FFAG Acceleration Stuff

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Types of Systems Studied

- Isochronous FFAGs
- Linear non-scaling FFAGs
- Scaling FFAGs
- Recirculating accelerators

FFAGs
Fixed Field Alternating Gradient Accelerators

- RF is expensive, so want to maximize number of passes
- FFAGs allow many passes through RF
- RF synchronization limits number of turns
  - Time of flight depends on energy
  - RF phase can't be varied fast enough to match this

Isochronous FFAGs

- Francois Méot will talk about tracking results from isochronous FFAGs
- Strong nonlinearities lead to
  - Dynamic aperture problems
  - High degree of sensitivity to parameters
- Designs thus far studied are problematic
- Improved designs on the way
- Nonscaling lattices with large nonlinearities have never had nearly a sufficient dynamic aperture
- I would like to take these out of consideration for the baseline: not ready for prime time

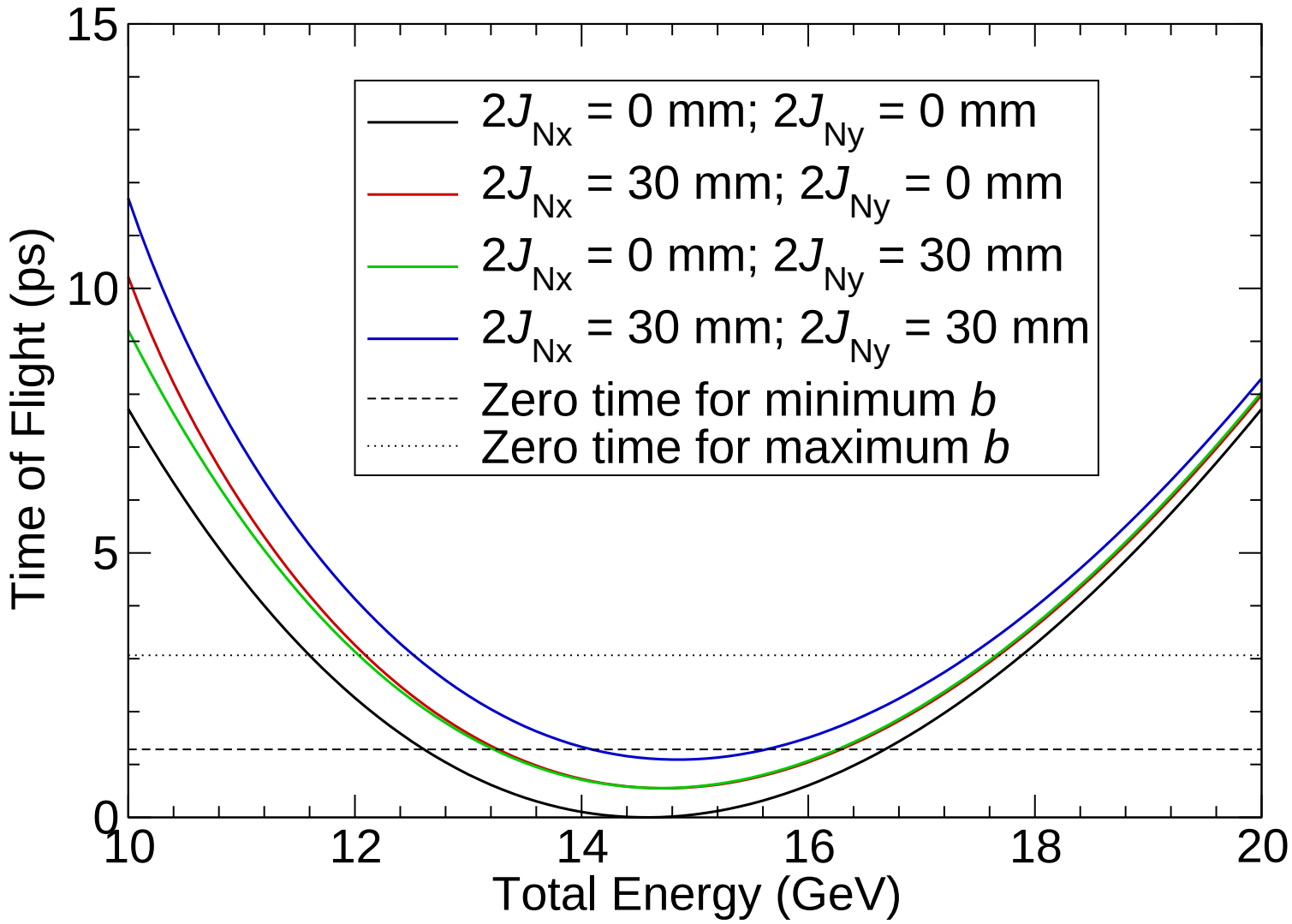
Linear non-scaling FFAGs

- These have looked like a very cost-effective option for higher energy acceleration
- Problem with time of flight depending on transverse amplitude

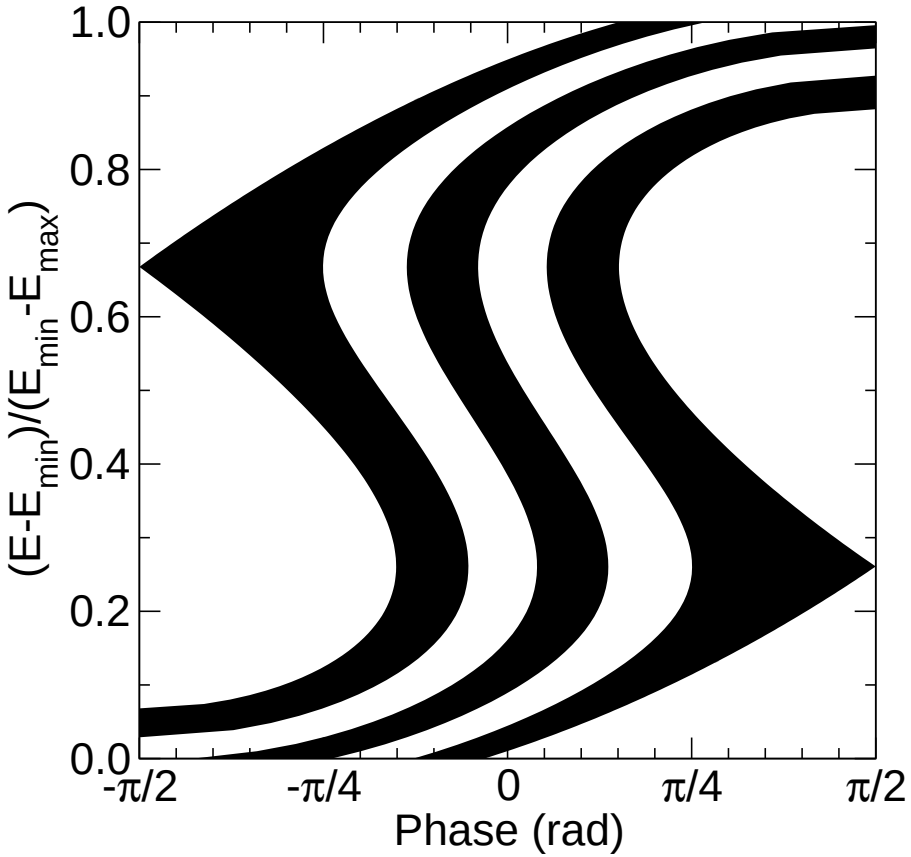
$$T = T_0(E) - 2\pi mc \frac{d\nu}{dE} J_n$$

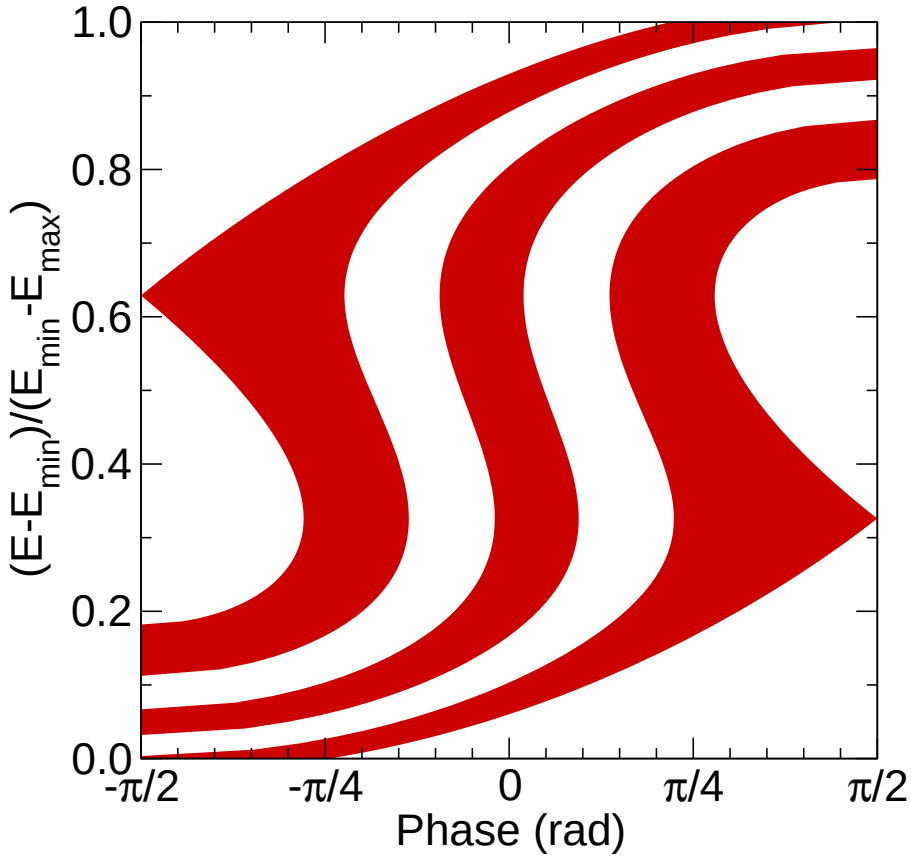
- High amplitude particles take longer than low amplitude
- Need to insure that RF is synchronized to rf for both low and high amplitude
  - Limits range of allowed RF frequencies (b)
  - Must increase voltage (a) to be able to accelerate all amplitudes to full energy
- Passing to next stage a problem: larger time spread, high ampliutde start late

Time of Flight vs. Amplitude

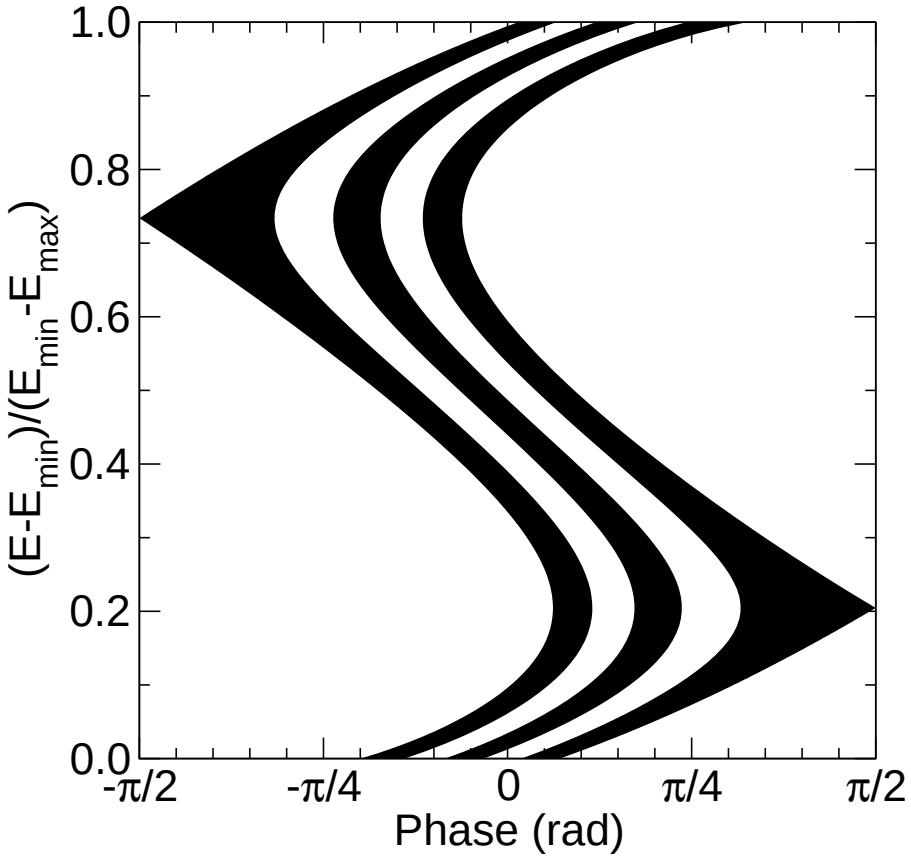


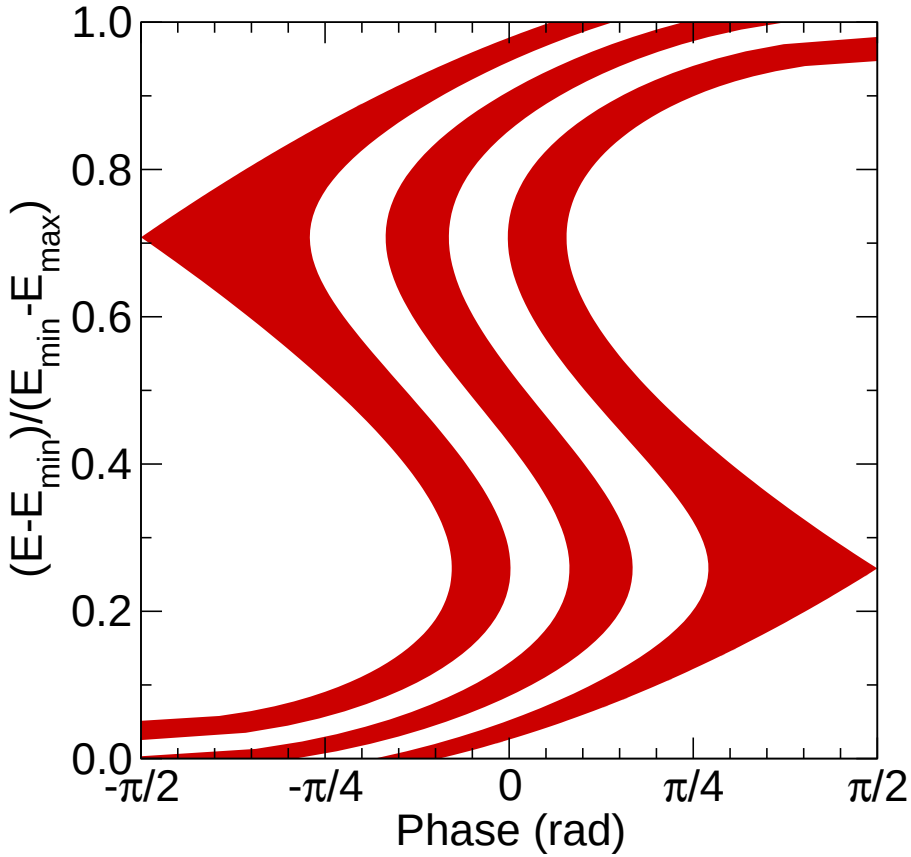
Longitudinal Phase Space
Baseline



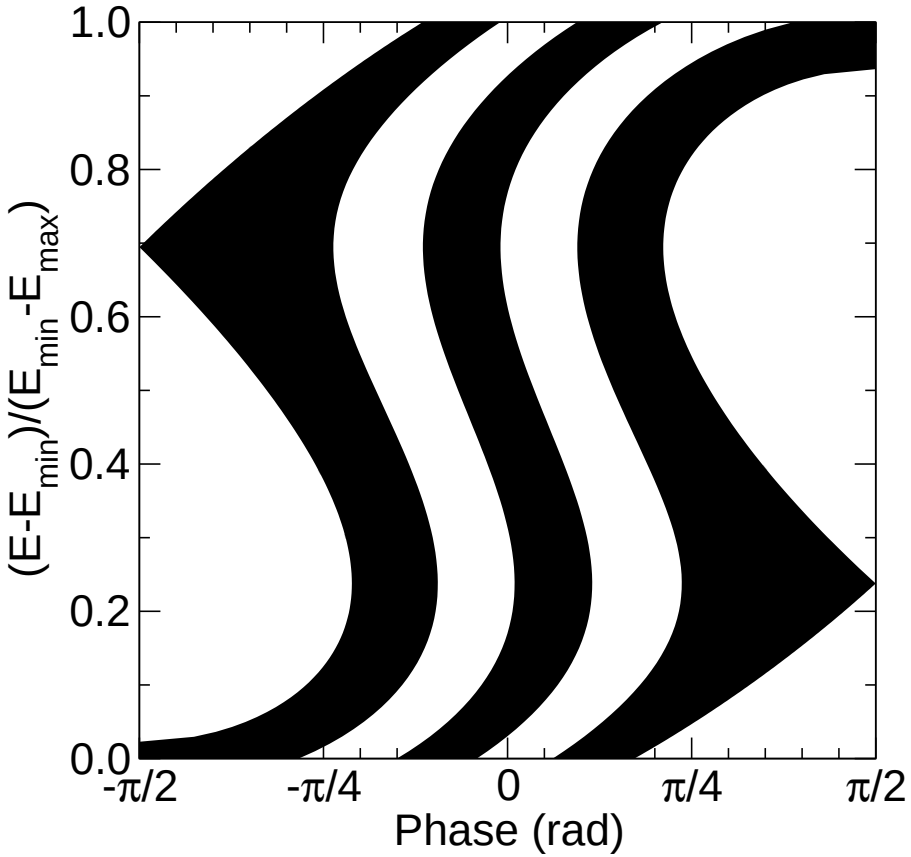


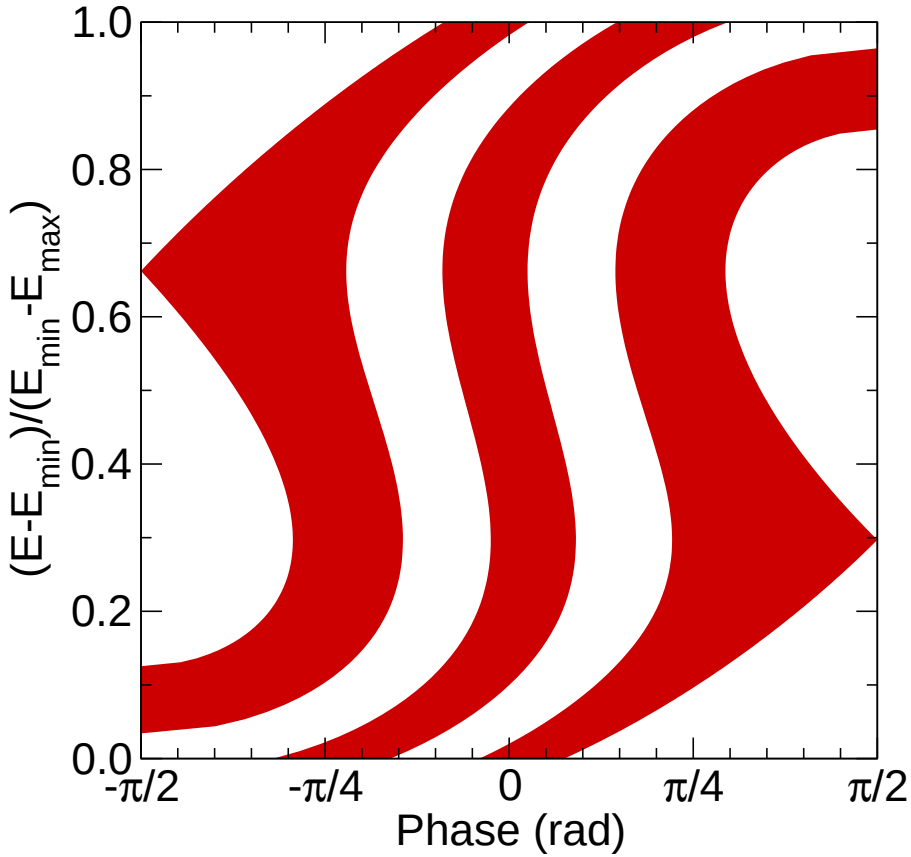
Longitudinal Phase Space
Increased b





Longitudinal Phase Space
Increased Voltage

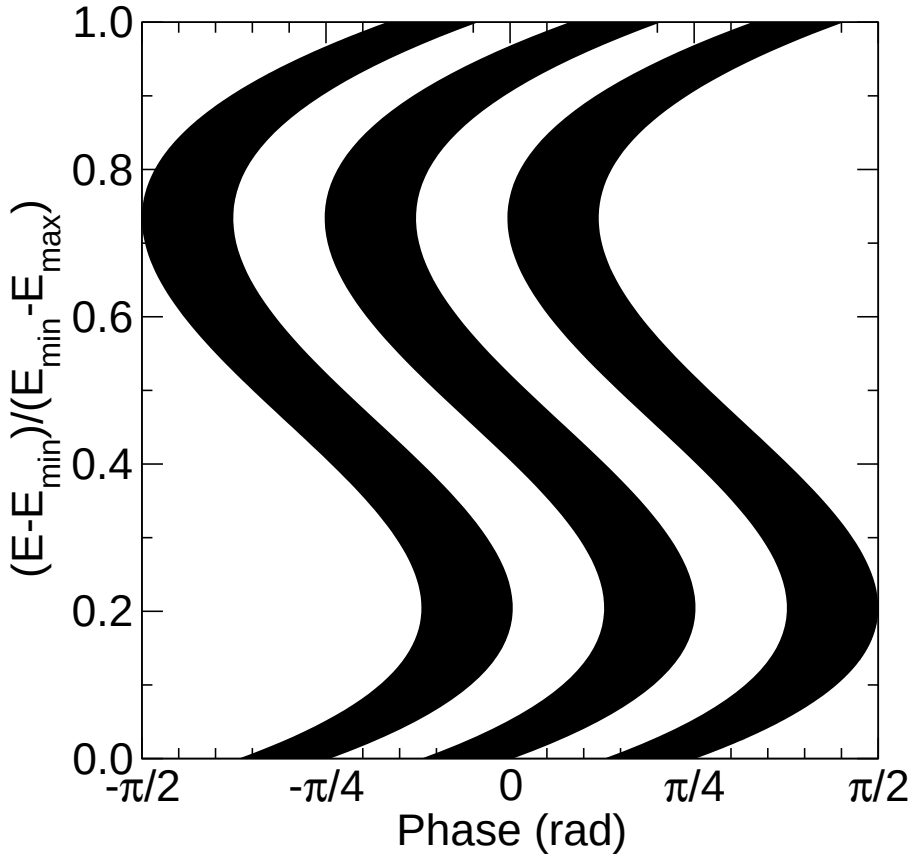


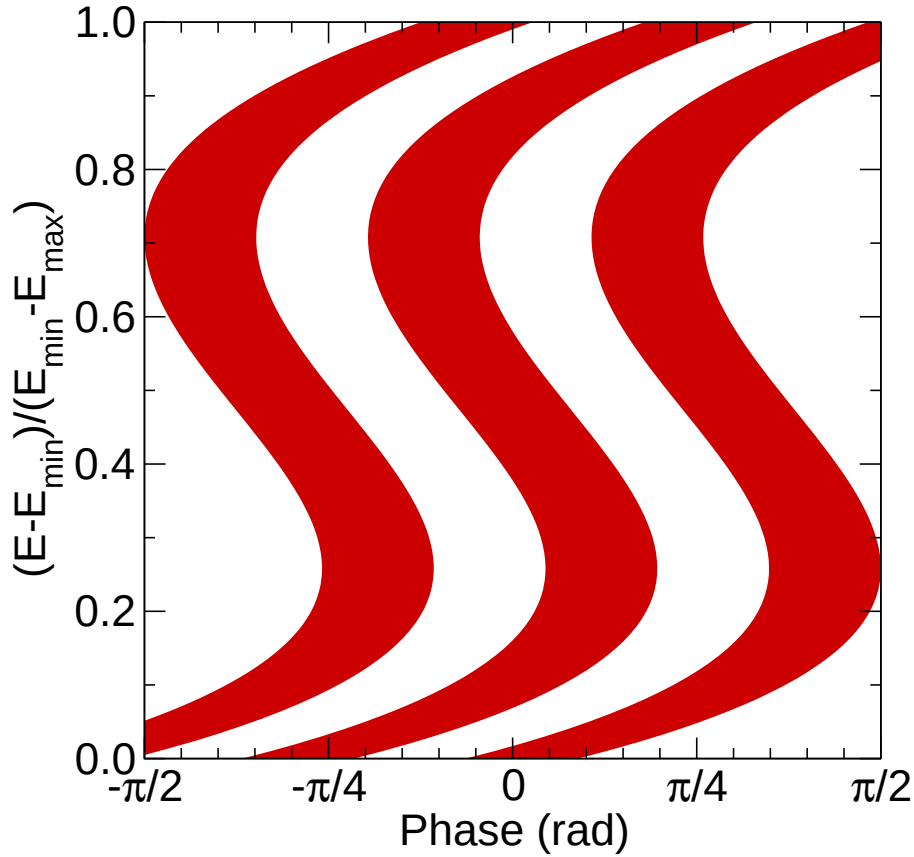


Linear non-scaling FFAGs
Addressing Problems

- Reducing time of flight range alone will ***not*** improve this effect
  - Phase space improves for low amplitude
  - High amplitude gets worse: more cells per turn
- Introduce small nonlinearities to correct chromaticity
- Time slip simply proportional to number of cells we go through
  - Fill maximum number of cells with RF
  - Make fewer turns: more voltage
- Introduce higher harmonic RF
  - Reduces energy spread correlated to different times of flight
  - Increases time of flight range that is accelerated
- Only promise ellipsiodal distribution transmitted: large longitudinal amplitude, low transverse amplitude

Longitudinal Phase Space
Square Wave RF





Scaling FFAGs

- Scaling FFAGs have tune independent of energy
  - No amplitude dependence of time of flight
- Generally larger time of flight range than non-scaling FFAGs
  - Forces low-frequency RF systems
  - More comments in a moment
- Baseline NuFactJ scheme seems very expensive
  - Demonstrated optimizations on high energy machine have made significant improvements
  - Need to get reasonably cost-optimized trackable lattices for all rings
  - Need to understand costing of low-frequency RF

Scaling FFAGs
High Frequency RF

- Find field index $k = 1220$ for 201.25 MHz and 10–20 GeV scaling FFAG, 1.5 MV/m average gradient

$$\frac{1}{k+1} = \frac{1}{\gamma_0^2} + \frac{16(1-\lambda)V\beta_0^3 E_0 c}{\omega(\Delta E)^2}\frac{2\pi R}{L_0}$$

  - This is not so much larger than existing designs
- This requires many cells (about 180):

$$n \approx 2\pi\sqrt{\frac{k}{\cos\mu_y - \cos\mu_x}} > 2\pi\sqrt{\frac{k}{2}}$$

  - Gradient must be maintained over cells, so very few turns (2.3 GV RF for 10–20 GeV)
- Basically forced to low frequency

Recirculating Accelerators

- Use long linacs connected by one arc for each energy
- Can only use a small number of passes
- Avoids time of flight problems
- Considering problems with FFAGs, we need to keep RLA in consideration

My Opinions

- Baseline should be 5–10 and 10–20 GeV FFAGs
  - Isochronous FFAGs don't have the dynamic aperture
  - Scaling FFAGs are more expensive with poorer performance
  - Have methods for addressing time of flight problem
    - ⋆ Higher harmonic
    - ⋆ More RF voltage
    - ⋆ Mild chromaticity correction