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**An Experiment to Study
 $K^+ \rightarrow \pi^+ + \text{"Nothing"}$
at LAMPF II**

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AN EXPERIMENT TO STUDY $K^+ \rightarrow \pi^+ + \text{"NOTHING"}$ AT LAMPF II

by

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ABSTRACT

An experiment to measure $K^+ \rightarrow \pi^+ + \text{"nothing"}$ at LAMPF II is described. This experiment is capable of measuring one $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ event for a branching ratio of 10^{-12} .

The past 15 years have witnessed a progression of experiments¹⁻⁴ designed to search for the decay $K^+ \rightarrow \pi^+ + \text{"nothing"}$, where "nothing" denotes unobservable neutral particles such as $\nu \bar{\nu}$, familons, or light supersymmetric particles. Even the most "likely" of these reactions, i.e., $K^+ \rightarrow \pi^+ \nu \bar{\nu}$, can proceed only through higher order weak diagrams, resulting in expected branching fractions well below the sensitivities of the experiments that have been completed thus far. In particular, the KEK experiment³ set an upper limit of 1.4×10^{-7} , which is well above the 10^{-11} to 10^{-10} range calculated⁵ within the framework of the standard model of electroweak interactions.

Observation of $K^+ \rightarrow \pi^+ + \text{"nothing"}$ signal with a branching ratio larger than the standard-model value would be indicative of new physics, not accounted for by currently accepted theories. The possibilities⁶⁻⁸ are numerous and include the existence of more than three quark and lepton generations or decays involving heretofore-undiscovered particles. Lepton flavor-changing reactions such as $K^+ \rightarrow \pi^+ + \nu_e \bar{\nu}_\mu$ might also show up. Finally, the π^+ could be observed to recoil against a single light object such as the familon,⁹ a particle introduced by Wilczek to account for quark and lepton masses. The latter reaction has the added experimental bonus of a monoenergetic π^+ signature ($P_{\pi^+} = 227 \text{ MeV}/c$ for K^+ 's decaying at rest).

A new experiment⁴ is now being readied for a run at the Brookhaven AGS by a BNL/Princeton/TRIUMF collaboration and will either observe a signal or lower the upper limit on the branching fraction for $K^- \rightarrow \pi^+ \nu \bar{\nu}$ to the few 10^{-10} level. Regardless of the outcome, a follow-up experiment is warranted either to acquire a large sample of events for detailed analysis or to achieve sufficient sensitivity to cleanly observe the $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ rate predicted by the standard model. Such a measurement would be an opportunity to study higher order weak diagrams in an environment free from long-range effects that complicate the analysis of reactions such as $K^0 \rightarrow \mu^+ \mu^-$.

Background estimates made in the process of designing the Brookhaven experiment indicate that all known backgrounds can be suppressed to levels smaller than the sensitivity that can be achieved at the AGS with runs of reasonable duration--i.e., a few thousand hours of actual data taking. Thus, in view of the technological improvements incorporated into the detector proposed here, it should be possible to take full advantage of the 100-fold increase in available beam intensity that LAMPF II will offer.

THE DETECTOR

Figures 1 and 2 show side and end views of the apparatus, respectively. Although the basic configuration of the detector is similar to the BNL detector, the axial magnetic field strength is 30 kG, three times stronger than the 10-kG field used in the E787 design. This, of course, requires that superconducting technology be employed and that a substantial iron return yoke surround the detector to reduce the field to tolerable levels in the region of the phototubes. The advantages^{10,11} of such a scheme are many, not the least of them being the improvement in momentum resolution and a reduction in the overall size of the detector.

A beam of 2×10^7 750-MeV/c K^+ mesons enters from the left, passes through an active degrader, and is brought to rest in a target consisting of scintillating fibers 2 mm in diameter. The high degree of target segmentation provides sensitivity to small-angle nuclear scattering in the material of the target. Moreover, the fine granularity will also be useful in rejecting backgrounds arising from $K^+ n \rightarrow K^0 p$ followed by $K^0 \rightarrow \pi^+ \mu^- \bar{\nu}$ or $K^0 \rightarrow \pi^+ e^- \bar{\nu}$ with the recoil proton and the decay lepton being lost in the target. For these events, the dis-

tance traveled by the K^0 will show up as a gap in the pattern of target energy deposition.

Once out of the target, the decay π^+ 's pass through a cylindrical drift chamber that measures their momenta to an accuracy of $\sigma = 0.5\%$. Even when target energy-loss uncertainties are taken into account, the overall resolution of the system remains well under 1%, providing a powerful tool for the rejection of $K_{\pi 2}$ events. The momentum measurement is also used for particle identification through momentum-range and momentum-energy comparisons.

The π^+ 's then range out in a plastic scintillator array segmented in both radius and azimuth into 2500 cells of approximately 1.0 cm^2 cross-sectional area. The range resolution from the small cells is $\sigma < 3.0\%$. Each cell is viewed from both ends by 3/8" phototubes read out by 1 Gigasample transient digitizers. The digitizers record a complete history of scintillator light output as a function of time. This affords further particle identification through detection of the $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ decay sequence and reduces the cost per channel by combining all the usual functions into a single circuit. The small-range stack element size and the use of transient recorders also reduces the problems of high rate operation.

The entire detector is completely surrounded by a BaF_2 gamma veto with TMAE chamber readout. The 660-ps decay time for the component of the light detected in the TMAE chambers and a high degree of segmentation facilitate high rate operation. The thickness of the veto is 35 cm, or about 16 radiation lengths. Monte Carlo calculations¹² indicate photon-detection inefficiencies between 10^{-4} and 5×10^{-3} , depending on the photon energy and resulting in an overall π^0 inefficiency well below 10^{-6} . The efficiency is limited mainly by photonuclear absorption, which is minimized by the use of a fully active gamma converter.

BACKGROUNDS AND ACCEPTANCE

Two of the largest backgrounds are considered below to illustrate the rejection power of the apparatus. Although the improved photon veto and enhanced sensitivity to nuclear interactions of the outgoing π^+ in this detector may enable the proposed experiment to search for $K^+ \rightarrow \pi^+ +$ "nothing" below the $K_{\pi 2}$ peak, the estimates in Table I were made assuming that the usual approach of looking only in the region above that peak is taken.

TABLE I

BACKGROUND SUPPRESSION

$K^+ \rightarrow \mu^+ \nu \gamma$		$K^+ \rightarrow \pi^+ \pi^0$	
<u>Cut</u>	<u>Suppression</u>	<u>Cut</u>	<u>Suppression</u>
π - μ -e timing	5×10^{-5}	γ Veto	10^{-6}
γ Veto	0.02	π^+ Range	0.01
Range/Energy	0.05	π^+ Energy	0.02
Momentum/Energy	<u>10^{-3}</u>	π^+ Momentum	<u>0.005</u>
Total Suppression	5×10^{-11}	Total Suppression	10^{-12}

Assuming that one-third of the incident K^+ 's come to rest in the active target and that the overall acceptance of the detector is 1.5% (this includes solid angle, the fraction of the signal above the $K_{\pi 2}$ peak, and inefficiencies introduced by the various cuts), one can expect one $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ event for each 10^{-12} of branching fraction in a 2000-h run. Using the total suppression factors from the table above and multiplying by the branching fractions in the range regions of interest (5×10^{-4} for $K^+ \rightarrow \mu^+ \nu \gamma$ and 0.21 and $K^+ \rightarrow \pi^+ \pi^0$) and the acceptance for these modes relative to $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ above the $K_{\pi 2}$ peak (Refs. 12 and 1, respectively), one expects less than one background event for the entire run.

SUMMARY

An experiment capable of exploiting the high K^+ fluxes of LAMPF II has been described. The experiment will collect between 10 and 100 $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events, depending on the top quark mass and weak mixing angles, or an even larger (or smaller) number of events if physics beyond the standard model comes into play. Such an experiment is an important check of our understanding of weak interactions.

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Figure 1

Side view of the Detector

Figure 2

End view of the Detector. A typical trajectory for a π^+ from $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ is shown.