E559 Search for Θ^+ with high resolution spectrometer SKS

K.Imai (Kyoto Univ.) for E559 collaboration

The purpose of E559 was to confirm the pentaquark Θ^+ via $K^+p\text{-}{>}\pi^+X$ reaction with a high resolution spectrometer, SKS, and to measure the width and decay angular distribution of Θ+. It should be noted that this experiment was proposed and approved when many positive evidences of Θ+ were reported especially by photon and electron beam experiments. The K6 beam line and the SKS spectrometer enabled high resolution missing mass spectroscopy which has been so far used for the study of hypernuclei. The missing mass resolution of about 2 MeV (FWHM) was expected for Θ^+.

The experiment has been carried out using the 1.2 GeV/c separated K^+ beam at the K6 beam line, where the K^+ beam was used for the experiment for the first time. The K^+/π^+ ratio was about 0.1. In the trigger level, protons were rejected by TOF and K^+'s were rejected by an Aerogel Cherenkov counter (BAC) in the beam line spectrometer. Off-line analysis of the TOF enabled to identify the K^+ beam particles with negligibly small backgrounds.

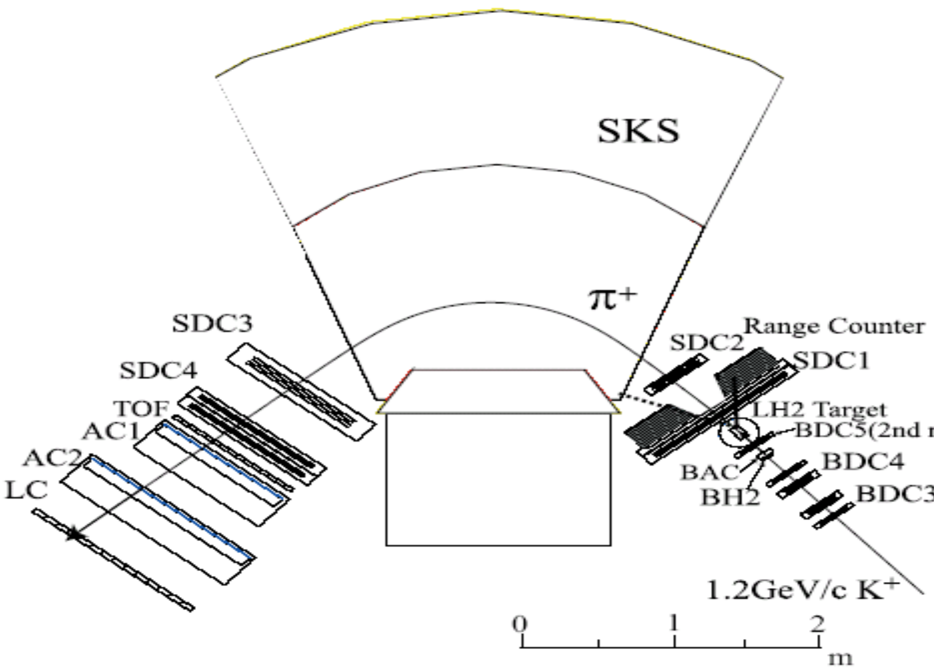
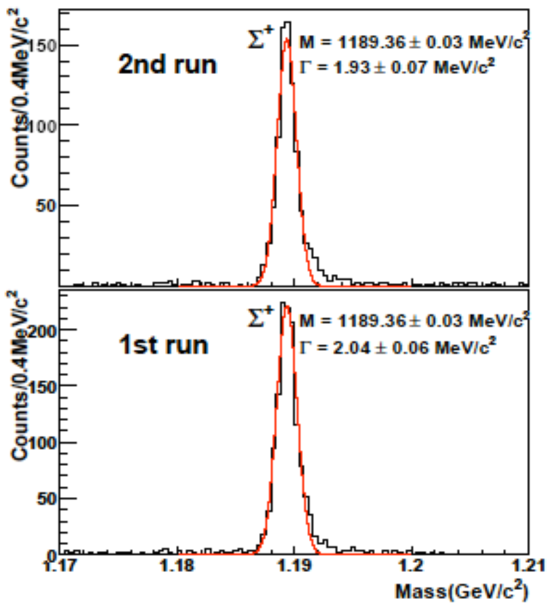


Fig.1 Experimental setup of SKS spectrometer. The SDC1 and a Range Counter (RC) were newly installed in order to detect the charged particles other than a π^+ detected with SKS. BDC5 was used only in the 2nd run to reject reaction events at BAC and BH2.

The setup of the SKS spectrometer is shown in Fig.1. A liquid hydrogen target was newly developed for this experiment. It has a cooling system using liquid helium and worked stably during the runs. The target was 6.87 cm in diameter and 12.5 cm in length. The scattered π^+'s were measured with the SKS spectrometer. The momentum acceptance of the spectrometer covers 0.46 ~ 0.60 GeV/c which covers the kinematical region for the Θ^+ production. The particle identification was made with Cherenkov detectors (LC) and TOF together with momentum measurement. The momentum resolution was 0.42%. For this experiment, a large drift chamber (SDC1) and a range counter were installed to kill backgrounds from in-flight K^+ decays and to measure decay angular distribution of Θ^+, if it is clearly observed. The effective area of SDC1 was 1200x1200mm and located just downstream of the target. It covered 0~60 degree for particles from the target region. Data were taken in two separated periods; one month in June 2005 (1st run) and two weeks in December 2005 (2nd run). For the calibration and background estimation, (π+,K+) and (π+,π+) reactions for the liquid hydrogen target and (K+,π+) reaction for the empty target were also measured.

FIG. 2: Missing mass spectra of the π_+p->K_+X reaction for 1st and 2nd runs. The peak of Σ_+ is seen. The obtained widths are consistent with the expected value of 1.98 MeV/c_2 obtained from a Monte Carlo simulation. The peak positions for both runs are consistent with each other.



In order to check the tracking performance, data of π^+p->K^+X reaction was analyzed. The results are shown in Fig.2. A Σ^+ peak is clearly seen and the obtained resolution (FWHM) are 1.93+-0.07 and 2.04+-0.06 MeV which is consistent with the expected missing mass resolution (1.98 MeV) estimated by a Monte Carlo simulation. From this data, we expect the mass resolution of Θ^+ to be 2.4MeV in FWHM. Most of the (K^+,π^+) events are due to in-flight three-body K^+ decays, K^+-->$\pi+\pi-\pi+$ and $\pi+\pi^0\pi^0$,$l^+\pi^0\nu$, in the target region. In order to suppress these decay events, we employed information of number of tracks just after the target and their angles. It should be noted that Θ^+

decays in to K^+n or K^0p. Tracks other than π^+ detected with the SKS were reconstructed from the hit information of SDC1 and 1st layer of the Range Counter, and the reconstructed vertex position. More than two tracks were required. If two tracks were detected with SDC1, i.e. one more particle other than π^+ detected with the SKS, the angle of the second particle was required to be larger than 10 degree. If three tracks were detected, the angles of the second and third particles were required to be more than 15 and 23 degrees, respectively. The cut positions of these angles were determined so as to make *S/N* a maximum, where *S* was the number of hadronic reaction events and *N* was the decay events in the target region.

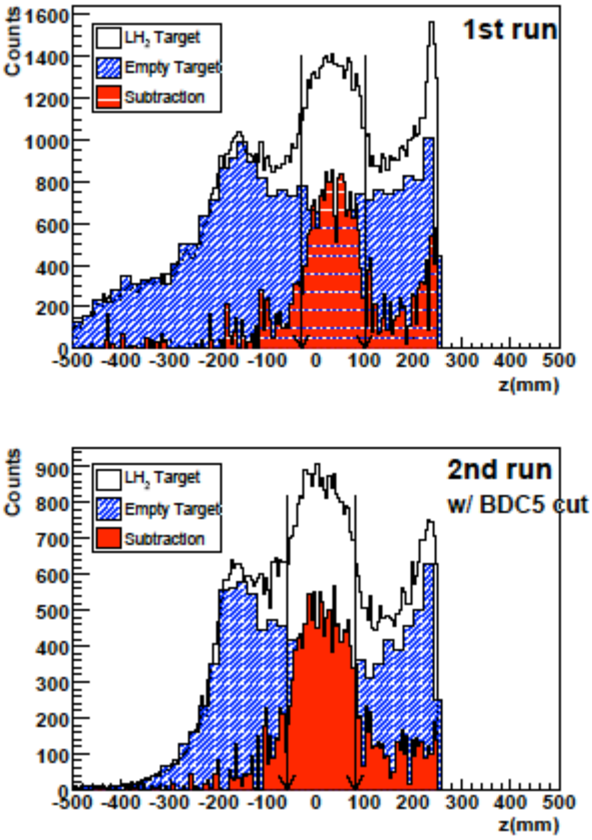


FIG. 3: Vertex distributions of (K^+, π^+) reaction after the decay suppression using SDC1 for 1st and 2nd runs. The open histogram shows the vertex distribution obtained using LH_2 target. The blue hatched histogram shows the empty target data, which are normalized using the beam flux. The red dotted histogram shows the subtraction of these histograms, which shows a net contribution of $K^+p \to \pi^+X$ reaction events. The arrows show the cut position for the vertex cut.

Fig.3 shows the vertex distribution after this SDC1 analysis. The hatched histogram shows the empty target data which is normalized by the beam flux. The dotted spectrum shows the subtraction of histogram of the LH_2 target data and the empty target data. It is the net contribution of the $K^+p \to \pi^+X$ reaction at the LH_2 target. The numbers of reaction events are 1.7×10^4 and 1.2×10^4 for 1st and 2nd runs, respectively. By the ADC1 analysis, 95% of decay events around the target were removed, but there are still decay events left. The empty target data is compared with a Monte Carlo simulation including the chamber efficiencies. We found the simulation can not completely explain the data. We consider the possibility of K^0 produced upstream of the target at BH2 and BAC could contribute to the background. Therefore, in the 2nd run, a new drift chamber (BDC5) was installed between the BAC and the target. The bottom figure of Fig.5 shows the vertex distribution using BDC5 information in the 2nd run. A slight improvement of *S/N* was achieved in the 2nd run. The vertex cut was made as shown by arrows to extract $K^+p \to \pi^+X$ events.

Fig.4 shows the missing mass spectrum of the $K^+p \to \pi^+X$ reaction. Data of 1st and 2nd runs are added in this figure. The hatched spectrum shows the expected spectrum assuming that the total cross section of the $K^+p \to \pi^+\Theta^+$ reaction is 50μb and isotropic distribution in the CM system, and natural width of 1 MeV. In the present experiment, no significant peak was observed. We have obtained the upper limit of the production cross section by estimating the number of K^+ beam particles, target thickness, and efficiency of the detectors and analysis, and the expected mass resolution (2.4 MeV). The cross section is a differential cross section averaged over 2 to 22 degree in the laboratory frame. The 90% CL upper limits have been obtained to be less than 3.5μb/sr for the mass region of 1.51~1.55 GeV for Θ^+.

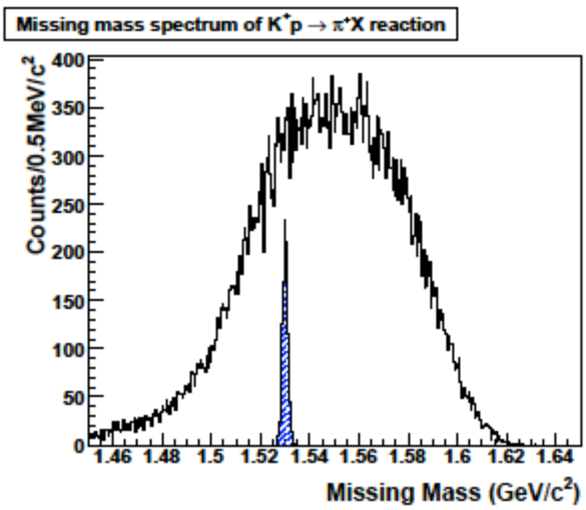


FIG. 4: Missing mass spectrum of the $K^+p \to \pi^+X$ reaction where the spectra of the 1st and 2nd runs are added. The hatched spectrum shows the expected spectrum assuming that the total cross section of the $K^+p \to \pi^+\Theta^+$ reaction is 50 μb and the angular distribution of the π^+ is isotropic in the K^+p CM system.

We discuss the comparison of our result with theoretical models of the Θ^+ production. In the model of K* exchange in the t-channel for the $K^+p \to \pi^+\Theta^+$ reaction, large cross sections in the forward angles were obtained. If the coupling constant, $g_{K^*N\Theta}$, is equal to + or – $g_{KN\Theta}$ and $g_{KN\Theta}$ is 1 which corresponds to the width of Θ^+ of about 1 MeV, the value of the cross section in the region of 2~22 degrees is about 140 μb/sr [1]. The present upper limit of 3.5 μb/sr excludes the t-channel K* exchange model for the Θ^+ production. In our previous experiment E522, the upper limit of the cross section for the $\pi^-p \to K^-\Theta^+$ reaction was obtained to be 3.9μb/sr [2]. The smallness of the cross section could be explained by the destructive interference between the t-channel K* exchange amplitude and a direct s-channel amplitude. The present result also excludes such explanation for the small $\pi^- p \to K^- \Theta^+$ cross section. Hyodo and Hosaka studied the production mechanism by contact interaction using the two meson couplings, scalar g_s and vector g_v [3]. They claimed that the small $\pi^- p \to K^- \Theta^+$ cross section can be explained by the destructive interference of two amplitudes but it predicts large cross sections (~600μb/sr for spin 1/2 and ~50μb/sr for spin 3/2) for the $K^+ p \to \pi^+ \Theta^+$ reaction . The present result is inconsistent with this model.

The result of E559 was reported at a few international conferences. A draft of the paper was made and the paper is going to be submitted in early December 2007.

References

[1] Y.Oh, H.Kim and S.H.Lee, Phys. Rev. D69, 014009 (2004).

[2] K.Miwa et al., (E522 collaboration), Phys. Lett. B635, 72 (2006).

[3] T.Hyodo and A.Hosaka, Phys. Rev. C72, 055202 (2005).

E559 collaboration

S.Ajimura, J.Arvieux, S.Dairaku, H.Fujimura, H.Fujioka, T.Fukuda, H.Funahashi, M.Hayata, K.Hicks, K.Imai, S.Ishimoto, T.Kaneyama, S.Kamigaito, S.Kinoshita, T.Koike, Y.Ma, T.Maruta, Y.Miura, M.Miyabe, T.Nagae, T.Nakano, K.Nakazawa, M.Naruki, H.Noumi, M.Niiyama, N.Saito, Y.Sato, S.Sawada, Y.Seki, M.Sekimoto, K.Senzaka,m K.Shirotori, K.Shoji, S.Suzuki, H.Takahashi, T.Takahashi, T.N.Takahashi, H.Tamura, N.Tanaka, K.Tanida, A.Toyoda, T.Watanabe, M.Yosoi, R.Zavislak

(Kyoto U., KEK, Gifu U., Osaka U., Riken, Tohoku U., U. of Tokyo, Paris-Sud U.)