THE Λ_c - NOT YOUR AVERAGE BEARYON

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ABSTRACT

We report on studies of hadronic Λ_c decay modes which are expected to proceed through diagrams other than the simple external W-emission diagram. Signals are reported for the decay modes: $pK_s^0\eta$, $\Lambda\eta\pi^+$, $\Sigma^+\eta$, and $\Lambda K_s^0 K^+$. Branching fractions are calculated relative to the normalizing mode: $\Lambda_c \to pK\pi$.

1. Introduction

Since its discovery almost 15 years ago, the Λ_c has been a source of important information on weak decays of heavy baryons. The last five years have witnessed increasingly precise measurements of the Λ_c lifetime,[1,2] as well as probes of the rare decay sector. The Λ_c is typically modeled as a system containing a heavy charm quark surrounded by an inert (ud) diquark, bound in an S=0 state, with L=0 relative to the heavy charm quark. The (ud) system is in an isospin=0 state, unlike the Σ_c, which has I=1. The simplest picture of Λ_c decays then is as the weak decay of the charm quark to the strange quark by external W-emission, such that the (ud) diquark is entirely decoupled from the $c \to s$ transition. In such a naive picture, $\mathcal{B}(\Lambda_c \to \Lambda X)$=100%. However, the tabulated value for this inclusive decay is 27$\pm$9%[7]; moreover, the simplest spectator decay $\mathcal{B}(\Lambda_c \to \Lambda\pi^+) = 0.58 \pm 0.16\%$[7]; by comparison the comparable decay in the charmed meson sector: $D^0 \to K^-\pi^+$ has a branching ratio about 8 times as large. This, coupled with the measurement of a Λ_c lifetime half that of the D^0 and the D_s, indicates that there is a large hadronic width proceeding by diagrams other than the simple external W-emission diagram. To some extent, this is to be expected in the baryonic sector, where exchange decays ($\Lambda_c \to \Sigma^+\phi$, e.g.) are not subject to the same helicity suppression operative in charmed meson decays. The fact that $\Lambda_c \to pK\pi$ is so large also indicates that internal W-emission could play a substantial role in charmed baryon decays. In this paper, we report on an analysis of Λ_c's to rare final states which are candidates for non-external spectator decays.

*With inspiration from Yogi Berra and Don Fujino

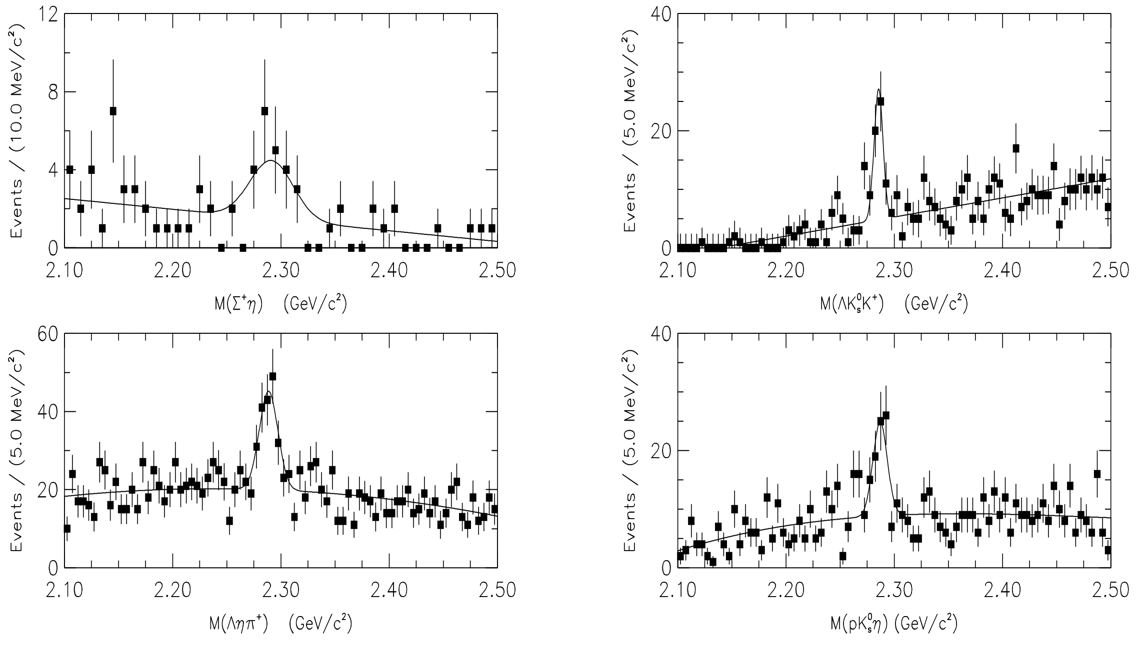
2. Data Sample and Event Selection

The data were collected with the CLEO II detector at the Cornell e^+e^- storage ring CESR, which operated on, and just below, the $\Upsilon(4S)$ resonance. The CLEO II detector[8] is a large solenoidal detector with 67 tracking layers and a CsI electromagnetic calorimeter that provides efficient π^0 and η reconstruction. We have used a total integrated luminosity of 3.25 fb^{-1}, which corresponds to roughly 4 million $c\bar{c}$ events. Events with three charged tracks originating from the known primary vertex which satisfy a minimum energy cut in the crystal calorimeter constitute the candidate hadronic event sample.

K_s^o and Λ candidates are selected through their decays $K_s^o \to \pi^+\pi^-$ and $\Lambda \to p\pi^-$ by reconstructing a secondary decay vertex. Protons, kaons, and pions are identified using dE/dx and time-of-flight information, when available. η and π^0 candidates are selected through their decays to $\gamma\gamma$ from pairs of well-defined showers in the CsI calorimeter. We kinematically fit the photon momenta to the nominal parent mass in order to improve the parent momentum estimate. The Σ^+ particle is identified through its decay into $p\pi^0$.[6] The Σ^+ momentum measurement is refined by computing the proton and π^0 momenta at the location of the Σ^+ decay vertex. Charged tracks that do not arise from long-lived particles (Λ, K_s^o, and Σ^+) must have a distance of closest approach in the $r-\phi$ plane of less than 5 mm to the interaction point, and be within 5 cm in $\hat{z}$.

3. Observation of new Λ_c decay modes

We search for the decay modes: $\Lambda_c \to pK^+\eta$, $\Lambda_c \to \Lambda K^o K^+$, $\Lambda_c \to \Sigma^+\eta$, and $\Lambda_c \to \Lambda\eta\pi^+$ by combining the candidate daughter particles and requiring that the scaled momentum $x_p(\Lambda_c^+) > 0.5$, where $x_p(\Lambda_c^+) = P_{\Lambda_c^+}/\sqrt{E_{beam}^2 - M_{\Lambda_c^+}^2}$. Invariant mass spectra for the four decay modes of interest are displayed in Figures 1.



Figs. 1. Candidate Λ_c invariant mass spectra for the modes indicated.

4. Results and discussion

Event yields, calculated efficiencies based on a GEANT-based full CLEO detector simulation, and the extracted ratio of branching ratios relative to the decay $\Lambda_c \to pK\pi$ are presented in Table 1. Table 2 gives the breakdown of our systematic errors. Table 3 presents our results in comparison with theoretical predictions.

Table 1. Summary of event yields for new Λ_c modes.

Λ_c^+ decay mode	Number of events	Efficiency (%)	$\mathcal{B}/\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$
$pK^0\eta$	53 ± 10	7.3	$0.25 \pm 0.05 \pm 0.04$
$\Lambda\eta\pi^+$	109 ± 16	8.5	$0.36 \pm 0.06 \pm 0.05$
$\Sigma^+\eta$	25 ± 7	5.2	$0.10 \pm 0.03 \pm 0.02$
$\Lambda\bar{K}^0K^+$	46 ± 8	7.9	$0.11 \pm 0.02 \pm 0.02$

Table 2. Summary of systematic errors

Source	Fractional Error (%)			
	$pK_s^0\eta$	$\Lambda\eta\pi^+$	$\Sigma^+\eta$	$\Lambda K_s^0K^+$
K_s^0, Λ, and Σ^+ finding	10	10	10	14
η and π^0 finding	5	5	7	—
Tracking efficiency	—	—	4	4
Proton and kaon identification	8	2	2	—
$pK^-\pi^+$ substructure	7	2	2	5
Λ_c^+ substructure	—	6	—	—
Uncertainties in $\sigma_{\Lambda_c^+}$	5	5	5	5
Monte Carlo statistics	3	3	3	3
TOTAL	16	14	14	16

Table 3. Results for $\Lambda_c \to \Sigma^+\pi^o$ compared with theoretical predictions.

	$\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^+\pi^0)}{B(pK^-\pi^+)}$	$\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^+\eta)}{B(pK^-\pi^+)}$
CLEO	$0.20 \pm 0.03 \pm 0.03$	$0.10 \pm 0.03 \pm 0.02$
Körner and Krämer[9]	0.10	0.05
Zenczykowski[10]	0.13	0.08

5. Comment on Results and $\mathcal{B}(\Lambda_c \to pK\pi)$

The branching ratios relative to $\Lambda_c \to pK\pi$ are shown in Figure 2.

We note the following:

1. $\frac{\mathcal{B}(\Lambda_c \to pK^o\eta)}{\mathcal{B}(\Lambda_c \to pK^o\pi^o)} \sim 0.5$. If the modes $\Lambda_c \to pKX$ occur through the internal spectator diagram, with $W_{int} \to u\bar{d}$ and $d\bar{d}$ or $u\bar{u}$ popping between the $\bar{d}$ and the s-quark (as shown in the diagram below), then, since $\pi^o = \frac{u\bar{u}-d\bar{d}}{\sqrt{2}}$, π^+=u$\bar{d}$, and $\eta^o = \frac{u\bar{u}+d\bar{d}-2s\bar{s}}{\sqrt{6}}$,

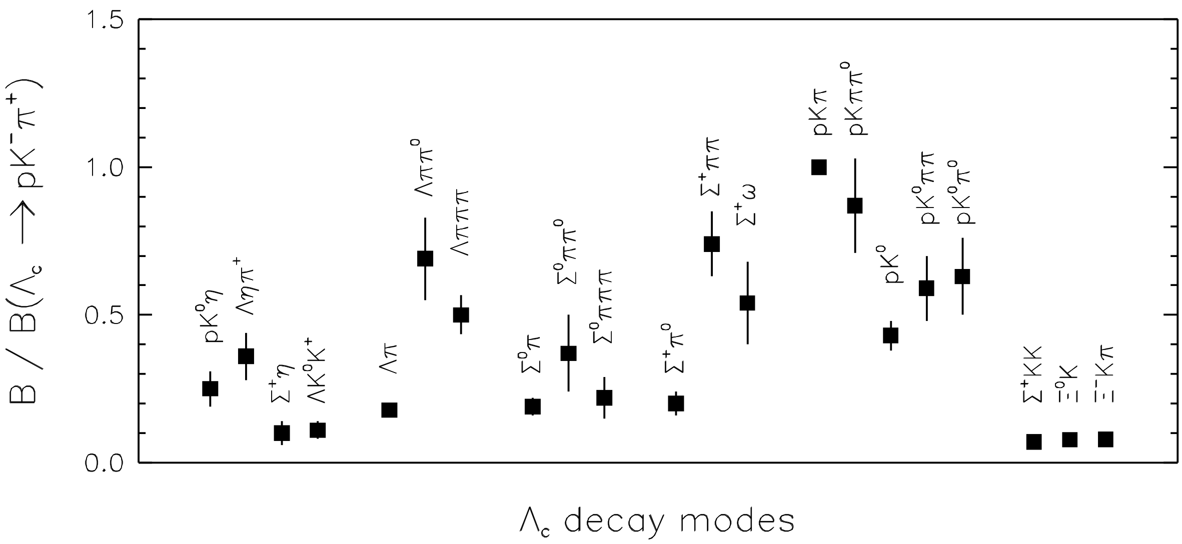
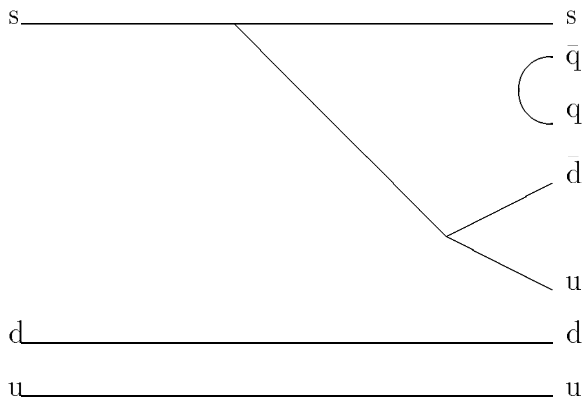


Fig. 1. Figure 2. Branching fractions of Λ_c^+ decays relative to the normalizing decay mode $\Lambda_c^+ \rightarrow pK^-\pi^+$ from recent CLEO measurements.

we would expect $\mathcal{B}(\Lambda_c \rightarrow pK\pi) : \mathcal{B}(\Lambda_c \rightarrow p\bar{K}^o\pi^o) : \mathcal{B}(\Lambda_c \rightarrow pK\eta)$ = 1:2:6. Our data are in agreement with this.



2. $\frac{\mathcal{B}(\Lambda_c\rightarrow\Lambda\eta\pi^+)}{\mathcal{B}(\Lambda_c\rightarrow\Lambda\pi^o\pi^+)} \sim 0.5$. By the same argument above, if there is no resonant enhancement of $\Lambda_c \rightarrow \Lambda\pi^o\pi^+$ through the external W-diagram: $\Lambda_c \rightarrow \Lambda\rho^+; \rho^+ \rightarrow \pi^o\pi^+$, then the ratio of these branching ratios should be again 1:3. In fact, examination of the $\pi^o\pi^+$ invariant mass spectrum in the $\Lambda\pi^+\pi^o$ final state is entirely consistent with phase space; our data are therefore consistent with a simple quark popping model.

3. $\frac{\mathcal{B}(\Lambda_c\rightarrow\Lambda K^oK^+)}{\mathcal{B}(\Lambda_c\rightarrow\Lambda\pi^o\pi^+)} \sim 0.15$. The ratio of inclusive kaon to inclusive pion yields at $\sqrt{s}$=10 GeV suggests that the fraction of times an s$\bar{s}$ pair is popped from the vacuum compared with the sum of u$\bar{u}$ and d$\bar{d}$ is about $\frac{1}{6}$. Our data are therefore once again consistent with the simple quark-popping model given above.

4. $\frac{\mathcal{B}(\Lambda_c\to\Sigma^+\eta)}{\mathcal{B}(\Lambda_c\to\Sigma^+\pi^o)}\sim 0.5$, and $\frac{\mathcal{B}(\Lambda_c\to\Sigma^+\eta)}{\mathcal{B}(\Lambda_c\to\Sigma^+\phi)}\sim 1.0$. The $\Lambda_c\to\Sigma^+\phi$ decay mode is expected to proceed dominantly through a W-exchange diagram, the $\Lambda_c\to\Sigma^+\pi^o$ mode through an internal spectator diagram. The $\Lambda_c\to\Sigma^+\eta$ mode is accessible through both of these diagrams, with some unknown fraction of each contributing to the final state. Non-observation of the $\Sigma^+\eta$ final state would then be somewhat surprising; given our large errors, we can only state here that this mode appears to have approximately the branching ratio one might expect by inference from the other Σ^+X modes.

Taken together, these modes constitute new evidence for diagrams other than the external W-diagram contributing to the total hadronic Λ_c decay width. This is consistent with the observed shortness of the Λ_c lifetime and also the fact that the inclusive $\Lambda_c\to\Lambda$+X rate is not large.

Finally, it should be remarked here that the normalizing mode, $\Lambda_c\to pK\pi$ was derived[11] using a model of $B\to baryons$ which has recently been shown to be incomplete.[12] The impact of this on the derived value of $\mathcal{B}(\Lambda_c\to pK\pi)$ has yet to be evaluated; it could result in a 20-30% shift in the branching fraction.

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