EMMA Upgrade: Slow Acceleration with Low-Frequency Cavity

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Outline

- Motivation for “slow” acceleration
- Problems with slow acceleration
- Performing slow acceleration in EMMA
- The low-frequency RF system

Motivation for "Slow" Acceleration

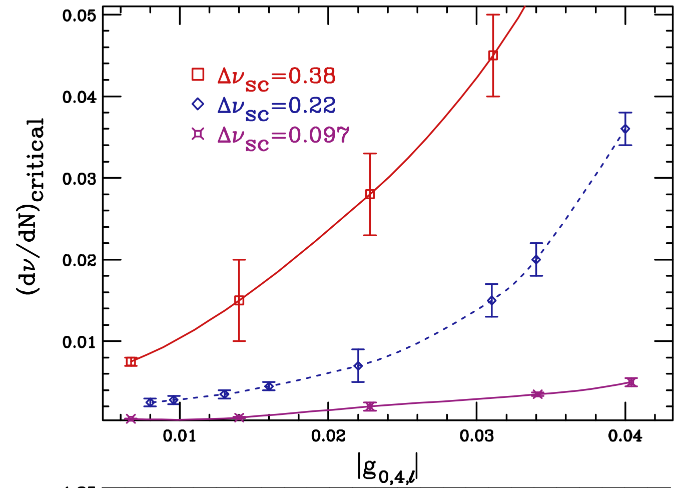
- Most circular accelerations take thousands of turns to accelerate
- Also true for most applications of FFAGs:
  - Medical accelerators
  - Proton drivers
  - "Accelerator driven systems"
- But linear non-scaling FFAGs cross many resonances…

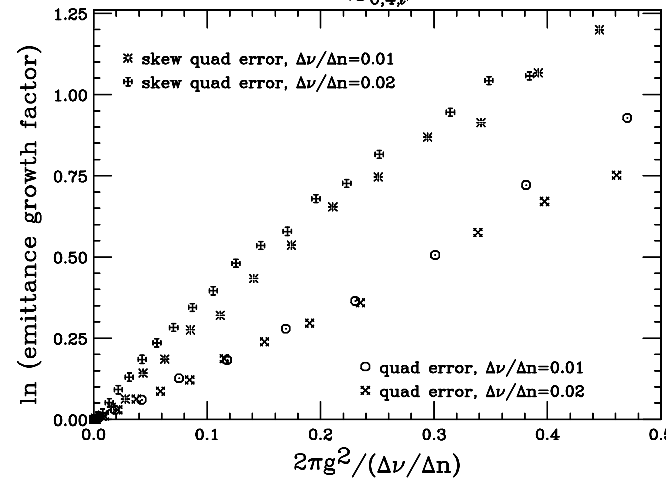
Problems with Slow Acceleration

- Tune changes in FFAG
- Cross resonances:
  - Single-cell nonlinear resonances
  - Linear imperfection resonances
  - Space charge resonances
- Consequences of this
  - Emittance growth and beam loss
  - Dynamic aperture reduction

FFAG Resonance Crossing

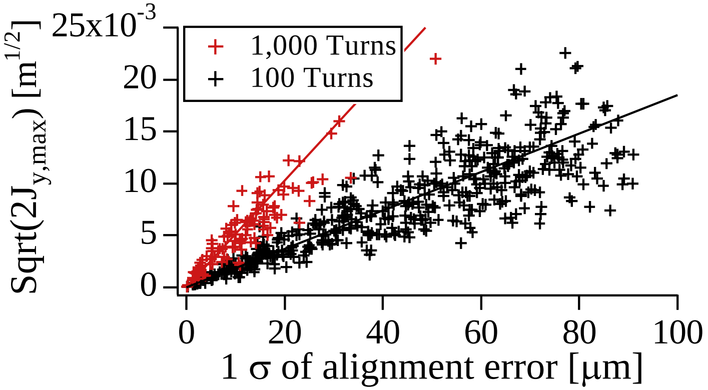
- S.Y. Lee *et al.*, New J. Phys. **8** 291 (2006) and PRL **97** 104801 (2006)
- Relationships between
  - Tolerable acceleration rate and space charge tune shift
  - Acceleration rate, emittance growth, and lattice errors

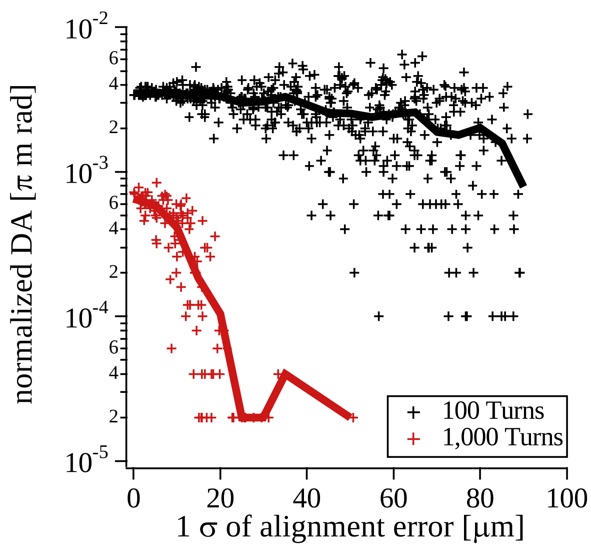




FFAG Resonance Crossing

- Machida, PRST-AB **11** 094003 (2008)
- Emittance growth and dynamic aperture related to alignment errors and acceleration rate
- EMMA used as example
- Dynamic aperture: significant reduction from 100 to 1000 turns





Slow Acceleration in Linear FFAGs

- Many FFAGs use tune stabilization to avoid resonance crossing
- This comes at a cost
  - Larger magnets
  - Nonlinearities reduce dynamic aperture
- Linear non-scaling FFAGs have a minimum tolerable acceleration rate
- Understand what that rate is
- Understand when linear FFAGs are better

Why EMMA?

- We have an existing linear non-scaling FFAG
- Slow acceleration was contemplated from the beginning
  - Probably dropped to keep the cost reasonable (?)
- Only necessary modification to perform slow acceleration is low-frequency RF
- Understanding the limits of linear FFAGs is important for “Many Applications”

Important Parameters

- Acceleration rate: 100 (safe) → 1000 turns
  - 100 kV of acceleration
- 18 MHz (harmonic 1)
- 3% frequency variation (more on next slide)
- Can keep everything else (but see next slide)
  - Add shunts to vary more quadrupole gradients
- Increase current/shrink bunch: space charge
- Extraction line *must* study emittance

Time of Flight Variation

- Could leave lattice as-is:
  - Slow serpentine acceleration (fix RF frequency). Likely requires cavity (could be 1.3 GHz) in injection line to prepare bunch (lengthening)
  - Could track time of flight (0.3% variation in RF frequency): bunch lengthening
- Modify lattice to eliminate ToF minimum
  - Requires 3% variation in RF frequency
  - May be challenging: lattice doesn't like this…

Resonance Crossing Studies

- Can accelerate arbitrarily slowly
- Can inject at arbitrary energy
- Can therefore attempt to cross any resonance
- Can change linear resonance strengths by
  - Changing magnet displacements
  - Varying quadrupole gradients (need shunts)
- Can vary (modest) space charge resonance strength

RF Cavity Challenges

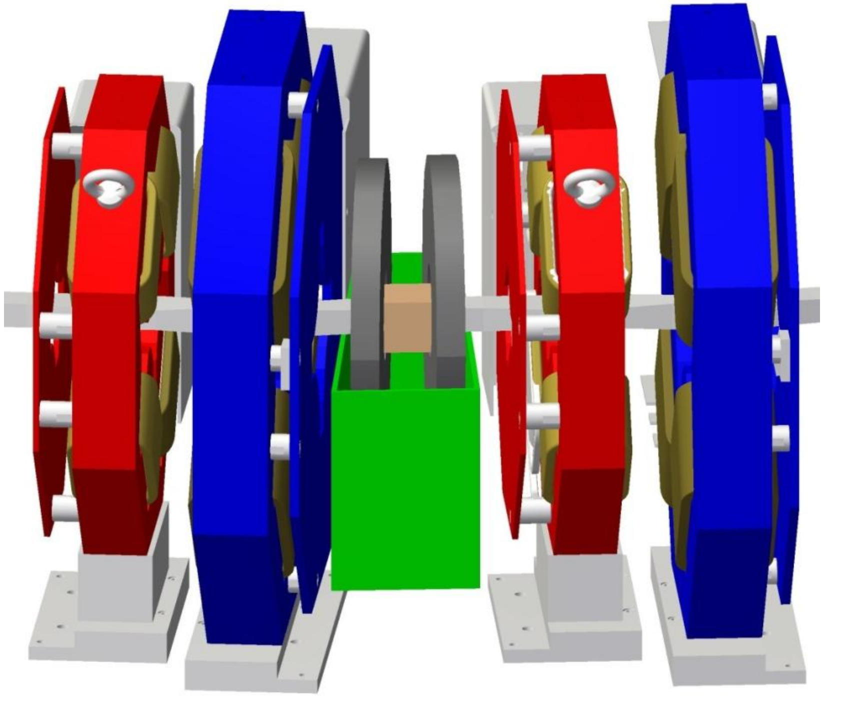
- High voltage for this frequency: 100 kV
- High frequency (18 MHz) for this type of cavity
- Compact size
- At least the frequency variation is easy…

Novel RF Technologies (Ohmori)

- New higher impedance core material (13 μm FT3L): twice ordinary magnetic alloy
  - Permits modest core size (27 cm OD, 10 cm ID)
  - Get high voltage (50 kV per cavity)
- Cut core to reduce inductance
  - Higher frequency
  - Higher Q
- New ceramic (Kyocera, 4 kV/mm) for high voltage

EMMA Low Frequency RF Parameters

Number of Cavities	3	3
Cavity voltage	33 kV	50 kV
Impedance	600 Ω	1000 Ω
Length	10 cm	10 cm
Cores	2	2
Core ID	10 cm	10 cm
Core OD	27 cm	27 cm
Core thickness	2.5 cm	2.5 cm
Q	11	11
Material	FT3M	FT3L
Peak Power	400 kW	



- Existing PRISM power supply sufficient

Advances in RF R&D

- The cavity itself would be an achievement
- No minimum rep rate requirement
  - Air cool cavity: water cooling limits performance
  - Power supply easier
- Not a disaster if we don't achieve voltage
  - Use FT3M instead of FT3L
  - More cavities or hope for best with lower voltage
  - Still a major advance
- Some of this R&D in progress

Summary

- A low-frequency RF system allows us to study slow acceleration, the case for most FFAGs
  - Important to understand limitations on rate
- Opportunity to study slow resonance crossing
- Only a modest modification of EMMA needed
- Simultaneously achieve major advance in RF R&D, with only modest risk
- All credit for RF work to Chihiro Ohmori (KEK)