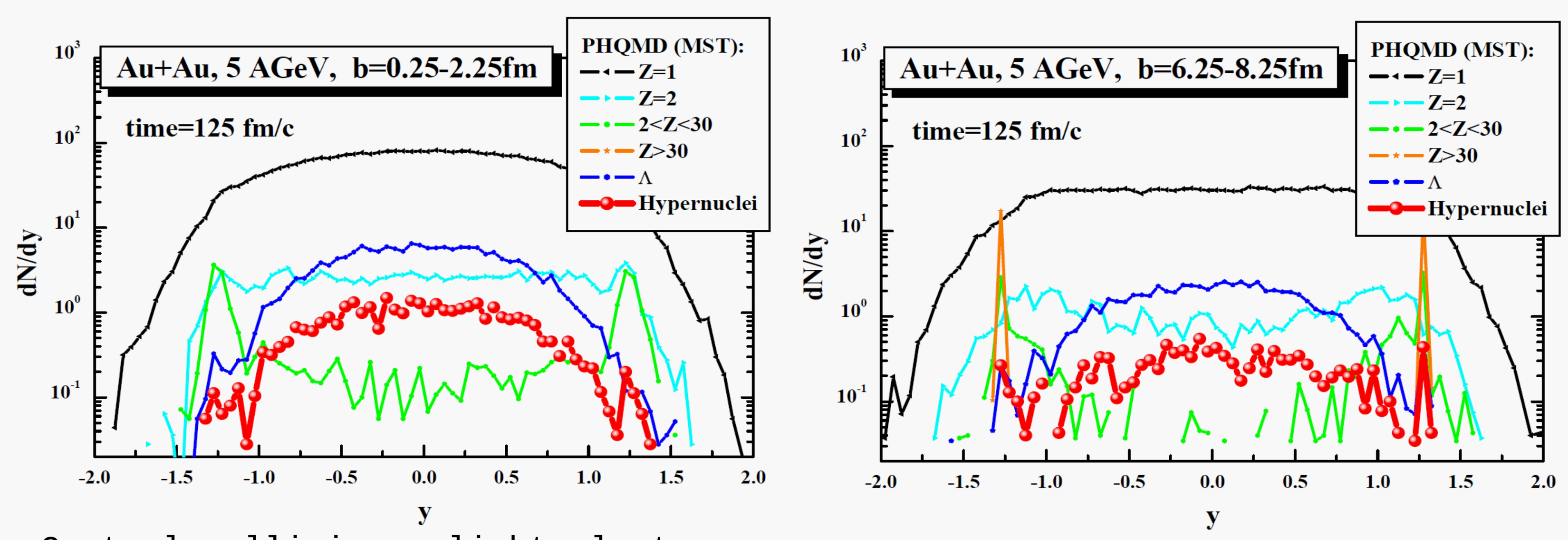



$\langle M_{IMF} \rangle$ – average number of medium mass fragments (2<Z<30)

$Z_{bound}$ – number of charges bounded in clusters (Z>1)

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 and neutrons, so $Z_{bound}$ is small as well as $M_{IMF}$. In mid-central reactions we observe multifragmentation, means several intermediate fragments are produced together with a lot of protons.

**Preliminary results of PHQMD+FRIGA for NICA energies**




Central collisions: light clusters;
Semi-peripheral collisions: existence of heavy clusters – remnants from spectators

Upper estimates for the hypernuclei production: visible contribution → opens perspectives for the new physics as hypernucleus spectroscopy, experimental determination of L-N potential etc.

## VI – Summary

We present here the first step towards an understanding of the production of isotopic yields and hypernuclei in heavy ion reactions.

The PHSD+SACA model already can produce clusters and hypernuclei, it describe well the experimental data for 11.45 GeV beam energy (√s=5 GeV). These predictions have already used for MPD performance studies.

Our clusterisation algorithm FRIGA, an improved version of the SACA approach, which includes pairing and asymmetry energies as well as other structure effects is able to describe more precisely the nuclear binding energy and allows for realistic predictions of absolute (hyper-)isotope yields, still under active development.

## VII – References

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