TRIUMF KAON FACTORY PRE-CONSTRUCTION STUDY

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Summary

TRIUMF has been awarded $11M for a 1-year pre-construction engineering design and impact study of the KAON Factory. This will enable prototypes to be built of various components of the Booster ring – a fast-cycling dipole magnet, dual frequency magnet power supply, ceramic beam pipe, rf cavities (both parallel and perpendicular bias versions) and extraction kicker – and a rotating target for the 3 MW 30 GeV beam. Reviews are being carried out of racetrack designs for all five rings, of the shielding and remote handling requirements, and of the layout of the experimental areas. The design of the tunnels and buildings will be finalized, various impact studies carried out, and international involvement pursued further.

Introduction

The TRIUMF KAON-Antiproton-Otherhadron-Neutrino Factory has been described in full in the original proposal[1] and outlined in various papers.[2–4] The basic aim is to accelerate a 100 μA beam of protons to 30 GeV, roughly 100 times more than available at present. This would provide correspondingly more intense – or pure – beams of secondary particles (kaons, pions, muons, antinucleons, hyperons and neutrinos) for particle and nuclear physics studies on the "precision frontier", complementary to the "energy frontier".

Following technically favourable reviews of the proposal by the funding agencies, the governments of Canada and British Columbia instituted supplementary studies on economic benefits, broader national management (the four founding universities have now been joined by the Universities of Manitoba, Montreal, Regina and Toronto) and international involvement. Exploratory discussions abroad at the end of 1987 (see below) indicated a potential for ~$200M (Cdn) in international contributions – about one third of the total cost of $571M. Furthermore the Province of British Columbia has given approval in principle to the funding of the buildings and tunnels ($87M).

The most recent development has been the joint funding by the federal and provincial governments of an $11M pre-construction Engineering Design and Impact Study. This began in October 1988 and is planned to take 15 months. It will enable prototypes of the major components to be built, the cost estimates to be updated and the international contributions to be better defined. In addition, impact studies will be carried out on Canadian industrial development, economic benefits, legal concerns and environmental effects. The status of the various technical projects is described in the sections below.

Basic Design

The TRIUMF H^- cyclotron, which routinely delivers 150 μA beams at 500 MeV, would provide a ready-made and reliable injector. It would be followed by two fast-cycling synchrotrons, interleaved with 3 storage rings, as follows:

A	Accumulator:	accumulates cw 450 MeV beam from the cyclotron over 20 ms periods
B	Booster:	50 Hz synchrotron; accelerates beam to 3 GeV; circumference 214 m
C	Collector:	collects 5 Booster pulses and manipulates longitudinal emittance
D	Driver:	main 10 Hz synchrotron; accelerates beam to 30 GeV; circumference 1072 m
E	Extender:	30 GeV stretcher ring for slow extraction for coincidence experiments

This arrangement allows the B and D rings to run continuous acceleration cycles without flat bottoms or flat tops. The use of a Booster permits a smaller normalized emittance and hence reduces the aperture and cost of the Driver magnets for a given space charge tune shift. The use of a Booster also simplifies the rf design by separating the requirements for large frequency swing and high voltage (33% and 600 kV respectively for the Booster, and 3% and 2400 kV for the Driver). These high rf voltages are associated with the high cycling rates; the use of an asymmetric magnet cycle with a rise 3 times longer than the fall in the Driver reduces the voltage required by one-third, and the number of cavities in proportion. In the Booster the saving would be less because half the voltage is needed for bucket creation.

Figure 1 shows a proposed site layout together with cross-sections through the tunnels, with the Accumulator above the Booster in the small tunnel, and the Collector and Extender rings above and below the Driver in the main tunnel. Identical lattices and tunes are used for the rings in each tunnel. This is a natural choice providing structural simplicity, similar magnet apertures and straightforward matching for beam transfer.

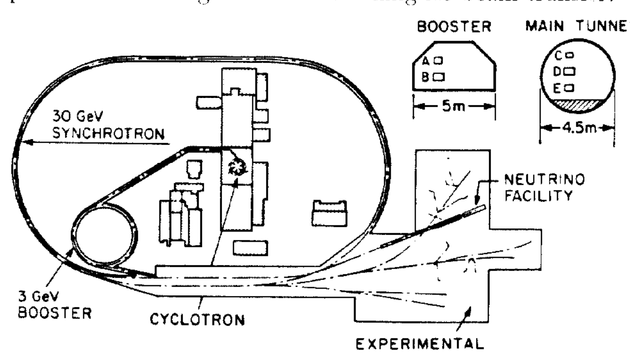

Fig. 1. Possible site layout.

Separated-function magnet lattices are used with the dispersion modulated so as to drive its mean value towards zero, enabling transition to be kept above top energy in all rings. This avoids transition-crossing problems, such as emittance mismatch and change of rf phase under high beam loading. Racetrack lattices have now been adopted for the C,D and E rings and are under consideration for the A and B rings.

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Injection into the Accumulator is achieved by stripping the H^- beam from the cyclotron enabling many turns to be injected into the same area of phase space. The small emittance beam from the injector is in fact "painted" over the much larger three-dimensional acceptance of the Accumulator to limit the space charge tune shift. Painting also enables the optimum density profile to be obtained and the number of passages through the stripping foil to be limited.

Beam Dynamics

In order to cut beam loss at slow extraction well below the usual 1%, racetrack lattices have now been adopted for the C,D and E rings (Servranckx *et al.*[4]). These provide long straights with high β (100 m) at the septa and room for an additional pre-septum and for collimators downstream. Tracking simulations, which include power supply noise effects, show that the beam loss can be kept below 0.2%. The 180° arcs contain 24 cells, and are second-order achromats, normally tuned to $5 \times 2\pi$. The tune for the whole ring may be varied by ±1 in each plane independently. A half-integer resonance may be used for extraction, to simplify the collimation process. Such a racetrack lattice is also convenient for the Driver synchrotron, allowing either for the insertion of Siberian snakes, or for tuning for low depolarization without snakes, using high-periodicity arcs and spin-transparent straight sections. Investigation of the properties of the lattice in detail show that its dynamic aperture is as large as for the old circular design. A bypass is being studied for the Extender, to separate the extraction straight from those of the C and D rings. Racetrack lattices are also being investigated for the Booster and Accumulator rings, where they would provide dispersion-free regions for rf cavities and beam transfer. FODO, doublet and triplet lattices are being investigated.[4]

Studies continue to determine the optimum strategy for painting the beam at injection. Developments in stripping foil construction suggest that two-sided "corner" foils may be usable, reducing the number of foil interceptions during accumulation. Better models are now available for scattering within thin foils (Butler *et al.*[5]).

The stability of unusual beam density distributions, such as those formed during painting or debunching, is under study. For distributions $\rho(p,\phi)$ hollow in longitudinal phase space simulations[6] reveal an intensity threshold for instability. The stability criterion can be expressed in terms of the slope $d\rho/dp$. The effects of space charge and of feedback control loops can be included in our longitudinal tracking codes, and have also been studied analytically.

Magnet Development

A preliminary design for a Booster dipole magnet has been prepared (Otter *et al.*[7]) and a prototype is under construction. The magnet will be 3 m long with a pole gap of 10.7 cm and will cycle at 50 Hz between 0.27 T and 1.05 T with a field uniformity $< \pm 2 \times 10^{-4}$ over ±5 cm. The prototype will be built from 26-gauge laminations of M17 (non-grain oriented) steel with 10-turn coils, each containing 12 square hollow copper conductors in a vertical array. Studies continue on the various other magnets needed in the accelerators and beam lines.

Magnet Power Supplies

As explained above, dual-frequency magnet excitation is being considered for the synchrotrons, with a rise time three times longer than the fall. To test the performance of such a system a high-power test stand has been set up (Fig. 2). Four magnets from the decommissioned NINA synchrotron are used, one as the load and three in series as the resonant 81 mH choke. A 1000 μF capacitor bank may be switched in parallel with a 125 μF bank to change the resonant frequency from 100 Hz to 33 Hz. Dual-frequency operation was achieved recently and tests are continuing (Reiniger[8]). A new power distribution scheme for the one reference and 24 Booster dipoles has been worked out, based on 5 cells with 5 magnets each.

Fig. 2. High-power test stand for dual-frequency magnet excitation studies.

Kickers

The kicker with the most challenging specifications is probably that for extraction from the Booster ring – about 30 kV across an 8 cm gap over a length of 2 m with a rise time ≤80 ns and operating at 50 Hz. Starting from scratch and with long delivery times on some items it seemed impractical to attempt to build a true prototype within 12 or 15 months. Instead we plan to gain experience in delay-line kicker technology by putting together a somewhat similar system with the help of some critical components obtained on loan.

A 1 MHz chopper will also be built for installation in the injection line from the cyclotron to create the 110 ns beam gap needed for kicker rise and fall. The chopper must provide 40 kV over 1 m with rise and fall <35 ns . Our aim is to have a prototype chopper operating by the end of 1989.

Radio Frequency Systems

The reference design for the Booster cavities is based on those used in the Fermilab booster. A full-scale prototype cavity is almost complete and should be ready for tests with an air tuner soon (Poirier *et al.*[9]). Under our collaboration with LAMPF their booster cavity, which employs perpendicularly-biased microwave ferrite, is now also at TRIUMF, being prepared for testing under ac bias conditions – a crucial test of its viability. Under dc bias it has produced relatively high voltages (140 kV), potentially reducing the number of cavities required and hence the impedance presented to the beam and the likelihood of inducing coupled-bunch instabilities. Enegren *et al.*[10] have studied the higher-order modes for both cavities and report on several damping schemes. To reduce the stray magnetic field seen by the beam in the LAMPF cavity, both shielding and redesign of the bias coils are being investigated.

Control of the rf systems under high beam loading is a crucial topic. Burge and Enegren[11] describe the operation of a generic regulator they have built for phase and amplitude control. This will be used in the low-level control system which TRIUMF is building for the LAMPF main ring cavity, along with the solid-state driver amplifier.

Beam Pipe & Vacuum

The vacuum and impedance requirements for all five rings are being carefully reviewed. The high circulating beam current makes beam-induced multipactoring and ion desorption from the walls the most critical processes. A hydrocarbon-free system is required, with all metal elements pre-baked to 300°C, and pumps spaced no more than 5 m apart, automatically producing vacua better than 10^{-8} Torr. An additional concern in the Extender ring, where the beam may be debunched, is the possibility of electron-proton oscillations; electrostatic collector plates will be needed to suppress these.

Ceramic chambers must be used within the fast-cycling magnets but must contain a conducting shield. Two shielding schemes are being considered and 4 m long prototypes incorporating each are being constructed for the Booster dipoles. SAIC (San Diego) is building a chamber with longitudinal silver stripes painted on the inside walls, while RAL (U.K.) is building one incorporating a separate wire cage, as used in ISIS.

Computer Control System

A comprehensive review of both hardware and software options was carried out in 1987, and recommended a segmented Ethernet communications backbone linking commercial workstations used as operator interfaces with microprocessor based equipment controllers. A test platform is being assembled based on a VAX3200 workstation with a bridged Ethernet connection to 2 VME crates. It will be tried out on selected cyclotron systems requiring beam control, such as the injection line or the new H^- extraction system. The possibility of incorporating expert systems techniques is also under study.

H^- Extraction from the Cyclotron

To extract H^- ions (instead of stripping them to protons as in normal operation) a conventional extraction system is being developed. With 18 kV on an rf deflector, which excites the $\nu_r=3/2$ resonance, and 50 kV on the electrostatic deflector, 90% of the beam (66 μA macropulses at 1% duty factor) has been transmitted through the latter. The other 10% is stripped by a narrow foil shadowing the septum and protecting it from irradiation; the resulting protons may be dumped or steered into an experimental beam line. In recent tests the average beam current was successfully raised to 10 μA. Design of the 4-segment magnetic channel which will steer the H^- beam out of the cyclotron is now under way and one segment will be built and tested this year. Detailed design of the front end of the external beam line is also under way.

Experimental Areas and Targets

A revised experimental area layout is shown in Fig. 3. The slow extracted proton beam will be shared between 2 lines each with 2 production targets. Each target will feed at least 2 forward K and $\bar{p}$ channels, and in some cases backward μ channels. A dedicated line and area is provided for polarized proton beams and the neutrino production target and area are now incorporated in the main hall for better crane access. Target development includes both modification of an existing rotating graphite target (driven and cooled by water) for tungsten, and the construction of a prototype target rotated by a flexible cooling line.

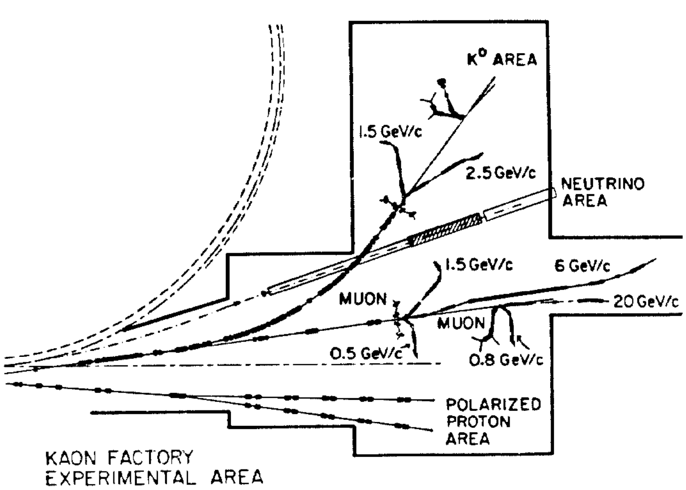

Fig. 3. Proposed experimental area layout.

International Consultations

A Canadian delegation visited West Germany, Italy, Japan and the U.S.A. in late 1987 to explore the potential for international participation in the KAON Factory. Each country agreed to consider supplying components for construction, and indeed the possibility of support is being explicitly allowed for in the planning scenarios of both Germany and Italy. In the U.S.A. the DOE and NSF requested advice from NSAC, which set up a subcommittee under Prof. H. Feshbach. This has recently completed its report, which characterizes the Canadian proposal as "a conservative design" and "cost-effective". In all it appears that there is a potential for about \$200M (Cdn) – or one-third of the total cost – in international contributions. Besides the countries mentioned above, Belgium, Britain, Israel and the People's Republic of China have all expressed interest in participating in experiments and in some cases in accelerator design and construction. International consultations will now continue more formally under the aegis of the pre-construction study, with a first round of visits scheduled for April and May 1989 to begin identifying suitable items to be supplied. Workshops will also be held in Canada, Germany, Italy and Japan this year to discuss the experimental possibilities.

Conclusion

The pre-construction study is expected to be complete by the end of 1989, leaving the way clear for final approval of the project in 1990.

Acknowledgements

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