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Σ_c^{++} and Σ_c^0 Production from e^+e^- Annihilation in the Υ Energy Region

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We have observed Σ_c^{++} and Σ_c^0 baryons in nonresonant e^+e^- interactions through their decays to $\Lambda_c^+\pi^\pm$ using the CLEO detector. The mass difference $M(\Sigma_c^{++})-M(\Lambda_c^+)$ is measured to be $167.8\pm0.4\pm0.3$ MeV; for $M(\Sigma_c^0)-M(\Lambda_c^+)$ we find $167.9\pm0.5\pm0.3$ MeV. Σ_c decay accounts for $(18\pm3\pm5)\%$ of Λ_c^+ production.

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In this paper we report the observation of two of the three isospin states of the Σ_c baryon, the Σ_c^{++} (uuc) and the Σ_c^0 (ddc). Measurement of the mass difference between the Σ_c and Λ_c^+ baryon-spectroscopy models. The mass difference $[\Delta_\Sigma \equiv M(\Sigma_c^0)-M(\Sigma_c^{++})]$ between Σ_c^0 and Σ_c^{++} test models of mass differences between hadrons that are members of the same isospin multiplet. The only two previous measurements of Δ_Σ are in disagreement.[1,2] The data sample used in this study was collected, with the CLEO detector at the Cornell Electron Storage Ring (CESR), in two sets. The older set comprises 27 pb^{-1} at the $\Upsilon(3S)$, 36 pb^{-1} just below the $B\bar{B}$ threshold, and 78 pb^{-1} at the $\Upsilon(4S)$. The data acquired with the improved CLEO tracking system consist of 101 pb^{-1} at energies just below the $B\bar{B}$ threshold, 212 pb^{-1} at the $\Upsilon(4S)$ resonance, and 117 pb^{-1} at the $\Upsilon(5S)$ resonance.

The CLEO detector used in the first data set, and our selection criteria for hadronic events, have been described in detail elsewhere.[3] Charged-particle tracking is performed inside a superconducting solenoid with a 1.0-m radius which produces a 1.0-T magnetic field. Prior to the improvement, tracking was done with 27 cylindrical layers of drift-chamber cells. The 17-layer central drift chamber provided an rms resolution in ionization of 11%; and the momentum resolution was given by $(\delta p/p)^2=(0.7\%p)^2+(0.6\%)^2$ (where p is in GeV/c). For the second set of data a new 64-layer drift-chamber system was installed,[4] resulting in a momentum resolution of $(\delta p/p)^2=(0.23\%p)^2+(0.7\%)^2$. The 51-layer drift chamber provides an rms resolution in track ionization of 6.5%.

We search for Σ_c baryons by forming the mass-difference spectra $M(\Lambda_c^+\pi^\pm)-M(\Lambda_c^+)$. Throughout this paper both baryon and antibaryon states are used. The Λ_c^+ decay modes used include $\Lambda_c^+\to pK^-\pi^+$, $\Lambda_c^+\to pK_S^0$, and $\Lambda_c^+\to\Lambda\pi^+\pi^+\pi^-$. In order to improve signal to background we exclude from our sample Σ_c

candidates with x_p less than 0.5 where $x_p = p/p_{\max}$. This requirement also has the effect of eliminating Σ_c baryons from B-meson decay.

To reduce the background due to fake Λ_c^+ candidates, particle identification was used for all three decay modes of the Λ_c^+. A combined weight of each (hadronic) particle type (π,K,p) is formed using information from the three devices, normalized such that the sum of the three weights is 1. If no information is available for a track, a weight of $\frac{1}{3}$ is assigned for each particle type. For the $\Lambda_c^+ \to pK^-\pi^+$ mode we require the proton weight be greater than 0.7 and the kaon weight be greater than 0.25. For both $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$ and $\Lambda_c^+ \to pK_S^0$, we demand that the proton weight be greater than 0.25. For the modes involving a K_S^0 (or a Λ) we use oppositely charged tracks which intersect more than 0.5 cm away from the primary event vertex. We require the net momentum of the two tracks to extrapolate back to the primary event vertex. In addition, we require that the invariant mass be either within ± 20 MeV of the nominal K_S^0 mass or within ± 5 MeV of the Λ mass. For the $\Lambda_c^+ \to pK^-\pi^+$ mode, we reduce combinatoric background by requiring the pion momentum to be greater than 200 MeV/c.

Figure 1 shows the combined mass distribution from all three decay modes of the Λ_c^+, for $x_p > 0.5$. The central value of the Λ_c^+ mass, given by a fit to the distribution, is 2288 ± 4 MeV.[5] Our sample contains 1325 ± 95 Λ_c^+ events[6] with $x_p > 0.5$. Λ_c^+ candidates with masses within ± 18 MeV of the central value are accepted for further analysis. Each Λ_c^+ candidate is combined with an unused positively charged track (assumed to be a π^+) to form a Σ_c^{++} candidate and a negatively charged track (assumed to be π^-) to form a Σ_c^0 candidate.

Figure 2 displays the mass-difference distributions $\Delta_m^{++} \equiv M(\Sigma_c^{++}) - M(\Lambda_c^+)$ and $\Delta_m^0 \equiv M(\Sigma_c^0) - M(\Lambda_c^+)$. The clear enhancements in each distribution are fit with a Gaussian of fixed width above a background function of the form $F(m) = A + B(m^2 - m_\pi^2)^{1/2} + Cm$, where A, B, and C are constants. The FWHM of the Gaussian was fixed at 4 MeV as determined by Monte Carlo studies. The Δ_m^{++} distribution contains 54 ± 11 events centered at $167.8 \pm 0.4 \pm 0.3$ MeV. The Δ_m^0 distribution contains 48 ± 12 events centered at $167.9 \pm 0.5 \pm 0.3$ MeV.[7] The first error is statistical and the second is systematic. We have fit the Δ_m^{++} and Δ_m^0 spectra with many background shapes, including one determined using sidebands of the Λ_c^+, and find that the central value of the peak varies by less than 0.1 MeV. Systematic errors are mainly due to uncertainties in the magnetic field normalization and in the energy-loss correction that is applied to charged particles traversing the beam pipe and the inner drift chambers. To estimate the systematic error we use our measurement of the mass difference $M(D^{*+}) - M(D^0)$,[8] where the momentum spectrum of the slow pions is similar and the mass-difference technique is identical. The Δ_m distributions are insensitive to shifts in the Λ_c^+ mass scale, changing the Λ_c^+ mass by 3.0 MeV shifts Δ_m by 0.03 MeV.

All the measured values of Δ_m^0, Δ_m^{++}, and Δ_Σ are given in Table I. We find Δ_Σ to be $+0.1 \pm 0.6 \pm 0.1$ MeV. This value is consistent with the result of -1.2

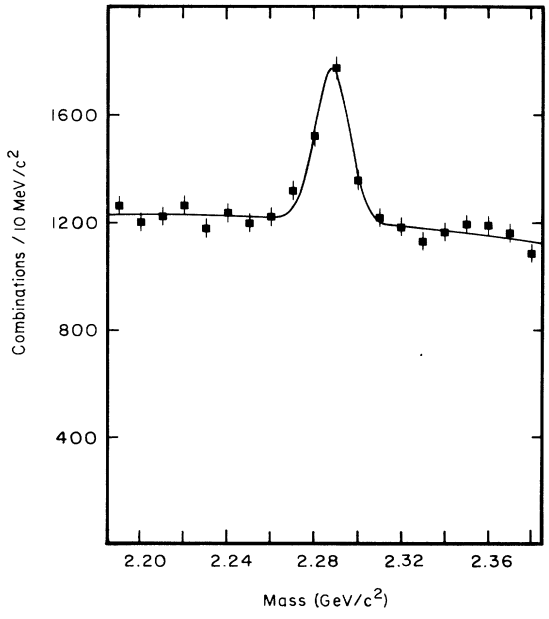

FIG. 1. The Λ_c^+ mass spectrum from the summed modes $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$, $\Lambda_c^+ \to pK^-\pi^+$, and $\Lambda_c^+ \to pK_S^0$.

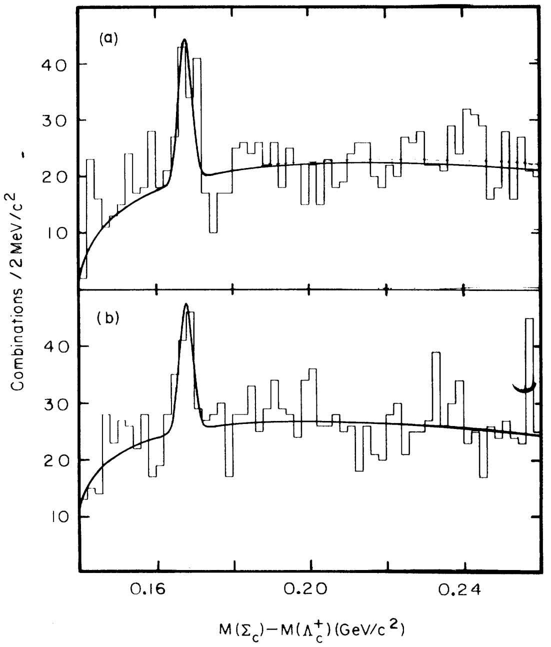

FIG. 2. $M(\Sigma_c) - M(\Lambda_c^+)$ mass-difference spectra. Solid lines are fits to a Gaussian plus a background shape (described in text). (a) $M(\Lambda_c^+\pi^+) - M(\Lambda_c^+)$, (b) $M(\Lambda_c^+\pi^-) - M(\Lambda_c^+)$.

TABLE I. Measurements of Δ_m^0, Δ_m^{++}, and Δ_Σ.

Experiment	Δ_m^0 (MeV)	Δ_m^{++} (MeV)	Δ_Σ (MeV)
E-400[a]	$178.2 \pm 0.4 \pm 2.0$	$167.4 \pm 0.5 \pm 2.0$	$+10.8 \pm 2.9$
ARGUS[b]	167.0 ± 0.5	168.2 ± 0.5	$-1.2 \pm 0.7 \pm 0.3$
CLEO	$167.9 \pm 0.5 \pm 0.3$	$167.8 \pm 0.4 \pm 0.3$	$+0.1 \pm 0.6 \pm 0.1$

[a] Reference 1.

[b] Reference 2.

$\pm 0.7 \pm 0.3$ MeV reported by Albrecht *et al.*[2] However, it disagrees with the result of $+10.8 \pm 2.9$ MeV published by Diesberg *et al.*[1] There are a number of theoretical predictions for Δ_Σ (Ref. 9); the values range from $+18.0$ to -6.5 MeV. The isospin mass splitting arises from a combination of the intrinsic quark mass difference ($m_d > m_u$) and electromagnetic interactions between the quarks, which consists of electrostatic Coulomb interactions and spin-spin interactions (hyperfine-interaction term). Our measurement indicates that the quark mass difference and the electromagnetic interactions give rise to (roughly) equal but opposite terms, the net result being an isospin mass splitting that is near zero. All previously measured baryons follow the empirical rule that the more negatively charges state is the more massive (i.e., the intrinsic quark mass difference is dominant).

To calculate the fraction of Λ_c^+ produced from Σ_c decays with $x_p > 0.5$, we multiply the efficiency corrected observed ratio $(\Sigma_c^0 + \Sigma_c^{++})/\Lambda_c^+$ by a factor of 1.5 to account for the unobserved Σ_c^+ (*udc*). We find that $(18 \pm 3 \pm 5)\%$ of Λ_c^+ arise from Σ_c. Our systematic error is dominated by the dependence of the number of events in the fit on the background shape. The ARGUS Collaboration found $(36 \pm 12 \pm 11)\%$.[2]

We have fit the x_p distribution with the Peterson function[10] with one parameter ϵ (for $x_p < 0.5$ only continuum data were used). We find $\epsilon = 0.27 \pm 0.10$, which is consistent with previous measurements for charmed baryons for Λ_c^+ ($\epsilon = 0.24 \pm 0.04$) and the Σ_c ($\epsilon = 0.29 \pm 0.06$).[2]

In summary, we have observed Σ_c^{++} and Σ_c^0 baryons in nonresonant e^+e^- interactions through their decays to $\Lambda_c^+\pi^\pm$. Our measurements determine the $M(\Sigma_c^0) - M(\Sigma_c^{++})$ mass difference to be $+0.1 \pm 0.6 \pm 0.1$ MeV. We find that $(18 \pm 3 \pm 5)\%$ of our Λ_c^+ signal is from the decay of Σ_c.

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[5] The error on the Λ_c^+ mass is dominated by systematics introduced by adding the data samples together. A Λ_c^+ mass value will be published later.

[6] The number of Λ_c^+ candidates from each of the three decay channels $\Lambda_c^+ \to pK^-\pi^+$, $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$, and $\Lambda_c^+ \to pK_S^0$ are 777 ± 68, 288 ± 45, and 270 ± 43, respectively.

[7] The E-691 Collaboration has reported a preliminary measurement of the mass difference $M(\Sigma_c^0) - M(\Lambda_c^+)$ of $168.0 \pm 1.0 \pm 0.3$ MeV; H. Schröder, in Proceedings of the Twenty-Fourth International Conference on High Energy Physics, Münich, Germany, 1988 (to be published).

[8] We measure the mass difference using the D^0 decay modes $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^-\pi^+$, and $D^0 \to \pi^+\pi^-K_S^0$. The measured values of the mass difference are 145.45 ± 0.02, 145.45 ± 0.03, and 145.43 ± 0.05 MeV for the three modes, respectively (errors are statistical only). These are in excellent agreement with the Particle Data Group value, which is 145.45 ± 0.07 MeV. We rely on Monte Carlo simulation to scale this error to our measurement of $M(\Sigma_c) - M(\Lambda_c^+)$.

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