Frascati Physics Series Vol. XVI (2000), pp. 000-000
PHYSICS AND DETECTORS FOR DAΦNE – Frascati, Nov. 16-19, 1999

BNL E787 results on $K^+ \to \pi^+ \nu \bar{\nu}$

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ABSTRACT

The E787 collaboration at BNL-AGS reported one clean event of the rare decay $K^+ \to \pi^+ \nu \bar{\nu}$ in 1997. The event was found in the 1995 data set. Further analysis of 1995-1997 data set led us to reach a sensitivity of 1.5×10^{-10}/event ,where we found no additional event of the decay.

1 Introduction

The rare decay $K^+ \to \pi^+ \nu \bar{\nu}$ is a flavor changing neutral current process and is not allowed at tree level. It is induced by loop effects in the form of weak penguin and box diagrams in the Standard Model. The top quark contribution is dominant in this process because of the large top mass and it is thought to be the best place to determine $\mid V_{td} \mid$,which is poorly constrained compared to other CKM matrix elements[1]. The decay $K^+ \to \pi^+\nu\bar{\nu}$ is free from long distance contributions and hadronic matrix elements are canceled out by taking the ratio with $Ke3$ branching ratio. The theoretical uncertainty of the branching ratio which comes mainly from QCD corrections to the charm contribution is estimated to be about 7 % [2]. The standard model expectation for this process is $(0.82 \pm 0.32) \times 10^{-10}$ [3]. A theoretical upper bound for this process is also calculated to be 1.67×10^{-10} given the current limit on $\Delta M_d/\Delta M_s$. If the measured branching ratio of $K^+ \to \pi^+\nu\bar{\nu}$ exceeds 2×10^{-10} , it indicates a clear conflict with the Standard Model and the presence of New Physics.

The CP violating rare decay $K^0 \to \pi^0\nu\bar{\nu}$ has been thought to be a theorist's dream and experimentalist's nightmare for a long time. However three experimental groups are planning to meet the challenge of searching for this difficult process at KEK, BNL and FNAL[4]. This is a direct CP violating process and is proportional to the square of Im(Vtd). By combining charged and neutral K decays, we can obtain valuable information for Vtd with rather small theoretical ambiguities.

Various groups including KEK and SLAC B factories are attempting to measure CKM matrix elements by studying B decays. In near future, much more detailed information about CKM matrix elements will be obtained from various experiments. If there is any conflict between them, it indicates the presence of New Physics.

2 E787 Detector

E787 measures a charged particle emerging from stopped K^+ decay. The signature for $K^+ \to \pi^+\nu\bar{\nu}$ is the observation of a π^+ with momentum $P \leq 227MeV/c$ from a K^+ decay and no other particles detected. Definitive π^+ identification and nearly 4π photon veto system are required to reduce backgrounds well below the sensitivity of the Standard Model prediction. Major background comes from $K^+ \to \mu^+\nu$ ($K\mu2$) with a 64% branching ratio and $K^+ \to \pi^+\pi^0$ ($K\pi2$) with a 21% branching ratio. Fig. 1 shows the charged particle momentum spectrum of $K^+ \to \pi^+\nu\bar{\nu}$ process together with other decay modes. The principal search region is between $K\pi2$ peak(205MeV/c) and $K\mu2$ peak(236MeV/c) and the search is concentrated in this region at present. The search region below $K\pi2$ peak is being studied.

E787 detector[5] is optimized to measure an event with a single charged

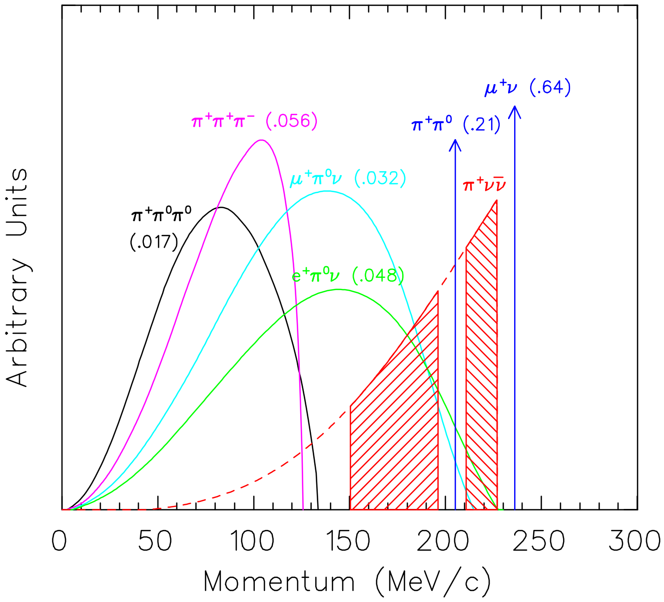

Figure 1: *Charged particle momentum spectra in the K^+ rest frame for the major K^+ decay modes and for $K^+ \to \pi^+\nu\bar{\nu}$. Only the region between $K\mu 2$ peak and $K\pi 2$ peak is searched for in this analysis.*

track and no other particles detected. It has a cylindrically symmetric shape like most of the colliding beam detectors. A thin material central drift chamber[6] in a 1 Tesla magnetic field measures the track momentum with a resolution of $\Delta p/p \sim 0.9\%$ at 205MeV/c. Twenty-one layers of range stack scintillation counters measure the kinetic energy and range of the track. They give us a redundant measurement of track kinematics. An active scintillation fiber target with 500MHz CCD transient digitizers [7] improves energy and dE/dx measurements. The range stack counters are equipped with 500 MHz transient digitizers which allow us a powerful π/μ separation ability by observing $\pi^+ \to \mu^+ \to e^+$ decay chain. This is a tool independent of kinematic measurements to separate pions from muons. Nearly 4π photon vetoing is achieved with barrel lead-scintillator sandwich counters and endcap CsI counters[8] which are also equipped with CCD transient digitizers. Collar and micro collar counters veto events with photons emitted along the incident kaon beam.

The K^+ beam is slowed by a BeO degrader and stopped in the scintillation

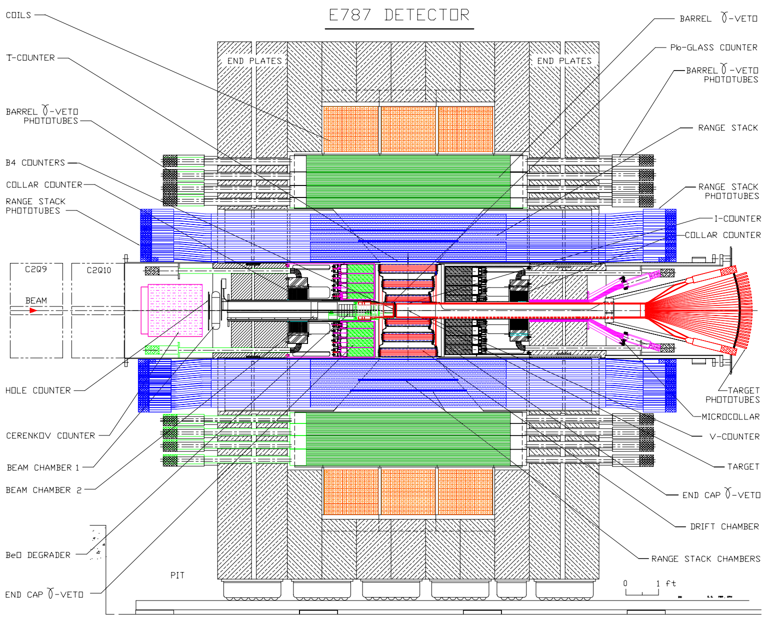

Figure 2: *E787 Detector*

fiber target which is fully active. A lucite Cerenkov counter and a lead glass counter separate kaons and pions in the incident beam. MWPC's and beam hodoscopes measure the position of the incident kaons. The typical rate is 5MHz of incident kaons.

In the 1995 run, the beam momentum was set to 790 MeV/c. In the 1996-1997 runs, it was lowered to 710MeV/c to increase the stopping fraction of the kaons from 20% to 28%. The trigger electronics was also improved in 1996-97 runs over 1995 run to reduce the dead time fraction from 28% to 17% per 1 MHz of stopped kaons. The efficiency of the 2nd level trigger was increased by a factor of 1.27. Extending the TD time range brought us an improvement factor of 1.05. Fig.2 shows the schematic drawing of E787 detector.

3 Analysis and Results

E787 searches for a very rare decay of the order 10^{-10} . It is essential to know the characteristics of the backgrounds and reduce them well below the order 10^{-10} in the signal region. The main background comes from $K\pi 2$ and $K\mu 2$ decays. In addition to these, beam related backgrounds and charge exchange($K^+ \to K^0$) backgrounds are also studied. The same data sample used for the signal search is used to study the backgrounds. In order to study the rejection ability of various cuts, two sets of independent cuts are selected for each background source. By inverting one set of cuts to enhance the background events, the rejection of another set of cuts is evaluated. For example, $K\pi 2$ background is studied by separating cuts into two sets; one set is kinematic cuts and the other is photon veto cuts. Each set of cuts has a rejection of order 10^{-6} . By inverting photon veto cuts, the rejection of kinematic cuts are studied, and by selecting events in the $K\pi 2$ peak region, photon veto rejection is studied. After studying 1/3 of event sample, all the cuts are fixed and likelihood functions for each background source are constructed with whole event sample. The likelihood functions are used to evaluate each background in the signal region.

Table 1: *Sensitivity and Backgrounds for 1995-1997 runs and for the future plan(E949)*

Background	1995(pub)	1995-97	E949
$K\pi 2$	(0.03 ± 0.02)	0.021	0.23
$K\mu 2$	(0.02 ± 0.02)	0.028	0.16
1-Beam	(0.012 ± 0.012)	0.004	0.09
2-Beam	(0.007 ± 0.009)	0.007	0.05
CEX	(0.01 ± 0.01)	0.01	0.07
Total	(0.08 ± 0.03)	0.07	0.6
1/Sensitivity(10^9)	2.4	6.7	58
Ratio to '95(pub)	1	2.8	24

E787 found one clean candidate event of $K^+ \to \pi^+ \nu \bar{\nu}$ in the sample of the 1995 run. In 1997, the branching ratio for this process of $(4.2^{+9.7}_{-3.5}) \times 10^{-10}$ was published, based on this clean event[9]. The background was estimated to be 0.08 event in the signal region. Reanalysis of 1995 data sample together

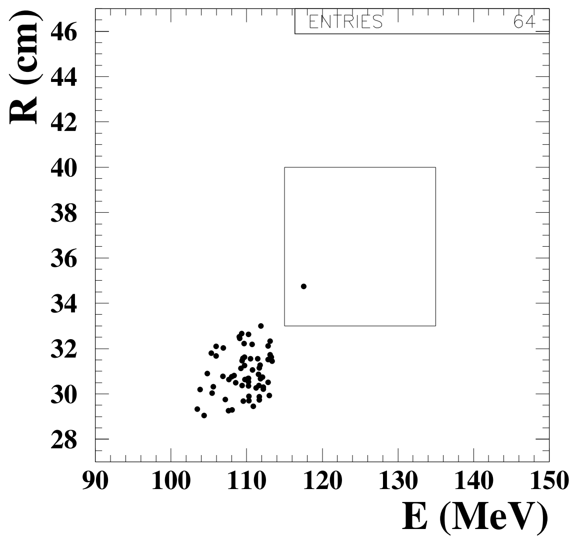

Figure 3: *Range versus momentum plot for 1995-1997 runs. The signal box is only a rough guide to the signal region actually used.*

with 1996-97 data sample was performed with more sophisticated analysis codes. Although the basic analysis method was maintained, some improvements were made. Tracking improvements in the range stack counters and the target brought better range resolution. A more sophisticated dE/dx analysis was developed for the range stack counters. Better momentum resolution was achieved via tracking code improvements in the central drift chamber. Better understanding of TD background in the $K\mu2$ peak compared to radiative $K\mu2$ and $K\mu3$ and a better electron finding algorithm increased the acceptance without increasing background. For beam related and charge exchange backgrounds, more sophisticated analysis codes were developed.

Fig.3 shows a range versus energy plot for $K^+ \to \pi^+\nu\bar{\nu}$ for the combined 1995-97 data sets. One clean event which was found in 1995 data set in the previous analysis is still the only event remaining in the signal region. Table 1 shows preliminary results of single event sensitivities of the published 1995 run and the reanalyzed 1995-1997 runs together with the expected number of background events. Table 1 also lists the estimated sensitivities and backgrounds for the successor experiment, E949. A very preliminary result for $B(K^+ \to \pi^+\nu\bar{\nu})$ is obtained to be $(1.5^{+3.5}_{-1.3}) \times 10^{-10}$ from the combined 1995-1997 runs. The expected number of background events stays at the same level as in the published 1995 data.

4 Future Prospects

E787 completed taking data in 1998. The 1998 data set is now being analyzed. The expected sensitivity of combined 1995-1998 runs will reach 0.7×10^{-10} with 0.1 background event.

The E787 detector is now being upgraded to the newly proposed E949 detector at BNL-AGS[10]. A barrel veto liner which is 13 layers of lead and scintillator sandwich counter adds an additional 2.3 radiation lengths to the barrel photon veto. A new photon veto system is added along the incident beam region. Finer segmentation of beam hodoscopes helps point to the K^+ decay vertex. The trigger counters which are the first layer of the range stack counters are also being replaced with new ones.

With these upgrades, E949 aims to get a sensitivity of 1.4×10^{-11} with 0.7 background event as listed in the last column of Table 1. The data below $K\pi 2$ peak will be also searched for with the improved photon veto system. This would lead us to reach a sensitivity of 0.8×10^{-11}/event.

5 Summary

E787 has published evidence of the rare decay $K^+ \to \pi^+\nu\bar{\nu}$ based on one clean event found in the 1995 run data. Reanalysis of the combined 1995-1997 run data was performed. One event found in 1995 run data is still the only event remaining in the signal region. The very preliminary value for $B(K^+ \to \pi^+\nu\bar{\nu})$ was obtained to be $(1.5^{+3.5}_{-1.3}) \times 10^{-10}$ with 0.07 background event.

E787 completed the data taking in 1998. The final sensitivity of E787 will reach 0.7×10^{-10}. Newly proposed E949 will increase the sensitivity for $K^+ \to \pi^+\nu\bar{\nu}$ to 1.4×10^{-11}. Including the data below $K\pi 2$ will be available, the sensitivity will reach 0.8×10^{-11}.

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