Observation of an Excited Charmed Baryon Decaying into $\Xi_c^0 \pi^+$

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Using data recorded by the CLEO II detector at the Cornell Electron Storage Ring, we report the first observation of an excited charmed baryon decaying into $\Xi_c^0 \pi^+$. The state has mass difference

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$M(\Xi_c^0 \pi^+) - M(\Xi_c^0)$ of $174.3 \pm 0.5 \pm 1.0$ MeV$/c^2$, and a width of <3.1 MeV$/c^2$ (90% confidence level limit). We identify the new state as the Ξ_c^{*+}, the isospin partner of the recently discovered Ξ_c^{*0}.
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Recently we reported [1] the observation of a narrow state decaying into $\Xi_c^+ \pi^-$, with a mass difference $M(\Xi_c^+ \pi^-) - M(\Xi_c^+)$ of $178.2 \pm 0.5 \pm 1.0$ MeV$/c^2$. We believe that the most likely explanation for this state is that it is the $J^P = \frac{3}{2}^+$ spin excitation of the Ξ_c^0. Clearly the Ξ_c^{*0} state will have an isospin partner, the Ξ_c^{*+}, which is expected to have a mass and width similar to those of the Ξ_c^{*0}. We have found evidence for such a state decaying into $\Xi_c^0 \pi^+$.

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 4.1 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 [2]. We detected charged tracks with a cylindrical drift chamber system inside a solenoidal magnet, and we detected photons using an electromagnetic calorimeter consisting of 7800 cesium iodide crystals. The analysis procedure is similar to that of our previous paper [1]. However, here we include an augmented data set.

We report the observation of a new particle decaying into $\Xi_c^0 \pi^+$, where the Ξ_c^0 charmed baryons were observed decaying into either $\Xi^- \pi^+$, $\Omega^- K^+$, $\Xi^- \pi^+ \pi^0$, or $\Xi^0 \pi^+ \pi^-$. The hyperons were observed by their decays $\Xi^- \to \Lambda \pi^-$, $\Omega^- \to \Lambda K^-$, $\Xi^- \to \Lambda \pi^-$, and $\Xi^0 \to \Lambda \pi^0$. (Charge conjugate modes are implicit throughout.) These decay modes of the Ξ_c^0 were chosen because they have the most significant signals. The first two of these decay modes were first observed by the CLEO 1.5 experiment [3,4]. A planned CLEO publication will detail branching ratio measurements of all four of the Ξ_c^0 decay modes.

The procedure for finding Λ, Ξ^0, and Ξ^- candidates has been presented elsewhere [1]. The Ω^- candidates were selected with a procedure similar to that used for Ξ^- candidates. Both kaon tracks in the decay $\Xi_c^0 \to \Omega^- K^+$ were required to be consistent with the kaon hypothesis using specific ionization measurements in the drift chamber, and when present, time-of-flight measurements.

In order to select Ξ_c^0 candidates, the hyperons were combined with the remaining charged and neutral tracks in the event. The π^0 candidates were made by combining two clusters of energy deposited in the CsI calorimeter. To suppress background in the $\Xi_c^0 \to \Xi^- \pi^+ \pi^0$ mode, we required that the π^0 candidates have a momentum greater than 300 MeV$/c$. Similarly, both π mesons from the $\Xi_c^0 \to \Xi^0 \pi^+ \pi^-$ decay are required to have momenta greater than 300 MeV$/c$. To illustrate the good signal to noise ratio of the Ξ_c^0 signals, we reduce the combinatorial background, which is worse for Ξ_c^0 candidates with low momentum, by applying a cut on x_p, where $x_p = p/p_{\max.}$, p is the momentum of the charmed baryon, $p_{\max} = \sqrt{E_{\text{beam}}^2 - M^2}$, and E_{beam} is the beam energy. The invariant mass spectra after this cut are shown in Fig. 1. For the fits, which are overlaid on these figures, the signals are parametrized by Gaussians with fixed widths ($\sigma = 10$ MeV$/c^2$, $\sigma = 5$ MeV$/c^2$, $\sigma = 13$ MeV$/c^2$, and $\sigma = 7.5$ MeV$/c^2$, respectively), together with a polynomial background function. They show yields of 106 ± 13, 14 ± 4, 118 ± 18, and 48 ± 12 events. These widths were determined using a GEANT based Monte Carlo simulation of the detector [5]. Combinations within 2.5σ of the mass of the Ξ_c^0 in each decay mode are taken as Ξ_c^0 candidates. The x_p cut used in Fig. 1 was released before continuing with the analysis; we prefer to apply an x_p cut only on the $\Xi_c^0 \pi^+$ combinations.

The Ξ_c^0 candidates defined above were then combined with each remaining π^+ track in the event, and the mass difference $M(\Xi_c^0 \pi^+) - M(\Xi_c^0)$ was calculated. We then placed an $x_p > 0.5$ cut on the $\Xi_c^0 \pi^+$ combination.

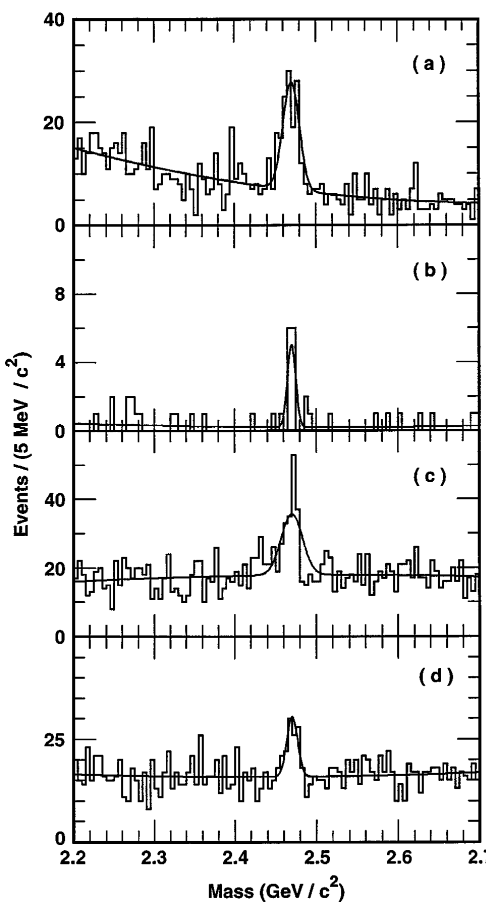

FIG. 1. Invariant mass spectra for (a) $\Xi^- \pi^+$, (b) $\Omega^- K^+$, (c) $\Xi^- \pi^+ \pi^0$, and (d) $\Xi^0 \pi^+ \pi^-$ combinations, all with $x_p > 0.5$. Clear Ξ_c^0 peaks are seen in all modes.

Charmed baryons produced from decays of B mesons are kinematically limited to $x_p < 0.4$, so this cut rejects those candidates, leaving only those produced by e^+e^- annihilation into $c\overline{c}$ jets, which are known to have a hard momentum spectrum. The mass difference spectrum, shown in Fig. 2, shows a clear peak at around 174 MeV$/c$. We fit this mass spectrum to the sum of a Chebychev polynomial with threshold suppression, and a Breit-Wigner convoluted with a Gaussian resolution function ($\sigma = 1.6$ MeV$/c^2$, calculated by Monte Carlo studies). The fit yields a signal area of $34.2^{+8.9}_{-7.9}$ combinations, a mean mass difference of 174.3 ± 0.5 MeV$/c^2$, and an intrinsic width, $\Gamma = 0.7^{+1.2}_{-0.7}$ MeV$/c^2$, where the errors shown are statistical errors only. Considering systematic errors due to the fitting procedures and to energy-loss corrections for charged tracks, we find a mass difference for this new state of $174.3 \pm 0.5 \pm 1.0$ MeV$/c^2$. The measurement of the width is consistent with zero, so we present a 90% confidence level upper limit of $\Gamma < 3.1$ MeV$/c^2$.

Figures 3(a)–3(d) show the same mass difference as presented in Fig. 2, but separated into combinations involving the four Ξ_c^0 decay chains separately. In the fits overlayed on these histograms, the mass and width of the signal were constrained to the values found by the fit to Fig. 2. The number of events in the peaks are found to be 12.0 ± 4.0 events for Fig. 3(a), 1.8 ± 1.4 events for Fig. 3(b), 14.7 ± 4.8 for Fig. 3(c), and 6.9 ± 3.1 for Fig. 3(d).

We identify this new state as the Ξ_c^{*+}. Taking the mass difference above and adding the Ξ_c^0 mass of 2470.3 ± 1.8 MeV$/c^2$ [6], we obtain a Ξ_c^{*+} mass of 2644.6 ± 2.3 MeV$/c^2$. The model predictions for this state are in the range 2620 to 2690 MeV$/c^2$ [7–11]. This measured mass is very similar to that found for the Ξ_c^{*+} [1], as is expected for isospin partners. The isospin splitting $M(\Xi_c^{*0}) - M(\Xi_c^{*+})$ is found to be $3.9 \pm 0.8 \pm 1.0 - [M(\Xi_c^0) - M(\Xi_c^+)]$ MeV$/c^2$. Here the dominating systematic uncertainty is due to differences in the central value of the masses that are obtained using different signal and background functions. Using a value [6] of 5.2 ± 2.2 MeV$/c^2$ for $M(\Xi_c^0) - M(\Xi_c^+)$ MeV$/c^2$ gives $M(\Xi_c^{*0}) - M(\Xi_c^{*+}) = -1.3 \pm 2.6$ MeV$/c^2$. As noted in our previous publication, the identification of these states as the $J = \frac{3}{2}^+$ Ξ_c^* states is due to the value of the mass difference with respect to the Ξ_c, and we have no other way of differentiating them from the $J = \frac{1}{2}^+$ Ξ_c' states.

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 efficiencies. Figure 4 shows dN/dx_p, and the overlayed fit which is of the Peterson [12] form of $dN/dx_p \propto x_p^{-1}[1 - 1/x_p - \epsilon/(1 - x_p)]^{-2}$. The fit gives a value of $\epsilon = 0.24^{+0.22}_{-0.10}$, which is very similar to that measured for the Ξ_c^{*0}. In order to calculate the number of Ξ_c^0 baryons that are the decay products of

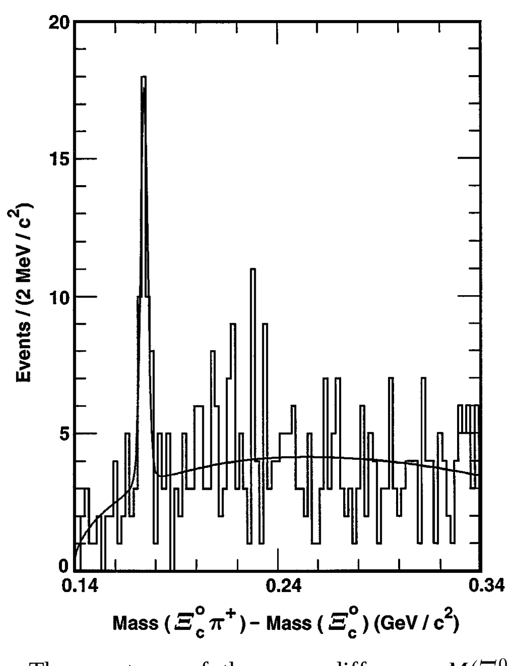

FIG. 2. The spectrum of the mass difference $M(\Xi_c^0\pi^+) - M(\Xi_c^0)$ for all four decay chains combined.

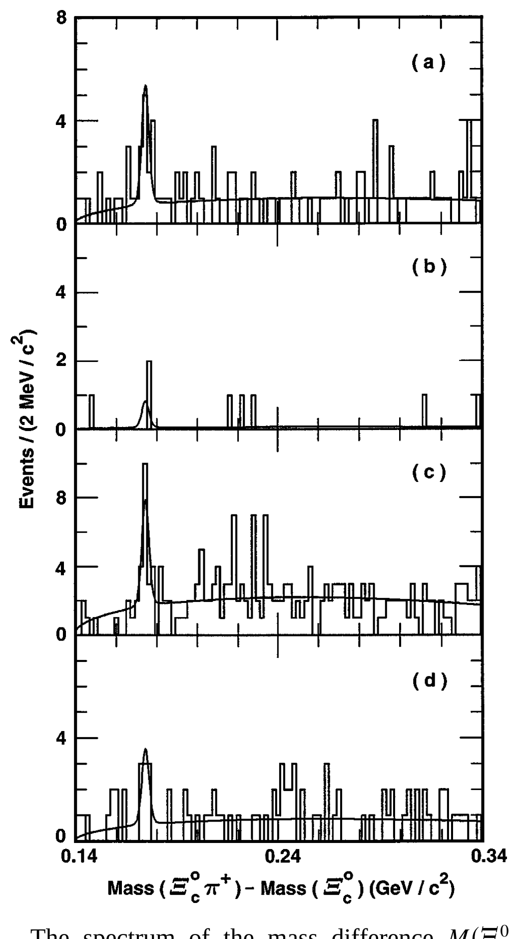

FIG. 3. The spectrum of the mass difference $M(\Xi_c^0\pi^+) - M(\Xi_c^0)$ for (a) only $\Xi_c^0 \to \Xi^-\pi^+$, (b) only $\Xi_c^0 \to \Omega^-K^+$, (c) only $\Xi_c^0 \to \Xi^-\pi^+\pi^0$, and (d) only $\Xi_c^0 \to \Xi^0\pi^+\pi^-$. The fits are described in the text.

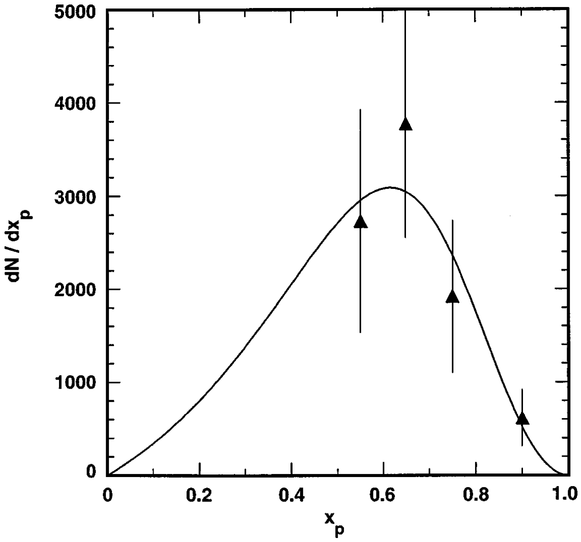

FIG. 4. The efficiency corrected spectrum of scaled momentum, x_p, for the observed Ξ_c^{*+} candidates. The fit is to the Peterson function.

Ξ_c^{*+} decays, we need to extrapolate the yield of Ξ_c^{*+} and Ξ_c^0 baryons down to $x_p = 0$. As it is expected that the isospin partners will have very similar momentum spectra, we use a fragmentation shape for the Ξ_c^{*+} which is the average of that obtained above and that of our previous measurement of Ξ_c^{*0}. Similarly, for the extrapolation for Ξ_c^0, we use a value of $\epsilon = 0.23^{+0.06}_{-0.05} \pm 0.03$ which we have measured for Ξ_c^+ production as this is the most accurate measurement of the fragmentation function of a Ξ_c state [13]. We calculate that $(17 \pm 5^{+4}_{-3})$ of Ξ_c^0 baryons are produced from Ξ_c^{*+} decays. The dominating systematic uncertainty is due to the extrapolation of the spectra down to $x_p = 0$.

In conclusion, we have observed a narrow ($\Gamma < 3.1\ \mathrm{MeV}/c^2$) peak which we believe corresponds to the decay $\Xi_c^{*+} \to \Xi_c^0 \pi^+$. The mass difference $M(\Xi_c^{*+}) - M(\Xi_c^0)$ is measured to be $174.3 \pm 0.5 \pm 1.0\ \mathrm{MeV}/c^2$.

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