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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

SELEX Collaboration

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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].

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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 ($\approx$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 $\chi^2_{\text{sec}} < 9$, 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