FFAG Designs for the International Design Study for the Neutrino Factory

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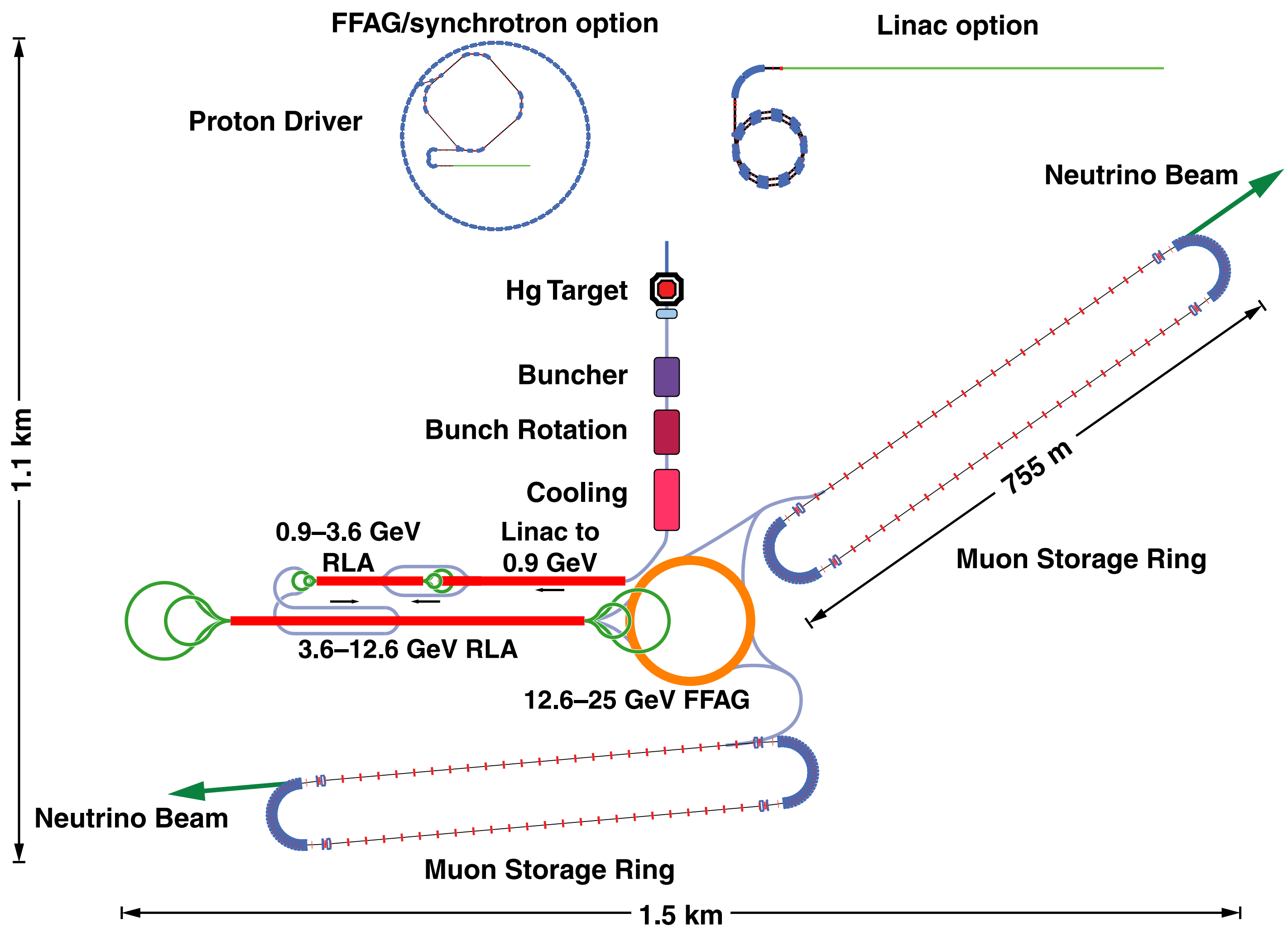
IDS-NF Overview

- Produce muons
- Reduce beam to manageable size
- Accelerate to 25 GeV
- Store and allow to decay toward far detector
- 50 Hz
- 10^{21} decays per year toward detectors
- See poster WE6RFP067, Wed. afternoon

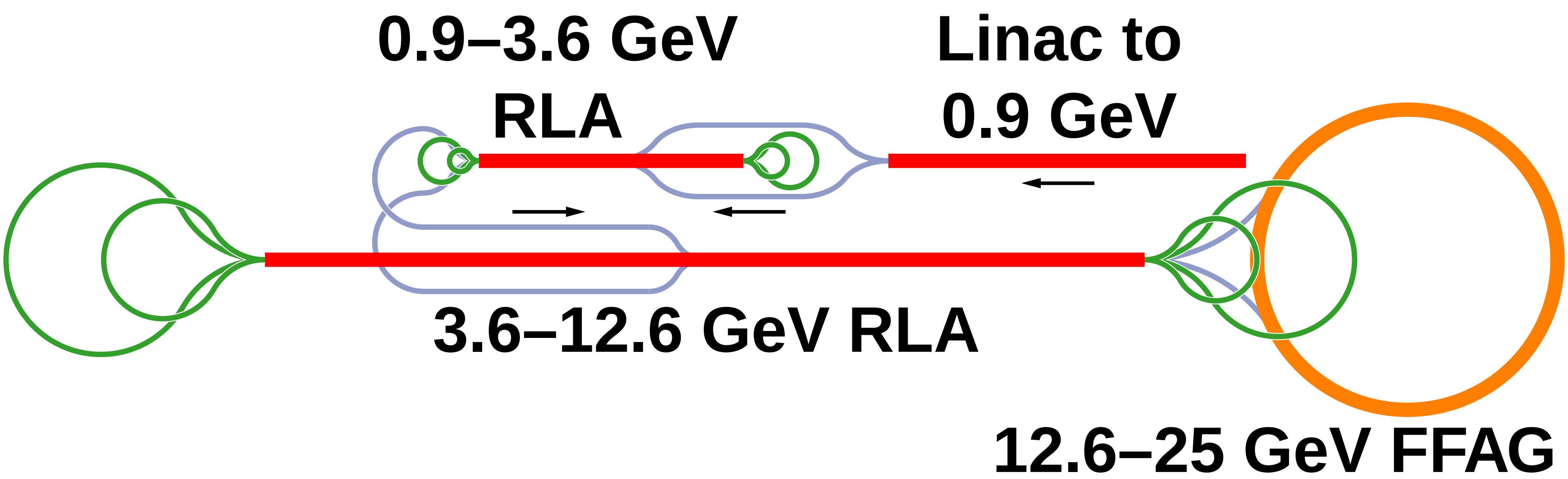
IDS-NF Accelerator Complex



IDS-NF Acceleration Scenario

- Reduce cost, maximize passes through RF
- Recirculating linear accelerator
  - Arcs steer beam back to linac
  - Different energy for each arc
  - Switchyard limits number of passes
- FFAG: single arc for all passes
  - No switchyard, more turns
  - Most efficient at high energy

IDS-NF Acceleration Scenario



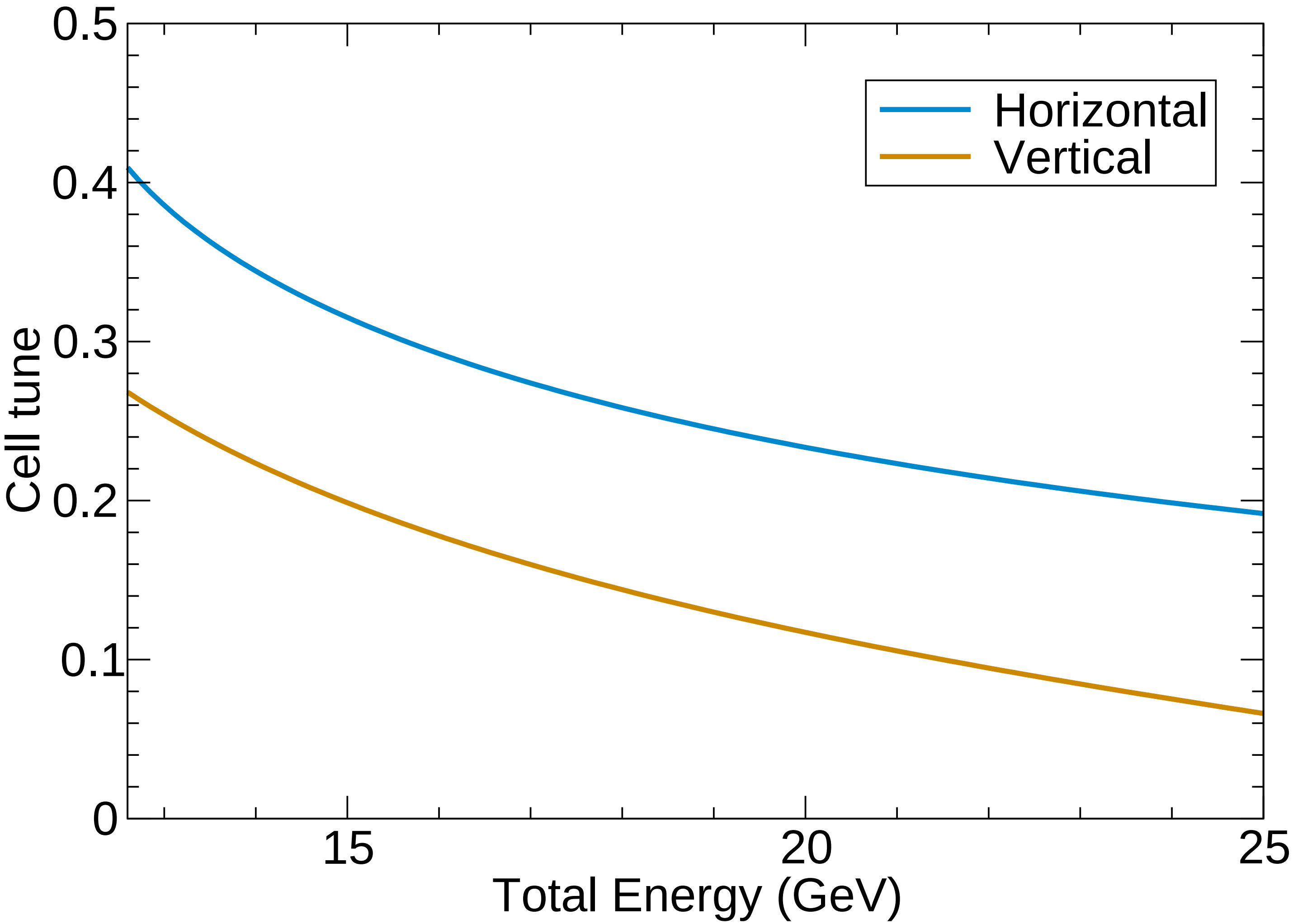
FFAG Introduction

- **F**ixed **F**ield **A**lternating **G**radient accelerator
- Large energy range (factor of 2 or more) with single arc
- **F**ixed **F**ield: don’t ramp magnets
- **A**lternating **G**radient: reduced aperture (compared to cyclotron)

FFAG Introduction Scaling and Non-Scaling

- Original FFAG: scaling
  - Tunes fixed, dynamics independent of energy
  - Nonlinear magnets, but good dynamic aperture
- Linear non-scaling FFAG (chosen for IDS-NF)
  - Apertures smaller than scaling
  - Less time variation with energy than scaling
  - Tunes vary with energy
  - Linear magnets give large dynamic aperture

Tune of Variation with Energy



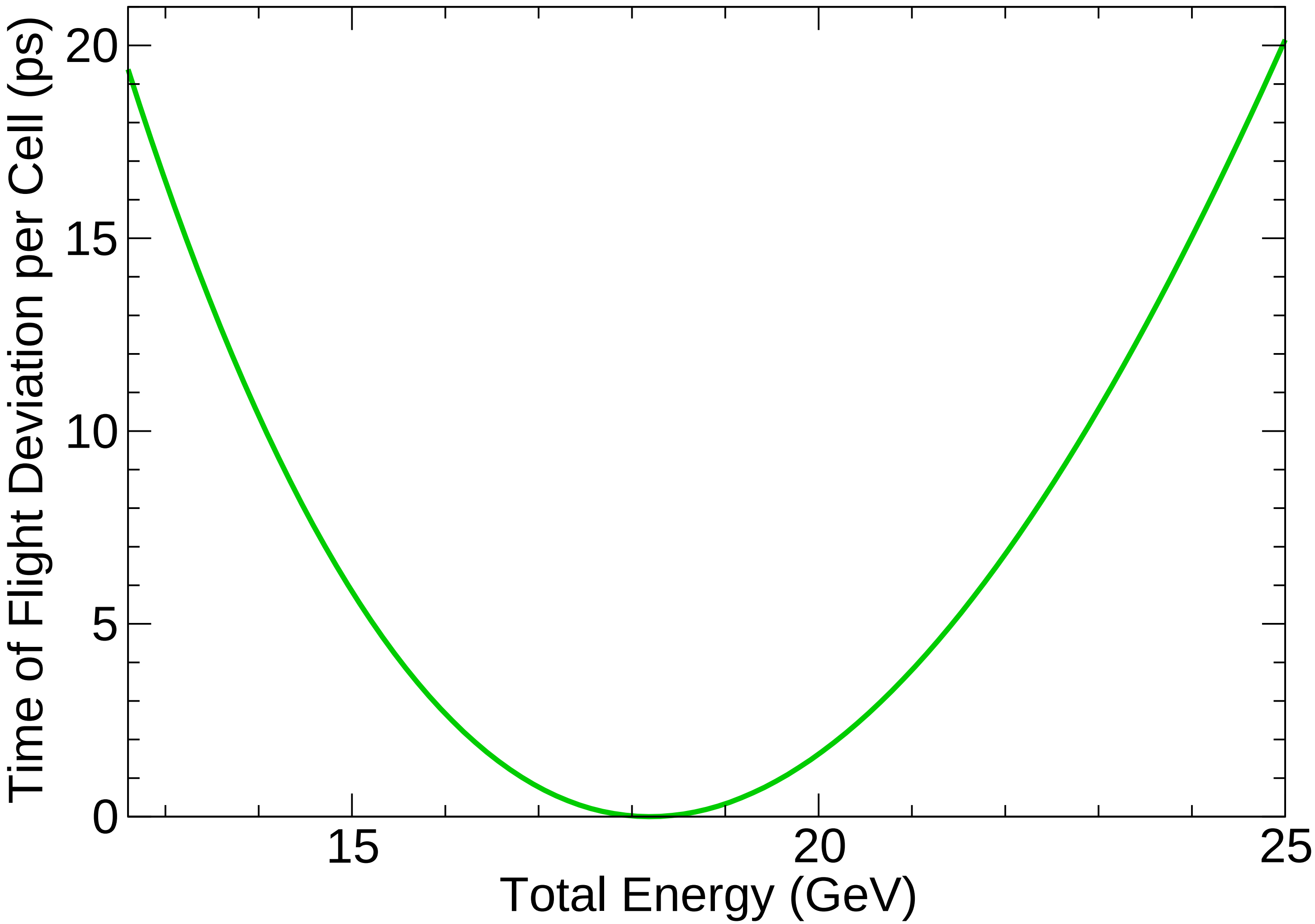
IDS-NF FFAG Requirements

- Accelerate from 12.6 to 25 GeV
- 30 mm normalized transverse emittance (full)
- 150 mm normalized longitudinal emittance (full)
- 201.25 MHz superconducting RF
  - Frequency can’t be varied
- Rapid acceleration

FFAG Design

- Simple, repetitive lattice (FODO, doublet, triplet)
  - High periodicity: less systematic resonances
- Time of flight depends on energy
  - Limits number of turns: RF synchronization
  - Less time variation, more turns
- Reducing time variation: reduce dispersion
  - Isochronous within energy range
  - Short drifts, combined function magnets

Time of Flight Variation with Energy



Time of Flight and Transverse Amplitude

- Time of flight depends on transverse amplitude
  - Longitudinal motion depends on transverse amplitude
  - Effective longitudinal emittance blowup
- Exists due to chromaticity
  - Hamiltonian term $(\xi \cdot J)\delta$
  - Large transverse emittance
- Reduced by increasing average RF gradient
  - Fill all available drifts with RF

Time of Flight Variation with Transverse Amplitude

IDS-NF FFAG Optimization

- Insert cavities in every drift
  - Time vs. transverse amplitude
  - One or two RF cells per lattice cell
    - Two: more cost, less time vs. amplitude
- Optimize ring circumference
  - Longer ring increases RF cost
  - Shorter ring increases magnet cost
    - Larger aperture, higher fields

IDS-NF FFAG Parameters

Configuration	FDC	FDFC	FCDC	FDCC	FDFCC
Cells	77	70	62	62	55
D radius (mm)	77	92	95	102	125
D field (T)	8.1	7.7	7.6	8.3	7.3
F radius (mm)	140	122	207	203	167
F field (T)	4.0	4.2	3.4	3.1	3.9
RF (MV)	903	814	1526	1424	1246
turns	14.6	16.2	8.7	9.3	10.6
Length (m)	426	422	462	467	445
Cost (A.U.)	134	144	176	175	181

Chromaticity Correction

- Reduce chromaticity
  - Reduce time of flight dependence on transverse amplitude
  - Reduce longitudinal distortion
- Nonlinearity hurts dynamic aperture
- Increases magnet apertures and thus cost

Chromaticity Correction

- Add sextupole component to magnets
- Chromaticity can be almost fully corrected
  - Poor dynamic aperture
  - Partial correction: better dynamic aperture
- Allows insertions with long drifts
  - Eases injection/extraction

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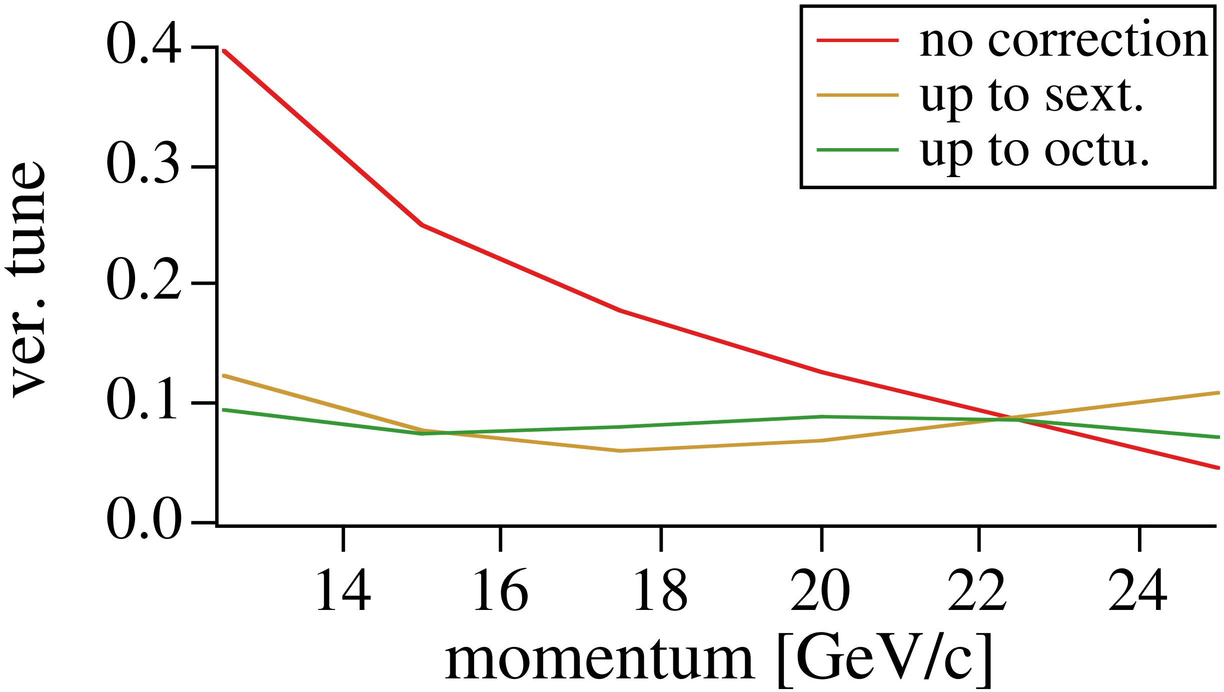
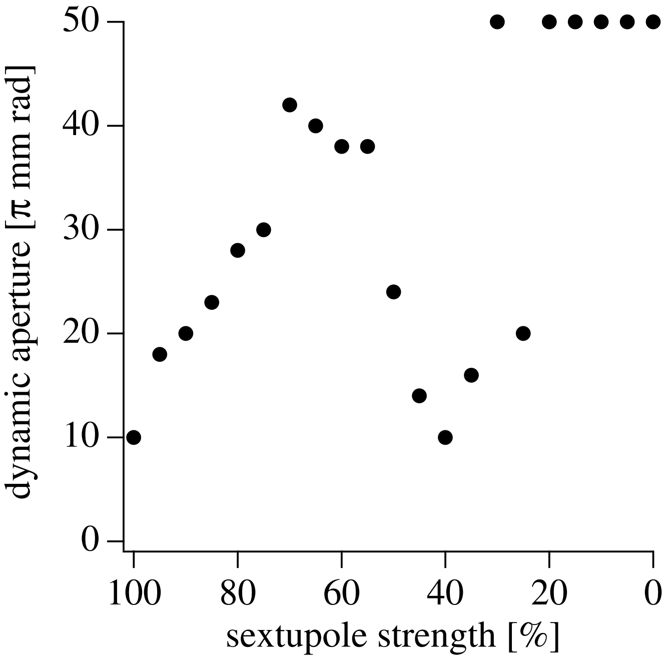
Chromaticity Correction





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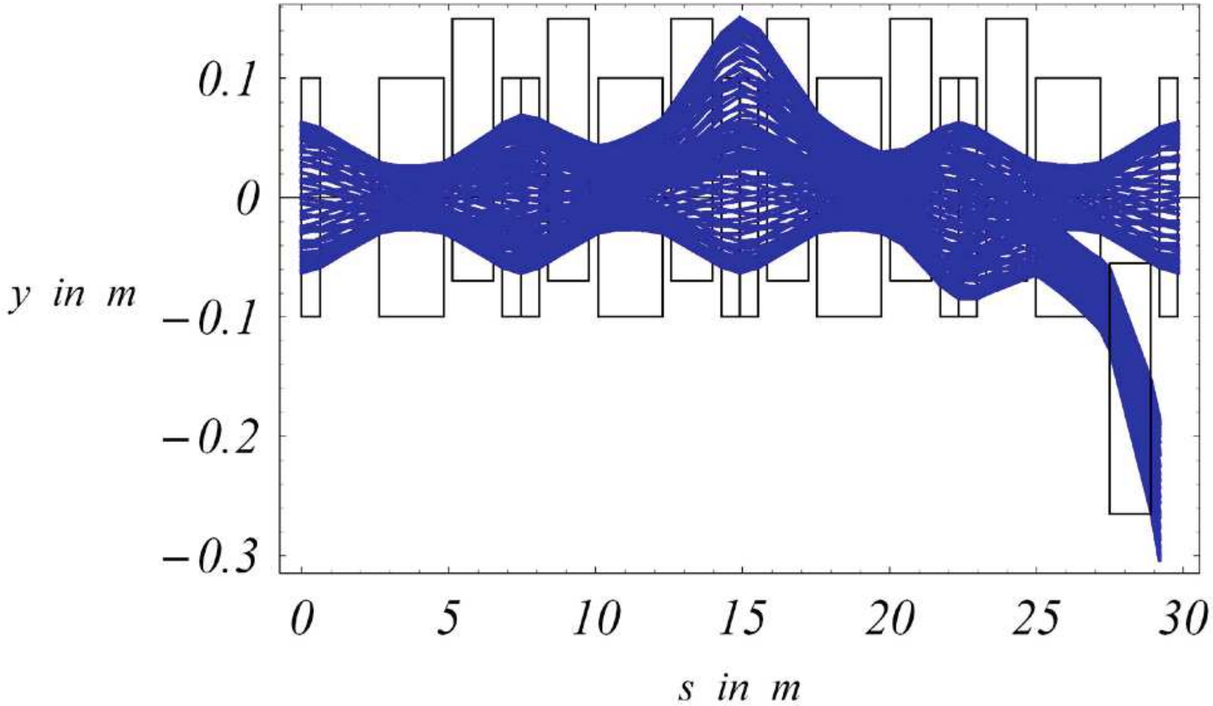
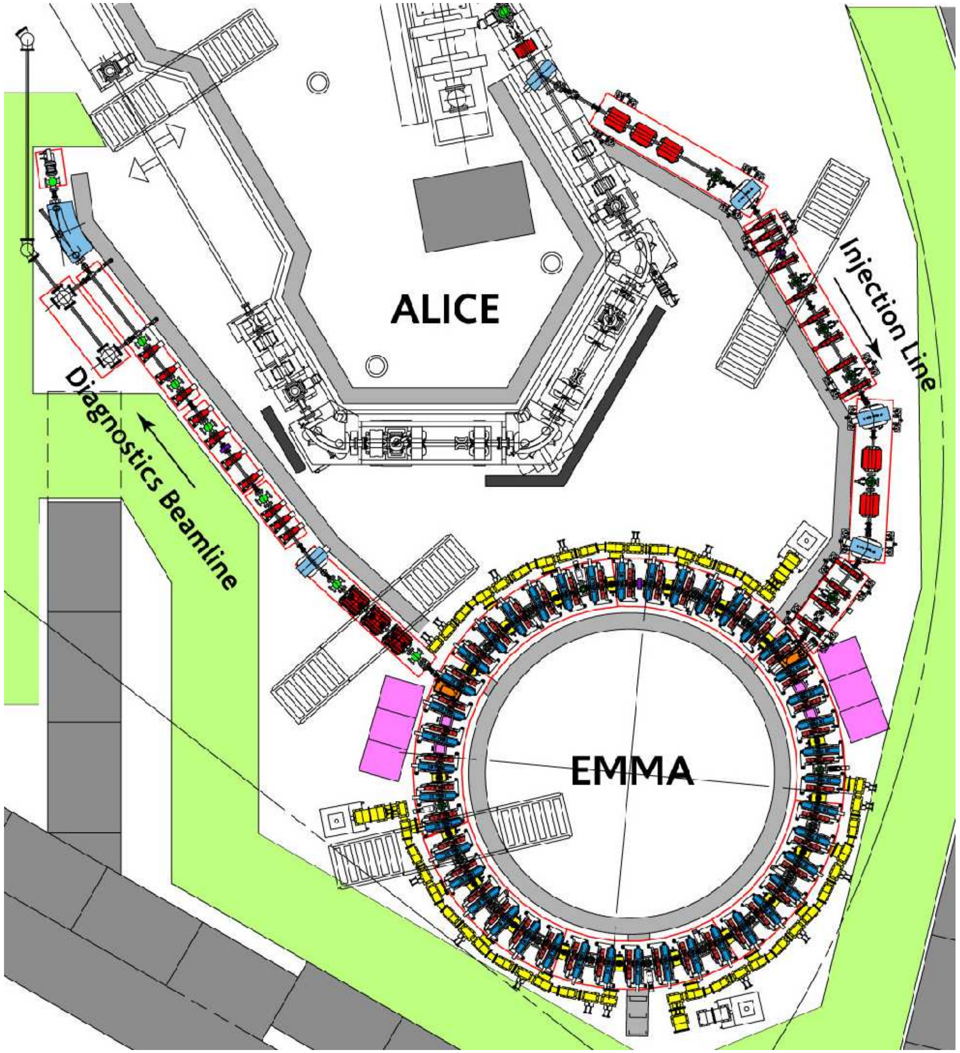
Injection and Extraction

- Most challenging aspect of FFAGs
- See poster WE6PFP092, Wednesday afternoon



EMMA, the World's First Non-Scaling FFAG Accelerator

- Experiment to study beam dynamics in linear non-scaling FFAGs
- Invited talk WE4PBI01, Wednesday 16:30



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Next Steps

- Modify designs to leave more space for injection/extraction
- Study effects of symmetry breaking required for injection/extraction
- Choose optimal chromaticity correction
  - Dynamic aperture and cost considerations
  - Study with errors
- Detailed tracking studies