OBSERVATION OF $D_1(2430)^+$ AND $D_2^*(2470)^+$ AND OTHER RECENT CLEO D^{**} RESULTS

JOHN BARTELT
Department of Physics & Astronomy, Vanderbilt University, Nashville, Tennessee USA 37235

(Representing the CLEO collaboration)

ABSTRACT

Six excited charmed mesons have been observed by CLEO: two neutral, two charged and two strange. The latest results, concerning the two charged mesons are presented: new mass and width measurements, plus angular distributions which support the spin-parity assignments of these states. We also present a summary of the published results on the other four states.

1. Introduction

Besides the six pseudoscalar and vector charmed mesons, six heavier charmed mesons, commonly called D^{**}'s, have been observed. They are believed to be states with orbital angular momentum $L = 1$. There should be a total of 12 such states. Heavy Quark Effective Theory[1,2] describes mesons with one heavy quark in terms of the total light angular momentum ($j_\ell = L + s_\ell$) plus the spin of the heavy quark ($m_{s_h} = \pm 1/2$). This leads to the prediction of two doublets of mesons for each each flavor of light anti-quark (up, down or strange).

The members of the $j_\ell = 1/2$ doublet, $J^P = 0^+$, 1^+ states, are predicted to be broad ($\Gamma \sim 200$ MeV/c^2). They should decay exclusively through the S-wave. The members of the $j_\ell = 3/2$ doublet, the $J^P = 1^+$, 2^+ states, should be narrow ($\Gamma \sim 20$ MeV/c^2). Their HQET-favored decay is through the D-wave. It is these narrow states which (presumably) have been observed.

Over the last two years, CLEO has made new measurements of all six narrow states. This includes the first observation of one mesons, the $D_{s2}^*(2573)^+$, and the first complete reconstruction of another, the $D_1(2430)^+$. Our measurements of the $D_{s1}(2536)^+$, the $D_{s2}^*(2573)^+$, and the neutral states, $D_1(2420)^0$ and $D_2^*(2460)^0$, have been published.[3–5] Our results on the charged states, the $D_1(2430)^+$ and $D_2^*(2470)^+$, are presented here and will be submitted for publication later this year. This paper will summarize the measurements of all six states.

The data were taken at the Cornell Electron Storage Ring (CESR), using the CLEO II detector. CLEO II is a general purpose detector with both excellent charged particle tracking and photon energy measurement. We also use dE/dx measurements from tracking chambers, and time-of-flight measurements, for particle identification.

The events were produced in e^+e^- annihilation in the energy region at and near the $\Upsilon(4S)$. Only continuum production of the charmed mesons was included in each analysis; no B decay products were used. In general, a cut of $x \geq 0.6$, or higher, was used on the reconstructed mesons. We define the scaled momentum $x \equiv p/p_{max}$, where $p_{max} \equiv [(E_b^2 - M^2)]^{1/2}$. The purpose of the x-cut is to reduce combinatoric background; it also eliminates any charmed mesons coming from bottom decay.

2. Data Analysis

2.1. Decay Modes

Angular momentum and parity conservation impose the following constraints on possible decay modes:

$1^+ \to 1^-0^-$	S- or D-wave
$2^+ \to 0^-0^-$ or 1^-0^-	D-wave only.

Thus, for example, the $D_1(2430)^+$ was reconstructed in the $D^{*0}\pi^+$ mode, while the $D_2^*(2470)^+$ was reconstructed in both the $D^0\pi^+$ and $D^{*0}\pi^+$ modes.

2.2. Masses and Widths

In Table 1, we present the CLEO measurements of the masses and widths of the D^{**}'s, along with statistical and systematic errors. We also show the intradoublet splitting derived from the mass measurements.

Table 1. CLEO Measurements of Masses and Widths (MeV/c^2)

Meson	Mass	Width	ΔM
$D_1(2430)^+$	$2425 \pm 2 \pm 2$	$26^{+8}_{-7} \pm 4$	38 ± 5
$D_2^*(2470)^+$	$2463 \pm 3 \pm 3$	$27^{+11}_{-8} \pm 5$	
$D_1(2420)^0$	$2421^{+1}_{-2} \pm 2$	$20^{+6}_{-5} \pm 3$	44 ± 5
$D_2^*(2460)^0$	$2465 \pm 3 \pm 3$	$28^{+8}_{-7} \pm 6$	
$D_{s1}(2536)^+$	$2535.1 \pm 0.2 \pm 0.5$	< 2.3 (90% C.L.)	38.1 ± 1.9
$D_{s2}^*(2573)^+$	$2573.2^{+1.7}_{-1.6} \pm 0.5$	$16^{+5}_{-4} \pm 3$	

The only previously reported observation of the $D_1(2430)^+$ was by E691,[6] which used only partial reconstruction to determine a mass of $2443 \pm 7 \pm 5$ MeV/c^2 and a width of $41 \pm 19 \pm 8$ MeV/c^2. The $D_2^*(2470)^+$ was first reported by ARGUS[7] with a mass of $2469 \pm 4 \pm 6$ MeV/c^2. More recently E687[8] measured the mass to be $2453 \pm 3 \pm 2$ MeV/c^2, and the width to be $23 \pm 9 \pm 5$ MeV/c^2.

We determine the isospin mass splittings between the charged and neutral states to be $M(D_1^+) - M(D_1^0) = +4^{+2}_{-3} \pm 3$ MeV/c^2 and $M(D_2^{*+}) - M(D_2^{*0}) = -2 \pm 4 \pm 4$ MeV/c^2. E687 measured the latter to be 0 ± 4 MeV/c^2.[6]

2.3. Helicity Angle Distributions: Spin-Parity and Partial Waves

In decays of a D^{**} to a D^* and a pseudoscalar, the subsequent decay of the D^* yields information about the helicity of the D^* and hence about its parent D^{**}. In the

decay sequence $D_1(2430)^+ \to D^{*0}\pi^+$, $D^{*0} \to D^0\pi^0$, the helicity angle α is defined to be the angle between the π^+ and the π^0, measured in the D^{*0} rest-frame. Thus measuring the helicity angle distribution can provide information on the spin-parity of the D^{**} and the relative sizes of partial waves.

For example, if the parent D^{**} is in the "natural" sequence (0^+, 1^-, $2^+ \ldots$), it must produce a $\sin^2\alpha$ distribution. Any particle that decays to two pseudoscalars must be natural; thus the higher mass member of each doublet (the D_2^{*+}, D_2^{*0}, and D_{s2}^{*+}) must exhibit the $\sin^2\alpha$ distribution. If it is also seen to decay to a vector and a pseudoscalar, 0^+ is eliminated as a possibility.

If a D^{**} had $J^P = 0^-$, the D^* decays would have a helicity angle distribution proportional to $\cos^2\alpha$. The pure S-wave decay of a 1^+ would produce a flat distribution, while a pure D-wave decay would produce a $1 + 3\cos^2\alpha$ distribution.

Table 2. Testing Helicity Angle Distribution Hypotheses

Meson	Angular Dist.	χ^2/N_{dof}	C.L.
$D_1(2430)^+$	$1 + 3\cos^2\alpha$	1.7/3	63.7%
	$\cos^2\alpha$	6.7/3	8.2%
	isotropic	8.7/3	3.4%
	$\sin^2\alpha$	27.8/3	4.0×10^{-6}
$D_2^*(2470)^+$	$\sin^2\alpha$	1.3/3	72.9%
	isotropic	6.1/3	10.7%
	$\cos^2\alpha$	29.2/3	2.0×10^{-6}
$D_1(2420)^0$	$1 + 3\cos^2\alpha$	2.3/4	68.1%
	$\cos^2\alpha$	28.2/4	11.4×10^{-6}
	isotropic	23.9/4	83.6×10^{-6}
	$\sin^2\alpha$	93.2/4	27.5×10^{-20}
$D_2^*(2460)^0$	$\sin^2\alpha$	1.2/4	87.8%
	isotropic	2.5/4	64.5%
$D_{s1}(2536)^+$	isotropic	7.6/4	10.7%
	$\cos^2\alpha$	68.3/4	5.2×10^{-14}
	$\sin^2\alpha$	16.4/4	2.5×10^{-3}

For the $D_2^*(2470)^+$, the data are well fit by $\sin^2\alpha$ as expected, though a flat function is also acceptable. For the $D_1(2430)^+$, $1+3\cos^2\alpha$ gives the best fit, indicating that the decay is consistent with being a pure D-wave. These results are similar to those found for the neutral states; see Table 2 for a summary. The $D_{s1}(2536)^+$ appears unusual in that its helicity distribution is consistent with a pure S-wave decay. The D-wave decay is apparently highly supressed by the very small phase space available. Note, however, that the S-wave width of the D_{s1}^+ is less than 2.3 MeV/c^2, which is very small for an S-wave decay. Compare, for example, the decay of the $a_1(1260) \to \rho\pi$.

2.4. Branching Ratios

We have measured the following branching ratios for the 2^+ states. Godfrey & Kokoski's predictions[2] for these ratios are given in brackets at the end of each line.

$$\frac{B[D_2^{*+} \to D^{*0}\pi^+]}{B[D_2^{*+} \to D^0\pi^+]} = 0.53 \pm 0.30 \pm 0.16 \qquad [0.43\text{–}0.61]$$

$$\frac{B[D_2^{*0} \to D^{*+}\pi^-]}{B[D_2^{*0} \to D^+\pi^-]} = 0.45 \pm 0.14 \pm 0.12 \qquad [0.43\text{–}0.61]$$

$$\frac{B[D_{s2}^{*+} \to D^{*0}K^+]}{B[D_{s2}^{*+} \to D^0K^+]} < 0.33 \text{ (90\%C.L.)} \qquad [0.10\text{–}0.16]$$

For a 1^+ state, decay to two pseudoscalars is forbidden by angular momentum and parity conservation. We set 90% C.L. upper limits on these decays:

$$\frac{B[D_1(2430)^+ \to D^0\pi^+]}{B[D_1(2430)^+ \to D^{*0}\pi^+]} < 0.18$$

$$\frac{B[D_{s1}(2536)^+ \to D^0K^+]}{B[D_{s1}(2536)^+ \to D^{*0}K^+]} < 0.12$$

2.5. Fragmentation

The momentum spectra for five of the D^{**}'s were fit with the Peterson fragmentation function.[9] We find $\epsilon_P = 0.013 \pm 0.005 \pm 0.004$ and $0.020^{+0.011}_{-0.006} \pm 0.003$ for the $D_1(2430)^+$ and $D_2^*(2470)^+$, respectively. These values are close to those found for the other D^{**}'s; thus they have much harder spectra than the D's and D^*'s.

3. Conclusions

The $D_1(2430)^+$ and $D_2^*(2470)^+$ are now well established, with good mass and width measurements. Branching ratios and helicity angle distributions are completely consistent with the spin-parity assignments of 1^+ and 2^+, respectively, though other assignments are not absolutely ruled out. Their status as isospin partners of the $D_1(2420)^0$ and $D_2^*(2460)^0$ seems obvious, and the spin-parity assignments of the neutral mesons is on even firmer ground. The $D_{s1}(2536)^+$ is almost certainly a 1^+ state, and it seems reasonable to believe that the $D_{s2}^*(2573)^+$ is its doublet partner. Thus all six narrow $L = 1$ charmed mesons (those with $j_\ell = 3/2$) are firmly established and their properties are in good agreement with those predicted by HQET models.

References

1. N. Isgur and M.B. Wise, *Phys. Rev. Lett.* **66** (1991) 1130.
2. S. Godfrey and R. Kokoski, *Phys. Rev.* **D43** (1991) 1679.
3. J. Alexander *et al.*, *Phys. Lett.* **B303** (1993) 377.
4. Y. Kubota *et al.*, *Phys. Rev. Lett.* **72** (1994) 1972.
5. P. Avery *et al.*, *Phys. Lett.* **B331** (1994) 236.
6. J.C. Anjos *et al.*, *Phys. Rev. Lett.* **62** (1989) 1717.
7. H. Albrecht *et al.*, *Phys. Lett.* **2331** (1989) 208.
8. P.L. Frabetti *et al.*, *Phys. Rev. Lett.* **72**, (1994) 324.
9. C. Peterson *Phys. Rev.* **D27** (1983) 105.