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Excited Charm States

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ABSTRACT

Characteristics of mass spectra and decays of orbitally excited charm mesons and baryons, expected on the basis of quark models and Heavy Quark Symmetry, are briefly described. The difficulties associated with measurements on these excited states are discussed. The accuracy and reliability of currently available experimental information is examined. The reasons, for the widely accepted spin-parity assignments to the observed excited mesons and baryons, are stated. Finally, the experimental data, with the accepted spin-parity assignments, is compared with expectations based on quark models and Heavy Quark Symmetry.

1 - Introduction

The first orbitally excited charm meson was observed by ARGUS1) in 1986. Since then, five more excited charmed mesons have been observed. We are beginning to see excited charm baryons. Two excited baryon states have been observed so far.

1.1 Motivation

The motivation for studying excited charm states is two-fold. A study of these states helps the understanding of strong interactions via quark models or via more model independent calculations using Heavy Quark Symmetry. Recent examples of the former are calculations of Godfrey and Kokoski2), and, Capstick and Isgur3). Some recent examples using Heavy Quark Symmetry are the work by Eichten, Hill and Quigg4), and Isgur and Wise5). The other reason for studying charm hadrons is that they help the study of beauty hadrons. The charm and beauty quarks are both considerably heavier than the u,d and s quarks and are also heavy on the QCD scale, which is determined by Λ_{QCD}. As a result, the charm system, with much more experimental data available, turns out to be especially useful in getting a reasonably good idea of the properties of beauty hadrons. An understanding of the charm hadrons is also needed because the beauty hadrons decay to charm hadrons and, for making measurements on beauty hadrons, a good knowledge of the decay products is essential.

1.2 Lowest Excitations of Mesons and Baryons

Excited charm mesons have a charm quark and a lighter quark (u, d or s) in a bound state with relative orbital angular momentum, L>0. For a given quark pair with a radial excitation number, n, and an orbital angular momentum, L, there are four possible total angular momentum states. There is one state corresponding to the case when the sum of quark spins, $\vec{S} = \vec{S}_c + \vec{S}_q$, $\vec{S}_c$ and $\vec{S}_q$ being the spin of the charm quark and the lighter quark respectively, has the value S=0. The total angular momentum $\vec{J} = \vec{L} + \vec{S}$ has the value J=L in this case. There are three states, with J=L-1, L, and L+1, corresponding to S=1.

There are experimental measurements on six of the twelve excited charm mesons with L=1. None of the higher excited charm mesons have been observed as yet. The excited charm baryons discussed here have three quarks with flavors c, u and d. The light-quark pair has an orbital angular momentum L>0, relative to the charm quark. For the lowest orbital excitation, L=1, the three quark spins and the orbital angular momentum combine to give seven states with isospin, I=0 (excited states of Λ_c^+) and seven states with isospin, I=1 (excited states of Σ_c^+). The two new baryon states observed recently are identified as the L=1 excitations6) above the Λ_c^+.

1.3 Heavy Quark Approximation

The system containing one heavy quark and one or more lighter quarks simplifies considerably5) if the mass, m_Q, of the heavy quark is large on the QCD mass scale, which is determined by Λ_{QCD}. In this case, which we will henceforth refer to as the *heavy quark approximation*, the motion of the heavy quark can be ignored. The spin of the heavy quark, $\vec{S}_Q$, and the total angular momentum of the light quarks, $\vec{j}$, are separately conserved. The energy spectrum is determined by j. There are two degenerate states for each value of j, corresponding to the two values, $J = j \pm \frac{1}{2}$ of the total angular momentum, $\vec{J} = \vec{j} + \vec{S}_Q$. Since the energy spectrum is determined by the dynamics of the light quark, the spectra of systems, where the heavy-quark approximation is valid, are expected to be identical except for a constant mass shift due to the difference in the mass of the heavy quark. For a finite mass of the heavy quark, corrections of order $O(\Lambda_{QCD}/m_Q)$ result in a mass-splitting between the two states. Again the splitting in systems with different varieties of the heavy quark is related. It is inversely proportional to the mass of the heavy quark. The existing experimental data suggests that the heavy-quark approximation is valid for calculations involving B and D mesons and perhaps for the K mesons.

2 - Challenges faced in Observation

The lowest excited charm hadrons decay strongly to a ground state charmed hadron and lighter mesons. The factors that make excited states more difficult to observe than the weakly decaying ground state are, 1) Larger Combinatoric background, 2) peaks due to other excited states overlapping with, or being in the vicinity of, the peak of interest, and 3) lower reconstruction efficiency. We dwell on these three factors in the remainder of this section.

2.1 Combinatoric Background

The higher combinatoric background results from more numerous decay products and larger intrinsic widths of the states. In fixed target experiments, there is an additional source contributing to the combinatoric background - one that perhaps dominates the other two sources in some cases. The additional background arises from the fact that there is no observable separation between the locations of production and decay of the state being studied. In case of a weakly decaying hadron, the production and decay vertices are visibly separated. Only tracks from the decay are used to construct candidates for the charm state. In case of the decay of an excited state, tracks from the decay of the excited state as well as those from fragmentation following charm production, can be used to construct candidates for the state. The background increases with primary vertex multiplicity. Consequently, it is expected to be worse in charm from hadroproduction than that from photoproduction.

2.2 Other Structures

When observing a peak due to an excited state in a mass distribution, structures in the vicinity due to other excited states, partially or fully reconstructed, can make it difficult to estimate the background shape under the peak. At times they can actually overlap with the state under study. An example is the two peaks in the $D^{*+}\pi^-$ mass distribution arising from the decay of the members of the $j^P=\frac{3}{2}^+$ doublet (see section 3.3.2). When ARGUS1) observed the first signal due to an excited charm state, it was interpreted as being due to the decay of a broad state of width ~40 MeV. As we know now, the broad peak is due to the two overlapping $j^P=\frac{3}{2}^+$ states.

Determination of the background under the peak requires a region of smoothly varying background around the peak. If there are structures in the vicinity of the peak of interest, they can hamper this determination. An example is the bumps close to the D_2^{*+} peak in the $D^0\pi^+$ mass plot (see section 3.2.1).

2.3 Reconstruction Efficiency

The excited states, in general, have a lower reconstruction efficiency. It is partly due to the larger number of decay products and partly, in case of current experiments, because the apparatus was probably not designed with much attention to the acceptance for these states.

3 - The Lowest Excited (L=1) Mesons

Popularly known as $D^{**}(c\bar{u}$ and $c\bar{d})$ or $D_s^{**}(c\bar{s})$, these mesons consist of a charm quark and a lighter quark with relative orbital angular momentum, L=1. Phenomenological models usually parameterize the spin-independent part of the inter-quark interaction with a Coulomb-type potential due to a single-gluon vector exchange and a linear confining potential arising from a multi-gluon scaler exchange. One of the quarks being light, the two quarks venture farther from each other than those in a similar charmonium. Consequently, the L=1 charmed mesons probe the inter-quark potential at larger distances than charmonium.

In the heavy-quark approximation, the energy levels are characterized by the two values, $\frac{1}{2}$ and $\frac{3}{2}$, of the total angular momentum of the light quark, $\vec{j} = \vec{L} + \vec{S_q}$, where $\vec{S_q}$ is the spin of the light quark. For each value of j, there are two degenerate states corresponding to the two values, $J = j \pm \frac{1}{2}$, of the total angular momentum, $\vec{J} = \vec{j} + \vec{S_c}$, $\vec{S_c}$ being the spin of the charm quark. The finite mass of the charm quark leads to a splitting, of order $O(\Lambda_{QCD}/m_Q)$, between the the two levels. The two members of the $j^P = \frac{3}{2}^+$ doublet have been observed for all three flavors of the light meson. The J=2 members are referred to as D_2^{*o}, D_2^{*+}, and D_{s2}^{*+} for the light quark flavors u, d and s respectively. The corresponding J=1 members are named D_1^o, D_1^+, and D_{s1}^+. The measured masses and widths are listed in Tables II and III. Members of the $j^P = \frac{1}{2}^+$ doublet, being wide, are difficult to observe and none has been observed so far.

3.1 Decays

The L=1 charmed mesons decay strongly, mostly through 2-body decays. The allowed 2-body decays are listed in Table I. Strong decays of D_s^{***+} to $D_s^+\pi$ or $D_s^{*+}\pi$ are prohibited by conservation of isospin in strong interactions. Other 2-body decays are prohibited due to conservation of parity in strong interactions and conservation of angular momentum. It should be noted that the D^{**} is only ~450 MeV more massive than the D^*. So the decays to $D\rho$ and $D^*\rho$ are possible only due to the large width of the ρ.

The J=2 state decays to $D\pi$ or $D^*\pi$ through a D-wave and is fairly narrow. The J=0 state decays to $D\pi$ through an S-wave and is expected to be wide (several hundreds of MeV according to Godfrey and Koksoki[2]). The J=1 states can decay to $D^*\pi$ through an S-wave or a D-wave. However, the J=1 state belonging to the $j^P=\frac{3}{2}^+$ doublet decays predominantly through a D-wave (only through a D-wave in the heavy-quark approximation) and is narrow, while that belonging to the $j^P=\frac{1}{2}^+$ doublet decays predominantly through an S-wave (only through an S-wave in the heavy-quark approximation) and its width is expected to be large (several hundreds of MeV according to Godfrey and Koksoki[2]).

Table I. Allowed 2-body strong decays of L=1 charmed mesons

j^P	J^P	D^{**}	D_s^{**}
$\frac{3}{2}^+$	2^+	$D\pi$, $D^*\pi$, $D\rho$, $D^*\rho$	D^*K, DK
$\frac{3}{2}^+$	1^+	$D^*\pi$, $D\rho$, $D^*\rho$	D^*K
$\frac{1}{2}^+$	1^+	$D^*\pi$, $D\rho$, $D^*\rho$	D^*K
$\frac{1}{2}^+$	0^+	$D\pi$, $D^*\rho$	DK

3.2 Spin-parity Assignment

3.2.1 *The $J^P=2^+$ States (D_2^{*0}, D_2^{*+} and D_{s2}^{*+})*

The state D_2^{*0} was observed in the $D^+\pi^-$ mass spectrum[7–11], while its isospin partner, D_2^{*+}, was observed in the $D^0\pi^+$ spectrum[10,12,13]. The following is a statement of the reasons for the assignment L=1, J=2 to the observed state, D_2^{*0}. The lowest excited states that can decay to $D^+\pi^-$ are the two L=1 states with J=0 and J=2. These states are expected to be separated by ~100 MeV. The J=0 states are expected to be several hundreds of MeV wide, while the J=2 state is expected to be narrow (a few tens of MeV). The mass and width of the observed state are consistent with the expected values for the J=2 state and inconsistent with those for the J=0 state. The higher excited states are expected to be ~300 MeV heavier than the observed state[4].

Now, if the observed state is indeed an L=1, J=2 state, it should also decay to $D^{*+}\pi^-$. A shoulder observed in the $D^{*+}\pi^-$ mass spectrum next to the peak due to another state (D_1^0), is consistent with arising from the decay of the D_2^{*0} to $D^{*+}\pi^-$. There is additional information available from an angular distribution of events in the shoulder (see section 3.3.2). The information is consistent with the decay of an L=1, J=2 state. However, its quality is not good enough to help significantly in the identification of the state. Considering all the available evidence, the state D_2^{*0} is accepted as the lowest L=1, J=2 state. Similar arguments lead to the assignment L=1, J=2 to the D_2^{*+}.

The state D_{s2}^{*+} was observed recently[14)] in a decay to D^oK^+. The possible spin assignments for the D_{s2}^{*+} corresponding to the lowest orbital excitation are J=0 and J=2, since it is observed to decay to DK. The narrow width supports a J=2 assignment. The decay of the state to D*K has not been observed. This, however, does not conflict with the J=2 assignment, since the decay to D*K is expected to be highly supressed due to a limited available phase space.

3.2.2 The $J^P=1^+$ States (D_1^0, D_1^+ and D_{s1}^+)

The state D_1^0 was observed[9–11,15)] in the decay to $D^{*+}\pi^-$. Apart from the D_2^{*0}, the lowest excited states that can decay to $D^{*+}\pi^-$ are the two L=1 states with J=1. Owing to its narrow observed width and some decay angular distributions (see section 3.3.2), the observed state is identified as the J=1 member of the $j^P=\frac{3}{2}^+$ doublet. The state is not observed in the $D^+\pi^-$ mass spectrum. This agrees with the expectation for a J=1 state. The state D_1^+ observed recently[13)] in the decay to $D^{*o}\pi^+$ is, based on similar considerations, identified as the charged isospin partner of the D_1^0.

The D_{s1}^+ has been observed[9,10,16)] in the decay to D*K but not to DK. Since it is observed to decay to D*K, its possible spin assignments corresponding to the lowest orbital excitation are J=1 and J=2. The fact that it has not been observed to decay to DK, indicates that it has J=1. The narrow measured width indcates that it is a member of the $j^P=\frac{3}{2}^+$ doublet decaying through a D-wave. Thus the state is identified as the J=1 member of the $j^P=\frac{3}{2}^+$ doublet.

3.3 Measurement of Masses and Widths

3.3.1 D_2^{*o} and D_2^{*+}

Fig. 1 shows distributions, from CLEO and E687, in the difference, $\Delta M=M(D^o\pi^+)-M(D^o)$, between the measured masses, $M(D^o\pi^+)$ and $M(D^o)$, of the D_2^{*+} candidate and the D^o from its decay. The peak due to the D_2^{*+} is seen at ΔM=600 MeV. There is no known state with a mass very close to that of the D_2^{*+} mass that can decay to $D^o\pi^+$. The J=0 state, which has not been observed as yet, is expected to be only ~100 MeV lighter. But it is expected to be very broad (several 100 MeV) and should not interfere with the observation of D_2^{*+}.

Unfortunately, the mass spectrum is marred by structures due to partially reconstructed states on the low-mass side of the peak of interest. These structures hamper accurate background determination. The enhancement at $\Delta M \sim 450$ MeV is due to the decay of the state being investigated, D_2^{*+}, and the other member of the $j^P = \frac{3}{2}^+$ doublet, the D_1^+, to $D^{*0}\pi^+$. The D^{*0} decays to $D^0\pi^0$, the π^0 escaping detection in the apparatus. Owing to the small q-value of the π^0 from the D^{*0} decay, the enhancement in the $D^0\pi^+$ mass spectrum has the same shape as it would have had, were the decay to $D^{*0}\pi^+$ fully reconstructed, but is shifted down in mass by approximately one pion mass. The gap, between the structure at ~450 MeV and the D_2^{*+}, is not large enough to allow a reliable background determination. It is necessary to use the mass range beyond this structure.

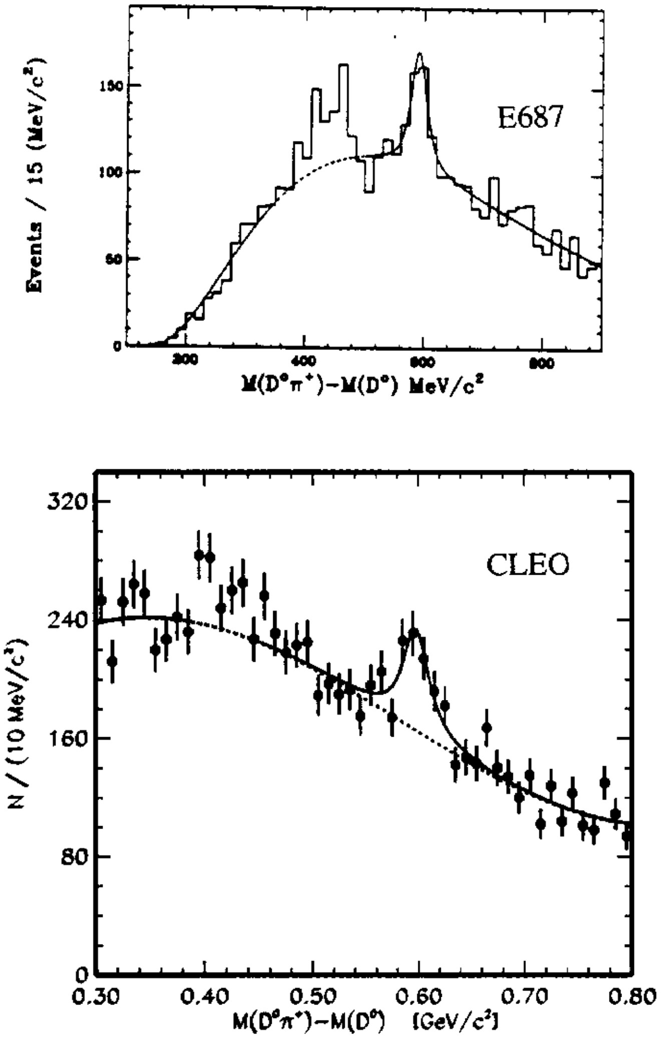

Fig.1 Distributions in the mass difference $\Delta M = M(D^0\pi^+) - M(D^0)$, from E687 and CLEO, showing the peak due to D_2^{*+} along with another structure due to partially reconstructed states.

However, there might be other structures that prevent extension of the mass range on the low mass side. One source that may lead to such a structure, is the decay of the D_1^+ to $D^o\rho^+$, or, of the D_1^o to $D^o\rho^o$. Partial reconstruction of the state, using the D^o and one of the pions from the ρ-decay, causes a broad enhancement at lower masses. The significance of the enhancement in the observed mass distribution depends on the fashion in which the charm is produced, and the acceptance of the apparatus. The study of the D_2^{*o} using the $D^+\pi^-$ mass spectrum entails tackling problems similar to those faced in the study of D_2^{*+}. Table II shows the experimental results on the masses and widths of the J=2 states. The problems in background determination are probably responsible for the large spread in the measured values of the masses of these states.

3.3.2 D_1^o and D_1^+

The J=1 state, D_1^o, of the $j^P=\frac{3}{2}^+$ doublet, was observed in its decay to $D^{*+}\pi^-$. The J=2 state and both the J=1 states can decay to $D^{*+}\pi^-$. In the heavy-quark approximation, the J=1 state belonging to the $j^P=\frac{1}{2}^+$ doublet is much wider (several 100 MeV) than the $j^P=\frac{3}{2}^+$ states. But the two $j^P=\frac{3}{2}^+$ states (J=1 and J=2) are very close to each other and have comparable widths. As a result they might be difficult to resolve. Indeed, a display of the appropriate mass range of the $D^{*+}\pi^-$ mass spectrum, shows a broad structure at a mass of ~2420 MeV. We expect the structure to have contributions from the two members of the $j^P=\frac{3}{2}^+$ doublet, the J=2 member decaying through a D-wave and the J=1 member decaying mainly through a D-wave (only through a D-wave in the heavy-quark approximation).

Due to the polarization of the D^{*+}, the distribution of these states in cosθ, θ being the angle, measured in the D^{*+} rest frame, between the pion from the decay of the D_1^o and that from the subsequent decay of the D^{*+}, is as follows.

$$\frac{dN}{d\cos\theta} \propto \begin{cases} \sin^2\theta & \text{for the J=2 state (D-wave decay),} \\ (1+3\cos^2\theta) & \text{for the D-wave decay of the J=1 state, and,} \\ \text{constant} & \text{for the S-wave decay of the J=1.} \end{cases} \qquad (1)$$

A cut on cosθ, for example $|\cos\theta|>0.8$, virtually eliminates the J=2 state, while preserving a large part of the contribution from the J=1 state, thus enabling the measurement of the mass and width of the latter. Measurement on the isospin partner,

D_1^+, of the D_1^0 is made in a similar fashion. Results of measurement of the masses and widths of these states by ARGUS, CLEO and E687 are listed in Table III. The recent measurements by CLEO and E687 are in fairly good agreemment.

3.3.3 The Strange States

There is no perceivable problem due to partially reconstructed states in the observation of the D_s^{**+}. The fundamental reason is that the states are very close to the edge of phase space, causing the J=1 state to be very narrow and the decay of the J=2 state to D*K to be highly supressed relative to that to DK. There is no reflection in the DK spectrum due to a partially reconstructed J=2 state. The reflection due to a partially reconstructed J=1 state is extremely narrow and easily identified. The results of measurements on the J=2 and J=1 states are listed in Tables II and III respectively. There is excellent agreement among the measurements on the J=1 state. The J=2 state has been observed only by CLEO14) so far.

Table II. Masses and widths in (MeV/c^2) of the $J^P = 2^+$ mesons, along with the decay modes used for measurement.

	D_2^{*0}		D_2^{*+}		D_{s2}^{*+}	
	$(D_2^{*0} \to D^+\pi^-)$		$(D_2^{*+} \to D^0\pi^+)$		$(D_{s2}^{*+} \to D^0K^+)$	
Experiment	Mass	Width	Mass	Width	Mass	Width
ARGUS	2455±3±5	15^{+13+5}_{-10-10}	2469±4±6	27±12		
CLEO I.5	2461±3±1	20^{+9+9}_{-12-10}				
CLEO II	2465±3±3	28^{+8+6}_{-7-6}	2463±3±3	27^{+11+5}_{-8-5}	$2573.2^{+1.7+0.}_{-1.6-0.9}$	16^{+5+3}_{-4-3}
E687	2453±3±2	25±10±5	2453±3±2	23±9±5		
E691	2459±3±2	20±10±5				

Table III. Masses and widths in (MeV/c^2) of the $J^P=1^+$ states, along with the decay modes used for measurement.

	D_1^0		D_1^+		D_{s1}^+	
	$(D_1^0 \to D^{*+}\pi^-)$		$(D_1^+ \to D^{*0}\pi^+)$		$(D_{s1}^+ \to D^{*0}K^+, D^{*+}K^-)$	
Experiment	Mass	Width	Mass	Width	Mass	Width(90%CL)
ARGUS	2414±2±5	13^{+6+10}_{-6-5}			2535.5±0.4±1.3	<3.9
CLEO I.5	2428±3±2	23^{+8+10}_{-6-4}			2536.6±0.7±0.4	<5.4
CLEO II	2421^{+1+2}_{-2-2}	20^{+6+3}_{-5-3}	2425±2±2	26^{+8+4}_{-7-4}	2535.1±0.2±0.5	<2.3
E687	2422±2±2	15±8±4			2535.0±0.6±1.0	<3.2

3.4 Branching Ratios

The statistical uncertainties in the number of events for the observed states in any decay mode are of the order of 25%. In addition, there are comparable systematic uncertainties. Consequently, with the currently available statistics, the ratio of rates for any two decays is not known to better than ~50%. The statistics and the understanding of the background will have to improve considerably before the data on ratios of decay rates can be used effectvely for developing theoretical models or making theoretical predictions.

4 - Charmed Baryons

A narrow (width<3.2 MeV at 90% CL) excited charmed baryon of mass ~2626 MeV was observed by ARGUS[17) in a decay to $\Lambda_c^+\pi^+\pi^-$. The state has since been confirmed by CLEO[18) and E687[19). The decay allows its identification as one of the excited states of Λ_c^+ or Σ_c^+, or the ground state, $J^P=\frac{3}{2}^+$, of Σ_c^+. Were it Σ_c^+ or one of its excited states, it would have favored the decay through $\Lambda_c^+\pi^0$, rather than $\Lambda_c^+\pi^+\pi^-$, since its mass is only slightly above the $\Lambda_c^+\pi\pi$ threshold. On the other hand, if it is an L=1 excitation of the Λ_c^+, it is prohibited from decaying to $\Lambda_c^+\pi^0$ due to conservation of isospin. Then it should decay to $\Lambda_c^+\pi\pi$ ($\Lambda_c^+\pi^+\pi^-$ or $\Lambda_c^+\pi^0\pi^0$). Thus the observed state is likely to be an excited Λ_c^+. The observed mass is close to the value expected for the lighter L=1 excited states of Λ_c^+.

Recently, another state was observed by CLEO[20) and then by E687[21), in the $\Lambda_c^+\pi^+\pi^-$ mass distribution at a mass of ~2593 MeV. This state, like the one at 2626 MeV, has not been observed to decay to $\Lambda_c^+\pi^0$. It is found to decay preferentially to $\Sigma_c\pi$, with the Σ_c subsequently decaying to $\Lambda_c^+\pi$. The two states, $\Lambda_c^{*+}(2593)$ and $\Lambda_c^{*+}(2626)$, have been interpreted as the two members with, $J^P=\frac{1}{2}^-$ and $J^P=\frac{3}{2}^-$, of the doublet with L=1, j=1. The state with $J^P=\frac{1}{2}^-$ decays preferentially to $\Sigma_c\pi$. Were Σ_c^* light enough, the state with $J^P=\frac{3}{2}^-$ would have favored the decay to $\Sigma_c^*\pi$. However, Σ_c^* is too heavy[22) for the decay to be possible. Consequently the state is expected to decay to $\Lambda_c^+\pi\pi$. Table IV summarizes the results of measurements on the two states.

Table IV. Measured Mass in (MeV/c^2) for $\Lambda_c^{*+}(2626)$ and $\Lambda_c^{*+}(2593)$

	$\Lambda_c^{*+}(2626)$		$\Lambda_c^{*+}(2593)$	
Experiment	Decay Mode	Mass	Decay Mode	Mass
ARGUS	$\Lambda_c^+\pi^+\pi^-$	2626.6±0.5±1.5		
CLEO II	$\Lambda_c^+\pi^+\pi^-$	2627.2±0.4±1.1	$\Sigma_c^{++}\pi^-$, $\Sigma_c{}^0\pi^+$	2593.1±0.4±2.6
CLEO II	$\Lambda_c^+\pi^0\pi^0$	2625.8±0.9±2.0		
E687	$\Lambda_c^+\pi^+\pi^-$	2625.5±0.6±0.9	$\Lambda_c^+\pi^+\pi^-$	2593.2±0.8±0.9

5 -Conclusions

5.1 Comparison of Experimental Measurements with Theoretical Predictions

The isospin splitting between the charged and neutral states is consistent with zero as expected. Table V shows the measured masses and widths averaged over the various experiments, compared with the predictions from Godfrey and Kokoski$^{2)}$ and Eichten, Hill and Quigg$^{4)}$. Godfrey and Kokoski use a QCD-inspired model. Their two predicted values in the table for the width of each state correspond to two different models used for the decay - the pseudo-scaler emission model and the flux tube breaking model. Eichten, Hill and Quigg use Heavy Quark Symmetry and the experimental data on the excited K and D mesons to predict the properties of the excited D_s, B and B_s mesons.

Table V. Comparison of the measured masses and widths (MeV/c^2) with Recent Theoretical Predictions

	$D_2^*(2^+)$		$D_1(1^+)$		$D_{s2}^{*+}(2^+)$		$D_{s1}^+(1^+)$	
	Mass	Width	Mass	Width	Mass	Width	Mass	Width
Experiment	2460±5	24±5	2423±3	18±6	2473±3	16±6	2435.3±.4	<2.3
Godfrey&Kokoski[3]	2500	63, 37	2460	26,38	2590	21,16	2555	0.4,1.9
Eichten,Hill&Quigg[4]					2561	11	2526	<1

5.2 Measurements desirable and probably feasible in the near future

None of the higher excited mesons (2S, 3D e.t.c.) has been observed as yet. They are expected to be wider than the L=1 states observed so far$^{4)}$. Some of them might be observable in the near future.

It is important to have better measurements of branching ratios for several of the observed decays, and some decays like $D^{**}\to D\rho$, that have not been observed as yet. A large part of the background in the mass distributions used to study the L=1 mesons arises from decays of other excited charmed mesons. As new excited states are observed and their decays understood, the background in these distributions will be known better, making more accurate measurements on the L=1 states possible.

The dominant problem with measurements on excited charm baryons so far, is low statistics. As we accumulate higher statistics in charm experiments we will observe more excited baryon states.

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