A MEASUREMENT OF THE $(K^+ \to e^+\nu)/(K^+ \to \mu^+\nu)$ BRANCHING RATIO[1,2]

K.S. HEARD [3], J. HEINTZE, G. HEINZELMANN,
P. IGO-KEMENES, W. KALBREIER, E. MITTAG [4],
H. RIESEBERG, B. SCHÜRLEIN [5], H.W. SIEBERT,
V. SOERGEL, K.P. STREIT,
A. WAGNER and A.H. WALENTA
CERN, Geneva, Switzerland
and I. Physikalisches Institut der Universität Heidelberg, Heidelberg, Germany

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The branching ratio $R = \Gamma(K^+ \to e^+\nu)/\Gamma(K^+ \to \mu^+\nu)$ has been measured on the basis of 534 observed $K^+ \to e^+\nu$ decays. The K^+ decay at rest; the momenta of the e^+ and μ^+ are measured in a magnetic spectrometer using multiwire driftchambers, and the electrons are identified in a gas Cerenkov counter. The result is $R = (2.37 \pm 0.17) \times 10^{-5}$. The value predicted for pure axial-vector interaction and μ-e-universality is $R = 2.57 \times 10^{-5}$.

We present here an experiment on the branching ratio $R = \Gamma(K^+ \to e^+\nu)/\Gamma(K^+ \to \mu^+\nu)$, in which we observed 534 $K^+ \to e^+\nu$ decays and obtained $R = (2.37 \pm 0.17) \times 10^{-5}$. Four previous experiments [1–4] give the combined result $R = (2.39 \pm 0.32) \times 10^{-5}$. If this value is corrected for the contribution from structure dependent $K^+ \to e^+\nu\gamma (K_{e\nu\gamma})$ decay, using the measured $K_{e\nu\gamma}$ branching ratio [5], this value is lowered to $R = (2.29 \pm 0.33) \times 10^{-5}$.

In our experiment, the K^+ decay at rest in a target. A magnetic spectrometer and a threshold gas Cerenkov counter are used to separate the rare $K^+ \to e^+\nu$ (K_{e2}) decay ($p_e = 247$ MeV/c) from $K^+ \to \mu^+\nu$ $(K_{\mu 2})$ decay ($p_\mu = 236$ MeV/c) and from $K^+ \to e^+\nu\pi^0$ (K_{e3}) decay ($p_e \leqslant 228$ MeV/c).

Fig. 1 shows the experimental setup. K^+ from a low energy K^+-beam at the CERN-PS [6] are stopped in a LiH target. The kaons are identified by their high pulse in the scintillation counter hodoscope E (8 cells), while pion are vetoed in a plexiglass Cerenkov

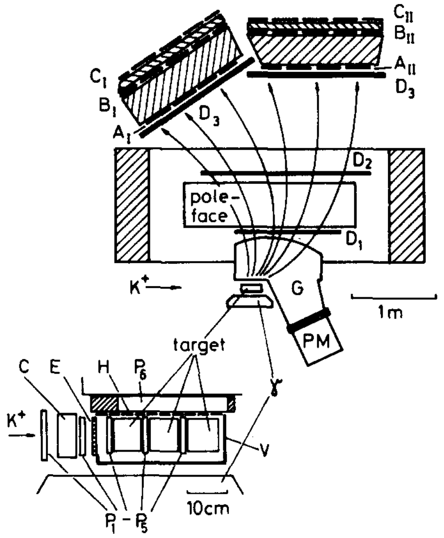

Fig. 1. The experimental setup. P_1–P_6: multiwire proportional chambers. D_1–D_3: multiwire driftchambers. C: plexiglass threshold Cerenkov counter. E, H, A, B, C: scintillation counter hodoscopes. G: gas Cerenkov counter, the location of its photomultipliers is denoted by PM. V: veto counters around the target. γ: leadglass γ counter. One leadglass block is shown, the two others are above and below the drawing plane. The poleface of the bending magnet and typical tracks for $p = 240$ MeV/c are indicated.

[1] A preliminary result of this experiment has been presented at the 17th Intern. Conf. on High energy physics, Chicago, 1972.
[2] Work supported by the Bundesministerium für Bildung und Wissenschaft.
[3] Now at AERE, Harwell, Didcot, Berks., UK.
[4] Now at Scientific Control Systems, D 2000 Hamburg, Überseering 8.
[5] Now at IDAS GmbH, D 6250 Limburg, Kornmarkt 9.

counter. The kaon track is recorded in proportional chambers P_1-P_5.

The momentum of the charged decay particle is measured in a magnetic spectrometer equipped with a multiwire proportional chamber (P_6) and multiwire driftchambers (D_1 to D_3) [7]. Charged particles coming from the target and passing the spectrometer are detected in the scintillation counter hodoscopes H (10 cells), placed beside the target, and A (8 cells), placed behind the last driftchamber D_3. For the selection of calibration samples, a range telescope is used consisting of the counter hodoscopes A, B and C and carbon plates.

For μ-e discrimination, we use a gas Cerenkov counter G operating at atmospheric pressure with isobutane as radiator. This counter will be described elsewhere [10]. A veto counter shields the gas counter phototubes against particles from the beam halo.

A γ-ray detector, consisting of three leadglass blocks, is placed beside the target, opposite to the spectrometer. It is used to detect γ-rays from the π^0 of K_{e3} decays and from $K_{e\nu\gamma}$ decays. Veto counters cover the part of the target surface left open by the two hodoscopes E and H, so that all charged particles entering or leaving the target will be detected.

For each trigger, the complete track information (wire addresses and drifttimes of the chambers and hodoscope patterns) and information on signal timings and pulse heights of all relevant counters is stored in an on-line computer.

The basic trigger for the data recording system requires one charged particle leaving the target and passing the spectrometer with a delay of −6 to +44 ns relative to an incoming K^+. The triggers are rejected, if either in hodoscope H or in hodoscope A more than one cell gives a signal, or if one of the veto counters, including the plexiglass counter in the beam, gives a signal in coincidence with either the incoming K^+ or the gas counter.

Data were recorded concurrently for three trigger modes:

1) Monitor trigger: The basic trigger was scaled down by a factor 1024, in order to obtain a sample of $K_{\mu 2}$ decays at an acceptable trigger rate.

2) Electron trigger, defined by a signal from the gas Cerenkov counter in coincidence with the basic trigger. The timing gate for the gas Cerenkov counter was 40 ns wide in order to record also random coincidences for background determination.

3) Calibration trigger, defined by signals in hodoscope C and in the γ-counter in prompt coincidence with the basic trigger. This mode selects K_{e3} decays by the electron range and by detection of one of the γ-rays from π^0-decay. These events are used for the efficiency calibration of the gas counter.

During the beam burst of the PS, the information of all triggering events is stored in an on-line computer. Between the bursts, counter patterns and timings are checked, the momenta of the decay particles are calculated and the full information is written on magnetic tape for events within suitable momentum limits.

In a detailed off-line analysis the momentum of the decay particle is determined with improved precision and the energy loss by ionization in target and gas counter is corrected for. This correction amounts to 4.5 MeV/c on the average and can be evaluated to ±1 MeV/c for the individual event.

In the further analysis only those events are used for which the decay particle falls inside a fiducial window in chamber D_1 defined such that the particle cannot hit the pole faces of the magnet. For the evaluation of the branching ratio, events are selected from the trigger modes 1 and 2 by the two following criteria:

1) The K^+ lives in the target at least 3 ns. This cut eliminates decays in flight.

2) The γ-detector gives no signal in coincidence with the decay particle. This criterion reduces the contribution from the decay modes K_{e3} and $K_{e\nu\gamma}$ to the sample of electron triggers.

Electron events have to fulfill an additional requirement:

3) The gas Cerenkov counter signal occurs in coincidence with the decay particle, within a timing window of 6 ns width, and its pulse height corresponds to at least 2.5 photoelectrons.

The timing of the K decay is given by the signal from hodoscope A, corrected for the different times of flight and for the different light path in the scintillator.

Fig. 2 shows the momentum spectrum of the electron events. It contains 2 peaks at the momenta corresponding to K_{e2} and $K_{\mu 2}$ decay. The background of events having a random signal in the gas counter is evaluated using the events with out-of-timing signals. After subtraction of this background, the peak from $K_{\mu 2}$ decay essentially disappears. From the

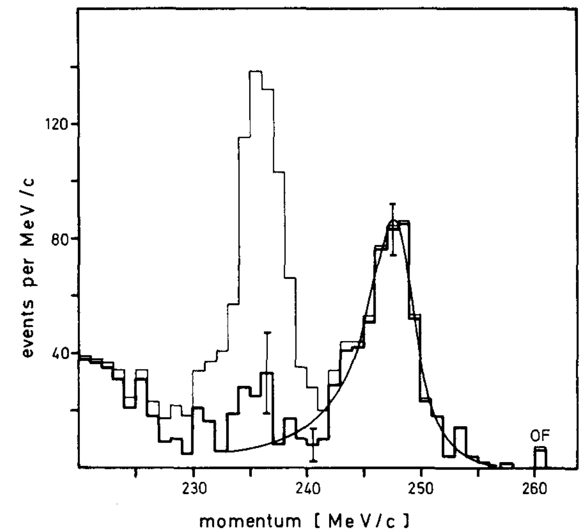

Fig. 2. Momentum spectrum of electron events. Thin histogram: all events. Thick histogram: events after subtraction of random background. Smooth curve: calculated line shape, normalised above 240 MeV/c to the thick histogram. OF: Sum of all events with momenta above 260 MeV/c.

events remaining in the region of the $K_{\mu 2}$ peak, the detection efficiency of the gas counter for muons from $K_{\mu 2}$ decay turns out to be $\epsilon_\mu < 2 \times 10^{-6}$.

In the momentum region 240 MeV/$c < p_e <$ 260 MeV/c, which will be used for the determination of the branching ratio R, the spectrum in fig. 2 contains 543 ± 6 events after subtraction of the accidental background (47 events), where the error is the statistical uncertainty of the background. This sample contains $<$ 1 event from K_{e3} decay, as evaluated from the high momentum part of the observed K_{e3} spectrum. The non-accidental background from $K_{\mu 2}$ decay is $<$ 5 events, obtained from the shape of the μ-line in the monitor events and from the upper limit of μ-breakthrough in the gas counter. The decay time distribution of these events is an exponential with a mean lifetime of (10.9±0.9) ns, in reasonable agreement with the world average for the K^+-lifetime, τ_{K^+} = 12.4 ns [8]. The structure dependent radiative decay $K_{e\nu\gamma}$ contributes a background of 9 ± 6 events, as determined from the measured branching ratio [5] and from the probability that the γ is not detected. We therefore attribute n_e = 534 ± 9 events to the decay mode $K^+ \to e^+\nu$. The statistical uncertainty of n_e amounts to ±26 events.

The detection efficiency of the gas Cerenkov counter with the pulse height and timing cuts applied is ϵ = 0.851 ± 0.019. The counter was calibrated with electrons from K_{e3} decay, which were selected from events obtained with the calibration trigger. The efficiency calibration was verified after the experiment in an electron beam.

Accidental coincidences between the veto counters and the gas counter give rise to an accidental rejection of electron events, which must be corrected for. The corresponding reduction factor r has been evaluated from the relation between the beam intensity and the rate of coincidences between the gas counter and the veto counters, which were recorded throughout the experiment. The result was r = 0.91 ± 0.03.

Only one out of 10 monitor events was used in the analysis. The monitor sample thus obtained contains n_μ = 4069 events from $K_{\mu 2}$ decay in the momentum window 220 MeV/$c \leqslant p_\mu \leqslant$ 252 MeV/c, which are used for determining the branching ratio R.

A detailed study of the line shape, using the range information, shows that due to the line width, $<$0.5% of the muons fall outside the accepted momentum window, and that the monitor sample contains $<$20 events from other sources than $K_{\mu 2}$ decay. The monitor events show an exponential decay curve with a mean life-time of (12.1 ±0.3) ns, in good agreement with the K^+-lifetime.

The solid angle of the spectrometer differs by less than 1% for K_{e2} and $K_{\mu 2}$ decay particles due to their nearly equal momenta, as has been worked out with a Monte Carlo program.

A small correction to the branching ratio R comes from knock-on electrons, which hit a second cell in hodoscope H and therefore cause a rejection of the events. This effect is bigger for electrons than for muons and causes a reduction in the ratio of observed e and μ events by a factor δ = 0.985 ± 0.005.

With the numbers given, we obtain for the branching ratio R' of the experimentally observed event rates

$$R' = \frac{n_e}{10240\, n_\mu} \cdot \frac{1}{\epsilon r \delta} = (1.68 \pm 0.11) \times 10^{-5}.$$

Internal bremsstrahlung and energy loss by radiation and by Bhabha scattering with large momentum transfer, cause a deformation in the μ^+ and e^+ spectra. For internal bremsstrahlung, we use the formula given by Berman [9] for π_{e2} decay, replacing the π-mass by the K-mass. The material traversed before the magnet amounts to 3.75×10^{-2} radiation lengths and contains 6.5×10^{23} electrons per cm^2, on the average.

In the e^+ spectrum, the three processes give rise to an important tail towards low momenta. The momentum spectrum to be expected in this experiment for e^+ from K_{e2} decay was calculated and folded with the resolution of the spectrometer. It is shown in fig. 2, normalized for $p \geqslant 240$ MeV/c to the observed number of K_{e2} events. By integration we find that $(30.0 \pm 2.0)\%$ of the e^+ from K_{e2} decay give measured momenta $p_e < 240$ MeV/c. The error is due to the uncertainty in the average amount of material traversed and to the uncertainty in the absolute position of the momentum cut. For infinitely good resolution, 27% would fall below the momentum cut, internal bremsstrahlung only would cause a loss of 12%, energy loss by radiation a loss of 15% and Bhabha scattering a loss of 2.4%.

In the μ spectru, 1.4% of the μ from $K_{\mu 2}$ decay have momenta below 220 MeV/c due to internal bremsstrahlung and therefore fall below the momentum cut. The other two processes give negligible effects.

The branching ratio obtained in this experiment then is

$$R = R' \frac{0.986}{0.700 \pm 0.020}$$

$$= (2.37 \pm 0.17) \times 10^{-5} = (0.920 \pm 0.065) \times R_{\text{theor}}$$

$$\text{where } R_{\text{theor}} = \left(\frac{m_k^2 - m_e^2}{m_k^2 - m_\mu^2}\right)^2 \frac{m_e^2}{m_\mu^2} = 2.57 \times 10^{-5}$$

is the value expected for pure axial vector interaction without a pseudoscalar contribution, and for μ-e universality. The value of R obtained in this experiment is in agreement with the theoretical prediction within 1.2 standard deviations.

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