Decay Ring status and field quality specifications

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Problematic due to the dipole errors

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To face the losses by decay, we recently have two possible structures for the decay ring:

_ structure with absorbers between the magnetic elements. The dipoles need large half-apertures (8 cm)

_ structure without absorbers. The dipoles are lengthened but we use open mid plane dipoles. Their magnetic field has decreased

The differences between the optical properties of the two structures are negligible. The betatron functions or the dynamic aperture are very similar.

To study the feasibility of such dipoles, we need to know the tolerances on the field quality. Multipolar defects in the dipoles have been studied for:

_ systematic errors

_ random errors

Notation

$$\int_{element} \frac{1}{(n-1)!}\frac{\partial^{n-1}B}{\partial x^{n-1}} R^{n-1} dl = k \int_{dipole} B dl$$

$$K_n = \frac{1}{B\rho}\frac{1}{(n-1)!}\frac{\partial^{n-1}B}{\partial x^{n-1}}$$

$$(K_n L) = \frac{k\theta}{R^{n-1}}$$

k : ratio between the multipolar component of the magnetic field at a distance R from the dipole center and the dipolar magnetic field

θ dipole angle

Integrated strength corresponding to

$\theta = \pi/86$, $R = 4$ cm, $k = 0.1\%$

Multipole order	$K_n L$ (m^{1-n})
n=2 Quadrupole	$0.913\ 10^{-3}$
n=3 Sextupole	$22.83\ 10^{-3}$
n=4 Octupole	0.571
n=5 Decapole	14.27

How to increase the dipole tolerances

Static and not dynamic errors

⇒The magnetic fields in the other magnetic elements could be changed to compensate these errors

⇒Enlargement of the tolerances

Best criteria to evaluate the stability of the beam is the dynamic aperture

⇒The dynamic aperture must be optimized in presence of multipolar errors in the dipoles to enlarge the dipole tolerances.

To realize an automatic optimization of the dynamic aperture, we have used the “Algorithm for chromatic sextupole optimization and dynamic aperture increase”, E. Lebichev, P. Piminov, EPAC06

The algorithm consists of compensating the natural chromaticity in *N* steps. At each step, each sextupole couple is evaluated to obtain the chromaticity equal to a given value. The one that gives the largest dynamic aperture is saved.

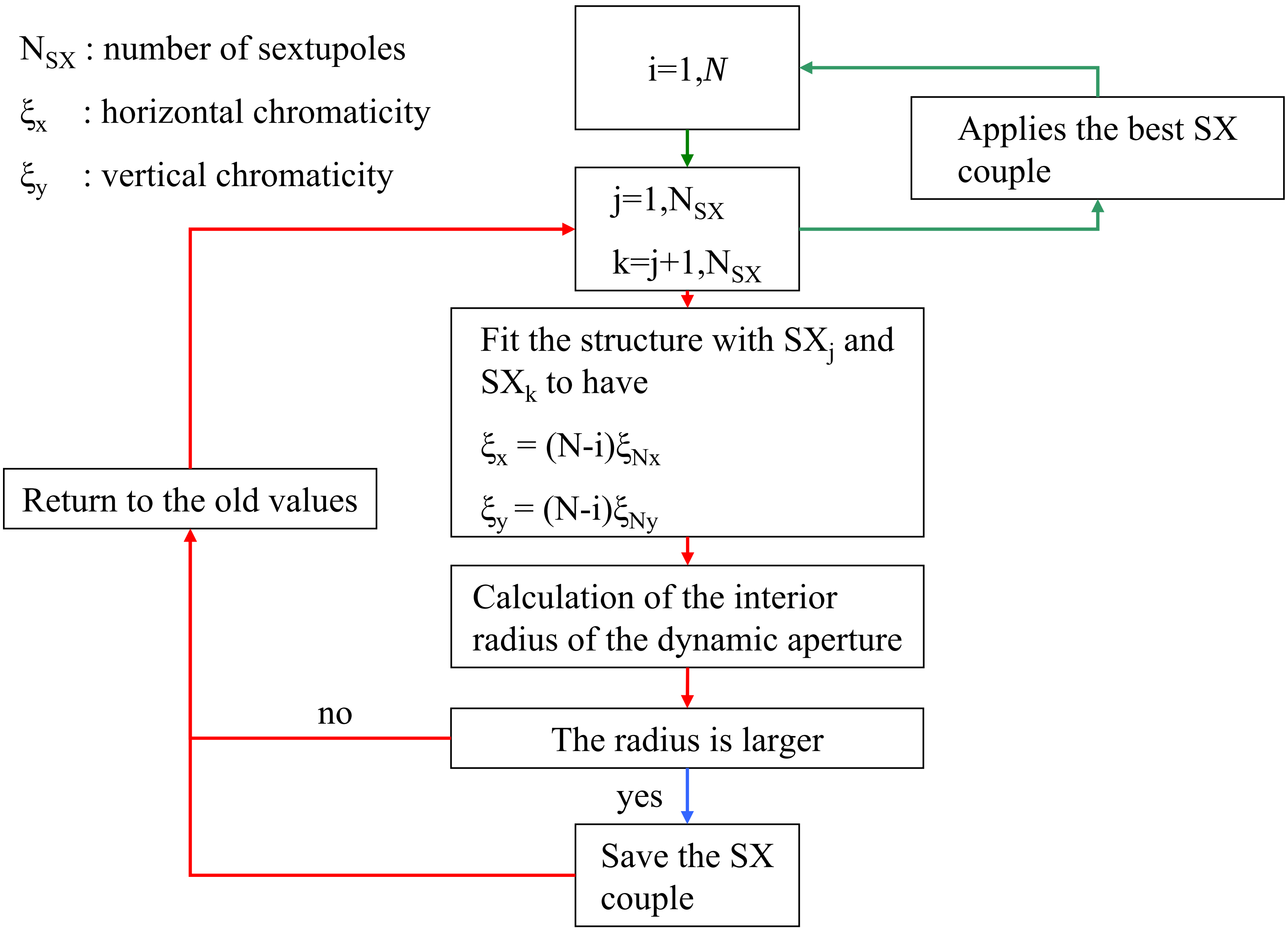
Algorithm principle

N : number of iterations

N_{SX} : number of sextupoles

ξ_x : horizontal chromaticity

ξ_y : vertical chromaticity



Generation of the errors

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We have inserted thin multipolar lenses at the entry and the exit of each dipole.

In the case of systematic errors, each lens has the same strength and its strength is given by:

$$K_n L = \frac{k\theta}{2R^{n-1}}$$

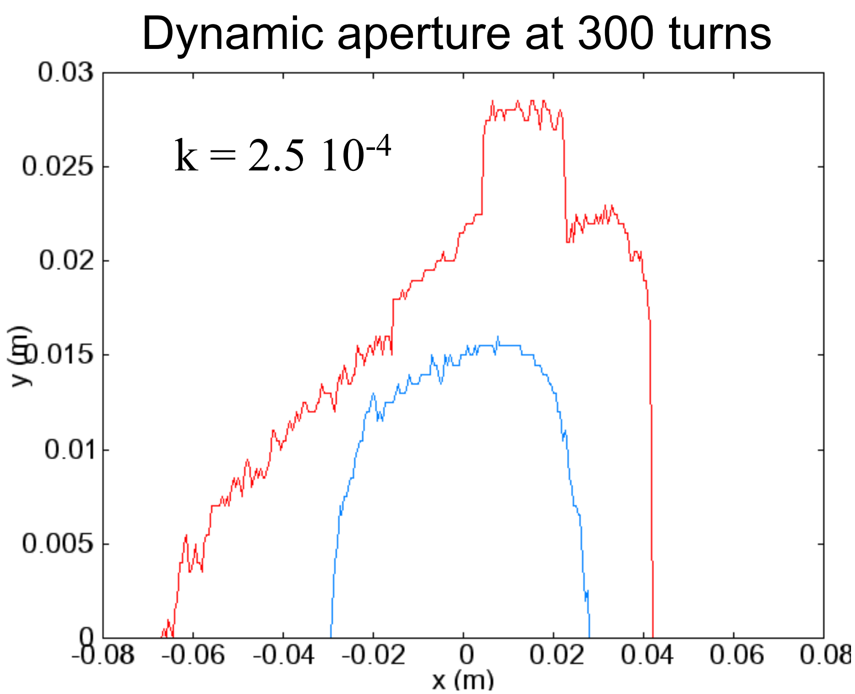
For the quadrupolar defects, the strength of the other quadrupoles has been changed to keep the right tune in the structure.

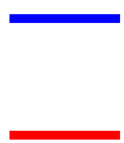
In the case of random errors, the strength of each lens is generated with a Gaussian distribution with a standard deviation given by the formula above.

To have a statistics on the random errors, we have generated structures with different seeds and applied an automatic dynamic aperture optimization in each case.

Systematic errors

Example of the sextupolar tolerances

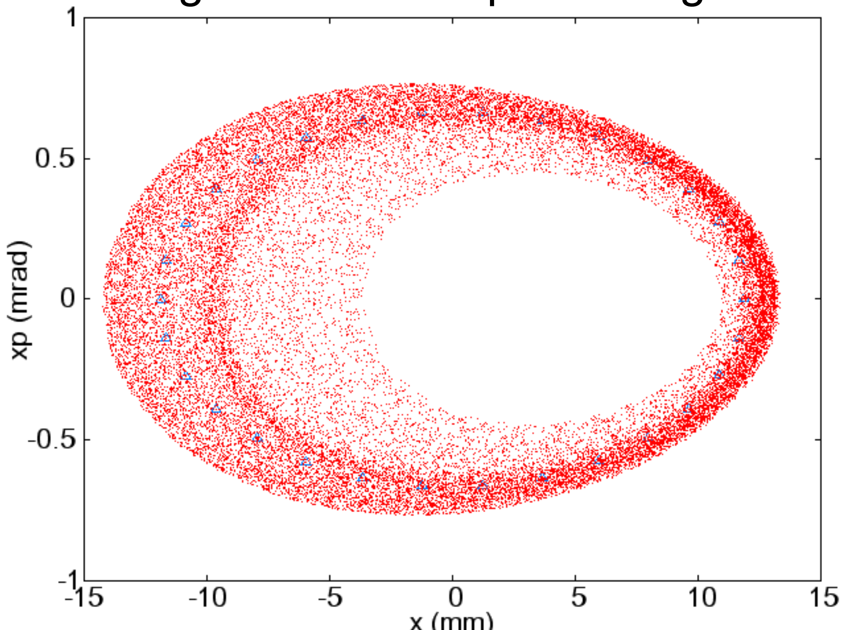


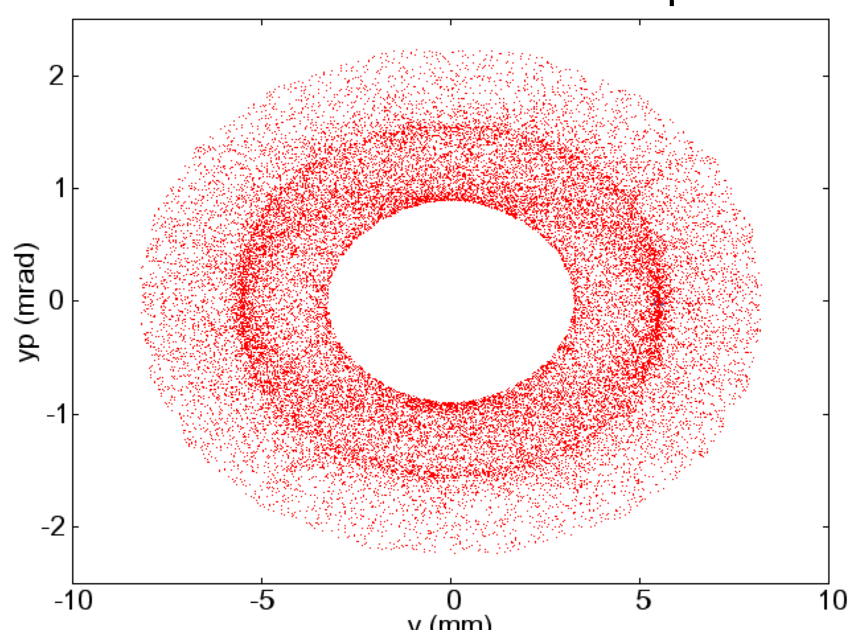


Strong coupling resonance

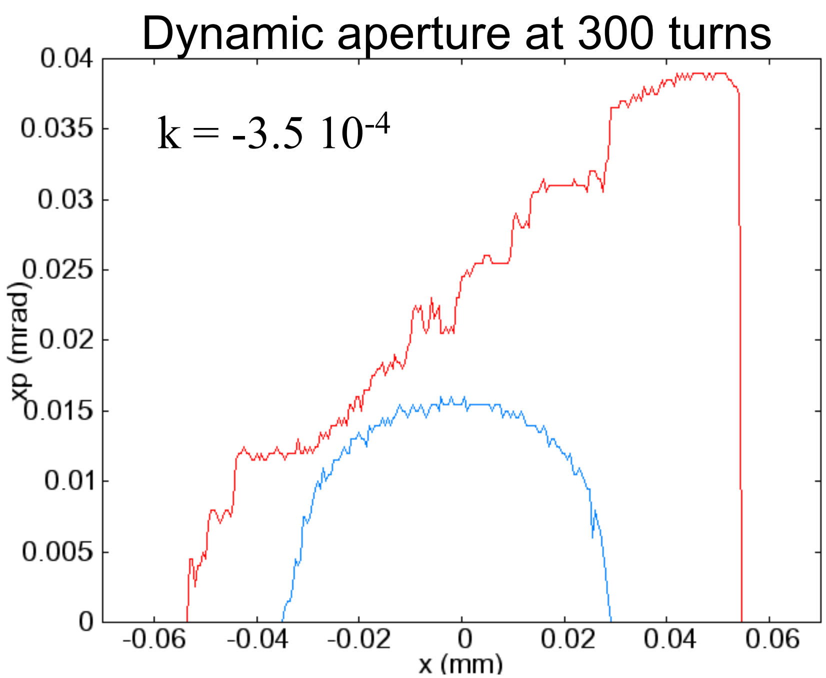
Difficult to improve the tolerance for the sextupolar mode

Tracking of the 6 σ ellipse during 300 turns in the horizontal and vertical planes





Example of the sextupolar tolerances



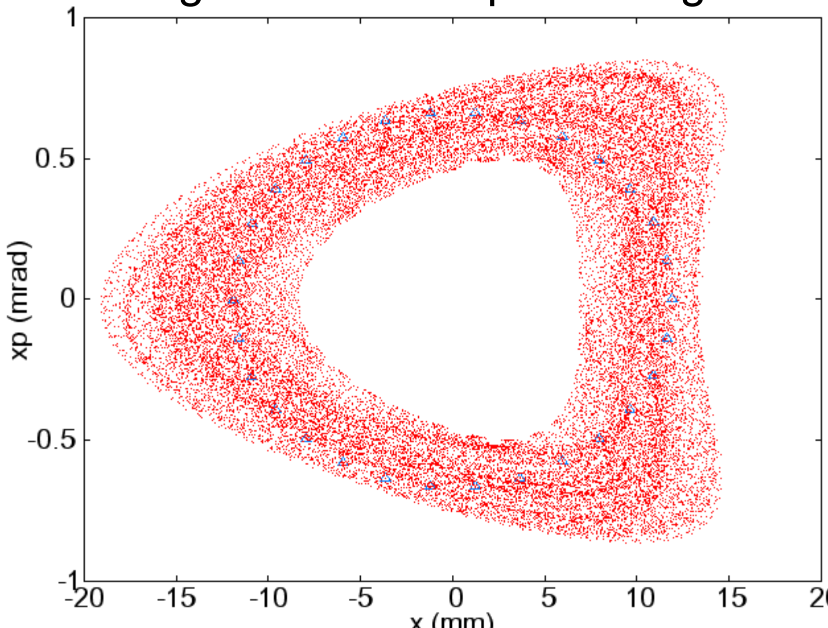
Chromaticity correction only

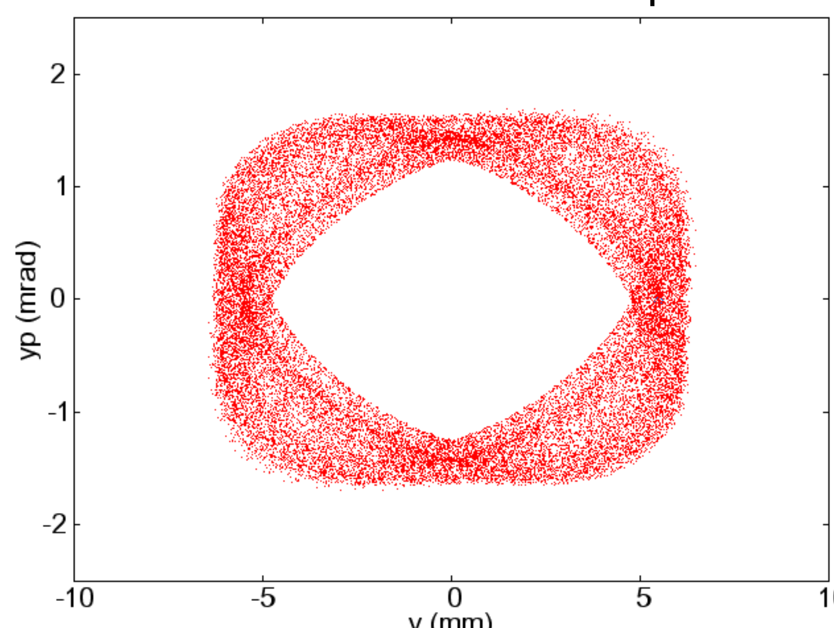
Dynamic aperture optimization

Very asymmetric aperture

Limit for the tolerances

Tracking of the 6 σ ellipse during 300 turns in the horizontal and vertical planes





Multipolar tolerances

Order of magnitude of the tolerances for the multipolar components in the dipoles at R = 4 cm from the machine axis

Type of defect	k Minimum	k Maximum
Quadrupolar defects	-.004	0.004
Sextupolar defects	$-3.5\ 10^{-4}$	$2.5\ 10^{-4}$
Octupolar defects	$-1.\ 10^{-4}$	$2.\ 10^{-4}$
Decapolar defects	$-3.\ 10^{-4}$	$2\ 10^{-4}$

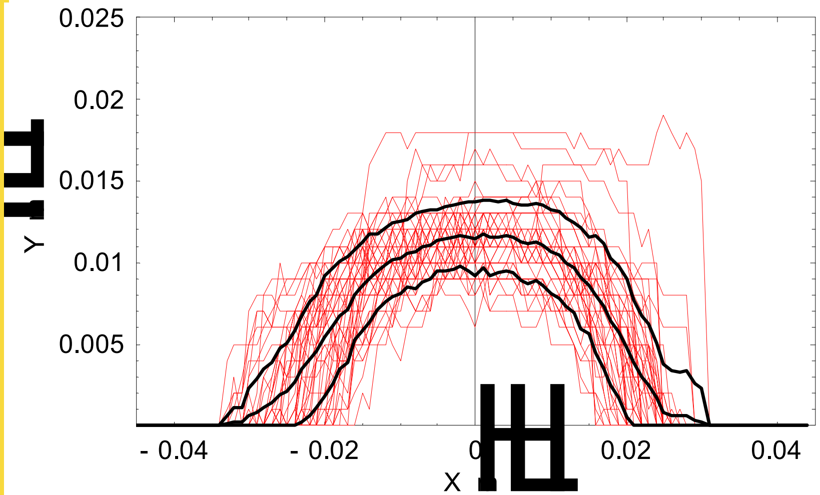
The tolerances are not very large for each multipolar component

Since we always have the same component, the dynamic aperture is very asymmetric. The optimization does not work well. The dynamic aperture is larger but the beam deformation stays the same.

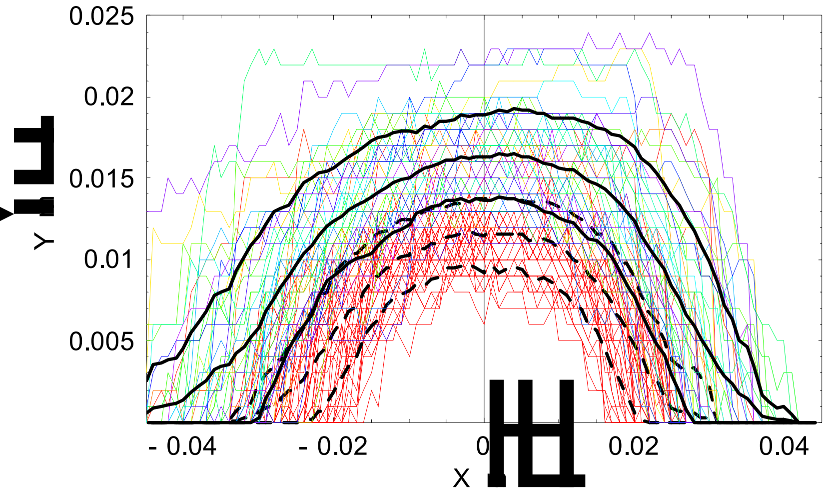
Random errors

Comparison of the dynamic apertures with and without optimization $k_{rms}=2.10^{-4}$

Before optimization



After optimization



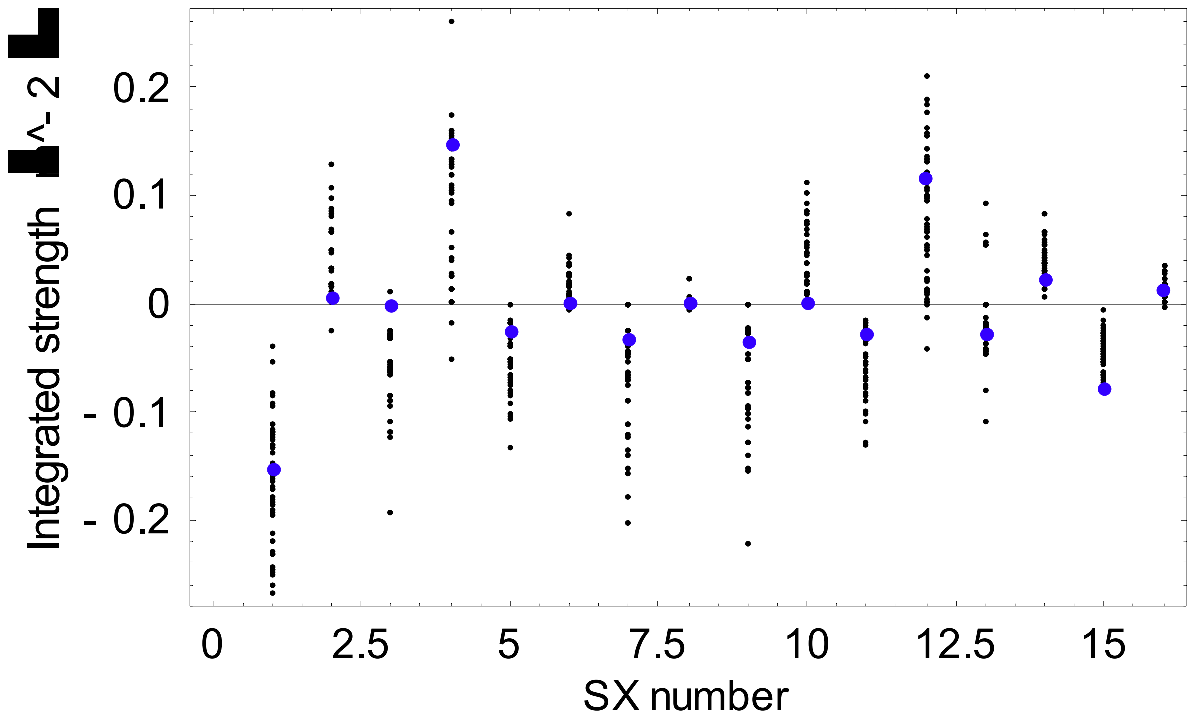
The dynamic aperture has been enlarged BUT:

_ strong dispersion in the results. Some cases are much more favorable than others

_ we may be able to improve the results but it is time costly (1h30 for 1 optimization at 300 turns and 30 iterations with a PIV 3.2 GHz 1Go of memory)

Sextupole strength dispersion

Integrated strengths of the sextupoles after optimizing the dynamic aperture for different samples. In blue, integrated strengths for the reference lattice



Very large dispersion for the sextupole strengths

It may be possible to do an optimization by preferring the strengths near the reference value

Pros and cons of this algorithm

Pros:

_ The dynamic aperture has been enlarged

_ Easy to use

_ Possibility to maximize the area or the interior radius of the dynamic aperture

Cons:

_ Needs a large number of calculation of the dynamic aperture:

$N \times N_{SX} \times (N_{SX}-1)/2$

_ Depends on the chosen number of iterations and the starting point

_ We are not sure to reach the optimum

_ The sextupoles must be in a dispersive area

Prospective

⇒Other algorithms are on development

1. Newton method (2nd order gradient method)

It calculates the second order derivatives matrix to estimate the descent direction to minimize the function

But, to evaluate it, we need $N_{SX} \times (N_{SX}+1)/2$ calculations, time costly

Not tested yet

2. Variable metric method

Only the gradient is calculated. It needs less function evaluations. The problem is the evaluation of the gradient. The variations of the dynamic aperture are too slow. It does not work for the moment.

3. Any other idea?