LEPS/RCNP proposal

Measurement of K^0 Photoproduction to Investigate Reaction Mechanism at Small $-t$ Region

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Measurement of K^0 Photoproduction to Investigate Reaction Mechanism at Small $-t$ Region

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1 Abstract

Recently, new measurements on the p(γ,K)Y reaction have been reported, and the quality of the experimental data was considerably improved in a photon beam energy wider range than that of the previous measurements [1, 2, 3]. On basis of the total cross section data obtained from the measurements, contributions of N^* and Δ^* resonances were discussed [4, 5]. Though the extension of the photon beam energy up to 2 GeV made the discussion of the resonance contributions more realistic, the reaction mechanism in this energy region is not clear yet due to non-negligible amounts of non-resonant contributions. It is important to systematically study the (γ,K) reaction with polarization observables to extract a clear understanding of the reaction mechanism.

The p(γ,K^0)Σ^+ reaction is one of the most poorly studied (γ,K) reactions. The p(γ,K^0) reaction at E_γ<1.55 GeV was reported by the SAPHIR collaboration [2]. The differential cross section and the Σ^+ polarization have been measured in a wide angular range. The photon beam energy 1.55 GeV corresponds to the c.m. energy of 1.9 GeV which is close to the mass of Δ^* resonances which may contribute to the p(γ,K^0)Σ^+ reaction, but the photon energy coverage of the measurement was not enough to extract the resonance component unambiguously only from the data. We can extend the cross section measurement up to 2.4 GeV and can perform a new measurement on the beam asymmetry (Σ) in the LEPS/RCNP

facility at SPring-8, and it will enable us to make the decomposition of the resonant and the non-resonant components.

The electroproduction measurement of K^0 is in progress at TJNAF [6]. The experiment covers a similar (virtual) photon energy range with that of the LEPS/RCNP facility and different Q^2. The electroproduction has the longitudinal cross section σ_L together with the transverse cross section σ_T which is closely related to the photoproduction cross section. Thus, we propose the measurement of the K^0 photoproduction as a complementary reaction with the TJNAF electroproduction experiment.

The photon-tagging system and the magnetic spectrometer system of LEPS/RCNP have a good performance of a reconstruction of event kinematics and particle identifications. The LEPS/RCNP system is ready to measure the (γ,K^0) reaction by the reconstruction of the K_S decay ($K_S \rightarrow \pi^+\pi^-$) by a minimal modification of the setup. Further, the linearly polarized photon beam makes it possible to measure the beam asymmetry Σ with small systematic errors.

2 Physics motivation

2.1 Missing baryon resonances and the (γ,K) reaction

Baryons and mesons are effective degrees of freedom in describing hadron reactions in the low energy. Since the baryons and mesons are made of quarks and gluons, various quark models have been proposed to describe baryons and mesons from the fundamental particles. One of typical data 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 its spectrum is successfully reproduced by the quark models.

The experimental studies on the kaon photoproduction reaction may contribute to the understanding of the baryon spectrum, because a large number of baryon resonances predicted in the quark models are still missing experimentally and some of them are expected to have large branching ratios of kaon decays. The experimental studies on the kaon photoproduction reaction had a considerable progress in recent years. One of the essential changes of the experimental studies is the increase of the top-energy of photon beams which enabled us to investigate a wide range of kinematical region. The decay widths of nucleon resonances are usually wide. Thus, it is important to see the global structure of the experimental observables as a function of the photon beam energy in order to discuss the possible baryon resonance. Another important change is the improvement in intensity and quality of photon beams which is essential to obtain experimental data with good accuracy.

Detail measurements of the reaction cross section for the K^+ photoproduction off proton was performed in the photon beam energy up to 2 GeV by the SAPHIR collaboration [1]. The global photon energy dependence of the total cross section for the p(γ,K^+)Λ reaction is interpreted by assuming several N^* resonances at $\sim$1.7 GeV/c^2 and another contribution from

N^* resonance at $\sim$1.9 GeV/c^2, which is one of candidates of the missing resonances [4]. The total cross section data of the p(γ,K^+)Λ reaction from TJNAF also has a prominent peak structure at $\sim$1.9 GeV/c^2 [3]. The photon energy dependence of the p(γ,K^+)Σ^0 reaction is interpreted with the 1.7 GeV/c^2 N^* resonances in the threshold region and several Δ^* resonances at $\sim$1.9 GeV/c^2 [4]. The SAPHIR collaboration also measured the cross section of the p(γ,K^0)Σ^+ reaction [2]. The energy dependence of the total cross section seems to be consistent with the interpretation with the N^* and Δ^* resonances [5].

Although some theoretical interpretations for the global structure of the total cross section are possible, there are many assumptions or ambiguities in resonance properties, strong coupling constants, form factors in the strong vertices, etc. It is not impossible to extract reliable parameters only from the reaction cross section data. In general, polarization observables are sensitive to extract the relative phase between several reaction amplitudes and to see a minor amplitude. For the polarization observables, the measurements of the polarization P of hyperons in the (γ,K^+) and (γ,K^0) reactions have been published [1, 2]. The RCNP/LEPS facility at SPring-8 can provide another polarization observable data, beam asymmetry Σ, by using the linearly polarized photon beam, and a high precision data of the beam asymmetry Σ has been obtained for the p(γ,K^+)Λ and the p(γ,K^+)Σ^0 reactions.

Other obserbables are the cross section $d\sigma/d\Omega$ and the beam asymmetry Σ for the p(γ,K^0)Σ^+ reaction. The p(γ,K^0)Σ^+ reaction is complementary with the p(γ,K^+)Σ^0 reaction. The p(γ,K^0)Σ^+ reaction is sensitive to the N^* resonances and the p(γ,K^+)Σ^0 reaction is sensitive to the Δ^* resonances due to the isospin Clebsch-Gordan coefficients associated to the resonance decay, where the strong coupling constants $g_{K\Sigma N}$ and $g_{K\Sigma\Delta}$ are common. Therefore, the ratio of the cross sections of the two reactions essentially tells the relative strengths of N^* and Δ^* resonances. Furthermore, the beam asymmetry data of the p(γ,K^0)Σ^+ reaction may provide detailed information on the baryon resonances by comparing that of the p(γ,K^+)Σ^0 reaction. Thus, it is quite interesting to obtain the p(γ,K^0)Σ^+ reaction data with good accuracy to investigate the baryon resonances.

2.2 Reaction mechanism in the multi-GeV energy region

In the previous section, we discussed only the resonance contribution in the s-channel, but in reality there are also t- and u-channels and Born term contributions to the kaon photoproduction reaction (see Fig. 1). Since these contributions have comparable strengths, it is inevitable to discuss the (γ,K) reaction with the contributions from all diagrams. To investigate a contribution from one diagram; e.g., resonance diagram, we need to decompose the contributions. The studies on the photon energy dependence, on various observables ($d\sigma/d\Omega$, P, Σ, etc.) and on various channels are necessary to decompose the contributions.

The energy range of the photon beam of the RCNP/LEPS facility at SPring-8 is suitable for such decomposition. At the higher end of the beam energy ($\sim$ 2.4 GeV), the resonance diagram contribution becomes minor and we can study the behavior of the non-resonant diagram contributions. By using the information, the study of the resonance diagram con-

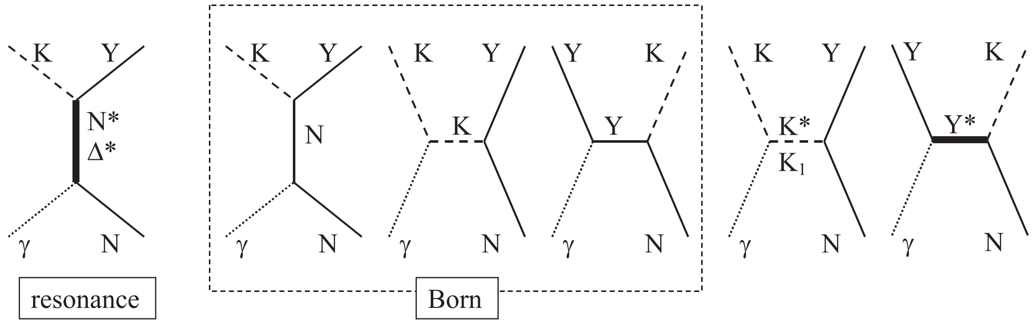

Figure 1: Various diagrams contribute to the kaon photoproduction reaction.

tribution may be possible at the lower beam energy where the non-resonant contribution is not negligible but minor.

One of outstanding features of the photon beam at the RCNP/LEPS facility is the large linear polarization of the beam. The beam is suitable to measure the beam asymmetry Σ with good accuracy. It is well known that the beam asymmetry Σ is positive and close to unity at the high energy (say 5 GeV or 10 GeV) due to a dominance of natural-parity meson exchange in the t-channel diagram [7, 8, 9]. The sign and the magnitude of the beam asymmetry Σ are good guides to estimate the t-channel diagram contribution in the (γ,K) reaction. A preliminary analysis of the beam asymmetry Σ for the p(γ,K^+)Λ and the p(γ,K^+)Σ^0 reactions at the RCNP/LEPS facility showed positive and large value at the photon beam energy over 2 GeV, and is supporting the picture of the dominance of the t-channel exchange at the energy.

Since different reaction channels, the p(γ,K^+)Λ , the p(γ,K^+)Σ^0 and the p(γ,K^0)Σ^+ reactions, have different composition of the reaction diagrams, it is interesting to measure all three reaction channels systematically. At this moment, the most poorly studied channel is the p(γ,K^0)Σ^+ reaction. The data from the SAPHIR collaboration is the only source of information, and the number of total events analyzed as the p(γ,K^0)Σ^+ reaction was *just 405 events*. The high intensity photon beam and newly installed thick liquid hydrogen target at the RCNP/LEPS facility make it possible to obtain the same level of experimental data in a quite short period of beam time as we will mention later. The experimental data to be obtained at the RCNP/LEPS facility for the p(γ,K^0)Σ^+ reaction is quite complementary with that of SAPHIR, because SAPHIR covered the beam energy up to 1.55 GeV and we will cover the beam energy from 1.5 to 2.4 GeV. The beam energy dependence of the p(γ,K^0)Σ^+ reaction in the photon energy region is quite important to decompose the resonant and the non-resonant contributions.

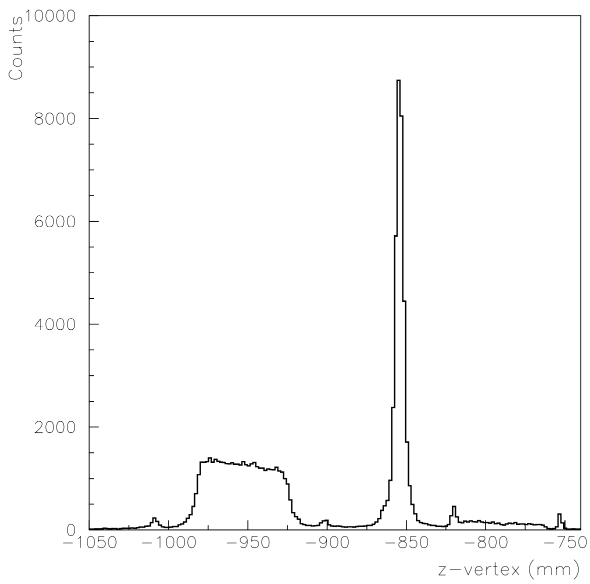

Figure 2: Typical two track vertex distribution in the beam direction for π^+ and π^- tracks. The bump from z=-985mm to -925mm corresponds to the liquid hydrogen target, and the peak at around z=-855mm is a image of the start plastic counter.

3 Experimental method

3.1 Basic setup and trigger system

Currently available setup at the LEPS/RCNP facility will be used in this experiment. We will use the laser and photon tagging system, the liquid hydrogen target (15 cm in length) and the magnetic spectrometer system for the charged particle detection. Minor modifications are necessary to detect the $\pi^+\pi^-$ pair from the K_S decay efficiently:

- The target position will be moved toward upstream by 10–15 cm to prepare a clean decay space for K_S (average decay length of K_S is about 9 cm). Current setup has almost no clean decay space between the vacuum box and the start plastic counter. Fig. 2 shows typical two-track vertex distribution for $\pi^+\pi^-$ pairs. A bump from z=-985mm to -925mm and a peak at z=-855mm correspond to the liquid hydrogen target and the start plastic counter, respectively. Small peaks at z=-1110mm and z=-905mm correspond to the entrance and the exit windows of the target vacuum box, respectively. A structure with small peaks and a bump from z=-825mm to z=-750mm corresponds to the aerogel Čerenkov detector. A clean decay space can be seen only from z=-900mm to -870mm (3 cm space).

- The index of the aerogel in the electron-veto Čerenkov detector will be changed. Since the index of refraction of the current aerogel is n=1.030, the Čerenkov detector vetoes

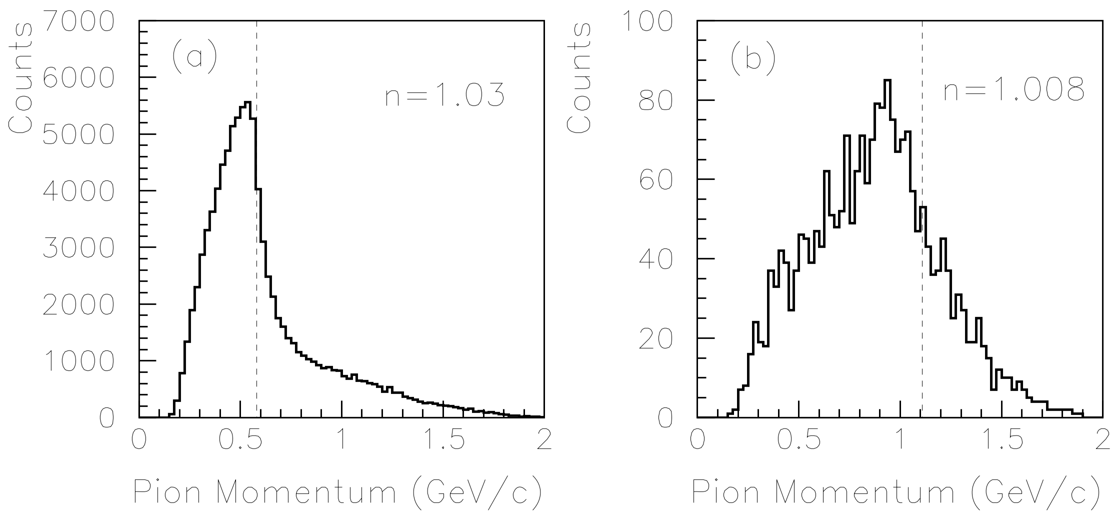

Figure 3: Momentum distributions of π^+ triggered with the threshold type aerogel veto counter. Aerogels with refractive indices (a) n=1.03 and (b) n=1.008 are used. These indices correspond to the threshold momenta of 0.58 GeV/c and 1.11 GeV/c for pion (broken lines), respectively.

almost all pions from the K_S decay. We will use n=1.008 aerogel to accept pions from the K_S decay. In a test run, we examined the effect of the change of the aerogel refractive index from 1.03 to 1.008. Fig. 3 (a) and (b) show π^+ momentum distributions of events triggered with the n=1.03 aerogel veto and the n=1.008 aerogel veto, respectively. The large difference of the momentum distributions came from the Čerenkov thresholds of 0.58 GeV/c and 1.11 GeV/c for aerogels of n=1.03 and n=1.008, respectively. The result showed that the trigger with the n=1.008 aerogel veto could accept a large fraction of pions from the K_S decay.

- Aerogel veto threshold will be changed. Fig. 4 shows relative photon numbers from n=1.008 aerogel Čerenkov radiator. The solid curve and the broken line are the results calculated for single charged pion and a e^+e^- pair, respectively. The maximum momentum of pion from the K_S decay is about 1.8 GeV/c (indicated with arrow), and either of pions from the K_S decay exceeds the Čerenkov threshold (see Fig. 5). For the K_S detection, a fine tuning of the threshold setting of the Čerenkov detector is necessary.

- We believe these two modifications are enough to detect K_S by reconstructing the $K_S \to \pi^+\pi^-$ decay. But, the separation of the K_S decay pions from the e^+e^- pair with the aerogel Čerenkov detector alone may introduce an over-veto which is usually K_S momentum dependent. To avoid an inefficiency due to the over-veto, we may make

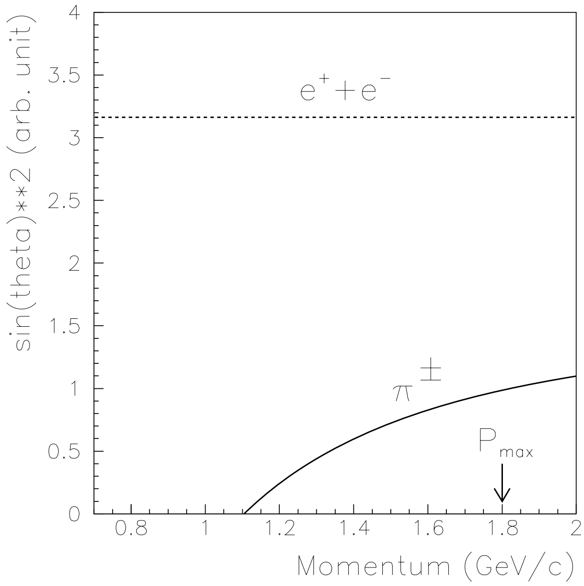

Figure 4: Relative light output of the Čerenkov detector with a n=1.008 aerogel radiator. The solid curve and the broken line are calculated for single charged pion and a e^+e^- pair, respectively. The Čerenkov threshold for pion is 1.1 GeV/c. Maximum momentum of pions from the K_S decay is indicated by the arrow (P_{max}).

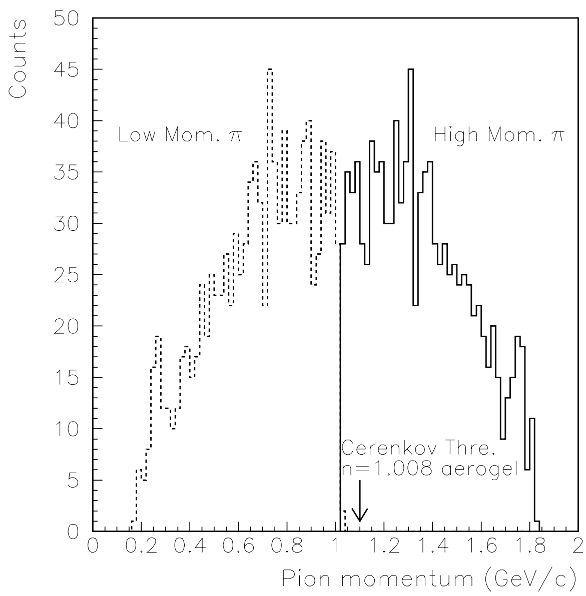

Figure 5: Pion momentum distribution from the K_S decay. K_S momentum is 2 GeV/c. Momentum distributions of pions with higher (solid) and lower (dashed) momenta are plotted separately.

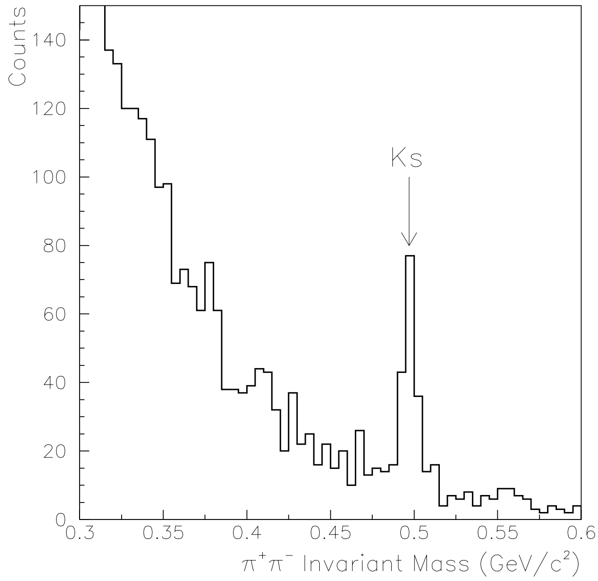

Figure 6: An invariant mass spectrum for $\pi^+\pi^-$ pairs. The aerogel Čerenkov radiator with n=1.03 is used.

the online threshold on the Čerenkov detector looser and use the multiplicity=2 trigger from the TOF-wall to enhance the hadron two track events. Another possibility of the efficient e^+e^- rejection is to introduce a small new plastic scintillation counter with a small hole in the center in front of the start plastic counter. Almost all background e^+e^- pairs go through the hole and do not create the trigger signal.

3.2 K_S identification

The K_S identification will be made with the vertex reconstruction of the $K_S \to \pi^+\pi^-$ decay and the invariant mass reconstruction.

Since we prepare clean decay space of 10–15 cm in the air, backgrounds from the multi-pion photoproduction reaction is negligible. If we assume position resolution of 300 μm and 100 μm for the drift chamber (DC1) and the tracking SSD, respectively, in the current setup, the vertex resolution in the beam direction for two charged pions from the K_S decay is estimated to be about 4 mm. This value is quite consistent with the widths (about 3.5 mm r.m.s.) of the peak in Fig. 2 which corresponds to the start plastic counter (5 mm in thickness). The vertex resolution is good enough to identify K_S decay in flight events from the background multi-pion production reactions. Additional information of the vertex position perpendicular to the beam axis also helps us to distinguish the K_S decay events from backgrounds for K_S emitted to angles larger than about 5 degrees.

Fig. 6 shows a plot of the $\pi^+\pi^-$ invariant mass measured at LEPS/RCNP. The peak at around 0.5 GeV/c^2 corresponds to the $K_S \to \pi^+\pi^-$ decay. The invariant mass resolution for

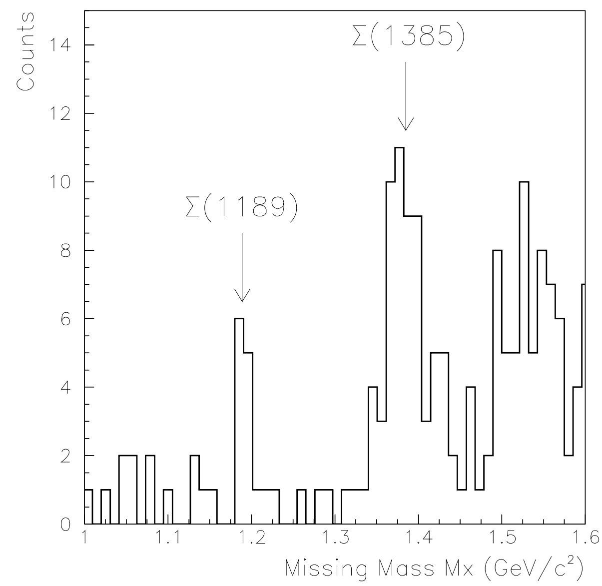

Figure 7: A preliminary missing mass (M_X) spectrum for the p(γ,K$_S$)X reaction. The aerogel Čerenkov radiator with n=1.03 is used.

K_S is about 5 MeV/c^2 (r.m.s.). Though the momentum of K_S in the proposed experiment is slightly larger than that in Fig. 6, we expect similar invariant mass resolution in the proposed experiment.

The combination of the decay vertex and the invariant mass cuts provides a clear identification of K_S .

3.3 Identification of Σ^+ formation

Hyperons excited via the (γ,K^0) reaction are only Σ(1189) and Σ(1385) at the LEPS/RCNP beam energy. The formation of the hyperons is identified by calculating the missing mass M_X by assuming the γ+p$\rightarrow$K^0+X kinematics.

The missing mass resolution of about 15 MeV/c^2 (r.m.s.) has been obtained for the (γ,K$^+$) reaction. Since the kinematics of the (γ,K^0) reaction is similar with that of the (γ,K$^+$) reaction, a missing mass resolution of $\sim$15 MeV/c^2 will be achieved, and this resolution is good enough to separate Σ(1189) and Σ(1385). Fig. 7 shows a preliminary missing mass M_X spectrum for the p(γ,K$_S$)X reaction. We can see a sharp peak at around 1.19 GeV/c^2 correspondind to the Σ(1189) formation, and the width of the peak is consistent with the missing mass resolution mentioned above. Another broad peak corresponds to the Σ(1385) resonance excitation, and the width of the peak is consistent with the width of the resonance (35.8 ± 0.8 MeV from the PDG compilation). The yields above 1.5 GeV/c^2 presumably comes from the ϕ photoproduction followed by the $\phi \rightarrow K^0\bar{K}^0$ decay.

Table 1: Summary of branching ratio and efficiency.

	branching ratio and efficiency
$K^0 \to K_S$	0.5
$K_S \to \pi^+\pi^-$	0.69
Finite K_S decay space	0.7
π^+ and π^- in the spectrometer	0.12
Overall efficiency ε	0.028

3.4 Detection efficiency

The estimation of the efficiency of K_S detection is summarized in Table 1. A half of K^0 produced by the (γ,K^0) reaction decay as K_S (others as K_L). The K_S dominant decay modes are $K_S \to \pi^+\pi^-$ (69%), which will be measured in this experiment, and $K_S \to \pi^0\pi^0$ (31%). About 70% of K_S decay within the clean decay space prepared in this experiment if we assume the average decay length of K_S is about 9 cm. The detection efficiency of the $\pi^+\pi^-$ pair by the magnetic spectrometer is estimated by a simulation calculation with realistic geometries of the detector elements and materials in the spectrometer. Over all K_S detection efficiency is about 2.8%.

4 Request for beam and equipment

4.1 Yield estimation

The differential cross section of the p(γ,K^0)Σ^+ reaction was measured by the SAPHIR collaboration [2] up to E_γ=1.55 GeV and typical cross section at forward angles was 0.1 μb/sr in the c.m. system. We expect the LEPS/RCNP provides 4×10^5 tagged photons per second on the target and the standard 15 cm liquid hydrogen target is available. The angular acceptance of the magnetic spectrometer is roughly 0.70×0.35 sr. The yield can be estimated as follows:

$$Y = \frac{d\sigma}{d\Omega_{cm}} \cdot \frac{d\Omega_{cm}}{d\Omega_{lab}} \cdot \Delta\Omega \cdot N_{Target} \cdot N_{Beam} \cdot \varepsilon$$

where ε is the overall K_S detection efficiency listed in Table 1. The factor $d\Omega_{cm}/d\Omega_{lab}$ is estimated to be about 5.7 by a kinematical calculation. By a numerical calculation, we get a K_S detection rate as follows:

$$Y \sim 0.1 \times 10^{-30} \cdot 5.7 \cdot 250 \times 10^{-3} \cdot 6 \times 10^{23} \cdot 4 \times 10^5 \cdot 0.028 \sim 1 \times 10^{-3} \text{event/s}$$

This rate corresponds to about 85 events detection of the p(γ,K^0)Σ^+ reaction in a day.

4.2 Run schedule

The experimental procedure consists of two steps.

1. Perform a test of the n=1.008 aerogel Čerenkov detector again. We saw the momentum acceptance of pions was largely improved by the change of the aerogel refractive index from 1.03 to 1.008 in the last aerogel Čerenkov detector test (see Fig. 3 and Sec.3.1). But, the over-veto probability was not well known and the threshold dependence study was not performed. The thickness of the aerogel should be increased from 6 cm to 9 cm in the next test. For the test, we need about 5 shifts (40 hours).

2. Data taking for physics run will be performed. We need about 42 shifts (14 days) of beam time to accumulate about 1000 events of the $p(\gamma,K^0)\Sigma^+$ reaction. The number of events is larger than that from the SAPHIR collaboration. Several short empty target runs are necessary to estimate the background from materials other than the liquid hydrogen target, and are included in the beam time estimation.

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