



# Hybrid Fast-Ramping Synchrotron to 750 GeV/c

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# Basic Concept (Summers)

- Synchrotron: many turns, small aperture
- Large average bending field: superconducting magnets
- Vary field rapidly (decays): room temperature
- Interleave warm and superconducting dipoles
- Ramp warm dipoles from negative to positive
- Experimental results on rapid cycling dipoles reported Sunday (Summers)

# Basic Lattice Structure

- Accelerate 375 GeV/c to 750 GeV/c
- 8 superperiods containing arc cells, 3 straight cells, matching between (2 cells each side)
- All FODO cells
- Quadrupoles split, leaving space for sextupole
- 8 T superconducting dipoles, 1.8 T maximum warm dipoles, 1.3 T maximum quadrupoles
- Keep tunes constant during acceleration

# First Lattice Design (Garren)

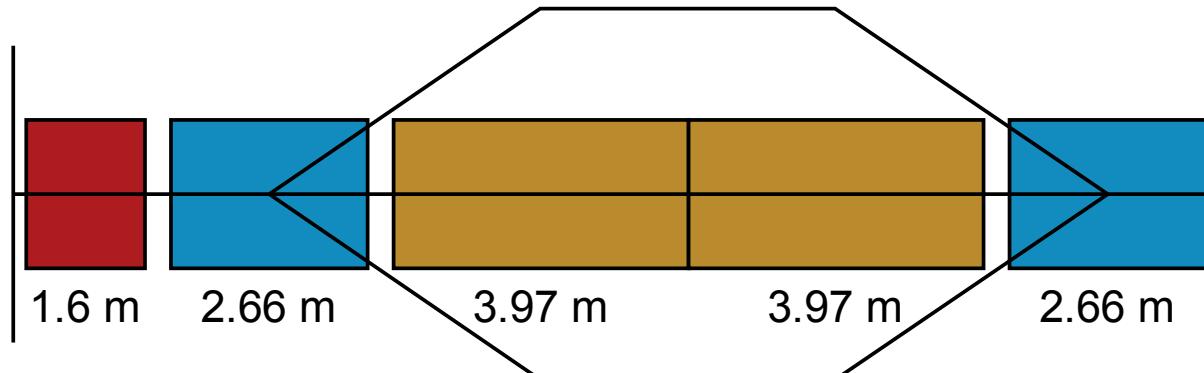
- Arc (6 cells/superperiod) and matching cells
  - Quarter cell: cold-warm-cold dipoles. Beam centered in quads at all energies
  - Tune 0.25
- 6294.5 m circumference
- Matching cells:  $\frac{3}{4}$  cell length,  $\frac{2}{3}$  dipole length,  $\frac{4}{3}$  quadrupole length w.r.t. arc
  - Half arc dispersion, half oscillation, dispersion zero
  - High dipole packing fraction

# First Lattice Design (Garren)

## Superperiod Structure



## Quarter Arc Cell



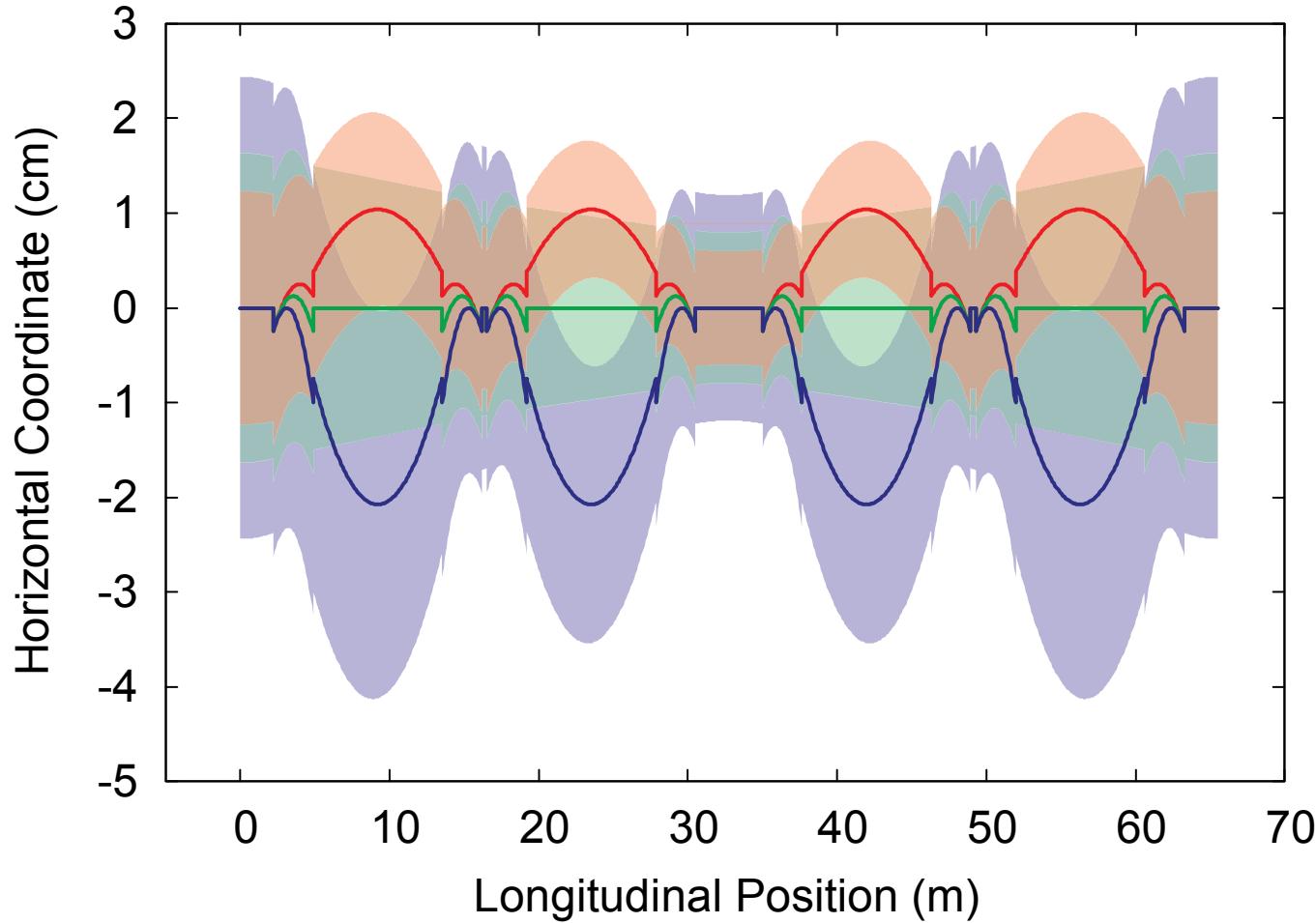
# Field Variation with Beam Energy

- Set fields depending on beam energy
- Phase advance constant in arc cells, matching section, straight section
- Dispersion, closed orbit zero in straight
- Beta functions matched to arc cells
- Resulting dipole, quadrupole fields linear in momentum to within 1%

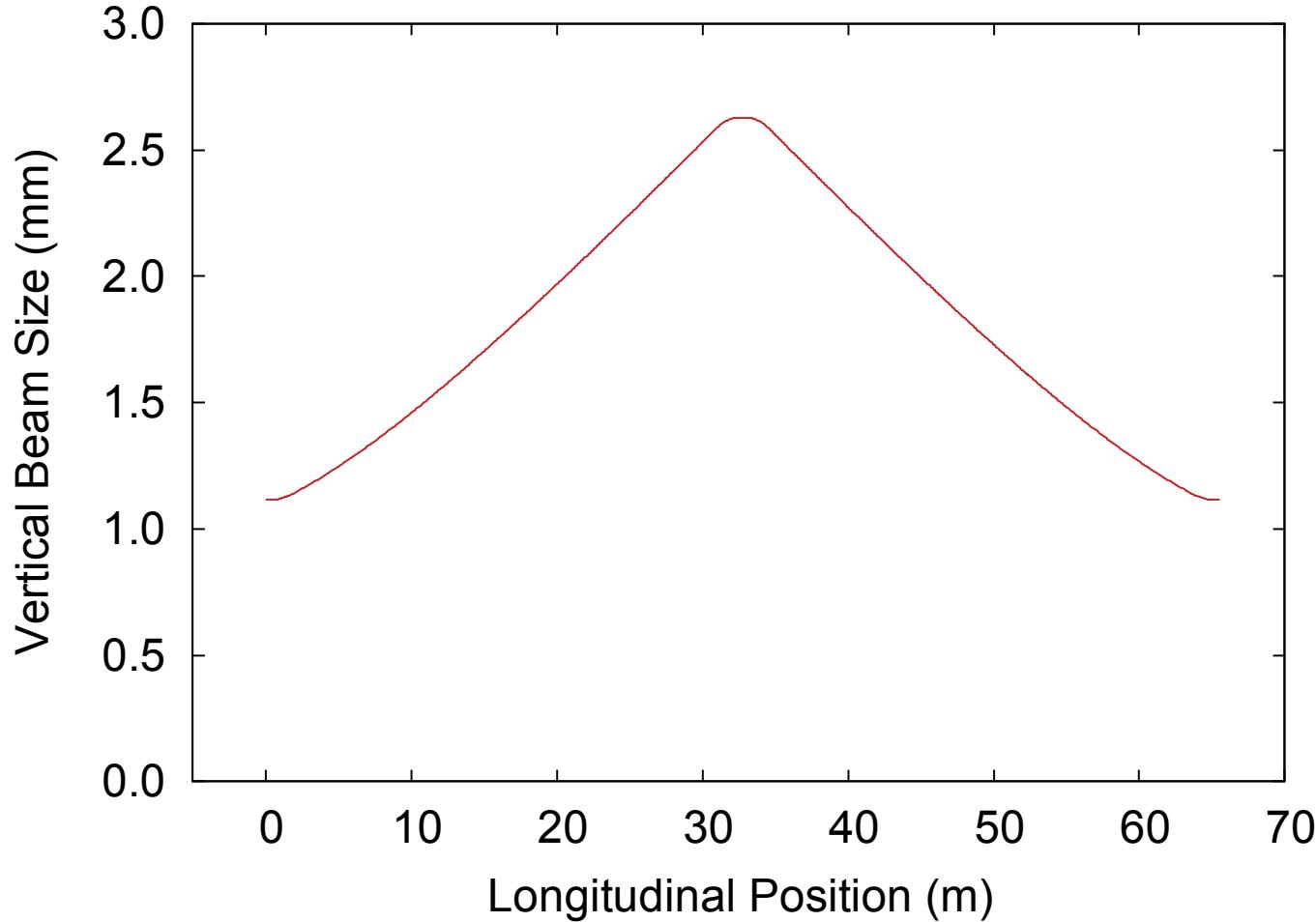
# Beam Size

- Horizontal beam size: two contributions
  - Closed orbit variation with energy
  - Dispersion size of beam
    - Large longitudinal emittance
  - Betatron size negligible
- Small vertical beam size
  - Impedance considerations drive vertical aperture

# Horizontal Aperture in Arc



# Vertical Aperture in Arc



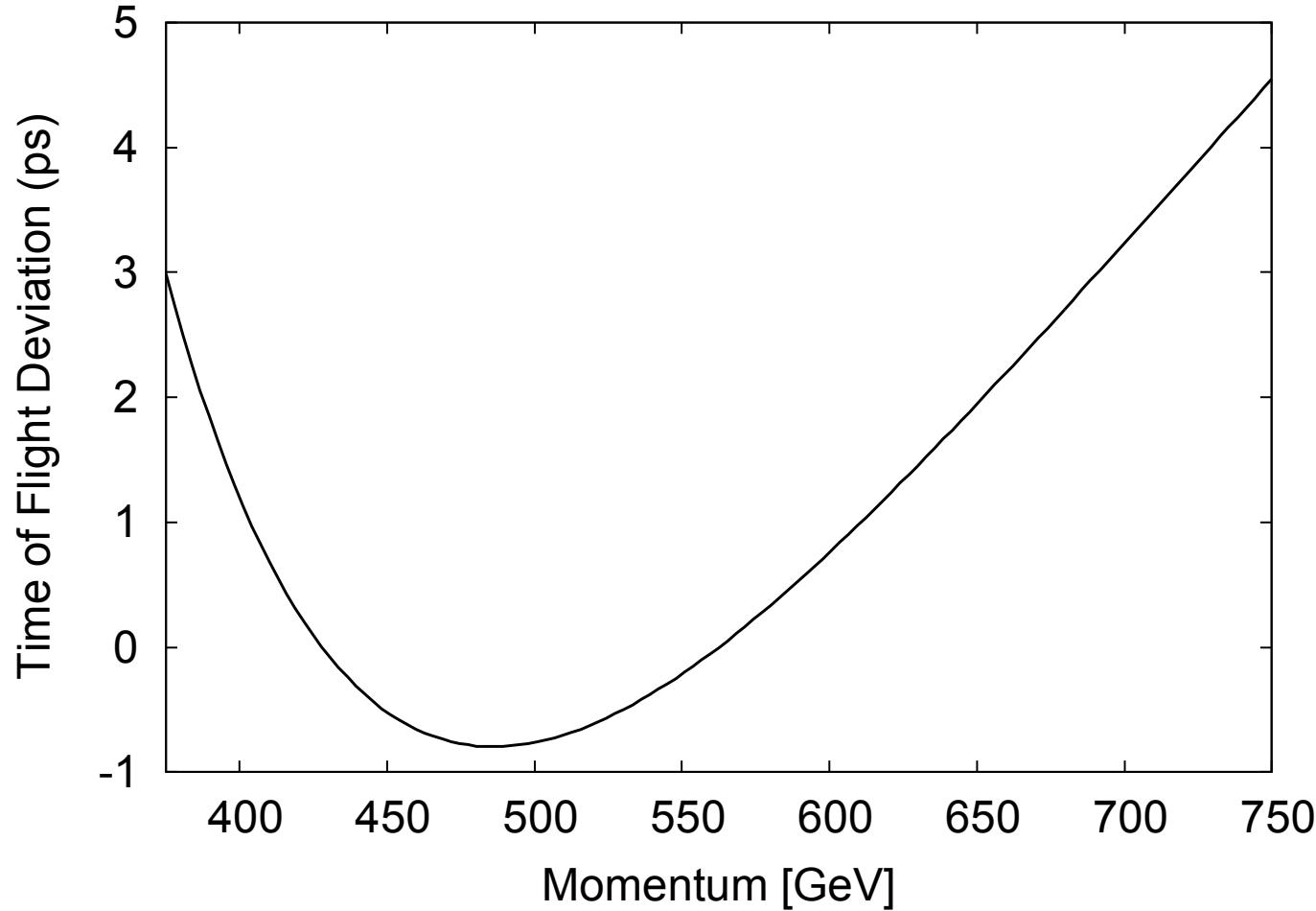
# Reducing Horizontal Size

- Shorter cells with same phase advance
  - Reduce closed orbit variation with energy
  - Reduce dispersion
- More dipoles per cell
  - Reduce closed orbit variation with energy
- Both add inter-magnet drifts
  - Increase decays and circumference
- Shorter cells require longer quads

# Time of Flight Variation

- Time of flight depends on momentum
- Variation large enough that
  - Likely cannot maintain stable synchrotron motion
  - Bucket size will vary during acceleration
- Could reduce variation
  - Shorter cells with same phase advance
  - More dipoles per cell

# Time of Flight



# Time of Flight Variation

- Can keep constant time of flight during acceleration
- Allow orbit motion in quadrupoles
- Some increase in horizontal aperture
- Combining with matching, straights more complex
- Have constructed sample arc cells, work in progress

# Longitudinal Parameters

- Momentum compaction 0.00241
- Assume 24 turns, 1.3 GHz RF
- $4\sigma$  to bucket, RF phase  $45^\circ$  off crest
  - Large longitudinal emittance (0.025 eV s)
  - To get closer to crest
    - Reduce momentum compaction: shorter cells, same phase advance
    - Fewer turns (more RF): probably not advantageous

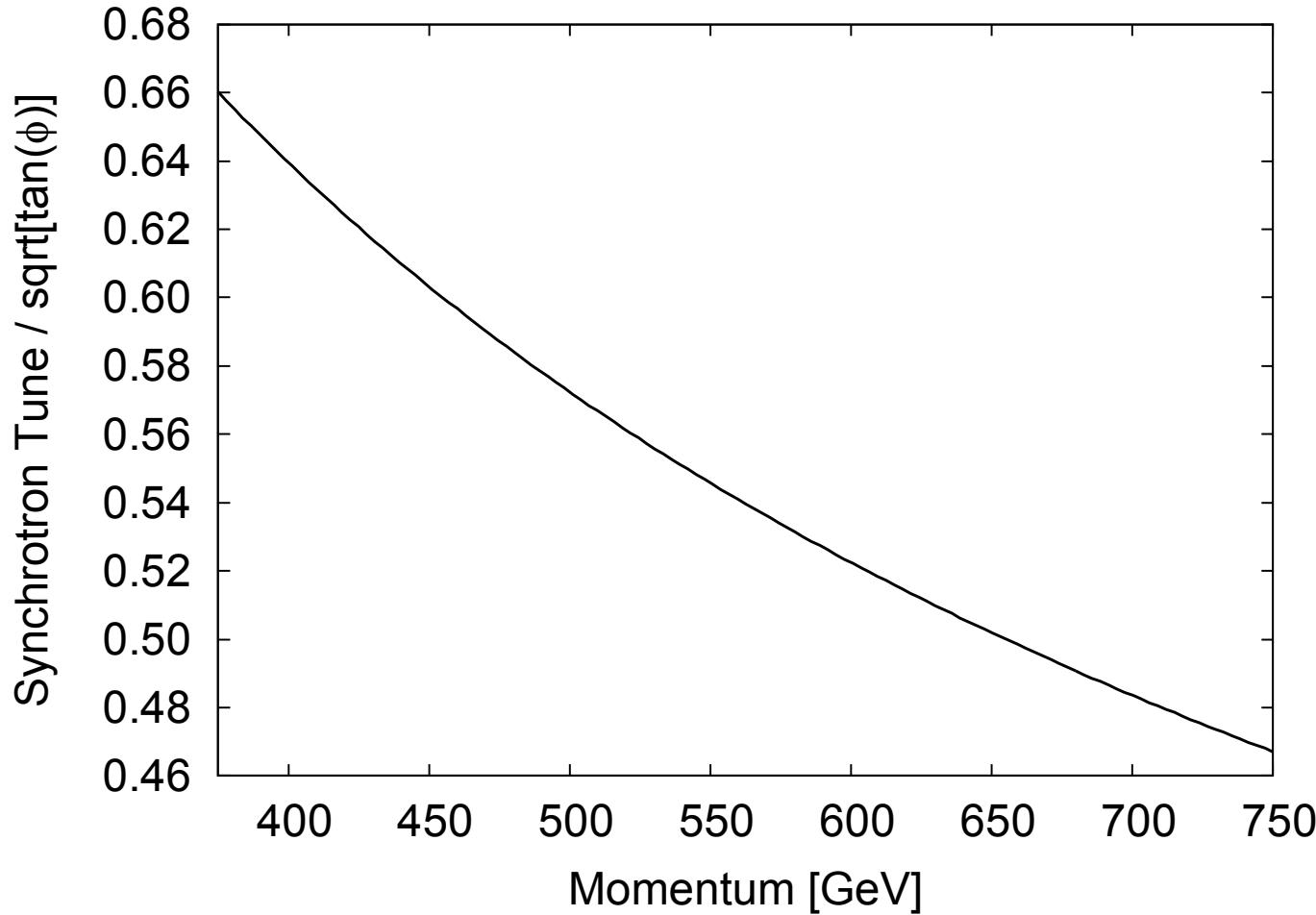
# Longitudinal Parameters

- Lowering RF frequency (e.g., 800 MHz)
  - More turns to get efficiency
    - More decays
    - Ultimately makes bucket area worse
  - Lower impedance
  - Reduction in synchrotron tune
    - Lower impedance probably a net win

# Longitudinal Parameters

- High synchrotron tune: as high as 0.66
- Helps stabilize some collective effects
  - To increase would make other parameters worse
    - Increase momentum compaction: RF phase, horizontal aperture, time of flight variation worse
    - More RF: less efficient
- Not large enough to require 8 superperiods
  - 6 would suffice

# Synchrotron Tune



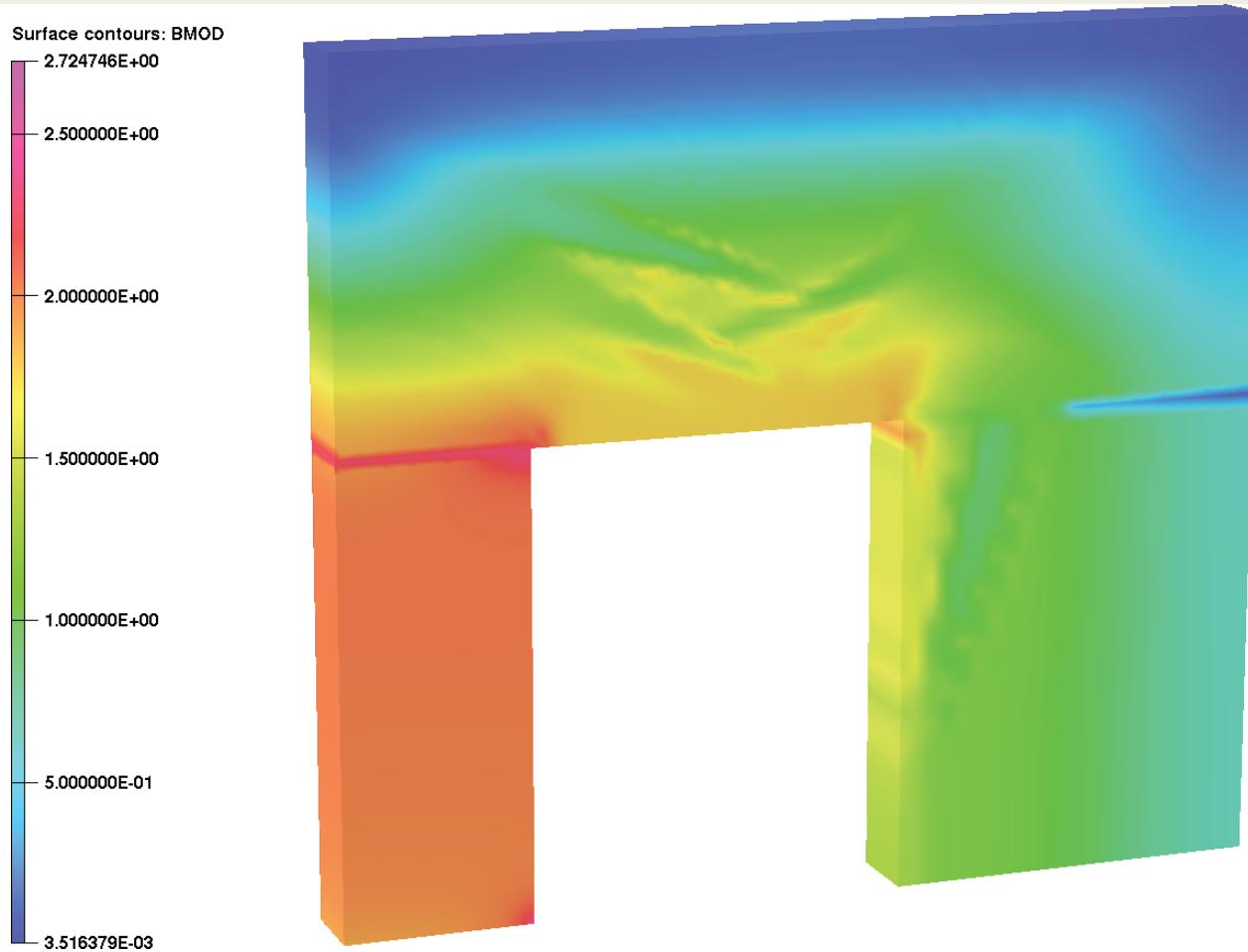
# Rapid Cycling Magnets

- Higher dipole/quadrupole fields enable
  - Shorter circumference: fewer decays
  - Larger energy range
- Some solutions studied (and built!)
  - Grain-oriented Silicon Steel:  $\geq 1.7$  T (Summers Experiment)
    - Low loss, high field
  - Fe-Co alloy with 6.5% Si Steel frame:  $\geq 2.0$  T (Witte Simulation)
    - Higher losses

# Simulating Grain Oriented Steel

- Commercial codes don't seem to handle anisotropic materials well (Witte)
  - Convergence problems
- If we want to explore grain oriented materials, will need effort devoted to simulations
  - Area of active research (generators, motors)
  - Potentially significant effort unless we can get commercial codes to behave

# Grain Oriented Steel Simulation Convergence



# Summary

- Have a first design for a hybrid synchrotron lattice (Garren)
- Would like to improve this
  - Time of flight control
  - More dipoles (alternating warm/cold) per cell
  - Fewer superperiods
  - Consider tradeoffs for shorter cells
- Anisotropic steel requires simulation program

# Long Term Plan

- Once final stage is decided, look into plan for earlier stages
- Study collective effects
- Study important effects in lattice
  - Eddy currents in vacuum chamber
  - Error tolerance, including deviation from design current profile
- Full 6-D simulation essential