Frascati Physics Series Vol. XXXVI (2004), pp.
DAΦNE 2004: Physics at meson factories – Frascati, June 7-11 , 2004
Selected Contribution in Plenary Session

RECENT RESULTS ON $K^+ \to \pi^+\nu\bar{\nu}$

Tetsuro Sekiguchi*
High Energy Accelerator Research Organization (KEK)
1-1 Oho, Tsukuba, Ibaraki, 305-0801 Japan

ABSTRACT

Experiment 949 at Brookhaven National Laboratory (BNL) has observed, in its first data set from 2002, an additional $K^+ \to \pi^+\nu\bar{\nu}$ candidate near the upper kinematic limit for this decay. Combining this data with previous E787 data, the branching ratio is $(1.47^{+1.30}_{-0.89}) \times 10^{-10}$ (68% CL) based on three events observed in the pion momentum region $211 < P < 229$ MeV/c.

1 Introduction

The rare decay $K^+ \to \pi^+\nu\bar{\nu}$ is a flavor changing neutral current process involving up, charm and top quarks in loop diagrams. The top quark loops dominate and thus the decay is sensitive to the magnitude of the CKM matrix

*On behalf of the BNL-E949 Collaboration.

element V_{td}. A precise measurement of $\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})$ is a stringent test for the standard model (SM), since the uncertainty in extracting fundamental SM parameters is very small, and is also a probe of new physics.

E787 at BNL observed two candidate events, with a branching ratio $(1.57^{+1.75}_{-0.82}) \times 10^{-10}$ [1], whereas the SM prediction is $(0.80 \pm 0.11) \times 10^{-10}$ [2]. Collecting more events and enlarging the statistics are needed for understanding this decay process.

2 Experimental Overview

E949 at BNL [3] is a successor to E787. Beams and apparatus were similar to those of E787, but with several significant upgrades [4]. The signature of $K^+ \to \pi^+ \nu\bar{\nu}$ is a single π^+ and no other particle observed from the decay of a K^+ at rest. Side and end views of the upper half of the E949 detector are shown in fig.1. The K^+ beam entering the detector was identified by beam detectors (a Čerenkov counter, two wire chambers and a dE/dx counter), came to rest in a target of scintillating fibers and decayed after a suitable delay. The π^+ from the decay passed through a drift chamber, entered the cylindrical range stack (RS) of plastic scintillators, came to rest and decayed in the RS. The π^+ was identified by measuring its momentum, energy and range in scintillator, and by observing the $\pi^+ \to \mu^+ \to e^+$ decay sequence in the π^+ stopping counter. Photons from the K^+ decay were detected by a hermetic γ detector consisting of lead/scintillator sampling calorimeters (BV and BVL) surrounding the RS, undoped CsI calorimeters in End Caps (EC), and other detectors which covered the small solid angle around the beam line.

The new data was taken during the 12-week physics run in 2002. The number of kaons stopped in the target was $N_K = 1.8 \times 10^{12}$. Although the

Figure 1: *Schematic views of the upper half of E949 detector from side (left) and end (right) views. The shaded detectors are the new γ detectors.*

instantaneous detector rate was twice that of E787, similar or even better kinematic measurement was achieved due to the detector upgrades (including, replacement of one third of the RS scintillators, installation of an RS gain monitor system, upgrades of electronics for the central drift chamber and replacement of electronics for the straw tube tracking chambers in the RS). Rejection of photons at the nominal acceptance increased by a factor of two compared to E787 because of the new γ detectors.

3 Analysis

The expected branching ratio is 10^{-10}, and large suppression of backgrounds is necessary. The reliable estimation of large rejection factors is challenging and required the development of a "bifurcated" method described below. A "blind" analysis was performed to avoid any bias due to small statistics. Background sources were identified a *priori* and a signal region was determined so that the sensitivity was optimized. The primary signal search is between the $K^+ \to \pi^+\pi^0$ ($K_{\pi2}$) and $K^+ \to \mu^+\nu$ ($K_{\mu2}$) momentum peaks, which is the cleanest search region. The main background sources are $K_{\pi2}$, $K_{\mu2}$, $K_{\mu m}$ (multibody decays with a muon, such as radiative $K_{\mu2}$ and $K_{\mu3}$) and scattered beam particles. The real data were used as much as possible for cut development and background estimation so that any unexpected bias or loophole could be suppressed. To reduce possible biases, a uniformly-sampled 1/3 portion of the whole data set was used for development of cuts and the remaining 2/3 portion for background estimation. The signal region was always masked out until the cut development and background estimation were finalized.

4 Likelihood Analysis

The backgrounds in the signal region were estimated with a "bifurcated" method. The method involved two uncorrelated cuts or group of cuts, which were independently inverted to enhance a particular background. That is, a background sample was created by selecting events which failed a specific cut. The rejection power of the complimentary cut was examined using the enhanced sample. Then a "background function" was developed by changing the severity of the cut. For example, the $K_{\mu2}$ background was enhanced by selecting events which failed the requirement of the $\pi^+ \to \mu^+ \to e^+$ decay sequence in the RS

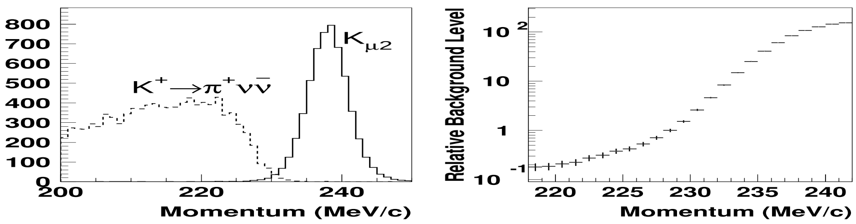

Figure 2: *The momentum distributions for $K_{\mu 2}$ (solid) and Monte Carlo $K^+ \to \pi^+\nu\bar{\nu}$ (dashed) events (left) and the relative background level for $K_{\mu 2}$ as a function of momentum (right).*

stopping counter. The momentum distribution of this sample was examined to investigate how many events would be expected in the signal region, and the relative background level as a function of momentum was then obtained (see fig.2). All background functions were derived from the corresponding cuts used in the bifurcated method. Acceptance functions were also obtained in the same manner. Both acceptance and background functions gave the relative acceptance and background level at each cut position. The signal region was divided into small cells by binning all parameters of the functions and then the expected signal $S_i \equiv \mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})N_K A_i$ and background b_i in each cell i were estimated, where A_i was the acceptance in cell i. The cells were characterized by the signal to background ratio S_i/b_i. Using a likelihood ratio technique [5], a confidence level (CL) and branching ratio were calculated from the S_i/b_i of the cells containing candidate events.

5 Sensitivity and Background Measurement

The acceptance and sensitivity are summarized in tab.1. With increased confidence in the likelihood technique the signal region was enlarged, increasing the background in the signal region (as summarized in tab.2), and increasing the acceptance by 30%. The total acceptance of E949 increased by about 10% (due to other losses) compared to that of E787.

Table 1: *Total acceptances and sensitivities for E787 and E949.*

	E787	E949
N_K (10^{12})	5.9	1.8
Acceptance (%)	0.20±0.02	0.22±0.02
Sensitivity (10^{-10})	0.83	2.6

Table 2: *Background levels in the signal region for E787 and E949.*

Sources	E787	E949
$K_{\pi 2}$	0.032	0.216
$K_{\mu 2}$	0.064	0.068
Beam	0.050	0.014
Total Backgrounds	0.146±0.005	0.298±0.026

6 Results

Examination of the signal region yielded one new event with $P = 227.3 \pm 2.7$ MeV/c, $R = 39.2 \pm 1.2$ cm (in equivalent cm of scintillator), and $E = 128.9 \pm 3.6$ MeV (see fig.3). This event has all the characteristics of the $K^+ \to \pi^+ \nu\bar{\nu}$ signal, although its momentum is near the upper kinematic limit for this decay and it has an early π^+ decay time of 6.2 ns, both of which increased the ambiguity in π^+ identification. The likelihood ratio technique gave $\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) = (0.96^{+4.09}_{-0.47}) \times 10^{-10}$ at 68% CL from the E949 data alone. The combined E787 and E949 result is $\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) = (1.47^{+1.30}_{-0.89}) \times 10^{-10}$ at 68% CL based on three candidate events. The signal to background ratio S/b and signal weight $W \equiv S/(S+b)$ based on the measured branching ratio are summarized in tab.3. The measured branching ratio is twice the SM prediction. This result is consistent with the SM and is consistent with more

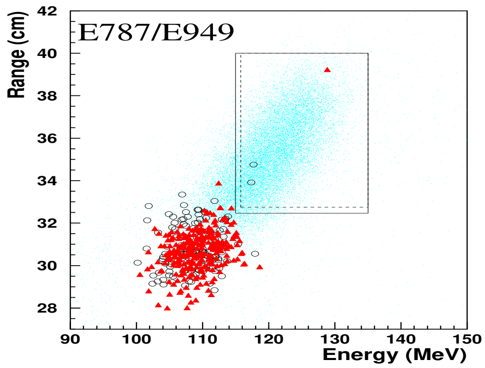

Figure 3: *Range and Energy of charged tracks for E787 (circles) and E949 (triangles) after all the other cuts are applied. Dots show the Monte Carlo $K^+ \to \pi^+ \nu\bar{\nu}$ events. Dashed and solid rectangles show the signal region for E787 and E949, respectively. A cluster near 110 MeV is due to $K_{\pi 2}$ events.*

Table 3: *Signal to background ratio and signal weight for E787 and E949.*

	E787		E949
Candidate	E787A	E787C	E949A
S/b	49	7	0.9
$W \equiv S/(S+b)$	0.98	0.88	0.48

than three times the SM and justifies the completion of the E949 experiment to increase the statistics and resolve the question.

7 Summary

BNL-E949 observed an additional $K^+ \to \pi^+\nu\bar{\nu}$ candidate in the new data and the measured branching ratio is $(1.47^{+1.30}_{-0.89}) \times 10^{-10}$ (68% CL) from the combined E787 and E949 data set.

Acknowledgments

This research was supported in part by the U.S. Department of Energy, the Ministry of Education, Culture, Sports, Science, and Technology of Japan, the Natural Sciences and Engineering Research Council and the National Research Council of Canada, the Russian Federation State Scientific Center Institute for High Energy Physics, and the Ministry of Industry, Science, and New Technologies of the Russian Federation.

References

1. S. Adler *et al*, Phys. Rev. Lett. **88**, 041803 (2002); S. Adler *et al*, Phys. Rev. Lett. **84**, 3768 (2000); S. Adler *et al*, Phys. Rev. Lett. **79**, 2204 (1997).

2. A.J. Buras *et al*, arXiv:hep-hp/0402112 (2004) and references therein.

3. V.V. Anisimovsky *et al*, Phys. Rev. Lett. **93** 031801 (2004); B. Bassalleck *et al*, E949 Proposal, BNL-67247, TRI-PP-00-06 (1999).

4. T. Yoshioka *et al*, IEEE Trans. Nucl. Sci, **51**, 199 (2004); O. Mineev *et al*, Nucl. Instr. Meth. **A494**, 362 (2002).

5. T. Junk, Nucl. Instr. Meth. **A434**, 435 (1999).