Orbit and dispersion correction in the injector of the European XFEL

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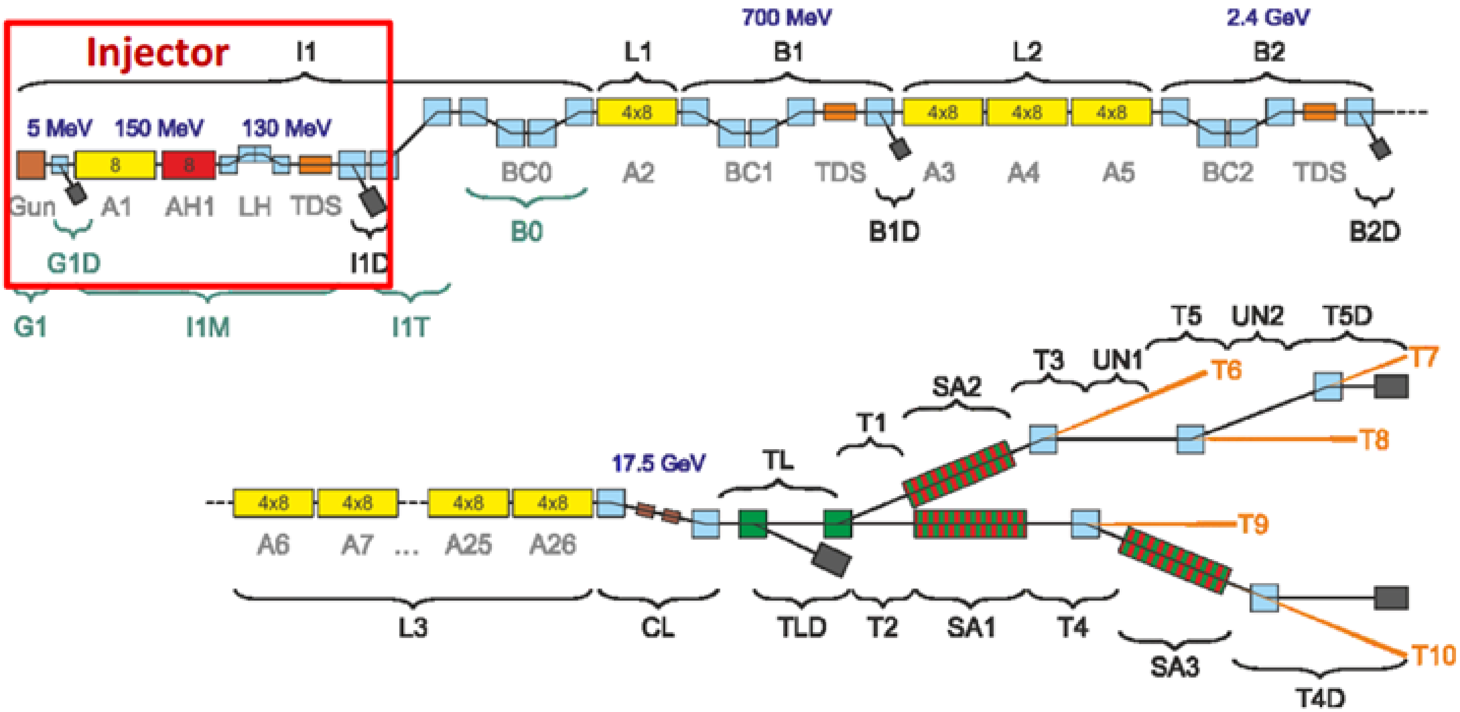
Introduction



Schematic diagram of XFEL

Using elements for correction:

- BPMs - 12
- Horizontal corrector - 7
- Vertical corrector - 8
- Quadrupole mover - 2
- Bending magnets - 2

Dispersion Free Steering Principle and Formalism

$$\Delta\vec{u} = OR \cdot \overrightarrow{\Delta\theta_u} \qquad \Delta\vec{d} = DR \cdot \overrightarrow{\Delta\theta_d} \qquad \begin{pmatrix} (1-\alpha)\cdot\Delta\vec{u} \\ \alpha\cdot\Delta\vec{d} \end{pmatrix} = \begin{pmatrix} (1-\alpha)\cdot OR \\ \alpha\cdot DR \end{pmatrix}\cdot\Delta\vec{\theta}$$

$$\begin{pmatrix} (1-\alpha)\cdot\Delta\vec{u} \\ \alpha\cdot\Delta\vec{d} \\ \vec{0} \end{pmatrix} = \begin{pmatrix} (1-\alpha)\cdot OR \\ \alpha\cdot DR \\ \beta I \end{pmatrix}\cdot\Delta\vec{\theta} \longrightarrow \overrightarrow{\Delta b} = T * \Delta\vec{\theta} \xrightarrow{\text{SVD}} T = U\cdot\Sigma\cdot V^T$$

$\beta \in$ [0-1].is a kick weight

α is a weight factor α= 0, 0.5, 1

$$\Delta\vec{\theta} = V\cdot\begin{pmatrix} \frac{1}{\sigma_1} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \frac{1}{\sigma_N} \end{pmatrix}\cdot U^T\cdot\overrightarrow{\Delta b}$$

Where Σ is an N×M rectangular diagonal matrix containing the singular values of the matrix *T*, with as many non-zero values as the range of *T*. N is monitors and M is correctors. $U_{N\times N}$ and $V_{M\times M}$ are two orthogonal matrices satisfying: $U^{-1} = U^T$ and $V^{-1} = V^T$.

In order to be able to implement the correction algorithms, two matrices are needed:

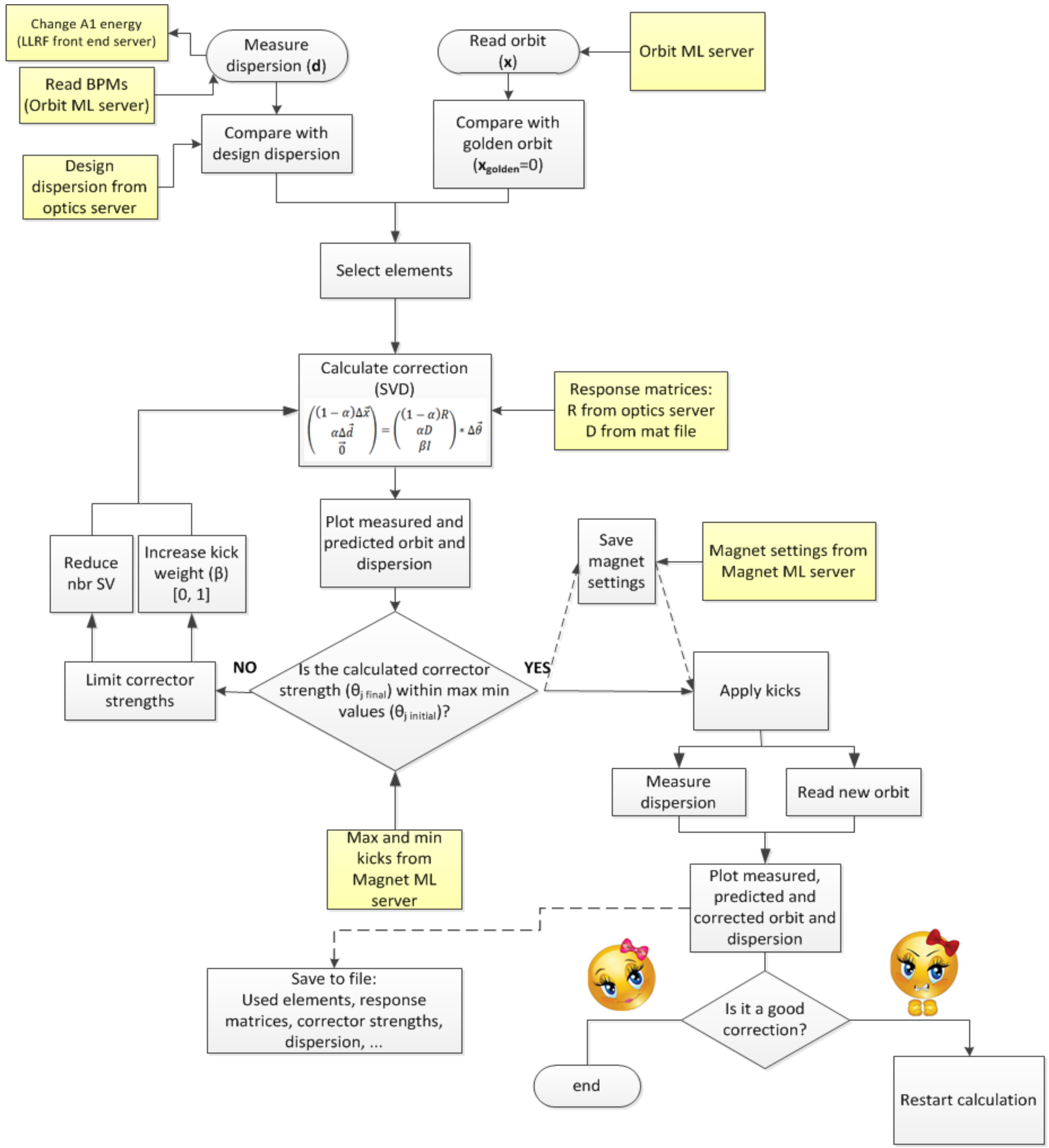
The orbit response matrix (*OR* (N×M))

$$OR_{x_{ij}} = \frac{\Delta\vec{u}_{x_i}}{\Delta\vec{\theta}_j} = R_{12_{j\to i}} \qquad OR_{y_{ij}} = \frac{\Delta\vec{u}_{y_i}}{\Delta\vec{\theta}_j} = R_{34_{j-i}}$$

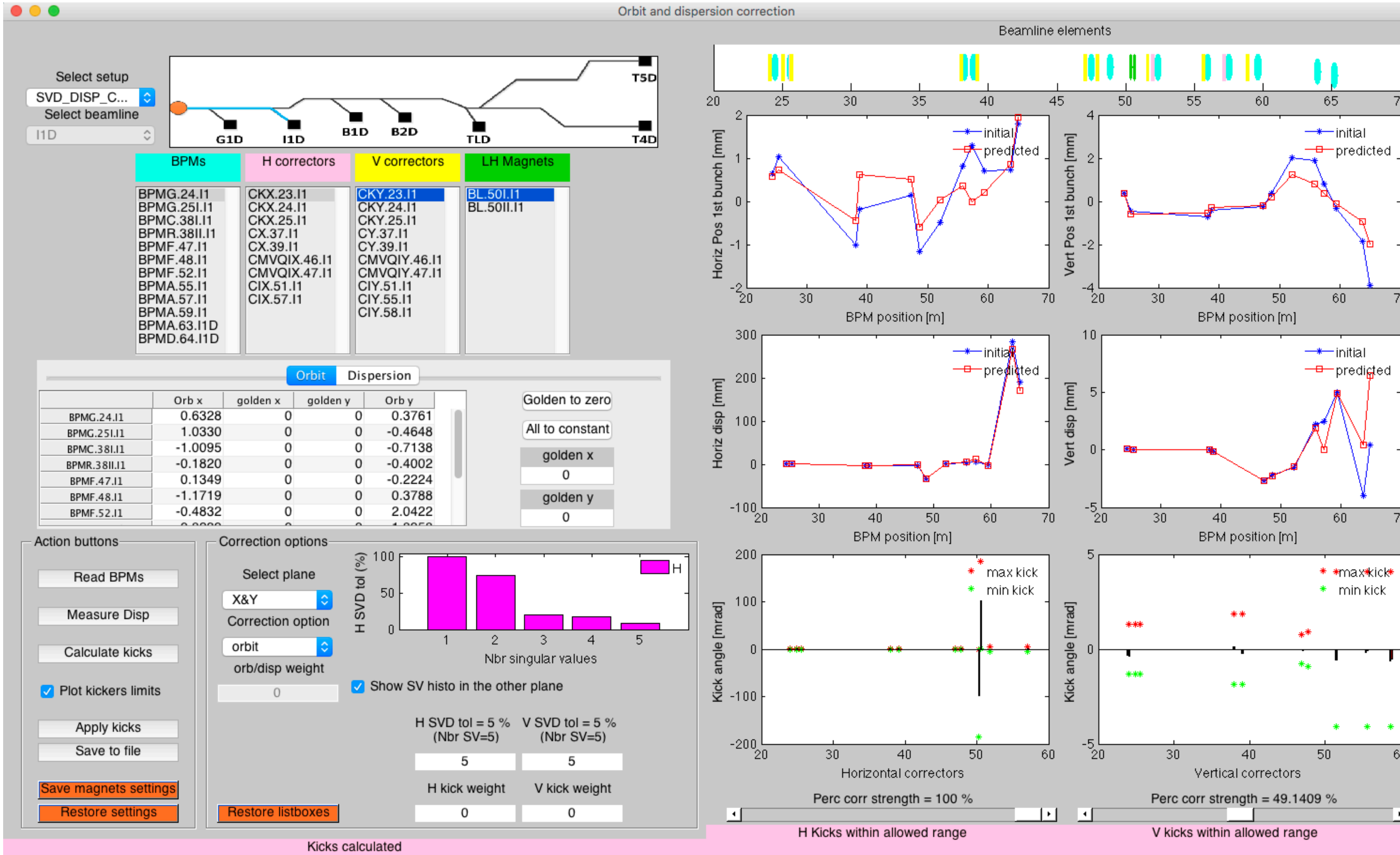
The dispersion response matrix (*DR* (N×M))

$$DR_{x_{ij}} = \frac{\Delta\vec{d}_{x_i}}{\Delta\vec{\theta}_j} = T_{126_{j-i}} \qquad DR_{y_{ij}} = \frac{\Delta\vec{d}_{y_i}}{\Delta\vec{\theta}_j} = T_{346_{j-i}}$$

Diagram of the orbit and dispersion correction algorithm



Orbit and Dispersion Tool



	Orb x	golden x	golden y	Orb y
BPMG.24.I1	0.6328	0	0	0.3761
BPMG.25I.I1	1.0330	0	0	-0.4648
BPMC.38I.I1	-1.0095	0	0	-0.7138
BPMR.38II.I1	-0.1820	0	0	-0.4002
BPMF.47.I1	0.1349	0	0	-0.2224
BPMF.48.I1	-1.1719	0	0	0.3788
BPMF.52.I1	-0.4832	0	0	2.0422

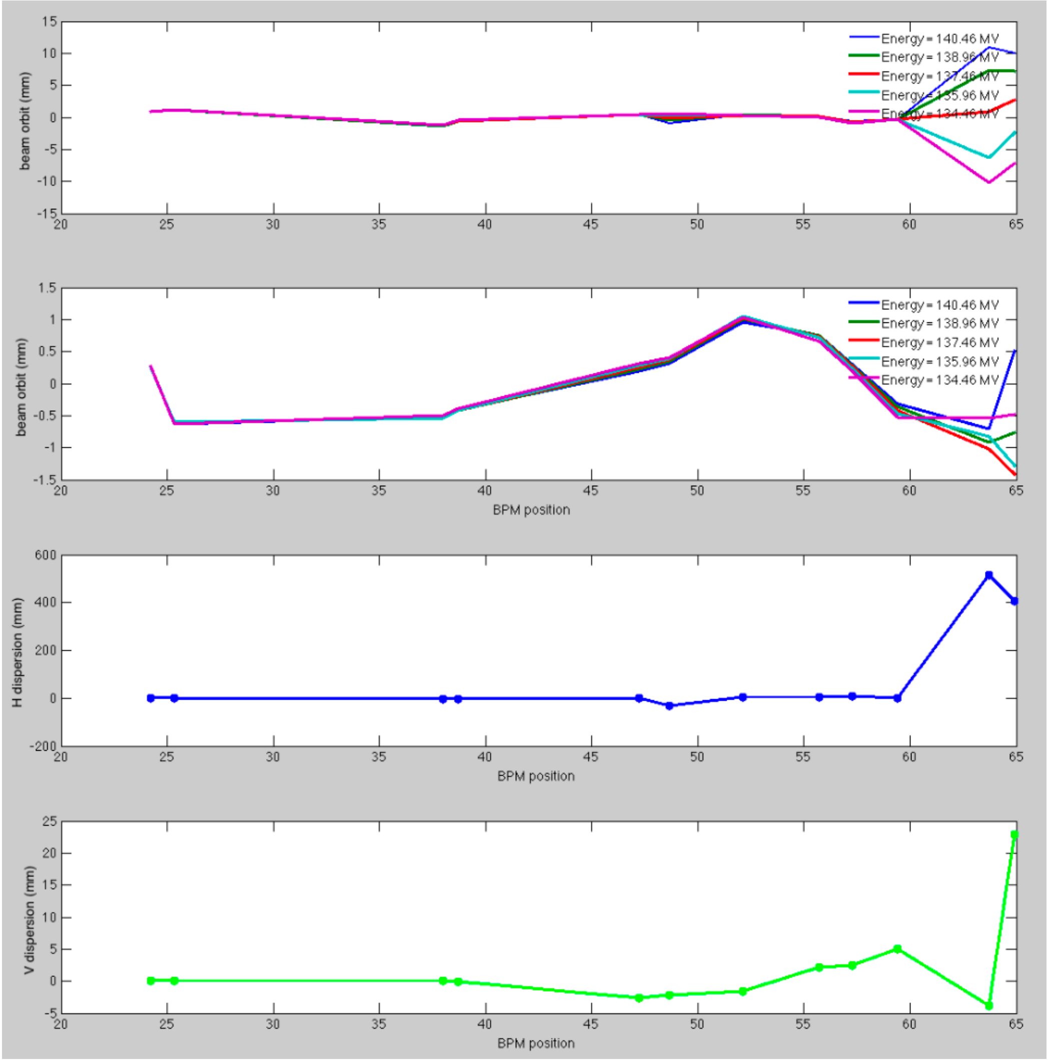
Screenshot of the GUI (Matlab)

Dispersion Measurement and Minimization

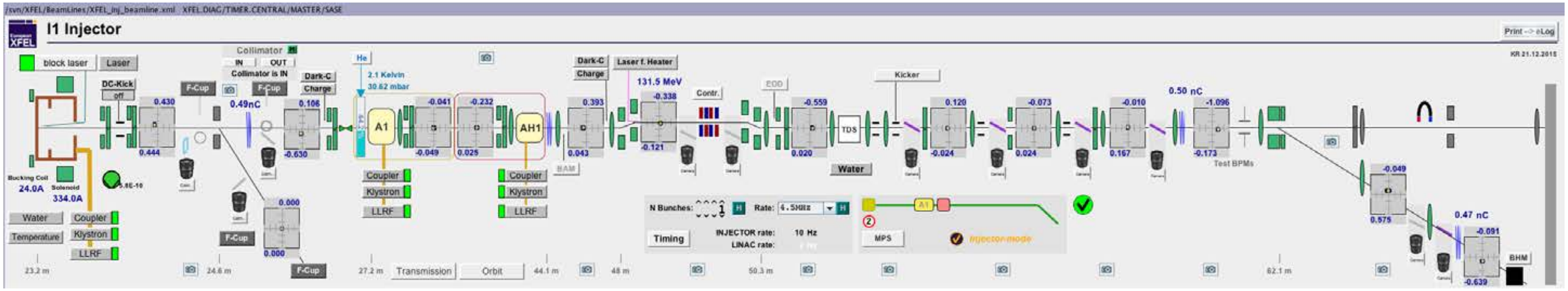
The dispersion measurement is based on reading out the orbit for different beam energies.

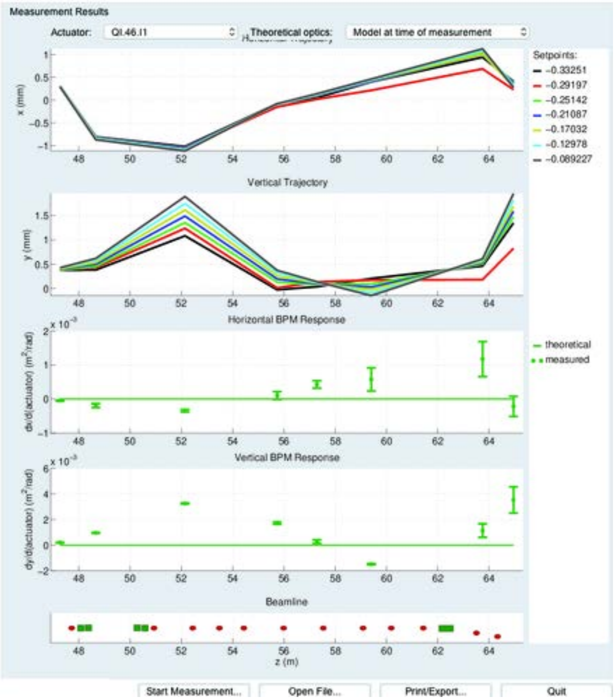
The process is the following

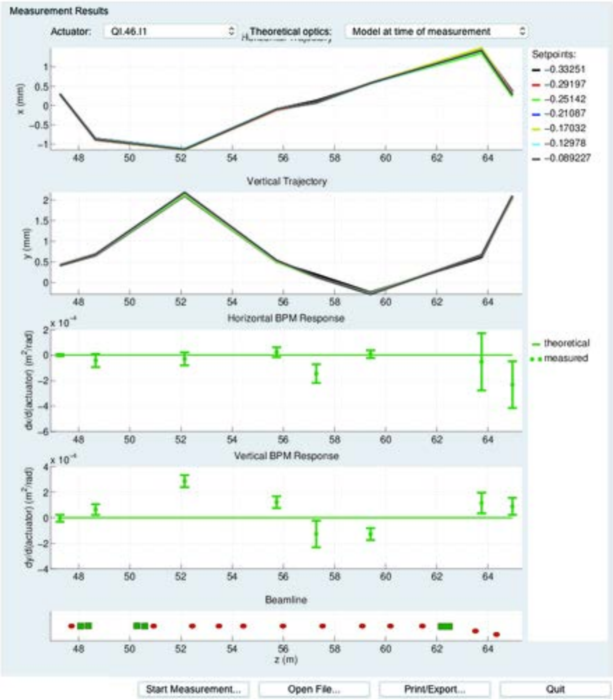
1. Change energy (changed 5 times in steps of 2 MV)
2. Measure orbit in the BPMs
3. Calculate the dispersion(we plot the orbit position versus $\Delta E/E_0$ and fit the curve to a second order polynomial.)



Dispersion Measurement and Minimization





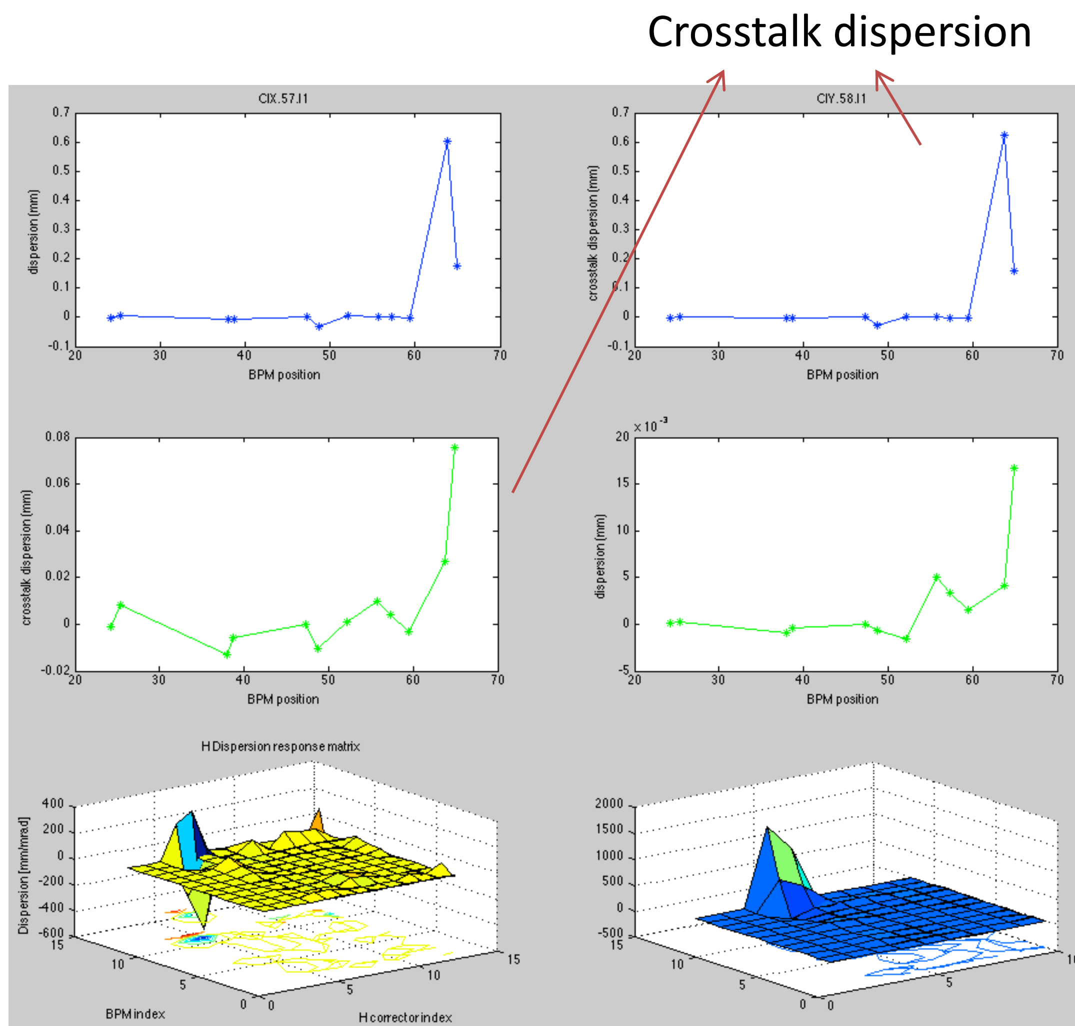


Dispersion measurement before and after minimizing.
After minimizing quadrupole movers are dispersion free.

Measurement of dispersion response matrix

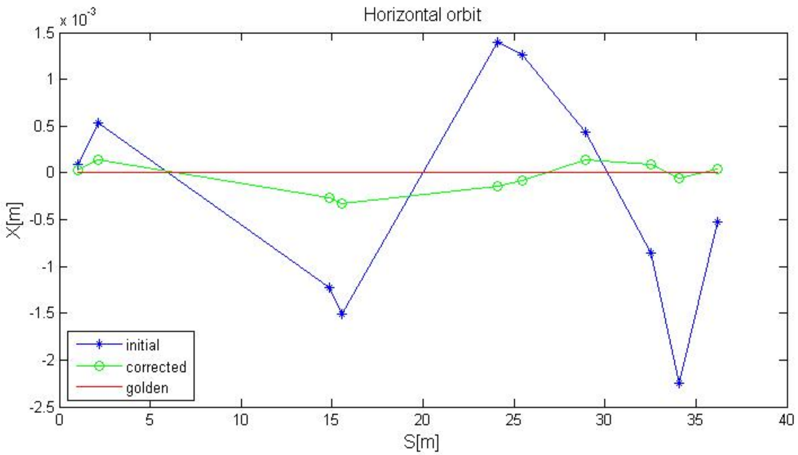
This measurement takes quite a lot of time since it requires the following steps:

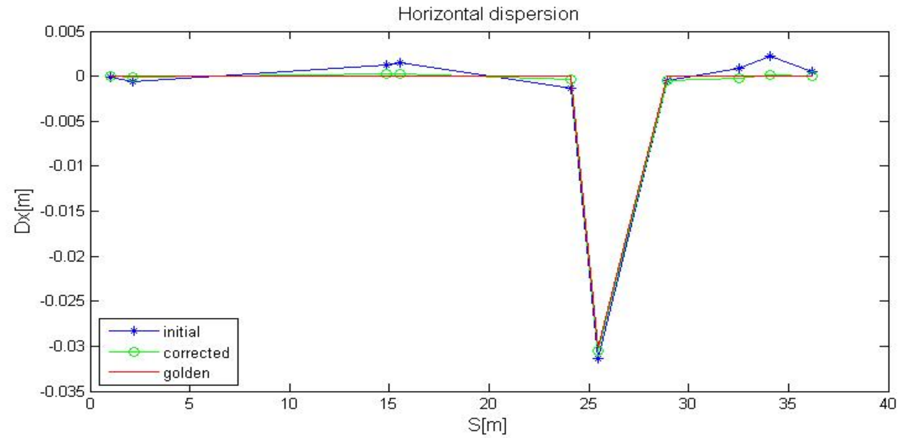
1. Measure initial dispersion
2. Apply a kick in one corrector upstream A1
3. Measure dispersion
4. Set back kick to initial value
5. A new column in the response matrix is obtained by subtracting the measured dispersion minus the initial dispersion
6. Repeat from point 2



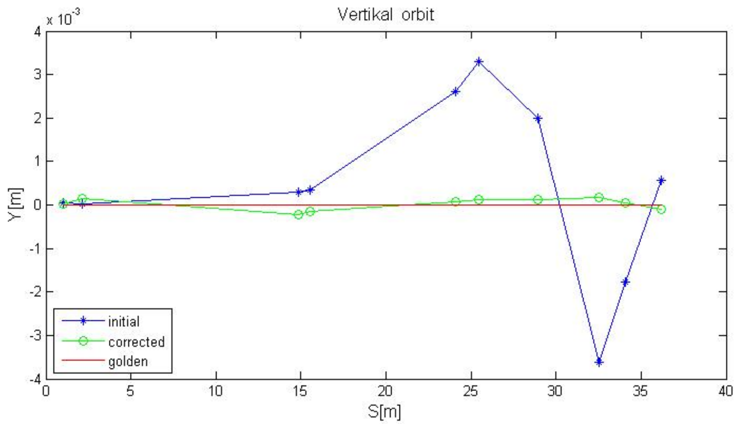
Note. This program will be of big help in the future for the commissioning of the rest of the XFEL.

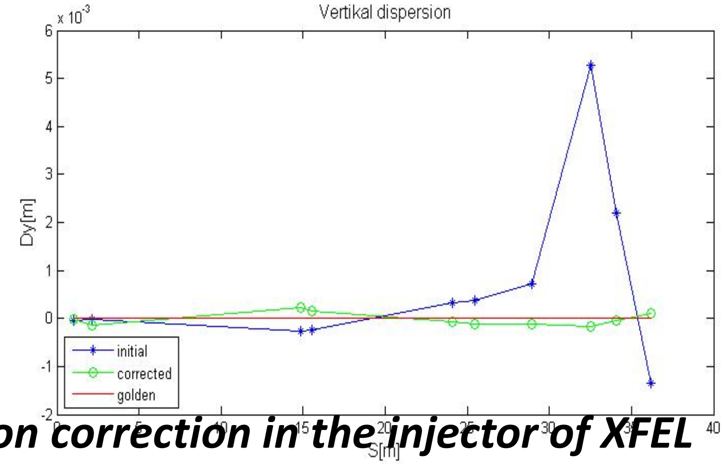
Simulations using ELEGANT





Example of simulated horizontal orbit and dispersion correction in the injector of XFEL





Example of simulated vertical orbit and dispersion correction in the injector of XFEL

The simulation was made taking into account the following machine imperfections:
Quadrupole misalignment = 100µm.
BPM offsets= 100µm
BPM resolution error= 10µm

We get an improvement of a factor 10

Conclusion

The principle of correction for orbit and dispersion correction works in simulation and in the tool for predicted results. However, because of the distribution of correctors and BPMs in the beamline and because of unpredictable machine imperfections, the real results do not follow the theory.

Some observations taken from experience are:

- Due to the lack of correctors, it is not possible to correct the orbit in the injector dump section. Usually BPMs BPMA.63.I1 and BPMD.64.I1 are removed from the elements' lists.
- The correction of the orbit up to BPMF.47.I1 can be done in several steps, discarding one of the BPMs at 38 m and without the first movers of the quadrupole QI.46.I1.
- We had problems with the quadrupole movers, the calculated kicks were usually exceeding by quite a lot the allowed range of operation. When we could not reduce the size of the kick, we just removed them.
- We can't do only dispersion correction because after correction we lose beam transmission. Do only orbit correction or orbit and dispersion correction at the same time.