# FIRST RESULTS FROM BNL E949 ON THE RARE DECAY $K^+ \to \pi^+\nu\bar{\nu}$


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We present the first results from BNL E949 on the rare decay $K^+ \to \pi^+\nu\bar{\nu}$. The E949 experiment, which is a successor of E787, aims to measure the branching ratio of $K^+ \to \pi^+\nu\bar{\nu}$. This decay mode is one of the cleanest processes to explore the CKM matrix with rather small theoretical uncertainty. Based on the analysis of our 12 weeks of data taken in 2002, we observed an additional event inside our signal box. Combining with two events observed by E787, we obtained a branching ratio of $Br = (1.47^{+1.30}_{-0.89}) \times 10^{-10}$.


## 1 Introduction

In recent particle physics, exploration of flavor dynamics is one of the most important issues. Even in the era of successful B factories, there still exist interesting subjects in the kaon sector to shed light on the Standard Model (SM) from another side. The studies of both neutral and charged $K \to \pi\nu\bar{\nu}$ are powerful tools since their theoretical uncertainties are very small and the results from experiments can be directly connected with the theory. According to a recent review, the branching fraction of $K^+ \to \pi^+\nu\bar{\nu}$ and $K_L \to \pi^0\nu\bar{\nu}$ are estimated to be $(0.78 \pm 0.12) \times 10^{-10}$ and $(3.0 \pm 0.6) \times 10^{-11}$, respectively.[1] At present, only the experiment for the charged mode has a sensitivity adequate to reach the SM prediction. Experiment E787 at Brookhaven National Laboratory (BNL), conducted with the 24 GeV Alternating Gradient Synchrotron (AGS), has reported the branching ratio of the decay to be $B(K \to \pi^+\nu\bar{\nu}) = (1.57^{+1.75}_{-0.82}) \times 10^{-10}$, based on a two-event observation.[2] The E949 experiment, as the successor of E787, aims to observe $\sim 10$ events with 60 weeks of running. In this talk, the first results from E949 experiment are presented using the 12 weeks of data taken in 2002.

## 2 E949 Experiment

Taking over the well-confirmed techniques of E787, E949 was designed to have a sensitivity of $10^{-11}$, an order of magnitude deeper than the SM prediction. Basically, the concept of the measurement is the same as E787's. The event signature is that a charged pion from $K^+$ decay at rest is observed without any associated activity. Thus, we need to have good pion identification and hermetic veto systems. An active target of scintillating fibers, where a $K^+$ stops and decays, recorded the position and decay time of the kaon. A central drift chamber and a cylindrical range stack of scintillators (RS), which are inside a 1 Tesla magnetic field, measured the energy, momentum and range of charged particles. Combinations of these observables enabled us to discriminate charged pions from other particles such as muons and electrons. In the RS counter, where a charged pion stops, the sequential signals of the $\pi - \mu - e$ decay chain were recorded to consolidate pion identification. In addition, we could reject the most dangerous backgrounds, $K^+ \to \mu^+\nu$ ($K_{\mu 2}$) and $K^+ \to \pi^+\pi^0$ ($K_{\pi 2}$), by kinematical requirements on reconstructed charged particles, since their charged products are monochromatic. In practice, we accepted a charged pion in the momentum region $221 < P < 229$ MeV/c, which is above that of $\pi^+$ from $K_{\pi 2}$ and below that of $\mu^+$ from $K_{\mu 2}$. In the upgrade to E949, one third of the RS was replaced to obtain more light output, and a gain monitoring system was installed to improve its energy resolution. Surrounding $4\pi$ solid angle of the target, there existed photon detectors: lead/scintillator sandwich counters in the barrel region, undoped CsI crystals in the endcap region, and other detectors around the beam direction. A part of the barrel photon detectors was added in the upgrade to E949 in order to increase the effective radiation length and reduce inefficiency for photons. As a result of the various upgrades, we can keep our detector performance similar to or even better than E787, though instantaneous detector rates are twice those in E787

In the 2002 run, the beam intensity was typically $65 \times 10^{12}$ protons in a 2.2 second spill. We have taken physics data during about 12 weeks in total. There were non-optimal conditions due to machine troubles. The primary proton momentum was lowered to be 21.5 GeV rather than 24 GeV, and the duty factor was 40% worse than that in E949 proposal. In addition, problems in beamline DC separators caused poor $K - to - \pi$ ratios. We expect we can solve these problems and get better sensitivity than described below, if we can obtain funding to finish the experiment.

## 3 Data Analysis

As mentioned in previous section, the main background sources are the two-body decays $K_{\mu 2}$ and $K_{\pi 2}$, multibody decays containing muons ($K_{\mu m}$) such as $K^+ \to \mu^+\nu\gamma$, $K^+ \to \mu^+\pi^0\nu$, and scattering and/or interactions of beam particles in the target. We prepared at least two independent cuts to suppress each background, and adjusted and measured their rejection power by changing criteria. For example, we used kinematic measurements of the $\pi^+$ and photon detection in $\pi^0$ decay to reduce $K_{\pi 2}$ backgrounds. We could obtain a larger rejection factor of the photon veto, for instance, by lowering energy thresholds and timing windows, but at the same time, we would lose the signal by accidental hits. Once we fixed the cut position after the adjustment with a sample of 1/3 of the data, and measured the rejection by inverting complementary cut conditions with the remaining 2/3 data, we could estimate the backgrounds with the whole data set in the signal region. As a check of the method, the observed background rates around the signal region were compared to those predicted before opening the signal box, and were found to be quite consistent. Table 1 summarizes our sensitivity and estimated backgrounds after all the cuts.

To estimate the branching ratio, we prepared the method to weight observed event candi-

Table 1: Sensitivities and estimated backgrounds in E787 and E949 experiment.

| | E787 | E949 |
|---|---|---|
| Sensitivity | | |
| $N_K$ ($10^{12}$) | 5.9 | 1.8 |
| Acceptance (%) | 0.20 $\pm$ 0.02 | 0.22 $\pm$ 0.02 |
| Sensitivity ($10^{-10}$) | 0.83 | 2.6 |
| Backgrounds | | |
| $K_{\pi 2}$ | 0.032 | 0.216 $\pm$ 0.023 |
| $K_{\mu 2}$ | 0.062 | 0.044 $\pm$ 0.005 |
| $K_{\mu m}$ | | 0.024 $\pm$ 0.010 |
| Beam | 0.050 | 0.014 $\pm$ 0.003 |
| Total | 0.146 $\pm$0.049 | 0.298 $\pm$ 0.026 |

dates and used a likelihood technique. Since we already knew the effectiveness of the cuts by the measurements described above, we could predict the expected number of events ($S$) and backgrounds ($b$) in any point in the phase space of the observables. Actually, we divided our signal region into 3781 cells and calculated $S$, $b$, and then their weight $S/(S+b)$. The branching ratio was calculated by a likelihood technique [3] that determined the confidence level of a given branching ratio based on the observed events. To this end, we were ready to open our signal region and obtain the branching ratio.

## 4 Results

Figure 1 shows the resultant range versus kinetic energy distribution of charged pions after all other cuts. As shown in the figure, we found an additional event candidate inside the signal region. For newly observed event, the weight was 0.48 ($S/b = 0.9$), while they were 0.98 ($S/b = 50$) and 0.88 ($S/b = 7$) for the two events observed by E787, respectively. Based on three observed candidates in E787 and E949, the branching ratio obtained from the likelihood method was $Br = (1.47^{+1.30}_{-0.89}) \times 10^{-10}$. The quoted 68% coincidence interval includes both statistical and systematic uncertainties. Detailed discussion of the results is found in our published paper [4].

## 5 Conclusion

Based on the 12 weeks of data taken in 2002, we measured branching ratio of the rare decay $K^+ \to \pi^+ \nu\bar{\nu}$. The E949 experiment observed one new event inside the signal region. Combined with two events observed in our former experiment E787, we obtained the branching ratio to be $Br = (1.47^{+1.30}_{-0.89}) \times 10^{-10}$. Although the statistical error is large, the central value is twice as large as the SM prediction. Further running, which had been approved in 1999 but halted in mid-stream by DOE, can reduce the statistical uncertainty significantly and could provide a sign of new physics beyond the SM.


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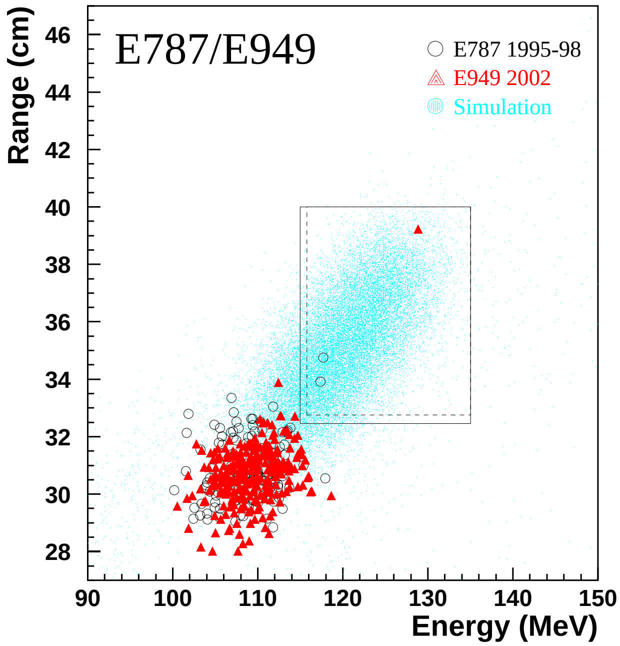


Figure 1: Range versus kinetic energy distribution with all other cuts applied. The circles and triangles represent E787 and E949 data, respectively, and dots indicate simulated events from $K^+ \to \pi^+\nu\bar{\nu}$. The signal box used in E949 is indicated by the solid line, while that in E787 is drawn by the dashed line.

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## References


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