A Search for the Strangeness Changing Neutral Current $K^+ \to \pi^+\mu^+\mu^-$

John S. Haggerty

Brookhaven National Laboratory,
Upton, New York 11973-5000, USA

On behalf of the Brookhaven E787 Collaboration[1]

Abstract

Preliminary results of a search for the rare decay $K^+ \to \pi^+\mu^+\mu^-$ using the E787 detector at Brookhaven are presented.

1. Introduction

Experiment 787 at the Brookhaven AGS is designed to be primarily a sensitive search for the strangeness changing neutral current $K^+ \to \pi^+\nu\bar{\nu}$. This extremely rare decay, expected to occur in the Standard Model with a branching ratio of about 2×10^{-10}, is particularly interesting because it is a second order weak decay which is not subject to large QCD corrections or non-perturbative effects. The current experimental limits on this process from E787 are still more than an order of magnitude away from the Standard Model prediction, but the E787 spectrometer can be used to search for many other rare and radiative decays. This report will discuss the preliminary results of a search for the rare decay $K^+ \to \pi^+\mu^+\mu^-$.

2. Expectations for $K^+ \to \pi^+\mu^+\mu^-$

The decay $K^+ \to \pi^+\mu^+\mu^-$ cannot be calculated in the Standard Model as cleanly as $K^+ \to \pi^+\nu\bar{\nu}$ because of the long distance effects due to the coupling of the $\mu^+\mu^-$ to intermediate photons. However, the closely related process $K^+ \to \pi^+e^+e^-$ has been measured to have a branching ratio of $(2.74 \pm 0.23) \times 10^{-7}$ in another Brookhaven experiment[2] from about 500 observed decays. Chiral Perturbation Theory[3] has been used to calculate both decays within a single theoretical framework and to predict them as a function of one parameter, called w_+. Figure 1 shows the predicted branching ratio as a function of w_+ for these two decays. The measured spectrum of e^+e^- masses from $K^+ \to \pi^+e^+e^-$ has been used to break the quadratic ambiguity and results in a value of $w_+ = 0.89^{+0.24}_{-0.14}$, which corresponds to a branching ratio for $K^+ \to \pi^+\mu^+\mu^-$ of $(3.1^{+2.5}_{-1.2}) \times 10^{-8}$. The previous limit on $K^+ \to \pi^+\mu^+\mu^-$ was set by E787[4] to be less than 2.3×10^{-7} at the 90% confidence level.

3. The E787 Detector

The E787 detector is shown in Figure 2. This detector is designed around an 800 MeV/c stopping K^+ beam with an intensity of about $3 \times 10^5 K^+$ per 3 sec spill. The K^+ beam is tagged by a Čerenkov counter, slowed by a BeO degrader, and stopped in a scintillating fiber target read out by 379 photomultiplier tubes. The target is surrounded by a hexagonal array of scintillation counters referred to as I counters used for triggering and particle identification.

The detector is designed for precision measurements of the range, energy, and momentum of the π^+ in $K^+ \to \pi^+\nu\bar{\nu}$. The momentum of charged particles is measured by the central drift chamber in a 1 T magnetic field. The chamber consists of five superlayers, each of which has

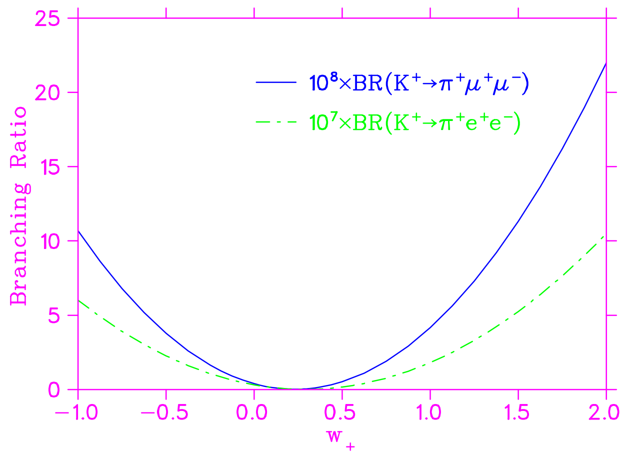

Figure 1. Expected branching ratio of $K^+ \rightarrow \pi^+\mu^+\mu^-$ and $K^+ \rightarrow \pi^+e^+e^-$ as a function of the Chiral Perturbation Theory parameter w_+.

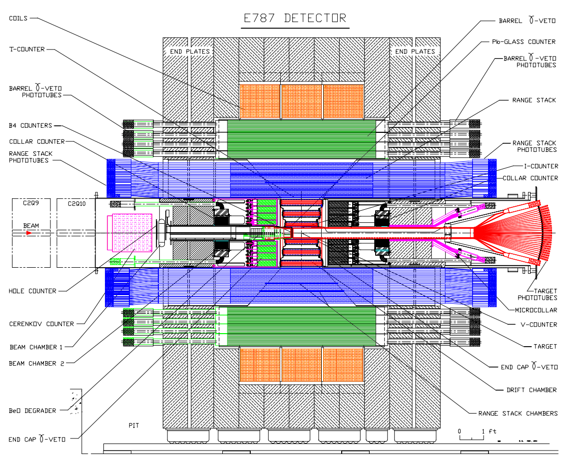

Figure 2. The E787 detector.

six sense wires in a jet cell configuration. The central chamber is surrounded by a range stack, consisting of 21 layers of scintillator read out at both ends, and instrumented with 500 MHz transient digitizers, which can record activity over many microseconds. The inner layers of the range stack are ganged together, so that after an initial 0.6 cm thick trigger layer, there are layers which are 7.6, 5.7, and 3.8 cm thick, followed by 11 1.9 cm thick layers.

The entire detector is surrounded by photon veto calorimeters consisting of layers of lead and scintillator. For π^0 from $K^+ \rightarrow \pi^+\pi^0$ decay, the measured π^0 inefficiency is on the order of 2×10^{-6}.

The trigger for $K^+ \rightarrow \pi^+\mu^+\mu^-$ requires that there be two or three tracks which penetrate at least to the second layer of the range stack, at least 20 target elements hit, and two or more non-adjacent hit I counters. The trigger constrains $K^+ \rightarrow \pi^+\mu^+\mu^-$ decays quite strongly, since a particle must have a momentum of at least 60 MeV/c to reach the range stack and the total kinetic energy available to the reaction is only 143 MeV/c^2. Events are vetoed if they have energy outside the first few layers of the range stack or in the photon vetoes. About 10% of all $K^+ \rightarrow \pi^+\mu^+\mu^-$ decays satisfy the trigger requirements.

4. Preliminary Requirements

The analysis began with a pass through the data making cuts consistent with the trigger requirements using calibrated offline data. These requirements use the veto system to reject events with photons, apply simple topological cuts consistent with the trigger, and limit the momentum of any particle to below kinematic limit of $K^+ \rightarrow \pi^+\mu^+\mu^-$ (172 MeV/c).

Most of the kaon decays which remain as background to $K^+ \rightarrow \pi^+\mu^+\mu^-$ have one or more $e^\pm$ from a π^0 which Dalitz decays or where one of the photons converts. Therefore, after the initial pass through the data, events with $e^\pm$ are rejected using particle identification techniques developed for this analysis. Finally, the kinematics of the remaining events are examined, and the mass and missing momentum are reconstructed. Successful candidates conserve momentum and reconstruct to the kaon mass.

In more detail, events are required to have:

- Two range stack tracks which connect to drift chamber tracks.
- The range stack and drift chamber tracks have the following properties:
  - Measured times in the range stack within ± 10 ns to reject accidentals,
  - Small number of range stack counters on each track at decay time, which rejects rejects $e^\pm$ which start to shower,
  - Momentum less than 172 MeV (rejects $K^+ \rightarrow \pi^+\pi^0$),
  - Energy in the first four layers of the range stack less than 150 MeV
- Less than 1 MeV photon energy visible outside the first four layers of the range stack, or in the photon vetoes in $\sim 1-3$ ns time window around decay time, and less than 10 MeV photon energy outside the tracks in the range stack.
- Another track in the drift chamber to at least superlayer 3, which requires a momentum of about 30 MeV/c.

In order to bring the full power of the detector to bear on the background, events are required to have both positively charged tracks in the range stack. This forces the e^+ in the most serious background ($K^+ \rightarrow \pi^+\pi^-e^+\nu$) into the range stack where it can be eliminated using the particle identification techniques

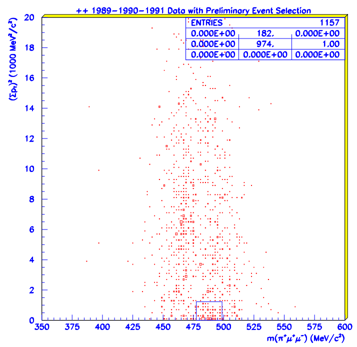

Figure 3. Kinematics of events after requiring that both positive tracks reach the range stack. The horizontal axis is the reconstructed kaon mass, the vertical axis is the magnitude of the vector sum of the transverse momentum.

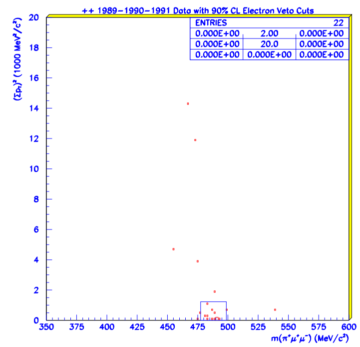

Figure 4. Kinematics of events after using the likelihood analysis to reject 90% of events with electrons or positrons.

described below. Finally, events are required to have one negative and two positive tracks, and the target vertex must be within 1.8 cm of the K^+ stop position. The events which remain are shown in Figure 3, where the mass combination with the minimum value of the magnitude of the vector sum of the transverse momentum is chosen.

5. Selection of the Final Sample

Samples of reference data were used to obtain the expected dE/dx and time of flight distributions. Data from the $\pi^+\mu^+\mu^-$ trigger was used so the event topology is similar to the final sample of events. Electrons from π^0 Dalitz or conversions were identified by a high momentum track consistent with $K_{\pi 2}$ with opposite charged tracks having opening angle less than 20°. Pions were identified by their decay $\pi \rightarrow \mu$ by the 500 MHz transient digitizers. Electrons and pions that make a complete orbit in the drift chamber were distinguished by time of flight from I counter to I counter.

Using these reference samples, likelihood functions for drift chamber dE/dx, dE/dx in the first layer of the range stack, and time of flight from I counter to the range stack were constructed in momentum bins. I counter dE/dx was also calibrated but was used only as a check on the contamination of the final sample with $e^\pm$.

The data that was used corresponds to about 2.5×10^{11} stopped kaons taken from 1989 to 1991. Although the detector had several major upgrades in this period they were largely irrelevant for this analysis; the exceptions were additional Level 1 trigger requirements and improved timing in 1990 and 1991, which were taken into account. The final sample of candidate events is shown in Figure 4, where 90% of events with $e^\pm$ were rejected by the likelihood analysis. A total of 13 events remain in the signal box.

Backgrounds were estimated by use of a full detector Monte Carlo with all kaon decay modes, an estimate from the data itself in nearby kinematic background regions, and an estimate from I counter dE/dx of electron contamination. The most serious background was $K^+ \rightarrow \pi^+\pi^-e^+\nu$ (K_{e4}) which trigger and analysis forced to peak in and around the signal region. Estimates agree on a background level of about 2 ± 1 events in the signal box. The decay $K^+ \rightarrow \pi^+\pi^+\pi^-$, which could be a serious background, has so little kinetic energy available (75 MeV), that it is suppressed strongly in the trigger and by later kinematic requirements.

Measurement of the acceptance depends on the Monte Carlo of the signal, checked in many ways with data and given an overall check by measurement of the K_{e4} branching ratio in a parallel analysis which resulted in about 500 candidates. The final analysis of the acceptance is still in progress, but the observed branching ratio is estimated to be in the region of 10^{-8}.

References

[1] The E787 collaboration consists of Brookhaven National Laboratory: S. Adler, M.S. Atiya, I-H. Chiang, J.S. Frank, J.S. Haggerty, T.F. Kycia, K.K. Li, L.S. Littenberg, A. Sambamurti, A. Stevens, R.C. Strand and C. Witzig; Los Alamos National Laboratory: W.C. Louis; Princeton University: D.S. Akerib, M. Ardebili, M. Convery, M.M. Ito, D.R. Marlow, R. McPherson, P.D. Meyers, M.A. Selen, F.C. Shoemaker, and A.J.S. Smith; and TRIUMF: E.W. Blackmore, D.A. Bryman, L. Felawka, P. Kitching, A. Konaka, Y. Kuno, J.A. Macdonald, T. Numao, P. Padley, J.-M. Poutissou, R. Poutissou, J. Roy, R. Soluk, and A.S. Turcot.

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