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

NAGARA event (KEK-E373)

Gifu: M.Kawasaki, H.Nakamura, K.Nakazawa, K.T.Tint, T.Watanabe
AMU: R.Hasan
BNL: R.E.Chrien
Chonnam: J.Y.Kim
Dongshin: M.Y.Pac
Fukui: T.Yoshida
Gyeongsang: K.S.Chung, S.H.Kim, J.S.Song, C.S.Yoon
KEK: M.Ieiri, H.Noumi, M.Sekimoto, H.Takahashi
NIRS: N.Yasuda
OsakaCity: K.Yamamoto
Pusan: J.K.Ahn, S.Y.Ryu
Toho: C.Fukushima, M.Kimura, S.Ogawa, H.Shibuya
UCL: D.H.Davis, D.Tovee
U.Houston: Ed.Hungerfold
U.New-Mexico: B.Bassalleck
Motivation of the proposed experiment

- detection of $10^2$ or more candidate events with $S = -2$, → Discovery of 10 or more nuclear species.

Our goal is to produce a $S=-2$ nuclear chart, by observing nuclei with $S=-2$ as many as possible.

More than 10 times statistics than previous E373.

Strange matter

$S=-\infty$ / N-star

double-hypernuclei

$S=-2$

$\Lambda, \Sigma$ hypernuclei

$S=-1$

$\Lambda, \Sigma$ hypernuclei

$S=0$

neutron

H-dibaryon, $\Xi$-Nucleus Interaction, Inside Neutron Stars (Quark-star?)
How to produce S=-2 Systems

- Direct process
- via $\Xi$ atom (KEK-E373)

Double-Hypernucleus

Twin-Hypernucleus

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Double-Hypernuclei found by KEK-E373

47 single-hypernuclear events
→ ~ 600 events Ξ\(^-\) capture at rest
  • 6 double-hypernuclei
  • 2 twin-hypernuclei
  • 1 Σ\(^-\)-emission

Demachi-yanagi event

Demachi-yanagi event

* two body case at point A
Ξ\(^-\) + \(^{12}\)C → \(^{10}\)Be + \(t\) or \(^{10}\)Be\(^*\) + \(t\)

* three body case at point A
Ξ\(^-\) + \(^{14}\)N → \(^{13}\)B + \(p\) + \(n\)

NAGARA event

\(\Delta^\Lambda\Lambda\) double-hypernucleus

Unique interpretation!!

\(e^- + \(^{12}\)C \rightarrow \Delta^\Lambda\Lambda\) + \(^{4}\)He + \(t\)
\(\Delta^\Lambda\Lambda\) → \(^{5}\)He + \(p\) + \(\pi\)

Lambphadi

\(m(\Delta^\Lambda\Lambda\)He\) = 5961.82 ± 0.54 MeV
\(B_{\Delta\Lambda\Lambda}\) = 7.25 ± 0.19 MeV
\(\Delta B_{\Delta\Lambda\Lambda}\) = 1.01 ± 0.20 MeV
(assumed \(B_e\) = 0.13 MeV)

\(m(\Pi) \geq 2223.7 \text{ MeV} \cdot c^2\)
(90% C.L.)

\(\Delta B_{\Delta\Lambda\Lambda} : \Delta\Lambda\Lambda\) Interaction Energy

\(\Delta B_{\Delta\Lambda\Lambda} = B_{\Delta\Lambda\Lambda}(\Lambda\Lambda^A Z) - 2B_{\Lambda}(A^{-1} \Lambda Z)\)

Found

Weakly attractive \(\Delta\Lambda\Lambda\) Interaction!

Hybrid Method ==> Reliable

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To determine $\Lambda\Lambda$ interaction independent on the nuclear structure, we need to measure $A$-dependence of $\Delta B_{\Lambda\Lambda}$. 
**H-dibaryon resonance (?) near the $\Lambda\Lambda$ threshold**

Recent result

**KEK-PS E522**

What is the ground state of $S=-2$ nuclei?

- $\Lambda\Lambda$ or H-dibaryon state
- or mixed in nuclei?

$|H\rangle = \sqrt{a} |\Lambda\Lambda\rangle + \sqrt{b} |\Xi N\rangle - \sqrt{c} |\Sigma\Sigma\rangle$

1. **A-dependence** of $\Delta B_{\Lambda\Lambda}$
2. **Decay branching ratio**
   
   $[S=-2] \Rightarrow \Sigma^- p, \Lambda n$

3. **Higher statistics** for $\Lambda\Lambda$ spectrum is expected.
First observation $\Sigma$-$N$ weak decay of double strangeness nuclei

$\Xi^- + (p) \rightarrow X \rightarrow \Sigma^- + p$

Decay mode ($X \rightarrow \Sigma^- + p$) $<\ldots$ Theoretical Prediction.

$X : \Lambda\Lambda \left(\sim 10^{-3}\right), H$–dibaryon (several tens’ %).

**E373 data**: One event for the Decay ($X_{[S= -2]} \Rightarrow \Sigma^- p$)

**Proposed experiment** can provide $Br(X_{[S= -2]} \Rightarrow \Sigma^- p)$

with more than 10 times higher statistics.
**Ξ-nucleus potential**

1) Level energy of $\Xi^-$ hyperon in nucleus by twin-hypernuclei.


2) The first measurement of $\Xi^-$ atomic X rays employing “Hyperball-J” (Ge detector array).

Energy shift $\rightarrow$ $\Xi^-$ nucleus potential $\rightarrow$ $\Xi^-$N interaction

**High accuracy** $\leftrightarrow$ P03 K. Tanida

$\sim 0.2$ keV (FWHM) $< 0.3 - 3$ keV (by Friedman, Gal)

**Very low background**

Clean $\Xi^-$ stopping events identified in emulsion.
Setup of the proposed experiment

Almost same as E373

# Beam: \( K^- \) (1.7GeV/c),
\[ 3 \times 10^5 \text{K}^-/\text{spill with } K^-/\pi^- > 6 \]
at \( K1.8 \) beam-line (~20% of 9\( \mu \)A)

# Trigger: \((K^-, K^+)\)

=> \(10^4\) \(\Xi^-\) stopping events

(more than 10 times higher stat. than E373)
Development #1
Double-sided Si Strip Detector (DSSD)

Silicon; 32 x 64mm area, 300μm thick
50μm strip pitch -> 16μm resolution
readout; VA-chip

Energy spectrum for β-ray (90Sr)
Equivalent electron noise; 600~1000
S/N; 23~34 for MIPS

PS-T594: + Track connection (DSSD ↔ Emulsion)
using the last beam at KEK-PS, on mid March
+ Analysis is going-on.
Development #2
Upgraded Hyperball-J

*Peak efficiency: × 2
* Very low background

Ξ⁻ atomic X-ray

Simulation (10⁴ stopped Ξ⁻)

Ag (8,7)→(7,6)
Br (7,6)→(6,5)
e⁺

ΔE\text{syst} \sim \pm 0.1 \text{ keV}
ΔE\text{stat} = \pm 0.14 \text{ keV}
ΔE\text{stat} = \pm 0.11 \text{ keV}

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H.Tamura
Development #3

Emulsion scanning system

New system

Area: $35 \times 35 \text{ cm}^2 \rightarrow 40 \times 40 \text{ cm}^2$
Light: Halogen Lamp $\rightarrow$ Ultra High-bright LED
speed: $\times 2$
tracking eff.: $\times 1.5$
# of System: 6 (old, E373) $\rightarrow$ 7 (new) + 3 (old)

Old system

New system

Scanning for this experiment: more speed-up $[\times 6$ than old system $]$

(1) Develop scanning algorism
(2) Optimize the area for scanning

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New method of Emulsion gel production
For the proposed exp., amount of emulsion gel => 2.6 tons
Fuji-film needs one year or more by conventional way.

Conventional way by hand

Using the production lines for commercial films

Tested by particle beams with good results.
Half of necessary emulsion has been made!

Emulsion cost will be saved 50%
# Physics

1) S=-2 nuclear chart $\sim 10^2 \Lambda\Lambda Z$ yields $10^4 \Xi^-$-stopping events.

$\Rightarrow$ $\Delta B_{\Lambda\Lambda}$ of several nuclides $\Lambda\Lambda$-stop events yield $\Lambda\Lambda$-stopping events via $\Lambda\Lambda$-stopped events.

2) H-dibaryon state $\Lambda\Lambda$-stopping events?

$\Rightarrow$ $A$-dependence of $\Delta B_{\Lambda\Lambda}$ & $\Sigma$-decay mode of $\Lambda\Lambda Z$.

3) $\Xi^-$-nucleus potential

$\Rightarrow$ $\Xi^-$-nucleus potential in twin hypernuclei

$\Rightarrow$ $\Xi^-$-nucleus potential in $X$-ray $\Xi^-\Xi^-$-atom
# Readiness of the Experiment ('Kakenhi / Tokubetsu-Suishin' : $3M)
  + DSSD (D ĶļĩijĬôĺİīĬīç Si S ĻĹİķ D ľļĬĻĬĪĽĶĹç )
  + Scanning system (6=>10 ľŀĺĻĬĴĺç : high speed and better efficiency)
  + Emulsion (50%)
  + Hyperball-J (other budgets)

# Requested Beam and Time (K-, K+) trigger
  $3 \times 10^5 K^- \text{ trigger rate } K^-/\pi^- > 6 \text{ on K1.8 beam-line (~20% of 9μA)}$
  150 \text{ hours } \text{ for preliminary setup, 600 hours } \text{ for data taking}$

# Detector: DSSD, Emulsion, Hyperball, KURAMA spectrometer, etc.

*Almost Ready*