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M. Atiya[2], E. Blackmore[10], G. Bock[3], D. Bryman[12], M. Cooper[5], H. Gordon[2], L. Littenberg[2], W. Louis[5], H. Lubatti[13], K. McFarlane[9], K. Nishikawa[11], J. Ritchie[8], L. Roberts[1], T. Shinkawa[4], M. Sivertz[9], A. J. S. Smith[6], G. Thomson[7], R. Tschirhart[6], T. Yamanaka[3]

1) Boston University, Boston, Massachusetts 02215
2) Brookhaven National Laboratory, Upton, New York 11973
3) Fermi National Accelerator Laboratory, Batavia, Illinois 60510
4) KEK, Ibaraki-ken, Japan 300-32
5) Los Alamos National Laboratory, Los Alamos, New Mexico 87544
6) Princeton University, Princeton,. New Jersey 08540
7) Rutgers University, New Brunswick, New Jersey 08903
8) Stanford University, Stanford, California 94305
9) Temple University, Philadelphia, Pennsylvania 19122
10) TRIUMF, Vancouver, British Columbia, Canada V 6T 1W5
11) University of Tokyo, Tokyo, Japan
12) University of Victoria, Victoria, British Columbia, Canada V 8W 243
13) University of Washington, Seattle, Washington 98195

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KAON PHYSICS IN THE 1990'S: RARE DECAYS AND CP VIOLATION*

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Boston University, Brookhaven National Laboratory, Fermilab, KEK, Los Alamos National Laboratory, Princeton University, Rutgers University, Stanford University, Temple University, TRIUMF, University of Tokyo, University of Victoria, University of Washington

ABSTRACT

The objective of this group was to assess the opportunities for experiments on the K system over the next few years. This necessitated evaluating the impact of recent experimental and theoretical activity on the motivation for this work, adducing the technical lessons of the experiments, projecting the experimental techniques toward future efforts, and reviewing the facilities at which future experiments might be carried out. By and large we tried to indicate the general directions in which we feel future efforts will be most productive. More detailed attention is given to certain cases which seem to us particularly promising.

MOTIVATION

Although studies of the K system have probably contributed as much as any to the Standard Model, the primary motivation to the latest round of experiments has been the prospect of going beyond the Model. There are a number of experimentally tractable K decays whose observation would unambiguously signal the existence of new physics. There are also several less exotic modes whose Standard Model contributions are orders of magnitude below the current experimental limits. If these were seen at a level clearly higher than the Standard Model prediction, they too would decisively signal new physics. What is more, almost all of the theoretical attempts to extend or replace the Standard Model predict or enhance these decays at some level. For example, one approach that was quite popular in the period during which the current round of experiments was proposed was that of extended Technicolor which both removes the need for spontaneous symmetry breaking and explains the fermion mass-scale. Technicolor models predicted that lepton flavor-violating decays such as $K^0_L \rightarrow \mu e$ would occur at levels $\geq 10^{-9}$. A crude idea of the scale being probed by experiments sensitive to this particular decay is given by the relationship $BR/10^{-8} \sim (20\ TeV/M_{heavy})^{1/4}$ (assuming that all couplings are equal to g). Since BR sensitivities down to 10^{-11} are possible from the current round of experiments, mass scales of > 100 TeV can be probed.

In the case of CP-violation, the motivation was somewhat different. It was realized in the late 70's that the Standard Model with three generations implied CP-violating phenomena that are not consistent with the previously all-explaining but intellectually unsatisfying superweak model. Although experiments with the potential to demonstrate these effects looked very difficult, the prospect of finally making progress on the long-standing mystery of CP-violation tempted a number of groups into action. Most of the efforts focussed on $K \to 2\pi$ decay.

Recently the motivation in both areas has undergone significant evolution. The lepton flavor-violation experiments have soaked up the "easy" orders of magnitude or sensitivity and shot down the original Technicolor target. Theorists, never at a loss, have released Technicolor from its shackle to the experiments. At the moment there does not seem to be a conspicuous theoretical target for lepton-flavor violation, although most new models continue to predict it in a generic fashion. Since the mass-scale probed goes only as the 1/4 power of the branching ratio sensitivity, considerable experimental advances are required if significant progress is to be made. Recent experimental experience suggests that beyond a BR sensitivity of 10^{-12} such advances will require new techniques. This may make such experiments relatively less attractive than some of the other possibilities discussed here. Of course, if theorists come up with a well-motivated, specific target not too far beyond the current limit this all changes. Moreover, it should always be kept in mind that a positive result from the current round of experiments is quite possible and would drastically change the context for this sort of work.

The motivation for the suppressed decay modes has also undergone significant evolution since the current round of experiments was proposed. For example, the discovery of the long b-quark lifetime and of large $b\text{-}\bar{b}$ mixing have permitted predictions of $K^+ \to \pi^+ \nu\bar{\nu}$ with less uncertainty than was previously possible. This allows a cleaner interpretation of any anomalously large result of this branching ratio. In addition the list of exotic candidates for the X in $K^+ \to \pi^+ X$ continues to grow as theorists exercise their imagination. The case of $K^0_L \to \pi^0 ee$ which attracted such attention in our subgroup is more complicated. Once again, significant improvements were made in our knowledge of the short distance contribution to this decay, but if anything, the situation regarding the long distance contribution has recently become more confusing than ever. We can still be confident that a branching ratio much larger than 10^{-10} betokens new physics, so that a window of at least a factor 100 still exists. As the various windows are closed by current and near-future experiments, the interest in these decays evolves from new physics jackpot to Standard Model study. One can still search for new physics but now one has to do it by making detailed comparisons with Standard Model prediction, rather than by sudden dramatic discovery. The particular nature of the interest in these decays will be strongly influenced by the outcome of the present round of CP-violation experiments. If the NA31 result is not confirmed, and the Standard Model explanation of CP-violation remains problematical, modes such as $K^0_L \to \pi^0 ee$ wherein large direct CP-violating effects are predicted will be of forefront interest. If the NA31 results is confirmed then $K^0_L \to \pi^0 ee$ and its sister modes will be viewed more symmetrically with $K^+ \to \pi^+ \nu\bar{\nu}$ as arenas for determining Standard Model parameters such as KM angles. These decays have the virtue with respect to $K \to 2\pi$, that there is no unknown hadronic matrix element to be calculated before the KM parameters can be meaningfully constrained.

LEPTON FLAVOR VIOLATION SEARCH

There have been four recent/on-going LFV searches, three searching for $K^0_L \to \mu e$ (AGS E780 and E791, and KEK E137), and one seeking $K^+ \to \pi^+ \mu^+ e^-$ (AGS E777). The most sensitive of each category now has data on tape sufficient to reach sensitivities of ~ 2x 10^{-10}. These decays are kinematically very well-constrained and so far the experiments do not appear to be background limited. In fact the experimenters are reasonably confident that this will remain true to at least the 10^{-11} level. Difficulties are more serious in the area of trigger rates and reconstruction efficiency. These experiments have had to deal with chamber singles in the region from several MHz to several tens of MHz. Counter plane singles over 10 MHz were also encountered. E780 and E777 ran at or near rate limits. E137 and especially E791 could have run somewhat faster. In E777 eliminating subsidiary triggers and other minor improvements would allow a factor of 2 or so in rate-taking capability, and an improved beam could reduce the rates/incident K^+ by a factor of ten or twenty. This would allow a measurement at the 10^{-11} level to be made. The rates observed in E791, although high in an absolute sense, are within a factor of 2 of being totally attributable to K decays. The experimenters are proposing to run in conditions which will increase the instantaneous flux of useful K^0_L, and therefore, most probably the instantaneous rates in general, by a factor of ~6. With improvements in running efficiency, and increased running time, this would allow them to get to <~3x 10^{-11} sensitivity in the next running period. The flux available to go beyond 10^{-11} will be available at BNL when the AGS Booster comes on line (~1991). At this point, hodoscope plane rates will likely be in the neighborhood of 200 MHz. If such rates could be handled, and modest improvements in background rejection made, a Stretcher + increased running/year would allow the sensitivity to be further improved by a factor ~5 to the near 10^{-12} level. For couplings equal to the electroweak, this B.R. corresponds to a mass scale of ~200 TeV, comfortably above what can be directly accessed by the SSC. Progress beyond this point may require a new approach. For example, rejecting the random background due to coincident K_{e3} and $K_{\mu 3}$ decay will require vetoing in an environment approaching the Ghz level. Further discussion of the problems of extrapolating this experiment is given in the accompanying paper by McFarlane and Cooper and in the Los Alamos and TRIUMF K Factory proposals.

$K^+ \to \pi^+ \nu\bar{\nu}$

We next consider $K^+ \to \pi^+ \nu\bar{\nu}$. This mode, or rather this topology (since the ν and ν can be replaced by any undetectable light objects) is a lightening rod for new physics of various sorts.[1] The present BR upper limit[2] of 1.4×10^{-7} is at least two orders of magnitude above the Standard Model prediction for this process (currently[3] 1-8 x 10^{-10}). This window for new physics is expected to be completely exploited by the one currently running experiment of this type, AGS E787[4] In the absence of new non-Standard physics, this process can be calculated with relatively little uncertainty in terms of the KM angles and top quark mass (estimates by the theorists present at Snowmass of this uncertainty ranges from 10-35%). Thus, if nothing new is found, the motivation for future experiments of this type will depend on our state of knowledge of the Standard Model parameters. The constraints on the KM parameters which such a measurement can yield then compare favorably with those obtainable from sources such as $B\bar{B}$ mixing, exclusive B decay, etc. To be useful in this context, depending on the actual value of the BR, one would need sensitivity at the one to few 10^{-11} level.

This is no mean task, however, since compared to the other decay modes we are considering, $K^+ \to \pi^+ \nu\bar{\nu}$ has a very poor signature. There is no kinematic constraint, so that one is thrown back on particle identification and vetoing. Fortunately, known sources of π^+'s emerging from K^+ decay are limited to momenta below 205 MeV/c (the recoil momentum from $K^+ \to \pi^+\pi^0$). The signature is then such a π^+ unaccompanied by any other particle. The necessity for excellent vetoing and particle i.d. push one towards a stopping K^+ geometry. At low momenta relatively intense and pure K^+ beams are obtainable, and the stopping geometry facilitates both high vetoing efficiency and high geometrical acceptance. Fig.1 shows the E787 apparatus. This detector features nearly hermetic gamma and charged particle vetoing and ~50% geometrical efficiency.

Since E787 is somewhat behind the other BNL experiments, having just ended its first real data run in May, extrapolation from its experiences is correspondingly less certain. E787 took the equivalent of about ten days worth of data, nominally enough to reach a few x 10^{-8} sensitivity if there are no problems with background. Raising the beam rate to the maximum allowed (~7 x 10^{12} pot), reducing various inefficiencies, and making slight improvements in triggering, this detector should be able to reach a sensitivity below 10^{-9} in a year or two. Since the yield of usable stopping K's has proved to be about half of what was originally anticipated (~ 150K/5 x 10^{12} pot instead of 300K), a beam upgrade will be needed to reach the experimental goal of 2×10^{-10} sensitivity. If the acceptance of the LESB-1 (the beam used by E787) were increased to equal that of the LESB-2, the K^+ flux would be expected to triple. If some of this increase could be traded in for improved beam purity (there are currently $2\pi+\mu/K$) one could hope to find an optimum wherein the K^+ is doubled, but the total beam rate only rises by 50%. Since the singles rates in E787 seem to be proportional to the number of π's and K's incident on the degrader (a BeO cylinder used to slow the K^+'s from ~800 MeV/c to ~300 MeV/c so that they can be stopped in a scintillator target), the corresponding increase in single rates could probably be accommodated with minor improvements in the electronics.

How could the sensitivity be improved beyond ~10^{-10} in the future at BNL or another facility? As in almost every case, the simplest improvement is just to run more weeks/year. At present the BNL AGS is underutilized in this respect by at least a factor 2. Second there is a potential improvement in the duty factor by at least a factor 2.5 (say at BNL via a stretcher) which like the utilization factor would not put additional demands on the instantaneous rate capability of the detector. One could again be in the same position vis a vis instantaneous rate, with a total improvement in sensitivity of a factor ~5. This would bring the statistical sensitivity to a few x 10^{-11} level, whereas the background rejection of E787 was designed to be sufficient for 2×10^{-10}. It is not yet clear whether much improved background rejection could be attained without a major upgrade to the detector. The observed π^0 rejection capability has proved to be $< 5\times10^{-6}$ as opposed to the 10^{-5} assumed in the proposal background estimates. The effectiveness of other background rejection modalities (mainly muon rejection through comparisons of range, momentum, and energy, and through following the $\pi\mu e$ decay chain with transient digitizers[5]) is still under study.

To get beyond the few x 10^{-11} level, one is forced to take an increase in instantaneous rates and a detector superior to that of E787 would certainly be necessary. At a Boosted and Stretched AGS, the K flux required to get to $\sim10^{-11}$ would be available, at instantaneous rates ~ six times higher than those which are now faced. Fluxes sufficient to get to $\sim10^{-12}$ would be available at K factories such as proposed by TRIUMF and LAMPF.

Reaching the level of 10^{-12} would entail the challenge of dealing with instantaneous rates 50 times higher than in the current experiment. This is very serious for an experiment which needs to veto on 1 MeV visible photon energy. At the moment (say for 150 Kstops/pulse), this entails ~10% dead time for a $\pm$ 10 nsec veto gate. Clearly, one cannot turn up the wick beyond a factor 10 without improving the timing. This is not as easy as it might seem since one needs $\sim< 10^{-3}$ inefficiency in rejection of high energy photons. To avoid compromising this rejection, the veto gate must be $> \pm\ 3.5\sigma$ in extent, and if there are non-Gaussian tails on the time distributions it must be longer still! Putting transient digitizers on all veto channels could help here.

High rates also imperil the ability of the detector to identify pions through their decay chains since a muon can be "promoted" to a pion via an accidental which deposits ~3 MeV within a few τ_{π^+} of the muon's stop. This method of muon rejection must not only be maintained in the face of increased rates but actually must be upgraded in order to keep pace with the improved sensitivity being sought. The problem can be addressed via increased segmentation. E787 has ~200 pion stopping counters in the region of primary sensitivity. This could be increased by an order of magnitude in a future experiment, if funds were available. At present the effective segmentation of the detector is increased by a factor ~5 since the range stack elements are read out on both ends, allowing end to end comparisons of timing and PH to identify non-local accidentals. This factor could be enlarged if light collection, pmts, cables, and electronics were upgraded. The second $\pi\mu$ discrimination technique, comparison of p-T-R (momentum-kinetic energy-range), would also be improved by greater segmentation of the range counters (better determination of R) as well as by enhanced light collection (better determination of T). This technique could be further improved by increasing the magnetic field imposed on the drift chamber from the 1 T of E787 to the perhaps 2.5 T a superconducting magnet could provide. The momentum resolution, currently ~2.4% at 200 MeV/c, could be improved to <-1%, to great benefit. The pion trajectories, currently mainly radial, would become largely azimuthal, allowing a thinner range array and a smaller apparatus overall. The π^0 rejection could be improved, perhaps as much as an order of magnitude by replacing the current lead-scintillator sandwich shower counters by a fast scintillating crystal such as BaF_2 or pure CsI. Finally, many potential backgrounds arise because the stopping K^+ and the outgoing π^+ must pass through the material of the stopping target. The imaging target of E787 is constructed of ~400 bundles of 6 2mm scintillating fibers epoxied into triangular clusters. Given sufficient funds, a demultiplexed version of this target with 2mm (or even finer) granularity could readily be constructed. Future progress in scintillating fiber fabrication techniques should allow targets with negligible dead material (the E787 target has 25% dead material). In sum, perhaps more than in the case of any of the other popular rare decays, techniques for improving the detection of $K^+ \to \pi^+ \nu\bar{\nu}$ lie within the reach current or near-future technology.

CP VIOLATION

The study of CP violation can still only be done within the K system. Perhaps the next decade of experiments with B mesons will yield new information on this phenomenon but for much of the next decade we will have to make whatever advances we can through more precision experiments within the Kaon system. Here we summarize the exciting situation which exists today in the two pion decay and the possible directions experiments will take over the next several years. Studies making use of initially pure K^0 and $\bar{K}^0$ will soon be underway. Also CP violation in the three pion decay will also likely be seen in the next decade. A discussion of the (rare) and CP violating decay $K_L \to \pi^0 e^+ e^-$ is given in the following section.

CP Violation in Two Pion Decay

The CERN and Fermilab experiments study CP violation through observations of the decays of neutral K mesons to two pions. More specifically these experiments address the issue of whether or not CP violation is confined to $\Delta S = 2$ interactions, as the Superweak Model predicts.

Recall that the physical neutral kaon states ($K_{L,S}$) are almost, but not quite, the CP eigenstates (K_1[CP = +1], K_2[CP = -1]) . Specifically the K_L is: $K_L \sim K_2 + \varepsilon K_1$, where $|\varepsilon| \approx 0.002$. The CP mixture of the K^0 states results from a small T violation in the $\Delta S = 2$ process $K^0 \leftrightarrow \bar{K}^0$ allowed by second order weak interactions. Until quite recently all observations of CP violation could be accounted for by the single parameter ε describing this imbalance. This is the prediction of the superweak model. There is also a parameter describing $\Delta S = 1$, or "milliweak" CP violation, ε', which is predicted to be small but non-zero in many models of the electroweak interactions. The usual definitions :

$$\eta_{+-} = \mathrm{Amp}(K_L \to \pi^+\pi^-) \;/\; \mathrm{Amp}(K_S \to \pi^+\pi^-),$$

$$\eta_{00} = \mathrm{Amp}(K_L \to \pi^0\pi^0) \;/\; \mathrm{Amp}(K_S \to \pi^0\pi^0),$$

expressed in terms of ε and ε' are:

$$\eta_{+-} = \varepsilon + \varepsilon', \quad \text{and} \quad \eta_{00} = \varepsilon - 2\varepsilon'$$

Since the phases of ε and ε' are nearly equal, a test of the equality of $|\eta_{+-}| = |\eta_{00}| = \varepsilon$ is a test for $\Delta S = 1$ CP violation and we can write:

$$\varepsilon'/\varepsilon = 1/6\ (1 - |\eta_{00}/\eta_{+-}|^2)$$

This is the essential strategy of both the CERN and Fermilab efforts.

A number of calculations predict $\varepsilon'/\varepsilon > +0.002$, so one is looking for deviations from unity of the quantity $|\eta_{00}/\eta_{+-}|^2$ of less than about one percent--statistics and systematics are crucial.

The most tantalizing result in over 20 years of CP violation studies comes from NA31 with the first report of direct CP violation at the three standard deviation level and comfortably within standard model ranges. The group's result is $\varepsilon'/\varepsilon = 0.0033 +/-0.0011$, where the statistical and sytematic contribution to the error are nearly equal.[6] This result awaits further confirmation from within that group and from the Fermilab experiment E731. NA31 has recently finished a run and has plans to continue. Their result is based on approximately 100K observed $K_L \rightarrow 2\pi^0$ events. E731 has collected 300K of these events and they are under analysis at this time. An early result from that experiment gave $\varepsilon'/\varepsilon = 0.0032 +/-0.0028$(statistical) and +/-0.0012 (sytematic).[7]

Three things can happen: If ε'/ε is nearly 0.003 that will be confirmed to roughly 5 standard deviations with the data in hand at E731 and NA31 and the case is closed--at least, that is, until the theoreticians are able to calculate the hadronic matrix elements needed to describe the process. On the other hand if the results converge at a value less than about 0.002 or if NA31 and E731 disagree we are likely to see new initiatives.

The experiments use quite different techniques and therefore must deal with different sytematics, as well as some commom ones. Both use double ratios to minimize systematic effects, but briefly, the differences are (for more details see Reference 6 and 7):

NA31 uses a single beam, detects charged and neutral decays simultaneously and K_S and K_L in separate runs. The decay region is 50 meters long; K_S are produced at different locations within this region by a moveable target train, approximating a "flat " distributuion in decay vertex postion to lessen acceptance effects. The heart of the detector is a liquid argon calorimeter used for both charged and neutral events and PWC's and a TRD for the charged mode. The resolution in the neutral mode is quite good , in the charged rather poor (there is no magnet) requiring stringent offline cuts. Because the K_S and K_L are detected at different times the detector must be stable and well monitored.

E731 uses two incident K_L beams, one with a regenerator to make K_S and detects both K_S and K_L decays simultaneously. The detector uses a drift chamber magnetic spectrometer and a lead glass calorimeter. A subset of the E731 data was taken with all four modes--charged, neutral, long and short collected simultaneously. Rate effects (accidentals) and spectrometer gain drifts with time are closely monitored but largely cancel because of the simulataneous triggering on K_S and K_L decays. Scattering of kaons in the regenerator from one beam to another and backgrounds (already below 0.5%) in the $K_L \rightarrow 2\pi^0$ will probably limit the ultimate sensitivity of this spectrometer to the statistics currently in hand.

If ε'/ε is larger than 0.002 we will know that within 2 years. To push our understanding below say .001 will require new spectrometers and probably new beamlines. A next generation E731 detector would require a higher resolution electromagnetic detector to further improve background levels and allow an analysis of the data in individual momentum and proper time bins further reducing the systematic effects of acceptance corrections.

Both the NA31 and the E731 (E773) groups have taken or will take data to measure the phase difference $\Delta\Phi = \mathrm{Arg}(\eta_{+-}) - \mathrm{Arg}(\eta_{00})$ which currently is inconsistent with CPT by two standard deviations. NA31 is analyzing their data now and E773 is scheduled for running in 1990. We make no comments on the effects of a confirmed violation of CPT.[8)]

CP Violation in Three Pion Decay

Experimenters from Fermilab E621 are analyzing data from an experiment designed to measure the paramater η_{+-0} which in analogy to the two pion case is defined as:

$$\eta_{+-0} = \mathrm{Amp}(K_S \to \pi^+\pi^-\pi^0) \; / \; \mathrm{Amp}(K_L \to \pi^+\pi^-\pi^0) .$$

By collecting three pion decays in a V spectrometer close to a kaon production target, the experimenters look for a small interference between the K_L and K_S decays as a signal of CP violation in the $\pi^+\pi^-\pi^0$ decay mode. Acceptance corrections are crucial for the expected value of $\eta_{+-0} \cong \eta_{+-} \cong 0.002$, and the acceptance for K_S decays is monitored by simultaneously collecting the more copious CP conserving $K_L \to \pi^+\pi^-\pi^0$ decays from a second target located upstream of the K_S target. Based on approximately 100,000 observed three pion decays from a run in 1984 the group reports preliminary values of $|\eta_{+-0}| = 0.022 \pm 0.026$ and $\Phi_{+-0} = -39^\circ \pm 80^\circ$. [9)] This is approximately one order of magnitude of improved sensitivity over previous published results. It is also one order of magnitude away from the expected signal. In hand and under analysis are approximately 3 million events from the 1985 run which should give a statistical improvement of one order of magnitude. The proponents have submitted a letter of intent to build a new beam and spectrometer to use a similar technique with factors of improvement of 2-3 in each of several areas: solid angle, decay volume increases, incident proton beam intensity, and spectrometer optimization, to push the experiment to a precision of of 0.0005 or roughly 20% of the expected value of $|\eta_{+-0}|$.

CP Violation Studies from Pure K^0 States

Starting in the Spring of 1989 the CP LEAR[10)] collaboration at CERN will begin a study of what is hoped to ultimately be 1E13 proton anti proton annhilations at rest yielding initial states of 10^{10} K^0 and K^0 respectively. Two and three pion decays as well as semileptonic decays will be collected in a 4 pi detector with full particle identification for complete reconstruction of primary and secondary vertices. CP violation appears as a rate difference between the process $K^0 \to f$ and $\bar{K}^0 \to (CP)f$. Expected precisions on the parameter ε'/ε, measurements is comparable to those of E731 and NA31 but with yet different systematics--a help if the situation remains cloudy for a few years. Additionally the measurement programs include η_{+-0}

and η_{000} with precisions of 10^{-3} or less on the magnitudes and about 1^0 on the phase differences. Detection of low energy photons from K and pion decays decays will be particularly challenging for at rest K decays.

Muon Polarization in $K\mu3$ and $K\to2\mu$ Decay

While not discussed in detail during this workshop, no discussion of CP violation studies would be complete without mention of searches for T or CP violation which could be revealed in measurements of the muon polarization in either $K\mu3$ or $K\to2\mu$ decay. In the case of searches for the transverse polarization of the muon from $K\mu3$ decay the most sensitive search to date probed the few X 10^{-3} level. Further reductions in both statistical and systematic errors could be pursued at either BNL or a K Factory. The observation of longitudinal polarization of the muons in $K\to2\mu$ would likewise signal T violation. Polarizations of order 10^{-4} to 10^{-3} are predicted in the standard model and some extensions to it. Further improvements in the $K\mu3$ search seem quite possible and polarization in $K\to2\mu$ may be in the provence of upgraded BNL experiments or K Factories.[11)]

$K^0_L \to \pi^0 ll$

Introduction

Much attention at this workshop has been focussed on the process $K_L \to \pi^0 e^+ e^-$ [12)]. Like the LFV processes discussed above, this process is graced with an excellent signature. At the levels for which it has been searched so far (~ few 10^{-8}), it has proved to be relatively background free. As in the case of $K^+ \to \pi^+ \nu\bar{\nu}$, there is a Standard Model prediction[13)] two or three orders of magnitude below the current upper limit on the branching ratio[14)]. There are many possible varieties of new physics that could fall into this window[15)]. One of particular interest is the production of a new scaler, S, in $K^0_L \to \pi^0 + S$, followed by $S \to e^+e^-$ [16,17)].

Since $K^0_L \to \pi^0 e^+ e^-$ is CP-violating in lowest order, if the Standard Model region can be reached, interesting CP-physics will become accessible. This is particularly true for two reasons. First the direct CP-violating amplitude is predicted to be of about the same size as the indirect CP-violating piece. This is to be contrasted to the case of $K^0 \to 2\pi$, wherein this ratio is predicted to be more like 1/300. Second, unlike the 2π case the prediction does not depend on a hard-to-calculate hadronic matrix element. Unfortunately, as discussed by the theorists at Snowmass, there is also a CP-conserving amplitude mediated by two photons. The size of this contribution is presently controversial, but it may be comparable to the CP-violating pieces[18-22)]. In what follows, we sketch out a method of extracting the CP-violating information from this decay even in the case where the CP-conserving amplitude is relatively large. Of course, if this amplitude is very small, as some theorists maintain, it will be much easier to pull out the CP information.

Disentangling the amplitudes

At fixed target proton accelerators, p-nucleus collisions create a K beam which is mainly K^0. For the purposes of exposing the essential physics, we will ignore this complication and assume we are dealing with a pure K^0 beam. Including the $\bar{K}^0$ component is straightforward but tedious and does not change the results in a qualitative manner. We take

$$|K^0> \sim 1/\sqrt{2}\ (e^{-im_L\tau}|K_L> + e^{-im_S\tau}|K_S>)$$

$$\sim 1/\sqrt{2}\ (e^{-im_L\tau}[|K_2> + \varepsilon|K_1>] + e^{-im_S\tau}[|K_1> + \varepsilon|K_2>])$$

and

$$<\pi^0 ee|T|K^0> = 1/\sqrt{2}\ [e^{-im_L\tau}(A_2 + \varepsilon A_1) + e^{-im_S\tau}(A_1 + \varepsilon A_2)]$$

where $A_{1,2} = <\pi^0 ee|T|K_{1,2}>$.

Noting that A_2 (CP-violating or higher order CP-conserving) is small compared with A_1 (CP-conserving in lowest order) and that $|\varepsilon| \sim .0023$, we discard the εA_2 term.

Then, $$|<\pi^0 ee|T|K^0>|^2 = 1/2\ [|A_2 + \varepsilon A_1|^2 e^{-\Gamma_L\tau} + |A_1|^2 e^{-\Gamma_S\tau} + 2\mathrm{Re}\ \{(A_1{}^* A_2 + \varepsilon|A_1|^2)\ e^{-i(M_L-M_S)\tau}\}]$$

Before proceeding, we need some more definitions and simplifying assumptions. First we take A_1 to be real, which is in general not quite true. A_1 and A_2 are functions of kinematic variables

$$W = 2M^2 + 2M^2 - 2M_K\ (E_{e-} + E_{e+})\ \text{and}$$

$$\Delta = 2M_K\ (E_{e-} - E_{e+}).$$

For future reference, note that $A_1{}^2$ is an even function of W and Δ[18]. We define the real constant η such that the direct CP-violating amplitude for $K_2{}^0 \to \pi^0 ee$ is given by ih $|\varepsilon|A_1$. The CP-conserving 2γ-mediated amplitude for $K_2{}^0 \to \pi^0 ee|_{CP\ odd}$, we call $A_{2\gamma}$. We then have

$$A_2 = A_{2\gamma} + i\eta|\varepsilon|A_1.$$

Noting that $\varepsilon \sim |\varepsilon|e^{i\pi/4}$, and setting $\delta = m_L - m_S$ we get
$R(\Delta,W,\tau) = |<\pi^0 ee|T|K^0>|^2$

$$= 1/2\ \{[|A_{2\gamma}|^2 + |\varepsilon|^2\ A_1(1 + \eta^2 + \sqrt{2}\eta)$$

$$+ 2|\varepsilon| \; \mathrm{Re}[(i\eta + e^{i\pi/4}) A_{2\gamma}^{*} A_1)] e^{-\Gamma_L \tau} + A^2{}_1 e^{-\Gamma_S \tau}$$

$$+ 2\mathrm{Re}\; [(A_1 A_{2\gamma} + (i\eta|\varepsilon| + \varepsilon) A^2{}_1) \; e^{-i\delta\tau}] e^{-\Gamma\tau}\}.$$

We now examine the three time regions separately, starting with the K_S region in which

$$R_S(\Delta, W, \tau) \sim 1/2 \; A^2{}_1 e^{-\Gamma_S \tau}.$$

If this formula is integrated over the Dalitz plot, we get simply 1/2 $\Gamma(K_1{}^0 \to \pi^0 ee)\; e^{-\Gamma_S \tau}$. Thus, a measurement at early times determines $\Gamma(K_1{}^0 \to \pi^0 e^+ e^-)$.

At times $>> \tau_S$, one gets

$$R(D, W, \tau) = 1/2 \; \{|A_{2\gamma}|^2 + |\varepsilon|^2 \; (1 + \eta^2 + \sqrt{2}\eta) \; A^2{}_1 + 2 \; |\varepsilon|\eta A_{abs} A_1$$

$$+ \sqrt{2} \; |\varepsilon| \; (A_{abs} + A_{disp}) \; A_1\} \; e^{-\Gamma_L \tau}$$

where A_{abs} and A_{disp} are respectively the absorptive and dispersive parts of $A_{2\gamma} = A_{disp} + A_{abs}$.

Note that A_1 is proportional to a function of W times $\bar{u}(k)\not{p}v(k')$. $A_{2\gamma}$ also has a term proportional to $\bar{u}(k)\not{p}v(k')$ as well as one proportional to $\bar{u}(k)v(k')$. The latter term is known to be very small as it is helicity suppressed. The former term may also be small, in which case the analysis of this decay is much simplified, but at the moment the expected size of this term is controversial so that we are not free to ignore it. In the lowest order[20].

$$A_{abs} \quad \alpha \quad \Delta\bar{u}(k)\not{p}v(k')$$

$$A_{disp} \quad \alpha \quad A_{abs} \text{ x a function of W.}$$

The above implies that $A_{abs}{}^2$ and $A_{disp}{}^2$ are each proportional to $\Delta^2 A_1{}^2$ times a function of W (different in each case). We define a_{abs}, a_{disp}, $f_a(W)$ and $f_d(W)$ such that

$$A^2{}_{abs} = |\varepsilon|^2 |f_a(W) \quad a_{abs}|^2 \; A^2{}_1 \Delta^2$$

$$A^2{}_{disp} = |\varepsilon|^2 |f_d(W) \; a_{disp}|^2 \; A^2{}_1 \Delta^2$$

and we find, that in the K_L region,

$$R(\Delta, W, \tau) = 1/2 \; \{|A_{2\gamma}|^2 + |\varepsilon|^2$$

$$A^2{}_1 \; [(1 + \eta^2 + \sqrt{2}\eta) + 2\eta \; a_{abs} \; \Delta f_a(W) + \sqrt{2} \; (a_{disp} f_d(W) + a_{abs} f_a(W))\Delta]\} e^{-\Gamma_L \tau}$$

Note that the terms odd in Δ integrate to 0 over the Dalitz plot so that integrating:

$$R_L(\tau) = 1/2 \; [\Gamma_{2\gamma} + |\varepsilon|^2 \; \Gamma \; (K^0{}_S \to \pi^0 ee) \; (1 + \eta^2 + \sqrt{2}\eta)] \; e^{-\Gamma_L \tau}$$

Thus if $\Gamma_{2\gamma}$ is non-negligible, without other measurements η cannot be extracted, i.e., one cannot just make a measurement in the large τ region and learn anything about the direct CP-violation.

Finally, the interference term is given by

$$R_I(\Delta,W,\tau) = |\varepsilon|\ A^2{}_1\ \{(1/\sqrt{2} + a_{disp}\ \Delta\ f_d(W)\ \cos\delta\tau$$
$$+ (\eta + 1/\sqrt{2}\ + a_{abs}\Delta\ f_a\ (W))\ \sin\delta\tau]\}\ e^{-\bar{\Gamma}\tau}$$

Once again, the terms odd in Δ integrate to 0 over the Dalitz plot:

$$R_I(\tau) = |\varepsilon|\ \Gamma\ (K^0 \to \pi^0 ee)$$
$$\{1/\sqrt{2}\ \cos\delta\tau\ +\ (\eta + 1/\sqrt{2})\ \sin\delta\tau\}\ e^{-\bar{\Gamma}\tau}$$

Note that η can be extracted from the integrated formulae if all three time regions are measured. Assuming that $\Gamma(K_S{}^0 \to \pi^0 e^+ e^-) \sim \Gamma(K^+ \to \pi^+ e^+ e^-)$, and that neither the direct CP-violation nor the 2γ term is orders of magnitude larger than the indirect (ε) term, the K_S and K_L contributions cross at ~10 τ_S. One must be sensitive to times as small as ~$7\tau_S$ in order to get any sort of measurement of $\Gamma(K^0{}_S \to \pi^0 ee)$. The large τ region must be measured well enough to subtract the contribution of the $e^{-\Gamma_L\tau}$ term from that of the interference region. Figure 2 shows the time distribution under various assumptions for the parameters. It's clear that extracting the parameters from this distribution will require reasonably high statistics, not easily achieved for a process with branching ratio ~ 10^{-11}.

To improve the statistical power of the experiment, it is very beneficial to fit the distribution $R(\Delta,W,t)$ without integrating over the Dalitz plot. Sehgal[20] has pointed out the possible large Dalitz plot interference between the CP-violating and CP-conserving contributions to $K_L{}^0 \to \pi^0 e^+ e^-$. Analyzing this interference as a function of time should constitute an efficient method of extracting the critical parameters. For example, in the K_S-K_L interference region, one can subtract symmetric points on the Dalitz plot:

$$R_I(\Delta,W,\tau)\ -\ R_I\ (-\Delta,W,t)\ =\ 2|\varepsilon|\ A^2{}_1\ [a_{disp}\ f_d\ (W)\ \cos\delta t$$
$$+\ a_{abs}\ f_a\ (W)\ \sin\delta t)]\ \Delta\ e^{-\bar{\Gamma}\tau}$$

This allows the separate extraction of the absorption and dispersive part of the 2γ amplitude. Knowing these then allows η to be extracted.

Experimental Considerations

Detailed studies of CP-violation in $K^0{}_L \to \pi^0 e^+ e^-$ could benefit greatly from sensitivities (< 10^{-13}) not available at any operating facility. However, more study is needed before the feasibility of such an experiment event at a new facility can be assumed. There are two areas where reality may intrude: high detector rates and backgrounds. Measurement of this decay will require both calorimetry and tracking. Naive scaling of rates from existing experiments suggests singles rates of order 10 to 100 MHz per channel for a 10^{-13} experiment. The required improvements are large and may necessitate detector breakthroughs. Background studies have been performed for $K_L \to$

$\pi^0 e^+ e^-$ in preparation for experiments at BNL and KEK (and a proposed experiment at Fermilab) with expected sensitivities between 10^{-10} and 10^{-11}. It is believed that backgrounds can be suppressed to the 10^{-11} level or below, although an experimental demonstration of this is 2 to 3 years away. As with rate problems, it is not clear without further study how difficult it will be to suppress the backgrounds to the level required for a kaon factory experiment.

Several sources of $K_L \to \pi^0 e^+ e^-$ backgrounds can be listed:

1. Either of the decays $K_L^0 \to \pi^0\pi^0\pi^0$ or $K_L \to \pi^0\pi^0$ followed by π^0 Dalitz decay or γ conversion, along with the appropriate number of missing γ's to fake the required topology.

2. $K_L \to \pi e \upsilon \gamma$, with the π misidentified as an electron, along with 2γ's from another K_L decay (usually $K_L \to \pi^0\pi^0\pi^0$),

3. $K_L \to \pi e \upsilon \gamma$, with the π misidentified as an electron, along with a γ from another K_L decay,

4. $K_L \to \pi^0 \pi e \upsilon$, with the charged pion misidentified as an electron,

5. $K_L \to \pi^+\pi^-\pi^0$, with double pion misidentification,

6. $K_L \to e^+e^-\gamma$, along with an additional γ from another K_L decay, and

7. $K_L \to \pi^0\pi^0$ followed by $\pi^0 \to e^+e^-$.

Consideration of item (1), those sources involving π^0 Dalitz decay or γ conversion, and of course item (7), lead quickly to the conclusion that events with $m_{ee} < m_{\pi^0}$, where m_{ee} is the invariant mass of the ee pair, must be rejected. The exact cut will depend on experimental details, but in general the low ee mass region presents intractible problems. The cut on the π^0 mass causes roughly 25% loss in acceptance.

A detector capable of rejecting the remaining backgrounds must have the following attributes: (1) large acceptance for observing photons, (2) good energy and position resolution for photons, (3) extremely good discrimination between pions and electrons, and (4) good timing of both charged particles and photons. A tracking system will be required, both to locate the decay vertex and determine electron sign, but the tracking resolution need not be extraordinary, since the errors in reconstruction will generally be dominated by the electromagnetic calorimetry at kaon factory energies (i.e., photon energies of a few GeV).

We have not specified a detector, nor performed calculations of acceptance, sensitivity or background rejection. Meaningful calculations of backgrounds at the 10^{-13} level are not simple. The best strategy for assessing the feasibility of a $K_L \to \pi^0 e^+ e^-$ experiment at a kaon factory appears to be to wait until the presently planned experiments at BNL and KEK accumulate some experience.

Related measurements - $K^0{}_L \to \pi^0 \mu^+ \mu^-$

The closely related process $K^0_L \to \pi^0\mu^+\mu^-$ affords an even larger window for new physics than does $K^0_L \to \pi^0e^+e^-$. The Standard Model expectation is smaller than that of the latter process because of the smaller Q-value. The current upper limit is also significantly higher[23]. Note also, that once the mass of the Higgs allows it, the decay $H \to \mu^+\mu^-$ will completely dominate the e^+e^- channel. The mass dependence of the coupling which is responsible for this may not obtain in the case of non-standard Higgs, but there is some prejudice that the $\mu^+\mu^-$ channel will dominate the e^+e^-.

If the Standard Model level can be reached, the CP physics mentioned above will also be accessible. However, the formalism will be more complicated because of the persistence in the muon case of terms proportional to powers of m_l. This may make the decay somewhat less promising than $K^0 \to \pi^0e^+e^-$ for detailed CP-violation studies, but if the theoretical controversy regarding the size of the two-gamma contribution to $K^0_L \to \pi^0l^+l^-$ has not been resolved, even a crude measurement of BR($K^0_L \to \pi^0\mu^+\mu^-$) could be quite valuable.

The experimental prospects for this decay seem somewhat worse than those for $K^0_L \to \pi^0e^+e^-$, at least at BNL energies. In the electron case, there are many more options for particle identification. In addition, the copious $K^0_L \to \pi^0\pi^+\pi^-$ decay is kinematically much closer to $K^0_L \to \pi^0\mu^+\mu^-$ than to $K^0_L \to \pi^0e^+e^-$. A study of the relative problems of the muon and electron modes at higher energies would be very welcome.

Related Measurements-$K^0_L \to \pi^0\gamma\gamma$

It is emphasized by the theorists at this workshop that a measurement of this branching ratio would help decide among the contending estimates of the CP-conserving contribution $K^0_L \to \pi^0l^+l^-$. It would be necessary to distinguish between predictions which vary by about a factor of two, centered near BR($K^0_L \to \pi^0\gamma\gamma$) = 10^{-6}. A rough measurement of the two-gamma mass spectrum would also be useful. FNAL E731 has the statistical power to make these measurements and is in the process of determining whether its background rejection is adequate. If so, an answer is to be expected in the next few months. If not, it would most likely be possible to make these measurements in a future FNAL experiment.

A new possibility

One of us has pointed out [24] that the decay $K^0_L \to \pi^0\nu\bar{\nu}$ affords a very new interesting opportunity in K decay. This decay has never been actively sought, and the Standard Model prediction is of the order of a few x 10^{-12}, leaving a huge window for new physics. Possibilities include new CP-violating currents and $K^0_L \to \pi^0S$ where S is a new scaler which either escapes undetected or decays into daughters which do so. If the Standard Model level could actually be reached, this decay would be of the utmost importance to the study of CP-violation. It is easy to show [24] that the indirect CP-violation in this decay is expected to be thousands of times smaller than the direct CP-violation. This is to be contrasted with the case of $K^0_L \to \pi^0l^+l^-$ where these contributions are about equal. In addition, there is no large long-distance contribution as in the charged lepton case. As in the charged lepton analog, there is no problematic hadronic matrix element to calculate so that a measurement of this branching ratio would give an unambiguous determination of $s_2s_3s_d$.

We have not seriously taken up the experimental problems of measuring this poor-signature process, but can offer a few remarks. The K^0_L flux necessary for a measurement at the 10^{-12} level would be available at the upgraded facilities discussed below. A guess at the current state of the art in background rejection for such a process is more like 10^{-8}. It is likely that this measurement would benefit from higher energy than is available at BNL or at K factories as now proposed. Although this measurement is extremely difficult, its ratio of interest/-difficulty seems to us to compare favorably to that of making detailed CP-violation studies in B-decay.

FACILITIES FOR KAON EXPERIMENTS

We consider the following types of facilities for future experiments in the Kaon system: the presently operating cadre, the present facilities with upgrades,and completely new facilities. The presently operating facilities are the AGS at BNL, TEVII at FNAL, the KEK proton synchrotron, LEAR and the SPS at CERN. In some cases (e.g., the AGS Booster) upgrades relevant to K physics are already in progress, in others there has been serious discussion of such upgrades. New facilities [25)] at which K physics can be pursued have been proposed or at least discussed by LANL (AHF), TRIUMP (KAON), BNL (AGS II), A European consortium (HEP), KEK (JHF), and INR Moscow.

Presently Operating Facilities

The first question is whether current facilities have been exploited to the fullest possible extent for these experiments. We ignore, for the moment, the question of running time as a fraction of the year. At the BNL AGS, E791 has used a 60 μsr beam at 2.75 degrees to improve the sensitivity to $K^0_L \to \mu e$ to the 3×10^{-10} level. They have proposed a series of improvements which would allow them to improve their sensitivity by a factor of 10 or more. These include running the AGS at the full 28.5 GeV and cycle time of 2.5 sec, improving the targeting efficiency by about 10%, reducing the production angle to 1 degree, and most importantly, increasing the average number of protons on the production target from 3.1 to 8×10^{12} protons. At this point, the beam available will be close to the most intense K^0_L beam deliverable by the AGS that is practical to use for rare decays. This beam will contain about 2×10^8 K's/burst and perhaps 10^{10} neutrons. In principle there are a number of improvements which could bring the number of K's/burst even higher, but these tend to be unacceptable for political or practical reasons. One could deliver about 50% more protons to the production target, but this would eliminate the rest of the AGS program. One could run at 0 degrees, but this would make the n/K^0_L ratio, already marginal at 1 degree, more than twice as bad. One could increase the beam solid angle, but this would probably make it impossible to eliminate the effect of neutron interactions on the experiment. AGS E777 presently uses a 6-GeV/c charged beam containing ~ 2×10^7 K^+/pulse. Less than 5% of the AGS intensity is needed to produce this beam. The proponents of E777 envision a beam consuming an order of magnitude more protons to produce > 5 times more K^+ in a cleaner environment. This would allow an experiment at the 10^{-11} level, and probably represents the maximum practical K^+ flux usable in a rare decay experiment at the AGS. AGS E787 sits at the end of the LESB-1 which produces about 200K stopping $K^+/7 \times 10^{12}$ protons. This is not the most intense low energy separated beam at BNL, however. The LESB-2 produces about 3 times more K^+, albeit at a slightly lower energy. Thus one could probably get ~ 500K K^+ stops/pulse without beggaring the rest of the AGS program. One can summarize the situation at the AGS by saying that the exploitation of the machine thus far has been between 1/3 and 1/10 of maximum, and it is probably only a couple of years from being fully exploited (note however, that the maximum protons on target cannot be supplied to all the experiments at once).

At present the KEK 12 GeV PS accelerates up to 4×10^{12} protons per pulse at a repetition rate of 2.5 secs/pulse including a 0.5 sec flat-top. About 1/2 of the accelerated protons are available at the secondary beam lines after splitting the extracted primary beam. E137, a search for $K^0_L \to \mu e$ decay, is currently using $0.8\text{-}1.3 \times 10^{12}$ protons on the target. Simultaneously one or two groups are using other secondary beam lines. Next year the duration of the flat-top will be extended to 1.0 sec at a repetition rate of 3 secs/pulse. In this condition E162, which is a new experiment to search for $K^0_L \to \pi^0 ee$ plans to use $\geq 2 \times 10^{12}$ protons/pulse on their production target. This experiment will start at the end of 1989. These experiments, which hope to get to the few x 10^{-11} sensitivity level are probably reasonably close to the limit of what can be accomplished in rare K^0_L decay at KEK, although there has been discussion of a new beam to get even further. This summer construction of a new experimental hall began. In this hall one high intensity stopping beam and one medium energy charged beam will be constructed and should come online in the spring of 1990. Although designed for hypernuclear experiments, they could probably be used for rare kaon experiments as well.

Fermilab is likely at the 10^{-8} level for $K_L \to \pi^0 ee$ already, having a recent result of BR< 4.2×10^{-8} based on an anlysis of 20% of their data. A new proposal from the group aims at sensitivities of 10^{-10} in the first stage of an experiment with the Tevatron K_L beam with an ultimate goal of 10^{-11}.

LEAR can product 4×10^{-3} (K and $\bar{K}$) per p for 10^{13} ($p\bar{p}$ total) or 4×10^{11} kaons. This will allow experiments which compliment the current generation of CP-violation experiments at other facilities. For rare decay experiments, this flux will limit experiments to sensitivity ~ 10^{-10}. Since no K decay experiments have yet been carried out there, it is hard to guess whether the flux can be fully exploited before experiments elsewhere get beyond the 10^{-10} level.

Upgraded Facilities

One upgrade already under way is the Brookhaven AGS Booster project. This will increase the available proton intensity by a factor 4. Some of this factor will be absorbed in mitigating the present AGS proton famine, but individual experiments at significantly higher instantaneous rates are possible. Since, as discussed above, the experiments now experiencing the highest rates are still about one order of magnitude under the maximum which can be achieved at the AGS, full exploitation of the Boosted AGS would imply an increase of ~40 in instantaneous rates. This is a formidable factor and will likely require significant advanced in technology. To go beyond the sensitivity of experiments at the Booster, it seems most sensible to exploit the available factors which do not raise the instantaneous rates. In recent years the AGS has run only 15-20 weeks/year in the slow extracted mode suitable for K experiments. This could be doubled without interfering with maintenance or of other uses of the AGS such as heavy ion acceleration. The increase in operating cost of such additional running would be ~$7M/yr. The other large available factor is that given by the duty cycle which at the AGS is ~ .35. This could be brought to ~1 by the addition of a stretcher ring, at a cost of ~$50M, according to AGS staff estimates. These seem the most economical and certain steps toward increasing the reach of K experiments in the near future.

Fermilab is likely to propose a new main injector[26)] which would operate at 120 GeV for slow spill with perhaps 2×10^{13} protons per 1 sec spill every 2 sec. This would bring FNAL within a factor of 2 of the boosted AGS in low energy Kaons/sec, and so allow comparable opportunities. For some of the experiments we are considering, the higher available K energies might constitute a considerable advantage. In the case of FNAL too, it should be kept in mind that maximal running time is the surest path to improved sensitivity.

New Facilities

We must temper our discussion of the influence of possible future K experiments on "kaon factories" with the observation that these facilities can study many other physics topics, and that in fact the proposers of some of these facilities have emphasized that is the requirements of non-K experiments that drive the parameters of their proposals.

The proposed facilities are generally in the BNL AGS energy range but promise a large increment in intensity over the present AGS, as much as a factor of 100 for slow beam running. With the advent of the AGS Booster, this advantage will be reduced to a factor 25. The most valuable piece of this factor is the 2.5 gained by implementing ~100% duty factor since detectors do not have to increase their instantaneous rate capability to realize the gain directly. As discussed above, this great advantage to physics could be realized by the relatively low cost construction of a stretcher at BNL. The advantage of the K Factories would then be a factor of 10 on roughly the same time scale but at considerably larger cost. Trading intensity for increased cleanliness does not seem desirable for the rare decay experiments since the typical cost of a factor of 100 would result in beams comparable to the present ones.

Regarding the specific proposals for future facilities, a number of points need to be made:

1. It is essential that the smoothest possible micro-duty cycle be available. It has to be possible to smooth out the rf structure for very high rate experiments which are bound to be limited by accidentals.

2. Efforts should be made to insure that the number of beamlines and size of the experimental areas are adequate to meet the physics demands. These issues do not seem fully addressed in the present proposals. A high energy (low production angle) neutral beam is a must, particularly if the machine energy is 30 GeV.

3. For the purposes of detecting in-flight K decays, it is not clear that 30 GeV is the perfect energy. The acceptance of the recent rare K^0_L decay experiments at BNL and KEK is peaked at energies considerably high than is the K^0_L spectrum, suggesting that higher beam energy could be dealt with by current techniques and would be an advantage. In addition certain experiments such as those involving multiple photon detection or those which deal with K^0_S, favor higher energy (so that the most recent examples of these have been run at FNAL and CERN, even though higher fluxes were available elsewhere). The whole question of the optimum energy for a new facility should be reopened

4. To assure that K factories offer clear advantages over the modestly enhanced AGS outlined above, efforts should be made to increase the K intensity proposed by up to a further factor 10. This would allow the tradeoffs of raw intensity versus beam purity mentioned above to pay off in increased attainable sensitivity.

5. K Factories are very costly so that it is essential that they be fully utilized. Therefore, there must be a commitment to running as much of the year as possible, preferably at least nine months.

THE FUTURE OF K PHYSICS

In recent years the center-pieces of kaon physics have been the lepton flavor-violation, $K^+ \rightarrow \pi\nu\bar{\nu}$, and $K^0 \rightarrow 2\pi$ experiments. For the latter, the future may already be here. For $K^+ \rightarrow \pi\nu\bar{\nu}$ there is a Standard Model target which should be reached in the next few years unless new physics intervenes. The same is true of $K^0_L \rightarrow \pi^0 e^+ e^-$. The related process $K^0_L \rightarrow \pi^0 \nu\bar{\nu}$ also has a SM target, which would be extremely interesting, albeit extremely difficult, to reach. It seems practical to pursue the LFV experiments to the 10^{-11} level without undue expense (i.e., without completely new apparatus') but much beyond this the going will become heavy and progress will be at the rate of M - $BR^{.25}$ toward no particular theoretical target. To push all categories beyond the above-mentioned sensitivities, the most certain and most economical approach is to increase the fraction of the year this kind of physics is run, and where possible increase the duty factor from ~1/3 to 1.

This would allow several more years of pursuing K physics with the very high value to money ratio such work has enjoyed recently.

The optimum course for the longer term depends on what is found in the near future in K physics and elsewhere. To take a concrete example, imagine that $K^0_L \to \mu e$ is observed at 5×10^{-11}. Many theorists will try to take credit for predicting this. It would then become extremely important, in order to sort out the new interaction, to press the search for $K^+ \to \pi^+ \mu e$ as far as possible and at least to the 10^{-12} level. One would also push on other LFV reactions, including those outside the K system (e.g., $\mu \to e\gamma$ et al.). In the scenario, building a "classic" K factory would become quite attractive. Dramatic discoveries outside LFV might elicit quite different responses. If there are no such discoveries, then pursuing say $K^0_L \to \pi^0 ll$ may compete with B decays in exploring the KM parameter space. In this case higher energy and much higher intensity would be boons. The demands on detector technology would be challenging, but probably no more so than in the attempt to study CP violation in B decay.

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FIGURES

Figure 1. The E787 Spectrometer for detecting $K^+ \rightarrow \pi^+ \nu\bar{\nu}$.

Figure 2. Time distribution of $\pi^0 e^+ e^-$ for a beam of 10^{15} produced 16 GeV K^0's, detected in an apparatus with 10% acceptance between 6 and 26 nsec.

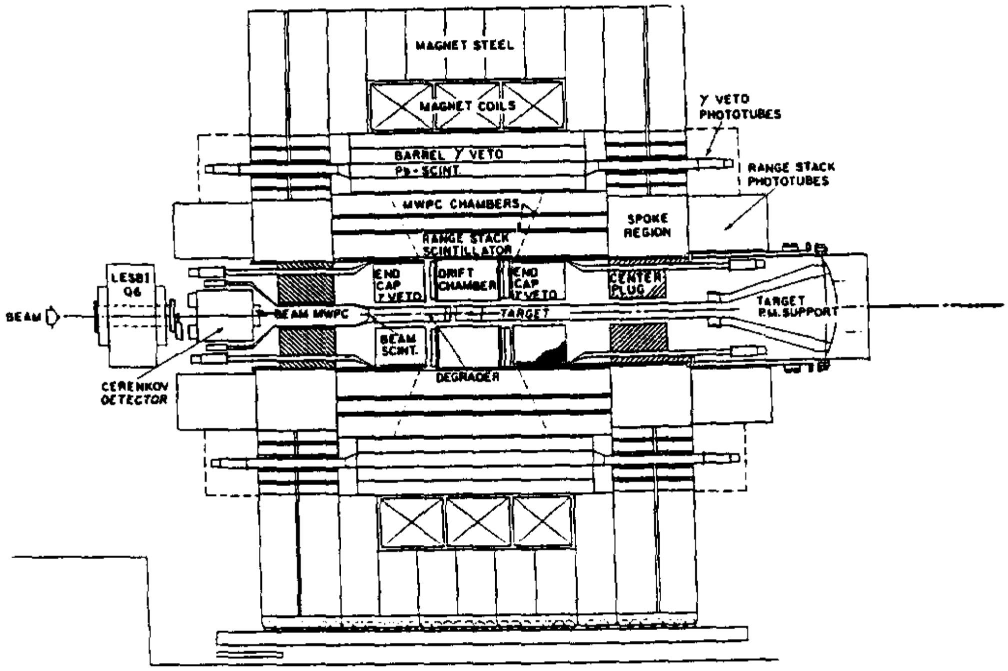
MAGNET STEEL
MAGNET COILS
γ VETO PHOTOTUBES
BARREL γ VETO
Pb - SCINT.
RANGE STACK PHOTOTUBES
MWPC CHAMBERS
SPOKE REGION
RANGE STACK SCINTILLATOR
LESBI Q6
END CAP γ VETO
DRIFT CHAMBER
END CAP γ VETO
CENTER PLUG
BEAM
BEAM MWPC
TARGET
TARGET P.M. SUPPORT
BEAM SCINT.
DEGRADER
CERENKOV DETECTOR

Fig. 1

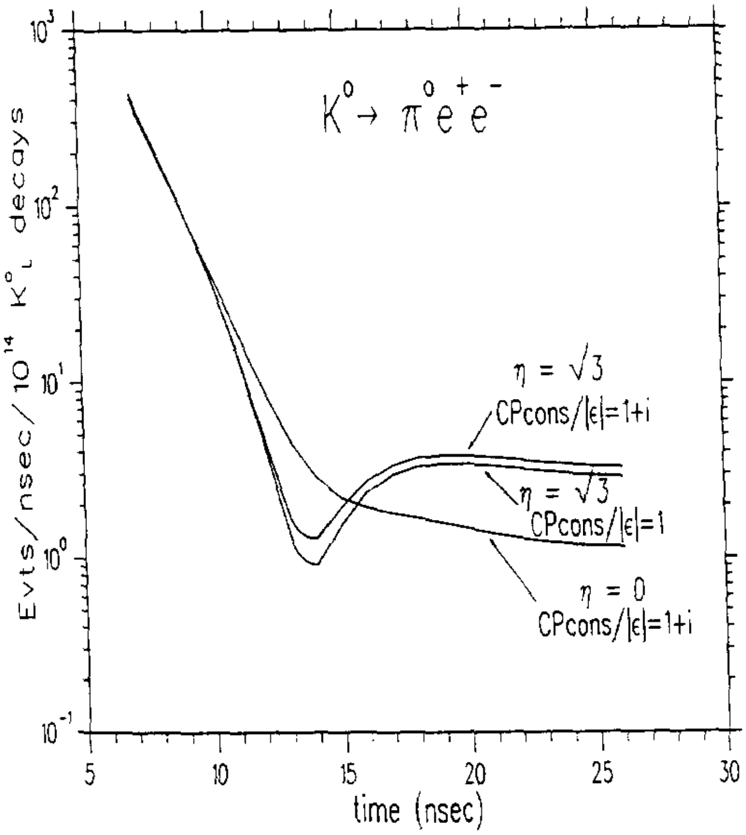
$K^0 \to \pi^0 e^+ e^-$
Evts/nsec/10^{14} K^0_L decays
$\eta = \sqrt{3}$
CPcons/|ε|=1+i
$\eta = \sqrt{3}$
CPcons/|ε|=1
$\eta = 0$
CPcons/|ε|=1+i
time (nsec)

Fig. 2