uate high-energy muons.

We plan to continue our investigations with better capabilities for studying large events.

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Measurement of Branching Ratio for $K^+ \to e^+\nu$†

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Using a 2π-sr magnetic spectrometer, the branching ratio for $K^+ \to e^+\nu$ relative to that for $K^+ \to \mu^+\nu$ has been measured to be $(2.42 \pm 0.42) \times 10^{-5}$, in good agreement with the predictions of the $V-A$ theory.

The branching ratio $R_M = \Gamma(M \to e\nu)/\Gamma(M \to \mu\nu)$, where M is a pseudoscalar meson, is a sensitive test of the $V-A$ theory, which has been generally successful in predicting decay rates and angular distributions in nuclear β decay and in the weak decays of the long-lived elementary particles. Because only the pseudoscalar P and axial vector A matrix elements can occur, a measurement of R_M effectively determines the pseudoscalar contamination. In particular

$$R_M = \left(\frac{m_M^2 - m_e^2}{m_M^2 - m_\mu^2}\right)^2 \left(\frac{m_M f_P + m_e f_A}{m_M f_P + m_\mu f_A}\right)^2 C_\gamma, \quad (1)$$

where m_M, m_e, and m_μ are particle masses, and f_P and f_A are the P and A form factors, respectively. In (1) the factor C_γ is an experiment-dependent radiative correction ($C_\gamma \lesssim 1$). For a pure P interaction $R_\pi \approx R_K \approx C_\gamma$, while for pure A, $R_\pi = 1.25 \times 10^{-4} C_\gamma$ and $R_K = 2.58 \times 10^{-5} C_\gamma$.

Current experimental values give $R_\pi = (1.25 \pm 0.03) \times 10^{-4} C_\gamma$.[1] There have been three measurements of R_K. Borreani, Rinuado, and Werbrouck[2] give $R_K < 2.6 \times 10^{-3}$. Bowen *et al.*[3] give $R_K = 3.3^{+2.8}_{-2.1} \times 10^{-5}$ and Botterrill *et al.*[4] give $R_K = 1.9^{+0.7}_{-0.5} \times 10^{-5}$ (with $R_K = 2.27 \times 10^{-5}$ for pure A).

In the present experiment[5] the kaons were produced at 0°, with momentum $p = 540$ MeV/c and $\Delta p/p = \pm 2\%$ in electrostatically separated beam 5B from an external target of the Bevatron.[6] At the second image the beam was focused onto a beryllium degrader and polyethylene stopper, located on the axis of the magnetic spectrometer (Fig. 1) used in the detection of the kaon secondaries. Kaons were selected relative to pions, muons, and electrons in the beam by a plastic Cherenkov counter, time-of-flight, and pulse height discrimination in scintillation counter S_3. The kaons were required to stop and decay in the 6.2-cm by 3.1-cm stopper which was enclosed within a cylindrical sleeve scintillator S_4. An acceptable decay was characterized by the absence of a large prompt pulse in S_4, and the presence of a minimum ionizing pulse in S_4, delayed by at least 10 nsec and no more than 70 nsec after the arrival of the incident kaon. There was no measurable pion contamination in this

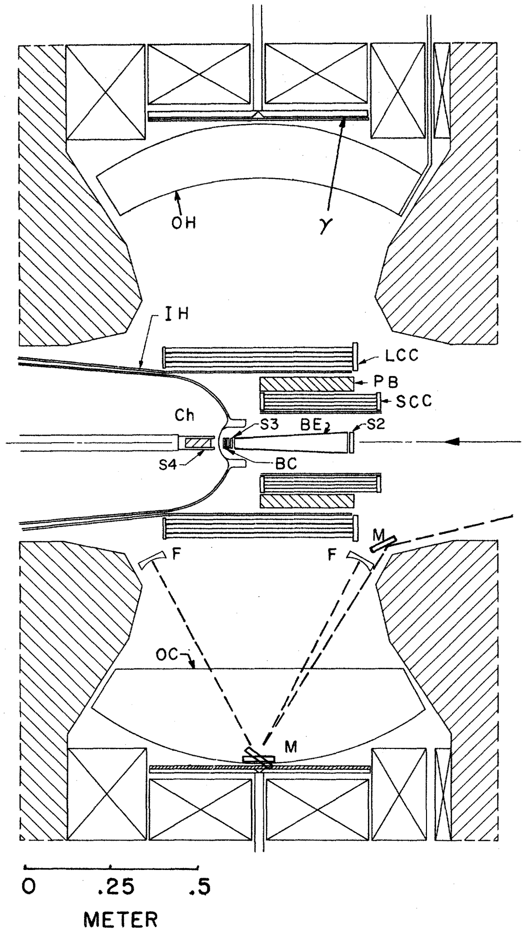

FIG. 1. Magnetic spectrometer for kaon secondaries. *BE* is a beryllium degrader for the kaon beam which enters from the right; S_2, S_3, and S_4 are scintillators; *IH* is an eighteen-counter hodoscope with 3-mm-thick scintillators; *OH* is a set of nine scintillators 6 mm thick; γ is a set of eighteen scintillators behind 6 mm of lead; *Ch* is a high-pressure (20 atm) gas Cherenkov counter; *BC*, *SCC*, *LCC*, and *OC* are optical spark chambers; *PB* is a lead cylinder; the *F* are front-surface focusing mirrors, and the *M* are plane mirrors.

sample of $\sim 10^3$ kaons per burst.

The properties of the magnetic spectrometer have been described previously.[7] Charged particles originating on or near the axis and median plane are focused back after one nearly circular orbit. Because of the azimuthal symmetry and rather large acceptance in polar angle, a solid angle of nearly 2π sr was obtained. In the present experiment decay secondaries from the stopper passed through a high-pressure (20 atm of ethane) gas Cherenkov counter, a cylindrical hodoscope consisting of eighteen scintillation counters, and a cylindrical spark chamber. The returning orbit passed first through the same spark chamber and hodoscope and then into a lead cylinder of outer radius 17.8 cm and inner radius 14.0 cm. Particles surviving the lead absorber passed through a six-gap thin-walled cylindrical spark chamber. At the outer radius a particle trajectory was detected in one of nine crescent-shaped scintillation counters and by one or more of eighteen spark chambers. Some efficiency for the detection of events with accompanying γ rays was provided by a set of eighteen scintillators, placed in the median plane at 90 cm radius behind 1 radiation length of lead. This γ-ray detector covered a solid angle of $4\pi/3$ sr.

The gas Cherenkov counter consisted of a reflecting parabolic shell, at the focus of which was the stopper. To suppress noise background in the electron signature, two out of four tubes were required to count in coincidence with those counters indicating an appropriate decay orbit. The efficiency of the Cherenkov counter for electrons had been measured as 98% in a separate setup by passing an electron beam through the counter.

All the spark chambers were optical. The cylindrical chambers together with a small rectangular beam chamber between the degrader and stopper were observed along the beam direction. For the outer-radius chambers an unusual optical system was used. Nine sets of short-focal-length (6.3 cm radius) spherical mirrors, located on either pole tip of the magnet, observed the chambers with an average stereoscopic angle of about 80 deg. Once outside the magnet, the highly compressed optical information from the outer-radius chambers was expanded to establish photographic conditions compatible with those for the other chambers. The spark chambers and data box, which contained counter and kaon decay information, were scanned and measured automatically with SASS, a programmed-spot cathode-ray tube film-measuring device with an online DDP-24 digital computer.

In experimental operation the spark-chamber trigger required an appropriate kaon decay signal, accompanied by counts in the inner and outer orbit hodoscope counters. A signal from the high-pressure Cherenkov counter was included in the trigger when the running was to detect electron events. It was omitted in $K_{\mu 2}$ and $K_{\pi 2}$ runs, which were used for rate normalization and to explore the acceptance window of the spectrometer. A parallel trigger mode included all events with an orbiting kaon secondary and a γ count.

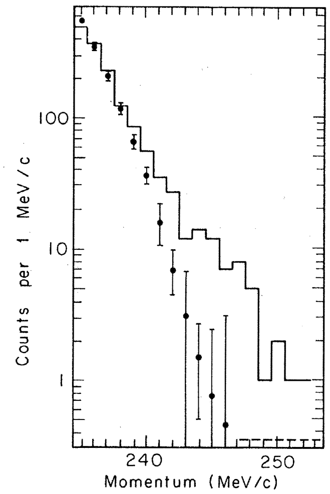

FIG. 2. Momentum spectra of secondary particles from K_{e2} runs. This histogram shows the spectrum for "electron candidates," as defined in the text; the dots show the normalized spectrum for "identified muons." The "muon" spectrum has been normalized to the "electron" spectrum in the momentum interval 235–239 MeV/c.

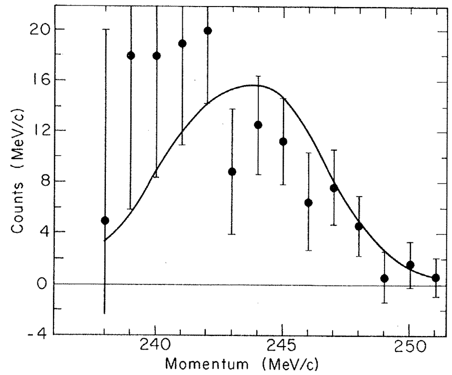

FIG. 3. Experimental K_{e2} spectrum obtained by subtraction of the spectra of Fig. 2. Errors are statistical only. The solid curve is the normalized predicted spectrum including the experimental momentum resolution (7.1 MeV/c full width at half-maximum) and the effects of inner and outer bremsstrahlung. The curve gives a χ^2 of 10 for twelve degrees of freedom.

By interposing short calibration runs on $K_{\mu 2}$, $K_{\pi 2}$, and K_{e3} decays between long runs with the K_{e2} settings, a continual monitoring of data rates, the performance of the electronics (including the efficiency of the gas Cherenkov counter), and of the momentum scale was provided. These three calibration rates were internally consistent with published experimental branching ratios, providing an absolute calibration for the K_{e2} measurement.

The data obtained during the K_{e2} runs contained a large background from $K_{\mu 2}$ muons accompanied by an accidental or δ-ray count in the Cherenkov counter. The muon breakthrough rate was independently measured to be 0.33%. Additional muon rejection was provided off line by examining the characteristics of the tracks in the small cylindrical chamber after the particles had passed through the lead cylinder. From the K_{e3} calibration runs it was found that this test correctly identified 99% of the electron events. Unfortunately because of large-angle scattering in the lead and less than perfect chamber performance, only 95% of the muons were correctly identified. Therefore, including both rejection by the Cherenkov counter and the lead survival test, the overall rejection factor against muons was about 6000, and a background subtraction was required to extract the K_{e2} signal.

Each event from the K_{e2} runs was classified as either an "electron candidate" or an "identified muon" on the appearance of the track in the small cylindrical chamber. The momentum spectra for these two categories are shown in Fig. 2. The "muon" spectrum has been normalized to the "electron" spectrum in the interval from 235 to 239 MeV/c for the purpose of background subtraction. The K_{e2} spectrum after subtraction is shown in Fig. 3. The solid curve is the normalized predicted spectrum, including the experimental momentum resolution (7.1 MeV/c full width at half-maximum) and the effects of inner bremsstrahlung[8] and radiation in 0.093 radiation lengths of material along the orbit (outer bremsstrahlung). This procedure gives 113 ± 13.8 K_{e2} events in the interval $240 \leq p_e \leq 252$ MeV/c; the error includes both statistical error and, because of uncertainty in the slopes of the spectra, a systematic error estimated at ± 7 events.

There are other possible sources of background. For example, energetic decay electrons from the so far undetected "structure" radiation in the decay $K^+ \to e^+\nu\gamma$ may be associated with energetic γ rays going in the opposite direction. This topology is in fact preferred in some theoretical models for the radiative decay. Such events would have been detected with the help of the γ counters for which the γ detection efficiency was about $\frac{2}{3}$. Within the fiducial momentum range there were a total of nine "electron candidates" accompanied by γ-counter signals. There is no evidence for γ-e angular correlation in these events, but the number was much too large to be ascribed to accidental counts in the γ counters,

TABLE I. Detection efficiencies.

	Electron candidates	Muons ($K_{\mu 2}$)
Momentum window		
$P_\mu = (228\text{–}239)$	...	0.941
$P_e = (240\text{–}251)$	0.949	...
Radiative corrections[a]		
Bare mass	0.963	1.000
Inner bremsstrahlung and virtual photons[b]	0.881	0.987
Cherenkov counter	0.98	...
Outer bremsstrahlung	0.636 ± 0.024	1.000
SCC identification	0.99	1.000
Product	0.498 ± 0.019	0.929

[a]Other than the factor $C_\gamma = 0.861$.
[b]See Ref. 8.

which occurred less than 1% of the time. It is possible that the apparent angular isotropy results from a combination of four hard backward γ's and five soft forward γ's associated with bremsstrahlung within either the Cherenkov counter or lead absorber. Assuming this, we have made a correction of -6 and $+5$ events, respectively, to the K_{e2} sample. Because of uncertainty in the origin of these events, we have included an additional systematic error of ± 5 events. With these corrections the total number of observed K_{e2} events is 112 ± 14.7.

The measured $K_{\mu 2}$ rate is based on about 10^4 events, normalized, as were the K_{e2} candidates, to an independent kaon beam monitor. Table I gives the various measured and calculated detection efficiencies necessary to determine the relative K_{e2} branching ratio, which is found to be $(R_K/C_\gamma)_{\text{expt}} = (2.42 \pm 0.42)\times 10^{-5}$ including both statistical and systematic errors.

Assuming that f_P and f_A are relatively real, in accordance with *TCP* invariance, we find using (1)

$$\frac{m_K f_P}{m_e f_A} = -0.030^{+0.081}_{-0.089} \text{ or } -1.96^{+0.09}_{-0.08}.$$

The first solution is consistent with a pure $V-A$ interaction.

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