CLEO RESULTS ON CHARMED HADRON SPECTROSCOPY

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ABSTRACT

We report the first observation of the Ξ_c^0 baryon, confirm the smallness of the isospin violating mass splitting of the Σ_c baryon and confirm two D^{**} states.

Although the main thrust of experiments at the e^+e^- storage rings of 10 GeV collision energy, CESR and DORIS, lies in b-physics, they are a fruitful source of information on c-physics as well. Charmed hadrons are mainly produced by $e^+e^- \rightarrow c\bar{c}$. The absolute cross section ($\approx$1.2 nb) at these energies is not as high as at the charm threshold studied at SPEAR and DCI but still 10 times larger than at PEP or PETRA. There is enough center-of-mass energy to produce even heavy charmed baryons, and searches for charmed mesons are free from the difficulties encountered at the kinematic threshold[1)].

Data presented here were obtained with the CLEO detector at CESR which was described in detail elsewhere[2)] . A data sample of 430 pb^{-1} of integrated luminosity was collected at different energies at the Υ(nS) resonances (n=1,3,4,5) and at the continuum just below the $B\bar{B}$ threshold.

The charm quark decays weakly to a strange quark, thus reconstruction of charmed hadrons depends on detection of strange particles, $K^{\pm}$, $K_s^0 \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow p\pi^-$. The last two are identified by observation of a secondary decay vertex and by measurement of invariant mass of their decay products. Particle hypotheses ($K/\ \pi/\ p$) can be verified by ionization and time of flight measurements. Charmed hadrons are identified by peaks in the invariant mass distribution of their decay products, unless they decay by soft pion emission, $H' \rightarrow \pi H$, in which case they are better resolved in the mass difference, $M(\pi H) - M(H)$. Charm signals are enhanced over combinatoric background from non-charm events by requiring high momentum of the decaying system, since the fragmentation function is harder for c-quark than for light quarks. A cut on $x_P > 0.5 - 0.6$ is usually applied for this purpose ($x_P = P/P_{max}$,

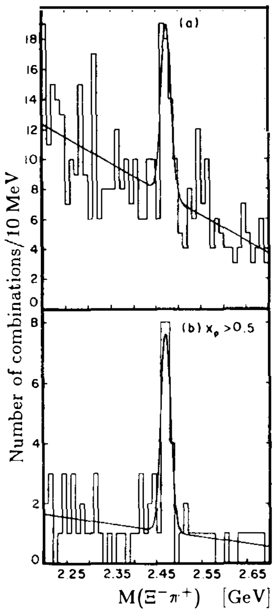

Figure 1.

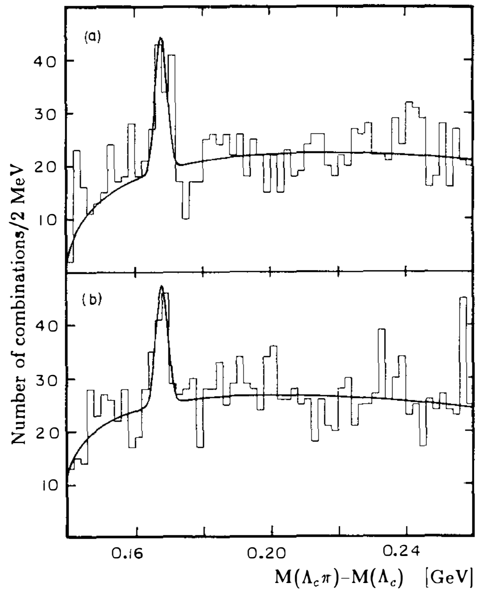

Figure 2.

$P_{max} = \sqrt{E_{beam}^2 - M(H)^2}$. This cut also removes charmed hadrons produced by the non-continuum process, $e^+e^- \to \Upsilon(4S)$, $\Upsilon(4S) \to B\bar{B}$, $B \to X_c$. Detailed cut descriptions for two of the three analyses presented here can be found elsewhere[3,4].

We report[3] the first observation of the Ξ_c^0 baryon. A cascade of three weak decays, $\Xi_c^0(csd) \to \pi^+\Xi^-(ssd) \to \pi^-\Lambda(sud) \to \pi^-p(uud)$, is used to reconstruct the Ξ_c^0 (charge conjugate modes are implied throughout this article). A peak of 32±8 events at 2471±3±4 MeV is observed in the invariant mass distribution of $\Xi^-\pi^+$ candidates (Fig.1a). The signal to background ratio improves (Fig.1b) after the cut on x_p, as expected for a charm baryon. The measured mass of Ξ_c^0(csd) is close to the mass of Ξ_c^+(csu) measured earlier in fix target experiments[5] . We also observe a Ξ_c^+ signal in our data. Analysis of the isospin violating mass splitting of the Ξ_c is in progress.

Such an isospin violating mass splitting is the main subject in our analysis[4] of the Σ_c(cqq) system (q= u or d). The Σ_c decays to Λ_c(cqq) by emission of a soft pion. The Λ_c is reconstructed in the decays to $pK^-\pi^+$, $\Lambda\pi^+\pi^-\pi^+$ and pK_s^0. The Σ_c^{++}, Σ_c^0 baryons are observed as narrow peaks in the mass difference spectra, $M(\Lambda_c^+\pi^+) - M(\Lambda_c^+)$ and $M(\Lambda_c^+\pi^-) - M(\Lambda_c^+)$ correspondingly (Fig.2a and Fig.2b). The data sample has been enlarged for this analysis by inclusion of 143 pb^{-1} of our older data obtained with a different tracking chamber. Though the momentum resolution for high momentum tracks was worse in the old chamber, there was almost no difference in momentum resolution for low momentum tracks, which actually dominates the resolution of the mass difference, $M(\Lambda_c\pi) - M(\Lambda_c)$. We observe 54±11 Σ_c^{++} events at $M(\Lambda_c^+\pi^+) - M(\Lambda_c^+) = 167.8 \pm 0.4 \pm 0.3$ MeV and 48±12 Σ_c^0 events at $M(\Lambda_c^+\pi^-) - M(\Lambda_c^+) = 167.9 \pm 0.5 \pm 0.3$ MeV. Thus the $M(\Sigma_c^0) - M(\Sigma_c^{++})$ mass difference is small, $+0.1 \pm 0.6 \pm 0.1$ MeV, confirming the ARGUS result[6] and contradicting the first measurement of this mass splitting[7] .

The Σ_c baryon is the first known hadron violating the phenomenological rule that members of isospin mutiplets containing d-quarks rather than u-quarks are heavier by a few MeV (see Table 1).

Table 1: Isospin violating mass splitting of various hadrons. The data are taken form ref.8 except for the last row which is an average value of the ARGUS[6] and the CLEO results[4] .

Hadrons	Quark content	Mass difference [MeV]
$K^0 - K^+$	$\bar{s}d - \bar{s}u$	$+4.02 \pm 0.03$
$K^{*0} - K^{*+}$		$+6.70 \pm 1.20$
$D^+ - D^0$	$c\bar{d} - c\bar{u}$	$+4.74 \pm 0.28$
$D^{*+} - D^{*0}$		$+2.90 \pm 1.30$
$B^0 - B^+$	$\bar{b}d - \bar{b}u$	$+1.90 \pm 1.10$
$n - p$	dud − duu	$+1.29 \pm 0.00$
$\Delta^0 - \Delta^{++}$	udd − uuu	$+2.70 \pm 0.30$
$\Sigma^- - \Sigma^0$	sdd − sdu	$+4.89 \pm 0.08$
$\Sigma^{*-} - \Sigma^{*0}$		$+3.50 \pm 1.10$
$\Sigma^- - \Sigma^+$	sdd − suu	$+8.07 \pm 0.08$
$\Sigma^{*-} - \Sigma^{*+}$		$+4.40 \pm 0.60$
$\Xi^- - \Xi^0$	ssd − ssu	$+6.40 \pm 0.60$
$\Xi^{*-} - \Xi^{*0}$		$+3.20 \pm 0.60$
$\Sigma_c^0 - \Sigma_c^{++}$	cdd − cuu	-0.50 ± 0.50

This rule can be traced to $m_d > m_u$. Because of the heavy c-quark mass, the Σ_c is supposedly smaller in size than baryons built out of ordinary quarks. Thus, as understood a long time ago[9] , electrostatic forces among quarks are enhanced and tend to cancel the $m_d > m_u$ effect out.

The absolute masses of Ξ_c^0 and Σ_c baryons can be roughly reproduced even in a crude quark model (Table 2), which accounts for masses of ground state hadrons by taking a sum over constituent quark masses and adding a contribution from spin-spin color interaction[10] . The free parameters of this model are determined from the masses of non-charm baryons and the Λ_c mass.

Table 2: Comparison between masses of the charmed baryons predicted by the simple quark model[10] and the CLEO measurements.

Quantity	Prediction	CLEO Results
$M(\Xi_c^0)$	2505 MeV	(2471±3±4) MeV
$[M(\Sigma_c^0)+M(\Sigma_c^{++})]/2 - M(\Lambda_c^+)$	157 MeV	(167.8±0.3±0.3) MeV

To account for radial and angular momentum excited states one can introduce the potential interaction between quarks. Such a model can be even more easily applied to describe a mass spectrum of charmed mesons ($c\bar{q}$), q = u or d. The ground singlet (1^1S_0) and triplet (1^3S_1) states correspond to the well known D and D^* mesons. The first angular momentum excitations (1^3P_2, 1^3P_1, 1^3P_0, 1^1P_1) are usually called generically D^{**} mesons. Their decays are expected to be dominated by π-transitions to the ground states. Because of spin-parity arguments the spin-2 state (1^3P_2) can decay to both πD and πD^*, whereas the spin-1 states (mixed 1^3P_1, 1^1P_1) can decay only to πD^* and the spin-0 state (1^3P_0) can decay only to πD. The spin-2 state is expected to be the heaviest and the narrowest[1] .

We present preliminary search for D^{**0} states in $\pi^- D^{*+}$ and $\pi^- D^+$ channels. The D^{*+} is detected in its subsequent π-transition to the D^0. The D^0 is reconstructed in decays to $K^+\pi^-$ and $K^+\pi^-\pi^+\pi^-$. The D^+ is reconstructed in the decay to $K^+\pi^-\pi^+$. The D^{**} signal is cleaner in the πD^* analysis than in the πD analysis due to the additional constraint to the D^* mass.

The mass difference sectrum, $M(\pi^- D^{*+}) - M(D^{*+})$, shows a prominent peak of 312±54 events due to the production of the $D^{**}(2420)$ resonance (Fig.3a), and the $M(\pi^- D^+) - M(D^+)$ spectrum shows a significant peak of 293±46 events at a mass coinciding with recently claimed by the other experiments[14,11] $D^{**}(2460)$ (Fig.3b). No evidence for other resonance structure is found. Results for masses, widths and production rates of the observed states are given in Table 3, where they are compared to similar results of the other experiments. All the experiments agree on the parameters of these states. Their masses fall into the range expected for $1P$ states in the potential models[15] .

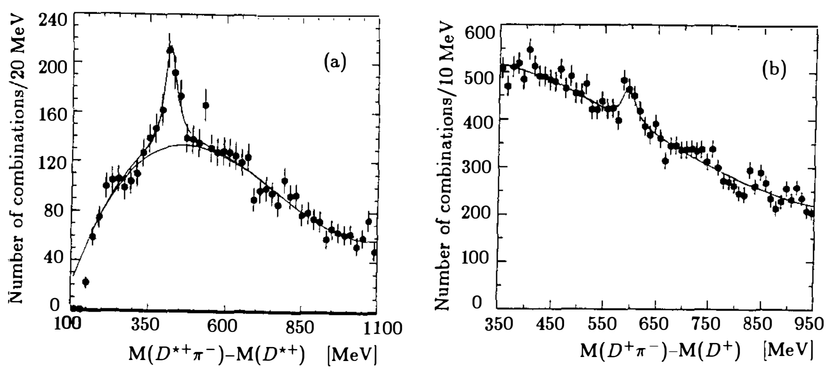

Figure 3.

Table 3: Compilation of Results on D^{**} States.

State	Experiment	Year	Mass [MeV]	Width [MeV]	$\sigma(D^{**})/\sigma(D^{(*)})\times BR(D^{**} \to \pi D^{(*)})$ [%]
$D^{**}(2420)$	ARGUS[12]	1986	2419±6	41^{+22}_{-14}	$9^{+3}_{-2}\pm3$
	CLEO[13]	1987	2424±6		12±4±3
	E691[14]	1988	2428±8±5	58±14±10	$13^{+3}_{-4}\pm2$
	CLEO(prel.)	1989	2427±5±5	53^{+30}_{-20}	13±2±3
$D^{**}(2460)$	E691[14]	1988	2459±3±2	20±10±5	7±2±2
	ARGUS[11]	1988	2455±3±5	15^{+13+5}_{-10-10}	11±4±5
	CLEO(prel.)	1989	2463±4±3	25±5	7.5±1.5±0.5

The $D^{**}(2420)$ is observed in the πD^* channel, thus it can be either the spin-1 or the spin-2 state. The spin-2 state can decay by the same D-wave transition to πD as well. This leads to a theoretical relation between the πD^* and πD branching ratios for this state, which is however somewhat uncertain because of uncertainty in a barrier factor in the π-emission[16] , $BR(D^{**}(1^3P_2)\to \pi D)/ BR(D^{**}(1^3P_2)\to \pi D^*) = 0.7–2.5$. The $D^{**}(2420)$ state is not observed in the πD channel. Our upper limit, $BR(D^{**}(2420)\to \pi D)/ BR(D^{**}(2420)\to \pi D^*) < 0.12$ (90 % C.L.), rules out the spin-2 hypothesis. Thus, the $D^{**}(2420)$ appears to be the spin-1 state.

The $D^{**}(2460)$ is observed in the πD channel, thus it can be either the spin-0 or the spin-2 state. It is heavier and narrower than the $D^{**}(2420)$ (see Table 3) therefore it is likely to be the spin-2 rather than the spin-0 state. Additional support for the spin-2 assignment is provided by the angular distribution analysis performed by the ARGUS experiment[11] .

Though these spin assignments are plausible, not everything has been experimentally clarified. If the $D^{**}(2460)$ is the spin-2 state, it should decay to πD channel as well. This decay has not been established by any of the experiments. In fact, our preliminary lower limit, BR(D^{**}**(2460)**$\to \pi D$)/ BR(D^{**}(2460)$\to \pi D^{*}$) > 2.3 (90 % C.L.), gets uncomfortably close to the upper range of the theoretical expectation quoted above. Furthermore, it should be possible to confirm the D^{**0}(2460) resonance by observation of its isospin partner D^{**+} in decay to $\pi^{+} D^{0}$, which remains to be demonstrated (our analysis of this channel is not completed yet).

In conclusion, CLEO and ARGUS demonstrated that $e^{+}e^{-}$ experiments in the energy range of Υ's are useful in uncovering charmed meson and baryon states. We are looking forward towards large luminosity samples with the upgraded CESR storage ring and the upgraded CLEO-II detector[17] due to start operation this year.

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[16] The lower limit quoted corresponds to no barrier factor. The upper limit given corresponds to the smallest value of the barrier factor obtainable in different calculations. See J.L.Rosner EFI 88-37, p. 35.
[17] CLNS 85/634.