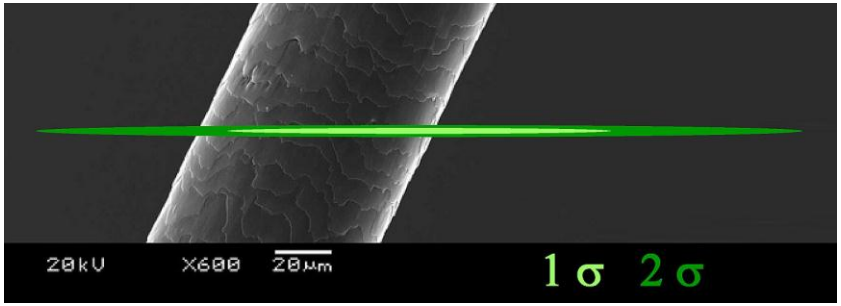
PAUL SCHERRER INSTITUT

SWISS LIGHT SOURCE

Reaching ultra-low emittance at SLS through (systematic and) random optimization

LCWS 2012
Joint CLIC/ILC Working Group – Damping Rings session
25.10.2012

M. Aiba, M. Böge, N. Milas, A. Streun, PSI



Introduction

- Vertical emittance minimization is motivated by:
  - increase of brightness and transverse coherence
  - operational margin for small gap insertion device (possibly even smaller undulator gap)
  - TIARA* WP6 SVET (SLS Vertical Emittance Tuning)
    - Collaboration: CERN / INFN / PSI+Maxlab
    - Establish VET means at SLS, for CLIC DR and SuperB
      - Fine corrections of betatron coupling and η_y
      - Maintaining small emittance during operation
    - Beam size monitor R&D → Natalia Millas' talk
    - Intra Bunch Scattering studies → Fanouria Antoniou's talk

* http://www.eu-tiara.eu/

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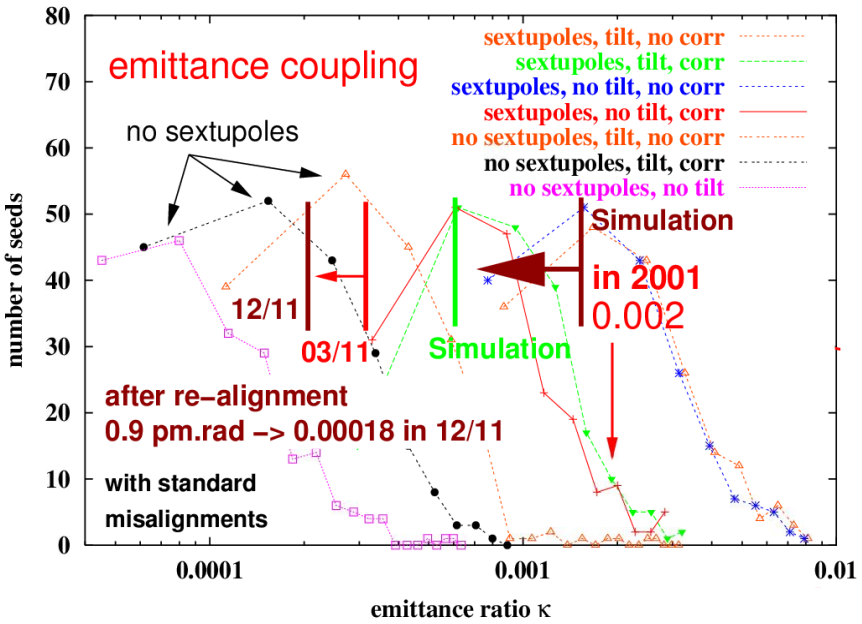
SLS vertical emittance

- What was expected and what is achieved



Emittance ratio ≡ $\varepsilon_v/\varepsilon_h$

ε_h~ 5 nm

(Insertion devices off)

  - Better emittance ratio than expected, thanks to
    - 30 more skew quads installed (6 skew quads initially)
    - Better alignment on girder than expected

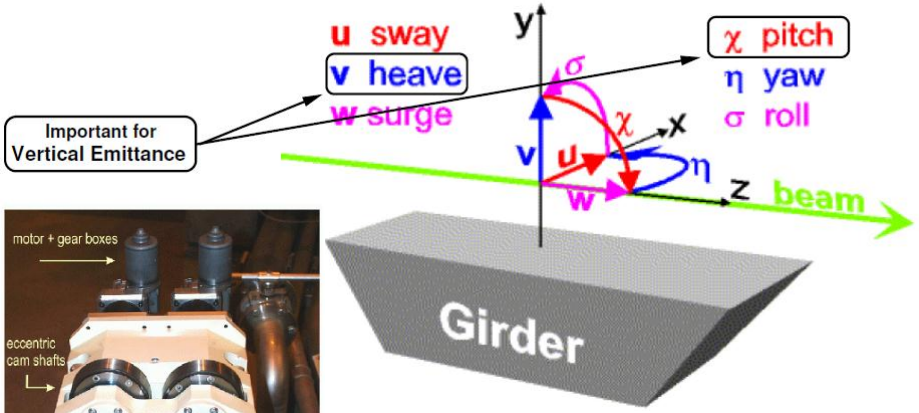
} 1.8 pm in March 2011

    - Girder realignment in 2011
    - Elaborated model based corrections
    - Random optimization

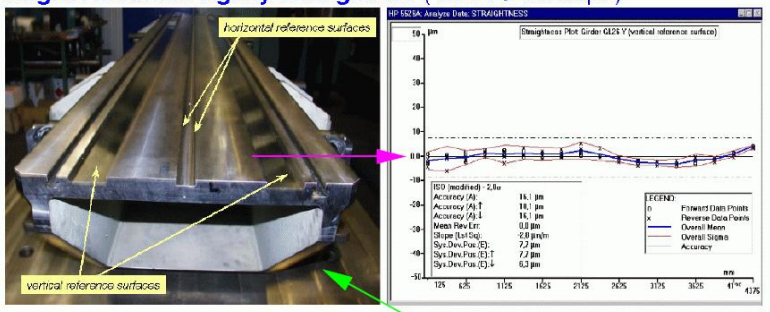
} Application of these methods achieved 0.9 pm!

Key component 1

- Magnet girder

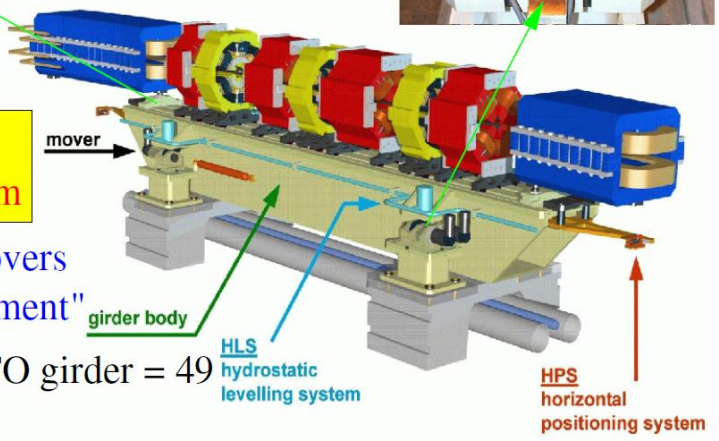


Magnet mounted rigidly onto girders ("MAX-2 concept")



Girders movable in 5 degrees of freedom

Position monitoring systems on girders



Girder Rail Precision: 15 µm
Magnet Axis Calibration: 30 µm

Remotely Controlled Girder Movers
–> "Beam–Based Girder Alignment"

12 sectors x 4 girders + 1 FEMTO girder = 49

Key component 2

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**

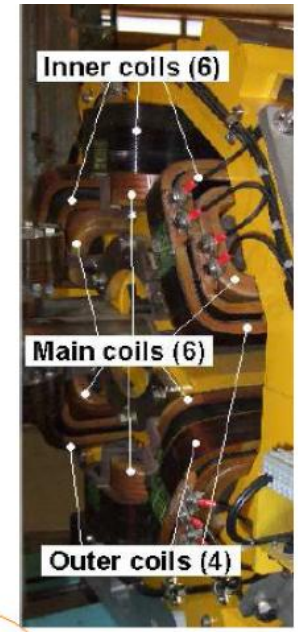
SSA(12), SSB(12), SMA(6), SMB(6), SLA(6), SLB(6) → **D.A.**

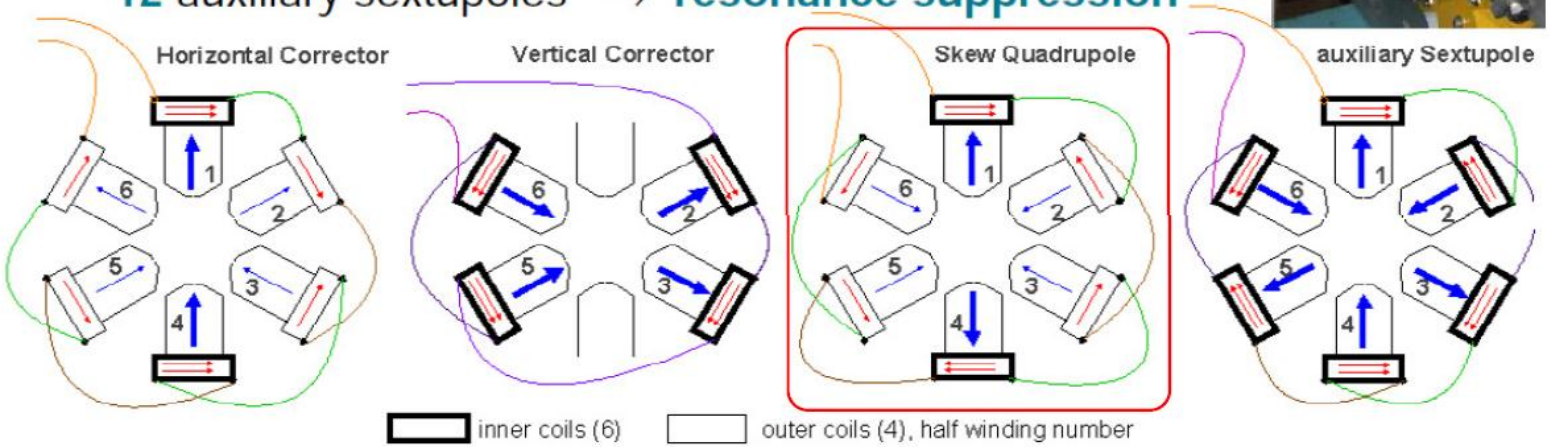
SD, SE, S∗B: **72** H&V correctors → **orbit correction**

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

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

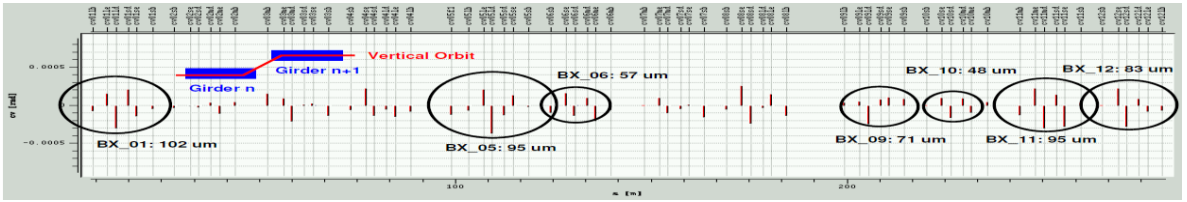
12 auxiliary sextupoles → **resonance suppression**



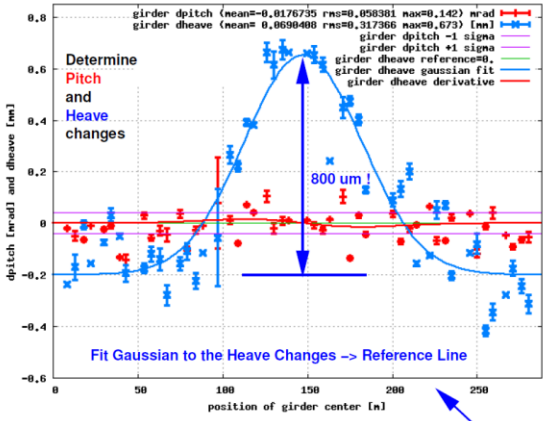


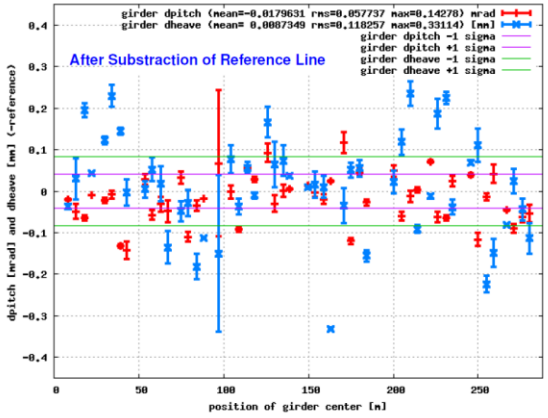
Girder realignment
Motivation and approach

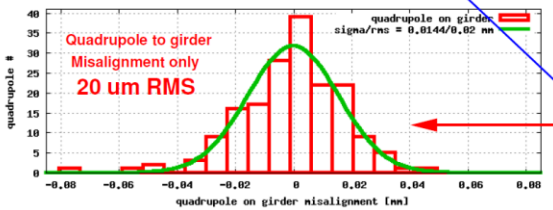
Girder discontinuity estimation from "corrector pattern" →



Survey data from 2010 and analysis







Vertical Quadrupole Alignment Data from 2010 (Courtesy K.Dreyer et al) !

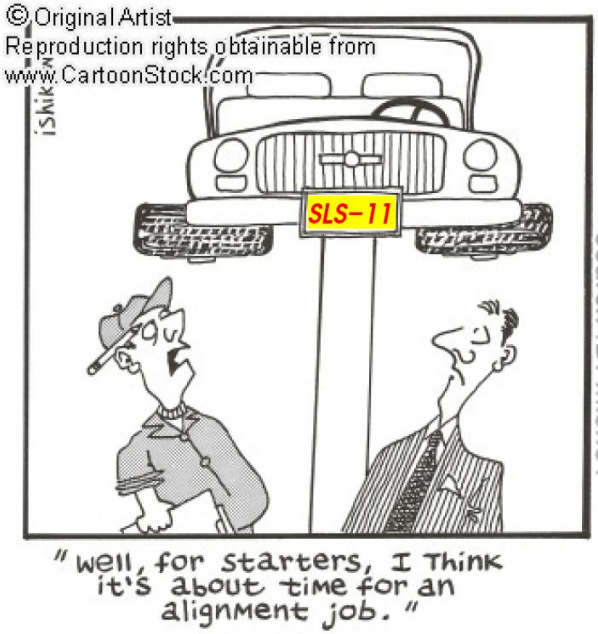
Girder Fit to Quadrupole Misalignments

Determine Pitch and Heave Changes

Determine Quadrupole to Girder Misalignment

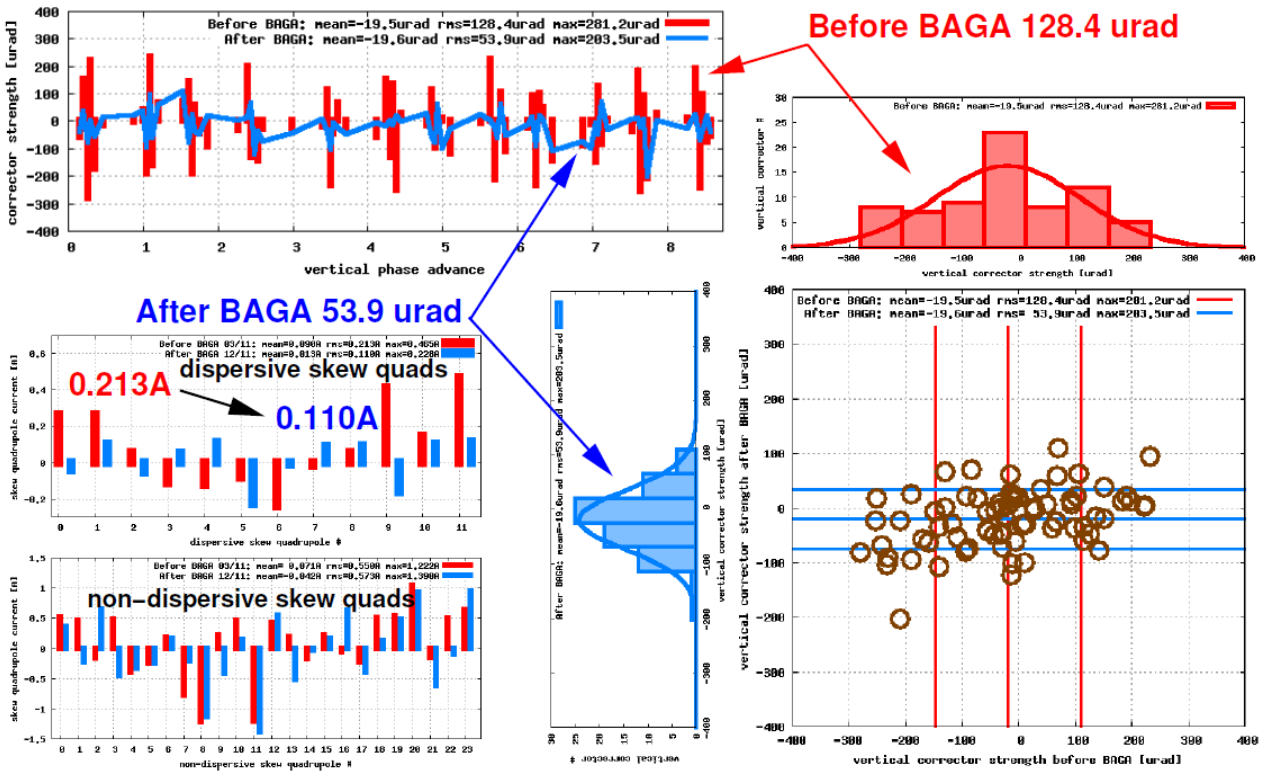
Adjust Girders to Reference Line With Beam and Fast Orbit Feedback On !

Beam Assisted Girder Alignment



- BAGA (Beam Assisted Girder Alignment)
  - Remotely align girders based on survey data
  - Confirm the result online with beam and fast orbit feedback running

Girder realignment result



BAGA resulted in:

-Gaussian like corrector kick distribution

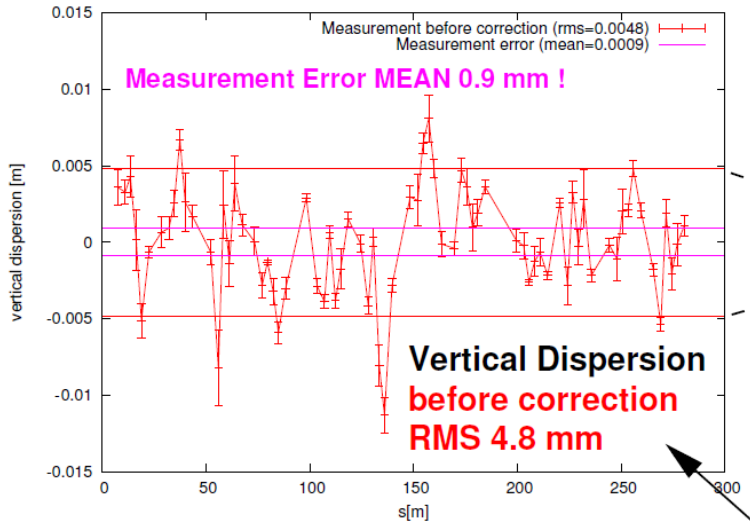
-About half corrector kick

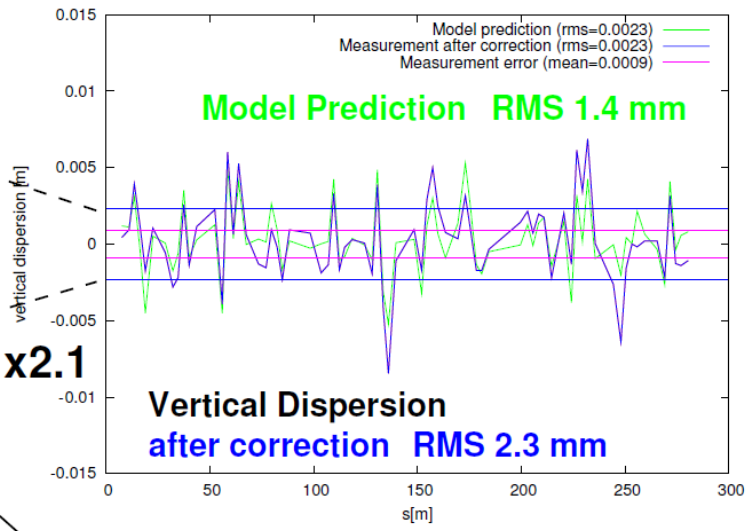
-About half dispersive skew correction

-Similar non-dispersive skew correction

Model based correction 1

Dispersion Correction





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

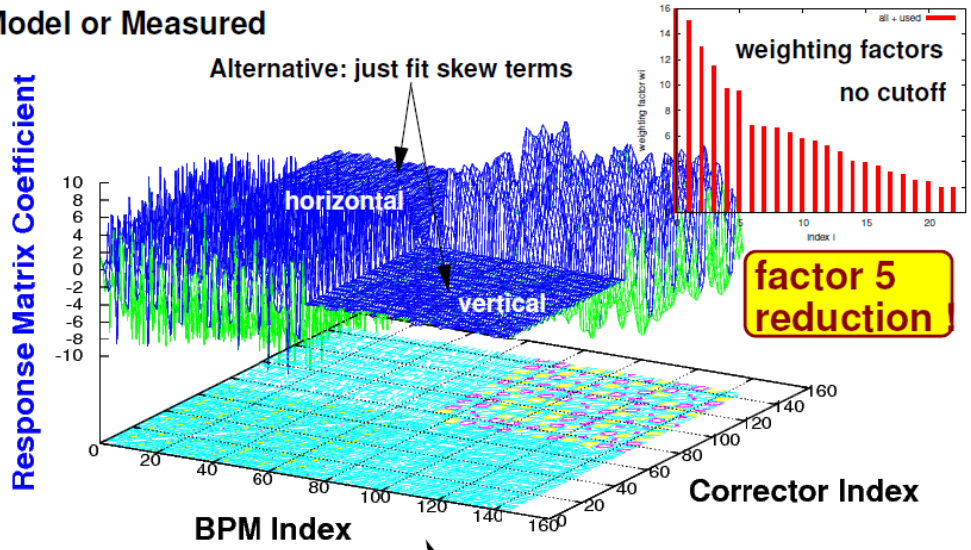
Model based correction 2

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

Alternative: just fit skew terms



skew quad #1–#n dk
BPM Index x+y
Corrector Index x+y
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 ORM 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.

* Contribution of BPM tilts subtracted

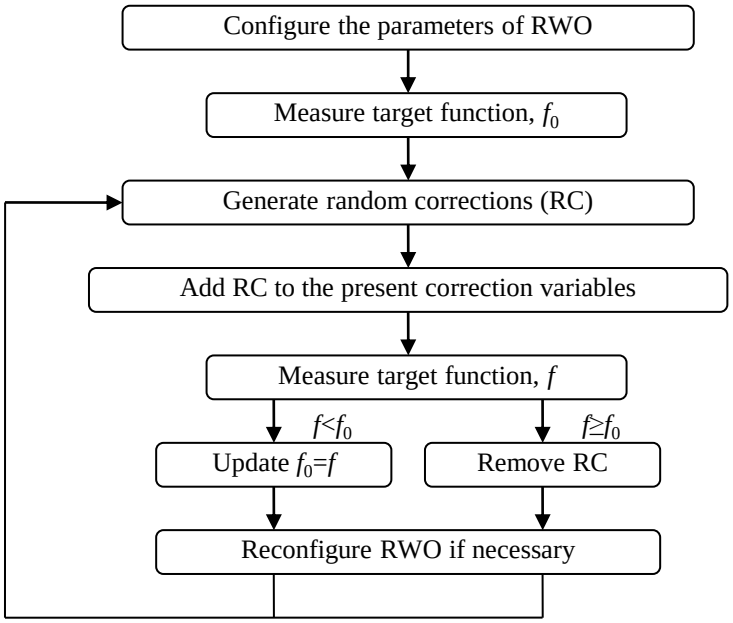
Random optimization*

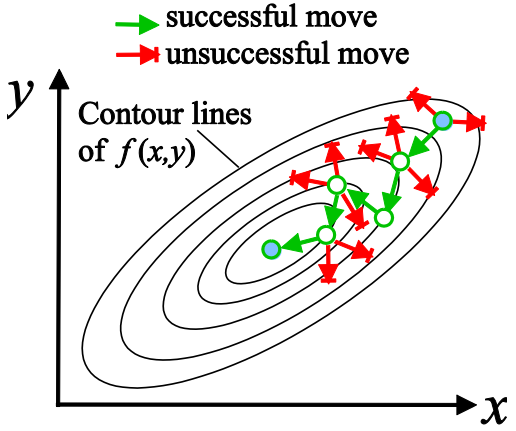
- Limitations in model based corrections…
  - Beam measurement errors
  - Model deficiencies
- Multi-variable optimization
  - Random optimization would be the best algorithm
    - Model independent correction
    - The curse of dimensionality is avoided (#Knobs=12/24/36)
    - The optimum solution is within “walking-distance” after systematic correction
    - Minimal effort to implement
    - Potential of online optimization, i.e. keeping small emittance during the operation
    - NB: the optimization needs a target function, which is the measured vertical beam size in our case

* J. Matyas, “Random Optimization”, Automation and Remote Control 26 (2) (1965) 246.
Note: “Random optimization” seems more accepted word than “Random walk optimization”

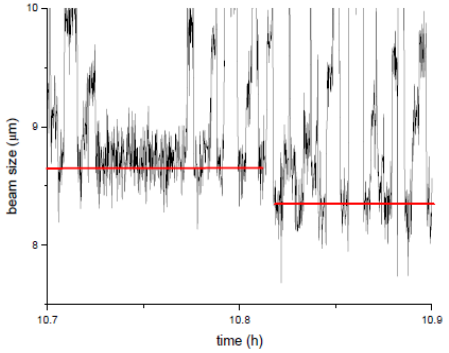
How it works

Flowchart



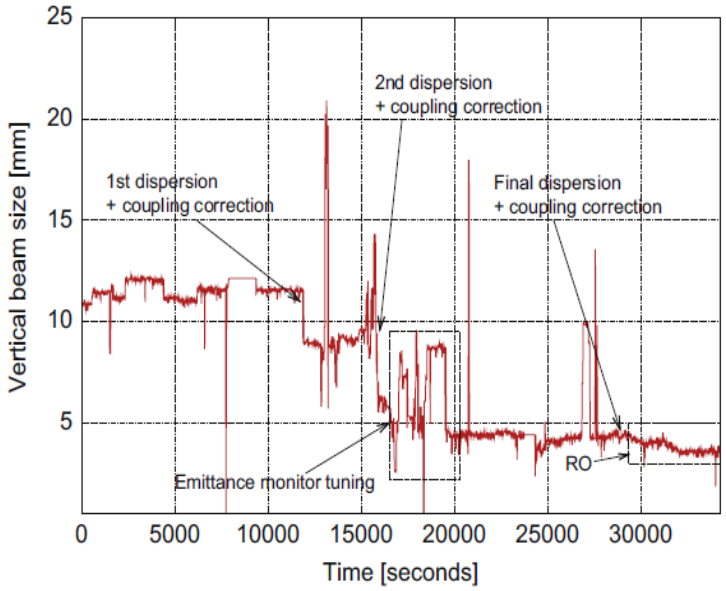


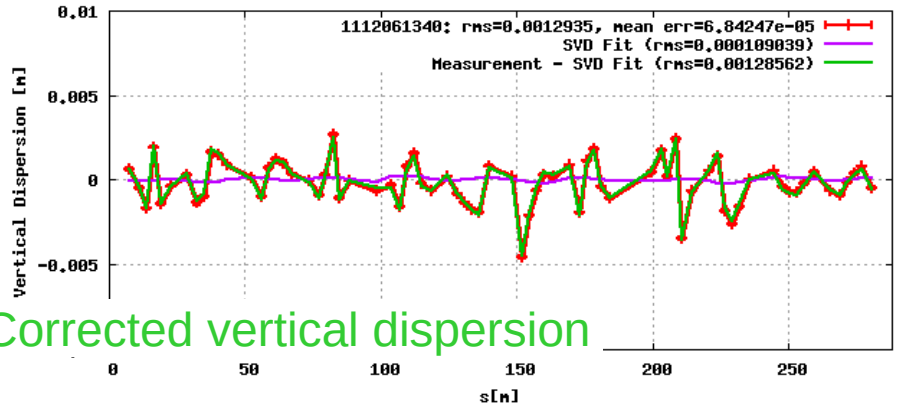
Typical successful step (Figure from first test)



MD on 6th Dec. 2011*

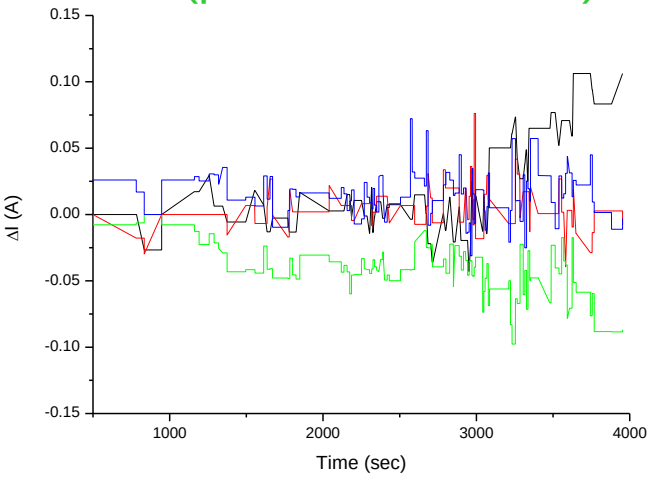
Beam size measurement during MD





Corrected vertical dispersion

ND skew Q currents during RO (plotted 4 out of 24)



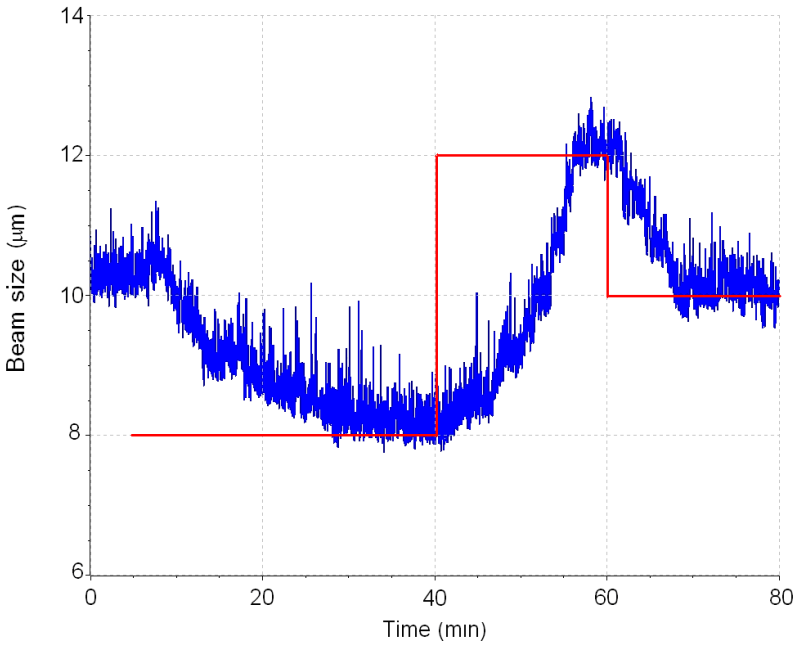
- First dedicated MD after BAGA
  - η_y~1.3 mm rms with model based correction!
  - ε_y~1.2 pm at the end of model based correction
  - ε_y~0.9±0.4 pm with RO in addition!
    (Only ND skew quads were optimized)
  - Better coupling correction with RO was confirmed with ORM before and after

M. Aiba, M. Böge, N. Milas and A. Streun, NIM A 694 (2012) 133–139

Demonstrations

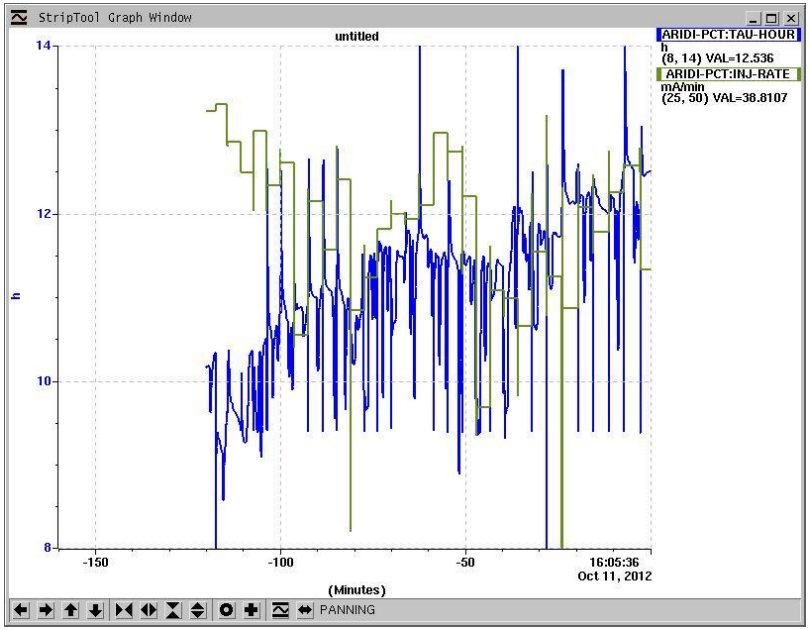
- Automated ROs

Beam size control with RO



Vertical beam size:
Measured and Requested

Lifetime optimization



Lifetime and Injection rate

Vertical beam size is detuned for demonstration purpose to create a room of lifetime improvement

Summary and outlook

- Ultra low vertical emittance of 0.9 pm is achieved at the SLS !
  - BAGA + Model based corrections + RO
- RO
  - Successfully demonstrated, a good performance booster
  - Potential for online optimization (like feedback)
- Even smaller vertical emittance is expected
  - Iteration/elaboration of BAGA
  - New monitor with better resolution
  - More knobs: Dispersive skews

    Orbit manipulation →Simone Liuzzo's talk