Study of double-$\Lambda$ hypernuclei

Phys. Dept., Gifu Univ.
K. Nakazawa

- Our goal
- Status of experiments
- Experiment at J-PARC
- Summary---statistics
Experimental motivation

Making a nuclear chart of double-hypernuclei

=> Information Λ-Λ force,

for understanding B-B int. in SU(3)_f

investigating Multi-strangeness system, “strange matter”

ΔB_{ΛΛ}(A_{ΛΛ}Z) = B_{ΛΛ}(A_{ΛΛ}Z) - 2B_{Λ}(A^{-1}_{Λ}Z)

= 2M(A^{-1}_{Λ}Z) - M(A^{-2}_{Λ}Z) - M(A_{ΛΛ}Z)

Existence of the H-dibaryon ⊗ resonance?

M_H ≥ 2m_Λ - B_{ΛΛ}

Coupling effect

|H> = √(1/8)|ΛΛ> + √(4/8)|NΞ> - √(3/8)|ΣΣ>
To know $\Lambda\Lambda$ int. independent on the core structure, we need to measure $A$-dependence of $B_{\Lambda\Lambda}$. 

FIG. 12. Summary of the energy levels of the double-$\Lambda$ hypernuclei $^6_\Lambda$He, $^7_\Lambda$He, $^7_\Lambda$Li, $^8_\Lambda$Li, $^9_\Lambda$Li, $^9_\Lambda$Be, and $^{10}_\Lambda$Be calculated using the $\alpha+x+\Lambda+\Lambda$ model with $x=0,n,p,d,t,^3$He, and $\alpha$, respectively.
Our goal is making a $S=-2$ nuclear chart, by observing so many nuclei with $S=-2$.

Flavor Nuclear Physics
Status of experiments

1963


10\(^{Be}\) in ~4 \(\Xi\) stops

\(\Xi B_{\Xi} \rightarrow \Xi B_{\Xi} + \Xi B_{\Xi}\)

if a daughter \(\Xi Be\) is in excited

\(\Xi B_{\Xi} \rightarrow \Xi B_{\Xi} + \Xi B_{\Xi}\)

1966

D.J. Prowse, PRL. 17(1966)782

6\(^{He}\) stops

The existence of Double-\(\Lambda\) hypernucleus was confirmed

1991

S. Aoki et al., PTP. 85(1991)1287

KEK-E176

13\(^{\Xi} B\) in ~80 \(\Xi\) stops

\(\Xi B_{\Xi} \rightarrow \Xi B_{\Xi} + \Xi B_{\Xi}\)

if a daughter \(^{13} C\) is in excited

\(\Xi B_{\Xi} \rightarrow \Xi B_{\Xi} + \Xi B_{\Xi}\)

or 10\(^{Be}\)

\(\Xi B_{\Xi} \rightarrow \Xi B_{\Xi} + \Xi B_{\Xi}\)
Status of experiments

Double-Λ hypernuclei from E373

2001

NAGARA event

6He double-hypernucleus

Unique interpretation!!

H. Takahashi et al.,

P. R. L. 87, 212502(2001)

Demachi-yanagi event

* two body case at point A

\[ ^{14}\text{C} \rightarrow ^{6}\text{He} + ^{4}\text{He} + t \]

\[ ^{14}\text{Be} + t \] or \[ ^{12}\text{Be} + t \]

\[ Q^{14}\text{Be} = -1.14^{0.19}_{-0.17} \text{MeV} \]

Demachi-yanagi event

* three body case at point A

1) \[ ^{14}\text{N} \rightarrow ^{6}\text{He} + p + n \]

\[ Q^{14}\text{N} = +1.47^{0.24}_{-0.20} \text{MeV} \]

http://www.phys.ed.gifu-u.ac.jp/Topics/NAGARA-e.htm

High Energy News

Vol.20 No.5 (2002)

KEK
2002

3rd double-Λ hypernucleus

Nuclear species of the double-Λ is perhaps $^6\Lambda\Lambda\text{He}$, $^7\Lambda\Lambda\text{He}$ or $^{11}\Lambda\Lambda\text{Be}$.

ΛΛ interaction is attractive but weak
Statistics of experiments via $\Xi^-$ hyperon capture at rest

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td># of $\Xi^-$ stop</td>
<td>$\sim 4$</td>
<td>$\sim 80$</td>
<td>$\sim 10^3$</td>
</tr>
<tr>
<td>Light nuclei with $S=2$</td>
<td>1</td>
<td>1</td>
<td>$\sim 6$</td>
</tr>
<tr>
<td>Twin single-$\Lambda$</td>
<td>0</td>
<td>2 $\sim 3$</td>
<td>2</td>
</tr>
</tbody>
</table>

95% finished

Quite poor statistics until now.
Nuclear Physics with double strangeness (S=−2)

KEK-E373 => AGS-E964

International collaboration
AGS-E964 (BNL)

Systematic Study of Double Strangeness System with an Emulsion-Counter Hybrid Method

AGS-E964 collaborators (now)

USA: BNL  R. E. Chrien, M. May, P. Pile, A. Rusek
       CMU  G. B. Franklin
       Houston  Ed. Hungerfold, K. J. Lan, Y. Cui, Song
       New Mexico  B. Bassalleck

CHINA: CIAE  H. Guo, Z. Liu, S. Lu, J. Zhou

INDIA: AMU  R. Hasan

JPN: Gifu  K. Nakazawa
       Kyoto  H. Funahashi, K. Imai, N. Saito, M. Yosoi
       OCU  K. Yamamoto, T. Yoshida
       Osaka E-C  H. Hotchi
       Riken  K. Tanida
       Toho  S. Ogawa, H. Shibuya
       Tohoku  Y. Miura, H. Tamura, M. Ukai

KOREA: GNU  J. S. Song, C. S. Yoon
       PUSAN  J. K. Ahn, S. J. Kim

MM: MANDALAY  M. Thein, K. S. Myint

UK: UCL  D. H. Davis, D. Tovee
+ Graduate students

Beam: K− (1.7GeV/c), 4 x 10^5 K−/spill
with K−/π− > 9 at D6-line

Detectors: Nuclear Emulsion, Double-sided Si strip Detector (DSSD), Ge-Detector (Hyperball), KURAMA magnet

Time requested:
150 hours for detector tune
600 hours for beam exposure

(K−, K+) trigger
10^4 Ξ− stopping events

We requested Beam time on FY2006
Ge detector for \( \Xi \)-atomic X-ray

Setup around target (upstream side)

- PMT
- BGO
- Ge
- LN2 Dewar
- SCIFI Block + diamond target

K-beam

30 cm
全体像
基板はBTレジンで1.2mmの厚さ

裏面

表面
Development of Automatic Scanning

**KEK-E373**
- stage drive: step-by-step
- image capture: 30Hz
  \[\Rightarrow 1.5\sim2.0 \text{ sec / one view}\]

Images are shown:
1. Surface detection => Grid measurement for position calib.
2. Track scanning

**Current system**
Surface & Grid: 22 sec.
Track scan: 15 sec.

**Developing system**
Surface & Grid: 9 sec.
Track Scan: 6 sec.

**AGS-E964 (BNL)**
- stage drive: Non-Stop
- image capture: 100Hz
  \[\Rightarrow \sim0.2 \text{ sec / one view} \text{ (designed value)}\]

Non-stop driving: speed \(\sim1\text{mm/sec}\)

Aug.02-04, 2004
NP04
Development of grid printing to get better position accuracy

Fabrication of sample mask from Korean Collaborators

Size of mask : 15x15cm²
Area of hole marks : 15 x 7.5cm² (half below)
Base : Quartz crystal (3.2mm thick)
Coated material : Chrome (10 µm thick)
Gap distance of each marks :
  x: 99.6 µm, x: 99.3 µm
Hole size : 0.89 µm φ
We will have precise calibration points

Mask holes

Exposed image in X-ray film

by \( \times 20 \) obj. lens

Exposure time : 1 sec
UV wave length : 255 nm
Distance from source to target : 30cm
New Hybrid-Emulsion Experiment at J-PARC

Aug.02-04,2004
NP04

Outline: No K$^+$ tagging → no spectrometer magnet
Trigger: $K^-$ + $^{12}$C reaction → X-ray(F→D)

- $\Xi^-$ production
  - $K^- + p \rightarrow \Xi^- + K^+ + \pi^0$
  - $\Xi^- + K^0 + \pi^+$
  - $K^- + n \rightarrow \Xi^- + K^0 + \pi^0$
  - $\Xi^- + K^+ + \pi^-$

- 10 times larger statistics than BNL-E964 (no K$^+$ tracking x 2)
- Quasi-free ($K^-, K^+$) reaction
- $x2.5 (\sigma_{\Xi^- prod.})$
- $K^- + (p,n) \rightarrow X: 3.5$ times

& Em.: 3
To get $\Lambda\Lambda$ hypernucleus via stopping events

Information:
- nuclear chart of $S=-2$ nuclei
- $\Xi$ -ray from double-$\Lambda$ hypernuclei

Developments:
- Hyperball
- fully automated scanning system
- nuclear emulsion itself $\rightarrow$ next speaker

- proposal will be submitted.
Fine grain emulsion crystal to get better position resolution at J-PARC

SEM Micrographs of AgBr Grains

SEM: scanning electron microscope

E373 emulsion (ET-7C,D) developed by Nagoya

Size of AgBr Grains

200nm

Size: 40nm
RMS: 9nm
Fine grain emulsion crystal

to get better position resolution at J-PARC

Tracks due to 5MeV $\pi^-$ - particles

Dark Field Image of Light Microscope

Development

1) density 2.8(g/cc) $\rightarrow$ 3.5(g/cc)

or 2) size: 40nm $\rightarrow$ 70~80[?]nm

Pions & fast protons without beam tracks

Higher dense exposure
## Summary

**Comparison of yields**

Roughly estimated outcome

<table>
<thead>
<tr>
<th>Experiment</th>
<th>KEK-E176</th>
<th>KEK-E373</th>
<th>BNL-E964</th>
<th>J-PARC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^-$/beam</td>
<td>1/4</td>
<td>1/5</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td># of $K^-$ beams (per spill)</td>
<td>$1 \times 10^9$</td>
<td>$1 \times 10^{10}$</td>
<td>$1 \times 10^{11}$</td>
<td>$3 \times 10^{11}$</td>
</tr>
<tr>
<td>Beam time (hr.)</td>
<td>~1000</td>
<td>1500</td>
<td>750</td>
<td>~3000</td>
</tr>
<tr>
<td>Trigger</td>
<td>$(K^-,K^+)$</td>
<td>$(K^-,K^+)$</td>
<td>$(K^-,K^+)$</td>
<td>$(K^-, X)$</td>
</tr>
<tr>
<td># of $\Xi^-$ stops</td>
<td>80</td>
<td>$10^3$</td>
<td>$10^4$</td>
<td>$10^5$</td>
</tr>
<tr>
<td>Em. Volume (ℓ)</td>
<td>30</td>
<td>70</td>
<td>210</td>
<td>600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>95% fin.</th>
<th>FY2006?</th>
<th>future</th>
</tr>
</thead>
</table>