

SUBCOMMITTEE ENCOURAGES U.S. TO JOIN CANADIAN KAON FACTORY

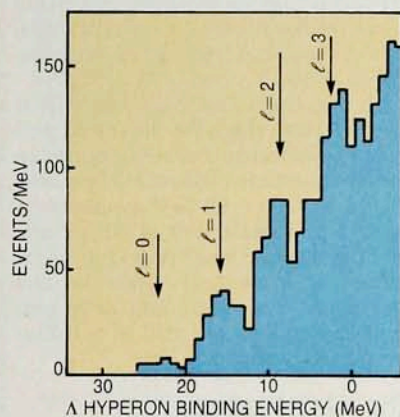
Since the mid-1970s, "pion factories" in Vancouver, Los Alamos and Zurich have been providing medium-energy experimenters in nuclear and elementary-particle physics with π mesons in great profusion. These small accelerators generate high-intensity beams of protons just energetic enough to make pions when they hit a fixed target.

But what passes for "medium energy" is, like everything else, subject to inflation. Nowadays one hears the call for "kaon factories," high-intensity accelerators capable of producing protons of about 30 GeV—enough to make K mesons in profusion. The nuclear physicists want intense kaon beams for the high-resolution study of strange quarks in the nuclear medium, and the particle physicists need them to investigate rare kaon decay modes.

Even the high-energy physicists are building factories. It's no longer enough simply to create a handful of some exotic heavy-particle species: One wants them in great numbers for experiments of high sensitivity or resolution. The recent discovery of strong particle-antiparticle mixing among bottom-flavored (B) mesons has evoked a worldwide call for "B factories." (See *PHYSICS TODAY*, August 1987, page 17.) The newly constructed large electron-positron colliders at Stanford and CERN will soon be functioning as "Z⁰ factories."

At TRIUMF

The 500-MeV TRIUMF cyclotron at the University of British Columbia in Vancouver has been serving as a pion factory since 1974. The Canadians are now planning to upgrade the TRIUMF facility into a kaon factory—an accelerator complex delivering an intense (100 microamp) beam of 30-GeV protons, which will in turn yield intense secondary beams of K mesons, antiprotons, other hadrons and neutrinos. Hence the acronym KAON by which this proposed \$450 million (US dollars) project is to be known.



Hypernucleus of yttrium-89. A π^+ beam at Brookhaven converts nuclear neutrons to Λ hyperons. Measuring the emerging K^+ gives the Λ binding energy in the nucleus. The histogram shows clear peaks for different states of orbital angular momentum l of the bound Λ , unrestricted by the Pauli principle. This is a striking verification of the nuclear shell model. At a kaon factory one could study such heavy hypernuclei with kaon beams. (Data of R. Chrien *et al.*, *Nucl. Phys. A* **478**, 705c, 1988.)

Thirty-GeV protons may be reminiscent of an earlier generation of accelerators. But KAON is designed to provide a continuous beam of 6×10^{14} protons per second—a hundred times the beam intensity of the older, pulsed synchrotrons still operating in this energy range. Nuclear physicists are eager to use a proton beam of such unprecedented intensity to produce intense beams of K mesons for the study of "hypernuclei"—nuclei in which the incident meson has briefly converted a proton or a neutron into a strange "hyperon." Such short-lived nuclei with nonzero strangeness number have been known since the 1940s, but the low intensity of available kaon beams has until now restricted their study to experiments of poor resolution, most-

ly with light nuclei. Hyperons, untrammelled by the Pauli exclusion principle, can serve as unique probes of nuclear matter. The nuclear medium, in turn, influences the behavior of hyperons. Furthermore, strange nuclei provide a rare opportunity to study the weak interaction of baryons with one another.

Elementary-particle physicists, whose usual domain is protons of much higher energy, are also eager to avail themselves of the intense beams of modest-energy kaons and other hadrons promised by the KAON project. The search for rare decay modes of the K mesons now under way at Brookhaven is impelled by the desire to pin down the parameters of the "standard model" of the elementary particles, and to seek out hints of physics beyond that highly successful but incomplete theory. But such rare-decay studies are seriously limited by meager beam intensities. Intense kaon beams will also facilitate the search for exotic dibaryon particles predicted by the standard model. One wants more intense antiproton beams at low energies to investigate particle-antiparticle symmetries. Do antiprotons, for example, fall under gravity with the same acceleration as protons?

A Canadian invitation

Responding to Canada's invitation to join an international collaboration in support of the proposed kaon factory at TRIUMF, the Nuclear Science Advisory Committee of DOE has formed a "Kaon Subcommittee" headed by Herman Feshbach (MIT). The subcommittee was asked to assist NSAC in responding to the request from DOE and NSF for advice as to the wisdom of joining the Canadian enterprise. The proposed US contribution would be \$75 million over five years of construction. In this connection the subcommittee was also asked to advise NSAC on upgrades that are being considered at Los Alamos and Brookhaven, which would provide high-

intensity, medium-energy beam capabilities similar to those proposed for the KAON facility at TRIUMF.

To inform itself, the kaon subcommittee held meetings at Los Alamos, Brookhaven and TRIUMF in recent months. The subcommittee submitted the written report of its findings to NSAC late last month for approval by the full committee. The chairman of NSAC is Peter Paul (State University of New York, Stony Brook).

The subcommittee had been asked, first of all, to assess the importance of the physics program foreseen for these proposed high-intensity, medium-energy hadron-beam facilities. Their report concludes that these facilities would "make a broad range of fundamentally important phenomena accessible to experimental study, ... [posing] significant and informative challenges to the standard model ... [and testing] speculative generalizations of [it]." The report points out how experiments at such facilities might improve our understanding of nuclear forces between nucleons and hyperons or antinucleons.

Asked to appraise "the adequacy and appropriateness" of the proposed KAON facility at TRIUMF to these ends, the subcommittee "judged [its] design to be conservative." The report finds "no major design problems that would seriously impede construction. ... The facility would certainly provide the needed experimental capability ... [but] TRIUMF will need to augment its staff. ..."

NSAC had also asked the subcommittee to assess the impact of the Canadian project on the long-range nuclear physics program in this country. The report argues that the KAON facility "would complement CEBAF [the electron accelerator under construction in Newport News, Virginia] and RHIC [the relativistic heavy-ion collider to be built in the Isabelle tunnel at Brookhaven]. KAON construction would be completed in a timely fashion (1995)."

The subcommittee estimates that KAON would attract about 800 users—somewhat more if the high-energy community finds it attractive. A third to a half of the users would be from US institutions. Therefore the subcommittee considers that a US contribution of \$75 million toward construction of the Canadian facility would be a "cost-effective investment."

The venerable Alternating Gradient Synchrotron at Brookhaven provides a pulsed 28-GeV proton beam with an intensity of $1 \mu\text{A}$. A "booster" upgrade, already under construction at the AGS, will raise the beam

intensity to $4 \mu\text{A}$. For the longer term, Brookhaven is proposing to build a \$50-million "stretcher" ring that would make the proton beam continuous and raise its intensity to $8 \mu\text{A}$. Continuous beams are particularly desirable in nuclear physics, where coincidence measurements are plagued by accidental coincidences when beam spills are too compressed.

Commenting on the Brookhaven program, the subcommittee finds that the booster "will enhance the investigations of rare K decays and hypernuclei presently under way. ... A stretcher would further facilitate these studies by providing [still more] protons without increasing instantaneous rates."

LAMPF, the existing pion factory at Los Alamos, provides 800-MeV protons. Los Alamos is developing a plan for an Advanced Hadron Facility that would include a 60-GeV synchrotron with a proton current of $25 \mu\text{A}$ and two compressor rings providing short pulses of low-energy neutrons and neutrinos. The subcommittee reports that these plans are still in a rather preliminary stage.

The KAON facility

Preliminary to a final commitment by the Canadian government, an \$11-million (Canadian dollars) "project definition study" of the KAON facility design is now under way. The design begins with the existing TRIUMF cyclotron, whose output is to be injected into an accumulator, followed by a booster synchrotron that accelerates the protons to 3 GeV. A subsequent collector ring prepares the beam for injection into the driver cyclotron, which will accelerate it to 30 GeV. Finally an extender ring is to store the 30-GeV protons for slow, continuous extraction to the experiments.

This chain of rapid-cycling synchrotrons and dc rings is designed to produce a continuous $100\text{-}\mu\text{A}$ output of 30-GeV protons. Such a six-ring circus may appear dauntingly elaborate, but the subcommittee report praises the operational simplicity and flexibility to be achieved by separating specialized functions in separate rings.

The KAON operating budget is to be borne entirely by the Canadians. It is assumed that about half the costs of doing experiments will be met by non-Canadian sources. The subcommittee suggests "that \$30 million would be an appropriate annual contribution of the US physics program" to experiments at KAON.

Strong interactions

Investigations of the strong (nuclear)

force at KAON and the Advanced Hadron Facility envisaged for Los Alamos would concentrate on hadronic structure and quark-gluon degrees of freedom in nuclei. A "major justification for such facilities," writes the subcommittee, would be the prospect of improving our understanding of the quark-confinement mechanism and nonperturbative processes in quantum chromodynamics. QCD is the generally accepted gauge field theory of the strong interaction within the standard model, but it is very difficult to carry out anything but perturbative calculations of hard quark scattering processes.

A striking prediction of QCD is the existence of bound dibaryon (six-quark) states. In general, finding such a "smoking gun," as the subcommittee describes it, will be very difficult. But one particular possibility becomes very promising with high-intensity beams of strange (K) mesons. Robert Jaffe (MIT) has shown that QCD requires the existence of a dibaryon state containing two strange quarks. Such a state, which he calls the "H particle," would have strangeness number -2 . Moreover, it would have less than twice the mass of the Λ hyperon, the lightest of the strange baryons. Thus an H dibaryon, produced for example in K^- collisions with helium-3 nuclei, would be stable against strong decay and therefore relatively easy to detect. Furthermore, such a particle would be particularly susceptible to the nuclear-medium effects of special interest to nuclear physicists. Quite generally, intense kaon beams will make it possible for the first time to examine in detail the behavior of strange quarks in extended nuclear matter. Muon scattering experiments at CERN have already indicated that the up and down quarks of ordinary matter experience unexpected effects of the nuclear medium.

The weak, strangeness-changing scattering of hyperons on nucleons can only be studied in hypernuclei. The influence of the nuclear medium on such processes is of particular interest. It is believed that Σ hyperons also form hypernuclei, but it is not known how broad a range of nuclear species can serve as hosts for a Σ . A systematic search for Σ hypernuclei with intense kaon beams would provide useful information about SU(3) symmetry among the baryons. Also, intense kaon beams will greatly facilitate the formulation of doubly strange nuclei.

The meager data already in hand from kaon scattering off nuclei indicate a puzzling result. The total cross

section of K^+ mesons on carbon-12 appears to be almost exactly six times their cross section on the deuteron—hardly what one expects in the face of multiple scattering in nuclei. This indication of peculiar collective effects even in such simple nuclear systems clearly calls for further study with intense kaon beams.

Electroweak interactions

The subcommittee report points out that the very success of the standard model, especially its "electroweak" sector, which unifies the electromagnetic and weak interactions, is a source of some frustration. Eventually, most theorists agree, one must find experimental indications of new physics beyond the standard model. The vanguard assault on the new physics, of course, is the quest for higher-energy accelerators that can reach the TeV regime (10^{12} eV) where new phenomena are confidently expected.

But the subcommittee report emphasizes a complementary low-energy route, involving more sensitive searches and more precise measurements, for which the proposed kaon factories would be particularly well suited. They would be used to search for various particles that "form the [low-energy] debris of theories involving very high energy scales": axions, new neutrino species, WIMPs (weakly interacting massive particles hypothesized to solve the problem of the missing solar neutrinos) and a possible very light Higgs boson.

Other quests on this low-energy, high-intensity route would be the search for neutrino oscillations and the further elucidation of the CP-violating mechanism in K^0 decay (see PHYSICS TODAY, October 1988, page 17). One would, of course, search for kaon decay modes strictly forbidden by the standard model and seek to examine other decays modes allowed but so highly suppressed that they cannot be adequately studied with existing beams.

Other beams

These proposed medium-energy "hadron facilities" are by no means restricted to kaon beams. Antiproton beams of high purity can be achieved by letting a negatively charged secondary beam run through a long magnetic channel until all the contaminating mesons decay. The small LEAR ring at CERN provides stochastically cooled antiproton beams, but its size limits it to significantly lower antiproton energies than one could reach at KAON or the Los Alamos AHF. Stochastic cooling provides very desirable shrinkage of beam

spread in phase space, but it's expensive. The present KAON plans do not call for stochastic cooling of the antiproton beam.

Comparing protons and antiprotons is of particular interest in the context of supergravity theories and tests of the sacrosanct principle of CPT invariance. The study of proton-antiproton annihilations has long been limited by available antiproton fluxes. Antiprotons in the KAON energy range can annihilate with protons to form the "charmonium" bound states of the charmed quark and its antiquark. The subcommittee report points out that charmonium states formed by $p\bar{p}$ annihilation are not limited to the spin-parity state of the photon, as are those formed by electron-positron collisions. Thus the proposed hadron facilities can play an important role in heavy-quark spectroscopy, complementary to that of e^+e^- collider rings.

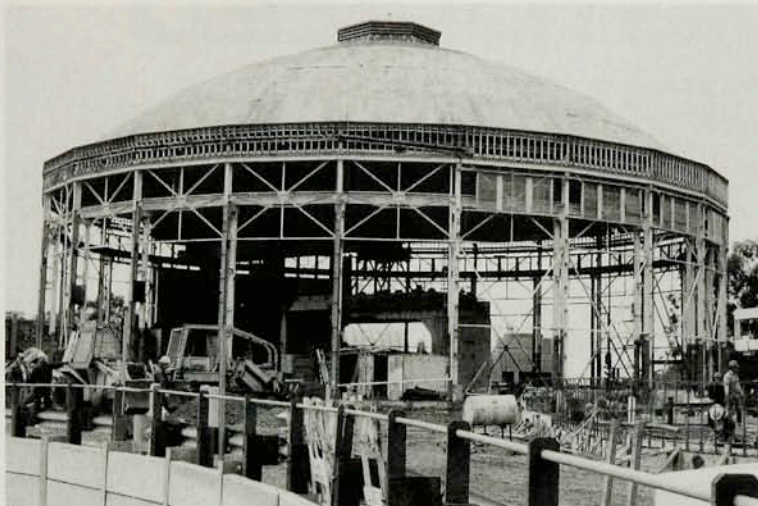
The high neutrino-beam fluxes an-

ticipated for KAON will facilitate neutrino-oscillation searches and precision measurement of the Weinberg mixing angle θ_w , a central parameter of the electroweak theory. Comparing such a measurement with the precise measurements of the mass of the neutral vector boson Z^0 expected within the next year from the new high-energy e^+e^- colliders at CERN and Stanford would provide a stringent test of the predictions of the standard model.

The kaon subcommittee, having praised the design of the proposed KAON facility in Vancouver, notes that the Canadians would welcome technical reviews by the US Department of Energy. Feshbach, who directed the preparation of the subcommittee's report, cautions that it must still be reviewed by the full Nuclear Science Advisory Committee before its views and recommendations are passed on to the funding agencies.

—BERTRAM SCHWARZSCHILD ■

184" Cyclotron Makes Way for Advanced Light Source



After almost half a century, Ernest Lawrence's 184-inch cyclotron is gone. Its familiar dome, perched like a sentinel in the hills above the Berkeley campus of the University of California, now covers little more than the massive magnet yoke—all that remains of the inventor's largest cyclotron. But this venerable shell will soon have a new tenant. Next year, installation of injectors for the Advanced Light Source will begin under the old roof, which is being preserved for historical and aesthetic reasons. The old magnet yoke will continue to do its duty as a crane support.

The \$100-million Advanced Light Source will be a 1.5-GeV, 400-milliamp electron storage ring, designed to produce ultraviolet and soft-x-ray synchrotron light beams of unprecedented brightness. The ring itself, considerably wider than the old cyclotron, will occupy an annular structure circling the dome. This new facility at the Lawrence Berkeley Laboratory is scheduled to become available to materials scientists, chemists, biologists, technologists and other users in 1993. Prospective users are participating in the design of beam lines, insertion devices and experimental facilities.

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