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


(CLEO Collaboration)

1University of Rochester, Rochester, New York 14627
2Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309
3Southern Methodist University, Dallas, Texas 75275
4Syracuse University, Syracuse, New York 13244
5Vanderbilt University, Nashville, Tennessee 37235

6Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061
7Wayne State University, Detroit, Michigan 48202
8California Institute of Technology, Pasadena, California 91125
9University of California, San Diego, La Jolla, California 92093
10University of California, Santa Barbara, California 93106
11University of Colorado, Boulder, Colorado 80309-0390
12Cornell University, Ithaca, New York 14853
13University of Florida, Gainesville, Florida 32611
14Harvard University, Cambridge, Massachusetts 02138
15University of Hawaii at Manoa, Honolulu, Hawaii 96822
16University of Illinois, Champaign-Urbana, Illinois 61801

17Carleton University, Ottawa, Ontario K1S 5B6 and Institute of Particle Physics, Canada
18McGill University, Montréal, Québec H3A 2T8 and Institute of Particle Physics, Canada
19Ithaca College, Ithaca, New York 14850
20University of Kansas, Lawrence, Kansas 66045
21University of Minnesota, Minneapolis, Minnesota 55455
22State University of New York at Albany, Albany, New York 12222
23Ohio State University, Columbus, Ohio 43210
24University of Oklahoma, Norman, Oklahoma 73019
25Purdue University, West Lafayette, Indiana 47907

(Received 1 March 1996)

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

810 0031-9007/96/77(5)/810(4)$10.00 © 1996 The American Physical Society
Recently we reported [1] the observation of a narrow state decaying into \( \Xi_c^+ \pi^- \), with a mass difference \( M(\Xi_c^+ \pi^-) - M(\Xi_c^0) \) of \( 178.2 \pm 0.5 \pm 1.0 \text{ MeV}/c^2 \). We believe that the most likely explanation for this state is that it is the \( J^P = \frac{3}{2}^+ \) spin excitation of the \( \Xi_c^0 \). Clearly the \( \Xi_c^0 \) state will have an isospin partner, the \( \Xi_c^+ \), which is expected to have a mass and width similar to those of the \( \Xi_c^0 \). 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 \( 4.1 \text{ fb}^{-1} \) from data taken on the \( Y(4S) \) resonance and in the continuum at energies just above and below the \( Y(4S) \). 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 \( \Xi_c^0 \) charmed baryons were observed decaying into either \( \Xi_c^- \pi^+ \), \( \Omega^- K^+ \), \( \Xi_c^- \pi^+ \pi^0 \), or \( \Xi_c^0 \pi^+ \pi^- \). The hyperons were observed by their decays \( \Xi_c^- \to \Lambda \pi^- \), \( \Omega^- \to \Lambda K^- \), \( \Xi_c^0 \to \Lambda \pi^- \), and \( \Xi_c^0 \to \Lambda \pi^0 \). (Charge conjugate modes are implicit throughout.) These decay modes of the \( \Xi_c \) 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 \( \Xi_c^0 \) decay modes.

The procedure for finding \( \Lambda \), \( \Xi_c^0 \), and \( \Xi_c^- \) candidates has been presented elsewhere [1]. The \( \Omega^- \) candidates were selected with a procedure similar to that used for \( \Xi_c^- \) candidates. Both kaon tracks in the decay \( \Xi_c^- \to \Omega^- K^+ \) 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 \( \Xi_c^0 \) candidates, the hyperons were combined with the remaining charged and neutral tracks in the event. The \( \pi^0 \) candidates were made by combining two clusters of energy deposited in the CsI calorimeter. To suppress background in the \( \Xi_c^0 \to \Xi_c^- \pi^+ \pi^0 \) mode, we required that the \( \pi^0 \) candidates have a momentum greater than 300 MeV/c. Similarly, both \( \pi \) mesons from the \( \Xi_c^0 \to \Xi_c^- \pi^+ \pi^- \) decay are required to have momenta greater than 300 MeV/c. To illustrate the good signal to noise ratio of the \( \Xi_c^0 \) signals, we reduce the combinatorial background, which is worse for \( \Xi_c^0 \) candidates with low momentum, by applying a cut on \( x_p \), where \( x_p = p/p_{\text{max}} \). is the momentum of the charmed baryon, \( p_{\text{max}} = \sqrt{E_{\text{beam}} - M^2} \), and \( E_{\text{beam}} \) 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 \( \sigma = 10 \text{ MeV}/c^2 \), \( \sigma = 5 \text{ MeV}/c^2 \), \( \sigma = 13 \text{ MeV}/c^2 \), and \( \sigma = 7.5 \text{ MeV}/c^2 \), respectively, together with a polynomial background function. They show yields of \( 106 \pm 13, 14 \pm 4, 118 \pm 18 \), and \( 48 \pm 12 \) events. These widths were determined using a GEANT based Monte Carlo simulation of the detector [5]. Combinations within \( 2.5\sigma \) of the mass of the \( \Xi_c \) in each decay mode are taken as \( \Xi_c \) 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 \( \Xi_c \) candidates defined above were then combined with each remaining \( \pi^+ \) 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 \( \Xi_c^0 \) 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 $c\bar{c}$ 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 $34.2^{+9.0}_{-8.9}$ combinations, a mean mass difference of $174.3 \pm 0.5$ 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 $\Xi_c^0$ 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 $12.0 \pm 4.0$ events for Fig. 3(a), $1.8 \pm 1.4$ events for Fig. 3(b), $14.7 \pm 4.8$ for Fig. 3(c), and $6.9 \pm 3.1$ for Fig. 3(d).

We identify this new state as the $\Xi_c^{++}$. Taking the mass difference above and adding the $\Xi_c^0$ mass of 2470.3 $\pm$ 1.8 MeV/c$^2$ [6], we obtain a $\Xi_c^{++}$ mass of 2644.6 $\pm$ 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 $\Xi_c^{++}$ [1], as is expected for isospin partners. The isospin splitting $M(\Xi_c^{0}) - M(\Xi_c^{+})$ is found to be $3.9 \pm 0.8 \pm 1.0 - [M(\Xi_c^{0}) - M(\Xi_c^{+})] \text{MeV/c}^2$. 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 $5.2 \pm 2.2$ 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 $J = \frac{1}{2}^+ \Xi_c^{++}$ states is due to the value of the mass difference with respect to the $\Xi_c$, and we have no other way of differentiating them from the $J = \frac{1}{2}^+ \Xi_c^{++}$ 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 $\Xi_c^{0}$. In order to calculate the number of $\Xi_c^{0}$ 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.](image)
The efficiency corrected spectrum of scaled momentum, $x_p$, for the observed $\Xi_c^{++}$ candidates. The fit is to the Peterson function.

For $\Xi_c^{++}$ decays, we need to extrapolate the yield of $\Xi_c^{++}$ and $\Xi_c^0$ 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 $\Xi_c^{++}$ which is the average of that obtained above and that of our previous measurement of $\Xi_c^0$. Similarly, for the extrapolation for $\Xi_c^0$, we use a value of $\epsilon = 0.23^{+0.06}_{-0.05} \pm 0.03$ which we have measured for $\Xi_c^+$ production as this is the most accurate measurement of the fragmentation function of a $\Xi_c$ state [13]. We calculate that $(17 \pm 5_{-3}^{+4})$ of $\Xi_c^0$ baryons are produced from $\Xi_c^{++}$ 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 ($\Gamma < 3.1$ MeV/$c^2$) peak which we believe corresponds to the decay $\Xi_c^{++} \rightarrow \Xi_c^0 \pi^+$. The mass difference $M(\Xi_c^{++}) - M(\Xi_c^0)$ is measured to be $174.3 \pm 0.5 \pm 1.0$ MeV/$c^2$.

We gratefully acknowledge the effort of the CESR staff in providing us with excellent luminosity and running conditions. J. P. A., J. R. P., and I. P. J. S. thank the NYI program of the NSF, M.S. thanks the PFF program of the NSF, G.E. thanks the Heisenberg Foundation, K. K. G., M. S., H. N. N., T. S., and H. Y. thank the OJI program of DOE, J. R. P., K. H., and M. S. thank the A. P. Sloan Foundation, and A. W. and R. W. thank the Alexander von Humboldt Stiftung for support. This work was supported by the National Science Foundation, the U.S. Department of Energy, and the Natural Sciences and Engineering Research Council of Canada.

*Permanent address: BINP, RU-630090 Novosibirsk, Russia.