Measurement of Excited Charm and Charm-Strange Mesons at HERA

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The production of excited charm $D_1^0 \to D^{*\pm}\pi^\mp$ and $D_2^{*0} \to D^{*\pm}\pi^\mp, D^\pm\pi^\mp$, and charm-strange $D_{s1}^\pm \to D^{*\pm}K_s^0, D^{*0}K^\pm$ mesons, was measured by the ZEUS detector at HERA. Masses, widths and helicity parameters were measured and converted to the rates of c quarks hadronizing as a given excited charm meson and to the ratios of the dominant $D_2^{*0}(2460)$ and $D_{s1}^\pm(2536)$ branching fractions. The results were compared to those of other experiments. A search for $D^{*'\pm} \to D^{*\pm}\pi\pi$ at ~ 2.64 GeV was done and upper limits were derived.

1 Introduction

Charm spectroscopy has been recently studied in several experiments and theoretical papers. The current status of the low lying charm states is shown in Fig.1. Recently many more new states have been discovered and studied in detail [1]. The charm meson ground states D^{*+}, D^0, D^+ and D_s have been previously studied by ZEUS , and the fragmentation ratios and fractions compared with those obtained in other experiments [2]. The data is based on an integrated luminosity $\mathcal{L}_{int} = 126\mathrm{pb}^{-1}$ (1995-2000) both deep inelastic and γp events. A large number of events were found for both the spin 0 (D) and spin 1 $(D^{*\pm})$ mesons. The number of $D^{*\pm}$ mesons was obtained by subtracting the wrong charge background [2] , and the numbers of $D^\pm$ and D^0 by a fit to a modified Gauss function, $Gauss^{mod} \sim exp(-0.5x^{1+\frac{1}{(1+0.5x)}})$, plus a background function.

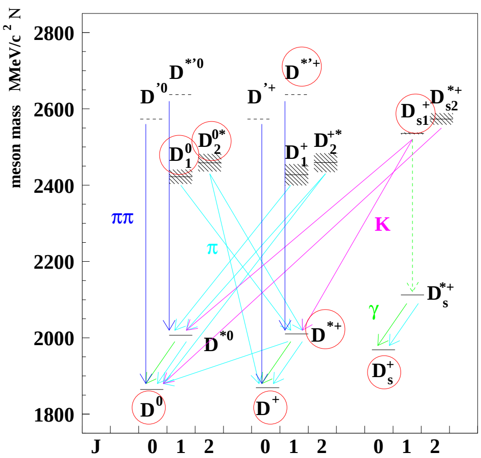

Figure 1: Charm states diagram

The D^0 mesons were required not to originate from $D^{*\pm}$. Thus they could be combined with charged kaons in order to construct the $D^0K^\pm$ excited charm-strange states (see sec.3). The tracks energy losses $\frac{dE}{dx}$ was used when possible to aid in particle identification.

2 Excited Charm Mesons

The excited charm mesons in the present study are : $D_1^0, D_2^{*0} \to D^{*\pm}\pi^\mp, D_2^{*0} \to D^\pm\pi^\mp$, and the charm-strange meson is $D_{s1}^\pm \to D^{*\pm}K_s^0, D^{*0}K^\pm$. The pair of non-strange mesons are identified as the narrow j=3/2 doublets with $J^P = 1^+$ and 2^+ respectivly [1], following the expectations of the Heavy Quark Effective Theory (HQET) [3]. Similarly a pair of narrow charm-strange excited mesons $D_{s1}(2536)^{\pm}$ and $D_{s2}(2573)^{\pm}$ were identified [1]. Only the $D_{s1}(2536)^{\pm}$ has been observed in this analysis.

Several cuts have been applied in order to obtain clean samples of events: $p_t(D^{*\pm}) > 1.35GeV$, $|\eta(D^{*\pm})| < 1.6$ for $D^0 \to K\pi$ decays ($D^{*\pm} \to D^0\pi^{\pm}$); $p_t(D^{*\pm}) > 2.80GeV$, $|\eta(D^{*\pm})| < 1.6$ for $D^0 \to K\pi\pi\pi$ decays. For the $D_2^{*0} \to D^{\pm}\pi^{\mp}$ decays the cuts $p_t(D^{\pm}) > 2.80GeV$, $|\eta(D^{\pm})| < 1.6$ were applied.

For the construction of the non-strange excited mesons the charged $D^*(D)$ was combined with a pion of opposite charge,π_e. The extended mass $\Delta M^{ext} = M(K\pi\pi_s\pi_e) - M(K\pi\pi_s)$ (and similarly for $D^0 \to K\pi\pi\pi$ decays) was used to improve the mass determination and the resulting mass plots , $M(D^{*\pm}\pi)$ and $M(D^{\pm}\pi)$ are shown in Fig.2. Note that by spin and parity arguments only D_2^{*0} (2^+ meson) can decay via an orbital D wave to two 0^- states ($D^{\pm}$ and a π).

It is difficult to separate D_1^0 from D_2^{*0}. A simultanious fit was performed to the two mesons in the two distributions of Fig.2, using 15 free parameters. The resulting fit was reasonable, $\chi^2/\mathrm{df} = 0.99$.

In the above fit the masses and widths of the charm mesons as well as the helicity parameter H were left as free parameters. The helicity angle α is defined in the rest frame of the D^* as the angle between extra $\pi_e^{\pm}$(K_s^0 in Sec.3) and π_s ($D^{*\pm} \to D^0\pi_s$). The expectation in the heavy quark effective theory [3] for the helicity angular distribution, for both the excited charm and charm-strange mesons decays is $\frac{dN}{dcos\alpha} \sim 1 + Hcos^2\alpha$, $H = 3(-1)$ for $J^P = 1^+(2^+)$ from the $j = 3/2$ doublet. Here H(D_1^0) was left as a free parameter in the above fit, and H(D_2^{*0}) was fixed in the fit to H(D_2^{*0}) = -1, since it is a pure $J^P = 2^+$ state.

The expectation is that H(D_1^0) would be 3 if it is, as expected, the $J^P = 1^+$ state from the $j = 3/2$ doublet [1].

The simultaneous fit to four helicity $M(D^{*\pm}\pi^{\mp})$ regions and to $M(D^{\pm}\pi^{\mp})$ is shown in Fig.3. The fit was to a variable width relativistic Breit-Wigner function convoluted with the experimental resolution and a backgound function and it yielded a good result as mentioned above.

The peak in the bin $|cos\alpha| = 0.75 - 1.0$ is because here D_2^{*0} ($H \sim 1$) does not contribute so it is dominated by D_1^0 with a helicity $H \sim 3$ having the distribution $D_1^0 \sim 1 + 3cos^2\alpha$. The results of the fit are:

$M(D_1^0) = 2420.5 \pm 2.1(stat) \pm 0.9(syst)\ MeV$
$M(D_2^{*0}) = 2469.1 \pm 3.7(stat)^{+1.2}_{-1.3}(syst)\ MeV$
$\Gamma(D_1^0) = 53.2 \pm 7.2^{+3.3}_{-4.9}(syst)$MeV (20.4±1.7 MeV PDG06)
$\Gamma(D_2^{*0}) = 43MeV$ (fixed PDG06)
$H(D_1^0) = 5.9^{+3.0}_{-1.7}(stat)^{+2.4}_{-1.0}(syst)$
$H(D_2^{*0}) = -1$ Fixed ($J^P = 2^+$)

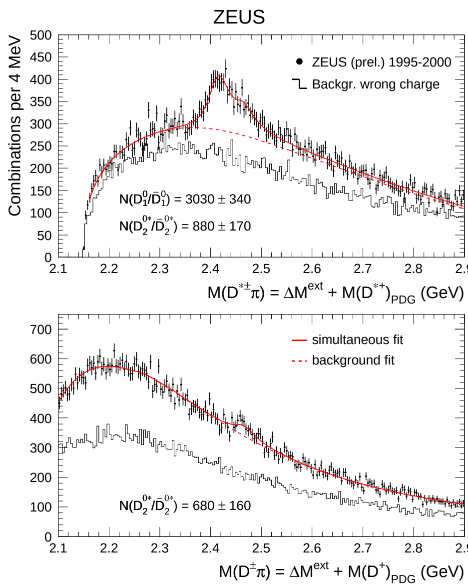

Figure 2: $M(D^{*\pm}\pi)$ and $M(D^{\pm}\pi)$ distributions

Extrapolating to the full phase space the fractions of charm quarks hadronizing to excited charm states is: f(c $\to D_1^0$) = $3.5 \pm 0.4(stat.)^{+0.4}_{-0.6}(syst)$ % ; f(c $\to D_2^{*0}$) = $3.8 \pm 0.7(stat.)^{+0.5}_{-0.6}(syst)$ % ; and for the excited charm-strange (see section 3 below) : f(c $\to D_{s1}^{+}$) $= 1.11 \pm 0.16(stat.)^{+0.08}_{-0.10}(syst)$ % . The rates agree with those of previous e^+e^- experiments [4, 5]. Also $B(D_2^{*0} \to D^+\pi^-)/B(D_2^{*0} \to D^{*+}\pi^-)$=$2.8 \pm 0.8(stat.) \pm 0.6(syst.)$ agrees with 2.3 ± 0.6 (PDG06)

3 Excited Charm-Strange Mesons

The excited charm strange meson studied was $D_{s1}^{\pm}(2536)$ in both decay modes $D_{s1}^{\pm} \to D^{*\pm}K_s^0, D^{*0}K^{\pm}$. $D_{s1}(2536)^{\pm}$ and $D_{s2}(2573)^{\pm}$ were tentatively [1] identified as the members of the j = 3/2 doublets with $J^P = 1^+$ and 2^+ respectively.

For the selection of $K_s^0 \to \pi{+}\pi{-}$ candidates a cut $p_t(\pi) > 0.15 GeV$ was applied. For the fit to the $\pi^+\pi^-$ distribution a $Gauss^{mod}$ function + a linear background was used. The fit results were $M(K_s^0)$=497.8 ± 0.1 ,$\sigma(K_s^0)$ = 4.1 ± 0.1 MeV and 8540 ± 120 events in the region $0.480 < M(K_s^0) < 0.515 GeV$.

A simultaneous unbinned liklihood fit of $M(D^{*\pm}K_s^0), M(D^0K^{\pm})$ and $cos(\alpha)$ to the distributions of Fig.4 has been performed in a similar way to that of the excited charm data discussed above: Gaussian ($Gauss^{mod}$) for $M(D^0K^{\pm})$ + background.
The fit result:
$\Delta M^{ext} = M(K\pi\pi_s\pi^+\pi^-) - M(K\pi\pi_s)$ and
$\Delta M^{ext} = M(K\pi\pi\pi\pi_s\pi^+\pi^-) - M(K\pi\pi\pi\pi_s)$
is shown in Fig.4, where $M(D^*)_{PDG}$ and $M(K_s^0)_{PDG}$ were added to obtain back $M(D^{*\pm}K_s^0)$ and similarly $M(D^0K^{\pm})$.
This method yields more accurate results.

The data selection cuts are similar to those of the excited non-strange charm mesons. The fit results are $M(D_{s1}) = 2535.57^{+0.44}_{-0.41}(stat.) \pm 0.10(syst.)\, MeV$, and $H(D_{s1}) = -0.74^{+0.23}_{-0.17}(stat.)^{+0.06}_{-0.05}(syst.)$.

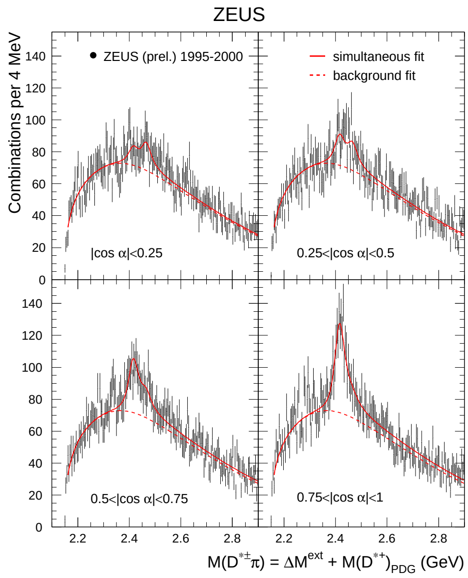

Figure 3: $M(D^{*\pm}\pi)$ in 4 helicity intervals

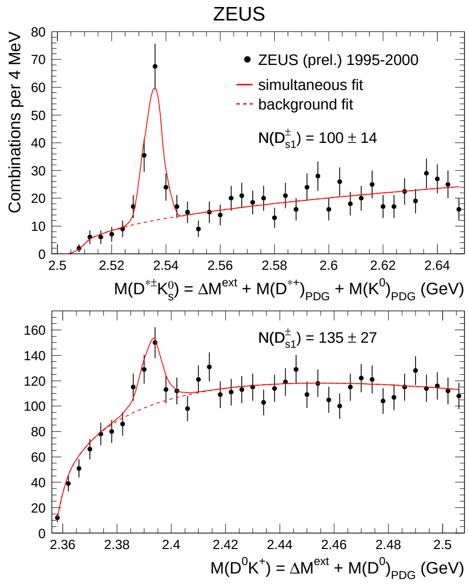

Figure 4: $M(D^{*+}K_s^0)$and D^0K^+ distributions

Extrapolated to the full kinematic phase space we get $\frac{B(D_{s1}^{+}\to D^{*0}K^{+})}{B(D_{s1}^{+}\to D^{*+}K^{0})} = 2.3 \pm 0.6(stat.) \pm 0.5(syst.)$ compared to a PDG value of 1.27 ±0.21. The agreement is reasonable.

The D_{s1}^{+} helicity parameter $H(D_{s1}) = -0.74^{+0.23}_{-0.17}(stat.)^{+0.06}_{-0.05}(syst.)$ is inconsistant with the prediction of a pure D-wave decay of the 1^+ state, H=3, and is more than two standard deviations away from the prediction for a pure S-wave, H=0. This suggests significant contribution of both D- and S-wave amplitudes for the $D_{s1}(2536)^+ \to D^{*+}K^0$ decay. The ZEUS measurement agrees with the CLEO measurement [6] and with the BELLE three-angle measurement [7].

The DELPHI collaboration [8] has reported an observation of a $D^{*'\pm}$ excited charm state at about 2.64 GeV decaying to $D^{*\pm}\pi^+\pi^-$. The OPAL Collaboration [9], has not seen it and set a limit of 0.9 % on it. Our limit is stronger: $f(c \to D^{*'})$x$BR(D^{*'\pm} \to D^{*\pm}\pi^+\pi^-)$ $< 0.4\%(95\%cl)$.

4 Conclusions

1. ZEUS has measured $f(c \to D_1^0), f(c \to D_2^{*0}), f(c \to D_{s1}^{\pm})$. The measured rates are consistent with those of e^+e^- experiments and in agreement with charm fragmentation universality.
2. The D_1^0 helicity $5.9^{+3.0}_{-1.7}$ agrees with H=3,pure D-wave $J^P = 1^+$
3. The width $\Gamma(D_1^0) = 53.2 \pm 7.2^{+3.3}_{-4.9}$ MeV is above the PDG 06 value of 20.4 ± 1.7 MeV.
4. The $D_{s1}^{\pm}$ Helicity parameter -0.74 $^{+0.23}_{-0.17}$ disagrees with a pure $J^P = 1^+$, S wave state , for which H = 0. It may be mixed with the $J^P = 1^+$ $D_{sj}^{\pm}(2460)$ state.
5. No $D^{*'\pm} \to D^{*\pm}\pi^+\pi^-$ signal at ~ 2.64 GeV was seen. A new upper limit was set.

References

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