Observation of a Broad L=1 $c\overline{q}$ State in $B^- \to D^{*+}\pi^-\pi^-$ at CLEO

Richard S. Galik[a*]

[a]Floyd R. Newman Laboratory of Nuclear Studies
Cornell University; Ithaca, NY, USA 14853

Using 4.7 fb^{-1} of data taken at CESR at energies at and near the $\Upsilon(4S)$ we have studied the decay $B^- \to D^{*+}\pi^-\pi^-$ (and its conjugate). We observe a new, broad charmed meson state, which we interpret as D_1^0(j=1/2), in its decay to $D^{*+}\pi^-$. Our preliminary results indicate the mass and width of this L=1 state to be $m = (2461^{+41}_{-34}\pm10\pm32)MeV$ and $\Gamma = (290^{+101}_{-79}\pm26\pm36)MeV$, with the third uncertainty associated with the parameterization of the relative strong phases. In addition we have measured several new branching fractions of charged B mesons.

1. Charmed Meson Spectroscopy

The lowest mass charmed mesons are the pseudoscalar D and the vector D^* , with '*' denoting that the spins of the c and $\overline{q}$ are aligned. For one unit of orbital angular momentum between these partons, there are four states of positive parity, which carry the labels D_1 and D_0^*, D_1^*, D_2^*; these four states are collectively referred to as D_J.

If $m_c << \Lambda_{QCD}$ (*i.e.,* if the charm quark mass is small on the scale of QCD energies), then the spectroscopy of these L=1 mesons would be a singlet and a triplet, much as with positronium in QED. On the other hand, if $m_c >> \Lambda_{QCD}$ then Heavy Quark Effective Theory (HQET) would predict that the light quark degrees of freedom decouple from those of the c quark so that the quantum number governing the spectroscopy would be $\vec{j} = \vec{L} + \vec{S_{\overline{q}}}$. This would result in two doublets, one with $j = 1/2$ and the other with $j = 3/2$. As with the hydrogen atom in QED, adding in the spin of the heavy partner results in 'hyperfine' splitting within these doublets. The c quark is not sufficiently massive for HQET to be considered perfect, but massive enough that the effects of HQET should be evident. Therefore some mixing is expected between the two states of $J^P = 1^+$.

Three of the D_J can decay to $D^*\pi$, as shown in the level diagram of Figure 1. The D_2^* decay can only be d-wave, whereas conserving J and P allow the decays of the 1^+ states to be either s-wave or d-wave. However, if HQET is invoked, then the 1^+ state with $j = 3/2$ would decay only via d-wave (and therefore be narrow) but the $j = 1/2$ state would be restricted to s-wave decay (and be correspondingly broader). Two narrow states *have* already been observed [1], the $D_1(2420)$ and the $D_2^*(2460)$.

*Representing the CLEO Collaboration

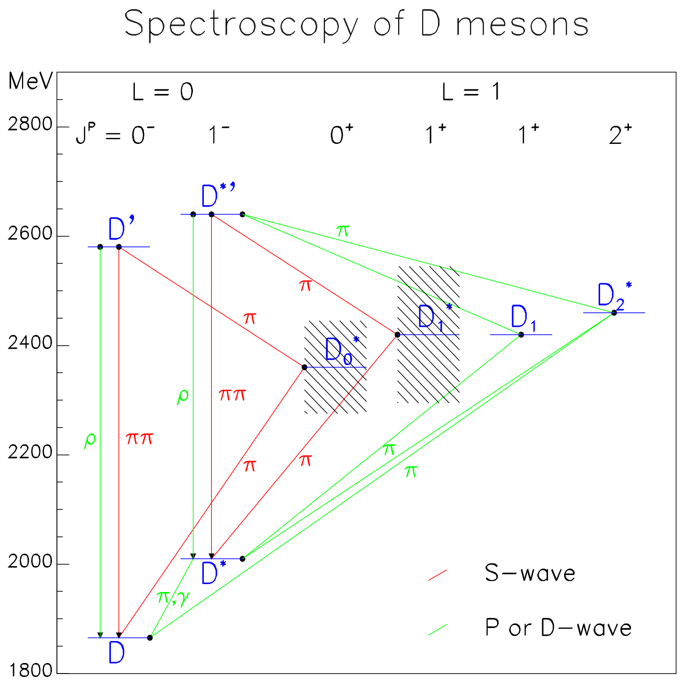

Figure 1. Spectrum of the charmed mesons. Prior to this analysis the two shaded L=1 states were unobserved. HQET would predict these two states to have $j = 1/2$ and the two observed L=1 states to have $j = 3/2$.

2. Search Procedure and Analysis

We have used the CLEO detector [2] at the Cornell Electron Storage Ring to search for the D_J in the decay chain (and its conjugate) $B^- \rightarrow D_J^0 \pi_1^-$, with $D_J^0 \rightarrow D^{*+} \pi_2^-$ and $D^{*+} \rightarrow D^0 \pi_3^+$. The pion subscripts identify which pion corresponds to which piece in the decay chain. The data used correspond to $3.1 fb^{-1}$ taken at the $\Upsilon(4S)$ energy and $1.6 fb^{-1}$ taken at a slightly lower energy to allow for subtraction of the underlying continuum.

Using only four-momentum conservation and the measurement of the momenta of the three pions gives 28 constraints on the seven-particle system, providing a "0C" fit. This "partial reconstruction" technique, in which we do not reconstruct the decay of the D^0, greatly enhances our statistics, although it also increases the overall level of background.

Because both the B and π are pseudoscalars, the D_J will be produced in a totally polarized state, so that the angular information in the decays will help sort among the various resonant contributions. Using B decays gives us four variables to use in our maximum likelihood fitting procedure. The first of these is the angle between the momenta of π_2 and π_1 in the D_J rest frame; these two vectors also define a plane denoted ϵ_{12}. The second variable, similarly, is the angle between the momenta of π_3 and π_2 in the D^{*+} rest frame; these vectors form the plane ϵ_{23}. The angle between the planes ϵ_{12} and ϵ_{23} is the third variable and the $D^{*+}\pi_2$ invariant mass, which will be the mass of the D_J candidates, is the fourth.

Backgrounds fall into three categories in this analysis. The off-$\Upsilon(4S)$ running gives us the shape of the *continuum background*, i.e., events that do not have $B\overline{B}$ parentage. Standard CLEO Monte Carlo simulations, with equivalent luminosity of several times the data, provide the shape of *generic B background*. Finally, there are several B decay channels that have kinematics similar to that of the signal, forming *correlated backgrounds* that have high efficiency. These include decay chains that do involve a D_J but with an incorrect pion in the reconstruction and are handled by specialized, high-statistics simulations.

The data is then fit[3] via maximum likelihood using the four variables described above to these expected background shapes plus an overall amplitude function that has three Breit-Wigner distributions for the three D_J that decay via a D^* and a non-resonant $B^- \to D^{*+}\pi^-\pi^-$ contribution. The two 1^+ states are allowed to mix, having angular contributions for both s-wave and d-wave decay. In addition we try several parameterizations that allow for strong interaction phase differences among the decay amplitudes.

3. Results

The $m(D^*\pi)$ distribution of the data is shown in Fig.2, along with the fit projections and the sum of all the expected backgrounds. In addition to the two established narrow resonances, there is clearly a need for the third, broad resonance which is taken to be the D_1^0(j=1/2) state. The fit also indicates there is a small non-resonant contribution.

The broad state, which we identify as the D_1^0(j=1/2), has mass and width of:

$$m = (2461\ ^{+41}_{-34}\ \pm 10\ \pm 32)\ \text{MeV}; \qquad \Gamma = (290\ ^{+101}_{-79}\ \pm 26\ \pm 36)\ \text{MeV}. \tag{1}$$

The three listed uncertainties are associated with statistics, general systematics (*e.g.*, selection criteria, mass and width of the known, narrow resonances), and the parameterization of the strong phases in the decay. Using efficiencies determined from simulation, the fit naturally gives us the product branching fractions $\mathcal{B}(B^- \to D_J^0\pi^-)\cdot\mathcal{B}(D_J^0 \to D^{*+}\pi^-)$, which are shown in Table 1 as $\mathcal{B}_B\cdot\mathcal{B}_{D_J}$. Based on Clebsch-Gordon coefficients and other theoretical inputs[4] about the D_J decays, we also show the branching fractions $\mathcal{B}(B^- \to D_J^0\pi^-)$, which, at 1 to 1.5 per mil, are somewhat larger than expected[5].

Table 1
Preliminary results form the 4D maximum likelihood fit. Shown are the product branching fractions and B decay branching fractions, as described in the text, and the significance of that decay chain in the overall fit to the data.

Resonance	Status	Width	$\mathcal{B}_B\cdot\mathcal{B}_{D_J}(10^{-4})$	$\mathcal{B}_B(10^{-3})$	Significance
$D_1(2420)$	Known	Narrow	$6.9^{+1.8}_{-1.4} \pm 1.1 \pm 0.4$	1.04 ± 0.33	$> 4.5\sigma$
D_1(j=1/2)	New	Broad	$10.6 \pm 1.9 \pm 1.7 \pm 2.3$	1.59 ± 0.52	$> 5.5\sigma$
$D_2(2460)$	Known	Narrow	$3.1 \pm 0.8 \pm 0.4 \pm 0.3$	1.55 ± 0.49	$> 4.5\sigma$
non-resonant				0.97 ± 0.44	$> 2.0\sigma$

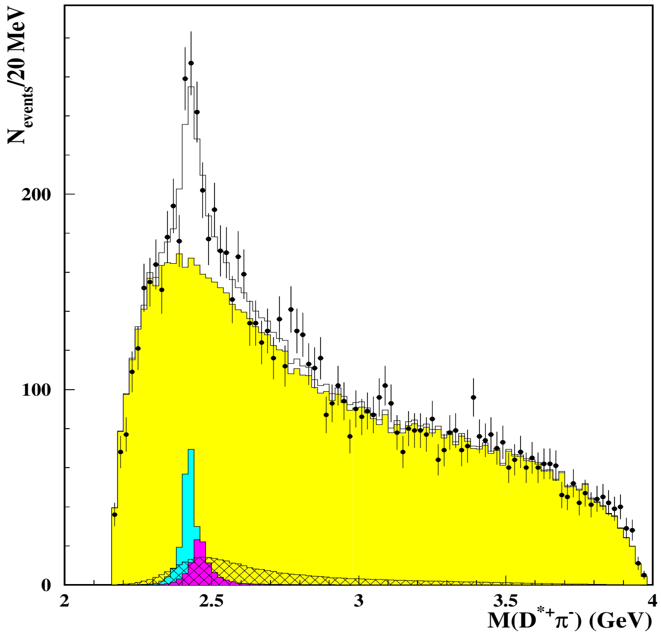

Figure 2. The distributions of data (points with error bars), total expected background (lower line), and best overall fit (upper line) in the $D^{*+}\pi^-$ invariant mass. Also shown are the three resonant structures from the fit minimization - the narrow, previously established 1^+ and 2^+ states and the new, broad state.

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