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SEARCH FOR $K^+ \to \pi^+\nu\overline{\nu}$

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ABSTRACT

The present status of an experiment E787 at Brookhaven National Laboratory (BNL), which is searching for the rare decay $K^+ \to \pi^+\nu\overline{\nu}$, is described.

1. Introduction

The rare kaon decay mode $K^+ \to \pi^+\nu\overline{\nu}$ is mediated by flavor-changing neutral currents (FCNC). It is forbidden in first order, but it occurs in higher-order diagrams in the standard model of electroweak interaction as shown in Fig.1.[1] Among several FCNC processes, this decay is known to have two significant advantages: First, it has long-distance contributions three-orders of magnitude smaller than the short-distance contributions.[2] Second, the induced hadronic matrix element can be given unambiguously by the $K^+ \to \pi^0 e^+\nu$ (K_{e3}) decay. Therefore, the measurement of the decay would give an extraordinarily-clean test of higher-order calculations in the standard model. Conversely, if the standard model is valid and the top quark mass (m_t) is known, it would provide a precise determination of the Cabbibo-Kobayashi-Maskawa (CKM) matrix element, V_{td}. Also, this decay is sensitive to the exotic two-body decay $K^+ \to \pi^+ f^0$ where f^0 is a weakly-interacting neutral particle such as the familon.[3]

2. Standard Model Prediction of $K^+ \to \pi^+\nu\overline{\nu}$

In the standard model, the branching ratio of the decay $K^+ \to \pi^+\nu\overline{\nu}$, $B(K^+ \to \pi^+\nu\overline{\nu})$, is given for three neutrino generations by

$$\begin{aligned} B(K^+ \to \pi^+\nu\overline{\nu}) &= \frac{3\alpha^2}{8\pi^2 \sin^4\theta_W} \frac{|V_{cs}^* V_{cd} \cdot \eta_c D(x_c) + V_{ts}^* V_{td} \cdot \eta_t D(x_t)|^2}{|V_{us}|^2} \\ &\times B(K^+ \to \pi^0 e^+\nu), \end{aligned} \tag{1}$$

where V_{ij}'s are the CKM matrix elements, and

$$D(x_i) = \frac{x_i}{4}\left[\frac{3(x_i-2)}{(x_i-1)^2}\ln x_i + \frac{x_i+2}{x_i-1}\right] \quad \text{and} \quad x_i = \frac{m_i^2}{m_W^2}, \tag{2}$$

*representing the E787 collaboration at BNL

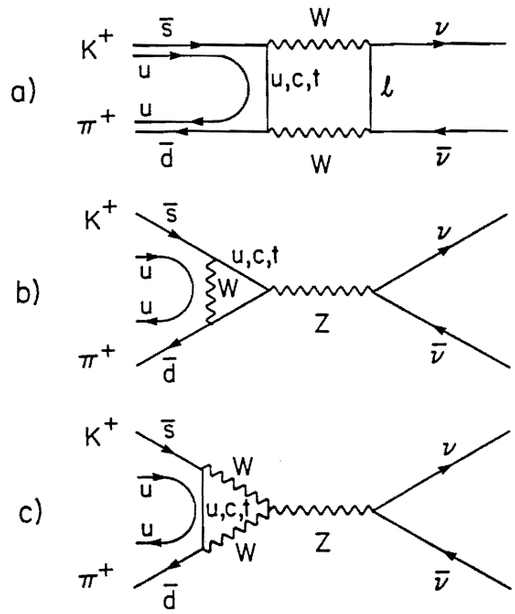

Fig.1 Typical diagrams contributing to $K^+ \to \pi^+\nu\overline{\nu}$

and m_i and η_i $(i = c, t)$ are masses and QCD corrections for the charge-2/3 quarks respectively. The QCD correction for the charm quark is known to be large ($\eta_c \sim 0.7$) but that for the top quark is negligibly small ($\eta_t \simeq 1.0$) for $m_t > m_W$.[4,5] m_W is the W boson mass. The contributions from the charm and top quarks are comparable, if one takes account of the relevant CKM matrix elements. The standard model prediction is $B(K^+ \to \pi^+\nu\overline{\nu}) = (1-4) \times 10^{-10}$.[6]

3. Experiment

A search for the decay $K^+ \to \pi^+\nu\overline{\nu}$ is being undertaken in Experiment 787 at BNL. The E787 collaboration, formed by BNL, Princeton University, TRIUMF, Institute for Nuclear Study (U. of Tokyo) and KEK in Japan, is aiming to reach a sensitivity of 10^{-10} level or better. Prior to E787, the upper limit was 1.4×10^{-7}.[7] It leaves us a large window of search in which new physics can be explored.

E787 is looking for the $K^+ \to \pi^+\nu\overline{\nu}$ decay primarily in the kinematic region above the $K_{\pi 2}$ peak, which covers about 20 % of the total spectrum. The signature of $K^+ \to \pi^+\nu\overline{\nu}$ is a single π^+ unaccompanied by other signals (i.e. $K^+ \to \pi^+ +$ "*nothing*"). The decays $K^+ \to \mu^+\nu$ $(K_{\mu 2})$ and $K^+ \to \pi^+\pi^0$ $(K_{\pi 2})$ are potential sources of background if a muon is misidentified as a pion for the former and if photons from the π^0 decay are undetected for the latter. Therefore, important characteristics of the detector to reduce backgrounds are (1) excellent π/μ particle identification and (2) efficient photon detection capability. In E787, for particle identification, the range, momentum and kinetic energy of the charged particles from stopped kaons are measured. In addition, the characteristic decay sequence of $\pi^+ \to \mu^+ \to e^+$ is observed by transient digitizers. The hermetic photon detector covering nearly 4π of solid angle is employed.

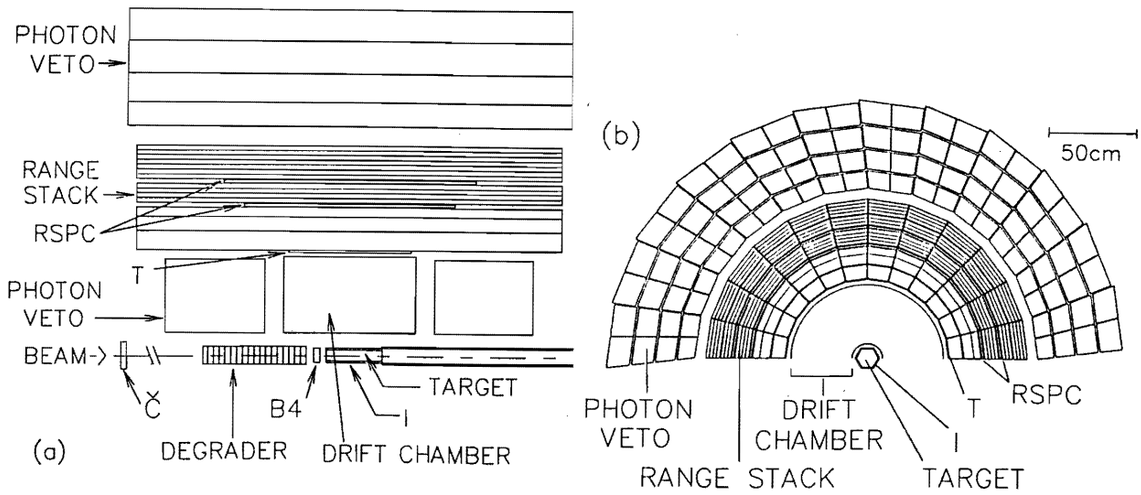

Fig.2 Schematic (a) side and (b) end views of the E787 detector

Schematic side and end views of the E787 detector are shown in Fig.2 (a) and (b), respectively. It has a large geometrical acceptance (2π sr) for $K^+ \rightarrow \pi^+\nu\overline{\nu}$ and was designed to maximize background rejection. A detail description of the detector can be found elsewhere.[8] In brief, incoming kaons of 800 MeV/c are stopped in a target consisting of plastic scintillating fibers. Pions from K^+ decay are momentum-analyzed as they pass through a cylindrical drift chamber and stopped in a stack of 21-layer plastic scintillators (range stack) which measures the range and kinetic energy of the pions. The decay sequence of $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ is measured by using 500-MHz flash ADC transient digitizers instrumented on the range-stack photomultiplier signals. Surrounding the range stack and drift chamber is the 4π photon detection system located at the barrel and endcap regions. The photon detector consists of alternating 1-mm lead and 5-mm plastic scintillator layers, covering 14 radiation lengths for the barrel and 12 radiation lengths for the endcap regions. All these systems are contained in a normal solenoid magnet which produces a magnetic field of 10 kG along the beam direction.

4. Preliminary 1989 Results

The offline analysis required a single π^+ track fully reconstructed in the target, drift chamber and range stack. The kinematic observables such as range, momentum and kinetic energy and their correlations were exploited for particle identification. Transient digitizer information in the pion-stopping counter was used to observe an unambiguous $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ decay sequence. Tight photon veto cuts using refined offline timing and energy information was applied. The residual candidates from a preliminary analysis of the 1899 $K^+ \rightarrow \pi^+\nu\overline{\nu}$ data are shown in a two-dimensional plot of kinetic energy vs. range in Fig.3(a), along with Monte Carlo $K^+ \rightarrow \pi^+\nu\overline{\nu}$ events in Fig.3(b). The box indicates the accepted signal region and no events fell into the box. The overall acceptance was estimated to be about 0.5 %. This result gave a very *preliminary* upper limit for the 1989 data of $B(K^+ \rightarrow \pi^+\nu\overline{\nu}) < 5 \times 10^{-9}$ at 90 % confidence level (C.L.). Similarly, it placed a preliminary upper limit of $B(K^+ \rightarrow \pi^+ f^0) < 1 \times 10^{-9}$. An extensive study of the potential backgrounds, such as the $K_{\mu 2}$, $K_{\pi 2}$ decays, $K^+ \rightarrow \mu^+\nu\gamma$, pion scattering and charged exchange reaction,

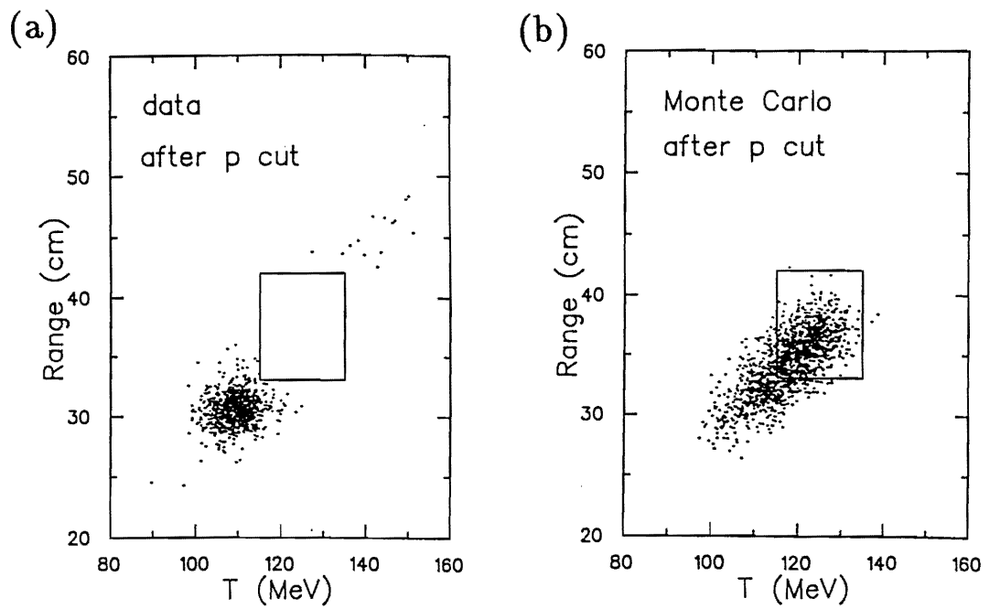

Fig.3 (a) Final sample of candidates and (b) Monte Carlo calculation

at a sensitivity level of 10^{-10} for $K^+ \to \pi^+\nu\overline{\nu}$ is in progress. The analysis of 1990 and 1991 data is also in progress.

Although the search has been focused in the kinematic region above the $K_{\pi 2}$ peak, E787 has started to seek the signals in the region below the $K_{\pi 2}$ peak, where pions in $K_{\pi 2}$ decay with nuclear interaction contribute as a major background. With the coming detector upgrade mentioned later, we will be able to reduce the background and expand the kinematic region of search in future.

In addition to $K^+ \to \pi^+\nu\overline{\nu}$, E787 can access to other interesting rare K^+ decay modes, such as $K^+ \to \pi^+\mu^+\mu^-$ [9] and $K^+ \to \pi^+\gamma\gamma$.[10] E787 can also study the rare π^0 decays such as $\pi^0 \to \nu\overline{\nu}$ [11] and $\pi^0 \to \gamma X^0$.

The first limit on the rare decay $\pi^0 \to \gamma X^0$ was measured in E787 by using tagged π^0s in $K_{\pi 2}$ decay, where X^0 is a hypothetical long-lived non-interacting neutral particle.[12] Owing to angular momentum conservation, X^0 must be a new *vector* particle such as those which appears in some extensions of the standard model with additional U(1) interaction. The signature is a π^+ kinematically consistent with $K_{\pi 2}$ decay along a single photon in the detector. The main potential background is $\pi^0 \to \gamma\gamma$ decay with one missing photon owing to the inefficiency of photon detection. After tight photon veto, eight events survived, while Monte Carlo calculation predicted fifteen events. Based on the assumption that the surviving events could be backgrounds due to photon-detection inefficiency, we can set the 90 % C.L. upper limits of $B(\pi^0 \to \gamma X^0)$ as a function of mass of X^0 (m_{X^0}) for different lifetimes, as shown in Fig.4. The upper limits on the three-body decay $\pi^0 \to \gamma X X'$ were also set.

5. Future Prospect

E787 continues the search for the decay $K^+ \to \pi^+\nu\overline{\nu}$ with the coming upgrade of the detector. The upgrade includes a new target of brighter plastic scintillating fibers, a new drift chamber with smaller mass, a new straw-chamber system interlayered in the range stack, a new photon detector comprised of fully-active scintillating crystals

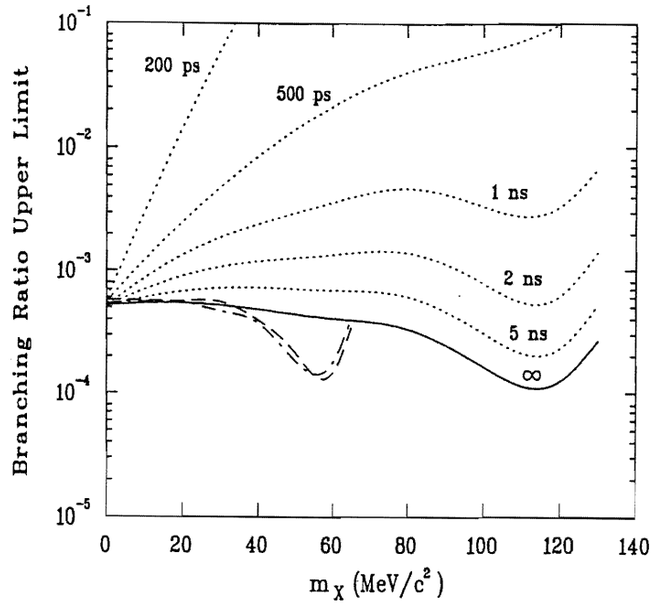

Fig.4 The upper limits for $B(\pi^0 \to \gamma X^0)$ as a function of m_{X^0} for different lifetimes. The limits of $B(\pi^0 \to \gamma X X')$ are also shown.

such as pure CsI, a new beam instruments with an active degrader, and 500 MHz GaAs CCD transient digitizers. In addition to the detector upgrade, a new kaon beam channel (LESB III) which produces two times more kaons with an improved ratio of kaons to pions of 3:1, is being commissioned this year (1992). A factor of four increase of the proton intensity in the BNL-AGS ring by the Booster is planned by 1994. Together with all these improvements, we anticipate to achieve our goal, a sensitivity of 10^{-10}.

References

1. T. Inami and C.S. Lim, Prog. Theor. Phys. 65 (1981) 297
2. D. Rein and L.M. Sehgal, Phys. Rev. D39 (1989) 3325
3. F. Wilczek, Phys. Rev. Lett. 49 (1982) 1549
4. J. Ellis and J.S. Hagelin, Nucl. Phys. B217 (1983) 189; J.S. Hagelin and L.S. Littenberg, Prog. Part. Nucl. Phys. 23 (1989) 1
5. C.O. Dib, I. Dunietz and F.J. Gilman, Report No. SLAC-PUB-4840, 1989
6. G. Bélanger and C.Q. Geng, Phys. Rev. D43 (1991) 140
7. Y. Asano *et al.*, Phys. Lett. 107B (1981) 159
8. M.S. Atiya *et al.*, Phys. Rev. Lett. 64 (1990) 21; M.S. Atiya *et al.*, Nucl. Instr. and Meth. to be submitted.
9. M.S. Atiya *et al.*, Phys. Rev. Lett. 63 (1989) 2177
10. M.S. Atiya *et al.*, Phys. Rev. Lett. 65 (1990) 1188
11. M.S. Atiya *et al.*, Phys. Rev. Lett. 66 (1991) 2189
12. M.S. Atiya *et al.*, Phys. Rev. Lett. 69 (1992) 733