Towards the Calibration of the Nonlinear Ring Model at Diamond

R. Bartolini

Diamond Light Source Ltd
John Adams Institute, University of Oxford

NLBD Workshop Grenoble
27 May 2008

Summary

- Motivations
- Theory and tracking results
- Pinger experiments at Diamond

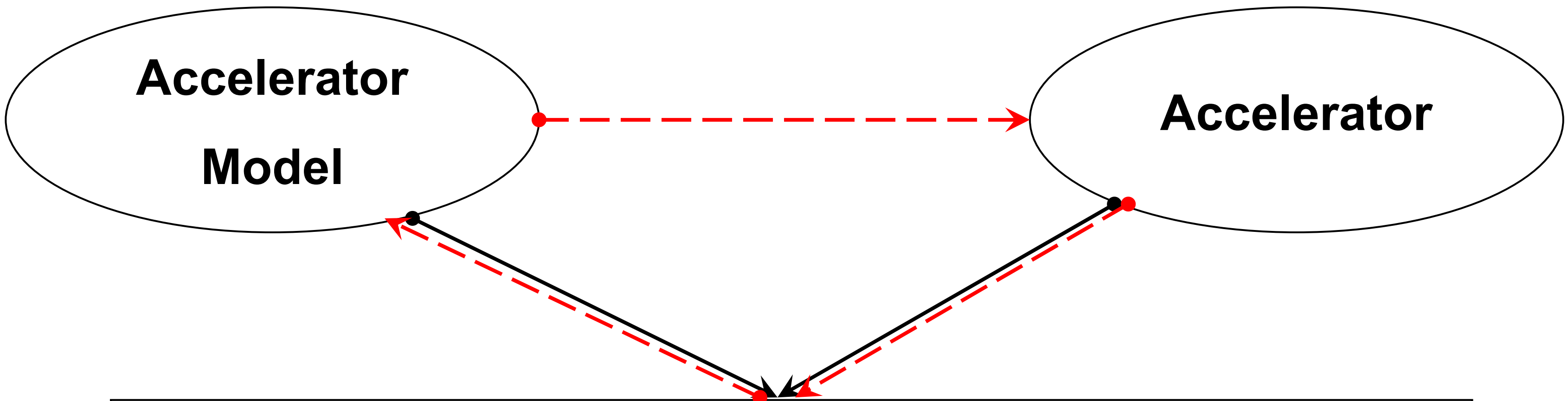
    Pinger calibration

    Spectral lines detection

    Correction of nonlinear resonances

- Conclusions: perspectives and limits

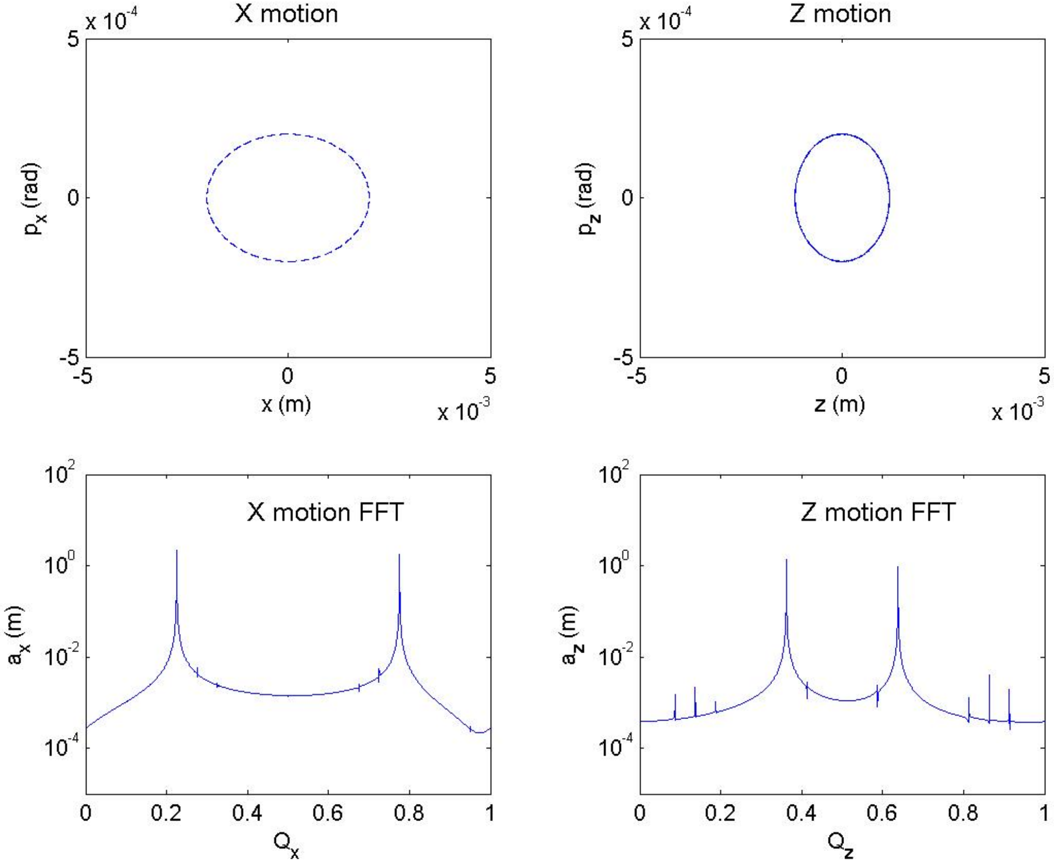
Comparison Real Lattice to Model



- Closed Orbit Response Matrix (LOCO)
- Detuning with amplitude (and with momentum)
- Frequency Map Analysis
- Apertures and Lifetime
- Frequency Analysis of Betatron Motion (resonance driving terms)

Frequency Analysis of betatron motion

Example: Spectral Lines for Diamond lattice
(.2 mrad kick in both planes – tracking data)



Spectral Lines detected with SUSSIX (NAFF algorithm)

e.g. in the horizontal plane:

- (1, 0) $1.10\ 10^{-3}$ horizontal tune
- (0, 2) $1.04\ 10^{-6}$ $Q_x + 2\ Q_z$
- (–3, 0) $2.21\ 10^{-7}$ $4\ Q_x$
- (–1, 2) $1.31\ 10^{-7}$ $2\ Q_x + 2\ Q_z$
- (–2, 0) $9.90\ 10^{-8}$ $3\ Q_x$
- (–1, 4) $2.08\ 10^{-8}$ $2\ Q_x + 4\ Q_z$

Spectral lines and nonlinear resonances

J. Bengtsson (1988): CERN 88–04, (1988).
J. Laskar's work: Physica D 56, 253, (1992)
R. Bartolini, F. Schmidt (1998), Part. Acc., **59**, 93, (1998).
R. Tomas, PhD Thesis (2003)

• The main spectral lines appear at frequencies which are linear combinations of the betatron tunes;

• Each resonance driving term f_{jklm} contributes to the Fourier coefficient of a definite spectral line; to the lowest perturbative order there's a one-to-one correspondence

$$\nu_H(f_{jklm}) = (1-j+k)Q_x + (m-l)Q_y$$

e.g the (3,0) resonance driving term f_{3000} excites the (-2,0) spectral line

• The amplitude and phase of spectral lines (and driving terms) vary along the ring;

Frequency Analysis of Betatron Motion and Lattice Model Reconstruction (1)

A possible Scheme (R. Bartolini, F.Schmidt PAC05)

Accelerator Model ↓

- tracking data at all BPMs
- spectral lines from model (NAFF)
- build a vector of Fourier coefficients

Accelerator ↓

- beam data at all BPMs
- spectral lines from BPMs signals (NAFF)
- build a vector of Fourier coefficients

e.g. targeting more than one line

$$\overline{A} = \left(a_1^{(1)} \quad \ldots \quad a_{NBPM}^{(1)} \quad \varphi_1^{(1)} \quad \ldots \quad \varphi_{NBPM}^{(1)} \quad a_1^{(2)} \quad \ldots \quad a_{NBPM}^{(2)} \quad \varphi_1^{(2)} \quad \ldots \quad \varphi_{NBPM}^{(2)} \quad \ldots \right)$$

Define the distance between the two vector of Fourier coefficients

$$\chi^2 = \sum_k \left(A_{Model}(j) - A_{Measured}(j) \right)^2$$

Frequency Analysis of Betatron Motion and Lattice Model Reconstruction (2)

Least Square Fit (SVD) of accelerator parameters θ

to minimize the distance χ^2 of the two Fourier coefficients vectors

- Compute the "Sensitivity Matrix" M $\quad \Delta\overline{A} = M\overline{\theta}$
- Use SVD to invert the matrix M $\quad M = U^T W V$
- Get the fitted parameters $\quad \overline{\theta} = (V^T W^{-1} U)\,\Delta\overline{A}$

MODEL → TRACKING → NAFF →

Define the vector of Fourier Coefficients (amplitude and phase of spectral lines) →

Define the parameters to be fitted (i.e. sextupole gradients) →

SVD → CALIBRATED MODEL

Comparison with LOCO-type of machine modelling

LOCO

Closed Orbit Response Matrix
from model

Closed Orbit Response Matrix
measured

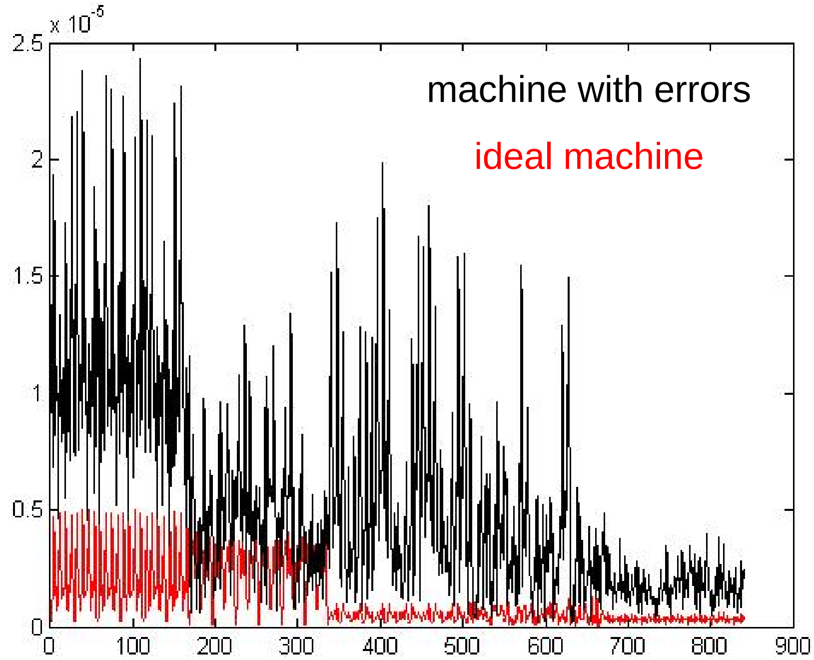
→ fitting quadrupoles, etc → Linear lattice correction/calibration

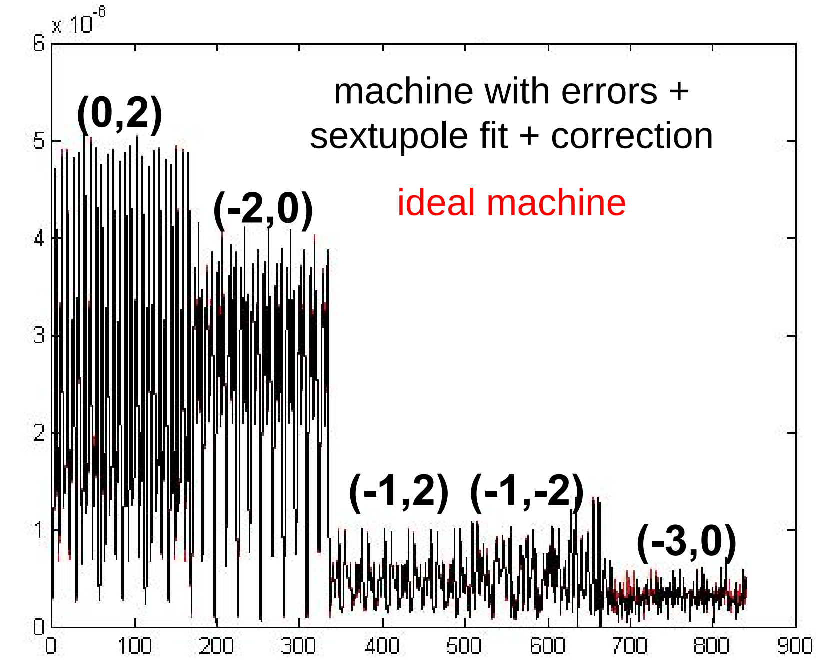
Spectral lines
from model

Spectral Lines
measured

→ fitting sextupoles → Nonlinear lattice correction/calibration

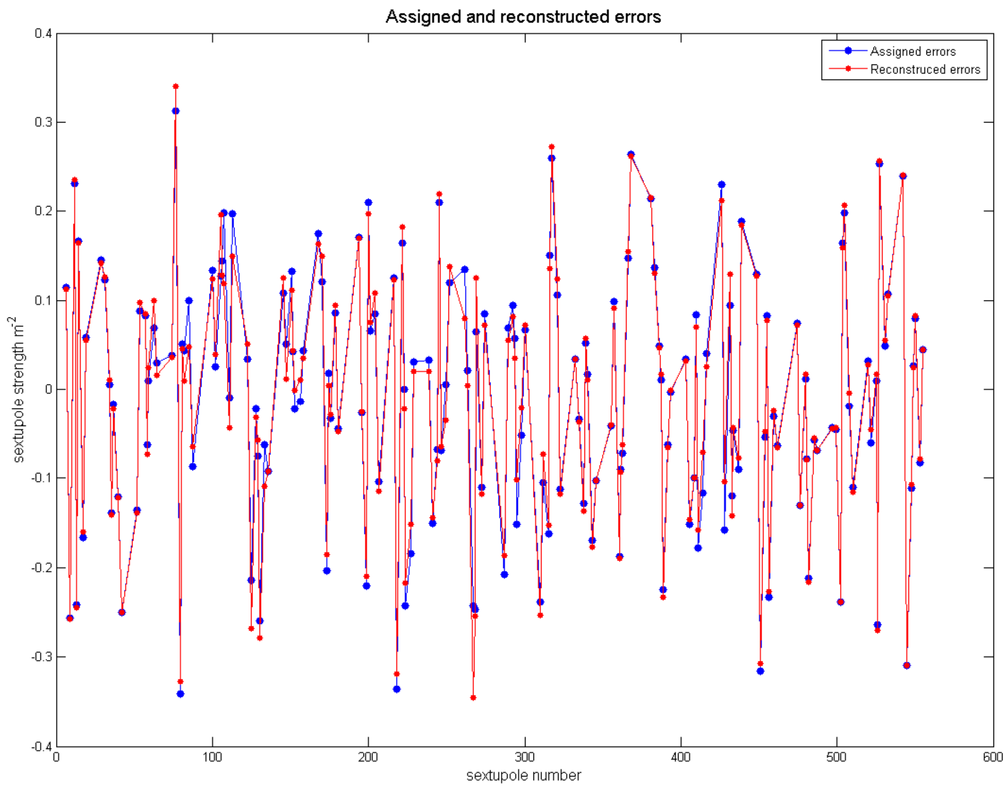
Fitting sextupole gradients to correct the s-dependence of the amplitude of the spectral lines





Given a machine with random sextupole errors, generating noisy spectral lines (black-left), the sextupole were fitted to reproduce the target vector (red-left) given by the ideal model. In this way we can correct the nonlinear model of the ring

Errors reconstruction from tracking data



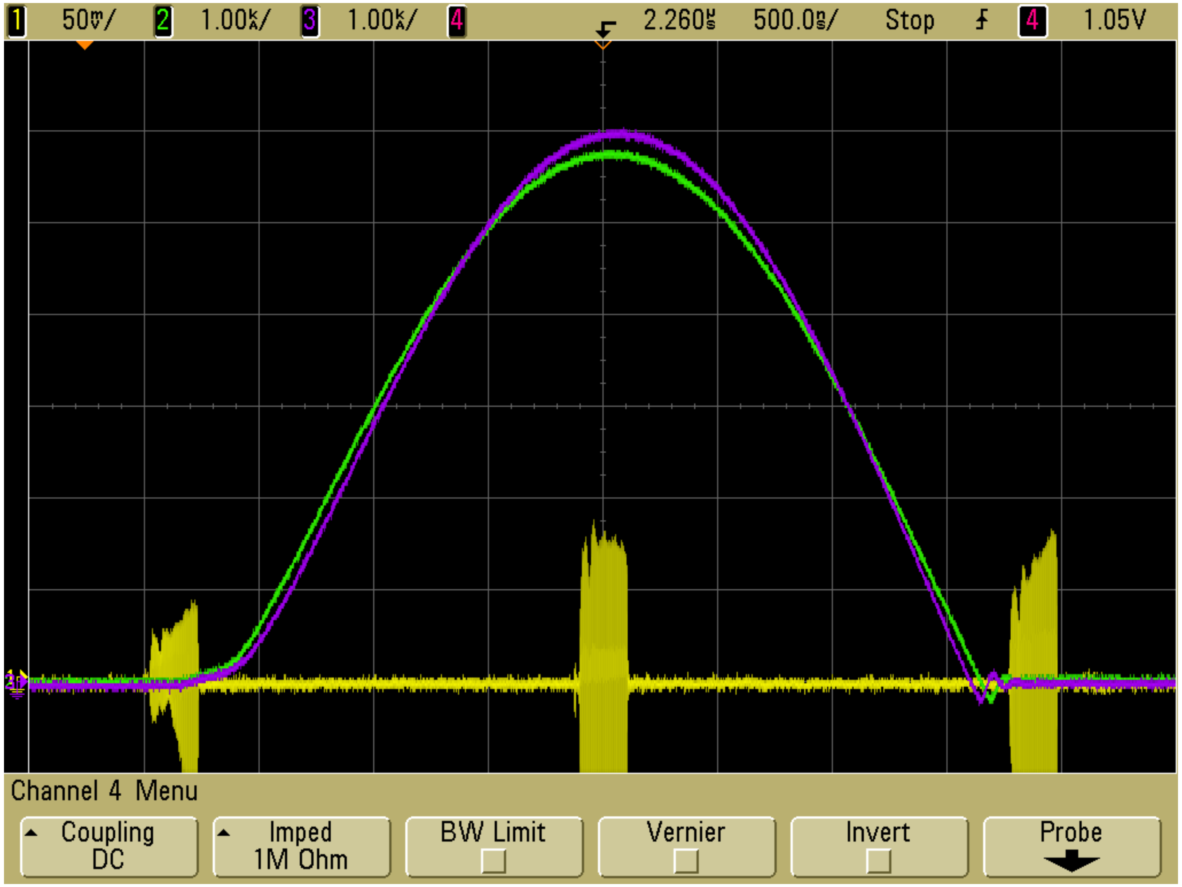
Blue dots are the originally assigned random errors

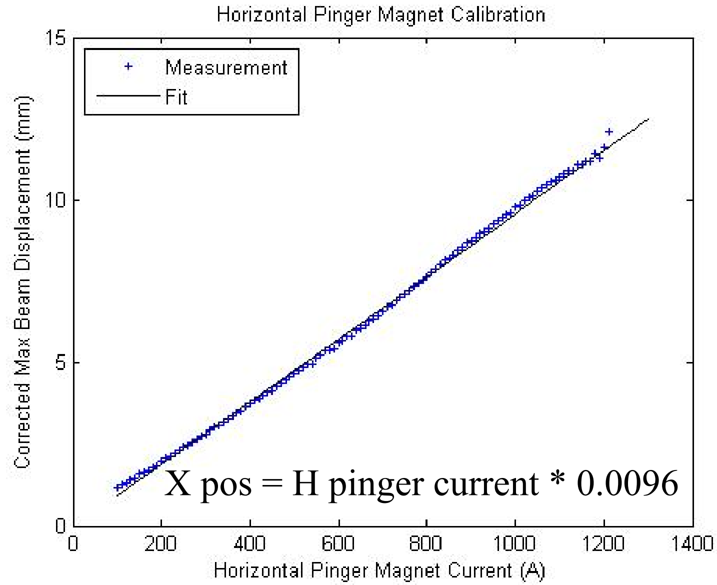
Red dots are the reconstruction of the errors obtained from the sextupole fit

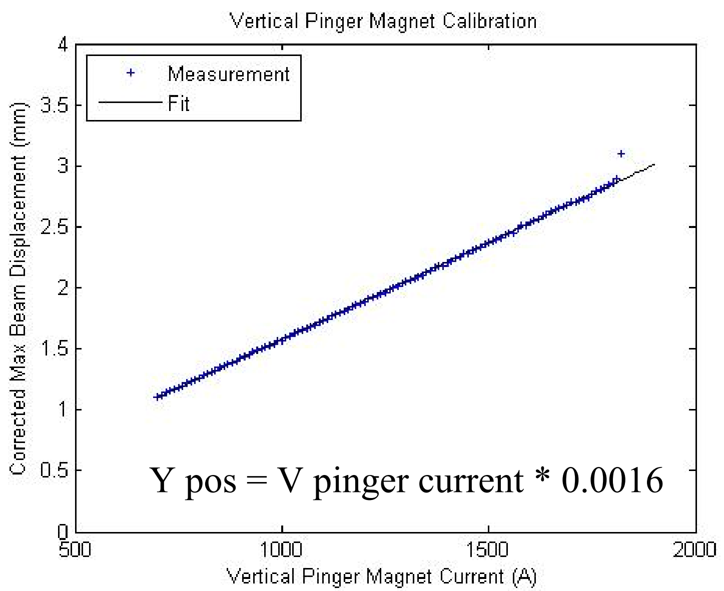
The fit procedure involves many spectral lines and many SVD iterations

A detail reconstruction of the machine model and its correction is possible on tracking data

Pinger Experiments at Diamond







Pingers Calibration

The pingers deliver a half sine pulse of ~ 3μs (Trev = 1.87 μs)

Experiments were performed using a fill with 100 bunches (~1/10 fill) and 25 mA, with slighlty positive chromaticity 0.5

Maximum H and V amplitude of the excited oscillation as a function of the kicker voltage shows a linear dependence <u>after correction of the non linearity of the BPM</u>

All BPMs have turn-by-turn capabilities

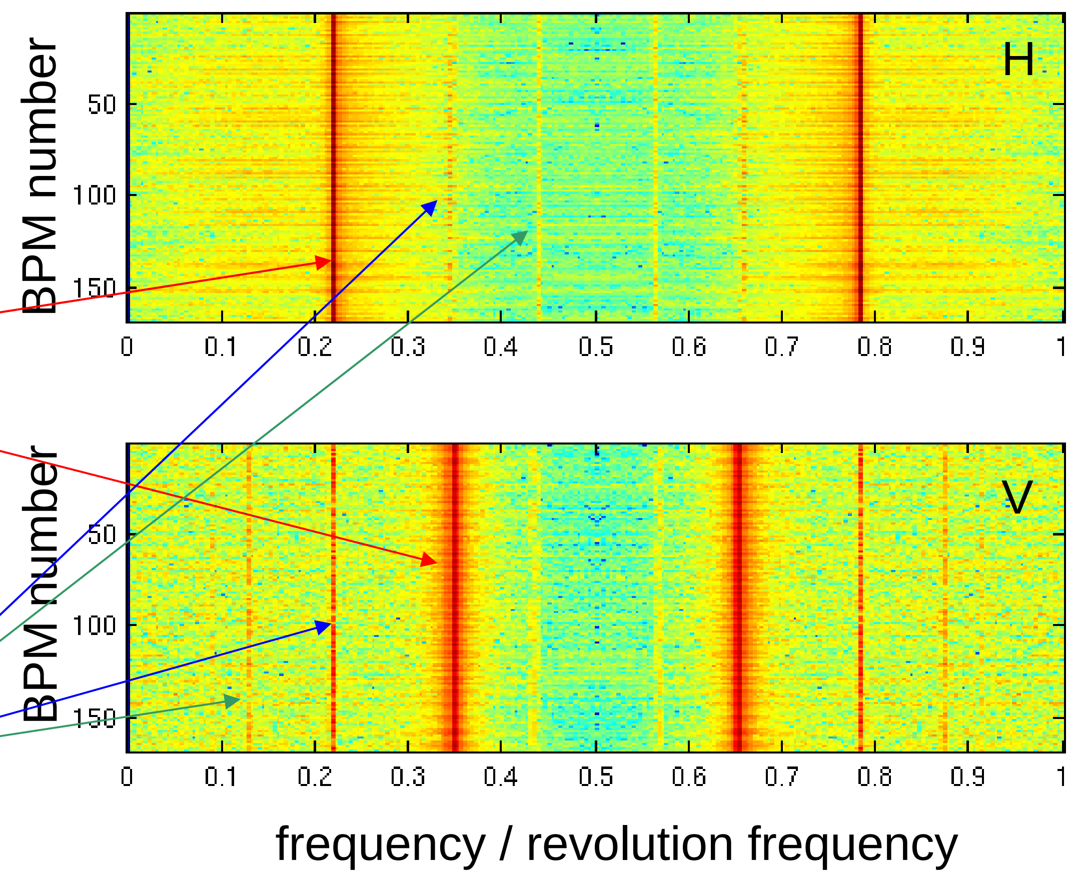
- excite the beam diagonally
- measure tbt data at all BPMs
- colour plots of the FFT

Q_X = 0.22 H tune in H

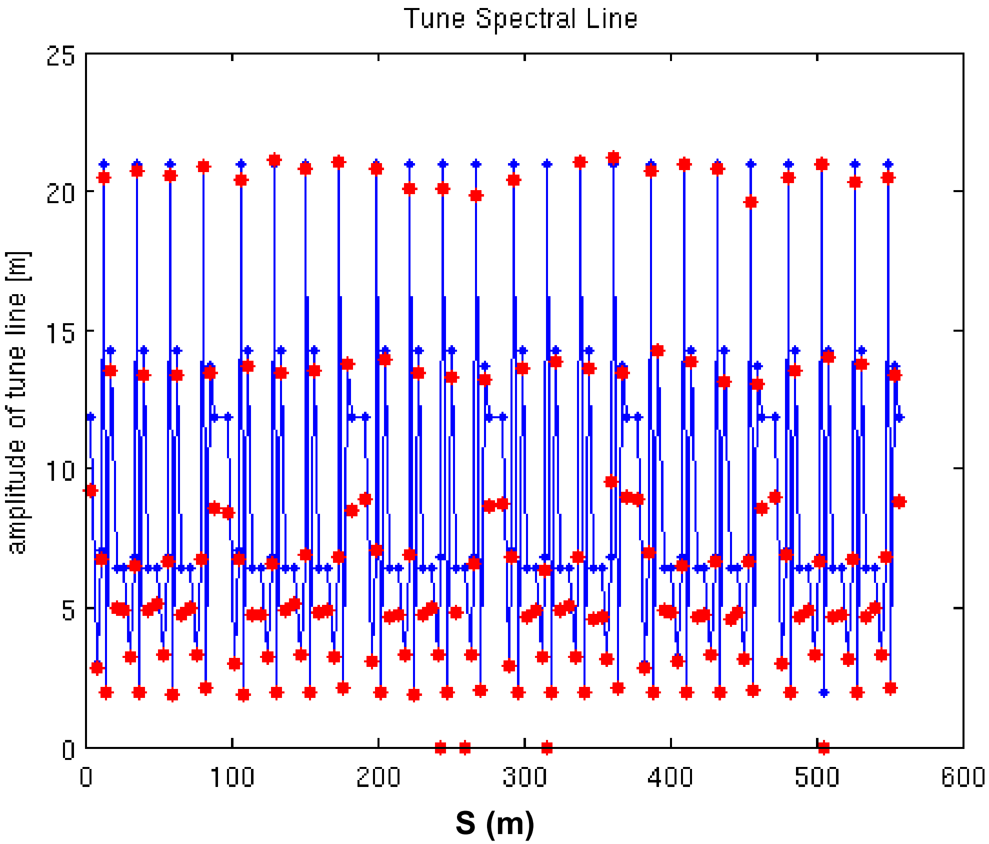
Q_y = 0.36 V tune in V

All the other important lines are linear combination of the tunes Q_x and Q_y

$m\ Q_x + n\ Q_y$



Linear lattice from turn-by-turn data beta functions



The amplitude of the tune line is proportional to the square root of the beta function

$$x(n) = \sqrt{\varepsilon\beta}\cos(2\pi Q_x n + \varphi)$$

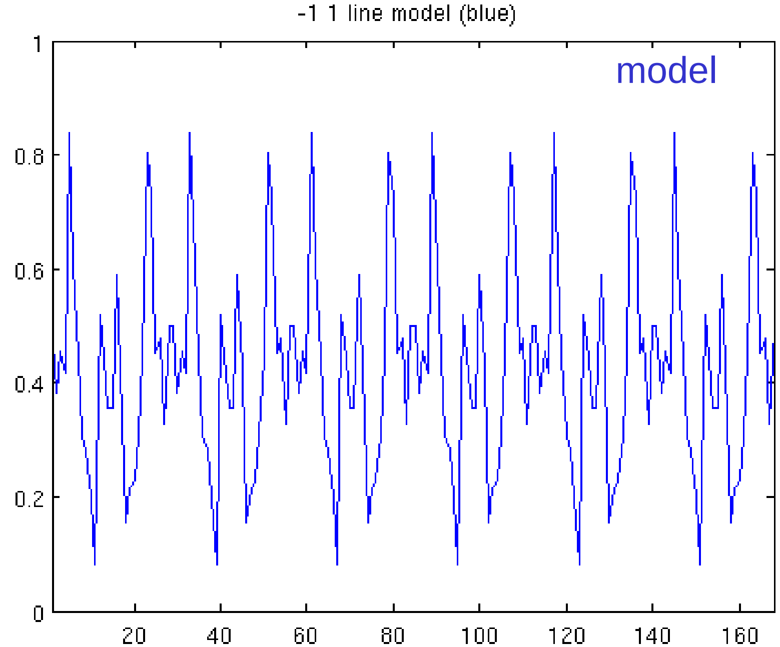
The beta functions at most BPMs are reproduced within few % except at the primary BPMs

Bpm gains on primary are low by 10-15% (confirmed by LOCO)

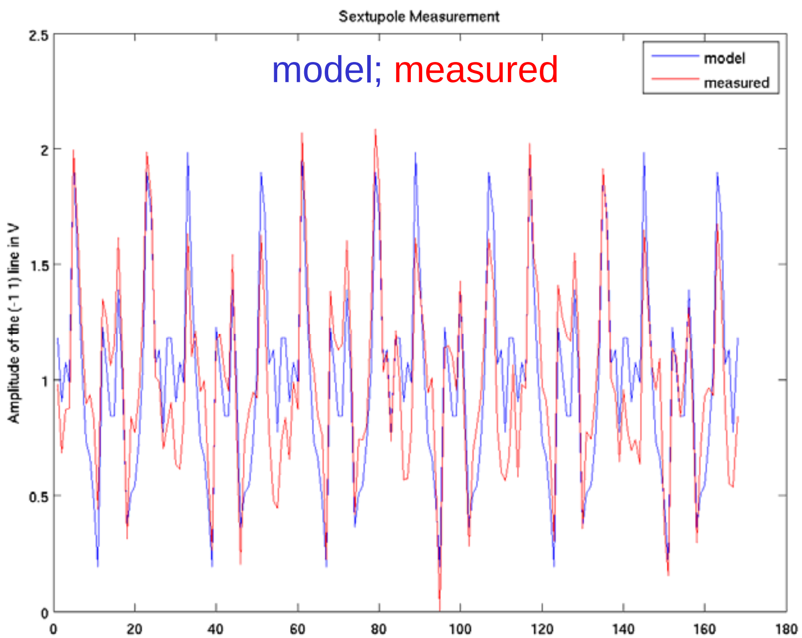
The linear optics was corrected with LOCO – coupling < 0.2%

Spectral line (-1, 1) in V associated with the sextupole resonance (-1,2)

Spectral line (-1,1) from tracking data observed at all BPMs

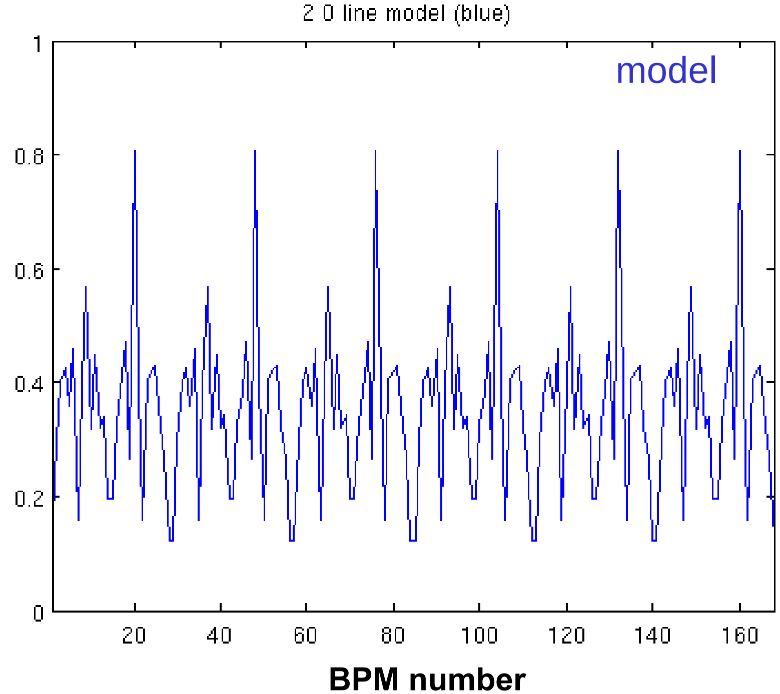


Comparison spectral line (-1,1) from tracking data and measured (-1,2) observed at all BPMs

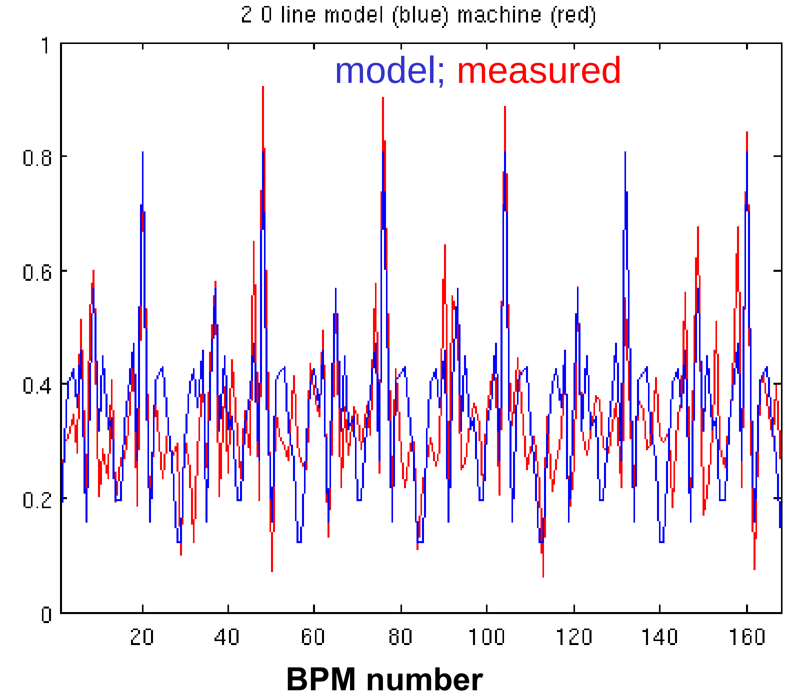


Spectral line (-2, 0) in H associated with the sextupole resonance (3,0)

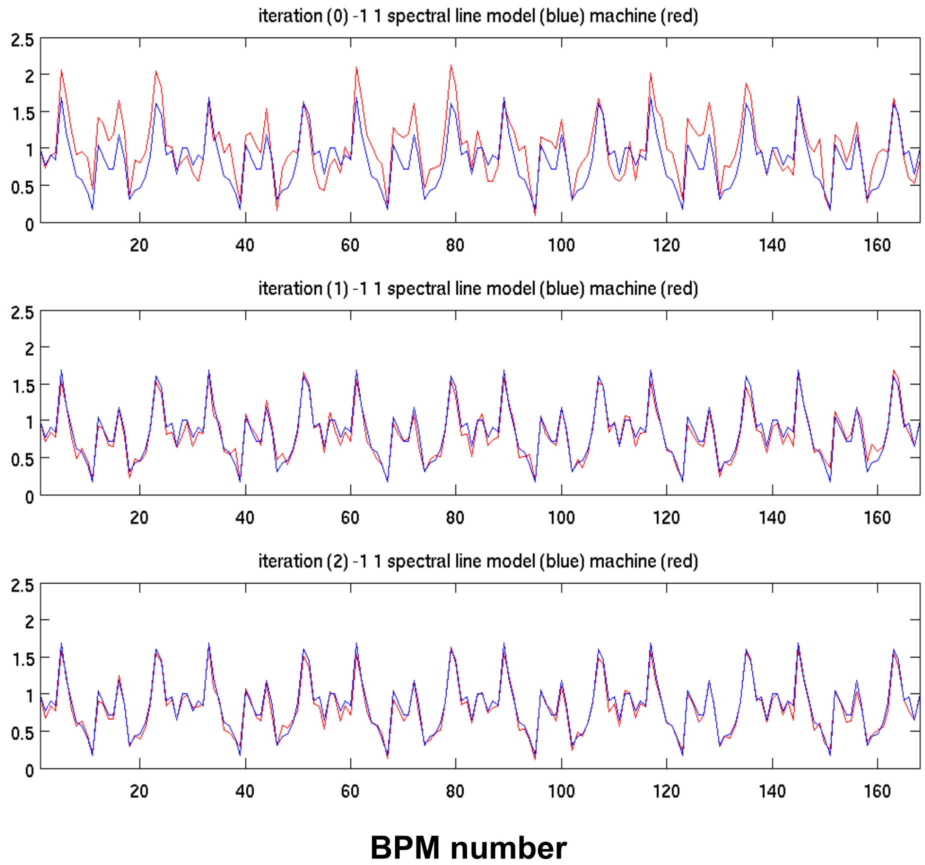
Spectral line (-2,0) from tracking data observed at all BPMs



Comparison spectral line (-2,0) from tracking data and measured (-2,0) observed at all BPMs



Spectral lines (-1,1) in V measured vs model a first fit of the sextupole gradient



Blue model; red measured

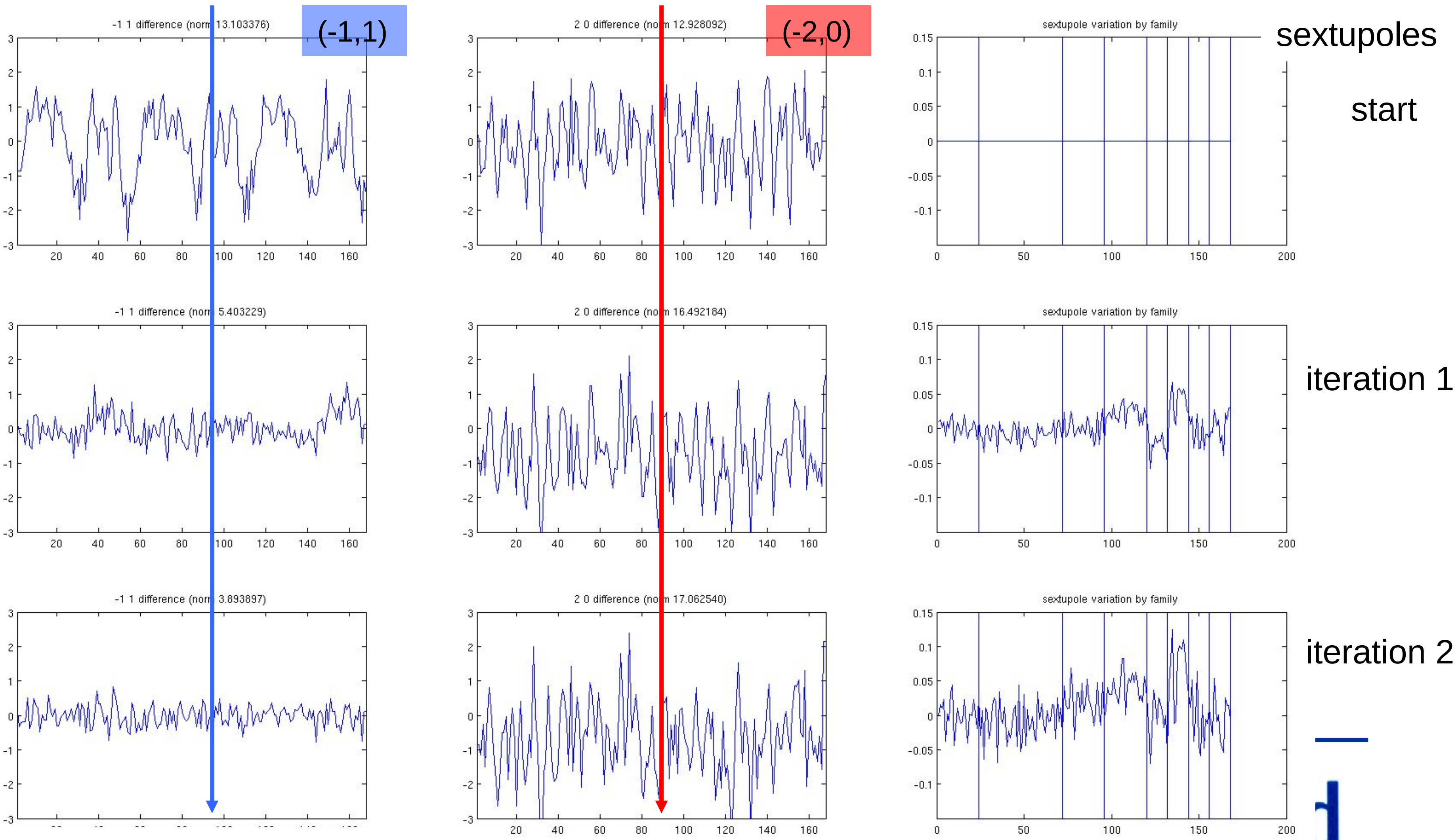
A first attempt to fit the spectral line (-1,1), determined by the resonance (-1,2), improved the agreement of the spectral line with the model

However the lifetime was worse by 15%

The fit produced non realistic large deviation in the sextupoles (>10%);

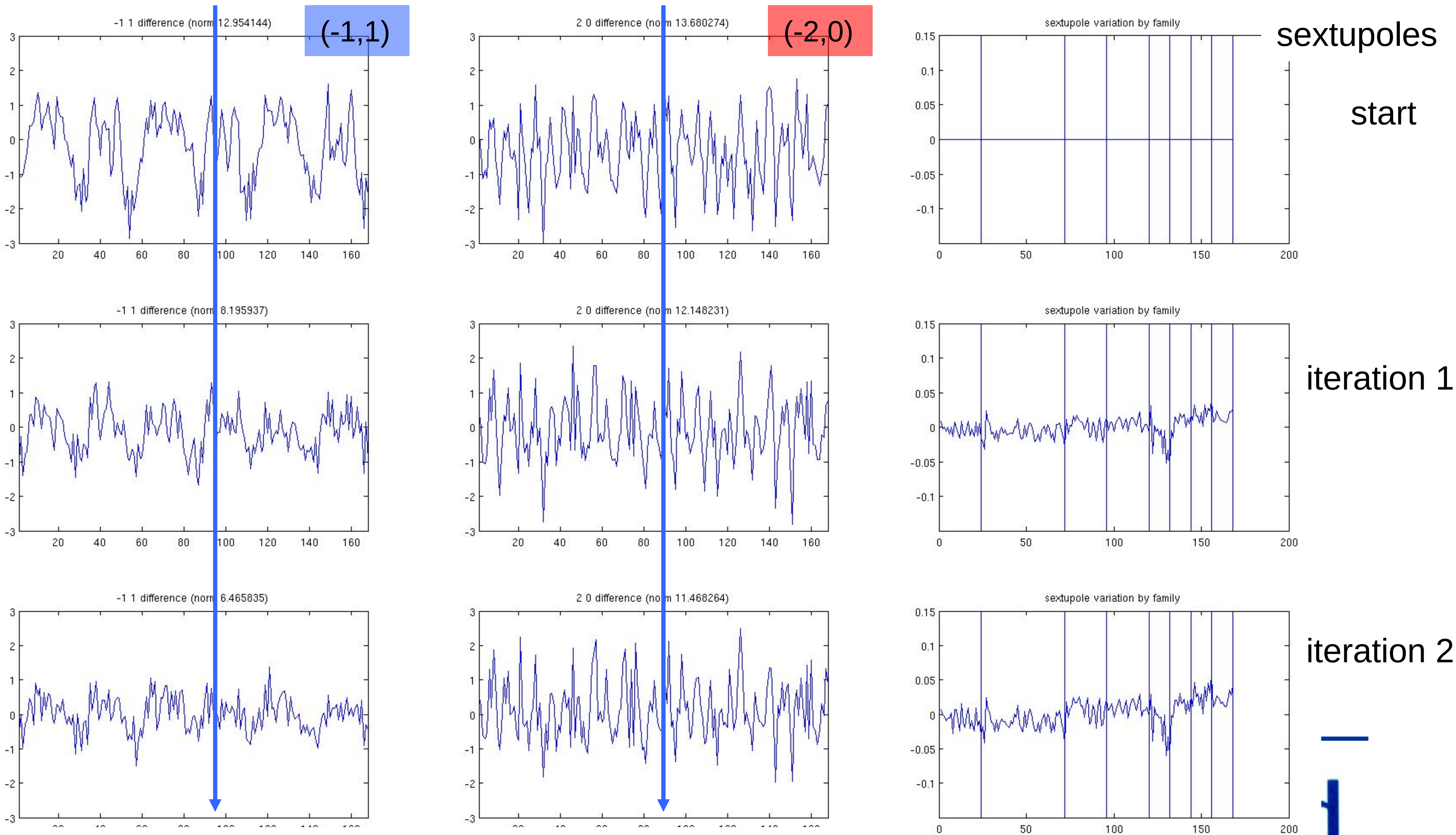
The other spectral lines were spoiled

fit of (-1,1) in V



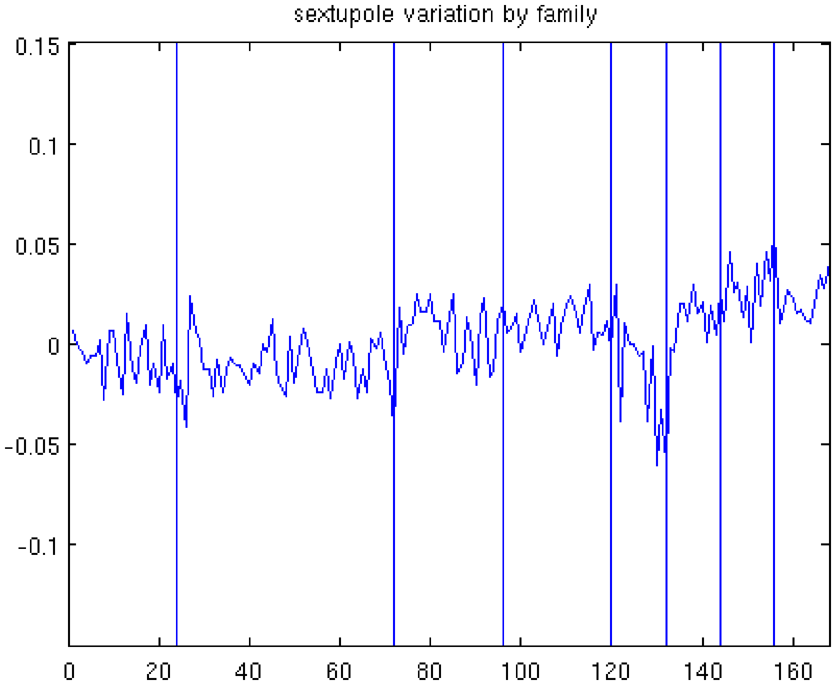
resonance correction This resonance is increasing!

Simultaneous fit of (-2,0) in H and (1,-1) in V



Both resonance driving terms are decreasing

Sextupole variation



Now the sextupole variation is limited to < 5%

Both resonances are controlled

and the **lifetime improved by 10%**

Limits of the Frequency Analysis technique

BPMs precision in turn by turn mode (+ gain, coupling and non-linearities)

10 μm with ~10 mA

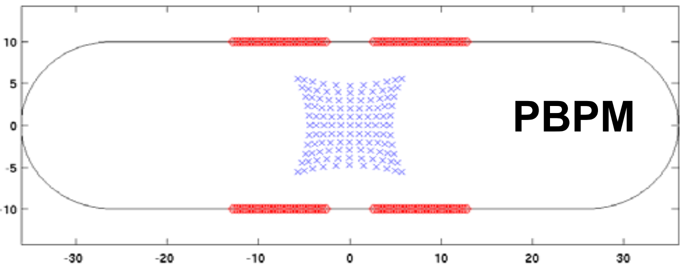
very high precision required on turn-by-turn data (not clear yet is few tens of μm is sufficient); Algorithm for the precise determination of the betatron tune lose effectiveness quickly with noisy data. R. Bartolini et al. Part. Acc. 55, 247, (1995)

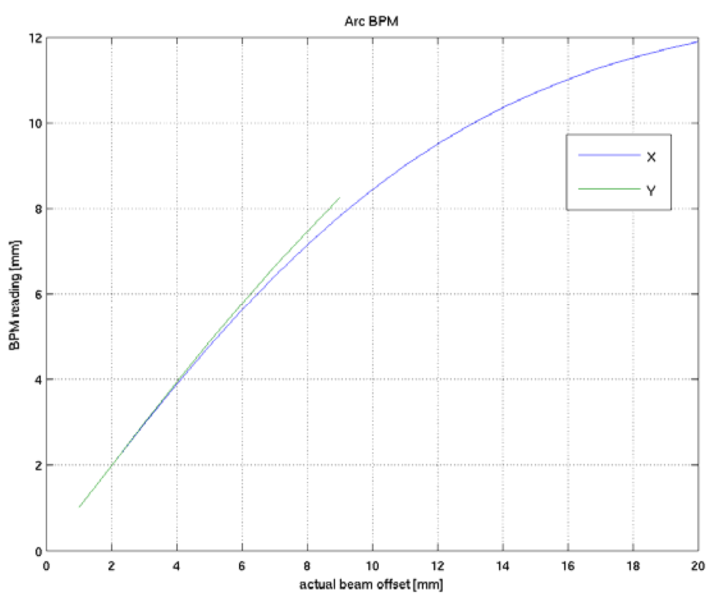
BPM gain and coupling can be corrected by LOCO, but nonlinearities remain (especially for diagonal kicks)

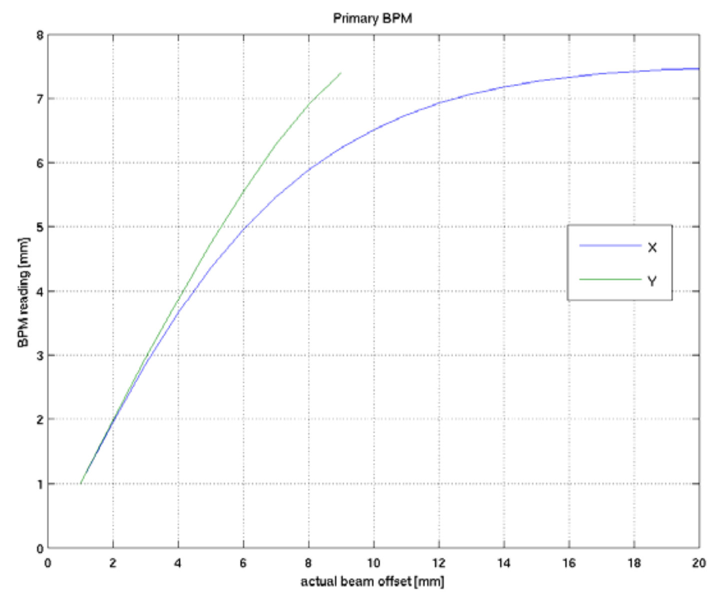
Decoherence of excited betatron oscillation reduce the number of turns available
Studies on oscillations of beam distribution shows that lines excited by resonance of order m+1 decohere m times faster than the tune lines. This decoherence factor m has to be applied to the data R. Tomas, PhD Thesis, (2003)

Non-#linearities of BPM readings

The relation between BPMs reading and beam position is linear only in a reduced region around the BPM block centre



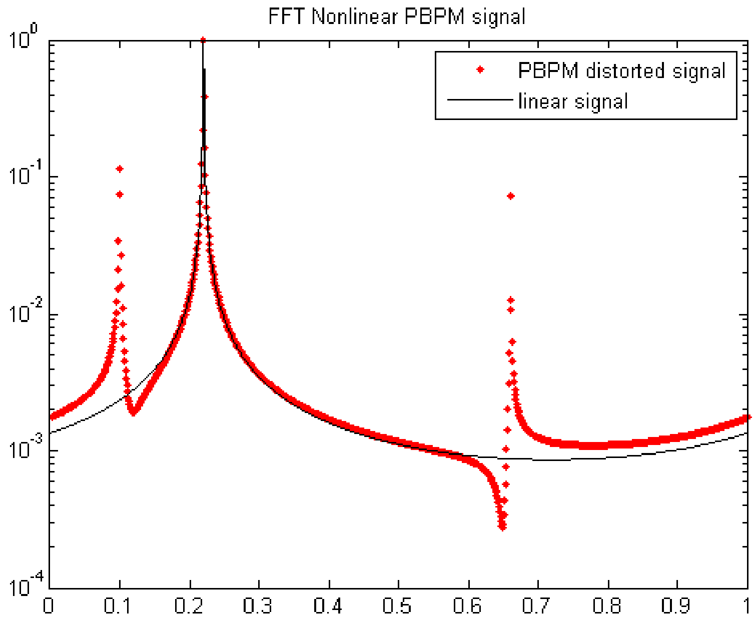




Effect of BPM nonlinearities on a simple harmonic signal (one frequency)

Signal from betatron oscillations is x;

BPM nonlinearity fit outputs: $ax^5 + bx^3 + c$



X_{max} = 5 mm

the $3Q_x$ and $5Q_x$ lines appear

due to X^3 and x^5 terms

This will compromise the detection of high order lines, but not the ones due to sextupoles…

The amplitude of the tune line is only slightly changed by the nonlinearities of the BPM

Conclusions

Pinger magnets were installed on the diamond storage ring and are operational since end September 07

Characterisation of the non-linear beam motion is ongoing: a wealth of information can be obtained from the turn-by-turn data

Correction strategies are under investigation with the ambitious aim to reconstruct a non-linear model of the ring

Multiple Resonance correction and Improvement in Touschek lifetime was achieved

Many thanks to P. Kuske, I. Martin, G. Rehm, J. Rowland, F. Schmidt