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Innovation in Research

PIC & REMEX Lattice Simulation

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Muons, Inc.

NFMCC Friday Meeting
20 April 2007

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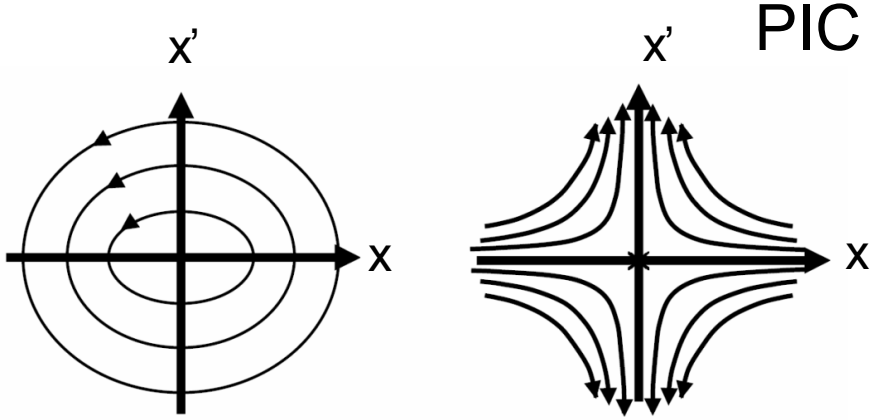
Innovation in Research

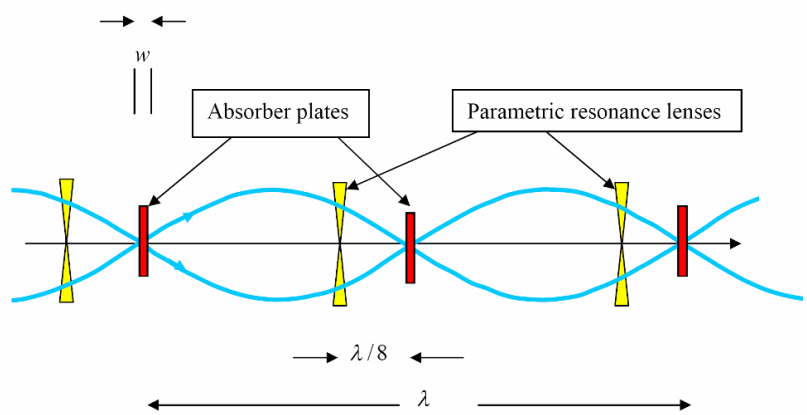
PIC & REMEX Lattice Simulation

- History
  - Concept
  - Synchrotron RF Correction
  - OptiM Model and Spherical Aberration Correction
  - Detuned Lattice G4BL Results
- New Stuff
  - Solenoid Model
  - Resonant Tuning
  - Emittance Growth
  - Resonant Tuning Redux
- Workshop 21-22 May at FNAL

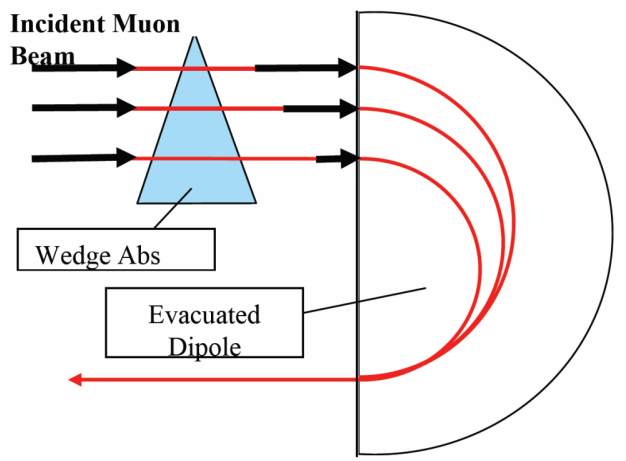
PIC/REMEX Concepts

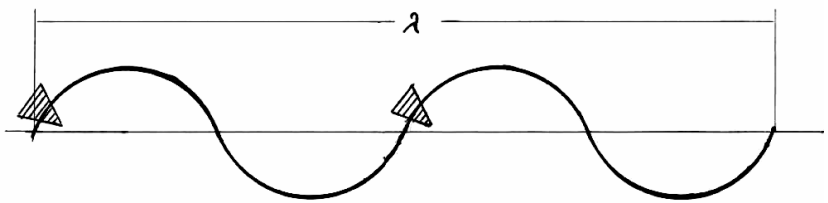
PIC



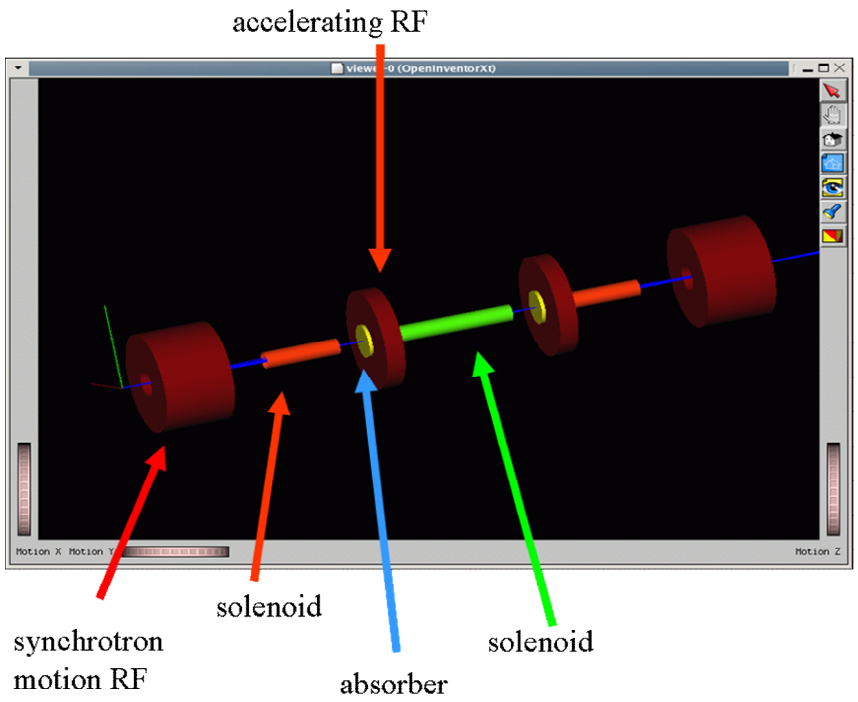


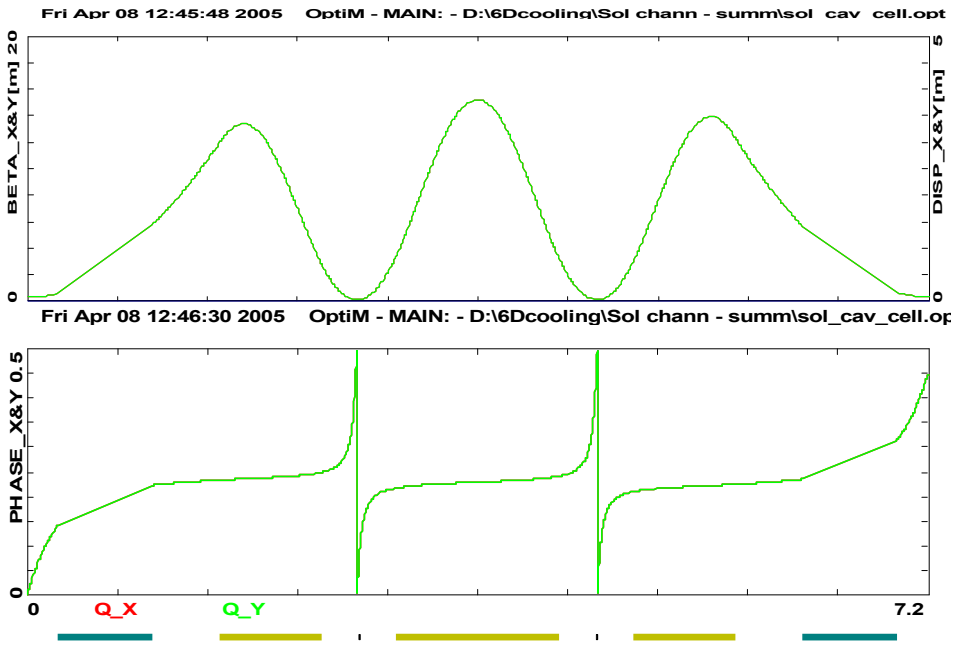
REMEX





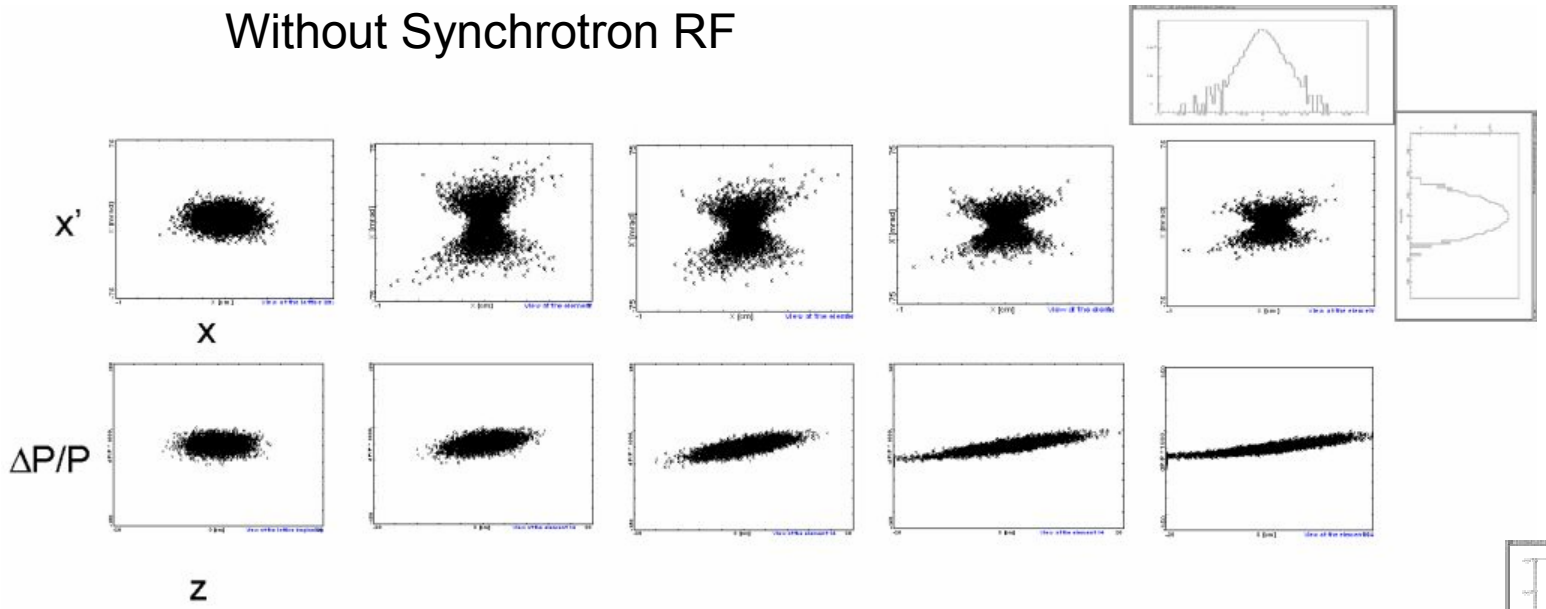
Solenoid Triplet Cell with Synchrotron RF Cavity



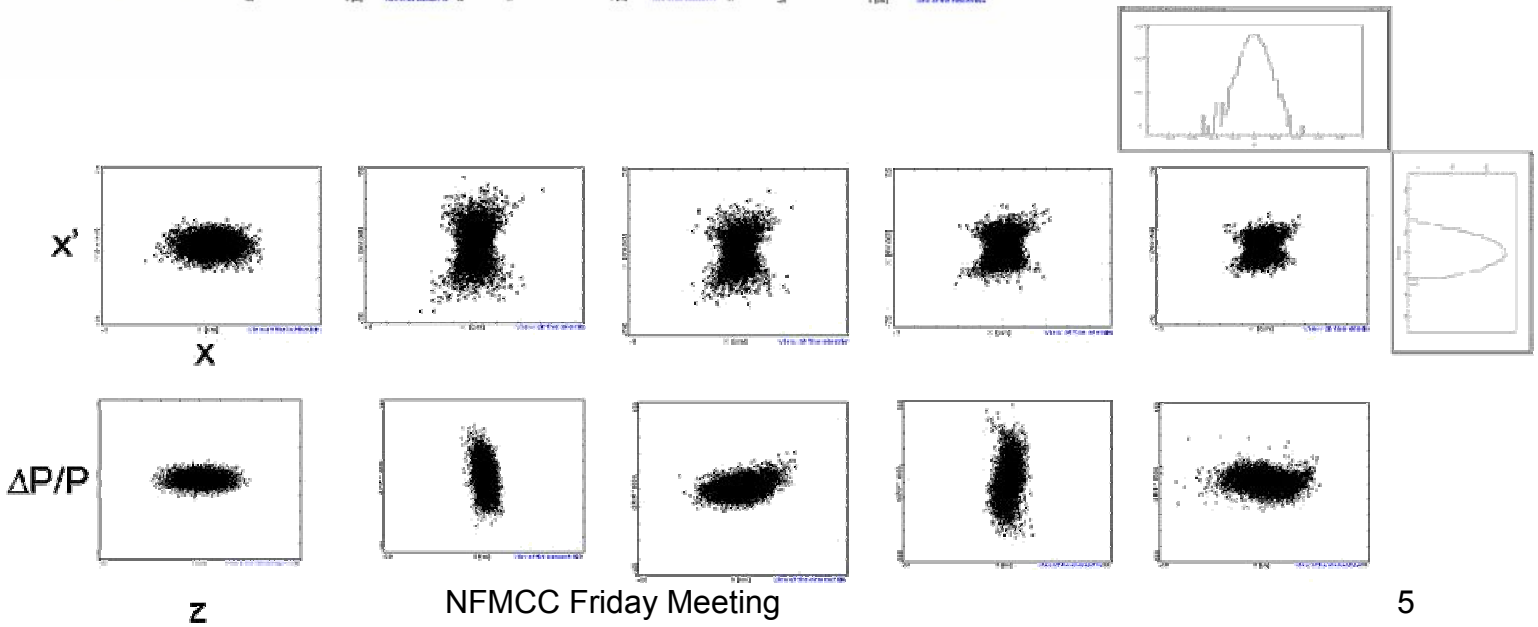


OptiM Synchrotron Results

Without Synchrotron RF

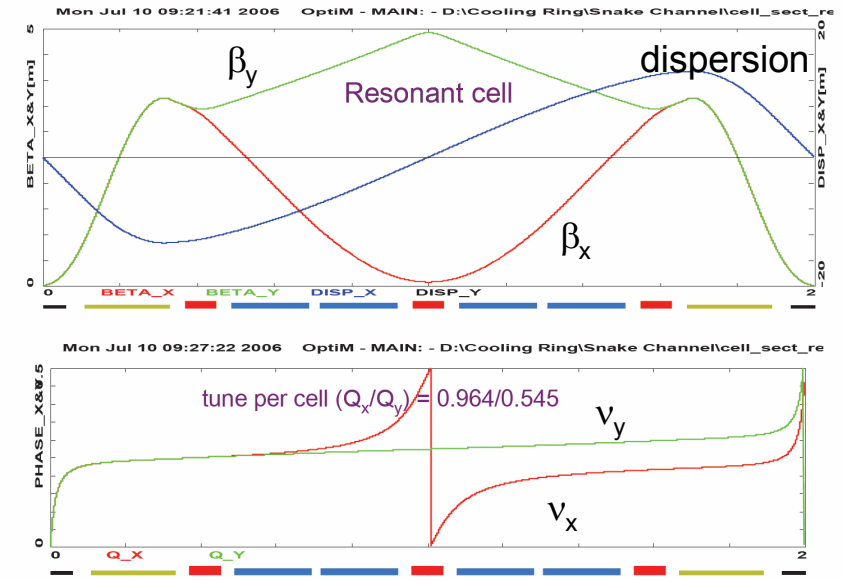


With Synchrotron RF

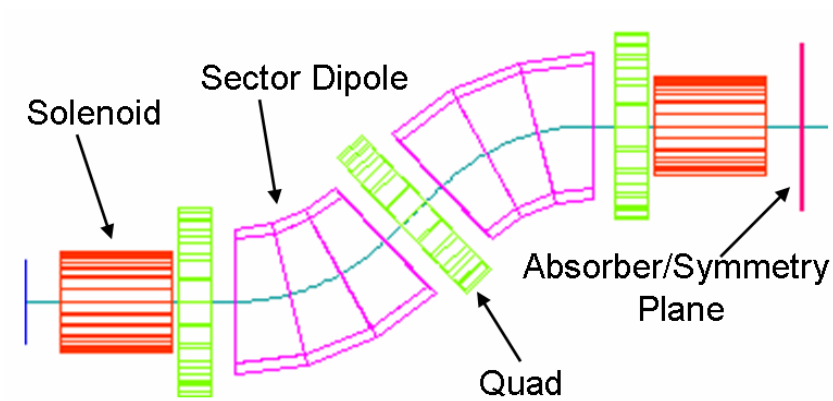


Lattice Layout

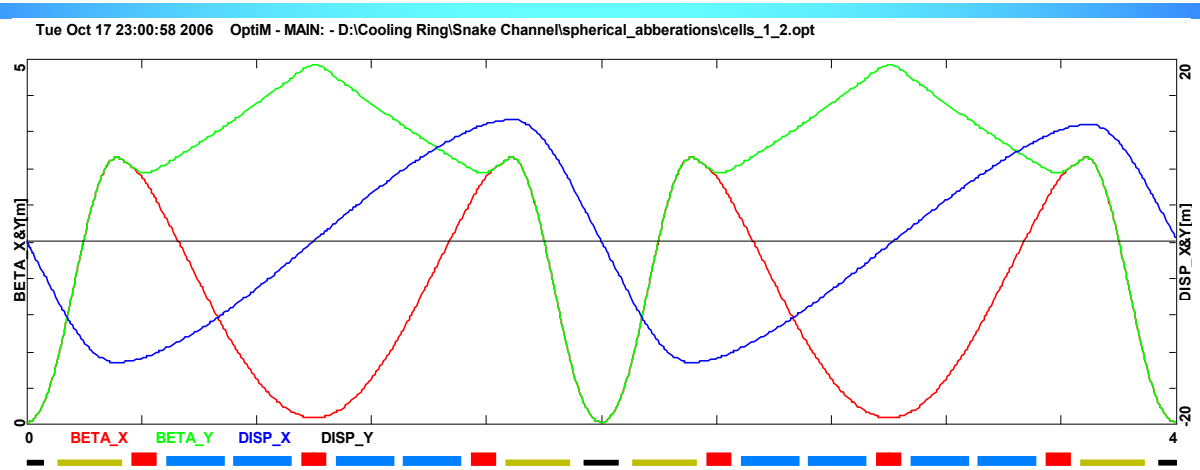
OptiM Model



G4Beamline Model

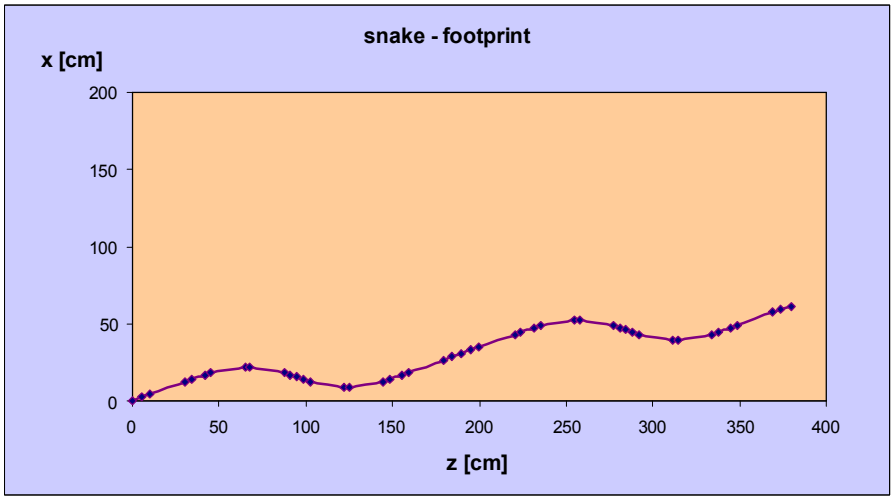


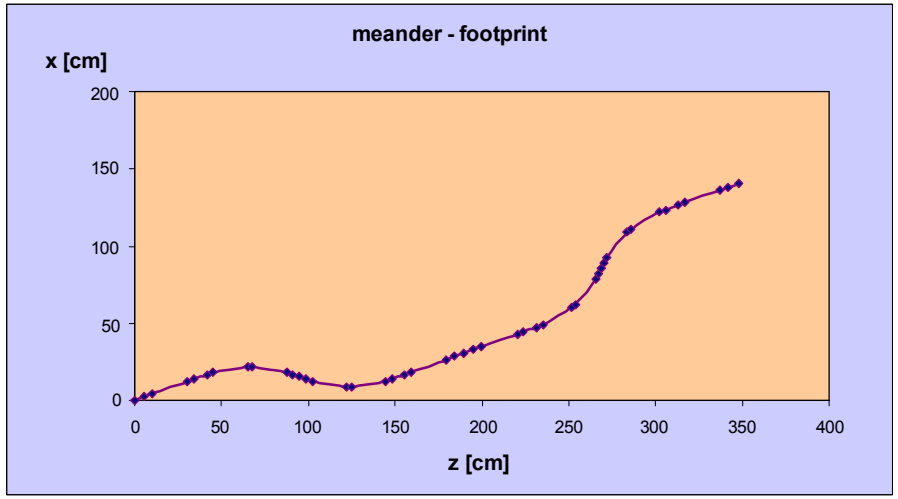
‘Snake’ vs. ‘Chicane’ Layout



‘snake’ L R L R

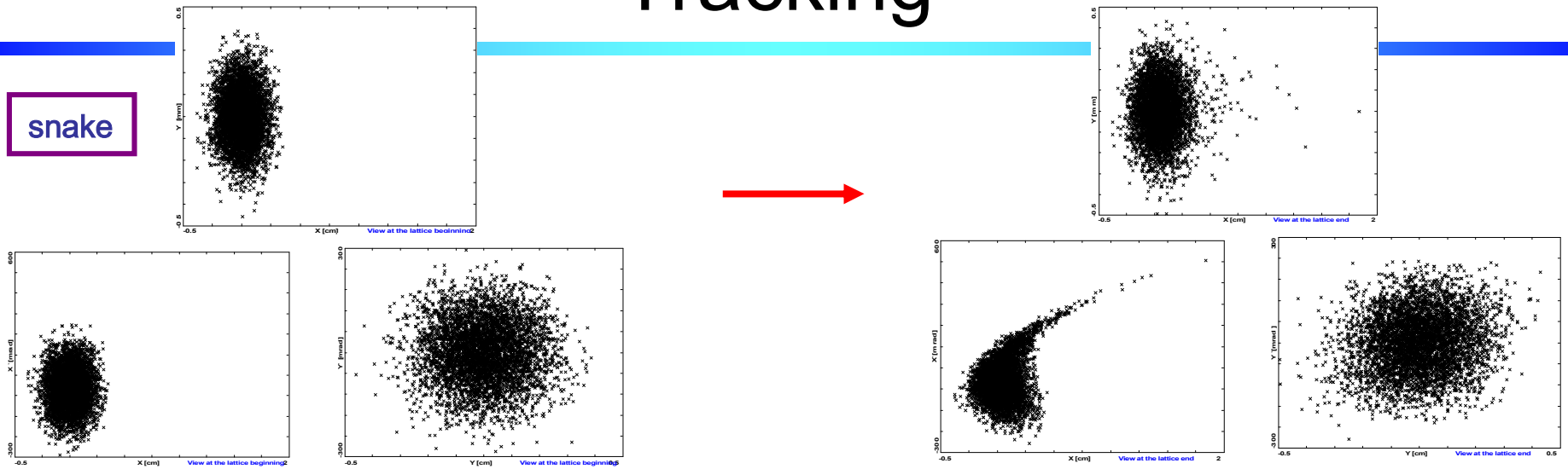
‘chicane’ L R R L



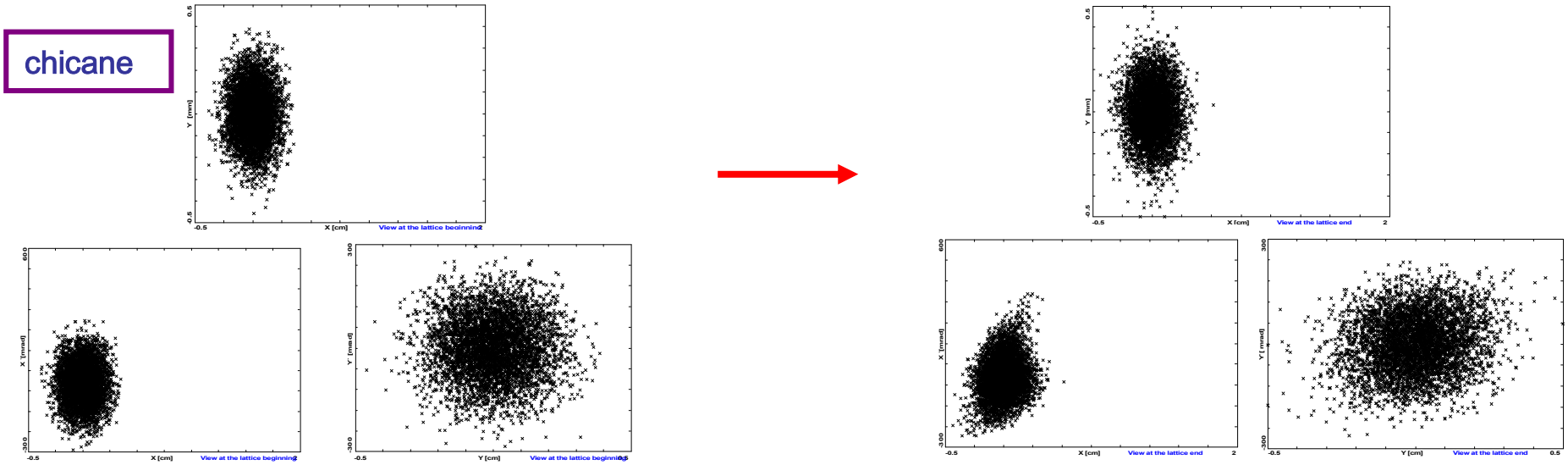


‘Snake’ vs. ‘Chicane’ – Tracking

snake

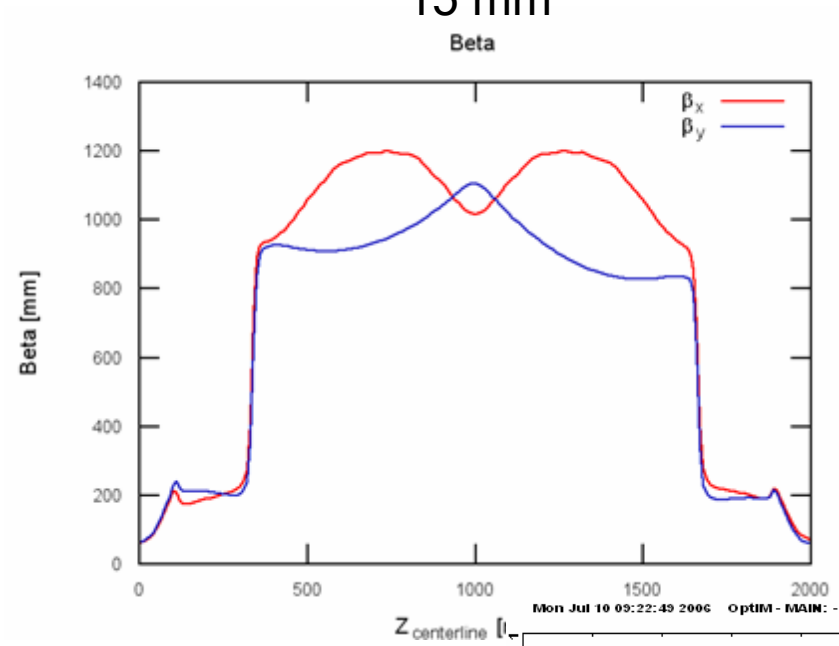


chicane

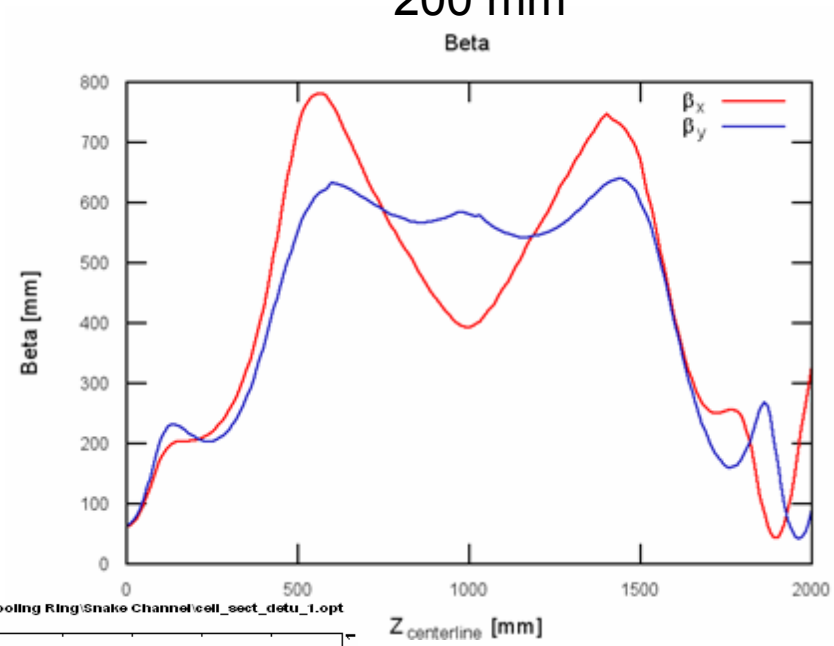


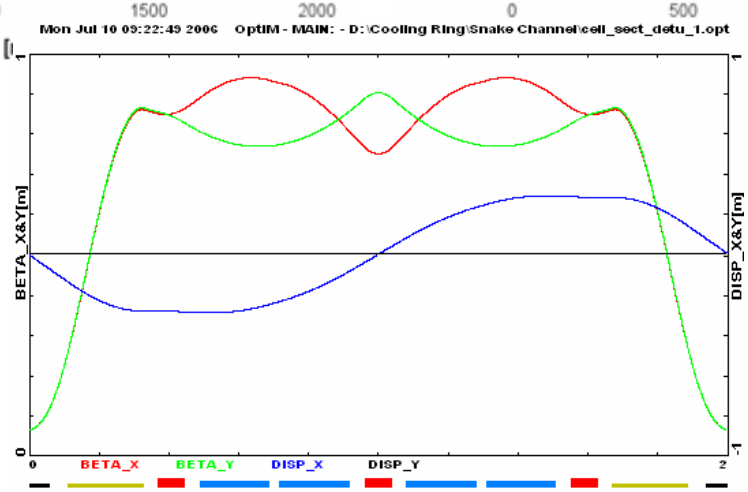
Detuned Single-Cell Beta

15 mm



200 mm



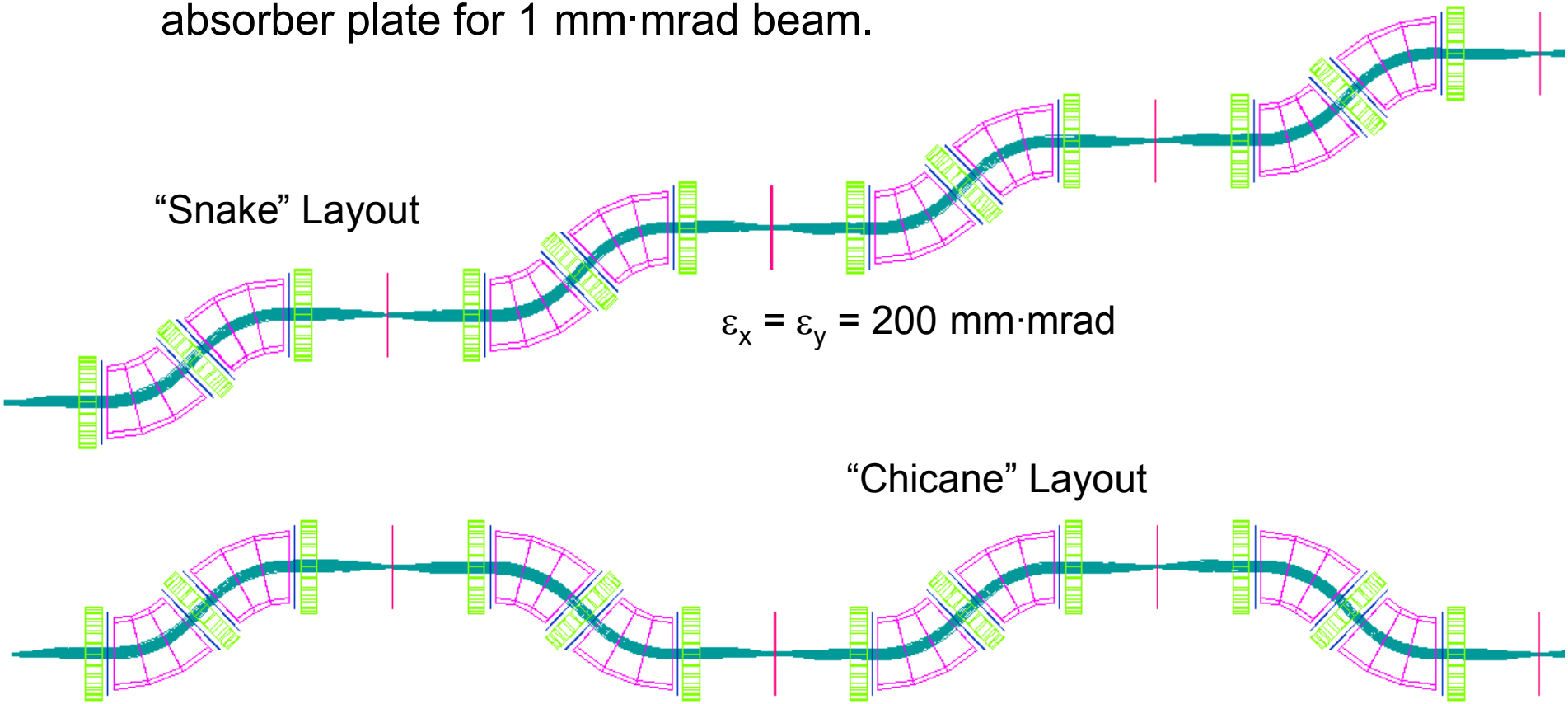


Detuned OptiM Result

Large Transverse Beams are Focused

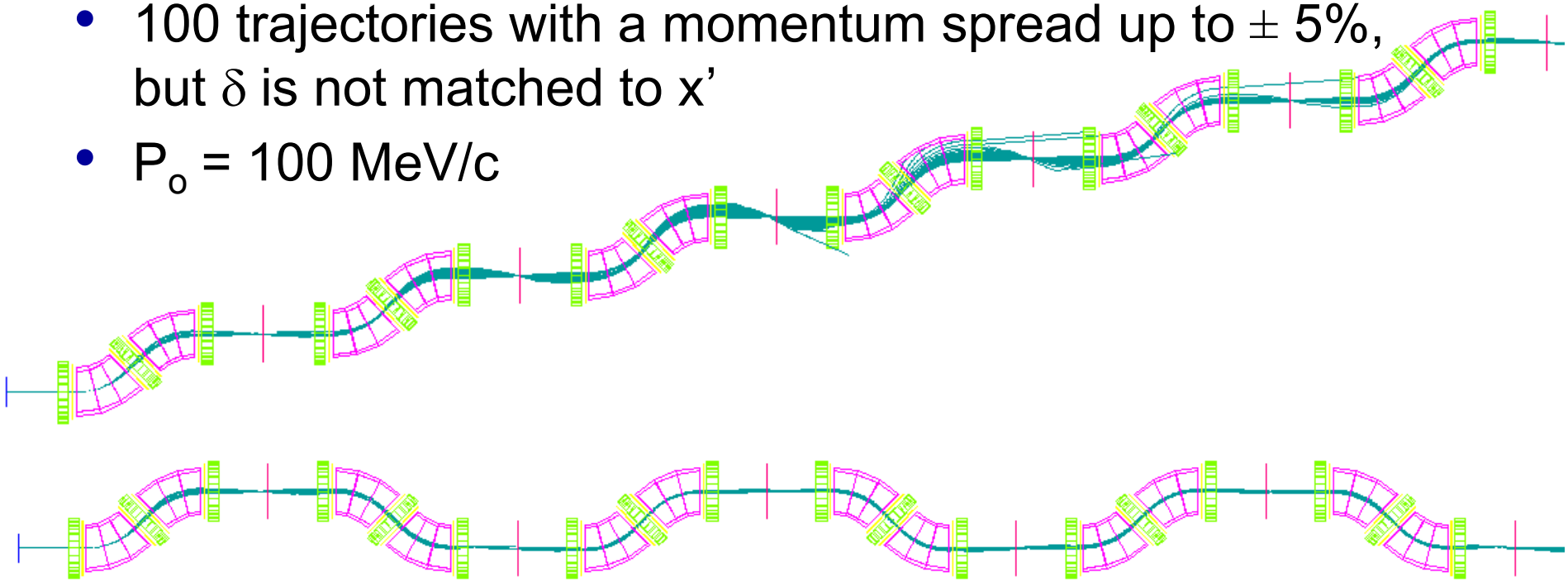
No momentum spread

Solenoid (invisible) and quadrupole (green) fields adjusted to give near constant beam size at absorber plate for 1 mm·mrad beam.



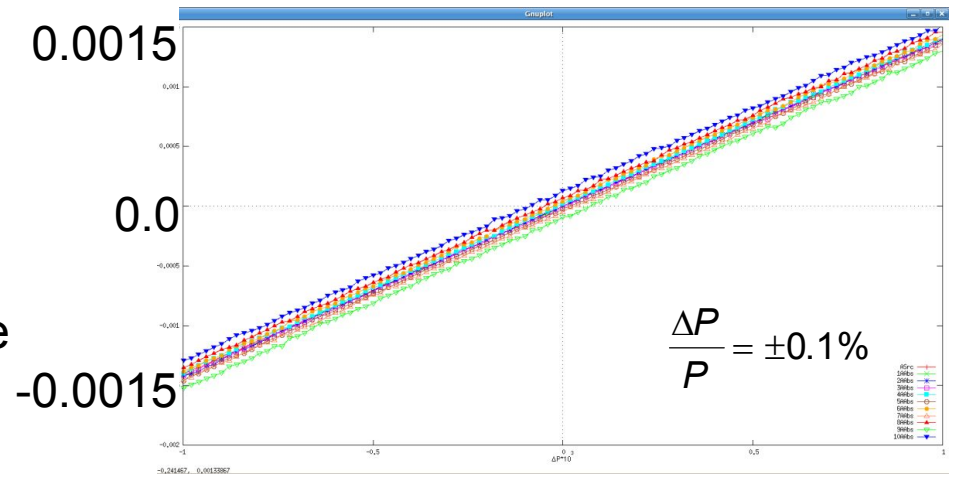
Dispersion Prime

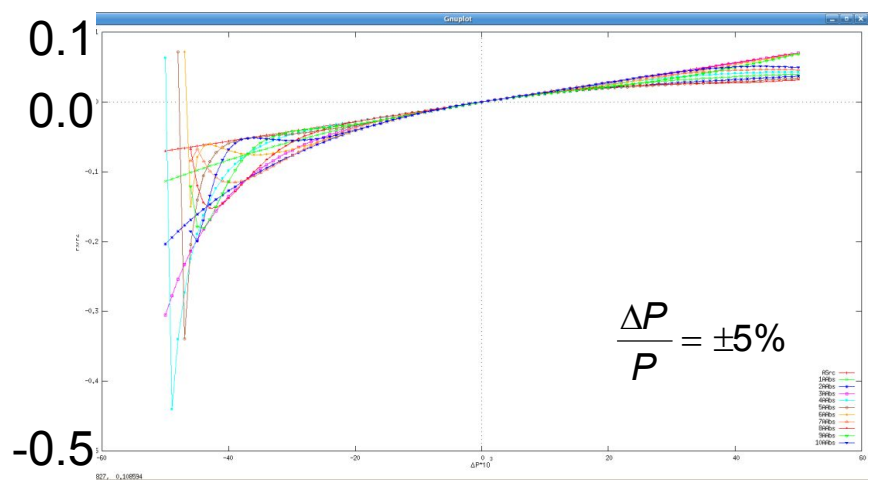
- Initial beam at $x = x' = y = y' = 0$
- 100 trajectories with a momentum spread up to $\pm$ 5%, but δ is not matched to x'
- P_o = 100 MeV/c



Matched Dispersion Prime

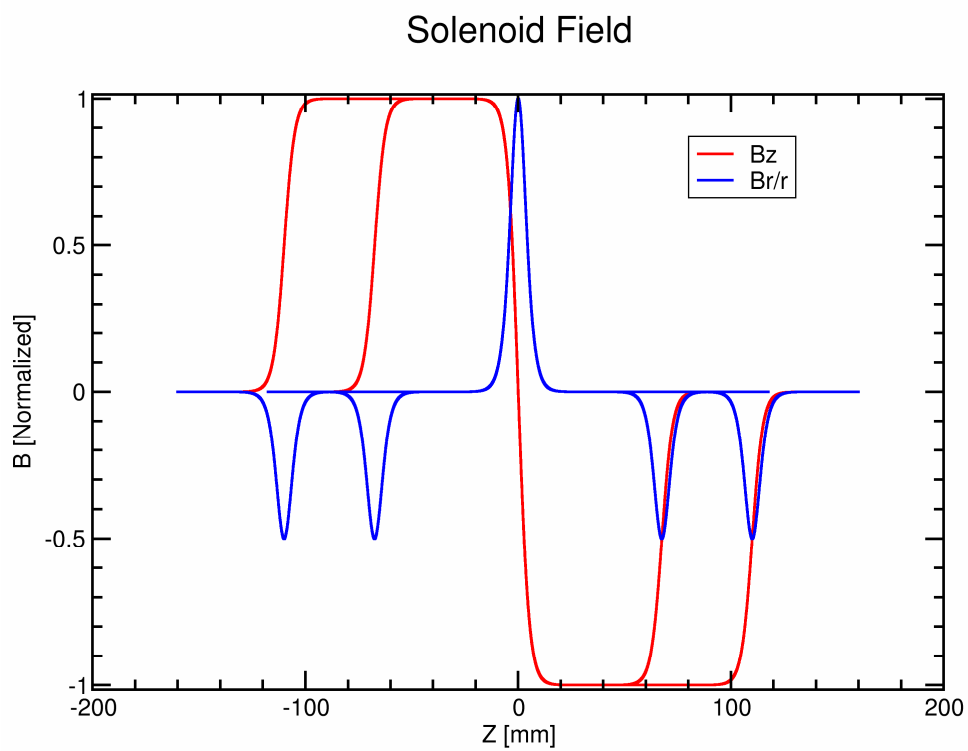
- Snake lattice studies
  - Match initial values of x' vs. δ to get best beam behavior along the beamline
  - Study wider momentum spread: chromatic aberrations cause particle loss at low momenta (10 cells)
- Chicane lattice shows very different behavior – unmatched but bound trajectories at the same dispersion prime





Lattice Solenoid

- G4BL “coil/solenoid” element was replaced with a field map that used a thin solenoid (tanh approximation) with no radial dependence and a rapid cutoff.
- Satisfies Maxwell’s equations, but corresponds to a small-aperture counter-wound solenoid.
- Although the fields did not extend to the symmetry planes (“absorbers”), the symmetry of the counter-wound solenoid provides for bucked fields at the absorbers.
- Shortened to provide more space for absorber/energy recovery.



Resonant Model

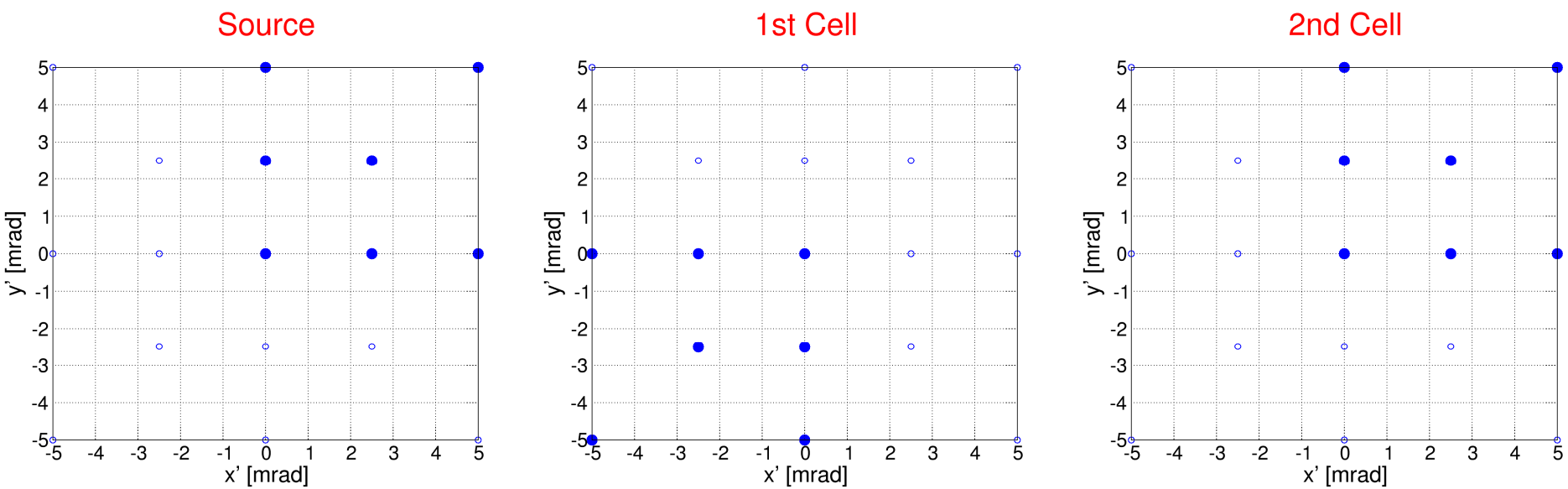
- Physical layout is the same; solenoid and quadrupole fields are adjusted so that

$$\lambda_x = \lambda_y = 2\lambda_{Dispersion} = 2 \text{ Cells}$$

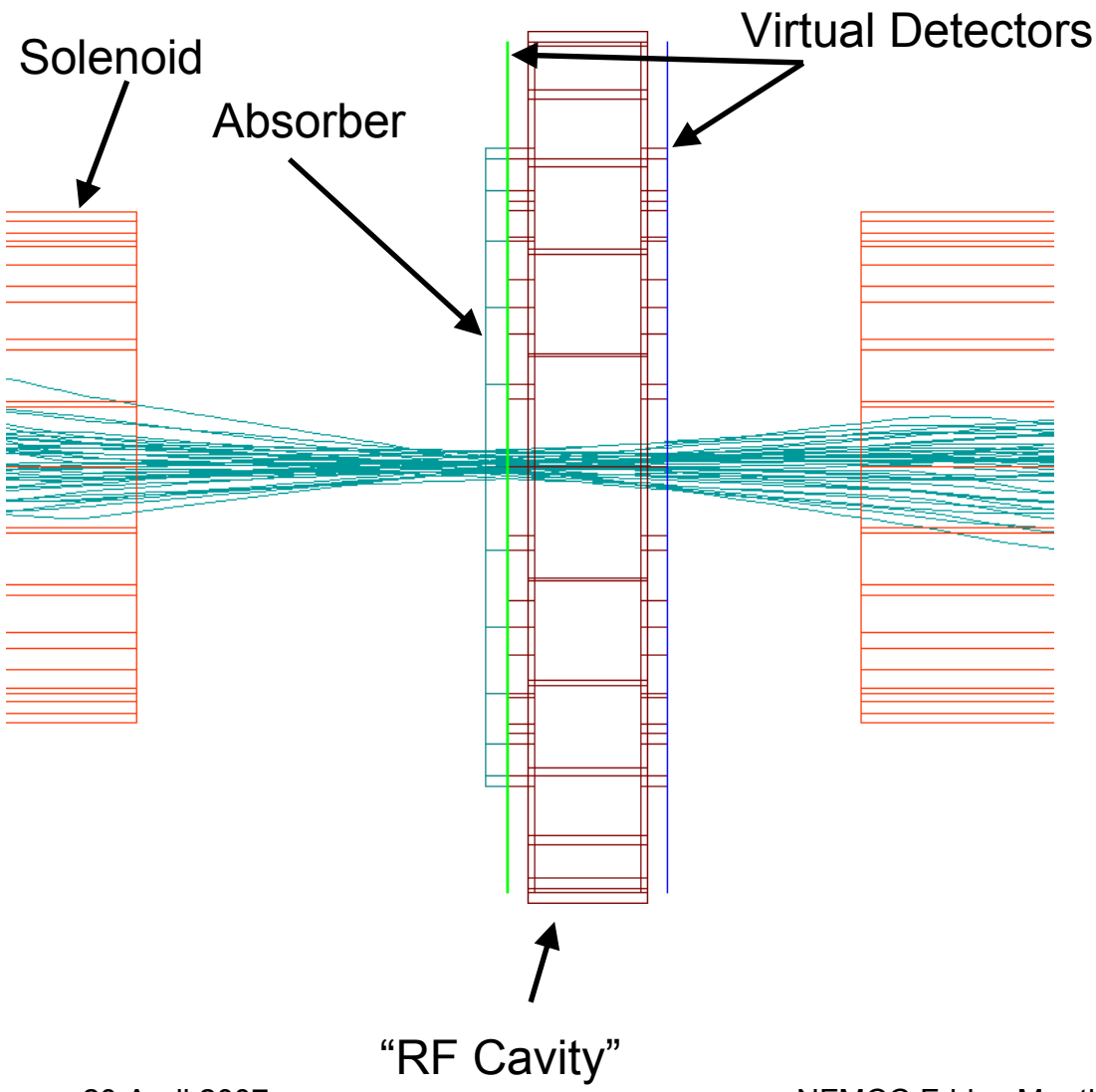
- π betatron phase advance/cell in horizontal (x) and vertical (y) means that from absorber to absorber, x' $\rightarrow$ -x' and y' $\rightarrow$ -y'.
- G4BL can automatically tune the dipoles so that the reference particle stays "centered" to within a tolerance.

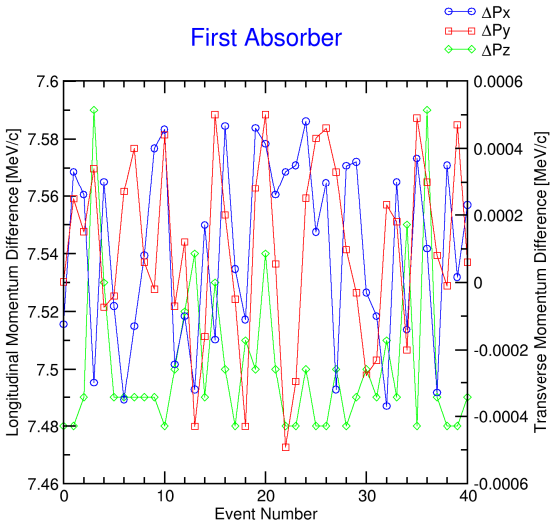
Resonant Tuning

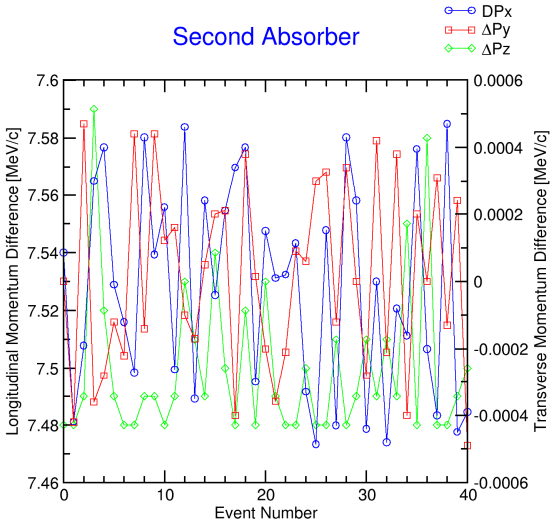
- 16 particle + reference fixed source distribution input, with x = y = δ = 0
- Deviations from anticipated conditions added at the absorber plane
  - Cell with largest deviation determines error
  - Last cell may not be dominant (but usually is)
- Solenoid and quadrupole fields are tuned to give a minimum error with all cells having the same field values



Absorber and Energy Recovery

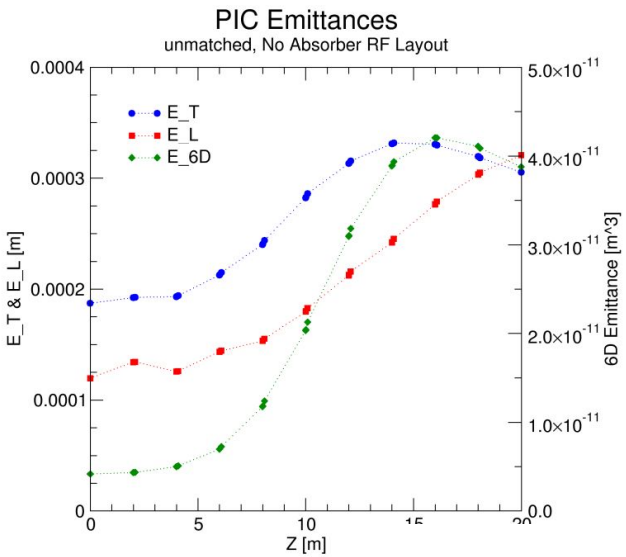




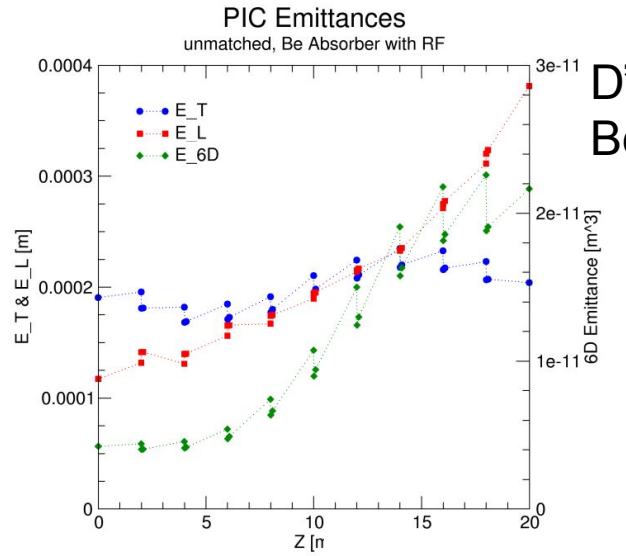


Emittance Calculations

2000 particles

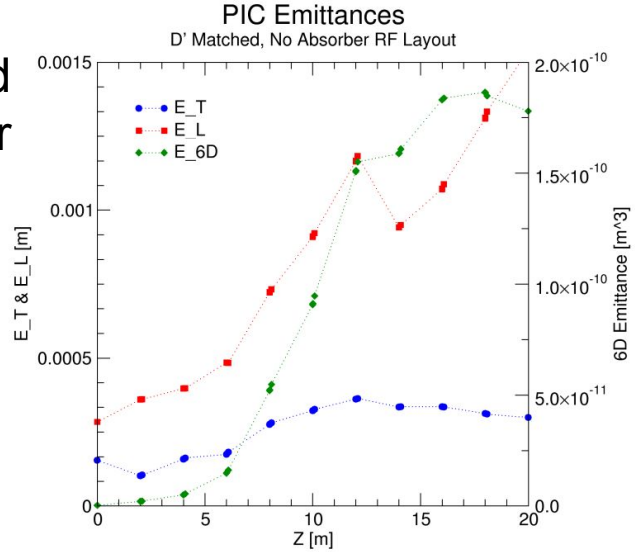


D' Unmatched
No Absorber

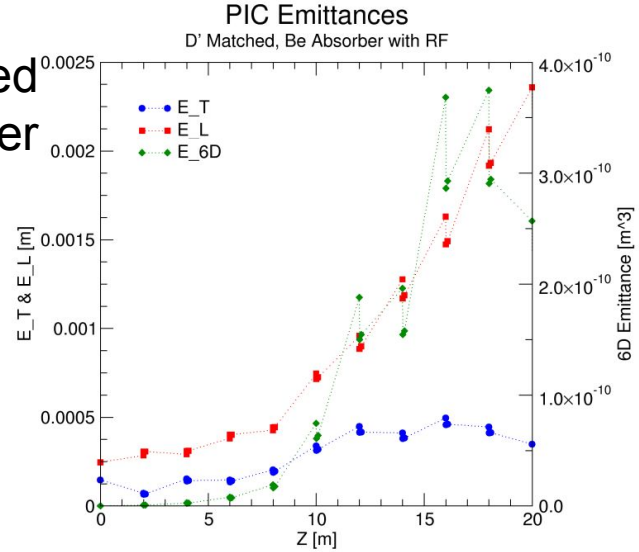


D' Unmatched
Be Absorber

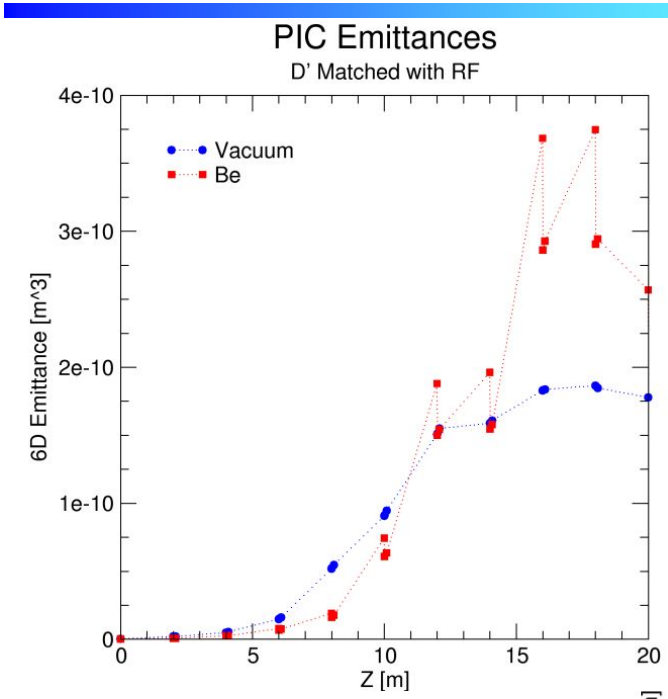
D' Matched
No Absorber

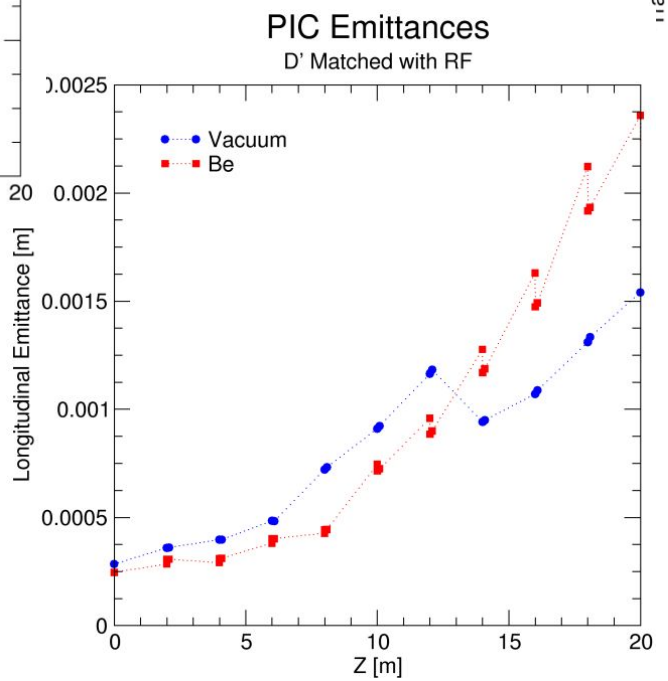


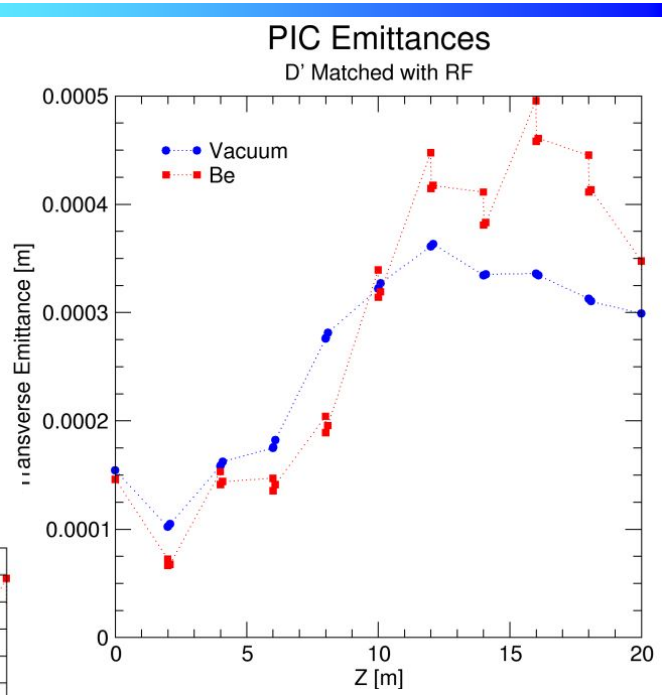
D' Matched
Be Absorber



Emittance Comparisons







Emittances showed growth even at small initial values.

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Emittance Growth

- Possible Sources
  - Improper Resonance Tune
  - Improper Dispersion Match
  - Higher Order Effects
    - Chromatic & Spherical Aberrations
    - Resonance Effects
  - Optimizations focused on beam parameters rather than particle tracking
  - “non-linear” drift emittance growth
- Next Steps
  - Review Particle Tracking Optimizations
  - Include Sextupole & Octupole Magnets
  - Understand details before moving onto next step

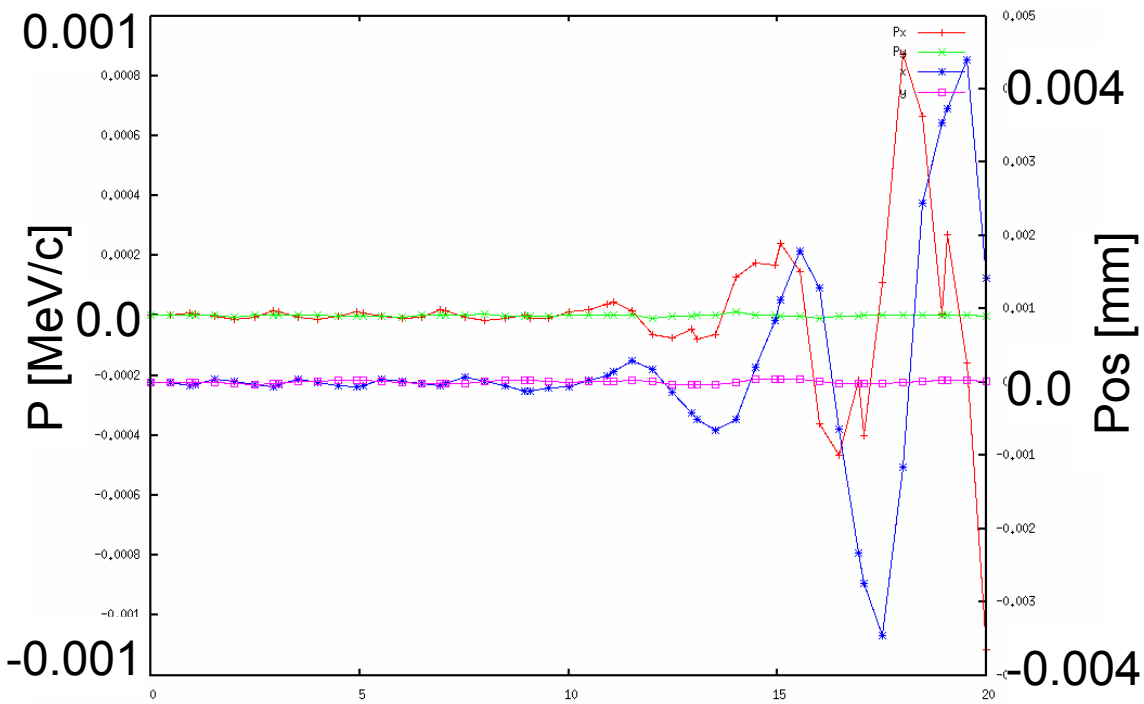
Resonant Tuning Redux

- Several Stages of Lattice Optimization Before Full Beam Studies
  - Is *Reference Particle* following best path? (*Dipole* Tune)
  - Are *Solenoids & Quads* at the correct values for ½ integer resonance?
    - Are *Dipoles* still at the correct value?
  - What is the correct value of the dispersion and the slope of the dispersion for the entrance beam?
  - Chromatic Aberration Correction
  - Spherical Aberration Correction

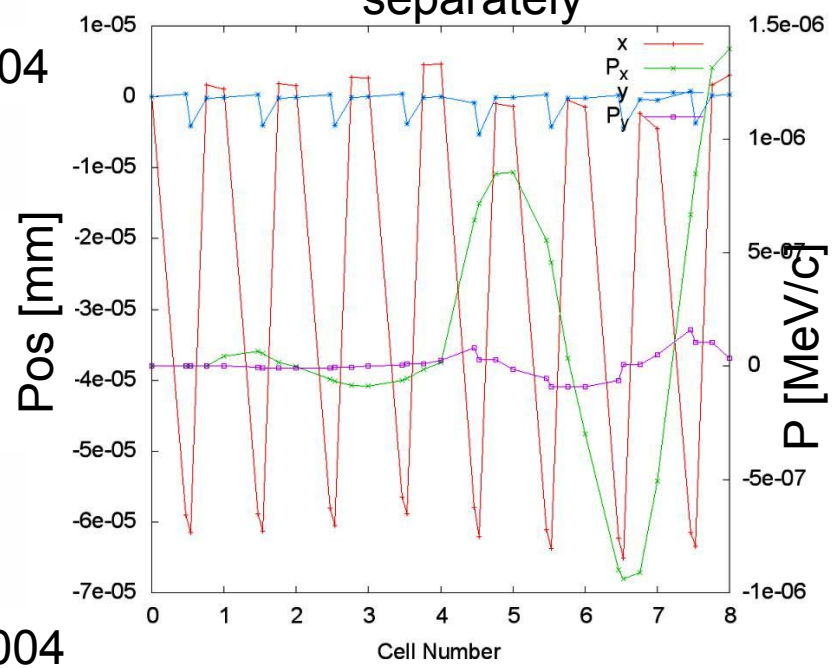
Step 1: Reference Particle

- G4BL has a modest ability to tune dipoles
  - Linear lattice makes latter values dependent on previous ones
  - G4BL searches for zero-crossing not minimum
- Optimization tuning of the dipoles in each cell gives a smaller deviation of the reference particle at the cost of simulation time and unrealistically precise field values.

G4BL "tune" element



Tune the dipoles of each cell separately

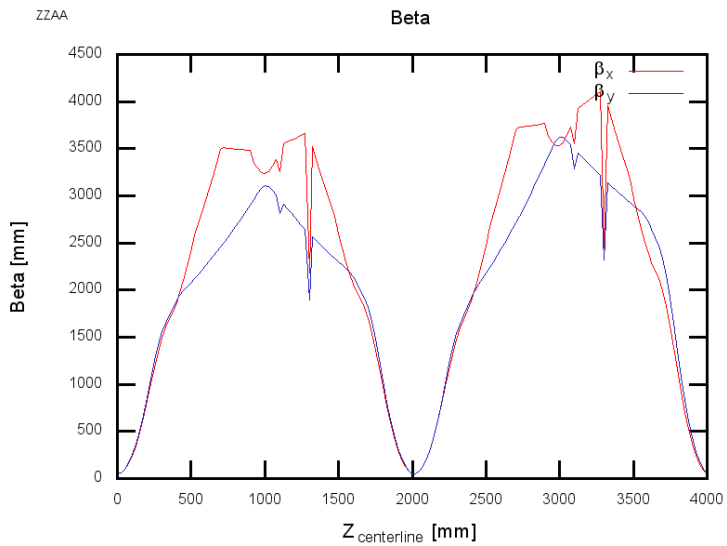


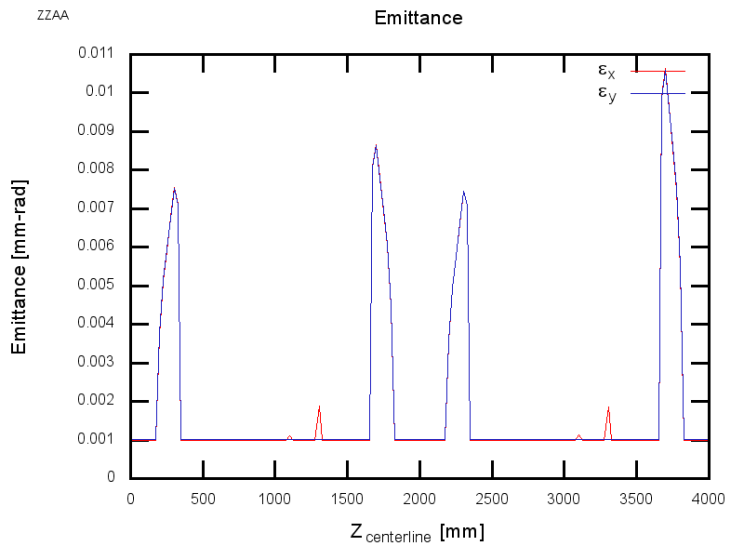
Step 2: Resonance Tuning

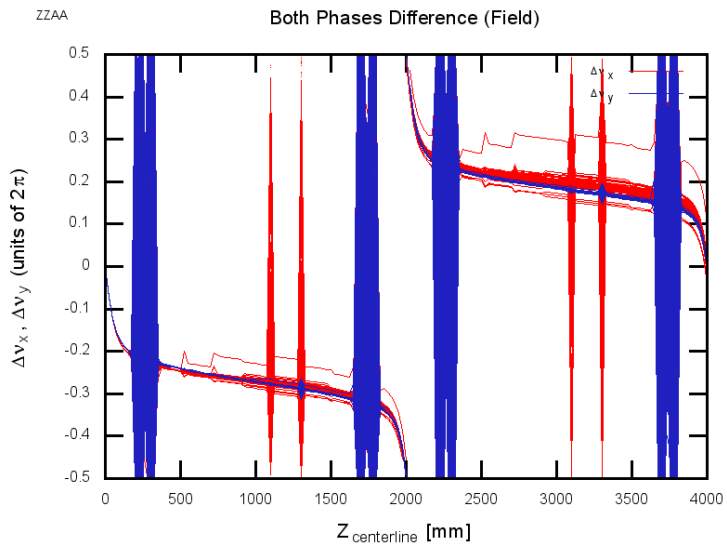
- This tuning is the same as before except
  - After each run in the optimization routine, check the deviation of the reference particle.
  - Re-optimize *dipole* tuning if the deviation is higher than some arbitrary value.
- Note that the method previously discussed is only effective for phase advances that are integers of π in each cell. The phase advances need not be the same in each transverse direction.
- There is no momentum spread in the optimization at this point.

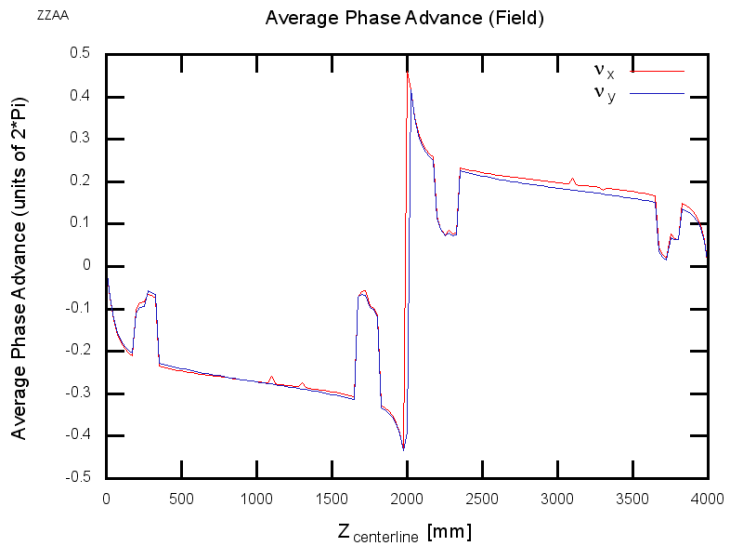
Resonant Twiss Functions

(2000 particles)









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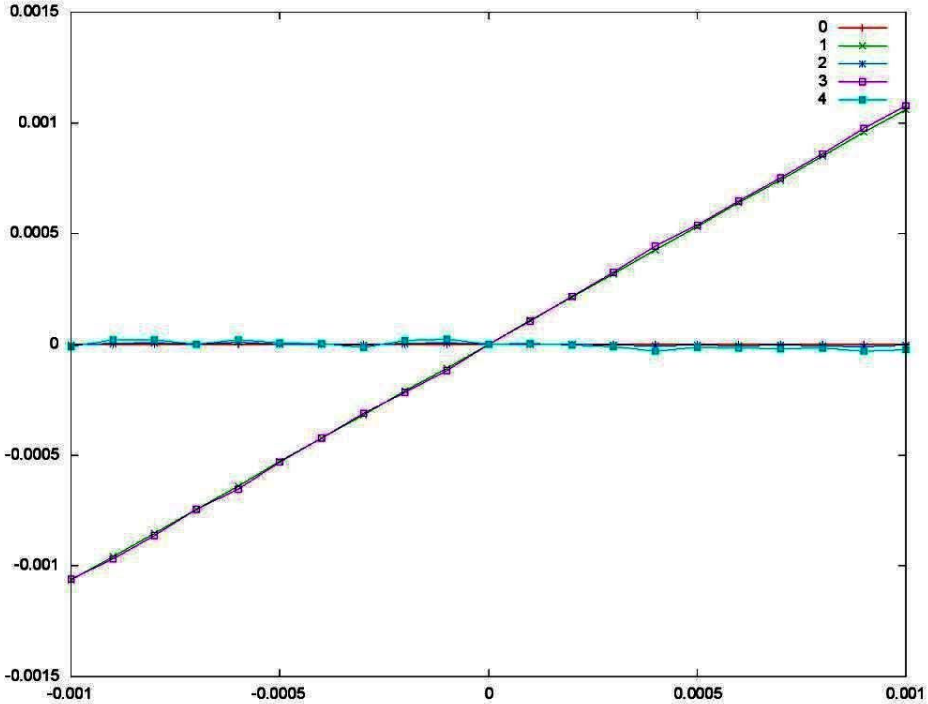
Step 3: Dispersion Prime

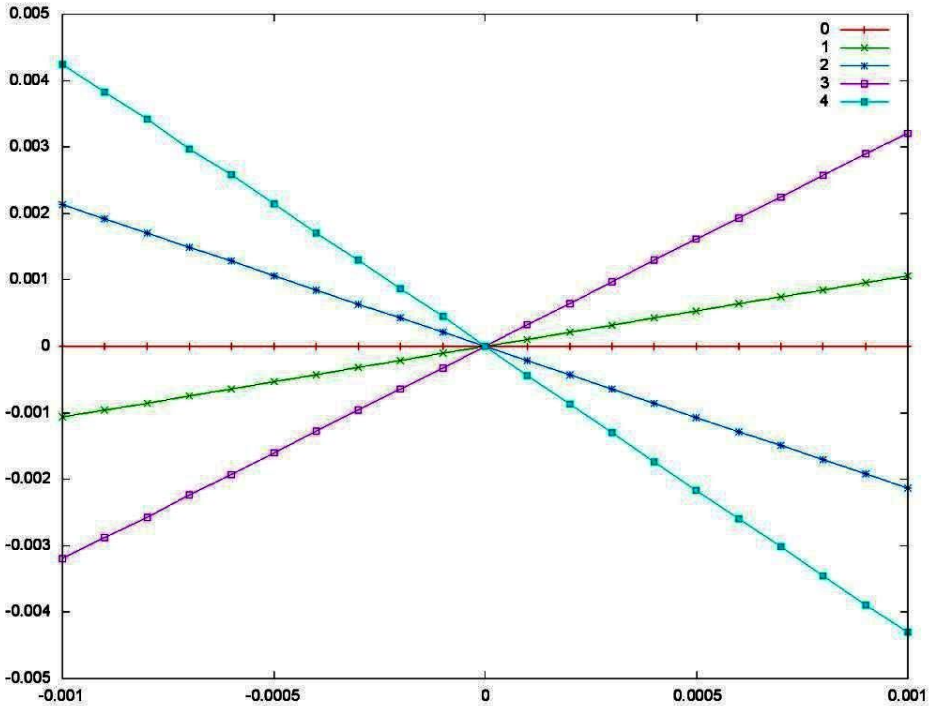
- Matched value of dispersion prime calculated the same as before
- Since no magnetic fields are changed, the tunes remain unchanged
- “Snake” and “Chicane” layouts have significant differences for π phase advance per cell.
- Chicane layout has no matched solution for this phase advance per cell

Zero Initial Dispersion Prime

Snake

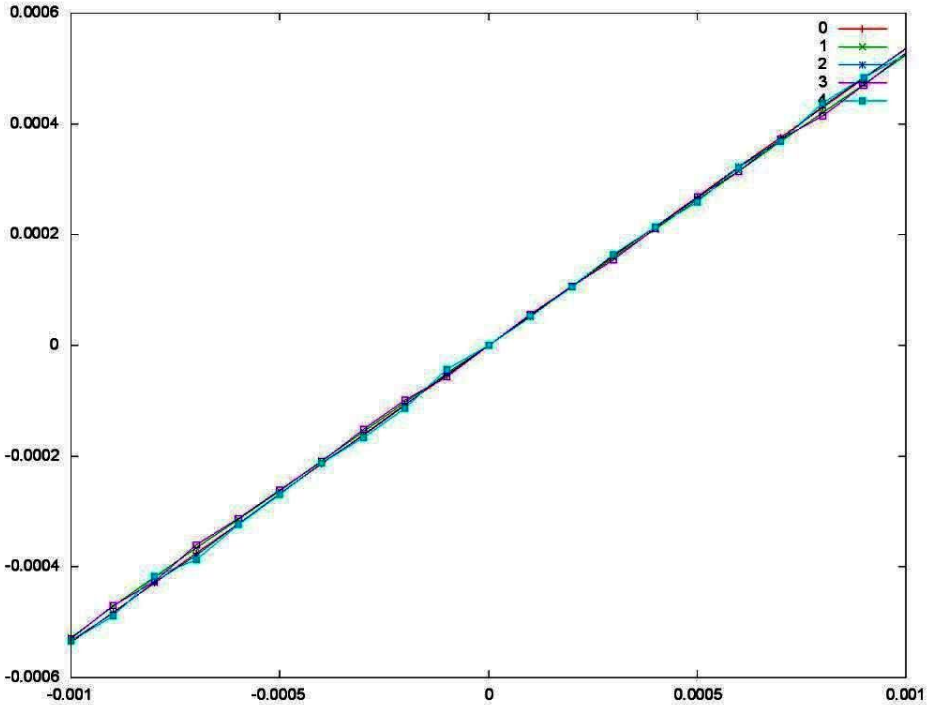


Chicane

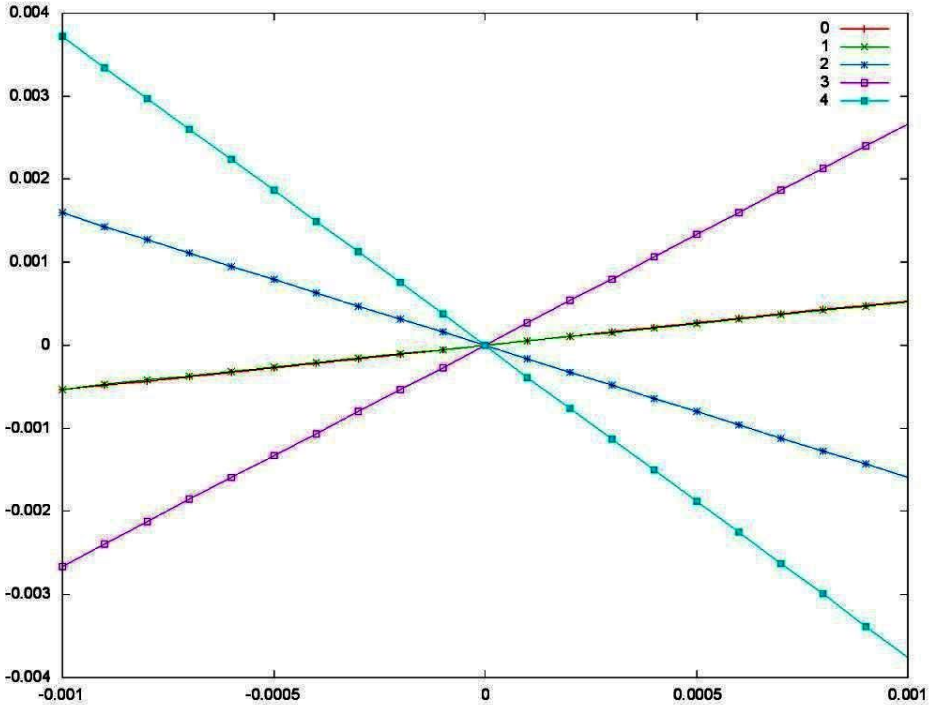


Matched Initial Dispersion Prime

Snake

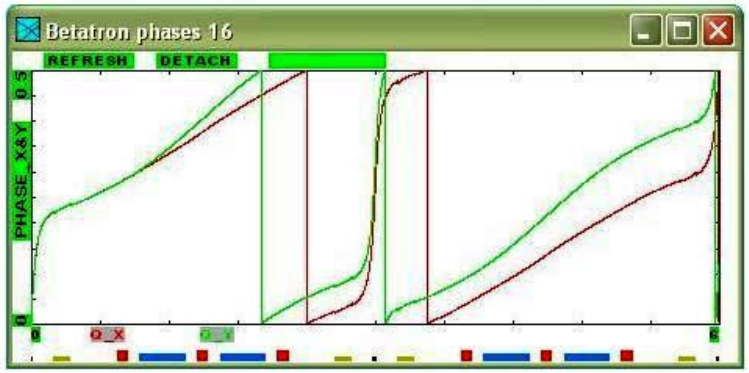


Chicane

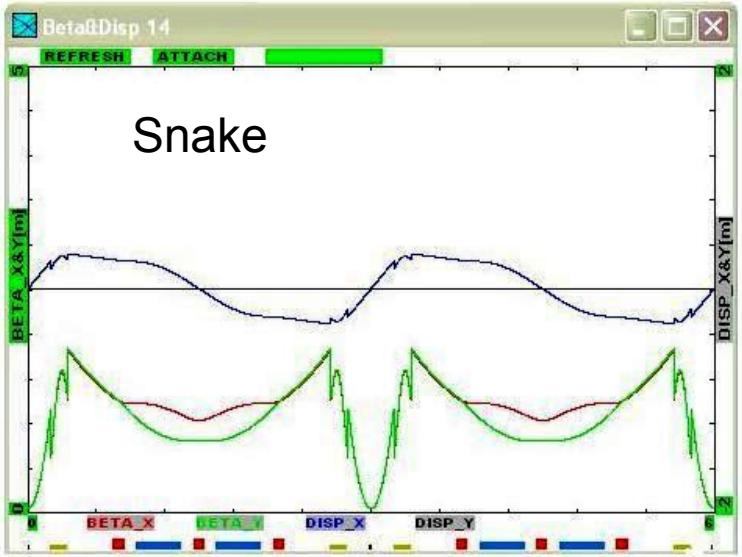


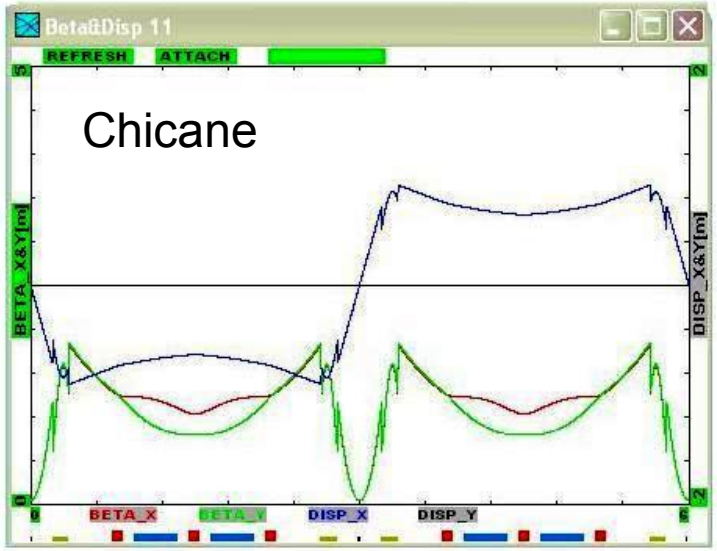
Snake vs. Chicane part II

- Both lattices have identical optics
- 3π betatron phase over 2 cells in x and y



- Dispersion periods are different
  - Snake: 2π per cell
  - Chicane: π per cell

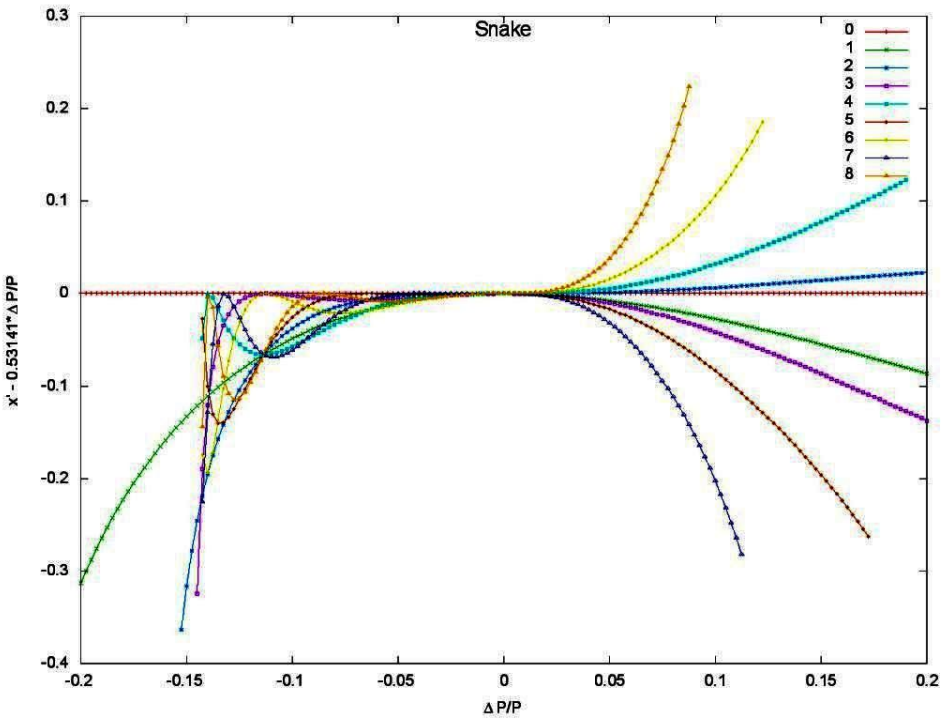




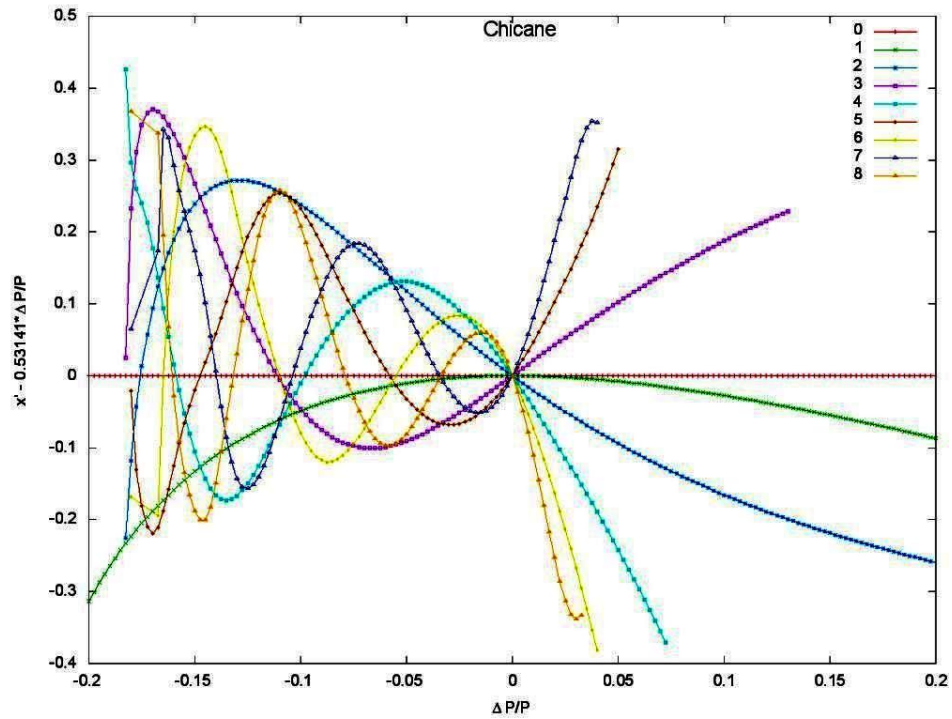
This is a different “resonant” tune from those developed in the G4BL simulations

Snake Matched Dispersion Prime

Snake



Chicane



Note that x' – D*δ is plotted in the vertical axis, so the initial values are matched

Step 4: Chromatic Aberration Plans

- Add sextupole component to 1st and 3rd quadrupole in each cell.
- Use the same pattern of particles from the resonance tuning.
  - Shift uniformly to alternate momentum
  - Shift x' by the appropriate dispersion prime
  - Optimize sextupole fields until *this* pattern displays π phase advance per cell.
- At each step in sextupole optimization
  - Verify Step 1: Reference Particle Path (dipoles)
  - Verify Step 2: On-Momentum Resonance
  - Any changes require redetermination of the dispersion prime

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Proposed Workshop Discussion Topics

21-22 May 2007 at FNAL

- Theory of PIC/REMEX
  - Aberration Control
  - Fundamental differences between PIC and REMEX in terms of design
- Lattice Design
  - Betatron Phase Advance
  - Dispersion Phase
  - Entrance and Exit Cells
  - RF
  - Increase “reality” while reducing size
- G4BL Simulation
  - Limits of particle tracking
  - Time vs. Accuracy vs. Physical Meaning
  - Absorber design
  - Energy Recovery
  - Beam Parameters and Input Distribution