NEW DETERMINATION OF THE K^+-DECAY BRANCHING RATIOS*

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Present knowledge of the branching ratios among the various decay modes of K^+ mesons has come exclusively from emulsion measurements.[1-3] The results of the most precise emulsion determinations are presented in the first three columns of Table I. Since some of the experimental values of the branching ratios are in disagreement by substantially more than the errors assigned, we have remeasured them using a different technique in order to obtain a new and independent set of values. The high efficiency for conversion of gamma rays from π^0 mesons into electron pairs and the ease of recognition of electrons in a xenon bubble chamber[4] have been used to separate the various K^+-decay modes in our experiment.

The results presented in this Letter are based on the analysis of a sample of 6300 K^+ mesons obtained from an exposure of the xenon chamber to a separated 700-Mev/c K^+ beam at the Bevatron. A moderator was used to reduce the beam momentum to about 400 Mev/c at the entry of the chamber, so that the K^+ mesons came to rest and decayed near the center of the chamber. The chamber has no magnetic field.

The scanning and measurement of the photographs led to the classification of the events into various categories. The requirements that characterize each of these categories are given below, followed in parentheses by a list of the K^+-decay modes that are the main constituents of the events classified therein: (a) events with more than one charged secondary (τ); (b) events with a single-charged secondary and three or four electron pairs (τ'); (c) events with two, one, or zero electron pairs and a charged secondary clearly identified as an electron by its large radiative energy loss or its production of a cascade shower (K_{e3}).

The remaining events were classified as follows: (d) events with a single-charged secondary and two electron pairs identified to be $K_{\pi 2}$ by the constraints imposed in the application of energy and momentum conservation to K^+ and π^0 decays ($K_{\pi 2}$); (e) events not in Category (d) which have a single-charged secondary and two electron pairs ($K_{\mu 3}, \tau'$); (f) events with a single-charged secondary and one electron pair ($K_{\pi 2}$, $K_{\mu 3}$); (g) events with a single-charged secondary and no electron pairs ($K_{\mu 2}$).

The μ secondary from a π^+ decay at rest has a range of only 1.3 mm and hence cannot always be reliably identified. Thus no separation was made

Table I. K^+ branching ratios, in percent.

Decay mode	Birge et al.[a]	Alexander et al.[b]	Taylor et al.[c]	Present expt.	ΔB for 2% change in γ scanning efficiency
$K_{\mu 2} \rightarrow \mu^+ + \nu$	58.5 ±3.0	56.9 ±2.6		64.2 ±1.3	0.2
$K_{\pi 2} \rightarrow \pi^+ + \pi^0$	27.7 ±2.7	23.2 ±2.2		18.6 ±0.9	0.1
$K_{\mu 3} \rightarrow \mu^+ + \pi^0 + \nu$	2.8 ±1.0	5.9 ±1.3	2.8 ±0.4	4.8 ±0.6	0.3
$K_{e3} \rightarrow e^+ + \pi^0 + \nu$	3.2 ±1.3	5.1 ±1.3		5.0 ±0.5	0.0
$\tau^+ \rightarrow 2\pi^+ + \pi^-$	5.6 ±0.4	6.8 ±0.4	5.2 ±0.3	5.7 ±0.3	0.0
$\tau^{+\prime} \rightarrow \pi^+ + 2\pi^0$	2.1 ±0.5	2.2 ±0.4	1.5 ±0.2	1.7 ±0.2	0.1

[a] See reference 1.
[b] See reference 2.
[c] See reference 3.

between π and μ secondaries on the basis of observed π-μ decays. Since most K^+ mesons stop near the center of the chamber, the 24-cm range of the π^+ from the $K_{\pi 2}{}^+$ decay mode is too long in a 30-cm diameter chamber to be useful as a method of separation of $K_{\pi 2}$ from other modes.

We now illustrate in a slightly oversimplified way the method of calculating the branching ratios from the data. We let N_1, N_2, $\cdots N_7$ denote the numbers of events in the above seven categories, and let $N = \sum_i N_i$. We also define $C(K_i, j)$ as the probability that in the decay mode K_i, j gamma rays are converted and observed in the appropriate fiducial volume of the bubble chamber, e.g., $C(K_{\mu 3}, 1)$ is the probability of observing one gamma ray from a $K_{\mu 3}$. Finally we let C_e be the probability of recognition of an electron, by virtue of its large energy loss or production of a shower in the chamber. In terms of the above quantities, the branching ratios can be calculated from the following relations:

$$B(\tau) = N_1/N,$$

$$B(\tau') = \frac{N_2}{N[C(\tau',4)+C(\tau',3)]},$$

$$B(K_{e3}) = N_3/C_e N,$$

$$B(K_{\mu 3}) = \frac{1}{C(K_{\mu 3},2)}[N_5/N - C(\tau',2)B(\tau') - B(K_{e3})(1-C_e)C(K_{e3},2)],$$

$$B(K_{\pi 2}) = \frac{1}{C(K_{\pi 2},2)+C(K_{\pi 2},1)}[(N_4+N_6)/N - C(\tau',1)(B(\tau') - C(K_{\mu 3},1)B(K_{\mu 3}) - (1-C_e)C(K_{e3},1)B(K_{e3})],$$

$$B(K_{\mu 2}) = N_7/N - C(\tau',0)B(\tau') - C(K_{\mu 3},0)B(K_{\mu 3}) - C(K_{\pi 2},0)B(K_{\pi 2}) - (1-C_e)C(K_{e3},0)B(K_{e3}).$$

The determination of the efficiencies $C(K_i, j)$ consists of two parts: computation of the conversion probabilities in the chamber, and estimation of the fraction of electron pairs missed because of scanning inefficiency. The first part was done by a Monte Carlo technique in which the observed spatial distribution of K^+-decay points and the theoretical gamma-ray conversion cross section were used to compute the probabilities of forming various numbers of electron pairs within the appropriate fiducial volume. These efficiencies are insensitive to assumptions about π^0 momentum distributions in the three-body decay modes and are approximately represented by multinomial distributions with conversion probability of 80% for a single gamma ray. From the Monte Carlo calculation, we find that the fraction of $K_{\pi 2}$ events in which neither gamma ray from the π^0 converts is only 5%.

The effects of scanning inefficiency were minimized in the following ways: (a) All pictures were scanned twice by technicians or physicists. (b) About 30% of the pictures were scanned independently by two physicists. (c) Only pictures of the best quality, without too many K^+ mesons, were used in the analysis. (d) All K^+-decay points were required to fall within an appropriate fiducial volume appreciably smaller than the bubble chamber.

An important check on the efficiency was afforded by a comparison of the experimentally found relative proportion of events with one and with two electron pairs and those obtained by the Monte Carlo computation. From this comparison, we conclude that the average scanning efficiency for electron pairs is (85 ± 2)%. Much of this loss can be ascribed to steeply dipping and low-energy pairs. An error of 2% in the efficiency estimate would change the branching ratios by the amounts shown in the last column of Table I.

The electron recognition efficiency C_e was obtained by measuring, for a sample of identified K_{e3} events, both the minimum amount of track required to identify the electron and its potential path length in the chamber. From these data, the electron recognition probability as a function of potential path was evaluated and, averaged over the potential path distribution, yielded $C_e = (89 \pm 2.5)\%$.

Small corrections were applied to the results obtained as described above for the following effects: (a) the presence of a small contamination of decays in flight, for which the kinematical $K_{\pi 2}$ tests discussed previously are incorrect; (b) the fact that, because of measurement errors, a small number of $K_{\mu 3}$ events pass the $K_{\pi 2}$ kinematical tests.

The final results are given in Table I, which for comparison also contains the results of emulsion determinations by Birge et al., Alexander et al., and Taylor et al.

No clear example of a decay mode other than the six considered above was found, but it must be emphasized that no systematic search aimed specifically at the identification of rare modes has yet been completed.

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INTERACTIONS OF LAMBDAS WITH PROTONS*

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In the course of an experiment to study the associated production processes,

$$\pi^- + p \rightarrow \Lambda + K^0 \qquad (1)$$

and

$$\pi^- + p \rightarrow \Sigma^0 + K^0, \quad \Sigma^0 \rightarrow \Lambda + \gamma, \qquad (2)$$

we have examined subsequent Λ interactions in hydrogen of the types

$$\Lambda + p \rightarrow \Lambda + p, \qquad (3)$$

$$\Lambda + p \rightarrow \Sigma^0 + p, \qquad (4)$$

$$\Lambda + p \rightarrow \Sigma^+ + n. \qquad (5)$$

In this Letter we present results for reactions (3) and (4), based on a sample of 5000 Λ's produced in the Alvarez 72-in. hydrogen bubble chamber. [We postpone discussion of reaction (5) to a later publication.] In addition, we set an upper limit to the pion-producing reactions,

$$\Lambda + p \rightarrow \Lambda + p + \pi^0$$

and

$$\Lambda + p \rightarrow \Lambda + n + \pi^+. \qquad (6)$$

The Λ "beam" momentum extends from 400 to 1000 Mev/c, and corresponds to the associated production processes (1) and (2) for incident π^-'s of 1035 Mev/c. The distribution of Λ momentum versus path length is shown in Fig. 1. It includes two cutoff corrections: (a) Single V^0 decays of K^0 or Λ (without subsequent scatter) are rejected if the neutral particle travels less than 0.5 cm before decaying; (b) only those Λ interactions that occur within 10 cm of the production point are accepted. Cutoff (a) serves to exclude spu-

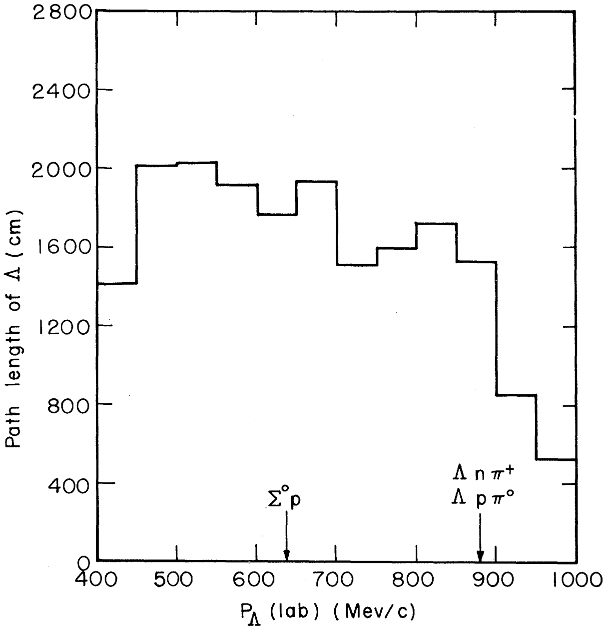

FIG. 1. Distribution of Λ path length versus momentum. The arrows indicate the thresholds for reactions (4) and (6).