Superconducting Wigglers at the Canadian Light Source

Ward A. Wurtz

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Joint School on Synchrotron Radiation and Free Electron Lasers

Erice, Sicily, Italy

Outline

- CLS has two superconducting wigglers for the production of hard x-rays
- These wigglers cause losses of electrons during injection not explained by an ideal model
- Through measurements we have constructed a non-linear model that has given us insights into the problem
- The injection losses are likely due to a sextupole resonance and amplitude dependent tune shifts
- After the scheduled shutdown of CLS is complete (May 2011), we will attempt to restore injection with wigglers by changing the betatron tunes

Properties of the Superconducting Wigglers

	SCW4.3 (BMIT)	SCW2.1 (HXMA)
Max. Working Field	4.3 T	2.1 T
Period Length	48 mm	34 mm
Main Poles	25	61
Side Poles	2	2
Pole Gap	13.9 mm	13.5 mm
K value	19	6.5
Photon Energy	10 - 100 keV	4 - 40 keV
Installation	Nov. 2007	Jan. 2005
Manufacturer	Budker INP	Budker INP

Beam Dynamics with Wigglers

Begin with relativistic **Lorentz Force Law**:

$$\frac{d\vec{p}}{dt} = q\vec{v} \times \vec{B}$$

Use the fact that the electrons are traveling at essentially the speed of light and change coordinates so that the longitudinal position is the independent coordinate instead of time

More Useful Equations of Motion:

$$x'' = -\alpha\sqrt{1 + x'^2 + z'^2}\left(z' B_s + x' z' B_x - (1 + x'^2) B_z\right)$$

$$z'' = -\alpha\sqrt{1 + x'^2 + z'^2}\left(-x' B_s - x' z' B_z + (1 + z'^2) B_x\right)$$

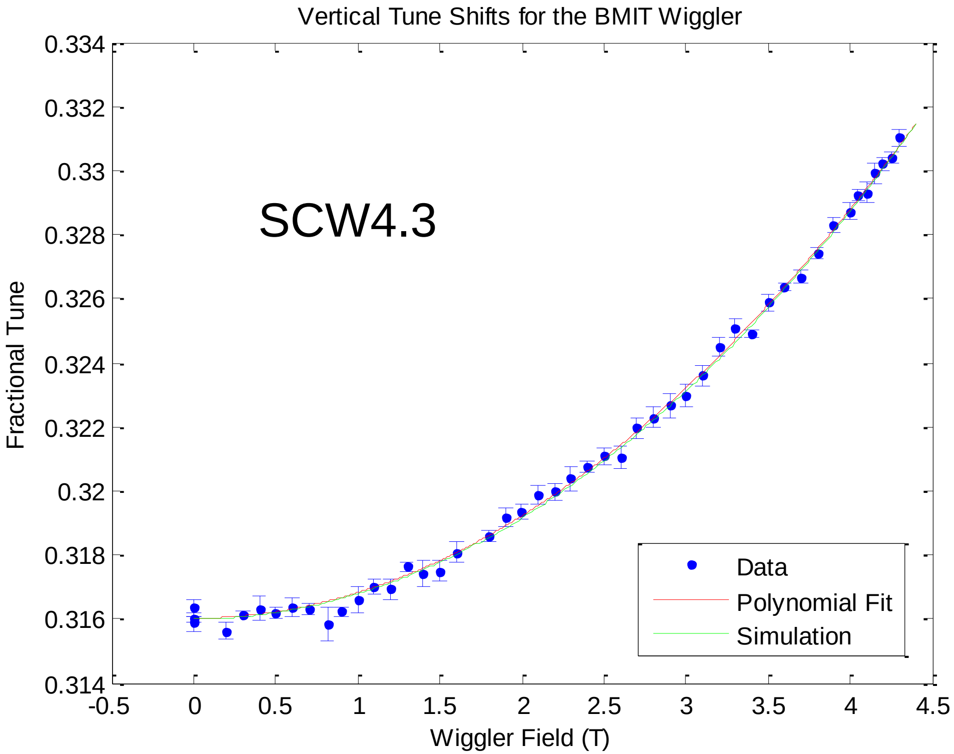
$$\alpha \equiv \frac{e}{\gamma mc} = \frac{e}{p} = \frac{1}{B\rho}$$

neglect terms with squared or multiplied velocities as these are very small

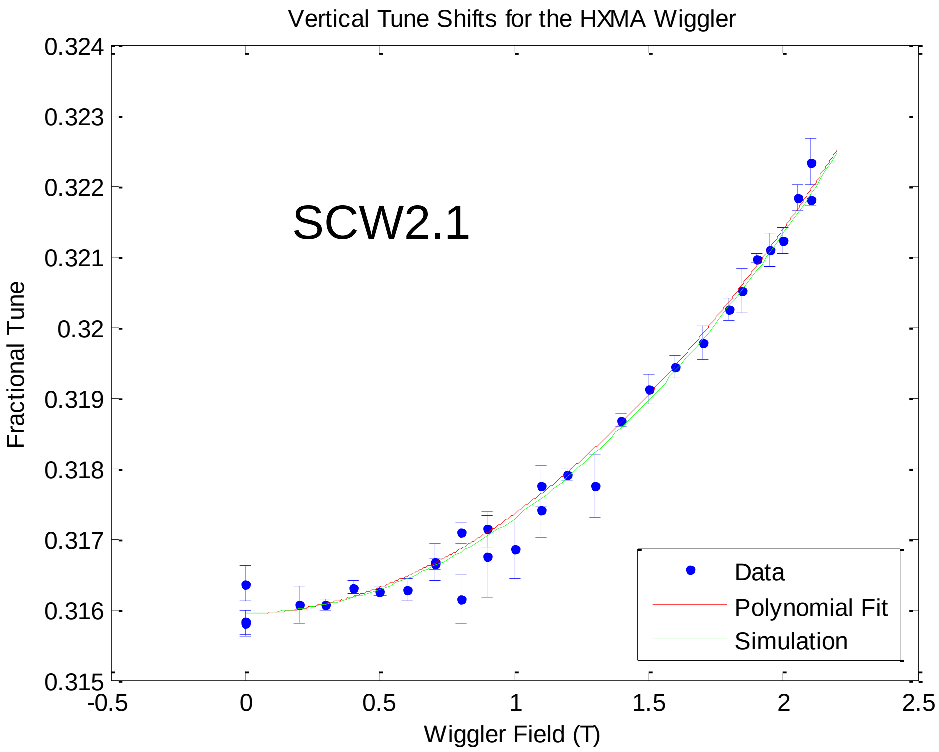
$$x'' = -\alpha\left(z' B_s - B_z\right) \qquad z'' = \alpha\left(x' B_s - B_x\right)$$

Reference: P. Elleaume, “A New Approach to the Electron Beam Dynamics in Undulators and Wigglers”, EPAC 1992

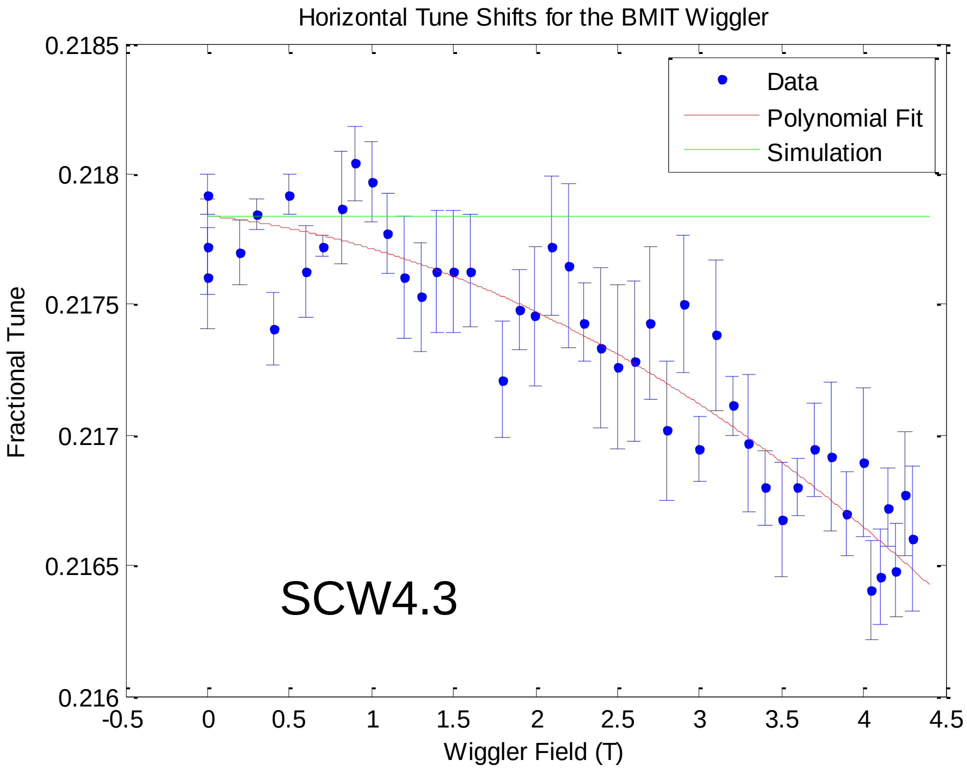
Measurement of Vertical Tune Shifts

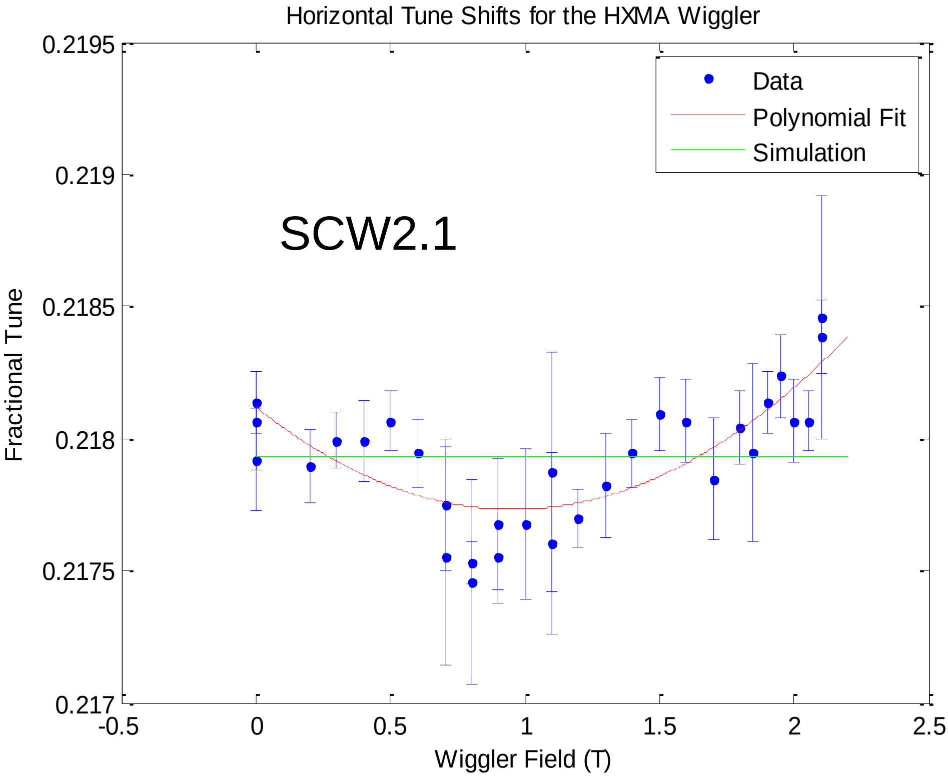


Simulation lines are not fits to data and have no arbitrary parameters



Measurement of Horizontal Tune Shifts





First indications of disagreement with ideal model predictions

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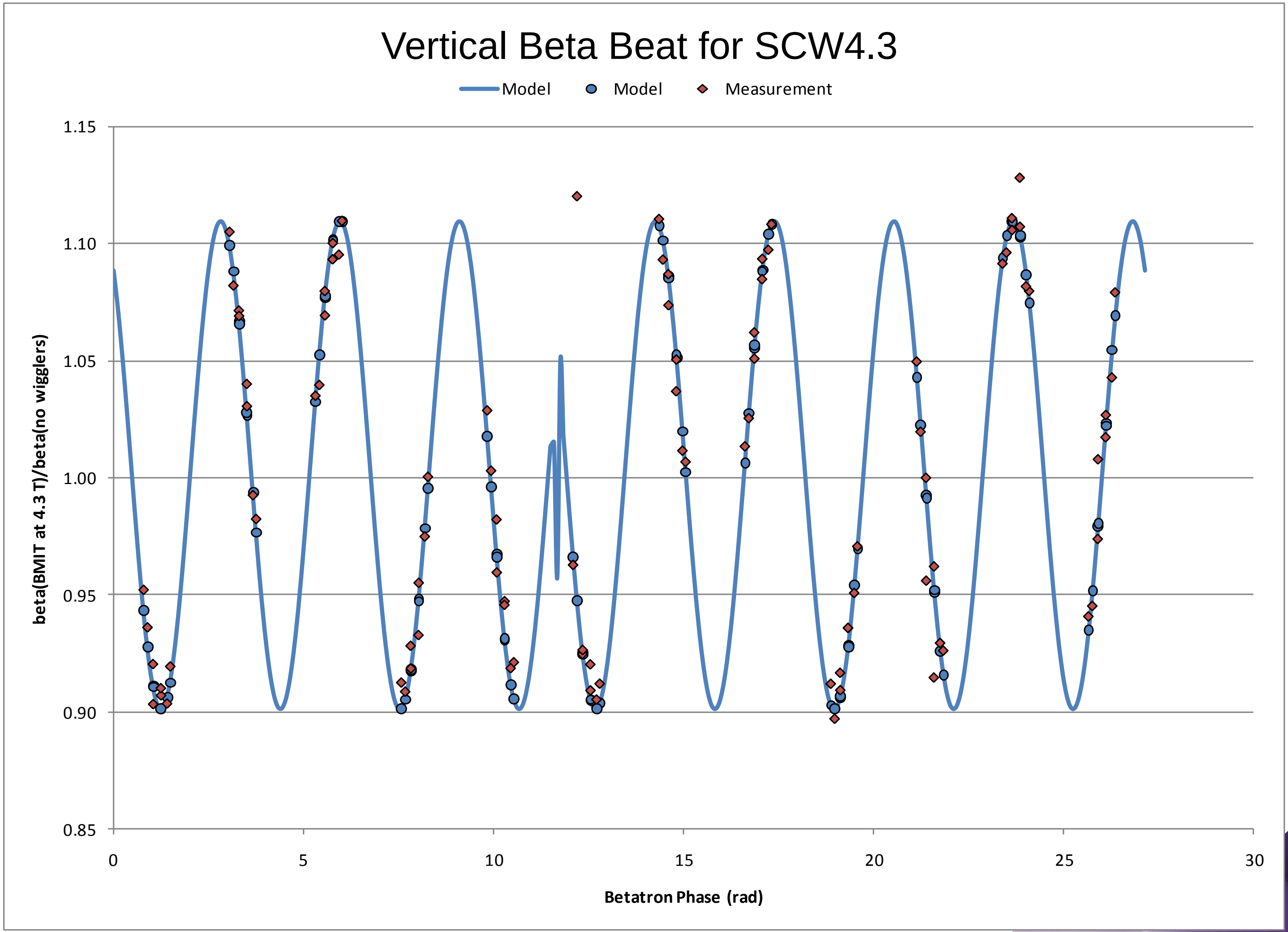
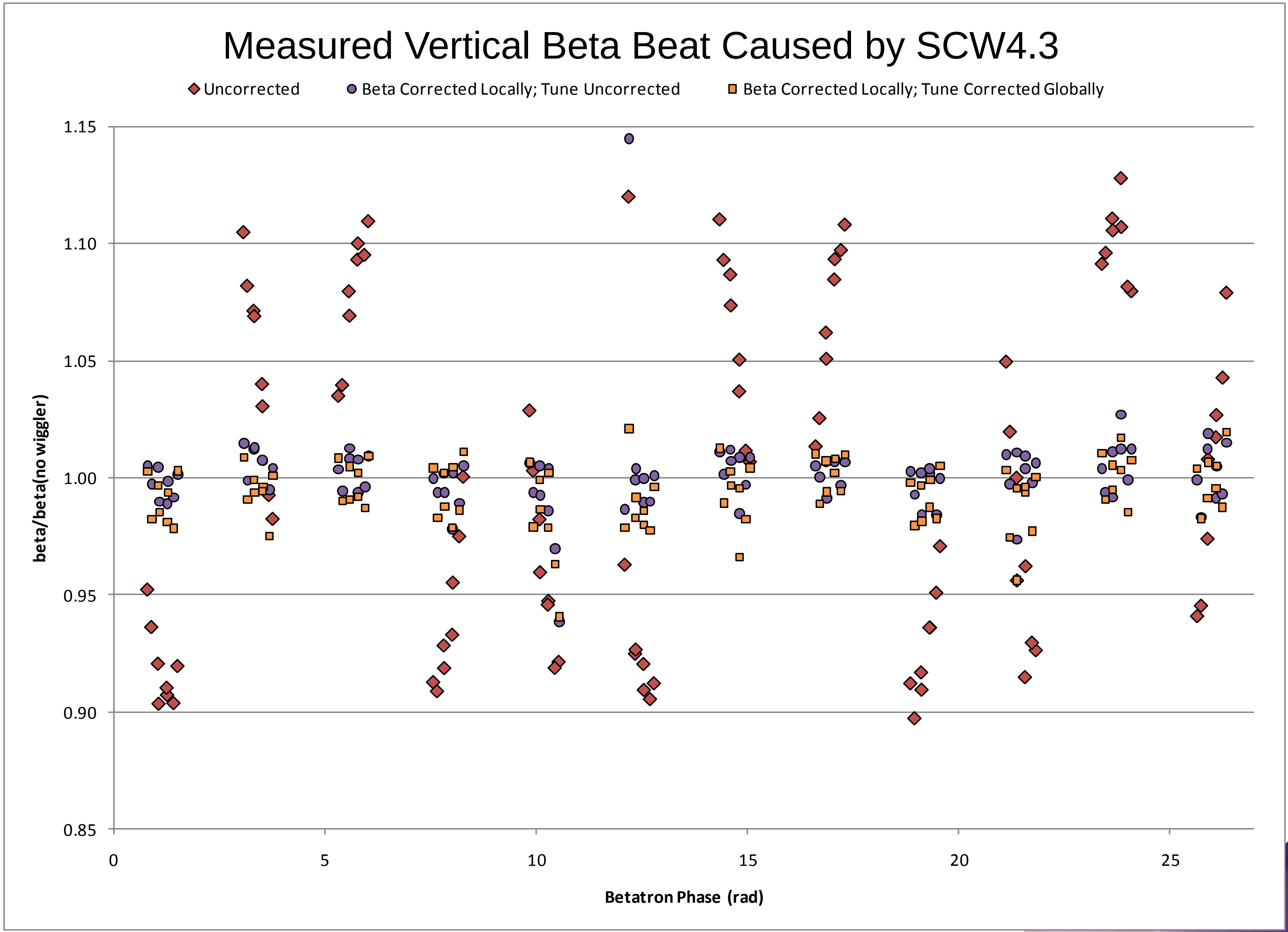
Measurement of Beta-Beat



Correction of beta-beating

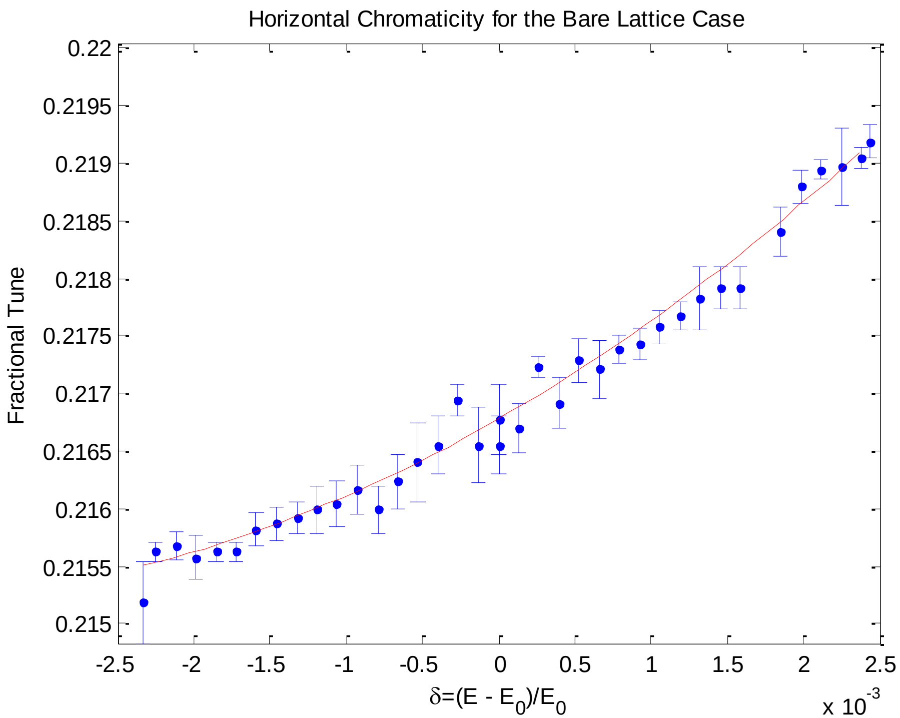


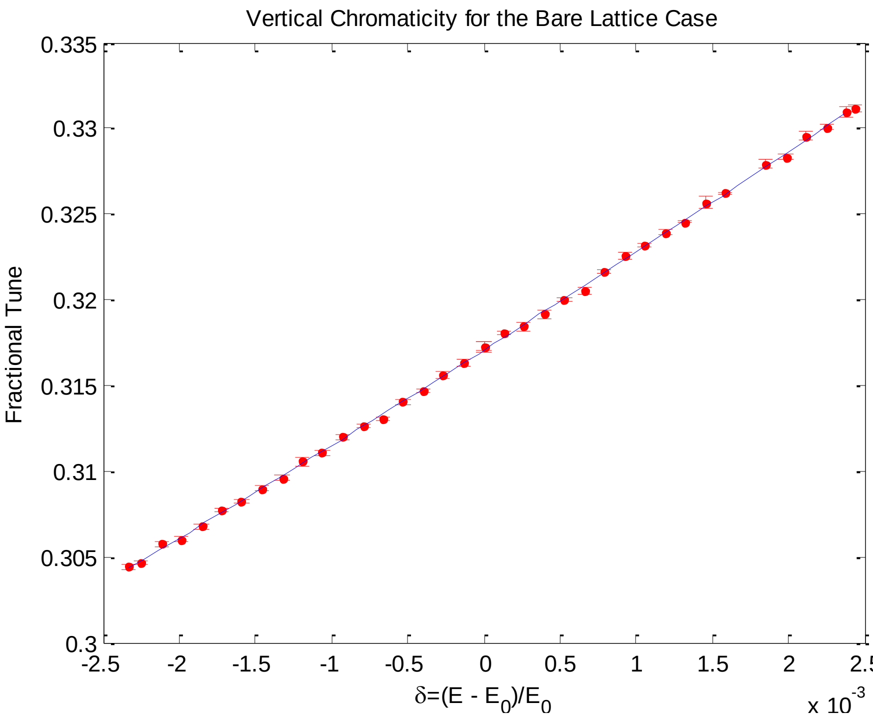
Chromaticity Measurements

- Measured chromaticity shifts
  - Measured shifts of first and second-order chromaticities for SCW4.3
  - Measured shift of first-order chromaticity for SCW2.1
    - Will attempt to measure shift in second-order chromaticity when wiggler cryogenic system repaired (May 2011)
- Shifts in first-order chromaticity indicate sextupole
  - Both wigglers show nearly equal shifts in first-order chromaticity
  - Likely due to a magnetic multipole moment
- Shifts in second-order chromaticity indicate octupole
  - SCW4.3 shows a moderate shift in second-order chromaticity
  - Likely due to a dynamic focusing effect (not a true multipole)

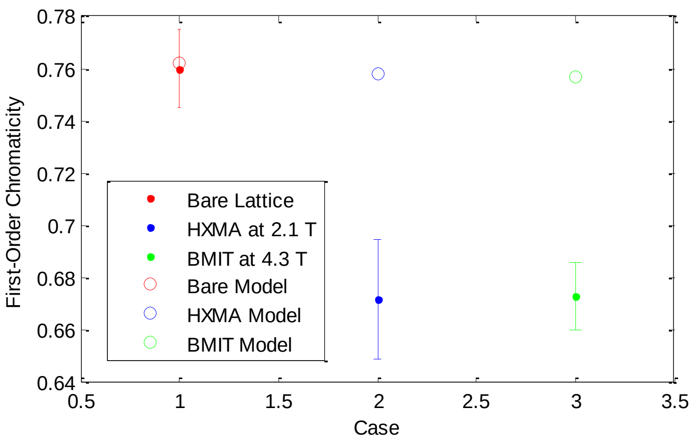
$$\nu_x(\delta) = \nu_{x,0} + \chi_x^{(0)}\delta + \chi_x^{(1)}\delta^2 + \chi_x^{(2)}\delta^3$$

First-order chromaticity measurement



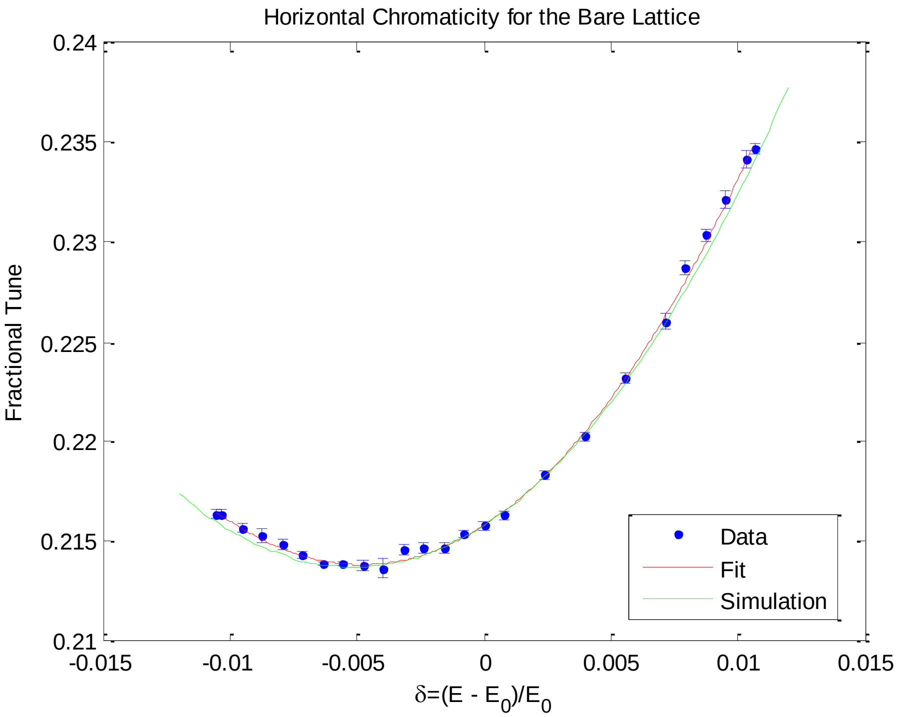


Measured, horizontal first-order chromaticity shifts
SCW2.1: -0.088 +/- 0.027
SCW4.3: -0.083 +/- 0.015



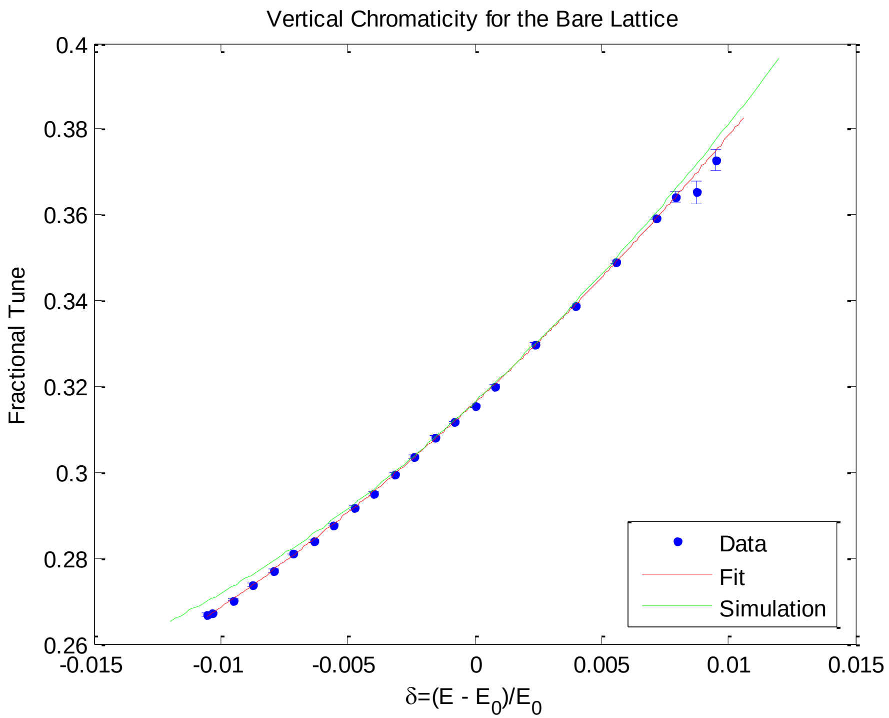
RF frequency range +/- 4.5 kHz

Second-order chromaticity measurement



RF frequency range +/- 20 kHz

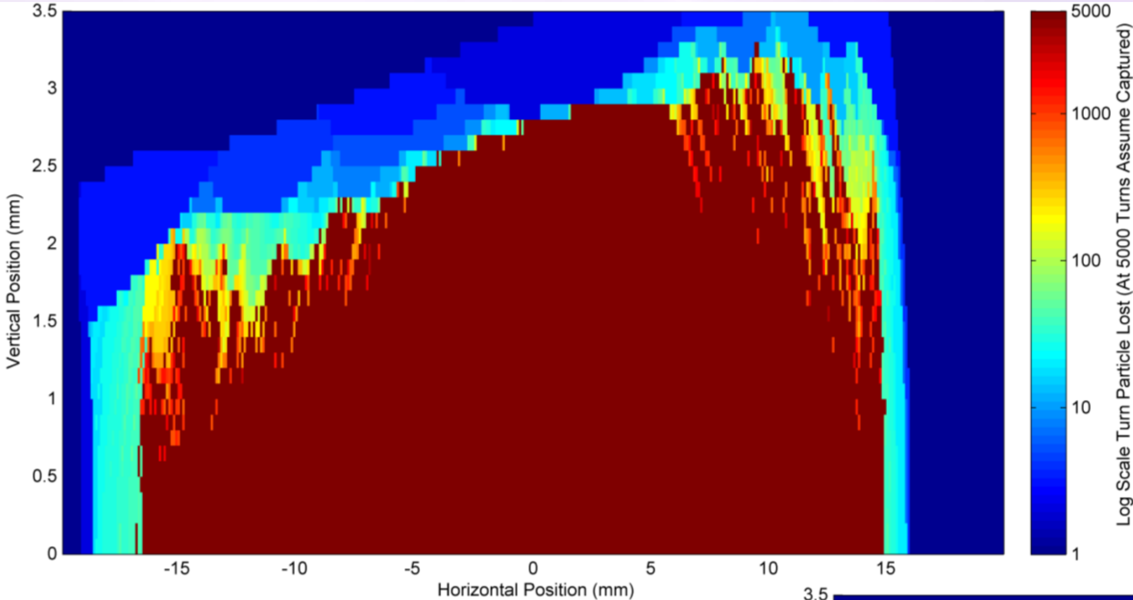
Measured, horizontal second-order chromaticity shift for SCW4.3:
-3.2 +/- 1.8



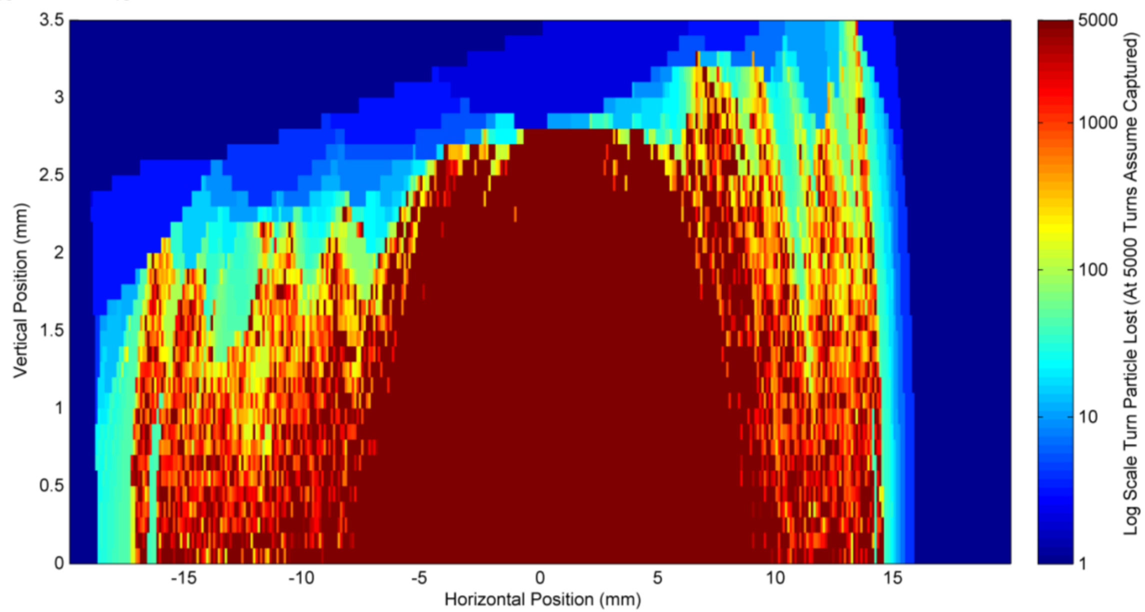
Building a Non-Linear Model for Particle Tracking

- Parameters for a model used in tracking derived from chromaticity measurements
  - Need to build better 3D magnetic models that predict the measured values
- For SCW4.3
  - Ideal wiggler model
  - Matrix with R_{21}=0.0019 m^{-1} (horizontal tune shift)
  - K_2L = -0.73 m^{-2} (chromaticity shift)
  - K_3L = -250 m^{-3} (second-order chromaticity shift)
- For SCW2.1
  - Ideal wiggler model
  - K_2L = -0.73 m^{-2} (chromaticity shift)

Effect of Linear Optics Correction

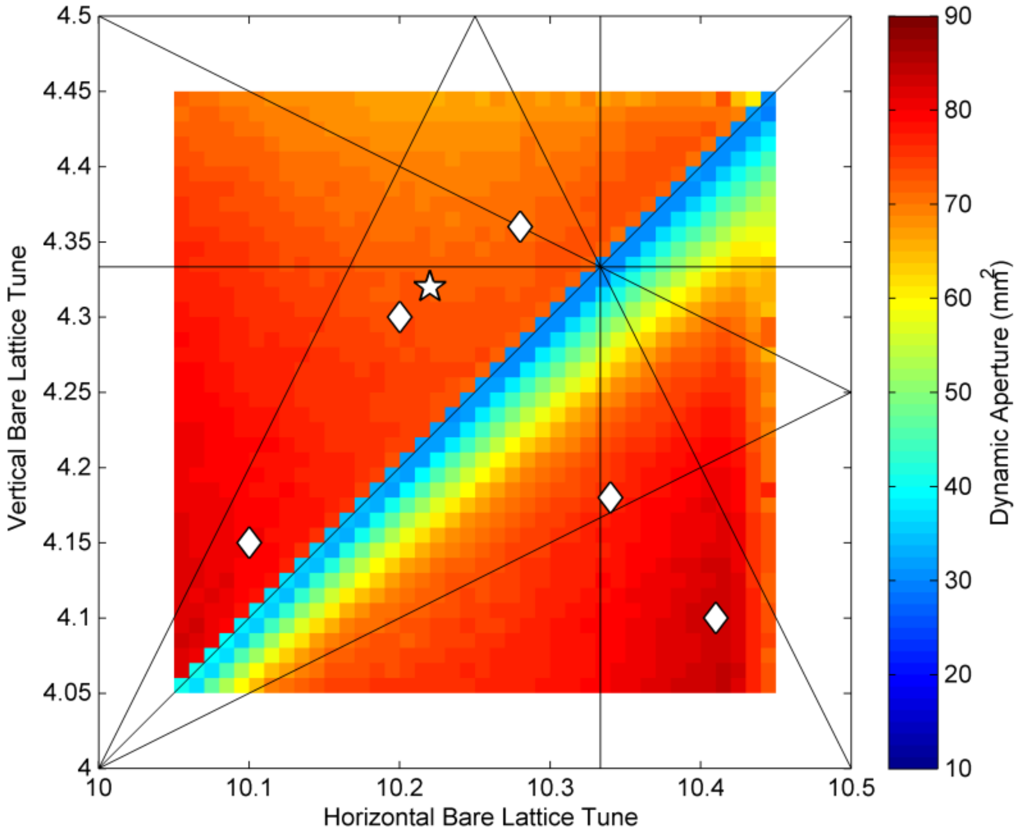


Off-momentum dynamic aperture is nearly recovered for an **ideal** SCW4.3 model (no damping)



Off-momentum dynamic aperture is not recovered for the **non-linear** SCW4.3 model (no damping)

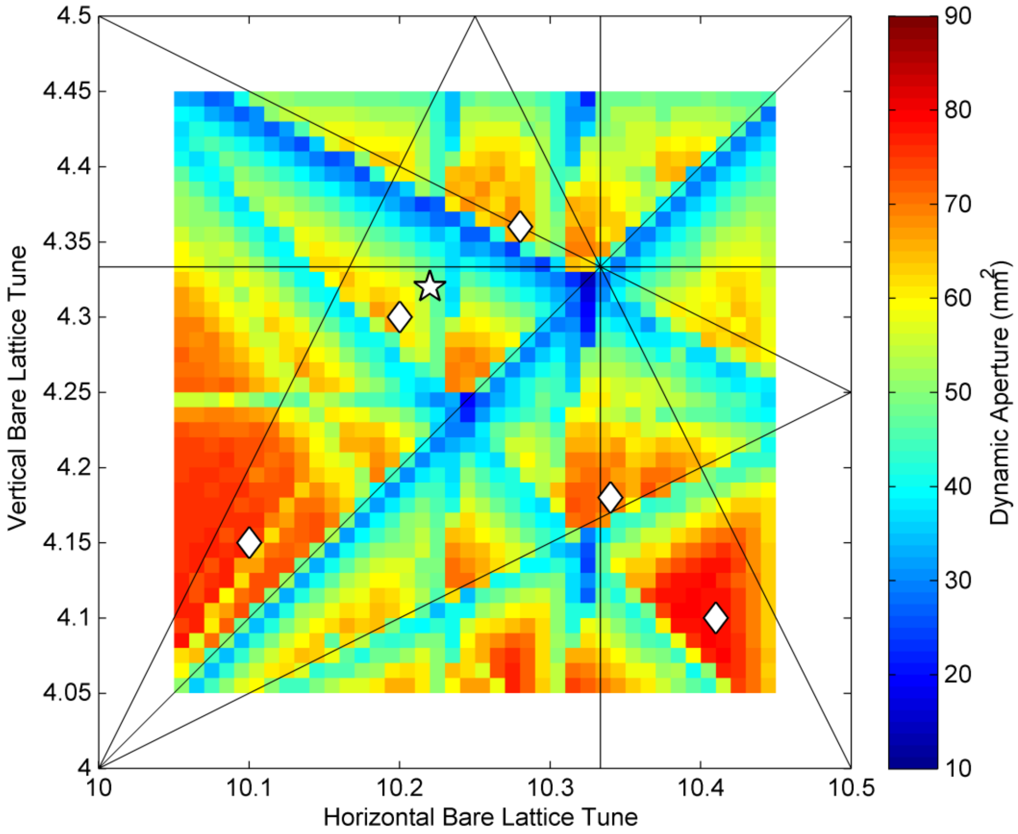
Dynamic Aperture Tune Scan



Simulations run with elegant on the Westgrid cluster Orcinus. Each data point represents ~1 hour of computer time.

Off-momentum dynamic aperture with no insertion devices, ideal lattice and realistic apertures

Dynamic Aperture Tune Scan



Simulations run with elegant on the Westgrid cluster Orcinus. Each data point represents ~1 hour of computer time.

Off-momentum dynamic aperture with non-linear model of SCW4.3, correction of linear optics, ideal lattice and realistic apertures

Continuing Work

- Computer models of wigglers
  - Create 3D magnetic RADIA model for SCW4.3
  - Improve 3D magnetic RADIA model for SCW2.1
- Measurements
  - Higher order chromaticity of SCW2.1
  - Use kickers and turn-by-turn BPM to measure tune shift as a function of amplitude
  - Many more (ideals always welcome)
- Attempt to restore injection by changing the operating point

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Discussion

Frequency Map Analysis

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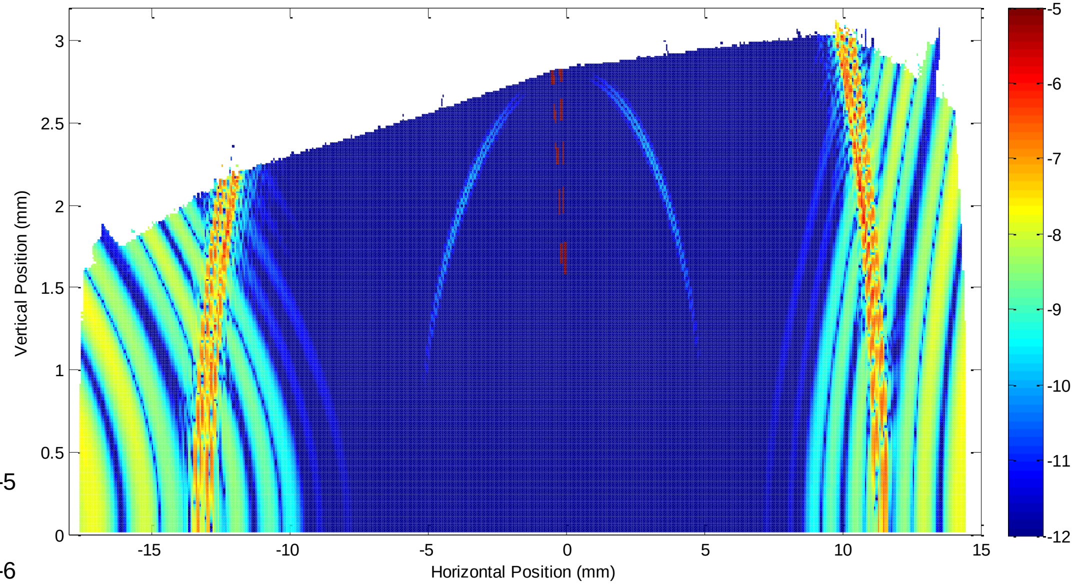
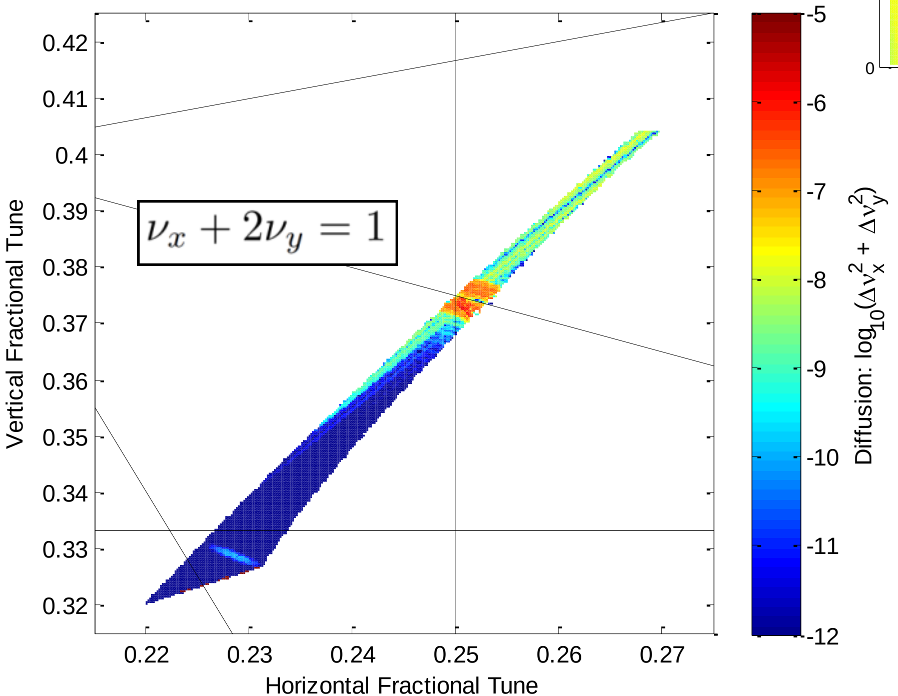
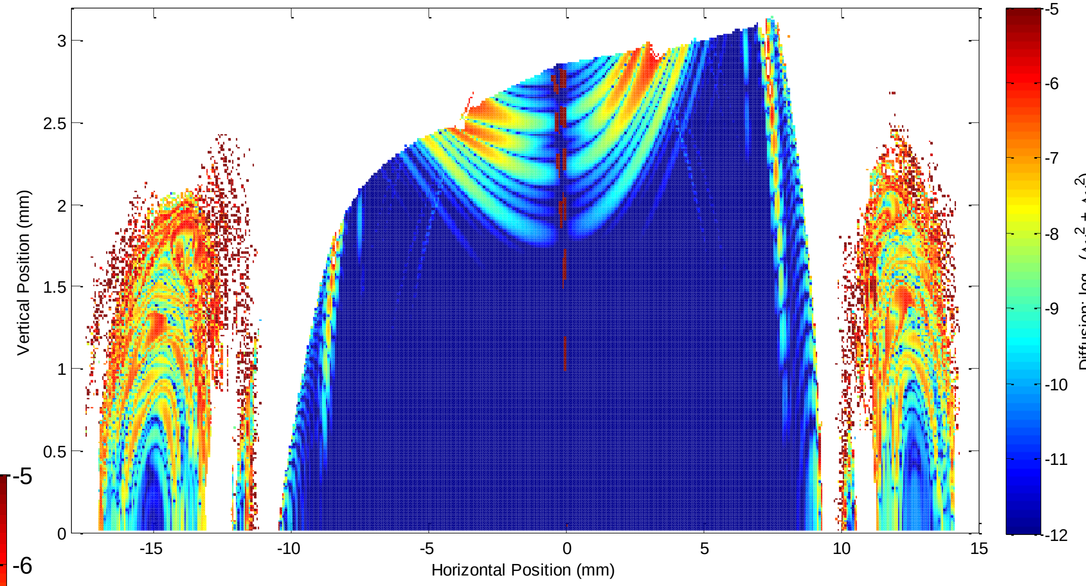
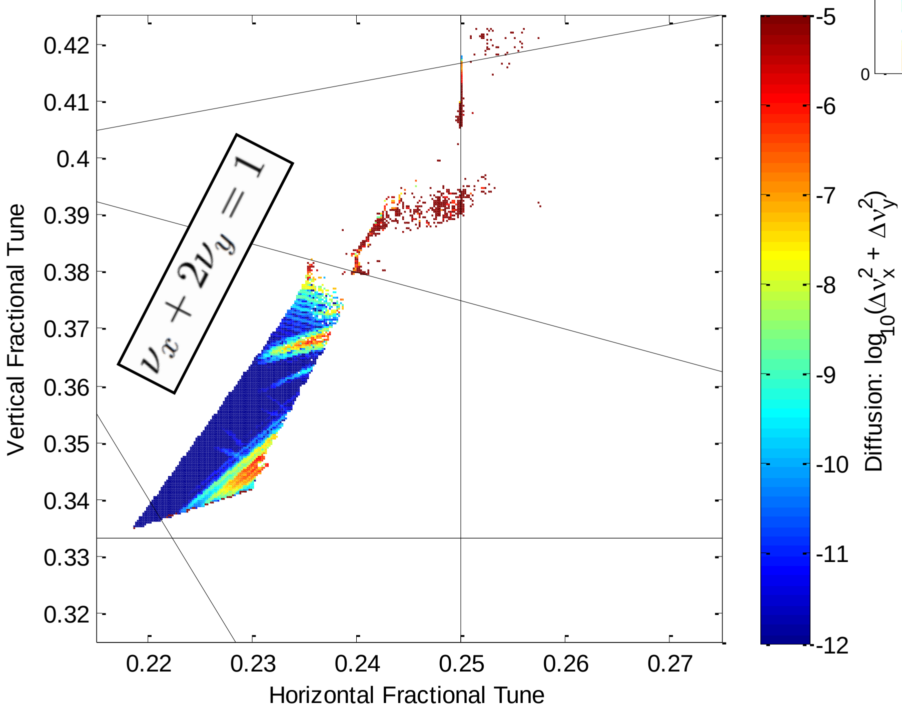




On-momentum frequency map for ideal lattice with realistic apertures and no insertion devices

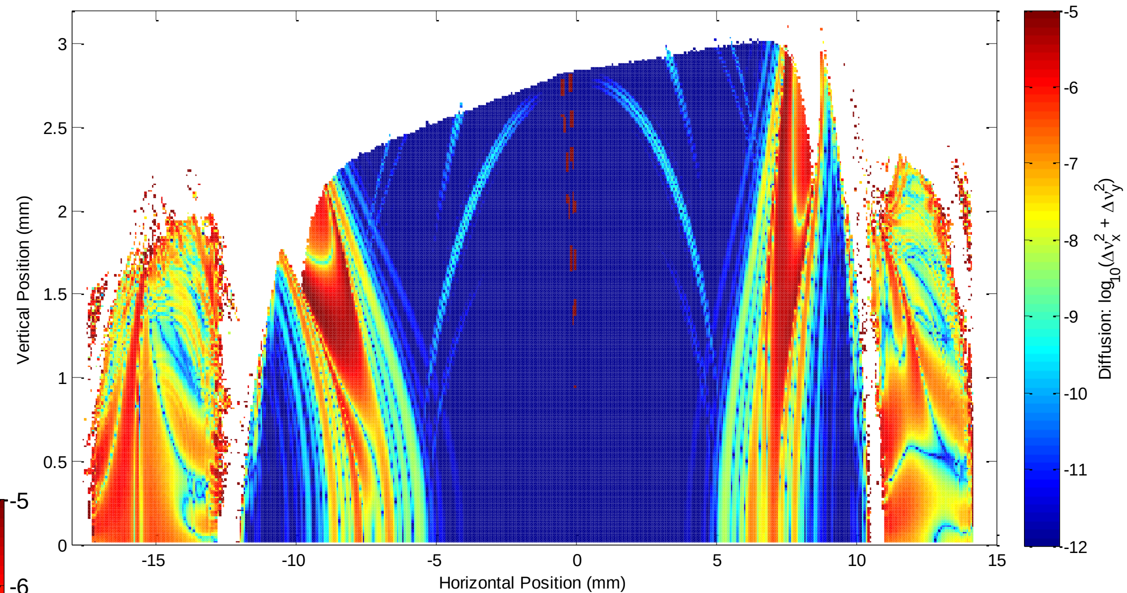
Frequency Map Analysis

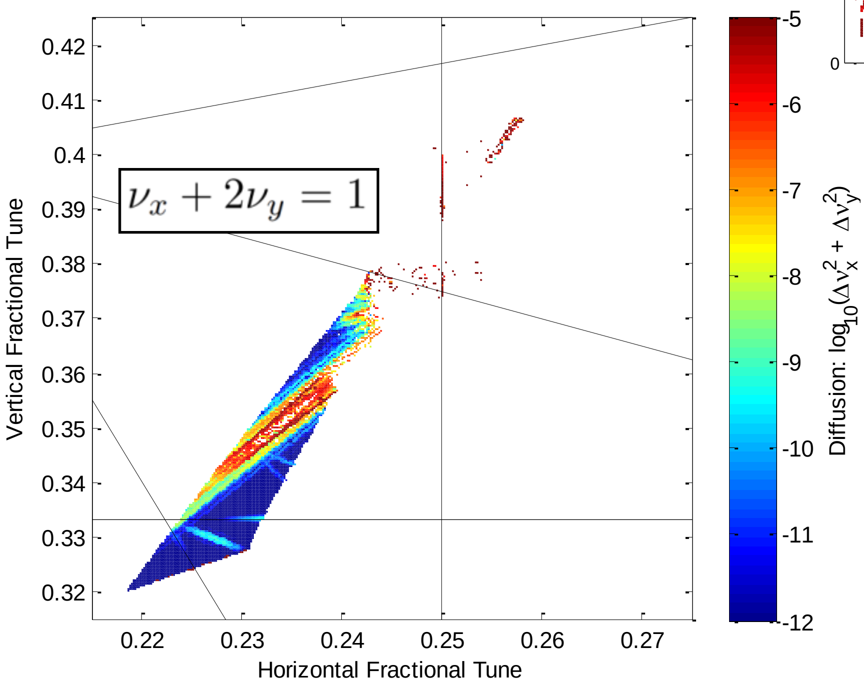




On-momentum frequency map for ideal lattice with realistic apertures, non-linear model of SCW4.3 and no correction of the linear optics

Frequency Map Analysis

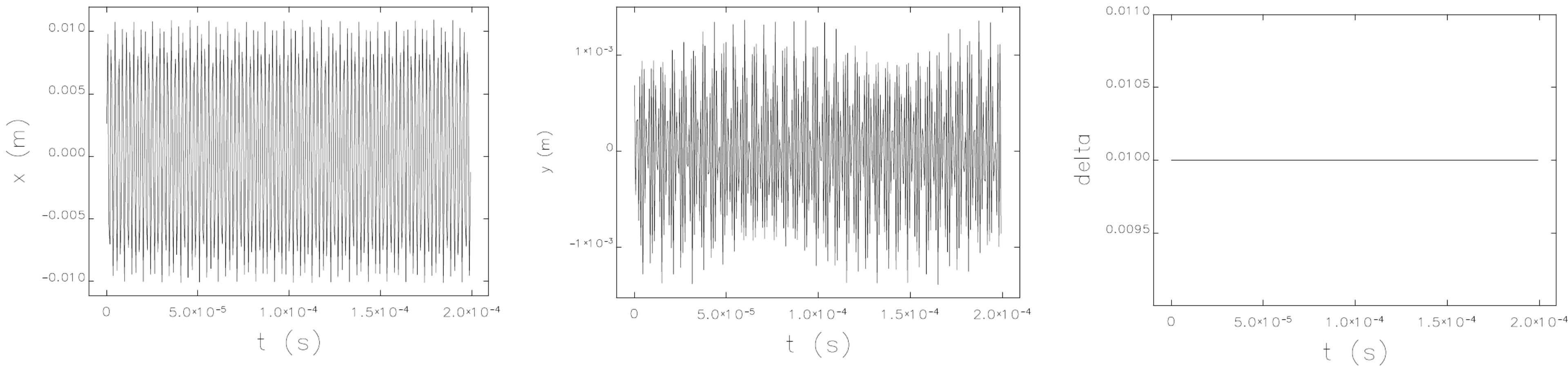




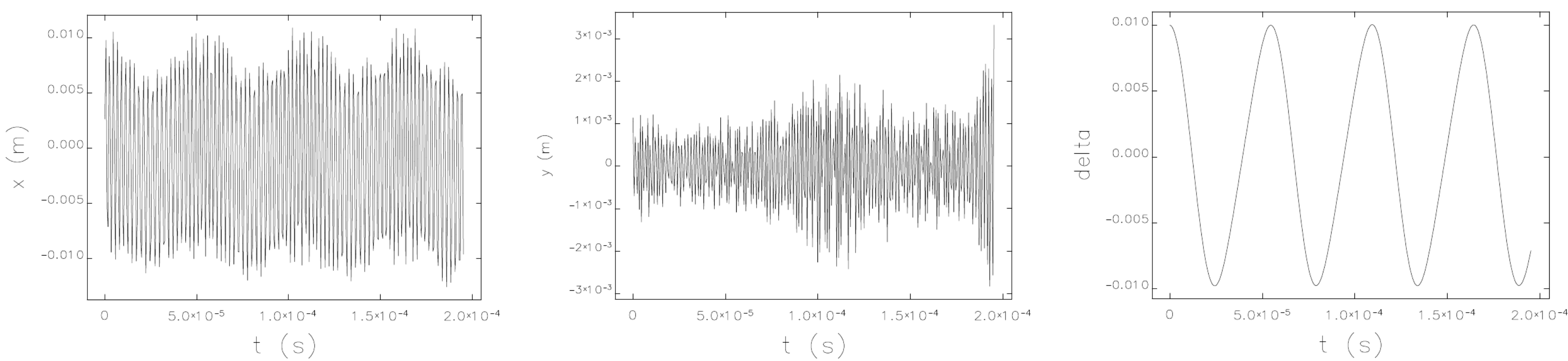
On-momentum frequency map for ideal lattice with realistic apertures, non-linear model of SCW4.3 and local correction of beta functions and tunes

Importance of RF: Lost Particles

Without RF and Synchrotron Radiation



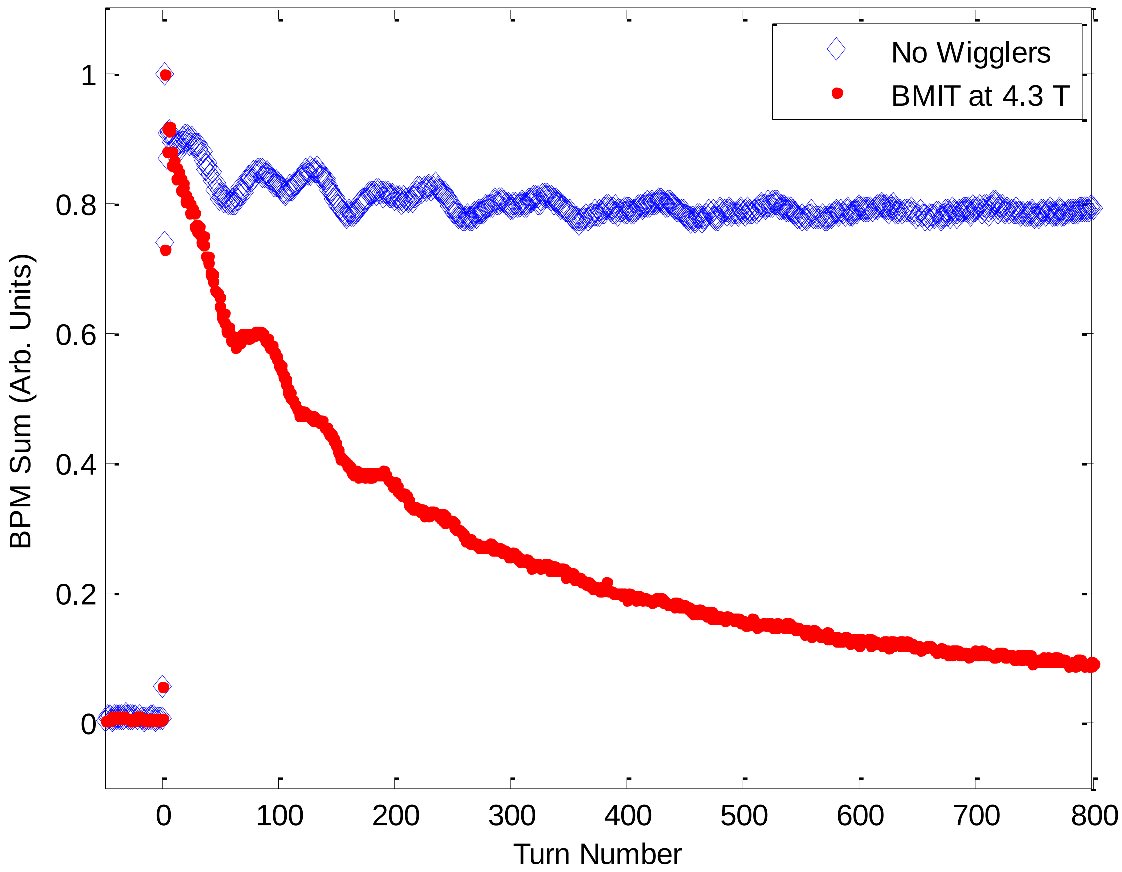
With RF and Synchrotron Radiation



Particle Lost on Vertical Aperture

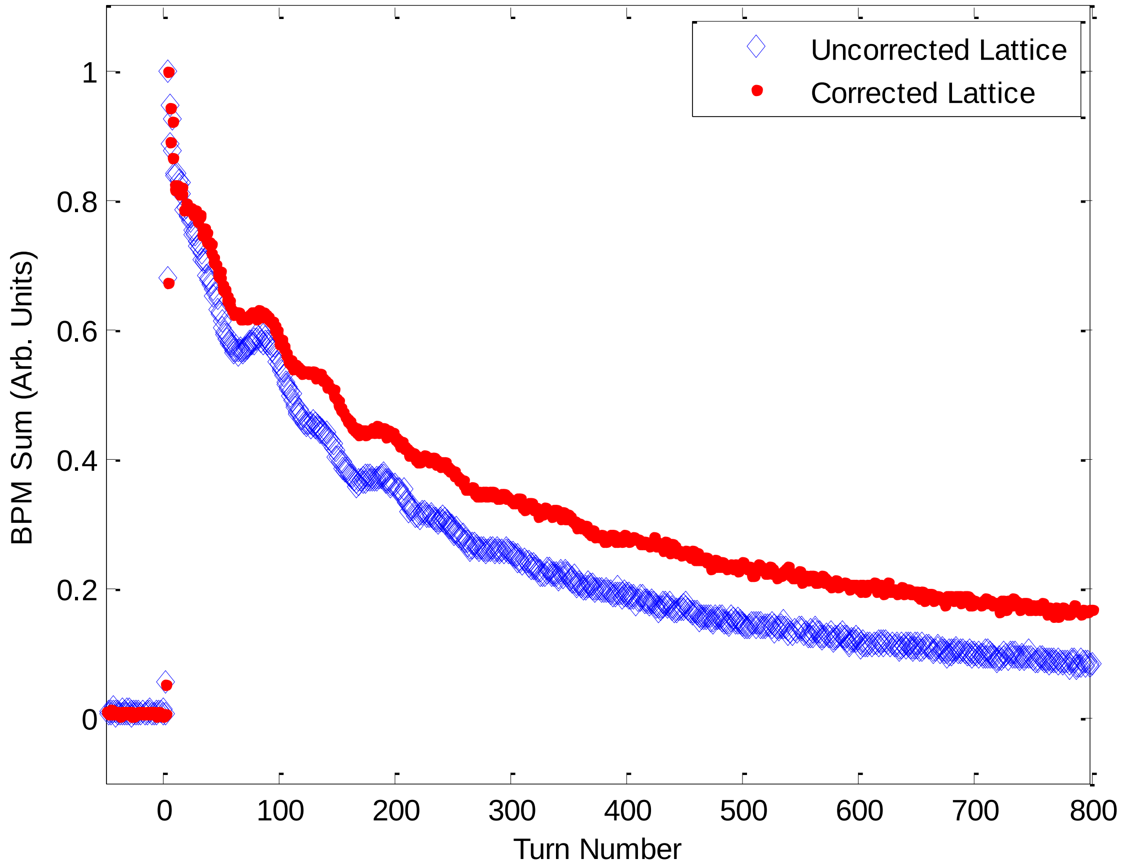
Injection Measurement

Turn by turn current measured at injection with and without SCW4.3 using a Libera Brilliance unit's BPM sum



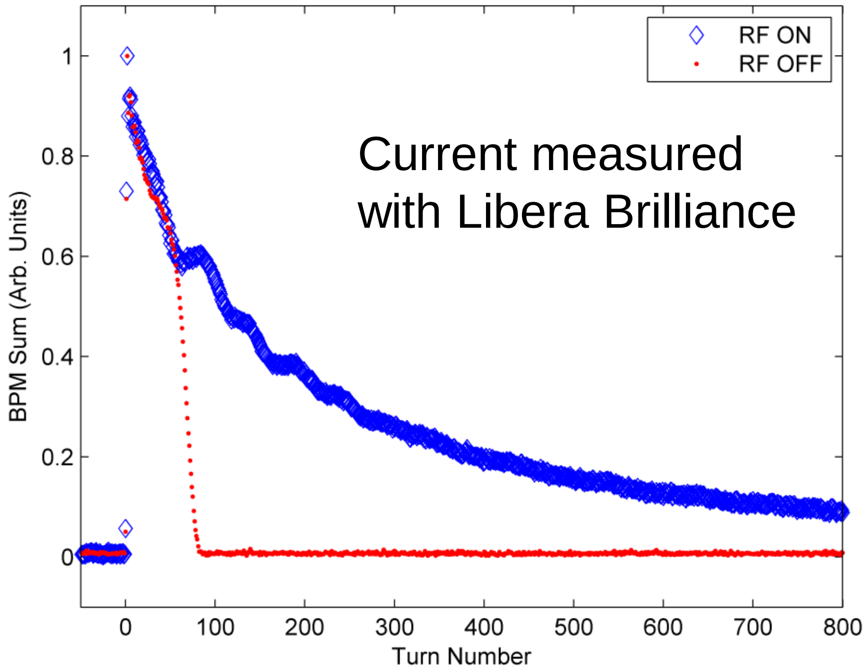
Efficiency Not Restored

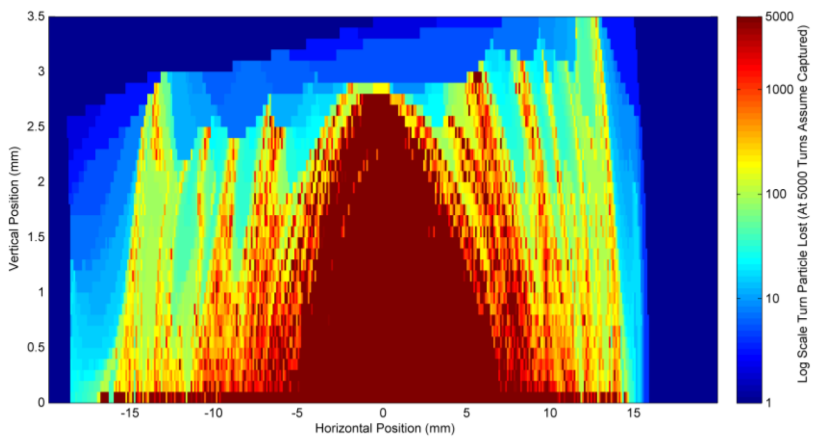
Turn by turn current measured at injection with SCW4.3: without any lattice correction and with a local beta correction and global tune correction



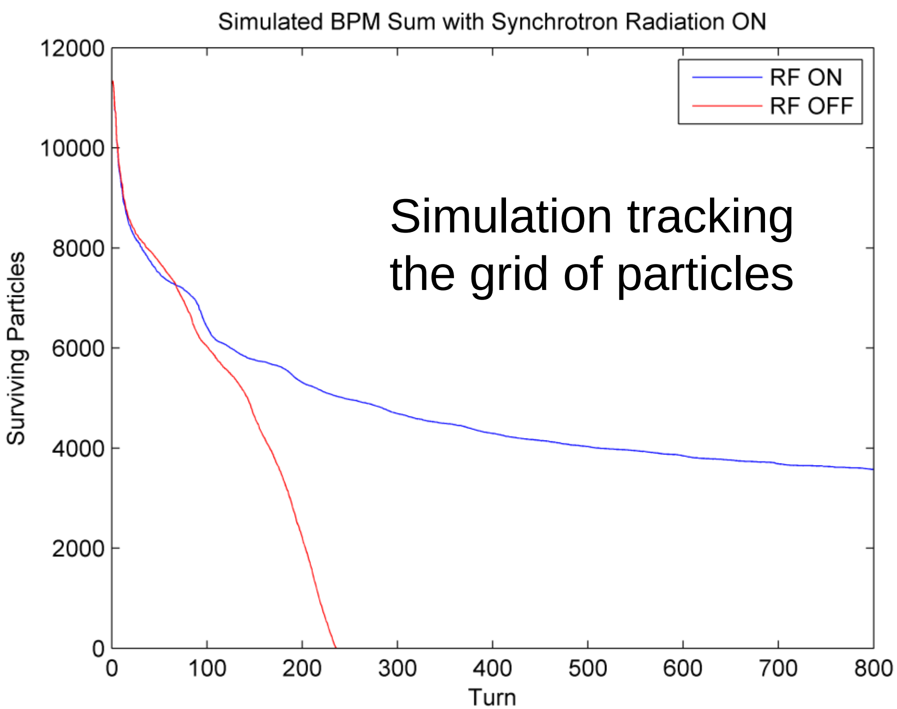
Marginal improvement in injection efficiency

Simulation of BPM Sum Data

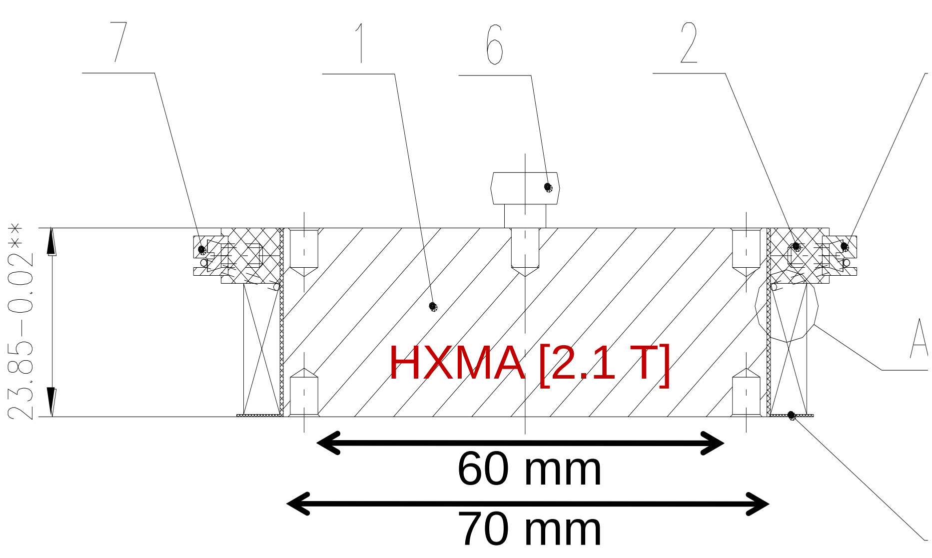


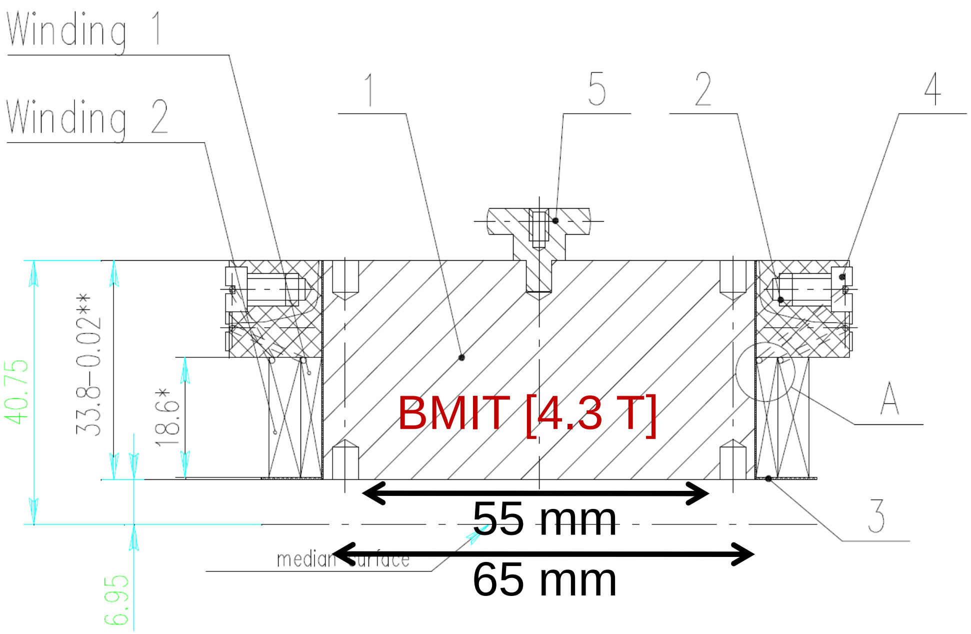


- Observe same initial losses whether or not RF is on
- Observe loss of captured particles over hundreds of turns
- Observe changes in loss rate at the synchrotron frequency



Pole Diagrams

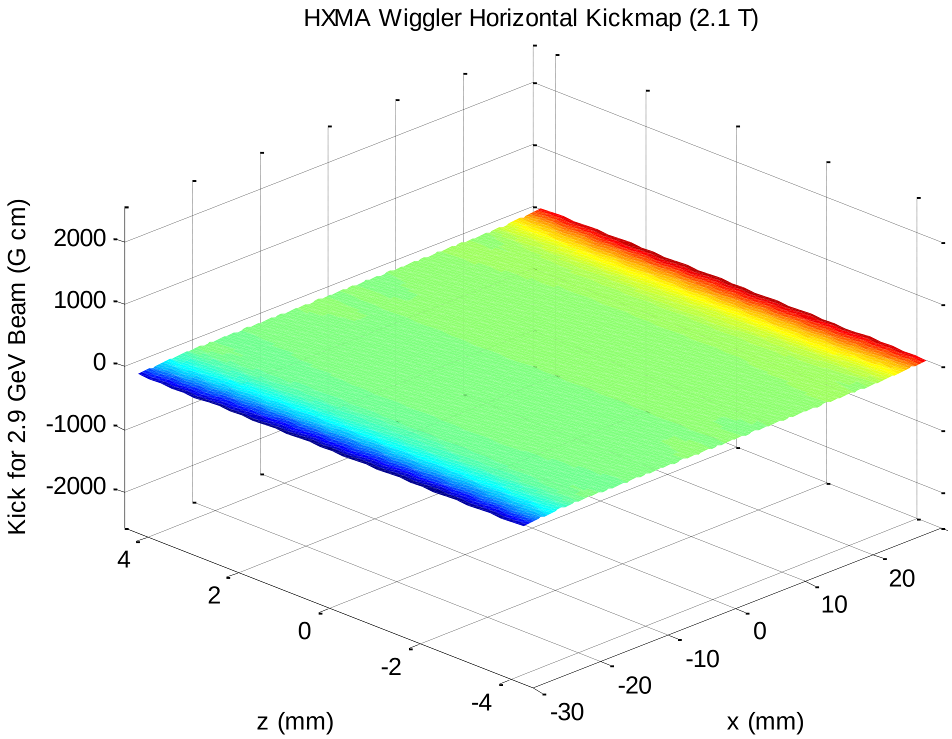


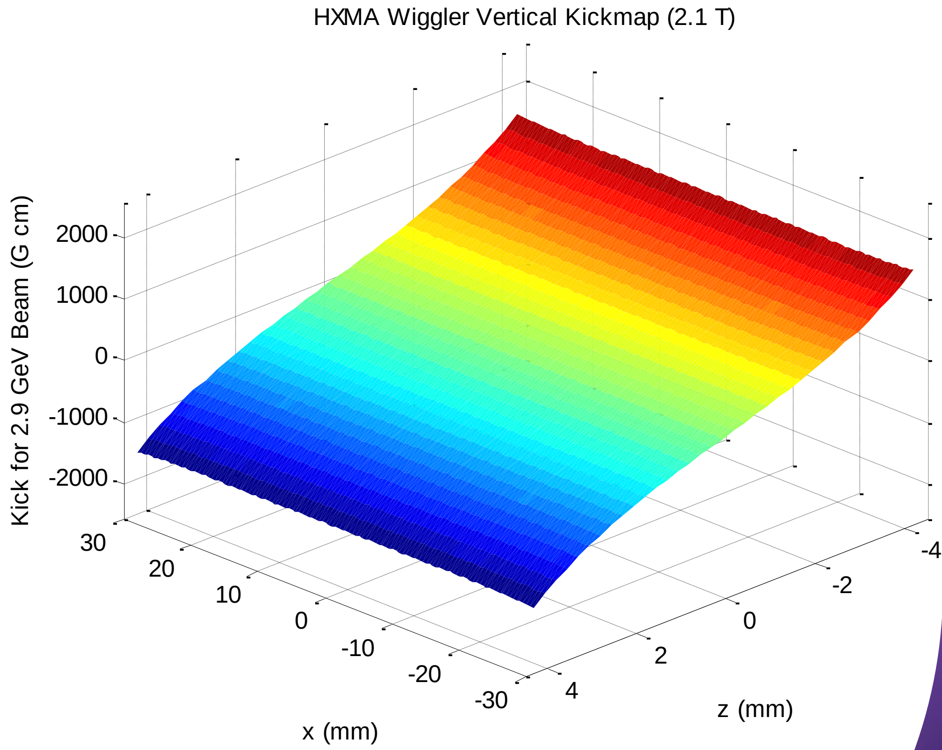


Some concern about field roll-off due to insufficient pole width, especially for SCW4.3. More modeling is needed.

Kickmaps

Kickmaps for SCW2.1 calculated by RADIA





No RADIA model for SCW4.3 yet exists

Kickmaps do not explain injection losses due to SCW2.1 wiggler