Electron Model of Linear-Field FFAG for Muon Acceleration

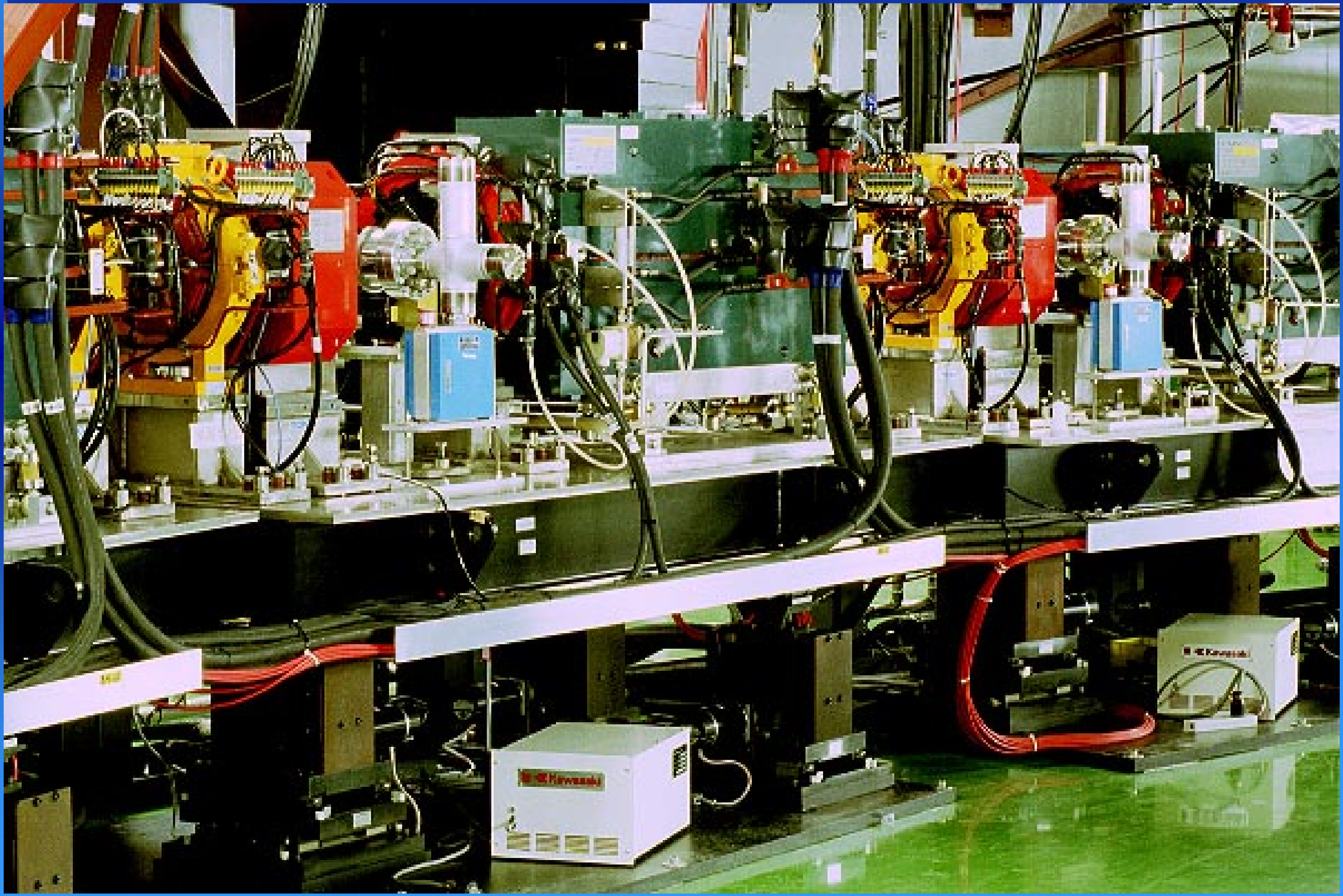
- The Study 2 FFAGs for muon acceleration are NOT MURA-style scaling FFAGs.
- They are a new breed of accelerator, using linear elements, with characteristics well matched to the rapid acceleration of beams with large 6D emittance.
- They rely on novel and, as yet, untested beam-physics
- They have been the subject of intensive study and simulation over the last 4 years at the FFAG workshops.
- It is important to build a proof of principle model, and plans for that are the subject of this talk.

The purpose of the electron model is to demonstrate and investigate the novel features of a nonscaling FFAG at a small fraction of the cost of the multi-GeV muon machine.

MUTAC Presentation, 25 April 2005,
Shane Koscielniak, Triumf, Vancouver, BC, Canada.

Electron Model What does it look like?

– like the KEK ATF (36 F0D0 arc cells) but without its straight sections, and scaled down from 1.5 GeV to 20 MeV



Electron Model - novel accelerator physics

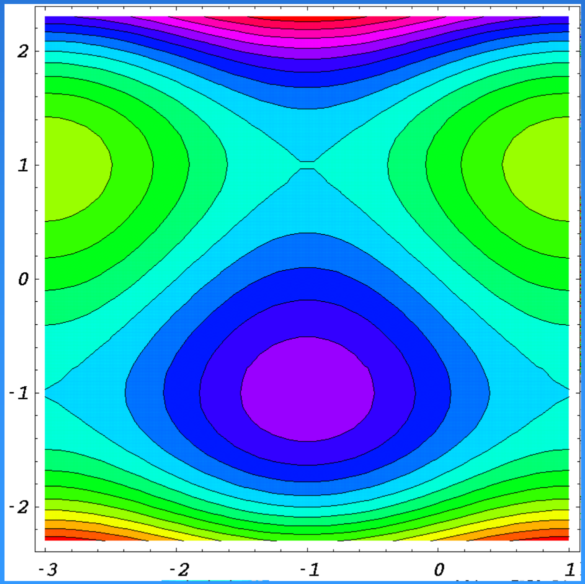
Momentum Compaction

The lattice will demonstrate the compaction of v. large range of momenta into remarkably narrow apertures. Under Livingood's definition $\alpha=(dp/p)/(dL/L)$, $\alpha \rightarrow \infty$ at mid-energy for this machine.

The FFAG operates at fixed magnetic field with a range of central momenta spanning $\pm 50\%$ in $\delta p/p$. This has two consequences.

Gutter Acceleration

The particle beam moves across the radial aperture, during acceleration, leading to changes in orbit shape which produce a quasi-parabolic time-of-flight variation. With fixed radio-frequency, this necessitates *asynchronous* acceleration within a rotation manifold outside the rf bucket.



Resonance Crossing

- Machine has natural negative chromaticity, but central momenta span $\pm 50\%$ in $\delta p/p$.
- This leads to crossing of many integer and ½-integer betatron resonances - this has not been done before.
- The new FFAG pins operation on the hope that if crossing is fast enough, no damage is done.

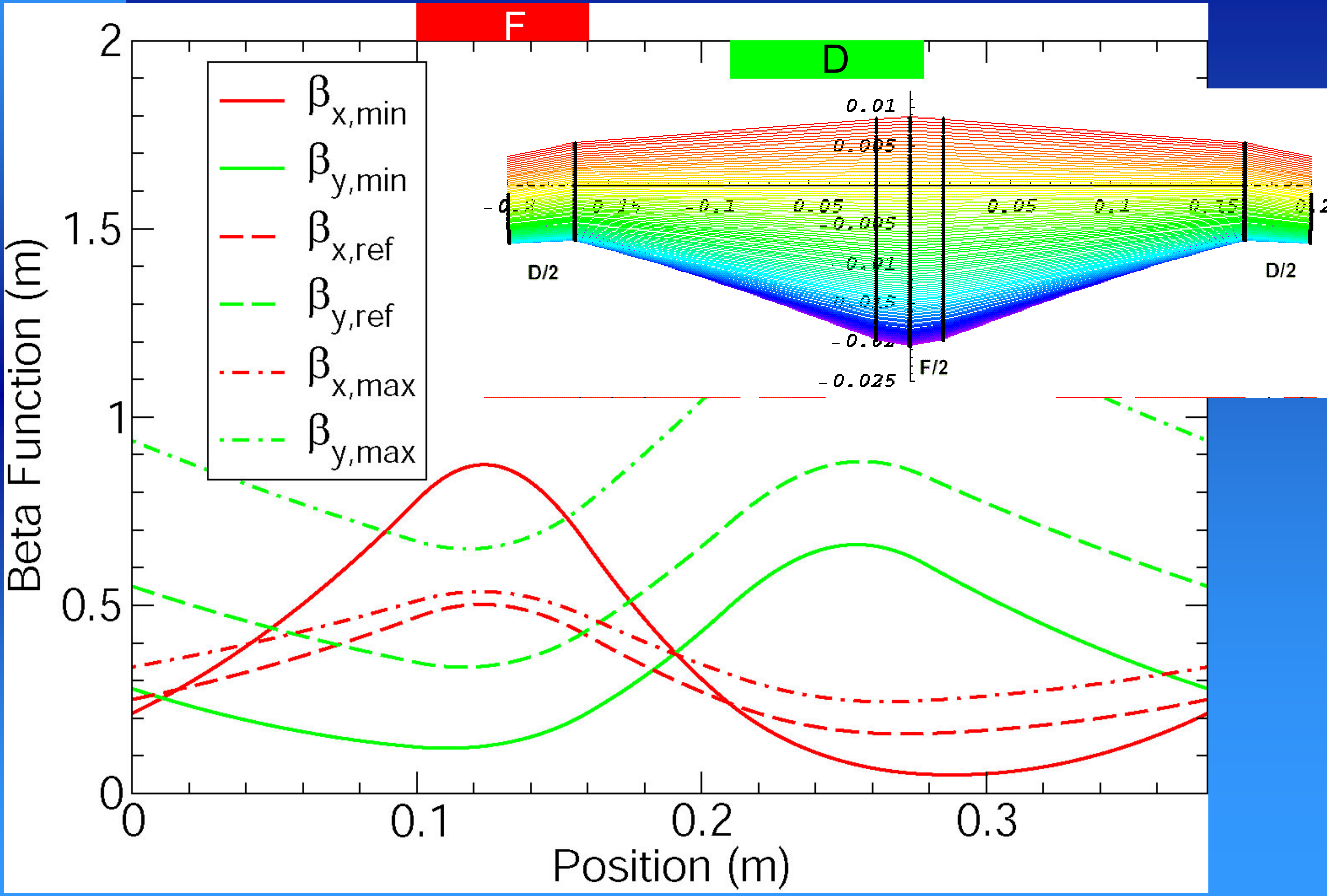
- October 2004: Based on tracking studies, Machida reported tolerances for alignment and quad strength rms errors of 0.05mm and 0.1% - these are feasible to achieve
- This successful demonstration of resonance crossing was a key milestone to proceeding with the design work.

- But verification on a real machine is important for confidence and credibility.
- The PoP model will determine what level of random driving terms may be tolerated.

Electron Model - Specifications

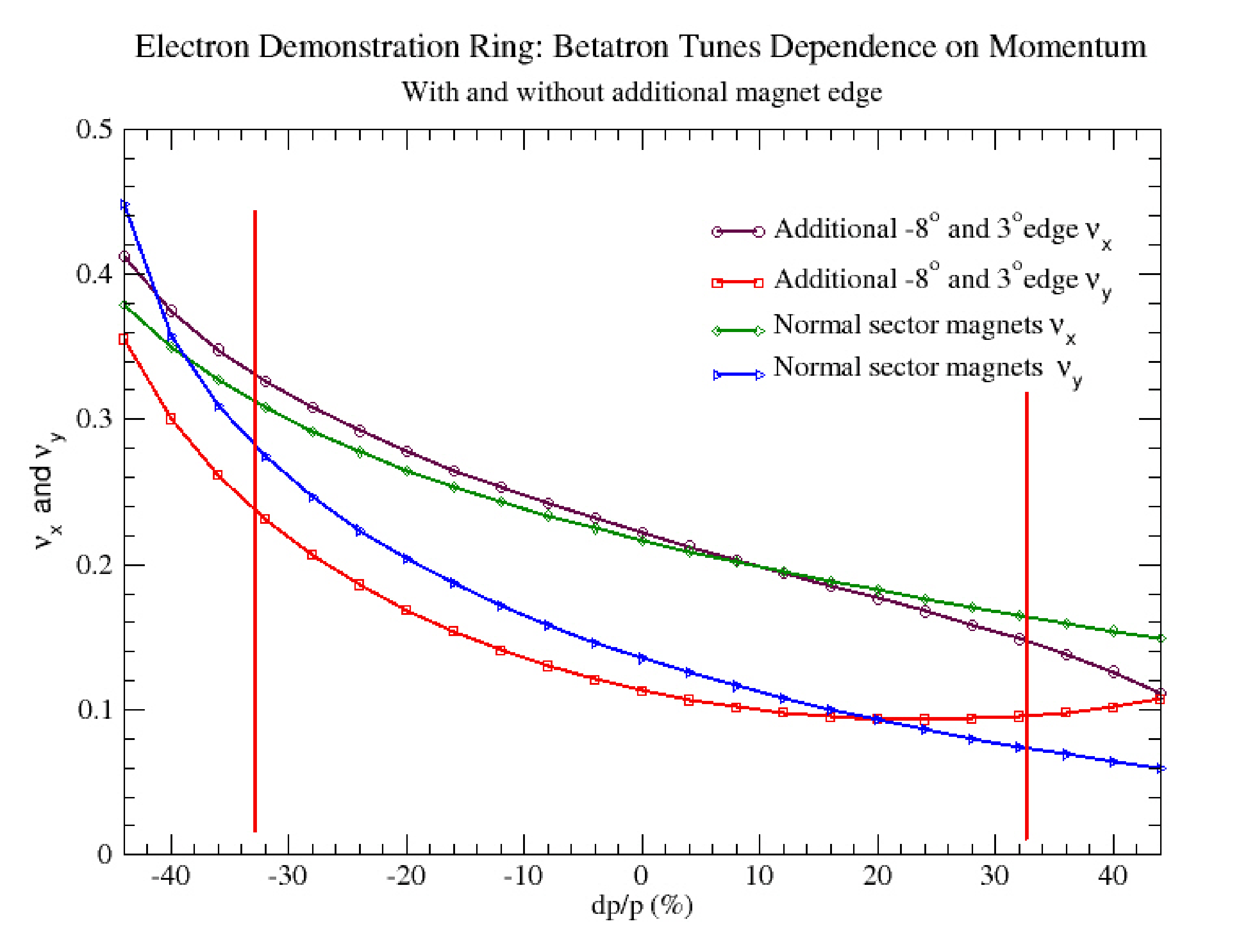
- 10 MeV injection, 20 MeV extraction
- 42 identical cells. High periodicity produces self-cancellation of terms driving 1/3-integer structure resonances.
- Doublet lattice – combined function D and quad F (lowest cost)
- Cell length 0.42 m. No insertions (long straight sections)
- Split betatron tunes $\nu_h > \nu_v$ to reduce path-length variation
- Magnets – peak field at pole tip less than 0.2T
- Injection/Extraction scenario – feasible (15cm)$\times$(0.1T)
- 20 of 1.3 GHz buncher-type cavities in alternate cells
- Voltage 40-120 kV each (18 to 6 turns)
- MA cavity or induction core for slow resonance crossing study

Lattice functions and example orbits versus momentum

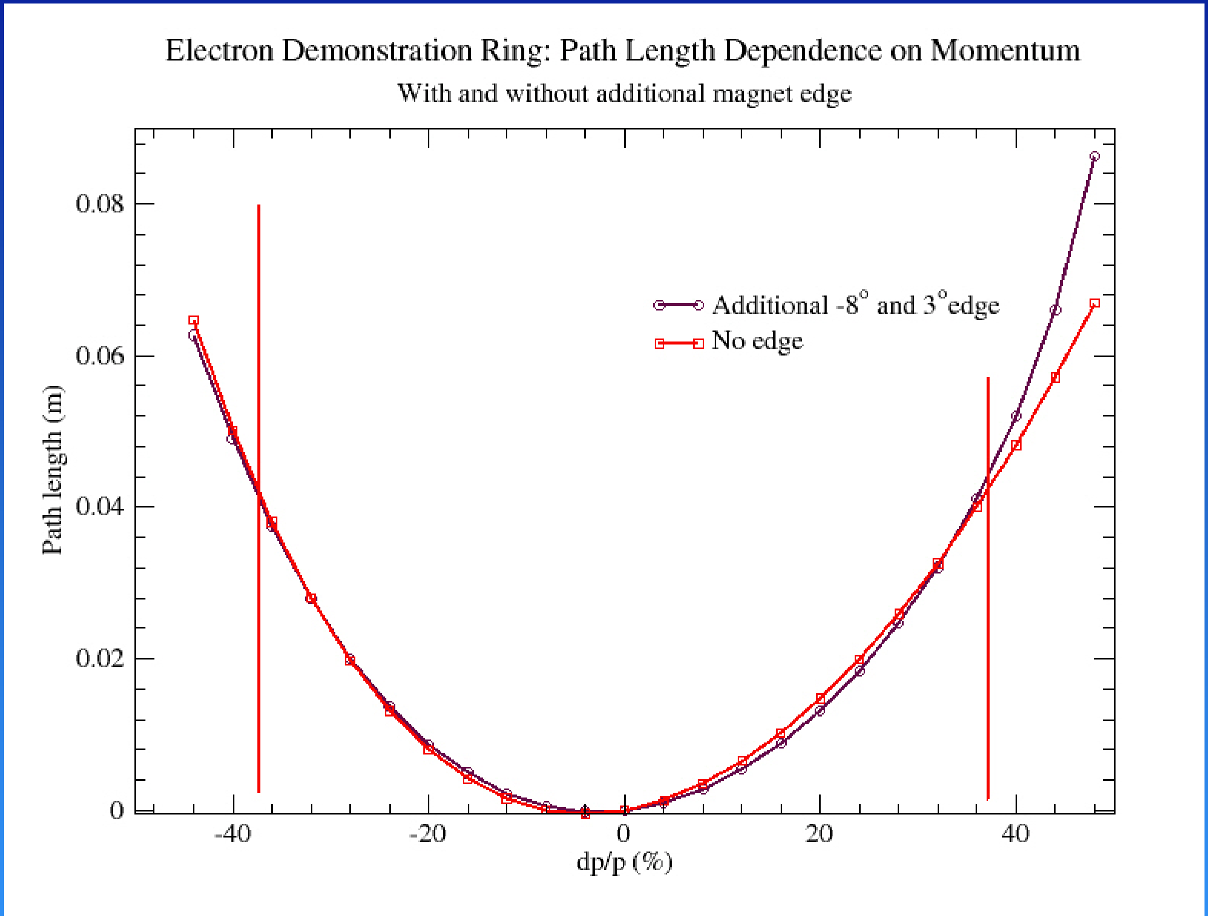


News from 3-7 April 2005 FFAG workshop at FNAL

- Until now,lattice models have used sector bends.
- Trbojevic points out that R-bends benefit from edge focusing, leading to an increase of vertical tune for high-momenta.



Insignificant effect on path-length variation



45 cell triplet lattice, 34 cm cell, 3 GHz RF.

Electron models will be revised because of benefit to ν_y.
High-angle edge effects noticeable for rings with few cells, but will have v. little impact on 80-100 cell muon rings.

Radiofrequency system

Where possible adopt designs already existing at the host laboratory.

Adopt 1.3 GHz ELBE buncher cavity to be used at Daresbury 4GLS

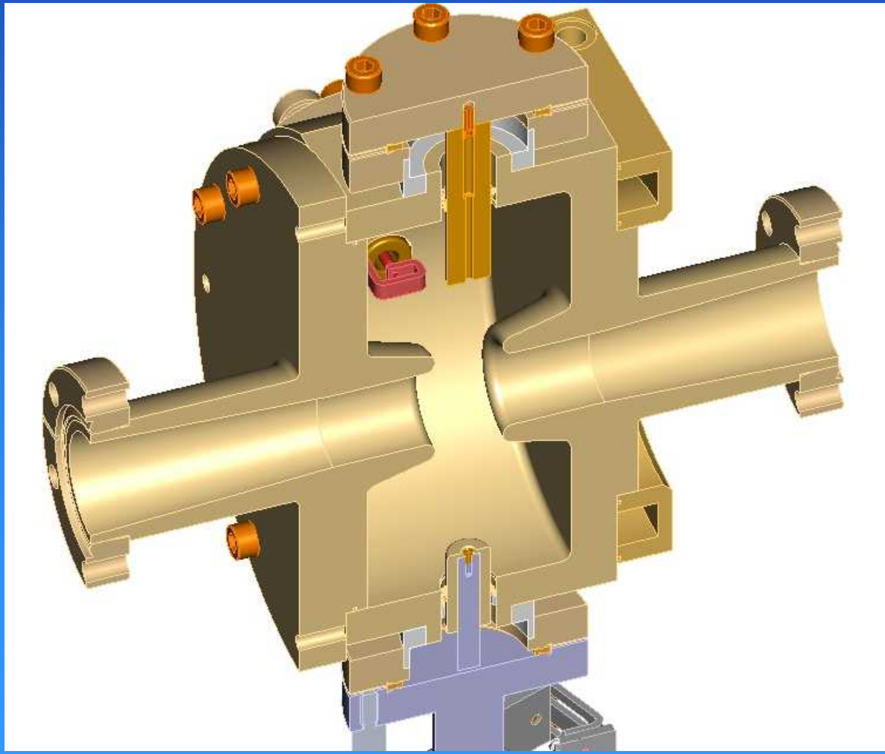
R=1MΩ, Q=1.4×10^4

1.3 GHz preferred over 3 GHz: reducing RF while magnet length is fixed, implies magnets become a smaller number of RF wavelengths. This implies smaller phase slip and more turns.

Frequency variation of few 10^{-4} to investigate 1 or 2 fixed points operation.

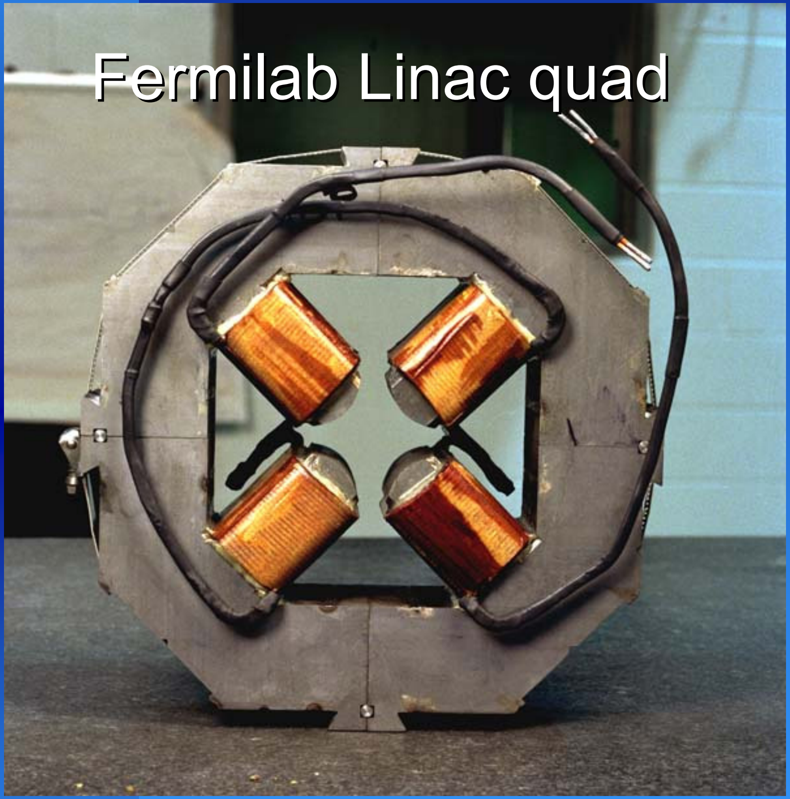
Adopt TESLA-style linear RF distribution scheme to reduce number of waveguides

20 cm straight for installation



Quadrupole Magnet

Hardware – general principle – copying or modifying existing hardware is to be preferred over developing new designs.



General requirements:

- Gradient: 7 T/m
- Slot length: 6 cm
- Aperture: 40 mm wide, 25 mm high
- Rep rate <1Hz

The 5cm long upgrade Fermilab linac quadrupole has peak pole-tip field near 3.5 kG, and the bore is 5cm. With a BPM installed the aperture is 3.7cm. This is ideal for the 3 cm orbit swing envisioned for the ring. Reverse bending is effected by offsetting of quad.

Combined function magnet

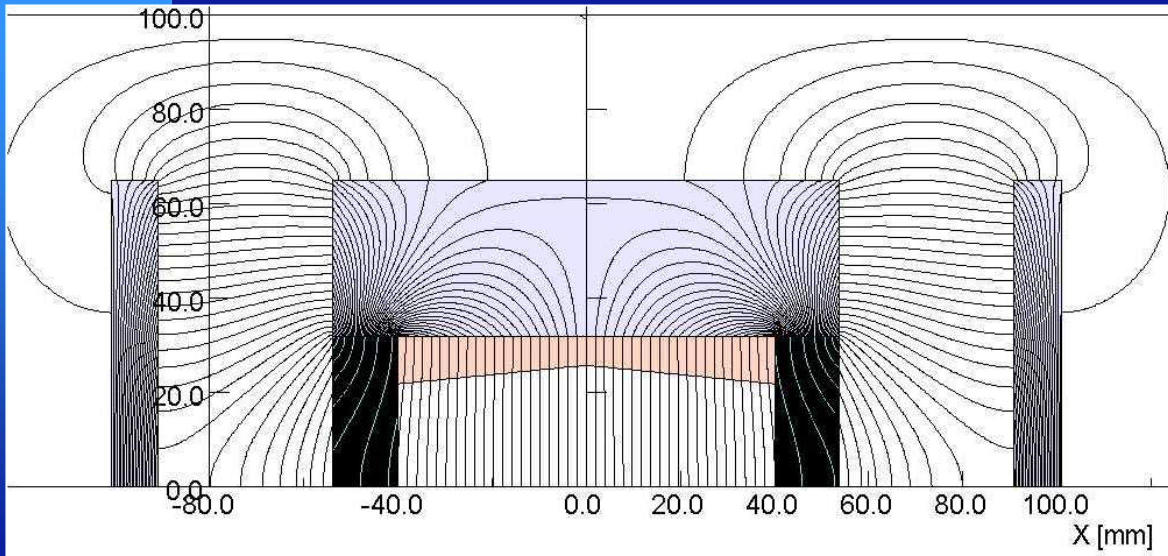
Specifications

- Permanent dipole component of 0.15 T
  - Slot length: 10 cm
  - Magnetic length: 7cm
- Permanent quad component of ~4T/m (steel shaping)
- Quad trim coil provides +/- 20%
- Magnet spacing: 5 cm
- Aperture (good field): 50 mm wide, 25 mm high
- Field uniformity ± 1% at pole tip
- Space for internal BPM
- 1Hz operation or less
  - No cooling
  - No eddy current problems

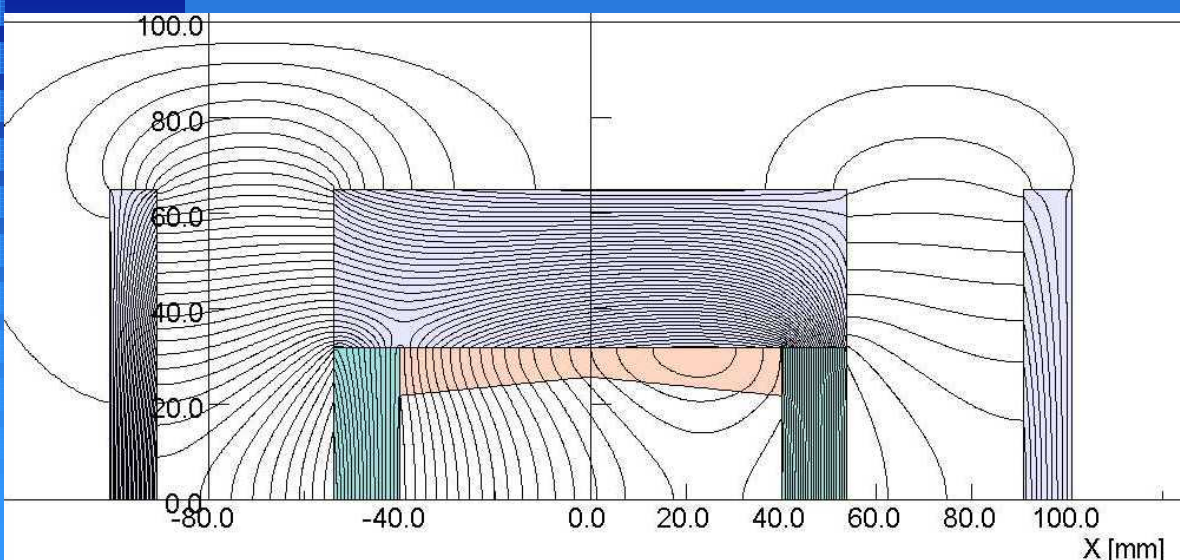
Challenges

- Aspect ratio (gap to length)
- Squeeze so much into such a short slot
- End field

Dipole only field lines



Dipole plus quad field lines



Magnet Concept

(Vladimir Kashikhin, FNAL)

- Power the dipole component with permanent magnets
  - Compact
  - No power issues
  - Thermally stable PM material
- Power the quadrupole component with a (modified) Panofsky coil
  - Compatible with rectangular aperture
  - Relatively short ends

Electron Model – who will host?

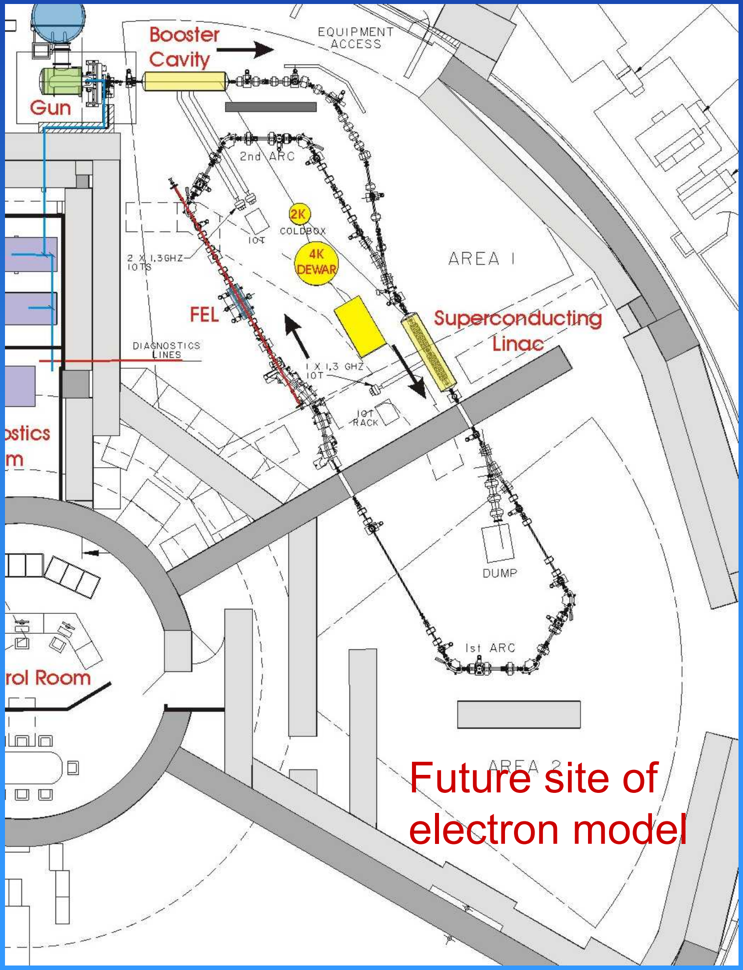
Daresbury Laboratory U.K. is very enthusiastic to host the electron model downstream of their 8-35 MeV Energy Recovery Linac Prototype (ERLP) of the 4the Generation Light Source (4GLS).

Funding Sources?

M£2.5 funding was applied for under the Basic Technology Program of the Engineering and Physical Sciences Research Council on 11th February.

The program supports basic, high quality technology research. Principal investigators: Leeds University (School of Physics and Astronomy) & CCLRC ASTeC

Funding adequate for a small ring with no RF cavities; use energy-variability of linac to characterize dynamics.



Funding - Continued

RESEARCH

M€2 applied for under the New and Emerging Science Technology (NEST) fund of the 6th Framework Program of the European Union.

Adventure projects criteria:

(i) outside Thematic Priorities of FP6

(ii) high novelty, ambitious, and has high-risk/high-impact character

Projects implemented through Specific Targeted Research Projects. There is a 2-Stage proposal.

- Outline submission 13th April 2005
- Invitation for full proposal mid-July 2005
- Signing of contracts April 2006
- Duration of project 2 years

Principal investigator: Council for the Central Laboratory of the Research Councils (CCLRC), Accelerator Science and Technology Centre (ASTeC).

Potential Collaborators: BNL, CCLRC, CEA Saclay, CERN, FNAL, TRIUMF; universities of Grenoble, Kyoto, Lancaster, Leeds, Liverpool, Rostock (Germany), Uppsala (Sweden).