HADRON SPECTROSCOPY IN ELECTRONS-PROTONS COLLISIONS AT HERA

BOB OLIVIER
DESY,
Notkestrasse 85,
22607 Hamburg, Germany
E-mail: bob.olivier@desy.de

Recent results from H1 and ZEUS on searches for exotic baryons in ep collisions at HERA are reviewed. Evidence for the production of the strange pentaquark Θ^+ and of a narrow anti-charmed baryon decaying to $D^{*-}p$ together with negative results of pentaquark searches at HERA are presented.

1. Introduction

Experimental evidence for an exotic baryon first came in 2003 from the observation of a $S = +1$ narrow resonance [1] at 1540 ± 10 MeV which can be associated with an exotic pentaquark state with content $uudd\bar{s}$. Confirmation came quickly from a series of experiments, with the observation of sharp peaks [2,3,4,5] in the nK^+ and pK^0_S invariant mass spectrum near 1540 MeV, in each case with a width limited by the experimental resolution.

Strong evidence in support of a baryon decuplet comes from the reported observation of an exotic $S = -2$, $Q = -2$ baryon resonance in pp collisions [6]. A narrow peak at a mass of about 1862 MeV in the $\Xi^-\pi^-$ invariant mass spectrum is proposed as a candidate for the predicted exotic $\Xi^{--}_{\frac{3}{2}}$ baryon with a quark content $dsds\bar{u}$. At the same mass, a peak is observed that is a candidate for $\Xi^{0}_{\frac{3}{2}}$

At HERA electrons (or positrons) of energy 27.5 GeV are collided with 920 GeV protons providing a center of mass energy $\sqrt{s}$ of 318 GeV. In the following we present the results of the searches for strange and charmed pentaquarks performed by the H1 and ZEUS experiments with an integrated luminosity of up to 126 pb^{-1} accumulated from 1995 to 2000 during the HERA-I data taking period.

2. Search for Θ^+ and Θ^{++}

ZEUS performed a Θ^+ search [7,8] at high energies using the ep data taken in the years 1996-2000 with an integrated luminosity of 121 pb^{-1}. The kinematic region is restricted to the exchanged boson virtuality domain $Q^2 > 1$ GeV^2 and the inelasticity domain $0.01 < y < 0.95$.

The decay chain $\Theta^+ \to pK^0_S \to p\pi^+\pi^-$ has been used. About 866800 K^0_S candidates are selected. They are combined with proton candidates selected via the energy-loss measurement dE/dx.

The $M_{\pi^+\pi^-}$ mass distribution shows sign of structure below about 1600 MeV. For $Q^2 > 10$ GeV^2, a peak is seen in the mass distribution around 1520 MeV. In Fig. 1 the $M_{\pi^+\pi^-}$ is shown for $Q^2 > 20$ GeV^2. The figure includes the Monte Carlo expectation from ARIADNE [11] scaled to the data for $M_{\pi^+\pi^-} > 1650$ MeV. After scaling ARIADNE does not describe the data at low masses, maybe due to the absence of the Σ bumps in the simulation. A fit to the data of a smooth background function and two

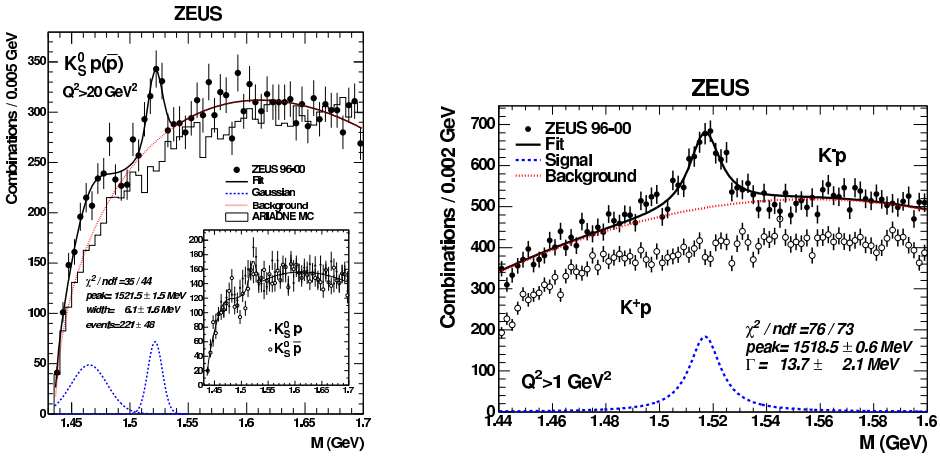

Figure 1. (left) Invariant mass distribution $M_{p\pi^+\pi^-}$ observed by ZEUS at $Q^2 > 20$ GeV^2. (right) Invariant mass distribution M_{pK^+} (open dots) and M_{pK^-} (full dots) observed by ZEUS.

Gaussians, also shown in Fig. 1, gives a signal of 221 ± 48 events at a mass of $1521.5 \pm 1.5(stat.)$ MeV with a significance of 4.6σ. The Gaussian width of 6.1 MeV is found to be consistent with the experimental resolution. The signal is observed at similar rate for protons and for antiprotons suggesting the existence of the anti-pentaquark Θ^-.

ZEUS has also measured the cross section for the production of the Θ^+ baryons and their antiparticles in the kinematic region $Q^2 > 20$ GeV^2, $0.04 < y < 0.95$, $p_T > 0.5$ GeV and $|\eta| < 1.5$, $\sigma(ep \to e\Theta X \to eK^0_S p(\bar{p})X) = 125 \pm 27(stat.)^{+36}_{-28}(syst.)$ pb. ZEUS also measured the Θ^+ production cross section for higher Q^2 thresholds 30, 40, and 50 GeV^2. The Θ^+ cross section shows no significant dependence on Q^2.

After the presentation of this talk were released results on the Θ^+ search performed by H1 [9] in a similar phase space region than ZEUS. No peak was observed in the $M_{\pi^+\pi^-}$ mass distribution. At a mass of 1522 MeV, H1 sets an upper limit on the Θ^+ production cross section of the order of 100 pb. This upper limit is compatible with the ZEUS observed cross section due to the large error on the latter one.

ZEUS has also searched for the Θ^{++} signal via its possible decay $\Theta^{++} \to K^+\pi^+$. Fig. 1 shows the M_{pK^-} and M_{pK^+} mass spectra. No peak structure is observed in the M_{pK^+} spectrum but in the M_{pK^-} spectrum the well established resonance $\Lambda(1520) \to pK^-$ is clearly seen. As no signal is found in the Θ^+ mass range, this suggests that the Θ^+ could be isoscalar.

3. Search for $\Xi^{--}_{\frac{3}{2}}$ and $\Xi^{0}_{\frac{3}{2}}$

ZEUS has performed an analysis in the channel $\Xi^-\pi^\pm$ to search for the strange pentaquark Ξ^{--} and its neutral partner [10]. The decay chain $\Xi^{--} \to \Xi^-\pi^- \to \Lambda\pi^-\pi^-$ has been considered. Λ baryons were identified by the charged-decay mode, $\Lambda \to p\pi^-$, using pairs of tracks from secondary vertices. These are then combined with another pion from the primary vertex. Fig. 2 shows the $M_{\Xi\pi}$ mass distribution for all possible $\Xi\pi$ charge combinations for $Q^2 > 1$ GeV^2 . While the $\Xi^0(1530)$ is clearly visible, no signal is observed around 1860 MeV as observed by the NA49 collaboration [6]. Even when restricting to $Q^2 > 20$ GeV^2, where the Θ^+ signal was best seen by ZEUS, no signal is observed.

4. Search for Θ_c

The production of a charmed pentaquark Θ_c has been studied via its decay into D^*p by H1 [12,13] and ZEUS [14].

The analysis of H1 is based on the DIS data taken in the years 1996-2000 with a luminosity of 75 pb^{-1} in the kinematic region $1 < Q^2 < 100$ GeV^2 and $0.05 < y < 0.7$. The $D^{*\pm}$ charmed meson has been reconstructed via its decay chain $D^{*+} \to D^0\pi^+_S \to (K^-\pi^+)\pi^+_S$. Around 3400 D^* candidates are selected, and are combined with proton candidates selected via dE/dx.

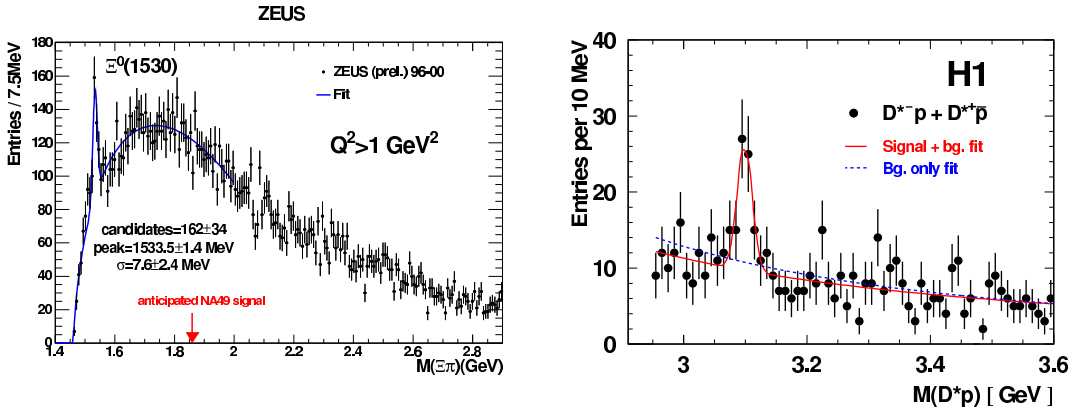

Figure 2. (left) Invariant mass distribution $M_{\Xi\pi}$ observed by ZEUS for $Q^2 > 1$ GeV^2 and for all four charge combinations combined. (right) Invariant mass distribution M_{D^*p} from H1 for $Q^2 > 1$ GeV^2 compared to the fit results with two hypotheses: signal plus background (solid line) and background only (dashed line).

The resulting $M_{D^{*-}p}$ distribution in Fig. 2 shows a clear narrow peak close to the threshold. The signal is both observed in the $D^{*-}p$ and in the $D^{*+}\bar{p}$ sample with compatible mass, width and rate. Log-likelihood fits to the M_{D^*p} distribution are performed. The background is parametrised by a power law while a Gaussian is used for the signal. A signal of 51 events is observed with a mass of $3099 \pm 3(stat.) \pm 5(syst.)$ MeV and a width of $12 \pm 3(stat.)$ MeV consistent with the experimental resolution. The background fluctuation probability has been estimated to be less than 4×10^{-8}.

A similar search has been performed by ZEUS in both photoproduction and DIS regimes. Data from the years 1995-2000 with an integrated luminosity of 126 pb^{-1} have been analyzed. About 9700 D^* candidates are selected for $Q^2 > 1$ GeV^2 and 43000 candidates for all data. No signal is observed at 3.1 GeV.

Upper limits on the fraction of D^* mesons originating from the Θ_c decays, $R = N(\Theta_c \to D^*p)/N(D^*p)$, were set by ZEUS in the signal window of $3.07 < M_{D^*p} < 3.13$ GeV. This window covers the H1 measurement. The 95% confidence level upper limit on the fraction R is 0.23%. The upper limit for DIS with $Q^2 > 1$ GeV^2 is 0.35%. Thus, the ZEUS results are not compatible with the report of the H1 collaboration of a charmed pentaquark which contributes to $1.59 \pm 0.33(stat.)^{+0.33}_{-0.45}(syst.)$% of the $D^{*\pm}$ production rate [13].

5. Conclusions

Recent results from H1 and ZEUS on searches for exotic baryons in ep collisions at HERA have been presented. ZEUS has found evidence for the production of the strange pentaquark Θ^+. H1 on the contrary has not found any signal compatible with the Θ^+ and has obtained limits for its production. ZEUS has not found any evidence for the signal seen by the NA49 collaboration attributed to the $\Xi^{--}_{\frac{3}{2}}$.

H1 has found evidence for the existence of a narrow anti-charmed baryon decaying to D^*p. This result has not been confirmed by the ZEUS search which has been performed in a similar kinematic region.

Pentaquark searches are still an open issue. Of the colliding beam experiments that are currently taking data, the HERA experiments H1 and ZEUS are the only ones which have reported the observation of pentaquark signals to date. Pentaquark production may be suppressed in e^+e^- annihilation due to the lack of any particles carrying baryon number in the initial state colliding beams. The complicated and high multiplicity hadronic final states produced in pp and $p\bar{p}$ scattering may obscure any pentaquark signal, especially if it is dominantly produced at low transverse momentum. The search for pentaquarks at HERA using the high statistics data from the HERA-II data taking period, to be completed in 2007, may thus represent a unique opportunity to make progress in the field of exotic hadron spectroscopy.

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