LEPS/RCNP proposal

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

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1 Abstract

A new measurement of the (γ,K^0) reaction at the sub-GeV energy region gives us rich information on the reaction mechanism of the kaon photoproduction if we combine the results of the new measurement with that of the (γ,K^+) reaction measurement which is already proceeding in LEPS/RCNP at SPring-8. We focus to the small $-t$ region ($-t$<0.4 GeV) where the t-channel diagram contribution is expected to be dominant over other diagrams. High-statistics measurements of the differential cross section ($d\sigma/dt$) and the polarized photon beam asymmetry parameter (Σ) for the (γ,K^0) reaction may provide information to make clear understanding of the reaction mechanism of the sub-GeV kaon photoproduction reactions. The Σ parameter has a simple and direct relation with t-channel diagrams with different exchange mesons, so the measurement of the Σ parameter is essential to understand the reaction mechanism in the kinematical region we wish to investigate.

Recently, the p(γ,K^0) reaction at E_γ<1.55 GeV was reported by the SAPHIR collaboration [1]. The differential cross section and the Σ^+ polarization have been measured in a wide angular range. The angular dependences of the cross section and the Σ^+ polarization are presumably determined by interplay of the s-, t- and u-channel diagrams, but clear discussion was not possible due to the poor statistics of the data. We can extend the measurements at the beam energy up to 2.4 GeV at LEPS/RCNP. The t-channel contribution is expected to

be enhanced as the increase of the beam energy, and more clear discussion of the reaction mechanism may be possible.

The electroproduction of K^0 is under proceeding at TJNAF [2]. 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, this proposed measurement of the K^0 photoproduction and the TJNAF electroproduction experiment are complementary each other.

The photon-tagging 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 ($K_S \to \pi^+\pi^-$) by a minimal modification of the setup. Further, the linear-polarized photon beam makes it possible to measure the Σ parameter with small systematic error.

2 Physics motivation

The study of the kaon photoproduction in the sub-GeV energy region is one of interesting fields of hadron physics.

The sub-GeV is a transitional energy region from the complex picture with numerous baryon resonances to relatively simple asymptotic picture. The knowledge from the asymptotic picture will help us much to understand the reaction mechanism in the sub-GeV energy region especially at the small $-t$ region. In the small $-t$ region, the contribution of the t-channel meson exchange (or exchange of series of mesons in Regge trajectories) is expected to be dominant over other channels. A recent measurement of the differential cross section of the p(γ,K^+)Λ and the p(γ,K^+)Σ^0 reactions by the SAPHIR collaboration shows forward peaking at E_γ>1.5 GeV and E_γ>1.75 GeV, respectively [3]. It may indicates the t-channel dominance of the (γ,K^+) reaction at the energy regions. An Λ electroproduction reaction data has been reported by the CLAS collaboration at TJNAF (W=1.6-2.7 GeV), a similar forward peaking in the kaon emission angle distribution was seen, and it was interpreted as a results of a large t-channel contribution [4].

Exchanged strange mesons relevant to the kaon photoproduction are K, K^*, etc. The contribution of the K-exchange is significant in the very small $-t$ region, $-t \sim m_K^2 (\sim 0.25\ \mathrm{GeV}^2)$, while contributions of other heavier strange mesons is significant in the $-t$ region larger than that. This t dependence is observed experimentally in the differential cross section, $d\sigma/dt$, of the p(γ,K^+)Λ and the p(γ,K^+)Σ^0 reactions in the energy range E_γ=5-16 GeV (summarized in Ref. [5]). By selecting the $-t$ region, we may separate contributions from different exchange diagrams in measured reaction cross sections and polarization observables. Thanks to the high energy photon beam at LEPS/RCNP, we can access to the small $-t$ region, at least, for the Λ and Σ photoproduction. Among the polarization observables, the polarized photon beam asymmetry Σ has close relation with the spin-parity of the exchanged meson for pseudo-scalar meson photoproduction in the asymptotic energy region; i.e., unnatural

parity exchange (like K-exchange) results in negative value of Σ and natural parity exchange (like K*-exchange) results in positive value [6, 7]. So, we may see rapid change of the value of the Σ parameter as the change of the $-t$ value if several exchange processes are competing.

Different reaction channels, (γ,K$^+$) and (γ,K^0), obey different reaction mechanisms. Since K^0 has no charge and no spin, the K^0-exchange do not contribute to the (γ,K^0) reaction and the K^{*0}-exchange is the dominant process, while exchanges of both mesons contribute to the (γ,K$^+$) reaction. The (γ,K^0) reaction is an ideal probe to investigate the K*-exchange contribution in the photoproduction reaction, and the information from the (γ,K^0) reaction is quite useful to extract the K-exchange contribution in the (γ,K$^+$) reaction.

Photoproduction reactions of different hyperons, Λ, Σ, $\Lambda^*$and Σ^*, have different values of parameters which determine relative amplitudes of various diagrams and may be related each other based on the SU(6) symmetry. An example is the KYN coupling constant, g_{KYN}. From experimental data and theoretical considerations, the coupling constant for Σ, $g_{K\Sigma N}$, is considerably smaller than that of Λ, $g_{K\Lambda N}$, and opposite in sign. This may affect to the difference of the t dependences of the cross section and the polarization observables between the p(γ,K$^+$)Λ and the p(γ,K$^+$)Σ^0 reactions. Similar analyses may be possible also for the K*YN coupling constants by using the data of the (γ,K$^+$) and the (γ,K^0) reactions. The SAPHIR measurement of the Λ and Σ^0 polarizations in the p(γ,K$^+$)Λ and p(γ,K$^+$)Σ^0 reactions show large negative and positive values, respectively, at the forward angles [3]. The different signs of the hyperon polarizations may be interpreted by the sign difference of the coupling constants in simple mind, while sophisticated theoretical calculations failed to reproduce the absolute value, usually too small, and the sign of the hyperon polarization. New knowledge from the experimental side is quite important to guide the theoretical works.

It is quite interesting to study and understand the reaction mechanisms of the two associate strangeness photoproduction reactions, the (γ,K$^+$) and the (γ,K^0) reactions, with the same level of the data quality and a common framework of analyses.

3 Experimental method

3.1 Basic setup and trigger system

Currently available setup at the LEPS/RCNP facility will be used in this experiment (see Fig. 1). We will use the laser and photon tagging system, the liquid hydrogen target (5 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 upstream by about 10 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 (a) and (b) show typical two track vertex distribution in the current setup for pπ^- and $\pi^+\pi^-$ pairs, respectively. A bump from z=-990mm to -920mm and a peak at z=-855mm

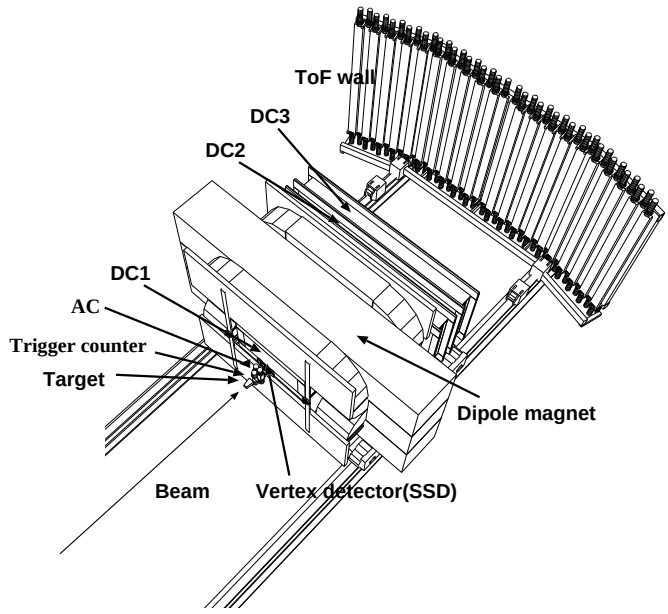

Figure 1: The current LEPS/RCNP setup (the magnetic spectrometer).

correspond to the liquid hydrogen target and the start plastic counter, respectively. A small bump at z=-905mm in Fig. 2 (b) corresponds to materials around the exit window of the target vacuum box. A clean decay space can be seen only from z=-900mm to -870mm. Since there is less contribution of particle decay in flight for the $\pi^+\pi^-$ pair, we see less events between the target and the start plastic counter in Fig. 2 (b) than events in (a).

- 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 all pions from the K_S decay. We will use n=1.008 aerogel to accept pions from the K_S decay. Fig. 3 shows relative photon numbers from 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 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. 4). 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 efficiently by the reconstruction of 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 inefficiency due to the over-veto, we may make 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.

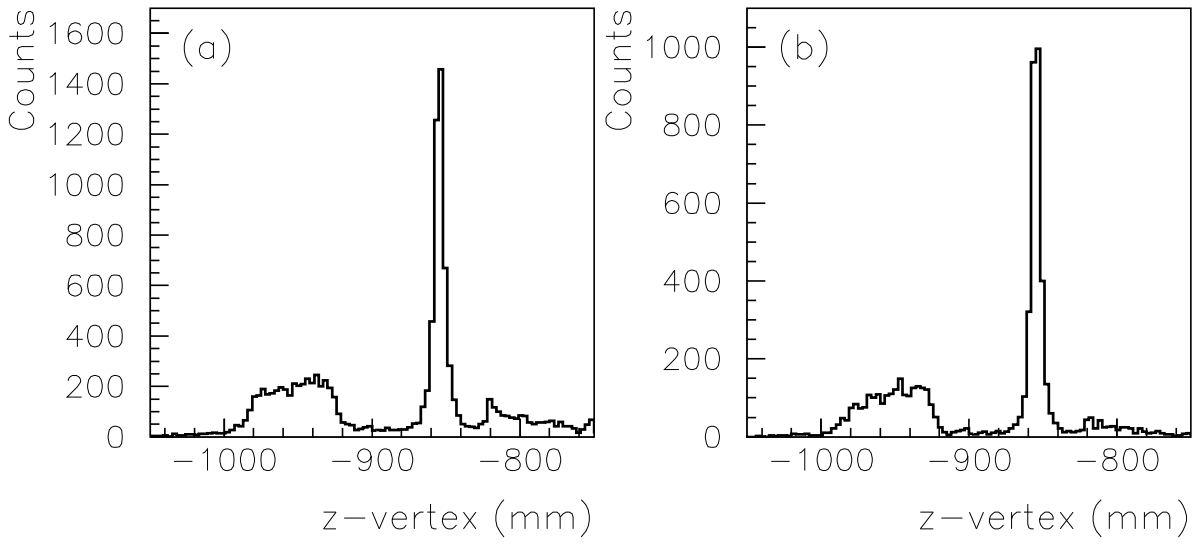

Figure 2: Typical two track vertex distribution in the beam direction for (a) proton and π^- tracks and (b) for π^+ and π^- tracks. The bump from z=-990mm to -920mm corresponds to the liquid hydrogen target, and the peak at around z=-855mm is a image of the start plastic counter. A small bump at z=-905mm in (b) corresponds to materials around the exit window of the target vacuum box.

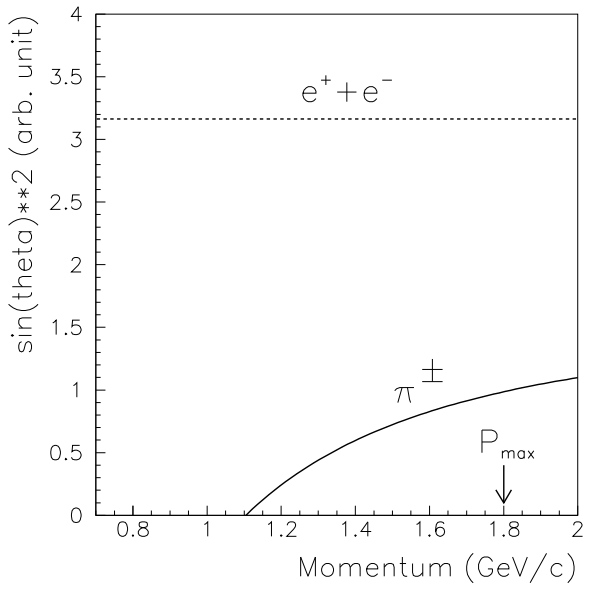

Figure 3: Relative light output of the Čerenkov detector with a n=1.008 aerogel radiator. The solid curve and the broken line are calculated for single charged pion and a e^+e^- pair, respectively. The Čerenkov threshold for pion is 1.1 GeV/c. Maximum momentum of pions from the K_S decay is indicated by the arrow (P_{max}).

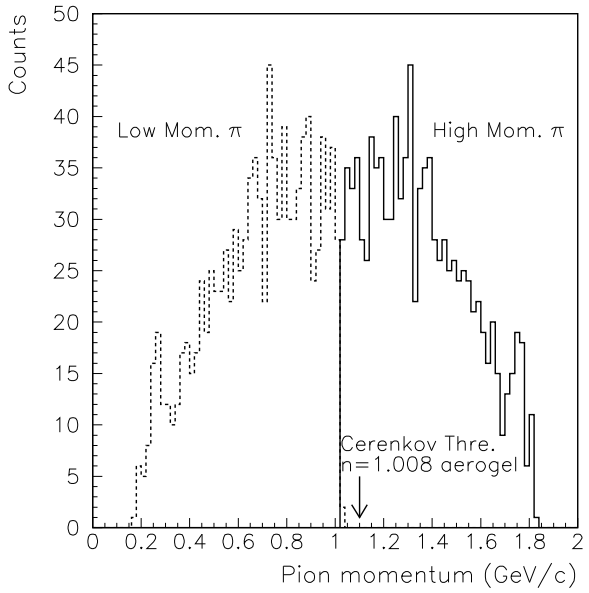

Figure 4: Pion momentum distribution from the K_S decay. Momentum distributions of pions with higher (solid) and lower (dashed) momenta are plotted separately. K_S momentum is 2 GeV/c.

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 about 10 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 peaks in Fig. 2 (a) and (b) which corresponds to the start plastic counter (5 mm in thickness). 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 the angles larger than about 5 degrees.

The invariant mass resolution was obtained for $\Lambda \to p\pi^-$ decay from LEPS/RCNP experimental data (see Fig. 5 (a)). The resolution of the invariant mass was about 2.5 MeV/c^2 (r.m.s.) for Λ with momentum around 1.5 GeV/c. In general, the invariant mass resolution in a X$\to$1+2 decay is estimated as follows:

$$M_X \delta M_X = (\frac{E_2}{E_1}\vec{p}_1 - \vec{p}_2) \cdot \delta\vec{p}_1 + (\frac{E_1}{E_2}\vec{p}_2 - \vec{p}_1) \cdot \delta\vec{p}_2$$

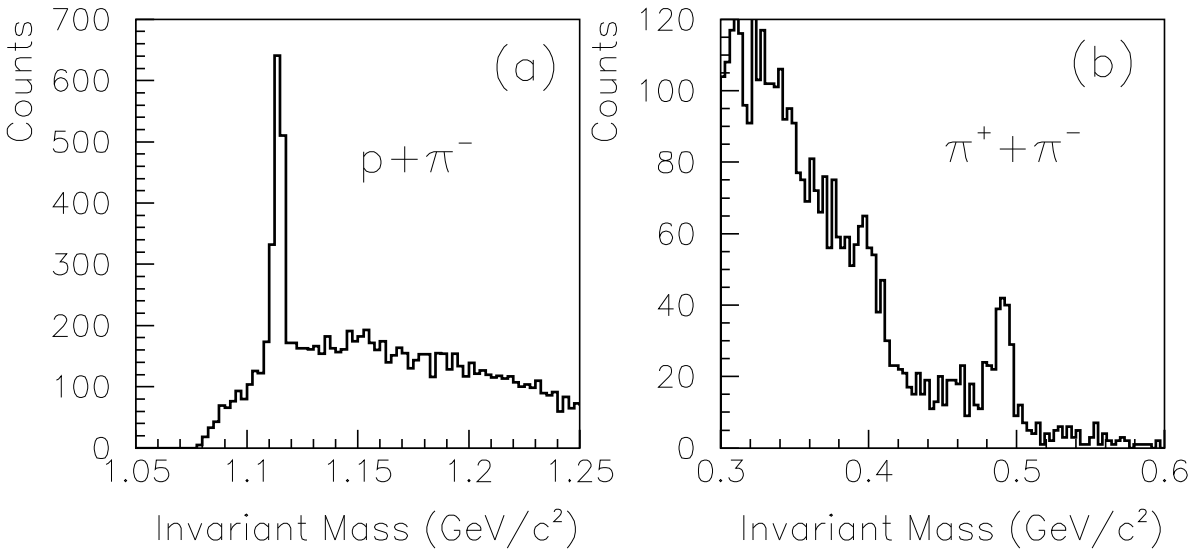

Figure 5: Invariant mass distribution (a) for $p\pi^-$ and (b) $\pi^+\pi^-$ pairs.

The Λ invariant mass resolution δM_Λ is estimated as follows:

$$\delta M_\Lambda^2 \sim (70\ \delta\theta_p)^2 + (80\ \delta\theta_{\pi^-})^2 + (50\ \frac{\delta p_p}{p_p})^2 + (60\ \frac{\delta p_{\pi^-}}{p_{\pi^-}})^2 \quad MeV^2$$

where $\delta\theta_p$, $\delta\theta_{\pi^-}$, $\delta p_p/p_p$ and δ_{π^-}/p_{π^-} are angular resolutions of proton and π^- and fractional momentum resolutions of proton and π^-, respectively. The angular resolution is mainly coming from the multiple scattering due to materials after the target, especially the aerogel Čerenkov radiator. Similar estimation for the $K_S \to \pi^+\pi^-$ decay tells:

$$\delta M_{Ks}^2 \sim (390\ \delta\theta_{\pi^+})^2 + (390\ \delta\theta_{\pi^-})^2 + (70\ \frac{\delta p_{\pi^+}}{p_{\pi^+}})^2 + (70\ \frac{\delta p_{\pi^-}}{p_{\pi^-}})^2 \quad MeV^2$$

Though the coefficients for the angular resolution contributions are considerably larger than that for the Λ decay, the angular resolutions themselves are smaller than that of Λ decay because the pion momentum is higher and the aerogel Čerenkov radiator is thiner in the K_S decay measurement. We believe the invariant mass resolution for K_S decay is about two times larger than that of the Λ decay; i.e., about 5 MeV/c^2 (r.m.s.).

The 5 (b) shows a preliminary plot of the $\pi^+\pi^-$ invariant mass measured at LEPS/RCNP. The peak at around 0.49 GeV/c^2 corresponds to the $K_S \to \pi^+\pi^-$ decay. Though the momentum of K_S in the plot is smaller than that of K_S to be measured in the proposed experiment, the peak width of about 5 MeV/c^2 (r.m.s.) is supporting the estimation of the invariant mass resolution.

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

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	0.5
π^+ and π^- in the spectrometer	0.15
Overall efficiency	0.026

3.3 Identification of Σ^+ formation

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

The missing mass resolution of about 15 MeV/c^2 (r.m.s.) has been obtained for the (γ,K^+) reaction at LEPS/RCNP, and it is good enough to separate the Λ and Σ formations. Since the kinematics of the (γ,K^0) reaction is similar with that of the (γ,K^+) reaction, the same level of missing mass resolution is expected to be achieved.

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 50% of K_S decay within the clean decay space prepared in this experiment (about 10 cm) 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 2.6%.

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 [1] up to E_γ=1.55 GeV and typical cross section at the forward angle was 0.1 μb/sr in the c.m. system. We expect the LEPS/RCNP provides 5×10^5 tagged photons per second and the standard 5 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 K_S detection efficiency listed in Table 1.

$$Y \sim 0.1 \times 10^{-30} \cdot 8 \cdot 250 \times 10^{-3} \cdot 2 \times 10^{23} \cdot 5 \times 10^{5} \cdot 0.026 \sim 5.2 \times 10^{-4} \text{events/s}$$

This rate corresponds to about 45 events detection of the p(γ,K^0)Σ^+ reaction in a day.

4.2 Run schedule

The experimental procedure consists of three steps.

1. Prepare the new Čerenkov trigger detector with lower index aerogel and study the performance of the detector with the LEPS/RCNP photon beam. Several prototypes of the new Čerenkov detector will be prepared because the increase of the average number of photons from the n=1.008 aerogel radiator to PMT tube(s) is essential to achieve a good trigger condition. At the same time, the trigger rate study is necessary combining the new Čerenkov detector and the TOF-wall multiplicity=2 trigger. Over-veto probability for several threshold settings should be estimated. For the procedure, we need about 5 shifts (40 hours).

2. To demonstrate a clear identification of K_S, we will accumulate about 120 events of the p(γ,K^0)Σ^+ reaction. It takes about 3 days (72 hours). Final adjustment of the target and detector geometries and the trigger condition will be made according to the results of the measurement. Information to estimate more precise K_S yield will be obtained.

3. Final data taking will be done to accumulate about 2000 events of the p(γ,K^0)Σ^+ reaction (1000 events for each polarization setting). Several short empty target runs are necessary to estimate the background from materials other than the liquid hydrogen target. We estimate the run time to be about 2 months (1440 hours).

4.3 New equipment to be installed

Essentially we need no new equipment to be installed in the current LEPS/RCNP setup. We need to update the aerogel Čerenkov detector. The n=1.008 aerogel radiator has been tested, but further test is need for the (γ,K^0) reaction measurement because the Čerenkov detector is a key detector to trigger the K_S decay events efficiently. We also need to move the liquid hydrogen target position by about 10 cm.

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