RECENT SPECTROSCOPY RESULTS FROM ZEUS

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Recent results on light hadron spectroscopy are reported, with special emphasis on the evidence for a narrow baryonic state decaying to $K^0_S\,p$ and $K^0_S\,\bar{p}$, compatible with the pentaquark state θ^+ observed by fixed target experiments. The data were collected with the ZEUS detector at HERA using an integrated luminosity of 121 pb^{-1}. The analyses were performed in the central rapidity region of inclusive deep inelastic scattering at an *ep* centre-of-mass energy of 300–318 GeV. Evidence for a narrow resonance in the $K^0_S\,p$ and $K^0_S\,\bar{p}$ invariant mass spectrum is obtained, with mass $1521.5 \pm 1.5(stat)^{+2.8}_{-1.7}(syst)$ and width consistent with the experimental resolution. If the $K^0_S\,p$ part of the signal is identified with the strange pentaquark θ^+, the $K^0_S\,\bar{p}$ part is the first evidence for its antiparticle, $\bar{\theta}^-$. Supporting results on other light hadron resonances are also discussed.

1 Introduction

Recently, interest in light hadron spectroscopy has been considerably revived by the observation of baryonic resonances [1,2,3] compatible with their interpretation in terms of pentaquark states, i.e. bound states of four quarks and an antiquark [4,5]. While almost all hadronic states observed previously can be interpreted in terms of baryons (bound states of three quarks, qqq) or mesons (bound quark-antiquark states, $q\bar{q}$), the theory of Quantum Chromo Dynamics (QCD) does not preclude the existence of other colour neutral quark combinations such as tetraquarks ($qq\bar{q}\bar{q}$), pentaquarks ($qqqq\bar{q}$), etc., or states including gluons such as glueballs (gg) or hybrids ($q\bar{q}g$).

Potential glueball candidates have already been discussed for many years [6] without firm conclusions. The ZEUS experiment at the HERA ep collider has recently added input to this discussion through the observation of at least one of these candidates in the $K^0_S K^0_S$ final state [7].

The first quantitative predictions for the existence of bound pentaquark states have been made only fairly recently [4], and their observation, mainly of the θ^+ state with quark content $uudd\bar{s}$, has triggered a large number of further theoretical predictions [5]. However, the first pentaquark observations were all obtained in fixed target experiments at low centre-of-mass energies [1,2], where valence quarks from the target nucleons can easily become part of the pentaquark final state. Consequently, only $qqqq\bar{q}$ states were found, in contrast to $\bar{q}\bar{q}\bar{q}\bar{q}q$ states.

Here we investigate the production of light narrow resonances in the central rapidity region of inclusive deep inelastic scattering (DIS) at an *ep* centre-of-mass energy of 300–318 GeV for exchanged photon virtuality, Q^2, above 1 GeV^2. In this kinematic region, hadrons are mainly produced from the fragmentation of a sea (anti)quark in the proton struck by the photon, and only faintly "remember", if at all, their proton parent. Hadrons and their antiparticles are hence produced in approximately equal proportions.

It is therefore a nontrivial question whether the pentaquarks observed in fixed target collisions should also be seen in high energy collider experiments. On the other hand, if at all, collider experiments should observe not only the pentaquarks, but also their antiparticles. The potentially first such observation in the light quark sector is presented in this document. Corresponding experimental evidence and/or searches for pentaquarks containing a heavier charmed quark are discussed in [8,9].

2 Evidence for a narrow baryonic state decaying to $K^0_S\,p\,(\bar{p})$

ZEUS has performed a search for pentaquarks in the $K^0_S\,p\,(\bar{p})$ decay channel [10]. The analysis used deep inelastic scattering events measured with exchanged-photon virtuality $Q^2 \geq 1$ GeV^2. The data sample corresponds to an integrated luminosity of 121 pb^{-1}. The charged tracks were selected in the central tracking detector (CTD) with $p_T \geq 0.15$ GeV and $|\eta| \leq 1.75$, restricting this study to a region where the CTD track acceptance and resolution are high.

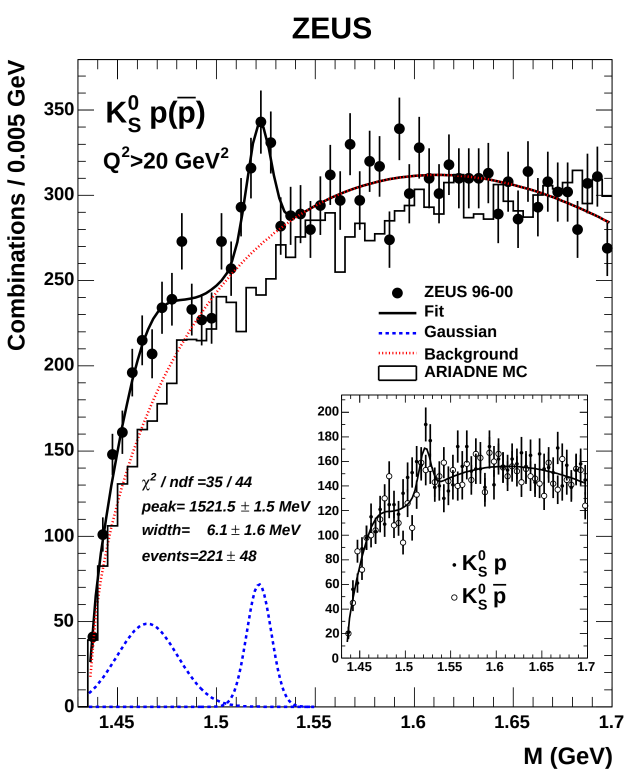

Figure 1: Invariant-mass spectrum for the $K^0_S\,p\,(\bar{p})$ channel for $Q^2 > 20$ GeV^2. The solid line is the result of a fit to the data using a threshold background plus two Gaussians. The dashed lines show the Gaussian components, while the dotted line indicates background. The prediction of the Monte Carlo simulation is normalised to the data in the mass region above 1650 MeV. The inset shows the $K^0_S\,\bar{p}$ (open circles) and the $K^0_S\,p$ (black dots) candidates separately, compared to the result of the fit to the combined sample scaled by a factor of 0.5.

The total number of K^0_S with $p_T(K^0_S) > 0.3$ GeV and $|\eta(K^0_S)| < 1.5$, identified using the decay mode $K^0_S \to \pi^+\pi^-$, was 867K. To eliminate contamination from $\Lambda(\bar{\Lambda})$ decays, candidates with a proton mass hypothesis $M(p\,\pi) < 1121$ MeV were rejected.

The (anti)proton-candidate selection used the energy-loss measurement in the CTD, dE/dx. $K^0_S\,p\,(\bar{p})$ invariant masses were obtained by combining K^0_S candidates in the mass region $480-510$ MeV with (anti)proton candidates in the (anti)proton dE/dx band with the additional requirements $p < 1.5$ GeV and $dE/dx > 1.15$ mips in order to reduce the pion background.

The CTD resolution for the $K_S^0\,p\,(\bar{p})$ invariant-mass near 1530 MeV, was estimated from Monte Carlo simulations to be 2.0 ± 0.5 MeV for both the $K_S^0\,p$ and the $K_S^0\,\bar{p}$ channels.

Fig. 1 shows the $K_S^0\,p\,(\bar{p})$ invariant mass for $Q^2 > 20$ GeV^2. The separated $K_S^0\,p$ and $K_S^0\,\bar{p}$ distributions are shown as inset. The choice of the higher Q^2 cut was motivated by the expected decrease in acceptance and increase in background at lower Q^2 values. Mass distributions for different Q^2 cuts can be found in [10]. The fit of two Gaussians on top of a continous background, also shown in Fig. 1, yields a clear narrow peak at 1522 MeV. The second Gaussian near 1470 MeV could either be attributed to another, broader resonance (e.g. the unestablished resonance $\Sigma(1480)$ [11]), or be regarded as the empirical parametrization of a more complicated background shape. A single Gaussian fit yields essentially identical results [10], indicating robustness against the choice of the background function. From the Ariadne Monte Carlo model, which contains only ordinary hadrons, no peaks are expected in this region.

The peak position obtained from Fig. 1 is $1521.5 \pm 1.5(\mathrm{stat.})^{+2.8}_{-1.7}(\mathrm{syst.})$ MeV (see [10] for details). It agrees well with the measurements by HERMES, SVD and COSY-TOF for the same decay channel [2], but is slightly lower than the mass found in experiments reconstructing the K^+n decay channel [1]. Its Gaussian width was found to be 6.1 ± 1.6 GeV, still compatible with the experimental resolution of 2 MeV. If the width of the Gaussian is fixed to this experimental resolution, the extracted Breit-Wigner width of the signal is $\Gamma = 8 \pm 4(\mathrm{stat.})$ MeV.

The number of signal events obtained from the fit in Fig. 1 is 221 ± 48. This corresponds to a statistical significance of 4.6σ. The number of events in the $K_S^0\,\bar{p}$ channel is 96 ± 34. It agrees with the signal extracted for the $K_S^0\,p$ decay mode. If the $K_S^0\,p$ signal corresponds to the θ^+ pentaquark observed by other experiments, this measurement provides the first evidence for its antiparticle with a quark content of $\bar{u}\bar{u}\bar{d}\bar{d}s$.

3 Other resonances and systematic checks

Searches for corresponding double strange and charmed pentaquark states have also been performed by ZEUS. The corresponding (negative) results can be found in [13] and [9], contrasting the positive evidence obtained by the NA49 [3] and H1 [8] collaborations.

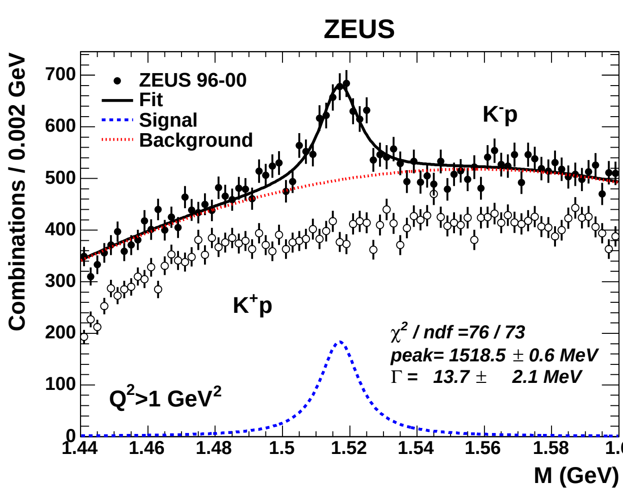

Figure 2: Invariant-mass spectra for the K^+p and K^-p channels (plus charge conjugates) for $Q^2 > 1$ GeV^2.

Previous studies on K^0 and Λ production in DIS [7] enhance the confidence in the K^0 reconstruction and selection procedure, and allow cross-checks of proton identification. Events with two K^0's have been successfully used to study resonances decaying into K_s^0 pairs [7]. Many further systematic checks are explained in [10].

For example, an important contribution to understand and check the efficiencies and resolutions can be obtained from the reconstruction of the well established $\Lambda(1520)D_{03}$ meson in its charged pK decay mode. The $K^{\pm}p(K^{\pm}\bar{p})$ invariant mass spectra were investigated in a wide range of minimum Q^2 values, identifying proton and charged kaon candidates using the dE/dx information. The proton candidates inside the dE/dx proton band were required to have $dE/dx > 1.8$ mips, while the kaon candidates were reconstructed in the kaon band after the restriction $dE/dx > 1.2$ mips. For $Q^2 > 1$ GeV^2, no peak was observed near 1522 MeV in the K^+p and $K^-\bar{p}$ spectra, see Fig. 2, while a clean signal was seen in the $K^-p(K^+\bar{p})$ channel at 1518.5 ± 0.6(stat.) MeV, corresponding to the $\Lambda(1520)D_{03}$ state. The fact that both mass and width are in good agreement with the PDG[11] values verifies that there are no significant reconstruction biases in the pentaquark mass range. Also, the absence of a peak in the like sign spectrum disfavours the isotensor interpretation of the θ^+ state [12].

4 Conclusions

Evidence for a narrow baryonic state decaying to $K^0_S\,p$ and $K^0_S\,\bar{p}$ is obtained in the central fragmentation region of deep inelastic scattering events by the ZEUS collaboration at HERA. This state is compatible with the pentaquark state θ^+ observed by fixed target experiments, and its antiparticle $\bar{\theta}^-$, presumably observed for the first time. Supporting results on other light hadron resonances are also presented.

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