The First Evidence of Ξ hypernucleus

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Kazuma Nakazawa

Phys. Dept., Gifu Univ., JAPAN

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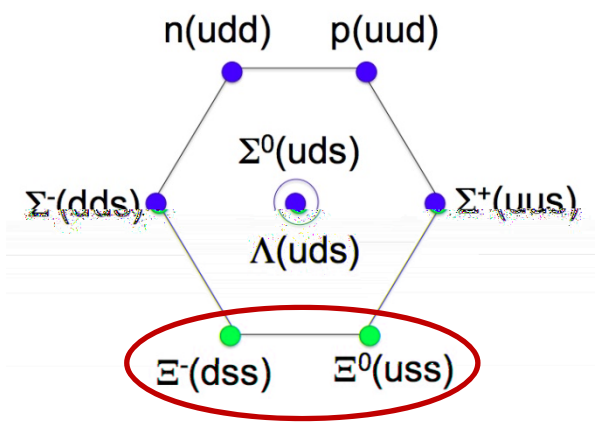
Nuclear Phys. with S=-2

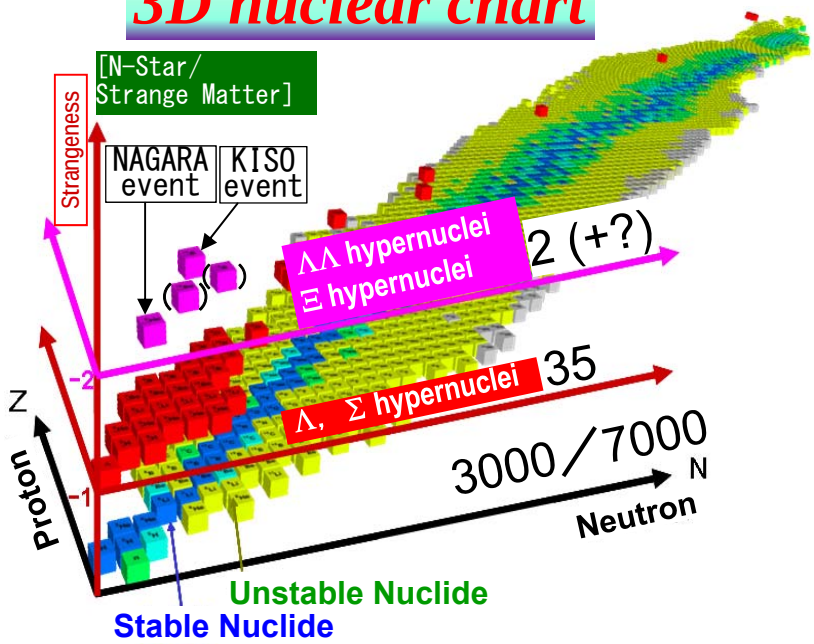
Main subject : *Study of hadron-hadron interaction*

∗ **Making a nuclear chart of double-hypernuclei**

Baryon octet



3D nuclear chart



In S=-2 sector,

➔ YY-mixing [ΛΛ⇔Ξ*N*⇔ΣΣ(⇔H)]

- m(ΞN) – m(ΛΛ) = (23~28) MeV
- m(ΣN) – m(Λ*N*) = 80 MeV

🡐 For those information;
uniquely available source is
double-Λ hypernucleus,
Ξ hypernucleus, H-dibaryon

Information of Λ-Λ and Ξ-*N* force,

for understanding B-B int. in SU(3)$_f$,
and as guide for us to Multi-strangeness system.

Remarks for Ξ-Nucleus potential

1983	-(21~24) MeV	K^- interaction => Twin Hyper.		
1994	~ -16 MeV	Ξ^- bound system ($\Xi^{-12}C$)		E176
1995	-(16~17) MeV	Same as above	**Nijimegen D**	Theory
	-16 MeV	Same as above	**Green function**	
1998	> -20 MeV	Missing mass spectrum		E224
2000	~ -14 MeV [?]	Same as above		E885
2001	**Ehime potential**	**Well reproduce Ξ^- bound state**		Theory

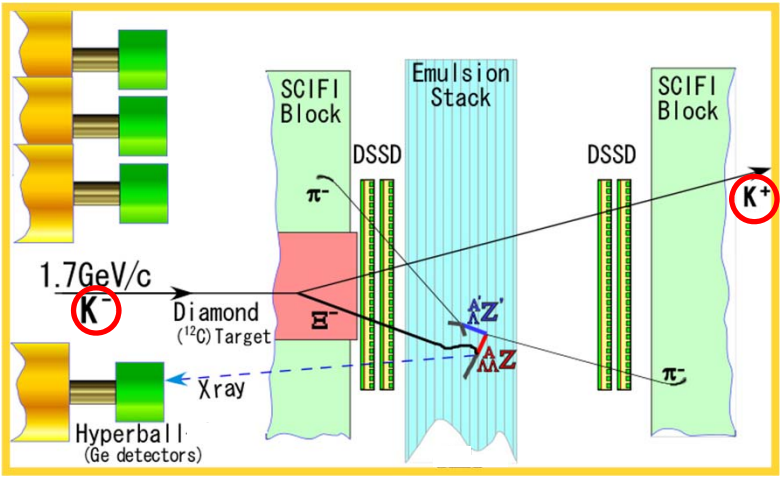
M.Yamaguchi, K.Tominaga, Y.Yamamoto and T.Ueda, Prog. Theor. Phys. **105,** 627 (2001)

However, information is quite limited, so far.
There is no conclusive report for Ξ deeply bound nucleus.
More S=-2 hypernuclei were waited for.

➔ E07, E03, E05 and E42 at J-PARC

To detect many S=-2 hypernuclei

1.New Hybrid method



J-PARC

1. Pure K-beam
   (better 3.5 times than KEK-PS)
2. More emulsion volume (x 3)

10^3 (E373) ➔ 10^4 Ξ- stop events

1. X ray measurement from Ξ **atom**
   with **Hyperball-X**
   ➔ study of **Ξ-N interaction**
2. ~10^2 double hypernuclei

Automated track-following

2. *Overall-scanning*

VP : Vertex Picker

Fully automatic detection of

3 vtx. event

like NAGARA event, KISO event

10 times statistics of that
with the hybrid method

(1/0.3) : free from
X acceptance & tracking
4 : ・'p'(K⁻, K⁺)Ξ⁻ in the emulsion
・'n'(K⁻, K⁰)Ξ⁻ reaction

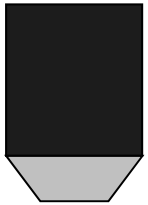
➔ 10^5 Ξ- stop events
Measurement of the mass of
~10^3 double hypernuclei
~10^2 Xi hypernuclei
with A<16

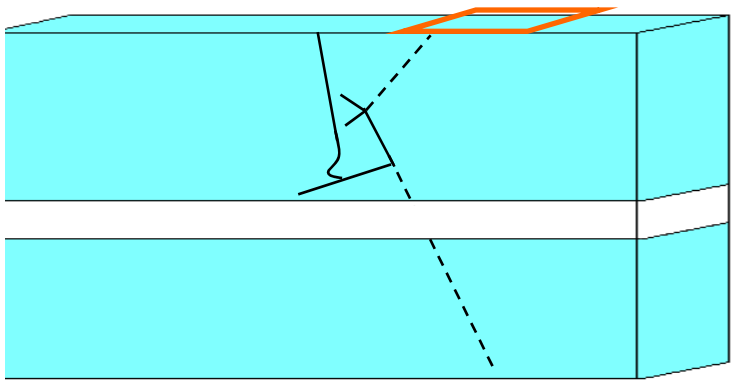
Concept of "*Overall-scanning (VP)*"

① *fast image capture* **② *fast image processing***

Our Strategy 1. Develop assured system, even if it is slow.
2. Improve such system to be more fast.

The 1st step VP with CCD camera





***8 M* images**

under test operation
using E373 emulsion

Under test operation of "Overall-scanning" among 8 M micrographs

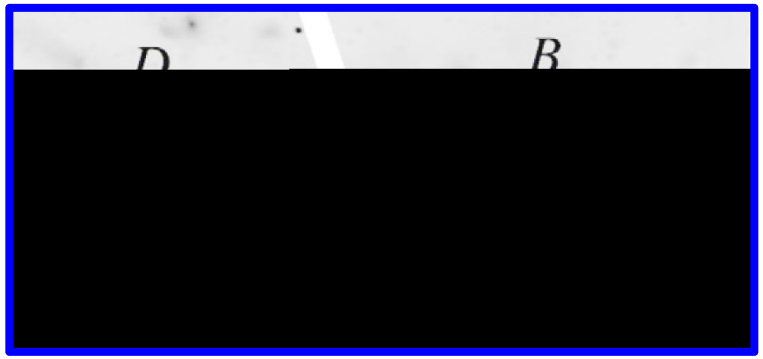
named

KISO event

Single hypernucleus emitted back-to-back direction (**Twin** hypernuclei event)

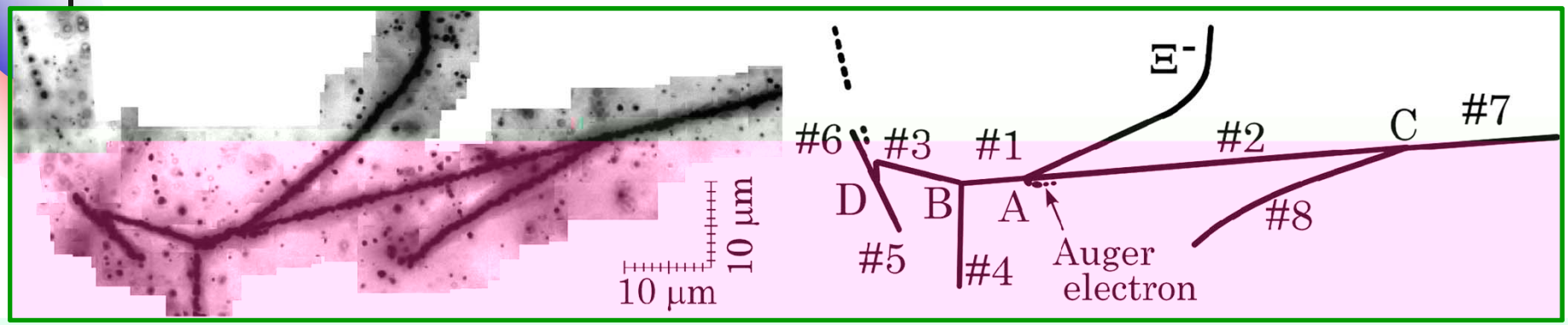
➔ Topology seems to be consistent with the past events of twin hypernuclei (E176).

Results of KEK-E176: S.Aoki et al., NP. A828 (2009) 191-232



=> Consistent with Ξ^- capture reaction occurred on C, N or O.

＊Event interpretation and the energy of B_{Ξ^-}



Process of the *KISO* event

$\Xi^- + {}^{14}N \rightarrow {}^{10}_{\Lambda}Be$ (#1) + ${}^{5}_{\Lambda}He$ (#2),

${}^{10}_{\Lambda}Be \rightarrow {}^{8}Li$ (#3) + p (#4) + n,

${}^{8}Li \rightarrow {}^{8}Be^*(2^+) + e^- (+ \bar{\nu}_e)$

${}^{8}Be^*(2^+) \rightarrow 2\alpha$ (#5 & # 6)

ex. ${}^{5}_{\Lambda}He \rightarrow p$(#7) + d(#8) + $2n$

B_{Ξ^-} = **4.38 +/- 0.25** MeV (by Mom. balance [#1 and #2]), if ${}^{10}_{\Lambda}Be$ in **g.s.**

Measurement error : 0.09 MeV

Mass (${}^{10}_{\Lambda}Be$, ${}^{5}_{\Lambda}He$, Ξ^-) error : 0.23 MeV

where, $B_{\Lambda\,g.s.}({}^{10}_{\Lambda}Be)$ = *9.11±0.22* MeV

If ${}^{10}_{\Lambda}Be$ was produced in **excited state**,
by using theoretical estimations ➔ B_{Ξ^-} = **1.11 +/- 0.25** MeV,
3.7 σ far from atomic 3*D* level (**0.17 MeV** for Ξ^--${}^{14}N$)

Consistent with 2*p* state (1.14 MeV)
theoretical prediction
Yamaguchi et al.
PTP. 105 (2001) 627

K. Nakazawa et al., PTEP. 2015, 033D02 / DOI : 10.1093/ptep/ptv008

Recent exp. result for levels of ${}^{10}_{\Lambda}$Be

JLab E05-115

Gogami et al., Phys. Rev. C **93**, 034314 (2016)

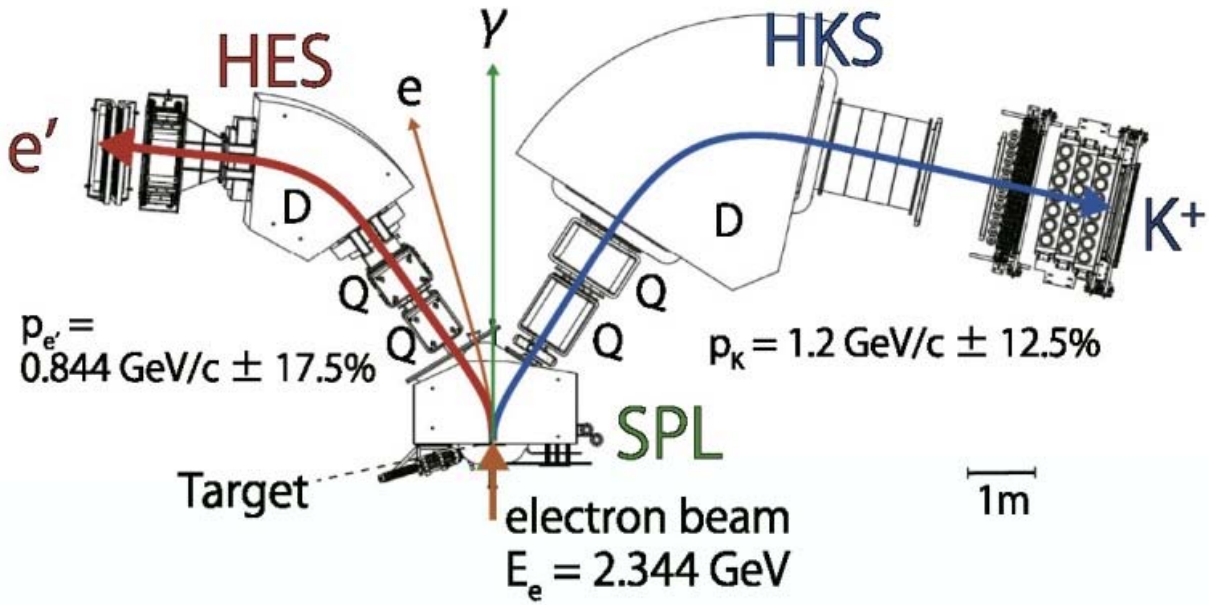
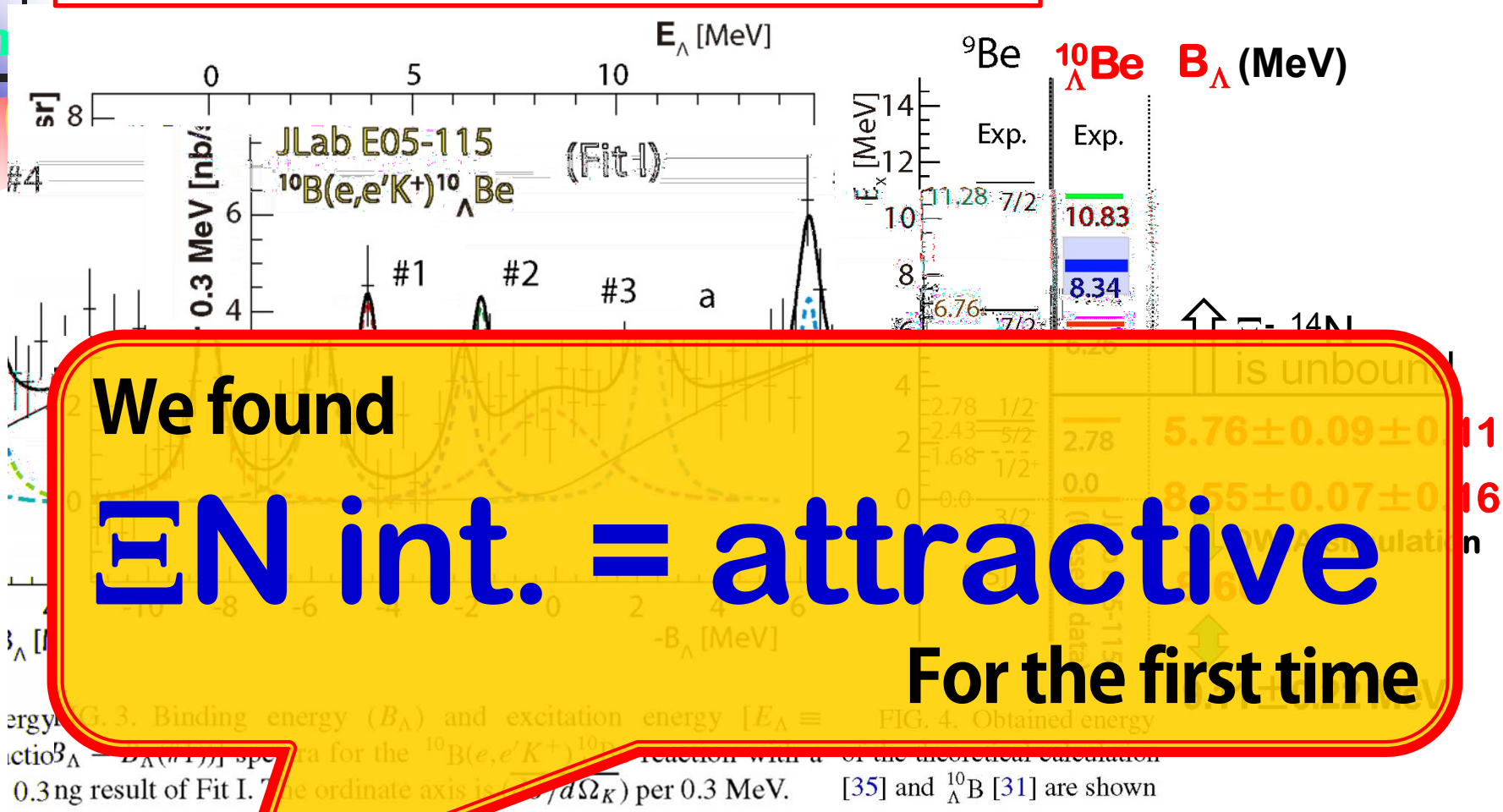


FIG. 1. A schematic drawing of the JLab E05-115 experimental geometry. The setup consists of SPL, HKS, and HES spectrometers. An electron beam with the energy of 2.344 GeV is incident on the target located at the entrance of SPL. A K^+ and an e' with the momenta of ~1 GeV/c are observed by HKS and HES, respectively.

- (e, $e'K^+$) reaction
- missing mass
- ^{10}B target
- Calibrated by Λ mass via $p(e, e'K^+)\Lambda$

Gogami et al., Phys. Rev. C **93**, 034314 (2016)



We found

ΞN int. = attractive

For the first time

For KISO event, taking JLab data

		deviation from 3*D* (0.17 MeV)	
B_{Ξ^-} ($^{10}_{\Lambda}$Be$_{g.s.}$)	= **3.87 +/- 0.21 (MeV)**	**17.5 σ**	(mass err = 0.19 [MeV])
B_{Ξ^-} ($^{10}_{\Lambda}$Be$_{1st\ ex.}$)	= **1.03 +/- 0.18 (MeV)**	**4.6 σ**	(mass err = 0.16 [MeV])

Topics of E07@J-PARC

1) s-shell DBL. hypernuclei : ${}^{4}_{\Lambda\Lambda}$H, ${}^{5}_{\Lambda\Lambda}$He and ${}^{5}_{\Lambda\Lambda}$H

$\Lambda\Lambda$-ΞN coupling interaction affects mass, since s-shell nucleons are not fully occupied. Thus, it can be determined.

2) A = 6~17 $\Lambda\Lambda$ hypernuclei (spectroscopy)

Confirmation of $\Lambda\Lambda$ interaction strength and nuclear structure effects such as shrinkage due to Λ, independent information of NAGARA event, ${}^{6}_{\Lambda\Lambda}$He.

3) Ξ-hypernuclei : Ξ^{-16}O, Ξ^{-14}N(KISO event), Ξ^{-12}C

From multiple events of Ξ-hypernucleus, we can determine the (natural) width of Ξ

Λ-Λ Ξ Λ $\Xi\Xi\sigma\Xi$

Summary

1. Information of S=-2 field is very limited, so far.
2. The development of "overall-scanning (VP)" method has been carried out for detection of typical topology relating double hypernuclei.
3. Under the test operation of it, a twin hypernucler event was detected and it was reported as the first evidence of a deeply bound $\Xi^{-}{}^{14}N$ system, KISO event, with its binding energy (B_{Ξ^-}) of **3.87 – 1.03 MeV**, which was far from atomic $3D$ level by at least **4.6σ** from 0.18 MeV error.
4. The KISO event dominated an **attractive $\Xi^{-}N$ interaction**.
5. Expecting 10 - 100 times statistics than before, the beam exposure run for E07 experiment at J-PARC has been performed this June, and it may give us fruitful information in S=-2 world.