Hypernuclei and hypermatter in relativistic heavy-ion reactions

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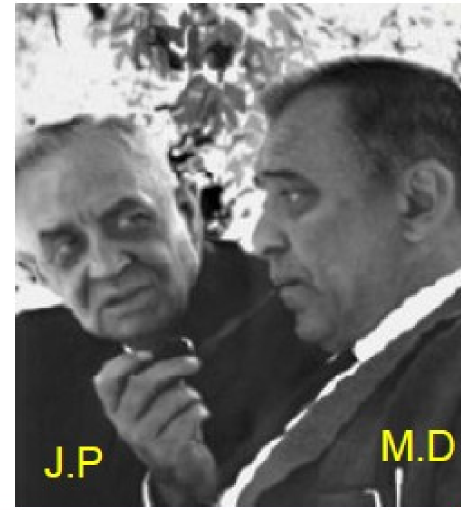
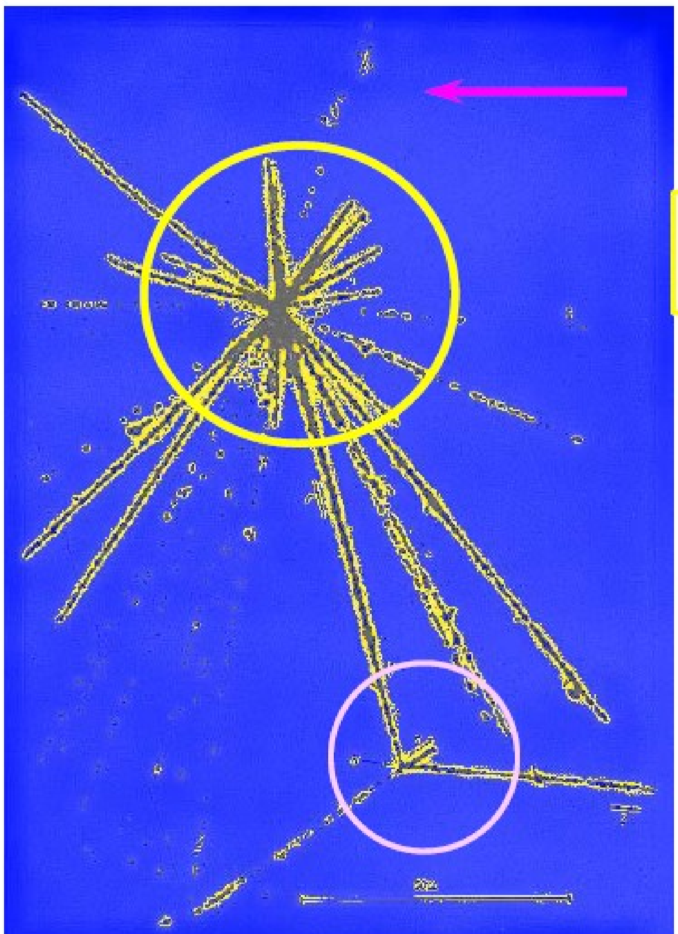
SPHERE workshop,
Prague, Czech Republic
September 9-11, 2014

Discovery of a Strange nucleus: Hypernucleus

M. Danysz and J. Pniewski, Philos. Mag. 44 (1953) 348



First-hypernucleus was observed in a stack of photographic emulsions exposed to cosmic rays at about 26 km above the ground.



Incoming high energy proton from cosmic ray

colliding with a nucleus of the emulsion, breaks it in several fragments forming a star. **Multifragmentation !**

All nuclear fragments stop in the emulsion after a short path

From the first star, 21 Tracks => $9\alpha + 11H + 1\ {}_{\Lambda}X$

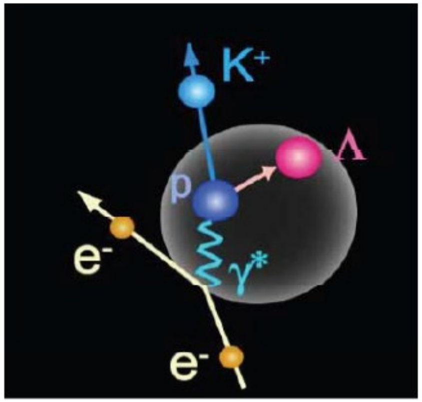
The fragment ${}_{\Lambda}X$ disintegrates later, makes the bottom star. Time taken ~ 10^{-12} sec (typical for weak decay)

This particular nuclear fragment, and the others obtained afterwards in similar conditions, were called **hyperfragments or hypernuclei.**

Nuclear reactions: production mechanisms for hypernuclei

Traditional way for production of hypernuclei:
Conversion of Nucleons into Hyperons
by using hadron and electron beams

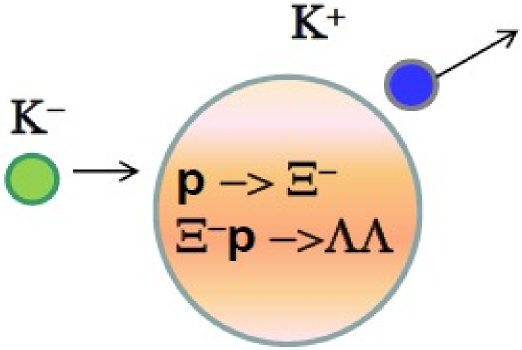
$e^- + p \rightarrow e^- + \Lambda + K^+$



(CERN, BNL, KEK, CEBAF, DAΦNE, JPARC, MAMI, ...)

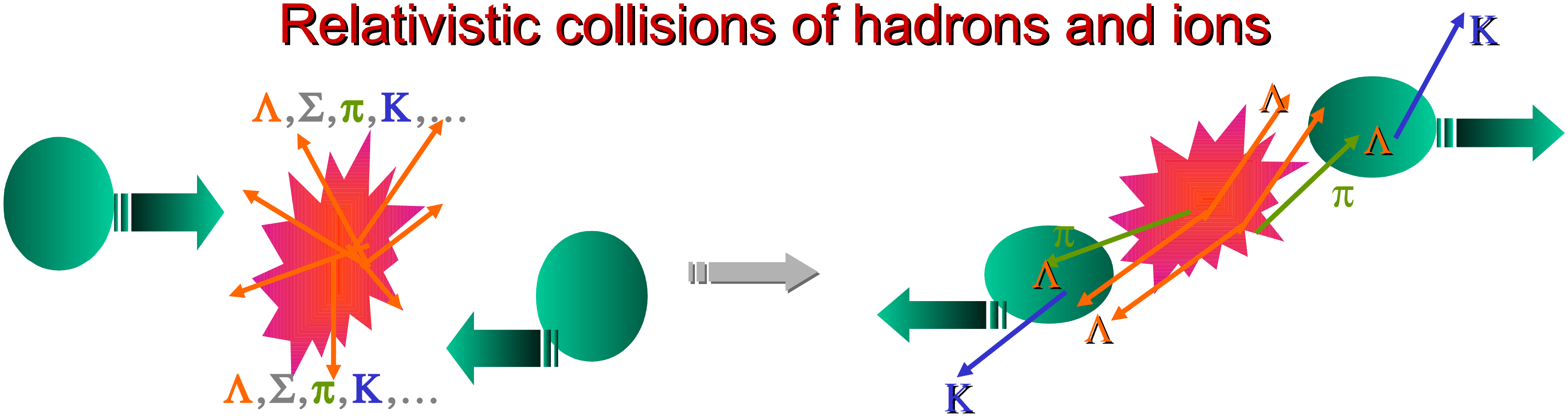
Advantages: rather precise determination of masses
(e.g., via the missing mass spectroscopy) :
good for nuclear structure studies !

Disadvantages: very limited range of nuclei in A and Z can beinvestsigated; the phase space of the reaction is narrow (since hypernuclei are produced in ground and slightly excited states), so production probability is low; it is difficult to produce multi-strange nuclei.



What reactions can be used to produce exotic strange nuclei and nuclei with many hyperons ?

Relativistic collisions of hadrons and ions

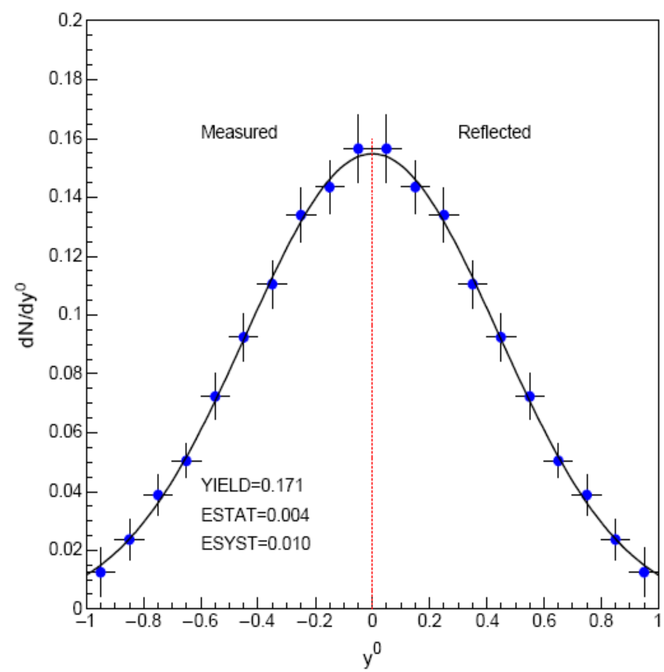


Production of hypermatter in relativistic HI and hadron collisions

- Production of strange particles and hyperons by "participants",
- Rescattering and absorption of hyperons by excited "spectators"

X. Lopez / Progress in Particle and Nuclear Physics 53 (2004) 149–151

Reconstructed Λ rapidity distribution for central ($\sigma_{geo} = 350$ mb) Ni + Ni reactions at 1.93 A GeV.



Central collisions of relativistic ions

Production of $^{3}_{\Lambda}H$ and $^{4}_{\Lambda}H$ in central 11.5 GeV/c Au+Pt heavy ion collisions

PHYSICAL REVIEW C 70, 024902 (2004)

(AGS)

Rapidity	1.6–2.6
p_t(GeV/c)	0–1.5

coalescence mechanism

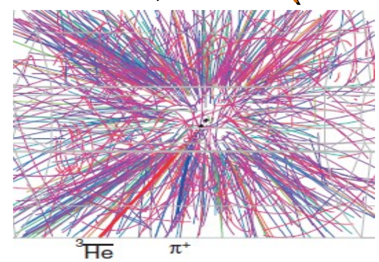
N_{event}	13.5×10^{9}	$^{3}_{\Lambda}H$
N_{count}	1220 ± 854	

STAR collaboration (RHIC):

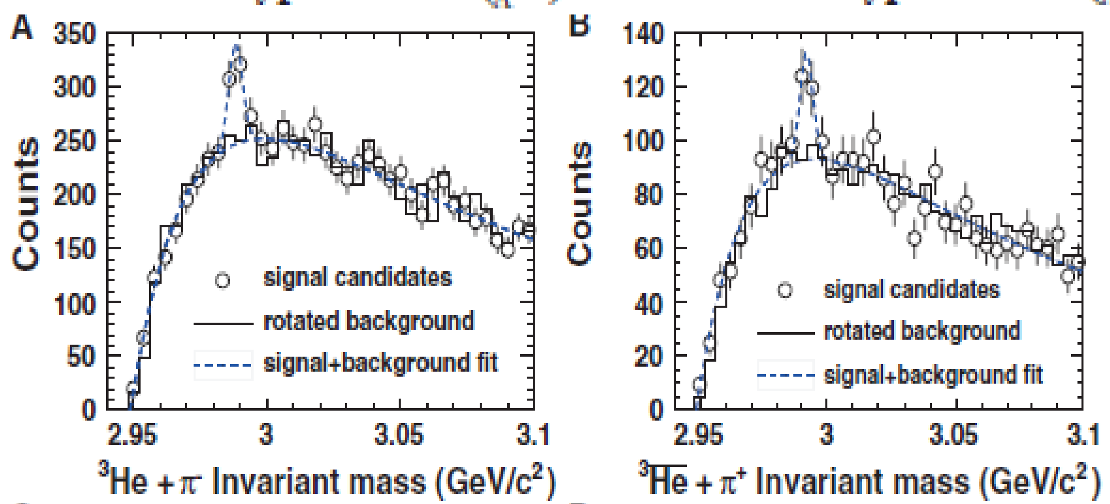
Science, 238 (2010) 58

Au + Au collisions at 200 A GeV

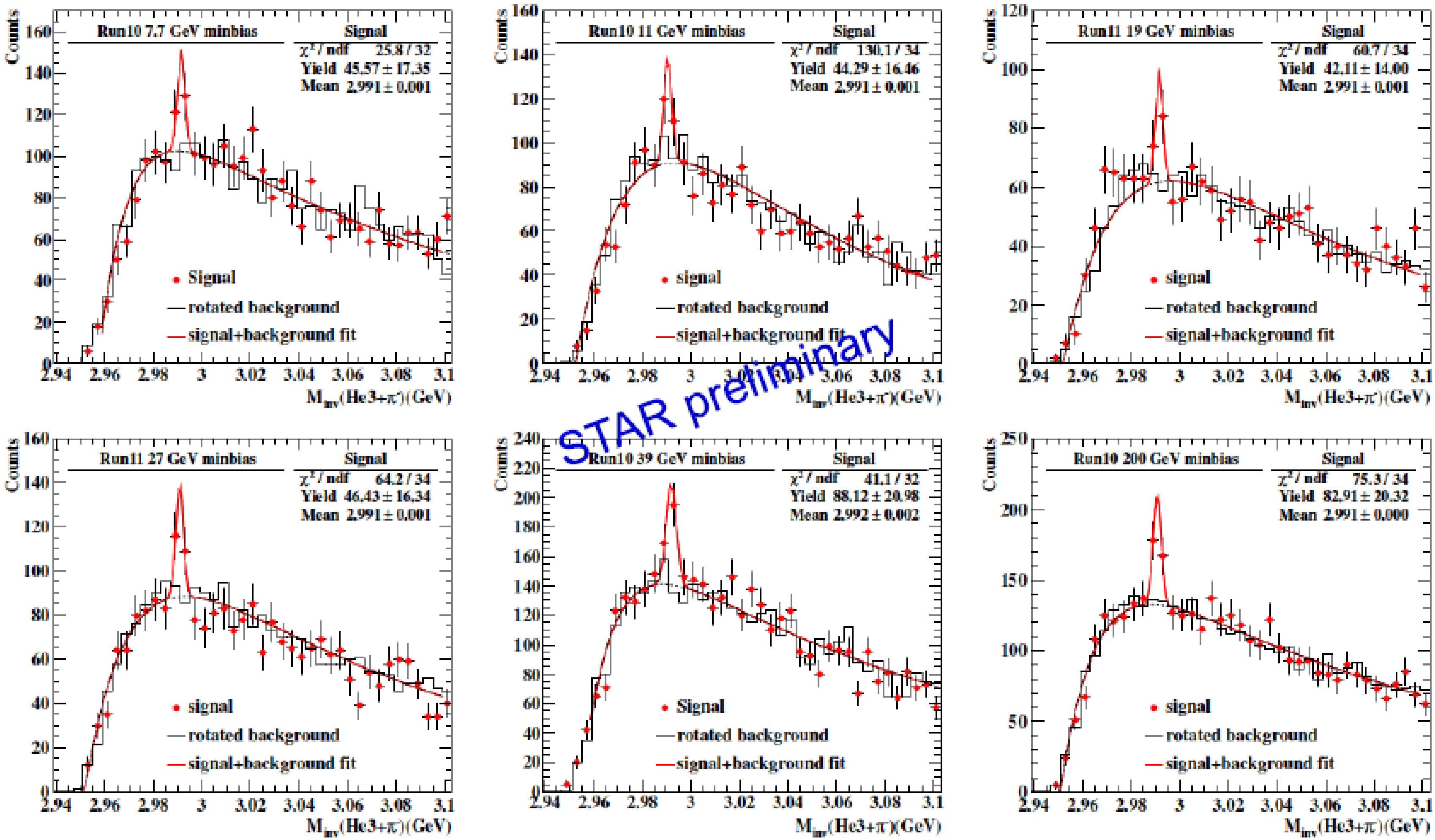
gas-filled cylindrical Time Projection Chamber



70 ± 17 antihypertritons ($^{3}_{\bar{\Lambda}}\overline{H}$) and 157 ± 30 hypertritons ($^{3}_{\Lambda}H$).



Hypertriton signal from STAR BES at $\sqrt{s_{NN}}$=7.7, 11.5, 19.6, 27, 39, 200GeV



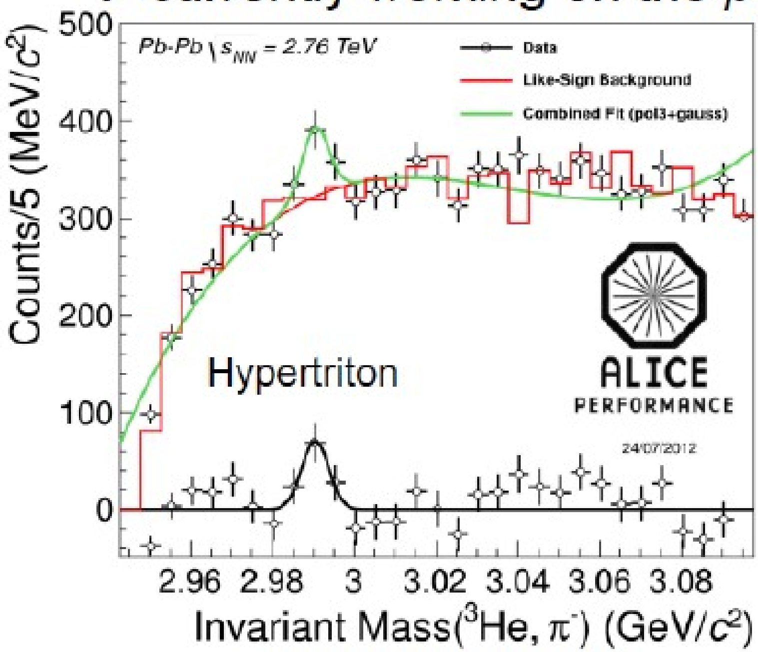
P. Camerini , NUFRA2013 (Kemer, Turkey) ; Nucl. Phys. A904-905 (2013) 547c

ALICE's observation for (anti-)hypertriton

Hypertriton

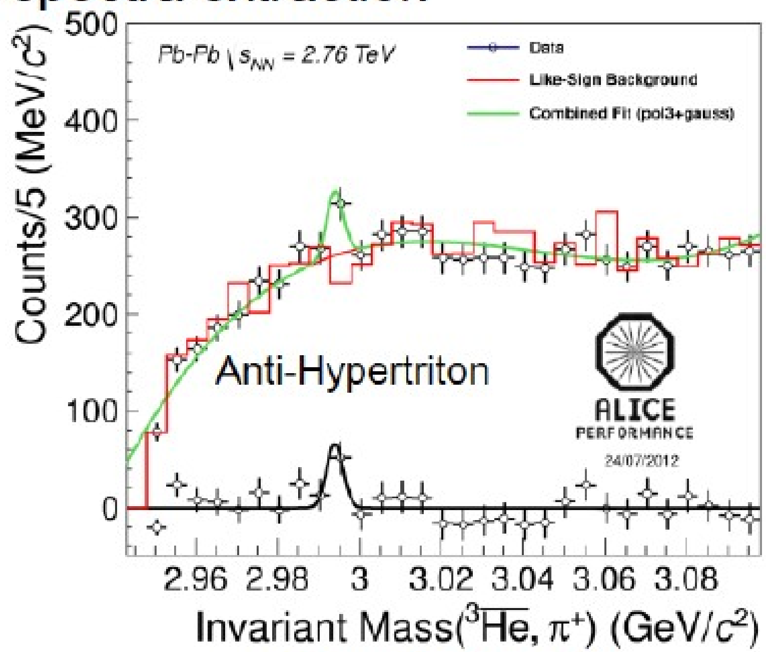
Signal of the hypertriton from the 2011 run

→ 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

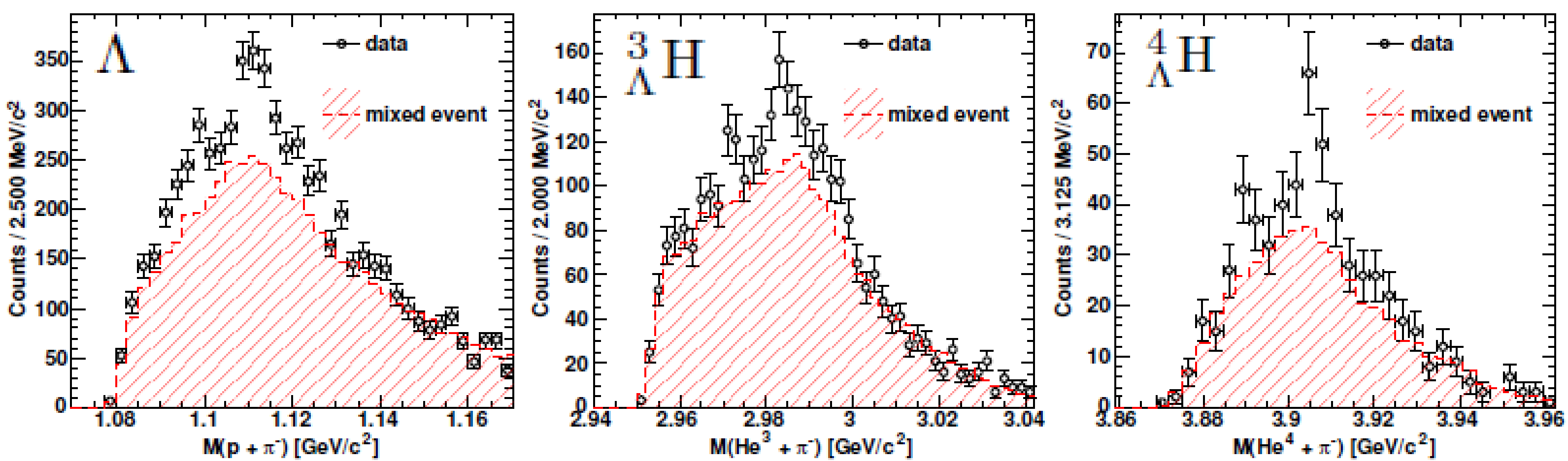
Production of hypernuclei in peripheral HI collisions: The HypHI project at GSI

T.Saito, (for HypHI), NUFRA2011 conference, and Nucl. Phys. A881 (2012) 218; Nucl. Phys. A913 (2013) 170.

T.R. Saito[a,b,c], D. Nakajima[a,d], C. Rappold[a,c,e], S. Bianchin[a], O. Borodina[a,b], V. Bozkurt[a,f], B. Göküzüm[a,f], M. Kavatsyuk[g], E. Kim[a,h], Y. Ma[a,b], F. Maas[a,b,c], S. Minami[a], B. Özel-Tashenov[a], P. Achenbach[b], S. Ajimura[i], T. Aumann[a], C. Ayerbe Gayoso[b], H.C. Bhang[f], C. Caesar[a], S. Erturk[f], T. Fukuda[j], E. Guliev[h], Y. Hayashi[k], T. Hiraiwa[k], J. Hoffmann[a], G. Ickert[a], Z.S. Ketenci[f], D. Khaneft[a,b], M. Kim[h], S. Kim[h], K. Koch[a], N. Kurz[a], A. Le Fevre[a,l], Y. Mizoi[j], M. Moritsu[k], T. Nagae[k], L. Nungesser[b], A. Okamura[k], W. Ott[a], J. Pochodzalla[b], A. Sakaguchi[m], M. Sako[k], C.J. Schmidt[a], M. Sekimoto[n], H. Simon[a], H. Sugimura[k], T. Takahashi[n], G.J. Tambave[g], H. Tamura[o], W. Trautmann[a], S. Voltz[a], N. Yokota[k], C.J. Yoon[h], K. Yoshida[m],

C. Rappold et al., Phys. Rev. C88 (2013) 041001: Λnn bound state ?

Projectile fragmentation: ^{6}Li beam at 2 A GeV on ^{12}C target



For the first, they have also observed a large correlation of $^{2}\mathrm{H} + \pi^{-}$
i.e., considerable production of a Λn bound states

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*

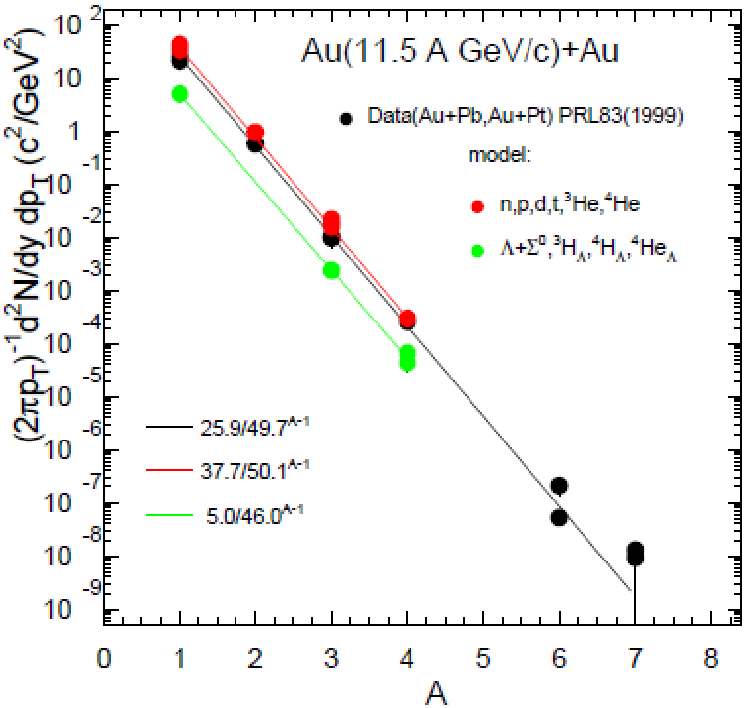
UrQMD approach: S.A. Bass et al., *Prog. Part. Nucl. Phys. 41 (1998)255.*
M.Bleicher et al. *J. Phys.G25(1999)1859, …* , J.Steinheimer ...

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 $\Lambda+N \to N+N$.

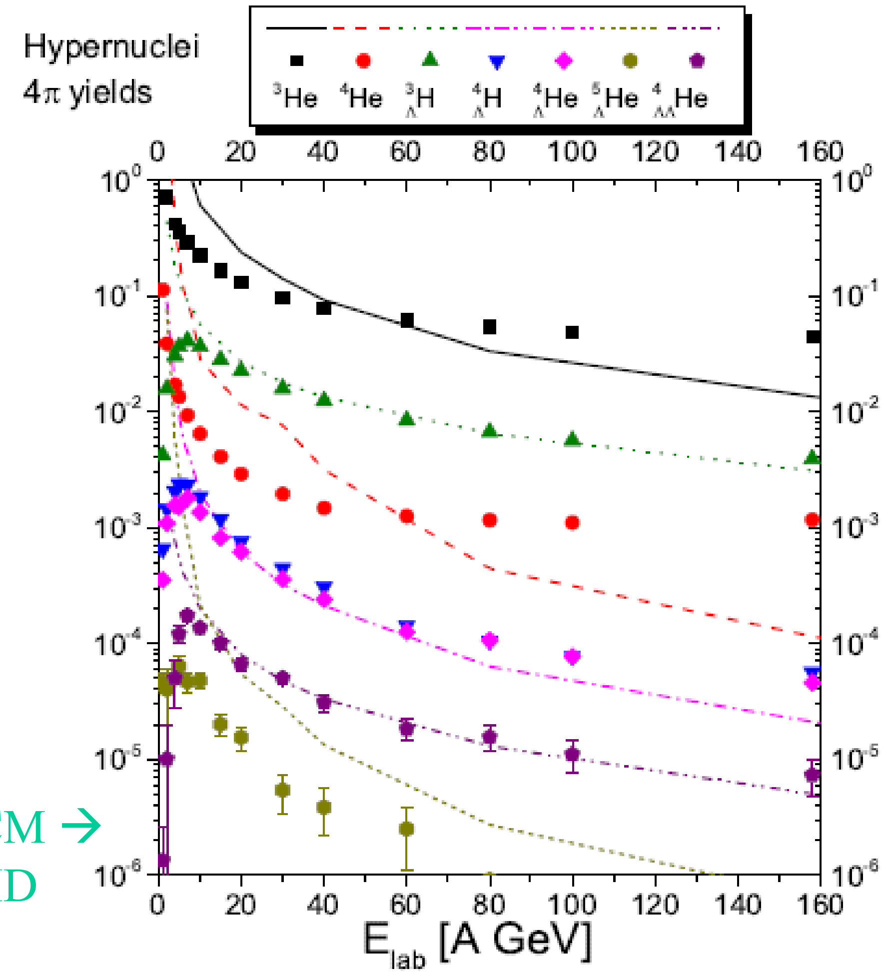
Production of light nuclei in central collisions : Au+Au

DCM and UrQMD calculations - J.Steinheimer et al., Phys. Lett. B**714**, 85 (2012)

DCM versus experiment : coalescence mechanism



Also predictions for hybrid approach : UrQMD + thermal hydrodynamics



It is not possible to produce big nuclei !

Symbols - DCM →
Lines - UrQMD

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.

Λ-Hypernucleus formation in proton-nucleus reactions

Z.Rudy, W.Casing et al., *Z. Phys. A351(1995)217*

BUU approach (Λ-potential in matter ~ 30 MeV)

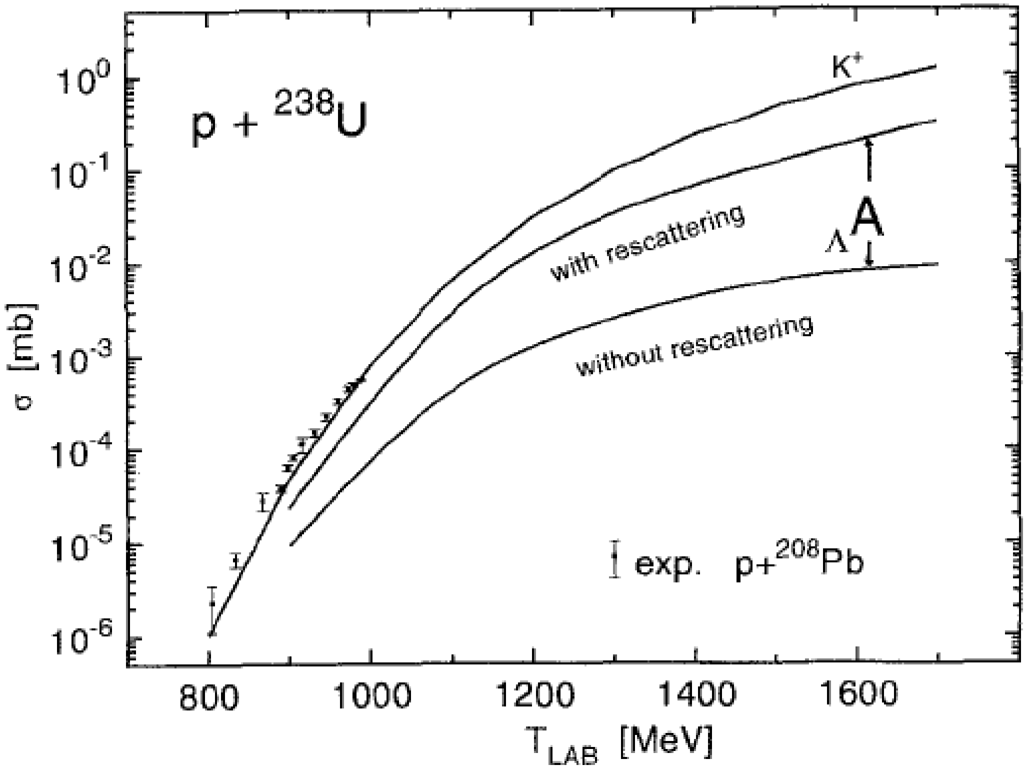


Fig. 5. The energy dependence of the ${}_{\Lambda}A$ production cross section for the cases with and without Λ hyperon-N rescattering. For relative orientation we also compare the calculated total K^+ cross section with the inclusive K^+ data from [30] for $p + {}^{208}$Pb

EXPERIMENT: fission of hypernuclei – T.Armstrong et al, PRC47, 1957 (1993); H.Ohm et al., PRC55, 3062 (1997).

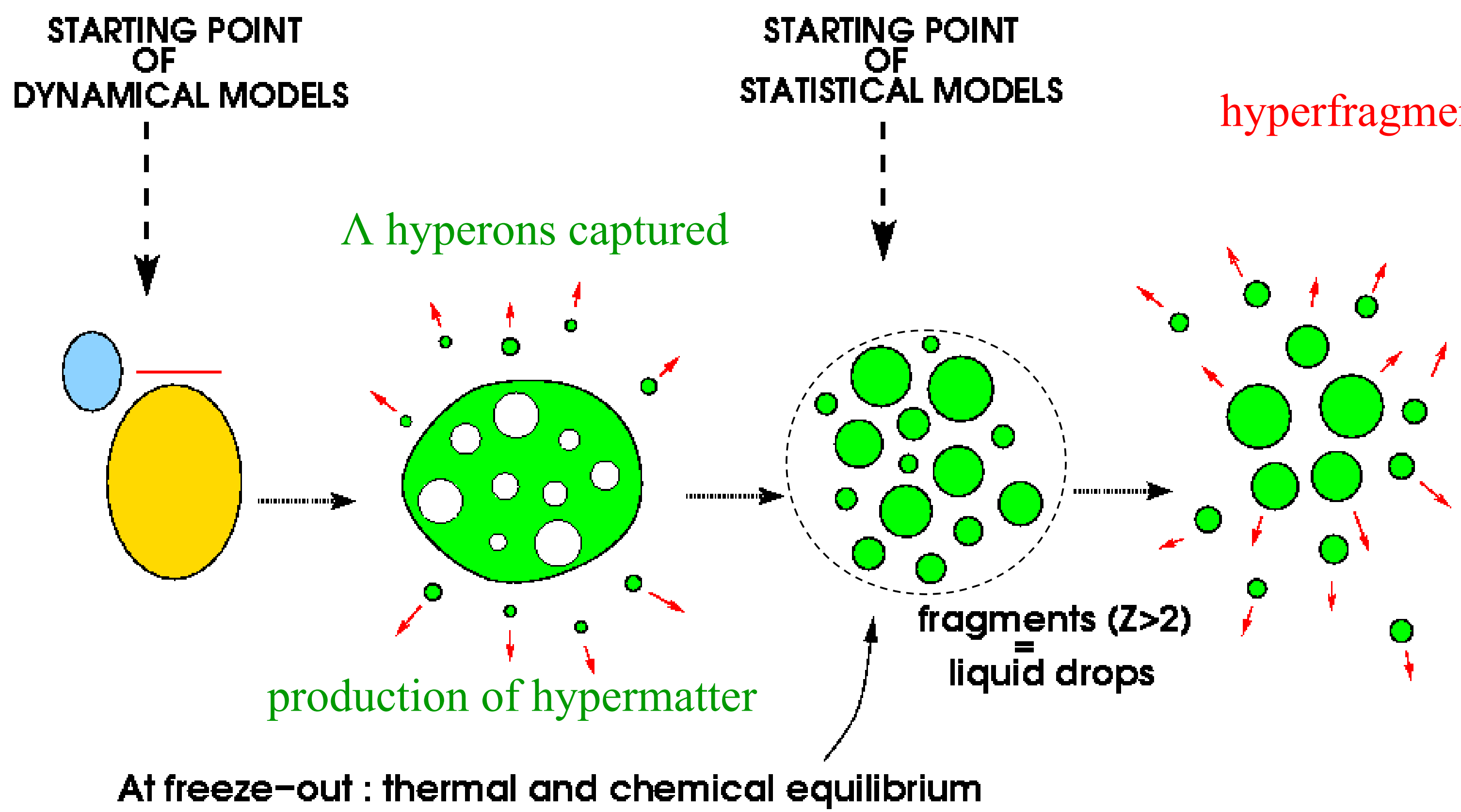
A.S.Botvina and J.Pochodzalla, Phys. Rev.C76 (2007) 024909

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

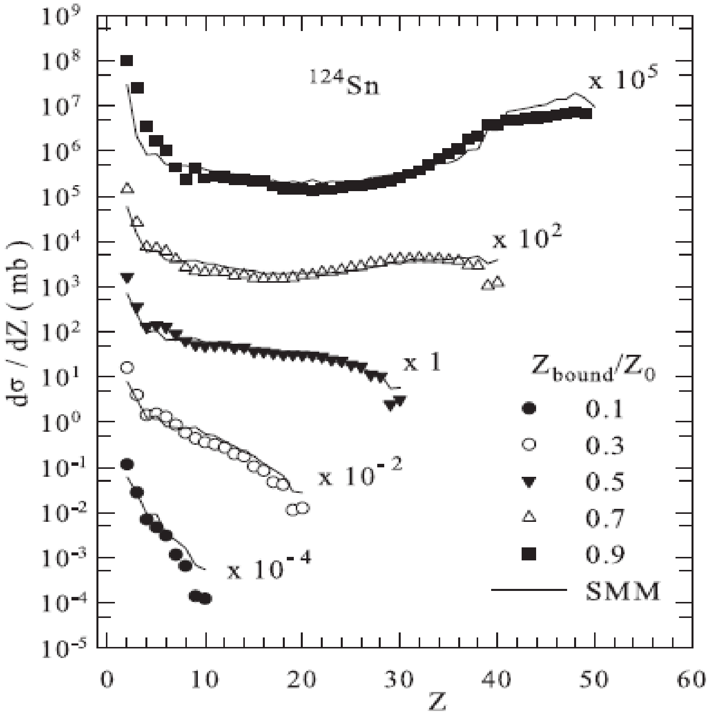


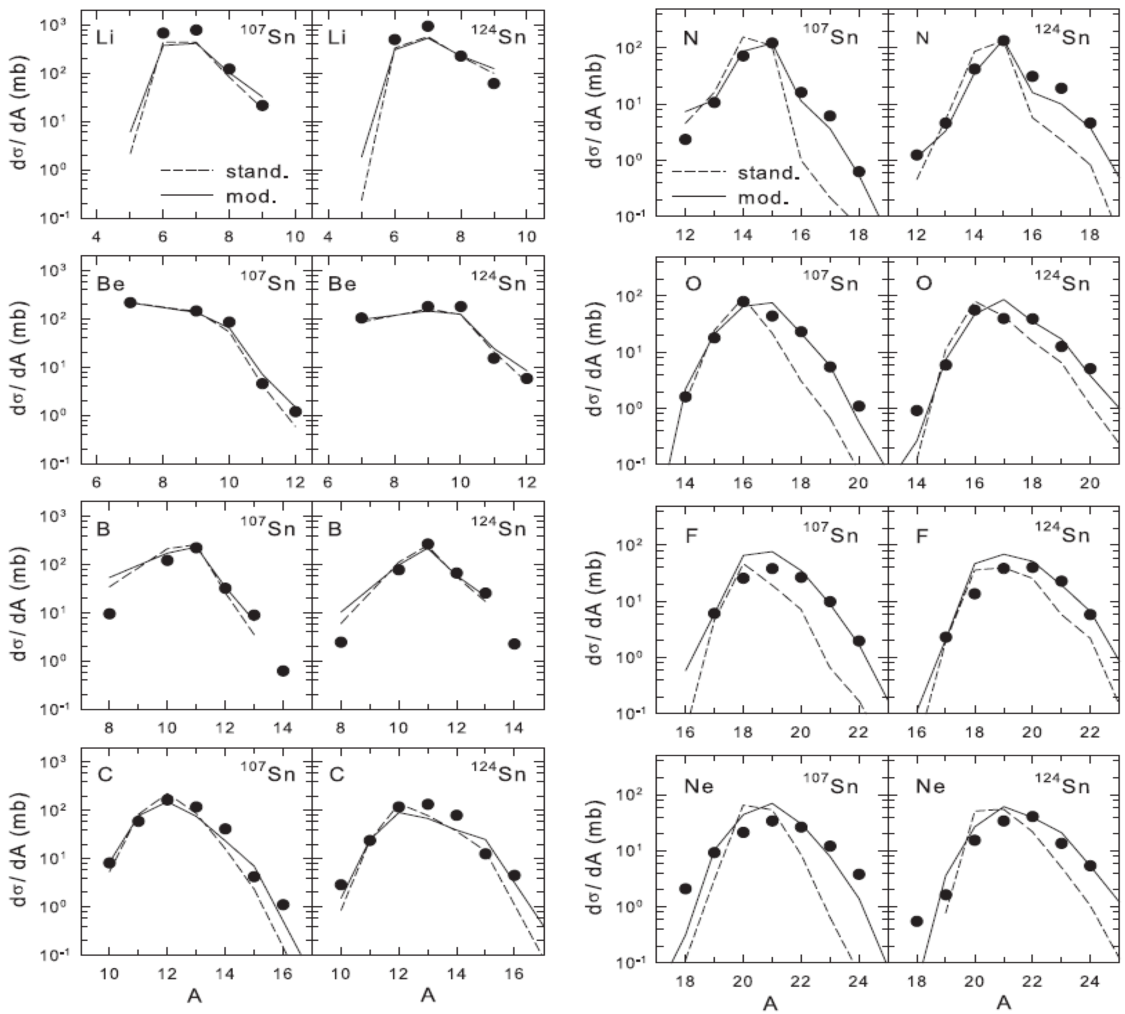
R.Ogul et al. PRC **83,** 024608 (2011) **ALADIN@GSI**

Isospin-dependent multifragmentation of relativistic projectiles

124,107-**Sn**, 124-**La** (600 A MeV) + **Sn** → projectile (multi-)fragmentation

Very good description is obtained within Statistical Multifragmentation Model, including fragment charge yields, isotope yileds, various fragment correlations.





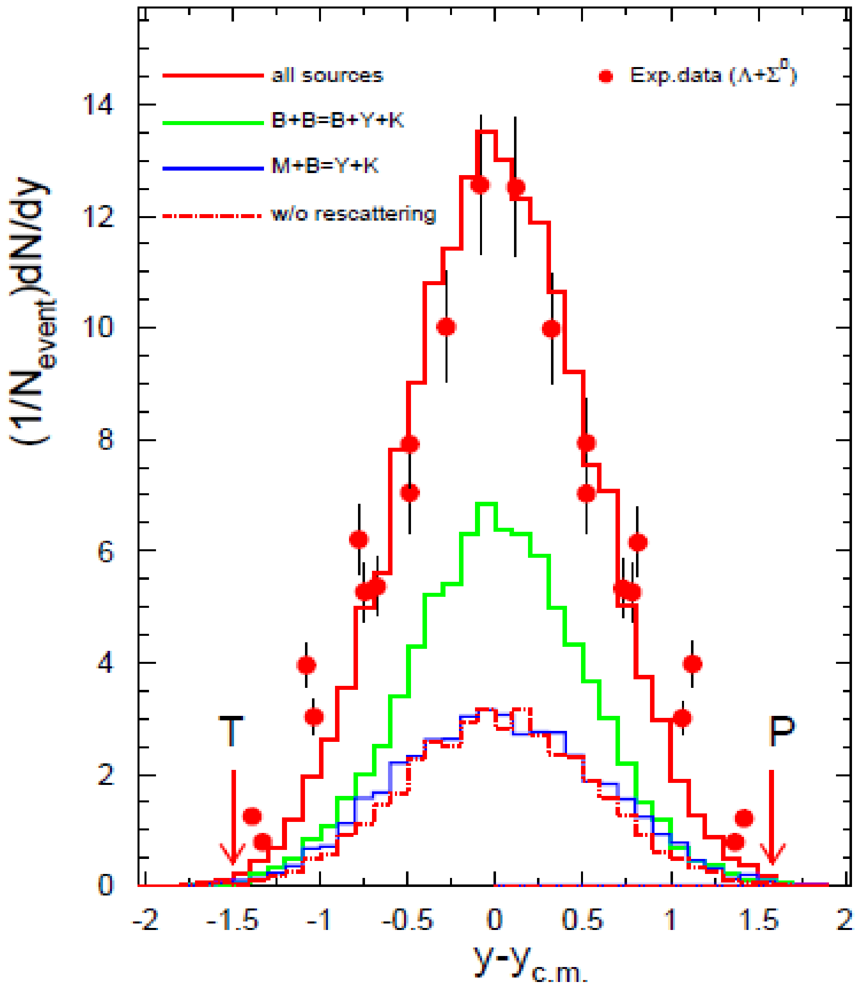
Statistical (chemical) equilibrium is established at break-up of hot projectile residues ! In the case of strangeness admixture we expect it too !

Verification of the models
DCM

Hyperon production
in central collisions
Au(11 A GeV/c)+Au

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

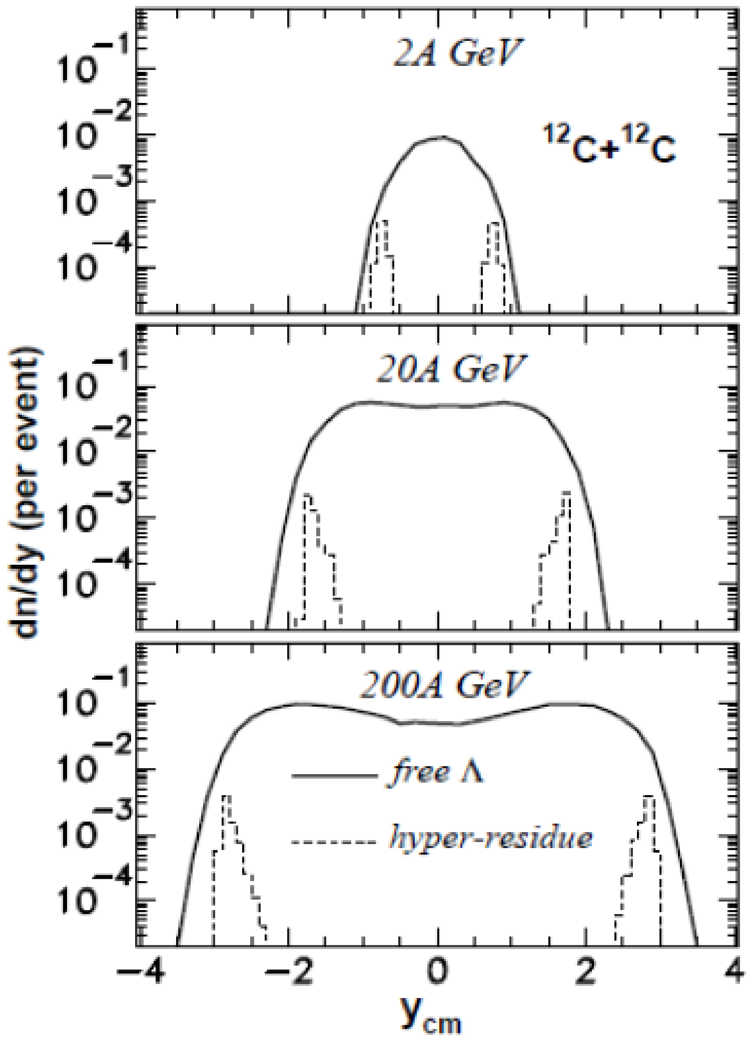
A.S.Botvina, K.K.Gudima,
J.Steinheimer, M.Bleicher,
I.N.Mishustin.
PRC **84** (2011) 064904



Rapidity distribution of free hyperons and hyper-residues in relativistic ion collisions (DCM calculations)

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

Wide distributions of produced Lambda-hyperons up to spectator rapidities at all incident energies. A stochastic process related to secondary interactions leads to the hyperon capture by residues.



The evolution to a double peak distribution with increasing energy tell us that the Lambda production is mainly caused by secondary processes too.

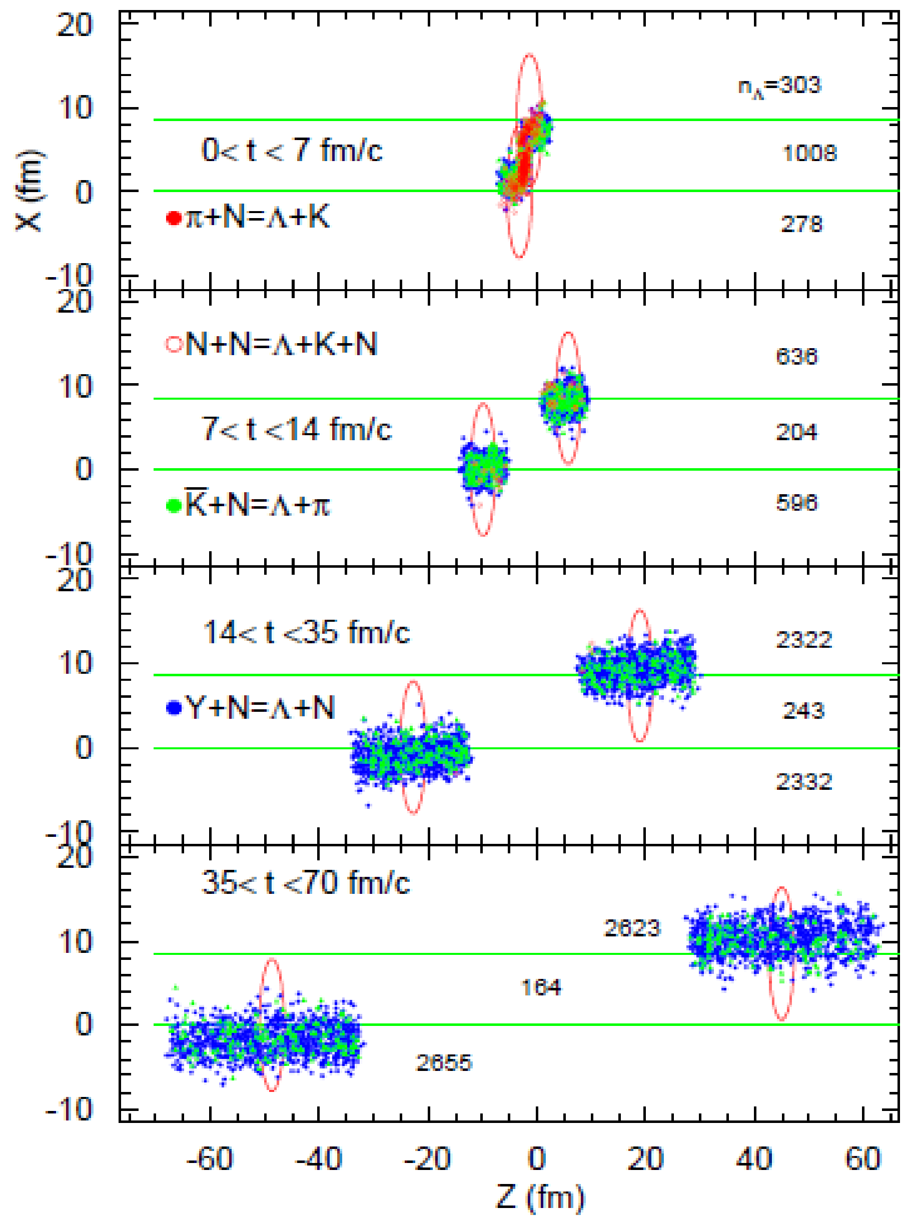
Peripheral relativistic ion collisions: Au (20 A GeV) + Au

impact parameter= 8.5fm

Absorption of Lambda hyperons by residual nuclei within DCM and UrQMD model description (times/coordinates of the absorption are given on the panels)

Secondary interactions of the particles dominates in the process.

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



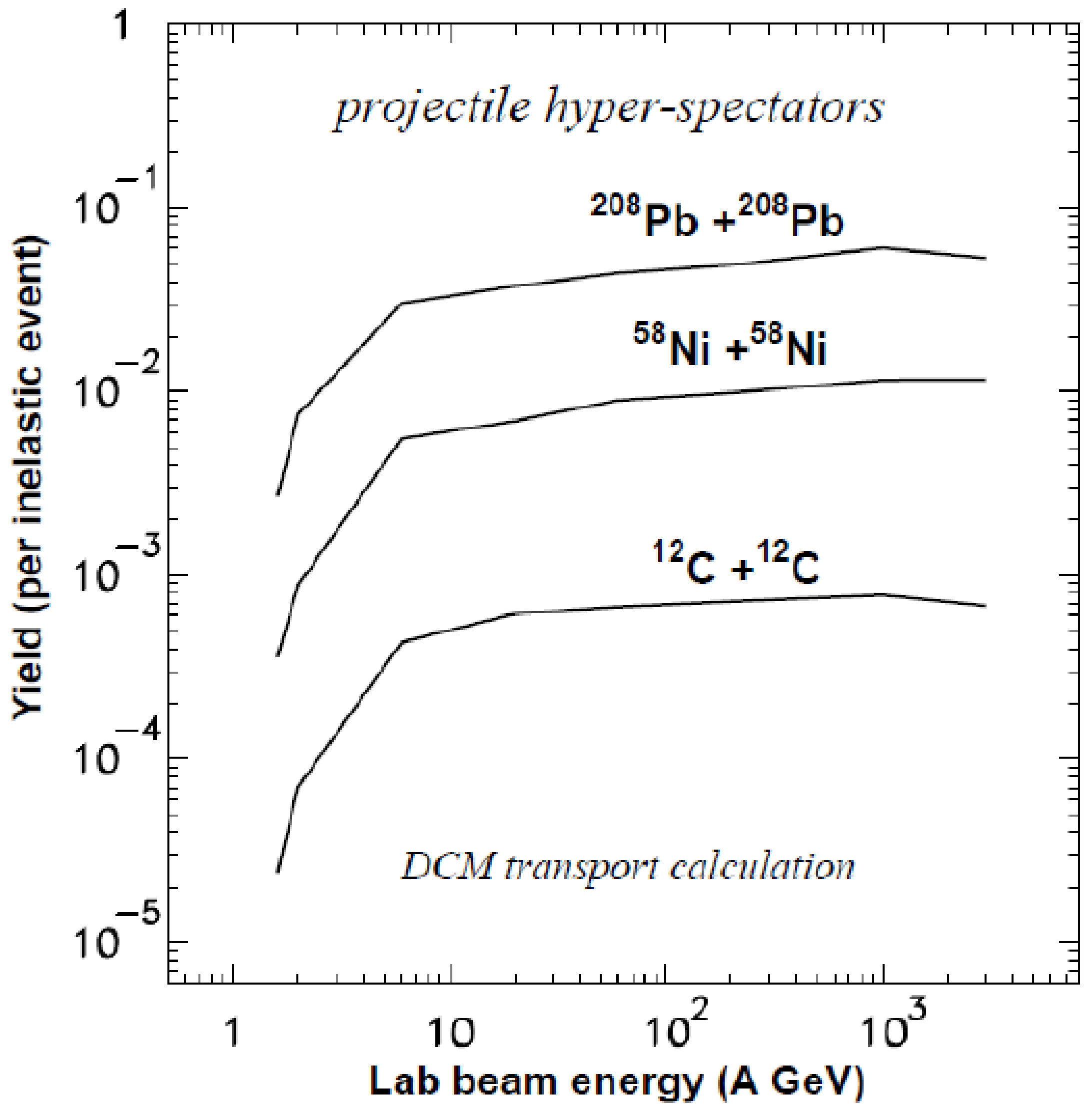
Yield of hypernuclei in peripheral collisions

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

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

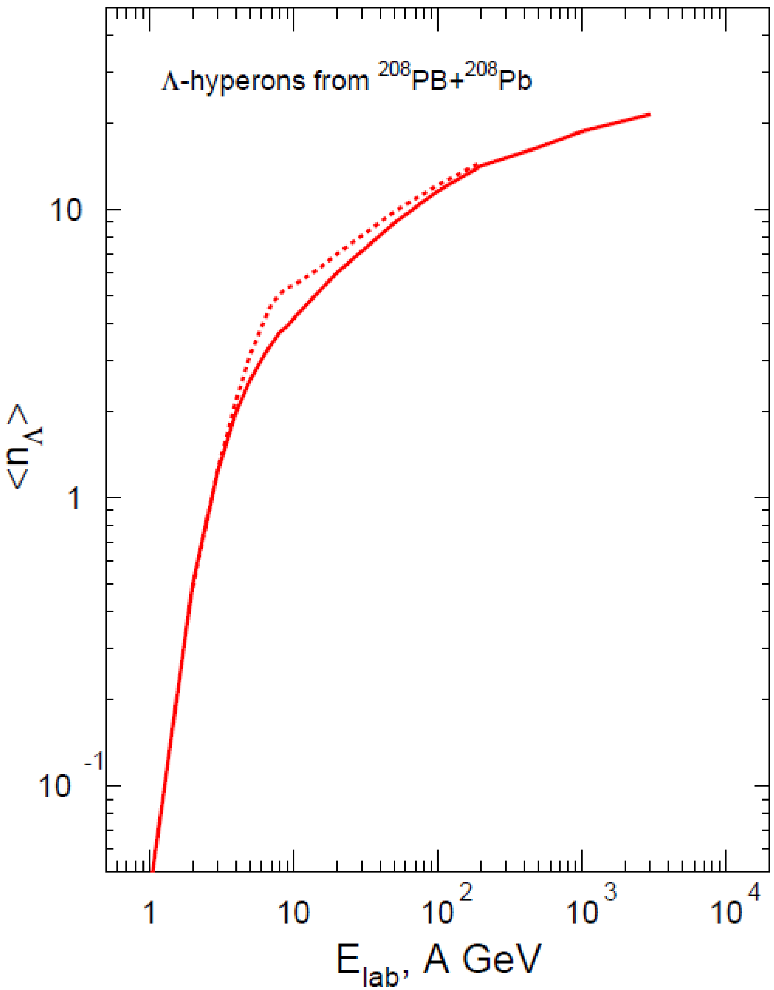
Yield is integrated over all impact parameters.

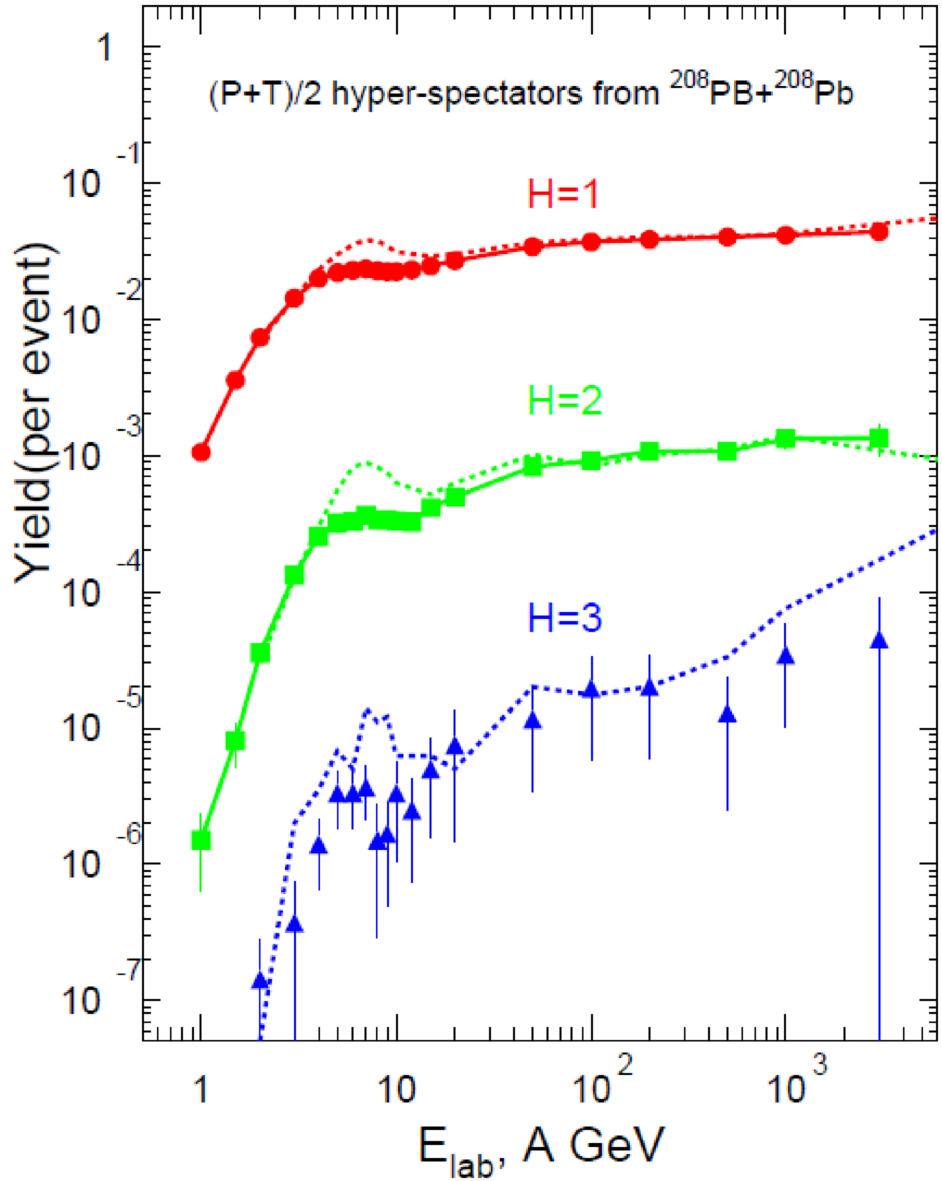
Reactions can be studied at GSI/FAIR and JINR/NICA facilities as well on operating RHIC and LHC.



preliminary

DCM

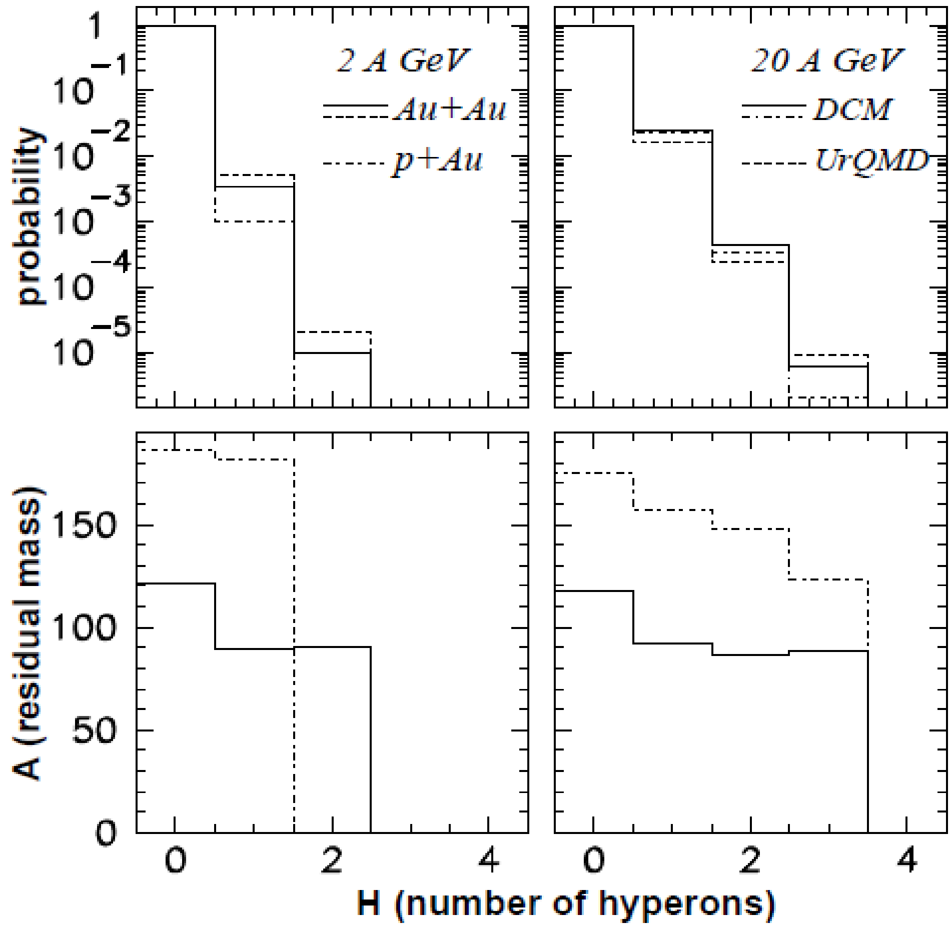




A.S.Botvina, K.K.Gudima, J.Steinheimer, M.Bleicher, I.N.Mishustin. PRC 84 (2011) 064904

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



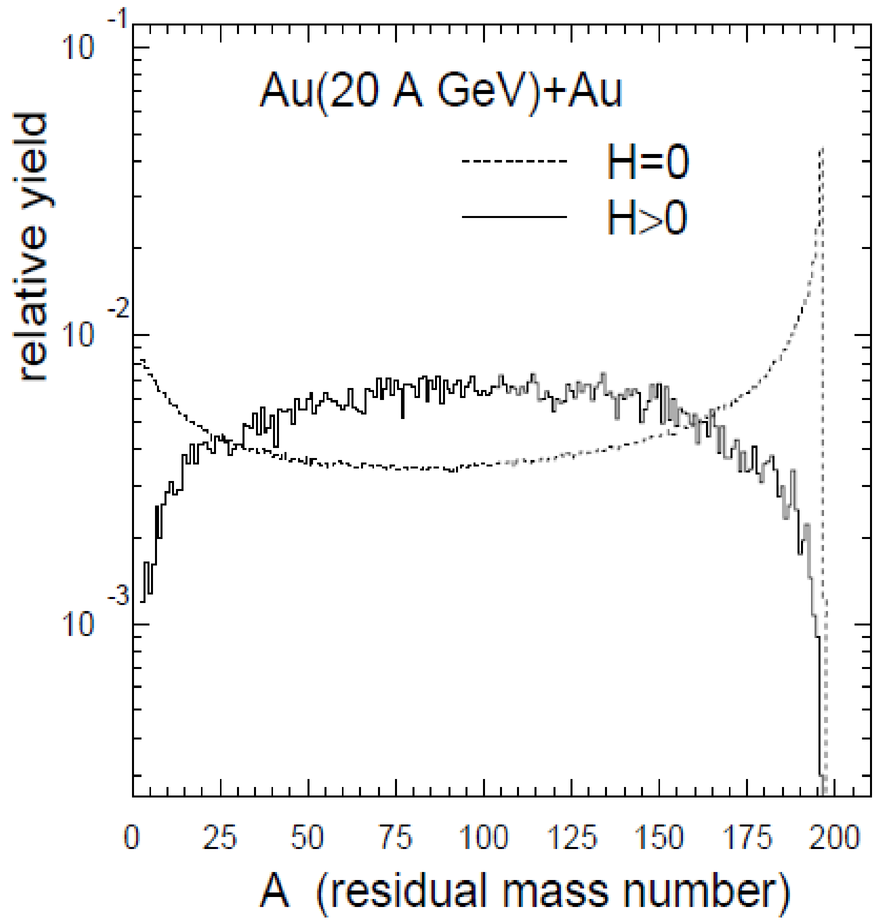
Integrated over all impact parameters

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

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

Masses of projectile residuals produced after DCM

different hyper-residuals (with large cross-section) can be formed
(from studies of conventional matter: expected temperatures - up to 5-8 MeV)



6b : H=0

200mb: H>0

Momentum distribution of Lambda captured in the spectators

(Connection of the potential capture and the coalescence)

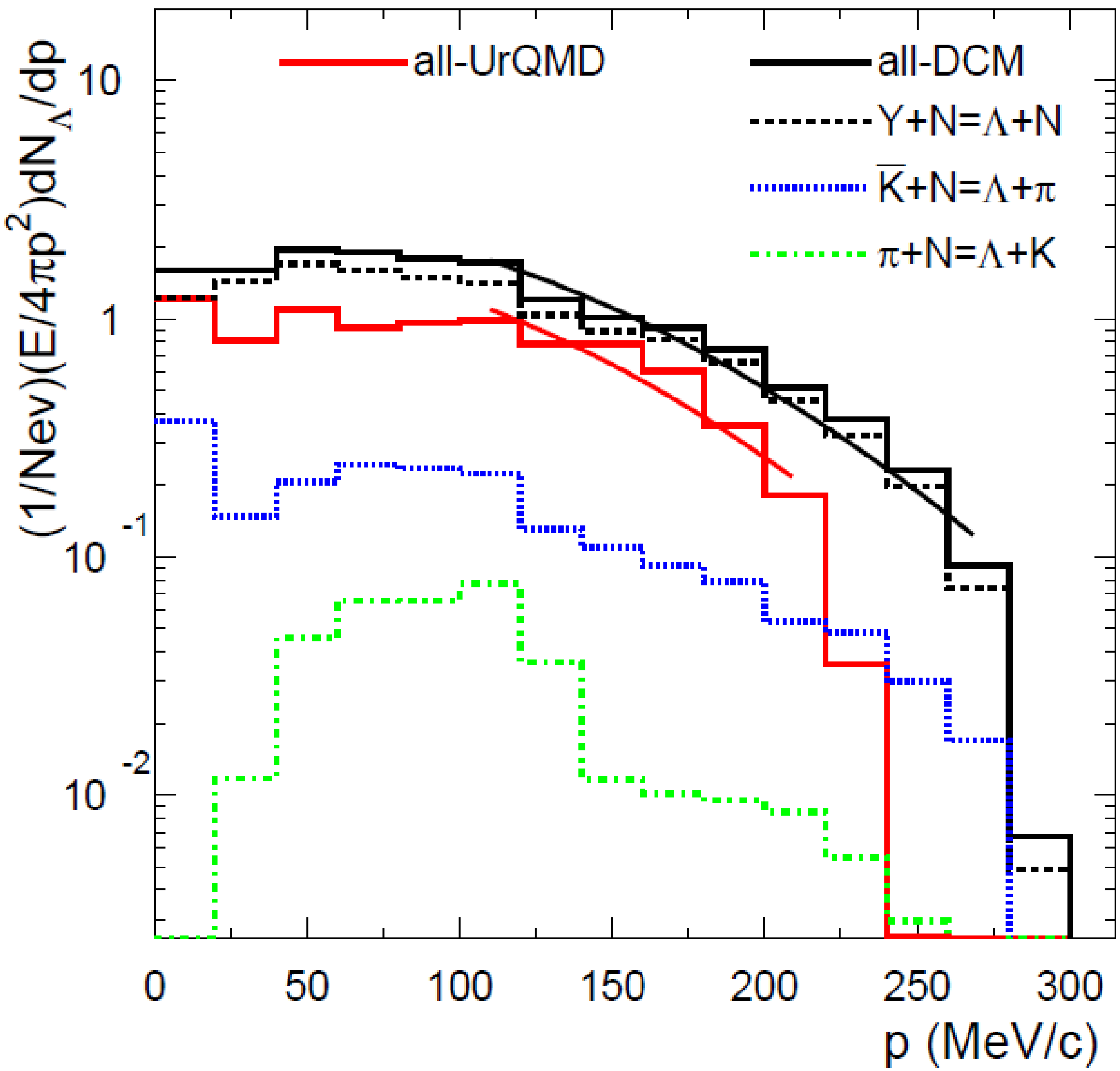
Coalescence of baryons

momenta:

$$|P_i - P_0| \leq P_c$$

coordinates:

$$|X_i - X_0| \leq X_c$$



W.Neubert and A.S.Botvina, EPJ **A7** , 101 (2000)

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.

A.Botvina, E.Bratkovskaya, J.Steinheimer, M.Bleicher, J.Pochodzalla

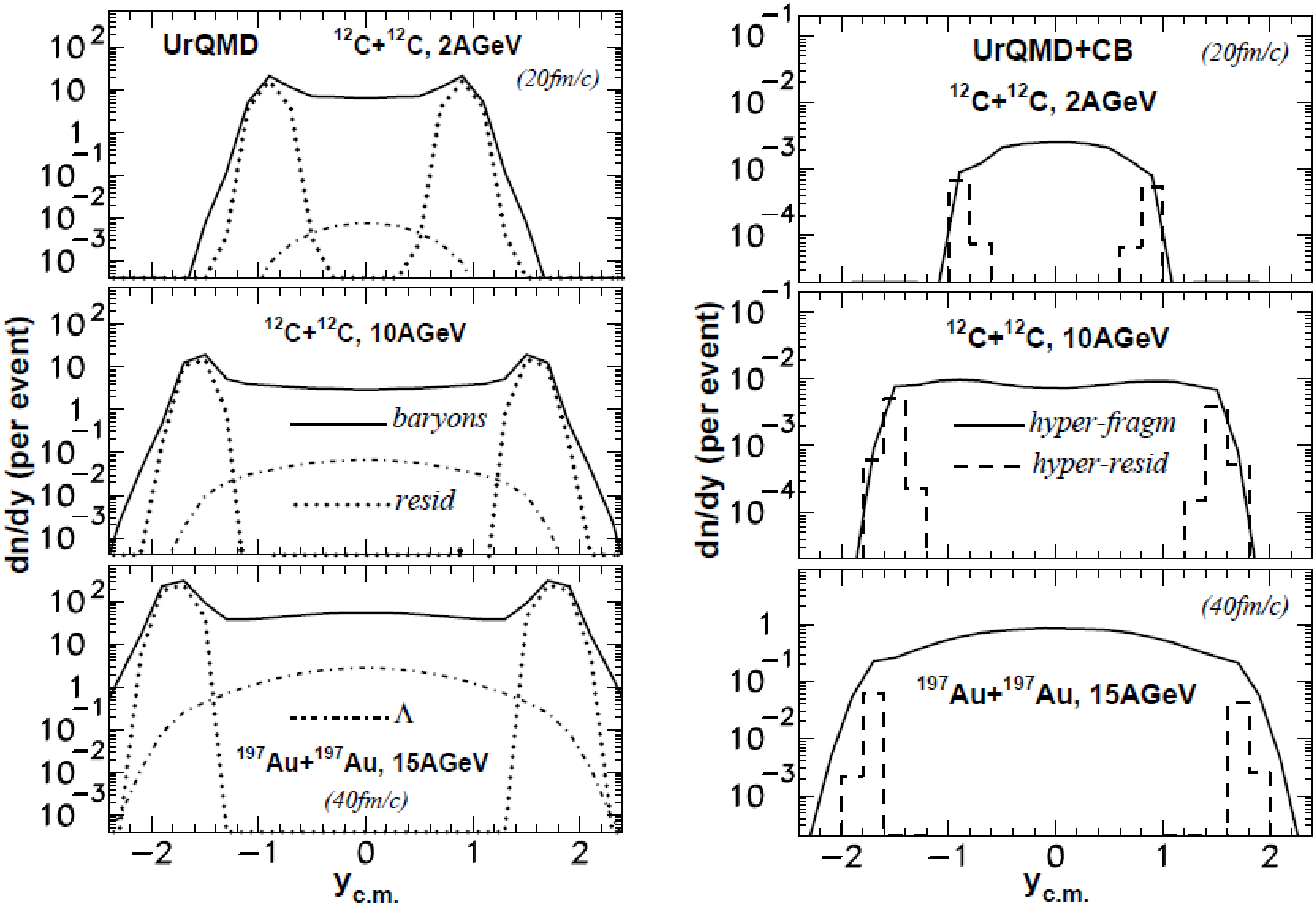
Combination of transport UrQMD and HSD models with CB:

1) 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.
2) Spectators' nucleons are always included in the residues.

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

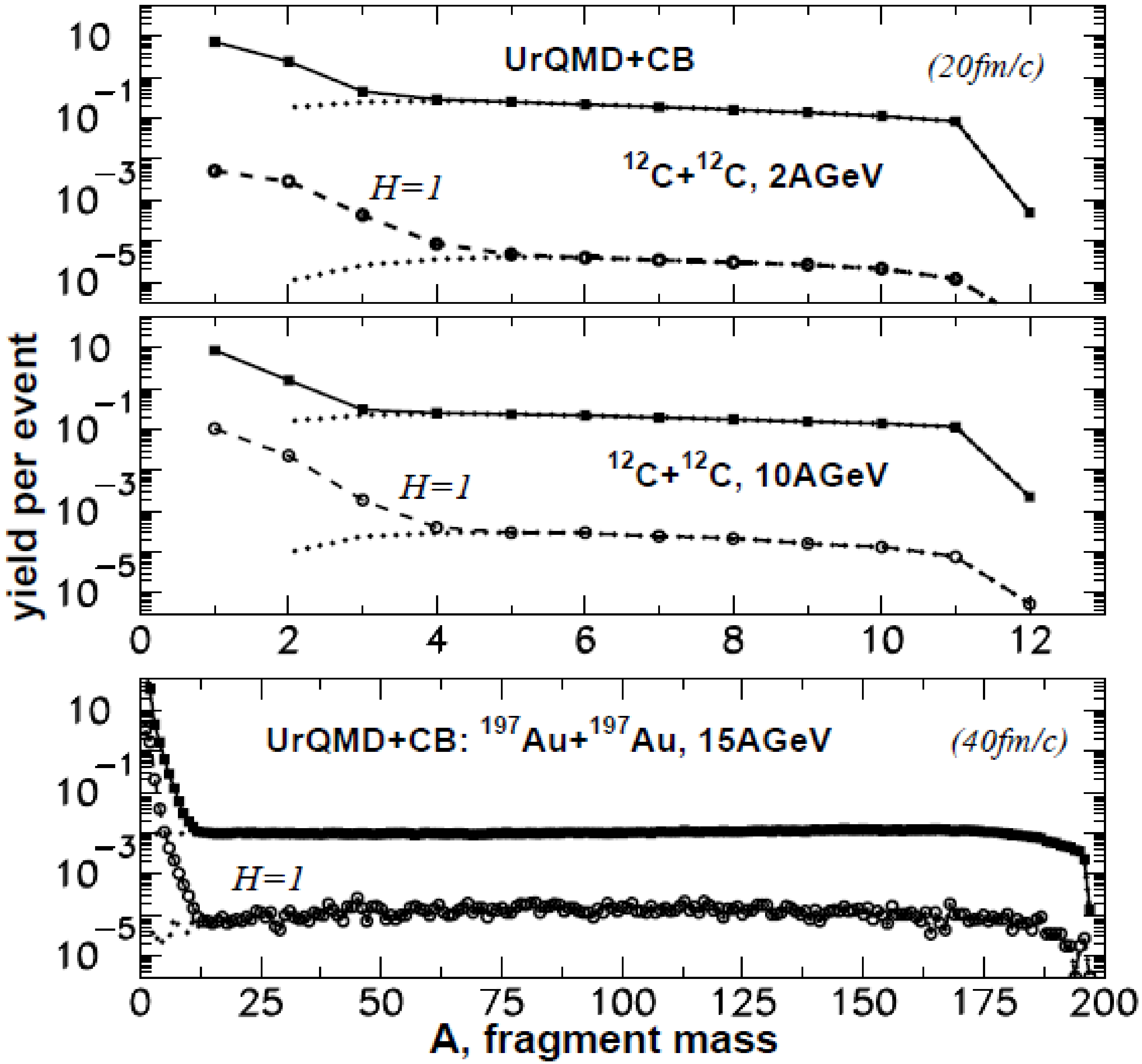
preliminary

baryons, Lambdas, hyper-fragments, hyper-residues



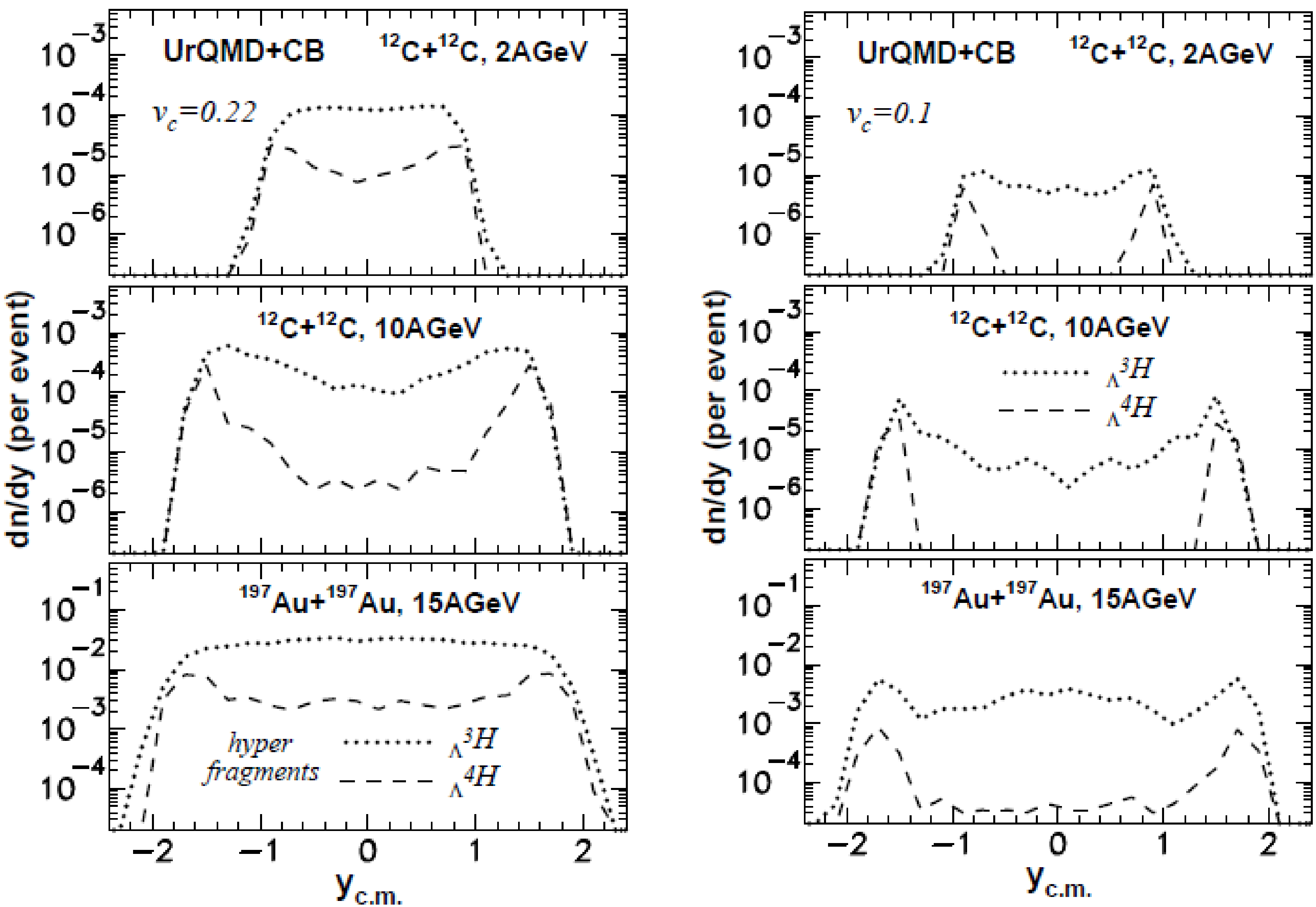
preliminary

normal fragments and hyper-fragments (with residue contribution)



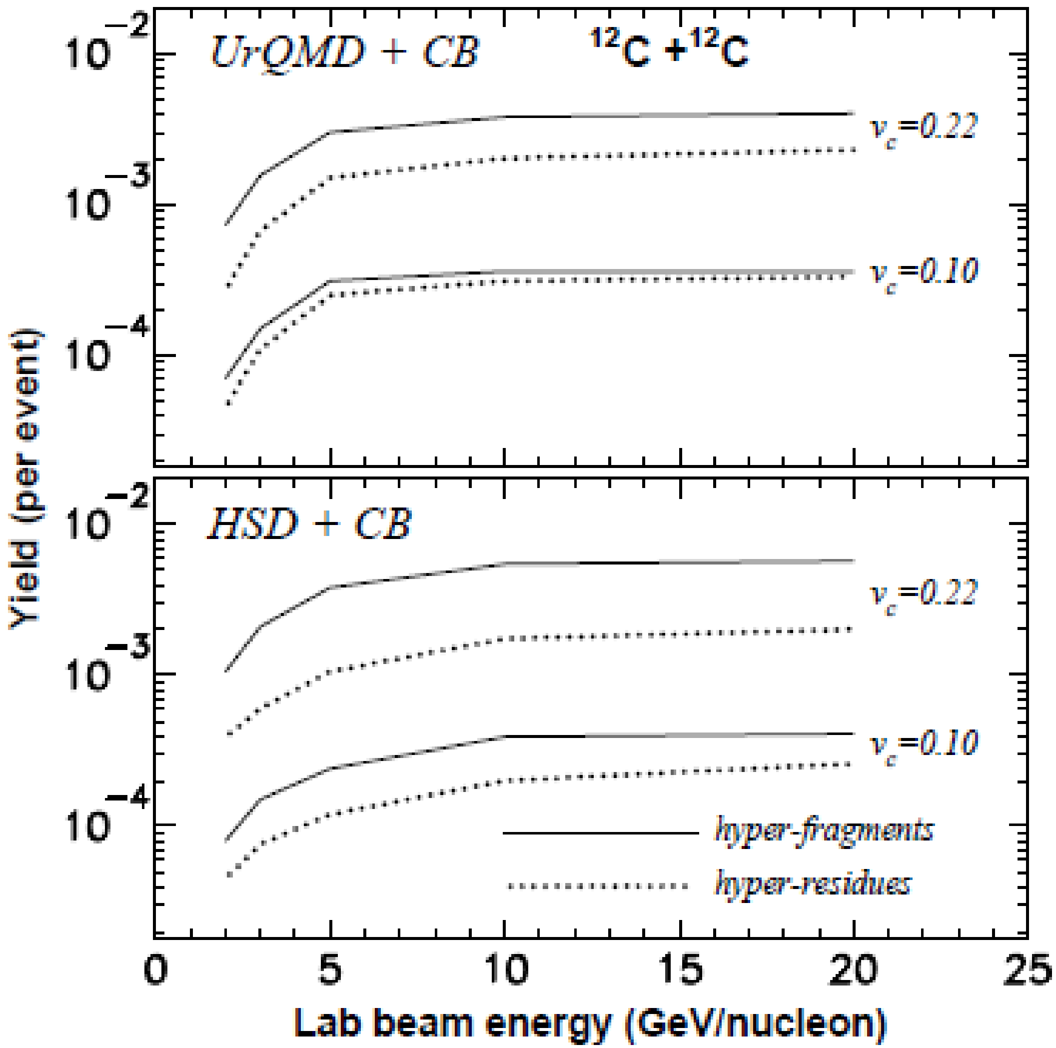
preliminary

light hyper-fragments



preliminary

Transport models are consistent (UrQMD, HSD)



Statistical approach for fragmentation of hyper-matter

$$Y_{AZH} = g_{AZH} V_f \frac{A^{3/2}}{\lambda_T^3} \exp\left[-\frac{1}{T}\left(F_{AZH} - \mu_{AZH}\right)\right]$$

$$\mu_{AZH} = A\mu + Z\nu + H\xi$$

mean yield of fragments with mass number ***A***, charge ***Z***, and **Λ**-hyperon number ***H***

$$F_{AZH}(T,V) = F_A^B + F_A^S + F_{AZH}^{sym} + F_{AZ}^C + F_{AH}^{hyp}$$

$$F_A^B(T) = \left(-w_0 - \frac{T^2}{\varepsilon_0}\right) A \quad ,$$

liquid-drop description of fragments: bulk, surface, symmetry, Coulomb (as in Wigner-Seitz approximation), and hyper energy contributions
J.Bondorf et al., Phys. Rep. **257** (1995) 133

$$F_A^S(T) = \beta_0 \left(\frac{T_c^2 - T^2}{T_c^2 + T^2}\right)^{5/4} A^{2/3} \quad ,$$

$$F_{AZH}^{sym} = \gamma \frac{(A - H - 2Z)^2}{A - H} \quad ,$$

parameters ≈ Bethe-Weizsäcker formula:

$w_0 = 16$ MeV, $\beta_0 = 18$ MeV, $T_c = 18$ MeV

$\gamma = 25$ MeV $\qquad \varepsilon_0 \approx 16$ MeV

$$\sum_{AZH} A Y_{AZH} = A_0, \sum_{AZH} Z Y_{AZH} = Z_0, \sum_{AZH} H Y_{AZH} = H_0.$$

chemical potentials are from mass, charge and *H*yperon number conservations

$$F_{AH}^{hyp} = E_{sam}^{hyp} = H \cdot (-10.68 + 48.7/(A^{2/3})).$$

-- C.Samanta et al. J. Phys. G: 32 (2006) 363 (motivated: single **Λ** in potential well)

$$F_{AH}^{hyp} = (H/A) \cdot (-10.68A + 21.27A^{2/3}).$$

-- liquid-drop description of hyper-matter

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

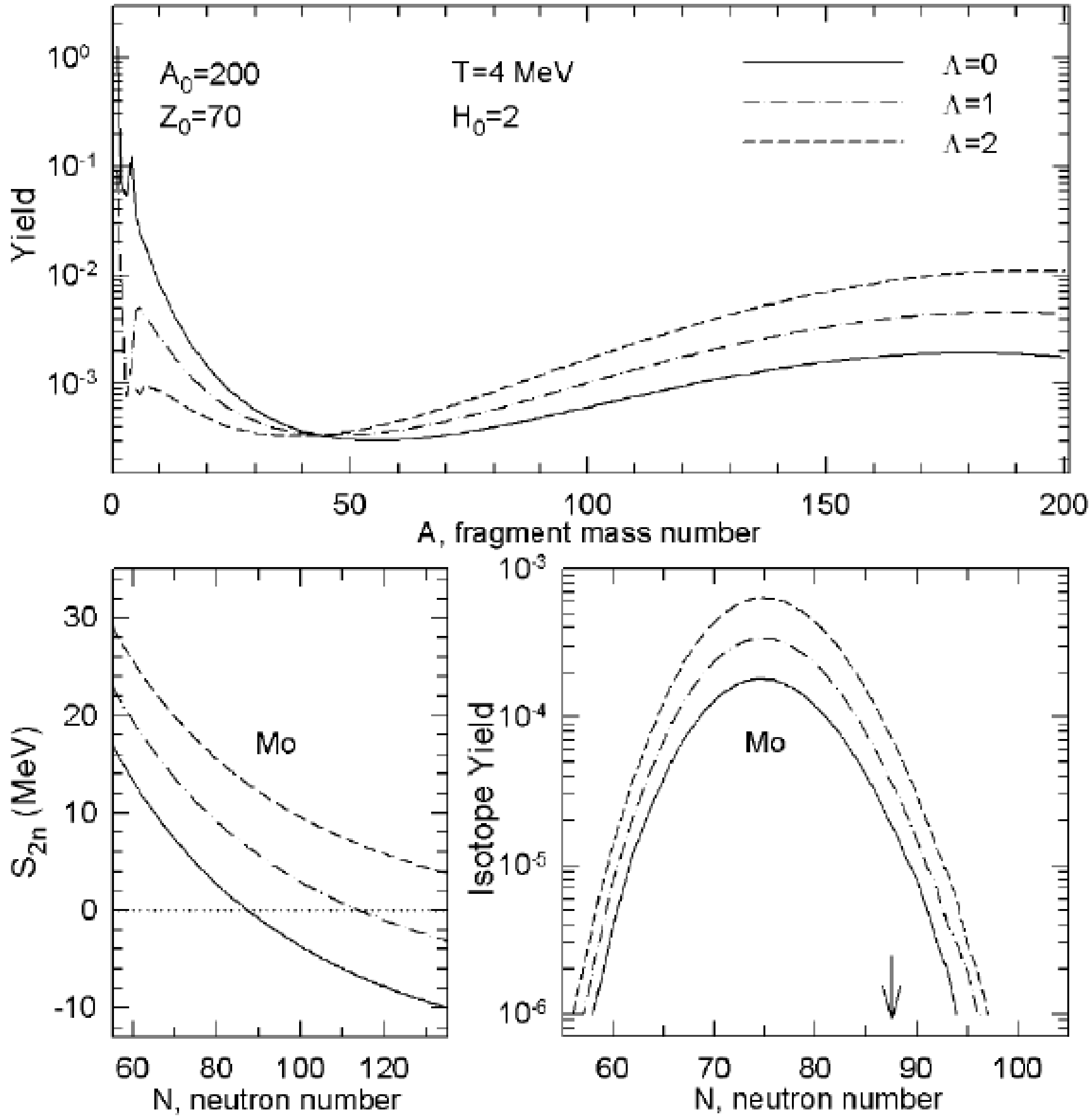
Break-up of excited hyper-residues

Normal nuclei + hypernuclei can be formed via evaporation, fission and multifragmentation processes.

Liquid-gas type phase transition in hyper-matter is expected at subnuclear densities.

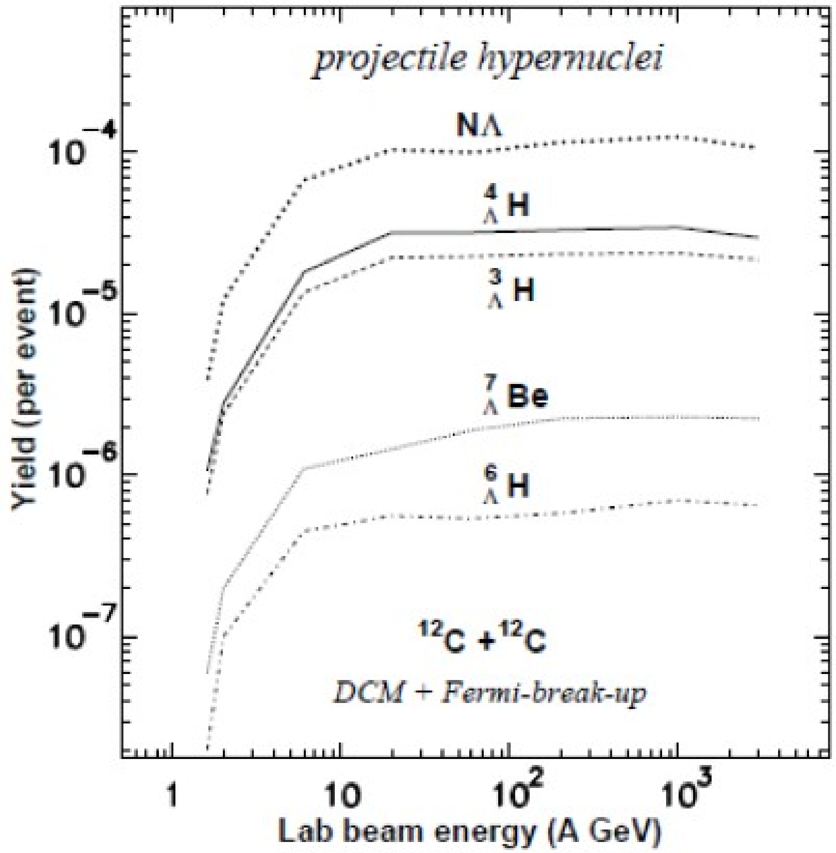
Very broad distributions of nuclei similar to ones in normal nuclear matter. At moderate temperatures hyperons concentrate in large species

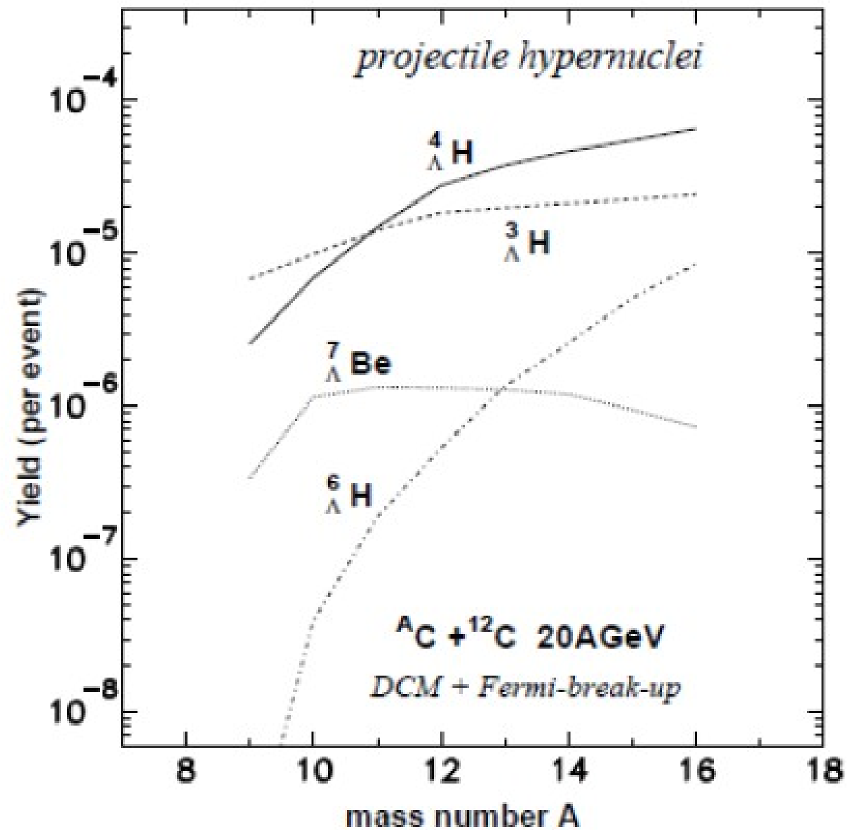
Important: formed hypernuclei can reach beyond traditional neutron and proton drip-lines



N.Buyukcizmeci et al., PRC88 (2013) 014611

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.

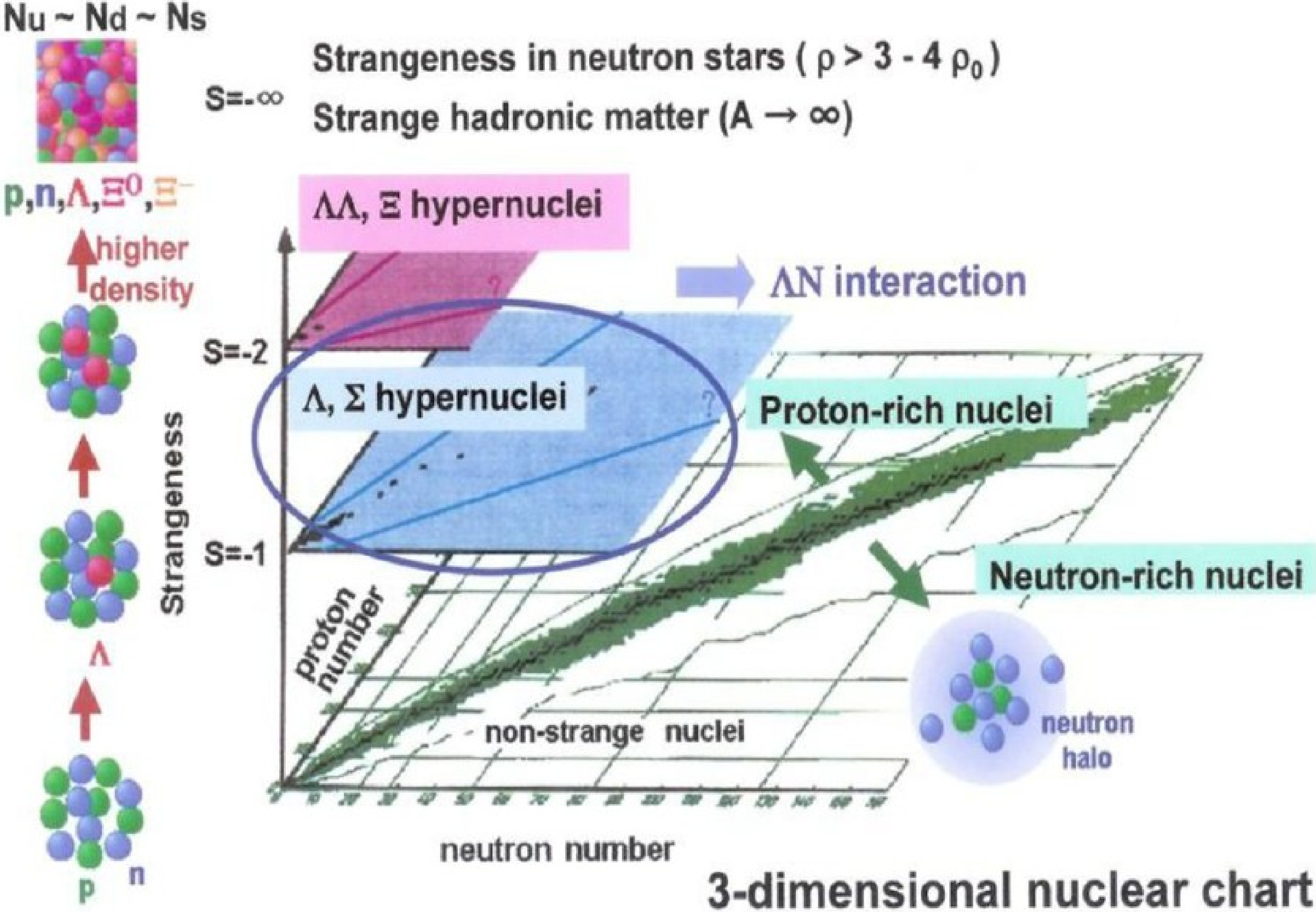
A.S.Botvina, KK.Gudima, J.Pochodzalla, PRC 88 (2013) 054605

Conclusions

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

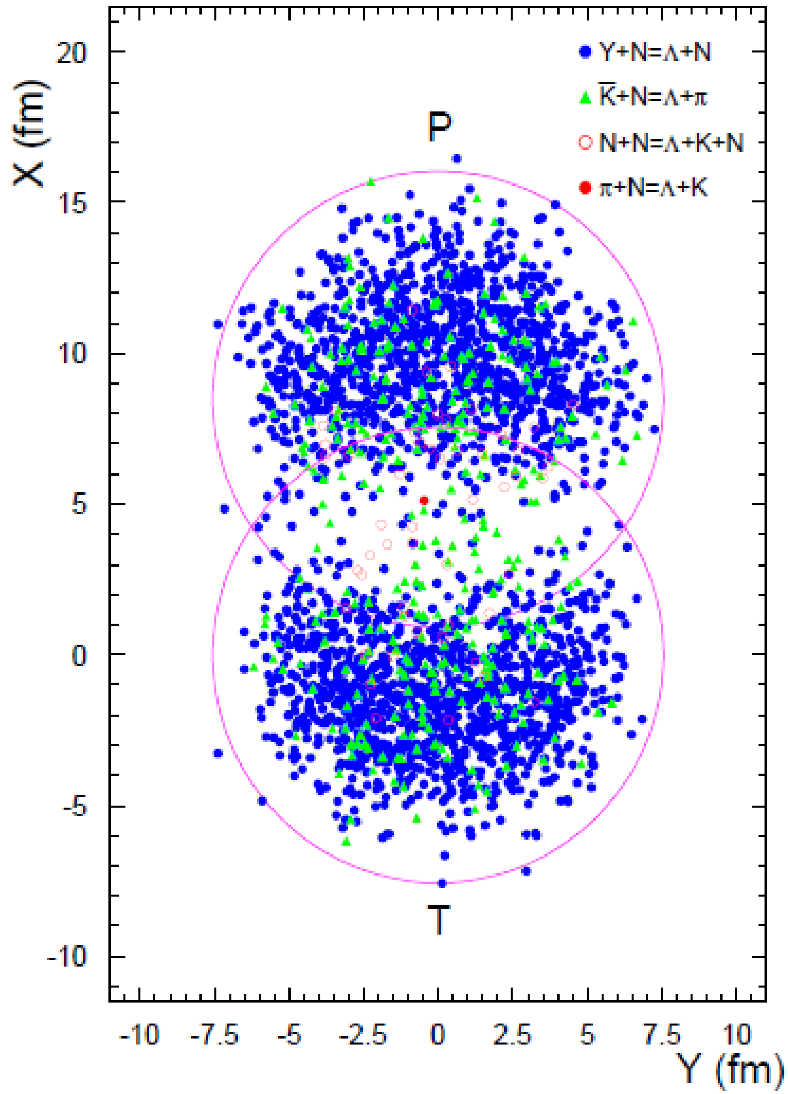
Mechanism of formation of hypernuclei in peripheral reactions: Strange baryons (Λ, Σ, Ξ, …) produced in particle collisions are transported to the spectator residues and are captured in nuclear matter. These strange systems are excited and after decay of such systems hypernuclei of all sizes (and isospin), including exotic weakly-bound states, multi-strange nuclei, and those beyond the drip-lines can be produced.

Advantages over other reactions producing hypernuclei: there is no limit on sizes and isotope content of produced nuclei; probability of their formation is very high; a large strangeness can be deposited in nuclei.
After decay of such hypernuclei exotic normal nuclei can be obtained.
Correlations (unbound states) and lifetimes can be naturally studied.
EOS of hypermatter at subnuclear density can be investigated.



Nu ~ Nd ~ Ns
Strangeness in neutron stars (ρ > 3 - 4 ρ0)
S=-∞
Strange hadronic matter (A → ∞)
p,n,Λ,Ξ0,Ξ−
higher density
ΛΛ, Ξ hypernuclei
ΛN interaction
S=-2
Λ, Σ hypernuclei
Proton-rich nuclei
Strangeness
S=-1
Neutron-rich nuclei
proton number
Λ
non-strange nuclei
neutron halo
neutron number
p n
3-dimensional nuclear chart

Absorption of Lambda hyperons inside residual nuclei after DCM
(different processes leading to Lambda production are noted)



Perpendicular beam axis view

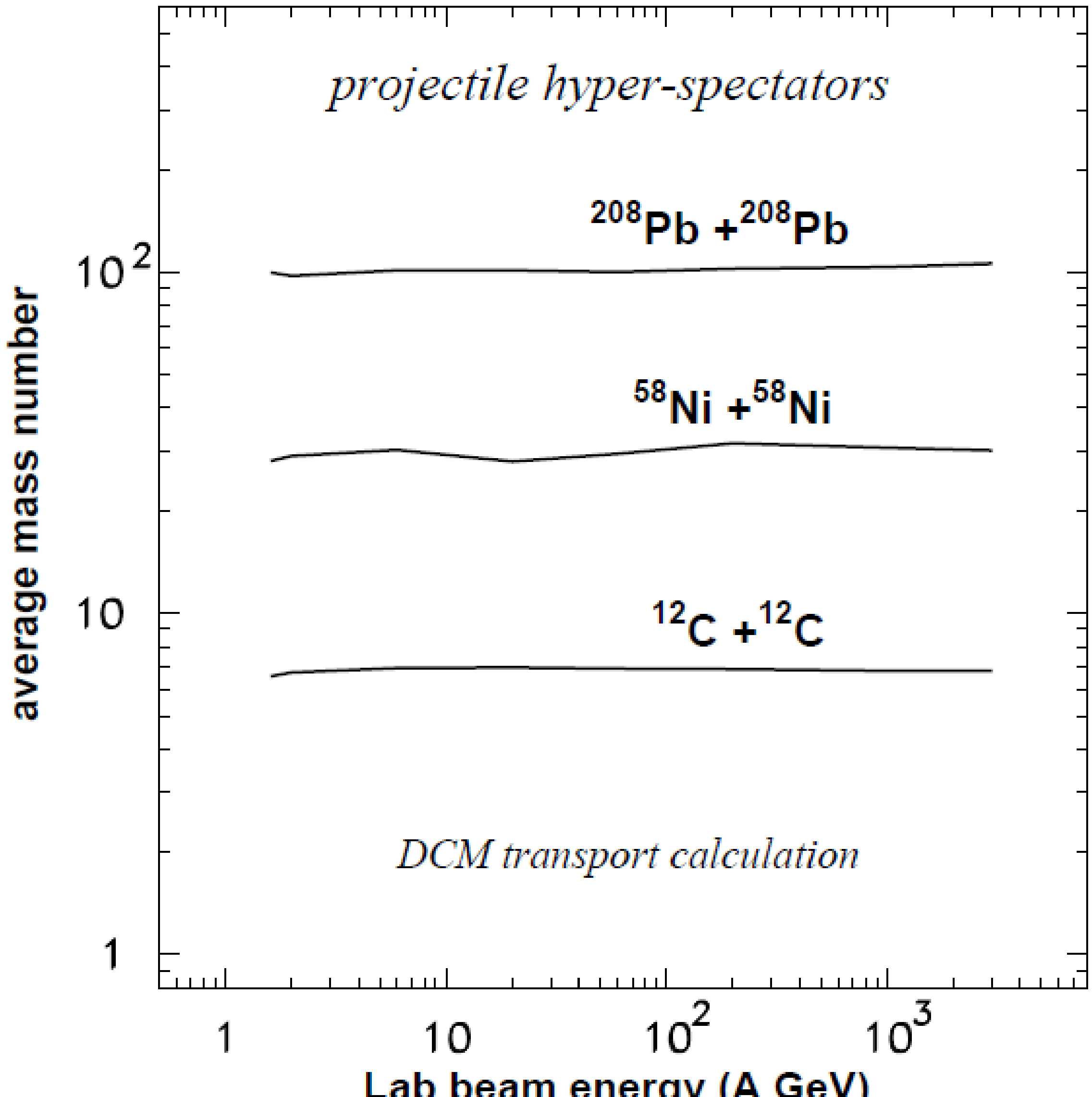
Au (20 A GeV) + Au

impact parameter= 8.5fm

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

Yield of hypernuclei in peripheral collisions

A.S.Botvina, K.K.Gudima, J.Pochodzalla (PRC)



With heavy ion collisions E_{beam}>1.6AGeV

(since $NN \to \Lambda KN$ energy threshold ~ 1.6 GeV)

we can obtain

Relativistic Hypernuclei – in peripheral collisions

Effective lifetime: longer by Lorentz factor γ

200 ps → 600 ps with γ=3 (2AGeV)

200 ps → 4 ns with γ=20 (20AGeV)

=> Detection of their decay products becomes feasible : target and hyper-fragment decay zones are separated in space, particle vertex methods can be used. At large γ direct separation of hypernuclei is possible.

Additional advantages of HI: Hypernuclei with multiple strangeness and exotic (e.g. neutron-rich) hypernuclei can be produced.

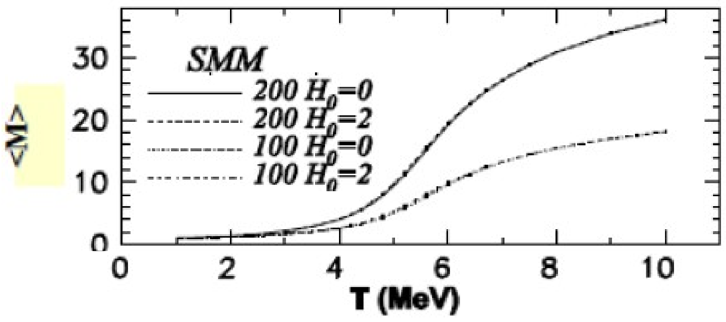
HypHi experimental program at GSI and FAIR

Multifragmentation of excited hyper-sources

H_0 is the number of hyperons in the system

General picture depends weakly on strangeness content (in the case it is much lower than baryon charge)

Mean multiplicity



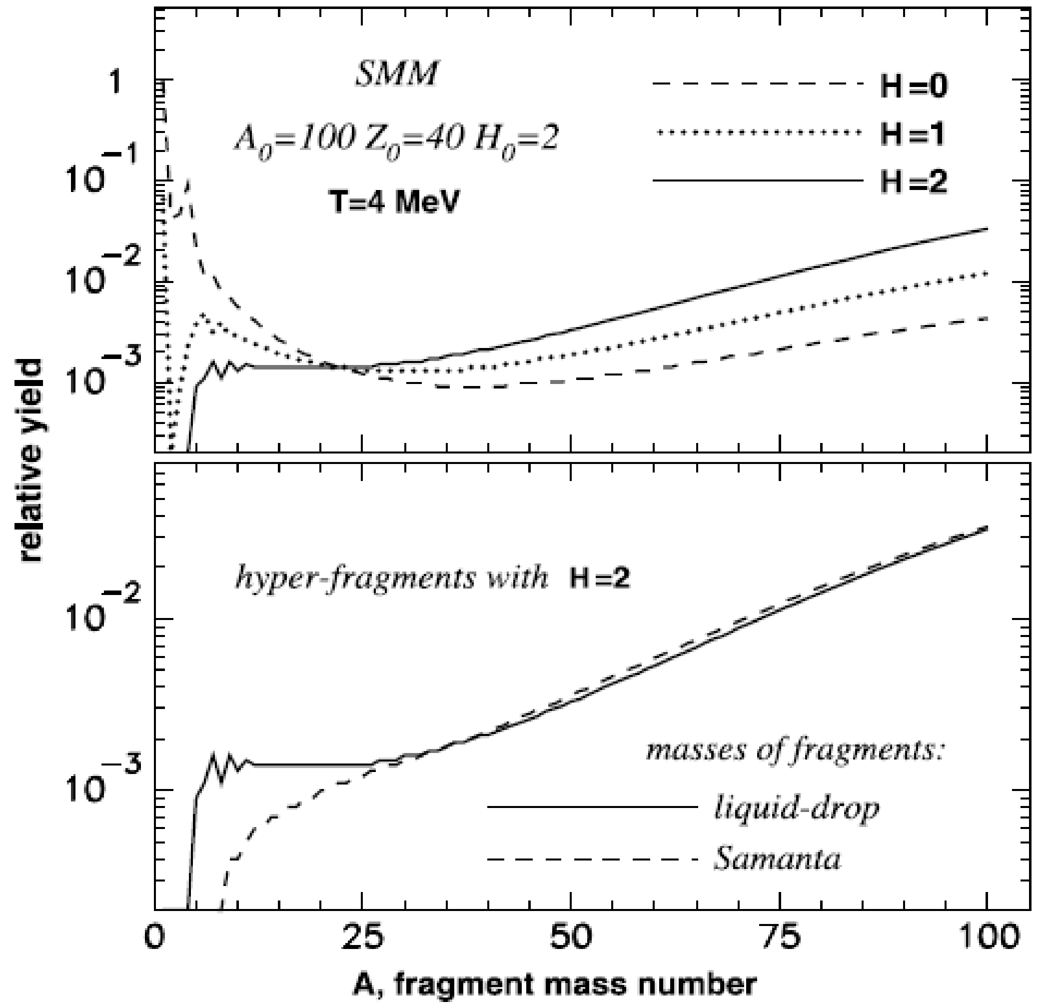


Fig. 3. Multifragmentation of an excited double-strange system with mass number 100 and charge 40, at temperature 4 MeV. Top panel – yield of fragments containing 0, 1, and 2 Λ hyperons. Bottom panel – effect of different mass formulae with strangeness on production of double hyperfragments [13].

However, there are essential differences in properties of produced fragments !

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

De-excitation of hot light hypernuclear systems

A.Sanchez-Lorente, A.S.Botvina, J.Pochodzalla, Phys. Lett. B697 (2011)222

For light primary fragments (with $A \leq 16$) even a relatively small excitation energy may be comparable with their total binding energy. In this case we assume that the principal mechanism of de-excitation is the explosive decay of the excited nucleus into several smaller clusters (the secondary break-up). To describe this process we use the famous Fermi model [105]. It is analogous to the above-described statistical model, but all final-state fragments are assumed to be in their ground or low excited states. In this case the statistical weight of the channel containing n particles with masses m_i $(i = 1, \ldots, n)$ in volume V_f may be calculated in microcanonical approximation:

$$\Delta\Gamma_f^{\text{mic}} \propto \frac{S}{G}\left(\frac{V_f}{(2\pi\hbar)^3}\right)^{n-1}\left(\frac{\prod_{i=1}^n m_i}{m_0}\right)^{3/2}\frac{(2\pi)^{(3/2)(n-1)}}{\Gamma(\frac{3}{2}(n-1))}\left(E_{\text{kin}} - U_f^C\right)^{(3/2)n-5/2}, \tag{58}$$

where $m_0 = \sum_{i=1}^n m_i$ is the mass of the decaying nucleus, $S = \prod_{i=1}^n (2s_i + 1)$ is the spin degeneracy factor (s_i is the ith particle spin), $G = \prod_{j=1}^k n_j!$ is the particle identity factor (n_j is the number of particles of kind j). E_{kin} is the total kinetic energy of particles at infinity which is related to the prefragment excitation energy E_{AZ}^* as

$$E_{\text{kin}} = E_{AZ}^* + m_0c^2 - \sum_{i=1}^n m_ic^2. \tag{59}$$

U_f^C is the Coulomb interaction energy between cold secondary fragments given by Eq. (49), U_f^C and V_f are attributed now to the secondary break-up configuration.

Generalization of the Fermi-break-up model: new decay channels with hypernuclei were included ; masses and spins of hypernuclei and their excited states were taken from available experimental data and theoretical calculations

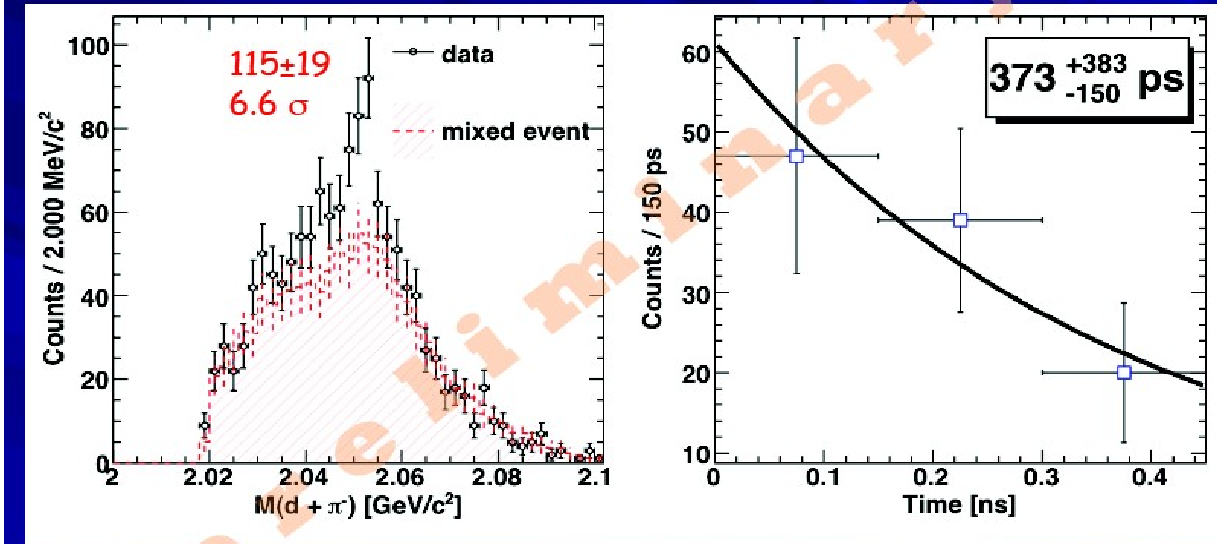
T.Saito (for HypHI), NUFRA2011 conference, and ETC* Workshop 'Strange Hadronic Matter' Trento, 2011

Λn bound state ?

C. Rappold et al., Phys. Rev. C (2013):

Λnn bound state ?

? -> d + π^-



- Calibrated mass: 2.054 - 2.064 GeV/c² (n+Λ threshold = 2.055)

Final state Initial state	$p + \pi^-$ Λ	$^3He + \pi^-$ $^3_\Lambda H$	$^4He + \pi^-$ $^4_\Lambda H$	$d + \pi^-$
Uncalibrated mass	1111.3 ± 0.4	2984.6 ± 0.6	3905.6 ± 0.6	2051.3 ± 0.5
Width	7.3	8.6	5.2	4.8
Peak integral	403 ± 41	178 ± 31	66 ± 14	115 ± 19
Significance in σ	7.1	6.2	5.3	6.6
Known mass	1115.683 ± 0.006 [26]	2991.68 ± 0.05 [3]	3923.03 ± 0.06 [3]	
Measured lifetime	231^{+112}_{-75}	141^{+67}_{-57}	162^{+99}_{-73}	373^{+383}_{-150}
Known lifetime	263.2 ± 2.0 [26]	$246^{+62}_{-41} \pm 27$ [27]	194^{+24}_{-26} [28]	
After the correction of the acceptance and efficiency		1.0	0.17	4.12

In reactions with light ions: production of hypernuclei via break-up of excited light strange systems

Generalization of the statistical Fermi Break-up model for hypernuclei:
A.Sanchez Lorente, A.S.Botvina and J.Pochodzalla, Phys. Lett. B697 (2011) 222

6Li (2 AGeV) + 12C collisions

DCM calculations lead to production of light hyper-spectators (from Li) with excitation energies around 1--10 MeV/n. Their decay produces hyper-nuclei.

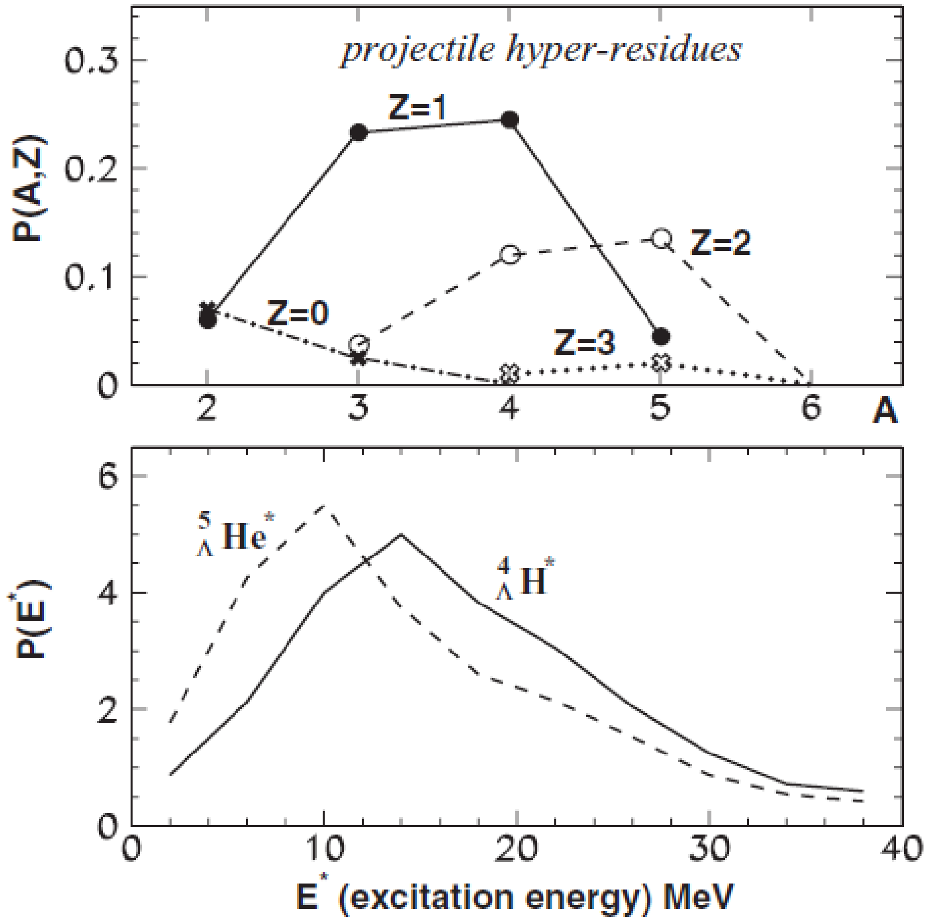
A new Lambda-N state was included into the break-up calculations with the bound energy of 50 keV and Spin=1. All known light hypernuclei were also included. Summing-up one can rough estimate the ratio of production of

$\Lambda N \quad {}^{3}_{\Lambda}H \quad {}^{4}_{\Lambda}H$

as 4.4 : 1 : 0.23

Recent HypHI experiment at GSI, T.Saito (@NUFRA2011)

----- 4.12 : 1 : 0.17



A.S.Botvina, I.N.Mishustin, J.Pochodzalla, Phys. Rev. C86, 011601 (2012).

Absorption of Ξ-minus may lead to production of H-dibaryons:

Consider: absorptions of Ξ^- by ^{7}Li and by ^{3}He,

leading to the formation of ${}^{8}_{\Lambda\Lambda}\mathrm{He}^*$ and ${}^{4}_{\Lambda\Lambda}\mathrm{H}^*$

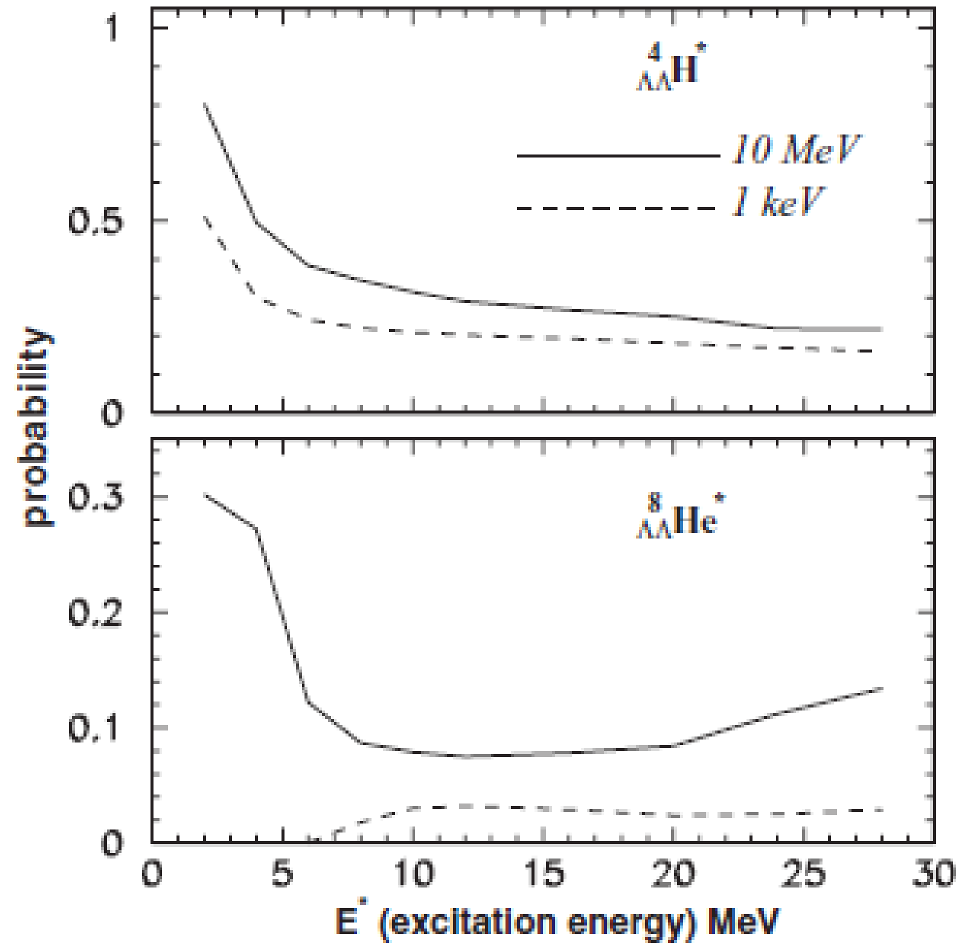
($\Xi^- p \rightarrow \Lambda\Lambda$ with release of 28 MeV)

The following disintegration of these nuclei calculated with the Fermi-Break-up model yields many normal and strange fragments, including exotic ones, if they exist. Different binding energies of H-dibaryons was assumed, from strongly bound to nearly unbound. In all cases the yield is considerable !

The nuclear reaction theory can show the most efficient experimental way for searching for specific species.

A.S.Botvina, I.N.Mishustin, J.Pochodzalla, Phys. Rev. C86, 011601 (2012).

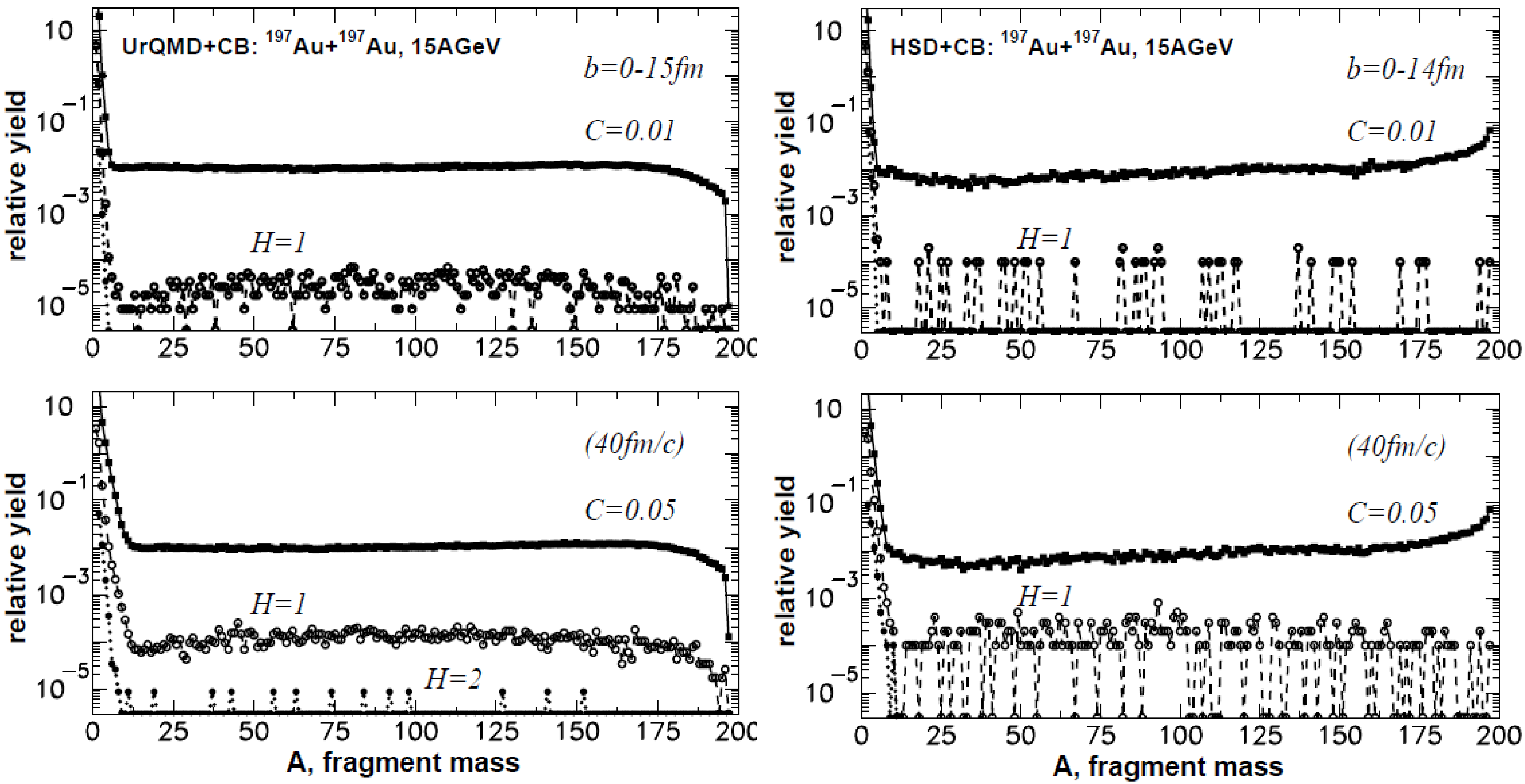
H-dibaryon (ΛΛ bound state) yield



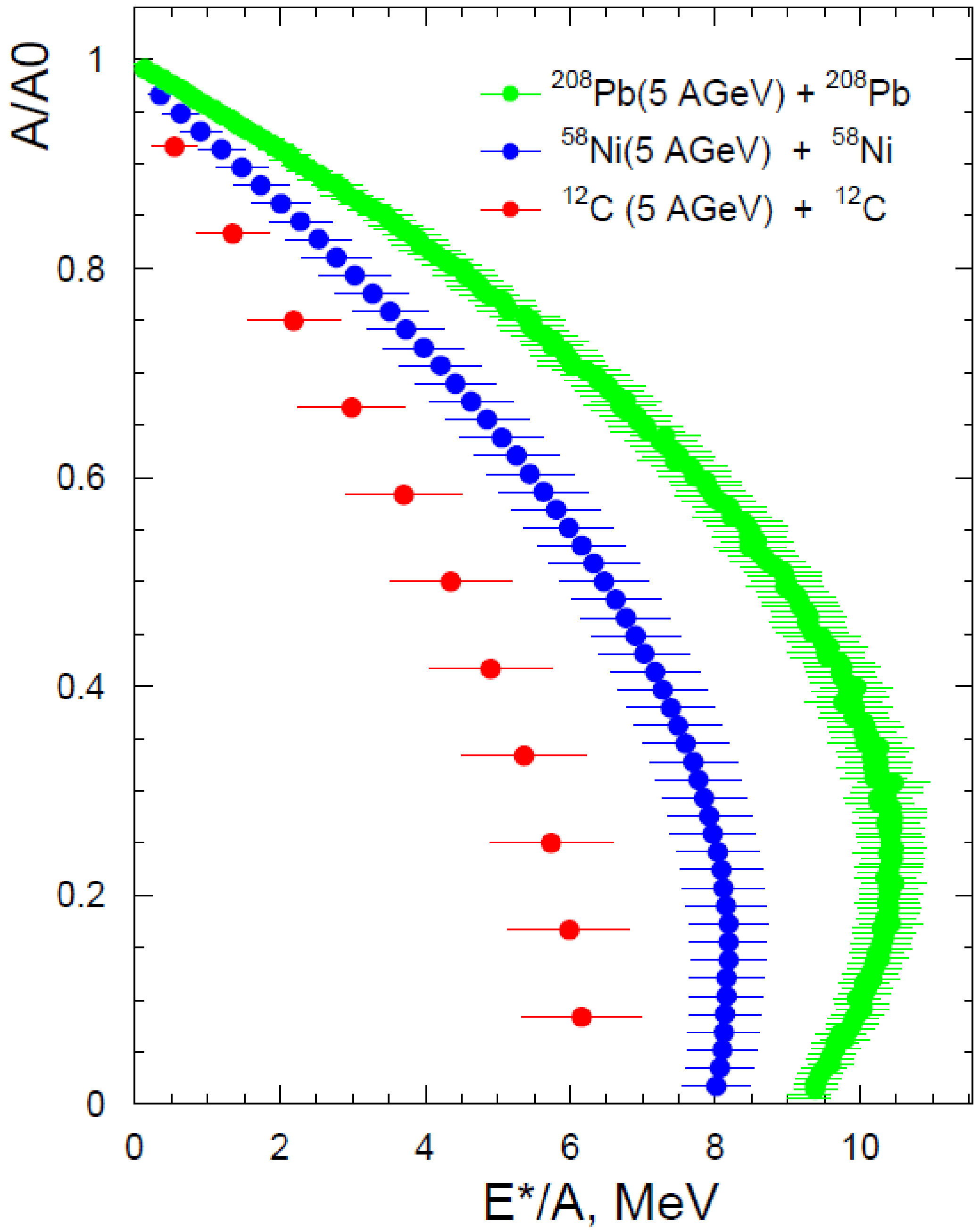
preliminary

Transport models are consistent (UrQMD, HSD)

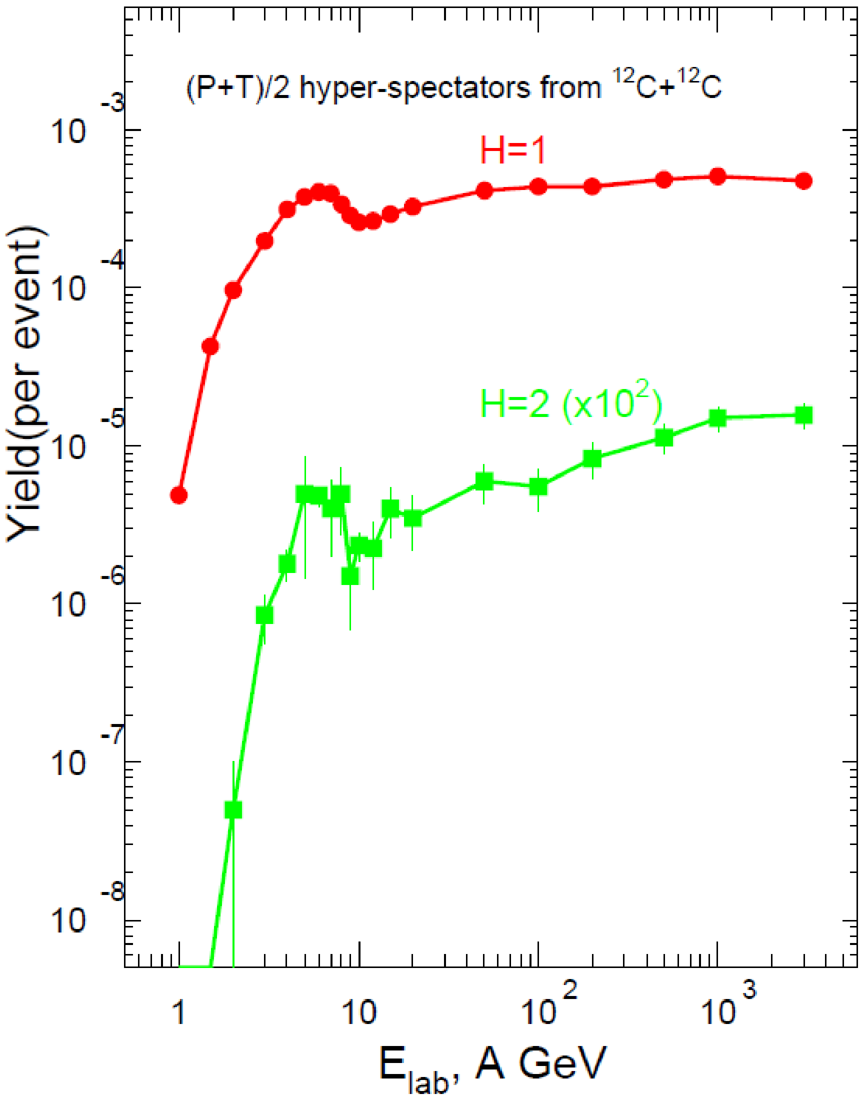
Large fragments and hyperfragments:



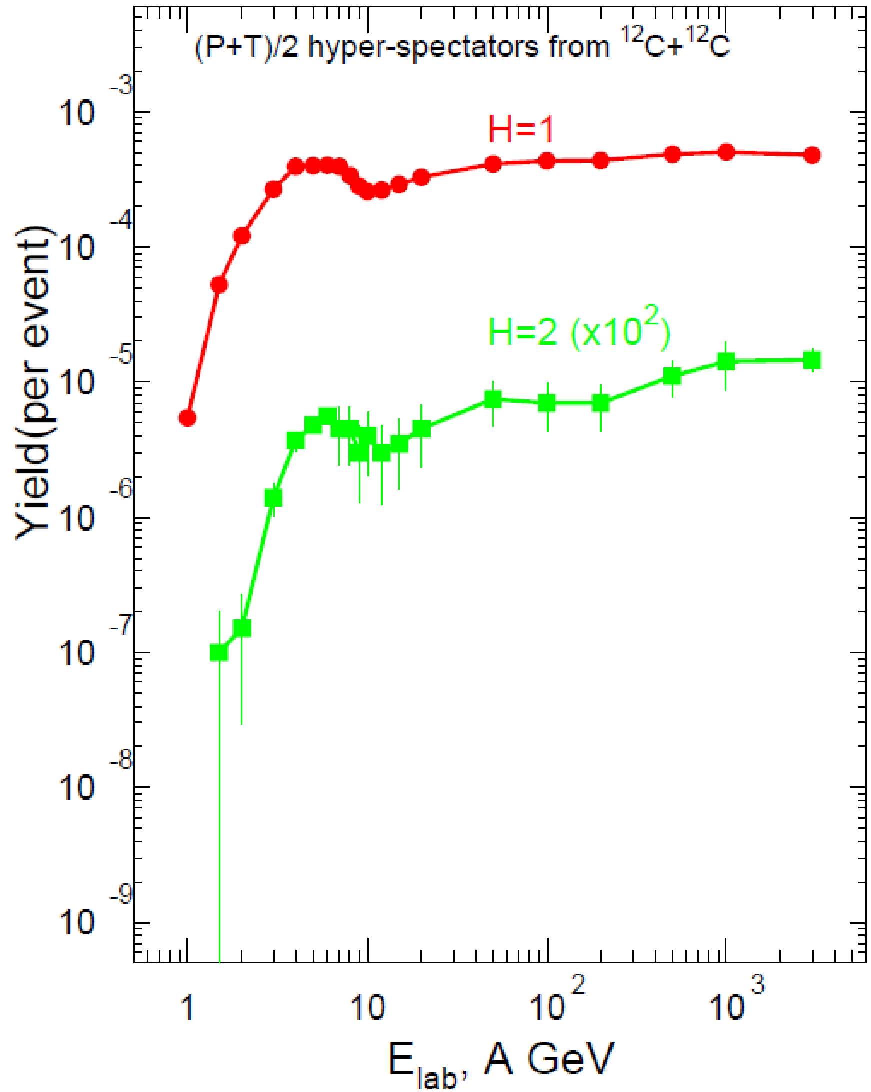
DCM


A/A0
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
E*/A, MeV
208Pb(5 AGeV) + 208Pb
58Ni(5 AGeV) + 58Ni
12C (5 AGeV) + 12C

DCM

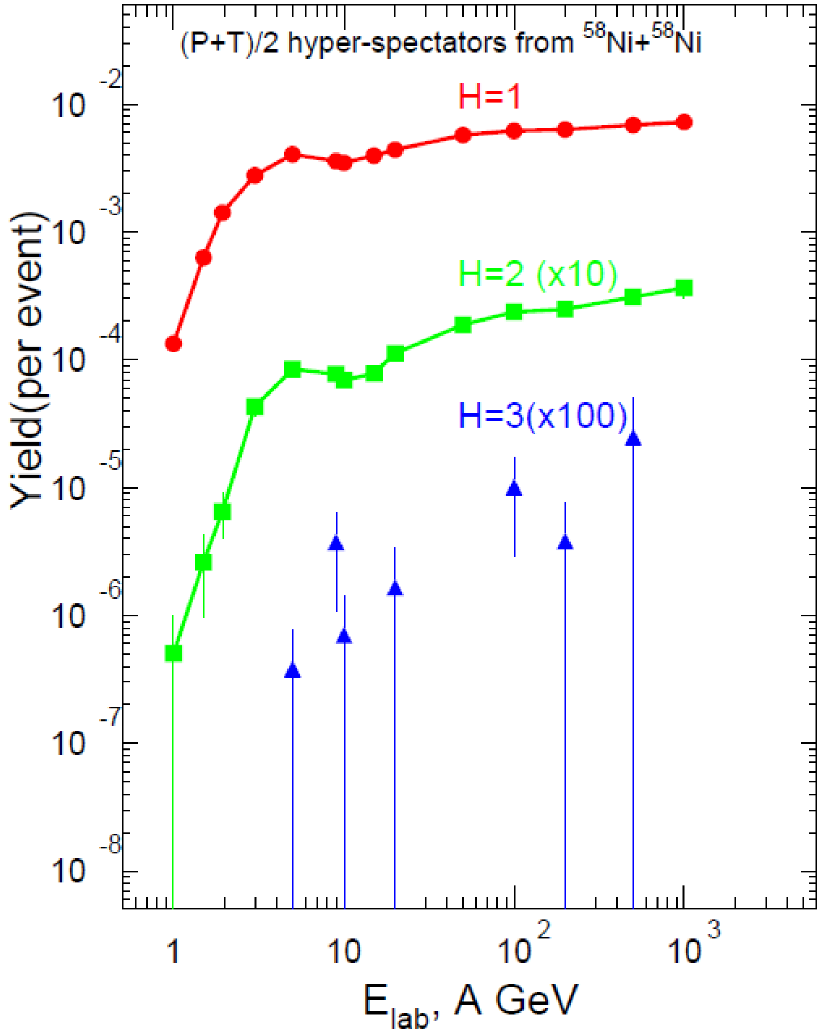


(P+T)/2 hyper-spectators from $^{12}C+^{12}C$
H=1
H=2 (x10^2)
Yield(per event)
E_{lab}, A GeV



(P+T)/2 hyper-spectators from $^{12}C+^{12}C$
H=1
H=2 (x10^2)
Yield(per event)
E_{lab}, A GeV

DCM



(P+T)/2 hyper-spectators from ^{58}Ni+^{58}Ni
H=1
H=2 (x10)
H=3(x100)
Yield(per event)
E_{lab}, A GeV

DCM

Description of elementary interactions in DCM transport code