

A MEASUREMENT OF THE BRANCHING RATIO

$$\frac{(K_L^0 \rightarrow \pi\mu\nu)/(K_L^0 \rightarrow \pi e\nu)}{}$$

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ABSTRACT

The results are presented of a study of K_L^0 decays observed in the CERN 1.1 m³ heavy-liquid bubble chamber. About 75,000 frames were scanned, and yielded some 7,500 examples of isolated K_L^0 decays to charged particles. Based on a sample of 4,000 events in a restricted fiducial region, the following branching ratios were found:

$$R_1 = N(K_L^0 \rightarrow \pi^\pm \mu^\mp \nu) / N(K_L^0 \rightarrow \pi^\pm e^\mp \nu) = 0.648 \pm 0.030$$

$$R_2 = N(K_L^0 \rightarrow \pi^+ \pi^- \pi^0) / N(K_L^0 \rightarrow \text{all charged}) = 0.157 \pm 0.010 .$$

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The CERN 1.1 m³ heavy-liquid bubble chamber was exposed to a neutral beam taken at 30° from an internal beryllium target in the CERN Proton Synchrotron. Approximately 2×10^{11} protons/pulse with a momentum of 19.2 GeV/c impinged on the target, giving rise to a flux at the bubble chamber of $50 K_L^0$, 1.8×10^3 γ rays (with energy > 1 GeV), and 9.0×10^3 neutrons (with kinetic energy > 0.3 GeV) per pulse. The distance from the target to the centre of the bubble chamber was 22.5 m, and the beam was collimated to a circular profile 2 cm in diameter at the chamber. In order to avoid all possible background and regeneration effects, the beam path was *in vacuo* (4×10^{-2} mm pressure of air) both inside the chamber and for 13 m before it. The beam had a momentum spectrum ranging from 0.3 GeV/c to 3.0 GeV/c peaking at about 1.0 GeV/c.

Within the chamber, the vacuum pipe was of aluminium and had an internal diameter of 4 cm. The wall was 2.5 mm thick. A lead collar was fitted to the pipe just within the chamber, and greatly reduced the background of tracks from K_L^0 decays occurring before the chamber. Tracks that emerged from the pipe on the far side from the cameras were observed through a mirror placed some 35 cm behind the pipe. The chamber was filled with heavy freon, CF₃Br, in which the radiation length was 11 cm and the collision length was 58 cm. The magnetic field in the chamber was 27.0 kilogauss.

The film was scanned for those frames on which there was a single decay of the type $K_L^0 \rightarrow$ charged particles in a region defined by the first track exiting the pipe not less than 5 cm from the lead collar and the second not more than 70 cm from the collar. The scan rules also rejected those frames on which there was evidence for any decays giving rise to tracks just outside this region. Events were accepted with one or two charged tracks, of either sign, together with up to three electron pairs or Compton electrons that could be associated with a possible origin for the charged tracks. Two independent scans were made; all frames found by either scan were checked and classified by physicists. The criteria used in the identification of particles were that: i) an electron (positron) could be identified by shower effects, or by the curvature of the track; ii) gamma rays could be recognized through electron pairs or Compton electrons; iii) charged pions could be identified through the occurrence

of an interaction, or of a single scatter with a momentum transfer greater than $0.1 \text{ GeV}/c$ ¹⁾, or of a π - μ - e decay chain; iv) the remaining non-electronic tracks could not be distinguished between π or μ , but the decay of such a track to an electron was recorded.

After identification of the individual tracks, events were assigned to the categories shown in Table 1. Also given in Table 1 is the number of events placed in each category when the first track was required to emerge from the pipe within a fiducial region 35 cm long, beginning 20 cm from the lead collar. This fiducial region was chosen to ensure reliable particle identification and a high gamma detection efficiency. The final results were shown to be insensitive to the precise choice of fiducial region.

A number of systematic effects were considered, which can influence both the efficiency of detecting events and the efficiency for identifying those events found. These effects are summarized in Table 2. The scanning efficiencies and identification efficiencies have been obtained ³⁾ by careful rescanning of film by different combinations of scanners and physicists from the two establishments collaborating in this work. The corrections due to stopping of pions and muons, and electron loss processes, are given in items 5-8 of Table 2. These corrections and the gamma detection efficiency have been derived from a study of the data and a Monte Carlo simulation of the experiment. The flux of gammas randomly associated with events has been estimated from the number of events found of the type $\pi\pi\pi\gamma$. The final totals after application of the corrections are given in line 12. From these we may immediately derive the two branching ratios:

$$R_1 = N(K_L^0 \rightarrow \pi^\pm \mu^\mp \bar{\nu}) / N(K_L^0 \rightarrow \pi^\pm e^\mp \nu) = 0.648 \pm 0.030$$

$$R_2 = N(K_L^0 \rightarrow \pi^+ \pi^- \pi^0) / N(K_L^0 \rightarrow \text{all charged}) = 0.157 \pm 0.010.$$

Previous measurements of R_1 are given in Table 3, together with the best fit value as given in the particle data tables ⁶⁾. We note that while R_2 is in good agreement with previous measurements ⁷⁾, R_1 is somewhat lower. We believe this may be because of the ability of the technique to detect decays from all parts of the Dalitz plot with close to 100 per cent efficiency, and to the insensitivity to any assumptions about the form of the interaction. The value of R_1 obtained in this work may be used to

derive the parameter ξ_0 , the ratio of the form factors at zero four momentum transfer, in the expression⁸⁾:

$$R_1(K_{\mu_3}/K_{e_3}) = 0.6487 + 0.1269 \operatorname{Re}(\xi_0) + 0.0193|\xi_0|^2 + 1.329\lambda_+ + \dots,$$

where a pure vector coupling and μ -e universality are assumed. The energy dependence of the form factors has been parametrized in the normal manner⁹⁾:

$$f_{\pm}(q^2) = f_{\pm}(0)[1 + \lambda_{\pm}q^2/m_{\pi}^2].$$

Assuming also time reversal invariance then $\operatorname{Im}(\xi_0) = 0$, and setting $\lambda_- = 0$ we obtain $\xi_0 = -3.287 \pm 7.198 (R_1 - 0.4403 - 1.329\lambda_+)^{1/2}$, whence, using $R_1 = 0.648 \pm 0.03$, and $\lambda_+ = 0.02 \pm 0.015$ ¹⁰⁾, $\xi_0 = -6.36 \pm 0.30$ or -0.22 ± 0.30 .

Results from polarization studies¹¹⁾ would predict $R_1 = 0.53 \pm 0.03$ using the same phenomenology. The agreement between these two sets of results is at the 5 per cent level; it is possible, as discussed, for example, by Cronin¹²⁾, that a strong contribution from the λ_- term may still be required to reconcile the data. A comparison of these data with the (K_{μ_3}/K_{e_3}) branching ratio from K^+ experiments allows a test of the $|\Delta I| = 1/2$ (leptonic) rule. The mean value obtained from the measurements of Eichten et al. and Botterill et al.¹³⁾, $R_1(K^+) = 0.636 \pm 0.01$, yields $R_1(+)/R_1(0) = 0.98 \pm 0.05$, in excellent agreement with the prediction of unity.

A preliminary analysis of part of these data was submitted to the 14th International Conference on High-Energy Physics, Vienna, 1968¹⁴⁾.

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Table 1

Event classification

Class	Class characteristics	No. in class
$K^0_{e_3}$	One electronic track, one non-electronic track of opposite sign which may or may not be identified as a pion. No γ rays other than those consistent with bremsstrahlung.	1897
$K^0_{\mu_3}$	Two non-electronic tracks, not more than one of which is identified as a pion. No γ rays.	1309
$K^0(\pi^+\pi^-\pi^0)$	Two non-electronic tracks and one or two γ rays associated with the likely decay point.	558
$\pi^+\pi^-$	Two identified pion tracks and no γ rays.	8
e^+e^-	Two identified electronic tracks.	41
Single tracks	One track of any nature with or without associated γ rays.	167
$K^0_{e_3} + \gamma$	As $K^0_{e_3}$, but with one associated γ ray not consistent with bremsstrahlung (see note 2).	19
TOTAL		3999

Table 2

Corrections and assignment of events to the K_{e_3} , K_{μ_3} and $K(+\text{-}0)$ class

Original class	K_{e_3}	K_{μ_3}	$K(+\text{-}0)$
1. Identified events	1897	1309	558
2. Scanning and identification efficiency*)	$(95.8 \pm 2.1)\%$	100%	$(93.9 \pm 3.7)\%$
3. Gamma detection efficiency	-	-	$(+1.3 \pm 0.3)\%$
4. $\pi^+\pi^-$ decay mode and $(+\text{-}0)$ events where neither γ materializes	-	$(-0.7 \pm 0.1)\%$	-
5. Single track + 1 or 2 gammas	$(+0.6 \pm 0.2)\%$	-	$(+2.0 \pm 0.6)\%$
6. Single tracks	$(+1.9 \pm 0.5)\%$	$(+0.4 \pm 0.1)\%$	-
7. Electrons on pipe **)	-	-	$(+5.0 \pm 3.0)\%$
8. Pion and muon decay in pipe	$(-0.1 \pm 0.1)\%$	$(+0.6 \pm 0.1)\%$	$(+0.5 \pm 0.2)\%$
9. Randomly associated gammas	-	-	$(-0.5 \pm 0.5)\%$
10. Dalitz pairs	-	-	$(+1.17 \pm 0.04)\%$ 5)
11. Geometrical detection efficiency	$(+0.0 \pm 1.0)\%$	$(+0.0 \pm 1.0)\%$	$(-4.2 \pm 1.0)\%$
12. Totals after corrections	2025 \pm 67	1313 \pm 39	621 \pm 39

*) Normalized to 100% for K_{μ_3} decays.

**) Gamma rays from $\pi^+\pi^-\pi^0$ decays passing through the pipe wall can give rise to single electrons leaving the pipe, which would then lead to event rejection at the scanning stage. See reference 4.

Table 3

$R_1 (K_{\mu_3}/K_{e_3})$	ΔR_1	Method	Reference
0.81	0.19	Hydrogen B. Ch.	a
0.73	0.15	Hydrogen B. Ch.	b
0.82	0.10	Spark Ch.	c
0.70	0.20	Hydrogen B. Ch.	d
0.81	0.08	Hydrogen B. Ch.	e
0.71	0.05	Heavy liq. B. Ch.	f
0.745	0.035	Fit	g
0.638	0.036	Spark Ch.	h
0.648	0.030	Heavy liq. B. Ch.	This work

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