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

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RECAP

- Realistic magnetic errors from MADX error tables
- Observables

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

- 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: 200μm
- 210 Variables:

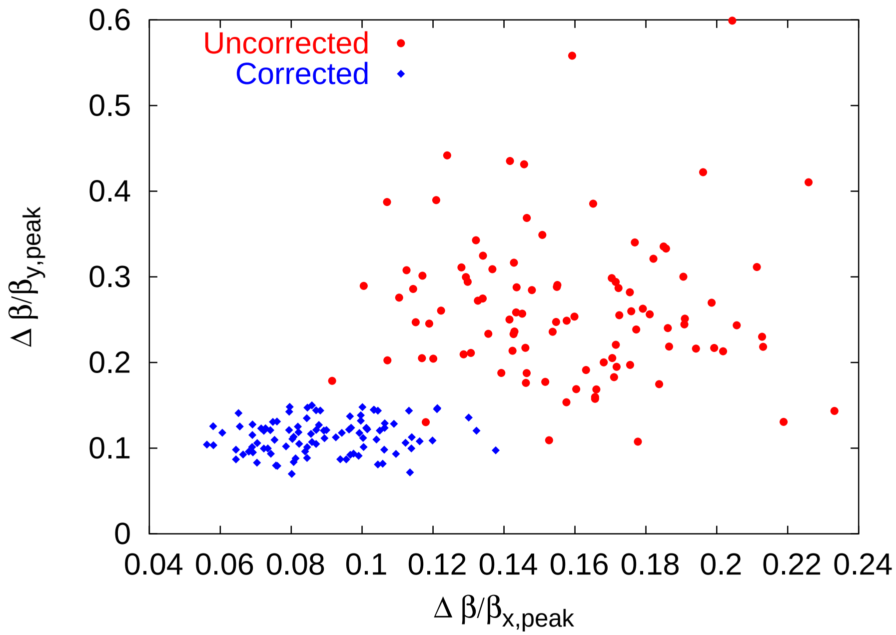
$$\vec{k}_1\text{: } \{\text{KQ[4-10], KQX, KQF, KQD, KQT}, \cdots\}$$

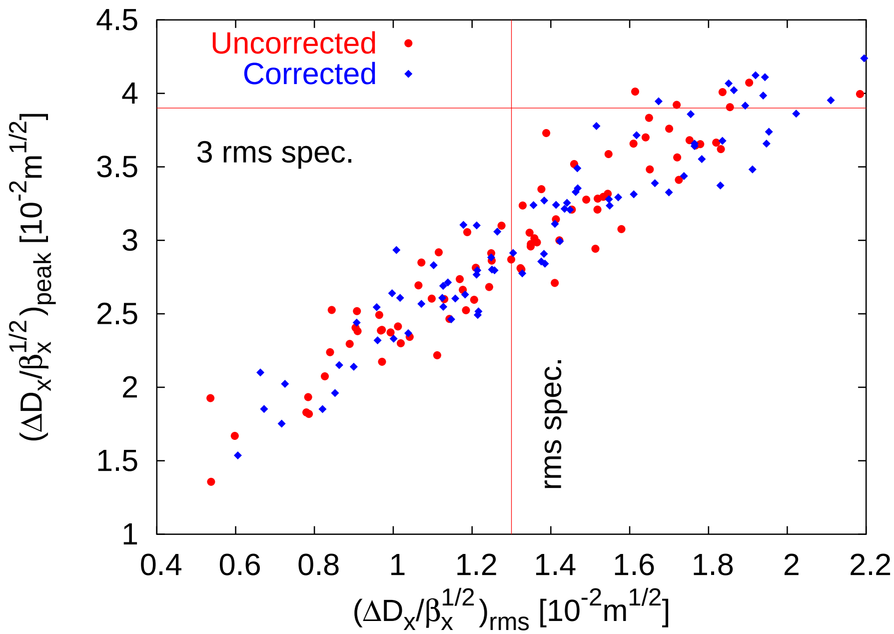
- Correction:

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

RECAP

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





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

Dispersion Correction Strategy

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

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

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

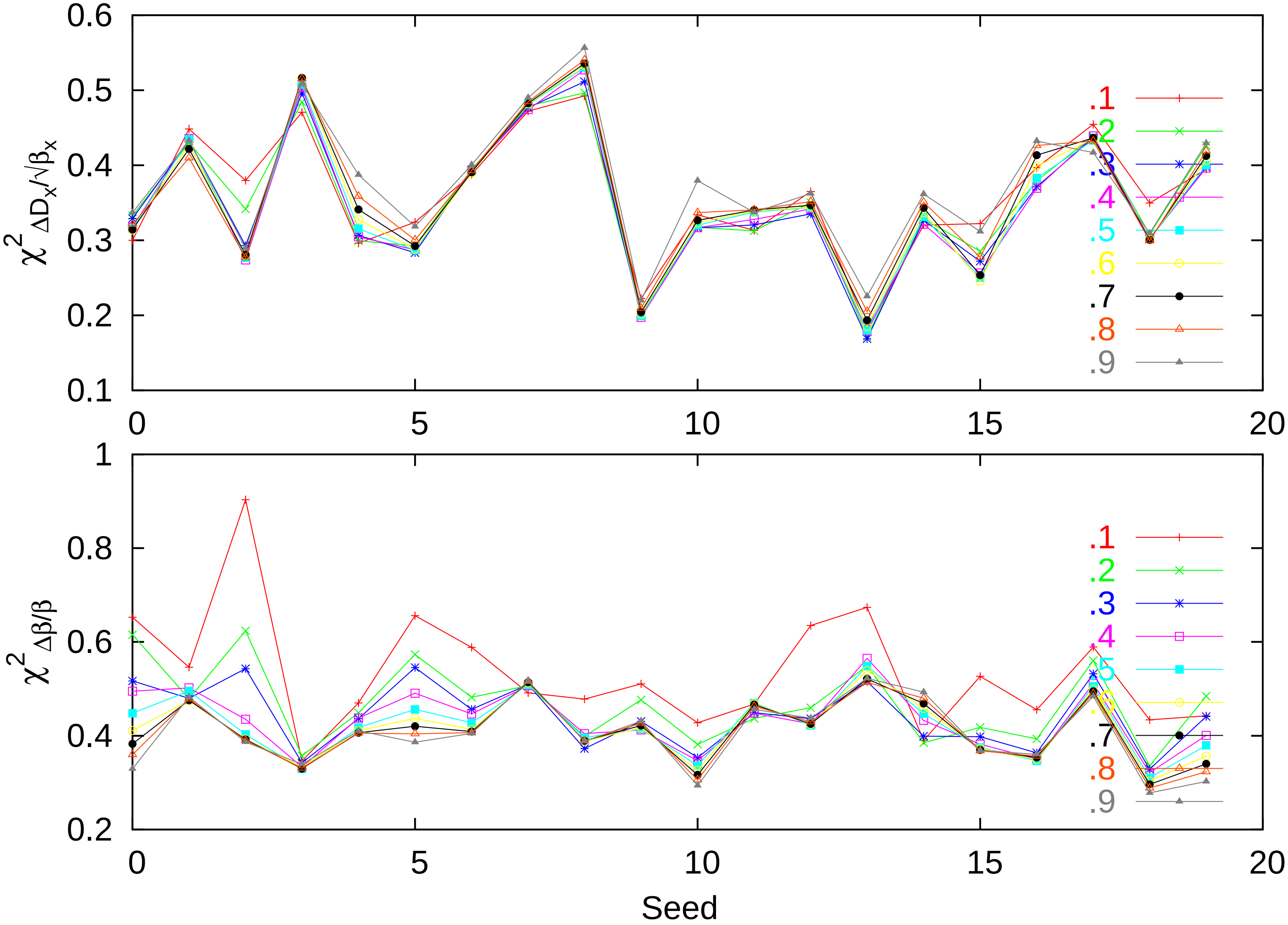
- Test with RANDOM ERRS instead of measured errs (speed):
  - Enlarged b_2 Errors, Sextupole Misalignments: $\sigma_{x,y} = 1$ mm
  - Gaussian nosie $\sigma_\phi = 0.25°$, $\sigma_{D_x} = 0.01$ m

- Effect of weights, # of Sing. Vals, Remove IR Quads, etc...

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

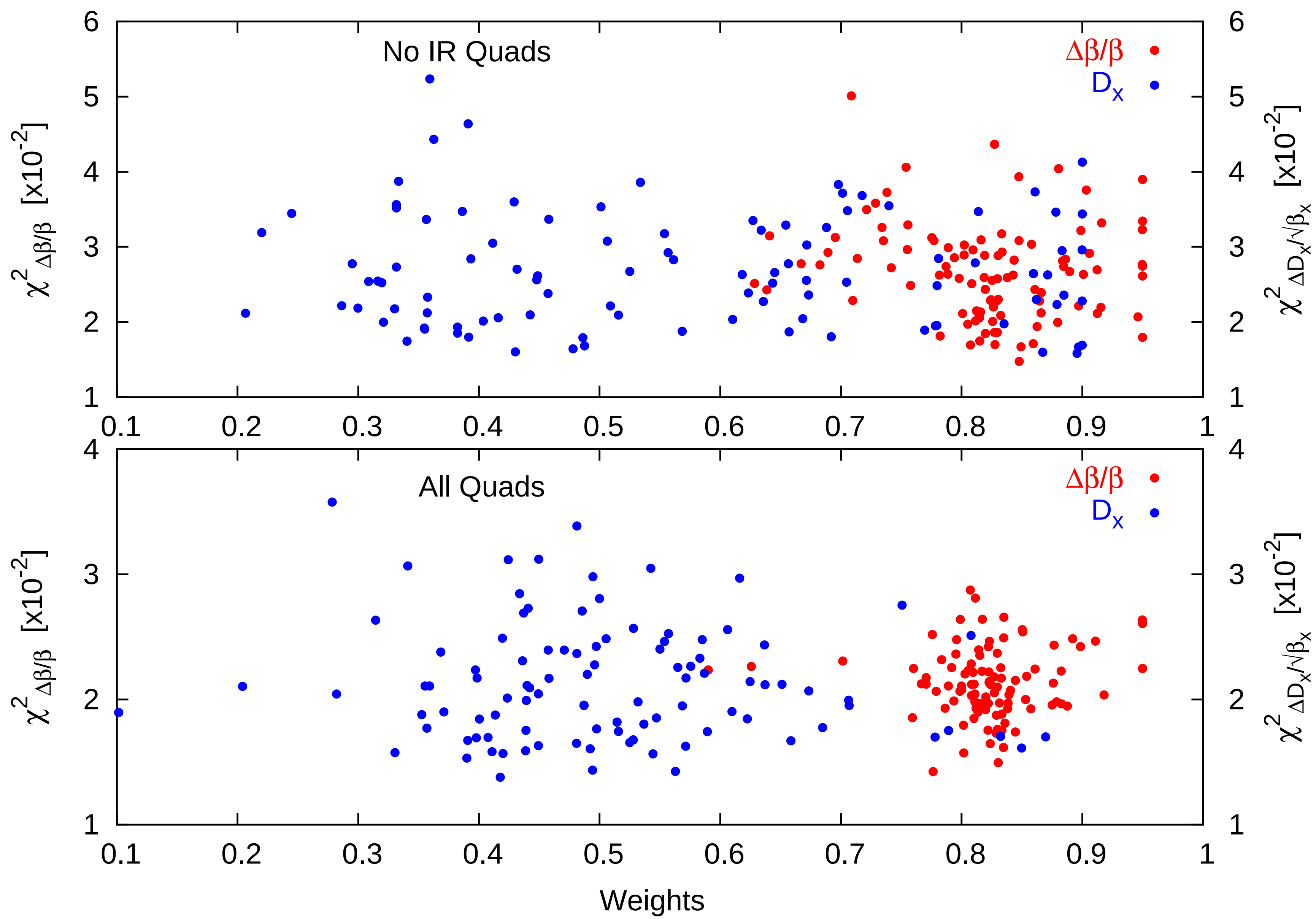
- R-Matrix Dispersion Observable (D_x or $D_x/\sqrt{\beta_x}$)

Effect of Weights

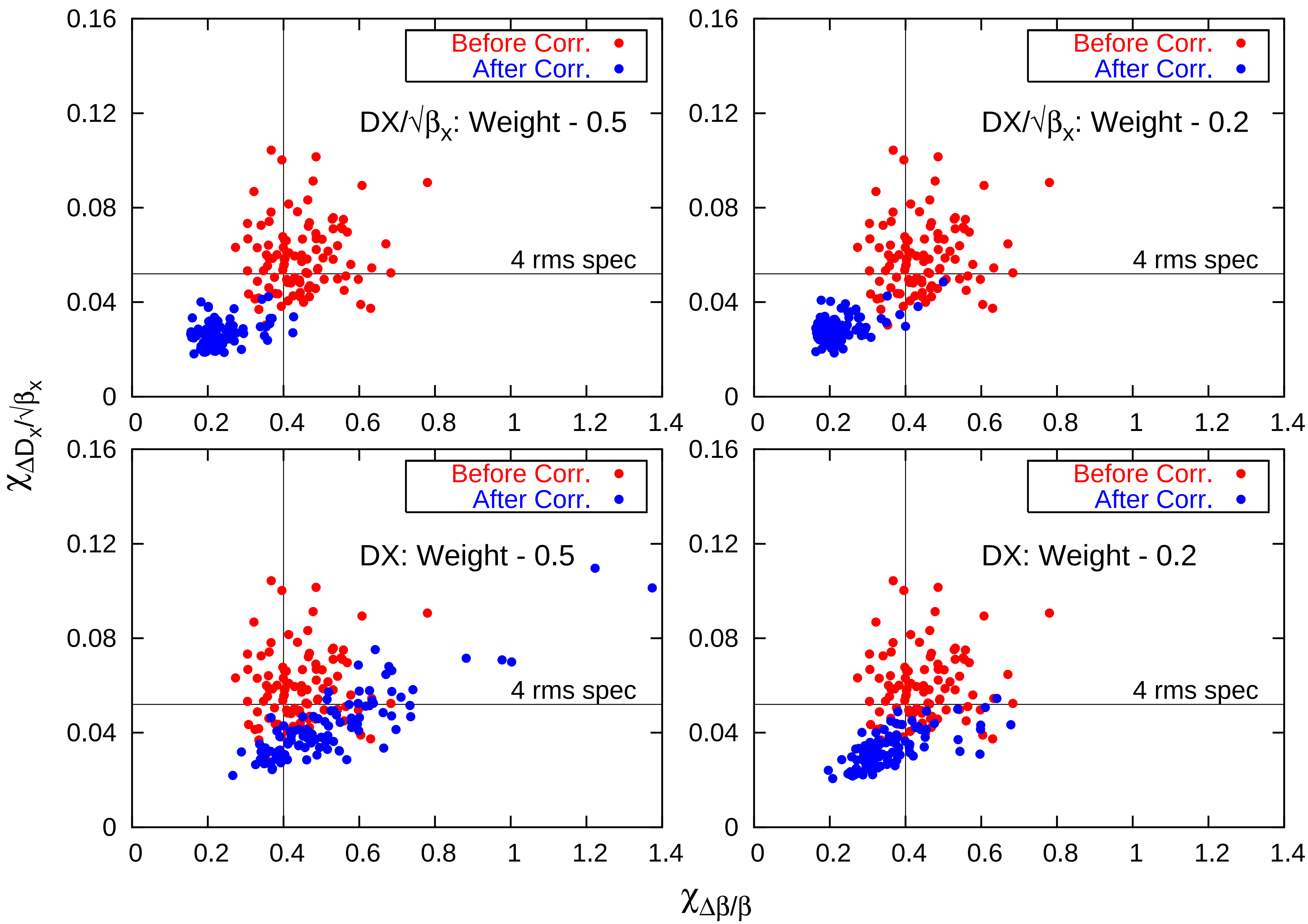


- β-beat correction sensitive to weights (most seeds)
- Dispersion correction is not significantly affected weights

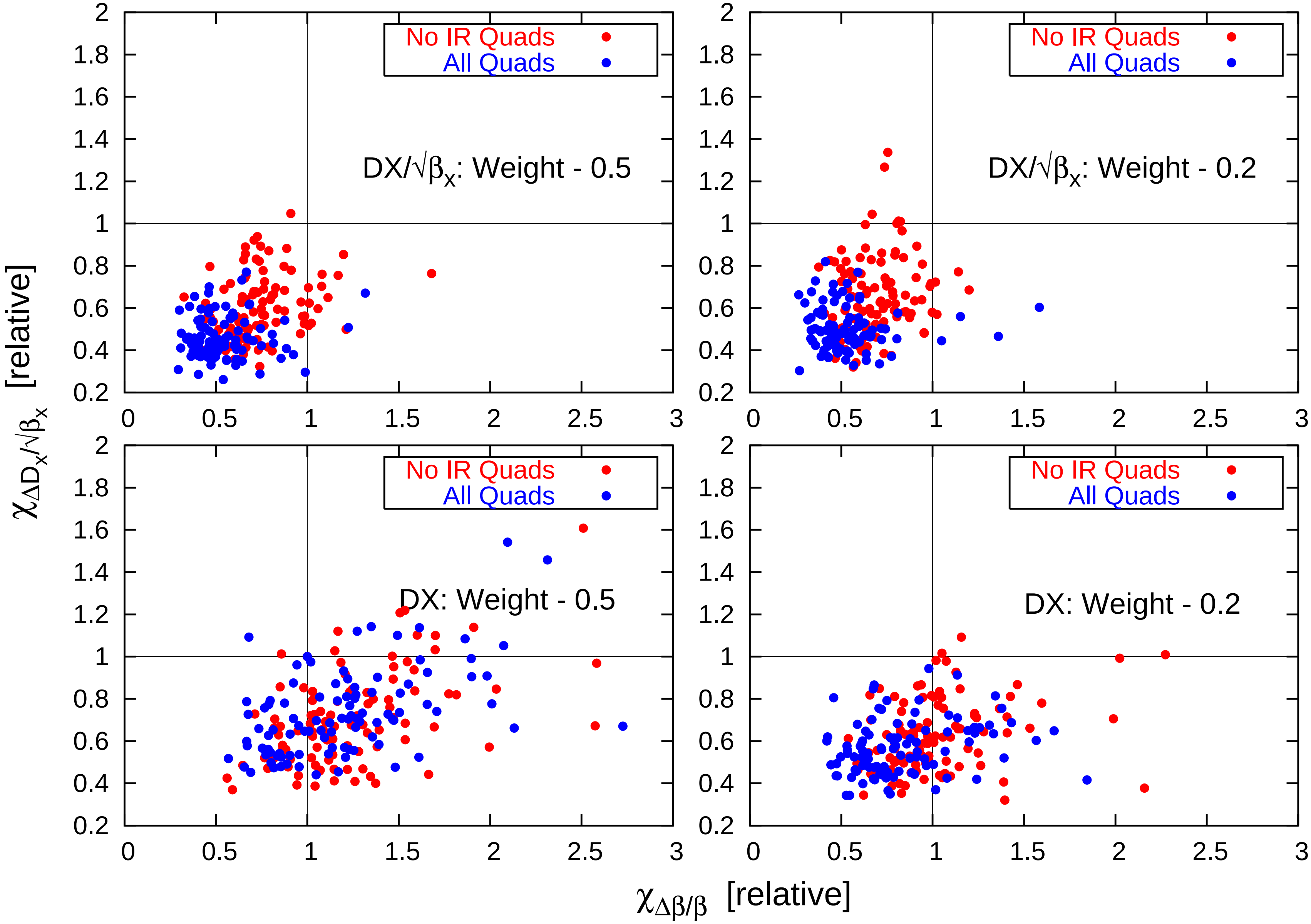
Simplex Weight Optimization



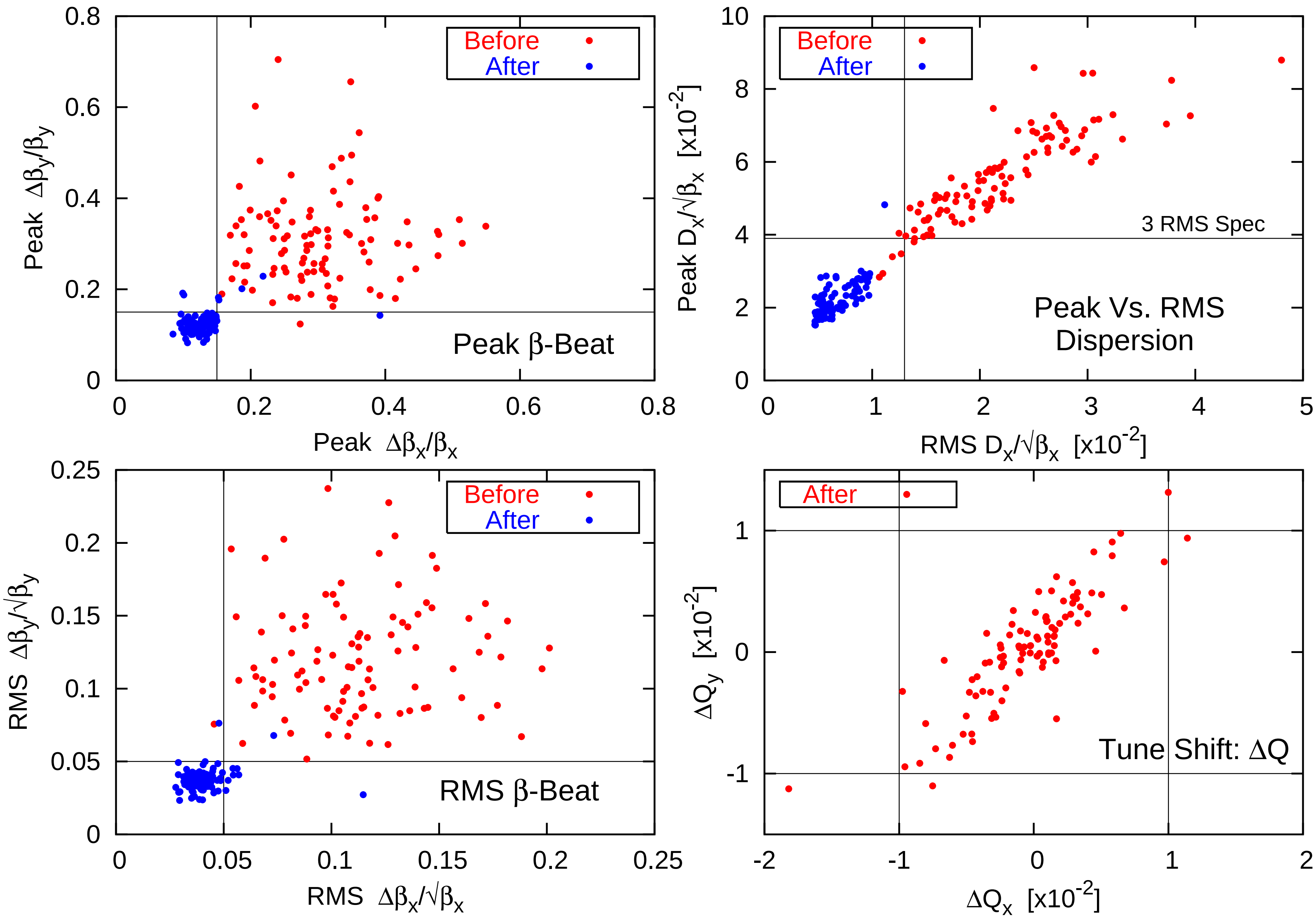
Dispersion Observable: D_x or $D_x/\sqrt{\beta}$



Inclusion or Exclusion of IR Quads



β & $D_x/\sqrt{\beta_x}$ Random Errs (Multiple Iterations)



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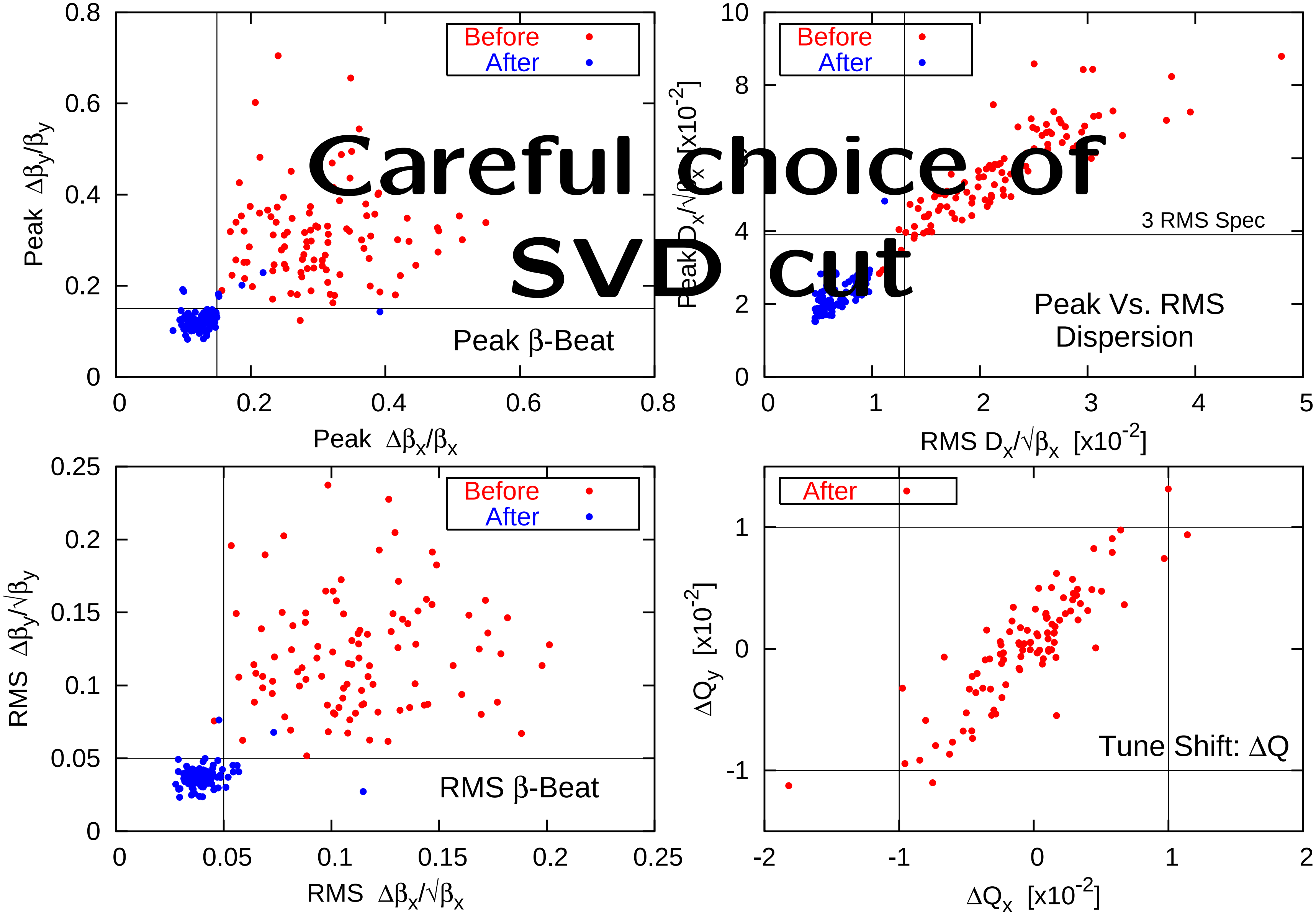

Careful choice of SVD cut

Apply Recipe to Measured Errors

Dispersion correction works

- $D_x/\sqrt{\beta_x}$ (Calibration Independent)
- All IR Quads needed
- Optimum # of Singular Values for each iteration

Input measured errors and check recipe:

- All errs from measurements + 5 units of Gaussian noise to b_2
- Chrom sextupole misalignments: $\sigma_{x,y} = 2$ mm
- RMS misalignments of MCS, $\sigma_{x,y} = 0.5$ mm
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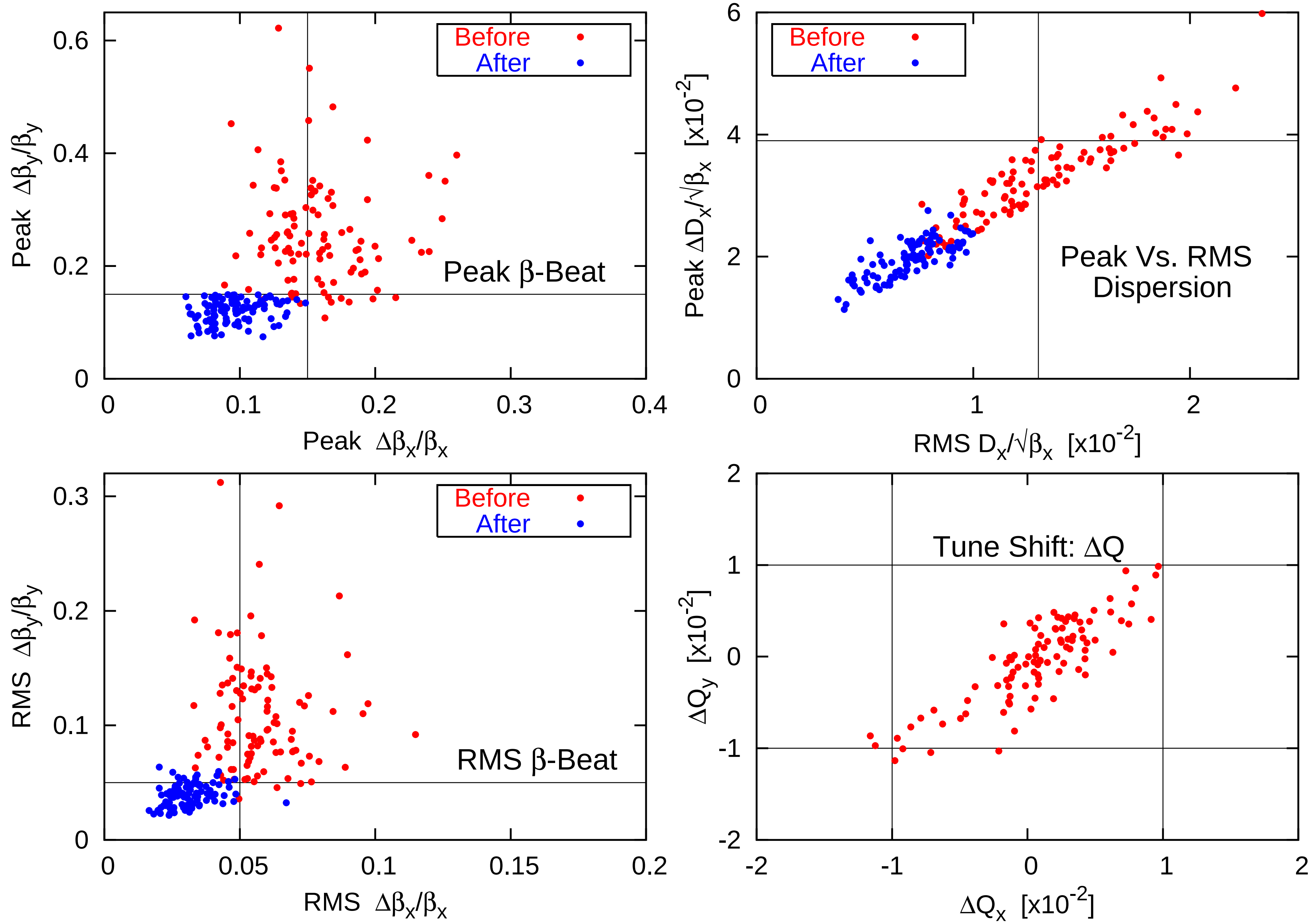
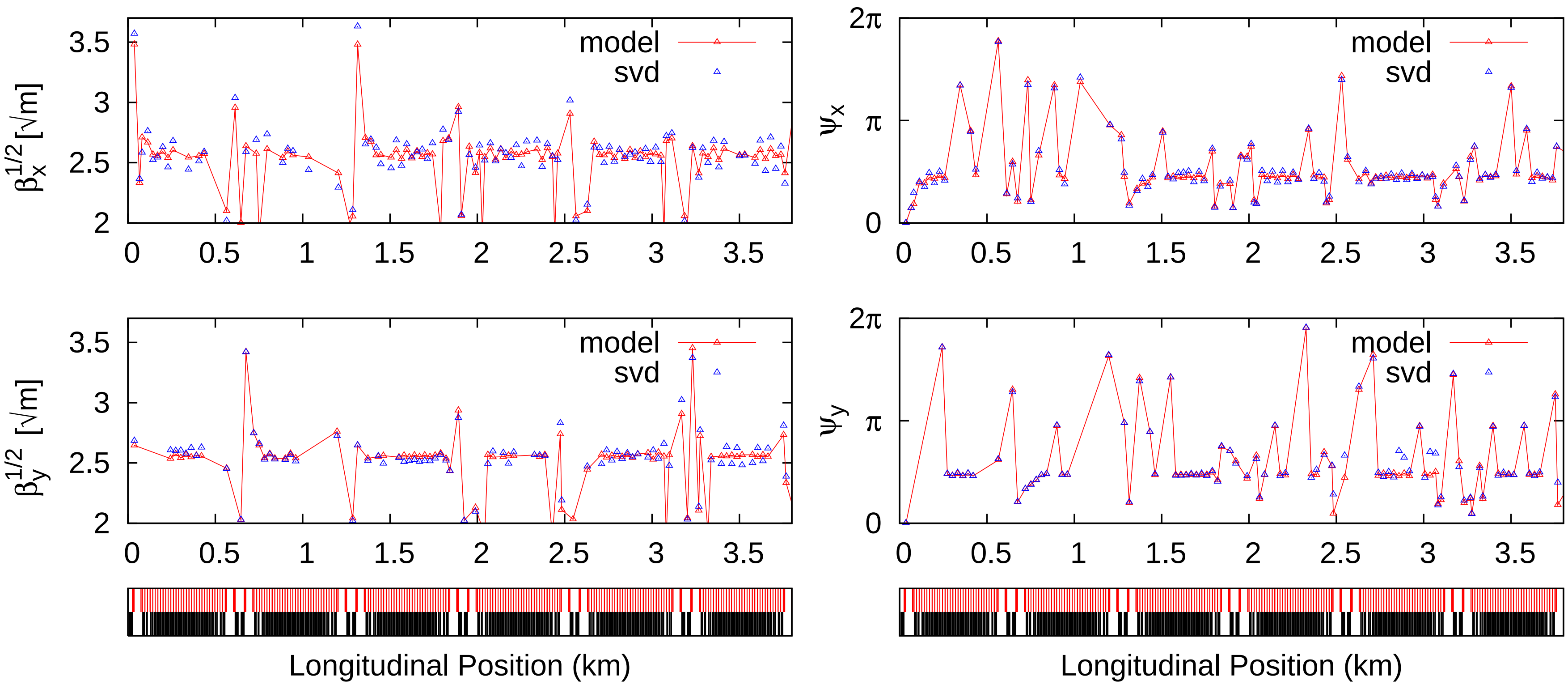
β & $D_x/\sqrt{\beta_x}$ Beat Corr. with Realistic Errors



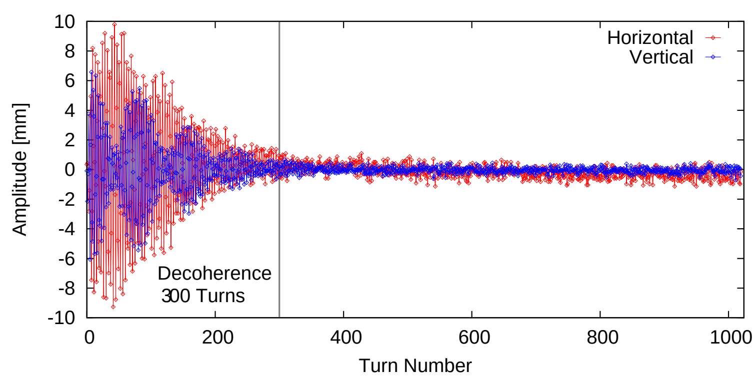
Benchmarking on Real Machines

- 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 $\sim$ 15-20%
  - Arc Circuits + IR Quads (many knobs, closer to LHC)
  - AC Dipole Vs. Free Oscillations (compare correction)
- Limitations - faulty BPMs, reproducibility

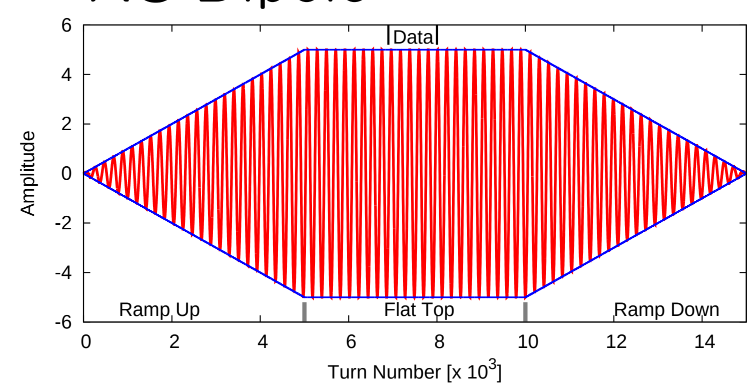
RHIC Optics Measurements



Kicked Data



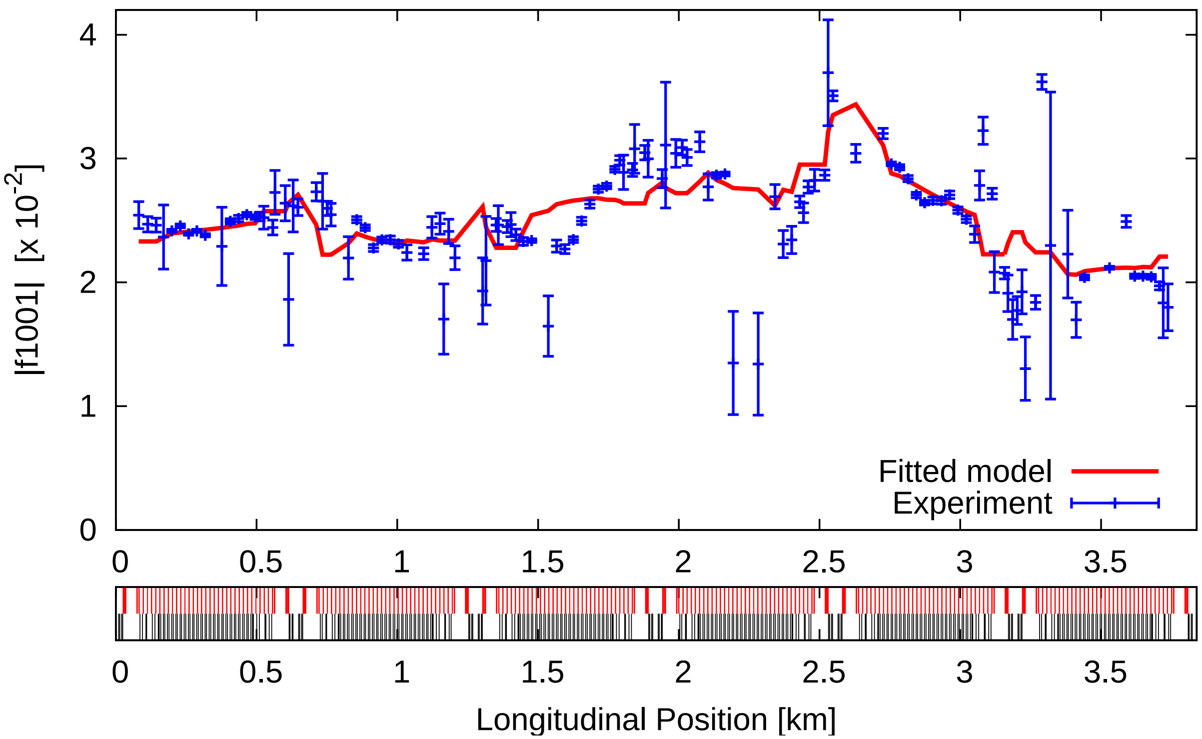
AC Dipole



RHIC Coupling Measurements

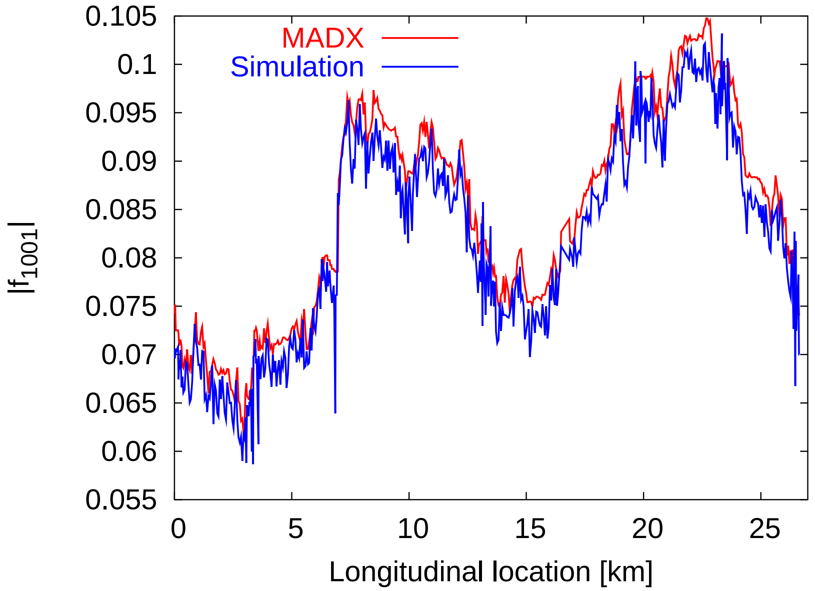
Fitting Variables:

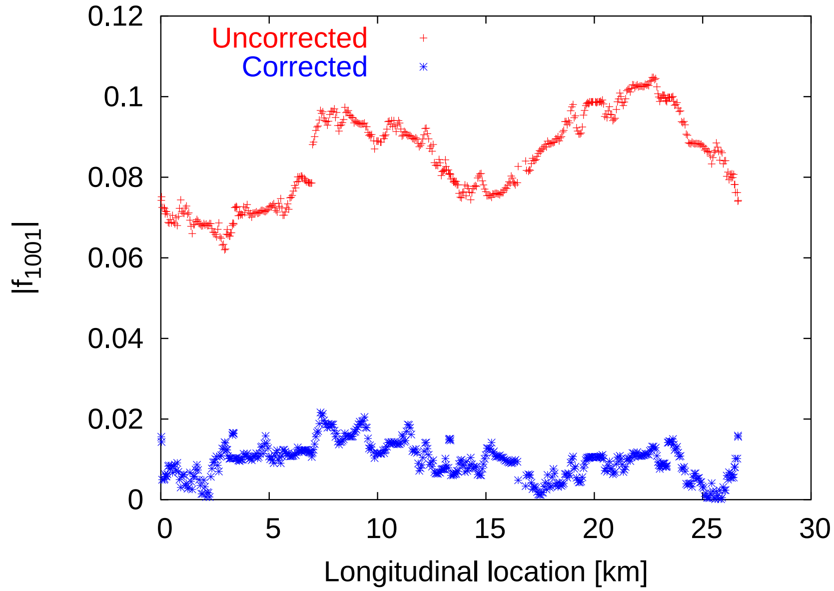
$$\lim_{\Delta\to 0}\left[\Delta f_{1001}^{(meas-mod)}\right] \to \left[\begin{array}{c}\text{Arc Quad Tilts (6-families)}\\ \text{IR Skew Correctors}\\ \text{IR Quad Tilts } (Q_1 \text{ - } Q_{10})\\ \vdots\end{array}\right] \to \text{MADX Iterate}$$



Local Coupling @LHC

- Random Quad Tilts + Large Tilt (6km) + BPM Tilts (2mrad)
- BPM Resolution: 200 μm
- Coherent Oscillations: 400 Turns





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

Application & Commissioning

- Requirements for Effective Corr:
  - Well Functioning and Synchronized BPM System (Turn-By-Turn)
  - Coherent Oscillations ($\sim$ 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
- Commissioing:
  - At most 5-6 Iterations (re-adjust injection)
  - Participants: Rogelio, Rama interested

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