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PARTICLE PHYSICS PROSPECTS FOR THE KAON FACTORY

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ABSTRACT

The Kaon Factory at TRIUMF will produce beams of kaons, antiprotons, neutrinos and other particles with a hundred-fold increase in intensity over existing machines in the 30 GeV region. This will make possible new high precision experiments designed to test current ideas as well as high sensitivity measurements which could potentially reveal new effects. A sample of particle physics experiments involving rare kaon decays, CP and T violation studies, neutrino properties and reactions and light quark spectroscopy which might take advantage of the new opportunities presented by the Kaon Factory is discussed.

I. INTRODUCTION

The prospects for particle physics experiments at the Kaon Factory are varied and the emphasis will be on attacking many of the same issues addressed at the energy frontier of the high energy colliders. The experiments to be done at the 30 GeV, 100 μA proton synchrotron proposed at TRIUMF will make use of the increase in current over existing machines in this energy range to achieve high precision or high sensitivity to carefully probe predictions of the standard model and to search for new effects. Unprecedented fluxes of kaons, antiprotons, hyperons, neutrinos, pions and muons will all be available to open up new possibilities for experimentation. Some particular areas of interest at the kaon factory include rare kaon decays, CP and T violation, neutrino properties and reactions and hadron spectroscopy. In the following, a few examples of the physics opportunities generated by the advent of the kaon factory will be discussed.

II. RARE DECAYS AND CP VIOLATION

Rare decays of mesons and leptons play a significant role in challenging the standard model and in searching for effects which could indicate new directions. Kaon decays have been a rich and often surprising source of information at every stage in the development of the present picture of fundamental particles and their interactions. Parity violation, CP violation, neutral currents and the existence of charm are all effects in which kaon decays exhibited crucial or unique features. Kaon decays remain in the forefront of modern high precision attempts to test the accuracy of standard model predictions, to define the nature of CP violation, and to search for neutral flavor changing currents and lepton number violation among other new interactions and particles. For recent reviews of rare kaon decays see Ref. 1 and 2.

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

Reactions which are allowed in the standard model can provide important, detailed information, and can also herald the presence of new effects. The process $K^+ \to \pi^+\nu\bar{\nu}$ offers a prime example of the unique opportunities available in the study of rare kaon

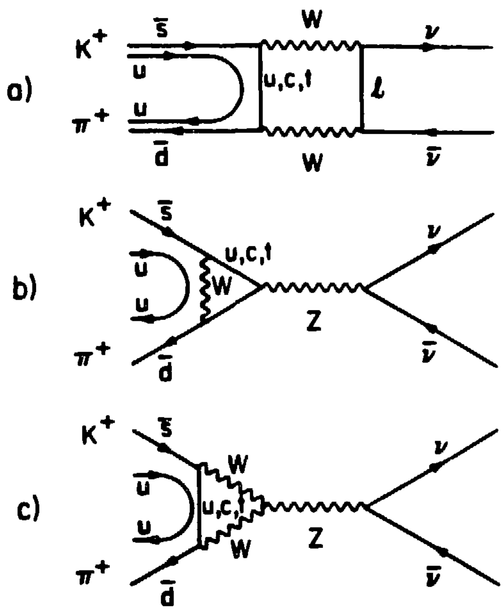

Fig. 1. Second order weak diagrams for $K^+ \to \pi^+ \nu\bar{\nu}$.

decays because a reliable higher order calculation assuming three generations can be confronted by experiment. Non-conformity with the standard model prediction could imply new physics in the form of extra generations or entirely new types of particles or interactions. The rate for $K^+ \to \pi^+ \nu\bar{\nu}$ depends on parameters of the Cabbibo-Kobayashi-Maskawa (CKM) matrix as evidenced by the diagrams in Fig. 1. Constraints on the CKM mixing parameters $V_{ts}^* V_{td}$ have been derived from semileptonic B-meson decays, from the measured b-quark lifetime and from the large observed $B_d^0 - \bar{B}_d^0$ mixing which, for example, fixes V_{td} (although with considerable uncertainty at present). The $K^+ \to \pi^+ \nu\bar{\nu}$ branching ratio as a function of the t-quark mass with the dependence on uncertainties of B-meson decay observables lies in the region 1 to 7×10^{-10} for m_t in the range 50 to 200 GeV/c^2.[2] Ellis and Hagelin[3] calculated radiative QCD effects indicating that if the mixing angles and t-quark mass were known a firm prediction for the $K^+ \to \pi^+ \nu\bar{\nu}$ branching ratio could be made. Conversely, a measurement of the branching ratio would be significant in constraining these parameters and would allow a direct test of higher order weak corrections in the standard model which is not significantly constrained by uncertain long distance effects as in calculations of $K_L^0 \to \mu\mu$ and the $K_L^0 - K_S^0$ mass difference.

A precise standard model prediction for the $K^+ \to \pi^+ \nu\bar{\nu}$ branching ratio allows the reaction to be used to search for new physics. The least exotic addition to the present picture would involve additional generations of quarks and leptons. Since experiments measuring $K^+ \to \pi^+ \nu\bar{\nu}$ do not observe the weakly interacting decay products, it is possible that this reaction is accompanied by $K^+ \to \pi^+ x x'$ or $K^+ \to \pi^+ x$, which occur at comparable or even much higher rates. The window for exotic effects appearing

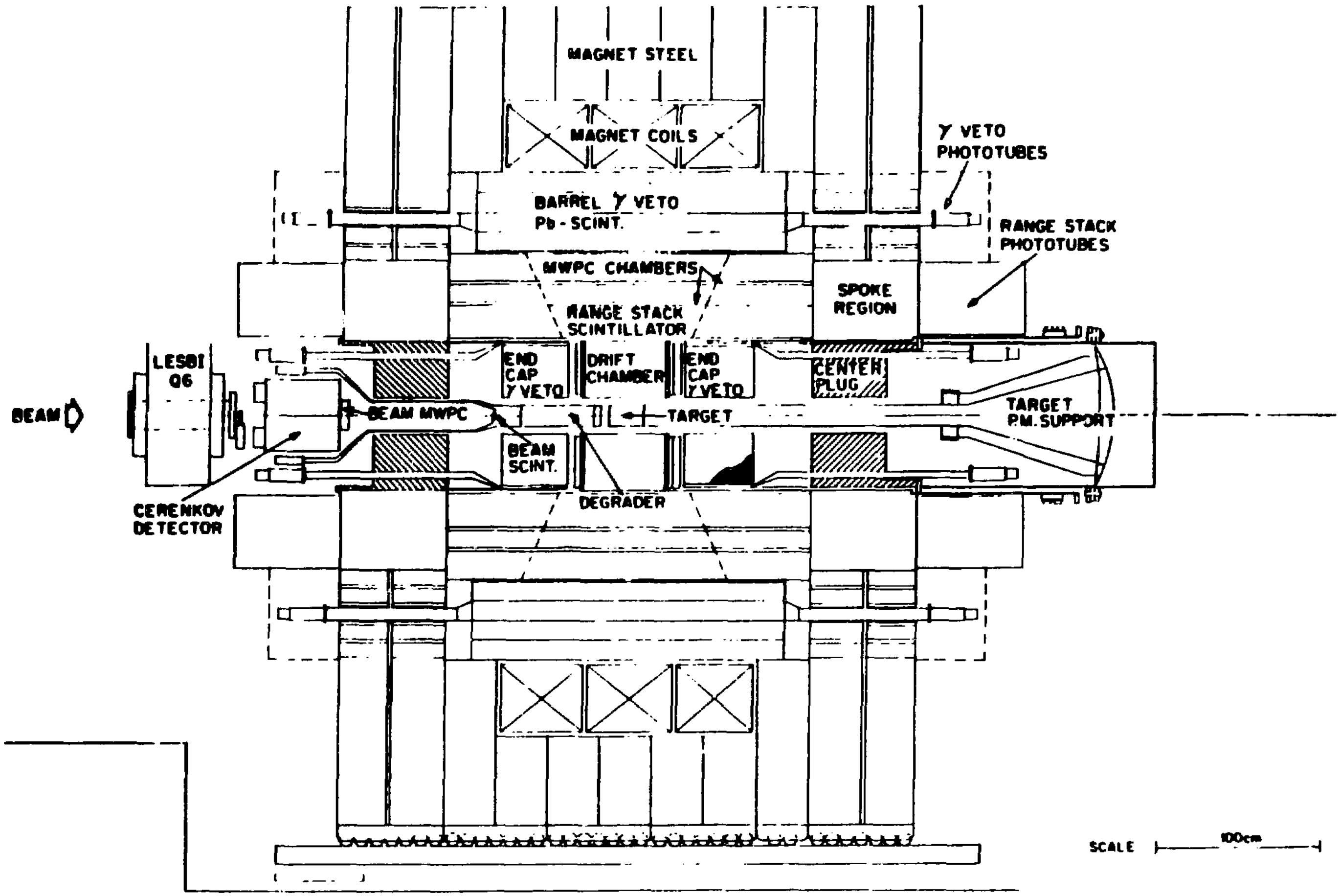

Fig. 2. Apparatus for BNL-787 measurement of $K^+ \to \pi^+ \nu \bar{\nu}$.

in the reaction $K^+ \to \pi^+ x x'$ extends two orders of magnitude from the current limit $B(K^+ \to \pi^+ x x') < 1.4 \times 10^{-7}$,[4] to the upper level of the standard model value $B(K^+ \to \pi^+ \nu\bar{\nu}) \sim 10^{-9}$. In supersymmetric theories a variety of new particles are hypothesized including the supersymmetric partners of the photon ($\tilde{\gamma}$), the Higgs particle ($\tilde{H}$), the leptons and the quarks. These could contribute to the rate for $K^+ \to \pi^+ x x'$, if the masses are sufficiently small. Schrock[5] estimated that if tree level graphs dominate in the decay $K^+ \to \pi^+ \tilde{\gamma}\tilde{\gamma}$, then the branching ratio could be as large as 10^{-7}, near the current limit. Other possibilities for exotic reactions $K^+ \to \pi^+ x x'$ and $K^+ \to \pi^+ x$ involving scalar or pseudoscalar particles have been suggested. The Majoran (a massless Nambu-Goldstone boson), the axion, light Higgs particles, the familion and hyperphotons are all potential candidates for x above.

An experiment is now in progress at Brookhaven National Laboratory (BNL) to measure the process $K^+ \to \pi^+ \nu\nu$.[6] The apparatus for BNL 787, a BNL-Princeton-TRIUMF collaboration, pictured in Fig. 2, is a state of-the-art detector which builds upon earlier work (such as Ref. 4) and points the way to future efforts at the kaon factory. The 787 detector has a large geometrical acceptance (2π sr) for the $K^+ \to \pi^+ \nu\bar{\nu}$ decay mode and has been designed to maximize the rejection of background processes such as $K^+ \to \pi^+ \pi^0$ ($K_{\pi 2}$), $K^+ \to \mu^+ \nu_\mu$ ($K_{\mu 2}$), $K^+ \to \mu^+ \nu \gamma$, and others. Sensitivity for identification of unaccompanied pions from $K^+ \to \pi^+ \nu\bar{\nu}$ is accomplished through measurements of momentum, kinetic energy, range, decay sequence $\pi \to \mu \to e$, and nearly 4π coverage for detection of photons. The 800 MeV/c K^+ beam is brought to rest in a 10 cm diameter target consisting of groupings of scintillating fibers 2 mm in diameter viewed by photomultiplier tubes. The decay pions pass through a cylindrical drift chamber which measures their momenta in a 1 T magnetic field. The pions then stop in a plastic scintillator range stack which also contains multiwire proportional chambers. Each range stack counter is viewed from both ends by 5 cm phototubes read out by 500 MHz transient digitizers, so that the decay chain $\mu \to \mu \to e$ can be observed for particle identification. The total energy of the decay pions is measured by summing the pulse heights of the target and range array elements. The pion detector is completely surrounded by a 15 radiation length Pb-scintillator gamma veto (1 mm Pb, 5 mm scintillator). Figure 3a shows an example of a calibration event of the type $K^+ \to \pi^+ \pi^0$. A blow-up of the segmented target is shown in Fig. 3b. Energy and time for each target element are available at present from an ADC and a TDC, respectively, so that the incident kaon and outgoing pion elements can be identified. The momentum calculated from the track in the drift chamber is 198 MeV/c, determined with resolution $\sigma_p = 2.5\%$. The pion track energy is found by summing the range stack and target energies to be 97 MeV with a resolution of $\sigma_E = 3\%$ and the range is 31 gm/cm^2 with a resolution of $\sigma_R = 3\%$. Correlation of range, energy and momentum are used to verify that the particle is a pion. In addition, the $\pi \to \mu\nu$ decay pulse is observed using the transient digitizer[7] (TD) in the last range stack counter hit as shown in Fig. 3c. The energy and timing of the 4 MeV muon pulse can be obtained and checked for consistency of position using the two ends of the counter. The $\mu \to e\nu\nu$ decay is also observed with the TD during an inspection period of 5 μs. In this event, the two photons from π^0 decay are both observed. We have determined from data that the inefficiency of the photon veto system is $\bar{\epsilon}_{\pi 0} < 4 \times 10^{-6}$ for π^0's from $K_{\pi 2}$ which is consistent with expectations of Monte Carlo calculations.

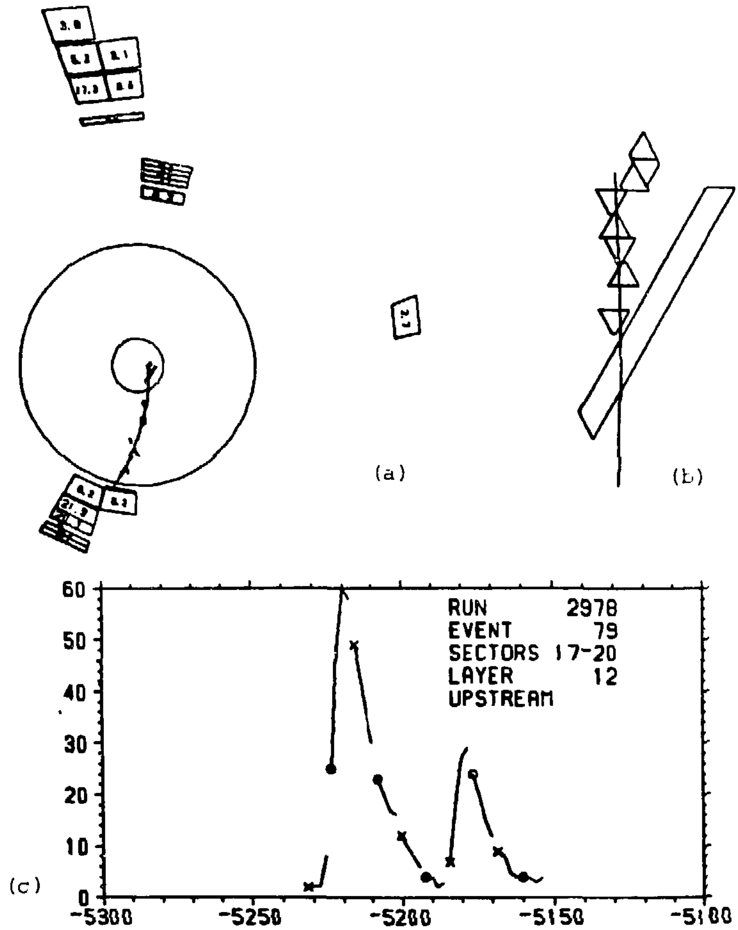

Fig. 3. $K^+ \to \pi^+ \pi^0$ event in the BNL-787 detector (see text).

The 787 experiment had a preliminary run in 1988. Present indications are that the experiment may be limited by the available flux of kaons rather than by background processes for the region of phase space (above the $K_{\pi 2}$ peak) being examined. If the standard model prediction is valid then at most a few events from $K^+ \to \pi\nu\bar{\nu}$ can be expected. To examine the spectrum for consistency with the standard model, to investigate any new phenomena which might eventually turn up or to continue the search for this unique process will require the intensity available at the kaon factory.

A conceptual design for a kaon factory detector for $K^+ \to \pi^+\nu\bar{\nu}$ capable of operating in a flux of one to two orders of magnitude greater than presently available is shown in Fig. 4. The basic configuration is similar to that of 787, although the magnetic field strength is 3 T, three times stronger. The primary motivations for the high field are

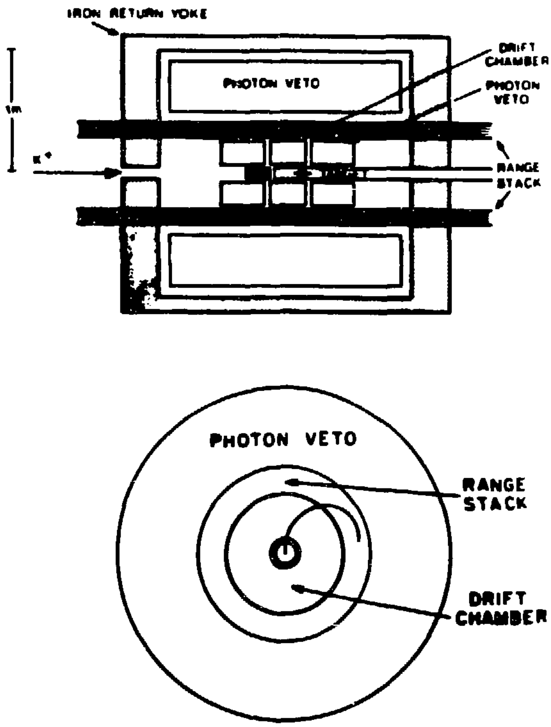

Fig. 4. Conceptual design of a kaon factory experiment to measure $K^+ \to \pi^+ \nu\bar{\nu}$.

improvement of the momentum resolution, improvement of the pion range stack tracking using greater segmentation (e.g. scintillation fibers) and improvement of the photon veto efficiency by the use of a fully active detection medium such as BaF_2. The later two improvements are possible due to the reduced size of the high field tracking apparatus. To handle the high rates anticipated, all detector channels would be instrumented with 0.5-1.0 GHz transient digitizers like the ones used in 787[7] and the GaAs CCD's under development at TRIUMF. A sensitivity of $< 4 \times 10^{-12}$ could be achieved with background levels estimated to be < 1 event. Alternatively, if the branching ratio is 5×10^{-10}, 200 to 300 events would be observed.

B. CP and T violation

CP violation has only been observed in the neutral kaon system in $K^0_L \to 2\pi$ decays and in the charge asymmetry in $K^0_L \to \pi e^{\pm}\nu$ (K^0_{l3}) decays. In the standard model with at least three generations a CP-violating phase can be accommodated in the quark-mixing matrix. The magnitude of CP violation is indicated by the parameter $\epsilon \sim 10^{-3}$, which has as its source the K^0, $\bar{K}^0$ mass matrix. CP violation is manifested by the level of CP impurity of K^0_L and K^0_S states. A second possible source of CP violation originates directly from the $K \to 2\pi$ decay amplitude and is represented by the parameter ϵ'. A recent CERN experiment[8] (NA31) reported consistency with the CKM picture of

CP violation, finding a non-zero value (at the three-standard deviation level) for the ratio $\epsilon'/\epsilon = (3.3 \pm 1.1) \times 10^{-3}$. Fermilab experiment E731[9] which collected over 300K $K_L^0 \rightarrow 2\pi^0$ decays is expected to report a result for ϵ'/ϵ later this year with comparable or greater precision. Whether a non-zero value of ϵ'/ϵ is confirmed or (especially) if an inconsistency appears future higher precision experiments with perhaps 10^8 $K_L^0 \rightarrow 2\pi^0$ events will be required for the next generation of experiments studying the origin of CP violation. This would allow the statistical precision to approach the 10^{-4} level, representing an order of magnitude improvement and presenting a severe challenge to the standard model. Of course, knowledge of systematic uncertainties must also be improved commensurately. Hence, the kaon factory has a definite role to play by permitting the creation of extremely clean beams (e.g. by charge exchange) while maintaining sufficient intensity or, perhaps, by employing entirely new techniques. New experiments at an upgraded Fermilab booster have also been suggested.[10]

One promising approach to the CP violation problem that may merit kaon factory intensities for future work is the production of pure, tagged K^0 and $\bar{K}^0$ states in $\bar{p}p$ annihilation. This method which is being pursued for the first time at LEAR,[11] employs the reactions $\bar{p}p \rightarrow K^0 K^- \pi^+$ and $\bar{p}p \rightarrow \bar{K}^0 K^+ \pi^-$ (branching ratios $\sim 10^{-3}$) in which the $K^0(\bar{K}_0)$ state is tagged by $K^-\pi^+(K^+\pi^-)$. Time dependent CP violating asymmetries

$$A_f(t) = \frac{\Gamma(\bar{K}^0 \rightarrow f)(t) - \Gamma(K^0 \rightarrow f)(t)}{\Gamma(\bar{K}^0 \rightarrow f)(t) + \Gamma(K^0 \rightarrow f)(t)} ,$$

where f represents a final state such as $\pi^0\pi^0$, can be measured with estimated precision comparable to the current round of tests at CERN and Fermilab. These measurements of ϵ'/ϵ as well as the associated phases and other CP violating K_S and K_L decay modes will be done with quite a different set of systematic uncertainties than in the CERN and Fermilab experiments and, thereby, will represent an important consistency check.

A further use of antiprotons in the quest for information on CP (or T) violation may come to fruition at the kaon factory by studying asymmetries of hyperon polarizations in reactions such as $\bar{p}p \rightarrow \Lambda\bar{\Lambda}$ and $\bar{p}p \rightarrow \bar{\Xi}^+\Xi^-$ as discussed by Hamann.[12] Such reactions could provide a clean way to study CP violation outside the neutral kaon system since large hyperon polarizations (required by parity conservation to be transverse to the production plane) occur in the context of initial and final states with definite CP properties. Non-zero measurement of one of several possible observables would constitute definite evidence for $\Delta S = 1$ CP violation (since due to baryon number conservation there is no final state mixing). Predictions for the CP violating asymmetries are at the 10^{-4} level while current experiments on $\bar{p}p \rightarrow \Lambda\bar{\Lambda}$[13] and $J/\psi \rightarrow \Lambda\bar{\Lambda}$[14] are in the neighborhood of 10^{-2} and new experiments at LEAR may obtain an additional factor of ten in sensitivity (see Ref. 12). To confront the standard model predictions one or two orders-of-magnitude more intensity will be necessary. Studies of cascade production $\bar{p}p \rightarrow \bar{\Xi}^+\Xi^-$ which are particularly attractive due to self-analyzing decay modes $\Xi \rightarrow \Lambda\pi$ (up-down asymmetry measured) and $\Lambda \rightarrow p\pi$ (Λ polarization measured) can occur with intense higher energy $\bar{p}$ beams at $\sqrt{s} > 2.64$ GeV/c.

Additional sources of CP or T violation could be revealed in rare kaon decay processes involving measurements of the transverse muon polarization in $K \rightarrow \pi\mu\nu$ ($K_{\mu 3}$) decays not expected in the standard model. The presence of nonzero muon polarization transverse to the decay plane is an indicator of T violation due to the T-odd product $\sigma_\mu \cdot (\bar{P}_\mu \times \bar{P}_\pi)$, where σ_μ is the muon polarization, and $\bar{P}_\mu$ and $\bar{P}_\pi$ are the muon and pion momentum vectors. In $K_{\mu 3}$ decay this effect might be due to the interference between the two form factors $f_+(\bar{P}_K + \bar{P}_\pi)$ and $f_-(\bar{P}_K - \bar{P}_\pi)$, since T-invariance requires f_+ and f_- to be relatively real. The results derived from measurement of the transverse μ polarization can be expressed in terms of Imξ, where Im$\xi \propto < \bar{\sigma}_\mu \cdot (\bar{P}_\mu \times \bar{P}_\pi) > m_K$ and $\xi = f_-/f_+$. The results of a $K^+ \rightarrow \pi^0 \mu^+ \nu_\mu$ study[16] gave Im$\xi = -0.016 \pm 0.025$. Combining this with a $K_L^0 \rightarrow \pi^+ \mu^- \nu_\mu$ experiment[15] (keeping in mind the possibility of complications due to electromagnetic final state interactions), the result is Im$\xi = -0.010 \pm 0.019$. Although, a null value for Imξ is consistent with the expectation based on the standard CKM model, the Weinberg Higgs model[17] of CP violation would predict Im$\xi \sim 10^{-3}$, an order of magnitude below the present limit. $K_{\mu 3}$ studies are ripe for a new generation of experiments using newer techniques and significant progress could be made even prior to the kaon factory era. Another semileptonic kaon decay K_{e4} has been examined theoretically by Castoldi, Frère and Kane[18] as a promising reaction to study for testing T-invariance.

The decay $K_L^0 \rightarrow \pi^0 e^+ e^-$ is a rare example of a reaction which can proceed through both CP-conserving and CP-violating paths at potentially comparable rates. Since K_L^0 consists of the CP odd state K_2 with a small admixture of the CP even state K_1, decays proceeding through two virtual photons and through a single virtual photon are, respectively, possible. Various calculations indicate the CP-conserving and CP-violating amplitudes may be comparable and, furthermore, that the CP-violating components due to the mass matrix ($\Delta S = 2$) and the direct 2π amplitude ($\Delta S = 1$) may also be comparable.[19] Essential theoretical work is in progress to understand this reaction and new experiments have been mounted at BNL, FNAL and KEK (see Ref. 2). Because the ranges of calculated values for the CP violating components and the CP conserving components (both due to mixing and direct contributions) are wide and overlap, there would be considerable difficulty in interpreting an observation of $K_L^0 \rightarrow \pi^0 e^+ e^-$ based on the rate alone. A measurement of $K_S^0 \rightarrow \pi^0 e^+ e^-$ (estimated to be at the 10^{-10} to 10^{-8} level)[20] would provide the most reliable input for determining the CP violating part of the $K_L^0 \rightarrow \pi^0 e^+ e^-$ amplitude due to mixing (i.e., the K_1 component). There may be sufficient variation in Dalitz plots to enable one to distinguish the CP violating from the CP conserving components if adequate statistics were available (a formidable task in light of the small branching ratio expected). Sehgal[21] calculated the phase of the 2γ amplitude and the interference between the 1γ and 2γ contributions to arrive at another possible observable, a CP violating asymmetry between e^+ and e^- energies. Littenberg (Ref. 2) has suggested measurement of the time dependence. In any case, since the branching ratio is expected to lie in the 10^{-12} to 10^{-11} region and significant statistics will be necessary to unravel the various contributions, $K_L^0 \rightarrow \pi^0 e^+ e^-$ is certainly an important reaction for study at the kaon factory to help elucidate the mechanism of CP violation.

Further evidence of CP violation would be observation of longitudinal muon polarization in $K_L^0 \rightarrow \mu\mu$ decay. In the context of the standard model,[22] the longitudinal polarization

$$P_L = \frac{N_L - N_R}{N_L + N_R} \sim 10^{-3} ,$$

where N_L (N_R) is the number of left- (right-) handed muons. However, much larger values can occur in Higgs models of CP violation. Here is an excellent example of a process which can be used to search for new effects such as alternate sources of CP violation while ultimately attempting to confront the standard model prediction. No experiments have yet been done and it appears that the intense beams at a kaon factory would be required to reach the 10^{-3} level.

C. Lepton flavor violation

Searches for rare kaon decays not expected in the standard model could also contribute dramatic new information. Lepton flavor violating (LFV) interactions are strictly absent in the standard model with massless neutrinos because neither the intermediate vector bosons nor the Higgs particle have LFV couplings. However, in many extensions of the standard model LFV interactions appear naturally, leading to decays like $K_L^0 \to \mu e$ and $K^+ \to \pi^+ \mu e$. Among these are models in which flavor violations are mediated by horizontal gauge bosons, additional neutral Higgs particles, vector or pseudoscalar leptoquarks and supersymmetric particles. The mass regions probed by rare kaon processes reach scales of order 100 TeV$/c^2$, which are inaccessible to direct experiments at any existing or planned higher energy accelerator. Table I (fom Ref. 1) gives a sample of the mass regions probed by current experiments. Thus, although kaon decay experiments are generally performed at relatively low energies, their implications are relevant and complementary to studies done at the highest energy facilities.

The ideas of quark and lepton substructure are motivated by the proliferation of fundamental particles and the lack of understanding provided by present theories. The existence of common substructure entities could conceivably lead to intergenerational rearrangement processes in which quarks and leptons are interchanged. Examples of reactions in which the net change of generation number is zero are $K_L^0 \to \mu e$, $K^+ \to \mu^+ \nu_e$, and $K^+ \to \pi^+ \mu^+ e^-$. In some models these processes are mediated by exchange of heavy bosons which distinguish the generations.

Other allowed rare kaon processes that might be accessible at the kaon factory could enable searches for exotic effects or new particles. The decays $K \to \pi e^+ e^-$ and $K \to \pi \mu^+ \mu^-$, involving both neutral and charged mesons, can be used to search for light scalar particles, e.g. Higgs particles which decay via $H \to l^+ l^-$. Several experiments have been performed to search for heavy neutrinos in $M \to l\nu$ decays, where $M = \pi$ or K and $l = \mu$ or e. Heavy neutrinos ν_i are not prohibited by any model (although there are some cosmological and other indirect constraints on masses and lifetimes) and could be mixed with the dominantly coupled light neutrinos if the weak eigenstates ν_e, ν_μ, $\nu_\tau \ldots$ are distinct from the mass eigenstates.

Other rare kaon decays, such as $K_L^0 \to \gamma\gamma$ and $K_S^0 \to \gamma\gamma$, are of interest due to the unknown aspects of low energy QCD and as additional sources of information on CP violation. Long distance (i.e., mesonic) effects generally contribute significantly to the uncertainties of calculations of such processes.

The present round of rare decay experiments at BNL and KEK has already begun to produce significant new results as indicated in Table I.[a] Because of the leverage that these experiments have in probing the standard model as well as in searching for new effects it can be expected that additional work taking advantage of new technology will

[a] See also the contribution of Inagaki to these proceedings.

Table I. Mass bounds from different processes.

Process	Higgs scalars (GeV/c^2)	Pseudoscalar leptoquarks (TeV/c^2)	Vector leptoquarks (TeV/c^2)	Experimental value
$\frac{\Gamma(K_L^0\to\mu e)}{\Gamma(K_L\to \text{all})}$	11	8	149	$<3\times10^{-10}$ [a]
$\frac{\Gamma(K_L^0\to\mu\mu)}{\Gamma(K_L\to \text{all})}$	4.7	3.6	62	9×10^{-9} [b]
$\frac{\Gamma(K_L^0\to ee)}{\Gamma(K_L\to \text{all})}$	8	2.6	108	$<1.2\times10^{-9}$ [c]
$\frac{\Gamma(K^+\to\pi^+\mu e)}{\Gamma(K^+\to \text{all})}$	1	0.5	5.6	$<1.8\times10^{-9}$ [d]
$\frac{\Gamma(\mu\to e\gamma)}{\Gamma(\mu\to \text{all})}$	0.3	–	–	$<4.9\times10^{-11}$ [e]
$\frac{\Gamma(\mu\to eee)}{\Gamma(\mu\to \text{all})}$	2.6	–	–	$<1.0\times10^{-12}$ [f]
$\frac{\Gamma(\mu Z\to eA)}{\Gamma(\mu Z\to\nu Z')}$	22	22	118	$<4.6\times10^{-12}$ [g]
$\Delta m(K_L^0-K_S^0)$	150	–	–	3.5×10^{-15} GeV [b]

[a] W.R. Molzon, Proc. Rare Decay Symposium, Vancouver (1988).
[b] Particle data group, Phys. Lett **170B**, 1 (1986).
[c] E. Jastrzembski *et al.*, Phys. Rev. Lett. **20**, 2300 (1988).
[d] M. Zeller, Proc. Rare Decay Symposium, Vancouver (1988).
[e] R.D. Bolton *et al.*, Phys. Rev. Lett. **56**, 2461 (1986).
[f] U. Bellgardt, Nucl. Phys. **B299**, 1 (1987).
[g] S. Ahmad *et al.*, Phys. Rev. **D38**, 2102 (1988).

be pursued at these facilities and that further improvements will be realized at the kaon factory. To chose an example, AGS experiment 791[23] is now aimed at a sensitivity of approximately $<10^{-11}$ for $K_L^0\to\mu e$ decay. If the final result is null, then a strong motivation exists, as it does now, for pursuing this reaction since it is one of the most favored in models which extend the boundaries of the standard model. A positive result would create a whole industry of experiments to explore the new effect. It appears that with evolutionary improvements to the beam, chamber systems and triggering and data acquisition systems that a level of sensitivity of $<10^{-13}$ could be achieved at the kaon factory using beams of one to two orders of magnitude higher intensity than are presently available. More drastic revisions to the approach such as attempting to increase the acceptance by an order of magnitude are worthy of consideration as well. Here, experience at the meson factories is relevant. The two orders of magnitude in flux compared with "pre-factory" machines coupled with advances in technology have already led to five orders of magnitude improvements in sensitivity of rare muon decay experiments with major advances still underway.

III. NEUTRINO PHYSICS

High intensity neutrino beams with 100 times the flux presently available at the BNL AGS will also open many opportunities for fundamental studies including neutrino-electron and neutrino-proton reactions and searches for neutrino oscillations. Determining $\sin^2\theta_w$ at low Q^2 may be an important objective of neutrino physics experiments at the kaon factory. A high precision low Q^2 measurement will enable tests of the calculations of radiative corrections which are required in order to connect low Q^2 and high Q^2 ($\sim M_Z^2$) measurements. However, currently proposed experiments e.g. LCD at Lampf[24] may succeed in reaching precision $\sin^2\theta_w \sim 10^{-3}$ comparable to that attainable at the kaon factory so the situation will require reevaluation at a later date. Neutrino beams potentially available at the kaon factory include $\overset{(-)}{\nu}_\mu$ from pion decay, medium energy electron neutrinos from $K_L^0 \to \pi^\pm e^\mp \overset{(-)}{\nu}_e$ decays-in-flight and low energy ν_e, ν_μ and ν_μ from a beam-stop source.

Neutrino mass and oscillation are currently active topics and can be expected to remain so through the kaon factory era. To explain the observed scarcity of solar neutrinos, a theory of matter oscillation has been proposed. If this approach were correct and $\nu_e \to \nu_\mu$ oscillations occur with $\Delta m^2 \sim 10^{-7} - 10^{-4}$ eV^2, then vacuum oscillations $\nu_\mu \leftrightarrow \nu_e$ would be virtually out of reach in terrestrial experiments. However, under various assumptions $\nu_\mu \leftrightarrow \nu_\tau$ oscillations might be accessible in the range $\Delta m^2 \sim 10^{-4} - 10^4$ eV^2. Presently, $\Delta m^2 \sim 0.3$ eV^2 have been searched for in $\nu_\mu \leftrightarrow \nu_\tau$ oscillations. A new proposal[25] for the AGS with the booster under construction at BNL is aiming at an order of magnitude improvement in a ν_μ disappearance experiment with a 10 km baseline (corresponding to L/E $\sim$ 10 where E is the energy (GeV) and L (km) is the observation-source distance). 2×10^{20} protons on target are requested for this purpose. At the kaon factory it is possible to consider the next generating experiment with 100 km baseline. This would enable examination of the vacuum oscillation region with large mixing at the level $\Delta m^2 \sim 10^{-3}$. New regions of oscillation parameters for $\nu_\mu \leftrightarrow \nu_e$ could also be explored through ν_e appearance experiments. Neutrino experiments of this scale, clearly major undertakings, would be done in the context of then-current results of terrestrial and solar neutrino experiments.

IV. LIGHT QUARK SPECTROSCOPY

Although in the above we have mainly dealt with electro-weak issues, strong interaction physics will also play a major role in the kaon factory program. For example, hadron spectroscopy is an area which still requires much effort in order to provide basic empirical information on the rich array of states expected in QCD inspired models. Figure 5 from Godfrey and Isgur shows a quark-antiquark potential for meson spectroscopy. Light quark states probe the non-perturbative QCD region whereas heavy quark production, W and Z production and jet physics studied at high energy colliders probes the perturbative regime. In light baryon and meson spectroscopy there are many states expected in the quark model which have not been observed. Many inconclusive searches have also been performed for states composed purely of glue and for quark-glue hybrid states. Similarly, the whereabouts of multiquark states such as $qqqq\bar{q}$ and baryonium remain a mystery. A well-founded knowledge of spectroscopy of quarks and gluons will

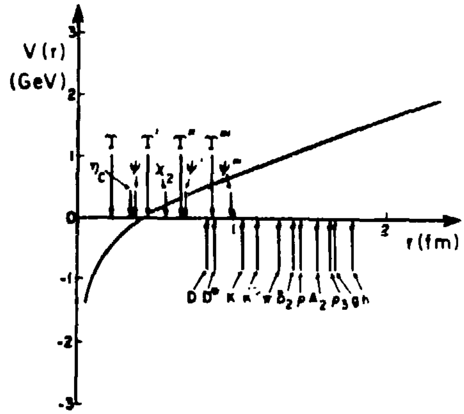

Fig. 5. The universal quark-antiquark QCD potential used by Godfrey and Isgur in their model of meson spectroscopy.

be complementary to high energy perturbative QCD studies, and both will be necessary to obtain a thorough understanding of the strong interaction. This will be essential to eventually confront theoretical approaches such as lattice gauge theories which may one day provide predictive power along with a quantitative picture of QCD.

Experiments at the kaon factory may include studies of light quark spectroscopy using $\pi^- p$, $K^- p$ and $\bar{p}p$ interactions. Because high statistics and high resolution will generally be necessary to sort out the complex spectrum of states, these experiments will require advanced detectors with fast triggers, high rate capabilities and the ability to process enormous data sets.

V. CONCLUSION

The kaon factory will provide a new capability for high precision, high sensitivity particle physics experiments that is unique and complementary to many current and proposed efforts. The sampler of inviting possibilities discussed above is by no means meant to be complete or even representative of the program at the kaon kaon factory which will be driven by future physics issues and priorities. What is more certain is that as new intense beams with hundred-fold higher fluxes become available, they will be used in imaginative and productive ways to significantly aid in the advancement of physics.

REFERENCES

1. D.A. Bryman, Int. Jour. Mod. Phys. A **4**, 79 (1989).

2. L.S. Littenberg and J.S. Hagelin, to be published.

3. J. Ellis and J.S. Hagelin, Nucl. Phys. **B217**, 189 (1983)

4. Y. Asano *et al.*, Phys. Lett. **107B**, 159 1981.

5. R. Shrock, *Proc. DPF Summer Study of Elementary Particle Physics and Future Facilities*, ed. R. Donaldson *et al.*, (Snowmass, 1982) p. 291.

6. See Y. Kuno *et al.*, *Proc. Workshop on Rare Decays*, ed. J.-M. Poutissou *et al.*, (Vancouver, 1988), to be published.

7. M. Atiya *et al.*, IEEE Nucl. Sci. Symposium, Orlando, FL, Nov. 1988.

8. H. Burkhardt *et al.*, Phys. Lett. **206B**, 169 (1988).

9. FNAL E731; M. Woods *et al.*, Phys. Rev. Lett. **60**, 1695 (1988); L.K. Gibbons *et al.*, Phys. Rev. Lett. **61**, 2661 (1988).

10. B. Winstein, G.J. Bock and R. Coleman, FNAL EFI 89-01.

11. L. Adiels *et al.*, Proposal for experiment PS195 CERN/PSCC/85-6, PSCC/P-82 (1985).

12. See N. Hamann, *Proc. Workshop on Rare Decays, ibid.*

13. P.D. Barnes *et al.*, Phys. Lett. **189B**, 249 (1987).

14. M.H. Tixier *et al.*, Phys. Lett. **212B**, 523 (1988).

15. S.R. Blatt *et al.*, **D27**, 1056 (1983).

16. W.M. Morse *et al.*, Phys. Rev. **D21**, 1750 (1980).

17. S. Weinberg, Phys. Rev. Lett. **37**, 651 (1976).

18. P. Castoldi, J.-M. Frère and G.L. Kane, Univ. Michigan preprint UM-TA-88-26.

19. See C.O. Dib, I. Dunietz and F.S. Gilman, to be published, SLAC-PUB-4762, and J. Flynn and L. Randall, LBL preprint UCB-PTH-88-21 and references therein.

20. M.K. Gaillard and B.W. Lee, Phys. Rev. **D10**, 897 (1974).

21. L.M. Sehgal, Phys. Rev. **D38**, 808 (1988).

22. P. Herczog, Phys. Rev. **D27**, (1983). L. Wolfenstein, *Selected Topics in Electroweak Int.*, ed. J.M. Cameron *et al.*, (World Scientific, Singapore, 1978), p. 236.

23. R.D. Cousins *et al.*, AGS experiment 791.

24. Large Cerenkov Detector Project, LASL report LA-11300-P.

25. M.J. Murtagh *et al.*, BNL AGS proposal 848.