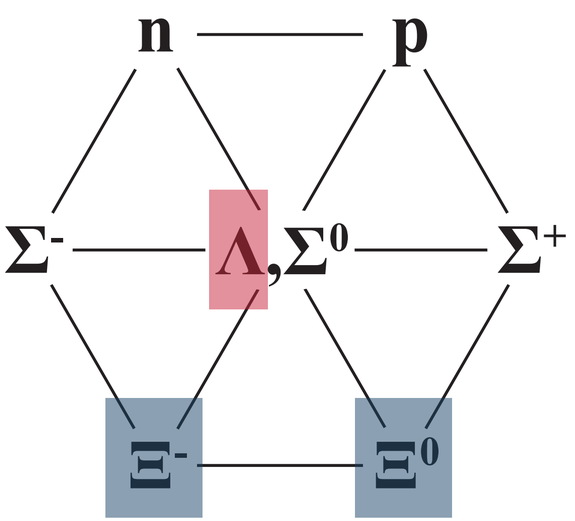
Production of light Ξ hypernuclei, ${}^{7}_{\Xi}\mathrm{H}$

Hiroyuki Fujioka (Tokyo Institute of Technology)
on behalf of the J-PARC E75 collaboration

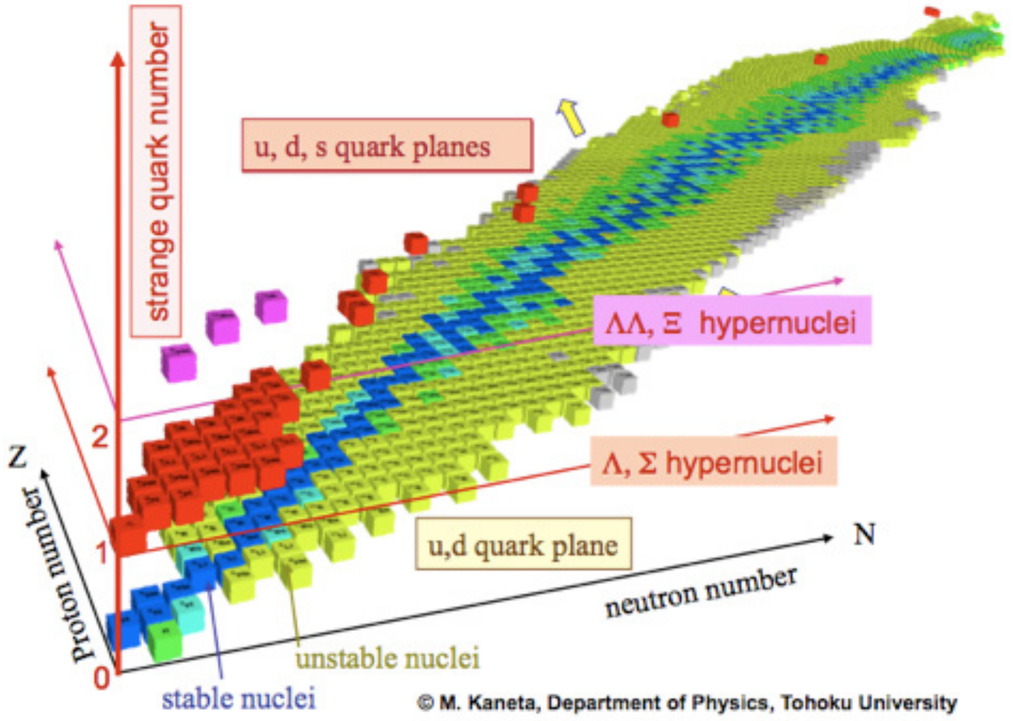
Hypernuclei with strangeness −2



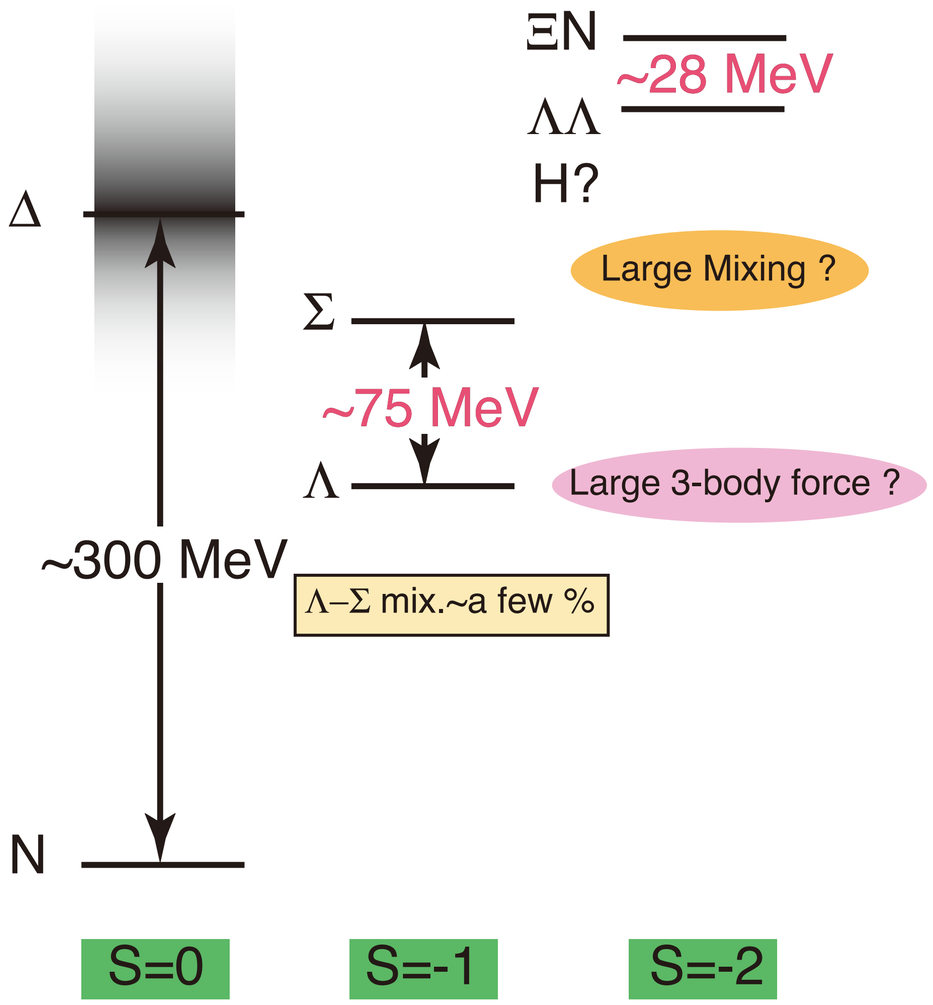
$S = 0$

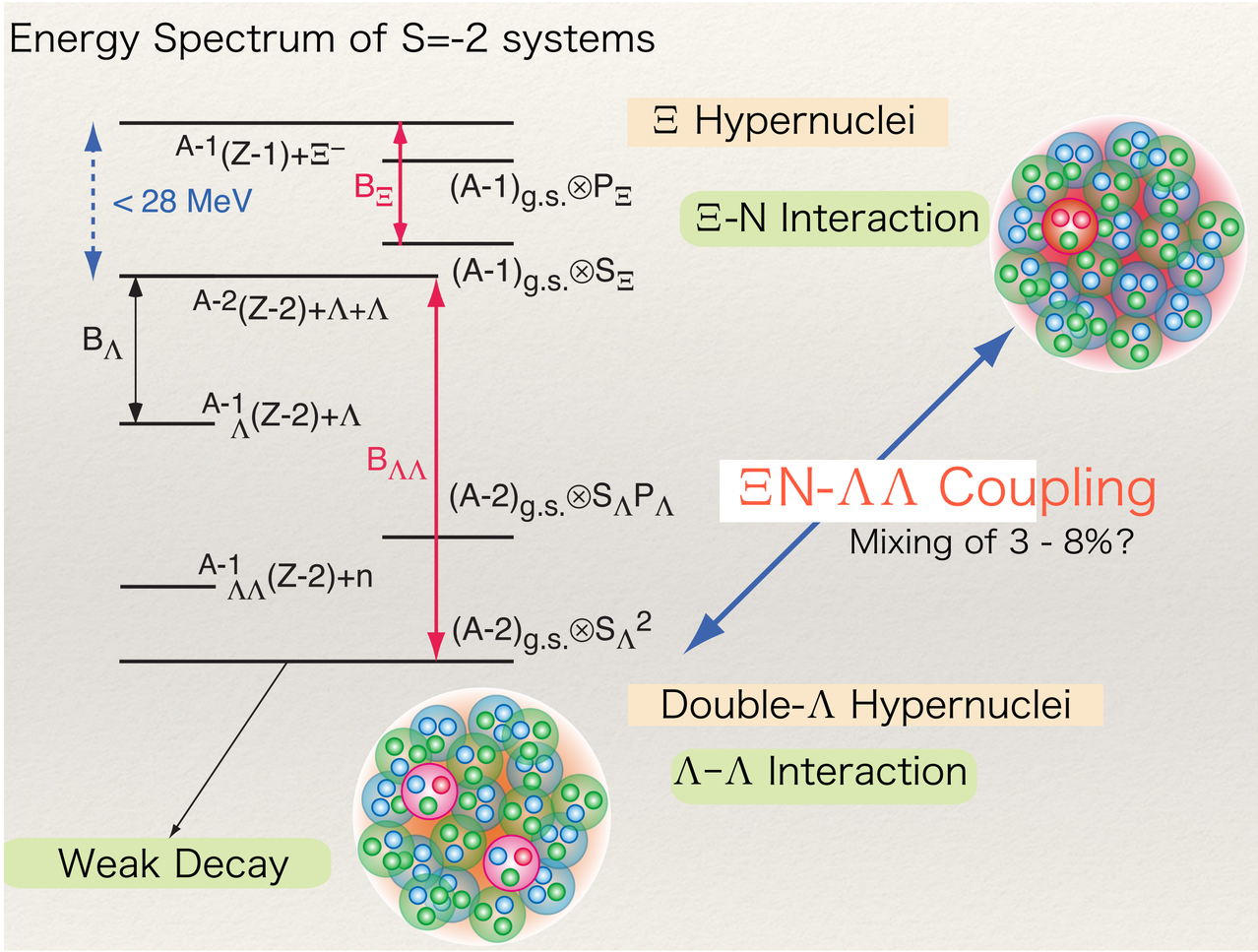
$S = -1$ ⟹ **Double Λ Hypernuclei**

$S = -2$ ⟶ **Ξ Hypernuclei**



ΞN-ΛΛ coupling in S=−2 systems





from HYP 2018 to HYP 2022 PRAGUE

June 2018

東京工業大学 Tokyo Institute of Technology

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

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

HYP 2018

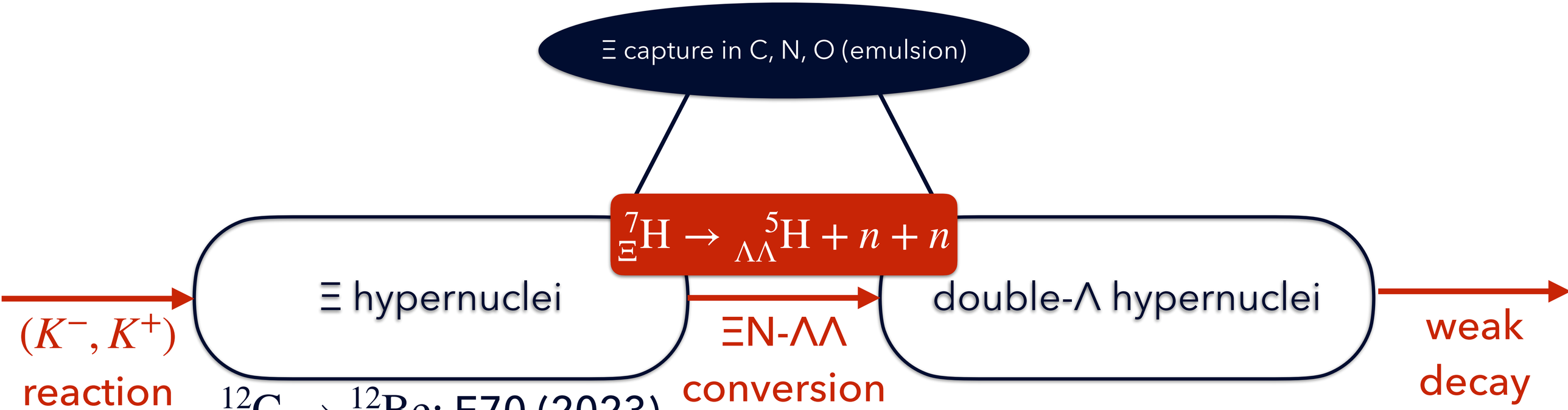
Dec. 2018

submitted a proposal on
decay pion spectroscopy of $_{\Lambda\Lambda}^{5}$H
(E75 Experiment)

Dec. 2019

submitted a proposal on
$_{\Xi}^{7}$H production
(E75 Phase-1 Experiment)

Ξ hypernuclei and double-Λ hypernuclei



$^{12}\mathrm{C} \rightarrow {}^{12}_{\Xi}\mathrm{Be}$: E70 (2023)

$^{7}\mathrm{Li} \rightarrow {}^{7}_{\Xi}\mathrm{H}$: E75 Phase-1 (2023)

${}^{5}_{\Lambda\Lambda}\mathrm{H}$: E75 Phase≧2

The E75 experiment will bridge
Ξ hypernuclei and double-Λ hypernuclei
with ΞN-ΛΛ conversion.

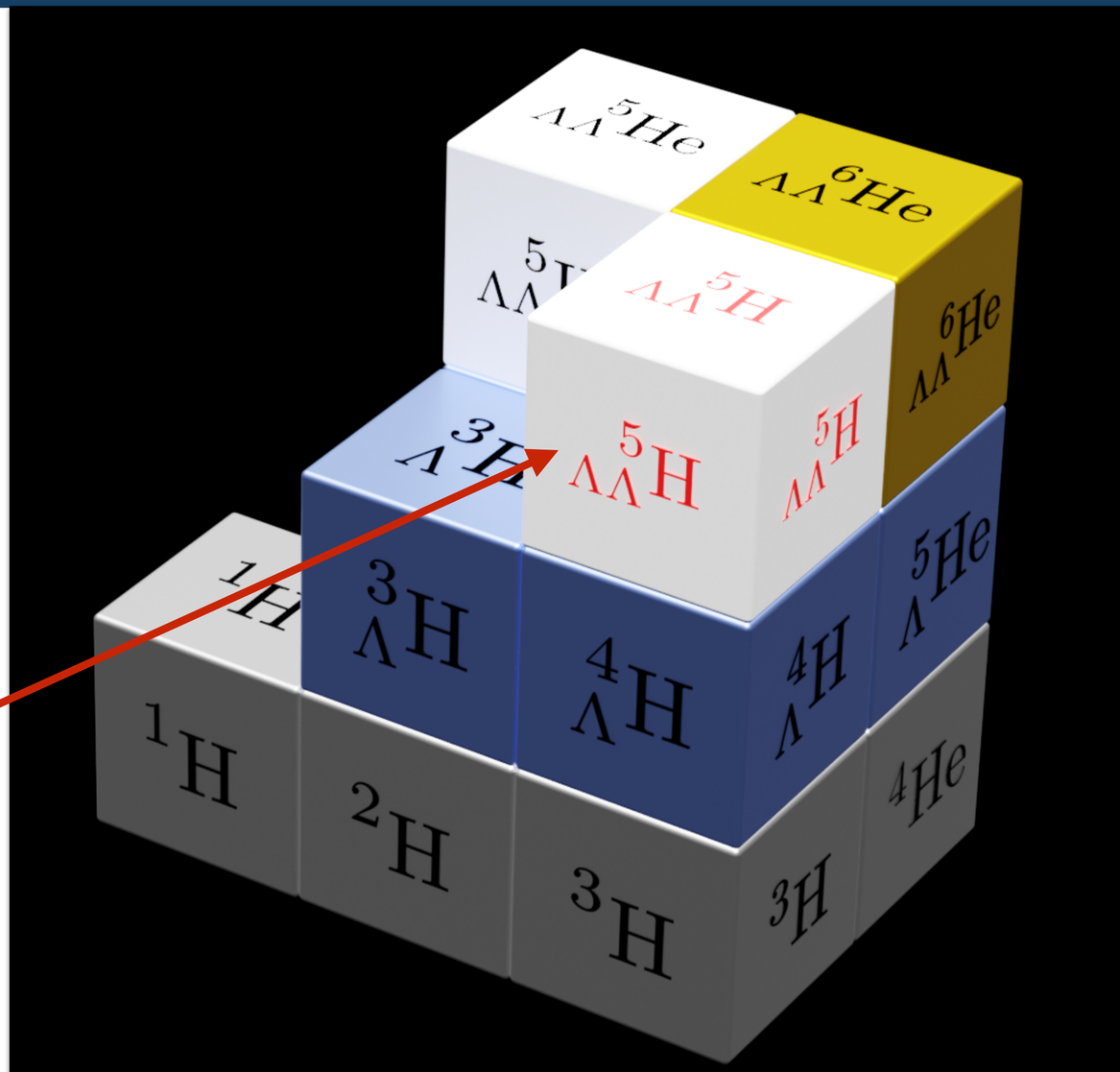
s-shell double-Λ hypernuclei

Many theoretical calculations
supports the existence of
the $A = 5$ isodoublet $\left({}^{5}_{\Lambda\Lambda}\mathrm{H}\text{-}{}^{5}_{\Lambda\Lambda}\mathrm{He}\right)$

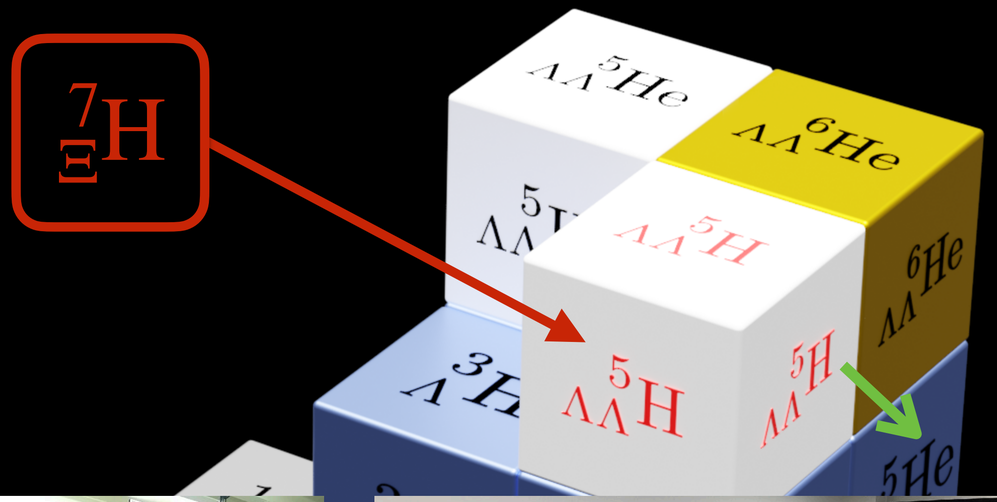
L. Contessi et al., Phys. Lett. B 797, 134893 (2019)
G. Meher and U. Raha, Phys. Rev. C 103, 014001 (2021)
H. Li et al., Eur. Phys. J. A 57, 217 (2021)
and references therein

J-PARC E75 Experiment
will investigate ${}^{5}_{\Lambda\Lambda}\mathrm{H}$.

H. Fujioka, T. Fukuda, E. Hiyama et al., J-PARC P75 Proposal
https://j-parc.jp/researcher/Hadron/en/pac_1901/pdf/P75_2019-09.pdf



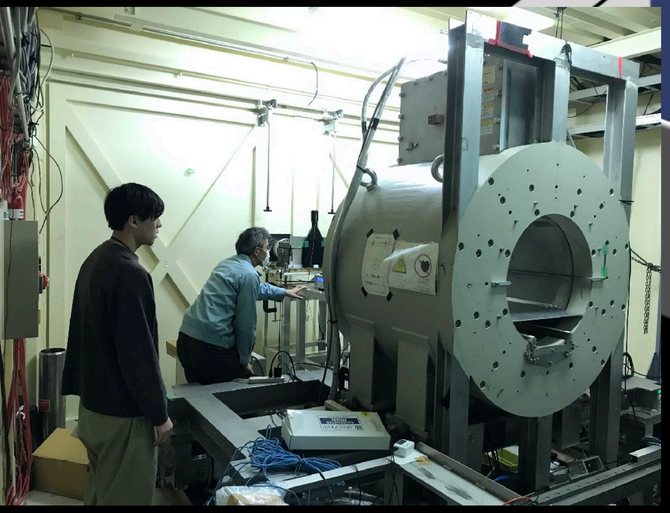
Production and Decay of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$



Mass of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ will be determined
(decay pion spectroscopy)

$$p_{\pi^-} \approx 132-135\ \mathrm{MeV}/c$$

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



Cylindrical Detector System
with a solenoid magnet
and a time projection chamber
(borrowed from LEPS/SPring-8 Gr.)

M. Uchida, Y. Taki, T. Tanaka (Tokyo Tech.)

Characteristics of ${}^{7}_{\Xi}\mathrm{H}$ $(= \alpha + n + n + \Xi^{-})$

1. **Close to the onset of Ξ binding**

   - Many calculations predict a bound state (next page)

   cf. A=4 NNNΞ: bound or unbound, depending on the ΞN interaction
   E. Hiyama et al., Phys. Rev. Lett. 124, 092501 (2020)
   H. Le et al., Eur. Phys. J. A 57, 339 (2021)

   - suited to investigate $\alpha\Xi$ interaction (Prof. Hiyama's talk on Monday)

   - simple level structure: probably only one bound state, no excited bound state

2. Limited decay modes

Ξ binding energy

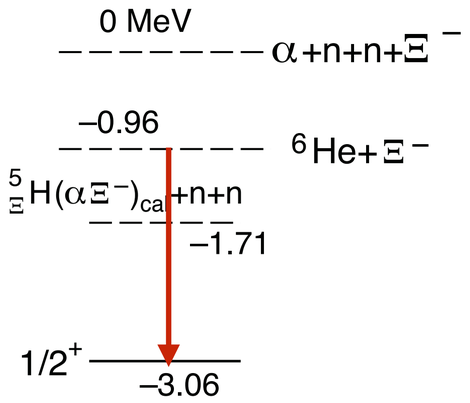
narrow (<1MeV) bound state or not?

Table 1 Ξ separation energies B_Ξ and estimated decay widths Γ for $A = 4 - 7$ Ξ hypernuclei. All calculations are based on the YY-ΞN interaction NLO(500) and the NN interaction SMS N^{4}LO+(450). Both potentials are SRG-evolved to a flow parameter of $\lambda_{\rm NN} = \lambda_{YY} = 1.6$ fm^{-1}. The values of B_Ξ in NNNΞ, ${}^{5}_{\Xi}$H and ${}^{7}_{\Xi}$H are measured with respect to the binding energies of the core nuclei ^{3}H, ^{4}He and ^{6}He, respectively

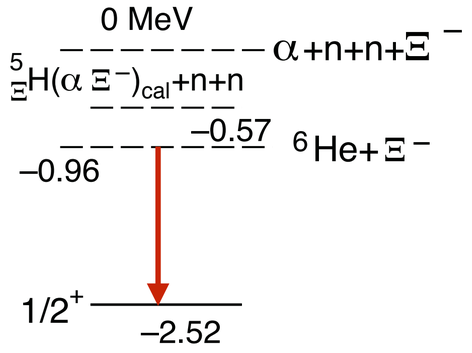
	B_Ξ [MeV]	Γ [MeV]
${}^{4}_{\Xi}$H$(1^+, 0)$	0.48 ± 0.01	0.74
${}^{4}_{\Xi}$n$(0^+, 1)$	0.71 ± 0.08	0.2
${}^{4}_{\Xi}$n$(1^+, 1)$	0.64 ± 0.11	0.01
${}^{4}_{\Xi}$H$(0^+, 0)$	–	–
${}^{5}_{\Xi}$H$(\frac{1}{2}^+, \frac{1}{2})$	2.16 ± 0.10	0.19
${}^{7}_{\Xi}$H$(\frac{1}{2}^+, \frac{3}{2})$	3.50 ± 0.39	0.2

H. Le et al., Eur. Phys. J. A 57, 339 (2021)

ESC04d



ND



E. Hiyama et al., PRC 78, 054316 (2008)

interaction model	B [MeV]	Γ [MeV]
ESC04d	1.80	2.64
ND	1.55	0.27
HAL $(t/a = 11)$	3.15	0.02

E. Hiyama, private communication

Characteristics of ${}^{7}_{\Xi}\mathrm{H}$ ($= \alpha + n + n + \Xi^-$)

1. Close to the onset of Ξ binding

2. **Limited decay modes**

PHYSICAL REVIEW C VOLUME 54, NUMBER 1 JULY 1996

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

$$
\begin{aligned}
{}^{7}_{\Xi}\mathrm{H} &\rightarrow {}^{5}_{\Lambda\Lambda}\mathrm{H} + n + n \quad \sim 11 \ \mathrm{MeV}, \quad \text{BR}\sim 90\% \\
&\rightarrow {}^{4}_{\Lambda}\mathrm{H} + \Lambda + n + n \quad \sim 7 \ \mathrm{MeV}, \\
&\rightarrow {}^{4}_{\Lambda}\mathrm{H}^{*} + \Lambda + n + n \quad \sim 6 \ \mathrm{MeV}, \\
&\rightarrow {}^{3}\mathrm{H} + \Lambda + \Lambda + n + n \quad \sim 5 \ \mathrm{MeV}.
\end{aligned}
$$

Only 4 decay modes kinematically allowed

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

pnn ΛΛ

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

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[3]*National Institute of Technology, Asahikawa College, Asahikawa 071-8142, Japan*
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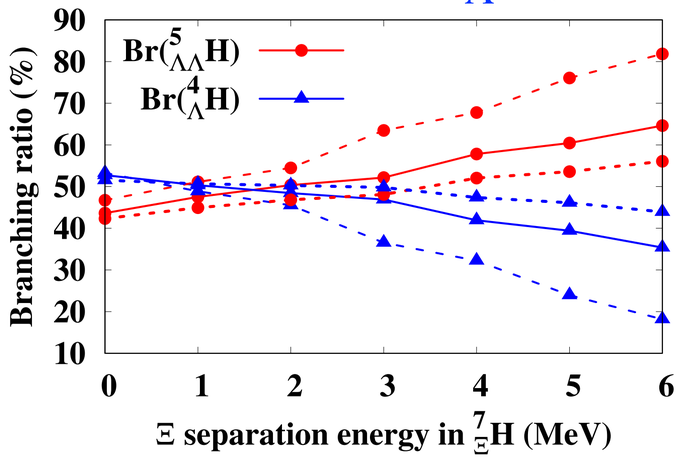
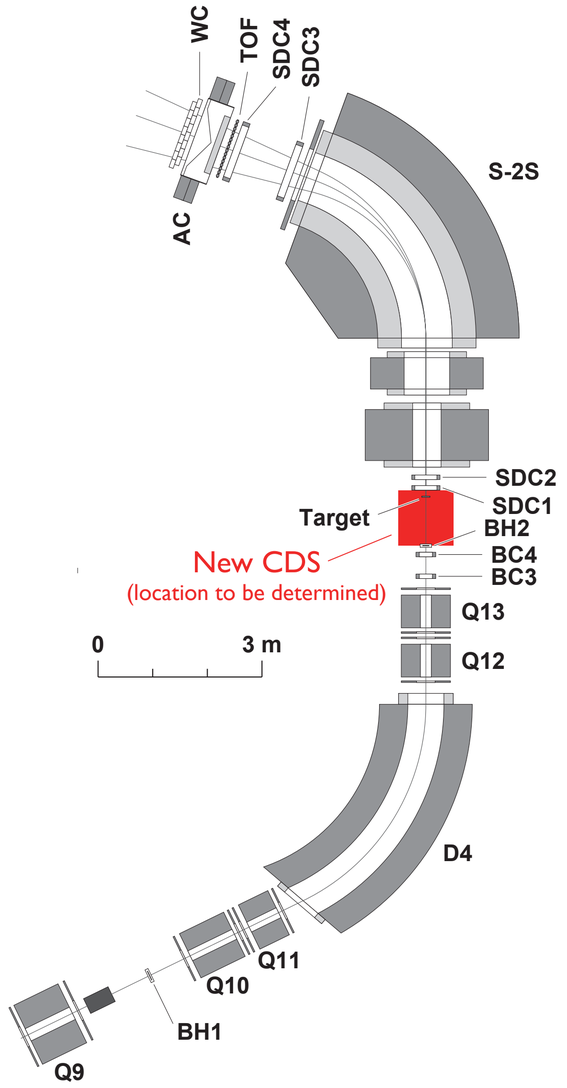
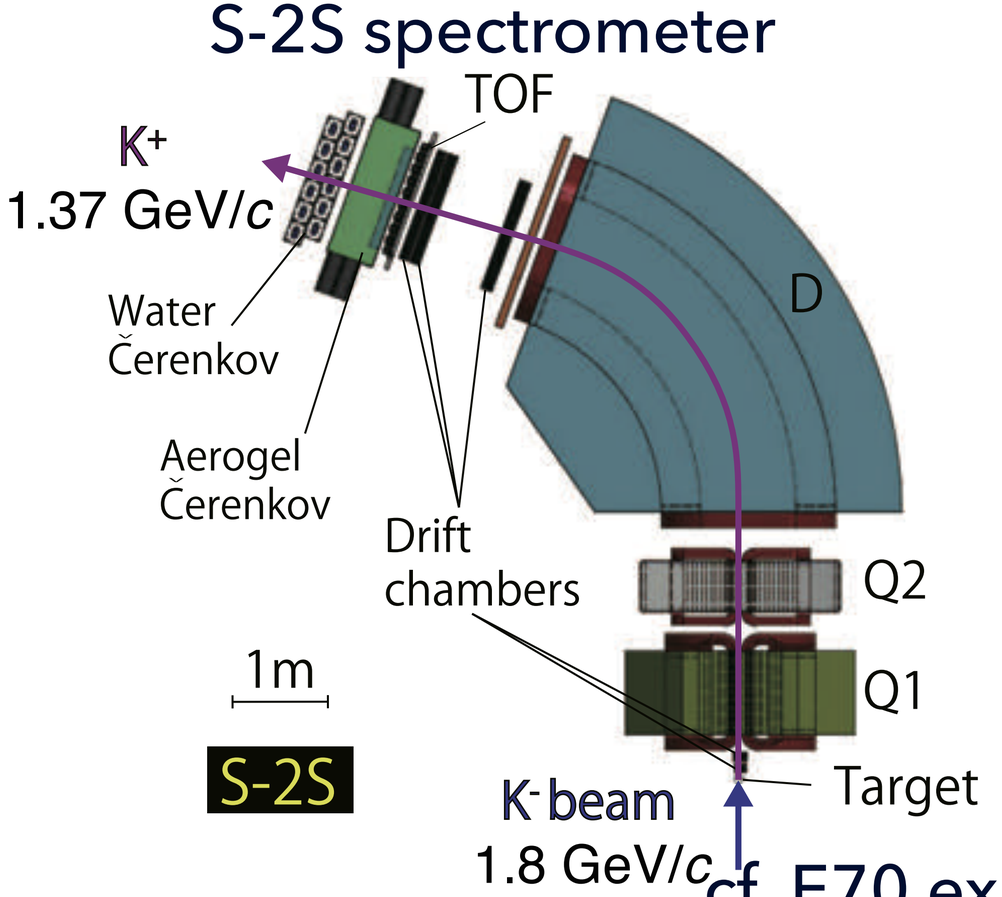
${}^{5}_{\Lambda\Lambda}\mathrm{H} + 2n$ BR~50% ${}^{4}_{\Lambda}\mathrm{H}(0^+,1^+) + \Lambda + 2n$



A. Ohnishi et al., Prog. Theor. Exp. Phys. 2020, 063D01 (2020)

Experimental setup





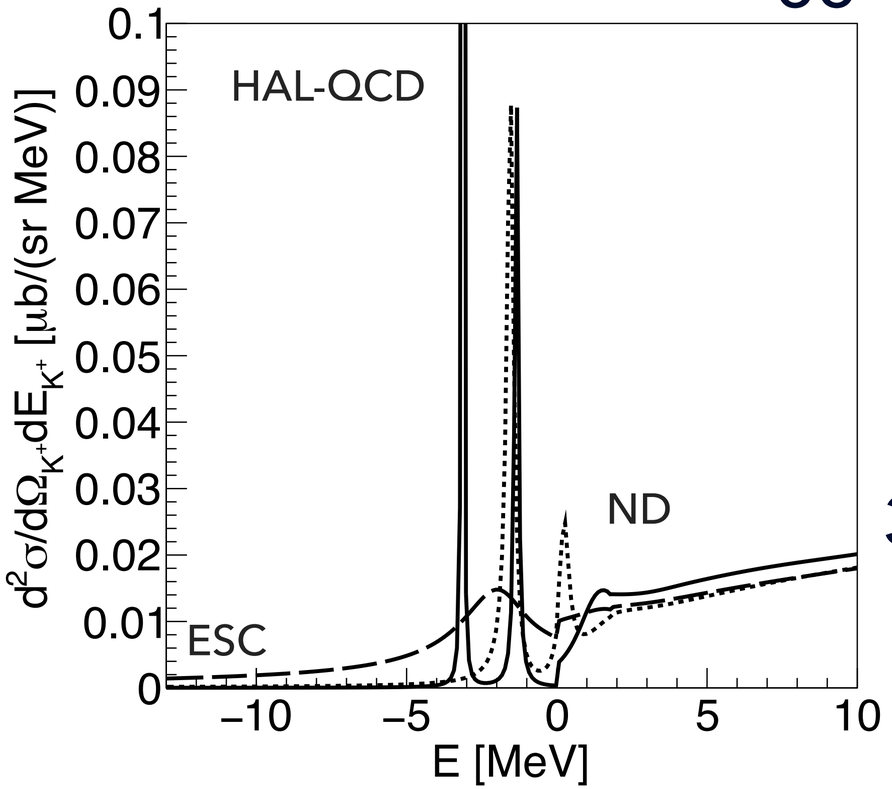
the same setup
as for the E70 exp.,
except for
the target
(10g/cm^2 Li target)

cf. E70 experiment w/ S-2S
Mr. Harada's talk (today, next session)
and Dr. Gogami's talk (tomorrow)

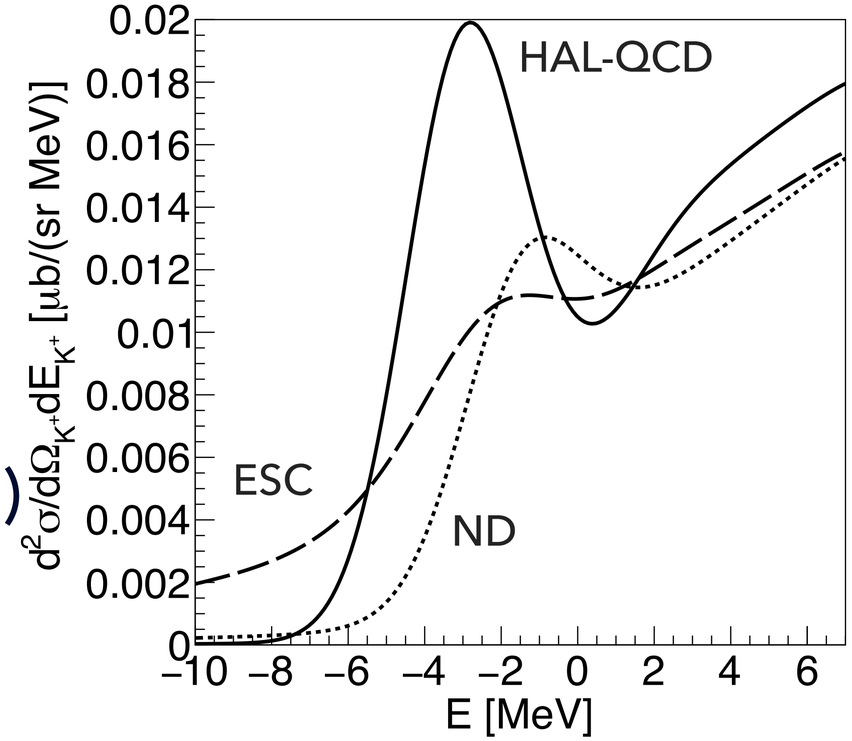
$^{7}_{\Xi}$H formation spectra

H. Fujioka. T. Fukuda, E. Hiyama et al., E75 Phase-1 Proposal
https://j-parc.jp/researcher/Hadron/en/pac_2001/pdf/P75_2020-02.pdf

56-104 “bound $^{7}_{\Xi}$H” events for 1-week measurement



exp. resolution
3.5MeV(FWHM)



E. Hiyama and T. Koike, private communication

Summary and Outlook

- The J-PARC E75 experiment will investigate almost the lightest double strange nuclei, ${}^{7}_{\Xi}\mathrm{H}$ and ${}^{5}_{\Lambda\Lambda}\mathrm{H}$.

- ${}^{7}_{\Xi}\mathrm{H}$ will be the lightest Ξ hypernuclei produced experimentally than ever. Probably it will be close to the onset of Ξ binding.

- Only four decay modes are allowed. Among them, a dominant decay mode into ${}^{5}_{\Lambda\Lambda}\mathrm{H} + 2n$ will be utilized to produce ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ in future.

- We expect the missing-mass resolution of 3.5 MeV in FWHM with a thick target. Possible extension with a thinner target to improve the resolution?