CA8004955

Invited paper, LAMPF Users Meeting,
October 28-29

TRI-PP-79-44
Dec 1979

KAON AND ANTIPROTON FACTORIES

(Report on the Vancouver Kaon Factory Workshop, August 1979)

M.K. Craddock

Physics Department, University of British Columbia,
Vancouver, B.C., Canada V6T 2A6

Abstract

A brief review is given of the physics potential and practical design of machines to produce beams of slow K's and $\overline{p}$'s 100-1000 times more intense than those at present available. Experiments with such beams would provide significant new information on (among other topics) weak decay processes and symmetry violations, the baryonic resonance spectrum, the kaon-nuclear interaction, hypernuclei, exotic atoms, the $\overline{p}$-p interaction and medium energy neutrino scattering. High intensity K and $\overline{p}$ projects from Brookhaven, CERN, Fermilab, KEK, LAMPF, SIN, TRIUMF and the USSR are described.

Introduction

First to define our terms: by kaon and antiproton factories I mean machines that will produce beams 100-1000 times more intense than those at present available of slow kaons (of which the best beams now provide about 10^5 K^-/s), of the Σ- and Λ-hyperons which these produce, and in the case of antiproton factories, of $\bar{p}$'s and $\bar{n}$'s. In addition, of course, there would be correspondingly more intense beams of the primary protons or electrons, of neutrons, pions, muons, and both muon- and electron-neutrinos.

Kaon and antiproton factories have aroused considerable interest in the last few years and studies have been made at the Brookhaven Summer Workshop[1] in 1976, at the Zvenigorod Seminar[2] in 1977, at LAMPF this last spring in a series of 15 seminars,[3] at TRIUMF in the Kaon Factory Workshop[4] this August, and immediately after that at LAMPF at the Program Options Workshop.[5] (Here I must acknowledge my debt to the authors who have contributed to these studies, which I have drawn on generously in the preparation of this talk.)

The Vancouver Kaon Factory Workshop was held in conjunction with the Eighth International Conference on High Energy Physics and Nuclear Structure and was attended by 230 delegates. Table I which lists the topics and invited speakers will give some idea of the areas of interest. In addition over 30 contributed papers are included in the Proceedings of the Workshop.

I do not plan to deal with each topic and speaker individually, because there were some omissions and some overlap as well, but rather give a general survey of the field. However, I do want to start from some of Reg Richardson's opening remarks. He posed four questions which have to be considered before a serious proposal for a kaon or antiproton factory is put forward, and these are:

1. What is the scientific justification for a K- or $\bar{p}$-factory?
2. Is it technically feasible to build such a machine?
3. Is it financially feasible?
4. Is it politically feasible? (And by this he meant not just feasible to the government, but also to the scientific community.)

The scientific justification

Why then do we need 100-1000 times more intensity? Well, of course, the present beams are just inadequate for many interesting and important experiments. Either the intensity is too low, preventing the experiment altogether or restricting the angular range over which it may be performed, or the energy or angular resolution is too poor, etc. The present intensities are just allowing tantalizing glimpses into areas of great potential, such as the study of hypernuclei or kaon-nuclear scattering or the spectrum of strange baryonic resonances. The situation is similar to that which held for pion and muon physics before the advent of the pion factories; if anything the situation is worse for kaon and hyperon beams, which are of poorer quality than pion and muon ones were 10 or 15 years ago. So then, the hope is that the kaon factories will open up the field of kaon and hyperon physics in the same way that the pion factories have in the last five years opened up the fields of muon and pion physics.

My talk is based on the assumption that the audience, like myself, are mostly not active workers in K and $\overline{p}$ physics. I have therefore tried to sketch in the present state of each topic to serve as an introduction and also to indicate the extent to which it is unexplored, before mentioning the experiments which K- and $\overline{p}$-factories would make possible. A more complete short review of the potentialities of K- and $\overline{p}$-factories has been given by E.M. Henley.[6] As I come to each topic I will try not to be too repetitive in pleading for more intensity but even if that need is not proclaimed explicitly I am sure it will be recognized implicitly throughout the following discussion.

The particles and their properties

The K-mesons form part of the same family as the familiar pions, the pseudoscalar meson octet (Fig. 1). Like the π^+ and π^-, the K^+ and K^- are anti-particles. However, there is an important difference: whereas the π's all belong to the same isospin family, the K^+ and K^- do not make an isospin doublet. The twin of the K^+ is the K^0 and of the K^- the $\overline{K}^0$, the former having strangeness $S = +1$, and the latter $S = -1$. These strangeness -1 kaons can be absorbed on nucleons to form the equally strange Λ and Σ hyperons, members of the same baryon octet as the neutron and proton and the cascade particles. Note, however, that there are no strangeness +1 baryons in this multiplet or, indeed, in any other yet discovered.

Weak interactions

The relatively high masses of the kaons and hyperons allow them a very large number of decay channels. Indeed, in the Particle Data listings 31 channels are listed for the decay of the charged kaons, and this total includes only those channels for which experimental data is available. In many cases no precise value for the branching ratio is known, only an upper limit being quoted. Not one muon-number non-conserving mode is listed for the $K^\pm$, in spite of the fashionableness of this topic at the moment. Even for the familiar baryon decay modes $B_1 \to B_2 \ell \nu$ we need more, and more accurate, information to tie down the form factors in the current-current interaction matrix elements. Not only decay rates are required but also energy spectra, angular correlations and spin-momentum correlations. Particularly useful examples would be the decays $\Sigma^\pm \to \Lambda^0 e^\pm \nu$ and $\Lambda^0 \to p e^- \nu$. Channels involving neutral currents, such as $K^\pm \to \pi^\pm \mu^+ \mu^-$, and $\Lambda \to n e^+ e^-$ would also be interesting to observe.

Then there is the influence of symmetry violations on decay rates, for instance CP violation, which so far has only ever been observed in the decay $K_L^0 \to 2\pi$. From what quark or boson properties or interactions does this arise? Does it come from coupling between the gauge bosons and quarks? In that case it appears that a more accurate measurement of the η_{+-} or η_{00} parameters would help. Or does it come through exchange of Higgs bosons? In that case we can expect CP-violating effects to show up also in the decays $K_L^0 \to \pi^- \mu^+ \nu$ and $K^+ \to \pi^0 \mu^+ \nu$ in the form of transverse polarization of the muons. The weak decays of polarized Σ's are also sensitive to CP violation.

Non-conservation of muon number would open up additional decay channels for strange, as for non-strange, particles. Various mechanisms in gauge theories could be responsible. For the decay $K_L^0 \to \mu^\pm e^\mp$, for instance, Herczeg[8] has shown that different effects may give rise to branching ratios ranging from 5×10^{-16} up to the present experimental limit of 2×10^{-9}. A branching ratio higher than 3×10^{-12}, for instance, would be an indication that there are more than the presently known three generations of quarks and electrons; this is a level which the TPC at TRIUMF and the Crystal Box at LAMPF should be ideally suited to study. Finally in this area, I would mention the violation of the $\Delta S = \Delta Q$ rule, the only evidence for which rests on just five $\Sigma^+ \rightarrow n\ell^+\nu$ events; this seems to call for better statistics!

The kaon-nucleon interaction

The interaction of kaons with nucleons is not only of fundamental interest, as being the simplest interaction of a strange meson with a baryon, but is also basic to our understanding of the scattering of kaons from nuclei. In Fig. 2 we see the cross-sections for kaon-proton and -deuteron scattering,[7] plotted against momentum up to about 3 GeV/c. Immediately we see the striking difference between the K^- cross-sections on the left and the K^+ cross-sections on the right-hand side. In the K^+ case there is very little structure except for the steep rise below 1 GeV/c, and the cross-sections are very small, below 20 mb everywhere for K^+-p, indicating a repulsive interaction. This is in line with the fact that there are no baryonic resonances with the +1 strangeness of this channel (exotic Z^* resonances have been suggested above 1 GeV/c, but there is no clear evidence for them in the data at the present level of accuracy).

On the other hand, the K^- cross sections are rich in structure, as we might expect from the $S = -1$ channel in which there are many baryonic resonances to be excited. In the lower diagram the cross sections have been separated into isospin singlet at the top and isospin triplet at the bottom, and the many proposed Λ and Σ resonances have also been marked in. The accompanying Michelin stars indicate the degree of reliability attributed to them by the Particle Data Group; note that only two have been assigned the full four stars. The phase shift analysis of the K^--nucleon data is 'still very confused,' according to the particle data compilers; the data is insufficiently accurate and complete to allow a unique solution to be extracted and they are driven to illustrating the scattering amplitudes with two alternative solutions. Even for such low partial waves as the S_{11} (Fig. 3) or P_{01}, these solutions can be quite different, even in the elastic channel. The resonances which have been predicted from the scattering amplitudes of Alston-Garnjost[9] and Gopal[10] are compared in Fig. 4. The two solutions are in good agreement over the lower lying resonances, but at higher energies there is much poorer agreement. As we see from the momentum scale on the right-hand side, this is just the region excited by present slow kaon beams. With lower momentum beams (say around 400 MeV/c) it would be interesting to study the narrow and relatively isolated $\Lambda_{3/2^-}(1520)$, especially its effects in nuclear scattering.

The determination of resonances is not just a higher form of butterfly collecting. With 'soft' QCD it has recently become possible to predict the energies and positions of resonances with some success. Isgur and Karl,[12] for example, achieve a reasonable correspondence between predicted and observed negative parity baryon resonances up to ~1800 MeV, particularly for the 7 N^*'s and Δ^*'s (S = 0), though rather less strongly for the 14 Y^*'s (S = -1); the comparison would benefit from improved experimental data, particularly in the latter case. The situation is much more confused for the positive parity resonances, both for the N^*'s and Δ^*'s (Fig. 5) and for the Y^*'s (Fig. 6). In these cases there are many predictions that have no experimental counterparts, and few of the experimental assignments have great accuracy or reliability. The need for better data is evident.

Kaon-nucleus interactions

The very different interactions of K^+ and K^- mesons with the nucleons are basic to the interactions of kaons with nuclei as well. Figure 7 illustrates[13] the total cross-sections for various particles with protons. The $\overline{p}$ and K^- are both relatively strongly interacting and are, therefore, particularly sensitive to the nuclear surface. The K^+-nucleon interaction, on the other hand, is weak and repulsive, especially for momenta under 800 MeV/c; in fact, the K^+ should have a mean free path of something like 6 fm in nuclear matter, making it the only strongly interacting probe weakly absorbed by the nucleus. The K^+ should, therefore, be a useful probe for the whole of the nucleus, not just the surface. In fact, it has been suggested that it could turn out to be as good a probe for neutron density as the electron is for proton density.

The K^+-p cross section can be fitted quite well up to about 700 MeV/c by elastic s- and p-waves only (Fig. 8), enabling a relatively simple K^+-nucleus optical potential to be derived for scattering in this energy region. Recently the Brookhaven 800 MeV/c kaon beam and spectrometer system has been used to take some beautiful new data on kaon elastic and inelastic scattering.[14] Figures 9-12 show the differential cross sections measured for elastic K^- and K^+ scattering from ^{12}C and ^{40}Ca. In the latter case the data extend beyond the second diffraction minimum. Also shown are various optical model calculations by Rosenthal and Tabakin.[15] The agreement with the data is reasonably good, especially for K^+. Note that there are no free parameters in these calculations; the potentials have been derived straight from the kaon-nucleon scattering amplitudes. In the case of ^{12}C, the experimenters were able to resolve scattering from the 4.4 and 9.6 MeV states; these data are shown in Figs. 13 and 14. The DWBA theoretical curves are in reasonable qualitative agreement.

Exotic atoms

Like pions and muons, very slow negative kaons may be captured into atomic orbits around the nuclei of material they are passing through. As they cascade down to lower levels kaonic X-rays are emitted. The study of the energies, fine structure and yields of the higher transitions has led to accurate values for the mass and magnetic moment of the K^-, and for the electron density in the outer regions of the atoms. Because of the relative smallness of the kaonic orbit radii, the lowest levels are strongly depopulated by absorption into the nucleus. When the lowest transitions can be observed, their shifts and widths therefore give valuable information on the strong interaction between the K^- and the nucleus, in particular on the density of the nuclear surface. A notable recent result is the first successful observation[16] of the K X-ray in kaonic hydrogen (the K^--p atom) (Fig. 15). From this result the level shift for the 1S state can be derived and hence the scattering length for the K^--p interaction.

Antiprotons and Σ^--hyperons can also be captured into atomic states and their X-rays observed. Figure 16 shows K^- and Σ^- X-ray lines observed in lead,[17] and Fig. 17 the recent first observation of L X-rays in protonium atoms ($\bar{p}$-p) by a UBC/Victoria/Mainz collaboration.[18] Efforts are now underway to detect the K X-ray in order to throw further light on the $\bar{p}$-p interaction. In all of these examples it is clear that the signals are only just observable above the noise and that the experiments would benefit greatly from improved intensity and quality of beam.

Hypernuclei

When a negative kaon is absorbed in a nucleus it may transfer its strangeness to a single proton, converting it into a Σ- or Λ-hyperon by means of the reactions $K^- p \rightarrow \Sigma^+\pi^-$, $\Sigma^0\pi^0$, $\Sigma^-\pi^+$, $\Lambda^0\pi^0$; or if it is absorbed on a neutron by means of $K^-n \rightarrow \Sigma^0\pi^-$, $\Sigma^-\pi^0$, $\Lambda^0\pi^-$. By means of the traditional emulsion technique, the binding energies for over 20 Λ-hypernuclear isotopes have now been measured. In the last five years, however, the advent of more intense K^- beams has permitted counter experiments and the field of hypernuclei has blossomed with a profusion of new physics. Excited states of hypernuclei have been seen for the first time by means of their γ-ray de-excitation. For instance, the γ-rays emitted by ${}^4_\Lambda H^*$ and ${}^4_\Lambda He^*$ are illustrated in Fig. 18 at 1.04 and 1.15 MeV respectively.[19]

The (K^-,π^-) reaction has proved to be a fruitful source of new information. The momentum of the present slow K^- beams turns out to be convenient for 'recoilless' production, where the hyperon is left with zero momentum in the nucleus (Fig. 19). For Λ's this occurs at a kaon momentum of 550 MeV/c and for Σ's at 300 MeV/c. For a fair range on either side of these values the hyperon will be left with relatively low momentum and there is a high probability that it will be captured into a state very similar to that of the metamorphosed neutron.

The work of the Heidelberg/Strasbourg/Saclay group in the last few years has shown that this technique yields clean spectra from identifiable nuclear states and significantly cuts down the background from quasi-free hypernuclear production. The missing mass spectra obtained for ${}^{32}S$

and ^{40}Ca are shown in Fig. 20. The zero of the B_Λ scale corresponds to zero relative energy between the Λ particle and the core nucleus ground state. We see that on top of the quasi-free background these spectra exhibit distinct peaks corresponding to the strangeness exchange (SEX) reaction occurring between specific neutron and Λ shells. The most prominent peak in each spectrum has $B_\Lambda \simeq 0$, as we would expect for a reaction taking place in the surface of the nucleus and leaving the Λ in a high and weakly bound shell. In the cases shown, the major peak has been identified as due to the Λ going into a $d_{5/2}$ state while a neutron is lost from that state. The levels involved in the other peaks are indicated in the diagram; note that several are common to calcium and sulphur, but that two others occur only in the calcium spectrum. These are identified as due to the loss of a $d_{3/2}$ neutron, which, of course, is not present in sulphur. Bouyssy[36] has fitted the data for $^{12}_{\Lambda}$C, $^{16}_{\Lambda}$O $^{32}_{\Lambda}$S and $^{40}_{\Lambda}$Ca using a simple shell model, and has obtained the best fit with a potential well depth of 32 ± 2 MeV for Λ's, compared to about 50 MeV for neutrons. The most striking result, though, is that the spin-orbit potential for the Λ is only 4 ± 2 MeV compared to 20 MeV for nucleons; thus the Λ appears to behave as a virtually spinless neutron in the nucleus.

This group has also recently observed (K,π) reactions resulting in the formation of Σ-hypernuclei.[21] In Fig. 21 we see spectra from the (K^-,π^-) reactions on ^{9}Be and ^{12}C. At the left near $B_\Lambda = 0$ are peaks due to the formation of the Λ-hypernuclei. Further to the right near $B_\Lambda \simeq 80$ MeV (corresponding to the Σ-Λ mass difference) is a weaker spectrum attributed to the formation of the Σ-hypernuclei. The prominence of these Σ^0 hypernuclei is, of course, quite surprising considering the lifetime of the Σ^0 is $\sim 10^{-20}$ s compared to $\sim 10^{-10}$ s for the Λ^0. Evidence for Σ^--hypernuclei was also found and Fig. 22 compares the spectra obtained for the Λ, Σ^0, and Σ^- ^{9}Be hypernuclei. From this first observation of Σ-hypernuclei the group has been able to deduce a potential well depth of about 20 MeV for both Σ^- and Σ^0. In many of these spectra the states are barely resolved and it is clear that much more detailed information will be forthcoming if the intensity and energy resolution of the kaon beams can be improved.

Another development in this field which awaits the arrival of more intense beams is the observation of (K^-,K^+) reactions, which can give rise to stable baryonic systems with $S = -2$, e.g. $K^- + d \to K^+ + (\Lambda\Sigma^-)$, or $\to K^+ + (\Xi^- n)$, or $K^- + {}^6Li \to K^0 + (\Lambda\Lambda ppnn)$, an interesting object in which all three baryon ground states are filled. (One example of this ${}^{6}_{\Lambda\Lambda}He$ nucleus and one of ${}^{10}_{\Lambda\Lambda}Be$ have been observed in nuclear emulsions.)

Non-strange experiments

Beams of protons, neutrons, pions and neutrinos will also be available. It should be possible to accelerate polarized proton beams, and from these, to produce polarized neutrons. It will thus be possible to study the nucleon-nucleon interaction in greater detail and with more accuracy than has been previously possible in the few-GeV region. It will also be possible to make more detailed investigations, including the spin dependence of π-, K-, η-, ρ- and ω-meson production, and the elastic and inelastic scattering of nucleons from nuclei in this energy region. High current proton beams of a few GeV will also provide intense sources of spallation neutrons for various studies including electromagnetic breeding. The pion beams will allow further study of the pion-nucleon system and of the elastic and inelastic scattering and reactions of pions with nuclei.

One of the most interesting prospects, however, is the availability of intense beams of medium energy (i.e. hundreds of MeV) neutrinos, both ν_e and ν_μ, for the study of neutrino scattering and reactions. The electron neutrinos are particularly interesting as the K_L^0 decay to $\pi e\nu$ with a 38% branching ratio is a unique source of medium energy electron neutrinos. Intense beams of electron neutrinos otherwise come from muon decay or nuclear reactors at a much lower energy.

Improved kaon beams

What then are the immediate prospects for better beams of kaons? Beams of improved performance are at present under consideration both at Brookhaven and at KEK (see Table II). At Brookhaven[22] the aim is to increase the kaon flux from about 8×10^4 800 MeV/c $K^-/10^{12}$ protons by a factor of 10 to about 10^6. This is to be accomplished partly by increasing the acceptance of the channel, but mainly by shortening it from

15 m to below 10 m. KEK's channel[23] is also a high-acceptance low length system, 8.5 m, made possible by the use of combined function superconducting current sheet magnets. At Brookhaven an achromatic spectrometer is being designed as an integral part of the system. This will have an energy resolution of about 200 keV, i.e. about 10 times better than at present. They are planning for high angular coverage (0-140°) in order to make good angular distribution measurements.

Improved antiproton beams

Here it appears that the immediate future will be dominated by the LEAR project[24] at CERN (Fig. 23). This low-energy antiproton storage ring will be fed from the 3.5 GeV/c antiproton accumulator via the PS, in which $\overline{p}$'s will be decelerated to 0.6 GeV/c (175 MeV). LEAR itself will be able to increase their energy to about 1200 MeV or decrease it to about 5 MeV, as desired. The antiproton intensities available will be 10^3 to 10^6 times greater than those in previous experiments. Beam cooling will eventually be installed in LEAR in order to improve the beam quality, but the most important characteristic of the LEAR beam will probably be its lack of any contamination. Figure 24 shows a possible layout for LEAR in the south hall of the PS, with indications of how proton and H^- beams could also be injected. The proton beam will enable LEAR to be used as a mini-collider up to centre of mass energies of 4.4 GeV. The ovelapping $\overline{p}$ and H^- beams will enable protonium atoms to be formed in flight, their X-ray energies being Doppler-shifted to a convenient region where they can be more accurately measured than at present. A comprehensive list of possible topics is being considered for experiments (see Table III). It seems clear that anyone planning to build an antiproton factory now, and wishing to remain competitive, will have to incorporate a LEAR in their design.

Kaon and antiproton factory designs

Here we come to the second question raised by Richardson; that of the technical feasibility of building a kaon or antiproton factory. First: what energy do we have to aim at to produce intense K or $\overline{p}$ beams? Figures 25 and 26 show how the relative cross sections for K and $\overline{p}$ production increase with energy.[25] This information is taken from measured beam intensities on beam lines at different laboratories. We see that both sets of data are characterized by a shoulder, for 850 MeV/c $\bar{p}$ at about 15 GeV and for 700 MeV/c K^- at about 8 GeV. These values would represent the most economical energies at which to produce intense $\bar{p}$ or K beams. However, the unnatural sharpness of the shoulder for kaon production, the fact that the data comes from different laboratories and the eventual disappearance of a similar shoulder in the pion production cross-section, suggests that it would be wise to remeasure the kaon cross section also; LAMPF is, in fact, considering such a measurement.

Figure 27 illustrates the present distribution of high energy accelerators in energy and current.[26] We see that, with one exception, all the super-GeV proton accelerators deliver currents $\lesssim 1$ μA. The exception is the Fermilab 8 GeV Booster Synchrotron which, by virtue of its fast cycling operation and H^- injection, has recently been able to accelerate a beam of 7 μA (the energy of this machine will eventually be raised to 10 GeV, and the current could be increased to 12 μA). A potential kaon factory, therefore, already exists with proton beams an order of magnitude more intense than those at present available. The duty factor is at present very low, but this could be improved by means of (for instance) slow resonant extraction. A more serious question, however, is can we square the users to whom the booster has already been committed? Here it appears that K-production could be interspersed with 400 or 1000 GeV fixed target operation, but not with $\bar{p}$-p collider operation.

Below 1 GeV the meson factories give beam intensities 100-1000 times greater (100 μA or more) than the high energy proton synchrotrons. LAMPF and SIN are eventually aiming to boost their intensities to several mA, TRIUMF to 400 μA. It is natural then to consider using these high intensity accelerators as injectors to higher energy machines. LAMPF has considered a machine of 15 or 30 GeV delivering currents of 50 or 100 μA. A fast cycling synchrotron is envisaged[3,28] and Fig. 28 shows how this would be fed by a high intensity H^- beam from the LAMPF Linac.

In the case of TRIUMF two alternative proposals are being considered: one involves a pair of proton synchrotrons,[29,30] the first (fast cycling) accelerating 30 or possibly 70 μA to 10 GeV and the second (superconducting) taking 30 μA to 30 GeV. These currents are somewhat smaller than the 400 μA which would be required from the present cyclotron, because beam can only be injected into the synchrotron over a fraction of its duty cycle; however, with synchrotrons there is no limit to the energy which can be reached. The other alternative[31] is for a pair of isochronous ring cyclotrons ('CANUCK'-Canadian University Cyclotrons for Kaons). The first would go to 3 GeV and the second to 8.5 GeV, about the maximum energy one can consider for a cyclotron. These machines have the advantage of being CW like the present cyclotron, so that they could accept the full current (100 or 400 μA) from that machine.

SIN is also considering a 2-3 GeV ring cyclotron[32] to accelerate currents of 4-5 mA as a high flux spallation neutron source. This could possibly feed into a 100-200 μA 8 GeV cyclotron kaon factory.

In the USSR Sarkisyan[33] has compared various particle accelerators as potential kaon factories, with particular attention to the problems of high energy cyclotron design. Active interest in kaon factories is also reported[3] at the Krasnaya Pakhra linac meson factory project.

Bugg[34] has pointed out that in kaon experiments, time of flight is an important factor for separating the wanted from unwanted events. This consideration would certainly favour a cyclotron as an injector, because of the relatively long pulse separation (20 ns at SIN, 44 ns at TRIUMF).

TRIUMF synchrotrons

Table IV lists the more significant parameters of the 10 and 30 GeV synchrotrons. The intensity of the fast cycling kaon factory synchrotron is limited by the phase space available at injection; depending on whether a repetition rate of 10 or 25 Hz is used, the final intensity will be 30 or 70 μA. The 30 GeV antiproton factory synchrotron would be superconducting and slow cycling, and would be limited in intensity only by what the 10 GeV machine could provide.

CANUCK ring cyclotrons

A possible arrangement for the 3 GeV and 8 GeV isochronous ring cyclotrons alongside the existing 500 MeV machine is illustrated in

Fig. 29. It turns out that the number of sectors must be at least three times the maximum value of γ, so that for the 3 GeV machine 15 sectors are used, between which are interspersed 12 SIN-style RF accelerating cavities. Nine of the cavities would run at 46 MHz and three at 92 MHz for flat-topping and improved turn separation, with a total RF power of 2 MW. The ion frequency is the same as in TRIUMF, so that the maximum radius is just a little larger, 10.1 m. The sector magnets would be superconducting with a maximum field of about 5T, and the total weight of steel would be about 2000 tonnes. The second stage 8.5 GeV machine has a radius of 20.6 m, twice that of the lower energy machine. There are 30 magnet sectors, with a total weight of 1800 tonnes. Fifteen 69 MHz cavities are used and six 207 MHz. The total RF power would be about 1.7 MW. Details of an individual magnet sector are shown in Fig. 30. Note the relatively small size of the magnet, weighing 60 tonnes, and the reverse field region to enhance the axial focusing. A possible physical arrangement of the machines on the TRIUMF site along with the experimental areas is shown in Fig. 31.

Final remarks

To return to the four questions mentioned at the beginning of this talk—if a kaon factory is never built I believe it will not be because of the lack of exciting physics, nor because the machines required cannot be built, nor even because of lack of money, but because of neglect by the nuclear and particle physics community! At present there is a relatively small number of scientists actually working with low energy kaons and antiprotons (though this number will probably rise when LEAR gets under way). There would seem to be two major reasons for this: first that the 10 GeV machines which have traditionally provided the slow kaon beams, have in many cases been shut down; and secondly that as the 400 GeV machines have come into operation many of the experimenters have moved up to the more fashionable higher energies. So, who should want a kaon factory? The answer to this seems clearly the users of pion factories now. After all, can we expect very much significant physics to be left for 500 to 800 MeV protons and the secondary beams they can produce by (say) 1990, at which time the pion factories will have been operating for 15 years? Surely by that time the significant experiments will have been largely cleaned up, and the present community will have to be considering moving on into fresh fields. There will be certain areas in which there remains an ongoing interest, particularly in *applied* physics (for instance, cancer therapy, isotope production, and perhaps muon spin resonance), but by and large we cannot realistically envisage doing the same physics until we retire. So, my conclusion is that this community must consider supporting a kaon factory, or else be content to see their present facilities become reduced to dedicated cancer treatment centres; exceedingly useful, but exceedingly uninspiring for students of physics.

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34. D.V. Bugg, Ref. 4, p. 224.
35. B. Povh, Proceedings of the 8th International Conference on High Energy Physics and Nuclear Structure (Vancouver, August 1979), eds. D.F. Measday and A.W. Thomas, Nucl. Phys. (to be published).
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Table I. Kaon Factory Workshop
August 13-14, 1979

Physics I (Chairman: D.V. Bugg)	Speaker
Opening remarks	J.R. Richardson
Nuclear physics with kaons	C.B. Dover
Physics for a new kaon facility at the AGS	M. May
Report on Los Alamos Kaon Factory Workshop: Physics	R.R. Silbar
Kaon elastic and inelastic scattering at 800 MeV/c	R.A. Eisenstein
Kaon-nucleus interaction	F. Tabakin
Contributed papers	
Accelerators and Beams (Chairman: J.R. Richardson)	
An improved kaon beam and spectrometer for the AGS	E.V. Hungerford III
The Fermilab booster as a kaon factory	B. Brown
Possible kaon and antiproton factory designs for TRIUMF	M.K. Craddock
A LAMPF kaon factory	D.E. Nagle
Contributed papers	
Physics II (Chairman: E. Boschitz)	
Symmetry-violating kaon decays	P. Herczeg
Hyperon physics and chromodynamics	N. Isgur
Physics possibilities with LEAR, a low-energy antiproton facility at CERN	U. Gastaldi
Contributed papers	
Poster session	
Joint session with 8-ICOHEPANS	
Summary of Kaon Factory Workshop	E.M. Henley
Related invited papers at 8-ICOHEPANS	
Hypernuclei	B. Povh
Baryonium	H.-M. Chan
Exotic atoms and hypernuclei	C.B. Dover

Table 11. Improved kaon beams

	BNL-AGS LESB I	BNL-AGS (new)	KEK (new)
Momentum (GeV/c)	0.5-0.8	0.5-0.8	0.5-0.7
Length (m)	15.2	≤ 10	8.5
$\Delta p/p$ (%)	4	4	6
$\Delta\Omega \cdot \Delta p/p$ (msr %)	10.6	~ 100	72
Flux (0.8 GeV/c $K^-/10^{12}p$)	8×10^4	$\sim 10^6$	
π/K ratio	10	≤ 10	
Spectrometer		Achromatic	
Energy resolution (keV)		200	
Angular resolution		0.25°-0.5°	
$\Delta p/p$ (%)		6	
$\Delta\Omega$ (msr)		30	
Angular coverage		0°-140°	

Table III. LEAR Workshop:[24] subjects for discussion

PHYSICS

- Annihilation
  - at rest
  - at low energies
  - rare decay channels
- Determination of quantum numbers and properties $(J^{\pi}\ I^{G}\ M\ \Gamma\ \ldots)$
  - of bound states
  - of resonances
- Antiprotonic atoms
  - $\bar{p}p$ in liquid and gas targets
  - $\bar{p}p$ in vacuum (parallel-going $\bar{p}H^-$ or $\bar{p}p$)
  - $\bar{p}$ atoms with heavier targets
  - annihilation from atomic states (X-ray coincidences)
- Fundamental properties of $\bar{p}$ (precision experiments)
- Isospin dependences (comparison of $\bar{p}p$, $\bar{n}p$, $\bar{p}d$, ...)
- Baryonium
- Vector mesons
- Charmonium (formation of other than $J^{\pi} = 1^-$ states)
- $\bar{p}$ on nuclei

EXPERIMENTAL TECHNIQUES: PROBLEMS AND POSSIBILITIES

- Experiments with extracted cooled beams
- Experiments with stored cooled beam on an internal gas jet target
  - jet target (with p, d, ...)
  - polarized jet target
  - high resolution $\bar{n}$ beam production
- Experiments with colliding cooled beams
  - single ring parallel (e.g. $\bar{p}H^-$) and antiparallel (e.g. $\bar{p}p$)
  - double ring parallel [e.g. ($\bar{p}H^-$, $\bar{p}d^-$)] and antiparallel (e.g. $\bar{p}d$)
- $\bar{n}$ factory (charge exchange)
- Role of phase-space cooling for energy resolution,
  luminosity duty cycle
- Detectors
- Fast on-line data processing
- Application of lasers in experiments with $\bar{p}$ atoms in flight

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Table IV. TRIUMF K- and $\overline{p}$-factory synchrotrons

	K-factory	$\overline{p}$-factory
Final energy	10 GeV	30 GeV
Type of magnets	Fast cycling	Superconducting
Radius	50 m	50 m
Aperture	10 × 6 cm^2	4 × 4 cm^2
Injection time	10 ms	4 s
Repetition rate	10-25 Hz	0.1 Hz
Acceleration time	11 ms	1 s
Nominal energy gain/turn	1.0 MeV	0.05 MeV
Space charge limit (protons/turn)	3×10^{14}	9×10^{16}
Phase space limit (protons/turn)	3×10^{13}	5×10^{15}
Protons/pulse	2×10^{13}	2×10^{15}
Proton current	$2\text{-}5 \times 10^{14}$/s 30-70 μA	2×10^{14}/s 30 μA

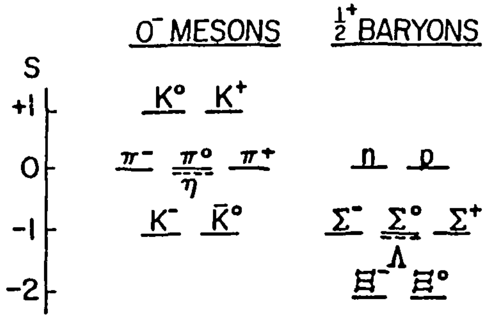


Fig. 1. The 0^- meson and $1/2^+$ baryon octets.

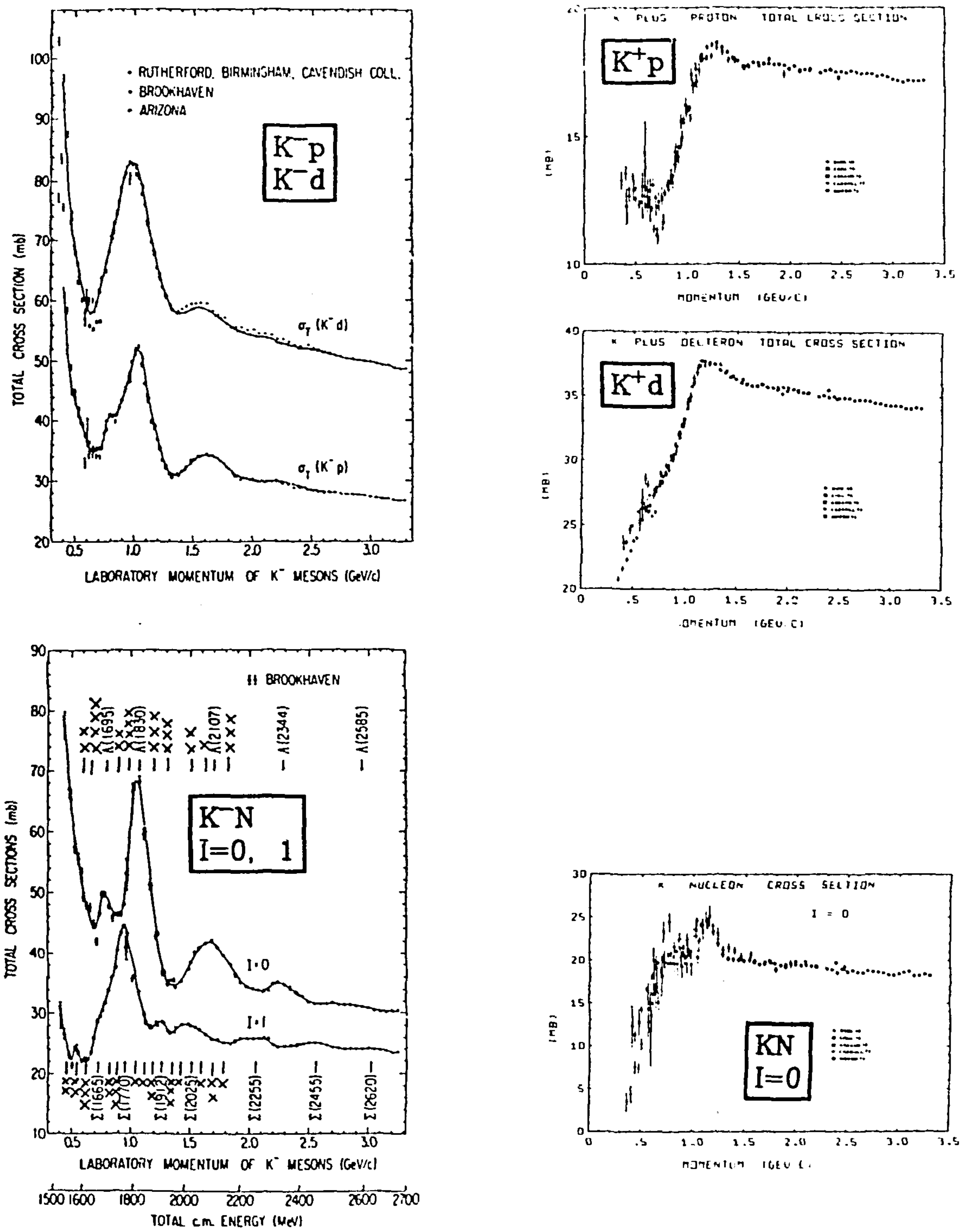


Fig. 2. KN total cross-sections up to ~3 GeV/c, (from 'Review of Particle Properties, April 1978', Ref. 7).

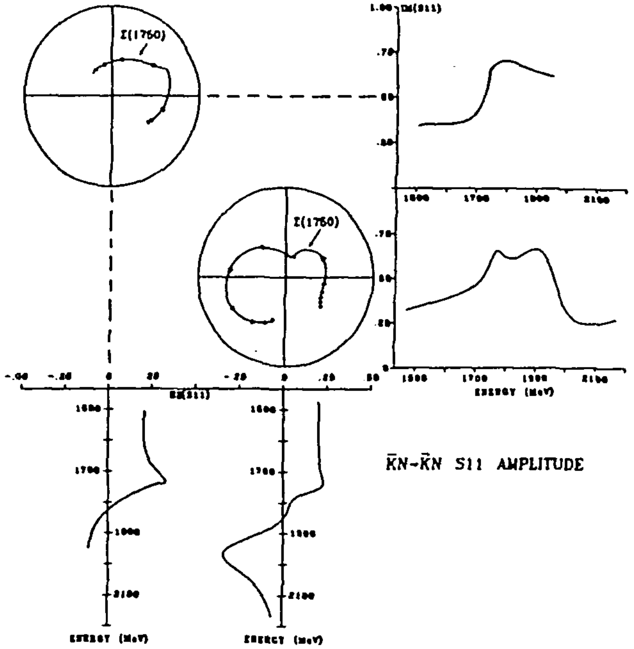


Fig. 3. Amplitudes for elastic $\bar{K}N$ scattering in the S_{11} partial wave.[7] The upper plot is taken from Alston-Garnjost *et al.*,[9] the lower from Gopal *et al.*[10]

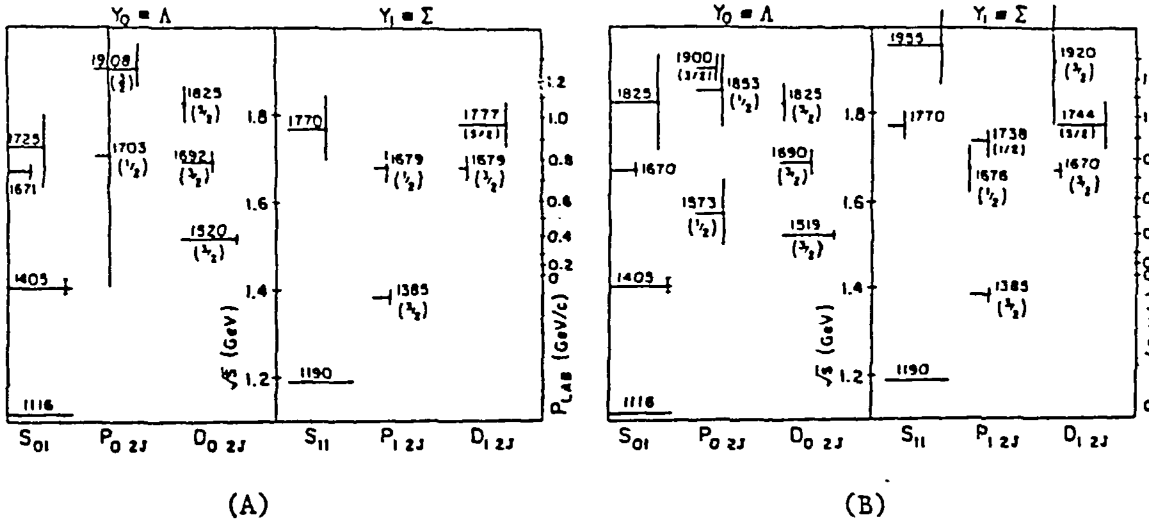
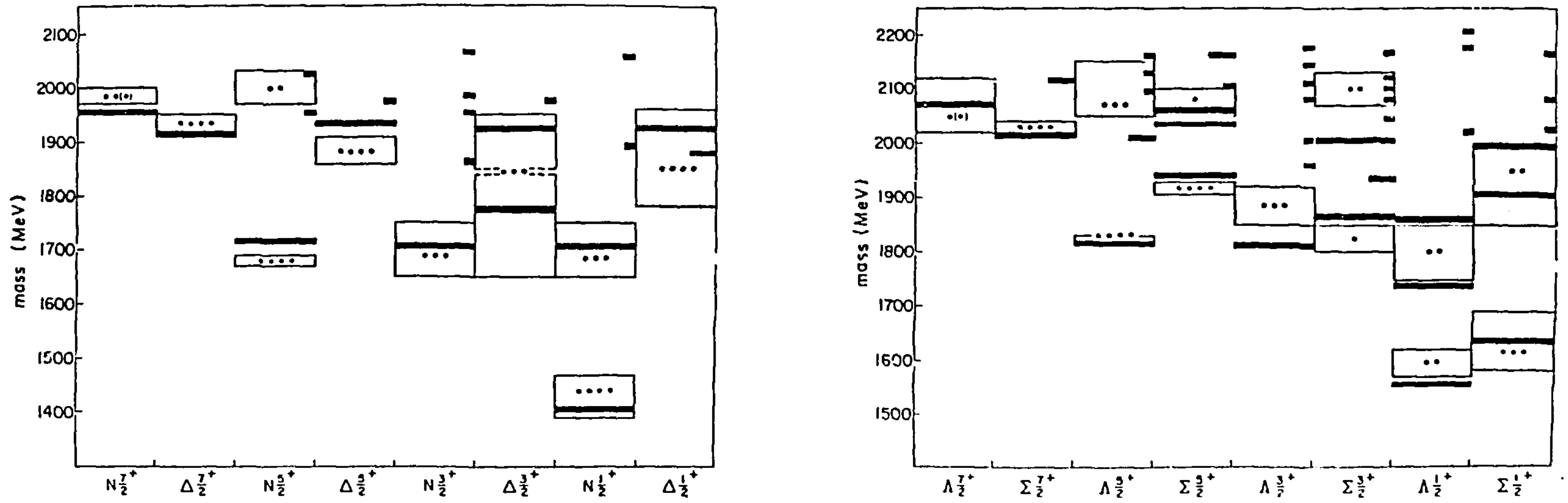


Fig. 4. The Y^* resonance spectrum:[11] (a) Alston-Garnjost,[9] (b) Gopal.[10] The lengths of the horizontal and vertical lines represent the elasticity and width of each state, respectively.



Figs. 5 and 6. The positive parity baryon resonances with S = 0 (left) and S = -1 (right) in Soft QCD.[12] The boxes represent observed resonances, the stars indicating their Particle Data Group rating. The predicted resonances are denoted by bars whose lengths indicate their predicted visibility relative to the strongest resonance in the partial wave.

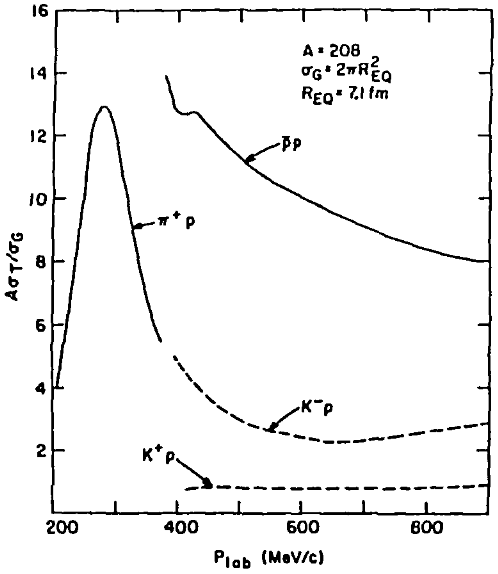


Fig. 7. Total cross-sections σ_T for slow $\bar{p}$, π^+, K^- and K^+ on protons,[13] scaled to give the 'geometricity' $A\sigma_T/\sigma_G$ for A = 208.

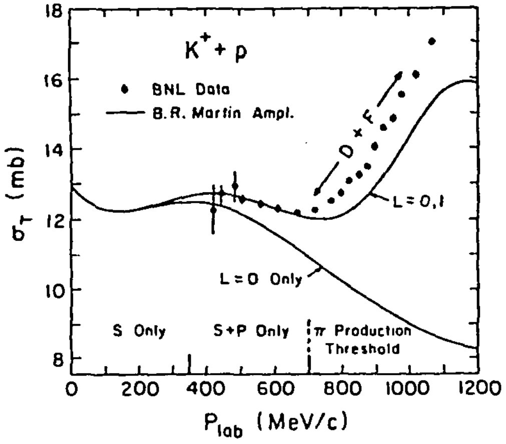
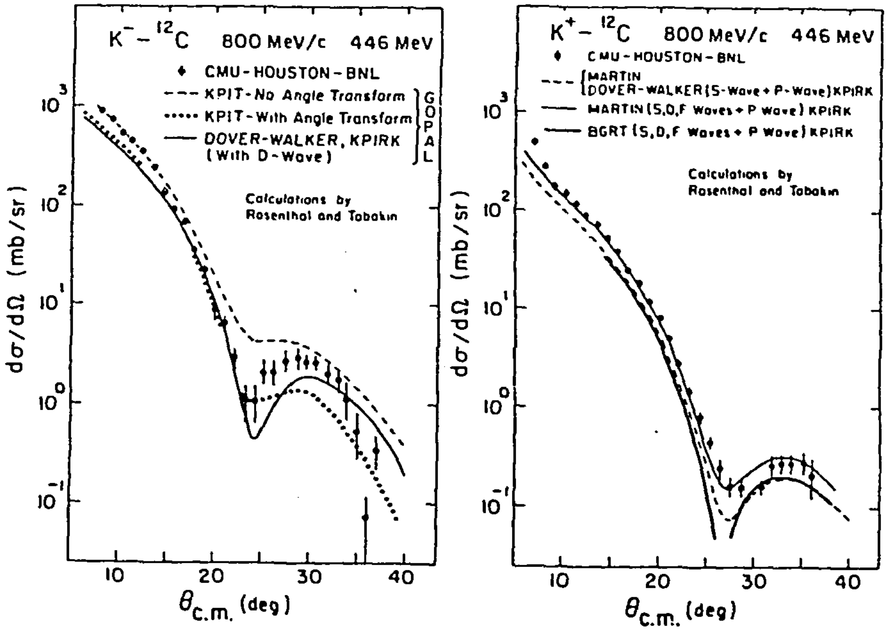
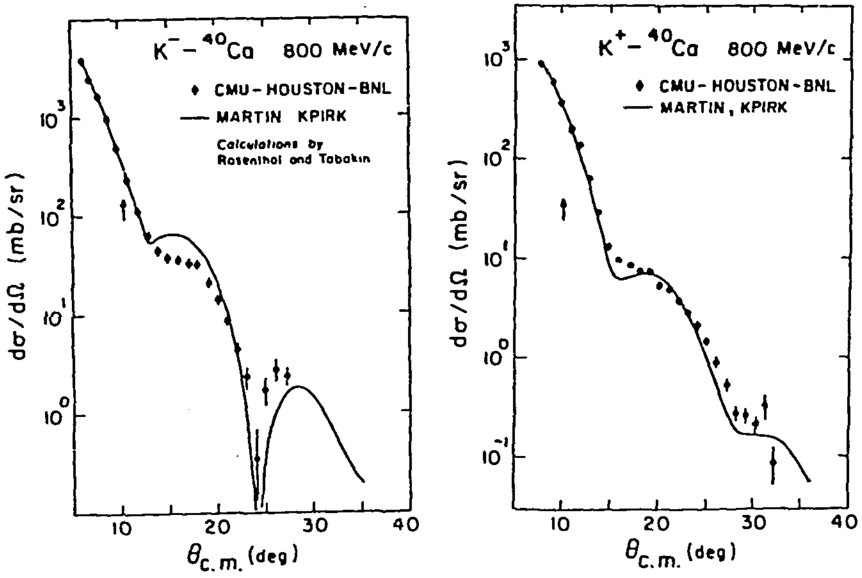


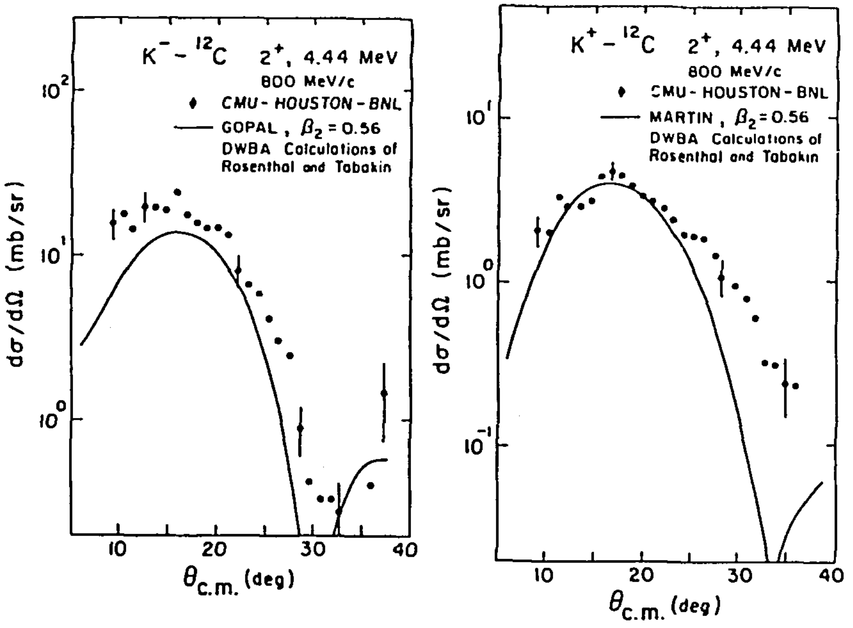
Fig. 8. Total cross-section σ_T for low energy K^+p scattering.[14] Martin's phase shift analysis included L ≤ 3.



Figs. 9 and 10. $K^\pm$ - ^{12}C elastic data and calculations. Both data and calculations are preliminary.[14]



Figs. 11 and 12. Same as Fig. 4 but for ^{40}Ca target.[14]



Figs. 13 and 14. $K^{\pm}$ - ^{12}C inelastic data and calculations. Both data and calculations are preliminary.[14]

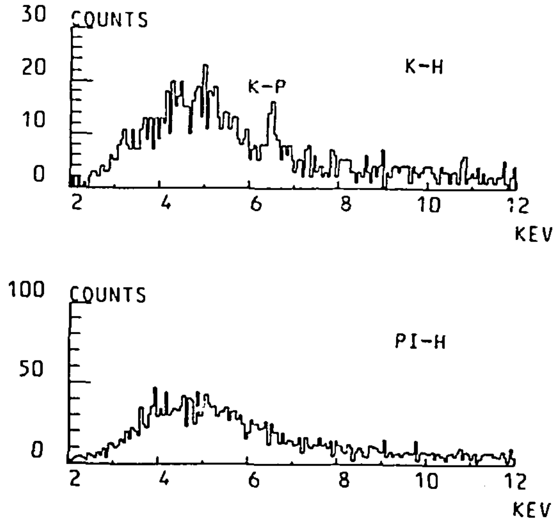


Fig. 15. First observation[16] of K X-rays in kaonic hydrogen (top) compared to background spectrum for pionic hydrogen (bottom).

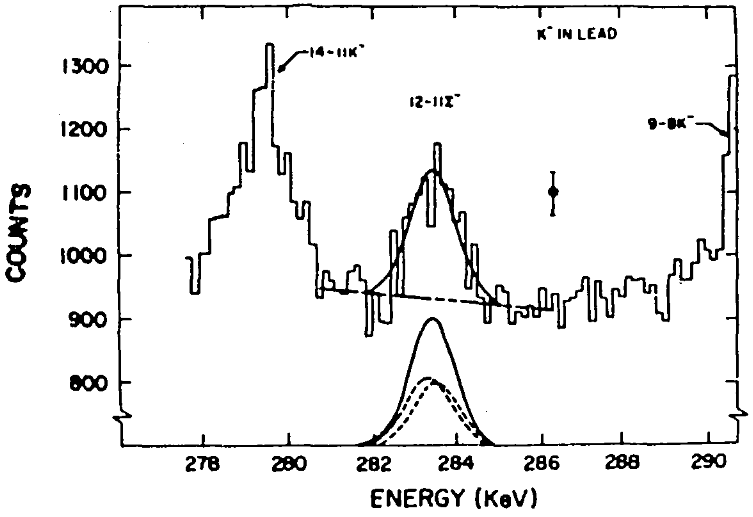


Fig. 16. Σ^- and K^- X-ray spectrum[17] obtained by stopping K^- in Pb.

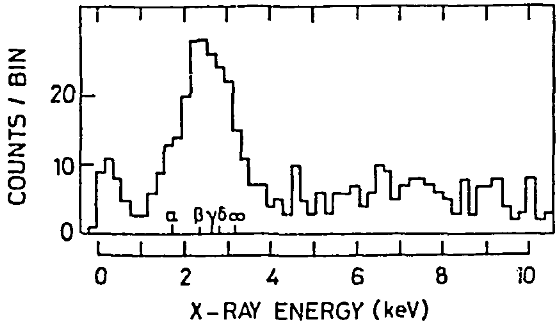


Fig. 17. Protonium ($\overline{p}p$) X-ray spectrum[18] showing L X-ray peak at 2-3 keV.

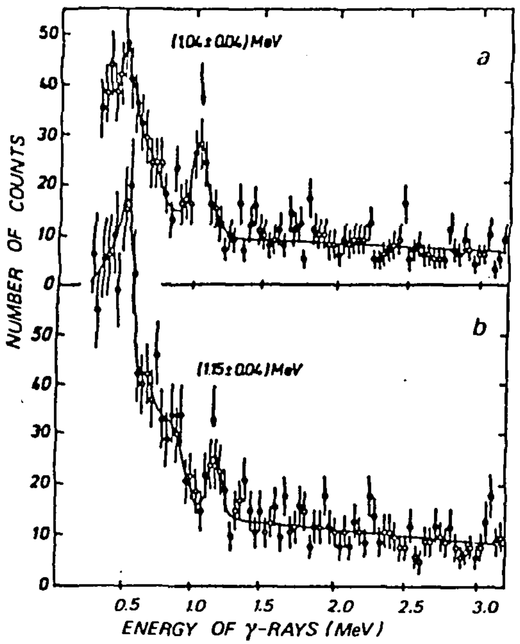


Fig. 18. Hypernuclear γ-rays from de-excitation of $^{4}_{\Lambda}H^*$ (top) and $^{4}_{\Lambda}He^*$ (bottom).[19]

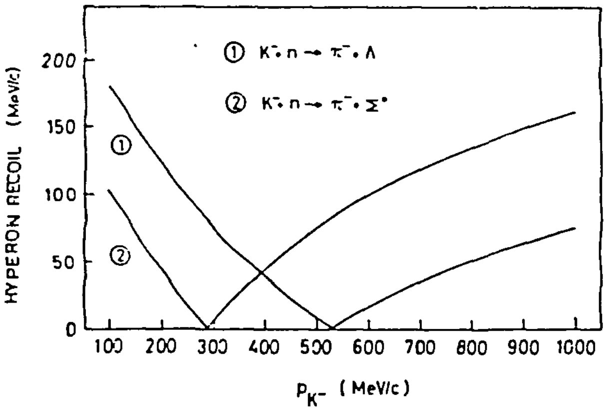


Fig. 19. Recoil momentum of Λ and Σ hyperons in the strangeness exchange reaction for collinear kinematics.[35]

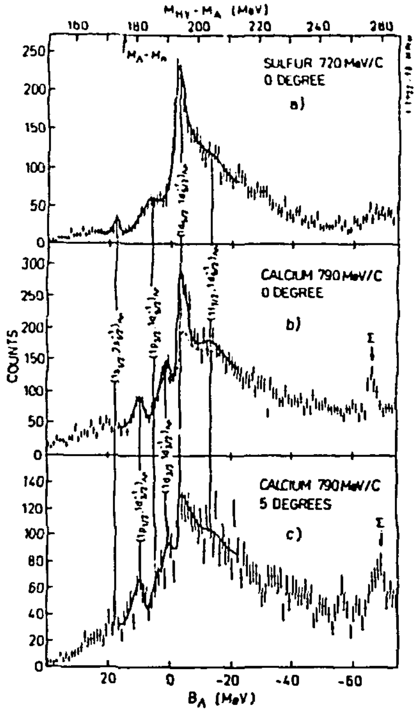


Fig. 20. Hypernuclear mass spectra for $^{32}_{\Lambda}S$ and $^{40}_{\Lambda}Ca$ obtained via the (K^-,π^-) reaction.[20]

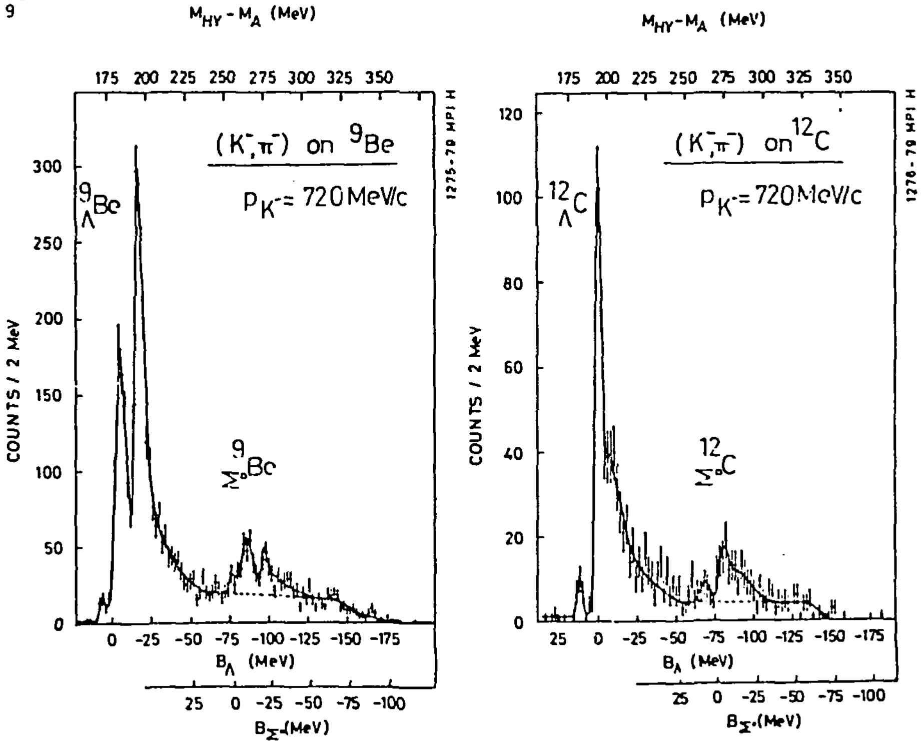


Fig. 21. Λ- and Σ^0-hypernuclear mass spectra for ^{9}Be and ^{12}C via the (K^-,π^-) reaction.[21]

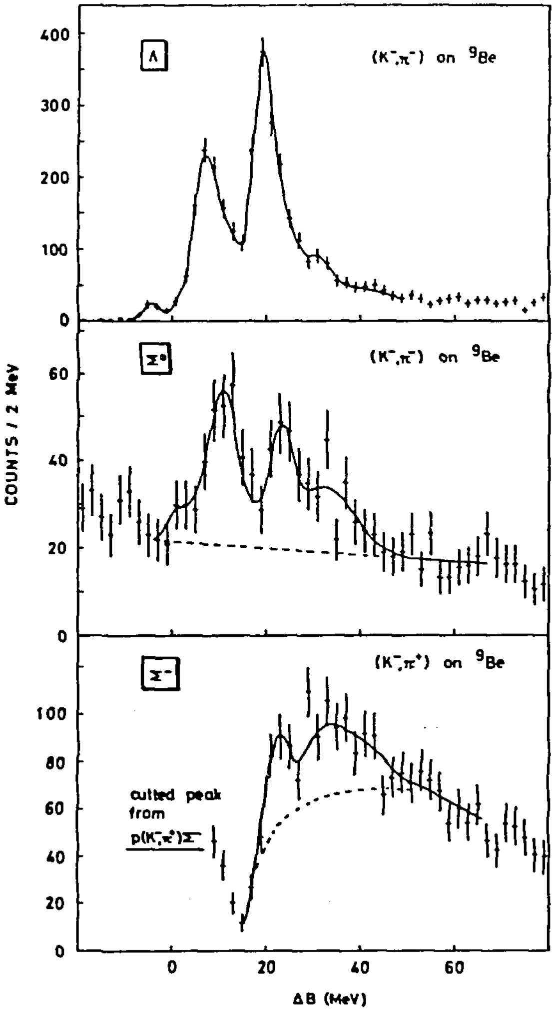


Fig. 22. Comparison of the Λ, Σ^0 and Σ^- hypernuclear spectra for ^9Be in the ΔB scale $[\Delta B = M_{HY} - M_A - (M_{\Lambda,\Sigma} - M_{n,p})]$.[21]

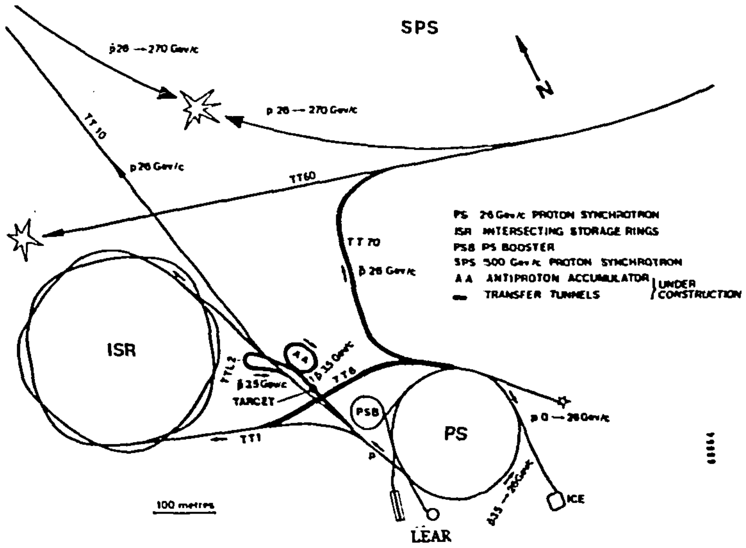


Fig. 23. Layout of the CERN accelerators and storage rings.

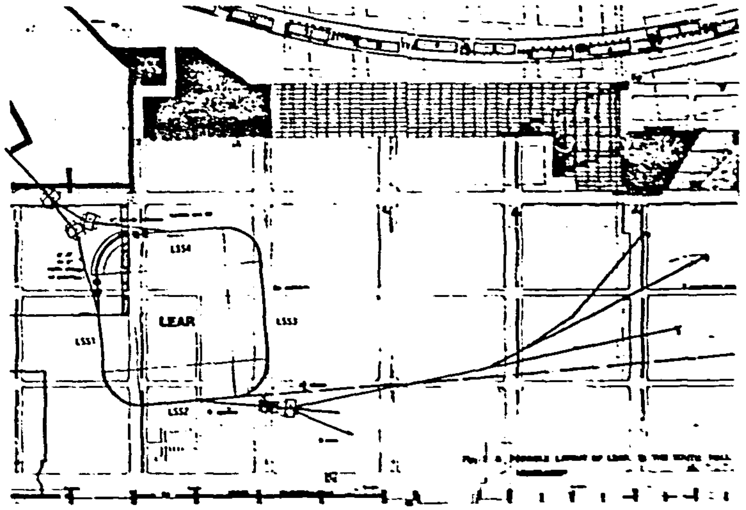


Fig. 24. Possible layout of LEAR in the South Hall of the PS.

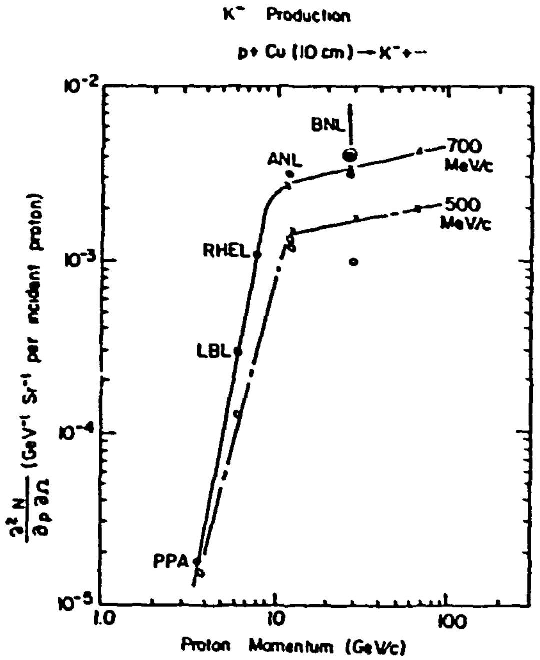


Fig. 25. K⁻ production versus proton momentum for a 10 cm Cu target.[25]

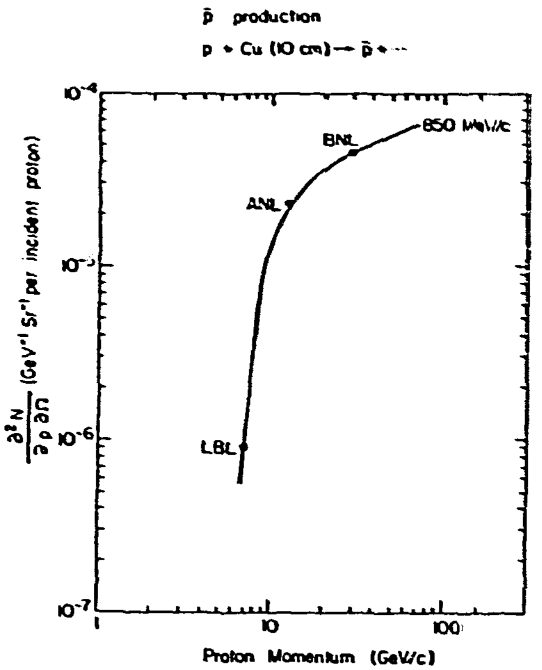


Fig. 26. production versus proton momentum for a 10 cm Cu target.[25]

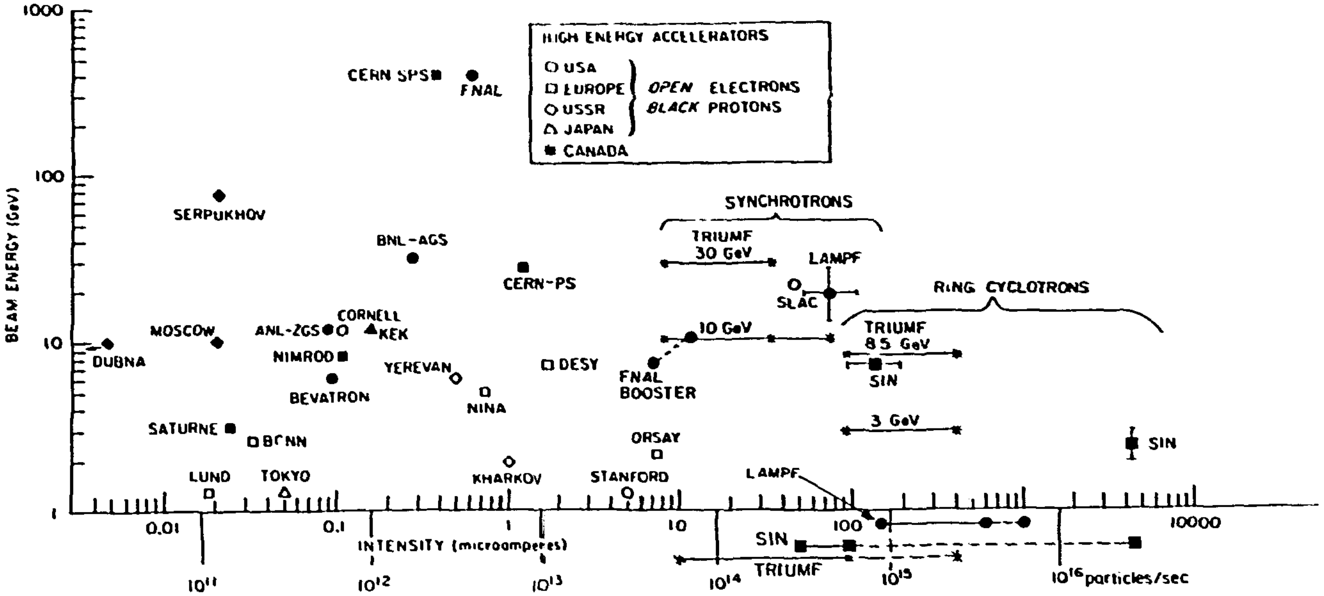


Fig. 27. Distribution of high energy accelerators in energy and intensity (adapted from Ref. 26).

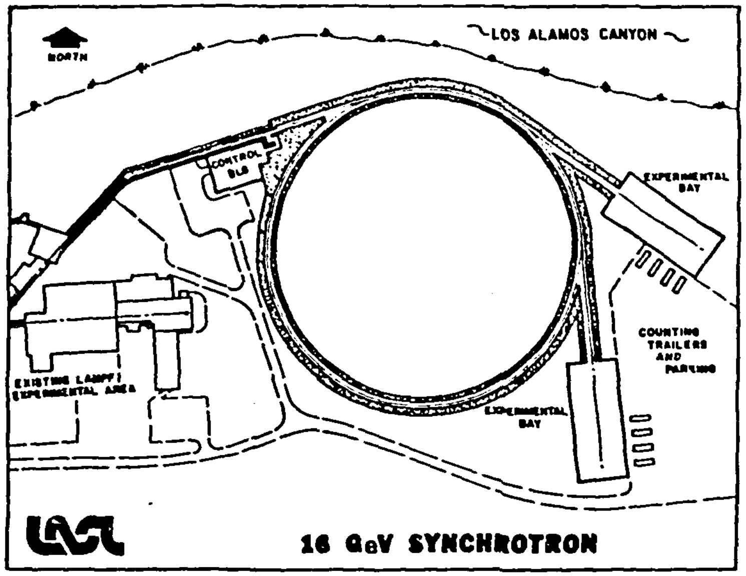


Fig. 28. Possible arrangement for a 16 GeV synchrotron to be fed by the LAMPF H⁻ beam.

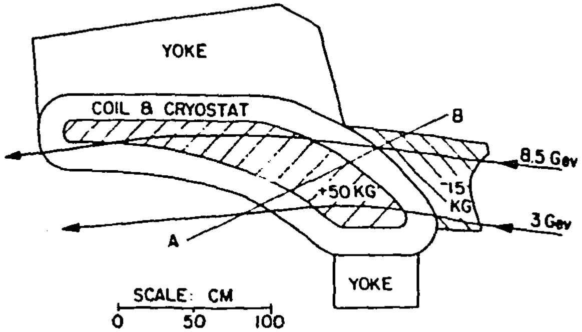


Fig. 30. Plan view of the superconducting sector magnet design for the second stage 3 to 8.5 GeV CANUCK cyclotron.

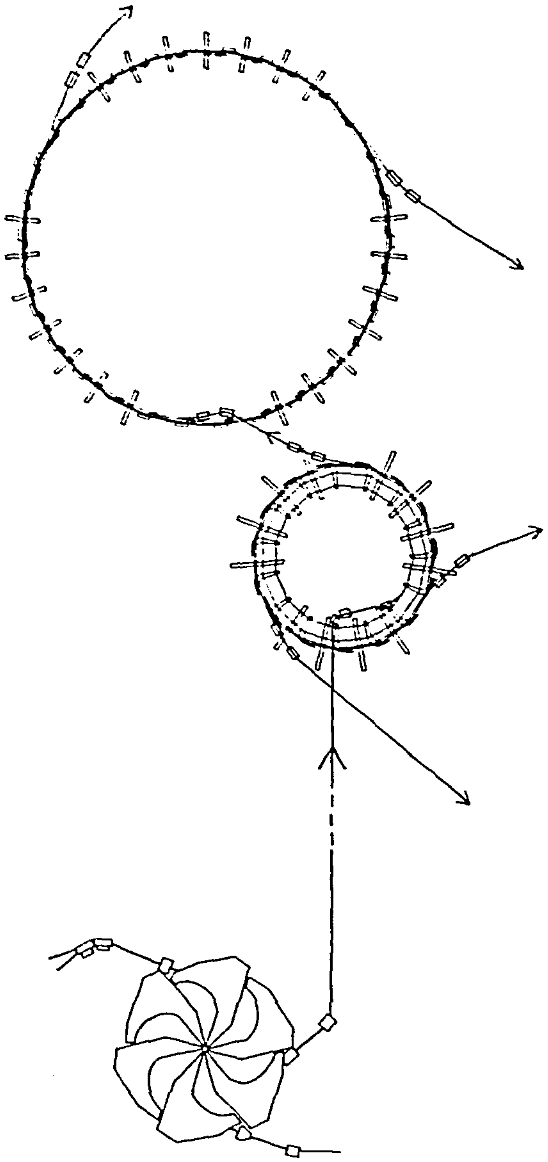


Fig. 29. Possible arrangement of the 3 and 8.5 GeV CANUCK cyclotrons fed from beam line 2A of the present TRIUMF cyclotron.

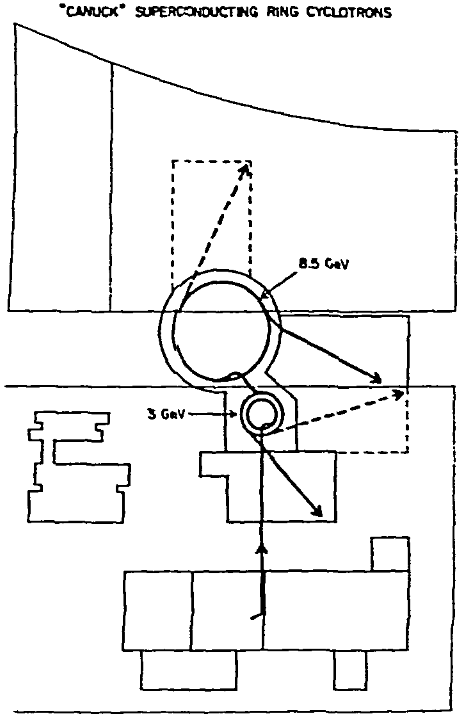


Fig. 31. Possible arrangement of the CANUCK cyclotrons and experimental halls on the TRIUMF site.