Corrections for multi-pass eRHIC lattice with large chromaticity

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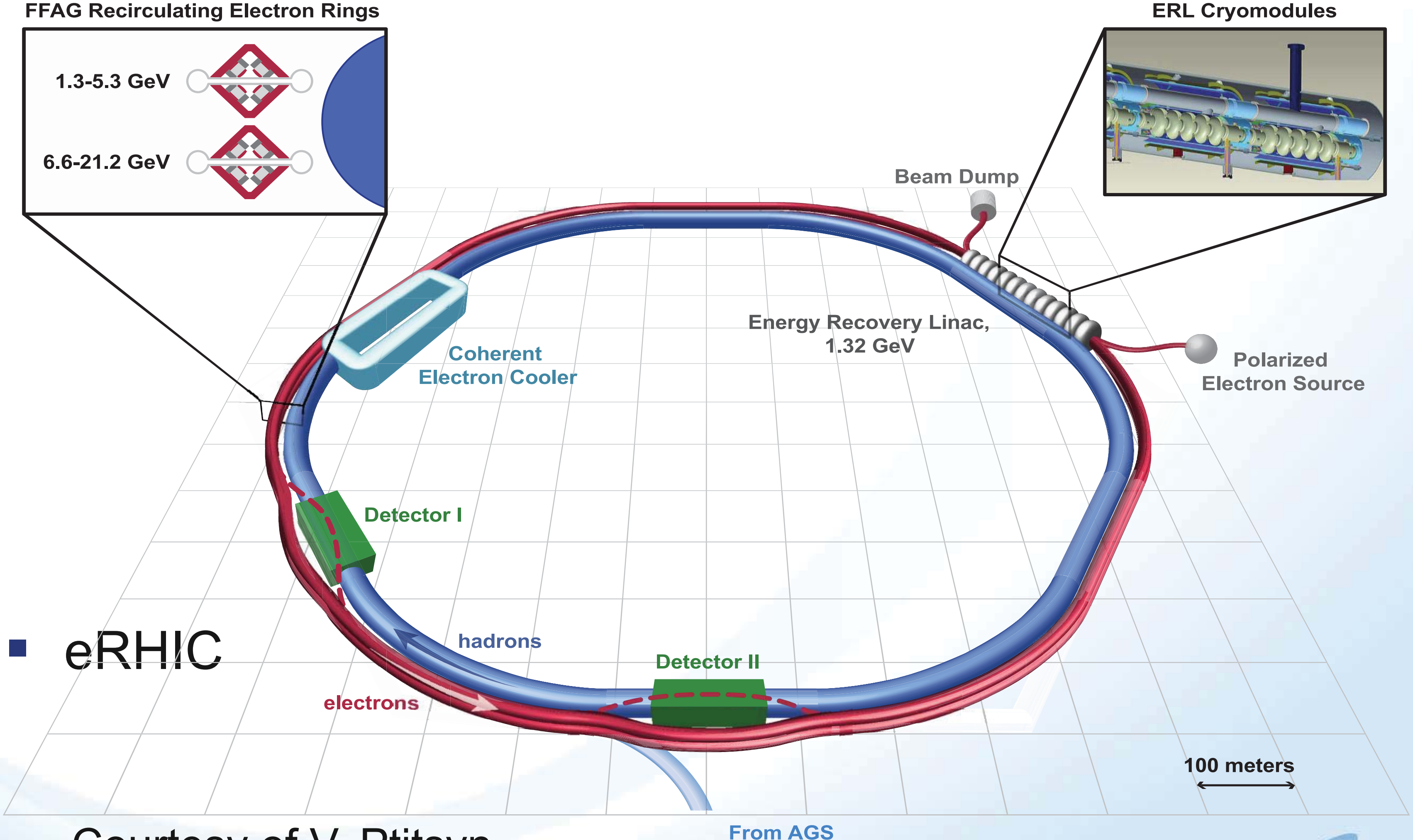
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Overview of eRHIC lattice
- Orbit correction principles
- Single particle orbit correction
- Chromaticity effect on orbit correction
- Optics correction
- Simulation results
- Summary

Overview of eRHIC



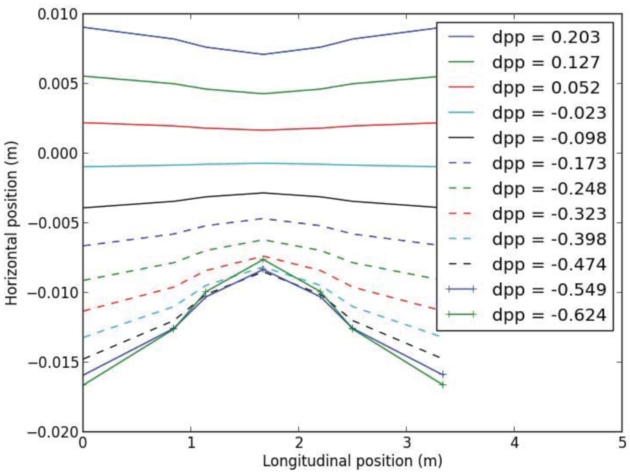
- eRHIC

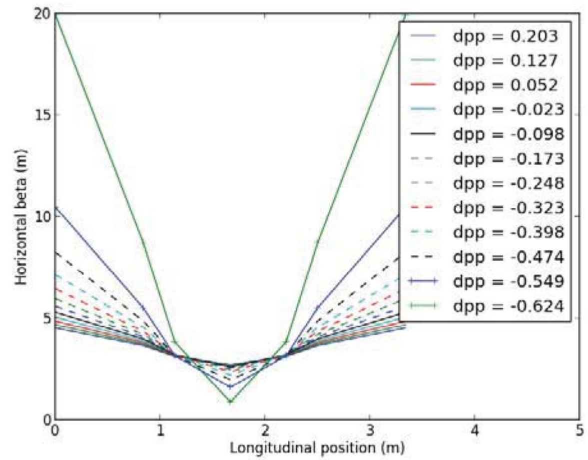
Courtesy of V. Ptitsyn

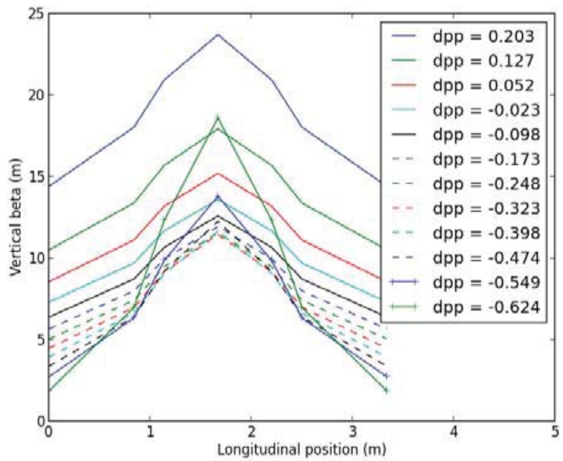
Properties of FFAG lattice

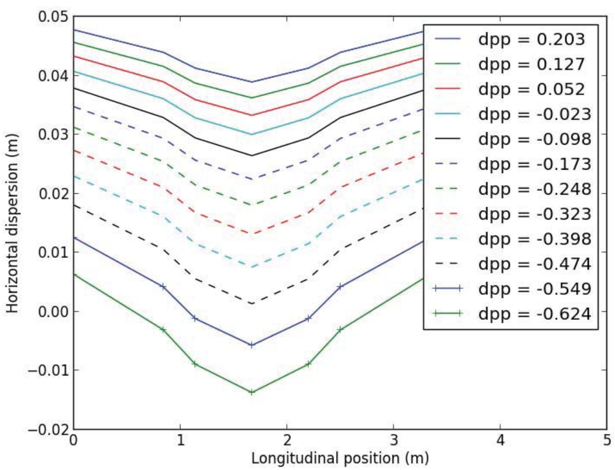
- Orbit of beams with various energies stay in a common vacuum pipe, horizontal offsets are small, ~10 mm for eRHIC.
- Large energy acceptance, 1.3-5.3GeV for FFAG I, 6.6-21.2GeV for FFAG II.
- Strong focusing with small dispersion function.
- Tunes vary as beam being accelerated, large chromaticity.
- Small magnet.

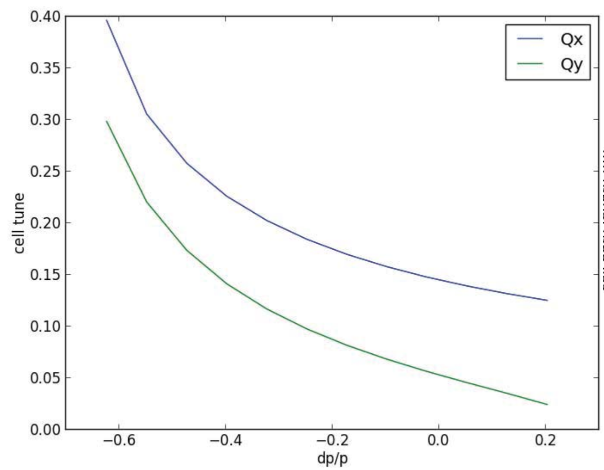
Plots of FFAG II

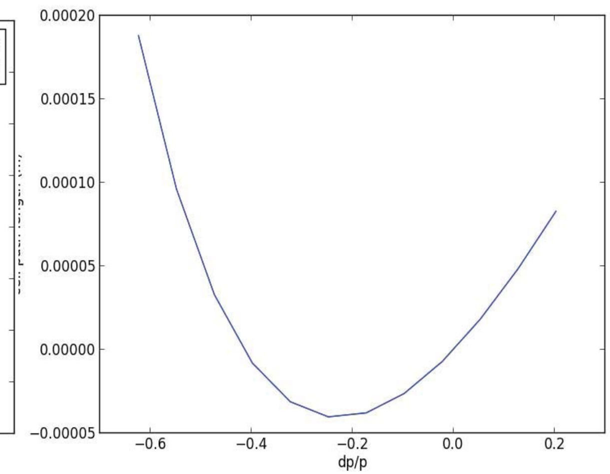




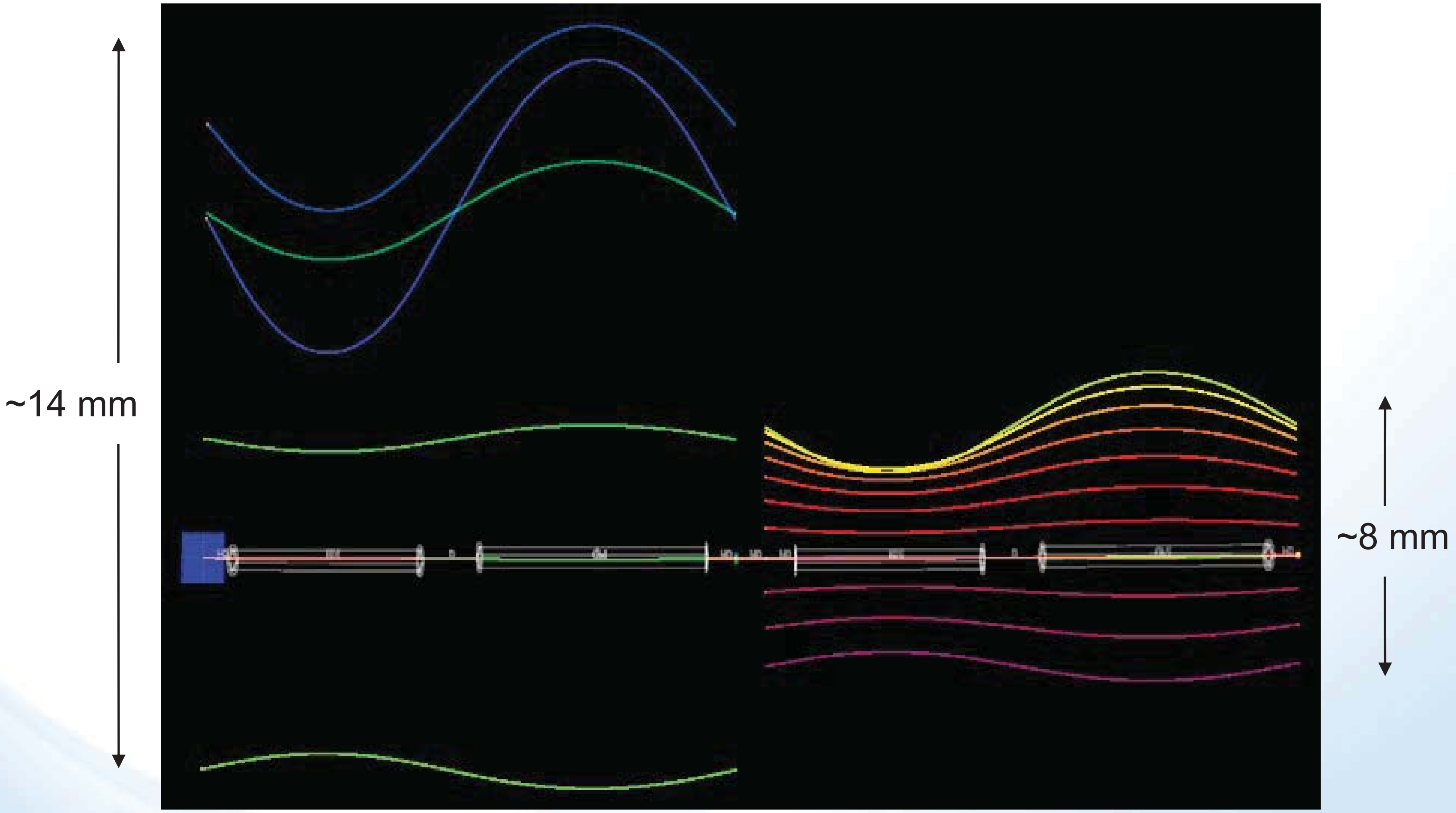








Design orbit



Courtesy of S. Brooks

Orbit correction principle

$$Y - Y_0 = R\theta$$

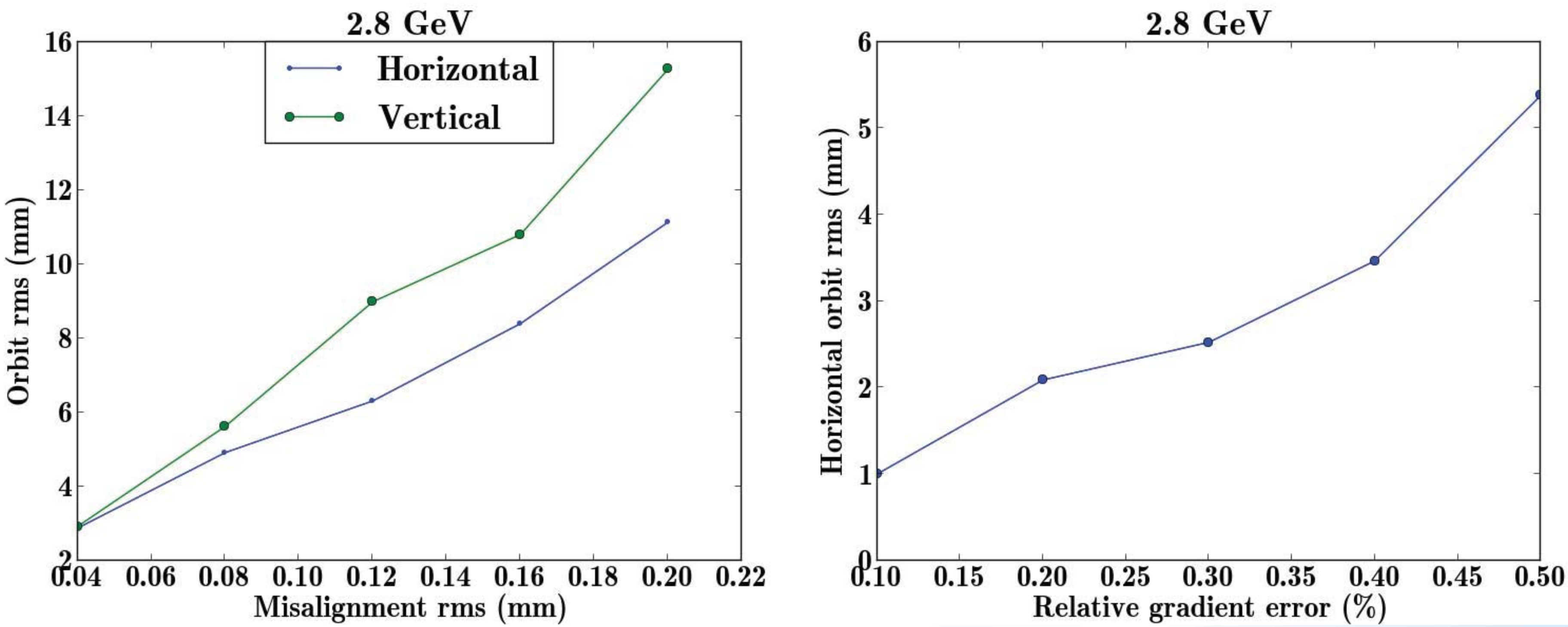
$$\Delta\theta = R^{-1}(Y_0 - Y)$$

- Y is the measured orbit. Y_0 is the design orbit. R is the orbit response matrix, $R_{ij}=dY_i/d\theta_j$. θ is the dipole errors.
- The corrections can be found by solving the second eq. Inverting matrix R using Singular Value Decomposition (SVD) provides a easy way to balance correction strength, corrector and orbit measurement errors.
- Common practice: corrections don't cancel errors exactly, only fixed orbit.
- Goal: emittance preservation!

eRHIC FFAG orbit correction

- For the first time, question of ‘is orbit correction a show stopper’ being raised.
- Dipole errors, quad errors distort orbit of all passes.
- Orbit measurement is challenging, a diagnostic bunch will be placed in the ‘abort gap’ to gain enough spacing for measurement.
- Same correctors for different passes, kick angle, orbit response (beta, phase) are all different.
- Ideally, dipole and quadrupole trims will be placed at each and every magnet center.
- Need enough BPMs for position measurements. General rule: # of orbit measurement is greater than # of errors. # of BPMs > # of magnets?

Orbit distortion



1. Field error due to misalignment is dB = G*dx, the same for all passes.

2. Field error due to gradient error is dB = dG*x, is different for all passes.

3. Should disentangle gradient error from misalignment, compensate gradient error by trim quads, and misalignment by dipole correctors.

4. Iteration of orbit and optics is necessary to reach satisfactory results?

Simultaneous correction of all passes

$$\Delta Y = (Y_0 - Y) = R * \theta$$

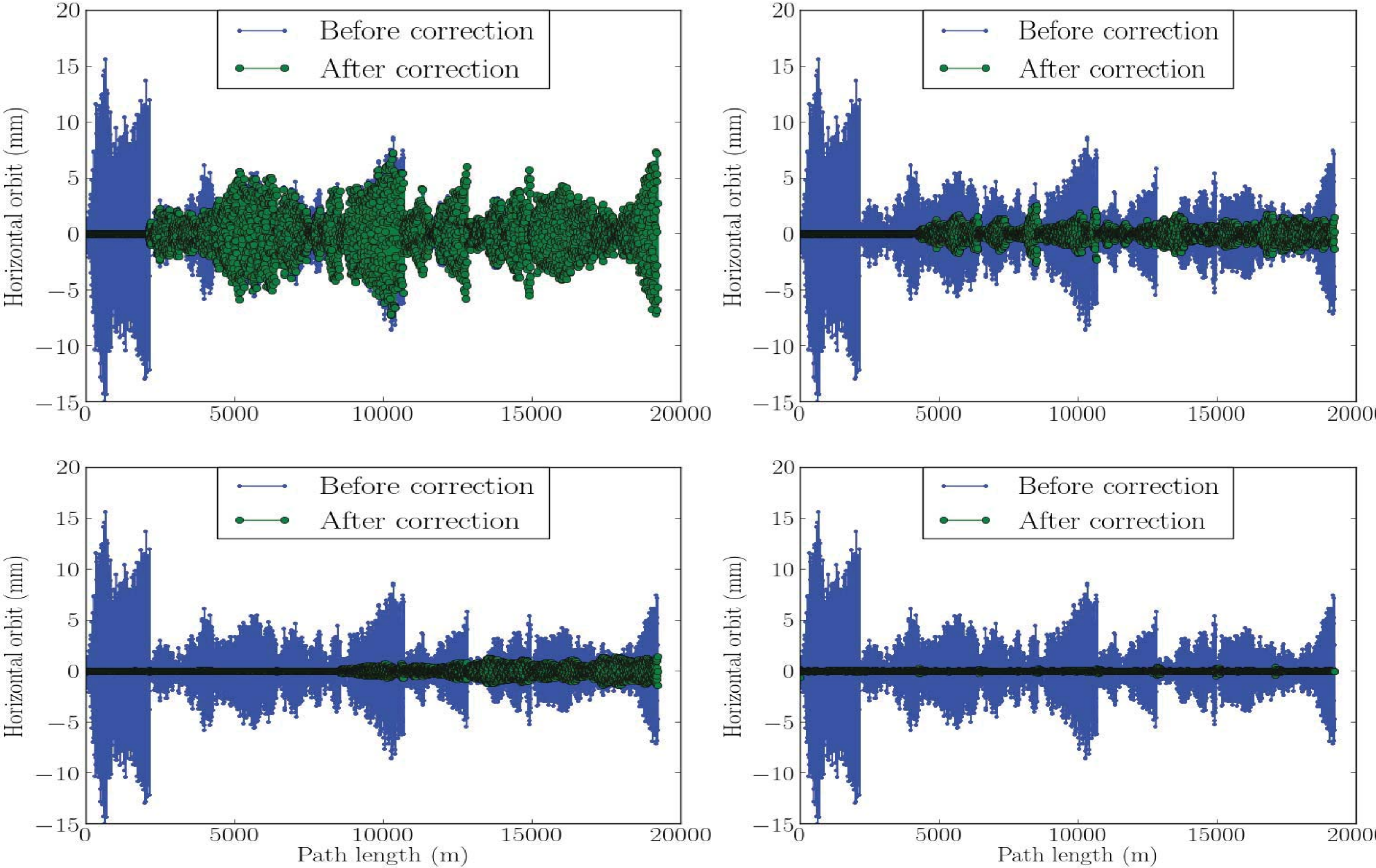
Y_o is the target orbit, Y is the measured orbit, R is the reponse matrix, θ is the correction strength

Extension to multipass correction,

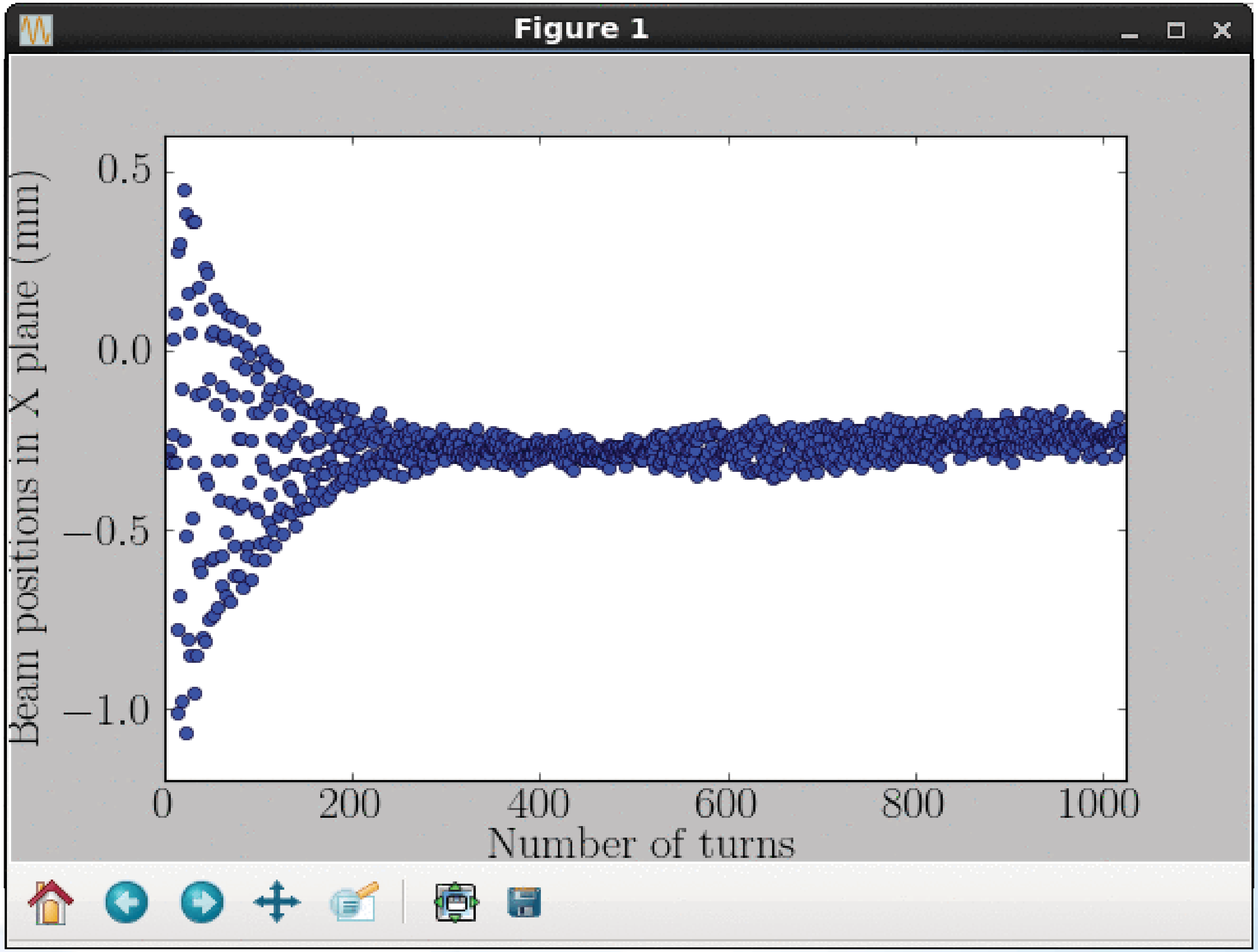
$$\begin{pmatrix} \Delta Y_1 \\ \vdots \\ \Delta Y_2 \\ \vdots \\ \Delta Y_m \end{pmatrix} = \begin{pmatrix} R_1 \\ R_2 \\ \vdots \\ R_m \end{pmatrix} * \theta$$

m is number of passes

Single particle orbit correction

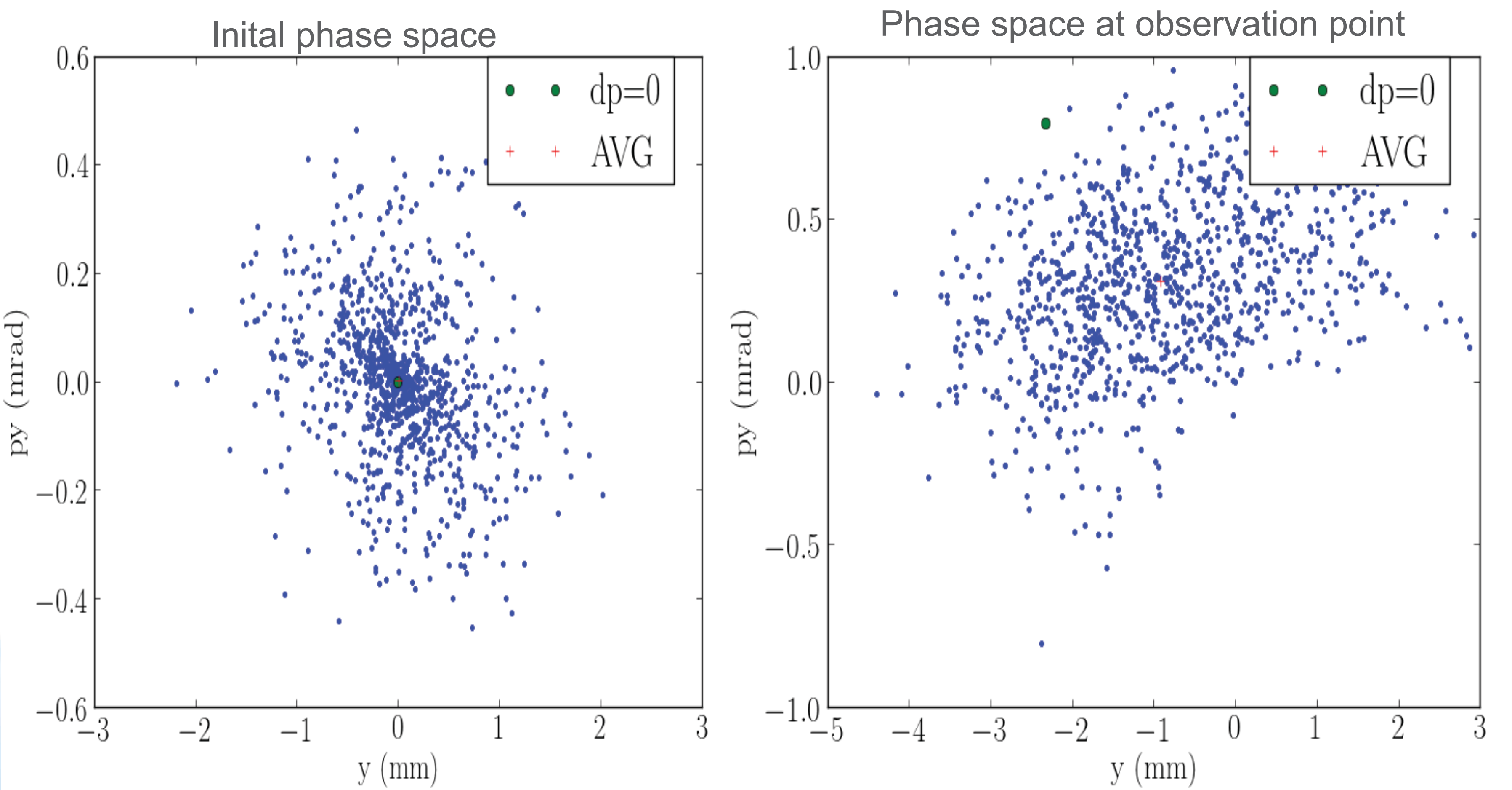


Chromaticity



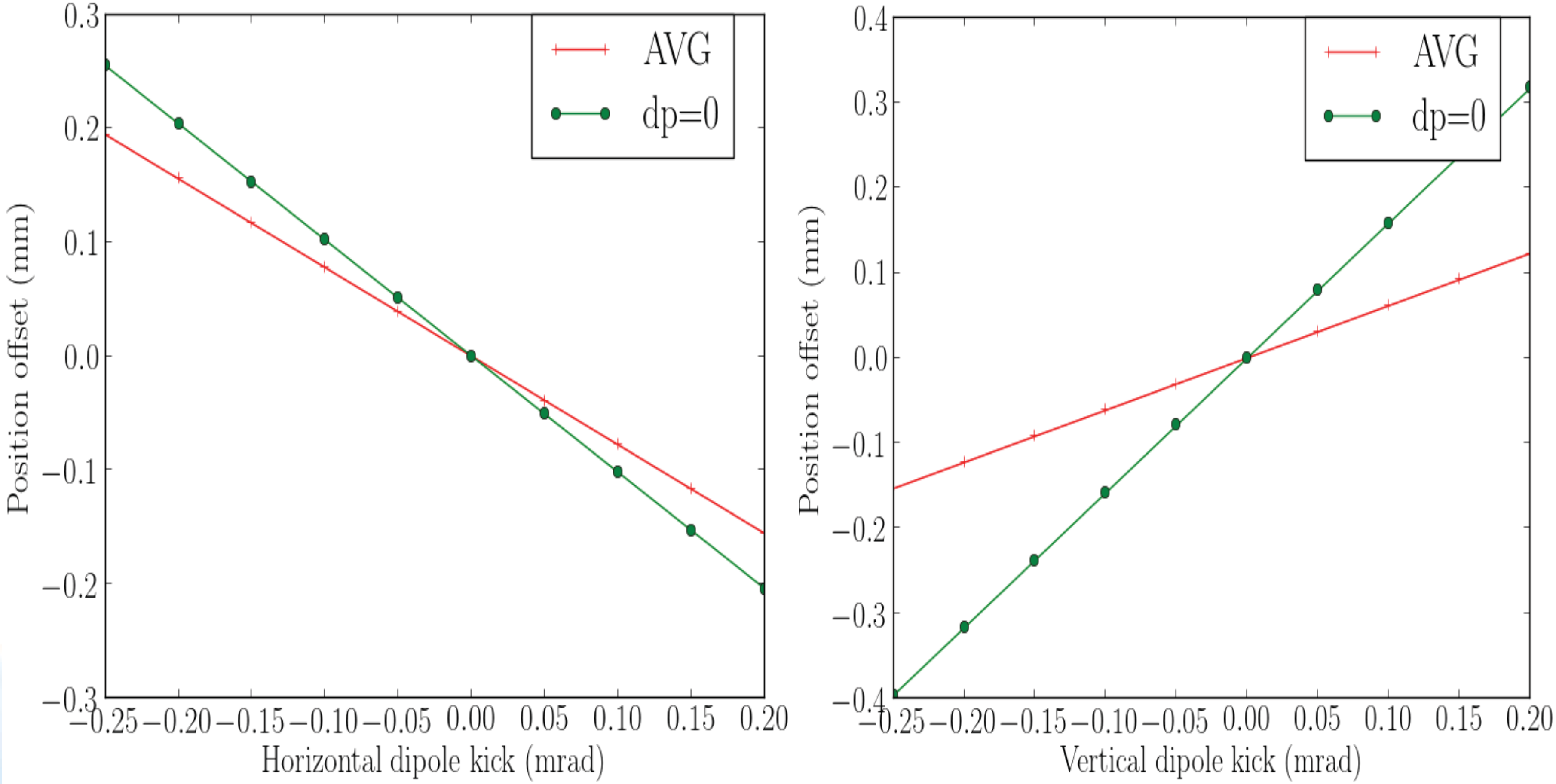
Phase space decoherence will be like going through hundreds of turns in a ring.

Orbit response

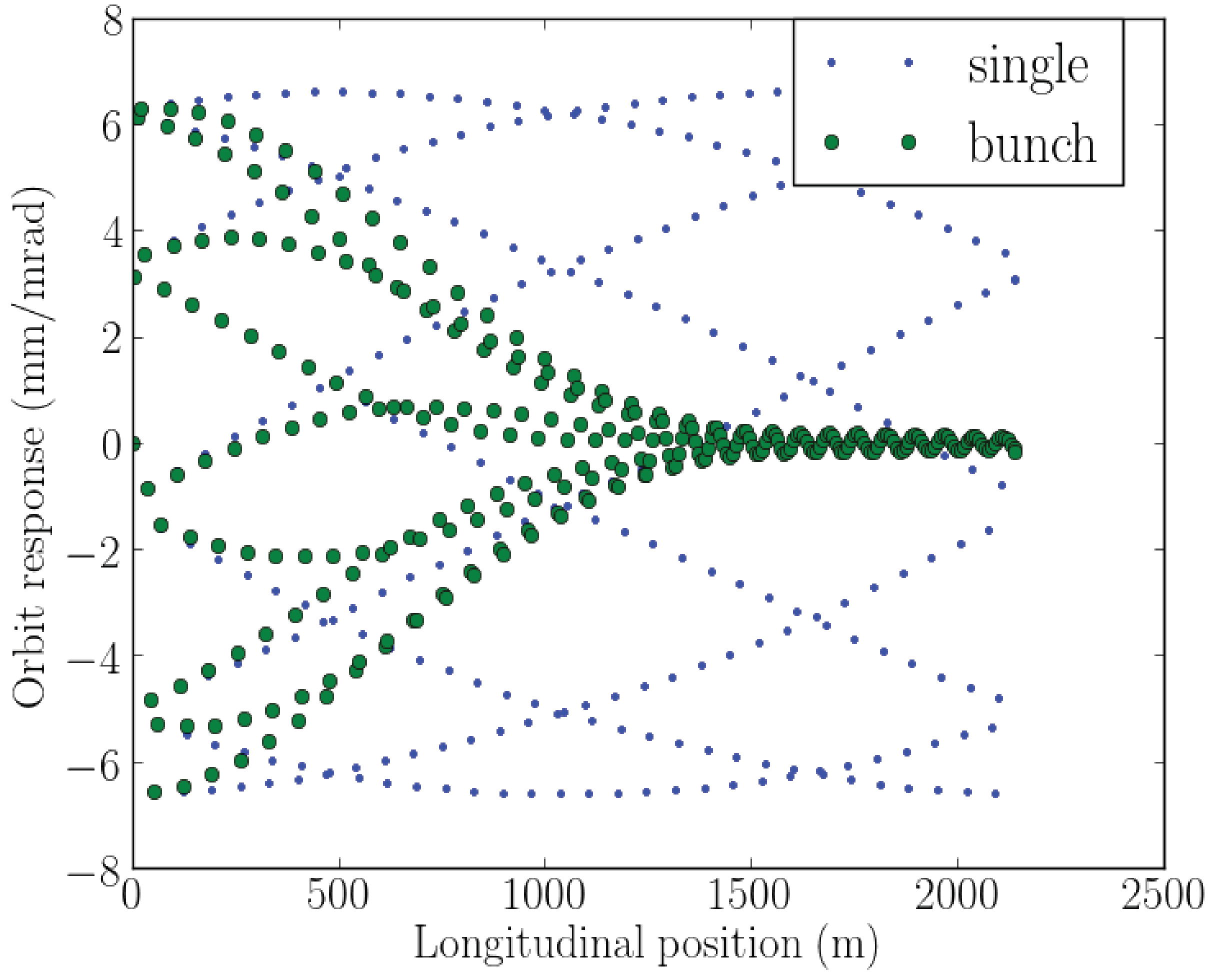


Measured position (red) deviate substantially from the on-momentum particle position (green).

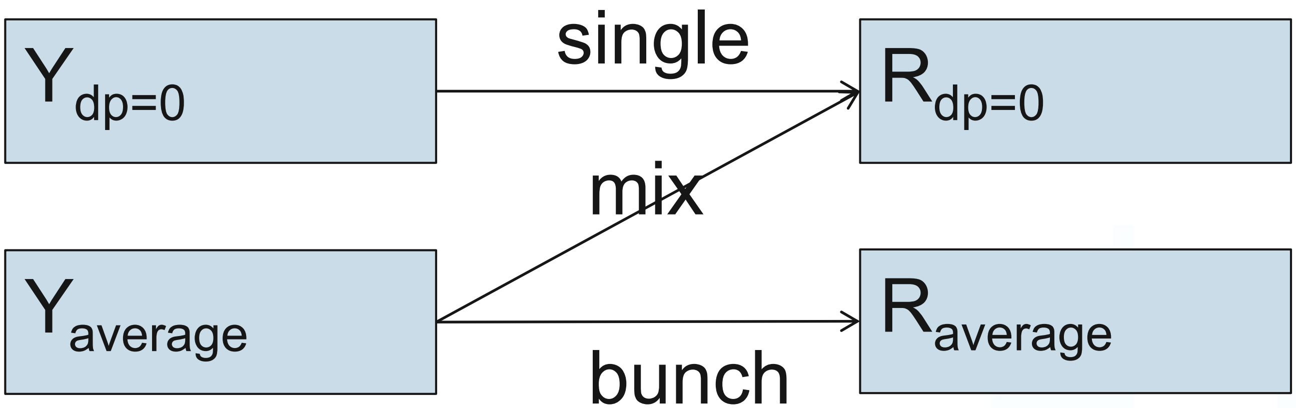
Is orbit response still linear with large chromaticity?



Orbit response



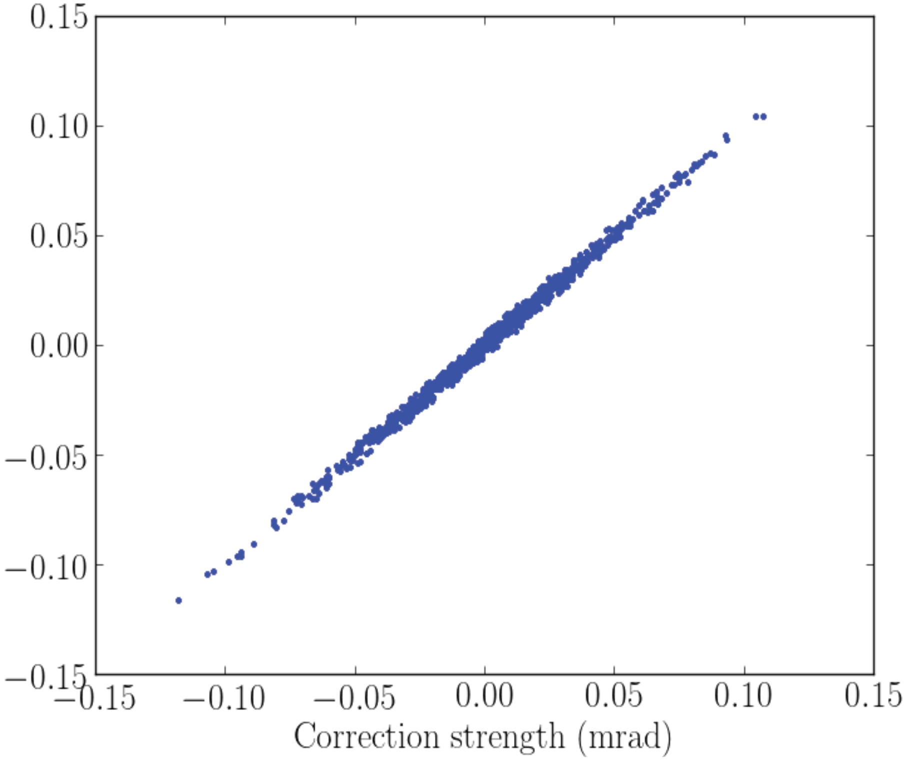
Correction options



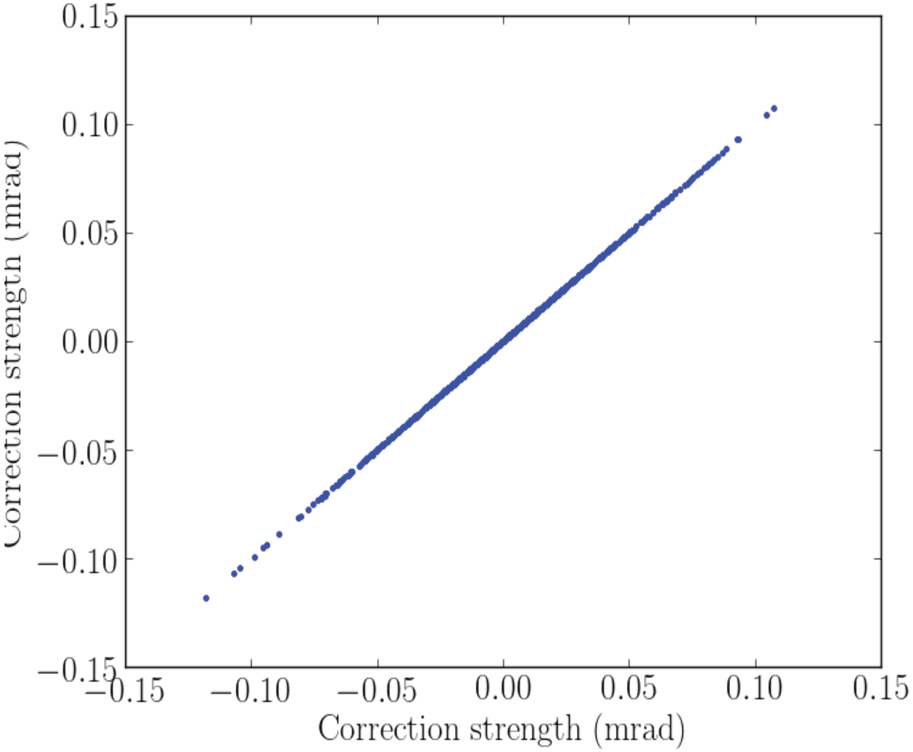
Questions: Is correction based on on-momentum orbit and response in simulation too good, or whether the correction based on real orbit and response can perform as good as the simulation promised. The second question is whether it is acceptable to correct orbit using the on-momentum particle (model) orbit response.

Comparison

Mix VS single:

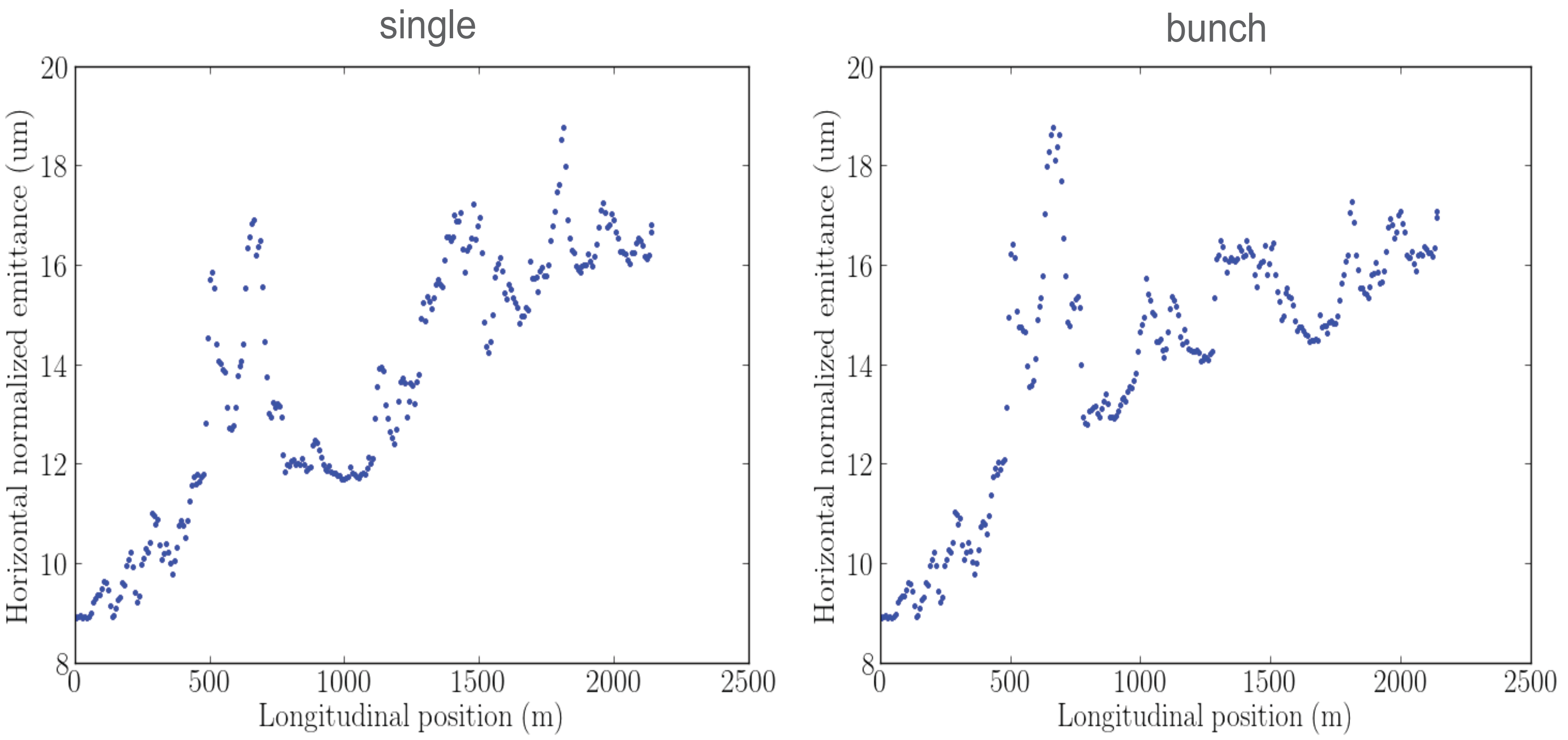


Bunch VS single



Correct measured average orbit globally with M_bunch is as good as
Correct single particle orbit with model response M_single!!!! Is it true in terms of emittance?

Emittance with correction



OC with large chromaticity

- For real machine, one correct the measured orbit (average orbit of all particles) with average orbit response of all particles. It achieved the same results in terms of orbit and beam emittance in simulation.
- In simulation, one correct the on-momentum particle orbit with the on-momentum particle orbit response. The result is not over-optimistic.
- The beam emittance in the first case was preserved as good as in the second as shown in simulation.

Optics correction principle

- In linear FFAG, orbit response deviation depends only on gradient errors LINEARLY.
- Orbit response deviation from the model can be measured by varying dipole correctors and recording orbits before and after.
- The gradient errors can be fitted with knowledge of the model.

Matrix form

For a linac machine with m BPMs and n correctors, the orbit response matrix

$$R = \begin{pmatrix} R_{1,1} & R_{1,2} & R_{1,3} & \cdots & R_{1,n} \\ R_{2,1} & R_{2,2} & R_{2,3} & \cdots & R_{2,n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ R_{m,1} & R_{m,2} & R_{m,3} & \cdots & R_{m,n} \end{pmatrix} \quad (1)$$

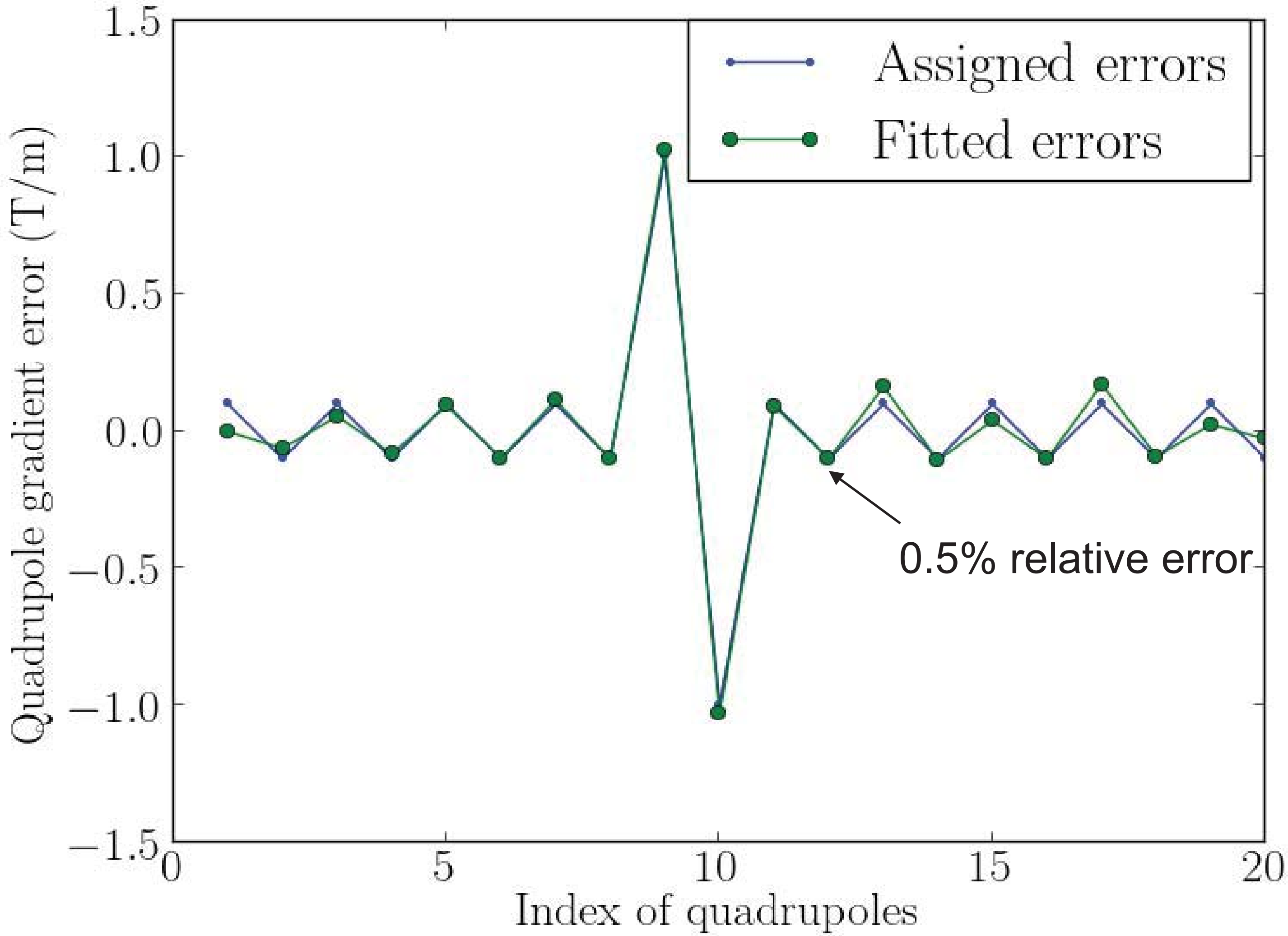
where $R_{i,j} = \begin{cases} \sqrt{\beta_i \beta_j} * \sin(\phi_i - \phi_j) & \text{if } \phi_i > \phi_j \\ 0 & \text{if } \phi_i <= \phi_j \end{cases}$

Vectorize R, the resulted vector depends on gradient error

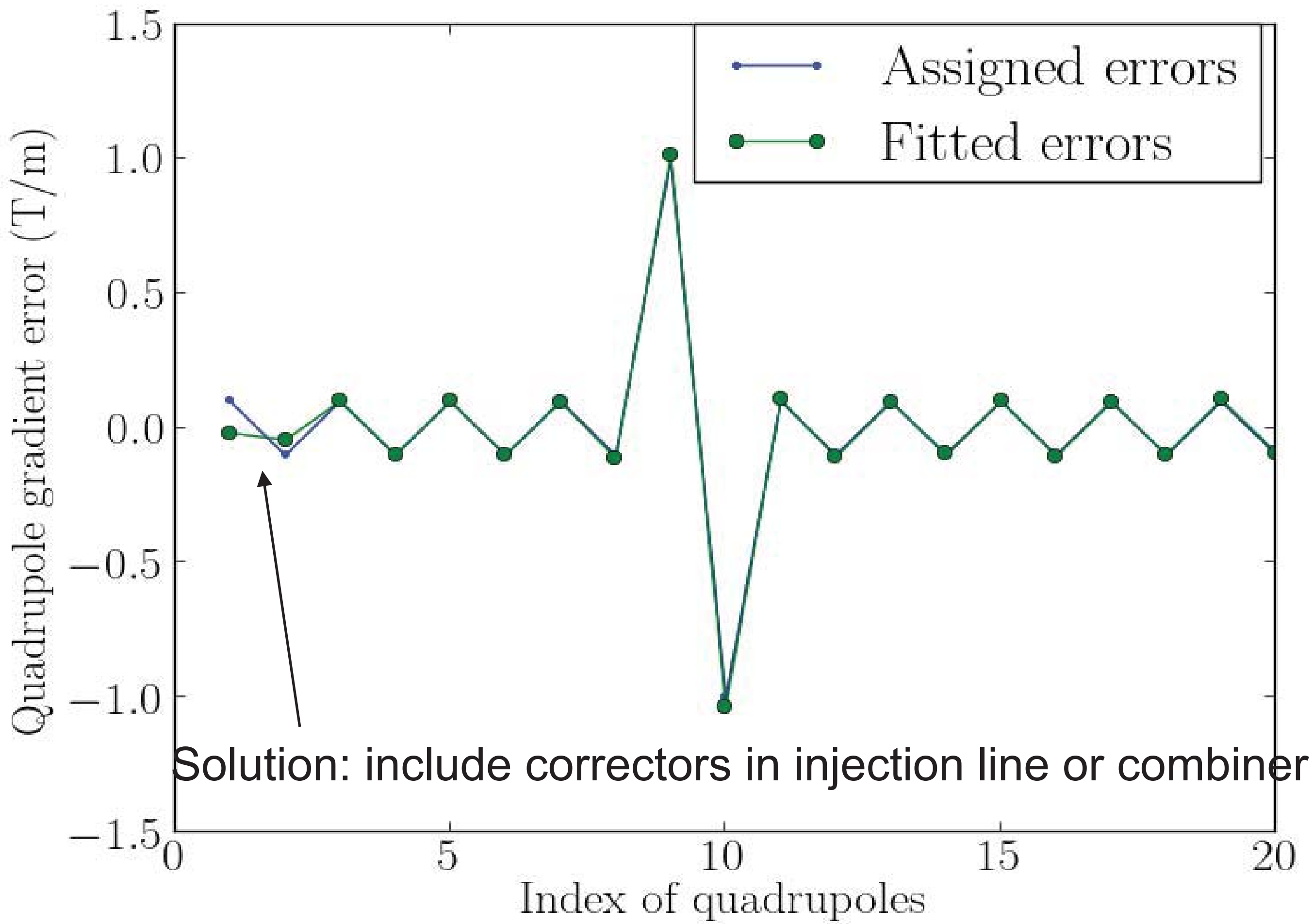
$$\begin{pmatrix} \Delta R_{1,1} \\ \vdots \\ \Delta R_{1,n} \\ \vdots \\ \Delta R_{2,1} \\ \vdots \\ \Delta R_{2,n} \\ \vdots \\ \vdots \\ \Delta R_{m,n} \end{pmatrix} = \begin{pmatrix} M_{1,1} & M_{1,2} & M_{1,3} & \cdots & M_{1,q} \\ M_{2,1} & M_{2,2} & M_{2,3} & \cdots & M_{2,q} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ M_{p,1} & M_{p,2} & M_{p,3} & \cdots & M_{p,q} \end{pmatrix} * \begin{pmatrix} \Delta k_1 \\ \Delta k_2 \\ \vdots \\ \Delta k_q \end{pmatrix} \quad (2)$$

where $p = m * n$, q is number of quadrupole magnets.

Correction, single pass



Correction, multi-pass



Solution: include correctors in injection line or combiner

Optics with large chromaticity

- Orbit response need to be measured, for both optics and orbit correction.
- The model orbit response should be the response of the whole bunch, instead of the on-momentum particle.
- The optics response matrix needs to be generated by tracking simulation.
- Simulation yet to be done, on a larger scale (multi-pass, whole machine) by doing the above.

Summary

- Orbit/optics correction for FFAG eRHIC is a multi-pass, multi-particle problem.
- Simultaneous multi-pass single particle orbit correction works fine for FFAG machine in simulation.
- Orbit of eRHIC FFAG needs to be corrected based on realistic/measured orbit response due to large chromaticity.
- Single particle optics correction has been demonstrated in simulation.
- Multi-particle optics correction (with large chromaticity) to be demonstrated in simulation.
- The difficulty of both are also associated with the large dimensions (# of orbit measurement, # of correctors), in addition to chromaticity.

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