Study of Clusters and Hypernuclei production within PHSD+SACA model

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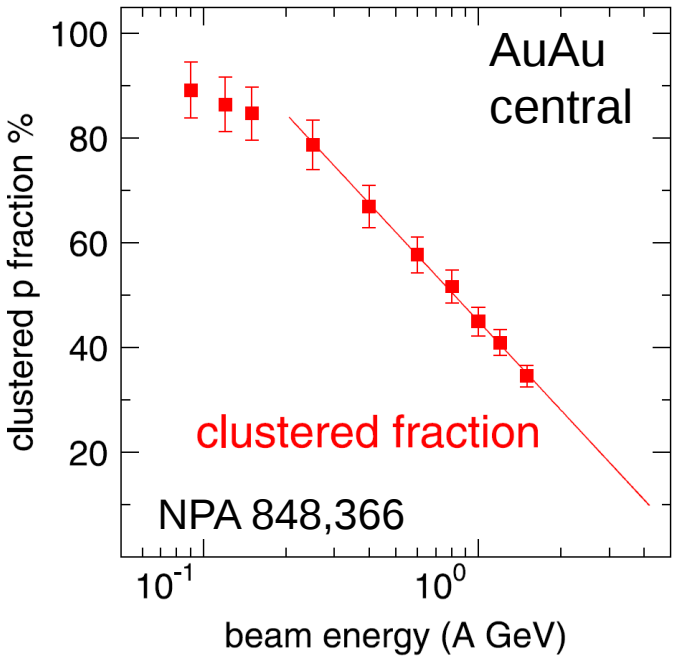
Outline

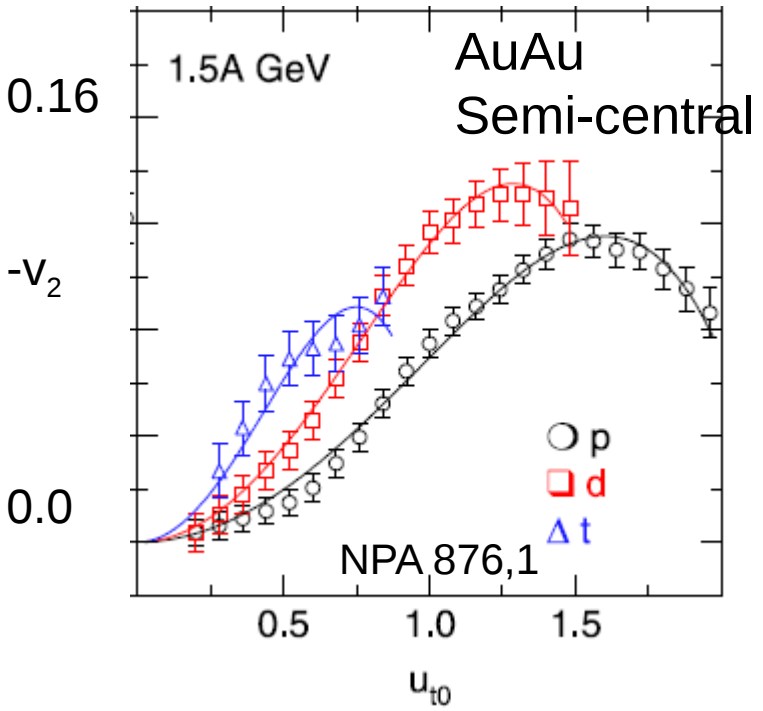
- Motivation
- Searching clusters with PHSD+SACA model
- Current state
- Summary

Motivation

At 3 A GeV, even in central collisions **20% of the baryons are in clusters**.



… and baryons in clusters have quite different properties



Motivation

If we do not describe the **dynamical formation** of fragments

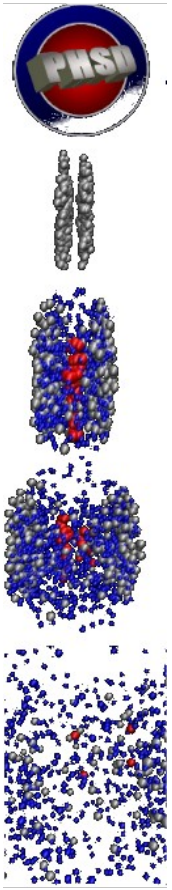
- we cannot describe the nucleon observables (v_1 , v_2, dn/dp_T)
- we cannot explore the new physics opportunities like
  hyper-nucleus formation
  1st order phase transition
  fragment formation at midrapidity (RHIC, LHC)

Present microscopic approaches fail to describe fragments at NICA/FAIR (and higher) energies.

- VUU(1983), BUU(1983), (P)HSD(96), SMASH(2016) solve the time evolution of the one-body phase space density -> **no fragments**
- UrQMD is a n-body theory but has no potential -> **nucleons cannot be bound to fragments**
- (I)QMD is a n-body theory but is limited to energies < 1.5 AGeV -> **describes nicely fragments at SIS energies, but conceptually not adapted for NICA/FAIR**

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

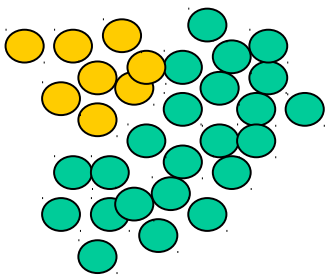
Simulated Annealing Clusterisation Algorithm

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

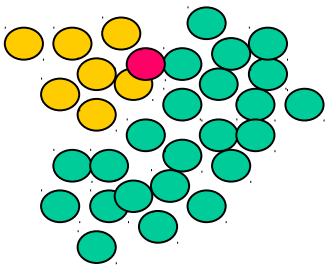
1) Pre-select good «candidates» for fragments according to proximity criteria: real space coalescence = Minimum Spanning Tree (MST) procedure.

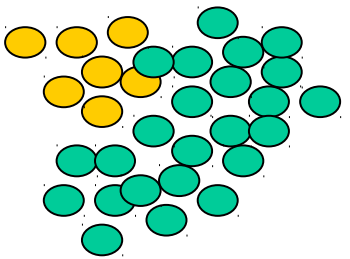
2) Take randomly 1 nucleon out of one fragment

3) Add it randomly to another fragment



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





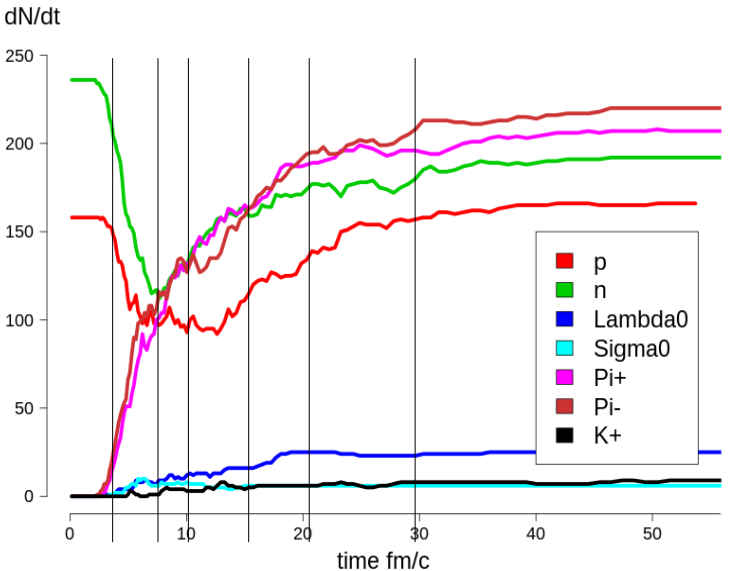
$E' = E^{1'}_{kin} + E^{2'}_{kin} + V^{1'} + V^{2'}$

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

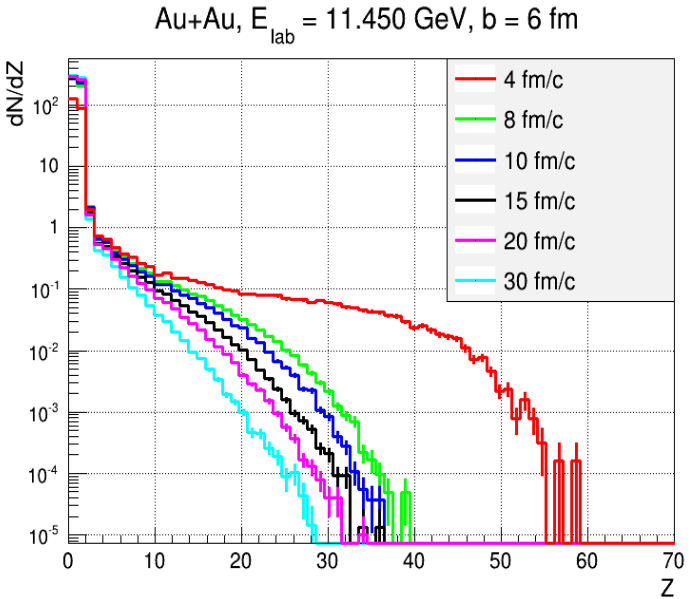
Searching clusters with PHSD+SACA model

(GSI & NANTES & JINR & FIAS collaboration)

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

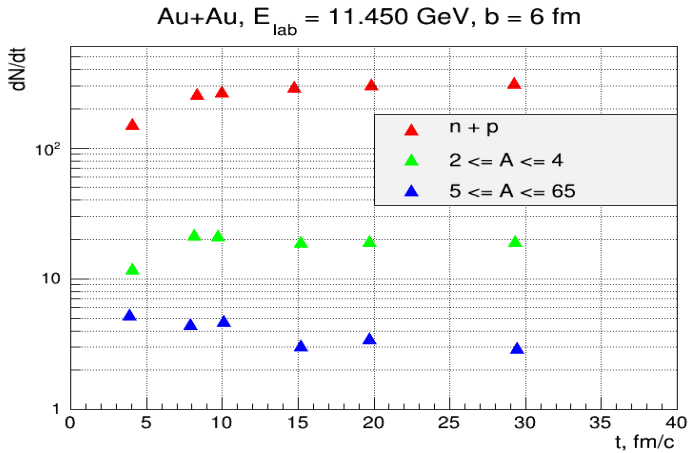


Particles multiplicity per step of PHSD evolution time

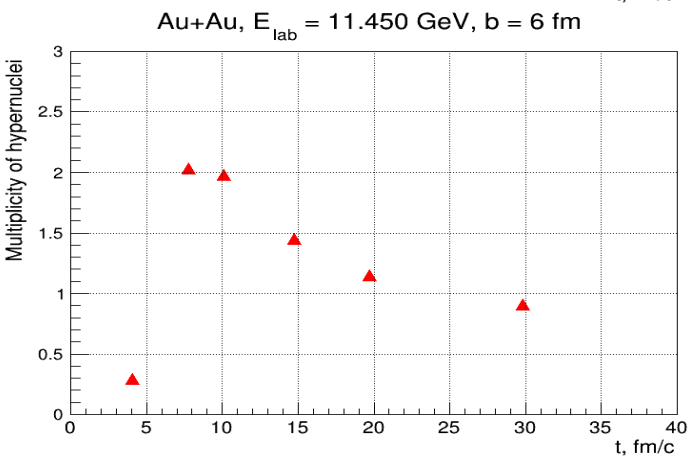


Charge distribution for different SACA starting times. (Red line here – passing time without interaction, for reference only)

Searching clusters with PHSD+SACA model

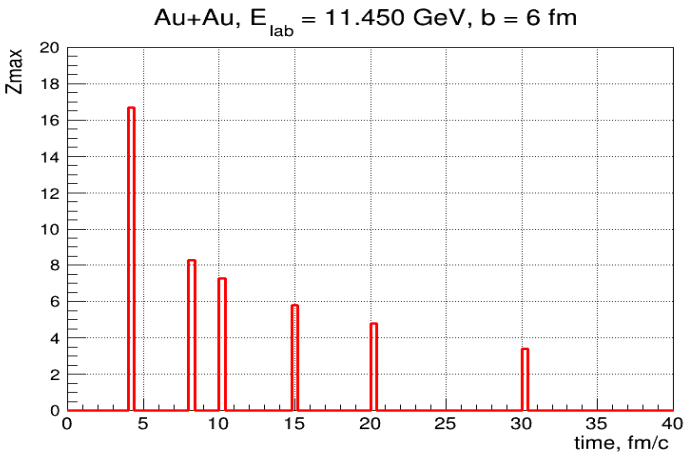


Multiplicity of different kind of particles and fragments



Hypernuclei multiplicity

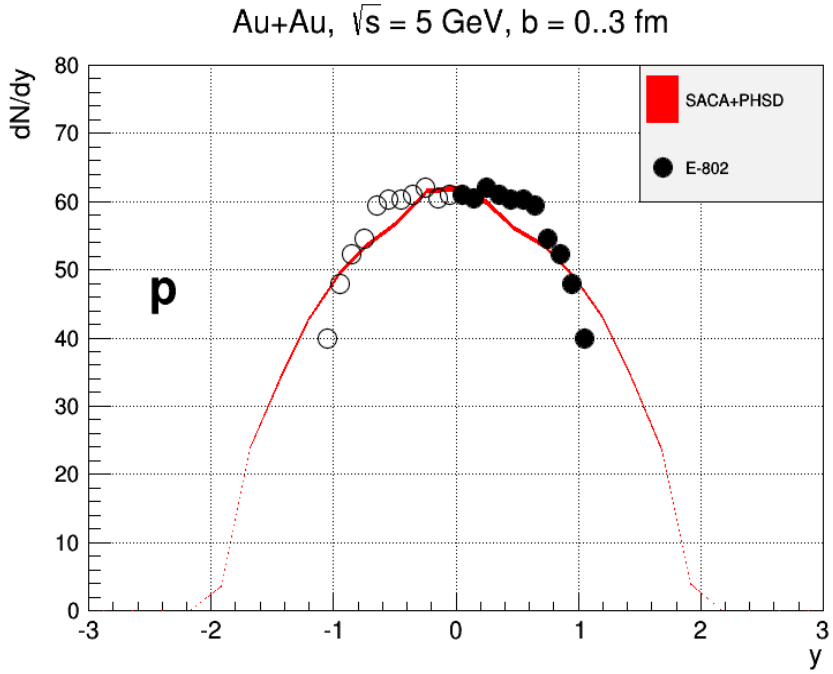
<Zmax> versus formation time

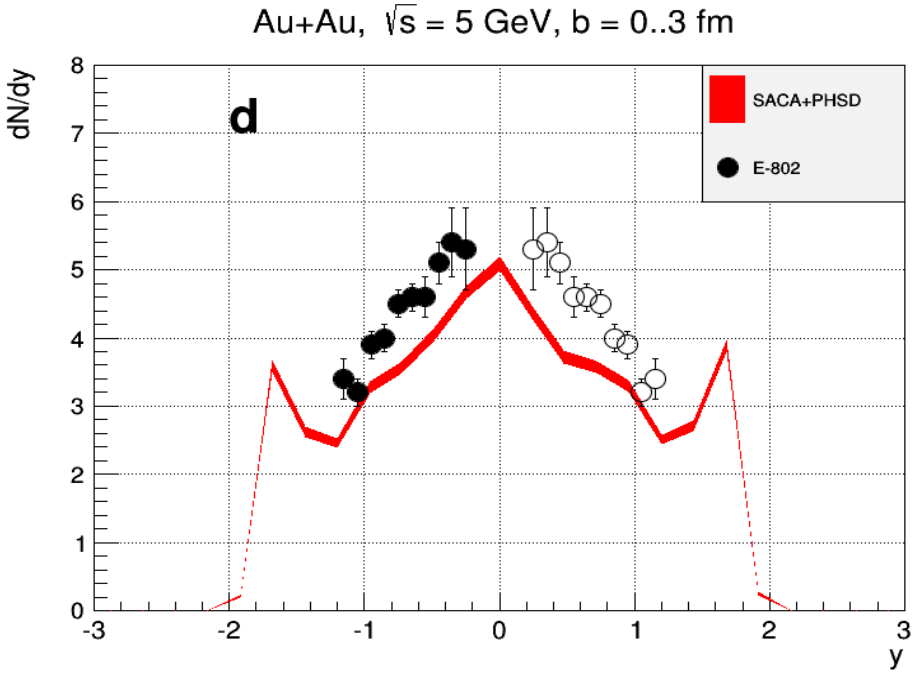


t = 15 fm/c has been chosen to start SACA simulations at 11.45 GeV

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

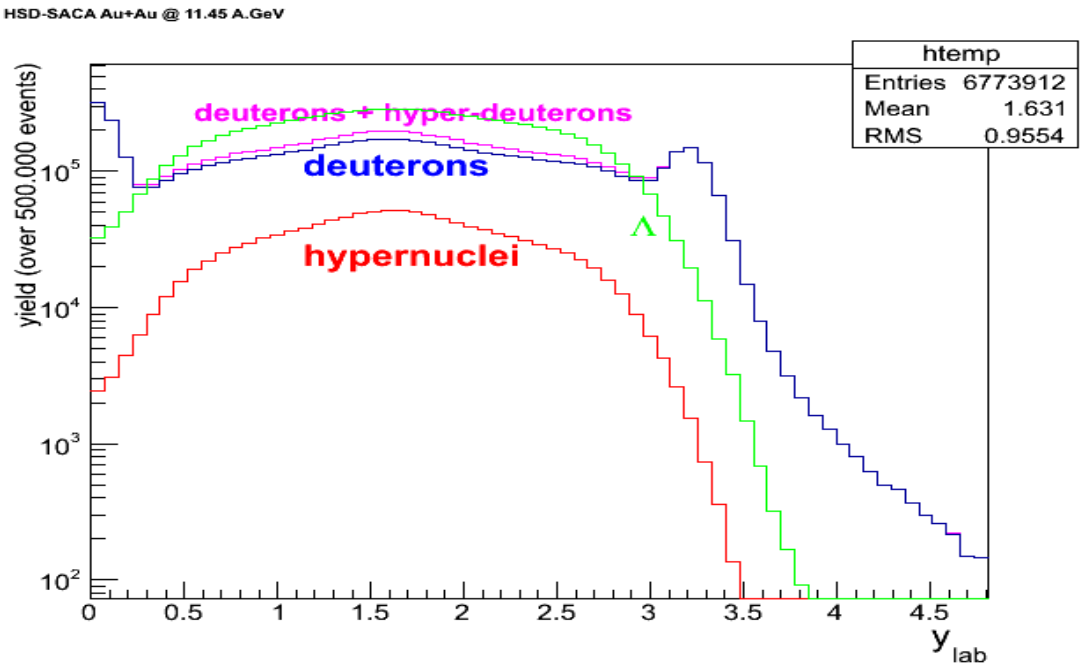




Model reproduce experimental data dN/dy distributions for protons and deuterons

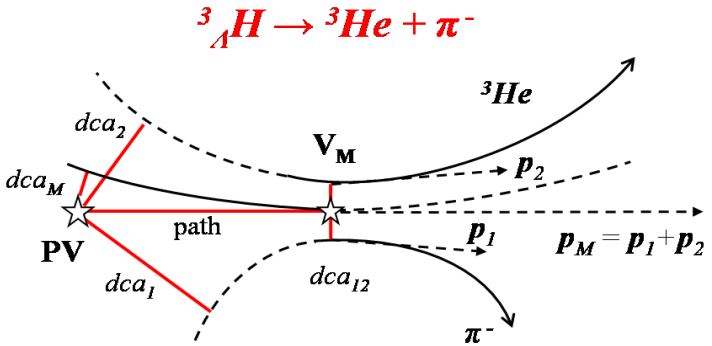
SACA hypernuclei production

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.



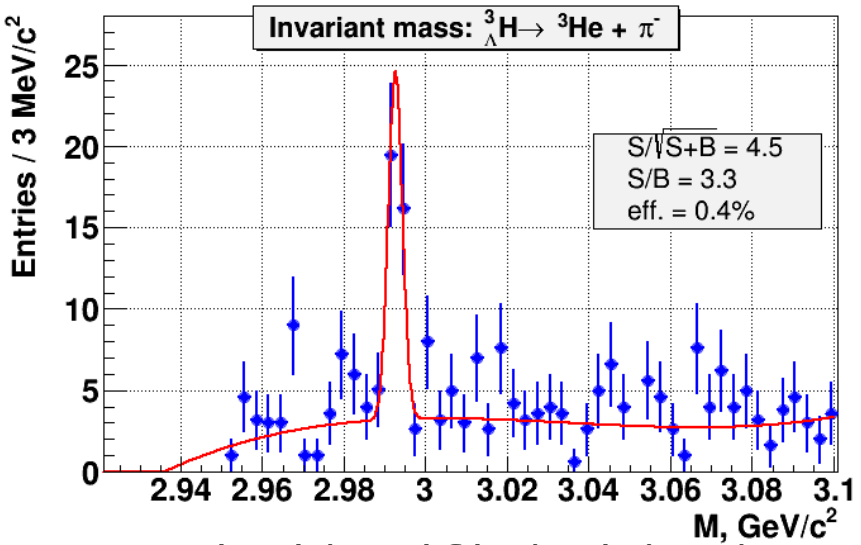
This plot shows the yields of hypernuclei and hyperons predicted by the PHSD+SACA approach in Au+Au collisions at 11.45A GeV.

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

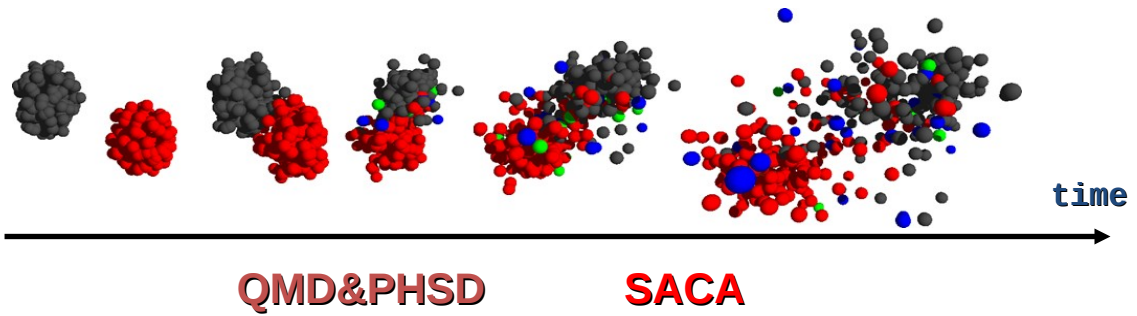
SACA → **FRIGA** (Fragment Recognition In General Application)

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

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

PHQMD = (QMD & PHSD) & SACA (FRIGA)

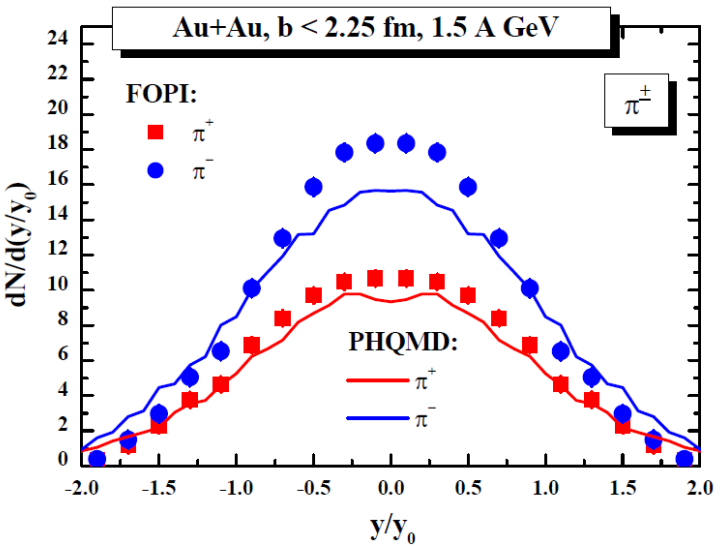
A non-equilibrium microscopic transport model which describes **n-body dynamics** based on **QMD propagation** with **collision integrals from PHSD** and **cluster formation by the SACA model** or by the Minimum Spanning Tree model (MST).

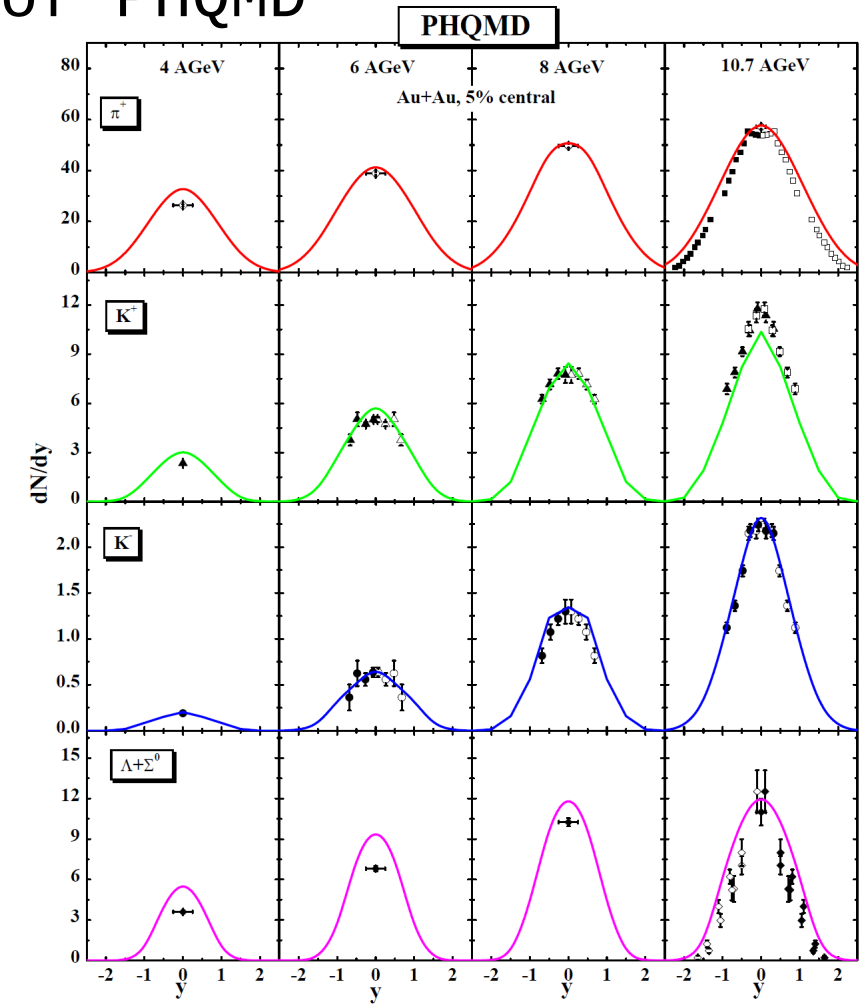


* QMD – **J. Aichelin and H. Stöcker, Phys. Lett. 176 B (1988) 14**

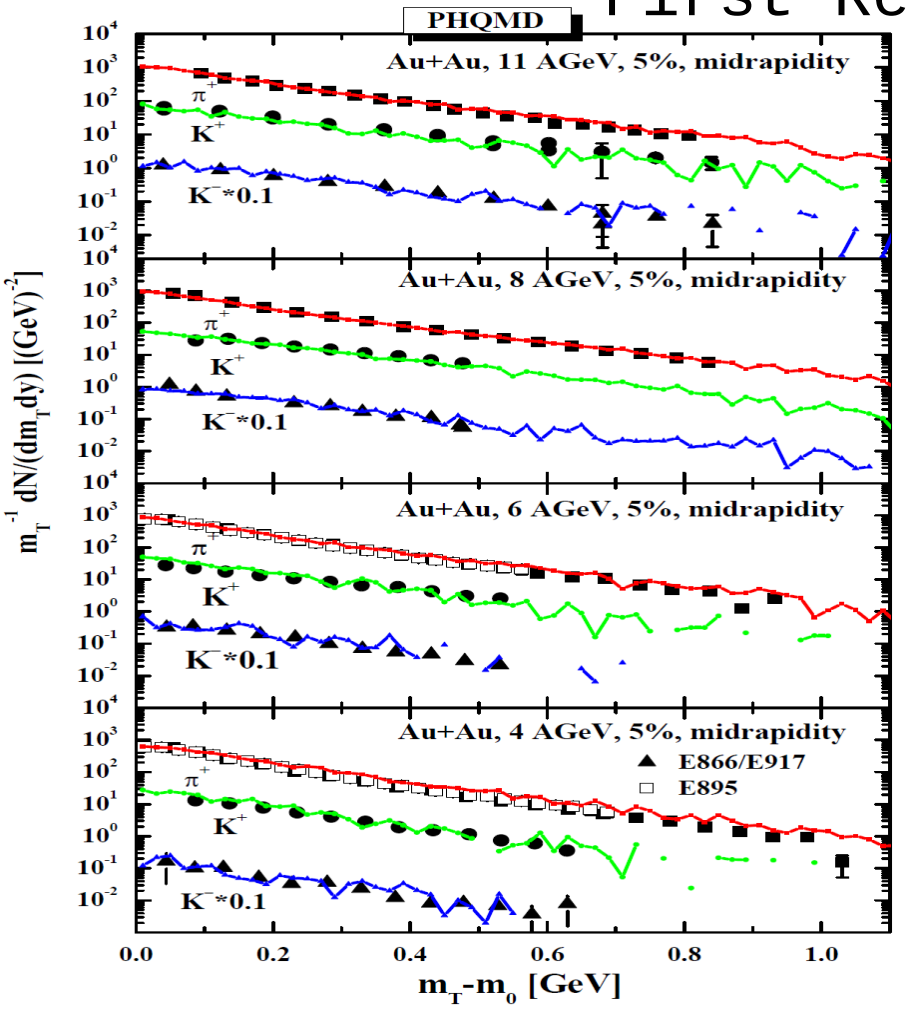
First Results of PHQMD

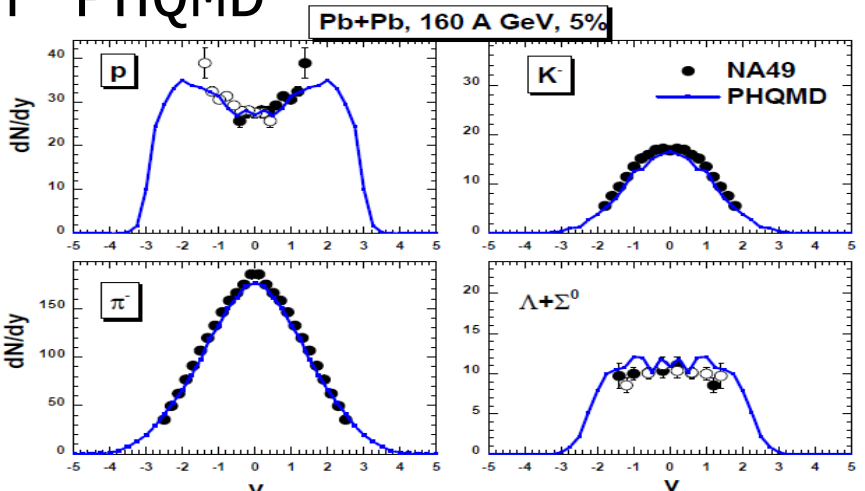
Produced particles
are well reproduced
at SIS/NICA/FAIR energies,
as well as at SPS energies.

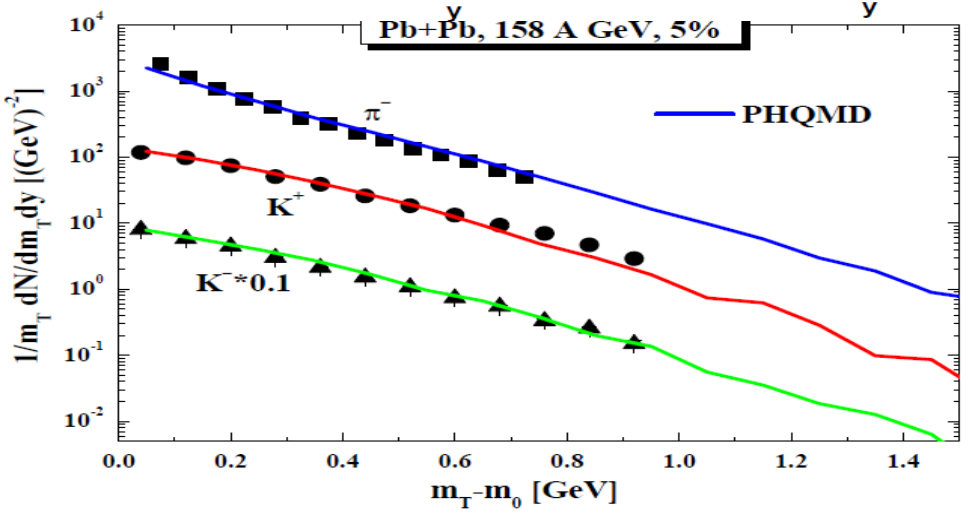




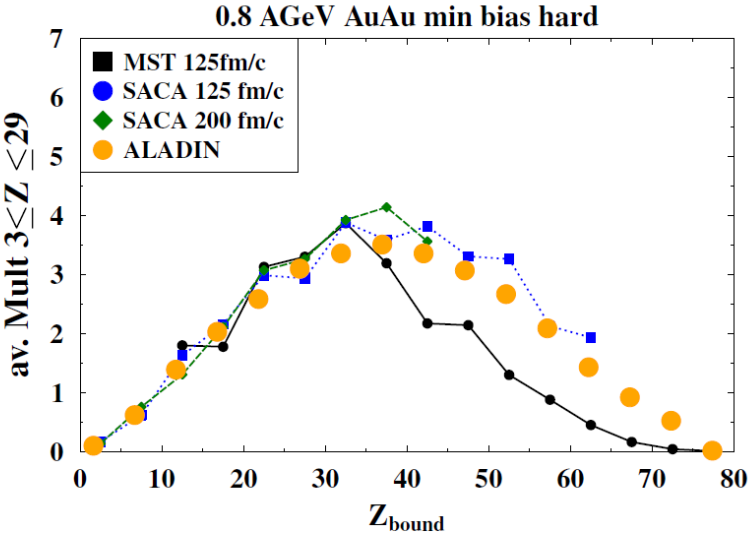
First Results of PHQMD







PHQMD: fragments and hypernuclei formation



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

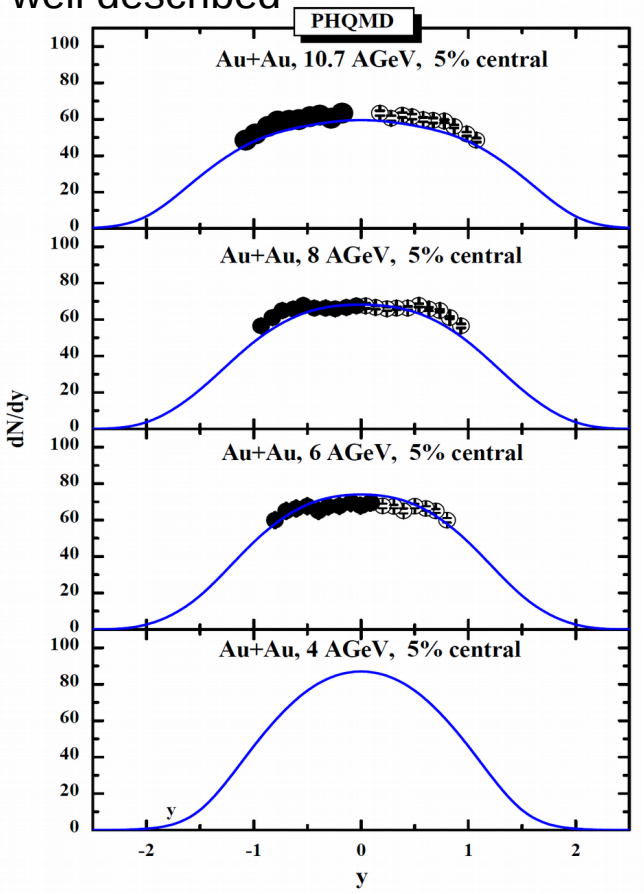
Z_{bound} – number of charges bounded in clusters (Z>1)

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

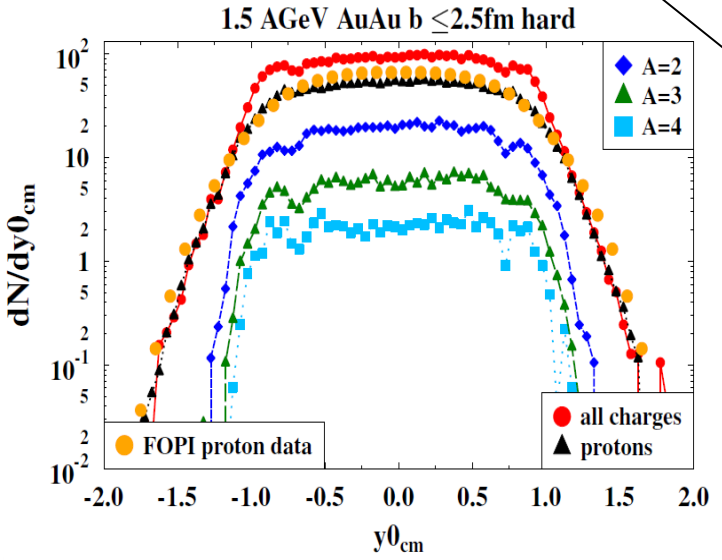
For very peripheral reactions we expect that only the remnant is bound and no intermediate mass clusters appear, at very central collisions we expect that a fireball is created which contains essentially protons and neutrons, so Z_{bound} is small as well as M_{IMF}. In mid-central reactions we observe 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.

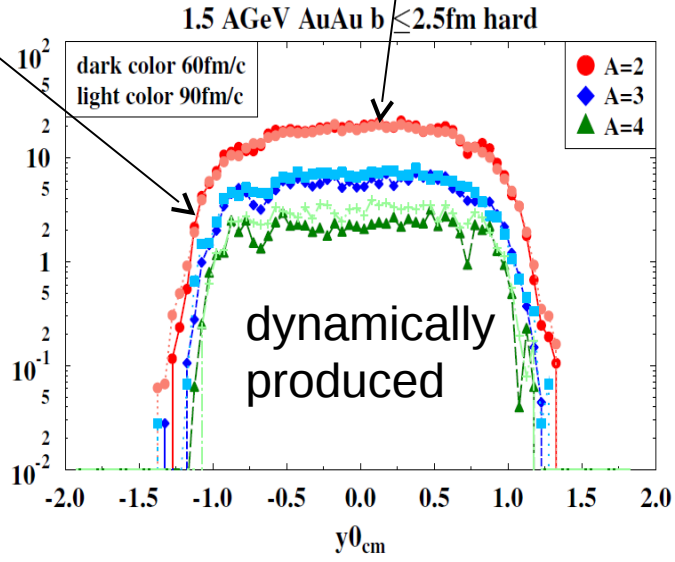
PHQMD: fragments and hypernuclei formation

Protons at **midrapidity** well described



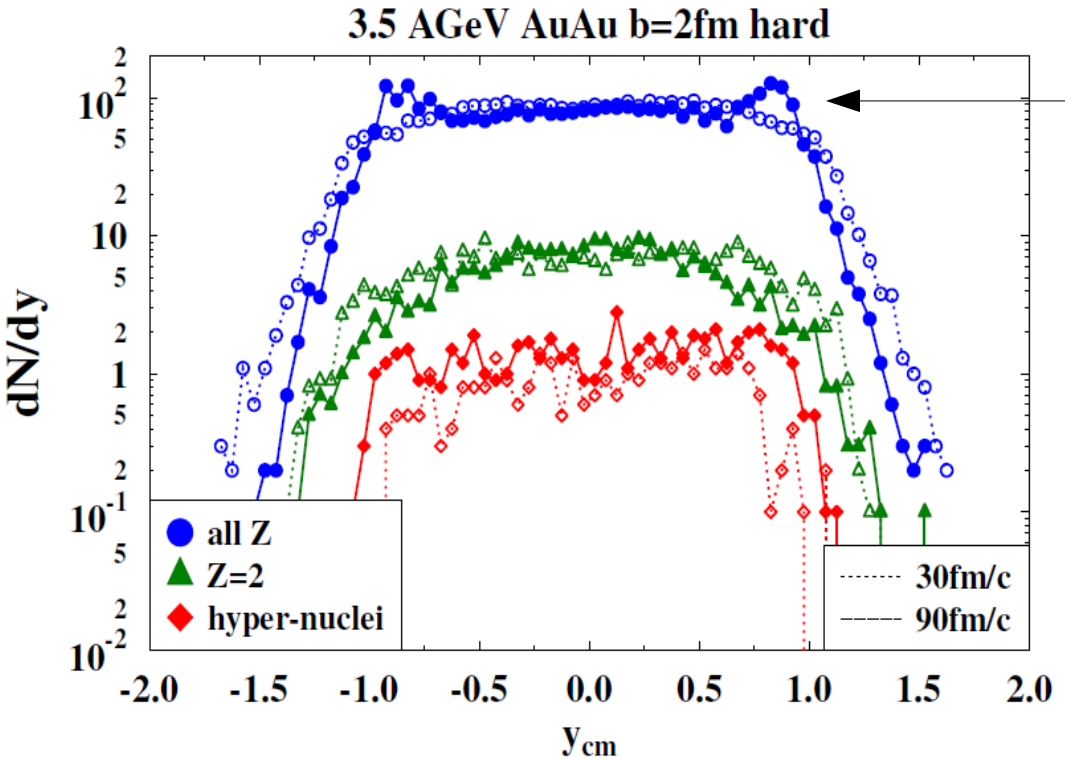
There are all kinds of fragments at midrapidity
and **they are stable**
(MST finds at 60fm/c the same fragments as at 90fm/c)





PHQMD: fragments and hypernuclei formation

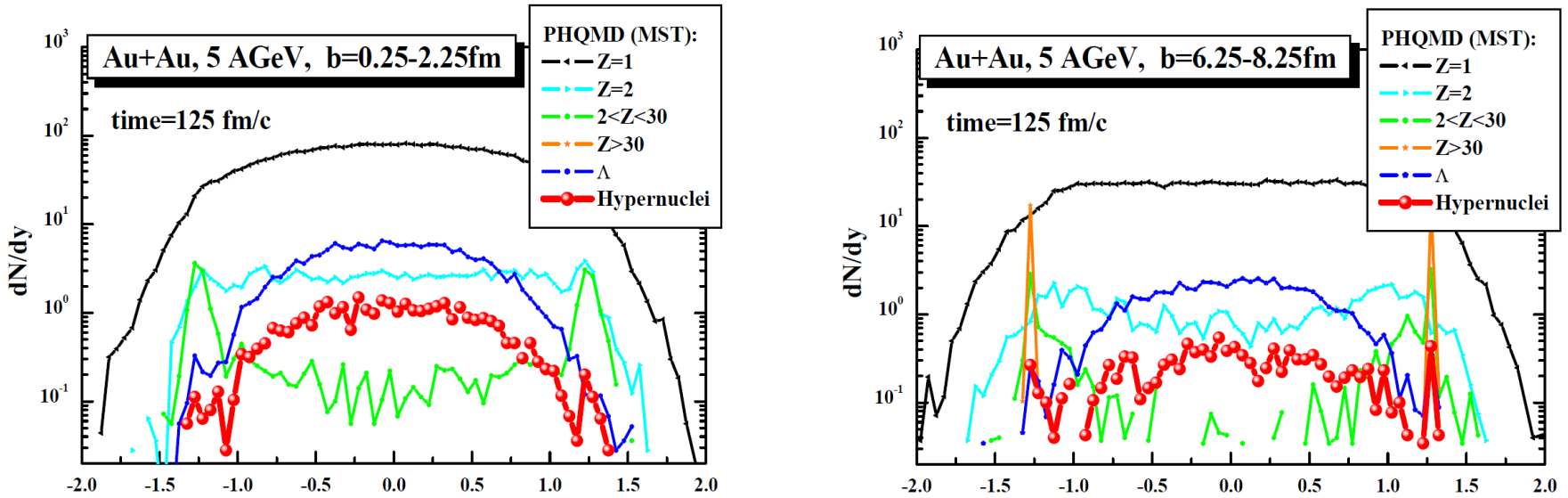
BM@N energy



Still activity in spectator matter after 30 fm/c

- Fragments are stable from 30 fm/c -> 90 fm/c
- Hyper-nuclei are produced in number

PHQMD: fragments and hypernuclei formation



(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.

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.

Backup slides

Simulation/reconstruction chain