Resonance crossing in proton FFAGs: a proposed experiment

Thanks to Hiromi Okamoto & Shinji Machida for prompting this discussion!

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Background

- Around the time that EMMA was being built & the PAMELA project was starting, many people said:

  "can we build a proton accelerator like EMMA"?
- Answer was "NO!" with two main arguments against:
  1. Very sharp injection/extraction angle
  2. Resonance crossing would blow up the beam
- So both Johnstone & Machida decided to 'flatten' the tunes and create long straight sections in different ways.
- But… the question of resonance crossing was never 'fully' answered, and still has not been answered experimentally.

“Can an EMMA-like FFAG work for protons?”

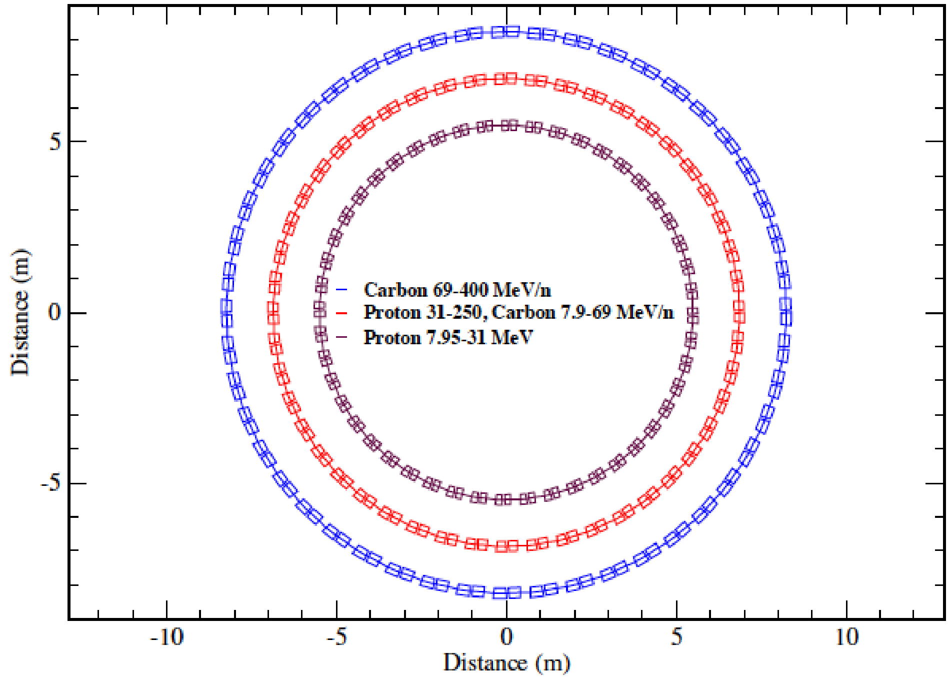
Or more specifically…

“Given a certain linear ns-FFAG proton lattice configuration with reasonable alignment errors, *how quickly* do we need to sweep the tune to accelerate with less than 10% emittance growth?”

(NB: 10% is arbitrary, could choose any reasonable number)

Keil-Sessler-Trbojevic cancer therapy design

Schematic layout of the rings

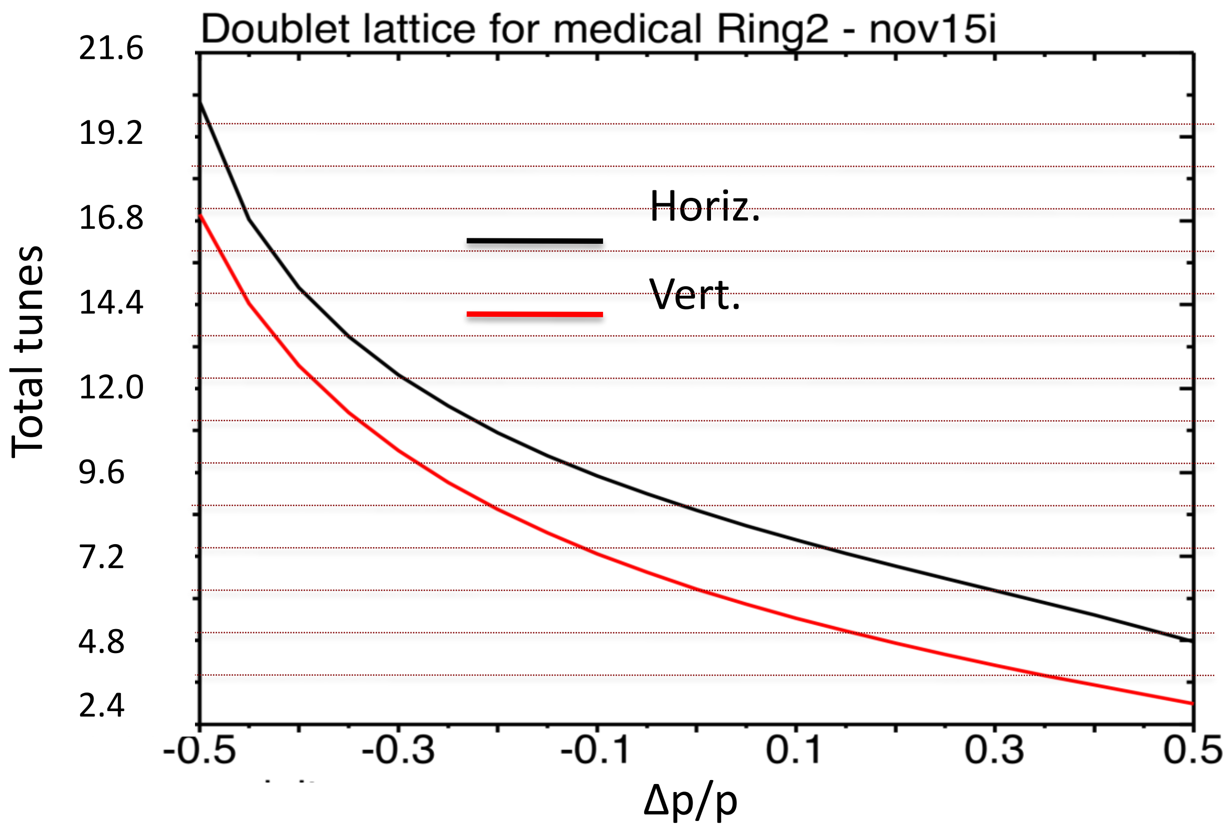


Alternative layout with rings on either side of straight beam line

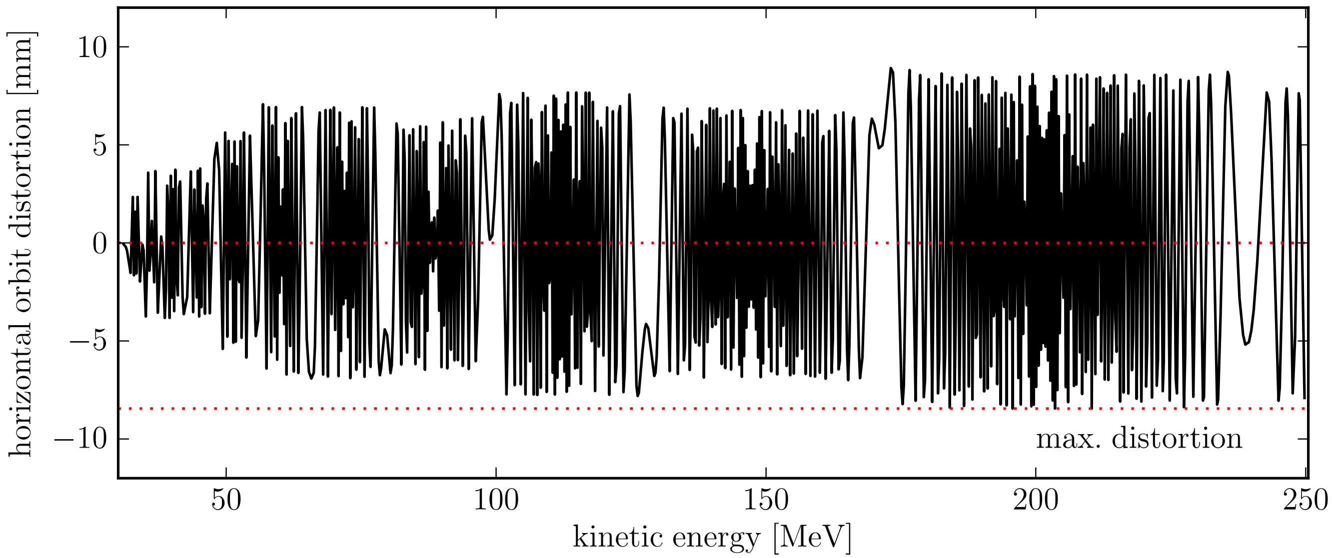
Ring 2 Parameters

Parameter	Injection	Reference	Extraction
Proton Kinetic Energy [MeV]	30.95	118.38	250
C^{6+} Kinetic Energy [MeV/u]	7.84	30.98	68.36
Bρ [Tm]	0.81071	1.62142	2.43213
Cells	48		
r_0 [m]	6.875		
Magnet length (F/D) [m]	0.26 / 0.27		
Bend angle (F/D) [rad]	-0.1149 / 0.2458		
Quadrupole strength K (F/D) [m^{-2}]	9.56 / -10.74		
Half gap height [m]	0.03		
Long drift [m]	0.29		
Short drift [m]	0.08		
Orbit excursion [m]	0.065		

Ring 2 tune variation



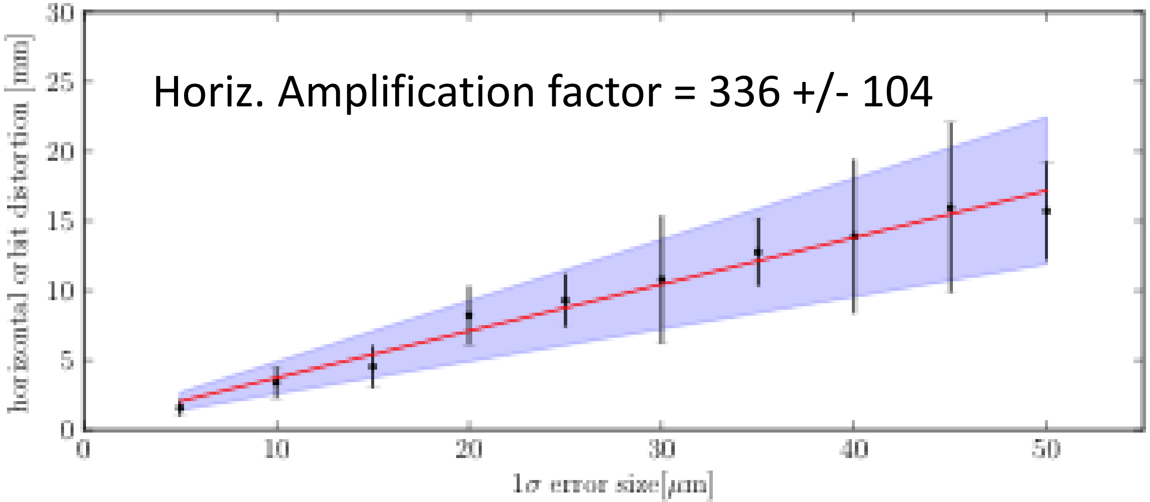
Previous error studies

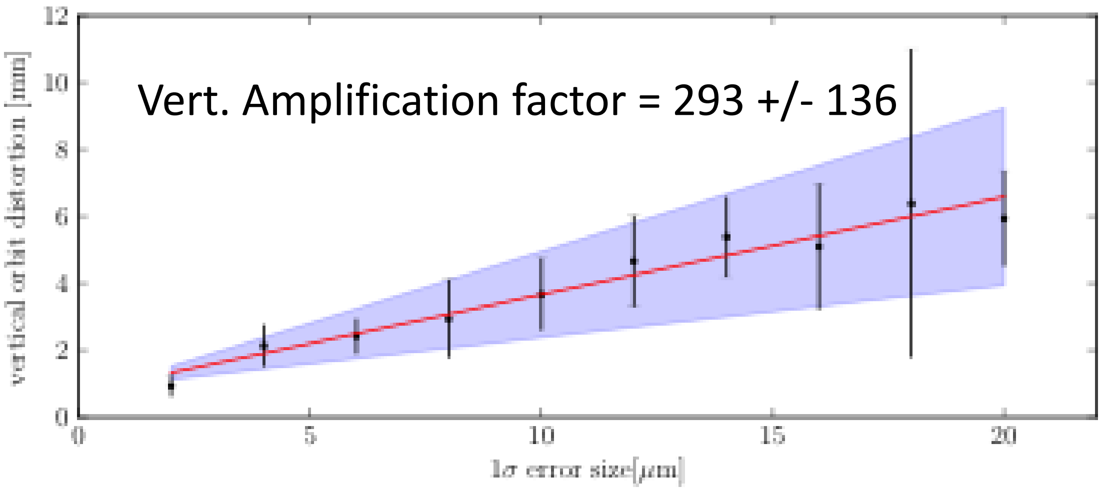


- Each FD doublet given random alignment error
- Track particle over 1000 turns to extraction
- Orbit shape changes throughout acceleration
- Orbit distortion: max deviation of tracked particle from closed orbit of zero-error lattice

From S. L. Sheehy, Dphil thesis, University of Oxford, 2010

Orbit distortion





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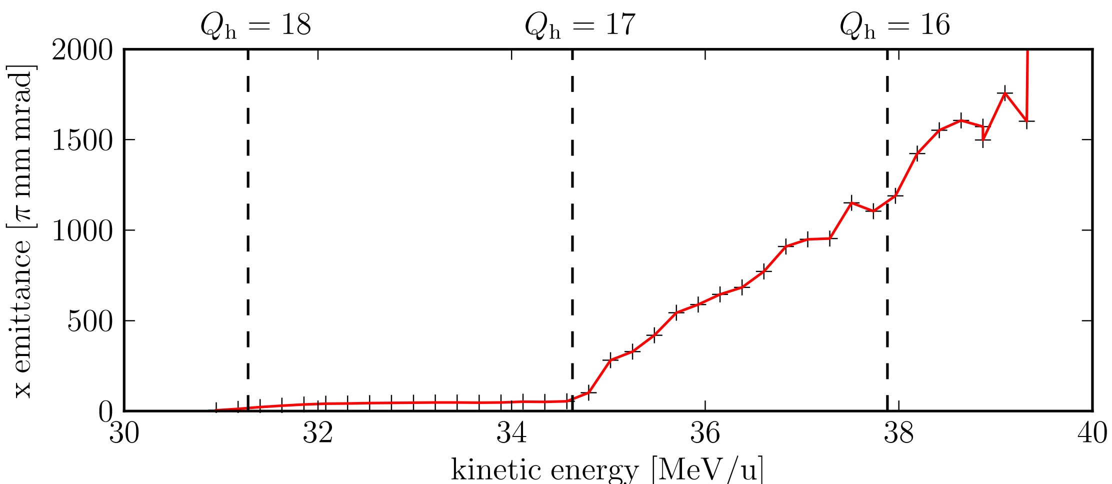
Emittance increase



- 36 particles on 10 pi mm mrad normalised emittance ellipse tracked through first 40 turns of acceleration
- Random horiz. Alignment errors of 50 micron (realistic)
- A beam would not survive!

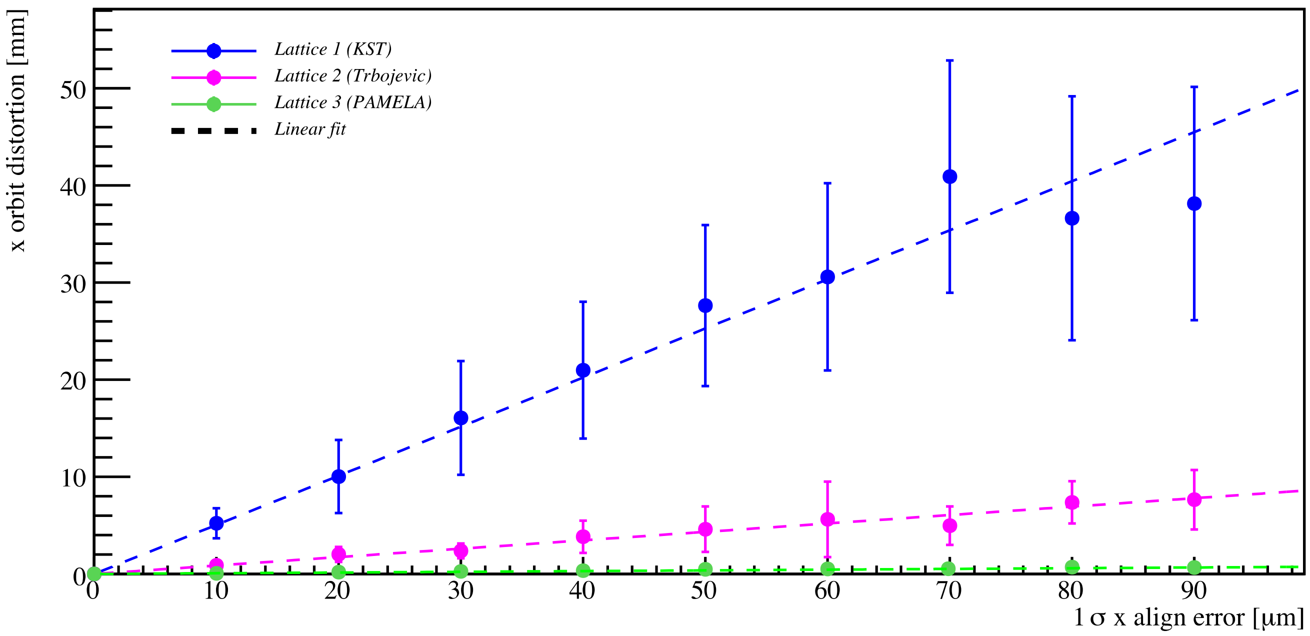
A few comments:

- I'm not quite sure I know why it grows *between* integers, but assume because particles are getting lost – out of dynamic aperture?
- I remember this being quite hard to simulate accurately – the beam did NOT want to stay in! Would need a bit more work…

From S. L. Sheehy, Dphil thesis, University of Oxford, 2010

Other lattices?

- Comparison done for FFAG'09 proceedings with D.Trbojevic lattice (& PAMELA non-linear lattice)
- Difference due to 24 doublet cells, sector shaped magnets, crosses less integer resonances
- Note this is only for horizontal alignment errors & in reality vertical, rotational & field errors also!



Lattice	Horizontal amplification factor, A
1 (KST)	505.4 ± 54.7
2 (Trbojevic)	86.7 ± 10.5
3 (PAMELA)	7.4 ± 1.2

Reference: S. L. Sheehy, Effects of alignment errors in proton non-scaling FFAGs, Int. J. Mod. Phys. A, Vol. 26, No.10n11, 2011.

HYPOTHESIS:

That a proton beam in a ns-FFAG of the type described earlier cannot realistically be accelerated to extraction in pulsed mode without excessive emittance growth due to slow resonance crossing.

S-Pod experiment?

AIM:

To determine the tune sweep rate (and thus acceleration rate) which would result in less than 10% emittance growth over the whole acceleration cycle in a medium-energy proton ns-FFAG.

METHOD:

- Use 'low current' equivalent S-Pod setup
- Set the correct primary focusing wave according to number of cells
- Set a secondary 'perturbation' wave for alignment errors (How do we do random errors? Is this possible? Or we could do just 'one' misalignment in ring instead of a random set, but this would need the comparable simulations)
- Determine emittance with & without errors (how?)
- Change tune ramp rate & repeat
- Ie. run similarly to Shinji's experiment!

Relevant parameters

- 48 FD doublet cells consisting of quadrupoles with an offset
- In the design the horizontal tune goes from 0.4->0.2 (19.2-9.6) in 3000 turns so dQ/dT=0.0032, for the vertical it's dQ/dT=0.004.
- Acceleration could conceivably be done a bit faster in say 1000 turns, making dQ/dT roughly 0.01.
- *I guess this would be considered very slow resonance crossing, which puts it in a different regime to the proposed EMMA-like PT experiments.*

A few questions & concerns

- Comment on p.2 of the recent PR-STAB (2012) paper which says the LPT is "physically equivalent to a charged particle beam travelling through a linear transport channel at relativistic speed". Should I take that to mean 'ultra-relativistic' or simply 'fast'? (ie. is this beam ‘relativistic’ enough for the assumptions to hold true?)
- Should we be concerned about effects of dispersion (alignment error kick distorts orbit – but with dispersion it then sees different field?) Will this have an effect?
- How do we set up the ‘perturbation’ wave?
- Diagnostics etc…