Feasibility of hypernuclei-production experiments with Nuclotron-M and NICA beams

K.K. Gudima
Institute of Applied Physics of AS of Moldova
In collaboration with
M.Bleicher, A.Botvina, I.Mishustin, J. Steinheimer
FIAS, Germany

WHY HYPERNUCLEI ?

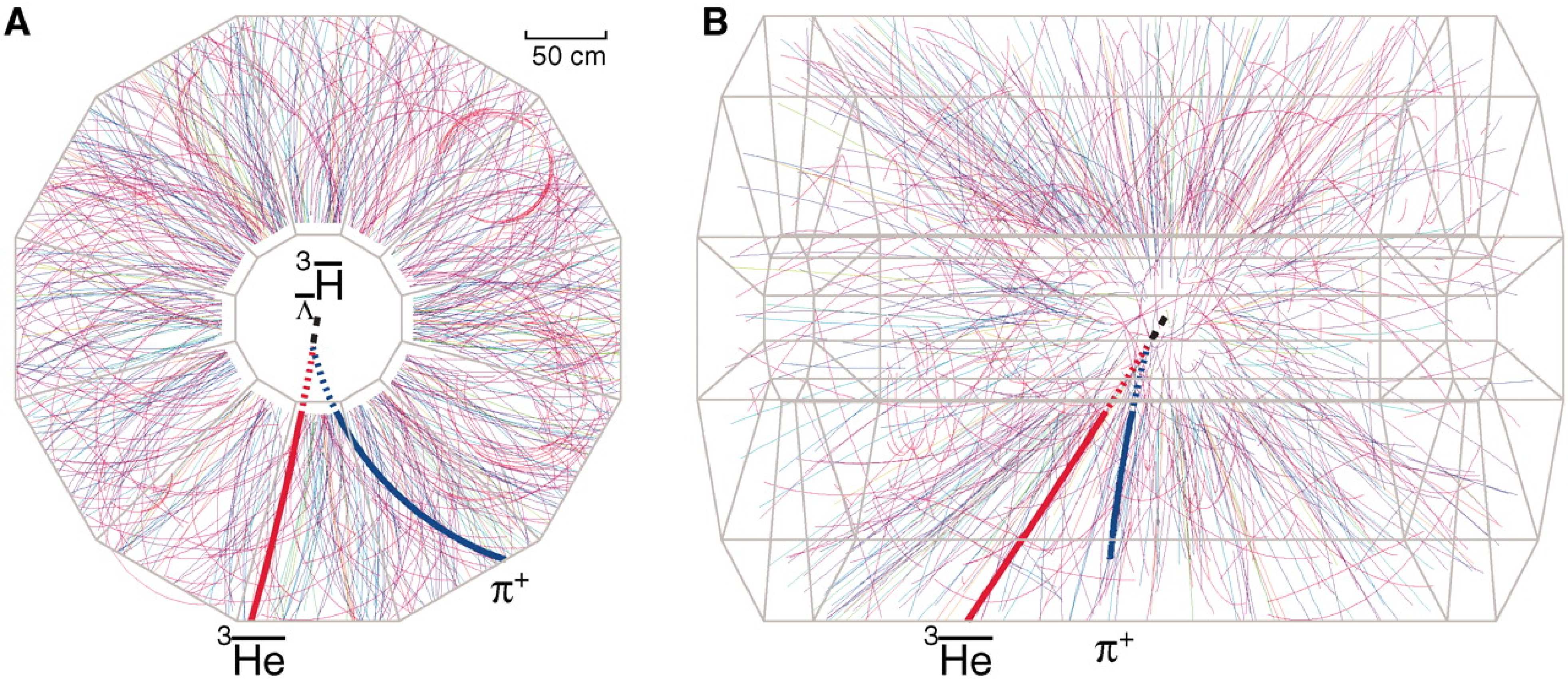
1. Theoretically proposed by Kerman and Weiss (Phys. Rev. C 8, 408 (1973).): relativistic heavy ion collisions offer the best possibility to create exotic finite nuclear system with finite strangeness.
2. Unusual structure: hyperon halo ($^{3}H_{\Lambda}$); neutron-rich hypernuclei; nuclei with an unstable core, where Λ is a sort of "glue" ensuring stability ($^{6}H_{\Lambda}$, $^{6}He_{\Lambda}$, $^{8}He_{\Lambda}$).
3. Possibility to study strangeness sector of hadronic EoS
4. Important for physics of neutron stars , "strange stars"
5. Additional advantage is that lifetime (~10^{-10} s) is much longer than HI collision timescale, and detection of their decay products becomes feasible. At large γ factor direct separation of hypernuclei is possible.

First experiments:

S. Avramenko et al., Nucl. Phys. A547, 95c (1992).
W. M. Alberico, G. Garbarino, Phys. Rep. 369, 1 (2002).
S. V. Averyanov et al., Phys. of Atom. Nucl. 71, 2101(2008); Yad. Fiz. 71, 2137 (2008)

Planned experiments: HypHI: 6Li+12C, SIS (in progress…),
FAIR A(20GeV/A)+A
J-PARC: p+A@50GeV
PANDA: Antiproton-Nucleus
RHIC ($s^{1/2}$ =5-50 GeV/A)
NUCLOTRON-M, NICA ($s^{1/2}$ =3-11 GeV/A)

WHY HYPERNUCLEI ? (CONTINUE)



V.I. Abelev et al. STAR Collaboration, Science Express, 4 March, 2010

157+/-17 hypertritons and 70+/30 antihypertritons were observed in Au+Au at RHIC, BNL

THEORETICAL DESCRIPTION OF SRANGENESS PRODUCTION

old models:
INC, QMD, BUU — W. Cassing et al. Z.Phys. A351(1995) 1217

DCM (+QGSM+…) model — V.D. Toneev, K.K. Gudima, Nucl.Phys. A400(1983)173
N.S. Amelin,K.K. Gudima, V.D. Toneev, Yad. Phys 51(1990)1730

…

GiBUU model — Th. Gaitanos, H.Lenske, U. Mosel, Phys.Lett B663(2008)197
Phys.Lett. B657(2009)297

HiJIING +CSM — V. Topor Pop and S. Das Gupta arXiv://1002.4824v1[hep-ph]

and

Coalescence model — M. Sano, M. Wakai, Prog.theor.Suppl. 117(1994)99

Firestreak model — K.K. Gudima, V.D. Toneev, "Particle and Nuclei"-Int.Conf.. Heidelberg, 1984

MODEL

At high energies we used the Quark-Gluon String Model (QGSM):
N.S. Amelin, K.K.G., V.D. Toneev, 1990 – 1993
At the energy of a few GeV the string dynamics is reduced to the earlier developed Dubna Cascade Model (DCM)-V.D. Toneev, K.K. G., Nucl. Phys. **A400,** 173 (1983), with recent upgrade of elementary cross sections and new channels.

Additional to nucleon nuclear potential, the Λ-nuclear potential was included:
(PRC 31(1985)1590: $U(\rho)=U_0\rho(1-\beta\rho^{2/3})$, at $\rho=0.16 fm^{-3}$ U~-25-30 MeV.
Density of spectator matter is calculated locally in the sphere with R=2fm.

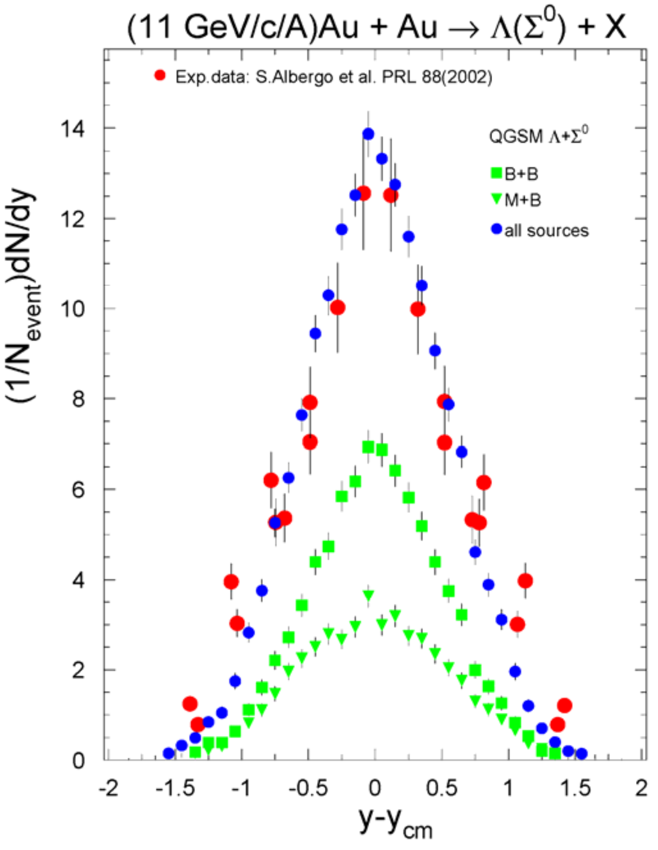
During collision dynamic produced Λ can be absorbed in spectator zone of projectile or target nuclei by attractive potential, thus forming the residual nuclei with nonzero strangeness.

After cascade stage of reaction the coalescence model is used to form light nuclear fragments.
This event by event coalescence was extended to form light hyperfragments

MODEL(CONTINUE)

Next stage: de-excitation of produced residuals - SMM (including evaporation/fission, multifragmentation) - in progress.

Model verification/validation (example):



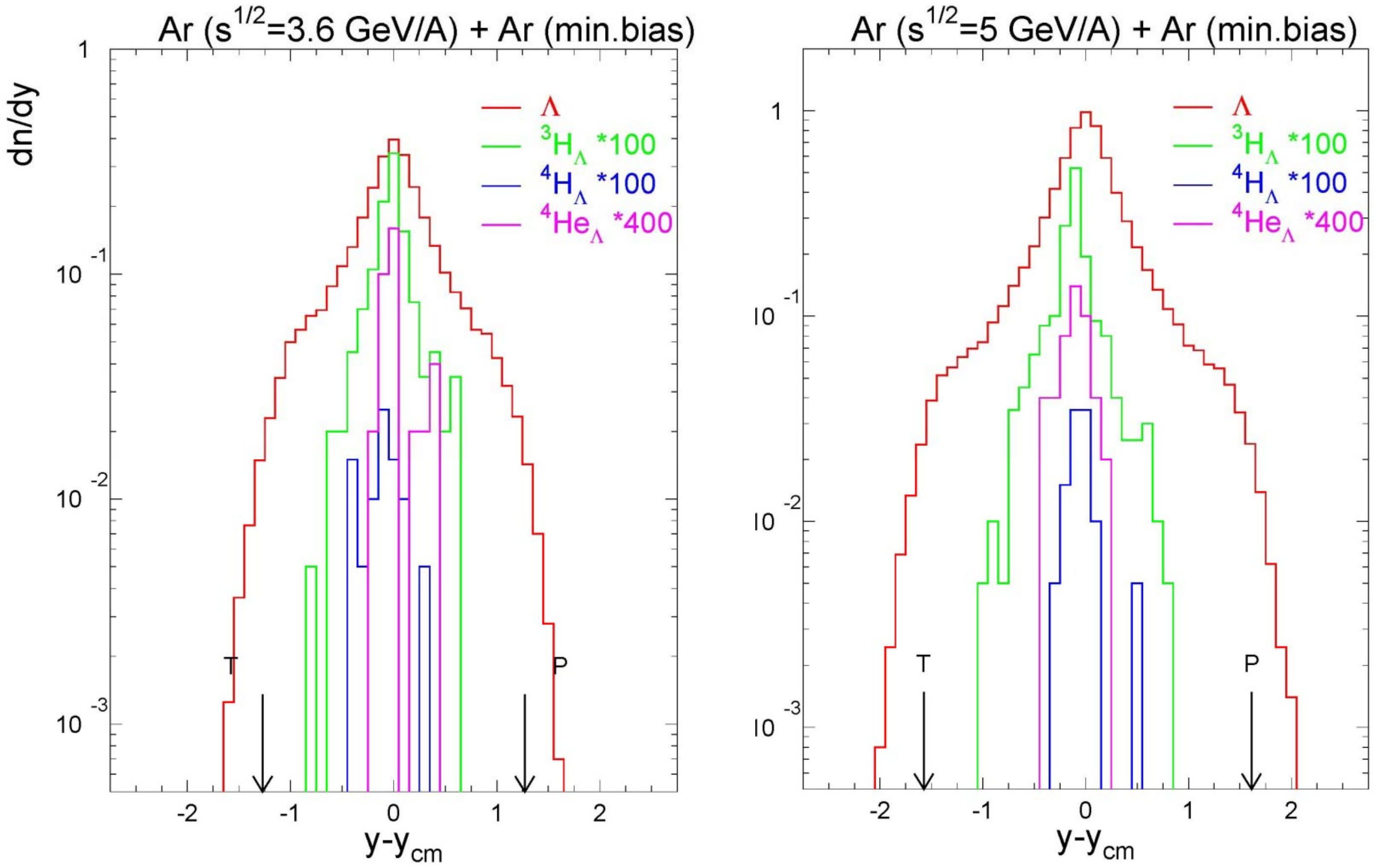
MODEL(CONTINUE)

Production of hypernuclei by coalescence- preliminary results:

Parameters-old DCM-QGSM set:
P2=90, P3=108,
P4=P5=115,
P6=120 MeV/c for mass number 2-6

- Only ~ 1.0 % of Λ are "used" to form Hypefragments

- A few of Λ are close to Projctile/Target rapidity

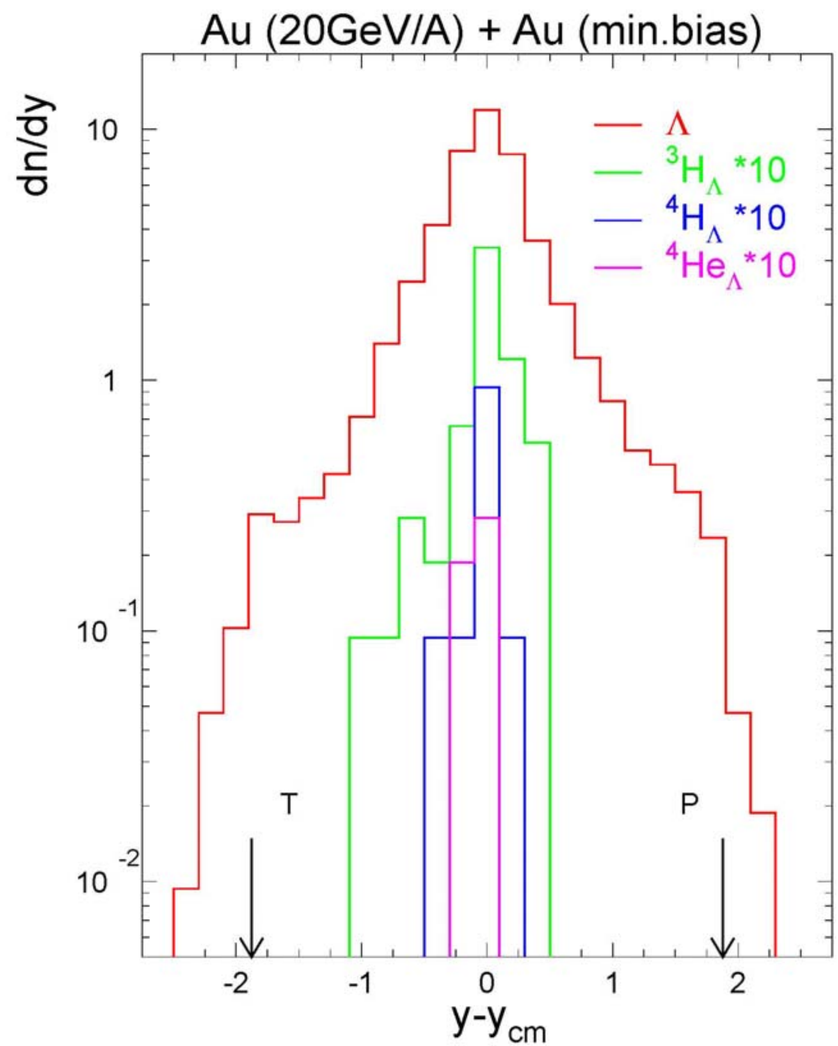


MODEL(CONTINUE)

Production of hypernuclei by coalescence-preliminary results (low statistics):

For Au+Au case we have more Λ but only ~ 1.0 % of Λ are "used" to form hypefragments

•A few of Λ are close to Projctile/Target rapidity



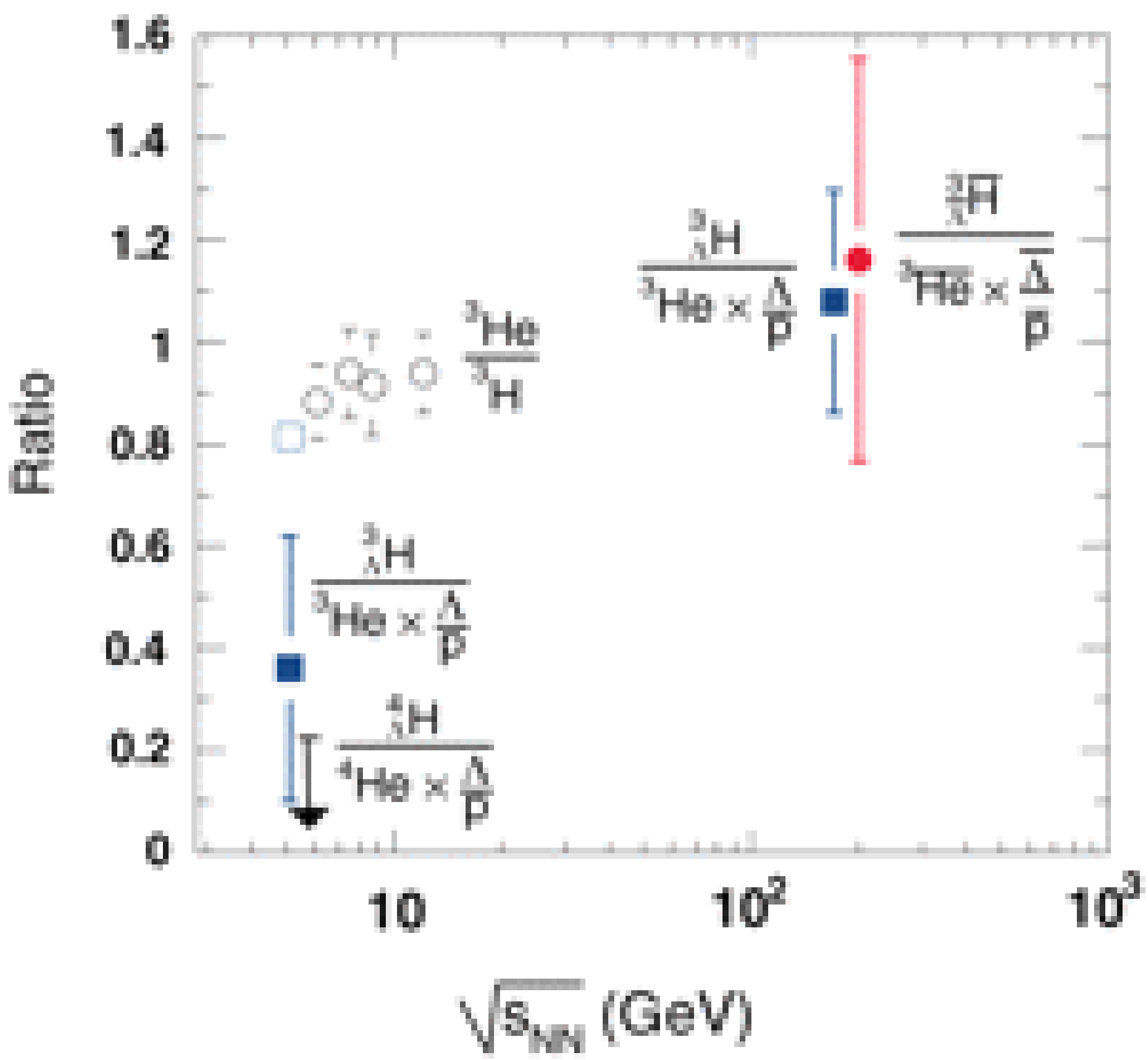
The coalescence process for formation of hypernuclei requires that nucleons and hyperons be in proximity in phase space. Therefore their production is sensitive to the correlations in phase-space distributions of nucleons and hyperons. For example $^{3}H_{\Lambda}$ and $^{4}H_{\Lambda}$ provide a natural and sensitive tool to extract this correlation. They yields can be compared to yields of ^{3}H,^{3}He and ^{4}He by strangeness population factors:

$S_3 = {}^{3}H_{\Lambda} / ({}^{3}He \times \Lambda/p) = 0.51$

$S_4 = {}^{4}H_{\Lambda} / ({}^{4}He \times \Lambda/p) = 0.14$

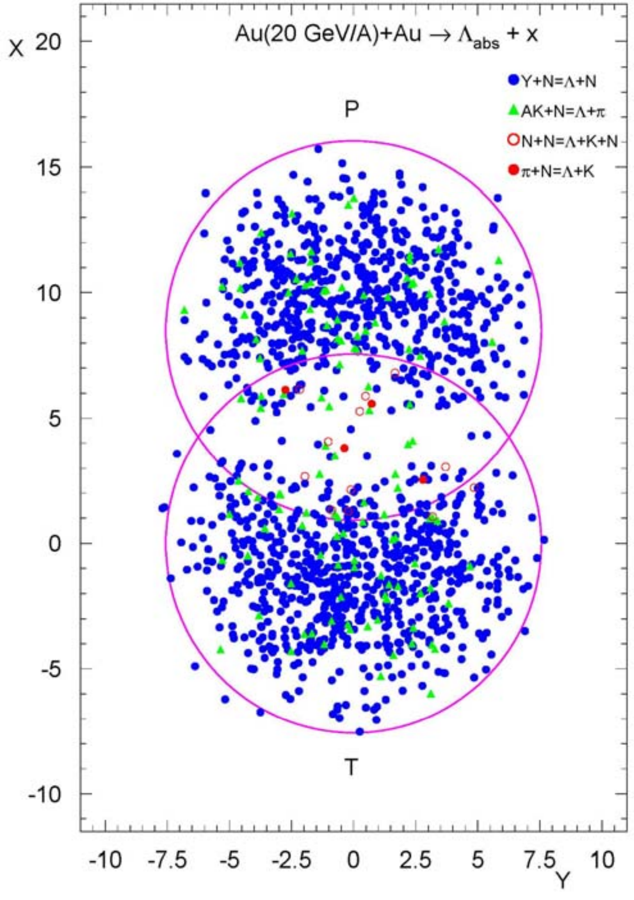
Numbers are our present results for Au+Au at 20 GeV/A($s^{1/2}$ =6.4) and are close to systematic of data (fig. from STAR collaboration,2010)

$^{3}He/^{3}H = 0.63$



MODEL(CONTINUE)

Projectile/Target residuals produced after intranuclear cascade – Λ absorption



Residual nuclei produced during intranuclear cascade may capture Λ if Λ are inside nuclei and their energy is lower than the hyperon potential in nuclear matter (~20-30 MeV). In the model a depletion of the potential with reduction of number of nucleons in nucleus is taken into account.

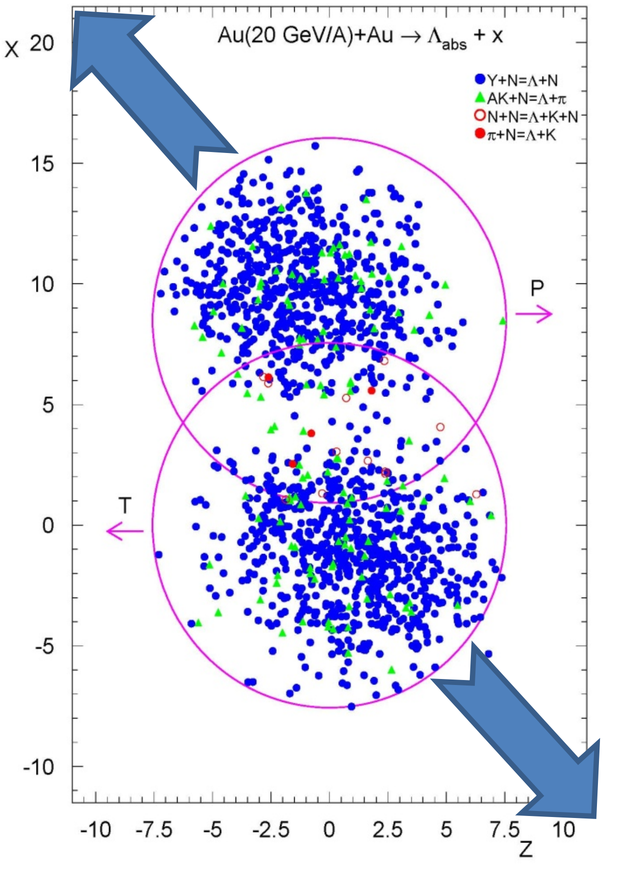
Residual nuclei with strangeness H=-1, -2, -3,..are produced mainly in pheripheral collisions. Only a few of Λ, originated from N+N=K+Λ+N, π+N=Λ+K, and K^- +N=π+Λ are captured in overlap zone.

MODEL(CONTINUE)

Projectile/Target residuals produced after intranuclear cascade – Λ absorption

The same in X-Z (reaction) plane. Residual nuclei are returned in Z=0 position. Points – capture coordinates of Λ originated from different channels. A non zero flow angle of Λ is observed. Equal velocity system is used for calculations.

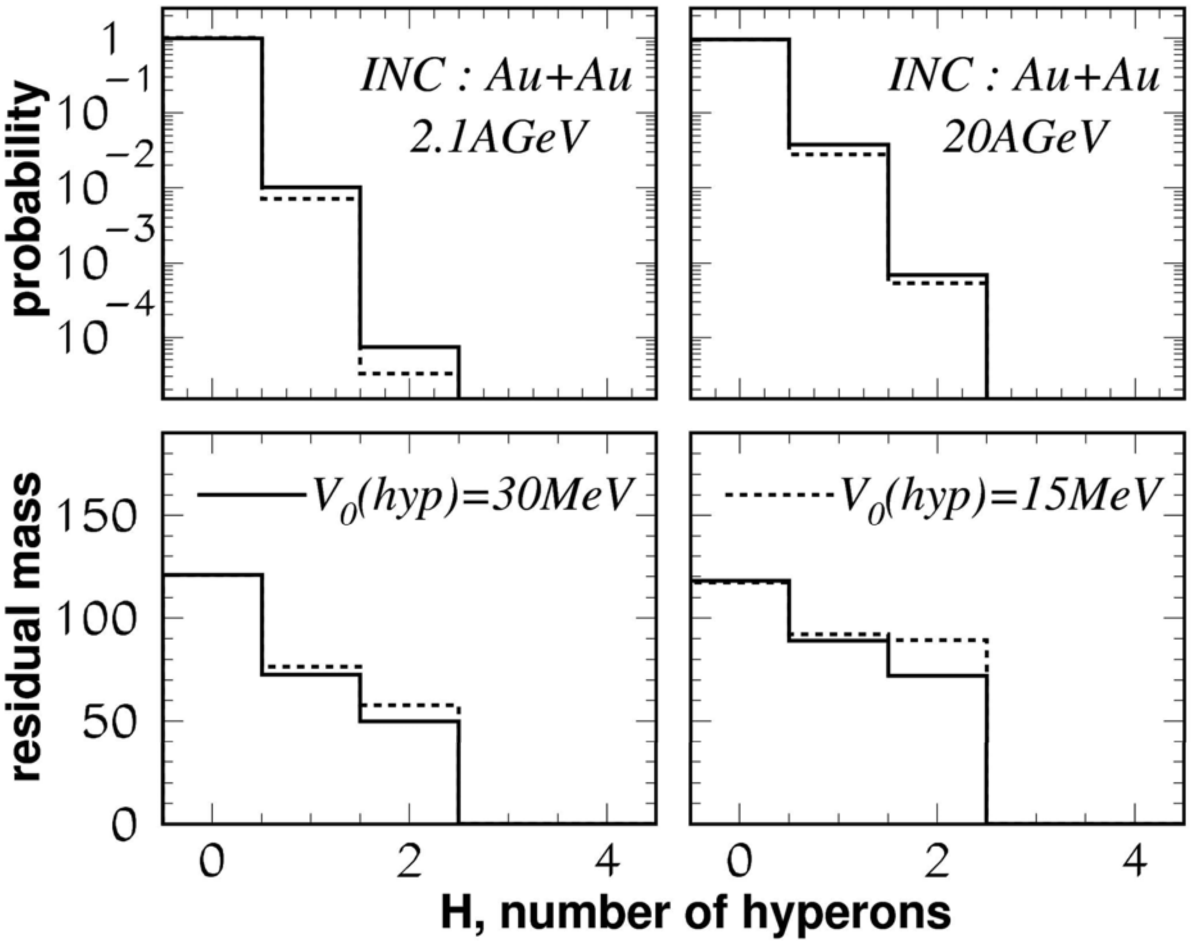
Only a few of Λ, originated from N+N=K+Λ+N, π+N=Λ+K, and K^- +N=π+Λ are captured in overlap zone.



MODEL(CONTINUE)

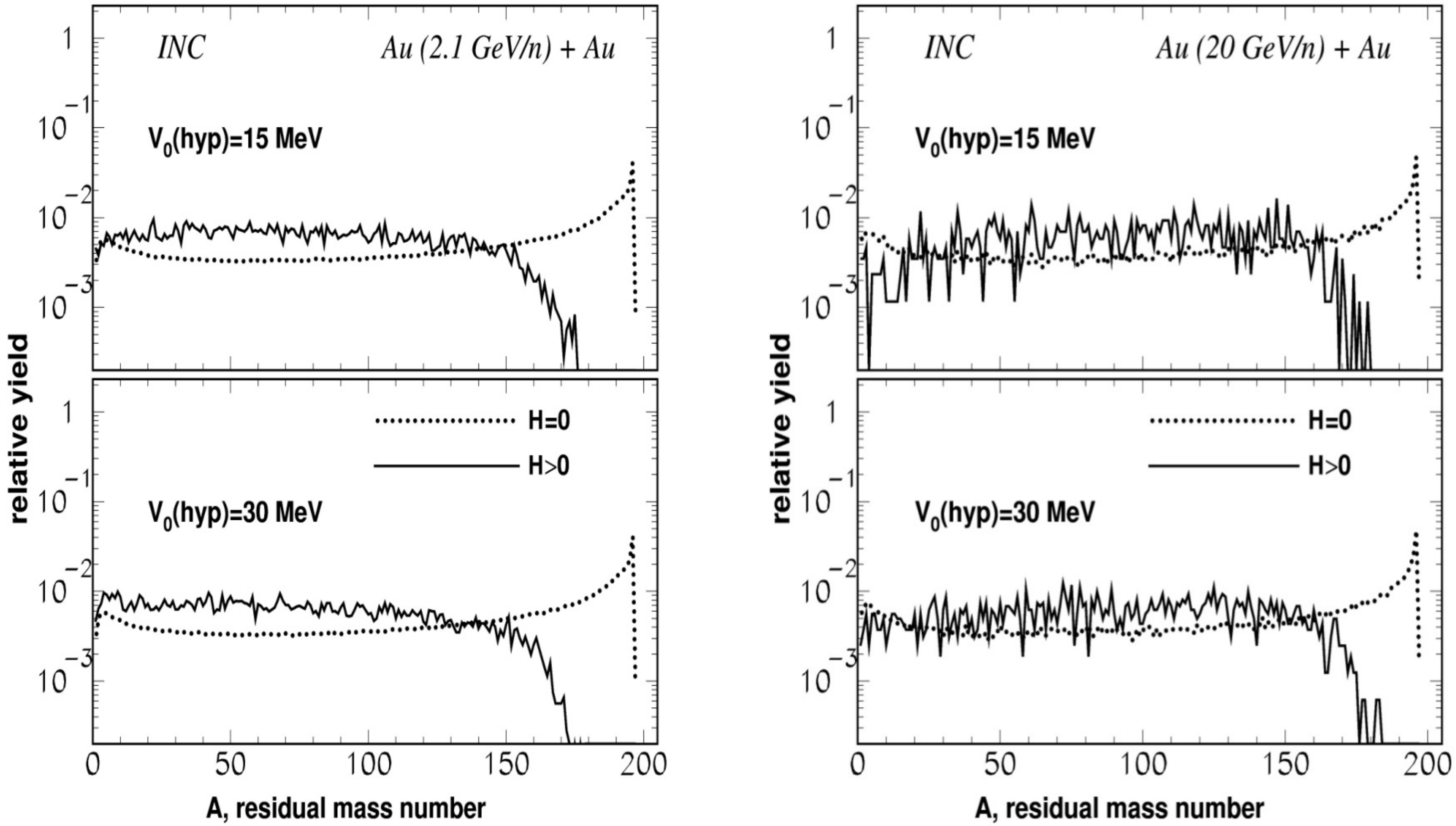
Minimum bias selection:

Total yield of residuals with single hyperons ~1% , with double ones ~0.01%, at 2.1 GeV per nucleon, and considerably more at 20 GeV per nucleon.
[P(H=3)/P(H=2)~1%]



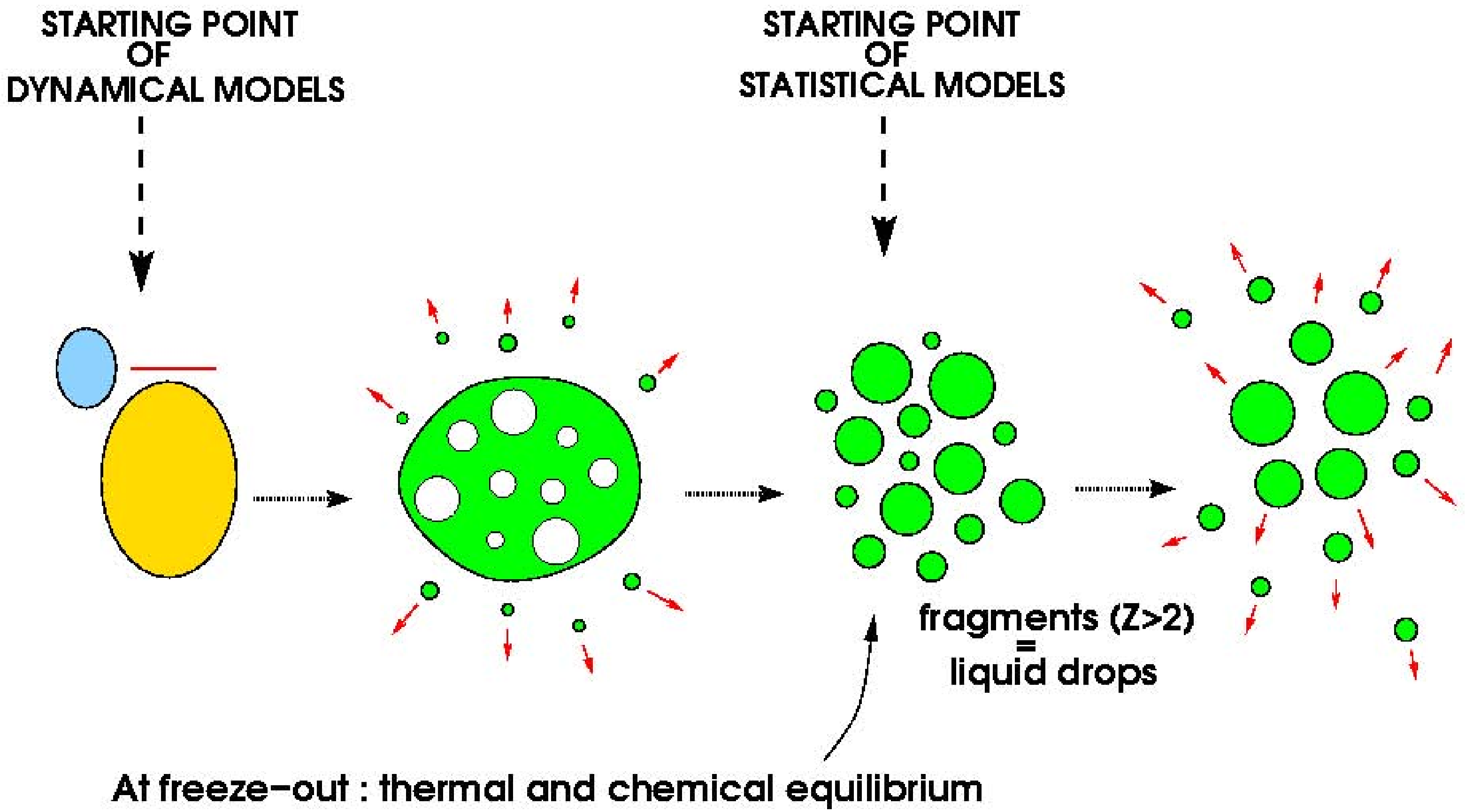
MODEL(CONTINUE)

Minimum bias selection:
different hyper-residuals (with large cross-section) can be formed
(from studies of conventional matter: expected temperatures - up to 8-10 MeV)



MODEL(NEXT STEP – IN PROGRESS)

We use Statistical Multifragmenation Model (SMM) to desintegrate excited residual nuclei with strangeness by A.S.Botvina and J.Pochodzalla, Phys. Rev.C76 (2007) 024909



Summary

We have proposed a hybrid model (DCM+QGSM+Coalescence+SMMS)
to predict strange particle and hyperfragment production in HI collisions.

This model can be used for predictions of yields of hyperfragments in the energy range of NUCLOTRON-M, NICA and FAIR.

Results for strangeness population factors are close to the data

Production of hypernuclei in relativistic Heavy-Ion collisions
is very promising !

Thank you !