Recent results from CLEOII : charm physics

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In the last decade the CLEO II collaboration, using the CESR e^+e^- storage ring, has accumulated nearly $15 fb^{-1}$ of luminosity. in the energy region around 10.5 GeV, corresponding to the production of more than $3 \cdot 10^7$ charmed particles (apart from daughters of B meson decay). This has produced new results in the spectroscopy of charmed baryons and mesons and a much improved limit on $D^0 - \overline{D^0}$ mixing. We present evidence for an excitation of the Ξ_c, seen in both charge states; namely, the Ξ_c' , the $J^p = \frac{1}{2}^+$ c{sq} state, which is *symmetric* under exchange of light quark quantum numbers. Another state is seen in the decays to $\Xi_c^+\pi^+\pi^-$ and $\Xi_c^0\pi^+\pi^-$ via an intermediate Ξ_c^*, and is consistent with the Ξ_{c1},the $J^p = \frac{3}{2}^-$ p-wave state analogous to the $\Lambda_{c1}^+(2625)$. The mass differences relative to the ground state are: $M(\Xi_c^{+\prime}) - M(\Xi_c) = (107.8 \pm 1.7 \pm 2.5)\mathrm{MeV}/c^2$, $M(\Xi_c^{0\prime}) - M(\Xi_c) = (107.0 \pm 1.5 \pm 2.5)\mathrm{MeV}/c^2$, $M(\Xi_{c1}^+) - M(\Xi_c^+) = (348.6 \pm 0.6 \pm 1.0)\mathrm{MeV}/c^2$, and $M(\Xi_{c1}^0) - M(\Xi_c^0) = (347.2 \pm 0.7 \pm 2.0)\mathrm{MeV}/c^2$. We have made the first (preliminary) measurements of the natural widths of the Σ_c^{++} and Σ_c^0 baryons: $\Gamma^{++} = (2.98^{+.38}_{-.35} \pm 0.5)$MeV, and $\Gamma^0 = (2.63^{+.36}_{-.33} \pm 0.5)$MeV. In the charmed meson sector we find evidence for a *wide* 1^+ state,the $D_1^0(2460)$. Its mass is $(2.461^{+.041}_{-.034} \pm .010 \pm .032)$GeV; its width is $(290^{+101}_{-74} \pm 26 \pm 36)$MeV. We find no supporting evidence for the $D^{*\prime +}$, a purported radial excitation claimed by the Delphi group at a mass of $(2637 \pm 2 \pm 6)$MeV. Finally we are able, using "wrong-sign" (DCSD) $K\pi$ decays to make the following measurements: 1) the observed ratio of DCSD decays relative to the Cabibbo-allowed rate is $R_{ws} = (0.34 \pm 0.7 \pm .06)\%$, 2) the mixing parameters are bounded, at 95% confidence, by $x'^2 < .001$ and $-.059 < y' < .003$. x' and y' are, in the absence of final state phase differences, the real and imaginary parts of $\delta M/\Gamma$.

1. INTRODUCTION TO CESR AND CLEO

The CLEO II experiment[1] has been taking data for more than ten years. During this time the detector has existed in two incarnations: the original CLEO II configuration, and, since 1997, as CLEO II.V. CLEO II.V added a three-layer, double-sided silicon vertex detector to the CLEO II's already excellent capabilities in charged and neutral particle tracking. The CESR e^+e^- storage ring has likewise evolved over those years, increasing its peak luminosity by nearly an order of magnitude, to as much as $8.5 \cdot 10^{32} cm^{-2}s^{-1}$. This combination of time, luminosity, and a capable detector, has produced a windfall yield of data in the charm sector in addition to B-physics (our major concentration) and

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τ physics. Our integrated luminosity of almost $15 pb^{-1}$ implies the production of more than 3 10^7 charmed particles.

2. CHARMED BARYON SPECTROSCOPY

The baryons formed from a (heavy) charmed quark and two light quarks (s, u, or d) can be conveniently classified[2] by the considering a) the relative angular momentum, L, between the light diquark and the charmed quark, or the angular momentum , ℓ, within the diquark, b) the combination of L or ℓ with the light spins to give a J^p_{light}, and c) the coupling of this light quark "spin" to the charmed quark spin to give the final J^p. The states fall into sextets (**6**'s) and anti-triplets (**3***'s) under the SU(3) of light quark flavor. The **3***'s are antisymmetric under interchange of light quark quantum numbers; the **6**'s are antisymmetric. When L=ℓ=0, the lowest lying **3*** has $J^p = \frac{1}{2}^+$ and contains the Λ_c , and the Ξ_c. The lowest lying **6** contains the Σ_c, Ω_c, as well as another symmetric $J^p = \frac{1}{2}^+$ state , the Ξ'_c, which is expected to decay to $\Xi_c\gamma$, and has been heretofore undetected, but will be reported in what follows. The other s-wave multiplet is a **6** with $J^p = \frac{3}{2}^+$, which contains the recently reported Ξ^*_c[3]. All of the states with $l = 0$ have been found,except for the $\frac{1}{2}^+$ Σ^{*+}_c and Ω^{*0}_c, which are experimentally challenging, requiring detection of a soft π^0.

The lowest-lying states with one unit of angular momentum are expected to have L=1, $\ell = 0$, with little configuration mixing. We thus expect to find a pair of antisymmetric **3***'s with $J^p = \frac{1}{2}^-$ and $J^p = \frac{3}{2}^-$, and five **6**'s: one with $\frac{5}{2}^-$, two $\frac{3}{2}^-$, and two $\frac{1}{2}^-$. Earlier experiments have found a likely candidate for a member of the $\frac{3}{2}^-$ **3***, the $\Lambda^+_c(2625)$[4].

3. CHARMED BARYONS AT CLEO

CLEO and CESR generally operate at the$\Upsilon(4S)$ resonance at $s^{1/2} = 10.58$ GeV. Charmed particles can be produced either from the decay of B mesons or from the underlying $c\bar{c}$ continuum. In this analysis, however, we have no contributions from B-decay, since we place a lower limit on the parent charmed baryon's scaled momentum, $x_p = p/p_{max} > 0.6$ to 0.7, where $p^2_{max} = E^2 - M^2_{baryon}$, in order to optimize the signal-to-noise.

The detector employs a cylindrical drift chamber system and a 1.5T solenoidal field to measure charged particles, and 7800 CsI(Tl) crystals provide excellent energy and spatial resolution for photons, electrons, and π^0's. The reconstruction of charmed-strange states begins with collection of a sample of Λ 's (antiparticles, too, are always implied) which do not come from the primary interaction point. These are combined with pions to form Ξ^0 and $\Xi^\pm$, or with charged kaons to form Ω^-. The Ξ or Ω^- must be consistent with the primary vertex, and must have decayed closer to the origin than did the daughter Λ. Charged tracks are required to be consistent with the particle identification information provided by the drift chamber's dE/dX system and (when available) by the time-of flight system. The "raw" Λ, Ω, and Ξ, and π^0 masses must be within ~ 3 standard deviations of their known values. They are later kinematically re-fit for improved resolution in the charmed baryon mass and momentum. The Ξ^0_c are reconstructed in the modes $\Xi^-\pi^+$, $\Xi^-\pi^+\pi^0$, and Ω^-K^+; Ξ^+_c in the modes $\Xi^-\pi^+\pi^-$ (dominant) , $\Xi^0\pi^+$, and $\Xi^0\pi^+\pi^0$. Σ^+_c and

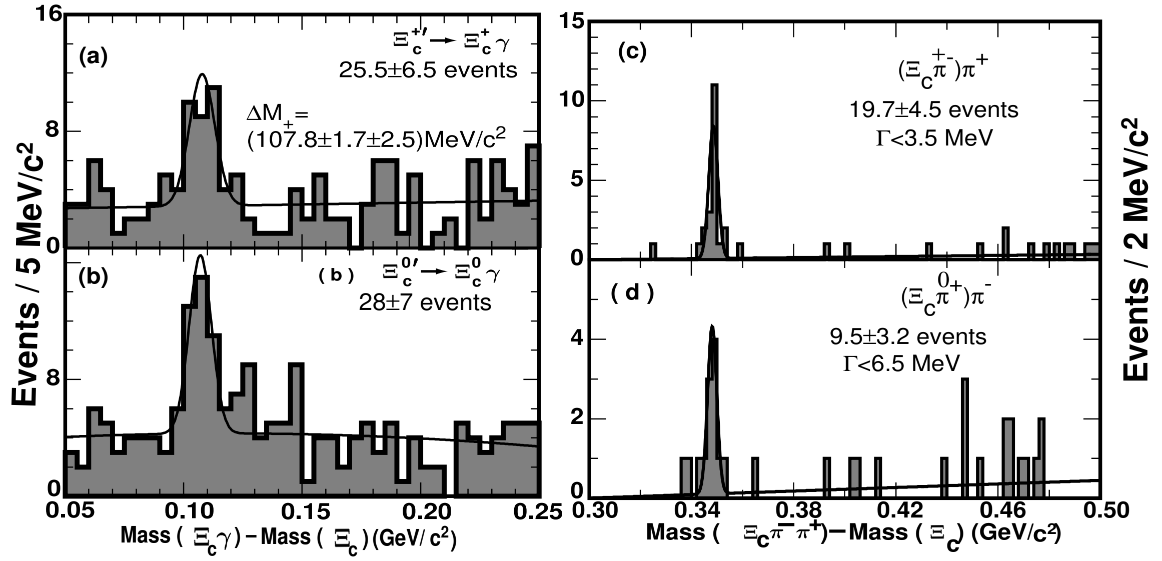

Figure 1. Distributions of mass-difference between $\Xi_c\gamma$ and Ξ_c candidates: a) charged channel, b) neutral channel, and mass-difference between $\Xi_c\pi^+\pi^-$ and Ξ_c candidates: c) charged channel, d) neutral channel.

Σ_c^0 are reconstructed by combining the appropriately signed pion with a Λ_c reconstructed in any of several decay modes.

4. ANALYSIS OF EXCITED Ξ_c STATES

4.1. Ξ_c and Ξ_c' reconstruction

This analysis has been recently published.[5] It uses the CLEO II data set of just less than $5pb^{-1}$. Ξ_c^+ are reconstructed in the modes $\Xi^-\pi^+\pi^+$ and $\Xi^0\pi^+\pi^0$. Ξ_c^0 modes are $\Xi^-\pi^+$, $\Xi^-\pi^+\pi^0$, and Ω^-K^+. Events which are within 2σ of the published CLEO II Ξ_c^+ and Ξ_c^0 masses for each channel are combined with well-measured γ's to form Ξ_c' candidates. The γ must have an energy 100 MeV, and must not form π^0's with other γ's in the detector. A decay-channel dependent x_p cut of 0.5 to 0.6 is applied. Figures 1a and 1b show the resultant distribution of mass-difference between the $\Xi_c\gamma$ and the Ξ_c candidates, with evident peaks containing 28 ± 7 and 25 ± 6 events in the neutral and charged channels, respectively. Each peak has a statistical significance of more than 4σ, and is robust when the π^0 veto is removed, and is fit with a width determined by Monte Carlo. The mass differences relative to the ground state are: $M(\Xi_c^{+\prime}) - M(\Xi_c) = (107.8 \pm 1.7 \pm 2.5)\mathrm{MeV}/c^2$, and $M(\Xi_c^{0\prime}) - M(\Xi_c) = (107.0 \pm 1.5 \pm 2.5)\mathrm{MeV}/c^2$. The last error is systematic, related to low-energy photon resolution.

4.2. $\Xi_c\pi^+\pi^-$ analysis

This result is described in more detail in another recent publication.[6]. We start with a sample of more than 600 reconstructed Ξ_c^+ and a like number of Ξ_c^0. We combine these with π^- or π^+ tracks to form Ξ_c^{*0} and Ξ_c^{*+} candidates, whose mass lies within ± 5 MeV of the appropriate Ξ_c^* mass, as measured by CLEO. These candidates are paired with the oppositely charged π, requiring the finalx_p to exceed 0.6, as was done in our earlier Λ_{c1}^* analysis. We plot the mass-differences distributions in Figure 1(c) and 1(d), where clean enhancements are seen in both charge states. The widths are fit with the Monte Carlo expectation of 2.5 MeV, consistent with the detector resolution. Auxiliary fits to Breit-Wigner resonances provide upper limits (indicated in the figures) to their natural widths. To avoid uncertainties from the imperfectly known Ξ_c widths, we quote the mass difference relative to the Ξ_c ground states. The result is: $M(\Xi_{c1}^+) - M(\Xi_c^+) = (348.6 \pm 0.6)\mathrm{MeV}/c^2$, and $M(\Xi_{c1}^0) - M(\Xi_c^+) = (347.2 \pm 0.7)\mathrm{MeV}/c^2$. Relaxing the Ξ_c^* requirement and cutting on the overall mass, we find the new states decay entirely through the Ξ_c^*.

Even though no spin-parity analysis has been performed, the features of the two $\Xi_c\gamma$ decays support the identification of these narrow peaks with the Ξ_c', the charmed-strange members of the **6** which contains the Σ_c triplet and Ω_c. Its electromagnetic decay is allowed by the quantum numbers and expected by theory to give a mass difference of about 110 MeV, in accord with this experiment.

The $\Xi_c\pi^+\pi^-$ states, which decay similarly to the Λ_{c1}, are tentatively identified as probable $\frac{3}{2}^-$ entities. The measured mass difference, relative to the Ξ_c accords well with expectations, and with the analogous number for the Λ_c. CLEO II is still studying the $\frac{1}{2}^-$ states, which should decay to $\Xi'\pi$.

5. Measurement of Σ_c widths and masses

Using all the CLEO II and II.V data, and exploiting excellent and well-understood mass resolution ($\sigma \sim 1$ MeV) CLEO has made preliminary measurements the natural widths of the Σ^{*++} and Σ^{*0}. Figure 2 shows the fits, which employ a convolution of the Monte-Carlo resolution with a p-wave Breit-Wigner. distribution, together with a polynomial background. The respective widths of $2.98^{+.38}_{-.35} \pm 0.5$ MeV and $2.63^{+.33}_{-.36} \pm 0.5$ MeV, are within the range of recent theoretical predictions, which lie between 1.3 and 2.8 MeV.[7] The precision in the mass-difference between the Σ_c's and the Λ_c^{++} has also been greatly improved; we find (preliminary): $\Delta M^{++} = (167.4 \pm 0.1 \pm 0.2)$ MeV and $\Delta M^{++} = (167.3 \pm 0.1 \pm 0.2)$ MeV.

6. CHARMED MESONS

Two new results can be discussed here only briefly. First, CLEO has preliminary results in the spectroscopy of p-wave D^{**} mesons, which can decay to $D^*\pi$, using the extra constraints which follow from the hypothesized process:$B^- \to D^{**0}\pi^-$, followed by $D^{**0} \to D^{*+}\pi^-$. Here the D^{*+} is not fully reconstructed, but is identified only by the "soft pion" associated with its decay to $D^0\pi^+$. Thus, statistics are greatly increased at the cost of decreased signal-to-noise. An elaborate likelihood fit to the data[8] finds evidence for a **wide** 1^+ state,the $D_1^0(2460)$. Its mass is $(2.461^{+.041}_{-.034} \pm .010 \pm .032)$GeV; its width is $(290^{+101}_{-74} \pm 26 \pm 36)$MeV. Second, We find no supporting evidence for the $D^{*'+}$, a purported radial excitation claimed by the Delphi group[9] at a mass of $(2637 \pm 2 \pm 6)$ MeV.The charm production mechanism differ at CESR and LEP, but we find (at 90% confidence) that the $D^{*'}$ rate in the $D^{*+}\pi^+\pi^-$ mode is < 0.16 the rate for $D_2^{0*} + D_1^0 \to D^{*+}\pi^-$. The

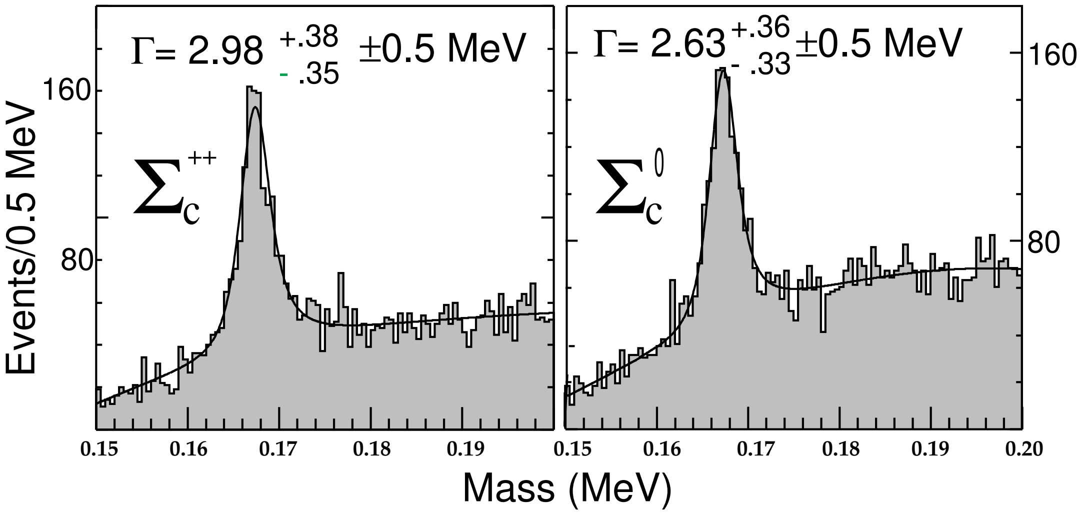

Figure 2. Data and fits to the two Σ_c states. Widths are indicated within the figures. Goodness of fit is acceptable and significantly better than a "floating width" gaussian.

analogous number for the Delphi claim is three times larger.

7. DCSD DECAYS AND $D^0 - \overline{D^0}$ MIXING

With the aid of CLEO III's precision silicon vertex-detector, we are able to investigate the separate amplitudes for 1) tree-level doubly-Cabibbo-suppressed (DCSD) decays of the D^0 and 2) production of the same final state via $D^0 - \overline{D^0}$ mixing (presumably engendered by the famous "box diagram"). The initial flavor of the D is tagged by the sign of the soft-pion emitted in the decay $D^{*0} \to D^0\pi^-$. We look at the proper time distribution of the "wrong-sign" $K\pi$ decays, those which don't have the expected correlation with the D^* charge, to make the decomposition, taking interference effects into account. The measurements hinge on high statistics, good momentum and temporal resolution, and extensive Monte-Carlo simulations to check our understanding of the fits and backgrounds. In the limit that mixing is small, and with time measured in units of the average D-lifetime:

$$R(t) = R_d + \sqrt{R_d}y't + \frac{1}{4}[x'^2 + y'^2]t^2e^{-t} \tag{1}$$

Here R(t), is the decay rate relative to the Cabibbo allowed rate, R_d is the squared DCSD amplitude; we use $x = \delta M/\Gamma, y = \delta\Gamma/\Gamma, y' = ycos\delta - xsin\delta$. The phase δ allows for the possibility that the mixing diagram leads to a state with different isospin content than the tree amplitude, and that there is a relative scattering phase between the two possible isospin states.

Space doesn't permit adequate discussion of the experimental details, which are presented elsewhere[10]. We merely mention here a few crucial features: 1) we have no bias toward large times, since we have no target to inhibit vertex finding near $t = 0$, 2) we use regions of the $K\pi\pi$ phase space outside the D and/or D^* mass peaks to check the Monte-Carlo understanding of the backgrounds, 3) we have very good resolution in the $(D^{*+} - D^0)$ Q-value, 4) all cuts are identical for both wrong-sign and right-sign events, 5) purely kinematic determination of proper particle ID assignment is achieved by excluding a modest fraction of decays where kaon and pion have nearly equal laboratory momenta.

The time-integrated wrong-sign/right-sign yield gives a value $R_{ws} = (0.34 \pm 0.7 \pm .06)\%$. The time dependent fit yield the following central values: $R_d = (.50^{+.11}_{-.021} \pm .08)\%, x' = (0 \pm 1.6 \pm 0.2)\%$, and $y' = (-2.7^{+1.5}_{-1.6} \pm 0.2)\%$. Note that the central value of y' is negative, implying destructive interference. Neither of the mixing parameters, x' and y' is found to be significantly different from zero; thus we bound them at 95% confidence, by $x'^2 < .001$ and $-.059 < y' < .003$.

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REFERENCES

1. (CLEO II) Y. Kubota, et al., Nucl. Instrum. Meth., A320, (1992), 66
2. J.G. Körner, M. Kramer, and D. Pirjol, Prog. in Part. Nucl. Phys. 33, (1994), 787 , D. Pirjol and T.-M. Yan, Phys. Rev. D56, (1997), 5483
3. (CLEO II) L. Gibbons, et al., Phys. Rev. Lett. 77, (1996), 810
4. H,. Albrecht, et al., Phys. Lett. B317 , (1993), 227, (CLEO II) P. Avery, et al., Phys. Rev. Lett. 74, (1995), 4364, P. Frabetti, et al., Phys. Lett. B364, (1996), 461
5. (CLEO II) C. P. Jessop et al., Phys. Rev. Lett. 82, (1999), 192
6. (CLEO II) J. P. Alexander, et. al, Phys. Rev. Lett. 83, (1999), 3390
7. J. Rosner, Phys. Rev. D52, 6461 (1995), D. Pirjol and T. M. Yan, Phys. Rev. D56, 5483 (1997), S. Tawfiq etal.,Phys. Rev. D58, 054010, M. Ivanov, et al., Phys. Lett. B442 (1998)
8. (CLEO II)D. Jaffe,et al., hep-ex/9908009 (1999)
9. (Delphi), Phy. Lett. B443 ,231 (1998), D. Melikhov and O. Péne, Phys. Lett. B 4463-4, 336 (1999)
10. (CLEO II) H. N. Nelson, et al., hep-ex9909028 (1999)