Near threshold $K^0\Lambda$ photoproduction on the neutron studied with an electromagnetic calorimeter FOREST

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

Outline

• Motivation and background

• Experiment
  – ELPH accelerator
  – $4\pi$ electromagnetic calorimeter FOREST

• Analysis
  – Particle identification
  – Background subtraction
  – Differential cross section

• Summary
Motivation and background

**Baryon spectroscopy**

One of the useful probes for revealing the QCD in low energy scale

*Photoproduction case*

$\pi N$, $\eta N$ channels

$\rightarrow$ well investigated

*KY channel*

$K^+ \Lambda (\Sigma)$:

recently investigated

(CLAS, LEPS, MAINZ...)

particularly

*charged kaon, Sigma*

T. Ishikawa “Baryon spectroscopy at ELPH and LEPS2” (Hawaii2014)

\[ \gamma n \rightarrow K^0 \Lambda \] reaction

- All of the participants are NEUTRAL
  \( \rightarrow \) no charged particle (e.g. \( K^+ \)) can be exchanged
  \( \rightarrow \) 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 \( \cos \theta_K^{\text{Lab}} = [0.9, 1.0] \)

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

- The prominent structure observed in the $\gamma n \rightarrow \eta n$
  - 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 $\gamma d \rightarrow \eta pn$ photoproduction cross sections

$N(1685)$

$N(1685)$

$J^P = \frac{1}{2}^-$

Phys. Rev. C 90, 015205


$N(1685)$

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$N(1685)$
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

$N_S^0(udd{ar{s}}s)$


How about in the $\gamma n \rightarrow K^0 \Lambda$ case?

1.2 GeV Electron Synchrotron and photon beam line @ Research Center for Electron Photon Science (ELPH)

STretcher-Booster Ring: 1.2 GeV electron synchrotron

GeV-γ Beam line: 0.5-1.2 GeV photon

Layout of ELPH beam lines (~2012)

May 25-28, 2015
1.2 GeV Electron Synchrotron and photon beam line

Layout of ELPH beam lines (~2012)

STretcher-Booster Ring: 1.2 GeV electron synchrotron

Radiator: $\varphi 11\mu m$ carbon fiber
Energy binning $\sim 1$ MeV

GeV-$\gamma$ Beam line: 0.5-1.2 GeV photon

STB-ring 1.2 GeV

2nd Exp. Hole

NKS2

BM4

BM5

STB-Tagger II

FTAGX

FOREST

150 MeV

LINAC

GeV-$\gamma$ Exp. Hole

Thermal electron gun

May 25-28, 2015

Y. Tsuchikawa
**FOREST**: 4π electromagnetic calorimeter complex

- **192 Pure CsI**
- **SCISSORS III**
- **PS 24 × 3 layers**
- **LEPS Backward Gamma**
- **PS × 12 LOTUS**
- **62 Lead/Glass Rafflesia II**

Energy resolution (for 1 GeV $\gamma$)

- **~3 %**
- **~7 %**
- **~5 %**

**Motivation and background**

Target: liquid H$_2$/D$_2$ target (45mm thick)

$E_\gamma = 750 - 1150$ MeV
Analysis – particle identification

Focusing on the following decay chains:

\[ K^0_S \rightarrow \pi^0 \rightarrow \gamma \rightarrow \pi^0 \rightarrow \gamma \rightarrow \pi^0 \rightarrow \gamma \rightarrow \gamma \rightarrow 4 \text{photons} \]

\[ \Lambda \rightarrow \pi^- \]

4 photons and 2 charged particles in the final state

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

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

$$\gamma d \rightarrow K_S^0 \Lambda p \rightarrow (\pi^0 \pi^0)(\rho \pi^-) p \rightarrow (4\gamma)(\rho \pi^-) p$$

4 photon search (neutral cluster)

$$2\pi^0$$ -> Then check the $\gamma\gamma$ invariant masses

The event timing criterion: average timing of 4 photons

No other neutral particles but more 2 charged particles are required both of hodoscope and calorimeter.
Kinematic fit with 3 constraints

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

“4γ missing mass = $m_\Lambda$”

3. $M^2_X(\gamma_1, \gamma_2, \gamma_3, \gamma_4) \equiv E_X^2 - P_X^2 = (E_\gamma + m_n - \Sigma_{i=1}^4 E_i)^2 - P_X^2(E_i, \theta_i, \phi_i, E_\gamma) = m_\Lambda^2$

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

Accidental events were subtracted by means of sideband

π0π0 invariant masses of prompt and accidental background region ($E_\gamma > E_{thr}^{K^0\Lambda}$)
Background subtraction

- Candidates of background events in the $M(\pi^0\pi^0)$ distribution

Candidate reactions for $\pi^0\pi^0\pi^-p$ final state

\[ \gamma n \rightarrow \pi X(\Delta, N^*, \rho N) \rightarrow \pi^-\pi^0\pi^0p, \]

\[ \gamma n \rightarrow \pi^0\pi^0\pi^-p. \]

\[ \gamma n \rightarrow \pi^0\rho^-p. \]

**May 25-28, 2015 Y. Tsuchikawa**

Background subtraction

Only this is used for yield extraction in this time
Acceptance and Yields

FOREST covers all of the $\cos \theta_{CM}^K$

Examples of the fit for yield counting
Differential Cross Sections

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

E_\gamma = 925.0 \text{ MeV}  \quad E_\gamma = 975.0 \text{ MeV}  \quad E_\gamma = 1025.0 \text{ MeV}  \quad E_\gamma = 1075.0 \text{ MeV}  \quad E_\gamma = 1125.0 \text{ MeV}

Arbitrary Unit

Theoretical curve: Kaon-MAID

This result supports the experimental remark in the previous measurement for the \( \gamma n \rightarrow K^0 \Lambda \) reaction reported by K. Tsukada et al.

K. Tsukada et al.,
Phys. Rev. C 83 039904
Summary

• The $\gamma d \rightarrow K^0 \Lambda p$ photoproduction reaction is studied with an electromagnetic calorimeter complex FOREST at ELPH, Sendai

• $K^0$ signals are well confirmed in the $\gamma d \rightarrow K_S^0 \Lambda p \rightarrow (\pi^0 \pi^0)(p\pi^-)p \rightarrow (4\gamma)(p\pi^-)p$ reaction with an exclusive analysis

• Shape of the background in the $\pi^0 \pi^0$ invariant mass distribution is enoughly reproduced by the $\gamma n \rightarrow \pi^0 \pi^0 \pi^- p$ non-resonant reaction

• Differential cross sections showed backward enhanced structures in high $E_\gamma$ regions

• The results supports the remark of the previous measurement