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EXPERIMENTAL LIMIT ON THE BRANCHING RATIO FOR V^tf-#

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EXPERIMENTAL LIMIT ON THE BRANCHING RATIO FOR $K_L^0 \to \ell\bar{\ell}$

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R. P. Johnson, L. T. Kerth, and W. A. Wenzel

August 17, 1970

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ADDENDUM TO

UCRL-20078, "Experimental Limit on the Branching Ratio for $K_L^0 \rightarrow \ell\bar{\ell}$"

Analysis of approximately another 35 percent of our total data has reduced the limits on the branching ratio for each of the decay modes

$$K_L \rightarrow \mu^+\mu^-$$

$$K_L \rightarrow e^+e^-$$

$$K_L \rightarrow e^\pm\mu^\mp$$

to 6.8 x 10^{-9} (90% C.L.). There are no new dilepton candidates.

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EXPERIMENTAL LIMIT ON THE BRANCHING RATIO FOR $K_L^o \rightarrow \ell\bar{\ell}$ *

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August 17, 1970

The $K_L^o \rightarrow \mu^+\mu^-$ decay is generally considered to be a sensitive test of the existence of weak neutral currents. Higher–order weak interactions have also been considered as a possible source of this decay.[1] Theorists have used current algebra techniques with the experimental limit on $K_L^o \rightarrow \mu^+\mu^-$ to set an upper bound on the weak interaction cut–off.[2] With the additional hypothesis that this cut–off is due to the electromagnetic properties of the intermediate vector boson (IVB), Ioffe and Shabalin[2] have set an upper limit on the mass of the IVB.

The $K_L^o \rightarrow \ell^+ \ell^-$ decays can also be induced by electromagnetic interactions.[3] Using the measured $K_L^o \rightarrow \gamma\gamma$ rate[4] and only the two photon intermediate state, branching ratios between 6 x 10^{-9} and 1 x 10^{-8} are generally predicted for the $K_L^o \rightarrow \mu^+ \mu^-$ decay.[5] However, other intermediate states may interfere, producing a unitarity limit different from that predicted from the two photon state. Martin et al.[6] have estimated that the effect is less than 20% for $\pi\pi\gamma$ and 3π intermediate states. The $K_L^o \rightarrow e^+e^-$ rate is suppressed by a factor of $(m_e/m_\mu)^2$ relative to the $K_L^o \rightarrow \mu^+\mu^-$ rate in weak models which use V–A and also in electromagnetic models.

The $K_L^o \rightarrow e^{\pm}\mu^{\mp}$ rate is not predictable from any known interaction. Limits on this decay, which violates lepton number conservation, can be compared with limits on $\mu^{\pm} \rightarrow e^{\pm}\gamma$ or $\mu^{\pm} \rightarrow e^{\pm}e^{+}e^{-}$. Table I shows the previously published experimental limits on the various dilepton decay modes of the K_L^o.

Figure 1 shows the plan view of the detection apparatus.[7] The 6 m long decay volume began 7.6 m from the production target in the Bevatron External Proton Beam. Initially, data were taken with helium in both the decay volume and the volume between the spark chambers to reduce Coulomb scattering. The decay volume was later replaced with a vacuum box to reduce neutron-induced background. The momenta of the decay secondaries were measured in symmetric spectrometers, each with a 0.9 m x 0.6 m aperture picture-frame magnet and five double gap magnetostrictive wire spark chambers. Two sets of x-y coordinates per trajectory were measured in each chamber. These chambers were designed with low mass to limit scattering. The aluminum wires were 75μ in diameter, and the windows were 25μ aluminized mylar (1000 Å Al). The line integral of each magnetic field, which was uniform within 1% over 95% of the aperture, was set to correspond to the center of mass momentum of the $K_L^o \rightarrow \mu^{+}\mu^{-}$ decay. Independent of kaon momentum, therefore, secondaries from nearly transverse two-body decays emerged from the magnets essentially parallel to the incident kaon direction. Downstream of the last spark chamber, two vertical counter hodoscopes selected trajectories with maximum horizontal divergences of ± 45 mrad from the beam line. A horizontal counter hodoscope was mounted in front of each upstream vertical hodoscope, and a large counter for fast timing was mounted behind each downstream vertical hodoscope. The trigger logic, employing primarily MECL-II integrated circuitry, required a particle on each side which satisfied the angle requirement and counted in the horizontal hodoscope and the timing counter. Electrons which were bent inward at angles between 15 and 45 mrad were rejected. This eliminated a large fraction of the K_{e3} background without affecting the dilepton acceptance significantly.

Electrons were identified in 2.3 meter long Freon Cherenkov counters, which were found to be more than 99.6% efficient during preliminary tests. Muons were identified by range measurements. The range detectors each contained a 1 m long carbon block followed by 17 cells of steel and scintillator. Each cell consisted of one or more 1.2 m x 1.2 m x 2.5 cm steel plates and a 1.2 m x 1.2 m x 1.9 cm plastic scintillator, arranged to give a muon range interval of approximately 7% for momenta between 0.5 and 1.6 GeV/c. The signals from the Cherenkov and range counters were not used in the trigger (except as noted above) but were recorded for use later in the analysis.

Data were accumulated, checked and stored on magnetic tape with a PDP-9 computer. The signals from each counter and the spark chamber information for each event were recorded on the tape; beam intensity and magnet currents were recorded each Bevatron pulse.

The data were analyzed on a CDC 6600 computer. An event was considered a two-body candidate if the two reconstructed trajectories met within 2 cm in the decay volume, and the reconstructed parent particle originated at a point less than 5 cm from the production target. In addition, each secondary was required to have a momentum below 2.1 GeV/c. These cuts retained essentially all of the two-body events from the $K_L^o \to \pi^+\pi^-$ mode. The two-pion invariant mass spectra from data taken with the vacuum decay volume are shown in Figures 2a and 2c for events appearing to originate within 7.6 cm and 4 cm, respectively, of the target. All secondaries without an electron signature have been assumed to be pions. Figure 3a shows the same plot for the helium-box data, with a 5 cm target cut. The background is mostly from $K_L^o \to \pi\mu\nu$ decays, which were assumed to contribute a flat background under the $K_L^o \to \pi^+\pi^-$ peak. After subtraction there remained 254,000 $K_L^o \to \pi^+\pi^-$ events.

The acceptance for $K_L^o \to \pi\pi$ was measured to be (75 ± 4)% relative to that for the $K_2^o \to \mu^+\mu^-$ decays, because of the lower c.m. momentum of the two pions. The equipment was designed to accept all charged two-lepton modes equally well. A detailed estimate of the decay-in-flight loss of $K_L^o \to \pi^+\pi^-$ has not been made. We estimate this loss to be about 5%.

To compare with the corrected sample of $K_L^o \to \pi^+\pi^-$, there were no $K_L^o \to e^+e^-$ or $K_L \to e^\pm \mu^\mp$ events. Five possible $K_L \to \mu^+\mu^-$ candidates survived the target cuts and had ranges within 3 cells of the predicted range for muons. These events appear in Figures 2d and 3b, which show the invariant mass spectrum for two-muon candidates with the target and range cuts described above.

For the analysis described above, an effective length parameterization of the magnetic field was used; this procedure retained good mass resolution but did not provide adequate rejection of events in which a secondary pion decayed in flight in the magnet. The $K_L^o \to \mu^+\mu^-$ candidates were therefore examined in more detail, using a step-by-step integration of the trajectories through the magnets. These fits were compared with those from similar trajectories from $K_L^o \to \pi^+\pi^-$ data.

The secondaries in the dimuon candidate of mass 499 MeV in Figure 2d have the wrong range to be muons by 6 and 9 standard deviations, respectively. We therefore exclude it as a candidate. In Figure 3b the dimuon candidates of mass 489 and 504 MeV/c^2 were rejected on the basis of the trajectory fits, which gave probabilities of less than 10^{-5} that the trajectory was that of a single particle. The candidate of mass 502 MeV/c^2 showed poor trajectory, mass and range fits; we would expect less than 0.03% of the $K_L^o \to \mu^+\mu^-$ events to fit so poorly. For the candidate of mass 496 MeV/c^2, the detailed analysis of one secondary trajectory showed that only 6% of the trajectories used for comparison had poorer fits; in addition the range of one secondary was shorter than that of 80% of muons of the same momentum. Each candidate is consistent with interpretation as a $K_L^o \to \pi^\pm\mu^\mp\nu$ decay with the pion decaying in flight in the magnet.

Interpreting these five candidates as background, we used the measured $K_L^o \rightarrow \pi^+\pi^-$ branching ratio[8] to obtain the limit:

$$\frac{\Gamma(K_L^o \rightarrow \mu^+\mu^-)}{\Gamma(K_L^o \rightarrow \text{all})} \leq \frac{\Gamma(K_L^o \rightarrow \pi^+\pi^-)}{\Gamma(K_L^o \rightarrow \text{all})} \times \frac{(\pi\pi/\mu\mu \text{ efficiency})}{N(K_L^o \rightarrow \pi\pi \text{ observed})} \times 2.3$$

$$= 1.1 \times 10^{-8} \text{ (90\% Confidence Level)}$$

The limits on $K_L^o \rightarrow e^+e^-$ and $K_L^o \rightarrow \mu^\pm e^\mp$ are the same as for $K_L^o \rightarrow \mu^+\mu^-$. These results are based on the analysis of approximately 50% of our data. Previous limits on these ratios are given in the table.

In terms of Ioffe and Shabalin's IVB calculation,[2] this $K_L^o \rightarrow \mu^+\mu^-$ limit leads to a weak interaction cut–off of 29 GeV (90% C.L.). In their model, this result suggests that the mass of the IVB is less than ~ 2.6 GeV (90% C.L.).

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TABLE I

Branching Ratio Limits at 90% Confidence Level

Rate	Previous Limit		This experiment
$\frac{\Gamma(K_L^o \to \mu^+\mu^-)}{\Gamma(K_L^o \to \text{all})}$	$\leq 2.1 \times 10^{-7}$	(a)	$\leq 1.1 \times 10^{-8}$
$\frac{\Gamma(K_L^o \to e^+e^-)}{\Gamma(K_L^o \to \text{all})}$	$\leq 1.5 \times 10^{-7}$	(a)	$\leq 1.1 \times 10^{-8}$
$\frac{\Gamma(K_L^o \to e^\pm \mu^\mp)}{\Gamma(K_L^o \to \text{all})}$	$\leq 3.7 \times 10^{-6}$	(b)	$\leq 1.1 \times 10^{-8}$
$\frac{\Gamma(\mu^+ \to e^+ \gamma)}{\Gamma(\mu^+ \to \text{all})}$	$\leq 2.2 \times 10^{-8}$	(c)	——
$\frac{\Gamma(\mu^+ \to e^+e^+e^-)}{\Gamma(\mu^+ \to \text{all})}$	$\leq 6.8 \times 10^{-8}$	(d)	——

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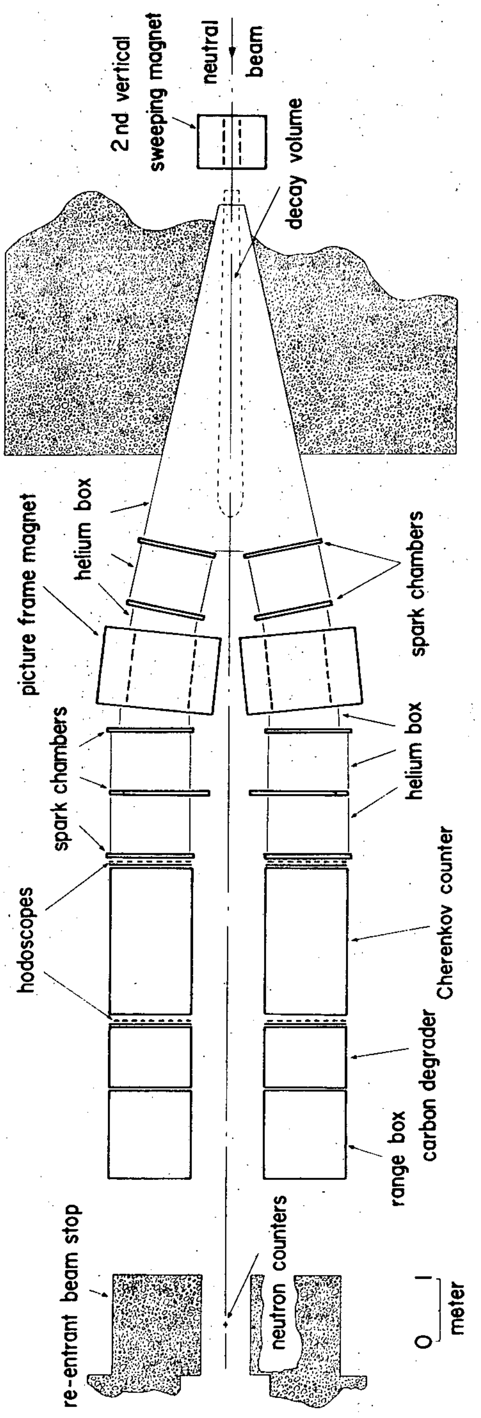
FIGURE CAPTIONS

Figure 1	Lay-out of apparatus.
Figure 2	Vacuum decay-volume data. The various cuts are described in the text. The histograms show invariant mass spectra of two-body candidates interpreted as: (a) $K_L^o \to \pi^+\pi^-$, originating within 7.6 cm of the target; (b) $K_L^o \to \mu^+\mu^-$, originating within 7.6 cm of the target; (c) $K_L^o \to \pi^+\pi^-$, originating within 4 cm of the target; (d) $K_L^o \to \mu^+\mu^-$, originating within 4 cm of the target.
Figure 3	Helium decay-volume data. The histograms show invariant mass spectra of two-body candidates interpreted as: (a) $K_L^o \to \pi^+\pi^-$, originating within 5 cm of the target; (b) $K_L^o \to \mu^+\mu^-$, originating within 5 cm of the target.



XBL 702-315

Figure 1

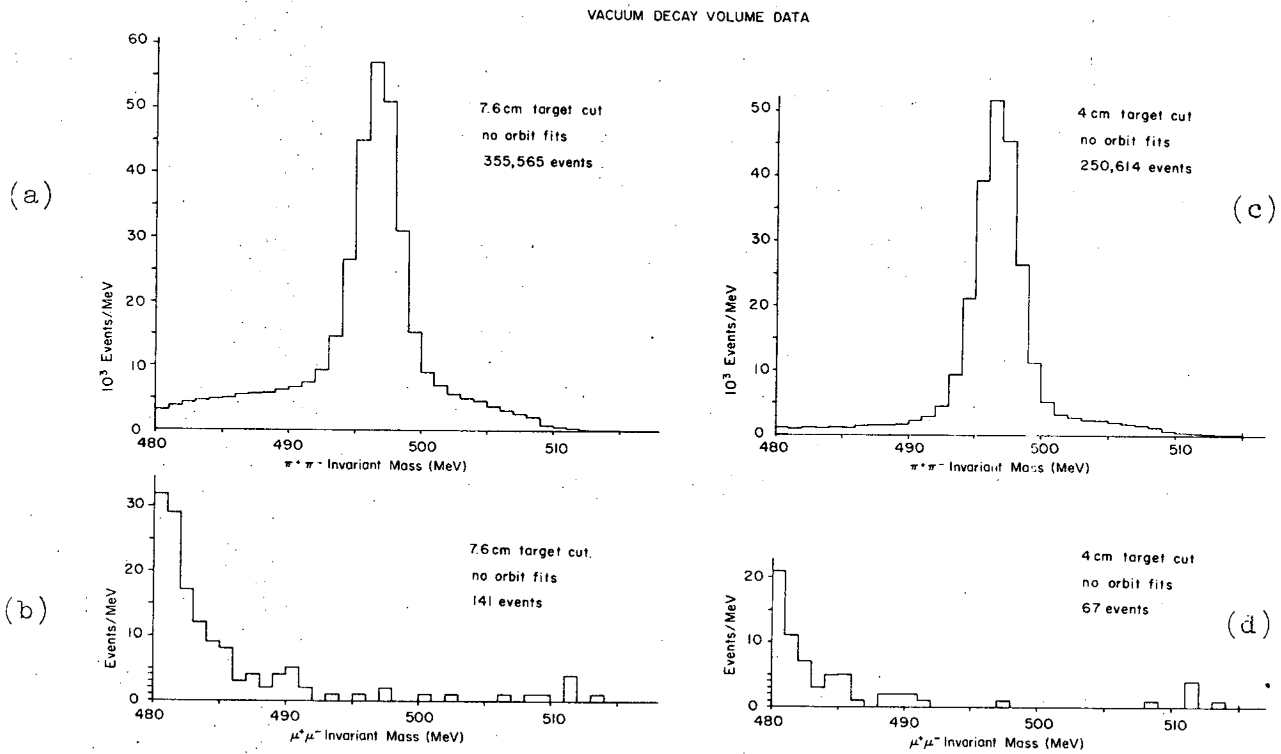


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Fig. 2

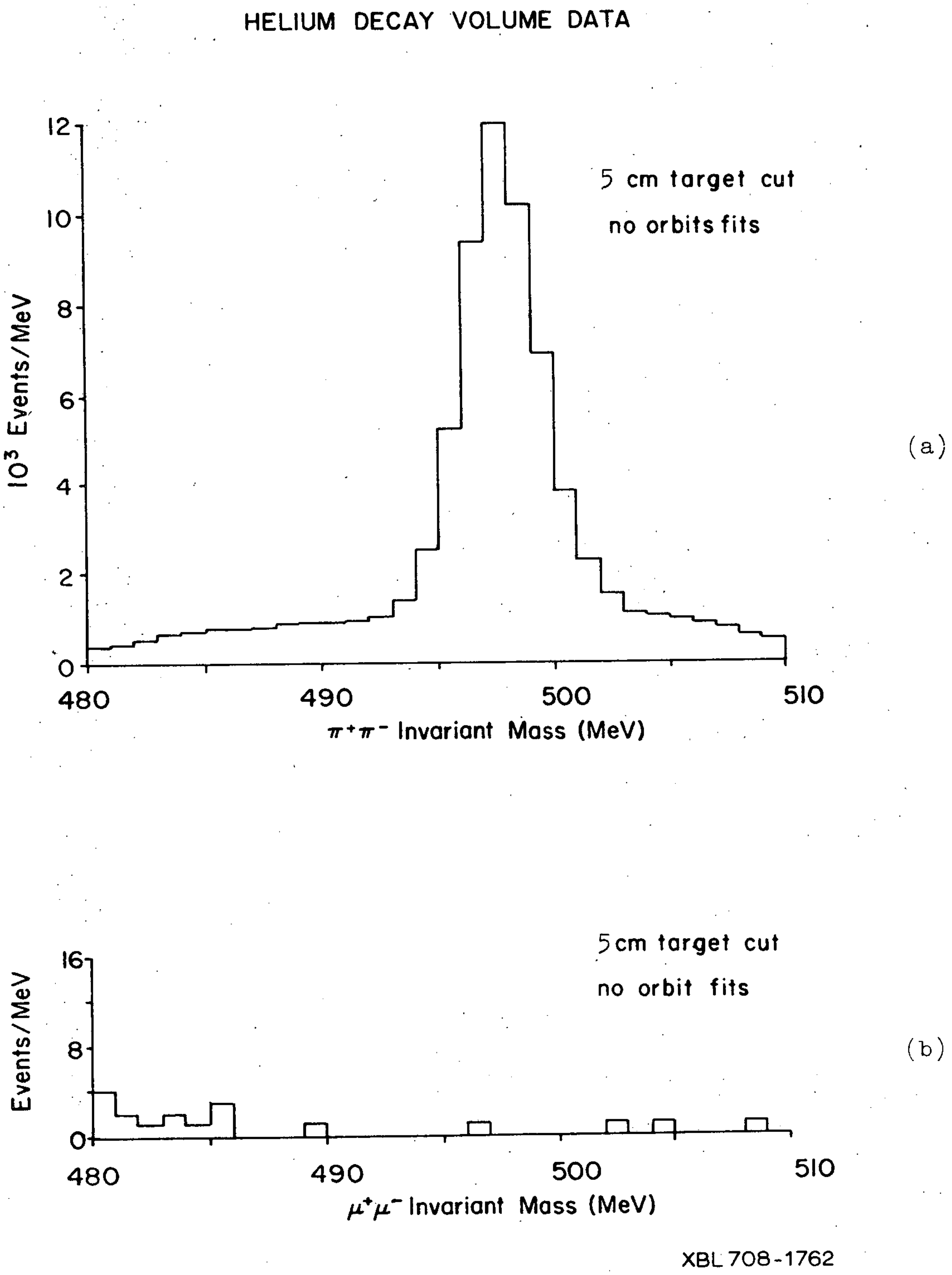
HELIUM DECAY VOLUME DATA
5 cm target cut
no orbits fits
10^3 Events/MeV
0
2
4
6
8
10
12
480
490
500
510
$\pi^+\pi^-$ Invariant Mass (MeV)
(a)
5cm target cut
no orbit fits
Events/MeV
0
8
16
480
490
500
510
$\mu^+\mu^-$ Invariant Mass (MeV)
(b)
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Fig. 3

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