Proton asymmetry from non-mesonic weak decay in light hypernuclei

Outline

- Motivation
- Analysis results
  - s-shell ($^5_\Lambda$He)
  - p-shell ($^{12}_\Lambda$C, $^{11}_\Lambda$B)
- Summary

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Asymmetry measurement of decay proton

Asymmetry: Volume of the asymmetric emission from $N$:

$$N(\theta) = N_0 (1 + A \cos \theta)$$

$$= N_0 (1 + \alpha P \cos \theta)$$

Asymmetry Parameter

$$A = \frac{r - 1}{1 + (r - 1)}$$

$$r = \frac{N(\theta^+)}{N(\theta^-)}$$

$$\phi_K > 0$$

$$\phi_K < 0$$

Difference of acceptance & efficiency is canceled out!

$r = \left\{ \frac{N(\theta^+(+\phi)) \times N(\theta^-(0))^{1/2}}{N(\theta^+(-\phi)) \times N(\theta^-(+\phi))} \right\}$
**Motivation**

**Present status**

|         | Asymmetry Parameter |
|---------|---------------------|
| Previous experiments |                  |
| $^5_\Lambda$He : $0.24 \pm 0.22$ | Theoretical prediction |
| $^{12}_\Lambda$C, $^{11}_\Lambda$B : $-1.3 \pm 0.4$ | $-0.6 \sim -0.7$ |

**The aim of E462/E508 experiment**

- Precise measurement of Asymmetry parameter
- with high statistics
- with np back-to-back events
- $\Delta p \rightarrow np$
Event selection ($\bar{\Lambda}$He)

$^6$Li mass spectra

- Inclusive: $5.2 \times 10^4$ events
- $\pi^-$-coin: $3.2 \times 10^3$ events
- $p$-coin: $1.7 \times 10^3$ events

$E_p > 30$ MeV

Particle identification

Systematic error

$\pi^-$ gate

$g.s.$ contamination

$\pi^-$ gate

$P^-$ gate
**Instrumental Asymmetry**

$(\pi, pC)$ reaction : Only Strong Interaction

Asymmetry = 0 expected

|       | Horizontal Scattering Angle | $^6\text{Li}$ target | $^{12}\text{C}$ target |
|-------|-----------------------------|-----------------------|-------------------------|
| **Proton** | 2 < $|\theta|$ < 6°            | -0.000 ± 0.002        | 0.000 ± 0.002           |
|        | 6 < $|\theta|$ < 9°            | 0.003 ± 0.002         | -0.003 ± 0.003          |
|        | 9 < $|\theta|$ < 15°           | 0.003 ± 0.002         | 0.001 ± 0.002           |
| **Pion** | 2 < $|\theta|$ < 6°            | -0.001 ± 0.001        | -0.002 ± 0.002          |
|        | 6 < $|\theta|$ < 9°            | 0.003 ± 0.001         | 0.002 ± 0.002           |
|        | 9 < $|\theta|$ < 15°           | 0.000 ± 0.001         | -0.003 ± 0.002          |

**Instrumental Asymmetry < 0.3%**
Procedure for $\alpha_{NM}$ calculation
($\bar{P}He$)

\[ A_\pi = \alpha_\pi P_\Lambda \varepsilon \]

- Polarization of $\Lambda$
- Estimated from mesonic decay

\[ A_\pi : \text{Asymmetry of } \pi \]
\[ \alpha_\pi : \text{Asymmetry Parameter of mesonic decay} \]
\[ (=-0.642 \pm 0.013) \]
\[ P_\Lambda : \text{Polarization of Lambda} \]
\[ \varepsilon : \text{Attenuation factor} \]

\[ A_p = \alpha_p^{NM} P_\Lambda \varepsilon \]

- Asymmetry Parameter of Proton

We can calculate $\alpha_p^{NM}$ without theoretical help.
Asymmetry parameter of $^5\Lambda$He

Preliminary

$\alpha_p^{NM} = 0.07 \pm 0.08^{+0.08}_{-0.00}$

Theory: $-0.6 \sim -0.7$
np coincidence analysis

np angular correlation

back-to-back events

| Scattering Angle | $N_{\text{upper}}/N_{\text{lower}}$ | Asymmetry | Asymmetry Parameter |
|------------------|-----------------------------------|-----------|---------------------|
| $6 < |\theta| < 15^\circ$ | 23/26 | 30/19 | 0.18±0.12 | 0.31±0.22 |
$^{12}_{\Lambda}C$ Hypernuclear mass spectra

- Inclusive:
  - $^{12}_{\Lambda}C$: $6.7 \times 10^4$ events
  - $^{11}_{\Lambda}B$: $1.2 \times 10^3$ events

- $N, \alpha$ decay
- LH
- Proton decay
- $\Lambda B$ decay
- $^{11}_{\Lambda}B + p$
  - $8.1$ MeV
  - $6.3$ MeV
  - $2.5$ MeV
  - $0.0$ MeV
- M1 transition
- Depolarized effect
- $E_p > 30$ MeV
Polarization of $\Lambda$

Itonaga et al.
Prog. of Theo. Phys. Supp. 117 (1994) 14

M1 transition reduces polarization of $\Lambda$

If assuming polarization is proportional to scattering angle.

| $P_\Lambda$ | Kaon Scattering angle |
|------------|------------------------|
|            | $2^\circ \sim 6^\circ$ | $6^\circ \sim 9^\circ$ | $9^\circ \sim 15^\circ$ |
| $^{12}_{\Lambda C}$ | 0.04                   | 0.08                   | 0.12                   |
| $^{11}_{\Lambda B}$ | 0.04                   | 0.07                   | 0.12                   |
Asymmetry of p-shell hypernuclei

Estimation of the contamination from other energy levels.

Pion coincidence

Proton coincidence

Blue : 6~9
Red : 9~15
Asymmetry parameter of $^{12}\Lambda C, ^{11}\Lambda B$

Preliminary

$$\alpha_p^{\text{NM}} = -0.24 \pm 0.26$$

Blue : $^{12}_{\Lambda} C$ : $\alpha^{\text{NM}} = -0.44 \pm 0.32$

Red : $^{11}_{\Lambda} B$ : $\alpha^{\text{NM}} = 0.11 \pm 0.44$
Comparison with recent results

\[ \Lambda^5_{\Lambda} \text{He} \quad \Lambda^{12}_{\Lambda} \text{C}, \Lambda^{11}_{\Lambda} \text{B} \]

Theoretical prediction

Unphysical region
Summary

- We performed precise $\alpha_{p}^{\text{NM}}$ measurements of $^5\Lambda\text{He}$ (s-shell) and $^{12}\Lambda\text{C}$, $^{11}\Lambda\text{B}$ (p-shell) hypernuclei.

- Slightly positive $\alpha_{p}^{\text{NM}} (0.07 \pm 0.08^{+0.08}_{-0.00})$ of s-shell hypernuclei was confirmed and $\alpha_{p}^{\text{NM}}$ of np back-to-back event also supports this tendency ($0.31 \pm 0.22$).

- In the case of p-shell hypernuclei, our result (- $0.24 \pm 0.26^{+0.08}_{-0.00}$) contradicts large negative $\alpha_{p}^{\text{NM}}$ which obtained previous experiment with several times higher statistics.

- Theoretical calculation is inconsistent with our results, it means new reaction mechanism are required.
Spare OHP
Summary

Asymmetry parameter of NMWD

- **s-shell**  
  \( ^5\text{He}, \Lambda : \text{E}462 \)  
  \[ 0.07 \pm 0.08 \pm 0.08 - 0.00 \]  
  (preliminary)

- np back-to-back:
  \[ 0.31 \pm 0.22 \]  
  (preliminary)

- **p-shell**  
  \( ^{12}\Lambda\text{C}, ^{11}\Lambda\text{B}, \Lambda : \text{E}508 \)  
  \[ -0.24 \pm 0.26 \pm 0.08 - 0.00 \]  
  (preliminary)

Large discrepancy

Theoretical prediction

\( \pm 0.6 \sim -0.7 \)  

(s/p-shell hypernuclei)
Asymmetry measurement of decay proton

Asymmetry: Volume of the asymmetric emission from NM

\[
N(\theta) = 1 \pm A \cos \theta = 1 + \Lambda \alpha P \cos \theta
\]

Asymmetry Parameter

Decay counter Acceptance

\[|\theta| > 0.7\]

Difference of acceptance & efficiency is canceled out!
**Setup**

(KEK-PS K6 beamline & SKS)

Solid angle: 26%
9(T)+9(B)+8(S)%

Charged particle:
- TOF (T2→T3)
- tracking (PDC)

Neutral particle:
- TOF (target→NT)
- T2/T3 VETO

**Decay arm**

N: 20cm×100cm×5cm
T3: 10cm×100cm×2cm
T2: 4cm×16cm×0.6cm
Charged particle ID

- E VS. TOF
- E VS. dE/dx
- T2 energy loss (MeVee) 
- TOF (1/β)
- Total E

Diagram showing charged particle identification with T4, T3, PDC, T2, and target, along with energy and time-of-flight plots.
$^5\Lambda\text{He spectrum (E462)}$

$^{12}\Lambda\text{C spectrum (E508)}$

$^5\Lambda\text{He gate}$

$^{12}\Lambda\text{C gate}$

$^{11}\Lambda\text{B gate}$

$\pi$

$p$

$d$
Production of Polarized hypernuclei

E462/E508 experiment 1.05GeV/c $\pi^+$ beam is injected.

Distribution of $\Lambda$ polarization in the $n(\pi^+, K^+)\Lambda$ reaction.

In large scattering angle, $\Lambda$ is much...
Significance of asymmetry measurement

If assuming initial S state

| Initial state | Final state | Amplitude | Isospin | Parity |
|---------------|-------------|-----------|---------|--------|
| $^1S_0$       | $^1S_0$     | a         | 1       | No     |
|               | $^3P_0$     | b         | 1       | Yes    |
| $^3S_1$       | $^1S_1$     | c         | 0       | No     |
|               | $^3D_1$     | d         | 0       | No     |
|               | $^1P_1$     | e         | 0       | Yes    |
|               | $^3P_1$     | f         | 1       | Yes    |

$$\alpha_p^{NM} = \frac{\sqrt{3}/2[-ae + b(c - \sqrt{2}d)/\sqrt{3} + (\sqrt{2}c + d)f]}{1/4\{a^2 + b^2 + 3(c^2 + d^2 + e^2 + f^2)\}}$$

We can know the Interference between states with different Isospin and Parity.

$$\Gamma_n / \Gamma_p = \frac{2(a^2 + b^2 + f^2)}{a^2 + b^2 + c^2 + d^2 + e^2 + f^2} \quad \text{(Applying } \Delta I=1/2 \text{ rule)}$$
### Theoretical and Experimental data

#### Theoretical calculation

|                | s-shell$_\alpha$(\(^5\)He) | p-shell$_\alpha$(\(^{12}\)C, \(^{11}\)B) |
|----------------|-------------------------------|------------------------------------------|
| $\Gamma_n/\Gamma_p$ | $\alpha_{NM}$ | $\Gamma_n/\Gamma_p$ | $\alpha_{NM}$ |
| Sasaki et al.[2] |                              |                                          |
| OPE           | 0.133                        | -0.441                                  |
| $\pi+K$       | 0.450                        | -0.362                                  |
| $\pi+K+DQ$    | 0.701                        | -0.678                                  |
| Parreño et al.[3] |                              |                                          |
| OPE           | 0.086                        | -0.252                                  |
| $\pi+K$       | 0.288$\sim$0.498            | -0.572$\sim$-0.606                     |
| OME           | 0.343$\sim$0.457            | -0.675$\sim$-0.682                     |
| BNL 1991[4]   | 0.93$\pm$0.55               | 1.33$\pm$1.12                           |
| KEK-E160[5][6] |                              | 1.87$\pm$0.67                           | -1.3$\pm$0.4 |
| KEK-E278[7][8] | 1.97$\pm$0.67               | 0.24$\pm$0.22                           |
| KEK-E307[9]   |                              | 1.17$\pm$0.22                           |
Estimation of Attenuation Factor

To estimate the attenuation factors ($\varepsilon$), I checked angle distribution of decay particles.

Decay Proton

Mean = 0.899

Decay Pion

Mean = 0.894

Attenuation Factor ($\varepsilon$) = ~0.9
Summary

- We performed precise $\alpha_{p}^{NM}$ measurements of $^5_\Lambda$He(s-shell)/$^{12}_\Lambda$C, $^{11}_\Lambda$B(p-shell) hypernuclei.

- Slightly positive $\alpha_{p}^{NM}$ ($0.07 \pm 0.08^{+0.08}_{-0.00}$) of s-shell hypernuclei was confirmed and $\alpha_{p}^{NM}$ of np back-to-back event also supports this tendency ($0.31 \pm 0.22$).

- In the case of p-shell hypernuclei, our result ($-0.24 \pm 0.26^{+0.08}_{-0.00}$) contradicts large negative $\alpha_{p}^{NM}$ which obtained previous experiment with several times higher statistics.
Spare OHP
(for E462 experiment)
### Proton Energy Dependence

#### Energy Spectrum of decay Proton

| $6 < |\theta_\kappa| < 15^\circ$ | 30~60MeV | 60~85MeV | 85MeV~ |
|-------------------------------|----------|----------|--------|
|                               | $-0.07 \pm 0.15^{+0.04}_{-0.00}$ | $0.17 \pm 0.14^{+0.09}_{-0.00}$ | $0.11 \pm 0.15^{+0.09}_{-0.00}$ |
Energy of decay Particle $^5_{\Lambda}He$ gate

$\pi^-$ Energy

31 MeV

$p$ Energy

32 MeV
Proton energy dependence

Preliminary

Very small even at highest energy data!

Energy of Decay Proton (MeV)
Spare OHPs
(for E508 experiment)
Asymmetry of p-shell hypernuclei

| Scattering Angle | Horizontal | $^{12}_\Lambda$C | $^{11}_\Lambda$B |
|------------------|------------|------------------|------------------|
|                  |            |                  |                  |
| $2<|\theta|<6^\circ$ | -0.040± 0.071 | 0.060± 0.059   |
| $6<|\theta|<9^\circ$ | 0.017± 0.080  | -0.084± 0.069  |
| $9<|\theta|<15^\circ$ | -0.094± 0.076 | -0.158± 0.065  |

- All the regions, Asymmetry is very strong.
## Statistical comparison with E160

| Event Type  | E160 Events | Scale Factor | E508 Events |
|-------------|-------------|--------------|-------------|
| $^{12}\Lambda C$ event | 246 events | $\times 11$ | 2779 events |
| $^{11}\Lambda B$ event | 393 events | $\times 5$ | 2122 events |
| **Total** | **639 events** | **$\times 8$** | **4901 events** |

**p-coin spectrum**
Polarization of $\Lambda$ (E160)

At the time of E160, transition probability to $2^-$ wasn’t known. So they calculated by changing it from 0% to 100%.

E160 result

| $P_\Lambda(\theta_K=14^0)$ | Asymmetry |
|-----------------------------|------------|
| $^{12}_\Lambda C$          | 0.06 ~ 0.09 | - 0.01± 0.11 |
| $^{11}_\Lambda B$          | 0.16 ~ 0.21 | - 0.19± 0.10 |
| LH                          | 0.15 ~ 0.26 | - 0.24± 0.09 |

$P_\Lambda$ of $^{12}_\Lambda C$ to $2^-$:
- $0.02 ~ 0.03$
- $0.03 ~ 0.05$
- $0.05 ~ 0.07$

$P_\Lambda$ of $^{11}_\Lambda B$ to $2^-$:
- $0.06 ~ 0.08$
- $0.09 ~ 0.12$
- $0.13 ~ 0.17$
### Asymmetry Parameter $\@ E160 \ P_\Lambda$

**Preliminary**

\[ \alpha_{\text{NM}}^{\Lambda} = -0.11 \pm 0.30 \pm 0.08 \]

Blue : $^{12}\Lambda\mathrm{C} : \alpha_{\text{NM}}^{\Lambda} = -0.78 \pm 0.66$

Red : $^{11}\Lambda\mathrm{B} : \alpha_{\text{NM}}^{\Lambda} = 0.07 \pm 0.33$
Comparison with E160

PID function

Energy spectrum

E160
Spare OHPs
(others)
Neutral particle analysis

- Good γ n separation
- Good S/N ratio (~15)

Resolution for neutron counter
σ ~ 11 MeV (around 80 MeV)

Width of γ peak

1 / β spectra (5ΛHe gate)

Constant background → very small

Decay modes:
Λ → n π₀
Λ → n n
Λ → pπ⁻
Λ → p p

Neutron gate

Threshold 2 MeVee

Neutron energy scale (MeV)