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First observation of the Cabibbo-suppressed decays $\Xi_c^+ \to \Sigma^+\pi^-\pi^+$ and $\Xi_c^+ \to \Sigma^-\pi^+\pi^+$ and measurement of their branching ratios

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ABSTRACT

We report the first observation of two Cabibbo-suppressed decay modes, $\Xi_c^+ \to \Sigma^+\pi^-\pi^+$ and $\Xi_c^+ \to \Sigma^-\pi^+\pi^+$. We observe 59 ± 14 over a background of 87, and 22 ± 8 over a background of 13 events, respectively, for the signals. The data were accumulated using the SELEX spectrometer during the 1996–1997 fixed target run at Fermilab, chiefly from a 600 GeV/c Σ^- beam. The branching ratios of the decays

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relative to the Cabibbo-favored $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ are measured to be $B(\Xi_c^+ \to \Sigma^+\pi^-\pi^+)/B(\Xi_c^+ \to \Xi^-\pi^+\pi^+) = 0.48 \pm 0.20$, and $B(\Xi_c^+ \to \Sigma^-\pi^+\pi^+)/B(\Xi_c^+ \to \Xi^-\pi^+\pi^+) = 0.18 \pm 0.09$, respectively. We also report branching ratios for the same decay modes of the Λ_c^+ relative to $\Lambda_c^+ \to pK^-\pi^+$.

1. Introduction

Studying Cabibbo-suppressed (CS) decays of hadrons provides insights into the weak interaction mechanism for non-leptonic decays [1]. Comparing the strengths of CS decays to their Cabibbo-favored (CF) analogs, one can, in a systematic way, assess the contributions of the various mechanisms. In addition, comparing the same or similar decay modes of different baryons allows some additional insights. Even though any CS decay mode of the Ξ_c^+ is a CF mode of the Λ_c^+, the detailed arrangement of the different final-state quarks into hadrons might be different, as shown in the spectator diagrams in Figs. 1 and 2. While in the case of the Λ_c^+ both final-state baryons, the Σ^+ and the Σ^-, can have the s quark resulting from the CF c decay, in the case of the Ξ_c^+ decays with the identical final-state hadrons, only the Σ^- can be formed with the CS c decay product. By comparing several decay modes of different hadrons some information about the importances of direct quark emission at the decay stage and from quark rearrangement due to final-state scattering might be obtained.

Modern methods for calculating non-leptonic decay rates of the charm hadrons employ heavy quark effective theory and the factorization approximation [2]. Nonetheless, the three-body decays of charm baryons are prohibitively difficult to calculate due to the complexity of associated final-state interactions. Measurements of the relative branching fractions of charm baryon states, both CF and CS, give additional information about the structure of the decay amplitude and the validity of the factorization approximation.

Until now, the only CS Ξ_c^+ decays reported are $\Xi_c^+ \to pK^-\pi^+$ [3,4] and $\Xi_c^+ \to \Sigma^+K^-K^+$ [5]. In this Letter, we present the first observations of $\Xi_c^+ \to \Sigma^+\pi^-\pi^+$ and $\Xi_c^+ \to \Sigma^-\pi^+\pi^+$, and determine their branching ratios relative to the CF $\Xi_c^+ \to \Xi^-\pi^+\pi^+$. To validate our analysis method, we also report the branching ratios $B(\Lambda_c^+ \to \Sigma^+\pi^-\pi^+)/B(\Lambda_c^+ \to pK^-\pi^+)$ and $B(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+)/B(\Lambda_c^+ \to \Sigma^+\pi^-\pi^+)$ and compare them to previously reported results [6–8].

2. Experiment

SELEX is a high energy hadroproduction experiment using a 3-stage spectrometer designed for high acceptance for forward ($x_F \gtrsim 0.1$) interactions. The main goal of the experiment is the study of production and decay properties of charm baryons. Particles in the negative (600 GeV/c, $\simeq$50% Σ^-, $\simeq$50% π^-) and positive beam (540 GeV/c, $\simeq$92% p, $\simeq$8% π^+) were tagged by a beam transition radiation detector. The data were accumulated from a five-foil segmented target (2 Cu, 3 C, each separated by 1.5 cm) with a total thickness of 5% of an interaction length for protons. The spectrometer had silicon strip detectors to measure the beam and outgoing tracks, giving precision primary and secondary vertex reconstruction. Momenta of particles deflected by the analyzing magnets were measured by a system of proportional wire chambers (PWCs), drift chambers and silicon strip detectors. Momentum resolution for a typical 100 GeV/c track was $\sigma_p/p \approx 0.5\%$. Charged particle identification was performed with a Ring Imaging Cherenkov detector (RICH) [9], which distinguished $K^\pm$ from $\pi^\pm$ up to 165 GeV/c. The proton identification efficiency was >95% above proton threshold (≈90 GeV/c). For pions reaching the RICH detector, the total mis-identification probability due to all sources of confusion was <4%.

Interactions were selected by a scintillator trigger. The trigger for charm required at least 4 charged tracks after the targets as indicated by an interaction counter and at least 2 hits in a scintillator hodoscope after the second analyzing magnet. It accepted about 1/3 of all inelastic interactions. Triggered events were further tested in an on-line computational filter based on downstream tracking and particle identification information. The on-line filter selected events that had evidence of a secondary vertex from tracks completely reconstructed using the forward PWC spectrometer and the vertex silicon. This filter reduced the data size by a factor of nearly 8 at a cost of about a factor of 2 in charm yield. From a total of 15.2×10^9 interactions during the 1996–1997 fixed target run about 10^9 events were written to tape. A more detailed description of the apparatus can be found elsewhere [3,10].

3. Data analysis

In this analysis, secondary vertex reconstruction was attempted when the χ^2 per degree of freedom for the fit of the ensemble of charged tracks to a single primary vertex exceeded 4. All combinations of tracks were formed for secondary vertices (in a first step with $\chi^2_{\rm sec} < 9$, but harder cut values were applied at later stages) and tested against a reconstruction table that specified selection criteria for each charm decay mode. Secondary vertices which occurred inside the volume of a target were rejected. Common identification criteria for the different decay modes were: proton and kaon candidate tracks were required to be identified by the RICH detector to be at least as likely as a pion; if a pion candidate track reached the RICH detector, we applied as a loose requirement that it had to have a likelihood of at least 10%, otherwise it was always accepted; hyperon ($\Sigma^\pm$, Ξ^-) decays were identified by disappearance of a track in a limited decay interval (5–12 m downstream from the target), requiring that the candidate track had hits in the tracking detectors before the first and in-between the first and second magnet, but no hits assigned along the extrapolated trajectory

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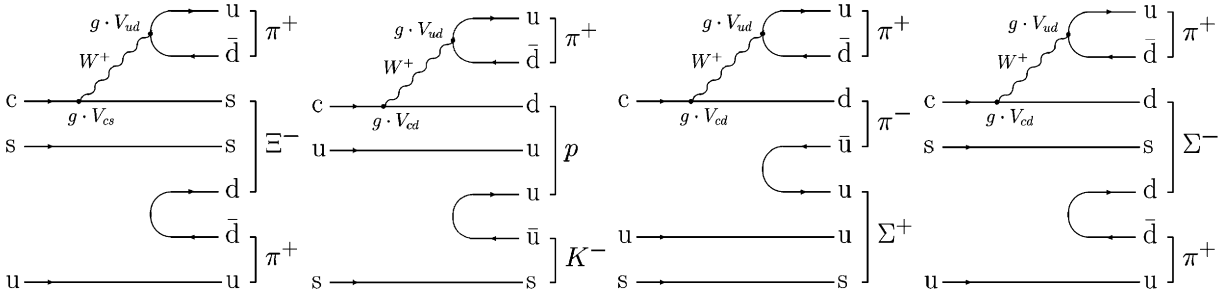

Fig. 1. Spectator diagrams for the decays (from left to right) $\Xi_c^+ \to \Xi^-\pi^+\pi^+$, $\Xi_c^+ \to pK^-\pi^+$, $\Xi_c^+ \to \Sigma^+\pi^-\pi^+$, and $\Xi_c^+ \to \Sigma^-\pi^+\pi^+$. The corresponding W-exchange diagrams and additional final-state quark rearrangements are not shown here.

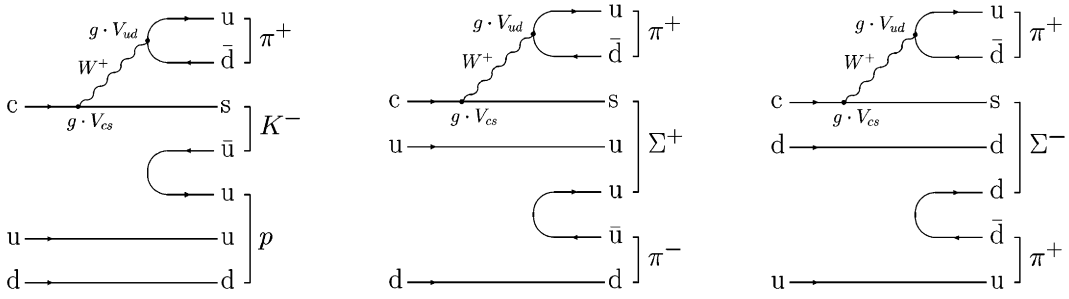

Fig. 2. Spectator diagrams for the decays $\Lambda_c^+ \to pK^-\pi^+$ (left), $\Lambda_c^+ \to \Sigma^+\pi^-\pi^+$ (middle), and $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$ (right). The corresponding W-exchange diagrams and additional final-state quark rearrangements are not shown here.

in the 14 chambers after the second analyzing magnet; this category of tracks gives unique Σ^+ identification but is ambiguous between Σ^- and Ξ^-. Additional ambiguities in the mass assignments may arise due to loose particle identification criteria for p, $K^\pm$, and $\pi^\pm$; tighter cuts on the identification criteria would reduce the accessible momentum range and the number of observed events.

As additional cuts with variable values depending on the decay modes and the relative branching ratio to be determined we used:

- the separation between the primary and secondary vertices in units of its error (L/σ) and the error itself (σ);
- the reconstructed charm momentum vector point-back to the primary vertex, expressed as the square of the distance of the reconstructed charm momentum vector to the primary vertex in the target plane in units of its error ($pvtx$);
- the sum of the squares of the transverse momenta of the daughter tracks with respect to the charm hadron direction of flight (Σ_{pt^2});
- the second-largest miss-distance of the daughter tracks in the target plane in units of its error ($scut$);
- minimum momenta for the $\pi^\pm$ (p_π) and hyperon ($p_{\rm hyp}$) daughter tracks.

The selection criteria and the actual values for these cuts are discussed in the following sections and are listed in Tables 2 and 3.

The total acceptance (geometrical acceptance and reconstruction efficiencies) for the different decay modes of interest was estimated by embedding Monte Carlo charm decay tracks into data events. Momentum and energy were not conserved in the process, but studies indicate this has little effect on the single-charm acceptance calculation. Events were generated with an average transverse momentum $\langle p_T \rangle = 1.0$ GeV/c and longitudinal momentum distributions according to $(1-x_F)^n$, with $n = 2.5$ ($n = 2.45 \pm 0.18$ for Λ_c^+ production with a Σ^- beam [11]). The value of n was varied during the systematic studies and did not affect the final branching ratio results. Detector hits, including resolution and multiple Coulomb scattering smearing effects, produced by these embedded tracks were folded into the hit banks of the underlying data event. The new ensemble of hits was passed through the SELEX off-line software. The acceptance is the ratio of the number of reconstructed events to the number of embedded events in a particular mode. For the determination of the branching ratios only the relative acceptances are relevant, leading to a cancellation of most systematic effects associated with the acceptance corrections.

Table 1
Results of the Gaussian parts of the fits to the distributions presented in Fig. 3

Mode	Mass [MeV/c^2]	Events	Mass [MeV/c^2]	Events
$\Sigma^+\pi^-\pi^+$	2288.1 ± 2.2	74.2 ± 13.8	2471.6 ± 3.9	58.7 ± 13.5
$\Sigma^-\pi^+\pi^+$	2286.0 ± 1.8	46.4 ± 10.1	2463.3 ± 3.0	22.3 ± 7.5

4. First observation of $\Xi_c^+ \to \Sigma^+\pi^-\pi^+$ and $\Xi_c^+ \to \Sigma^-\pi^+\pi^+$

In Fig. 3 we show the invariant mass distributions of $\Sigma^+\pi^-\pi^+$ and $\Sigma^-\pi^+\pi^+$, over the full mass range evaluated. In each distribution we can see two peaks, corresponding to the Λ_c^+ and Ξ_c^+ decays. The cuts used for the two distributions are shown in the first two rows of Tables 2 and 3. Additionally we required in both channels that at least one of the pions reached the RICH detector. For $\Sigma^+\pi^-\pi^+$ we applied $\sigma < 0.10$ cm, $\chi^2_{\rm sec} < 7$, $p_{\rm hyp} > 70$ GeV/c and events with an invariant mass around the Ξ_c^+ mass in the $\Sigma^+K^-\pi^+$ interpretation were removed; for $\Sigma^-\pi^+\pi^+$ $\sigma < 0.08$ cm, $\chi^2_{\rm sec} < 6$, $p_{\rm hyp} > 80$ GeV/c, $scut > 4$ and events with an invariant mass around the Ξ_c^+ mass in the $\Xi^-\pi^+\pi^+$ interpretation were removed. The selection of the individual cut values was based on prior SELEX analyzes and tuned to suppress backgrounds mostly present in the Ξ_c^+ mass region. To both distributions we adjust the sum of two Gaussians with fixed widths (given by Monte Carlo) and a second degree polynomial. The results of the fits are summarized in Table 1. For the decay $\Xi_c^+ \to \Sigma^+\pi^-\pi^+$ we observe $S = 58.7 \pm 13.5$ signal events over a background of $B = 87.3 \pm 6.7$, corresponding to a significance $S/\sqrt{B} = 6.3 \pm 1.5$. For the decay $\Xi_c^+ \to \Sigma^-\pi^+\pi^+$ we observe $S = 22.3 \pm 7.5$ sig-

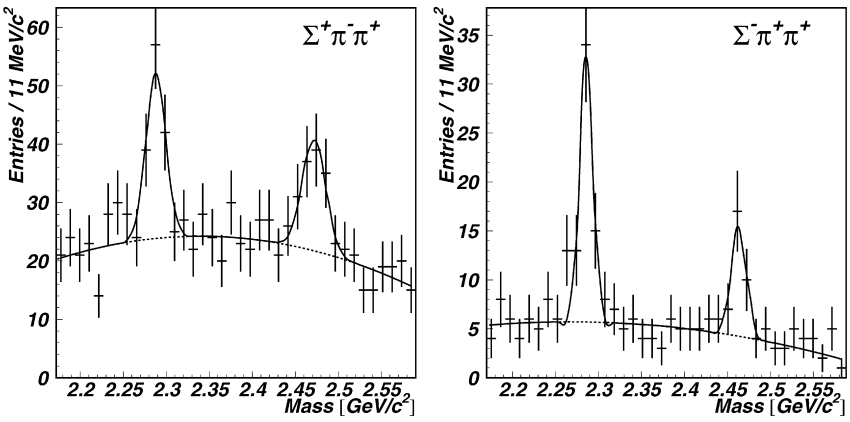

Fig. 3. Invariant mass distributions of $\Sigma^+\pi^-\pi^+$ (left) and $\Sigma^-\pi^+\pi^+$ (right).

nal events over a background of $B = 12.8 \pm 2.5$, corresponding to a significance $S/\sqrt{B} = 6.2 \pm 2.2$. The masses of both the Λ_c^+ and the Ξ_c^+ are slightly higher (in the case of $\Sigma^+\pi^-\pi^+$) and lower ($\Sigma^-\pi^+\pi^+$) than the nominal values. Varying the bin width and the fixed widths of the Gaussians also gives consistent results. We verified that the number of observed events varies as a function of the cut variables, especially L and L/σ, in the same way as expected from Monte Carlo (e.g. the observed events have the lifetime of the Ξ_c^+).

5. Measurement of branching ratios

For the different branching ratio measurements we used different selection cuts, chosen under the criteria to minimize systematic effects on the final result. We selected central cut values within a region where the Monte Carlo described well the distributions of all the observables, for both the decay mode of interest and the normalization mode. If the same mode was used in different branching ratio determinations, this selection could result in a different set of cuts. We only used interactions initiated by a Σ^- as beam particle and all decay products (with the exception of the hyperons) had to be within the RICH acceptance and correspondingly identified. In the different modes we removed events stemming from the following reflections due to ambiguities in the mass assignments: $D^+ \to K^-\pi^+\pi^+$ (1), $D^+ \to K^+K^-\pi^+$ (2), $D^+ \to K^+\pi^-\pi^+$ (3), $D_s^+ \to K^+K^-\pi^+$ (4), $D_s^+ \to K^+\pi^-\pi^+$ (5), $\Lambda_c^+ \to p\pi^-\pi^+$ (6), $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$ (7), $\Lambda_c^+ \to pK^-\pi^+$ (8), $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ (9), $\Xi_c^+ \to \Sigma^+K^-\pi^+$ (10). We indicate the removed reflections and the corrections due to the removal in Tables 2 and 3.

In Fig. 4 we show the invariant mass distributions of $\Sigma^+\pi^-\pi^+$, $\Sigma^-\pi^+\pi^+$, $pK^-\pi^+$, and $\Xi^-\pi^+\pi^+$ in the Ξ_c^+ mass region.

To verify our analysis method we determine the relative branching ratios of two Λ_c^+ decay modes which are identical to our newly observed Ξ_c^+ modes, using the fact that every CF Λ_c^+ decay mode is also a CS Ξ_c^+ mode. In Fig. 5 we show the invariant mass distributions of $\Sigma^+\pi^-\pi^+$, $\Sigma^-\pi^+\pi^+$, and $pK^-\pi^+$ in the Λ_c^+ mass region.

The number of observed events was determined by adjusting a Gaussian of fixed width (given by Monte Carlo) and a first-order polynomial to the distributions shown in Figs. 4 and 5.[17] While most of the reflections lie outside of the mass peaks and are removed to smoothen the backgrounds, some of them extend below the peaks and remove good events; we studied this effect carefully with Monte Carlo and corrected the number of observed events for these losses. To determine the correction we simulated the shape of the invariant mass distribution of the reflected mode (including all cuts) and scaled the number of events below the peak region to the number of observed events in the reflected mode, keeping the same relative error for the number of observed events. We also studied correlations for the cases where more than one reflection was removed and found them to be small and negligible. The corrected yields for the different modes are, along with the

[17] Counting the number of entries above the extrapolated background, and using a second-order polynomial for the background, we obtain within errors the same number of events.

Table 2
Number of observed events and total acceptances for the different Ξ_c^+ decay modes, with the corresponding cuts applied to each mode. Common cuts are: $\chi^2_{\rm sec} < 8$, $\sigma < 0.10$ cm, $scut > 8$, $p_{\rm hyp} > 40$ GeV/c. The first two rows refer to the signals shown in Fig. 3, with different common cuts as described in Section 4. "Corrected Events" are the number of observed events plus the corrections due to the removal of reflections and are shown separately in parenthesis; we keep the relative error from the fits

Ξ_c^+ mode	L/σ	$pvtx$	Σ_{pt^2} [GeV$^2/c^2$]	Removed reflections	Corrected events	Acceptance [%]
$\Sigma^+\pi^-\pi^+$	>12	<13	>0.4	(10)	58.7 ± 13.5	0.750
$\Sigma^-\pi^+\pi^+$	>8	<10	>0.5	(9)	22.3 ± 7.5	0.950
$pK^-\pi^+$	>11	<13	>0.3	(1, 2, 4, 6)	$(47.4 + 14.0) \pm 14.0$	4.164
$\Xi^-\pi^+\pi^+$				(7)	$(67.0 + 2.4) \pm 10.9$	0.915
$\Sigma^+\pi^-\pi^+$	>13	<13	>0.35	(6)	$(20.7 + 1.6) \pm 8.6$	0.586
$\Xi^-\pi^+\pi^+$				(7)	$(63.3 + 2.0) \pm 10.4$	0.825
$\Sigma^-\pi^+\pi^+$	>13	<10	>0.35	(2, 3, 5, 9)	$(9.5 + 5.0) \pm 6.4$	0.988
$\Xi^-\pi^+\pi^+$				(7)	$(61.1 + 2.6) \pm 9.3$	0.800
$\Sigma^-\pi^+\pi^+$	>13	<10	>0.35	(2, 3, 5, 9)	$(9.5 + 5.0) \pm 6.4$	0.988
$\Sigma^+\pi^-\pi^+$				(6)	$(18.4 + 1.5) \pm 7.5$	0.570

Table 3
Number of observed events and total acceptances for the different Λ_c^+ decay modes, with the corresponding cuts applied to each mode. Common cuts are: $\chi^2_{\rm sec} < 4$, $\sigma < 0.10$ cm, $scut > 8$, $p_{\rm hyp} > 40$ GeV/c. The first two rows refer to the signals shown in Fig. 3, with different common cuts as described in Section 4. "Corrected Events" are the number of observed events plus the corrections due to the removal of reflections and are shown separately in parenthesis; we keep the relative error from the fits

Λ_c^+ mode	L/σ	$pvtx$	Σ_{pt^2} [GeV$^2/c^2$]	Removed reflections	Corrected events	Acceptance [%]
$\Sigma^+\pi^-\pi^+$	>12	<13	>0.4	(10)	74.2 ± 13.8	0.450
$\Sigma^-\pi^+\pi^+$	>8	<10	>0.5	(9)	46.4 ± 10.1	0.500
$\Sigma^+\pi^-\pi^+$	>11	<7	>0.3	(8)	$(46.6 + 3.0) \pm 9.6$	0.292
$pK^-\pi^+$				–	$(561.2 + 0.0) \pm 25.5$	2.367
$\Sigma^-\pi^+\pi^+$	>11	<4	>0.4	(5, 9)	$(29.7 + 2.2) \pm 6.6$	0.434
$pK^-\pi^+$				–	$(450.7 + 0.0) \pm 22.3$	1.923
$\Sigma^-\pi^+\pi^+$	>11	<4	>0.4	(5, 9)	$(29.7 + 2.2) \pm 6.6$	0.434
$\Sigma^+\pi^-\pi^+$				(8)	$(43.0 + 3.4) \pm 8.1$	0.241

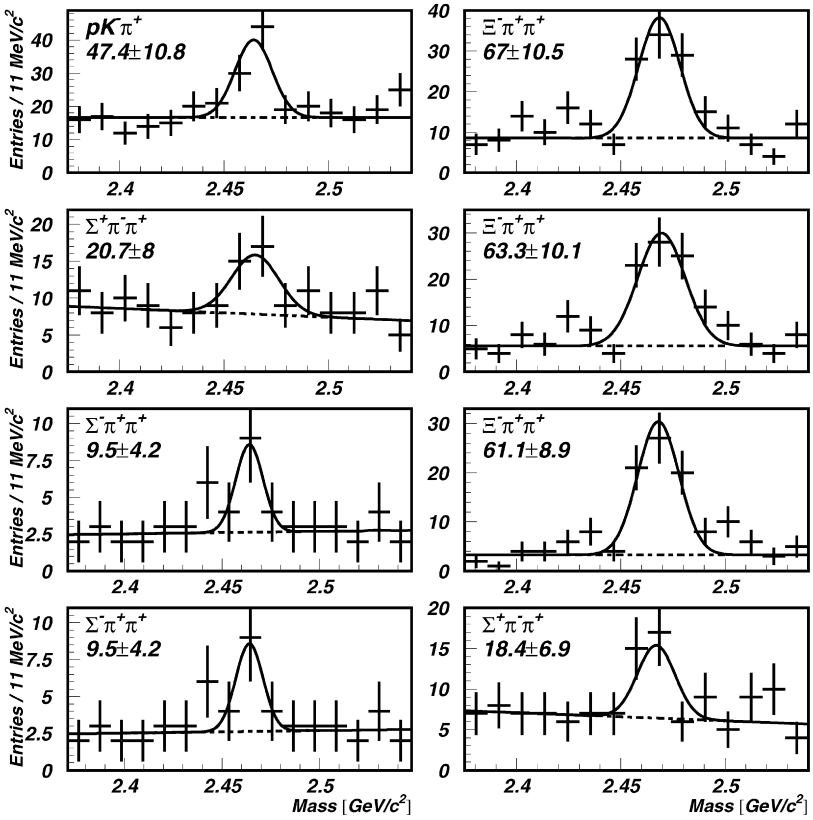

Fig. 4. Eight invariant mass distributions of: $pK^-\pi^+$, $\Sigma^+\pi^-\pi^+$, $\Sigma^-\pi^+\pi^+$, $\Xi^-\pi^+\pi^+$, used to determine the four relative branching ratios (in pairs from top to bottom) $B(\Xi_c^+ \to pK^-\pi^+)/B(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$, $B(\Xi_c^+ \to \Sigma^+\pi^-\pi^+)/B(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$, $B(\Xi_c^+ \to \Sigma^-\pi^+\pi^+)/B(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$, and $B(\Xi_c^+ \to \Sigma^-\pi^+\pi^+)/B(\Xi_c^+ \to \Sigma^+\pi^-\pi^+)$, respectively. Different selection cuts were used for each branching ratio (see text). We adjust a Gaussian (fixed width given by Monte Carlo) over a linear background to each of the distributions. The event yields are summarized in Table 2.

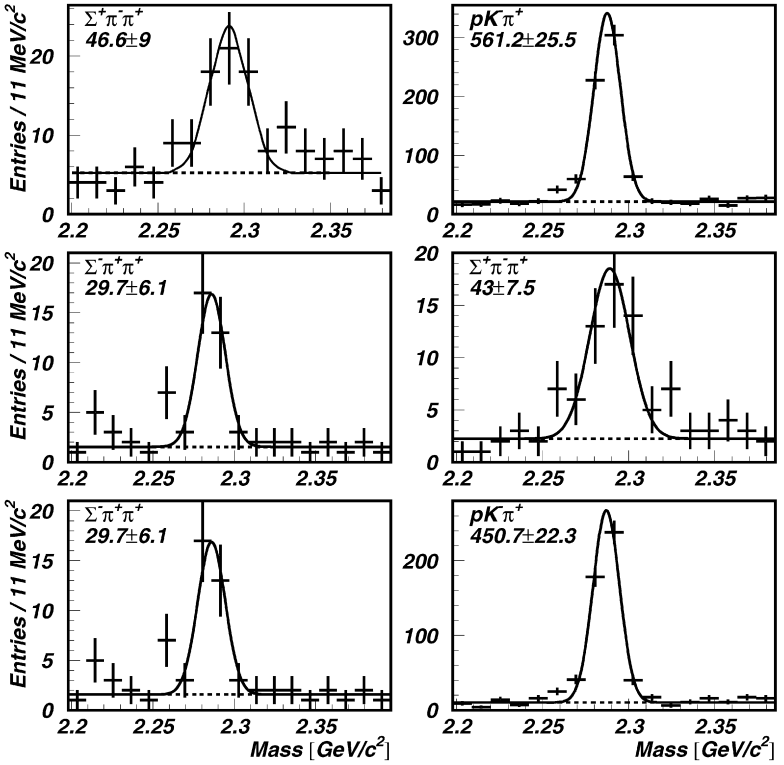

Fig. 5. Six invariant mass distributions of: $\Sigma^+\pi^-\pi^+$, $pK^-\pi^+$, $\Sigma^-\pi^+\pi^+$, used to determine the three relative branching ratios (in pairs from top to bottom) $B(\Lambda_c^+ \to \Sigma^+\pi^-\pi^+)/B(\Lambda_c^+ \to pK^-\pi^+)$, $B(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+)/B(\Lambda_c^+ \to \Sigma^+\pi^-\pi^+)$, and $B(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+)/B(\Lambda_c^+ \to pK^-\pi^+)$, respectively. Different selection cuts were used for each branching ratio (see text). We adjust a Gaussian (fixed width given by Monte Carlo) over a linear background to each of the distributions. The event yields are summarized in Table 3.

Table 4
Results of the different branching ratios measured in this analysis, and comparison to previously published results (if available). Also shown is the α-parameter (see text) for each branching ratio result

Branching ratio	This analysis	Other measurements
$B(\Xi_c^+ \to \Sigma^+\pi^-\pi^+)/B(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$	0.48 ± 0.20 $\alpha = 6.4 \pm 2.7$	–
$B(\Xi_c^+ \to \Sigma^-\pi^+\pi^+)/B(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$	0.18 ± 0.09 $\alpha = 2.5 \pm 1.2$	–
$B(\Xi_c^+ \to \Sigma^-\pi^+\pi^+)/B(\Xi_c^+ \to \Sigma^+\pi^-\pi^+)$	0.42 ± 0.24 $\alpha = 0.43 \pm 0.25$	–
$B(\Xi_c^+ \to pK^-\pi^+)/B(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$	0.194 ± 0.054 $\alpha = 2.6 \pm 0.7$	$0.234 \pm 0.047 \pm 0.022$ [4] $0.20 \pm 0.04 \pm 0.02$ [3]
$B(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+)/B(\Lambda_c^+ \to pK^-\pi^+)$	0.314 ± 0.067 $\alpha = 0.30 \pm 0.07$	–
$B(\Lambda_c^+ \to \Sigma^+\pi^-\pi^+)/B(\Lambda_c^+ \to pK^-\pi^+)$	0.72 ± 0.14 $\alpha = 0.68 \pm 0.14$	$0.74 \pm 0.07 \pm 0.09$ [7] $0.54^{+0.18}_{-0.15}$ [6]
$B(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+)/B(\Lambda_c^+ \to \Sigma^+\pi^-\pi^+)$	0.38 ± 0.10 $\alpha = 0.39 \pm 0.11$	$0.53 \pm 0.15 \pm 0.07$ [8]

cuts used to obtain the distributions and the corresponding total acceptances, presented in Tables 2 and 3.

To obtain the branching ratios, we divided the number of observed (corrected) events of the two modes, and divided again by the relative acceptance. The statistical error on the acceptance is negligible, and most systematic errors cancel in the relative acceptance.

For the systematic studies we varied any single cut value, as well as the parameter n for the x_F distribution in the Monte Carlo simulation, within some range and determined the branching ratio for every set of parameters; for the set of cuts used we did not observe evidence of any trend; all systematic variations are small compared to the statistical error and will be ignored in the final results since they would not affect the quadrature sum of the total error.

The resulting branching ratios are shown, together with previously measured values, in Table 4.

6. Discussion and conclusions

In Table 4 we summarize the results for the different branching ratios measured in this work. Comparing our results with previously measured ones (where available) shows good agreement.

To quantify the effects of final-state quark rearrangements in the different decays via the relevant relative matrix elements, we calculate α, which is defined as the measured relative branching ratio corrected for phase space differences and, in the case of comparing CF and CS modes, for the ratio of the CKM matrix elements ($V_{cd}/V_{cs} = 0.233 \pm 0.001$ [12]). We note that the α-parameter for $B(\Sigma^-\pi^+\pi^+)/B(\Sigma^+\pi^-\pi^+)$ is consistent in the decays of both the Λ_c^+ and the Ξ_c^+. Comparing the diagrams in Figs. 1 and 2 we conclude that the source of the final-state quark does not affect the relative matrix element significantly.

In summary, we observe for the first time the Cabibbo-suppressed decay modes $\Xi_c^+ \to \Sigma^+\pi^-\pi^+$ and $\Xi_c^+ \to \Sigma^-\pi^+\pi^+$ and estimate their branching ratios. With the same analysis method we also analyze previously reported modes of both the Ξ_c^+ and the Λ_c^+ and find good agreement.

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