Trajectory and jitter measurements

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March 20, 2012

Outline

1. ATF2 GOALS
2. Orbit reconstruction
3. Transfer Matrix reconstruction
4. Monitoring input parameters
5. Jitter studies
6. Coclusions

Goal 1

Goal 1 and 2

- Main target: reach 37nm beam size at the IP.
- Reproducibility and stability of the extracted beam to get a 2nm stability at the IP.

Question

Can trajectory reconstruction reliably monitor input parameters?

Orbit reconstruction

Question

Can trajectory reconstruction reliably monitor input parameters?

Challenge (P.Bambade)

Not only the short time variations which should be stabilized by feedback, but also longer term reproducibility on the time scale of one to several weeks.

Transfer Matrix Reconstruction

Define the state vector in phase space:

$$\psi(s) \equiv \left(x(s), x'(s), y(s), y'(s), \delta = \frac{\Delta E}{E} \right)$$

in linear approximation we have:

$$\psi_i(s) = R_{ij}(\mathrm{IEX} \to s)\psi^j(\mathrm{IEX})$$

where s is given by the BPMs positions and IEX is the starting point of the Extraction Line.

From BPMs we can measure only ψ_1 and ψ_3 and then:

$$\Phi = (\psi_1(1), \ldots, \psi_1(N), \psi_3(1), \ldots, \psi_3(N))$$

$$\Phi = \mathcal{R}\psi(\mathrm{IEX})$$

where $\mathcal{R}$ is a $2N \times 5$ matrix of the form:

$$\mathcal{R}_{ij} = R_{1j}(i), i = 1, , \ldots, N$$

$$\mathcal{R}_{ij} = R_{3j}(i), i = N+1, , \ldots, 2N$$

explicitly:

$$\begin{pmatrix} \psi_1(1) \\ \vdots \\ \psi_1(N) \\ \psi_3(1) \\ \vdots \\ \psi_3(N) \end{pmatrix} = \begin{pmatrix} R_{11}(1) & R_{12}(1) & R_{13}(1) & R_{14}(1) & R_{16}(1) \\ & & \vdots & & \\ R_{11}(N) & R_{12}(N) & R_{13}(N) & R_{14}(N) & R_{16}(N) \\ R_{31}(1) & R_{32}(1) & R_{33}(1) & R_{34}(1) & R_{36}(1) \\ & & \vdots & & \\ R_{31}(N) & R_{32}(N) & R_{33}(N) & R_{34}(N) & R_{36}(N) \end{pmatrix} \begin{pmatrix} \psi_1(IEX) \\ \psi_2(IEX) \\ \psi_3(IEX) \\ \psi_4(IEX) \\ \psi_6(IEX) \end{pmatrix}$$

- We need to test the accuracy of the linear model.
- To prove it, we can measure the elements R_{12} and R_{34} and compare them with the model.

We need three measurements to extract R_{12} and R_{34}:

- $\psi_{\mathrm{BPM}} = (x, x', y, y')$
- $\psi_{\mathrm{COR}_x} = (x, x' + \theta_x, y, y')$
- $\psi_{\mathrm{COR}_y} = (x, x', y, y' + \theta_y)$

then

$$\psi_0^{1,3} = R_{11,33}\psi_0^{1,3}(0) + R_{12,34}\psi_0^{2,4}(0)$$
$$\psi^{1,3} = \psi_0^{1,3} + (R_{12,34})\theta_{x,y}$$

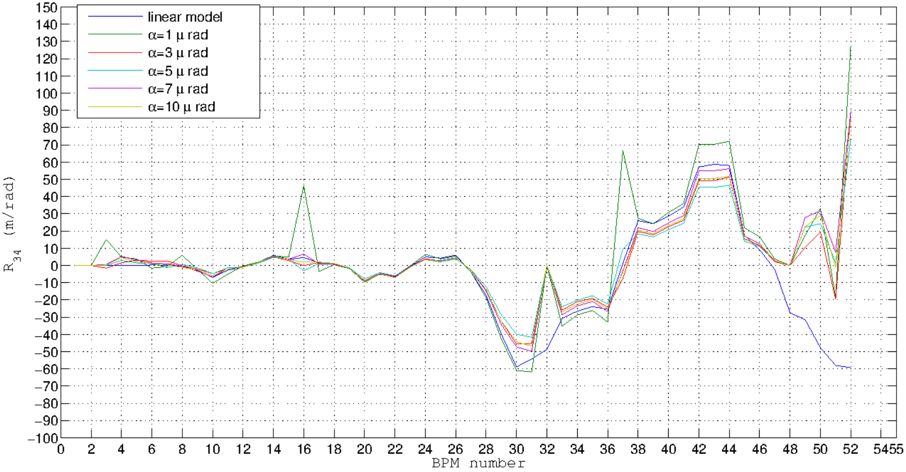
hence

$$R_{12} = \frac{\Delta x}{\theta_x} \qquad R_{34} = \frac{\Delta y}{\theta_y}$$

Measurement

- Horizontal corrector ZH1X.
- Vertical corrector ZV1X.
- Correction angles: $\theta = (1, 3, 5, 7, 10)\mu\mathrm{rad}$
- The reconstructed orbit is the average of the data for all the angles.

R_{34}

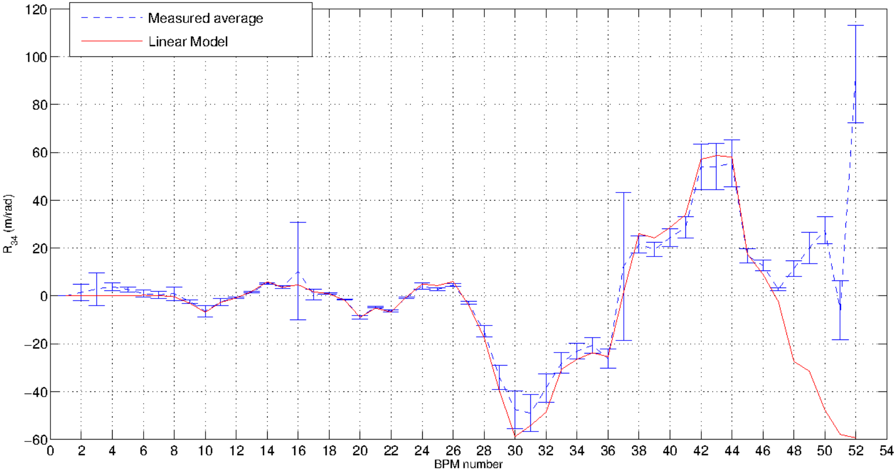

linear model
α=1 μ rad
α=3 μ rad
α=5 μ rad
α=7 μ rad
α=10 μ rad
R34 (m/rad)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
−90
−100
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
5455
BPM number

Cleaning the results

Due to some fluctuations, some measurements are far from the expected. We need to clean them.

- Remove zero BPM readings.
- Remove orbit $\alpha = 5\mu$rad for R_{12}
- Remove a few readings form orbit $\alpha = 1\mu$rad for R_{34}

All removed points are replaced by the average of the two BPM readings from just upstream and downstream of the point.


Measured average
Linear Model
R_{34} (m/rad)
BPM number
120
100
80
60
40
20
0
−20
−40
−60
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54

Monitoring input parameters

- We have seen that the model agrees with the measured matrix elements.
- We can use the orbit reconstruction to extract the initial beam jitter.
- We do the calculation over 50 pulses and 47 BPMs.
- For each pulse (set of BPM readings) we can reconstruct (x, y) at IEX.
- We extract the rms jitter as: $\sigma_{\text{jitt}} = \sqrt{\langle u^2 \rangle},\ u = x, y, x', y'$

Jitter

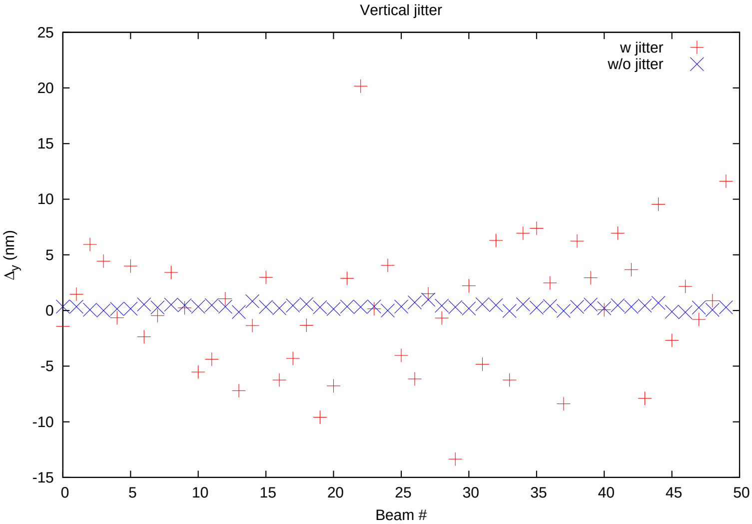
$$\sigma_x^{\text{jitt}} = 0.09\sigma_x \ , \quad \sigma_{x'}^{\text{jitt}} = 0.17\sigma_{x'}$$

$$\sigma_y^{\text{jitt}} = 0.13\sigma_y \ , \quad \sigma_{y'}^{\text{jitt}} = 0.22\sigma_{y'}$$

Jitter simulations

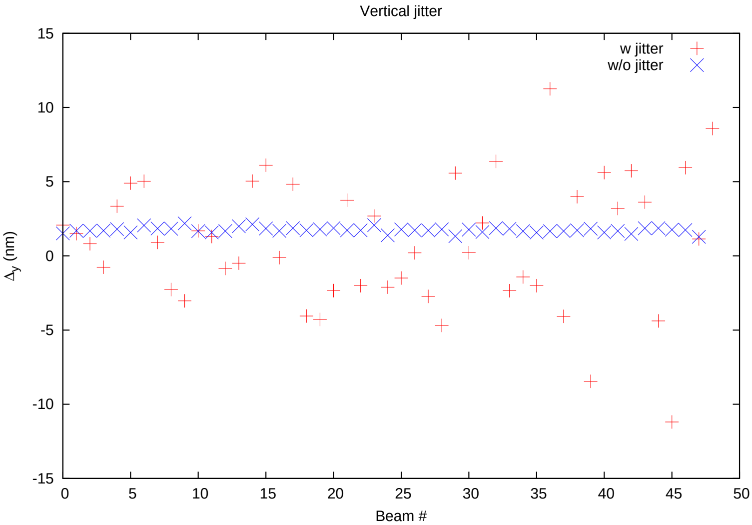
- We see the influence of the EXT→FFS jitter in goal 1 and goal 2.
- 50 Gaussian Beams of 50000 particles.
- Without jitter:
  $(\Delta x, \Delta y, \Delta p_x, \Delta p_y) = (0, 0, 0, 0)$
- With jitter:
  $(\Delta x, \Delta y, \Delta p_x, \Delta p_y) = (0.09\sigma_x, 0.13\sigma_y, 0.17\sigma_{x'}, 0.22\sigma_{y'})$
- MADX+PTC tracking.
- We compare both Nominal and Ultra-low β^* lattices with both current FD and new FD proposed by CERN.

Stability influence: Nominal lattice



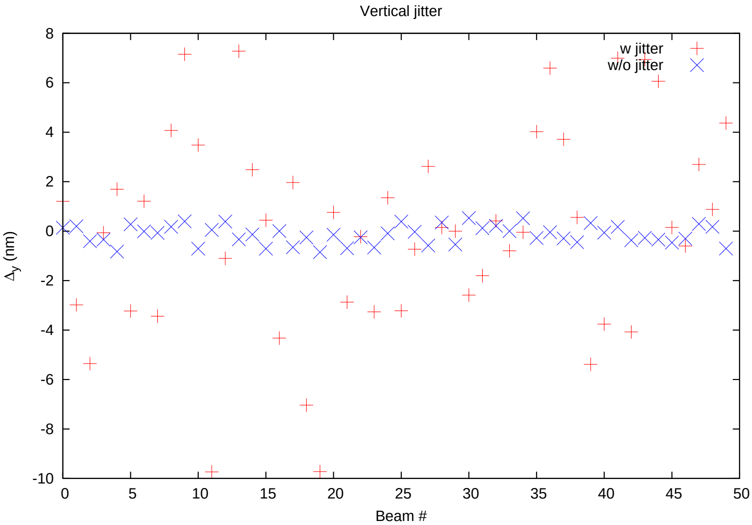
$$\langle y \rangle = 0.33\text{nm}, \Delta_y = \sqrt{\langle y^2 \rangle} = 6.00\text{nm}$$

Stability influence: Nominal lattice with New FD



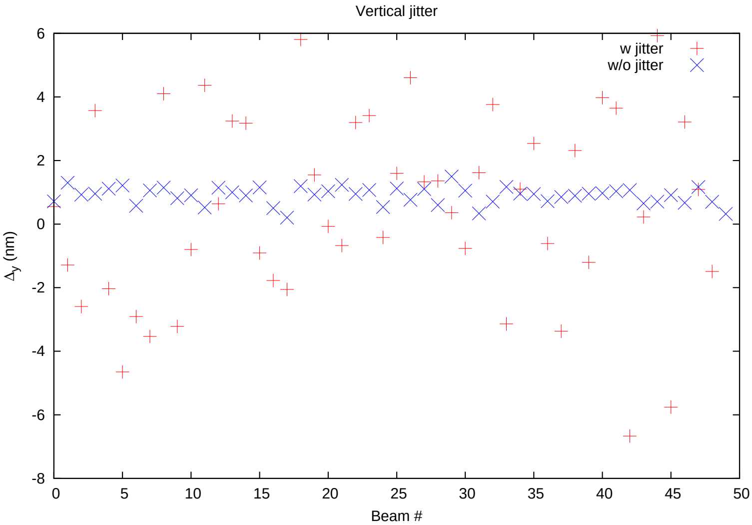
$$\langle y \rangle = 0.84\text{nm}, \Delta_y = \sqrt{\langle y^2 \rangle} = 4.41\text{nm}$$

Stability influence: Ultra-low β^* lattice



$$\langle y \rangle = 0.03\text{nm}, \Delta_y = \sqrt{\langle y^2 \rangle} = 4.06\text{nm}$$

Stability influence: Ultra-low β^* lattice with new FD



$$\langle y \rangle = 0.45\text{nm}, \Delta_y = \sqrt{\langle y^2 \rangle} = 3.02\text{nm}$$

Jitter transport to IP

Initial jitter at EXT:

$$\sigma_{\text{jitt}}^{\text{EXT}} = 0.13\sigma_y^{\text{EXT}}$$

Jitter at IP:

Lattice	Jitter w. Curr. FD (σ_y^*)	Jitter w. New FD (σ_y^*)
Nominal	0.18	0.13
Ultra-low β	0.24	0.18

$$\sigma_{\text{jitt}}^* = M(\text{EXT} \to \text{IP})\sigma_{\text{jitt}}^{\text{EXT}}$$

$$\sigma_{\text{jitt}} \sim R\sigma_{\text{jitt}_0} + \underbrace{e^{:\mathcal{H}:}}_{\text{nonlinear}} \sigma_{\text{jitt}_0}$$

- If new FD, jitter doesn't increase for Nominal.
- In UL, non linear effect might appear.

Influence on the Beam Size, Nominal lattice

	σ_y^*(core) [nm]	σ_y^*(shi) [nm]	σ_y^*(rms) [nm]
Ideal w/o jitter	33.7	34.90	34.4
Ideal w jitter	33.8	34.94	34.9
Curr. FD w/o jitt.	41.7	46.4	59.1
Curr. FD w jitt	41.9	46.8	60.1
New FD w/o jitt	39.2	42.1	44.6
New FD w jitt	39.4	42.5	45.5

$$\sigma_{\text{eff}}^* = \sqrt{{\sigma_{\text{jitt}}^*}^2 + \sigma^{*2}}$$

Influence on the Beam Size, Ultra-low β^* lattice

	σ_y^*(core) [nm]	σ_y^*(shi) [nm]	σ_y^*(rms) [nm]
Ideal w/o jitter	17.46	19.5	18.4
Ideal w jitter	17.50	19.6	18.7
Curr. FD w/o jitt.	35.0	55.6	85.8
Curr. FD w jitt	34.8	56.3	89.9
New FD w/o jitt	29.0	45.1	54.4
New FD w jitt	29.0	45.9	56.1

$$\sigma^*_{\text{eff}} = \sqrt{{\sigma^*_{\text{jitt}}}^2 + \sigma^{*2}}$$

Conclusions

- In order to reach the goal 2 (2nm stability), we need to correct the jitter before the FFS.
- Although 4nm stability, the beam size remains quite constant.
- To reach Goal 1 (37nm) we need to re-optimize the system.
- With the new FD and for the Nominal lattice, there would not be jitter enhancement at the FFS.
- Ultra-low β^* enhances the jitter at the IP due to nonlinearities.

To be done...

- Study of the long term stabilization.
- Apply jitter results to the Ultra-low β^* with swapped magnets.