Low Emittance Tuning through Dispersion Free Steering

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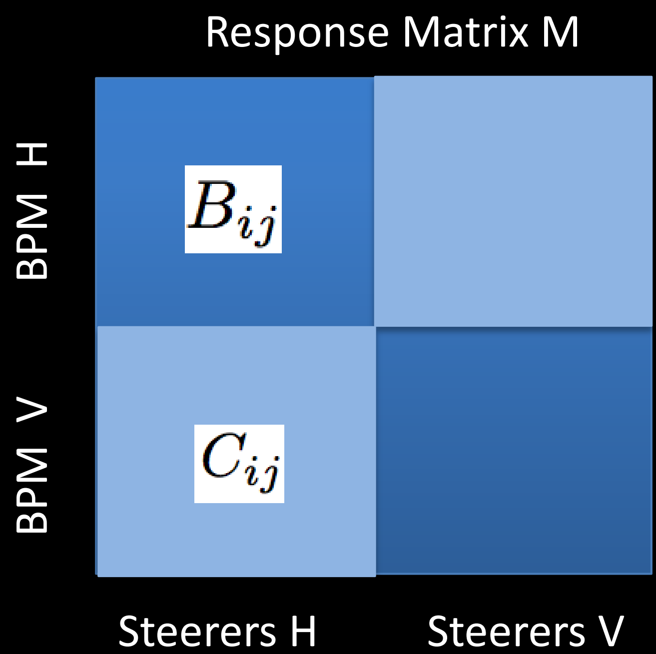
Response matrix



Orbit correction

$$\vec{x} = M\vec{\theta}$$

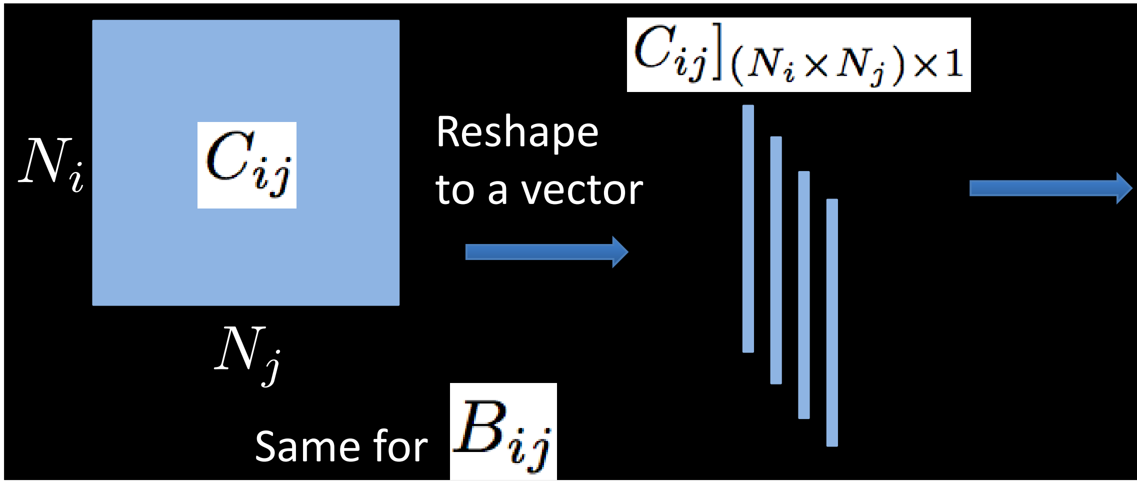
$$M_{ij} = \frac{\partial x_i}{\partial \theta_j}$$

Dispersion response matrix (deviation from reference)

$$\vec{\eta} = M^{disp}\vec{\theta}$$

$$M^{disp}_{ij} = \frac{\partial \eta_i}{\partial \theta_j}$$

SVD of M to calculate Correction $\vec{\theta}$



$$M^{C_{ij}}_{ik} = \frac{\partial}{\partial \theta_k}\frac{\partial x_i}{\partial \theta_j}$$

Mainly determined by sextupoles

Low Emittance Tuning Technique

$$\begin{pmatrix} (1-\alpha-\omega)\,\vec{y} \\ \alpha\,\vec{\eta}_y \\ \omega\,C_{ij}]_{(N_i \times N_j)\times 1} \end{pmatrix} = \mathcal{M}_v \begin{pmatrix} \vec{\theta}_V \\ \vec{K} \\ \vec{T} \end{pmatrix}$$

$$\begin{pmatrix} (1-\alpha-\omega)\,\vec{x} \\ \alpha\,\vec{\eta}_x \\ \omega\,B_{ij}]_{(N_i \times N_j)\times 1} \end{pmatrix} = \mathcal{M}_h \begin{pmatrix} \vec{\theta}_H \\ \vec{T} \end{pmatrix}$$

CORRECTORS USED

- V steerers
- Skew quad gradients
- Bpm Roll (Gains in progress)
- H Steerers
- Bpm Roll

N_j may be only 1 corrector

$C_{ij}]_{(N_i \times N_j)\times 1}$ Deviation from reference off diagonal block of the ORM reshaped to be a vector

$B_{ij}]_{(N_i \times N_j)\times 1}$ Deviation from reference diagonal block of the ORM reshaped to be a vector

Off axis orbit in quadrupoles and sextupoles used as correctors

- Matrix M simulated from Model without errors
- SVD inversion for simultaneous minimization of dispersion coupling and β-beating

Measurements at Diamond (UK)

Diamond aerial view

Diamond is a third generation light source open for users since January 2007

100 MeV LINAC; 3 GeV Booster; 3 GeV storage ring

2.7 nm emittance – 300 mA – 18 beamlines in operation (10 in-vacuum small gap IDs)

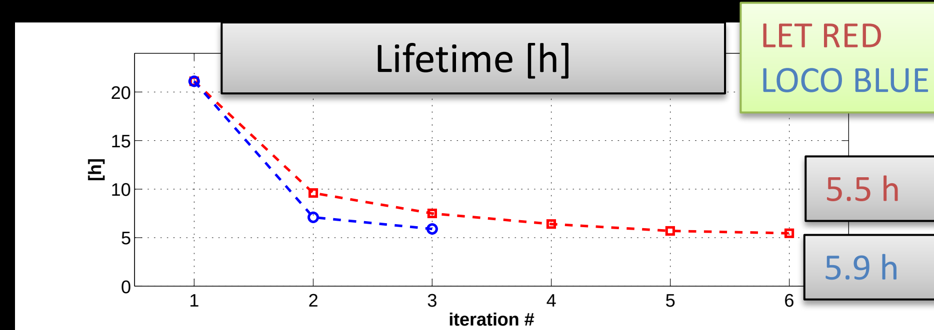
Curtesy R.Bartolini

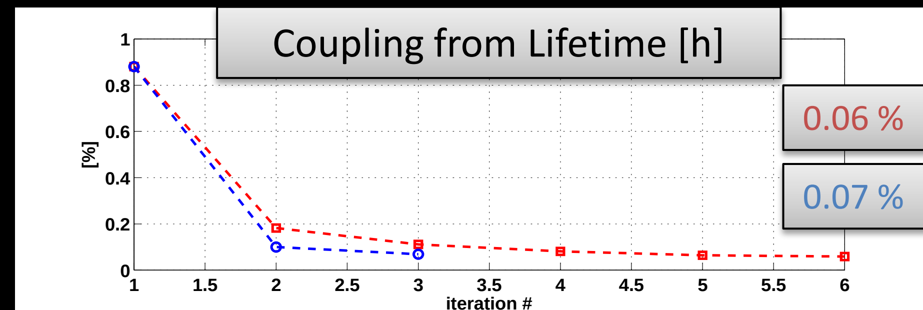
Skew quadrupole Correctors only

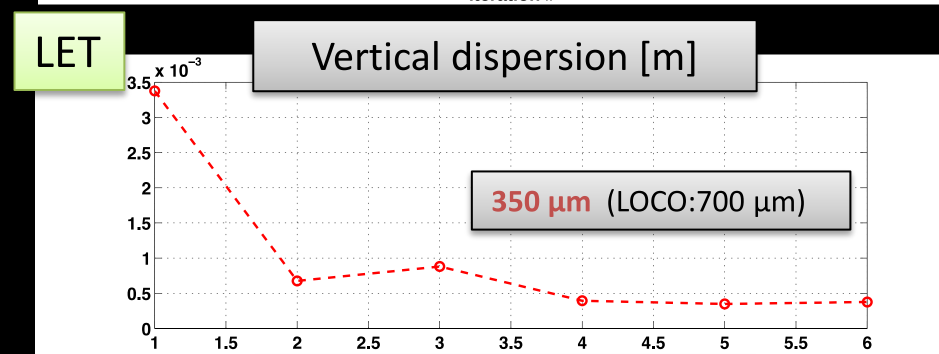
Coupling estimated from lifetime:

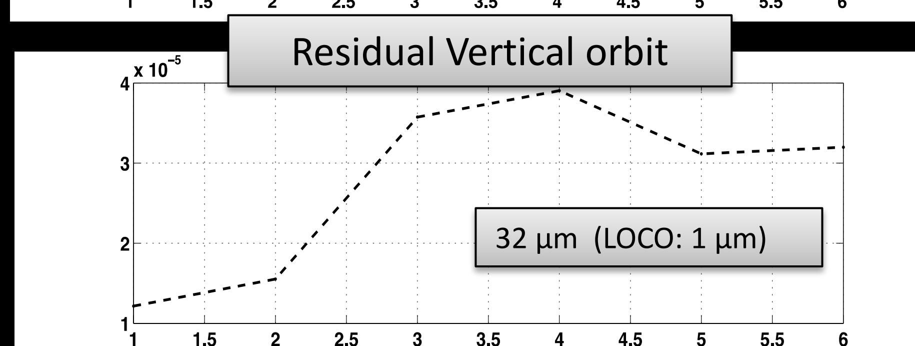
$$K_{end} = \frac{\tau_{end}^2}{\tau_{initial}^2} K_{initial} = 0.06\%$$

$$\varepsilon_y = 1.7\ 10^{-12}\ \text{m rad}$$









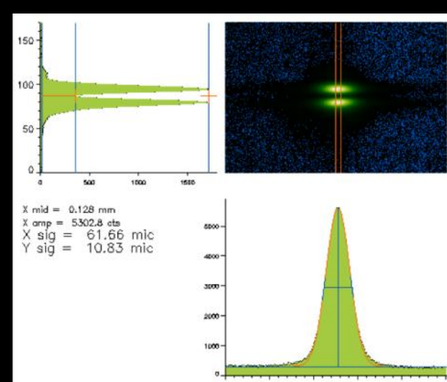
Measurements at SLS

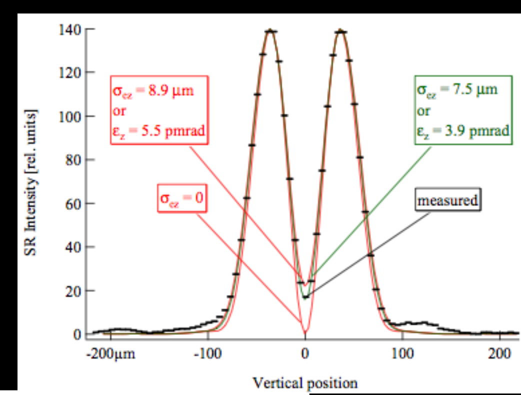
Measurements aimed to achieve low vertical emittance in the TIARA framework

SWISS LIGHT SOURCE
2.411 GeV, 288m, 12 beamlines, 400 mA, 5.4 nm Hor. Emit.

Same Tool used for Diamond, modified for direct access to Control System

Vertical beam size measurements performed using vertically polarized Shynchrotron Light Monitor



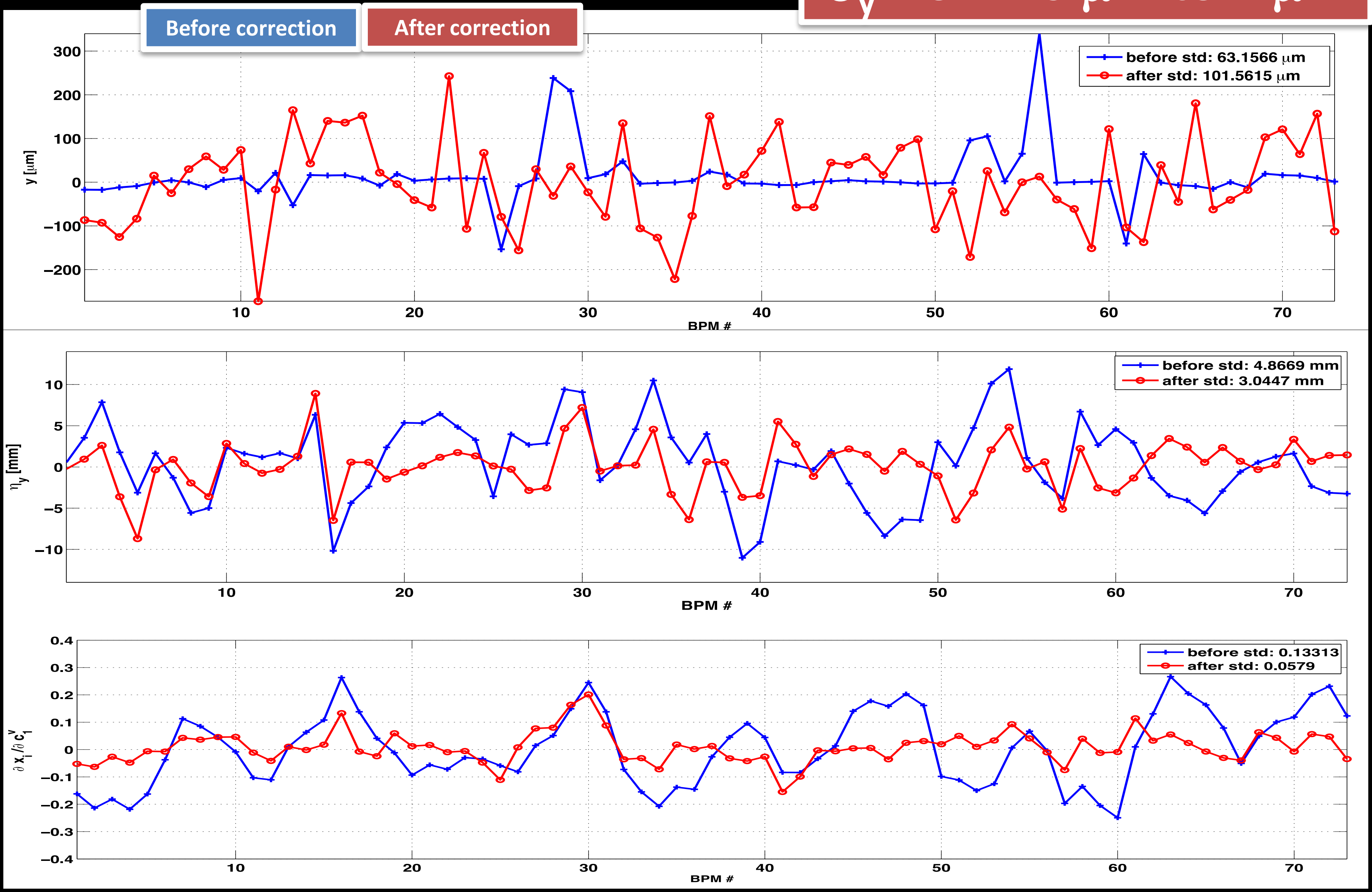


TUPB27 Proceedings of DIPAC 2007, Venice, Italy

SLS measurements

Vertical steerers only

σ_y from 16 μm to 7 μm



SLS measurements

Skew Quadrupoles only

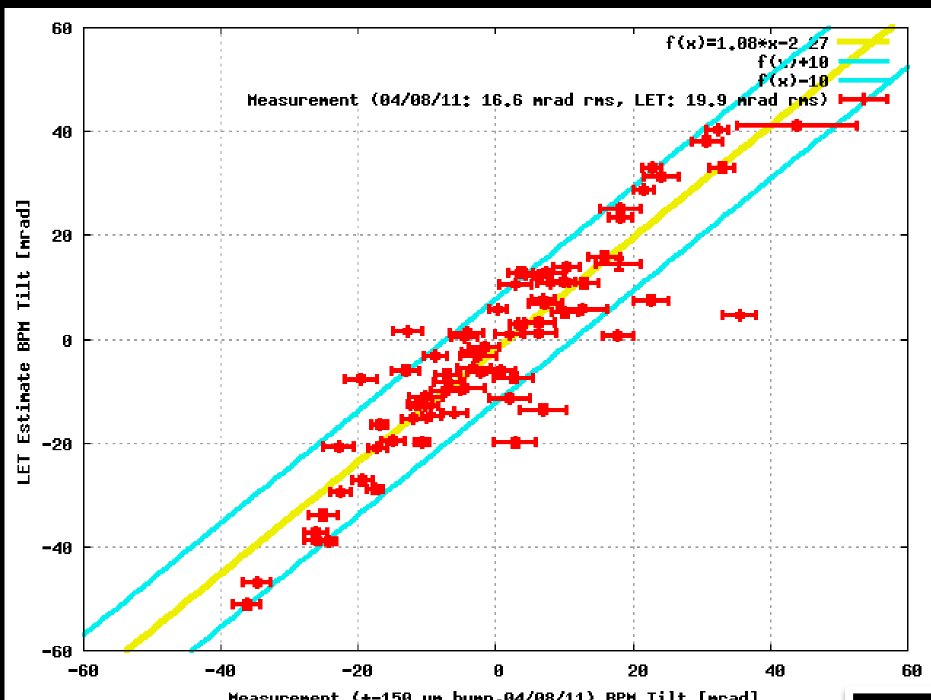
$\varepsilon_y = 1.6\ 10^{-12}$ m rad

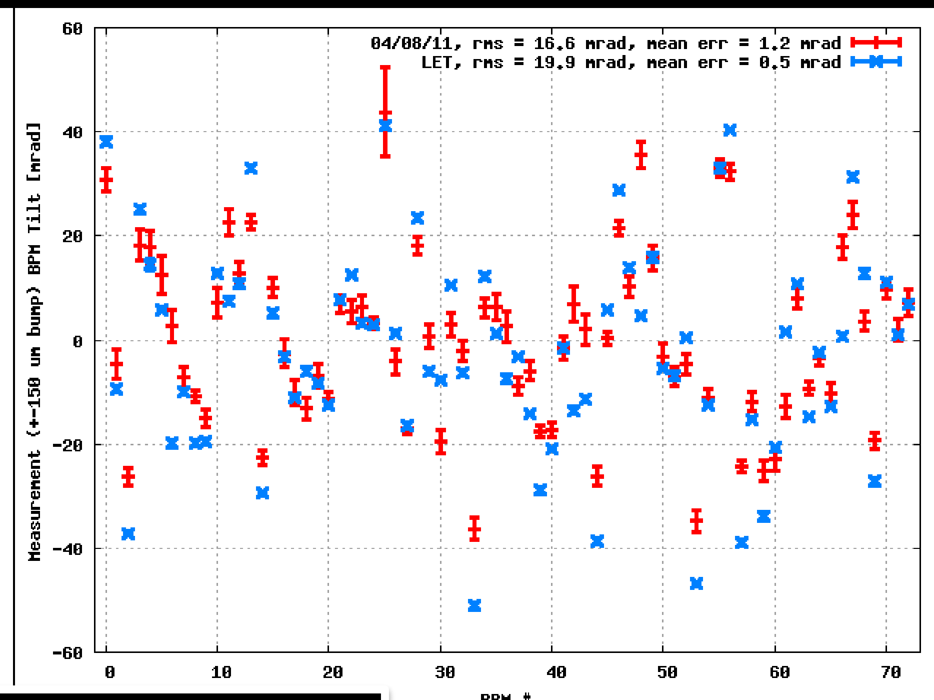
$\sigma_y = 4.7 \pm 0.7\ \mu m$

BPM ROLL error estimation

Ex. For dispersion: $$\eta'_{\mathbf{yi}} = \eta_{\mathbf{yi}}\mathbf{cos}(\mathbf{T_i}) + \eta_{\mathbf{xi}}\mathbf{sin}(\mathbf{T_i})$$

Evaluated simultaneously to the correction set evaluation





Courtesy Michael Boge (PSI-SLS)

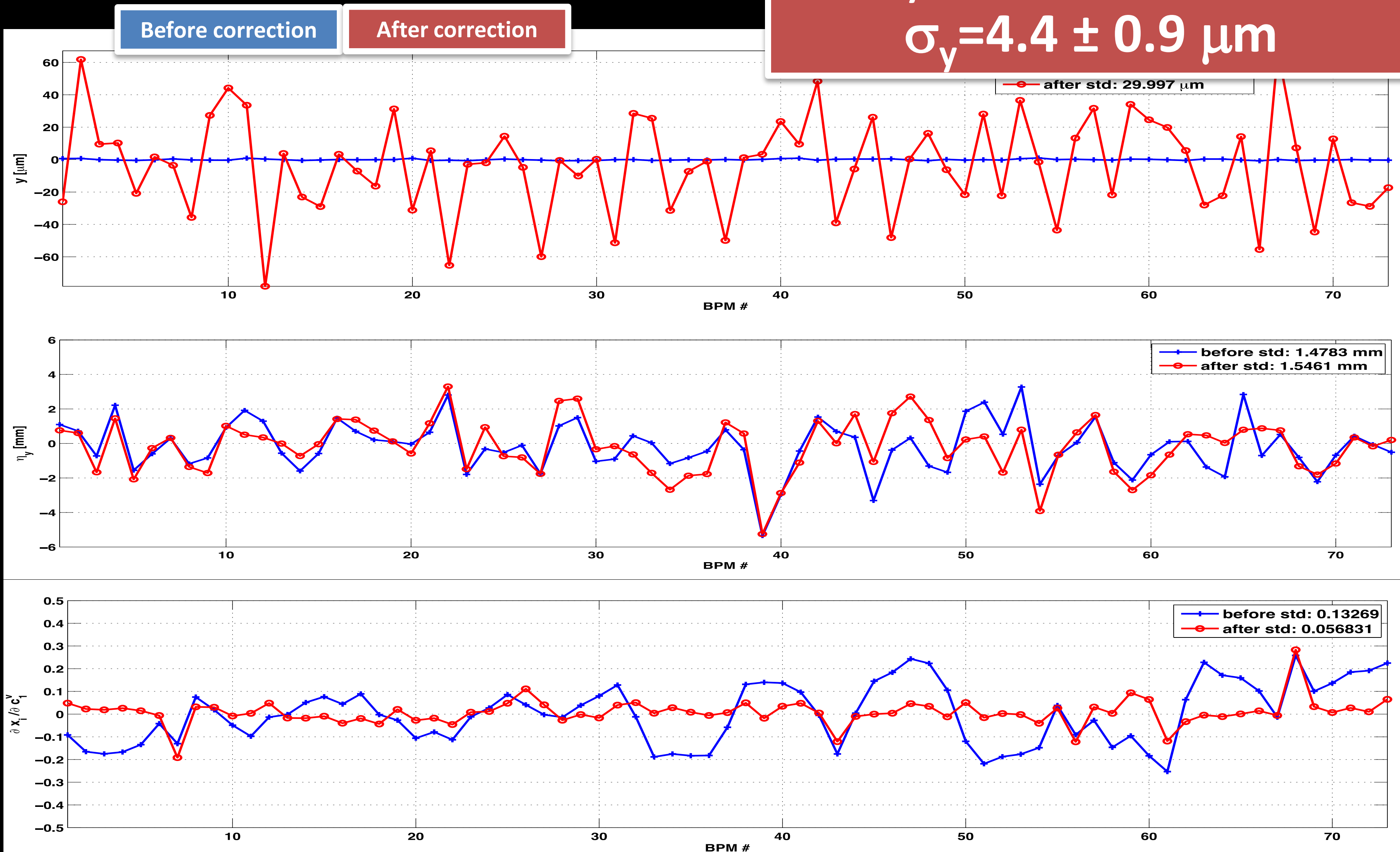
Comparable to the previous BPM roll estimates measured at SLS

SLS measurements

Skew Quad followed by vertical correctors and bpm roll estimations

$\varepsilon_y = 1.3\ 10^{-12}$ m rad

$\sigma_y = 4.4 \pm 0.9\ \mu m$

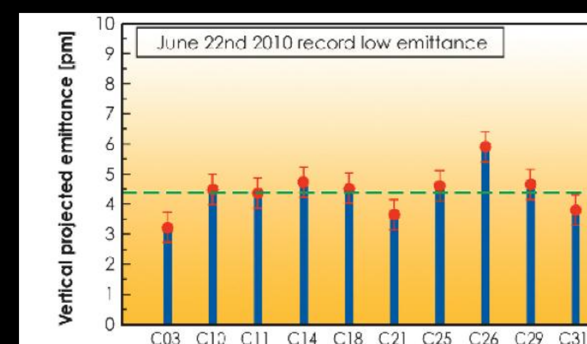


ESRF

6.03 GeV
844 m
200mA
992 bounches
ε_x=4 nm rad
ε_y=4 pm rad

Various vertical beam size monitors,
2 pinhole monitors and 11 In-Air-X-Ray- projection monitors

Coupling feedback system using skew quadrupoles

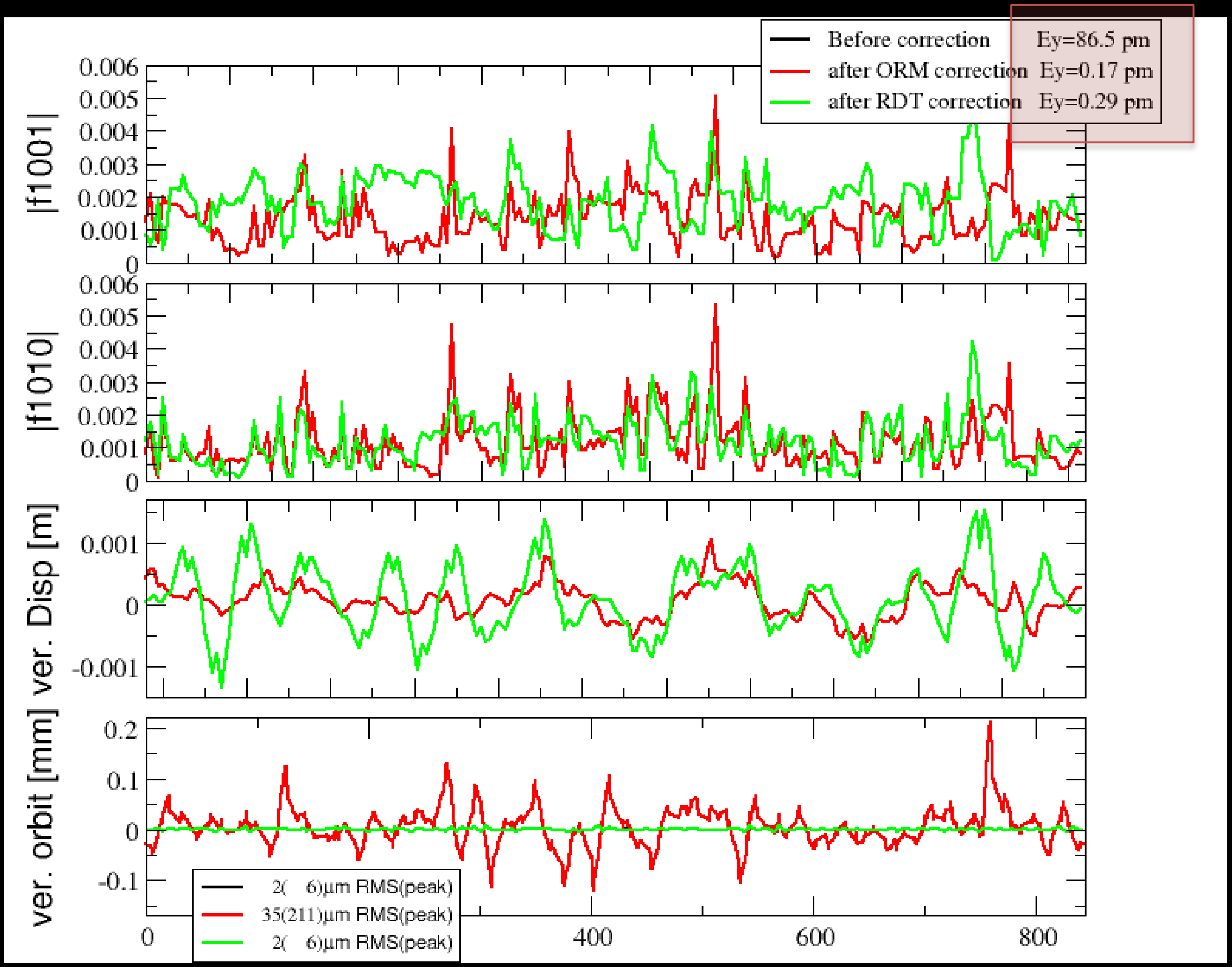


Measurements at the in air x-ray monitors

Simulated Comparison with RDT

Comparison of the methods using RDT calculations on simulated distorted lattice.

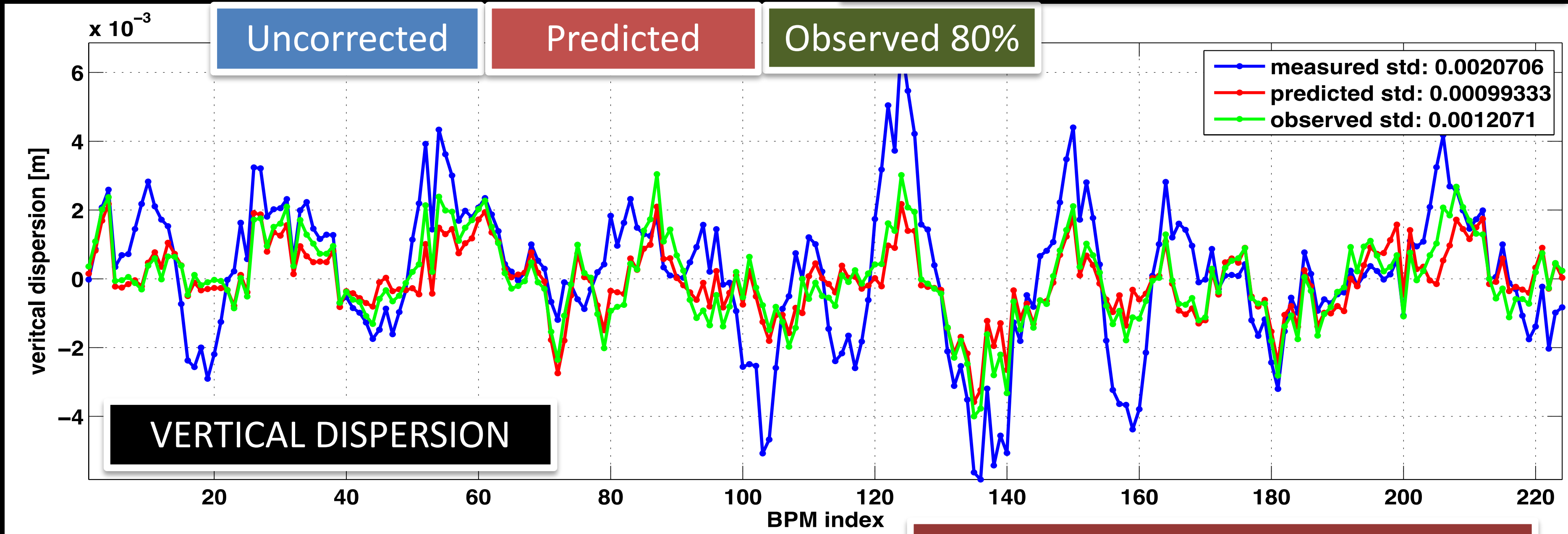
Starting from the same set of errors we calculate a correction set and evaluate the resiudual RDT.



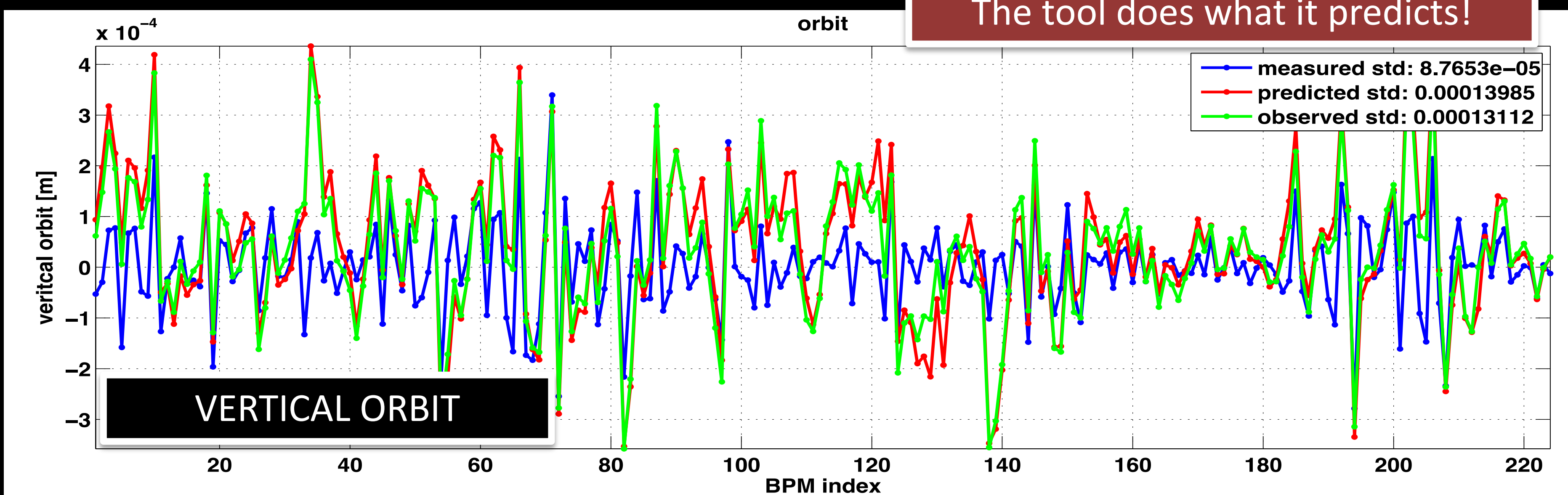
A.Franchi

Tests of the Tool

Correction with skew quad and vertical correctors, applied 80%

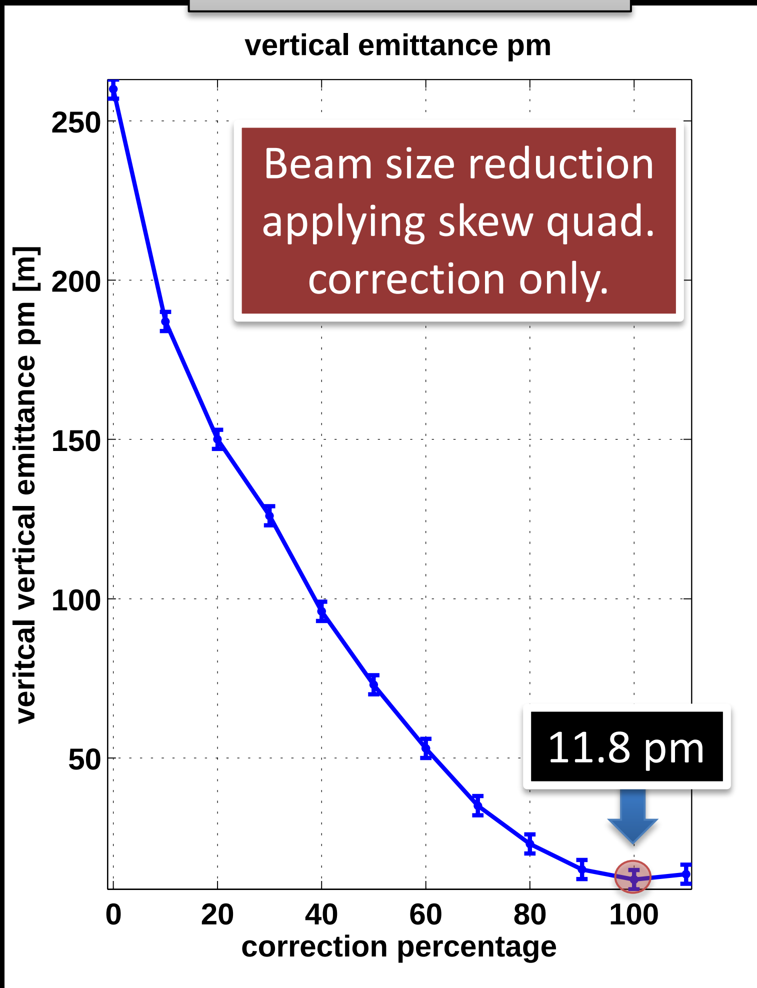


The tool does what it predicts!

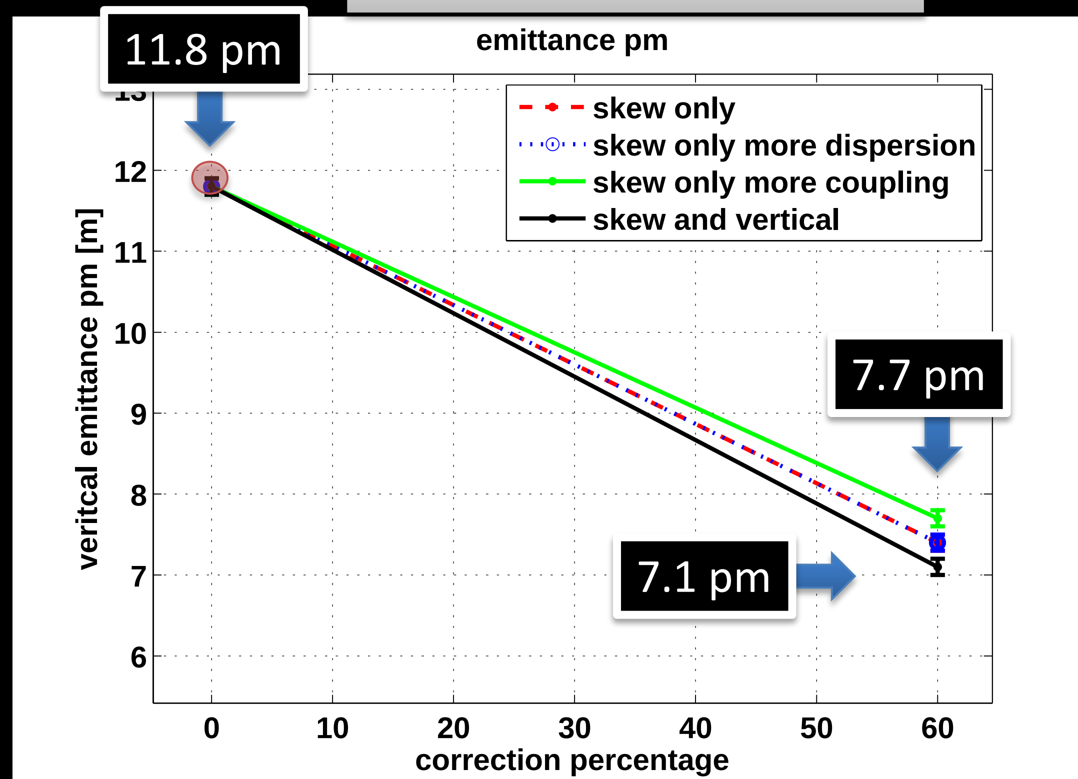


Skew Correction Starting from zero set

First correction



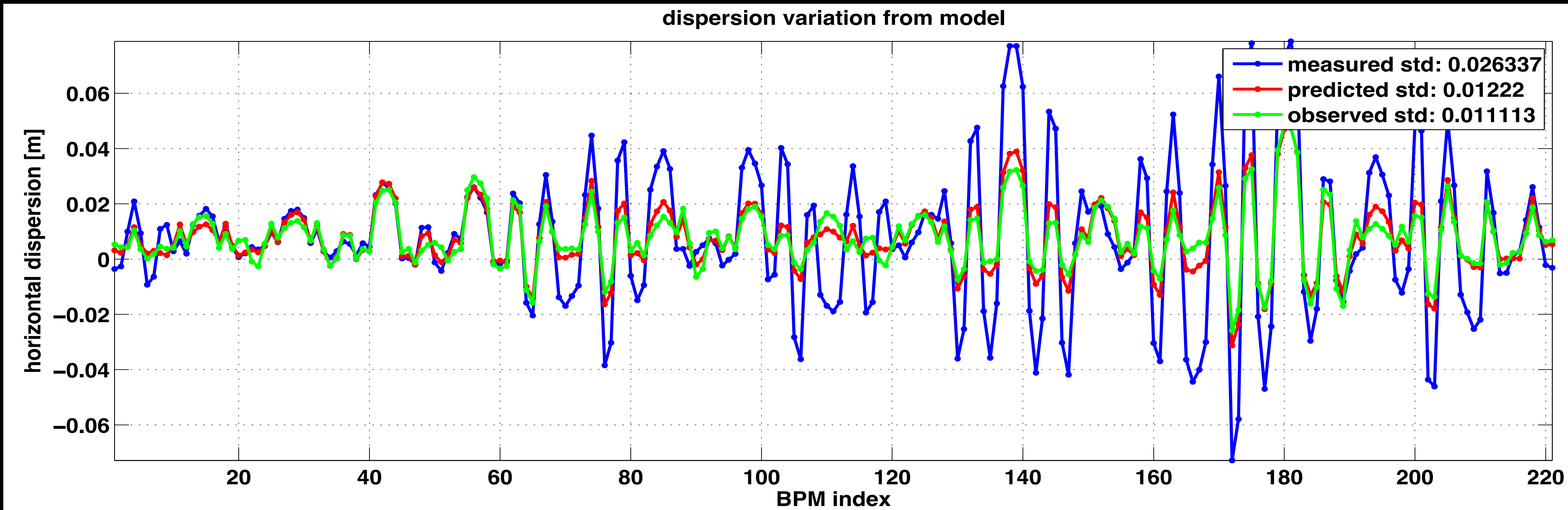
Correction iteration

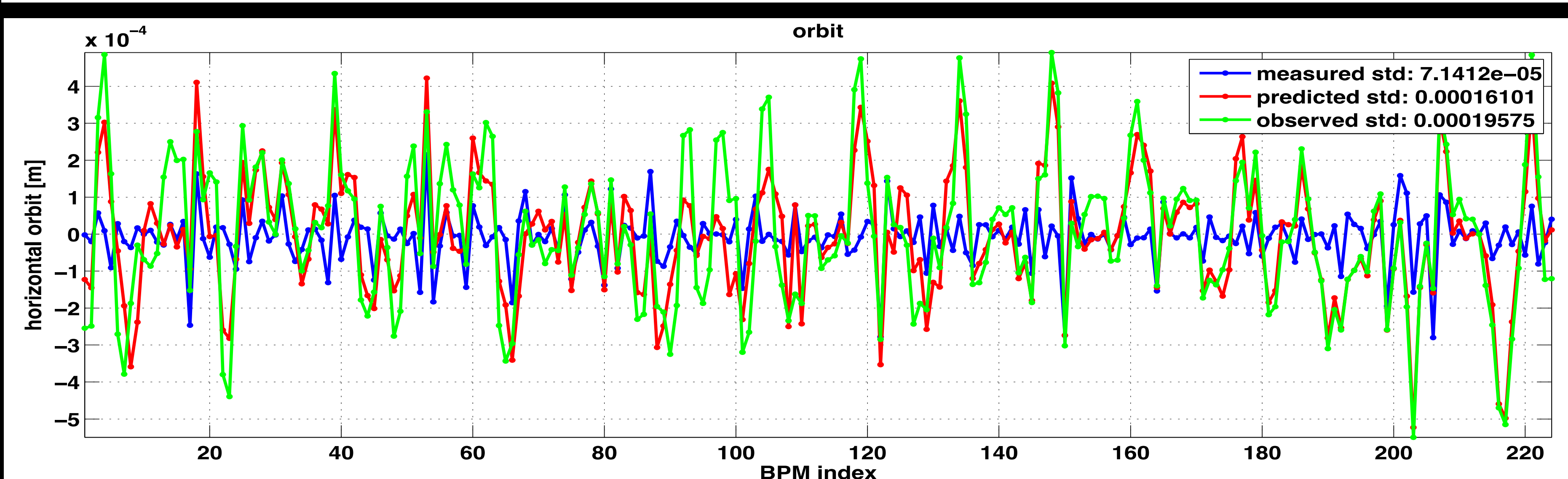


New measurement. Further improvements with various correction settings

Horizontal Steerers

Correction of horizontal dispersion and beta-beating using horizontal steerers only





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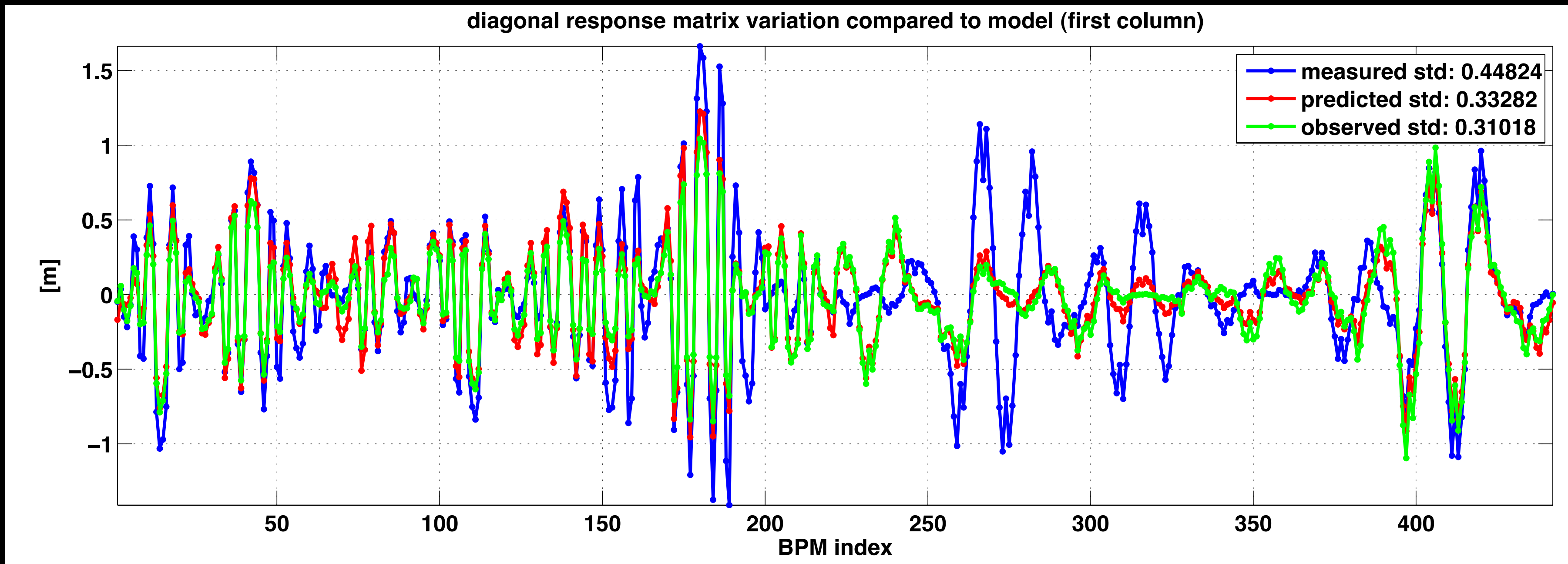
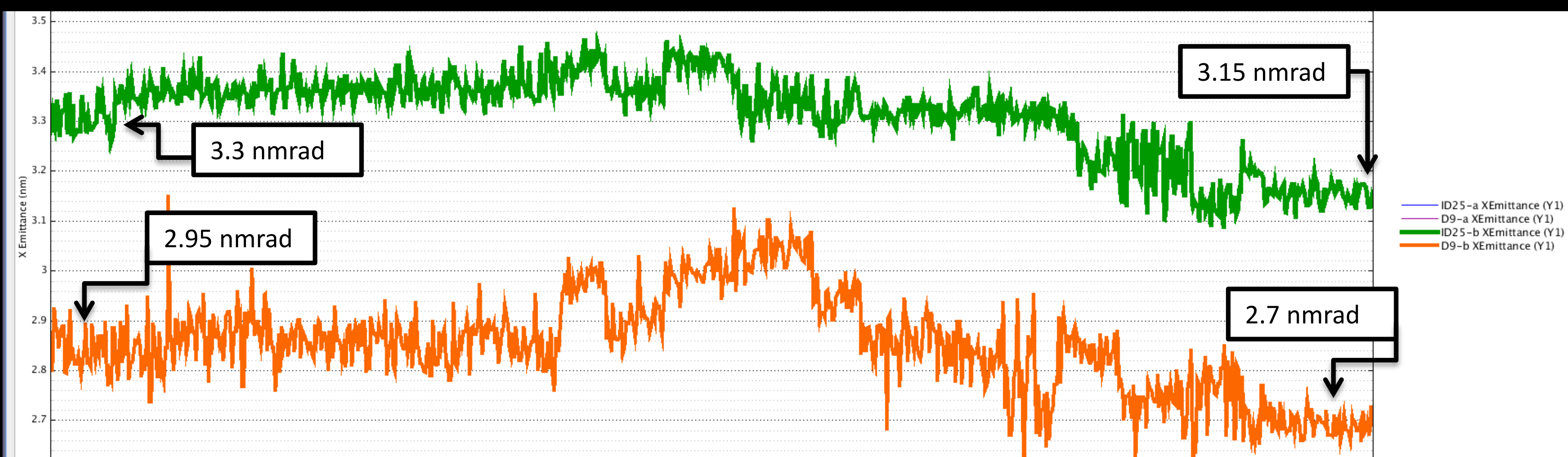
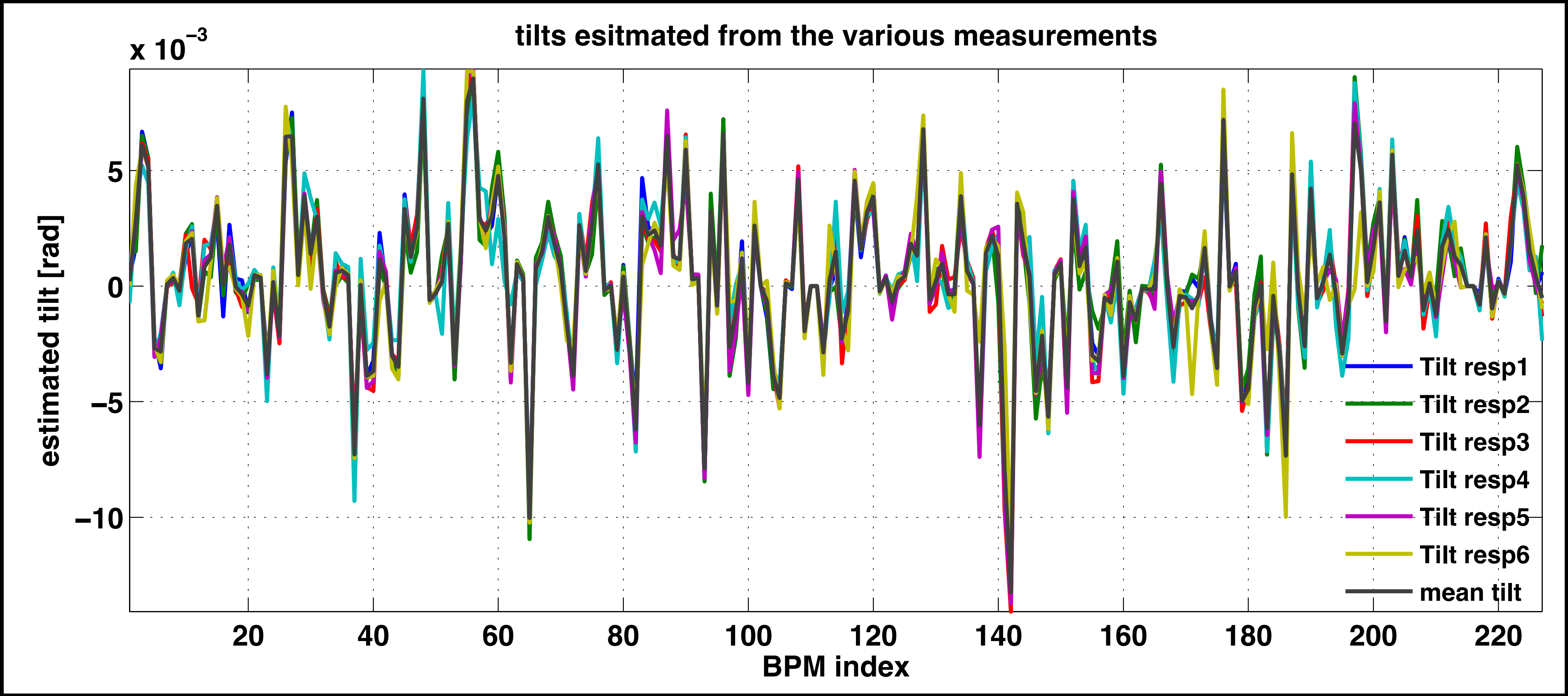




Beam Position Monitor Roll estimations

Roll errors may be estimated from all the measurements taken.



Not used for the correction

Conclusions

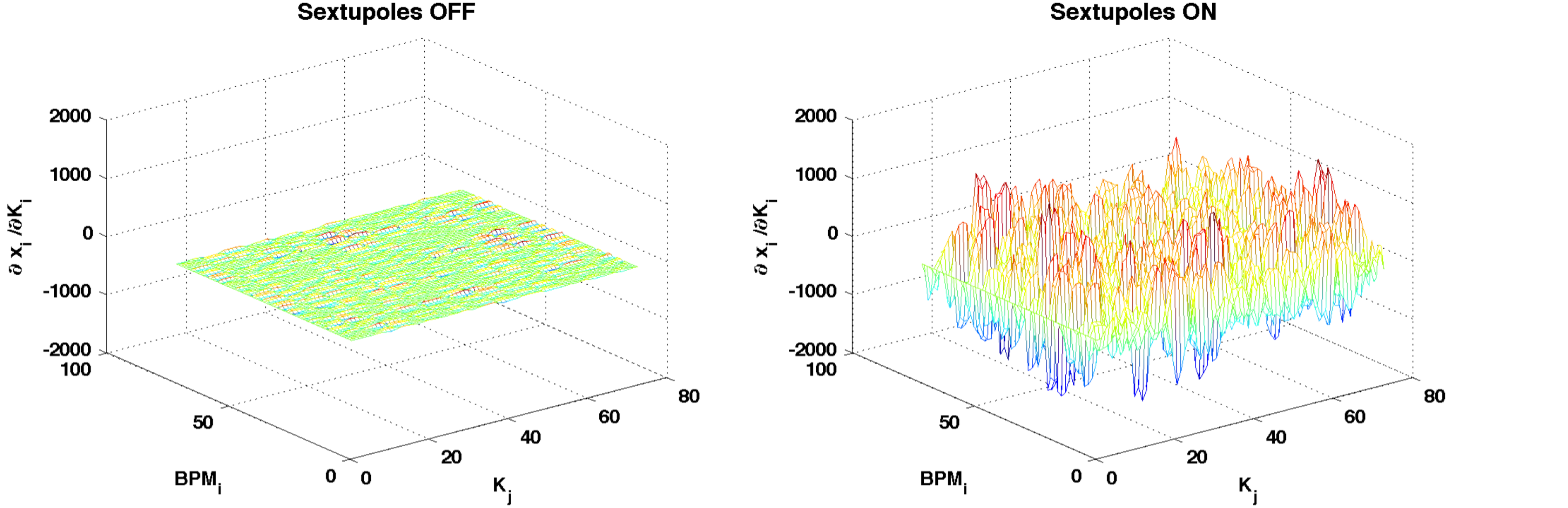
- Low emittance technique that exploits the off axis orbit in sextupoles and quadrupoles is tested at Diamond, at SLS and at ESRF:
  - Releasing the vertical orbit constraint to reduce dispersion and coupling allows reduction of vertical beam size
  - Skew quadrupole correction reach beam sizes and emittance comparable to previously obtained results at SLS (using skew quadrupoles) and at ESRF (using RDT)
  - Vertical steering including the evaluation of psudo-bpm roll errors allows further improvement in the correction
  - Horizontal dispersion and Beta-Beating correction leads to an improvement in Horizontal emittance

Future steps

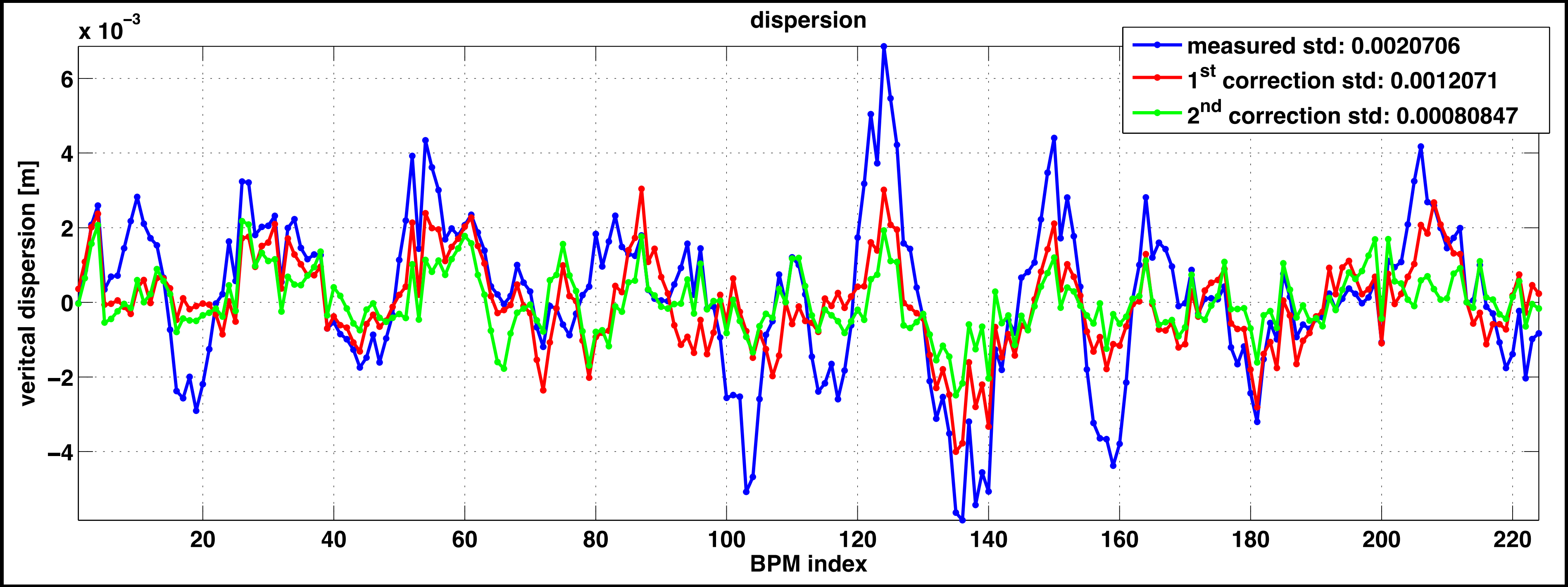
- Include Quadrupoles correctors, steerers tilts and BPM gain errors in the correction parameters.
- Human readable quantities (coupling and beta functions)
- More measurements
- Introduce the possibility to exclude a region from the correction (ID’s, IP’s).

Backup

C_{ij} and B_{ij} mainly determined by sextupoles (corrector 1 (j=1))



Minimum observed vertical dispersion AT ESRF during May-8-2012 MDT



2 iterations of correction with skew quadrupoles lead to 810 micron vertical dispersion.