# The experimental search for CHARM pentaquarks in the ZEUS detector at HERA[1]

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**Abstract.** Using the full 1996 - 2000 ZEUS data at HERA (121 pb$^{-1}$) we have searched for the $\Theta_c^0(3100)$ pentaquark in the photoproduction and DIS regime. The search has yielded negative results. The 95% C.L. upper limits on the visible rate $R(\Theta_c^0 \to D^* p/D^*)$ is 0.23% (0.35% for DIS).

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## INTRODUCTION: PENTAQUARKS

Observation of a narrow exotic baryon with strangeness $+1$ around 1530 MeV decaying into $K^+n$ was reported during the last 2 years by a few low energy experiments [1]. It was suggested that these are due to the $\Theta^+ = uudd\bar{s}$ pentaquark candidate predicted by Diakonov et al. [2], at the top of a $SU(3)$ spin $1/2$ anti-decuplet of baryons. Narrow peaks were also seen at a similar mass in the final state $K_S^0 p$, which is exotic if the $K_S^0$ strangeness is +1. In high energy experiments ZEUS searched for the $\Theta^+(1530) \to K_S^0 p$ [3] in the DIS regime ($Q^2 > 20$ GeV$^2$) and reported observation of the $\Theta^+(1530)$.

It should be noted however that other high energy experiments at LEP, BaBar, CDF and FOCUS searched and have not seen the $\Theta^+(1530)$ pentaquark [5]. Recently some theoretical arguments have been presented [6] suggesting possible reasons why the $\Theta^+(1530)$ can be seen only in very specific experiments.

## SEARCH FOR CHARM PENTAQUARK DECAYING TO $D^{*\pm}P^{\mp}$

The existence of the strange pentaquark $\Theta^+$ suggests that charmed pentaquarks, $\Theta_c^0 = uudd\bar{c}$, may also exist.

The H1 Collaboration reported [9] observation of a narrow signal in the $D^{*\pm}p^{\mp}$ at 3.1 GeV with a width consistent with the detector resolution. The signal was seen in a DIS sample of $\approx 3400$ $D^{*\pm} \to D^0\pi^\pm \to (K^\mp\pi^\pm)\pi^\pm$ with a rate of $\approx 1.5\%$ of the visible

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$D^*$ production. A less clean signal of a comparable rate was seen also in the H1 PHP sample (see previous talk by K.Daum in this session )

The $\Theta_c^0$ search of ZEUS in the $D^{*\pm}p^{\mp}$ mode was performed with the full HERA-I data [10]. Clean $D^{*\pm}$ signals were seen in the $\Delta M = M(D^{*\pm}) - M(D^0)$ plots (Fig. 1 left). Two $D^{*\pm} \to D^0\pi^{\pm}$ decay channels were used with $D^0 \to K^{\mp}\pi^{\pm}$ and $D^0 \to K^{\mp}\pi^{\pm}\pi^{+}\pi^{-}$. The $\Theta_c^0$ search was performed in the kinematic range $|\eta(D^*)| < 1.6$ and $p_T\ (D^*) > 1.35\ (2.8)$ GeV and with $\Delta M$ values between $0.144 - 0.147 (0.1445 - 0.1465)$ GeV for the $K\pi\pi$ ($K\pi\pi\pi\pi$) channel. The shaded bands in Fig.1a,b contains a total of $\approx 62000$ $D^*$'s after subtracting wrong-charge combinations with charge $\pm 2$ for the $D^0$ candidate. Selecting DIS events with $Q^2 > 1$ GeV$^2$ yielded smaller, but cleaner $D^*$ signals with a total of $\approx 13500$ $D^*$'s (Fig. 1c-d left).

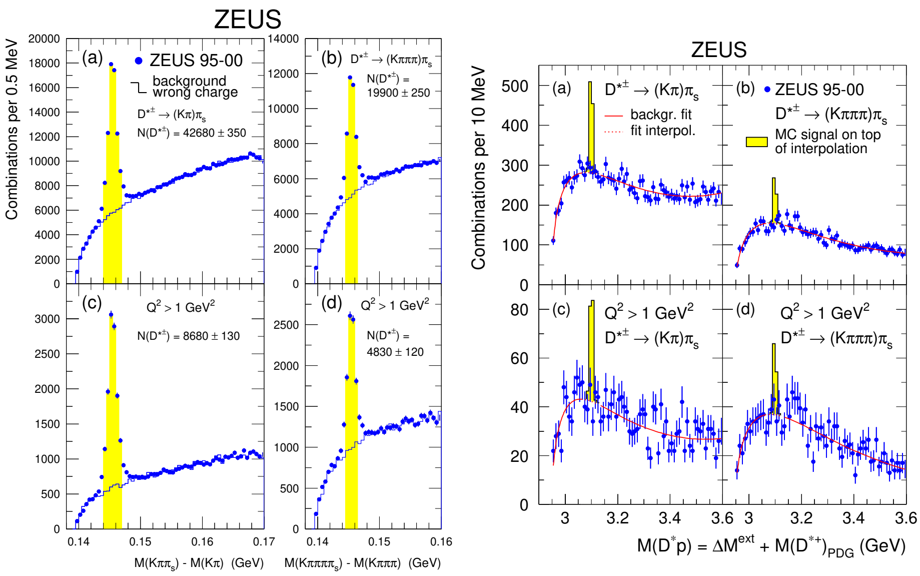


**FIGURE 1.** Left: $\Delta M$ distributions (dots) for (a) $D^* \to K\pi\pi$ and (b) $D^* \to K\pi\pi\pi\pi$ candidates. Events with $Q^2 > 1$ GeV$^2$ for the two channels, respectively, are shown in (c) and (d). The histograms are for wrong charge combinations. Right: $M(D^{*\pm}p^{\mp})$ distributions (dots) for the same samples. Solid curves are fits to a background function (see text). Shaded historgams are MC $\Theta_c^0$ signals, normalised to $\Theta_c^0/D^* = 1\%$, on top of the background fit.

Protons were selected with $p_T(p) > 0.15$ GeV. To reduce the pion and kaon background, a parameterisation of the expected $dE/dx$ as a function of $P/m$ was obtained using tagged protons from $\Lambda$ decays and tagged pions from $K_S^0$ decays. The $\chi^2$ probability of the proton hypothesis was required to be above 0.15. Fig. 2 shows the $M(D^*p) = M(K\pi\pi p) - M(K\pi\pi) + M(D^*)_{PDG}$ distributions for the $K\pi\pi$ channel for the full (left) and the DIS (right) samples, where $M(D^*)_{PDG}$ is the $D^{*\pm}$ mass [4]. In the low-$P$ selection (Fig. 2b), a clean proton sample separated from the $\pi$ and $K$ $dE/dx$ bands was obtained by taking only tracks with $P < 1.35$ GeV and $dE/dx > 1.3$ mips. In the high-$P$ selection (Fig. 2c) only tracks with $P(p) > 2$ GeV were used. The latter selection was prompted by the H1 observation [9] of a better $\Theta_c^0$ signal-to-background ratio for high proton momenta. No narrow signal is seen in the $K\pi\pi$ (Fig. 2) as well as in the $K\pi\pi\pi\pi$ (Fig. 1b,d right,Fig.3a,b left) channel. The $K\pi\pi$ analysis was repeated using very similar selection criteria as in the H1 analysis [9]. No indication of a narrow resonance was found in either the DIS or the PHP event sample [10].

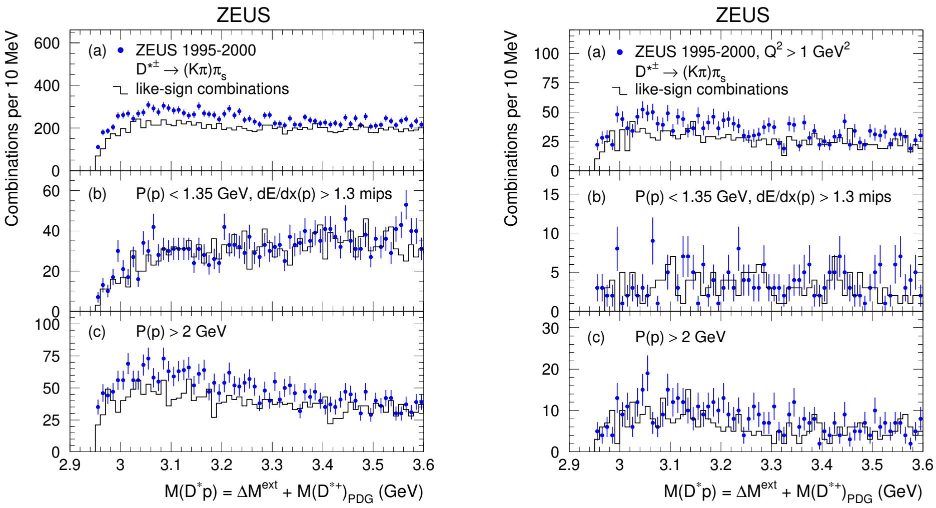


**FIGURE 2.** Left: $M(D^{*\pm}p^{\mp})$ distributions for the $K\pi\pi$ channel (dots) with (a) all proton candidates, (b) candidates with $P(p) < 1.35$ GeV and $dE/dx > 1.3$, and (c) candidates with $P(p) > 2$ GeV. Histograms show the $M(D^{*\pm}p^{\pm})$ like-sign combinations. Right: Same for DIS events with $Q^2 > 1$ GeV$^2$.

95% C.L. upper limits on the fraction of $D^*$ mesons originating from $\Theta_c^0$ decays, $R(\Theta_c^0 \to D^*p/D^*)$, were calculated in a signal window $3.07 < M(D^*p) < 3.13$ GeV for the $K\pi\pi$ and $K\pi\pi\pi\pi$ channels. A visible rate of 1% for this fraction (Fig. 1 right), as claimed by H1 [9], is excluded by $9\sigma$ ($5\sigma$) for the full (DIS) combined sample. The $M(D^*p)$ distributions were fitted to the form $x^a e^{-bx+cx^2}$, where $x = M(D^*p) - M(D^*) - m_p$ (Fig. 1 right). The number of reconstructed $\Theta_c^0$ baryons was estimated by subtracting in the signal window the background function from the observed number of events, yielding $R(\Theta_c^0 \to D^*p/D^*) < 0.23\%$ and $< 0.35\%$ for the full and DIS combined two channels. The acceptance-corrected rates are, respectively, 0.37% and 0.51%. The 95% C.L. upper limit on the fraction of charm quarks fragmenting to $\Theta_c^0$ times the branching ratio $\Theta_c^0 \to D^*p$ for the combined two channels is $f(c \to \Theta_c^0) \cdot B_{\Theta_c^0 \to D^*p} < 0.16\%$ ($< 0.19\%$) for the full (DIS) sample.

We conclude that the ZEUS data are not compatible with the H1 result of $\approx 1.5\%$ rate of $\Theta_c^0 \to D^*p/D^*$. Such a rate is excluded by more then $9\sigma$ for the full data and $5\sigma$ for the ZEUS DIS data. Further experiments perhaps with HERA II may help resolve this discrepancy. No other experiment reported the observation of $\Theta_c^0$ [5].

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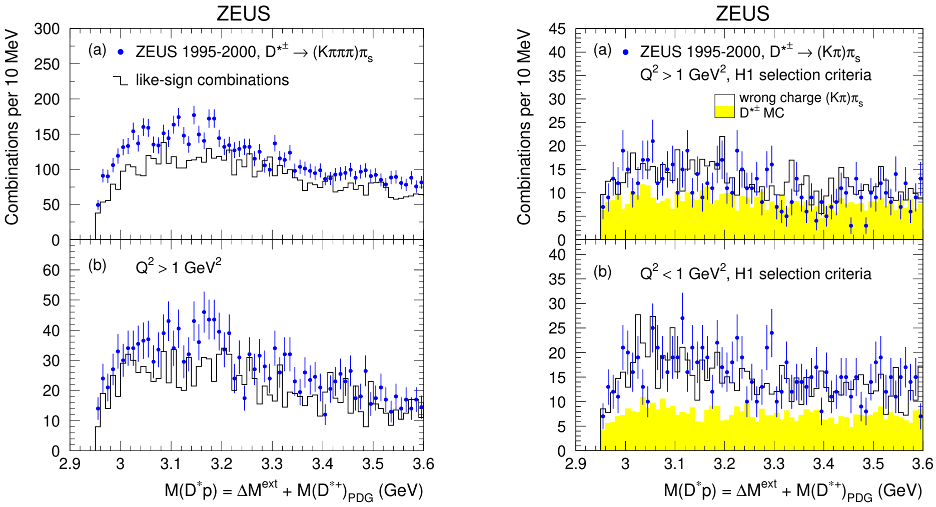


**FIGURE 3.** Left: $M(D^{*\pm}p^{\mp})$ distributions for the $K\pi\pi\pi\pi$ channel (dots) with (a) full sample, (b) DIS sample, $Q^2 > 1 GeV^2$. Right: same distributions for the $K\pi\pi$ channel for DIS ($Q^2 > 1$ GeV$^2$) and photoproduction using the H1 event selection criteria.


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