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Search for exotic baryons at HERMES

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Abstract. An experimental search for the $\Theta(1540)$- and $\Lambda(1520)$-resonance was performed in quasi-real photoproduction on deuterium at the HERMES experiment. While evidence for $\Theta(1540)$ was found in the decay channel $pK^0_S \to p\pi^+\pi^-$, no evidence for the corresponding anti-particle was found. In some models it is expected that the $\Theta(1540)$ and the $\Lambda(1520)$ have similar production mechanisms. The photoproduction cross-sections for the $\Lambda(1520)$ in the decay channel $\Lambda(1520) \to pK^-$ and the corresponding anti-particle are determined. The partial photoproduction cross-sections for $\Lambda(1520)$ and $\bar{\Lambda}(1520)$ are obtained as $\sigma_{\Lambda(1520)} = 65.3 \pm 8.8(\text{stat}) \pm 6.9(\text{syst})$ nb and $\sigma_{\bar{\Lambda}(1520)} = 9.8 \pm 2.6(\text{stat}) \pm 0.9(\text{syst})$ nb, corresponding to a ratio $R_{\Lambda(1520)} = \sigma_{\bar{\Lambda}(1520)}/\sigma_{\Lambda(1520)} = 0.15 \pm 0.05(\text{stat}) \pm 0.02(\text{syst})$.

PACS. 12.39.Mk Glueball and nonstandard multi-quark/gluon states – 13.60.-r Photon and charged-lepton interactions with hadrons – 13.60.Rj Baryon production – 14.20.-c Baryons (including antiparticles)

1 Introduction

The theory of Quantum Chromodynamics describes the interactions of quarks and gluons as constituents of mesons and baryons. It does not explicitly prohibit exotic states consisting of more than three quarks. Recently, several experimental groups have reported evidence for a manifestly exotic baryon resonance Θ with a mass near 1540 MeV, whose quantum numbers can be explained only with five or more quarks. On the other hand, searches at several high-energy experiments show no evidence for an exotic resonance near 1540 MeV, casting serious doubt on the existence of the $\Theta(1540)$. For a review of the current experimental status of exotic baryons the reader is referred to ref. [1].

At HERMES, in a search for the $\Theta(1540)$ in quasi-real photoproduction on a deuterium target through the decay channel $\Theta(1540) \to pK^0_S \to p\pi^+\pi^-$, a narrow peak at $1528 \pm 2.6(\text{stat}) \pm 2.1(\text{syst})$ MeV with 59 ± 16 events was observed [2]. The $M(p\pi^+\pi^-)$ invariant-mass spectrum is shown in fig. 1. Using the same data and event selection criteria, a search for the anti-particle $\overline{\Theta}(1540)$ was performed. The $M(\overline{p}\pi^+\pi^-)$ invariant-mass spectrum is shown in fig. 2. A similar fit as for the $\Theta(1540)$ but with a fixed Gaussian width results in 3±6 events, consistent with zero.

Recent results of the LEPS Collaboration [3] point to a similar production mechanism on deuterium for the exotic $\Theta(1540)$ and the hyperon $\Lambda(1520)$ with mass close to the observed $\Theta(1540)$ mass. Therefore the ratio of the $\overline{\Theta}(1540)$ and $\Theta(1540)$ cross-sections is expected to be similar to that of the $\bar{\Lambda}(1520)$ and $\Lambda(1520)$. More generally, knowledge of the ratios of anti-hadrons to hadrons

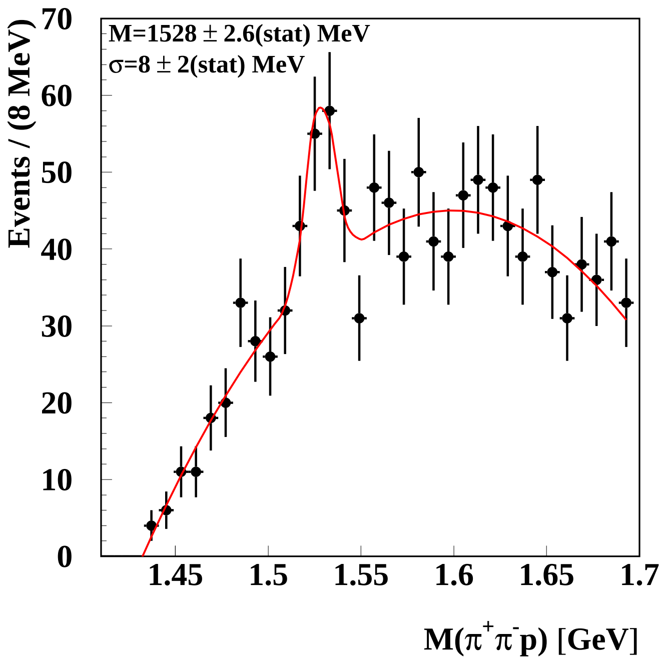

Fig. 1. Distribution of the invariant mass of the $p\pi^+\pi^-$ system. A fit to the data with a Gaussian plus a third-order polynomial is shown.

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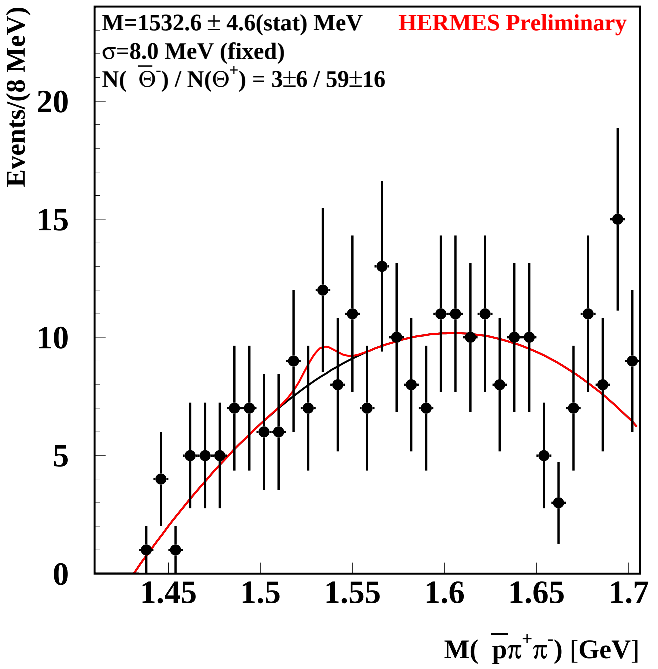

Fig. 2. Distribution of the invariant mass of the $\bar{p}\pi^+\pi^-$ system. A fit similar to fig. 1 but with fixed width for the $\overline{\Theta}(1540)$-resonance is shown.

could help understand the production mechanism of the $\Theta(1540)$ [4].

In this analysis the cross-section ratio of the $\bar{\Lambda}(1520)$ to $\Lambda(1520)$ is determined. For details about the $\Theta(1540)$ analysis, the reader is referred to ref. [2].

2 Experiment

For this analysis, data were obtained at the HERMES experiment with the 27.6 GeV positron beam of the HERA accelerator at DESY. An integrated luminosity of 209 pb^{-1} was collected on a longitudinally polarized deuterium gas target, and the yields were summed over the two spin orientations. The HERMES spectrometer [5] consists of two identical halves located above and below the positron beam pipe, and has an angular acceptance of ±170 mrad horizontally and ±40–140 mrad vertically.

The trigger was formed by a coincidence between scintillating hodoscopes, a preshower detector and a lead-glass calorimeter. Lepton and hadron tracks are distinguished by combining the signals from a transition radiation detector, a preshower detector, a ring-imaging Čerenkov detector and a lead-glass calorimeter. Identification of pions, kaons and protons is accomplished with the dual radiator ring-imaging Čerenkov (RICH) detector [6]. Data from simulations indicate that cross contaminations are negligible in a momentum range 1–15 GeV for pions, 2–15 GeV for kaons, and 4–9 GeV for protons, the kinematic restrictions subsequently used in this analysis.

3 Analysis

This analysis searched for inclusive photoproduction of the hyperon $\Lambda(1520)$ followed by the decay $\Lambda(1520) \to pK^-$, and of its anti-particle $\bar{\Lambda}(1520)$ followed by the decay $\bar{\Lambda}(1520) \to \bar{p}K^+$. Using the simulated effects of acceptance and efficiency the partial cross-sections for $\Lambda(1520)$ and $\bar{\Lambda}(1520)$ are determined.

To maximize the yield of the $\Lambda(1520)$ peak in the $M(pK^-)$ invariant-mass spectrum while minimizing its background, restrictions on the event topology of the pK system were applied. Based on the intrinsic tracking resolution, a distance of closest approach between the proton and kaon tracks less than 0.6 cm and a radial distance of the pK vertex to the HERA beam axis less than 0.4 cm are required. Because the $\Lambda(1520)$ has a mean path length much smaller than the longitudinal tracking resolution of 3 cm, a decay length of the $\Lambda(1520)$ less than 5 cm is required. Kaons mis-identified as protons were rejected when the $M(K^+K^-)$ invariant mass was within the reconstructed $\Phi(1020)$-resonance peak. The same event selection criteria were applied to the candidate $\bar{\Lambda}(1520)$ events.

The resulting $M(pK)$ invariant mass spectra for the pK^- and $\bar{p}K^+$ systems are shown in figs. 3 and 4. The invariant-mass spectra were fitted using an unbinned maximum-likelihood technique with the sum of a Breit-Wigner resonance shape convolved with the Gaussian de-

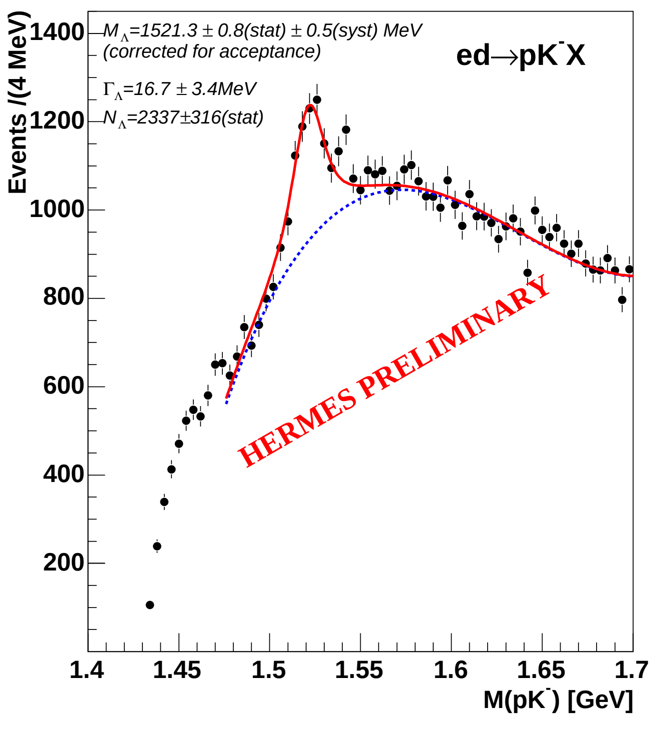

Fig. 3. Distribution of the invariant mass of the pK^- system. A fit to the data with a Breit-Wigner resonance shape convolved with the Gaussian resolution plus a third-order polynomial is shown. The position of the peak has been corrected for the effects of the HERMES acceptance.

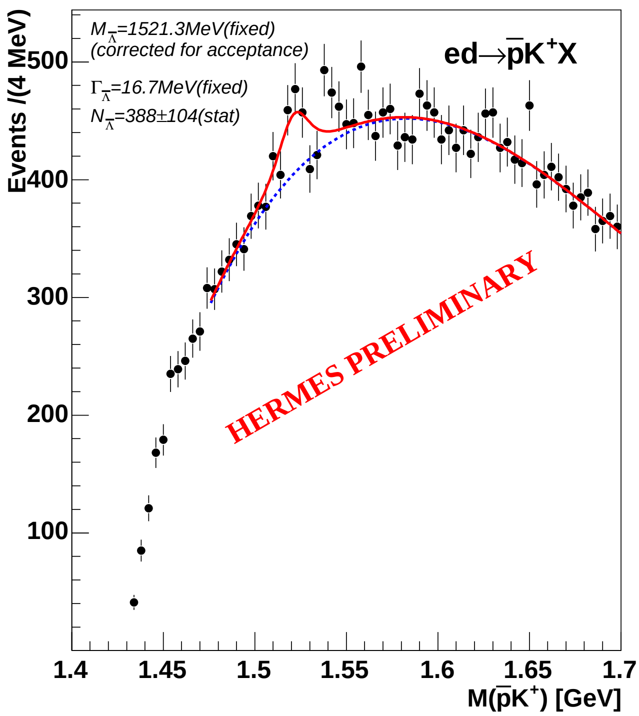

Fig. 4. Distribution of the invariant mass of the $\overline{p}K^+$ system. A fit similar to fig. 3 but with fixed width and position for the $\bar{\Lambda}(1520)$-resonance is shown.

tector resolution, in addition to a third-order polynomial for the description of the background. The resolution in $M(pK)$ was determined using a Monte Carlo simulation of the full spectrometer and is $\sigma = 4\,\text{MeV}$ for both the pK^- and $\overline{p}K^+$ system. For the $\Lambda(1520)$ a peak is observed at $1521.3 \pm 0.8(\text{stat}) \pm 0.5(\text{syst})$ MeV with an intrinsic width $\Gamma = 16.7 \pm 3.4\,\text{MeV}$, in agreement with the PDG estimates [7]. For the $\bar{\Lambda}(1520)$ the peak position and width were fixed to the results for the $\Lambda(1520)$. The extracted number of resonance events are $N_{\Lambda(1520)} = 2337 \pm 316$ and $N_{\bar{\Lambda}(1520)} = 388 \pm 104$.

The shoulder in the $M(pK^-)$ invariant-mass spectrum at a mass slightly below the $\Lambda(1520)$ mass is caused by kinematic effects and reproduced in the background shape obtained by event mixing. The excess of events near 1540 MeV can be removed by requiring more stringent cuts for correct particle identification, and is likely due to background of wrongly identified particles.

Monte Carlo simulations of $\Lambda(1520)$ events tracked through a full model of the spectrometer show that the variation of the detector acceptance in the region around the $\Lambda(1520)$ peak causes a shift in the resonance position of 1.2 ± 0.5 MeV towards higher masses. The reported masses and their systematic uncertainties have been corrected for this effect.

For the calculation of the cross-section, the combined effect of the geometrical and kinematic acceptance and of the event selection efficiency was determined using Monte Carlo simulations. The Pythia Monte Carlo generator does not include the $\Lambda(1520)$ hyperon, so the initial momentum distribution for $\Lambda(1520)$ and $\bar{\Lambda}(1520)$ production is assumed to be similar to that of other hyperons available in Pythia (Λ, Σ, Ξ, $\Sigma(1385)$, $\Xi(1530)$). The acceptance for $\Lambda(1520)$ events exhibits a steady increase with the mass of the hyperon whose momentum distribution is used. Due to the kinematic acceptance of the HERMES spectrometer for $\Lambda(1520)$ decays, only candidates with a longitudinal momentum P_z greater than 6 GeV were considered. The determined acceptance for $\Lambda(1520)$ and $\bar{\Lambda}(1520)$ is $3.8 \pm 0.4\%$ and $4.2 \pm 0.4\%$, respectively. No $\Lambda(1520)$ polarization was taken into account for this calculation.

The resulting partial photoproduction cross-sections are $\sigma_{\Lambda(1520)} = 65.3\pm8.8(\text{stat})\pm6.9(\text{syst})$ nb and $\sigma_{\bar{\Lambda}(1520)} = 9.8\pm2.6(\text{stat})\pm0.9(\text{syst})$ nb. The systematic uncertainties take into account the change of acceptance related to the uncertainty on the peak position, and the uncertainty in the choice of initial momentum distribution. The corresponding cross-section ratio $R_{\Lambda(1520)} = \sigma_{\bar{\Lambda}(1520)}/\sigma_{\Lambda(1520)}$ is $R_{\Lambda(1520)} = 0.15 \pm 0.05(\text{stat}) \pm 0.02(\text{syst})$.

4 Discussion

Assuming similar production processes for the $\Theta(1540)$ and the $\Lambda(1520)$, and equal ratios for the particle and antiparticle cross-sections of these resonances, the expected number of $\overline{\Theta}(1540)$ events at HERMES can be estimated as 10 ± 4. This is in agreement with the experimental result 3 ± 6 within statistical uncertainties.

At HERMES we are currently analyzing the data collected on a polarized hydrogen target between the years 2003 and 2005. Additional data on a high-density hydrogen and deuterium target are still being collected.

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