12 January 1995

PHYSICS LETTERS B

Physics Letters B 342 (1995) 397–401

Evidence for W-exchange in charmed baryon decays

ARGUS Collaboration

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Received 1 November 1994
Editor: K. Winter

Abstract

Using the detector ARGUS at the e^+e^- storage ring DORIS II at DESY, we have observed the decays $\Lambda_c^+ \to \Xi^- K^+ \pi^+$ and $\Lambda_c^+ \to \Xi^{*0} K^+$ and obtained evidence for the decay $\Xi_c^0 \to \Lambda K_s^0$. All three of these decays are of interest as they provide information about W-exchange processes. The products of cross sections and branching ratios for $\Lambda_c^+ \to \Xi^- K^+ \pi^+$ and $\Lambda_c^+ \to \Xi^{*0} K^+$ are $(1.7 \pm 0.3 \pm 0.3)$ pb and $(0.6 \pm 0.2 \pm 0.1)$ pb, respectively, which implies that $(35 \pm 17)\%$ of the $\Xi^- K^+ \pi^+$

SSDI 0370-2693(94)01513-9

final state is generated through a two-body decay via intermediate W-exchange. The product of production cross section and branching ratio for $\Xi_c^0 \to \Lambda K_s^0$ is $(2.1 \pm 1.0 \pm 0.6)$ pb.

Recent experimental advances have stimulated renewed interest in the properties of the charmed baryons [1]. Charmed baryons provide an interesting laboratory in which to study the charmed quark, as they can decay not only via straightforward spectator processes, but also through the more exotic W-exchange mechanism. The advantage of studying charmed baryons over charmed mesons is that W-exchange, though helicity-suppressed in the latter (in analogy to the decay $\pi^- \to e^-\bar{\nu}$) is not suppressed in the former [2]. For a recent review see [3].

In this letter, we report on a search for the charmed baryon decays [11]

$$\Lambda_c^+ \to \Xi^- K^+ \pi^+ \quad (1)$$

$$\Lambda_c^+ \to \Xi^{*0} K^+ \quad (2)$$

$$\Xi_c^0 \to \Lambda K_s^0. \quad (3)$$

In the absence of final state interactions, the only way in which decays 2 and 3 can occur is via a W-exchange process. Therefore, observation of these decays provides strong evidence for W-exchange in charmed baryon decays. The Feynman diagrams for these decays are shown in Fig. 1. Observation of the channel $\Lambda_c^+ \to \Xi^- K^+ \pi^+$ and its subchannel $\Lambda_c^+ \to \Xi^{*0} K^+$ has been reported by the CLEO Collaboration [4].

The analysis described in this paper is based on a data sample of 396 pb^{-1} taken at an average centre-of-mass energy of 10.4 GeV using the detector ARGUS at the e^+e^- storage ring DORIS II of DESY. ARGUS is a 4π spectrometer described in detail elsewhere [5]. Charged particle identification is made on the basis of specific ionization in the drift chamber, velocity measurements through the time of flight system, energy deposits in the shower counters, and muon chamber hits. Information from these devices is used to calculate, for all charged tracks, a normalized likelihood for each of the particle hypotheses (π, K, p). All particle hypotheses with a normalized likelihood greater than 1% were accepted. Unless otherwise specified, all tracks were required to fit to the associated vertex with a χ^2 less than 36 and to have $dr < 1.5$ cm and $dz < 5$ cm, where dr and dz are the radial and z distances, respectively, of the track from the vertex.

We first describe the Λ_c^+ decays. The final state $\Xi^- K^+ \pi^+$ was reconstructed, and the extent to which the two-body channel contributed to the total $\Xi^- K^+ \pi^+$ signal was determined.

Λ candidates were identified in the decay mode $\Lambda \to p\pi^-$. All $p\pi^-$ combinations having a mass within ± 9 MeV/c^2 of the nominal Λ mass [6] and fitting to a secondary vertex with a χ^2 less than 36 were accepted as Λ candidates. Surviving combinations which satisfied the Λ mass hypothesis with a χ^2 of less than 25 were accepted and subjected to a mass-constrained fit. Backgrounds from beam-wall and beam-gas interactions, in which many Λ's but no $\bar{\Lambda}$'s are produced, were removed by requiring that the momentum vector of the $p\pi^-$ combination point back to the main vertex. This condition was enforced by demanding that the cosine of α, the angle between the $p\pi^-$ momentum vector and the vector between main and secondary vertices, be greater than 0.985.

The Ξ^- candidates were selected from $\Lambda\pi^-$ combinations. When reconstructing the Ξ^-, we made use of the fact that its $c\tau$ is 4.91 cm [6] and that it therefore need not decay at the main vertex. Conse-

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[1] DESY, IfH Zeuthen.
[2] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054DO51P.
[3] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 056DD11P.
[4] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054ER12P.
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[9] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 055KA11P.
[10] Supported by the Ministry of Science and Technology of the Republic of Slovenia and the Internationales Büro KfA, Jülich.
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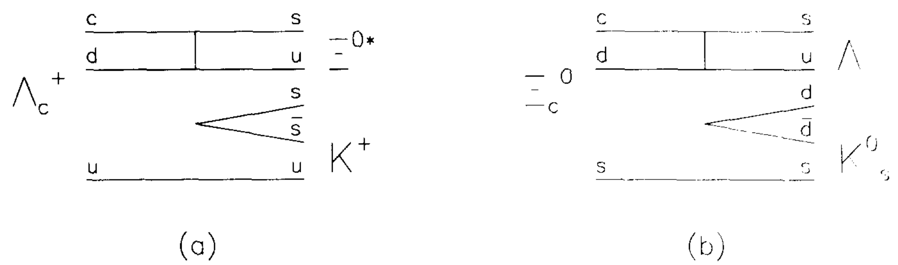

Fig. 1. The Feynman diagrams for the decays $\Lambda_c^+ \to \Xi^{*0} K^+$ and $\Xi_c^0 \to \Lambda K_s^0$.

quently no cuts were made on the radial or z distances of the pion track from the main vertex, and the χ^2 of the vertex fit for the π^- candidate was required to be greater than 16. This cut reduces the background beneath the Ξ^- signal by 81% while retaining 56% of the signal. Accepted $\Lambda\pi^-$ combinations were required to lie within 12 MeV$/c^2$ of the nominal Ξ^- mass and were subjected to a mass-constrained fit. The cosine of the angle between the Λ_c^+ boost and the pion flight direction in the Λ_c^+ rest frame was required to be greater than -0.8 to reduce combinatorial background, since for an unpolarized Λ_c^+ this distribution is expected to be flat. Finally, surviving $\Xi^- K^+ \pi^+$ combinations were required to have x_p greater than 0.5, where $x_p = p(\Xi^- K^+ \pi^+)/p_{\max}$, and $p_{\max} = \sqrt{E_{\text{beam}}^2 - m^2(\Xi^- K^+ \pi^+)}$.

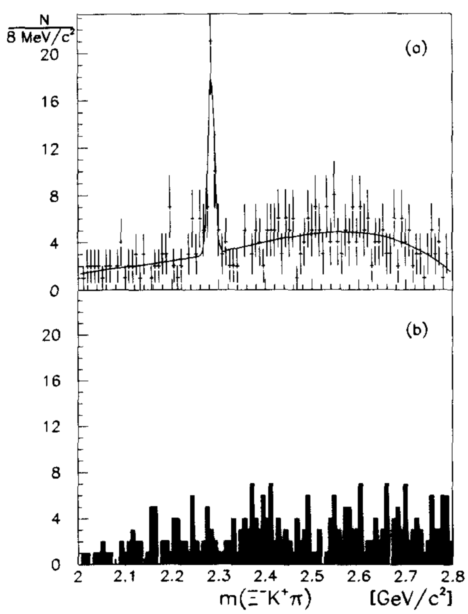

Fig. 2. (a) The invariant mass of all accepted $\Xi^- K^+ \pi^+$ combinations. The curve displays the fit described in the text. (b) The wrong sign distribution.

The resulting $\Xi^- K^+ \pi^+$ mass spectrum is shown in Fig. 2(a) and displays a clear peak at the Λ_c^+ mass. The spectrum was fitted with a third order polynomial multiplied by a square root threshold factor to describe the background, and a Gaussian with width fixed at 7 MeV$/c^2$ as determined in a Monte Carlo simulation. The signal contains (33.6 ± 6.7) events at a mass of (2284.8 ± 1.8) MeV$/c^2$ in excellent agreement with the nominal value [6].

In Fig. 2(b) the wrong sign mass spectrum is plotted. It was obtained by selecting all $\Xi^- K^+ \pi^-$ combinations which survived the above cuts. This distribution was studied to ensure that no enhancement at the position of the Λ_c^+ mass appears in the background whose shape is the same as that in the right sign distribution.

We next examine the $\Xi^- \pi^+$ submass. In Fig. 3 the mass spectrum of all $\Xi^- \pi^+$ combinations surviving the above cuts is displayed. There is a clear signal at the Ξ^{*0} mass of 1.532 GeV$/c^2$. To determine how

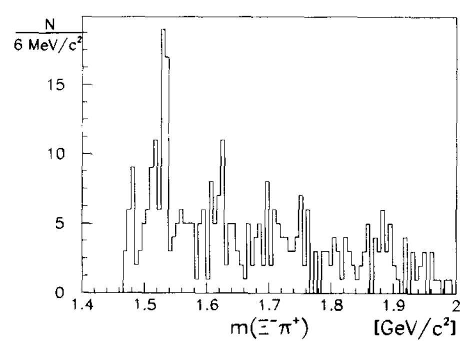

Fig. 3. The invariant mass of all accepted $\Xi^- \pi^+$ combinations which survived the cuts on the $\Xi^- K^+ \pi^+$ combinations. There is a clear signal at the Ξ^{*0} mass.

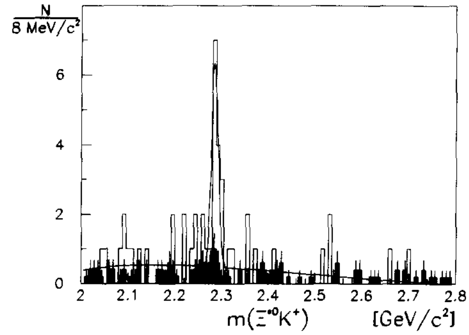

Fig. 4. The $\Xi^- K^+ \pi^+$ invariant mass spectrum after a cut around the Ξ^{*0} signal (unshaded histogram). Shaded: The scaled mass spectrum obtained from the Ξ^{*0} sidebands; it displays no enhancement in the Λ_c^+ signal region.

much this signal contributes to the Λ_c^+ signal and how much of the Λ_c^+ is non-resonant we have fitted the Λ_c^+ signal while applying a cut around the Ξ^{*0} mass. We have also looked at the Λ_c^+ signal from the Ξ^{*0} sidebands.

The $\Xi^- K^+ \pi^+$ distribution after a ± 12 MeV$/c^2$ cut on the Ξ^{*0} is shown in Fig. 4. It was fitted to the function described above with the mass fixed to the measured value. A total of (13.1 ± 3.9) events were found in the signal region. The $\Xi^- K^+ \pi^+$ distribution from 60 MeV$/c^2$ sidebands above and below the accepted Ξ^{*0} region was also obtained, and when fitted, contained (8.4 ± 3.4) events at the Λ_c^+ mass. Since the sideband region taken was five times wider than that of the signal region, the latter number was scaled down by a factor of five, yielding (1.7 ± 0.8) events. Subtracting the two numbers yielded (11.4 ± 3.9) events which can be attributed to the decay $\Lambda_c^+ \to \Xi^{*0} K^+$.

To obtain the branching ratios for the two Λ_c^+ decay channels, two sets of Monte Carlo events were generated. A total of 8000 events were generated in each of the decay channels $\Lambda_c^+ \to \Xi^- K^+ \pi^+$ and $\Lambda_c^+ \to \Xi^{*0} K^+$. When determining the $\Xi^- K^+ \pi^+$ reconstruction efficiency, a study was done to check if the efficiency for reconstruction was different in the presence of an intermediate state. As expected, no difference was found.

Extrapolation to zero momentum was done with the Peterson et al. fragmentation function [7] with an ϵ of 0.24 ± 0.04 [8]. The reconstruction efficiency for $\Lambda_c^+ \to \Xi^- K^+ \pi^+$ including the extrapolation to zero momentum, was found to be 8.0% , and that for the decay $\Lambda_c^+ \to \Xi^{*0} K^+$ was found to be 6%, the difference being due to the cut on the Ξ^{*0} mass. The systematic error was determined by varying the cuts and the background shape, as well as the extrapolation to zero momentum and the efficiency determination, and the background subtraction method. It was found to be about 12% for both decay channels. The final results for the two products of production cross section and branching ratio are

$$\sigma(\Lambda_c^+) \cdot (\Lambda_c^+ \to \Xi^- K^+ \pi^+) = (1.7 \pm 0.3 \pm 0.2) \text{ pb}$$

and

$$\sigma(\Lambda_c^+) \cdot (\Lambda_c^+ \to \Xi^{*0} K^+) = (0.6 \pm 0.2 \pm 0.1) \text{ pb},$$

implying that $(35 \pm 17)\%$ of the decay $\Lambda_c^+ \to \Xi^- K^+ \pi^+$ proceeds via a two-body intermediate state. Using the recent ARGUS value [8]

$$\sigma \cdot \text{BR}(\Lambda_c^+ \to p K^- \pi^+) = (12.0 \pm 1.1 \pm 1.3) \text{ pb}$$

, we arrive at the two ratios

$$\frac{\text{BR}(\Lambda_c^+ \to \Xi^- K^+ \pi^+)}{\text{BR}(\Lambda_c^+ \to p K^- \pi^+)} = 0.14 \pm 0.03 \pm 0.02$$

and

$$\frac{\text{BR}(\Lambda_c^+ \to \Xi^{*0} K^+)}{\text{BR}(\Lambda_c^+ \to p K^- \pi^+)} = 0.05 \pm 0.02 \pm 0.01,$$

where the reduction in systematic error occurs because the uncertainty due to fragmentation has been removed. Our results on these channels are in agreement with those obtained by the CLEO Collaboration [4].

The second decay under study, $\Xi_c^0 \to \Lambda K_s^0$ is another possible W-exchange process. In the search for this decay, Λ's were reconstructed exactly as for the Λ_c^+ decays. The K_s^0 candidates were formed from $\pi^+ \pi^-$ combinations which fit to a secondary vertex and have an invariant mass within 40 MeV$/c^2$ of the nominal K_s^0 mass. Surviving candidates were subjected to a mass-constrained fit. The K_s^0 momentum was required to point back to the main vertex by requiring that $\cos\alpha$ be greater than 0.995. Since hadrons from charmed quark jets are collimated around the jet axis, events are required to have a thrust, T, such that $T > 0.9$. The x_p of the ΛK_s^0 combination was required to be greater than 0.6.

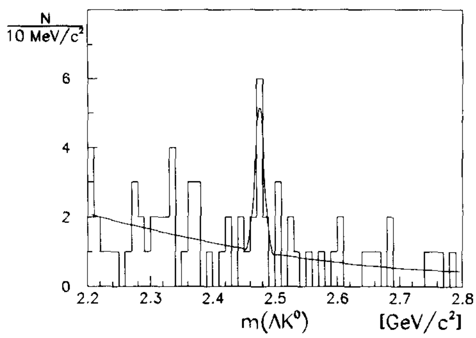

Fig. 5. The ΛK_s^0 invariant mass spectrum showing the Ξ_c^0 signal

The resulting ΛK_s^0 mass spectrum is shown in Fig. 5. An indication of a peak is visible at the mass of the Ξ_c^0, $m(\Xi_c^0 = (2470.3 \pm 1.8)$ MeV$/c^2$ [6]. The spectrum can be fit with a third order polynomial to describe the background, plus a Gaussian to describe the enhancement. With the width fixed at 11 MeV$/c^2$ as determined by a Monte Carlo study, we find 7.4 ± 3.2 events at a mass of (2474 ± 4) MeV$/c^2$, in agreement with the table value quoted above.

Interpreting this enhancement as a signal, the product cross section times branching ratio was determined as $\sigma \cdot \mathrm{BR} = (2.1 \pm 1.0 \pm 0.6)$ pb. The Peterson fragmentation function as measured by ARGUS for the Ξ_c^0 was applied and extrapolated to zero momentum in order to extract this value, which is comparable with those obtained for the other hadronic Ξ_c^0 decays [9].

Among the decays discussed above, the only theoretical information available concerns the decay $\Lambda_c^+ \to \Xi^{*0} K^+$ for which the branching ratio has been calculated to be 0.5% [10]. Using the PDG value for the branching ratio for $\Lambda_c^+ \to pK^-\pi^+$ which is $(4.4 \pm 0.6)\%$ [6], as well as the ARGUS value for $\sigma \cdot \mathrm{BR}(\Lambda_c^+ \to pK^-\pi^+)$, our measurement for the branching ratio for the decay $\Lambda_c^+ \to \Xi^{*0} K^+$ is $(0.2 \pm 0.1)\%$.

Theoretical predictions of the importance of the W-exchange mechanism in Λ_c^+ decays vary, but some authors predict a substantial contribution from W-exchange diagrams [12]. It is likely that non-spectator effects are an explanation of the differences in the charmed baryon lifetimes [2]. Of the three baryons Λ_c^+, Ξ_c^0 and Ξ_c^+, only the first two can decay via W-exchange diagrams. The lifetimes of the Ξ_c^0 and Ξ_c^+ are $0.82^{+0.59}_{-0.30} \times 10^{-13} s$ and $3.0^{+1.0}_{-0.6} \times 10^{-13} s$ respectively [6], consistent with the idea that W-exchange is an important amplitude in charmed baryon decays. The indication for the decays $\Xi_c^0 \to \Lambda K_s^0$ and, if rescattering effects do not contribute, $\Xi_c^0 \to \Xi^{*0} K^+$ supports this assumption.

It is a pleasure to thank U. Djuanda, E. Konrad, E. Michel, and W. Reinsch for their competent technical help in running the experiment and processing the data. We thank Dr. H. Nesemann, B. Sarau, and the DORIS group for the excellent operation of the storage ring. The visiting groups wish to thank the DESY directorate for the support and kind hospitality extended to them.

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