Photoproduction of Λ(1405) and Σ^0(1385) on the Proton at E_γ = 1.5-2.4 GeV

The quark model has succeeded in explaining the fundamental properties of hadrons, such as the mass, spin and parity. Despite great success of the quark model, there remain several mysteries in the understanding of hadrons. For example, some hadrons are predicted by the quark model but not observed experimentally (missing resonance), and the masses of some hadrons are significantly different from quark-model predictions.

Hyperons are particles consisting of three quarks with a strange quark. Photoproduction of hyperons is of interest because we can search for a missing resonance that couples to a *K*-meson hyperon pair rather than a pion nucleon pair. The cross section of hyperon photoproduction depends on its production mechanism and the form factor of the hyperon. Figures 1(a) and 1(b) show Feynman diagrams for hyperon photoproduction for t-channel K^- exchange process and s-channel direct reaction with a nucleon resonance (N^*) that couples to *K*Λ. By investigating cross sections of hyperon photoproduction in detail, we can extract the contribution of s-channel reaction and search for missing resonances. Some theorists predicted nucleon resonances that couple to *K*Σ(1385) and *K*Λ(1405). Therefore, it is important to study these resonances.

In addition to searching for missing resonances, it is of interest to study the internal structure of hyperon resonances. Both of Σ(1385) and Λ(1405) hyperons contain u, d and s quarks. The Σ(1385) hyperon is firmly established as a three-quark baryon (q^3 baryon). On the contrary, the internal structure of the Λ(1405) hyperon is ambiguous [1]. In the quark model, Λ(1405) is assigned as a *p*-wave q^3 baryon. However, the mass of Λ(1405) is much smaller than the quark-model calculation, and therefore, Λ(1405) is widely considered as a candidate for a kaon-nucleon molecular state or a q^4 anti-*q* pentaquark baryon.

Photoproduction of Σ(1385) has been measured by the CLAS Collaboration at TJNAF. A theoretical calculation by Oh *et al.* [2] using an effective Lagrangian was then compared with the data and the contributions from nucleon resonances were discussed. Experimentally, Λ(1405) has been studied in meson-induced and proton-induced reactions so far. However, understanding of the photoproduction of Λ(1405) is very limited because of the lack of experimental data.

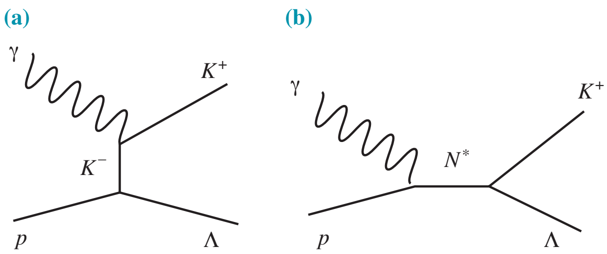

Fig. 1. Feynman diagrams of hyperon photoproduction.

We have studied photoproduction of Λ(1405) and Σ(1385) hyperons on the proton for an energy range of 1.5-2.4 GeV at the Laser-Electron Photon facility at SPring-8 (LEPS), beamline **BL33LEP**. We measured production cross sections of Λ(1405) and Σ(1385). This is the first measurement of the cross section of Λ(1405) photoproduction. The production cross section of Λ(1405) decreased largely in the higher photon energy region with respect to that of Σ(1385). Thus, the production mechanisms or form factors for these two hyperons must be quite different. The production cross sections were compared with theoretical calculations. We found that the production cross sections of Λ(1405) could not be explained by a conventional theoretical model. Thus, an exotic production mechanism, such as nucleon resonance contribution, might be necessary to understand the photoproduction of Λ(1405) [2]. A brief overview of the experiment is described below.

In this experiment, forward going K^+'s from the $\gamma p \rightarrow K^+X$ reaction were detected in the LEPS spectrometer. Using the energy-momentum conservation and measuring the momentum of a K^+-meson and the energy of a photon, we can obtain the missing mass of the $\gamma p \rightarrow K^+X$ reaction, MM(K^+), which corresponds to the masses of Λ(1405) and Σ(1385). However, in principle, it is impossible to separate Λ(1405) and Σ(1385) in *MM*(K^+) because the intrinsic widths of these resonances, 36 MeV/c^2 for Σ(1385) and 50 MeV/c^2 for Λ(1405), are much larger than their mass difference.

To distinguish these two resonances, a time projection chamber (TPC) was used together with the LEPS spectrometer to facilitate the detection of the decay products of these hyperon resonances. Figure 2 shows a schematic view of the experimental setup. The main decay mode of Σ(1385) is the Λπ channel, where Λ is the ground state. On the other hand, Λ(1405) is prohibited from decaying into a Λπ pair due to the conservation of isospin. Thus, Σ(1385) production can be identified by detecting a Λ hyperon. Both of Λ(1405) and Σ(1385) decay into the Σπ channel, where Σ is the ground state, but we can estimate the contamination of Σ(1385) using the yield obtained from its Λπ decay mode and the known

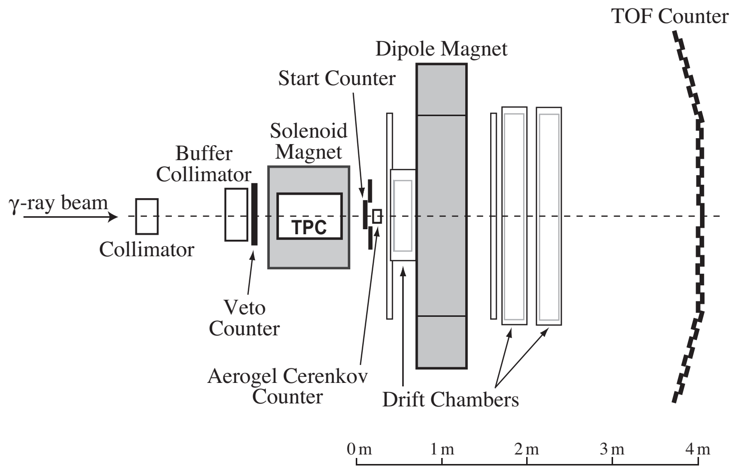

Fig. 2. Schematic view of experimental setup.

branching ratio of the $\Lambda\pi$ and $\Sigma\pi$ decay channels of $\Sigma(1385)$. The production ratios of $\Lambda(1405)$ to $\Sigma(1385)$ were obtained in two photon energy ranges. The scattering angle of K^+ in the center-of-mass frame, Θ_K was required to satisfy $0.8 < \cos\Theta_K < 1.0$. The production ratios of $\Lambda(1405)$ to $\Sigma(1385)$ were obtained as $\Lambda(1405)/\Sigma(1385) \approx 0.54$ and 0.084 for $1.5 < E_\gamma < 2.0$ GeV and $2.0 < E_\gamma < 2.4$ GeV, respectively. The absolute values of the production cross sections were obtained from high statistics liquid hydrogen data with the input of production ratios of $\Lambda(1405)/\Sigma(1385)$ obtained above. The differential cross sections of $\Lambda(1405)$ production were found to be $d\sigma/d(\cos\theta) \approx 0.43$ μb and 0.072 μb for $1.5 < E_\gamma < 2.0$ GeV and $2.0 < E_\gamma < 2.4$ GeV, respectively. Those of $\Sigma(1385)$ production were $d\sigma/d(\cos\theta) \approx 0.80$ μb and 0.87 μb for $1.5 < E_\gamma < 2.0$ GeV and $2.0 < E_\gamma < 2.4$ GeV, respectively.

The production cross sections of $\Sigma(1385)$ were almost constant with respect to the photon energy and consistent with a theoretical prediction in both photon energy ranges. Closed circles with error bars in Fig. 3 show the experimental data for the cross sections of $\Lambda(1405)$ production and a solid line and a shaded area show theoretical calculations. The production cross section in the lower photon energy region is much higher than theoretical values. The production mechanisms that are not considered in the theoretical model are necessary to explain the production cross section of $\Lambda(1405)$ in this photon energy region. Recently, Jido and Kanada-En'yo have proposed a nucleon-like molecular state consisting of K^+K^-p, which decays into $K^+\Lambda(1405)$ [3]. If this nucleon resonance is created in the intermediate state, the production cross section is enhanced. However, in view of our limited statistics, further data are needed for more quantitative discussions, which will be available in future experiments at SPring-8/LEPS. We already obtained data with higher statistics to study photoproduction of $\Lambda(1405)$ at SPring-8/LEPS, and more precise data will be shown in the near future.

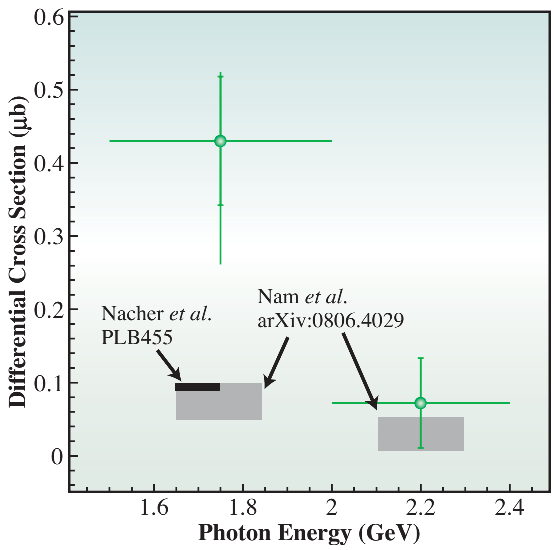

Fig. 3. Differential cross section of Λ(1405) photoproduction.

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