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TRIUMF KAON FACTORY AS A POTENTIAL NEUTRON SOURCE

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Summary

TRIUMF is considering the construction of a "kaon factory" post-accelerator to take the present 100 μA proton beam (6×10^{14} p/s) from 500 MeV to energies in the range of 15-30 GeV. This facility would produce secondary beams of kaons, antiprotons, neutrinos and other particles with an intensity of the order of 100 times present accelerators and would open up new fields in both nuclear and particle physics in the same way that the meson factories LAMPF, SIN and TRIUMF have done at sub-GeV energies. Although the production of neutron beams is not one of the prime motivations for constructing this facility, the high proton currents, in particular from the booster stage of acceleration, would make a unique spallation neutron source. This paper gives a brief report on the status of the kaon factory accelerator studies and describes the parameters of the proton beams which could be made available for neutron production.

Introduction

The TRIUMF cyclotron[1] is a six-sector isochronous machine accelerating H^- ions to a maximum energy of 520 MeV. Five H^- bunches per turn are accelerated, each bunch separated by 43 ns (23 MHz) and with a bunch width of 5 ns (±20°). A 5 mg/cm^2 carbon foil is used to strip the H^- to H^+ for extraction and at the present time three proton beams may be extracted simultaneously, two with an energy range 180-520 MeV and a low energy beam 60-100 MeV.

The cyclotron delivers currents of 150 μA cw with an emittance of 2π mm-mrad. A plan view of the facility is shown in Fig. 1. The proposed kaon factory will be fed by beam line 2A although for some of the schemes beam extraction by foil stripping will not be used as it is more advantageous to extract the H^- ions directly to allow for charge exchange injection to the next stage.

Accelerator Energy and Beam Characteristics

The physics justification for a kaon factory is well documented.[2,3] The interest in such a facility ranges from experimental studies of rare kaon decays, CP violation, neutrino and antinucleon interactions, hypernuclear physics to extensions of studies carried out at meson factories such as hadron-nucleon interactions and μSR. The energy chosen for a kaon factory accelerator depends on the range of secondary particles ($K, \bar{p}, \nu$) desired, their intensities and momenta. Some typical cross sections[4] for low momentum kaon and antiproton production are shown in Fig. 2 as a function of incident proton energy. If the assumption is made that facility costs scale with proton energy, the Fig. 2(b) curves show how the relative cost/particle varies with incident energy. This puts the optimum energy between 15-20 GeV for the production of low momentum < 2 GeV/c secondary particles but higher if momenta > 5 GeV/c are required.

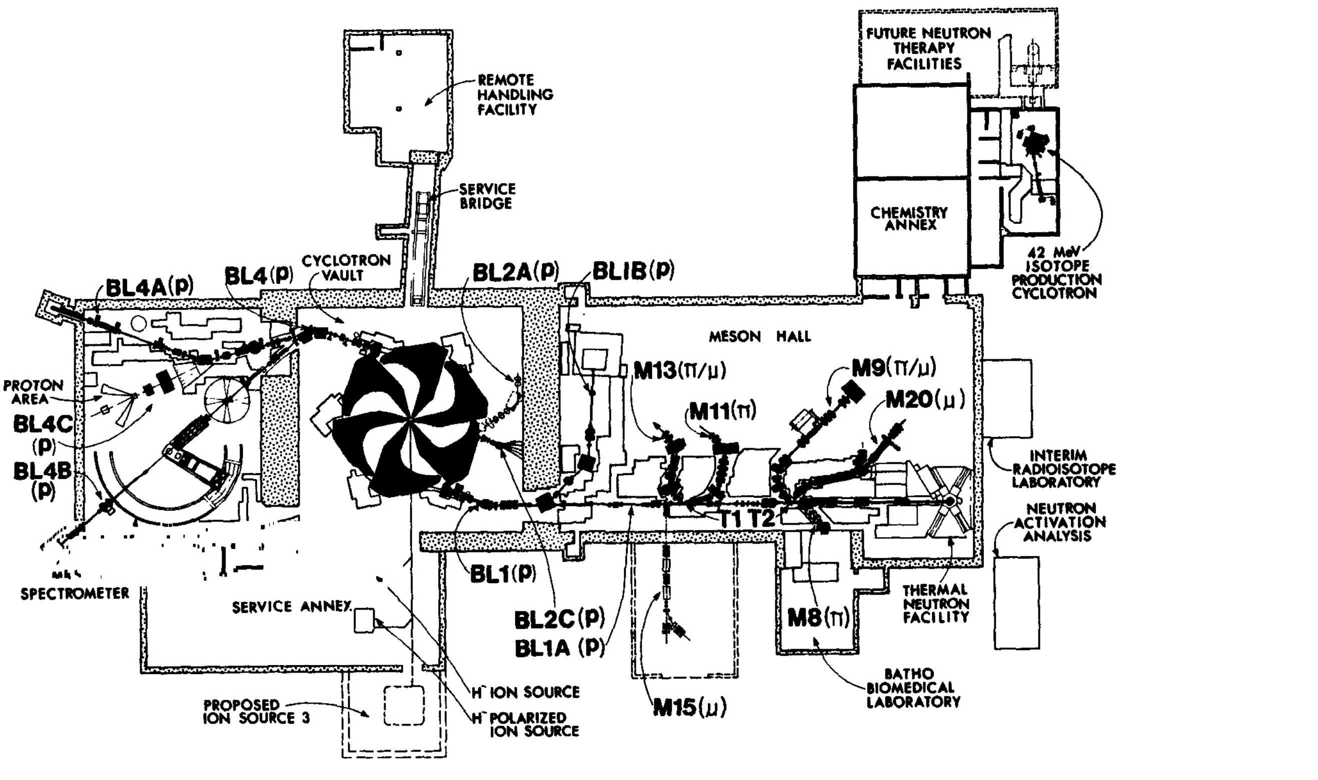

Fig. 1. Layout of TRIUMF cyclotron and beam lines (—— existing, ---- proposed).

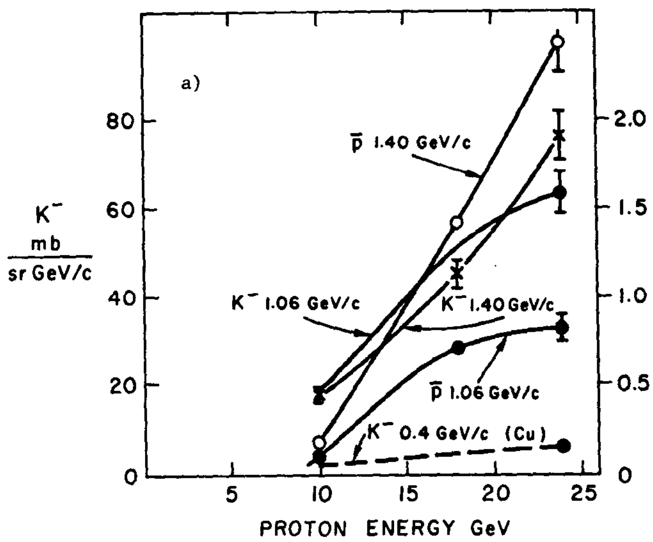

Fig. 2(a). Production cross sections on a 1 cm tungsten target as a function of proton energy.

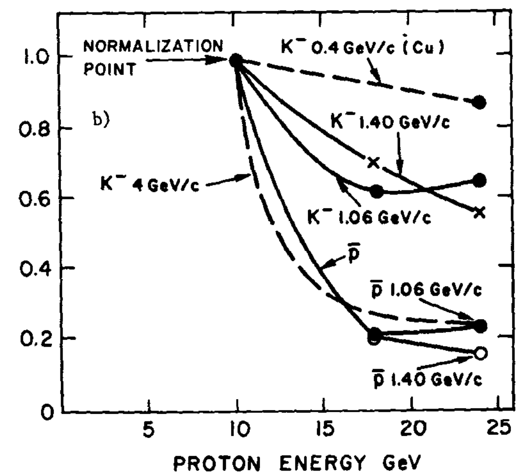

Fig. 2(b). Relative cost per particle assuming facility costs scale with proton energy.

The required time structure of the beam is continuous (cw) for most applications, in particular those requiring many-particle coincidences, but for neutrino experiments a macroscopic duty cycle of 10^{-5} or better is needed.

For a neutron spallation source the four parameters that establish the accelerator requirements are intensity, energy, pulse length and repetition rate. The intensity of 100 μA (6×10^{14}/s) would make the facility competitive with the SNS.[5] The energy of the kaon factory is too high for optimum neutron production from target, moderator and shielding considerations. The yield of neutrons is linear with [E(MeV) - 120] to approximately 2 GeV[6] and then rises more slowly due to range and moderator effects. An energy in the range of 1-3 GeV is therefore required.

The pulse length of existing or proposed facilities ranges from the 1 ns option of the LAMPF PSR[7] to 500 μs for the SNQ.[8] The repetition rates vary from 12-100 Hz. P. Egelstaff[9] has described two new directions for neutron scattering and their beam requirements:

- neutron diffraction with 100 eV neutrons
- single pulse diffraction

In the first case a pulse length of 100 ns or less is required but the repetition rate can be as high as 1-5 kHz. In the second case the maximum number of protons/pulse is desired ~10^{15} protons/pulse and the repetition rate can be less than 1 Hz.

The beam requirements for a neutron spallation source are very similar to those required for both a neutrino source and a pulsed muon facility, a fact recognized at LAMPF, SNS and KEK where these installations either exist or are planned. For a pulsed muon facility the pulse length must be a small fraction (<5%) of the muon lifetime which is 2.2 μs.

Accelerator Options

A number of accelerator options are being considered at TRIUMF and are shown in Fig. 3. Possible neutron sources within these accelerator schemes are also indicated.

Cyclotron Option

Matching to higher energy cyclotrons is obviously the most straightforward and designs have been made for a pair of superconducting cyclotrons with parameters as shown in Table I. Pole shape designs have been found which can maintain isochronism and vertical focusing to 15 GeV.[10] Although the proton beam would be cw, with the same 23 MHz microstructure as for the TRIUMF cyclotron, the possibility exists just as for the ASTOR[11] ring of using phase-expansion techniques to stack up to 500 turns in the intermediate ring at 3.5 GeV. These turns would then be extracted as a single turn giving a 10 kHz pulse structure to the beam. This pulse repetition rate could be reduced with commensurate reduction in average intensity by pulsing the ion source. However, there is no current limit to this scheme and it would be feasible to operate at the equivalent current of 400 μA cw.

Synchrotron Option

The intensity limit of a synchrotron is usually set at injection by space charge and phase-space considerations. The transverse space charge defocusing effects lead to an incoherent tune shift which from experience has to be kept to a value around 0.25.

Table I. Superconducting cyclotron specifications

Stage	I	II
Injection energy	430 MeV	3.5 GeV
Extraction energy	3.5 GeV	15 GeV
# sectors	15	42
Radius (max)	10.1 m	41.4 m
Radius (min)	7.5 m	40.6 m
# cavities (1 MV)	9	54
RF frequency	46 MHz	115 MHz
Harmonics	10	100
Excitation currents	2.1×10^{6} At	2.5×10^{6} At
Coil dimensions	8×60 cm^2	8×60 cm^2
Sector field	4 T	5 T
Gap width	7 cm	7 cm

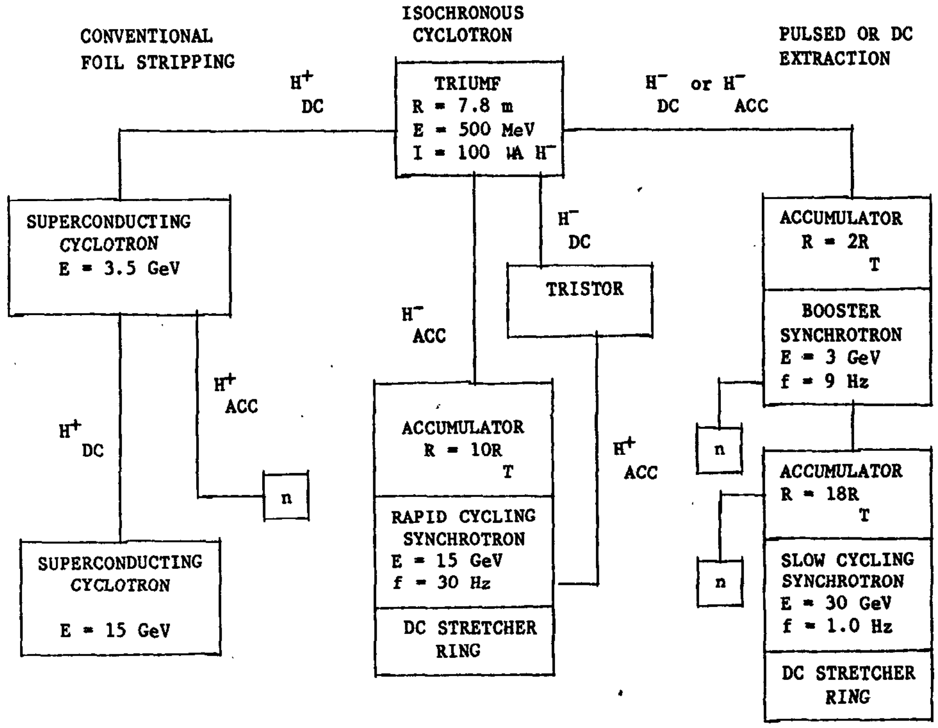

Fig. 3. Post-accelerator options using the TRIUMF cyclotron as injector.

Figure 4 shows the dependence of the total charge of protons (N) in the ring on energy for a tune shift $\Delta Q_y = 0.25$, a magnet aperture of 16 cm × 9 cm and a bunching factor of 2/3. At low energy (<<1 GeV) the self-force term dominates and $N \sim \beta^2\gamma^3$, and at higher energies the image force terms take over and $N \sim \gamma$. To achieve the desired 100 µA at 500 MeV injection energy, where the space charge limit is 11 µC, a repetition rate of 9 Hz is required. For a slow-cycling synchrotron with a repetition rate of 1 Hz an injection energy of 3 GeV is required. Two synchrotron options are being studied, a 16 GeV rapid-cycling synchrotron which would not need an injection booster for space charge reasons, although for rf reasons a booster would be an advantage, and a 30 GeV slow-cycling synchrotron injected from a 3 GeV booster.

The lattice design for these options will not be described here. Longitudinal defocusing effects at transition are eliminated by raising the transition energy to above the maximum energy of the synchrotron by imposing a superperiodicity close to the value of the horizontal tune: this can be achieved either by adding quadrupoles or by spacing the dipoles appropriately.

The matching of a 23 MHz isochronous cyclotron to a synchrotron operating at 9-30 Hz is perhaps the most difficult technical problem. Three schemes are being considered,[12] all of which require extracting the H^- ions from TRIUMF:

- stacking 160 turns in TRIUMF with pulsed extraction
- extracting as a cw H^- beam and stacking 15,000 turns in an external phase expansion ring TRISTOR
- extracting as a cw H^- beam and injecting directly into an accumulator ring using the extremely good emittance of the TRIUMF beam to reduce foil traversals

This extraction will be achieved using an auxiliary rf cavity shown in Fig. 5 to either decelerate the beam to provide turn compaction for the pulsed extraction or to accelerate the beam to provide sufficient turn separation for the installation of a septum for cw extraction.

Figure 6 shows one scheme for matching to a 1 Hz synchrotron. After rf stacking in the TRIUMF cyclotron a beam pulse consisting of 160 turns (800 TRIUMF pulses) is injected by charge exchange on a 200 µg/cm^2 carbon foil into a dc accumulator ring in the booster tunnel. Foil traversals are reduced by using a stripping foil much smaller than the accumulator magnet

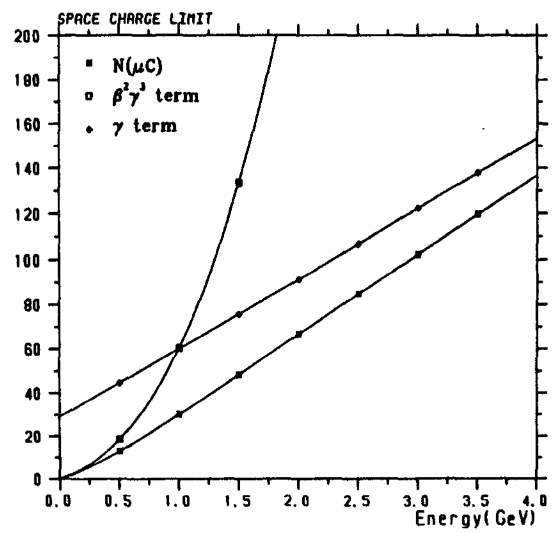

Fig. 4. Transverse space charge limit for the synchrotron option as a function of injection energy.

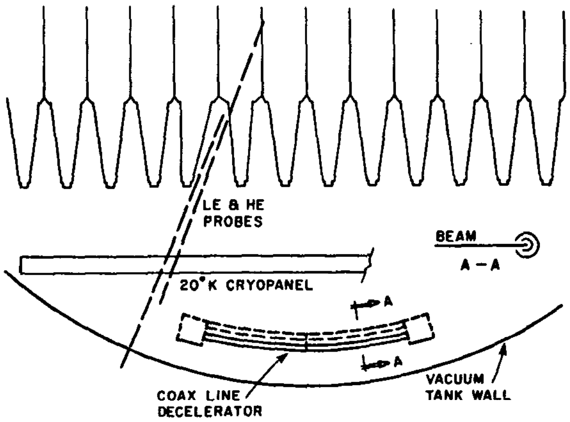

Fig. 5. Auxiliary rf cavity for decelerating or accelerating beam for H⁻ extraction.

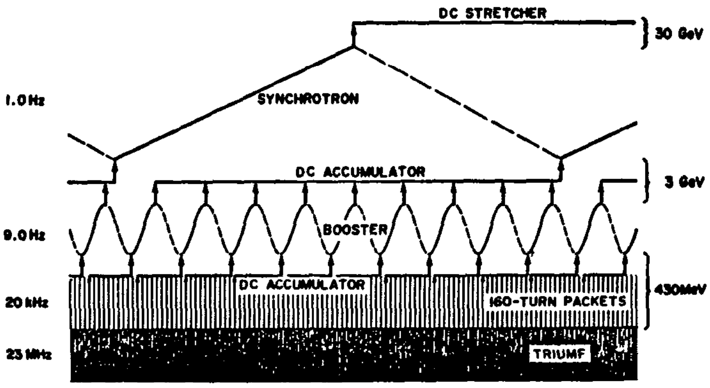

Fig. 6. Scheme for matching the TRIUMF cyclotron to a slow-cycling synchrotron.

aperture and by "painting" the beam across the magnet aperture in transverse and longitudinal phase space. The booster is then filled on each cycle and after acceleration the pulses are transferred in boxcar fashion to a dc accumulator in the main ring, which has a circumference 9 times the booster.

A layout of the proposed 30 GeV ring is shown in Fig. 7. The synchrotron tunnel would be approximately 1 km in circumference and buried 8-20 m below grade level.

Potential Neutron Sources

Both the 3.5 GeV intermediate stage of the cyclotron option and the 3 GeV booster/accumulator offer unique but quite different proton beams which could be used for a spallation neutron source. The relevant beam parameters are listed in Table II.

The short pulse length and high repetition rate of the cyclotron beam could provide a neutron source compatible with high energy (100 eV) neutron diffraction experiments. The large number of protons/pulse, especially from the main synchrotron accumulator ring could provide a high intensity neutron pulse for single pulse diffraction.

The kaon factory design study is still in progress, many problems remain to be solved, and none of the options has yet been singled out as the direction for detailed studies. This progress report is intended to indicate the potential of the proton beams from the proposed kaon factory and to elicit input from the neutron scattering community to ensure that their requirements are not overlooked in the design study.

Acknowledgements

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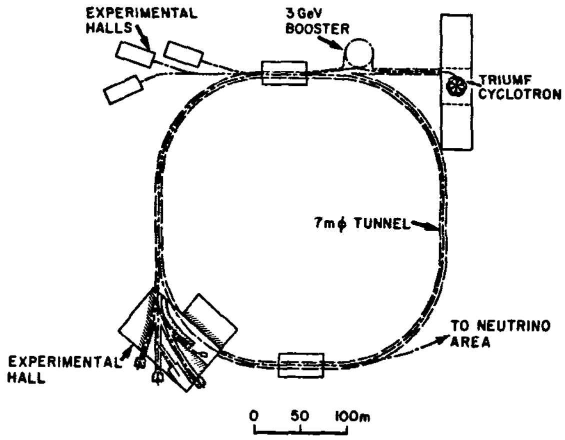

Fig. 7. Proposed 30 GeV accelerator layout.

Table II. Potential neutron sources using TRIUMF kaon factory

	booster synchrotron	slow-cycling accumulator	ring cyclotron
Energy	3 GeV	3 GeV	3.5 GeV
Radius	15 m	135 m	7.5–10.1 m
Repetition rate	9 Hz	1.0 Hz	dc or 10 kHz
Protons/second	6×10^{14} (100 μA)	6×10^{14} (100 μA)	6×10^{14} (100 μA)
Protons/pulse	7×10^{13}	6×10^{14}	6×10^{10} (10 kHz)
Pulse duration	0.32 μs	2.9 μs	0.22 μs
Pulse period	0.11 s	1 s	100 μs
Microstructure	2 ns/16 ns	2 ns/16 ns	10 ns/43 ns 0.3 ns/43 ns(dc)

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