
$\{\beta, D_x\}$ Beat & Coupling Correction @LHC

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Sources for β -beat

Project Rep 501:

- Random b_2 errors of LHC main dipoles
- Field errors of all quadrupoles
- Feed down from sextupoles (alignment & closed orbit errors)
- Errors due to tune shift from trim quadrupoles (not considered)

Sources not included (Under Investigation):

- Faulty BPMs
- Quadrupole tilts, Feed down from b_3 ??

Ingredients

- Realistic magnetic errors from MADX error tables

- Observables

$\Delta\vec{\phi}_x, \Delta\vec{\phi}_y$: Indep. of BPM Calibration (FFT, SVD)
 $\Delta\vec{D}_x$: Calibration Dependent - $\pm 4\%$ (Rad. Steering)

- Specifications:

$$\left\{ \frac{\Delta\beta_x}{\beta_x}, \frac{\Delta\beta_y}{\beta_y} \right\}_{peak} < 15\% \quad [\text{Rep.501}]$$

$$\left| \frac{\Delta D_x}{\sqrt{\beta_x}} \right|_{RMS} < 0.013\sqrt{m} \quad [\text{Rep. 501}]$$

- BPM Resolution: $200\mu\text{m}$

- 210 Variables:

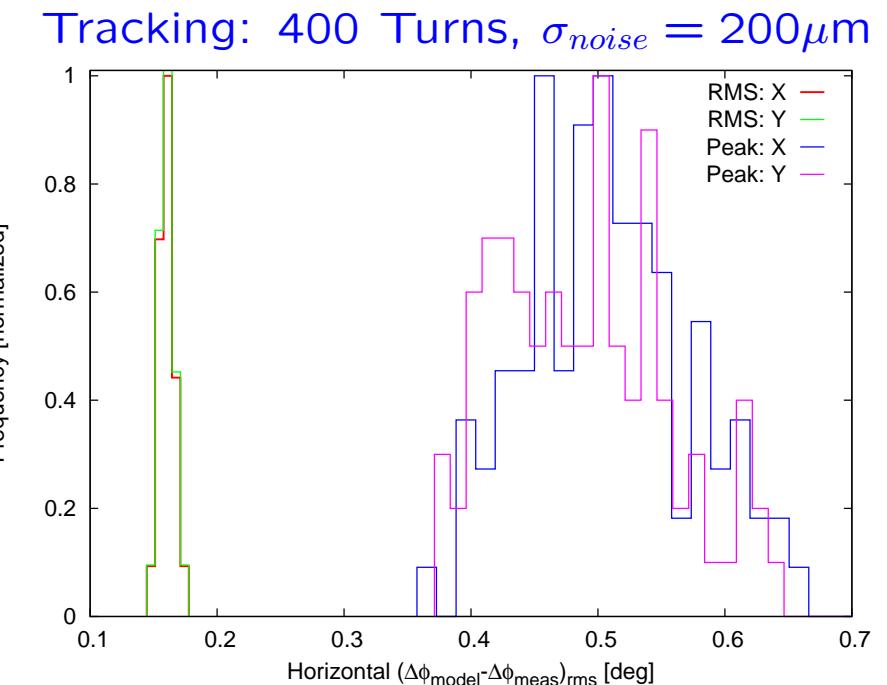
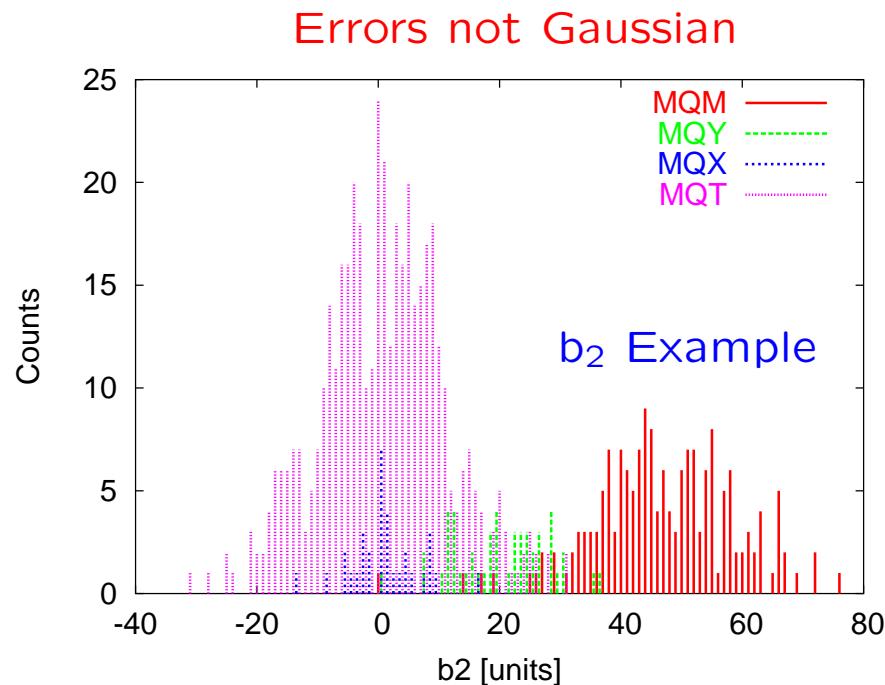
$$\vec{k}_1: \{KQ[4-10], KQX, KQF, KQD, KQT, \dots\}$$

- Correction:

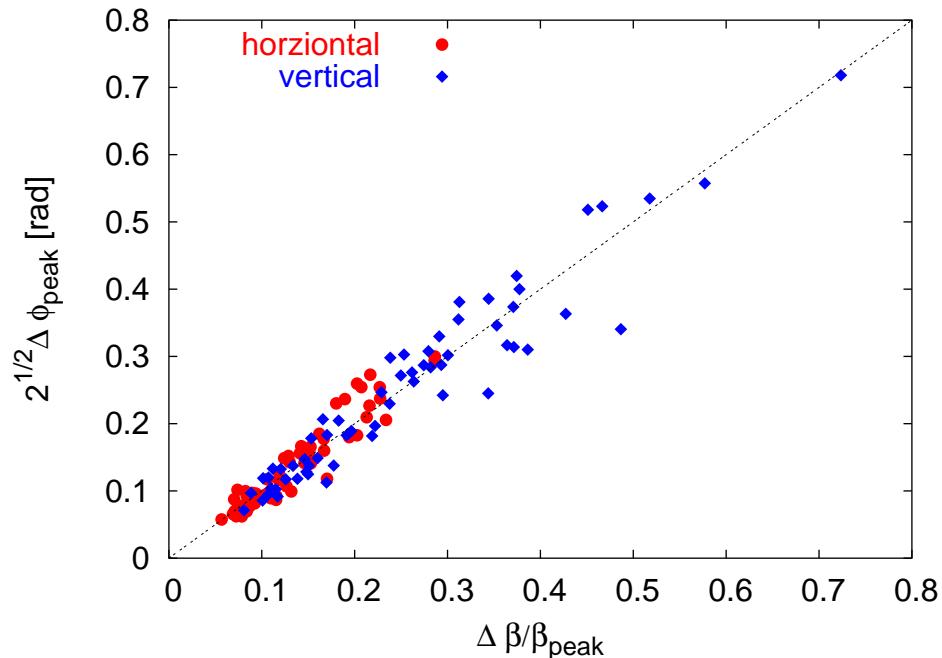
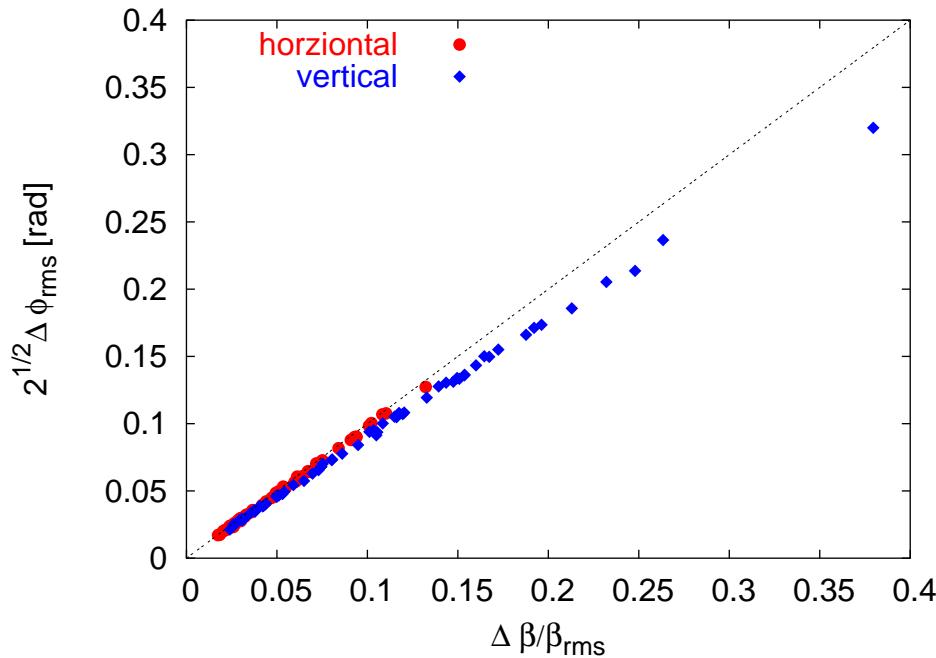
$$\Delta\vec{k}_1 = -R^{-1} \left[w_\phi \Delta\vec{\phi}_{(x,y)}, w_D \Delta\vec{D}_x, \Delta Q_x, \Delta Q_y \right]^T$$

Ingredients II

- All errs from measurements + 5 units of Gaussian noise to b_2
- Chrom sextupole misalignments: $\sigma_{x,y} = 2 \text{ mm}$
- RMS misalignments of MCS, $\sigma_{x,y} = 0.5 \text{ mm}$
- Gaussian noise $\sigma_\phi = 0.25^\circ$, $\sigma_{D_x} = 0.01 \text{ m}$

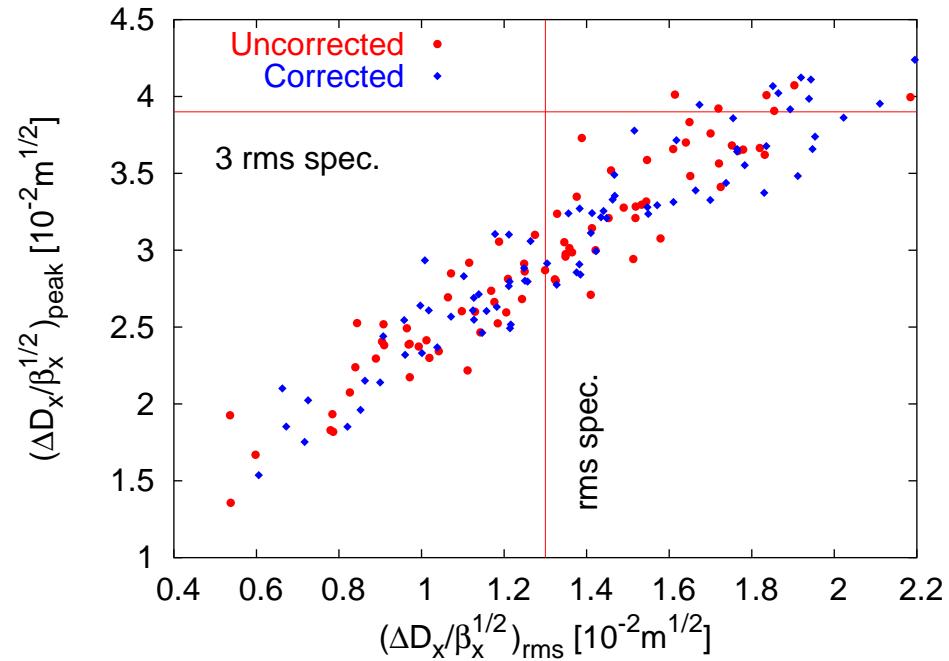
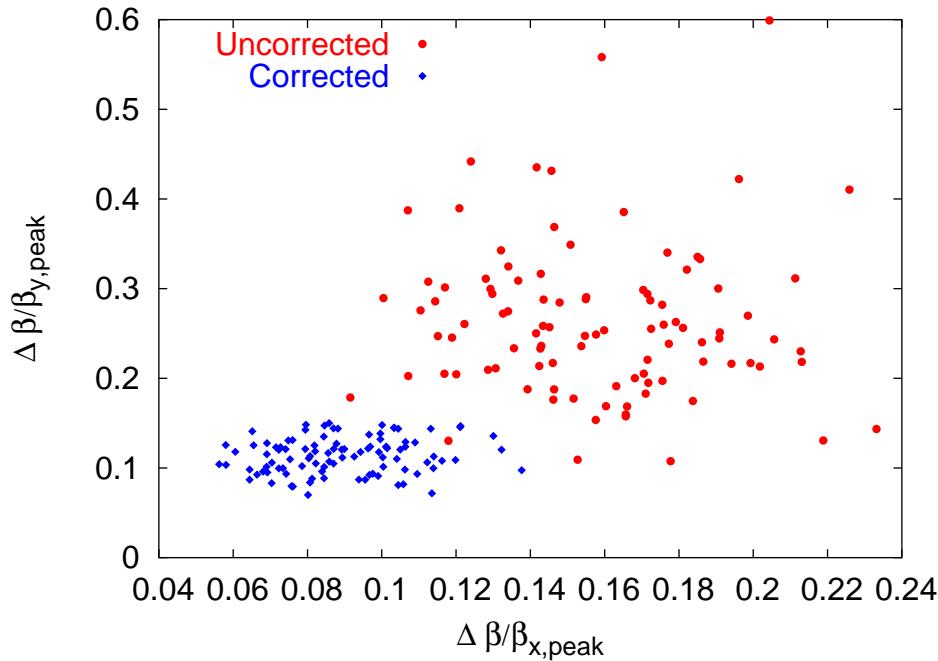


Beta Vs. Phase Correction



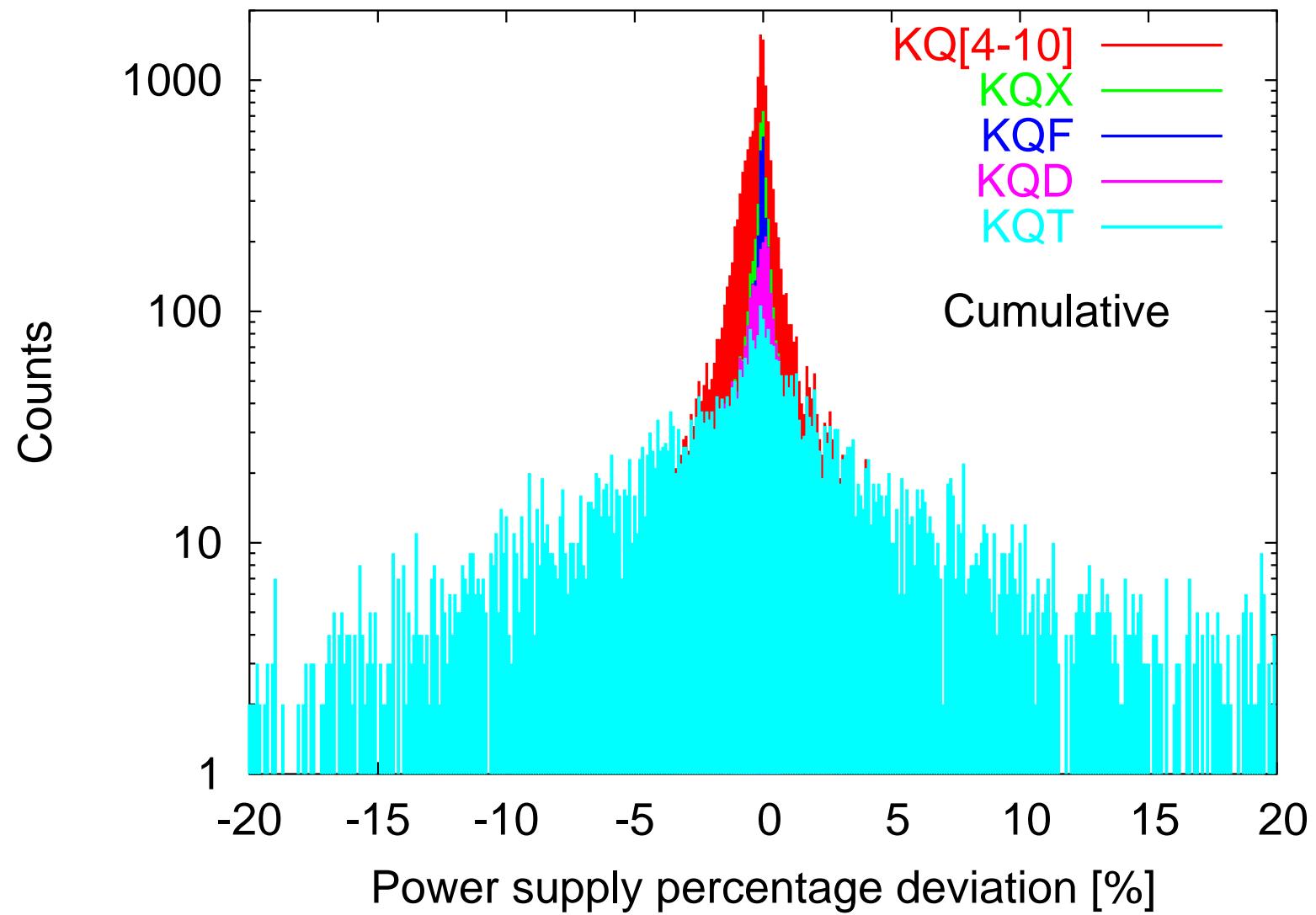
- Precise relation between beta and phase beat
- Phase advance is calibration independent
- Ph. adv. can be calculated from TBT using FFT, SVD, ...

β & D_x Beat Correction (EPAC 06)



- Best β -beat correction in the 5% level
- Dispersion gets worse if not included in response matrix
- Dispersion impossible to correct !! (misuse of KQ[4-10] ?)

Correction Strengths (Injection)



Correction strength variation is within a few % (except for trim)

Dispersion Correction Strategy

- Allow for flexible weights (Ex: $w, 1 - w$):

$$\begin{aligned} R\Delta\vec{k} &= \vec{b} \\ \Delta\vec{k} &= (R^T W R)^{-1} R^T W \vec{b} \end{aligned}$$

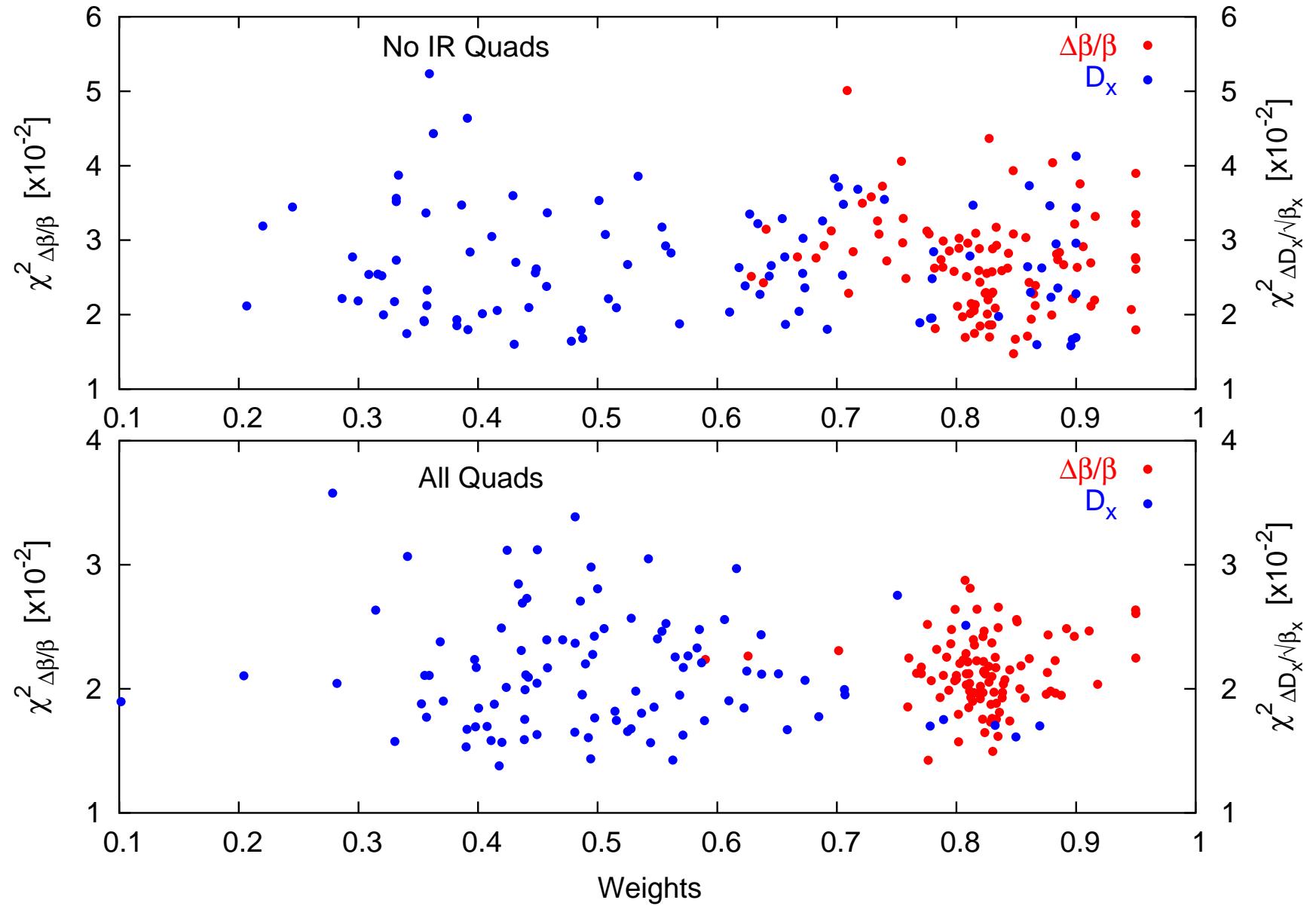
where $W = [\phi_x, \phi_y, D_x, Q_x, Q_y]$

- Test with RANDOM ERRS instead of measured errs (speed):
 - Enlarged b_2 Errors, Sextupole Misalignments: $\sigma_{x,y} = 1$ mm
 - Gaussian noise $\sigma_\phi = 0.25^\circ$, $\sigma_{D_x} = 0.01$ m
- Effect of weights, # of Sing. Vals, Remove IR Quads, etc...

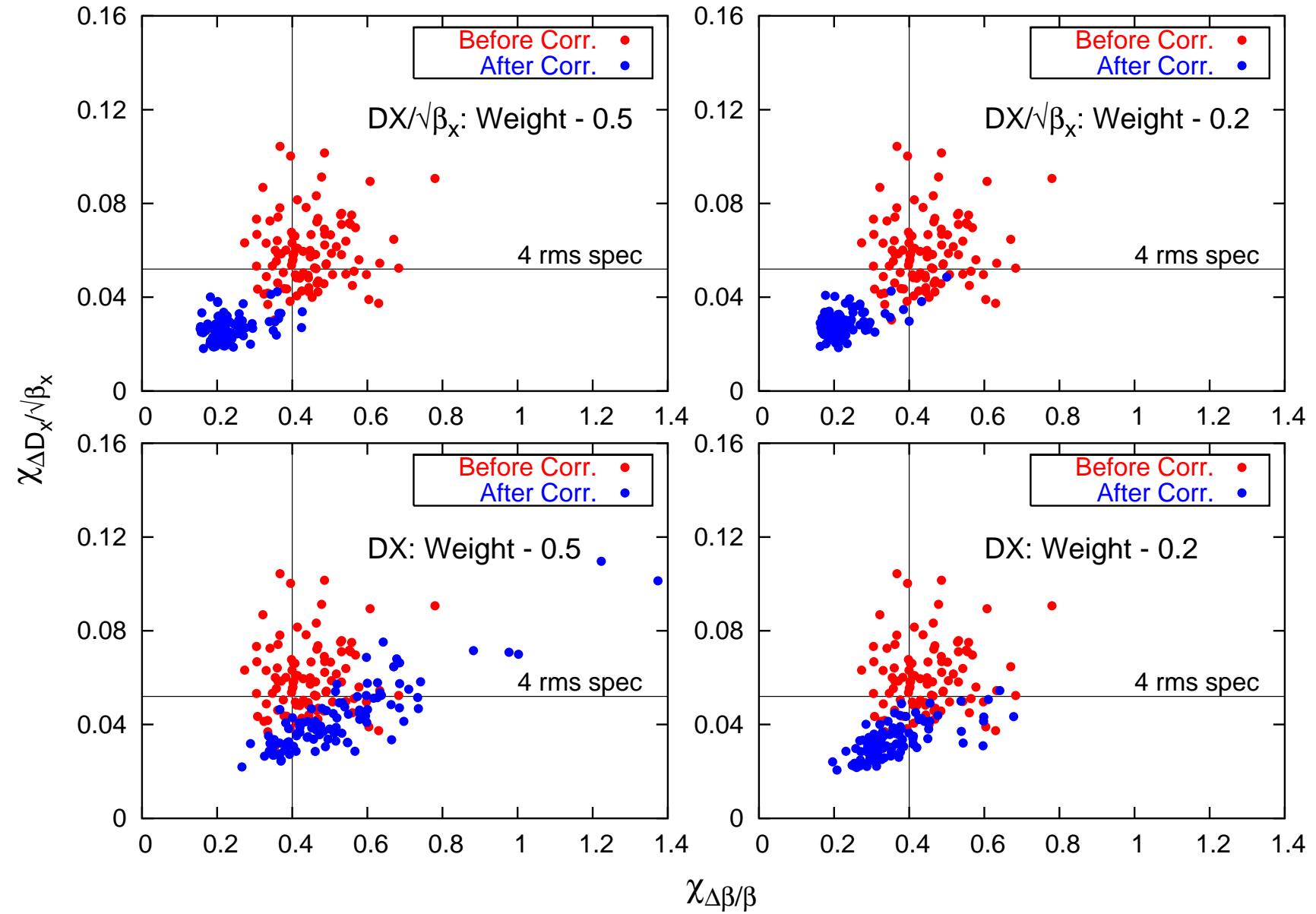
$$\chi^2_{\frac{\Delta\beta}{\beta}} = \sum \left(\frac{\Delta\beta_{x,y}}{\beta_{x,y}} \right)_{rms}^2 + \left(\frac{\Delta\beta_{x,y}}{\beta_{x,y}} \right)_{peak}^2, \quad \chi^2_{\frac{\Delta D_x}{\sqrt{\beta_x}}} = \sum \left(\frac{\Delta D_x}{\sqrt{\beta_x}} \right)_{rms}^2 + \left(\frac{\Delta D_x}{\sqrt{\beta_x}} \right)_{peak}^2$$

- R-Matrix Dispersion Observable (D_x or $D_x/\sqrt{\beta_x}$)

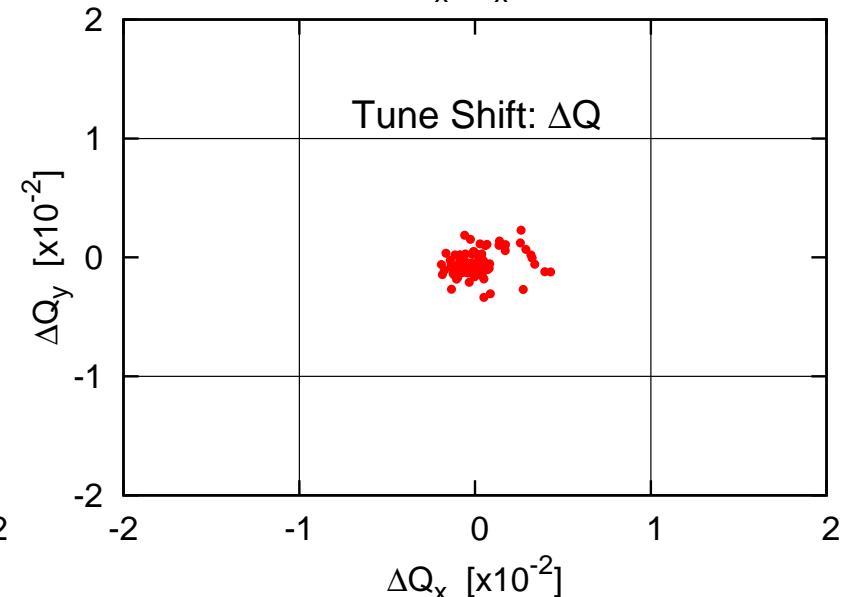
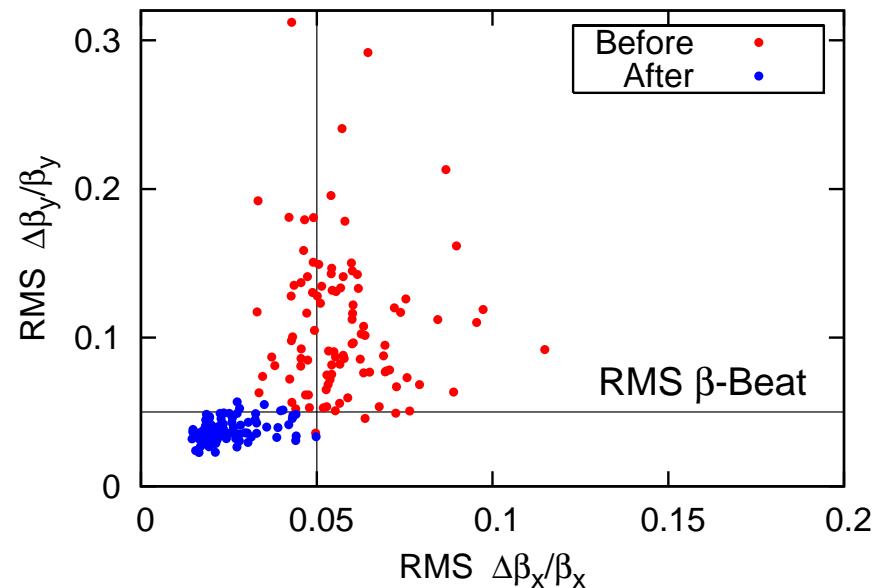
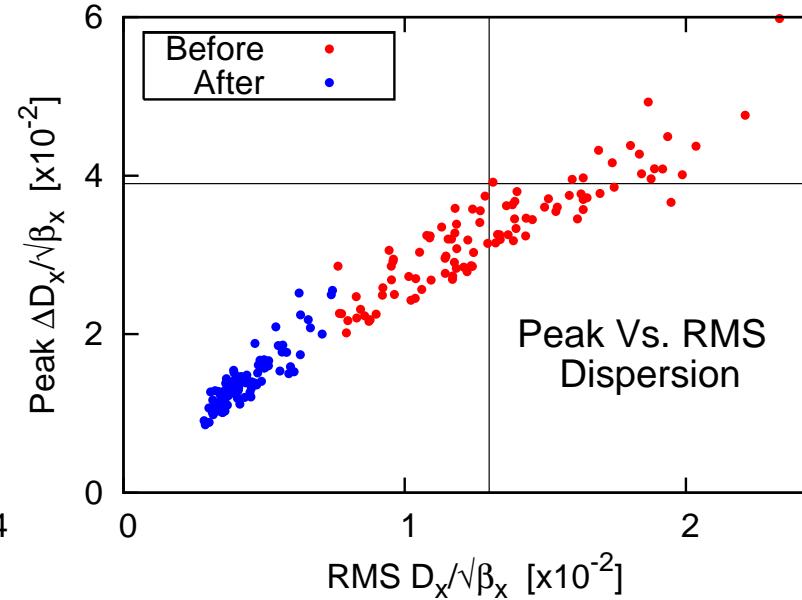
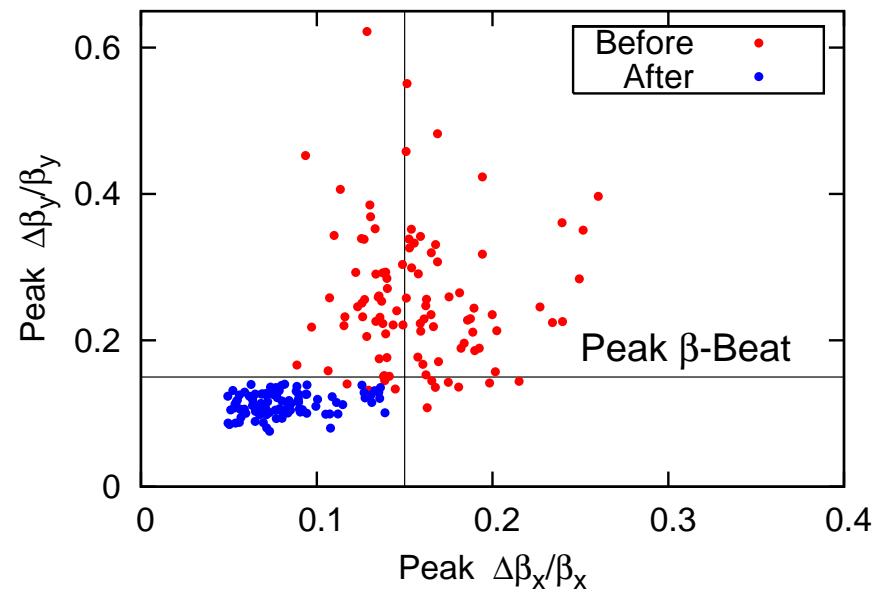
Weight Optimization using Simplex



Dispersion Observable: D_x or $D_x/\sqrt{\beta}$



β & $D_x/\sqrt{\beta_x}$ Beat Corr. (Multiple Iterations)

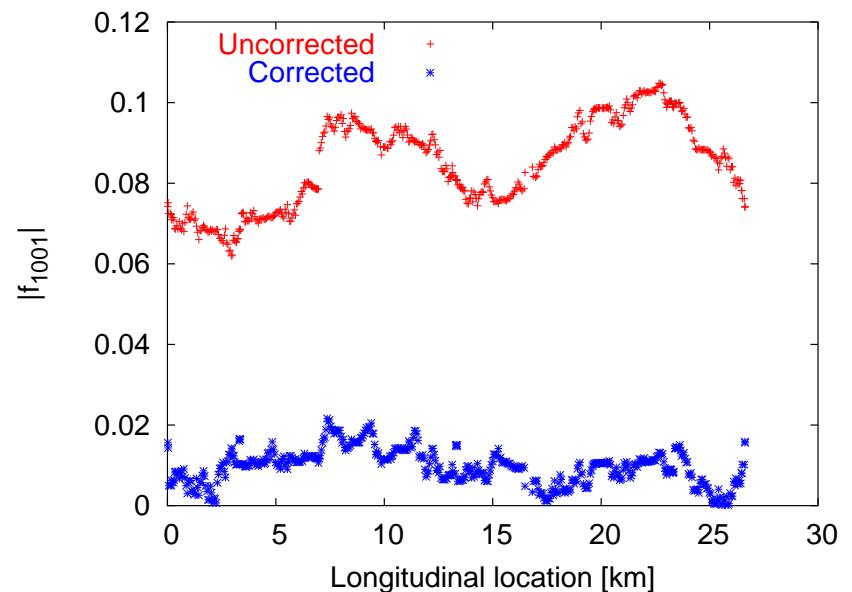
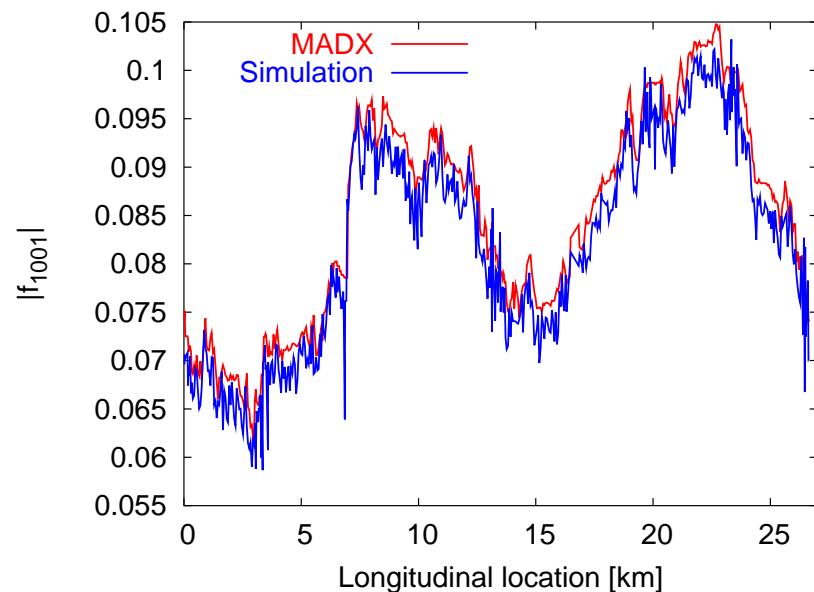


Benchmarking on Real Machines

- SPS:
 - Very linear & well behaved optics
 - Introduce β -beat and apply correction
 - Only 4 knobs (too few, not really scalable to LHC case)
- RHIC:
 - Observable β -beat $\sim 15\text{-}20\%$
 - Arc Circuits + IR Quads (many knobs, closer to LHC)
 - AC Dipole Vs. Free Oscillations (compare correction)
- Limitations - faulty BPMs, reproducibility

Local Coupling @LHC

- Random Quad Tilts + Large Tilt (6km) + BPM Tilts (2mrad)
- BPM Resolution: $200 \mu\text{m}$
- Coherent Oscillations: 400 Turns

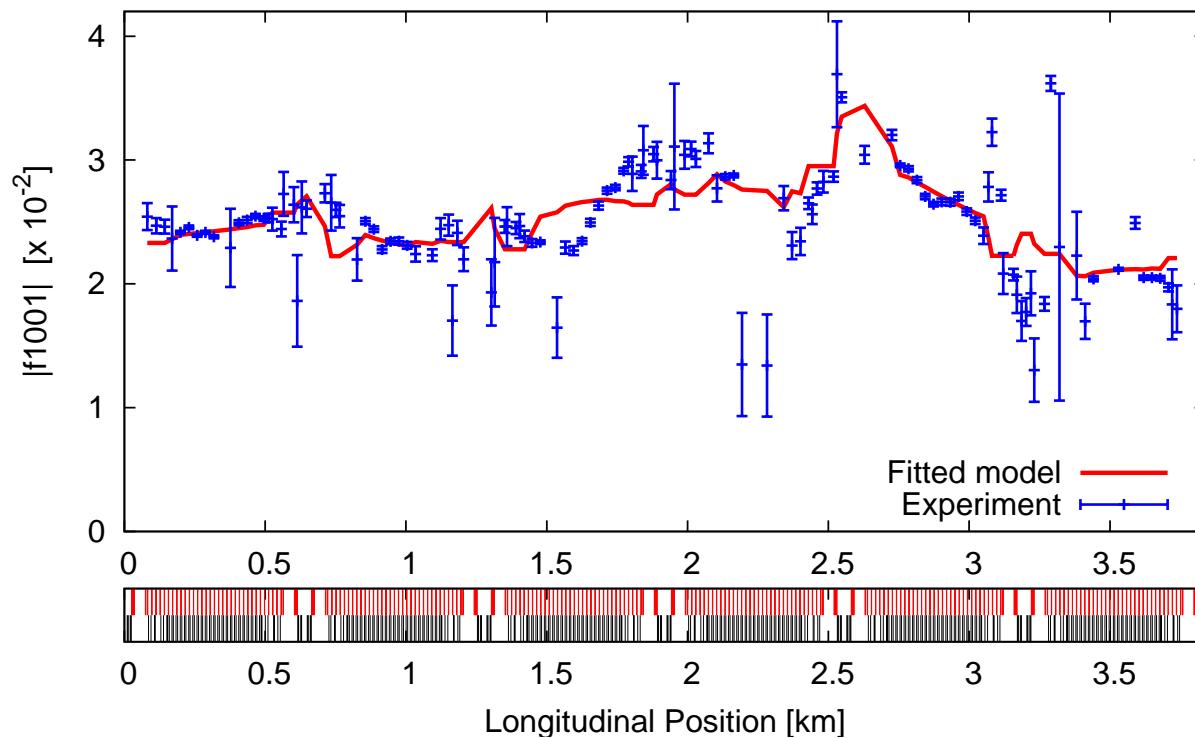


Large Coupling Source Identified, and local correction feasible
Further improvements to algorithms is foreseen

RHIC Coupling Measurements

Fitting Variables:

$$\lim_{\Delta \rightarrow 0} \left[\Delta f_{1001}^{(meas-mod)} \right] \rightarrow \begin{bmatrix} \text{Arc Quad Tilts (6-families)} \\ \text{IR Skew Correctors} \\ \text{IR Quad Tilts } (Q_1 - Q_{10}) \\ \vdots \end{bmatrix} \rightarrow \text{MADX Iterate}$$



Application & Commissioning

- Requirements for Effective Corr:
 - Well Functioning and Synchronized BPM System (Turn-By-Turn)
 - Coherent Oscillations (~ 400 turns, perhaps AC Dipole)
 - Reproducibility
- Application:
 - High level JAVA application (Optics, Coupling, Correction)
 - Interface with FESA and Online MAD Model
 - Option to apply trim corrections
- Commissioning:
 - At most 5-6 Iterations (re-adjust injection)
 - Participants: Rogelio, Rama interested

$\Delta\beta/\beta$ & $\Delta D_x/\sqrt{\beta_x}$ correction feasible