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PROSPECTS FOR OBSERVING $K^+ \rightarrow \pi^+ \nu\bar{\nu}$

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ABSTRACT

We report on the progress of experiment 787 at Brookhaven national laboratory designed to study $K^+ \mapsto \pi^+ + '....'$, where '....' is a one or more feebley interacting neutrals. The experiment will have an initial sensitivity of 2×10^{-10} for two or more particles(e.g. $K^+ \mapsto \pi^+\nu\overline{\nu}$),and 4×10^{-11} for one particle(e.g. $K^+ \mapsto \pi^+ + axion$). The experiment can also study such reactions as $K^+ \mapsto \pi^+\gamma\gamma$,$K^+ \mapsto \pi^+\mu^\pm e^\mp$,$K^+ \mapsto \mu^+\nu\gamma$,$\pi^0 \mapsto \nu\overline{\nu}$,and$\pi^0 \mapsto e^+e^-$.

INTRODUCTION

Rare kaon decays are one of the few immediately available means of studying the Multi-Tev region [1]. This partly explains the wide interest in studying the reaction $K^+ \mapsto \pi^+ + '....'$ both as a test of the standard model through the channel $K^+ \mapsto \pi^+\nu\overline{\nu}$,and a search for new particles or interactions through the channels $K^+ \mapsto \pi^+ + axion$,and $K^+ \mapsto \pi^+ nuinos$,where the nuinoes refer to any of the light animals in the supersymmetric zoo [1]. There is sufficient literature on the decay to warrant a simple reference rather than a detailed exposition. Certainly the previous speaker has managed to arouse interest in it [2]. $K^+ \mapsto \pi^+\nu\overline{\nu}$ proceeds through the diagrams shown in figure 1 and as such it is sensitive to the top quark mass and the various mixing angles [1].

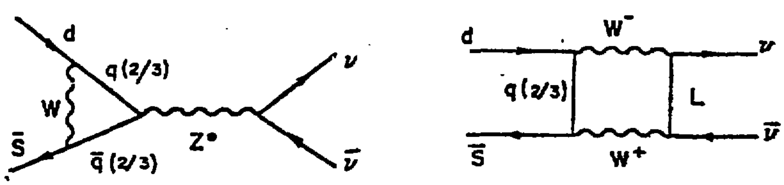

Figure 1.

From known branching ratioes of the bottom quark states and from their measured lifetimes one can set an upper as well as a lower limit on the branching ratio $K^+ \mapsto \pi^+\nu\bar{\nu}$. Figure 2 shows these limits as a function of the top quark mass. It is clear that any experiment aiming for a serious study of that decay mode has to reach a minimum sensitivity of better than 10^{-9} [3]. The present limit is 1.4×10^{-7} [4] . An increase of two to three orders of magnitudes in sensitivity is needed. Similar statements can be made about $K^+ \mapsto \pi^+ + axion$ [5]. Supersymmetric models have lately become quite the fashion,but as yet no evidence as to the validity of the theories or the range of masses has been found. A search in the decay mode $K^+ \mapsto \pi^+ nuinos$ is a fruitful pursuit as least as constraint on future or present speculations,and perhaps as a method of discovery,assuming that the strength of decays are significantly larger that the standard model $K^+ \mapsto \pi^+\nu\bar{\nu}$ [1].

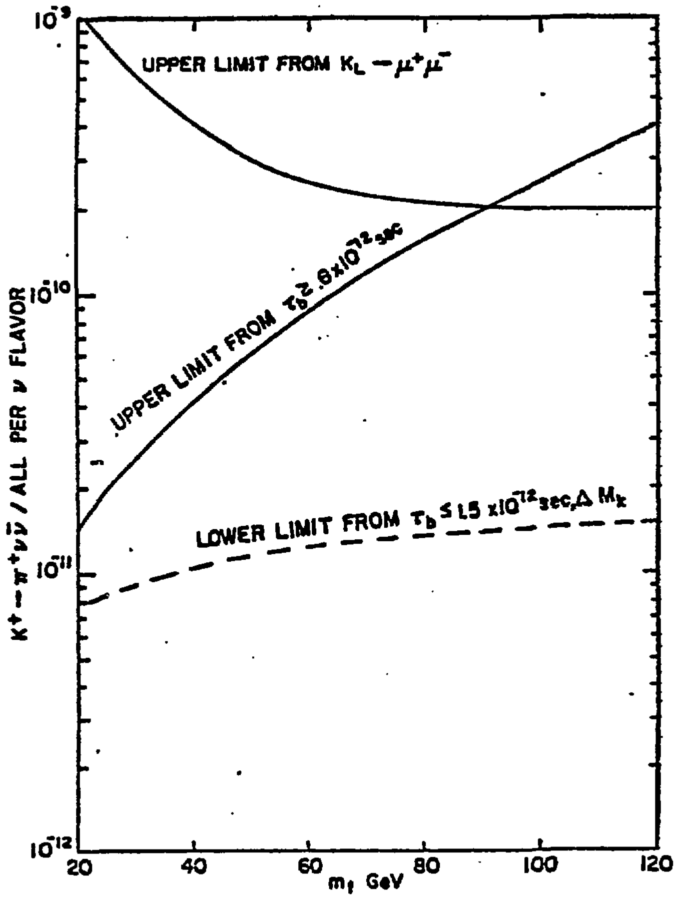

Figure 2.

Since this is a neutrino mass meeting one is almost obligated to note that the decay $\pi^0 \mapsto \nu\bar{\nu}$ can be used to set limits on the neutrino mass,since a spin zero particle can not decay into two massless spin 1/2 particles without violating angular momentum conservation [6]. To constrain the neutrino mass to the region outside 25 to 70 Mev a sensitivity of 10^{-9} is needed, as shown in figure 3. We anticipate reaching at least 10^{-7} at the initial stage. This leaves a window of three orders of magnitude for the observation of any new or unusual phenomena. Again ,the previous speaker said quite a bit about this topic.

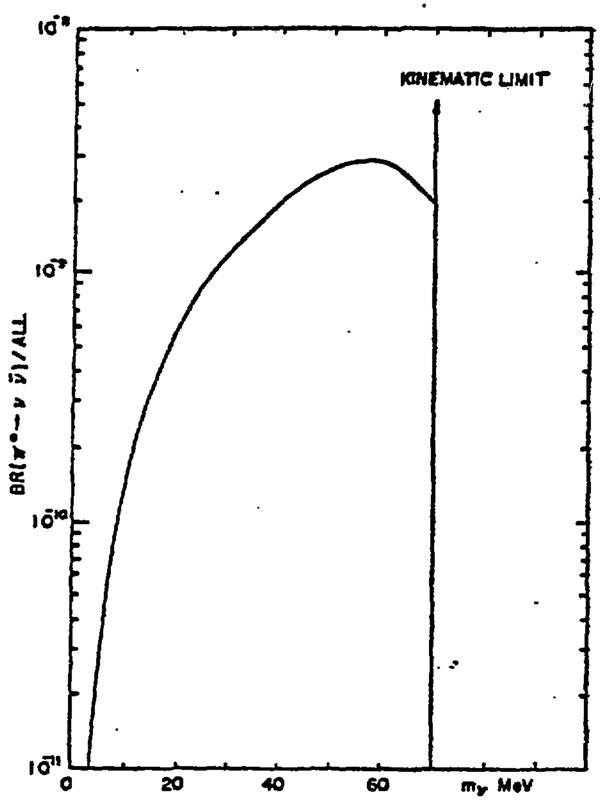

Figure 3.

PHILOSOPHY OF DETECTION

The decay $K^+ \mapsto \pi^+\nu\bar{\nu}$ can simulated by a multitude of backgrounds, most are common kaon decays,and some are beam related. The decays $K^+ \mapsto \mu^+\nu$ where the muon is misidentified as a pion, $K^+ \mapsto \pi^+\pi^0$ where the photons from the neutral pions are not detected,$K^+ \mapsto \mu^+\nu\gamma$ where the soft photon is also undetected, and several other three body decays where one of the particles is misidentified or where neutral pions or photons are missing can also simulate the decay $K^+ \mapsto \pi^+\nu\bar{\nu}$. In suppressing copius backgrounds to the level of 10^{-11} or better one has to rely on several **independant** mechanisms of suppression. Also to reach the level of sensitivity we desire we have to improve the acceptance of the detector by three orders of magnitude over previous experiments. The later is done through an order of magnitude improvement in geometrical acceptance,and two orders of magnitude improvement in beam rate and running time. I will briefely describe the detector and then discuss acceptance and background suppression.

DETECTOR

The detector is shown in figure 4. The incoming beam is an admixture of kaons and pions at a momentum of 850 Mev/c, and with a rate of several millions per one second flat top spill. The typical π/K ratio is about 3 to 1. The kaons are degraded in a BaF_2 live degrader and stopped in a 10 cm diameter, 20 cm long scintillator target.

The target is constructed of 2000 2mm thick scintillating fibres running along the beam direction. Each group of fibres (a group is one to four fibres) is read out by a 1 cm phototube and instrumented with an ADC and an TDC. The target segmentation allows clean identification of the stopping kaon and identification of subsequent decay products. A delay of 2 nsec between the incoming kaon time and the decay product time allows for the elimination of beam related backgrounds.

The decay products are measured in a cylindrical drift chamber of an inner radius of 11 cm and an outer radius of 44 cm,and a length of 45 cm. The 1 Tesla solenoidal magnetic field allows for a 2% measurement of the particle momentum in the region around 200 Mev/c.

A 40 cm thick scintillator stack stops the decay particles and allows the measurement of both range and energy of the particle. Total energy measurement will include the correction due to energy loss in the target,and is expected to have a σ of 2% at 100 Mev. The range resolution allows for a better than 10^{-3} π/μ separation at the same momentum,and better than 10^{-4} rejection of $K^+ \mapsto \mu^+\nu$ background. The scintillator counter signals will be viewed by 500 Mhz 8 bit transient digitizers which will allow for a π/μ due to the decay sequence $\pi \mapsto \mu \mapsto e$ of about 10^{-4}, with the limitation due to unassociated background hits of 4 Mev energy within 85 nsec of the stopping pion time.

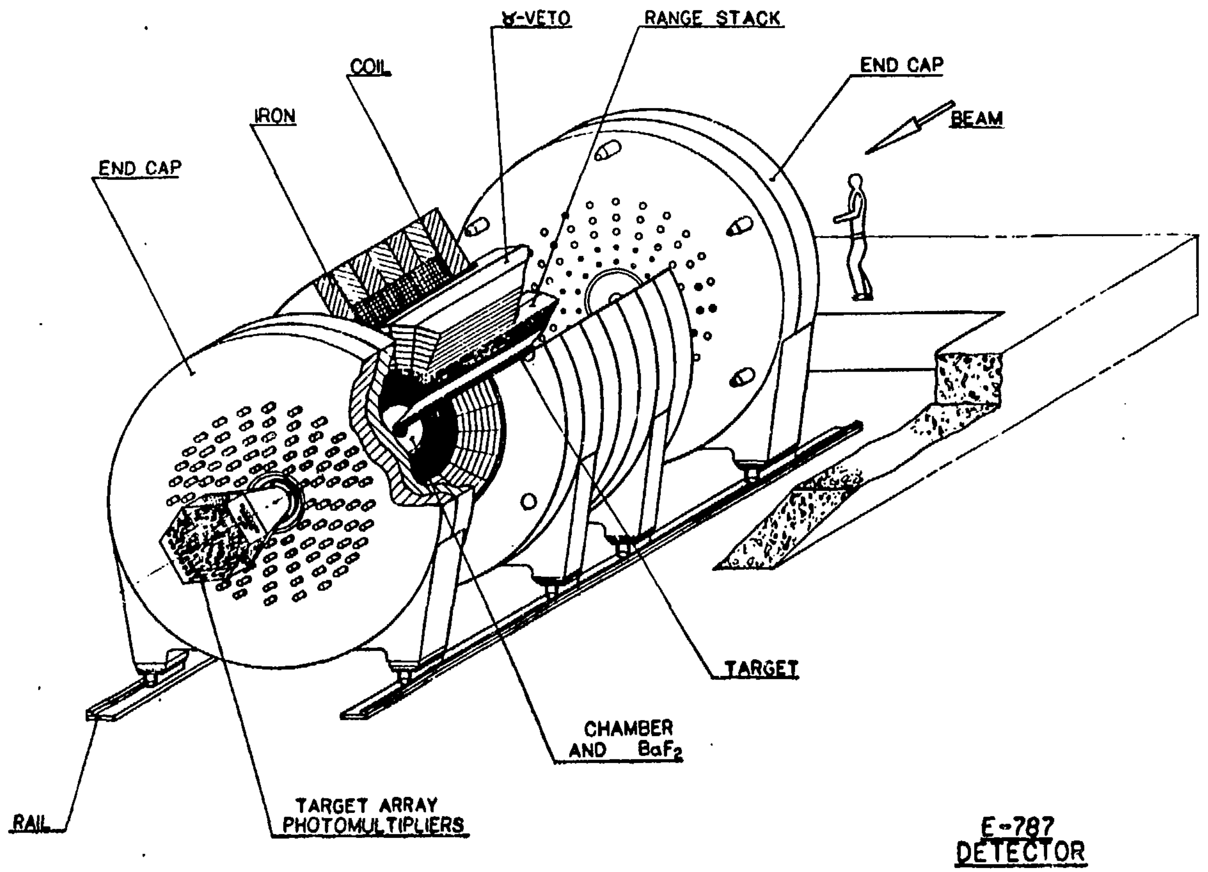
γ-VETO
RANGE STACK
COIL
IRON
END CAP
END CAP
BEAM
TARGET
CHAMBER AND BaF_2
RAIL
TARGET ARRAY PHOTOMULTIPLIERS
E-787 DETECTOR

Figure 4.

The entire detector is placed inside a hermetically sealed photon veto capable of rejecting photons of energy as low as 10 Mev to a level close to .1% and high energy photons to a level close to 10^{-5}. The total rejection of π^0 from $K^+ \mapsto \pi^+\pi^0$ is estimated to be close to 10^{-6}. The barrel photon veto is composed of Pb-scintillator stack of 1mm lead and 5 mm scintillator sheets. The two end plate photon vetoes will be made of BaF_2 viewed by TMAE readout chambers to capture the fast (1 nsec) component of light. BaF_2 is prefered becasue it is both fully active ,thus able to detect very low energy photons, and of its subnanosecond component of light,thus making it possible to work in the noisy beam region.

The entire detector is placed inside a copper coil of 3 meters diameter and capable of supplying a 1 Tesla field, using almost 1 Mw of power. There is also an iron yoke for field return and photomultiplier shielding.

ACCEPTANCE

The total acceptance of the detector for the decay mode $K^+ \mapsto \pi^+\nu\overline{\nu}$ is 2×10^{-2} ,which is the product of
(1) .5 geometrical acceptance.
(2) .2 acceptace of the decays with the pion above the momentum of 205 Mev/c.
(3) .4 which is the fraction of pions not interacting in the range stack.
(4) .6 which is due to various timing cuts on the kaon decay time and the decay times of the pion and muon in $\pi \mapsto \mu \mapsto e$.
(5) .9 which is the efficiency of triggers and other cuts.

Our acceptance represents an order of magnitude improvement over that of Asano et al. Coupled with two orders of magnitude improvement in stopping kaon rate, we expect a three orders of magnitude improvement in the total sensitivity. We intend to run for 2500 hours (six month at present AGS efficiency) with about 3×10^5 stopping kaons, for a total of 10^{12} total stopping kaons.

BACKGROUND REJECTION

Our acceptance for all background modes is well below 10^{-11}. Rather than bore the audience wiht a long list of acceptances,I will mention only two of the more prominent decay modes $K^+ \mapsto \mu^+\nu$,and $K^+ \mapsto \pi^+\pi^0$.

The acceptance for $K^+ \mapsto \mu^+\nu$ is 7×10^{-12} which is the product of the following
(1) .64 branching ratio.
(2) .5 total geometrical acceptance.
(3) .9 total trigger and other acceptances
(4) 10^{-4} due to range suppression.
(5) 10^{-4} due to $\pi \mapsto \mu \mapsto e$ decay chain observation.
(6) .05 due to momentum suppression.
(7) .05 due to energy suppression.

The acceptance for $K^+ \mapsto \pi^+\pi^0$ is 5×10^{-11} which is the product of the

following
(1) .21 branching ratio.
(2) .1 total acceptance (geometrical and otherwise). Note that this is a factor of 5 higher than the acceptance of the pions from $K^+ \mapsto \pi^+\nu\bar{\nu}$ due to the .2 phase space cut on $K^+ \mapsto \pi^+\nu\bar{\nu}$ and also is a factor of 2 less than that for muons from $K^+ \mapsto \mu^+\nu$ due to interactions in the range stack.
(3) 10^{-6} photon veto rejection of neutral pions.
(4) .05 due to momentum suppression.
(5) .05 due to energy suppression.

Other backgrounds can be estimated to have similar rejections. At our inital projected sensitivity we expect to see 2.3 $K^+ \mapsto \pi^+\nu\bar{\nu}$ events (if the branching ratio is 2×10^{-10}) and less than one background event. Further improvements will have to come through improvements of the barrel photon veto through the addition of BaF_2 fully active photon detectors.

SCHEDULE

We expect to take test data in late spring 1986 and physics data with a fully debugged detector by late 1986. Physics results will be forthcoming in 1987.

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