Study of Clusters and Hypernuclei production within PHSD+SACA model

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Outline

- Motivation
- Searching clusters with PHSD+SACA model
- Current state
- Summary

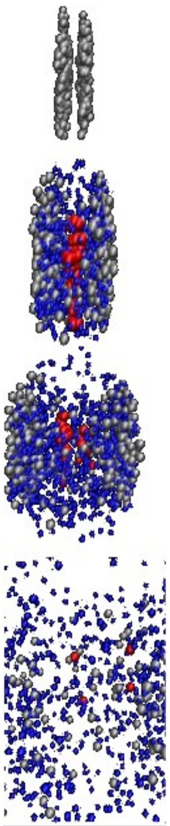
Motivation

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 modeling 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. Modeling of the clusters formation is a complicated problem, there are very few transport models that can provide it.

PHSD – basic concepts

E.L. Bratkovskaya, W. Cassing, Nucl.Phys. A856 (2011) 162-182.



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

DQPM: Peshier, Cassing, PRL 94 (2005) 172301; Cassing, NPA 791 (2007) 365: NPA 793 (2007)

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

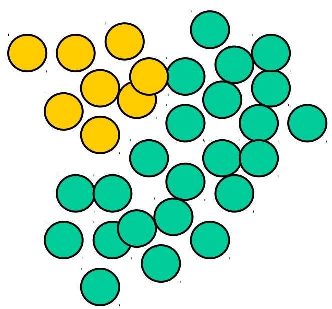
Hadronization: based on DQPM - massive, off-shell quarks and gluons with broad spectral functions hadronize to off-shell mesons and baryons:
gluons → q + qbar; q + qbar → meson (or string);
q + q +q → baryon (or string) (strings act as 'doorway states' for hadrons)
Hadronic phase: hadron-string interactions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

Simulated Annealing Clusterisation Algorithm

R. K. Puri, J. Aichelin, J.Comput.Phys. 162 (2000) 245-266

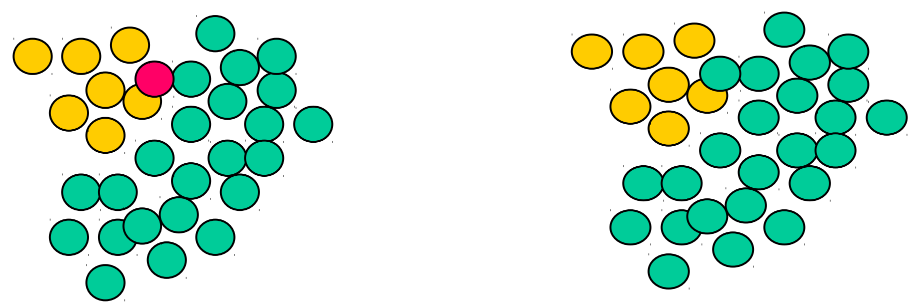
1) Pre-select good «candidates» for fragments according to proximity criteria: real space coalescence = Minimum Spanning Tree (MST) procedure.

2) Take randomly 1 nucleon out of one fragment



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

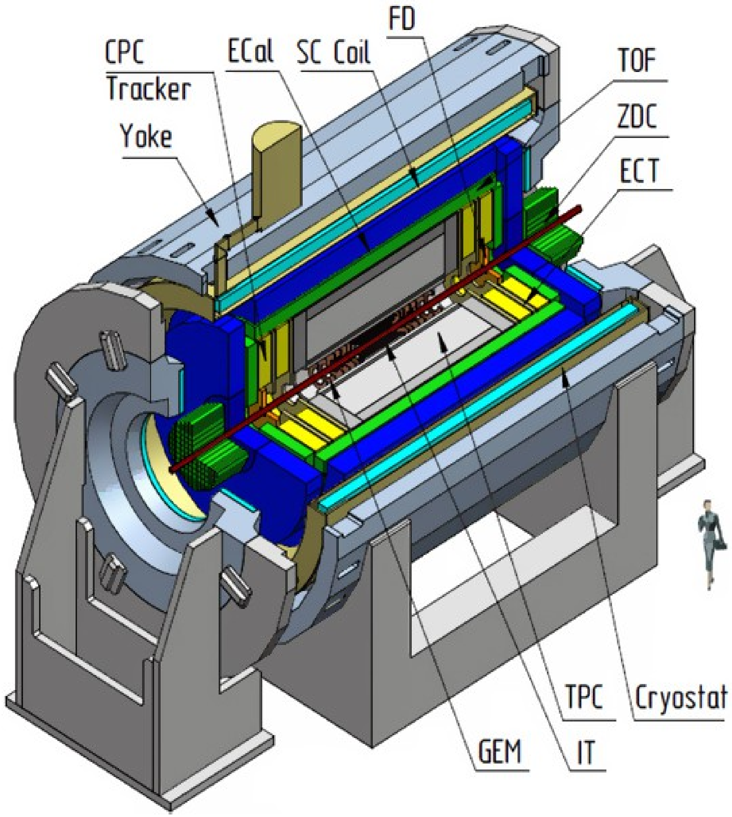
3) Add it randomly to another fragment



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

<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.

Software chain



PHSD → SACA («afterburner»)

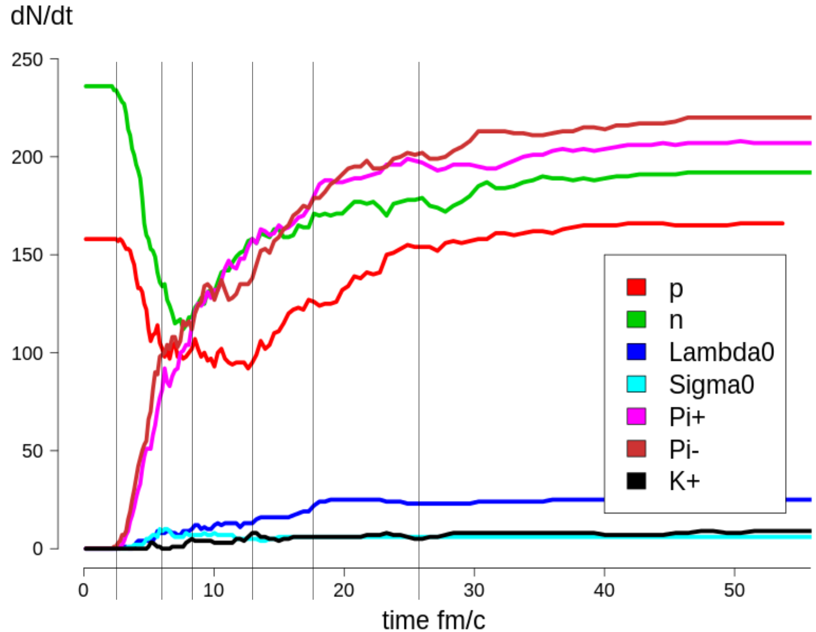
SACA → MpdRoot

SACA → R (statistical computing language)

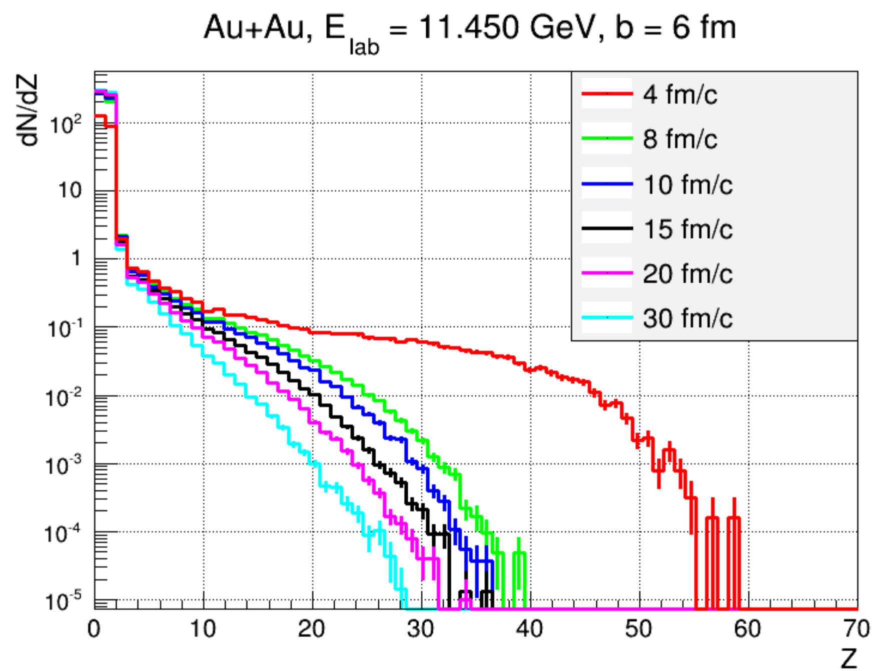
Searching clusters with PHSD+SACA model

(GSI & NANTES & JINR & FIAS collaboration)

It is very important to choose a good starting time for clusterisation algorithm

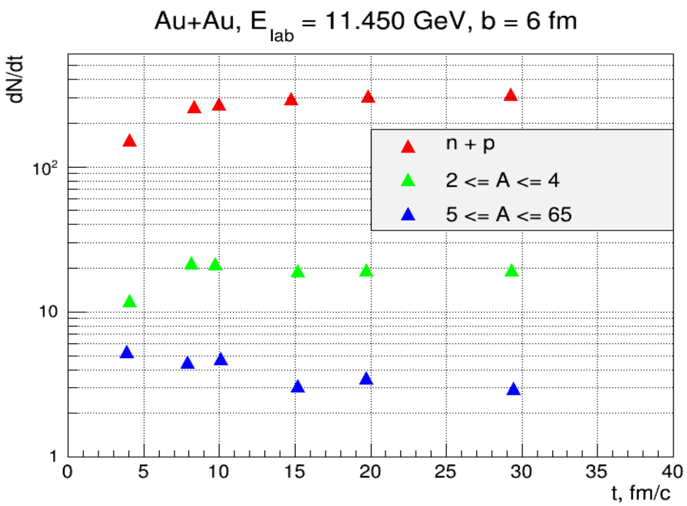


Particles multiplicity per step of PHSD evolution time

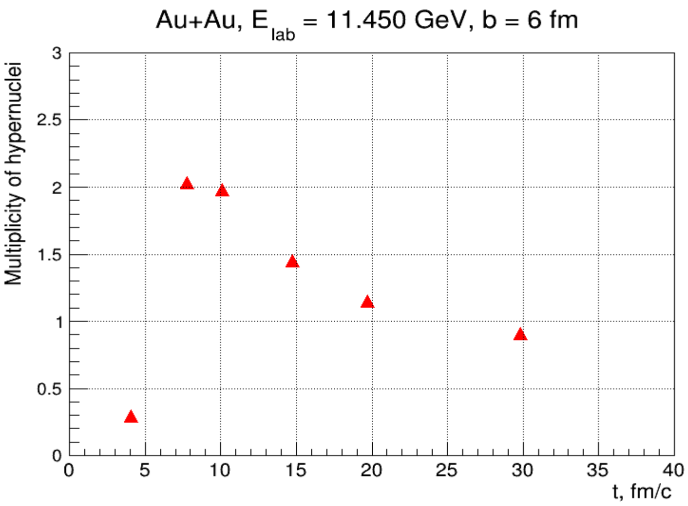


Charge distribution for different SACA starting times. (Red line here – passing time without interaction, for reference only)

Searching clusters with PHSD+SACA model

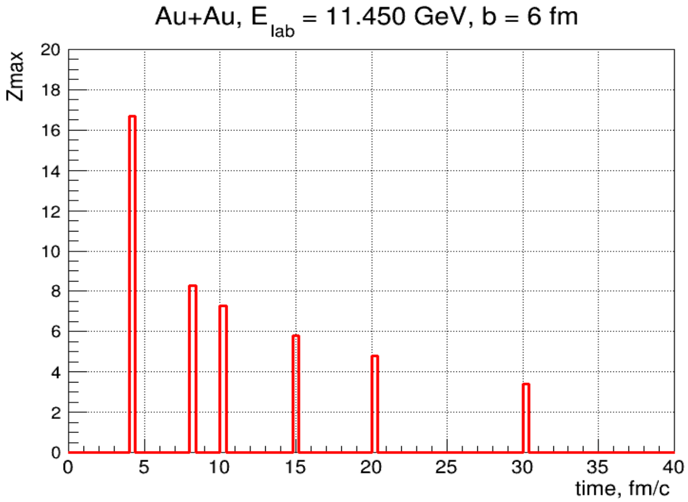


Multiplicity of different kind of particles and fragments



Hypernuclei multiplicity

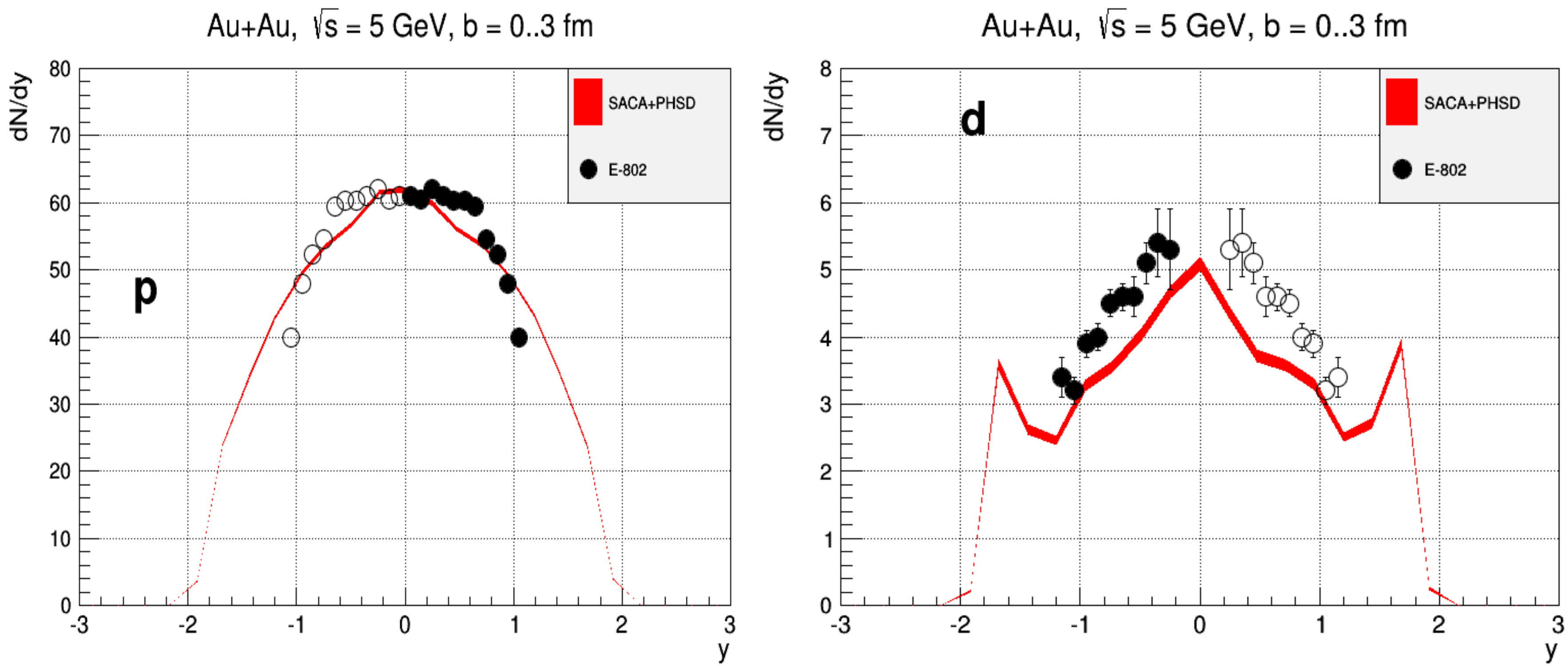
<Zmax> versus formation time



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

SACA comparison with E-802 experimental data 11.45 GeV

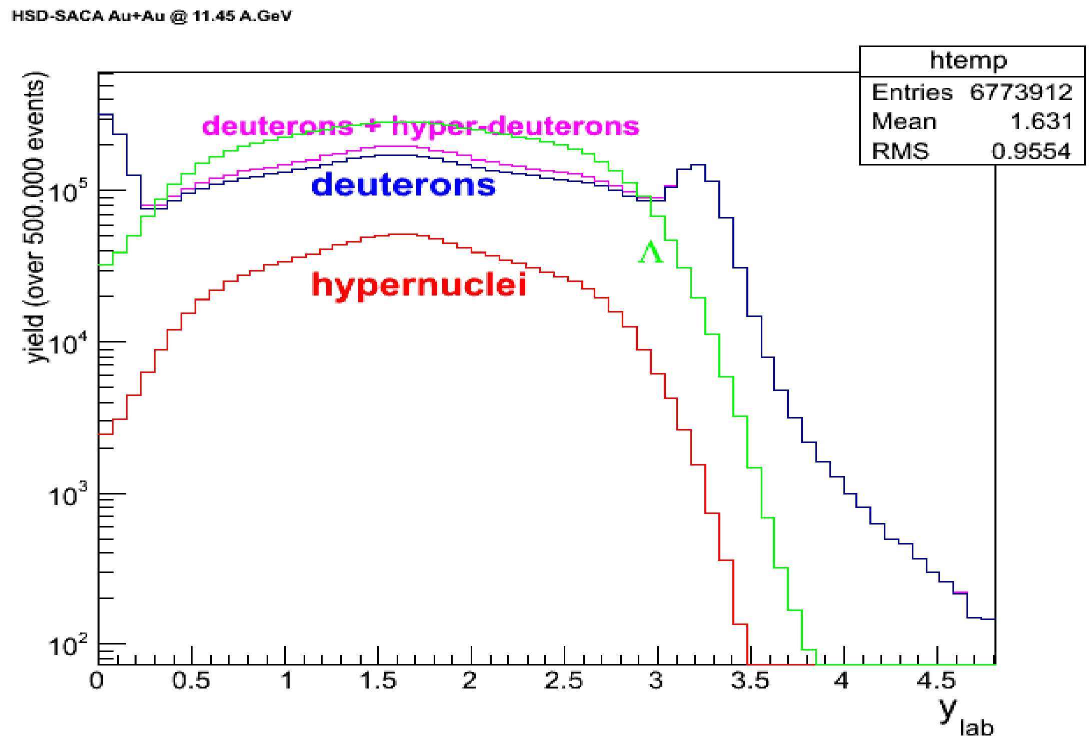
«Proton and deuteron production in Au+Au reactions at 11.6A GeV/c» Phys. Rev. C, 60 064901



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

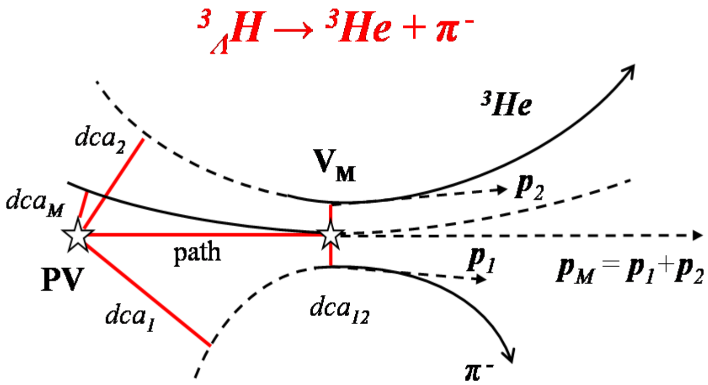
SACA hypernuclei production

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



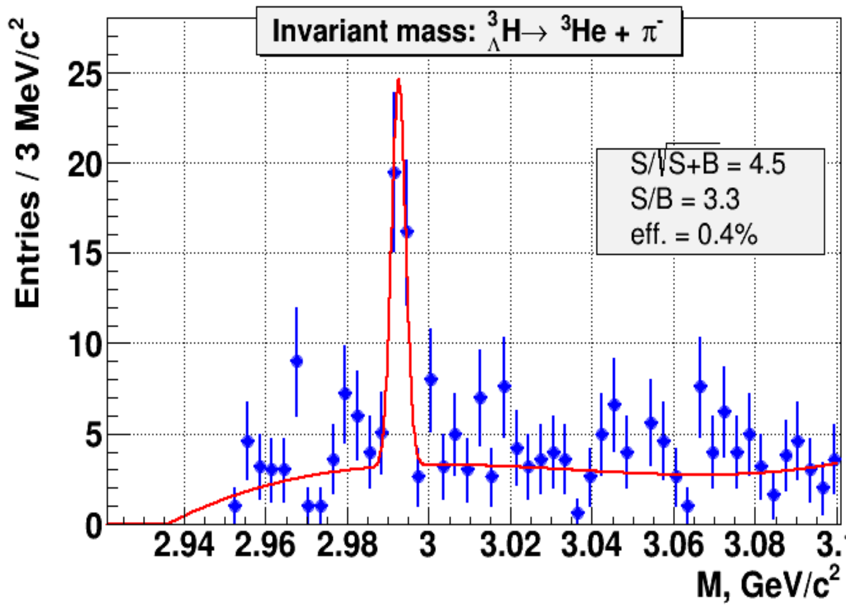
This plot shows the yields of hypernuclei and hyperons predicted by the PHSD+SACA approach in Au+Au collisions at 11.45A GeV.

MPD hypertriton feasibility study



Event topology of two-particle decay of the particle:

- ✓ PV – primary vertex
- ✓ V_M – vertex of $^3_\Lambda H$ decay
- ✓ dca – distance of the closest approach
- ✓ path – decay length



H3L is identified with S/B ratio = 3.3 and efficiency about 0.4%.

Dataset:
500 000 events, Au+Au, b = 0..3 fm, 5 A GeV (11.45 GeV in lab frame)

Current state

SACA → FRIGA (Fragment Recognition In General Application)

A. Le Fèvre et al., J. Phys.: Conf. Ser. 668 (2016) 012021.

improved hypernuclei predictions

PHSD → PHQMD (Parton-Hadron Quantum Molecular Dynamics*)

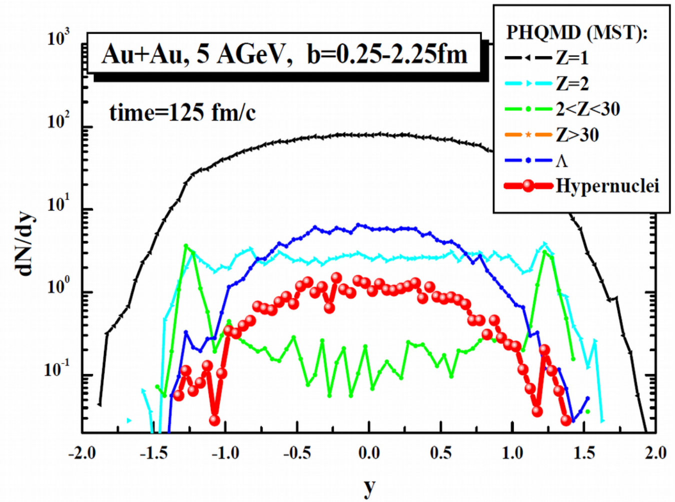
implementation of the n-body approach

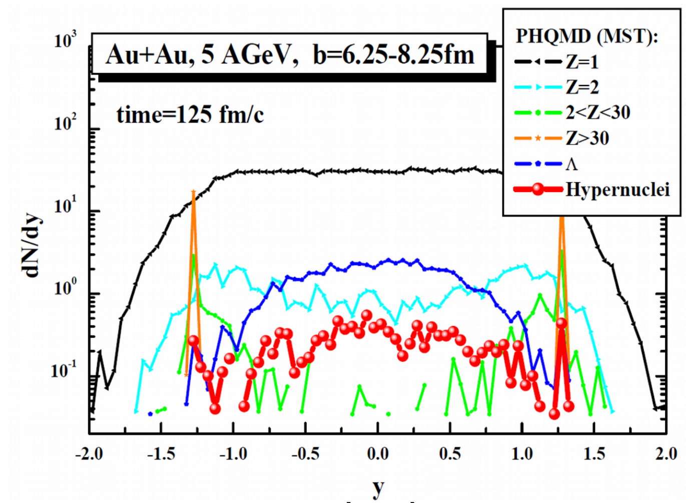
FRIGA is **inside** PHQMD now, not an «afterburner»

* QMD – **J. Aichelin and H. Stöcker, Phys. Lett. 176 B (1988) 14**

PHQMD: fragments and hypernuclei formation

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



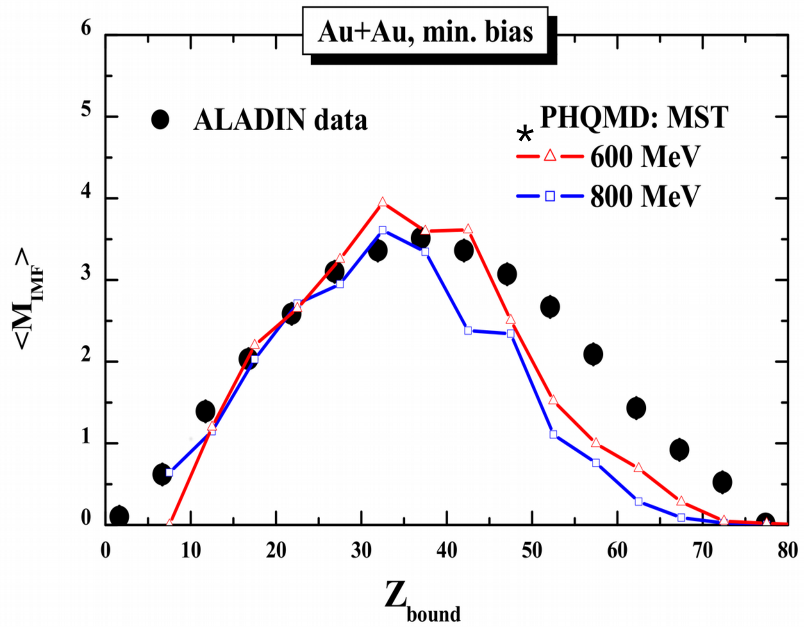


(preliminary results at NICA energies)

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.

PHQMD: fragments and hypernuclei formation



<M_{IMF}> – average number of medium mass fragments (2<Z<30)

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

** A. Schuttauf et al./Nuclear Physics A 607 (1996) 457-486*

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. The understanding of this is a big challenge in present day heavy ion physics.

Summary

- PHSD+SACA can produce clusters and hypernuclei;
- These predictions have been used for MPD performance studies;
- PHSD+SACA model reproduce experimental data for 11.45 GeV;
- Model is actively developing, soon there will be some new results.