The search for strange pentaquarks at ZEUS

Z.Ren on behalf of ZEUS collaboration

DESY ZEUS Columbia, Notke Str. 85, 22607 Hamburg, Germany
Pupin 5283, 538 W. 120th Str., New York, NY 10027, USA

Abstract. A study of states and enhancements reconstructed using the invariant-mass spectra associated with strange baryons has been performed in *ep* collisions with the ZEUS detector at HERA using an integrated luminosity of 121 pb^{-1}. The invariant-mass spectra were reconstructed in several kinematic regions with the main emphasis on the spectra which are sensitive to the production of pentaquarks. The candidate Θ^+ signal was found to be produced predominantly in the forward hemisphere in the laboratory frame. This is unlike the case for the $\Lambda(1520)$ or the Λ_c, and indicates that the Θ^+ may have an unusual production mechanism related to proton-remnant fragmentation.

Keywords: pentaquark, ZEUS, HERA
PACS: 14.80.-j

INTRODUCTION

This paper describes an inclusive search for new states whose decay products include strange hadrons. The searches involving Ξ baryons have already been published [1]. The invariant-mass spectra were reconstructed in several kinematic regions with the main emphasis on spectra which are sensitive to the production of pentaquarks. The invariant masses of known states with similar decay channels as for pentaquarks were also studied in order to show the sensitivity to new resonances and to compare their respective production mechanisms.

DATA SAMPLE

The data sample for this analysis was taken during the 1996–2000 running period of HERA, and corresponds to an integrated luminosity of 121 pb^{-1}. In this analysis, the data sample was divided into two categories: photoproduction (PHP) and DIS. The latter sample was studied at low ($Q^2 > 1$ GeV^2) and medium ($Q^2 > 20$ GeV^2) values of the exchanged photon virtuality, Q^2.

The present analysis was based on tracks measured in the CTD. The energy-loss measurement in the CTD, dE/dx, was used for particle identification [2].

The K^0_S mesons and Λ baryons were identified by their charged decay mode, $K^0_S \to \pi^+\pi^-$ and $\Lambda \to p\pi^-$ using the pairs of tracks originating from secondary vertices. The resulting $\pi^+\pi^-$ and $p\pi^-$ invariant-mass spectra are shown in previous publications. About 4.4M K^0_S and 840k $\Lambda(\bar{\Lambda})$ candidates were reconstructed in both PHP and DIS samples [1, 2].

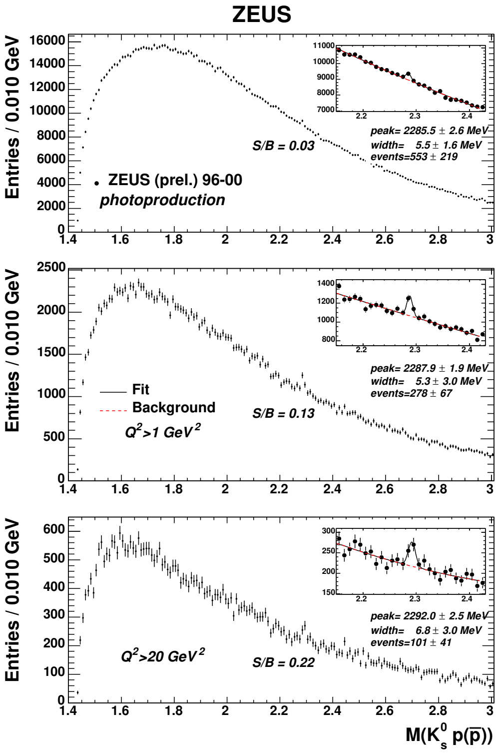

FIGURE 1. The $K^0_S p$ invariant-mass spectra in PHP and DIS ($Q^2 > 1$ GeV^2 and $Q^2 > 20$ GeV^2). The insets show the invariant-mass distribution near the Λ_c mass region. The solid line shows a fit using a Gaussian plus a second-order polynomial background function using 5 MeV bins. The signal-over-background ratio (S/B) for the Λ_c peak is indicated on each figure.

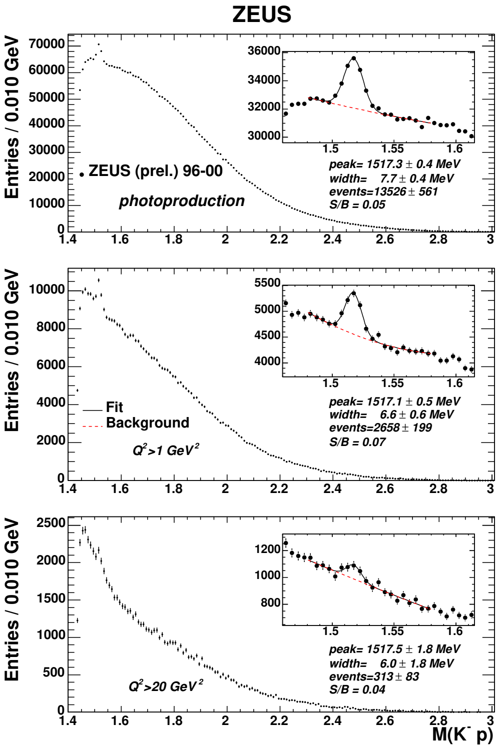

FIGURE 2. The $K^- p$ ($K^+ \bar{p}$) invariant-mass spectra in PHP and DIS ($Q^2 > 1$ GeV^2 and $Q^2 > 20$ GeV^2). The solid line in the insets shows the result of a fit using a Gaussian plus a second-order polynomial background function. The signal-over-background ratio (S/B) is indicated on each figure.

RESULTS

Figure 1 shows the $K^0_S p(\bar{p})$ invariant-mass spectra for three data samples: 1) all data which passed the ZEUS trigger chain after removing DIS events. This data sample is dominated by PHP events as explained in Section ; 2) DIS events with $Q^2 > 1$ GeV^2. This sample represents the largest DIS data sample taken; 3) DIS events at medium $Q^2 > 20$ GeV^2. The latter sample was used in the previous ZEUS publication [2]. The $K^0_S p(\bar{p})$ distribution has two peaks, at around 1522 MeV ($Q^2 > 20$ GeV^2) and at around 2286 MeV (PHP and DIS). The first peak is attributed to the Θ^+ state, which has been discussed in detail in the previous ZEUS publication [2]. The second peak, which corresponds to the established Λ_c, was fitted using a Gaussian with a second-order polynomial function for the background. Both peaks are best seen at $Q^2 > 20$ GeV^2. This is a region where the Λ_c peak has largest signal-over-background ratio (S/B=0.22). The signal-over-background ratio in PHP is rather small, since the average charged-track multiplicity in PHP is larger by 50% than in DIS at $Q^2 > 1$ GeV^2. Since the combinatorial background is larger for low Q^2 DIS and PHP, this may explain the non-observation of the Θ^+ for these two samples [2]. The Λ_c peak was further studied in the forward ($\eta > 0$) and in the rear ($\eta < 0$) pseudorapidity regions, shown in Fig. 3, and for protons and antiprotons. The fit was performed using a Gaussian with a second-order polynomial function. Due to low statistics, the peak position and the width were fixed from the fit to the overall mass spectra for $Q^2 > 1$ GeV^2 (shown in Fig. 1) in order to obtain stable fits. The numbers of the extracted Λ_c candidates are about the same for all four mass distributions. This indicates that the production of Λ_c is consistent with the fragmentation of $c(\bar{c})$ quarks produced by the boson-gluon-fusion mechanism, $\gamma^* g \to c\bar{c}$.

Figure 2 shows the invariant mass of $K^- p$ (and $K^+ \bar{p}$) combinations for PHP and DIS ($Q^2 > 1$ GeV^2 and $Q^2 > 20$ GeV^2). The fits of the invariant-mass distributions shown in this figure lead to significant numbers of reconstructed $\Lambda(1520)$ baryons (13500 for PHP, 2600 for DIS). Unlike Λ_c, the signal-over-background ratio for $\Lambda(1520)$ is similar for PHP and DIS. This is possible if the production rate of the $\Lambda(1520)$ baryons is proportional to the energy available for the fragmentation process. This indicates that $\Lambda(1520)$ can be produced by pure fragmentation mechanism, without partons from the hard interaction. The $\Lambda(1520)$ was also studied in the forward ($\eta > 0$) and in the rear$\eta <$ 0 pseudorapidity regions, shown in Fig. 4. The fit was performed using a Gaussian with a second-order polynomial function. There are similar numbers of $\Lambda(1520)$ candidates for these two pseudorapidity regions. Also the fits give similar numbers of $\Lambda(1520)$ baryons and antibaryons. Both observations strengthen the conclusion that the dominant production mechanism of $\Lambda(1520)$ is pure fragmentation.

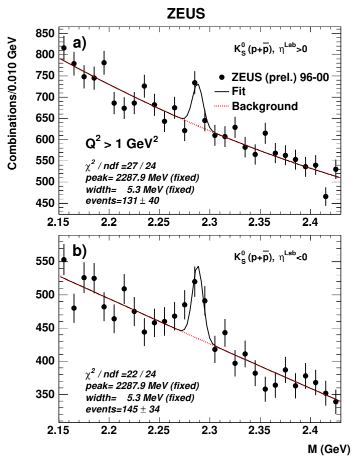

FIGURE 3. The $K^0_S p(\bar{p})$ invariant-mass distribution near the Λ_c mass for $\eta > 0$ and $\eta < 0$ regions in DIS for $Q^2 > 1$ GeV^2.

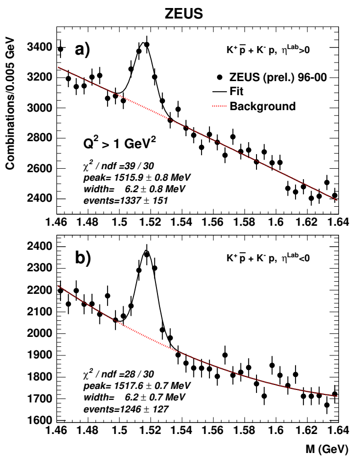

FIGURE 4. The $K^- p (K^+ \bar{p})$ invariant-mass distribution near the $\Lambda(1520)$ mass in the forward ($\eta > 0$) and in the rear ($\eta < 0$) regions for $Q^2 > 1$ GeV^2.

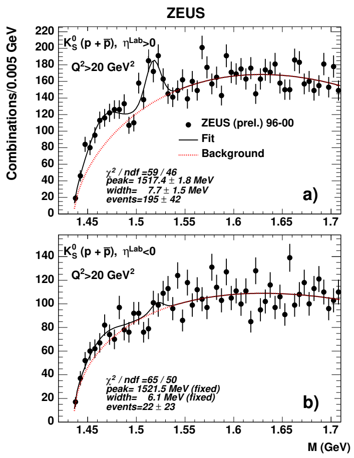

FIGURE 5. The $K^0_S p(\bar{p})$ invariant-mass distribution near the 1520 MeV mass for the forward ($\eta > 0$) and rear ($\eta < 0$) region in DIS for $Q^2 > 20$ GeV^2.

The Θ^{++} state was searched in the $K^+ p$ ($K^- \bar{p}$) invariant-mass spectrum in PHP and DIS. However, no signal was found in either distribution. This indicates that Θ^+ is not an isotensor. If the peak in the $K^0_S p$ invariant mass spectrum near 1520 MeV corresponds to a new Σ state rather than to the strange pentaquark, the decay $\Theta^+ \to \Lambda \pi^+$ should also be allowed. Peaks due to the known PDG states, $\Xi(1320)$ and $\Sigma(1385)$ baryons, are clearly observed in the reconstructed $\Lambda\pi$ invariant mass. However, no statistically significant peak is seen near 1520 MeV.

If the observed $K_S^0 p(\bar{p})$ peak near 1520 MeV corresponds to a new state, then the studies of this peak in different pseudorapidity regions, as well as for proton and antiproton samples, can help to qualify the production mechanism of this baryonic state. The results of the fits of the $K_S^0 p$ invariant mass near 1520 MeV are shown in Fig. 5 for a region where the contribution from the proton remnant is expected to be more pronounced (the upper figure), and a region dominated by pure fragmentation (the bottom figure). The fit was performed using a double Gaussian with the threshold function: $P_1(M - m_p - m_{K_S^0})^{P_2} \times (1 + P_3(M - m_p - m_{K_S^0}))$, where M is the $K_S^0 p(\bar{p})$ candidate mass, m_p and $m_{K_S^0}$ are the masses of the proton and the K_S^0, respectively, and P_1, P_2 and P_3 are parameters. For the fit in the $\eta < 0$ region, the peak position and the Gaussian width were fixed to the sum of these two distributions. The signal is found to occur predominantly in the first pseudorapidity region. Also the fits give relatively larger number of Θ^+ candidates than Θ^- candidates. However, no strong conclusion can be made since the background spectra for $K_S^0 \bar{p}$ is too complicated near 1480 MeV region.

CONCLUSIONS

The invariant-mass spectra sensitive to possible baryonic states decaying to strange hadrons have been investigated. The candidate Θ^+ signal reported earlier [2] was found to be produced predominantly in the forward pseudorapidity region, unlike the well-established baryons, $\Lambda(1520)$ and Λ_c. This indicates that the Θ^+ may have an unusual production mechanism related to proton-remnant fragmentation. The production of Θ^- has lower rate relative to Θ^+, however, the statistical significance of this observation is low, and the background for antiproton spectra is too complicated to draw a strong conclusion.

As for the previous ZEUS studies [2], the candidate Θ^+ signal exists predominantly at medium Q^2 events. The studies of Λ_c indicate that combinatorial background for this Q^2 region is rather favorable for the reconstruction of a state whose production is not driven by pure fragmentation mechanism.

A significant number of $\Lambda(1520)$ baryons were reconstructed in the $K^- p$ decay channel. There is a strong indication that the main production mechanism of this baryon is pure fragmentation. A search was performed for $\Theta^{++} \to K^+ p$ signal, however, the results were negative.

The $K_S^0 p$ peak near 1520 MeV could also be a new Σ state, which can decay to $\Lambda\pi$. To check this, $\Lambda\pi$ mass combinations were investigated for PHP and DIS. No significant peak near the Θ^+ mass region was found.

REFERENCES

1. S. Chekanov, et al., *Phys. Lett.*, **B 610**, 212 (2005), `hep-ex/0501069`.
2. S. Chekanov, et al., *Phys. Lett.*, **B 591**, 7–22 (2004), `hep-ex/0403051`.