PENTAQUARK SEARCHES IN H1

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Talk given on behalf of the H1 Collaboration at ICHEP06, Moscow, Russia

We report on searches in deep inelastic ep scattering for narrow baryonic states decaying into $\Xi^-\pi^-, \Xi^-\pi^+, K^0_S p$ and their charge conjugates, at centre-of-mass energies of 300 and 318 GeV. No signal for a new narrow baryonic state is observed in the mass ranges 1600-2100 MeV ($\Xi\pi$) and from threshold up to 1700 MeV ($K^0_S p$). The standard baryon $\Xi(1530)^0$ is observed in the decay mode $\Xi^-\pi^+$, and mass dependent upper limits on the ratio of the hypothetical pentaquark states Ξ^{--}_{5q} and Ξ^0_{5q} to the $\Xi(1530)^0$ signal are given. Also for the hypothetical strange pentaquark Θ^+ mass dependent upper limits on $\sigma(ep \to e\Theta^+ X) \times BR(\Theta^+ \to K^0 p)$ are obtained.
Finally measurements of the acceptance corrected ratios $\sigma(D^* p(3100))/\sigma(D^*)$ for the electroproduction of the anti-charmed baryon state $D^*p(3100)$ decaying into D^* and p are presented.

Keywords: pentaquark; HERA.

1. Introduction

Pentaquarks are exotic to the standard quark model of mesons and baryons, although not excluded in QCD. Combination of the meson and baryon octets leads to the anti-decuplet $qqqq\bar{q}$, where q stands for the light quarks u, d and s. These 5-quark states are non-minimal, colour neutral combinations. The apex states $uudd\bar{s}$, $ssdd\bar{u}$ and $uuss\bar{d}$ are predicted to have masses in the range $1.5 - 2.1$ GeV and to be very narrow[1]. For two of these states decay modes are experimentally relatively easily accessible, and consequently many searches have been performed, both in fixed target and colliding beam environments. For the $uudd\bar{s}$ state, called Θ^+, a large number of observations in the mass range $1.52 - 1.54$ GeV is matched by an equally large number of non-observations[2]. The doubly strange $ssdd\bar{u}$ state, Σ^{--}, has only been observed by one experiment so far[3]. Also here many non-observations have been reported[2].

Pentaquarks which contain a charm quark have also been searched for. One observation[4], named $D^*p(3100)$ by the H1 collaboration, has so far not been confirmed by any other experiment.

In this report the current results of searches by the H1 experiment for the Θ^+ and Σ^{--} states are briefly presented. The searches have been performed in the HERA-I ep data (1996-2000), which encompass $75 - 100$ pb^{-1}. In the last section some details of the characteristics of the $D^*p(3100)$ production are presented.

2. The strange pentaquark Θ^+

The Θ^+ was first seen by the LEPS collaboration[5] in the decay mode K^+n, at a mass of 1.52 GeV. The H1 collaboration searched[6] for a narrow state decaying to $K^0_S p$ in the mass interval from threshold 1.48 GeV to 1.7 GeV, using DIS data with $5 < Q^2 < 100$ GeV^2 and $0.1 < y < 0.6$. The K^0_S was identified through the decay $K^0_S \to \pi^+\pi^-$ and events were accepted if they contained at least one K^0_S and at least one proton[a] candidate. Charged tracks had $p_t > 0.15$ GeV and pseudorapidity $|\eta| < 1.75$, while the K°_S candidate had $p_t > 0.3$ GeV. Backgrounds

[a]Charge conjugation is always implied, unless otherwise stated.

from Λ and converted photons were rejected with the restrictions $M_{p\pi} > 1.125$ GeV and $M_{ee} > 0.05$ GeV on the $\pi\pi$ system. Protons were identified through the specific ionization loss dE/dx in the inner drift chambers, with efficiencies between 65 and 100%.

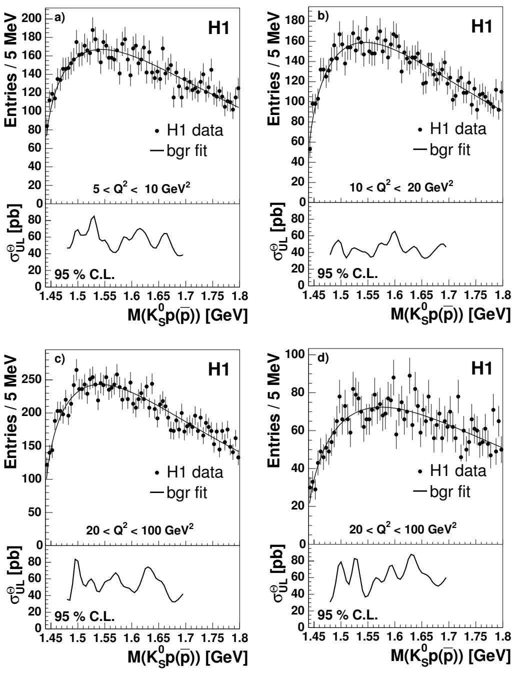

Fig. 1. $K^0_S p(\bar{p})$ invariant mass. a-c) in bins of Q^2, d) in the highest Q^2 bin and with $p_p < 1.5$ GeV. The full curves show the background function fits. Upper limits $\sigma_{U.L.}$ at 95% C.L. on the cross section are shown below the mass distributions.

In the resonance search, $K^0_S p$ combinations were selected under the restriction $p_t > 0.5$ GeV and $|\eta| < 1.5$ for the $K^0_S p$ system. Mass distributions $K^0_S p$ in three Q^2 intervals are shown in Fig. 1a-c. No significant resonance signal is seen, and the distributions are well described by a smooth background function. Mass dependent upper limits for the cross section $\sigma(ep \rightarrow e\Theta X) \times BR(\Theta \rightarrow K^0 p)$, obtained using a modified frequentist approach[7] based on likelihood ratios and taking into account both statistical and systematic errors, are shown below the mass distributions in Fig. 1.

The search was repeated with separation of the $K^0_S p$ and $K^0_S \bar{p}$ distributions, with no significant peak as result. The obtained upper limits vary between 30 and 90 pb.

The ZEUS collaboration has reported evidence[8] for a 1.52 GeV signal in the $K^0_S p$ mass distribution. The H1 upper limit at 1.52 GeV is $\sigma < 72$ pb, which translates to $\sigma < 100$ pb (95% C.L.) when extrapolated to the ZEUS y-range. This value is barely compatible with the ZEUS preliminary cross section[9], $\sigma = 125 \pm 27^{+36}_{-28}$ pb.

The ZEUS collaboration also found that the observed resonance is most prominent with the cuts $Q^2 > 20$ GeV and proton momentum $p_p < 1.5$ GeV. Also in this kinematic range the H1 collaboration observes no peak, see Fig. 1d.

3. The pentaquarks Ξ^{--}_{5q} and Ξ^0_{5q}

The NA49 collaboration observed a narrow resonance structure at 1862 ± 2 MeV in $\Xi(1321)\pi$ mass spectra[3]. Both Ξ^{--} and Ξ^0 peaks were seen, leading to the interpretation of these states being the neutral and doubly charged members of the $\Xi_{3/2}(1862)$ pentaquark multiplet. Other experiments could not yet confirm this observation.

The H1 search for this state[10] uses the decay chain $\Xi \rightarrow \Xi(1321)\pi$, $\Xi(1321) \rightarrow \Lambda\pi$, $\Lambda \rightarrow p\pi$. DIS events were selected with $2 < Q^2 < 120$ GeV^2 and $0.05 < y < 0.7$. In a mass window of $\pm$ 8 MeV $\sim$ 158000 Λ candidates were identified with a 3-dimensional vertex fit, using cuts on the momentum $p_{t,p\pi} > 0.3$ GeV and decay length > 0.75 cm. $\Lambda\pi$ combinations were also subjected to a 3-dimensional vertex fit, with a further cut on the distance of closest approach to the primary vertex. The significance of the $\Xi(1321)$ signal is increased by a restriction to < 0.6 rad on the angle between secondary and tertiary vertex vectors. In the resulting mass distribution of $\Lambda\pi$, $\sim$ 1650 $\Xi(1321)$ form a clear narrow peak.

Finally the $\Xi(1321)$, in a mass window of $\pm$ 15 MeV, was combined with a charged pion from the primary vertex. A cut $p_t > 1.0$ GeV was imposed on the $\Xi(1321)\pi$ combinations. Fig. 2 shows the final mass distributions.

In the neutral $\Xi(1321)\pi$ combinations there is a clear signal of the wellknown $\Xi(1530)^0$, with $\sim$ 170 events. The doubly charged $\Xi(1321)\pi$ combinations do not show any resonant structure, in particular not at 1.86 GeV, the mass of the NA49 observation. This is also true when separating $\Xi^-\pi^-$ and $\Xi^+\pi^+$ distributions. The $\Xi(1530)^0$ is well seen in both neutral charge combinations.

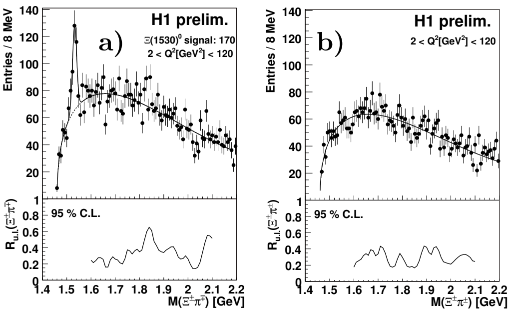

Fig. 2. $\Xi\pi$ invariant mass, summed for a) two opposite and b) two equal charge combinations. Solid lines show fits of a background function, in a) including a Gaussian. Upper limits $R_{U.L.}$ at 95% C.L. on the ratio of the number of events of a hypothetical $\Xi(1321)\pi$ resonance to the $\Xi(1530)^0$ are shown below the mass distributions.

Mass dependent upper limits are defined in terms of the ratio of a hypothetical $\Xi(1321)\pi$ resonance to the $\Xi(1530)^0$, using a narrow Gaussian for a possible signal in the range 1.6 – 2.1 GeV. The background is a smooth function and again the modified frequentist approach[7] is used. Separate upper limits were obtained for neutral and doubly charged combinations, as well as for their sum. The ratio limits are shown in the lower plots of Fig. 2 and lie in the range 0.15 – 0.6, with the value $R_{U.L.}(1860) \sim 0.5(0.2)$ for the neutral (doubly charged) combination. Summing all combinations, the limit $R_{U.L.}(1860) \sim 0.5$ is obtained, which is fully compatible with the upper limit value 0.29, obtained by the ZEUS experiment in a similar analysis[11].

4. $D^*p(3100)$ production in DIS

Pentaquark multiplets containing the heavier c or b quarks have also been considered[12]. If the anti-charmed pentaquark Θ_c^0, with the quark content $uudd\bar{c}$, is heavy enough the decay $\Theta_c^0 \to D^{*-}p$ would be possible. Evidence for a narrow peak, provisionally labelled $D^*p(3100)$, in the D^*p mass distribution in DIS and photoproduction has been given by the H1 collaboration[4]. In subsequent searches, no other experiment was able to confirm this observation.

Additional preliminary information for the $D^*p(3100)$ production is provided by the H1 collaboration[13]. Acceptance corrected yield ratios relative to inclusive D^* production, and differential distributions of the visible cross section ratio as function of event kinematics and D^* quantities are presented, the latter hinting at some features of the $D^*p(3100)$ production mechanism.

The acceptance corrected yields ratio $R_{cor}(D^*p(3100)/D^*)$ is defined in the visible range given by $p_t(D^*p(3100)) > 1.5$ GeV, $-1.5 < \eta(D^*p(3100)) < 1.0$, $p_t(D^*) > 1.5$ GeV, $-1.5 < \eta(D^*) < 1.0$ and $z(D^*) > 0.2$ (including the D^* from the $D^*p(3100)$ decay). η and z are the pseudorapidity and elasticity, respectively. The acceptance corrections are calculated using RAPGAP, under the assumption that pentaquarks are produced by the fragmentation (simulated with the Lund string model). The observed yields ratio $R(D^*p(3100)/D^*) = 1.46 \pm 0.32\%$ becomes, after the acceptance correction, $R_{cor}(D^*p(3100)/D^*) = 1.59 \pm 0.33^{+0.33}_{-0.45}$. The

ZEUS collaboration found $R_{cor} < 0.59$ % (at 95% C.L.), using larger statistics and a different definition of the visible range[14].

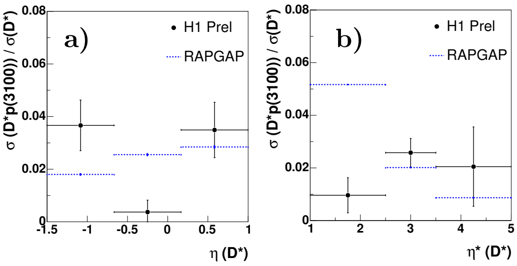

Fig. 3. Acceptance corrected ratio $\sigma_{vis}(D^*p(3100))/\sigma_{vis}(D^*)$ as a function of the D^* pseudorapidity, in the a) laboratory and b) hadronic c.m. system. Only statistical errors are shown.

Extrapolating to the full phase space, the visible cross section ratio is obtained: $\sigma_{vis}(D^*p(3100))/\sigma_{vis}(D^*) = 2.48 \pm 0.52^{+0.85}_{-0.64}$ %. The differential distribution of this cross section ratio in the variables $\eta(D^*)$ and $\eta^*(D^*)$ (i.e. pseudorapidity in the laboratory and hadronic c.m. systems), are shown in Fig. 3, and compared with the RAPGAP simulation. Data show that the $D^*p(3100)$ production is suppressed in the central region and occurs mainly in the direction of the virtual photon, in contrast to the standard fragmentation expectation.

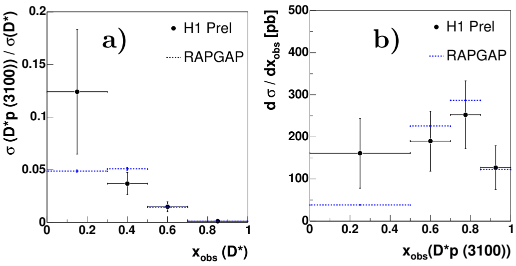

Fig. 4. Acceptance corrected ratio $\sigma_{vis}(D^*p(3100))/\sigma_{vis}(D^*)$ as a function of the D^* hadronization fraction $x_{obs}(D^*)$ in a) and differential cross section $d\sigma(D^*p(3100))/dx_{obs}(D^*p(3100))$ in b). Errors are statistical only.

In order to gain information about the $D^*p(3100)$ fragmentation function, the variable

$$x_{obs}(charm) = \frac{(E-p_z)_{charm}}{\sum_{h\in hemi}(E-p_z)_h}$$

is defined. The dependence of the cross section ratio $\sigma(D^*p(3100))/\sigma(D^*)$ on $x_{obs}(D^*)$ and the differential cross section $d\sigma(D^*p(3100))/dx_{obs}(D^*p(3100))$ are shown in Fig. 4a and 4b, respectively. The comparison with the RAPGAP expectation (in which D^* and $D^*p(3100)$ have the same production mechanism) shows that the D^* from the $D^*p(3100)$ decay is softer than the inclusive D^*, and that the fragmentation of $D^*p(3100)$ is harder than the inclusive D^* fragmentation.

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