Acceleration System: Issues and Plans

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2008 MUTAC Review

9 April 2008

Outline

- Design criteria for acceleration
- Acceleration for a neutrino factory
- Acceleration for a muon collider

Design Criteria
Basic Goals

- Initial momentum 220 MeV/c
- Final energy:
  - Low energy neutrino factory: 4 GeV
  - Neutrino factory: 25 GeV
  - Collider: as high as 4 TeV
- Avoid decays: high real-estate gradient
  - $\geqslant 1$ MV/m for neutrino factory
  - $\geqslant 4$ MV/m for muon collider

Design Criteria Basic Goals

- Large emittances (full quoted here)
  - Longitudinal: 50 meV-s and higher
  - Transverse
    - Neutrino factory: 30 mm
    - Muon collider: 25 μm RMS
- Reduce costs
  - Hardware cost
  - Wall plug power
  - More passes through RF

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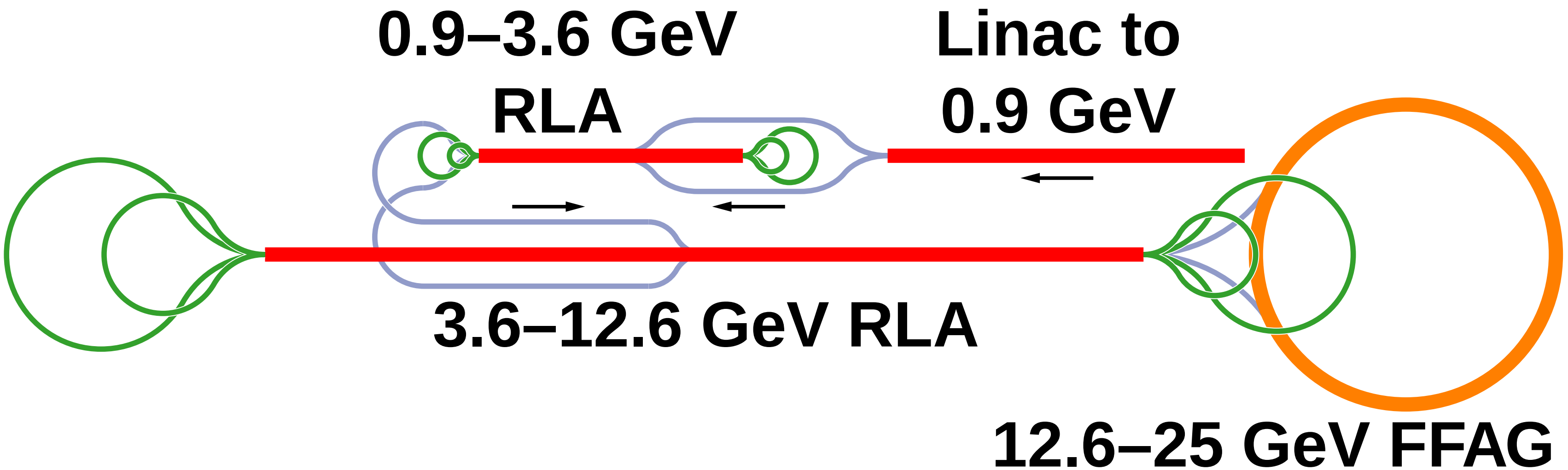
IDS Acceleration Overall Plan

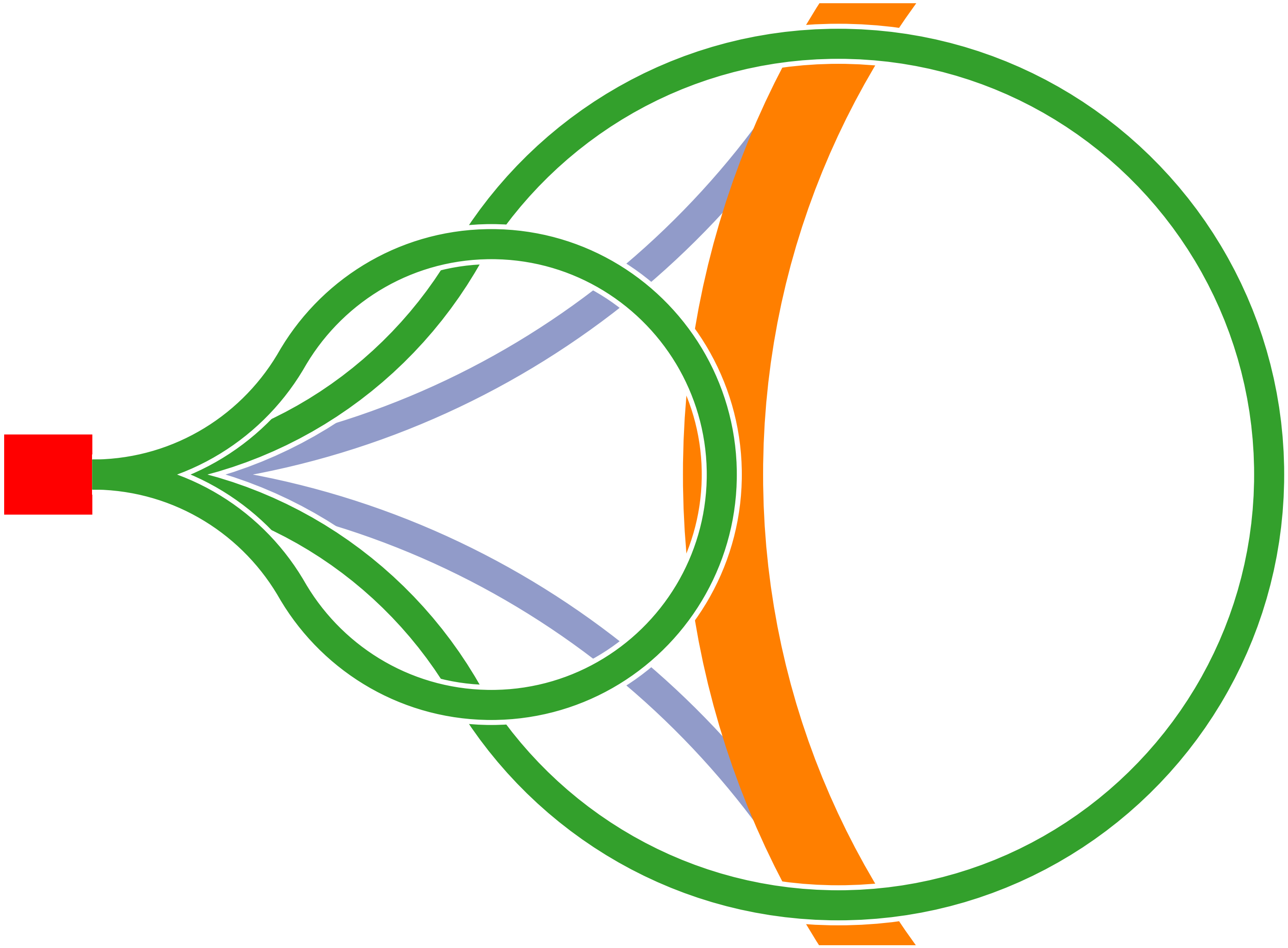
- Maximize passes through RF
- Linear non-scaling FFAGs at high energy
- RLAs at energies below where FFAGs efficient
- Linac at energies below where RLAs work



IDS Acceleration RLA

- Multiple passes through linac
- Switchyard limits passes
  - Dogbone: increased energy separation for given total linac, compared to racetrack
- Low-energy limit: different velocity each pass
  - Effect largest on first pass
  - Inject at linac center to improve
  - Linac at lower energy

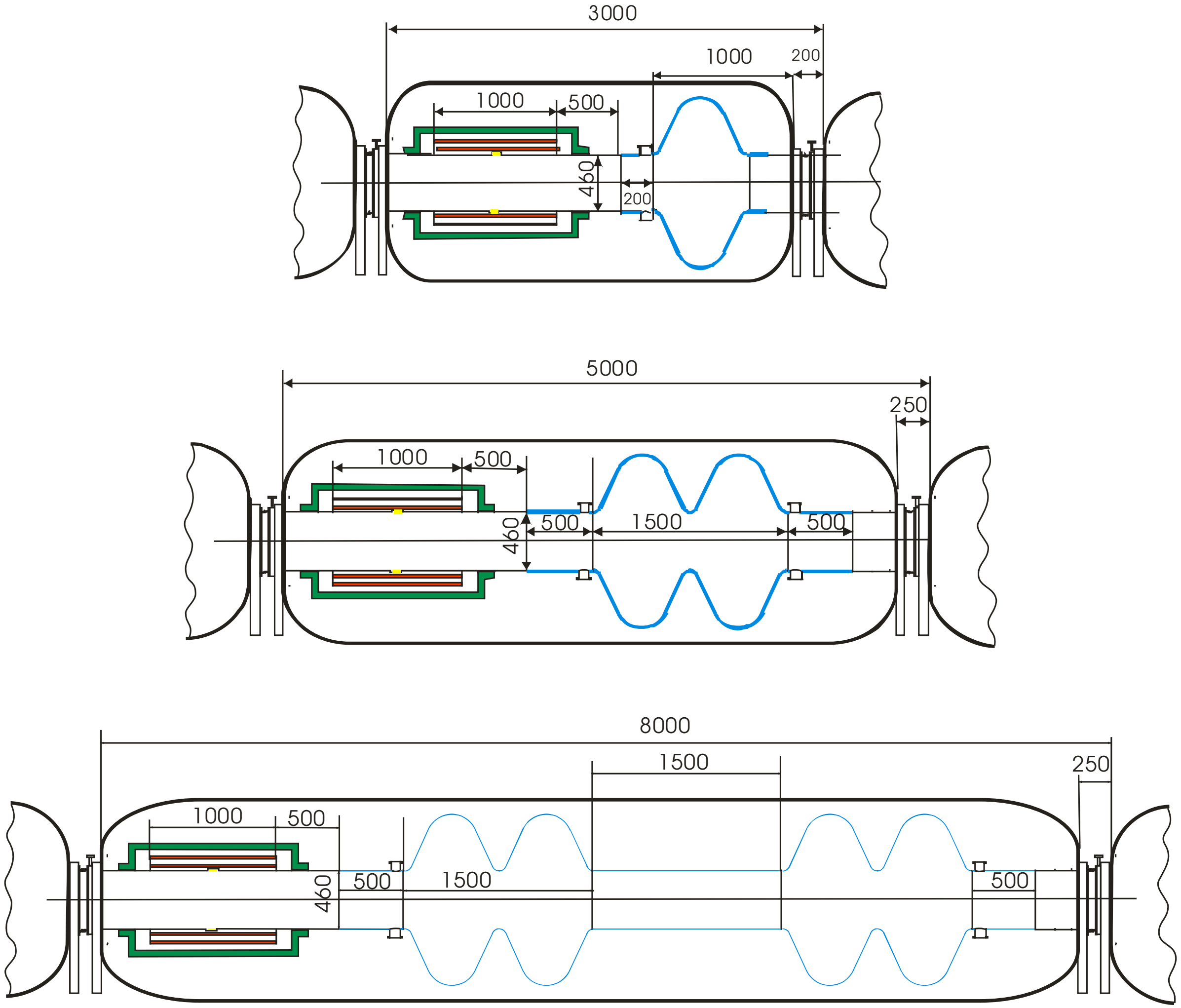
IDS Acceleration Dogbone Arcs



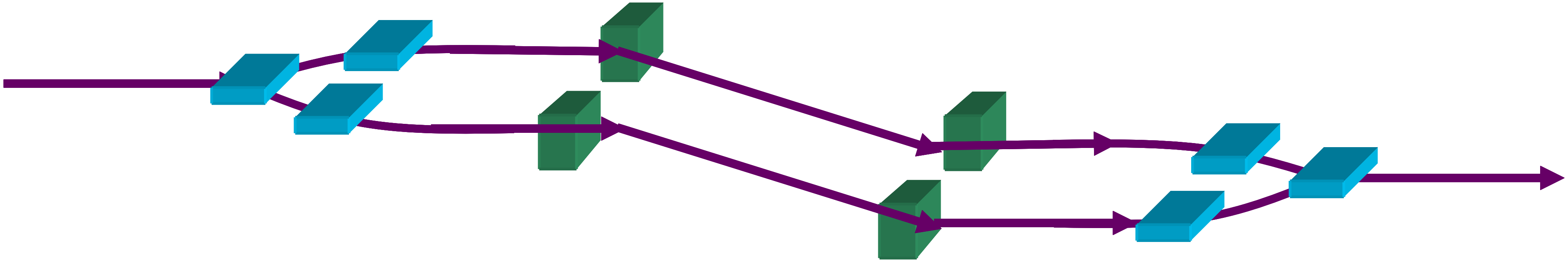
IDS Acceleration Linac and RLA Status (Bogacz)

- Pre-accelerator linac is designed
  - 146 m solenoid-focused 201 MHz SCRF
- Injection chicane into first RLA with matching
- RLA Linacs
  - 1st: 79 m FODO 0.6 GeV 201 MHz SCRF
  - 2nd: 264 m FODO 2 GeV 201 MHz SCRF
- First arc of first RLA

IDS Acceleration
Pre-accelerator Linac Cryostats



IDS Acceleration Injection Chicane



IDS Acceleration
RLA and Linac Plans

- Full linear design of all RLA arcs
- Chromatic corrections (large energy spread)
- Design of arc crossings
- Transfer lines
- Tracking studies through systems
- Engineering of systems: cost
  - Verify separator and arc crossing

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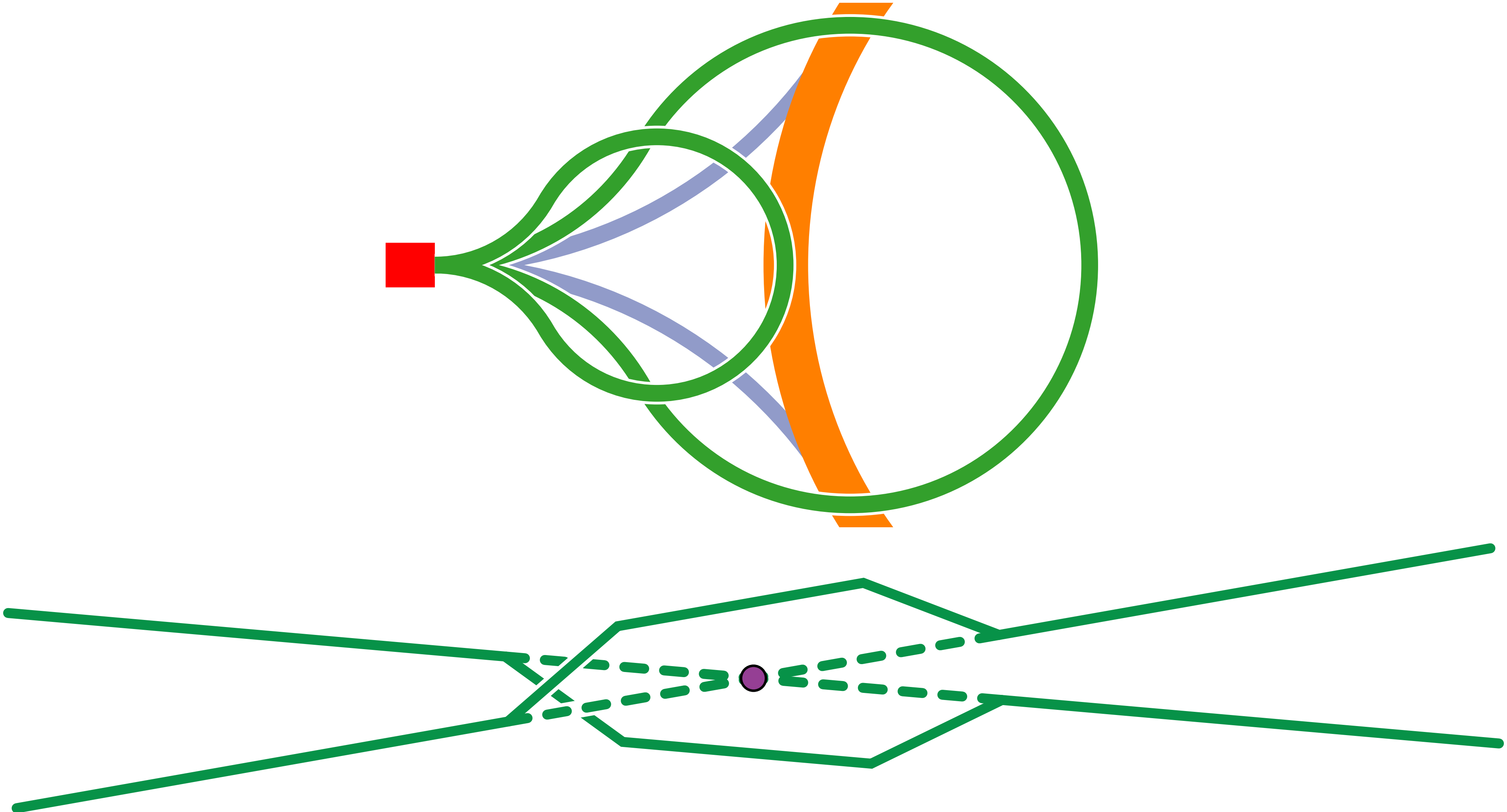
IDS Acceleration
Arc Crossings

Neutrino Factory
Muon Collider



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IDS Acceleration
Linear Non-Scaling FFAG

- Eliminate switchyard which limits passes
- All energies in same arc
- Magnet fields not time varying: too fast
- Avoid problems with resonances
  - Highly symmetric: short, identical cells
  - Linear magnets: avoid driving nonlinear resonances
  - Rapid acceleration through resonances

IDS Acceleration
EMMA Experiment

- FFAGs: significant potential for improving efficiency
  - Allow “large” number of turns
- Potential use in proton driver as well
- Important to ensure we understand dynamics
  - Purpose of EMMA experiment (next talk!)

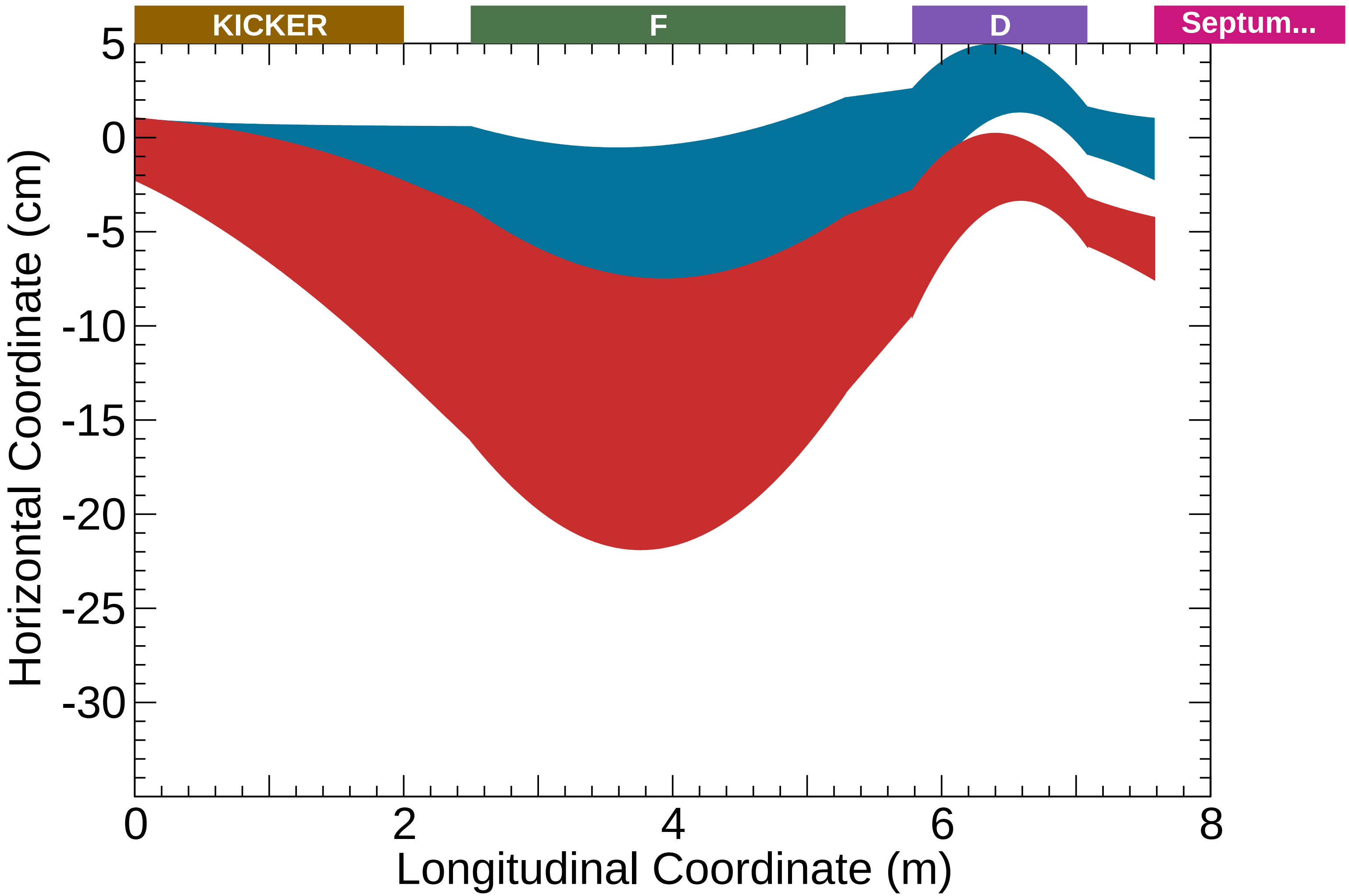
IDS Acceleration FFAG Design

- Studied doublet and FODO cells
- Two 201 MHz RF cells per lattice cell
  - More voltage than earlier designs
  - Time of flight depends on transverse amplitude
  - Less efficient use of RF
  - Still better than RLAs

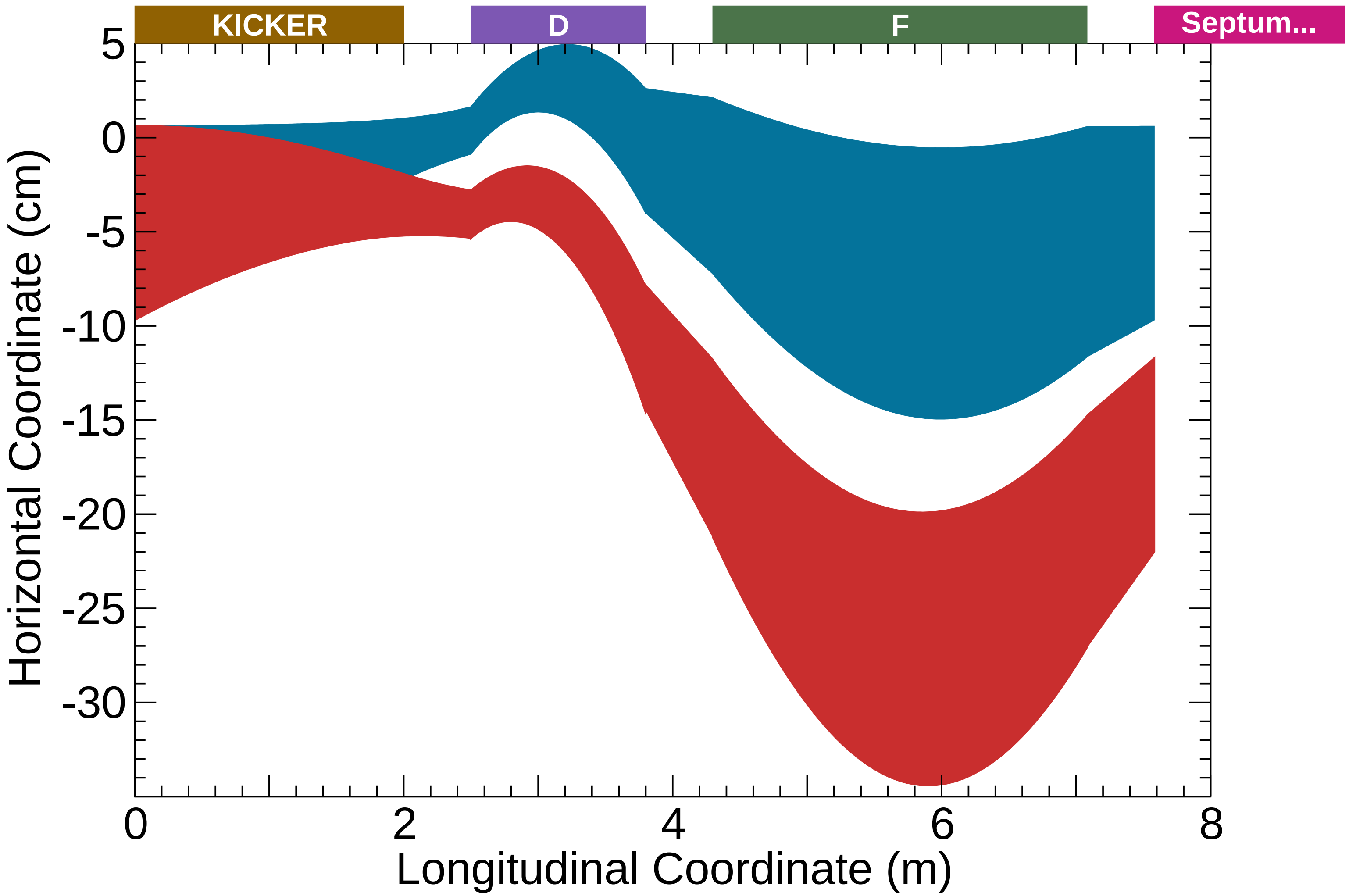
IDS Acceleration FFAG Injection

- Doublet: not reflection symmetric
  - "Right" and "wrong" directions
  - "Wrong" requires significant extra aperture
    - Undesirable: symmetry, field strength
  - Two signs: both can't be right
- FODO: use "good" drift
- Single kicker: strength too high
  - FODO: about 0.9 T (0.5 T limit?)

Injection Doublet, D Near Septum



Injection
Doublet, F Near Septum



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IDS Acceleration FFAG Plans

- Study longitudinal dynamics more carefully
- Tracking
- Consider fewer cavities (more efficient)
  - FODO works poorly
- Modest chromatic correction
  - Reduces time dependence on transverse amplitude
  - Dynamic aperture reduced

IDS Acceleration FFAG Plans

- Injection/extraction
  - 2-kicker solution
  - Vertical
- Consider triplet design
  - FODO inefficient with fewer cavities
  - Doublet problems with injection/extraction
  - Vertical injection/extraction required

IDS Acceleration Bunch Structure

- Proton driver: prefer multiple bunches at 50 Hz
- Hg target: bunches must arrive within short time
- Each bunch train must gain same energy
- Beam loading
  - Early trains extract energy
  - Must replace before next train
  - Limited by power delivery

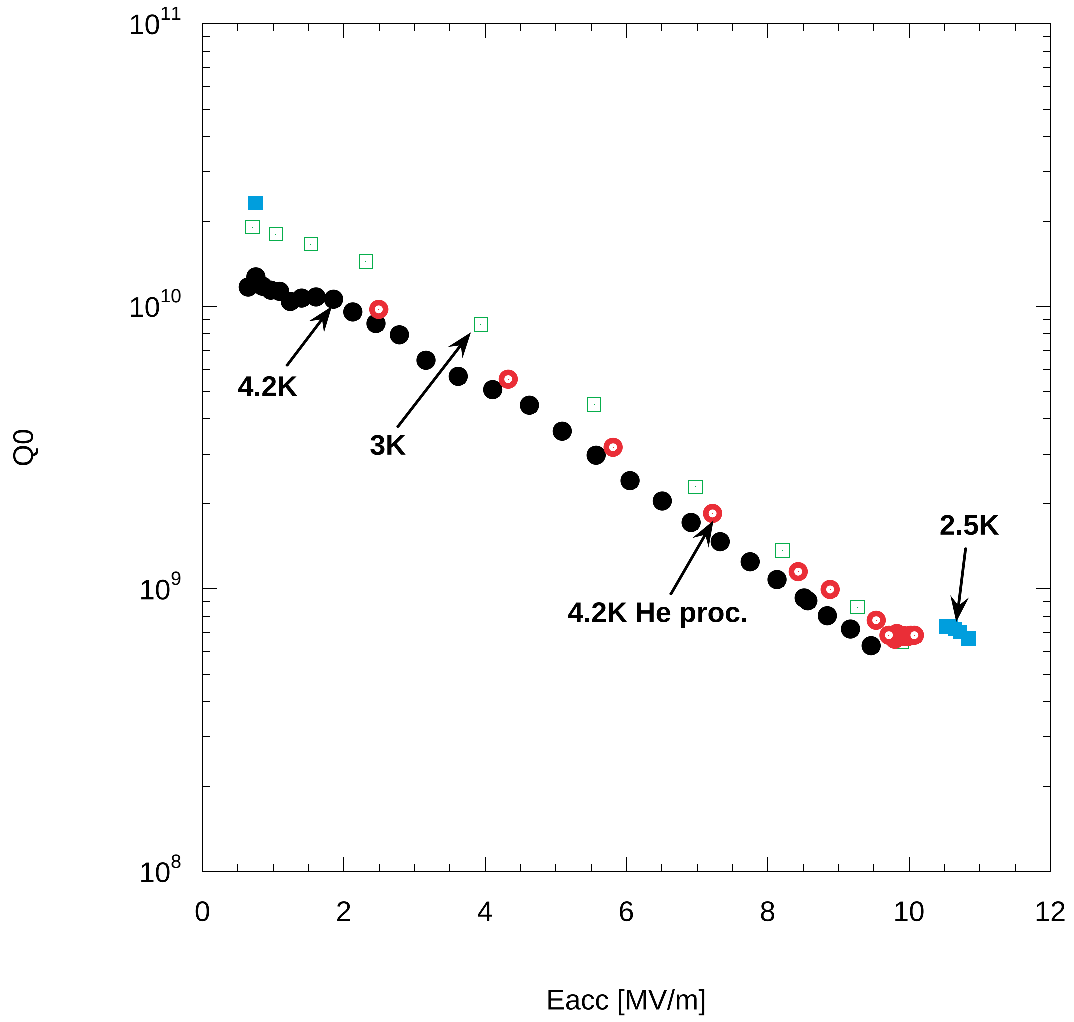
IDS Acceleration Bunch Structure

- Earlier results
  - Hg Target: all trains in $\leqslant 40\ \mu$s
    - Update to come from MERIT analysis
  - 1 MW coupler limit: all trains in $\geqslant 150\ \mu$s
    - More efficient FFAG
- Fix energy gain in later bunch trains: avoid!
  - Requires many nearby RF frequencies
  - Reduces efficiency

Superconducting RF

- 201 MHz high-gradient SCRF needed
  - Large stored energy
    - Can't restore energy in short rings
  - Large longitudinal emittance
  - Neutrino factory: large transverse aperture
- Earlier results (Cornell): 11 MV/m
  - Large Q-slope
  - Higher gradient (17 MV/m) for efficiency

201 MHz SCRF Cavity Test



Superconducting RF R&D

- Nb on Cu needed for large cavities
- Q-slope caused by surface problems
- Cornell: 500 MHz program to study surfaces
  - Explosion bonding looks promising
  - Lacking funding to complete
    - Proposal in to DoE ($200 k to complete one cavity, $300 k to construct another)
- Argonne/IIT: study atomic layer deposition

Superconducting RF R&D

- Magnets desirable close to cavities
  - Keep average gradient high
  - Especially important in
    - Initial linac
    - FFAGs
- Know 0.1 T possible for short time
- Long-term (months to year) test
  - How often warm up and cool down magnets?

Muon Collider Efficiency

- Two meanings of efficiency
  - Operating: wall plug power
    - Acceleration likely dominates power
  - Construction: multiple passes, fewer cavities
- Same result: more passes better
  - Except for decays. . .
  - Optimal probably around 20 turns

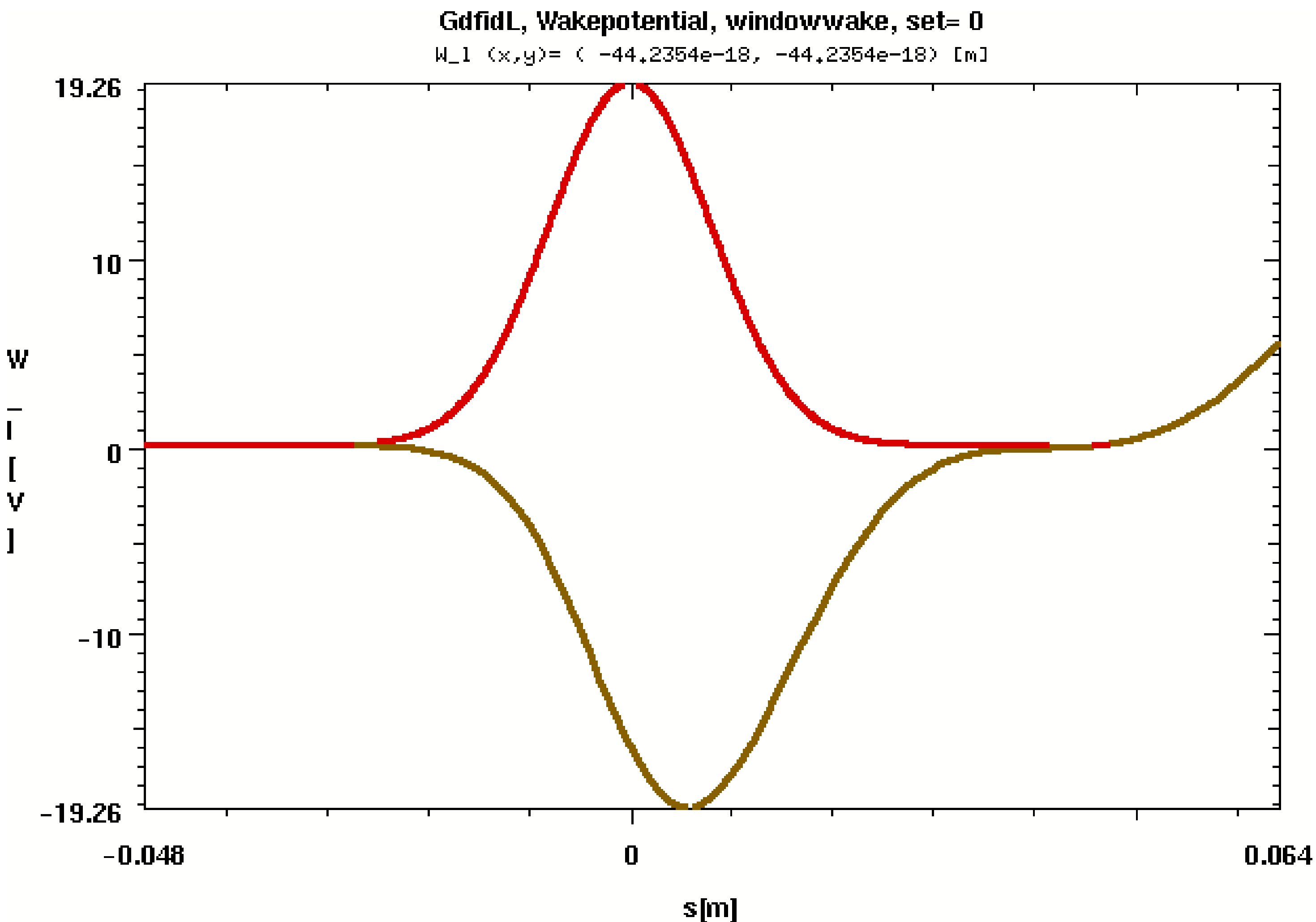
Muon Collider
Beam Loading

- Bunch charge of 2×10^{12}
- Assuming Tesla/ILC accelerating structure
- Extracts $\approx 8.3\%$ of stored energy per pass
  - Good for efficiency
  - Large fractional extraction for single bunch!

Muon Collider Wakefield

- Wake: maximum 6.2 MV/m for $\sigma = 8$ mm (Solyak & Yakovlev, Fermilab)
- Concerned with collective effects
  - Few turns
  - Lots of impedance
  - Large synchrotron tune helps
- Large potential well distortion
- Large HOM losses

Muon Collider Wakefield (Solyak & Yakovlev)



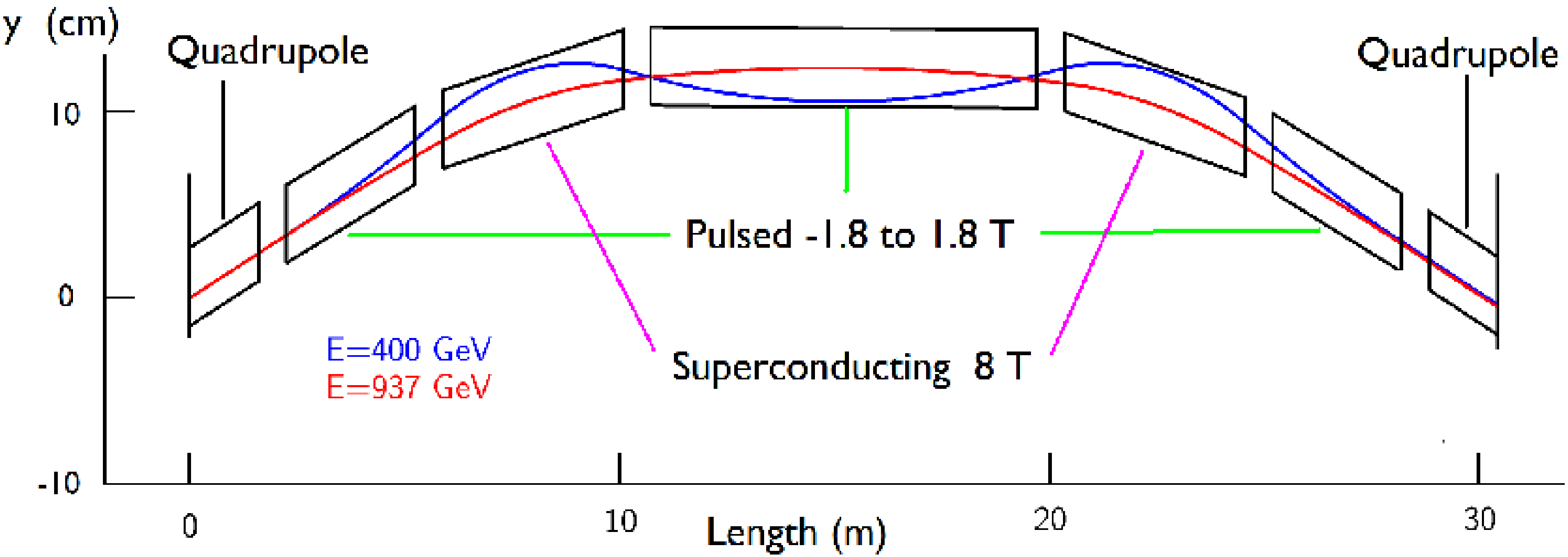
Muon Collider
Fast Ramping Synchrotron

- Hard to imagine 20-pass RLAs
  - Switchyard
  - Lots of arcs
- High energy: large circumference, consider ramping magnets
- Reduce eddy current losses
  - Thin (0.28 mm) laminations
  - Grain-oriented Si steel
  - Eddy current losses around 2 MW

Muon Collider
Fast Ramping Synchrotron

- Initial designs using Tevatron tunnel (Summers)
  - Accelerating to 750 GeV
  - Two stages
- High energy stage
  - Hybrid to get high average fields
  - Some magnets ramp -1.8 T to +1.8 T
  - Others fixed at high field
    - Watch coupling from ramped magnets!

Muon Collider
Fast Ramping Synchrotron



Muon Collider
Time of Flight

- Time of flight depends on energy
  - Fast ramping synchrotron or FFAG
  - Easily fixed in RLA
- Must adjust cavity frequency somehow
  - Ramp synchrotron to keep isochronous?
- Effective loaded Q to adjust frequency
  - Maybe OK for non-hybrid synchrotron
  - Hybrid too low ($\approx 4 \times 10^4$)

Muon Collider R&D Tasks

- Study various acceleration options
  - Refine fast ramping synchrotron lattices
  - R&D on fast ramping magnet design
    - Coupling to static magnets in hybrid
  - Consider FFAG
- Collective effects with high bunch charge

Conclusions

- IDS neutrino factory design
  - Have acceleration scenario
  - Have initial designs for some components
  - Will continue to complete design
  - MERIT results important: bunch structure
- Research on Nb on Cu cavities important

Conclusions

- Muon collider acceleration design
  - Need to work out scenarios
  - Study collective effects with large single bunch currents