Exclusive Photoproduction of $K^+\Sigma^- (n)$ Off Deuteron

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Abstract. We are using the CEBAF Large Acceptance Spectrometer (CLAS) to study the exclusive photoproduction of $K^+\Sigma^- (1385)$ off the deuteron. It will be the first published total cross section of this reaction channel. We show the preliminary results of the total cross section, while we present all the key steps of achieving it. In order to study the reaction mechanism, we also study and show the angular distribution in the Gottfried-Jackson frame.

Keywords: Hyperon, photoproduction, deuteron, Gottfried-Jackson frame.

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INTRODUCTION

The so-called “missing” resonances are those nucleon excitations predicted that have not been discovered by experiments. One possible explanation is that these resonances are barely coupling to the nucleon-pion channels, while they may couple to hyperon-kaon channels.

The quark components of $\Sigma^- (1385)$ are dds, and the spin is $J=3/2$ according to Particle Data Group [1]. The resonance is part of the standard baryon decuplet of spin 3/2 together with well known $\Delta$ resonances [2]. Therefore, it is of great interest to measure its production cross section and to compare with well known photoproduction amplitudes of $\Delta$ to test the SU(3) symmetry [3].

However, there is only one paper on the $\Sigma^-$ photoproduction published till now, whose photon beam energy ranges up to 2.4 GeV [4]. We use CLAS to extract the exclusive quasi-free photoproduction total cross section off the neutron on a deuteron target from the EG3 data set. The electron beam energy goes from the production threshold to about 5.5 GeV [5].

FIGURE 1. The only published cross section of $K^+\Sigma^-$ from LEPS Collaboration [4].
DATA ANALYSIS

The reaction channel is quasi-free photon scattering off neutrons by producing $K^+ \Sigma^-$. The $\Sigma^-$ decays into $\Lambda \pi$ and $\Lambda$ into $p \pi$. Thus, the final particles are $K^+ p \pi^- \pi^-$.

Particle Identification

After detector calibration, the particle identification (PID) is usually the first thing to check. However, the EG3 experiment has a high-intensity beam, which gives the opportunity of high statistics. On the other hand, it also causes problems in particle identification, because there are too many photons recorded in each event. The standard CLAS offline software does not give a satisfactory result. A new PID method dedicated to this channel requires that two $\pi$'s have a consistent vertex time, which leads to the satisfying results as shown in Fig. 2.

![FIGURE 2](image)

**FIGURE 2.** Left: $\beta$ vs. momentum of negative particles; right: $\beta$ vs. momentum of positive particles.

Event Selection

Only events with two positive charged particles and two negative charged particles are selected. The invariant masses of the proton-pion pairs are fitted with a Gaussian distribution function around the $\Lambda$ mass position and cut around $3\sigma$.

After the cut, the invariant mass of $p \pi^- \pi^-$ and the missing mass of all four particles are calculated and plotted in Fig. 3. A clear signal of the $\Sigma^-$ channel is shown.

![FIGURE 3](image)

**FIGURE 3.** Invariant mass of $p \Lambda$ vs. missing mass. The red spot is $\Sigma^-$ vs. spectator proton.

In order to enrich the quasi-free scattering process, the missing momentum of the spectator proton from the experimental data and simulation are compared in Fig. 4. They are normalized to each other, and there is no significant sign of deviation. However, the cut on 0.4 GeV is applied to minimize the final state interaction.
FIGURE 4. Comparison of missing momentum from the data and the simulation; the red line is from the data and the blue is from the simulation.

Yield Extraction and Preliminary Cross Section

The data is then grouped into 17 bins according to the incoming photon energy from 1.25 to 5.5 GeV. The missing mass peak is fitted with a Gaussian distribution function and cut $3\sigma$ around the mean value to select exclusive events as shown in Fig. 5.

FIGURE 5. Missing mass of $K^+\Lambda\pi^-$; yellow line is polynomial fit of background and red line is fit of Gaussian and background.

After that, the invariant mass is plotted and fitted by a Breit-Wigner distribution, and an integral is performed to get the yield. The background is fitted by a polynomial function up to high enough order to get a good fit. Figure 6 shows the calculated invariant mass of $\Sigma^-$ and fit. The green line is the Breit-Wigner distribution and the yellow line is the background while the red is the overall fit.
**FIGURE 6.** Invariant Mass of $\Lambda\pi$ and fitted by Breit-Wigner function and polynomial background.

A side-band subtraction on the missing mass is performed in order to enhance the exclusivity. After that, a preliminary yield is obtained. Acceptance of the detector is obtained after a phase-space event generator, CLAS simulation and cooking package are used. The preliminary total cross section is obtained by accounting for the photon flux, target luminosity, decay branching ratios and other corrections. The result is shown in Fig. 7.

**FIGURE 7.** Top left: preliminary total cross section; top right: photon-flux corrected yield; bottom left: events from event generator; bottom right: acceptance of detector.

**DECAY ANGULAR DISTRIBUTION**

In order to study the reaction mechanism, the angular distribution in Gottfried-Jackson frame is analyzed. The distribution has the form [6]:

$$
\sigma = a \left( \frac{1}{3} + \cos^2 \theta \right) + \beta \sin^2 \theta + \gamma \cos \theta .
$$

The angle in the formula is between $\pi$ and the z direction as shown in Fig. 8. The first term is corresponding to $K$ exchange and the second term is corresponding to $K^*$ exchange [6].

**FIGURE 8.** Left: Gottfried-Jackson frame; the distribution between the p and the z direction is calculated; right: different shape of the distribution shows different exchange mechanism.

The distribution is plotted in Fig. 9 and fitted with the formula. The result shows the ratio between $K^*$ exchange and $K$ exchange is 4:1. However, a preliminary result of $\Sigma^*$ production was extracted [7] and shows the same ratio is below 1:1, while a similar result is expected according to constituent quark model.
FIGURE 9. Angular distribution in Gottfried-Jackson frame and fitted.

FIGURE 10. Left: preliminary angular distribution of $\Sigma^*$ production; right: dependence on beam energy [7].

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REFERENCES