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SOME PHYSICS POSSIBILITIES FOR THE KAON FACTORIES

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During the last few years the three meson factories, LAMPF, TRIUMF and SIN, have essentially reached their design specifications and produced extraordinarily high intensity beams of protons, pions and muons. These laboratories were built primarily for doing high precision, high sensitivity nuclear physics experiments. Detailed studies of nucleon-nucleon scattering, the pion nucleus interaction and nuclear reactions and spectroscopy with intermediate energy protons have begun in earnest justifying the original motivations.

As expected, unexpected developments are also playing major roles in the lives of these laboratories. The burgeoning field of solid state physics using μSR techniques is a prime example of an unanticipated area having an important impact on the scientific programs at all three accelerators.

Coincident with the development of the meson factories there has been a revolution in particle physics in which outstanding theoretical and experimental leaps forward have been made toward the goals of identifying the fundamental constituents of matter and of determining an underlying theory which describes all interactions. Here also, important, perhaps unanticipated, contributions are being made at the medium energy laboratories.

Now that the meson factories are reaching maturity, it is natural to ask "what next?". Where are the new developments in nuclear and particle physics leading us? What facilities will be required in the not so distant future to explore new areas and build on the knowledge gained thus far? It is in this context that serious consideration is being given to the prospects for a machine which could provide proton beams with intensities comparable to those at the meson factories ($\geq$0.1 mA) in the energy range 5-30 GeV.

In this talk, I will discuss some of the motivations behind the development of such a facility. I will concentrate on aspects of particle physics because these have received less attention in previous discussions of kaon factories than is deserved and because these are close to my personal interests. The prospects for nuclear physics experiments are equally appealing; for reference see the 1979 Kaon Factory Workshop proceedings.[1] Physics with antiprotons is dealt with elsewhere at this meeting.

Particle physicists and nuclear physicists share an interest in a new machine with beams of considerably higher energy than at existing meson factories, because of a shared interest in the strange quark. The weak and strong interactions of the s quark form the basis of a new frontier in medium energy physics that could be investigated with the equally high precision and sensitivity which now characterize the physics of pions and muons. Kaon factories would open the door to explorations with the second quark generation.

The present geneology of "elementary" particles involves two families, quarks and leptons. Within each family there are apparent similarities in the structure of three generations, each generation characterized by an increasing mass scale:

$$\text{leptons} \quad \begin{pmatrix} e^- \\ \nu_e \end{pmatrix}_L , \quad \begin{pmatrix} \mu^- \\ \nu_\mu \end{pmatrix}_L , \quad \begin{pmatrix} \tau^- \\ "\nu_\tau" \end{pmatrix}_L , \quad e_R, \mu_R, \tau_R$$

$$\text{quarks} \quad \begin{pmatrix} u \\ d \end{pmatrix}_L , \quad \begin{pmatrix} s \\ c \end{pmatrix}_L , \quad \begin{pmatrix} "t" \\ b \end{pmatrix}_L , \quad u_R, d_R, s_R, c_R, t_R, b_R .$$

L and R above indicate left- and right-handed components and " " indicates an unconfirmed status.

The weak and electromagnetic interactions of the two families are described by the Weinberg-Salam-Glashow (WSG) unified gauge theory based on the group $SU(2)_L \times U(1)$.[2-4] This "standard" theory predicted the existence of neutral weak currents, showed the necessity for the charmed quark, and passed numerous other experimental tests. Important elements of the theory require the existence of four gauge bosons: the massive $W^\pm$ and Z^o transmit the charged and neutral weak interactions, respectively, and the massless photon is the carrier of the electromagnetic interaction. The heavy gauge bosons and the fermions acquire their masses through spontaneous symmetry-breaking, a mechanism by which massless gauge bosons develop nonzero vacuum expectation values. This also results in the existence of a massive scalar particle known as a Higgs particle. The theory is characterized by a parameter θ_W which determines the relative strengths of the weak and electromagnetic coupling constants g and g′, respectively, through the relation $\tan \theta_W = g'/g$.

There are still important questions and problems associated with the standard model of weak interactions. Some of these are:

- Verification of the existence of and mass predictions for the $W^\pm$ and Z^0 bosons; verification of the existence of Higgs particles (How many? Are they elementary fields? What are the observable effects associated directly with Higgs particles?).
- Determination of the neutrino mass spectrum and other neutrino properties such as the existence of oscillations.
- Understanding of the nature of the generations; finding other generations; determining the extent of lepton mixing.
- Understanding of CP violation.

Speculations have also been made leading to so-called grand unification theories (GUT) which encompass the electroweak theory and quantum chromodynamics (QCD), the candidate theory of strong interactions based on the group $SU(3)_c$, where the subscript c denotes colour. In general, theories based on groups such as SU(5)[5] or O(10),[6] which are strongly broken down to $SU(3)_c \times SU(2) \times U(1)$, enable the prediction of certain parameters in the standard models, such as θ_W, the mass ratio of the b and t quarks, the existence of several additional charged and neutral Higgs particles and conservation of the quantity B-L, where B is baryon number and L is lepton number. Experimental consequences would include decay of the proton and lepton flavour-changing or generation-changing interactions mediated by Higgs particles, which would not arise from the gauge couplings alone. Testing the limits of the predictive power of the proposed theories and searching for evidence of new interactions and new particles are important elements on the frontier of particle physics.

Medium energy physics is contributing to this decade-long revolution in particle physics by critically examining weak interaction phenomena of muons and pions and by investigating the generation puzzle with unprecedented precision. The great intensities available at the meson factories have been put to full use in experiments dealing with lepton number violation. Searches for direct transitions between lepton generations involving lepton number nonconservation in reactions such as $\mu \rightarrow e\gamma$[7] and μ^{-}+Nucleus $\rightarrow$ e^{-}+Nucleus[8] have been improved in sensitivity by two orders of magnitude in recent years. New experiments in progress at TRIUMF and LAMPF expect to reach between one and two orders of magnitude lower, approaching the level of 10^{-12} relative to ordinary lepton number-conserving reactions.[9,10] These searches for flavour-changing interactions may be naturally suppressed by the leptonic analog of the Glashow-Iliopoulos-Maiani (GIM) mechanism, which suppresses the strangeness-changing neutral weak currents. Consequently they are particularly sensitive to the existence of superheavy neutral leptons or additional Higgs scalars present in many versions of modern theories, and therefore might provide a window for observing the effects of the ultra high mass scale (~100 TeV) of GUT theories.[11]

The primary source of knowledge about the leptonic charged current with its presumed (V,A) structure has been muon decay $\mu^{+} \rightarrow e^{+}\nu_{e}\bar{\nu}_{\mu}$. Measurements of the Michel parameters, which describe muon decay in terms of general interactions, are in the process of being refined by factors of 5-10 in experiments at LAMPF, TRIUMF and SIN.[12] These experiments will place exacting constraints on unified theories. Deviations from the values of the Michel parameters predicted by the standard models would have far-reaching consequences. They could favour, for example, the alternative choice of left-right symmetric models, such as $SU(2)_L \times SU(2)_R \times U(1)_{L+R}$,[13] and the existence of right-handed $W^{\pm}$ bosons with $M_{W_R} >> M_{W_L}$.

Precise studies of pion decays also probe the detailed structure of the weak interaction in unique ways. Experiments are now under way to improve measurement accuracies by a factor of ~5 in the decays $\pi \rightarrow e\nu_e$,[14] $\pi \rightarrow e\nu_e\gamma$,[15] and $\pi \rightarrow \pi^0 e\nu_e$,[16] reaching levels at which the standard models can be severely tested. The branching ratio $\pi \rightarrow e\nu_e/\pi \rightarrow \mu\nu_\mu$ is now being measured at TRIUMF. This ratio provides the most stringent test available of the principle of electron-muon universality, a fundamental assumption in the WSG model with which a firm prediction has been made at the level of ±0.3%. A violation of universality here could indicate, for example, the existence of charged Higgs particles. The decays $\pi^{+} \rightarrow e^{+}\nu_e\gamma$ and $\pi^{+} \rightarrow \pi^0 e^{+}\nu_e$ (pion beta decay) being studied at TRIUMF and SIN, and at LAMPF, give sensitive information on the nature of pion structure and weak interaction couplings. Specifically, the $\pi \rightarrow e\nu_e\gamma$ reaction allows one to obtain the relative strengths of vector and axial vector couplings in the $u\bar{d}$ system. The branching ratio for pion beta decay, one of the crucial tests of the conserved vector current (CVC) hypothesis, is another essential element of the WSG theory for which predictions are made at the 1% level.

Determining the fundamental properties and interactions of neutrinos, such as rest mass and ability to oscillate, is another active area of interest. This is especially true in light of recent indications of possible nonzero rest mass and oscillations of ν_e. The best limit on the ν_μ mass has been determined in an ongoing study of pion decay at SIN.[17] A major effort to measure $\nu_e e$ elastic scattering[18] is under way at the LAMPF neutrino facility. It will provide basic information on the purely leptonic neutral current. The LAMPF neutrino facility is the only suitable source of medium energy electron neutrinos. In spite of high flux $\sim 10^7/\mathrm{cm}^2/\mathrm{sec}$, the low neutrino cross sections at low energy (~30 MeV) are dominated by severe cosmic-ray backgrounds which make experiments extremely difficult. Reducing the duty factor by orders of magnitude for neutrino production, as is proposed for the Proton Storage Ring (PSR) at LAMPF, would greatly facilitate neutrino experiments. The need for new medium energy neutrino facilities with neutrinos of higher energy and greater intensity is evident.

Fundamental studies dealing with muonium, muon g-2, other sensitive tests of QED,[19] the form of lepton number conservation, and parity violation in the interference between strong and weak interaction amplitudes are also being pursued at the meson factories.

The future for particle physics at the medium energy facilities lies with increasing experimental capabilities to improve, even further, constraints on the validity of our theoretical understanding of the electroweak interaction. Some major challenges lie in neutrino physics: significantly reducing the limit on the ν_μ mass, searching for medium mass neutrinos, and establishing the presence or absence of neutrino oscillations. In pion decays serious obstacles must be overcome to reduce systematic effects and backgrounds by developing more sensitive and discriminating detectors, so that, for example, extremely rare processes such as $\pi^0 \rightarrow 3\gamma$, an indication of C violation, and $\pi \rightarrow e\nu_e e^+e^-$, which would give improved information on pion structure, could be searched for at meaningful levels. Muon capture in hydrogen is another important area which should be attacked at the meson factories in the near future.

Physics with pions has proved interesting because of the pion itself and because of the access it has afforded to the second lepton generation. Detailed experiments involving the second quark generation may hold even greater promise.

Studies of kaon decays are continuing to be extremely important in the development of weak interaction theory. By far, the most striking area warranting further experimental and theoretical investigation involves CP violation. Following the assumption of CPT invariance, CP violation implies violation of time reversal invariance (T). This is among the most fascinating and least understood effects observed in particle physics.

CP violation has only been observed in the neutral kaon system. The K^0 and $\overline{K^0}$ are eigenstates of isospin and strangeness, whereas the eigenstates of the weak interaction are K_L^o and K_S^o. If CP invariance were valid

$$CP|K_L^o\rangle = -|K_L^o\rangle ,$$

$$CP|K_S^o\rangle = +|K_S^o\rangle .$$

Consequently the K_L^o can decay into $(\pi^+\pi^-\pi^o)$ which must be CP ~~even~~ odd, but not into $(\pi^+\pi^-)$, which is CP ~~odd~~ even. Similarly K_S^o normally decays only to $\pi^+\pi^-$ and not to 3π states.

However, it is observed that the CP violating $K_L^o \to \pi^+\pi^-$ decay occurs at the rate[20]

$$\frac{\Gamma(K_L^o \to \pi^+\pi^-)}{\Gamma(K_L^o \to \text{all})} = (2.03 \pm 0.05) \times 10^{-3} .$$

A further indication of CP violation in the neutral kaon system is the observed value of the charge asymmetry in $K_{\ell 3}^o$ decays[21]

$$\delta_L = \frac{[\Gamma(K_L^o \to \pi^-\ell^+\nu) - \Gamma(K_L^o \to \pi^+\ell^-\bar{\nu})]}{[\Gamma(K_L^o \to \pi^-\ell^+\nu) + \Gamma(K_L^o \to \pi^+\ell^-\bar{\nu})]} = (3.30 \pm 0.13) \times 10^{-3} ,$$

where $\ell = \mu, e$ and the value for δ_L given has been averaged over both μ and e modes.

Basically there are two approaches to CP violation. The first is the superweak model, which postulates a new interaction with coupling strength 10^{-9} G,[22] where G is the ordinary weak coupling strength. Observable CP violation would be effectively confined to the neutral kaon system, since all other CP-violating or T-violating effects are at the 10^{-9} level or less. The neutron electric dipole moment, an indicator of T violation would be $<10^{-29}$ e-cm in superweak theories compared with the present experimental limit $<3 \times 10^{-24}$ e-cm.[23]

In milliweak models CP effects occur at the level 10^{-3} compared to ordinary weak amplitudes. Therefore, CP-violating processes other than those in the neutral kaon system may be observed.

A prominent milliweak theory contender is the six-quark Kobayashi-Maskawa[24] model based on the Glashow-Weinberg-Salam $SU(2)_L \times U(1)$ electroweak theory. Although CP violation could not reasonably be accommodated in the original four-quark model, with three quark doublets it can be incorporated in the weak coupling of the quarks to the gauge bosons. In this model, the charged current Lagrangian density is

$$L \propto g\, J_\mu W^\mu + \text{h.c.} ,$$

where W^μ is the charged W-boson field, g is the SU(2) gauge coupling constant and J_μ is the charged current,

$$J_\mu = q_i(2/3)\gamma_\mu(1-\gamma_5)\, V\, q_j(-1/3) ,$$

where $q_i(2/3)$ = u, c, t are the quarks with charge 2/3; and $q_j(-1/3)$ = d, s, b are the -1/3 charged quarks; V is a unitary 3 × 3 matrix which governs the transformation between weak eigenstates and mass eigenstates:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} c_1 & -s_1c_3 & -s_1s_3 \\ s_1c_2 & c_1c_2c_3 - s_2s_3e^{i\delta} & c_1c_2c_3 + s_2c_3e^{i\delta} \\ s_1s_2 & c_1s_2c_3 + c_2s_3e^{i\delta} & c_1s_2s_3 - c_2c_3e^{i\delta} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix},$$

where $c_i = \cos\theta_i$, $s_i = \sin\theta$; $i = 1,2,3$. V depends on three CP-conserving rotation angles θ_1, θ_2 and θ_3 and one CP-violating phase δ.

Another milliweak mechanism for CP violation is possible if there exist two or more Higgs doublets instead of only one as in the standard model.[25] The masses of the Higgs bosons and fermions involved can provide an explanation for the magnitude of the observed effect of order GM_F^2/M_H^2 where M_F and M_H are the fermion and Higgs masses, respectively, as described by Weinberg.[26] This has also been discussed in the context of Higgs which are not elementary[27] (i.e., composite Higgs). The latter models would result in flavour-changing interactions such as the decays $\mu \to e\gamma$ and $K \to \mu e$. These and other models make predictions of the magnitude for CP- and T-violating effects in the neutral kaon system which can be experimentally tested.

CP violation in the neutral kaon system is conventionally parametrized in terms of ratios of amplitudes $A(K^o \to \pi\pi)$ for the two-pion decay modes of K_L^o and K_S^o:

$$\eta_{\pm} = \frac{A(K_L^o \to \pi^+\pi^-)}{A(K_S^o \to \pi^+\pi^-)} = \varepsilon + \varepsilon'$$

and

$$\eta_{oo} = \frac{A(K_L^o \to \pi^o\pi^o)}{A(K_S^o \to \pi^o\pi^o)} = \varepsilon - 2\varepsilon' .$$

Experimentally,[21,28,29] $|\eta_{\pm}| = (2.274 \pm 0.022) \times 10^{-3}$ and $|\eta_{oo}| = (2.325 \pm 0.082) \times 10^{-3}$ resulting in $|\varepsilon'/\varepsilon| \sim< 0.03$ (90% CL). Table I gives some of the theoretical predictions for $|\varepsilon'/\varepsilon|$. Also shown are predictions for the neutron electric dipole moment. New experiments[30] at FNAL and BNL may improve the experimental limits to the 1% level. However, it is clear that very sensitive and detailed studies, perhaps reaching levels of 10^{-3} - 10^{-4} accuracy in $|\varepsilon'/\varepsilon|$, may be required to choose between models. High quality kaon beams with intensities far greater than those available now will be required to meet this challenge.

Table I. Predictions of CP-violating quantities.

Model	$\lvert\varepsilon'/\varepsilon\rvert$	D_n (e-cm)
Superweak	0	$<10^{-29}$
Kobayashi-Maskawa	$0.7 - 2 \times 10^{-2}$	$\sim 10^{-30}$
Weinberg-Higgs	2×10^{-2}	10^{-24}
Eichten *et al.* - composite Higgs		10^{-24}
$SU(2)_L \times SU(2)_R \times U(1)$	0	$<10^{-29}$
experiment	3×10^{-2} (90% CL)	$\lesssim 10^{-24}$

Although CP violation has only been detected in the neutral K systems discussed above, there are other processes involving kaons which may play an important role in determining the nature of CP violation. Examples of processes which can be experimentally studied for evidence of time reversal invariance are $K_L^o \to \pi\mu\nu$, $K_L^o \to \mu\nu\gamma$ and $K_L^o \to \mu\nu e^+e^-$ decays. Here, the presence of nonzero muon polarization transverse to the decay plane is the indicator of T violation. In $K_L^o \to \pi\mu\nu_\mu$ decay this effect might be due to the interference between the two amplitudes $f_+(P_K+P_\pi)$ and $f_-(P_K-P_\pi)$. The results derived from measurement of the transverse μ polarization can be expressed in terms of Imξ, where

$$\mathrm{Im}\xi \propto < \overline{\sigma}_\mu \cdot (\overline{p}_\mu \times \overline{p}_\pi) > m_k .$$

Recently it was found that Imξ = 0.009 ± 0.03.[31] The Weinberg Higgs model of CP violation would predict an effect at the level 10^{-3}, an order of magnitude below the present limit and where final state interactions are non-negligible. Determining the level at which such effects exist is crucial to the development of weak interaction theory.

Other possible sources of potentially vital information on CP violation could come from high sensitivity studies of rare neutral current processes (see Table II), such as $K \to \gamma\gamma$, $\mu^+\mu^-$, πe^+e^-, $\pi\nu\overline{\nu}$, which only occur in higher order and at rates suppressed by the GIM mechanism. Consequently, these decays may provide particularly sensitive tests of milliweak models. Table II shows the present experimental limits for some of these. Of course, the ratios expected in milliweak theories are extremely small ($\lesssim 10^{-11}$) and will almost certainly require the intense beams from a kaon

Table II. Rare neutral current K decays.

	Experimental branching ratio [a]	Milliweak production
$K_L^o \to e^+e^-\gamma$	$(17.4 \pm 8.7) \times 10^{-6}$	
$K_L^o \to \mu^+\mu^-\gamma$	$(2.8 \pm 2.8) \times 10^{-7}$	
$K_L^o \to e^+e^-\pi^o$	$<2.3 \times 10^{-6}$	10^{-11} [b]
$K_L^o \to \mu^+\mu^-\pi^o$	$<1.2 \times 10^{-6}$	
$K_L^o \to \pi^+\pi^-\gamma$	$(1.52 \pm 0.16) \times 10^{-5}$	
$K_L^o \to \pi^o\nu\overline{\nu}$		10^{-13} [c]
$K_S^o \to \gamma\gamma$	$<0.4 \times 10^{-3}$	
$K_S^o \to \mu^+\mu^-$	$<3.2 \times 10^{-7}$	
$K_S^o \to e^+e^-$	$<3.4 \times 10^{-4}$	

[a]See Ref. 20.
[b]See Ref. 32.
[c]See Ref. 33.

factory to reach the realm of effective constraints on model building.

As discussed by Herzceg,[34] observation of muon number violating K decays, such as $K_L^o \rightarrow e^{\pm}\mu^{\mp}$, $K_S \rightarrow e^{\pm}\mu^{\mp}$, $K_L^o \rightarrow \pi^o e^+\mu^-$, $K^+ \rightarrow \pi^+e^+\mu^-$, could add an extra dimension to the understanding of flavour-changing interactions. These processes, along with the ones mentioned earlier ($\mu \rightarrow e\gamma$, $\mu^-Z \rightarrow e^-Z$, etc.), may occur through neutral gauge boson exchange, scalar boson exchange if flavour-changing Higgs particles exist, or through the existence of heavy neutral leptons. Assuming Higgs exchange, estimates for the branching ratio of $K_L^o \rightarrow \mu^+e^-$ are in the range $\sim 10^{-12}$ compared to the present limit of $\leqslant 7 \times 10^{-9}$.

There are many other areas involving the weak interactions of kaons which would merit further study using the intense beams potentially available at a K-factory. Some examples are determinations of the other Kobayashi-Maskawa mixing angles using $\Delta S=1$ semileptonic processes, such as K_{e3} decay, hyperon decays, and the K_L^o - K_S^o mass difference.[35] Studies of electron-muon universality in K_{e2} decays, studies of the structure dependence of the $\bar{s}d$ vertex in $K \rightarrow \mu\nu\gamma$ and $K \rightarrow e\nu\gamma$ decays, and experiments dealing with the $\Delta I=1/2$ rule are other examples.

I have not touched on the many important problems in strong interactions which could also be studied in detail at a K-facility. A partial list of these includes:

- hypernuclei, charmed nuclei?
- Y^*, Z^* resonances, QCD studies?
- K^+, K^- nuclear scattering
- K^o, $\bar{K}^o$ regeneration
- exotic atoms
- pion nuclear scattering

Another subject that could play a significant role in the life of a kaon factory and that could make substantial contributions to physics involves neutrinos. It is apparent that we are now embarking on a long road which will eventually lead to an understanding of the basic nature of the neutrino. Within the last few months at least five new experiments have been proposed at LAMPF dealing with neutrino oscillations. As discussed by Rosen and Kayser,[36] if oscillations exist, then it is not going to be easy to interpret the results of experiments which measure $\sin^2\theta_W$. Precise experiments done with high flux neutrino beams will obviously be needed. Consider neutrino electron scattering involving the reactions

$$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$$
$$\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$$
$$\nu_e + e^- \rightarrow \nu_e + e^-$$
$$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^- \ .$$

These purely leptonic reactions provide fundamental information necessary for testing models of the weak interactions involving neutral currents and the interference between neutral and charged currents. The cross sections are extremely small

($\sim 10^{-42}$ cm^2/GeV) and relatively few events ($<10^3$) of all types have been observed so far.[37] The potential for intense neutrino beams at a K-factory could result in detailed studies of electron neutrino scattering.

Two approaches are under active consideration at TRIUMF for accelerating proton beams with sufficient energy for production of high flux beams of kaons, neutrinos and other particles with intensities two orders of magnitude or more greater than at existing facilities. The first approach[38] is based on a pair of superconducting ring cyclotrons used to accelerate the 0.45 GeV TRIUMF beam to 3 GeV and then to 8.5 GeV. Proton currents up to ~ 400 μA are possible. The macroscopic duty factor would be 100% as in the present operation at TRIUMF. The RF time structure of the beam would also be similar to that of the present operation and could possibly be put to great advantage in conjunction with RF particle separators to produce clean charged kaon beams. Time-of-flight measurements for neutral beams would be another feature.

The second alternative[39] involves the use of proton synchrotrons. In order to match the continuous time structure of the cyclotron to the discontinuous structure of the synchrotron, it is suggested that ~ 100 turns could be stacked in the cyclotron and then repeatedly injected into the synchrotron. Two designs are presently being considered to reach 20 GeV. One involves a single 20 GeV synchrotron and the other is based on a 3 GeV accumulator-booster stage followed by a slow-cycling synchrotron. The proton intensities could be in the range of 100 μA, with duty factors of $\sim 10^{-5}$ and 50% possible under different modes of extraction. Low duty factor operation would be an important feature for neutrino experiments.

Although knowledge of production cross sections is very sketchy, it is possible to identify several varieties of neutrino beams which might be available at a kaon factory:

1. In-flight decay beams

a. ν_μ from $\pi^+ \to \mu^+\nu_\mu$. Using the BNL[40] wide band ν beam as a reference, a proton current of Ip = 100 μA at ~ 20 GeV would result in a ν_μ flux $\sim 10^8$/cm^2/sec/GeV at $E_\nu \sim 1$ GeV. This would be a gain of about a factor of 200 over present ν_μ beams at these energies.

b. $\overset{(-)}{\nu}_e$ from $K^o_L \to \pi^\pm e^\mp \overset{(-)}{\nu}_e$. A neutral beam would contain ν_e and $\overline{\nu}_e$ peaked at $E \sim 1$ GeV with flux $\sim 10^5$/cm^2/sec/GeV. This would yield event rates for $\nu_e e \to \nu_e e$ comparable to those at the present AMPF neutrino facility and would enable the first studies in this energy range to be done with electron neutrinos and antineutrinos.

2. Beam stop beams

Monoenergetic ν_μ beams from $K^+ \to \mu^+\nu_\mu$ (branching ratio 63%) and $\pi^+ \to \mu^+\nu_\mu$ at P_{ν_μ} = 200 MeV/c and P_{ν_μ} = 30 MeV/c, respectively, would be produced in the beam stop along with ν_e and $\overline{\nu}_\mu$ from $\mu^+ \to e^+\nu_e\overline{\nu}_\mu$ decays. Crude estimates indicate that the flux at 220 MeV/c may be in the 10^6-10^7/cm^2/sec range at ~ 10 m from the beam stop and the ν_μ, ν_e, and $\overline{\nu}_\mu$ fluxes may be considerably higher.

In conclusion, serious consideration is now being given to a high intensity accelerator which would boost the meson factory proton beam to energies of 5-30 GeV. Such a facility would be much more than just a "kaon factory" since beams of pions, muons, protons, hyperons, and neutrinos would also be available with intensities greater by factors of 100-1000 than those at existing accelerators. As was the case for the meson factories, a new and exciting era in the development of nuclear and particle physics can be eagerly anticipated.

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References

1. Proceedings of the Kaon Factory Workshop, ed. M.K. Craddock, TRIUMF report TRI-79-1 (1979).
2. S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967).
3. A. Salam, Proc. 8th Nobel Symp. Stockholm, ed. N. Svarthölm (Almqvist and Wihsell, Stockholm, 1968).
4. S.L. Glashow, Nucl. Phys. 22, 579 (1961).
5. H. Georgi and S.L. Glashow, Phys. Rev. Lett. 32, 438 (1974).
6. H. Georgi and D.V. Nanopolous, Nucl. Phys. B159, 16 (1979).
7. J.D. Bowman *et al.*, Phys. Rev. Lett. 42, 556 (1979).
8. Previous limits have been reported by
   P. Depommier *et al.*, Phys. Rev. Lett. 39, 1113 (1977);
   A. van der Schaaf *et al.*, Nucl. Phys. A340, 249 (1980).
9. D. Bowman, C.M. Hoffman *et al.*, LAMPF proposals 400, 455.
10. D. Bryman, C.K. Hargrove *et al.*, TRIUMF proposal 104.
11. See for example, R. Barbieri *et al.*, CERN preprint TH.2900 (1980).
12. H.L. Anderson *et al.*, LAMPF proposal 455;
    K. Crowe *et al.*, TRIUMF proposal 134;
    J. Egger, Proc. 8th Int. Conf. on High Energy Physics and Nuclear Structure, ed. D.F. Measday, A.W. Thomas, Nucl. Phys. A335, 87 (1980).
13. See R. Mohapatra and J.C. Pati, Phys. Rev. D 11, 566 (1975).
14. D. Bryman *et al.*, TRIUMF proposal 52.
15. P. Depommier *et al.*, TRIUMF proposal 23.
16. M. Macfarlane *et al.*, LAMPF proposal 32.
17. M. Daum *et al.*, Phys. Lett. 74B, 126 (1978).
18. H. Chen *et al.*, LAMPF proposal 225.
19. For discussion see C.S. Wu, P.O. Egan, Chairmen, Panel P-4, Proc. of the Workshop on Program Options, LA-8335-C, vol. 1, 49-63.
20. Particle Data Group average. Rev. Mod. Phys. 52, S18 (1980).
21. This value is the average of all experiments given by the Particle Data Group in Rev. Mod. Phys. 52, Part II, S90 (1980).
22. L. Wolfenstein, Phys. Rev. Lett. 13, 562 (1964).
23. N.R. Ramsey, Phys. Reports 43C, 409 (1978).
24. M. Kobayashi and T. Maskawa, Prog. Theor. Phys. 49, 652 (1973).
25. T.D. Lee, Phys. Reports 9C, 143 (1974).
26. S. Weinberg, Phys. Rev. Lett. 37, 657 (1976);
    A.A. Anselm and D. D'Yakonov, Nucl. Phys. B145, 271 (1978).
27. E. Eichten *et al.*, Phys. Rev. Lett. 45, 225 (1980).
28. See J.H. Christenson *et al.*, Phys. Rev. Lett. 43, 1212 (1979).
29. J.H. Christenson, *ibid.*, 1209.
30. BNL proposal and FNAL proposal.
31. M.M. Morse *et al.*, Phys. Rev. D 21, 1750 (1980).
32. J. Ellis, M.K. Gaillard and D.V. Nanopoulos, Nucl. Phys. B109, 213 (1976).
33. F.J. Gillman and M.B. Wise, Phys. Rev. D 21, 3150 (1980).
34. P. Herczeg, Proc. of the Kaon Factory Workshop, *op. cit.*, 20.
35. R. Schrock *et al.*, Phys. Rev. Lett. 42, 1589 (1978).
36. P. Rosen and B. Kayser, Purdue preprint (1980).
37. L.W. Mo, VPI preprint VPI-HEP-80/8.
38. M.K. Craddock, private communication.
39. J.R. Richardson, private communication.
40. W. Lee *et al.*, Proc. Int. Neutrino Conf. Aachen 1976, 319 (1977).