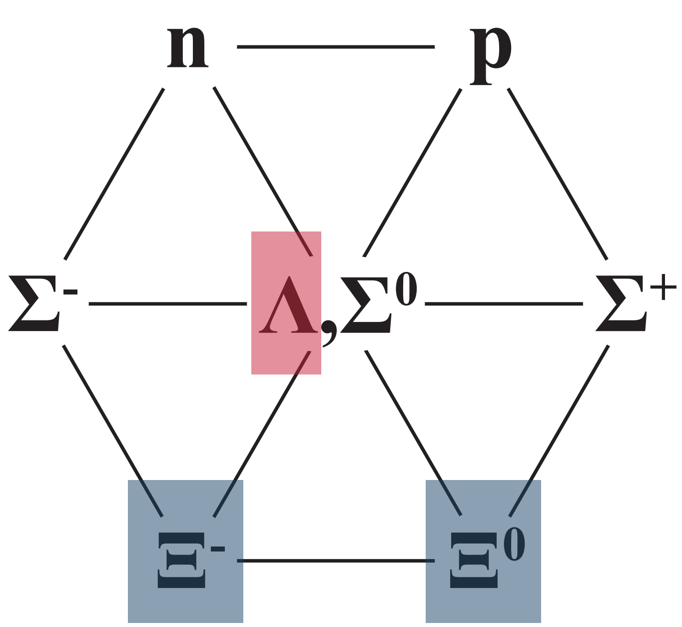
Decay Pion Spectroscopy of the Lightest Double-Λ Hypernuclei at J-PARC

Hiroyuki FUJIOKA (TokyoTech)
for the J-PARC E75 collaboration

Hypernuclei with $S = -2$

Strangeness: (-1)×#(strange quark)

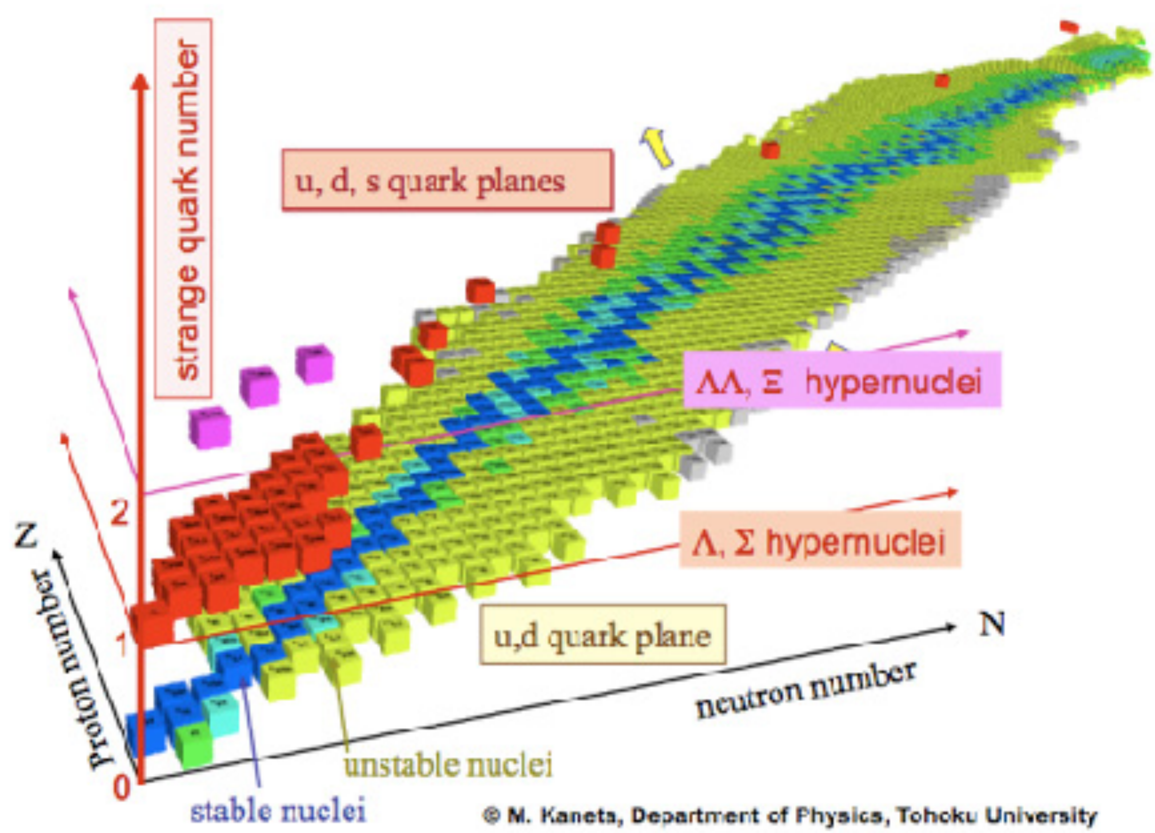


$S = 0$

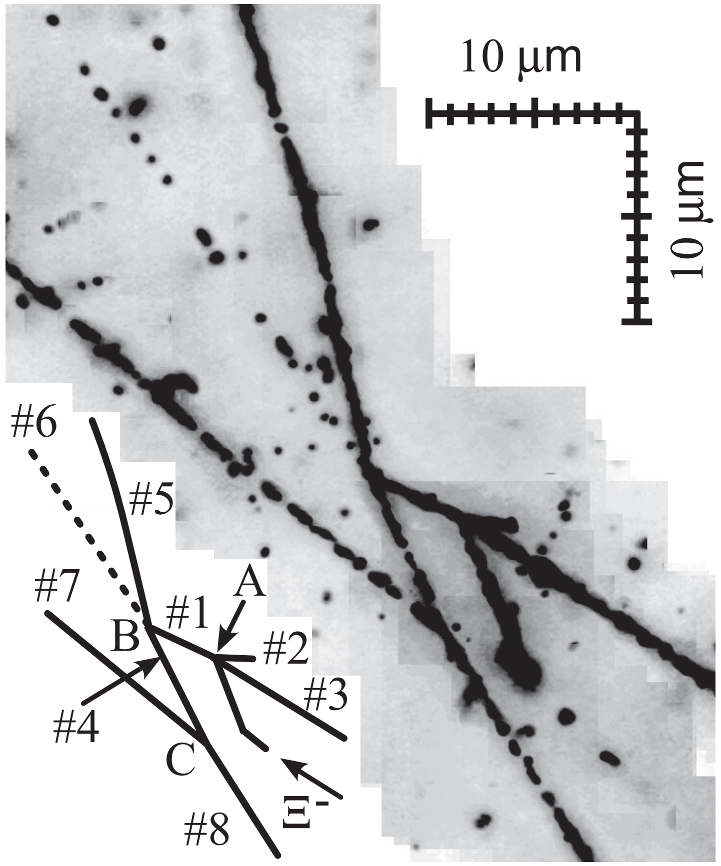
$S = -1$ ⟹ **Double Λ Hypernuclei**

$S = -2$ ⟶ **Ξ Hypernuclei**

Double Λ Hypernuclei are formed by $\Xi^- p \to \Lambda\Lambda$ conversion in nuclei, where a Ξ^- hyperon is produced in the $p(K^-, K^+)\Xi^-$ reaction.



Nagara event



captured from an atomic orbital of ^{12}C

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

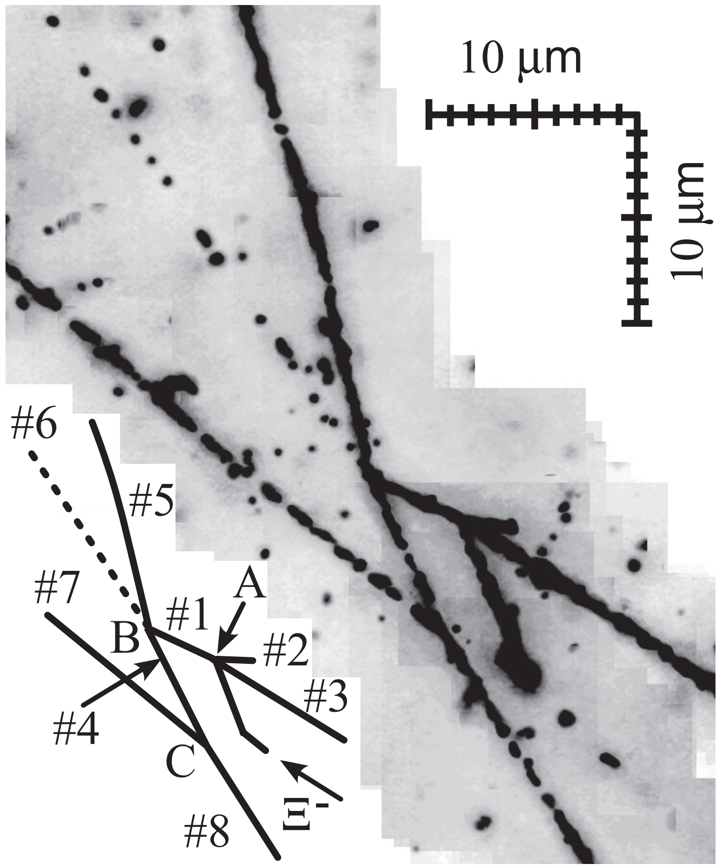
$${}^{\ 6}_{\Lambda\Lambda}\mathrm{He} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + p + \pi^-$$

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

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

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

Nagara event



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tials. Moreover, the Ξ^- capture probability in ^{12}C from *P* states is a few percent at most. The most likely capture in ^{12}C, as discussed in Sec. III B, occurs from atomic *D* states.

C. J. Batty, E. Friedman, and A. Gal, Phys. Rev. C **59**, 295 (1999)

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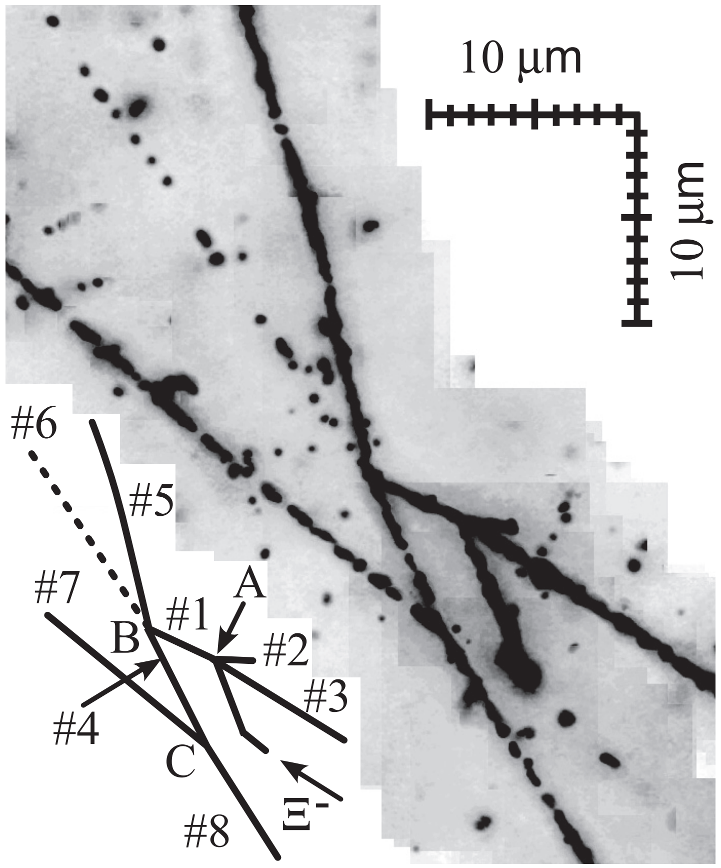

captured from an atomic orbital of ^{12}C

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

$$B_{\Lambda\Lambda} = 6.79 + 0.91 B_{\Xi^-} \pm 0.16\,\mathrm{MeV}$$

$$\Delta B_{\Lambda\Lambda} = 0.55 + 0.91 B_{\Xi^-} \pm 0.17\,\mathrm{MeV}$$

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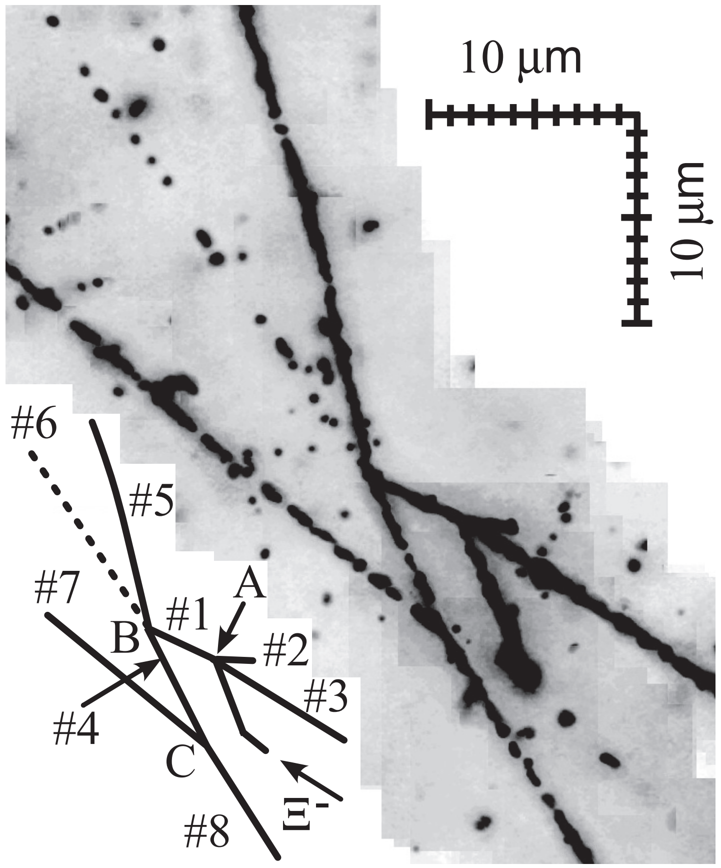

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C. J. Batty, E. Friedman, and A. Gal, Phys. Rev. C **59**, 295 (1999)

Assumption: $B_{\Xi^-}(3D) = 0.13\,\mathrm{MeV}$

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

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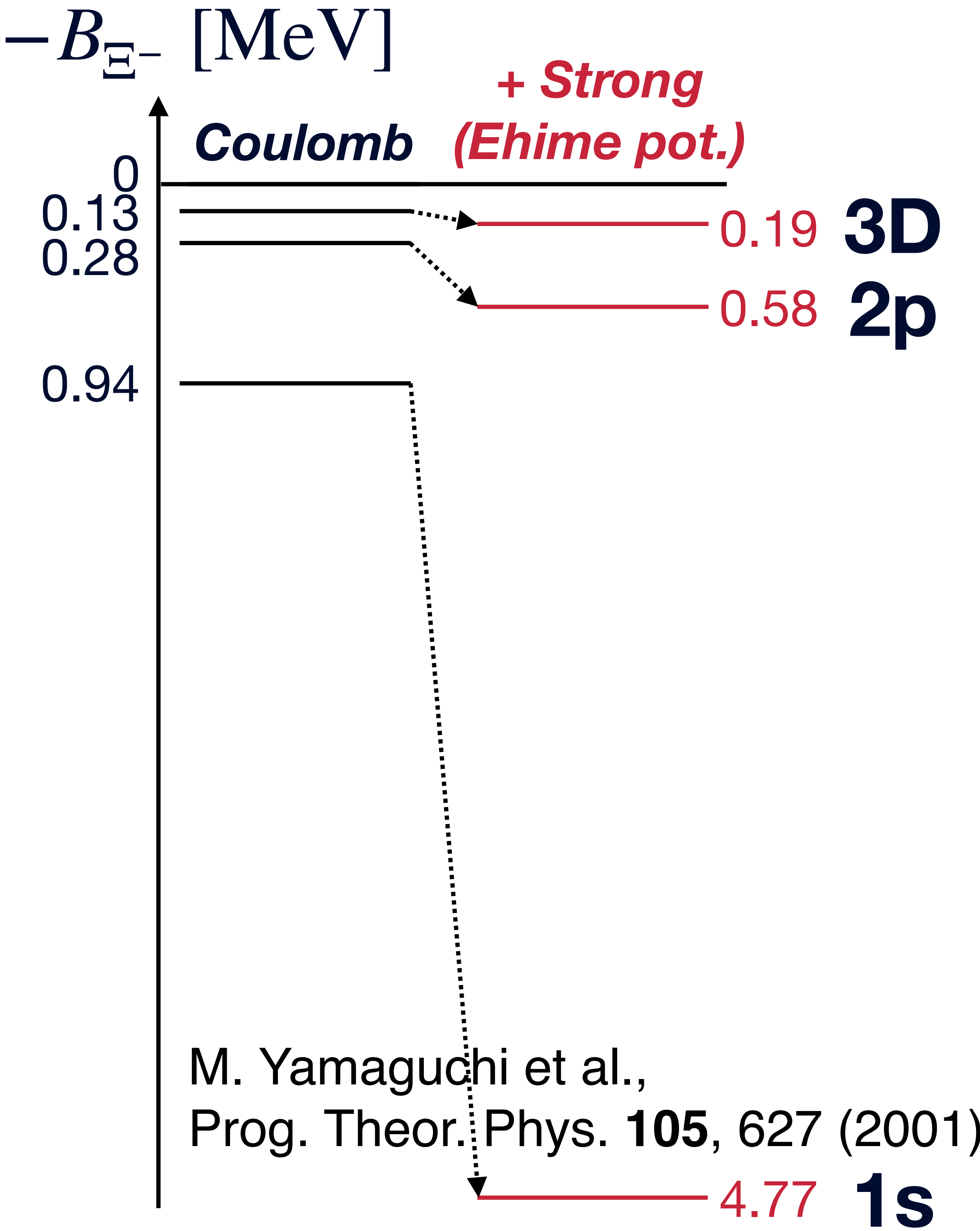
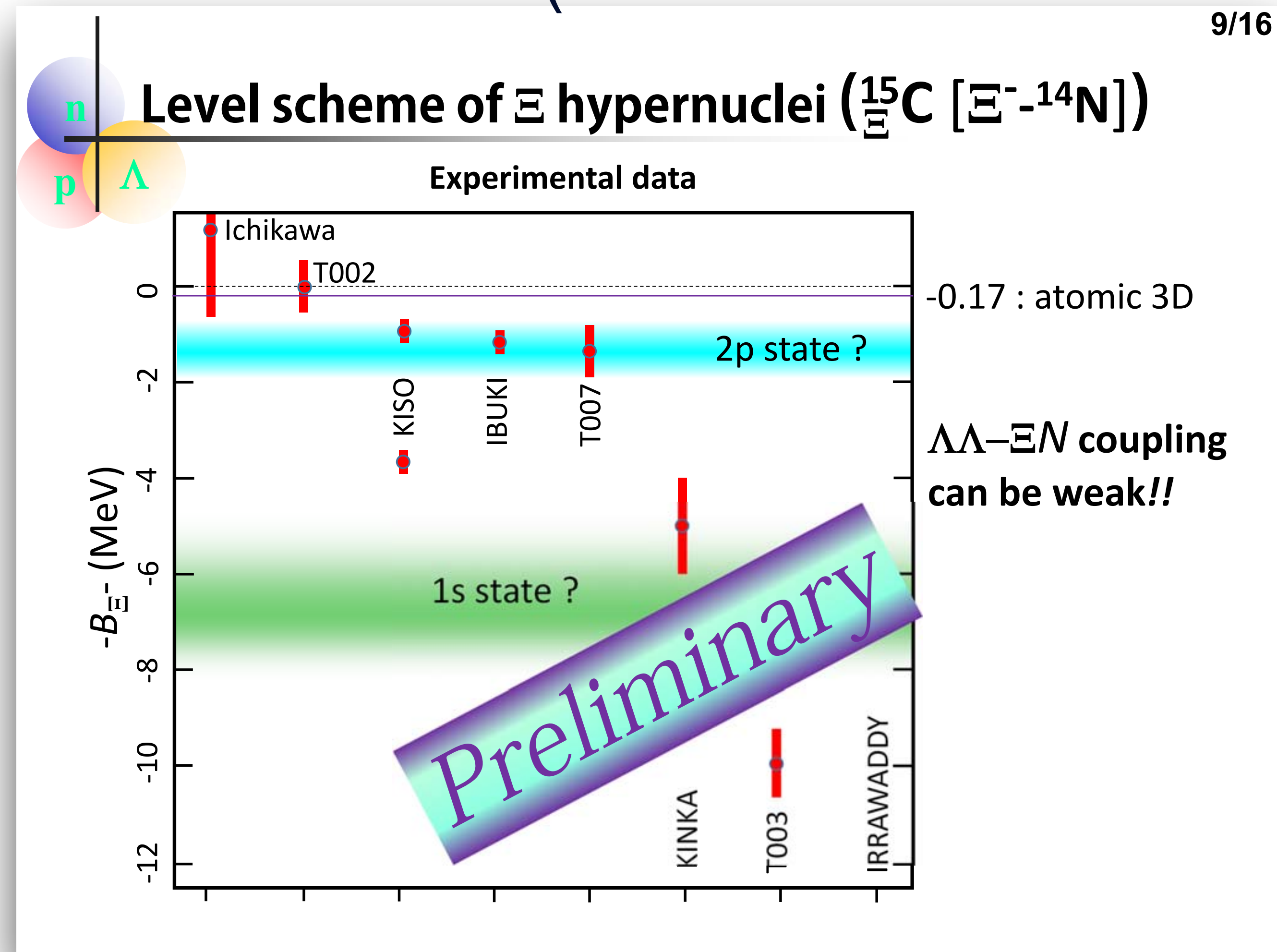
Ξ^--^{12}C atomic levels



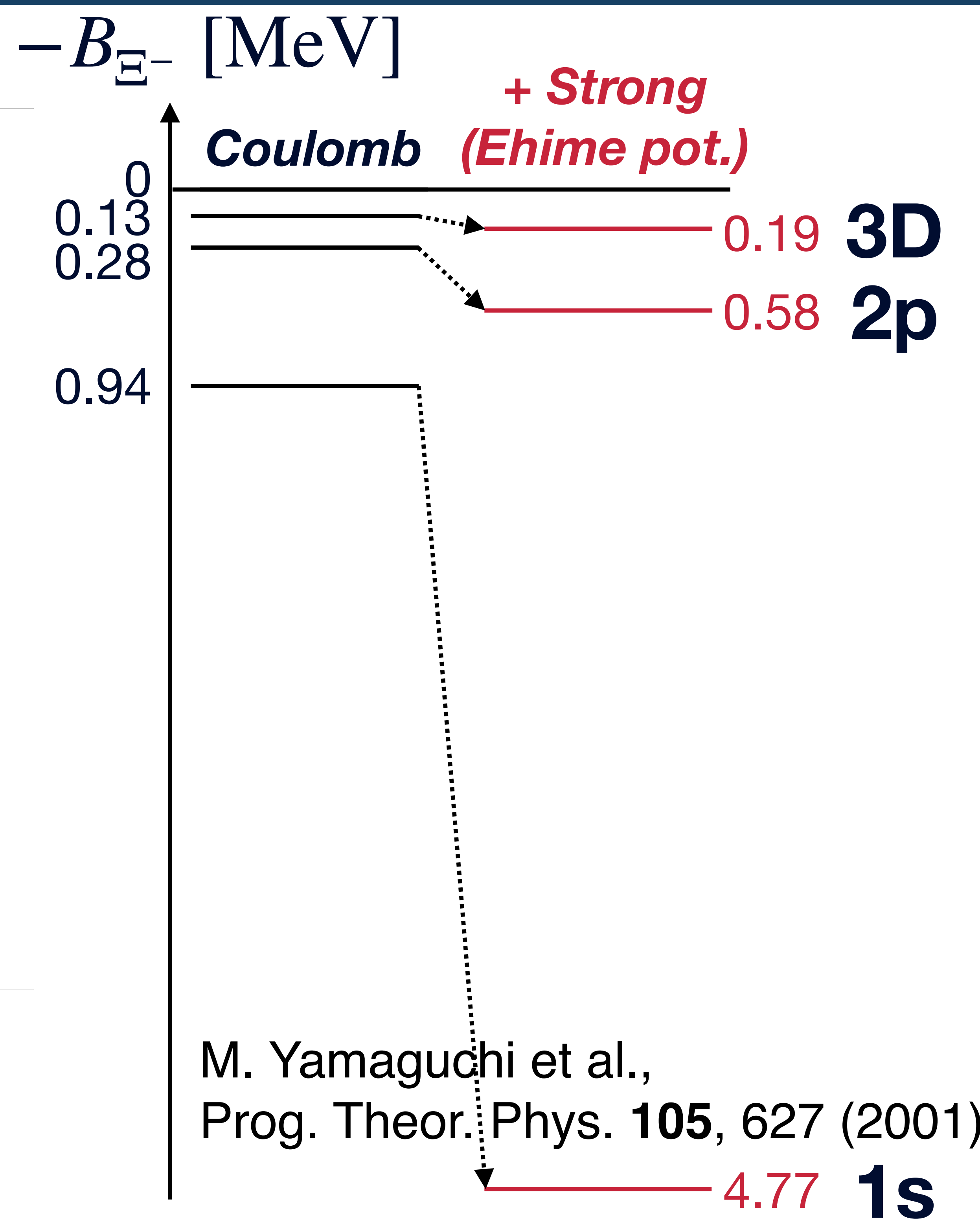
M. Yamaguchi et al.,
Prog. Theor. Phys. **105**, 627 (2001)

Ξ^{-}-^{12}C atomic levels

Deeply-bound Ξ^{-}-^{14}N states have been observed (cf. Yoshida-san's talk)



仲澤さん、第3回クラスター階層領域研究会



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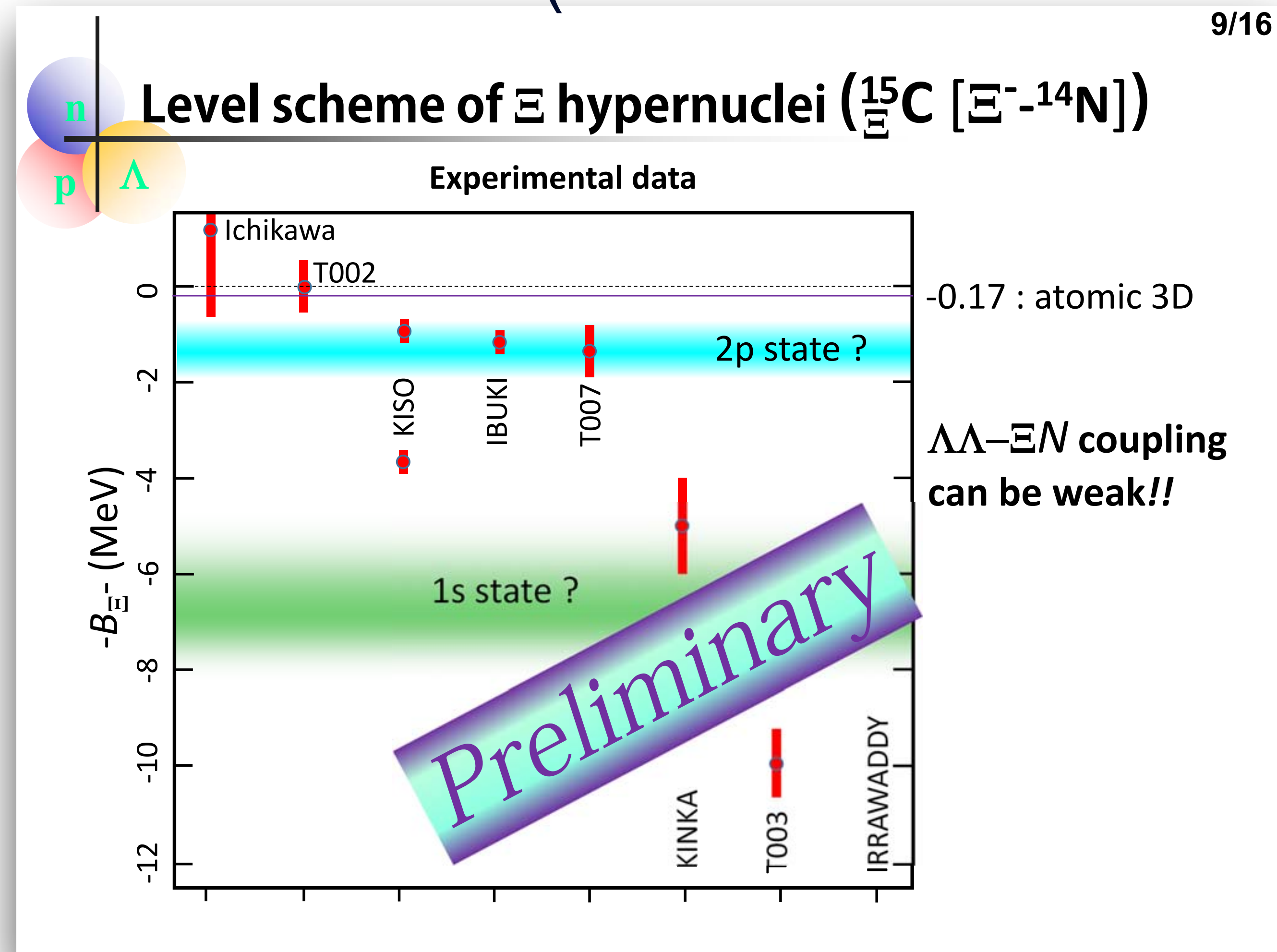
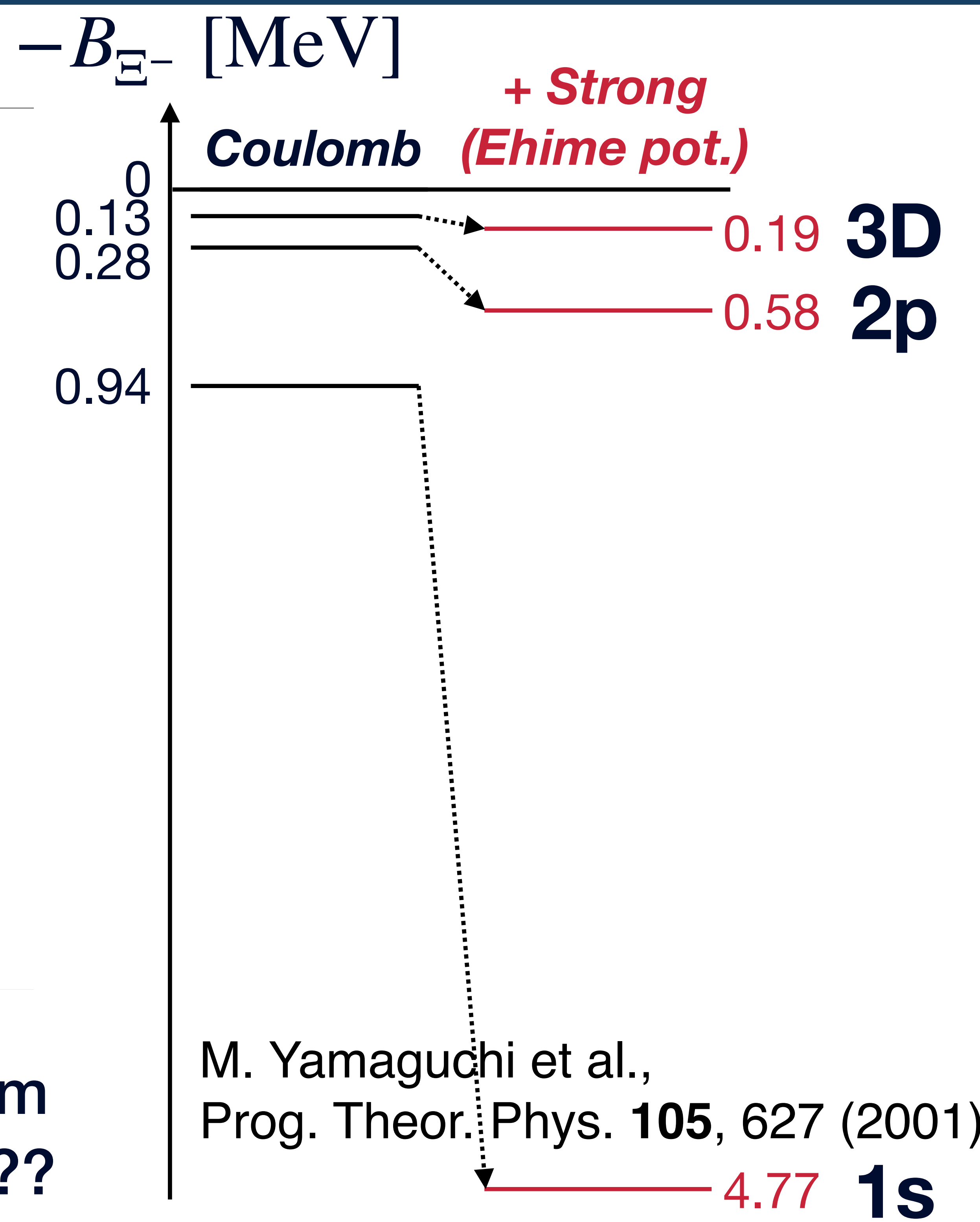


仲澤さん、第3回クラスター階層領域研究会

Was the Ξ^- hyperon absorbed from the 3D orbital in the Nagara event??



J-PARC E75 Experiment

- **Novel production method for $^{5}_{\Lambda\Lambda}\mathrm{H}$ ($pnn\Lambda\Lambda$)**
  - (Step-1) Production of Ξ Hypernuclei $^{7}\mathrm{Li}(K^{-}, K^{+})^{7}_{\Xi^{-}}\mathrm{H}$
  - (Step-2) Decay of Ξ Hypernuclei $^{7}_{\Xi^{-}}\mathrm{H} \rightarrow {}^{5}_{\Lambda\Lambda}\mathrm{H} + 2n$
- **Decay Pion Spectroscopy for $^{5}_{\Lambda\Lambda}\mathrm{H}$**
  - Momentum measurement of pions from two-body $^{5}_{\Lambda\Lambda}\mathrm{H} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + \pi^{-}$ decay at rest
  - **analysis unaffected by (poorly-known) Ξ-nucleus interaction and production mechanism of $^{5}_{\Lambda\Lambda}\mathrm{H}$**

J-PARC E75 Experiment

E75 Phase-1 (2022-23?)
cf. E70: $^{12}\mathrm{C}(K^-, K^+)^{12}_{\Xi}\mathrm{Be}$

- Novel production method for $^{5}_{\Lambda\Lambda}\mathrm{H}$ (pnn
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- Decay Pion Spectroscopy for $^{5}_{\Lambda\Lambda}\mathrm{H}$
  - Momentum measurement of pions from two-body $^{5}_{\Lambda\Lambda}\mathrm{H} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + \pi^-$ decay at rest
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J-PARC E75 Experiment

- **Novel production method for ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ (*pnn***

  E75 Phase-1 (2022-23?)
  cf. E70: ${}^{12}\mathrm{C}(K^-, K^+){}^{12}_{\Xi}\mathrm{Be}$

  - (Step-1) Production of Ξ Hypernuclei ${}^{7}\mathrm{Li}(K^-, K^+){}^{7}_{\Xi^-}\mathrm{H}$
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- **Decay Pion Spectroscopy for ${}^{5}_{\Lambda\Lambda}\mathrm{H}$**

  E75 Phase≧2

  - Momentum measurement of pions from two-body ${}^{5}_{\Lambda\Lambda}\mathrm{H} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + \pi^-$ decay at rest
  - **analysis unaffected by (poorly-known) Ξ-nucleus interaction and production mechanism of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$**

Formation Probability of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$

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)

PTEP Prog. Theor. Exp. Phys. **2020**, 063D01 (17 pages)
DOI: 10.1093/ptep/ptaa047

Statistical double Λ hypernuclear formation from Ξ^- absorption at rest in light nuclei

Akira Ohnishi[1,*], Chikako Ishizuka[2], Kohsuke Tsubakihara[2,3], and Yuichi Hirata[4]
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[2]*Laboratory for Advanced Nuclear Energy, Institute of Innovative Research, Tokyo Institute of Technology, Tokyo 152-8550, Japan*
[3]*National Institute of Technology, Asahikawa College, Asahikawa 071-8142, Japan*
[4]*Central Institute of Isotope Science, Hokkaido University, Sapporo 060-0815, Japan*
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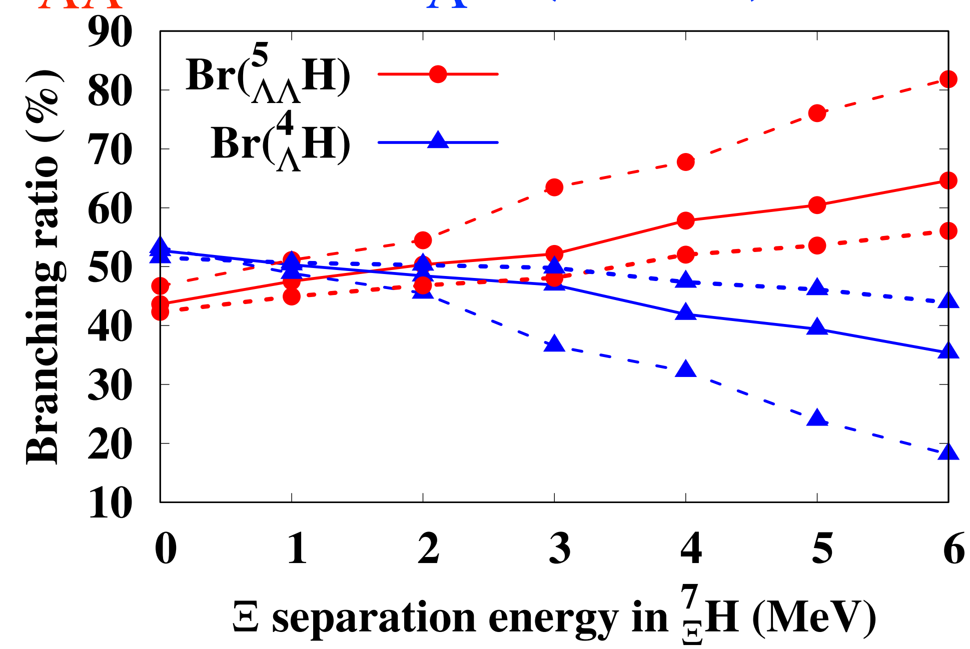
A. Ohnishi et al., Prog. Theor. Exp. Phys. **2020**, 29 (2020)

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

B.R. ~90%

${}^{5}_{\Lambda\Lambda}\mathrm{H}+2n$ ${}^{4}_{\Lambda}\mathrm{H}(0^+,1^+)+\Lambda+2n$



B.R. ~50%

Formation Probability of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$

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

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

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

B.R. ~90%

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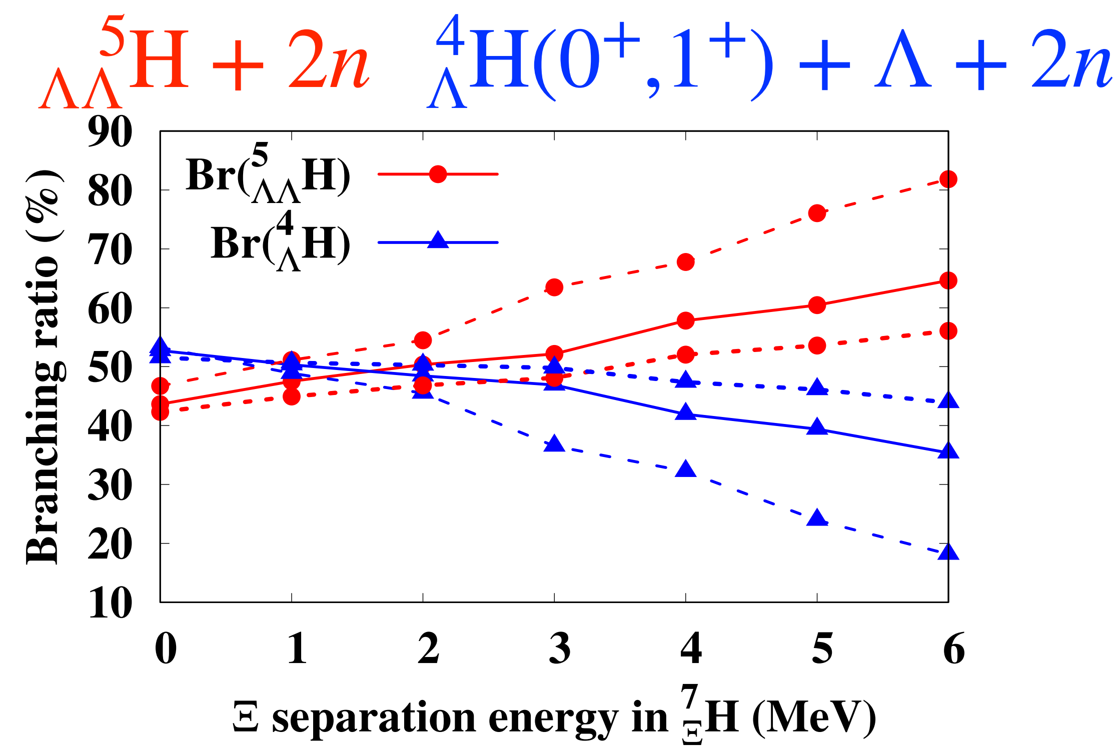


B.R. ~50%

Comparison

- Hybrid-Emulsion method (J-PARC E07)
  - Systematic studies on Double-Λ Hypernuclei with $4 \leq A \leq 17$
- Decay Pion Spectroscopy (J-PARC E75)
  - **aims at $^{5}_{\Lambda\Lambda}\mathrm{H}$**
    Two-body decay into a daughter hypernucleus in the ground state is unlikely in case of $A \neq 6$

$$^{4}_{\Lambda\Lambda}\mathrm{H} \rightarrow {}^{4}_{\Lambda}\mathrm{He}^{(*)} + \pi^-$$
$$^{5}_{\Lambda\Lambda}\mathrm{H} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + \pi^-$$
$$^{6}_{\Lambda\Lambda}\mathrm{He} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + p + \pi^-$$

Comparison

- Hybrid-Emulsion method (J-PARC E07)
  - Systematic studies on Double-Λ Hypernuclei with $4 \le A \le 17$
- Decay Pion Spectroscopy (J-PARC E75)
  - aims at ${}_{\Lambda\Lambda}^{5}\mathrm{H}$

    Prospects: study of weak decay, including lifetime measurement

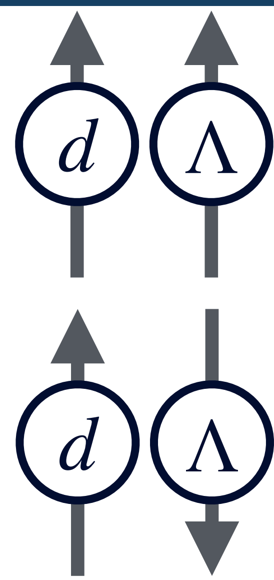
    Two-body decay into a daughter hypernucleus in the ground state is unlikely in case of $A \neq 6$

$$ {}_{\Lambda\Lambda}^{4}\mathrm{H} \to {}_{\Lambda}^{4}\mathrm{He}^{(*)} + \pi^- $$
$$ {}_{\Lambda\Lambda}^{5}\mathrm{H} \to {}_{\Lambda}^{5}\mathrm{He} + \pi^- $$
$$ {}_{\Lambda\Lambda}^{6}\mathrm{He} \to {}_{\Lambda}^{5}\mathrm{He} + p + \pi^- $$

Why is ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ special? (1)

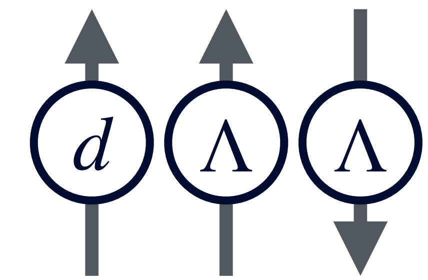
$A = 4$

${}^{3}_{\Lambda}\mathrm{H} \Rightarrow {}^{4}_{\Lambda\Lambda}\mathrm{H}$



$3/2^{+}$: unbound

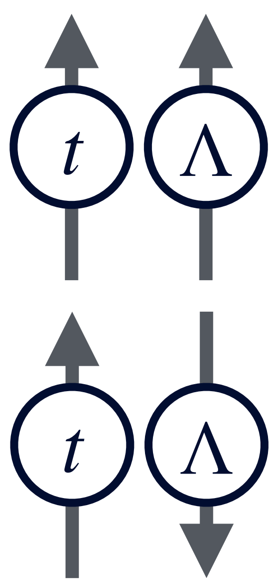
$1/2^{+}$: $B = 0.13\,\mathrm{MeV}$



most likely unbound

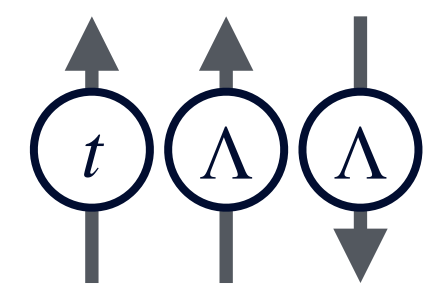
$A = 5$

${}^{4}_{\Lambda}\mathrm{H} \Rightarrow {}^{5}_{\Lambda\Lambda}\mathrm{H}$



1^{+}: $B = 1.07\,\mathrm{MeV}$

0^{+}: $B = 2.16\,\mathrm{MeV}$



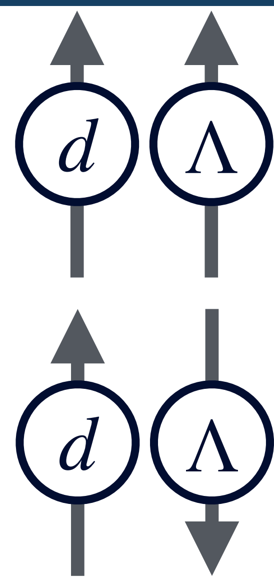
expected to be bound

L. Contessi et al., Phys. Lett. B **797**, 134893 (2019)

Why is $^{5}_{\Lambda\Lambda}\mathrm{H}$ special? (1)

$A = 4$

$^{3}_{\Lambda}\mathrm{H} \Rightarrow {}^{4}_{\Lambda\Lambda}\mathrm{H}$



$3/2^{+}$: unbound

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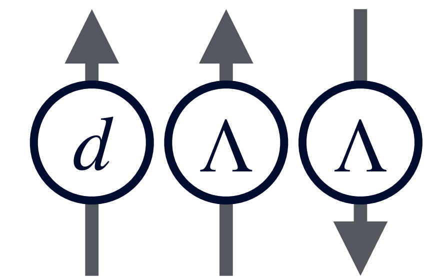

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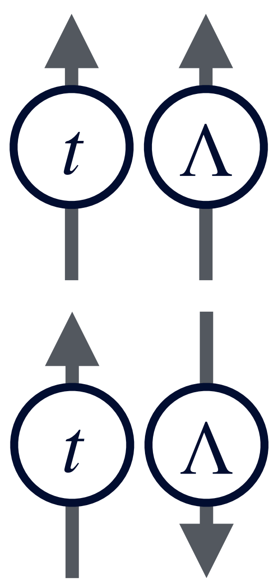

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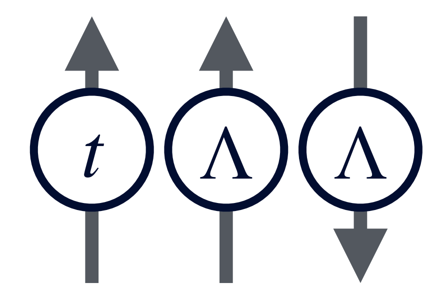


expected to be bound

The lightest Double Λ Hypernuclei will be $^{5}_{\Lambda\Lambda}\mathrm{H}/{}^{5}_{\Lambda\Lambda}\mathrm{He}$

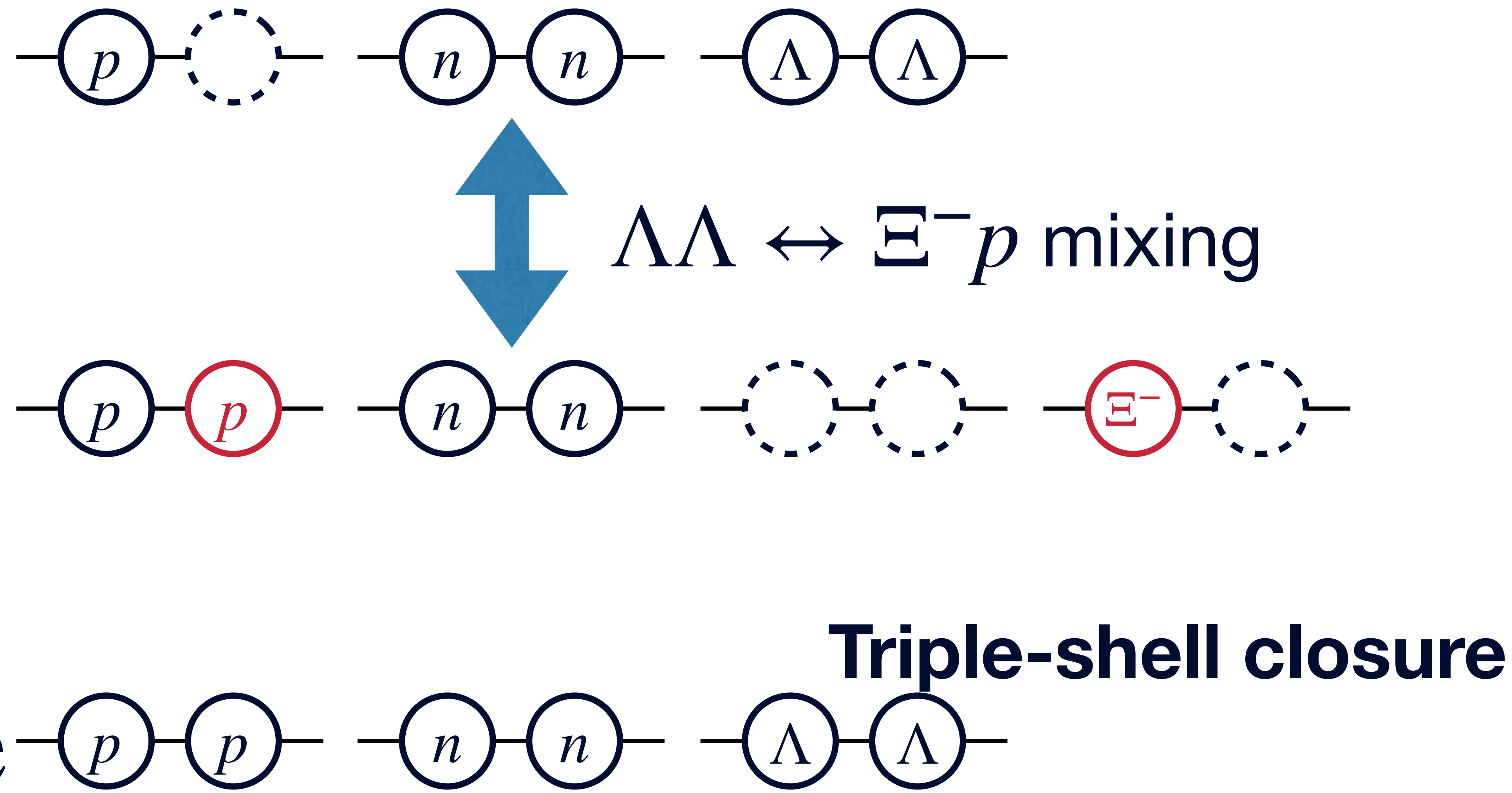
L. Contessi et al., Phys. Lett. B **797**, 134893 (2019)

Why is ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ special? (2)

$A = 5$

${}^{5}_{\Lambda\Lambda}\mathrm{H}$

${}^{5}_{\Xi^-}\mathrm{H}$

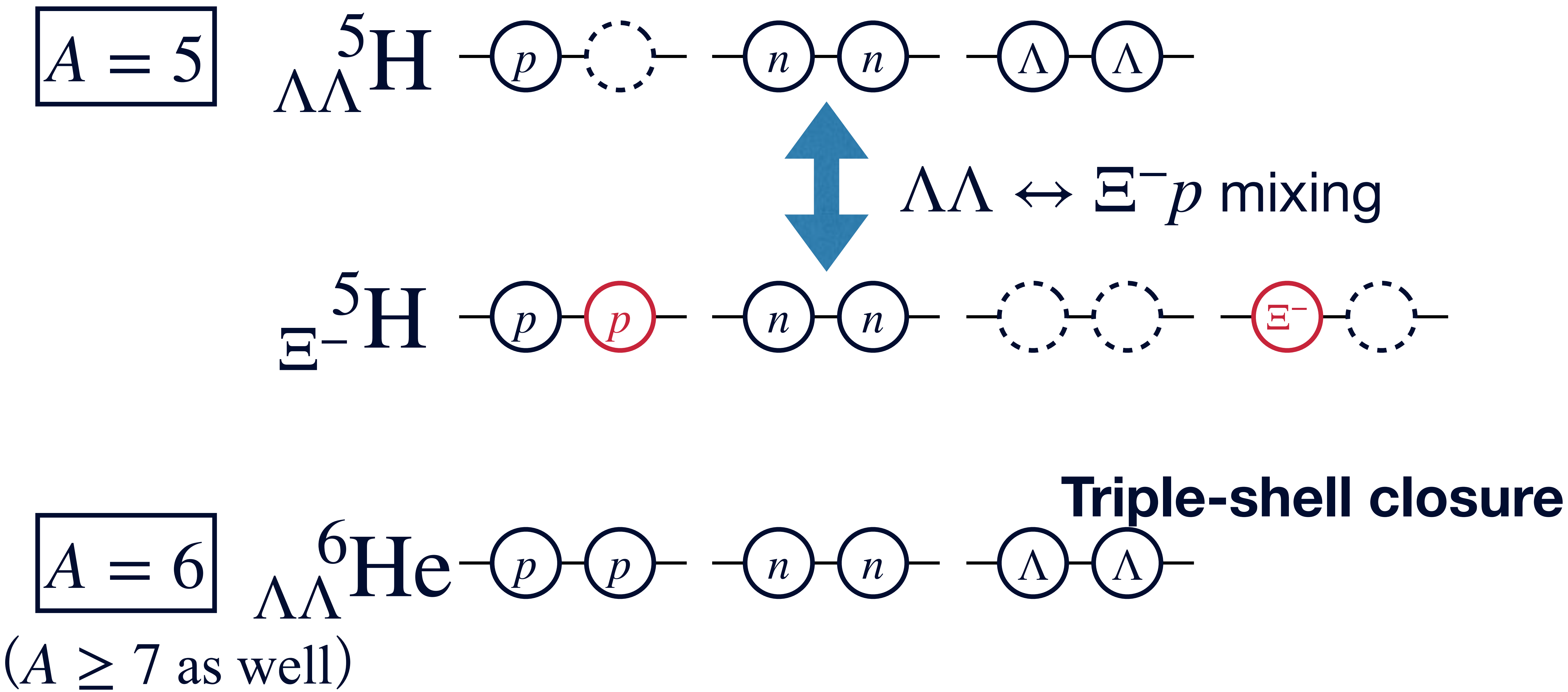


$A = 6$

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

($A \geq 7$ as well)

Why is ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ special? (2)



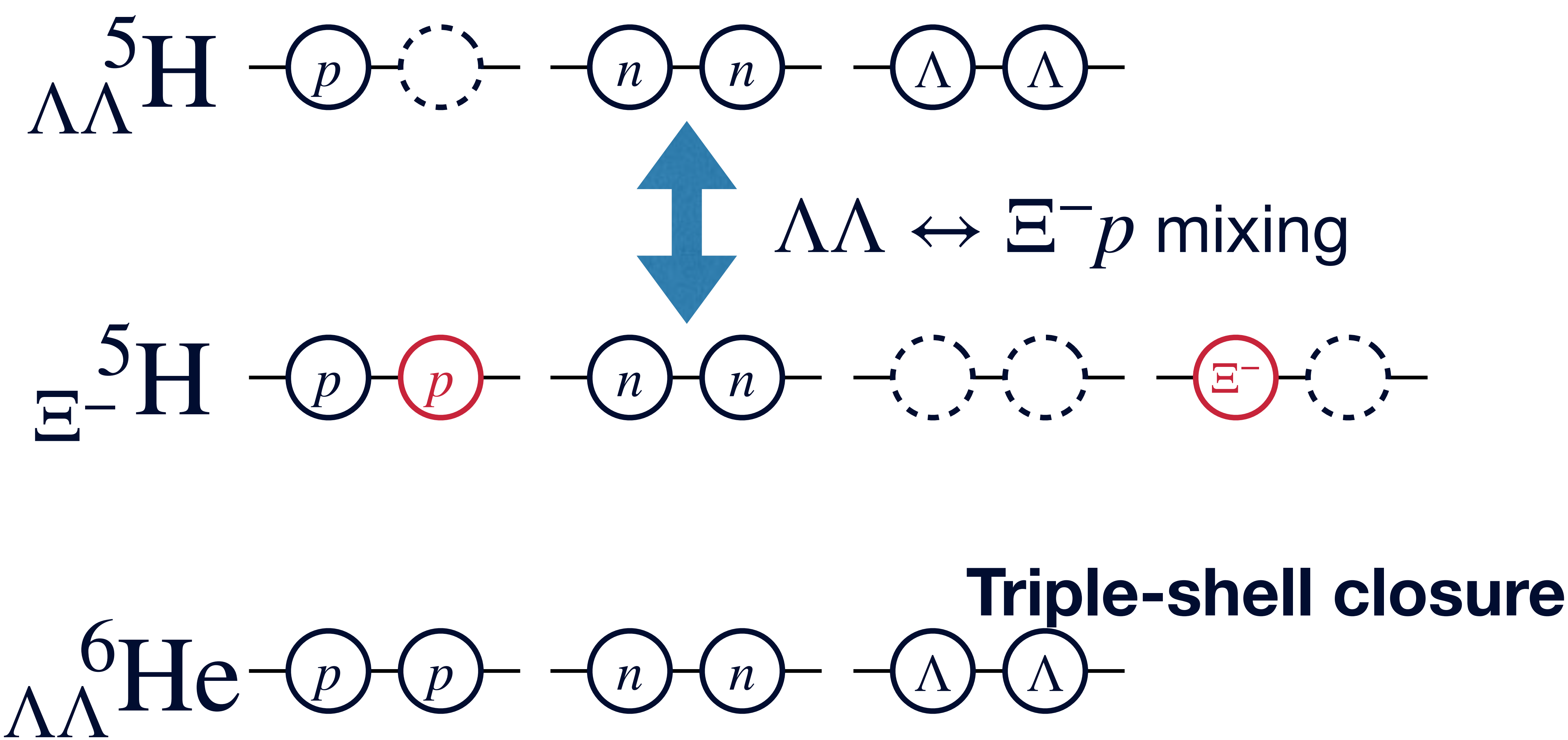
Suppression of $\Lambda\Lambda \leftrightarrow \Xi^{-}p$ mixing due to the Pauli principle

Why is ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ special? (2)

$A = 5$

$A = 6$

($A \geq 7$ as well)



study of ΛΛ interaction

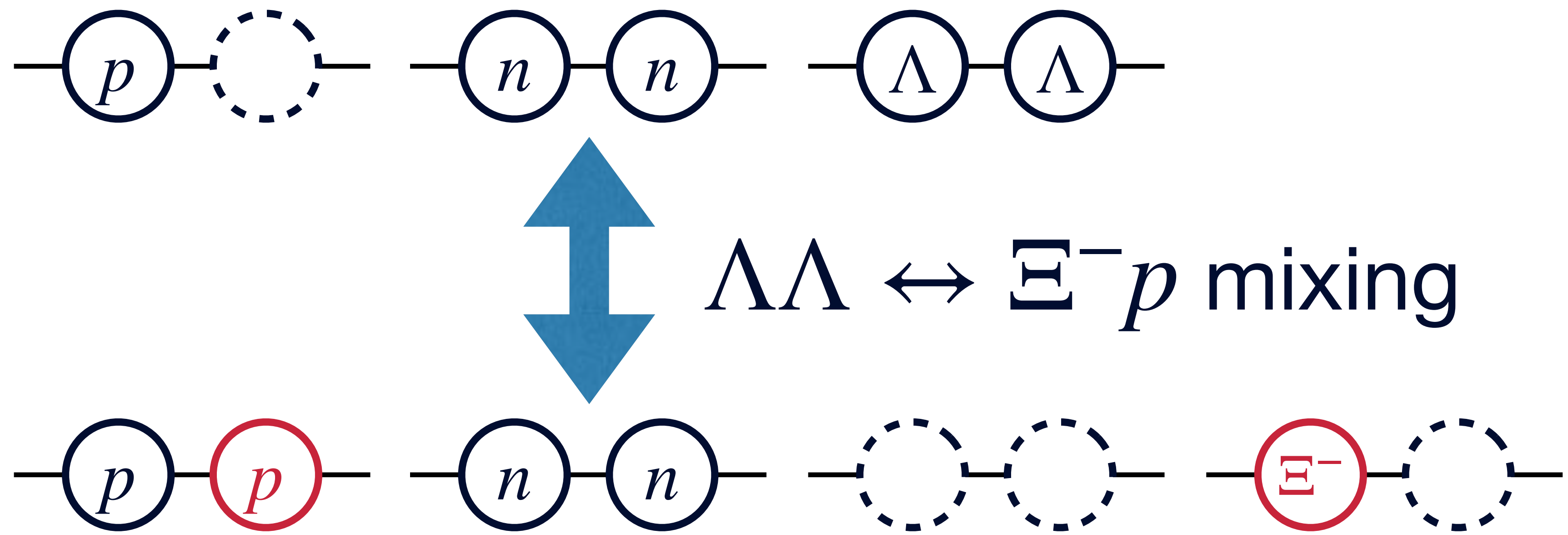
Suppression of $\Lambda\Lambda \leftrightarrow \Xi^{-}p$ mixing due to the Pauli principle

Why is ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ special? (2)

$A = 5$

${}^{5}_{\Lambda\Lambda}\mathrm{H}$

${}^{5}_{\Xi^-}\mathrm{H}$

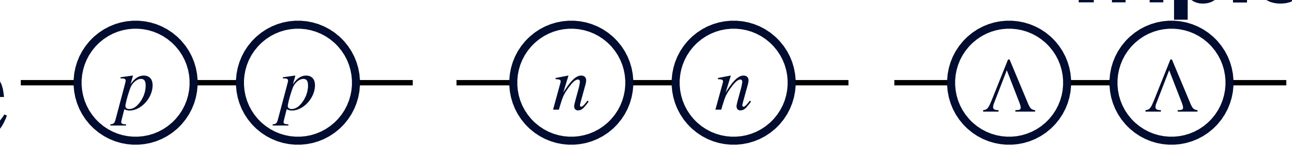


study of ΞN-$\Lambda\Lambda$ interaction as well as $\Lambda\Lambda$ interaction

Triple-shell closure

$A = 6$

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



$(A \geq 7$ as well$)$

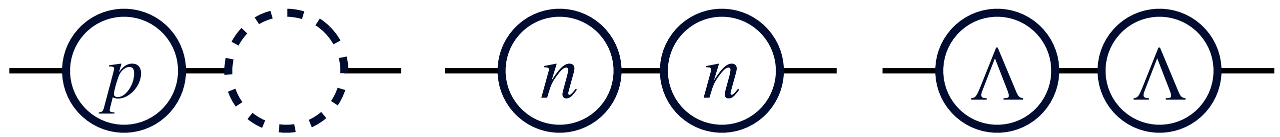
study of $\Lambda\Lambda$ interaction

Suppression of $\Lambda\Lambda \leftrightarrow \Xi^- p$ mixing due to the Pauli principle

Why is ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ special? (2)

$A = 5$

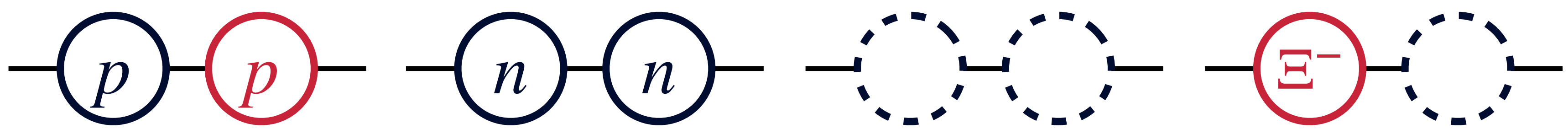
${}^{5}_{\Lambda\Lambda}\mathrm{H}$



~11MeV mass difference

$\Lambda\Lambda \leftrightarrow \Xi^{-}p$ mixing

${}^{5}_{\Xi^-}\mathrm{H}$



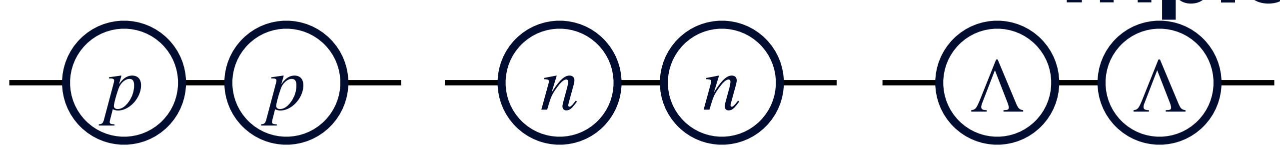
study of ΞN-$\Lambda\Lambda$ interaction as well as $\Lambda\Lambda$ interaction

Triple-shell closure

$A = 6$

$(A \geq 7$ as well$)$

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

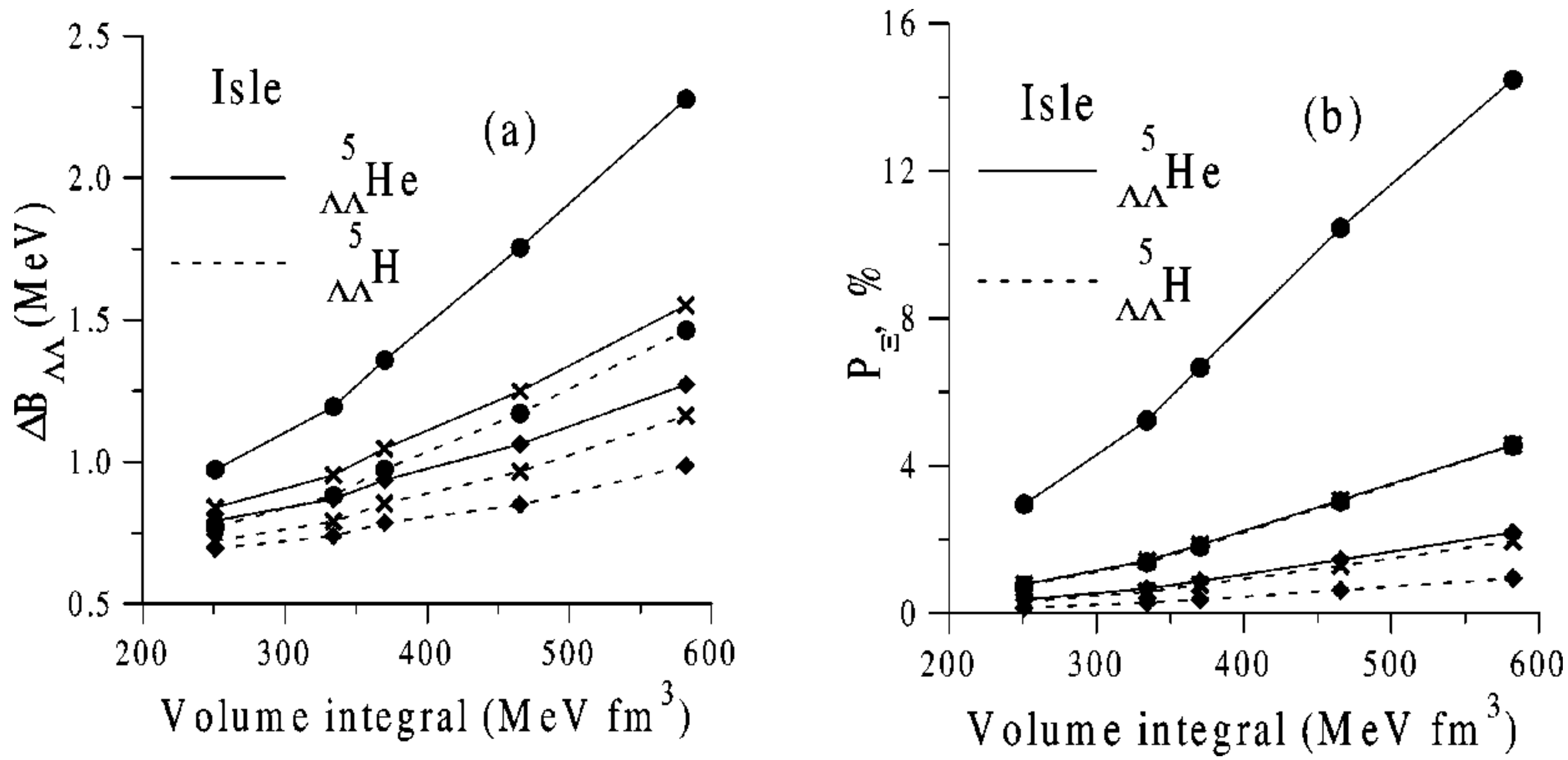


study of $\Lambda\Lambda$ interaction

Suppression of $\Lambda\Lambda \leftrightarrow \Xi^{-}p$ mixing due to the Pauli principle

ΞN-$\Lambda\Lambda$ int. and $\Delta B_{\Lambda\Lambda}$, Ξ mixing

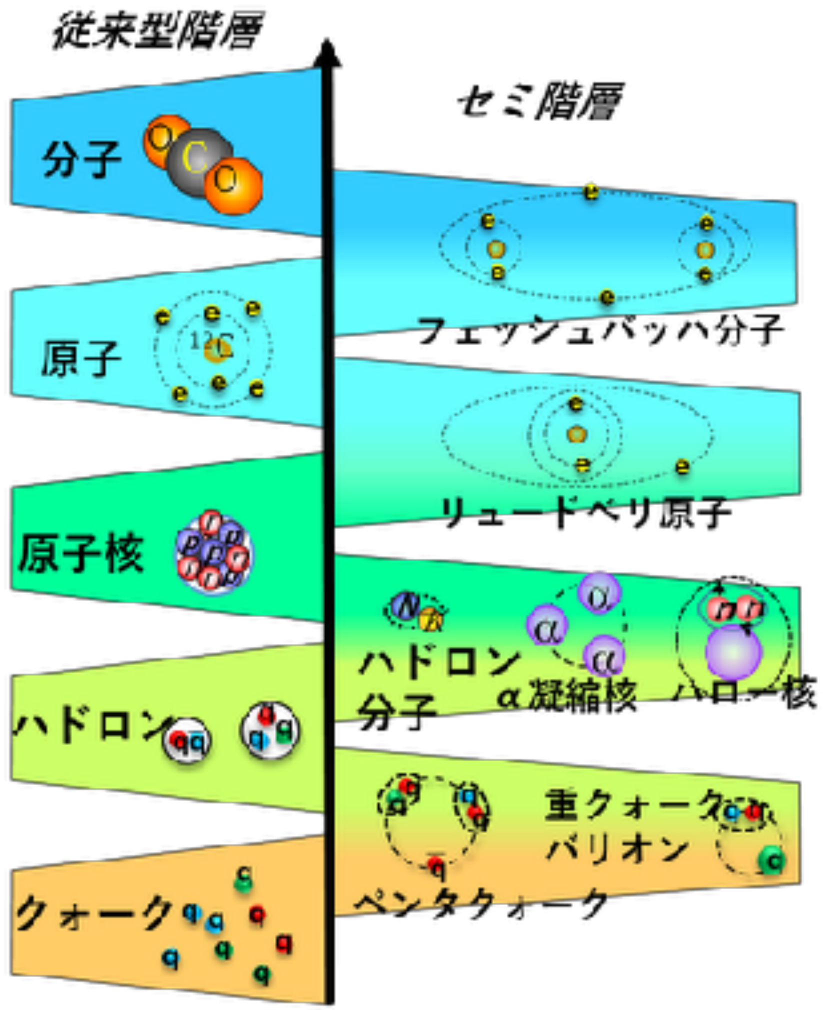
$\Delta B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{6}\mathrm{He}) = 1.0\,\mathrm{MeV}$ (fixed)



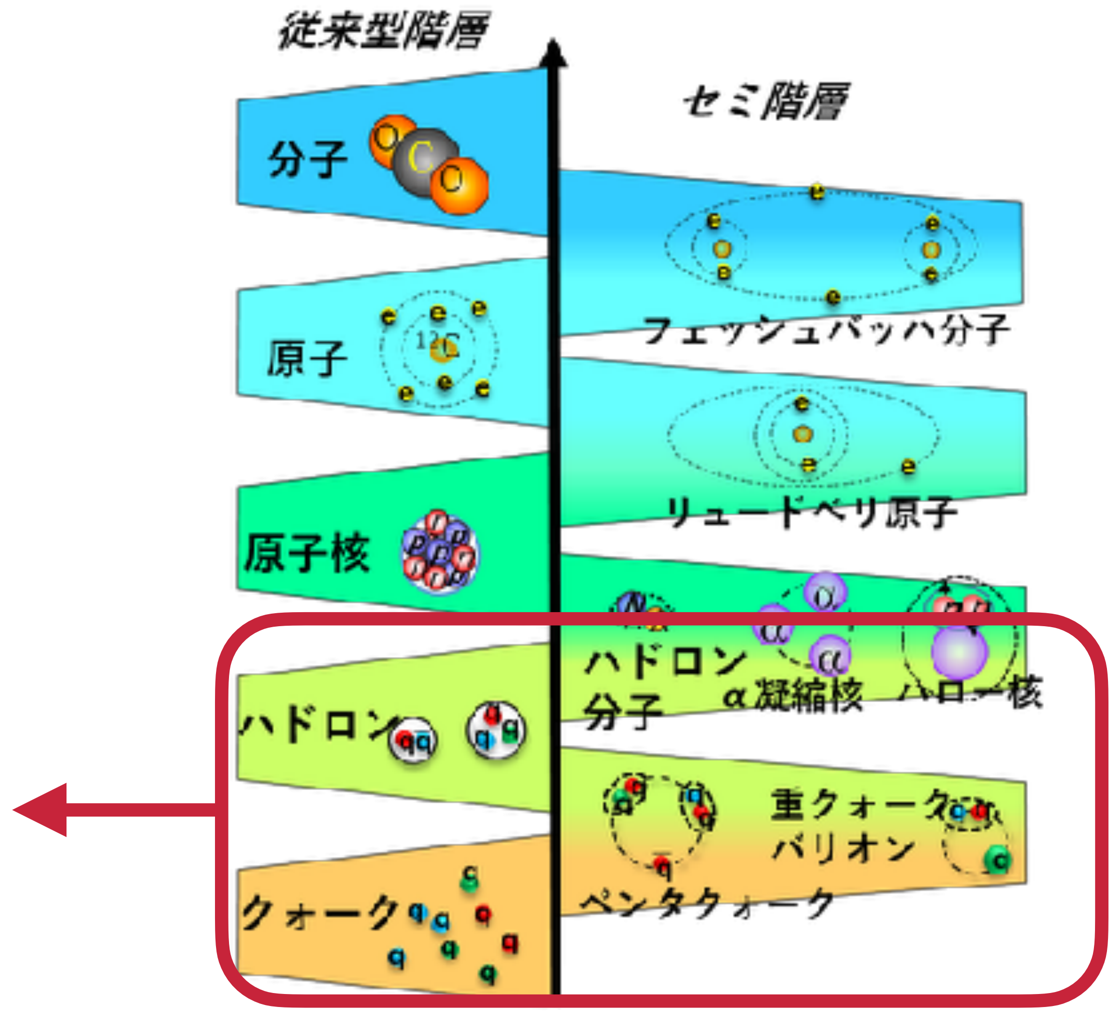
$$\int V_{\Lambda\Lambda,\Xi N}(r)d^3r$$

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

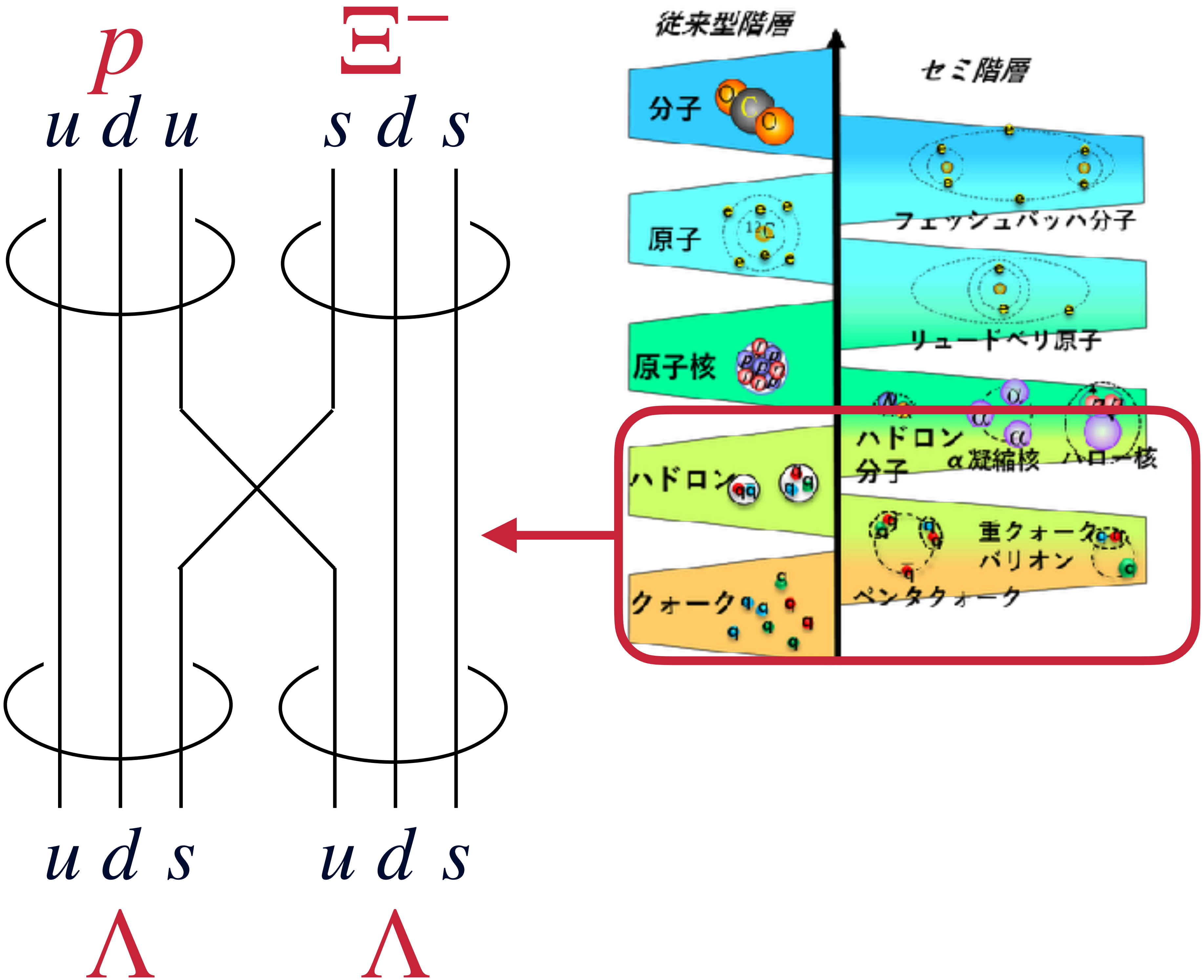
$^{5}_{\Lambda\Lambda}\mathrm{H}$ and re-clustering



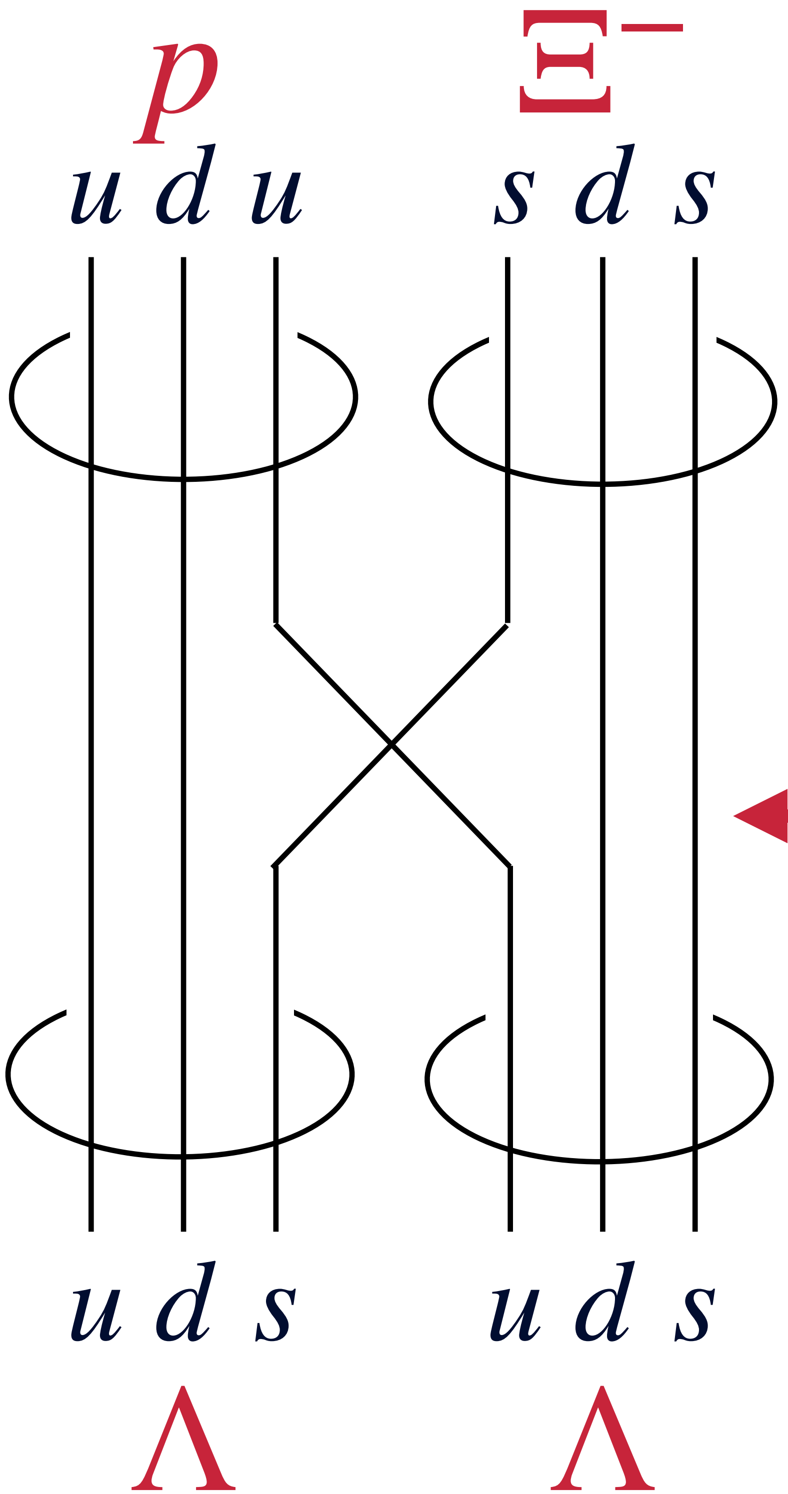
${}^{5}_{\Lambda\Lambda}\mathrm{H}$ and re-clustering

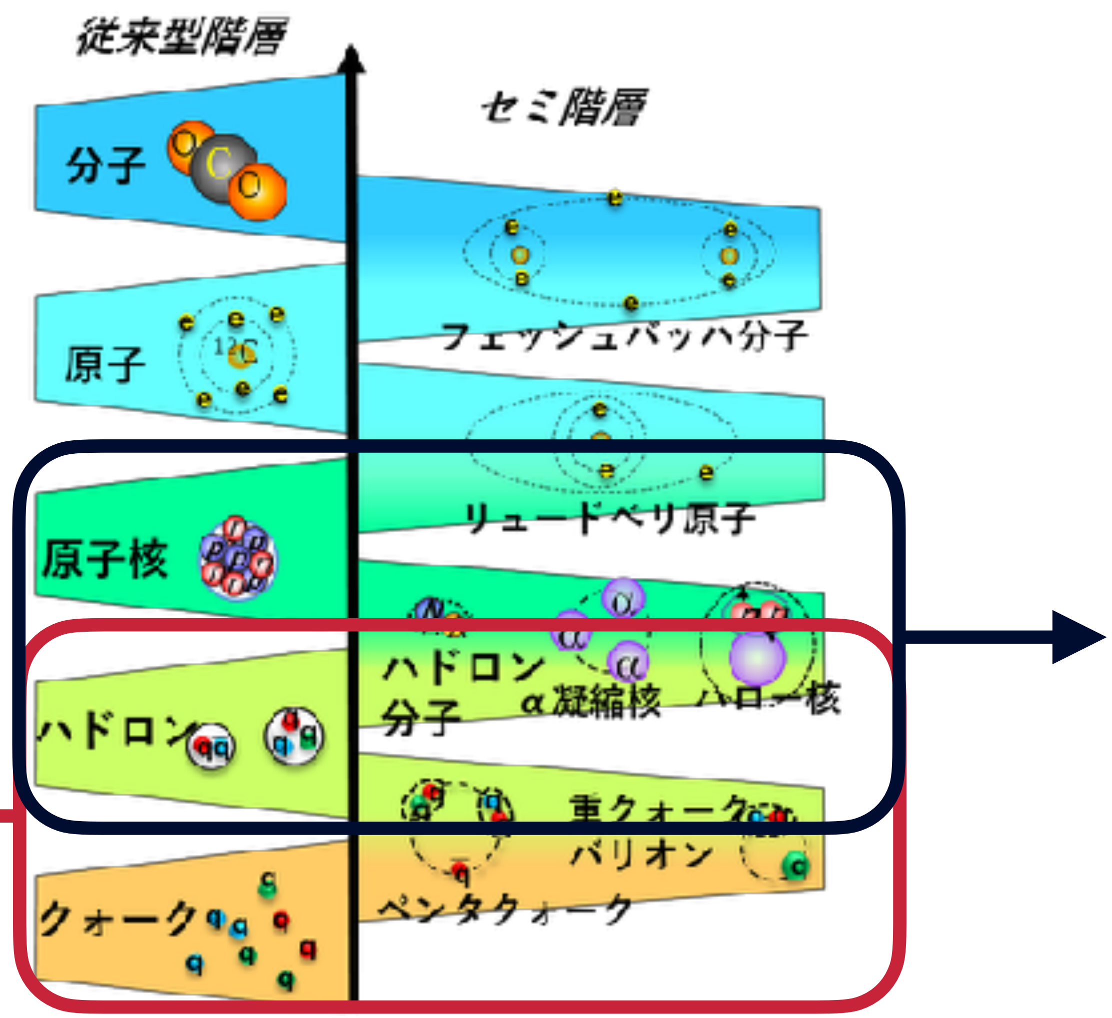


$^{5}_{\Lambda\Lambda}\mathrm{H}$ and re-clustering

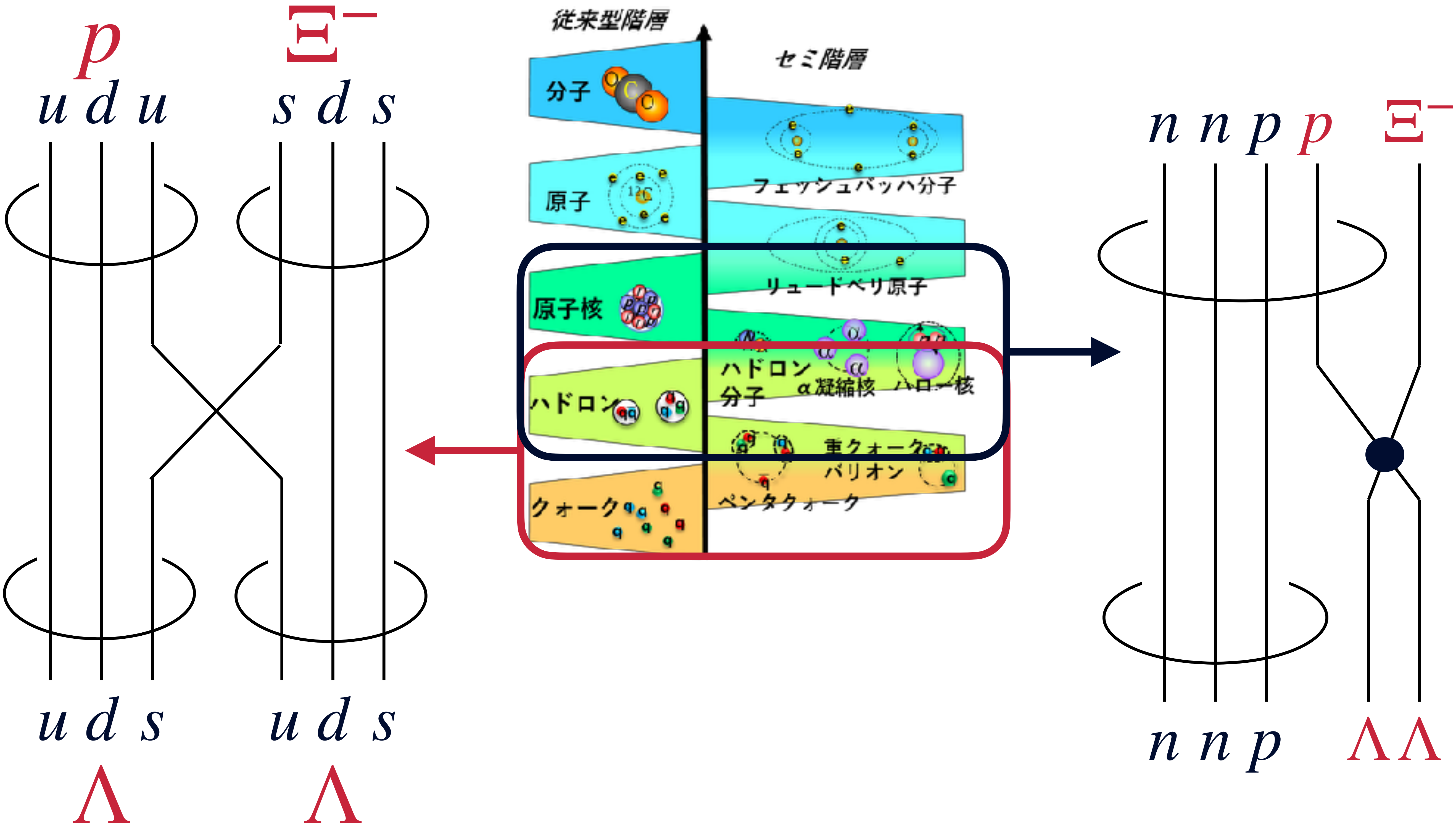


$^{5}_{\Lambda\Lambda}$H and re-clustering

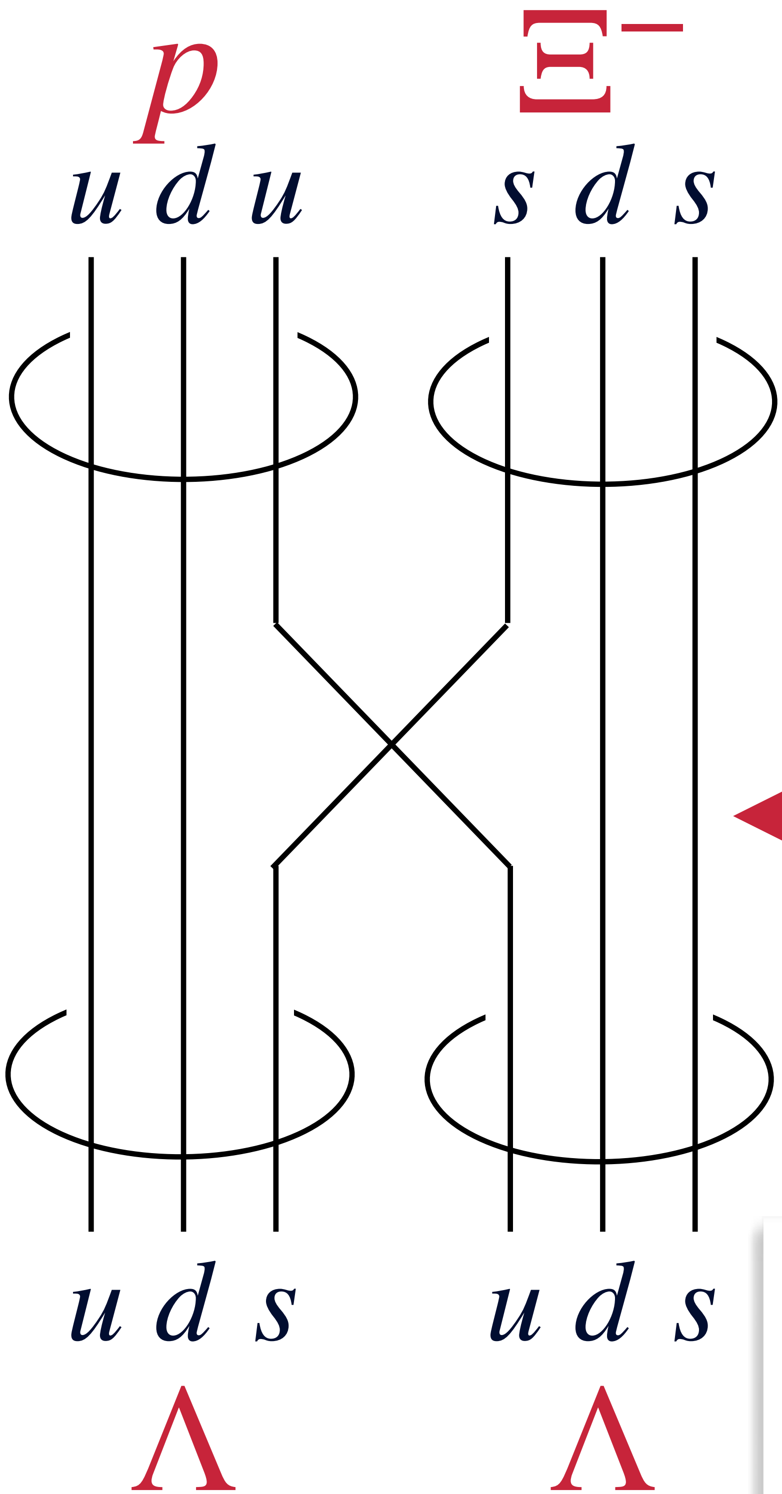


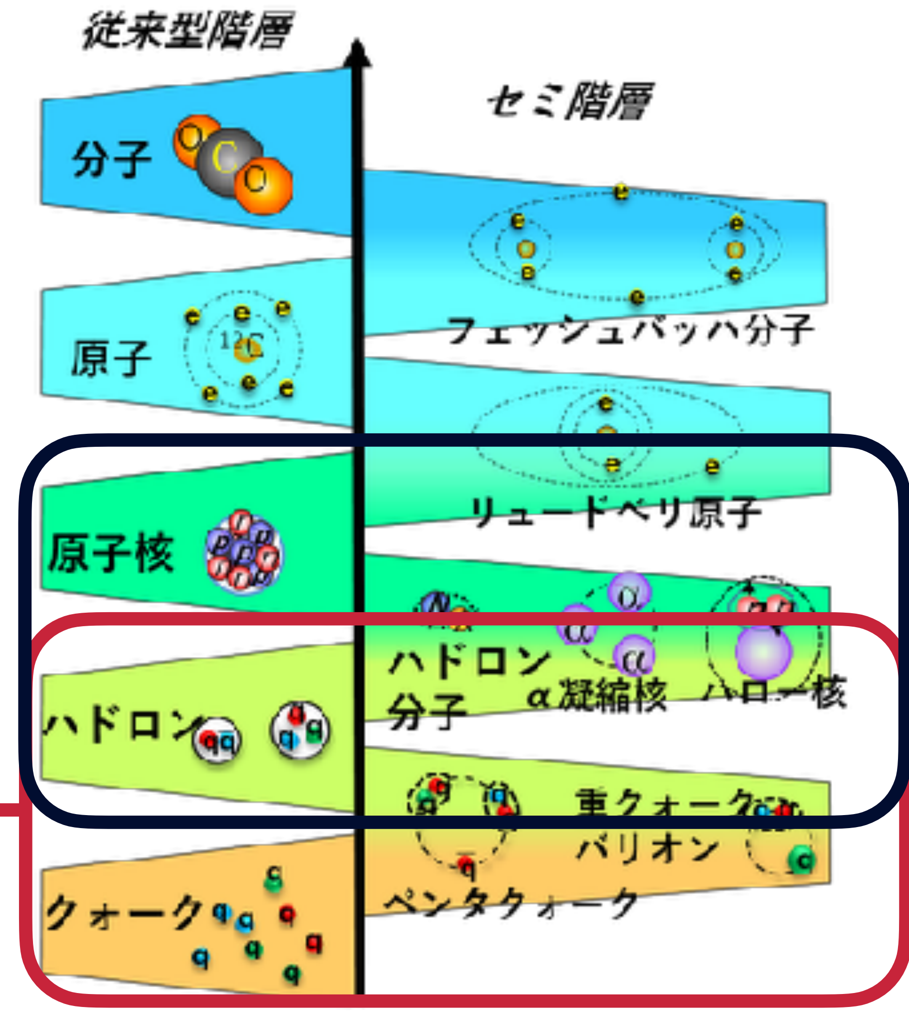


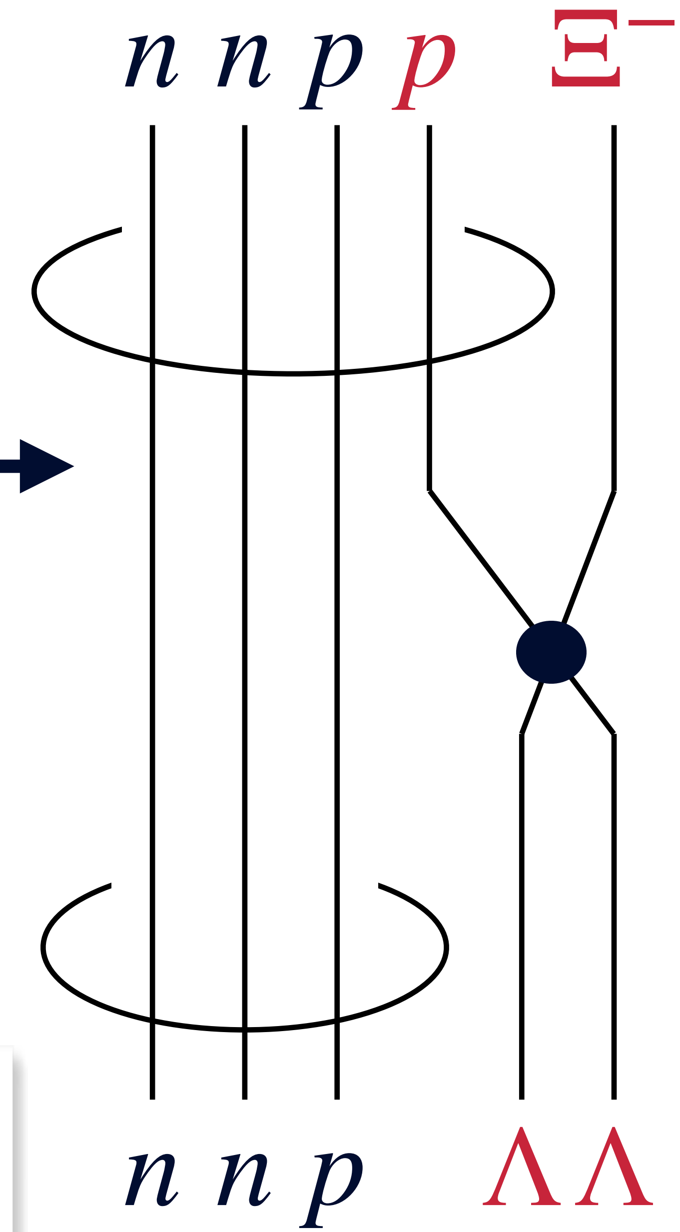
$^{5}_{\Lambda\Lambda}\mathrm{H}$ and re-clustering



${}^{5}_{\Lambda\Lambda}\mathrm{H}$ and re-clustering







"re-clustering"
in two semi-hierarchies

2つのセミ階層にまたがる
「クラスター組み替え」

KEKにおける原子核物理のロードマップ2020

2 J-PARC における原子核ハドロン物理の現状と将来

2.1 ストレンジネス核物理: S=−1

2.2 ストレンジネス核物理: S=−2

2.2.1 ハイブリッド・エマルジョン実験 (→吉田さん)

2.2.2 Ξ 原子 X 線分光 (→山本さん)

2.2.3 Ξ ハイパー核分光

S=−2 分光の将来

2.2.4 SU(3)f 一重項の大きさと H ダイバリオン

2.3 高運動量ビームラインを用いた計画

(後略)

E75 Phase-1
(stage-1 approved)

明を目指す。

スピン・アイソスピンに依存しない項は、$\alpha+\Xi$（${}^{5}_{\Xi}\mathrm{He}$, ${}^{5}_{\Xi}\mathrm{H}$ ）あるいは、$\alpha+\alpha+\Xi$（ ${}^{9}_{\Xi}\mathrm{Be}$, ${}^{9}_{\Xi}\mathrm{Li}$ ）のポテンシャル深さを測定するのが直接的であるが、これらの核種は、安定核種標的を使う (K^-, K^+) 反応では直接生成できない。代わりに、${}^{7}\mathrm{Li}(K^-, K^+){}^{7}_{\Xi}\mathrm{H}$ （$\alpha+2n+\Xi^-$）や ${}^{10}\mathrm{B}(K^-, K^+){}^{10}_{\Xi}\mathrm{Li}$ $(2\alpha+n+\Xi^-)$ を測定することが提案されている。これらの例では、n の波動関数は外側に拡がっているため Ξ^- との相互作用に与える影響は小さいと考えられている。このように理論との協力による精密構造計算との比較により、ΞN 相互作用の詳細を決定していくことが考えられる。

Ξ^- は負電荷を持つので、中重 Ξ ハイパー核においては、クーロンポテンシャルの深さが強い相互作用によるポテンシャルと同レベルに大きくなり、いわゆる Coulomb Assisted Bound States が形成されるようになる。この状態は、質量数とともに束縛が深くなり一方で転換幅は狭くなることが期待されている。

加えて、$S = -2$ のハイパー核系は、ΞN と $\Lambda\Lambda$ の系が 27 MeV 程度しか離れていないという特徴を持つ。そこでこの二つのチャンネル間に $\Xi N \to \Lambda\Lambda$ 相互作用を通して、強い相互作用による結合があると、二つの系はチャンネル結合により強く結合したバリオン系ということになる。実際に、理論的には $\Xi N \to \Lambda\Lambda$ 相互作用によって (K^-, K^+) 反応をつかって直接ダブル Λ 核が生成されることが予言されている。これによると、Ξ ハイパー核の基底状態が 1^- 状態にあるため、これと結合して励起されやすいダブル Λ ハイパー核のスピン・パリティは同じ 1^- 状態となり、これは、ダブル Λ ハイパー核の基底状態 (0^+) ではなく、2 個あるうちの 1 個の Λ が $\ell = 1$ の $p-$ 軌道に励起された励起状態である。この励起強度が大きいとすると (K^-, K^+) 反応を使ったダブル Λ 核の励起状態の研究という新しい分野が開拓されることとなろう。

S-2S により (K^-, K^+) 反応で S=−2 の系の生成さらにはその状態を標識化したうえでその崩壊を標的周辺に設置した別の検出器で測定する実験も検討・提案されている。P75 実験では、${}^{7}\mathrm{Li}(K^-, K^+){}^{7}_{\Xi}$ H 反応で生成した ${}^{7}_{\Xi}\mathrm{H}$ を S-2S で同定した上で、高い分岐比で生じる ${}^{7}_{\Xi}\mathrm{H} \to {}^{5}_{\Lambda\Lambda}\mathrm{H} + 2n$ 崩壊からの ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ の

$$ {}^{5}_{\Lambda\Lambda}\mathrm{H} \to {}^{5}_{\Lambda}\mathrm{He} + \pi^- \quad (1) $$

$$ {}^{5}_{\Lambda}\mathrm{He} \to {}^{4}\mathrm{He} + p + \pi^-, \quad (2) $$

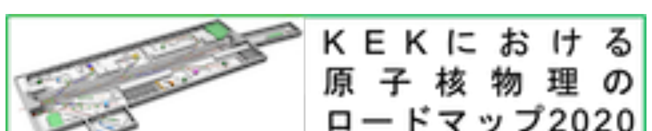
という連続弱崩壊を、S-2S の上流・標的周辺に設置したソレノイド電磁石と TPC で構成された大立体角スペクトロメータで測定し、特に反応 1 の π^- の運動量測定により、${}^{5}_{\Lambda\Lambda}\mathrm{H}$ の分光を行う（崩壊 π 分光法）計画である。目的は、$\Xi N \to \Lambda\Lambda$ 相互作用の大きさの決定である。最初のステップとして ${}^{7}_{\Xi}\mathrm{H}$ の収量を測定する実験が認められた。ある程度よい分解能で測定できれば、収量に加え、Ξ^- の束縛エネルギーも決定でき、前述した ΞN 相互作用のスピン・アイソスピン非依存項の大きさも決定できると期待される。

2.2.4 SU(3)$_\mathrm{f}$ 一重項の大きさと H ダイバリオン

E75 Phase-2

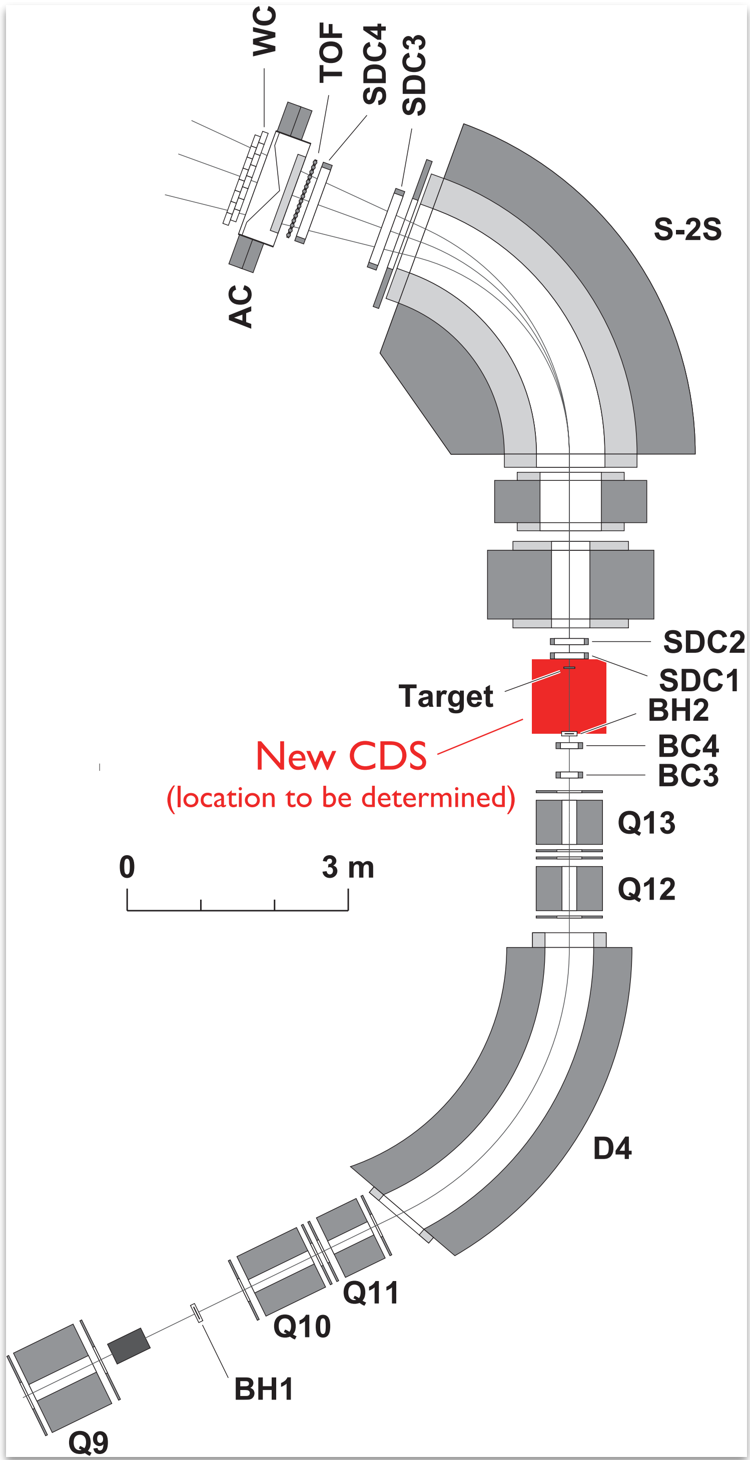
S=−2 のバリオン間相互作用で特に重要で興味深いのは、SU(3)$_\mathrm{f}$ 一重項である。クォーク描像に基づく模型によるとバリオン間力（核力）の短距離部分は、クォーク間のパウリ排他律とグルーオン交換によるカラー磁気力で説明できる。クォーク間のパウリ排他律が働かず、カラー磁気力が引力となる SU(3)$_\mathrm{f}$ 一重項では、大きな引力芯が予想される。この状態に対応するのは、$uuddss$ の 6 クォーク状態の H ダイバリオンであり、その実験的な観測・

16



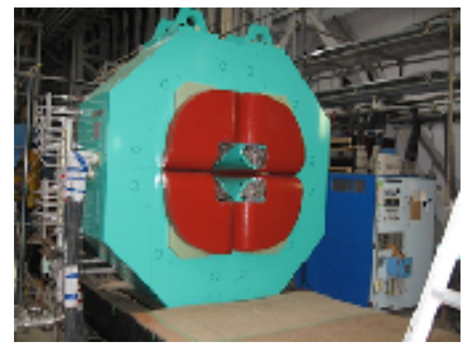
http://kakudan.rcnp.osaka-u.ac.jp/jp/researcher/kakudan/KEK_RM_NPTF.pdf

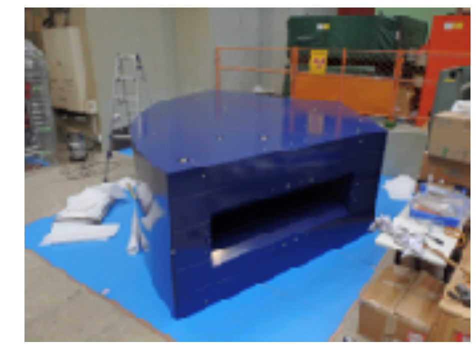
Experimental Setup



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

K1.8 + "S-2S" (common to E70 Exp.)





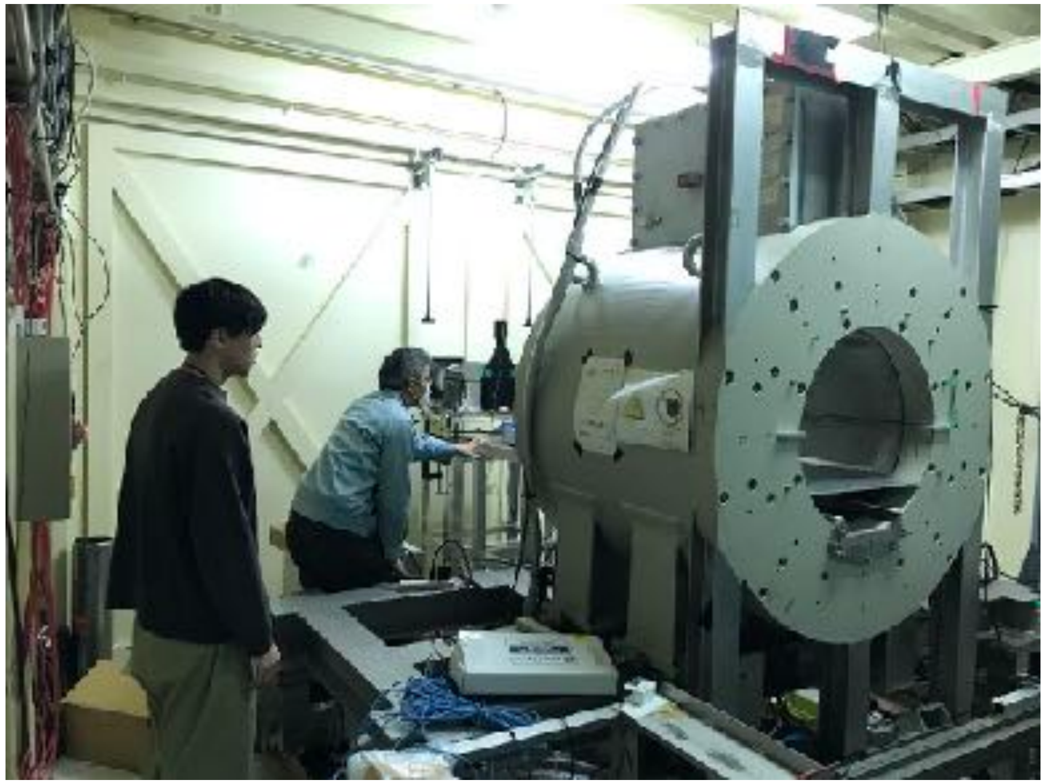
${}^{5}_{\Lambda\Lambda}\mathrm{H} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + \pi^{-}$ (decay pion spectroscopy)

Cylindrical Detector System

solenoid magnet + TPC + …

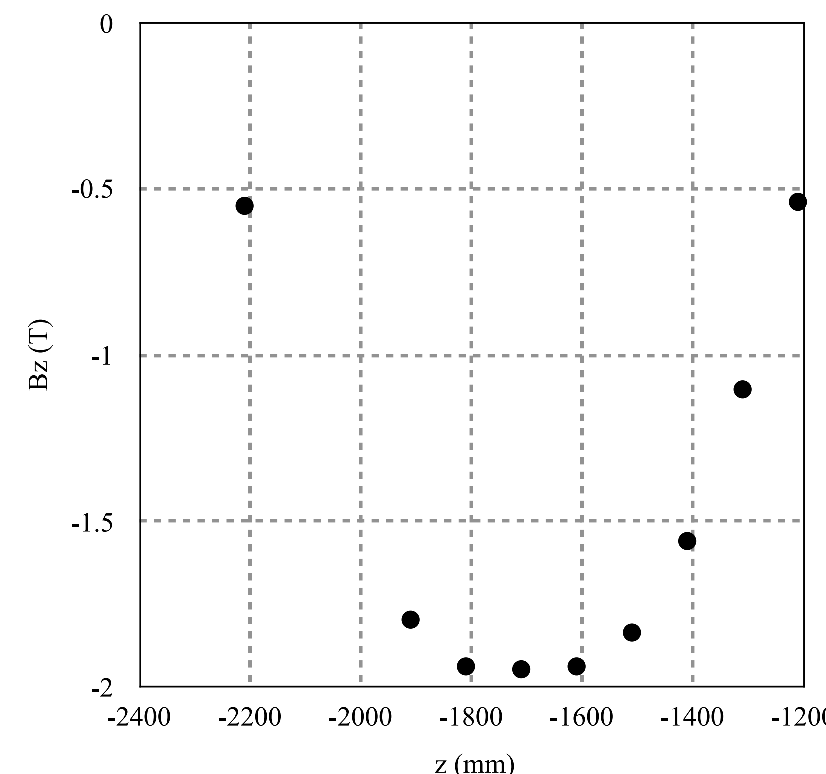
to be borrowed from LEPS/SPring-8 group

Superconducting solenoid

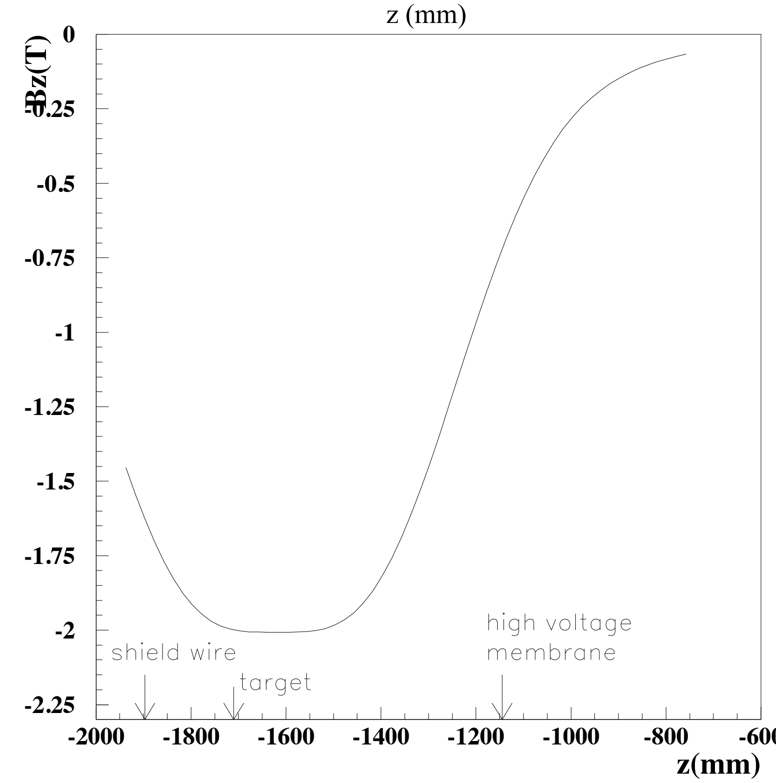


Excitation Test
in Nov.-Dec. 2019

Measurement
(2019/12/16)



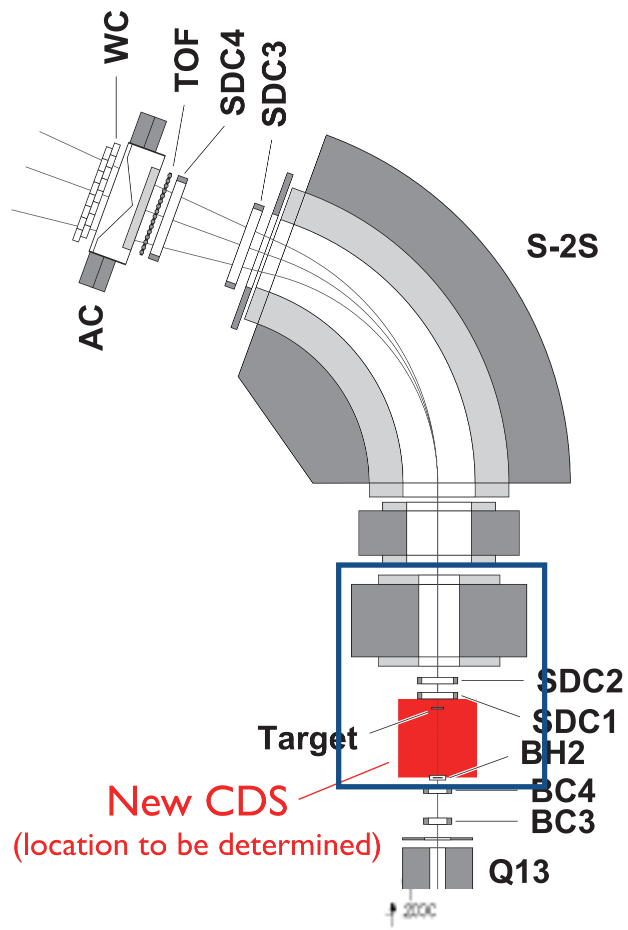
calculation by
OPERA-3D (TOSCA)

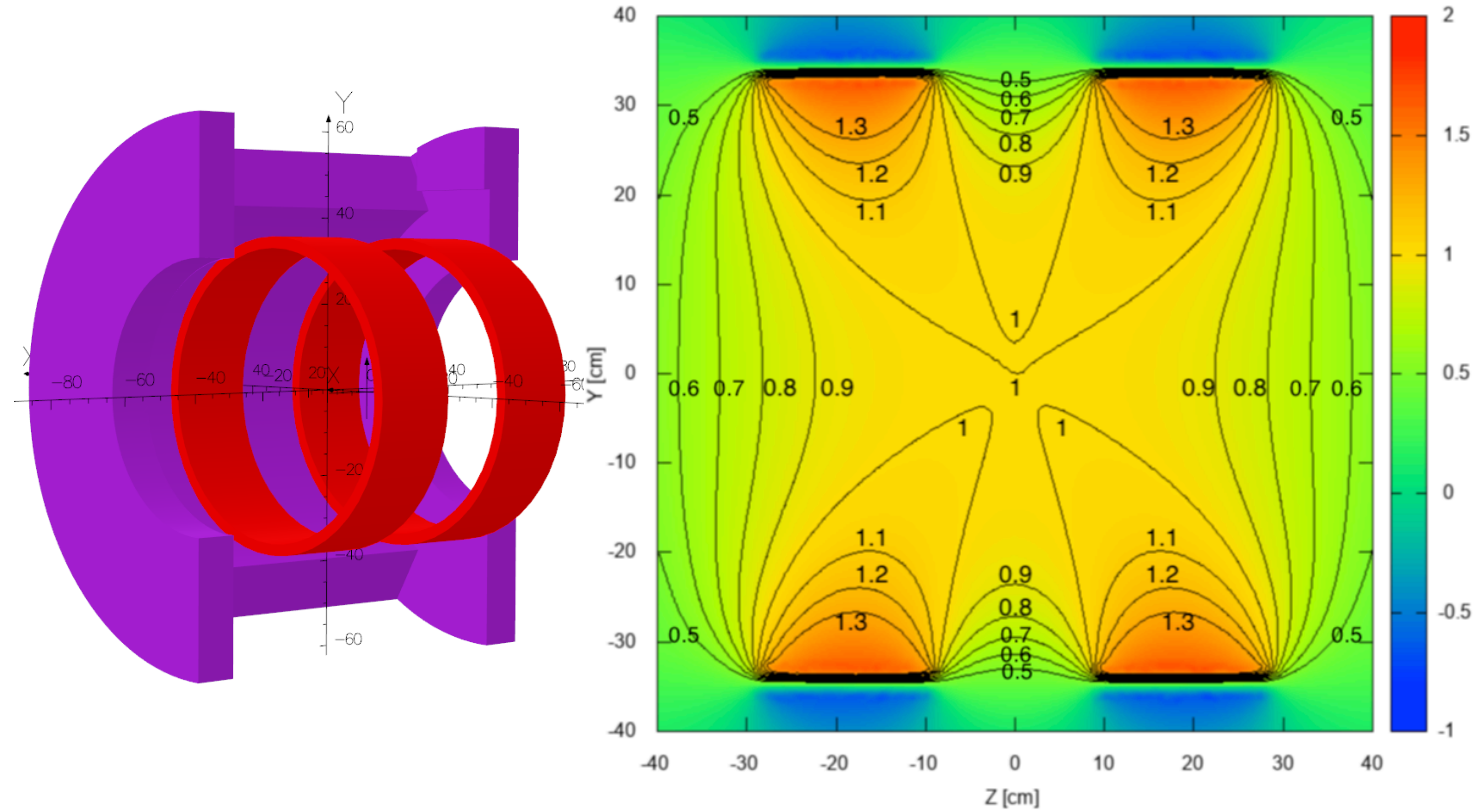


Y. Nakatsugawa et al.,
Ph. D thesis, Osaka Univ. (2013)

supported by Joint Usage/Research Programs of RCNP

Superconducting solenoid





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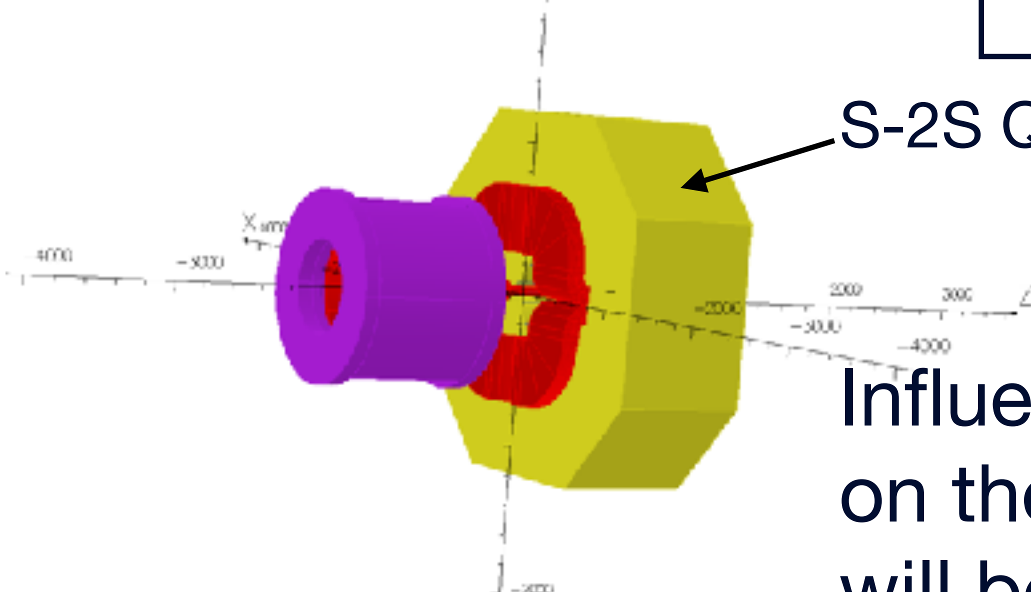
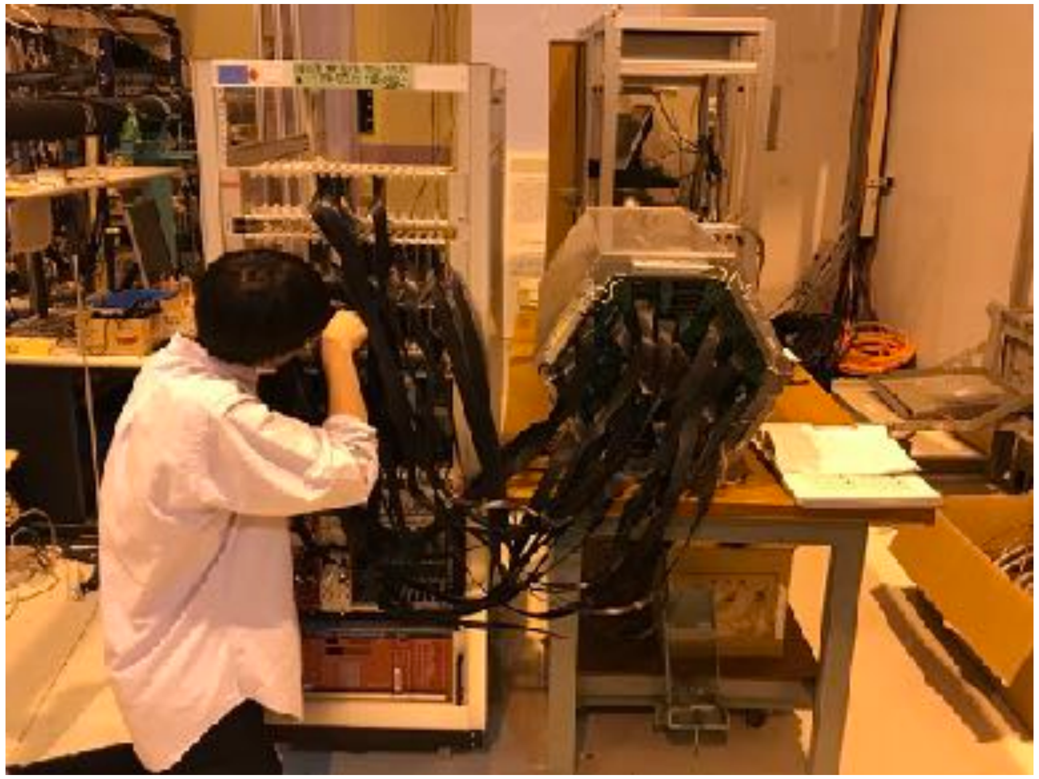
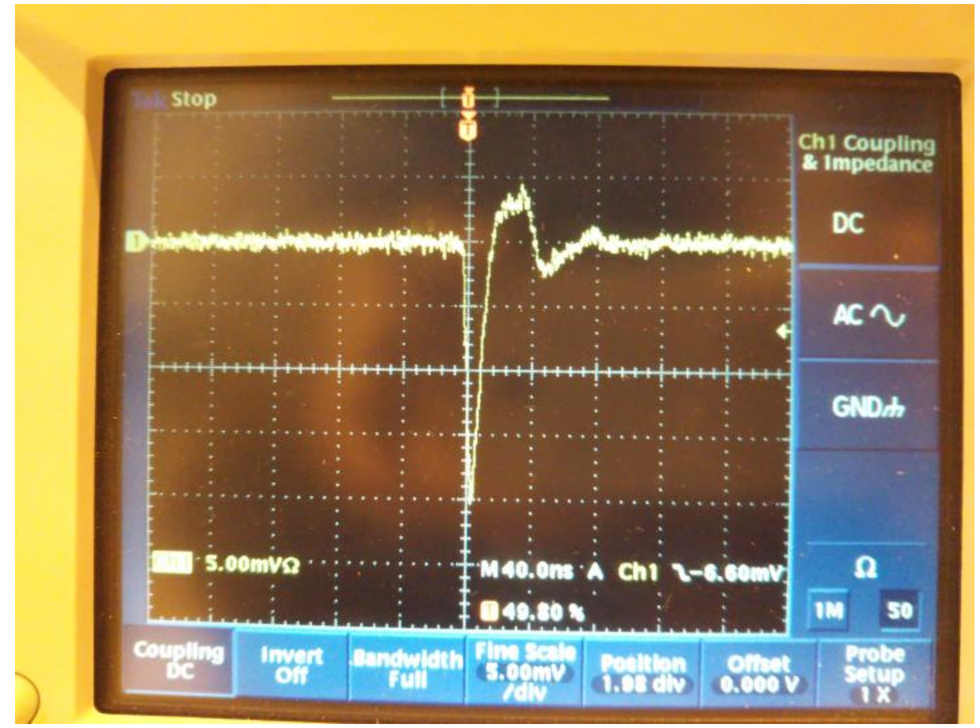


S-2S Q1 magnet

Influence of the fringing field of the solenoid on the ion-optics of the S-2S spectrometer will be carefully evaluated by OPERA-3d (TOSCA).

Time Projection Chamber





- Integrity assessment in Oct.-Nov. 2019
  We observed analog signals from every sense wire.

supported by Joint Usage/Research Programs of RCNP

- The TPC will be moved to TokyoTech in near future.
- To-do: R&D of the readout system for the TPC and its migration into HDDAQ

Summary

- We propose a production/spectroscopy experiment of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ in order to investigate ΞN-$\Lambda\Lambda$ interaction.
  - ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ will be produced by decay of ${}^{7}_{\Xi^-}\mathrm{H}$ with a large probability ($\gtrsim 50\,\%$?)
  - Mass measurement by measuring the momentum of a pion from two-body decay of ${}^{5}_{\Lambda\Lambda}\mathrm{H} \to {}^{5}_{\Lambda}\mathrm{He} + \pi^-$.
- Preparation of a Cylindrical Detector System for momentum analysis of pions etc. is on-going.