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Observation of the Ω_c^0 Charmed Baryon at CLEO

CLEO Collaboration

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Abstract

The CLEO detector at the CESR collider has used 13.7 fb^{-1} to search for the production of Ω_c^0 (css-ground state) in e^+e^- collisions at $\sqrt{s} \simeq 10.6$ GeV. The modes used to study the Ω_c^0 are $\Omega^-\pi^+$, $\Omega^-\pi^+\pi^0$, $\Xi^-K^-\pi^+\pi^+$, $\Xi^0K^-\pi^+$, and $\Omega^-\pi^+\pi^+\pi^-$. We observe $40.4 \pm 9.0(stat)$ combined events at a mass of $2694.6 \pm 2.6(stat) \pm 2.4(syst)$ MeV/c^2. We have also measured the $\sigma \cdot \mathcal{B}r$ of the above modes for scaled momentum $x_p > 0.5$ to be $11.3 \pm 3.9 \pm 2.3$ fb, $47.6 \pm 18.0 \pm 2.8$ fb, $45.1 \pm 23.2 \pm 4.1$ fb, $18.2 \pm 10.6 \pm 3.8$ fb, and < 5.1 fb @ 90 % CL, respectively. The results described here are all preliminary.

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Various experimental groups have published results for Ω_c^0 in many decay modes, but the results are ambiguous. The WA62 experiment [1], claimed the first evidence of Ω_c^0 in the $\Xi^- K^- \pi^+ \pi^+$ decay mode with a mass of 2746.0 ± 20.0 MeV/c^2. The ARGUS Collaboration [2], published a Ω_c^0 signal in the $\Xi^- K^- \pi^+ \pi^+$ mode, with a mass of $2719.0 \pm 7.0 \pm 2.5$ MeV/c^2 and $\sigma \cdot \mathcal{B}r$ of $2.41 \pm 0.90 \pm 0.30$ pb using 0.380 fb^{-1} of integrated luminosity. The result was contradicted by CLEO (using $1.8 fb^{-1}$) in an unpublished conference paper [3]. Later, E687 [4] published Ω_c^0 with a mass of $2705.9 \pm 3.3 \pm 2.3$ MeV/c^2 in the $\Omega^- \pi^+$ mode and a significant signal at $2699.9 \pm 1.5 \pm 2.5$ MeV/c^2 in the $\Sigma^+ K^- K^- \pi^+$ decay mode. In 1995, the WA89 Collaboration [5] reported 200 Ω_c^0 events in seven decay modes, with an average mass of $2707.0 \pm 1.0(stat)$ MeV/c^2; WA89 never published the Ω_c^0 mass.

The Ω_c^0 ($c\{ss\}$) is a $J^p = \frac{1}{2}^+$ ground state baryon, where $\{ss\}$ denotes the symmetric nature of its wave function with respect to the interchange of light-quark spins. Different theoretical models [6–9] predict the Ω_c^0 mass in a range from 2664 - 2786 MeV/c^2.

The data used in this analysis were collected with CLEO II [10] and the upgraded CLEO II.V [11] detector operating at the Cornell Electron Storage Ring (CESR), and correspond to an integrated luminosity of 13.7 fb^{-1} from the $\Upsilon(4S)$ resonance and the continuum region at energies just below. We searched for the Ω_c^0 in the five decay modes $\Omega^-\pi^+$, $\Omega^-\pi^+\pi^0$, $\Omega^-\pi^+\pi^+\pi^-$, $\Xi^- K^- \pi^+ \pi^+$, and $\Xi^0 K^- \pi^+$. These five modes were chosen as most likely to show an Ω_c^0 signal, based upon the pattern of other charmed baryon decays, considerations of detector efficiency, and the size of the combinatorial backgrounds. A sixth channel, $\Sigma^+ K^- K^- \pi^+$, was also investigated because E687 [4] showed a significant signal in this decay mode.

Charmed baryons at CESR are either produced from the secondary decays of B mesons or directly from e^+e^- annihilations to $c\bar{c}$ jets. We introduce x_p as the scaled momentum of a Ω_c^0 candidate, where $x_p = p/p_{\max}$, and $p_{\max} = \sqrt{E_\mathrm{b}^2 - m^2}$ with E_b equal to the beam energy and m the mass of the Ω_c^0 candidate. Our search is limited to $x_p > 0.5$ or $x_p > 0.6$, depending on decay mode, to avoid the combinatorial backgound that dominates at low x_p. Charmed baryons from B meson decays are kinematically limited to $x_p < 0.5$, so our search is limited to the Ω_c^0 baryons produced by e^+e^- continuum. We implemented $p/k/\pi$ identification by means of a joint probability for the $p/k/\pi$ hypotheses by combining the specific ionization (dE/dx) in the wire drift chamber and the time-of-flight in the scintillation counters. A charged track is defined to be consistent with a particular particle hypothesis if the corresponding probability is greater than 0.1%.

We begin by reconstructing $\Lambda \to p\pi^-$, $\Xi^0 \to \Lambda\pi^0$, $\Xi^- \to \Lambda\pi^-$, $\Omega^- \to \Lambda K^-$, and $\Sigma^+ \to p\pi^0$. The analysis procedure for reconstructing these particles closely follows that presented earlier, [12–14]. The hyperons were required to have vertices well separated from the beamspot, with the flight distance of the Λ greater than that of the Ξ^0, Ξ^-, or the Ω^-. We then combine these hyperons with tracks from the primary event vertex to reconstruct Ω_c^0 candidates. Below we present Ω_c^0 reconstruction in the six decay modes described above.

In all modes, the signal area above the background is obtained by fitting with a sum of a Gaussian signal function (with widths fixed at signal Monte Carlo predicted values) and a second order polynomial background. Charge conjugation is implied throughout the analysis. In the $\Omega^-\pi^+$ mode, we required x_p to be greater than 0.5 and the π^+ momentum to be greater than 0.5 GeV/c. Figure 1(a) shows the invariant mass distribution; a fit to this distribution yields a signal of 13.3 ± 4.1 events. In the $\Omega^-\pi^+\pi^0$ mode, we assume the photons used for reconstructing $\pi^0 \rightarrow \gamma\gamma$ come from the event vertex. Only $\gamma\gamma$ combinations having invariant mass within 12.5 MeV/c^2 (2.5σ) of the nominal mass are used as π^0 candidates. Figure 1(b) shows the invariant mass distribution. Here we required x_p to be greater than 0.5 and the π^+ and π^0 momenta to be greater than 0.3 and 0.5 MeV/c, respectively. The fit gives a yield of 11.8 ± 4.9 events. Figure 1(c) shows the $\Omega^-\pi^+\pi^-\pi^+$ invariant mass distribution for x_p greater than 0.5. All the charged pions are required to have momenta greater than 0.2 MeV/c. The fit yields a signal of -0.9 ± 1.4 events. In the $\Xi^0 K^-\pi^+$ mode, we considered combinations with x_p greater than 0.6, since combinatorial background is higher in this mode. Figure 1(d) shows the invariant mass distribution with a fit yielding a signal of 9.2 ± 4.9 events. In the $\Xi^- K^-\pi^+\pi^+$ mode, we required x_p to be greater than 0.6 and pion and kaon momenta to be greater than 0.2 and 0.3 GeV/c, respectively. A fit to the $\Xi^- K^-\pi^+\pi^+$ distribution yields a signal of 7.0 ± 3.7 events. Finally, in the $\Sigma^+ K^- K^-\pi^+$ mode, we required x_p to be greater than 0.5 and required charged track momenta to be greater than 0.3 GeV/c. We find the yield to be < 9.5 @ 90 % C.L. Figure 1(f) shows the invariant mass distribution for $\Sigma^+ K^- K^-\pi^+$ mode. The efficiency for $\Sigma^+ K^- K^-\pi^+$ reconstruction is $\sim 15\%$ of that for the $\Omega^-\pi^+$ mode, our highest-yield. We have not included the $\Sigma^+ K^- K^-\pi^+$ mode in the mass measurement. The total yield in five modes combined, excluding $\Sigma^+ K^- K^-\pi^+$, sums to 40.4 ± 9.0, as shown in Table I. The mass distribution for the five modes combined is shown in Figure 2.

To determine the mass, we have performed an unbinned maximum-likelihood fit using the sum of a single Gaussian and a second order polynomial background. There are two inputs to the fit, the invariant mass M_i and the corresponding mass resolution σ_i of each mass candidate from 2.55 to 2.85 GeV/c^2. The likelihood function to maximize is the product of probability density functions (PDFs) for all the candidate events, and has the following form:

$$\mathcal{L}(M(\Omega_c^0), f_s, a_1, a_2) = \prod_i \left[f_s G(M_i - M(\Omega_c^0)|S\sigma_i) + (1 - f_s)\frac{P(M_i)}{\int_{2.55}^{2.85} P(M_i) dM_i} \right], \tag{1}$$

where $\mathrm{G}(y|\sigma) = (1/\sqrt{2\pi\sigma})\exp(-y^2/2\sigma^2)$ and $\mathrm{P}(y) = 1.0 + a_1(y - 2.7) + a_2(y - 2.7)^2$. $M(\Omega_c^0)$ is the fitted Ω_c^0 mass, S is the global scale factor multiplying σ_i, and f_s is the fraction of signal events under $\mathrm{G}(y|\sigma)$. The fitted mass for the above PDF is 2694.9 ± 0.1 MeV/c^2 for the Monte Carlo and 2694.6 ± 2.6 MeV/c^2 for the data. The Ω_c^0 Monte Carlo was generated at a mass of 2695 MeV/c^2. The fitted scale factor S is 1.72 ± 0.42 for the data and 1.16 ± 0.02 for the simulated events.

We have also checked for goodness-of-fit by performing ten different "toy" Monte Carlo experiments. In each experiment we took sideband events from the wrong sign combinations in the data and signal events from the Monte Carlo. The $-2\ln\mathcal{L}$ of the fit ranged from 518 to 576; the $-2\ln\mathcal{L}$ of the fit to the data is 564. Twenty percent of the experiments have greater $-2\ln\mathcal{L}$ than the data.

We also studied the momentum spectrum of Ω_c^0, finding consistency with that for other charmed baryons [16].

The mass calibration of our detector was checked by the Ξ_c^0, which has similar spectator decay modes with the same number of charged tracks in the final state as the Ω_c^0. The mass of the reconstructed Ξ_c^0 from the π^0 mode is lower than from the all-charged modes. The asymmetric π^0 mass peak, due to the mismeasured photons at low energies, accounts for this low mass. The mass difference for Ξ_c^0 with and without π^0 involved in the final state is 2.0 MeV/c^2. The Λ_c^+ mass, studied in different decay modes, shows a spread of 1.3 MeV/c^2. Adding these in quadrature, we assign a total systematic error of 2.4 MeV/c^2 to our Ω_c^0 mass measurement.

We have also measured $\sigma \cdot \mathcal{B}r$ for $\Omega^-\pi^+$, $\Omega^-\pi^+\pi^0$, $\Xi^-K^-\pi^+\pi^+$, $\Xi^0K^-\pi^+$,$\Omega^-\pi^+\pi^+\pi^-$and $\Sigma^+K^-K^-\pi^+$ to be 11.3$\pm$3.9$\pm$2.3 fb, 47.6$\pm$18.0$\pm$2.8 fb, 45.1$\pm$23.2$\pm$4.1 fb, 18.2$\pm$10.6$\pm$3.8 fb, $<$ 5.1 fb @ 90 % CL, and $<$ 53.8 fb @ 90 % C.L. fb, respectively, as shown in Table I. We estimated the systematic errors for the branching fraction by changing the Ω_c^0 mass by $\pm 1.0\sigma$ from its best fit value.

TABLE I. Fit to mass distribution.

	σ_{MC}(MeV/c^2)	Fitted Yield mode dependent x_p	Relative $\mathcal{B}r$ all $x_p > 0.5$	$\sigma \cdot \mathcal{B}r$ (fb) all $x_p > 0.5$
$\Omega^-\pi^+$	5.87	13.3$\pm$4.1	1.0	$11.3 \pm 3.9 \pm 2.3$
$\Omega^-\pi^+\pi^0$	9.71	11.8$\pm$4.9	$4.2 \pm 2.2 \pm 1.2$	$47.6 \pm 18.0 \pm 2.8$
$\Xi^0\pi^+K^-$	6.72	9.2$\pm$4.9	$4.0 \pm 2.5 \pm 0.6$	$45.1 \pm 23.2 \pm 4.1$
$\Xi^-\pi^+\pi^+K^-$	5.46	7.0$\pm$3.7	$1.6 \pm 1.1 \pm 0.4$	$18.2 \pm 10.6 \pm 3.8$
$\Omega^-\pi^+\pi^+\pi^-$	4.89	-0.9$\pm$1.4	< 0.56	< 5.1 @ 90 % CL
Combined 5 modes		40.4$\pm$9.0		
$\Sigma^+K^-K^-\pi^+$	6.18	2.8$\pm$4.1	< 4.8	< 53.8 @ 90 % CL

In conclusion, we observe a narrow resonance with a mass around $2694.6 \pm 2.6 \pm 2.4$ MeV/c^2 in five decay modes $\Omega^-\pi^+$, $\Omega^-\pi^+\pi^0$, $\Omega^-\pi^+\pi^+\pi^-$, $\Xi^-K^-\pi^+\pi^+$, and $\Xi^0K^-\pi^+$. Although the signal is not statistically significant in any individual mode, the combined signal stands out over the background with a yield of $40.4 \pm 9.0(stat)$ events.

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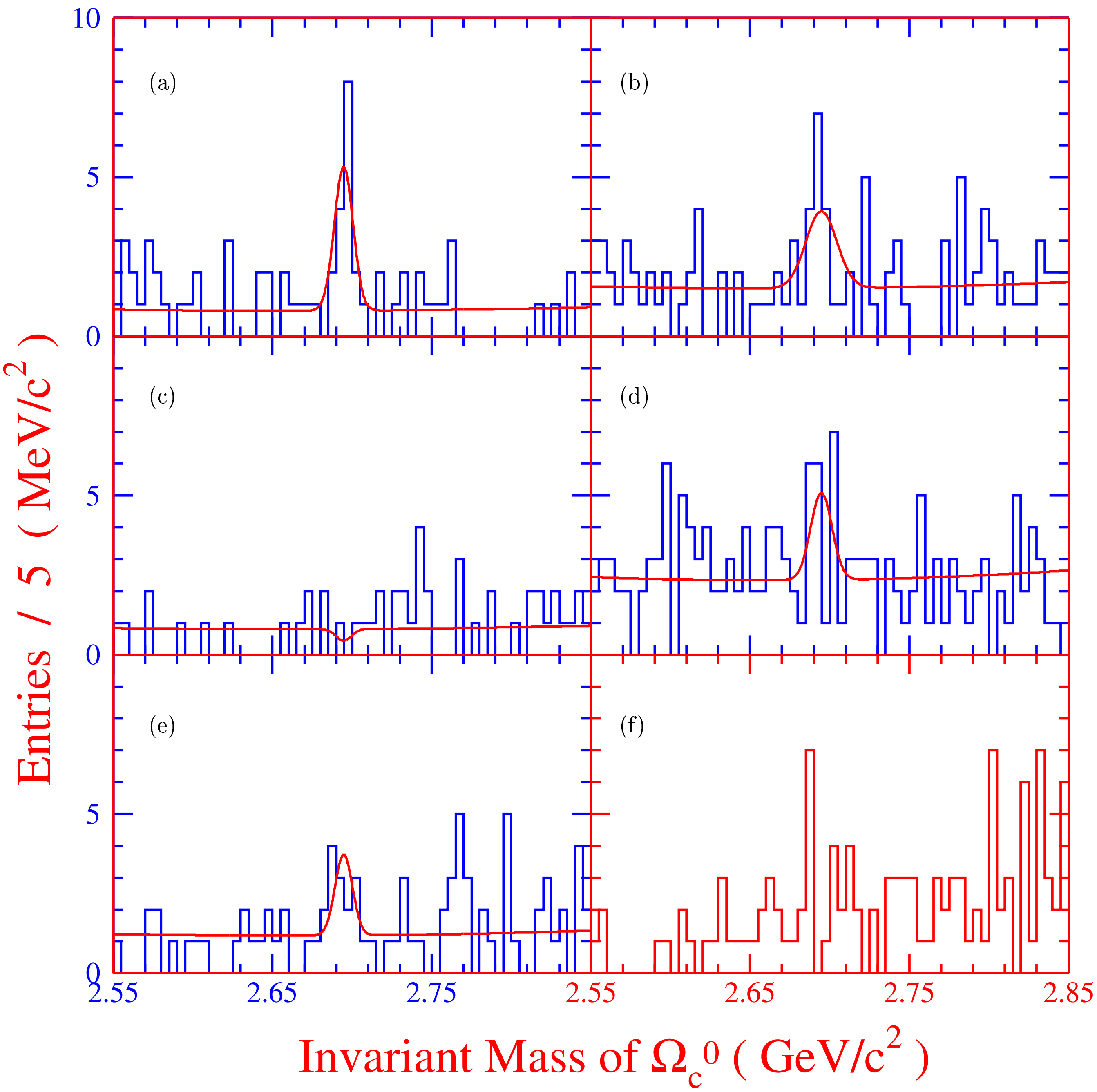

FIG. 1. The above plot shows simultaneous fits to the five Ω_c^0 modes: (a) $\Omega^-\pi^+$, (b) $\Omega^-\pi^+\pi^0$, (c) $\Omega^-\pi^+\pi^+\pi^-$, (d) $\Xi^0 K^-\pi^+$, (e) $\Xi^- K^-\pi^+\pi^+$. The mode (f) $\Sigma^+ K^- K^- \pi^+$ has not been included in the fit.

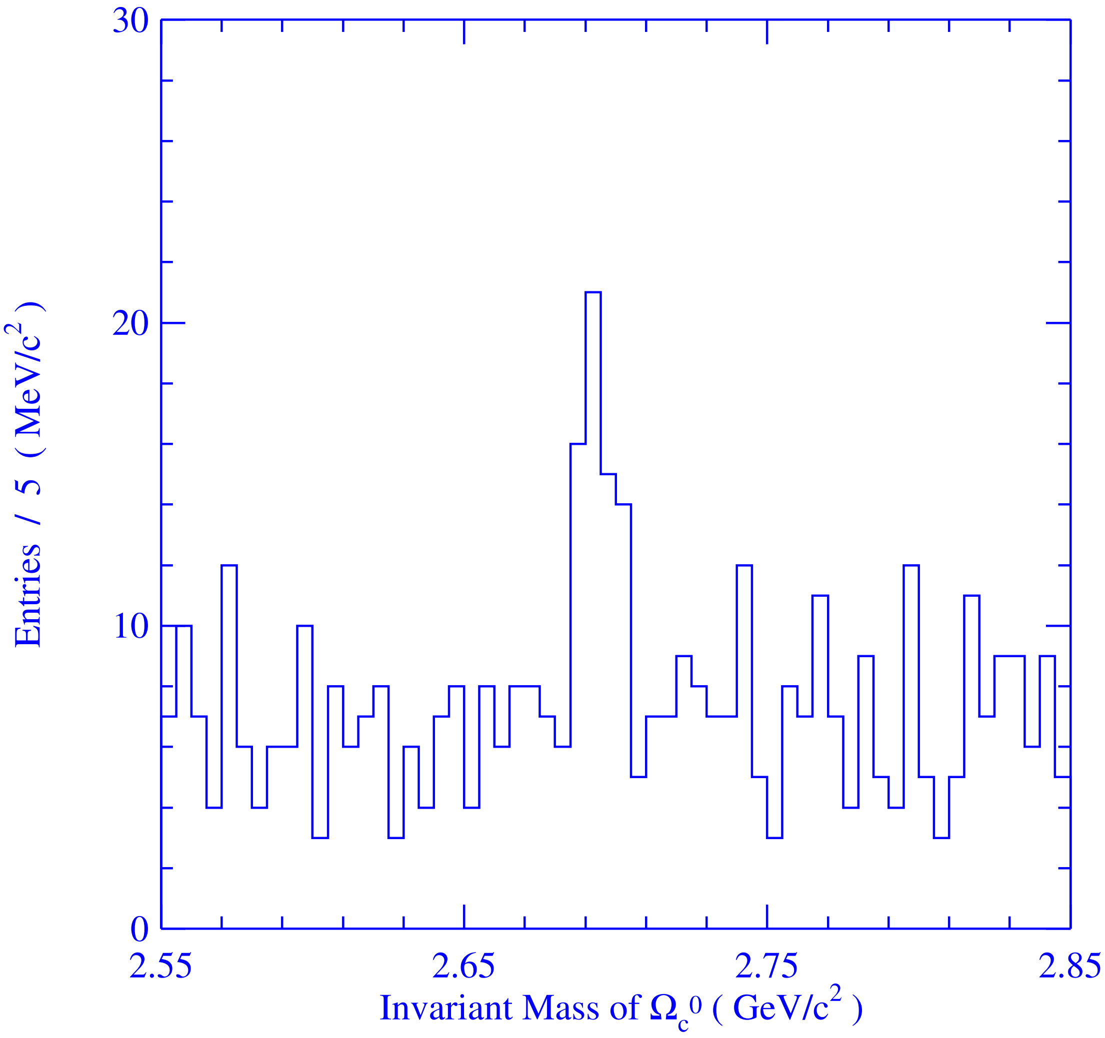

FIG. 2. The summed plot for $\Omega^-\pi^+$, $\Omega^-\pi^+\pi^0$, $\Omega^-\pi^+\pi^+\pi^-$, $\Xi^0K^-\pi^+$, and $\Xi^-K^-\pi^+\pi^+$.