New results on Θ^+ from LEPS

In 2003, the LEPS (Laser Electron Photon Facility at SPring-8) collaboration reported an evidence of a baryon with the strangeness quantum number S=+1 and charge +1, now called Θ^+, in the $\gamma C \rightarrow K^+K^-X$ reaction [1]. The minimal quark content of Θ^+ is $uudd\bar{s}$. Therefore, Θ^+ is a genuine pentaquark state, which contains four quarks and one antiquark. Θ^+ has attracted attention not only because it is a new type of baryon, but also because it has two features, namely, low mass and narrow width. The mass of Θ^+ is measured to be 1520–1550 MeV/c^2. A naive consideration from the constituent quark model tells us that the sum of the mass of the constituent quark is about 1900 MeV. This is much larger than the measured value. The width of Θ^+ is measured to be at least less than 1 MeV/c^2 from several experiments. This value is too narrow to be explained by current knowledge of hadron physics. Therefore, Θ^+ has the possibility to provide new knowledge of hadron physics.

Since the first report by LEPS, a considerable number of experiments have been performed to confirm the existence of Θ^+. However, its existence is still controversial.

The LEPS collaboration analyzed data with a liquid deuterium target, which were taken in 2002-2003, and reported evidence of Θ^+ in the $\gamma d \rightarrow K^+K^-pn$ reaction [2]. The statistical of the narrow peak in the spectrum of missing mass for the system K^+ and a nucleon, M(NK), was obtained to be 5.1σ.

The CLAS collaboration in the Jefferson Laboratory also searched for the Θ^+ in the same reaction but no narrow peak was observed [3]. However, the two results might be consistent if the differential production cross section has a strong angle dependence, since the detector acceptances of LEPS and CLAS are almost exclusive. To check the LEPS result further and to clarify the controversial situation concerning the existence of Θ^+, the LEPS collaboration performed a new experiment with almost the same setup as in the previous experiment [2] in 2006-2007.

The experiment was carried out at beamline **BL33LEP**. A linearly polarized photon beam was produced by Compton back scattering of the 355 nm laser and 8 GeV electrons circulating in the storage ring of SPring-8. The photon energy range was from 1.5 to 2.4 GeV. For this experiment, we upgraded the laser injection system so that two lasers were simultaneously injected into the storage ring. Figure 1 shows a schematic view of the two-laser injection system. As a result, beam intensity was almost doubled and produced approximately 2.6 times higher statistics.

The reaction of interest is quasi-free production of Θ^+ from a neutron and its decay into nK^+, i.e., $\gamma n \rightarrow K^-\Theta^+ \rightarrow K^-K^+n$. First, we carried out blind analysis to check the previous result. Cut conditions were not changed from those in the previous analysis [2] and detector calibration was performed before opening the box. We detected K^+ and K^- with the LEPS detector. In the previous analysis, the target nucleon was not identified and events from a proton and a neutron were combined. Figure 2(a) shows the M(NK^+) distribution for two data sets. The strong narrow peak structure seen in the previous analysis was not observed.

To determine the reason for the inconsistency in the M(NK^+) distributions between the two data sets, we developed a new analysis method, in which a proton was detected using the energy loss information of the start counter (SC), which is a plastic scintillation counter located just behind the target chamber. When a proton is struck by a photon, it hits the SC and induces a large energy loss on the SC. In contrast, when a neutron is struck by a photon, it does not induce energy loss because the neutron is a neutral particle. The proton tagging efficiency is approximately 60%. Figures 2(b) and 2(c) show the M(pK^+) mass distribution for a proton-tagged sample for each data set. In the previous data, a peak structure is seen in the proton-tagged sample, which cannot be from a single charged Θ^+. While such a structure is not seen in the present data. This suggests that part of the peak structure seen in the previous data comes from statistical fluctuation. It is possible to increase

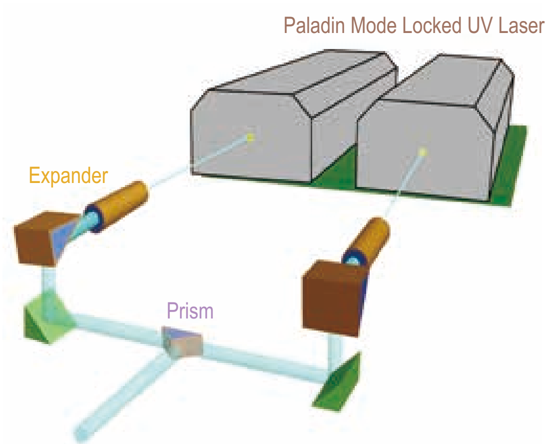

Fig. 1. Schematic view of the two-laser injection system.

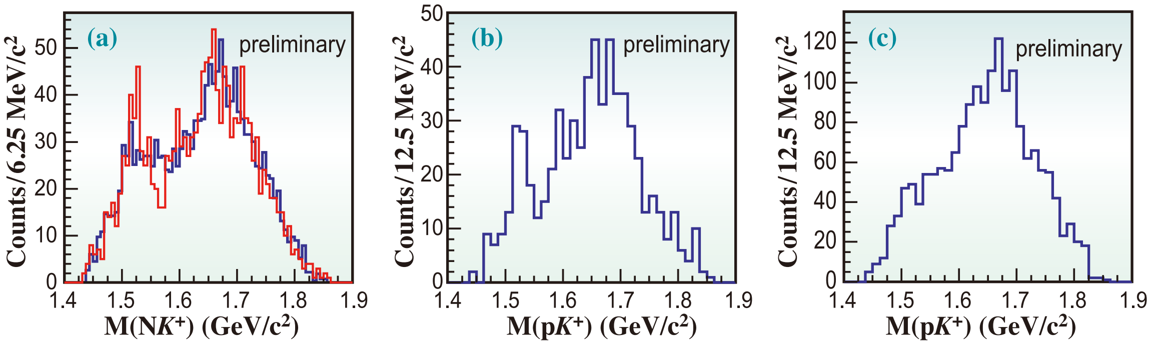

Fig. 2. **(a)** M(NK^+) distributions for previous data (blue) and present data (new). **(b)** M(pK^+) distribution for previous data. **(c)** M(pK^+) distribution for present data.

the proton tagging efficiency by selecting the event with the reaction vertex downstream of the target. The proton tagging efficiency is improved to 90% by selecting approximately one-third of the target volume. Figure 3(a) shows the M(nK^+) mass distribution for a proton-rejected sample after vertex selection. A clear enhancement near the Θ^+ mass region is seen. Because the vertex cut reduced the statistics, we also estimated the proton contributions by fitting a proton-tagged sample with a distribution generated by Monte Carlo simulation and subtracted it from the data sample without the proton rejection cut and the vertex cut.

Figure 3(b) shows the M(NK^+) mass distribution for data and the M(pK^+) mass distribution estimated by Monte Carlo simulation. The blue histogram in Fig. 3(c) shows the difference between the blue histogram and the red histogram in Fig. 3(b). Red points in Fig. 3(c) show the results of the energy loss based exclusive analysis after subtracting proton contributions that miss the SC. The M(nK^+) distributions for the two methods are consistent.

The estimation of the statistical significance and position of the peak is under way. The LEPS collaboration has just started a new experiment with a large SC in October 2012.

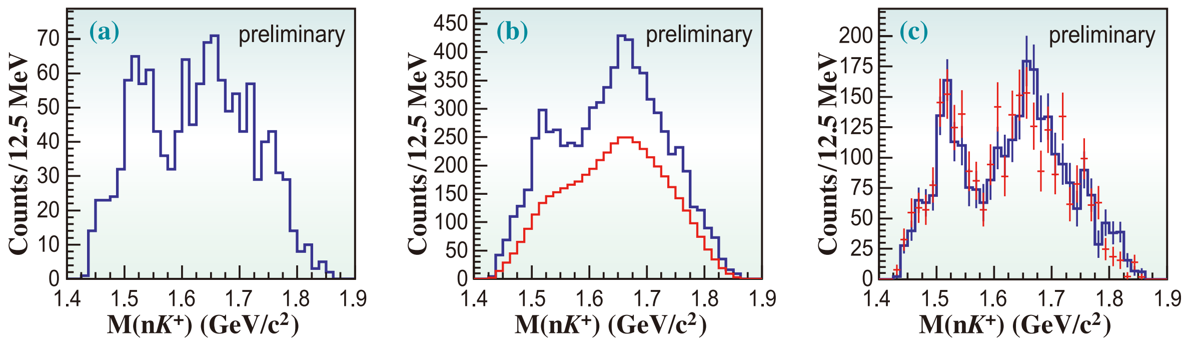

Fig. 3. **(a)** M(nK^+) distribution with vertex cut and proton rejection cut for summed data. **(b)** The blue histogram shows the M(NK^+) distribution without the vertex cut and proton rejection cut for summed data. The red histogram shows the M(pK^+) distribution estimated from MC. **(c)** The blue histogram shows M(nK^+) distribution with MC-based exclusive analysis. Red points show the results of the energy loss based exclusive analysis after subtracting proton contributions that miss the SC, normalized by the area of the blue histogram.

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