Beam Dynamics Measurements with Fast Acquisition BPMs and AC correctors at ALBA

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on behalf of
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Outline

- ✓ Motivation
- ✓ Fast Acquisition BPM Archiver
- ✓ Corrector Magnets
- ✓ Fast ORM Measurements
- ✓ Non-linear Measurements
- ✓ Fast BBA
- ✓ Summary

Motivation

The usual Orbit Response Matrix (ORM) measurement with DC Corrector Magnets (CM) and Slow Acquisition (SA) BPM data, based on Tango Device Server commands, relies on network synchronization.

At ALBA, with 88H+88V DC corrector magnets x 120 BPMs, **the SA ORM measurement takes 7 min.**

By exploiting the Fast Acquisition (FA) BPM data and the AC CM capabilities, the **FA ORM measurement can be speeded up to only 2 min.**

Having a fast linear optics diagnostics eases considerably both:

- ✓ Operational procedures
- ✓ Dedicated machine development time

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Fast Acquisition Archiver

ALBA Synchrotron Light Facility

- ✓ The software was developed at Diamond and minimally adapted at ALBA
- ✓ This system stores the **synchronous data at 10 kHz rate** of the 120 Libera BPMs
- ✓ The server can be accessed using both Matlab and Python scripts
- ✓ **Python** has been eventually chosen since its **threading capabilities** are very helpful

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Corrector Magnets

The CM are controlled by OCEM cards.

Thought the OCEM PSI power supply controller allows **triggering** of **hardware** waveforms, this feature was not implemented in the Tango Device Server.

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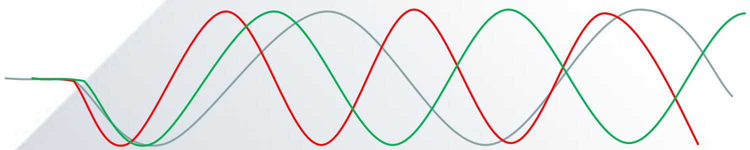
FA ORM Measurements

Parallel excitation of a set of CM with sinusoidal waveforms of different **frequencies** makes much faster the ORM measurement, since we can measure the BPM response to several CM at a time.



Fourier-like analysis allows measuring the amplitude $M_{j,l}$ and phase $\phi_{j,l}$ at the j^{th} BPM produced by the l^{th} CM.

The ORM is then obtained by:

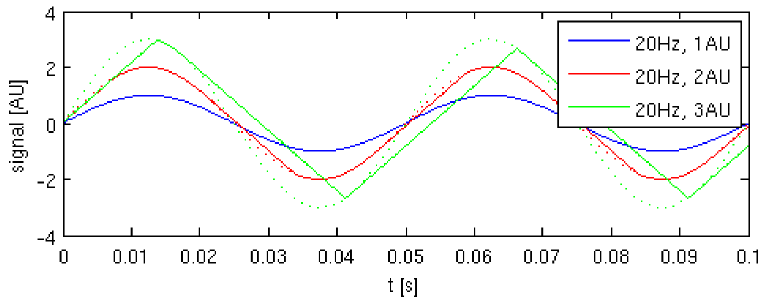
$$ORM_{l,j} = M_{j,l} sign\left(\phi_{j,l} - min(\phi_{j,l}) - \frac{\pi}{2}\right)$$

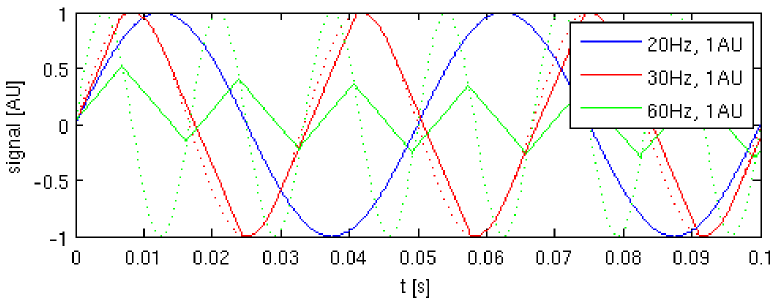
Setting Multi-cycle Sinusoidal CM Waveforms

Parameters to be set:

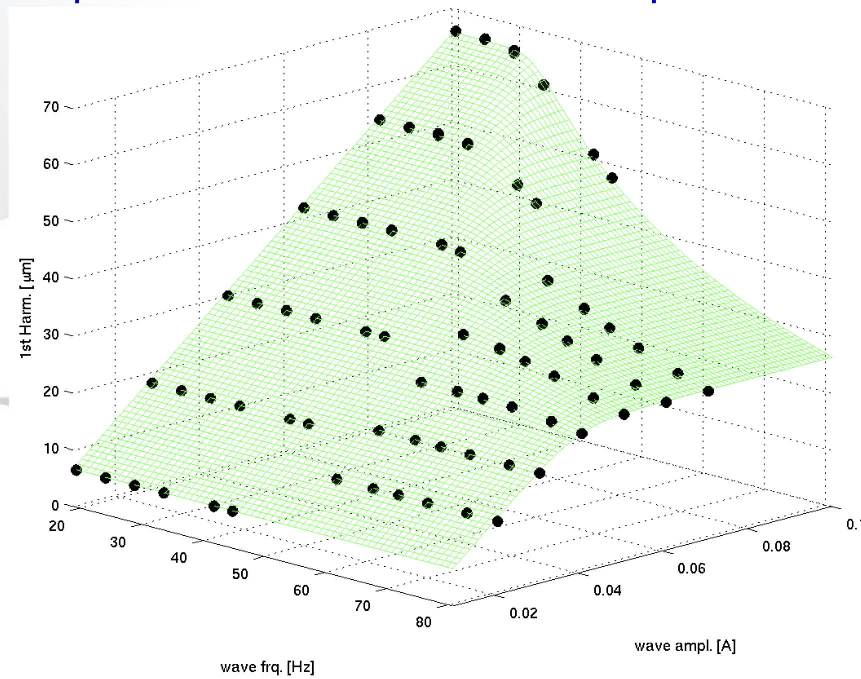
- **Amplitude** of the CM waveforms
- **Number of CMs** excited in parallel
- **Frequencies** of the CM waveforms
- For how long exciting CM (**# of cycles**)

The response limitations of the CM power supplies to high frequencies and high amplitudes must be take into account.





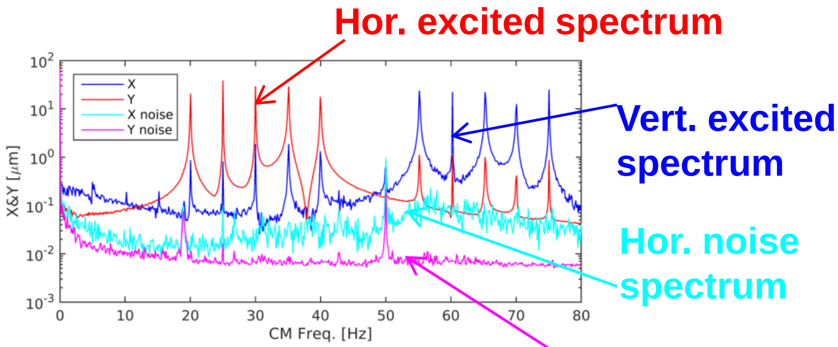
Scans of waveforms frequencies and amplitudes to chose the best compromise.



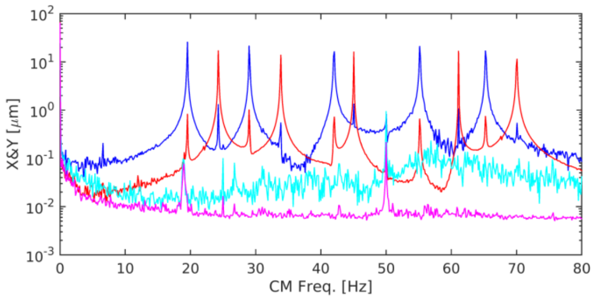
CM frequencies pattern

3 cases with different sets of frequencies were compared:

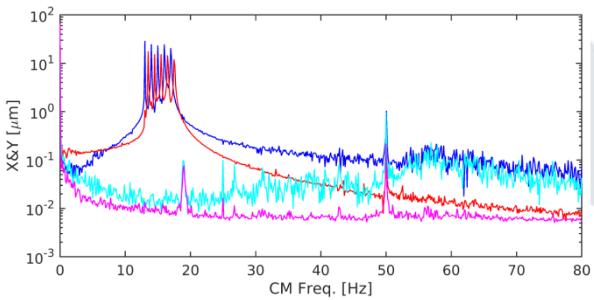
A. Hor. and Vert. CM excited with separated frequencies: below and above 50Hz



B. Hor. and Vert. CM excited with alternated frequencies.



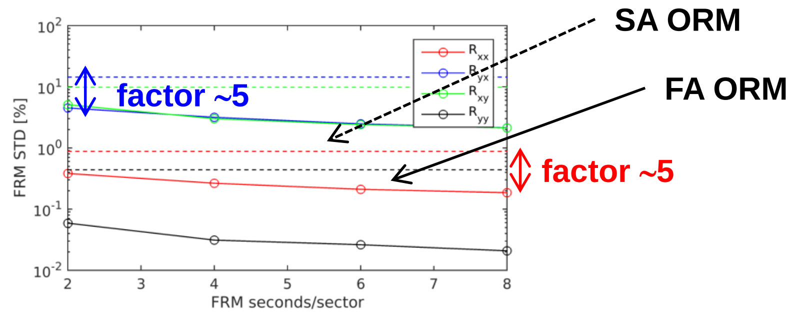
C. Hor. and Vert. CM close by frequencies in the lowest BPM noise region: 10-20 Hz



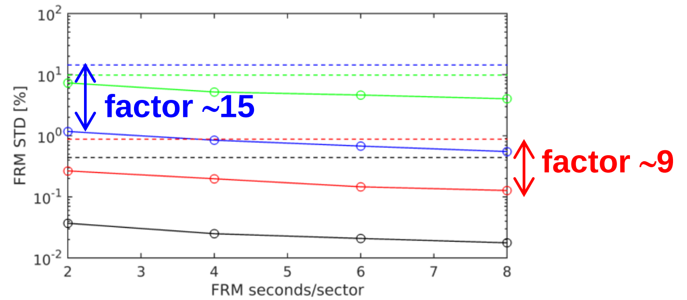
FA ORM repeatability

FA ORM repeatability STD against usual SA ORM:

A. Hor. and Vert. CM excited with separated frequencies: below and above 50Hz



B. Hor. and Vert. CM excited with alternated frequencies.



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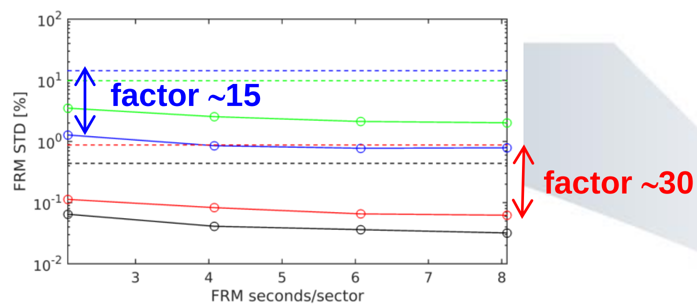
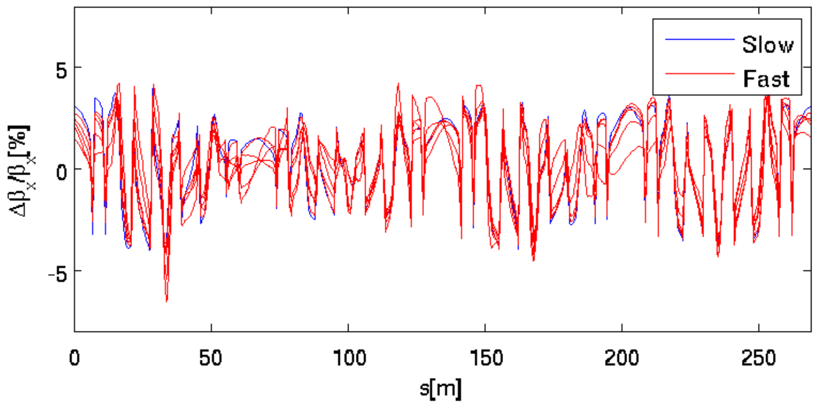


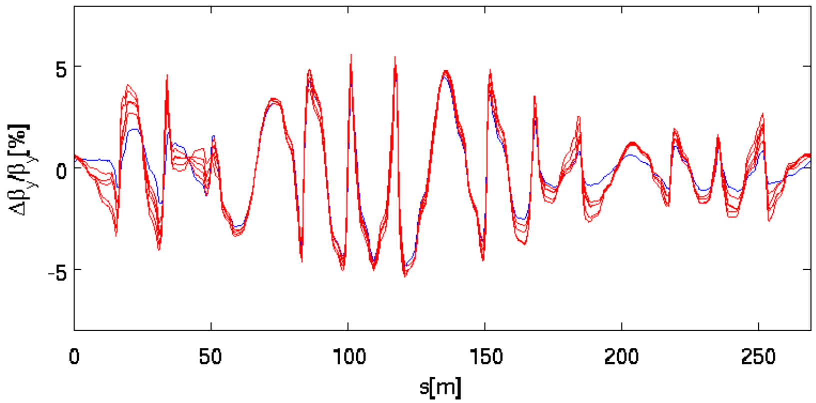
FA ORM: optics fit

Comparing beta beating (LOCO) from SA ORM and FA ORM:

Despite the better ORM precision and repeatability, the improvement in the beta beating is not so good: why?

First, the BPM noise is also much smaller.
Second, we found that the sign of some ORM elements with smaller values is flipping from an measurement to another, especially in the coupled planes.
We are still carrying out studies to understand how this problem.





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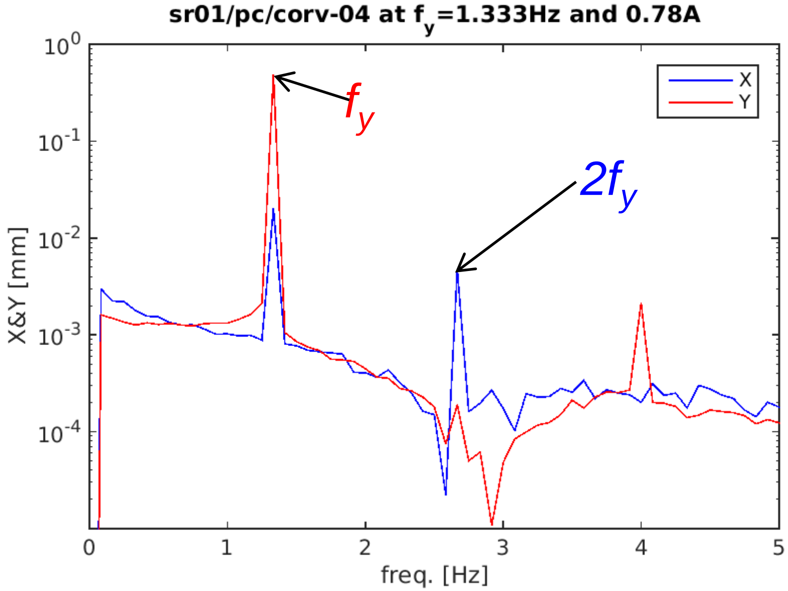
Non-linear FA ORM

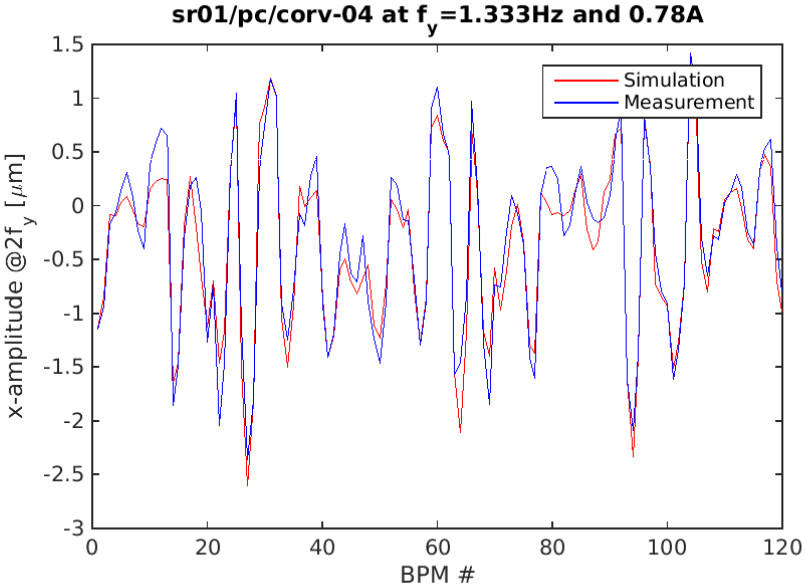
For **large orbit oscillations (>500 um)**, the **sextupolar** fields induce second order harmonics of the excited CM waveform frequency (ORM^2).

$$B_y = m\left(x^2 - y^2\right) \longrightarrow \quad \textit{Hor. spectrum: } 2f_x \,\&\, 2f_y$$

$$B_x = 2mxy, \longrightarrow \quad \textit{Vert. spectrum: } f_x+f_y \,\&\, f_x-f_y$$



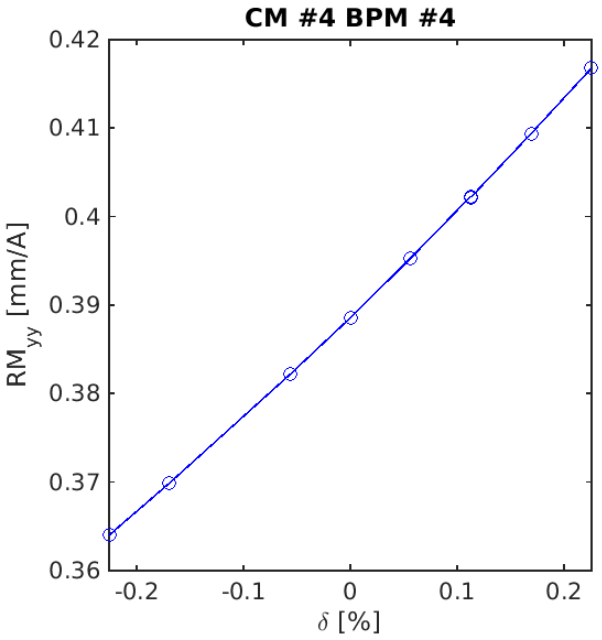
Discrete FFT of the BPM signals excited with a single vertical CM



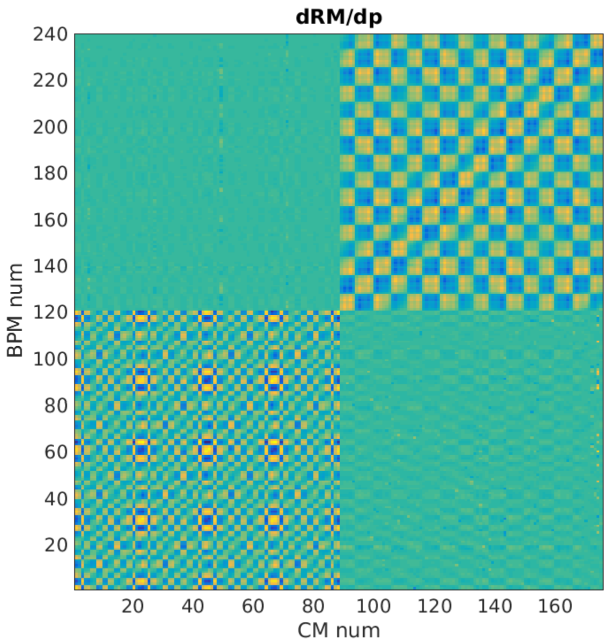
Measured amplitude of the second harmonic of the vertical plane CM frequency for all the horizontal BPM .

FA ORM with Energy

ORM element measured as a function of the relative energy deviation produced by a RF frequency change.



ORM derivate with respect to the relative energy deviation which can be used to fit non linear fields.



Both $\partial ORM/\partial\delta$ and ORM^2 depend linearly on the **sextupole** strengths and in principle can be used to fit the non-linear fields present in the machine.

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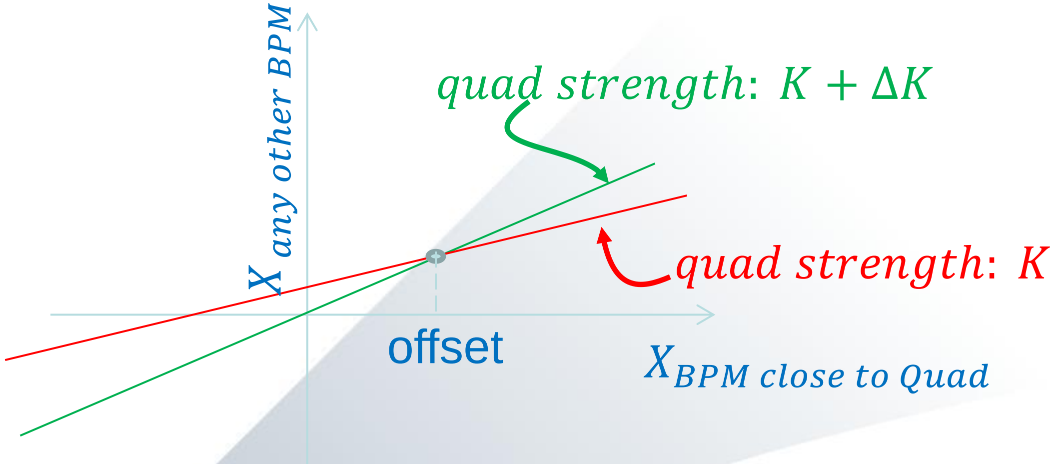
Fast Beam Based Alignment

The BPM 10 kHz data excited with a AC corrector can be used to measure offset of each BPM with respect to the nearest quadrupole (BBA):



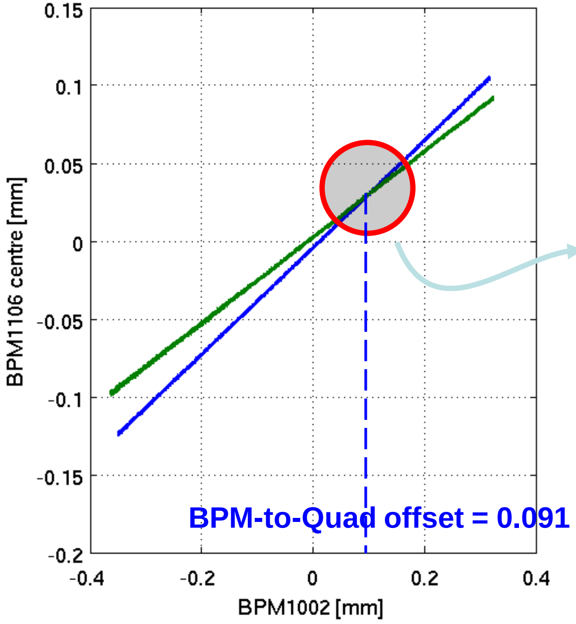
Exciting a single corrector, the positions measured at any BPM are linearly correlated among them.

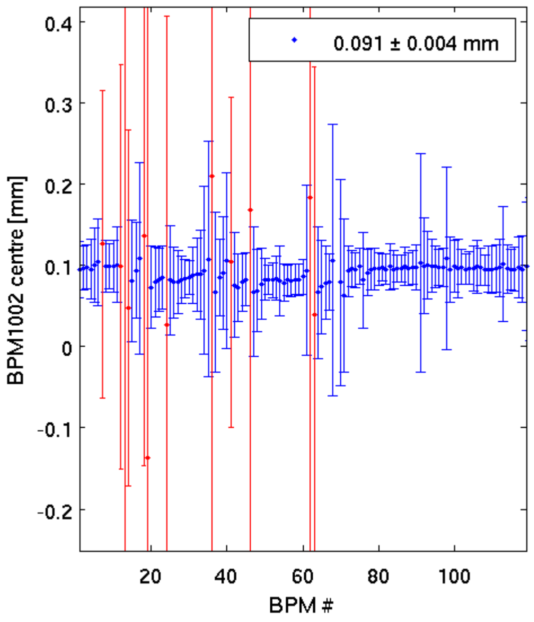
The BPM-to-Quad offset corresponds to the BPM reading where the orbit do not change at any BPM when the Quad is varied. This means that the orbit is passing through the quad centre.

This position is given by the intersection of the correlation straight lines.

Fast BBA: detail for a BPM

Tests on the 120 ALBA BPMs show that this technique is reliable and around a factor 5 faster than DC BBA.



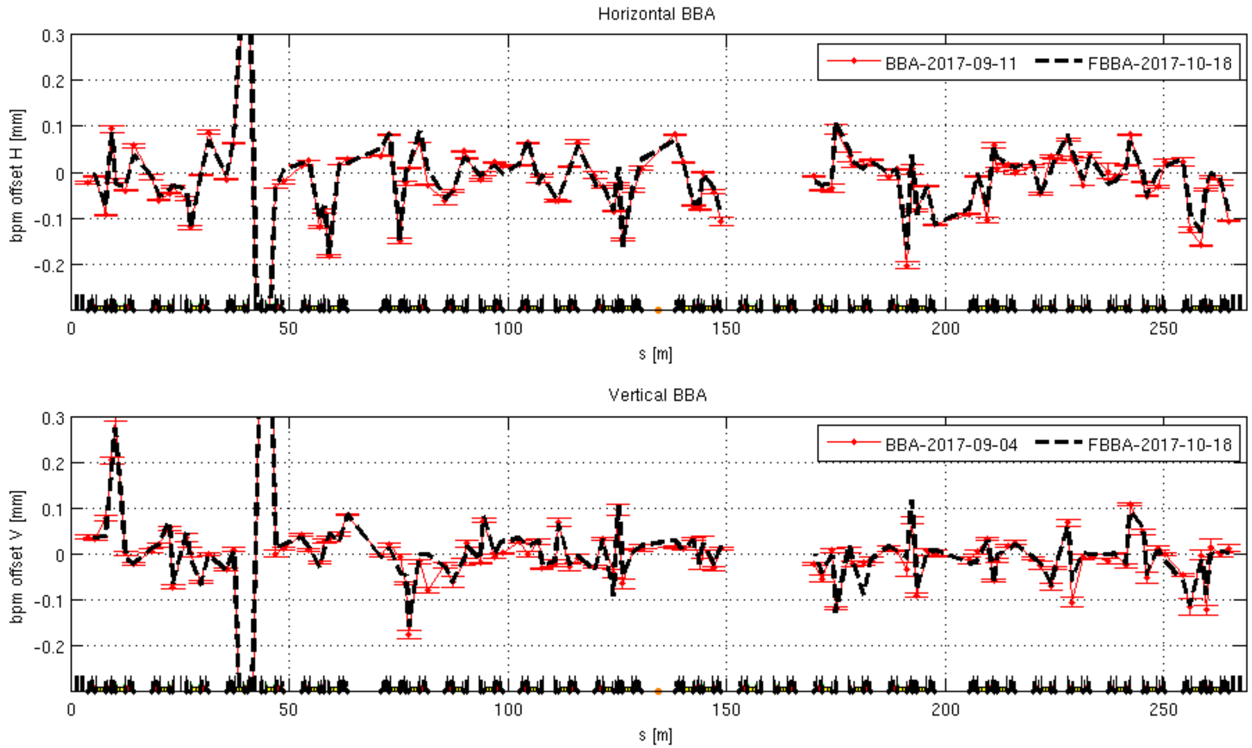


Offset and error bar from correlation between the BPM of interest and all the other 119 BPMs

For BPM offset the Fast BBA gives 0.091±0.004 mm which agrees with usual DC BBA offset of 0.095±0.004 mm

Fast BBA: results for all BPMs

For the 120 ALBA BPMs, Fast BBA measurement agree with the DC BBA with **equivalent precision and repeatability**:



Fast BBA

- ✓ **Hor and Ver plane can be simultaneously excited** using two different frequencies
- ✓ For BBA, **large orbit distortions (~500 um)** are needed so the excitation frequencies must be low: **6Hz and 7Hz**
- ✓ Hysteresis effects due to CM are minimized
- ✓ Large amounts of BPMs’ synchronized data
- ✓ In the Fourier analysis, using the information of a **single point of the spectrum** helps to get rid of lots of noise
- ✓ **A complete FA BBA (120 BPMs) takes 30 min instead of 5 hours**

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Summary

- ✓ Measurements with 10 kHz BPM data and AC CM excited with sinusoidal waveforms are ready to be implemented at ALBA
- ✓ The ORM repeatability is reduced by a factor 5 to 30 depending on the plane
- ✓ Non-linear studies (sextupole calibration) can be started thanks to precision of FA ORM
- ✓ A complete FA ORM takes 2 min instead of 7 min
- ✓ A complete FA BBA takes 30 min instead of 5 hours
- ✓ Both efficiency of operation procedures and machine studies benefit from this techniques

Thanks!

Questions?

Extra slides

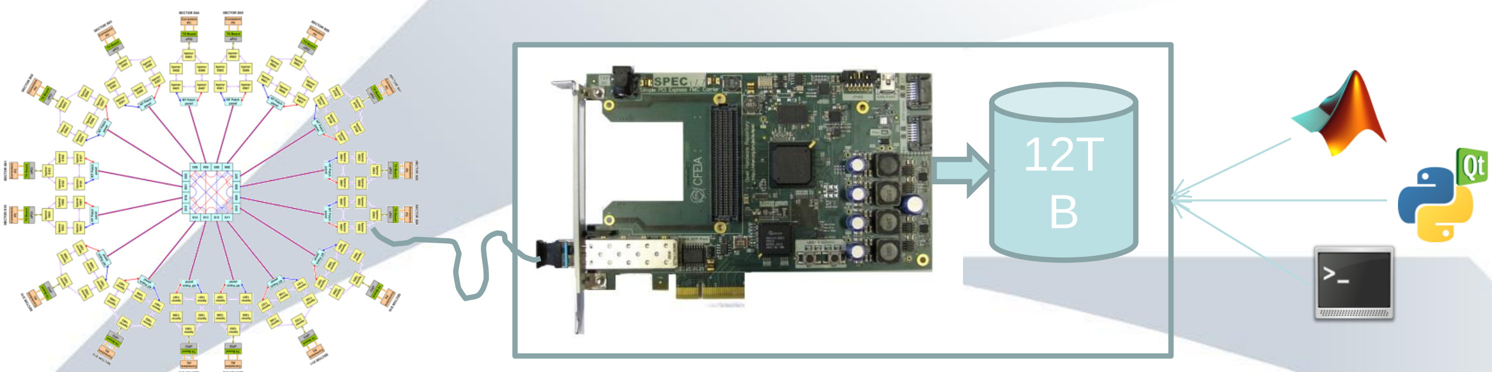
Fast Acquisition Archiver

System developed by Diamond and used by other facilities since 2011

Server with few HDs allowing many TBytes of archived BPM data @ 10kHz rate

Our current Fast Archiver consists of:

- a PCIe SPEC card as sniffer to the FOFB network
- 12 Tbyte HD in an Industrial PC, allowing for ~2 weeks of data
- BPMs position data @ 10kHz
- Data can be retrieved from Matlab, Python Qt GUI or command line tools



Choice of Multicycle Sinusoidal Waveforms

1. For linear optics analysis, total orbit amplitude must be as in the usual DC ORM → ~150 um
2. To detect the 1st harmonic with enough precision, the single waveform amplitude must be ~20-30 um → up to 5-10 CM excited in parallel during for more than 10 cycles
3. 1st harmonic peak of 20-30 um → waveform frequency range 0-80 Hz
4. Lower BPM noise region + proof no interference among close by frequencies → 5H + 5V CM excited in parallel with 10-20 Hz waveforms

Fourier analysis of FA ORM

In an **ideal linear machine**, N_c correctors in parallel will induce the following **orbit** :

$$x_{j,n} = \sum_{l=1}^{N_c} M_{j,l} \cos\left(2\pi n \nu_l + \phi_{j,l}\right) \qquad M_{j,l} e^{i\phi_{j,l}} = a_{j,k} + i b_{j,k}$$

Where the **ORM** elements are given by:

$$ORM_{j,l} = M_{j,l} \cdot \operatorname{sign}\left(\phi_{\mathrm{j,1}}\right)$$

Fourier analysis of FA ORM

That information can be retrieved as a first approach using the **signal projection** at the already know relative frequencies ν_k:

$$\hat{c}_{j,k} = \sum_{n=0}^{N-1} x_{j,n} e^{-2\pi i n \nu_k}$$

$$\hat{c}_{j,k} = \hat{a}_{j,k} + i\hat{b}_{j,k}$$

Expanding the previous equation we conclude that, due to frequency cross talk and finite sampling time, the projection **does not correspond** to the **ORM** elements $(a_{j,k} + b_{j,k})$.

Fourier analysis of FA ORM

However, the coefficients are **linearly related**:

$$\hat{a}_{j,k} = \sum_{l=1}^{N_c} \left[\Re\left(\xi_{kl}^{+} + \xi_{kl}^{-}\right) a_{j,l} - \Im\left(\xi_{kl}^{-} - \xi_{kl}^{+}\right) b_{j,l} \right]$$

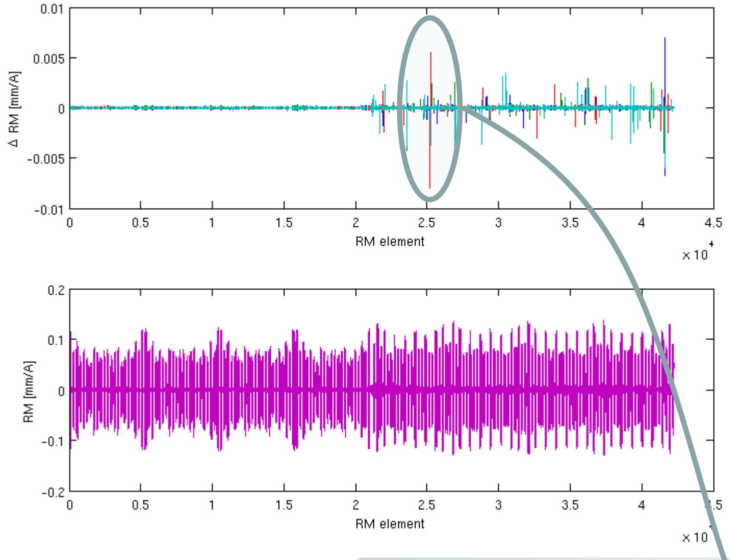
Where:

$$\hat{b}_{j,k} = \sum_{l=1}^{N_c} \left[\Im\left(\xi_{kl}^{+} + \xi_{kl}^{-}\right) a_{j,l} + \Re\left(\xi_{kl}^{-} - \xi_{kl}^{+}\right) b_{j,l} \right]$$

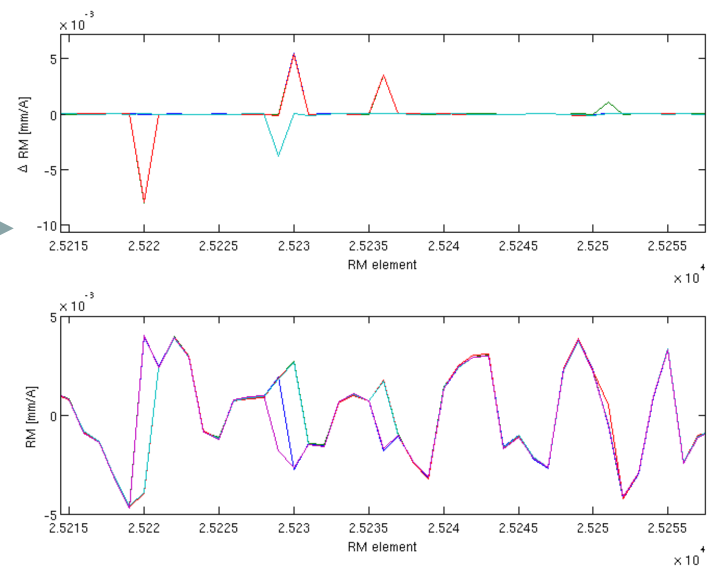
$$\xi_{kl}^{\pm} = \frac{1}{2} \frac{1 - e^{-2\pi i N(\nu_k \pm \nu_l)}}{1 - e^{-2\pi i(\nu_k \pm \nu_l)}}$$

(Note that it becomes the **identity** if frequencies are **multiple of the acquisition frequency**)

The pi/2 coupled component



Despite having overall much better repeatability, the method gives large noise in the **coupled plane** response matrix elements.

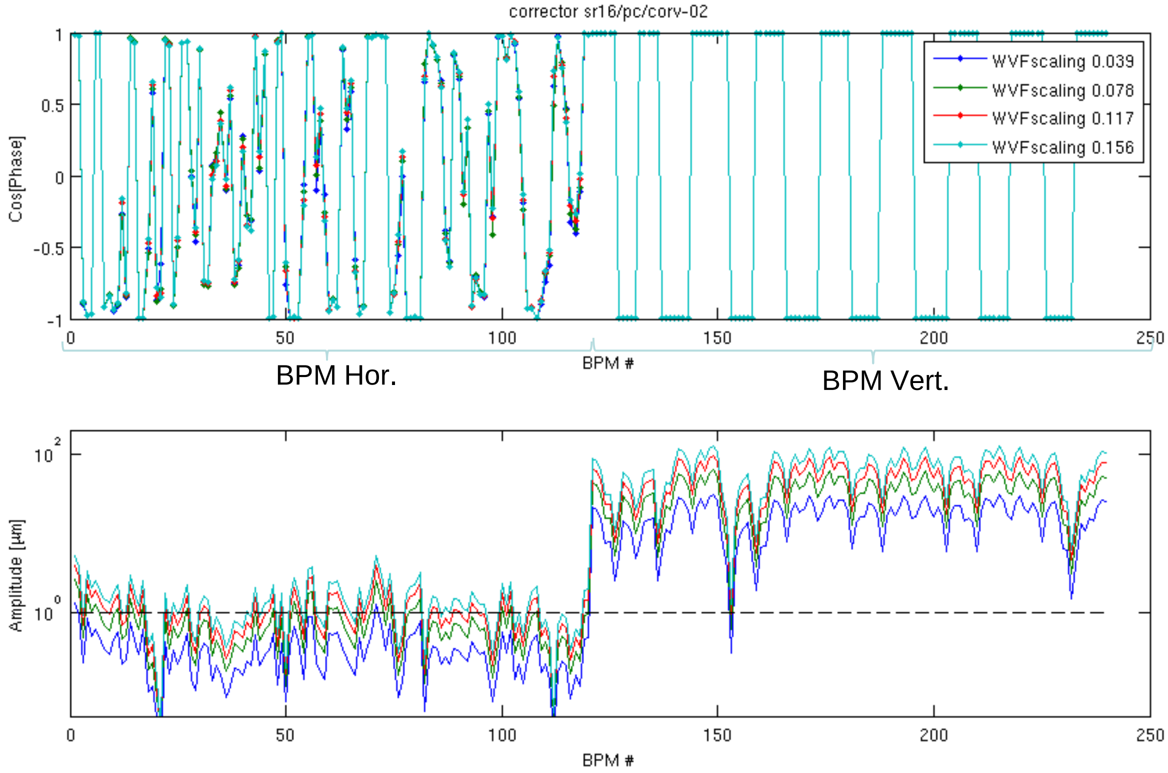


Some ORM elements change sign for different acquisitions. This comes from not having a defined phase:

$$RM_{l,j} = M_{j,l} sign\left(\phi_{j,l} - min(\phi_{j,l}) - \frac{\pi}{2}\right)$$

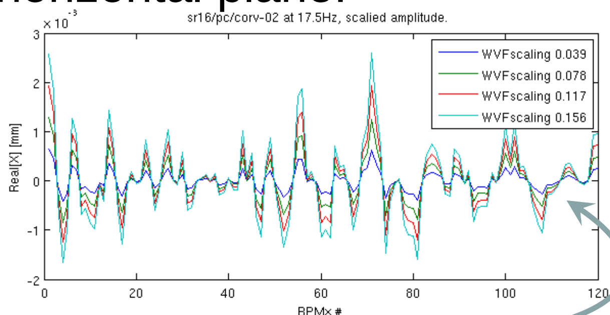
The pi/2 coupled component

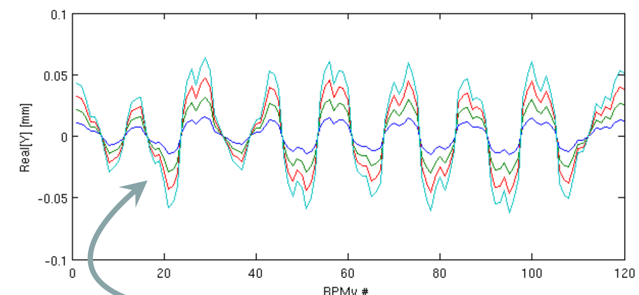
The phase in the coupled plane consistently gives values that do not follow the main plane oscillation. It is more pronounced for BPMs with the small signal amplitude:



More on the pi/2 coupled component

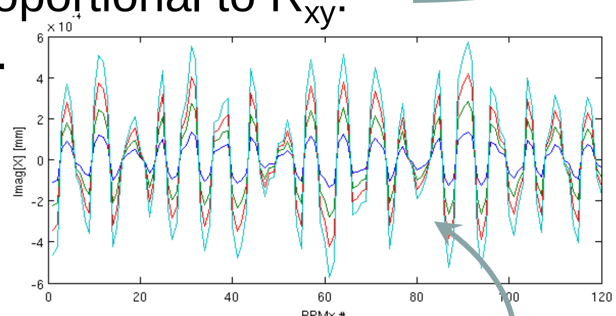
The repeatability issue seems to be caused by an unexpected component delayed ¼ of the waveform period ($\frac{\pi}{2}$). In the case of a vertical CM, the proportional to the $\frac{\pi}{2}$ component is proportional to the vertical kick but occurs in the horizontal plane!

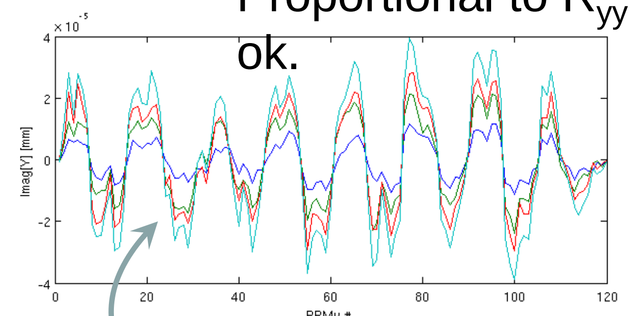




Proportional to R_{xy}: ok.

Proportional to R_{yy}: ok.



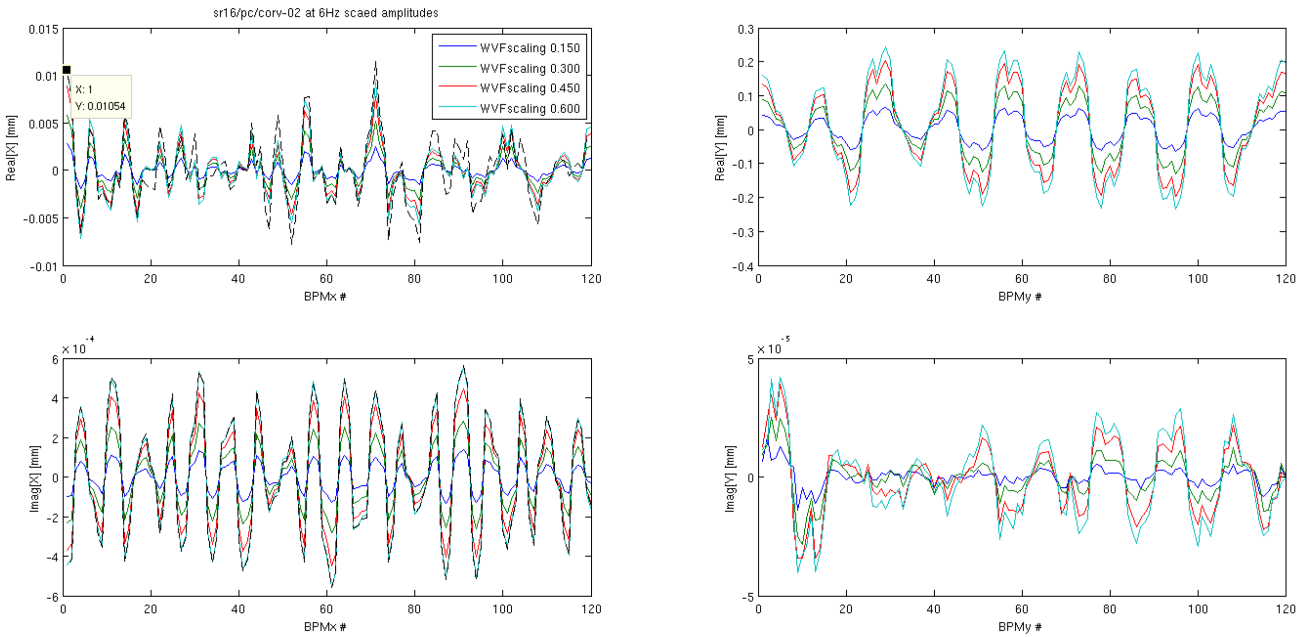


Proportional to R_{xx}!

Proportional to R_{yx}!!

More on the pi/2 coupled component

Instead of the 17.5Hz of the vertical corrector we also used **6Hz** and higher amplitudes:

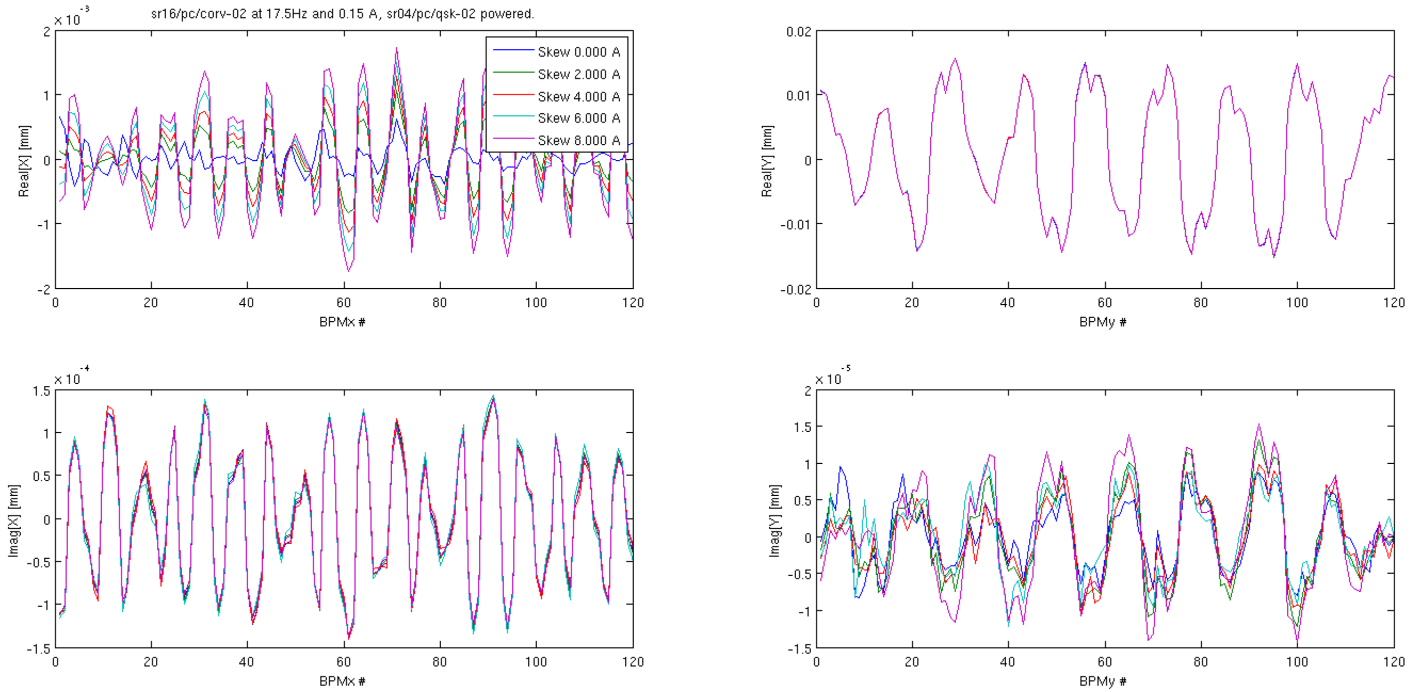


At 6Hz, the effect seems to be **4 times weaker**.

More on the pi/2 coupled component

Synchrotron Light Facility

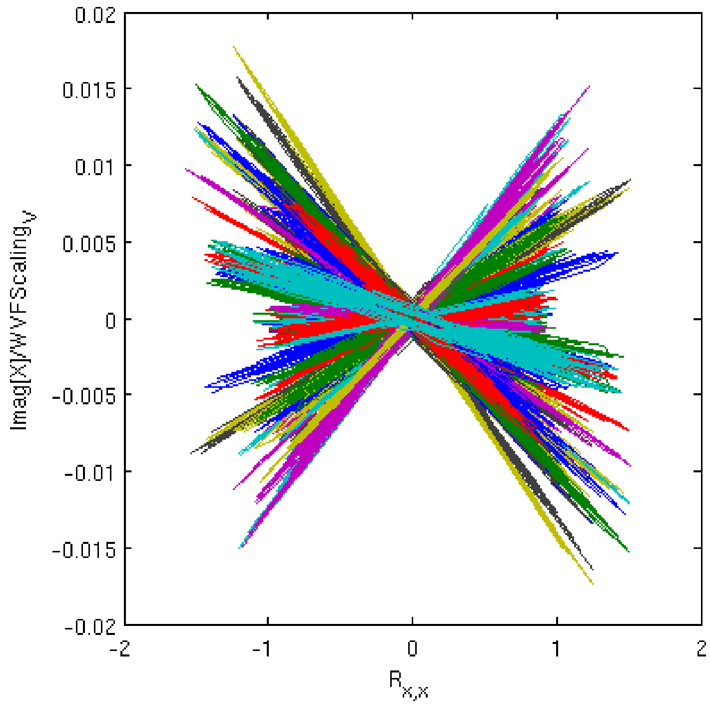
Scaling an skew corrector:

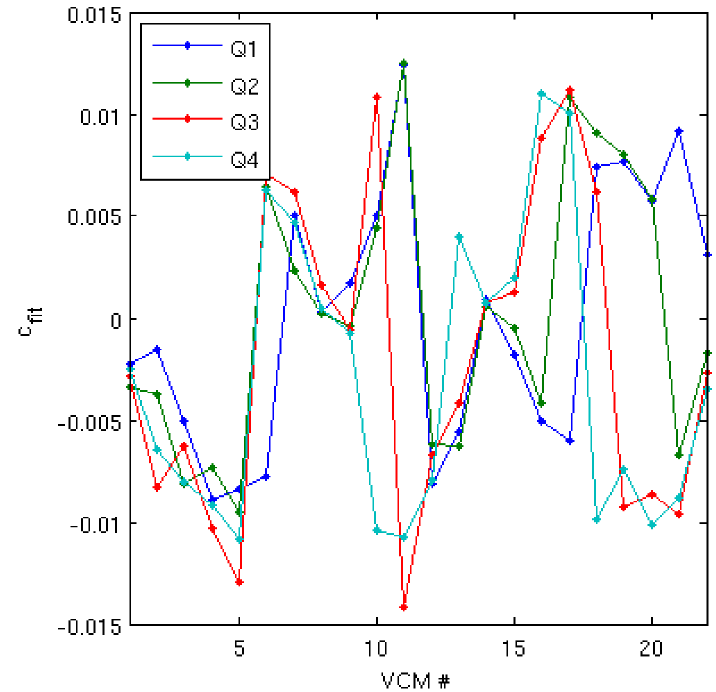


At 6Hz, the effect seems to be **4 times weaker**. Notice how the Pi/2 effect us unchanged by the skew magnet.

More on the pi/2 coupled component

Now considering all the ring vertical correctors, we see that all the coupled plane pi/2 signal is proportional to the response matrix $R_{x,x}$:





The proportionality factor c_{fit} has a 4-fold pattern, but it changes sign sometimes…

FRM measurements

The $\frac{\pi}{2}$ component in the coupled plane is **yet not understood**. According to electromagnetic simulations (**eddy currents**), it should be in the main plane.

In any case, now the response matrix can still be measured. First, for every corrector l, one has to calculate the main plane phase $\phi_{0,l}$ having large amplitudes (0.8 times the maximum value is used here):

$$\phi_{0,l} = \langle \phi_{j,l} \left(M_{j,l} > 0.8 \max(M_{j,l}) \right) mod\ \pi \rangle$$

Then, the response matrix elements can be retrieved using:

$$RM_{j,l} = Real\left[M_{j,l} e^{i(\phi_{j,l} - \phi_{0,l})} \right]$$

$$RM_{l,j} = M_{j,l} sign\left(\phi_{j,l} - min(\phi_{j,l}) - \frac{\pi}{2} \right)$$