PENTAQUARK SEARCH AT SPRING-8 LEPS

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The LEPS experiment at SPring-8 has collected data in the reactions of 1.5-2.4 GeV photons with a liquid deuterium target. The pentaquark baryon Θ^+ was searched for in the missing mass spectrum of K^- and proton from the deuteron. Preliminary results show a peak structure at 1.53 GeV/c^2 above the background spectra which were estimated by two complementary methods. Further confirmations of the Θ^+ are planned at the current beamline with higher intensity and the newly proposed facilities.

1. Overview of the Θ^+ searches

Since the LEPS collaboration reported the first evidence for the Θ^+ as a pentaquark baryon with strangeness +1 [1], its existence has been examined at many other facilities. Observations of the resonance structure corresponding to the Θ^+ were followed by DIANA, CLAS, SAPHIR, neutrino experiments with bubble chambers, HERMES, ZEUS, COSY-TOF, and SVD-2 [2]. On the contrary, many high energy experiments have reported null results and 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 $\gamma\ d \to p\ K^-\ \Theta^+$ was not supported. The upper limit for the total cross section was set to 0.3 nb at the 95% confidence level.

2. Θ^+ search in the LEPS experiment

A photon beam which had the maximum energy at 2.4 GeV was produced by backward Compton scattering of an Ar laser from 8-GeV electrons in SPring-8. Photon energies were measured in the region above 1.5 GeV by analyzing the momenta of recoil electrons. The liquid hydrogen (LH_2) or deuterium (LD_2) target was exposed to the photon beam with the intensity of $\sim 10^6$/sec. Photoproduced charged particles were detected by the forward spectrometer which measured the momentum and the time-of-flight. Details of the detector setup are described elsewhere [4].

After upgrading the target system to have three times larger thickness (15 cm), the integrated number of tagged photons reached $\sim 1.4\times 10^{12}$ for the LH_2 runs and $\sim 2\times 10^{12}$ for the LD_2 runs in the years 2002 - 2003. The number of events for the reaction $\gamma n \to \Theta^+ K^-$ 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.

The Θ^+ was searched for by detecting two charged particles. In the case that K^+ and K^- were detected (K^+K^- mode), the Θ^+ was identified 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. The final state of the K^-p mode is the same as the CLAS analysis, but the acceptance coverage of the K^-p detection was different, and the events where the K^-p invariant mass formed the $\Lambda(1520)$ resonance were analyzed.

3. Preliminary results in the K^-p detection mode

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 invariant mass regions.

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

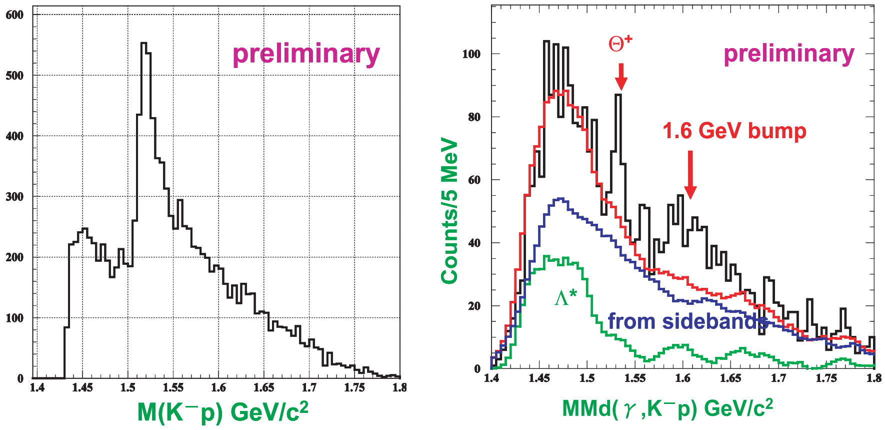

Figure 1. The left panel shows the K^-p invariant mass distribution in the LD_2 data. The right panel shows the missing mass spectrum of the K^-p from the deuteron after selecting the $\Lambda(1520)$ production region in the LD_2 data. Estimates for the background spectra based on side bands are also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

method to estimate the individual background spectra by MC simulations. The kinematics of those background processes were extracted from the LH_2 data. Then the 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 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 $\gamma\, d \rightarrow \Theta^+ \Lambda(1520)$.

4. Future prospects at SPring-8 and J-PARC

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.

In near future, J-PARC will give good oppotunities to explore hadron physics. By injecting a 420 MeV/c K^+ beam into a nuclear target, the K^+n resonance due to the Θ^+ is formed at 1.53 GeV/c^2 if it exists. The detection of two charged pions from K^0_S and proton will clarify the Θ^+ formation reaction. The detail setup for the experiment is under considerations.

5. Summary

The existence of the Θ^+ was examined in the photoreaction with a liquid deuterium target by detecting K^- and proton in the forward spectrometer. A peak structure was observed at 1.53 GeV/c^2 in the missing mass spectrum of the K^-p 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. Efforts to confirm the existence of the Θ^+ will continue.

References

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