PHYSICAL REVIEW D VOLUME 14, NUMBER 3 1 AUGUST 1976

Branching ratio of K_S^0 decays into $\pi^+\pi^-$ and $\pi^0\pi^0$ modes*

G. Everhart,† D. Kraus,‡ K. Lande, R. Long,§ D. Łowenstein,‖ J. Niederer, and D. C. Potter¶
Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19174

E. Fenyves
University of Texas at Dallas, Richardson, Texas 75080

(Received 23 February 1976; revised manuscript received 21 April 1976)

We have measured the branching ratio $R = \Gamma(K_S^0 \to \pi^+\pi^-)/\Gamma(K_S^0 \to \pi^0\pi^0)$ of K_S^0 produced in the reaction $\pi^- + p \to \Lambda^0 + K^0$ in the 1.45 GeV/c π^- beam of the Princeton-Pennsylvania Accelerator. The K_S^0 decay secondaries were detected in an array of magnetostrictive-readout wire spark chambers interleaved with lead and copper radiators to convert γ rays. The position of K^0 production in the target was detected with a unique trigger-target apparatus allowing a correction for the background produced by K_L^0 decays. The branching ratio corrected for this background and other standard effects is $R = 2.11 \pm 0.09$, in good agreement with the world average.

I. INTRODUCTION

The hadronic weak interactions have been of great theoretical and experimental interest since their discovery. The study of the nonleptonic decays of strange particles leads among other most exciting discoveries to the suggestion of the $|\Delta I| = \frac{1}{2}$ rule. However, a slight violation of the $|\Delta I| = \frac{1}{2}$ rule was indicated by the $K^+ \to \pi^+\pi^0$ decay. Clear evidence for the violation of the $|\Delta I| = \frac{1}{2}$ rule was shown in accurate measurements of the K^0 branching ratio.[1-9] The world average of the branching ratio, $R = \Gamma(K_S^0 \to \pi^+\pi^-)/\Gamma(K_S^0 \to \pi^0\pi^0)$, calculated from previous measurements is $R = 2.204 \pm 0.026$.[9] A detailed analysis showed that the contribution of the $\Delta I = \frac{5}{2}$ component is much less than that for $\Delta I = \frac{3}{2}$ and that the magnitude of the violation as determined from K^+ and K_S^0 decays is of the order of 6% or less.[8,9]

We have measured the branching ratio R of the decays of K^0 produced in the reaction

$$\pi^- + p \to \Lambda^0 + K^0 . \quad (1)$$

The K_S^0 decay secondaries were detected with an array of wire spark chambers interleaved with lead and copper radiators. The present experiment features high and comparable detection efficiencies for charged and neutral decay modes, well-defined decay volumes for both modes, and a method of substracting backgrounds which depends only on a knowledge of the K_S^0 lifetime, and hence is insensitive to kinematic-reconstruction errors.

II. EXPERIMENTAL METHOD

The K^0 particles were produced in reaction (1) by the 1.45-GeV/c π^- beam of the Princeton-Pennsylvania Accelerator. The 1.45-GeV/c momentum was chosen because it was high enough to give a large geometric efficiency (96%) for having both charged pions from the K^0 decay enter our chambers. Because one of the γ rays from each π^0 of the neutral-mode decay in most cases would lie inside the π^- direction with respect to the K^0, the efficiency for having two or more γ's pass through our chambers was similarly high.

The experimental apparatus consists of three parts: a production section, a decay section, and a secondary detection apparatus (Fig. 1). The production section, or trigger target, is a sandwich of 24 plastic scintillators, each approximately 6.9 mm thick, which detects the K^0 production in reaction (1) and the subsequent Λ^0 decay by means of the pulse sequence and pulse height of its constituent counters. The trigger target is the most unique aspect of the apparatus. The counters in this array define the incident pion beam, provide a target for associated $K^0\Lambda^0$ production, and detect the associated production of K^0 and Λ^0 by serving as veto counters downstream of the target counter and recognizing the subsequent $\Lambda^0 \to p\pi^-$ decay.[10] The electronic trigger criteria used as a signature of associated production and Λ^0 decay were

(1) pulse heights corresponding to a minimum ionizing particle in all counters upstream of the target counter,

(2) an absence of discernible energy deposition in at least two counters downstream of the trigger counter (specifying that only neutral particles were produced),

(3) at least three subsequent successive counters within 11 counters of the target having pulse heights $\geq 3.5x$ minimum (characteristic of $\Lambda^0 \to p + \pi^-$ decay).[11] The pulse heights for each of the 24 target counters were digitized and recorded on tape whenever a trigger occurred. Thus the entire target pat-

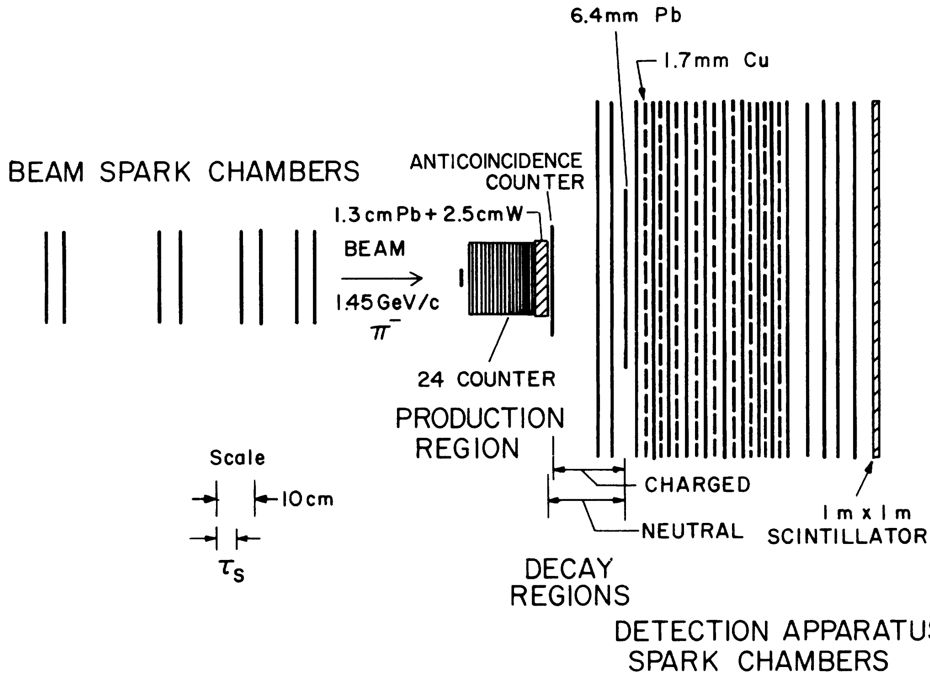

FIG. 1. Experimental apparatus.

tern was available, and the coordinates of $K^0\Lambda^0$ production and Λ^0 decay could be determined to within 6.4 mm in the beam direction. The incoming pion track was recorded in the beam spark chambers upstream of the trigger target, and we required that one and only one π was visible in the chambers.

The upstream end of the decay region was defined by a radiator wall consisting of 1.3 cm lead followed by 2.5 cm tungsten and anticoincidence counter 3.2 mm thick, and the other end, about $4K_S^0$ decay lengths downstream, by a 6.4-mm lead plate. This arrangement vetoes γ rays and charged particles arising in the trigger target and also defines the end of the decay region. The effect of the difference in the size of the decay regions for charged and neutral decays on the branching ratio, owing to γ conversion in the lead-tungsten wall scintillators and the "dead layer" of the anticoincidence counter for detecting charged particles was evaluated by a Monte Carlo calculation. Although the decay-volume correction is momentum-dependent, the almost monochromatic character of our K^0 particles, as shown in Fig. 2, significantly reduced this effect.

The detection apparatus for charged-particle track direction and shower measurement from K^0 decay consisted of an array of 16 magnetostrictive-readout wire spark chambers[12] with nine copper radiator plates, each 1.6 mm thick, placed between them. The copper plates and the 6.4-mm lead plate defining the downstream end of the decay region served to convert the γ rays arising from π^0 decays. An array of 16 magnetostrictive-readout spark chambers with an active area of 1 m×1 m provided seven interleaved horizontal and vertical coordinate measures, X and Y, with two diagonal spark chambers at 45° to these axes to resolve ambiguities in track specification. The 6.4-mm lead plate was placed after the first X and

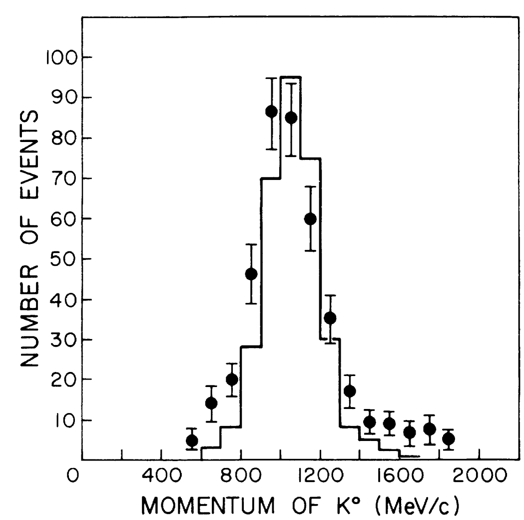

FIG. 2. K^0 momentum spectrum measured for $\pi^+\pi^-$ decays. The solid-line histogram is the Monte Carlo prediction.

Y chamber, and the copper plates were placed in the gaps between next nine chambers. The two spark chambers ahead of the lead radiator helped to distinguish charged from neutral decays.

The data which were digitized in a system specifically designed for digitizing outputs from magnetostrictive spark-chamber systems,[13] was read into a PDP8 computer, and was recorded on magnetic tape. An on-line cathode-ray-tube display of the location of sparks in the chambers provided a monitor during data taking of how an event would have appeared in an optical spark chamber, and subsequent use was made of this facility for visual scanning. Data analysis was carried out on the IBM 360/65 computer of the University of Pennsylvania.

Approximately 10^6 triggers were recorded, satisfying the three criteria of associated $K^0\Lambda^0$ production and subsequent Λ^0 decay in the trigger target. In order to reduce these triggers to a manageable sample a "loose computer filter" was employed. This filter removed only the obviously useless triggers, like events with no sparks, accidental triggers, more than one particle in the beam defining chambers entering the target, and those with too few sparks in the decay spark chambers to form at least two tracks or three sparks each in the region protected by the anticoincidence counter. The computer filter reduced the sample to less than 10^5 triggers. The reduced sample, which still contained a large number of non-K^0 decays, was now subjected to a human visual scan. Most of the triggers rejected by this scan consisted of random collections of sparks or events which did not satisfy our K^0 decay criteria.

Events showing two or more clean tracks pointing back to a point not past the lead plate defining the decay volume were selected as "charged-decay" candidates, and those showing evidence of two or more tracks (pointing back into the decay volume), at least one of which must show evidence of showering behavior, were selected as "neutral-decay" candidates. Late vertices were recorded separately, and in both charged and neutral modes these vertices agreed in production distribution with the calculated K_L^0 distribution. This scan selected approximately 4500 charged-decay and 3300 neutral-decay candidates. Concurrently with this main scan a second scan was done covering about 20% of the data to establish the scanning efficiently, which turned out to be 88.2% for the charged mode and 80.2% for the neutral mode.

A kinematically reconstructed subset of the charged-decay data was used to establish the electronic target patterns and pulse heights associated with the $\pi^- + p \to \Lambda^0 + K^0$ production reactions and $\Lambda^0 \to \pi^- + p$ decays. The data cuts so determined are as follows:

(1) Pulse height in the pion interaction target counter was required to be $\lesssim I_{\min}$ (to eliminate events in which more than K^0 and Λ^0 particles were in the final state).

(2) Λ^0 flight path was cut at one Λ^0 lifetime (five counters) to reduce contamination due to non $K^0\Lambda^0$ events in which an interaction on a carbon nucleus produces neutrons which subsequently interact in downstream counters simulating the electronic patterns associated with Λ^0 decay.

Using these additional criteria, the scanning output was cut to 1971 charged and 1315 neutral-decay events.

III. CORRECTIONS AND RESULTS

The K_S^0 branching ratio can be extracted from the observed numbers of charged and neutral decays upon application of several corrections. The true branching ratio can be obtained from the observed one by

$$R_{\text{true}} = \epsilon R_{\text{obs}} , \tag{2}$$

where ϵ is the product of all correction factors.

A. K_L^0 Contribution

The contribution of K_L^0 decays to the charged and neutral decay events cannot be eliminated on the basis of kinematic analysis of individual events without introducing biases between charged and neutral decay modes. A target distribution criterion that can be imposed, however, is that the K^0 flight paths between the production point and the anticoincidence counter show an appropriate superposition of K_S^0 and K_L^0 lifetimes (Figs. 3 and 4). The K_L^0 contribution to the target distribution was estimated by a Monte Carlo calculation using the known K_S^0 and K_L^0 decay rates and the measured K^0 momentum and production-angle distributions. When subjected to our scanning criteria, (16 ± 2)% of K_L^0 leptonic decays in our fiducial volume were selected as neutral, and (54 ± 4)% as charged, while (81 ± 2)% of $K_L^0 \to 3\pi$ decays were selected as neutral, and (18 ± 2)% as charged. Combining these numbers with the probability of K_L^0 decay in the decay volume, we find that the K_L^0 decays then constitute (10 ± 0.6)% of the charged decay sample, and (14 ± 1)% of the neutral one.

These results can be verified by comparing the observed K^0 decay length in the target to the decay length calculated for a pure K_S^0 beam with the measured momentum distribution. These data indicate that (11 ± 5)% of the charged decays, and (15 ± 10)% of the neutral decays arise from K_L^0, in agreement with the Monte Carlo predictions.

Using the Monte Carlo results the correction

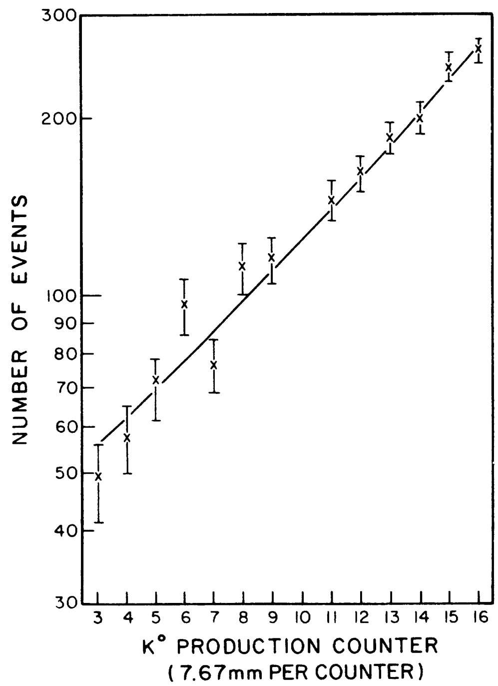

FIG. 3. Distribution of production position of K^0 that decay into $\pi^+\pi^-$. The smooth curve is a Monte Carlo prediction of the expected distribution.

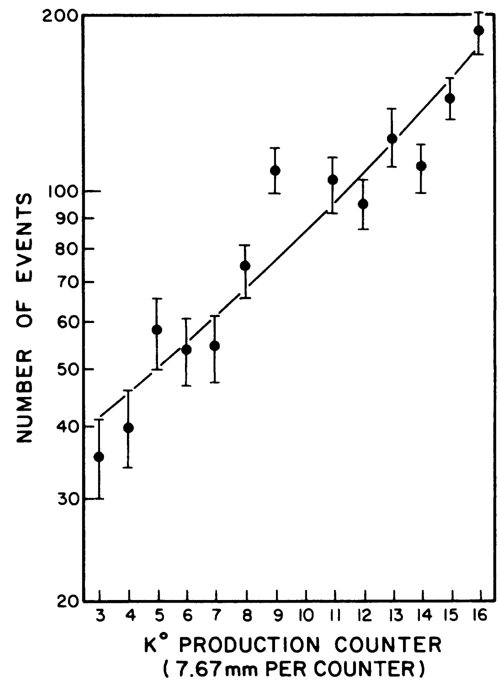

FIG. 4. Distribution of production position of K^0 that decay into $\pi^0\pi^0$. The smooth curve is a Monte Carlo prediction of the expected distribution.

factor calculated for the effect of K_L^0 contribution turns out to be 1.040 ± 0.010.

B. Decay-volume differences

Decay-volume differences for the charged and neutral decay modes due to the finite region in which neutral decays would be accepted by the trigger electronics but charged decays would be vetoed by the anticoincidence counter were calculated, as mentioned above, by the Monte Carlo method. This calculation, in which all angle and momentum spectra were reproduced and which also included Dalitz pair effects, gave a correction factor of 1.455 ± 0.010.

C. Scanning-efficiency differences

The scanning efficiencies determined by a rescanning of about 20% of the data were different for the charged and neutral decays, and contributed a correction factor of 0.910 ± 0.021 to the branching ratio.

D. Nuclear interaction of pions

Pion-nuclear interactions reduced the number of charged-decay events because of absorption or large-angle deflection of charged pions, and production of neutral pions by charge exchange increased the apparent number of neutral decays.

TABLE I. Number of charged and neutral decays, summary of correction factors, and corrected branching ratio.

Number of $K_S^0 \to \pi^+\pi^-$ decays	1971 ± 44
Number of $K_S^0 \to \pi^0\pi^0$ decays	1315 ± 36
Correction factor for	
K_L^0 contribution	1.040 ± 0.010
Decay-volume differences	1.455 ± 0.010
Scanning-efficiency differences	0.910 ± 0.021
Nuclear interaction of pions	1.166 ± 0.005
γ conversions in the anticoindence counter	0.991
Relative detection efficiences	0.943
Mistaken neutral decays	0.940 ± 0.002
Corrected branching ratio	2.11 ± 0.09

The correction for these effects to the branching ratio is 1.166 ± 0.005, calculated from the relevant cross sections and the observed pion-momentum spectrum.

E. γ conversions in the anticoincidence counter

The correction for the γ conversions in the anticoincidence scintillation counter is 0.991, with errors negligible on the scale we are using.

F. Relative detection efficiencies

The relative detection efficiencies for charged and neutral decays, including geometric efficiencies, electromagnetic interactions of pions, and γ conversion efficiencies, give a correction factor of 0.943 to the branching ratio, again with a very small uncertainty in the correction. In order to calculate relative geometric efficiencies, pion absorption, and γ conversion with a minimum of assumptions, a total of 71 000 K_S^0 decays were generated in each mode using the observed K^0 momentum distribution, and each decay was subjected to tests on range of pions in the charged case or tests on the number of charged particles from γ conversion in the neutral case. Spark location in chambers was recorded, and the number of sparks was tested to determine whether or not this particular decay would satisfy our criteria. As a check on these figures, K^0 directions and momenta calculated from the Monte Carlo of the trigger were used for a recalculation, and neutral conversion efficiency was calculated for a sample of neutral Monte Carlo events.

G. Mistaken neutral decays

Neutral decays in which two γ's are both mistaken for charged particles (so called "straight" γ events) caused a loss of neutral decays and a gain of charged events, giving a correction factor to the branching ratio of 0.940 ± 0.002. In order to determine this correction separate calibration exposures to pion beams at various momenta corresponding to those involved in our K^0 decays were carried out. The target trigger conditions for these runs were those appropriate to pion charge exchange. These data were visually scanned with the same criteria as applied to the K^0 decays.

TABLE II. Comparison of our branching ratio with previous measurements.

$R=\Gamma(K_S^0\to\pi^+\pi^-)/\Gamma(K_S^0\to\pi^0\pi^0)$	Reference
2.282 ± 0.043	Moffett *et al.*[3]
2.10 ± 0.06	Morfin *et al.*[2]
2.22 ± 0.095	Baltay *et al.*[4]
2.22 ± 0.08	Morse *et al.*[5]
2.22 ± 0.10	Alitti *et al.*[6]
2.10 ± 0.11	Nagy *et al.*[7]
2.16 ± 0.08	Hill *et al.*[8]
2.169 ± 0.094	Cowell *et al.*[9]
2.11 ± 0.09	This experiment
2.197 ± 0.025	World average

IV. FINAL RESULTS

When all corrections and errors are combined, the K_S^0 branching ratio obtained from the observed numbers of charged and neutral decays using Eq. (2) is (Table I):

$$R=\frac{\Gamma(K_S^0\to\pi^+\pi^-)}{\Gamma(K_S^0\to\pi^0\pi^0)}=2.11\pm0.09\ .$$

This result is in good agreement with the world average of the branching ratio, $R=2.204\pm0.026$, calculated from previous measurements. The new world average including the present experimental result turns out to be $R=2.197\pm0.025$ (Table II). The deviations of the individual experiments from this average yield a χ^2 of 8.7 for eight degrees of freedom.

---

*Research supported in part by the U. S. Atomic Energy Commission.

†Present address: Massachusetts Institute of Technology, Cambridge, Mass. 02139.

‡Present address: University of Pittsburgh, Pittsburgh, Pa. 15260.

§Present address: Mitre Corporation.

‖Present address: Brookhaven National Laboratory, Upton, N. Y. 11973.

¶Present address: Ministry of Health, London, England.

[1]B. Gobbi, D. Green, W. Hakel, R. Moffett, and J. Rosen, Phys. Rev. Lett. 22, 682 (1969).

[2]J. G. Morfin and D. Sinclair, Phys. Rev. Lett. 23, 660 (1969).

[3]R. Moffett, B. Gobbi, D. Green, W. Hakel, and J. Rosen, Bull. Am. Phys. Soc. 15, 512 (1970).

[4]C. Baltay, A. Bridgewater, W. A. Cooper, L. K. Gershwin, M. Habibi, and N. Yeh, Phys. Rev. Lett. 27, 1678 (1971).

[5]R. Morse, U. Nauenberg, E. Bierman, D. Sager, and A. P. Colleraine, Phys. Rev. Lett. 28, 388 (1972).

[6]J. Alitti, E. Lesquoy, and A. Muller, Phys. Lett. 39B, 568 (1972).

[7]E. Nagy, F. Telbisz, and G. Vesztergombi, Nucl. Phys. B47, 94 (1972).

[8]D. G. Hill, M. Sakitt, N. P. Samios, R. W. Burris,

A. Engler, R. W. Kraemer, and C. M. Meltzer, Phys. Rev. D 8, 1290 (1973).
[9]P. Cowell, J. Lee-Franzini, R. Orcutt, P. Franzini, R. Newman, and S. Zubarick, Phys. Rev. D 10, 2083 (1974).
[10]D. E. Kraus, Jr., thesis, University of Pennsylvania, 1974 (unpublished).
[11]The $I > 3.5\, I_{min}$ requirement vetoes also undesired events in which the $K_S^0 \rightarrow \pi^+\pi^-$, rather than the $\Lambda^0 \rightarrow p\pi^-$, would decay in the target counters followed by $\pi^- + p \rightarrow \pi^0 + n$ and subsequent γ conversion or n interaction. Although none of these backgrounds would produce misleading events in the spark-chamber detector, if not suppressed they could unnecessarily increase the trigger rate. Other backgrounds including charge exchange of a pion in the target, with subsequent conversion of π^0 γ rays, were also suppressed by this criterion.
[12]R. J. Long, thesis, University of Pennsylvania, 1974 (unpublished).
[13]G. Everhart, thesis, University of Pennsylvania, 1974 (unpublished).