First attempts with orbit measurement

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Outline

Goal 1

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- Main target: reach 37nm beam size at the IP.
- Reproducibility and stability of the extracted beam to get a 1nm stability at the IP.

Question

Can trajectory reconstruction reliably monitor input parameters?

Orbit reconstruction

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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.

Tools and issues

- Flight Simulator for simulations and real BPM readings.
- Coupling.
- Non-linear dynamics.

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:

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

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:

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

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

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

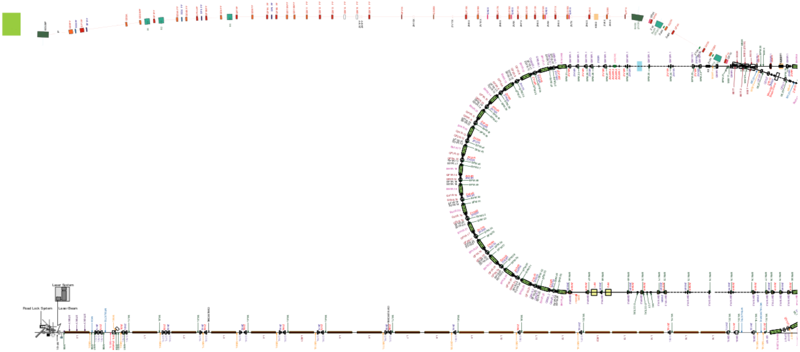
$$\psi_0^{1,3} = R_{11,33}\psi_0^{1,3}(0) + R_{12,34}\psi_0^{2,4}(0)$$
$$\psi^{1,3} = \psi_0^{1,3} + (R_{12,34})\theta_{x,y}$$

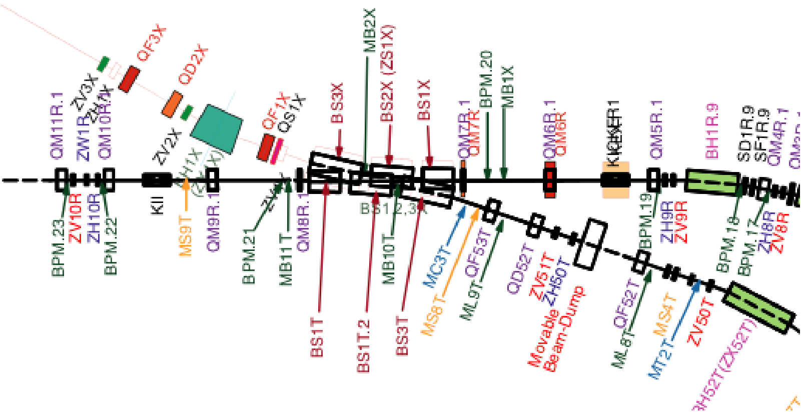
hence

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

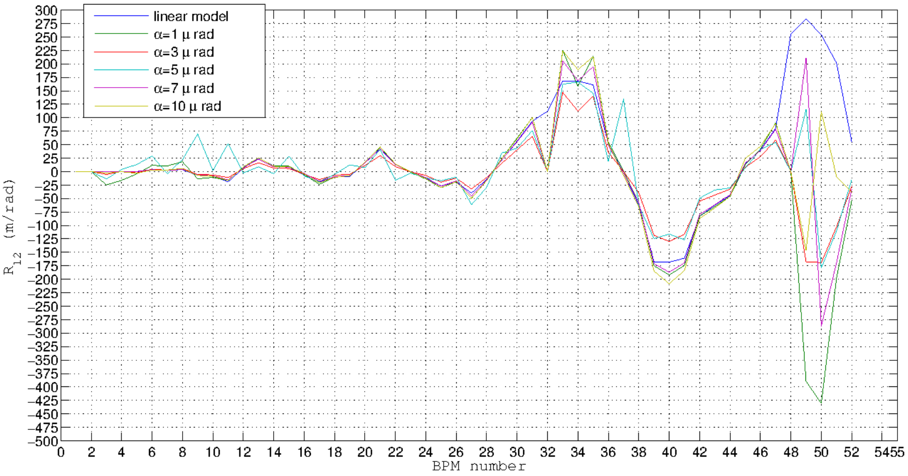
Measurement

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

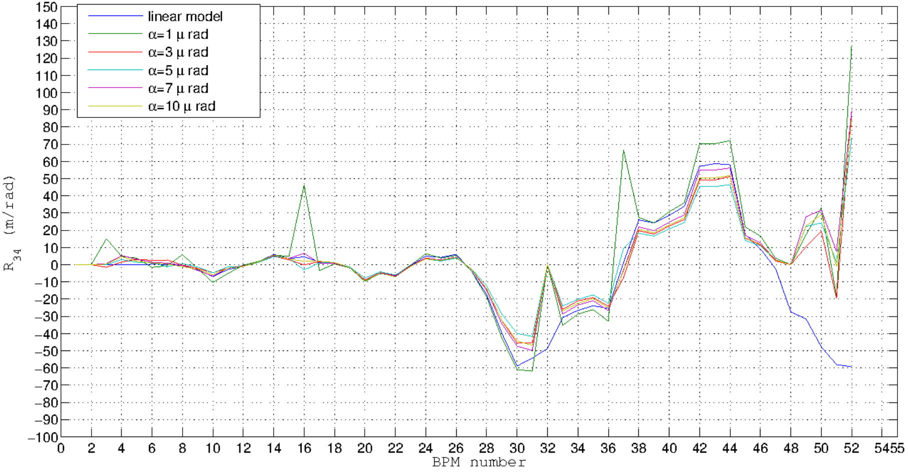

Laser System
Laser Beam


QM11R.1
QM10R.1
QF3X
QD2X
ZV2X
QF1X
QS1X
BS3X
MB2X
BS2X (ZS1X)
BS1X
QM7R.1
BPM.20
MB1X
QM6R.1
QM5R.1
BH1R.9
SD1R.9
SF1R.9
QM4R.1
BPM.23
ZV10R
ZH10R
BPM.22
KII
MS9T
QM9R.1
BPM.21
MB11T
QM8R.1
BS1T
BS1T.2
MB10T
BS3T
BS1,2,3X
MC3T
MS8T
QF53T
ML9T
QD52T
ZV51T
ZH50T
Movable Beam-Dump
BPM.19
ZH9R
ZV9R
QF52T
ML8T
MS4T
MT2T
ZV50T
BPM.18
BPM.17
ZH8R
ZV8R

R_{12}


linear model
α=1 µ rad
α=3 µ rad
α=5 µ rad
α=7 µ rad
α=10 µ rad
R12 (m/rad)
BPM number

R_{34}

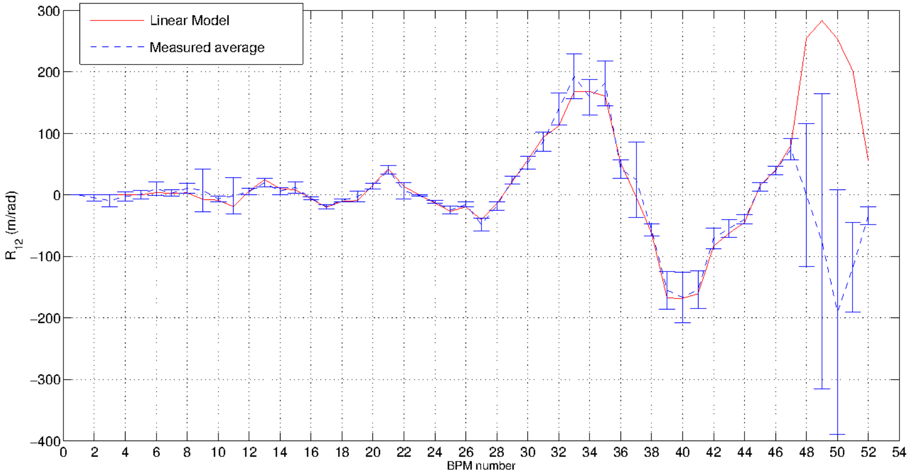

linear model
α=1 μ rad
α=3 μ rad
α=5 μ rad
α=7 μ rad
α=10 μ rad
R34 (m/rad)
BPM number
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
−90
−100
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 5455

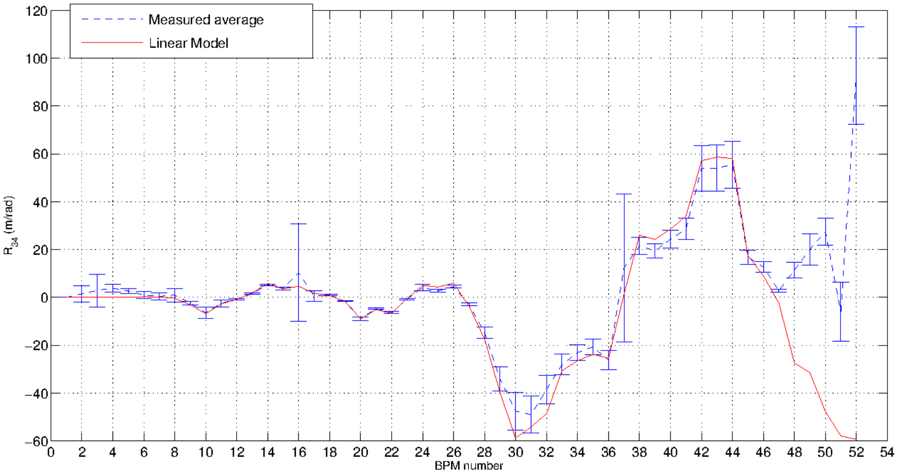
Cleaning the results

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.


Linear Model
Measured average
300
200
100
0
−100
−200
−300
−400
R_{12} (m/rad)
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
BPM number


Measured average
Linear Model
R34 (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: $\sigma_{\rm jitt} = \sqrt{\langle u^2 \rangle}$, $u = x, y, x', y'$

Jitter

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

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

Influence at the IP beam size

The beam size is affected by the jitter:

$$\sigma^\star_{\text{eff}} = \sqrt{(\sigma^\star)^2 + (\sigma^\star_{\text{jitt}})^2}$$

The jitter propagates to the IP:

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

Very important for the Ultra-low β where the sextupoles are stronger and the nonlinear terms are more notorious.

Conclusions and prospects

- The agreement between the linear model and the measured R_{12} and R_{34} is quite good.
- Some disagreement appears well inside the Final Focus due to the bad calibration of the Final Focus BPMs.
- We have reconstructed the initial jitter and we can see how it affects to the IP beam size.

Future plan

- Study the long term stability and reproducibility.