Overview

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- SR - Betatron Coupling Correction
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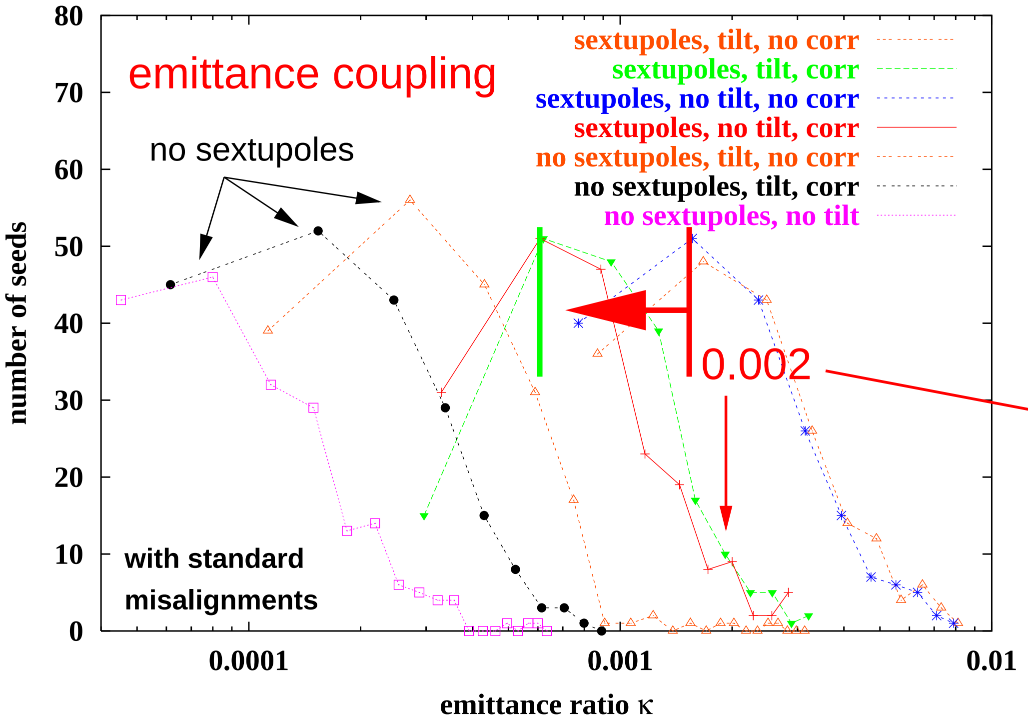
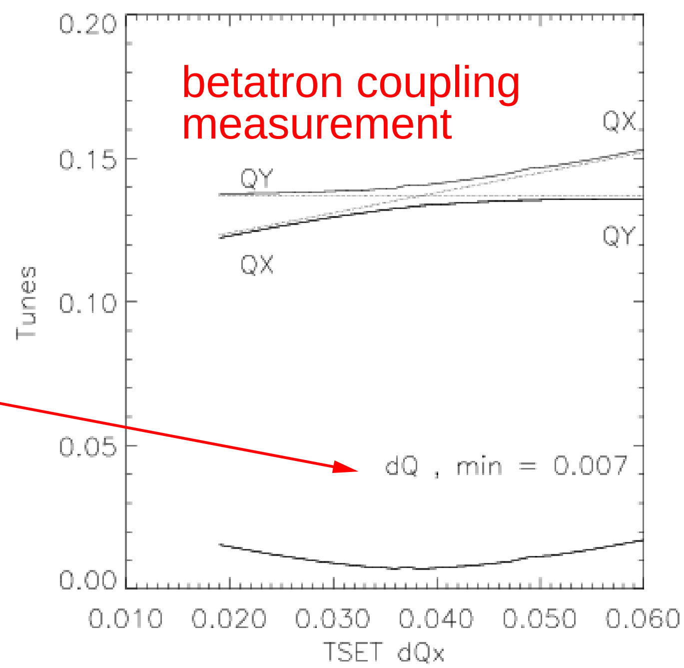
- SR - Summary
- SR - Lattice Errors
  - SR - Sextupole Beam-Based Alignment
  - SR - Girder Re-alignment

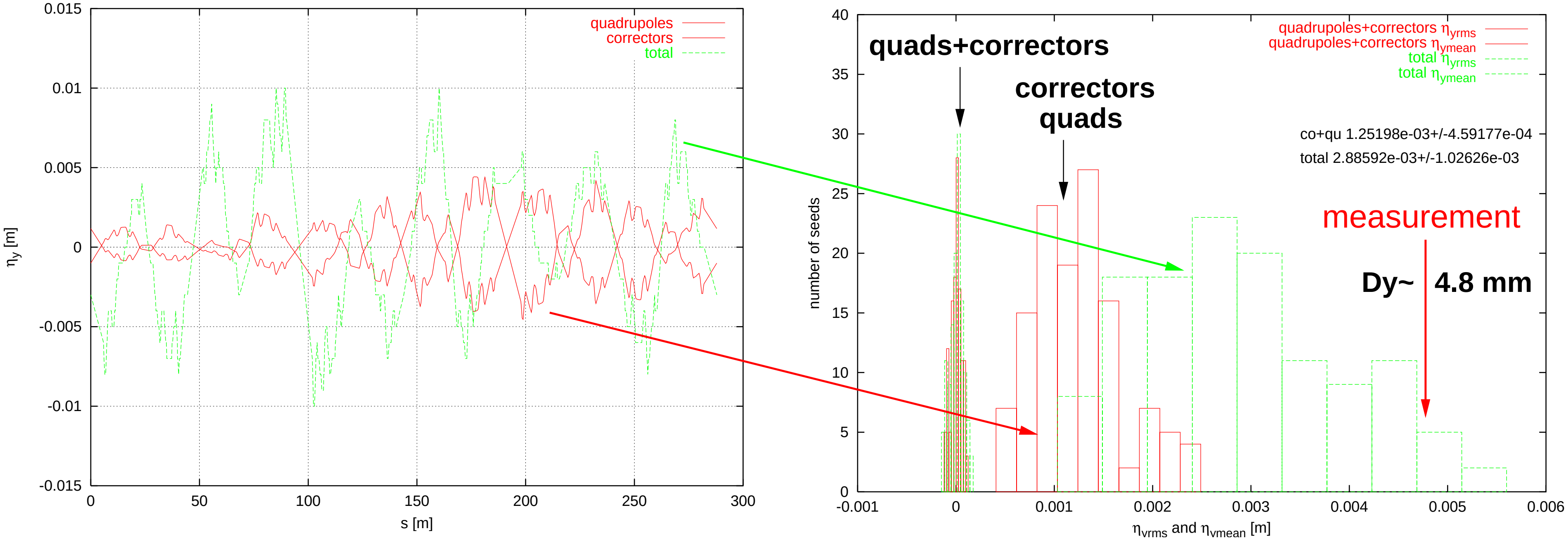
SR - Lattice Errors - Sources of Vertical Emittance I





- Betatron coupling: dQ=0.007 (in commissiong year 2001)
  - Emittance coupling in absence of spurious vertical dispersion: 0.2% (Guignard)
- Left: Emittance coupling after betatron coupling correction with initially 6 skew quadrupoles ≈ 0.1% (simulation for 200 seeds)

SR - Lattice Errors - Sources of Vertical Dispersion



- Left: Dispersion waves from quadrupoles and correctors in antiphase if BPM-quadrupole errors are small (<50 μm RMS) (→ Beam-Based Alignment) after correction to quad centers using “hard correction” (all SVD weighting factors used).
- Right: Main contribution to dispersion from sextupoles through betatron coupling (simulation for 200 seeds) ! Contributions from quads and correctors cancel !

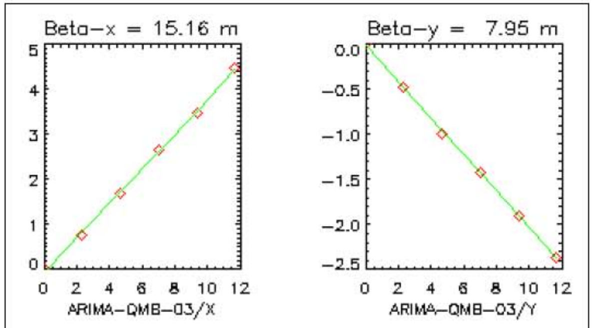
SR - Lattice Calibration - Beta Function Measurement I

- Quadrupole correction **(177 Quads with individual PS)**

  β-Measurement from quadrupole variation

$$\Delta Q = \frac{1}{4\pi} \Delta k_q \langle\beta\rangle_q L_q$$

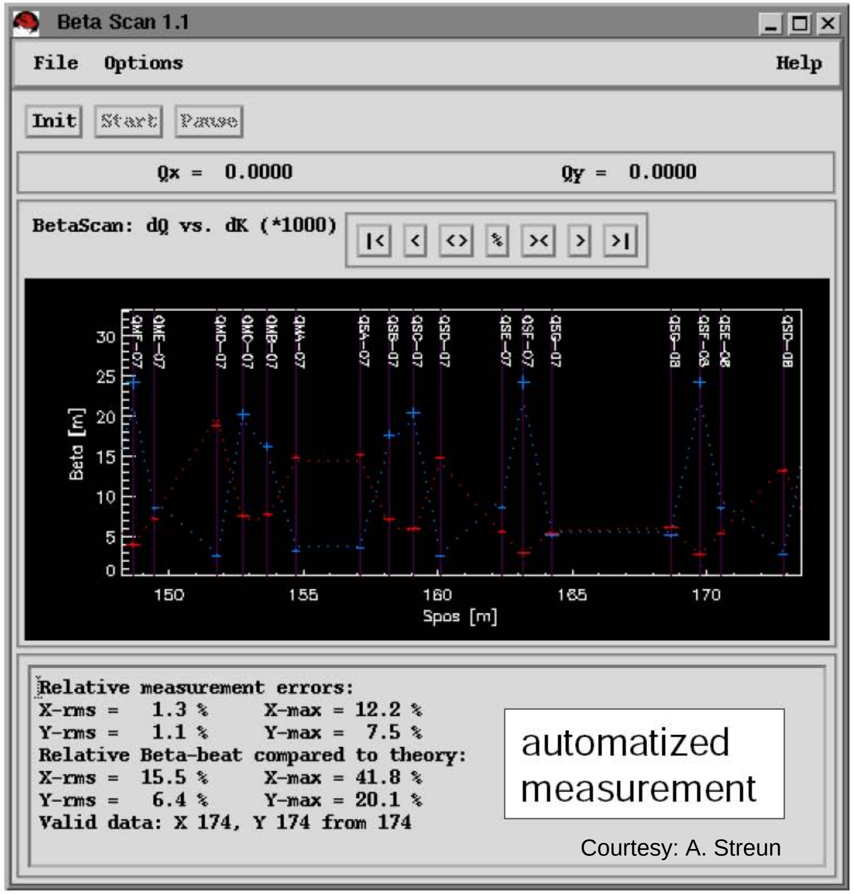
$$\Delta k_q = \left.\frac{dk}{dI}\right|_{I_o} \Delta I$$



ΔQ (x1000) vs Δk_q (x1000)

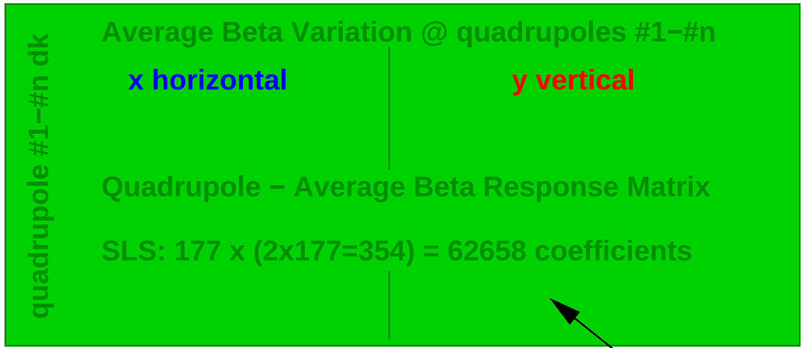
Hysteresis Correction based on tune measurement before and after the quad variation. Allows to restore the original average beta function in the quad.

−> important in order to minimize optics distortions during the measurement !

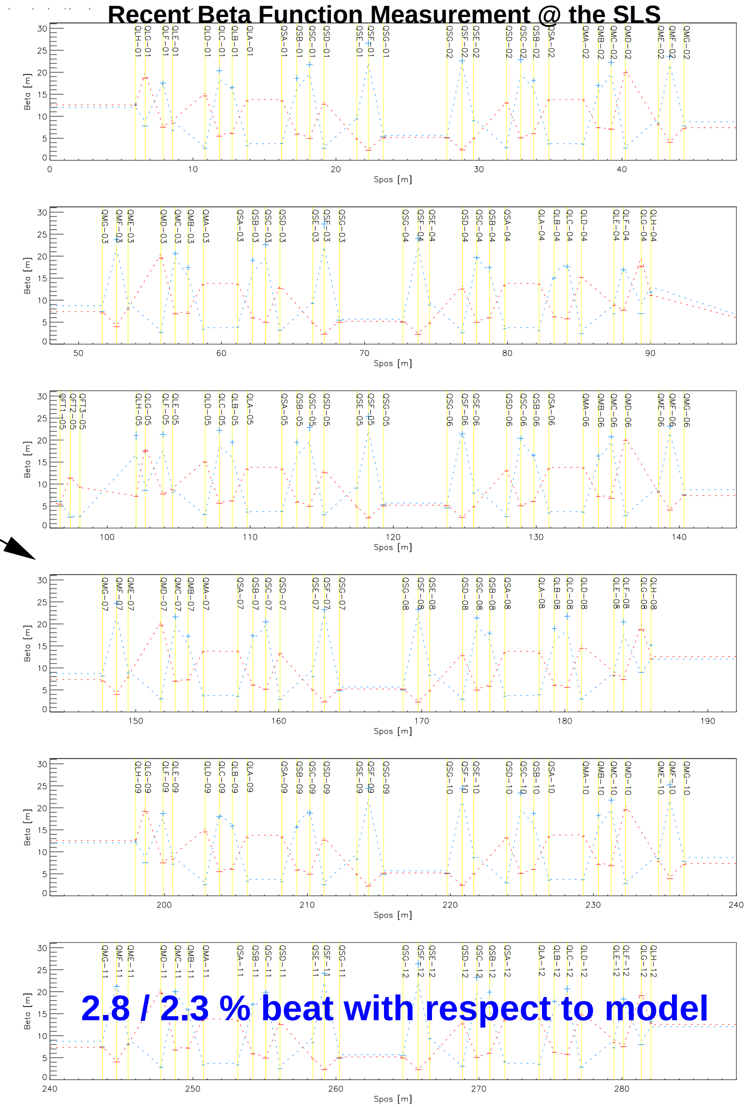


Courtesy: A. Streun

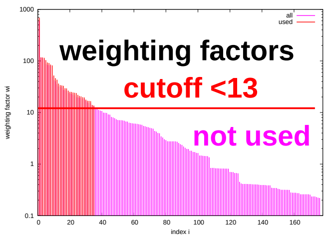
SR - Lattice Calibration - Beta Function Correction I

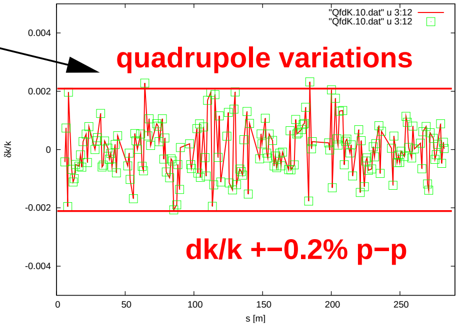


From Model or Measured



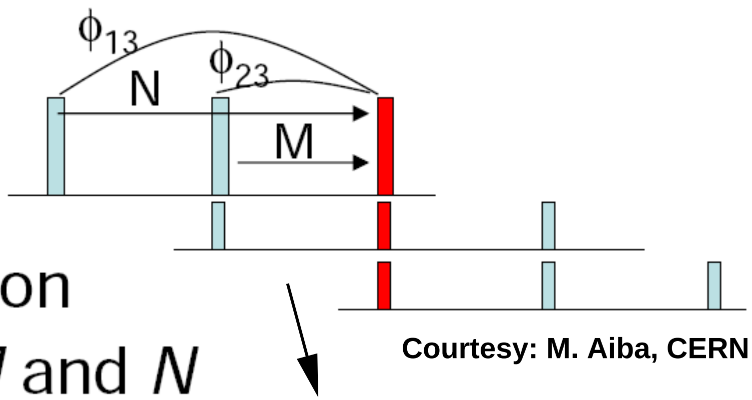
- measure average beta functions in quadrupoles
- Invert 177 x 354 Matrix using SVD
- plug the measured average beta functions into the "inverted" matrix
- calculate quadrupole variations dk_i which fit model best to the measured average beta functions (cut weighting factors since quadrupoles are not the only the only source of beta variations !)
- apply the −dk_I to the machine in order to correct the beta beat.





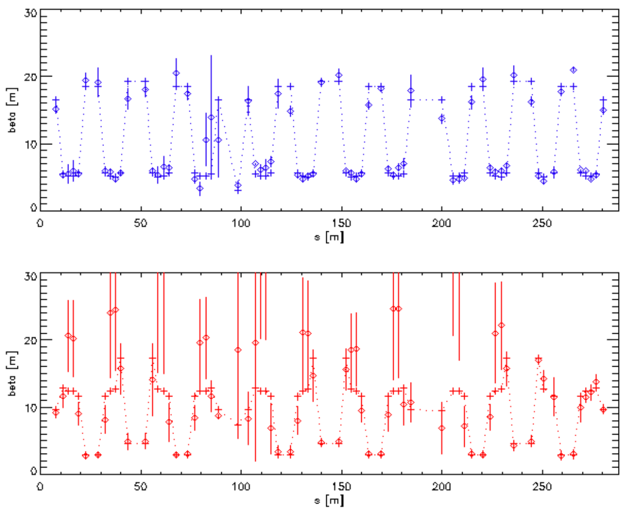
SR - Lattice Calibration - Beta Function Measurement II

- Beta and alpha inferred from phase
  - $$\beta_3 = \frac{\cot\phi_{23} - \cot\phi_{13}}{M_{22}/M_{12} - N_{22}/N_{12}}$$
  - Similar eq. for $\beta_{1,2}$, $\alpha_{1,2,3}$
  - Measure 3 times for single location
  - Assume model transfer matrix *M* and *N*
  - Free from BPM scale error **!**
- Beta inferred from spectrum height
  - Complementary
  - $$Tune\ Spectrum \propto \sqrt{2\beta J_{coh.}}$$
  - Assume the average of beta is const
  - BPM scale error

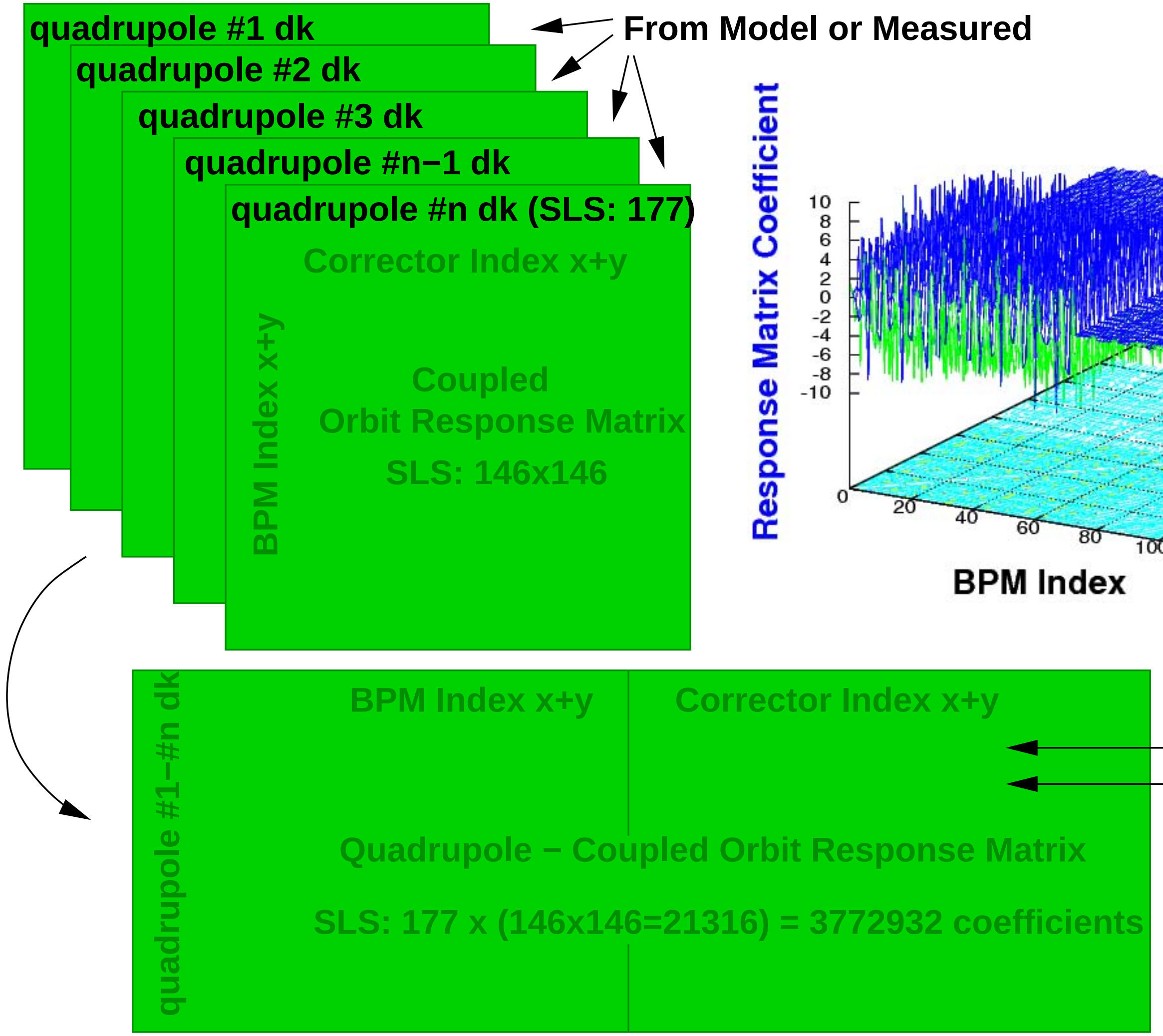


Courtesy: M. Aiba, CERN

First measurements at the SLS



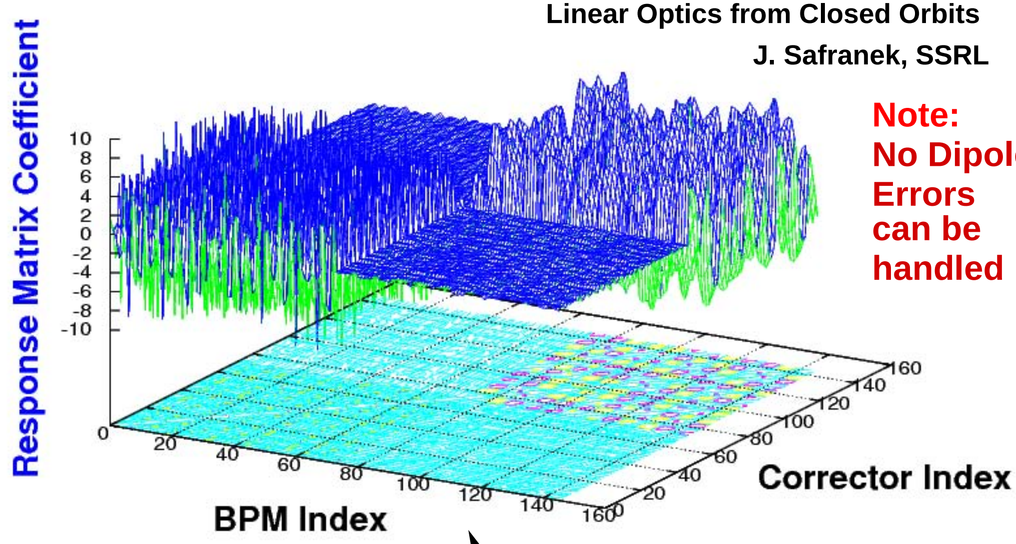
SR - Lattice Calibration - Beta Function Correction II



Doing it the LOCO way

Linear Optics from Closed Orbits

J. Safranek, SSRL



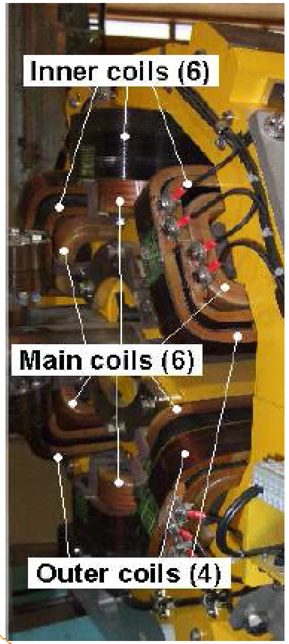
Note: No Dipole Errors can be handled !

- measure the Orbit Response Matrix
- invert 177 x 21316 Matrix using SVD
- plug ORP into the "inverted" Matrix
- calculate quadrupole variations dk_i which fit the model best to the Orbit Response Matrix (cut weight. facs)
- *iterate within model for large errors*
- apply −dk_i to the machine in order to correct the beta beat.

SR - Multipole Correctors

Versatile Sextupoles

all 120 sextupoles were delivered with H&V corrector coils
⇨ make skew quadrupoles and auxiliary sextupoles



120 sextupoles in 9 families:

SF(24), SD(24), SE(24) → **chromaticities**

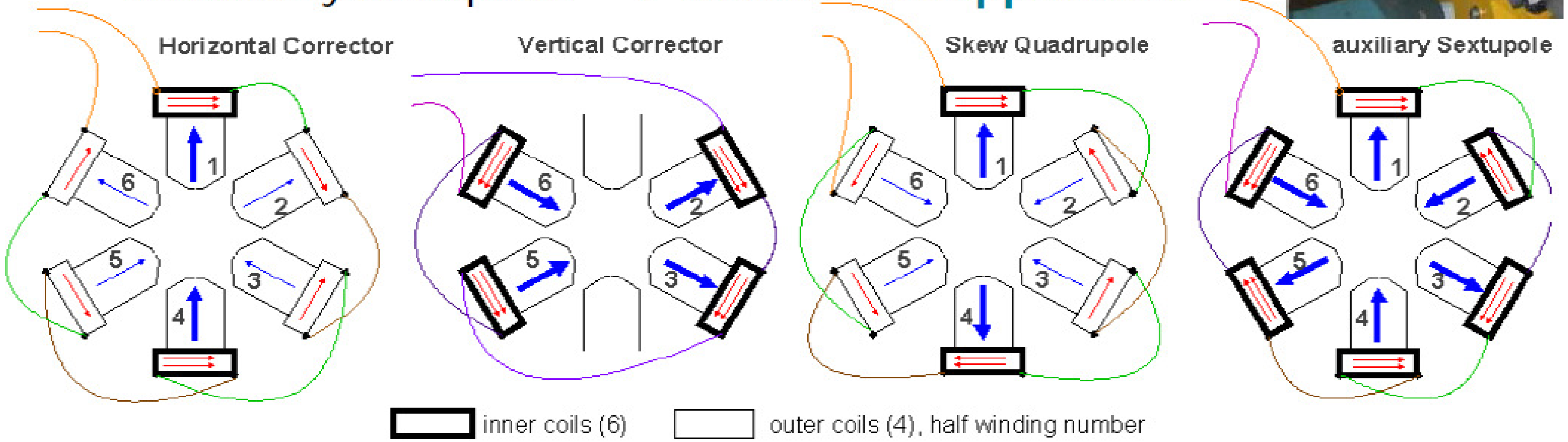
SSA(12), SSB(12), SMA(6), SMB(6), SLA(6), SLB(6) → **D.A.**

SD, SE, S∗B: **72** H&V correctors → **orbit correction**

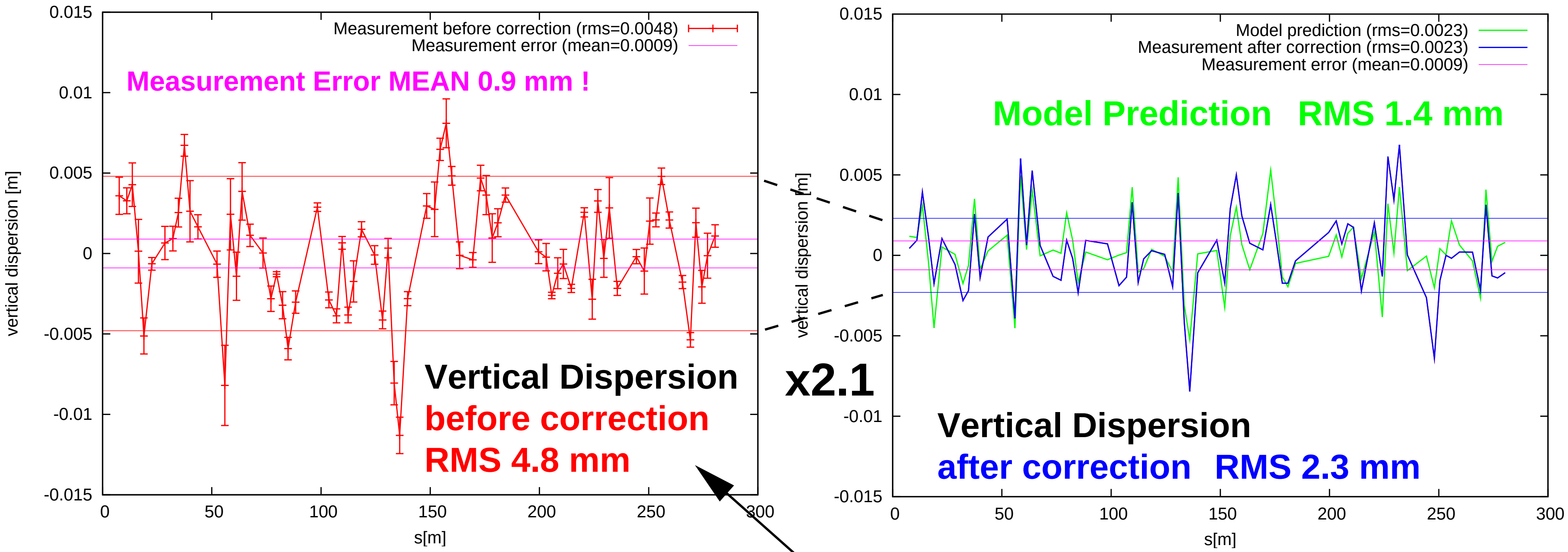
S∗A: **24** skew quads (η=0) → **betatron coupling**

SF: **12** skew quads (η>0) → **vertical dispersion**

12 auxiliary sextupoles → **resonance suppression**



SR - Dispersion Correction I



Disp Skew Quads

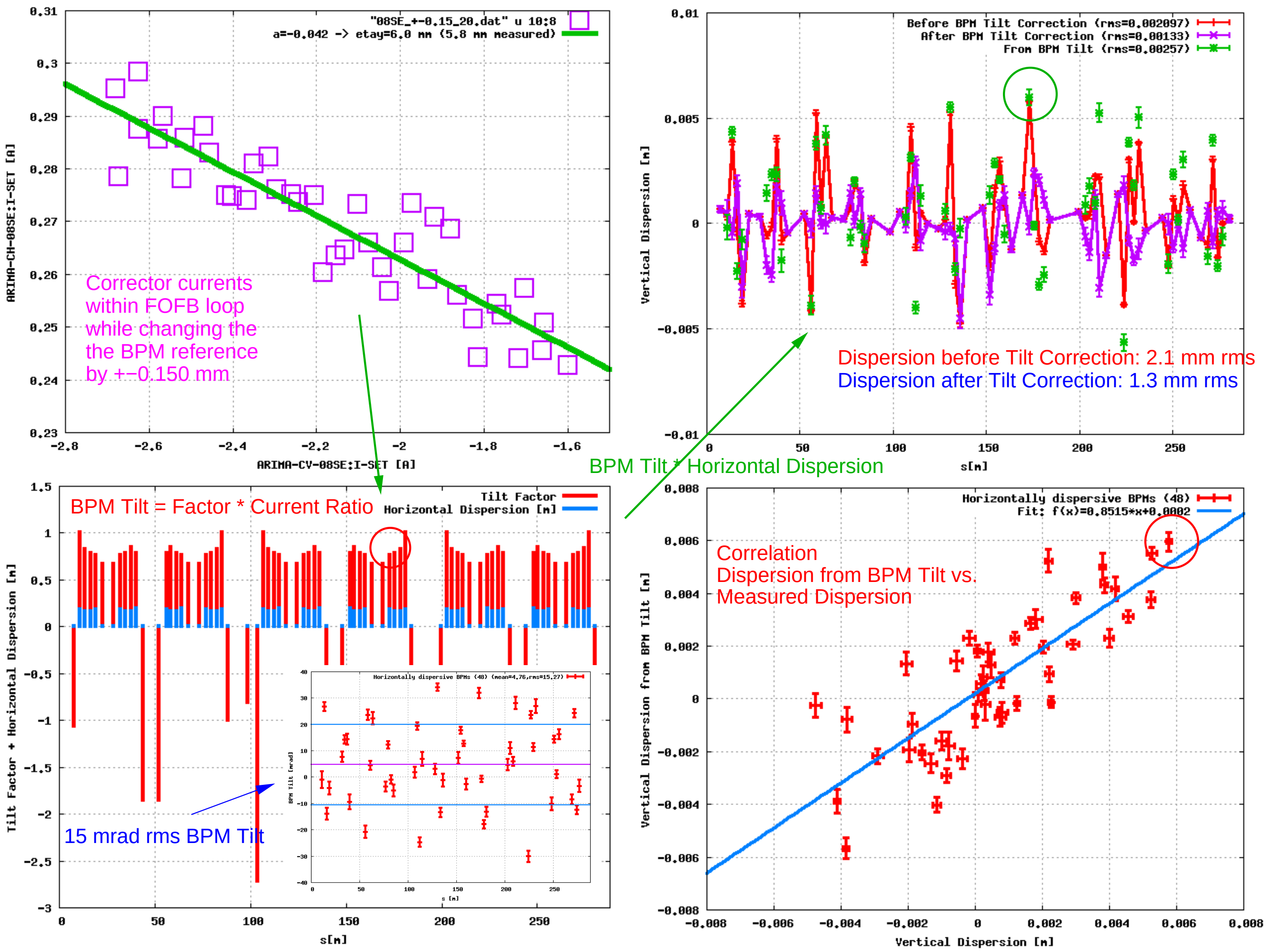
Vertical Dispersion @ BPMs

Skew Quad – Dispersion Response Matrix

SLS: 12 x 73 coefficients

- **measure difference orbits for various dp/p**
- **determine vertical dispersion knowing dp/p**
- **invert Skew Quad – Dispersion Response Matrix**
- **feed measured dispersion into it to determine Dispersive Skew Quads values for correction**
- **Get a Model Prediction**
- **Apply correction and remeasure**

SR - Dispersion Correction II

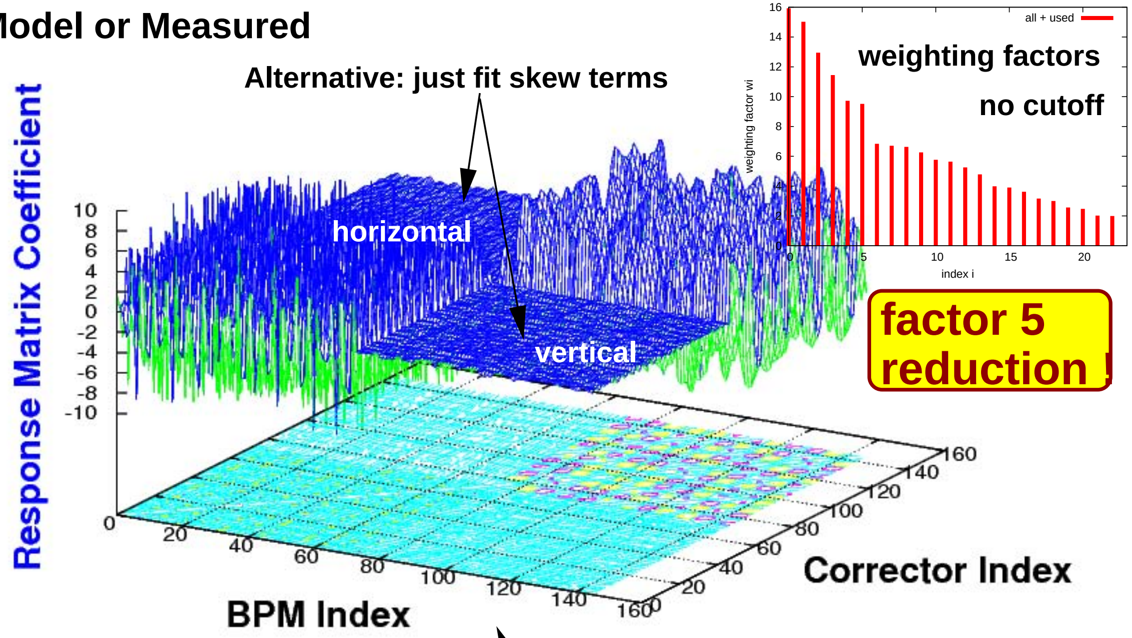


SR - Betatron Coupling Correction

skew quad #1 dk
skew quad #2 dk
skew quad #3 dk
skew quad #n−1 dk
skew quad #n dk (SLS: 24)

Corrector Index x+y
BPM Index x+y
Coupled Orbit Response Matrix
SLS: 146x146

From Model or Measured



BPM Index x+y | Corrector Index x+y

skew quad #1−#n dk

Skew Quad − Coupled Orbit Response Matrix

SLS: 24 x (146x146=21316) = 511584 coefficients

SLS Alternative: 24 x (73x73=5329) = 127896 coefficients

- measure the Orbit Response Matrix
- invert 24 x 21316 Matrix using SVD
- plug ORP into the "inverted" Matrix
- calculate quadrupole variations dk_i which fit the model best to the Orbit Response Matrix
- *iterate within model for large errors*
- apply −dk_i to the machine in order to correct the betatron coupling.

SR - Dispersion/Betatron Coupling Correction

Dispersive and non-dispersive Skew quads

h_{00101}
⇨ Q_y ⇨ η_y

h_{10100}
⇨ $Q_x + Q_y$

h_{10010}
⇨ $Q_x - Q_y$

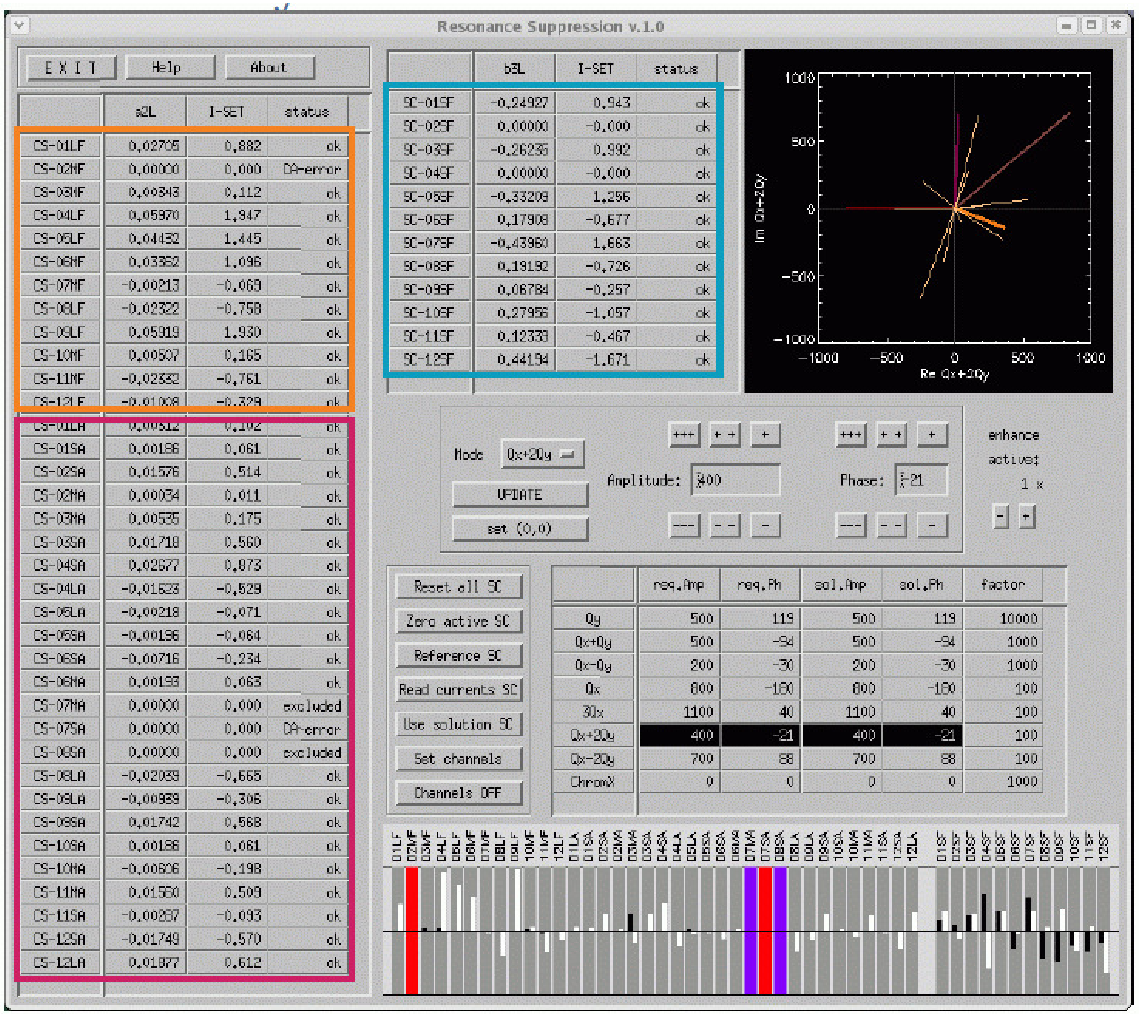
Sextupoles

h_{21000}
⇨ Q_x

h_{30000}
⇨ $3Q_x$

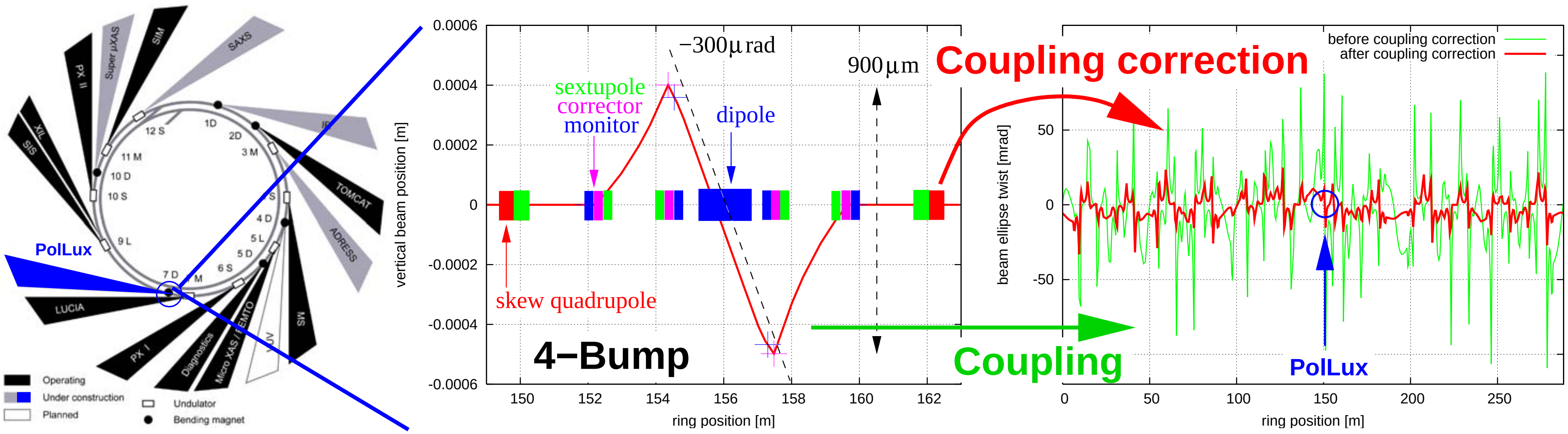
h_{10200}
⇨ $Q_x + 2Q_y$

h_{10020}
⇨ $Q_x - 2Q_y$



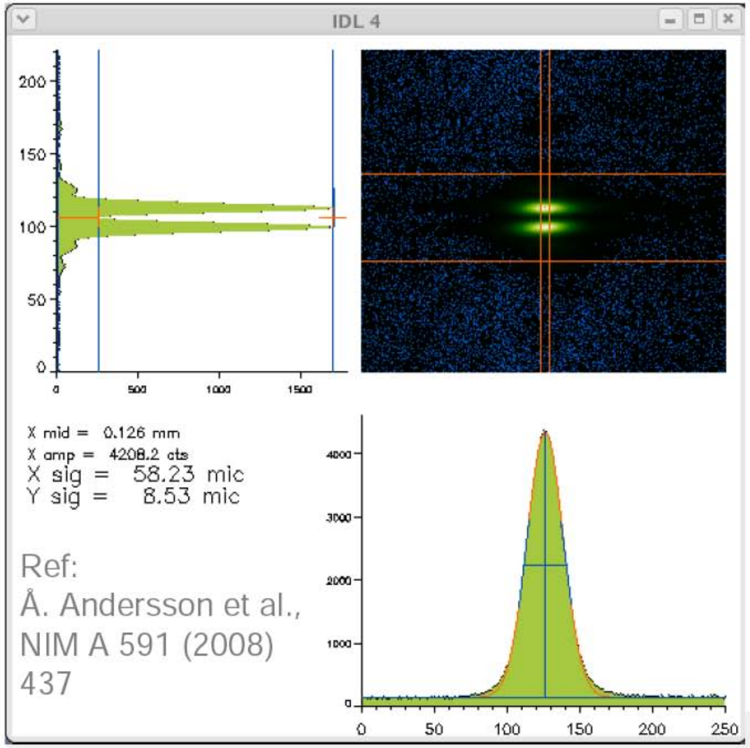
Empirical Optimization of skew quads by mini–mization of driving terms in the hamiltonian by observing beamsize over lifetime. (court. A. Streun)

SR - Betatron Coupling Feed-Forward

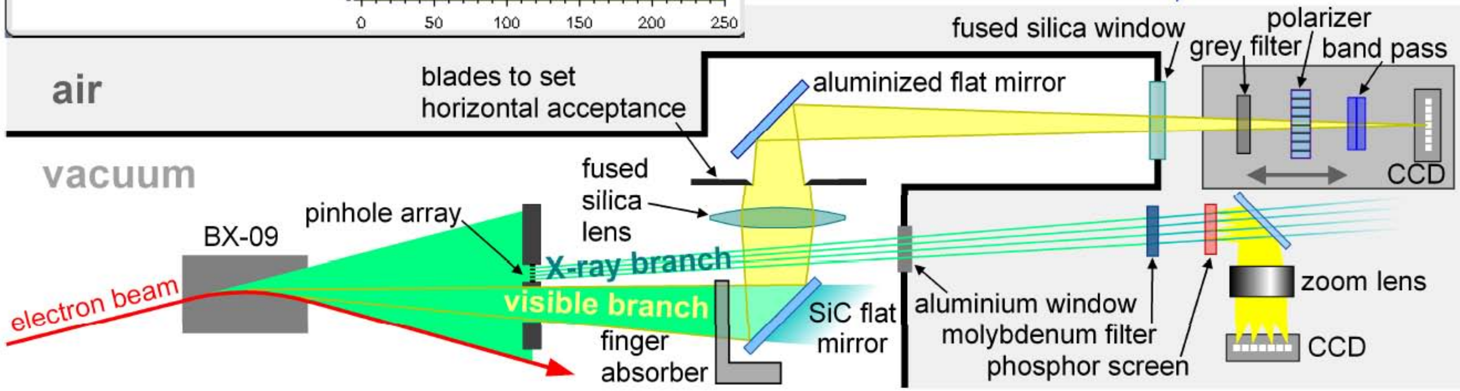


- **Left:** Layout of the vertical asymmetrical "polarization" bump consisting of four successive dipole correctors (magenta bars) for the dipole (thick blue bar) beamline PolLux. Dedicated skew quadrupoles (red bars) are used to locally compensate for the betatron coupling induced by the sextupoles (green bars) within the bump (→coupling feed-forward).
- **Right:** Twist of the electron beam ellipse as a function of the longitudinal SLS storage ring position for a -300 μrad steering for the PolLux beamline before (green line) and after (red line) betatron coupling correction. The arrow denotes the location of the 4-bump for the PolLux beamline.
- The 4-bump is implemented as a reference change of 2 BPMs within the framework of the Fast Orbit Feedback with a feed-forward table for the skew quadrupoles ($<$ 2 Hz switching frequency).

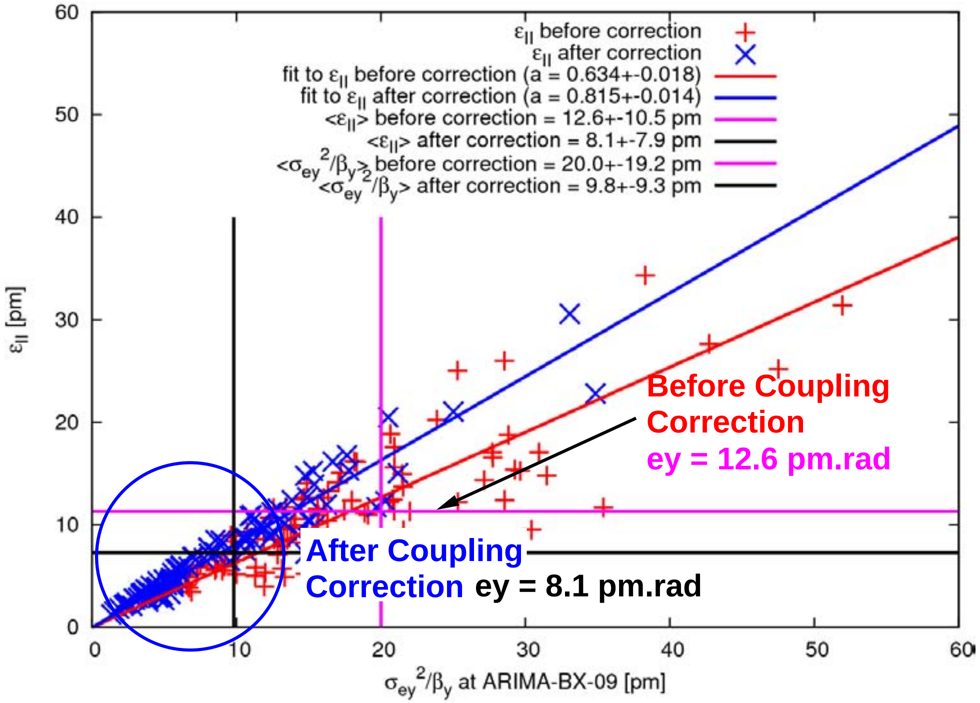
SR - Emittance (Sigma) Coupling Monitor

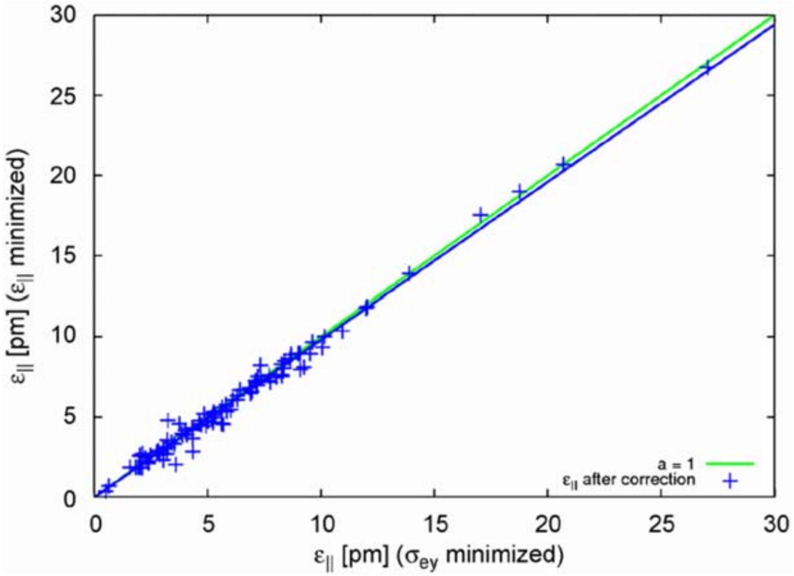


- An important instrument for optics correction: the beam size monitor
- ➢ vertically polarized, near-UV (384 nm) synchrotron light
- ➢ better resolution than X-ray pinhole array monitor
- ⇨ control of coupling
- ⇨ optimization of Touschek lifetime → T/σ_y !



SR - Sigma and Emittance





- Does the minimization of the beam size σ_y @ one dipole imply the minimization of the emittance ϵ_y ?
  Yes, at least for a small number of skew quadrupoles (22 skew quads, simulation for 100 seeds) → left plot !
- Is it equivalent to minimize the beam size σ_y instead of the emittance ϵ_y ?
  Yes, it nearly is (22 skew quads, simulation for 100 seeds) → right plot !

SR - Dispersion/Betatron Coupling Correction - Summary

1. Suppression of η_y by 12 $\eta_x > 0$ skew quads:
   η_y from off-momentum orbit measurement and SVD fit
2. Suppression of $Q_x \pm Q_y$ by 24 $\eta_x = 0$ skew quads.
   response matrix measurement and SVD fit using model RM
3. \+ some empirical tuning of skew-quad Hamiltonian modes
   h_{00101} , h_{10100} and h_{10010}
   for best ratio $T/\sqrt{\varepsilon_y}$

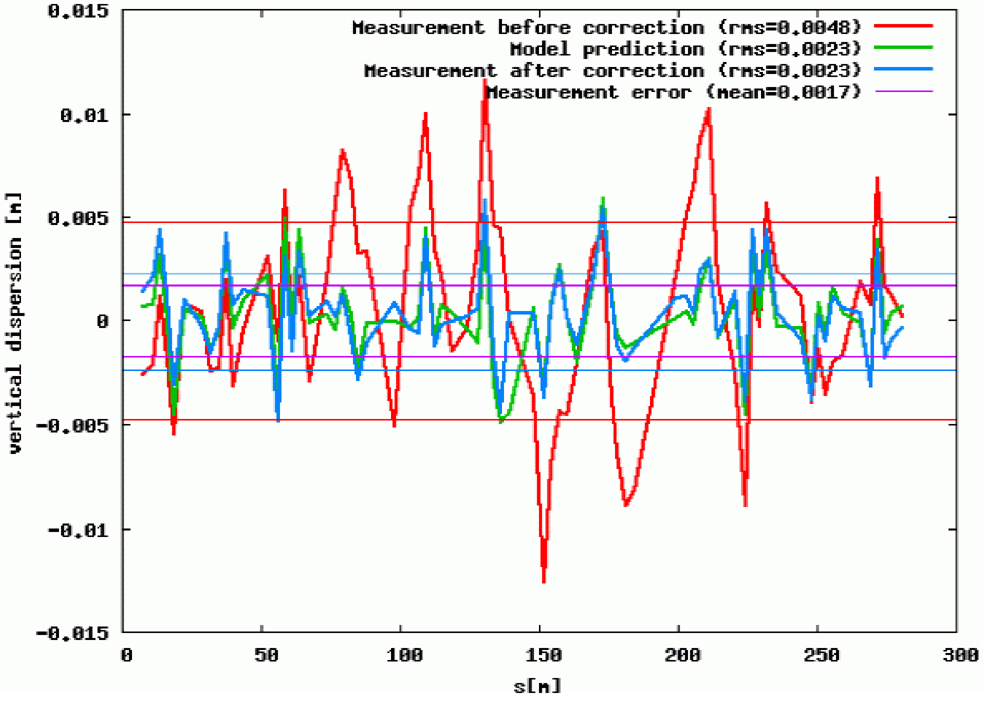
➔ lowest V-emittance:

$\varepsilon_y = 2.8\ (\pm\ 0.4)$ pm rad

$= 5 \times \varepsilon_{yo}$ from $1/\gamma$

$= 0.05\%$ of ε_x

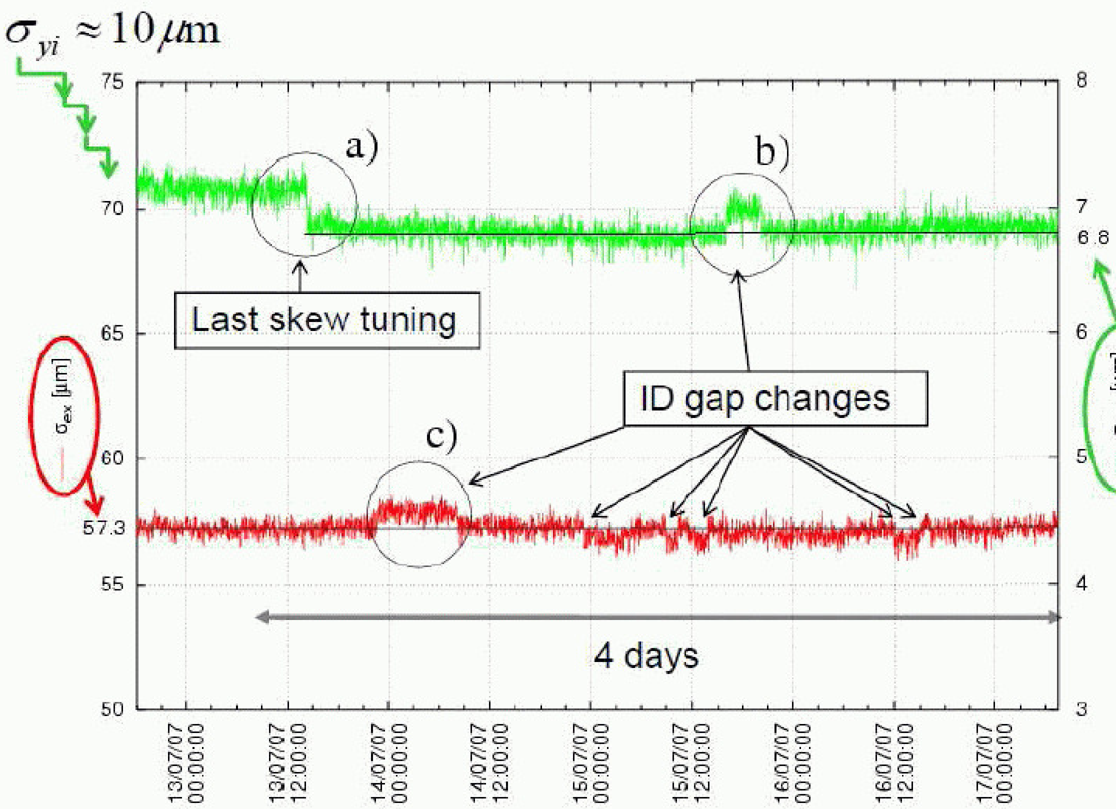
➔ option: η_y-wave to adjust $\varepsilon_y \leftrightarrow T$ on $T \propto \sqrt{\varepsilon_y}$ scaling curve



SR - Sigma and Emittance - Operation

Åke Andersson, CLIC workshop, Oct.16, 2008:

ε_y reduction in user top-up operation, I=400mA



$\beta_y = (13.55 \pm 0.14)\,\mathrm{m}$

$\eta_y = (2.3 \pm 0.55)\,\mathrm{mm}$

$\varepsilon_y = (3.2 \pm 0.7)\,\mathrm{pm}$

$\frac{\varepsilon_y}{\varepsilon_x} = (0.05 \pm 0.02)\,\%$

$\beta_x = (0.431 \pm 0.009)\,\mathrm{m}$

$\eta_x = (27.3 \pm 1.0)\,\mathrm{mm}$

$\varepsilon_x = (6.3 + 0.7 - 0.9)\,\mathrm{nm}$

SR - Lattice Errors - Sources of Vertical Emittance II

For randomly distributed alignment errors, the vertical dispersion makes a contribution to the vertical emittance, given by:

$$\varepsilon_y = 2J_\varepsilon \frac{\langle \eta_y^2 \rangle}{\langle \beta_y \rangle}\sigma_\delta^2 \qquad 1)$$

Vertical dispersion, in turn, is generated entirely by COD and skew quads:

$$\eta_y(s) = \frac{\sqrt{\beta_y(s)}}{2\sin(\pi\nu_y)} \int_s^{s+C} F(s')\sqrt{\beta_y(s')} \cos\left[\phi(s') - \phi(s) - \pi\nu\right] ds' \qquad 2)$$

with

$$F(s) = (K + S\eta_x)\, y_c - K_{sq}\eta_x + G_y$$

where K, S, K_{sq} and G_y are the normal quad, sextupole skew quad strengths and vertical steering respectively and y_c is the closed orbit displacement

- Term $K + S\eta_x$ related to local chromaticity ξ ($\approx$0 for corrected local ξ).
- Term $G_y \approx 0$ for well (to centers of quadrupoles) corrected y_c.
- Term $K_{sq}\eta_x$ is small since the quadrupole roll errors are small.
- Local ξ ONLY ≈ 0 if y_c is corrected in quadrupoles and sextupoles simultaneously !

SR - Lattice Errors - Sextupole Beam-Based Alignment I

- With stable orbit, measure beam position with BPMs where individual magnet strength changes has a null effect
- Gradient error from sextupoles is source of DA reduction, so ideal would be to align to sextupole magnetic centers
- First order effect is a tune shift due to gradient

$$\Delta Q_x \approx \frac{1}{4\pi}\beta_x(s)(K_2 L)x = \frac{1}{2\pi}\beta_x(s)(b_3 L)x$$

$$\Delta Q_y \approx \frac{1}{4\pi}\beta_y(s)(K_2 L)x = \frac{1}{2\pi}\beta_y(s)(b_3 L)x$$

Courtesy: S.L. Kramer, NSLS–II

No tune shift with y coordinate except through coupling

Resolution of tune shift dependent on energy spread and chromaticity, at best <30µm

Synchro-betatron coupling could easily increase resolution to ~100µm

M. Kikuchi, et.al. (KEK), introduced gradient coils to shift orbit rather than tunes

SR - Lattice Errors - Sextupole Beam-Based Alignment II

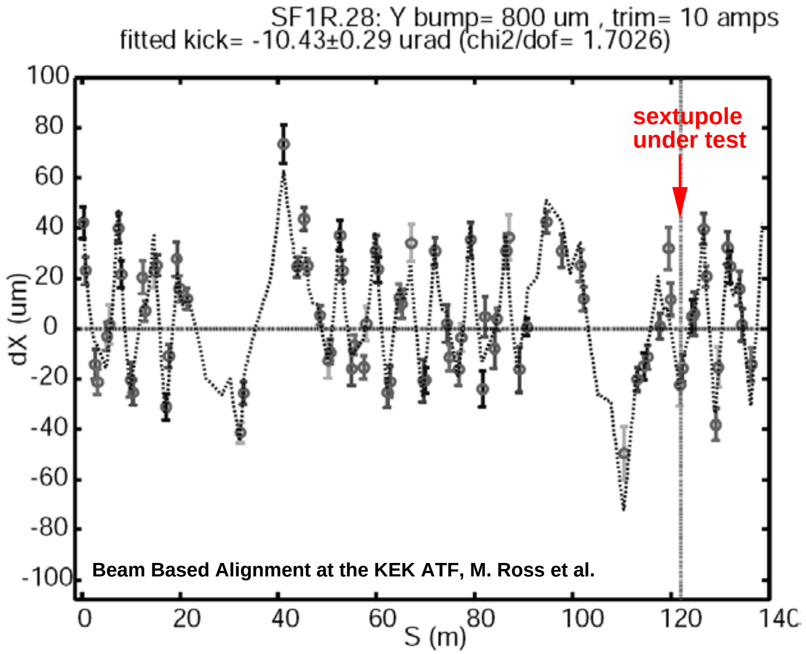


Figure 3. Example orbit with the superimposed fit. The dashed line shows the location of the sextupole under test.

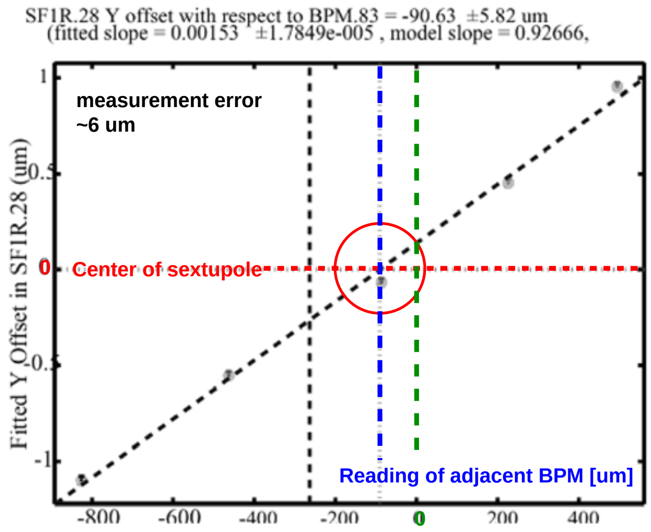
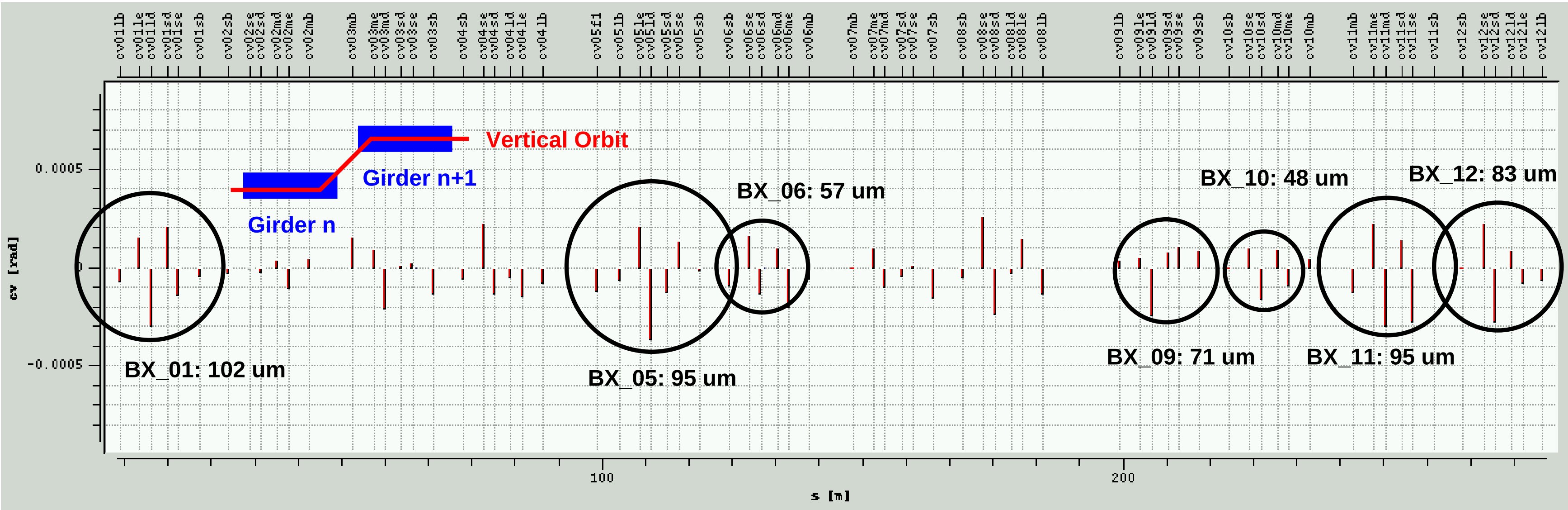


Figure 4: Fitted offsets, derived from trim kicks, as a function of the reading in the nearby BPM. The reported error in the intercept is 6 microns.

- At KEK ATF skew quadrupole trims (K=0.01 m^{-1}) on the sextupoles were used (sextupole center = skew quad center). The kick induced by the offset of the beam in the skew quad is determined from the difference orbit using the machine model. This fit is done for several closed orbit bump amplitudes at the location of the sextupole under test. At the SLS 36 out of 120 sextupoles are equipped with auxiliary skew quadrupoles (K=0.03 m^{-1}) for betatron coupling and dispersion correction.

SR - Lattice Errors - Girder Re-alignment



- Corrector Pattern can be used to determine alignment errors (→No Cutoff).
- Prominent girder-girder alignment errors related to local corrector patterns (circles).
- Girder-girder errors introduce mechanical steps driving the adjacent correctors.
- Leads to saturation of correctors in machines with large alignment errors (→Eigenvalue Cutoff = “Long Range Correction”).
- →Beam-based girder alignment (magnets on girders as super-correctors).