Improved Determination of the Neutral Decay Branching Ratios of the K_1^0 Meson and the Λ^0 Hyperon*

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Using a 15-in. bubble chamber filled with methyl iodide, propane, and ethane, we have measured the neutral branching ratios of the K_1^0 meson and the Λ^0 hyperon. The neutral modes of the decays were observed directly from the materialized γ rays. The results are

$$B_K \equiv \frac{(K_1^0 \to \pi^0+\pi^0)}{(K_1^0 \to \pi^+ + \pi^-)+(K_1^0 \to \pi^0+\pi^0)} = 0.288 \pm 0.021$$

and

$$B_\Lambda \equiv \frac{(\Lambda^0 \to n+\pi^0)}{(\Lambda^0 \to p+\pi^-)+(\Lambda^0 \to n+\pi^0)} = 0.291 \pm 0.034.$$

The B_K ratio suggests an admixture of $|\Delta I| = \frac{3}{2}$ in the K_1^0 decay consistent with that implied by the decay $K^+ \to \pi^+ + \pi^0$. The relative phase φ between the $|\Delta I| = \frac{1}{2}$ and $\frac{3}{2}$ amplitudes is determined to be $\varphi = 0_{-0}^{+54}$ deg.

I. INTRODUCTION

THE mechanism of the decays of the K mesons and the hyperons has been of primary interest since their discovery. Many experiments studying these decays can be satisfactorily interpreted on the assumption that the isotopic spin change ΔI in the decays is predominantly one-half (the $|\Delta I| = \frac{1}{2}$ rule). This rule is not absolute, however, as seen in the decay $K^+ \to \pi^+ + \pi^0$ which requires a $|\Delta I|$ of at least $\frac{3}{2}$. A precise measurement of the neutral branching ratios

$$B_K \equiv \frac{(K_1^0 \to \pi^0+\pi^0)}{(K_1^0 \to \pi^+ + \pi^-)+(K_1^0 \to \pi^0+\pi^0)}$$

and

$$B_\Lambda \equiv \frac{(\Lambda^0 \to n+\pi^0)}{(\Lambda^0 \to p+\pi^-)+(\Lambda^0 \to n+\pi^0)}$$

provides information on the relative $|\Delta I| = \frac{1}{2}$ and $|\Delta I| = \frac{3}{2}$ amplitudes in these transitions.

In the early experiments on V^0 particles, only the charged modes of decay were observed. The fraction which decayed by a neutral mode (or modes) was only inferred[1] from the relative numbers of charged decays and production events observed. This indirect method of determining the neutral branching ratio has generally given results consistent with the value $\frac{1}{3}$. This value is predicted[2] by the $|\Delta I| = \frac{1}{2}$ rule for (1) the K_1^0 meson, assuming that its neutral mode of decay is $K_1^0 \to \pi^0 + \pi^0$, and (2) the Λ^0 hyperon, assuming that its neutral mode is $\Lambda^0 \to n + \pi^0$.

Gamma rays from the presumed neutral decays of K_1^0's and Λ^0's were first observed by Eisler *et al.*[3] in a propane bubble chamber (through their materialized e^+e^- pairs). Other direct measurements of B_K were obtained with a multiplate cloud chamber[4] and a hydrogen bubble chamber.[5] These experiments yielded widely

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[1] R. Budde, M. Chrétien, J. Leitner, N. P. Samios, M. Schwartz, and J. Steinberger, Phys. Rev. **103**, 1827 (1956).

[2] R. H. Dalitz, Proc. Phys. Soc. (London) **A69**, 527 (1956); M. Gell-Mann, Nuovo Cimento **5**, 758 (1957); M. Gell-Mann and A. Pais, in *Proceedings of the 1954 Glasgow Conference on Nuclear and Meson Physics* (Pergamon Press, London, 1955).

[3] F. Eisler, R. Plano, N. Samios, M. Schwartz, and J. Steinberger, Nuovo Cimento **5**, 1700 (1957).

[4] E. Boldt, H. S. Bridge, D. O. Caldwell, and Y. Pal, Phys. Rev. **112**, 1746 (1958).

[5] F. S. Crawford, Jr., M. Cresti, R. L. Douglass, M. L. Good, G. R. Kalbfleisch, M. L. Stevenson, and H. K. Ticho, Phys. Rev. Letters **2**, 266 (1959).

varying values for B_K, and some differed considerably from the value $\frac{1}{3}$. Only very few γ rays were observed in these experiments because the chambers used had very low efficiencies for their detection.

It was thus considered desirable to use a large bubble chamber filled, in part, with a high-Z element in order to observe the neutral modes directly with high efficiency. In the present experiment such a chamber has been used and a large body of data has been obtained. Since the inception of this experiment, several additional investigations of the branching ratios have been performed using high-Z chambers[6–8] and a large hydrogen chamber.[9]

II. THE BUBBLE CHAMBER AND THE BEAM

A cylindrical stainless steel bubble chamber was used, 15 in. in diameter, 14 in. deep, and containing 51.5 liters of liquid.[10] The chamber was contained in a magnet providing a magnetic field of 19 500 G over the liquid volume.

The chamber was filled with a mixture of methyl iodide, propane, and ethane. The component densities at the time of track formation were: 0.061 g/cm^3 of hydrogen, 0.252 g/cm^3 of carbon, and 0.948 g/cm^3 of iodine. The radiation length at the operating condition was 8.4 cm, giving a probability for converting two or more or the four γ rays from the neutral decay of the $K_1{}^0$ meson, averaged over the chamber geometry, of 82%.

The chamber was photographed in bright field illumination by three cameras, using 100-ft rolls of 35-mm Kodak Linagraph Shellburst film.

A beam of negative pions (Beam No. 1B) from the Brookhaven Cosmotron was directed into the bubble chamber (see Fig. 1). The pions were produced in a thin polyethylene target placed in external proton beam No. 1, and the thickness of the target was changed by remote control to maintain a constant mean number of pions entering the chamber. The π^- mesons were deflected and focused first at the thin slit S, and then deflected again and refocused onto the thin entrance window of the bubble chamber. This resulted in a narrow momentum spread of about $\pm1\%$ at the chamber ($\pm0.5\%$ by calculation and wire test, but increased to $\pm1\%$ by magnet current fluctuations).

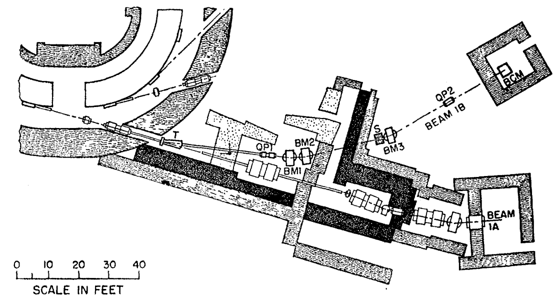

FIG. 1. The experimental arrangement on the floor of the Cosmotron. The bubble chamber and its magnet (BCM) were in the concrete blockhouse in Beam 1B. QP and BM represent the quadrupole and bending magnets used. Beams 1A and 1B were run simultaneously.

80% of the film was taken with an incident-beam momentum of 1144 MeV/c, the remaining 20% being taken mostly at 1060 MeV/c.

III. GENERAL METHOD

In order to determine the branching ratios B_K and B_Λ, three types of events are obtained from the film.

(1) The Λ_cK_c sample[11]—these events are of the type

$$\pi^-+p\to\Lambda_c+K_c\,, \tag{1}$$

where

$$\Lambda_c\to p+\pi^-\,,$$
$$K_c\to\pi^++\pi^-,$$

and the target proton is either free or bound in a C or I nucleus. In the latter case, charged or uncharged particles may also emerge from the interaction. Since the basic production is on a proton, and nuclear effects do not affect the measurements or the results, no further differentiation between free and bound protons will be made.

(2) The Λ_cK_n sample—these events are of the type

$$\pi^-+p\to\Lambda_c+K_n\,, \tag{2}$$

where

$$\Lambda_c\to p+\pi^-\,,$$
$$K_n\to\pi^0+\pi^0 \quad (\searrow 2\gamma \;\; \searrow 2\gamma)\,,$$

and where two or more of the γ rays are converted into e^+e^- pairs.

(3) The $K_c\Lambda_n$ sample—these events are of the type

$$\pi^-+p\to K_c+\Lambda_n\,, \tag{3}$$

where

$$K_c\to\pi^++\pi^-\,,$$
$$\Lambda_n\to n+\pi^0 \quad (\searrow 2\gamma)\,,$$

[6] C. Baglin, M. Bloch, V. Brisson, J. Hennessy, A. Lagarrigue, P. Mittner, P. Musset, A. Orkin-Lecourtois, P. Rancon, A. Rousset, A. M. Sarius, X. Sauteron, and J. Six, Nuovo Cimento **18**, 1043 (1960).

[7] J. L. Brown, H. C. Bryant, R. A. Burnstein, D. A. Glaser, R. Hartung, J. A. Kadyk, J. D. Van Putten, D. Sinclair, G. H. Trilling, and J. C. Van der Velde, Nuovo Cimento **19**, 1155 (1961).

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[9] F. S. Crawford, in *Proceedings of the 1962 International Conference on High-Energy Physics at CERN* (CERN, Geneva, 1962), pp. 832–836, and private communication; J. A. Anderson, F. S. Crawford, B. B. Crawford, R. L. Golden, L. J. Lloyd, G. W. Meisner, and L. Price (to be published).

[10] L. Rosenson, in *Proceedings of an International Conference on Instrumentation for High-Energy Physics, Berkeley, 1960* (Interscience Publishers, Inc., New York, 1961), p. 133; I. A. Pless *et al.* (to be published).

[11] We shall hereafter use the subscript c to indicate a charged V decay: $K_c\equiv(K_1{}^0\to\pi^++\pi^-)$, $\Lambda_c\equiv(\Lambda_c\to p+\pi^-)$, and V_c denotes either a K_c or a Λ_c. Correspondingly, we shall use the subscript n to indicate a neutral V decay: $K_n\equiv(K_1{}^0\to\pi^0+\pi^0)$, $\Lambda_n\equiv(\Lambda^0\to n+\pi^0)$, and V_n denotes either K_n or Λ_n.

and where the two γ rays are converted into e^+e^- pairs.

The ratio B_K is determined from the numbers of events in the $\Lambda_c K_c$ and $\Lambda_c K_n$ samples. The charged Λ^0 decay (Λ_c) acts as an identifying mark, or "signature," for the events in these two samples.

The ratio B_Λ is determined from the numbers of events in the $\Lambda_c K_c$ and the $K_c \Lambda_n$ samples. Here the charged $K_1{}^0$ decays (K_c) act as the "signatures" for the events in these two samples.

Because of our reliance on the finding of the signature decays, it is essential that the signatures be found with as equal efficiencies as possible, and be analyzed under identical conditions in the corresponding pairs of samples. The scanning, checking, measuring, and analysis procedures described in Sec. IV were developed with this goal in mind. In Sec. V various checks are described to verify that systematic errors and biases were reduced to a minimum.

IV. DATA REDUCTION

A total of 220 000 pictures were taken, containing on the average 12.3 beam tracks per picture. All three views of each picture were scanned twice, in order to obtain the scanning efficiencies.

A. Scanning and Measuring of Charged *V* Decays

The scanners searched for all two-pronged (V-like) track configurations associated with a π^- interaction in the liquid. These events were then carefully checked by physicists, who also searched for all γ rays which could possibly be associated with the event. All possible alternate origins of the charged V decays and of the γ rays were marked for measuring. Pictures containing more than 24 beam tracks were eliminated. The charged decays were then measured at least twice by different measurers on digitized precision machines, and close agreement among the measurements was required.

The π^- interaction point could either have charged tracks emerging from it or no charged tracks. In the former case the interaction occurred on a C or I nucleus. In the latter case it could have occurred on either H, C, or I nucleus. The fraction of associated productions in which charged tracks emerged from the interaction point was found to be approximately 25%. Only the prongless events were used in approximately two-thirds of the film because the inclusion of the pronged events about doubled the over-all checking, measuring, and analysis time. Since no requirement was made that an event be consistent with production from a free stationary proton, the mixture of V origins has no effect on the measurement of the branching ratios.

B. Computations and Analysis of Charged *V* Decays

All of the geometric reconstruction and most of the kinematic analysis of the events was done on IBM 704, 709, and 7090 computers. A modified form of the Berkeley KICK program was mainly used for the kinematic analysis. This was systematically checked by hand analysis.

A charged V (denoted[11] V_c) was accepted as "good" if the measured angles and track lengths or ranges[12] of the two secondary tracks were consistent with the decay kinematics of either a $K_1{}^0$ or a Λ^0 particle, within the measuring errors. The uncertainties in the angles and the momenta arising from the multiple scattering of the secondaries and the range-energy uncertainty for stopping secondaries were taken into account. The decision on the acceptability of a V_c was made *independently* of the decision on the associated V_c or the associated γ rays.

A small fraction of the "good" individual charged V's (from both double V_c and single V_c events) were consistent with both the Λ^0 and $K_1{}^0$ decay kinematics. These V's were carefully remeasured under the supervision of a physicist, and their tracks were also systematically graded as to their bubble density. The additional information provided by the bubble density and the remeasurements was sufficient in all but 0.8% of the cases to resolve the ambiguity. These unresolved cases were not included in the accepted samples, but are accounted for in the corrections for analysis uncertainties.

C. Measurement and Analysis of Neutral *V* Decays

The γ rays from possible V_n decays associated with accepted V_c decays were measured in the following manner. From the materialized electron-positron pairs, the line of flight of each γ ray was estimated on each projected view with a ruled straight line and measured on the precision digitized machines. The line of flight in space was then calculated, with associated errors, from these projected trajectories. It was then required that the two or more γ rays of an event be consistent with originating at a single point in space within the associated uncertainties. Each event was measured at least twice and again close agreement among the measurements was required.

Gamma rays which could reasonably be considered to originate from an alternate source visible within or on the edge of the chamber were discarded. A correction must then be made (see Secs. VI and VII) to take account of the good events which were thus eliminated.

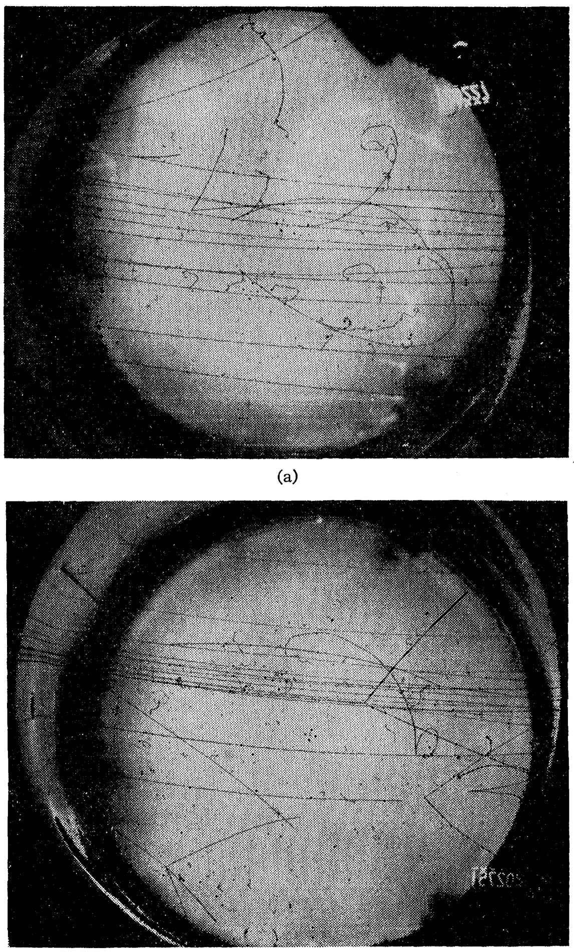
D. The Fiducial Criteria and the Samples

To determine the branching ratios, the three categories of events [reactions (1), (2), and (3)] should be obtained from the same set of film, which has been scanned under identical instructions. For part of the film, however, the $K_c \Lambda_n$ events were taken only from

[12] R. M. Sternheimer, Phys. Rev. **115**, 137 (1959); **118**, 1045 (1960); and private communication.

prongless π^- interactions, while the $\Lambda_c K_n$ and $\Lambda_c K_c$ events were taken from both prongless and pronged interactions. For this section of the film, therefore, only those $\Lambda_c K_c$ events from the prongless interactions correspond to the $K_c \Lambda_n$ events and should be used to calculate the Λ branching ratio. We shall identify the subsample of $(\Lambda_c K_c)$ corresponding to the sample $(K_c \Lambda_n)$ by the symbol $(\Lambda_c K_c)_s$.

The $K_1{}^0$ branching ratio B_K is directly related to the ratio of the number of events in samples $(\Lambda_c K_c)$ and $(\Lambda_c K_n)$, while B_Λ is related to the ratio of the number



(a) (b)

FIG. 2. (a) An event from the $\Lambda_c K_n$ sample:

$$\pi^- + p \to \Lambda_c + K_n,$$
$$\Lambda_c \to p + \pi^-,$$
$$K_n \to 2\pi^0 \to 4\gamma.$$

Three of the γ rays are observed to materialize in the bubble chamber and point back to the $K_1{}^0$ decay point. The fourth γ ray did not materialize in the chamber. (b) An event from the $K_c \Lambda_n$ sample:

$$\pi^- + p \to K_c + \Lambda_n,$$
$$K_c \to \pi^+ + \pi^-,$$
$$\Lambda_n \to n + \pi^0 \searrow 2\gamma.$$

Both γ rays from the π^0 decay materialize in the chamber.

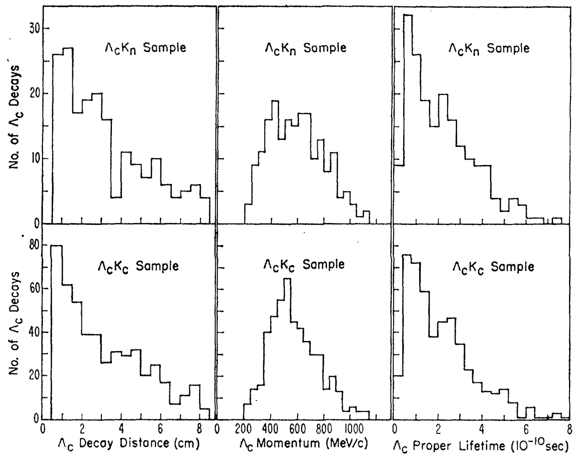


FIG. 3. A comparison of the properties of the Λ_c decays (the "signatures"), between the $\Lambda_c K_c$ and the $\Lambda_c K_n$ samples. The Λ_c decay distance, momentum, and proper lifetime distributions for the $\Lambda_c K_c$ events are shown in the three lower histograms. The corresponding distributions for the $\Lambda_c K_n$ events are shown in the three upper histograms.

of events in samples $(\Lambda_c K_c)_s$ and $(K_c \Lambda_n)$. It is, of course, necessary that all systematic errors affecting these ratios, such as scanning, measuring, and analysis biases, be reduced to a minimum. To this end a set of geometric and kinematic fiducial criteria has been applied to the data. These criteria, which are detailed in Appendix I, are in addition to those mentioned in Secs. IVA, IVB, and IVC.

After the imposition of the fiducial criteria, there are 508, 436, 198, and 67 events in samples $(\Lambda_c K_c)$, $(\Lambda_c K_c)_s$, $(\Lambda_c K_n)$, and $(K_c \Lambda_n)$, respectively. Examples of accepted events with neutral decays are shown in Figs. 2(a) and 2(b).

V. CONSISTENCY CHECKS OF THE SAMPLES

There are two main consistency checks that can be made on the accepted events to search for possible biases in the selection process. First, the K_c and the Λ_c decays must be consistent with the known properties of $K_1{}^0$ and Λ^0 particles, respectively. The individual selection of events, of course, ensures that each one has the proper decay kinematics. There remains only the group property of lifetime to be checked. This is discussed in Secs. VA and VB.

The second kind of check to be made is the verification that biases do not exist between samples $(\Lambda_c K_c)$ and $(\Lambda_c K_n)$ and between $(\Lambda_c K_c)_s$ and $(K_c \Lambda_n)$. This is considered in Secs. VC and VD.

A. The Lifetime of the Charged Λ^0 Decays (Λ_c)

For each of the 706 Λ_c cases in samples $(\Lambda_c K_c)$ and $(\Lambda_c K_n)$, the flight distance from V origin to the decay point and the momentum are known. Since the potential flight path of each Λ_c [to the boundary of the fiducial volume FV_2 (see Appendix I) or the distance 8.2 cm,

TABLE I. Comparison of the observed number of K_n decays having m materialized γ rays ($m=2, 3, 4$) with the expected numbers from a Monte Carlo calculation.

	0γ	1γ	2γ	3γ	4γ	Total
1. Probability P_m of m γ's converting inside fiducial volume FV_2	0.034	0.147	0.313	0.349	0.157	1.000
2. Probability P_m' of m γ's converting inside fiducial volume FV_2 and not pointing to an alternate source	0.046	0.182	0.338	0.316	0.118	1.000
3. Observed number of events	...	...	92	79	27	198
4. Expected number of events (for total of 198, based on P_m')	...	...	86.7	81.0	30.3	198

whichever is the lesser] is also known, the Bartlett S function[13] can be determined. This gives a mean lifetime for our Λ_c's of

$$\tau_\Lambda = (2.76\pm0.20)\times10^{-10}\text{ sec},$$

in good agreement with recent values[14,15] which lie in the range of $(2.3\text{–}2.8)\times10^{-10}$ sec.

B. The Lifetime of the Charged K_1^0 Decays (K_c)

For the 503 K_c decays in samples $(\Lambda_cK_c)_s$ and $(K_c\Lambda_n)$, the Bartlett S function can also be determined. This gives a mean lifetime

$$\tau_{K_1^0} = (0.87\pm0.05)\times10^{-10}\text{ sec},$$

which agrees well with the present best value[16] of $(0.91\pm0.02)\times10^{-10}$ sec.

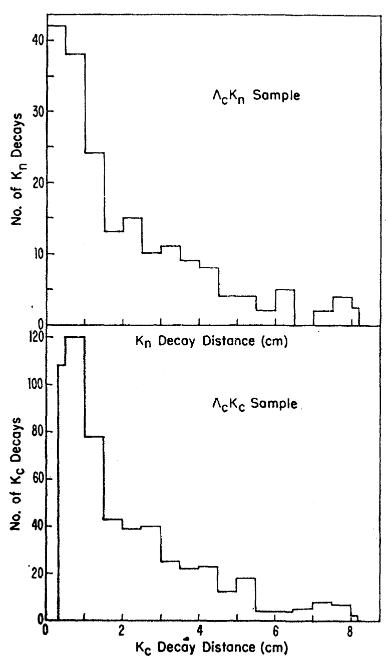


FIG. 4. A comparison between the K_c decay distance distribution of the Λ_cK_c sample, and the K_n decay distance distribution of the Λ_cK_n sample.

[13] M. S. Bartlett, Phil. Mag. 44, 249 (1953).
[14] F. S. Crawford, in *Proceedings of the 1962 International Conference on High-Energy Physics at CERN* (CERN, Geneva, 1962), p. 839.
[15] S.-Y. Fung, Bull. Am. Phys. Soc. 7, 619 (1962).
[16] This value is a weighted average of the measurements listed in Ref. 14.

C. Checks Upon Samples (Λ_cK_c) and (Λ_cK_n)

A necessary condition that there be no relative biases between samples (Λ_cK_c) and (Λ_cK_n) is that the Λ_c particles, the "signatures," in each sample have identical properties.

The lower half of Fig. 3 presents the decay distance distribution, the momentum distribution, and the proper lifetime distribution of the Λ_c's in sample (Λ_cK_c), while the upper half of this figure presents these same distributions for the Λ_c's in sample (Λ_cK_n). The χ^2 probabilities for the observed agreement between these three sets are 48, 67, and 90%, respectively.

The mean lifetimes of the Λ_c's in samples (Λ_cK_c) and (Λ_cK_n) are $(2.77\pm0.24)\times10^{-10}$ sec and $(2.74\pm0.38)\times10^{-10}$ sec, respectively. Other characteristics of the Λ_c's, such as the opening angle distributions and production angle distributions in the two samples, have been compared with equally good results.[17]

A different kind of check between samples (Λ_cK_c) and (Λ_cK_n) is upon comparable properties of the K_c and K_n decays in these samples. For the K_n events, the decay point is obtained from the fitted intersection point of the pertinent γ rays. In Fig. 4 the decay distance distributions of these decays are drawn. The agreement between the two histograms is good, with a χ^2 probability of 83%. For the neutral decays we do not know the K momentum and, hence, the K proper lifetime, and thus cannot compare these properties.

A third kind of check has been made upon sample (Λ_cK_n) by itself. The relative numbers of K_n decays having 2, 3, or 4 γ rays materializing inside the fiducial volume (FV_2) can be calculated and compared with the corresponding observed numbers. The calculated probabilities P_m that m of the γ's ($m=0, 1, 2, 3, 4$) will be converted into e^+e^- pairs within the volume FV_2 have been obtained from a Monte Carlo calculation which is described in Appendix II. The uncertainties in the values of P_m are at most 0.01–0.02, resulting mainly from the uncertainty in the radiation length of the chamber mixture.

Before the comparison is made, the calculated probabilities P_m must be corrected for the possible pointing of the γ's to an alternate source in which case they would be discarded. The alternate source correction has been determined experimentally by a method

[17] For further details see E. E. Ronat, Ph.D. thesis, Harvard University, 1962 (unpublished).

described in Sec. VI B2. The corrected probabilities P_m', along with the Monte Carlo values P_m and the observed and calculated numbers of events, are presented in Table I.[18] The agreement between the observed and calculated numbers is very good, with a χ^2 probability of 68%. This is the best evidence to date that the neutral decay mode of the K_1^0 is into two π^0's.

The comparisons presented in Fig. 4 and Table I are evidence that the K_n decays have been correctly found, measured, and identified.

D. Checks Upon Samples $(\Lambda_c K_c)_s$ and $(K_c\Lambda_n)$

In the finding of Λ_n and Λ_c decays, the associated K_c acts as the identifying mark or the Λ^0 "signature." A necessary condition that there be no relative biases between samples $(\Lambda_c K_c)_s$ and $(K_c\Lambda_n)$ is that these signatures have identical properties.

The lower half of Fig. 5 presents the decay distance, the momentum, and the proper lifetime distributions of the K_c's in sample $(\Lambda_c K_c)_s$, while the upper half of this figure presents these same distributions for the K_c's in sample $(K_c\Lambda_n)$. The χ^2 probabilities for the observed agreement between these three sets are 58%, 14%, and 37%, respectively.

The mean lifetimes of the K_c's in samples $(\Lambda_c K_c)_s$ and $(K_c\Lambda_n)$ are $(0.85\pm0.05)\times10^{-10}$ sec and $(1.09\pm0.20)\times10^{-10}$ sec, respectively. Other characteristics of the K_c's have also been tested and these further indicate uniformity between the two samples.[19]

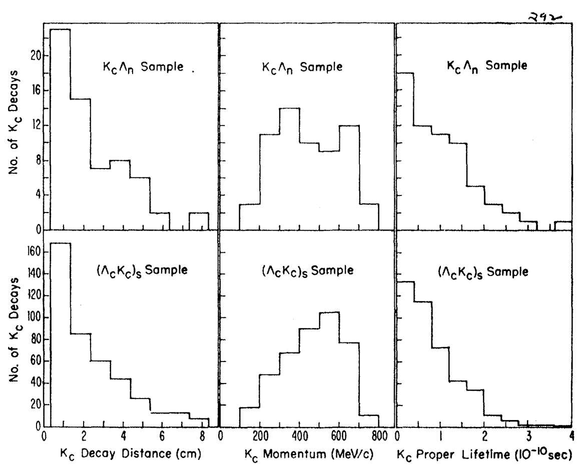


FIG. 5. A comparison of the properties of the K_c decays (the "signatures"), between the $(\Lambda_c K_c)_s$ and the $K_c\Lambda_n$ samples. The K_c decay distance, momentum, and proper lifetime distributions for the $(\Lambda_c K_c)_s$ are shown in the three lower histograms. The corresponding distributions for the $K_c\Lambda_n$ events are shown in the three upper histograms.

[18] Included in all three samples are some events from the production process $\pi^-+p\rightarrow\Sigma^0+K^0$. The γ ray from the Σ^0 decay might in some cases be counted as coming from a K_n or Λ_n decay. However, an analysis of the data (the number of single γ rays associated with $\Lambda_c K_c$ events, the number of 5 γ-ray events in the $\Lambda_c K_n$ sample, and the number of 3 γ-ray events in the $K_c\Lambda_n$ sample) shows this effect to be very small.

[19] For further details, see J. P. Averell, Ph.D. thesis, Harvard University, 1963 (unpublished).

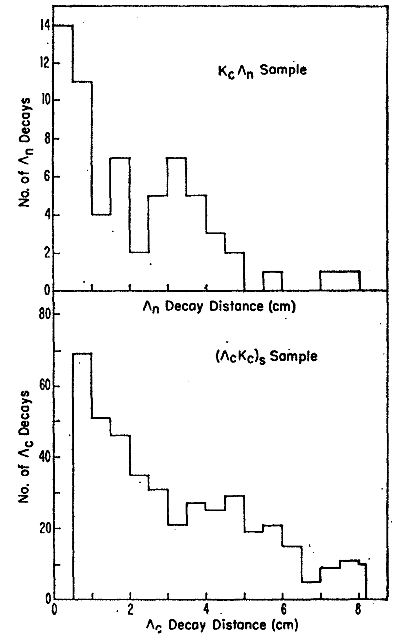


FIG. 6. A comparison between the Λ_c decay distance distribution of the $(\Lambda_c K_c)_s$ sample, and the Λ_n decay distance distribution of the $K_c\Lambda_n$ sample.

The comparison between the decay distance distributions of the Λ_c's and Λ_n's in samples $(\Lambda_c K_c)_s$ and $(K_c\Lambda_n)$, respectively, is presented in Fig. 6. The agreement is again good, with a χ^2 probability of 32%.

VI. THE NEUTRAL BRANCHING RATIO B_K

The ratio B_K of the K_1^0 meson will be computed on the basis of the number of K_c decays in sample $(\Lambda_c K_c)$ [which we will call $N(\Lambda_c K_c)$] compared to the number of K_n decays in sample $(\Lambda_c K_n)$ [called $N(\Lambda_c K_n)$]. The number of accepted events in the samples [$N(\Lambda_c K_c)=508$ and $N(\Lambda_c K_n)=198$] must be corrected, because the detection efficiencies for the K_c and K_n decays are not equal, and because the fiducial criteria affect the two samples differently.

The corrected number of charged decays [$N'(\Lambda_c K_c)$] and of neutral decays [$N'(\Lambda_c K_n)$] are given by

$$N'(\Lambda_c K_c)=fN(\Lambda_c K_c)=\left[\prod_{i=1}^{5} f_i\right]N(\Lambda_c K_c),$$

and

$$N'(\Lambda_c K_n)=gN(\Lambda_c K_n)=\left[\prod_{i=1}^{6} g_i\right]N(\Lambda_c K_n),$$

where the f_i's and g_i's are correction factors discussed below.[17]

A. Corrections to Sample $(\Lambda_c K_c)$

(1) f_1 is the correction for the K_c decays which occurred within 0.3 cm of the V origin. These K_c events were eliminated by the fiducial criteria, but this cutoff was not applied to the K_n events. f_1 is calculated from

the relation

$$f_1=\frac{1}{N}\sum_{i=1}^{N}\frac{1-\exp(-T_i/\tau)}{\exp(-t_i/\tau)-\exp(-T_i/\tau)},$$

where

$$T_i=\frac{mS_i}{p_i},\quad t_i=\frac{m(0.3\text{ cm})}{p_i},$$

and N is the number of accepted events $[=N(\Lambda_cK_c)]$, m and τ are the K_1^0 mass ($=497.8$ MeV) and mean lifetimes[16] ($=0.91\times10^{-10}$ sec), p_i is the measured momentum of the ith K_c, and S_i is its potential path ($=8.2$ cm or the distance to the boundary of the fiducial volume FV_2, whichever is the lesser). The error in f_1 is compounded from the measurement error of the decay distance of 0.3 cm, the uncertainty in the K_1^0 lifetime, and the statistical uncertainty in the measured K_1^0 momentum distribution. It is found that

$$f_1=1.164\pm0.033.$$

(2) f_2 is the correction for K_c's having a secondary which stops or interacts in less than 0.5 cm and/or having an opening angle, between the π^+ and π^-, either less than 15° or greater than 160° in the laboratory system. Such K_c's were also eliminated by the fiducial criteria. The correction was calculated from kinematic tables and the experimental K_c momentum distribution, and includes the effects of $\pi^\pm$ interaction in the first 0.5 cm of flight. The correction is calculated to be

$$f_2=1.038\pm0.010.$$

(3) f_3 is the correction for K_c's having a momentum less than 100 MeV/c. Particles with such low momenta have a very low detection efficiency because they decay very close to the V origin with large opening angles; and, therefore, they were eliminated by the fiducial criteria. The correction is obtained by extrapolating the measured K_c momentum distribution, corrected for the losses in (1) and (2) above, below 100 MeV/c. We estimate that 10 additional K_c events are contained under the extrapolated curve between 0 and 100 MeV/c, and an equal uncertainty has been associated with this number, thus giving

$$f_3=1.017\pm0.017.$$

(4) f_4 is the correction for those K_1^0's which interact in flight, before decaying, in such a manner that a subsequent charged decay would not be kinematically acceptable while the neutral decay would be acceptable. From the available data on K_1^0 cross sections,[20] this effect is estimated to be small, and we calculate

$$f_4=1.007\pm0.003.$$

[20] B. A. Arbuzov, E. N. Kladnitskaya, V. N. Penev, and R. N. Faustov, Zh. Eksperim. i Teor. Fiz. **42**, 979 (1962) [translation: Soviet Phys.—JETP **15**, 676 (1962)]. For the corresponding correction to B_Λ, see this reference, and also G. Alexander, J. A. Anderson, F. S. Crawford, Jr., W. Laskar, and L. J. Lloyd, Phys. Rev. Letters **7**, 348 (1961); and T. Groves, Phys. Rev. **129**, 1372 (1963).

(5) f_5 is a correction for background and analysis uncertainties in the sample. The background events can occur due to spurious V_c's which satisfy the kinematic criteria and which occur on the same picture with a good V_c, thus producing a fake Λ_cK_c event. An estimate for this effect was obtained by examining all pictures with good Λ_cK_c events and carefully searching them for a third V_c which would pass the kinematic criteria. This procedure yielded an upper limit of 0.06% for the background contamination of the Λ_cK_c sample.

In addition, it was estimated that an error in the checking and analysis procedure could result in a mistaken decision about a V_c in no more than 1% of the accepted events. This estimate was obtained by comparing decisions on individual Λ_c and K_c decays in sample (Λ_cK_c), with decisions based on a joint analysis of both V_c's in those events. This gives

$$f_5=1.000\pm0.010.$$

B. Corrections to Sample (Λ_cK_n)

(1) g_1 is the correction for the efficiency of converting two or more γ's from a K_n decay. The Monte Carlo calculation used to obtain the conversion probabilities P_m (Table I) is described in Appendix II. The error in this correction is also discussed in Appendix II. We obtain

$$g_1=1.221\pm0.024.$$

(2) g_2 is the correction for the loss of events resulting from the accidental pointing of one or more γ rays from an otherwise acceptable K_n decay to an alternate source inside the chamber. An alternate source was defined as any possible origin of γ rays (such as a π^- beam interaction, or a possibily radiating electron or positron), with the exception of the beam interaction which was the origin of the associated charged V.

In order to apply this correction, it was necessary to find the probability of a neutral decay pair pointing to an unassociated random source. Overlays were prepared of the pairs coming from the neutral decay of a representative sample of K_1^0's. Then for each such neutral decay overlay, the 16 adjacent frames were examined, and all the possible alternate sources on the unrelated frames were recorded on the overlay. The original K_n decay was now put back on the projector screen, and it was determined in what fraction of the cases a neutral decay γ ray could point consistently in all three views to an unrelated alternate source. The probability of a single neutral decay γ ray pointing to an unrelated alternate source was found to be $(7\pm3)\%$, where the large error was due to the subjectivity of pointing an e^+e^- pair.

The correction for good K_n's rejected because of such accidental pointing to alternate sources by one or more of the neutral decay γ rays, is calculated to be

$$g_2=1.061\pm0.030.$$

(3) g_3 is the correction factor for spurious γ rays accidentally giving a consistent intersection with a

neutral decay γ ray inside the fiducial volume FV_2 and, thus, producing a fake K_n decay. Spurious γ rays can originate from interactions in the wall, or from the production of Σ^0K^0 or $\Lambda^0K^0\pi^0$ at the π^- interaction point. An upper limit of about 2% was calculated for the $\Lambda^0K^0\pi^0$ production in our film, by carefully searching all pictures in the Λ_cK_c sample for two associated γ rays.

The fraction of fake intersections was calculated on the basis of the Λ_cK_c events in which an additional γ ray was found. The γ rays were transferred from the Λ_cK_c events in which they occurred onto Λ_cK_n events so that their relative position with respect to the π^- interaction point remained unchanged. It was then possible to find the probability of getting a consistent intersection between such a spurious γ ray and one valid neutral decay γ ray. This probability is calculated to be 0.07 ± 0.03.

It should be stated that in order to produce a fake event, such a spurious γ ray had to intersect a neutral decay γ ray of a Λ_cK_n event in which only one of the four γ rays had materialized in the chamber [the Monte Carlo calculation, corrected for alternate sources (see Appendix II and Table I), gives the probability for the materialization of only one γ ray as 0.182].

The over-all correction for such accidental intersections is

$$g_3=0.980\pm0.010.$$

(4) g_4 is a correction for the difference in scanning efficiencies between samples (Λ_cK_c) and (Λ_cK_n) as determined from the two separate scans and a third very careful scan of a small fraction of the film by physicists. It was determined that the over-all efficiencies for finding events in samples Λ_cK_c and Λ_cK_n (and also $K_c\Lambda_n$) was correctly given by the usual simple assumption of a random missing of events.

As would be expected, the efficiency for finding Λ_cK_c events (which passed all the fiducial criteria) was slightly higher than the corresponding efficiency for Λ_cK_n events, and the correction is determined to be

$$g_4=1.016\pm0.007.$$

(5) g_5 is a correction for the contamination of sample (Λ_cK_n) from charge exchange events, such as $\pi^-+p\rightarrow n+\pi^0$. For some charge exchange events the two γ's from the π^0 may be converted and the neutron may produce a two-prong star which is acceptable as a Λ_c decay. The contamination from such charge exchange events was determined by making use of methods and results developed in our charge exchange experiment.[21] This analysis shows that $1.9_{-1.9}^{+3.8}$ events in the Λ_cK_n sample could be such charge exchange interactions and, therefore,

$$g_5=0.991_{-0.018}^{+0.009}.$$

(6) g_6 is the correction for background and analysis uncertainties. It also includes a correction for the ambiguous charged V's, i.e., those V_c's which satisfy all criteria of both Λ_c and K_c events. This correction is estimated as

$$g_6=1.008\pm0.018.$$

[21] A. Weinberg, A. E. Brenner, and K. Strauch, Phys. Rev. Letters 8, 70 (1962).

TABLE II. Summary of the numbers of events and the corrections used in the calculation of B_K.

	Events	Correction factors
1. The Λ_cK_c sample:		
$N(\Lambda_cK_c)$: No. of accepted Λ_cK_c events	508 ± 22.8	
f_1: Correction for K_c decays between 0 and 0.3 cm from V origin		1.164 ± 0.033
f_2: Correction for K_c decays with prong <0.5 cm, $\omega<15°$, $\omega>160°$ (ω =opening angle of V prongs)		1.038 ± 0.010
f_3: Correction for K_c decays with momentum <100 MeV/c		1.017 ± 0.017
f_4: Correction for $K_1{}^0$'s which interact in flight before decaying as K_c's		1.007 ± 0.003
f_5: Correction for background and analysis uncertainties in the sample		1.000 ± 0.010
$f=f_1f_2f_3f_4f_5$		1.237 ± 0.045
$N'(\Lambda_cK_c)$: Corrected No. of Λ_cK_c events	628 ± 35.9	
2. The Λ_cK_n sample:		
$N(\Lambda_cK_n)$: No. of accepted Λ_cK_n events	198 ± 14.1	
g_1: Correction for conversion efficiency of two or more γ's from K_n decay		1.221 ± 0.024
g_2: Correction for loss of events due to "good" γ's pointing to visible alternate sources		1.061 ± 0.030
g_3: Correction for accidental intersection of γ's giving spurious K_n decays		0.980 ± 0.010
g_4: Correction for relative scanning efficiencies in samples (Λ_cK_c) and (Λ_cK_n)		1.016 ± 0.007
g_5: Correction for contamination from charge exchange events		$0.991_{-0.018}^{+0.009}$
g_6: Correction for background and analysis uncertainties in the sample		1.008 ± 0.018
$g=g_1g_2g_3g_4g_5g_6$		1.288 ± 0.057
$N'(\Lambda_cK_n)$: Corrected No. of Λ_cK_n events	255 ± 21.2	

C. The Value of B_k

All the above correction factors and the resulting corrected values of $N'(\Lambda_cK_c)$ and $N'(\Lambda_cK_n)$ are summarized in Table II. The value of the neutral branching ratio of the $K_1{}^0$ is, thus,

$$B_K=\frac{N'(\Lambda_cK_n)}{N'(\Lambda_cK_c)+N'(\Lambda_cK_n)}=0.288\pm0.021.$$

The quoted error in B_K is a quadratic combination of the contribution of the statistical sampling of 0.017 and the contribution from the correction factors of 0.013.

VII. THE NEUTRAL BRANCHING RATIO B_Λ

The ratio B_Λ of the Λ^0 hyperon will be computed on the basis of the number of Λ_c decays in sample $(\Lambda_cK_c)_s$ [which we will call $N(\Lambda_cK_c)_s$] compared to the number of Λ_n decays in sample ($K_c\Lambda_n$) [called $N(K_c\Lambda_n)$]. The numbers of accepted events in these samples are 436 and 67, respectively.

$N(K_c\Lambda_n)$ must be adjusted because over a portion of the film the upper decay distance cutoff for the Λ_n

TABLE III. Summary of the numbers of events and the corrections used in the calculation of B_Λ.

	Events	Correction factors
1. The $(\Lambda_c K_c)_s$ sample:		
$N(\Lambda_c K_c)_s$: No. of accepted $(\Lambda_c K_c)_s$ events	436 ± 20.9	
r_1: Correction for Λ_c decays between 0 and 0.5 cm from V origin		1.158 ± 0.025
r_2: Correction for Λ_c decays with prong <0.5 cm, $\omega<15°$, $\omega>160°$ (ω = opening angle of V prongs)		1.110 ± 0.020
r_3: Correction for Λ_c decays with momentum <200 MeV/c		1.030 ± 0.030
r_4: Correction for Λ^0's which interact in flight before decaying as Λ_c's		1.012 ± 0.006
r_5: Correction for background and analysis uncertainties in the sample		1.000 ± 0.010
$r=r_1r_2r_3r_4r_5$		1.340 ± 0.058
$N'(\Lambda_c K_c)_s$: Corrected No. of $(\Lambda_c K_c)_s$ events	584 ± 37.6	
2. The $K_c\Lambda_n$ sample:		
$N(K_c\Lambda_n)$: No. of accepted $K_c\Lambda_n$ events (adjusted as in Sec. VII)	75.7 ± 9.8	
s_1: Correction for conversion efficiency of two γ's from Λ_n decay		2.825 ± 0.090
s_2: Correction for loss of events due to "good" γ's pointing to visible alternate sources		1.156 ± 0.074
s_3: Correction for accidental intersection of γ's giving spurious Λ_n decays		0.978 ± 0.010
s_4: Correction for relative scanning efficiencies in samples $(\Lambda_c K_c)_s$ and $(K_c\Lambda_n)$		1.018 ± 0.010
s_5: Correction for contamination from charge exchange events		0.985 ± 0.015
s_6: Correction for background and analysis uncertainties in the sample		0.988 ± 0.027
$s=s_1s_2s_3s_4s_5s_6$		3.164 ± 0.250
$N'(K_c\Lambda_n)$: Corrected No. of $K_c\Lambda_n$ events	240 ± 36.4	

decays was taken as 4.4 cm instead of the 8.2 cm used for all the rest of the events. Twenty-two $K_c\Lambda_n$ events were originally accepted in this subsample. This number must be adjusted to 30.7 ± 7.1 in order to make the entire sample $[N(K_c\Lambda_n)=75.7\pm9.8]$ consistent with the fiducial criteria of Appendix I. The adjustment can be accurately made because the decay distance distribution is well known from the Λ_c events in sample $(\Lambda_c K_c)_s$.

The numbers $N(\Lambda_c K_c)_s=436$ and $N(K_c\Lambda_n)=75.7$ must now be corrected because the detection efficiencies of the Λ_c and Λ_n decays are not equal and because the fiducial criteria affect the two samples differently.

The corrected numbers of charged decays $N'(\Lambda_c K_c)_s$ and of neutral decays $N'(K_c\Lambda_n)$ are given by

$$N'(\Lambda_c K_c)_s = r\cdot N(\Lambda_c K_c)_s = \Big[\prod_{i=1}^{5} r_i\Big] N(\Lambda_c K_c)_s\,,$$

and

$$N'(K_c\Lambda_n) = s\cdot N(K_c\Lambda_n) = \Big[\prod_{i=1}^{6} s_i\Big] N(K_c\Lambda_n)\,,$$

where the r_i's and s_i's are the correction factors.

A. The Correction Factors r_i and s_i

The corrections r_1 to r_5, to sample $(\Lambda_c K_c)_s$, for the calculation of B_Λ are completely analogous to the corrections f_1 to f_5, to sample $(\Lambda_c K_c)$, used in the calculation of B_K. Likewise, corrections s_1 to s_6, to sample $(K_c\Lambda_n)$, are similar to corrections g_1 to g_6, applied to sample $(\Lambda_c K_n)$. The values of the corresponding factors are different because the fiducial criteria are somewhat different for the Λ's and K's and because the properties of these hyperons and mesons are different. But the methods for determining these corrections are identical.[19] Since these methods have been described in detail for the $K_1{}^0$'s in Secs. VIA and VIB, the factors for the calculation of B_Λ need only to be listed in Table III.

B. The Value of B_Λ

All the correction factors and the resulting corrected values of $N'(\Lambda_c K_c)_s$ and $N'(K_c\Lambda_n)$ are listed in Table III. The value of the neutral branching ratio of the Λ^0 is, thus,

$$B_\Lambda = \frac{N'(K_c\Lambda_n)}{N'(\Lambda_c K_c)_s + N'(K_c\Lambda_n)} = 0.291\pm0.034\,.$$

The quoted error in B_Λ is a quadratic combination of the contribution of the statistical sampling of 0.028, and the contribution from the correction factors of 0.019.

VIII. DISCUSSION

A. The $K_1{}^0$ Decay

The neutral branching ratio B_K is predicted by the $|\Delta I|=\frac{1}{2}$ rule to be

$$B_K = 0.337$$

(i.e., $\frac{1}{3}$ with a small phase-space correction). If the transition is considered to contain a small admixture of $|\Delta I|=\frac{3}{2}$ and none of higher $|\Delta I|$'s, the ratio may be written as[2]

$$B_K \cong 0.337\frac{|1-\sqrt{2}\epsilon_3|^2}{1+|\epsilon_3|^2} \cong 0.337\left[1-4\left(\frac{2\lambda^+}{3\lambda^0}\right)^{1/2}\cos\varphi\right], \quad (4)$$

where ϵ_3 is the complex amplitude of $|\Delta I|=\frac{3}{2}$ relative to that for $|\Delta I|=\frac{1}{2}$, φ is the phase angle between the two amplitudes, λ^+ is the reaction rate for the decay $K^+\to\pi^++\pi^0$, and λ^0 is the total reaction rate for the decay of the $K_1{}^0$.

B_K may, therefore, lie in a region around the value 0.337, depending on the ratio λ^+/λ^0 and on the phase angle φ. Taking (1) the mean lifetime of the K^+ meson to be [22] 1.224×10^{-8} sec, (2) the branching ratio of the decay of the K^+ by the $\pi^++\pi^0$ mode to be 0.256 from the weighted average[23,24] of several emulsion experi-

[22] G. A. Snow and M. M. Shapiro, Rev. Mod. Phys. **33**, 231 (1961).

[23] R. W. Birge, D. H. Perkins, J. E. Peterson, D. H. Stork, and M. W. Whitehead, Nuovo Cimento **4**, 834 (1956); G. Alexander, R. H. W. Johnston, and C. O'Ceallaigh, *ibid.* **6**, 478 (1957); W. Becker, M. Goldberg, E. Harth, J. Leitner, and S. Lichtman (to be published).

[24] The value (0.186 ± 0.009) of Roe *et al.* (Ref. 25) was not included in the average since it is several standard deviations from (0.256 ± 0.015)—the average of the experiments of Ref. 23. Its effect on the limits of the B_K range is very slight, and it is considered later.

TABLE IV. Compilation of measurements of the branching ratio B_K.

Method	B_K	Experimenters	Reference	Bubble chamber used
Count neutral mode directly	0.288±0.021	Chrétien *et al.* (this experiment)		15-in. methyl iodide, propane, and ethane
	0.335±0.014	Brown *et al.*	8	12-in. xenon
	0.30 ±0.035	Brown *et al.*	7	12-in. xenon
	0.26 ±0.06	Baglin *et al.*	6	34-cm methyl iodide and propane
	0.27 ±0.11	Crawford *et al.*	5	10-in. hydrogen
	0.14 ±0.06	Eisler *et al.*	3	12-in. propane
Count charged mode only	0.260±0.024	Anderson *et al.*	9	72-in. hydrogen
	0.30 ±0.08	Columbia	26	12-in. hydrogen
	0.32 ±0.04	Crawford *et al.*	5	10-in. hydrogen

ments and a helium bubble chamber experiment, and (3) the mean lifetime of the K_1^0 to be[16] 0.91×10^{-10} sec, the acceptable region for B_K is

$$0.289 \leqslant B_K \leqslant 0.385.$$

The lower limit corresponds to $\varphi=0°$ and the upper limit to $\varphi=180°$.

Our measurement of $B_K=0.288\pm0.021$ agrees very well with the lower limit of the acceptable range. It is 2.3 times the error ΔB_K away from the value 0.337 for a pure $|\Delta I|=\frac{1}{2}$ transition. This suggests that some admixture of $|\Delta I|=\frac{3}{2}$ is present in the K_1^0 decay.

Substituting $B_K=0.288\pm0.021$ into Eq. (4), we obtain for the relative phase angle

$$\varphi=0_{-0}^{+54} \text{ deg},$$

using the constants listed above. If we use for the branching ratio of the K^+ by the $\pi^++\pi^0$ mode the value 0.186 from Roe *et al.*,[25] the result is only slightly different:

$$\varphi=0_{-0}^{+47} \text{ deg}.$$

Our value of B_K is also in reasonable agreement with other measurements.[3,5–9,26] A compilation of these is presented in Table IV.

TABLE V. Compilation of measurements of the branching ratio B_Λ.

Method	B_Λ	Experimenters	Reference	Bubble chamber used
Count neutral mode directly	0.291±0.034	Chrétien *et al.* (this experiment		15-in. methyl iodide, propane, and ethane
	0.35 ±0.05	Brown *et al.*	7	12-in. xenon
	0.28 ±0.08	Baglin *et al.*	6	34-cm methyl iodide and propane
	0.43 ±0.14	Crawford *et al.*	5	10-in. hydrogen
	0.23 ±0.09	Eisler *et al.*	3	12-in. propane
Count charged mode only	0.315±0.017	Anderson *et al.*	9	72-in. hydrogen
	0.35 ±0.05	Columbia	26	12-in. hydrogen
	0.373±0.031	Crawford *et al.*	5	10-in. hydrogen
	0.35 ±0.06	Eisler *et al.*	3	12-in. propane

[25] B. P. Roe, D. Sinclair, J. L. Brown, D. A. Glaser, J. A. Kadyk, and G. H. Trilling, Phys. Rev. Letters 7, 346 (1961).

[26] M. Schwartz, in *Proceedings of the 1960 International Conference on High-Energy Physics at Rochester* (Interscience Publishers, Inc., New York, 1960), p. 726; and private communication.

B. The Λ^0 Decay

The neutral branching ratio B_Λ is predicted by the $|\Delta I|=\frac{1}{2}$ rule, to be

$$B_\Lambda=0.340$$

(i.e., $\frac{1}{3}$ with a small phase-space correction).

Most measurements have agreed well with this prediction. Our value of 0.291 ± 0.034 is not inconsistent with the decay of the Λ^0 being a pure $|\Delta I|=\frac{1}{2}$ transition.

Table V is a compilation of the measurements of the Λ^0 branching ratio.

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APPENDIX I. THE FIDUCIAL CRITERIA

1. Fiducial Volumes FV_1 and FV_2

(a) The π^- interaction point (i.e., the V origin) had to be within a central fiducial volume FV_1. This had the following unusual shape. Consider three cones with apexes at the centers of the three camera lenses and with a common base centered on the inside of the back glass of the bubble chamber of radius 18.0 cm. A V origin was within FV_1 if it was within at least two of the three cones and it was further than 2.0 cm from the front and back windows.

This unusual shape was used because of the bright field illumination system. If, in a particular camera view, a point lay outside that camera's cone having a base of 19.1-cm radius (the full illuminated radius of the back window), the point was frequently difficult to observe. Therefore, the fiducial volume FV_1 required the V origin to be seen clearly in at least two of the three views.

(b) The decay point or vertex of all K_c and Λ_c decays had to occur within a fiducial volume FV_2. Also, all accepted γ rays had to materialize within FV_2, and the intersection point of the two or more γ's from a neutral decay (i.e., the decay points of the K_n and Λ_n decays) had to be within FV_2. FV_2 was defined to be the same as FV_1, except that the base radius was made 17.5 cm.

FV_2 was made to be slightly smaller than FV_1 in order to allow the secondary particles (including the e^+e^- pairs) a longer path length in the chamber. This reduced the analysis uncertainties greatly.

2. Criteria on Decay Distances

(a) The distances from the V origins to the decay points of all Λ_c's and K_c's, and to the intersection points of the γ's from the neutral modes, had to be $\leqslant 8.2$ cm. This restriction reduced very much the number of spurious background events which had to be measured and analyzed, while it eliminated only a few of the good events. (This criterion did not introduce any bias among the samples.)

(b) The distances from the V origins to the decay points of all Λ_c's had to be $\geqslant 0.5$ cm; and the distances from the V origins to the decay points of all K_c's had to be $\geqslant 0.3$ cm. At distances smaller than these it was difficult to find the V's reliably and then to analyze those which were found.

No similar restrictions were placed upon the intersection points of the γ's from the neutral modes. Hence, a correction must be made for the difference introduced here among the different samples. Corresponding corrections must be made for all of the succeeding fiducial criteria.

3. Other Geometric Criteria

(a) The laboratory opening angles ω between the two secondaries from the Λ_c and K_c decays had to be inside the limits: $15° \leqslant \omega \leqslant 160°$ (in space). The lower limit was imposed in order to prevent any confusion between V_c decays and e^+e^- pairs. The upper region was excluded because of the difficulty in first finding and then analyzing such wide-angle decays.

(b) The range of each secondary of each V_c decay had to be greater than 0.5 cm, and no observable interaction was allowed in this first half-cm. This criterion served to eliminate many spurious background events and also a class of good events which were very difficult to measure and analyze.

4. Kinematic Criteria

The calculated momenta of the accepted K_c and Λ_c decays had to be $p_K \geqslant 100$ MeV/c and $p_\Lambda \geqslant 200$ MeV/c, respectively. For momentum values smaller than these, the momentum-dependent corrections (f_1, f_2, r_1, and r_2) became very large. It was, therefore, considered preferable to correct for the loss of events in the regions $p_K < 100$ MeV/c and $p_\Lambda < 200$ MeV/c by an extrapolation technique described under correction f_3 (Sec. VIA.3).

APPENDIX II. THE MONTE CARLO CALCULATION

A Monte Carlo calculation was performed to obtain the conversion probability (P_m) inside our fiducial volume FV_2 of m γ rays resulting from

(a) the neutral decay of a $K_1{}^0$:

$$K_1{}^0 \to 2\pi^0 \to 4\gamma$$

and

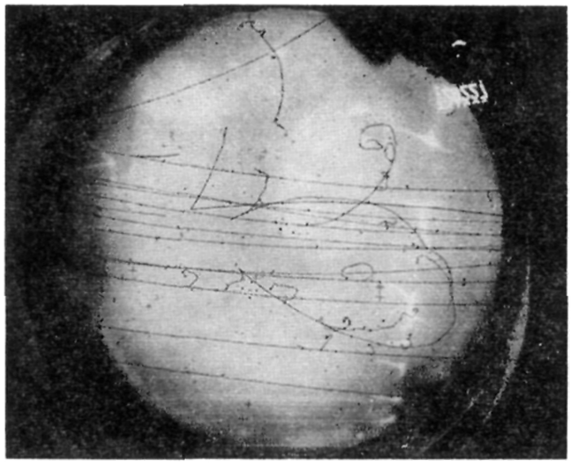
(b) the neutral decay of a Λ^0:

$$\Lambda^0 \to p + \pi^0 \searrow 2\gamma .$$

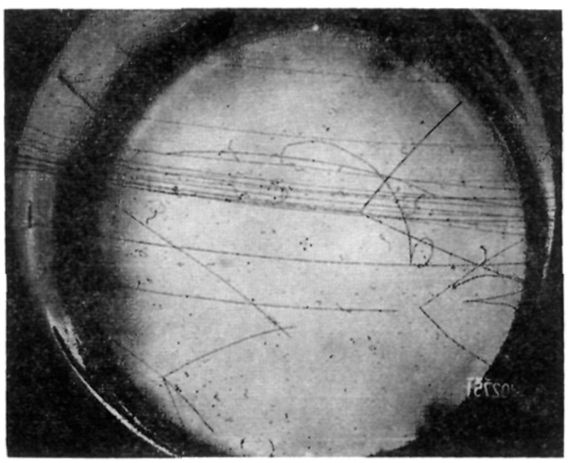
The procedure will be described below in detail with reference to the neutral $K_1{}^0$ decays, but is quite analogous for the neutral Λ^0 decays.

The Monte Carlo calculation made use of information derived from the charged $K_1{}^0$ decays in a representative sample of 199 $\Lambda_c K_c$ events. The input data to the Monte Carlo program consisted of the coordinates of the vertex point of all K_c decays, and the momenta of the decay π^+ and π^- particles given by the KICK program. The assumption was then made that the K_1 meson decayed neutrally and, therefore, two π^0's replace the π^+ and π^-. As the masses of the π^0 and $\pi^\pm$ are very similar it is valid to assume that the π^0's had the same momenta as the π^+ and the π^-. The decay angles of the two γ's in the center-of-mass system of each π^0 were then determined by selecting a random γ-ray direction for each π^0 decay. These directions were subsequently converted into the laboratory system and the potential paths and energies of all 4 γ rays inside the fiducial volume were calculated. The fiducial volume for the γ's was the same as the one (FV_2) for the charged V_c decays. Using the potential paths and energies of the γ's, the probability C_m of converting m γ rays from each K_n decay was then determined, where $m=0, 1, 2, 3, 4$. Each one of the 199 $\Lambda_c K_c$ events was used 25 times as an equivalent neutral decay. The probabilities C_m were, thus, calculated for the 4975 equivalent neutral decays, and then the average probabilities P_m for conversion of m γ rays could be obtained. The results are shown in Table I.

As the function for the pair production cross section in our mixture was known only to within 2–3%, and as the radiation length X_0 in the chamber was also known only to within 2–3% (mainly due to the uncertainty of the density of the mixture), the Monte Carlo calculation was performed for the central value of the radiation length ($X_0 = 8.4$ cm) and also for the values $\pm 5\%$ off. It should be noted that a 5% error in the radiation length produces only a 2% error in the average conversion efficiency of 2 or more γ rays from a neutral $K_1{}^0$ decay.



(a)



(b)

FIG. 2. (a) An event from the $\Lambda_c K_n$ sample:

$$\pi^- + p \rightarrow \Lambda_c + K_n,$$
$$\Lambda_c \rightarrow p + \pi^-,$$
$$K_n \rightarrow 2\pi^0 \rightarrow 4\gamma.$$

Three of the γ rays are observed to materialize in the bubble chamber and point back to the $K_1{}^0$ decay point. The fourth γ ray did not materialize in the chamber. (b) An event from the $K_c\Lambda_n$ sample:

$$\pi^- + p \rightarrow K_c + \Lambda_n,$$
$$K_c \rightarrow \pi^+ + \pi^-,$$
$$\Lambda_n \rightarrow n + \pi^0 \searrow 2\gamma.$$

Both γ rays from the π^0 decay materialize in the chamber.