ESRF | The European Synchrotron

Magnets cross-talk and impact on the lattice for ESRF-EBS

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Low Emittance Ring Workshop − LER2020
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Outline

1. Introduction
2. Evidences for quad cross-talks
3. Models
4. Measurements
5. Impact on the lattice
6. Conclusion

1. Introduction

THE EBS LIGHT SOURCE

The Extremely Brilliant Source

- New generation 6 GeV synchrotron light source
- Low emittance storage ring
- Restarted end 2019
- User mode since end of August

Credit J. Chavy / ESRF

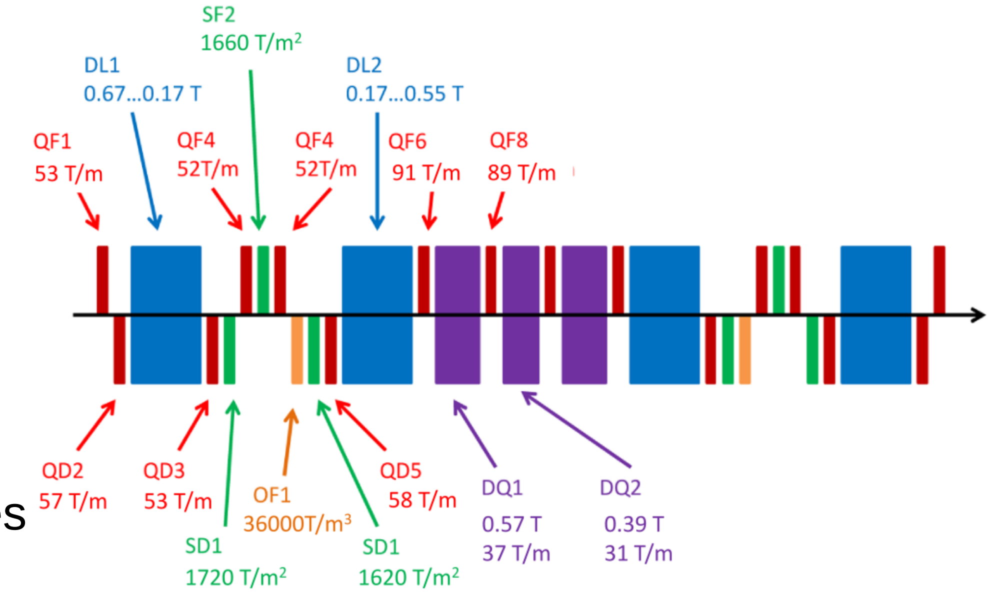
THE EBS LIGHT SOURCE

The Extremely Brilliant Source

- New storage ring
- 130 pm·rad horizontal emittance
- 10 pm·rad vertical emittance
- 6 GeV electrons
- 200 mA current
- Same buildings and infrastructures

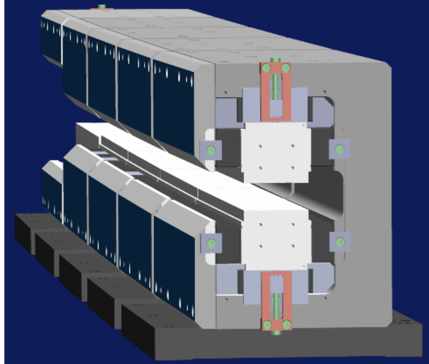
How to decrease the emittance?

- More dipoles (7 per cell)
- Strong quadrupoles between dipoles



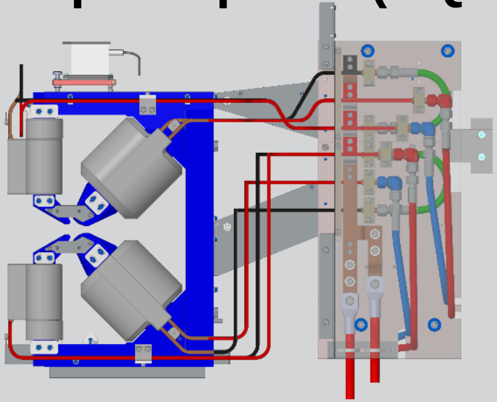
Main magnets

Dipoles



128 PM magnets
$0.17\ \mathrm{T} < B < 0.67\ \mathrm{T}$

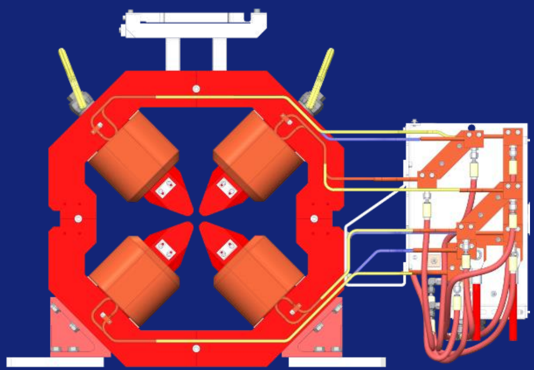
Dipole-quads (DQs)



96 magnets
$0.39\ \mathrm{T} < B < 0.57\ \mathrm{T}$
$31\ \mathrm{T/m} < G < 37\ \mathrm{T/m}$

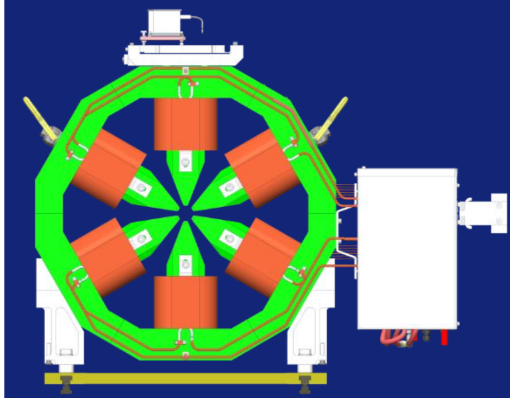
Main magnets

Quads



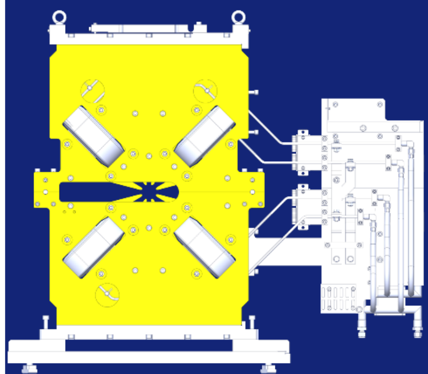
521 magnets
$50\ \mathrm{T/m} < G < 90\ \mathrm{T/m}$
$25\ \mathrm{mm} < \phi < 33\ \mathrm{mm}$

Sextupoles



192 magnets
$S = 1700\ \mathrm{T/m^2}$
$\phi = 38.4\ \mathrm{mm}$

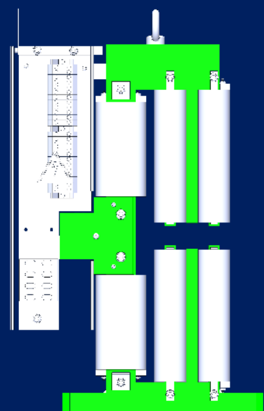
Octupoles



64 magnets
$O = 57\ \mathrm{kT/m^3}$
$\phi = 38.2\ \mathrm{mm}$

Other magnets

Correctors



96 magnets
Dipoles + skew quad (+sextupole)

Injection

Specific magnets

SBM sources

Short PM dipoles

Some specificities of the EBS magnets

PM dipoles

No trimming coil (tunning in lab)

High gradient quads

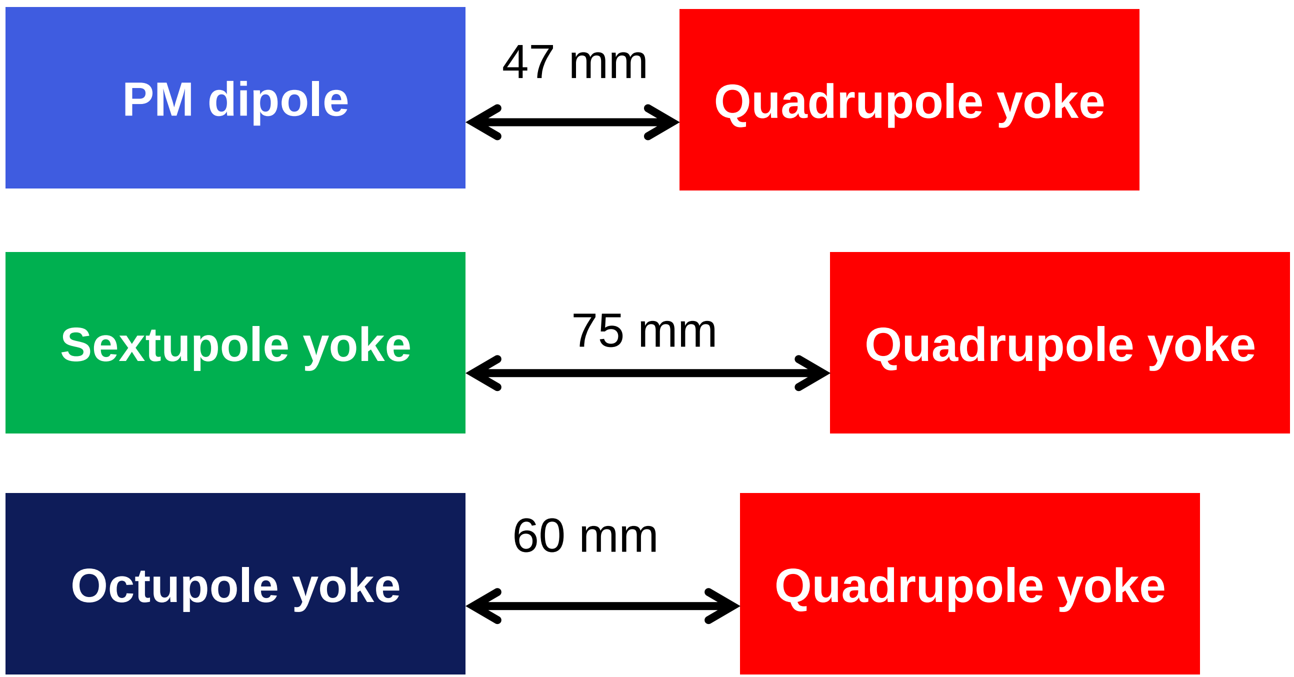
Saturated at nominal current

Combined magnets

Dipole-quads
Sextupoles + dipole correctors + skew quads
Combined correctors + skew quads

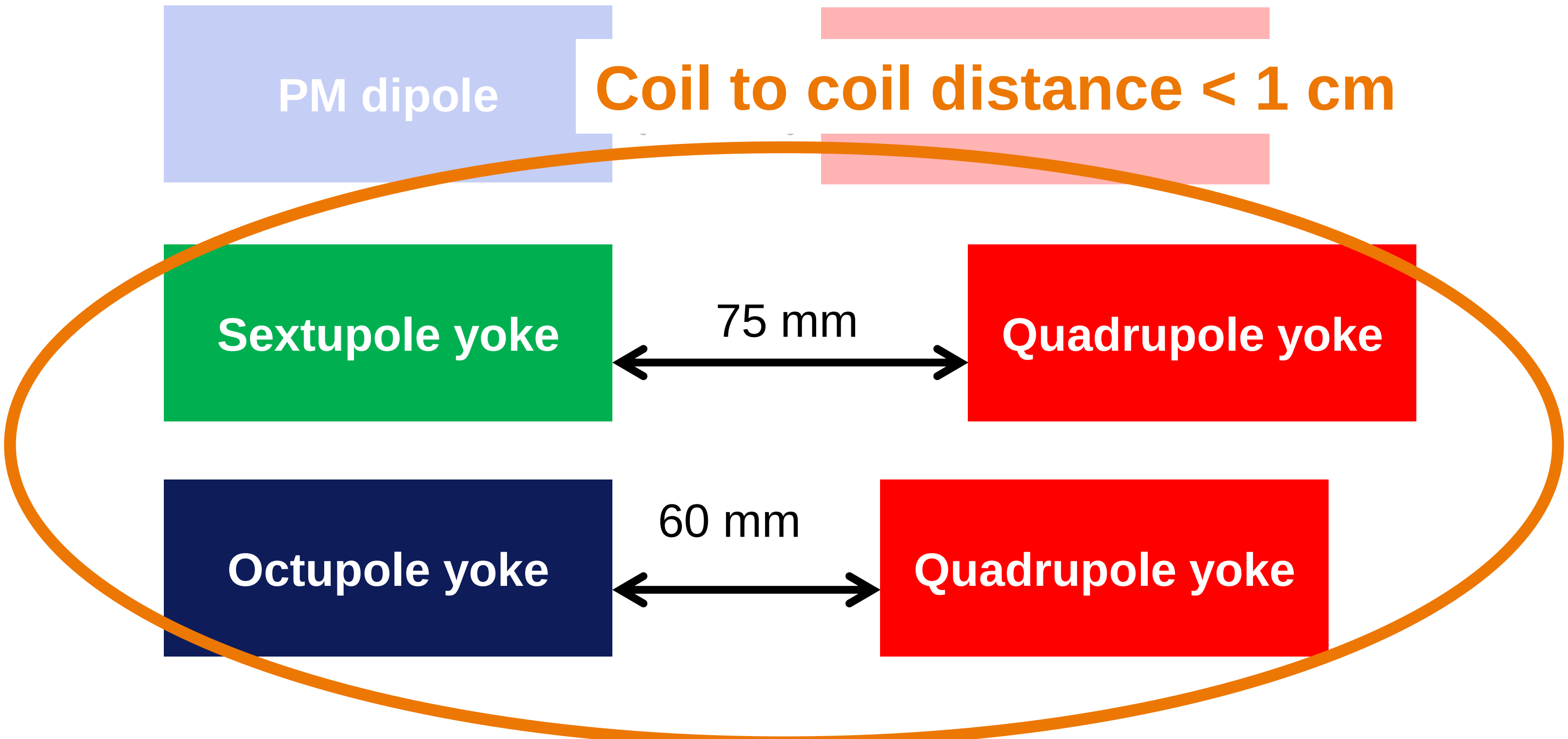
A very compact storage ring!

Short distances between magnets



A very compact storage ring!

Short distances between magnets



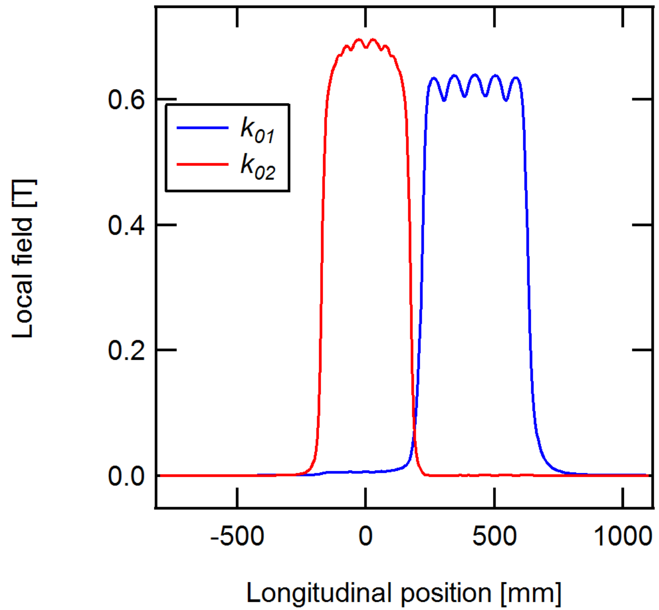
All ingredients for strong cross-talks

Between magnets

- Short distances
- Saturation
- Cross-talk induced PM dipole error pre-corrected in lab

Between channels of combined magnets

- Not in the scope of this talk



Dipole to quad crosstalk [LER2013, Oxford]

2. Evidences for quad cross-talks

EVIDENCES FOR QUAD CROSS-TALK

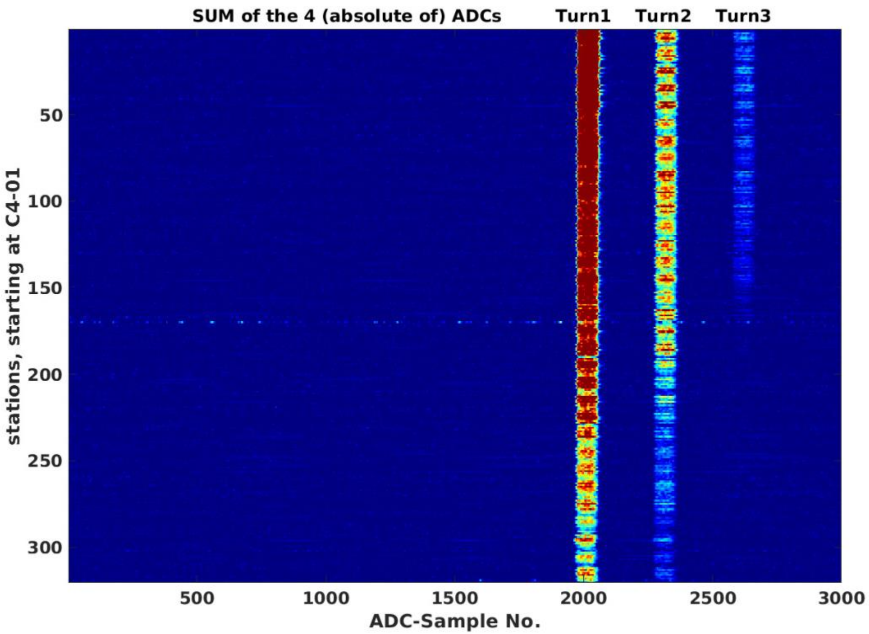
28th November 2019

First turns

Tune measurements from turn-by-turn data

Large discrepencies between measurements and model

$$\Delta\nu_X = -0.4$$
$$\Delta\nu_Y = -1.4$$



EVIDENCES FOR QUAD CROSS-TALK

Mid-December 2019

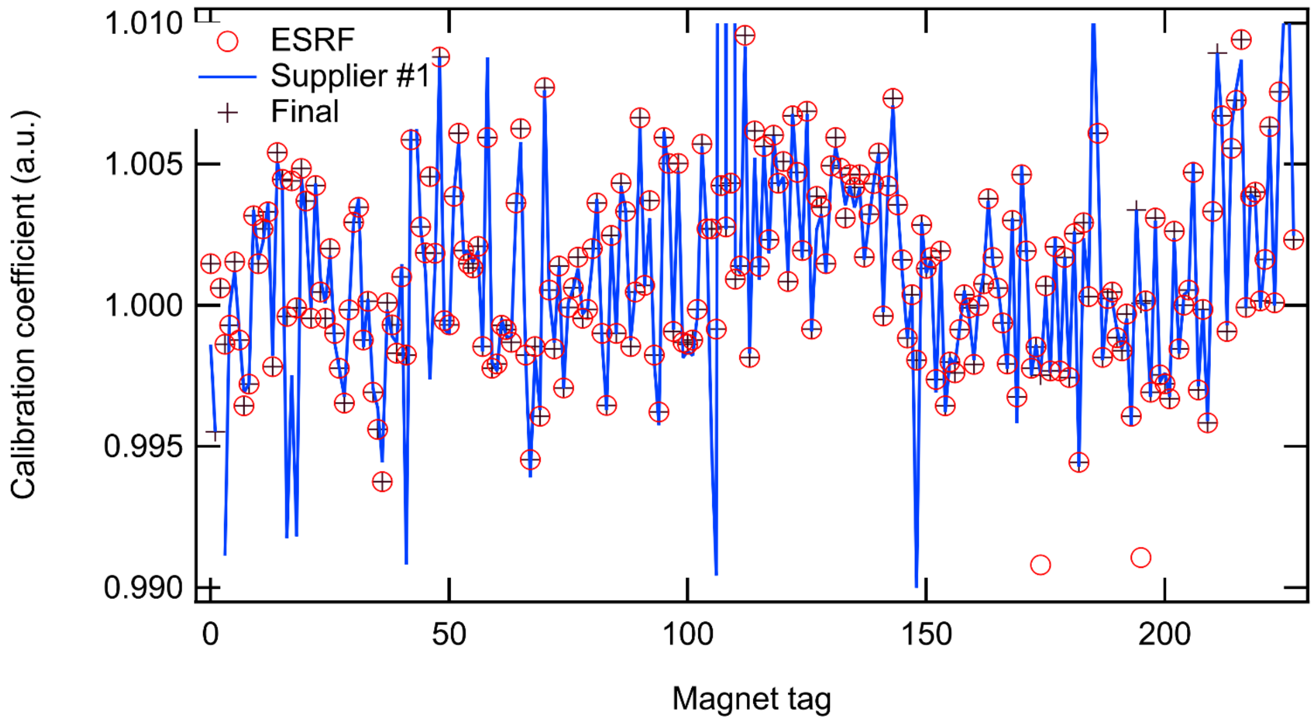
Quadrupole calibrations

- Excitation curves for quad families
- Individual calibration coefficients for quadrupoles (close to 1)
- Bugs found, e.g. divisions instead of multiplications…
- Two sets of measurements available (by suppliers and at ESRF)

EVIDENCES FOR QUAD CROSS-TALK

Mid-December 2019

Quadrupole calibration errors



Calibration coefficients for one magnet familly

EVIDENCES FOR QUAD CROSS-TALK

Mid-December 2019

Quadrupole calibration errors

- Excitation curves for quad families
- Individual calibration coefficients for quadrupoles (close to 1)
- Bugs found, e.g. divisions instead of multiplications…
- Two sets of measurements available (by suppliers and at ESRF)

Calibration uncertainties

- Estimated to $U = 3.2 \times 10^{-4}$
  (supplier vs ESRF, accounting for benches, power supplies, etc.)

Much larger errors expected from lattice measurements!

EVIDENCES FOR QUAD CROSS-TALK

Mid-December 2019

Quadrupole calibration errors

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Calibr

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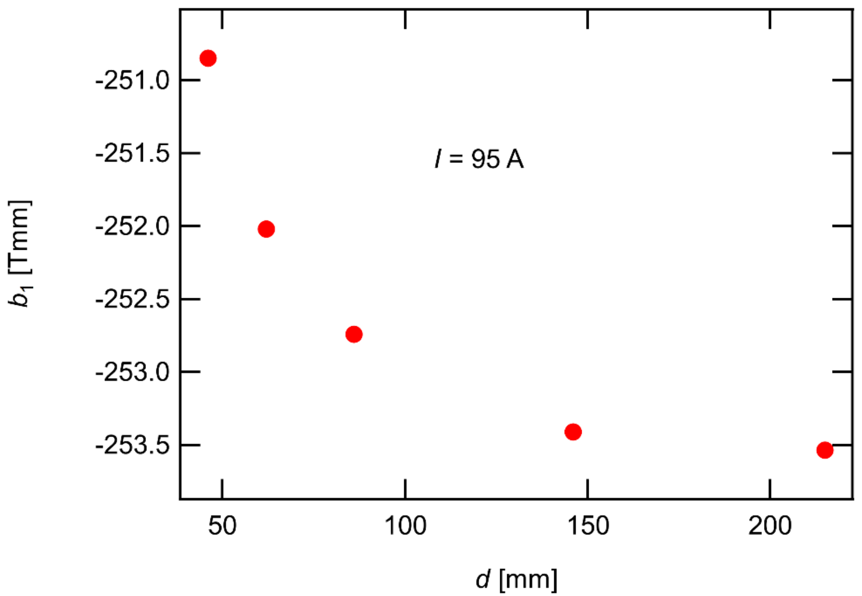
Much

Can cross-talks generate large quadrupole errors?

Preliminar measurements in 2017

- Dipole to quadrupole cross-talk
- Needed for PM dipole tuning
- Focused on dipole errors due to quads
- Impact on gradient not investigated in details at that time



Integrated dipole vs dipole-to-quad distance

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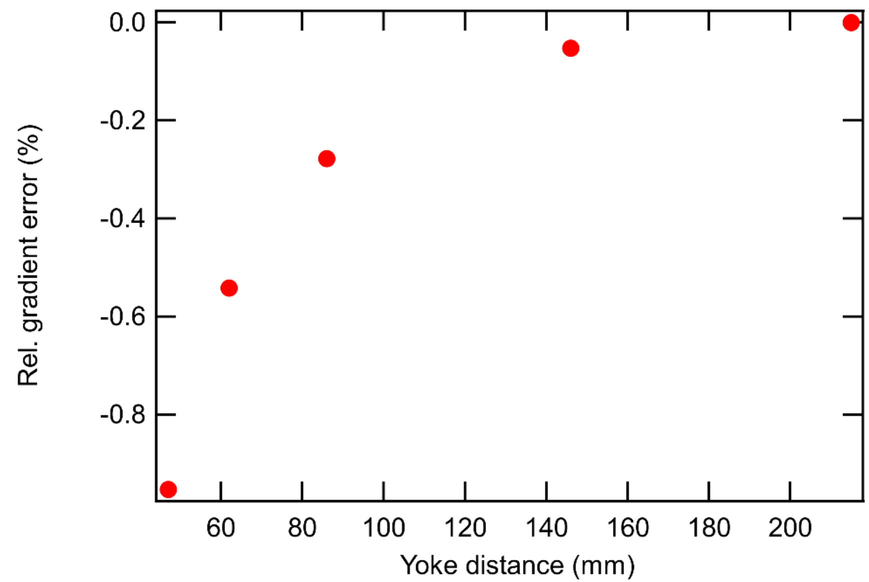


Integrated gradient vs dipole-to-quad distance

A later analysis of the data shown a 1 % gradient error at nominal distance

3. Models

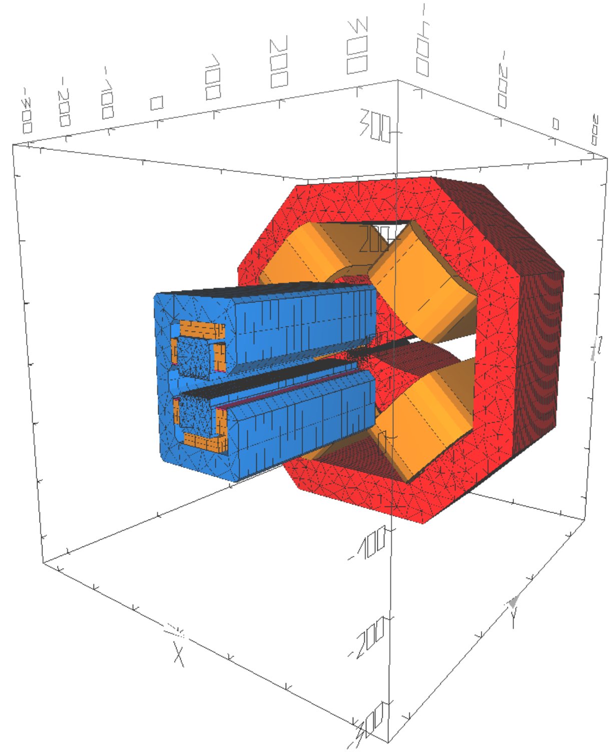
MODELS

Magnetic simulations

- Non-linear 3D models
- Strong dependence in current (magnets are saturated)
- Radia software used

Needs a lot of CPU time on the ESRF cluster!

~ 1 CPU hour / current settings



Radia magnetic model of a dipole and a quadrupole

About the Radia code

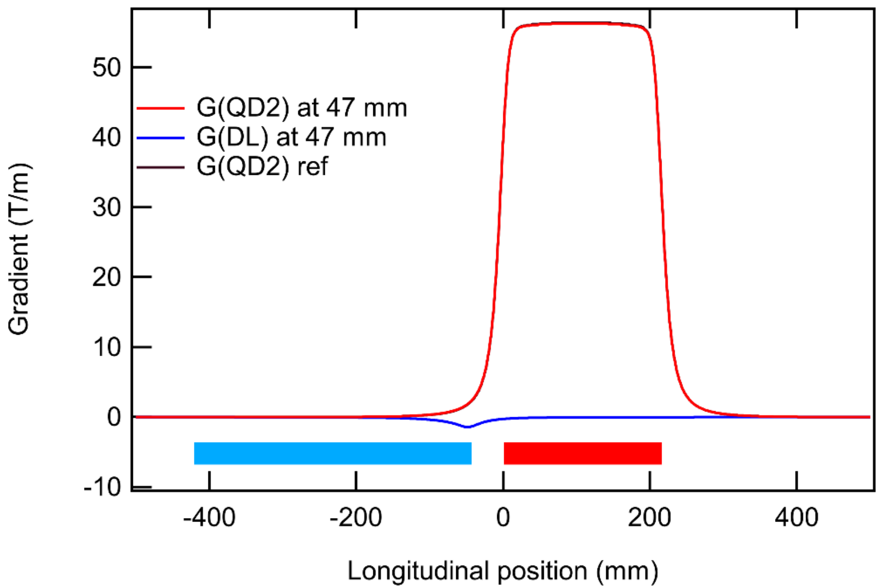
- Magnetostatic simulation code
- Initially developed for PM insertion device simulations
- It does not rely on FEM, but on a boundary integral approach, i.e. it computes the magnetization of small elements using currents and magnetizations of other elements

This is convenient for cross-talk problems, as it allows to separate easily the contribution of the different magnets

[https://github.com/ochubar/Radia]

Dipole to quadrupole cross-talk

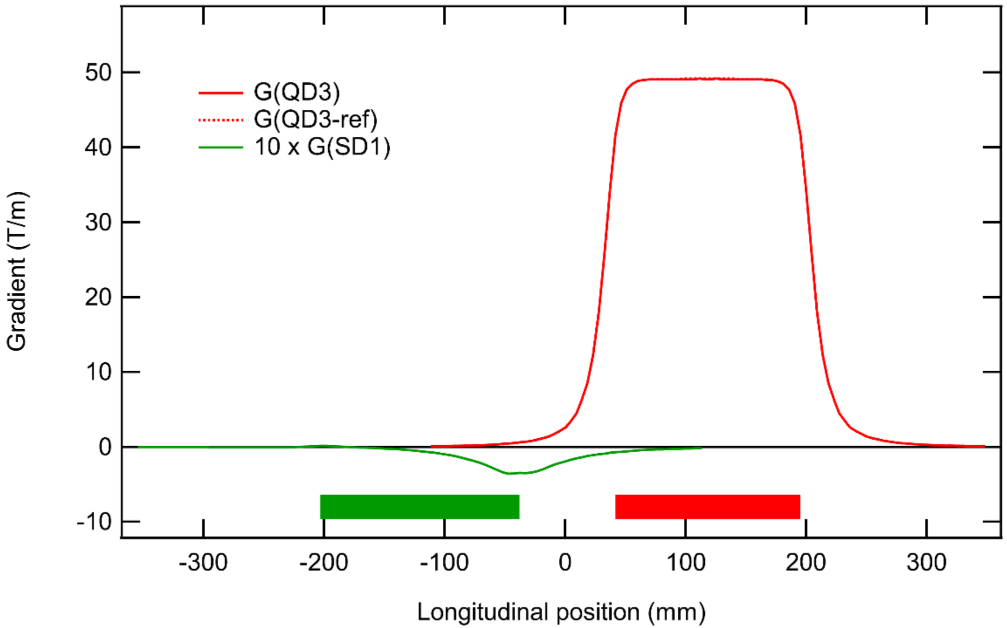
- 0.8 to 0.9 % decrease of integrated gradient (depending on magnets)
- Effect localized on the dipole edge
- Almost no change in the quad
- Can be modelled by a thin lens with opposite polarity



Gradient distribution in a dipole and a quadrupole

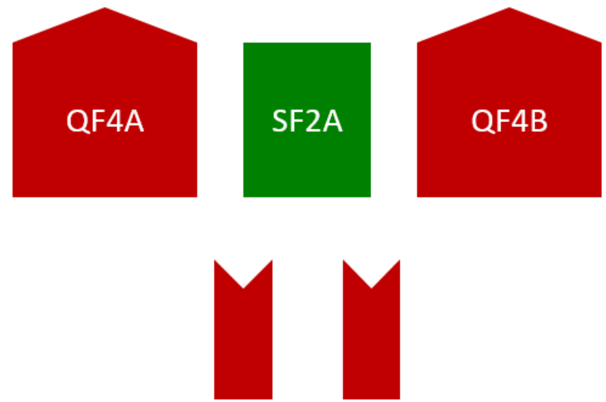
Sextupole to quadrupole cross-talk

- 0.3 % decrease of integrated gradient
- Effect localized on the sextupole edge



Gradient distribution in a sextupole and a quadrupole

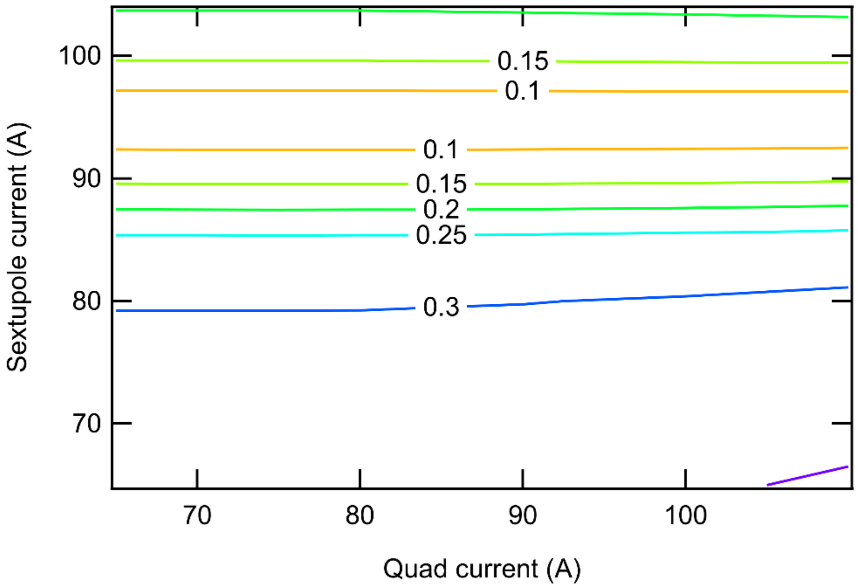
Sextupole to quadrupole cross-talk



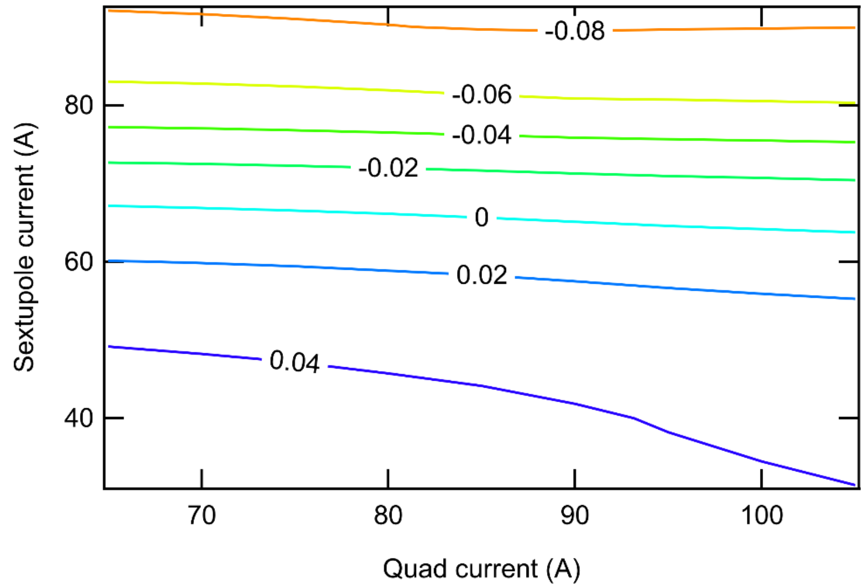
	QF4A	SF2-ext	SF2	SF2-ext	QF4B	
Gradient error	-0.03	-0.27		-0.27	-0.03	%

MODELS

Sextupole to quadrupole cross-talk



Integrated gradient error from sextupole edge



Integrated gradient error from quadrupole

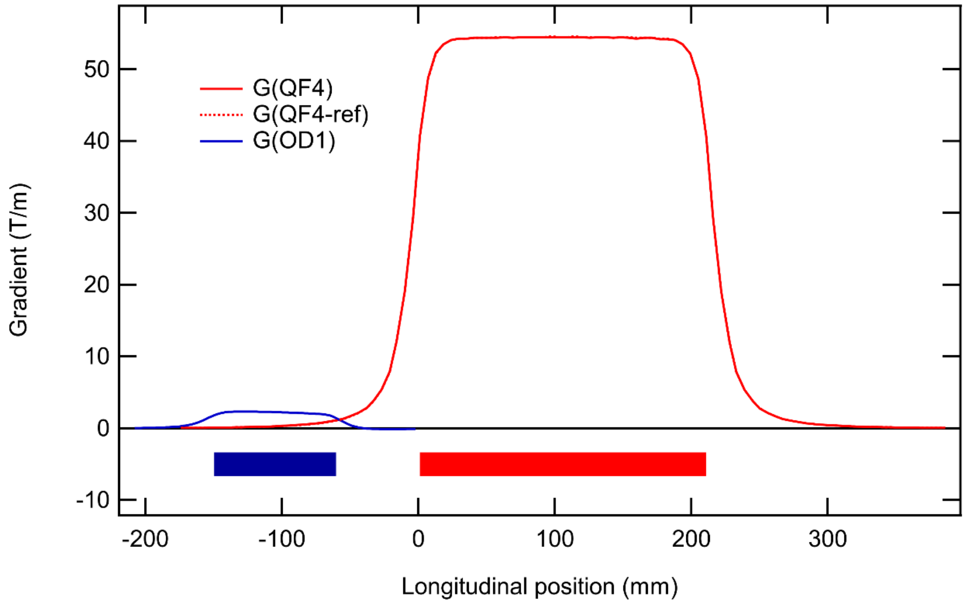
(All errors in (%) of the integrated gradient without sextupole)

MODELS

Octupole to quadrupole cross-talk

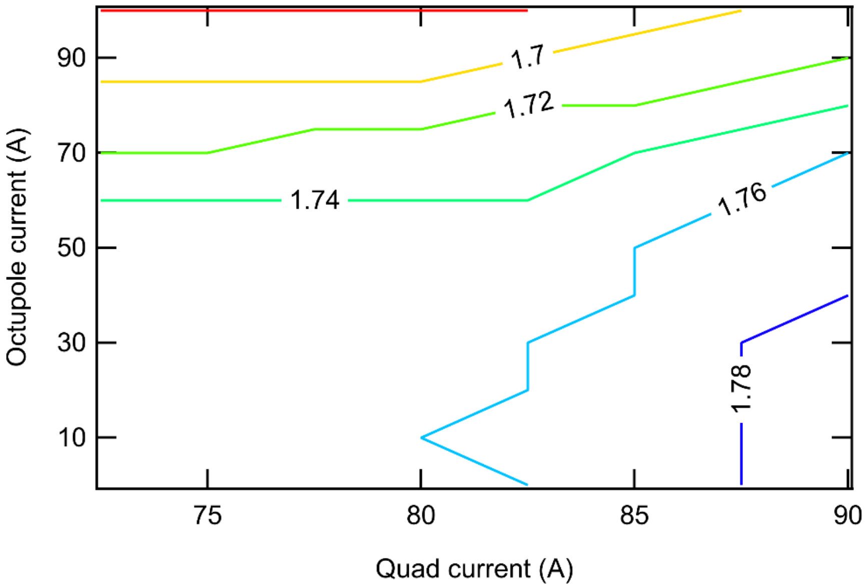
- 1.7 % increase of integrated gradient
- Gradient error all along the octupole

Errors distribution and sign are magnet dependent

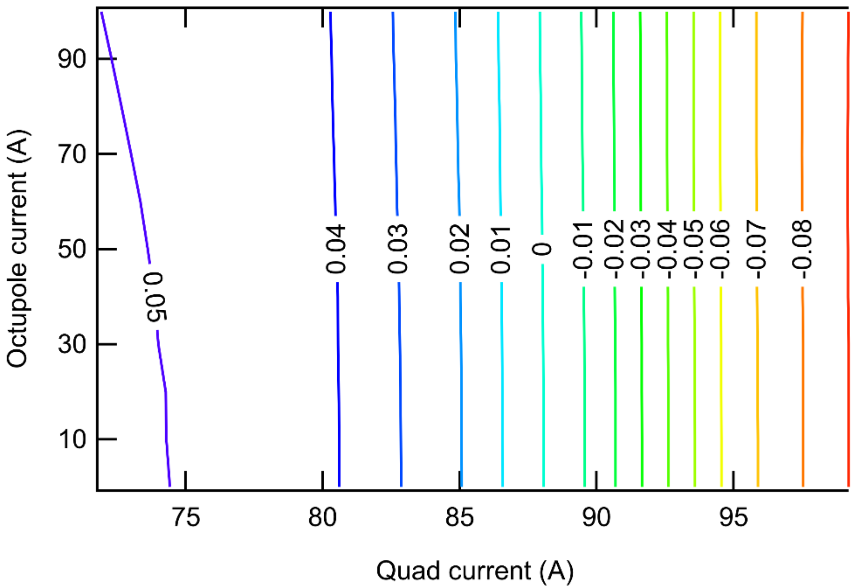


Gradient distribution in an octupole and a quadrupole

Octupole to quadrupole cross-talk



Integrated gradient error from octupole



Integrated gradient error from quadrupole

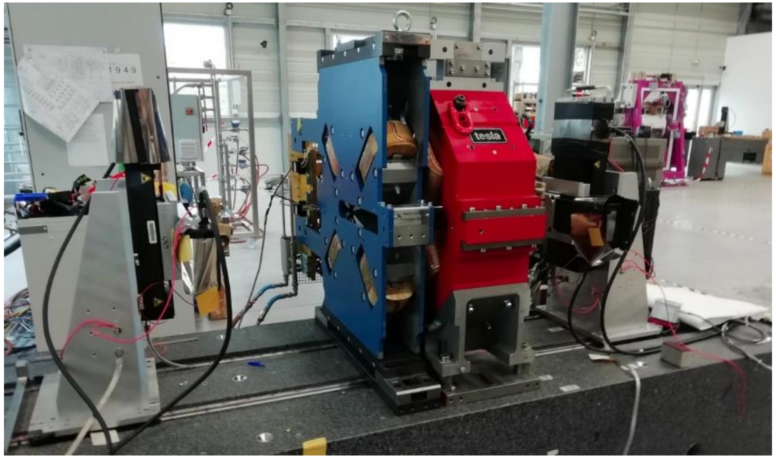
(All errors in (%) of the integrated gradient without octupole)

4. Measurements

MEASUREMENTS

Magnetic measurements

- Integrated gradient
- Stretched wire method used
- Crosstalk with dipole, sextupoles and octupoles measured



Octupole and quadrupole installed on a measurement bench

Main purpose
To check the simulations in a few sample configurations

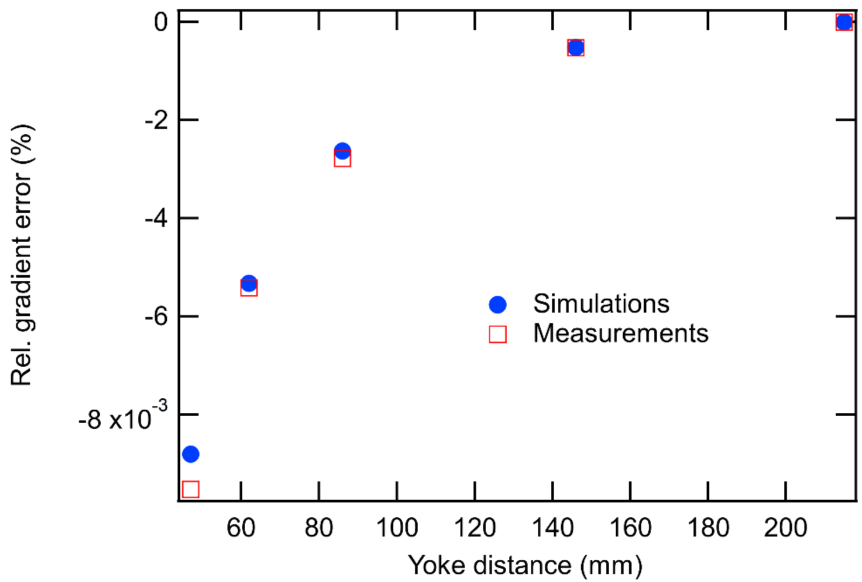
PM Dipole / quadrupole

Measured in 2017
(focused on field)

Discrepency:

$$\frac{\mathrm{Sim} - \mathrm{Meas}}{\mathrm{Meas}} < 7 \times 10^{-4}$$

(Magnet positioning could have been improved)



Quadrupole gradient vs distance between quad and PM dipole (nominal value: 47 mm, first point)

MEASUREMENTS

Sextupole / quadrupole

Simulation

$\Delta G/G = -\,0.30\ \%$

Measurements

$\Delta G/G = -0.306\ \%$

(Quad at 85 A, sextupole at 0 A,
distance 75 ± 0.5 mm, $UG \approx 10^{-4}$)

Octupole / quadrupole

Simulation (quad current: 85 A)

$\Delta G/G = 1.78\ \%$

Measurements

$\Delta G/G = 1.77\ \%$

Simulation (quad current: 100 A)

$\Delta G/G = 1.69\ \%$

Measurements

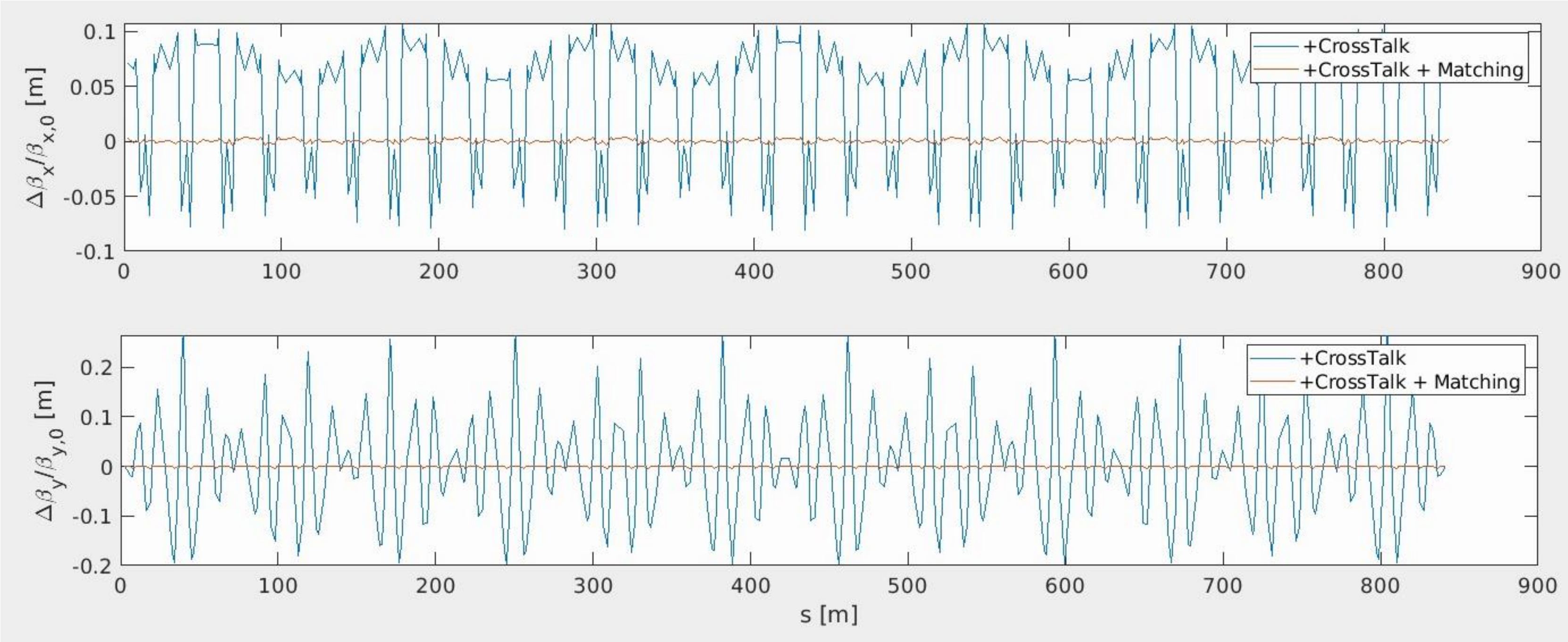
$\Delta G/G = 1.76\ \%$

(octupole at 0 A, distance 60 ± 0.5 mm, $UG \approx 10^{-4}$)

5. Impact on lattice

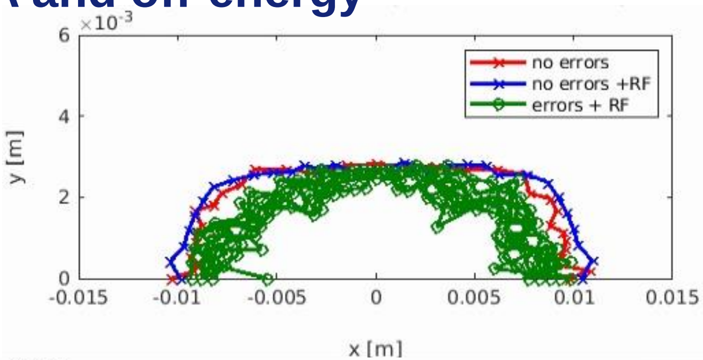
IMPACT ON LATTICE

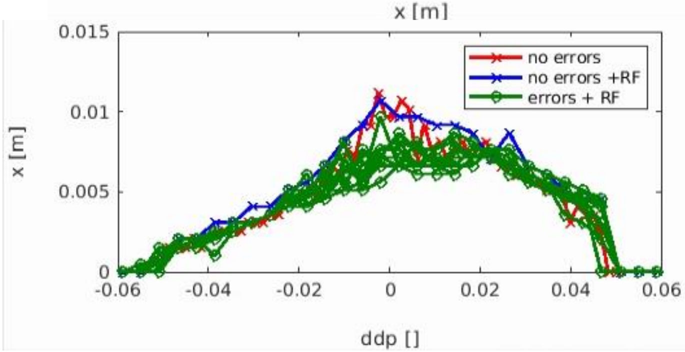
Optics with cross talk quadrupole fields



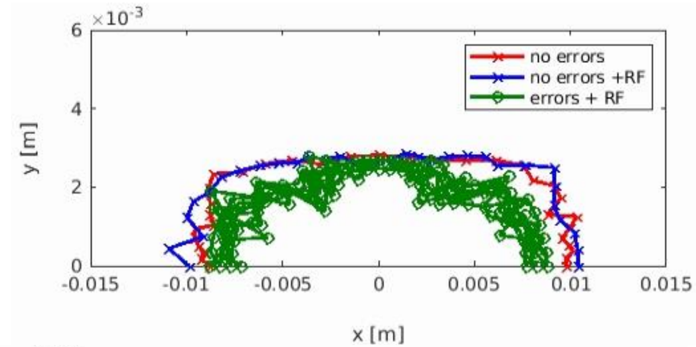
- Cross-talks (thin elements) introduce $\Delta\beta_X/\beta_X \approx 10$ % and $\Delta\beta_X/\beta_X \approx 20$ %
- Recovered after matching
- Changes in quadrupole setting points up to 1.7 %

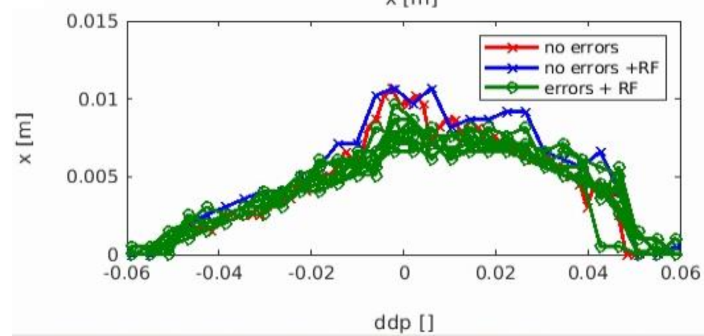
DA and off-energy





Ideal lattice model
DA : -8.7 +/- 0.3 mm
T.L.T. : 19.6 +/- 0.7 h
I.E. : 85 +/- 5 %

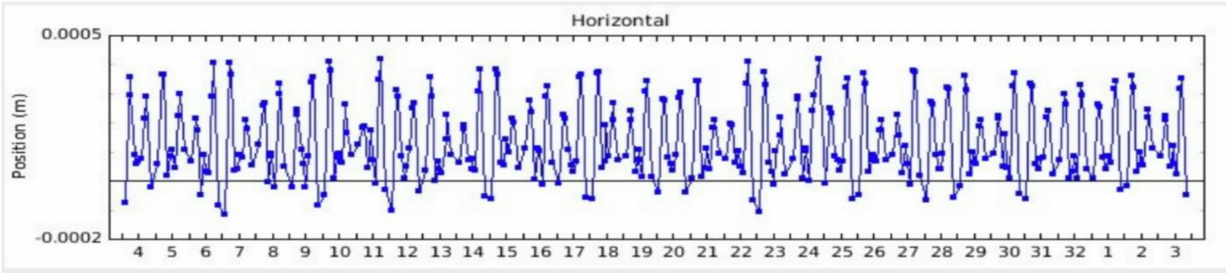




Ideal lattice model + cross talks
DA : -8.3 +/- 0.4 mm
T.L.T. : 19.7 +/- 1.4 h
I.E. : 88 +/- 7 %

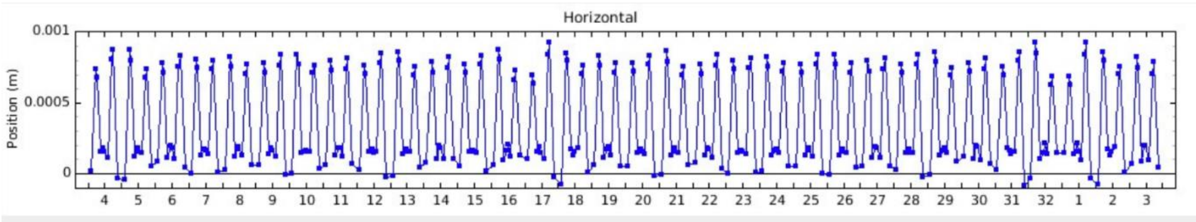
Synchrotron | ESRF

Horizontal dispersion measurements



09 Dec 2019, first measurement

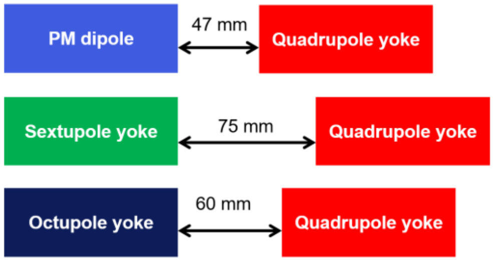
calibrations, cross-talks, steering with more singular values than foreseen, *BBA*,
NO quadrupole correction (except tunes)



30 Jan 2020, "uncorrected"

6. Conclusion

CONCLUSION

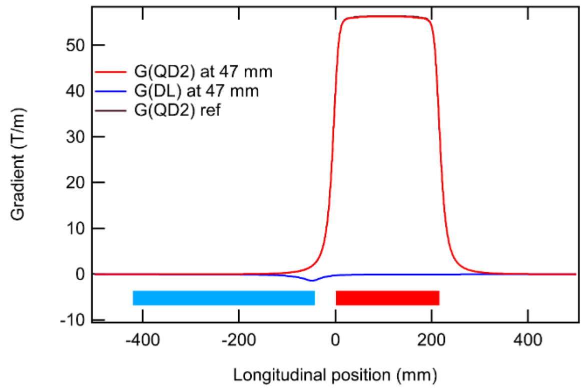


Causes of cross-talks

- Short distances between magnets

Effect on the lattice

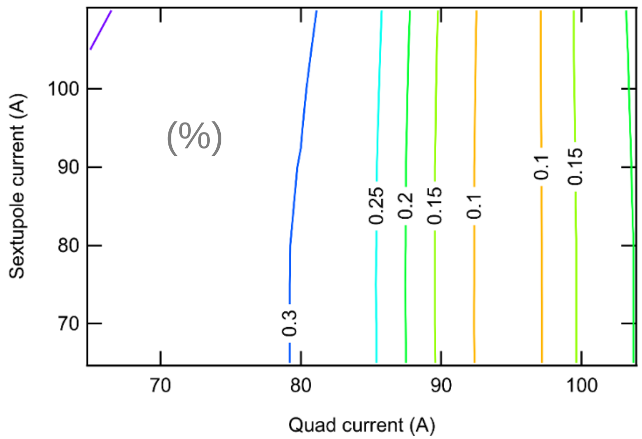
- Similar to magnet calibration issues
- Large discrepencies between model and real lattice at the restart
- Recovered by inserting cross-talk effects in the model
- No change in lattice performances at the end



CONCLUSION

Simulations

- 3D magnet models at several currents
- Fine localization of the errors (at magnet edges or not)
- Used to update the lattice model



Magnetic measurements

- Stretched-wire measurements of the integrated field
- Good agreement with simulations