ОБРАЗОВАНИЕ
ГИПЕРЯДЕР
в ядерных столкновениях

Д.Ланской

Семинар НИИЯФ, 18 октября 2011

Эксперименты

- 1976, Berkeley. $^{16}O + ^{12}C$, E_{LAB}=2.1 A GeV, $^{16}_{\Lambda}O$, $^{16}_{\Lambda}N$??
- 1988, Дубна. $^{4}He + ^{12}C$, E_{LAB}=3.7 A GeV, $^{4}_{\Lambda}H$, ($^{3}_{\Lambda}H$) !!
- 2004, BNL, AGS. Au+Pt, p_{LAB}=11.5 A GeV, $^{3}_{\Lambda}H$
- 2010, BNL, RHIC. Au+Au, E_{cm}=200 A GeV, $^{3}_{\Lambda}H$, $\overline{^{3}_{\Lambda}H}$

Перспективы

Дубна, BNL + Darmstadt, LHC

2004, BNL, AGS. Au+Pt, p_{lab}=11.5 A GeV, $^{3}_{\Lambda}$H

$$^{3}_{\Lambda}\mathrm{H} \rightarrow \pi^{-} + {}^{3}\mathrm{He}$$

$$Y(^{3}_{\Lambda}\mathrm{H})/Y(^{3}\mathrm{He}) \sim 1/20$$

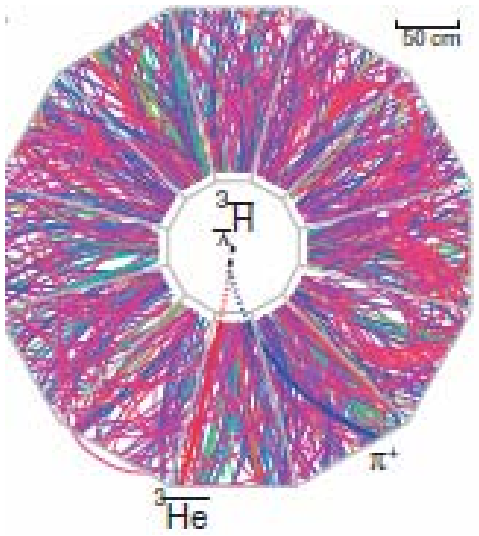
$$R = \frac{Y_{^{3}_{\Lambda}\mathrm{H}}}{\sum_i \left(Y_{^{3}\mathrm{He}} \times \frac{Y_\Lambda}{Y_p} \times \epsilon \right)_i \Big/ \sum_i \epsilon_i} = 0.36 \pm 0.26$$

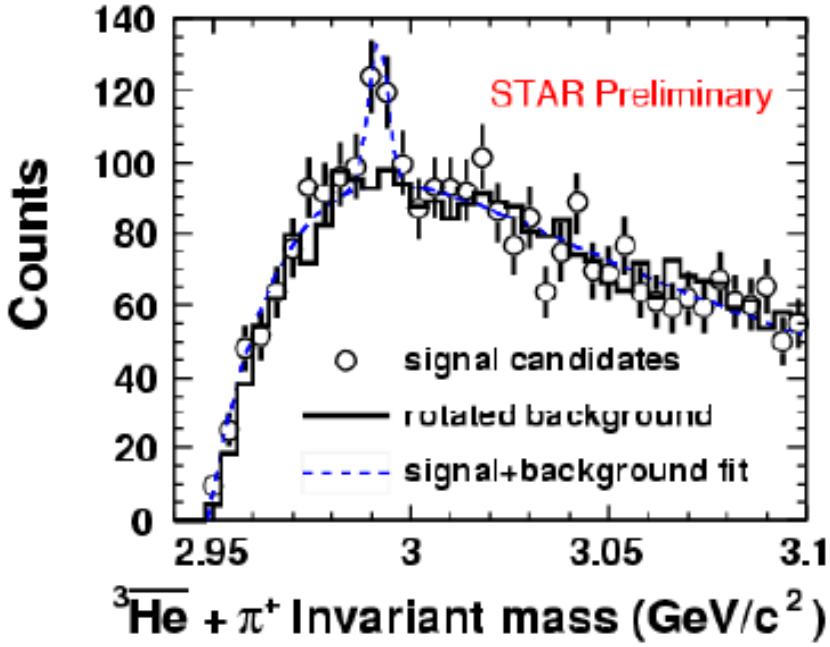
Гипертритон очень слабо связан (B_Λ=0.13±0.05 MeV)

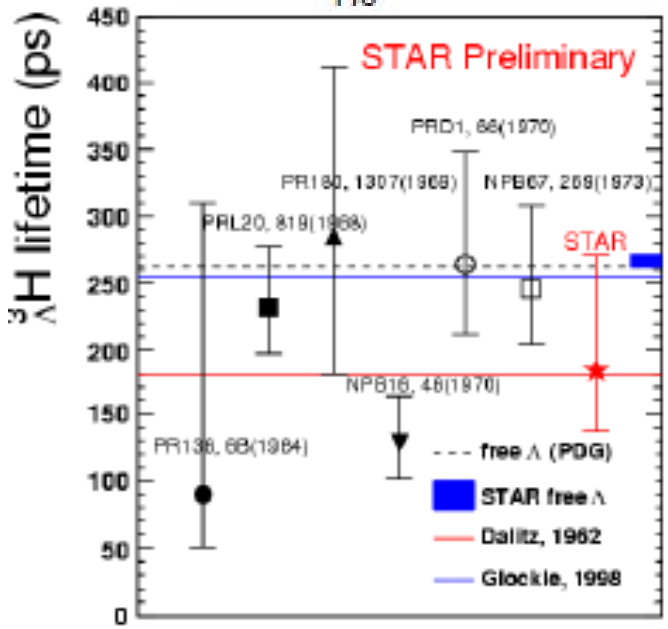
$$R(^{4}_{\Lambda}\mathrm{H}) < 0.225$$

E864 Collab., Phys.Rev. C70(2004)024902

2010, BNL, RHIC. Au+Au, E_{cm}=200 A GeV, $^{3}_{\Lambda}H$, $\overline{^{3}_{\Lambda}H}$







$^{3}_{\Lambda}H$ – 157 ± 30 событий

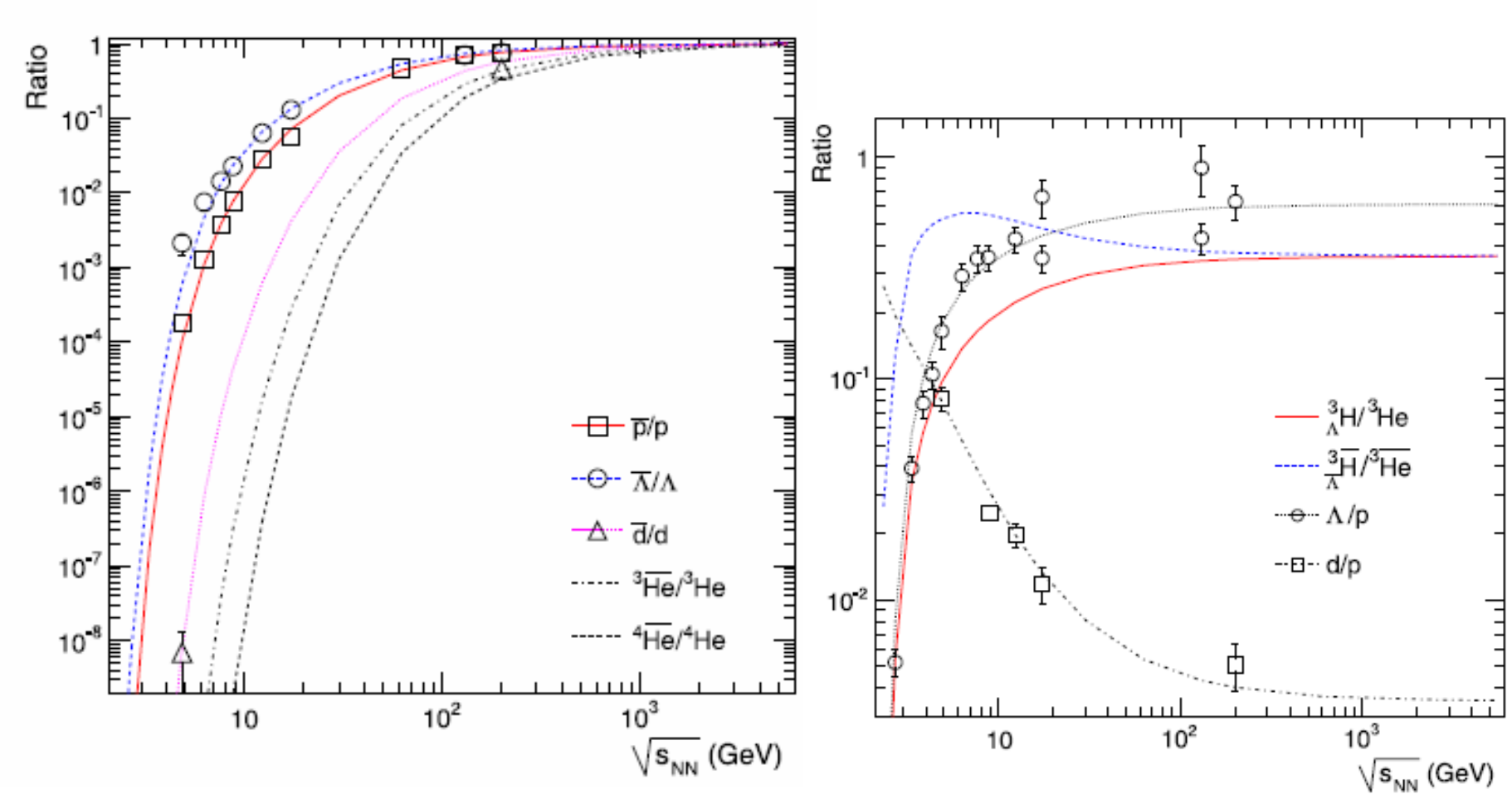
$\overline{^{3}_{\Lambda}H}$ – 70 ± 17 событий

STAR Collab., Science 328(2010)58

Particle type	Ratio
$^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}/^{3}_{\Lambda}\mathrm{H}$	0.49 ± 0.18 (stat.) ± 0.07 (sys.)
$^{3}\bar{\mathrm{He}}/^{3}\mathrm{He}$	0.45 ± 0.02 (stat.) ± 0.04 (sys.)
$^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}/^{3}\bar{\mathrm{He}}$	0.89 ± 0.28 (stat.) ± 0.13 (sys.)
$^{3}_{\Lambda}\mathrm{H}/^{3}\mathrm{He}$	0.82 ± 0.16 (stat.) ± 0.12 (sys.)

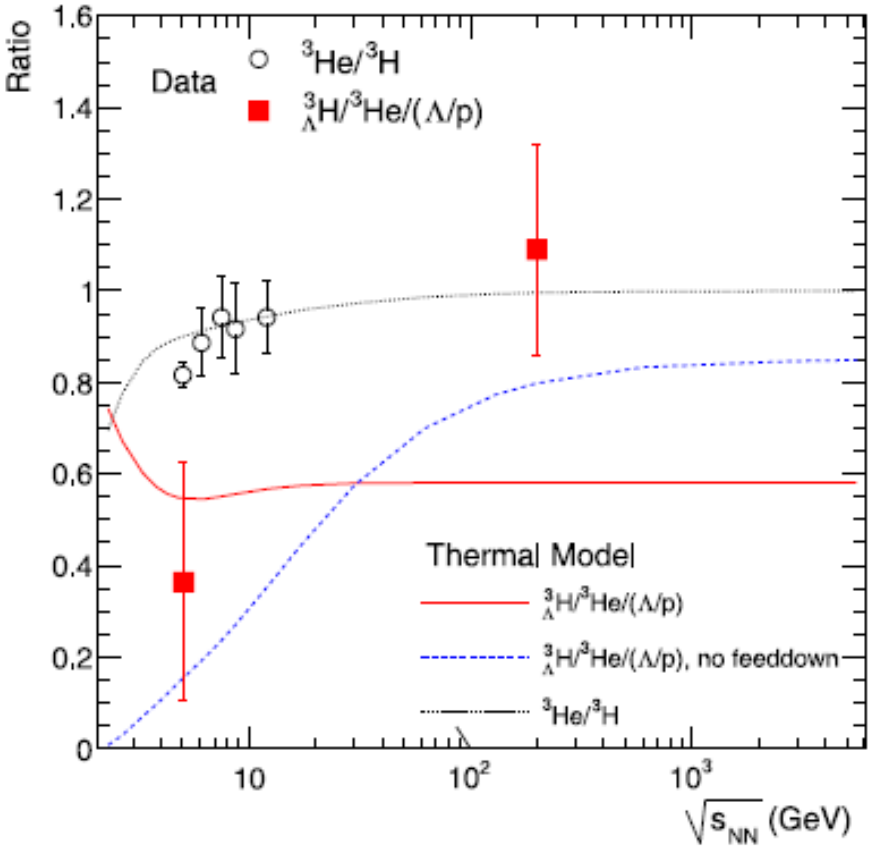
$$\left.\begin{aligned} {}^{3}_{\bar{\Lambda}}\bar{\mathrm{H}} \Big/ {}^{3}_{\Lambda}\mathrm{H} &\propto (\bar{\mathrm{p}}/\mathrm{p})(\bar{\mathrm{n}}/\mathrm{n})(\bar{\Lambda}/\Lambda) \\ {}^{3}\bar{\mathrm{He}} \Big/ {}^{3}\mathrm{He} &\propto (\bar{\mathrm{p}}/\mathrm{p})^{2}(\bar{\mathrm{n}}/\mathrm{n}) \end{aligned}\right\} \approx 0.77^{3} = 0.46$$

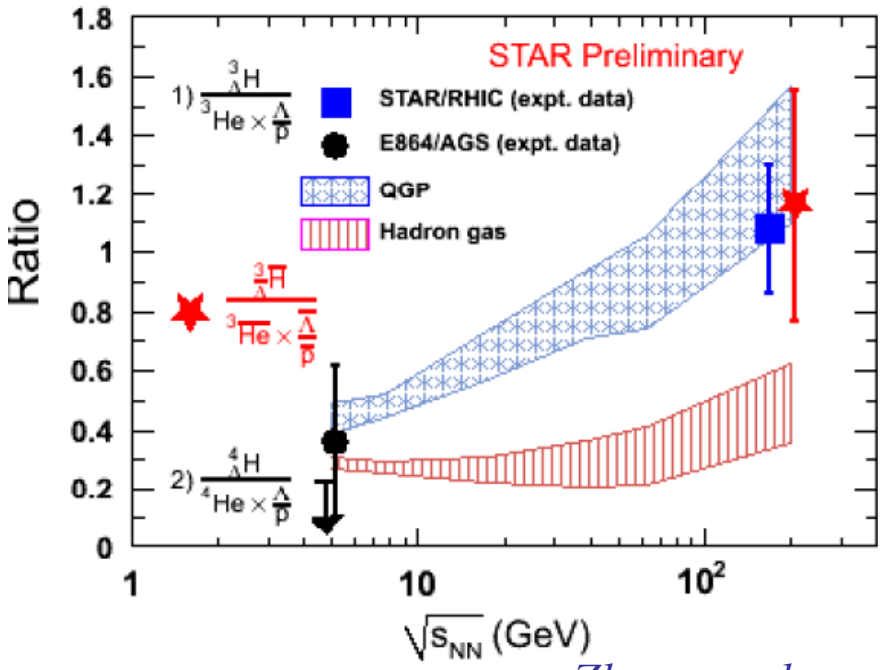
Thermal model (Braun-Munziger et al.)



Andronic et al., Phys. Lett. B697(2011)203

Ratio	Experiment	Model
$^3\overline{\mathrm{He}}/^3\mathrm{He}$	$0.45 \pm 0.02 \pm 0.04$	0.42 ± 0.03
$^3_\Lambda\bar{\mathrm{H}}/^3_\Lambda\mathrm{H}$	$0.49 \pm 0.18 \pm 0.07$	0.45 ± 0.03
$^3_\Lambda\mathrm{H}/^3\mathrm{He}$	$0.82 \pm 0.16 \pm 0.12$	0.35 ± 0.003
$^3_\Lambda\bar{\mathrm{H}}/^3\overline{\mathrm{He}}$	$0.89 \pm 0.28 \pm 0.13$	0.37 ± 0.003





Zhang et al., Phys.Lett. B684(2011)224

Outlook

- **Lifetime:**
  - –data samples with larger statistics (~factor 10 more within a few years)
- **Production rate:**
  - –baryon-strangeness correlation
    - – a case for energy scan
    - – establish trend from AGS-SPS-RHIC-LHC

- $^{3}_{\Lambda}H \rightarrow d+p+\pi$ channel measurement: *d*-identification via ToF.
- Search for other hypernucleus: $^{4}_{\Lambda}H$, $^{4}_{\Lambda}He$, $^{4}_{\Lambda\Lambda}H$, $^{3}_{\Xi}H$,

AGS-E906, Phys. Rev. Lett. 87, 132504 (2001)

- Search for anti-α

ΛΛ-гиперядра

	${}^{A}_{\Lambda\Lambda}Z$ Captured Ξ^-	$B_{\Lambda\Lambda}$ - B_{Ξ^-} [MeV]	$\Delta B_{\Lambda\Lambda}$ - B_{Ξ^-} [MeV]	Assumed level	$B_{\Lambda\Lambda}$ [MeV]	$\Delta B_{\Lambda\Lambda}$ [MeV]
NAGARA	${}^{6}_{\Lambda\Lambda}He$ ${}^{12}C$	$B_{\Lambda\Lambda}$ = 6.79 + 0.91B_{Ξ^-} (+/- 0.16) $\Delta B_{\Lambda\Lambda}$ = 0.55 + 0.91B_{Ξ^-} (+/- 0.17) B_{Ξ^-} < 1.86		3D	6.91 +/- 0.16	0.67 +/- 0.17
MIKAGE	${}^{6}_{\Lambda\Lambda}He$ ${}^{12}C$	9.93 +/- 1.72	3.69 +/- 1.72	3D	10.06 +/- 1.72	3.82 +/- 1.72
DEMACHI-YANAGI	${}^{10}_{\Lambda\Lambda}Be^{*}$ ${}^{12}C$	11.77 +/- 0.13	-1.65 +/- 0.15 *cf. Ex = 3.0*	3D	11.90 +/- 0.13	-1.52 +/- 0.15 *cf. Ex = 3.0*
HIDA	${}^{11}_{\Lambda\Lambda}Be$ ${}^{16}O$	20.26 +/- 1.15	2.04 +/- 1.23	3D	20.49 +/- 1.15	2.27 +/- 1.23
	${}^{12}_{\Lambda\Lambda}Be$ ${}^{14}N$	22.06 +/- 1.15	------	3D	22.23 +/- 1.15	------
E176	${}^{13}_{\Lambda\Lambda}B$ -> ${}^{13}_{\Lambda}C^{*}$ *Ex = 4.9*	------	-------	3D	23.3 +/- 0.7	0.6 +/- 0.8
	${}^{10}_{\Lambda\Lambda}Be$ -> ${}^{9}_{\Lambda}Be^{*}$ *Ex = 3.0*	------	-------	not checked, yet.	14.7 +/- 0.4	1.3 +/- 0.4

M.Danysz et al., PRL.11(1963)29;
R.H.Dalitz et al., Proc. R.S.Lond.A436(1989)1

$$\Delta B_{\Lambda\Lambda} = B_{\Lambda\Lambda} - 2B_{\Lambda}$$

Существует ли ${}^{4}_{\Lambda\Lambda}\mathrm{H}$?

Легчайшее ядро – ${}^{2}\mathrm{H}$

Легчайшее гиперядро – ${}^{3}_{\Lambda}\mathrm{H}$

Легчайшее $\Lambda\Lambda$-гиперядро?

Теория

Nemura et al., Phys.Rev. C67(2003)051001 - ${}^{4}_{\Lambda\Lambda}\mathrm{H}$ связано

Filikhin et al., Phys.Rev.Lett. 89(2002)172502 – нет

Эксперимент

Ahn et al., Phys.Rev.Lett. 87(2001)132504 – неоднозначная интерпретация

Λ_c-ядра!?

Гиперядра на LHC

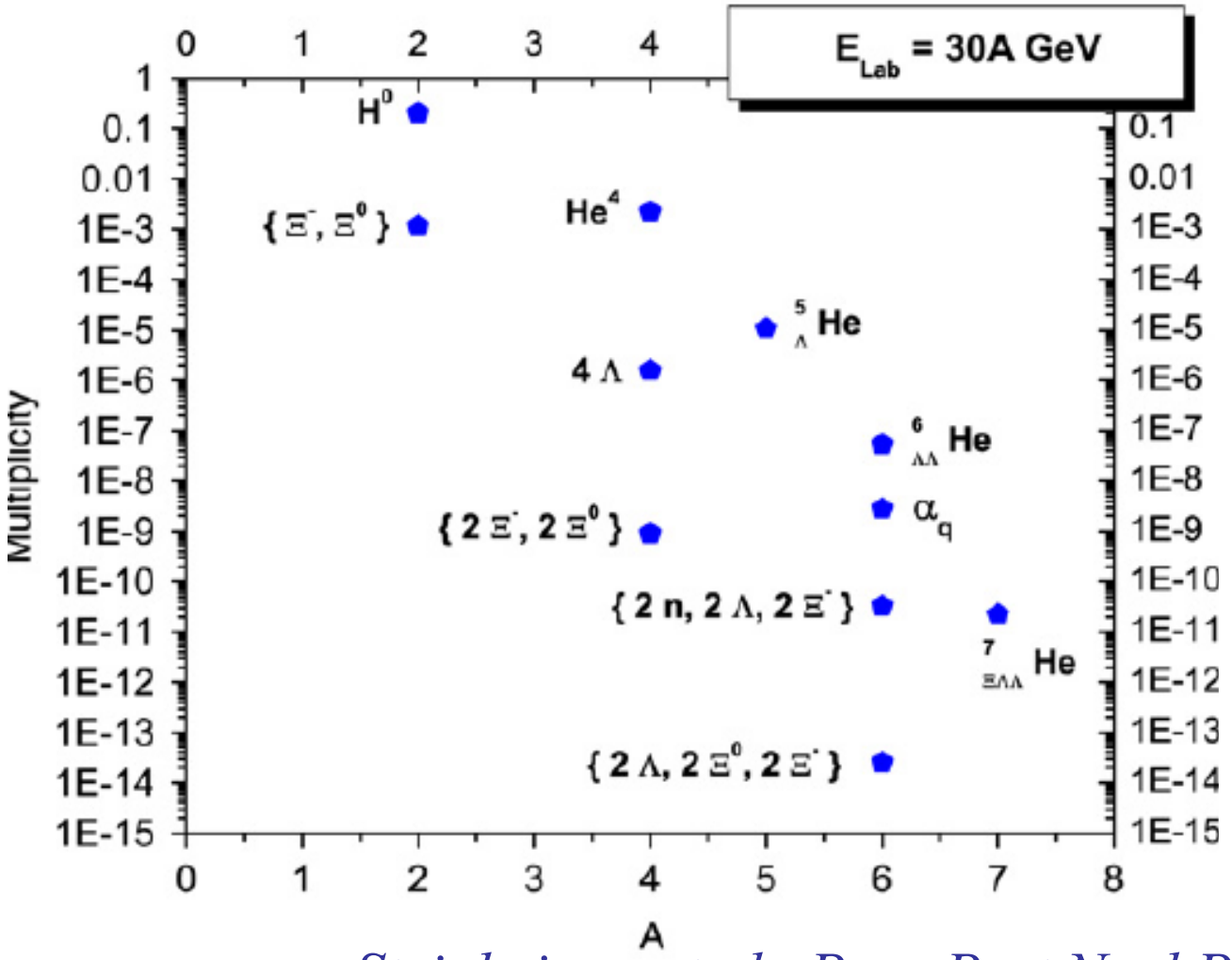
p+p

	PACIAE		PYTHIA	
	7 TeV	14 TeV	7 TeV	14 TeV
k^+	4.563	5.576	3.802	4.946
k^-	4.416	5.331	3.689	4.778
p	4.152	4.678	3.491	4.074
$\overline{p}$	3.040	3.588	2.472	3.078
n	4.094	4.677	3.397	4.107
$\overline{n}$	3.336	3.938	2.565	3.335
Λ	1.648	1.940	1.285	1.608
$\overline{\Lambda}$	1.518	1.769	1.136	1.386
D^a	6.906E-05	9.111E-05	5.586E-05	6.724E-05
$\overline{D}^a$	6.247E-05	8.553E-05	4.852E-05	6.048E-05
	5.456E-05[b]			
${}^3_{\Lambda}H^c$	2.547E-07	3.814E-07	1.833E-07	9.677E-08
${}^3_{\Lambda}\overline{H}^c$	2.453E-07	3.305E-07	1.000E-07	1.048E-07
${}^3He^c$	2.453E-07	3.898E-07	1.500E-07	1.774E-07
${}^3\overline{He}^c$	2.642E-07	4.407E-07	1.417E-07	2.419E-07

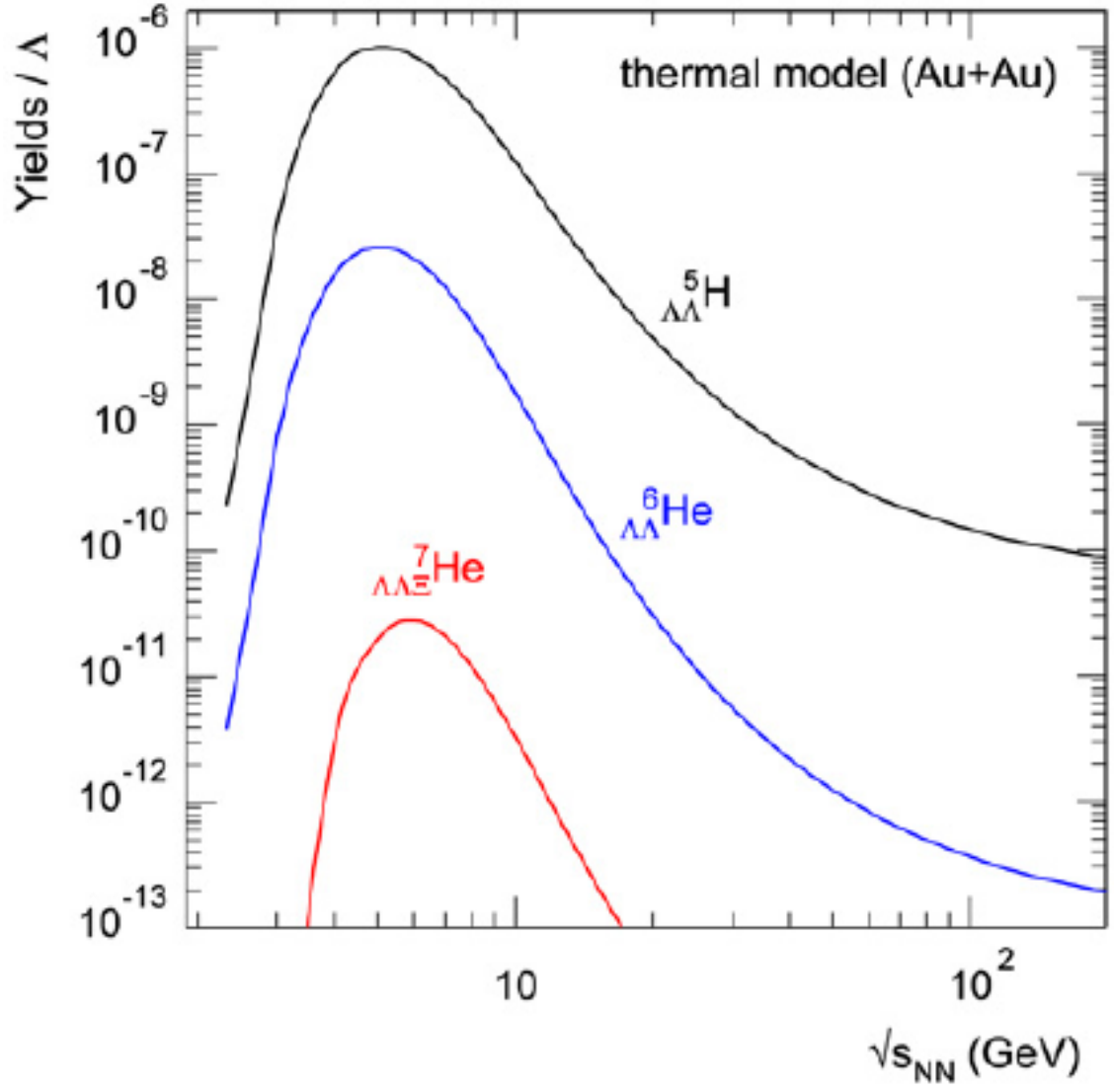
Yan et al., nucl-th/1107.3207

Экзотические гиперядра

Pb+Pb



Steinheimer et al., Prog.Part.Nucl.Phys. 62(2009)313



$^{7}_{\Lambda\Lambda\Xi}$He

Конверсия $\Xi N \rightarrow \Lambda\Lambda$ запрещена принципом Паули!

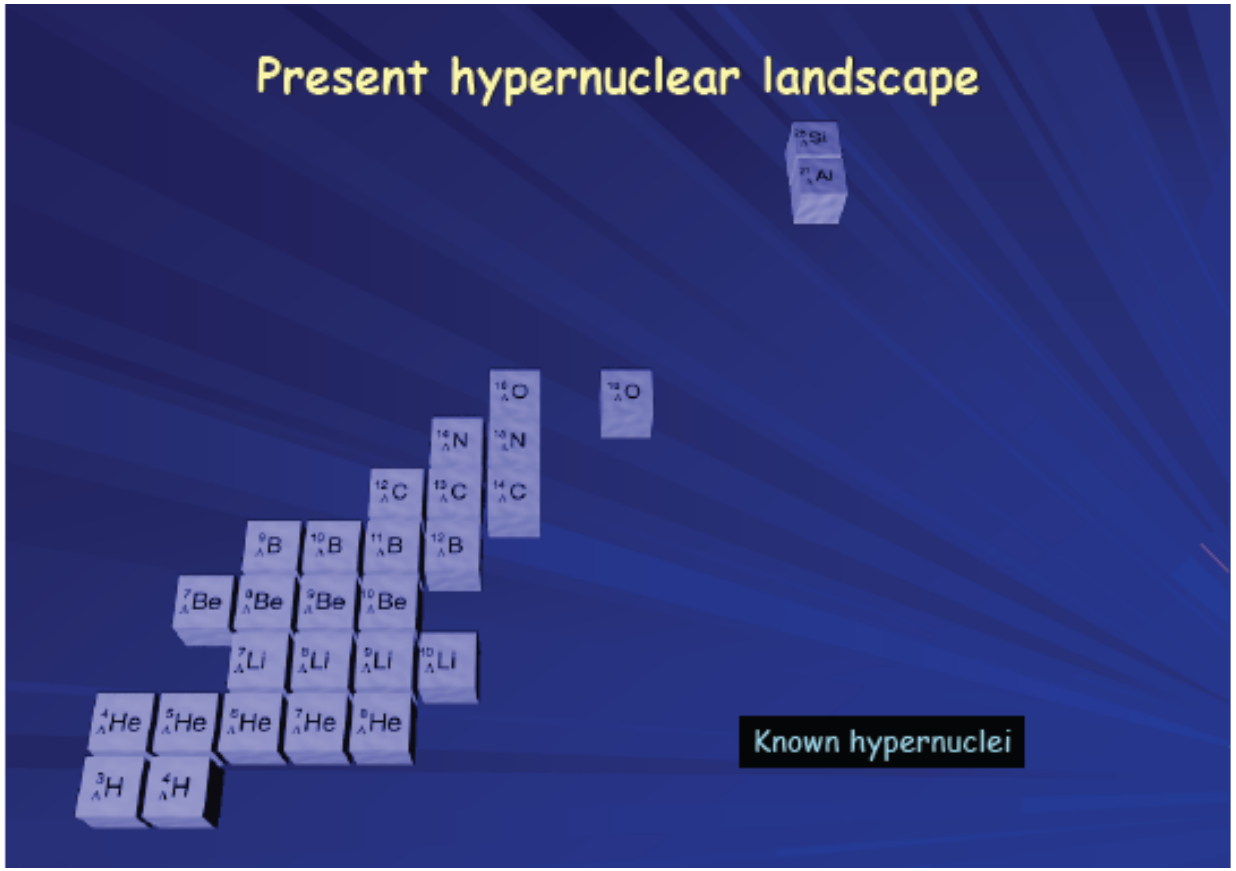
Проект HypHI (GSI, Darmstadt)

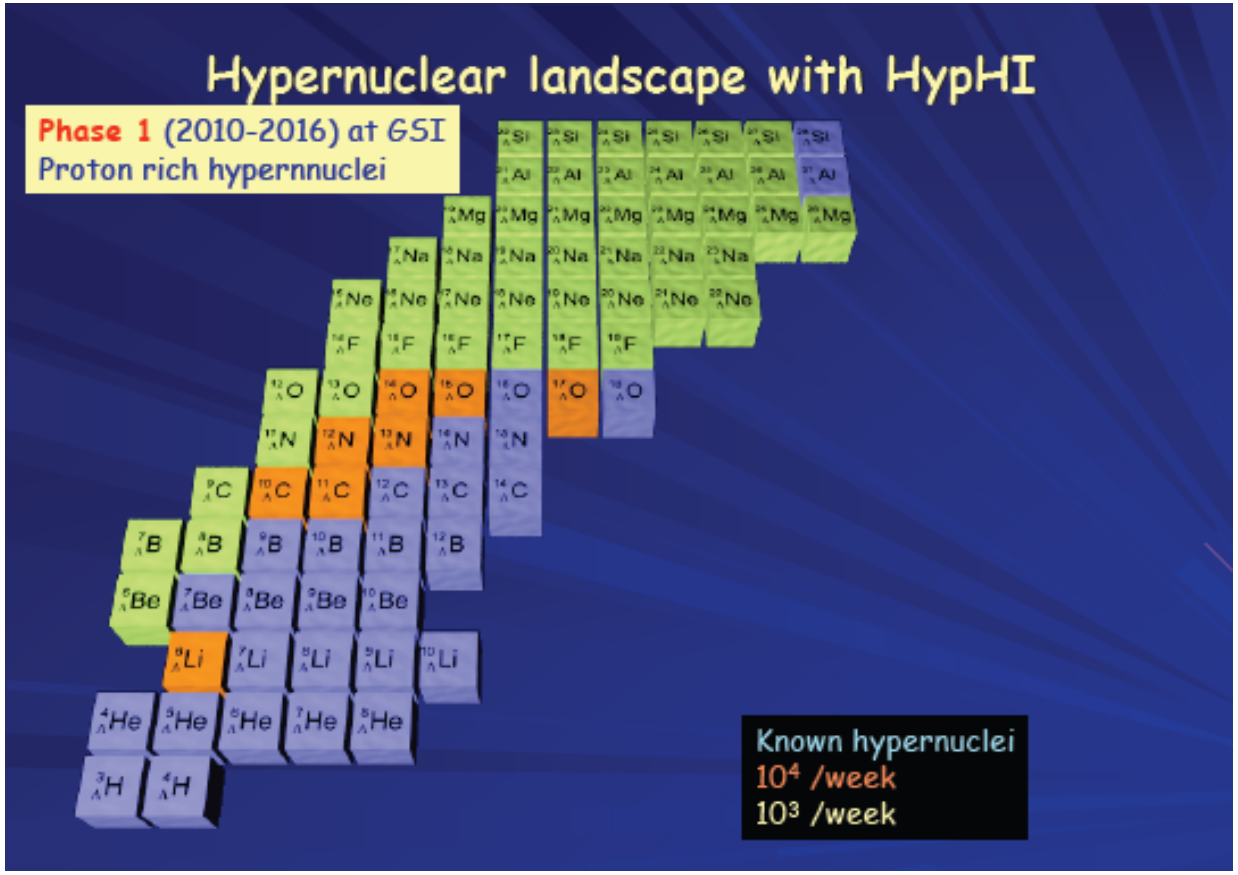
$^{6}Li+^{12}C$, E_{lab}=2A GeV

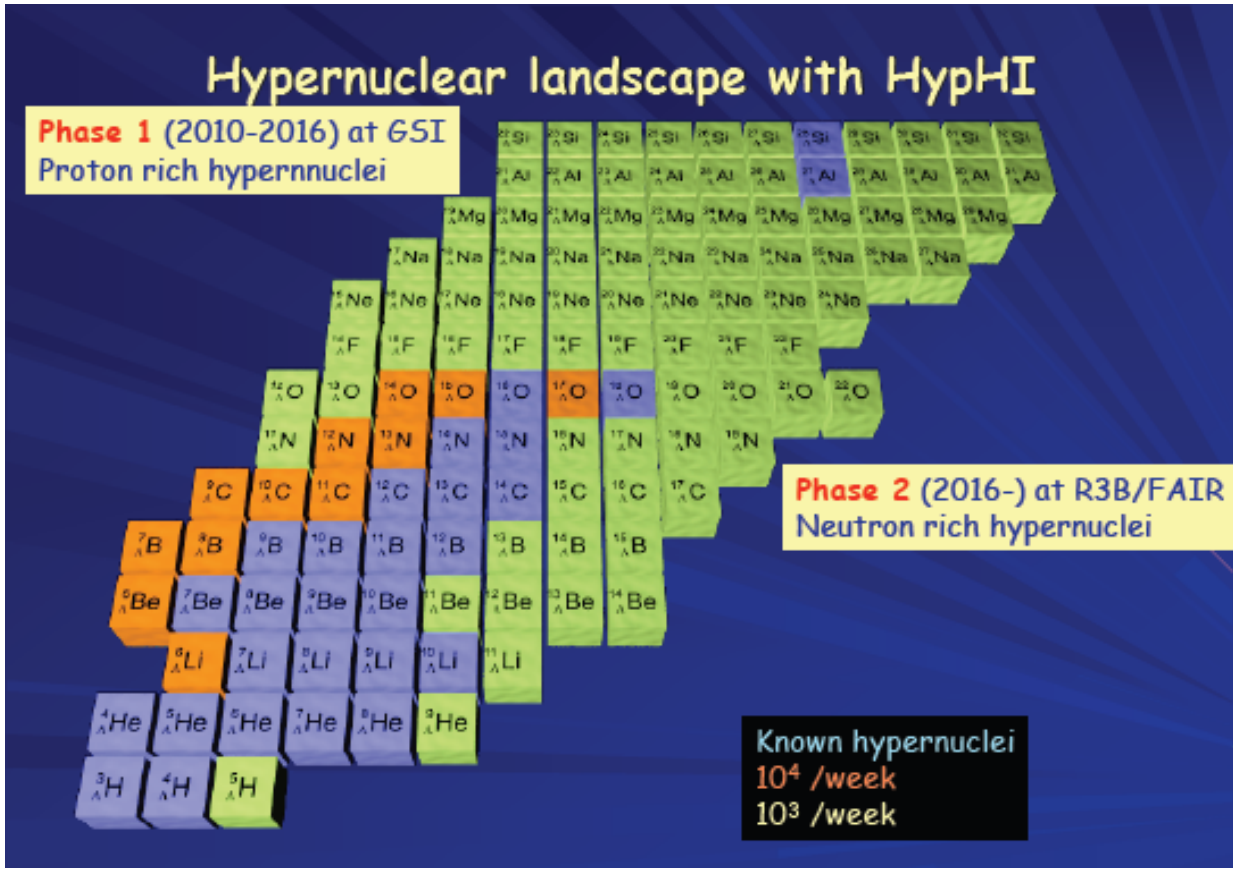
- **Production mechanism of hypernuclei with heavy ion beams**
  - $^{3}_{\Lambda}H$, $^{4}_{\Lambda}H$ and $^{5}_{\Lambda}He$
  - Cross section
  - Coalescence factor
- **Lifetime**
  - Precise measurements : a few % accuracy
- **Mesonic weak decay**
  - Precise measurement of pion distributions
  - Final-state-interaction
- **Non-mesonic weak decay**
  - $\Lambda N \rightarrow NN$
  - Exotic decay: example $^{4}_{\Lambda}He \rightarrow d+d$
- **Hypernuclear polarization of $^{5}_{\Lambda}He$**
  - Asymmetry of π^- from mesonic weak decay
  - For the future hypernuclear magnetic moment measurements

T.Saito, Nucl.Phys. A835(2010)110

- **Exotic hypernuclear decay: π^+ weak decay**
  - Σ^+ - Λ coupling
  - Dependence on the hypernuclear isospin
  - Coherent ΛN-ΣN coupling
- **Neutral hypernucleus: Z=0**
  - Possibility: ${}^{3}_{\Sigma^-}0$
  - Invariant mass: $\Sigma^- pn \rightarrow {}^{3}H + \pi^-$
- **Hypernuclear dynamic motion**
  - Giant dipole resonance, giant quadrupole resonance
  - By hypernuclear dissociation in the target
- **Hypernuclear radii**
  - Active target system
  - Neutron/proton radii by interaction cross section
  - Λ radii by coalescence factor


Present hypernuclear landscape
Known hypernuclei


Hypernuclear landscape with HypHI
Phase 1 (2010-2016) at GSI
Proton rich hypernnuclei
Known hypernuclei
10⁴ /week
10³ /week


Hypernuclear landscape with HypHI
Phase 1 (2010-2016) at GSI
Proton rich hypernnuclei
Phase 2 (2016-) at R3B/FAIR
Neutron rich hypernuclei
Known hypernuclei
10⁴ /week
10³ /week

People working for HypHI Phase 0

- **GSI Helmholtz-University Young Investigators Group VH-NG-239**
  - S. Bianchin
  - O. Borodina (Mainz Univ.)
  - V. Bozkurt (Nigde Univ.)
  - B. Göküzüm (Nigde Univ.)
  - S. Ketenci (Nigde Univ.)
  - E. Kim (Seoul Univ.)
  - D. Nakajima (Tokyo Univ.)
  - B. Özel
  - C. Rappold (Strasbourg Univ.)
  - T.R. Saito (Spokes person)
- **Mainz University**
  - P. Achenbach, J. Pochodzalla
- **GSI HP2 and Mainz University**
  - D. Khaneft, F. Maas
- **GSI HP1**
  - W. Trautmann
- **GSI EE department**
  - J. Hoffmann, K. Koch, N. Kurz, S. Minami, W. Ott, S. Voltz
- **GSI Detector Lab.**
  - M. Träger, C. Schmidt
- **KEK**
  - T. Takahashi, Y. Sekimoto
- **KVI**
  - M. Kavatsyuk
- **Kyoto University**
  - T. Nagae
- **Osaka University**
  - S. Ajimura, A. Sakaguchi, K. Yoshida
- **Osaka Electro-Communication University**
  - T. Fukuda, Y. Mizoi
- **Seoul National University**
  - H. Bhang, M. Kim, S. Kim, K. Tanida, C.J. Yoon
- **Tohoku University**
  - T. Koike, Y. Ma, H. Tamura
- **Theoretical support**
  - T. Gaitanos (Giessen), E. Hiyama (RIKEN), D. Lanskoy (Moscow), H. Lenske (Giessen), U. Mosel (Giessen)

Student
Postdoc
Tenure track

1988, Дубна. $^{4}He+^{12}C$, E_{LAB}=3.7 A GeV, $^{4}_{\Lambda}H$, ($^{3}_{\Lambda}H$)

$\sigma(^{4}_{\Lambda}H)=0.4^{+0.4}_{-0.2}$ mcb – 17 событий

$\tau(^{4}_{\Lambda}H)=2.2^{+0.5}_{-0.4}\ 10^{-10}$ s

$^{3}_{\Lambda}H$ – 1 событие

С.А.Авраменко и др., Письма ЖЭТФ 48(1988)474

Проект HyperNIS (ОИЯИ)

HyperNIS hypernuclei program at Nuclotron with light ion beams

1. **Lifetime and production cross sections** of light (hydrogen, helium) hypernuclei (energy dependence of the production cross section)

$$^{6}\mathrm{Li} \rightarrow {}^{6}_{\Lambda}\mathrm{He} \rightarrow \pi^{-} + {}^{6}\mathrm{Li}$$
$$^{7}\mathrm{Li} \rightarrow {}^{A}_{\Lambda}\mathrm{H} \rightarrow \pi^{-} + {}^{A}\mathrm{He}$$

2. **Binding energy** of loosely bound hypernuclei ${}^{3}_{\Lambda}\mathrm{H}$, ${}^{6}_{\Lambda}\mathrm{He}$ to be obtained by measuring the Coulomb dissociation cross sections in different targets ($\sigma_{Coulomb}$ increases at low binding energy values!)

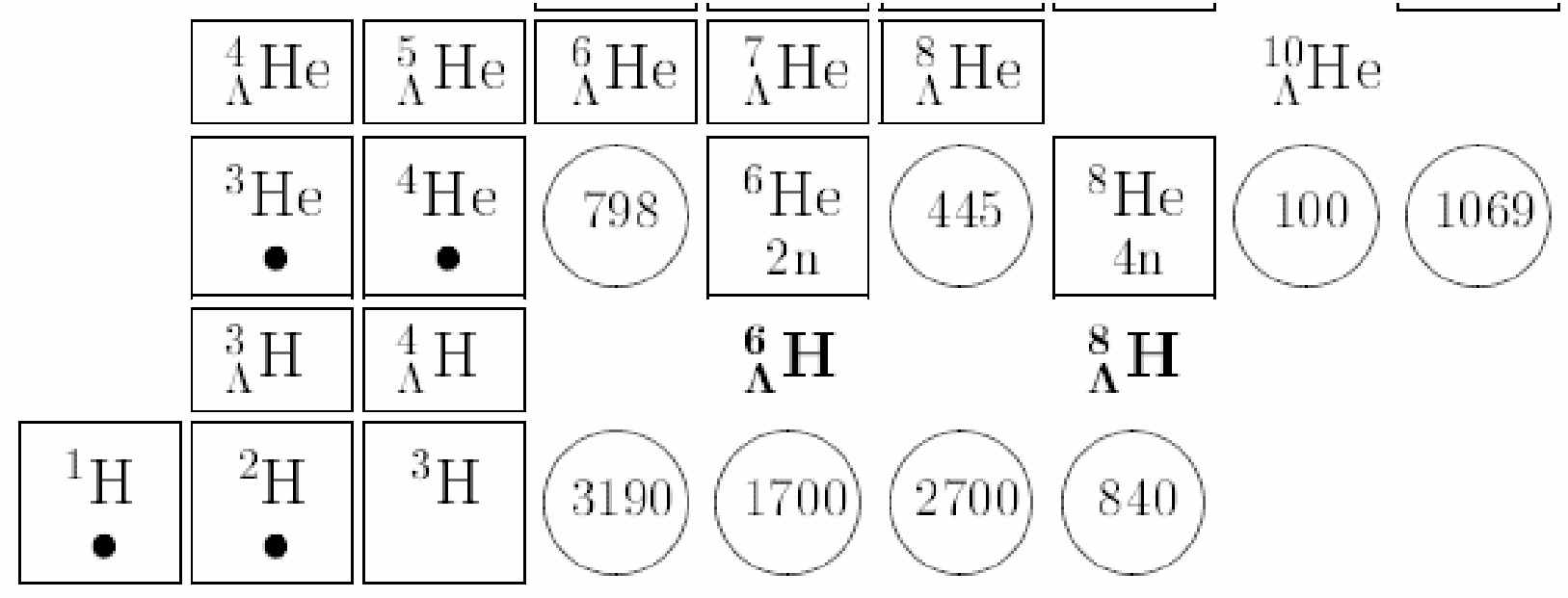
$$\sigma_{Coulomb} \sim Z^{1.92} \quad \sigma_{Nucl} \sim A^{0.6}$$

3. **Matrix elements of the weak ΛN interaction** (study of non-mesonic decay of hypernuclei ${}^{10}_{\Lambda}\mathrm{Be}$ and ${}^{10}_{\Lambda}\mathrm{B}$ **partial widths of nonmesonic weak decay** via intermediate chain $^{8}\mathrm{Be} \rightarrow \alpha + \alpha$)

Yu.Lukstins, HYP-X Conf., Tokai, 2009

Существует ли ${}^{8}_{\Lambda}$H?

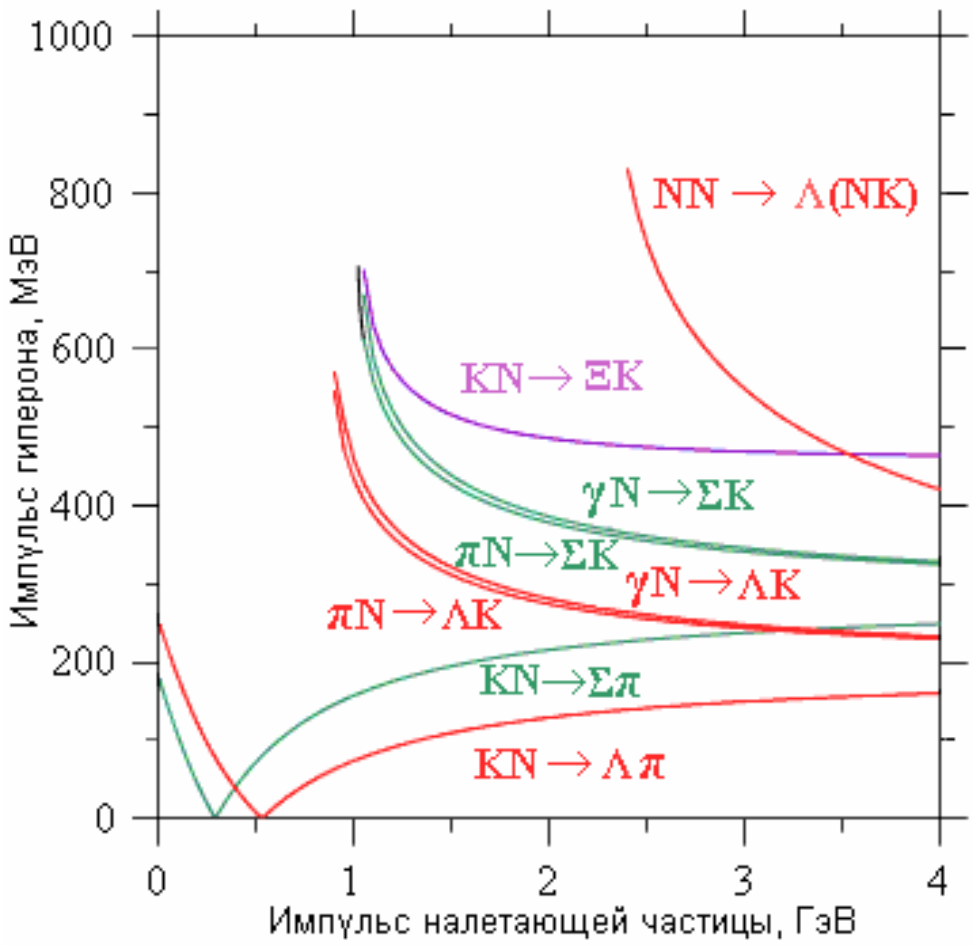
L.Majling:

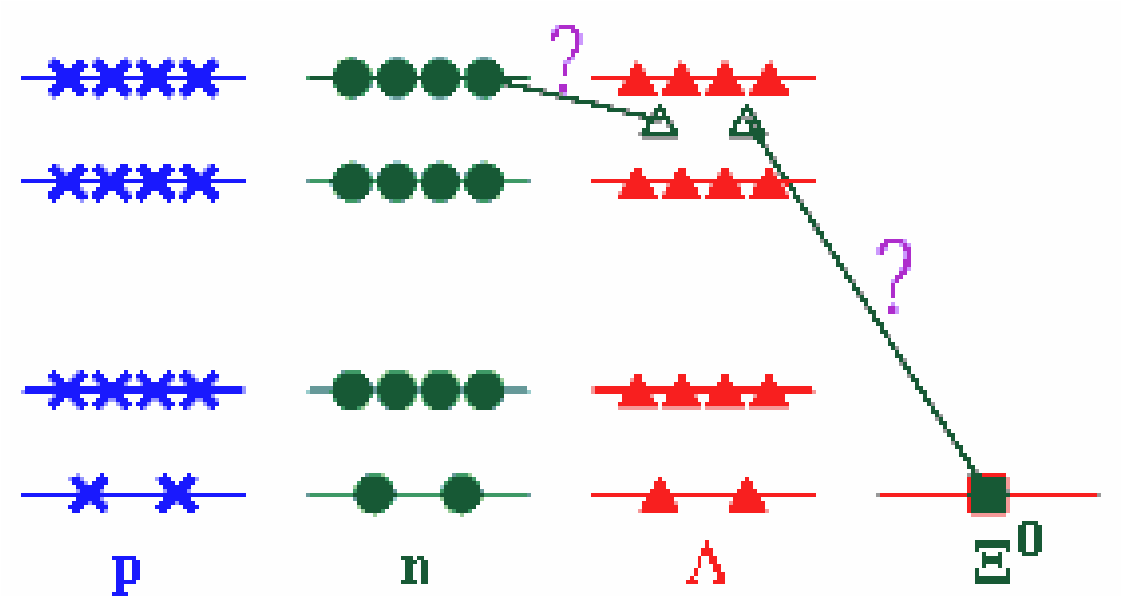


СПАСИБО

ЗА

ВНИМАНИЕ!


1000
800
600
400
200
0
0
1
2
3
4
Импульс гиперона, МэВ
Импульс налетающей частицы, ГэВ
NN → Λ(NK)
KN→ ΞK
γN→ΣK
πN→ΣK
γN→ΛK
πN→ΛK
KN→Σπ
KN→Λπ


?
?
p
n
Λ
Ξ0