Electromagnetic $K^+$ production on the deuteron with hyperon recoil polarization

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Photo- and electroproduction processes of $K^+$ on the deuteron are investigated theoretically. Modern hyperon-nucleon forces as well as an updated kaon production operator on the nucleon are used. Sizable effects of the hyperon-nucleon final state interaction are seen in various observables. Especially the photoproduction double polarization observable $C_z$ is shown to provide a handle to distinguish different hyperon-nucleon force models.

1. INTRODUCTION

Recent rigorous calculations of light hypernuclei \cite{1} have contributed interesting insight into low-energy properties of the $YN$ interaction above the $\Lambda$ threshold. However, no clear understanding of the $YN$ interaction has emerged around the $\Sigma$ threshold. Electro- and photoproduction processes of $K^+$ on light nuclei offer a unique possibility for studying the $YN$ interaction in the continuum, especially near the $\Sigma$ threshold. An inclusive $d(e, e'K^+)YN$ experiment has already been performed, and the data for $d(\gamma, K^+YN)$ and $^3\text{He}(\gamma, K^+Y)N$ are being analyzed at TJNAF.

We have analyzed the inclusive $d(\gamma, K^+)$ and exclusive $d(\gamma, K^+\Lambda(\Sigma))$ processes \cite{2}, and report here preliminary results of the electroproduction process $d(e,e'K^+)$. This study aims to investigate the coupled $\Lambda N - \Sigma N$ interaction in the final state and incorporates the modern $YN$ interactions of the Nijmegen group, NSC97f \cite{3} and NSC89 which have been found to give a reasonable binding energy for the hypertriton. Kaon photoproduction on the deuteron is also important since it allows access to the elementary cross sections on the neutron, such as $\gamma + n \rightarrow K^+ + \Sigma^-$, in kinematic regions where final-state interaction effects are small.
2. PHOTOPRODUCTION

![Figure 1](image1.png)

Figure 1. Inclusive $d(\gamma, K^+)$ cross section as a function of kaon lab momentum $P_K$. The $K^+\Lambda N$ and $K^+\Sigma N$ thresholds are indicated by the arrows.

![Figure 2](image2.png)

Figure 2. Exclusive $d(\gamma, K^+\Lambda)$ cross section for lab momentum $P_K = 870$ MeV/c.

![Figure 3](image3.png)

Figure 3. Double polarization observable $C_z$ for the reaction $d(\gamma, K^+\Lambda)$ at lab momentum $P_K = 870$ MeV/c.
Numerical results of the inclusive $d(\gamma, K^+)$ cross sections, using an updated production operator [4], are shown as a function of lab momentum $P_K$ in Fig. 1. For the details of our theoretical formulation, we refer the reader to Ref. [2]. The incident photon energy is 1.3 GeV, while the outgoing kaon angle is fixed to 1 degree. The two pronounced peaks around $P_K = 945$ and 809 MeV/c are due to the quasifree scattering between photon and one of the nucleons. The results with the final state $YN$ interaction NSC97f are compared to the PWIA results. Sizable FSI effects are seen around both $\Lambda$ and $\Sigma$ thresholds, and to a lesser degree at the two quasifree peak positions.

For the same $E_\gamma$ and $\theta_K$, the exclusive $d(\gamma, K^+\Lambda)n$ cross section and double polarization observable $C_z$ at $P_K = 870$ MeV/c are shown in Figs. 2 and 3, respectively. Figures 4 and 5 depict these observables for $d(\gamma, K^+\Sigma^-)p$ at $P_K = 810$ MeV/c. As indicated in Fig. 1, the former value of $P_K$ is close to the $K^+\Sigma N$ threshold, while the latter one corresponds to the $\Sigma$ quasifree peak position. While the values for $C_z$ in PWIA are almost 100%, the FSI results show dramatic deviations. Furthermore, the two $YN$ forces of NSC97f and NSC89 become clearly distinguishable for this observable. Experimentally, measuring this observable involves using circularly polarized photons along with detecting the recoil polarization of the hyperon in the final state.

3. ELECTROPRODUCTION

Here we present first preliminary results for the electroproduction process $d(e, e'K^+)$. Two sets of results are shown in Figs. 6 and 7. The incident electron energy $E_e$ and momentum transfer $Q^2$ in Fig. 6 is set to reproduce the conditions of the recent Hall C experiment at TJLAB [5]. As in the case of the photoproduction $d(\gamma, K^+)$, $YN$ FSI effects are seen near both $\Lambda$ and $\Sigma$ threshold. However, in Fig. 6, the FSI has effects in a
Figure 6. Missing mass spectrum for the reaction $d(e,e'K^+)$. Results with the $YN$ final state interaction NSC97f are compared to PWIA results.

Figure 7. Same as Fig. 6, but for $Q^2 = 0.20 \text{ (GeV/c)}^2$, $\theta_e = 17^\circ$.

wide range above the $\Sigma$ threshold. Figure 7 shows a prominent enhancement around the $\Sigma$ threshold which is not a simple threshold effect but is caused by a $YN$ $t$-matrix pole in the complex momentum plane [6].

4. OUTLOOK

We investigate cross sections and hyperon polarization for the $K^+$ photoproduction on the deuteron, and find large hyperon-nucleon FSI effects in the double polarization observable $C_z$. Also, in the electroproduction, for suitable $Q^2$ values, cross sections show a prominent enhancement around the $\Sigma$ threshold. A systematic analysis for a wide range of kinematics for both photo- and electroproduction processes is in progress. Future studies will investigate final-state interaction effects in kaon photo- and electroproduction on the $A=3$ system.

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