Gamma-ray spectroscopy of $^{12}_{\Lambda}C$ via the $(\pi^+,K^+)$ reaction

Kenji Hosomi
for the KEK-E566 collaboration

Department of Physics, Tohoku University
contents

• Introduction
• KEK E566 experiment
  – setup and analysis
  – recent results
• Summary
Physics Motivation

- Spin-dependent $\Lambda N$ interaction
  - $\Delta$: spin-spin
  - $S_\Lambda, S_N$: spin-orbit
  - $T$: tensor

- Hypernuclear fine structure
  - $\sim 100$ keV spacing
  - Investigated by gamma-ray spectroscopy
### TABLE IX. Results of the fitting for the KEK-E369 (\(\pi^+, K^+\)) (PhysRevC.64.044302) and FINUDA (stopped \(K^+\)) (PhysLettB.622.35-44) with a theoretical one wave impulse approximation calculation with a fixed parameter, 

<table>
<thead>
<tr>
<th>KEK-E369 ((\pi^+, K^+))</th>
<th>FINUDA (stopped (K^+))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(E_{\text{ex}})</td>
<td>Cross Section</td>
</tr>
<tr>
<td>((\theta=2-14^\circ))</td>
<td></td>
</tr>
<tr>
<td>6.3(1)</td>
<td>1.3(2)</td>
</tr>
<tr>
<td>2.5(2)</td>
<td>1.0(1)</td>
</tr>
<tr>
<td>0</td>
<td>8.1(4)</td>
</tr>
</tbody>
</table>

Angular distributions of kaons leading to the observed peaks for KEK-E369 (\(\pi^+, K^+\)) (PhysRevC.64.044302).
KEK-E566 EXPERIMENT

- KEK-PS K6 beam line (2005)
- $^{12}\text{C} (\pi^+, K^+)$ @ 1.05 GeV/c
Experimental setup

Beam line spectrometer + SKS
-> \((\pi^+, K^+)\) reaction tag
-> Hypernuclear state selection

acceptance (sim.)

\[\text{Solid angle (msr/0.1 deg)}\]

\[\begin{array}{c}
0 \\
0.1 \\
0.2 \\
0.3 \\
0.4 \\
0.5 \\
0.6 \\
0.7 \\
0.8 \\
0.9 \\
1.0 \\
\end{array}\]

\[\begin{array}{c}
0 \\
10 \\
20 \\
30 \\
40 \\
50 \\
60 \\
70 \\
80 \\
90 \\
100 \\
\end{array}\]

\(\text{(\pi, K) reaction angle (deg)}\)

\(0 - 15^\circ\)
Experimental setup

Beam line spectrometer + SKS
-> $(\pi^+, K^+)$ reaction tag
-> Hypernuclear state selection

+ reaction-$\gamma$ coincidence

Hyperball2 (Ge detector array)
-> $\gamma$-ray measurement
Previous results

Three \( \gamma \)-ray transitions of \(^{12}\Lambda\)C were reported in HYP-X. (Nucl. Phys. A835, 422-425)

1/2\(^{-}\) \[\begin{array}{c}
\rightarrow \hline
\rightarrow \hline
\end{array}\] 0\(^{-}\) \[\begin{array}{c}
\rightarrow \hline
\rightarrow \hline
\end{array}\] 2\(^{-}\) \[\begin{array}{c}
\rightarrow \hline
\rightarrow \hline
\end{array}\] 3/2\(^{-}\)

\(^{11}\)C \[\begin{array}{c}
\rightarrow \hline
\rightarrow \hline
\end{array}\] 1\(^{-}\) \[\begin{array}{c}
\rightarrow \hline
\rightarrow \hline
\end{array}\] 2\(^{-}\) \[\begin{array}{c}
\rightarrow \hline
\rightarrow \hline
\end{array}\] 1\(^{-}\)

\(^{12}\Lambda\)C
Updated missing mass spectrum

Resolution: 6.5 MeV (FWHM), \(\sim 10\%\) better than before
Updated $\gamma$-ray spectrum

Peak sensitivity is improved

$1/2^-$

$3/2^-$

$1^{11}\text{C}$

$0^-$

$1_2^-$

$1^{12}\Lambda\text{C}$

$2^-$

$2_1^-$

$2^{+}\Lambda\text{C}$

Counts/10 keV

Counts/10 keV

$E_\gamma$ (keV)

$E_\gamma$ (keV)

Updated $\gamma$-ray spectrum of $^{12}\Lambda\text{C}$ state [keV]

2670 keV  2834 keV

before

w/ Doppler correction

w/ Doppler correction

updated

Peak sensitivity is improved
New transition candidate

KEK-E369
6.3(1) MeV

mass gate

1\(^{+}\)
2\(^{+}\)
3/2\(^{-}\)
5/2\(^{-}\)
1/2\(^{-}\)

\(^{11}\)C
\(^{12}\)C

significance: 3\(\sigma\)

6045 \(\pm\) 10 keV

[Graph showing mass gate and energy levels]
New transition candidate

- Expected γ-ray yield from E369 cross section
  → 35 ± 9 (w/ branching ratio by Millener)
  
  $(1^- \rightarrow 1^-)$ : other transition = 7 : 3

- Measured γ-ray yield
  → 18 ± 6
(π,K) reaction angle and γ-ray yield

(HB2 eff. and SKS acceptance corrected)

\[ \begin{align*}
\text{γ2 (2670 keV)} & \quad \text{γ1 (161 keV)} \\
\end{align*} \]

\[ \begin{align*}
\text{γ1 distribution is different from γ2 distribution} \\
\rightarrow \text{evidence of direct population of spin-flip state}
\end{align*} \]

No direct population of \( 2^-_1 \) → γ1 is fed by γ2

\[ \begin{align*}
\text{spin-non-flip state} \\
\text{spin-flip state} \\
\text{spin-non-flip state}
\end{align*} \]
spin flip/ non-flip ratio

Decomposition of $\gamma_1$ yield based on theoretically calculated distribution

\[
\frac{Y(2_1^-; \text{spin-flip})}{Y(1_1^-; \text{non spin-flip})} = 0.06(3)
\]
Summary

- KEK-E566 experiment
  - $^{12}\text{C} (\pi^+, K^+) @ 1.05 \text{ GeV/c}$
  - Missing mass spectroscopy + $\gamma$-ray spectroscopy
- $(1^-_3 \rightarrow 1^-_1)$ $\gamma$-ray transition candidate in $^{12}_{\Lambda}\text{C}$
  - Energy: $6045 \pm 10 \text{ keV}$
  - $\gamma$ yield support this assignment
- Ratio of directory produced $^{12}_{\Lambda}\text{C}$ g.s. doublet
  - $\text{spin-flip}(2^-)/\text{non-flip}(1^-) = 0.06(3) \ (0 - 15^\circ)$
Thank you for your attention.
BACKUP
(π,K) reaction angle vs γ-ray yield

(HB2 eff. and SKS acceptance corrected)

γ2 (2670 keV)

γ1 (161 keV)

KEK-E369 (Phys. Rev. C 64 044302)

DWIA calculations by Itonaga

γ2 distribution is consistent of KEK-E369
6-MeV $\gamma$-ray simulation
Experimental setup

Beam line spectrometer + SKS
-> \((\pi^+, K^+)\) reaction tag
-> Hypernuclear states selection

CH\(_2\) target (18.6 g/cm\(^2\))
spin non-flip/flip ratio

\[
Y(1^-_{12}) = \frac{N(2670) + N(2830)}{\epsilon} = \frac{N(161)}{\epsilon} \times \frac{\Gamma(M1) + \Gamma(weak)}{\Gamma(M1)}
\]

\[
Y(2^-_{11}) = Y(1^-_{12}) \times \frac{\#1 \text{ peak}}{\#2 \text{ peak}} (\text{KEK-E369})
\]

\[
\frac{\text{spin flip}}{\text{non flip}} = \frac{Y(2^-_{11})}{Y(1^-_{g.s.})}
\]