東京工業大学
Tokyo Institute of Technology

J-PARCにおける
シングル・ダブルΛハイパー核の
崩壊π中間子分光実験計画

藤岡　宏之（東工大）
fujioka@phys.titech.ac.jp

Letter of Intent for J-PARC 50 GeV Synchrotron

Decay Pion Spectroscopy of ${}^{5}_{\Lambda\Lambda}$H produced by ^{7}Li(K^-, K^+) reactions

Hiroyuki Fujioka[1*], Tomokazu Fukuda[2,4†], Emiko Hiyama[3,4], Toshio Motoba[2,5], Tomofumi Nagae[6], Sho Nagao[7], Toshiyuki Takahashi[8]

Abstract

Proposed is a novel method to produce a double-Λ hypernucleus without using nuclear emulsion. A Ξ^- bound in ^{6}He and a part of quasi-free Ξ^-'s, produced in ^{7}Li(K^-, K^+) reactions, are absorbed in the reaction point, and ${}^{5}_{\Lambda\Lambda}$H may be formed via $\Xi^- p \to \Lambda\Lambda$ conversion. Decay pion spectroscopy for ${}^{5}_{\Lambda\Lambda}\mathrm{H} \to {}^{5}_{\Lambda}\mathrm{He} + \pi^-$ will be performed after event selection requiring a fast proton from non-mesonic weak decay of ${}^{5}_{\Lambda}$He. The experimental setup will be based on the Ξ-hypernuclear spectroscopy experiment E70; a new cylindrical detector system will be installed between the K1.8 beamline spectrometer and the S-2S spectrometer for detection of the decay pion and the proton.

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Proposed is a novel method to produce a double-Λ hypernucleus without using nuclear emulsion. A Ξ^- bound in ^{6}He and a part of quasi-free Ξ^-'s, produced in ^{7}Li(K^-, K^+) reactions, are absorbed in the reaction point, and ${}^{5}_{\Lambda\Lambda}$H may be formed via $\Xi^- p \to \Lambda\Lambda$ conversion. Decay pion spectroscopy for ${}^{5}_{\Lambda\Lambda}\mathrm{H} \to {}^{5}_{\Lambda}\mathrm{He} + \pi^-$ will be performed after event selection requiring a fast proton from non-mesonic weak decay of ${}^{5}_{\Lambda}$He. The experimental setup will be based on the Ξ-hypernuclear spectroscopy experiment E70; a new cylindrical detector system will be installed between the K1.8 beamline spectrometer and the S-2S spectrometer for detection of the decay pion and the proton.

(1) 特定のダブルΛハイパー核 ($^{5}_{\Lambda\Lambda}\mathrm{H}$) の生成

$$^{7}\mathrm{Li}(K^{-},K^{+})^{5}_{\Lambda\Lambda}\mathrm{H}+2n$$

cf. $^{12}\mathrm{C}(\pi^{+},K^{+})^{12}_{\Lambda}\mathrm{C}$

$^{6}\mathrm{Li}(\pi^{+},K^{+})^{5}_{\Lambda}\mathrm{He}+p$

(2-1) $^{5}_{\Lambda\Lambda}\mathrm{H}$ 生成を実証する方法について

$$^{5}_{\Lambda\Lambda}\mathrm{H}\rightarrow {}^{5}_{\Lambda}\mathrm{He}+\pi^{-}$$

(2-2) 崩壊パイ中間子分光による質量の決定

(3) J-PARC における実験計画 (from S=−1 to S=−2)

(1) 特定のダブルΛハイパー核 ($^{5}_{\Lambda\Lambda}\mathrm{H}$) の生成

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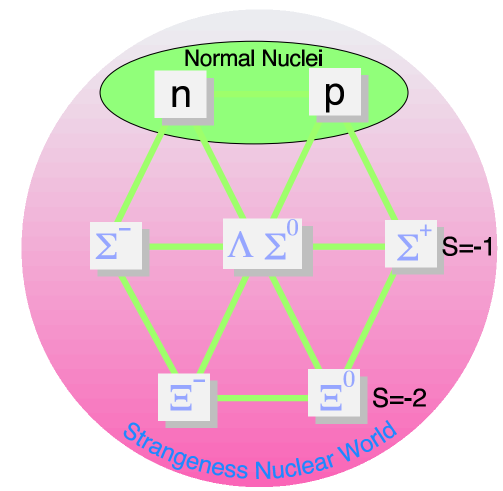
J-PARC LoI L06 (2002)

Letter of Intent
for
New Generation Spectroscopy
of
Hadron Many-Body Systems
with Strangeness $S = -2$ and -1



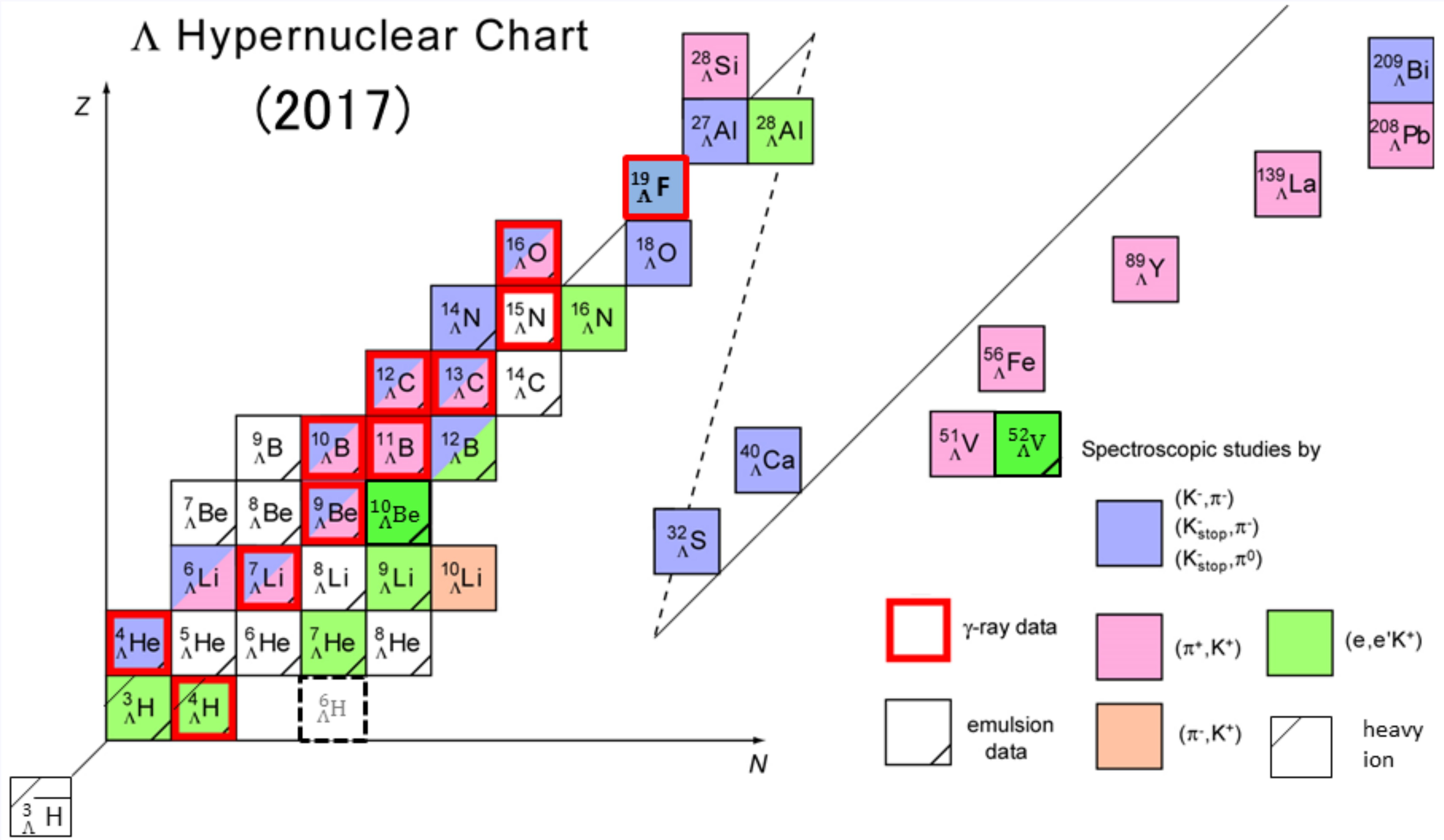
December 31, 2002

2.2.3 Proposed experiments

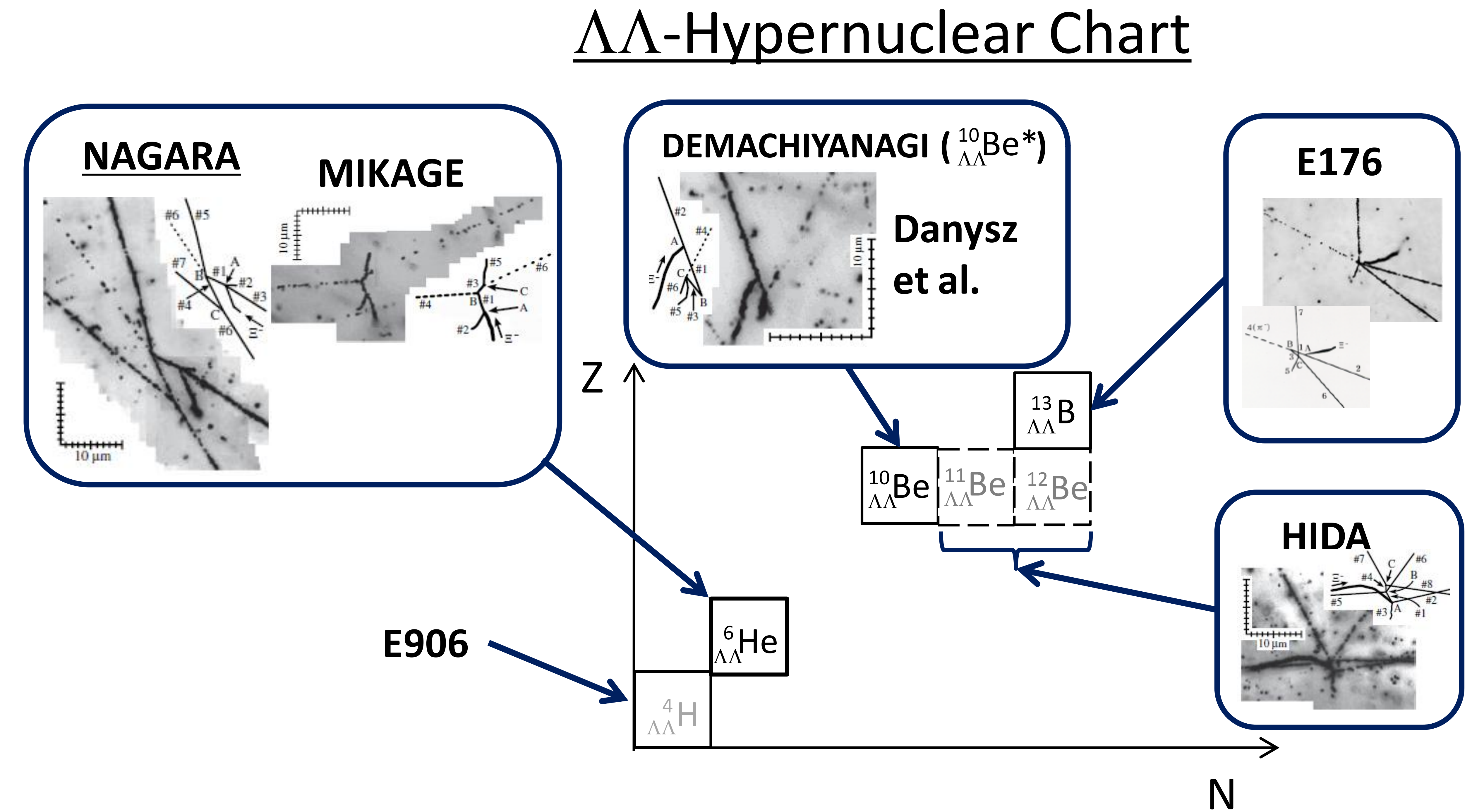
Based on the result of E906, we are going to propose a study of the double-Λ hypernuclei by means of decay-pion spectroscopy. In E961, we will identify ${}^{4}_{\Lambda\Lambda}$H by using a ^{7}Li target, and will determine the mass within 0.5 MeV accuracy. At the Joint Project, we expect a K-beam with an intensity of 5-10 times greater than the AGS and therefore we will be able to identify several weaker channels than ${}^{4}_{\Lambda\Lambda}$H case, e.g. ${}^{6}_{\Lambda\Lambda}$He. Another interesting possibility is that the Ξ-hypernuclei produced in the (K^-, K^+) reaction on ^{7}Li will decay to ${}^{5}_{\Lambda\Lambda}$H with a large branching ratio of about 90% [14] (Fig. 15). When we use heavier targets like ^{12}C, we can expect heavier double-Λ hypernuclei like ${}^{10}_{\Lambda\Lambda}$Be.

http://www-ps.kek.jp/jhf-np/LOIlist/LOIlist.html

ハイパー核図表 (S=−1)


Λ Hypernuclear Chart
(2017)
Z
N
Spectroscopic studies by
(K⁻,π⁻)
(K⁻stop,π⁻)
(K⁻stop,π⁰)
γ-ray data
(π⁺,K⁺)
(e,e'K⁺)
emulsion data
(π⁻,K⁺)
heavy ion

ハイパー核図表 (S=−2)



「日本の核物理の将来レポート」(2013)

ハイブリッド・エマルション法

KEK-PS E373

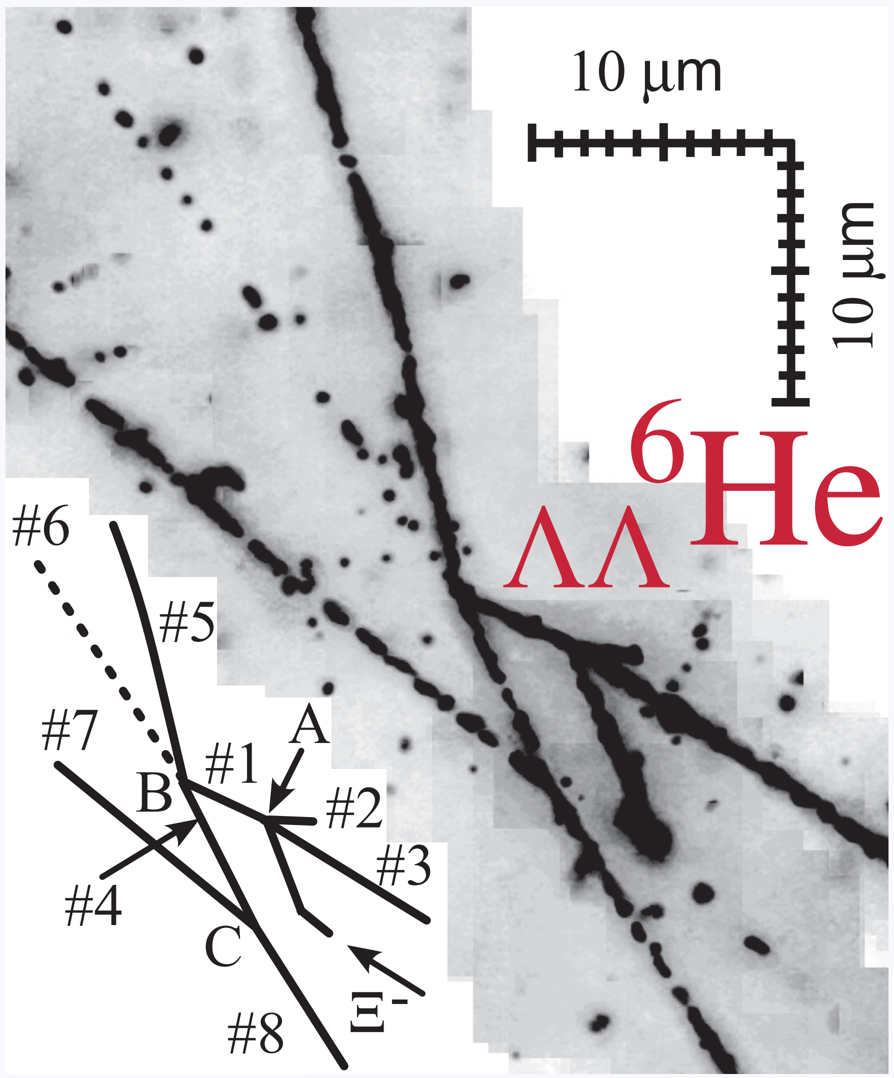
H. Takahashi et al., Phys. Rev. Lett. **87**, 212502 (2001);
J.K. Ahn et al., Phys. Rev. C **88**, 014003 (2013)

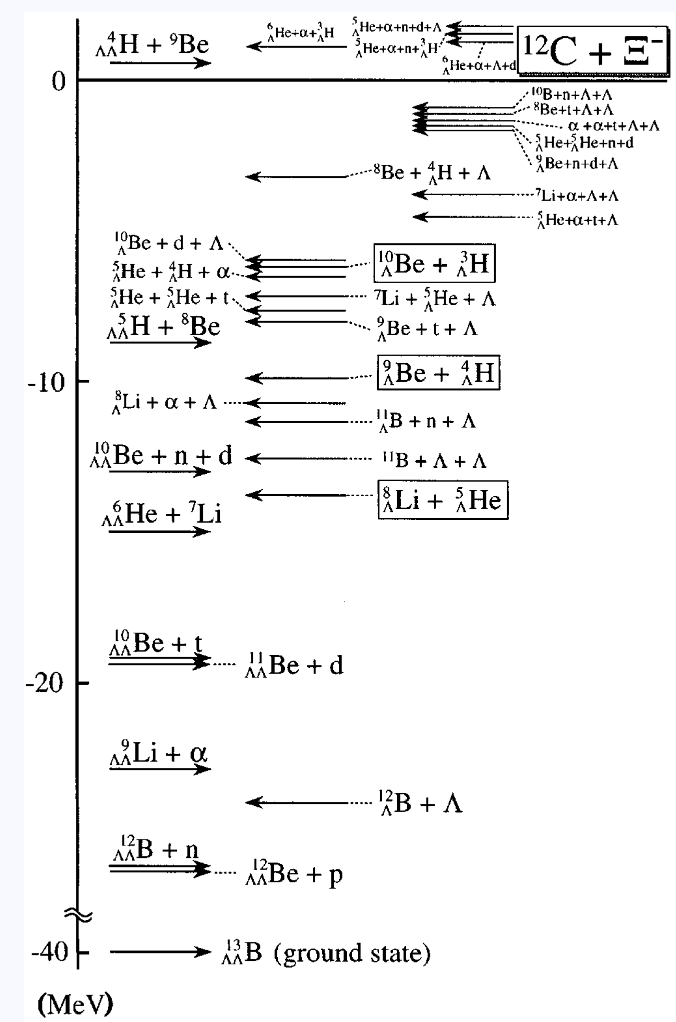
$$\Xi^- + {}^{12}\mathrm{C} \rightarrow {}^{6}_{\Lambda\Lambda}\mathrm{He} + {}^{4}\mathrm{He} + t$$

$$ {}^{6}_{\Lambda\Lambda}\mathrm{He} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + p + \pi^-$$

$$B_{\Lambda\Lambda} = 6.91 \pm 0.16\,\mathrm{MeV}$$

$$\Delta B_{\Lambda\Lambda} = 0.67 \pm 0.17\,\mathrm{MeV}$$





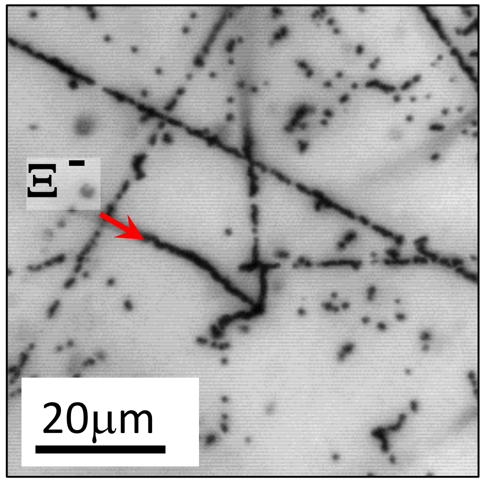
不定性なく核種を確定できた唯一の例

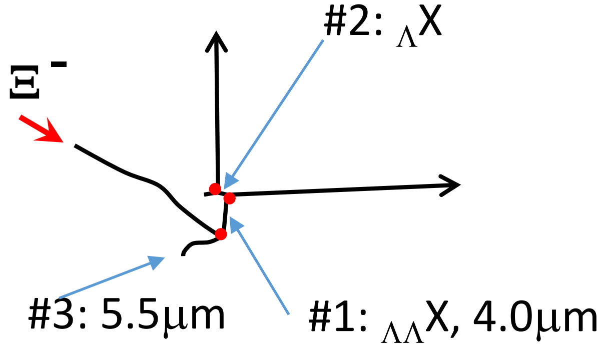
様々なダブルΛハイパー核が作られうる

T. Yamada and K. Ikeda, Phys. Rev. C **56**, 3216 (1997)

J-PARC E07

DLH event in Mod098 pl04





* 2 prong from Ξ^- stop point
* twice non-mesonic-decay
* charge of #1 >= 3

initial state: (Ξ^-+^{16}O), (Ξ^-+^{14}N), (Ξ^-+^{12}C)
track #1: $_{\Lambda\Lambda}{}^{7}$Li, $_{\Lambda\Lambda}{}^{8}$Li … (30 nuclides)
track #3: p, d, t, ^{4}He… (57 nuclides)
invisible particles: null, n, 2n, 3n

For all combination,
☑ conservation laws
☑ kinematic consistency, etc.
within 3σ of measurement error

Possible solutions sorted by Abs($\Delta B_{\Lambda\Lambda}$ - B_{Ξ}):

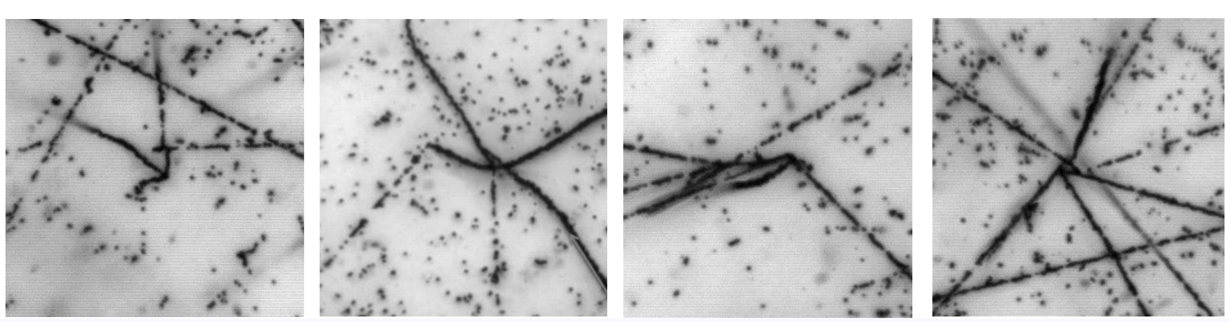
preliminary result

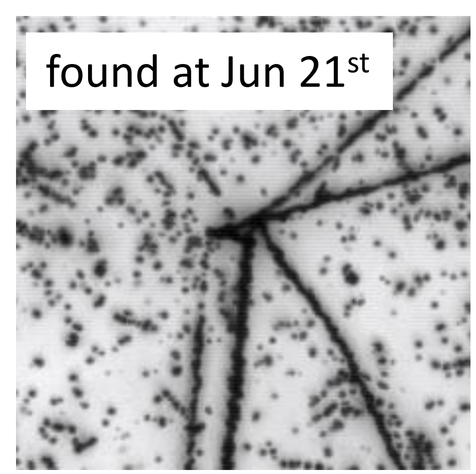
Ξ^- + ^{14}N -> $_{\Lambda\Lambda}{}^{10}$Be + ^{4}He + n , $\Delta B_{\Lambda\Lambda}$ - B_{Ξ} = ~1 +- 3 MeV
Ξ^- + ^{12}C -> $_{\Lambda\Lambda}{}^{8}$Li + ^{4}He + n , $\Delta B_{\Lambda\Lambda}$ - B_{Ξ} = ~6 +- 2 MeV
…

Preliminary results are rounded to one significant figures. 28

Fruits of J-PARC E07

5 DLH events

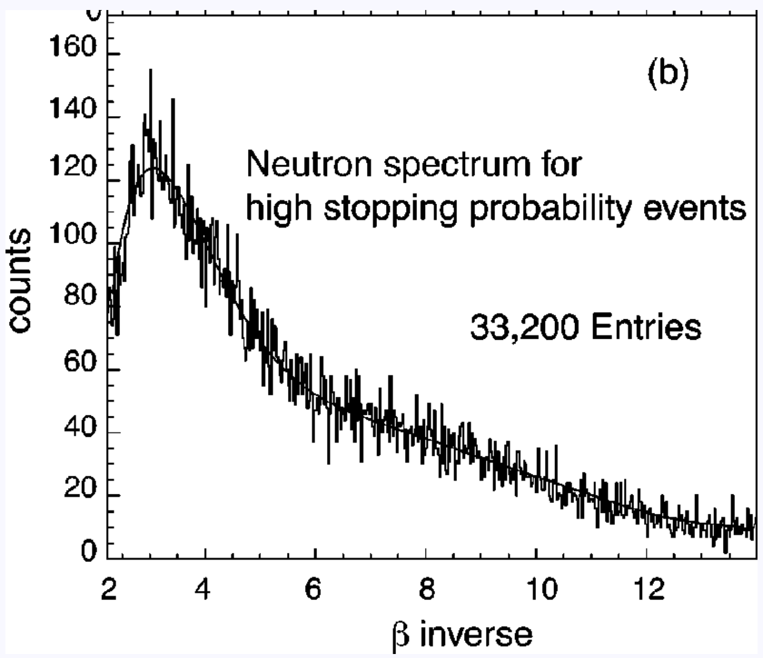


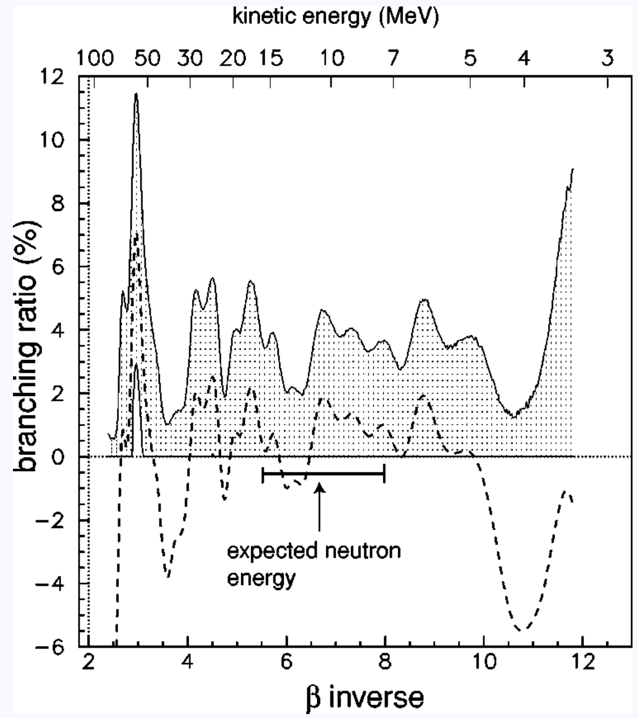


吉田さん@HYP2018

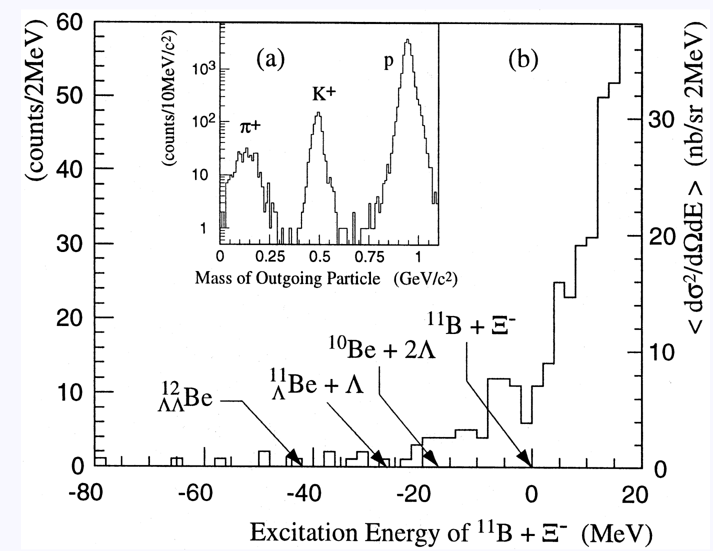
カウンタ実験による探索 (1)

BNL-AGS E885 $(\Xi^-, {}^{12}\mathrm{C})_{\mathrm{atom}} \to {}^{12}_{\Lambda\Lambda}\mathrm{B} + n$

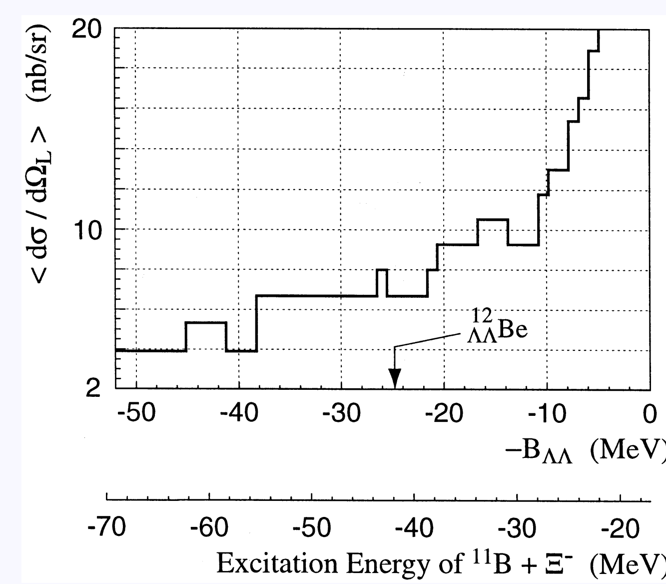




P. Khaustov et al., Phys. Rev. C **61**, 027601 (2000)



$^{12}\mathrm{C}(K^-, K^+)^{12}_{\Lambda\Lambda}\mathrm{Be}$



K. Yamamoto et al., Phys. Lett. B **478**, 401 (2000)

カウンタ実験による探索 (2)

BNL-AGS E906: ^{9}Be(K^{-},K^{+})反応

Quasi-free 過程の一部→ダブルΛ複合核を形成

その分裂片としてダブルΛハイパー核を生成

ΞN rescattering & ΞN-ΛΛ conversion

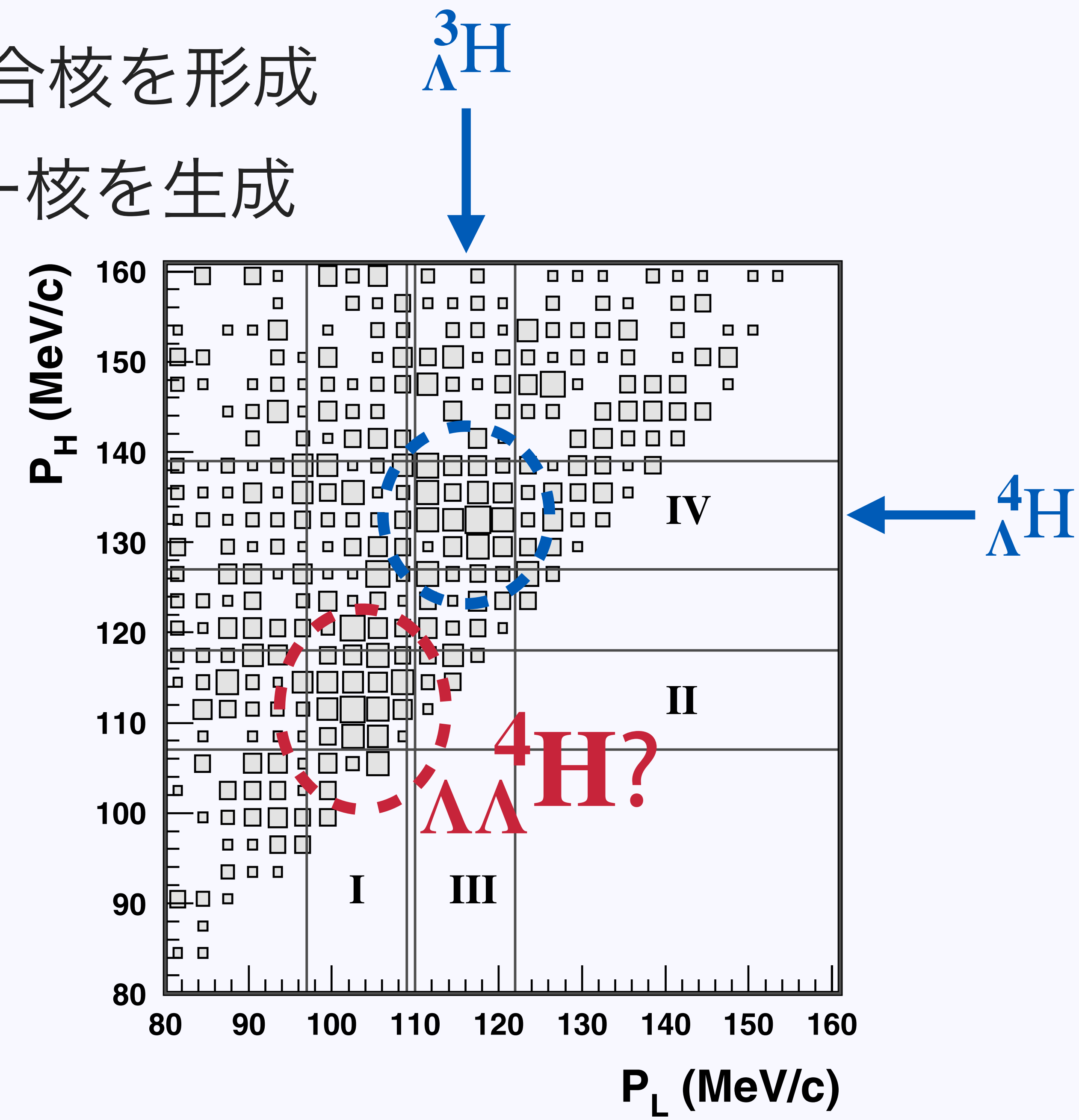
$$^{9}\mathrm{Be}(K^{-},K^{+})\{\Xi^{-}+{}^{8}\mathrm{Li}^{*}\} \longrightarrow \underline{[{}^{8}_{\Lambda\Lambda}\mathrm{He}^{*}]} + n$$

$$\longrightarrow \underline{[{}^{8}_{\Lambda\Lambda}\mathrm{H}^{*}]} + p$$

<u>"double-Λ compound nucleus"</u>

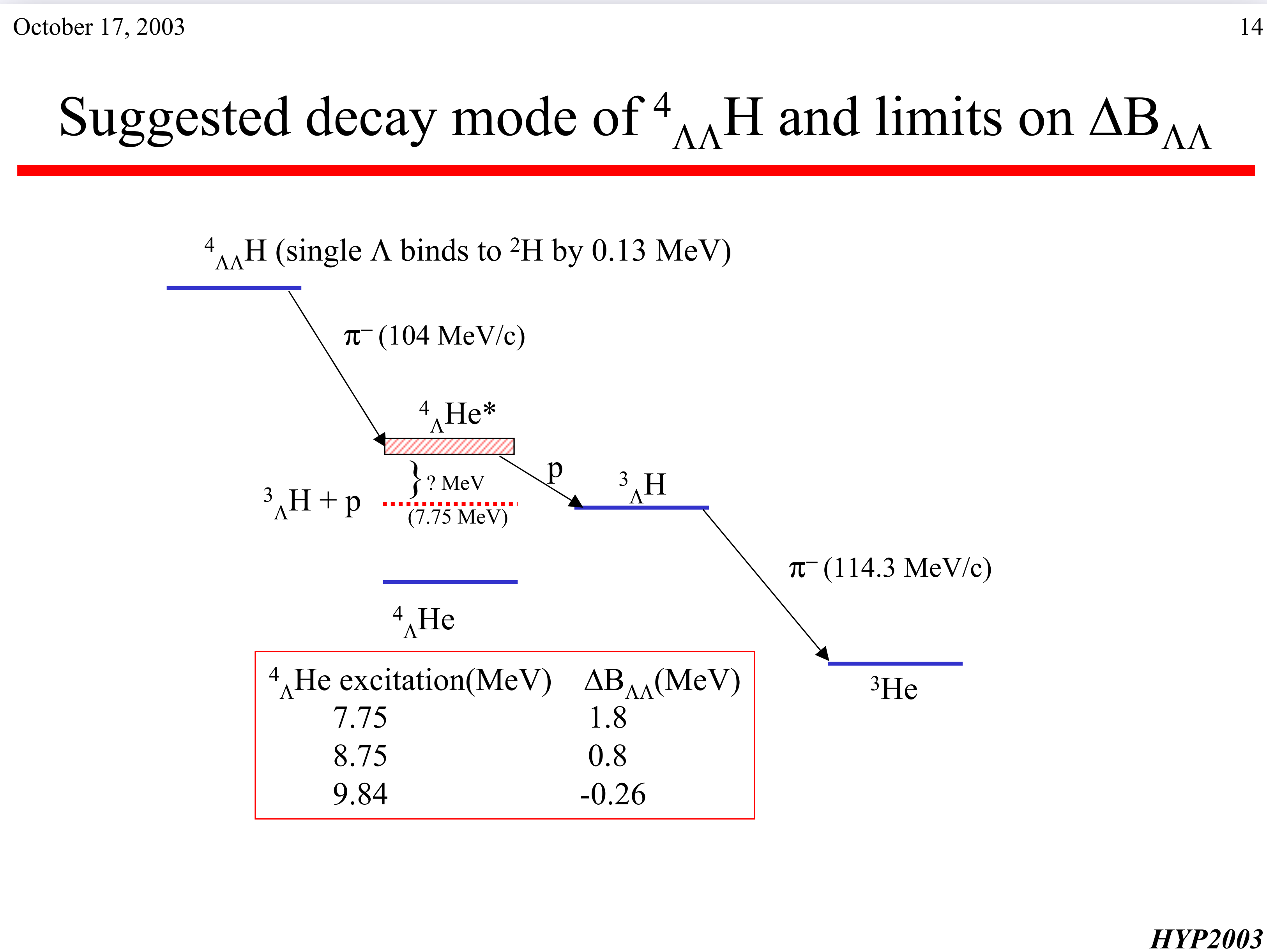
→ *fragmented into double-Λ hypernuclei, single-Λ hypernuclei etc.*

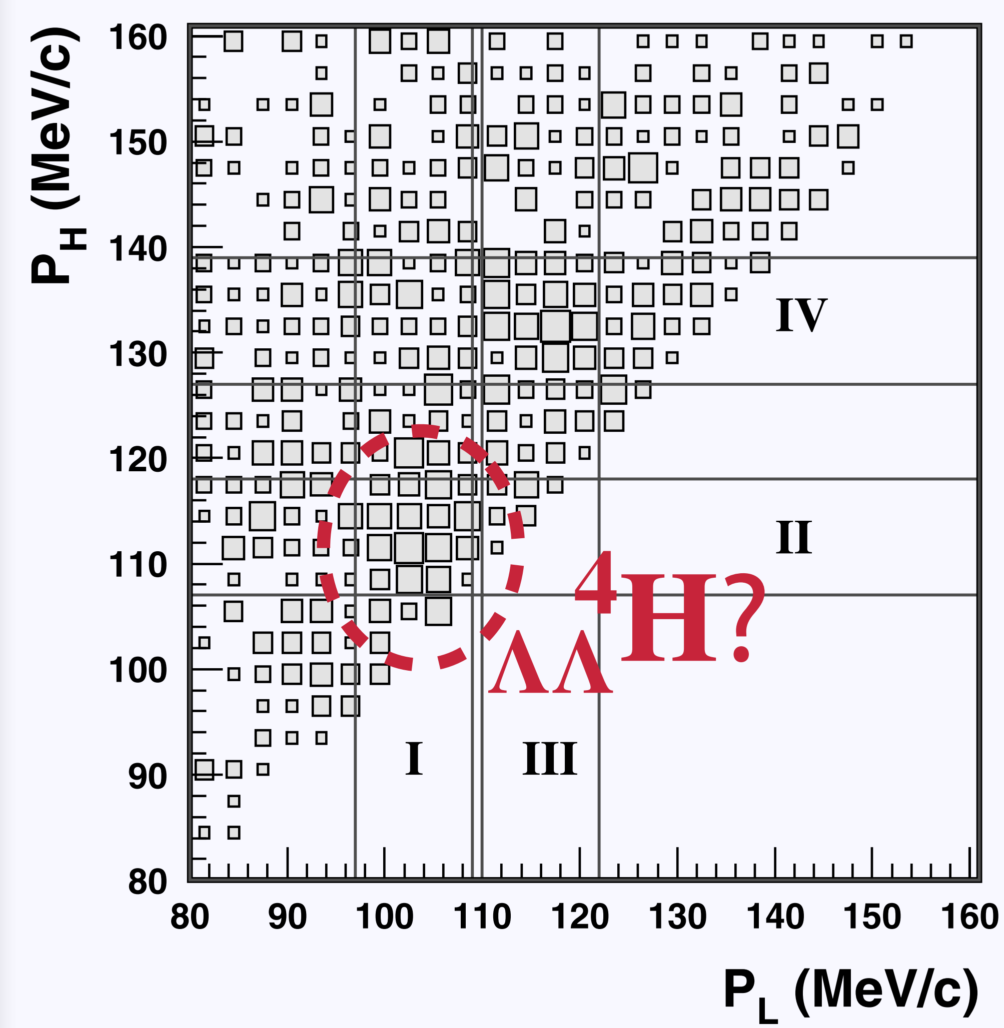
Y. Yamamoto, M. Wakai, T. Motoba, T. Fukuda, Nucl. Phys. A **625,** 107 (1997)



J.K. Ahn et al., Phys. Rev. Lett. **87**, 132504 (2001)

E906 experiment





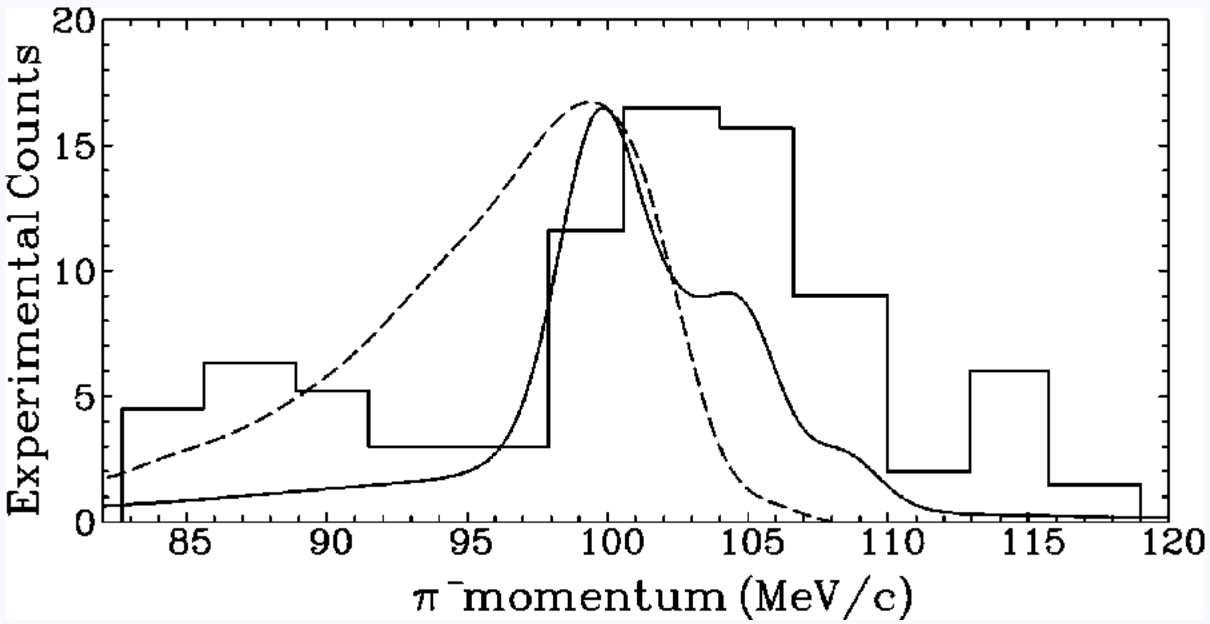
P. Pile, HYP2003

Interpretations other than ${}_{\Lambda\Lambda}^{4}\mathrm{H}$

1) Twin hypernuclei

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

$${}_{\Lambda}^{6}\mathrm{He} \rightarrow {}^{6}\mathrm{Li}^{(*)} + \pi^{-}$$

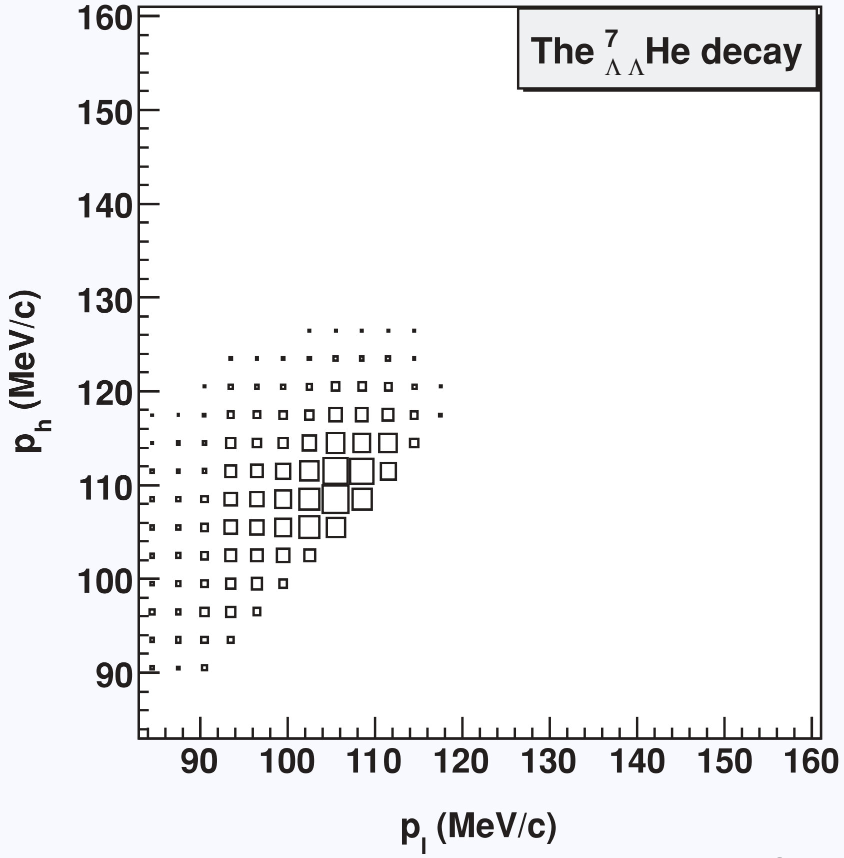


I. Kumagai-Fuse and S. Okabe,
Phys. Rev. C **66**, 014003 (2002)

2) Double-Λ hypernuclei

$${}_{\Lambda\Lambda}^{7}\mathrm{He} \rightarrow {}_{\Lambda}^{7}\mathrm{Li}^{(*)} + \pi^{-}$$

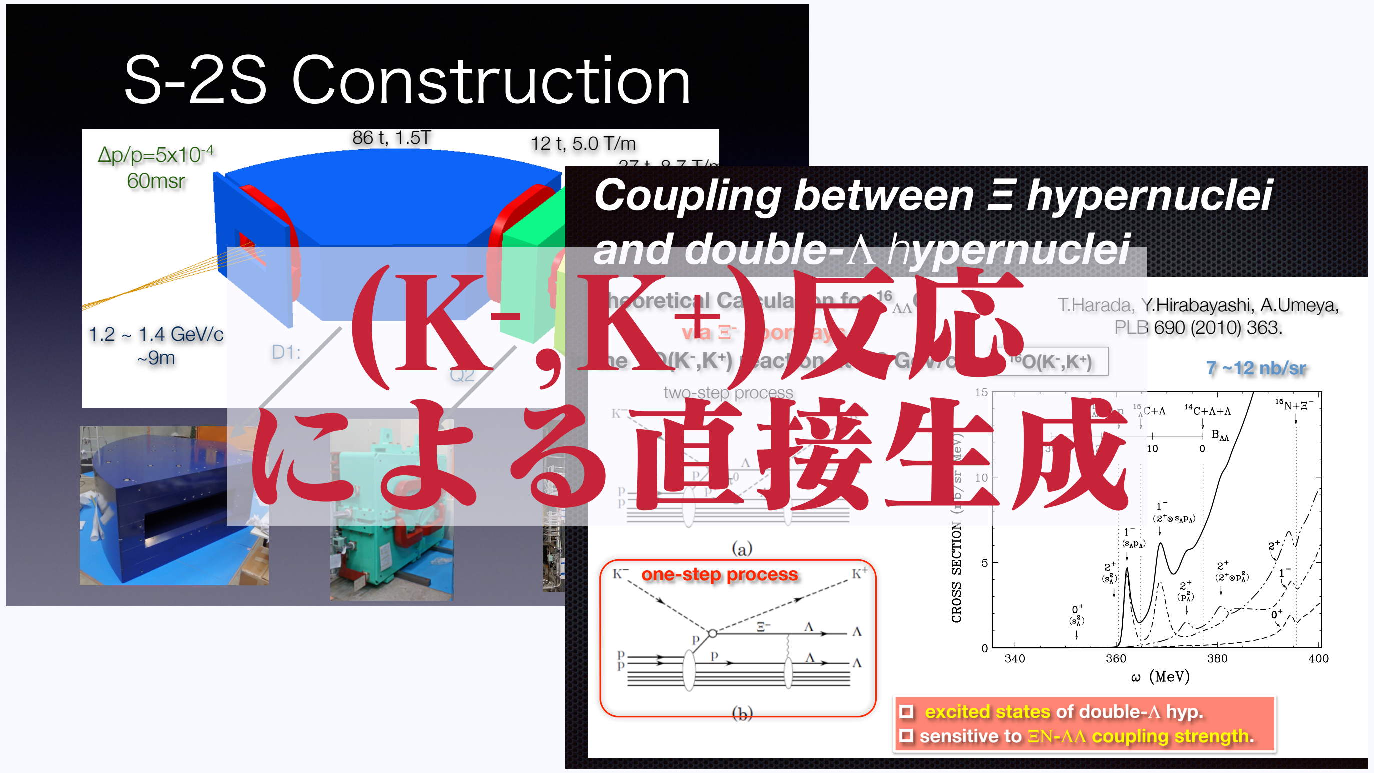
$${}_{\Lambda}^{7}\mathrm{Li} \rightarrow {}^{7}\mathrm{Be} + \pi^{-}$$



S.D. Randeniya and E.V. Hungerford,
Phys. Rev. C **76**, 064308 (2007)

They may be produced from $\left[{}_{\Lambda\Lambda}^{8}\mathrm{He}^{*}\right]$ or $(\Xi^{-}, {}^{9}\mathrm{Be})_{\mathrm{atom}}$

≧2020年代のカウンタ実験

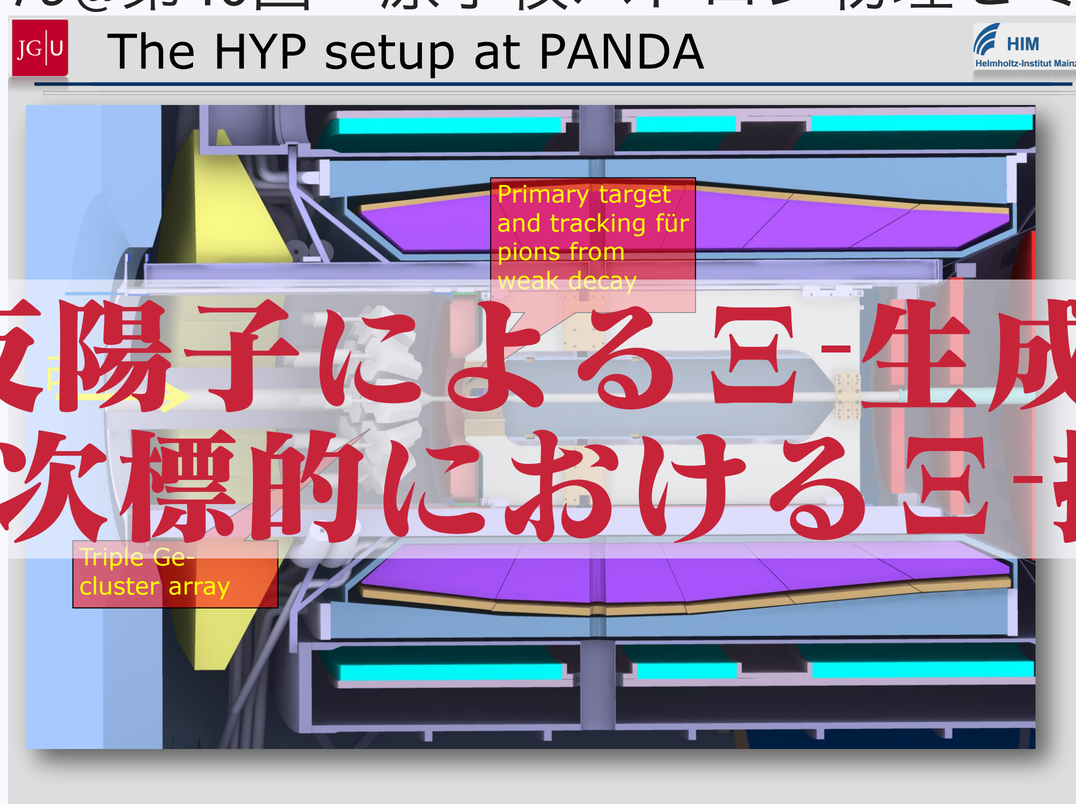


(K-,K+)反応
による直接生成

永江さん@第40回「原子核ハドロン物理セミナー」

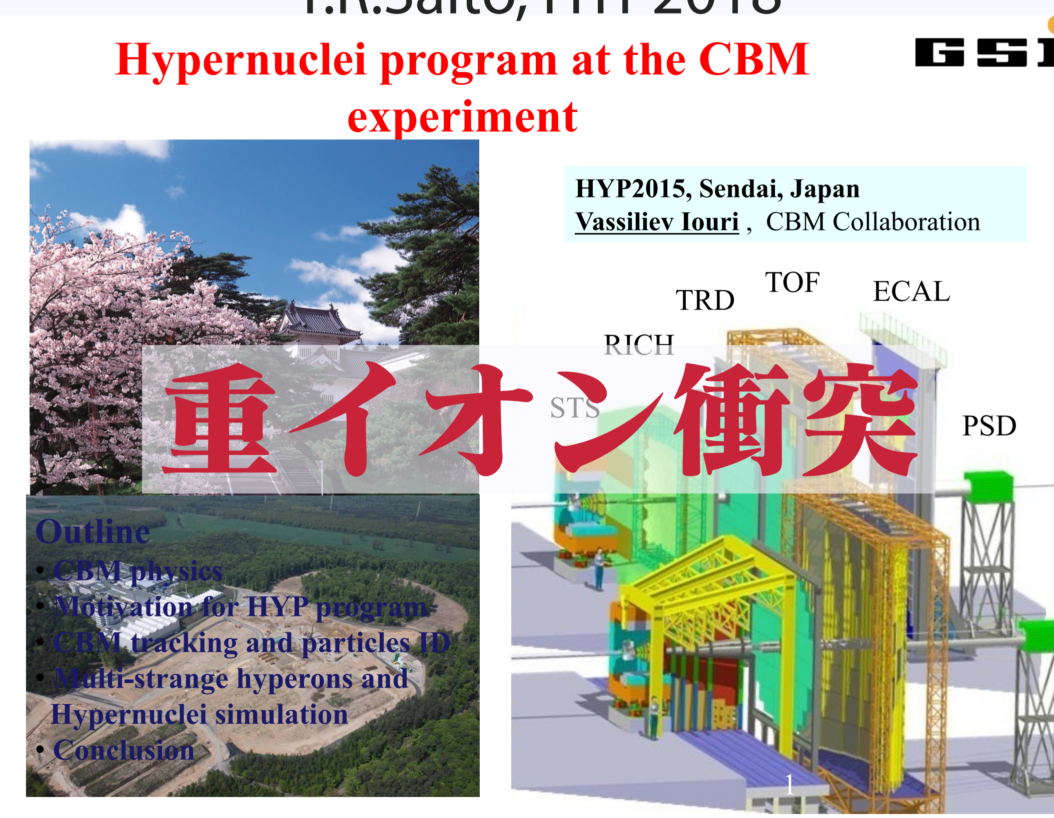
重イオン衝突

T.R.Saito, HYP2018



反陽子によるΞ-生成&
二次標的におけるΞ-捕獲

J. Pochodzalla, HYP2015



重イオン衝突

I. Vassiliev, HYP2015

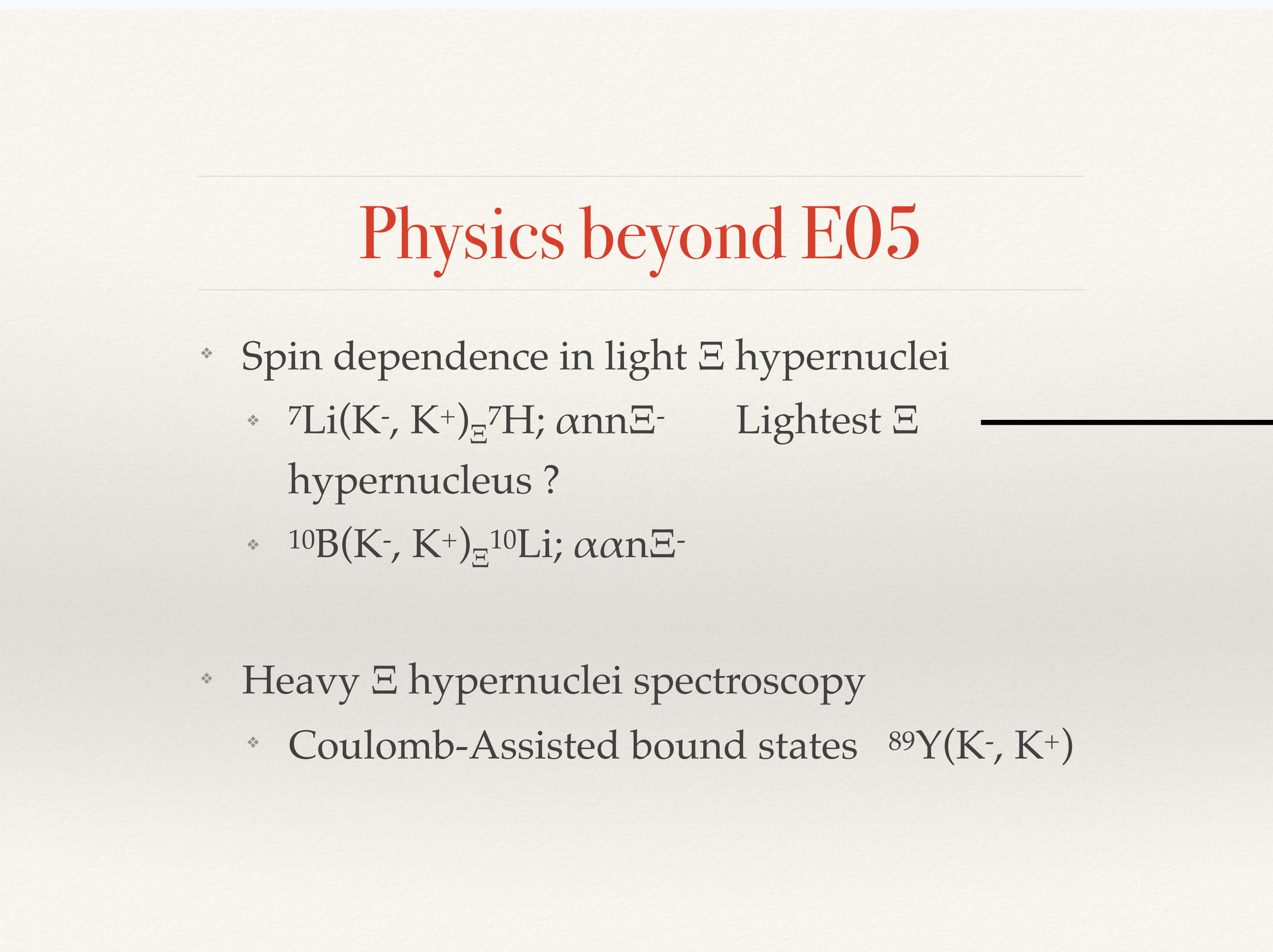
J-PARCにおける実験計画

BNL E906実験のアップグレード

ダブルΛ複合核経由

$$^{7}\mathrm{Li}(K^-,K^+)\{\Xi^- + {}^{6}\mathrm{He}^*\} \longrightarrow [{}_{\Lambda\Lambda}^{\;6}\mathrm{H}^*] + n$$
$$[{}_{\Lambda\Lambda}^{\;6}\mathrm{H}^*] \to {}_{\Lambda\Lambda}^{\;5}\mathrm{H} + n$$

^{7}Li(K^{-},K^{+})反応のΞ束縛領域・非束縛領域に対応



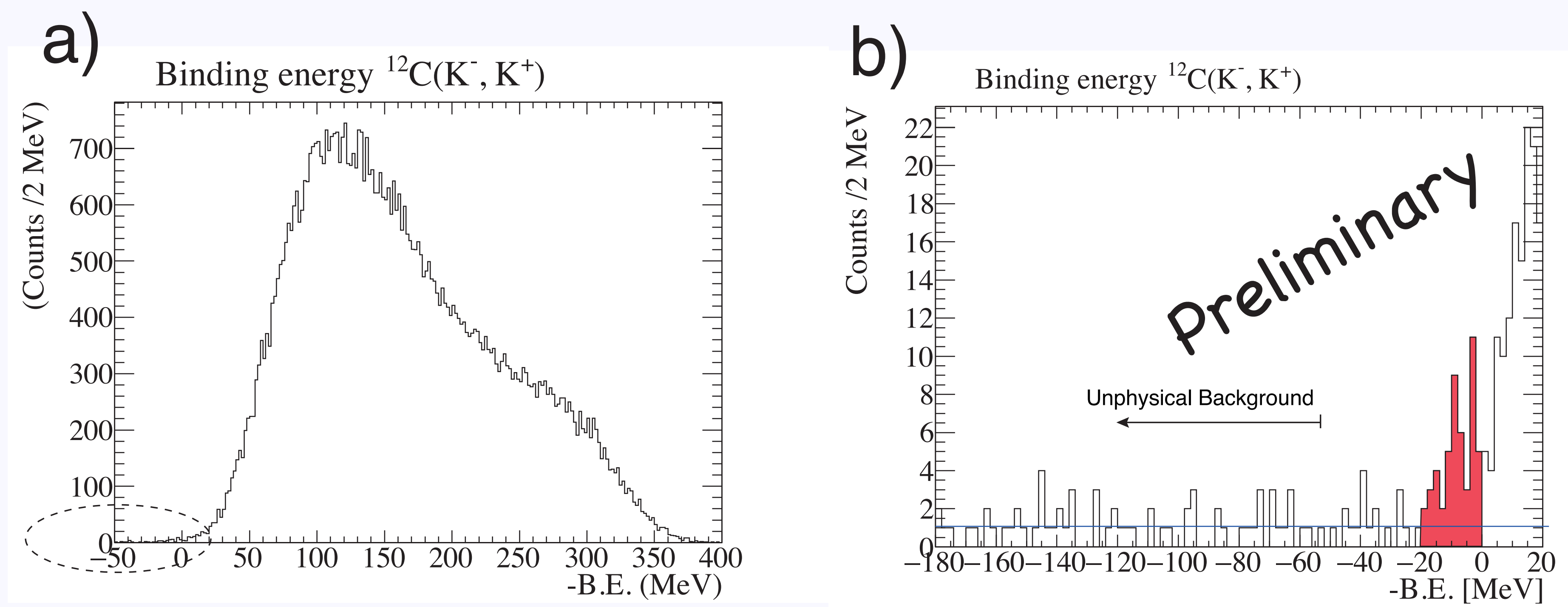
T. Nagae, HYP2018

Ξハイパー核経由

$${}_{\Xi^-}^{\;7}\mathrm{H} \to {}_{\Lambda\Lambda}^{\;5}\mathrm{H} + 2n$$

を用いた${}_{\Lambda\Lambda}^{\;5}\mathrm{H}$生成

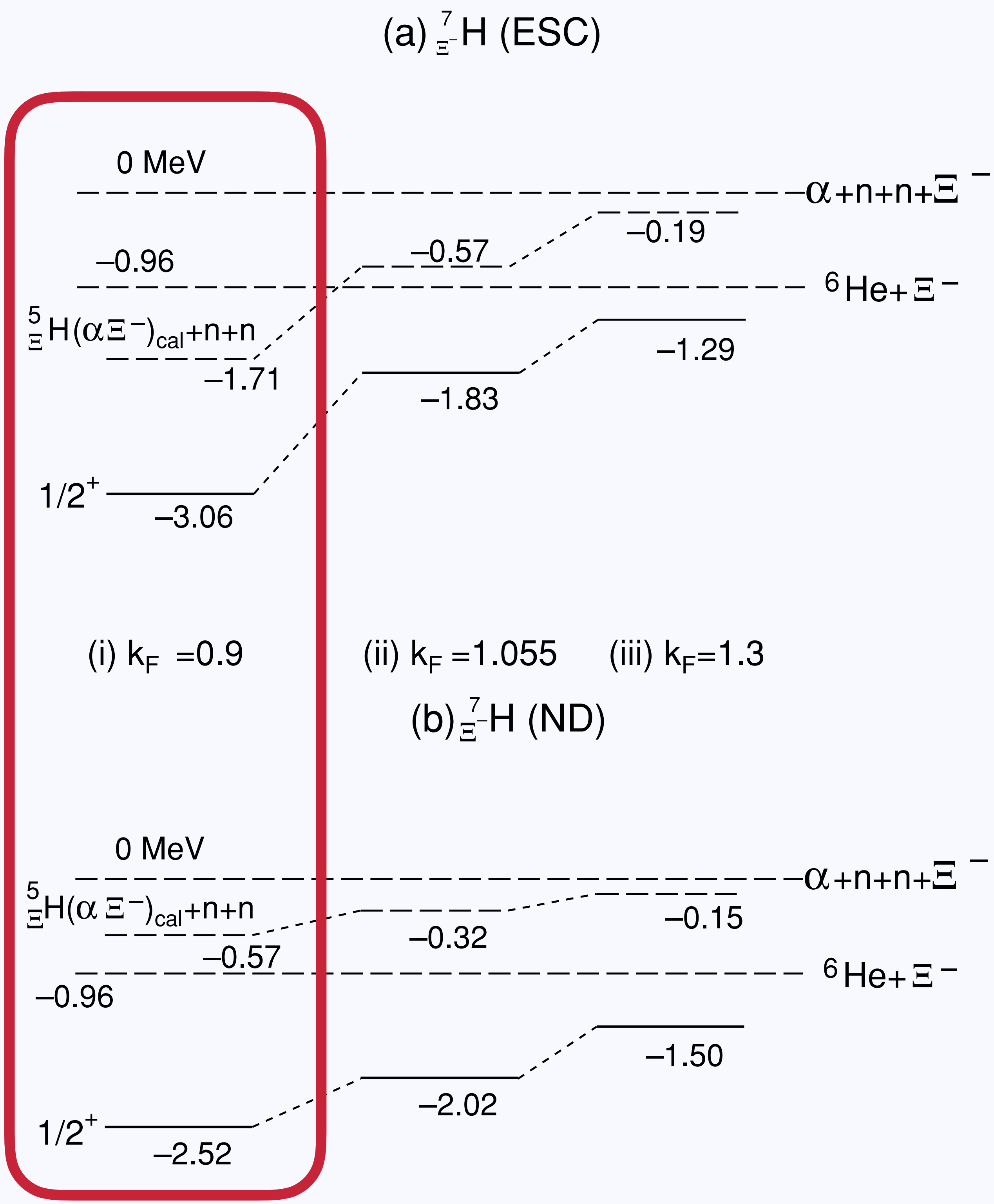
参考：^{12}C(K$^-$,K$^+$) 反応



Run Conditions	Pilot Run	Next physics Run
K^- intensity (M/spill)	0.6	1.31
MR beam power (kW)	39	85
Spill cycle (s)	5.52	4.7
Target thickness (g/cm^2)	9.3	10
Spectrometer acceptance (msr)	110	55
Missing-mass resolution (FWHM)	6 MeV	<2 MeV
Signal events/days of run	40/10 days	~110/20 days

T. Nagae et al., P70 proposal

^{7}Li$(K^{-}, K^{+})^{7}_{\Xi^{-}}$H reaction



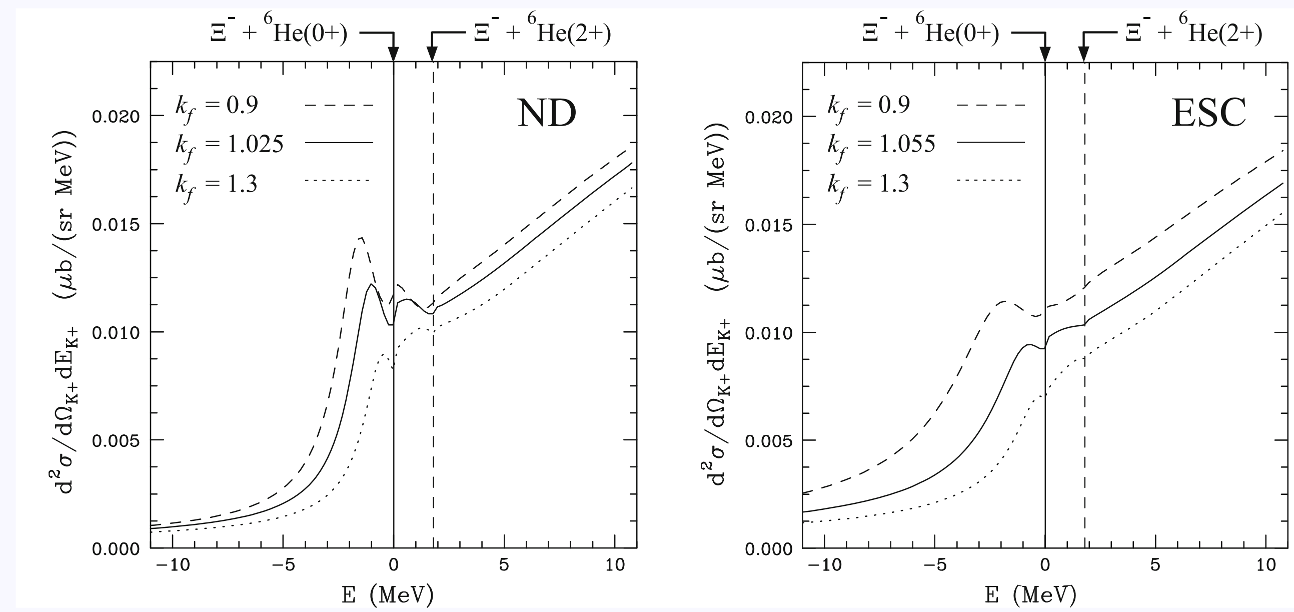


Fig. 1 Calculated ^{7}Li(K^{-}, K^{+}) inclusive spectra for $p_{K^{-}}$ = 1.65 GeV/c and $\theta_{K^{+}}$ = 0°. The *left* and *right panel* show the results corresponding to the case using potential ND and ESC with three k_f parameters listed in Table 1, respectively. These spectra are smeared assuming 2 MeV detector resolution

Koike and Hiyama, Few-Body Syst. **54**, 1275 (2013)

E. Hiyama et al., Phys. Rev. C **78**, 054316 (2008)

Production via Ξ-hypernuclear decay

PHYSICAL REVIEW C VOLUME 54, NUMBER 1 JULY 1996

Double-Λ hypernuclear formation via a neutron-rich Ξ state

Izumi Kumagai-Fuse and Yoshinori Akaishi
Institute for Nuclear Study, University of Tokyo, Tanashi, Tokyo 188, Japan
(Received 21 March 1996)

Conversion processes for ${}^{7}_{\Xi}\mathrm{H}$ are discussed as a typical example of the double-Λ hypernuclear formation via a neutron-rich Ξ state. ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ is formed with a surprisingly large branching ratio of about 90% from ${}^{7}_{\Xi}\mathrm{H}$ that is produced by the (K^-,K^+) reaction on the ${}^{7}\mathrm{Li}$ target. The ${}^{7}_{\Xi}\mathrm{H}$ state has a narrow width, 0.75 MeV, and its population can be confirmed by tagging K^+ momentum. [S0556-2813(96)50507-8]

PACS number(s): 21.80.+a. 21.45.+v. 25.80.Nv, 25.80.Pw

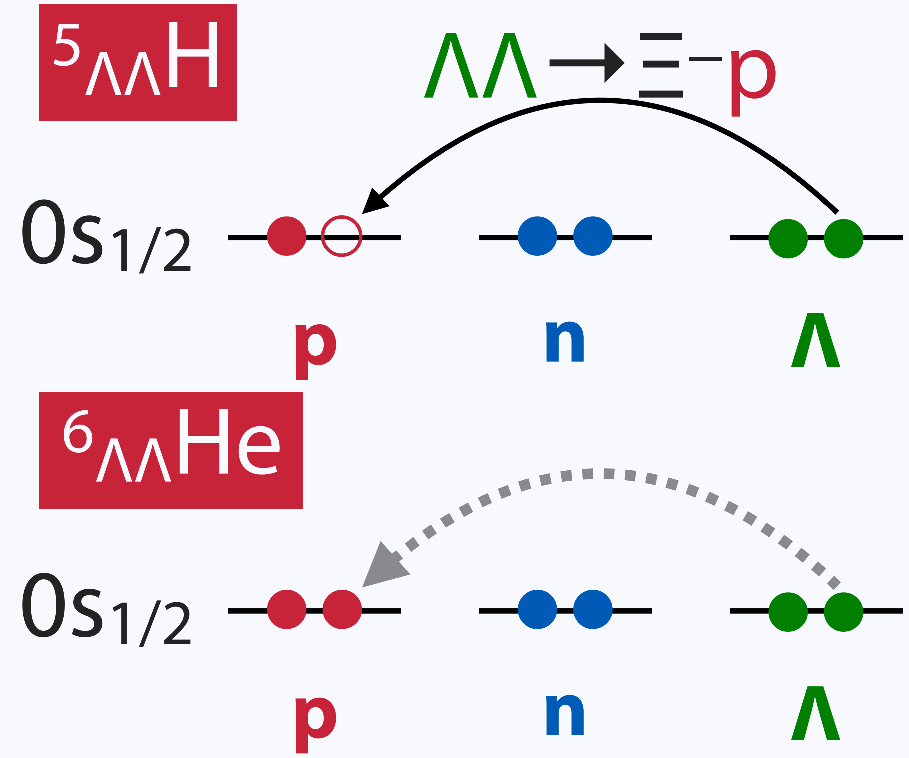
I. Kumagai-Fuse, Y. Akaishi, Phys. Rev. C **54**, R24 (1996)

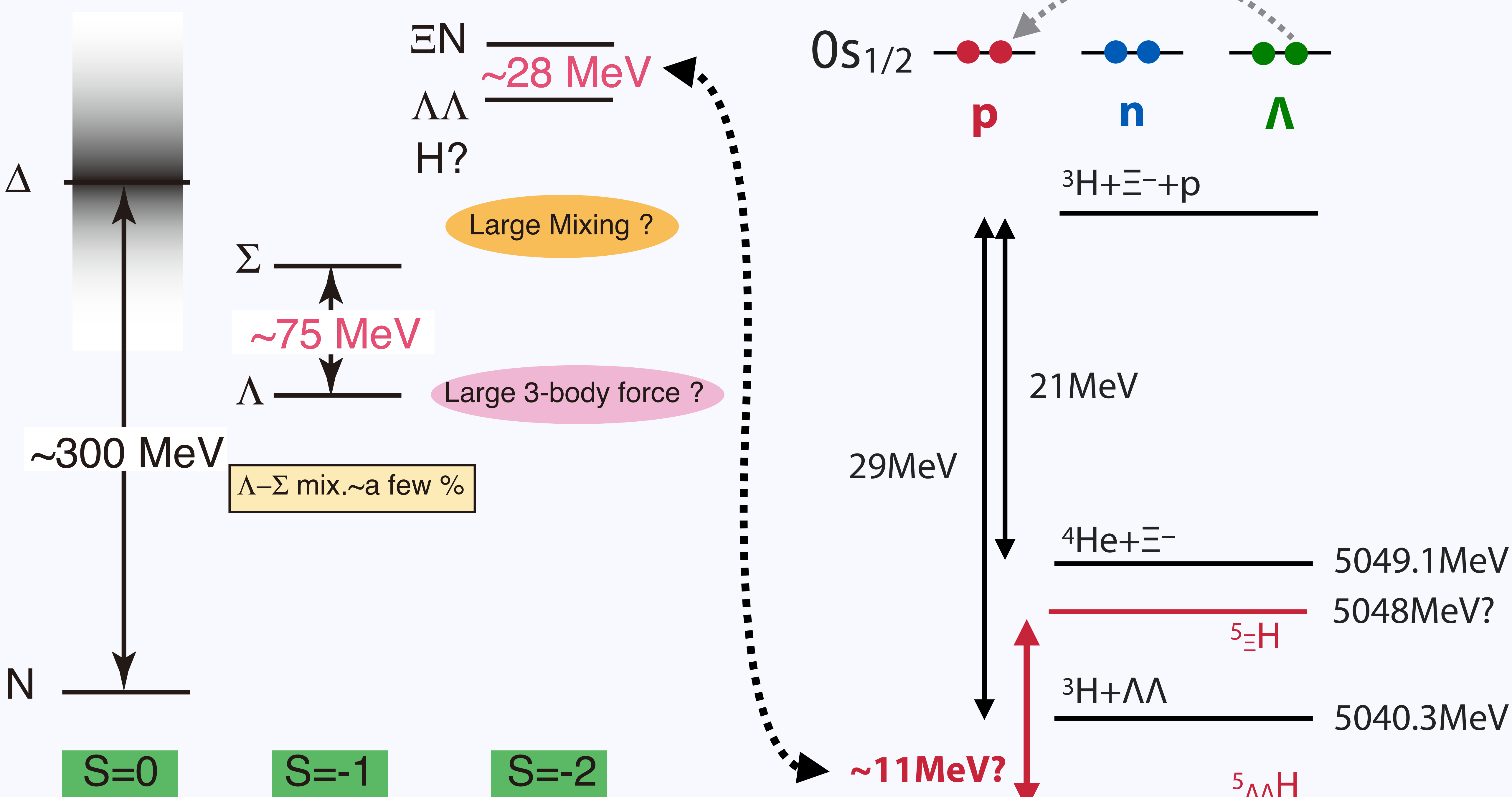
$$\boxed{{}^{7}_{\Xi}\mathrm{H} \to {}^{5}_{\Lambda\Lambda}\mathrm{H} + n + n \quad \sim 11 \ \ \mathrm{MeV},}$$
$$\to {}^{4}_{\Lambda}\mathrm{H} + \Lambda + n + n \quad \sim 7 \ \ \mathrm{MeV},$$
$$\to {}^{4}_{\Lambda}\mathrm{H}^{*} + \Lambda + n + n \quad \sim 6 \ \ \mathrm{MeV},$$
$$\to {}^{3}\mathrm{H} + \Lambda + \Lambda + n + n \quad \sim 5 \ \ \mathrm{MeV}.$$

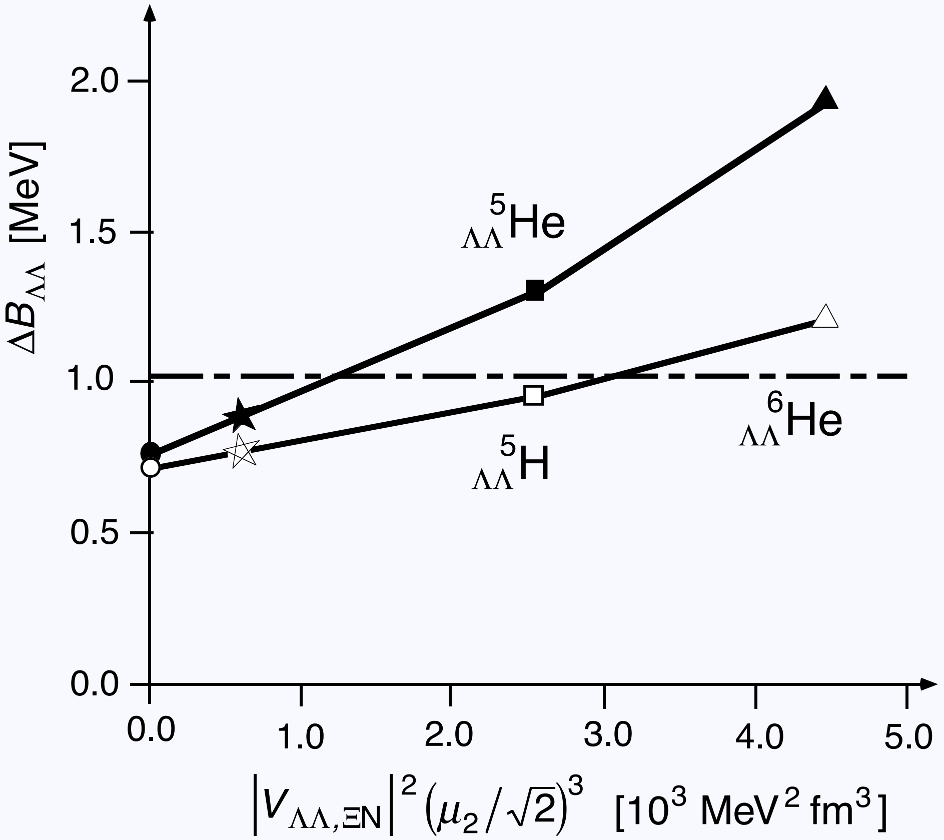
- Only 4 decay channels are allowed energetically
- Among them, the channel with the **fewest** bodies and the **largest** Q-value is most predominant (B.R. ~ 90% !!)

ΛΛ-ΞN mixing in $^{5}_{\Lambda\Lambda}\mathrm{H}$

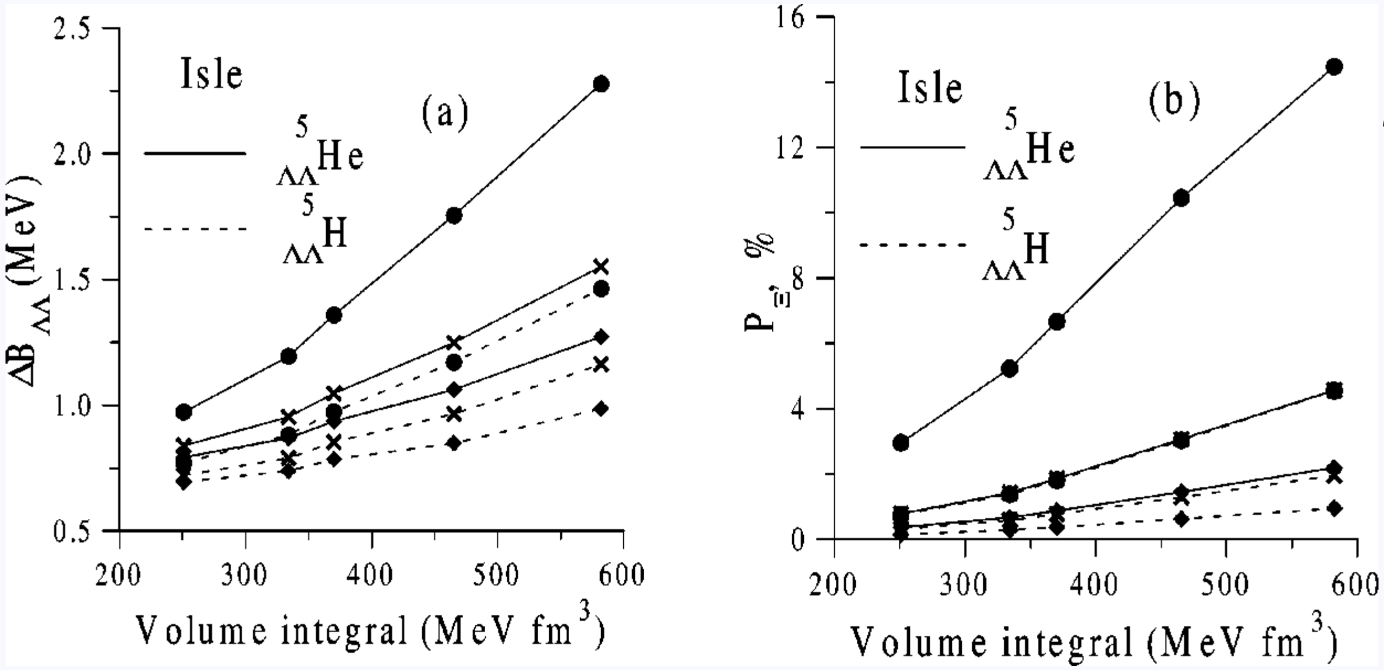
B.F. Gibson et al.,
Prog. Theor. Phys. Suppl. **117**, 339 (1994)



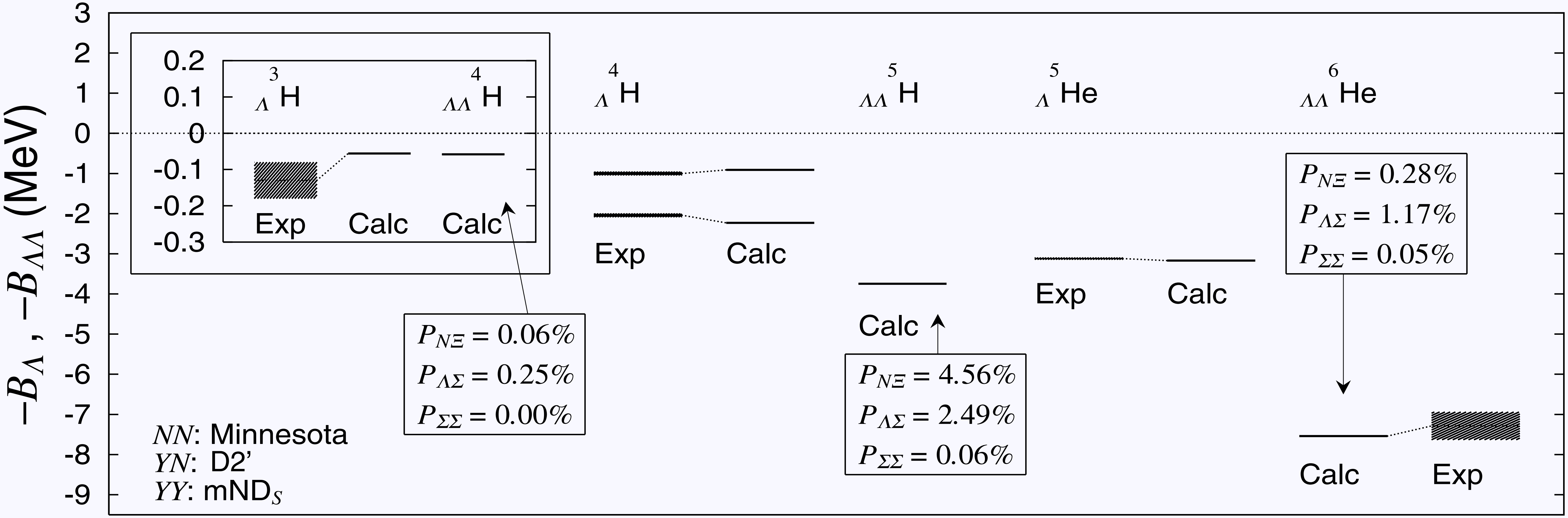




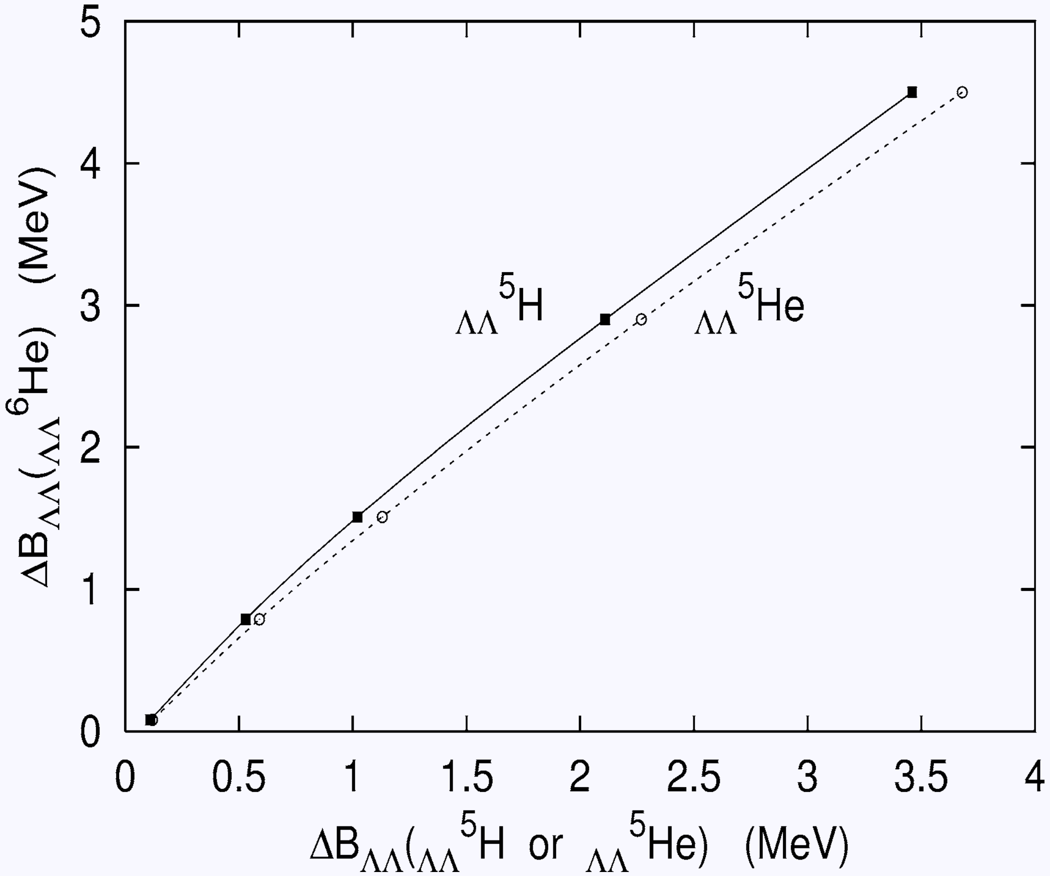
Khin Swe Myint, S. Shinmura, and Y. Akaishi, Eur. Phys. A **16**, 21 (2003)



D. E. Lanskoy and Y. Yamamoto, Phys. Rev. C **69**, 014303 (2004)



H. Nemura et al., Phys. Rev. Lett. **94**, 202502 (2005)



I.N. Filikhin and A. Gal, Nucl. Phys. A **707**, 491 (2002)

Finally, we commented on the size expected for the $\Lambda\Lambda$-ΞN mixing effect in these light $\Lambda\Lambda$ hypernuclei. For models such as NSC97e which are close to describing well the $\Lambda\Lambda$ interaction as deduced from $B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{6}\mathrm{He})$, we have argued that the $\Lambda\Lambda$-ΞN coupling effect should not exceed 0.2 MeV in ${}_{\Lambda\Lambda}^{6}\mathrm{He}$, and a similar order of magnitude is expected for this and other medium effects in the $A=5$ $\Lambda\Lambda$ hypernuclei. For comparison with the better studied $S=-1$

I. N. Filikhin, A. Gal, and V. M. Suslov, Phys. Rev. C **68**, 024002 (2003).

- Many theoretical calculations support the existence of bound ${}^{5}_{\Lambda\Lambda}\mathrm{H}$.

- caveat: the ΛΛ interaction might be too strong so as to account for the “old” binding energy of ${}^{6}_{\Lambda\Lambda}\mathrm{He}$.

$$\Delta B_{\Lambda\Lambda} = 1.01 \pm 0.20^{+0.18}_{-0.11}\,\mathrm{MeV}\ \ (2002) \longrightarrow 0.67 \pm 0.17\,\mathrm{MeV}\ \ (2013)$$

- The comparison of the ΛΛ bond energy between ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ and ${}^{6}_{\Lambda\Lambda}\mathrm{He}$ will be very important.

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cf. $^{12}\mathrm{C}(\pi^+, K^+)^{12}_{\Lambda}\mathrm{C}$

$^{6}\mathrm{Li}(\pi^+, K^+)^{5}_{\Lambda}\mathrm{He} + p$

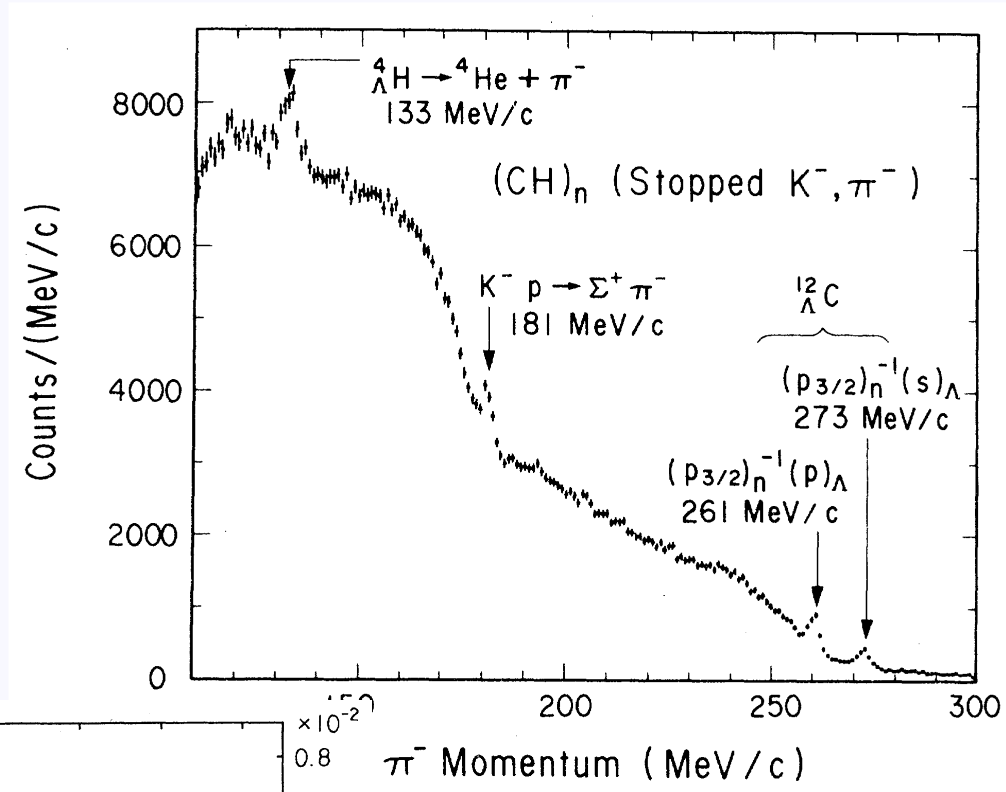
(2-1) $^{5}_{\Lambda\Lambda}\mathrm{H}$ 生成を実証する方法について

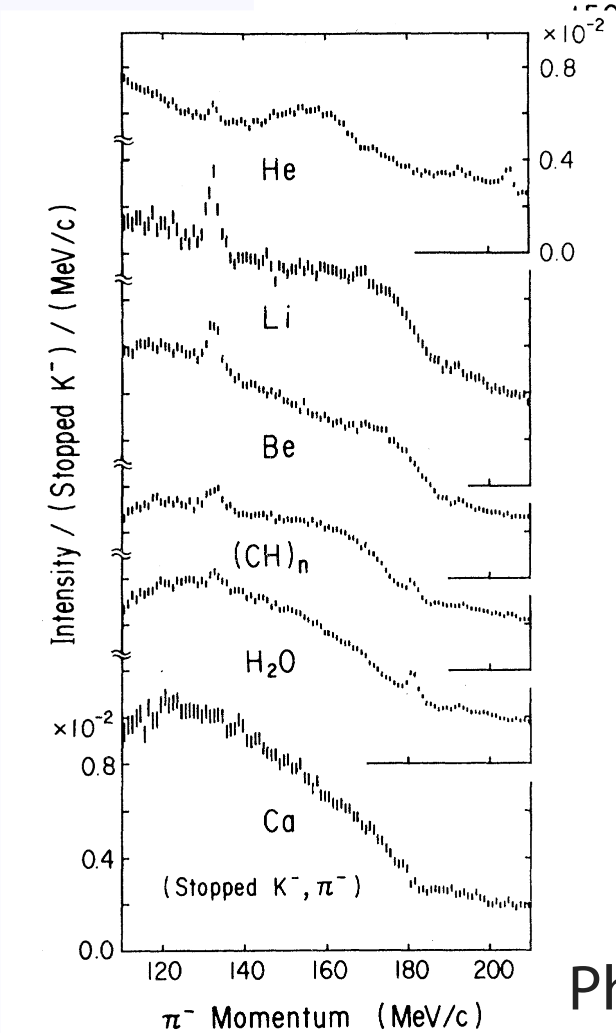
$$^{5}_{\Lambda\Lambda}\mathrm{H} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + \pi^-$$

(2-2) 崩壊パイ中間子分光による質量の決定

(3) J-PARC における実験計画 (from S=−1 to S=−2)

Decay pion spectroscopy



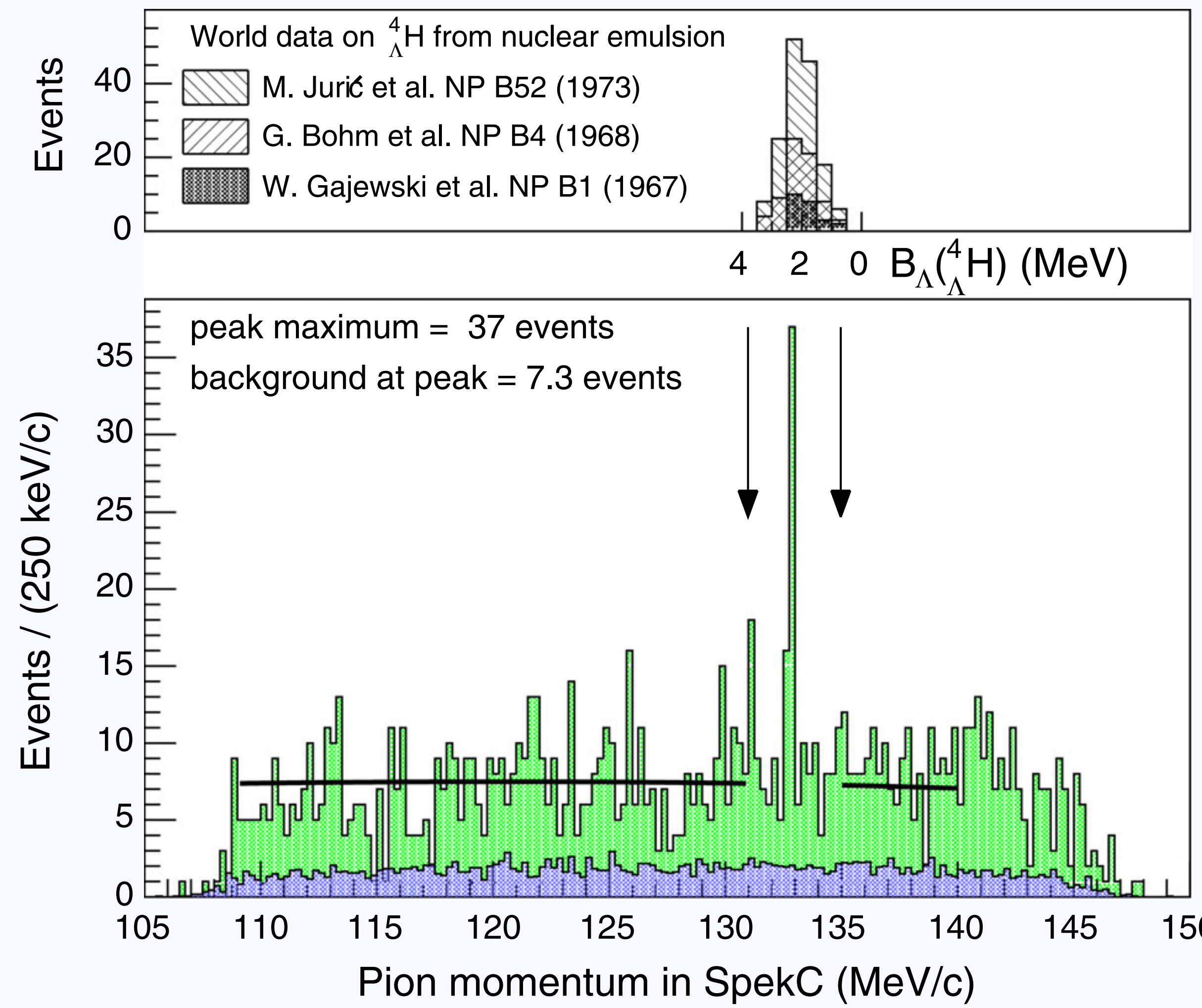


生成の証拠

H. Tamura et al.,
Phys. Rev. C **40**, R479 (1989)

$${}^4_\Lambda H \to {}^4He + \pi^-$$

2体崩壊→単色ピーク

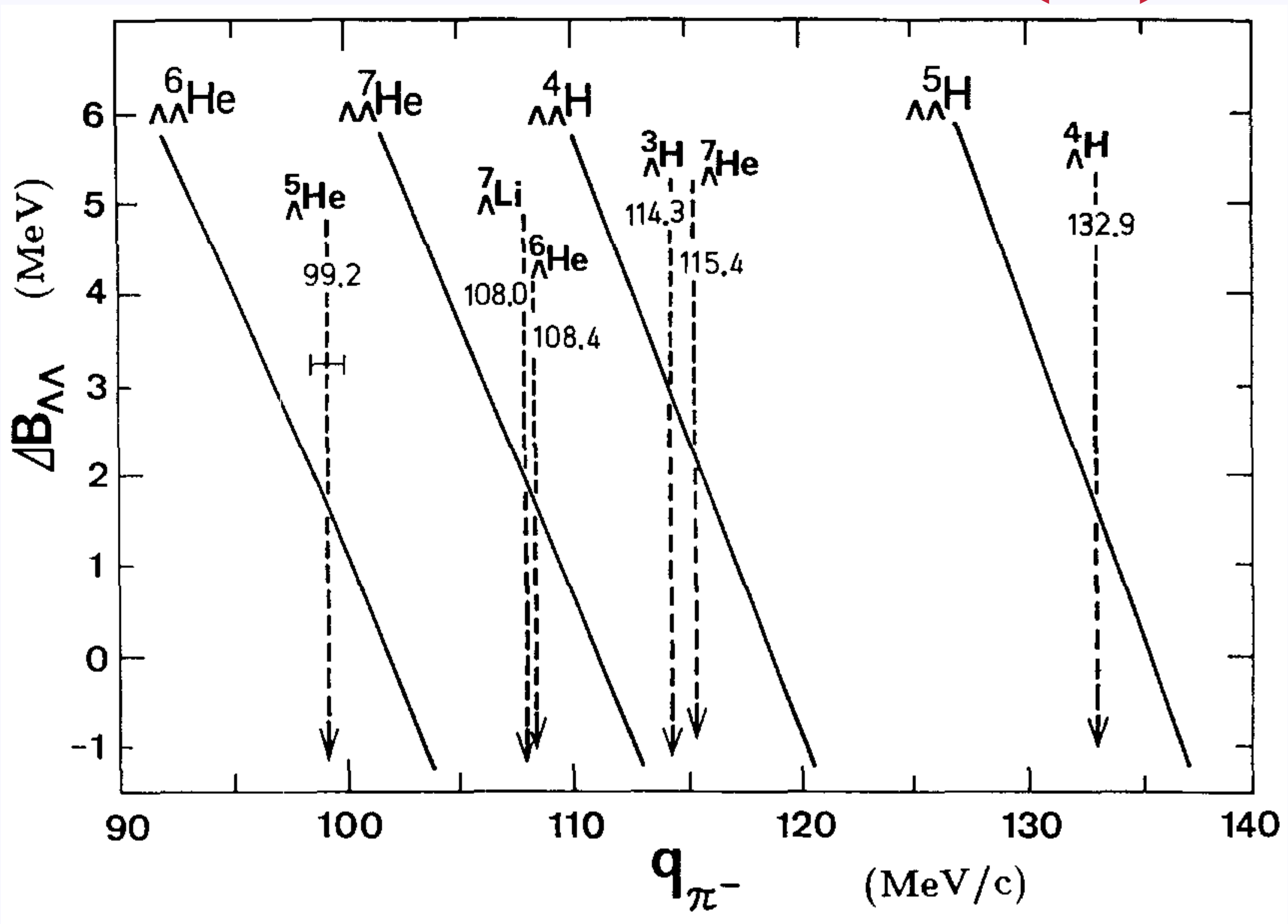


精密分光（質量測定）

A. Esser et al.,
PRL **114**, 232501 (2015)
A1 Collaboration,
NPA **954**, 149 (2016)

Momentum of decay pion

Region of Interest

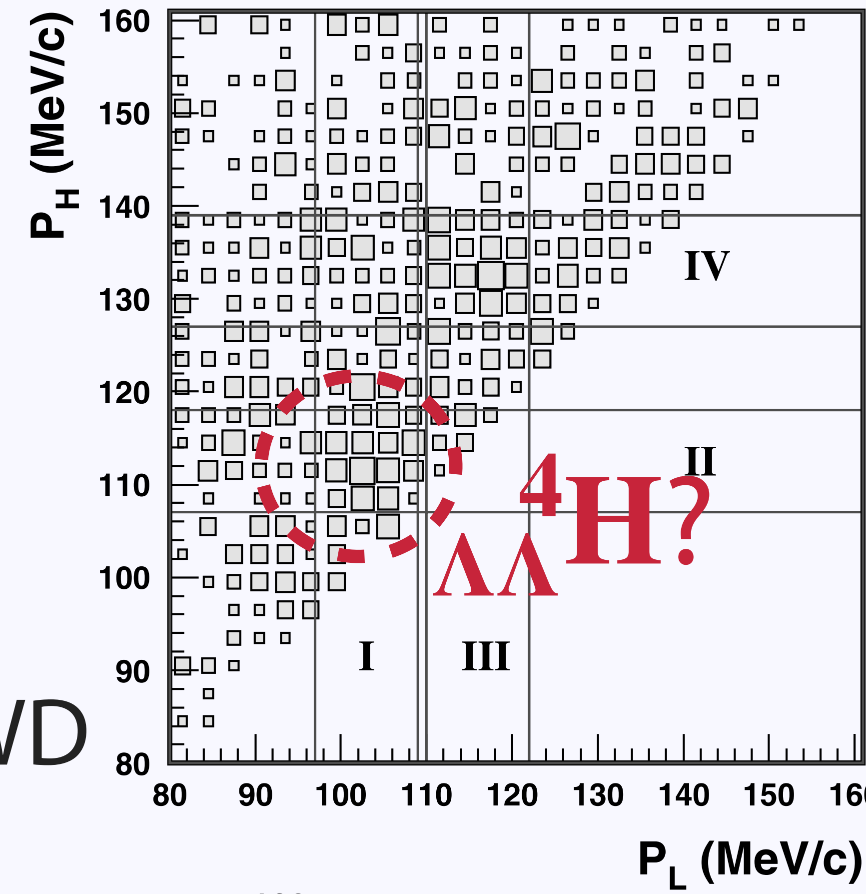


can be used for calibration

Only pions from $^{4}_{\Lambda}$H two-body decay (discrete)
and from hyperon decay (continuous) will contaminate the RoI.

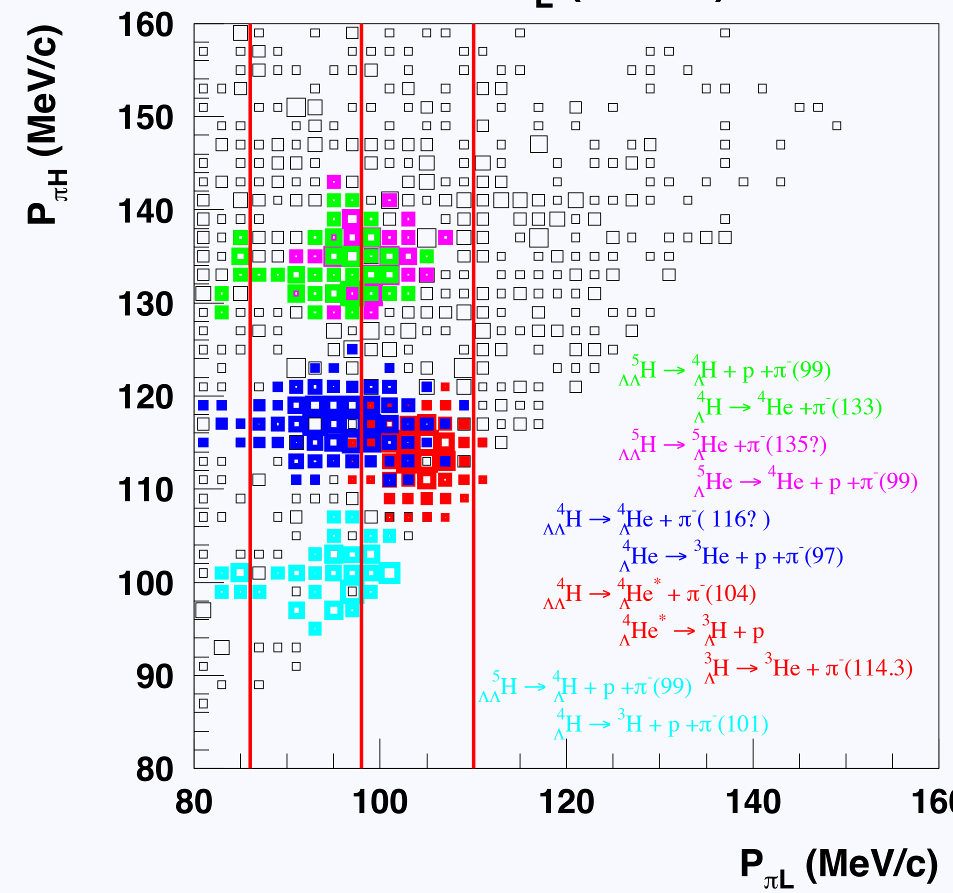
Y. Yamamoto, M. Wakai, T. Motoba and T. Fukuda, Nucl. Phys. A **625**, 107 (1997)

How to identify ${}_{\Lambda\Lambda}^{5}\mathrm{H}$?



- <u>BNL-AGS E906 (P961R)</u>
  two pions from sequential MWD
  → clue to identify
  parent double-Λ hypernuclei and
  daughter single-Λ hypernuclei

- This method is difficult to apply
  in case of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ decay



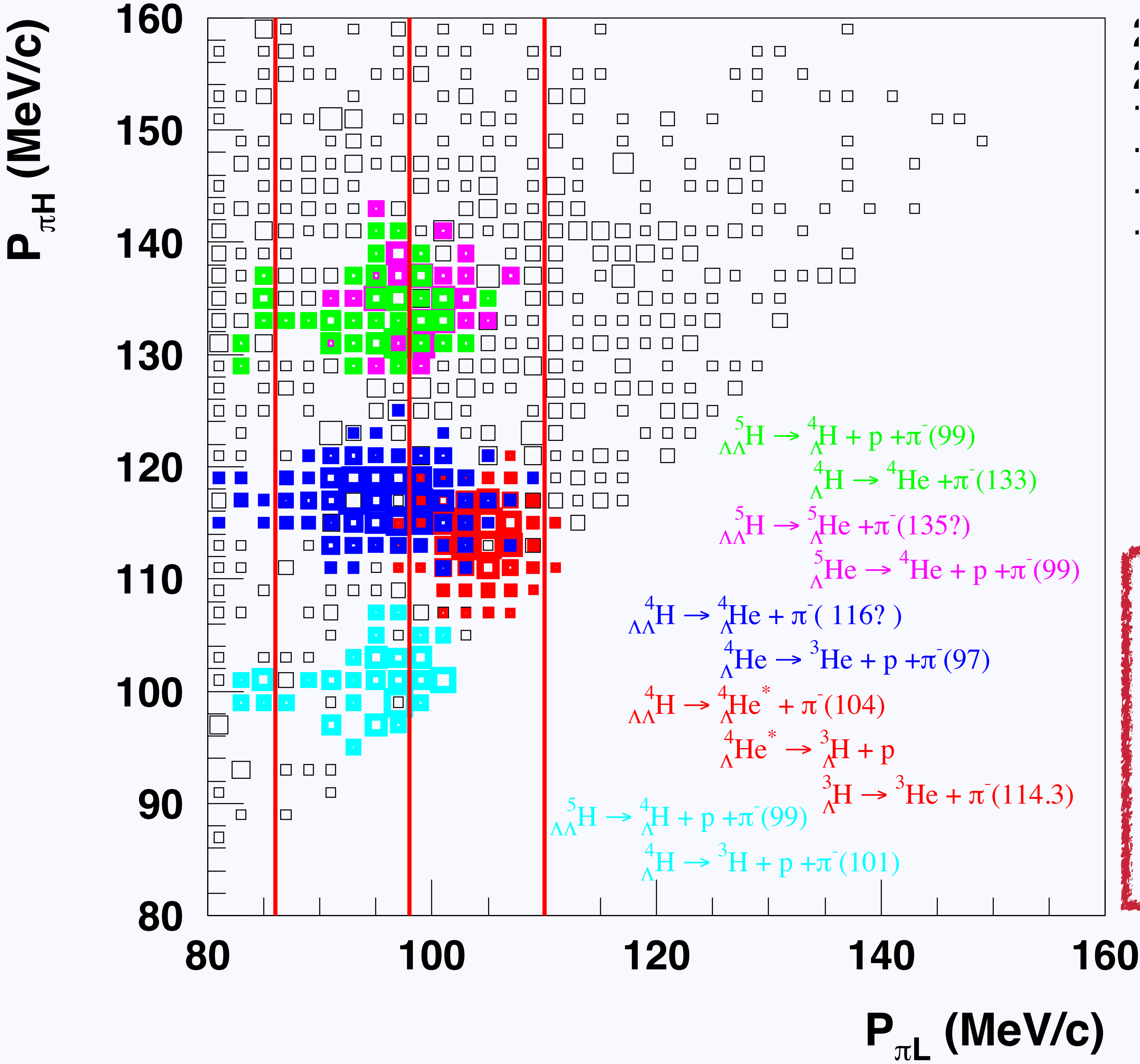
simulation (P961R proposal)

≈ 99MeV/c

$$ {}^{5}_{\Lambda\Lambda}\mathrm{H} \rightarrow {}^{4}_{\Lambda}\mathrm{H} + p + \pi^{-} \qquad {}^{5}_{\Lambda\Lambda}\mathrm{H} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + \pi^{-} $$

$$ {}^{4}_{\Lambda}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \pi^{-} \qquad {}^{5}_{\Lambda}\mathrm{He} \rightarrow {}^{4}\mathrm{He} + p + \pi^{-} $$

≈ 133MeV/c



The distinction between the two decay modes are experimentally difficult.

From a point of view of decay pion spectroscopy, the decay mode on the left side is regarded as a background process.

Novel method for ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ identification

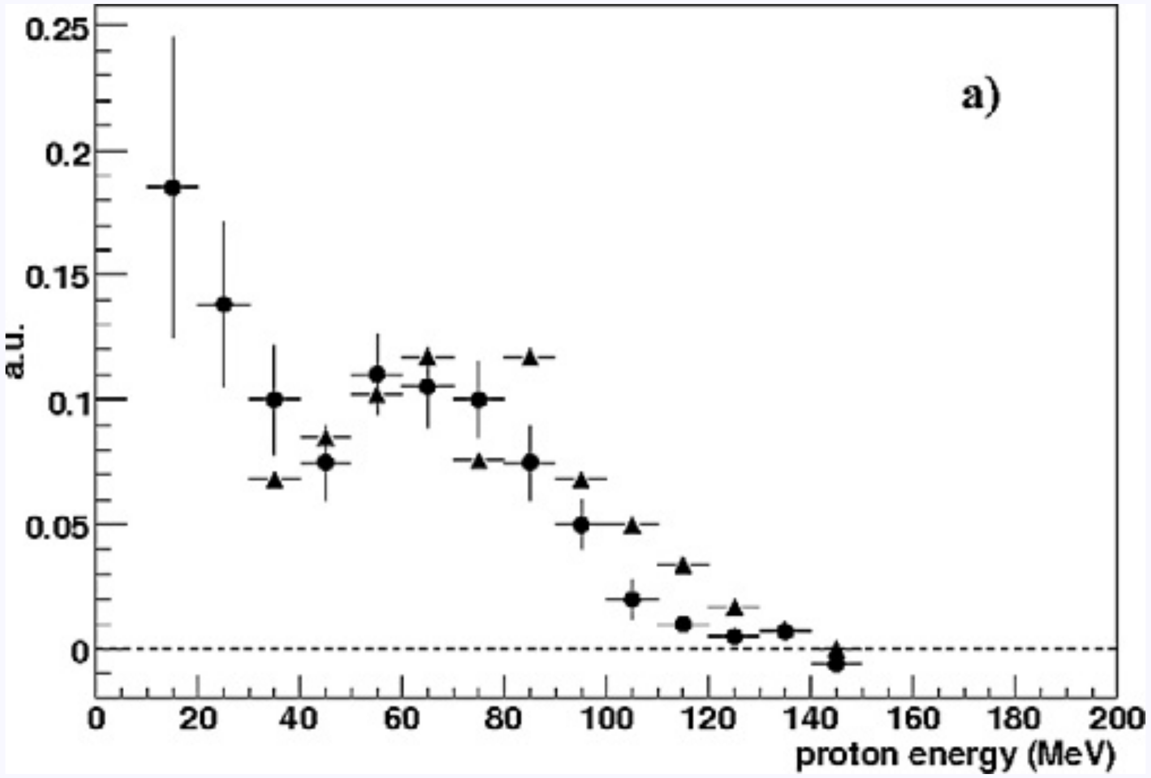
Decay pion spectroscopy with tagging a proton from NMWD

(referred to as a "fast proton")

$$ {}^{5}_{\Lambda\Lambda}\mathrm{H} \to {}^{5}_{\Lambda}\mathrm{He} + \pi^- $$

$$ {}^{5}_{\Lambda}\mathrm{He} \to {}^{3}\mathrm{H} + p + n $$

proton energy distribution



25±7% of ${}^{5}_{\Lambda}\mathrm{He}$ (FINUDA)

M. Agnello et al., Nucl. Phys. **804**, 151 (2008)

MWD $\Lambda \to p + \pi^- + 38\,\mathrm{MeV}$

π^- carries away most of the released energy

(1N-induced) NMWD

$$ \Lambda + p \to n + p + 176\,\mathrm{MeV} $$

BG rejection with fast proton tagging

three processes with ${}^{4}_{\Lambda}\mathrm{H}(\rightarrow {}^{4}\mathrm{He}+\pi^{-})$ in the final state

(a)

$${}^{7}_{\Xi}\mathrm{H} \rightarrow \boxed{{}^{5}_{\Lambda\Lambda}\mathrm{H}}+n+n \quad \sim 11 \ \ \mathrm{MeV},$$

$$\rightarrow \boxed{{}^{4}_{\Lambda}\mathrm{H}}+\Lambda+n+n \quad \sim 7 \ \ \mathrm{MeV},$$ slow $\Lambda \rightarrow p+\pi^{-}$

$$\rightarrow \boxed{{}^{4}_{\Lambda}\mathrm{H}^{*}}+\Lambda+n+n \quad \sim 6 \ \ \mathrm{MeV},$$ slow $\Lambda \rightarrow p+\pi^{-}$

$$\rightarrow {}^{3}\mathrm{H}+\Lambda+\Lambda+n+n \quad \sim 5 \ \ \mathrm{MeV}.$$

(b) $\left[{}^{6}_{\Lambda\Lambda}\mathrm{H}^{*}\right] \rightarrow \boxed{{}^{4}_{\Lambda}\mathrm{H}}+\Lambda+n$ slow $\Lambda \rightarrow p+\pi^{-}$

(c) $\boxed{{}^{5}_{\Lambda\Lambda}\mathrm{H}} \rightarrow \boxed{{}^{4}_{\Lambda}\mathrm{H}}+(p+\pi^{-}/n+\pi^{0})$ proton from MWD/no proton

$\boxed{{}^{4}_{\Lambda}\mathrm{H}} \rightarrow {}^{4}\mathrm{He}+\pi^{-}$

A fast proton from NMWD has a larger kinetic energy than from MWD (including free Λ decay)

Perspective

- Selective production of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ in a counter experiment
  - Determination of ΛΛ bond energy
  - Lifetime measurement of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$
  - Constraint on branching ratios such as:

$$
\begin{aligned}
{}^{7}_{\Xi^-}\mathrm{H} &\to {}^{5}_{\Lambda\Lambda}\mathrm{H} + 2n \\
{}^{5}_{\Lambda\Lambda}\mathrm{H} &\to {}^{4}_{\Lambda}\mathrm{H} + p + \pi^- \\
{}^{5}_{\Lambda\Lambda}\mathrm{H} &\to {}^{5}_{\Lambda}\mathrm{He} + \pi^-
\end{aligned}
$$

Only possible by a counter experiment

(1) 特定のダブルΛハイパー核 ($^{5}_{\Lambda\Lambda}\mathrm{H}$) の生成

$$^{7}\mathrm{Li}(K^{-}, K^{+})^{5}_{\Lambda\Lambda}\mathrm{H} + 2n$$

cf. $^{12}\mathrm{C}(\pi^{+}, K^{+})^{12}_{\Lambda}\mathrm{C}$

$^{6}\mathrm{Li}(\pi^{+}, K^{+})^{5}_{\Lambda}\mathrm{He} + p$

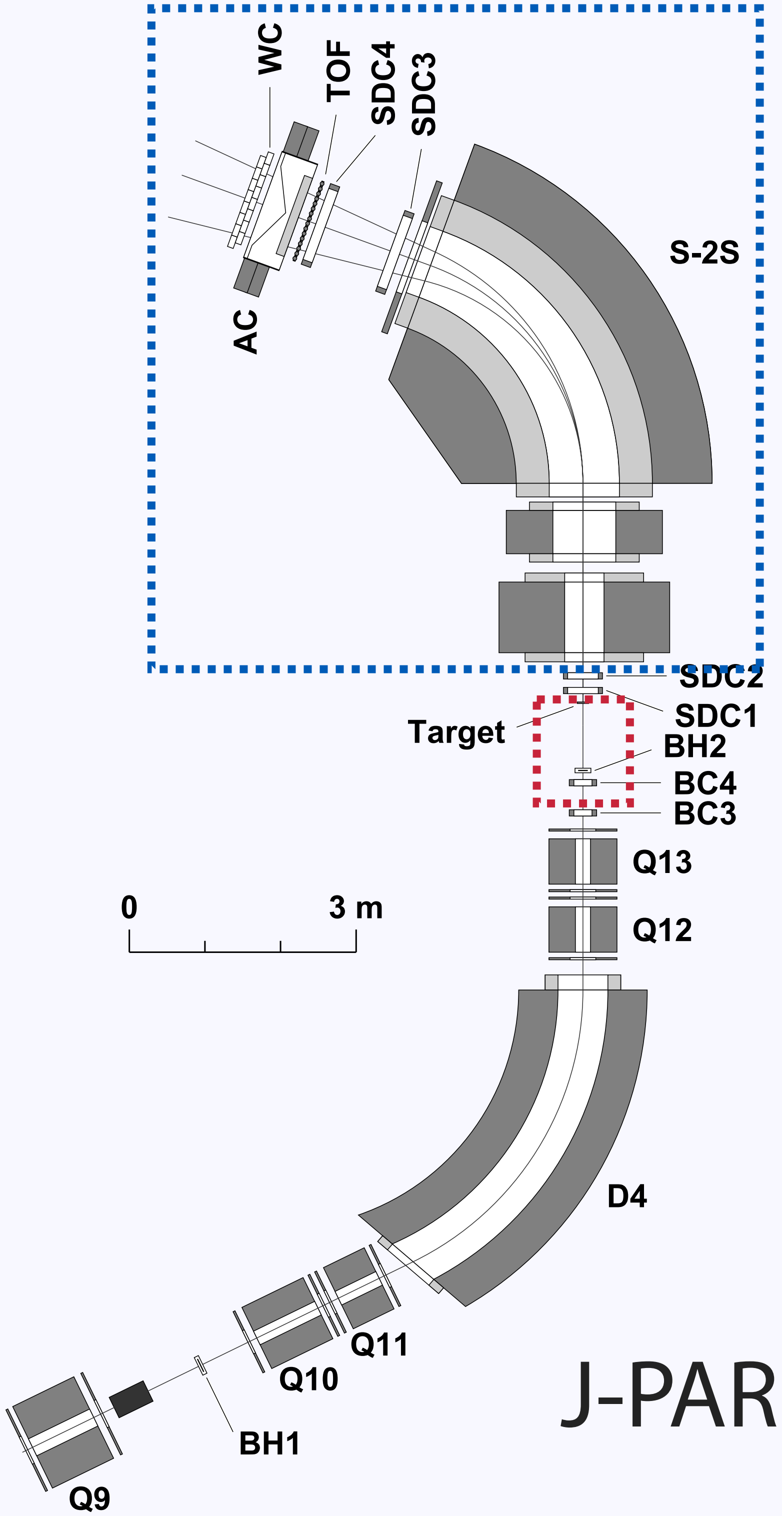
(2-1) $^{5}_{\Lambda\Lambda}\mathrm{H}$ 生成を実証する方法について

$$^{5}_{\Lambda\Lambda}\mathrm{H} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + \pi^{-}$$

(2-2) 崩壊パイ中間子分光による質量の決定

(3) J-PARC における実験計画 (from S=−1 to S=−2)

Experimental setup



requirements

1. High resolution for (K^-,K^+) spectroscopy in order to distinguish ${}^{7}_{\Xi^-}\mathrm{H}$ from QF events
   → S−2S will be the best option
2. Decay π^- and proton measurement
   → a large-acceptance and compact CDS (cylindrical detector system)

superconducting magnet (≧2Tesla)
gaseous detector (drift chamber? TPC?)
plastic scintillator hodoscopes

J-PARC K1.8 beamline

パイロット実験 (phase-1)

^{7}Li標的+ CDS + S-2S @ K1.8 beamline

1. 本測定と同じ条件で予備データ取得 (目標の数%)
 ～バックグラウンドの理解～

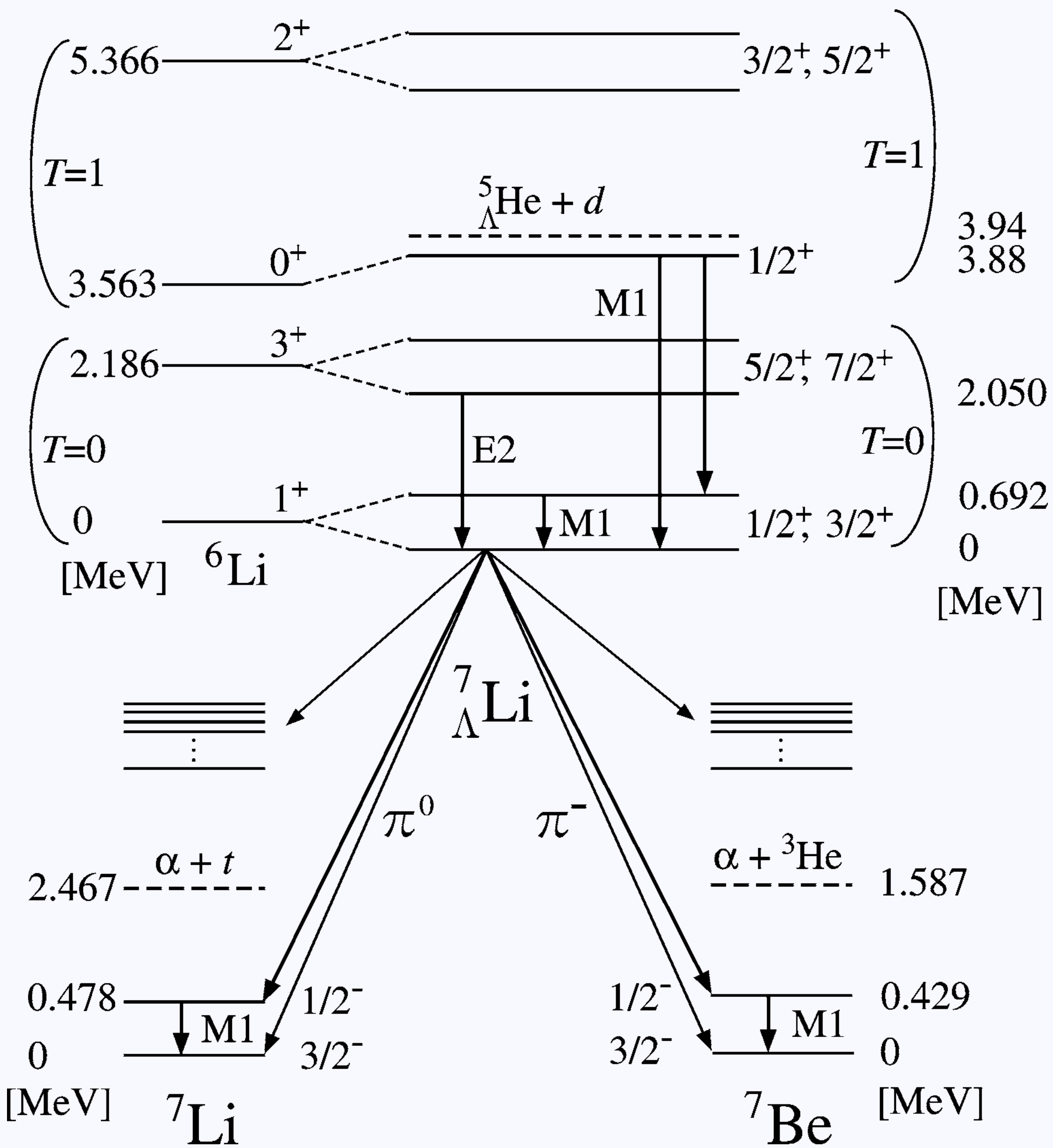
2. シングルΛハイパー核に対する崩壊π中間子分光

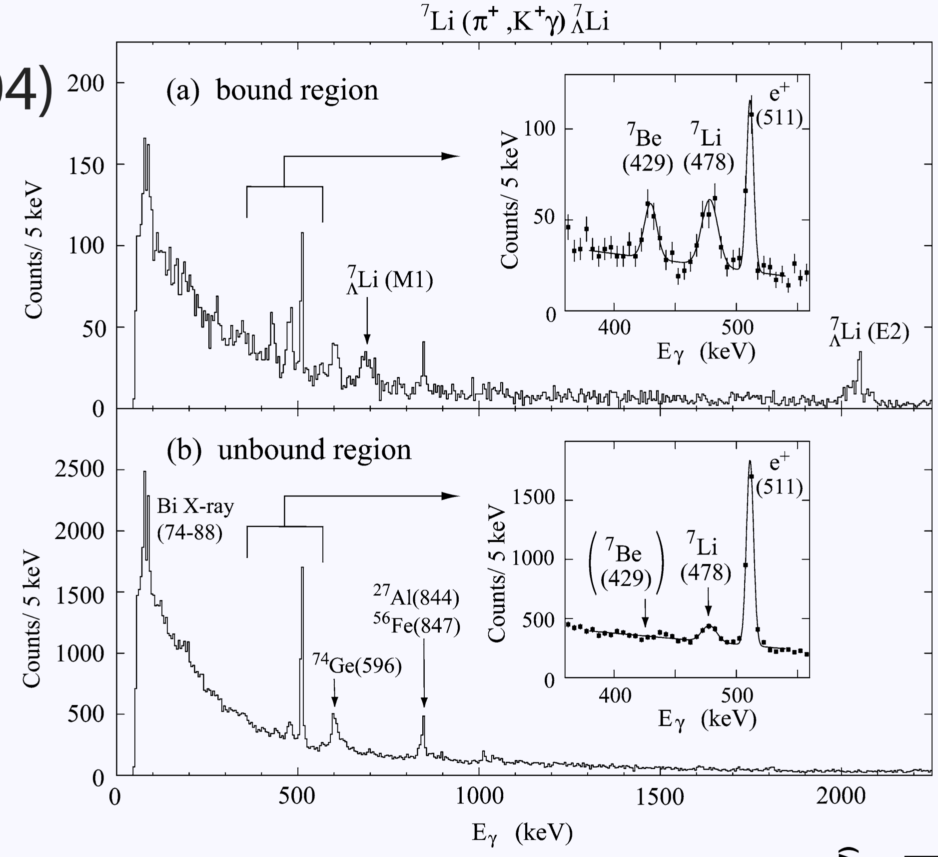
$$^7\mathrm{Li}(\pi^+, K^+)^7_\Lambda\mathrm{Li}^{(*)} \Longrightarrow \begin{cases} ^7_\Lambda\mathrm{Li} \to {}^7\mathrm{Be} + \pi^- \\ ^6_\Lambda\mathrm{He} \to {}^6\mathrm{Li} + \pi^- \\ ^4_\Lambda\mathrm{H} \to {}^4\mathrm{He} + \pi^- \\ ^3_\Lambda\mathrm{H} \to {}^3\mathrm{He} + \pi^- \end{cases}$$

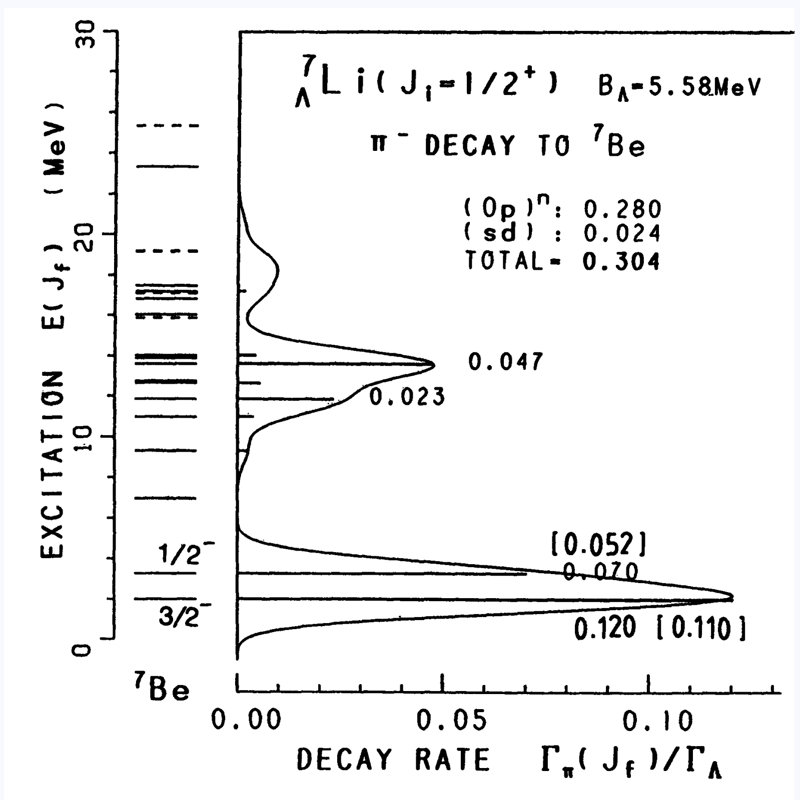
cf. $^5{}_\Lambda$He は準二体崩壊 (^{5}Li+π^-)

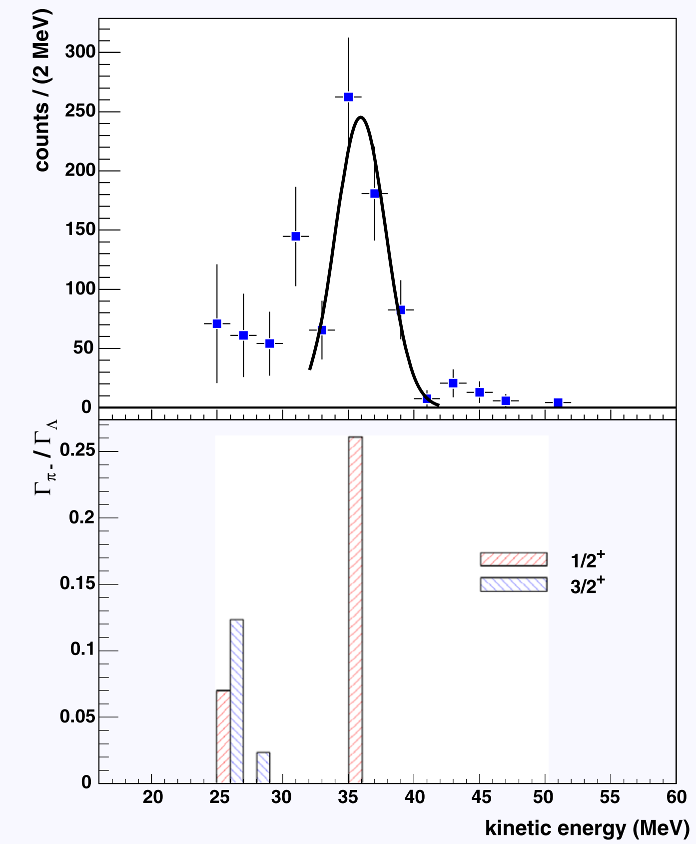
7Li に対する崩壊π中間子分光

J. Sasao et al., Phys. Lett. B 579, 258-264 (2004)









T. Motoba, K. Itonaga, PTPS 117, 477 (1994)　FINUDA collaboration, PLB 681, 139 (2009)

$^{6}{}_{\Lambda}$He?

αコア+Λスキン+中性子ハロー

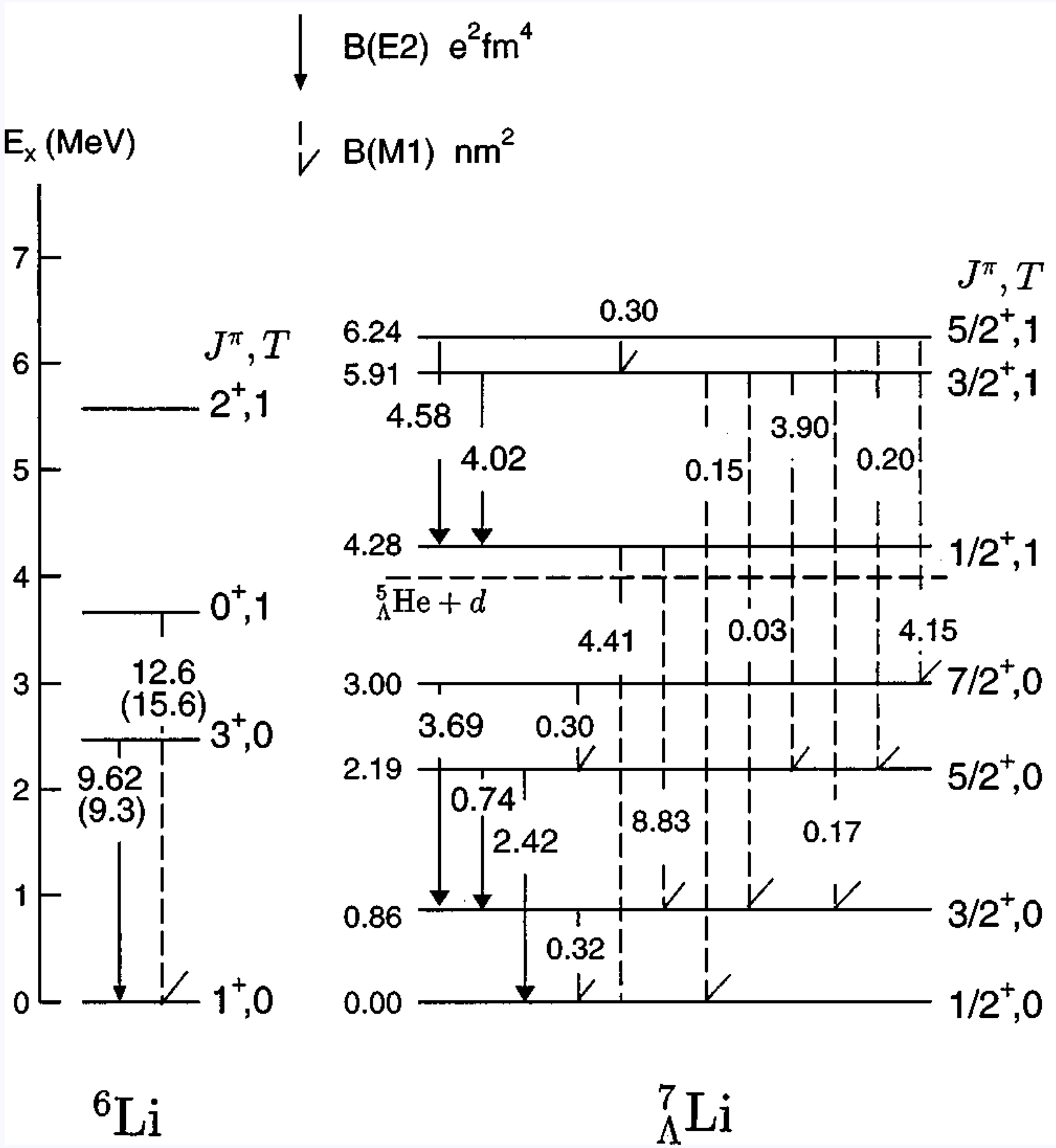


FIG. 2. Calculated $B(E2)$ and $B(M1)$ values for ^{6}Li and $^{7}_{\Lambda}$Li. The observed values for ^{6}Li are in parentheses. The particle-decay thresholds are 3.94 MeV ($^{5}_{\Lambda}$He$+d$), 5.58 MeV (^{6}Li$+\Lambda$), 5.99 MeV ($^{6}_{\Lambda}$He$+p$), and 6.16 MeV ($^{5}_{\Lambda}$He$+p+n$).

Hiyama et al., PRC 59, 2351 (1999)

$^{6}_{\Lambda}\mathrm{He} + p$

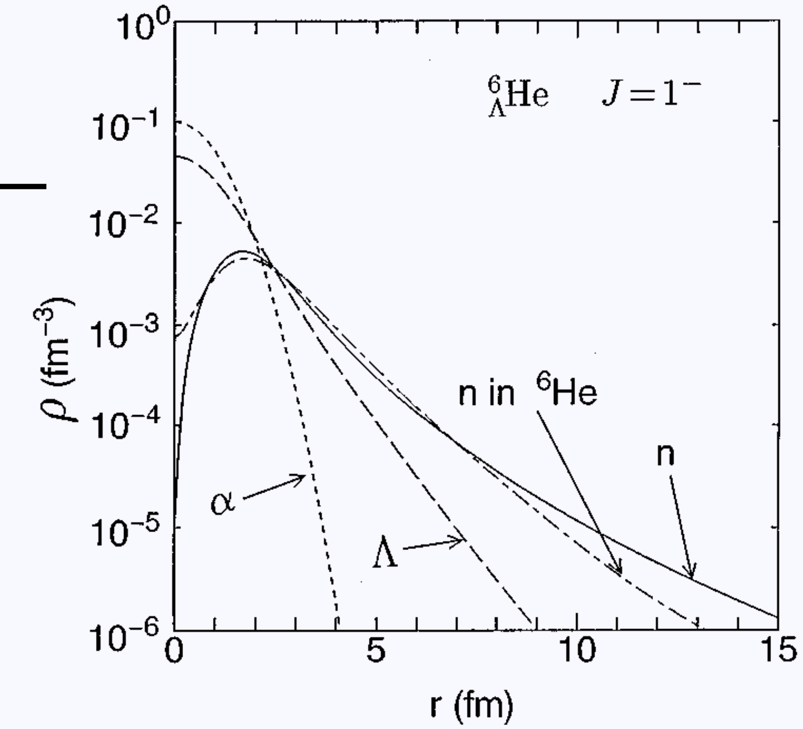


FIG. 2. Density distribution of the valence neutron, ρ_n, in the ground state of $^{6}_{\Lambda}$He together with those of the Λ particle, ρ_Λ, and a single nucleon in the α core. The radius r is measured from the c.m. of the α core.

Hiyama et al., PRC 53, 2075 (1996)

MAMI の次の実験

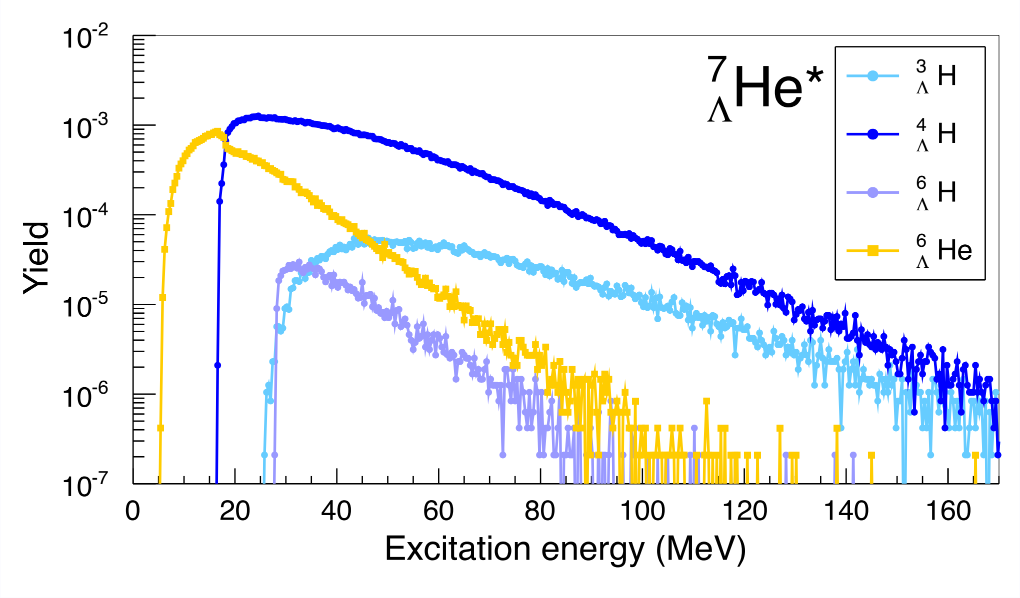
High-Precision Measurement of the Hypertriton Mass

PoS(Hadron2017)207

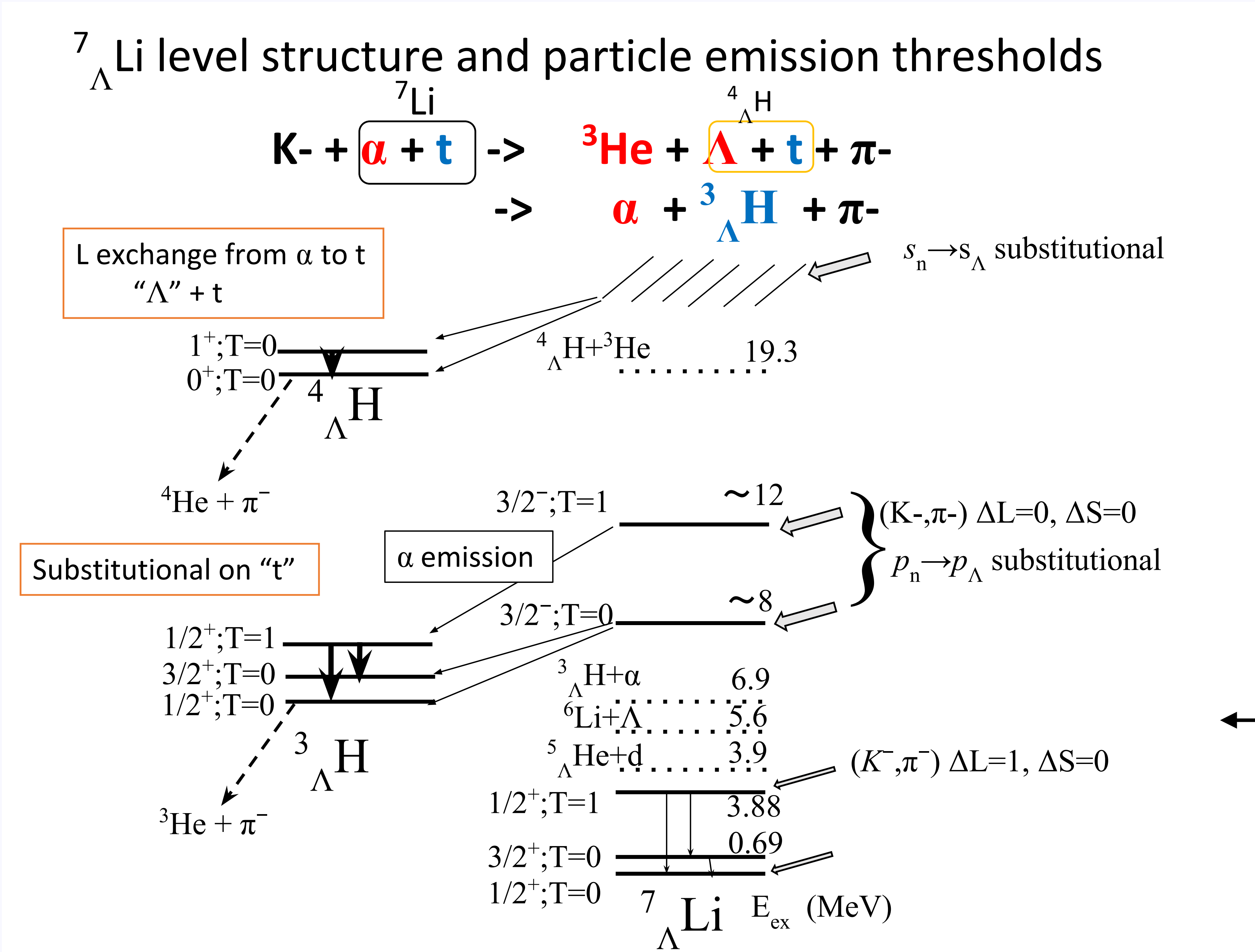
Patrick Achenbach*, Sebastian Bleser, Josef Pochodzalla*, Marcell Steinen
Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, Germany
and Helmholtz Institute Mainz, Germany
E-mail: achenbach@uni-mainz.de, pochodza@uni-mainz.de

^{7}Li標的を用いると、$^{6}_{\Lambda}$Heが比較的多く生成される

		^{9}Be target			^{7}Li target	^{6}Li target
$^{A}_{\Lambda}Z$	p_{π} (MeV/c)	$^{9}_{\Lambda}$Li*	$^{8}_{\Lambda}$Li*	$^{8}_{\Lambda}$He*	$^{7}_{\Lambda}$He*	$^{6}_{\Lambda}$He*
$^{3}_{\Lambda}$H	114.37 ± 0.08	0.56	1.18	0.67	1.49	2.48
$^{4}_{\Lambda}$H	132.87 ± 0.06	3.56	3.74	7.51	12.61	8.81
$^{6}_{\Lambda}$H	135.13 ± 1.52	0.03	<0.01	0.23	0.10	–
$^{6}_{\Lambda}$He	108.47 ± 0.18	2.44	1.25	1.47	3.53	–
$^{7}_{\Lambda}$He	$114.97 \pm 0.15 \pm 0.17$	2.12	0.44	1.35	–	–
$^{8}_{\Lambda}$He	116.50 ± 1.08	0.04	–	–	–	–
$^{7}_{\Lambda}$Li	108.11 ± 0.05	1.54	1.68	–	–	–
$^{8}_{\Lambda}$Li	124.20 ± 0.05	0.85	–	–	–	–



$^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H



$^{6}_{\Lambda}\mathrm{He} + p$ ←

鵜養氏 第4回『ストレンジネス核物理を考える会』(2017.8.7) より

O. Hashimoto and H. Tamura, PPNP 57, 564 (2006)

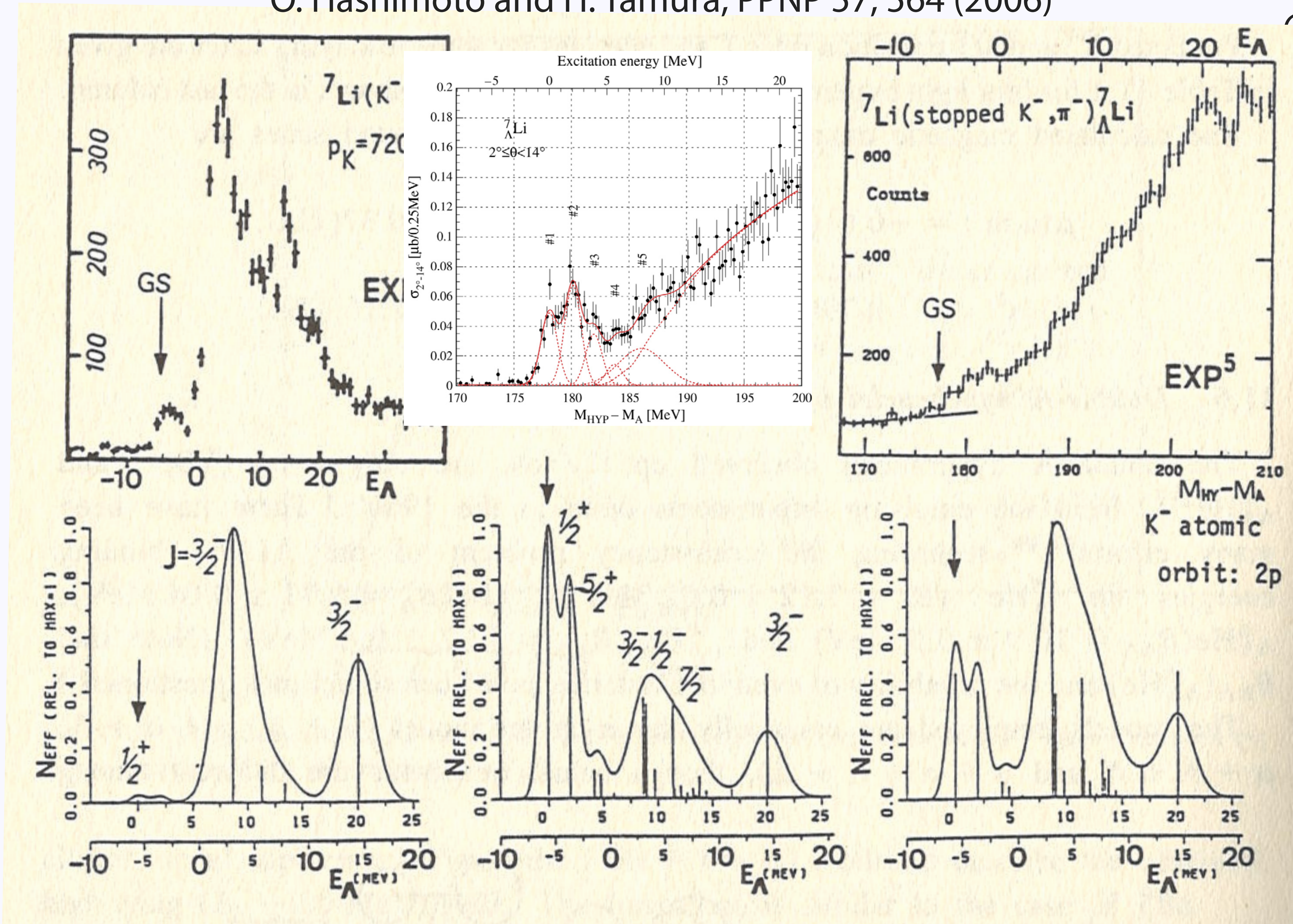
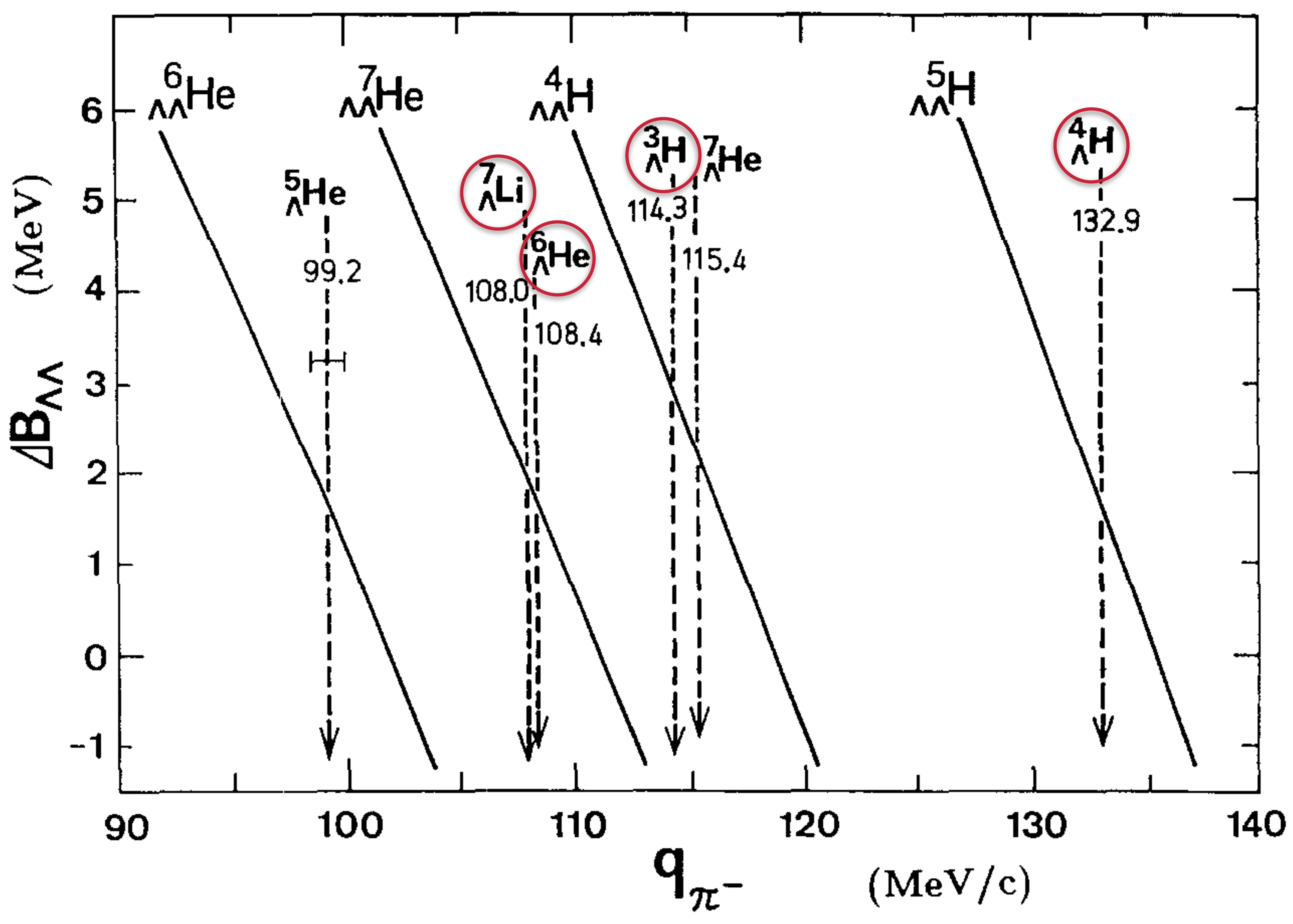


Fig. 11.10. Experimental[59,243,244] and theoretical excitation functions for the inflight (K^-, π^-), (π^+, K^+) and (K^- *stopped*, π^-) reactions producing $^7_\Lambda$Li. The (π^+, K^+) data are not available yet. Comments as for Fig. 11.7.

H. Bandō, T. Motoba, J. Zofka, Int. J.Mod. Phys. A 5, 4021(1990)



$^{6}_{\Lambda\Lambda}$He
$^{7}_{\Lambda\Lambda}$He
$^{4}_{\Lambda\Lambda}$H
$^{5}_{\Lambda\Lambda}$H
$^{5}_{\Lambda}$He
99.2
$^{7}_{\Lambda}$Li
108.0
$^{6}_{\Lambda}$He
108.4
$^{3}_{\Lambda}$H
114.3
$^{7}_{\Lambda}$He
115.4
$^{4}_{\Lambda}$H
132.9
$\Delta B_{\Lambda\Lambda}$ (MeV)
q_{π^-} (MeV/c)

結論

- $^{5}_{\Lambda\Lambda}$H の崩壊π中間子分光実験を計画中
  - $^{7}_{\Xi}$Hの崩壊 or ダブルΛ複合核 経由で $^{5}_{\Lambda\Lambda}$H を生成
  - 娘ハイパー核 $^{5}_{\Lambda}$He の NMWD 由来の陽子をタグ
- パイロット実験として ^{7}Li(π^{+},K^{+}) 反応による $^{3,4}_{\Lambda}$H, $^{6}_{\Lambda}$He, $^{7}_{\Lambda}$Li の崩壊π中間子分光を検討中
  - J-PARC においてハドロンビームを用いた崩壊π中間子分光による束縛エネルギー決定の原理実証を兼ねる