INTERNATIONAL LINEAR COLLIDER

SLAC

Simulation of Alignment and Tuning of ATF2 FF

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ATF2 Meeting, KEK

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Overview

- Porting simulation developed for ILC alignment and tuning, first look at simulation of ATF2 tuning performance.
- Assuming set of initial starting errors, take 100 seeds of Woodley-tuned v3.6 lattice (dispersion and coupling fixed in diagnostic section).
  - Add FF errors.
  - Apply BPM alignment, BBA and sextupole tuning knobs for each of 100 seeds using design measurement system resolutions.
- Here, simulation is static- next step is to add dynamic imperfection to tuning (Ground Motion, component + incoming beam jitter, magnet and BPM drifts etc.).
- Lucretia used for simulations.

Initial Error Parameters

- Initial errors taken from ILC assumptions.
- Assume movers on all FF quadrupoles and sextupoles.
- Shintake monitor assumed to have 100nm dynamic range.
- Also assume IP BPM with 5nm RMS resolution for initial tuning requirements.

Quad, Sext, Oct x/y transverse alignment	**200 um**
Quad, Sext, Oct x/y roll alignment	**300 urad**
Initial BPM-magnet field center alignment	**30 um**
dB/B for Quad, Sext, Octs	**1e-4**
Mover resolution (x & y)	**50 nm**
BPM resolutions	**100 nm**
Power supply resolution	**14 - bit**
Shintake Monitor Resolution	**2nm**

Alignment and Tuning Procedure

- Switch off Sextupoles.
- Perform initial BBA using Quad movers + BPMs to get rough orbit -> IP.
- Quadrupole BPM alignment (quad-shunting).
- Perform Quadrupole BBA (DFS-like algorithm).
- Align Sextupole BPMs (move through beam + downstream BPM fits).
- Activate sextupole magnets.
- Rotate whole BDS about first quadrupole to pass beam through nominal IP position or iteratively move final quad and re-apply DFS BBA.
- Apply sextupole multiknobs to tune out IP aberrations.
  - Initially, tune on just IP dispersion and coupling using direct measurement with IP-BPM until beamsize <100nm.
  - Measure IP dispersion by +/- 0.5% incoming E shift + linear fit to 10 IP BPM readings.
  - Measure coupling by kicking the beam at an appropriate phase upstream of FF in x and fit slope in y to 10 IP BPM readings.
  - When 100nm IP spot size reached, iteratively tune on vertical spot-size using Dy, Wy, <xy> and <x'y> knobs + sextupole tilt and dB scans.

BBA/Steering with Quad Movers

- DFS + mover minimisation solution, use Matlab lscov to solve in a leas-squares sense, A*c=b with weight vector, ie. minimise: (b- A*c)'*diag(1/w^2)*(b - A*c), where:

$$b=\begin{pmatrix} B_x^0 \\ B_y^0 \\ B_x^- \\ B_y^- \\ B_x^+ \\ B_y^+ \\ c \end{pmatrix} \quad B=\begin{pmatrix} b_2 \\ b_3 \\ \vdots \\ b_n \end{pmatrix} \quad A=\begin{pmatrix} T^0 \\ T^- \\ T^+ \\ diag(1) \end{pmatrix}$$

$$\boxed{\begin{aligned}
M_{i,j}^{XX} &= R_i^q(2,1).R_{i,j}(1,2)+\left(R_i^q(1,1)-1\right).R_{i,j}(1,1)+R_i^q(3,1).R_{i,j}(1,3)+R_i^q(4,1).R_{i,j}(1,4) \\
M_{i,j}^{XY} &= R_i^q(2,3).R_{i,j}(1,2)+R_i^q(1,3).R_{i,j}(1,1)+\left(R_i^q(3,3)-1\right).R_{i,j}(1,3)+R_i^q(4,3).R_{i,j}(1,4) \\
M_{i,j}^{YY} &= R_i^q(1,3).R_{i,j}(3,1)+R_i^q(2,3).R_{i,j}(3,2)+\left(R_i^q(3,3)-1\right).R_{i,j}(3,3)+R_i^q(4,3).R_{i,j}(3,4) \\
M_{i,j}^{YX} &= \left(R_i^q(1,1)-1\right).R_{i,j}(3,1)+R_i^q(2,1).R_{i,j}(3,2)+R_i^q(3,1).R_{i,j}(3,3)+R_i^q(4,1).R_{i,j}(3,4)
\end{aligned}}$$

$$T=\begin{pmatrix}
-1 & 0 & 0 & \cdots & \cdots & R_{1,2}(1,2) & 0 & 0 & 0 & \cdots & \cdots & R_{1,2}(1,4) \\
M_{2,3}^{XX} & -1 & 0 & \cdots & \cdots & R_{1,3}(1,2) & M_{2,3}^{XY} & 0 & 0 & \cdots & \cdots & R_{1,3}(1,4) \\
M_{2,4}^{XX} & M_{3,4}^{XX} & -1 & \cdots & \cdots & R_{1,4}(1,2) & M_{2,4}^{XY} & M_{3,4}^{XY} & 0 & \cdots & \cdots & R_{1,4}(1,4) \\
\vdots & \vdots & \ddots & \ddots & \ddots & \vdots & \vdots & \vdots & \ddots & \ddots & \ddots & \vdots \\
M_{2,n}^{XX} & M_{3,n}^{XX} & M_{4,n}^{XX} & \cdots & M_{n-1,n}^{XX} & R_{1,n}(1,2) & M_{2,n}^{XY} & M_{3,n}^{XY} & M_{4,n}^{XY} & \cdots & M_{n-1,n}^{XY} & R_{1,n}(1,4) \\
0 & 0 & 0 & \cdots & \cdots & R_{1,2}(3,2) & -1 & 0 & 0 & \cdots & \cdots & R_{1,2}(3,4) \\
M_{2,3}^{YX} & 0 & 0 & \cdots & \cdots & R_{1,3}(3,2) & M_{2,3}^{YY} & -1 & 0 & \cdots & \cdots & R_{1,3}(3,4) \\
M_{2,4}^{YX} & M_{3,4}^{YX} & 0 & \cdots & \cdots & R_{1,4}(3,2) & M_{2,4}^{YY} & M_{3,4}^{YY} & -1 & \cdots & \cdots & R_{1,4}(3,4) \\
\vdots & \vdots & \ddots & \ddots & \ddots & \vdots & \vdots & \vdots & \ddots & \ddots & \ddots & \vdots \\
M_{2,n}^{YX} & M_{3,n}^{YX} & M_{4,n}^{YX} & \cdots & M_{n-1,n}^{YX} & R_{1,n}(3,2) & M_{2,n}^{YY} & M_{3,n}^{YY} & M_{4,n}^{YY} & \cdots & M_{n-1,n}^{YY} & R_{1,n}(3,4)
\end{pmatrix}
\quad
c=\begin{pmatrix} q_2^x \\ q_3^x \\ \vdots \\ q_{n-1}^x \\ k_1^x \\ q_2^y \\ q_3^y \\ \vdots \\ q_{n-1}^y \\ k_1^y \end{pmatrix}$$

Quadrupole BPM Alignment

- Nulling Quad Shunting technique:
- To get BPM-Quad offsets, use downstream ~10 BPMs for each Quad being aligned (include IP bpm for last few quads).
- Quad dK 100-80 %, use change in downstream BPM readouts to get Quad offset.
- Move Quad and repeat until detect zero-crossing.
- For offset measurement, use weighted-fit to downstream BPM readings based on model transfer functions: $x_{Quad} = \Delta x_{BPM} / \left(\Delta R_Q(1,1) * R(1,1) + \Delta R_Q(2,1) * R(1,2) \right)$

Sextupole BPM Alignment

- Move Sextupole +/- 0.5mm through beam.
- Fit quadratic function to downstream BPM response.
- Alignment from minimum of fit.

Sextupole Multi-Knobs

- Use orthogonalised x- and y-moves of sextupoles to correct vertical waist and dispersion + <x'y> coupling term.
- Additionally use orthogonal moves of 2 skew quads to tune <xy>.
- Higher-order aberrations tuning performed by simply scanning sextupole tilts + strengths.
- In simulation, apply iteratively until beamsize within 10% of perfect-lattice value (~35nm).

Linear Sextupole Multi-Knobs

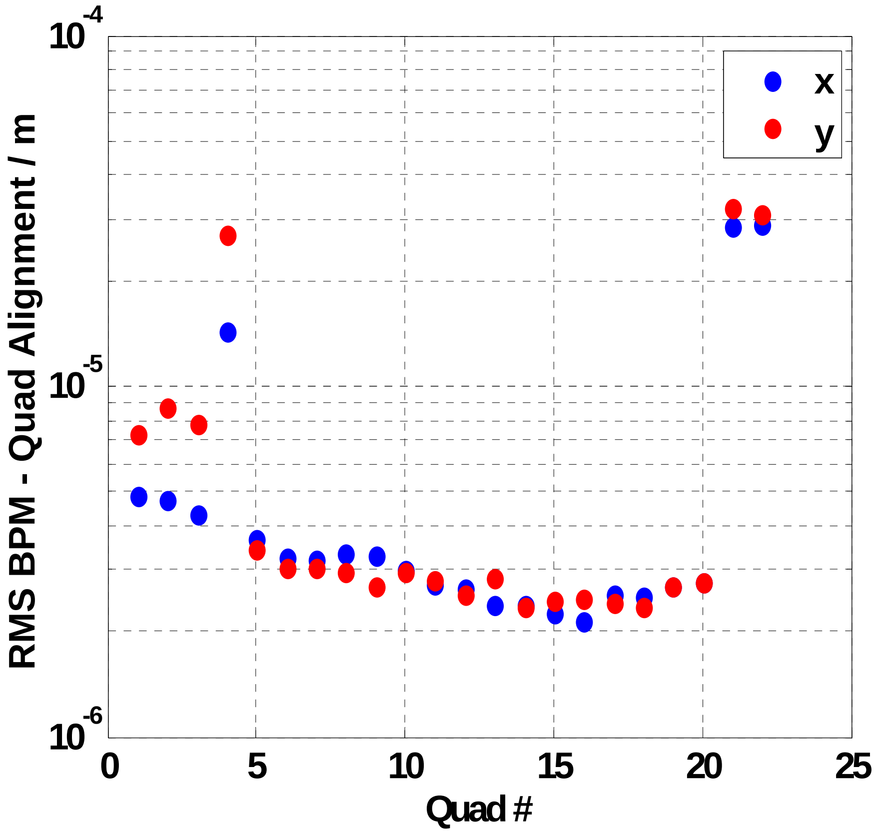
	SF5	SD4	SF1	SD0
Y Waist	-0.47(x)	1(x)	-0.2(x)	-
Y Disp.	-	-	-0.68(y)	-1(y)
<x’y>	-	-	1(y)	-0.99(y)

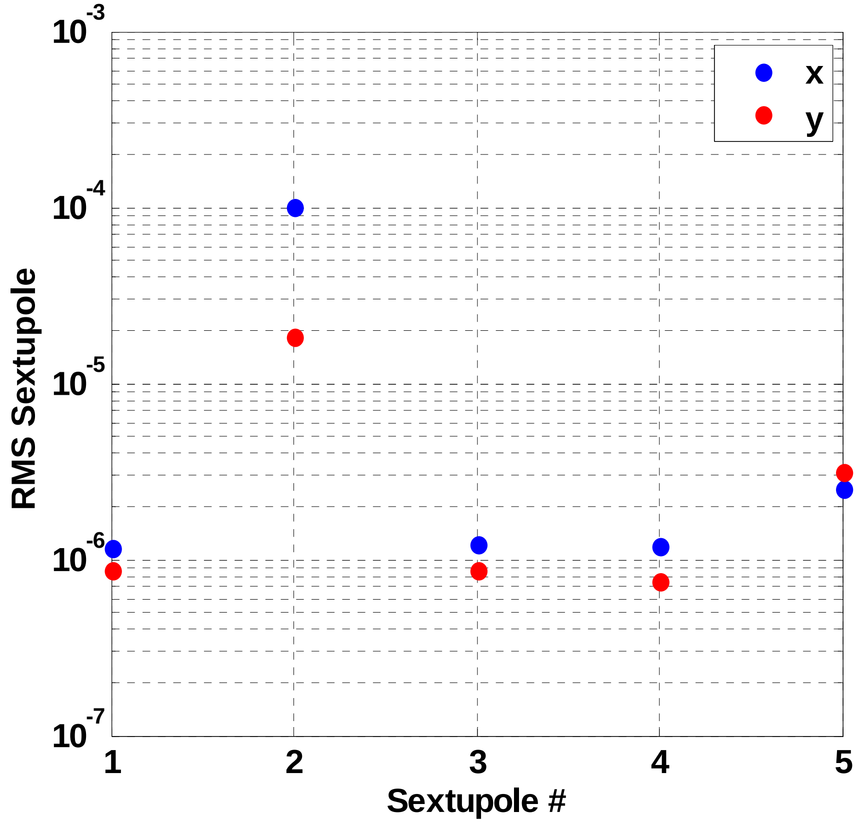
	QK1X	QK2X	QK3X	QK4X
<xy>	-0.92	0.21	0.20	1

Preliminary Results

- WARNING:
- What follows are very preliminary results, optimisation of knob application needs to be carried out still.
- Also done with slightly older lattice.

Magnet – BPM Alignment

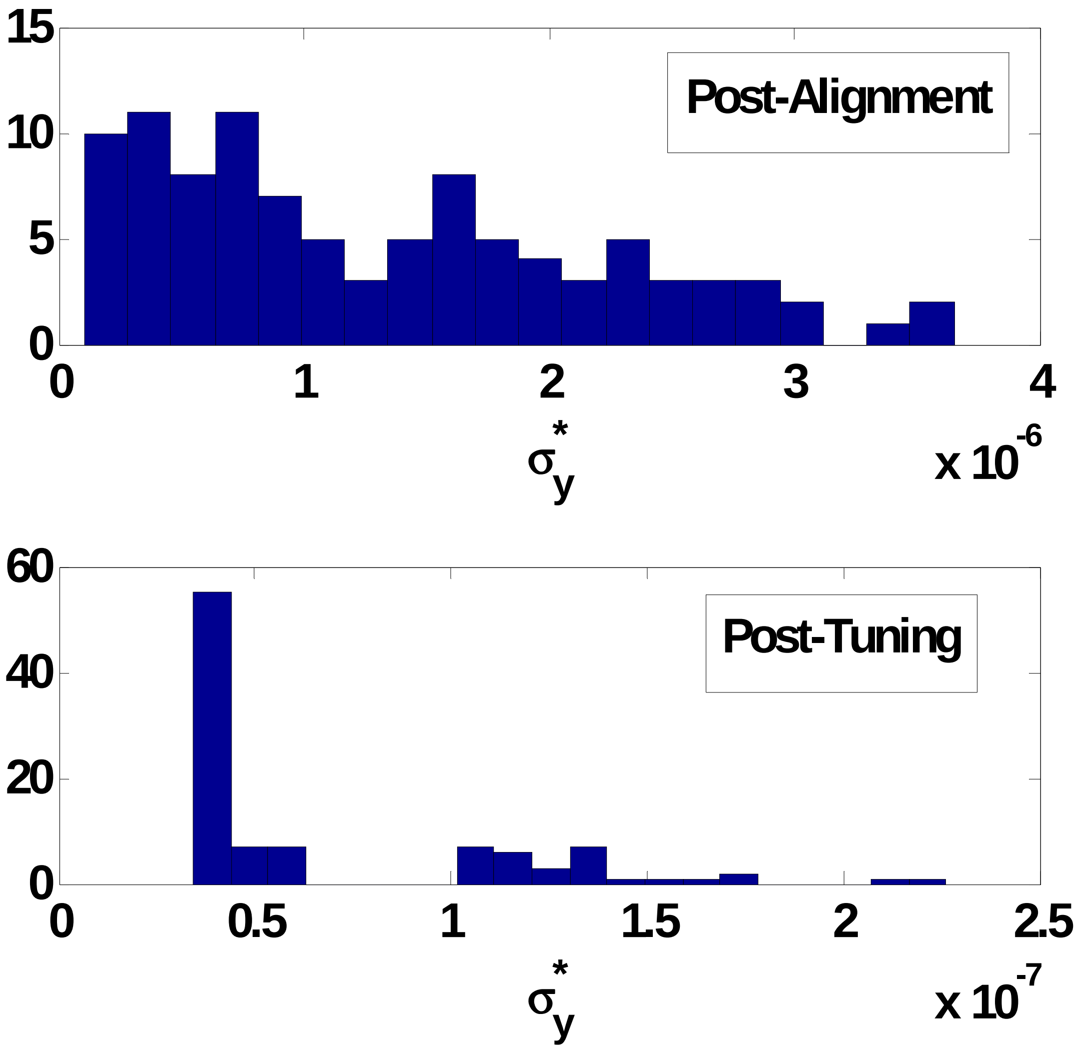




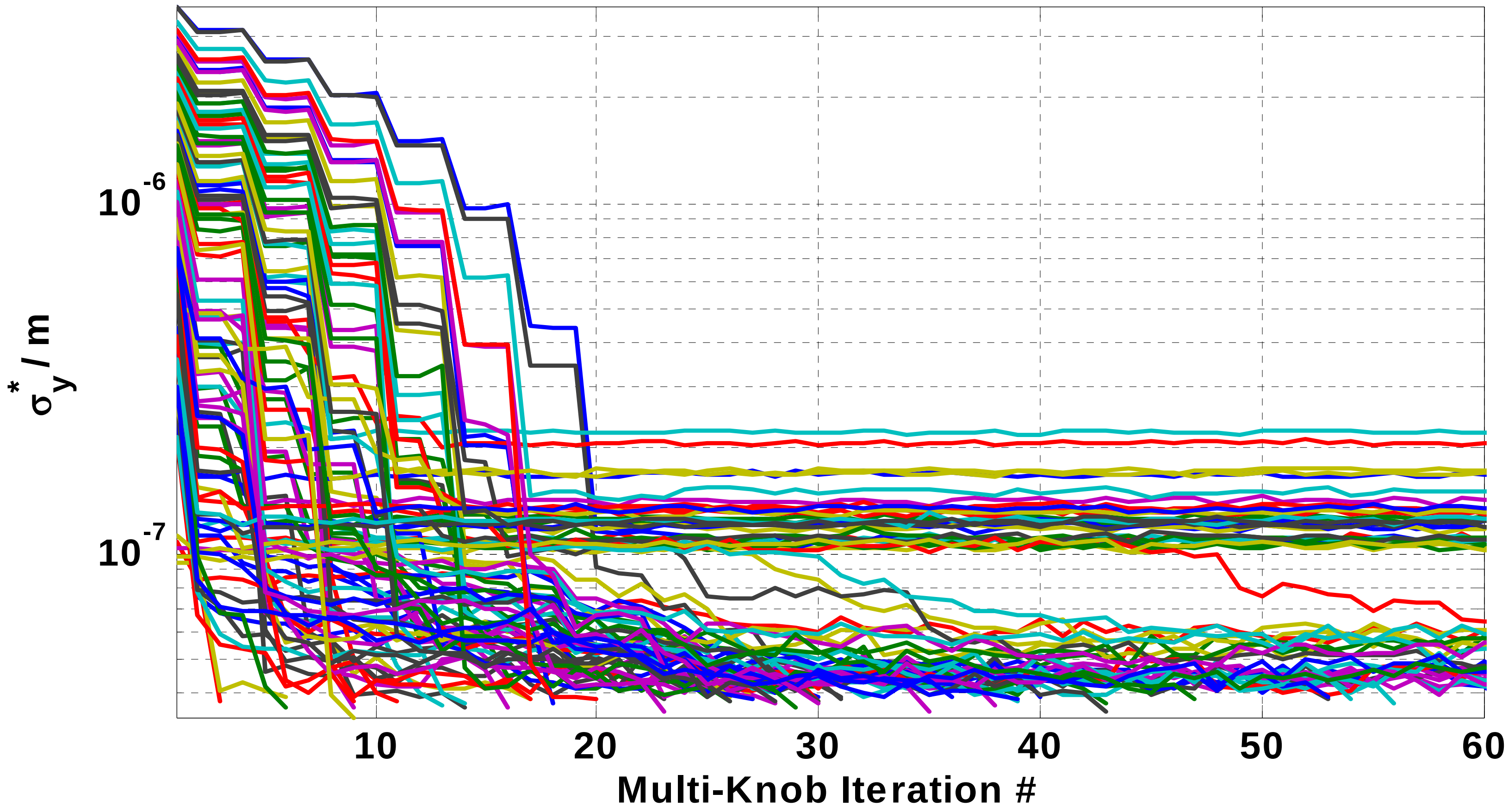
- RMS alignment (100 seeds)

Final Spot-Size Results

- 54% seeds converge <~ 39nm.
- 30% seeds never get to <100nm.



IP Size vs. Knob



- Typically, convergence seen in ~20 tuning steps.

Summary

- More work needed getting all seeds to converge.
  - Evaluate order of knob application.
  - More averaging per scan.
- Convergence typically in <20 iterations:
  - Assuming 1 min per IP spot-size measurement (90 bunches @ 1.5Hz), 10 scan points per knob iteration and 1 cycle through Sext tilt/dB scans:
  - If completely automated, tuning would take ~ 4.5 Hours.
- Need to add Ground Motion, component jitter, incoming beam orbit + energy jitter, BPM scale and magnet strength drifts…