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FIRST OBSERVATION OF THE Σ_c^{*+} CHARMED BARYON, AND NEW MEASUREMENTS OF THE Σ_c^0, Σ_c^+, Σ_c^{++}, AND Ω_c^0 CHARMED BARYONS

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Using $\sim$13.7 fb^{-1} of $e^+ e^-$ collision data recorded at near the $\Upsilon(4S)$ resonance by the CLEO II and CLEO II.V detector configurations on the Cornell Electron Storage Ring, we present the world's most precise measurements of the Σ_c^0, Σ_c^+, and Σ_c^{++} charmed-baryon masses as well as the first measurements of the intrinsic widths of the Σ_c^0 and Σ_c^{++} baryons. We also report on the first observation and mass measurement of the Σ_c^{*+} charmed baryon, $M(\Sigma_c^{*+}) - M(\Lambda_c^+) = (231.0 \pm 1.1[\text{stat}] \pm 2.0[\text{syst}])$ MeV$/c^2$, and the first CLEO observation of the Ω_c^0 baryon, for which we measure a mass $M(\Omega_c^0) = (2694.6 \pm 2.6[\text{stat}] \pm 2.4[\text{syst}])$ MeV$/c^2$ from a sample of $(40.4 \pm 9.0[\text{stat}])$ candidate events. All new results are preliminary.

1 Introduction

The charmed baryons consist of a c quark and a light diquark with a specific J$^{\text{P}}$ spin-parity configuration and can be organized in terms of isospin and strangeness using the theory of SU(4) multiplets. Several new observations and improved measurements in charmed-baryon spectroscopy have been made in the past decade[a]. We report here on new CLEO measurements of the Σ_c and Ω_c^0 states [1,2].

2 The Experiment

The results described herein come from studies of $e^+ e^-$ collisions conducted at the Cornell Electron Storage Ring (CESR) operating near the $\sim$10.58 GeV$/c^2$ $\Upsilon(4S)$ bottomonium resonance. The 4π general purpose CLEO II detector configuration [3], comprising a cylindrical drift chamber system for charged-track detection inside a 1.4 T solenoidal magnetic field and a CsI electromagnetic calorimeter for π^0 detection, was employed to take a data sample with time-integrated luminosity $\int \mathcal{L} dt \simeq 4.7$ fb^{-1}. An additional 9.0 fb^{-1} of data were taken with the CLEO II.V detector configuration [4], which had improved charged-track measurement capabilities.

For the searches and measurements described in this paper, the analysis approaches have sought to optimize signal efficiency and background suppression. Identification of p, K^+, and π^+ candidates[b] was achieved through the use of specific ionization dE/dx in the drift chamber and, when available, time-of-flight information. Hyperons, in the modes $\Xi^- \to \Lambda\,\pi^-$, $\Xi^0 \to \Lambda\,\pi^0$, $\Omega^- \to \Lambda\,K^-$, $\Sigma^+ \to p\,\pi^0$, and $\Lambda \to p\,\pi^-$, were reconstructed by detecting their decay points separated from the primary event vertex.

Charmed baryons at CESR are either produced from the secondary decays of B mesons or directly from $e^+ e^-$ annihilation to $c\bar{c}$ jets. Combinatorial backgrounds, which are highest for low-momentum charmed baryons, are reduced by requiring candidates to exceed an optimum scaled momentum x_p, defined as $x_p \equiv |\vec{p}|/p_{\max}$, where $\vec{p}$ is the momentum of the charmed baryon candidate, $p_{\max} \equiv \sqrt{E_{\text{beam}}^2 - M^2}$, E_{beam} is the beam energy, and M is the reconstructed candidate's mass. We use decay-mode dependent scaled-momentum criteria[c] of $x_p > 0.5$ or $x_p > 0.6$, based on the optimization results.

[a] Note, however, that none of the J$^{\text{P}}$ quantum numbers of the charmed baryons has yet been measured.

[b] Charge conjugate modes are implicit throughout.

[c] Charmed baryons with threshold-produced B-meson parents are kinematically limited to $x_p < 0.4$.

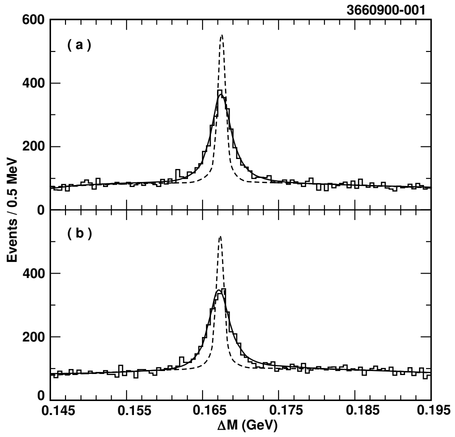

Figure 1. The $\Delta M \equiv M(\Lambda_c^+ \pi^\pm) - M(\Lambda_c^+)$ mass difference, where in (a) the Λ_c and π candidates have like charges (Σ_c^{++} candidates) and in (b) they have opposite charges (Σ_c^0 candidates). The solid curve shows the results of the fit described in the text. The dashed curve represents the resolution function of the detector response.

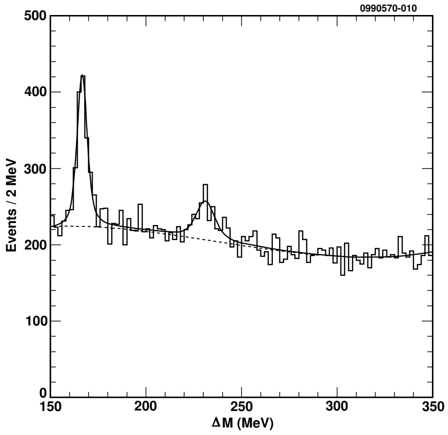

Figure 2. The $\Delta M \equiv M(\Lambda_c^+ \pi^0) - M(\Lambda_c^+)$ mass-difference distribution. The solid line represents a fit to a third-order polynomial background shape and two p-wave Breit-Wigner functions smeared by Gaussian resolution functions for the two signal shapes. The dashed curve indicates the background function.

3 The Σ_c and Σ_c^* Baryon Isotriplets

The Σ_c baryons [5] consist of one charm and two light (u or d) valence quarks in an $I = 1$ isospin configuration. The Σ_c states in this study decay strongly into final states with a Λ_c^+ baryon and either a π^+ or π^0 transition meson. We reconstruct ~58 000 Λ_c^+ signal candidates using 15 different decay modes [6].

3.1 Σ_c Final States involving $\Lambda_c^+ \pi^\pm$

Candidates in the Λ_c^+ sample described in Sec. 3 were combined with $\pi^\pm$ charged-track candidates and the mass difference, $\Delta M \equiv M(\Lambda_c^+ \pi^\pm) - M(\Lambda_c^+)$, was calculated for those combinations satisfying an $x_p > 0.5$ criterion. Each of the resulting mass-difference distributions, depicted in Fig. 1, indicated an unambiguous signal of ~2000 Σ_c^{++} and Σ_c^0 candidates, respectively. The two distributions were fit to a sum of a polynomial background function with threshold suppression and a p-wave Breit-Wigner line shape convolved with a double-Gaussian detector resolution function.

The fitted masses and widths are summarized in Tab. 1. Scaling from the strange-baryon widths, Rosner [9] has predicted $\Gamma(\Sigma_c) \simeq 1.32$ MeV/c^2, somewhat narrower than our measured values. Other authors [10] have employed measurements of the Σ_c^* widths to derive $\Gamma(\Sigma_c)$ predictions consistent with our values listed in Tab. 1.

3.2 $\Sigma_c^{(*)}$ Final States involving $\Lambda_c^+ \pi^0$

In a manner similar to that described in Sec. 3.1 but with an $x_p > 0.6$ requirement [1], Λ_c^+ candidates were combined with transition π^0 candidates, which were required to have momenta greater than 150 MeV/c and masses consistent with and kinematically fit to the known π^0 mass [11], to form the mass difference $\Delta M \equiv M(\Lambda_c^+ \pi^0) - M(\Lambda_c^+)$ shown in Fig. 2. Note the higher background level.

The lower-mass peak[d] in Fig. 2, containing (661^{+63}_{-60}[stat]) events, is due to the Σ_c^+ baryon. The second peak in Fig. 2, with (327^{+78}_{-73}[stat]) signal candidates, we as-

[d] Note that, for the purpose of yield determination, the fit function described in Fig. 2 was replaced with a third-order Chebyshev polynomial background function and two Gaussian signal line shapes.

Table 1. A summary of the CLEO mass and width measurements, in MeV/c^2, of the $J^P = \frac{1}{2}^+$ and $J^P = \frac{3}{2}^+$ Σ_c charmed baryons. The first uncertainties are statistical and the second are systematic. Values marked with a † were reported in Ref. [7]. We note that the isospin mass splittings are consistent with theoretical expectation [8].

J^P	Observable	$\Sigma_c^{(*)0}$	$\Sigma_c^{(*)+}$	$\Sigma_c^{(*)++}$
$\frac{1}{2}^+$	$M(\Sigma_c) - M(\Lambda_c^+)$	$167.2 \pm 0.1 \pm 0.2$	$166.4 \pm 0.2 \pm 0.3$	$167.4 \pm 0.1 \pm 0.2$
	$\Gamma(\Sigma_c)$	$2.4 \pm 0.2 \pm 0.4$	< 4.6 (90% CL)	$2.5 \pm 0.2 \pm 0.4$
$\frac{3}{2}^+$	$M(\Sigma_c^*) - M(\Lambda_c^+)$	$232.6 \pm 1.0 \pm 0.8^\dagger$	$231.0 \pm 1.1 \pm 2.0$	$234.5 \pm 1.1 \pm 0.8^\dagger$
	$\Gamma(\Sigma_c^*)$	$13.0^{+3.7}_{-3.0} \pm 4.0^\dagger$	< 17 (90% CL)	$17.9^{+3.8}_{-3.2} \pm 4.0^\dagger$

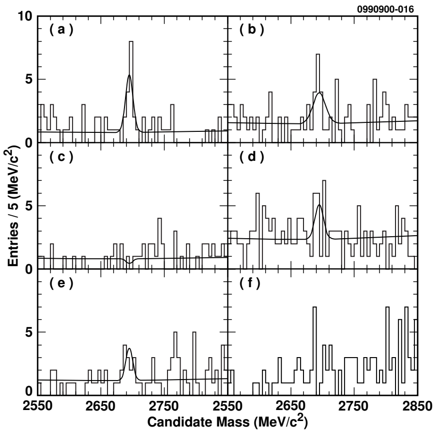

Figure 3. The invariant mass distribution and simultaneous fit to the five Ω_c^0 search modes: (a) $\Omega^- \pi^+$, (b) $\Omega^- \pi^+ \pi^0$, (c) $\Omega^- \pi^+ \pi^+ \pi^-$, (d) $\Xi^0 K^- \pi^+$, and (e) $\Xi^- K^- \pi^+ \pi^+$. The final state (f) $\Sigma^+ K^- K^- \pi^+$ was not included in the fit. The signal region was fitted with a fixed-width Gaussian while the background was fitted to a second-order polynomial.

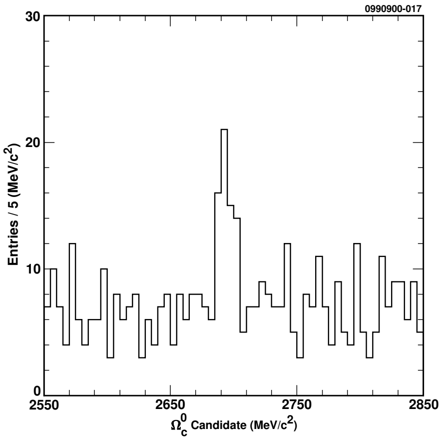

Figure 4. The invariant mass distribution for the sum of the $\Omega^- \pi^+$, $\Omega^- \pi^+ \pi^0$, $\Omega^- \pi^+ \pi^+ \pi^-$, $\Xi^0 K^- \pi^+$, and $\Xi^- K^- \pi^+ \pi^+$ search modes.

cribe to the first observation of Σ_c^{*+} baryons. The fitted masses and limits on the intrinsic widths of the Σ_c^+ and Σ_c^{*+} states are listed in Tab. 1.

4 The Ω_c^0 Baryon Isosinglet

The Ω_c^0 baryon is a $J^P = \frac{1}{2}^+$ ground state with valence quarks $(c\{ss\})$, where $\{ss\}$ denotes a symmetry in the wave function under the exchange of the light-quark spins. Several experimental groups have reported the observation of an Ω_c^0 state; the mutual consistency of the claimed masses, however, is marginal [2,11].

4.1 First Ω_c^0 Observation by CLEO

Based on patterns observed in other charmed baryon decays and considerations of reconstruction efficiency and combinatorial background, we searched [2] for Ω_c^0 candidates in the five weak decay modes $\Omega^- \pi^+$, $\Omega^- \pi^+ \pi^0$, $\Omega^- \pi^+ \pi^+ \pi^-$, $\Xi^0 K^- \pi^+$, and $\Xi^- K^- \pi^+ \pi^+$. We separately investigated a sixth channel, $\Sigma^+ K^- K^- \pi^+$, because E687 [2,11] showed a significant signal in this mode. The invariant mass distributions of the six modes are shown in Fig. 3, the sum of the five search modes is depicted in Fig. 4, and the fitted event yields are listed in Tab. 2. We observe $(40.4 \pm 9.0[\text{stat}])$ Ω_c^0 candidates.

Table 2. The Ω_c^0 charmed baryon search results in the six decay modes. The fitted yields were computed with a mode-dependent x_p criterion, whereas the relative branching fraction ($\mathcal{B}$) and cross-section-branching-fraction product ($\sigma \cdot \mathcal{B}$) were determined with a uniform $x_p > 0.5$ requirement. The first uncertainties are statistical and the second are systematic.

Ω_c^0 Search Channel	Fitted Yield	Relative $\mathcal{B}$	$\sigma \cdot \mathcal{B}$ [fb]
$\Omega^- \pi^+$	13.3 ± 4.1	1.0	$11.3 \pm 3.9 \pm 2.3$
$\Omega^- \pi^+ \pi^0$	11.8 ± 4.9	$4.2 \pm 2.2 \pm 1.2$	$47.6 \pm 18.0 \pm 2.8$
$\Xi^0 K^- \pi^+$	9.2 ± 4.9	$4.0 \pm 2.5 \pm 0.6$	$45.1 \pm 23.2 \pm 4.1$
$\Xi^- K^- \pi^+ \pi^+$	7.0 ± 3.7	$1.6 \pm 1.1 \pm 0.4$	$18.2 \pm 10.6 \pm 3.8$
$\Omega^- \pi^+ \pi^+ \pi^-$	-0.9 ± 1.4	< 0.56 (90% CL)	< 5.1 (90% CL)
Above 5 modes combined	40.4 ± 9.0	–	–
$\Sigma^+ K^- K^- \pi^+$	2.8 ± 4.1	< 4.8 (90% CL)	< 53.8 (90% CL)

4.2 Measurement of the Ω_c^0 Mass

The mass of our Ω_c^0 candidates we measure by performing an unbinned maximum-likelihood fit using the sum of a single Gaussian signal and a second-order polynomial background. We find the Ω_c^0 mass to be $M(\Omega_c^0) = (2694.6 \pm 2.6[\text{stat}] \pm 2.4[\text{syst}])$ MeV/c^2, where the systematic uncertainty is dominated by our sensitivity to the fitting method employed.

5 Conclusion

The CLEO collaboration has made new measurements of the Σ_c^0, Σ_c^+, and Σ_c^{++} baryon masses as well as preliminary measurements of the Σ_c^0 and Σ_c^{++} intrinsic widths. We report the first observation of the Σ_c^{*+} baryon and determine its mass difference to be $M(\Sigma_c^{*+}) - M(\Lambda_c^+) = (231.0 \pm 1.1[\text{stat}] \pm 2.0[\text{syst}])$ MeV/c^2. We also observe, for the first time, a significant signal for the Ω_c^0 baryon and measure its mass to be $M(\Omega_c^0) = (2694.6 \pm 2.6[\text{stat}] \pm 2.4[\text{syst}])$ MeV/c^2.

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