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Evidence of New States Decaying into $\Xi_c'\pi$

CLEO Collaboration

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Abstract

Using 13.7 fb^{-1} of data recorded by the CLEO detector at CESR, we report preliminary evidence for two new charmed baryons; one decaying into $\Xi_c^{0\prime}\pi^+$ with the subsequent decay $\Xi_c^{0\prime} \to \Xi_c^0\gamma$, and its isospin partner decaying into $\Xi_c^{+\prime}\pi^-$ followed by $\Xi_c^{+\prime} \to \Xi_c^+\gamma$. We measure the following mass differences for the two states: $M(\Xi_c^0\gamma\pi^+) - M(\Xi_c^0) = 318.4 \pm 1.5 \pm 2.9$ MeV, and $M(\Xi_c^+\gamma\pi^-) - M(\Xi_c^+) = 323.9 \pm 1.4 \pm 3.0$ MeV. We interpret these new states as the $J^P = \frac{1}{2}^-$ Ξ_{c1} particles, the charmed-strange analogues of the $\Lambda_{c1}^+(2593)$.

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The Ξ_c states consist of a combination of a charm quark, a strange quark and an up or down quark. Each angular momentum combination of these quarks exists as an isospin pair. The ground states, the Ξ_c^0 and Ξ_c^+, are the only members of the group that decay weakly, and over the past decade their masses, lifetimes, and many of their decay modes have been measured. In 1995 and 1996 CLEO found evidence for a pair of excited states [1] that were interpreted as the $J^P = \frac{3}{2}^+$ Ξ_c^* states, and one of these observations has since been confirmed [2]. In 1999, CLEO discovered [3] the Ξ_c' states, which like the ground states have $J^P = \frac{1}{2}^+$, but have a wave-function that is symmetric under interchange of the two lighter quarks, and are the charmed-strange analogs of the Σ_c. Also in 1999, CLEO reported the discovery [4] of a pair of states decaying into $\Xi_c^*\pi$ with a mass about 348 MeV above the ground states. These are interpreted as the $J^P = \frac{3}{2}^-$ Ξ_{c1} states, the analogs of the $\Lambda_{c1}^+(2630)$, where the numerical subscript refers to the light quark angular momentum. Here, using data from the CLEO II and CLEO II.V detector configurations, we present the first evidence of two peaks corresponding to particles decaying to $\Xi_c'\pi$. This is the expected decay mode of the $J^P = \frac{1}{2}^-$ Ξ_{c1} states. That fact, in addition to our measured masses, lead us to identify our peaks with these particles.

The data presented here were taken by the CLEO detector operating at the Cornell Electron Storage Ring. The sample used in this analysis corresponds to an integrated luminosity of 13.7 fb^{-1} from data taken on the $\Upsilon(4S)$ resonance and in the continuum at energies just below the $\Upsilon(4S)$. Of this data, $4.7 fb^{-1}$ was taken with the CLEO II configuration [5] and the remainder with the CLEO II.V configuration [6] which includes a silicon vertex detector in its charged particle measurement system. 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 first obtain large samples of reconstructed Ξ_c^+ and Ξ_c^0 particles, using their decays into Λ, Ξ^-, Ω^- and Ξ^0 hyperons as well as kaons, pions and protons[1]. The analysis chain for reconstructing these particles follows closely that presented in our previous publications [1,3,4]. We fitted the invariant mass distributions for each decay mode to a sum of a Gaussian signal function and a second order polynomial background. Ξ_c candidates were defined as those combinations within 2σ of the known mass of the Ξ_c^+ or Ξ_c^0, where σ is the detector resolution for the detector configuration, calculated mode-by-mode by a GEANT-based [7] Monte Carlo simulation program. To illustrate the good statistics and signal to noise ratio of the Ξ_c signals, and to reduce the combinatorial background, we have placed a cut $x_p > 0.6$, where $x_p = p/p_{max}$, p is the momentum of the charmed baryon, $p_{max} = \sqrt{E_{beam}^2 - M^2}$, where M is the calculated Ξ_c mass. Table 1 details the number of signal and number of background events obtained from each decay mode. The x_p cut used to obtain the results in Table 1 was not used in the final analysis, as we prefer to apply an x_p cut only on the $\Xi_c'\pi$ combinations.

The Ξ_c candidates defined above were then combined with a photon and the mass differences $M(\Xi_c^0\gamma) - M(\Xi_c^0)$ and $M(\Xi_c^+\gamma) - M(\Xi_c^+)$ were calculated. The transition photons were required to each have energy in excess of 100 MeV, to come from the part of the detector that had the best resolution ($\cos\theta < 0.7$, where θ is the polar angle), and to have an energy

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[1] Charge conjugate states are implied throughout.

TABLE I. Ξ_c^0 and Ξ_c^+ Decay Mode Yields

Particle	Mode	Ξ_c Yield, $x_p > 0.6$	Background
Ξ_c^0			
	$\Xi^-\pi^+$	440	112
	$\Xi^-\pi^+\pi^-\pi^+$	106	133
	$\Xi^-\pi^+\pi^0$	357	377
	Ω^-K^+	59	12
	$\Xi^0\pi^+\pi^-$	196	202
	$\Lambda K^-\pi^+$	179	238
	ΛK_s^0	106	80
Ξ_c^+			
	$\Xi^0\pi^+$	84	168
	$\Xi^0\pi^+\pi^-\pi^+$	216	460
	$\Sigma^+K^-\pi^+$	83	62
	$\Xi^-\pi^+\pi^+$	668	200
	$\Xi^0\pi^+\pi^0$	345	650
	$\Lambda K_s^0\pi^+$	188	270
	$\Lambda K^-\pi^+\pi^+$	38	78

profile consistent with being due to an isolated photon. Any photon which, when combined with another photon, made a combination consistent with being a π^0, was rejected. Those combinations with calculated mass differences within 8 MeV ($\approx 2\sigma$) of the measured mass differences for the Ξ_c' particles [3], were retained for further analysis. As the Ξ_c' decays electromagnetically, its instrinsic width is negligible, and so the candidates were kinematically fit to the Ξ_c' masses using these measured mass differences.

We then combine these Ξ_c' candidates with an appropriately charged track in the event and plot $M(\Xi_c'\pi) - M(\Xi_c)$ for each isospin state. Figure 1(a) shows $M(\Xi_c^{0\prime}\pi^+) - M(\Xi_c^0)$, and Figure 1(b) shows $M(\Xi_c^{+\prime}\pi^-) - M(\Xi_c^+)$, each with a requirement of $x_p > 0.7$ on the combination. In both figures there is a peak at about 320 MeV, indicative of the decay of a Ξ_{c1}^+ (Figure 1a) and a Ξ_{c1}^0 (Figure 1b). We fit each of the two peaks to a sum of Gaussian signal function of floating width, and a polynomial background function. For the $\Xi_c^{0\prime}\pi^+$ case, we find a signal of $18.4^{+5.6}_{-4.9}$ events with a width, σ, of 5.6 ± 1.7 MeV. For the $\Xi_c^{+\prime}\pi^-$ case, we find an excess of $14.2^{+4.6}_{-3.9}$ events and a width, σ, of 3.9 ± 1.5 MeV. The mass resolution of the detector for these decays are from our Monte Carlo simulation program to be about 1.2 MeV in the CLEO II.V data, and around 1.4 MeV in the CLEO II data. This indicates the likelihood that the states have non-negligible intrinsic widths. We have also fit the plots to Breit-Wigner functions convolved with a Gaussian resolution function. The results of this fit are, $M(\Xi_c^{0\prime}\pi^+) - M(\Xi_c^0) = 318.4 \pm 1.5$ MeV, and $\Gamma = 7.9^{+5.7}_{-3.9}$ MeV, for Figure 1a, and $M(\Xi_c^{+\prime}\pi^-) - M(\Xi_c^+) = 323.9 \pm 1.4$ MeV, and $\Gamma = 6.5^{+4.4}_{-2.8}$ MeV for Figure 1b. It is these fits that are superimposed on the data in Figure 1. The results for Γ are limited in their accuracy by the low statistics, but indicate that it is very likely that these states have an instrinsic width of the order of MeV. However, we prefer to place 90% confidence level upper limits on the width of these states, of $\Gamma(\Xi_{c1}^+) < 16$ MeV and $\Gamma(\Xi_{c1}^0) < 13$ MeV, dominated by the statistical error.

In order to check that all the Ξ_{c1} decays proceed via an intermediate Ξ_c', we release the cuts on $M(\Xi_c\gamma) - M(\Xi_c)$, select combinations within 8 MeV of our final signal peaks and plot $M(\Xi_c\gamma) - M(\Xi_c)$. The plots (Figures 2a and b) show signals which are consistent with our published results for the Ξ_c' pair [4]. It is clear that our data are consistent with all the $J^P = \frac{1}{2}^-$ Ξ_{c1} decays proceeding via an intermediate Ξ_c'.

When quoting our results as a mass difference with respect to a ground state, our systematic uncertainty is dominated by the uncertainty in the $M(\Xi_c') - M(\Xi_c)$ mass differences. Alternatively, we can quote the mass difference with respect to the Ξ_c' states, and we find $M(\Xi_c^{+\prime}\pi^-) - M(\Xi_c^{+\prime}) = 216.1 \pm 1.4 \pm 1.0$ MeV and $M(\Xi_c^{0\prime}\pi^+) - M(\Xi_c^{0\prime}) = 211.4 \pm 1.5 \pm 1.0$ MeV. The quoted systematic uncertainties include the spread in our results obtained with different fitting procedures, and an estimate of the systematic uncertainty of our mass difference scale.

The decay patterns of the Ξ_{c1} states should be closely analogous to those of the Λ_{c1}^+. The preferred decay of the $J^P = \frac{1}{2}^-$ Ξ_{c1} should be to $\Xi_c'\pi$ because the spin-parity of the baryons allows this decay to proceed via an S-wave decay, whereas decays to Ξ_c^* would have to proceed via a D-wave. In Heavy Quark Effective Theory (HQET) [8], where the angular momentum and parity of the light di-quark degrees of freedom must be considered separately from those of the heavy quark, decays of the Ξ_{c1} directly to ground state Ξ_c baryons are not allowed. Thus we identify our two peaks as the $J^P = \frac{1}{2}^-$ Ξ_{c1}^0 and Ξ_{c1}^+. Also in the HQET picture, the splitting between the $J^P = \frac{1}{2}^-$ and $J^P = \frac{3}{2}^-$ states is expected to be similar to that between the two Λ_{c1}^+ states and also the analagous splitting in charmed meson states. Combining our results found here with our previous results on the $J^P = \frac{3}{2}^-$ Ξ_{c1} states [4], and using world average values [10] for the isospin splitting of the ground state Ξ_c baryons, we find the splitting between the $J^P = \frac{3}{2}^-$ and $J^P = \frac{1}{2}^-$ of $24.8 \pm 1.8 \pm 3.2$ MeV in the charged case, and $28.8 \pm 1.6 \pm 4.0$ MeV for the neutral case. These are similar to the analogous splittings in the Λ_c^+ and charmed meson systems. We can also measure the isospin splitting between the new states we have find, $M(\Xi_{c1}^0) - M(\Xi_{c1}^+) = 0.0 \pm 2.0 \pm 4.5$ MeV, where the quoted systematic uncertainties include the systematic uncertainties of our mass difference measurement as well as the uncertainty in the mass difference of the ground states.

Although the uncertainties are large, this confirms the picture that the excited states of the Ξ_c have smaller isospin splittings than that of the ground states. The $J^P = \frac{1}{2}$ Ξ_{c1} particles are the analogs of the $\Lambda_{c1}^+(2593)$. Although the latter decays with very little phase space, it has been measured to have an instrinsic width of a few MeV. It is not surprising, therefore, that the $J^P = \frac{1}{2}^-$ Ξ_{c1} pair, which has more phase space available for two-body decays, should also appear as wide peaks in our data.

In conclusion, we present evidence for the production of two new states. The first of these states decay into $\Xi_c^{0\prime}\pi^+$ with measured mass given by $M(\Xi_c^0\gamma\pi^+) - M(\Xi_c^0) = 318.4 \pm 1.5 \pm 2.9$ MeV. The second state decays into $\Xi_c^{+\prime}\pi^-$ with a mass given by $M(\Xi_c^+\gamma\pi^-) - M(\Xi_c^+) = 323.9 \pm 1.4 \pm 3.0$ MeV. Although we do not measure the spin or parity of these states, the observed decay modes, masses, and widths are all consistent with the new states being the $J^P = \frac{1}{2}^-$ Ξ_{c1}^+ and Ξ_{c1}^0 states, the charmed-strange analogues of the $\Lambda_{c1}^+(2593)$.

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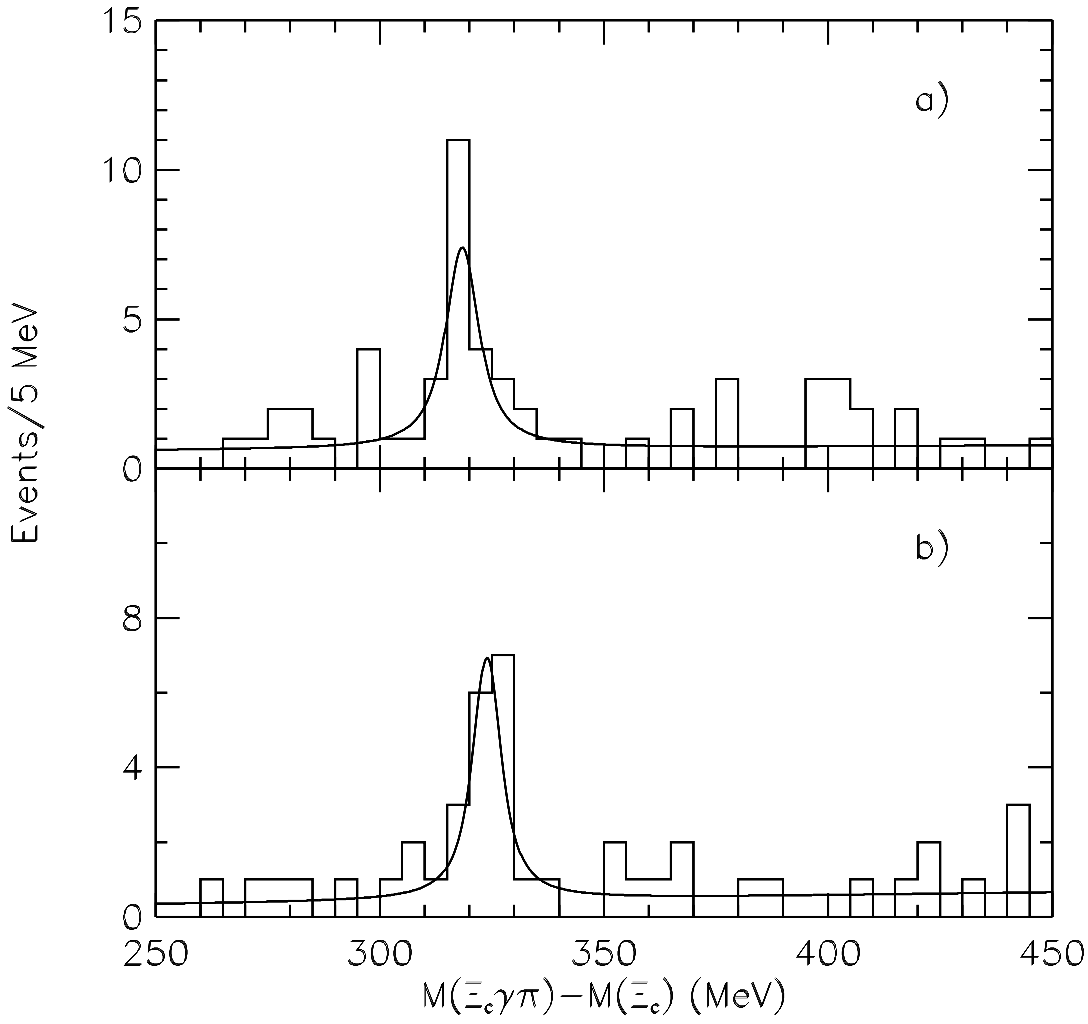

FIG. 1. a) $M(\Xi_c^0\gamma\pi^+) - M(\Xi_c^0)$ and b) $M(\Xi_c^+\gamma\pi^-) - M(\Xi_c^+)$. Each plot shows a distinct peak. Note that the Ξ_c' mass has been fixed in these plots, so that we could equivalently show $M(\Xi_c'\pi) - M(\Xi_c)$ as this would just be a translation of the horizontal axis.

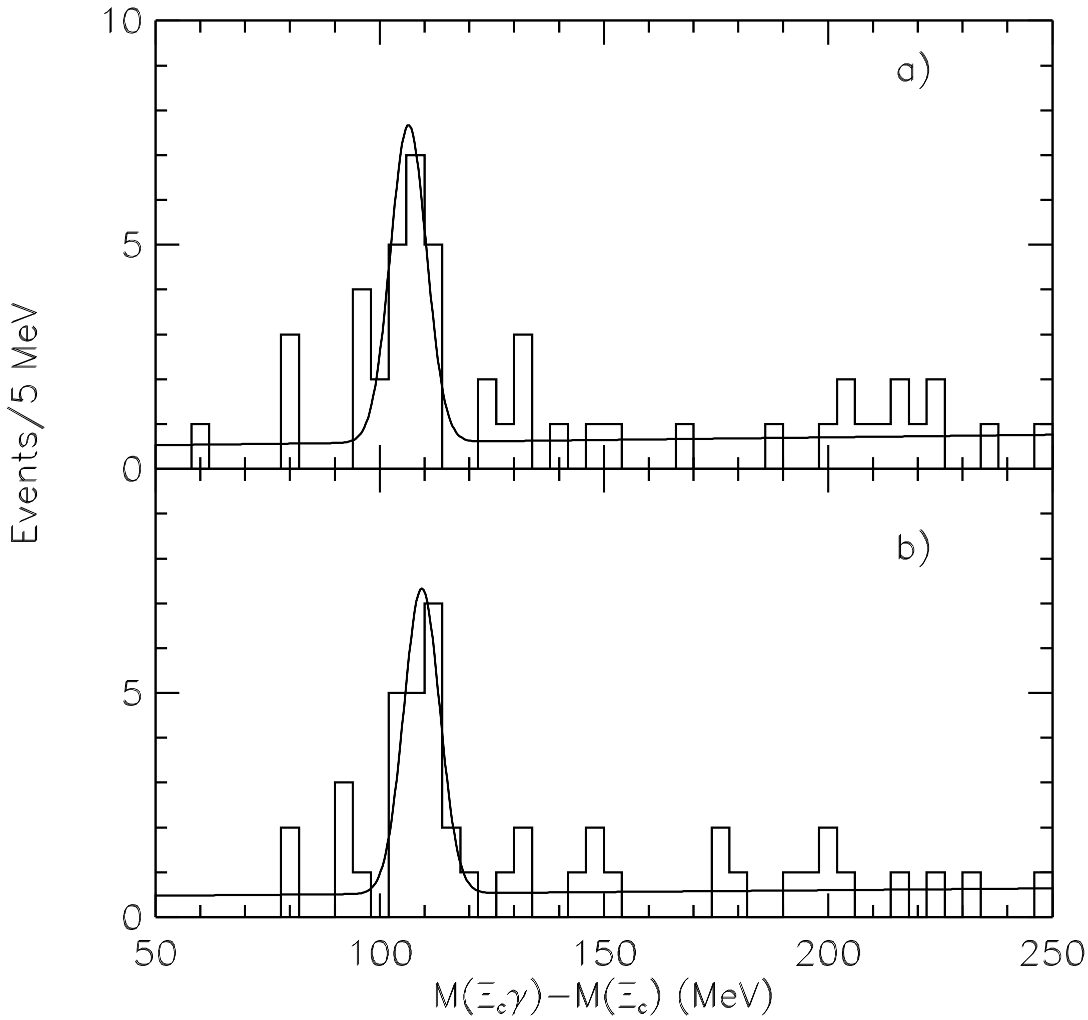

FIG. 2. Cutting first on the Ξ_{c1} masses, we plot $M(\Xi_c\gamma) - M(\Xi_c)$. a) $M(\Xi_c^0\gamma) - M(\Xi_c^0)$ having cut on the Ξ_{c1}^+, and b) $M(\Xi_c^+\gamma) - M(\Xi_c^+)$ having cut on the Ξ_{c1}^0. Each plot is fit using a fixed width Gaussian signal function obtained from Monte Carlo simulation of Ξ_c' decays. The mass differences of the peaks are consistent with the published values for the $\Xi_c^{0\prime}$ and $\Xi_c^{+\prime}$ [3].