Experience with Low Emittance Tuning tool for SuperB, Diamond, SLS, and DAΦNE

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SuperB design is based on very low emittances

HER e^+

$$\epsilon_x = 2\, nm\, rad$$
$$\epsilon_y = 5\, pm\, rad$$

LER e^-

$$\epsilon_x = 2.5\, nm\, rad$$
$$\epsilon_y = 6.2\, pm\, rad$$

Studies of alignment tolerances are necessary

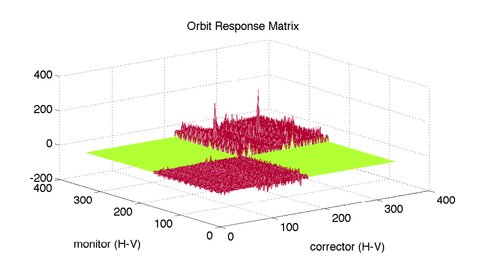
A tool for tuning very low emittance has been developed

Response Matrix

Response Matrix:
$M \times N$ matrix that determines
the change of the i^{th} BPM due to the j^{th} corrector

$$\vec{R} = \mathcal{M}\,\vec{K}$$

- $\vec{R}$ BPM readings (M)
- $\vec{K}$ kick vector (N)
- $\mathcal{M}_{i,j} = \frac{\Delta R_i}{\Delta K_j}$



Using Singular Value Decomposition
$svd(\mathcal{M}) = TSV^t$

$$\vec{R} + \mathcal{M}\,\vec{K} = \vec{0}$$

$$\vec{K} = -VS^{-1}T^t\vec{R}$$

Correctors minimization $\vec{K} = -VS^{-1}T^t(\vec{R} + \mathcal{M}\vec{K}_0)$

LET Coupling Free Steering

New scheme adds to the quantities to be corrected DISPERSION, COUPLING and β-BEATING

$$\eta = \frac{\vec{y}_{+\Delta E} - \vec{y}_{-\Delta E}}{2\Delta E} \quad \vec{C} = \frac{\vec{x}_{+\Delta V} - \vec{x}_{-\Delta V}}{2\Delta V} \quad \vec{\beta} = \frac{\vec{x}_{+\Delta H} - \vec{x}_{-\Delta H}}{2\Delta H}$$

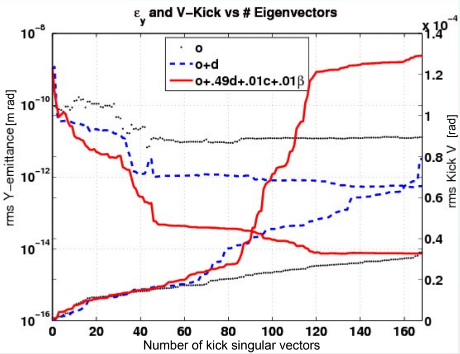
$$\begin{pmatrix} (1-\alpha-\omega)\vec{P} \\ \alpha\vec{\eta} \\ \omega\vec{C} \\ \omega\vec{\beta} \end{pmatrix} = \mathcal{M} \begin{pmatrix} \vec{K} \\ \vec{K_s} \\ \vec{T} \end{pmatrix}$$

it is necessary to measure more quantities and the response matrix becomes very large $\Rightarrow$ SIMULATED MATRIX

need to optimize relative weigths α and ω and SVD parameters

SVD tuning and corrections comparison

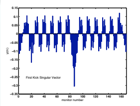
SVD($\mathcal{M}$), we obtain kick eigen-vectors $\vec{v}$ and monitor readings $\vec{u}$, related by: $\mathcal{M}\vec{v} = \sigma\vec{u}$.



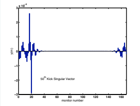
SuperB HER ϵ_y vs number of kick eigenvectors used in the correction

Coupling Free Steering correction works better!

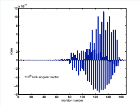
optimum truncating at 65-80 eigenvectors



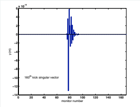
1^{st} ($\sigma \sim 10^{-1}\, m$)



50^{th} ($\sigma \sim 10^{-3}\, m$)



110^{th} ($\sigma \sim 10^{-4}\, m$)

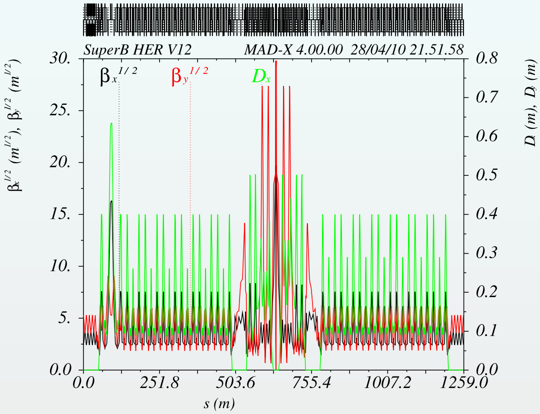


160^{th} ($\sigma \sim 10^{-5}\, m$)

eigenvectors ordered for decreasing eigenvalue σ. small σ contribute with localized bumps

LET Tool simulations

SuperB Arcs + 168 Dipole Correctors + 168 BPMs + 60 BPM and correctors in the FF with final doublet rigidly misaligned



Response matrices simulated with MADX for lattice without misalignments

SuperB Tolerance estimate

Before Correction

SuperB HER V12 Arcs

Quadrupoles

$[0\ 300]\,\mu m\ \ \Delta H,\ \Delta V$

$[0\ 300]\,\mu rad\ \ \Delta\phi$

Sextupoles

$[0\ 300]\,\mu m\ \ \Delta H,\ \Delta V$

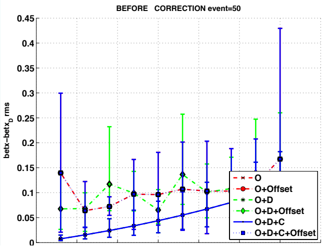
BPM Offsets

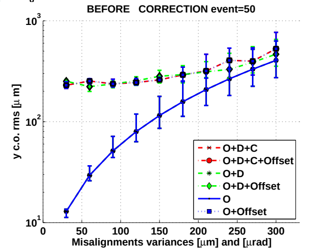
$[0\ 300]\,\mu m$

168 H-V correctors

168 H-V BPM

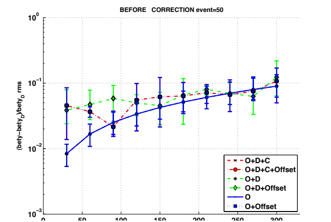
$$\sqrt{\langle(\frac{\beta_x-\beta_{x0}}{\beta_{x0}})^2\rangle}$$

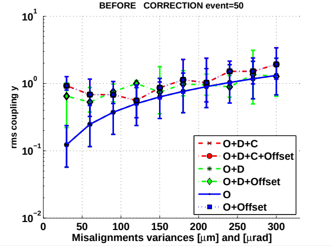




$$\sqrt{\langle(y)^2\rangle}$$

$$\sqrt{\langle(\frac{\beta_y-\beta_{y0}}{\beta_{y0}})^2\rangle}$$





$$\sqrt{\langle(r_{12})^2\rangle}$$

SuperB Tolerance estimate

After Correction

SuperB HER V12 Arcs

Quadrupoles

$[0\,300]\,\mu m\ \ \Delta H,\,\Delta V$

$[0\,300]\,\mu rad\ \ \Delta\phi$

Sextupoles

$[0\,300]\,\mu m\ \ \Delta H,\,\Delta V$

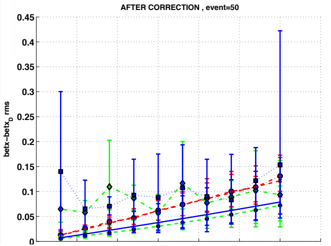
BPM Offsets

$[0\,300]\,\mu m$

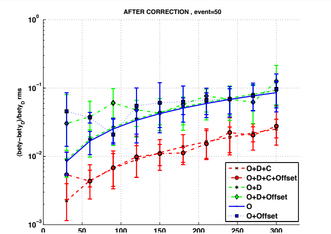
168 H-V correctors

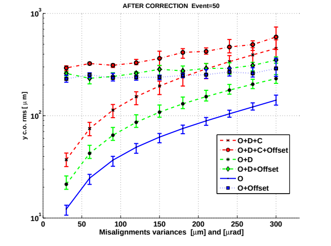
168 H-V BPM

$$\sqrt{\langle(\frac{\beta_x-\beta_{x0}}{\beta_{x0}})^2\rangle}$$

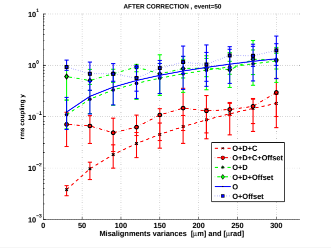


$$\sqrt{\langle(\frac{\beta_y-\beta_{y0}}{\beta_{y0}})^2\rangle}$$





$$\sqrt{\langle(y)^2\rangle}$$



$$\sqrt{\langle(r_{12})^2\rangle}$$

SuperB Tolerance estimate : ϵ_y vs misalignment

After Correction

SuperB HER V12 Arcs

Quadrupoles

[0 300] μm ΔH, ΔV

[0 300] μrad $\Delta \phi$

Sextupoles

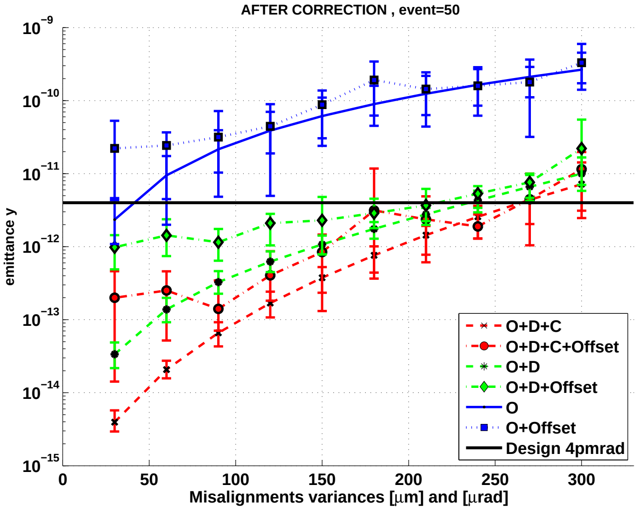
[0 300] μm ΔH, ΔV

BPM Offsets

[0 300] μm

168 H-V correctors

168 H-V BPM



Tolerances

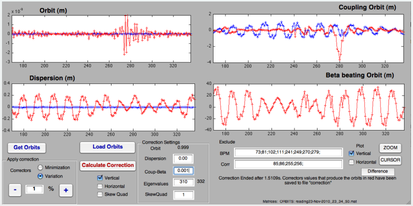
With LET tool Tolerances have been estimate for SuperB Rings

rms misalignment	LER e^-			HER e^+		
	ARCS only	**ARCS**+FF	ARCS+**FF**	ARCS only	**ARCS**+FF	ARCS+**FF**
BPM offset	200 μm	50 μm	20 μm	400 μm	- μm	- μm
quadrupole vertical	200 μm	50 μm	20 μm	300 μm	- μm	- μm
quadrupole horizontal	200 μm	50 μm	20 μm	300 μm	- μm	- μm
quadrupole tilt	200 μrad	50 μrad	20 μrad	300 μrad	- μrad	- μrad
sextupole vertical	100 μm	50 μm	20 μm	150 μm	- μm	- μm
sextupole horizontal	100 μm	50 μm	20 μm	150 μm	- μm	- μm
BPM resolution	1 μm	1 μm	1 μm	1 μm	- μm	- μm

Tolerances Estimate in the FF is in progress

MD shifts+Tool

+



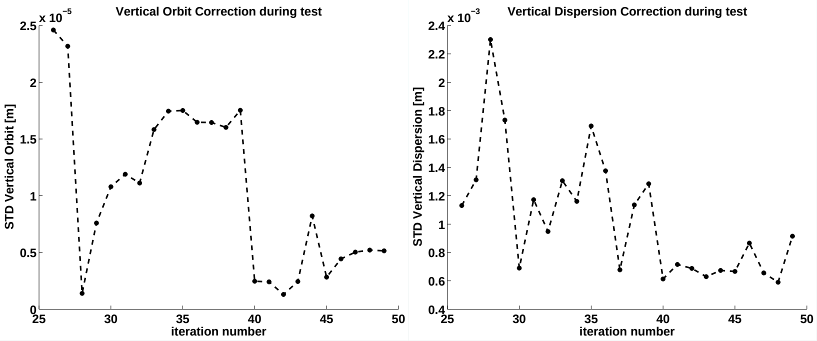
4 MD Shifts to test the LET tool and compare it to LOCO

Correction with Vertical correctors, Skew Quadrupoles, and both.

LOCO $\frac{\epsilon_y}{\epsilon_x} = 0.18\%$
LET $\frac{\epsilon_y}{\epsilon_x} = 0.2\%$

Expected factor 10 NOT observed

some correction reiterations, using skew quadrupoles. $\langle \eta_y^2 \rangle \simeq 600 \mu m$

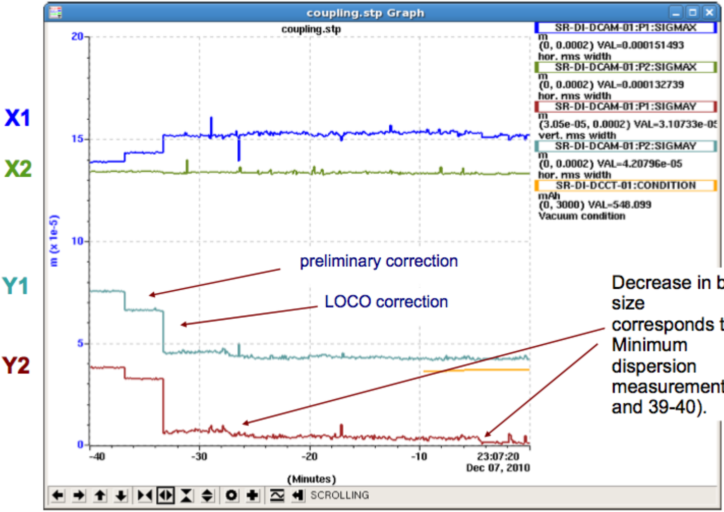


Limits:

- BPM tilts and offsets
- correctors rotations effects
- ecc.

Beam sizes at the two pinhole cameras

During correction with skew quadrupoles



Decrease in beam size corresponds to Minimum dispersion measurements (30 and 39-40).

SLS First Shift

Blue line is vertical beam size. 15 to 10 μm

Correction performed with skew quadrupoles, and/or using Feedback to reproduce the orbit predicted by LET

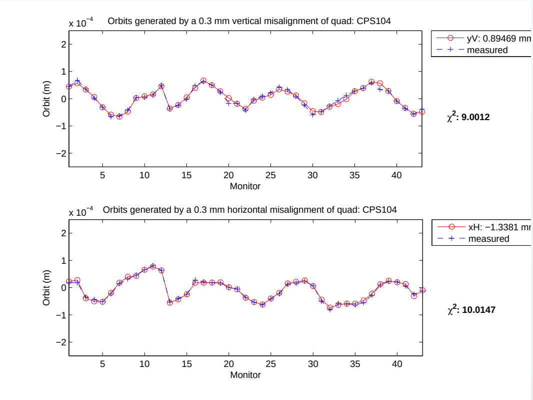
First Tests show that the tool works also for SLS.

Beam Based alignement @ DAΦNE

Currently estimating misalignments. For every quadrupole in the ring:

$$y_m = y_{\Delta H}\, k\Delta H + y_{\Delta V}\, t\Delta V$$
$$x_m = x_{\Delta H}\, k\Delta H + x_{\Delta V}\, t\Delta V$$

- y_m measured orbit
  $\Delta I_q = \pm 1A$
- $x_{\Delta H,\Delta V}$ simulated orbit generated by misalignment
- $\Delta H, \Delta V$ simulated misalignments value
- t, k fit parameters (coupled estimations)

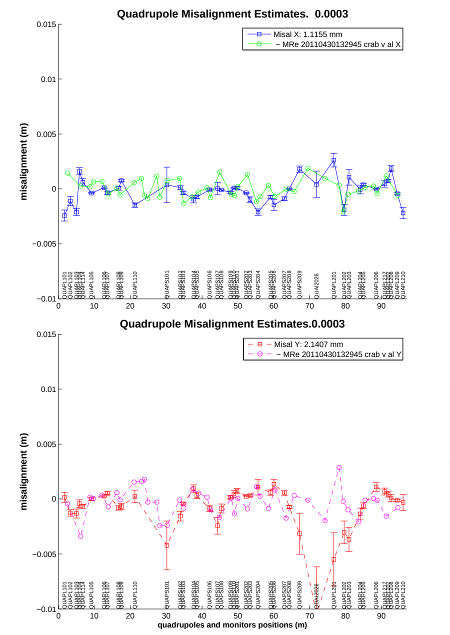


Application of LET tool to DAΦNE to be done in near future

Beam Based Alignment e^- ring

Horizontal

Vertical



before

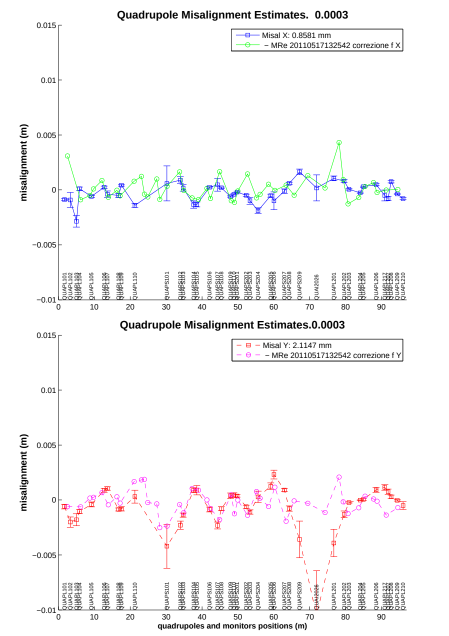
Quadrupoles Alignment esitmate overlapped to the orbit

- 1 cm vertical bump at IP2 wanted
- Physically realigned one quadrupole
- orbit bump at injection
- second measurements with $\Delta I_q = \pm 2A$

Beam Based Alignment e^- ring

Horizontal

Vertical



after

Quadrupoles Alignment esitmate overlapped to the orbit

- 1 cm vertical bump at IP2 wanted
- Physically realigned one quadrupole
- orbit bump at injection
- second measurements with $\Delta I_q = \pm 2A$

Conclusioni

SuperB	Tolerances estimate in progress using LET
Diamond	Comparison of LET to LOCO in progress
SLS	Application of LET tool in progress
DAΦNE	Misalignments estimate done Future application of LET tool