FFS tuning with pre-calculated optical multi-knobs[1]

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[1] Based on proceeding proposed at EPAC08 "Feedback Corrections for Ground Motion Effects at ATF2"

Guidelines

Steering

Steering is mainly due to :

- Quadrupoles displacements
- Sextupole displacement
- Propagation along the line

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Effects of magnets displacements

- Displacement of a quadrupole or a sextupole kick the beam
- Kick is proportional/quadreatic to the displacement and the magnet strength

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Propagation

- A kick α at point A is converted in displacement at a downstream point B according to the phase advance (betatron oscillation).
- Amplitude of the displacement is given by : $R_{12}(A \rightarrow B) \times \alpha_x$ or $R_{34}(A \rightarrow B) \times \alpha_y$
- Big beta functions $\Rightarrow$ big R_{12} and R_{34}

Focusing errors

Focusing errors move the waist and so increase size at IP.

Focusing errors come from :

- Horizontal displacement of the beam in sextupoles.
- Mismatch of twiss parameters at injection in EXT line.

Horizontal displacement in sextupoles

- Horizontal displacement in a sextupole focuses the beam.
- Focusing is proportional to the displacement and the sextupole strength.

Mismatch

Mismatch at injection of $\alpha_x, \alpha_y, \beta_x$ or β_y will propagate until the end of the line.

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Coupling and vertical dispersion

As $\sigma_x \simeq 100 \times \sigma_y$ even weak coupling can increase a lot σ_y.

Coupling come from :

- Vertical displacement of the beam in sextupoles.
- Inperfect coupling correction in the ring.

Vertical displacement in sextupoles

- Vertical displacement in a sextupole kickes the beam in y.
- Kick is proportional to the displacement, the sextupole strength and horizontal particle coordinate.

Vertical dispersion

Coupling in a dispersive region $\Rightarrow$ vertical dispersion

Higher order aberation effects

- To obtain $35nm$ beam size :
  - Cancel second order aberations
  - Minimize third order
- Done in design creating symetries and respecting precise relations between the sextupoles of the Final Focus (FF).
- Before-mentioned errors break these relations $\Rightarrow$ High order aberations can have large effects on the beam size.

Parameters and measurements

What can be measured ?

- Beam position at BPM locations (each pulse or average).
- Beam size at wire scaners and OTR locations, at IP with Shintake monitor, Honda Monitor, or wire scaner.

What parameters can be changed ?

- Strength of magnets and correctors.
- Position of magnets which are on movers.

Obtain response matrix

For a variation ΔP_i of a parameter i, in a linear approximation, the variation of all the measurements is written in a vector ΔV_i. The M response matrix defined by :

$$M = \left[\left(\frac{\Delta V_1}{\Delta P_1} \right) \left(\frac{\Delta V_2}{\Delta P_2} \right) \quad \cdots \right]$$

give the variation of all the measurements ΔV for a variation ΔP of all parameters. Obtained from model or experimentally.

$$M \times \Delta P = \Delta V$$

Invert response matrix

Once we get ΔV the difference between measurements and what is wanted, the correction ΔP is given by :

$$\Delta P = M^{-1} \times \Delta E$$

The response matrix is usually not square (m parameters n measurements) $\Rightarrow$ Use SVD to invert it.

Thanks to SVD

- If $m < n$ the correction will minimize the spread of the measurements ($\| \Delta E \|$).
- If $m = n$ Simple inversion ("1 to 1").
- If $m > n$ the correction will minimize the amplitudes of corrections ($\| \Delta P \|$).

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Obtain knobs and correct aberation

- The i^{th} column of M^{-1} is called a knob for the i^{th} measurement :
  It gives the variation of the parameters (ΔP) to obtain an unitary variation of this measurement and this one only.
- Correlations introduced by aberation at IP can only be measured througth the evolution of the size varying this correlation.
- Parabola given by size function of the amplitude of parameters accordingly to the corresponding knob has its minimum when correlation is null.
- Correcting aberation is done by scanning amplitude of the knob and set correctors to the minimum of the parabola

Example of waist correction

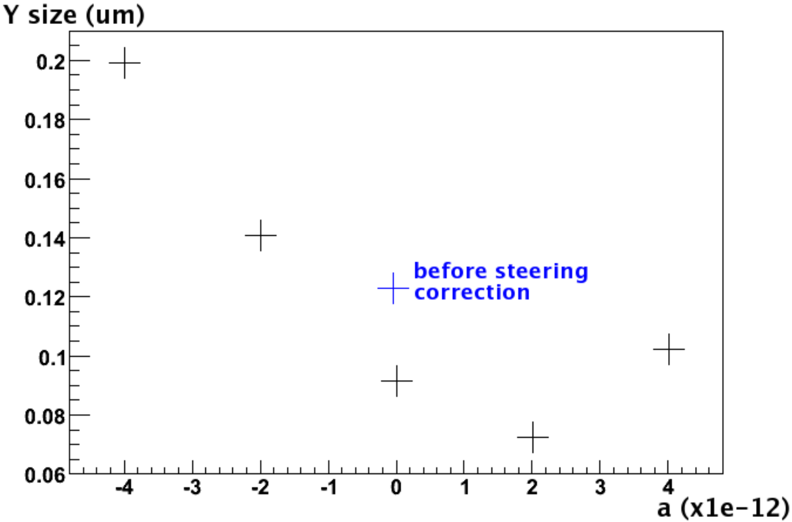
correction of α_x

- The knob for $\alpha_x (< x_p x >)$ is :

$$K = \begin{bmatrix} dQD0_{strength} \\ dQF1_{strength} \end{bmatrix} = \begin{bmatrix} -5.28\ 10^6 \\ 4.33\ 10^5 \end{bmatrix}$$

- To correct α_x, one has to vary the QD0 and QD1 strength by $a \times K$ choosing a to have reasonable size variation.
- Here $a = [0 \ \ -2.10^{-8} \ \ -1.10^{-8} \ 1.10^{-8} \ 2.10^{-8}]$.
- See Sha's talk for futher information on waist correction.

Example of waist correction



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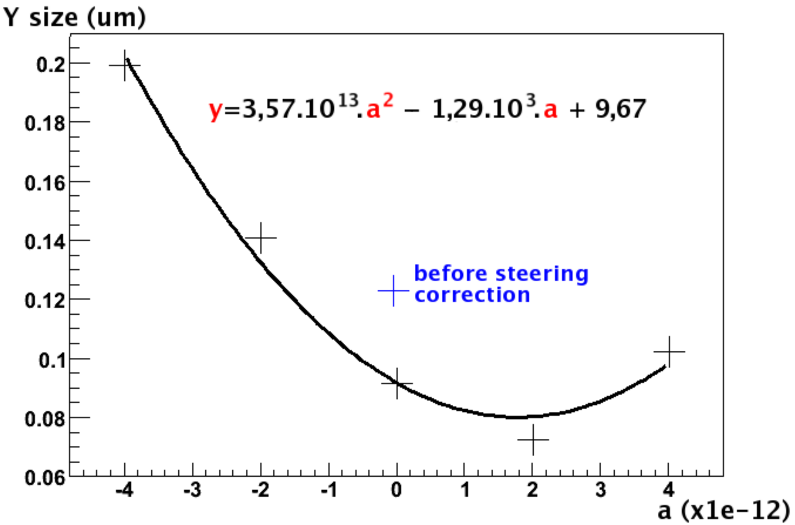

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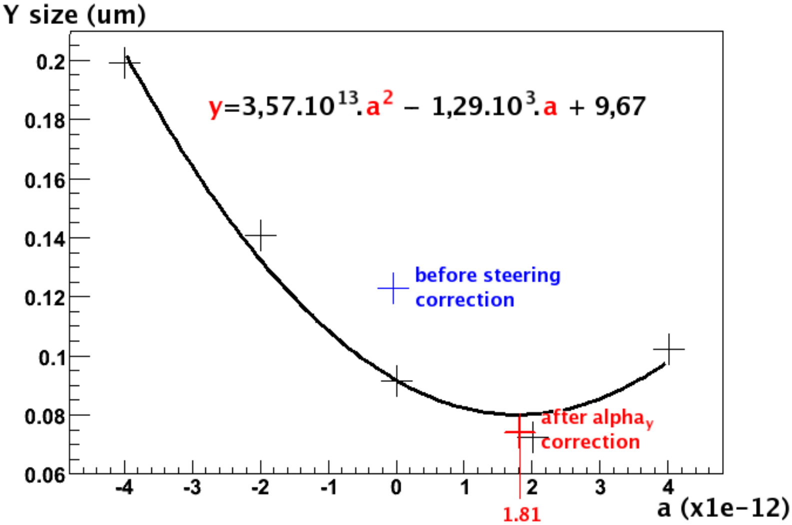
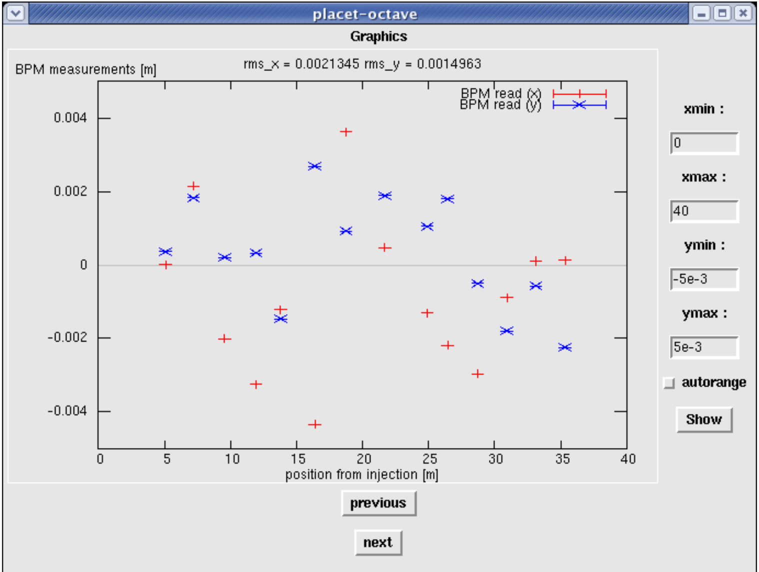


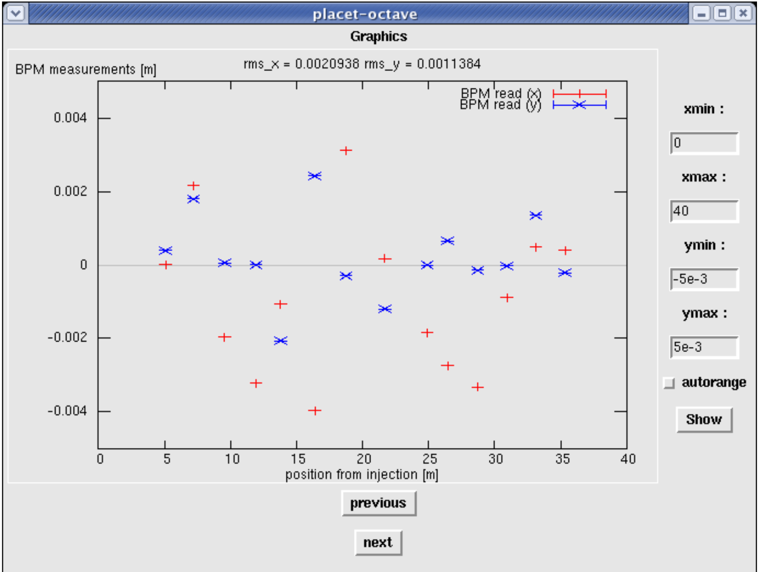
Implementation of "1 to all" algorithm

1. Get BPM readings of the perfect line B_0 ($\simeq$ get transfer matrix).
2. For each corrector i, apply an unitary correction.B are values of BPM readings.
   $B_i - B_0$is a vector proportional to the correction (linear approximation).
3. Get $B_i^{-1} = (B_i - B_0)^{-1}$ SVD-invert of this vector. It allows to have the measure of what should have the value of the corrector to have such displacement of the beam.
4. For a corrector i, apply the correction C_i given by $C_i = -\alpha(B_{exp} - B_0) \times B_i^{-1}$ where B_{exp} is the "experimental" BPM measurements.

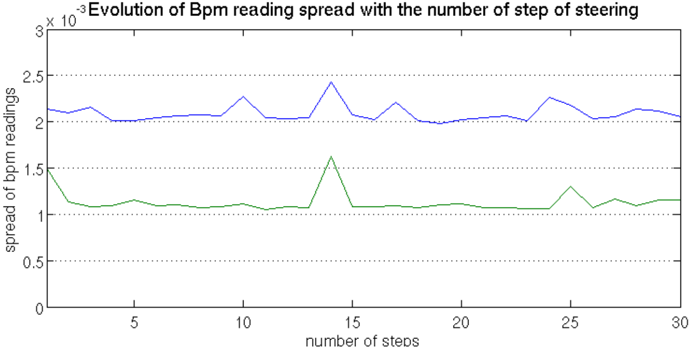
BPM readings before steering correction



BPM readings after just 1 correction



Evolution of steering during correction



Implementation of optical corrections

1. Get the main correlations D_0 introduced by the perfect line at the IP. ($\simeq$ get transfer matrix).
2. Look for ways to introduce it (sextupole displacement, variation of strength of quadrupole or sextupole)
3. For most efficient way found, get the values D_i of the correlations of the beam at IP introduced by an unitary perturbation of the magnet.
4. Get D^{-1},invert of matrix made by $D_i - D_0$.
5. Vector of D^{-1} are the knobs that change an unique correlation.
6. Use the knobs one by one as shown before to make the correction.

Knobs used in the simulation

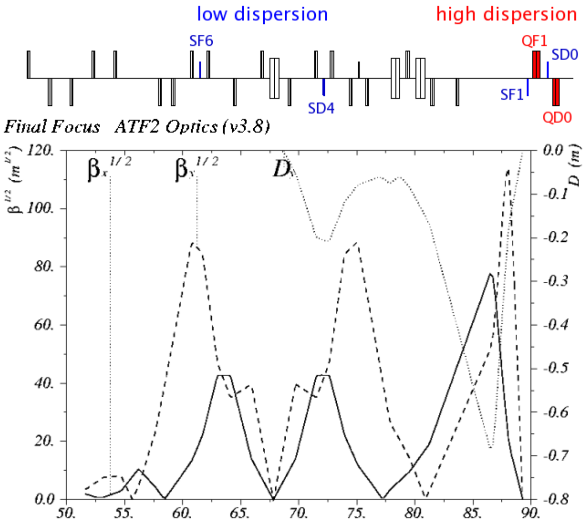
- QD0 and QF1 are used for α_x and α_y correction.

$$\begin{bmatrix} < xx' > \\ < yy > \end{bmatrix} = \begin{bmatrix} -1.49\ 10^4 & -5.35\ 10^6 \\ 5.70\ 10^4 & 4.39\ 10^5 \end{bmatrix} \times \begin{bmatrix} dK_{QD0} \\ dK_{QD1} \end{bmatrix}$$

- SF6, SD4, SF1 and SD0 are used to correct other aberations.

$$\begin{bmatrix} < x'y > \\ < Ey > \\ < x'x'y > \\ < x'Ey > \end{bmatrix} = \begin{bmatrix} 2.84\ 10^{12} & -1.40\ 10^{12} & 4.27\ 10^{15} & 6.50\ 10^{16} \\ 1.26\ 10^{12} & 1.08\ 10^{12} & -1.78\ 10^{15} & -2.67\ 10^{16} \\ 1.58\ 10^{12} & -2.29\ 10^{11} & 8.05\ 10^{15} & -2.96\ 10^{16} \\ 1.81\ 10^{12} & -2.42\ 10^{11} & 2.72\ 10^{15} & -3.67\ 10^{16} \end{bmatrix} \times \begin{bmatrix} dy_{SF6} \\ dy_{SD4} \\ dy_{SF1} \\ dy_{SD0} \end{bmatrix}.$$

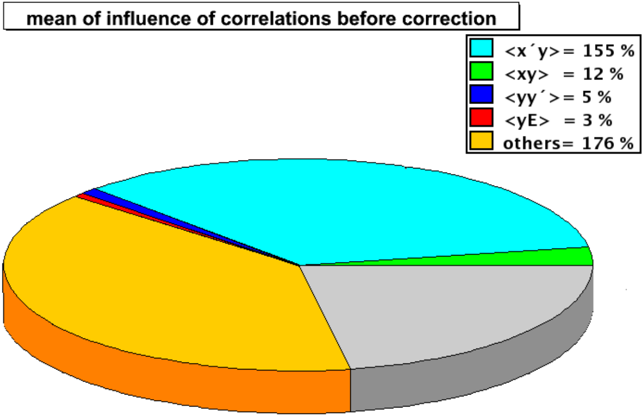
Location of SF6 SD4 SF1 and SD0



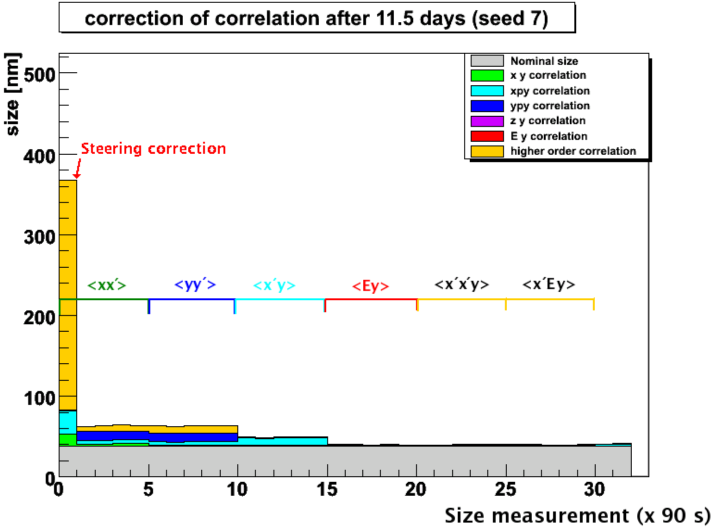
Simulation in PLACET

- Initial displacement generated by 11.5 days ground motion.
- Steering correction each second.
- Size measurement are 90 *s* long (Shintake monitor).
- 20 seeds for the ground motion generator fitted on measurement at KEK. (cf: "Expected ground motion at ATF2 and resulting effects at IP" at Fifth ATF2 Project meeting)
- 100 *nm* of resolution on BPM (7 *nm* on IPBPM)

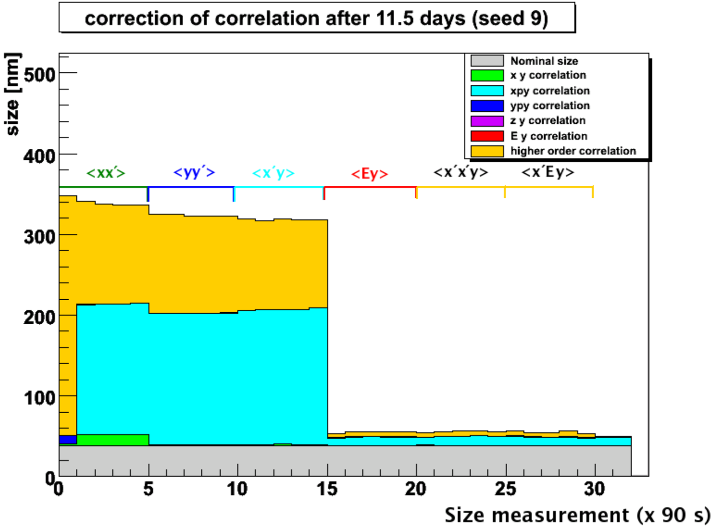
Main correlation at IP before correction



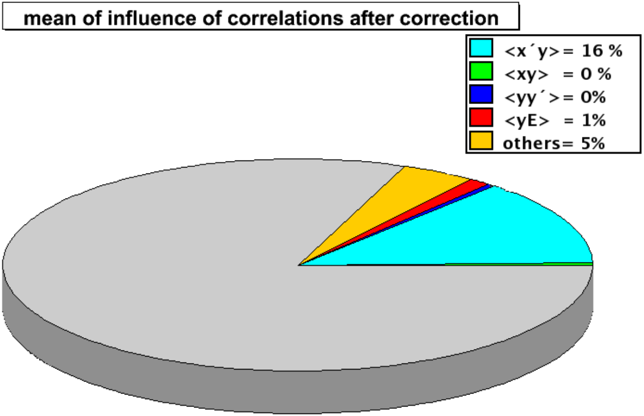
Results for a seed



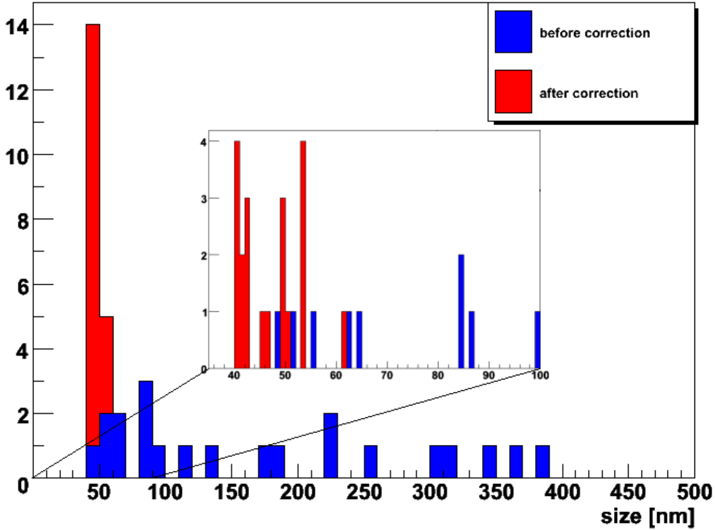
Results for an other seed



Correlation at IP after correction



Size at IP before and after correction



Conclusion and prospects

1. Conclusion :
   - Stable and efficient steering correction obtained.
   - "1 to all" steering algorithm tested with success in Flight Simulator at ATF.
   - Main distortions of the beam at IP are corrected by the knobs found.
   - Quick correction : 45 min long for 1 iteration of correction.
   - Beam size down to 40-60 nm.
2. Prospects :
   - Introduce other effects (beam injection jitter, magnets power supply, magnets rotation, ...).
   - Add IP beam stability feedback (previously optimized).
   - Test a second iteration of beam correction on biggest beam ($\simeq 60\ nm$).
   - Interface optics correction with Flight Simulator.