eRHIC Orbit Correction Studies (Minor Update)

Using Oct'14 lattice and dispersion diagnostic

Lattice and Beam

- Oct'14 lattice, FFAG1, beam 1 (1.334GeV)
  - 1982 cells
  - $Q_x = 0.4077$, $Q_y = 0.3299$
  - $C_x = -0.9343$, $C_y = -0.5727$ (1852, 1135 per ring)
- Gaussian beam, 20 mm.mrad RMS normalised emittance in X and Y
- Energy spread ±0.1%, uniform distribution

Errors, BPMs and Correctors

- Errors: 100um RMS <u>Gaussian</u> in X and Y quadrupole positions (initially no quad errors)
- BPMs every 2 cells/4 magnets
  - Measure <x> and <y> beam centroids
- Correctors: X and Y dipole with ±0.005T maximum field (~1% of max primary field)
- Tunable in 100 steps of 0.5 Gauss in each direction

Generic Correction Algorithm

- The 8 correctors before each BPM are tweaked by ±81, ±27, ±9, ±3, ±1 steps
- Changes that decrease the error measure are kept, all BPM sections are swept start-to-end
- An error measure is summed over the next L BPMs, where L is the "look-ahead"
- Error measure can be calculated by measured centroid $\langle x \rangle, \langle y \rangle$ and ideal closed orbit x_{cl}, y_{cl}

New Dispersion Error Measure

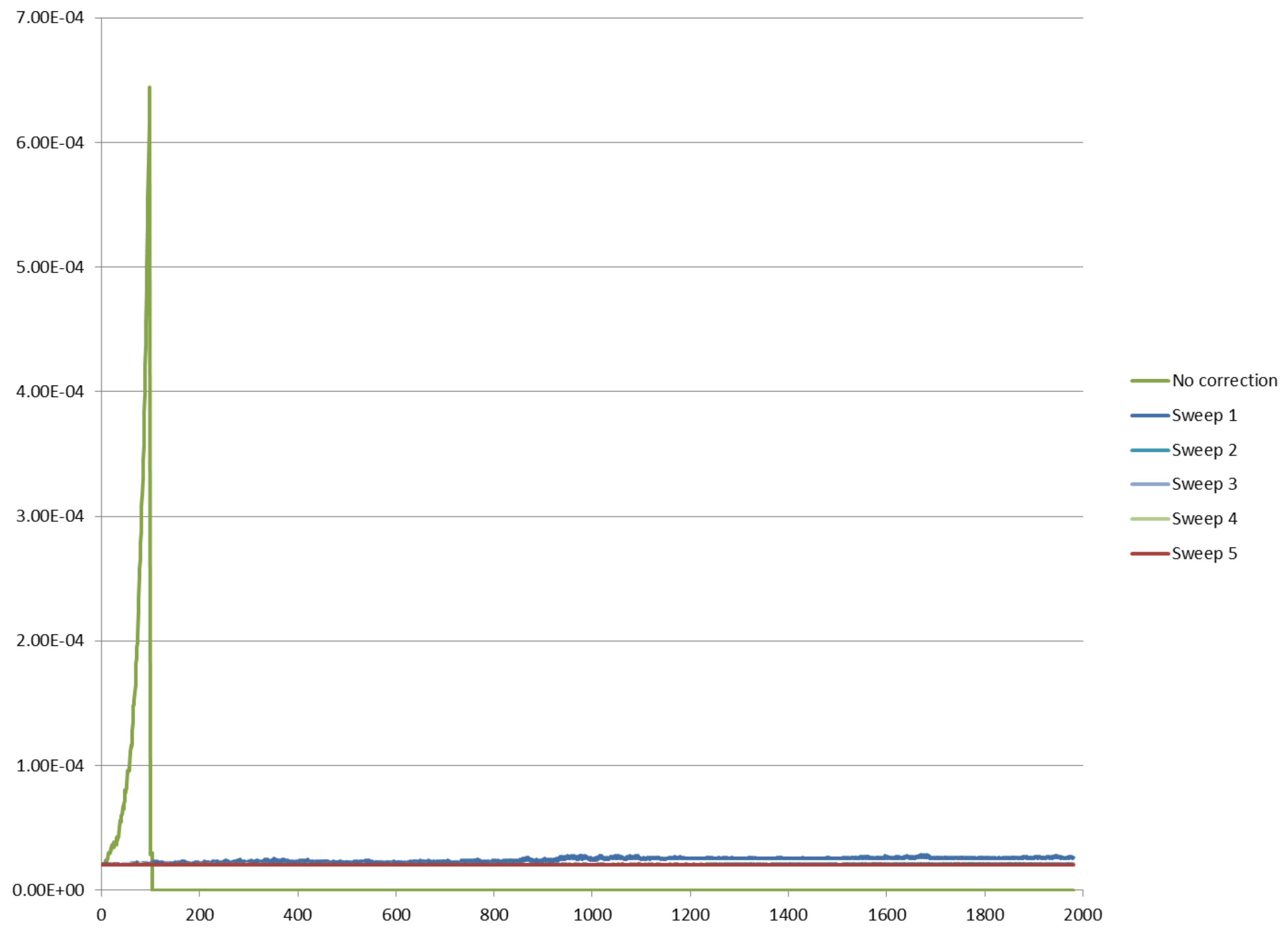
- 1344MeV beam "B" is tracked as well as the 1334MeV beam "A" through the same lattice
- The new error measure at each BPM is:

  $(\Delta x_B - \Delta x_A)^2 + (\Delta y_B - \Delta y_A)^2$, where $\Delta x_A = \langle x \rangle_A - x_{cl,A}$
- Thus: $\Delta x_B - \Delta x_A = \langle x \rangle_B - \langle x \rangle_A - (x_{cl,B} - x_{cl,A}) = \delta_{B\text{-}A}(D_{x,measured} - D_{x,closed})$
- So error measure is proportional to vector dispersion error squared

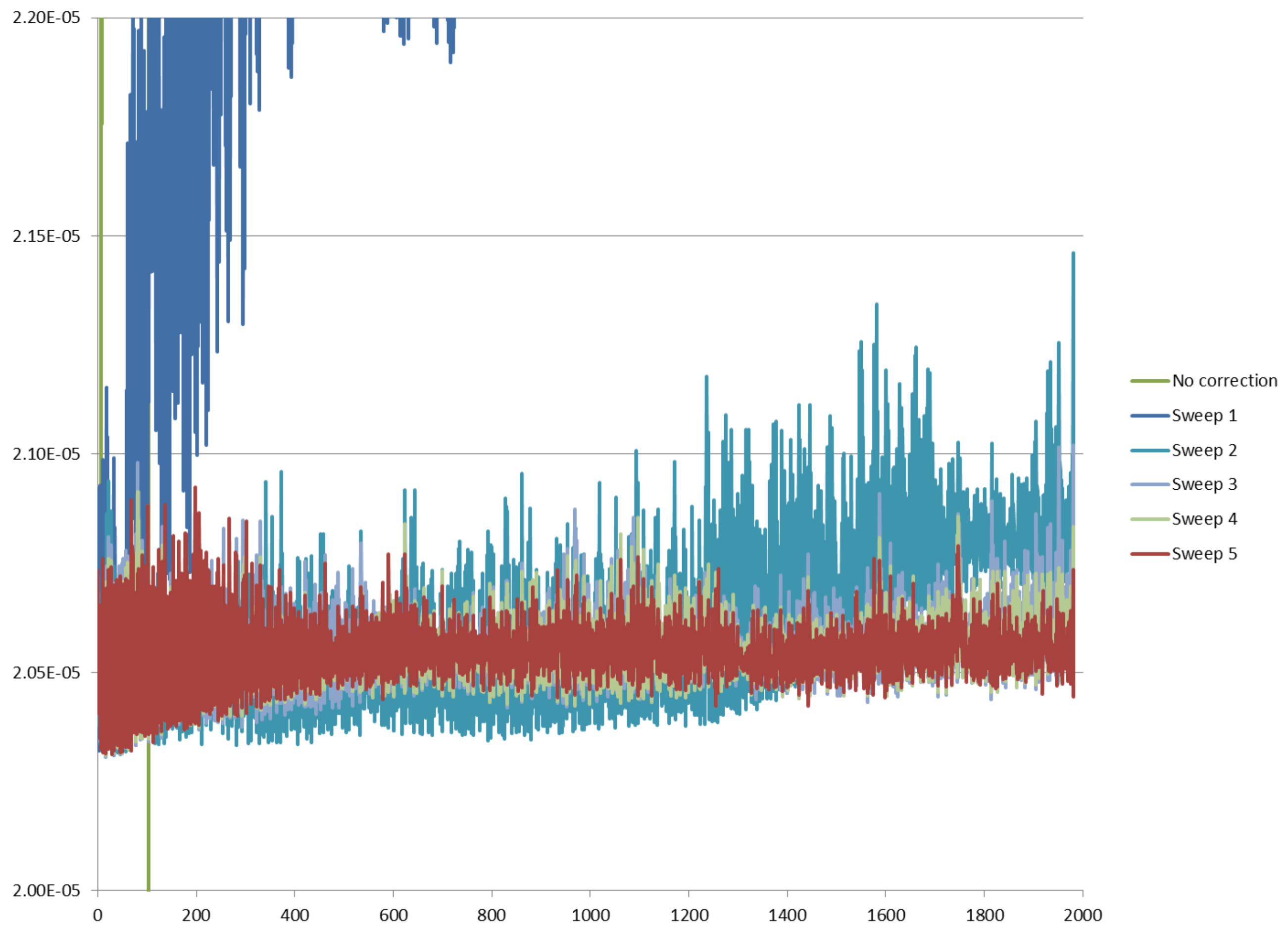
Increased Number of Particles

- Old simulations had 50 particles to run the algorithm quickly
- Calculated emittance oscillates due to different phase advance rates of particles
- New simulations here have 4000 particles

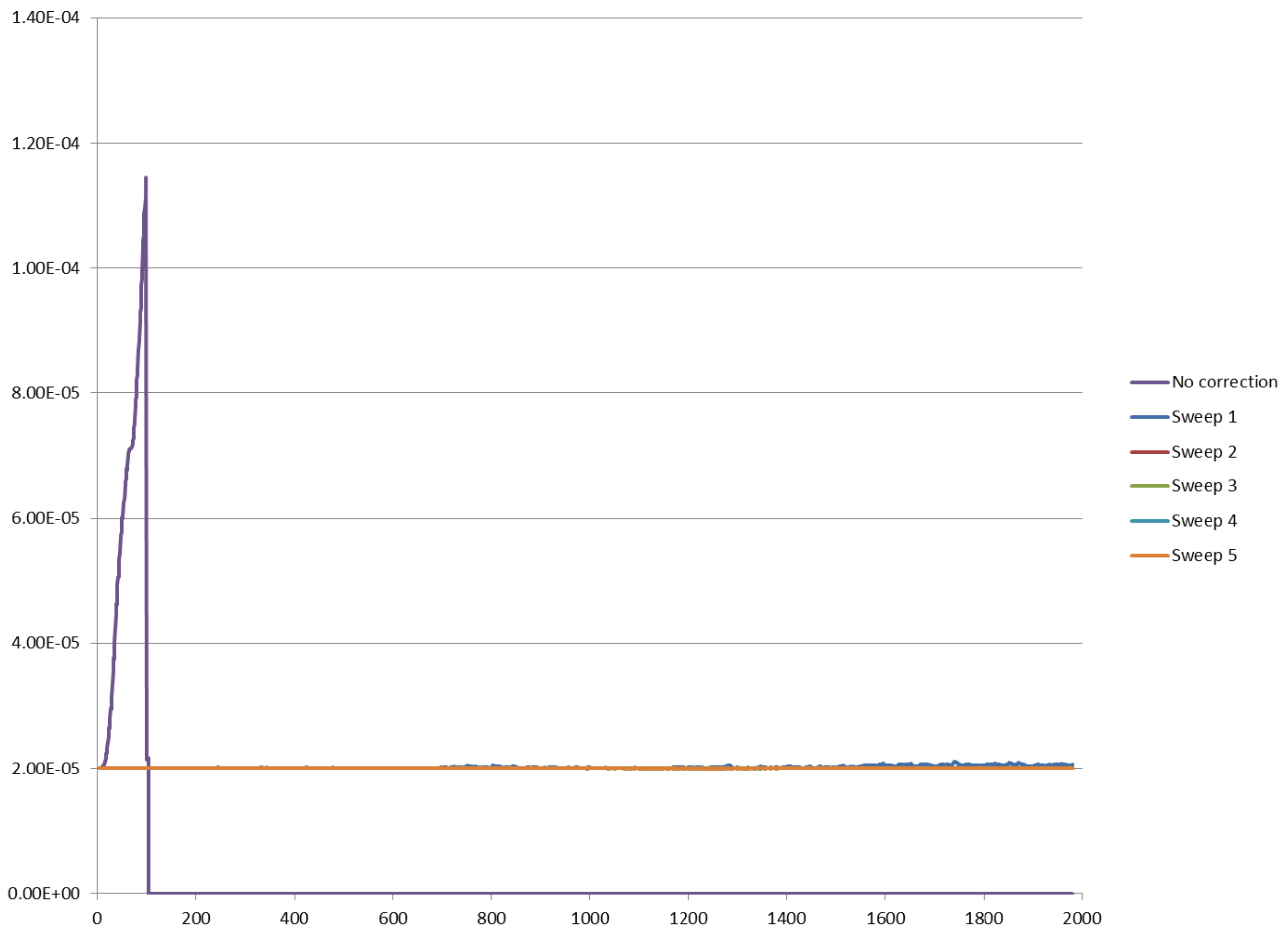
5 Sweeps, X emittance



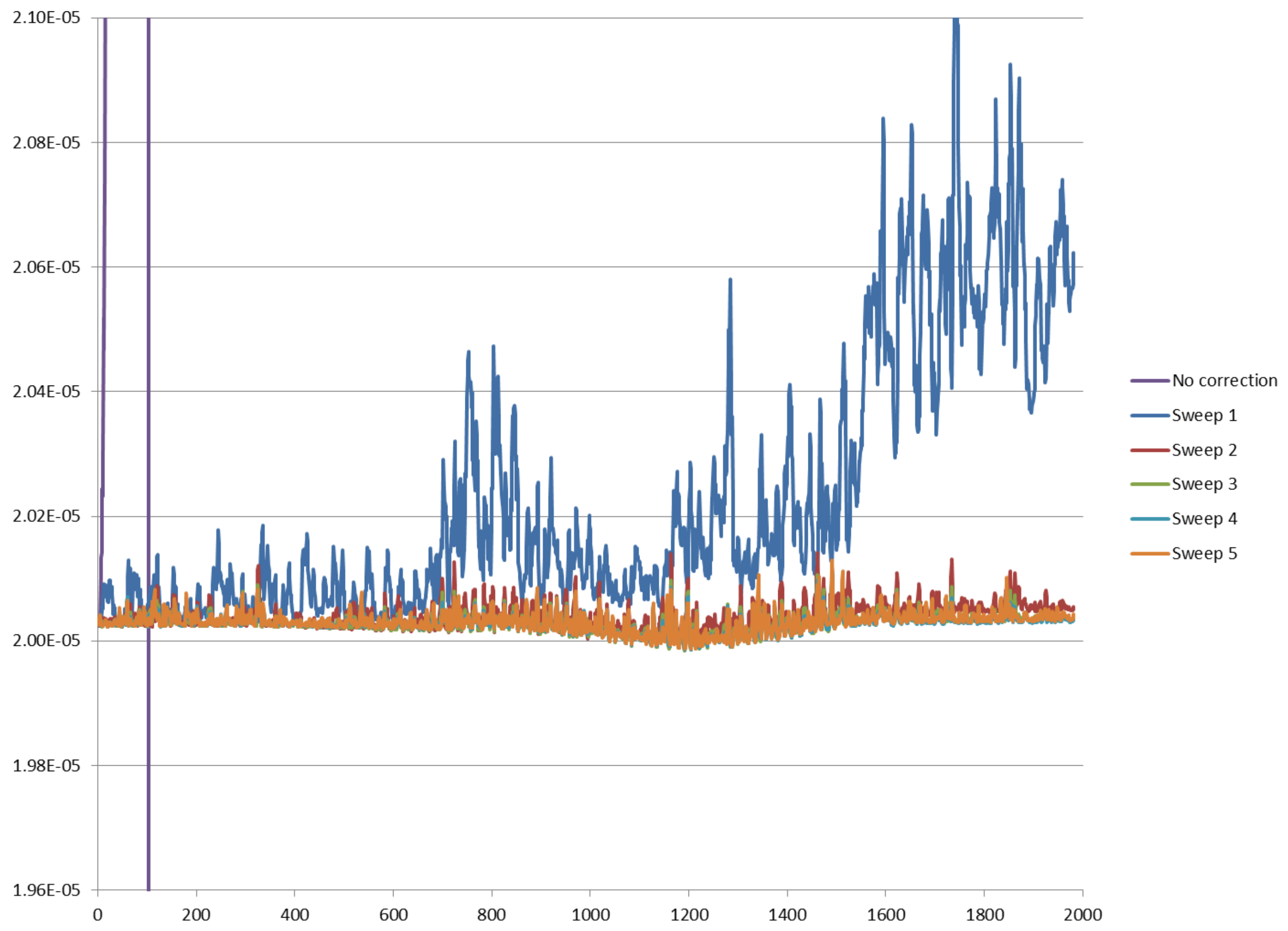
5 Sweeps, X emittance zoom



5 Sweeps, Y emittance



5 Sweeps, Y emittance zoom



Summary with no quad errors

L (BPM look-ahead)	Initial X, Y emittances mm.mrad	Final X, Y emittances mm.mrad	X, Y emittance growth
5	20.7343, 20.0268	20.4431, 20.0424	-1.40%, 0.08%

- Negative growth from statistical noise! Try averaging first and last 100 cells:

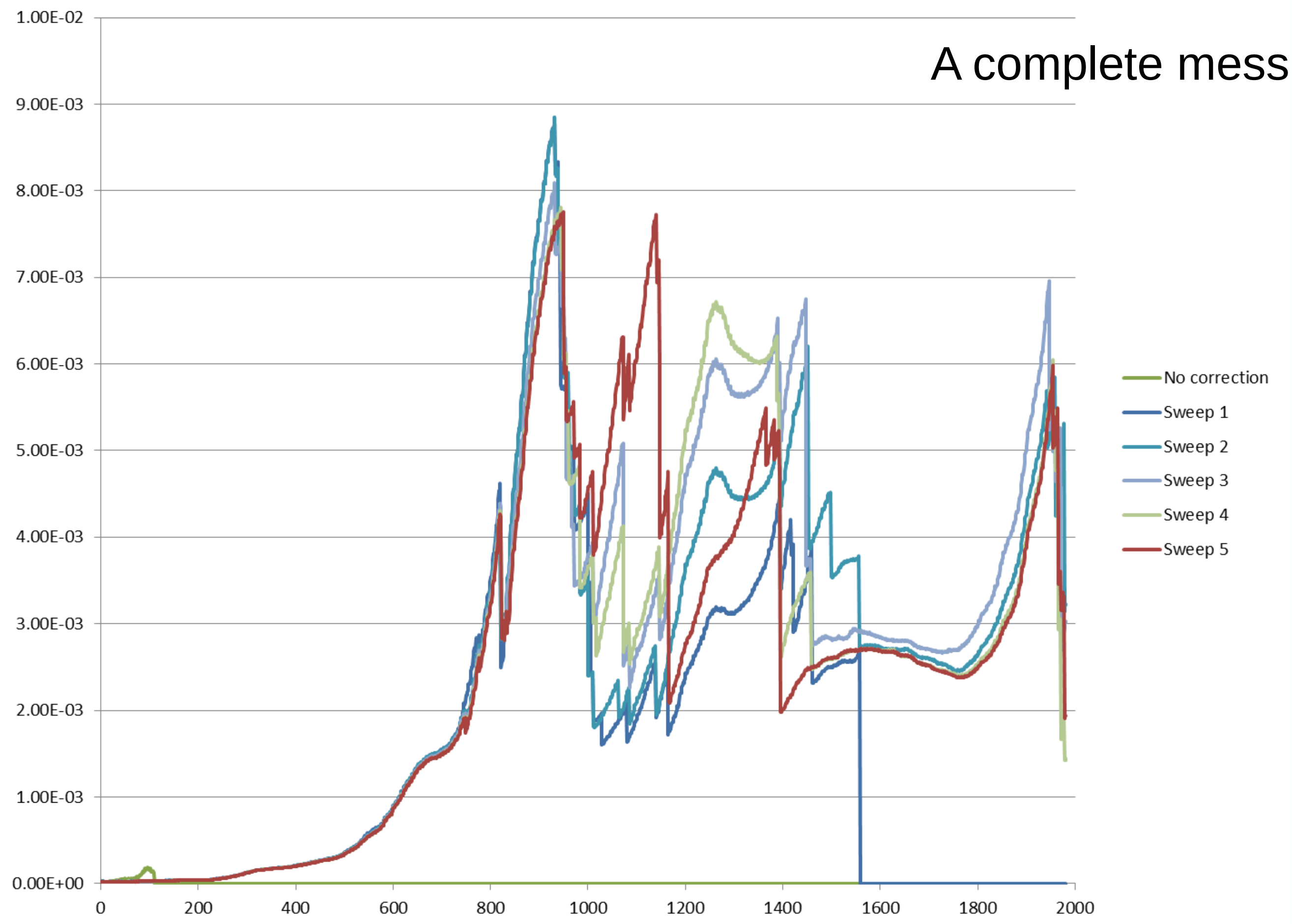
L (BPM look-ahead)	Initial X, Y emittances mm.mrad (100 cells)	Final X, Y emittances mm.mrad (100 cells)	X, Y emittance growth
5	20.5297, 20.0314	20.5568, 20.0387	0.13%, 0.04%

- Growth is effectively zero, still within the noise

Quad errors

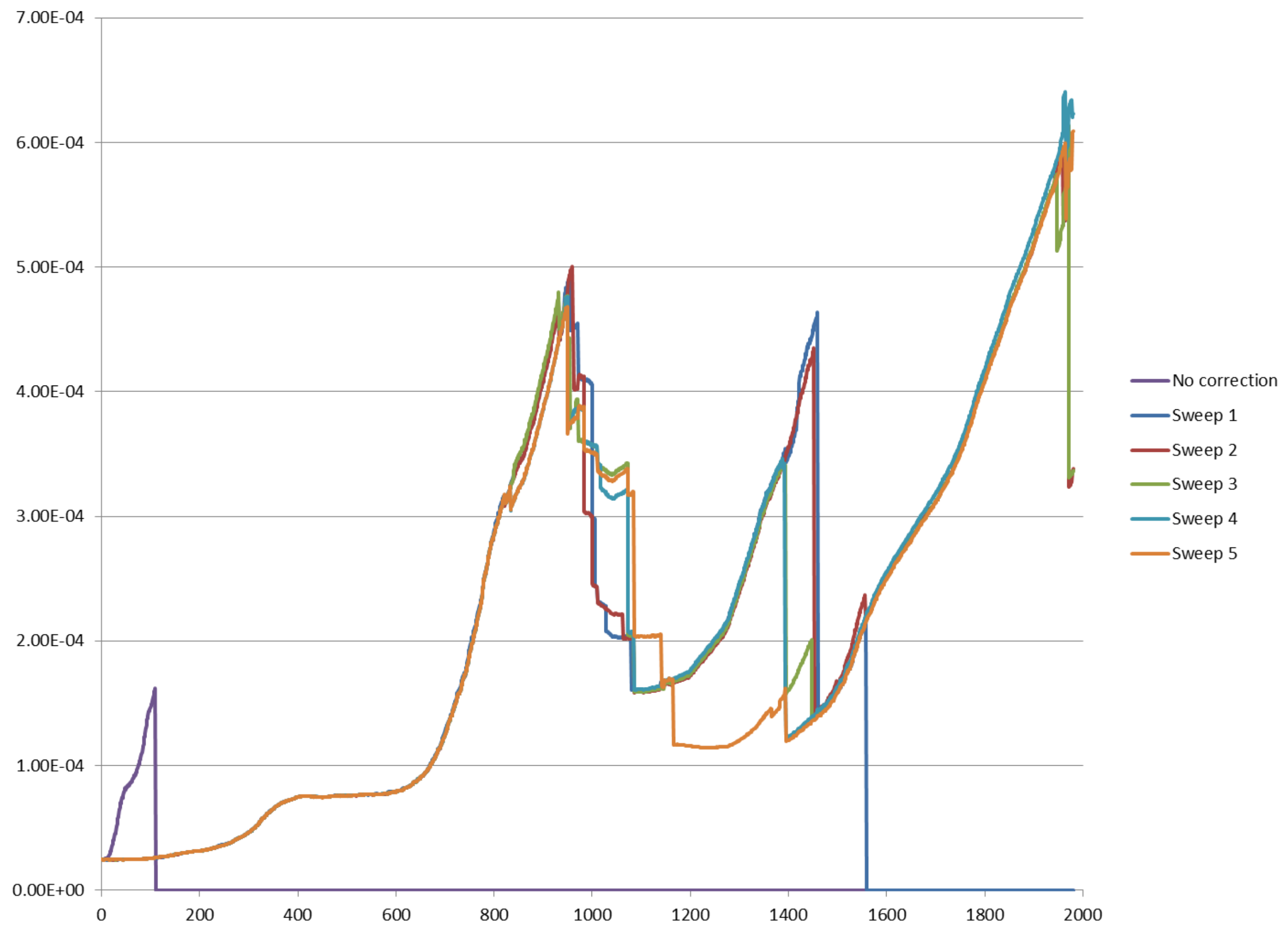
- Previous simulation had only dipole/alignment errors
- Tried applying the same error-minimising algorithm to quad correctors, doesn't work
  - Need something more like Chuyu's method
- Following graphs show what happens if quad errors are introduced but only dipole corrections are made, using existing algorithm

1% RMS quad error, X emittance

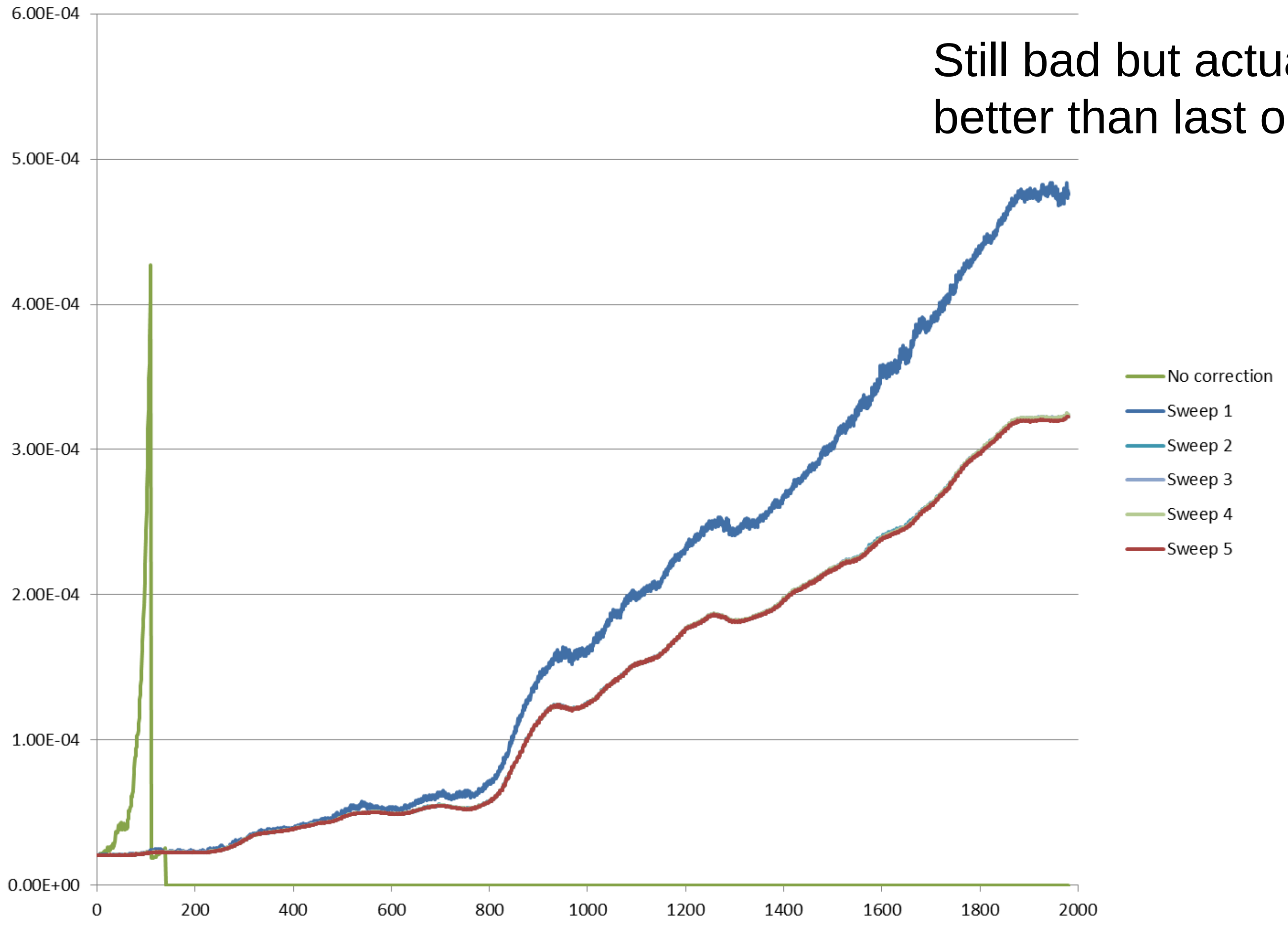


A complete mess! (losses)

1% RMS quad error, Y emittance

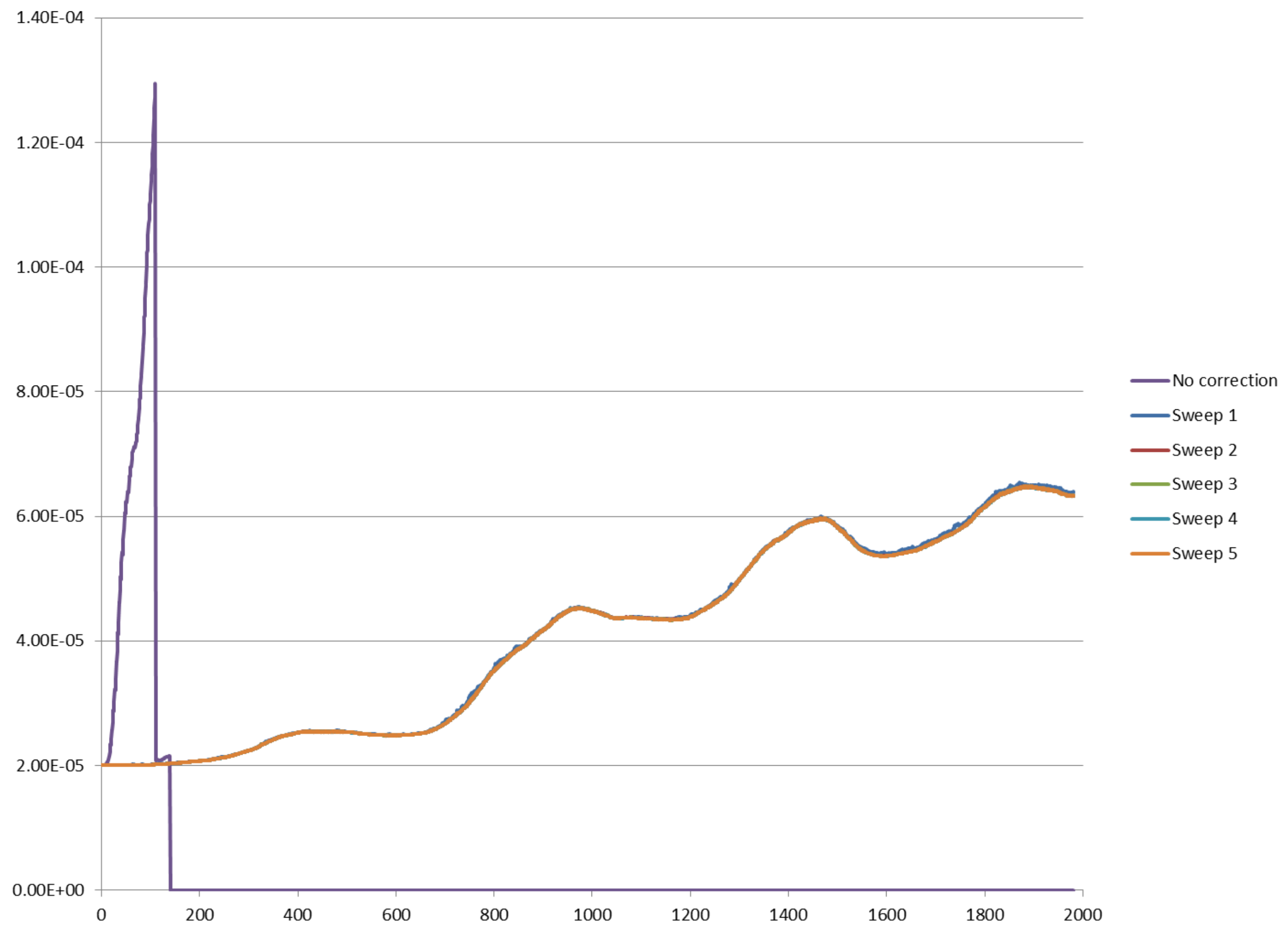


0.5% RMS quad error, X emittance

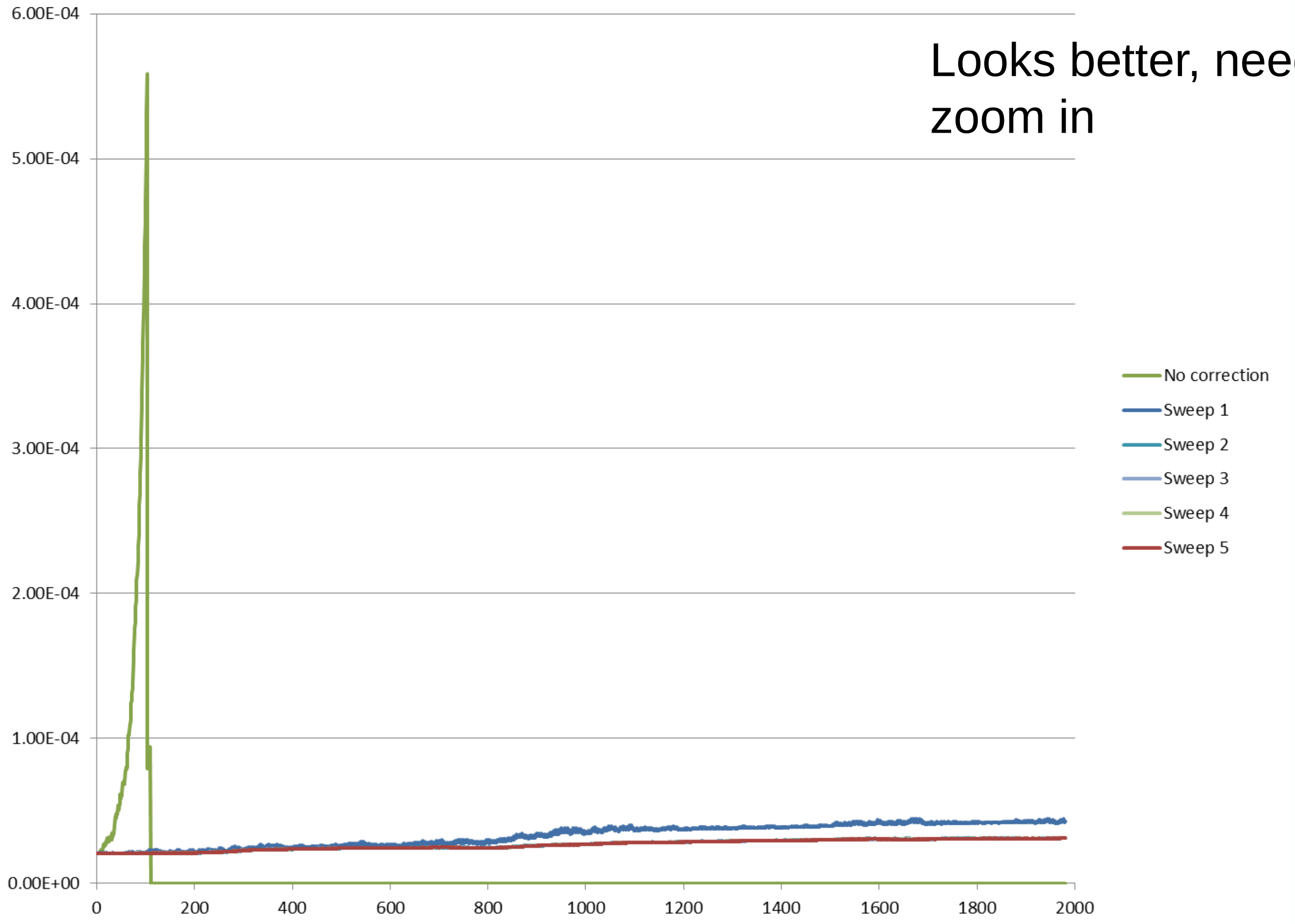


Still bad but actually 10x better than last one

0.5% RMS quad error, Y emittance

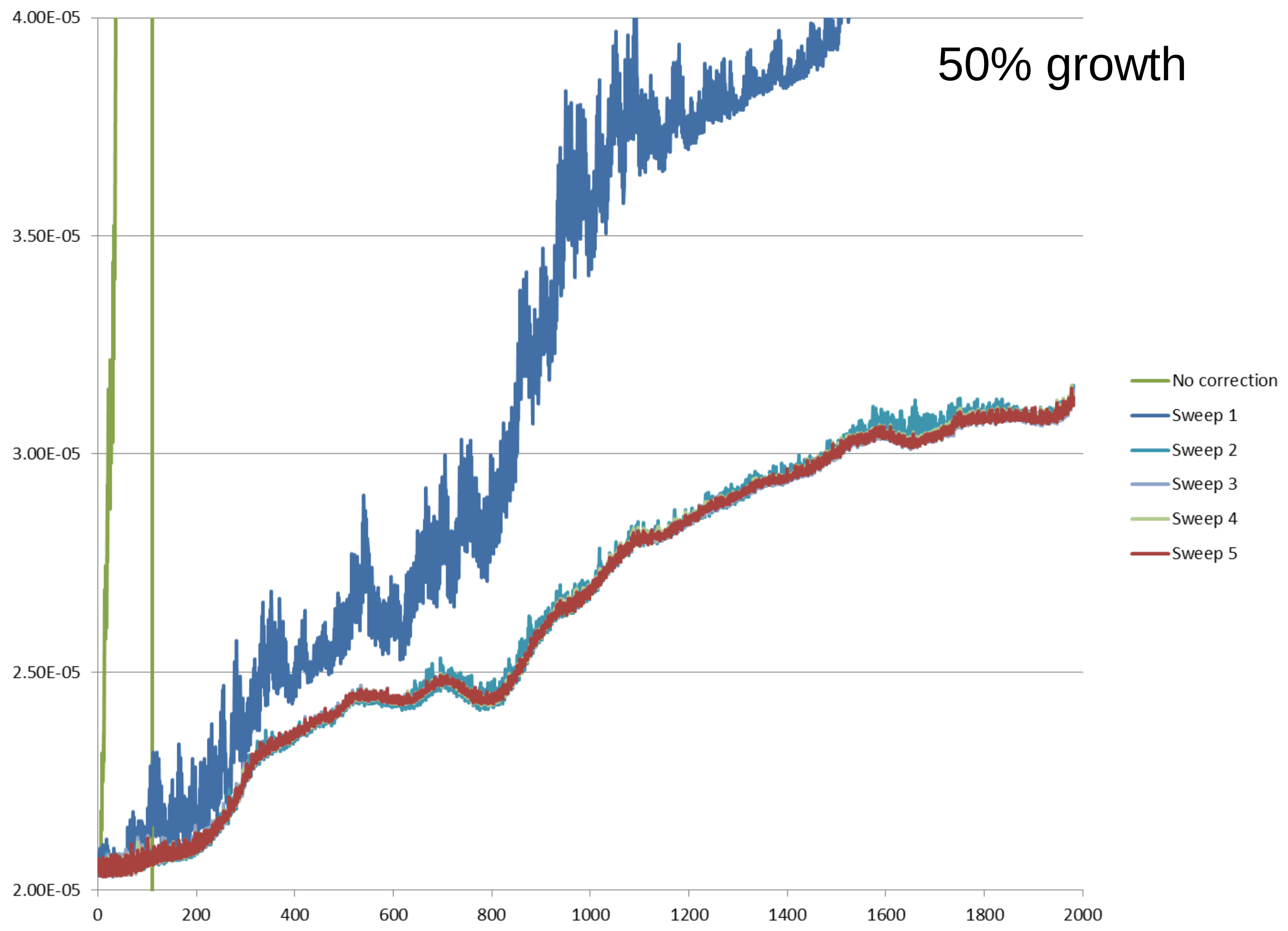


0.2% RMS quad error, X emittance

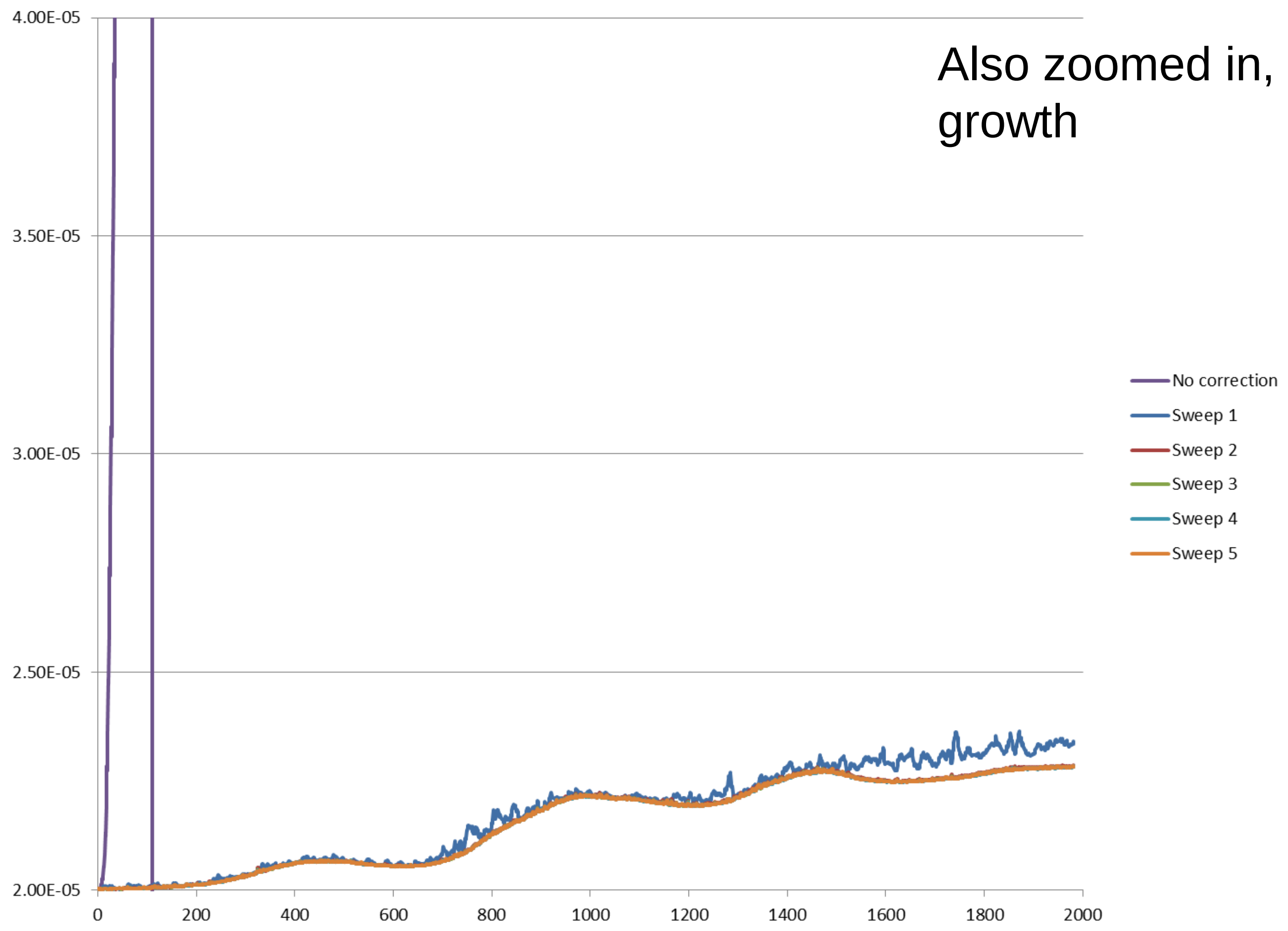


Looks better, need to zoom in

0.2% RMS quad error, X emittance

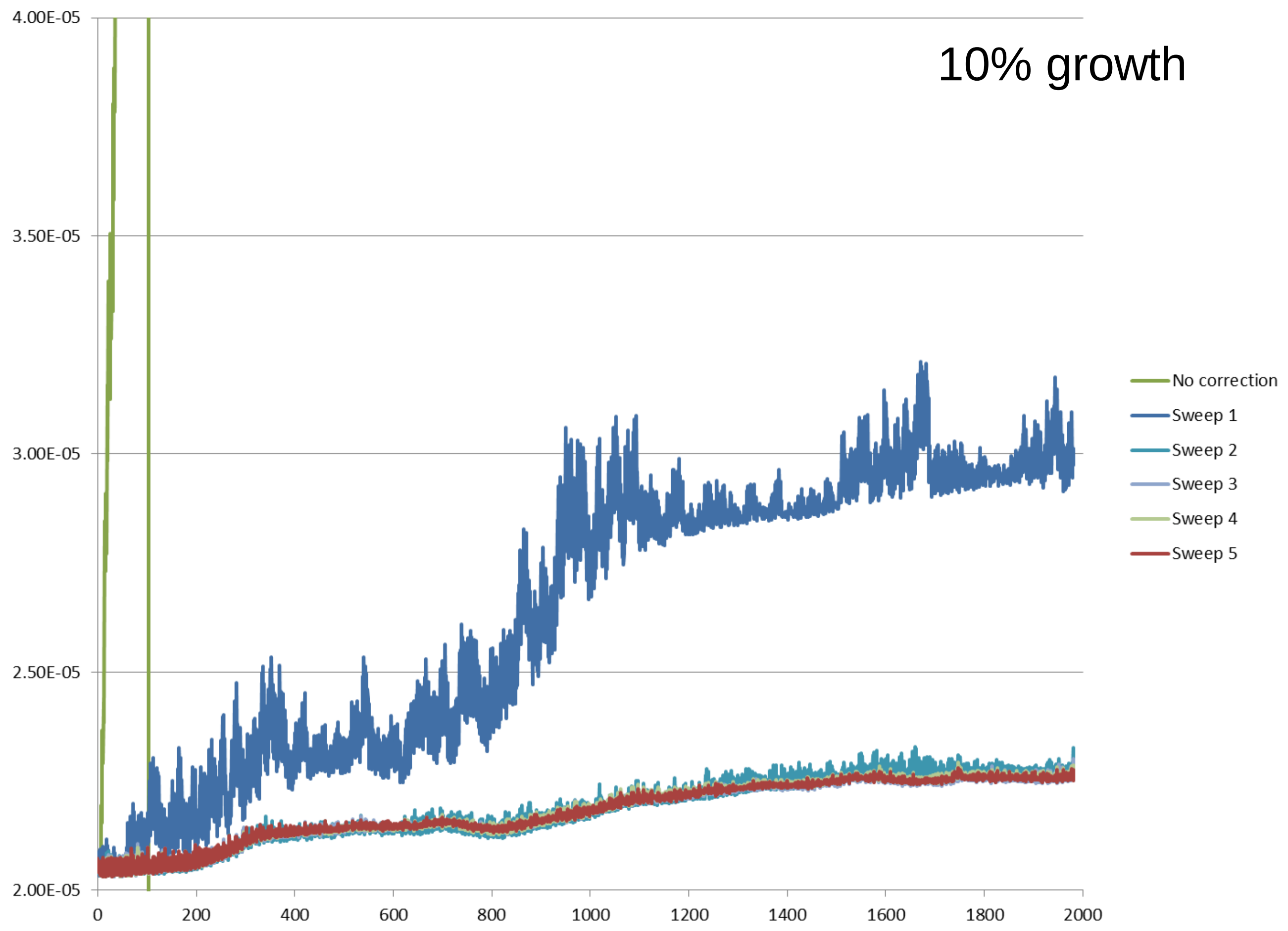


0.2% RMS quad error, Y emittance

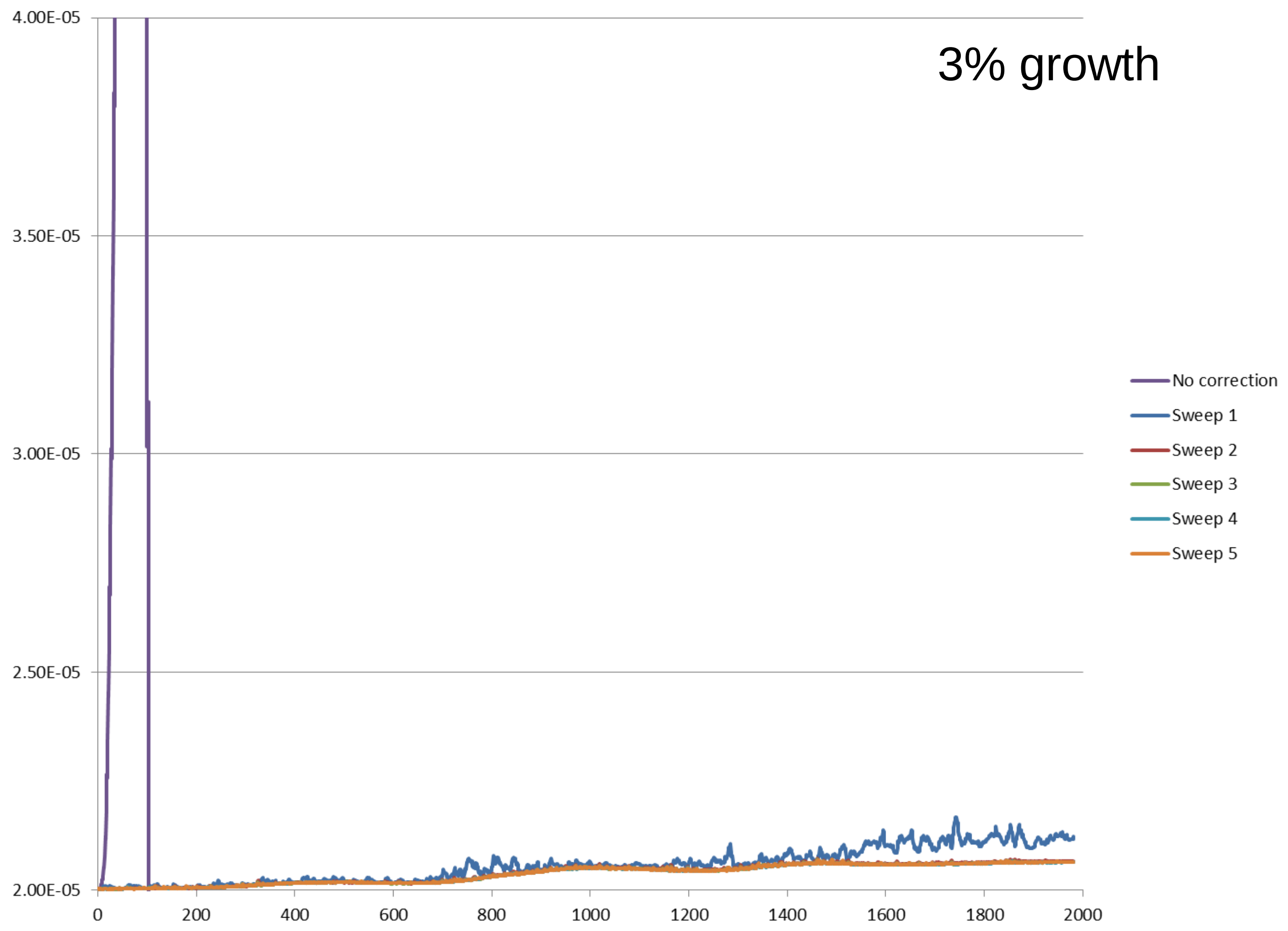


Also zoomed in, 15% growth

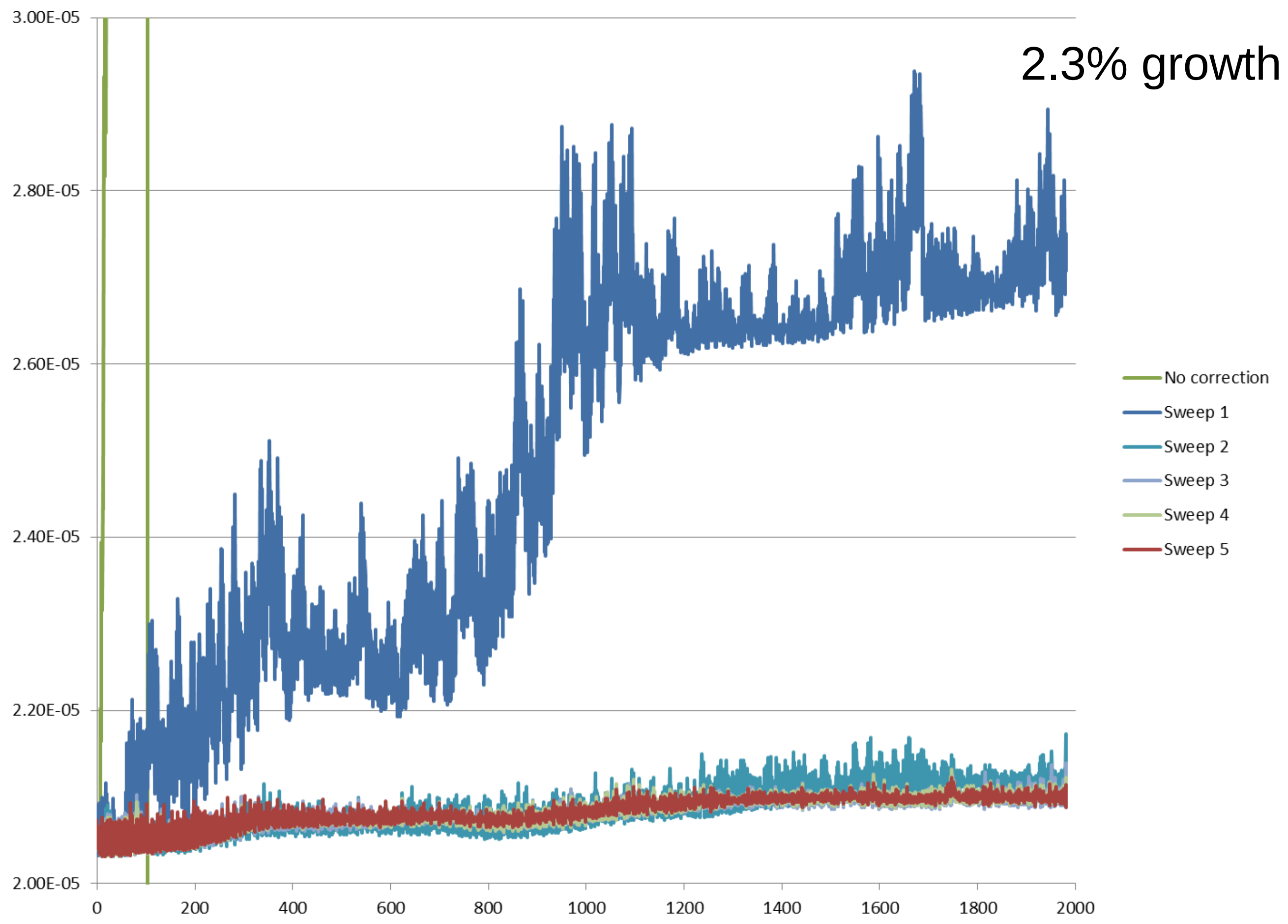
0.1% RMS quad error, X emittance



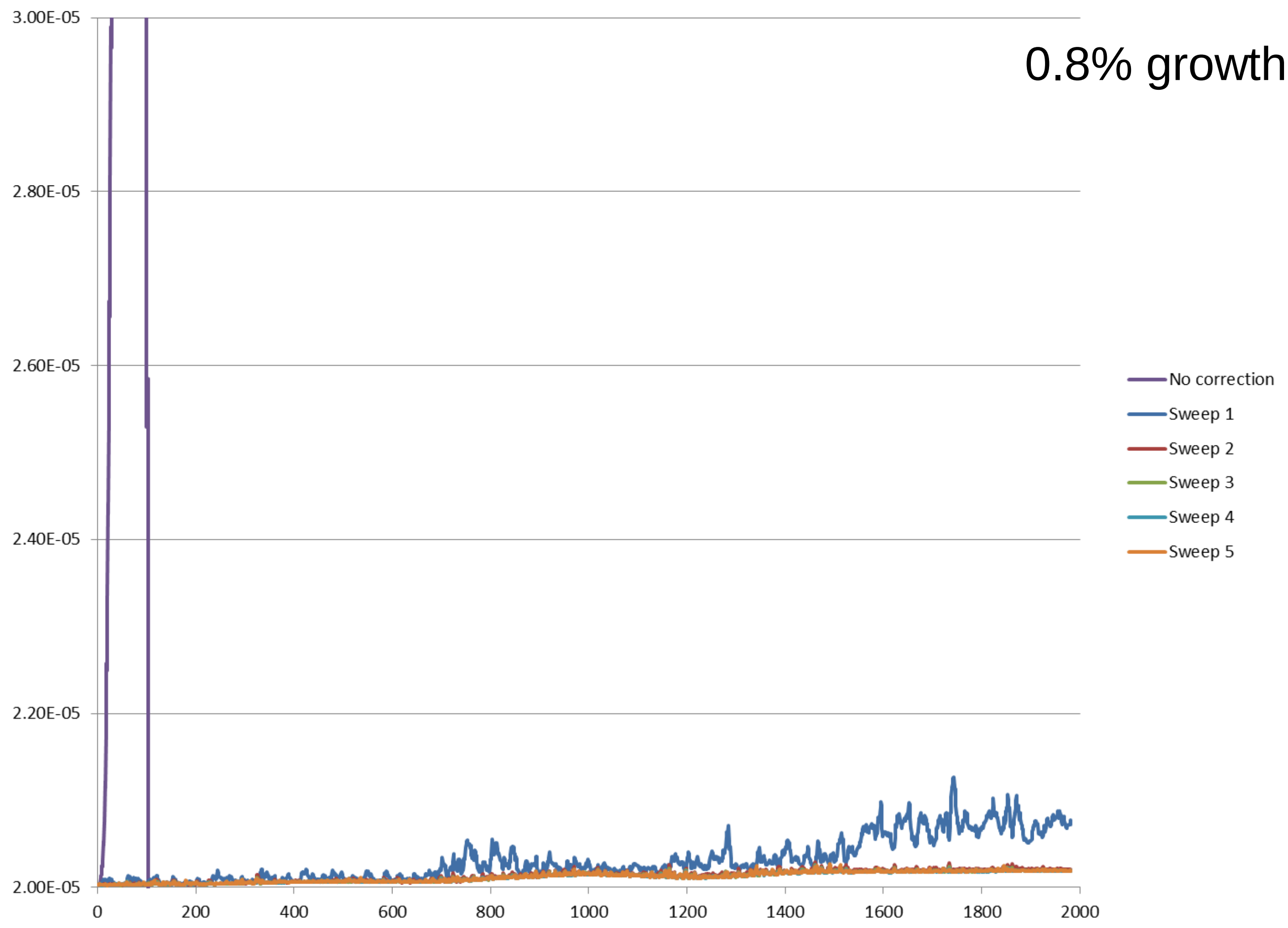
0.1% RMS quad error, Y emittance



0.05% RMS quad error, X emittance



0.05% RMS quad error, Y emittance



Summary: uncorrected quad errors

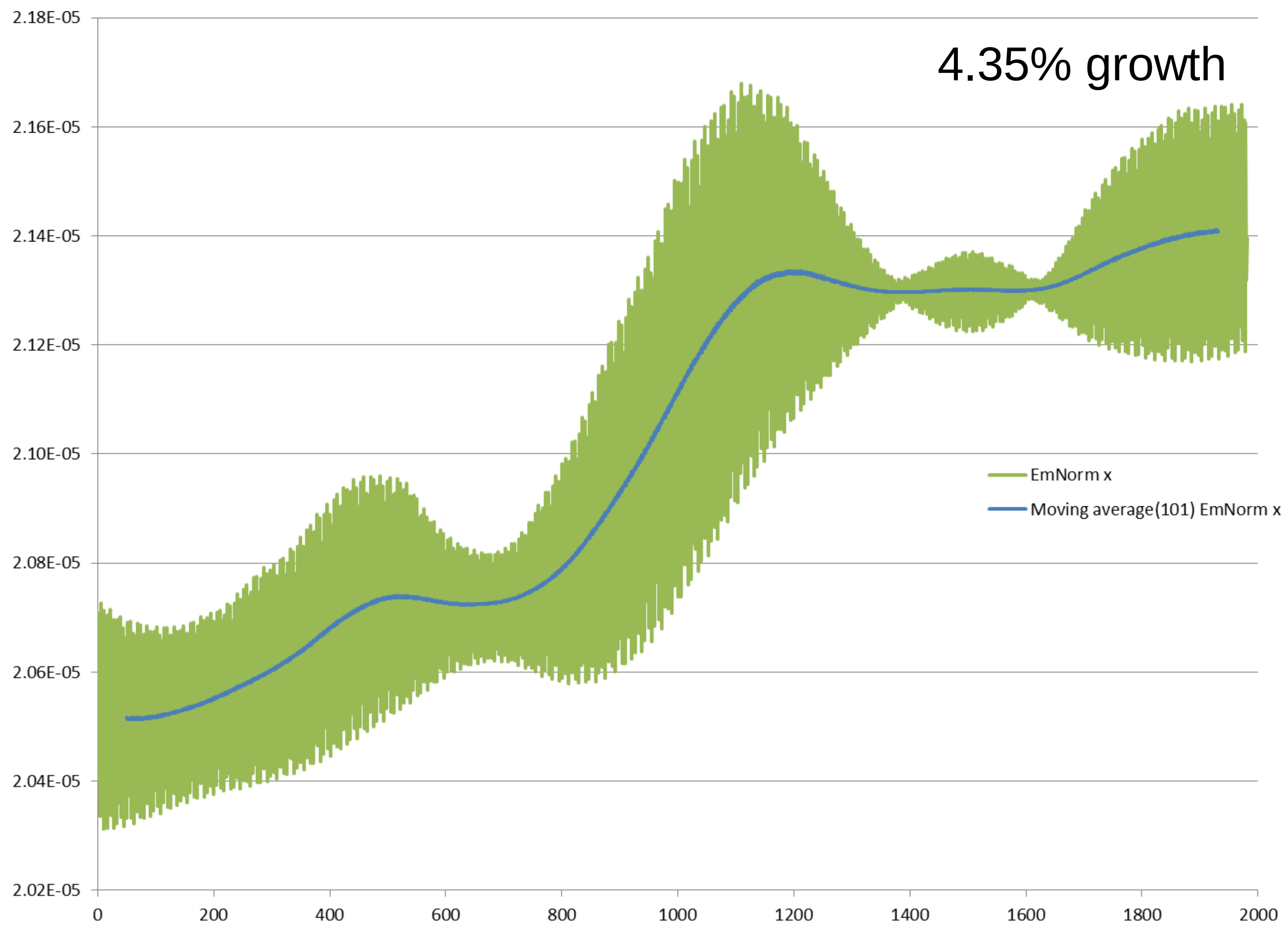
RMS quad errors	X emittance growth (ring chrom = 1852)	Y emittance growth (ring chrom = 1135)
0	0.13%	0.04%
0.05%	2.28%	0.80%
0.1%	9.96%	3.05%
0.2%	50.0%	14.1%
0.5%	15.6x	3.17x
1%	>400x (losses)	>30x (losses)

- Emittance growth roughly proportional to quad errors squared
- Definitely want a quad correction algorithm

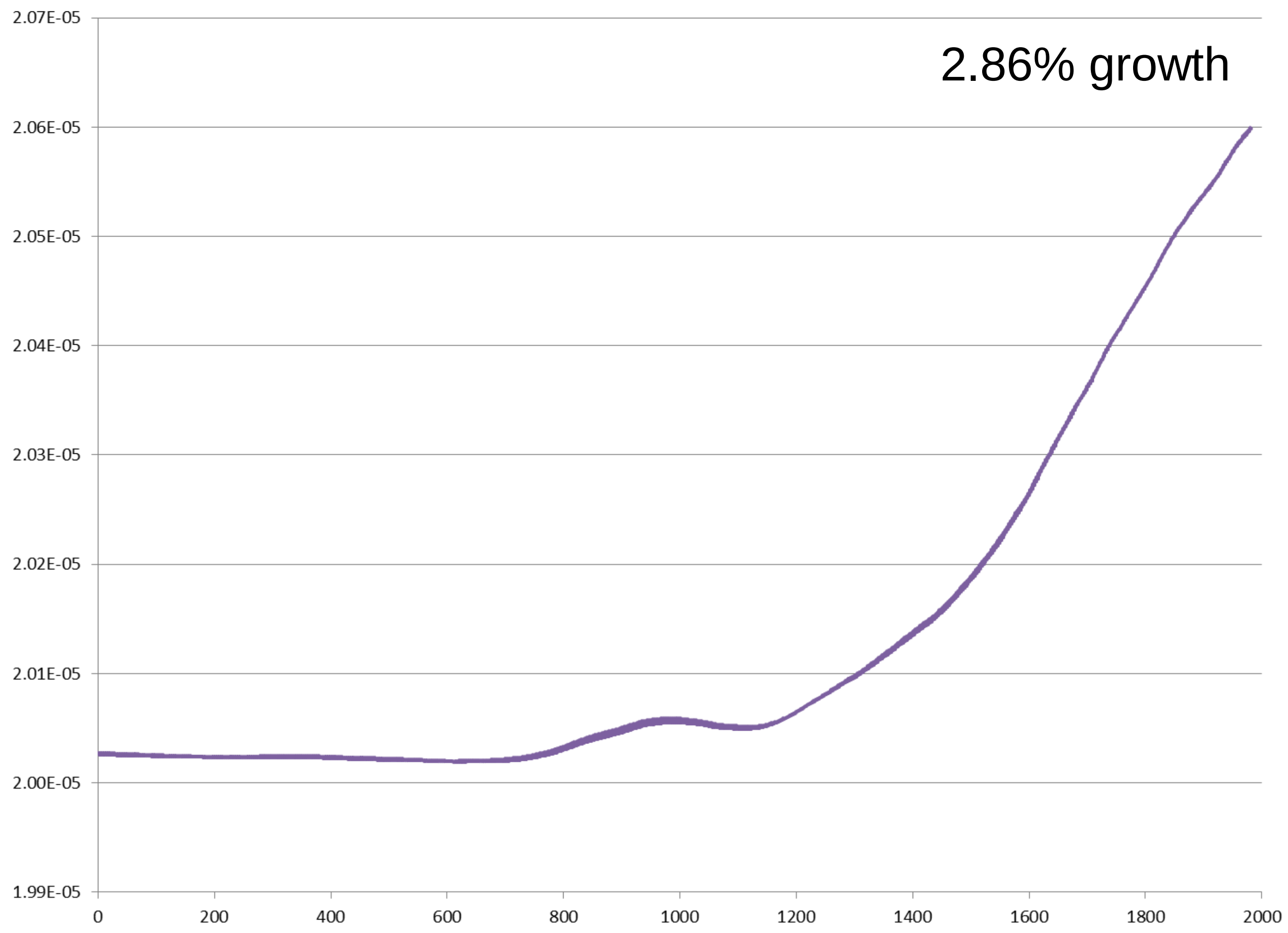
Fast Vibrations

- Vadim's e-mail:
  - For RHIC, according to Christoph Montag, who was leading corresponding ground vibration measurements, the rms of vertical vibrations:
  - integrated over the range above 2 Hz: 100 nm
  - integrated over the range above 1/7 Hz: 1 micron
- Next two slides show effect of 100nm RMS uncorrected vibrations in this lattice

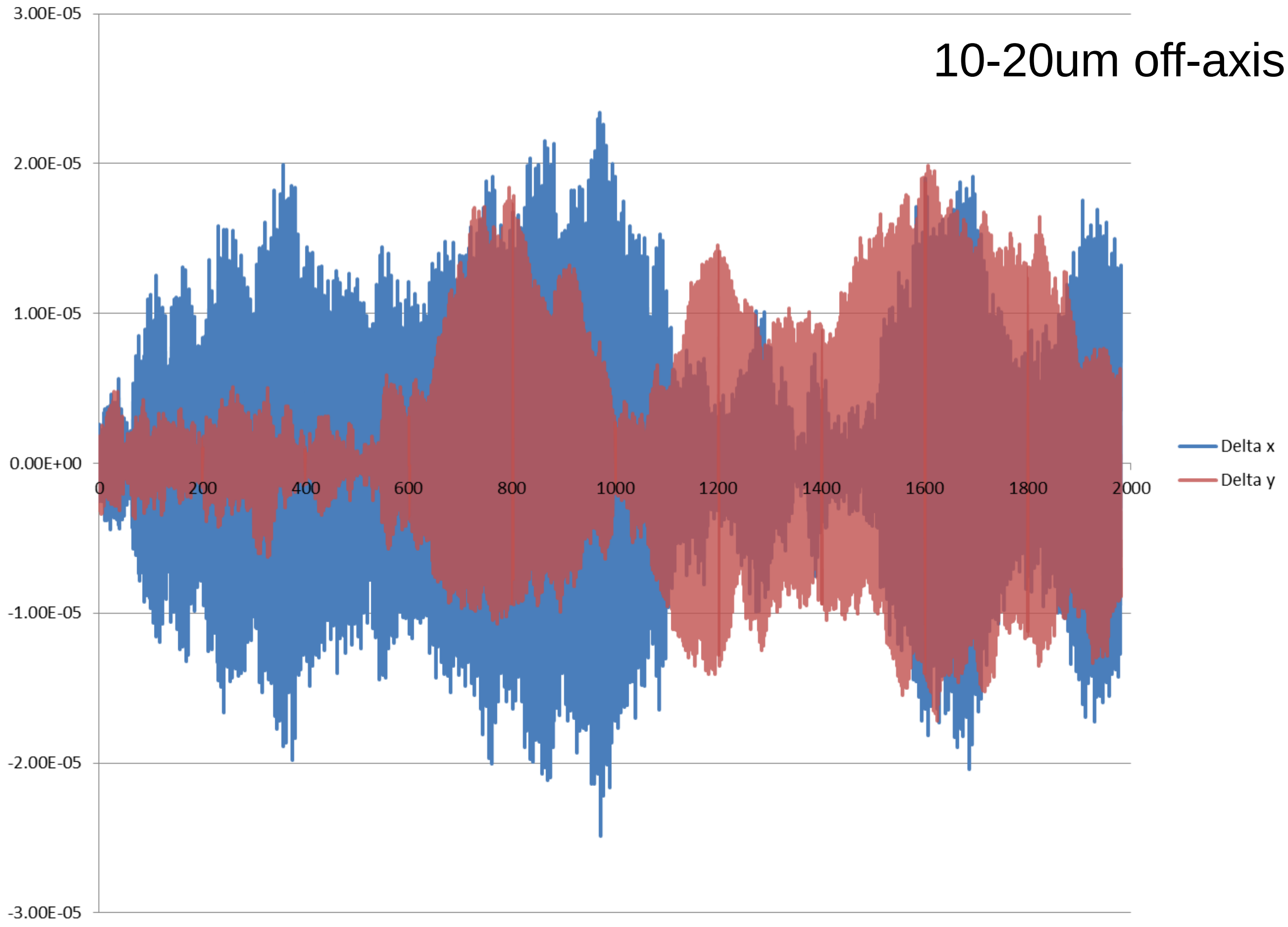
100nm fast vibrations, X emittance



100nm fast vibrations, Y emittance



100nm fast vibrations, centroid



Vibrations mitigation

- Would be useful to have the complete integrated vibration spectrum
  - If we can correct at 5Hz or 10Hz this may be acceptible
- This study assumes spatially random errors but in a 2Hz cycle, sound travels 160m in air and much further in solid material
  - Vibration correlation length scale would be useful to know