ESRF | The European Synchrotron

Sextupole calibrations via measurements of off-energy orbit response matrix and high order dispersion

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DELTA

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OUTLINE

- Some definitions
- Motivation
- Simulations
- Measurements

PRELIMINARY DEFINITIONS

Chromatic functions:

$$\left.\frac{\mathrm{d}\beta_x}{\mathrm{d}\delta}\right._i = \frac{\beta_{xi}}{2\sin(2\pi\nu_x)} \sum_{j=1}^{N} \left[(K_1L)_j - (K_2L)_j\eta_{xj}\right] \beta_{xj} \cos(|2\mu_{i\rightarrow j,x}| - 2\pi\nu_x)$$

$$\left.\frac{\mathrm{d}\beta_y}{\mathrm{d}\delta}\right._i = -\frac{\beta_{yi}}{2\sin(2\pi\nu_y)} \sum_{j=1}^{N} \left[(K_1L)_j - (K_2L)_j\eta_{xj}\right] \beta_{xj} \cos(|2\mu_{i\rightarrow j,y}| - 2\pi\nu_y)$$

$$\left.\frac{\mathrm{d}\eta_x}{\mathrm{d}\delta}\right._i = -\eta_{xi} + \frac{\sqrt{\beta_{xi}}}{2\sin(\pi\nu_x)} \sum_{j=1}^{N} \left[(K_1L)_j - \frac{1}{2}(K_2L)_j\eta_{xj}\right] \eta_{xj}\sqrt{\beta_{xj}} \cos(|\mu_{i\rightarrow j,x} - \pi\nu_x|)$$

These functions are linear with sextupole strengths.

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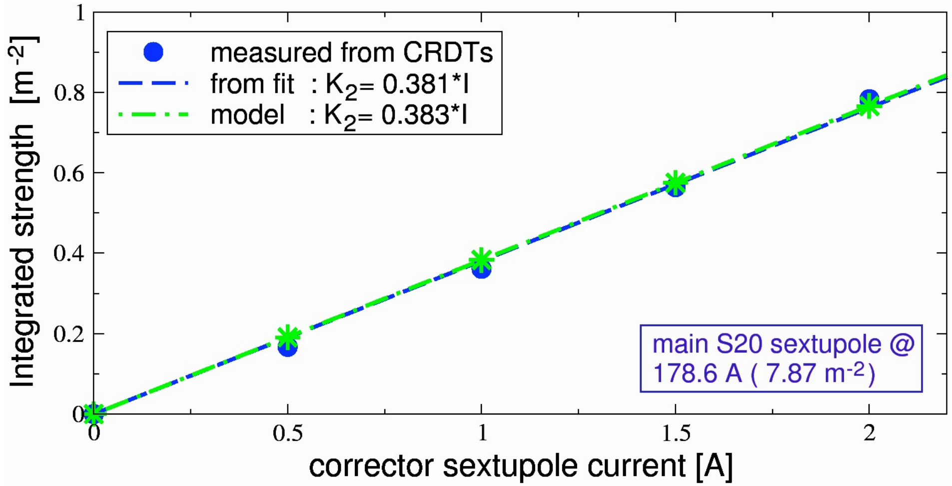
MOTIVATION: SEXTUPOLE CALIBRATION

There are different beam-based methods to calibrate sextupole strengths, such as:

- measurements of Resonance Driving Terms via turn-by-turn BPM data (PRSTAB 17, 074001, 2014)



This method requires optics with low chromaticity and detuning with amplitude

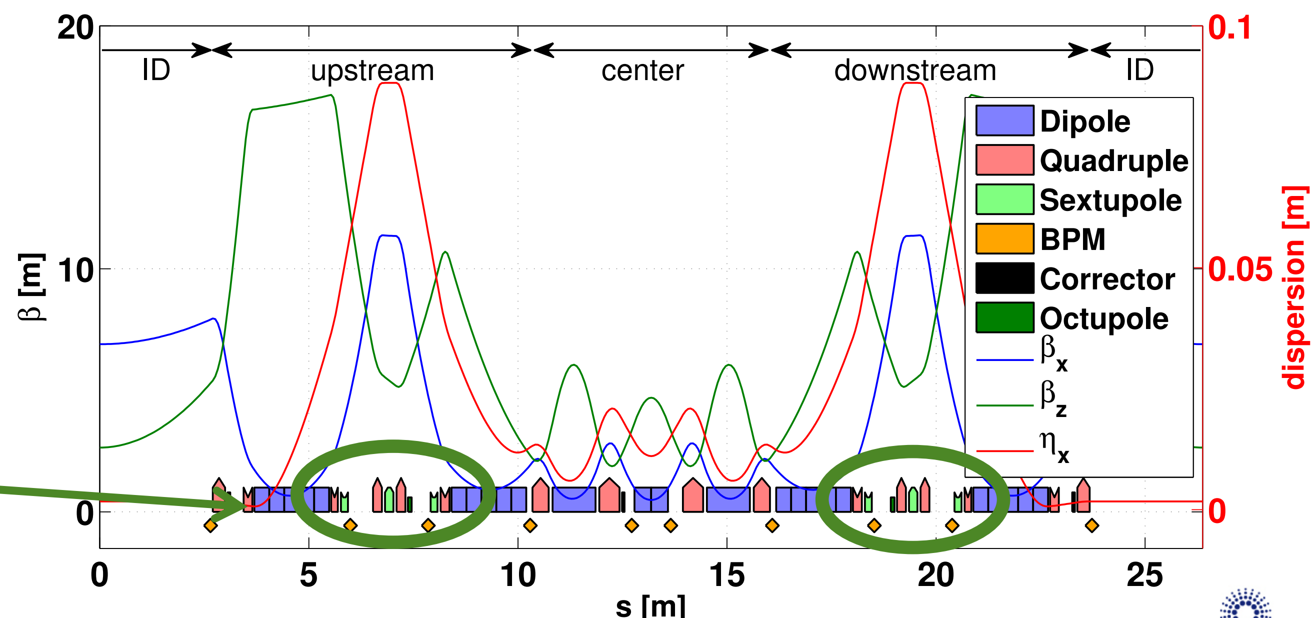
- tune response with orbit distortions (PRSTAB, 11, 094001, 2008)
- betatron phase advance response with orbit distortions (IPAC 17, MOPIK124)
- others

MOTIVATION: SEXTUPOLE ERROR MODEL

- We want to extend the weekly measurements and corrections of linear optics and coupling via orbit response matrix (ORM) to sextupole magnets and first-order nonlinear optics.

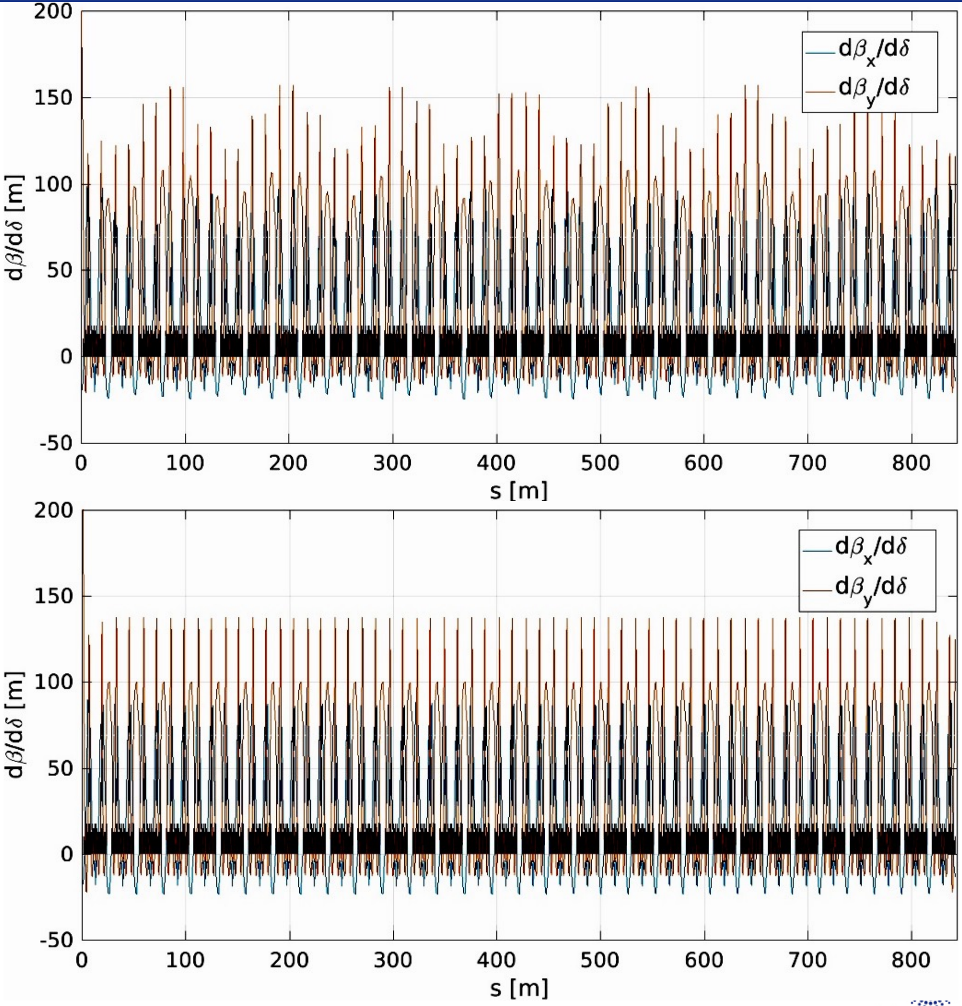
- The idea is to measure and fit the off-energy ORM and the 2nd order dispersion to infer and correct the chromatic functions.

Caveat of the off-energy analysis: it is effective only for chromatic sextupoles.
OK for ESRF upgrade like lattices, where all the sextupoles are in the dispersion bump.



MOTIVATION: TOUSCHEK LIFETIME

From simulation, we see that correcting the chromatic functions we increase the momentum acceptance and the Touschek lifetime.



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SIMULATIONS

We want to measure ORM using a frequency shift large enough to see some beta variation but small enough to be in the linear regime. With simulations we seek the best energy deviation.

- Simulation and fit of the off-energy ORM for several different energy deviations
- Compute the chromatic functions from the effective models
- Repeat after varying the strength of some sextupole correctors
- Compute the difference between chromatic functions (Sext on and Sext off) for several energy deviations
- Extract the sextupole values and find the best energy deviation that retrieves the sextupole values

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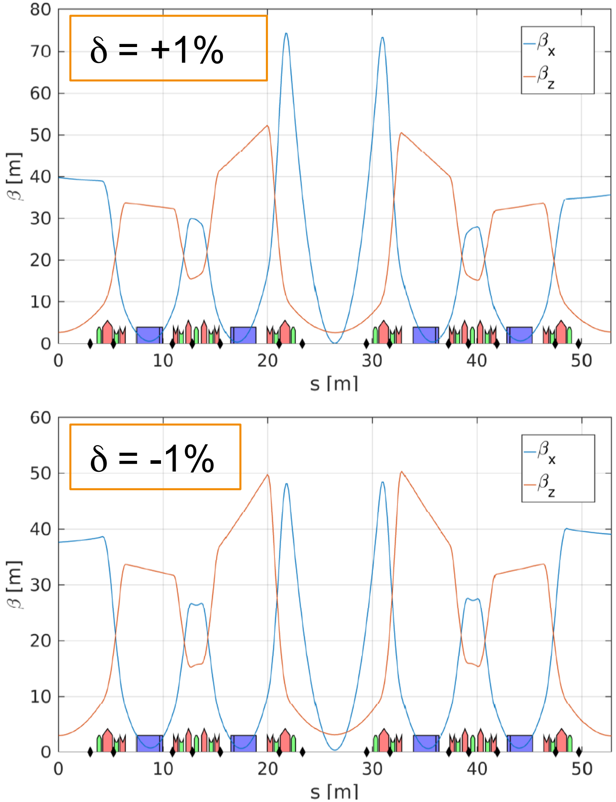

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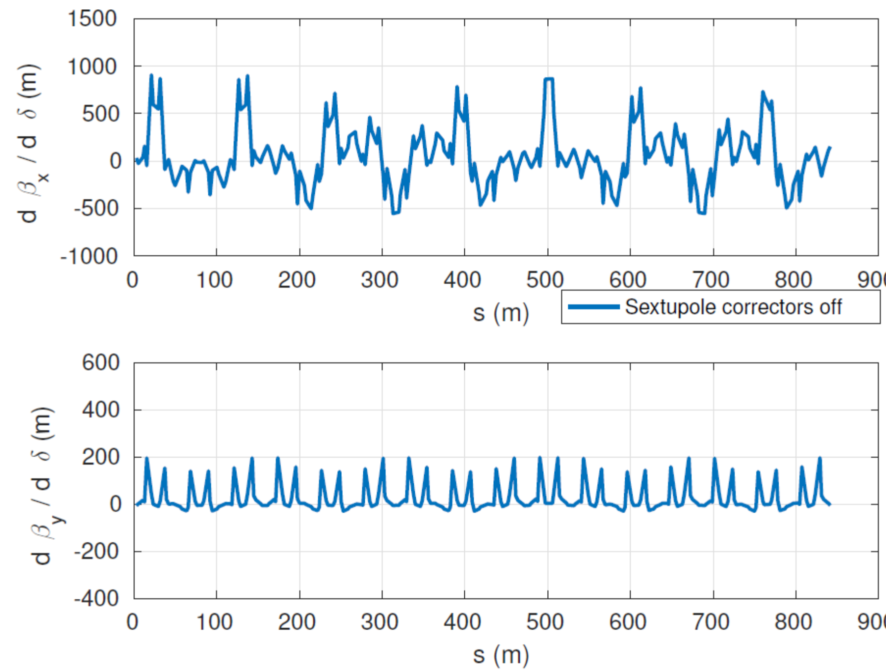

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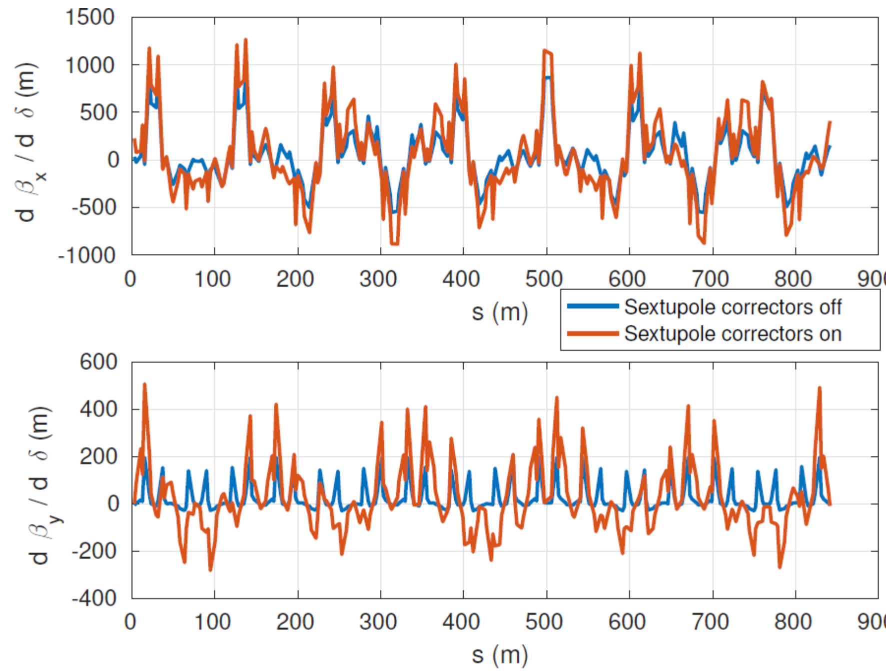

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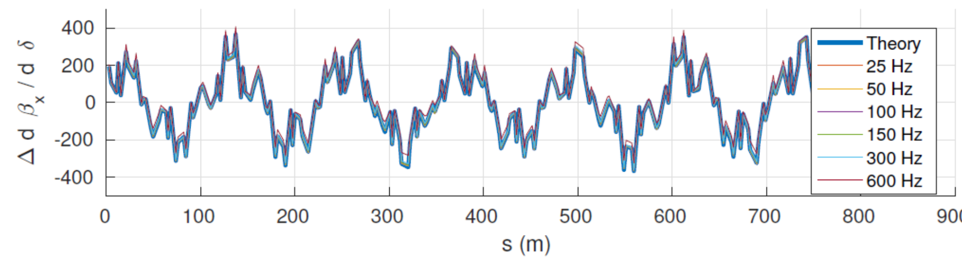

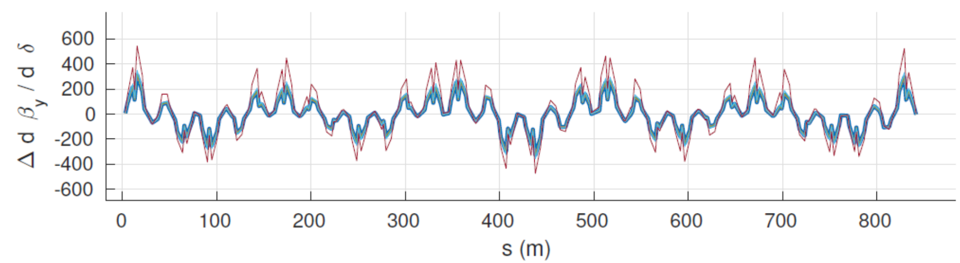

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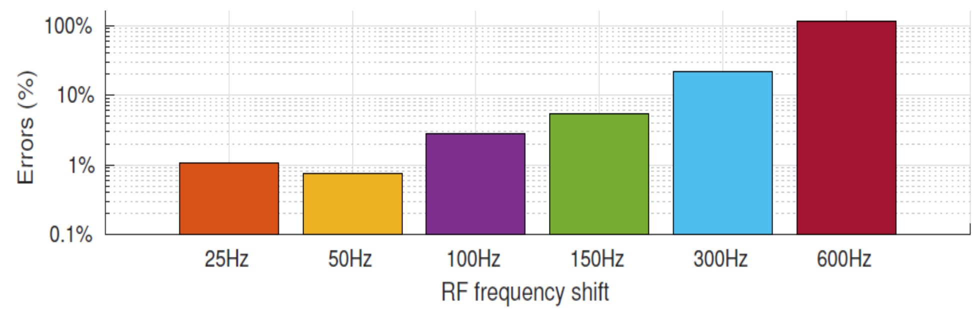

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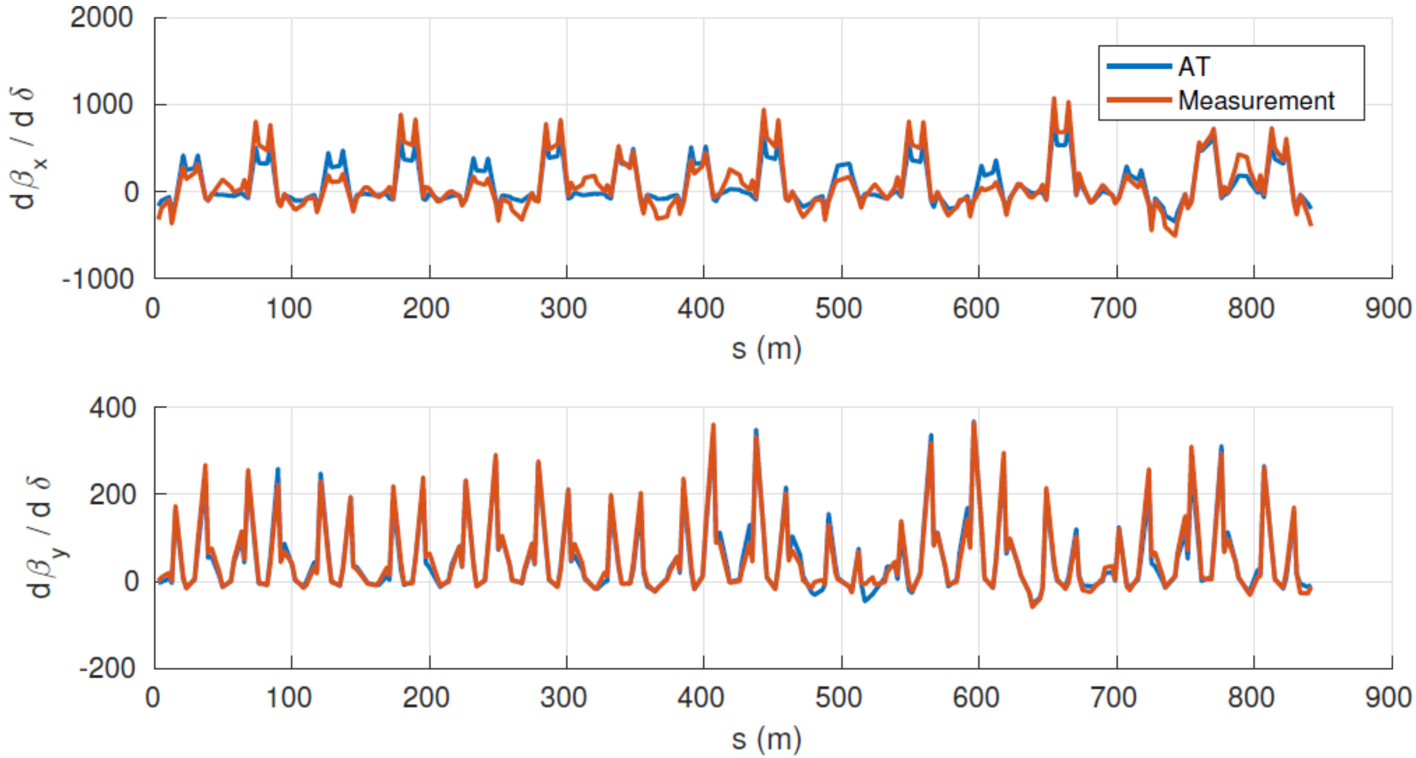
MEASUREMENTS: DERIVATIVE OF BETA FUNCTIONS

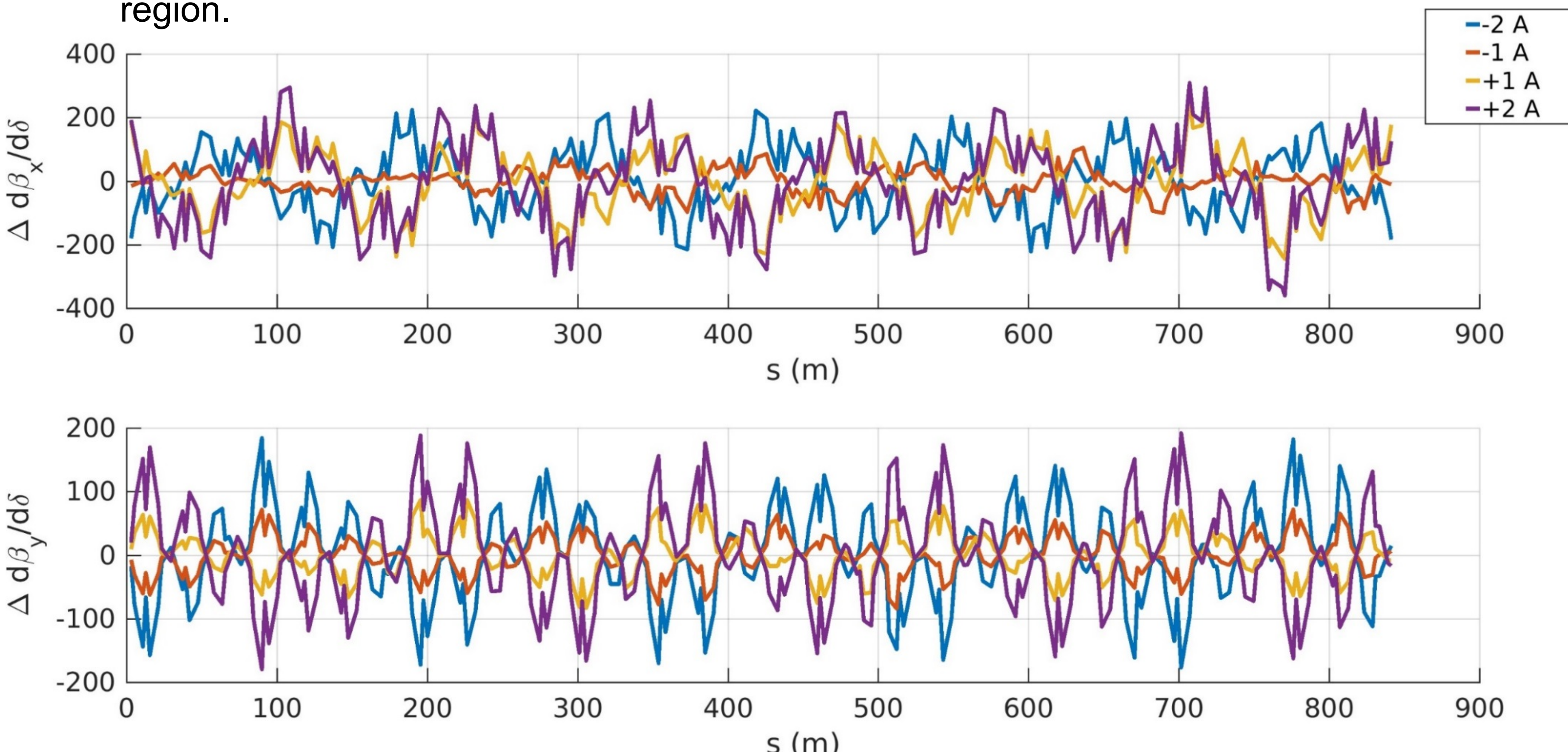
We take off-energy ORM at +- 100Hz (delta=0.16%).



The agreement between measurement and AT simulation is much better in vertical than in horizontal.

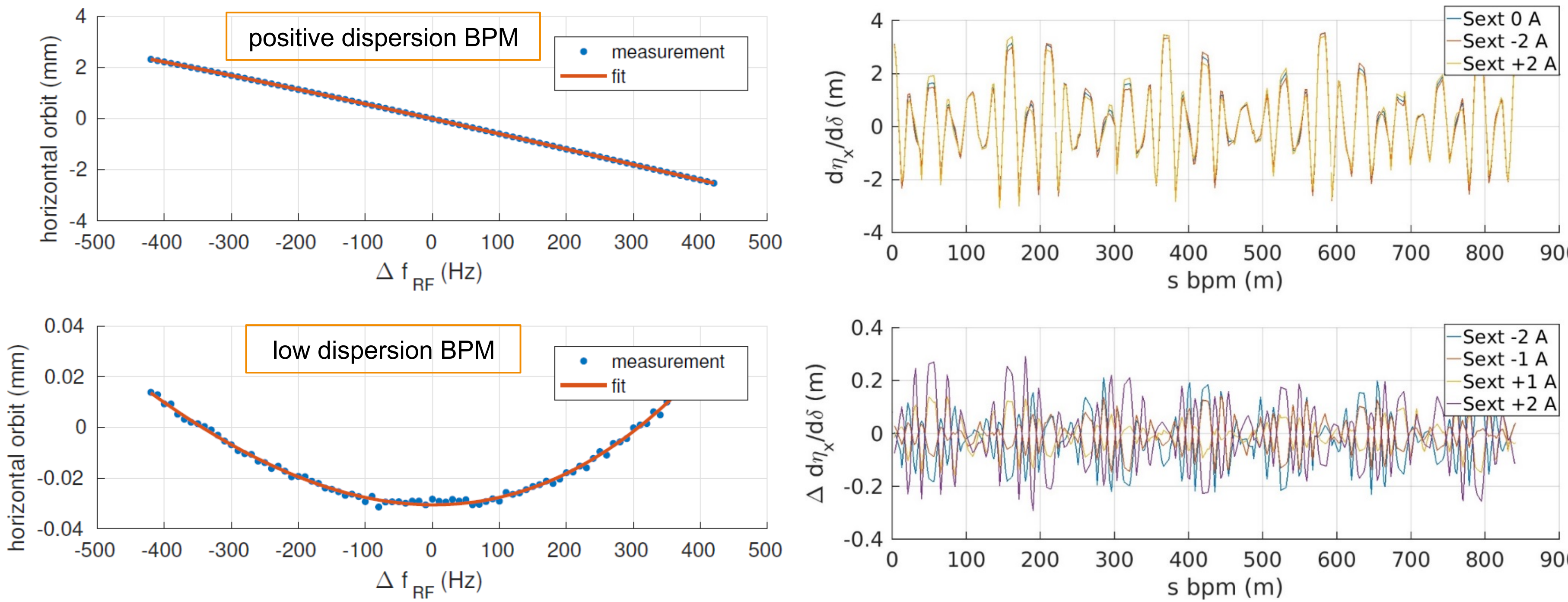
MEASUREMENTS: DERIVATIVE OF BETA FUNCTIONS

We take off-energy ORM for 4 currents of a single sextupole corrector in dispersive region.

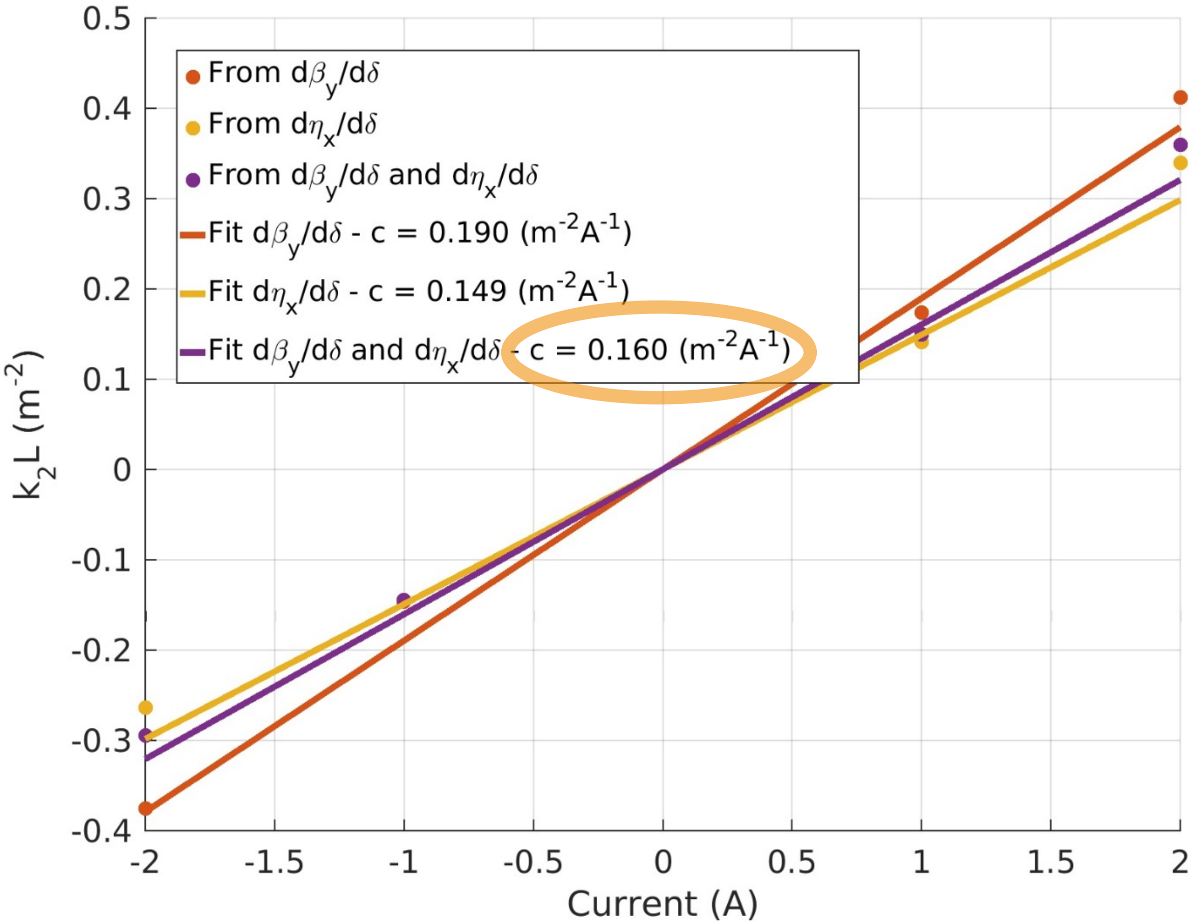


MEASUREMENTS: SECOND ORDER DISPERSION

We measure the horizontal closed orbit at all BPMs for different RF frequencies from -400 Hz to 400 Hz in 10 Hz steps and we fit a third order polynomial at each BPM.



MEASUREMENTS: CALIBRATION OF A SEXTUPOLE CORRECTOR



residuals $d\beta_y/d\delta$: 0.027
residuals $d\eta_x/d\delta$: 0.024
residuals $d\beta_y/d\delta$ and $d\eta_x/d\delta$: 0.019

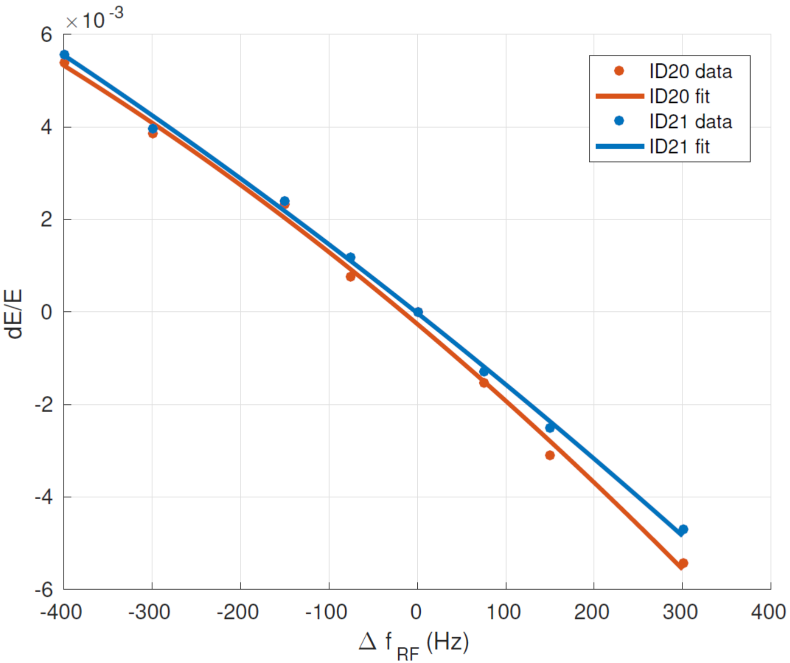
The calibration factor from magnetic measurements is 0.1569 m^{-2} A^{-1}

MOMENTUM COMPACTION FACTOR FROM UNDULATOR RADIATION

δ is not an observable. It is controlled by the RF frequency via the momentum compaction factor (α).

$\Delta f_{RF}/f = - \alpha \delta$

Any deviation of α from the model is introducing a scaling to the chromatic functions and hence to the fitted sextupole strengths. So we want to measure it.



	α value (10^{-4})
Ideal model	1.7795
Model with errors	1.8316
ID 20	1.76 ±0.14
ID 21	1.87 ± 0.11

MOMENTUM COMPACTION FACTOR FROM HARD X-RAYS CAMERA

δ is not an observable. It is controlled by the RF frequency via the momentum compaction factor (α).

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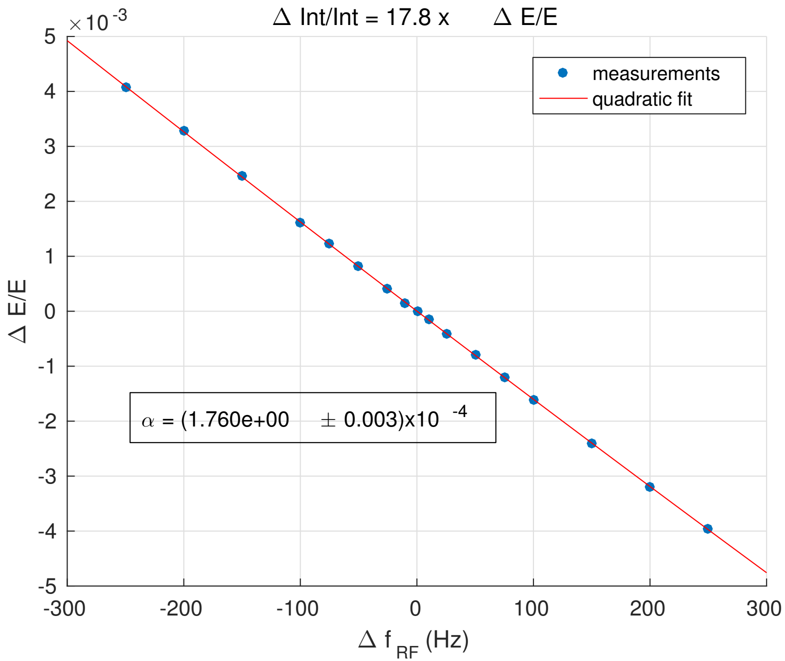
Any deviation of α from the model is introducing a scaling to the chromatic functions and hence to the fitted sextupole strengths. So we want to measure it.



	α value (10^{-4})
Ideal model	1.7795
Model with errors	1.8316
ID 20	1.76 ±0.14
ID 21	1.87 ± 0.11
hard x-ray camera	1.760 ± 0.003 (*)

(*) preliminary result

CONCLUSION

- The analysis of off-energy Orbit Response Matrix can be used to calibrate sextupole magnets and, possibly, to infer and correct sextupole errors in the ESRF-EBS storage ring.
- Chromatic functions are used as observable because their correction improves Touschek lifetime (according to simulations).
- As a proof of principle, the calibration of a sextupole corrector has been carried out from this analysis.
- The measured second-order dispersion and $\frac{d\beta_y}{d\delta}$ are in better agreement with the theoretical values than $\frac{d\beta_x}{d\delta}$.
- Three independent measurements of the momentum compaction have been carried out for a correct conversion $\Delta f_{RF}/f_{RF}$ -> δ.
- A full sextupole error model and its correction are the ultimate goal of the study.

Many thanks for your attention