Θ^+ Search at the SPring-8 LEPS Experiment

D. S. Ahn[1], J. K. Ahn[2], H. Akimune[3], W. C. Chang[4], S. Date[5], H. Fujimura[6], M. Fujiwara[1], S. Fukui[7], T. Ishikawa[8], K. Imai[6], K. Hicks[9], K. Horie[1], T. Hotta[1], K. Kino[1], H. Kohri[1], T. Matsuda[10], T. Matsumura[11], T. Mibe[9], M. Miyabe[6], N. Muramatsu[1], T. Nakano[1], M. Niiyama[6], Y. Ohashi[5], D. S. Oshuev[4], C. Rangacharyulu[12], A. Sakaguchi[13], Y. Shiino[14], H. Shimizu[8], Y. Sugaya[13], M. Sumihama[1], Y. Toi[10], T. Yorita[5], M. Yosoi[1], and R. G. T. Zegers[15]

[1]*Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka 567-0047, Japan*
[2]*Department of Physics, Pusan National University, Busan 609-735, Korea*
[3]*Department of Physics, Konan University, Kobe, Hyogo 658-8501, Japan*
[4]*Institute of Physics, Academia Sinica, Taipei 11529, Republic of China*
[5]*Japan Synchrotron Radiation Reasearch Institute, Sayo, Hyogo 679-5143, Japan*
[6]*Department of Physics, Kyoto University, Kyoto 606-8502, Japan*
[7]*Department of Physics, Nagoya University, Aichi 464-8602, Japan*
[8]*Laboratory of Nuclear Science, Tohoku University, Sendai, Miyagi 982-0826, Japan*
[9]*Department of Physics and Astronomy, Ohio University, Athens, Ohio 45701, USA*
[10]*Department of Applied Physics, Miyazaki University, Miyazaki 889-2192, Japan*
[11]*National Defence Academy in Japan, Yokosuka, Kanagawa 239-8686, Japan*
[12]*Department of Physics and Engineering Physics, University of Saskatchewan, Saskatoon SK S7N 5E2, Canada*
[13]*Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*
[14]*Department of Physics, Chiba University, Chiba 263-8522, Japan*
[15]*National Superconducting Cyclotron Laboratory, Michigan State University, Michigan 48824-1321, USA*

1 Introduction

The LEPS collaboration reported the first evidence for the Θ^+ in the reaction γ C $\rightarrow \Theta^+$ K$^-$ X from the plastic scintillating counter [1]. The Θ^+ was identified as a pentaquark baryon with strangeness +1 in the missing mass spectrum of K$^-$ with the Fermi motion correction. Its existence has been examined at many other facilities, and observations of the resonance structure were followed by DIANA, CLAS, SAPHIR, neutrino experiments with bubble chambers, HERMES, ZEUS, COSY-TOF, and SVD-2 [2]. On the other hand, many high energy experiments including BaBar, Belle, HERA-B, SPHINX, HyperCP, CDF, FOCUS have reported null results, and some of them have set upper limits to the production ratio of the Θ^+ to the $\Lambda(1520)$ below a few %. Since the statistical siginificances in a series of early observations were not high enough, further confirmations with the high statistics data continued, and some of new results appeared recently [3]. Especially the CLAS experiment collected 30 times more data with a liquid deuterium target, and their earlier observation in the reaction γ d $\rightarrow$ p K$^-$ Θ^+ was not supported. The upper limit for the total cross section was set to 0.3 nb at the 95% confidence level.

2 The LEPS experiment

A photon beam was produced by backward Compton scattering of an Ar laser from 8-GeV electrons in SPring-8. The maximum photon energy is 2.4 GeV, and photons above 1.5 GeV were tagged by detecting recoil electrons whose momenta were measured with a SPring-8 bending magnet. The liquid hydrogen (LH_2) or deuterium (LD_2) target was exposed to the photon beam with the intensity of $\sim 10^6$/sec. Charged particles produced in the photoreactions were detected by the forward spectrometer which consisted of a silicon vertex detector, three drift chambers and a dipole magnet (0.7 Tesla). Particle indentification was done by measuring the time-of-flight at the plastic scintillator wall 4-m downstream of the target. The mass of the detected particle was calculated by combining the measured momentum and the time-of-flight. Electrons, positrons, and pions (P_π > 0.6 GeV/c) were vetoed by the aerogel Čerenkov counter (n = 1.03).

The target system was upgraded to have three times larger thickness (15 cm) after the first production runs with the LH_2 target, which had provided the first evidence for the Θ^+. New data was collected in the years 2002 - 2003, and the integrated number of tagged photons reached $\sim 1.4\times10^{12}$ for the LH_2 runs and $\sim 2\times10^{12}$ for the LD_2 runs. The number of events for the reaction $\gamma n \rightarrow \Theta^+ K^-$ in the LD_2 runs was expected to be 5 times larger than for the data set analyzed to obtain the first evidence. The LH_2 data was used to calibrate the detectors and to provide estimates for the background spectrum.

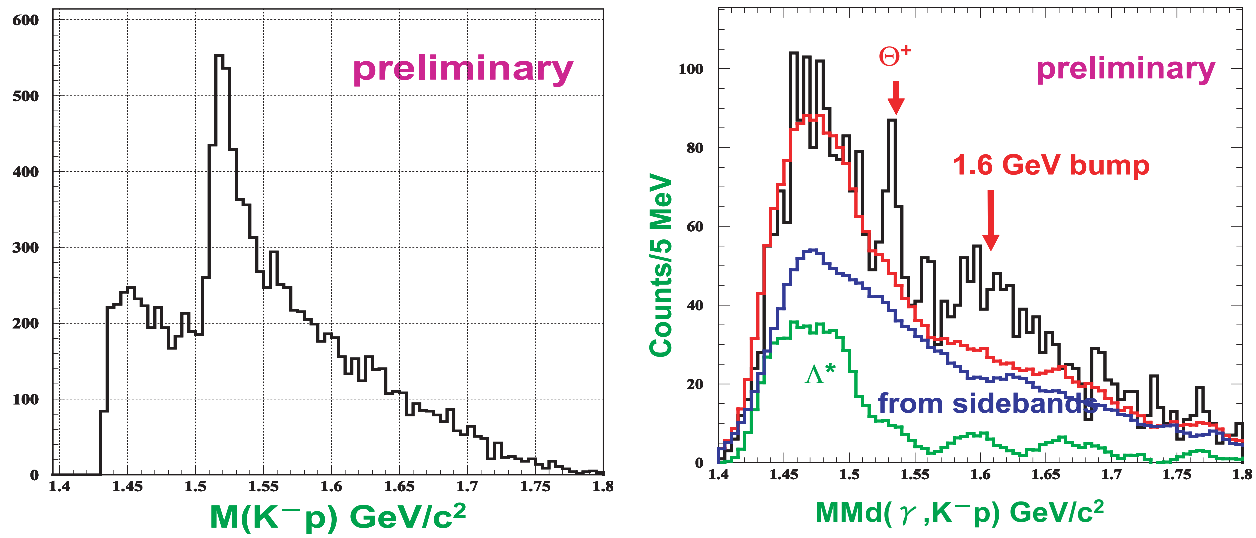

Figure 1: The left panel shows the K^-p invariant mass distribution in the LD_2 data. The right panel shows the missing mass spectrum of the K^-p from the deuteron after selecting the $\Lambda(1520)$ production region in the LD_2 data. Estimates for the background spectra based on side bands are also shown.

3 Preliminary results

Events where two charged particles were detected at the forward spectrometer were selected from the collected data. In the case that K^+ and K^- were detected (K^+K^- mode), the Θ^+ was searched for in the missing mass spectrum of K^- from the neutron by applying a correction for the Fermi motion. When K^- and proton were detected (K^-p mode), the Θ^+ was identified in the missing mass of the K^-p from the deuteron without the Fermi correction. In the present analysis, the final state of the K^-p mode is the same as the CLAS analysis described above. But the acceptance coverage of the K^-p detection was different, and the kinematical region where the K^-p invariant mass formed the $\Lambda(1520)$ resonance was analyzed.

In the K^-p mode, their missing mass assuming the proton mass in the initial state was required to be around the K^+ mass (0.40 to 0.62 GeV/c^2) in order to remove events which had an additional pion in the final state or where a pion was misidentified as a K^-. The left panel of Figure 1 shows the K^-p invariant mass distribution. The selected sample includes quasi-free production of $K^+\Lambda(1520)$ and non-resonant K^+K^-p final states in addition to ϕp which is clearly seen in the Fermi-corrected missing mass of proton. The right panel of Figure 1 shows the missing mass spectrum of the K^-p from the deuteron after requiring that the invariant mass corresponds to the $\Lambda(1520)$ mass (1.50 to 1.54 GeV/c^2). A peak structure was observed at 1.53 GeV/c^2 in addition to a bump structure around 1.6 GeV/c^2. These structures were not observed in the other regions of the K^-p invariant mass spectrum.

A reliable estimate of the background spectrum is essential in order to judge whether the observed structures are due to fluctuations or not. Two complementary methods were adopted for this purpose. One is the method to estimate the individual background spectra by MC simulations. The kinematics of those background processes were extracted from the LH_2 data. Then Fermi motion was taken into account in the simulations so that the background spectra represent the LD_2 data. In the other method, the spectra for non-resonant K^+K^-p and ϕp production were obtained by averaging the missing mass spectra in the side-band regions of the K^-p invariant mass. The component from $\Lambda(1520)$ production was estimated from the LH_2 data because the effect by the Fermi motion was small. The estimated background spectra from the latter method is overlayed in the right panel of Figure 1. These methods gave a statistical significance of 4-5σ in the missing mass region of 1.520 - 1.545 GeV/c^2.

The width of the cut to select $\Lambda(1520)$ production was varied as shown in Figure 2 in order to check whether the Θ^+ production was associated with the $\Lambda(1520)$. The S/N ratio of the peak structure was increased with the narrower cut while it dropped with the wider cuts. The peak height was kept while varying the width. This dependence shows a signal-like behavior of the reaction $\gamma\ d \to \Theta^+\ \Lambda(1520)$.

In the K^+K^- detection mode, the incoherent photoproduction of the K^+K^- final state was selected by omitting events in the lower tail of the missing mass spectrum of the K^+K^-. A ϕ exclusion cut which depended on the photon energy was also applied. Figure 3 shows the missing mass spectrum of K^- with the Fermi motion correction. An excess is observed at 1.53 GeV/c^2 above the background spectrum which was deduced by mixing K^+, K^-, and initial photons from different events in the real data. More studies of the missing mass spectrum

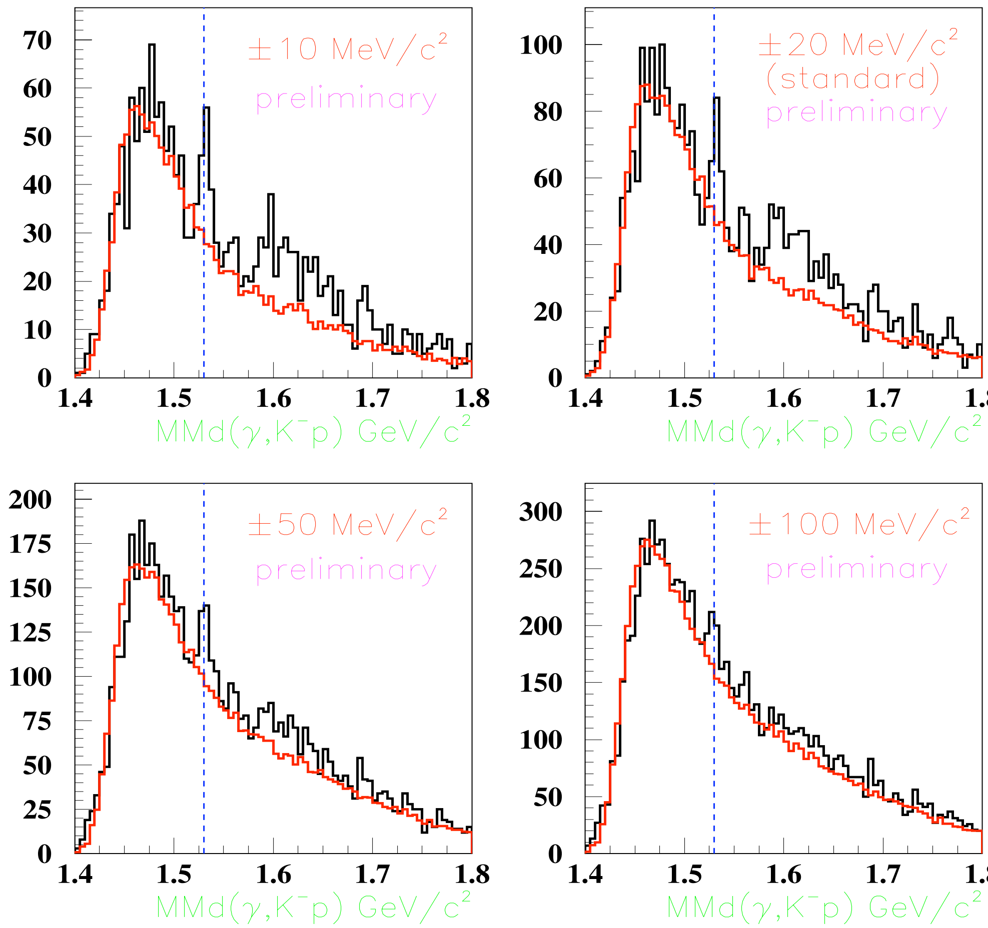

Figure 2: The K$^-$p missing mass distributions in the LD$_2$ data. The width of the cut to select the $\Lambda(1520)$ resonance was varied from ± 10 MeV/c^2 to ± 100 MeV/c^2. The background spectra from the MC simulations are also overlayed.

are in progress.

4 Summary and future prospects

The existence of the Θ^+ was examined in the photoreaction with a liquid deuterium target by detecting two charged particles in the forward spectrometer. In the K$^-$p detection mode, a peak structure was observed at 1.53 GeV/c^2 in the K$^-$p missing mass spectrum from the deuteron. This peak structure was associated with $\Lambda(1520)$ production. The background spectrum was estimated with two complementary methods, and the statistical significance of the observed structure was 4-5σ. Differential cross sections are being measured, and the connections with the CLAS experiment and the high energy experiments will be examined. A peak structure at 1.53 GeV/c^2 was also observed in the K$^+$K$^-$ detection mode, where the K$^-$ missing mass from the neutron was plotted with the Fermi motion correction.

Data collection with a higher intensity beam is desired to confirm the existence of the Θ^+. Currently, a new method that injects two lasers simultaneously into SPring-8 is being tested. Additional data will be collected with this high intensity beam in the year 2006. It is also planned to cover acceptance regions other than the forward direction. A new time projection chamber is under construction in order to surround the target. It is expected to cover the CLAS acceptance region in addition to the LEPS region. A higher intensity and higher energy photon beam may become available at the new beamline proposed at SPring-8. In the poposed project, a larger detector system based on the BNL-E949 detector is under considerations to cover the 4π solid angle with better mass resolution. Efforts to confirm the existence of the Θ^+ will continue.

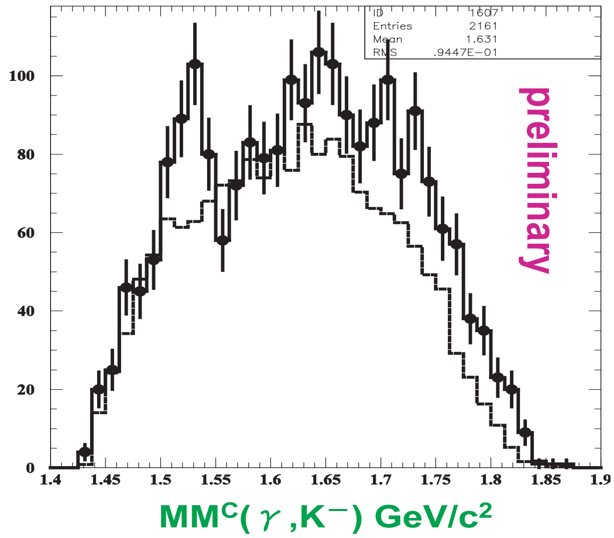

Figure 3: The K^- missing mass from a neutron in the LD_2 data. The Fermi motion correction was applied based on the deviation of the K^+K^- missing mass from the neutron mass. The background spectrum described in the text is also overlayed.

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