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FIRST RESULTS FROM BNL E949

G. Redlinger

Physics Department, Brookhaven National Laboratory
Upton, New York 11973, USA

The first result from BNL E949 for the rare kaon decay $K^+ \to \pi^+\nu\overline{\nu}$ is described. One candidate event was seen with a signal-to-noise ratio of 0.9. Combined with the two events previously reported by E787, the best estimate of the branching ratio is $\mathcal{B}(K^+ \to \pi^+\nu\overline{\nu})= 1.47^{+1.30}_{-0.89} \times 10^{-10}$.

Keywords: CKM Matrix; Rare Kaon Decays; CP Violation

1. Introduction

The rare kaon decays $K^+ \to \pi^+\nu\overline{\nu}$ and $K_L \to \pi^0\nu\overline{\nu}$ have attracted interest in recent years due to their potential to completely determine the CKM Unitarity Triangle from kaon decays alone. For a recent review, see [1]. An inconsistency between the unitarity relation in kaon decays ($s \to d$ transitions) with that in B decays ($b \to d$ sector) would be a sign of physics beyond the Standard Model, and measurements of the inconsistencies could give some clues to the flavor and CP structure of the new physics.

Experimental challenges include the poor kinematic signature due to the 3-body final state with two neutrinos and the low branching ratio, estimated to be $(0.78 \pm 0.12) \times 10^{-10}$ and $(0.30 \pm 0.06) \times 10^{-10}$ for the charged and neutral modes respectively [1], where the quoted uncertainties are dominated by the measurement uncertainties on the CKM matrix parameters. The theoretical uncertainties in the branching ratios are estimated to be ~7% for $K^+ \to \pi^+\nu\overline{\nu}$ and ~2% for $K_L \to \pi^0\nu\overline{\nu}$ with an anticipation that the uncertainty for the charged mode could be brought down to ~2% with a NNLO QCD calculation [1].

2. BNL E949

Following the observation by E787[2] at BNL of two clean candidates of the decay $K^+ \to \pi^+\nu\overline{\nu}$, the E949 experiment was proposed in 1998 to improve the sensitivity by about one order of magnitude, running during RHIC beam stores. First data were taken in 2002 and results have been published recently[3].

E949 is based on "modest" upgrades to the E787 apparatus; as such, the background level and signal sensitivity can be predicted with confidence. The experiment uses the entire proton flux from the AGS, increasing the proton intensity from

15×10^{12} per spill to 65×10^{12}; however, to keep instantaneous rates constant in the detector, the spill length is increased so the gain is not linear with proton intensity. The running time per year is increased to $\sim$ 25 weeks, taking advantage of the long RHIC running. Detector upgrades included an addition to the barrel photon veto to increase the number of radiation lengths, better photon veto coverage along the beam direction, higher segmentation of beam tracking elements, improved pion tracking resolution via changes to the readout electronics of the central drift chamber and range stack straw chambers, improved pion energy resolution by replacing scintillator and by the addition of a phototube gain monitoring system, and finally, upgrades to the trigger/DAQ to handle higher data rates. Most details can be found from the references in [3].

The proton intensity during the 2002 run was according to design, although the experiment ran independently of RHIC for ease of scheduling. The typical intensity was 65×10^{12} protons in a 2.2 sec spill with a 3.2 sec interspill. Peak intensity reached 76×10^{12} protons/spill. However, there were several non-optimal features of the 2002 run, the first being the short duration, about 12 weeks in total. Next, damage to the primary AGS motor generator set meant running with the backup supply, forcing the proton momentum to be lowered to 21.5 GeV with a resulting $\sim$ 10% loss in K flux; this also resulted in 20% (40%) worse duty factor compared to E787 (E949 proposal). Finally, problems with the beamline separators resulted in a $K : \pi$ ratio of about 3, compared to a typical value of 4 in E787; the resultant instantaneous rates were roughly twice those seen in E787. The integrated kaon flux was about one-third of the total accumulated by E787 over $\sim$ 80 weeks.

3. Data Analysis

The main sources of background are the two-body decays $K^+ \to \mu^+\nu$ $(K_{\mu2})$ and $K^+ \to \pi^+\pi^0(K_{\pi2})$, multibody decays containing muons $(K_{\mu m})$ such as $K^+ \to \mu^+\nu\gamma$, $K^+ \to \mu^+\pi^0\nu$, and $K_{\pi2}$ with π decay-in-flight, scattered beam pions (either from kaon decay/interaction or pions from the K^+ production target) and K^+ charge exchange (CEX) reactions, resulting in decays $K_L^0 \to \pi^+ l^- \overline{\nu}$, where $l = e$ or μ. To elude rejection, $K_{\mu2}$ and $K_{\pi2}$ events have to be reconstructed incorrectly in range, energy and momentum. In addition, any event with a muon has to have its track misidentified as a pion. The most effective weapon here is the waveform digitizer analysis, requiring observation of the $\pi^+ \to \mu^+ \to e^+$ decay sequence; this provides a muon rejection factor of about 10^5. Events with photons, such as $K_{\pi2}$ decays, are efficiently eliminated by photon detection in calorimeters; the rejection factor for events with $\pi^0 s$ is around 10^6. A scattered beam pion can survive the analysis only by misidentification as a K^+ and if the track is mismeasured as delayed, or if the track is missed entirely by the beam counters after a valid K^+ stopped in the target. CEX background events can survive only if the K_L^0 is produced at low enough energy to remain in the target for at least 2 ns, if there is no visible gap between the beam track and the observed π^+ track, and if the additional charged lepton goes unobserved.

The heart of the offline analysis is a robust estimate of the background at the level of a fraction of an event. Two independent cut sets, each with high rejection, are used to determine each background. These cut sets are played off against each other to measure their background rejection power. For example, for $K_{\pi 2}$ background, the two independent cut sets are the kinematic cuts and the photon veto cuts. By inverting the photon veto cuts (i.e. by demanding the presence of photons), after first removing the non-$K_{\pi 2}$ backgrounds, one can isolate a sample of $K_{\pi 2}$ events from which the kinematic rejection can be measured. And vice versa. Small residual correlations between the cut sets are studied and removed; the rejection of the two cut sets can then be multiplied to give the total rejection. The background estimates are checked by counting the number of events near, but outside, the signal region.

Reflecting a growing confidence in the ability to predict the background level and a shift in philosophy from "discovery" mode to "measurement" mode, the predetermined signal region was expanded, letting in more background but allowing a 30% gain in acceptance. The total background expected in the signal region was 0.30 ± 0.03 events, dominated by $K_{\pi 2}$ background (0.216 ± 0.023). The $K_{\mu 2}$, $K_{\mu m}$, and beam-related backgrounds (including CEX) contributed 0.044 ± 0.010, 0.024 ± 0.003, and 0.014 ± 0.003 events, respectively. The assessment of candidate events and the computation of the $K^+ \to \pi^+ \nu \overline{\nu}$ branching ratio was done with a likelihood ratio technique. An event characterization function consisting of a set of discrete bins S_i/b_i describes the relative probability for events occurring in bin i to originate from $K^+ \to \pi^+ \nu \overline{\nu}$ or background. Here b_i is the expected number of background events from all sources in bin i, and S_i is the expected number of signal events in each bin, given as $\mathcal{B} A_i N_K$ where A_i is the acceptance in bin i and $\mathcal{B}$ is the branching ratio from the fit.

After all cuts were applied, one candidate near the $K^+ \to \pi^+ \nu \overline{\nu}$ endpoint was observed. The estimated probability that the background alone gave rise to this event (or any more signal-like event) was 0.07. At the measured branching ratio (see below) the S_i/b_i for this event was 0.9. The best estimate of the branching ratio, combining data from E787 and E949 is $\mathcal{B}(K^+ \to \pi^+ \nu \overline{\nu}) = 1.47^{+1.30}_{-0.89} \times 10^{-10}$, consistent with Standard Model expectations, but also possibly higher; completion of the experiment could help resolve the ambiguity. Although E949 was approved to run for 60 weeks, DOE HEP operations at the BNL AGS were halted after the 2002 run of only 12 weeks. The future of the experiment is uncertain.

References

1. A.J. Buras *et al.*, hep-ph/0405132.
2. S. Adler *et al.*, *Phys. Rev. Lett.* **88**, 041803 (2002).
3. V.V. Anisimovsky *et al.*, *Phys. Rev. Lett.* **93**, 031801 (2004).