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LEPS RESULTS ON Θ^+ *

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In order to search the pentaquark state Θ^+, the $\gamma n \to K^+K^-n$ reaction has been measured at the Laser Electron Photon facility at SPring-8 (LEPS), where the photon beam is produced by the backward Compton scattering of laser photons off the 8-GeV electrons circulating in the storage ring. The present status and prospects of the experimental study of the Θ^+ at the LEPS are reported.

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1. Introduction

The Θ^+ is a pentaquark state with a quark configuration of $uudd\bar{s}$. Since the flavor of the antiquark $\bar{s}$ is different from those of other four quarks, Θ^+ must contain at least five quarks, and it is called an "exotic" pentaquark. Diakonov, Petrov and Polyakov predicted the antidecuplet of pentaquark particles by using their chiral quark soliton model in 1997 [1]. As the lightest member of the antidecuplet, they predicted that the mass of the Θ^+ is $\sim$ 1530 MeV and the width is $\sim$ 15 MeV. Motivated by this prediction, we analyzed the existing experimental data to search for an evidence for the Θ^+ [2]. The experiment was carried out at the Laser Electron Photon facility at SPring-8 (LEPS). The photon beam was generated by backward Compton scattering of laser photons with the 8-GeV electrons circulating in the storage ring. The charged particles produced from the target were momentum analyzed by a dipole magnetic spectrometer placed in the forward direction.

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In the analysis, we selected the events with a pair of K^+ and K^- produced in a plastic scintillator located 9.5 cm downstream from the liquid-hydrogen (LH_2) target. The main source of the physics background was the ϕ meson photoproduction. The events in the ϕ peak in the K^+K^- invariant mass distribution were removed to eliminate the background events. The Fermi motion corrected missing mass of the $N(\gamma, K^-)X$ reaction was calculated by assuming that the target nucleon has zero momentum. We found a narrow peak at 1.54 ± 0.01 GeV$/c^2$. The estimated number of the events above the background level is 19.0, which corresponds to a Gaussian significance of 4.6 σ. The narrow peak indicates the existence of an $S = +1$ resonance which may be attributed to the exotic pentaquark proposed as the Θ^+.

After the LEPS announced the preliminary result of the first evidence for the Θ^+, a lot of experimental groups reported the positive results mainly from the analysis of the old data. However, there are some inconsistencies in the measured mass and widths, which are larger than the experimental uncertainties. There are also the counter-evidences for the Θ^+. Several high-energy experiments have searched for the pentaquarks with a high statistics but found no peak [3–5]. It is obvious that the most important issue of the Θ^+ is to confirm the existence or non-existence experimentally. The LEPS carried out a new experimental search for the Θ^+ with a liquid deuterium target.

2. The LEPS beamline

A high energy photon beam produced by laser-induced backward Compton scattering off the circulating electrons (laser electron photon) is utilized for hadron physics studies at SPring-8, the world's highest energy third-

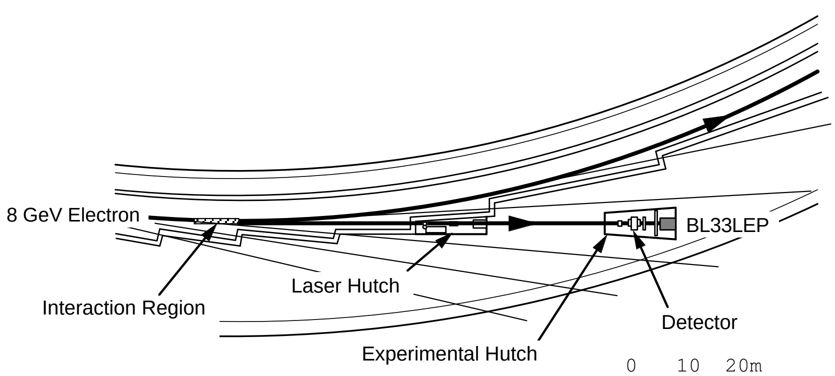

Fig. 1. The laser electron photon beamline at SPring-8.

generation synchrotron radiation facility. The schematic view of the beamline is shown in Fig. 1. At SPring-8, the 8 GeV electron beam is circulating in the ring with the beam current of 100 mA. The laser beam is injected from the Laser Hutch to the straight section, or the interaction region. The Compton scattering of the laser photon with an 8 GeV electron produces GeV photons which are used for the hadron physics experiments in the Experimental Hutch. The maximum energy of the laser electron photon is determined by the electron energy and the laser wavelength. The LEPS facility usually produces the maximum photon energy of 2.4 GeV with 350 nm Ar laser.

3. Experimental setup

The setup in the experimental hutch is shown in Fig. 2. The LEPS beamline is equipped with a dipole magnetic spectrometer. The particle trajectories are measured with a set of silicon-microstrip detector and drift chambers on the magnet. The trigger requires a hit on the photon tagging

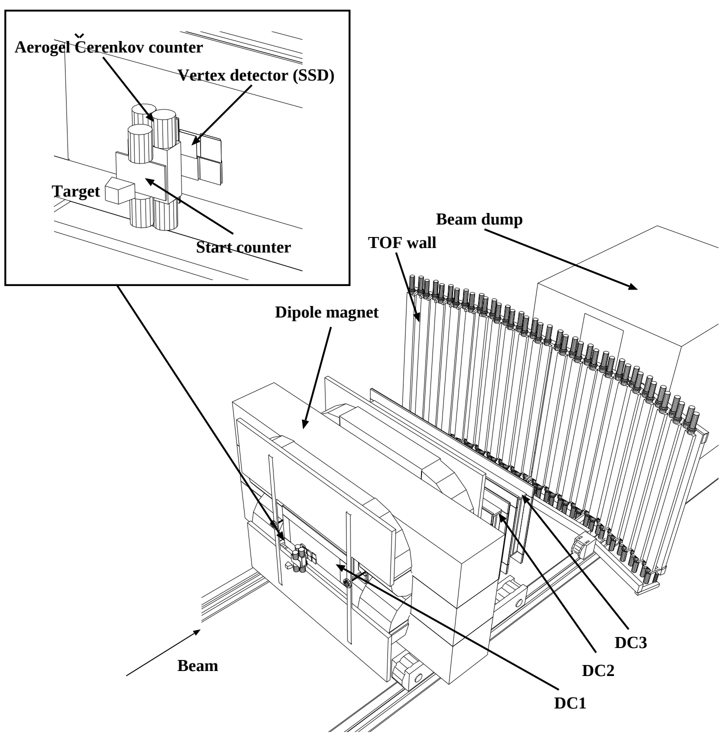

Fig. 2. The LEPS detector setup. The closeup around the target is drawn in the box.

counter, charged particles on the start counter after the target, and at least one hit on the TOF counters. Electrons, positrons, and high energy pions are vetoed by requiring no signal from the Cherenkov counter. The detector measures the momenta of the charged particles produced at the target with about 0.1 % resolution. The particle identification is performed by measuring the time of flight of particles from the target to the TOF wall.

At the first Θ^+ search experiment, K^+K^- pair events produced in the "Start Counter", drawn in the box of Fig. 2, were selected to study the photoproduction reaction on a neutron in C nucleus. Events from the liquid hydrogen target were used for the background estimation. At the new experiment in 2003, a 15 cm-long liquid deuterium target was used as a neutron target.

4. Analysis of deuterium target data

For the measured K^+K^- pair photoproduction process, two quasi-free baryon production reactions can be considered. The "exotic" one is $\gamma n \to \Theta^+K^-$, then $\Theta^+ \to K^+n$. Another is $\gamma p \to \Lambda^*(1520)K^+$, then $\Lambda^*(1520) \to K^-p$, which is standard hyperon production. The major background process for both the Θ^+ and the $\Lambda^*(1520)$ is ϕ meson photoproduction, $\gamma N \to \phi(1020)N \to K^+K^-N$. In order to exclude the ϕ contribution, we applied the photon-energy dependent cut for the K^+K^- invariant mass distribution. The cut point was determined by using Monte Carlo sample and the $\Lambda(1520)$ production events from a liquid hydrogen target, which were taken with the same detector setup. Contributions from elastic K^+K^- photoproduction, $\gamma D \to K^+K^-D$, were eliminated by removing events in the deuteron mass region in the $D(\gamma, K^+K^-)$ missing mass distribution.

In order to ensure that the Θ^+ peak is not artificially generated by the event selection cuts, we analyzed the following data sample with the same cut conditions. (1) K^+K^-N phase-space Monte Carlo sample, (2) Monte Carlo sample of ϕ photoproduction, and (3) real data taken with a liquid hydrogen target. No peak structure was observed for all of them. A preliminary missing mass distribution of $N(\gamma, K^-)$ reaction is shown in Fig. 3. A peak at ~ 1.53 GeV is seen. To confirm the existence of the peak, reliable background estimation is essential. Since we do not have enough statistics of the liquid hydrogen data, we carried out a mixed event analysis to estimate the background. In this method, a K^+, a K^-, and a photon were picked up randomly from different events. In general the energy and momentum are not conserved for a mixed event. However, in this case, they are approximately satisfied automatically by applying the cut on the $N(\gamma, K^+K^-)$ missing mass. After applying the same selection cuts on the mixed events, the shape of the $N(\gamma, K^-)$ distribution for the K^+K^-N phase

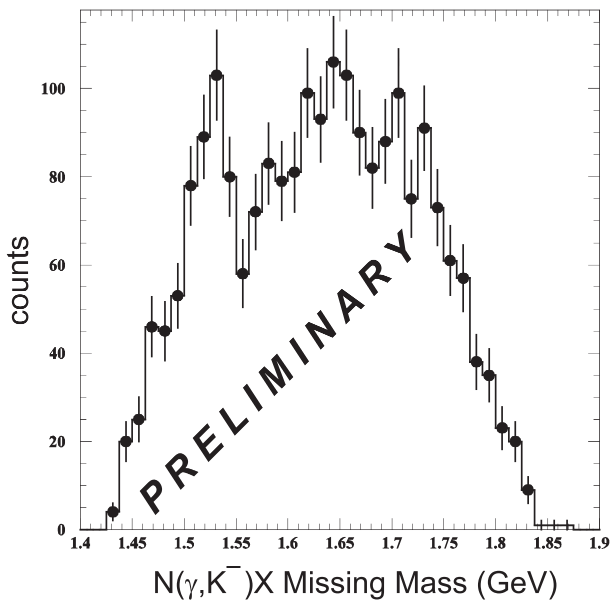

Fig. 3. Fermi-motion corrected $N(\gamma, K^-)$ missing mass distribution.

space Monte Carlo sample is well reproduced by the mixed event sample. If we take the smooth background shape estimated from the mixed event analysis, the number of events in the peak was about 90 with the S/N ratio of 0.4. Further analysis is in progress to improve the background estimation and to check if the peak is not generated by event selection cuts, detector acceptances and so on.

5. Summary and outlook

We have taken higher statistics data with liquid deuterium target to confirm the Θ^+ evidence. A peak at $\sim$ 1.53 GeV is observed again. It implies that the peak is not due to simple statistical fluctuations. Further analysis to confirm the existence of the Θ^+ is still in progress.

A new experiment with a time projection chamber (TPC) is planned. The TPC will cover a larger angle region and will provide us rich information about the background and production mechanism of the Θ^+, if it exists. The photon beam energy is also increased to 3.0 GeV with a deep-UV laser. It will allow us to study the Θ^+ in a wider kinematical region. The new experiment is scheduled in 2005.

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