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Search for Pentaquarks at HERA-B

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Abstract. A search for Θ^+ and $\Xi_{3/2}$ pentaquarks has been performed in channels $p\,K^0_S$ and $\Xi\,\pi$ in proton - nucleus interactions at mid-rapidity and $\sqrt{s} = 41.6$ GeV/c^2 . No evidence for pentaquarks has been found in analyzed channels. Upper limits have been set on pentaquark production cross sections.

Experimental evidence for a new hadron state at 1540 MeV/c^2 decaying to $n\,K^+$ was presented by experiment LEPS [1] in 2003. The particle was named $\Theta^+(1540)$. Due to a quark picture of neutron and K^+, the hadron Θ^+ must contain at least four quarks and one antiquark. After that, several other collaborations reported evidence for a peak in the invariant mass spectrum of $n\,K^+$ or $p\,K^0_S$. The $p\,K^0_S$ peak was regarded as evidence for $\Theta^+ \to pK^0_S$ on the grounds "no narrow $\Sigma^{\star+}$ is known around 1.5 GeV/c^2 ". Currently, there are 12 experiments that have claimed evidence for decays $\Theta^+ \to nK^+$ or $\Theta^+ \to pK^0_S$. The measured mass lies in the range 1521 - 1555 MeV/c^2 . There is a peculiarity that $p\,K^0_S$ experiments report smaller value of mass than $n\,K^+$ ones. The measured widths have all been consistent with the experimental resolution which is typically 20 MeV/c^2 . The presented peaks have statistical significance of about 5 σ. In theoretical models Θ^+ is a member of an antidecuplet which also contains isospin 3/2 family $\Xi_{3/2}$ of doubly strange pentaquarks. Evidence for doubly charged and neutral member of the family was observed in $\Xi\,\pi$ decay channels at mass of 1862 MeV/c^2 by NA49 [2]. The statistical significance of $\Xi_{3/2}$ peak is also about 5 σ. Up to now, this has been the only evidence for $\Xi_{3/2}$. From the other side, the number of high statistics experiments reporting negative search results for Θ^+ and $\Xi_{3/2}$ is growing. Direct comparison of positive and negative search results is not possible because the experiments are not of the same type. However, the negative search results reported much larger yield of common particles like $\Lambda(1520)$ and $\Xi(1530)^0$, thus proving their ability to search for possible pentaquark signals in channels $p\,K^0_S$ and $\Xi\,\pi$. This short survey of experimental situation suggests that existence of pentaquarks is not proven beyond reasonable doubt. The search for Θ^+ and $\Xi_{3/2}$ was done also at HERA-B. The main features of the analysis are presented here, while details can be found elsewhere [3].

HERA-B is a fixed target experiment at the 920 GeV proton storage ring of DESY. It is a forward magnetic spectrometer with a high resolution vertexing and tracking system and good particle identification. The detector has good

acceptance in the mid-rapidity region. The informations from the silicon vertex detector, the main tracker system, ring imaging Cherenkov (RICH) counter and the electromagnetic calorimeter (ECAL) were used in this analysis. The present study was performed on a sample of about 200 millions of minimum bias events that were taken at $\sqrt{s} = 41.6$ GeV/c^2 using carbon, titanium and tungsten targets. Strange particles are frequent in proton - nucleus interactions at this energy, and HERA-B has reconstructed a large number of $K^0_S \to \pi^+\pi^-$, $\Lambda \to p\pi^-$ and $\bar{\Lambda} \to \bar{p}\pi^+$ decays. A clean sample of Ξ hyperons was obtained in decay modes $\Xi^- \to \Lambda\pi^-$ and $\bar{\Xi}^+ \to \bar{\Lambda}\pi^+$. Background in all fore mentioned channels was efficiently reduced using decay topology, so there was no need for particle identification. Table 1 summarizes the statistics of relevant signals together with the measured mass resolutions. All measured masses are within 1 MeV/c^2 compatible with the table values.

Signal	C target	all targets	σ [MeV/c^2]
K^0_S	2.2M	4.9M	4.9
Λ [$\bar{\Lambda}$]	440k[210k]	1.1M[520k]	1.6
Λ (1520) [$\bar{\Lambda}$(1520)]	1.9k[1.1k]	5.1k[2.3k]	2.3
Ξ^- [$\bar{\Xi}^+$]	4.7k [3.4k]	11.8k [8.2k]	2.6
$\Xi(1530)^0$ [$\bar{\Xi}(1530)^0$]	610 [380]	1.4k [940]	2.9

Table 1. Statistics and experimental mass resolution (σ) for relevant particles are given for carbon target and for all targets.

HERA-B does not have capabilities for the identification of neutrons. Therefore, the search for Θ^+ was performed in the decay channel $p\,K^0_S$. Protons were identified requiring the proton likelihood from the RICH to be larger than 0.95. Probability that a particle which is not proton passes this cut is below 1%. Both particles, proton and K^0_S had to point to the main vertex. K^0_S candidates had to lie in $\pm 3\sigma$ mass window around the table mass. A clean K^0_S sample remained after removing particles whose mass was consistent with Λ or $\bar{\Lambda}$. The invariant mass spectrum of selected $p\,K^0_S$ pairs is shown for p+C data in Fig. 1a. The shape of background was obtained by event mixing technique and is represented by a full line. MC studies show that the mass resolution in the presented mass region is in 2.6 - 6.1 MeV/c^2 range. At the Θ^+ mass, the resolution is 3.9 MeV/c^2. We determined the upper limit on the number of signal events in the invariant mass plot as a function the signal mass. The resulting nuclear cross section as a function of the signal mass is presented in Fig. 1b (full line).

Assuming $A^{0.7}$ dependence of the nuclear cross section on the atomic number, we obtained the upper limit on $Br \times d\sigma/dy|_{y=0} < 3.7$ μb/nucleon in the mid-rapidity region for Θ^+ mass of 1530 MeV/c^2. The upper limit varies from 3 to 22 μb in the mass region 1521 - 1555 MeV/c^2. The upper limits obtained using data from all targets are similar. We also tried with other search strategies,

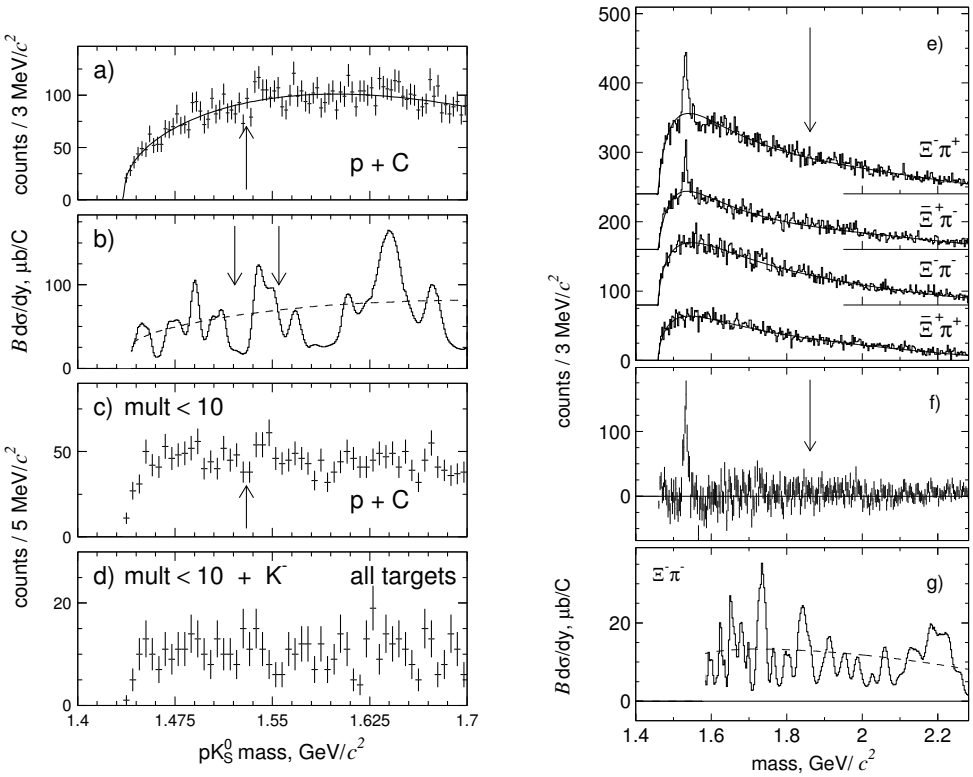

Fig. 1. Invariant mass distributions and upper limits on nuclear cross section for channels p K^0_S (left) and $\Xi\pi$ (right). Arrows denote mass region 1521 - 1555 and mass of 1530 MeV/c^2 (left) and mass of 1862 MeV/c^2 (right). Data were taken with carbon target. See text for details.

like: a) requiring a low track multiplicity in an event (Fig. 1c), b) strangeness tagging, by requiring a particle with an s quark (Λ , K^-) in an event, c) combination (Fig. 1d) of criteria a) and b), d) relaxation of the proton identification cut. None of the attempts resulted in a significant narrow peak in the mass spectrum. We checked capabilities of the HERA-B detector by reconstruction of $\Lambda(1520) \to pK^-$. Masses of Θ^+ and Λ (1520) are similar as well as geometrical acceptances for $\Theta^+ \to pK^0_S$ and $\Lambda(1520) \to pK^-$. Using RICH likelihood cut for both proton and K^- , we obtained a clean signal for Λ (1520). Assuming Br($\Theta^+ \to pK^0_S$)=1/4, we determined the UL(95%) on the particle ratio $\frac{\Theta^+}{\Lambda(1520)} < 0.92\%$ in the mid-rapidity region. This upper limit is more than one order of magnitude lower than predictions of statistical hadronization models. We also found that $\frac{\Theta^+}{\Lambda(1116)} < 0.27\%$.

We searched for members of $\Xi_{3/2}$ family in decay channels $\Xi^-\pi^-$, $\Xi^-\pi^+$ and c.c. Ξ^- candidates had to lie in $\pm 3\sigma$ mass window around the table mass. Both Ξ^- and π candidates had to point to the main vertex. Weak identification cuts with RICH and ECAL removed tracks with clear electron, kaon or proton identity from the π sample. The invariant mass spectra of $\Xi\pi$ pairs obtained from

p+C data are shown in Fig. 1e for all four charge combinations. The background shape is obtained from event mixing and is normalized to the data. The experimental resolution in the analyzed mass region is in 2.9 - 10.6 MeV/c^2 range and has value of 6.6 MeV/c^2 at the mass of 1862 MeV/c^2 . The only observed structure in the spectra are signals for $\Xi(1530)^0$ and $\bar{\Xi}(1530)^0$ in neutral channels. Fig. 1f gives sum of invariant mass distributions of all four charge channels after subtraction of background. Particularly, there is no enhancement in mass region around around 1862 MeV/c^2 , where NA49 observed $\Xi_{3/2}$ candidates. We determined UL(95%) on $Br \cdot d\sigma/dy|_{y=0}$, which at mass of 1862 MeV/c^2 are 2.5, 2.3, 0.85 and 3.1 μb/nucleon in $\Xi^-\pi^-$, $\Xi^-\pi^+$, $\bar{\Xi}^+\pi^+$ and $\bar{\Xi}^+\pi^-$ channels, respectively. The corresponding upper limits using all targets are 2.7, 3.2, 0.94 and 3.1 μb /nucleon. We also found the UL(95%) on particle ratio $Br \cdot \Xi^{--}/\Xi^0(1530) < 4\%$ and $Br \cdot \Xi^{--}/\Xi^- < 3\%$. As an illustration, the UL(95%) on nuclear cross section is presented in Fig. 1g (full line) as function of Ξ^{--} mass.

To conclude, we searched for pentaquark signals in channels $p\,K^0_S$ and $\Xi\pi$. Having found no evidence for signals we set upper limits on production cross sections and particle ratios in mid-rapidity region. If existent, strange pentaquarks (Θ^+ and $\Xi_{3/2}$) also seem to have exotic production mechanisms.

References

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