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Observation of Two Excited Charmed Baryons Decaying into $\Lambda_c^+\pi^\pm$

CLEO Collaboration

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Abstract

Using data recorded by the CLEO-II detector at CESR, we report preliminary evidence of a pair of excited charmed baryons, one decaying into $\Lambda_c^+\pi^+$ and the other into $\Lambda_c^+\pi^-$. The doubly charged state has a measured mass difference $M(\Lambda_c^+\pi^+) - M(\Lambda_c^+)$ of $234.5 \pm 1.1 \pm 1.0$ MeV/c^2 and a width of $17.9^{+3.8}_{-3.2} \pm 4.0$ MeV/c^2, and the neutral state has a measured mass difference $M(\Lambda_c^+\pi^-) - M(\Lambda_c^+)$ of $232.6 \pm 1.0 \pm 1.0$ MeV/c^2 and a width of $13.0^{+3.7}_{-3.0} \pm 4.0$ MeV/c^2. We identify these states as Σ_c^{*++} and Σ_c^{*0}, the spin $\frac{3}{2}^+$ excitations of the Σ_c baryons.

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Recently we reported [1,2] the observation of two narrow states decaying into $\Xi_c\pi$, which we identified as the $J^P = \frac{3}{2}^+$ spin excitations of the charmed-strange Ξ_c^0 and Ξ_c^+ baryons. Until now, however, evidence for $J^P = \frac{3}{2}^+$ spin excitations of their non-strange analogues, the Σ_c^* baryons, has been restricted to a cluster of 6 $\Lambda_c^+\pi^+$ events [3] with an estimated mass difference of $245 \pm 5 \pm 5$. Here we report preliminary evidence for two particles decaying into $\Lambda_c^+\pi^+$ and $\Lambda_c^+\pi^-$, respectively. The two states have similar cross sections, masses and widths. We identify these states as the Σ_c^{*++} and Σ_c^{*0} baryons.[1]

The data presented here were taken by the CLEO II detector operating at the Cornell Electron Storage Ring. The sample used in this analysis corresponds to an integrated luminosity of 4.8 fb^{-1} from data taken on the $\Upsilon(4S)$ resonance and in the continuum at energies just above and below the $\Upsilon(4S)$. The CLEO II detector is described elsewhere [4]. We detected charged tracks with a cylindrical drift chamber system inside a solenoidal magnet. Photons were detected using an electromagnetic calorimeter consisting of 7800 cesium iodide crystals.

We reconstructed Λ_c^+ baryons using 13 different decay modes.[2] Measurements of the branching fractions into all these modes and the general procedures for finding them have previously been presented by the CLEO collaboration [5,6]. For this search and data set, the exact cuts have been optimized for high efficiency and low background. Briefly, particle identification of p, K^-, and π candidates was performed using specific ionization measurements in the drift chamber, and when present, time-of-flight measurements. Hyperons were found by detecting their decay points separated from the main event vertex. Combinations within 1.6 σ of the mass of the Λ_c^+ in each decay mode are taken as Λ_c^+ candidates.

For the purpose of illustrating the good statistics and signal to noise ratio of the Λ_c^+ signals, we have reduced the combinatorial background by applying a cut on x_p, where $x_p = p/p_{max}$, p is the momentum of the charmed baryon, $p_{max} = \sqrt{E_{beam}^2 - M^2}$, and E_{beam} is the beam energy. We fitted the invariant mass distributions for these modes to a sum of a Gaussian signal and a low-order polynomial background. The signal yield and background is integrated between $\pm1.6\sigma$ of the Λ_c^+ mass. The results of this procedure are summarized in Table 1. The x_p cut used for Table 1 was not used in the Σ_c^* analysis, as we prefer to apply an x_p cut only on the $\Lambda_c^+\pi^\pm$ combinations.

The Λ_c^+ candidates defined above were then combined with each remaining charged track in the event and the mass difference $M(\Lambda_c^+\pi^\pm) - M(\Lambda_c^+)$ was calculated. We placed an $x_p > 0.5$ cut on the $\Lambda_c^+\pi^\pm$ combination to reject combinatorial background. We note that charmed baryons produced from decays of B mesons are kinematically limited to $x_p < 0.4$, so this cut restricts our analysis to charmed baryons produced by e^+e^- annihilation into $c\bar{c}$ jets which are known to have a hard momentum spectrum. We define θ_{dec} to be the angle between the π momentum measured in the rest frame of the $\Lambda_c^+\pi$, and the direction of the $\Lambda_c^+\pi$ in the laboratory frame. The combinations are required to pass a cut of $cos(\theta_{dec}) > -0.4$, which

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[1] Our sensitivity to the decay $\Sigma_c^{*+} \to \Lambda_c^+\pi^0$ is considerably less than that of $\Sigma_c^* \to \Lambda_c^+\pi^\pm$ due to larger backgrounds and smaller reconstruction efficiency.

[2] Charge conjugate modes are implicit throughout.

Mode	Signal	Background
$pK^-\pi^+$	7465	11662
$p\overline{K^0}$	870	297
$\Lambda\pi^+$	941	675
$\Lambda\pi^+\pi^0$	729	570
$\Lambda\pi^+\pi^-\pi^+$	873	805
$\Sigma^0\pi^+$	658	630
$\Sigma^+\pi^+\pi^-$	727	465
$\Sigma^+K^+K^-$	55	10
$\Xi^-K^+\pi^+$	205	46
Ξ^0K^+	118	43
$pK^-\pi^+\pi^0$	339	444
$p\overline{K^0}\pi^0$	224	130
$p\overline{K^0}\pi^+\pi^-$	246	180

TABLE I. The number of Λ_c^+'s found with $x_p > 0.5$

suppresses the large background from low momentum π mesons. The mass difference spectra, shown in Figure 1, each show clear peaks at around 167 MeV/c^2 due to Σ_c decays, broad enhancements below 204 MeV/c^2 due to feed-down from $\Lambda_c^{*+}(2630) \rightarrow \Lambda_c^+\pi^+\pi^-$ decays [7], and broader excesses at around 233 MeV/c which we consider to be our signals. The overlaid histogram in each case shows the mass difference spectrum using normalized sidebands of the Λ_c^+; no enhancements are observed in these histograms, and good fits are obtained to them when fit with smooth second-order polynomials.

The fits shown for the signal spectra in Figure 1 each have five components as follows. Firstly, the fits to the normalized sidebands are used as representations of the contribution to $\Lambda_c^+\pi$ candidates from fake Λ_c^+ candidates. Secondly, second order polynomials of shape derived from Monte Carlo simulation, are used with floating normalizations for the contributions of real Λ_c^+ baryons with random pions. Thirdly, Gaussians of floating mean and width were used for the Σ_c contributions. Fourthly, the excesses in the region below 204 MeV/c^2 due to $\Lambda_c^{*+}(2630)$ production are accounted for using the $\Lambda_c^+\pi^\pm$ spectra from fully reconstructed $\Lambda_c^{*+}(2630) \rightarrow \Lambda_c^+\pi^+\pi^-$ data events, with the normalization corrected using a Monte Carlo program. Lastly we use signal functions of P-wave Breit-Wigners convoluted with a Gaussian resolution function of standard deviation, $\sigma = 2.3$ MeV/c^2. This resolution was determined using a Geant based Monte Carlo simulation [8].

The fits yield significant signals for both $\Lambda_c^+\pi^+$ and $\Lambda_c^+\pi^-$. In the case of $\Lambda_c^+\pi^+$ we obtain a signal of 677^{+101}_{-93} events, a width of $\Gamma = 17.9^{+3.8}_{-3.2}$ MeV/c^2, and a mass difference of $\Delta M = 234.5 \pm 1.1$ MeV/c^2. For the the $\Lambda_c^+\pi^-$ combinations, we obtain a signal area of 504^{+93}_{-83} events, a width of $\Gamma = 13.0^{+3.7}_{-3.0}$ MeV/c^2, and a mass difference of $\Delta M = 232.6 \pm 1.0$ MeV/c^2, where the errors are all statistical.

The parameters of the found signals are sensitive to the fitting procedure used. We have tried many variations of the background functions including allowing the first two components of each fit to be incorporated into second-order polynomials with floating shape and normalization. We have also tried varying the shape of the Λ_c^{*+} feed-down component, varying the normalization of this component by as much as 50%, and varying the ΔM range over which the fits are made. The systematic uncertainties in the measurements due to the fitting procedures are taken as being the maximum range of parameters obtained using different reasonable fits of these types. This is the dominant systematic uncertainty for both the yields and widths; we note that these two parameters are highly correlated. For each charged state we estimate the systematic uncertainty on the yield to be ± 120 events, and the systematic uncertainty on the width to be ± 4.0 MeV/c^2. The masses of the signals are relatively stable for all fitting techniques used. In each case we estimate the systematic uncertainty to be ± 1.0 MeV/c^2 due to a combination of fitting uncertainty (0.7 MeV/c^2) and uncertainty in the mass difference scale (0.7 MeV/c^2). This last uncertainty cancels in the measurement of the isospin mass splitting, which we find to be $M(\Sigma_c^{*++}) - M(\Sigma_c^{*0}) = 1.9 \pm 1.4 \pm 1.0$ MeV/c^2.

Since the discovery of charm, many models [9] have been used to predict the spectroscopy of charmed baryons. The range of the predicted mass difference, $\Delta M = M(\Sigma_c^*) - M(\Lambda_c^+)$ is around 200-300 MeV/c^2. Two recent models [10,11] have the benefit of having data for the Ξ_c^* and Ω_c masses available as constraints. Rosner uses spin-flavor wave-functions and predicts $\Delta M = 229$ MeV/c^2; Savage uses chiral perturbation theory and predicts $\Delta M = 233$ MeV/c^2. The mass differences we measure are in very good agreement with these models. Combining our result with previous results [12] we find the mass splitting between the spin-state weighted mass of the $\Sigma_c^{(*)}$ system and the Λ_c^+, $(4M(\Sigma_c^*) + 2M(\Sigma_c))/6 - M(\Lambda_c^+)$, to be ≈ 211 MeV/c^2. This value is similar to the analogous value for the non-charmed hyperons of ≈ 206 MeV/c^2, and also the value of ≈ 210 MeV/c^2 obtained using preliminary DELPHI results for the masses of the bottom baryons [13]. These three values are predicted to be the same in naive baryonic mass models [14]. We also note that the width of the Σ_c^* has been estimated [10] from extrapolation of the Σ^* hyperon width to be around 20 MeV, with the possibility of QCD corrections lowering this number; this is also in good agreement with our measurements. We therefore identify these peaks as the Σ_c^{*++} and Σ_c^{*0} baryons.[3]

In order to study the decay angle and momentum distribution of the Σ_c^* candidates, we relax the decay angle cut and refit our signals in bins of $\cos(\theta_{dec})$ and x_p, fixing the mass and width of each of the particles to the values obtained above. We restrict the ΔM plots to $205 < \Delta M < 380$ MeV/c^2 so that there are no complications from Σ_c production and Λ_c^* feed-down. We find no significant differences between the characteristics of the two isospin states, so we add the yields from the two in each bin to increase the accuracy of the measurements.

Figure 2 shows the data divided into five bins of $cos(\theta_{dec})$. Using the treatment of Falk and Peskin, this distribution can be fit to a form $\frac{1}{\Gamma}\frac{d\Gamma}{d\ cos\theta_{dec}} = \frac{1}{4}(1 + 3cos^2\theta_{dec} - \frac{9}{2}w_1(cos^2\theta_{dec} - \frac{1}{3}))$, where w_1 is the fraction of the light diquark in a helicity ± 1 configuration. We find $w_1 = 0.71 \pm 0.13$, where statistical errors dominate. This is very consistent with a value of $w_1 = 2/3$, which corresponds to a flat $\cos(\theta_{dec})$ distribution and unaligned Σ_c^* production. This value of w_1 is very different from the value of ≈ 0 found by the DELPHI collaboration

[3]We note that one author [15] has suggested an alternative identification of the observed charmed baryon mass spectrum.

in their preliminary analysis of Σ_b^* production from Z^0 decays [13].

In order to study the fragmentation function we divide the data into bins of x_p, determine the yields in each bin and correct the yields using efficiencies obtained from Monte Carlo simulations. Figure 3 shows the $\frac{dN}{dx_p}$ distribution, and the overlaid fit using the Peterson [17] form of $dN/dx_p \propto x_p^{-1}(1 - 1/x_p - \epsilon/(1 - x_p))^{-2}$. The fit gives a value of $\epsilon = 0.30^{+0.10}_{-0.07}$. This is similar to the CLEO measurements [1,2,5,18] for Λ_c^+, Ξ_c^+, Ξ_c^{*0} and Ξ_c^{*+} baryons, but corresponds to a softer momentum spectrum than the charmed baryons with non-zero orbital angular momentum [7]. In order to calculate the percentage of Λ_c^+ baryons that are the decay products of Σ_c^* decays, we need to extrapolate the yields of Λ_c^+ and Σ_c^* baryons down to $x_p = 0$. We calculate that $(12.8^{+1.5}_{-1.3} \pm 3.2)\%$ of Λ_c^+ baryons are produced from the sum of Σ_c^{*++} and Σ_c^{*0} decays. Here, the systematic error includes the uncertainties in fitting the signals and the uncertainty in the extrapolation down to $x_p = 0$.

In conclusion, we present preliminary evidence of two resonances which we identify as the Σ_c^{*++} and Σ_c^{*0} baryons. For the doubly charged state, $M(\Sigma_c^{*++}) - M(\Lambda_c^+)$ is measured to be $234.5 \pm 1.1 \pm 1.0$ MeV/c^2 and $\Gamma = 17.9^{+3.8}_{-3.2} \pm 4.0$ MeV/c^2, and for the neutral state $M(\Sigma_c^{*0}) - M(\Lambda_c^+)$ is measured to be $232.6 \pm 1.0 \pm 1.0$ MeV/c^2 and $\Gamma = 13.0^{+3.7}_{-3.0} \pm 4.0$ MeV/c^2. The isospin mass splitting $M(\Sigma_c^{*++}) - M(\Sigma_c^{*0})$ is measured to be $1.9 \pm 1.4 \pm 1.0$ MeV/c^2.

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REFERENCES

[1] P. Avery et al., PRL **95**, 4365 (1995).
[2] L. Gibbons et al., to appear in PRL.
[3] V. Ammosov et al., JETP Letters **58**, 247 (1993).
[4] Y. Kubota et al., Nucl. Instr. and Meth. **A320**, 66 (1992).
[5] P. Avery et al., Phys. Rev. D43, 3599 (1991).
[6] P. Avery et al., PRL **71** 3255 (1993), Y. Kubota et al., PRL **71** 3255 (1993), P. Avery et al., Phys. Lett. **B325** 257 (1994), D. Cinabro et al., CLEO-CONF 93-27.
[7] P. Avery et al., PRL 74, 3331 (1995).
[8] R. Brun et al., CERN/DD/EE/84-11.
[9] L. Copley, N. Isgur and G. Karl, Phys. Rev. **D20**, 78 (1978), A. Sakharov, JETP 51, 1059 (1980), S. Gariorowicz and J. Rosner, Am. J. Phys, 49, 954 (1981), C. Kalmna, Phys. Rev. **D27**, 1648 (1983), J. Richard and P. Taxil, Phys. Lett. **B128**, 453 (1983), S. Samuel, Phys. Lett. **B166**, 413 (1986), J. Basdevant and S. Boukraaq, Z. Phys. **C 30**, 103 (1986), C. Iton et al., Phys. Rev. **D40**, 3660 (1989), J. Korner and H. Siebert, Ann. Rev. of Nucl. and Part. Science **41**, 511 (1991), P. Geiger and R. Cutkosky, Phys. Rev. **D48**, 1315 1(1993).
[10] J. Rosner, Phys. Rev. **D52**, 6461 (1995).
[11] M. Savage, Phys. Lett. **B359**, 189 (1995).
[12] Review of Particle Properties, Phys. Rev. **D54**, 1 (1996).
[13] DELPHI 95-107 PHYS 542, Submitted to the EPS-HEP 95 conference, Brussels.
[14] This material is covered in many introductory High Energy Physics textbooks, see for example "Introduction to High Energy Physics" by D.H.Perkins, 3^{rd} edition, Table 5.4.
[15] A. Falk JHU-TIPAC-96007.
[16] A. Falk and M. Peskin, Phys. Rev. **D 49** 3320 (1994).
[17] C. Peterson et al., Phys. Rev. **D27**, 105 (1983).
[18] K.W. Edwards et al., Phys. Lett. B373, 261 (1995).

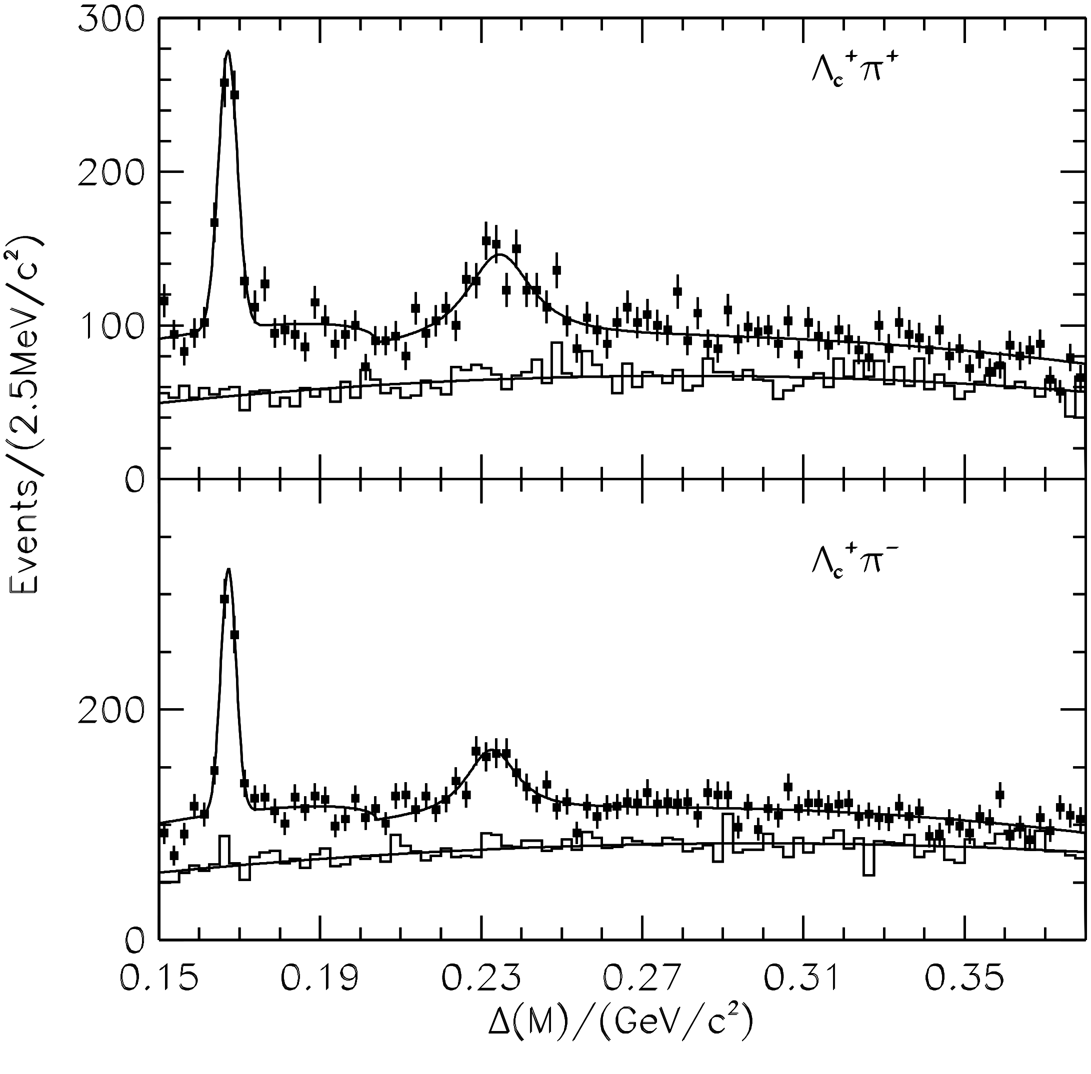

FIG. 1. Mass difference spectra for (a) $\Lambda_c^+\pi^+$ candidates, and (b) $\Lambda_c^+\pi^-$ candidates. The histogram shows the spectra for normalized sidebands of the Λ_c^+. The fits are described in the text.

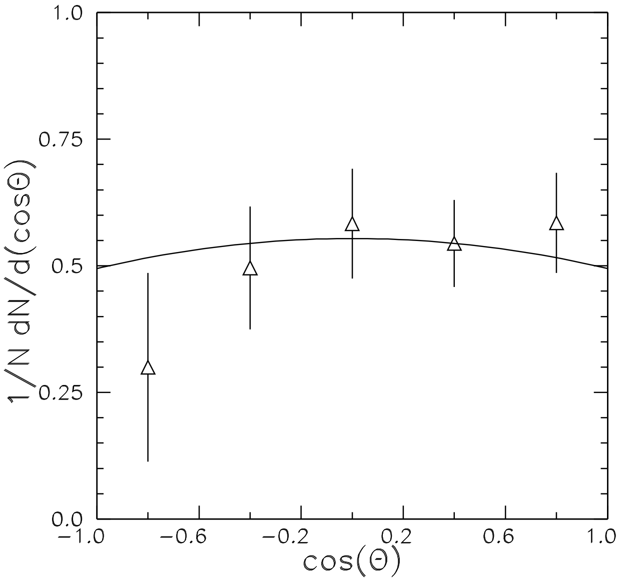

FIG. 2. The decay angle Θ_{dec} distribution for the observed Σ_c^* candidates.

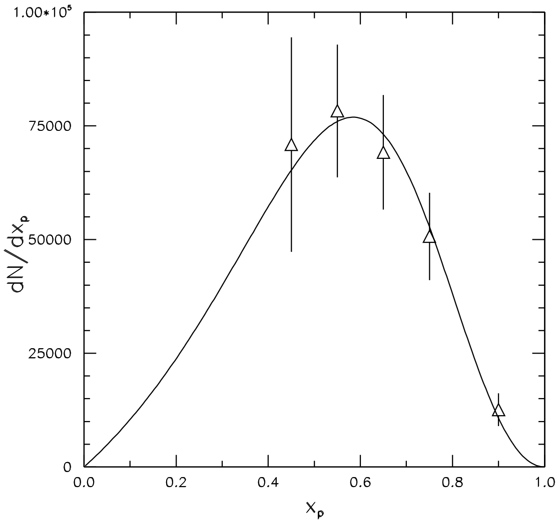

FIG. 3. The efficiency corrected spectrum of scaled momentum, x_p, for the observed Σ_c^* candidates. The fit is to the Peterson function.