$K^+\Lambda$ and $K^+\Sigma^0$ Photoproduction in View of the New CLAS Data

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Abstract. We have investigated the effect of the new CLAS data consisting of the recoiled $\Lambda$ polarization $P$, photon asymmetry $\Sigma$, target asymmetry $T$, and the double polarizations $O_x$ and $O_z$, on the latest isobar models constructed for the kaon photoproduction processes $\gamma p \rightarrow K^+\Lambda$ and $\gamma p \rightarrow K^+\Sigma^0$. We found that these data might have significant effect, especially in the $K^+\Lambda$ channel, where apparent changes are observed in the predicted differential cross sections after including the new CLAS data in the fitting database. The isobar model for the $K^+\Lambda$ photoproduction must be accordingly modified in order to improve the agreement between model calculation and previous experimental data.

1. Introduction
During the last twenty years kaon photoproduction has attracted a lot of attention from theorists and experimentalists in the field of hadronic physics. This is due to the interesting application of kaon photoproduction process that involves the strangeness degrees of freedom. By using this process one can investigate a number of related but important phenomena, e.g., the missing resonances [1], hypernuclear production [2, 3], the strength of certain hadronic coupling constants [4], and the Gerasimov-Drell-Hearn (GDH) sum rule [5].

Recently, the CLAS collaboration released a set of experimental data that include the recoiled $\Lambda$ polarization $P$, photon asymmetry $\Sigma$, target asymmetry $T$, and the double polarizations $O_x$ and $O_z$ [6]. The data accuracy is clearly much better than the previous one and the number of data is considerably large. Unfortunately, these data could not be reproduced by our recent model, unless the data were included in the fitting database and the free parameters in the model were refitted to the new database [7]. It is shown in Ref. [7] that only the recoiled $\Lambda$ polarization $P$ can be nicely reproduced by the model, whereas the model predictions for other polarization observables are mostly in disagreement with the new CLAS data. This is of course understandable, because before the CLAS collaboration released these new data, only the recoiled polarization $P$ were hitherto available.

In spite of the fact that the new CLAS data have substantial impact on the model, the effect of including these data on other observables has not yet been investigated. It is the purpose of the present paper to discuss the effect of these data on the corresponding differential cross section, where experimental data are mostly available in the $\gamma p \rightarrow K^+\Lambda$ channel. Furthermore, it is also necessary to extend this investigation to the $\gamma p \rightarrow K^+\Sigma^0$ channel, since the CLAS collaboration has also released the corresponding data.
For the purpose of present discussion we will use the same multipole model as in Ref. [7] for the $\gamma p \rightarrow K^+\Lambda$ channel, whereas for the $\gamma p \rightarrow K^+\Sigma^0$ channel a similar multipole model, though with different number of nucleon resonances and with the addition of Delta resonances, will be exploited. The multipole model for the $\gamma p \rightarrow K^+\Sigma^0$ channel is part of an on-going research. The final and complete result of this channel will be published soon.

2. The Multipole Model
In the case of $\gamma p \rightarrow K^+\Lambda$ channel the model is described in details in Ref. [7]. Here we will just briefly summarize the ingredient of the model. The background part of this model consists of the standard $s$-, $t$-, and $u$-channel intermediate states, along with the $K^*$ and $K_1$ meson exchanges, and 7 hyperon resonances. To avoid the divergence the magnitude of this background is controlled by using a hadronic form factor. The resonance part includes all nucleon resonances listed in the particle listing of the Particle Data Group (PDG) [8], with the status of at least two-star rating and spins up to $13/2$. In total, there are 22 nucleon resonances included in the model. All nucleon resonance properties are extracted from fitting to experimental data. Nevertheless, the allowed fitted values are constrained to the PDG uncertainties.

For the $\gamma p \rightarrow K^+\Sigma^0$ channel the model is similar. However, since the isospin conservation allows for the Delta transitions, 13 Delta resonances are included in the model. As a result, the model has more flexibility to fit the experimental data, although this only happens in the $\gamma p \rightarrow K^+\Sigma^0$ channel. Extension of this model to include the other three isospin channels is still difficult.

3. Results and Discussion
Figure 1 displays the angular distribution of the recoil polarization $P$, photon asymmetry $\Sigma$, target asymmetry $T$, and the double polarization asymmetries $O_x$ and $O_z$ for the $K^+\Lambda$ photoproduction for two different c.m. energies [7]. Except for the recoil polarization, it is clear that without including the new data the model cannot predict these data correctly. Especially in the case of high energy (i.e., $W = 2.1$ GeV in this case) the discrepancy is enormous. In the case of the recoil polarization $P$, the agreement of the model calculation and the new experimental data is not surprising, since for this polarization observable experimental data had been available in the wide range of kinematics before the new CLAS data were released.

The differential cross sections shown in Fig. 2 exhibits unexpected result. The discrepancy between model calculation and experimental data becomes tremendous after the inclusion of the new CLAS data. Especially in the forward and backward directions at $W \approx 2.0$ GeV, where the model yields very different differential cross section compared to the experimental data. The reason can be traced back to Fig. 1, where we can see that the model dramatically changes the values of $\Sigma$, $T$, $O_x$ and $O_z$ polarizations near this energy region. Except for the recoil polarization $P$, the difference is large near the forward and backward directions.

A similar situation also happens in the $K^+\Sigma^0$ channel as shown in Fig. 3. However, for this channel the model does not have a big problem to reproduce the differential cross section as shown in Fig. 4. Presumably, this phenomenon originates from the contribution of Delta resonances, which is not available in the $K^+\Lambda$ channel. Furthermore, the number of experimental data for differential cross section is huge, as can be clearly seen in Fig. 4. We note that the Crystal Ball collaboration [12] contributes very fine energy distribution of differential cross section from threshold up to $W \approx 1.9$ GeV. The large error bars in polarization observables shown in Fig. 3 might also be the reason behind this result.

The result shown in Figs. 1-4 indicates that the multipole model for $\gamma p \rightarrow K^+\Lambda$ channel urgently requires improvement. The angular distribution of polarization observables is usually controlled by the $t$ and $u$-channel intermediate states. Therefore, the addition of hyperon or kaon resonances could presumably solve this problem. The work to this end is in progress.
Figure 1. Angular distributions of the recoiled $\Lambda$ polarization $P$, photon asymmetry $\Sigma$, target asymmetry $T$, and the double polarization asymmetries $O_x$ and $O_z$ for the $\gamma p \rightarrow K^+\Lambda$ process [7]. Solid curve is obtained from the model fitted with the new CLAS 2016 data [6], whereas dashed curve is obtained by excluding these data. Solid circles represent the new CLAS 2016 data [6], solid squares are the CLAS 2006 data [9], open circles and open squares are the CLAS 2010 [10] and GRAAL 2007 [11] data, respectively. The corresponding total c.m. energy $W$ in GeV is written in each panel.

Figure 2. The predicted differential cross section of the $\gamma p \rightarrow K^+\Lambda$ process obtained by excluding (dashed curves [7]) and including (solid curves) the new CLAS 2016 data [6]. Data are from the Crystal Ball 2014 (open circles [12]), CLAS 2010 (solid circles [10]), CLAS 2006 (solid squares [9]), and LEPS 2006 (solid triangles [13]) collaborations.
Figure 3. As in Figure 1, but for the $\gamma p \rightarrow K^+\Sigma^0$ channel.

Figure 4. As in Figure 2, but for the $\gamma p \rightarrow K^+\Sigma^0$ channel. Experimental data shown in this Figure are taken from the Crystal Ball (open circles [12]), SAPHIR 2004 (solid squares [14]), CLAS 2004, 2006, and 2007 (open squares [15], solid diamonds [9], and solid circles [16]), and LEPS 2006 (solid triangles [13] and open inverted triangles [17]) collaborations.

4. Summary and Conclusion
We have investigated the effect of the new CLAS data that consist of three single polarization observables and two double polarization observables. It is shown that the effect is significant in the case of the $K^+\Lambda$ photoproduction, whereas in the case of the $K^+\Sigma^0$ one the effect is mild. The result of our present investigation indicates that the recent multipole model for the $\gamma p \rightarrow K^+\Lambda$ channel requires substantial improvement. Since the number of nucleon resonances
used in this model is already large, a possible improvement can be performed in the background sector. A number of hyperon or kaon resonances can be included in the background amplitude to this end.

5. Acknowledgments
The author acknowledges support from the PITTA Grant of Universitas Indonesia under contract No. 2320/UN2.R3.1/HKP.05.00/2018.

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