Study of nucleon resonances in the photoproduction $\gamma p \rightarrow K^{*+} \Lambda$

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The mechanism of K^* vector meson photoproduction off the proton target, $\gamma p \rightarrow K^{*+} \Lambda$, is deeply studied by using an effective Lagrangian method. Based on the (t,s,u)-channel Born diagrams, we included higher resonance terms, i.e., $S_{11}(2090)$ and $G_{17}(2190)$, along with the $D_{13}(2080)$ and $D_{15}(2200)$, which are already considered in a previous theoretical analysis. The total and differential cross section are computed and we obtain quite precise results in comparison with the recent CLAS data.

Keywords: $K^* \Lambda$ photoproduction; effective lagrangian; nucleon resonances.

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1. Introduction

The first high-statistics experimental data for the reaction, $\gamma p \rightarrow K^{*+} \Lambda$, was reported by the CLAS Collaboration at the Thomas Jefferson National Accelerator Facility recently.¹ This $K^* \Lambda$ photoproduction, one of the strangeness meson and baryon interaction mechanisms, can be a useful tool for the study of nucleon resonances near the threshold region $\sqrt{s} \sim 2$ GeV, which is rarely done for the KY channel because of their tendency to couple weakly to this channel as seen in the Particle Data Group.²

As for the corresponding theoretical analysis, Oh *et al.*³ computed by using an effective Lagrangian method. The K^* -, K -, and κ - exchanges in the t channel,

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N -exchange in the s channel, and u -channel hyperon ($\Lambda, \Sigma, \Sigma^*$) diagrams are considered. Kim *et al.*⁴ also have done using the same model, but in addition to these Born terms, two additional nucleon resonances, $D_{13}(2080)$ and $D_{15}(2200)$, are considered near the threshold. On the other hand, Ozaki *et al.*'s approach is based on a Regge model.⁵ These three calculations were all underestimated in comparison with the experimental data, although the contributions of two extra resonances $D_{13}(2080)$ and $D_{15}(2200)$ improve the results near the energy region of $E_\gamma \sim 2$ GeV.

The motivation of our work is that we need to include possible nucleon resonances further and check whether there exist any nucleon resonances which couple strongly to $K^*\Lambda$ channel. Among the candidates, we are to take into account two other resonances, $S_{11}(2090)$ and $G_{17}(2190)$, the latter is omitted because of its complexity of spin in the previous analysis. The $P_{11}(2100)$ is not included here because of the lack of coupling information.

2. Effective Lagrangian Model

We make use of an effective Lagrangian method at tree-level Born approximation. The relevant diagrams are shown in Fig. 1. The structures of Lagrangians and the values of coupling constants for ground state exchanges are given in Refs. 3, 4. The Lagrangians of the resonance terms for electromagnetic part are given as follows:

$$\begin{aligned}\mathcal{L}_{\gamma NS_{11}} &= \frac{eh_1}{2M_N} \bar{N} \gamma_5 \sigma_{\mu\nu} \partial^\nu A^\mu R + \text{h.c.}, \\ \mathcal{L}_{\gamma NG_{17}} &= ie \left[\frac{h_1}{(2M_N)^3} \bar{N} \gamma_\nu - \frac{ih_2}{(2M_N)^4} \partial_\nu \bar{N} \right] \partial^\alpha \partial^\beta F^{\mu\nu} R_{\mu\alpha\beta} + \text{h.c.}\end{aligned}\quad (1)$$

Those for the strong interaction part are expressed as

$$\begin{aligned}\mathcal{L}_{K^*\Lambda S_{11}} &= \frac{1}{2M_N} \bar{\Lambda} \left[g_1 \frac{\gamma_\mu \gamma_5 \partial^2}{M_R + M_\Lambda} + g_2 \gamma_5 \sigma_{\mu\nu} \partial^\nu \right] \bar{K}^{*\mu} R + \text{h.c.}, \\ \mathcal{L}_{K^*\Lambda G_{17}} &= \left[\frac{ig_1}{(2M_N)^3} \bar{\Lambda} \gamma_\nu + \frac{g_2}{(2M_N)^4} \partial_\nu \bar{\Lambda} - \frac{g_3}{(2M_N)^4} \bar{\Lambda} \partial_\nu \right] \partial^\alpha \partial^\beta \bar{K}^{*\mu\nu} R_{\mu\alpha\beta} + \text{h.c.},\end{aligned}\quad (2)$$

where R stands for a resonance field. Here, we take into account only the g_1 term for simplicity as was the case in Ref. 4. The corresponding coupling constants are

Fig. 1. Tree-level diagrams for $\gamma p \rightarrow K^{*+} \Lambda$.

estimated from Refs. 2, 6 and 7, which gives $h_{1S_{11}} = +0.055$, $h_{1G_{17}} = +7.69$, $h_{2G_{17}} = -7.17$, $g_{1S_{11}} = -1.87$, and $g_{1G_{17}} = -41.0$.

The invariant amplitudes which satisfy the gauge invariance are written as

$$\begin{aligned} \mathcal{M} = & [\mathcal{M}_{K^*} + \mathcal{M}_N + \mathcal{M}_c] F_{\text{com}}^2 + \mathcal{M}_K F_K^2 + \mathcal{M}_\kappa F_\kappa^2 + \\ & \mathcal{M}_\Lambda F_\Lambda^2 + \mathcal{M}_\Sigma F_\Sigma^2 + \mathcal{M}_{\Sigma^*} F_{\Sigma^*}^2 + \mathcal{M}_R F_R^2, \end{aligned} \quad (3)$$

where the form factors are included to explain the structures of each vertices. The detailed forms are

$$F_M = \frac{\Lambda_M^2 - M_M^2}{\Lambda_M^2 - p^2}, \quad F_B = \frac{\Lambda_B^4}{\Lambda_B^4 + (p^2 - M_B^2)^2}, \quad F_{\text{com}} = F_{K^*} F_N - F_{K^*} - F_N, \quad (4)$$

where $\Lambda_{(M,B)}$, M_M , and p denote the cutoff value, the mass, and the momentum of the exchanged particle, respectively. The F_M is used for meson exchange and the F_B for baryon one. Here, for the K^* and N exchanges, they do not satisfy gauge invariance, but the sum of them with the contact term does. For this case we introduce the common form factor written as above. The cutoff parameters are determined phenomenologically as $\Lambda_{K^*,N,\Lambda,\Sigma,\Sigma^*} = 0.9$, $\Lambda_{K,\kappa} = 1.1$, and $\Lambda_R = 1.0$ GeV.

3. Results and Discussion

In the left panel of Fig. 2, the numerical results for the total cross sections with the CLAS data¹ are drawn as functions of the photon energy E_γ . We can notice that, with only Born term, the theoretical results underestimate the data in the range $1.9 < E_\gamma < 3.0$ GeV. However, with the inclusion of resonance terms, the model explains the data quite well except for the energy region of $E_\gamma \sim 2$ GeV.

The contributions of each of resonances are described in the right panel of Fig. 2. Among them, it turns out that the effects of the D_{13} and G_{17} are remarkable. On the other hand, the S_{11} and D_{15} play a minor role. Here, the latter is not shown because it is almost negligible.

In Fig. 3, the angle dependence of the differential cross sections is plotted as functions of $\cos \theta$ for different photon energy range $1.7 < E_\gamma < 3.9$ GeV. We can

Fig. 2. (Color online) Total cross sections for the $\gamma p \rightarrow K^{*+} \Lambda$ reaction in the left panel. The black circles denote the CLAS data. The contributions of resonance terms in the right panel.

Fig. 3. (Color online) Differential cross sections for the $\gamma p \rightarrow K^{*+}\Lambda$ reaction for different photon energies from 1.7 to 3.9 GeV. The black circles denote the CLAS data.

find that the theoretical results are in good agreement with the experiment showing the forward angle enhancement except for the range $1.9 < E_\gamma < 2.2$ GeV. The bump structures near this region are not explained by nucleon resonances and on debate.

The role of nucleon resonances for this reaction, $\gamma p \rightarrow K^{*+}\Lambda$, is quite different from that of $\gamma p \rightarrow K^*\Sigma$, where all the possible resonances almost does not affect the Born term. More details are given in Refs. 8, 9.

4. Summary

In this talk, we presented a recent investigation on $K^*\Lambda$ photoproduction, emphasizing the role of the excited nucleon resonances near the threshold region. The results are in general in agreement with the data. Note that in the present analysis we fitted almost all the parameters, based on the PDG 2010 data. However, the data for $D_{13}(2080)$ were much changed in the new PDG 2012. Thus, it is of great interest to investigate the role of N^* resonances in $K^*\Lambda$ photoproduction. The corresponding study and detailed results will appear elsewhere.

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