POSSIBILITY OF EXPERIMENTAL STUDY ON THE (γ,K) REACTION MECHANISM

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Theoretical model calculations on the (γ,K) reaction had large improvement in recent years, and one may discuss the reaction mechanism by comparing experimental data with the model calculations. Further polarization observables are relatively sensitive to the difference of the reaction mechanism included in the model calculations. A result of a preliminary analysis on the beam asymmetry observable for the $p(\gamma,K^+)\Lambda,\Sigma^0$ reaction in the photon energy range E_γ=1.5-2.4GeV is discussed in the relation with data and an analysis at E_γ>5GeV. A possibility to measure the (γ,K^0) reaction at the SPring-8/LEPS facility is also discussed.

1 Introduction

In this talk, I discuss motivations of experimental studies on the (γ,K) reaction and possible experimental approaches to investigate the reaction mechanism of the reaction. I focus my talk mainly on experimental studies feasible with a good quality of polarized high energy photon beam at the SPring-8/LEPS experimental facility.

1.1 Baryon Spectrum and Kaon Production Reactions

Baryons and mesons are effective degrees of freedom in describing hadron reactions in the low energy. Since we know the baryons and mesons are made of quarks and gluons, various quark models have been studied to describe baryons and mesons from the fundamental particles. One of experimental data to be compared with the quark models is the spectrum of baryons. Many quark models can predict masses of baryons and also decay branching ratios. Many non-strange baryons have been identified by the π+N and the (γ,π) reactions, and are successfully reproduced by the quark models. As shown in Table 1, all predicted resonances have been observed experimentally up to the baryon mass of 1.7 GeV/c^2. On the other hand, the number of well established resonances is considerably smaller than predicted over the baryon mass. This situation is well known as the missing resonance problem.

Since the KΛ and the KΣ decay channels open near the baryon mass of 1.7 GeV/c^2, theoretical models predict non-negligible decay widths to the KΛ

Table 1. Numbers of baryon resonances observed experimentally and predicted theoretically. The numbers come from the PDG database and a theoretical model calculation [1].

Mass Region (GeV/c^2)	N and N*		Δ and Δ^*	
	Observed	Predicted	Observed	Predicted
$M_N \sim 1.7$	7	7	3	3
$1.7 \sim 2.0$	3	13	5	8
$2.0 \sim 2.2$	1	14	2	6

and the KΣ channels for several missing resonances. The (π,K) and the (γ,K) reactions are candidate reactions to investigate the missing resonance strongly decay to the KΛ and the KΣ channels. Recently, the D_{13} resonance, which is a candidate of the nucleon resonances, was discussed [2] related on a bump structure SAPHIR experiment observed [3] in the photon energy dependence of the total cross section of the p(γ,K$^+$)Λ reaction at around a total energy of 1.9 GeV. Since the spacing of the resonances is smaller than the decay width of the resonances at the baryon mass, additional experimental data on polarization observables may provide more clear evidence of the resonance and its properties.

1.2 Reaction Mechanism of Pion and Kaon Photoproduction Reactions

The pion and the kaon photoproduction reactions on a proton are suitable to study electromagnetic properties of baryons and properties of the strong interaction between mesons and baryons. Due to a lower energy threshold of the (γ,π) reaction ($E_{\gamma(threshold)}$~0.15 GeV), the reaction has been studied in many experimental facilities and the amount of compiled data is considerably large. Although the (γ,K) reaction has a higher energy threshold ($E_{\gamma(threshold)}$~0.91 GeV) and one require a facility that provides a higher energy photon beam, but the reaction has several advantages in the study of the reaction mechanism.

In the t-channel meson exchange diagram, the (γ,π) reaction has contributions from exchanges of π (IJ^P=1$0^-$), ρ (1$1^-$), ω (0$1^-$), etc. The (γ,K$^+$) reaction has contributions from K (IJ^P=$\frac{1}{2}0^-$), K^* ($\frac{1}{2}1^-$), etc. Further, since K^0 has no charge and no spin, the (γ,K^0) reaction has no contribution from the K exchange. The smaller numbers of exchange mesons contribute to the

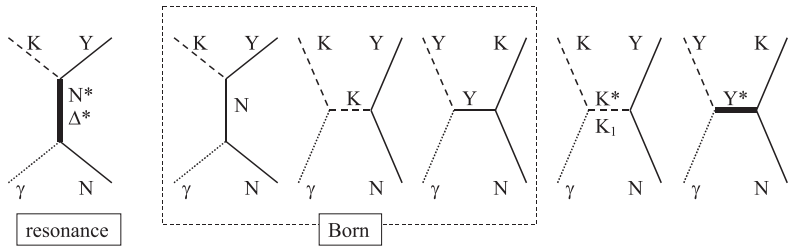

Figure 1. Dominant diagrams contribute to the (γ,K) reaction.

(γ,K) reaction are coming from a simple isospin structure of the reaction.

In the s-channel diagrams, the p(γ,π)N reaction has contributions from both N^* and Δ^*. On the other hand, the p(γ,K^+)Λ reaction has only N^* contribution. The smaller number of the contributing baryon resonances is an advantage to study the resonances in the energy region much higher than the threshold region, at where the energy spacing of the resonances is comparable with or smaller than the resonance decay widths.

The (γ,K) reaction on a nucleon produces a hyperon or a hyperon resonance, and the hyperon decays by the weak interaction. Due to the parity violation in the hyperon decay, one can measure the polarization of the hyperon easily and it is an advantage to measure polarization observables for the reaction.

Since the kaon photoproduction reaction is a member of pseudo-scaler meson photoproduction reactions, like the (γ,π) and the (γ,η) reactions, theoretical works on other pseudo-scaler mesons, especially on pion, are quite helpful to understand the reaction mechanism of the (γ,K) reaction.

1.3 Status of Studies on the (γ,K) Reaction

Fig. 1 shows dominant diagrams contribute to the (γ,K) reaction. The diagrams are grouped into resonance, Born and other t-channel and u-channel exchange terms. The resonance term has a large contribution in low energy, say E_γ<1.5GeV. The contributions of non-resonant terms expected to grow with the photon beam energy and become comparable with the resonant term at around E_γ=1.5GeV. This grow comes mainly from an increase of the t-channel exchange diagram. It is expected from some theoretical calculations [4] and also confirmed by a strong forward peaking of the differential cross section of the (γ,K) reaction at higher energy [3].

Historically, there was a problem that theoretical calculations had an un-

physical divergence of the total cross section with the increase of the photon beam energy originated from the non-resonant term contributions. Recently, this situation was improved by introducing hadronic form factors with keeping the gauge invariance [4,5]. All total cross section data of the (γ,K^+) and the (γ,K^0) reactions are reproduced well by theoretical calculations up to E_γ=2GeV [4,6]. In the photon energy region over 2 GeV, there is a tendency that theoretical calculations still overestimate the experimental total cross section. This is partly coming from an approximation that only finite number of mesons are included in the t-channel exchange diagram. A model that treats exchange mesons as several groups of mesons in the same Regge trajectories, Reggeons, seems to be successful to describe the photon energy dependence of the total cross section over 2 GeV [7].

Almost all discussions on the theoretical treatments have been made only on the total cross section data, but new experimental data including polarization observables become important because theoretical parameters are too many to be fixed only with the total cross section data and polarization observables are often sensitive to small components of reaction amplitudes.

Another interesting study is a comparison between the p(γ,K^+)Σ^0 and the p(γ,K^0)Σ^+ reactions. A N^* resonance in the s-channel decays to $K^+\Sigma^0$ and $K^0\Sigma^+$ with a ratio of 1:2, and a Δ^* resonance decays with a ratio of 2:1. The two reactions have different sensitivity for the N^* and Δ^* resonances. For the t-channel diagrams, the p(γ,K^0)Σ^+ reaction has no contribution of the K exchange, and one can estimate the K exchange and other exchange contributions separately by comparing the two reactions.

1.4 Hints from High Energy Behavior

Since the photon energy region over 1.5 GeV is a transitional region from the low energy (resonance dominant) to the high energy (exchange diagram dominant), it is worthwhile to see the properties of the (γ,K) reaction in more higher energy.

Available experimental data of the p(γ,K^+)Λ and the p(γ,K^+)Σ^0 reactions at 5, 8, 11, 16 GeV were compared with a theoretical calculation based on the Reggeon exchange [8]. The theoretical calculation predicted possible separation of the K/K_1 (unnatural parity) and the K^* (natural parity) Regge trajectory contributions from the t-dependence of the differential cross section of the reactions. Since the mass of K is considerably smaller than K^*, the K contribution can be observed clearly at small -t region, say -t<0.2GeV^2. The authors also discussed the difference of the t-dependences for the p(γ,K^+)Λ and the p(γ,K^+)Σ reactions related on the difference in the strengths of the

$Kp\Lambda$ and the $Kp\Sigma$ couplings.

Another interesting point was a prediction on the beam asymmetry (Σ). The values of the experimental beam asymmetry were close to 1 for both Λ and Σ channels, and it was interpreted as a dominance of the K* Regge trajectory contribution because exchanges of natural (unnatural) parity mesons result in $\Sigma\sim1$ ($\Sigma\sim$-1) at the small -t region [9].

These features are apparently clear down to the photon energy of 5 GeV, and one should keep in mind that such features may be observed also in the 2-3 GeV region.

2 Possible Experimental Approach at SPring-8/LEPS

2.1 Parameters of SPring-8/LEPS

The SPring-8/LEPS beamline was constructed at the electron storage ring of the SPring-8 synchrotron radiation facility by a collaboration of Research Center for Nuclear Physics (RCNP), Osaka University and Japan Atomic Energy Research Institute (JAERI). At the SPring-8/LEPS beamline, a high energy photon beam is produced by the backward Compton scattering of laser photons by 8 GeV electrons circulating in the storage ring. 351 nm Ar laser photons create a 1.5-2.4 GeV photon beam. The energy of the high energy photon is tagged by measuring a bending angle of an electron by a dipole magnet in the storage ring after the Compton scattering. Typical tagged photon beam intensity on the target is 500 kcps. A laser beam with linear or circular polarization is used to produce a highly polarized photon beam. A liquid hydrogen target of 5 cm in thickness is available and another hydrogen target of 15 cm thick will be available in near future.

SPring-8/LEPS facility has a magnetic spectrometer system to measure charged particles produced in the target by photon induced hadron reactions (see Fig. 2). The angular coverage of the spectrometer is 0 to 20 degrees in the laboratory frame and it corresponds to $\cos\theta_K$(cm)$<$0.6 for the (γ,K) reaction. The photon beam and the spectrometer system are suitable for the measurement of the differential cross section and polarization observables for the (γ,K) reaction at the forward angle or at the small -t region.

2.2 The ($\vec{\gamma}$,K^+) Reaction

The (γ,K^+) reaction has been studied well. Differential cross section and hyperon (Λ and Σ^0) polarization data were obtained at photon energies up to around 2 GeV [3]. A preliminary data from JLAB extended the photon energy range of the cross section measurement up to around 2.4 GeV [10].

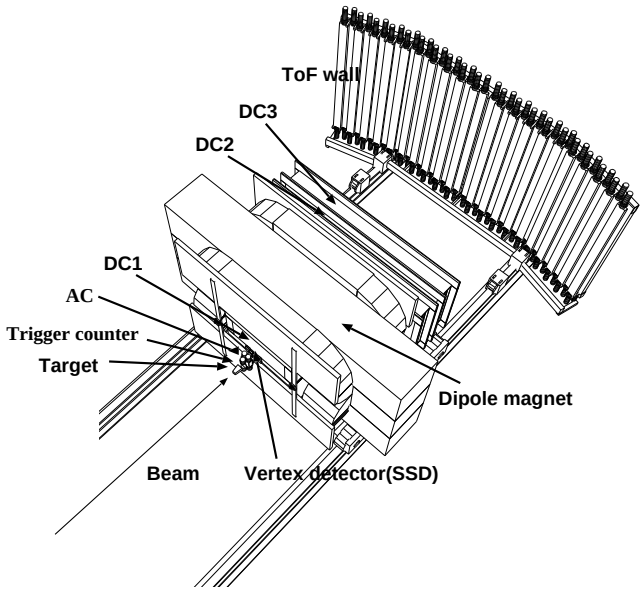

Figure 2. Schematic view of the magnetic spectrometer system in the SPring-8/LEPS facility.

SPring-8/LEPS can cover the energy range and provide a new information on the beam asymmetry observable. SPring-8/LEPS already has a set of high statistics data on the reaction, and a preliminary analysis shows the value of the beam asymmetry is positive and considerably large [11], and it glows with the increase of the photon beam energy. It is consistent with the t-channel K^* exchange dominance at higher energy which is mentioned in Sec. 1.4.

The analysis of the t-dependence of the differential cross section is also an interesting subject for the (γ,K^+) reaction. The SPring-8/LEPS magnetic spectrometer covers a -t region up to around 0.45 GeV^2. The lower limit of -t is determined kinematically, and the value comes down to 0.05 GeV^2 for the (γ,K^+) reaction. Fig. 3 shows lower limits of -t (solid curves) as functions of photon beam energy for several channels of the (γ,K^+) reaction together with the upper limit of -t (broken horizontal line). The SPring-8/LEPS experiment covers interesting region of -t where one may see the K exchange (-t<0.2GeV^2) and the K^* exchange (-t>0.2GeV^2) contributions.

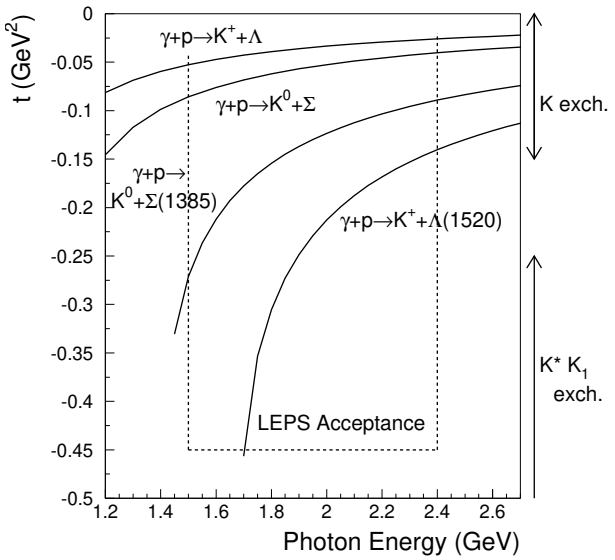

Figure 3. Solid curves show lower limits of -t as functions of photon beam energy for several channels of the (γ,K$^+$) reaction. The broken horizontal line shows the upper limit of -t coming from the spectrometer acceptance. The vertical broken lines show lower and upper limits of the photon beam energy available at the SPring-8/LEPS facility.

2.3 The ($\vec{\gamma}$,K^0) Reaction

Experimental data on the (γ,K^0) reaction is scarce. Differential cross section and Σ^+ polarization data were obtained at photon energies up to around 1.5 GeV [12], but statistical precision is not so high. Theoretical calculations have large ambiguity mainly due to the poor statistics of the experimental data.

In the K^0 measurement, a half of K^0 goes to K$_S$ and detected by the 2π decay mode, and another half goes to K$_L$ which runs through the experimental setup without any interaction and is undetectable. A magnetic spectrometer can detect only the charged pion decay mode, K$_S \to \pi^+\pi^-$ (68.6% branch).

The SPring-8/LEPS facility can provide a new differential cross section data on the reaction in the photon energy region from 1.5 to 2.4 GeV, and also provide a new data on the beam asymmetry. Modification of the experimental setup necessary for the (γ,K^0) reaction measurement from that for the (γ,K$^+$) reaction is small. The yield of the p(γ,K^0)Σ^+ reaction at SPring-8/LEPS is

Table 2. Parameters used for the yield estimation of the p(γ,K^0)Σ^+ reaction at SPring-8/LEPS.

Parameter	Value
Differential cross section $\left(\frac{d\sigma}{d\Omega}\right)_{LAB}$	0.8 μb/sr
Geometrical solid angle of spectrometer $\Delta\Omega$	250 msr
Tagged photon beam intensity N_{Beam}	500 k photon/s
Number of target N_{Target}	2×10^{23} cm^{-2}
Overall K^0 detection efficiency ε	0.026

Table 3. Breakdown of the overall K^0 detection efficiency.

Item	Efficiency
$K^0 \to K_S$ fraction	0.5
$K_S \to \pi^+\pi^-$ branching ratio	0.69
Finite decay space	0.5
$\pi^+\pi^-$ in spectrometer	0.15
Overall efficiency ε	0.026

estimated as follows by using parameters listed in Table. 2:

$$Y = \left(\frac{d\sigma}{d\Omega}\right)_{LAB} \cdot \Delta\Omega \cdot N_{Target} \cdot N_{Beam} \cdot \varepsilon \sim 45 events/day$$

where $\left(\frac{d\sigma}{d\Omega}\right)_{LAB}$, $\Delta\Omega$, N_{Target}, N_{Beam} and ε stand for differential cross section in the laboratory frame, geometrical solid angle of the spectrometer, number of target hydrogen atoms in a unit area, number of photon beam in a unit time and overall efficiency of the K^0 detection. The differential cross section is estimated from the experimental cross section in the c.m. system [12], and a kinematical factor is multiplied to obtain the cross section in the laboratory frame. The value used for the number of target atoms corresponds to a 5 cm liquid hydrogen target. If a new 15 cm target is available, the yield becomes roughly 3 times larger. Table 3 shows a breakdown of the overall K^0 detection efficiency.

The result of the estimation tells one can obtain data with the same level of statistics as that of the SAPHIR experiment (405 events) in about 10 days.

3 Summary

New experimental data of the (γ,K) reaction may provide information on the missing resonances and also on the reaction mechanism of the reaction. Recent data from SAPHIR and JLAB provided precise measurement on the cross section of the reaction, and theoretical studies have been made extensively to reproduce the new data. Since the resonance and meson exchange contributions are not separable only with one measurement, one have to study the reaction in a wide range of the photon energy and also have to measure observables other than cross section. SPring-8/LEPS may provide a new type of experimental data by using the good quality of polarized photon beam.

References

1. Simon Capstick and W. Roberts, *Phys. Rev.* D **58**, 074011 (1998).
2. C. Bennhold, H. Haberzettl and T. Mart, nucl-th/9909022; C. Bennhold, A. Waluyo, H. Haberzettl, T. Mart, G. Penner and U. Mosel, nucl-th/0008024.
3. SAPHIR Collaboration: M.Q. Tran *et al.*, *Phys. Lett.* B **445**, 20 (1998).
4. F.X. Lee, T. Mart, C. Bennhold, H. Haberzettl and L.E. Wright, *Nucl. Phys.* A **695**, 237 (2001).
5. K. Ohta, *Phys. Rev.* C **40**, 1335 (1989).
6. T. Mart, S. Sumowidagdo, D. Kusano, C. Bennhold and H. Haberzetl, *Nucl. Phys.* A **684**, 502 (2001).
7. T. Mart, S. Sumowidagdo, C. Bennhold and H. Haberzetl, in *Proceedings of the 2nd KEK-Tanashi International Symposium on Hadron and Nuclear Physics with Electromagnetic Probes*, Tanashi, Tokyo, Japan, 1999; T. Mart, S. Sumowidagdo, C. Bennhold and H. Haberzetl, nucl-th/0002036.
8. M. Guidal, J.-M. Laget and M. Vanderhaeghen, *Nucl. Phys.* A **627**, 645 (1997).
9. P. Stichel, *Z. Phys.* A **180**, 170 (1964).
10. Reinhard A. Schumacher (for the CLAS Collaboration), *Nucl. Phys.* A **663&664**, 440 (2000).
11. See report of M. Sumihama in this proceedings.
12. SAPHIR Collaboration: S. Goers *et al.*, *Phys. Lett.* B **464**, 331 (1999).