The $\gamma n \rightarrow K^0\Lambda$ photoproduction studied with an electromagnetic calorimeter FOREST

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Outline

• Motivation and background
• Experiment
  – ELPH accelerator
  – $4\pi$ electromagnetic calorimeter FOREST
• Analysis
  – Particle identification
  – Comparison with the previous data
  – Differential cross section
  – Total cross section
• Summary
Motivation and background

**Baryon spectroscopy**

- One of the useful probes for understanding QCD in low energy scale

**Photoproduction**

- $\gamma N \rightarrow \pi N$, $\gamma N \rightarrow \eta N$
  - investigated

**$K\Lambda$ photoproduction**

$K^+\Lambda(\Sigma)$:
- recently investigated
- (CLAS, LEPS, MAINZ...)
  - particularly about charged kaon

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T. Ishikawa “Baryon spectroscopy at ELPH and LEPS2” (1WG.0003, Hawaii2014)

PHYSICAL REVIEW C **73**, 035202 (2006)
Motivation and background

$\gamma n \rightarrow K^0 \Lambda$ reaction

- All of the participants are NEUTRAL
  - no charged particle (e.g. $K^+$) can be exchanged
  - Born term contribution is smaller than that of $K^+ \Lambda$ case
- Previous measurement: one publication for this channel
  for $E_\gamma = [0.9, 1.1]$ GeV and $\cos \theta_K^{Lab} = [0.9, 1.0)$

The first measurement of $\gamma n \rightarrow K^0 \Lambda$ photoproduciton by NKS
K. Tsukada et al., Phys. Rev. C 83 039904
Motivation and background

• The prominent structure observed in the $\gamma n \to \eta n$
  – Reported by LNS, ELPH, GRAAL, MAINZ, CB-ELSA/TAPS
  – Each results are well agreed with each other:
    • Observed in $n(\gamma, \eta)n$ reaction but no such structure in $p(\gamma, \eta)p$
    • Narrow width ($\sim 25$ MeV) and peak position $\sim 1670$ MeV

The $\gamma d \to \eta pn$ photoproduction cross sections

Phys. Rev. C 90, 015205

Motivation and background

• The prominent structure observed in the $\gamma n \rightarrow \eta n$

Theoretical interpretations
– Intrinsic narrow state
– Pentaquark
– Coupled-channel effect
– Interference effects
– $KY$ threshold effect

$N_s^0(udds\bar{s})$


$\rightarrow$ How about in the $\gamma n \rightarrow K^0 \Lambda$ case?
1.2 GeV Electron Synchrotron and photon beam line

Layout of ELPH beam lines (~2012)

STretcher-Booster Ring: 1.2 GeV electron synchrotron

GeV-γ Beam line: 0.5-1.2 GeV photon
Experiment

1.2 GeV Electron Synchrotron and photon beam line

Layout of ELPH beam lines (~2012)

STretcher-Booster Ring: 1.2 GeV electron synchrotron

GeV-γ Beam line: 0.5-1.2 GeV photon

Radiator: φ11μm carbon fiber
Energy binning ~1MeV

Nov. 4, 2014

Y. Tsuchikawa
FOREST - $4\pi$ electromagnetic calorimeter complex

192 Pure CsI
SCISSORS III

(Forward)

PS $24 \times 3$ layers
SPIDER

Energy resolution
(for 1 GeV $\gamma$)
~3%

252 Lead/SciFi mod.s
LEPS Backward Gamma

~7%

PS $\times 18$
IVY

62 Lead/Glass
Target: liquid H2/D2 target
(45mm thick)

(Backward)

$E_\gamma = 750 - 1150$ MeV

Target: liquid H2/D2 target
(45mm thick)
Analysis – particle identification

Focusing on the following decay chains:

\[ K_S^0 \rightarrow \pi^0 \rightarrow \gamma \rightarrow \gamma \rightarrow \gamma \rightarrow \gamma \]
\[ \Lambda \rightarrow p \rightarrow \pi^- \]

4 photons and 2 charged particles in the final state

\[ \gamma d \rightarrow K_S^0 \Lambda p \rightarrow (\pi^0 \pi^0)(p\pi^-)p \rightarrow (4\gamma)(p\pi^-)p \]

Proton in deuteron is assumed as a spectator
Analysis – particle identification

\[ \gamma d \rightarrow K_S^0 \Lambda p \rightarrow (\pi^0 \pi^0)(p \pi^-) p \rightarrow (4\gamma)(p \pi^-) p \]

2\(\pi^0\)  
4 photon search (neutral cluster)  
-> Then check the \(\gamma\gamma\) invariant masses

\(\rho, \pi^-\)  

No other neutral particles but more 2 charged particles are required both of hodoscope and calorimeter
Analysis – particle identification

\[ \gamma d \rightarrow K_S^0 \Lambda p \rightarrow (\pi^0 \pi^0)(p\pi^-)p \rightarrow (4\gamma)(p\pi^-)p \]

\[ 2\pi^0 \quad \text{4 photon search (neutral cluster)} \]

\[ \rightarrow \text{Then check the } \gamma\gamma \text{ invariant masses} \]

Kinematical fitting with 3 constraints

“\(\gamma\gamma\) invariant mass = \(m_{\pi^0}\)”

1. \(M^2(\gamma_1, \gamma_2) \equiv 2E_1E_2(1 - \sin \theta_1 \sin \theta_2 \cos(\phi_1 - \phi_2) - \cos \theta_1 \cos \theta_2) = m_{\pi^0}^2\)

2. \(M^2(\gamma_3, \gamma_4) \equiv 2E_3E_4(1 - \sin \theta_3 \sin \theta_4 \cos(\phi_3 - \phi_4) - \cos \theta_3 \cos \theta_4) = m_{\pi^0}^2\)

“4\(\gamma\) missing mass = \(m_\Lambda\)”

3. \(M_X^2(\gamma_1, \gamma_2, \gamma_3, \gamma_4) \equiv E_X^2 - P_X^2\)

\[ = (E_\gamma + m_n - \sum_{i=1}^{4} E_i)^2 - P_X^2(E_\gamma, \theta_i, \phi_i, E_\gamma) = m_\Lambda^2\]

13 variables:

- \(\gamma_i\) energy, polar and azimuthal angles: \(E_i, \theta_i, \phi_i\) (\(i = 1, \ldots, 4\)) and Photon beam energy: \(E_\gamma\)

Nov. 4, 2014

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12
Analysis

Accidental coincidence events are shown in the timing difference distribution between FOREST and tagging counter. -> subtracted by means of sideband

\[ \pi^0 \pi^0 \text{ invariant masses of prompt and accidental background region} \]

\[ (E_\gamma > E_{thr}^{K^0 \Lambda}) \]
Analysis

Additional cuts were applied after the kinematical fitting.

Low statistics but high S/N ratio

Proton and charged pion ID @ forward detector system

High statistics but low S/N ratio
Differential Cross Section [Condition I]

Comparisons with the previous data


\[ \frac{d\sigma}{dp} \propto \frac{\text{Yield}(\cos \theta_{K_{\text{Lab}}}^L, E_\gamma)}{N_{\text{targ}} N_\gamma \eta_{\text{acc}} \text{BRs} \delta p} \]

Our cross sections are scaled by arbitrary

0.9 \leq E_\gamma < 1.0 \text{ GeV}
0.9 \leq \cos \theta_{K_{0\text{Lab}}} < 1.0

1.0 \leq E_\gamma < 1.1 \text{ GeV}
0.9 \leq \cos \theta_{K_{0\text{Lab}}} < 1.0

This work

NKS

Arbitrary Unit

\[ \text{Arbitrary Unit} \]

\[ \text{Arbitrary Unit} \]

\[ \text{Arbitrary Unit} \]
Differential Cross Section [Condition I]

Comparisons with the previous data

\[ \frac{d\sigma}{dp} \propto \frac{Yield(E_\gamma, \cos \theta_{K_{Lab}})}{N_{targ}N_\gamma \eta_{acc} BR_{s} \delta p} \]

\[ E_\gamma = [0.9, 1.0) \text{ GeV} \]

Our cross sections are scaled by arbitrary
\[ \star E_\gamma = [1.0, 1.1) \text{ GeV for this work} \]
\[ E_\gamma = [1.0, 1.08) \text{ GeV} \]

This work (a. u.)
K. Futatsukawa
Differential Cross Section [Condition I]

As a function of $\cos \theta_{K}^{CM}$

\[ \sigma \propto \frac{\text{Yield} (E_\gamma, \cos \theta_{K}^{CM})}{N_{targ} N_\gamma \eta_{acc} BR_S} \]

- For $900 \leq E_\gamma < 1000$
- For $1000 \leq E_\gamma < 1100$
- For $1100 \leq E_\gamma < 1150$
Background subtraction [Condition II]

• **Background candidates**
  
  Likely candidates for $\pi^0\pi^0\pi^-p$ final state
  
  $\gamma n \rightarrow \pi \Delta \rightarrow \pi(\pi\pi p)$
  
  $\gamma n \rightarrow \pi \rho p \rightarrow \pi(\pi\pi)p$
Background subtraction [Condition II]

Background distributions are fitted by MC

$$\gamma n \rightarrow \pi^- \Delta^+$$

$$\gamma n \rightarrow \pi^0 \rho^- p$$

SUMMED

Well reproduce the background shapes of real data
Background subtraction [Condition I]

S/N ratio estimation of “Analysis I” with subtraction by likely candidates of BG grounds: $\gamma n \rightarrow \pi \Delta$ and $\gamma n \rightarrow \pi \rho \rho$

$\gamma n \rightarrow \pi^{-} \Delta^{+}$
$S/N=46\%$

$\gamma n \rightarrow \pi^{0} \rho^{-} \rho$
$S/N=53\%$
Total Cross Section

A preliminary result of the $\gamma n \rightarrow K^0 \Lambda$ total cross section

$$\sigma \propto \frac{Yield (E_\gamma)}{N_{targ}N_\gamma \eta_{acc} BRs}$$

Differential cross sections (as a function of $\cos \theta_K^{CM}$) will be developed soon.

Condition I (scaled: with $\pi\Delta$ assumption of BG)
Condition I (scaled: with $\pi\rho$ assumption of BG)
Condition II

Preliminary
Summary

- The $\gamma d \rightarrow K^0 \Lambda p$ photoproduction reaction is studied with an electromagnetic calorimeter FOREST at ELPH.
- $K^0$ signals are well confirmed in the $\gamma d \rightarrow K^0_s \Lambda p \rightarrow (\pi^0 \pi^0) (p \pi^-) p \rightarrow (4\gamma) (p \pi^-) p$ reaction with an exclusive analysis.
- The shapes of differential cross sections agree with the previous data.
- Shape of the background in $\pi^0 \pi^0$ invariant mass distribution was well explained by $\pi \rho$ and $\pi \Delta$ photoproduction contamination.
- Total cross sections computed under different cut conditions are agreed with each other in substance.