Σ⁻ Photoproduction on the Neutron: Results from CLAS

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Abstract

As part of a broader study of kaon photoproduction on deuterium, the \( \gamma n \to K^+ \Sigma^- \) channel was investigated. The data were acquired at Jefferson Lab using the CLAS detector and the Photon-Tagging Facility installed in Hall B. The photon energy range covered was from 0.50 to 2.95 GeV. For the present analysis, the \( \gamma n \to K^+ \Sigma^- \) channel was identified by detecting the positive kaon in coincidence with both decay products of the \( \Sigma^- \) hyperon, \( \pi^- \) and \( n \). Preliminary differential cross-sections are shown as a function of the invariant energy \( W \) and the kaon polar angle in the center of mass system.

1 Introduction

The electromagnetic strangeness production is an important part of the Jefferson Lab’s experimental program. Several experiments have been approved to run in all three experimental halls. These experiments include kaon electro- and photoproduction on hydrogen, deuterium, \(^3\)He, and \(^4\)He.

Kaon photoproduction on deuterium is governed by three main mechanisms:

- The elementary amplitudes of the six kaon production reactions possible on the nucleon (\( \gamma p \to K^+ \Lambda, \gamma p \to K^+ \Sigma^0, \gamma p \to K^0 \Sigma^+, \gamma n \to K^+ \Sigma^-, \gamma n \to K^0 \Lambda, \gamma n \to K^0 \Sigma^0 \)).
• The Fermi motion of the proton and neutron inside the deuteron. The momentum distribution of nucleon momenta can be calculated using the deuteron wave function.

• The interaction between the final–state hadrons.

Experimental information exists for the first three exclusive kaon photoproduction channels. As shown in Fig. 1, there are no previous data for the kaon photoproduction on the neutron. One of the goals of experiment E89-045 was to investigate open strangeness photoproduction on the neutron. These studies will provide additional information about isospin dependence since the elementary operator for the $\Sigma^{-}$ production could be quite different than the operator for $\Sigma^{0}$ production.

2 Experiment

The data presented here were obtained in Hall B in August–September 1999. The total running time was 23 days. Real photons were produced by tagged bremsstrahlung provided by the Photon-Tagging Facility of Hall B. Experimental data were obtained for two incident electron energies: 2.47 and 3.11 GeV. Since the tagging range is 20% – 95% of the electron-beam energy, the photon energy range covered was from 0.50 to 2.95 GeV. The rate of tagged photons was approximately $10^{7}$/sec. The outgoing particles were detected in the CEBAF Large Acceptance Spectrometer (CLAS), a magnetic toroidal multi–gap spectrometer, covering a range of polar angles from $10^\circ$ to $150^\circ$, with almost $2\pi$ azimuthal coverage.

3 Data Analysis and Results

Charged particle identification is achieved in CLAS using information about the flight time and momentum of the particle obtained using the time–of–flight (TOF) detectors and drift chambers, respectively. A spectrum for positive hadrons as detected in CLAS is shown in panel a) of Figure 2. The peak corresponding to the positive kaons is barely visible between the pion and proton peaks. The dashed curve in the bottom panel shows the kaon peak after filtering the data by applying a mass cut from 0.3 to 0.7. There is still a significant background underneath the kaon peak, coming mostly
Figure 1: The six possible kaon photoproduction channels compared to experimental data. The two curves represent two theoretical calculations by Yamamura et al. [1].
from misidentified pions and protons. The solid curve represents the same spectrum after applying additional timing cuts to minimize the number of pions and protons produced by photons coming from neighbouring beam bunches.

In the present analysis the reaction $\gamma n \rightarrow K^+\Sigma^-$ was selected by detecting the positive kaon and the decay products of the $\Sigma^-$, the neutron and the negative pion. The pion was detected using the time–of–flight counters and the drift chambers (Figure 2 c)), while the neutron was detected in the electromagnetic calorimeter. The neutron momentum was determined from the time–of–flight information given by the electromagnetic calorimeter.

The efficiency for detecting neutrons in CLAS was studied using the reaction $\gamma d \rightarrow pn\pi^+\pi^-$. The results are shown in Figure 3 compared to a GEANT–based Monte Carlo simulation of the CLAS detector (GSIM). The agreement between the data and Monte Carlo, while not perfect, was deemed reasonable for the limited precision required for the present experiment. Detection inefficiencies and geometric acceptance corrections for charged particles were also obtained using GSIM. The events for the reaction $\gamma n \rightarrow K^+\Sigma^-$ were generated as quasifree production on a neutron with initial momentum distribution calculated using the Bonn potential [5, 6].

Figure 2: a) The positive hadron mass as determined from time–of–flight measurement in CLAS. Panel b) shows the positive kaon mass before (dashed line) and after (solid line) applying additional timing cuts. c) The negative hadron mass as determined from time–of–flight measurement in CLAS.
Figure 3: Comparison of neutron detection efficiency from the data (full symbols) and Monte Carlo (open symbols) for the electromagnetic calorimeter in CLAS
Figure 4: a) \( \Sigma^- \) Invariant mass, summed over all possible photon energies and all kaon angles b)\((\pi^-, n)\) invariant mass for one bin in photon beam energy and \( \theta_K^* \). The solid line represents the data, the dashed line shows the simulation plus the background, and the dotted line is the background.

In Figure 4a the invariant mass of the \( (\pi^-, n) \) system reconstructed using the energy and momentum of the negative pion and neutron is shown, integrated over all photon energies (incident electron beam energy was 2.47 GeV) and \( K^+ \) angles. The expected value for the \( \Sigma^- \) mass is indicated by the dashed vertical line.

For the present analysis the data were binned in a 2D grid with 100 MeV bins in incident photon energy and five bins in the center of mass polar angle of the \( K^+ \) \( (\theta_K^*) \). For each bin a cut around the \( \Sigma^- \) peak was used to identify the \( \gamma + n \rightarrow K^+ + \Sigma^- \) events. Due to the large uncertainty in the determination of the neutron momentum, this cut was kept loose, so as to minimize the rejection of good \( \Sigma^- \) events.

The experimental yield was extracted by fitting (using a log-likelihood method) the shape of the invariant mass, as obtained from the simulation to the experimental data, allowing for a small amount of residual background. This procedure is illustrated in Figure 4b for events having photon energies between 1.4 and 1.5 GeV and \( 0.1 \leq \cos(\theta_K^*) \leq 0.4 \). The dashed line shows the simulation (signal) plus the background, while the dotted line represents the background alone. The data are represented by the solid line.
In order to obtain the differential cross-section the extracted yield was corrected for all known detector inefficiencies and geometric acceptance effects. The target density and length as well as the tagged photon flux were also taken into account.

Figure 5 shows preliminary differential cross-sections for four of the five angular bins. The uncertainties shown are statistical only. Extensive studies of the systematic uncertainties are well underway (current estimates indicate a systematic uncertainty of 15% or less for most bins).

For all angles one sees that the cross-section rises rather sharply from threshold, reaching a maximum for $W$ between 1.8 and 1.9 GeV. The data do not rule out the existence of structures (bumps) in the higher $W$ range, although further investigation is needed.

4 Summary

The reaction $\gamma d \rightarrow K^+ \Sigma^- (p)$ was studied using tagged photons and the CLAS detector in Hall B at Jefferson Lab. The strange $K^+$ meson was detected before its in-flight decay, while the associated $\Sigma^-$ hyperon was identified by observing both its decay products ($\pi^-$ and $n$). Preliminary differential cross-sections were presented. The current analysis provides complementary information to that obtained in photoproduction off the proton, furthering our understanding of the reaction mechanism that governs open strangeness production. Future work, besides finalizing the present analysis, will focus on the extraction of the final state YN interaction.

5 Acknowledgments

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References

[1] Yamamura, H., Miyagawa, K., Mart, T., Bennhold, C., and Glockle, W. Phys. Rev. C61 014001 (2000)

Note that at present time there is a $\sim$20% uncertainty in the determination of the photon flux. Final normalization constants will be available in the near future.
Figure 5: Preliminary differential cross-sections for $\gamma n \rightarrow K^+\Sigma^-$ as a function of $W$ for four bins in the kaon (center of mass) angle.
[2] Li, X., Wright, L.E., and Bennhold, C., \textit{Phys. Rev.}, \textbf{C45} 2011–2014 (1992)

[3] Sober, D.I. \textit{Nucl. Instr. Meth.} \textbf{A440} 263–284 (2000)

[4] Brooks, W. \textit{Nucl. Phys.} \textbf{A663} 1077–1080 (2000)

[5] Reinhold, J. \textit{et. al}, \textit{Nucl. Phys.} \textbf{A684} 470–474 (2001)

[6] Machleidt, R. \textit{Phys. Rev. C} \textbf{63} 024001 (2001)