Muon Acceleration Overview

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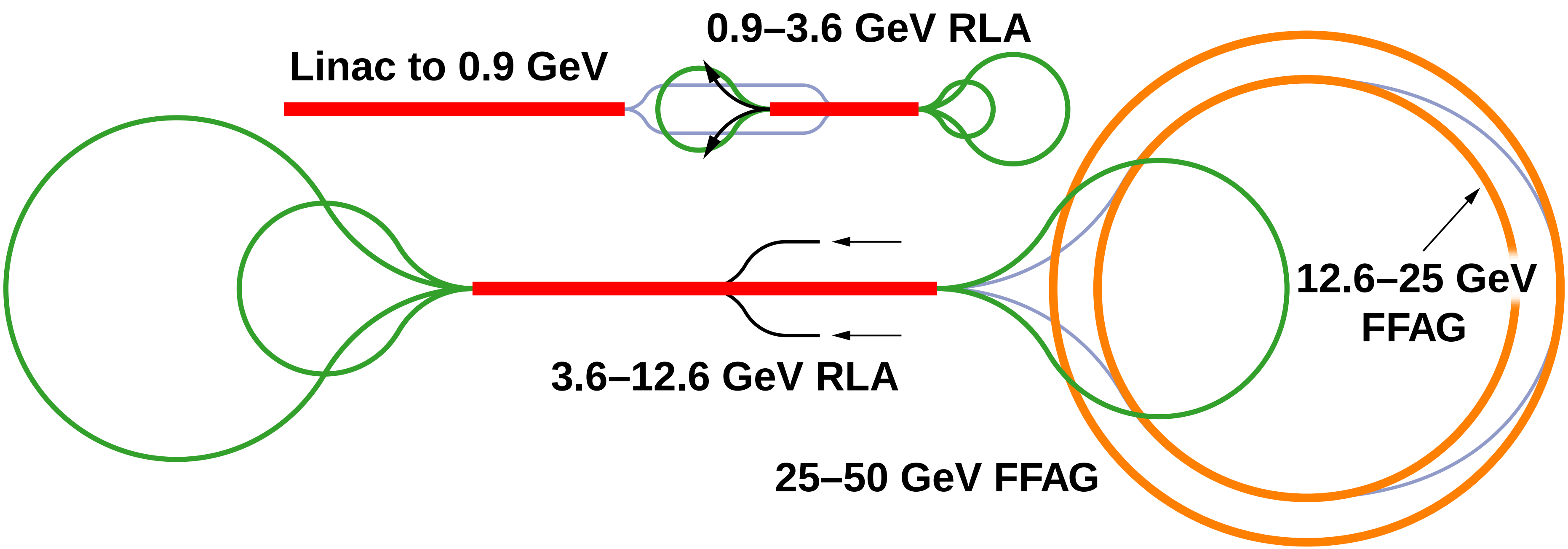
Outline

- The ISS acceleration layout
- Non-scaling FFAGs
  - Effect of errors
- Scaling FFAGs
- Bunch trains
- EMMA
- Muon Colliders

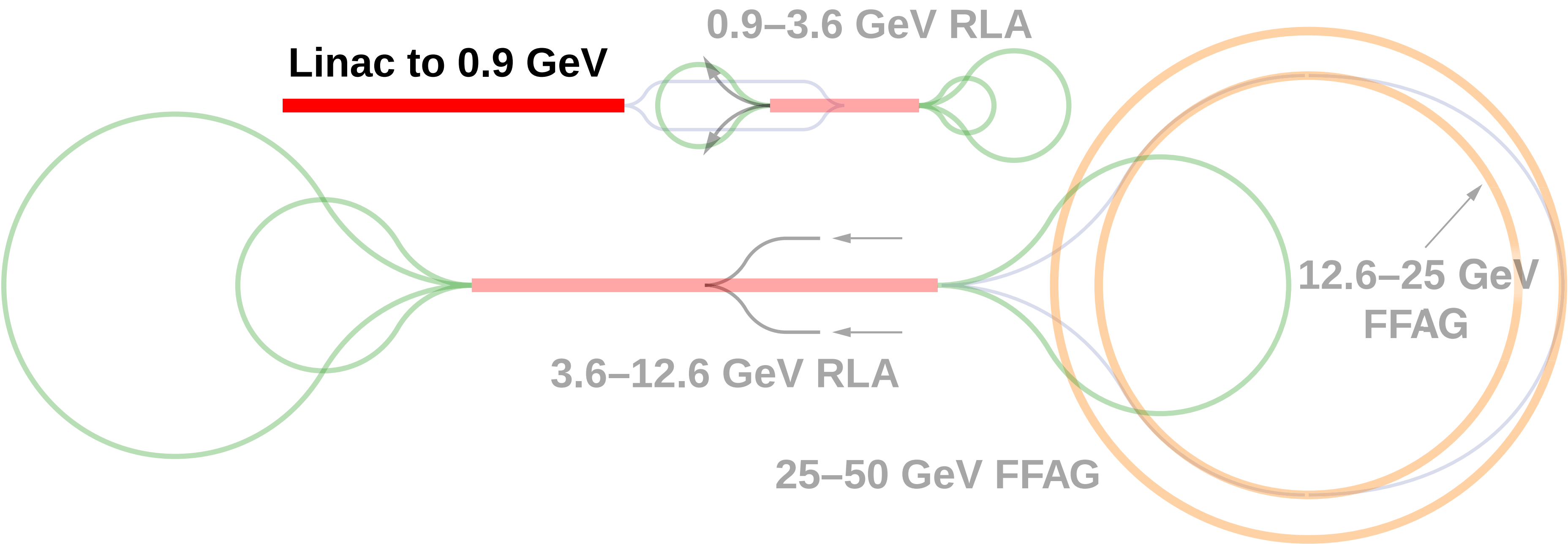
ISS Acceleration Layout

- The usual set of stages
  - Linac
  - RLA(s) (more from Alex Bogacz)
  - FFAG(s)
- Major changes from past
  - 5–10 GeV FFAG has been dropped
    - Reason: concerns about dependence of time of flight on transverse amplitude
  - Other changes flow from that
  - Last FFAG stage optional

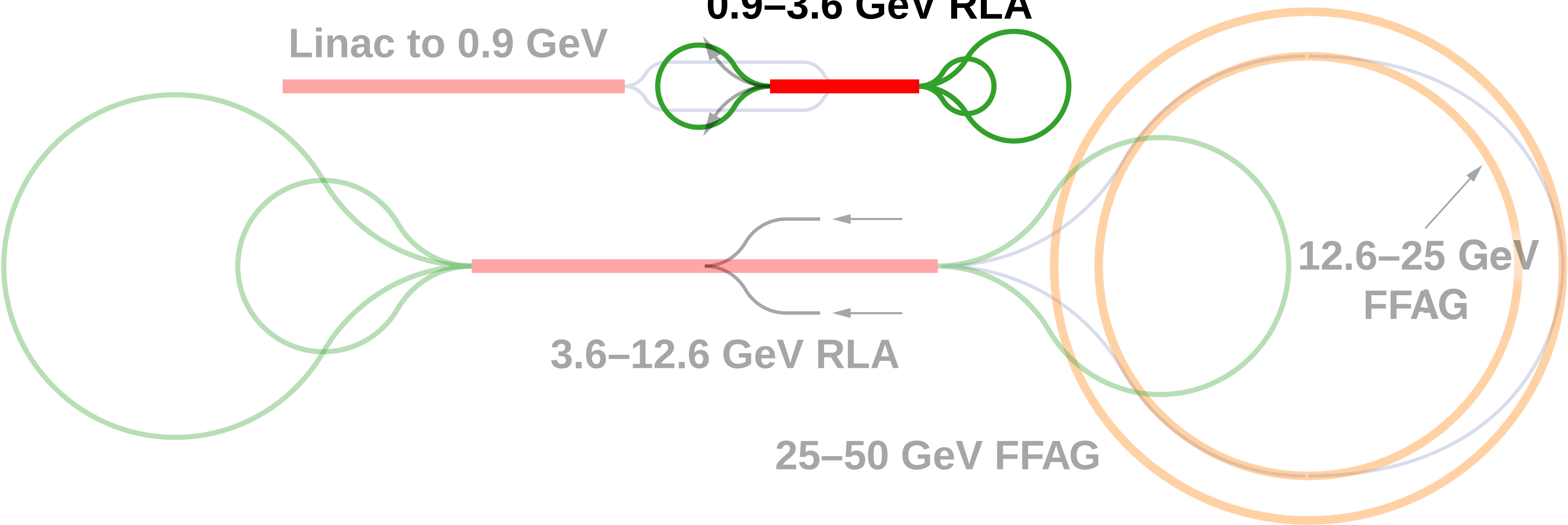
ISS Acceleration Layout



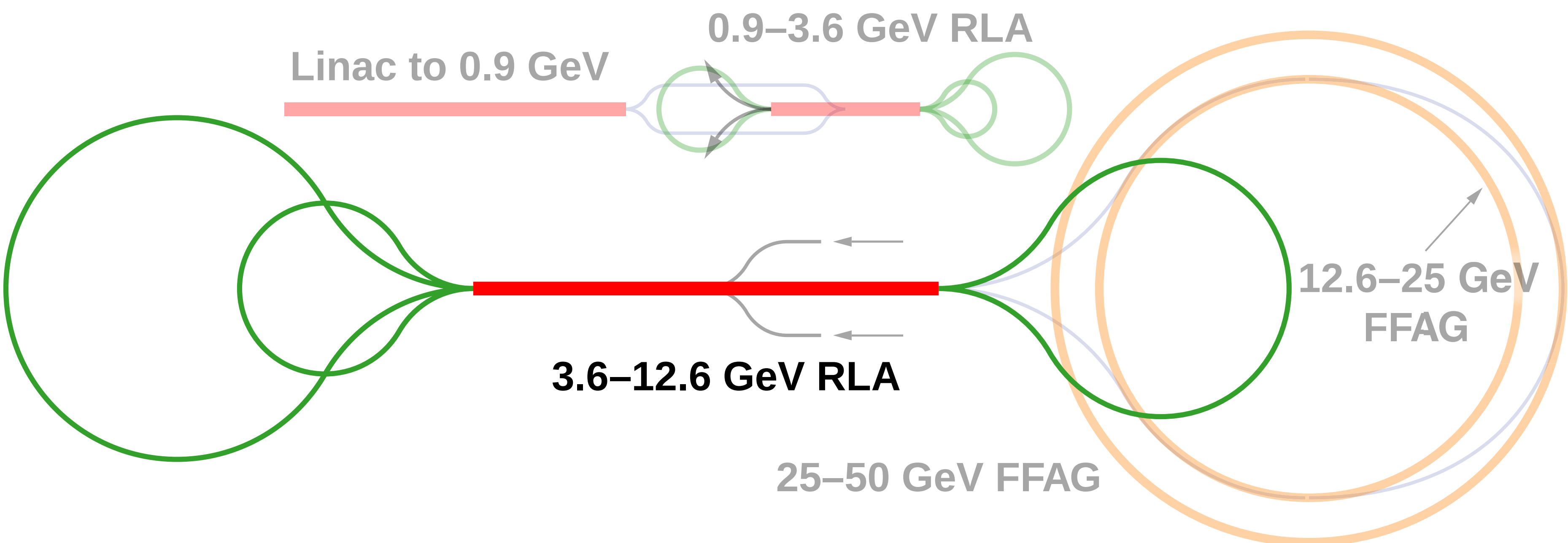
ISS Acceleration Layout
Linac to 0.9 GeV



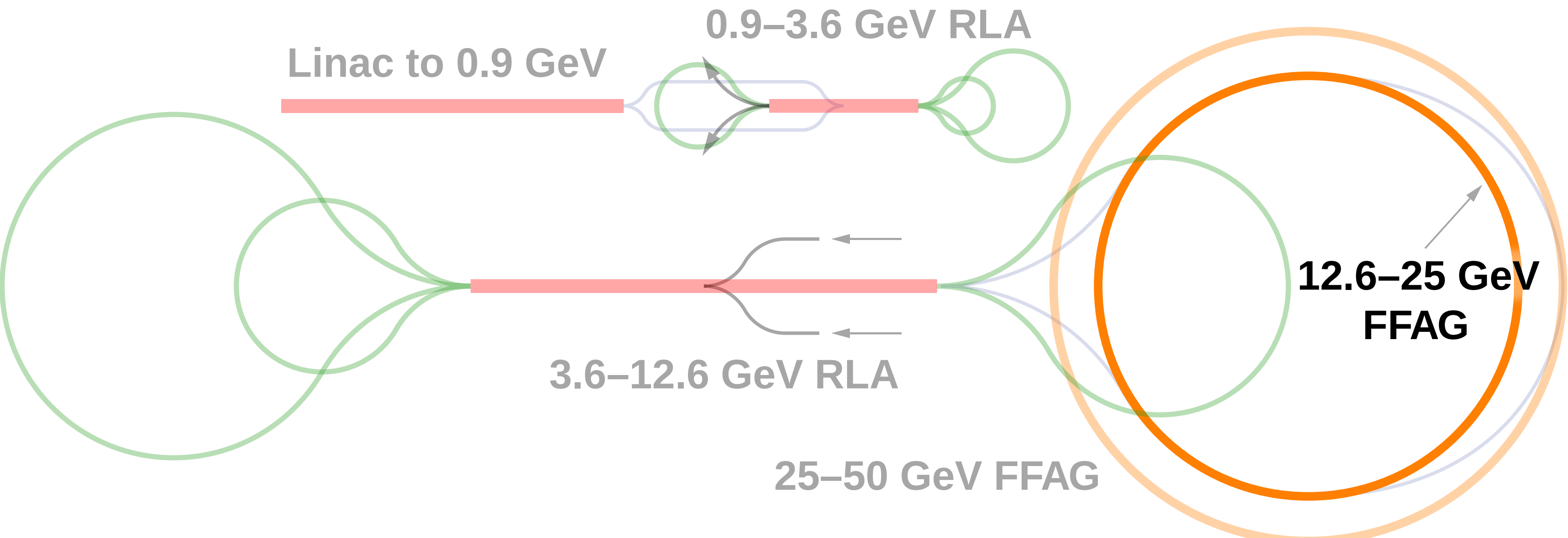
ISS Acceleration Layout
0.9–3.6 GeV RLA



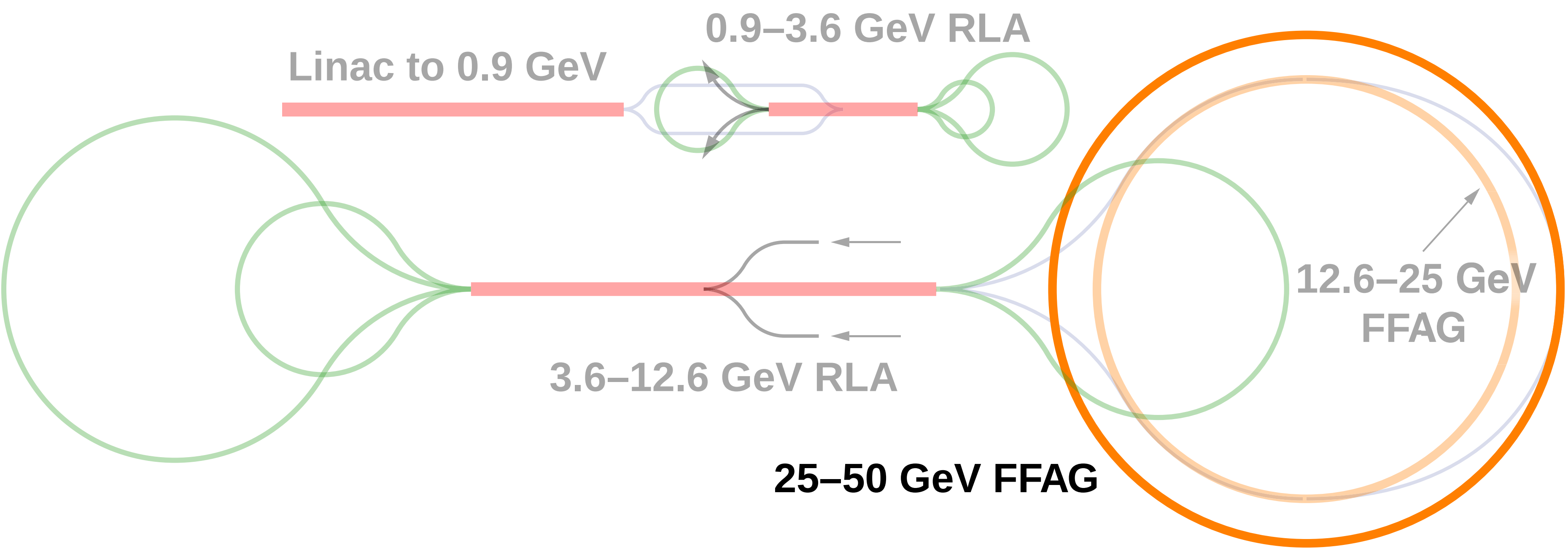
ISS Acceleration Layout
3.6–12.6 GeV RLA



ISS Acceleration Layout
12.6–25 GeV FFAG

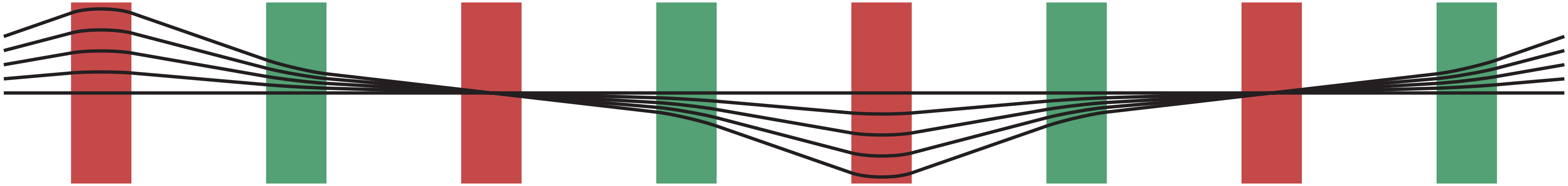


ISS Acceleration Layout
25–50 GeV FFAG



Dependence of Time of Flight on Transverse Amplitude

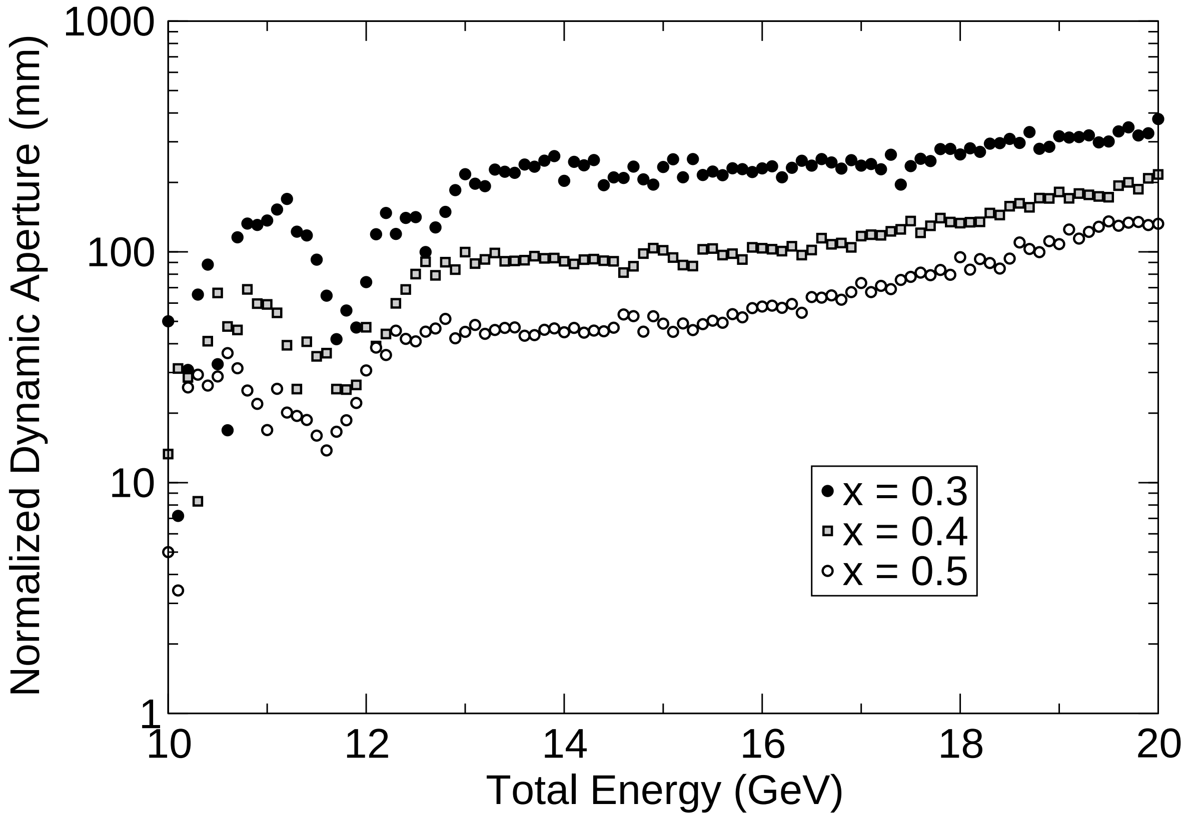
- Particles with large transverse amplitudes: longer time of flight
- Low amplitude particles can be synchronized with the RF while high-amplitude particles aren't



- Addressing the problem
  - Time of flight difference: $-2\pi\Delta\boldsymbol{\nu}\cdot\boldsymbol{J}_n/(\Delta E)$
  - More cooling (expensive, won't say much more)
  - Reduce the tune range during acceleration
  - Increase energy gain per cell
  - Add higher harmonic RF

Reduce Tune Range

- Must add nonlinear magnets to reduce the tune range
- Dynamic aperture will be reduced
- Can potentially reduce the effect by 20–30%, maybe more?



Increase Energy Gain per Cell

- Previous baseline had left many cells empty
  - Making the ring longer reduced its aperture and fields, reducing magnet costs
  - Filling every cell with cavities would be very expensive, and decay cost didn't justify this
- Now we want to increase average gradient as much as practical
  - Fill every cell with single-cell cavities
  - Instead, use two-cell cavities to get even more gradient
    - Requires longer drifts

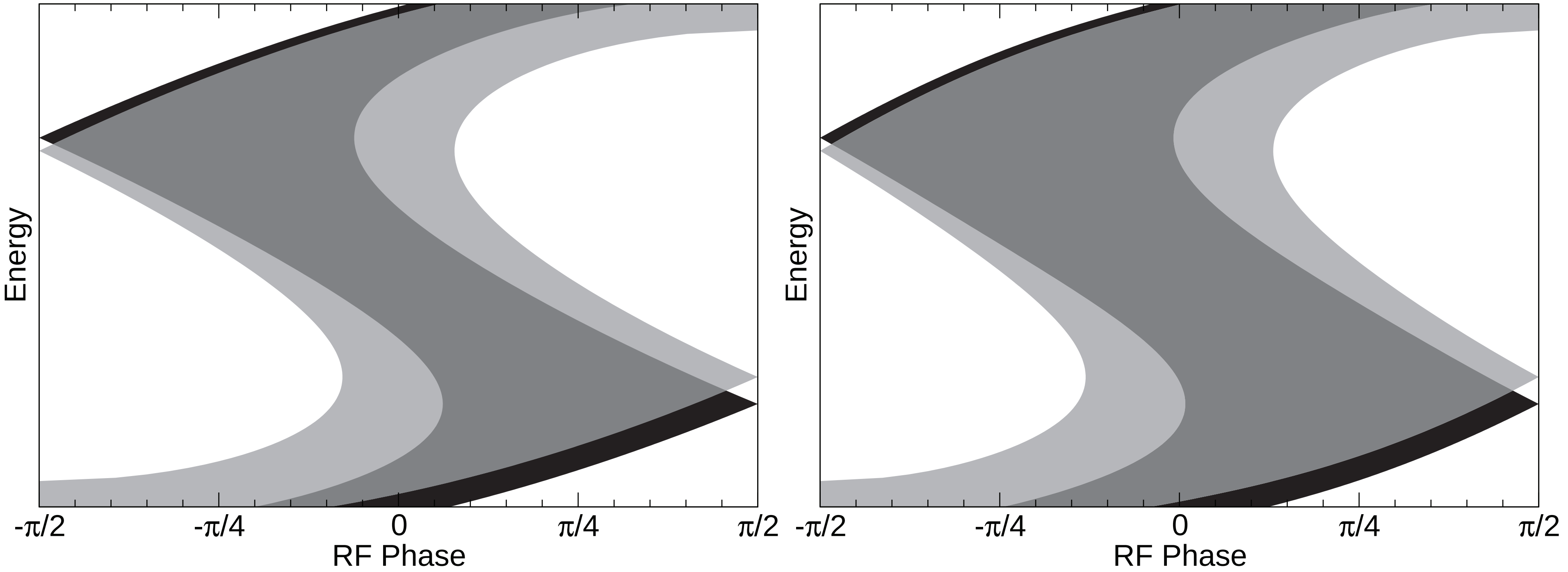
More Energy Gain per Cell
Lattice Parameters

Energy (GeV)	6.25–12.5			12.5–25		
Method	Empty	1/Cell	2/Cell	Empty	1/Cell	2/Cell
Cells	69	61	50	93	78	63
Cavities	48	55	44	58	72	57
Turns	10.8	9.3	5.8	18.2	14.6	9.2
Cost	80.7	82.3	116.8	95.0	98.7	140.2
ΔE/cell (MV)	8.7	11.5	22.4	7.9	11.7	23.0

- Cost reduced to account for fewer decays
- Filling every cell with cavities gives substantial increase in voltage per cell for very little cost
- Two cavities per cell gives even more voltage per cell, but at a substantial increase in cost
- Motivates concern about low-energy FFAG (turns)

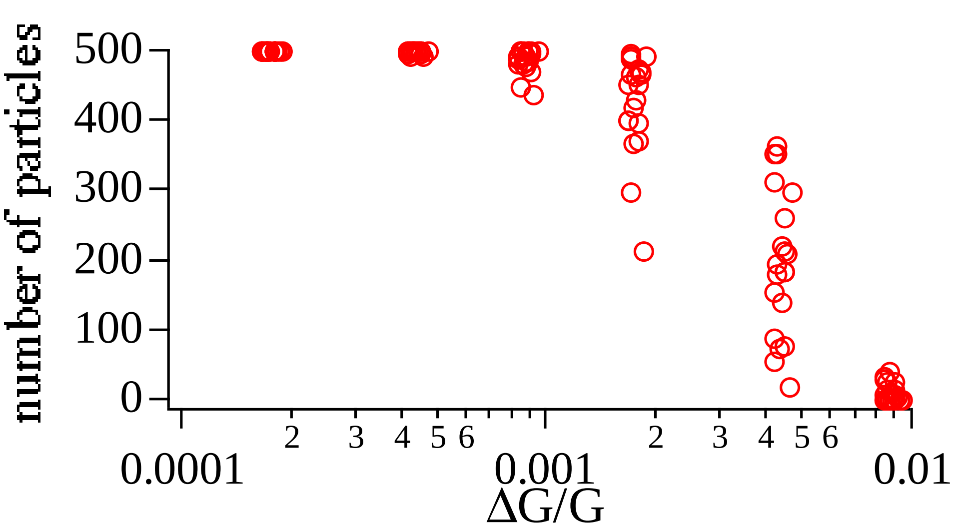
Higher Harmonic RF

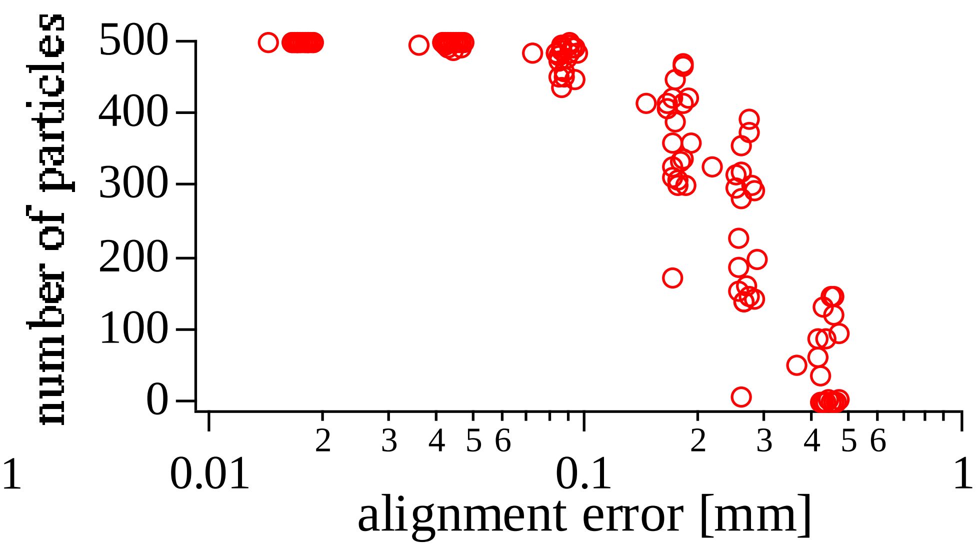
- Doesn't reduce time of flight variation; reduces effects
- Potential problems since higher harmonic cavities have less stored energy
- Reduce average gradient from main cavities



Error Studies

- Error studies performed on sample 10–20 GeV linear nonscaling FFAG (Machida)
- Acceptable error levels
  - Better than 100 μm RMS displacements
  - Better than 10^{-3} fractional gradient error

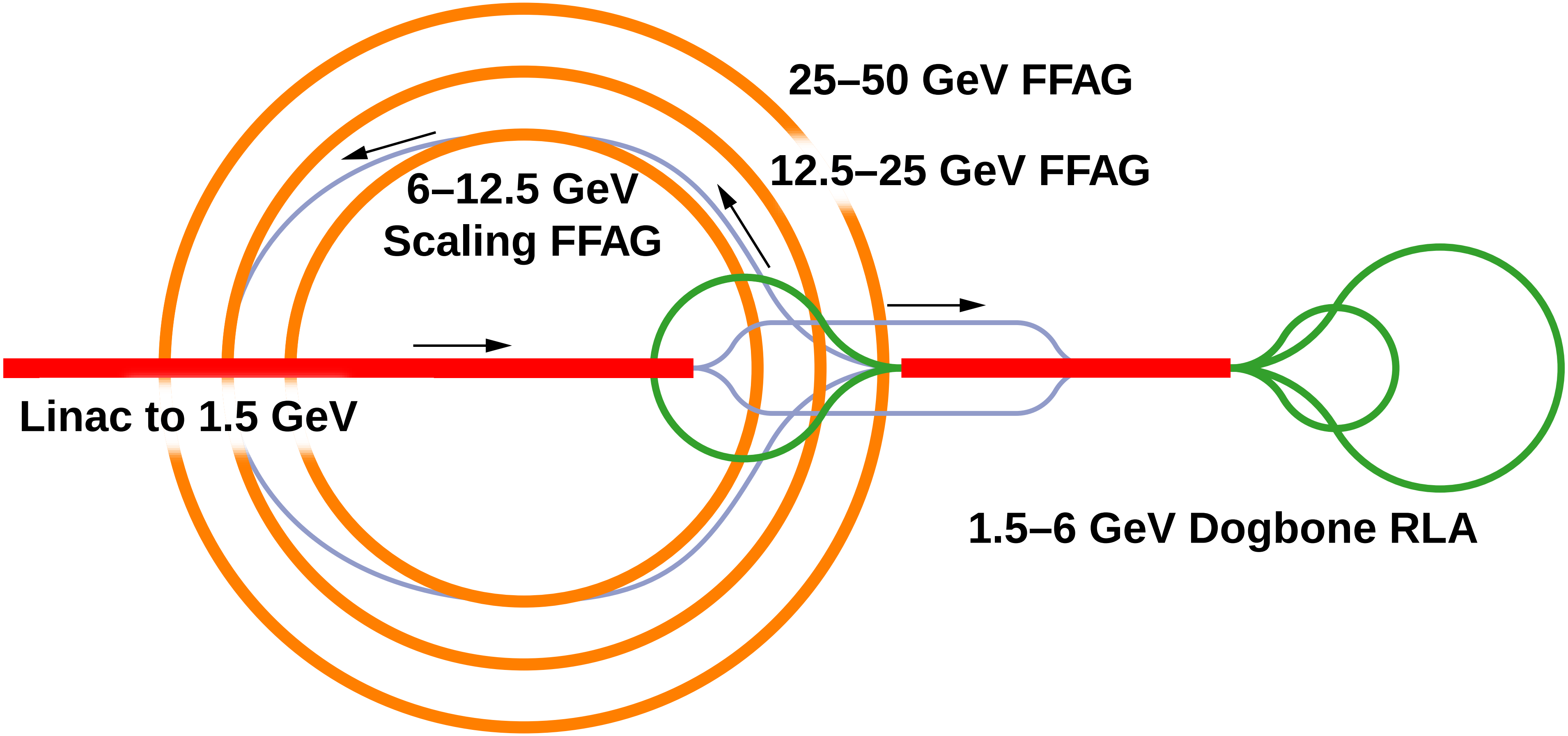




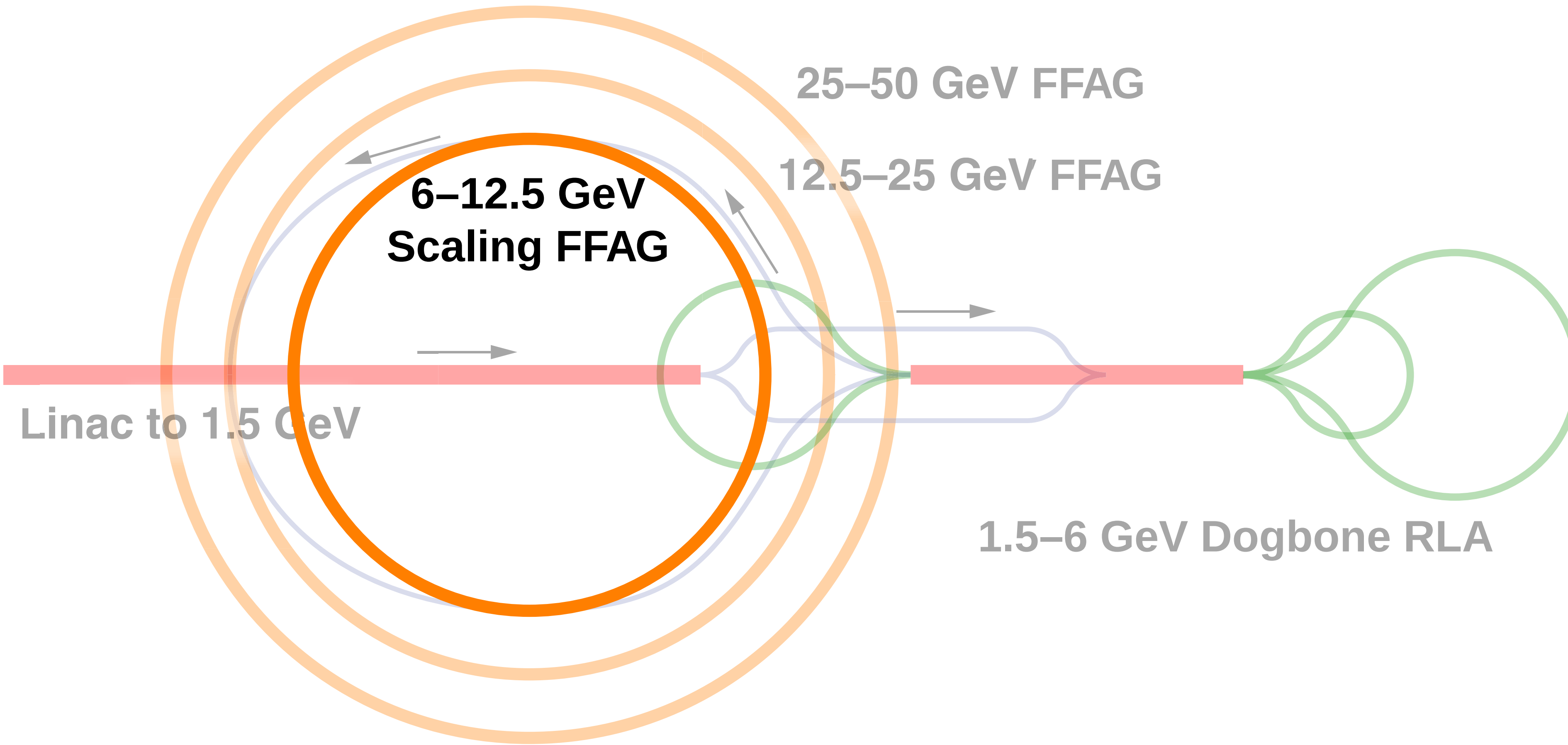
Scaling FFAGs

- Time of flight independent of transverse amplitude
- Doing everything with scaling FFAGs seems expensive
  - Large magnet apertures in superconducting magnets
  - By default, forced to low-frequency RF
    - Large amount of peak power at low frequency
    - Forces everything to low frequency: front end less efficient
- Make low-energy FFAG with scaling FFAG (Mori)
  - Can use room temperature magnets since low energy
  - High-frequency RF using harmonic number jump
    - Need to fill ring with RF, so can't do both signs
- More on Scaling FFAG R&D from Sato

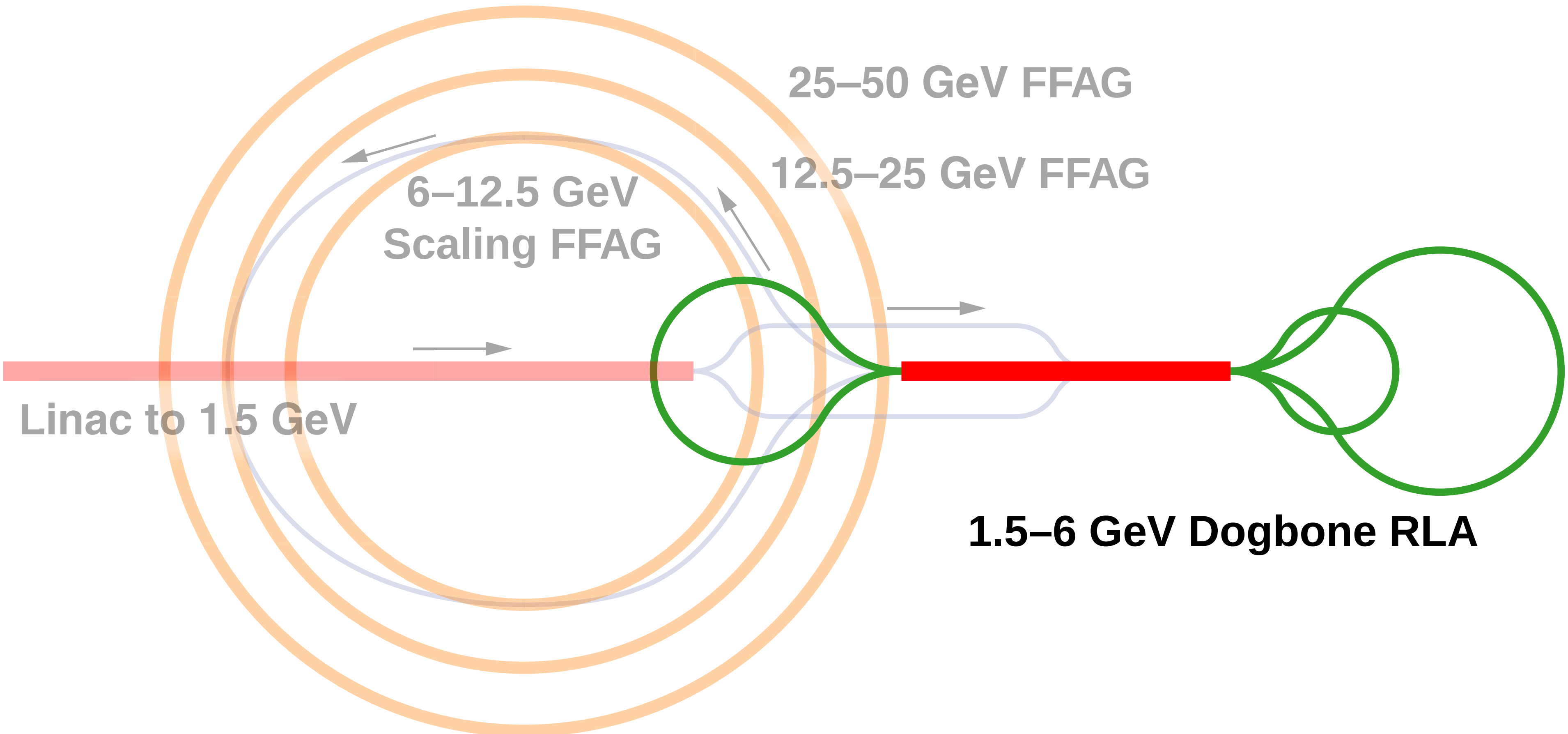
Acceleration with Low-Energy Scaling FFAG



Acceleration with Low-Energy Scaling FFAG
Inserted Scaling FFAG

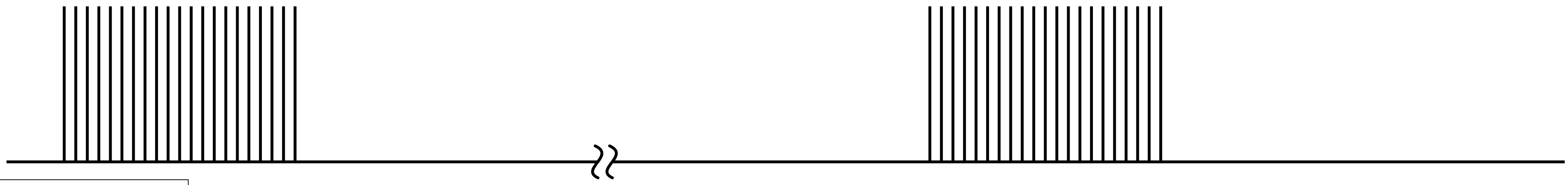


Acceleration with Low-Energy Scaling FFAG Only One RLA



Multiple Bunch Trains

- We expect multiple bunch trains arriving in rapid succession
- Due to breakup of the jet target, the bunch trains arrive over a time of 50 μs
- SC cavities need over 100 μs to replace the energy the bunch train extracts
- Will need to use off-frequency cavities so different trains gain same energy
  - Reference particle may see same voltages, other particles won't
  - Need to develop a scheme



EMMA

- Non-scaling FFAGs are a critical component for reducing the cost of acceleration
- No non-scaling FFAG has ever been built
- We want to test that a non-scaling FFAG behaves as we expect it to
- A small linear non-scaling FFAG is being built in the UK to do this
- More from Rob Edgecock

Muon Colliders

- I'm not going to say much!
- Neutrino factory acceleration as front end to muon collider acceleration
  - Larger longitudinal emittance for muon collider
  - Much smaller transverse emittance
    - No problem with dependence of time of flight on transverse amplitude
- Still face many neutrino factory problems at higher energy
  - Limited stored energy in cavities for multiple passes
  - Need large longitudinal acceptance
  - Will all get better at higher energy

Concluding Remarks

- The neutrino factory acceleration design has evolved slightly
- Dependence of time of flight on transverse amplitude in non-scaling FFAGs has led to this
- We are studying methods to reduce this effect
- We have some preliminary error studies
- A scaling FFAG at low energies may replace a non-scaling FFAG there, but there are concerns
- Bunch trains arriving in rapid succession require RF manipulations that need to be studied
- A model of a linear non-scaling FFAG will be built
- Muon collider acceleration needs more detailed study