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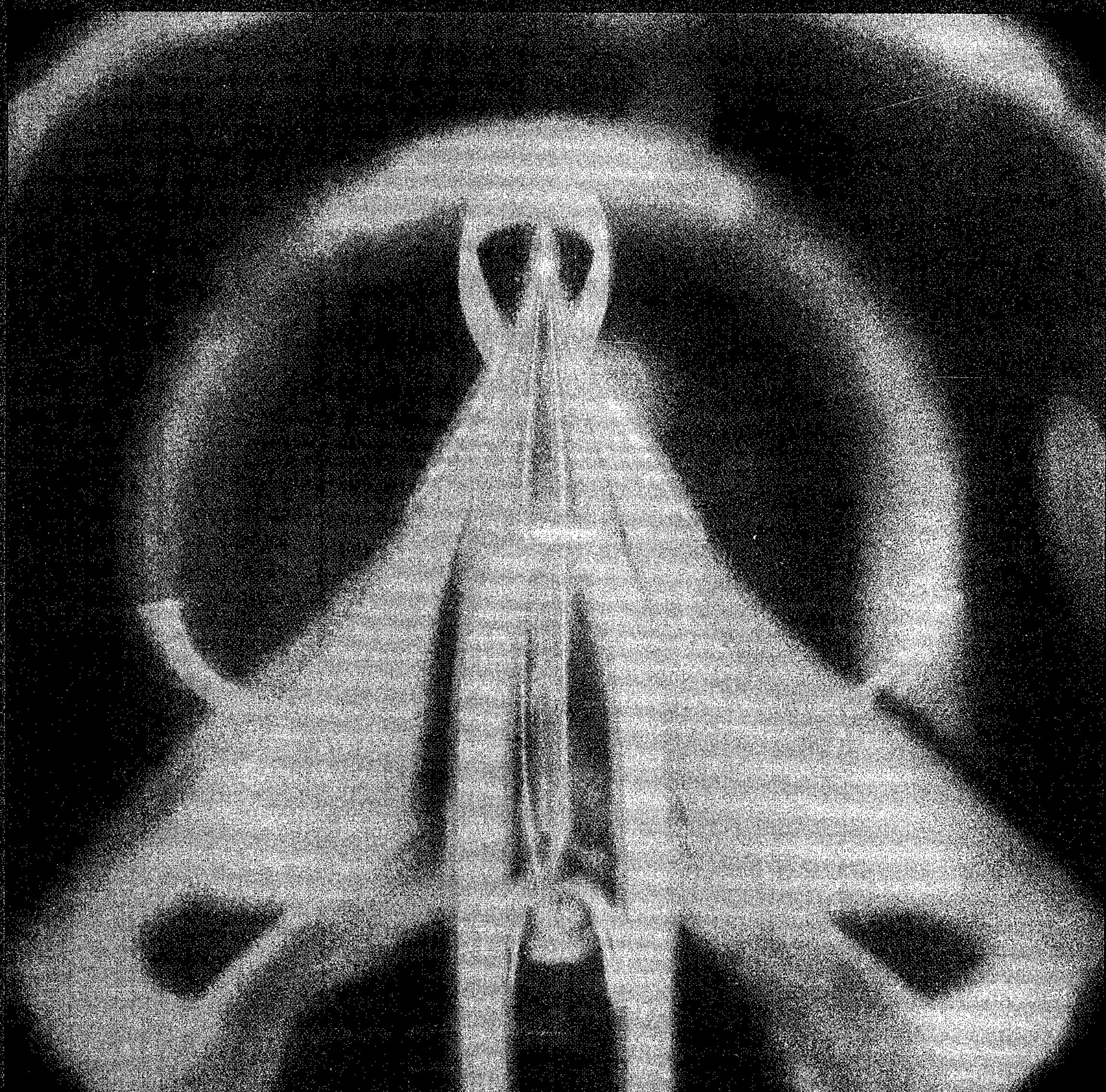

Beam Line

A PERIODICAL OF PARTICLE PHYSICS

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Cover: Measurement of the submicron beam spots that will be created at future linear colliders poses a formidable challenge. Physicists at SLAC are experimenting with narrow jets of liquid metals that might be used to intercept such a beam profile. The "nozzle" shown has been formed from a glass tube heated and drawn to pinch the opening to a submicron orifice.

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FEATURES

DEPARTMENTS

Printed on Recycled Paper

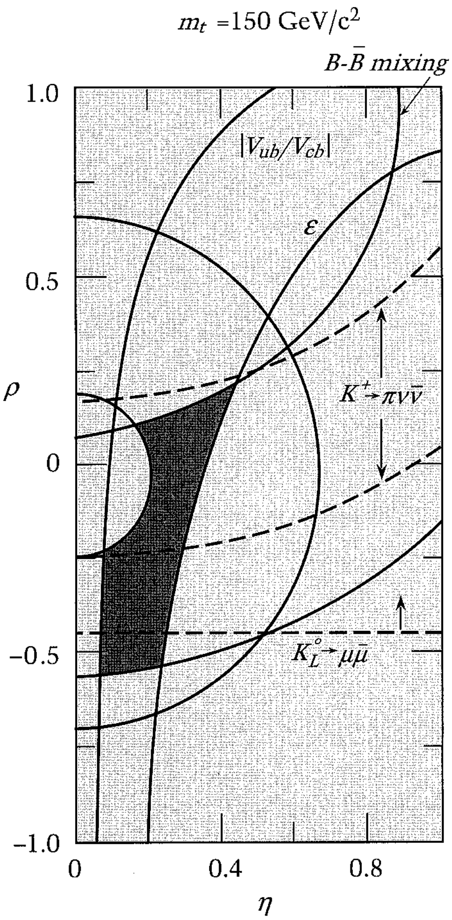
THE TRIUMF KAON FACTORY

by MICHAEL CRADDOCK
and PETER KITCHING

A powerful new Canadian facility for a broad range of particle and nuclear physics studies

"There is no excellent beauty that hath not some strangeness in the proportion." —Francis Bacon

STRANGENESS WILL CERTAINLY BE AVAILABLE IN PROFUSION at the KAON Factory, in the form of intense beams of kaons, the lightest particles carrying the strange quark—and through KAON we look forward to much beautiful physics. But this new 30 GeV, 100 μA facility, to be built at TRIUMF in Vancouver, British Columbia, Canada, will be a factory for more than kaons. It will also produce beams of antinucleons, hyperons, pions, muons, and neutrinos, 100 times more intense, or cleaner, than are available now—hence the acronym Kaon-Antiproton-Otherhadron-Neutrino Factory. The existing 500 MeV H^- cyclotron at TRIUMF will provide the required 100 μA injector. To accelerate this intense beam to 30 GeV will require an interleaved sequence of two fast-cycling synchrotrons and three storage rings, with some novel design features. One-third of the construction costs (Cdn $708 million) has been promised by British Columbia, the second third has recently been offered by the government of Canada, and it now remains to secure the pledges previously made by other countries, including the United States, following the model used in financing HERA.



Limits of the Kobayashi-Maskawa matrix parameters (η, ρ) from present experiments (solid area) and from future K-decay experiments [B.R. ($K^+ \to \pi^+ \nu \bar{\nu}$) < 2×10^{-10}, B.R. ($K_L^o \to \mu\bar{\mu})_{SD}$ < 1.5×10^{-9}].

SCIENTIFIC PROGRAM

THE MUCH MORE INTENSE, or pure, beams of secondary particles mentioned above will make possible a broad range of particle and nuclear physics studies on the "precision frontier," complementary to the "energy frontier." Major areas of investigation will be rare decay modes of kaons, CP violation, meson and baryon spectroscopy, meson and baryon interactions, neutrino scattering and oscillations, quark structure of nuclei, properties of hypernuclei, K^+ and $\bar{p}$ scattering from nuclei, and polarization effects.

The improved low-energy pion and muon beams will also greatly enhance the existing programs in muon spin resonance and cancer therapy. The range of physics that can be studied at KAON is very large, and only some of the highlights can be touched on here.

Rare Decay and CP Violation

The basic motivation for studying rare and forbidden kaon decay processes is still very strong. The emphasis will continue to be on attacking many of the same issues addressed at the energy frontier of the high energy colliders, by searching for processes forbidden in the Standard Model and looking for rare processes that are sensitive to the effects of virtual heavy particles. At KAON one can envisage experiments with sufficient sensitivity to probe such processes at a level that will critically test the Standard Model predictions. Although the main emphasis is on looking for physics beyond the Standard Model, one can also gain important information from K decay experiments on the parameters inside the Standard Model. This information can be used to make predictions of increasing accuracy for various processes, as our knowledge of the Standard Model parameters and hadronic corrections improves. The experimental measurement of the rate for these processes then becomes a more sensitive test of the Standard Model.

A prime example of such a process is $K^+ \to \pi^+ \nu \bar{\nu}$, one of the few second-order weak processes where reliable calculations can be confronted by experiment. Although this decay mode has not yet been seen, an experiment to search for it is now under way at the Brookhaven National Laboratory AGS. The predicted branching ratio is so small (2×10^{-10}) that even if the decay is unambiguously detected at Brookhaven, an accurate measurement must await the more intense beams which will become available at the KAON Factory. Such a measurement would provide an important constraint on the two least well-known of the Kobayashi-Maskawa mixing matrix elements (ρ and η) as indicated in the drawing above.

A second example is the CP-violating decay $K_L^0 \to \pi^0 \nu \bar{\nu}$, predicted by the Standard Model to occur with a branching ratio of a few times 10^{-11}. Since the direct CP-violating term is a thousand times larger than the indirect term, the observation of even a single unambiguous event of this type at the predicted level would confirm the existence of direct CP violation, a process whose existence is still uncertain in spite of many years of heroic experimentation. A measurement of the branching ratio would immediately give the value of the Kobayashi-Maskawa mixing matrix element η, which is responsible for CP violation in the Standard Model.

In both the examples cited above, the long-range effects are small, so that QCD corrections are much easier to handle than is usually the case in kaon decay, allowing sensitive tests of the Standard Model to be made that are relatively free of theoretical ambiguity.

Kaon decays that are forbidden in the Standard Model, such as $K_L \rightarrow \mu\bar{e}$, have been the subject of numerous experiments because their discovery would immediately signal new physics, in particular the existence of new forces whose quanta mediate the decay (such as neutral Higgs, horizontal gauge bosons, leptoquarks or supersymmetric particles). KAON will be able to probe their existence even if they are a thousand times as heavy as the W and Z, with a sensitivity unequaled in experiments done so far (see the table at the top of the page).

Mass Bounds from Different Processes

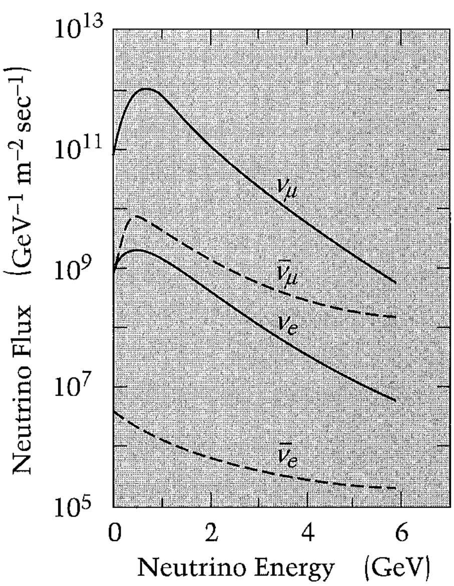
Process	Branching Ratio	Higgs Scalars (GeV/c^2)	Pseudoscalar Leptoquarks (TeV/c^2)	Vector Leptoquarks (TeV/c^2)
$K_L^0 \rightarrow \mu\bar{e}$	$<3.3\times10^{-11}$	19	14	260
$K_L^0 \rightarrow \mu\bar{\mu}$	7.6×10^{-9}	4.7	3.6	62
$K_L^0 \rightarrow e\bar{e}$	$<1.2\times10^{-10}$	14	4.6	190
$K^+ \rightarrow \pi^+\mu\bar{e}$	$<2.1\times10^{-10}$	1.7	0.9	9.6
$\mu A \rightarrow eA$	$<4.6\times10^{-12}$	22	22	118

Neutrino Physics

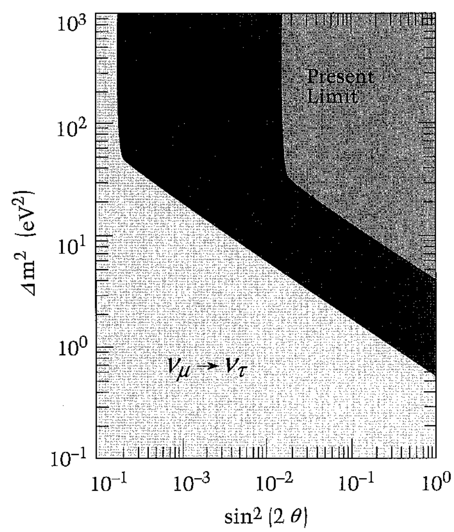
The Standard Model assumes that neutrinos are left handed while antineutrinos are right handed, both being massless, and that neutrinos are point-like, with zero charge and magnetic moment, and only participate in the weak interaction. There is no known general principle that requires strict masslessness for electrically neutral fermions, however, and non-vanishing neutrino masses arise naturally in most extensions to the Standard Model. If neutrinos have finite mass, then they can oscillate from one generation to another, although no such oscillations have yet been seen.

The neutrino beams that will be available at KAON, two orders of magnitude more intense than at other facilities, will enable many of these assumptions about the properties of neutrinos to be tested. For example, neutrino-electron scattering can be used to search for interactions that change the handedness of the leptons and are thus forbidden in the Standard Model. The same reaction can be used to look for evidence of neutrino charge and magnetic moment, both of which have astrophysical implications. The search for neutrino oscillations could be pushed to unprecedented levels of sensitivity (see graph at right) since the neutrino intensity from KAON would enable much longer baseline experiments (up to 100 km) to be performed. The relatively high flux of neutrinos above 3.5 GeV gives the possibility of searching for $\nu_\mu \rightarrow \nu_\tau$ oscillations (see graph on next page).

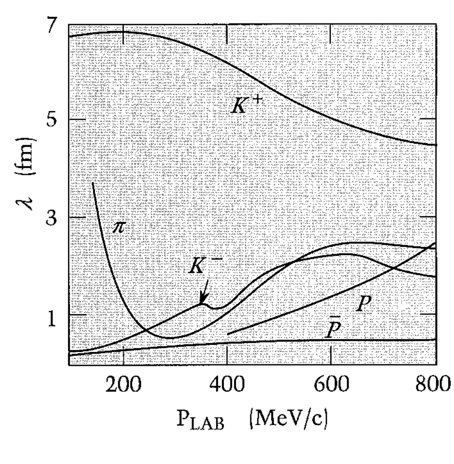
Neutrino-proton scattering will also be a topic of great interest, since it has the potential to give new information on the weak axial-vector form factor and on the heavy quark



Anticipated neutrino fluxes at KAON.



Limits on neutrino oscillation parameters.



Mean free paths of hadrons in nuclear matter.

content of the nucleon. This latter is of great current interest as a result of the SMC experiment at CERN that seems to imply that the strange-quark content of the proton is much higher than expected.

Hadron Spectroscopy

Because the quark model remains the most useful tool in understanding hadron spectroscopy, it is reasonable to divide spectroscopy into conventional quark model states (in which mesons are quark-antiquark pairs and baryons consist of three quarks) and exotic gluonic and multiquark (four or more) states.

As far as conventional quark model states are concerned, many more states are predicted than have been observed. At least part of the reason for this state of affairs is that the states are often broad and overlapping, they can and often do mix, and there is the possibility of exotic gluonic and multi-quark states in the spectrum. Recent experimentation has been aimed at trying to untangle this confused state of affairs and establish whether or not exotic gluonic and multiquark states exist. KAON has the potential to play a leading role in the future development of this subject. It will make available intense beams of pions, kaons and antiprotons with unprecedented purity and momenta up to 20 GeV/c. The possible discovery of a glueball state, made entirely of gluons, is but one example of the potential of KAON to profoundly affect our understanding of the strong interactions.

Antiproton Physics

Present plans for the experimental facilities available at KAON do not include an antiproton accumulator or storage ring, at least initially, though space has been left to add them later. Nevertheless KAON could deliver antiproton beams with intensities in the range of 10^6 to 10^8 per second at momenta between 500 MeV/c and several GeV/c. These intensities would be quite competitive with other antiproton facilities such as LEAR, except at momenta below 500 MeV/c. In particular, the energy regime above the maximum LEAR energy of 2 GeV/c is relatively unexplored. It thus appears that a rich and varied program of physics could be carried out with antiprotons at KAON, encompassing hadron spectroscopy, tests of fundamental symmetries, studies of the nucleon-antinucleon force and use of the antiproton as a nuclear probe.

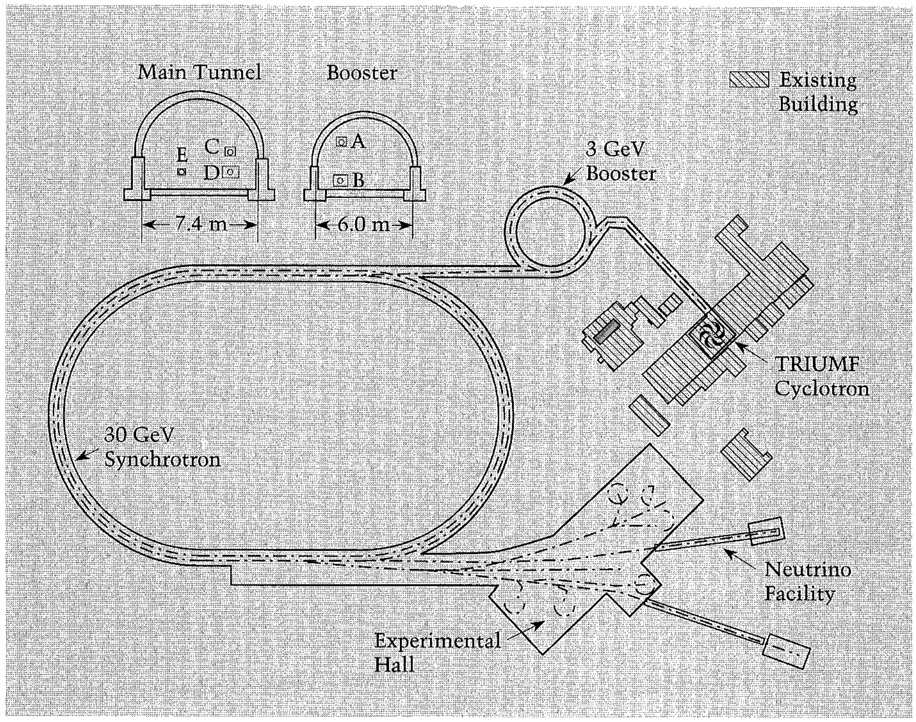
Nuclear Physics

The basic aim of the nuclear physics program at KAON will be to shed light on non-perturbative QCD and its relation to conventional nuclear physics. The 1970s and 1980s saw the issue of mesonic exchange currents and 'non-nucleon' exotic particles in nuclei emerge, with the role of π's and Δ's as nuclear constituents. Now and in the near future we see the question of the role of quarks in nuclei come to the forefront, i.e., what are the relevant degrees of freedom in nuclei? Can we continue to think of nuclei as made up of protons and neutrons (with a few π's and Δ's thrown in), or are there nuclear phenomena which will force us to take the underlying quarks and gluons into account explicitly? At KAON, intense beams of K^+, the most weakly interacting of the hadrons (see figure bottom left), could be used to probe the inner regions of the nucleus. This is a promising technique which has not been made use of in the past because of the feeble beams of kaons hitherto available.

A second example is the study of hypernuclei, in which a strange quark is deposited in the nucleus in the form of a Λ or Σ particle. The Λ hypernuclei are well established, but the existence of Σ hypernuclei, particularly in long-lived states, is fraught with controversy and awaits better experiments. The possibility of forming "double" hypernuclei, containing two strange quarks, is an even more exciting prospect opened up by KAON. The study of such states, if they exist, will require the most intense possible beams of kaons, but could provide information about, for instance, the $\Lambda\Lambda$ force, that can be obtained in no other way.

THE FACILITIES

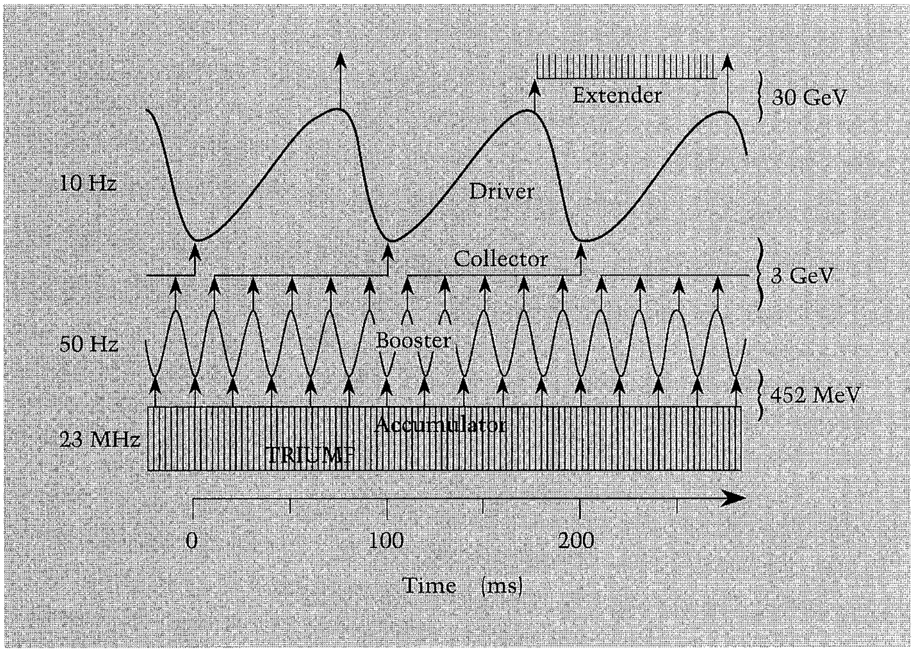
THE TRIUMF H$^-$ CYCLOTRON, which routinely delivers 150 μA beams at 500 MeV, provides a ready-made and reliable injector for KAON. It will be followed by two fast-cycling synchrotrons, interleaved with three storage rings for time matching. The diagram above right shows the general site layout, with the A and B rings in the Booster tunnel and the C, D and E rings in the main tunnel. The illustration on the next page indicates the time sequence of beam pulses through the five rings.



Proposed layout of the accelerators, showing cross sections through the tunnels.

The initial Accumulator ring gradually accumulates the regular 23 MHz stream of beam bunches produced by the cyclotron in forty notional "buckets" around the circumference. The process is similar to filling a moving circular train of boxcars from regularly spaced piles on a conveyor belt. It continues for 20 ms, time enough for about 20,000 orbits of the ring. Liouvillean prohibitions on continually injecting into the same region of phase space are avoided by stripping the H$^-$ beam from the cyclotron into a circulating beam of protons. Finally the forty bunches are transferred to the Booster, which has the same circumference.

In the next 10 ms the Booster synchrotron accelerates the beam bunches from 74% to 97% the speed of light, increasing their energy sixfold to 3 GeV. The use of a booster stage reduces the cost of the whole system. Because the beam shrinks in



Energy-time plot showing the progress of the beam through the five rings.

diameter during acceleration it enables the magnets in the much longer 30 GeV synchrotron to be significantly reduced in size and cost. It also reduces the complexity and cost of the radiofrequency accelerating system by restricting the problem of providing a large frequency rise, matching that in velocity, to the Booster, a small ring where only a low radiofrequency voltage is required (750 kV).

The Collector is a fixed-energy ring in the main tunnel, five times longer than the Booster, used to collect five successive bunch trains from it end-to-end over a period of 100 ms. Special radiofrequency cavities are used to lengthen the bunches and avoid the microwave instabilities that would otherwise be expected at full intensity.

The Driver synchrotron is located immediately beneath the Collector and is used to accelerate the 200-bunch train assembled there from 3 GeV to 30 GeV. The speed of the protons increases from 97% to 99.95% of the speed of light and the frequency of the accelerating voltage (2,550 kV) must also increase by 3%. The bunch train extracted from the Driver is about 3 μs long and can be used directly for neutrino experiments, for which sharp pulses are desirable in order to better distinguish real signals from background.

For experiments with strongly interacting particles, like kaons, pions and antiprotons, a sharp pulse would produce too many simultaneous interactions, indistinguishable from one another. For these the beam is transferred to the Extender. This is a deliberately imperfect storage ring from which the protons are gradually extracted into the main experimental hall over the full 100 ms cycle time.

This functional separation of acceleration and storage allows the Booster and Driver rings to run continuous acceleration cycles without flat bottoms or flat tops, thus providing maximum intensity and 100% duty factor. The other major difference from existing machines in this energy range is the fast cycling rate: 50 Hz for B and 10 Hz for D, compared to ~0.5 Hz for the Brookhaven AGS or CERN PS. This increase is necessary in order to achieve the greater intensity desired, because the number of protons storable per pulse is already at the limit (a few $\times 10^{13}$) set by space-charge defocusing effects, for reasonable magnet apertures.

The high intensity and record beam power (3 MW) have influenced the design in many ways. Highly efficient collimation systems have been designed for each of the rings, and lossy processes have been avoided or minimized in the design. For instance, H^- stripping is used for injection, bunches are transferred from bucket to bucket between rings, the buckets are never filled more than 60%, transition is kept above the acceleration range to avoid both beam dynamic and rf beam-loading problems, and a highly efficient three-element slow extraction system is planned.

To provide the long straight section for the slow extraction system, a racetrack-shaped lattice is used in the Extender. Simulations indicate that the spills can be kept below 0.2%. Similar lattices and tunes are used for the rings in each tunnel—a natural choice providing structural simplicity, similar magnet apertures and straightforward matching for beam transfer. Separated-function magnet lattices are used, with the dispersion modulated so as to lower its mean value and keep transition above top energy. The reference designs for the A and B rings are almost circular, with superperiodicities of 3 and 6 respectively, although racetrack designs are also being investigated.

Because the number of protons stored is similar, beam stability problems are expected to be similar in scope to those in existing machines. The rapid-cycling rate tends to push the challenges towards the hardware. Fortunately, experience with rapid-cycling synchrotrons is available from electron and low-energy proton machines, such as the Argonne IPNS, Fermilab Booster, and especially the 800 MeV 165 μA ISIS at Rutherford. Prototype construction and testing has been an important component of the preparations for KAON over the last three years.In this we have been supported by an $11 million pre-construction study.

Under this program, prototype dipole and quadrupole magnets for the Booster have been built, powered at 50 MHz and had their fields measured. A novel power supply allows the resonant frequency to be switched between 33 Hz and 100 Hz each cycle, to make the rise three times longer than the fall and reduce the rf accelerating voltage requirement.

The prototype rf cavity for the Booster has recently provided the first full-scale demonstration of the superior performance achievable with a perpendicularly biased yttrium-garnet ferrite tuner (a LAMPF suggestion), as opposed to conventional parallel-biased nickel-zinc ferrite. Gap voltages of 65 kV have been obtained with 50 Hz pulse rate and 46–61 MHz frequency swing.

Two designs are being evaluated for the ceramic beam pipe needed within the fast-cycling magnets. One, built in the UK, follows the Rutherford ISIS scheme with a separate internal wire shield to provide a low impedance path for the image currents. The other, being developed by Science Applications International Corporation (San Diego), has silver conducting stripes laid down in grooves on the internal surface of the pipe.

The kicker prototype follows the CERN PS transmission-line design and, in a collaborative effort, has been shown to be capable of operating at 50 Hz. Another pulsed deflection device that is quite novel is the 1 MHz chopper needed to remove 10% of the pulses from the cyclotron, to leave beam gaps for kicker operation in the new rings. The prototype uses a 0.5 μs coaxial delay line cable for energy storage and has achieved 6 kV pulses with rise and fall times below the 40 ns specification.

Because H^- ions are normally extracted from the cyclotron by stripping, a new resonant extraction system has had to be developed to extract the ions whole. The rf deflector, electrostatic septum, and first magnetic channel have already been installed and tested, demonstrating approximately 90% extraction efficiency; the 10% lost is intercepted by a special stripper, avoiding any irradiation of the extraction elements.

The slow extracted proton beam will be shared between two lines, each with two production targets. Each target will feed at least two forward K and p channels, and in some cases backward μ channels. The six charged kaon channels will have maximum momenta of 0.55, 0.8, 1.5, 2.5, 6 and 21 GeV/c. With solid angle and momentum acceptances ranging from 8 msr × 6% for the lowest momentum channel to 0.1 msr × 1% for the highest, the maximum fluxes range from 0.6 to 3.7×10^8 K^+/s and from 0.7 to 11×10^7 $\bar{p}/s$. A dedicated line and area is provided for polarized proton beams. The neutrino production target, fed by the fast extracted beam, is located in the main experimental hall for good crane access, but the neutrino experimental area is in a separate building. Target development has included both modification of an existing rotating graphite target (driven and cooled by water) from graphite to tungsten, and the construction of a prototype target rotated by a flexible cooling line.

Environmental, industrial and economic impact studies have also been completed and the cost estimates and schedule updated. The plan is to share the total cost of Cdn $708 million equally among the governments of Canada, British Columbia, and other participating countries, along similar lines to the funding of HERA. The $236 million federal and provincial shares have each now been approved, subject to successful negotiations on the operating costs and successful negotiations abroad for the remaining one-third. In view of the pledges made in previous international discussions, the prospects for this look good on the time scale envisaged.

In the U.S. there is a potential user community of several hundred, and the Nuclear Science Advisory Committee (NSAC) recommended strongly in favor of a U.S. $75 million contribution in its recent Long Range Plan; this has been included in DOE budget planning. Germany, France, and Italy have promised financial support proportional to the number of their potential users. Participation is also expected from Japan, where there is strong scientific support. A number of other countries—Israel, PR China, South Korea, UK, and USSR—will contribute manpower towards design and construction and equipment for experiments. The negotiations to confirm these pledges are expected to take several months, but we look forward with confidence now to starting construction in 1992. ○

CP VIOLATION IN B MESON DECAYS

by David Hitlin and Sheldon Stone

An asymmetric electron-positron storage ring called a "B Factory" can provide a critical test of the Standard Model.

The intriguing phenomenon of *CP* violation, well-established, but not well-understood, is at the heart of a number of initiatives throughout the world to build an asymmetric e^+e^- *B* Factory. In this new type of storage ring, the energies of the electrons and positrons are not identical. This presents new challenges to accelerator physicists as well as to experimenters. We will briefly describe the physics motivation for the widespread interest in *B* Factories, as well as some of the unique characteristics of the experiments to be done at these new accelerators.

After twenty seven years of continuous experimental effort, we do not yet have a detailed understanding of the phenomenon of *CP* violation (see sidebar). The latest and most precise measurements, one done at Fermilab, the other at CERN, are not in agreement as to whether the so-called superweak model of Wolfenstein can explain *CP* violation in the *K* meson system. The superweak model postulates a new type of interaction that causes *CP*-violating transitions but produces no other observable phenomena. The idea of producing an explanation that deals with a particular phenomenon and is not testable in other situations is unpalatable, but the superweak theory has survived more than a generation of experimental challenges.

THE STANDARD MODEL, the current reigning theory of elementary particle physics, has withstood numerous experimental assaults. The Standard Model has built in to it a natural explanation for *CP* violation that can be tested in areas beyond the *K* meson system. The first challenge is to distinguish between the superweak and Standard Model explanations of *CP* violation; the second challenge is to ascertain whether the Standard Model can explain *CP* violation in both the K^0 and *B* systems, along with a host of other decay phenomena. How this is done is best described using a construct called the unitarity triangle

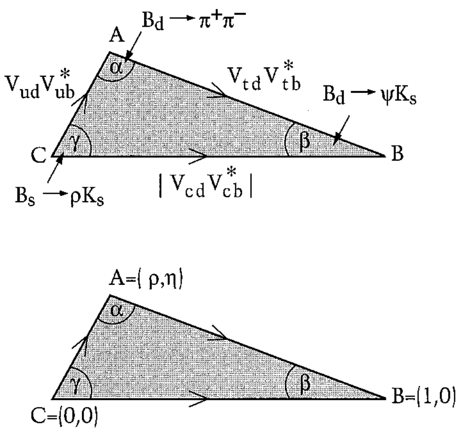
This triangle, which compactly summarizes the relation of *CP*-violating phenomena to other parameters of the Cabibbo-Kobayashi-Maskawa (CKM) matrix, is shown in the illustration on the next page. It is necessary to explain several features of the CKM matrix in a bit of detail in order for us to explain the significance of the unitarity triangle. Cabibbo showed in 1963, when only three quarks were known, that the slow rates of strange particle weak decays could be understood if a distinction was made between eigenstates (basis vectors) of the weak interaction and physical eigenstates of definite mass. Thus, with a single parameter, the Cabibbo angle, he was able to explain an entire class of decay processes. In 1973, Kobayashi and Maskawa generalized this idea to systems with larger numbers of quarks. They showed that six quarks were the minimum number required to encompass *CP* violation. The six quarks are grouped into three "generations" of doublets: $\binom{u}{d}\binom{s}{c}\binom{t}{b}$. The mixing between weak eigenstates and mass eigenstates in this picture can be described in terms of three real numbers (the so-called CKM angles) and one imaginary number (the CKM phase). The presence of this imaginary phase means that the Standard Model can accommodate, in a natural way, the phenomenon of *CP* violation. That is not to say, however, that the Standard Model interactions described so economically by the four CKM parameters **are** able to explain *CP* violation, just that the theory is sufficiently rich that it has the potential to do so. Whether it does or not is one of the most important open questions in elementary particle physics, one that is elegantly addressed by the relation summarized in the unitarity triangle.

Further insight into the structure of the CKM matrix was provided by

CP Violation

BY *CP* VIOLATION WE MEAN a lack of symmetry between the weak decays of particles and antiparticles. Until 1957, it had been assumed that certain symmetries of nature were self-evident. The discovery of the non-conservation of parity in the weak interactions upset this notion. The violation of parity meant that it is possible to distinguish between an event viewed directly and its mirror image, for most of us a non-intuitive concept. It was then proposed that a semblance of intuition could be recovered by asserting that symmetry could be restored by comparing the direct view of a particle with the mirror image of its antiparticle, a concept known as *CP* symmetry. This notion held until 1964 when Christensen, Cronin, Fitch, and Turlay found *CP*-violating decays of the K_L^0 meson. This lack of symmetry in the weak interactions is quite small (two parts per thousand), as opposed to parity violation, which is maximal. Nonetheless, the lack of *CP* symmetry in nature has far-reaching consequences.

Andrei Sakharov showed in 1967 that *CP* violation, operating at times of the order of 10^{-35} seconds after the big bang, as the universe entered thermal equilibrium, was capable of explaining why the universe we inhabit is dominated by matter, rather than being a mixure of matter and antimatter, as it was initially. This connection with the *CP*-violating decays seen in K_L^0 decays gave the phenomenon a role as central to cosmology as it had acquired in elementary particle physics. Ironically, this observation, one of the primary motivations for our desire to understand whether the mechanism of *CP* violation can be explained by the so-called "Standard Model," *ipso facto* requires physics beyond the Standard Model, in that as yet unobserved baryon-number-violating interactions are also required to describe the parameters of the known universe.



Two representations of the unitary triangle. The upper figure shows how the unitarity relation is represented as a closed triangle. The three angles of the triangle, α, β, and γ can be directly measured by measuring CP-violating asymmetries in B^0 meson decay. The lower figure shows the unitary triangle described by the two Wolfenstein paramaters ρ and η. If the base of the triangle is placed along the ρ axis and scaled to length one, then the apex of the triangle (A) lies at the point ρ, η.

The program of CP-violation measurements seeks to overdetermine the unitarity triangle. That is, since only three quantities suffice to determine a triangle, the measurement of a fourth or fifth quantity allows one to make a variety of triangles from the experimental quantities, any three of which must form a triangle consistent with any of the triangles made from different combinations of three quantities. If they do not, the Standard Model will be overthrown.

Wolfenstein's observation that the size of the elements decreased with distance from the diagonal of the matrix. The "Wolfenstein parametrization" has become a standard notation for discussions of the CKM matrix. In this approach, there are, of course, still four parameters. The first, λ, is essentially the original Cabibbo angle; the second, A, is related to the lifetime of B mesons. The other two, η and ρ, are less well understood; a series of measurements of weak decays is required for their determination.

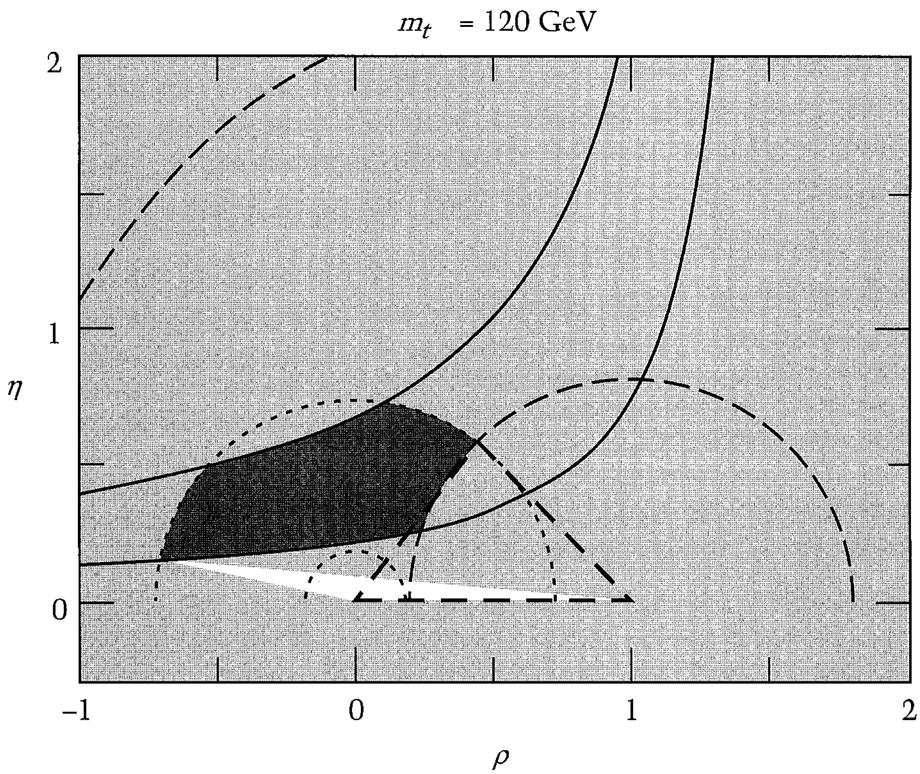
The CKM matrix is a unitary matrix,which imposes certain relations between its elements. In particular

$$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0,$$

which is just the definition of the unitarity triangle. The six CKM matrix elements related by the unitary triangle relation are not precisely known, for several reasons. The first is experimental uncertainty. For example, V_{cb} is related to the measured rate of B meson semileptonic decay, which has an associated experimental error. The second is theoretical uncertainty in relating measurements to CKM matrix elements. An example is V_{ub}, which suffers from model dependence in relating the matrix element to the measured high momentum end of the B-to-lepton decay spectrum. A third uncertainty is our lack of knowledge of the top quark mass, which could be remedied within the next few years by experiments at the Tevatron. The net result of these uncertainties is that the exact shape of the unitarity triangle is not precisely known. Taking into account the values of λ and A, and assuming the top quark mass to be 120 GeV, we can say that the point η, ρ must lie in the shaded region of the figure at the right. Improved measurements in the next few years can reduce the area of the shaded region to some extent. Our knowledge of the three sides of the unitarity triangle, while it does not completely specify the geometric figure, does limit the possible range of values of the angles of the triangle. For example, with a top quark mass of 120 GeV, the angle β can be no smaller than 15° and no larger than 150°. That is where *CP*-violating asymmetry measurements enter; these asymmetries are directly related to the angles of the unitarity triangle. Thus measurements of these asymmetries have the potential to test the self-consistency of the Standard Model: if the angles fall within the permitted range, we will have shown that the imaginary parameter of the six-quark CKM matrix can describe *CP* violation. If they fall outside the permitted range, this would represent the first failure of the Standard Model and potentially the first hint of the new physics that lies beyond it.

THE DISCOVERY of unexpectedly large B^0–$\bar{B}^0$ mixing by ARGUS in 1987 made it possible to consider the measurement of *CP* violation in the neutral B meson system as a plausible goal. Indeed, the expected *CP*-violating asymmetries could be as large as many tens of percent. The difficulty is that the modes in which these large asymmetries could occur have very small decay rates. Since the branching fraction for these modes is expected to be of the order of 10^{-4} to 10^{-5}, measuring these large asymmetries requires large samples of B mesons, as many as 10^8. In order to acquire a sufficient number of B mesons in a reasonable time, it is necessary to build a storage ring that can operate at the $Y(4S)$ resonance with a luminosity 15–20 times that achieved thus far. The $Y(4S)$ decays into either $B^0\bar{B}^0$ or B^+B^- pairs. Even this does not suffice, however; it is also necessary that in the B Factory accelerator the energies of the electron and positron beams be unequal, hence the name "asymmetric B Factory." The motivation for this comes from a combination of physics and technology. The *CP*-violating asymmetries we wish to measure at the $Y(4S)$ resonance are proportional to $\sin(t_1 - t_2)$, where t_1 and t_2 are the times at which the B^0 and $\bar{B}^0$ mesons decay. Since the two B mesons can decay in either time order, a measurement that includes all possible times and time orders is in effect an integration from $-\infty \le t_1 - t_2 \le \infty$, which is an even function of $t_1 - t_2$. Since $\sin(t_1 - t_2)$ is an odd function of $t_1 - t_2$, such a measurement of necessity yields an answer of zero.

The way around this conundrum was proposed in 1987 by Pier Oddone of Lawrence Berkeley Laboratory. Clearly, the way to come up with a non-zero result is to make a measurement that is not symmetric in $t_1 - t_2$. How can we do this? Such a measurement requires the ability to measure distances less than the average flight path of a B^0 meson before it decays. In a conventional storage ring, with the $Y(4S)$ stationary in the laboratory, B^0 mesons produced in



The shaded area shows the region of the (ρ, η) plane in which the apex of the unitarity triangle must fall (based on the measurement of CP-violating asymmetries) if the Standard Model description of CP violation is correct. The dashed-line triangle represents the largest value of β allowed (i.e., the largest CP asymmetry in the decay $B_d^0 \rightarrow J/\psi K_s^0$). The white triangle represents the smallest value of β allowed.

The CKM Matrix and the Unitarity Triangle

THE CABIBBO-KOBAYASHI-MASKAWA MATRIX describes the mixing between the three quark generations. It is a 3×3 matrix, with nine elements

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Each of the elements describes the strength of the weak transition between two quark species. The value of each element is typically determined by measuring the absolute decay rate of a semileptonic decay between hadrons containing the relevant quark species. For example, the element V_{cs} can be found from the rate for the process $D^0 \rightarrow K^- e^+ \nu_e$, since the D^0 contains a charmed (c) quark and the K^- a strange (s) quark.

The CKM matrix is a unitary matrix. This imposes certain relations between its elements. In particular,

$$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0.$$

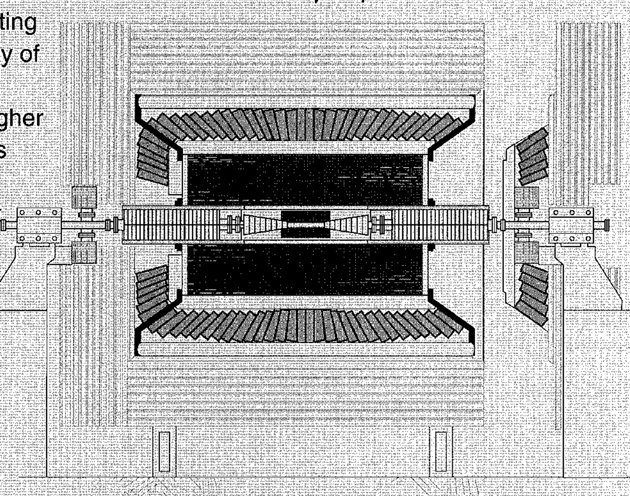
This means that the products of these three *CKM* matrix elements and three complex conjugates form a closed geometric figure, the unitarity triangle.

$\Upsilon(4S)$ decay travel a mean distance of 19 μm before decay. In spite of the rapid progress in precision vertex detection over the last several years, this accuracy is well beyond anything we can hope to achieve in the forseeable future. Oddone proposed to resolve this problem by taking advantage of the Lorentz boost in the lifetime of a particle that is moving rapidly with respect to the laboratory system. That is, if the $\Upsilon(4S)$ state were to be made in motion in the laboratory, the B^0 and $\bar{B}^0$ mesons produced when it decays would also be moving rapidly in the lab. If the velocity of the $\Upsilon(4S)$ were to be around half the speed of light, the mean distance traveled in the laboratory before a B meson decayed could be boosted to perhaps 200 μm, a distance that is readily measurable. Now it would be possible to effectively make the limits of integration unsymmetrical, so that the measured CP asymmetry is non-zero. This can be accomplished by making the energies of the electron and positron beams unequal, typically with a ratio of energies of about three to one.

AN EXPERIMENT TO MEASURE *CP* violation in the *B* meson system requires a detector that is conceptually similar to existing e^+e^- detectors, such as CLEO II now operating at the CESR storage ring at Cornell. A new detector must cope with higher crossing frequencies of the beams (there are, for example, 1658 bunches in the proposed PEP-based *B* Factory at SLAC, which means that there would be a beam crossing every four nanoseconds), much higher event rates, and higher

Experimental Measurements

HOW ARE THE *CP* ASYMMETRY MEASUREMENTS MADE? The desired measurements consist of determining the angles α, β, and γ. This is done by measuring the *CP*-violating asymmetries in decays of B^0 mesons to particular *CP* eigenstates. For example, the *CP*-violating asymmetry in the decay $B^0, \bar{B}^0 \rightarrow J/\psi K_S^0$ is directly proportional to sin 2β, while that for the decay to $\pi^+\pi^-$ is proportional to sin 2α. Direct measurement of sin 2γ requires measuring a *CP*-violating asymmetry in a decay of the B_S^0 meson, which demands energies higher than the $\Upsilon(4S)$ and is much more difficult. Several novel indirect methods of measuring γ have, however, been proposed.



A schematic detector showing its main subsystems.

To measure a *CP*-violating quantity we consider a particular combination of the final states, in which the time-order of the decays of the initial B^0, $\bar{B}^0$ pair is ascertained. It is important to note that if, for example, the final state $J/\psi K_S^0$ is measured, it is not possible to ascertain whether the parent was a B^0 or a $\bar{B}^0$ meson, but that in semileptonic decay a B^0 meson always produces a negative lepton, while a $\bar{B}^0$ meson always produces a positive lepton. We can thus, by measuring final states with knowledge of the time order of the decay, distinguish four combinations:

$$
\begin{array}{llll}
B^0, \bar{B}^0 \rightarrow & l^-(t_1),\ J/\psi K_S^0(t_2) & (N_1) & t_1 > t_2 \\
& l^+(t_1),\ J/\psi K_S^0(t_2) & (N_2) & t_1 > t_2 \\
& l^-(t_2),\ J/\psi K_S^0(t_1) & (N_3) & t_2 > t_1 \\
& l^+(t_2),\ J/\psi K_S^0(t_1) & (N_4) & t_2 > t_1
\end{array}
$$

The quantity $A_{CP} = (N_1 + N_3 - N_2 - N_4)/(N_1 + N_2 + N_3 + N_4)$ is then a measure of *CP* violation: if A_{CP} is non-zero, *CP* is violated in B^0 meson decay. In decays to *CP* eigenstates, such as $J/\psi K_S^0$ and $\pi^+\pi^-$, A_{CP} is easily related to the angles of the unitarity triangle, with small theoretical uncertainties.

backgrounds and radiation levels. In addition to the conventional drift chamber tracking system in a 1 to 1.5 Tesla solenoidal magnetic field and a high quality electromagnetic calorimeter, such as the CLEO II cesium iodide device, a *B* factory detector must have a high precision vertex detector capable of measuring positions of charged tracks to a spatial accuracy of 15 μm and, in order to reduce backgrounds in *B* decay final states, a system for positively identifying charged particle species. A data acquisition system capable of coping with very high event rates is, of course, also needed. A possible detector is shown schematically on the previous page. It consists of the vertex detector followed by a charged particle tracking chamber, the charged particle identification system, and the electromagnetic calorimeter. These devices are contained in a solenoidal coil, which is in turn inside a magnetic flux return that incorporates a system for identifying muons. Development work on these detector subsystems is underway in laboratories throughout the world.

The measurment of *CP* violation in B^0 meson decay presents one of the most exciting experimental challenges in high energy physics for the coming decade. Groups in the United States (at SLAC and Cornell), at KEK in Japan, in Novosibirsk in Russia, and in Europe are currently working on *B* factory initiatives. We are confident that one or more of these efforts will come to fruition. A *B* Factory presents our best hope for confronting the Standard Model with a novel test in the '90s: ascertaining whether it can indeed explain the crucial phenomenon of *CP* violation.

DATES TO REMEMBER

Mar 16–20	General Meeting of the American Physical Society, Indianapolis, IN (N. R. Werthamer, American Physical Society, 335 E. 45th Street, New York, NY 10017)
Mar 16–20	CERN Accelerator School: Magnetic Measurement and Alignment, Montreux, Switzerland (S. von Wartburg, CERN Accelerator School, SL Division, 1211 Geneva 23, Switzerland, or CASMAG@CERNVM)
Mar 24–28	Third European Particle Accelerator Conference (EPAC 92), Berlin Germany (H. Bottcher, EPAC 92 Conference Secretariat, Einsteinufer 1, D-1000, Berlin, Germany)
Apr 13	US High Energy Physics Advisory Panel, Washington, DC
Apr 13–15	SSC Physics Symposium, Madison, WI (Linda Dolan, Physics Department, University of Wisconsin, Madison, WI 53706 or LDOLAN@WISCPHEN)
Apr 20–23	General Meeting of the American Physical Society, Washington, DC (N. R. Werthamer, American Physical Society, 335 E. 45th Street, New York, NY 10017)
May 15	Fermilab Users Annual Meeting, Batavia, IL (Bert Forester, Fermilab Users Office, MS 103, Box 500, Batavia, IL 60510 or USERSOFFICE@FNAL)
May 26–29	Summer School on Quantitative QCD Phenomenology, Batavia, IL (C. M. Sazama, Fermilab, Box 500, Batavia, IL 60510)
Jun 1–4	Baryons '92: International Conference on the Structure of Baryons and Related Mesons, New Haven, CT (Moshe Gai, Yale University, 272 Whitney Avenue, New Haven, CT 06511 or GAI@YALEVM)
Jun 1–4	4th Rencontres de Blois: Particle Astrophysics, Blois, France (Rencontres de Moriond, Bat. 211, Univ. de Paris-Sud, F-91405, Orsay Cedex, France)
Jun 15–19	CEBAF 1992 Summer Workshop, Newport News, VA (Lynne Chamberlin, CEBAF Physics Div., MS 12H, 12000 Jefferson Avenue, Newport News, VA 23606 or LYNNE@CEBAF)
Jun 15–26	US Particle Accelerator School, Stanford, CA (US Particle Accelerator School, Fermilab, MS 125, Box 500, Batavia, IL 60510 or USPAS@FNAL)
Jun 24–27	3rd International Symposium on the History of Particle Physics (N. Adelman Stolar, SLAC, MS 70, Box 4349, Stanford, CA 94309 or NINA@SLACVM)
Jul 6–10	13th International Conference on Cyclotrons and Their Applications, Vancouver, Canada (M. K. Craddock, TRIUMF, 4004 Wesbrook Mall, Vancouver, BC V6T 2A3, Canada)
Jul 13–17	Particle Physics in the 90s: 1992 Gordon Research Conference, Andover, NH (Joseph Lach, Fermilab, Box 500, Batavia, IL 60510 or LACH@FNAL)
Jul 13–24	SLAC Summer Institute on Particle Physics (School Jul 13–24; Topical Conf. Jul 22–24) Stanford, CA (Jane Hawthorne, SLAC, MS 62, Box 4349, Stanford, CA 94309 or SSI@SLACVM)
Jul 20–24	15th International Conference on High Energy Accelerators, Hamburg, Germany (by requested invitation) (F. Willeke, Conf. Secretary, DESY, Notkestr. 85, D-2000, Hamburg 52, Germany or HEAC92@DHHDESY3)

Fermilab and SLAC
Co-Sponsor History Symposium

THE RISE OF THE STANDARD MODEL

The Third International Symposium on the History of Particle Physics will be held June 24–27, 1992, at Stanford Linear Accelerator Center

IN LATE JUNE 1992, SLAC WILL HOST the Third International Symposium on the History of Particle Physics, which it will sponsor jointly with Fermilab. At this gathering, a group of eminent physicists will meet with historians, philosophers, and sociologists of science to explore the major scientific, technological, and social developments of the 1960s and 1970s that led to the currently dominant Standard Model of elementary particles and forces.

This symposium will be the third in a series that began at Fermilab in 1980. The first, titled "The Birth of Particle Physics," explored the early roots of the field—from about 1930 through the discovery of the pion in 1947. In 1985, the second conference, "Pions to Quarks," picked up where the first left off and examined developments that occurred during the 1950s, when particle physics passed through its "adolescence" and became an independent subfield; this period ended in 1963 with the formulation of the quark hypothesis.

The theme and title of this third symposium is "The Rise of the Standard Model." Most of the theoretical foundations for this major advance in our thinking about elementary particles were laid down in the 1960s, followed immediately by a decade of experimental discovery and consolidation. Although there are plenty of loose ends remaining, the Standard Model has endured in essentially its present form for more than a decade. The time has come to begin reviewing the events and processes that led to its establishment as the dominant theory of particle physics today.

The focus of the Symposium will be on the major advances that occurred during the core period from 1964 to 1979, but related events that happened before or after this time will be included in the program. Several theoretical developments that began in prior years—including gauge field theories and spontaneous symmetry breaking—reached their full flowering during this period. Colliding-beam techniques came to the fore, replacing fixed-target experiments as the principal means of probing the high-energy frontier, while the 4 pi electronic detector replaced the bubble chamber as the instrument of choice. To build this increasingly massive and costly equipment, the experimental collaborations grew to almost a hundred physicists hailing from a number of different institutions.

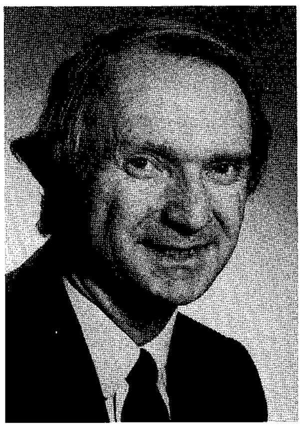
The Symposium will begin on Wednesday, June 24, and continue through Saturday, June 27. In addition to opening and closing sessions, there will be five plenary sessions organized around the following topics: Heavy Quarks and Leptons; Accelerators, Detectors, and Laboratories; Toward Gauge Theories; The Search for Electroweak Unification; and From Quarks to QCD. There will also be two panel discussions: one on Symmetry Breaking and the other on Science Policy and the Sociology of Big Laboratories.

Steven Weinberg will deliver the opening talk, and Sheldon Glashow will summarize the Symposium; the featured banquet speaker is Murray Gell-Mann. Other physicists speaking in the sessions include: James Bjorken, Jerome Friedman, Gerhard 't Hooft, Makoto Kobayashi, Leon Lederman, Burton Richter, Samuel Ting, and Robert Wilson. Among the scholars of science who will share their insights on this period are Peter Galison, John Heilbron, John Krige, Michael Redhead, Sylvan Schweber, and Sharon Traweek.

The Symposium is being organized by Lillian Hoddeson, Michael Riordan, Laurie Brown, Max Dresden, and Nina Adelman Stolar. For further information, contact Ms. Stolar at SLAC, MS 70, Box 4349, Stanford, CA 94309, telephone (415) 926-2282; telefax (415) 926-4999; and the BITNET address is NINA@SLACVM.

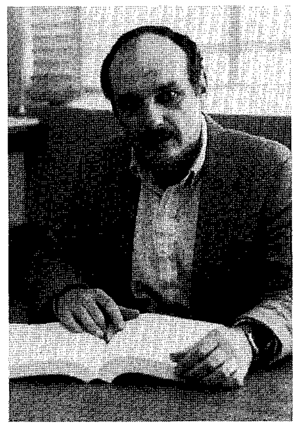
CONTRIBUTORS

Michael Craddock



Peter Kitching

David Hitlin



Marina Artuso

Sheldon Stone

Michael Craddock is head of the KAON Factory Accelerator Division at TRIUMF and deputy project leader. He joined the faculty at the University of British Columbia in 1964, played a major role in preparing the propopsal for the TRIUMF cyclotron, and became group leader for beam dynamics. Since 1977 he has worked on designing and promoting the KAON Factory and still believes that he will see it working before he retires.

Peter Kitching is a professor of physics and Director of the Centre for Subatomic Research at the University of Alberta. He was Associate Director and Head of the Science Division of TRIUMF from 1983 to 1988 and acted as Head of the Science Division of the KAON Factory Project Definition Study. As a part of this study, jointly funded by the Canadian federal government and the British Columbia provincial government and completed in 1990, he organized a series of workshops on the science that could be pursued at the KAON Factory. These workshops were held in North America, Europe, and Japan. His main scientific interest is the experimental search for rare kaon decays, and he is currently a member of the collaboration carrying out an experiment to look for the decay of a kaon into a pion and a neutrino-antineutrino pair (E787) at Brookhaven National Laboratory.

David Hitlin is Professor of Physics at Caltech. He has been active in experiments at SLAC since 1969, emphasizing the study of the weak decays of K_L^0 mesons and of charmed particles and the J/ψ with the Mark II and Mark III detectors at SPEAR. He also managed the design and construction of the SLAC Large Detector Liquid Argon Calorimeter system. He has for the past few years been heavily involved in the effort to upgrade the PEP storage ring into a high-luminosity asymmetric-energy *B* Factory for the study of *CP* violation. He is the current chairman of the SLAC users organization.

Sheldon Stone did his undergraduate work at Brooklyn College and his graduate work at the University of Rochester. He has been a member of the CLEO collaboration since its beginning. He has made a contribution to both hardware development and physics analysis. He participated in the construction of the dE/dx wire proportional chambers for the original detector and the construction of the CsI calorimeter for CLEO II. His analysis work has been mostly in the areas of *B* meson and charm meson decays. This work includes the discovery of the *B* and D_s mesons and measurement of many properties of their decays. He is now a professor at Syracuse University.

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