東京工業大学
Tokyo Institute of Technology

${}^{5}_{\Lambda\Lambda}\mathrm{H}$ production experiment by use of ${}^{7}_{\Xi^-}\mathrm{H}$ production and decay at J-PARC

H. Fujioka (Tokyo Tech),
T. Fukuda, E. Hiyama, T. Motoba,
T. Nagae, S. Nagao, T. Takahashi

Letter of Intent for J-PARC 50 GeV Synchrotron

Feel free to contact me (fujioka[at]phys.titech.ac.jp) if you need a pdf file.

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

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[4] *RIKEN Nishina Center*

[5] *Yukawa Instutute for Theoretical Physics, Kyoto University*

[6] *Department of Physics, Kyoto University*

[7] *Institute for Excellence in Higher Education, Tohoku University*

[8] *Institute of Particle and Nuclear Studies, High Energy Accelerator Research Organization*

June 15, 2018

Abstract

Proposed is a novel method to produce a double-Λ hypernucleus without using nuclear emulsion. A Ξ^- bound in ${}^{6}\mathrm{He}$ and a part of quasi-free Ξ^-'s, produced in ${}^{7}\mathrm{Li}(K^-, K^+)$ reactions, are absorbed in the reaction point, and ${}_{\Lambda\Lambda}^{5}\mathrm{H}$ may be formed via $\Xi^- p \to \Lambda\Lambda$ conversion. Decay pion spectroscopy for ${}_{\Lambda\Lambda}^{5}\mathrm{H} \to {}_{\Lambda}^{5}\mathrm{He} + \pi^-$ will be performed after event selection requiring a fast proton from non-mesonic weak decay of ${}_{\Lambda}^{5}\mathrm{He}$. 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.

Letter of Intent for J-PARC 50 GeV Synchrotron

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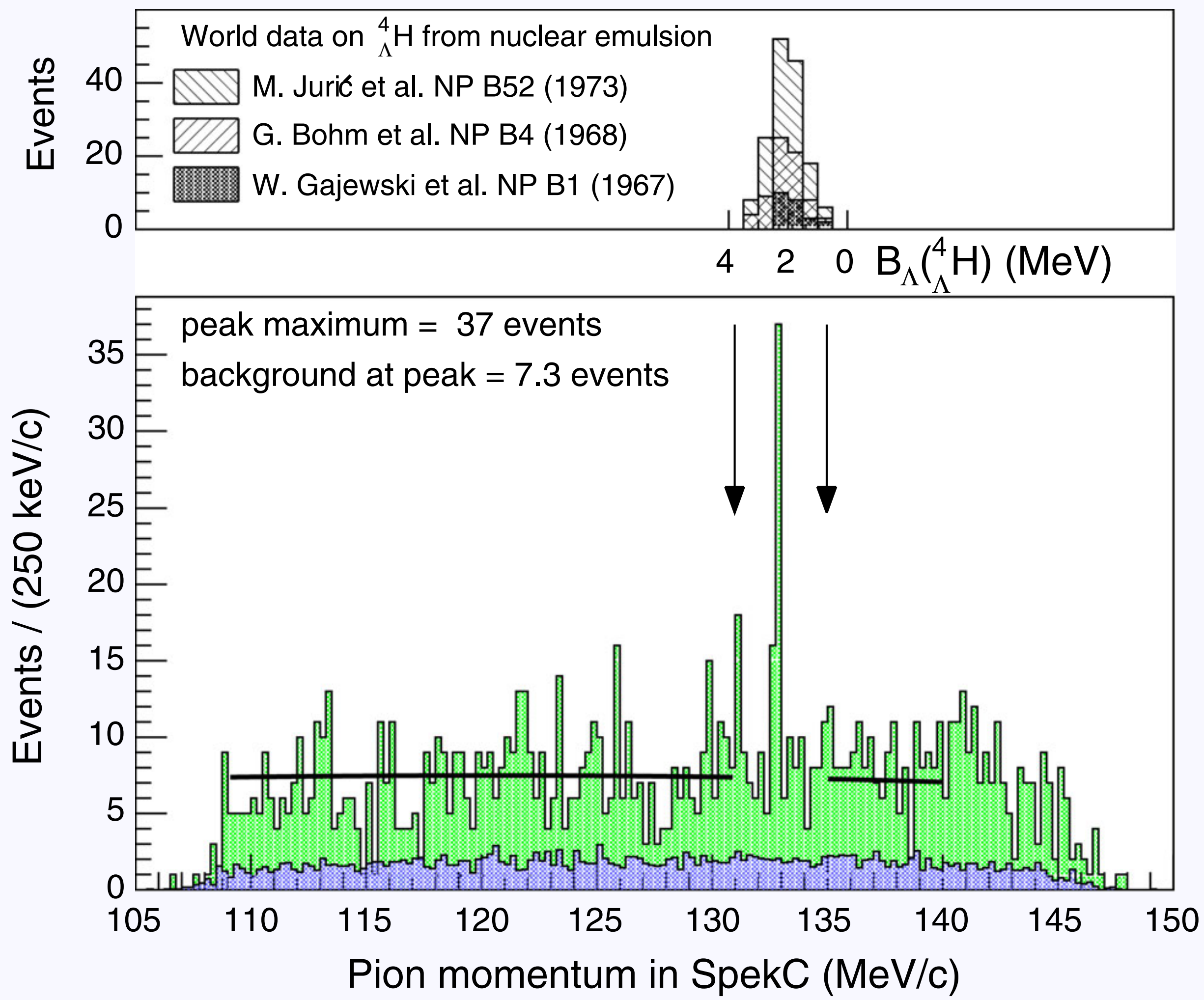
Decay pion spectroscopy

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



A. Esser et al.,
PRL **114**, 232501 (2015)
A1 Collaboration,
NPA **960**, 165 (2017)

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

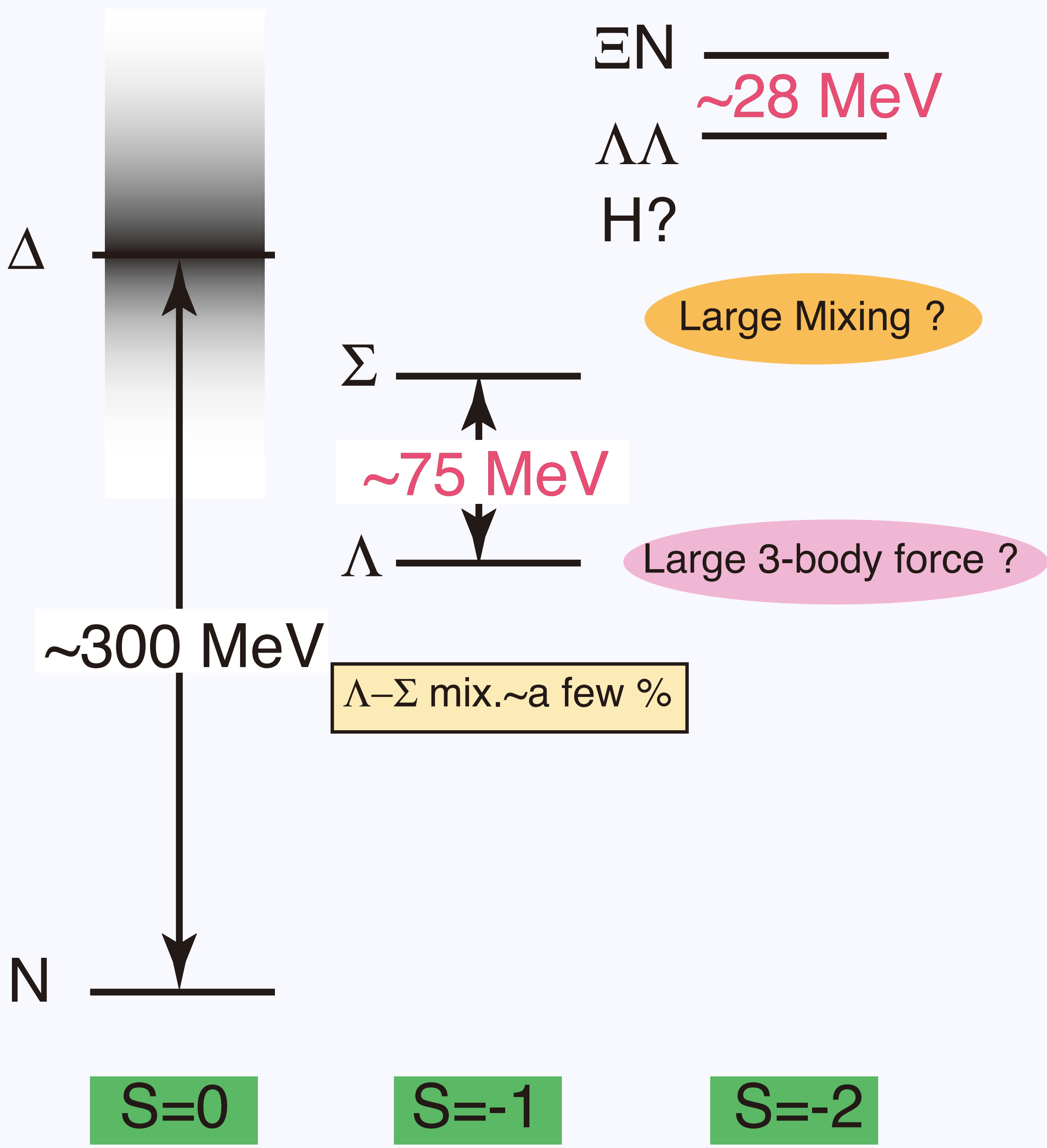
"mass production"
(>10 /month identified)
w/o using emulsion

Contents

1. Physics Motivation
— Structure of $^{5}_{\Lambda\Lambda}\mathrm{H}$
2. Experimental Principle
a) Production of $^{5}_{\Lambda\Lambda}\mathrm{H}$
b) Identification of $^{5}_{\Lambda\Lambda}\mathrm{H}$
3. Experimental Setup

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

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



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

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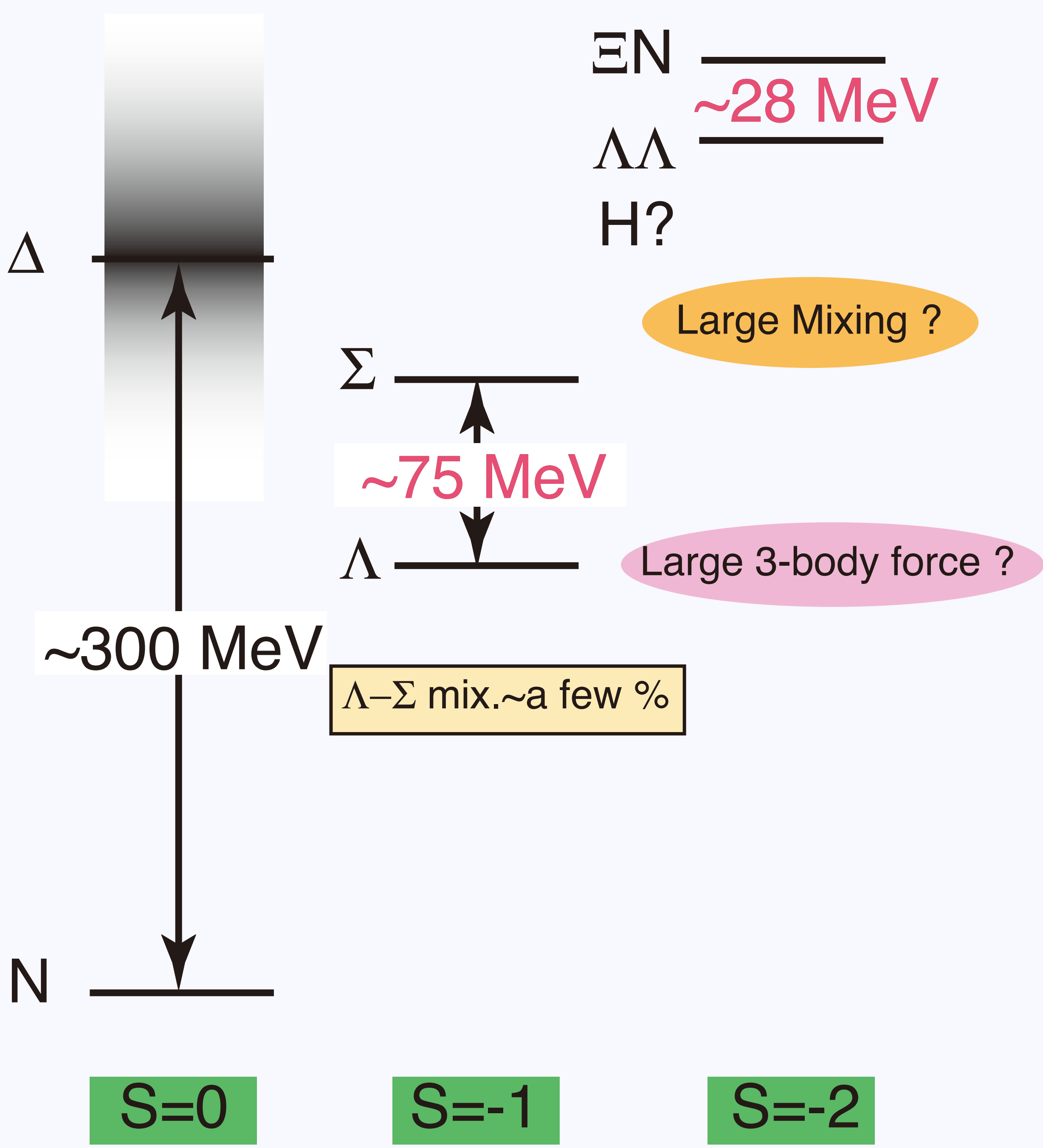
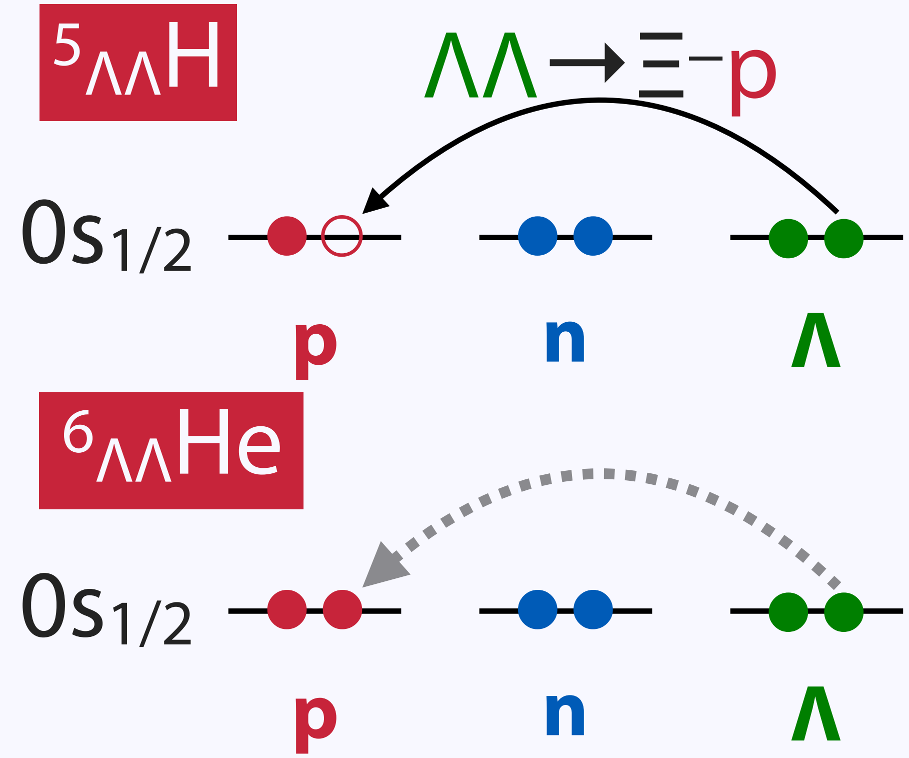
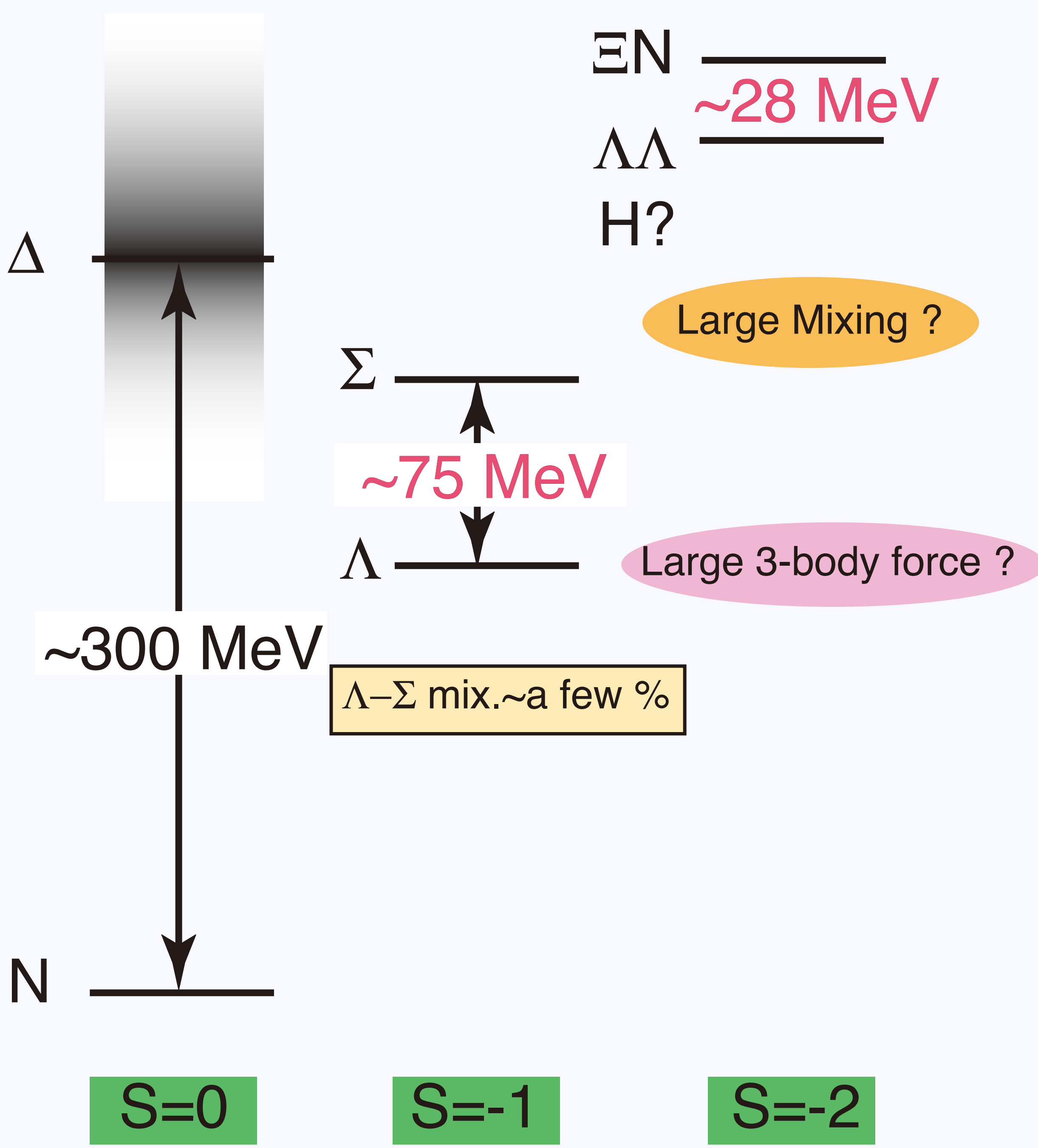
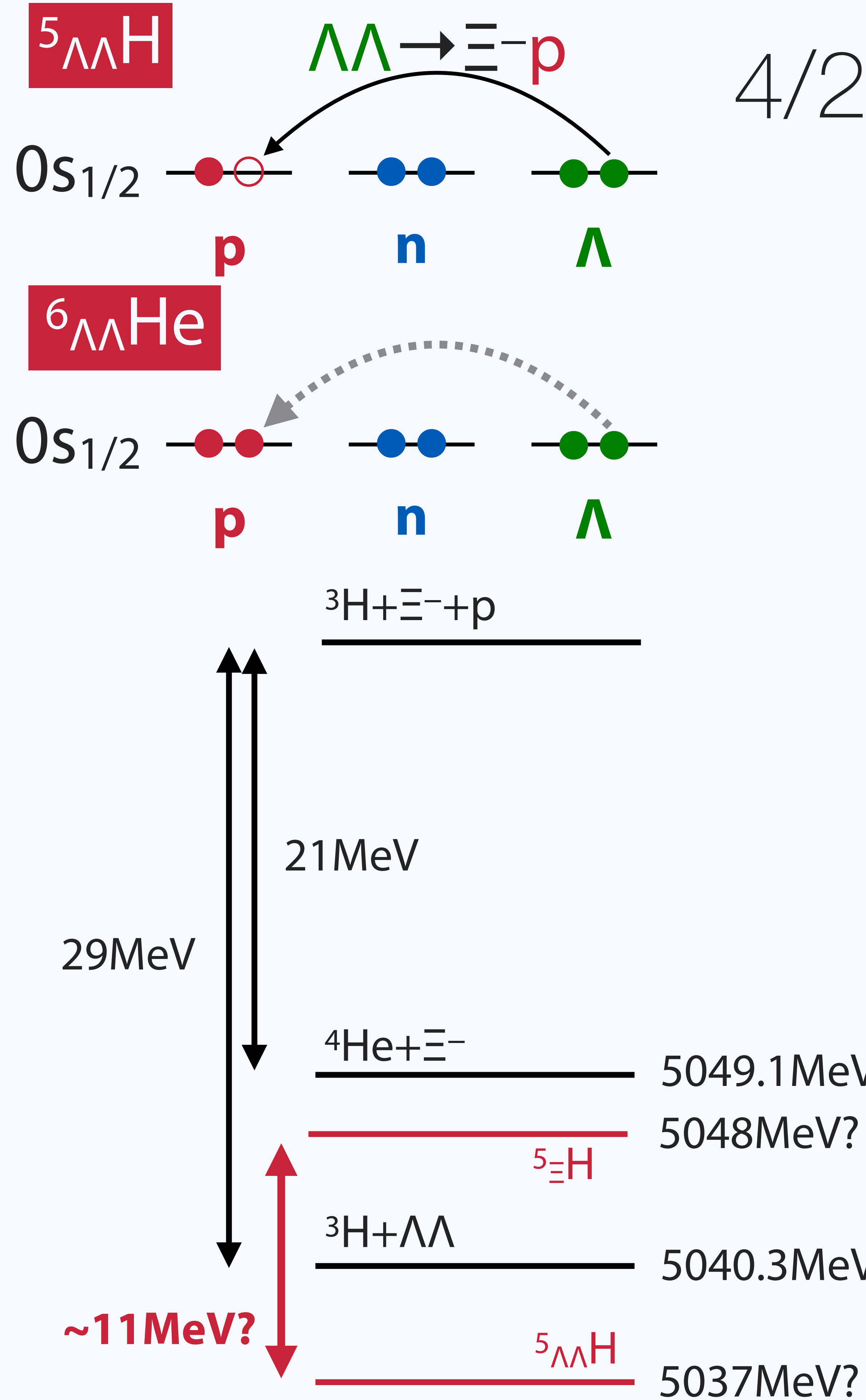




ΛΛ-ΞN mixing in ${}^{5}_{\Lambda\Lambda}$H

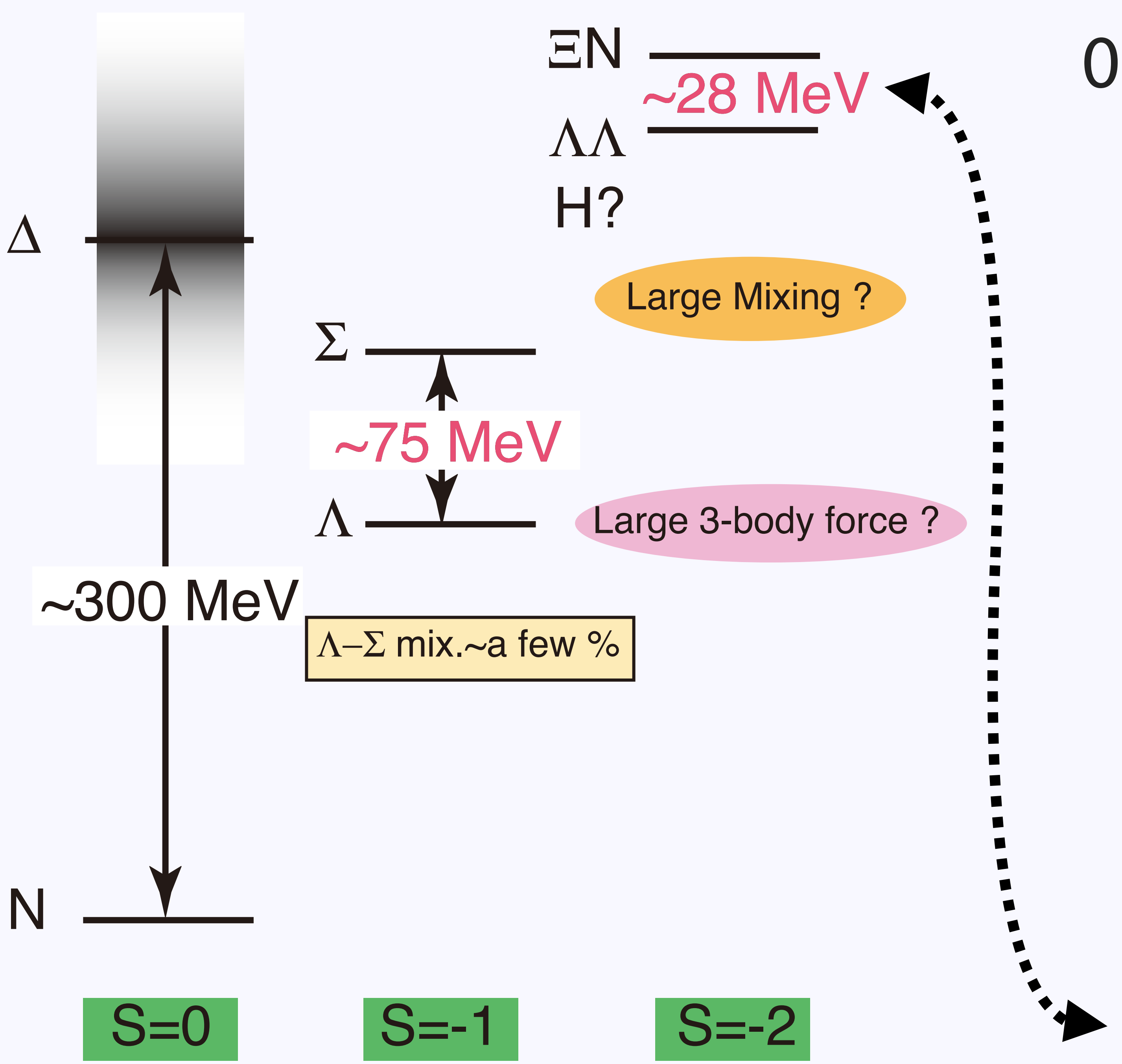
B.F. Gibson et al.,
Prog. Theor. Phys. Suppl. **117**, 339 (1994)

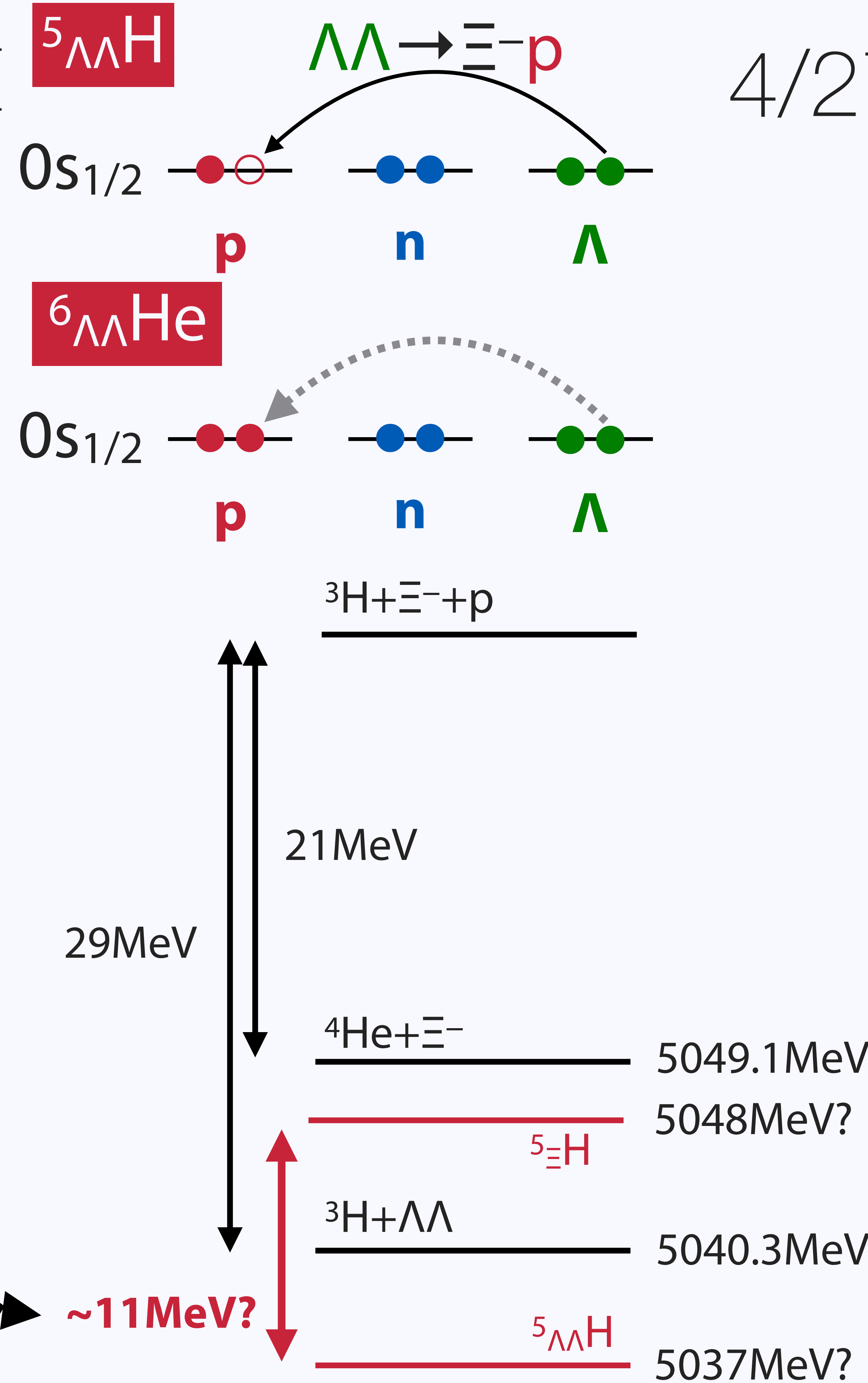


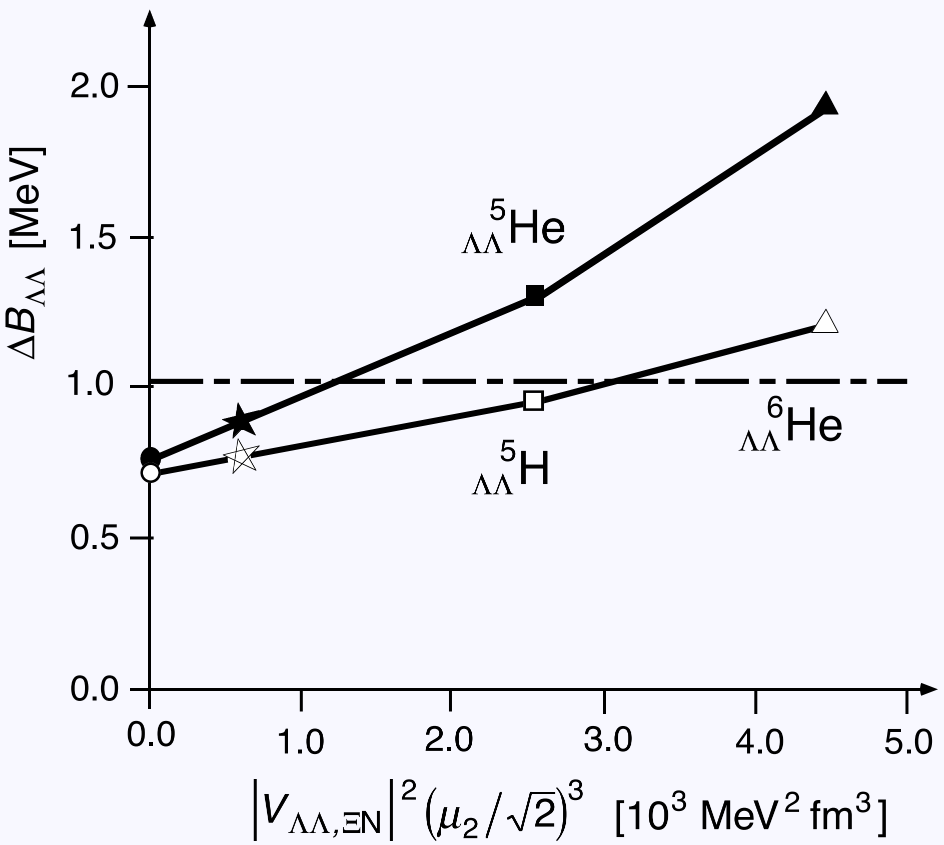


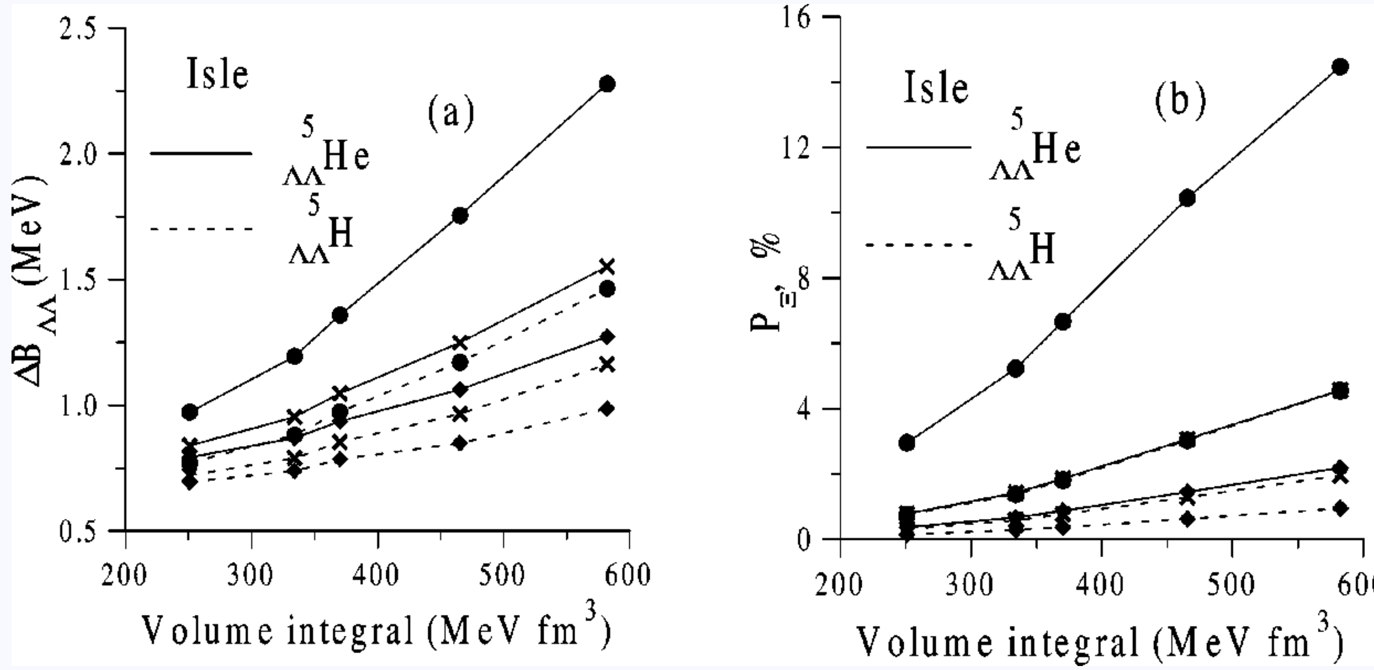
ΛΛ-ΞN mixing in ${}^{5}_{\Lambda\Lambda}\mathrm{H}$

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



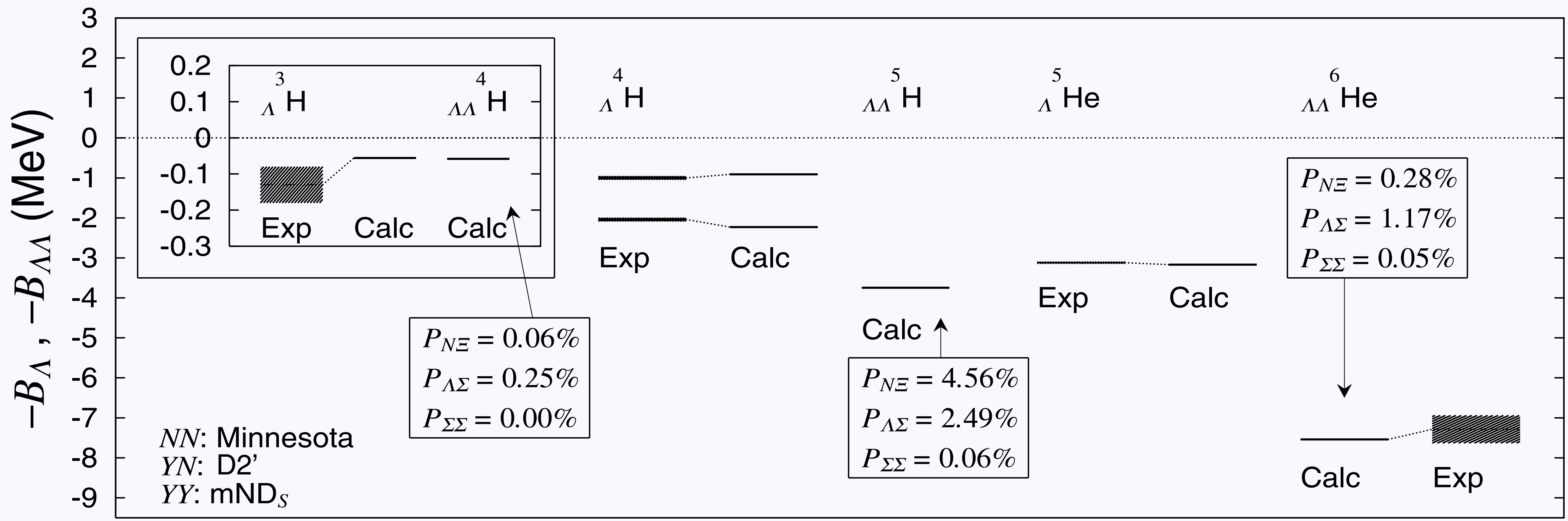




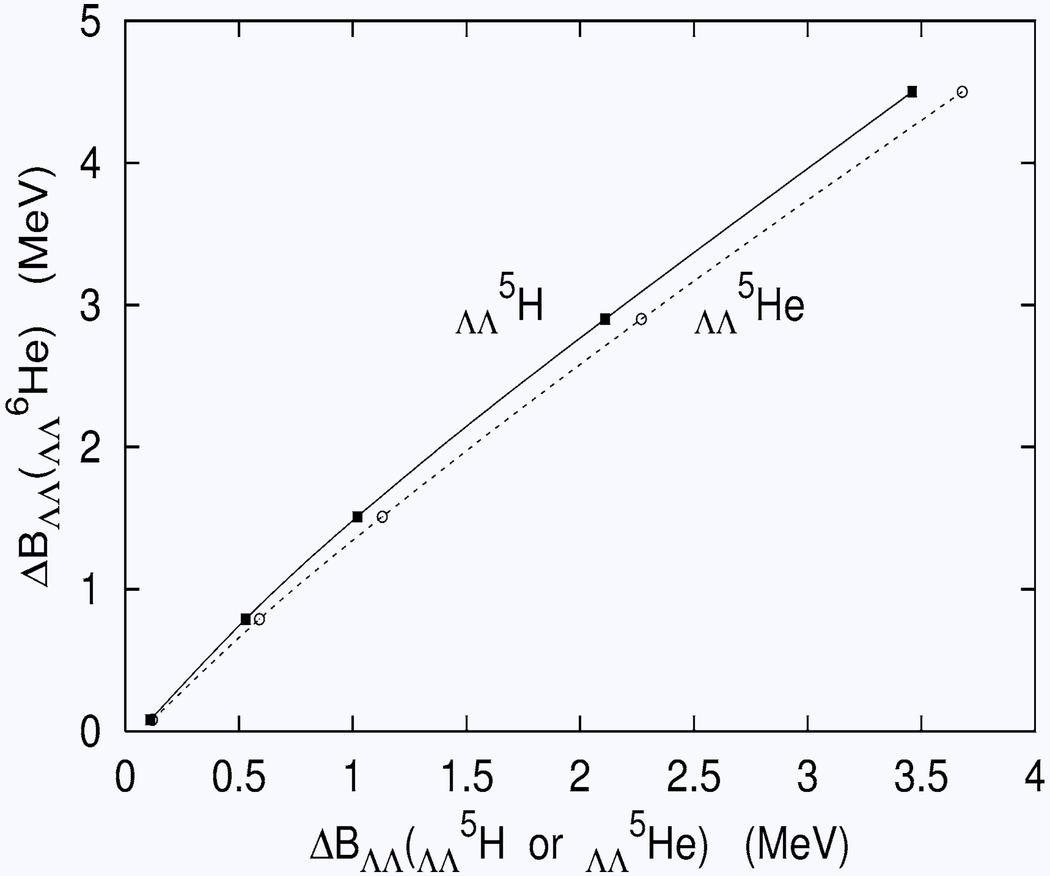


D. E. Lanskoy and Y. Yamamoto, Phys. Rev. C **69**, 014303 (2004)

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



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 $B_{\Lambda\Lambda}(^{6}_{\Lambda\Lambda}\mathrm{He})$, we have argued that the $\Lambda\Lambda$-ΞN coupling effect should not exceed 0.2 MeV in $^{6}_{\Lambda\Lambda}$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 $^{5}_{\Lambda\Lambda}$H.

- caveat: the ΛΛ interaction might be too strong so as to account for the "old" binding energy of $^{6}_{\Lambda\Lambda}$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 $^{5}_{\Lambda\Lambda}$H and $^{6}_{\Lambda\Lambda}$He will be very important.

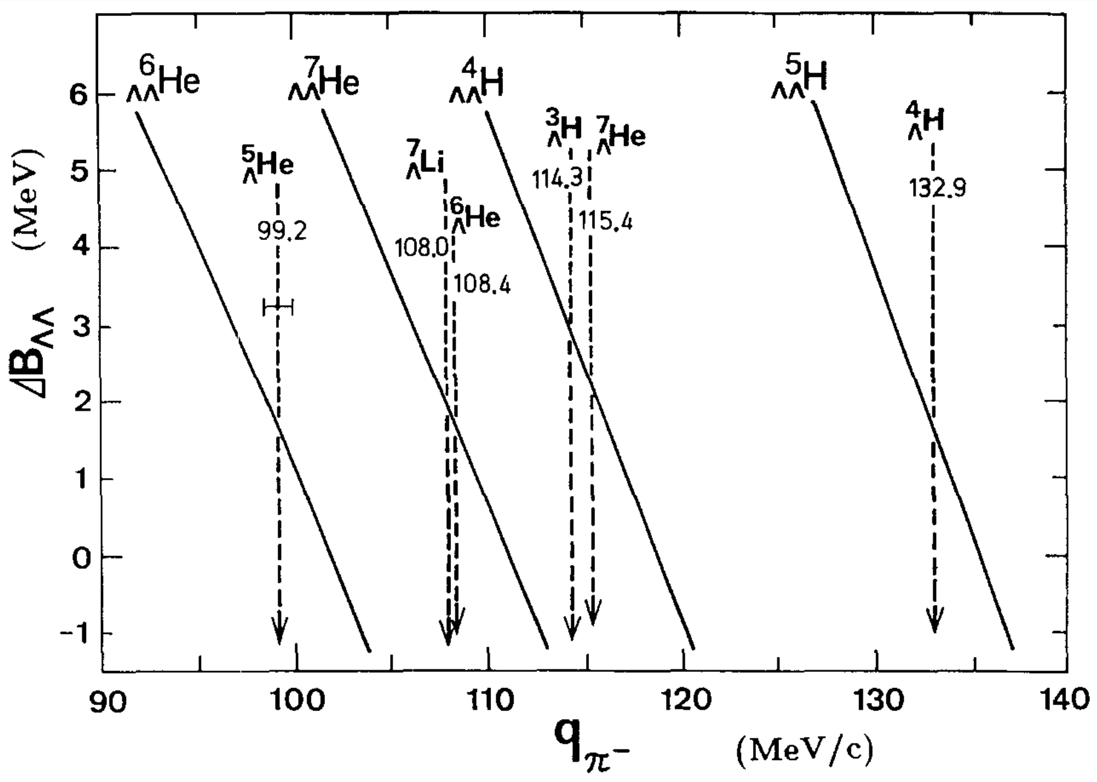
From an experimental point of view

- Two-body pionic decay possible $^{5}_{\Lambda\Lambda}\mathrm{H} \to {}^{5}_{\Lambda}\mathrm{He} + \pi^-$
  cf. $^{6}_{\Lambda\Lambda}\mathrm{He} \to {}^{6}_{\Lambda}\mathrm{Li} + \pi^- \to {}^{5}_{\Lambda}\mathrm{He} + p + \pi^-$

- No excited state in the daughter hypernucleus
  cf. $^{4}_{\Lambda\Lambda}\mathrm{H} \to {}^{4}_{\Lambda}\mathrm{He}^{(*)} + \pi^-$

- Remarkably high momentum of decay pion
  - All but $^{4}_{\Lambda}\mathrm{H}$ are excluded from the region of interest

- **How to produce $^{5}_{\Lambda\Lambda}\mathrm{H}$, and how to distinguish it from $^{4}_{\Lambda}\mathrm{H}$?**



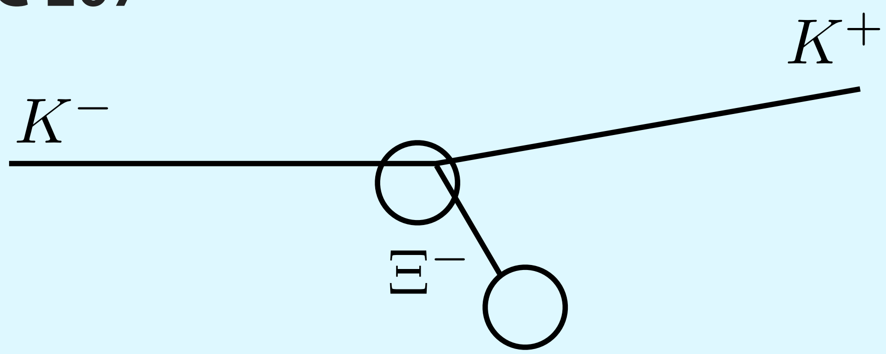
Y. Yamamoto, M. Wakai, T. Motoba and T. Fukuda, Nucl. Phys. A **625**, 107 (1997)

Production of double-Λ hypernuclei

Ξ⁻ capture at rest

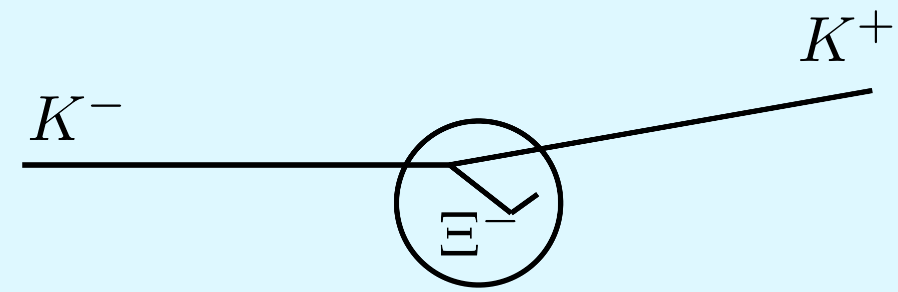
[emulsion exp.]
Danysz et al.,
KEK-PS E176, E373
J-PARC E07

[counter exp.]
BNL-AGS E885, E906
cf. $\overline{\text{P}}$ANDA ($\bar{p}p \to \Xi^-\Xi^+$)



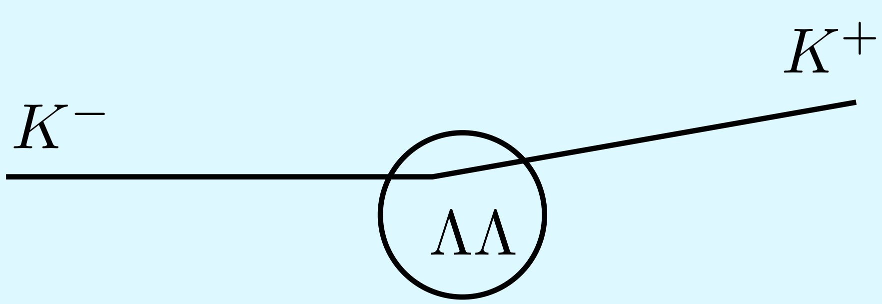
Quasi-free Ξ⁻ rescattering

BNL-AGS E906

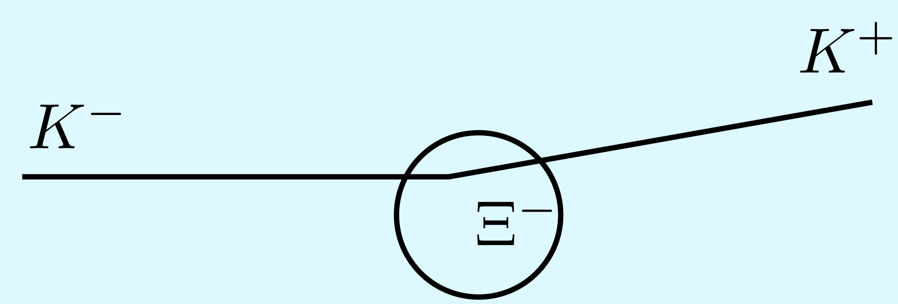


Direct production

BNL-AGS E885
planned at J-PARC (K1.8+”S-2S”)



Ξ-hypernuclear decay



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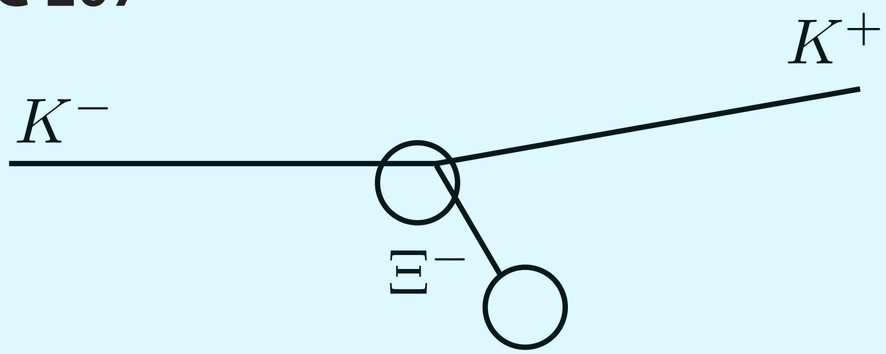
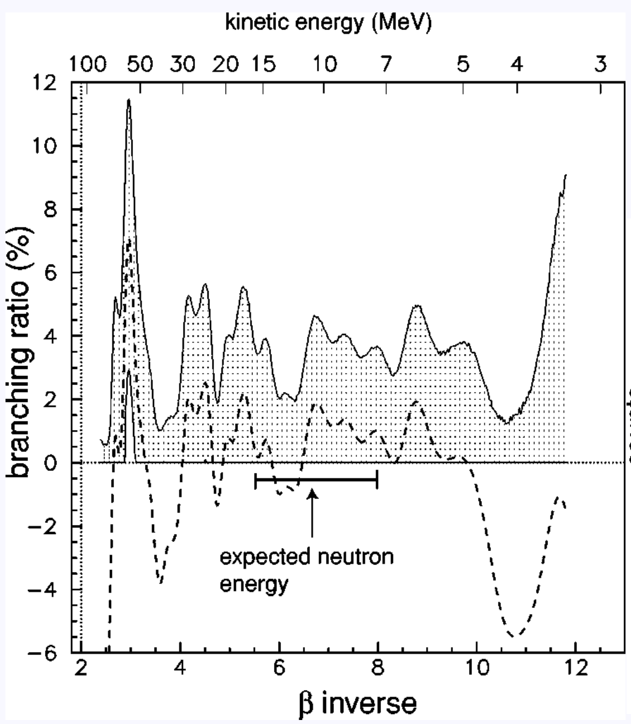
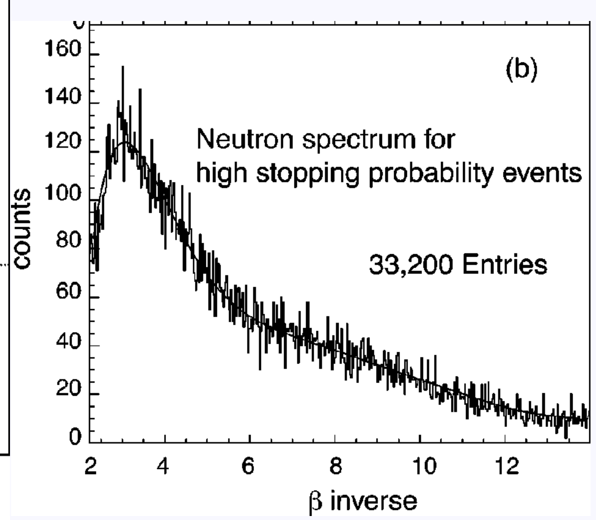


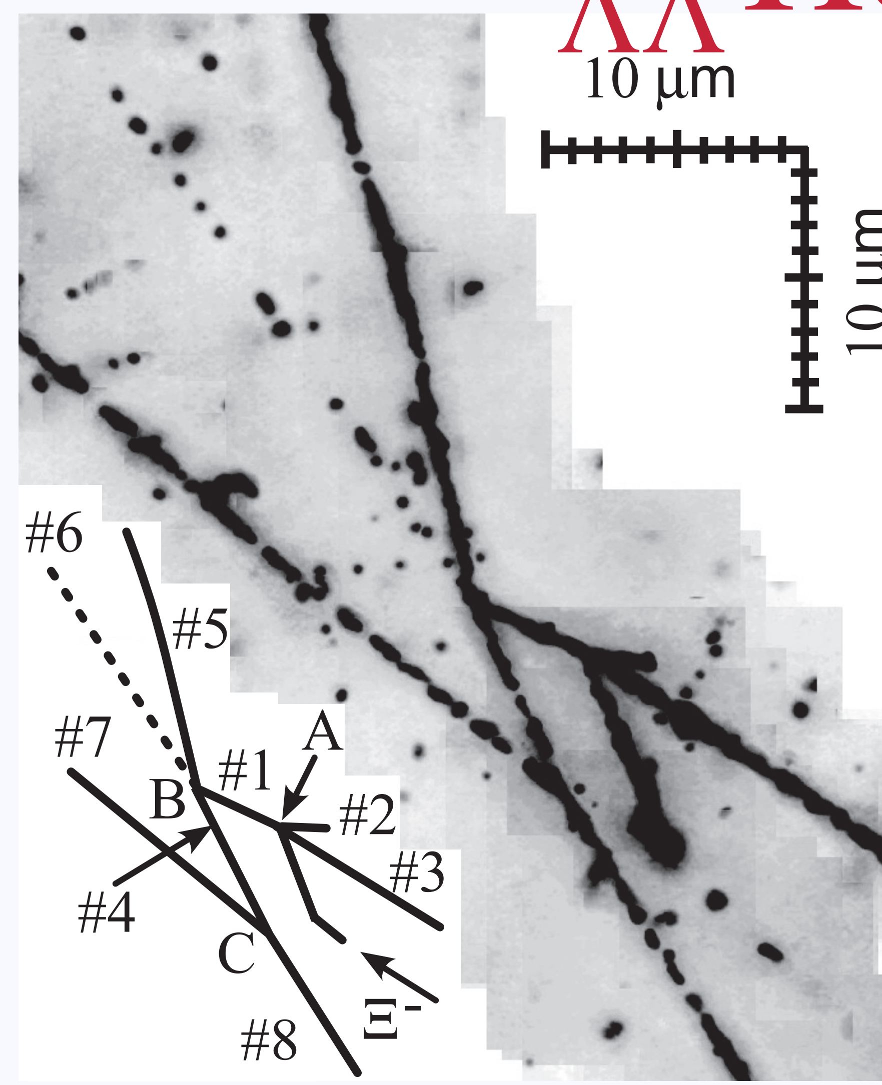
BNL-AGS E885 $(\Xi^-, {}^{12}\mathrm{C})_{\mathrm{atom}} \to {}^{12}_{\Lambda\Lambda}\mathrm{B} + n$



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



KEK-PS E373 ${}^{6}_{\Lambda\Lambda}\mathrm{He}$



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

J-PARC E07

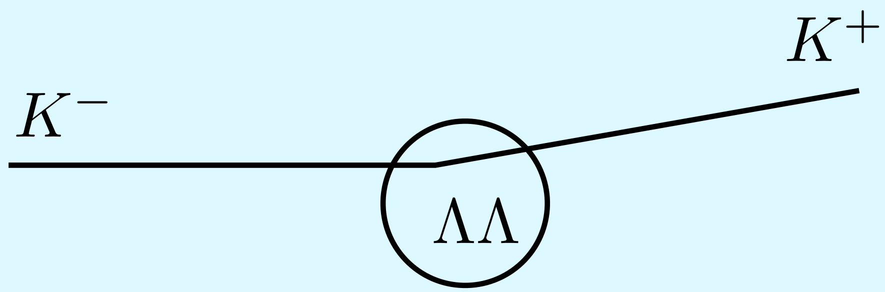
talk by Yoshida (Wed.)
posters by Ekawa, Hayakawa

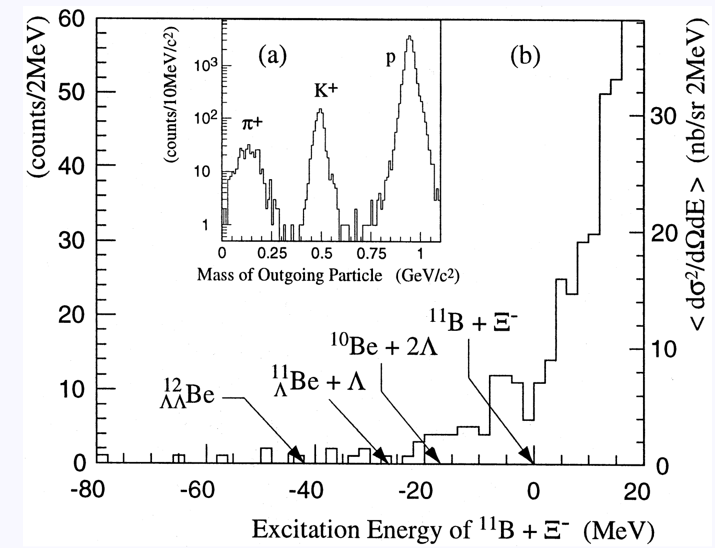
Production of double-Λ hypernuclei

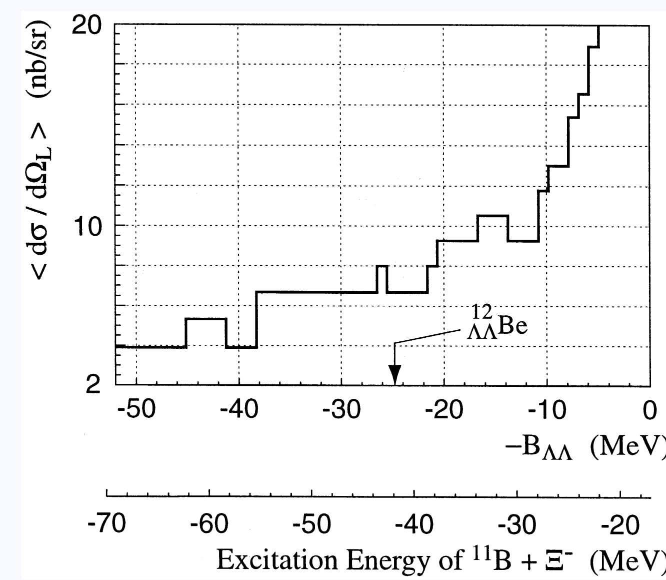
BNL-AGS E885 $^{12}\mathrm{C}(K^-,K^+)^{12}_{\Lambda\Lambda}\mathrm{Be}$

Direct production

BNL-AGS E885
planned at J-PARC (K1.8+"S-2S")

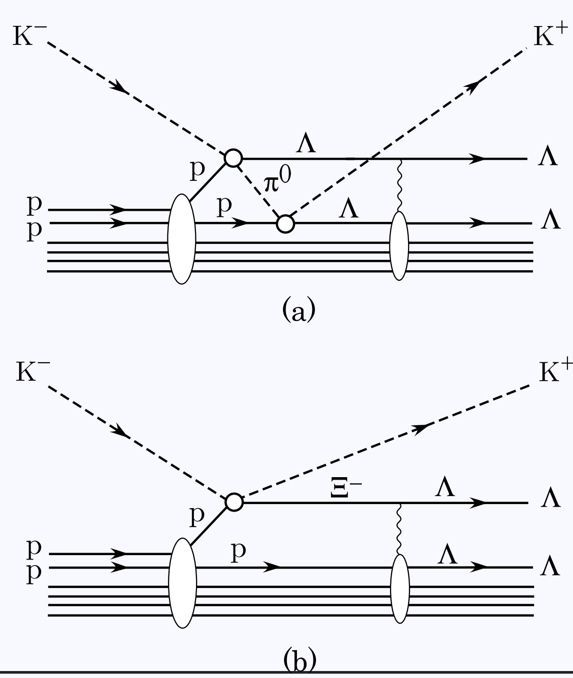


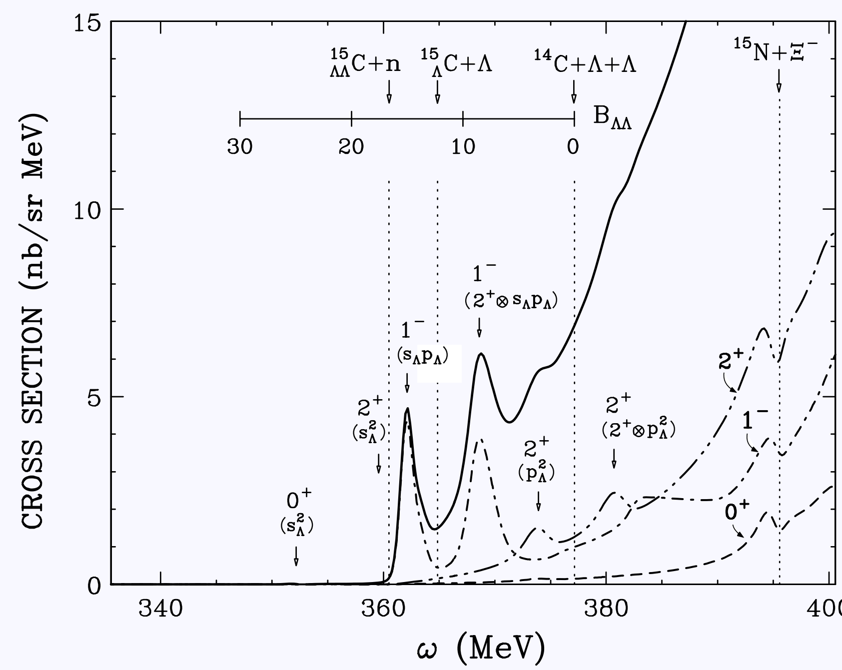




K. Yamamoto et al.,
Phys. Lett. B **478**, 401 (2000)

Theory $^{16}\mathrm{O}(K^-,K^+)^{16}_{\Lambda\Lambda}\mathrm{C}$



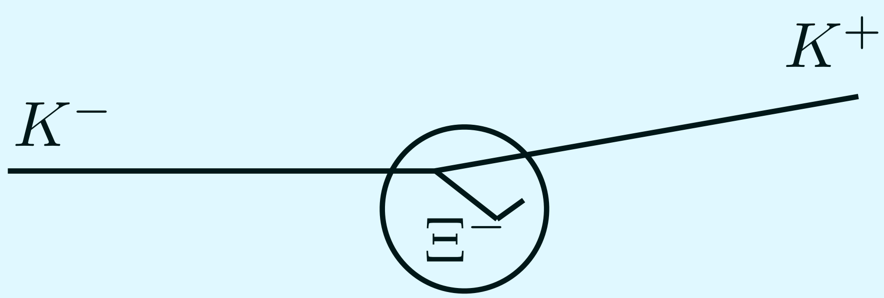


T. Harada, Y. Hirabayashi, A. Umeya,
Phys. Lett. B **690**, 363 (2010)

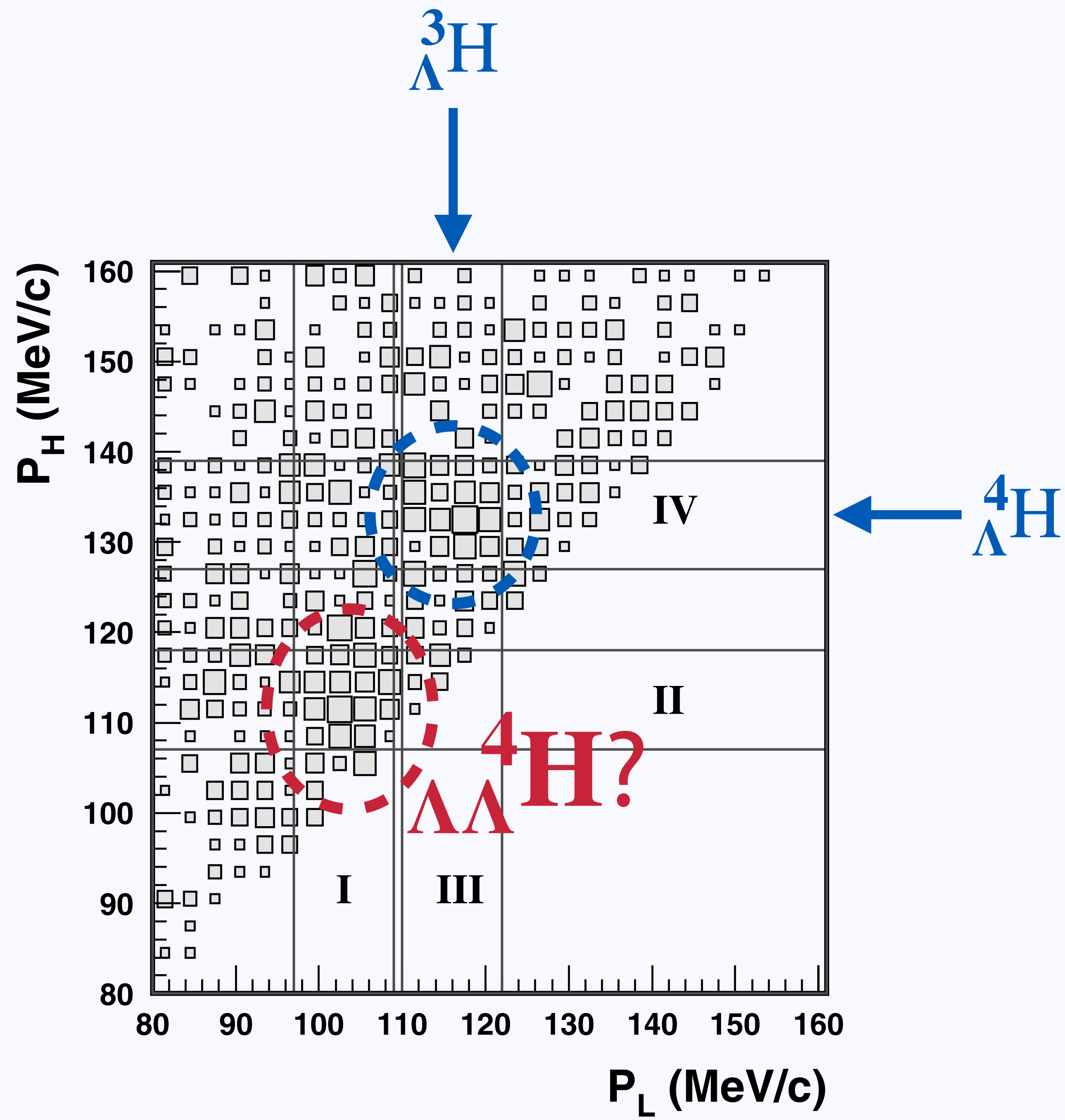
Production of double-Λ hypernuclei

Quasi-free Ξ^- rescattering

BNL-AGS E906



BNL-AGS E906



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

Theory

ΞN rescattering & ΞN-ΛΛ conversion

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

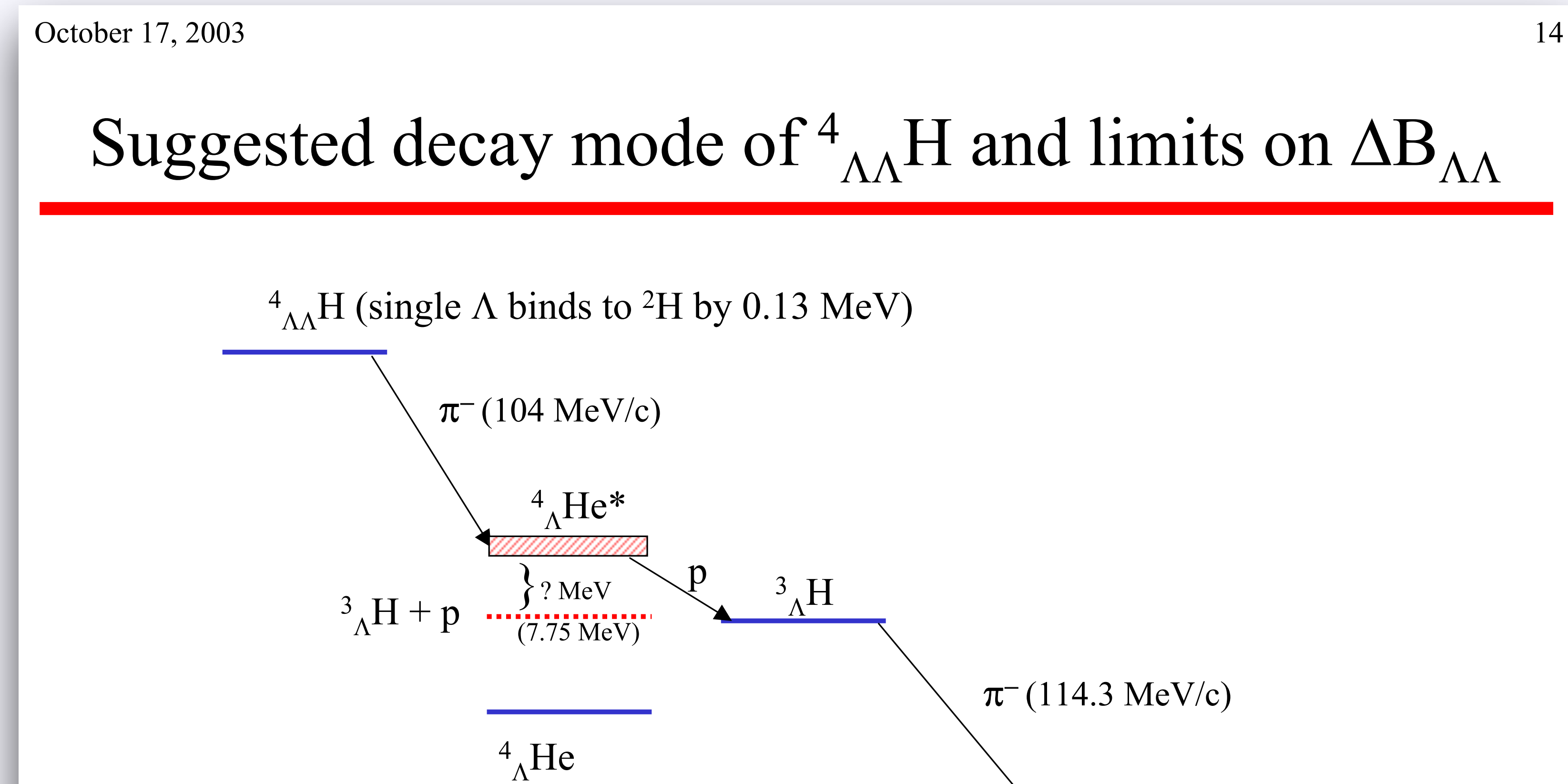
$$\longrightarrow \underline{\left[{}^{8}_{\Lambda\Lambda}\mathrm{H}^*\right]} + p$$

"double-Λ compound nucleus"

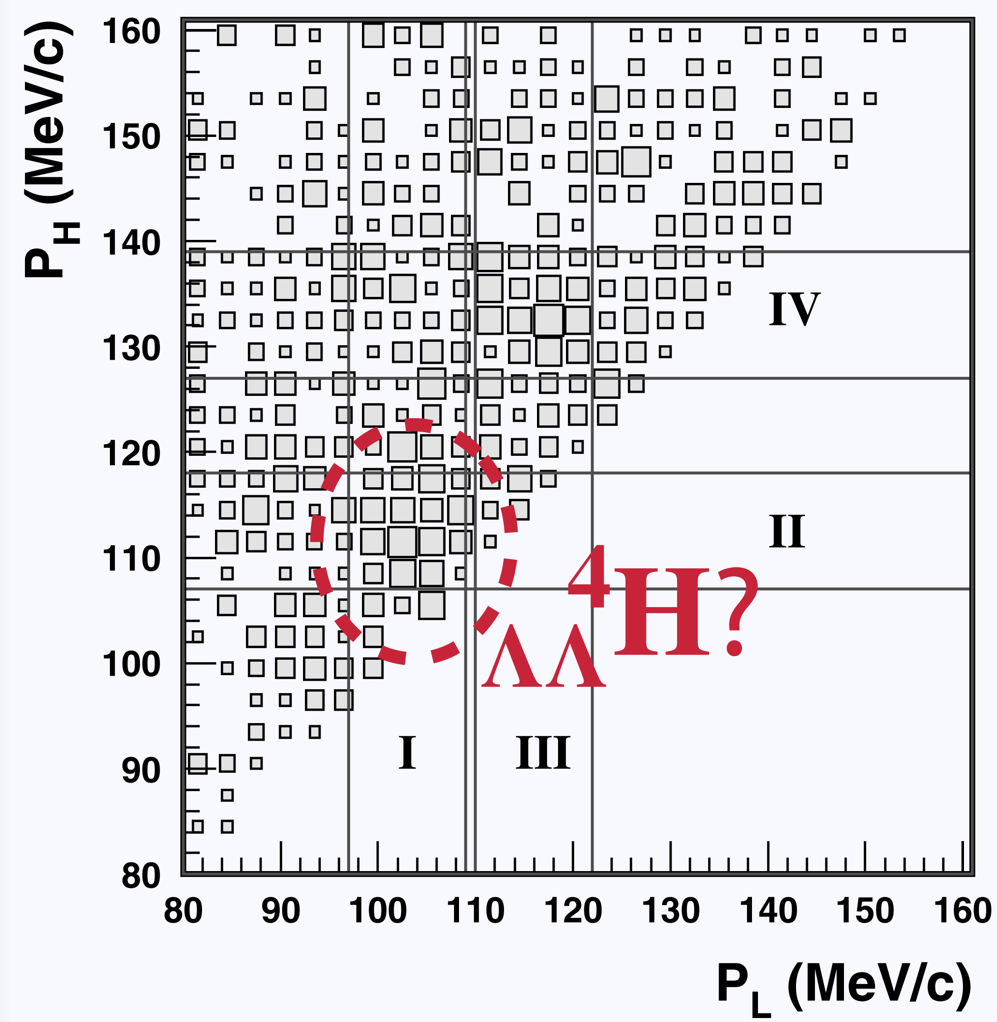
→ fragmented into double-Λ hypernuclei, single-Λ hypernuclei etc.

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

E906 experiment



$^{4}_{\Lambda}He$ excitation(MeV)	$\Delta B_{\Lambda\Lambda}$(MeV)
7.75	1.8
8.75	0.8
9.84	-0.26



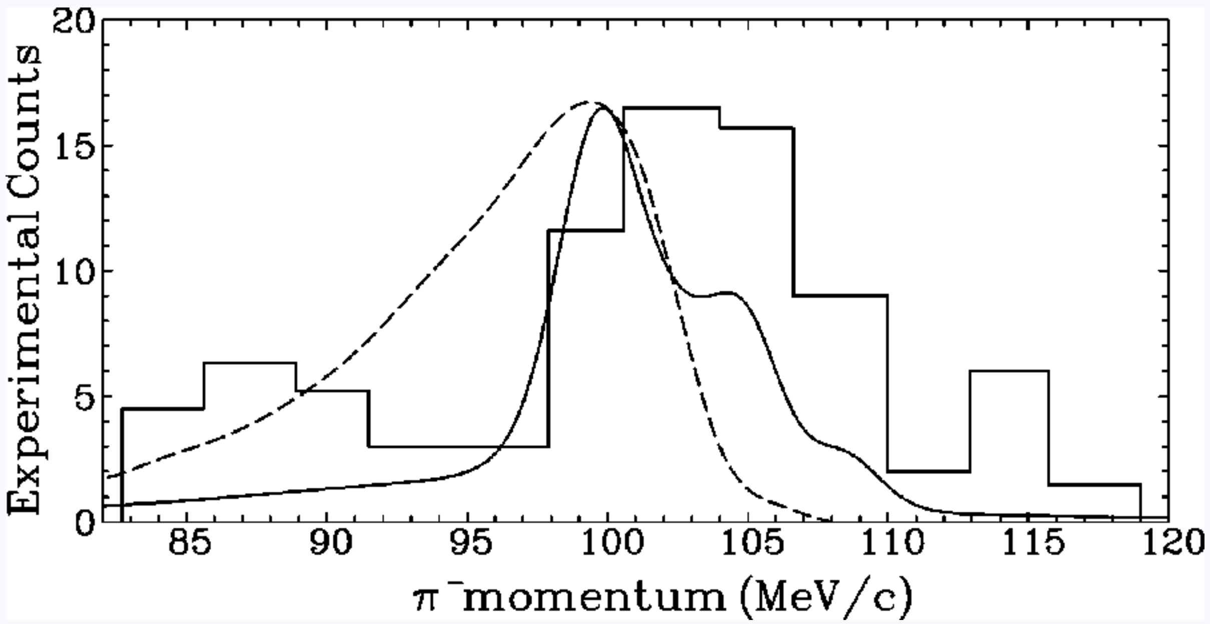
P. Pile, HYP2003

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

1) Twin hypernuclei

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

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

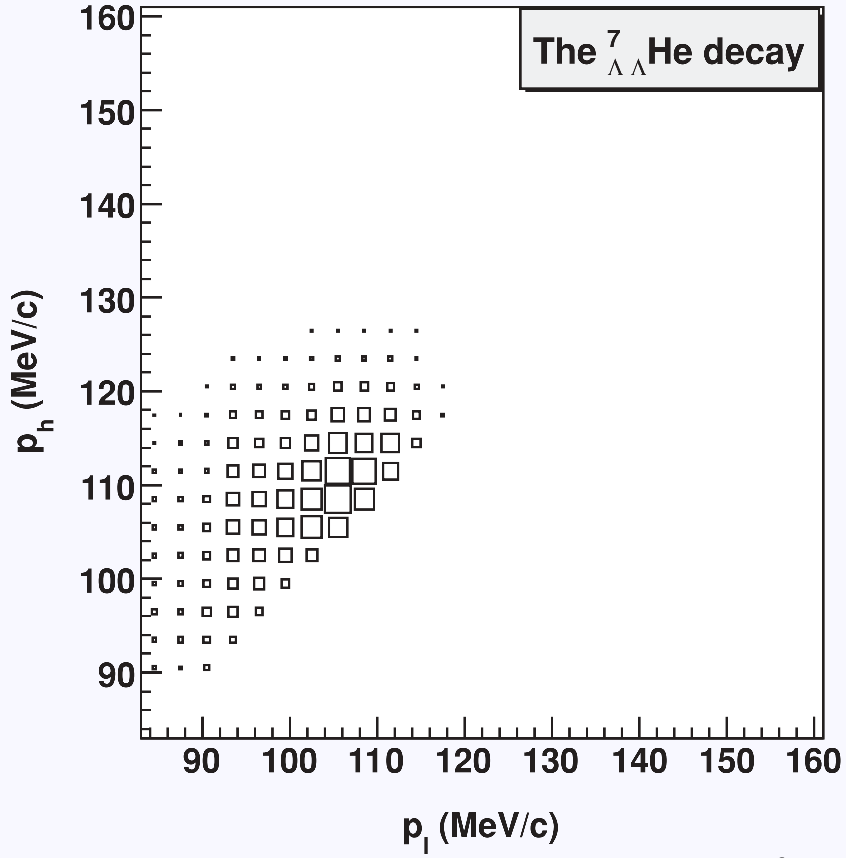


I. Kumagai-Fuse and S. Okabe,
Phys. Rev. C **66**, 014003 (2002)

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 $(\Xi^{-}, {}^{9}\mathrm{Be})_{\mathrm{atom}}$

E961, An improved search for double Λ hypernuclei

- **E961: Collaboration** *(same as E906)*
  - BNL, CMU, Gifu, Freiburg, Hampton, INR-Russia, KEK, Kyoto, Manitoba, New Mexico, Osaka, Osaka Electro-Communication, Pusan, Temple, Tokyo, TRIUMF
  - Spokesmen: T. Fukuda (Osaka Electro-Comm.), A. Rusek (BNL), R. Chrien (BNL)
- **The Improvements/Changes**
  - Improved statistics (run time, protons/spill, spectrometer acceptance)
  - CDS momentum resolution
    - New target vertex chamber
    - Higher CDS magnetic field
  - Ξ^- decay background reduction
    - New target vertex chamber
    - Better target geometry
  - Replace ^{9}Be target with ^{7}Li
    - Direct reaction cannot produce two single Λ hyperfragments
    - Eliminates Z > 1 double Λ hypernuclei in direct reaction
    - Stopping Ξ^- reduced due to lower density of Li

HYP2003

October 17, 2003 23

Outlook for the Future

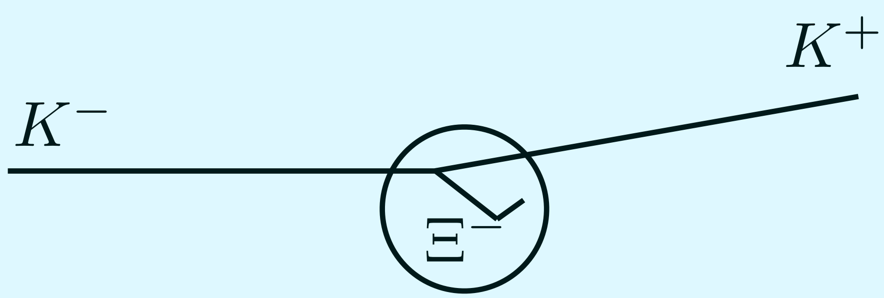
- ***AGS Fixed target experiments are no longer supported concurrent with RHIC operations since HEP base support was terminated at the end of 2002.***

P. Pile, HYP2003

New experiment at J-PARC

Quasi-free Ξ⁻ rescattering

BNL-AGS E906



Ξ⁻ capture at rest

[emulsion exp.]
Danysz et al.,
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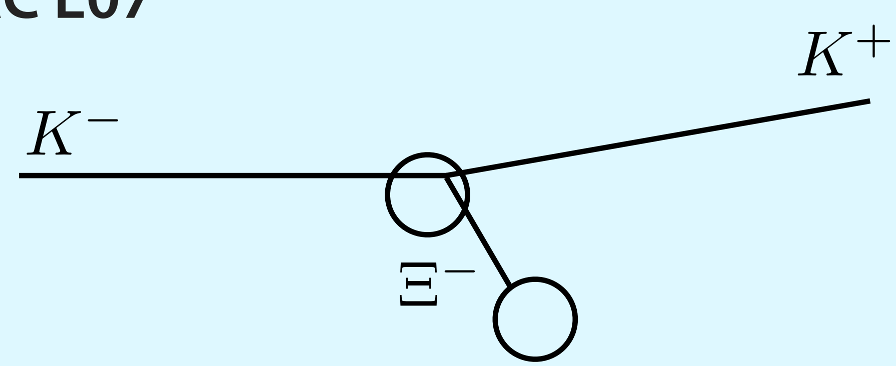
BNL-AGS E885, E906
cf. $\overline{\text{P}}$ANDA ($\bar{p}p \to \Xi^-\Xi^+$)



^{7}Li target instead of ^{9}Be

fragmented from $[{}^{6}_{\Lambda\Lambda}\mathrm{H}^*]$

→double-Λ hypernuclei ${}^{4,5}_{\Lambda\Lambda}\mathrm{H}$

→~~twin hypernuclei~~

Ξ- stopping probability will be small because of the material density (Lithium: 0.53g/cm³, Beryllium: 1.85g/cm³)

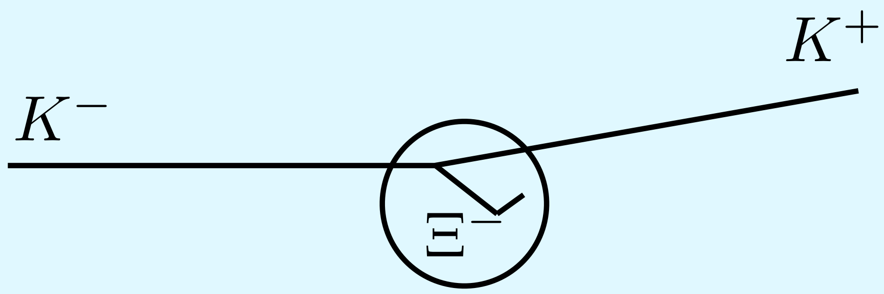
fragmented from $(\Xi^-, {}^7\mathrm{Li})_{\text{atom}}$

→double-Λ hypernuclei w/ A≦7 and Z=1,2

→twin hypernuclei ${}^{3,4}_{\Lambda}\mathrm{H} + {}^{3,4}_{\Lambda}\mathrm{H}$

New experiment at J-PARC

Quasi-free Ξ^- rescattering



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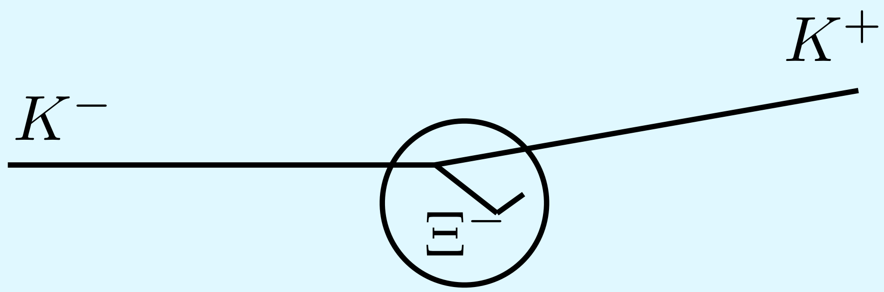
BNL-AGS E906



^{7}Li target instead of ^{9}Be

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→double-Λ hypernuclei ${}^{4,5}_{\Lambda\Lambda}\mathrm{H}$

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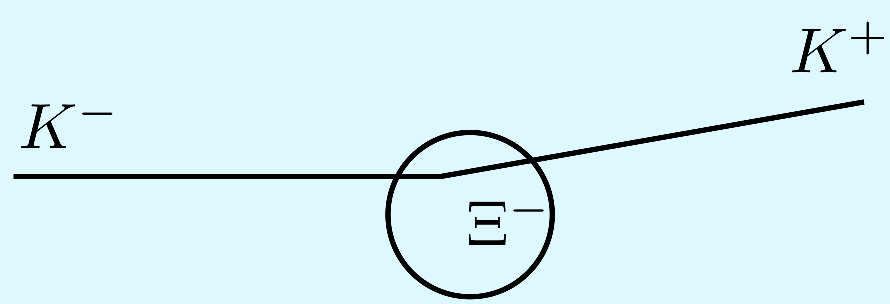
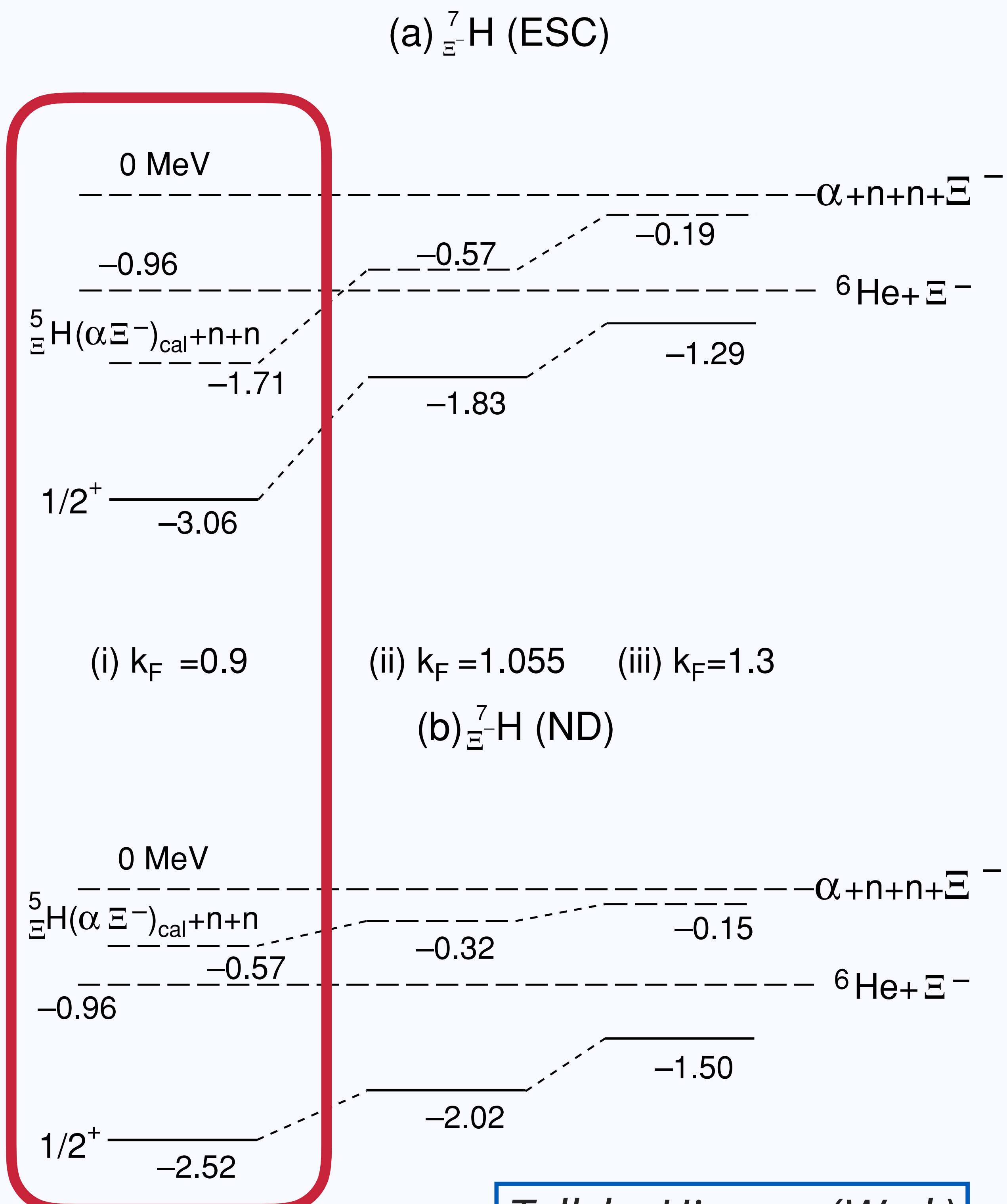
Ξ-hypernuclear decay



At the same time,
${}^{7}_{\Xi^-}\mathrm{H}\ (=\alpha nn\Xi^-)$
will be produced via
the $^7\mathrm{Li}(K^-, K^+)$ reaction

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



Talk by Hiyama (Wed.)

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

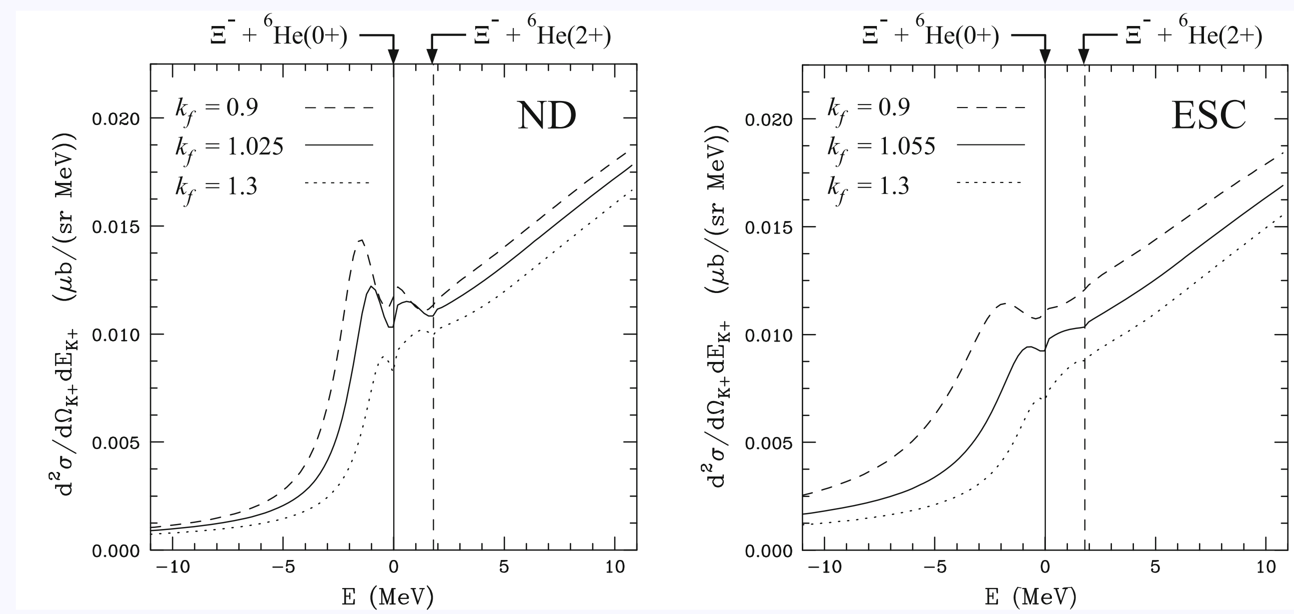


Fig. 1 Calculated $^{7}\mathrm{Li}(K^-, K^+)$ inclusive spectra for p_{K^-} = 1.65 GeV/c and θ_{K^+} = 0°. The *left* and *right panel* show the results corresponding to the case using potential ND and ESC with three k_f parameters listed in Table 1, respectively. These spectra are smeared assuming 2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

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

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)

$$
\begin{aligned}
{}^{7}_{\Xi}\mathrm{H} &\rightarrow {}^{5}_{\Lambda\Lambda}\mathrm{H}+n+n \quad \sim 11 \ \ \mathrm{MeV},\\
&\rightarrow {}^{4}_{\Lambda}\mathrm{H}+\Lambda+n+n \quad \sim 7 \ \ \mathrm{MeV},\\
&\rightarrow {}^{4}_{\Lambda}\mathrm{H}^{*}+\Lambda+n+n \quad \sim 6 \ \ \mathrm{MeV},\\
&\rightarrow {}^{3}\mathrm{H}+\Lambda+\Lambda+n+n \quad \sim 5 \ \ \mathrm{MeV}.
\end{aligned}
$$

- 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% !!)

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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% !!)

$^{7}\mathrm{Li}(K^{-}, K^{+})$ reactions

(1) $^{7}_{\Xi^{-}}\mathrm{H} \rightarrow {}^{5}_{\Lambda\Lambda}\mathrm{H} + 2n$

(2) Quasi-free Ξ → fragmentation from $[{}^{6}_{\Lambda\Lambda}\mathrm{H}^{*}]$

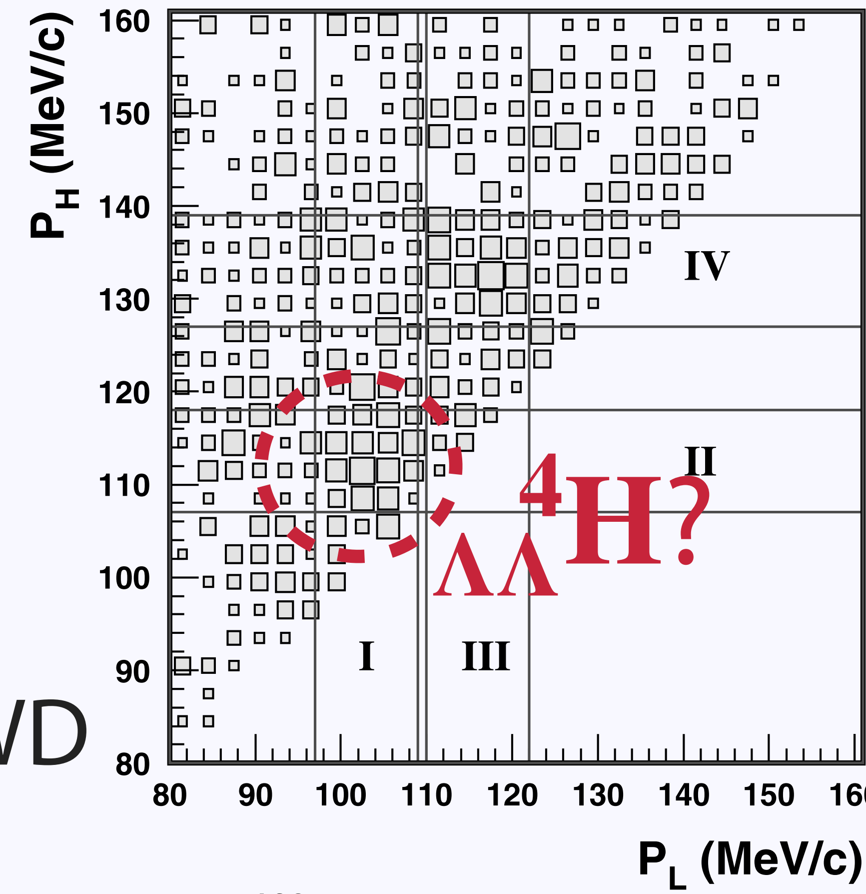
⟨*production*⟩

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

⟨*structure*⟩ ΛΛ-ΞN mixing in $^{5}_{\Lambda\Lambda}\mathrm{H}$

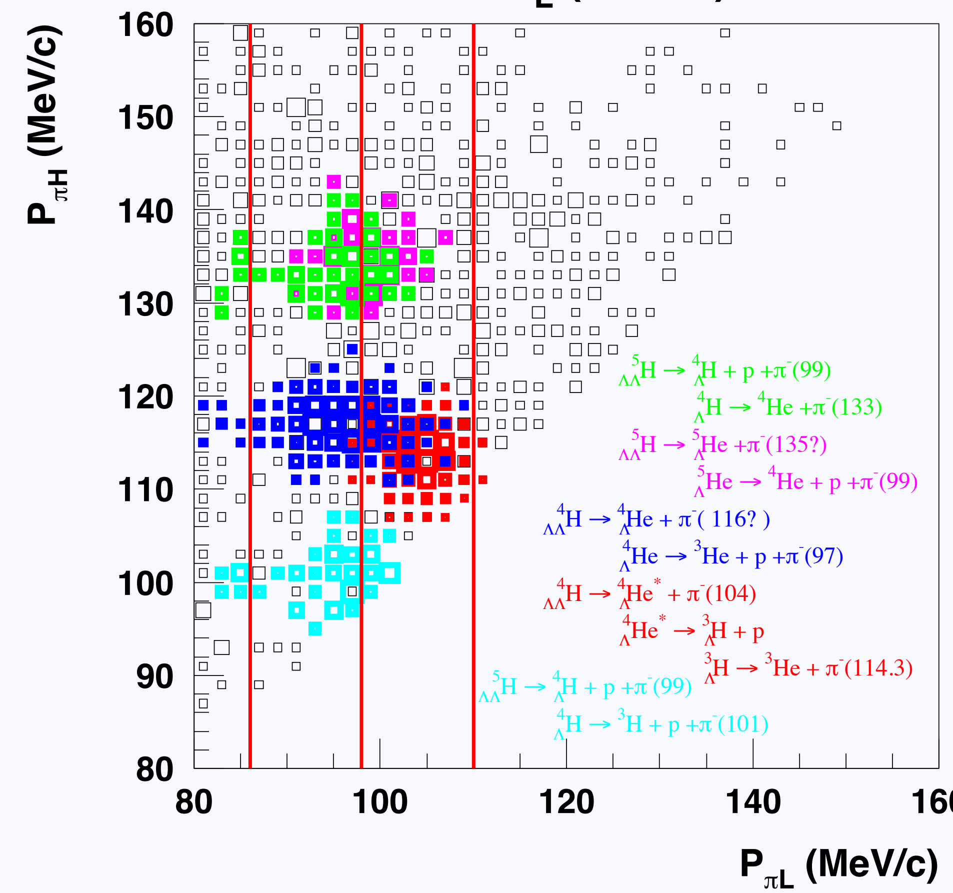
⟨*decay*⟩ How to identify $^{5}_{\Lambda\Lambda}\mathrm{H}$?

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



- <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 ${}^{5}_{\Lambda\Lambda}H$ decay



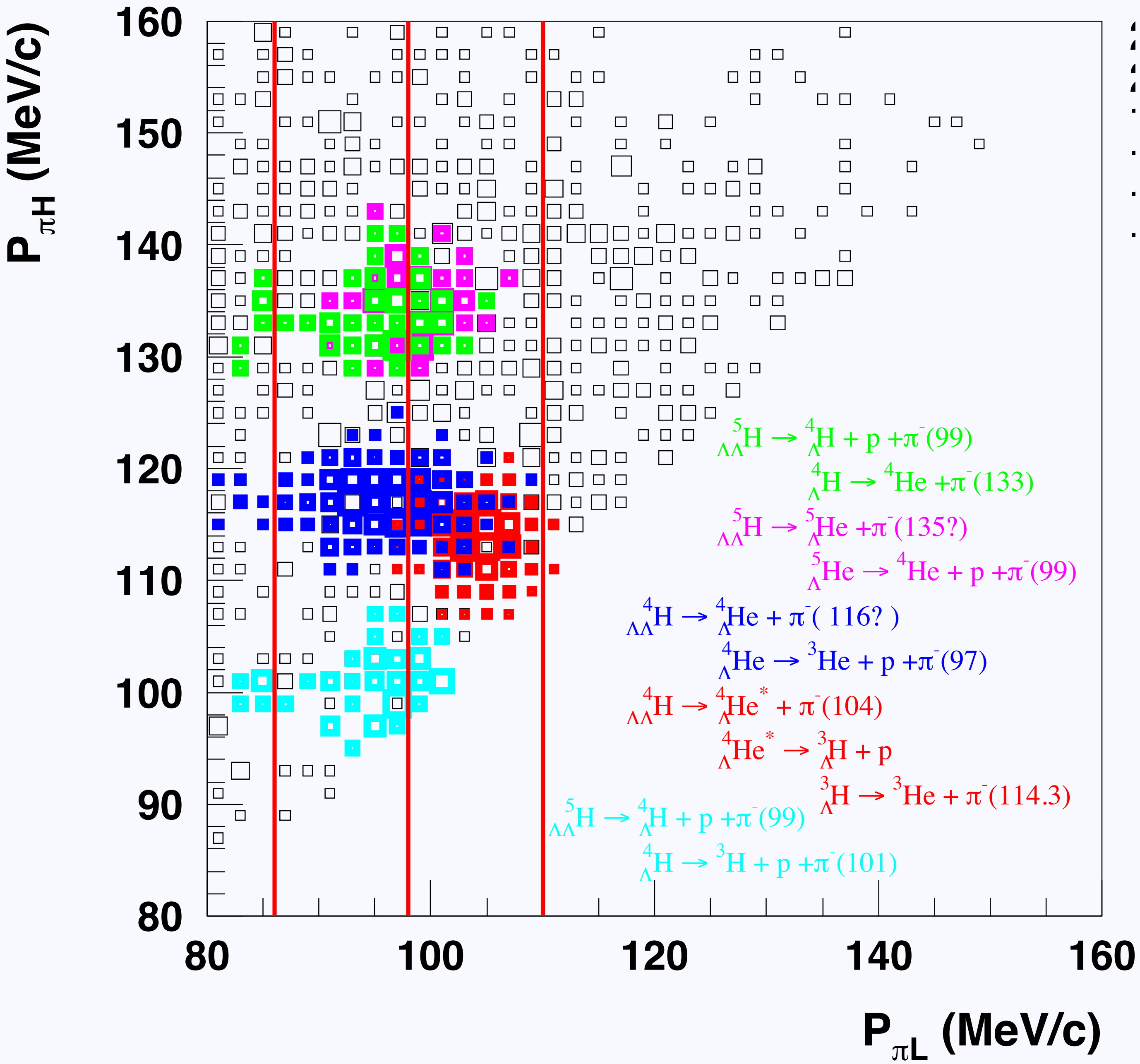
simulation (P961R proposal)

$\approx$ **99MeV/c**

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

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

$\approx$ **133MeV/c**



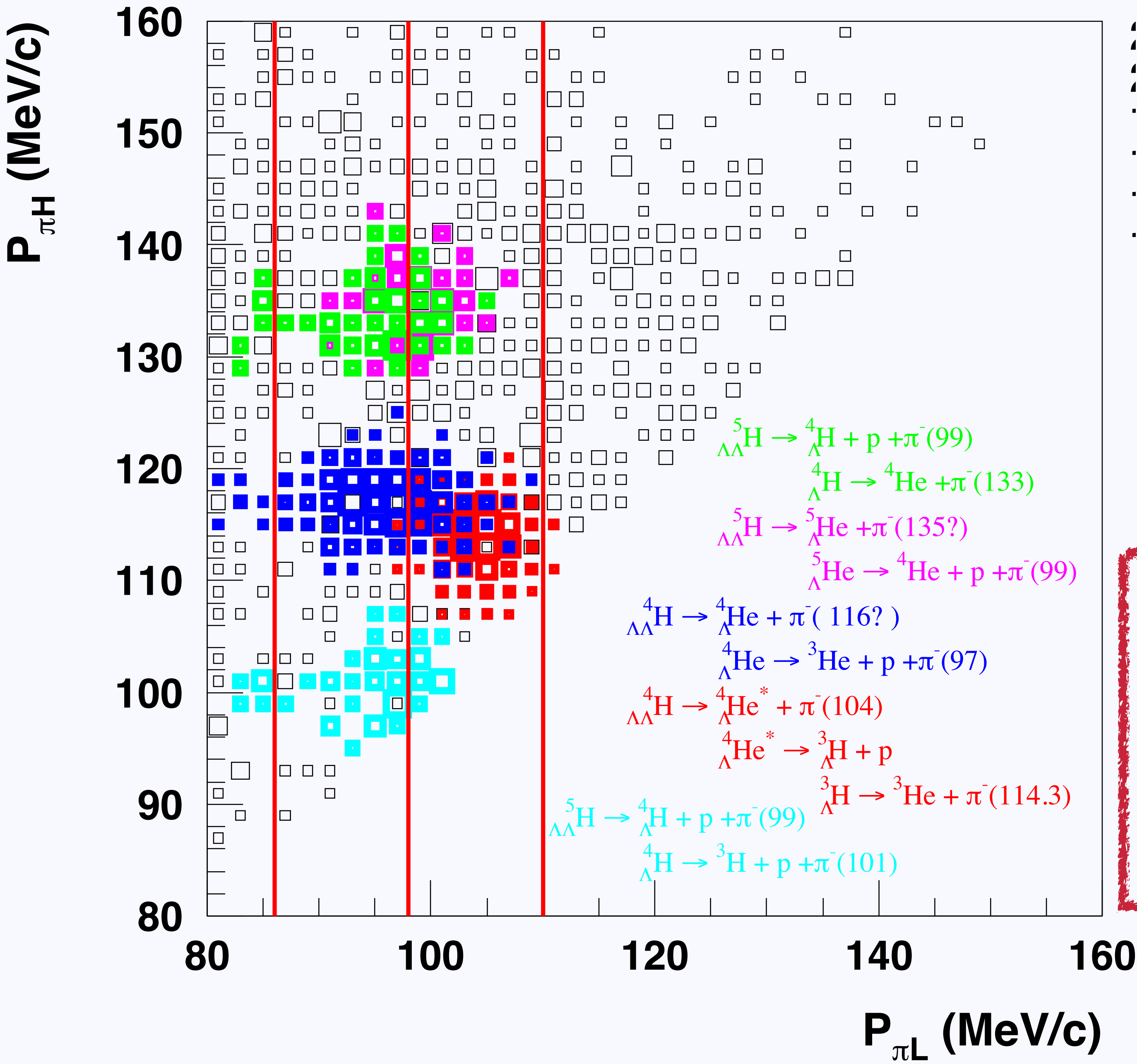
The distinction between
the two decay modes
are experimentally difficult.

≈ 99MeV/c

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

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

≈ 133MeV/c

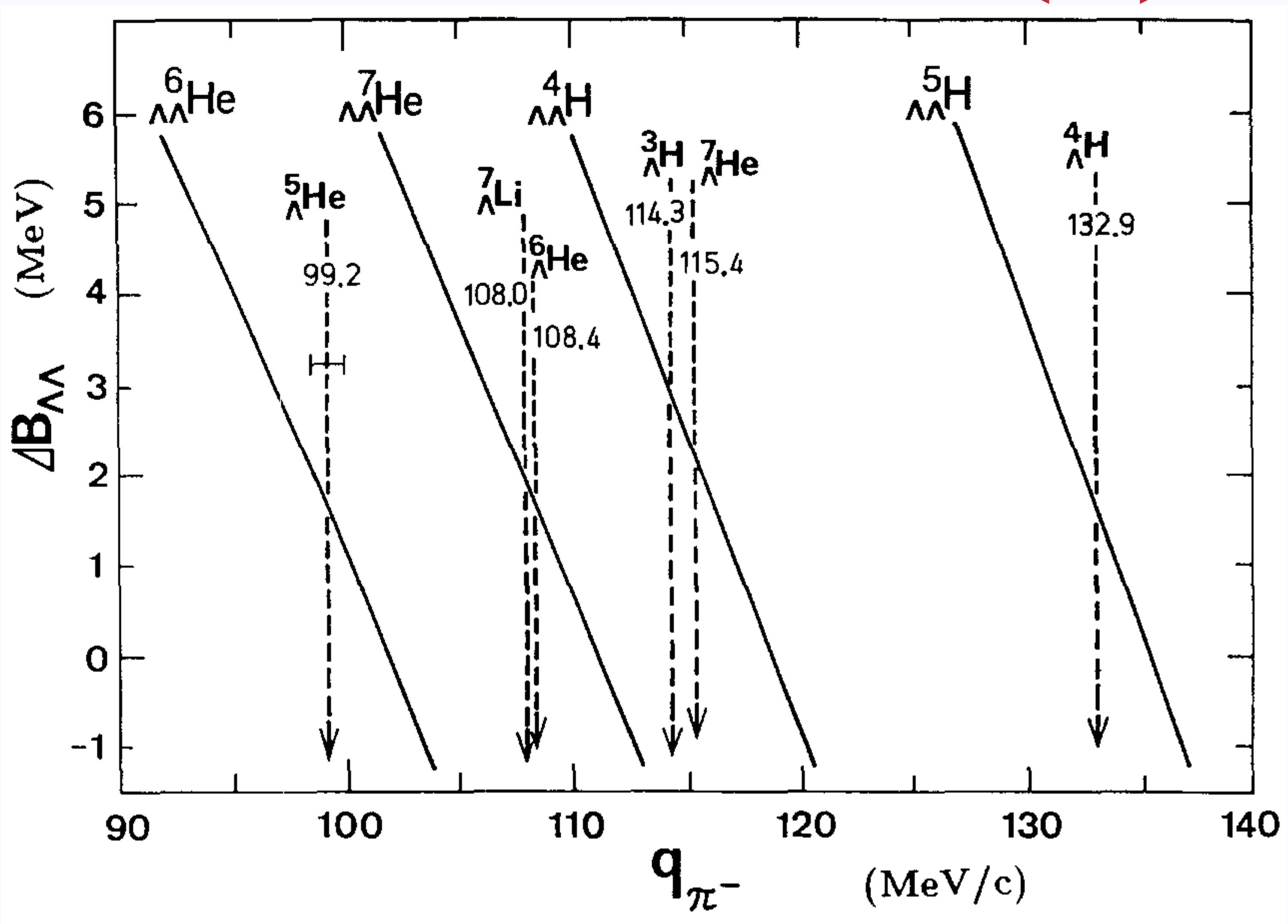


The distinction between
the two decay modes
are experimentally difficult.

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

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)

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

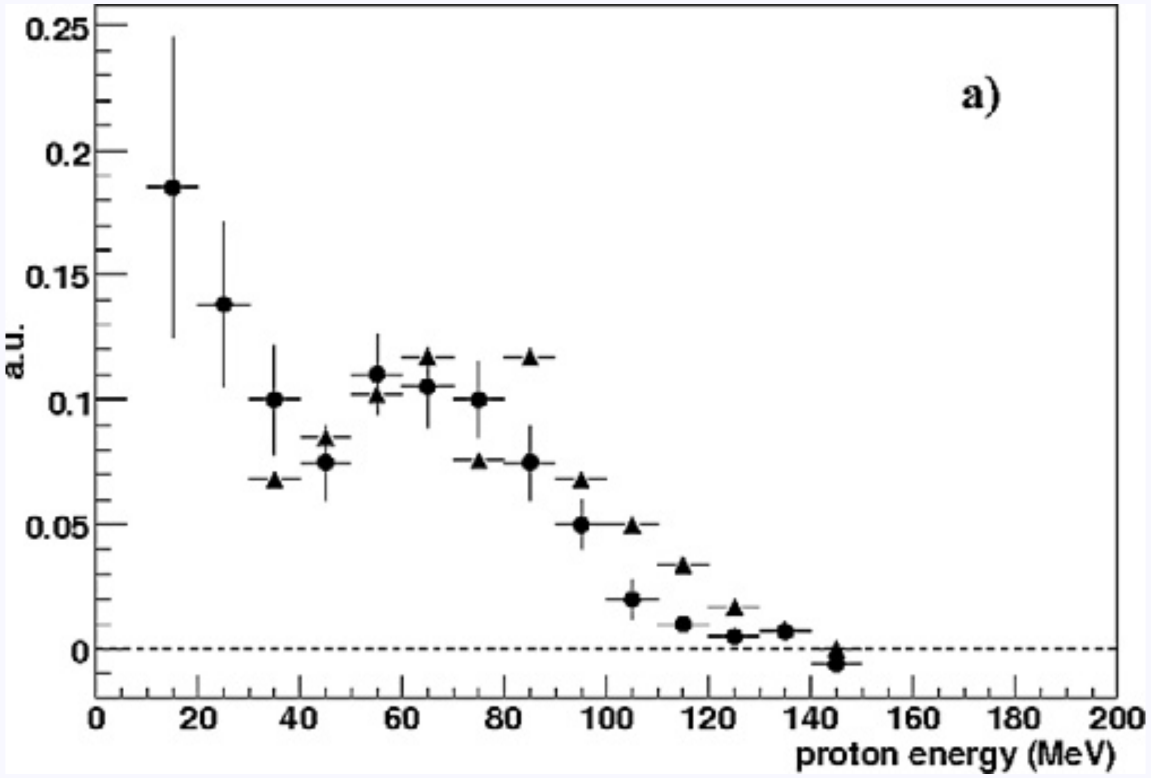
Decay pion spectroscopy with tagging a proton from NMWD

(referred to as a "fast proton")

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

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

proton energy distribution



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

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

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

π^{-} carries away most of the released energy

(1N-induced) NMWD

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

BG rejection with fast proton tagging

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

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

(a)

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

slow $\Lambda \rightarrow p + \pi^-$

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

slow $\Lambda \rightarrow p + \pi^-$

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

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

slow $\Lambda \rightarrow p + \pi^-$

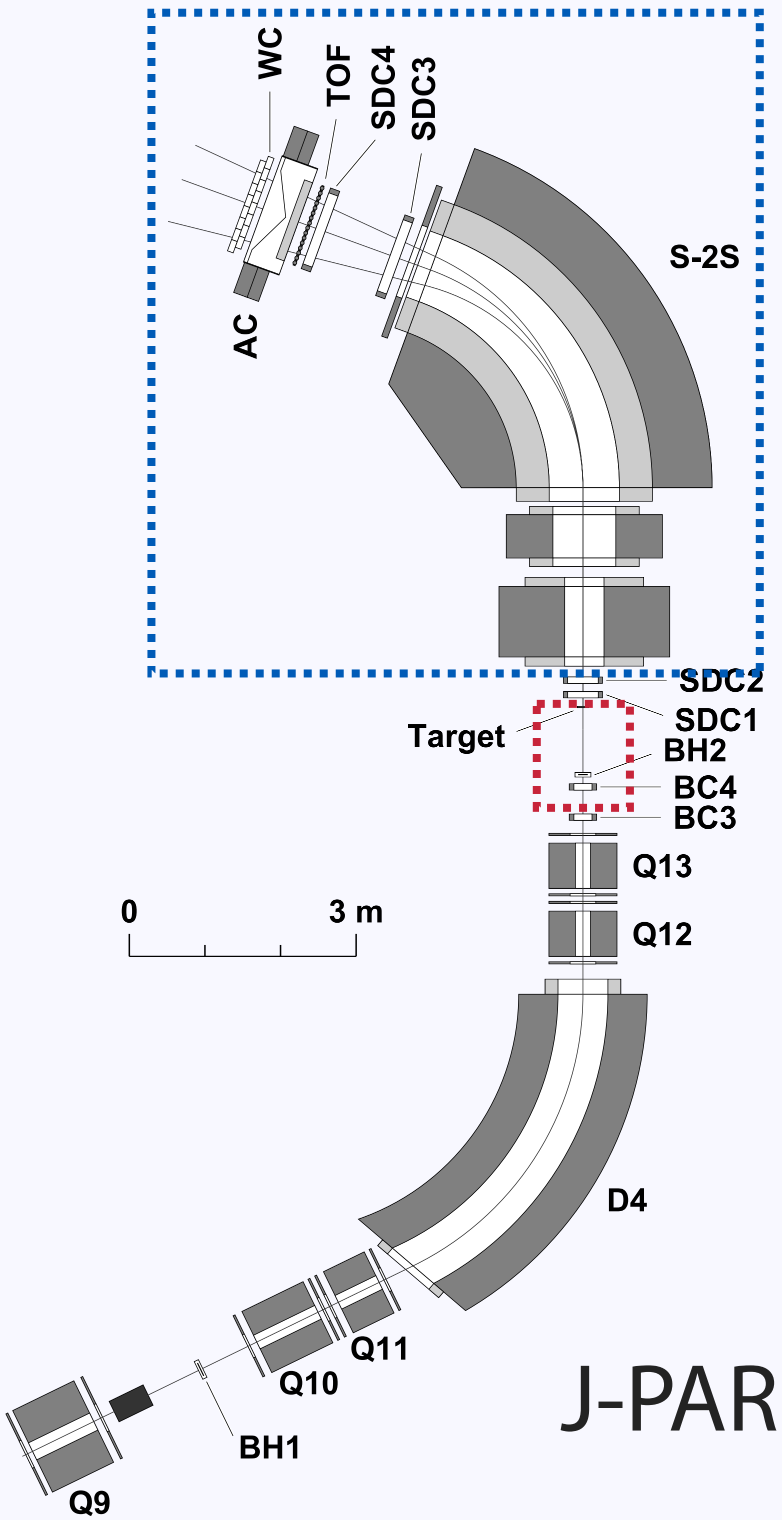
(c) $\boxed{{}^{5}_{\Lambda\Lambda}\mathrm{H}} \rightarrow \boxed{{}^{4}_{\Lambda}\mathrm{H}} + (p + \pi^- / n + \pi^0)$

proton from MWD/no proton

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

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

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

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:

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

Only possible by a counter experiment

- Production of ${}^{4,5}_{\Lambda\Lambda}\mathrm{H}$ with a ${}^{6}\mathrm{Li}$ target (depending on the B.E. of ${}^{5,6}_{\Xi^-}\mathrm{H}$ and ${}^{4,5}_{\Lambda\Lambda}\mathrm{H}$)

$$
\begin{aligned}
{}^{6}_{\Xi^-}\mathrm{H} &\rightarrow {}^{5}_{\Lambda\Lambda}\mathrm{H} + n \\
&\rightarrow {}^{4}_{\Lambda\Lambda}\mathrm{H} + 2n
\end{aligned}
$$

$$
\begin{aligned}
{}^{6}_{\Xi^-}\mathrm{H} &\rightarrow {}^{5}_{\Xi^-}\mathrm{H} + n \\
{}^{5}_{\Xi^-}\mathrm{H} &\rightarrow \cancel{{}^{5}_{\Lambda\Lambda}\mathrm{H}} \\
&\rightarrow {}^{4}_{\Lambda\Lambda}\mathrm{H} + n
\end{aligned}
$$

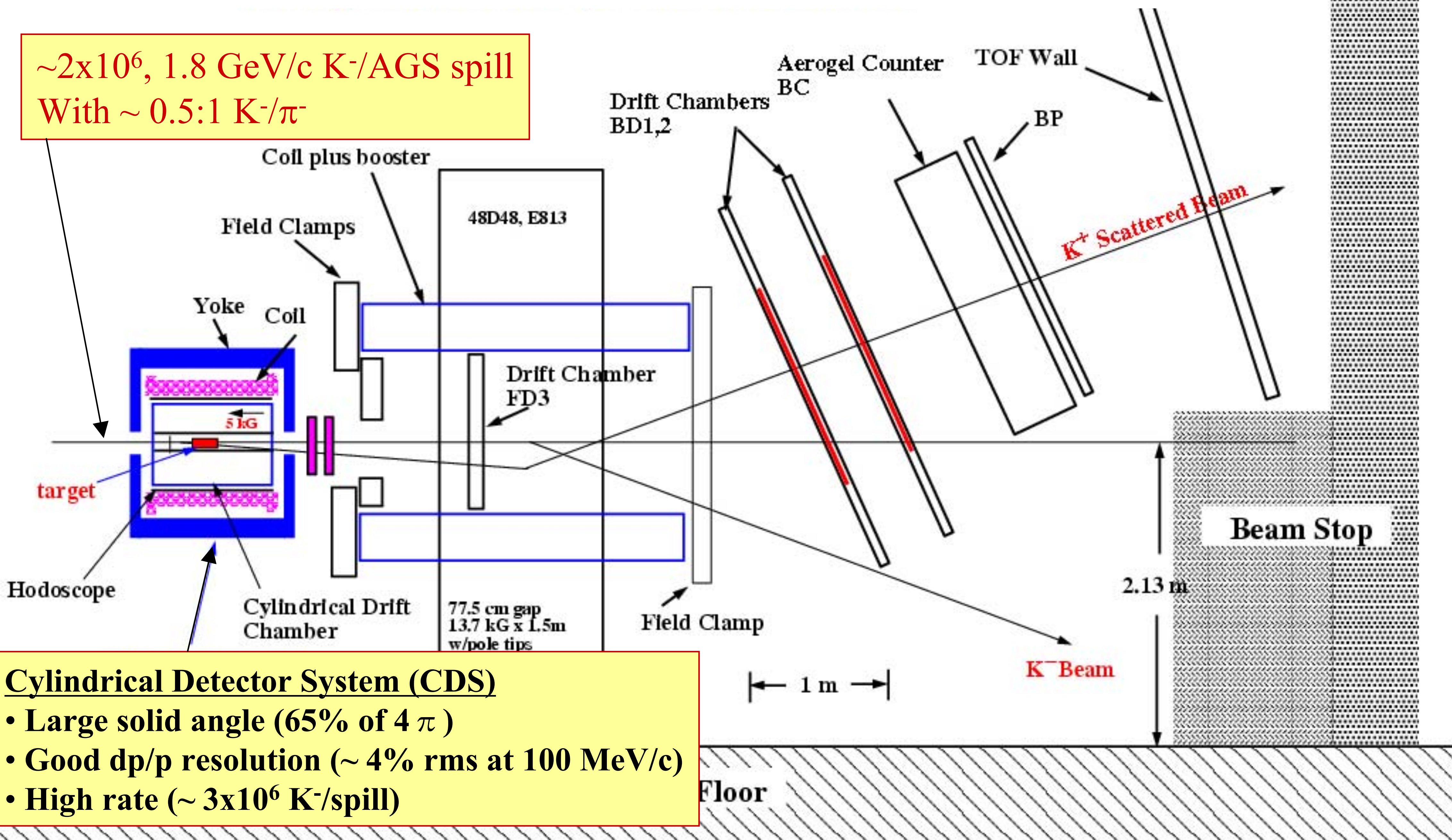
Conclusion

- A new method of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ production via Ξ-hypernuclear decay and quasi-free Ξ rescattering is proposed.
- "Mass production" in comparison with emulsion experiments will open new possibility to investigate properties of double-Λ hypernuclei.
  - lifetime, weak-decay B.R. as well as ΛΛ bond energy
- A Letter of Intent has been submitted to J-PARC.
- If you are interested, please contact us!

E906, ΛΛ Hypernuclei

K^+ Spectrometer and Cylindrical Detector System

~2x10^6, 1.8 GeV/c K^-/AGS spill
With ~ 0.5:1 K^-/π^-



Cylindrical Detector System (CDS)
- **Large solid angle (65% of 4 π)**
- **Good dp/p resolution (~ 4% rms at 100 MeV/c)**
- **High rate (~ 3x10^6 K^-/spill)**

Table 7
Calculated pionic decay rates of light double-Λ hypernuclei to be produced in the (K^-, K^+) reaction on ^{9}Be. The calculations are made for the two-body and three-body final states. DW denotes the use of pion distorted waves described in the text. All decay rates are given in units of the free-Λ decay rate Γ_Λ

		π^- DW		π^0 DW
$^{4}_{\Lambda\Lambda}$H	$\Longrightarrow {}^{4}_{\Lambda}\mathrm{He}+\pi^-$	0.25	$\Longrightarrow {}^{4}_{\Lambda}\mathrm{H}+\pi^0$	0.13
	$\Longrightarrow {}^{3}_{\Lambda}\mathrm{H}+p+\pi^-$	0.52	$\Longrightarrow {}^{3}_{\Lambda}\mathrm{H}+n+\pi^0$	0.28
$^{5}_{\Lambda\Lambda}$H	$\Longrightarrow {}^{5}_{\Lambda}\mathrm{He}+\pi^-$	0.38	$\Longrightarrow$ (No 2-body)	–
	$\Longrightarrow {}^{4}_{\Lambda}\mathrm{H}+p+\pi^-$	0.61	$\Longrightarrow {}^{4}_{\Lambda}\mathrm{H}+n+\pi^0$	0.31
$^{5}_{\Lambda\Lambda}$He	$\Longrightarrow$ (No 2-body)	–	$\Longrightarrow {}^{5}_{\Lambda}\mathrm{He}+\pi^0$	0.18
	$\Longrightarrow {}^{4}_{\Lambda}\mathrm{He}+p+\pi^-$	0.48	$\Longrightarrow {}^{4}\mathrm{He}+n+\pi^0$	0.22
$^{6}_{\Lambda\Lambda}$He	$\Longrightarrow$ (No 2-body)	–		
	$\Longrightarrow {}^{5}_{\Lambda}\mathrm{He}+p+\pi^-$	0.60		
$^{7}_{\Lambda\Lambda}$He	$\Longrightarrow {}^{7}_{\Lambda}\mathrm{Li}+\pi^-$	0.26		
	$\Longrightarrow {}^{5}_{\Lambda}\mathrm{He}+d+\pi^-$	0.06		
	$\Longrightarrow {}^{6}_{\Lambda}\mathrm{He}+p+\pi^-$	0.21		

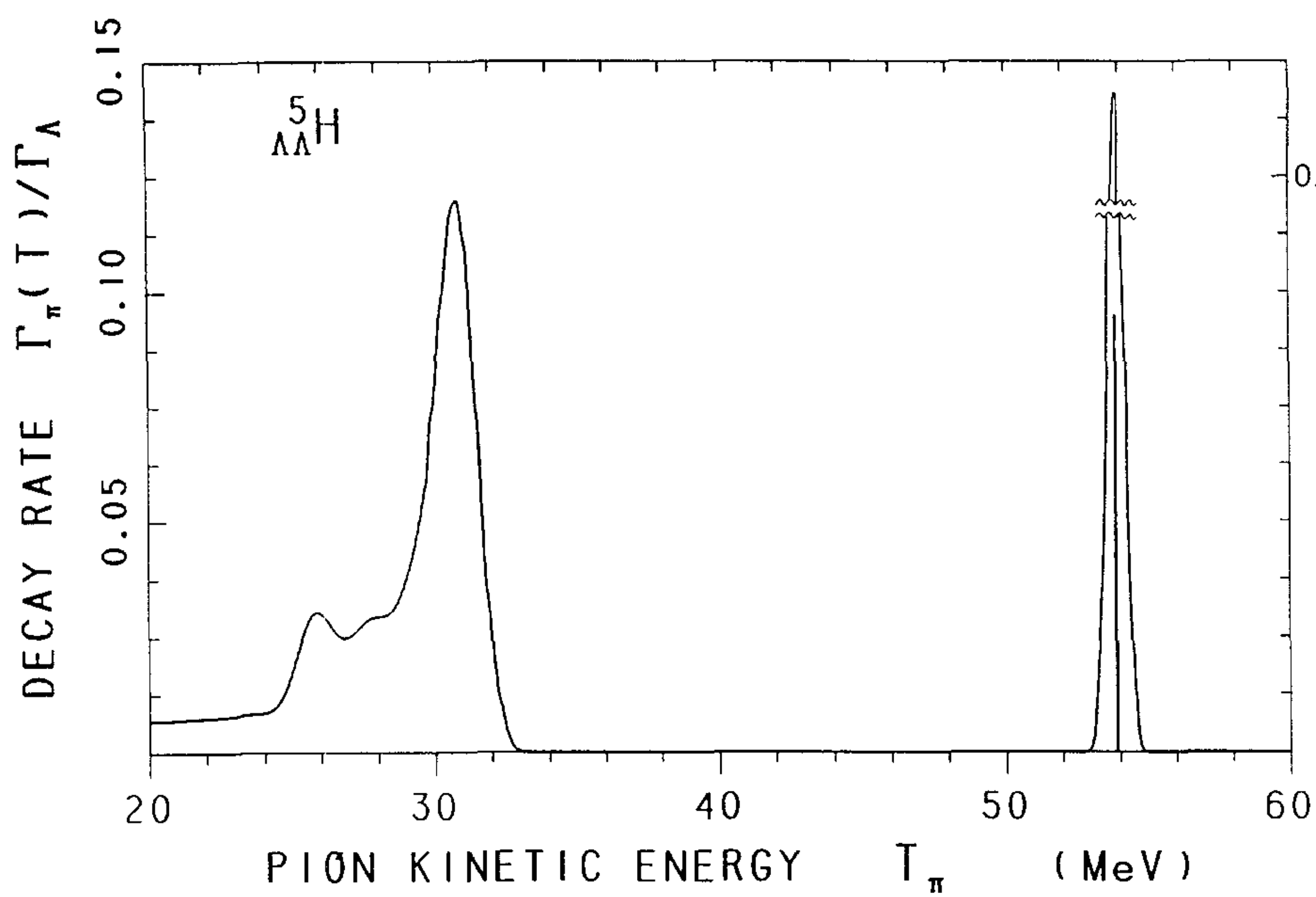


Fig. 9. The calculated π^- spectrum from the weak decay of $^{5}_{\Lambda\Lambda}$H, which consists of the monochromatic peak for the two-body decay ($^{5}_{\Lambda}$He$+\pi^-$) and the continuum part for the three-body decays ($^{4}_{\Lambda}$H$+p+\pi^-$).

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

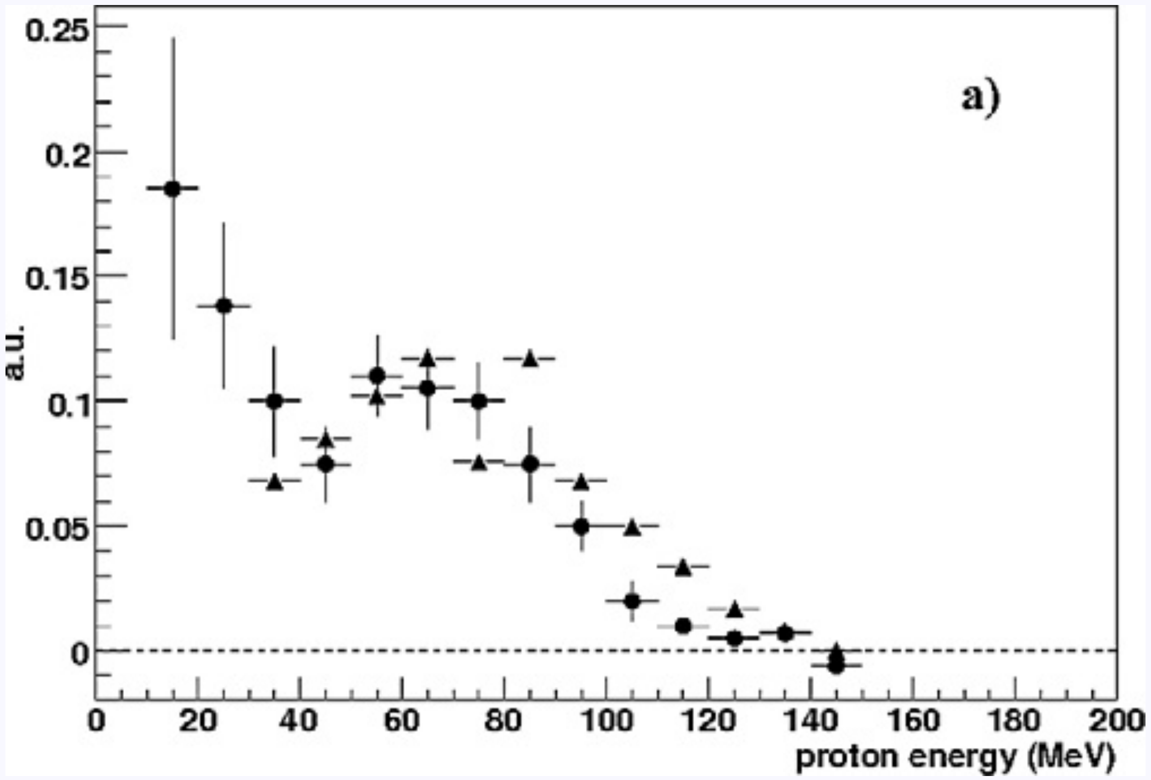
Novel method for ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ identification

Decay pion spectroscopy with tagging a proton from NMWD

$${}^{5}_{\Lambda\Lambda}\mathrm{H} \to {}^{5}_{\Lambda}\mathrm{He} + \pi^{-}$$ *(referred to as a "fast proton")*

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

proton energy distribution



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

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

(KEK-PS E462)

$$\Gamma_n/\Gamma_p = 0.45 \pm 0.11 \pm 0.03$$

B.H. Kang et al., Phys. Rev. Lett. **96**, 062301 (2006)

$$\Gamma_{\mathrm{nm}}/\Gamma_{\Lambda} = 0.406 \pm 0.020$$

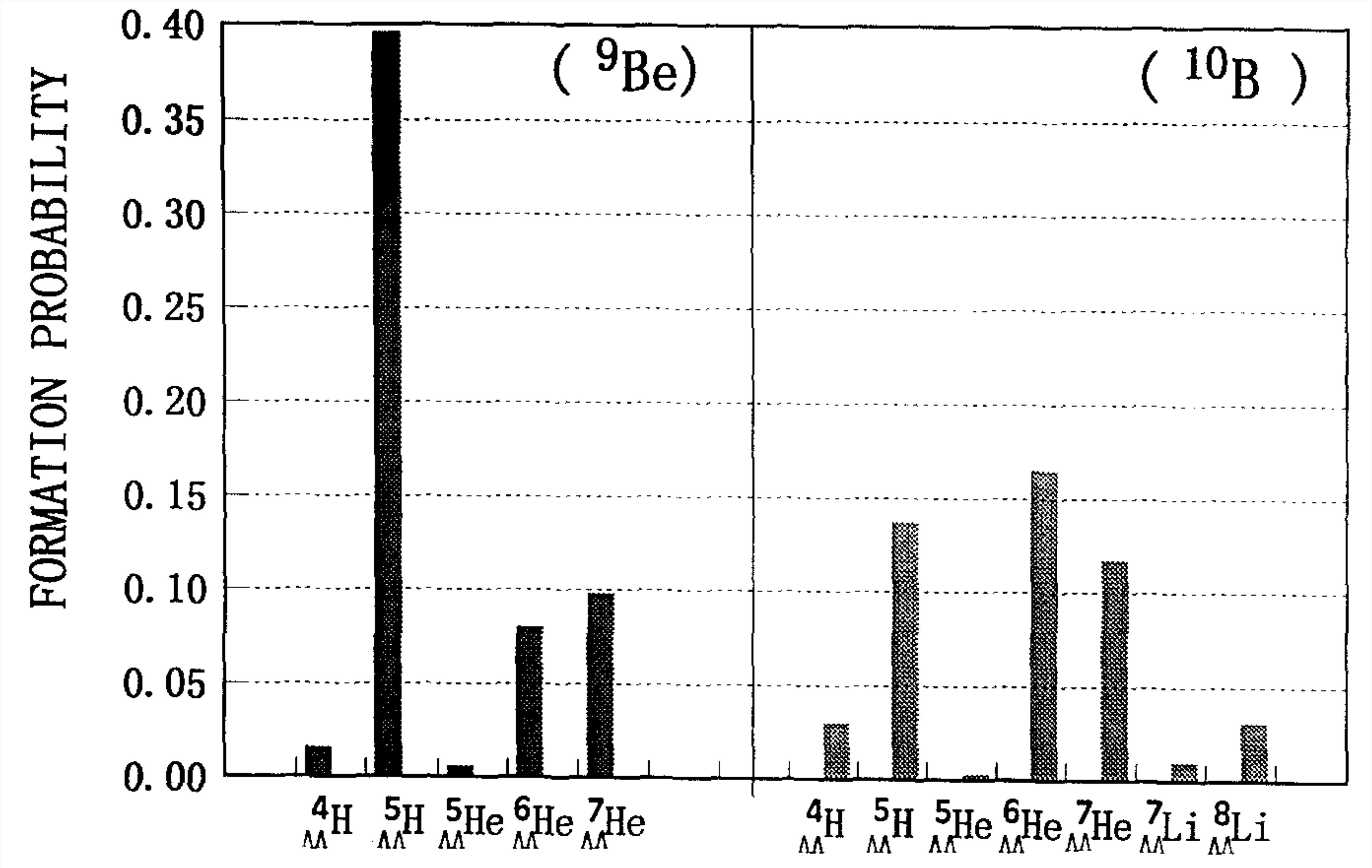
S. Okada et al., Nucl. Phys. A **754**, 178 (2005)

cf. $${}^{5}_{\Lambda}\mathrm{He} \to {}^{4}\mathrm{He} + p + \pi^{-}$$

$$\Gamma_{\pi^-}/\Gamma_{\Lambda} = 0.340 \pm 0.016$$

S. Kameoka et al., Nucl. Phys. A **754**, 173 (2005)

Γ_p is comparable to Γ_{π^-}!



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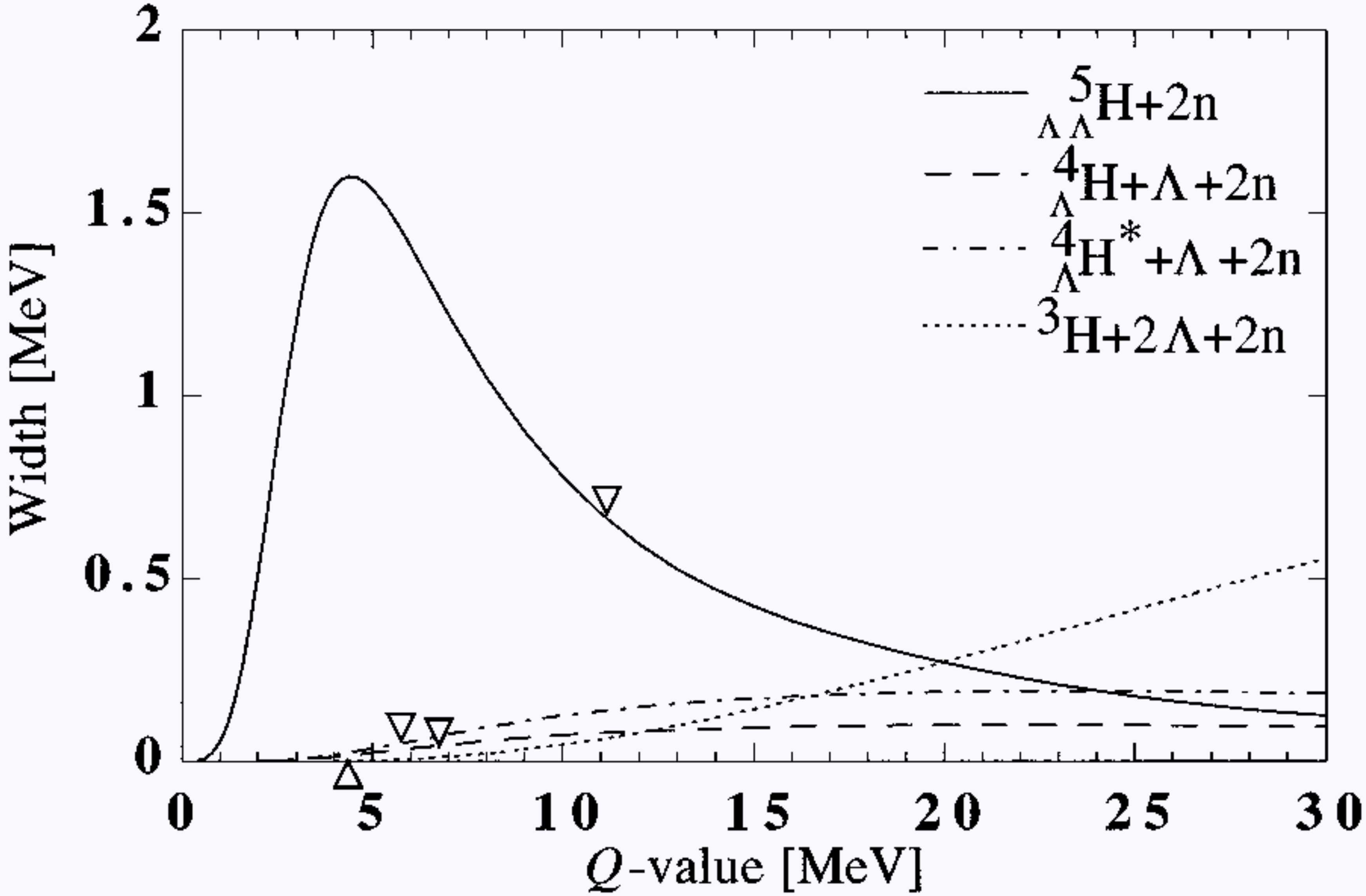
Nucl. Phys. A **625**, 107 (1997)



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