# Observation of the Charmed Strange Baryon $\Xi_c^0$

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We present evidence from the CLEO detector for the charmed strange baryon $\Xi_c^0$. It is seen in nonresonant $e^+e^-$ annihilations at $\sqrt{s}$ of 10.5 GeV through its decay to $\Xi^-\pi^+$. The measured $\Xi_c^0$ mass is $2471 \pm 3 \pm 4$ MeV/$c^2$.

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The discovery of the charmed quark led to the prediction of many baryon states containing this quark flavor. Evidence for the production of the charmed strange baryon, called $\Xi_c^+$ $(csu)$, with a mass of $2460 \pm 15$ MeV/$c^2$ has been reported with a hyperon beam at CERN.[1] This observation was later confirmed from a neutron-beam experiment at Fermilab,[2] and also by a $\pi^-$-beam experiment at CERN.[3] In this Letter we report the observation of a narrow state in the reaction $e^+e^- \rightarrow \Xi^-\pi^+ + X$. We identify this state as the previously unobserved $\Xi_c^0$ baryon with the quark content $(csd)$. The $\Xi_c^0$ mass can be useful in distinguishing between models of baryon spectroscopy.

The data used in this analysis were collected with the

 

CLEO detector at the Cornell Electron Storage Ring (CESR). The sample consists of 101 $\text{pb}^{-1}$ of integrated luminosity at energies just below the $\Upsilon(4S)$ resonance, 212 $\text{pb}^{-1}$ at the $\Upsilon(4S)$, and 117 $\text{pb}^{-1}$ at the $\Upsilon(5S)$. The CLEO detector and our hadronic-event selection criteria have been described elsewhere.[4] For all the data used in this study, the central tracking system consisted of a 51-layer drift chamber,[5] augmented by a 10-layer high-resolution inner drift chamber and a three-layer straw-tube vertex detector. The momentum resolution achieved by this system is $(\sigma_p/p)^2=(0.23\%p)^2+(0.7\%)^2$, where $p$ is in GeV/$c$. Particle identification is achieved with measurements of specific ionization ($dE/dx$) in the drift chambers, together with a time-of-flight measurement using scintillation counters positioned outside the central tracking system.

The $\Xi_c^0$ candidates[6] are observed through the decay chain $\Xi_c^0 \to \Xi^-\pi^+$, $\Xi^- \to \Lambda\pi^-$, $\Lambda \to p\pi^-$. $\Lambda$ candidates are formed from two oppositely charged tracks, intersecting with a vertex at least 5 mm away from the beam position. The $dE/dx$ and time-of-flight measurements of the proton candidate are required to be consistent with a proton mass hypothesis. The invariant mass of the two tracks, when interpreted as proton and a pion, is required to be within 6 MeV/$c^2$ of the $\Lambda$ mass. Combinations were made of each $\Lambda$ candidate with an additional negatively charged track in the event (assumed to be a $\pi^-$), and the point of intersection of the two is required to be at least 2 mm away from the beam spot and closer to the beam spot than the $\Lambda$ decay vertex. The $\Lambda\pi^-$ invariant-mass plot is shown in Fig. 1. $\Xi^-$ candidates were defined as those combinations with a reconstructed invariant mass within 5 MeV/$c^2$ of our fitted $\Xi^-$ mass (1321.5 MeV/$c^2$). Within this mass interval, we have $996 \pm 43$ $\Xi^-$'s, with a signal-to-background ratio of approximately 1.5:1.

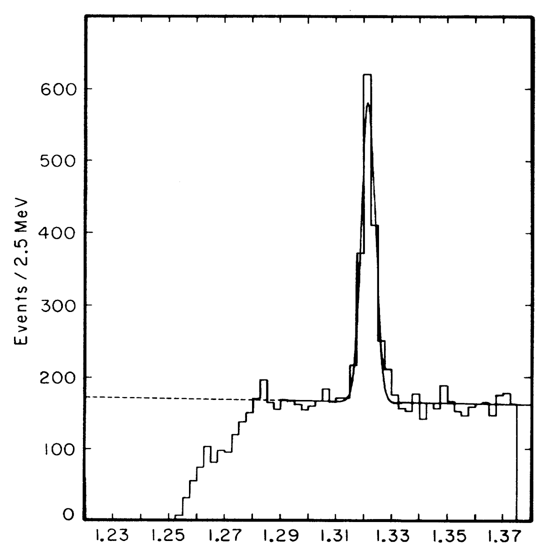


FIG. 1. The $\Lambda\pi^-$ invariant-mass distribution. The fit is a Gaussian of mean 1321.5 MeV/$c^2$ and full width at half maximum of 5.9 MeV/$c^2$.

Combinations are then made of each candidate $\Xi^-$ with all remaining positively charged tracks in the event assuming them to be $\pi^+$'s. The decay angle $\Theta$ of the $\pi^+$ in the $\Xi^-\pi^+$ center-of-mass frame is required to be within the bounds $-0.8 < \cos\Theta < 1.0$. This cut improves the signal-to-background ratio, because it eliminates a large number of slow pions. The invariant masses of the $\Xi^-\pi^+$ combinations passing this cut are shown in Fig. 2(a). A clear enhancement exists at a mass of around 2470 MeV/$c^2$, which we identify as the $\Xi_c^0$ baryon. The data are fitted with a Gaussian function of fixed width above a polynomial background shape. The full width at half maximum of the Gaussian function is fixed at 26 MeV/$c^2$ corresponding to the detector resolution determined by Monte Carlo simulation. The fit yields a total of $32 \pm 8$ events. Figure 2(b) shows the same $\Xi^-\pi^+$ invariant-mass distribution with a cut of $x_p > 0.5$, where $x_p$ is defined as the combination's momentum divided by its maximum possible momentum, $x_p^2 = p^2/(E_{\text{beam}}^2 - M_{\Xi\pi}^2)$. Any $\Xi_c^0$'s that are produced

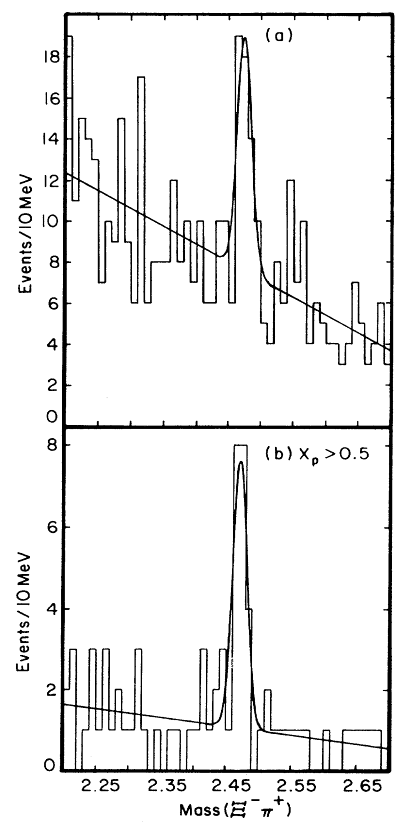


FIG. 2. The $\Xi^-\pi^+$ invariant-mass distribution for (a) all $x_p$ and (b) $x_p > 0.5$. The fits are Gaussians with a fixed width of 26 MeV/$c^2$ (FWHM).

from $B$-meson decays are kinematically constrained to $x_p < 0.5$. The observation of $\Xi_c^0$'s with $x_p > 0.5$ provides evidence for the continuum production of $\Xi_c^0$. Furthermore, the fragmentation function for charmed particles is known to be hard, so a cut on $x_p$ should increase the signal-to-background ratio, as is observed. Using the $\Xi^-\pi^+$ mass spectrum for $x_p > 0.5$, a fit to the enhancement yields a signal of $18.1 \pm 4.9$ events. In a signal region, defined to be $2460\ \text{MeV}/c^2 < M_{\Xi\pi} < 2480\ \text{MeV}/c^2$, there are 16 events observed whereas the estimated background level is 2.1 events.[7]

Using the fit shown in Fig. 2(b), the invariant mass of $\Xi_c^0$ is $2471 \pm 3\ \text{MeV}/c^2$. The absolute mass scale of the CLEO detector can be checked by using the $D^+ \rightarrow K^-\pi^+\pi^+$ and $D^0 \rightarrow K^-\pi^+$ decays. The track momenta in these decays are similar to the track momenta in $\Xi_c^0 \rightarrow \Xi^-\pi^+$. We also use the $\Xi^0(1530) \rightarrow \Xi^-\pi^+$ decay, which has the feature of having a $\Xi^-$ in the final state. We find $M(D^+) = 1869.8 \pm 0.3\ \text{MeV}/c^2$ compared with a world average[8] of $1869.3 \pm 0.6\ \text{MeV}/c^2$, $M(D^0) = 1865.9 \pm 0.4\ \text{MeV}/c^2$ compared with a world average of $1864.5 \pm 0.6\ \text{MeV}/c^2$, and $M(\Xi^0(1530)) = 1534.9 \pm 1.2\ \text{MeV}/c^2$ compared with a world average of $1531.8 \pm 0.3\ \text{MeV}/c^2$. The uncertainties quoted in our measurements of these masses are purely statistical. The total systematic uncertainty in the mass measurement of the $\Xi_c^0$ is estimated to be $\pm 4\ \text{MeV}/c^2$, including uncertainties in the absolute mass scale and fitting procedures used. This mass is consistent with measurements of the $\Xi_c^+$ mass.[1-3] The uncertainties of the experiments are too great for a determination of the isospin mass splitting of the $\Xi_c$ multiplet.

The $\Xi_c^0$ is formed from the $c$, $s$, and $d$ quarks. There are two possible states, one being flavor SU(3) symmetric under $s$ and $d$ exchange and the other being antisymmetric. Examples of other pairs of baryons which have the same quark content but exist in two distinct states are the $\Lambda$-$\Sigma^0$ and $\Lambda_c^+$-$\Sigma_c^+$. In both of these cases the isospin symmetry concerns interchange of $u$ and $d$ quarks. The masses of the baryons have been described by a simple model based on QCD where the particle mass is the sum of constituent quark masses plus a term proportional to $\boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j / m_i m_j$, $\boldsymbol{\sigma}_i$ being the Pauli spin operator for the $i$th quark.[9] This model predicts that the symmetric states are heavier than the antisymmetric ones. Using this model for the $\Xi_c$ case, Kwong, Rosner, and Quigg[9] predict the antisymmetric state to have a mass of $2505\ \text{MeV}/c^2$ and the symmetric state to have a mass of $2604\ \text{MeV}/c^2$. Our mass value is close to the predicted antisymmetric one. Furthermore, we could not reconstruct the heavier state by the techniques used here since it can decay into the lighter one by emission of a $\gamma$ (or a $\pi^0$ if the actual mass difference is large enough).

The efficiency for observing the decay $\Xi_c^0 \rightarrow \Xi^-\pi^+$ has been determined using a Monte Carlo program to be $9.7\% \pm 1.0\%$ averaged over $x_p > 0.5$. The production cross section times branching fraction for the sum of both the $\Xi_c^0$ and its antiparticle, with the $\Xi_c^0$ decaying into $\Xi^-\pi^+$, is measured to be $0.45 \pm 0.13$ pb for $x_p > 0.5$. The error includes both statistical and systematic uncertainties.

In conclusion, we have observed a narrow enhancement in the $\Xi^-\pi^+$ invariant-mass spectrum which we identify with the $\Xi_c^0$. We measure its mass to be $2471 \pm 3 \pm 4\ \text{MeV}/c^2$, and its production cross section times branching fraction to be $0.45 \pm 0.13$ pb for $x_p > 0.5$.

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[6] Mention of $\Xi_c^0$ production or decay process implies the charge conjugate.

[7] We have examined invariant-mass combinations where we use $\Xi^-$ sidebands and $\Xi^-\pi^-$ combinations. In neither case do we see signals.

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