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First Observation of the $\Sigma^{-}\pi^{+}\pi^{+}$ Decay Mode of the Λ_C Baryon and its Branching Ratio Relative to the $\Sigma^{+}\pi^{+}\pi^{-}$ Mode

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Abstract

We report the first observation (103 ± 17 events) of the decay $\Lambda_c^+ \to \Sigma^- \pi^+ \pi^+$ and the charge conjugate. A measurement of the relative branching ratio $\frac{\Gamma(\Lambda_c^+ \to \Sigma^- \pi^+ \pi^+)}{\Gamma(\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-)} = 0.53 \pm 0.15(stat) \pm 0.07(sys)$ is also presented.

Until recently, few observations of charm decays into final states containing the $\Sigma^\pm$ baryon have been made. The first observation of $\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-$ was made in 1986 in an emulsion experiment that found one event [1]. Five events with $\Lambda_c^+ \to \Sigma^\pm$ (+ anything) were reconstructed in a photoproduction experiment at 20 GeV at SLAC [2]. Recently, the CLEO collaboration has shown a significant signal for $\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-$ where the Σ^+ decays to $p\pi^0$ [3]. There are no published observations of the Σ^- decay channels. Recent studies of the lifetimes of different charm baryons [4] have suggested the importance of W-exchange as compared to the spectator decay mechanism. The numerical value of the ratio of the two partial widths $\Gamma(\Lambda_c^+ \to \Sigma^- \pi^+ \pi^+)/\Gamma(\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-)$, may shed some light on the relative importance of the two decay mechanisms, give additional understanding of the role played by the QCD strong interaction in the decay process, and provide information on color suppression and W-exchange [5]. In this paper we present the first evidence for the decay mode $\Lambda_c^+ \to \Sigma^- \pi^+ \pi^+$ and measure the branching ratio relative to the decay mode $\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-$. The decay channels discussed in this paper also include charge conjugate states.

The two decay modes are similar from an experimental point of view. They have the same multiplicity and event topology, requiring the same cuts and particle identification requirements. Both modes can be analyzed using essentially the same procedures, thus minimizing systematic effects. Two minor differences are the slightly larger mass of the Σ^- and the shorter lifetime of the Σ^+, both of which are taken into account.

The Wide Band Photon Laboratory and the Fermilab E687 Spectrometer were used to perform a high statistics study of charmed particles. The E687 detector is a large aperture magnetic spectrometer with excellent vertex measurement, particle identification, and calorimetric capabilities. The experiment used a bremsstrahlung photon beam, with an average triggered photon momentum of 220 GeV, impinging on a beryllium target. Both spectrometer and beam have been described extensively elsewhere [6].

Event selection was made by requiring that at least 40 GeV of energy be detected in the hadron calorimeter [7] and at least two charged particles be observed in the spectrometer outside the electron pair region. This trigger is effective in enhancing the sample of events containing charm particles by selecting events having a large hadronic component in the final state, and by rejecting e^+e^- pairs from beam photon conversion. The data used for this analysis, consisting of about 5×10^8 recorded events, were taken during the 1990-1991 Fermilab fixed target run.

The Σ hyperons which decay downstream of the silicon strip detector system (SSD) are reconstructed through the decay mode $\Sigma^\pm \to n\pi^\pm$. Such candidates appear in the spectrometer as the intersection between the Σ track which is reconstructed in the SSD, but missing in the multiwire proportional chambers (MWPC), and a pion track found in the MWPC system but missing in the SSD. The Σ decay region is limited to the 3.6 meters between the end of the microstrip detector and the first MWPC chamber. We do not use the

$\Sigma^+ \to p\pi^0$ channel in order to minimize systematic differences between the two Λ_c^+ decay modes compared.

Two cases of Σ decays were considered: ones that decay within the magnetic field of the upstream spectrometer magnet and ones that decay upstream of the magnet and downstream of the SSD. If the Σ decayed within the magnetic field then its momentum can be fully determined by tracing it through the magnetic field to the Σ decay vertex. This momentum is then improved by constraining the reconstructed Σ mass. When the Σ decay occurs upstream of the magnetic field, the direction of Σ is given by its SSD track and, since the pion momentum can be determined, the magnitude of the momentum of the Σ can be calculated using energy and momentum conservation. In this case there is a two-fold ambiguity in this calculation of the Σ momentum.

Particle identification cuts are used to reject false Σ candidates. We require that the daughter $\pi^\pm$ from the $\Sigma^\pm$ decay not be identified as an electron, kaon or proton by the Čerenkov system. For the daughter neutron, we required an energy deposition in the electromagnetic and hadronic calorimeters consistent with a neutron hypothesis using the following method. First, the locations at which the neutron strikes the inner electromagnetic (IE) and the hadron calorimeter (HC) are determined from the reconstructed Σ and daughter π momenta. An electromagnetic shower is associated with the candidate neutron if the transverse centroid of the shower is within 10 cm of the projected impact point. In the hadron calorimeter, energy deposited within the 16.8 cm radius about the calculated impact point (which is a typical transverse size for hadronic showers [8]) is associated with the neutron. Candidates which overlap with showers from charged particles were discarded. Using the sum of electromagnetic and hadronic energies E and the neutron momentum p (determined indirectly by kinematics), we required the ratio E/p to lie in the range 0.3 to 1.7, which is appropriate for our apparatus as discussed below.

We cannot distinguish between Σ^+ and $\overline{\Sigma}^+$ and between Σ^- and $\overline{\Sigma}^-$ until we reconstruct a Λ_c^+ or a $\overline{\Lambda_c}^-$ candidate. The Σ candidate track is associated with all appropriate $\pi\pi$ track combinations found using both the proportional wire chambers and the silicon microstrip system. The tracks identified by the Čerenkov system as definite electrons, kaons, protons, or kaon/proton ambiguous are rejected. The $\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$ and $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$ combinations are selected using a candidate vertex algorithm [6]. The secondary vertex is formed from the three tracks. A seed track is constructed using the momentum vectors of the Σ and the two pions. Any other SSD tracks consistent with intersecting the seed track and each other are used to form the primary vertex candidate. The $\Sigma\pi\pi$ combinations having confidence levels greater than 3% for fits to both the primary and the secondary vertex are selected.

Two cuts which ensure vertex isolation are also applied to the data. The first cut requires that the probability be less than 80% that a track included in the secondary vertex actually belongs to the primary. The second cut eliminates all $\Sigma\pi\pi$ combinations for which a track belonging to neither the primary nor the secondary vertices can be included in the secondary vertex with a probability greater than 0.5%. Our primary method in reducing background is to cut on the statistical significance of vertex detachment l/σ_l, where l is the spatial separation between the reconstructed production and decay vertices and σ_l is the uncertainty in l.

The non-shaded histogram of fig. 1 shows the $\Sigma^-\pi^+\pi^+$ invariant mass distribution for the events surviving the cuts described above and with $l/\sigma_l > 3.5$. In order to avoid double counting the events which are twofold ambiguous (about 10% of the events), we tried several different methods: weighting all doubles by 0.5, choosing the solution having the better primary vertex confidence level and, after defining a $\pm 3\sigma$ interval around the mass of the Λ_c^+, using a weighting factor of 0.5 for the events having both solutions inside the interval (signal double counting) or outside the interval (background double counting). The method adopted here is the third one. Any differences in the yields obtained with these methods are reflected in the quoted systematic error as discussed below. The shaded histogram in Fig. 1 shows the signal with the weighting factor. The distribution of the shaded histogram is fitted with a Gaussian and a linear background. The width of the Gaussian is fixed at the value obtained from our Monte Carlo simulation (12 MeV/c^2). From this fit, we find the yield to be 103 ± 17 events. The mass is 2291 ± 2 MeV/c^2.

To measure the relative branching ratio we adopted the more conservative cut $l/\sigma_l > 5.0$ because of the higher combinatorial background for the $\Sigma^+\pi^-\pi^+$ decay mode. The signals for both decay modes (shaded histograms of Fig 2a, 2b) were fitted with a linear background plus a Gaussian of fixed width as determined from Monte Carlo. After correcting for the Monte Carlo efficiencies for $\Sigma^-\pi^+\pi^+$, for $\Sigma^+\pi^+\pi^-$ and for branching fraction of $\Sigma^+ \to n\pi^+$ decay, the measured width ratio is:

$$\frac{\Gamma(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+)}{\Gamma(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+)} = 0.53 \ \pm \ 0.15(stat) \ \pm \ 0.07(sys).$$

The yields and efficiencies are summarized in Table I.

The systematic error has been estimated by investigating several effects such as double solution counting, the effect of the fixed width for the Gaussian fit, momentum dependence of the Λ_c production and the l/σ_l cut. We considered possible biases in our measurement which would be sensitive to the lifetime difference between Σ^+ and Σ^- by dividing our data sample into upstream and downstream Σ decay regions. We have also studied the effect of the E/p cut by analyzing the responses of the calorimeters to 5×10^4 protons from $\Lambda^0 \to p\pi^-$ decays and an equivalent number of pions from $K_s^0 \to \pi^+\pi^-$ to cover the complete momentum range. The charged decay products were traced to the IE and HC calorimeters using the tracking system. Fig. 3 shows the distribution of the E/p ratio for the protons from Λ^0 decays as measured using the electromagnetic and hadronic calorimeters. The proton momenta range from about 20 to about 120 Gev/c. The data were used to parameterize the efficiency of the E/p cut as a function of track momentum. The cut $0.3 < E/p < 1.7$ selects about 85% of the protons striking the two calorimeters and improves the background rejection by about a factor of 4.

The largest contribution to the systematic error comes from the background shape used in the fit and from the uncertainty in our efficiency correction as a function of the Σ decay region. The uncertainty in the value for the branching fraction $\Sigma^+ \to n\pi^+$, $(0.483 \pm .003)$ [9] also provides a negligible contribution.

In conclusion, we present the first observation of the $\Sigma^-\pi^+\pi^+$ decay channel of the Λ_c^+ charmed baryon. We have also measured the relative branching ratio of the Λ_c^+ decay modes $\Sigma^-\pi^+\pi^+$ and $\Sigma^+\pi^-\pi^+$. Both spectator decay and W-exchange diagrams can contribute to the two decay channels. While the spectator diagrams differ only in the $q\bar{q}$ pair picked up from the sea, the W-exchange diagram for the $\Sigma^-\pi^+\pi^+$ decay channel indicates a possible colour-suppression. This, together with possible interference effects, may account for the observed relative branching ratio whose numerical value is more than three standard deviations from unity.

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FIGURES

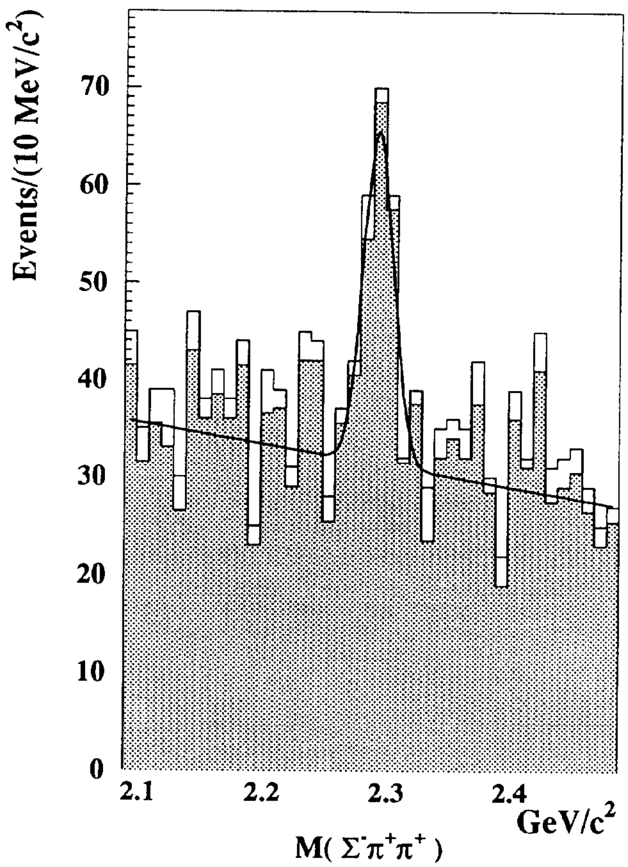

FIG. 1. Mass distribution for $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$ at $l/\sigma_l > 3.5$ with double counting (non-shaded histogram) and without double counting (shaded histogram).

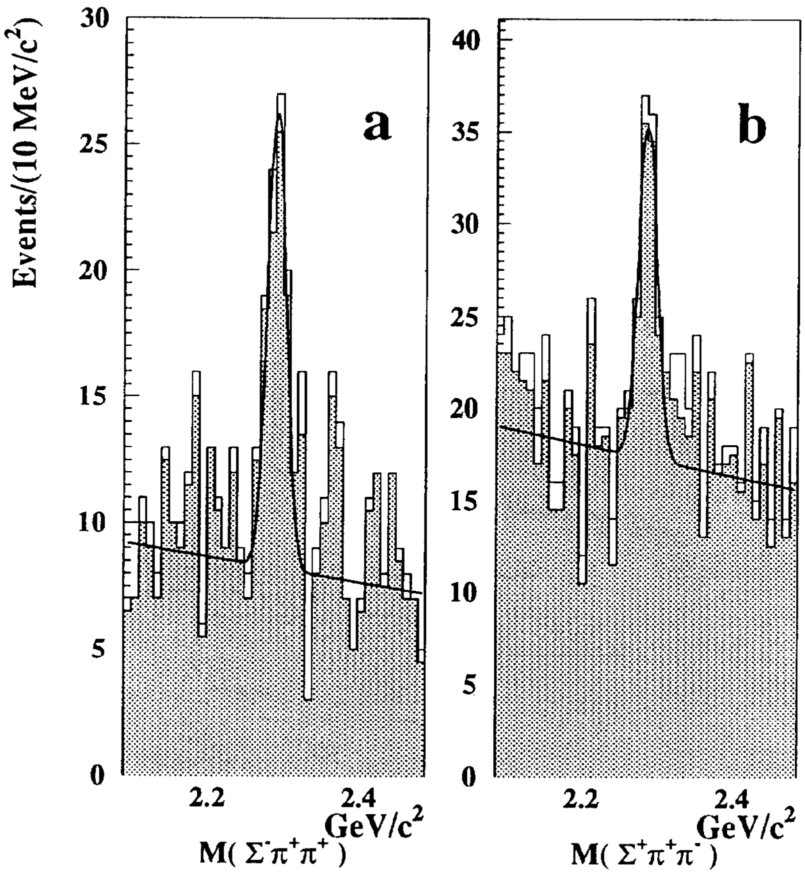

FIG. 2. Mass distributions at $l/\sigma_l > 5$ with double counting (non-shaded histograms) and without double counting (shaded histograms) for $\Lambda_c^+ \rightarrow \Sigma^-\pi^+\pi^+$ candidates (fig.a) and for $\Lambda_c^+ \rightarrow \Sigma^+\pi^+\pi^-$ candidates (fig.b).

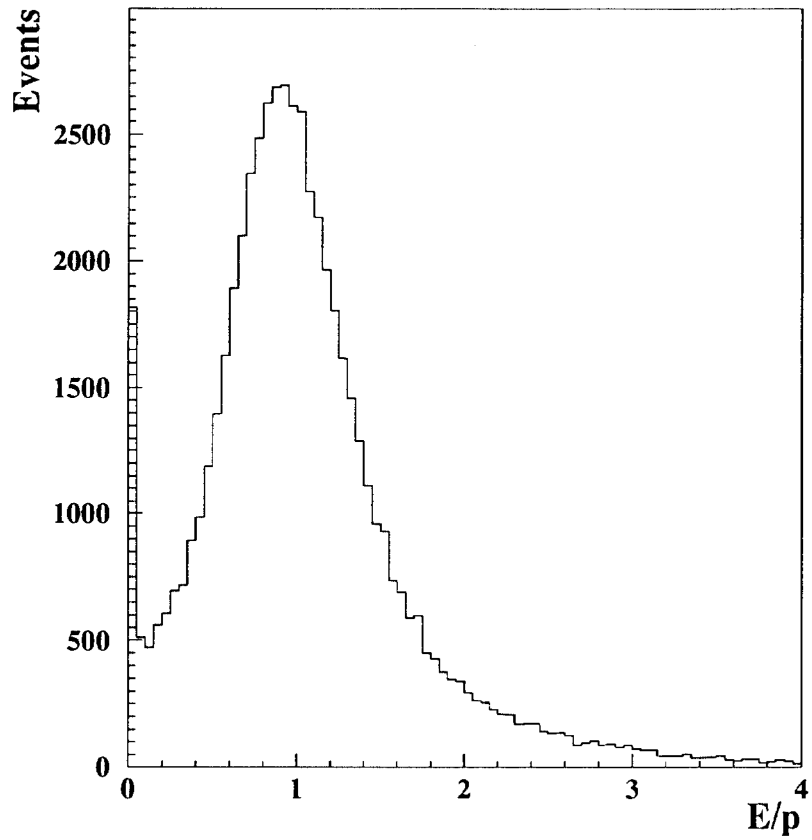

FIG. 3. E/p curve for protons from Λ^0 decays hitting on the electromagnetic and hadronic calorimeters.

TABLES

TABLE I. Yields, branching ratios and efficiencies for observed $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$ and $\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$ events with $l/\sigma_l > 5$.

	BR ($\Sigma \to n\pi$) [9]	Raw Yield	Efficiency
$\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$	100 %	55.89±9.50	0.00378
$\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$	48.3 %	56.02±12.36	0.00415