Study of Baryon Resonances in the Photoproduction 
\( \gamma p \rightarrow K^*\Sigma(1190) \)

Sang-Ho Kim\(^1\), Atsushi Hosaka\(^1\), Seung-il Nam\(^2\) and Hyun-Chul Kim\(^3\)

\(^1\) Research Center for Nuclear Physics (RCNP), Osaka 567-0047, Japan
\(^2\) School of Physics, Korea Institute for Advanced Study (KIAS), Seoul 130-722, Republic of Korea
\(^3\) Department of Physics, Inha University, Incheon 402-751, Republic of Korea

E-mail: shkim@rcnp.osaka-u.ac.jp, hchkim@inha.ac.kr

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In this talk, we report the theoretical studies of baryon resonances for the \( \gamma p \rightarrow K^0\Sigma^+ \) and \( \gamma p \rightarrow K^+\Sigma^0 \) reaction processes by making use of the effective Lagrangian method in the tree-level Born approximation. The numerical results for the total and differential cross sections are shown with the presently available data. It turns out that the contributions from the \( N^* \) and \( \Delta^* \) resonances are almost negligible near the threshold energy. On the other hand, the effects of the \( K \) exchange in the \( t \) channel and \( \Delta(1232) \) in the \( s \) channel are considerably larger than other ones in the scattering process, being in good agreement with the experimental data.

**KEYWORDS:** \( K^* \Sigma \) photoproduction, effective Lagrangian, \( N^* \) and \( \Delta^* \) resonances

1. **Introduction**

Various efforts to understand the baryon resonances and to find missing resonances have been made for decades via the hadron production processes. Photoproduction is one of them, and, especially, it turns out that the strange meson-baryon production off the nucleon target is very useful. In the present talk, we would like to investigate the reaction process of \( K^*\Sigma(1190) \) photoproduction off the proton target. Recently, CBELSA/TAPS collaboration at Electron stretcher and Accelerator (ELSA) [1], the CLAS collaboration at Thomas Jefferson National Accelerator Facility (Jefferson Lab) [2, 3], and LEPS collaboration at Super Photon Ring-8 GeV (Spring-8) [4] have provided the experimental data for this reaction channel. The related theoretical studies also exist in both models using the chiral quark model [5] and effective Lagrangian method [6]. The theoretical prediction from Ref. [5] turned out to be hard to reproduce the recent experimental data. In Ref. [6], the effective Lagrangian method was employed at the tree-level Born approximation, considering the \( K \) and \( \kappa \) exchanges in the \( t \) channel, \( N^- \) and \( \Delta(1232) \)-pole contributions in the \( s \) channel, and hyperons (\( \Sigma, \Sigma^* \)) in the \( u \) channel. The motivation of our present work is to include all the possible \( N^* \) and \( \Delta^* \) resonances, in a full relativistic manner, such as \( D_{13}(2080), S_{11}(2090), G_{17}(2190), D_{15}(2200), S_{31}(2150), G_{37}(2200), \) and \( F_{37}(2390) \).

2. **Formalism**

We employ the effective Lagrangian method in the tree-level Born approximation. The relevant diagrams are shown in Fig.2, and the effective Lagrangians for the interaction vertices are defined in Ref. [7]. The coupling constants are obtained by using experimental data [8] and the SU(6) relativistic quark model [9, 10]. As for the resonances, we use the following relation:
can be understood that we find that the numerical results are in good agreement with the CLAS data, and the $\Delta$ and $
abla$ explicitly to reproduce the experimental data:

\[
\Gamma(R \rightarrow N\gamma) = \frac{k^2}{2j+1} \left( |A_{1/2}|^2 + |A_{3/2}|^2 \right),
\]

\[
\Gamma(R \rightarrow K^\ast \Sigma) = \sum |G(l, s)|^2,
\]

for the photo- and strong-coupling constants, respectively. Here, $A_{1/2}$ and $A_{3/2}$ represent the helicity amplitudes, computed by using the experimental or theoretical values [8,9], from which the transition magnetic moments are given [7]. In addition, the scattering amplitudes $G(l, s)$ are estimated by the SU(6) quark model [10], based on which the strong coupling constants are calculated [7]. For simplicity, we consider only the resonance states $\sqrt{s} \lesssim 2500$ MeV, since we are interested in the vicinity of the threshold. The scattering amplitudes can be written with the phenomenological form factors that satisfy the Ward-Takahashi identity as follows:

\[
M(\gamma p \rightarrow K^{\ast 0}\Sigma^\ast) = [M_{\text{elec}}^{\Sigma(N)} + M_{\text{mag}}^{\Sigma(N)}]F_{\text{com}}^2 + [M_{\text{elec}}^{\Sigma(K)} + M_{\text{mag}}^{\Sigma(K)}]F_N^2 + M_{\text{had}}F_{\text{had}}^2 + M_{\text{had}}F_{\text{had}}^2
\]

\[
M(\gamma p \rightarrow K^{\ast+}\Sigma^0) = [M_{\text{elec}}^{\Sigma(N)} + M_{\text{mag}}^{\Sigma(N)}]F_{\text{com}}^2 + [M_{\text{elec}}^{\Sigma(K)} + M_{\text{mag}}^{\Sigma(K)}]F_N^2 + M_{\text{had}}F_{\text{had}}^2 + M_{\text{had}}F_{\text{had}}^2.
\]

Table 1. Cutoff masses for the form factors in Eq. (3) for each channel.

| $\Lambda_\Phi$ for $t$ channel | $\Lambda_B$ for $s$ channel | $\Lambda_B$ for $u$ channel |
|-----------------------------|-----------------------------|-----------------------------|
| $\Lambda_K$ | $\Lambda_K, \Lambda_\Xi$ | $\Lambda_K, \Lambda_K, \Lambda_\Xi$ |
| $\Lambda_N$ | $\Lambda_N, \Lambda_\Xi$ | $\Lambda_N, \Lambda_N, \Lambda_\Xi$ |
| $\Lambda_\Phi$ | $\Lambda_\Phi$ | $\Lambda_\Phi$ |
| $\Lambda_B$ | $\Lambda_B$ | $\Lambda_B$ |
| 0.80 GeV | 1.15 GeV | 1.50 GeV |

3. Numerical Results

3.1 Total Cross Section

The contributions of each of channels are shown separately in Fig. 2. In the left panel of Fig 2, it turns out that the $K$-exchange and $\Delta(1232)$-pole contributions are crucial, and in the right panel, it can be understood that $\Delta(1232)$-pole one almost dominates the reaction process. From those figures, we find that the numerical results are in good agreement with the CLAS data, and the effect of $N^\ast$ and $\Delta^\ast$ resonance contributions turns out to be almost negligible.
3.2 Differential Cross Section

Here we show the numerical results for the differential cross sections as functions of \( \cos \theta_{K^*} \) for different photon energies \( E_\gamma = (1.925 - 2.9125) \) and \( (1.85 - 3.75) \) GeV for \( K^0\Sigma^+ \) and \( K^{++}\Sigma^0 \) production, respectively. As shown in Figs. 3 and 4, we can see that the \( t \)-channel exchanges (\( K \) and \( \kappa \)) play an important role in the forward angle scattering region, whereas the backward scattering regions are dominated by the \( u \)-channel contributions (\( \Lambda, \Sigma, \Sigma^* \)).

4. Summary

We investigated the reaction processes of \( \gamma p \to K^{*0}\Sigma^+ \) and \( \gamma p \to K^{++}\Sigma^0 \), emphasizing on the roles of baryon resonances. We found that the resonance contributions gave only negligible effects. On the other hand, \( K \)-exchange and \( \Delta(1232) \)-pole contributions turned out to be crucial for both of reaction processes. This observation is quite different from the \( K^*\Lambda \) photoproduction [11]. More details can be found in Ref. [7].
Fig. 4. (Color online) Differential cross sections for $\gamma p \rightarrow K^+\Sigma^0$ as functions of $\cos \theta$ for different photon energies ($E_\gamma$) in the range ($1.85 - 3.75$) GeV. The experimental data of the CLAS collaboration are taken from Ref. [3].

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