

Shane Koscielniak, Triumf, Vancouver, BC, Canada, 18 March 2005

Electron Model of Linear-Field FFAG for Muon Acceleration

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



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



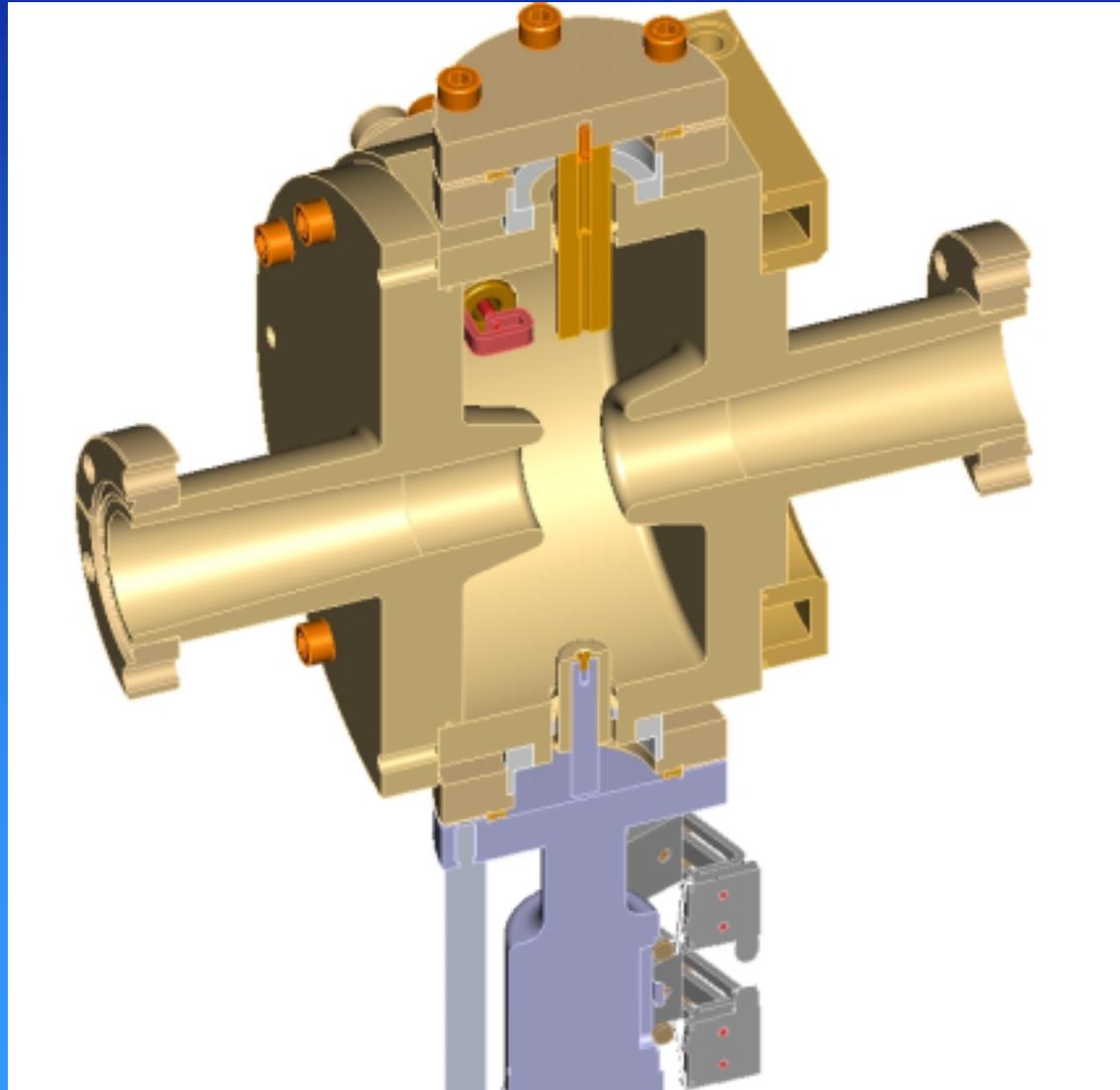
Possible magnet design: the upgrade Fermilab linac quadrupole (the 2" long green magnet). Its peak poletip field is near 3.5 kG, the poletip bore is 2" and has a BPM design which fits inside the quad. With a BPM installed the aperture is 1.5". This is ideal for the 2-3 cm orbit swing envisioned for the ring.

Where possible adopt designs already existing at the host laboratory.

Radiofrequency system: based around 1.3 GHz
ELBE buncher cavity to be used at Daresbury 4GLS

Adopt
TESLA
Linear RF
distribution
scheme to
reduce
number of
waveguides

$R=1\text{M}\Omega$,
 $Q=1.4\times 10^4$



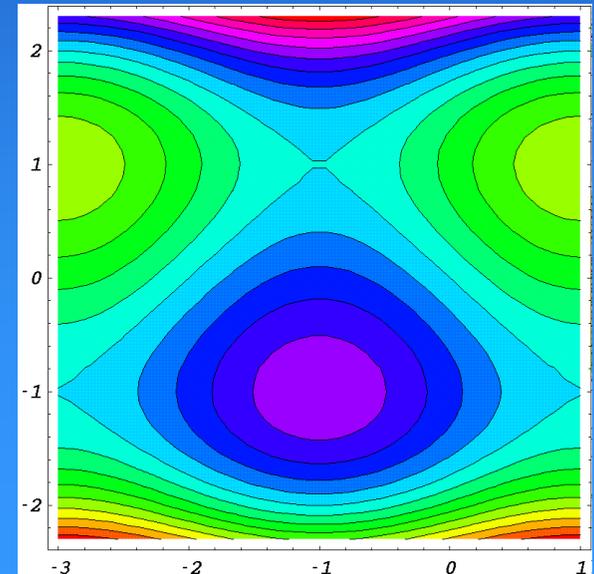
Electron Model of Linear-Field FFAG for Muon Acceleration

What does it do? 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.

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

Resonance Crossing: The transverse focusing strength falls with increasing momentum leading to natural negative chromaticity. This leads to crossing of many integer and $\frac{1}{2}$ -integer betatron resonances.

Gutter Acceleration: The particle beam moves across the radial aperture, during acceleration, leading to change 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. (MURA 423)



How has the design evolved over the year(s)?

Dec 1997: Johnstone devises lattice to give infinite momentum compaction ($\alpha \rightarrow \infty$) at mid energy and remarkably narrow apertures $\alpha = (dp/p)/(dL/L)$ – Livingood definition of compaction

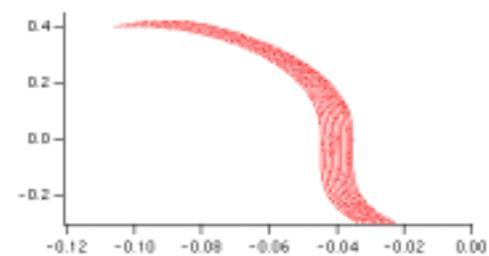
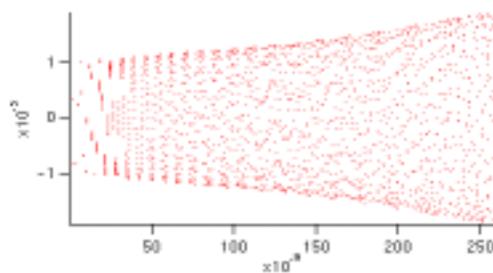
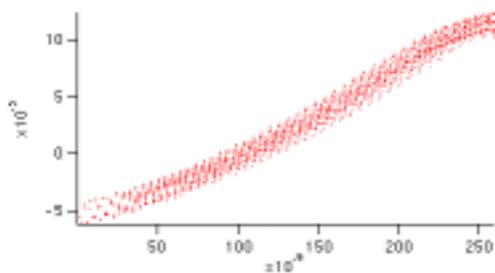
- Oct 2003: J.S. Berg sets basic parameters for an electron model (0.2T peak field, 3GHz RF, 5 & 15 cm drifts, 35 cm long cells)
- Between Oct 2003 and April 2004, understanding of relation between optics and ToF gleaned from muon FFAG is applied to the model. F0D0, Doublet and Triplet cells are all considered.
- April 2004: Keil realizes that longitudinal motion can be made less dispersive by operating at bottom of ToF parabola ($\delta T_2/\delta T_1 = 0$ instead of $\delta T_2/\delta T_1 = 1/3$) – at cost of more cells.
- Other designers obsessed by rings with small circumference.
- E.g.s Berg: 25 cell doublet, 8.8m. Koscielniak: 23 cell triplet. Trbojevic: 45 cell triplet, 15.8m. Keil: 45 cell doublet.
- Some designs published in EPAC 2004 (MOPLT023,112 & THPLT006). Keil reports alignment study via tracking with errors.

Integer resonance crossing

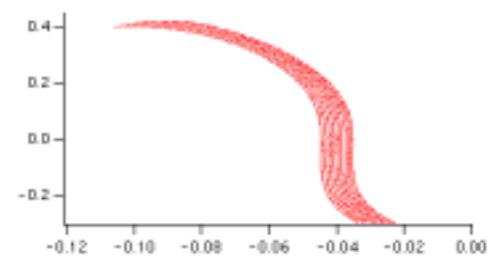
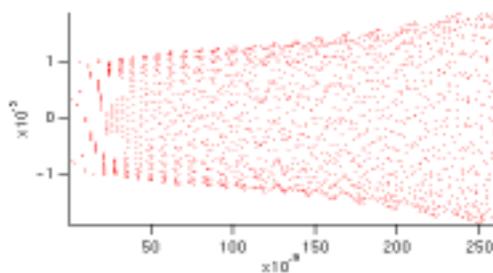
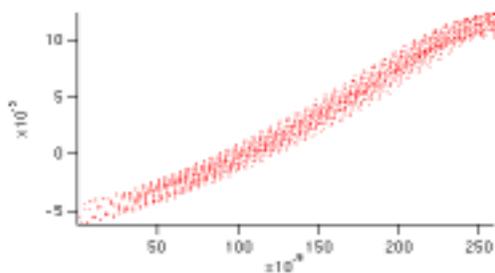
- Alignment errors as well as crossing speed are parameters.
 - Alignment errors: 0.01, 0.02, 0.05, 0.1, 0.2, 0.5, 1mm (+- 100%, uniform).
 - Crossing speed: nominal to 5 times slower.
- Crossing speed
 - Instead of nominal operation parameter: 1.5 GHz, 2.5 MV total,
 - 315 MHz, 0.500 MV, 25 turns
 - 747 MHz, 1.25 MV, 10 turns
 - 1.5 GHz, 2.50 MV, 5 turns
 - Observer betatron oscillations and acceleration.

Freq=1.49 GHz (h=76), 2.5 MV, 5 turns

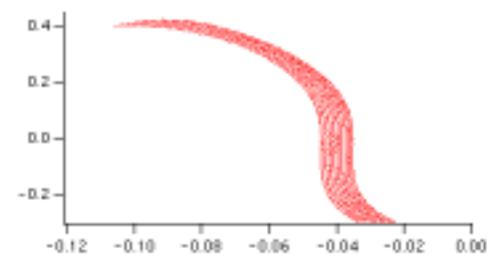
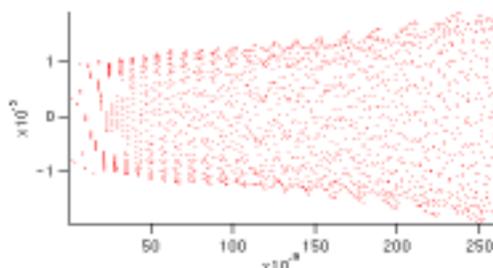
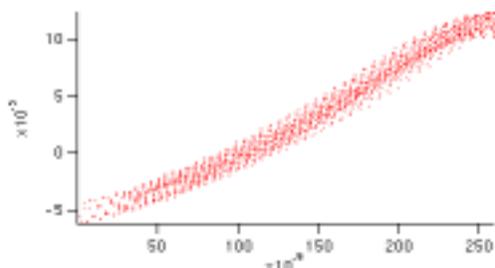
0mm



0.01mm

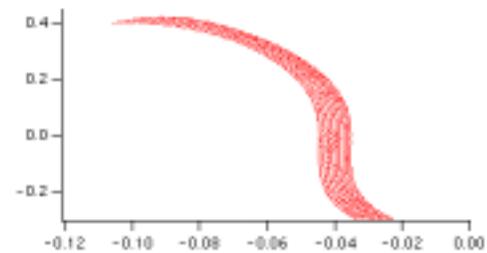
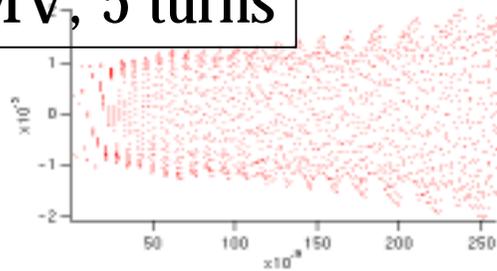
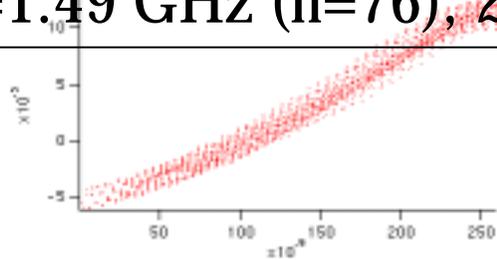


0.02mm

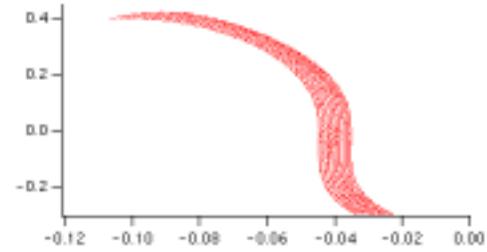
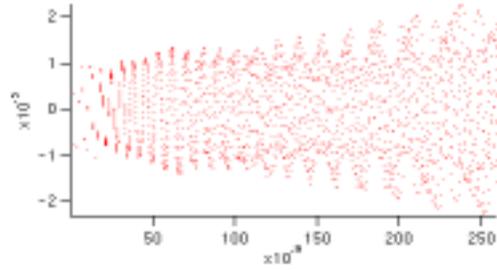
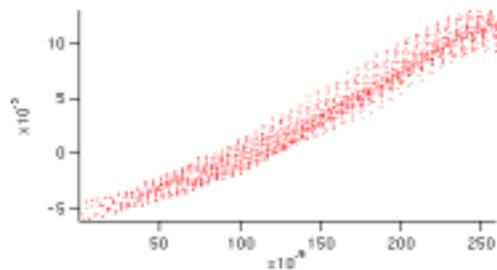


Freq=1.49 GHz (h=76), 2.5 MV, 5 turns

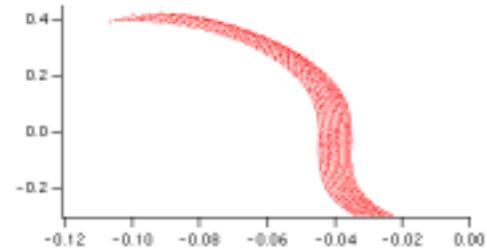
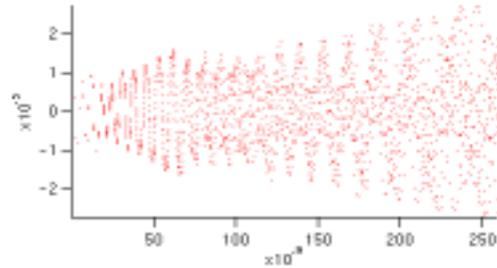
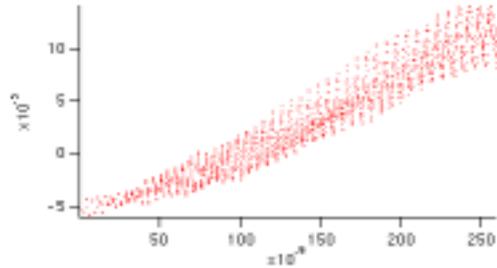
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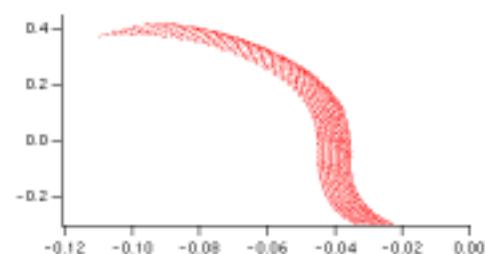
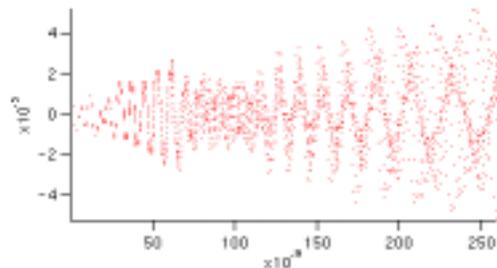
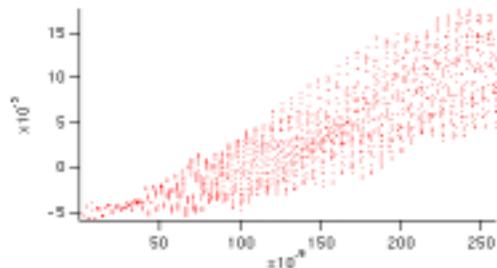
0.1mm



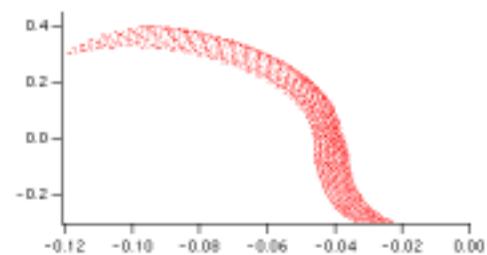
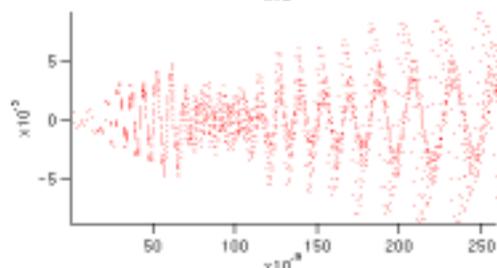
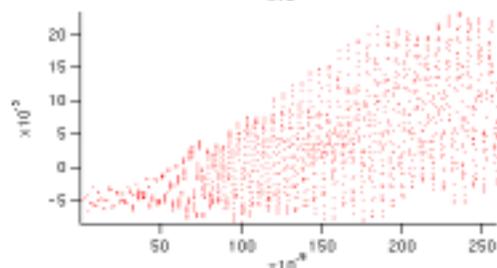
0.2mm



0.5mm



1mm

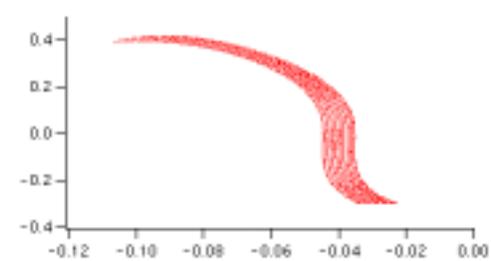
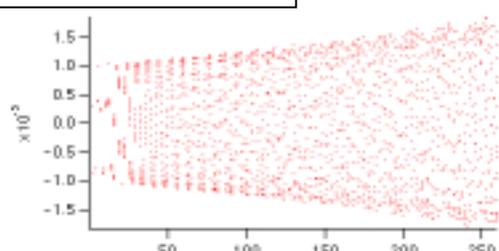
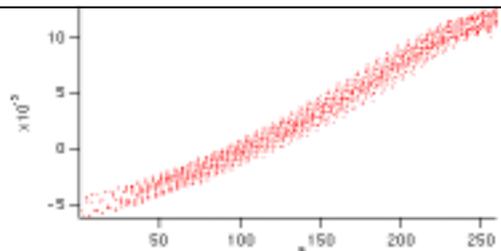


Half-integer resonance crossing

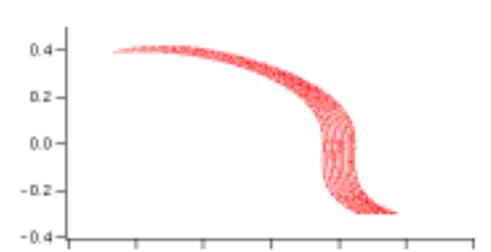
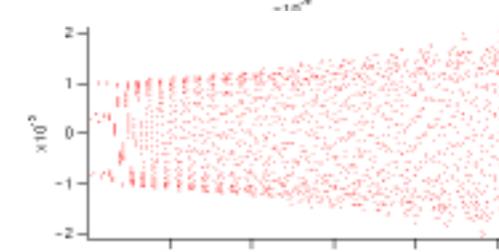
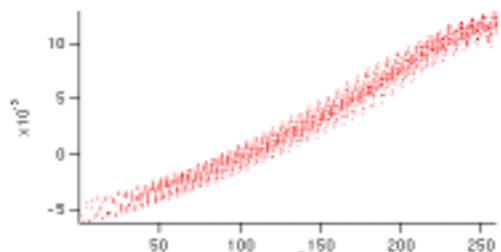
- Gradient errors as well as crossing speed are parameters.
 - Gradient errors: 0.01, 0.02, 0.05, 0.1, 0.2, 0.5, 1, 2, 5 %
 - Crossing speed: nominal to 80 times slower.
- Crossing speed
 - Instead of nominal operation parameter: 1.5 GHz, 2.5 MV total,
 - 19.7 MHz, 0.032 MV, 400 turns
 - 78.7 MHz, 0.125 MV, 100 turns
 - 157 MHz, 0.250 MV, 50 turns
 - 315 MHz, 0.500 MV, 25 turns
 - 747 MHz, 1.25 MV, 10 turns
 - 1.5 GHz, 2.50 MV, 5 turns
 - Observer betatron oscillations and acceleration.

Freq=1.49 GHz (h=76), 2.5 MV, 5 turns

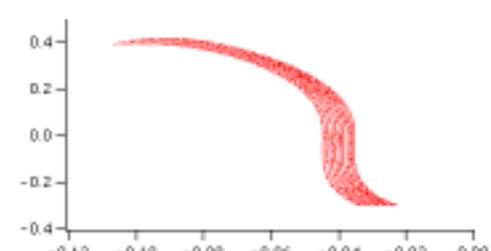
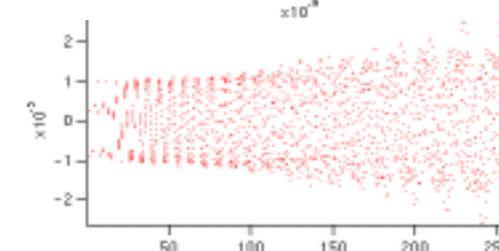
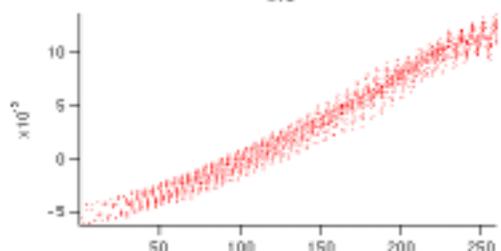
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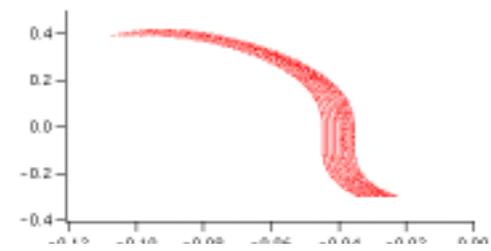
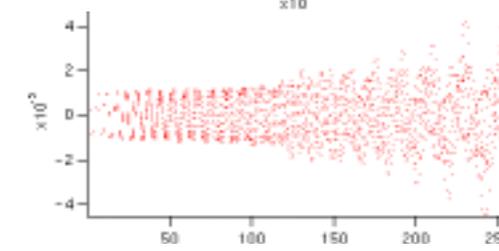
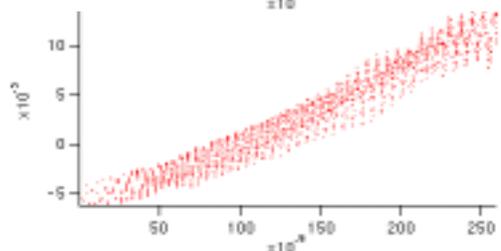
0.5%



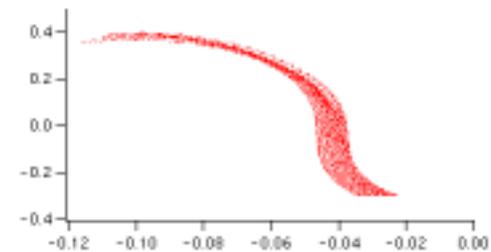
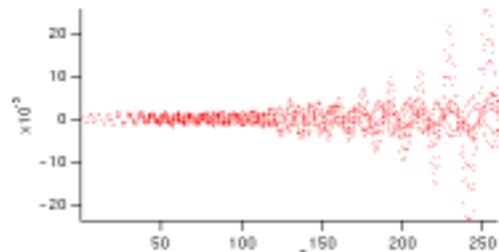
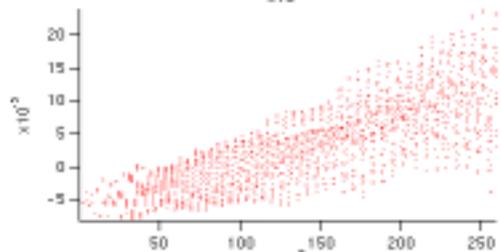
1%



2%



5%



How has the design evolved ? - continued

October 2004: Machida reports tolerances for alignment and quad strength errors based on particle tracking (i.e. integer & $\frac{1}{2}$ -integer resonances); former agrees with Keil (30 μ m r.m.s.).

Demonstration (by tracking) of successful resonance crossing is a key milestone to proceeding with the design work.

Koscielniak suggests that 25-30 cell 3GHz electron model is too small: too few cells and turns (only 4 or so) – adversely impacts the study of *new* accelerator physics. For example, resonance crossing speed inversely proportional to (cells) \times (turns).

Recommends reducing RF and or increasing number of cells – but with fixed magnet length; hence magnets become a smaller number of RF wavelengths.

January-March 2005: all designers working on lattices with 36,42 or more cells and 1.3GHz cavities; circumference 15 to 20 m (or more). Turns range from 7 to 12 or so.

Electron Model Concept/Specification – consensus with loud objections

- 10-20 MeV
- High periodicity to produce self-cancellation of terms driving 1/3-integer structure resonances. 42 cells if affordable
- No straight sections
- Doublet lattice – combined function D and F
- Magnets – iron core or $\cos\theta$ air-core type? Latter gives more flexibility (& head aches) but may be limited to 0.1T
- Peak field at pole tip less than 0.2T
- 1.3 GHz buncher-type cavities in alternate cells
- Cell length 0.42 m
- Split betatron tunes $\nu_h > \nu_v$ to reduce path-length variation
- MA cavity or induction core for resonance crossing study
- Injection/Extraction scenario – feasible (15cm)×(0.1T)

Electron Model – who will host?

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

M£2.5 funding has been applied for under the Basic Technology Program of the EPSRC (Engineering and Physical Sciences Research Council) on 11th February.

The program supports only basic, high quality technology research and training. 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.





M€2 will be applied for under the New and Emerging Science Technology (NEST) ADVENTURE projects fund of the 6th Framework Programme of the European Union.

Adventure projects criteria:

- (i) outside Thematic Priorities of FP6
- (ii) high novelty, ambitious, and has high-risk/high-impact character

Adventure projects are implemented through Specific Targeted Research Projects (STREPs). There is a 2-Stage proposal, outline and full STREP.

- Stage-1 deadline 13th April 2005
- Invitation for full proposal mid-July 2005
- Signing of contracts April 2006
- Duration of project 2-3 years

Draft of outline proposal will be subject of FFAG workshop held at FNAL 3-7 April 2005.

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