Formation of hypernuclei in relativistic ion collisions

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J.Pochodzalla, J.Steinheimer)

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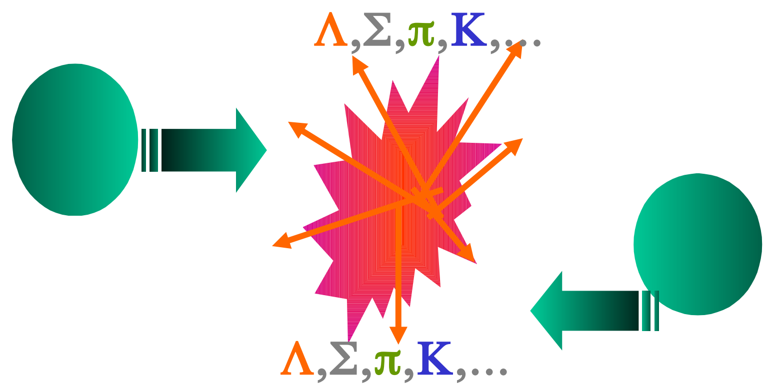
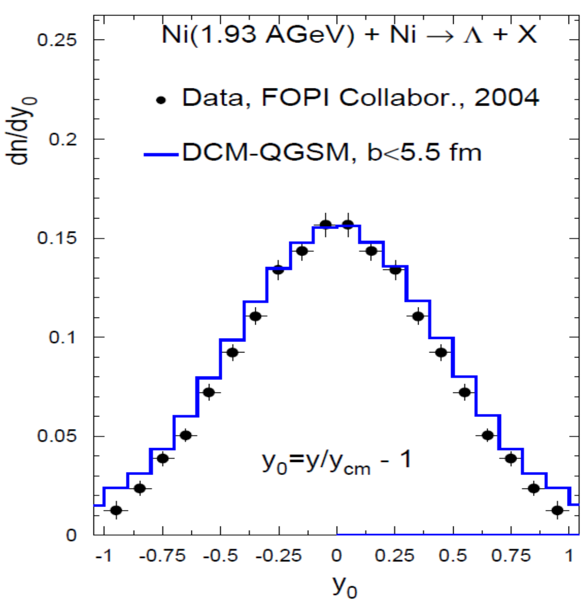
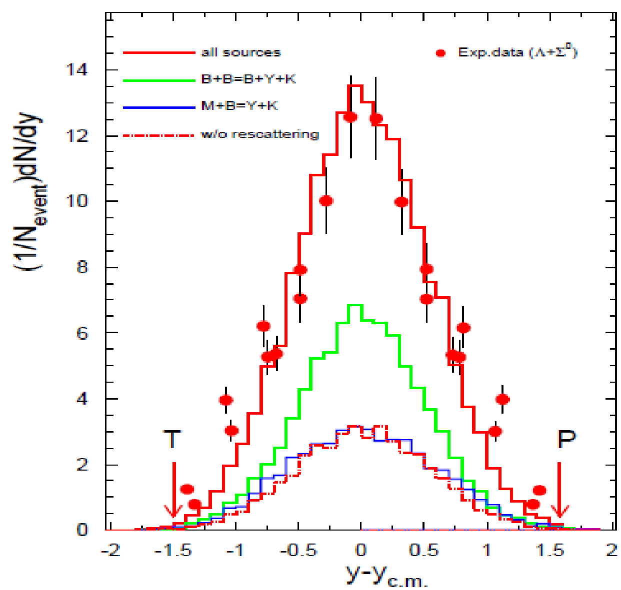
Relativistic collisions of hadrons and ions



Production of hypermatter in relativistic HI and hadron collisions

- Production of strange particles and hyperons by "participants",
- Rescattering and absorption of hyperons by excited "spectators",
- Coalescence of produced baryons.





S.Albergo et al., E896: PRL88(2002)062301

Au(11AGeV/c)+Au

Calculation: DCM PRC**84**(2011)064904

Wide rapidity distribution of produced Λ!

Theoretical descriptions of strangeness production within transport codes

old models : e.g., Z.Rudy, W.Casing et al., *Z. Phys.A351(1995)217*
INC, QMD, BUU

GiBUU model: Th.Gaitanos, H.Lenske, U.Mosel , *Phys.Lett. B663(2008)197,*
(+SMM) *Phys.Lett. B675(2009)297*

PHSD model: E.Bratkovskaya, W.Cassing, … *Phys. Rev. C78(2008)034919*

DCM (INC) : JINR version: K.K.Gudima et al., *Nucl. Phys. A400(1983)173, ...*
(+QGSM+SMM) *Phys. Rev. C84 (2011) 064904*

UrQMD approach: S.A. Bass et al., *Prog. Part. Nucl. Phys. 41 (1998)255.*
M.Bleicher et al. *J. Phys.G25(1999)1859, … ,* J.Steinheimer ...

Main channels for production of strangeness in individual hadron- nucleon collisions: $BB \to BYK$, $B\pi \to YK$, … (like $p+n \to n+\Lambda+K^+$, and secondary meson interactions, like $\pi+p \to \Lambda+K^+$). Rescattering of hyperons is important for their capture by spectators. Expected decay of produced hyperons and hypernuclei: 1) mesonic $\Lambda \to \pi+N$; 2) in nuclear medium nonmesonic $\Lambda+N \to N+N$.

Physical picture of peripheral relativistic HI collisions:

nucleons of projectile interact with nucleons of target, however, in peripheral collisions many nucleons (spectators) are not involved. All products of the interactions can also interact with nucleons and between themselves. The time-space evolution of all nucleons and produced particles can be calculated with transport models.

All strange particles: Kaons, Lambda, Sigma, Xi, Omega are included in the transport models

ABSORPTION of LAMBDA :

The residual spectator nuclei produced during the non-equilibrium stage may capture the produced Lambda hyperons if these hyperons are (a) inside the nuclei and (b) their energy is lower than the hyperon potential in nuclear matter (~30 MeV). In the model a depletion of the potential with reduction of number of nucleons in nucleus is taken into account by calculating the local density of spectator nucleons.

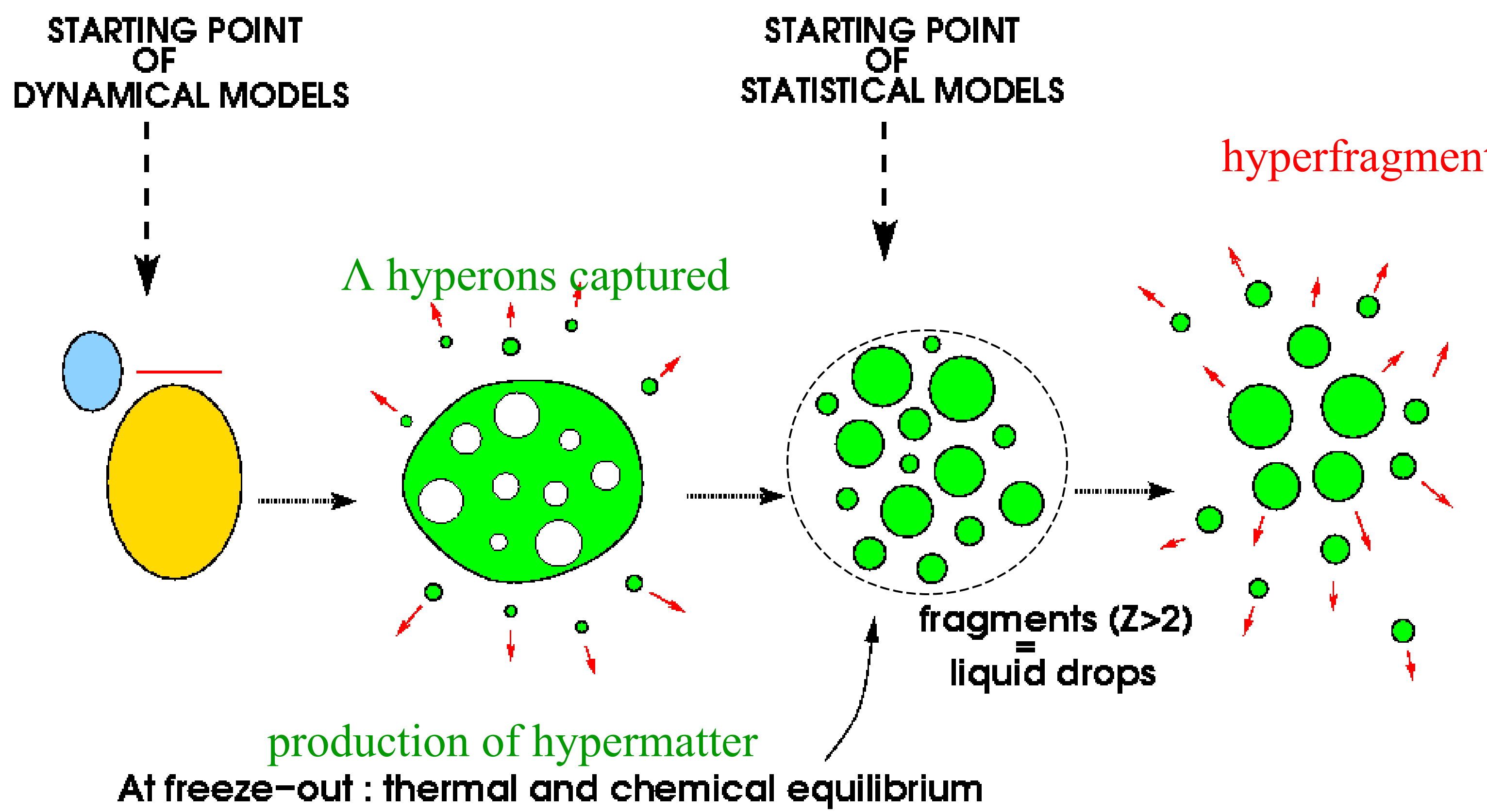
A.S.Botvina and J.Pochodzalla, Phys. Rev.C76 (2007) 024909

Generalization of the statistical de-excitation model for nuclei with Lambda hyperons

In these reactions we expect analogy with

multifragmentation in intermediate and high energy nuclear reactions

+ nuclear matter with strangeness



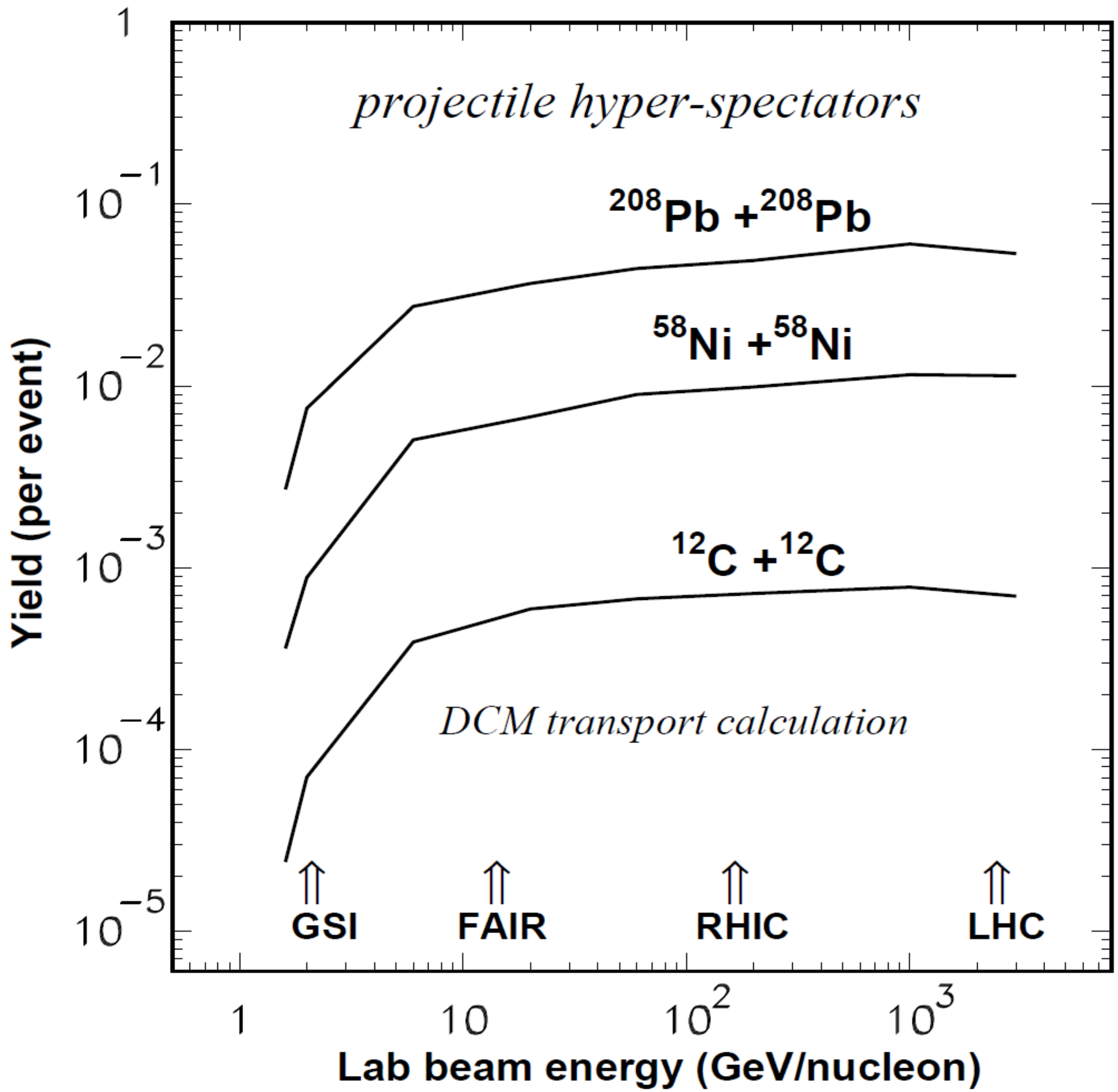
Yield of hypernuclei in peripheral collisions

A.S.Botvina, K.K.Gudima, J.Pochodzalla (PRC88, 054605, 2013)

Threshold behavior with saturation at high energies (for single hypernuclei)

Yield is integrated over all impact parameters.

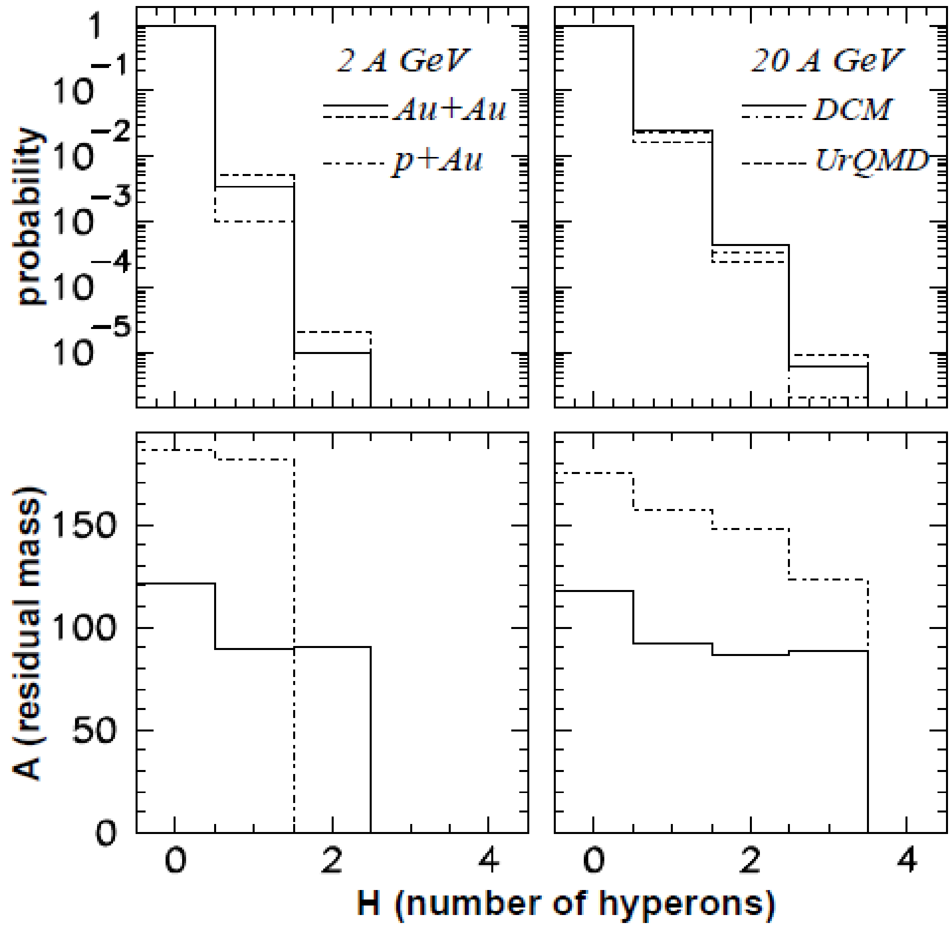
Reactions can be studied at GSI/FAIR and JINR/NICA facilities as well as on operating RHIC and LHC (fixed target experiments).



A.S.Botvina, K.K.Gudima, J.Steinheimer, M.Bleicher, I.N.Mishustin. PRC 84 (2011) 064904

projectile residuals produced after non-equilibrium stage

total yield of residuals with single hyperons ~1% , with double ones ~0.01%, at 2 GeV per nucleon, and considerably more at 20 GeV per nucleon

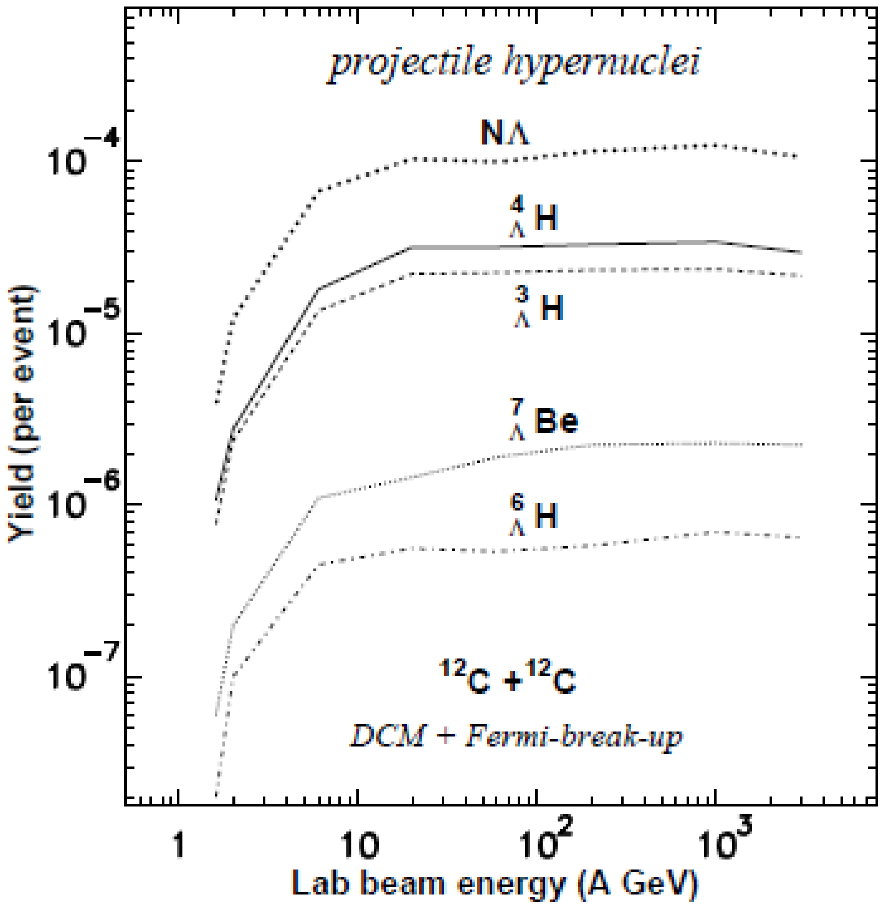


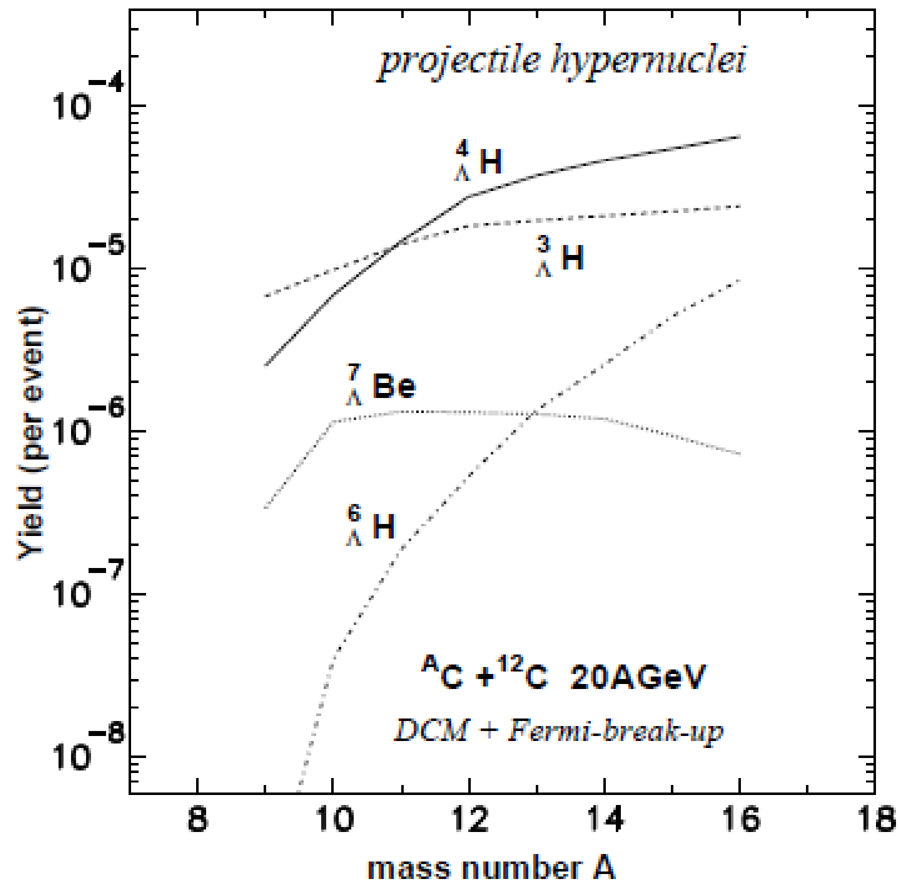
Integrated over all impact parameters

Formation of multi-strange nuclear systems (H>2) is possible!

The disintegration of such sytems can lead to production of exotic hypernuclei.

Production of light hypernuclei in relativistic ion collisions





One can use exotic neutron-rich and neutron-poor projectiles, which are not possible to use as targets in traditional hyper-nuclear experiments, because of their short lifetime. Comparing yields of hypernuclei from various sources we can get info about their binding energies and properties of hyper-matter.

A.S.Botvina, K.K.Gudima, J.Pochodzalla, PRC 88, 054605, 2013

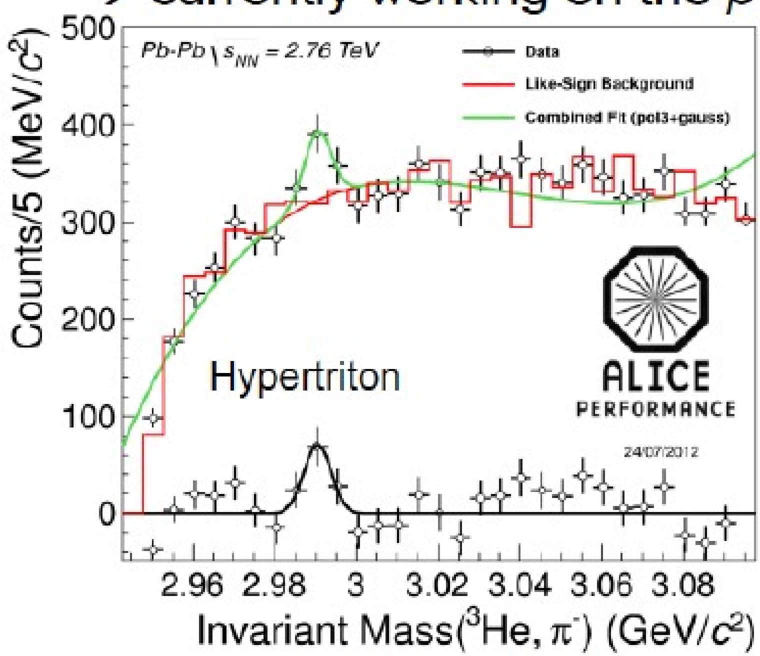
B. Doenigus et al., Nucl. Phys. A904-905 (2013) 547c

ALICE's observation for (anti-)hypertriton

Hypertriton

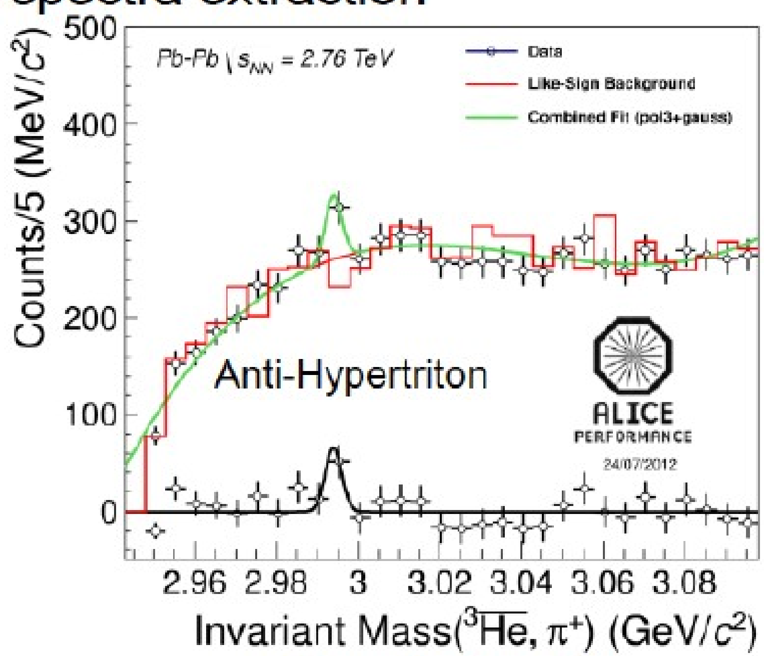
Signal of the hypertriton from the 2011 run

→ currently working on the p_T spectra extraction



μ = (2.990 ± 0.001) GeV/c^2

σ = (3.35 ± 0.7)x10^{-3} GeV/c^2



μ = (2.993 ± 0.001) GeV/c^2

σ = (2.00 ± 1.2)x10^{-3} GeV/c^2

A.Botvina, J.Steinheimer, E.Bratkovskaya, M.Bleicher, J.Pochodzalla, PLB742(2015)7

Coalescence of Baryons (CB) Model :

Development of the coalescence for formation of clusters of all sizes

1) Relative velocities between baryons and clusters are considered,
   if ($|\mathbf{V}b-\mathbf{V}_A|$)<$\mathbf{V}c$ the particle b is included in the A-cluster.
2) Step by step numerical approximation.

3) In addition, coordinates of baryons and clusters are considered,
   if $|\mathbf{X}b-\mathbf{X}_A|$<R*A**(1/3) the particle b may be included in A-cluster.
4) Spectators' nucleons are always included in the residues.

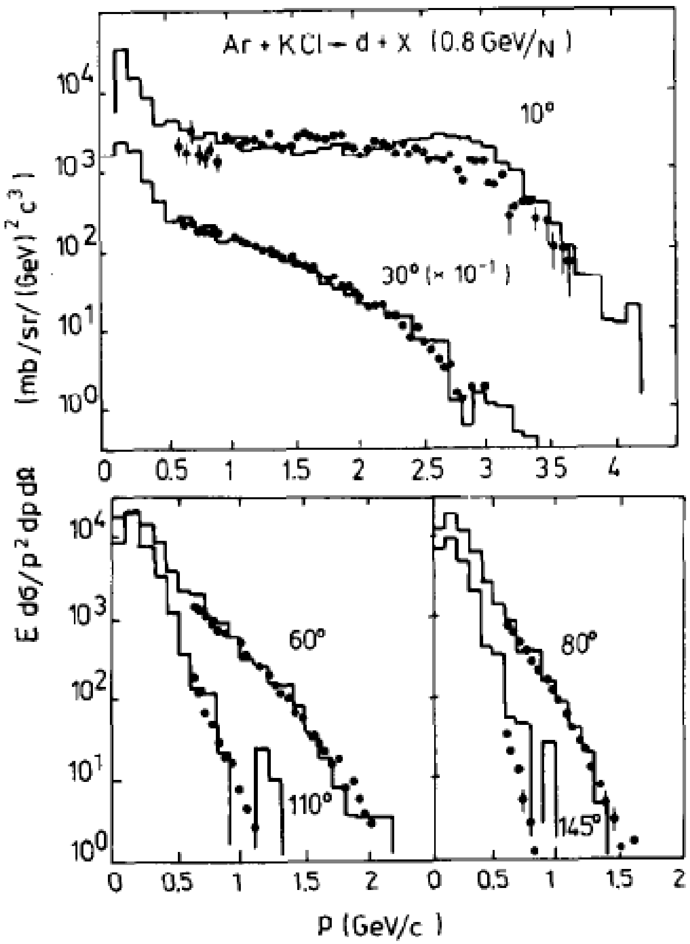
Combination of transport UrQMD and HSD models with CB:

Investigation of fragments/hyperfragments at all rapidities !
(connection between central and peripheral zones)

DCM + Coalescence

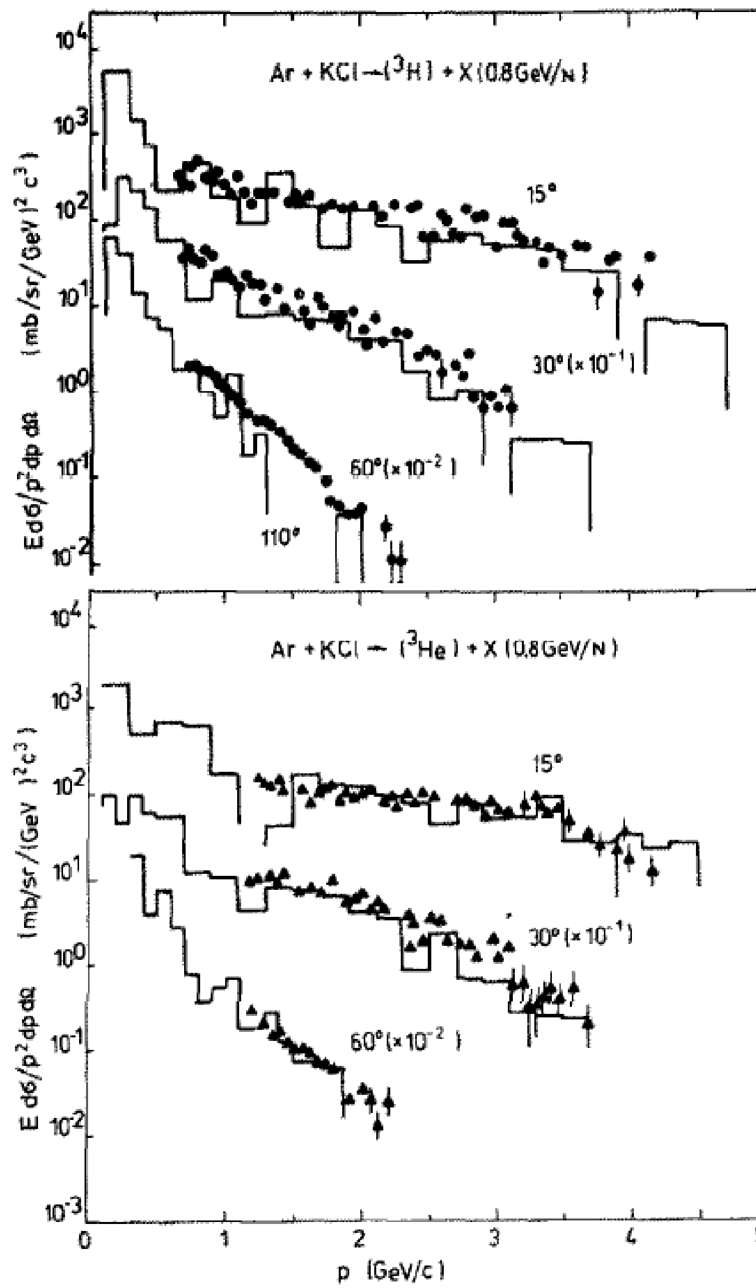
momentum: $|\mathbf{P}_i - \mathbf{P}_0| \le \mathbf{P}_c$

V.Toneev, K.Gudima,
Nucl. Phys. A400 (1983)173c



Deutrons:
Pc=90 MeV/c

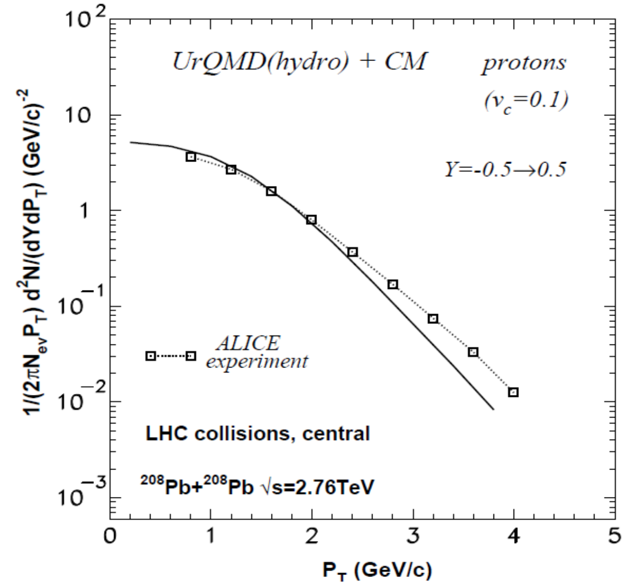
A=3:
Pc=110 MeV/c

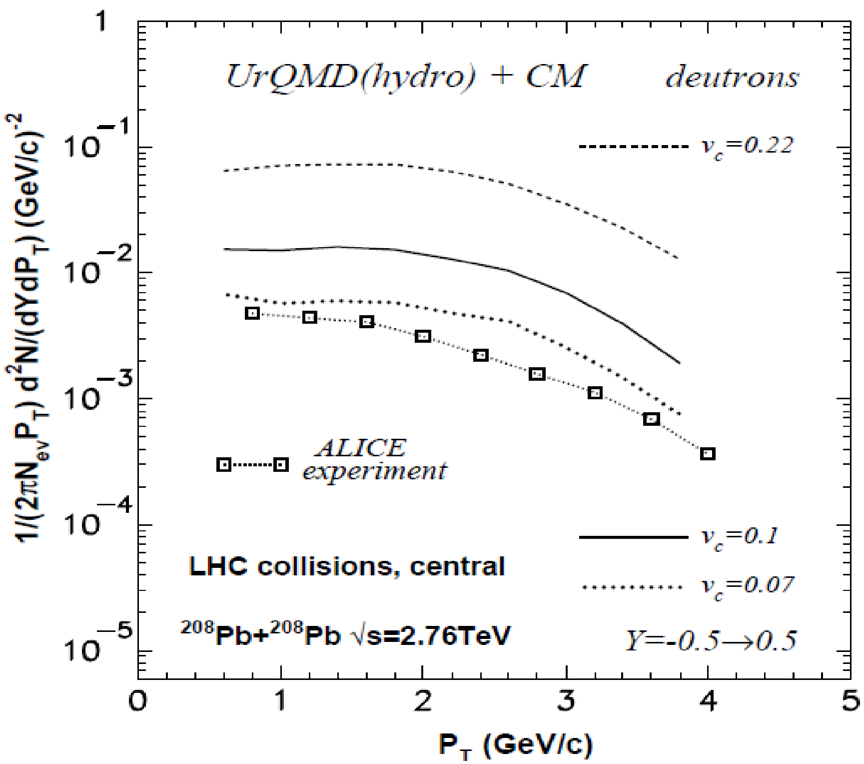


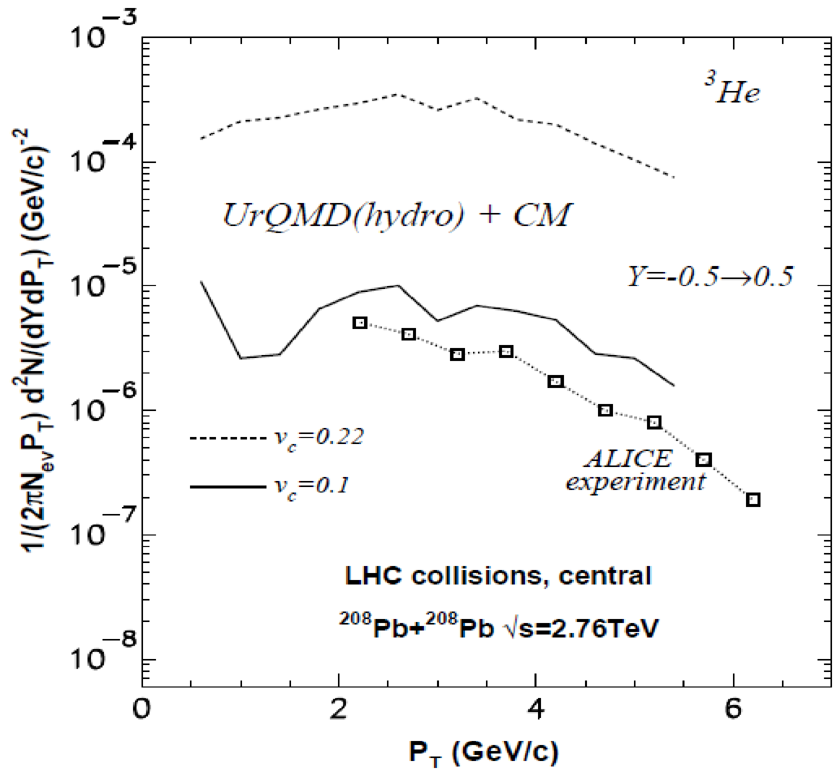
PRELIMINARY:

UrQMD + CB model calculations:
(LHC collider) 208Pb + 208Pb at 2.76 A TeV

ALICE: arXiv: 1303.0737v3 (2014)
arXiv: 1506.08951v1 (2015)







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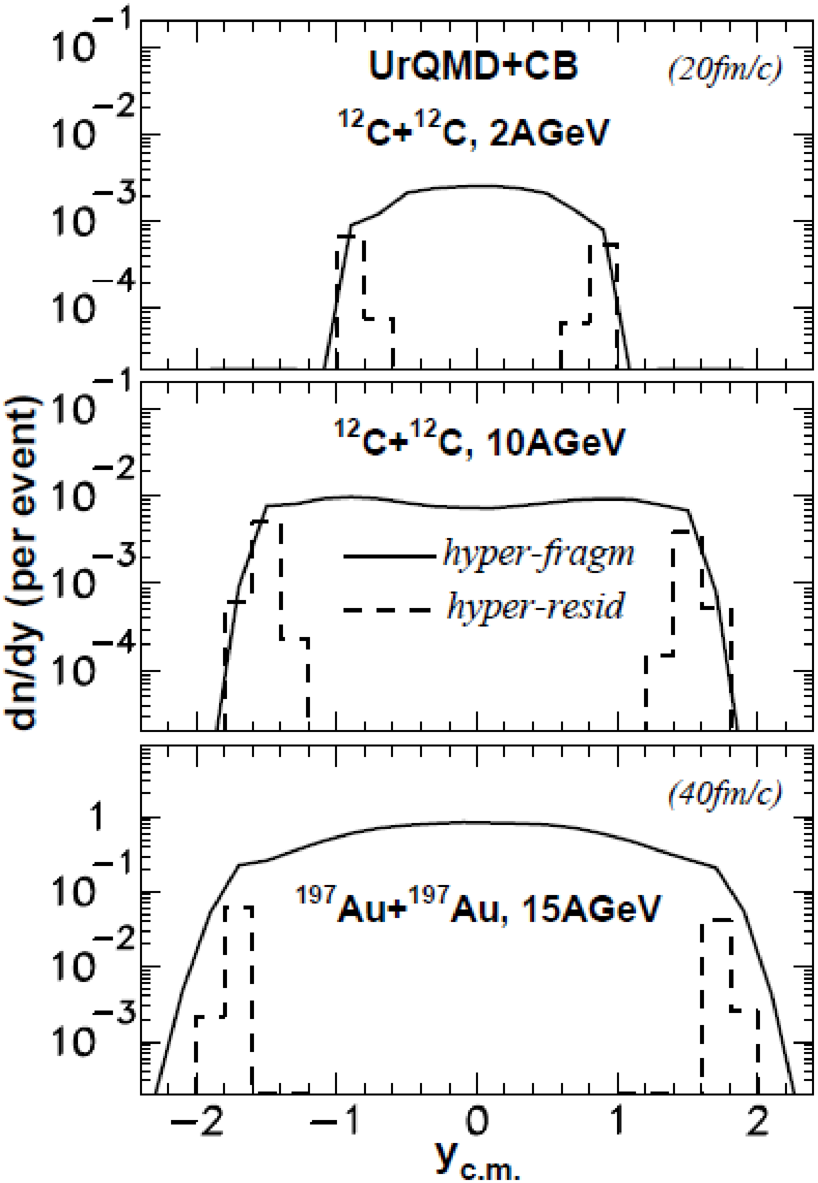
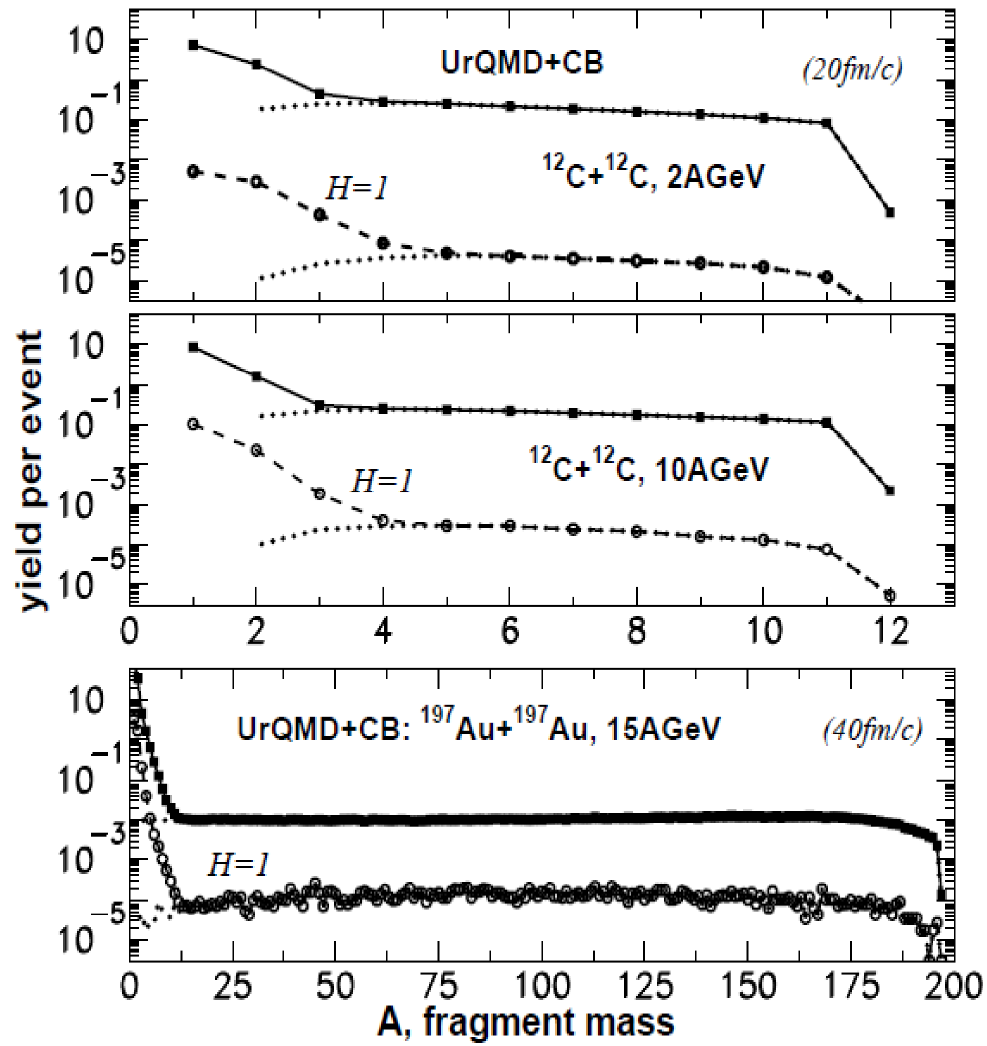
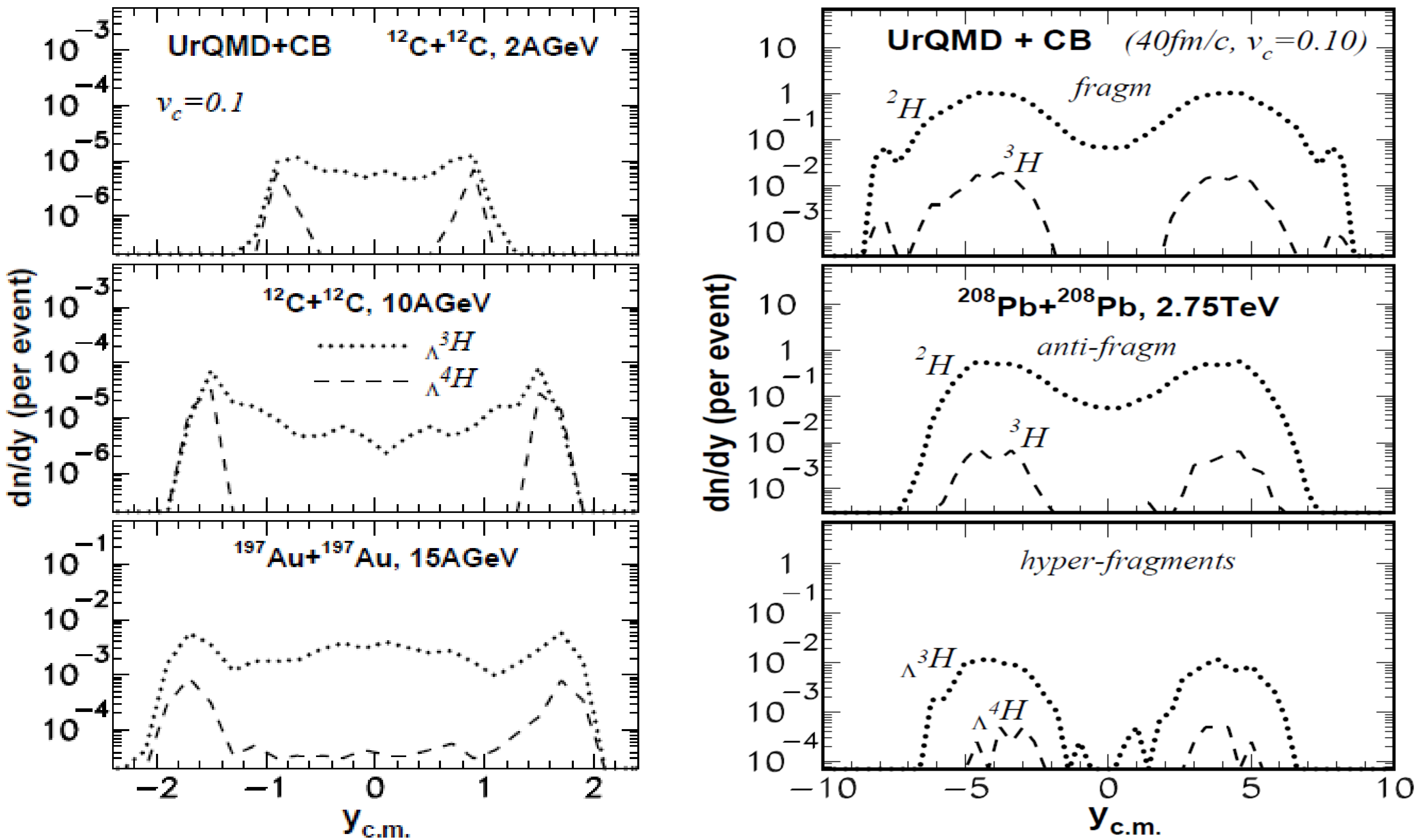
normal fragments, hyper-fragments, hyper-residues



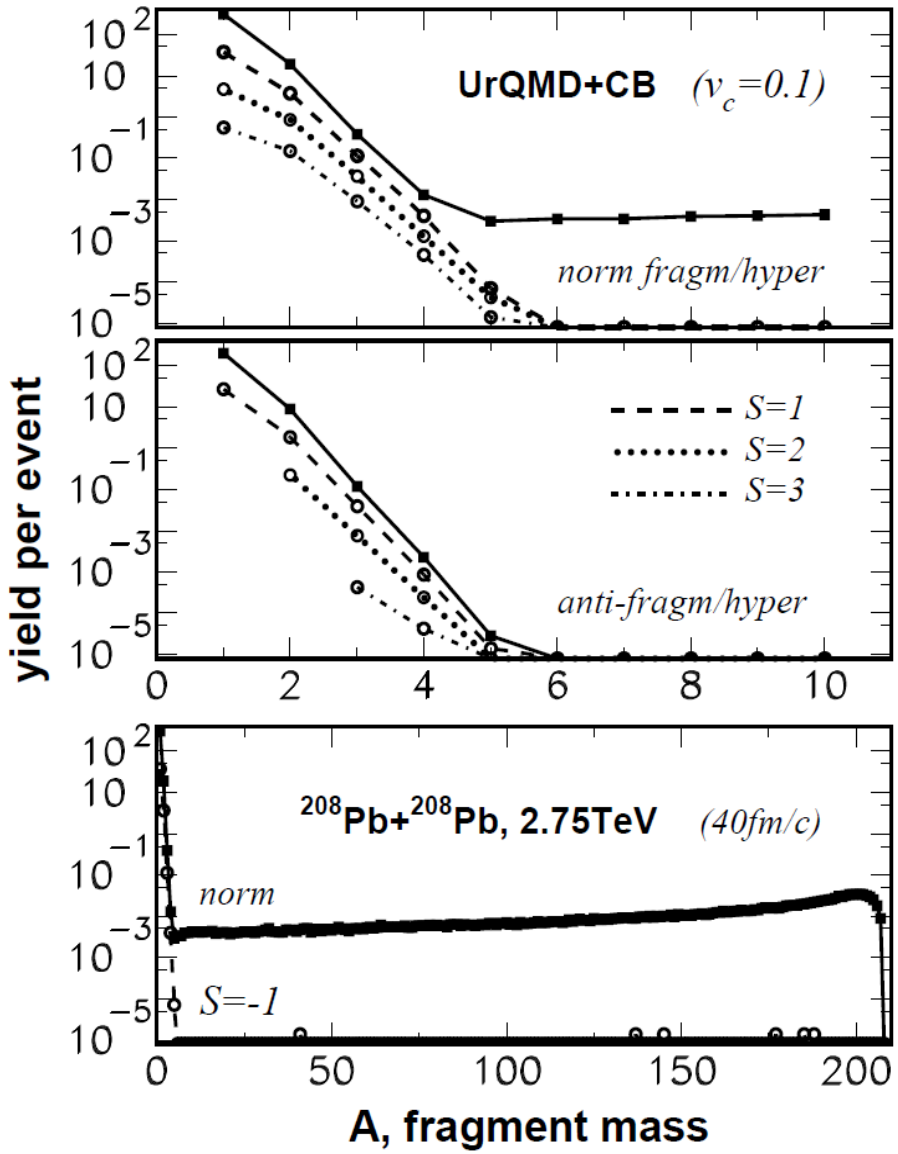


Because of the secondary interactions the maximun of the fragments production is shifted from the midrapidity. Secondary products have relatively low kinetic energies, therefore, they can produce clusters with higher probablity (even for light fragments/hyper-fragments).



Mass distributions of produced fragments: Combining Ξ and Omega with nucleons may lead to exotica production (shown, preliminary, for normal fragments only)

However, an advantage of ultra-relativistic collisions is the production of multi-strange particles, which can be captured too with the formation of nuclear exotics.



Conclusions

Collisions of relativistic ions and hadrons with nuclei are promising reactions for novel research of hypernuclei, anti-nuclei, and exotic nuclei. These processes are theoretically confirmed with various models.

Mechanisms of formation of hypernuclei in peripheral reactions: Strange baryons (Λ, Σ, Ξ, …) produced in particle collisions can be transported to the spectator residues and captured in nuclear matter. Another mechanism is the coalescence of baryons leading to light clusters, including anti-matter, will be effective at all rapidities. These exotic systems are presumably excited and after their decay novel hypernuclei of all sizes (and isospin), including exotic weakly-bound states, multi-strange nuclei, anti-nuclei can be produced.

Advantages over other reactions: in the spectator matter there is no limit on sizes and isotope content of produced exotic nuclei; probability of their formation may be high; a large strangeness can be deposited in nuclei.
Correlations (unbound states) and lifetimes can be naturally studied.
EOS of hypermatter at subnuclear density can be investigated.