Status of J-PARC E07:
ダブルΛハイパー核検出実験の現状

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Double strangeness nuclei:

* Exotic nuclei made up of two s-quarks (lifetime $\approx 10^{-10}$ sec)
* Tiny neutron-star on the ground

\[ \Lambda\Lambda \text{ hypernuclei} \]

$^6\Lambda\Lambda\text{He } (^4\text{He} + \Lambda + \Lambda)$

\[ \Xi \text{ hypernuclei} \]

$^{15}\Xi\text{C } (^{14}\text{N} + \Xi^-)$

*Essential subject to understand baryon-baryon interactions and EOS of NS
Photographic emulsion sheet for double strangeness nuclei

Sheet after photographic development

Optical microscope

*Photographic film having sub-micron of special resolution
*Thick sheets: $T=\sim 1\text{mm} \rightarrow \sim 0.5\text{mm}$ (after development)
*7stages in Gifu-University and JAEA
Focal depth: 6 μm, equal to 18 μm before dev.

Thickness: 1.0mm → 0.6mm after dev.

Under 20x objective lens
Emulsion sheet

Thickness: 1.0mm → 0.6mm after dev.

Focal depth: 6 μm, equal to 18 μm before dev.

Under 20x objective lens
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Emulsion sheet

Thickness: 1.0mm → 0.6mm after dev.

Focal depth: 6 μm, equal to 18 μm before dev.
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Thickness: 1.0mm → 0.6mm after dev.

Under 20x objective lens
Hybrid method for J-PARC E07, double strangeness nuclei search

K^- beam
1.8GeV/c

Cross-sectional view

SSD

Cross section
K^- beam
~ 0.16 mb

Diamond target

Emulsion stack (13 layers)

Hypernuclei as nuclear fragment

Frontal view

K^- beam

Silicon Strip Detector (SSD)

Emulsion stack
35cm*34.5cm*13layers
\[ p + \Xi^- \rightarrow \Lambda + \Lambda + 28\text{MeV} \]

**Twin \( \Lambda \) hypernuclei**

\[ \Xi^- \text{ capture} \]

**\( \Lambda \Lambda \) hypernucleus**

\[ \pi^- \rightarrow \Lambda + \Lambda + 28\text{MeV} \]
Kiso Event

Bound state $\Xi^-$ and 14N with strong interaction
$B_{\Xi^-} = 1.11\sim4.38 + - 0.25 \text{ MeV}$

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2015年1月19日 中日新聞 朝刊

岐阜、宇宙創生の謎に一歩 中性子星に「グザイ」存在

岐阜県の伊味和馬教授（実験物理学科）と日本原子力研究開発機構（茨城県）などのグループは、恒星の最終形態である中性子星に含まれていると推定されている希有なグザイ（中性子）の存在を示唆した。中性子星にグザイが存在することをはっきり示す成果で、宇宙創生の謎解きに迫る大きな一歩として注目される。

結果は、日本物理学会などがインターネットで発表する学術講演誌に掲載される。
Nagara event

The interaction between nucleons and hyperons can be represented as:

\[
p + \Xi^- \rightarrow \Lambda + \Lambda + 28\text{MeV}
\]

Where, \(\Delta B_{\Lambda\Lambda} = 0.67 \pm 0.17\text{ MeV}\)

\(\Delta B_{\Xi^-} = 0.13\text{ MeV}\)

\[M(\Lambda\Lambda A_Z) = M(A-2Z) + 2M_\Lambda - B_{\Lambda\Lambda}\]

\[M(\Lambda A_Z) = M(A-1Z) + M_\Lambda - B_{\Lambda}\]

\(\Lambda\Lambda\) interaction is weekly attractive
2000年代までに
検出された事象数: 9
核種決定、質量再構成に成功した事象数: 1

J-PARC E07 : 過去10倍の統計量でダブルストレンジネス核を生成する実験
* Photographic emulsion gel 800kg→2.1t
* Purity of K- beam 25%→85%
* Automated Tracking in emulsion sheets

*A = 6~17 ΛΛ hypernuclei : ΛΛ interaction, nuclear structure, ΛΛ-ΞN coupling.
*Ξ hypernuclei (Ξ−16O, Ξ−14N, Ξ−12C) : ΞN interaction, ΛΛ- ΞN coupling.
First measurement of X-ray from $\Xi$-atoms

- Simulated for $\Xi^-$-stopping for $10^4$ events in the Emulsion
- Energy resolution for Ge : 2keV FWHM

Statistical accuracy of shift energies : Br(316 keV): 400 eV, Ag(370 keV): 200 eV

<table>
<thead>
<tr>
<th>$Z(n,l)$</th>
<th>$E$ (keV)</th>
<th>Shift (keV)</th>
<th>Width (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag(8,7)$\rightarrow$(7,6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case 1</td>
<td>370.45</td>
<td>0.28</td>
<td>0.15</td>
</tr>
<tr>
<td>Case 2</td>
<td>3.3</td>
<td>0.79</td>
<td>0.79</td>
</tr>
<tr>
<td>Br(7,6)$\rightarrow$(6,5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case 1</td>
<td>315.5</td>
<td>0.73</td>
<td>0.44</td>
</tr>
<tr>
<td>Case 2</td>
<td>5.5</td>
<td>1.74</td>
<td>1.74</td>
</tr>
</tbody>
</table>

Case 1: assuming potential shape to be the same as the nuclear density ($t\rho$ potential)
Case 2: Nijmegen D model correcting to produce the potential depth of $\sim$ 14 MeV.
K^- beam 1.8GeV/c
Beam size:
(σX, σY) = ~ (10, 6) mm

* Track density = 10^6/cm^2 (Observable limit)
* Sliding emulsion stack spill by spill
* 6 hours / stack
K\(^-\) beam 1.8GeV/c

Beam size:
\((\sigma_X, \sigma_Y) = \sim(10, 6)\) mm

* Track density = \(10^6/\text{cm}^2\) (Observable limit)
* Sliding emulsion stack spill by spill
* 6hours / stack
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>Emulsion sheet making -&gt; in Kamioka mine</td>
</tr>
<tr>
<td>2015</td>
<td>2015 May. Test experiment</td>
</tr>
<tr>
<td>2016</td>
<td>1st physics run</td>
</tr>
<tr>
<td></td>
<td>*Commissioning</td>
</tr>
<tr>
<td></td>
<td>*18 modules</td>
</tr>
<tr>
<td>2016</td>
<td>2nd physics run</td>
</tr>
<tr>
<td></td>
<td>*Commissioning</td>
</tr>
<tr>
<td></td>
<td>*100 modules</td>
</tr>
<tr>
<td>2017</td>
<td>~60%</td>
</tr>
</tbody>
</table>
The emulsion facility at Gifu University

pouring room

drying room

Tanks for photographic development
Emulsion pouring

Pouring melted nuclear emulsion
40 degrees Celsius, 3.1kg

Drying
28 degrees Celsius, 75% R.H., 2 days

Flattened base-film by vacuum

Pouring yard

!!Mock-up!!
Lead shield in Kamioka mine

Cooling at 17 °C.

In a refrigerator in Gifu Univ.: ~400 days

In Kamioka mine.: ~400 days
Refreshing

- 4 days in Temp.: 25 deg C, Humi.: 90 %
- Humidification 2 days + 4 days + drying 2 days
- $4Ag + O_2 + 2H_2O \rightarrow 4Ag^+ + 4OH^-$

Compton-elec. Tracks / (100mm)$^3$

88.6 ± 3.4

48.1 ± 2.5

Refresh chamber capacity: 100 sheets

!!Mock-up!!
Photographic development


<table>
<thead>
<tr>
<th>timetable</th>
<th>preparation</th>
<th>presoak, dev.</th>
<th>fix</th>
<th>washing</th>
<th>drying</th>
</tr>
</thead>
<tbody>
<tr>
<td>1day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>next cycle -&gt;</td>
<td>preparation</td>
<td>presoak, dev.</td>
<td>fix</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Emulsion sheet after photographic dev.
K⁺ tagging: momentum and missing mass measurement by KURAMA

*Momentum resolution : 1.4%  
*Missing mass resolution: ~14MeV/c²

reconstructed Ξ⁻ mass: 1319.5 ± 14.2 MeV/c² with SSD Ξ⁻ tagging

*K⁺ yield : 1.03*10⁵ events in 17.5 stacks in 1st physics run
'p'($K^-, K^+)\Xi^-$ event reconstruction

\begin{itemize}
\item SSD dE
\item Kinematics is consistent with simulation
\item Yield of $\Xi^-$ stop event
\begin{enumerate}
\item 1.6$\times$10$^3$ events in 1$^{st}$ run
\item 12.2$\times$10$^3$ events in 2$^{nd}$ run
\item 13.8$\times$10$^3$ events (Total)
\end{enumerate}
\end{itemize}
Alignment of SSD & Emulsion sheet
With pattern matching of p-bar beam tracks

Pattern matching

1st emulsion sheet (after development)

Pattern matching - dy:dx

X-projection

\( \sigma_x = 21 \mu m \)

y-projection

\( \sigma_y = 22 \mu m \)

SSD

Emulsion

~10^4/cm^2
Track following: In Operation.

- SSD-pl01 connection
- beam pattern matching for adjacent sheets
- image taking around stopping point

**Found events**

- Stop w/o fragment
- $\Xi^-$→$\Lambda\pi^-$ Decay

$\Xi^-$→$\Lambda\pi^-$ Decay

Beam direction

10μm
Event reconstruction in emulsion sheet

* Track measurement: range, theta and phi
* Initial state: bound system \(^{12}\text{C}\) or \(^{14}\text{N}\) or \(^{16}\text{O}\) and \(\Xi^-\)
* Selection possible decay modes.
  Conservation of charge, energy, momentum, Nbaryon, Nstrangeness etc.
* PID with grain-density and “track boldness”
* PID with Multiple Coulomb Scattering

### TABLE III. Possible production modes of the double hypernucleus. The errors on the mass of \(\Xi^-\) hyperon and the binding energies of single hypernuclei are not included in the errors on \(B_{AA}\) and \(\Delta B_{AA}\). Only the cases of \(\Delta B_{AA} < 20\text{ MeV}\) are listed.

<table>
<thead>
<tr>
<th>Target</th>
<th>No. 1</th>
<th>No. 2</th>
<th>No. 3</th>
<th>(B_{AA}) [MeV]</th>
<th>(\Delta B_{AA}) [MeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{12}\text{C}) (\Lambda^-\text{He})</td>
<td>(^{6}\text{He})</td>
<td>4He</td>
<td>(p)</td>
<td>2n</td>
<td>(&gt;16.9)</td>
</tr>
<tr>
<td>(^{12}\text{C}) (\Lambda^-\text{He})</td>
<td>(^{6}\text{He})</td>
<td>4He</td>
<td>(d)</td>
<td>1n</td>
<td>14.5 ± 0.7</td>
</tr>
<tr>
<td>(^{12}\text{C}) (\Lambda^-\text{He})</td>
<td>(^{6}\text{He})</td>
<td>4He</td>
<td>(t)</td>
<td>1n</td>
<td>7.3 ± 0.2</td>
</tr>
<tr>
<td>(^{12}\text{C}) (\Lambda^-\text{He})</td>
<td>(^{7}\text{He})</td>
<td>4He</td>
<td>(p)</td>
<td>1n</td>
<td>21.6 ± 1.3</td>
</tr>
<tr>
<td>(^{14}\text{N}) (\Lambda^-\text{He})</td>
<td>(^{6}\text{He})</td>
<td>7Li</td>
<td>(p)</td>
<td>1n</td>
<td>24.4 ± 2.1</td>
</tr>
<tr>
<td>(^{14}\text{N}) (\Lambda^-\text{He})</td>
<td>(^{6}\text{He})</td>
<td>6Li</td>
<td>(d)</td>
<td>1n</td>
<td>25.8 ± 1.3</td>
</tr>
<tr>
<td>(^{14}\text{N}) (\Lambda^-\text{He})</td>
<td>(^{6}\text{He})</td>
<td>4He</td>
<td>4He</td>
<td>1n</td>
<td>17.9 ± 1.5</td>
</tr>
<tr>
<td>(^{14}\text{N}) (\Lambda^-\text{Li})</td>
<td>(^{7}\text{He})</td>
<td>4He</td>
<td>(t)</td>
<td>1n</td>
<td>26.2 ± 0.9</td>
</tr>
<tr>
<td>(^{14}\text{N}) (\Lambda^-\text{Li})</td>
<td>(^{9}\text{Li})</td>
<td>(p)</td>
<td>4He</td>
<td>1n</td>
<td>31.5 ± 1.8</td>
</tr>
<tr>
<td>(^{16}\text{O}) (\Lambda^-\text{Li})</td>
<td>(^{8}\text{Li})</td>
<td>4He</td>
<td>4He</td>
<td>1n</td>
<td>31.1 ± 0.9</td>
</tr>
</tbody>
</table>

P.R.L. 87, 212502 (2001)
Alpha decay event search by “Vertex-picker”

“Overall scanning”

Finding vertex-like objects with image processing

*96% accuracy for 3 categories

Density and Shrinkage measurement

Beam Intl.

Alpha decay

Cross-tracks

Classification

vertex-like objects

$^{212}\text{Po (8.785 MeV)}$
E07実験はこれから収穫期に入る

* Spectrometer system is well working
* Successful establishment of Hybrid-Emulsion method for E07
* Emulsion analysis has just started.
* Expected Xi stop event: $14 \times 10^4$

We will detect NEW ONES
pattern matching

* Put the both pattern on a temporary field.
* Draw vectors for all the combination.

peak detection in 2D histogram