Kaon Photoproduction off Hydrogen at SPring-8/LEPS

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1 Introduction

Recently, experimental studies on the kaon photoproduction reactions off hydrogen had a considerable progress. Several experimental groups in new facilities, which provided high energy and good quality photon beams, published new experimental data. The SAPHIR collaboration in ELSA/Bonn facility reported on the $p(\gamma,K^+)\Lambda$ and $p(\gamma,K^+)\Sigma^0$ reactions in a photon energy range up to 2 GeV[1]. The measurement by the SAPHIR collaboration was the first precise measurement on the cross section of the kaon photoproduction reactions in the photon energy range well over the kaon production threshold. The photon energy dependence of the total cross section showed a bump structure at the photon energy around 1.5 GeV (about 1.9 GeV in the CM total energy), and a possibility of contribution of a nucleon resonance, $D_{13}(1895)$, was proposed[2]. The new data motivated many theoretical works, and the importance of inclusion of baryon resonances, choice of hadronic form factors and coupling constants, effect of u-channel contributions, etc., was realized. Another reaction cross section data from the CLAS collaboration in JLAB basically supported the SAPHIR data, and also suggested a possibility of contributions of several nucleon resonances with masses around 1.9 GeV[3].

Other categories of data also became available. The SAPHIR collaboration and the CLAS collaboration provided the recoil polarization data for the kaon photoproduction reactions[1, 3, 4]. The LEPS collaboration in SPring-8 and the GRAAL collaboration in ESRF/Grenoble provided the beam polarization asymmetry (Σ) data[5, 6]. The new category of data were, in principle, quite sensitive to interference between various amplitudes contribute to the kaon photoproduction reactions, and thus quite important to understand the reaction mechanism.

In this talk, I present recent experimental results obtained at the LEPS facility in SPring-8, mainly on the beam polarization asymmetry measurement. I also present experimental setup of an on going experiment for the (γ,K_S) reaction measurement at LEPS.

2 LEPS Facility and Experimental Setup

At the beamline BL33 of the SPring-8 electron storage ring, a Laser-Electron Photon facility (LEPS) was constructed by a collaboration of Research Center for Nuclear Physics (RCNP) of Osaka University, Japan Atomic Energy Research Institute (JAERI) and several universities in Japan. A laser system was built and installed in, so called, laser hutch in the beam line to inject the laser light into the electron storage ring. The laser light is scattered backward by the Compton effect with 8 GeV electrons in the ring. A 351nm Ar laser generated a high energy photon beam with energy up to 2.4 GeV and typical beam intensity was 10^6 photon/s. The energy of the beam photon was determined event-by-event by a tagging system installed in the SPring-8 storage ring. A linearly polarized laser light was usually used in the LEPS experiment, and about 90% (50%) linearly polarized high energy photon beam was obtained at 2.4 GeV (1.5 GeV).

The high energy photon beam was transported to, so called, experimental hutch located downstream of the laser hutch through a vacuum pipe (see Fig.1). In the experimental hutch, the photon beam was collimated with a lead blocks, and injected into a liquid hydrogen target.

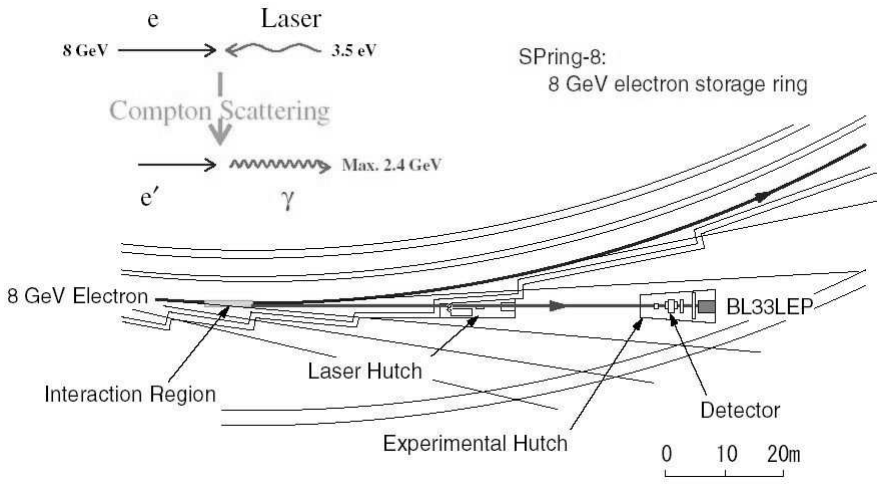

Figure 1: Schematic view of the LEPS beamline.

A plastic scintillation counter was placed between the lead blocks and the target to veto electrons and positrons converted in the upstream. Particles produced from the target were detected by a magnetic spectrometer system. Fig.2 shows the LEPS spectrometer system. A plastic scintillation counter was placed just behind the target, and used to trigger charged particles produced from the target. Since the most serious background in the measurement of photon-induced hadron reactions was the electron-positron pair creation reaction in the target, an aerogel Čerenkov detector (AC) was used to veto the electron-positron pair events. The index of refraction of the aerogel was 1.03, and almost all electron/positron and pions with momentum higher than 0.6 GeV/c were rejected in the trigger level. A silicon strip detector (SSD) and three drift chambers (DC1, DC2, and DC3) were used to track charged particle trajectories in a dipole magnet and analyze momenta of particles. SSD was also used to determine reaction vertices precisely. A wall made of 40 modules of plastic scintillation counters was placed at the end of the spectrometer system for the time-of-flight (TOF) measurement. To determine TOF, the trigger counter just behind the target and also the RF signal from the SPring-8 electron storage ring were used.

3 Some results of the p(γ,K^+) reaction measurement

The details of the measurement of the p(γ,K^+) reaction were reported in other papers[6, 7], so I show the analysis procedure and results very briefly. The selection of the p(γ,K^+) reaction was made by the K^+ identification with the momentum and TOF information from the spectrometer system. After the selection, the missing mass, M_X , was calculated by assuming the p(γ,K^+)X reaction kinematics as shown in Fig.3. Productions of Λ , Σ^0 and other hyperon resonances ($\Sigma(1385)$, $\Lambda(1405)$ and $\Lambda(1520)$) were clearly identified.

With the linearly polarized photon beam, we could obtain values of the beam polarization asymmetry (Σ). The azimuthal angle dependence of the kaon photoproduction reaction cross section can be written as follows:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{unpol} (1 + P\Sigma \cos 2\phi')$$

where $(d\sigma/d\Omega)_{unpol}$ and P are the cross section for unpolarized beam and beam polarization, respectively. The azimuthal angle ϕ' is the angle between the beam polarization plane and

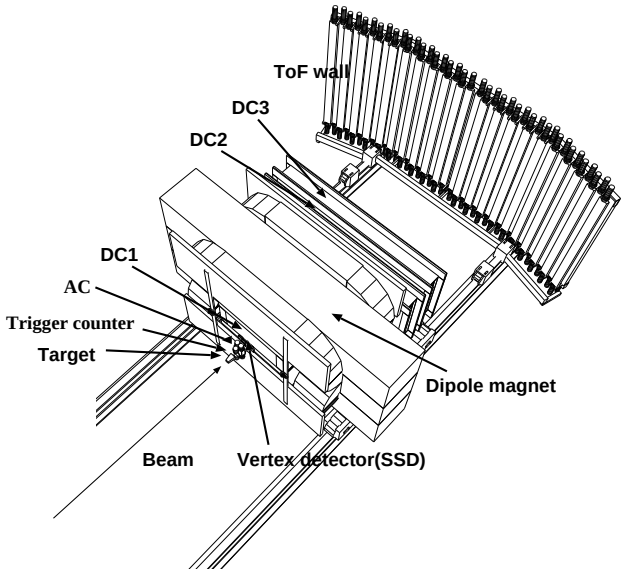

Figure 2: The LEPS magnetic spectrometer system.

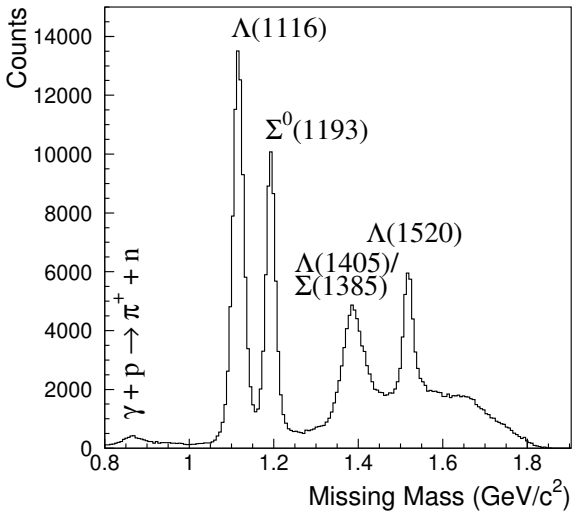

Figure 3: Missing mass spectrum by assuming the p(γ,K$^+$)X kinematics.

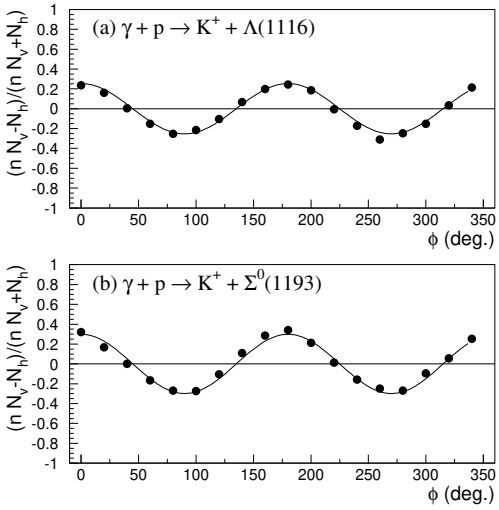

Figure 4: Values of $(N_V - N_H)/(N_V + N_H)$ as functions of the azimuthal angle ϕ for the Λ (up) and Σ^0 (down) productions.

the normal vector of the reaction plane. To reduce systematic errors, the beam polarization plane was periodically changed between horizontal and vertical modes. Actual estimation of the beam polarization asymmetry was made by using following relation:

$$\frac{N_V - N_H}{N_V + N_H} = P\Sigma \cos 2\phi$$

where N_V and N_H are numbers of events accumulated in the vertical and horizontal polarization modes, respectively. The azimuthal angle ϕ is measured from the horizontal plane.

Fig.4 shows the values of $(N_V - N_H)/(N_V + N_H)$ as functions of the azimuthal angle. The amplitudes in the plots tell the values of $P\Sigma$ and one can estimate the values of Σ by using calculated values of the beam polarization P. Fig.5 shows photon energy (up) and CM polar angle (down) dependences of the beam polarization asymmetry for the Λ (left) and Σ^0 (right) production reactions. The photon energy dependences (upper plots) were obtained after an integration over polar angles within the LEPS spectrometer. The increase of the beam polarization asymmetry as increase of the beam energy may be interpreted as the t-channel dominance at higher beam energy especially the dominance of a t-channel K^* exchange. The CM polar angle dependences (bottom plots) were obtained after integration over the photon beam energy from 1.5 to 2.4 GeV. The beam polarization asymmetries of both Λ and Σ^0 production reactions quickly rise at the forward angle ($\cos\theta_{CM} = 0.9 - 1$). The angular dependences were slightly different between two reaction channels at the larger angle ($\cos\theta_{CM} = 0.6 - 0.8$). Namely, the angular dependence of the Λ production reaction had a gradual decrease as the increase of the CM polar angle, and the beam polarization asymmetry was almost constant for the Σ^0 production reaction.

The measured beam polarization asymmetry were compared with existing model calculations, but no model calculation reproduce the photon energy and angular dependences well. Adjustments of model parameters were necessary, and the adjustments may restrict the acceptable region of the model parameter sets.

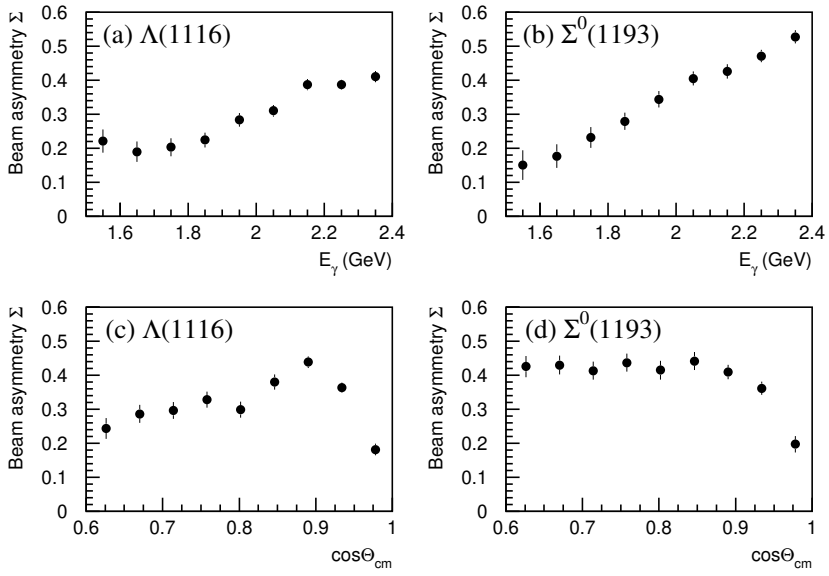

Figure 5: Photon energy (up) and CM polar angle (down) dependences of the beam polarization asymmetry for the Λ (left) and Σ^0 (right) production reactions.

4 K_S measurement at LEPS

The progress of the theoretical model calculation on the kaon photoproduction reaction was considerably large, but still there were several ambiguous model parameters for which some experimental inputs were necessary. There are two directions to go to fix the ambiguous model parameters. One is to measure new polarization observables because the polarization observables usually sensitive to relative phases between different reaction amplitudes which can not be accessible only with the cross section data. Another is a measurement of new reaction channels of the kaon photoproduction reaction because the measurement of the new channels is quite efficient to break down the total reaction amplitude into various partial amplitudes. The kaon photoproduction reaction has been studied well only for the $p(\gamma,K^+)$ reaction. New measurements of the $p(\gamma,K^0)$ or $n(\gamma,K^+)$ channels may provide useful information to understand the reaction mechanism of the kaon photoproduction reaction[8].

The $p(\gamma,K^0)$ reaction has been studied only by the SAPHIR collaboration[9] and the statistical errors are still large[10]. At LEPS, a new measurement on the $p(\gamma,K^0)$ reaction is in progress. A half of the produced K^0 are detected as K_S in the $\pi^+\pi^-$ decay mode (68.6% branching). The $\pi^+\pi^-$ pairs from the K_S decays can be detected with a small modification of the LEPS spectrometer system. The momenta of pions from the K_S decay ranges up to about 2 GeV/c, while the standard LEPS spectrometer setup vetoes all pions with momenta larger than 0.6 GeV/c as mentioned in Sec.2. To accept high momentum pions, the aerogel Čerenkov detector is replaced with a gas Čerenkov detector with iso-butane radiator gas in 1 atm. The threshold of the gas Čerenkov detector for pion is higher than 2 GeV/c, so all pions from the K_S decay are accepted by the experimental trigger with keeping the electron/positron veto efficiency high. A minor modification is necessary also to the trigger scintillation counter. Fig.6 shows pion momentum distributions triggered with the standard aerogel Čerenkov veto detector (n=1.03), another aerogel Čerenkov veto detector (n=1.008) and the gas Čerenkov

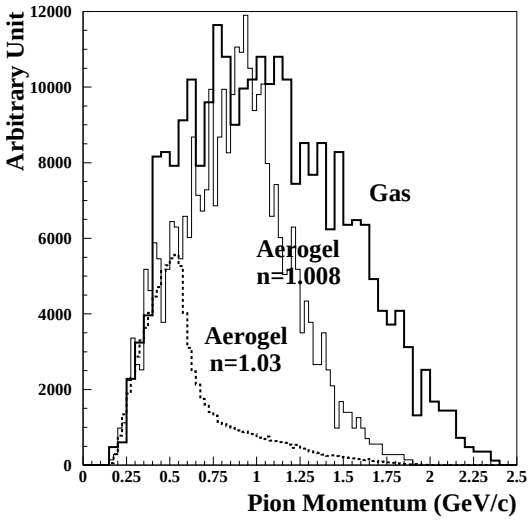

Figure 6: Pion momentum distributions triggered with the standard aerogel (dashed), another low index aerogel (thin line), and the gas Čerenkov detectors (thick line).

veto detector (n=1.0014–1.0019). The figure shows the trigger with the gas Čerenkov detector accepts high momentum pions.

An yield estimation of the p(γ,K^0) reaction measurement for the Σ^+ production case can be made with the cross section information from the SAPHIR experiment[9]. A typical differential cross section of the reaction was reported to be 0.1 μb/sr (in CM) in the forward angles at around 1.5 GeV beam energy. The standard LEPS hydrogen target (15 cm in length), typical beam intensity 4×10^5 photon/s, 250 msr geometrical solid angle of the LEPS spectrometer and overall K_S detection efficiency 2.8% gives an yield of 85 evens/day. About 1000 events of the p(γ,K^0) reaction can be accumulated in a beamtime for 2 weeks.

Recent topic related on the K_S measurement is the production of the exotic Θ^+ resonance. The production of the Θ^+ resonance in the photon induced reaction reported by the LEPS collaboration[11], and several groups supported the production of the resonance[12, 13, 14]. Diakonov et al. predicted a pentaquark S=+1 baryon ($uudd\bar{s}$) at a mass 1.53 GeV/c^2 as a narrow resonance, $\Gamma \sim$15MeV/c^2[15], and above experiments observed a narrow peak at 1.54 GeV/c^2 in the K-nucleon invariant mass spectra. In most of the experiment, the Θ^+ resonances were produced by quasi-free processes with neutrons in nuclear targets. Only the experiment reported in Reference [14] (SAPHIR collaboration) reported the production of the Θ^+ resonance in a free process, p(γ,K_S)Θ^+, and estimated the reaction cross section about 300 nb. The cross section is accessible at the LEPS facility with the new setup and polarization related information may be obtained. The overall detection efficiency of K_S is smaller than that of the Σ^+ production reaction due to the larger mass of the Θ^+ resonance, and estimated to be about 0.5%.

5 Summary

I reported on the results of the K^+ photoproduction reaction and on going experiment to measure K_S production reactions at SPring-8/LEPS. The study on the K^+ photoproduction reaction had a considerable progrss in recent years, and the experimental data gave rich in-

formation including polarization observables. Such information may be useful to investigate hyperon-nucleon interaction if we will measure the details of the kaon photoproduction reaction off nuclear targets. The study on the hyperon-nucleon interaction has been one of important subjects of the strangeness nuclear physiscs, and continues to be important in the J-PARK project. If the Θ^+ resonance is real and the predicted pentaquark compoment is predominant, the pentaquark states introduce a new degree of freedom in the baryon structure, which will be an important subject also in J-PARK.

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