Photoproduction of Neutral Kaons on Liquid Deuterium Target

K. Tsukada[1], T. Takahashi[1*], T. Watanabe[1†], P. Bydžovský[2], M. Ejima[1], Y. Fujii[1],
K. Futatsukawa[1], O. Hashimoto[1], K. Hirose[1], T. Ishikawa[3], S. Kameoka[1‡], H. Kanda[1],
F. Kato[1], S. Kinoshita[1], T. Kinoshita[3], T. Kon[1], O. Konno[5], K. Maeda[1],
A. Matsumura[1], Y. Miura[1], H. Miyahara[3], H. Miyase[1], T. Nakabayashi[3], K. Nonaka[1],
A. Ohtani[1], Y. Okayasu[1], M. Oyamada[1], A. Sasaki[4], H. Shimizu[3], T. Tamae[3],
H. Tamura[1], T. Terasawa[3], H. Tsubota[1], S. N. Nakamura[1], H. Nomura[1], M Ukai[1§],
D. Uchida[1], H. Yamauchi[1], H. Yamazaki[3], K. Yawata[1], and M. Wakamatsu[1]

[1]*Department of Physics, Tohoku University, Sendai, 980-8578*
[2]*Nuclear Physics Institute, 25068, Řež, Czech Republic*
[3]*Laboratory of Nuclear Science, Tohoku University, Sendai, 982-0826*
[4]*Department of Electrical and Electronic Engineering, Akita University, Akita, 010-8502*

We have performed the experiment of K^0 photoproduction on the liquid deuterium target with Neutral Kaon Spectrometer (NKS) at LNS-Tohoku. The K^0s were measured via $K^0_S \to \pi^+\pi^-$ decay channel in the threshold region. The momentum spectra of K^0 photoproduction cross sections were derived and compared with the calculations using representative models.

§1. Introduction

The investigation of the kaon production on a nucleon by the electromagnetic interaction provides invaluable information on the strangeness production mechanism, strength of meson-baryon coupling constants and structure of hadrons, being labeled by the strangeness degree of freedom. Such studies using beams of real photons and electrons have been conducted both experimentally and theoretically since the 1950′s, taking advantage of the electromagnetic interaction that is understood better than the hadronic interaction. Until now, the experimental studies have been carried out in $p(\gamma, K^+)\Lambda$, $p(\gamma, K^+)\Sigma^0$ and $p(\gamma, K^0)\Sigma^+$ reactions among six isospin channels [1-5]. However, no data have been measured for the other three channels on a neutron. Theoretically, phenomenological models have been constructed based on measured channels so far. The isobar models, Kaon-MAID [6] and SLA [7], were adopted in the present analysis. The predictions of the photon energy dependence and the kaon angular distribution of the other three channels on a neutron using these models are quite different.

The lack of the key data for strangeness photoproduction of the three channels on a neutron is due to the experimental difficulties to measure neutral kaons and to prepare a neutron target. The measurement of these three strangeness production channels provides much information on the strangeness photoproduction mechanism. In particular, the $n(\gamma, K^0)\Lambda$ reaction has following features. (1) Since no charge is involved, the t-channel Born term does not contribute. (2) It is a mirror reaction to $p(\gamma, K^+)\Lambda$. For the hyperon resonance exchange terms, a coupling constant, $g_{K\Sigma N}$, changes its sign from the isospin symmetry, $g_{K^0\Sigma^0 n} = -g_{K^+\Sigma^0 p}$, resulting the different interference effect. Furthermore, the number of resonances to be considered is small in the threshold region. Therefore, the $n(\gamma, K^0)\Lambda$ reaction is expected to play an essential role to investigate the strangeness photoproduction mechanism.

In this paper, we present the results of photoproduction of neutral kaons on deuterons near the threshold.

§2. Experiment

We carried out the experiment of the $d(\gamma, K^0)$ reaction in the threshold region, $E_\gamma = 0.8 \sim 1.1$ GeV. The K^0s were measured in $\pi^+\pi^-$ decay mode with Neutral Kaon Spectrometer (NKS) which we installed in LNS-Tohoku. Figure 1 shows a schematic view of NKS which consists of a dipole magnet of 107 cm diameter and 60 cm gap with 0.5 T, straw drift chambers (SDC), cylindrical drift chambers (CDC), an inner hodoscope (IH), an outer hodoscope (OH) and electron veto counters (EV). The detector configuration was symmetric against the beam line. The solid angle of NKS was about π sr. The CDC and SDC were used to measure particle momenta in the horizontal plane by trajectory reconstruction. The magnetic field map was calculated by TOSCA. IH and OH were used for the time-of-flight measurement and event triggers. The momenta and time-of-flights were used for the particle identification. As a trigger condition, we required more than two charged particles; at least one event both in the left and right arms in coincidence with a tagger signal. EVs were employed to reduce the serious background triggered by $\gamma \to e^+e^-$ conversion. They covered vertically ± 2.5 cm in the horizontal plane at OH's positions. The geometrical acceptance was reduced by 8 %.

The photon beam was generated from the 1.2 GeV electron beam via bremsstrahlung and its energy was tagged by the STB-tagger system [8]. Typical tagged photon intensity was 2×10^6/sec and tagging efficiency was 79 ± 1 %. Total experimental period was about 1000 hours.

In order to investigate the K^0 elementary production process on a neutron, the liquid deuterium target with a thickness of 3.2 cm was used. The target system was developed for this experiment and provided the stable liquid-state deuterium during the experimental period [9]. The density of the target was estimated to be 0.17 g/cm^3 from the temperature of the target and the pressure.
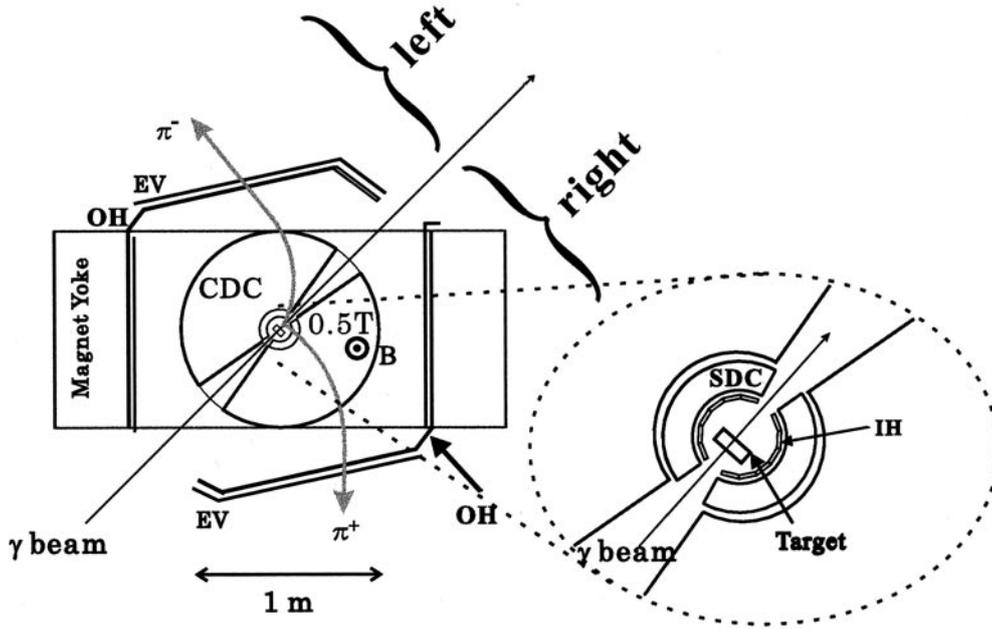
Fig.1. Schematic view of the Neutral Kaon Spectrometer (NKS).

§3. Analysis

The momenta of particles were derived from the curvature of trajectories. Besides, the velocities of particles were calculated from the time of flight and the flight length. The e^+e^- events were removed by rejecting the events of which the vertex position was upstream the target. Figure 2(a) shows the vertex point distribution of the $\pi^+\pi^-$ events. An opening angle (η) cut of $-0.9 < \cos\eta < 0.8$ was applied in order to remove the e^+e^- or vertex mis-reconstruction events. The vertex resolution was estimated to be 1.3 mm in RMS in the beam direction. Most of events were originated in the target. Backgrounds through such as a multi pion productions, N* and ρ, whose production cross sections are much larger than that of kaon production. Hence, no peak is observed in the invariant mass spectrum as shown in Fig. 2(b) for events in the target region. K^0 events are enhanced by selecting vertex points in the decay volume, because K_S^0 has a relatively long life time of $c\tau$=2.68 cm. Figure 2(c) shows the invariant mass spectrum when events in the decay volume are chosen. The peak of K_S^0 is clearly seen as shown in the figure. The number of K^0 events is about 900 for the present data. In order to obtain the cross section, we defined the gate in the invariant mass spectrum, $0.46 \le M(\pi^+\pi^-) < 0.54$ GeV/c^2. Momentum distributions of K^0 were obtained after subtracting background contributions. The origin of the backgrounds were considered as (1) leakage from the target region due to the finite resolution of the vertex point reconstruction, and (2) wrong combination between π^+ from K^0 and π^- from Λ. The first one was estimated from the events originated in the target region, and the second one was estimated by Geant4 simulation. These estimations gave the shape of the backgrounds, and the magnitude of the backgrounds were adjusted by fitting the invariant mass spectrum. Figure 3 shows the fitting result assuming a gaussian for K^0 and the shapes of backgrounds as estimated in the photon energy from 0.9 to 1.0 GeV (ELow) and
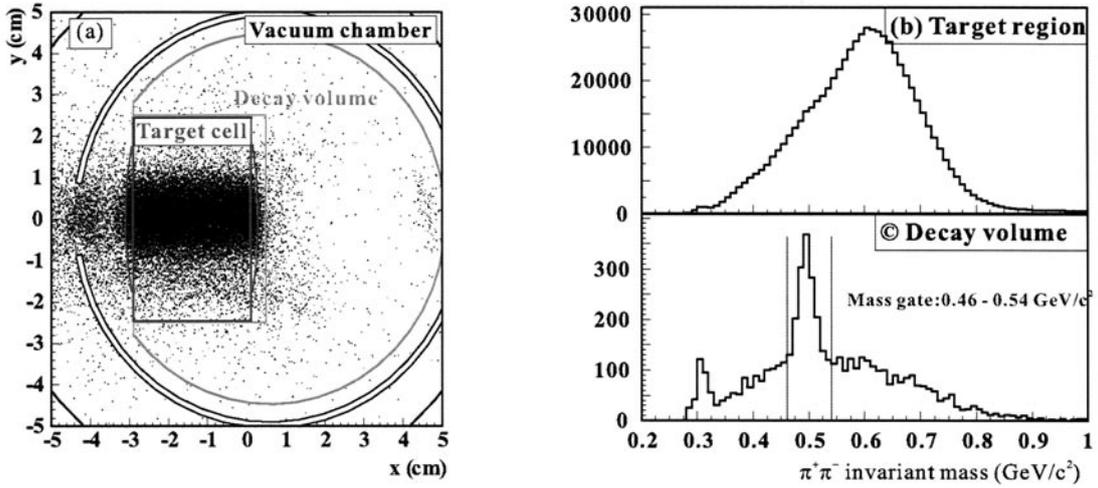
Fig.2. (a) Vertex distribution for $\pi^+\pi^-$ events. The beam comes from left to right. Events come mainly from the target region. (b), (c) An invariant mass spectrum of $\pi^+\pi^-$ events with the gate that the vertex is in the target for (b) and outside the target denoted by decay volume for (c).

form 1.0 to 1.1 GeV (EHigh).

The acceptance of NKS was calculated by a Geant4 simulation. The geometry of NKS was considered realistically, and the position and time resolution of the detectors were taken into account. Various analysis efficiencies were also estimated in the acceptance. Figure 4 shows the contour plot of the acceptance map. We used the data with momentum (P) and angle ($\cos\theta$) of K^0 in the effective regions shown in the figure because the acceptance is very low out of these regions. In this paper, the results in Region 1 are presented.

§4. Results and Discussion

The obtained momentum spectra of K^0s are shown in Fig.5. The backgrounds contributions are already subtracted. The integrated momentum range is limited as mentioned in the previous section. The obtained spectra are compared with the calculations using the representative two models, Kaon-MAID [6] and Saclay-Lyon A (SLA) [7]. The lines represent calculations in the plane wave impulse approximation framework using Bonn OBEPQ (One-Boson-Exchange-Potential in Q-space) deuteron wave function [10] by Bydžovský *et al.* [11]. The Kaon-MAID model is the only model to predict the elementary cross section of K^0 photoproduction on a neutron assuming SU(3) symmetry. On the other hand, SLA has an adjustable parameter for $K^0\Lambda$ photoproduction, since the ratio of the decay width between the charged and neutral K_1 resonance ($R_{K_1^0 K_1\gamma}$) is unknown. In Kaon-MAID, this ratio was obtained from the $\gamma + p \rightarrow K^0 + \Sigma^+$ process. Therefore, the elementary cross sections of SLA are calculated assuming various $r_{K_1 K_\gamma}$. Kinematical regions are also selected for the calculations similarly to the experimental data.

Since we measured only K^0, the Σ production process may contribute in addition to $K^0\Lambda$ production. From the estimation using Kaon-MAID, the contributions of Σ production are negligibly small in the
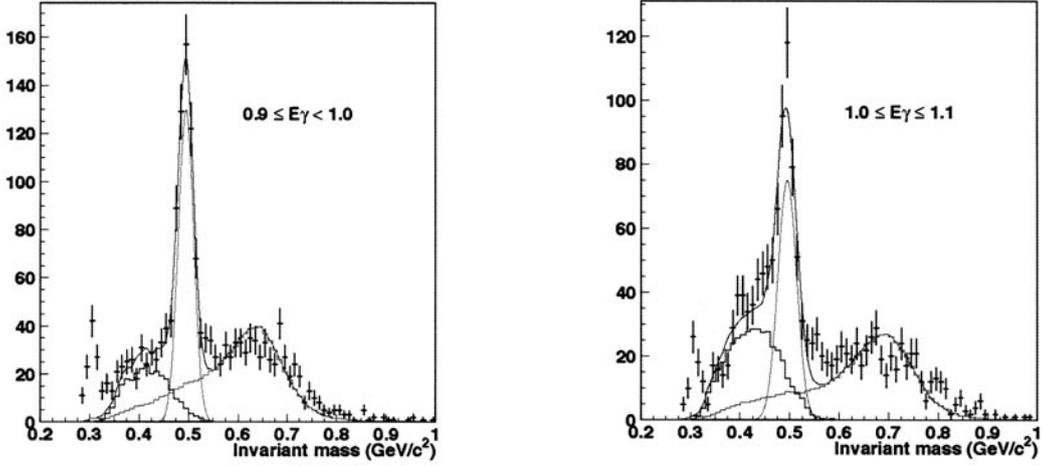
Fig.3. Fitting results of invariant mass spectra in photon regions from 0.9 to 1.0 GeV (ELow, left) and from 1.0 to 1.1 GeV (EHigh, right). The contribution around 0.4 GeV/c^2 comes from the wrong combination background and that around 0.6 GeV/c^2 comes from the leakage of the target events. The peak near 0.3 GeV/c^2 comes from the e^+e^- events.
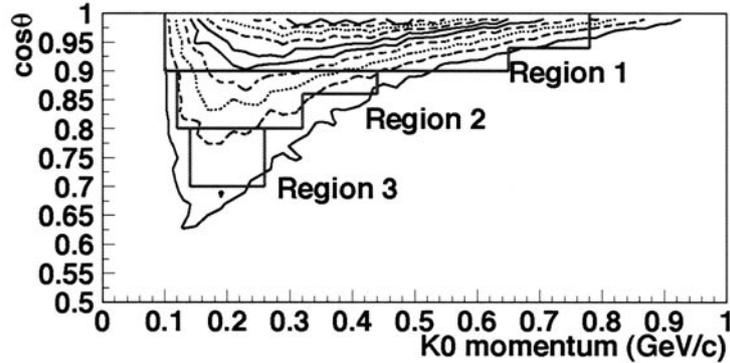

Fig.4. The contour plot of the acceptance map of NKS. The effective regions, Region 1, Region 2 and Region 3, are overdrawn by solid lines.

ELow region and sizable large at lower momentum in the EHigh region. The prediction based on the Kaon-MAID model is consistent with our data in the ELow region but too large in the EHigh region even if the Σ contribution is involved. The spectra calculated by SLA with $r_{K_1K_\gamma} = -1.9$ well account for the present results at both energy regions.

In the ELow region, the shape of the momentum spectrum in the laboratory system mainly depends on the angular distribution in the center of mass system. From the momentum distributions using SLA with various $r_{K_1K_\gamma}$ values, it is favored that the K^0 photoproduction on a neutron has a backward peak in the center of mass system.
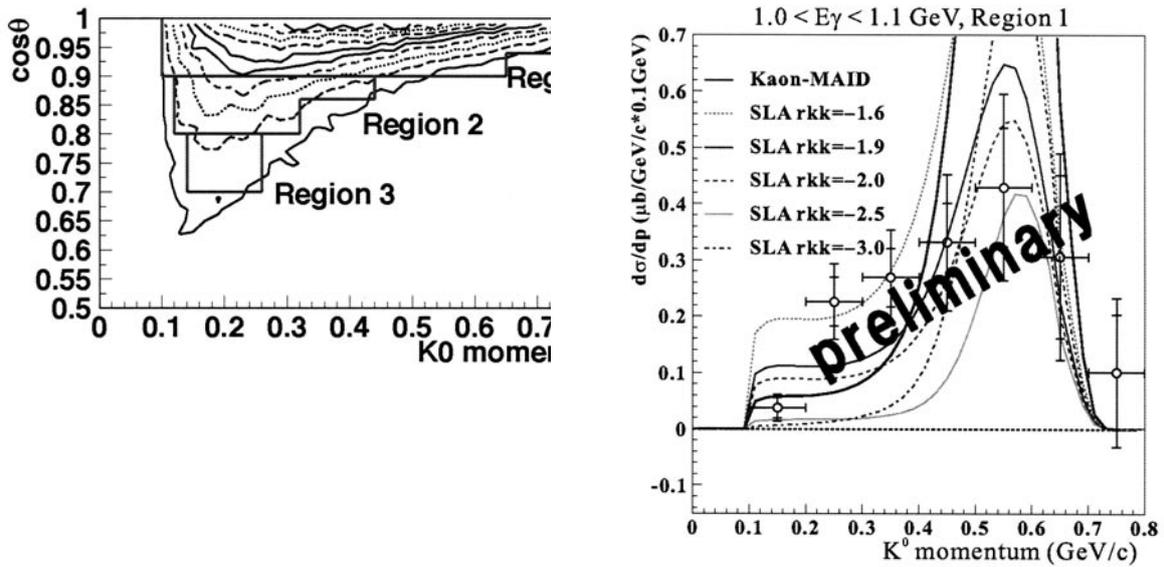
Fig.5. Momentum dependences after the correction for efficiencies and subtraction of backgrounds. The lines represent the calculations using Kaon-MAID (solid), SLA($r_{K_1 K_\gamma}= -$ 1.6, dotted), SLA($r_{K_1 K_\gamma}=-1.9$, solid), SLA($r_{K_1 K_\gamma}=-2.0$, dashed), SLA($r_{K_1 K_\gamma}=-2.5$, solid) and SLA($r_{K_1 K_\gamma}=-3.0$, dash-dotted). The photon energy ranges are from 0.9 to 1.0 GeV(ELow, left) and from 1.0 to 1.1 GeV(EHigh, right). Error bars are overdrawn for the (statistic) and (statistic + systematic) errors.

§5. Summary

We have successfully measured neutral kaons, bombarding a liquid deuterium target with a photon beam in the threshold region from 0.8 to 1.1 GeV. It was the first data for K^0 photoproduction on the deuteron in this energy region. The momentum spectra of K^0 production were compared with theoretical spectra calculated assuming isobar models for the elementary process and a realistic deuteron wave function for the target nucleus. The present experiment has demonstrated the usefulness of the neutral kaon measurement for the investigation of photo strangeness production reactions.

Acknowledgement

References

[1]   D. S. Carman *et al.*: Phys. Rev. Lett. **90** (2003) 131804.

[2]   J. W. C. McNabb *et al.*: Phys. Rev. C**69** (2004) 042201.

[3]   K. H. Glander *et al.*: Eur. Phys. J. A**19** (2004) 251.

[4]   M. Q. Tran *et al.*: Phys. Lett. B**445** (1998) 20.

[5]   R. G. T. Zegers *et al.*: Phys. Rev. Lett. **91** (2003) 092001.

[6]   F. X. Lee, T. Mart, C. Bennhold, and L. E. Wright : Nucl. Phys. A**695** (2001) 237.

[7]   T. Mizutani, C. Fayard, G. H. Lamot, and B. Saghai : Phys. Rev. C**58** (1998) 75.

[8]   H. Yamazaki *et al.*: Nucl. Instr. and Meth. A**536** (2005) 70.

[9]   H. Kanda *et al.*: Research Report of LNS, Tohoku University **37** (2004) 27.

[10]   R. Machleidt, K. Holinde, and C. Elster : Phys. Rept. **149** (1987) 1.

[11]   P. Bydzovsky, M. Sotona, O. Hashimoto, and T. Takahashi : private communications.