KAON
ANTIPROTON
OTHER HADRON
NEUTRINO
FACTORY PROPOSAL

TRIUMF

CANADA'S NATIONAL MESON FACILITY
OPERATED AS A JOINT VENTURE BY:

UNIVERSITY OF ALBERTA
SIMON FRASER UNIVERSITY
UNIVERSITY OF VICTORIA
UNIVERSITY OF BRITISH COLUMBIA

UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

SEPTEMBER 1985

The TRIUMF KAON factory era circa 1982-1992

Kaon factories first proposed circa 1976

Concept taken up at TRIUMF circa 1978

Kaon

Antiproton

Other hadron

Neutrino

Factory Proposal

The physics

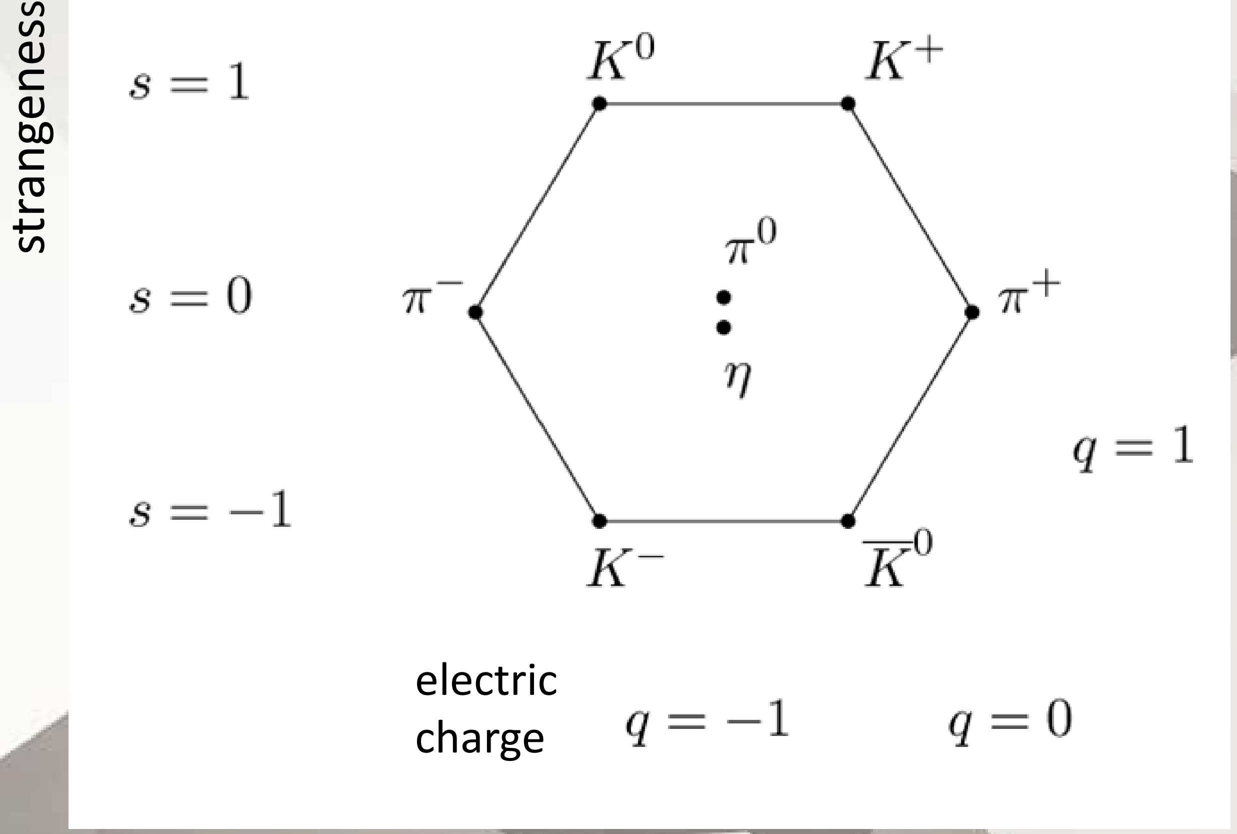
- rare decay modes of kaons and hyperons
    - lightest mesons/baryons containing a strange quark
- CP violation, meson and baryon spectroscopy
- meson and baryon interactions
- neutrino scattering and oscillations
- quark structure of nuclei
- properties of hypernuclei
    - nucleon with an up or a down quark replaced by a strange quark
- K+ and p-bar scattering from nuclei

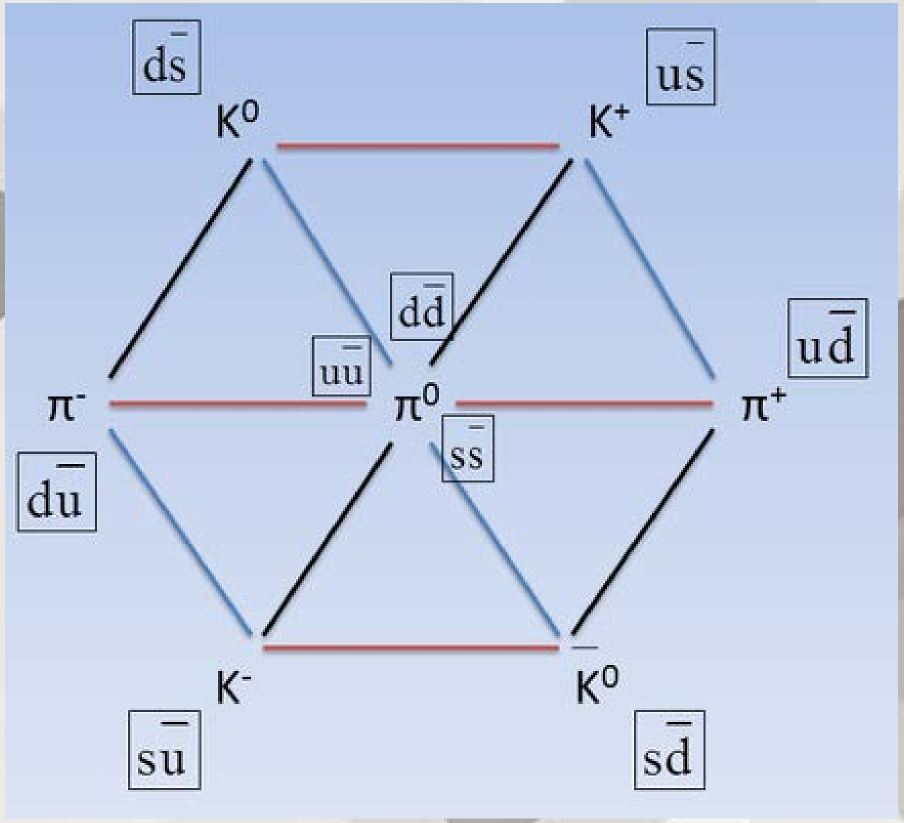
The Context

- Particle “zoo” growing from 1960’s to 70’s and beyond
- Electroweak interaction became understood over the period 1961 to 1999
- Strong interaction (QCD) became understood over the period 1964 to 2012
- Kaons: the first found CP violating objects

Mesons: quark-antiquark pairs

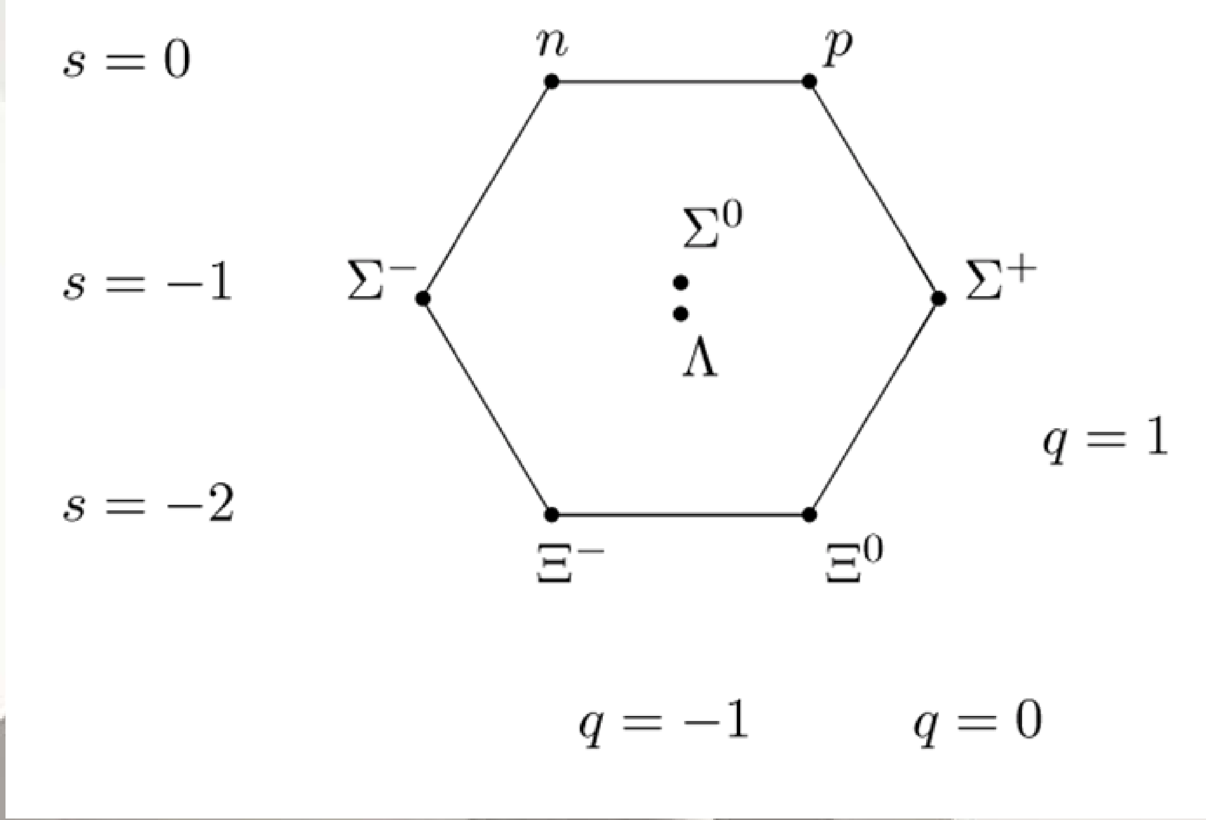
> “Neutral kaons are are even more crazy than silly putty”
> Gerard ‘t Hooft

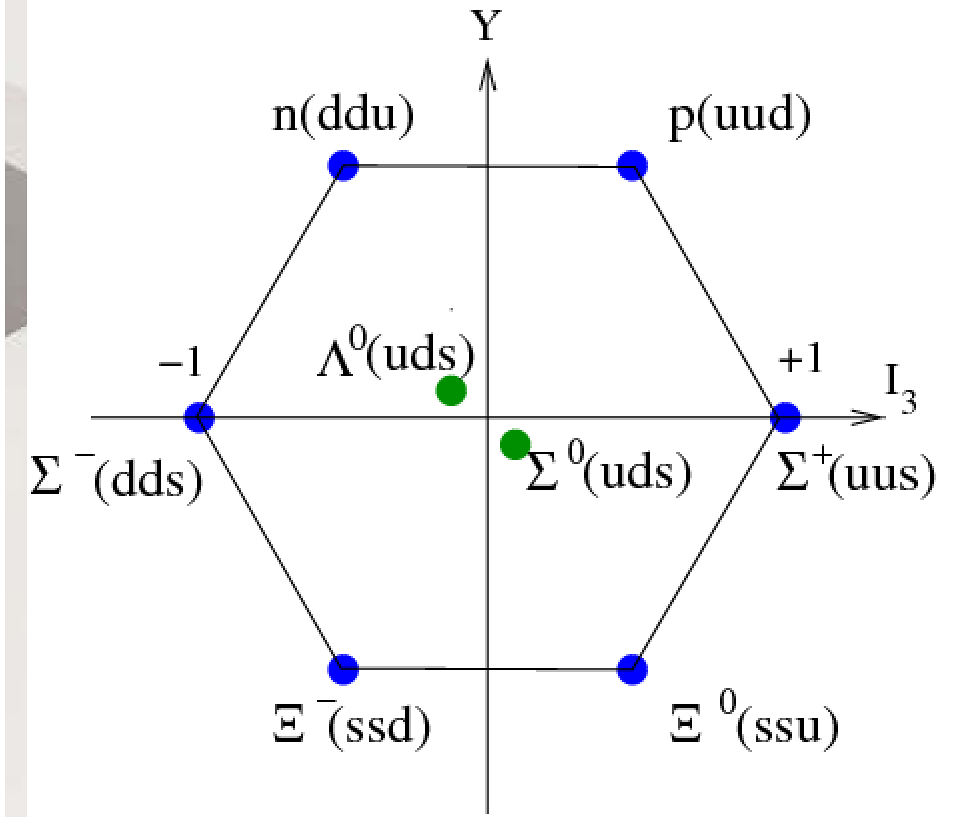




- Complicated: they participate in both the weak and strong interactions.
- Complicated: many “zoo” particles are actually excited states of “simpler” mesons

Baryons: colour-neutral quark triplets





Also complicated. Although they interact via the strong but not weak force, there are many more combinations of 3 quarks than of 2 quarks.

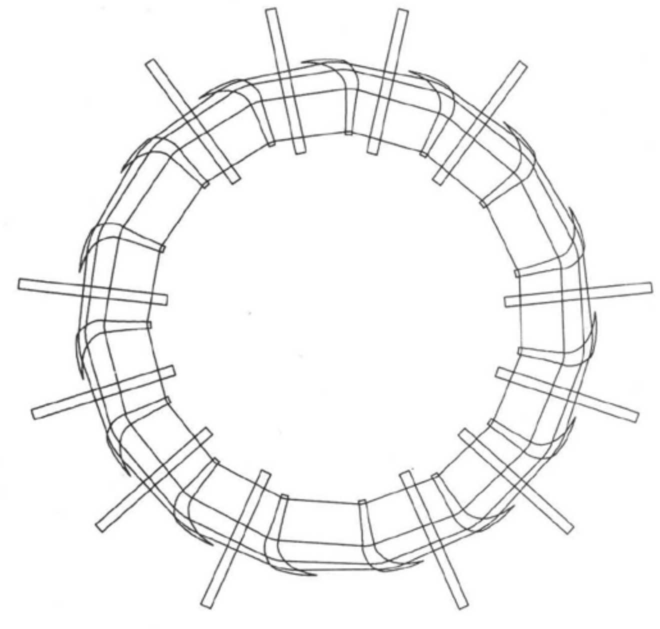
TRIUMF KAON factory cyclotrons

Initial designs were ring-cyclotron based (1978)

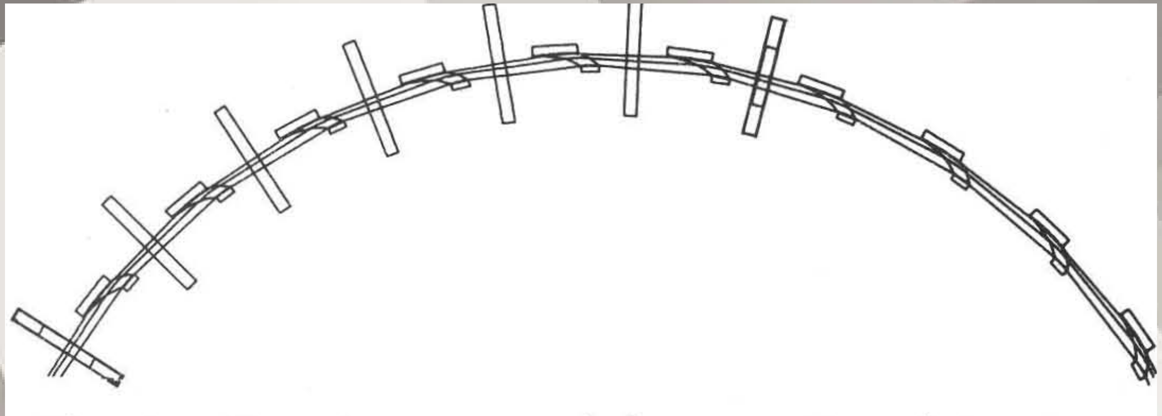
CANUCK - Canadian University Cyclotrons for Kaons

Two high energy superconducting isochronous ring cyclotrons.

1) 430 MeV to 3.5 GeV
2) 3.5 GeV to 15 GeV



The 15-sector first-stage cyclotron showing the 12 accelerating cavities and the 0.45, 1, 2 and 3 GeV orbits.



10-sector super-period of N = 30 cyclotron showing five 69 MHz and two 207 MHz cavities, and the 3, 5 and 8.5 GeV orbits.

TRIUMF KAON factory synchrotrons

- Synchrotron-based designs considered 1982 onwards
- At this time, ambitions leaped from a Canadian regional facility to an International HEP facility
- One among several proposals (AHF, EHF, JHF, MKF) that addressed the intensity frontier, the counterpart of the energy frontier.
- Beams 100 to 1000 times more intense than currently available at the time in the range 10-30 GeV
- The accelerator challenges were those of high current and high repetition rate and low beam losses, answered by a suite of five rings with new and special properties and innovative technologies

- **A** Accumulator: accumulates cw 450 MeV H- beam from the cyclotron over 20 ms periods
- **B** Booster: 50 Hz rapid cycling synchrotron; accelerates beam to 3 GeV
- **C** Collector: collects 5 Booster pulses and performs longitudinal emittance blow-up to avoid microwave instability in D and E
- **D** Driver: main 10 Hz synchrotron; accelerates beam to 30 GeV
- **E** Extender: 30 GeV stretcher ring for slow extraction for coincidence experiments

Synchrotron Expertise Is Needed!

Craddock brought friends from RAL and the CERN-PS
Dutto leveraged contacts in Italy and the USSR
working on EHF and MKF

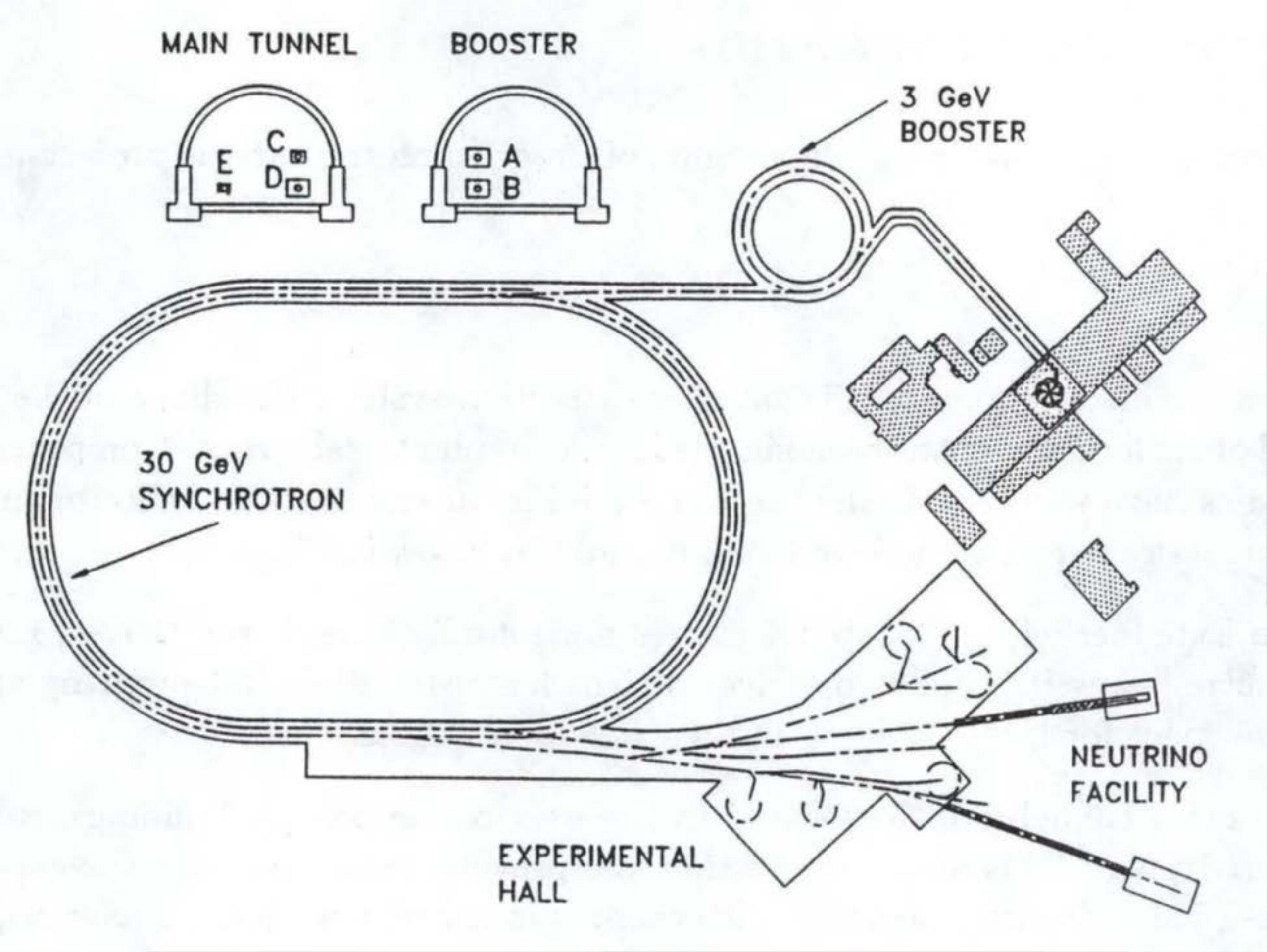
INR-Troitsk (Moscow)

- Yury V. Senichev
- Sergei K. Essine
- Elena Chapochnikova
- Andrej Iliev
- Misha Dyachkov
- Alexei Budzko
- Leonid Kravchuk
- Valentin Paramanov

- Vittorio G. Vaccaro INFN-Napoli
- Maria R. Masullo (INFN-Napoli)
- Francesca Gallucio (INFN-Napoli)
- Eliana Gianfelice-Wendt (INFN-Frascati, later FNAL)
- Fulvia C. Pilat (U. Trieste, later BNL, JLAB, ORNL)

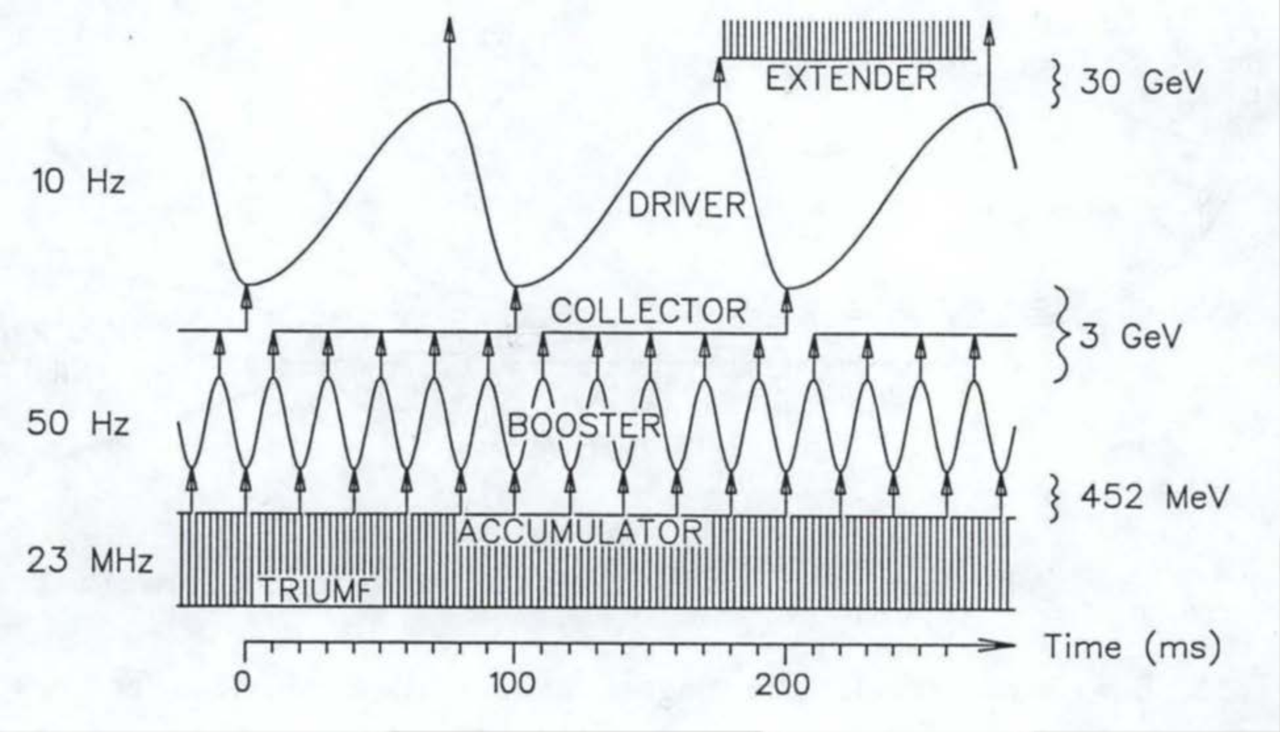
An aside: Gerardo was instrumental in bringing Alessandra Lombardi to TRIUMF to work on the ISAC-RFQ design

KAON Factory: Two Synchrotrons & Three Storage Rings



Layout of the site, with cross-sections through the tunnels showing the five rings:
A - Accumulator, B - Booster, C - Collector, D - Driver, E - Extender

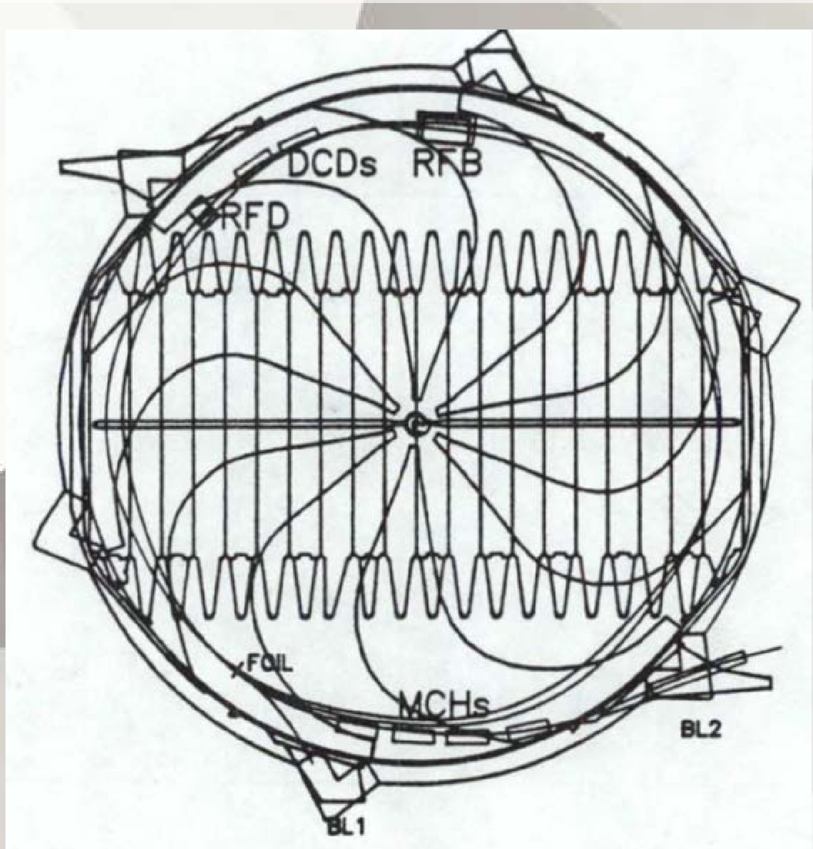
Energy-time plot showing the progress of the beam through the five rings

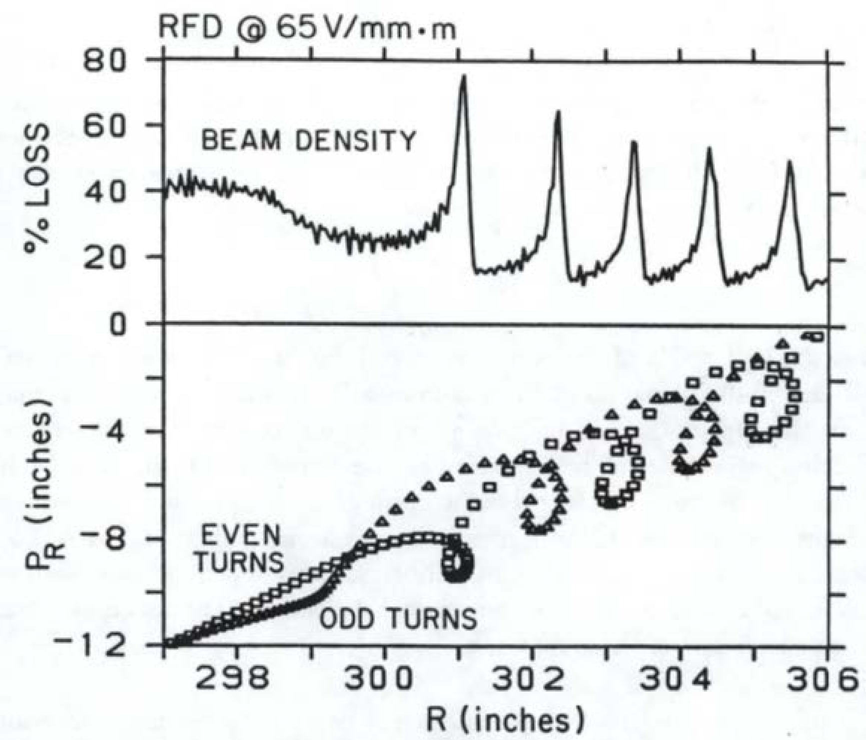


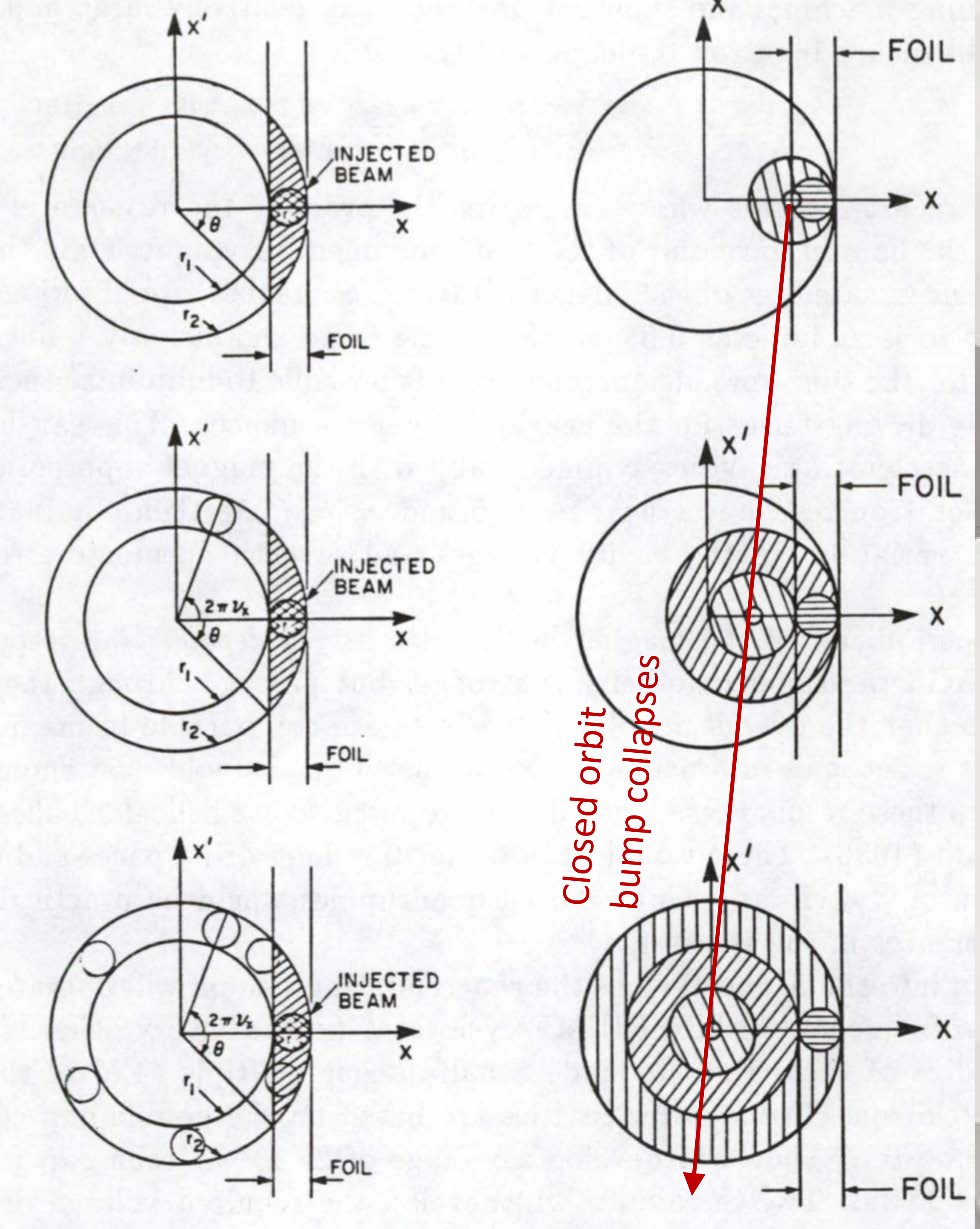
Cyclotron & Accumulator

Extract H- from the cyclotron and inject through a stripping foil H+ into the Accumulator

Direct extraction of an H- beam requires the use of electrostatic deflectors (DCD) and magnetic channels (MC) to peel off the outermost orbits. The extraction efficiency is significantly improved by implying an RF deflector (RFD) to excite a coherent radial oscillation at the ν_r=3/2 resonance







Closed orbit bump collapses

Accumulator

Accumulator – receives (100 μA) H- beam from 500 MeV Cyclotron

Small emittance H- beam is "painted' over the much larger three-dimensional acceptance of the Accumulator to limit the space-charge tune shift and spread.

Improved hardware and materials for longer foil life-time and to avoid hits on the back side of the foil frame

Stripping foils with two unsupported edges

Disappointment: cannot find documents describing this innovation

LATTICES

NO TRANSITION

At transition energy the longitudinal focusing disappears, causing longitudinal mismatch effects and results in beam loss. All KAON rings are transitionless. Transition is a property of the lattice.

A and B rings: dipole pattens are arranged to modulate the dispersion function, raising transition to 15 GeV.

C,D,E rings: Since the bending structure in the arcs is completely regular, transition has to be pushed up by modulating the beta function rather than the bending radius. Sixfold periodicity is introduced in the arcs by modulating the focusing quadrupole strengths in three families, FDF$_1$DFDF$_2$D. The dispersion function develops oscillations, bringing its average value below zero and giving imaginary transition.

NO SYNCHRO-BETATRON COUPLING

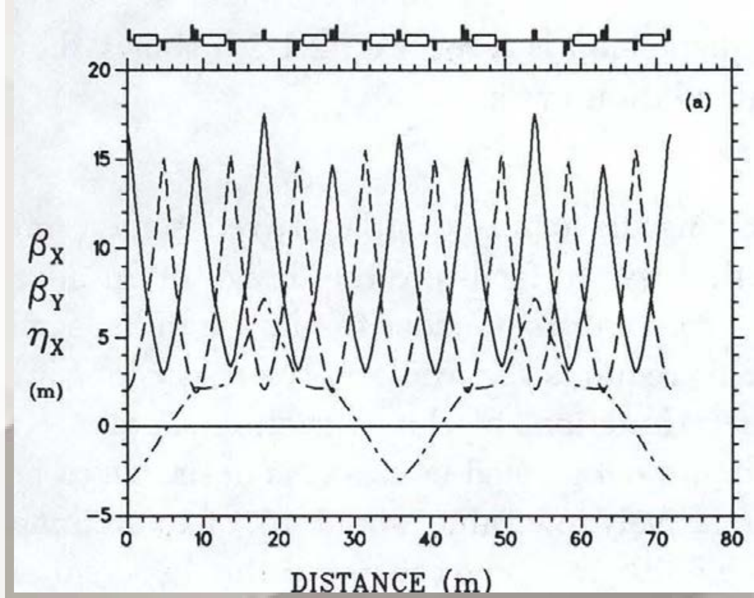
Synchrotrons are prone to resonances occurring from synchro-betatron coupling due to RF voltage installed in dispersive locations. Particularly susceptible if high synchrotron frequency, as occurs with large cavity voltage (B,D).

This is avoided in A & B, and eliminated in C,D,E rings.

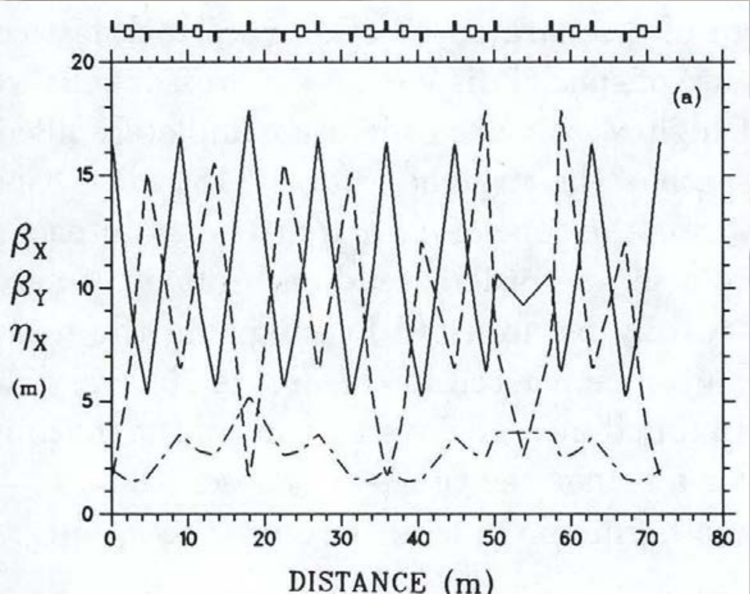
A/B have 3/2-fold symmetric, respectively, placement of RF to cancel main resonances.

C,DE have long dispersionless straight sections for installed RF.

Booster Lattice Functions



Accumulator Lattice Functions



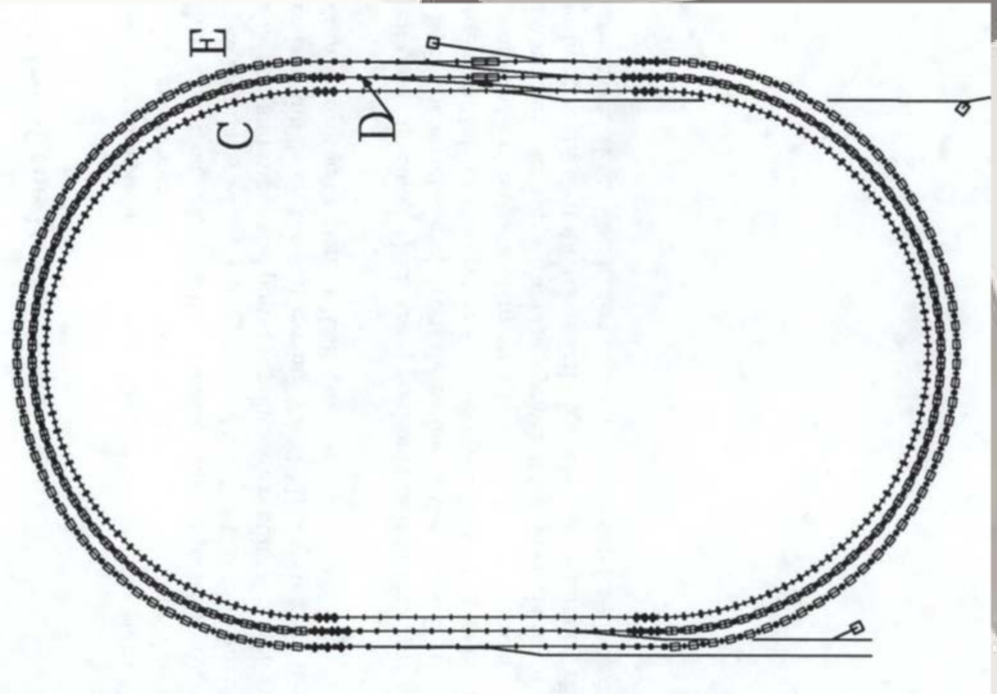
LATTICES

RACE TRACKS – flexible tuning, betatron resonance driving terms cancelled

Racetrack lattices are adopted for the C,D,E rings. Straights and arcs independently tunable.

The 180^o arcs contain 24 cells, and are second-order achromats, (normally tuned to 5 x 2π) for cancellation of betatron resonances. All geometric & chromatic second-order matrix elements vanish.

The tune for the whole ring may be varied by ±1 in each plane independently (via tuning of the straights)



LOW LOSS EXTRACTION

Long straights with high CS β (100 m) at the septa provide room for an additional pre-septum and for collimators downstream. Losses kept below 0.2% at 30 GeV.

SPIN-POLARIZED

Racetrack lattice is convenient for the Driver 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.

Radio-Frequency Acceleration

Fast cycling rings (B,D) need large installed RF voltage. This implies compact and tunable RF cavities with large gap voltage, and moderately high quality factor to minimize installed RF power.

Bunch to bucket transfer from cyclotron to accumulator implies a harmonic of 23 MHz.

The rf cavity for the Booster requires a frequency swing of 46 MHz to 61 MHz at a repetition rate- of 50 Hz

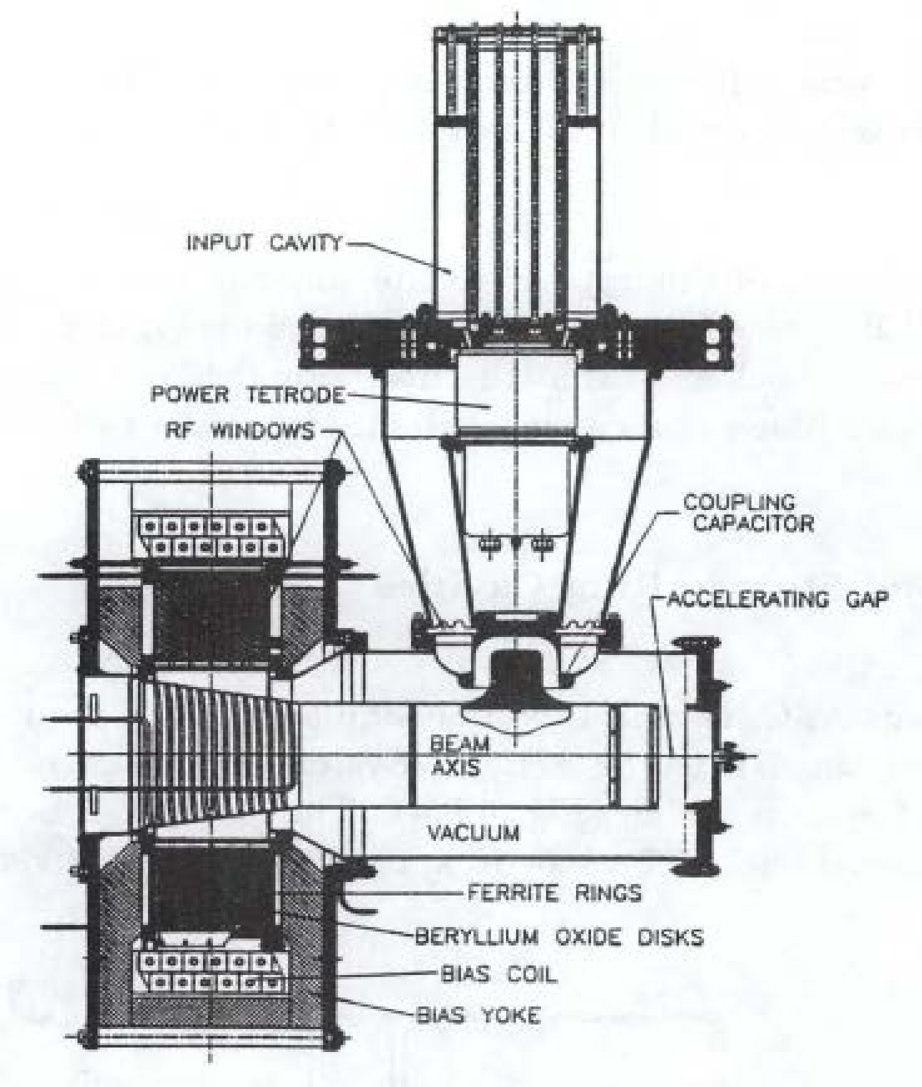
Swing accomplished by loading cavity inductance with ferrite, and varying the permeability by externally applied biasing magnetic field.

Innovation: replace parallel biased Ni-Zn ferrites with perpendicular bias of yttrium-garnet ferrites, gives higher magnetic and electric Qs, higher gap voltages, absence of non-linear rf loss mechanisms.

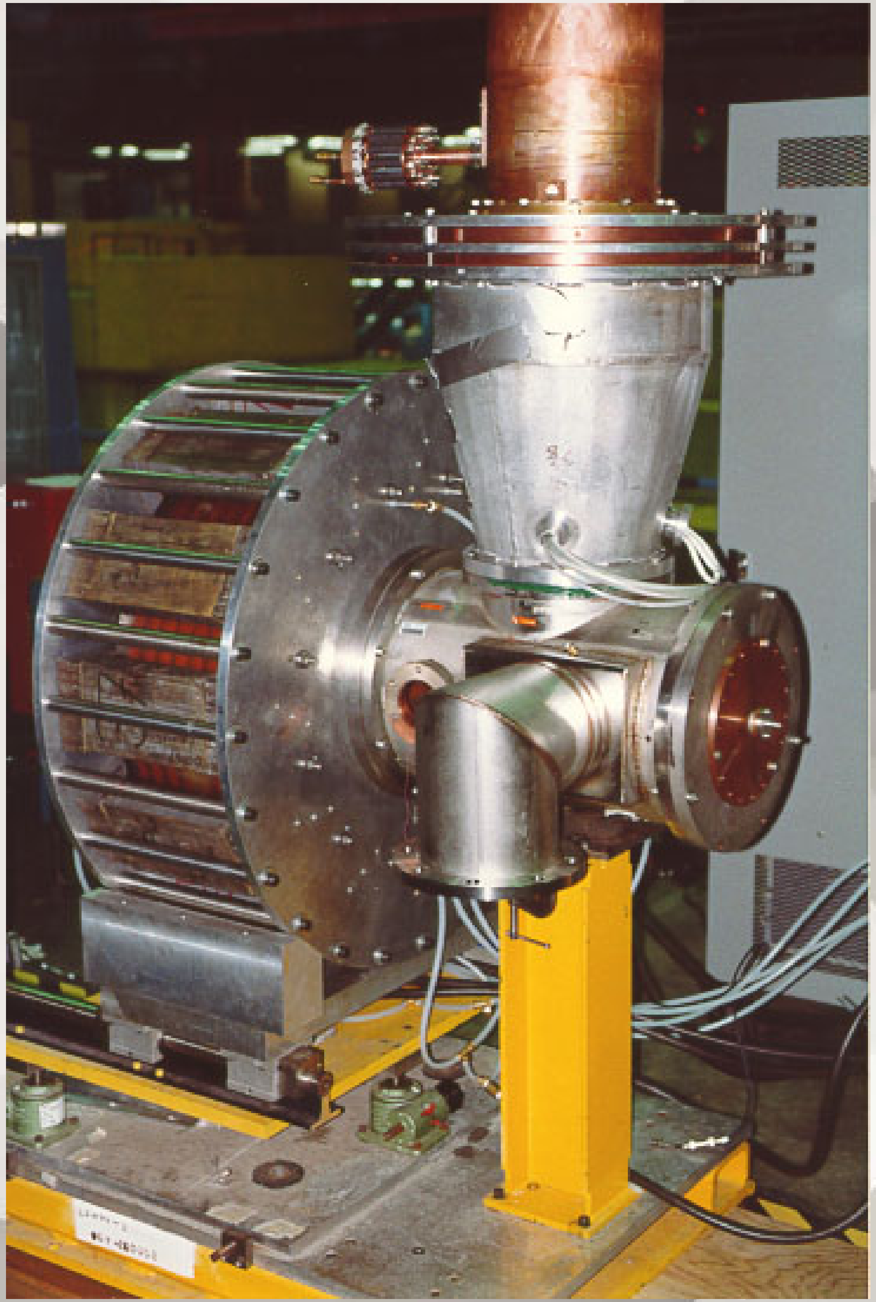
But the ac magnetizing circuit is more complicated and care must be taken to minimize the induced eddy current losses when designing the magnetic circuit, tuner cavity and cavity support structure.

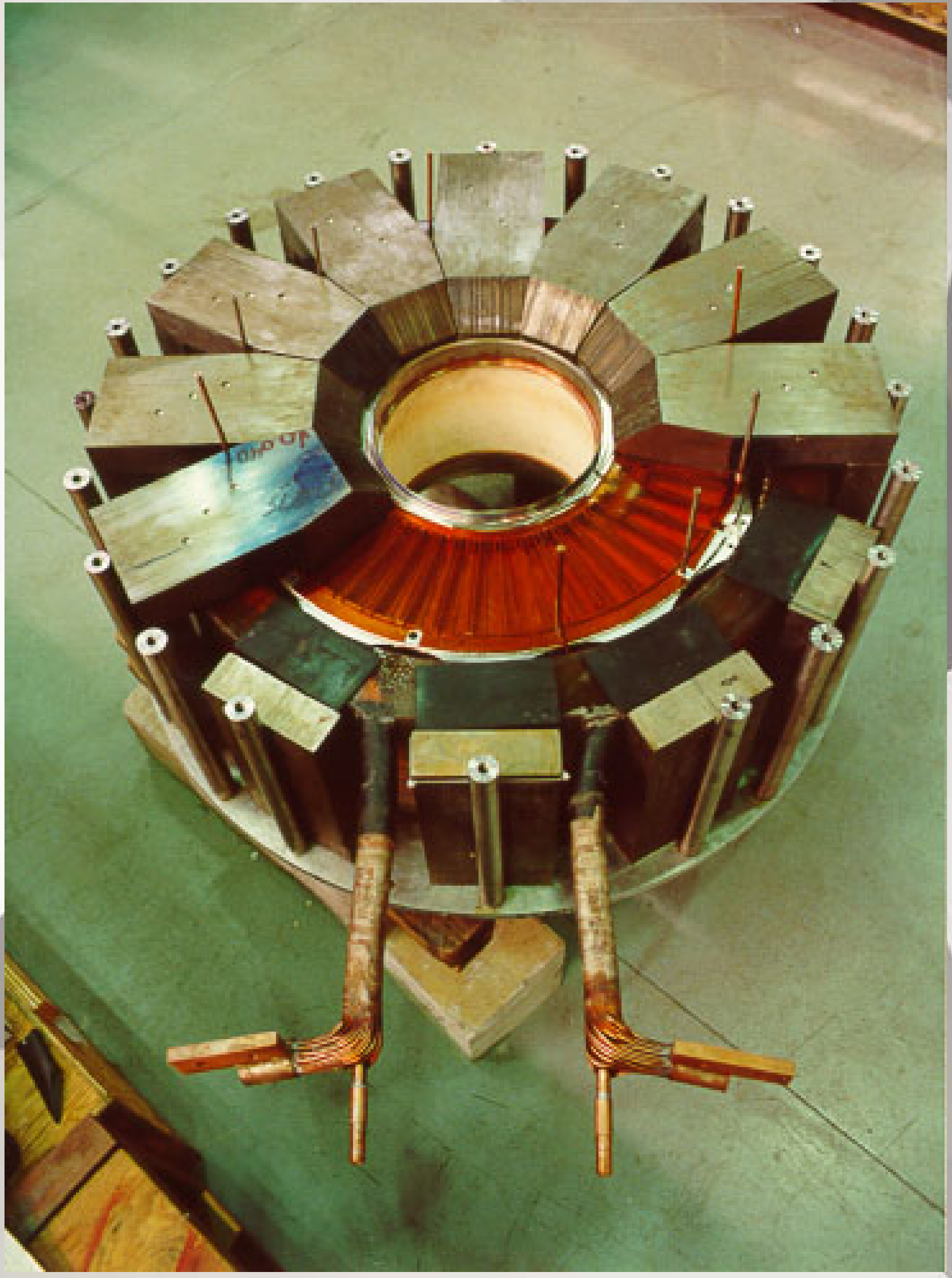
The perpendicular bias technology was demonstrated (next slide), but has not been adopted.
Contrastingly, JHF (now JPARC) adopted magnetic-alloy loaded cavities. They are suited to much lower RF. These have the greater permeability of iron and are very compact. They are rather lossy, with quality factor 1-10, implying significantly more RF power.
The resonance is so broad that multi-harmonic operation is possible with a single RF cavity resonator; and there is no need for a swept bias supply, leading to much simplification.

Radio-Frequency Acceleration

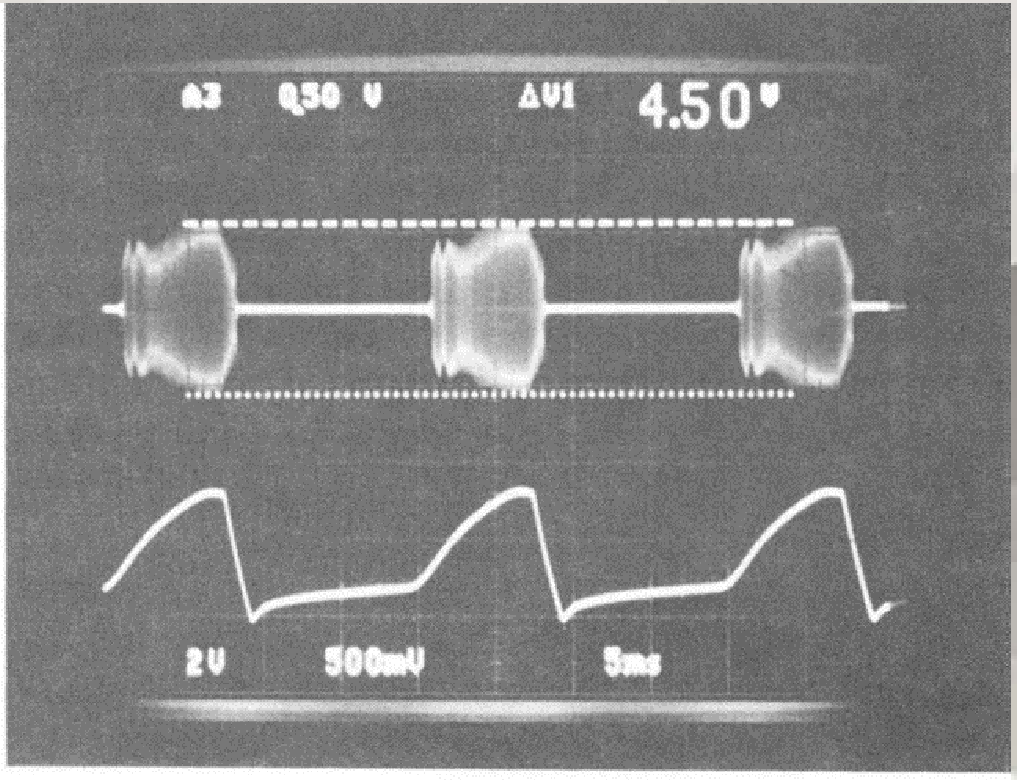


Ferrite tuned cavity for the Booster





High power operation of rf cavity using perpendicularly biased ferrite.

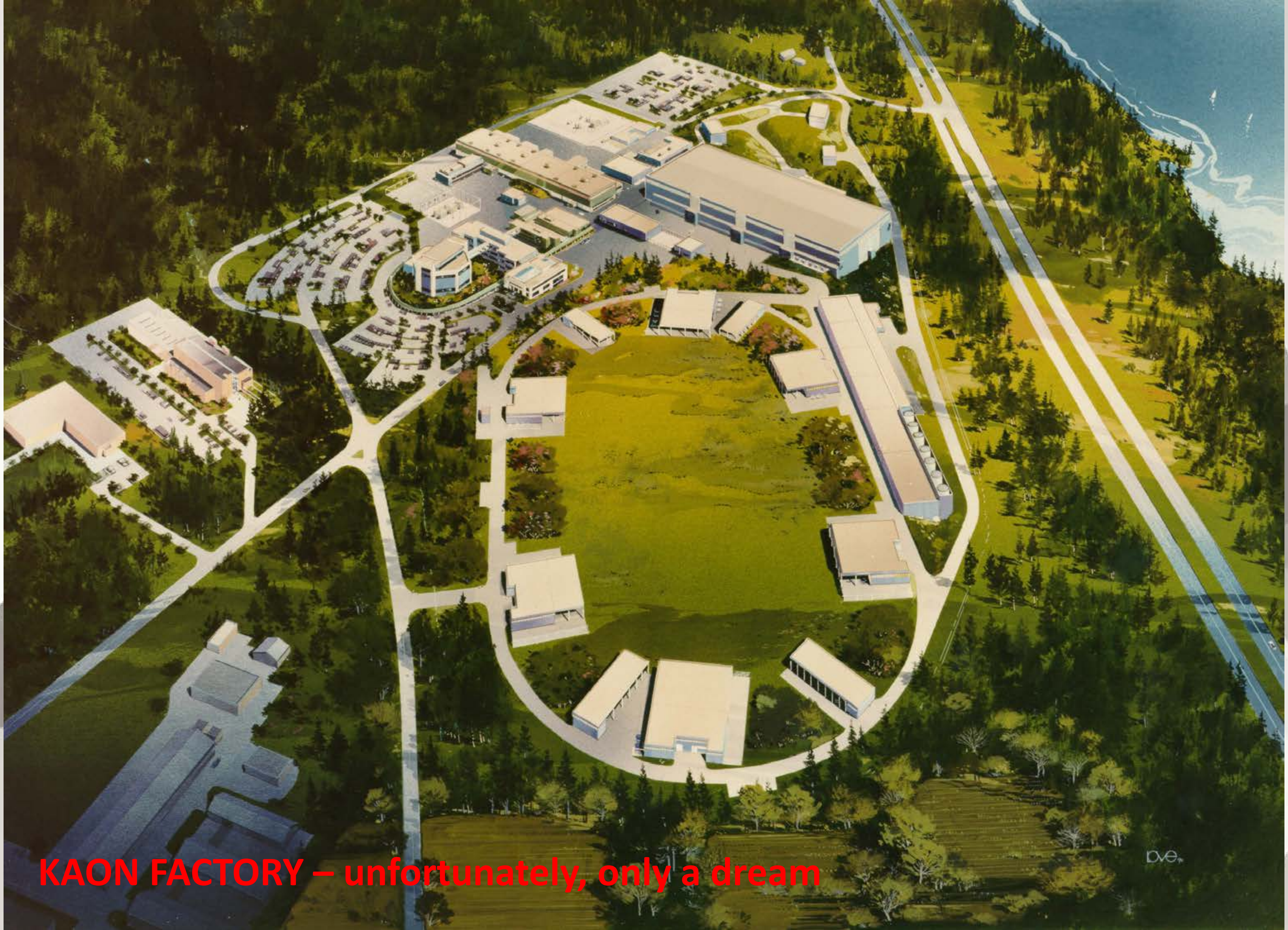


Top trace shows voltage at the accelerating gap (dashed lines indicate 65 kV), the lower trace the bias power supply current

COLLECTIVE EFFECTS

- **“Collective effects” are the automatic corollary of “high intensity”**
- Space-charge: many and various destabilizing mechanisms
- Coupled-bunch instability driven by many “impedance” sources
- Beam-loading (Robinson-type instabilities, injection & periodic transients, etc)
- Microwave instability (high frequency coasting beams)

Material to keep Fred, Rick & Shane busy for many years. Followed by knowledge transfer to JHF-JPARC



KAON FACTORY – unfortunately, only a dream