Upper Limit for the Nonleptonic $\Delta S=2$ Decay Mode of Ξ^-†

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No example of a Ξ^- decay into $n+\pi^-$ has been found in a sample of 200 normal Ξ^- decays into $\Lambda+\pi^-$.

INTRODUCTION

THE weak decays of strange particles seem to obey the empirical rule that strangeness changes only by unity ($\Delta S=1$). This is suggested by two pieces of evidence:

(a) A $\Delta S=2$ decay of Ξ^- into $n+\pi^-$ has never been reported (no $\Delta S=2$ leptonic decay has been reported either).[1] However, the mode $\Xi^-\rightarrow n+\pi^-$ is more difficult to observe than is $\Xi^-\rightarrow\Lambda+\pi^-$, and no systematic search has ever been made.[2] In the case of Ξ^0 the difficulty is that only a few $\Xi^0\rightarrow\Lambda+\pi^0$ decays have been reported. Therefore, although the $\Xi^0\rightarrow p+\pi^-$ mode is distinctive, it might not yet have been found. Furthermore, much of the ($\Delta S=2$) Ξ^0 decay might proceed via the invisible mode $\Xi^0\rightarrow n+\pi^0$, because in this case the $\Delta I=\frac{1}{2}$ rule obviously does not hold and, therefore, the ratio of the $p\pi^-$ to the $n\pi^0$ rates is completely undetermined.

(b) The measured K_1-K_2 mass difference δm is of second order in the weak interaction.[3] According to Okun' and Pontecorvo[4] this excludes most $\Delta S=2$ nonleptonic weak interactions. However, Glashow has pointed out that such interactions that are odd under charge conjugation (or parity) do not give first-order K_1-K_2 mass splitting.[5]

We have studied a sample of 200 negative cascades, looking for the decay modes

$$\Xi^-\rightarrow\Lambda+\pi^- \quad \text{(A)}$$

and

$$\Xi^-\rightarrow n+\pi^-. \quad \text{(B)}$$

We do not find any evidence for the second mode and can set an upper limit of 0.5% on the rate of decay mode (B) with respect to (A). As for the *leptonic* $\Delta S=2$ decays, we are still unable to set an experimental upper limit.

EXPERIMENT

The events studied were produced by interactions of 1.51-BeV/c K^- mesons in the Lawrence Radiation Laboratory's 72-in. hydrogen bubble chamber (the center-of-mass energy is 2025 MeV).

The typical sequence in which a Ξ^- is produced and subsequently decays in the chamber appears as a two-prong event where the negative outgoing track decays. In addition, two-thirds of the time there is a visible lambda associated with the decay vertex. Alvarez *et al.* already have reported on a study of 450 Ξ^- produced in the same experiment at 1.51-BeV/c and other momenta.[2] Their study concerns only cascades with a visible Λ. Here we report on the analysis of events without a visible Λ. We restricted our study to a smaller sample than they used mainly because of the very large background of events with the same topology which become involved.[6]

The production and decay reactions that have been considered are

$$K^-+p\rightarrow\Xi^-+K^+,\quad \Xi^-\rightarrow\Lambda+\pi^-, \quad (1)$$

where the Λ decays neutrally, and

$$K^-+p\rightarrow\Xi^-+K^+,\quad \Xi^-\rightarrow n+\pi^-. \quad (2)$$

These events are topologically the same as the Σ^- or the K^- production and decay chains in (3) through (5) below; a kinematical fit to all these hypotheses is necessary for the identification.

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[1] One probable leptonic $\Delta S=1$ decay, $\Xi^-\rightarrow\Lambda e^-\bar{\nu}$ is reported by L. Bertanza, V. Brisson, P. L. Connolly, E. L. Hart, I. S. Mittra, G. C. Moneti, R. R. Rau, N. P. Samios, I. O. Skillicorn, S. S. Yamamoto, J. Leitner, and J. Westgard, in Phys. Rev. Letters **9**, 19 (1962), but no estimate of a branching ratio is given.

[2] The world's supply of information on Ξ^- to date is mainly contained in the following papers: W. B. Fowler, R. W. Birge, P. Eberhard, R. Ely, M. L. Good, W. M. Powell, and H. K. Ticho, Phys. Rev. Letters **6**, 134 (1961) (18 Ξ^- in a propane bubble chamber); L. W. Alvarez, J. P. Berge, R. Kalbfleisch, J. Button-Shafer, F. T. Solmitz, M. L. Stevenson, and H. K. Ticho, in *Proceedings of the 1962 Annual International Conference on High-Energy Physics, CERN, 1962*, edited by J. Prentki (CERN, Geneva, 1962), p. 433 (450 Ξ^- in a hydrogen bubble chamber); L. Bertanza, V. Brisson, P. L. Connolly, E. L. Hart, I. S. Mittra, G. C. Moneti, R. R. Rau, N. P. Samios, I. O. Skillicorn, S. S. Yamamoto, M. Goldberg, L. Gray, J. Leitner, S. Lichtman, and J. Westgard, Phys. Rev. Letters **9**, 229 (1962) (85 Ξ^- in a hydrogen bubble chamber); G. M. Pjerrou, D. J. Prowse, P. Schlein, W. E. Slater, D. H. Stork, and H. K. Ticho, *ibid.* **9**, 114 (1962) (180 Ξ^- in a hydrogen bubble chamber).

[3] E. Bolt, D. O. Caldwell, and Y. Pal, Phys. Rev. Letters **1**, 150 (1958); R. H. Good, R. P. Matsen, F. Muller, O. Piccioni, W. M. Powell, H. S. White, W. B. Fowler, and R. W. Birge, Phys. Rev. **124**, 1223 (1961); V. L. Fitch, P. A. Piroué, and R. B. Perkins, Nuovo Cimento **22**, 1160 (1961); V. Camerini, W. F. Fry, J. A. Gaidos, H. Huzita, S. W. Natali, R. B. Willmann, R. W. Birge, R. P. Ely, W. M. Powell, and H. S. White, Phys. Rev. **128**, 362 (1962).

[4] L. Okun' and B. Pontecorvo, Zh. Eksperim. i Teor. Fiz. **32**, 1587 (1957) [translation: Soviet Phys.—JETP **5**, 1297 (1957)].

[5] S. L. Glashow, Phys. Rev. Letters **6**, 196 (1961).

[6] We have analyzed a film sample corresponding to 1.3 events per μb of cross section. The work of Alvarez *et al.* [reference 2 and (private communication)], has now been extended, at 1.51 BeV/c, to a total path length corresponding to 5.1 events per μb.

About 2200 events of the above topology have been analyzed. Each event was fitted to several noncascade interpretations, namely,

$$K^-+p\rightarrow\Sigma^-+\pi^+,\quad \Sigma^-\rightarrow n+\pi^-, \tag{3}$$

$$K^-+p\rightarrow\Sigma^-+\pi^++\pi^0,\quad \Sigma^-\rightarrow n+\pi^-, \tag{4}$$

$$K^-+p\rightarrow K^-+p,\quad K^-\text{ then decays;} \tag{5}$$

as well as to the cascade interpretations (1) and (2). The fitting procedure involved an adjustment of the measured variables so that the constraining equations of conservation of energy and momentum were simultaneously satisfied at both the decay and production vertices. An event was considered to fit a given four-constraint production-and-decay hypothesis [reactions (1), (2), (3), and (5)] if it gave a χ^2 value less than 30, or a one-constraint hypothesis [reaction (4)] if the χ^2 value was less than 10.

The kinematics of the two "elastic" ΞK reactions, (1) and (2), are sufficiently different from those of the other reactions so that the kinematical fit alone is ordinarily sufficient to separate them from the other processes. The results of the fitting procedure are illustrated in Table I.

TABLE I. Numbers of good fits (as defined in the text) for the set of hypotheses indicated by the rows and columns. Diagonal elements represent fits to one hypothesis only.

Hypothesis	(1)	(2)	(3)	(4)	(5)	Final apportionment[b]
(1) Ξ^-K^+, $\Xi^-\rightarrow\Lambda\pi^-$	46	1	0	22	0	67
(2) Ξ^-K^+, $\Xi^-\rightarrow n\pi^-$	1	1	1	6	2	0
(3) $\Sigma^-\pi^+$, $\Sigma^-\rightarrow n\pi^-$	0	1	363	46	?[a]	390
(4) $\Sigma^-\pi^+\pi^0$, $\Sigma\rightarrow n\pi^-$	22	6	46	719	?[a]	771
(5) K^-p	0	2	?[a]	?[a]	149	151
Total						1379

[a] The data-processing flow was such that if an event fitted the most likely hypotheses (3) and (4) then hypothesis (5) was never tried.
[b] The numbers in this column can be smaller than the sum of the elements of the corresponding row because some events are ambiguous between several hypotheses and thus appear more than once in the table.

In addition to these satisfactory fits a total of 830 events failed to give a satisfactory χ^2 to any of the above hypotheses. These fall into one of three categories:

(a) Events involving the production of two or more neutrals, which have too many missing variables to allow a fit. These are mainly reactions of the type $\Sigma^-\pi^+\pi^0\pi^0$, $K^-p\pi^0\pi^0$, and $K^-\pi^+n\pi^0$; their charged counterparts, $\Sigma^-\pi^+\pi^+\pi^-$ and $K^-p\pi^+\pi^-$, account for 150 and 200 events, respectively, in the same film sample.

(b) Weakly constrained events of the type $\bar{K}N\pi$ or $\Xi K\pi$. These are difficult to separate out unambiguously because they involve one missing particle and, therefore, were not used in the analysis.

No fit has been tried to the $K^-p\pi^0$ and $K^-\pi^+n$ hypothesis. An indication of how many events may be expected to belong to this category is given by the number of reactions of the type $\bar{K}^0p\pi^-$ observed in the same film sample (multipled by three to take into account the invisible decays). This number is $\sim$600, and if we assume that there might be as many examples of each $K^-p\pi^0$ and $K^-\pi^+n$ as there are of $\bar{K}^0p\pi^-$, we may guess that $\sim$400 of our unfitted events are of this kind.

(c) Examples of reactions (1) through (5) which fail to fit because of mismeasurements.

The small number of events ambiguous between the various reactions (ideally the matrix of Table I should be diagonal) illustrates the fact that the separation is relatively clean. Furthermore only *one* event gives a satisfactory χ^2 distribution to both modes of decay for Ξ^-. Most of the ambiguities result from the relatively loose χ^2 cutoff. The fact that the probability for one hypothesis is ordinarily much higher than that of the other one, combined with the visual inspection of the relative ionization, enabled us to resolve all ambiguities. Table II lists in detail the relevant data for all the candidates for reaction (2).

The final results on the two decay modes of Ξ^- are: 67 examples of $\Xi^-\rightarrow\Lambda+\pi^-$ without visible Λ decay; no example of $\Xi^-\rightarrow n+\pi^-$.

We feel quite confident that these 67 events are genuine examples of reaction (1). Firstly, all Ξ^-K^+ candidates were inspected visually to make sure that the ionization agreed with the fitted momenta. All the 46 unambiguous events (see Table I) were found to be consistent with the Ξ^-K^+ hypothesis; of the 22 other events 21 were found to be also Ξ^-K^+. We were helped here by the fact that at this incident momentum the K^+ goes preferentially backwards in the center-of-mass system and thus has a relatively low velocity in the laboratory system. Secondly, the χ^2 distribution for this four-constraint hypothesis is consistent within statistics with the one obtained for the much more numerous $\Sigma^-\pi^+$ reactions (also four constraint). Thirdly, the number found is in good agreement with the number $N_{\Lambda\rightarrow p\pi^-}$ of reactions (1) with the Λ decaying via its charged mode in the chamber.[6] Normalizing to the same film sample (1.3 events per μb) and correcting to account for the different failure rate in the data analysis flow, we have $N_{\Lambda\rightarrow p\pi^-}=144$. This gives a Λ-decay branching ratio equal to $67/(144+67)=0.68\pm0.07$, in excellent agreement with the expected 0.69 ± 0.02.[7] Fourthly, the center-of-mass angular distribution of our 67 Ξ^- and of those with visible Λ of reference 6 appear to be the same within statistics.

We feel that there are no experimental biases tending to discriminate against reaction (2). Fitting failures due to poor measurements would effect reaction (1) as often as reaction (2). The fact that the scanning efficiency is $\sim$95% would probably tend to discriminate

[7] Frank S. Crawford, in *Proceedings of the 1962 Annual International Conference on High Energy Physics at CERN 1962*, edited by J. Prentki (CERN, Geneva, 1962), p. 827.

TABLE II. Analysis of the 10 "ambiguous" events. The first row of each event describes the fit to reaction (2); lower rows describe competing reactions.

Event No.	Fitting reactions	χ^2 probability of fit (%)	Fitted momentum, p^+ (MeV/c)	Relative ionization[a] I^+/I_{min}	Fitted momentum p^- (MeV/c)	Relative ionization[b] I^-/I_{min}
1	(2)	2	402±9	1.9[c]	1657±22	1.5
	(5)	41	414±9	4.2[c]	1509±68	1.0
2	(2)	4	1019±11	1.0[d]	837±10	2.6
3	(2)	0.2	264±6	3.1[e]	1503±12	1.6
	(5)	72	279±6	7.6[e]	1487±14	1.0
4	(2)	0.005[f]	730±34	1.2	1385±47	1.7
	(4)	37	631±47	1.0	683±70	2.9
5	(2)	0.08[f]	968±23	1.0	873±17	2.5
	(4)	90	973±23	1.0	528±40	4.0
6	(2)	0.05[f]	503±12	1.5	1177±14	1.9
	(4)	15	570±57	1.0	621±71	3.3
7	(2)	4	687±25	1.2	843±5[g]	2.6
	(4)	4	670±24	1.0	1162±132[g]	1.7
8	(2)	1[f]	413±7	1.8	1324±9	1.8
	(1)	91	413±7	1.8	1324±9	1.8
	(4)	90	351±62	1.0	526±61	4.2
9	(2)	0.005[f]	630±8	1.3	1109±7	2.0
	(4)	0.5	674±48	1.0	628±66	3.2
10	(2)	0.01[f]	1254±11	1.0	563±10	4.4
	(3)	66	1254±11	1.0	287±10	11.0

[a] Calculated from p^+.
[b] Calculated from p^-.
[c] The ionization of the positive track shows it to be a proton.
[d] The ionization of the positive track excludes that it is a K^+.
[e] The positive track stops in the chamber and has all the characteristics of a proton.
[f] The first hypothesis is ruled out by its probability level.
[g] The negative track is much too long (61 cm) to be a hyperon; its ionization also excludes both hypotheses. The event is probably $K^-\pi^+n$.

more against reaction (1), insofar as the Q value for that decay is considerably lower than in the $n\pi^-$ decay. Thus on the average the decay pion would make a smaller angle with the Ξ^- and thus be more likely to be missed.

CONCLUSIONS

Applying the known branching ratio for Λ decay, as well as the escape correction, we estimate that our 67 events correspond to 200 total events of the type $K^-+p\rightarrow\Xi^-+K^+$, $\Xi^-\rightarrow\Lambda+\pi^-$. On the other hand, the topology studied here represents all the examples of reaction (2). Accordingly, we are able to place an upper limit on the $\Delta S=2$ decay of Ξ^-, namely

$$R=(\Xi^-\rightarrow n\pi^-)/(\Xi^-\rightarrow\Lambda\pi^-)\approx 0.5\%.$$

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