Paper presented at Excited Baryons - 1988,
Rensselaer, August 4-6

TRI-PP-88-99
Nov 1988

A Kaon Factory for TRIUMF

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ABSTRACT

The design study for the TRIUMF Kaon Factory has recently been funded. A short discussion of the scientific motivation is given first, followed by a brief description of the 30 GeV synchrotron which is being proposed. There will be five rings altogether using the present TRIUMF 500 MeV cyclotron as an injector. If the project is funded in 1990 the accelerators would be completed in 1995 or so, and the experimental programme would start a year later.

1. INTRODUCTION

We at TRIUMF are delighted that the Canadian Federal Government and the B.C. Provincial Government have decided to jointly fund an $11M design study for a 30 GeV proton synchrotron. The announcement was made only a month ago, on July 21, 1988, at the Pan Pacific Hotel, which is on the waterfront of Vancouver harbour. The government spokesmen were Frank Oberle, federal Minister of State (Science and Technology) and Stan Hagen, the B.C. Minister for Advanced Education and Job Training. The funds will cover what is technically called the Project Definition Study which will include construction of various prototypes for the R.F. cavities, magnets and power supplies etc. In addition external consultants will prepare initial drawings for the buildings and the services. This phase will take about fifteen months and then a more accurate cost estimate will be established.

The Project Definition Study will be led by Prof. Alan Astbury of the University of Victoria. Dr. E.W. Vogt will remain as Director of TRIUMF, but major changes in the laboratory will be necessary to accommodate this study. Between 30 and 40 staff will be assigned to the project which will temporarily dilute the effort on the ongoing programme, but it is expected that there will be no major changes in the scientific research on the existing 500 MeV cyclotron as some of the secondary staff will be replaced.

2. SCIENTIFIC GOALS

There has already been a significant investigation of kaon and hypernuclear physics, but there is a vast amount left to study. Present experiments are severely limited by the kaon flux as well as the purity of the beams (ten times as many pions normally accompany the kaons). We shall briefly outline the research areas which are stalled at present due to the lack of adequate facilities.

In a few pages it is impossible to do more than outline the scientific program. More complete discussions are available in the proposal itself[1]) as well as in proposals from the AGS[2]), LAMPF[3,4]) and a European Collaboration[5]).

First there is the area of kaon decays. Here the goal is to further investigate the standard model which is the framework of our understanding of the quark and lepton structure of matter. The kaon has probably been the most fertile laboratory in particle physics. The decays of the muon and pion presented the basic information about the weak interactions, but the kaon added the complexity of strangeness which presented more dimensions and thus more information. Since the Kaon Factory proposals were written, experiments have continued at BNL, FNAL and CERN and have recently been reviewed by Bryman[6]). For example the study of CP violation has taken a major step forward with the recent report[7]) that a CERN collaboration has obtained a non-zero value for ε'/ε, viz $(3.3 \pm 1.1) \times 10^{-3}$. Further results can be expected in the near future. Although the discovery of B^0-$\bar{B}^0$ mixing is now well established, the investigation of CP violation in that system is likely to be very difficult[8,9]. Thus further experiments on the kaon system are inevitable.

The other major topic in kaon decay is the search for rare and exotic channels. A typical effort is Exp 787 at Brookhaven which is trying to identify the decay $K^+ \to \pi^+ \nu_\ell \bar{\nu}_\ell$. Other searches are being made for the breakdown of the separate conservation of muons and electrons. So far no evidence is forthcoming but there is a general conviction that sooner or later something unusual will be discovered. All such experiments will benefit by the extra flux and superior beam quality that will be available at a Kaon Factory. Experience on Exp 787 has shown however that extra flux will bring with it many problems. It will be necessary to refine experimental detectors to withstand high rates and it will also be essential to improve data acquisition systems, initially using parallel processing, but ultimately faster computers will be required.

In the area of multi-body physics, the principle topic is hypernuclei. How does a nuclear environment respond to the addition of other baryons, and how can one calculate the properties of the system from the basic baryon-nucleon interaction? At present we have some information about Λ-hypernuclei, but even there our knowledge of the Λ-N interaction is relatively rudimentary. Almost no spin parameters have been measured, yet the system is as complex as proton-proton scattering. Experimental studies of hypernuclei have continued although at a gentle pace. The Bad Honnef conference contains several useful reviews.[10]

At BNL there have been extensions of the (π^+,K^+) experiments[11], whilst at KEK there have been studies of K^- interactions at rest. These experiments have clearly indicated the Λ-shell structure in nuclei, but details are still lacking. It is clear that future experiments will need to study all the various reactions, viz (K^-,π^-) (π^+,K^+) (K^-,π^0) but with an energy resolution appropriate for nuclear physics studies, i.e. 100 keV or better.

If a Σ is produced in a nucleus the situation is complicated by the strong exothermic conversion $(\Sigma + N \to \Lambda + N)$ which is allowed in the nuclear environment. It was thought that for unbound levels, the Σ was sufficiently outside the nucleus that this conversion to a Λ was suppressed. However the situation is now confused with conflicting interpretations coming from the KEK experiments for K^- at rest.[12,13] Of course it is possible that at rest production is sufficiently different from in flight reactions that the spectra are fairly different. Anyway the overall situation is now more confusing than it was a few years ago, not less!

One of the most exciting possibilities is to inject two strange hadrons into a nucleus. It might even be possible that $\Lambda\Lambda$ is bound, the so called H dibaryon. Little new has been established in the last few years, though conservative calculations have progressed and Bodmer and Usmani[14] have studied several light double hypernuclei, viz ${}^{6}_{\Lambda\Lambda}$He and ${}^{10}_{\Lambda\Lambda}$Be. The $\Lambda\Lambda$ interaction however is poorly understood, and it is still not at all clear whether the H dibaryon exists or whether it is simply a $\Lambda\Lambda$ resonance, or even just a strong attractive interaction. The double hypernuclei can be studied via the (K^-,K^+) reaction, but at present the K^- fluxes are too small to be useful.

A final word should be said about antiproton physics. A lot of interesting experiments have been done recently at LEAR and CERN. This is a ring which cools and stores antiprotons at energies of from about 100 to 2000 MeV/c (5 to 1240 MeV). However this was only possible because CERN had built the AA (antiproton accumulator) to produce Z° particles in the SPS. As the CERN Courier expressed it, the experiments went from AA to Z. They have now constructed an improvement on the AA called the collector (ACOL). To compete with CERN a Kaon Factory would have to build both a collector and a LEAR ring which would cost at least $50M and so such a facility is not yet planned.

However it is possible to study antiproton physics at a few GeV because that is the maximum of the production cross-section. No unusual equipment would be required, only a fairly standard separated beam. It turns out that a few GeV is the perfect energy to study the Ψ region.

Thus a $\bar{p}$ momentum of 3679 MeV/c is needed to produce the η_c while 5192, 5548 and 5723 MeV/c are needed to produce χ_0, χ_1, χ_2 respectively. In the dying days of the ISR an experiment was attempted and these states were identified in $\bar{p}p$ collisions, so the cross-sections are known, but very little extra could be determined because of the lack of beam time[15]. This experiment also had a tentative identification of the $^1P_1$ state of charmonium at (3525.4 ± 0.8) MeV/c^2 which is a unique measurement.

A summary of some important physics is given in Table I. Surveying this menu it is possible to ask what machine is needed to study these topics. One asterisk means that a high energy (>30 GeV) is useful, two asterisks means that it is essential. Thus

(i) For neutrino production and for K^+ beams below 1 GeV, a proton energy of 10 GeV is sufficient.

(ii) For K^- beams below 1 GeV a proton energy of 15 GeV is optimum.

(iii) For K beams above 1 GeV and for antiproton beams, 30 GeV is essential but 40 or 50 GeV is better.

To express the same thought in a different way:

A 15 GeV synchrotron is adequate for:

(a) all K decays

(b) hyp rnuclear studies

(c) most neutrino reactions

(d) some meson and quark spectroscopy

TABLE 1

PARTICLE PHYSICS

A. Very Rare Kaon Decays
   1. Muon number conservation ($K^0 \rightarrow \mu e$)
   2. Searches for new effects ($K^+ \rightarrow \pi^+ + X^0$)

B. Established Kaon Decays
   1. CP violation
   2. Kobayashi-Maskawa angles
   3. Form factors

C. 1. $\nu_\mu(\nu_e?)\ e^-$ scattering
   2. ν oscillations
   3. ν masses

D. Baryon Spectroscopy
   1. N and Δ resonances (πN scattering and reactions)
   *2. Λ and Σ resonances ($K^- N$ scattering and reactions)

E. Meson Spectroscopy
   *1. $s\bar{s}$ states between 1 and 2 GeV/c^2
   **2. Glueballs (or gluerings?)
   ***3. Exotics (hermaphrodites, meiktons, or hybrids)

F. Hyperon-Nucleon Interactions
   *1. Direct scattering for Λn, ΣN, ΞN (tagged hyperons)
   2. Final-state interactions ($K^- d \rightarrow \gamma \Lambda n$: $K^-\,{}^3He \rightarrow \Lambda pn$)
   *3. Hyperonic atoms (Σ^-, Ξ^-, Ω^-)

G. Antiproton Studies
   **1. New charmonium states via $\bar{p}p \rightarrow \Psi$
   **2. Annihilation and baryonium
   **3. $\bar{p}$ scattering on nuclei and 'hot spots'

H. Muon Physics
   1. New (g – 2) with ×20 precision

I. Polarization Studies
   **1. Polarized proton beam and target
   *2. Polarization effects in reactions such as $\pi^- p \rightarrow \rho n$

NUCLEAR (OR MANY-BODY) PHYSICS

A. Λ *Hypernuclei*
   1. Spectroscopy of excited states via (K^-,π^-), (π^+, K^+) (K^-, π at rest), (K^-, γ)
   2. Effective spin-orbit forces
   3. Binding energy anomalies (eg. ${}^5_\Lambda He$)
   4. Λ lifetime in hypernuclei

B. Σ Hypernuclei
   1. Why are states so long-lived?
   2. Spin-orbit forces (${}^7_\Sigma Li$)
   3. Isospin violation

C. Double Hypernuclei
   *1. Do they really exist? $\Lambda\Lambda$ or Ξ [via (K^-,K^+)]
   2. Relation to possible S = -2 dibaryons

D. Neutron Radii in Nuclei
   1. K^+ and p nucleus scattering
   2. Kaonic and hyperonic atoms

E. *Resonance Propagation*
   1. $\Lambda(1520)$ behaviour in nuclear matter

F. Miscellaneous
   1. Regenerative amplitudes
   2. Neutrino-nucleus interactions

At a 30 GeV synchrotron one could also study:

(e) charmonium studies via $\bar{p}p\to\psi$

(f) hyperon-nucleon interactions

(g) more meson and baryon spectroscopy (especially strange baryons coupled weakly to K^-p)

(h) glueballs and exotica.

Thus at TRIUMF we have opted for a 30 GeV synchrotron. At LAMPF they have pressed for higher energies. It is always possible to argue for a little bit more energy for some reason or another. We have thus decided on a reasonable compromise, but a higher or lower energy would still be an excellent new facility.

3. THE ACCELERATOR COMPLEX

The details of the accelerator can be found in the proposal[1]. The overall plan is a set of five rings which eventually reach 30 GeV with 100μA of available protons (3 MW of beam power!) Some changes have been made since the proposal, the main one being that it is now planned to have a race-track shape for the main tunnel, not a circular one as originally proposed. The overall plan is illustrated by Fig. 1.

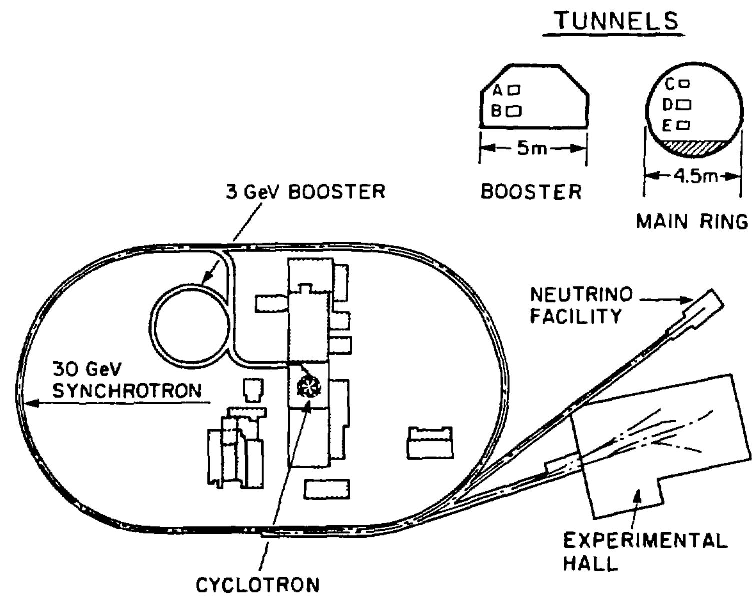

Figure 1

The present TRIUMF cyclotron will be used as an injector into a 3 GeV booster. Brookhaven has shown that H^- injection is a significant advantage, so this feature will be utilized. Now TRIUMF is of course the highest energy H^- cyclotron in the world, but this advantage is not as powerful as it may appear, because all our external beams are obtained by stripping the H^- inside the machine, so externally only proton beams are available at present. It is thus necessary to make important modifications to the present cyclotron to extract the H^- ions intact. It is proposed to add extra decelerating electrodes, as well as an extraction channel, so that H^- ions can be transferred to an accumulator ring at an energy of 430 MeV, which is slightly less than the normal maximum energy.

After storage in the accumulator ring the beam, now in the form of protons, will be pulsed into a fast-cycling booster which will accelerate the beam to 3 GeV at a rate of 50 Hz. Five pulses will be stored in another ring, the collector, before ejection into the final driver which will take the protons to the full energy of 30 GeV at a rate of 10 Hz. To improve the duty cycle for experiments it would be better to add a fifth ring, an extender which would spill the beam at a uniform rate to the experimental areas. Such a facility might not be available initially, so the duty cycle would not be ideal but depend on some flat-topping of the main magnet. Some parameters of the proposed complex are listed in table 2, to give a more specific idea of the goals.

These parameters illustrate why it is common to have a booster stage before the main ring. It means that the RF cavities of each ring can be optimized for different tasks. The booster provides all the frequency swings (33%) whilst the main ring provides most of the energy gain (90%). The booster will have twelve 50 kV cavities, whilst the main ring will be equipped with eighteen 135 kV cavities. The magnetic structures are illustrated in Figure 2.

An important fact to remember is that the ultimate goal is to achieve a current of 100 μA which implies a beam power of 3 MW. There are two major difficulties which are the consequences of this ambitious proposal. First the RF system will have to develop this power. In a linac the efficiency is normally less than 10%, although in a synchrotron one can hope to achieve 30% during the period of maximum acceleration. One will have to anticipate a considerable RF power and a total site power requirement of the order of 50 MW. Fortunately British Columbia is blessed with abundant hydropower, so this is not a major concern. The second major problem that the beam power implies is adequate radiation shielding, and most estimates show that tens of millions of dollars will be expended on beam shielding.

Table 2

Synchrotron design parameters

	Booster	Driver
Energy	3 GeV	30 GeV
Radius	4.5 $R_\tau = 34.11$ m	22.5 $R_\tau = 170.55$ m
Current	100 μA = 6×10^{14}/s	100 μA = 6×10^{14}/s
Repetition rate	50 Hz	10 Hz
Charge/pulse	2 μC = 1.2×10^{13} ppp	10 μC = 6×10^{13} ppp
Long straights	0	2 × 168 m
Superperiods in arcs	6	12
Lattice structure		
Focusing	FODO	FODO
Bending	OBOBBOBO	BBBB
Focusing cells/superperiod	4	4
Maximum $\beta_x \times \beta_y$ (arcs)	15.8 m × 15.. m	35 m × 30 m
Dispersion η_{max}	4.0 m	6.6 m
Transition $\gamma_t = 1/\sqrt{\eta}$	9.2	∞
Tunes $\nu_x \times \nu_y$	5.23 × 7.22	13.2 × 14.2
Space charge $\Delta\nu_y$	−0.15	−0.09
Emittances at injection		
$\epsilon_x \times \epsilon_y$	$139\pi \times 62\pi$ (μm)	$37\pi \times 16\pi$ (μm)
ϵ_{long}	0.064 eV–s	0.192 eV–s
Harmonic	45	225
Radiofrequency	46.1–61.1 MHz	61.1–62.9 MHz
Energy gain/turn	210 keV	2000 keV
Maximum rf voltage	576 kV	2400 kV
Rf cavities	12 × 50 kV	18 × 135 kV

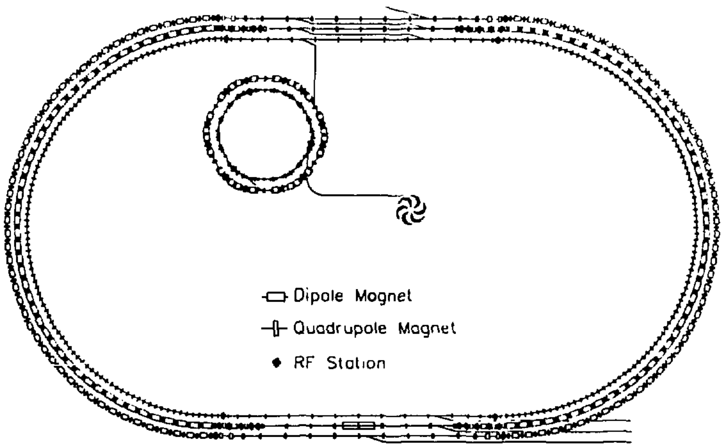

Figure 2

The total cost is estimated to be CDN $571M in present dollars. Of this it is expected that the Province of British Columbia will provide about $90M for the land and the buildings. This sum has already been promised and the B.C. Government is supporting this proposal very strongly. It is expected that some of the remaining cost would be contributed by foreign governments, probably as specific components of the accelerator complex. At least $100M, if not $150M, is expected to be provided in this manner, leaving just over $300M to be granted by the Canadian Federal Government.

The annual operating costs would be approximately $80M and a staff of about 800 would be needed, both being somewhat more than double the present situation.

In 1989 it is anticipated that scientific workshops will be held in countries such as the U.S.A., Japan, Italy, West Germany, France and the U.K. These would establish the scientific goals and would identify scientists across the world who are interested in participating in this exciting venture. Negotiations with the appropriate governments would then follow and contracts would be proposed for contributions to the construction of the accelerators.

Final approval of the project should occur in 1990 which would mean that the accelerator would be complete in 1995 and an experimental programme could begin in 1996. As CERN has found at LEP, planning for major detectors takes many years, so this is not as far away as might appear, because the approval of experimental budgets will take some time before the whole process starts.

4. CONCLUSIONS

It seems that we are in a very positive situation for sub-atomic physics as a whole. CEBAF and LEP are progressing well and the SSC appears to be well on track. RHIC seems relatively certain and now we can add a Kaon Factory. There is plenty to do and the prospects for our science are excellent.

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