Charm hadron spectroscopy with ZEUS

Uri Karshon [a]
Weizmann Institute of Science, Rehovot, Israel
For the ZEUS Collaboration

Neutral orbitally excited P-wave charm mesons have been reconstructed in the $D^{*\pm}\pi^{\mp}$ final state and the charm-strange meson $D_{s1}^{\pm}(2536)$ was found in the $D^{*\pm}K_s^0$ final state. A search for radially excited charm mesons in the $D^{*\pm}\pi^+\pi^-$ final state has also been performed. A search for a charm pentaquark state near 3.1 GeV was made in the decay mode $D^{*\pm}p^{\mp}$. Using more than 40,000 reconstructed D^* mesons, no resonance structure was observed.

1 Introduction

The years 2003-2004 brought new life to hadron spectroscopy. New unexpected narrow states were found in various places: in the D_s sector, a higher charmonium state $X(3872)$ and, of most interest, new pentaquark candidates have been claimed by various experiments. The most established one by now is the exotic baryon state $\theta^+(1530)$ decaying into K^+n or K^0p with strangeness=+1, as predicted by Diakonov et al. [1] at the top of a $SU(3)$ anti-decuplet of baryons. The minimal quark composition of this new state is $uudd\bar{s}$.

In March 2004, the H1 Collaboration at HERA reported [2] the observation of a narrow state in the $D^{*\pm}p^{\mp}$ spectrum at 3.1 GeV and attributed it to the charm pentaquark $\theta_c^0(uudd\bar{c})$. In this talk preliminary ZEUS results are presented on charm spectroscopy of states decaying into a $D^{*\pm}$ plus other hadrons.

2 Charm tagging for spectroscopy

The charmed meson $D^{*\pm}$ has been reconstructed via its decay chain $D^{*+} \rightarrow D^0\,\pi_S^+ \rightarrow (K^-\pi^+)\,\pi_S^+$ (+c.c.). Fig. 1(a) shows the mass difference distribution, $\Delta M = M(K\pi\pi_S) - M(K\pi)$, in the kinematic range $p_\perp^{D^*} > 1.35\,\mathrm{GeV}$ and $|\eta^{D^*}| < 1.6$, where $p_\perp$ is the transverse momentum and η is the pseudorapidity. The region $1.83 < M(K\pi) < 1.90\,\mathrm{GeV}$ was used for low $p_\perp^{D^*}$ and a somewhat wider region was applied for high $p_\perp^{D^*}$. The plot includes all the ZEUS data collected during 1995-2000 and corresponds to an integrated luminosity of 126.5 pb^{-1}. A clear $D^{*\pm}$ signal is seen. The combinatorial background is estimated from the wrong charge combinations, where both D^0 tracks have the same charge and π_S has the opposite charge. For the following charm spectroscopy studies, $D^{*\pm}$ candidates were defined as events with $0.144 < \Delta M < 0.147\,\mathrm{GeV}$. In this range (shaded band in Fig. 1(a)) a signal of 42730 ± 350 $D^{*\pm}$ mesons was found after wrong charge background subtraction. This corresponds to a statistical precision of better than 1%. In Fig. 1(b) only deep inelastic scattering (DIS) events are considered with a

[a]Supported by the Israel Science Foundation and the U.S.-Israel Binational Science Foundation

scattered electron energy $> 8\,\mathrm{GeV}$ and $Q^2 > 1\,GeV^2$. The signal is cleaner but ≈ 4.5 times smaller than in the inclusive case, with $N(D^*) = 9697 \pm 145$.

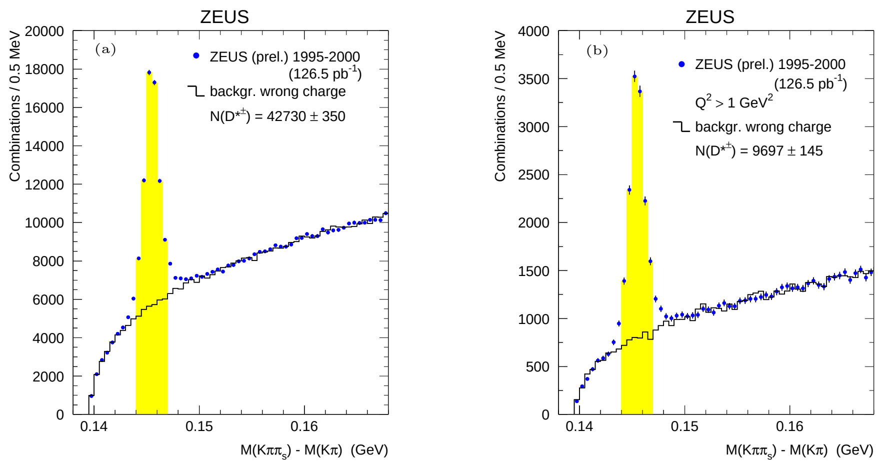

Figure 1. (a) $M(K\pi\pi_S) - M(K\pi)$ distribution in the D^0 mass region (dots). The histogram is the distribution for wrong charge combinations. (b) Same as (a) for DIS events $Q^2 > 1\,GeV^2$.

3 Excited charm mesons

$D_1^0(2420)$ and $D_2^{*0}(2460)$ mesons were reconstructed [3] via their decays to $D^{*\pm}\pi_4^{\mp}$, followed by the $D^{*\pm}$ decays, $D^{*+} \to D^0\pi_S^+ \to (K^-\pi^+)\pi_S^+(+c.c.)$. Fig. 2(a) shows the "extended" mass difference distribution, $M(K\pi\pi_S\pi_4) - M(K\pi\pi_S) + M(D^*)$, where $M(D^*)$ is the PDG $D^{*\pm}$ mass [4]. A clear excess is seen around the D_1^0 and D_2^{*0} mass region. No enhancement is seen for wrong charge combinations, where the D^* and π_4 have the same charges. The solid curves in Figs. 2(a-b) are an unbinned likelihood fit to two Breit-Wigner shapes with masses and widths fixed to the nominal D_1^0 and D_2^{*0} values [4], convoluted with a Gaussian function and multiplied by helicity spectrum functions for $J^P = 1^+$ and 2^+ states, respectively. The background shape was parametrised by the form $x^\alpha \cdot exp(-\beta \cdot x + \gamma \cdot x^2)$, where $x = M(K\pi\pi_S\pi_4) - M(K\pi\pi_S) - M(\pi)$. The fitted curves describe the distribution reasonably well, except for a narrow enhancement near $2.4\,\mathrm{GeV}$ (Fig. 2(b)). In Fig. 2(c), a similar fit is shown with an additional Gaussian-shaped resonance with free mass and width. The fit yielded 211 ± 49 entries for the narrow enhancement with mass value $2398.1 \pm 2.1\,(\mathrm{stat.})^{+1.6}_{-0.8}\,(\mathrm{syst.})$ MeV. The width was consistent with the resolution expected from the tracking detector. The enhancement may indicate a new excited charm meson, a result of an interference effect or a statistical fluctuation. The number of reconstructed D_1^0 and D_2^{*0} mesons in the 3-resonance fit are 526 ± 65 and 203 ± 60, respectively.

$D_{s1}^{\pm}(2536)$ mesons were reconstructed [5] via the $D^{*\pm}K_S^0$ decay mode with $K_S^0 \to \pi^+\pi^-$. K_S^0 candidates were identified by using pairs of oppositely charged tracks with $p_\perp > 0.2\,\mathrm{GeV}$. A clean $K_S^0 \to \pi_3\pi_4$ signal was extracted after applying V^0-finding cuts [5]. K_S^0 candidates with $0.480 < M(\pi_3\pi_4) < 0.515\,\mathrm{GeV}$ were kept for the $D_{s1}^{\pm}$ reconstruction. Fig. 2(d) shows the effective $M(D^{*\pm}K_S^0)$ distribution in terms of $\Delta M^{\text{ext}} + M(D^{*+})_{\text{PDG}} + M(K^0)_{\text{PDG}}$, where $\Delta M^{\text{ext}} = M(K\pi\pi_S\pi_3\pi_4) - M(K\pi\pi_S) - M(\pi_3\pi_4)$ and $M(D^{*+})_{\text{PDG}}$ $(M(K^0)_{\text{PDG}})$ is the nominal $D^{*\pm}$ (K^0) mass [4]. A clear signal is seen at the $M(D_{s1}^{\pm})$ value. The curve is an unbinned likelihood fit to a Gaussian resonance plus background of the form $A(\Delta M^{\text{ext}})^B$. The fit yielded $62.3 \pm\ 9.3$ $D_{s1}^{\pm}$ mesons with $M(D_{s1}^{\pm}) = 2534.2 \pm 0.6 \pm 0.5\,\text{MeV}$, in rough agreement with the PDG value [4]. The last error is due to the uncertainty in $M(D^{*+})_{\text{PDG}}$. The angular distribution of the D_{s1} signal was studied via the helicity angle, α, between the K_S^0 and π_S momenta in the $D^{*\pm}$ rest frame. The $dN/d\cos\alpha$ distribution was fitted to $(1 + R\cos^2\alpha)$. An unbinned likelihood fit yielded $R = -0.53 \pm 0.32\,(\text{stat.})^{+0.05}_{-0.14}\,(\text{syst.})$, consistent with the CLEO value [6] $R = -0.23^{+0.40}_{-0.32}$. Both measurements are consistent with $R = 0$, i.e. $J^P = 1^+$ for the D_{s1} meson. However, the result presented here is also consistent with $R = -1$, i.e. $J^P = 1^-$ or 2^+ [7].

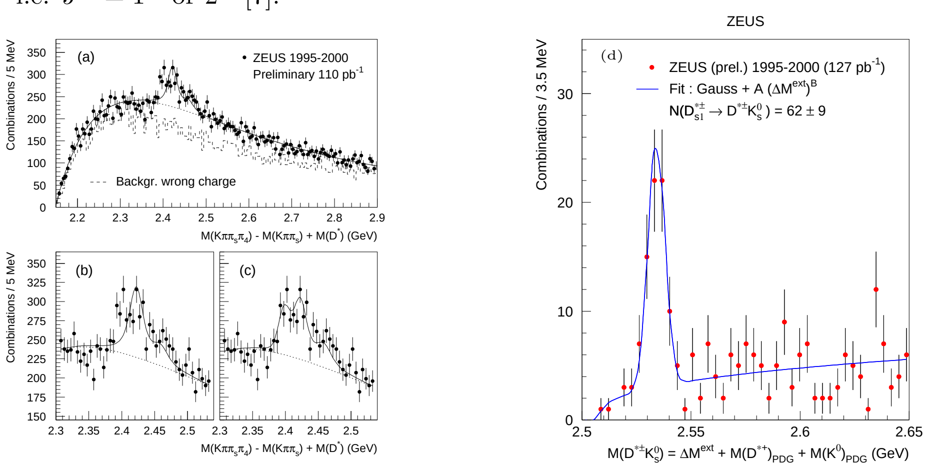

Figure 2. (a-c) Extended mass difference distribution, $M(K\pi\pi_S\pi_4) - M(K\pi\pi_S) + M(D^*)$ (dots). The histogram is for wrong charge combinations. The curves are from the unbinned likelihood fits. In (a) and (b) the solid curves are a fit to background parametrisation and two Breit-Wigner distributions convoluted with a Gaussian function. In (c) an additional Gaussian-shaped resonance near 2.4 GeV is assumed in the fit. The dotted curves are fitted shapes of the combinatorial background. (d) Effective $M(D^{*\pm}K_S^0)$ distribution (dots). The solid line is a fit to a Gaussian resonance plus background of the form $A(\Delta M^{\text{ext}})^B$.

Radially excited charm mesons, $D^{*'}$, with mass around 2.6 GeV are predicted [8] to decay to $D\pi\pi$ or $D^*\pi\pi$. A narrow ($\Gamma < 15$ MeV) signal of 66 ± 14 events was reported in $M(D^{*\pm}\pi^+\pi^-)$ by DELPHI [9] at 2637 MeV and interpreted as a radially excited $D^{*'\pm}$. No evidence for this state has been found by OPAL and CLEO [10,11]. $D^{*'\pm}$ candidates were reconstructed [3] from their decays to $D^{*\pm}\pi_4^+\pi_5^-$. No narrow resonance is seen in the extended mass difference $M(K\pi\pi_S\pi_4\pi_5) - M(K\pi\pi_S) + M(D^*)$. An upper limit for the fraction of $D^{*\pm}$ originating from $D^{*'\pm}$ decays in the measured kinematic region is obtained within a signal window $2.59 < M(D^{*'\pm}) < 2.67\,\text{GeV}$, which covers theoretical predictions [8] and the DELPHI measurement [9]. Extrapolating by a MC simulation to the full kinematic phase space and using the known $f(c \to D^{*+})$ value [12], a $D^{*'\pm}$ production limit of $f(c \to D^{*'+}) \cdot B_{D^{*'+} \to D^{*+}\pi^+\pi^-} < 0.7\%$ (95% $C.L.$) is obtained. A similar limit of 0.9% has been reported by OPAL [10].

4 Search for a charm pentaquark

Various QCD models speculate that the existence of the strange pentaquark $\theta^+ = u\ u\ d\ d\ \bar{s}$ implies that heavy pentaquarks, such as $\theta_c^0 = uudd\bar{c}$, should also exist. Some models [13] predict $M(\theta_c^0) \approx 2700$ MeV, which is too light to decay strongly to D mesons. Other models [14] predict $M(\theta_c^0) = 2985 \pm 50$ MeV with $\Gamma(\theta_c) \approx 21$ MeV with a dominant decay mode to $D^- p$ or $D^0 n$ (+c.c.). If $M(\theta_c^0) > M(D^{*\pm}) + M(p) = 2948$ MeV, θ_c^0 can decay to $D^{*\pm}p$. The H1 Collaboration reported recently [2] evidence for a narrow resonance in the $D^{*\pm}p^{\mp}$ mass spectrum around 3.1 GeV and attributed it to the charm pentaquark. They find that $\approx 1\%$ of the $D^{*\pm}$ mesons originate from this state.

A search for narrow charm pentaquark states was done in the $M(D^{*-}p)$(+c.c.) decay channel with the full 1995-2000 data set. Here charm pentaquark candidates were formed by combining $D^{*\pm}$ candidates from Fig. 1 with a fourth track, assumed to be a proton, with a charge opposite to the $D^{*\pm}$. Proton and anti-proton tracks with momentum P lie within a wide $(dE/dx)_p$ band: $0.3/P^2 + 0.8 < dE/dx < 1/P^2 + 1.2$. To suppress the large π/K background, two proton selections were used: $P < 1.35$ GeV and $(dE/dx)_p > max(1.3, 0.3/P^2 + 0.8)$ or $P > 2$ GeV and $(dE/dx)_p < 1/P^2 + 1.2$. For each charm pentaquark candidate the extended mass difference, $\Delta M^{\text{ext}} = M(K\pi\pi_s p) - M(K\pi\pi_s)$, was calculated.

Fig. 3 shows the $M(D^*p) = \Delta M^{\text{ext}} + M(D^{*+})_{\text{PDG}}$ distribution for the low- and high-P proton selections. The upper plots include all candidates, while the lower plots have DIS events only. The histograms are $M(D^*p)$ distributions for like-sign combinations of D^* and proton. No narrow resonance is seen. In order to check if a charm pentaquark signal was not lost due to the selection requirements or hidden in the combinatorial background, the cuts were varied. The main systematic checks were: varying the dE/dx requirements in both low- and high-P proton selection; remove reflections from $D_1^0, D_2^{*0} \to D^{*\pm}\pi^{\mp}$ decays; make all cuts as close as possible to the H1 selection [2]. No signal was seen in any of the selection variations.

To compare the measurement qualitatively with the H1 charm pentaquark 3.1 GeV signal [2], a naive estimation of the expected signals was performed, assuming a rate of 1% for $D^{*\pm}$ mesons originating from the reconstructed charm pentaquark. Assuming that the signal contributes 30% and 40%, respectively, to the low- and high-P selections, 128 and 171 events are expected in these mass distributions. In Fig. 4 the curves are minimal χ^2 fits to the form $A(\Delta M^{\text{ext}} - m_p)^B exp[-(\Delta M^{\text{ext}} - m_p)C]$, where m_p is the proton mass. The fake Gaussian signals with the above estimated number of events and the mass and width of the H1 signal are shown on top of the fitted curves. The data constrain the uncorrected fraction of $D^{*\pm}$ mesons originating from a hypothetic $\theta_c^0 \to D^{*\pm}p^{\mp}$ resonance at 3.1 GeV to be well below 1%.

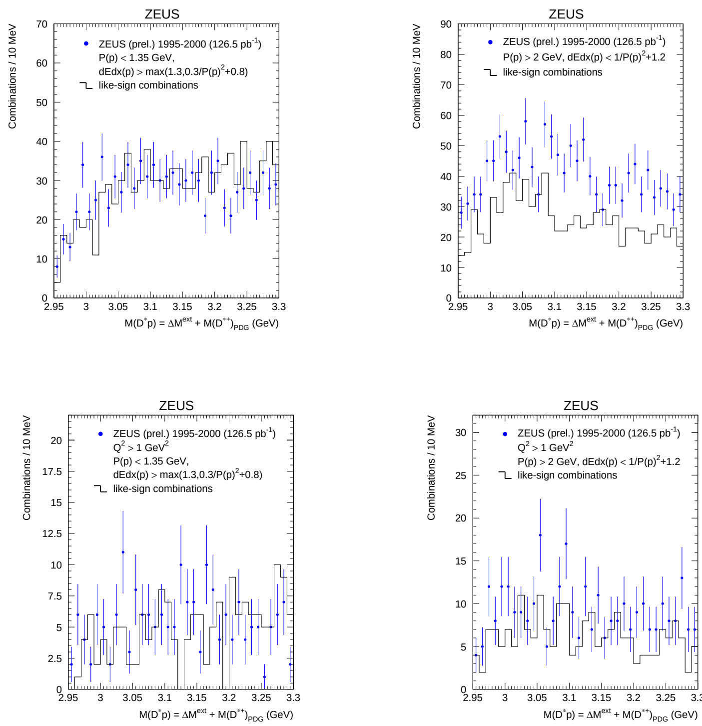

Figure 3. $M(D^*p)$ distributions for charm pentaquark candidates (dots) with low-P (up-left) and high-P (up-right) proton selections. The histograms are $M(D^*p)$ distributions for like-sign D^* and p combinations. The lower plots are the same for DIS events.

5 Conclusions

The ZEUS 1995-2000 data sample was used to study charm spectroscopy of states decaying into a $D^{*\pm}$ plus other hadrons. The P-wave charm mesons $D_1^0(2420)$, $D_2^{*0}(2460)$ and $D_{s1}^{\pm}(2536)$ are clearly seen. No evidence is found for the radially excited state $D^{*'\pm}(2637) \to D^{*\pm}\pi^+\pi^-$ seen by DELPHI. No resonance structure is seen in the $M(D^{*\pm}p^{\mp})$ spectra. The data is not compatible with a contribution from θ_c to the overall D^* rate of $\approx 1\%$, as reported by the H1 Collaboration.

References

1. D. Diakonov, V. Petrov and M. V. Polyakov, Z. Phys. A **359** (1997) 305.
2. H1 Collaboration, A. Aktas et al., Phys. Lett. B **588** (2004) 17.
3. ZEUS Collaboration, XXX Int. Conf. on High Energy Physics, ICHEP2000, Osaka, Japan, July-August 2000, paper 448.
4. Particle Data Group, K. Hagiwara et al., Phys. Rev. D **66** (2002) 10001.
5. ZEUS Collaboration, Int. Europhysics Conf. on High Energy Physics, Budapest, Hungary, July 2001, abstract 497.
6. CLEO Collaboration, J. P. Alexander et al., Phys. Lett. B **303** (1993) 377.

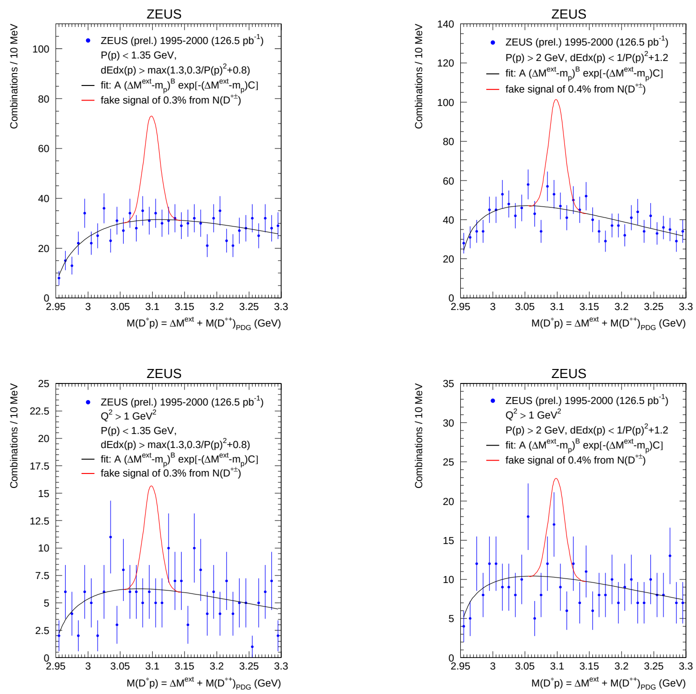

Figure 4. $M(D^*p)$ distributions for charm pentaquark candidates (dots) with low-P (up-left) and high-P (up-right) proton selections. The curves are described in the text. The lower plots are for DIS events.

7. S. Godfrey and R. Kokoski, Phys. Rev. D **43** (1991) 1130.
8. D. Ebert et al., Phys. Rev. D **57** (1998) 5663.
9. DELPHI Collaboration, P. Abreu et al., Phys. Lett. B **426** (1998) 231.
10. OPAL Collaboration, G. Abbiendi et al., Eur. Phys. J **C20** (2001) 445.
11. J. L. Rodriguez (CLEO Collaboration) hep-ex/9901008 and Proceedings of "Heavy Quarks at Fixed Targets", Fermilab, October 1998, ed. H. W. K. Cheung and J. N. Butler (1999).
12. L. Gladilin, Preprint hep-ex/9912064, 1999.
13. R. L. Jaffe and F. Wilczek, Phys. Rev. Lett. **91** (2003) 232003.
14. M. Karliner and H. Lipkin, hep-ph/0307343 (2003).