The First Evidence of $\Xi$ hypernucleus

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Main subject: Study of hadron-hadron interaction

* Making a nuclear chart of double-hypernuclei

In S=-2 sector,

→ YY-mixing [$\Lambda\Lambda \leftrightarrow \Xi N \leftrightarrow \Sigma(\leftrightarrow H)$]
  • $m(\Xi N) - m(\Lambda\Lambda) = (23\sim 28)$ MeV
  • $m(\Sigma N) - m(\Lambda N) = 80$ MeV

← For those information;
  uniquely available source is double-$\Lambda$ hypernucleus,
  $\Xi$ hypernucleus, $H$-dibaryon

Information of $\Lambda$-$\Lambda$ and $\Xi$-$N$ force,
  for understanding B·B int. in SU(3)$_f$,
  and as guide for us to Multi-strangeness system.
Remarks for $\Xi$-Nucleus potential

1994  ~ -16 MeV  $\Xi^-$ bound system ($\Xi^{-12}C$) E176
1995  -(16~17) MeV  $\Xi^-$ bound system ($\Xi^{-12}C$)  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 $\Xi^-$ bound state Theory

However, information is quite limited, so far.
There is no conclusive report for $\Xi$ deeply bound nucleus.
More $S=-2$ hypernuclei were waited for.
$\Rightarrow$ E07, E03, E05 and E42 at J-PARC
To detect many $S=-2$ hypernuclei

1. New Hybrid method

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

- $10^3$ (E373) $\rightarrow$ $10^4$ $\Xi^-$ stop events
  - 1. X-ray measurement from $\Xi$ atom with Hyperball-X
  - study of $\Xi$-N interaction
  - $\sim 10^2$ double hypernuclei

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
- $4 \rightarrow \epsilon'(K^-,K^+)$ $\Xi^-$ in the emulsion
- $\epsilon'(K^-,K^0)$ $\Xi^-$ reaction

- $10^5$ $\Xi^-$ stop events
- Measurement of the mass of
  - $\sim 10^3$ double hypernuclei
  - $\sim 10^2$ 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.

<table>
<thead>
<tr>
<th></th>
<th>1st step VP (2011年)</th>
<th>Full-auto VP (Present)</th>
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<tbody>
<tr>
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<td>× 20 (NA 0.3)</td>
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<td>CMOS (300 fps)</td>
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<td>Capture (view/s)</td>
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<td>4.0 Hz</td>
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<tr>
<td>Speed / sheet</td>
<td>3 yrs.</td>
<td>3 days (74 hrs.)</td>
</tr>
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8 M images
under test operation
using E373 emulsion
Under test operation of "Overall-scanning" among 8 M micrographs

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

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


=> Consistent with $\Xi^-$ capture reaction occurred on C, N or O.
Event interpretation and the energy of $B_{\Xi^-}$

Process of the *KISO* event

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

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

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

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

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

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

Measurement error : 0.09 MeV

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

where, $B_{\Lambda\text{gs.}}(^{10}_\Lambda\text{Be}) = 9.11 \pm 0.22$ MeV

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

Consistent with $2p$ state (1.14 MeV) theoretical prediction

Yamaguchi et al., PTP. 105 (2001) 627
Recent exp. result for levels of $^{10}_\Lambda$Be

JLab E05-115


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

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 $\sim 1$ GeV/c are observed by HKS and HES, respectively.
We found

\( \Xi N \) int. = attractive

For the first time

For KISO event, taking JLab data

\[
B_{\Xi^-}^{(10\text{Be, g.s.})} = 3.87 \pm 0.21 \text{ (MeV)}
\]

17.5 \( \sigma \) (mass err = 0.19 [MeV])

\[
B_{\Xi^-}^{(10\text{Be, 1st ex.})} = 1.03 \pm 0.18 \text{ (MeV)}
\]

4.6 \( \sigma \) (mass err = 0.16 [MeV])
Topics of E07@J-PARC

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

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

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

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

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

From multiple events of $\Xi$-hypernucleus, we can determine the (natural) width of $\Xi$-hypernucleus, which is related to $\Lambda\Lambda-\Xi N$ coupling interaction.

4) $\Xi N$ interaction with X-ray from $\Xi$-atoms

Expected yields for X-rays from Br and Ag are so small. To observe the shifts, it is necessary for detecting peak shapes with 10 times statistics.

5) $\Lambda-\Lambda$ P-wave interaction (?)

If $\Lambda\Lambda$ hypernuclei can be detected in excited states with one $\Lambda$-hyperon in p-orbit, it may present information on $\Lambda\Lambda$ p-wave interaction, where that will be recognized via the spectroscopy of $\Lambda\Lambda$ hypernuclei. The interaction might change max. mass of n-star.
**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 $(B_{\Xi^-})$ of $3.87 \pm 1.03$ MeV, which was far from atomic 3$D$ level by at least $4.6\sigma$ 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.