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Search for Pentaquarks in Proton-Nucleus Collisions with HERA-B

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We report on search for $\Theta^+(1540)$ and $\Xi_{3/2}(1860)$ pentaquark candidates in proton-induced reactions on various nuclear targets at $\sqrt{s}$=41.6 GeV/c^2. The analyzed data sample consists of 200 million minimum bias events recorded at HERA-B which is a fixed target experiment having acceptance at mid-rapidity. No evidence for narrow ($\sigma \approx 5$ MeV/c^2) signals in $\Theta^+ \to pK^0_S$ and $\Xi_{3/2} \to \Xi\pi$ channels is observed. We present upper limits for the inclusive production of pentaquark candidates as well as upper limits for particle ratios such as $\Theta^+/\Lambda(1520)$ and Ξ^{--}/Ξ^0.

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1. Introduction

Evidence for a narrow baryonic resonance $\Theta^+(1540)$ has been reported by the LEPS collaboration [1]. The decay mode nK^+ implies that the minimal quark content of Θ^+ is four quarks and one antiquark. The possible discovery of the exotic baryon triggered strong experimental activity. As a result more than ten experiments reported evidence for a narrow resonance in the mass region 1521 - 1555 MeV/c^2 in decay channels nK^+ or pK^0_S. Pentaquark search was not limited to channels nK^+ or pK^0_S; collaborations NA49 [2] and H1 [3] reported evidence for exotic states $\Xi_{3/2}(1860) \to \Xi\pi$ and $\Theta^0_c(3099) \to D^\star p$. The statistical significance of all presented peaks is typically about 5 σ. On the other side, a number of high statistics experiments did not find any evidence for existence of Θ^+, $\Xi_{3/2}$ and Θ^0_c. A more detailed survey of the experimental situation in this controversial topic is also available [4].

Preliminary results of the HERA-B search for narrow resonances decaying into pK^0_S and $\Xi\pi$ can be found elsewhere [5], while here we briefly present the final results [6].

2. Experiment and Data Sample

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 million 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. The statistics of all relevant signals together with the respective mass resolutions is given in Table 1.

Table 1: Statistics and experimental resolutions of the relevant signals.

Signal	C target	all targets	σ (MeV/c^2)
K^0_s	2.2M	4.9M	4.9
Λ [c.c]	440k [210k]	1.1M [520k]	1.6
$\Lambda(1520)$ [c.c]	1.3k [760]	3.5k [2.1k]	2.3
Ξ^- [c.c]	4.7k [3.4k]	12k [8.2k]	2.6
$\Xi(1530)^0$ [c.c]	610 [380]	1.4k [940]	2.9

3. Search for Θ^+

HERA-B does not have capabilities for the identification of neutrons. Therefore, the search for Θ^+ was performed in the decay channel pK^0_S . Protons were identified requiring the proton

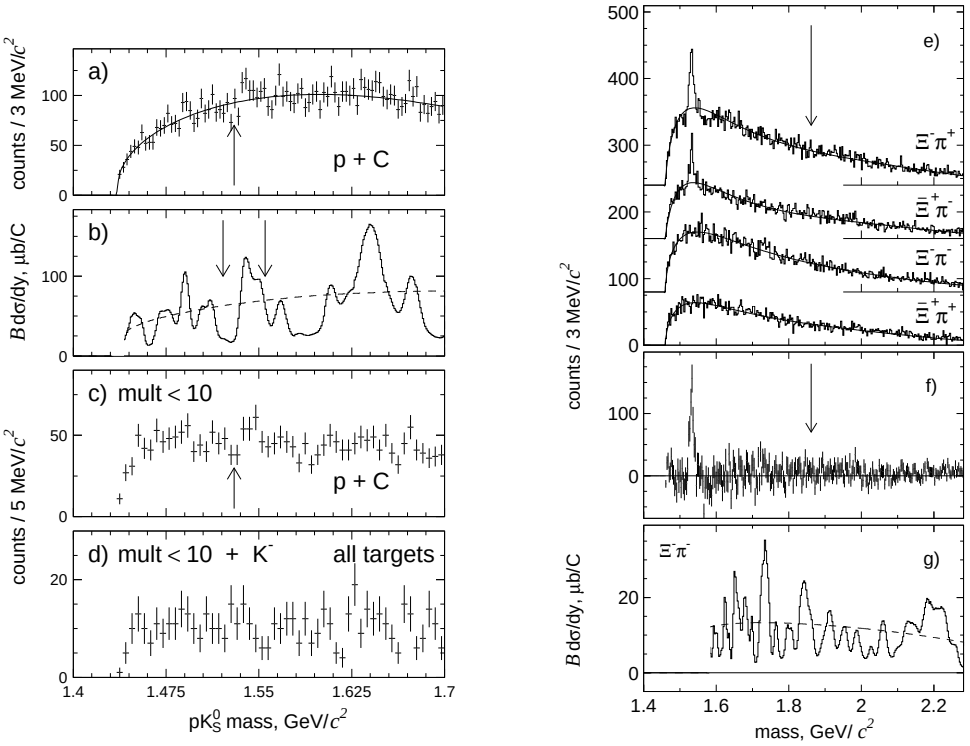

Figure 1: Invariant mass distributions and upper limits on nuclear cross section for channels pK_S^0 (left) and $\Xi\pi$ (right). The arrows denote mass region 1521 - 1555 and mass of 1530 MeV/c^2 (left) and mass of 1862 MeV/c^2 (right). Data were taken with carbon target. See text for details.

likelihood from the RICH [7] to be larger than 0.95. The probability that a particle which is not proton passes this cut is below 1%. Both particles, proton and K_S^0 had to point to the main vertex. K_S^0 candidates had to lie in a $\pm 3\sigma$ mass window around the table mass. A clean K_S^0 sample remained after removing particles whose mass was consistent with Λ or $\bar{\Lambda}$. The invariant mass spectrum of selected pK_S^0 pairs is shown for p+C data in Fig. 1a. The spectrum exhibits a smooth shape that is well described with the background estimate (full line) obtained by the event mixing technique. MC studies show that the mass resolution in the presented mass region increases from 2.1 to 6.1 MeV/c^2, and takes the value of 3.9 MeV/c^2 at the mass of 1530 MeV/c^2 (approximate mean of the mass of peaks observed in the channel pK_S^0). 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 an $A^{0.7}$ dependence of the nuclear cross section on atomic number, we obtained the upper limit on $Br \times d\sigma/dy|_{y=0} < 3.7\,\mu b/\text{nucleon}$ in the mid-rapidity region for the 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, 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 statistically

significant narrow peak in the mass spectrum. We checked the capabilities of the HERA-B detector by the 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 the 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 at variance with results of experiments which reconstructed both Θ^+ and $\Lambda(1520)$, if the condition of similar production mechanism may be assumed [4]. We also found that $\frac{\Theta^+}{\Lambda(1116)} <$ 0.27%.

4. Search for $\Xi_{3/2}$

We searched for doubly charged and neutral members of the $\Xi_{3/2}$ family in decay channels $\Xi^-\pi^-$, $\Xi^-\pi^+$ and c.c. Ξ^- candidates had to lie in a $\pm 3\sigma$ 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 presented mass region increases from 2.9 to 10.6 MeV/c^2 and has the 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 the 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 a 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. As an illustration, the UL(95%) on nuclear cross section is presented in Fig. 1g (full line) as function of the Ξ^{--} mass. We also found the UL(95%) on the particle ratio $Br \cdot \Xi^{--}/\Xi^0(1530) < 4\%$ (in contradiction with NA49 if similar reconstruction efficiencies are assumed for both experiments) and $Br \cdot \Xi^{--}/\Xi^- < 3\%$.

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

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