Acceleration Overview

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Outline

- General design criteria
- Neutrino Factory (IDS-NF) Acceleration Scenario
  - Recirculating Linear Accelerators
  - Fixed Field Alternating Gradient accelerator
- Muon Collider Acceleration
  - Proposed techniques
  - RF and collective effects

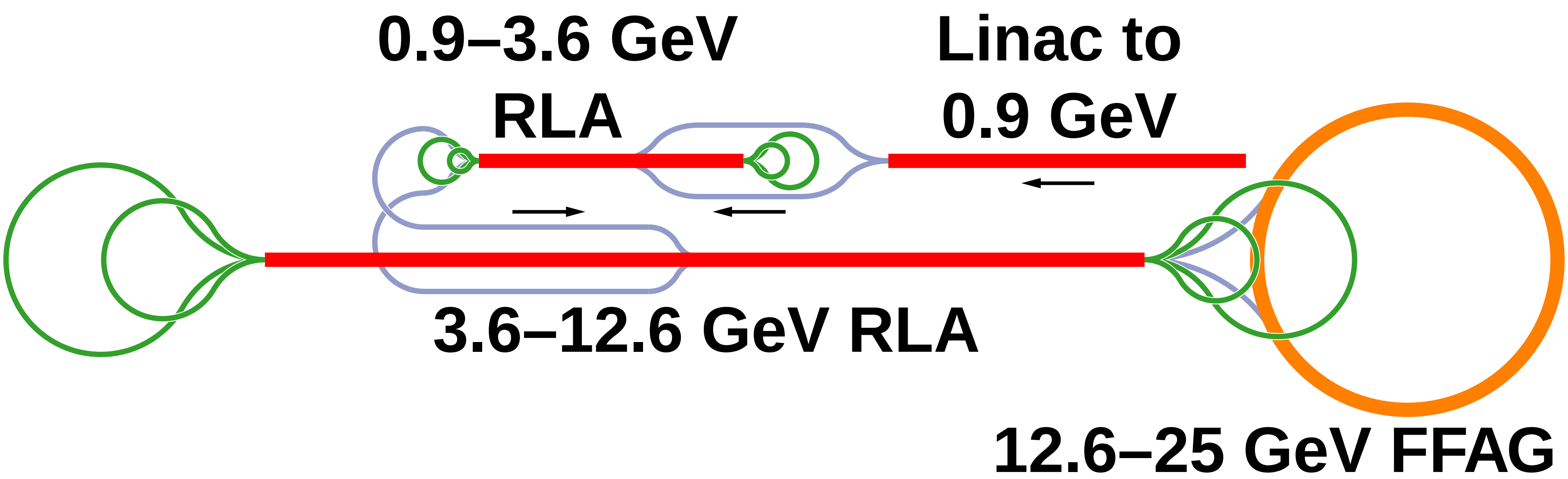
General Design Criteria

- Designs driven by RF efficiency
  - Use of RF structures
  - RF power efficiency
- Maximize number of passes through RF

Neutrino Factory (IDS-NF) Acceleration Scenario

- Accelerate to 25 GeV
- Maintain emittances
- Keep costs low
  - Efficiency: multiple passes through cavities
- Multiple stages: optimize efficiency
  - Linac
  - Two recirculating accelerators
  - FFAG

Acceleration Scenario



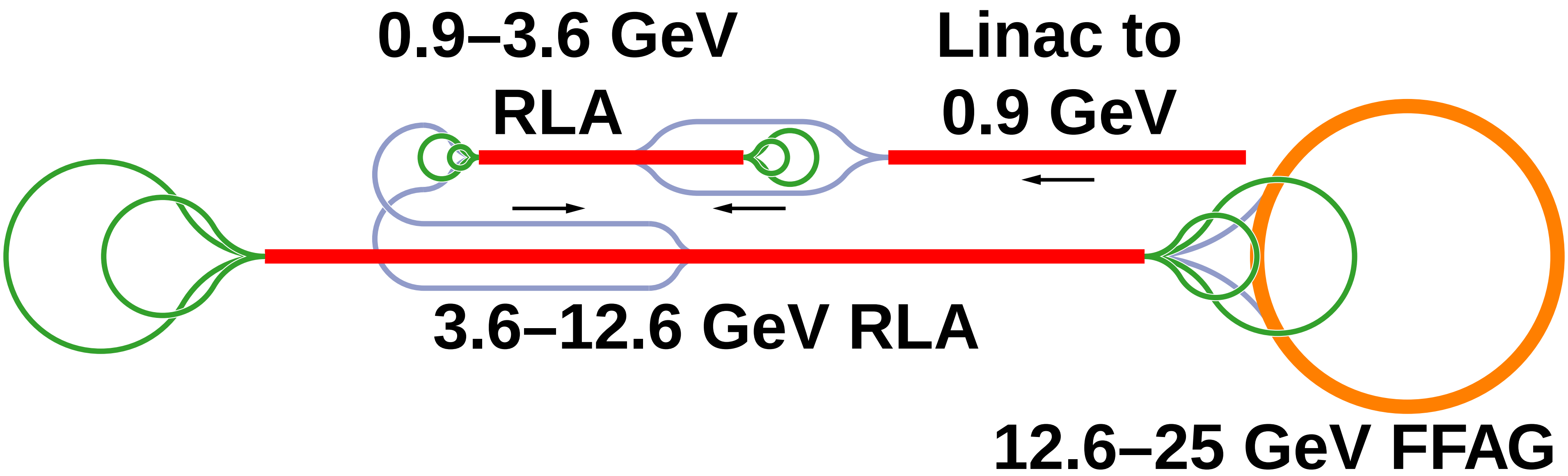
Acceleration Stage Choices

- Linac: only one pass, works all energies
- RLA: multiple passes through RF
  - Switchyard limits passes: 4 or so
  - Problems at very low energy
- FFAG: avoid switchyard
  - No switchyard: 8–16 passes
  - Inefficient at low energy
  - Induces longitudinal distortion

Acceleration
IDS-NF Baseline

- 201.25 MHz 17 MV/m superconducting RF
- Linac to 0.9 GeV
- Dogbone RLAs to 3.6 GeV and 12.6 GeV
  - 4.5 passes
- FFAG to 25 GeV
- System normalized acceptance: 30 mm transverse, 150 mm longitudinal

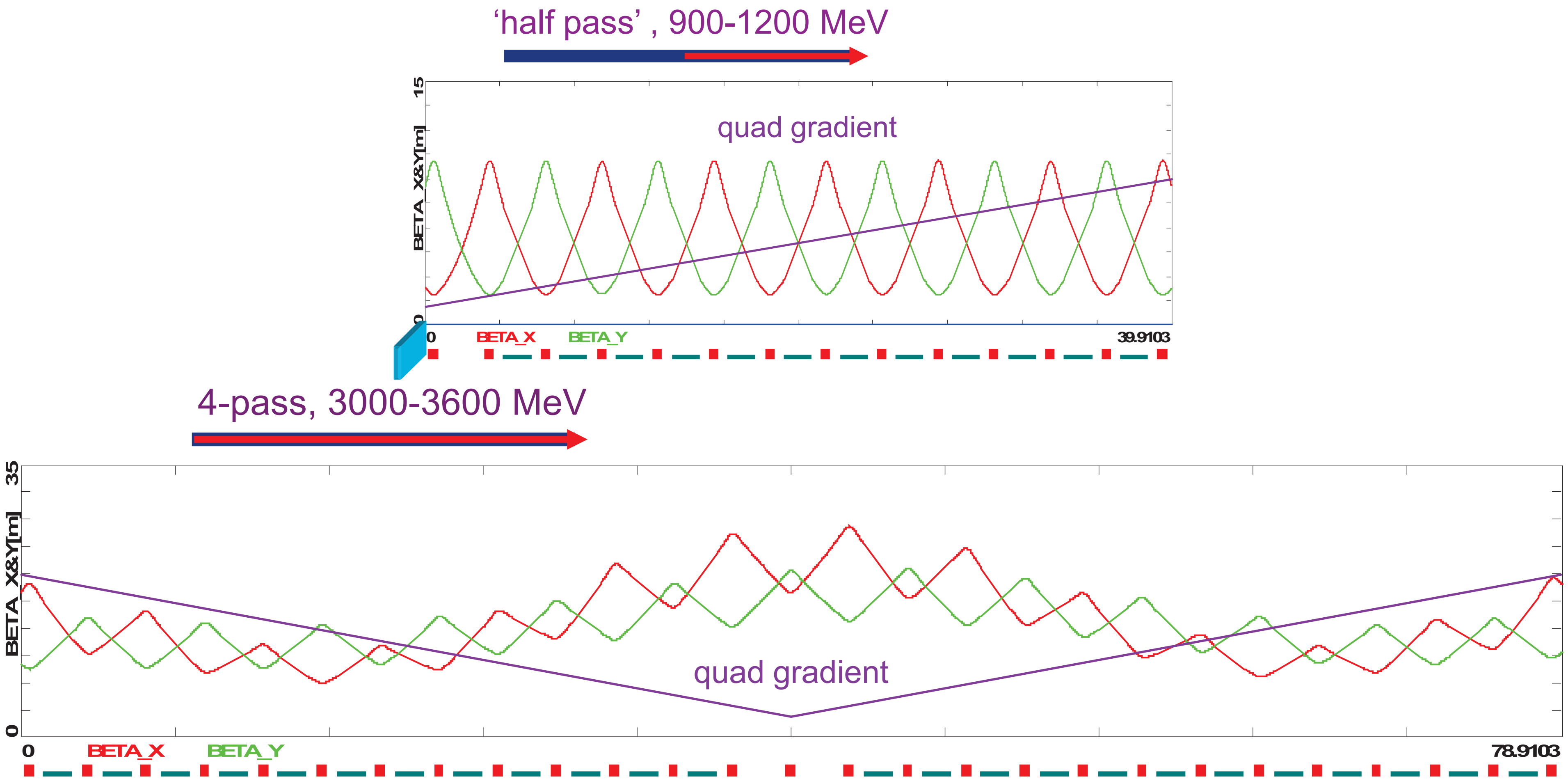
Acceleration Scenario



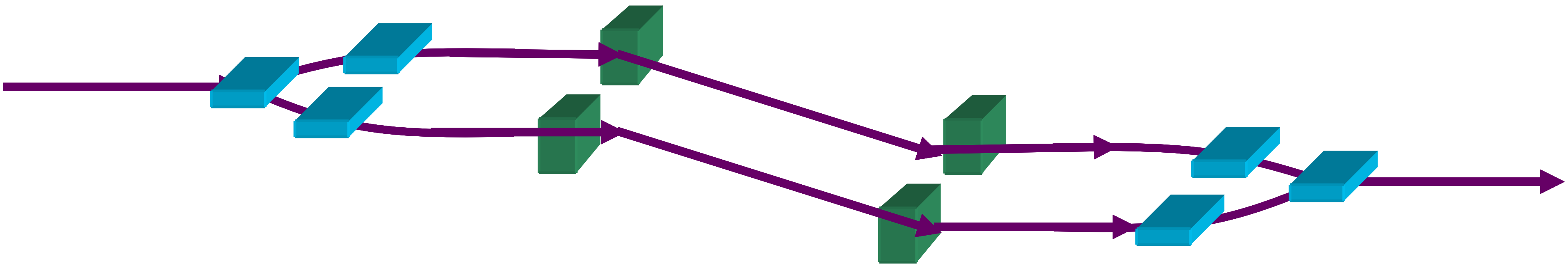
IDS-NF Acceleration Linac/RLA Status (Bogacz)

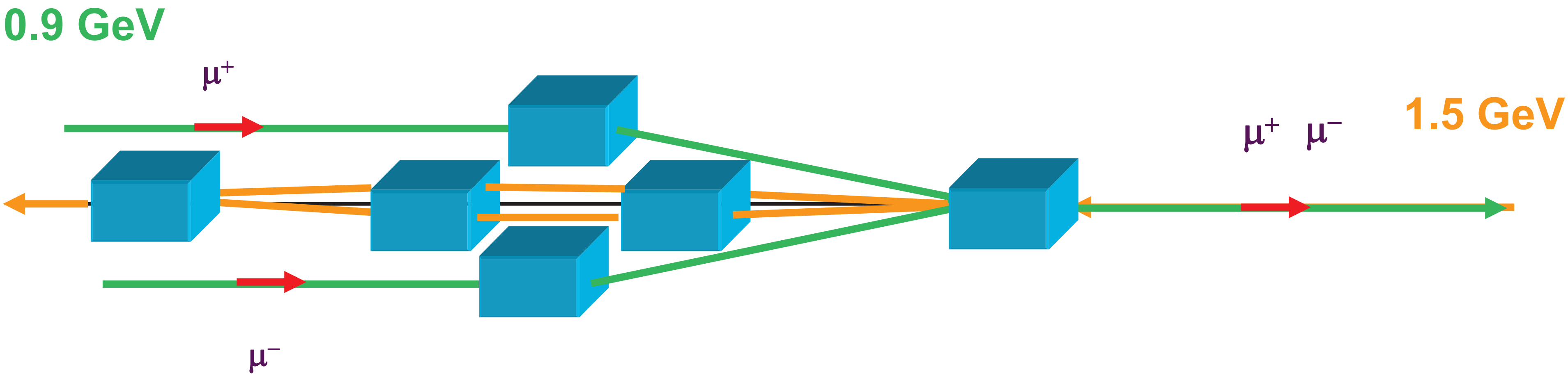
- Linac and RLAs designed
- RLA linacs: symmetric non-uniform focusing
  - First half pass: increase fields for uniform focusing
  - Make field profile symmetric
  - Allows more linac passes than uniform fields
- Injection chicane
- Beamline bypass at arc crossings

IDS-NF Acceleration
RLA Linac Focusing (Bogacz)

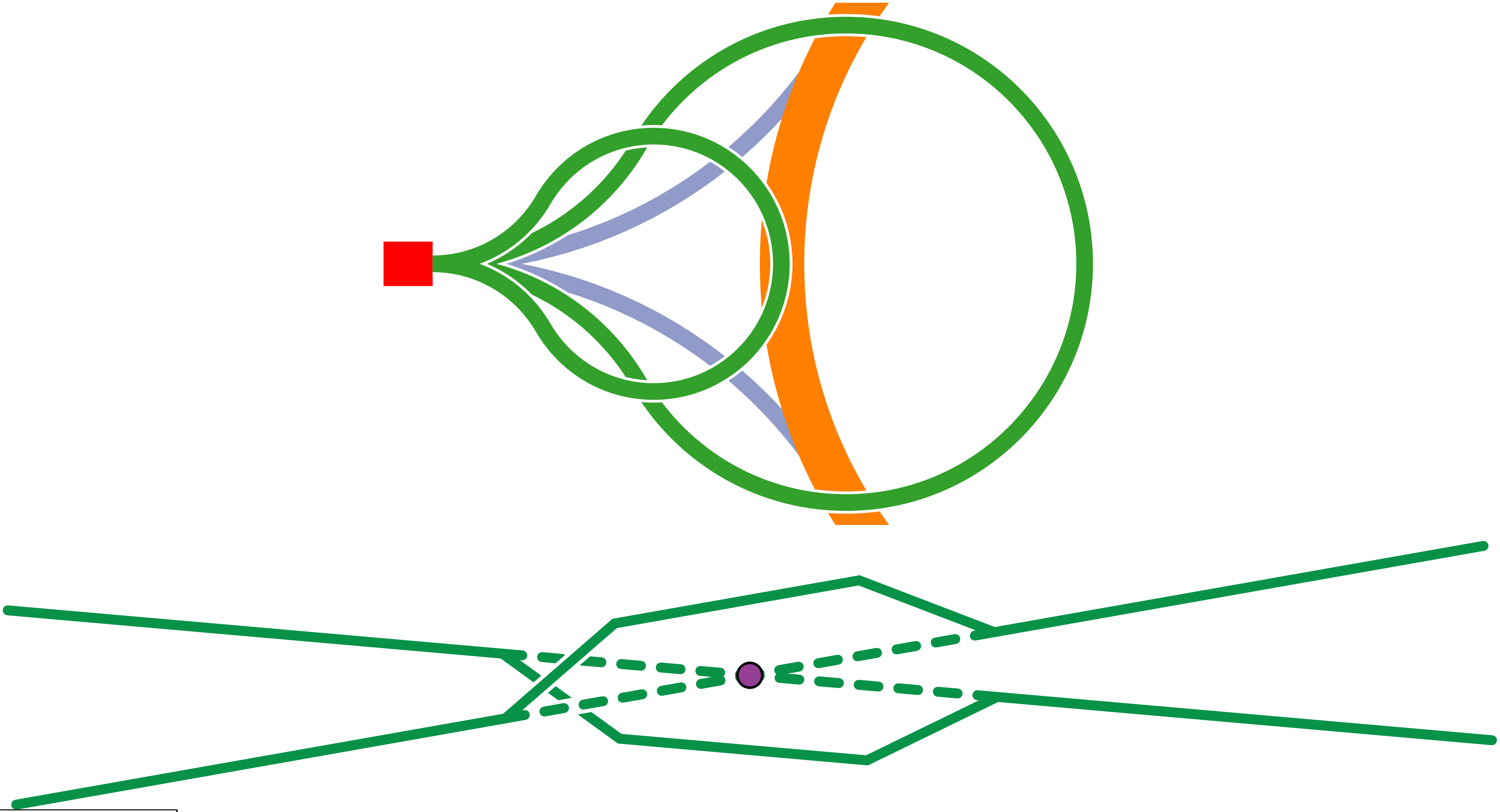


IDS-NF Acceleration
RLA Injection Chicane (Bogacz)





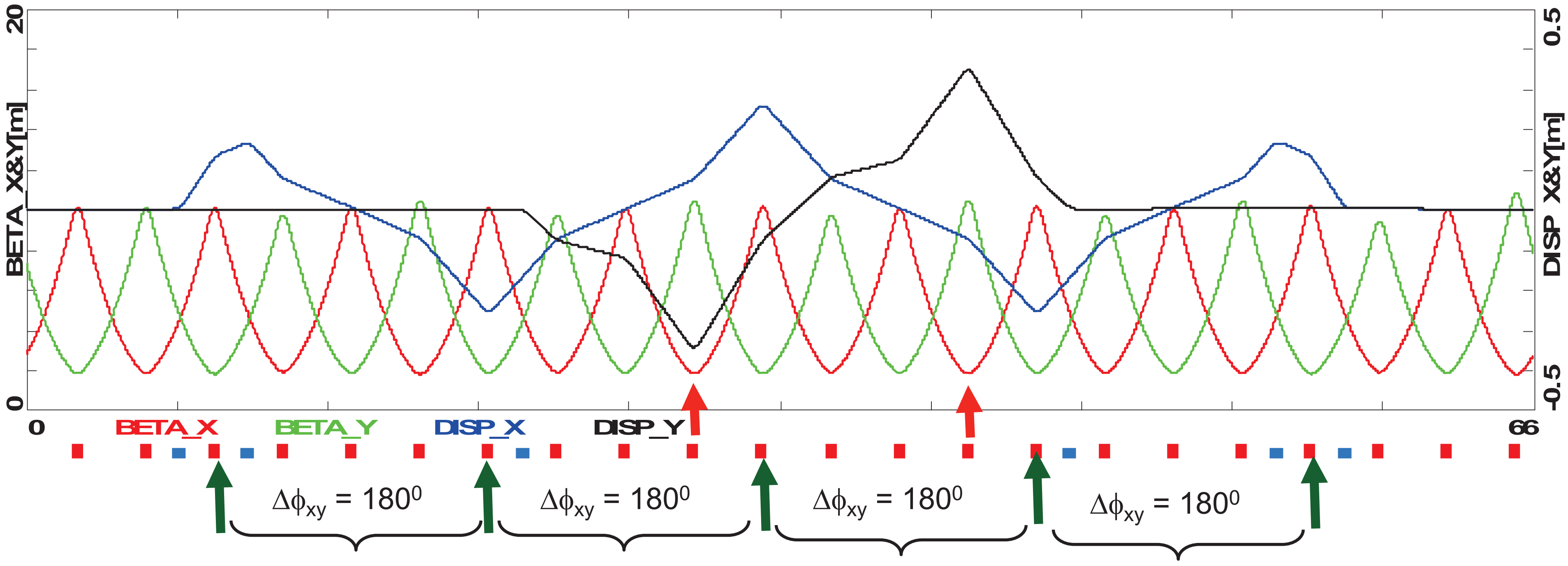
IDS-NF Acceleration
Crossing Bypass (Bogacz)



IDS-NF Acceleration RLA Chromatic Corrections (Bogacz)

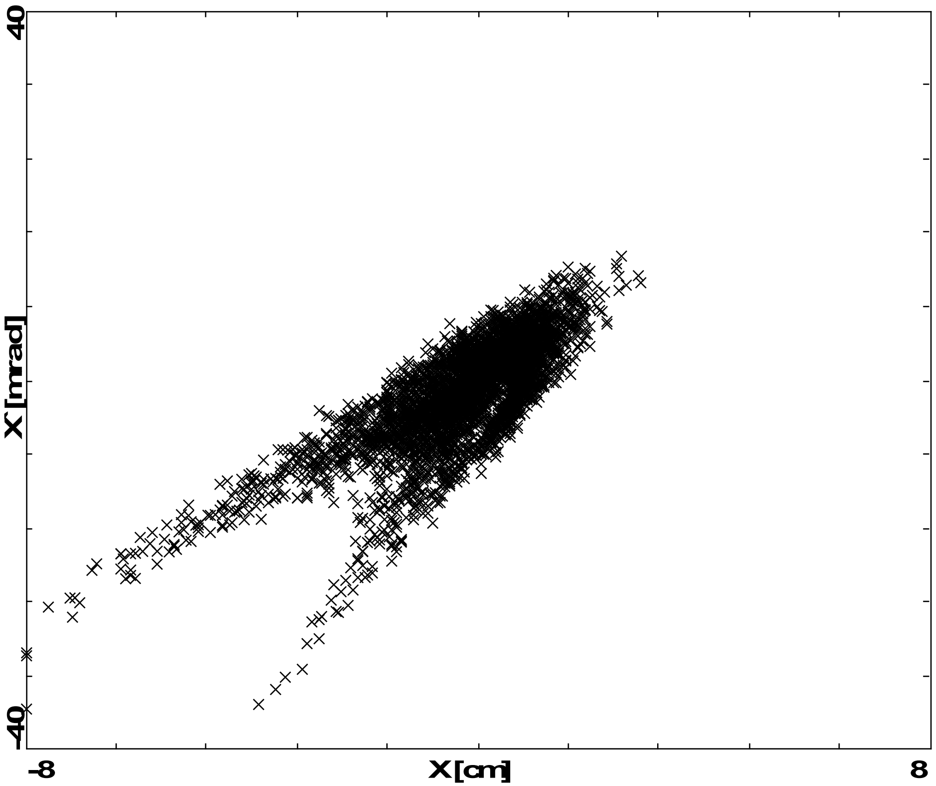
- Chromatic corrections added
- Injection chicane
- At separators/recombiners
  - Sextupoles best around bend direction change
- Not needed elsewhere

RLA Chromatic Corrections Injection Chicane (Bogacz)

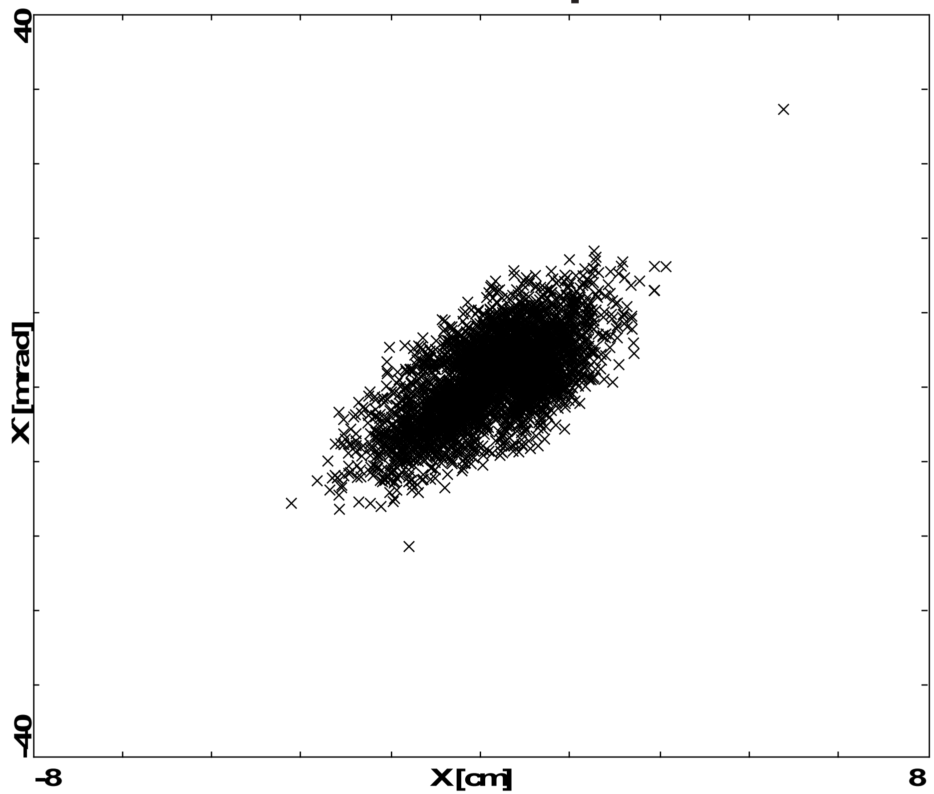


RLA Chromatic Corrections Injection Chicane (Bogacz)

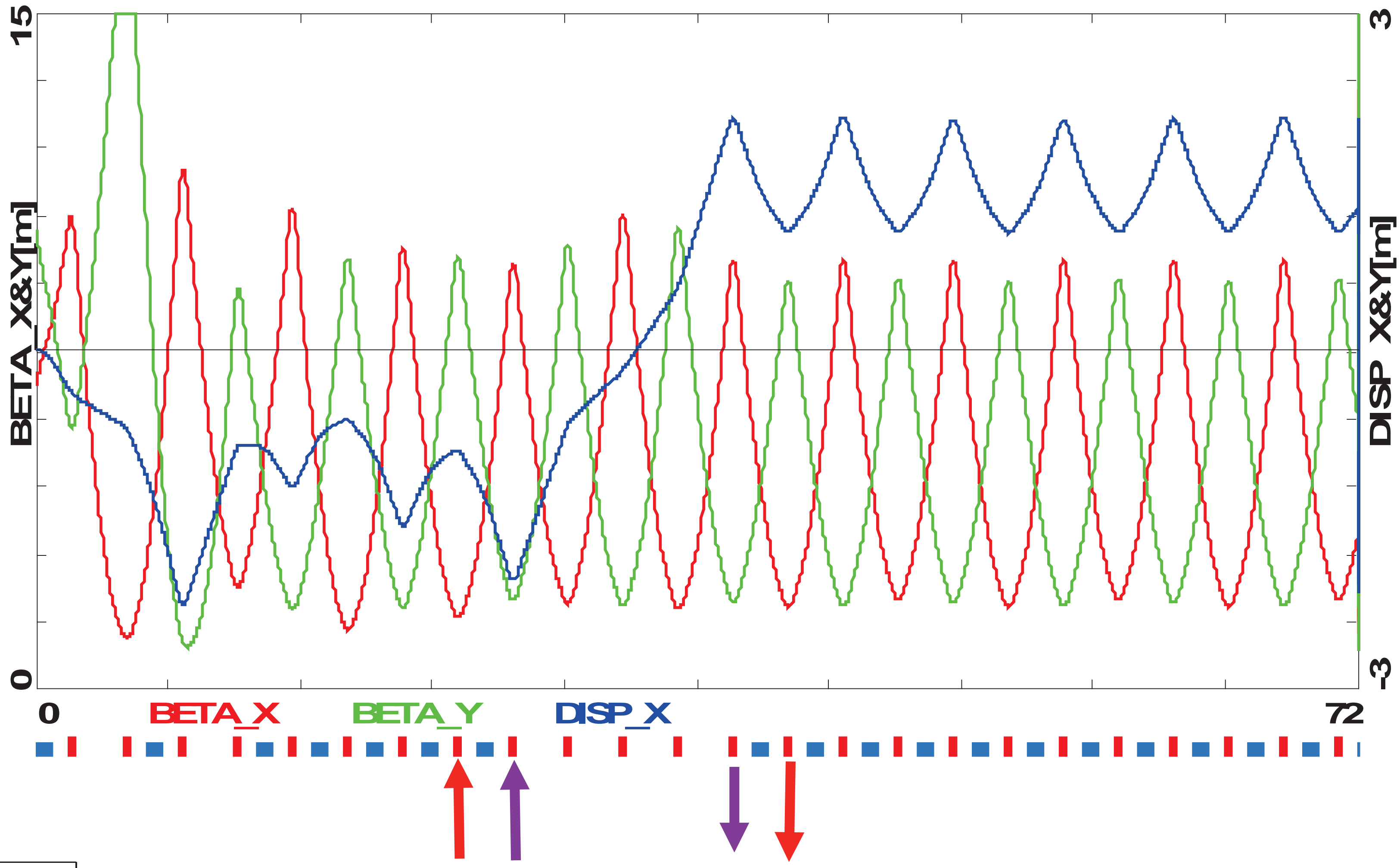
Without sextupoles



With sextupoles



RLA Chromatic Corrections Separator/Recombiners (Bogacz)



IDS-NF Linacs and RLAs Next Steps

- Tracking through full system
- Engineering and costing
  - Detailed look at floor layout, especially crossings and switchyard
  - Individual components
- Transfer lines

FFAG
One Slide 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)
- Scaling: tunes independent of energy
- Linear non-scaling: tunes vary, but magnets linear giving good dynamic aperture

IDS-NF Acceleration FFAG

- Single arc, no switchyard: many passes through RF
- Time varies with energy
  - Limits number of passes
  - Keep cells as compact as possible
  - Varies with transverse amplitude
- Circular machine
- Many simple identical cells

IDS-NF FFAG
Design Considerations

- Considering several designs
- Machine cost
  - Weakly affected by cell type
  - Two-cavity cells more expensive
- Injection/extraction
  - May be easier for different cell types
  - Doublet probably most challenging
- Two-cavity cells improve longitudinal dynamics

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

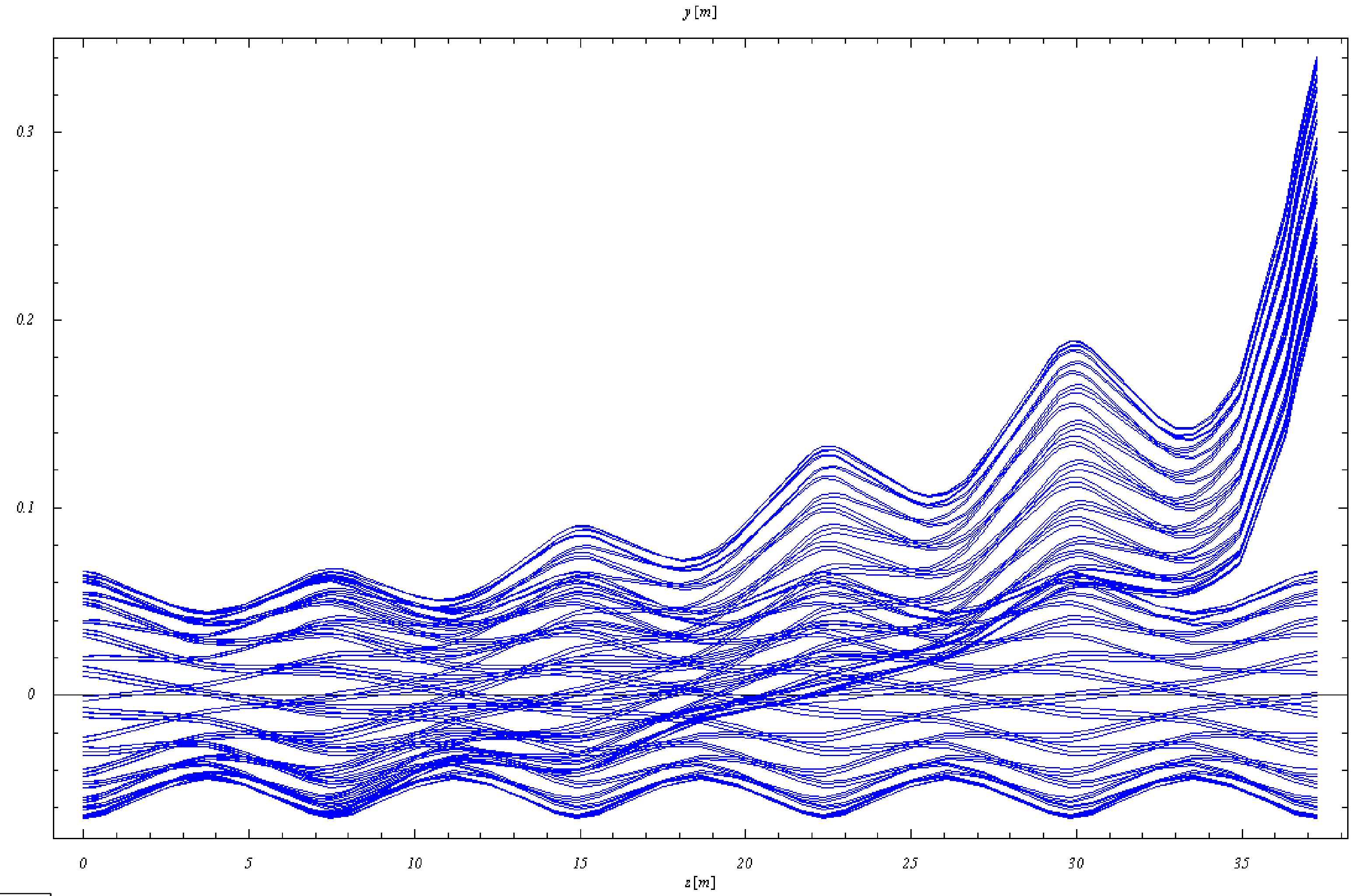
IDS-NF FFAG Injection/Extraction

- Injection/extraction most challenging part of FFAGs
  - Large beam and magnet apertures
  - Compact lattice: short drifts
  - Relatively short circumference

IDS-NF FFAG Injection/Extraction (Pasternak)

- First study for IDS-NF: extraction
- Use FODO: most flexible with two signs
- Easiest in vertical
- Use 6 kickers, 0.07 T each
  - Horizontal: need 10 kickers, 0.125 T each
- 4 T superconducting septum
  - Less separation with warm 1 T septum

IDS-NF FFAG Injection/Extraction (Pasternak)



IDS-NF FFAG Injection/Extraction Insertions (Machida)

- Studied adding cells with longer drifts
  - Makes injection/extraction easier
  - Introduces additional resonances
  - Cross resonances quickly
- Nonlinearities match orbits and beta functions
- Requires chromatic correction (later)
- Without errors, dynamic aperture maybe acceptable (more later)

IDS-NF FFAG Injection/Extraction Next Steps

- Do injection study as well
- Look at triplets
- Engineering of kickers
- Add drift spaces to lattice for additional kickers
- Study insertions

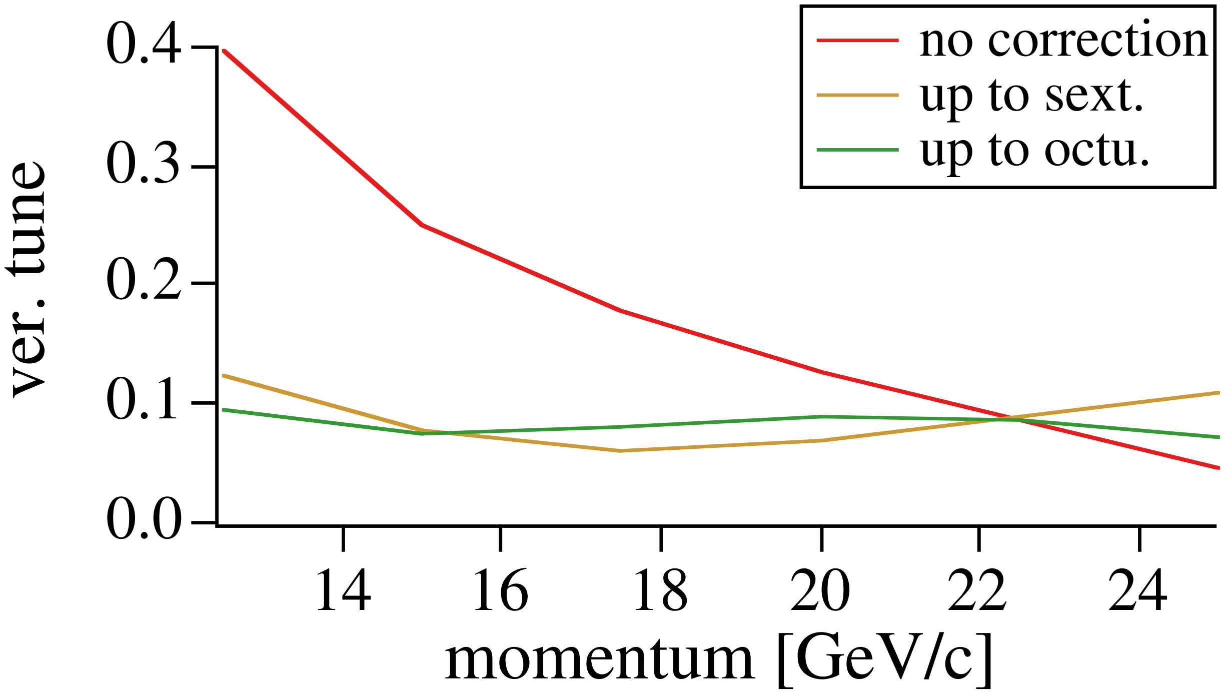
IDS-NF FFAG
Chromaticity Correction

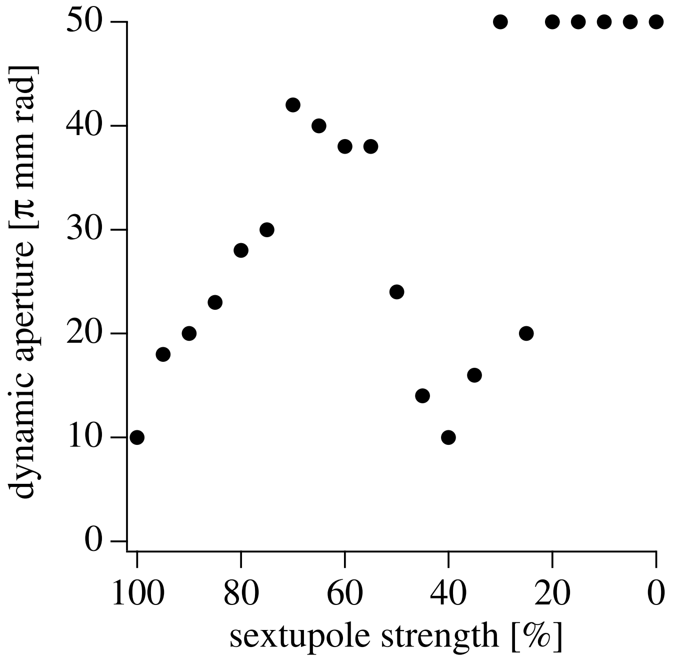
- Time of flight depends on transverse amplitude
  - Different transverse amplitude, different longitudinal motion
  - Effective longitudinal emittance blowup
  - Reason for considering more costly lattices
- Correcting chromaticity reduces the effect
  - Hamiltonian term $(\xi \cdot J)\delta$
  - Hurts dynamic aperture

FFAG Chromaticity Correction (Machida)

- Add sextupoles to minimize tune variation
- Poor dynamic aperture
- Good dynamic aperture with less sextupole
  - Good with small ($<$ 20%) corrections
  - Just acceptable with (50–70%) correction
    - Dip caused by approach to $\nu_x = 1/3$
    - Must study robustness with errors
  - Still improves time-of-flight behavior

FFAG Chromaticity Correction (Machida)





FFAG
EMMA Experiment

- EMMA experiment at Daresbury Laboratory
- Study beam dynamics in linear non-scaling FFAGs
- Verify machine behaves as we expect
- Hope to begin commissioning with beam in November 2008
- NFMCC plays an important role: experiment design, beam dynamics studies

Muon Collider

- Large amount of acceleration
- Efficiency is essential
  - Reduce number of RF structures
  - Reduce power consumption
- Try to get more turns

Muon Collider Acceleration Design Options

- RLA: get more passes (Bogacz)
  - Ramp linac magnets, get more passes (12)
  - Non-scaling FFAG arcs: get 2 passes per arc, maybe more (Wang, Trbojevic)
- Fast ramping synchrotron (next talk)
  - Potential for many more passes
- FFAG: not studied much as yet
- Challenge: synchronize RF to beam

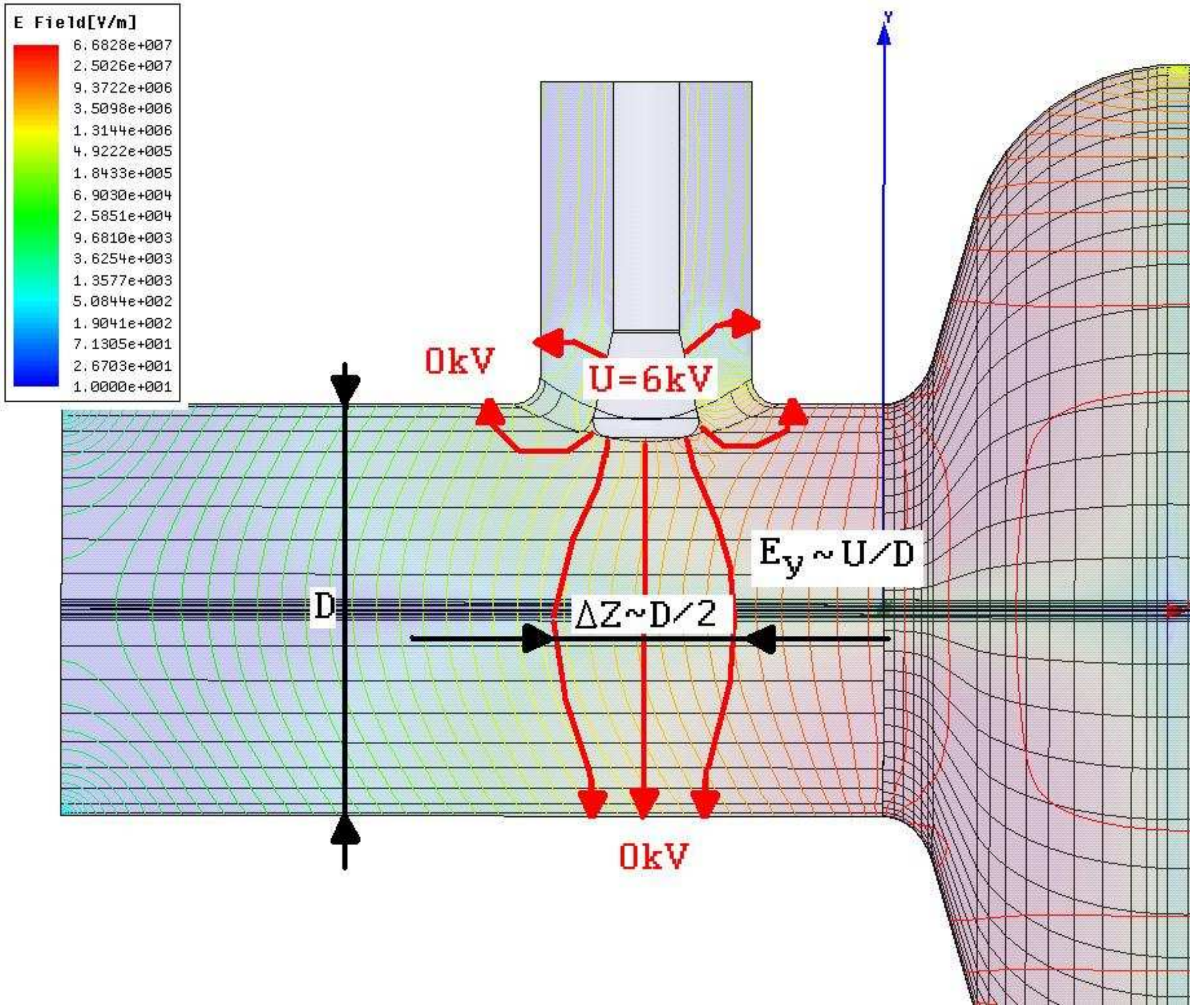
Muon Collider Acceleration Beam Loading

- Very high single bunch charge (2×10^{12})
- High-frequency SCRF
  - Extract as much as 10% of stored energy
  - Must restore energy between passes
    - Input power coupler limitation
    - Use shorter structures
  - Good for power efficiency
  - Significant wakefields

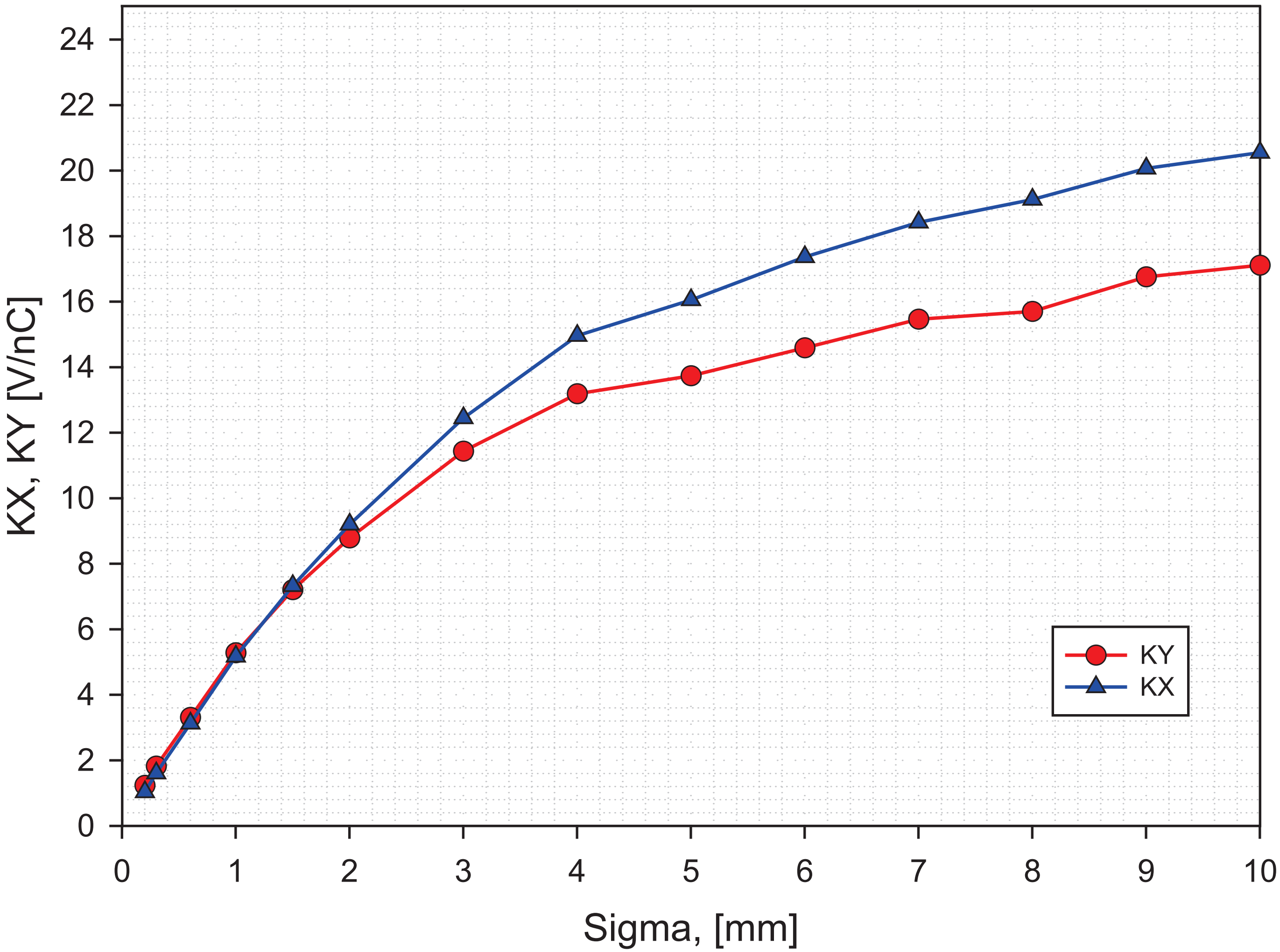
Muon Collider Acceleration Collective Instabilities

- High currents: significant potential for instabilities, emittance growth
- Asymmetric input coupler: transverse kick
  - Increases with increasing bunch length
  - Potentially 1000 times higher than ILC
- May not be so bad
  - Small number of turns
  - Strong synchrotron oscillations

Muon Collider Acceleration Input Coupler



Transverse Wake Kick (Lunin *et al.*)



Muon Collider Acceleration Future Work

- Beam dynamics studies of collective effects
  - Cost/benefit of lower frequency RF
- Further study of options, make choices
  - Investigate FFAGs for some stages
- Hardware studies of ramping magnets

Conclusions

- Have solid RLA designs for the IDS-NF
- Rapidly converging on an IDS-NF FFAG design
  - Primary concern is injection/extraction
- Beginning to study options for muon collider acceleration
  - Efficiency is important
  - Collective effects due to large bunch charge must be studied