Study of the Dipolar Imperfections in the Decay Ring

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Outline

1. Statistical defects due to misalignment of the elements

2. Multipolar defects in the dipoles. Effects on the transportation in the decay ring.

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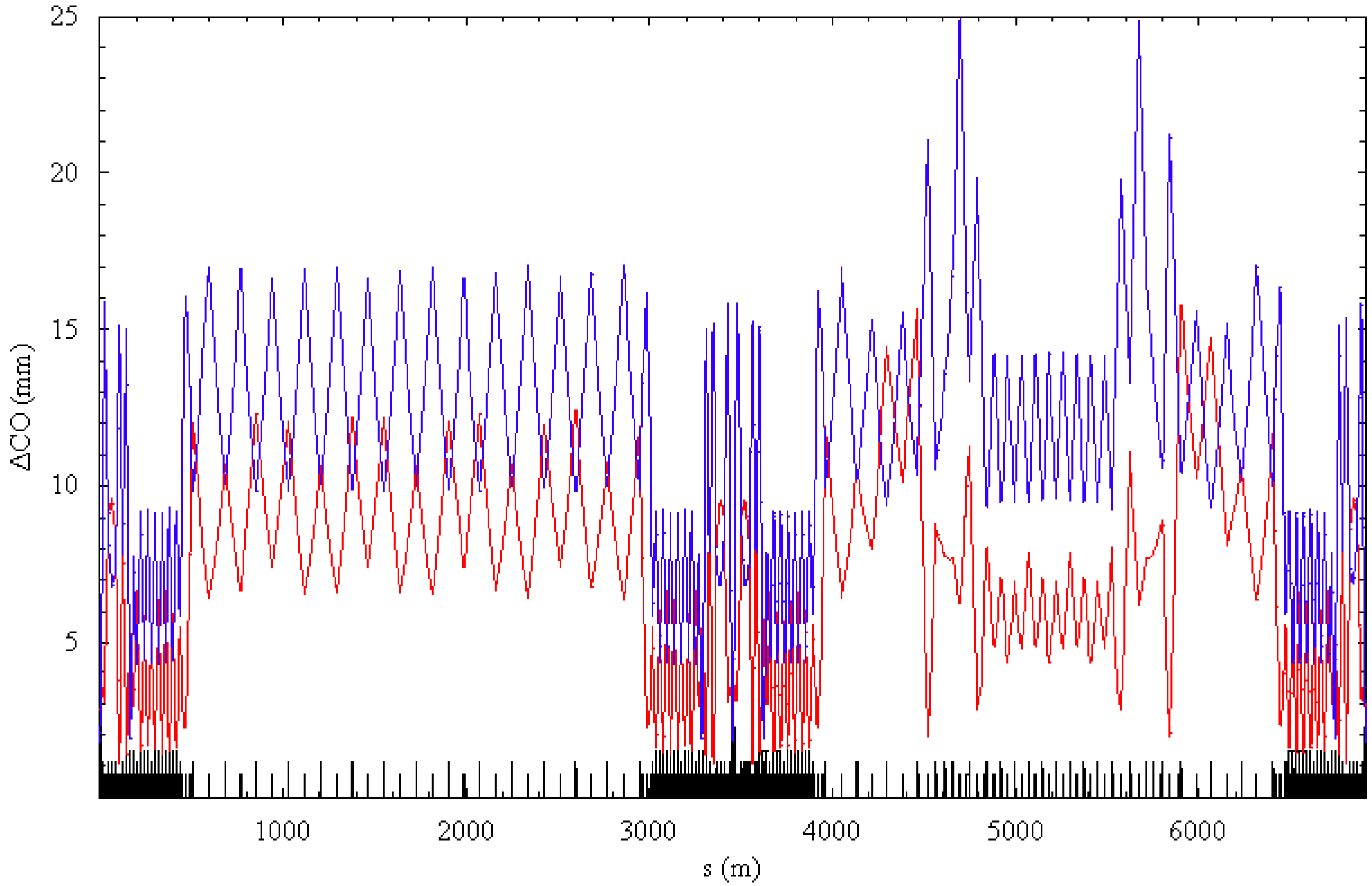
2. Multipolar defects in the dipoles. Effects on the transportation in the decay ring.

Random errors in the magnetic elements
Linear contributions

Defect Type	rms value	units
DIPOLES		
$\frac{\Delta B}{B}$	0.1	10^{-3}
Horizontal misalignment	0.2	mm
Vertical misalignment	0.2	mm
Rotation error/ s axis	0.1	mrad
QUADRUPOLES		
$\frac{\Delta B}{B}$	0.1	10^{-3}
Horizontal misalignment	0.2	mm
Vertical misalignment	0.2	mm

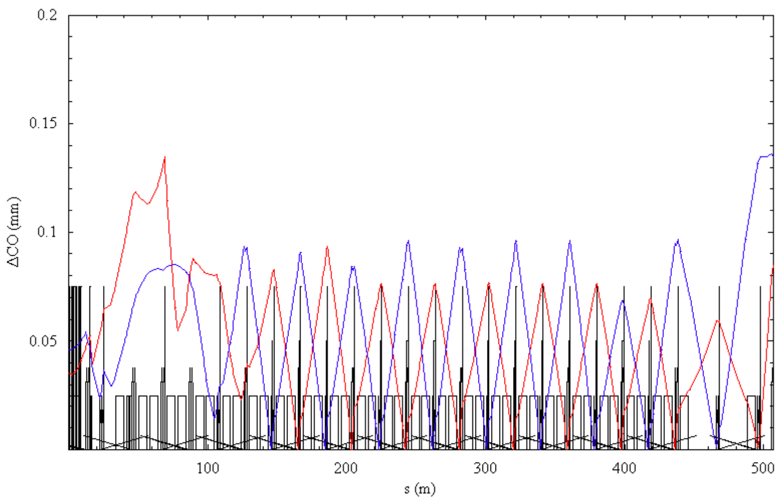
In this part, every statistical value is given at 1 σ and is calculated for the working point $\nu_X = 22.228, \nu_Z = 12.16$

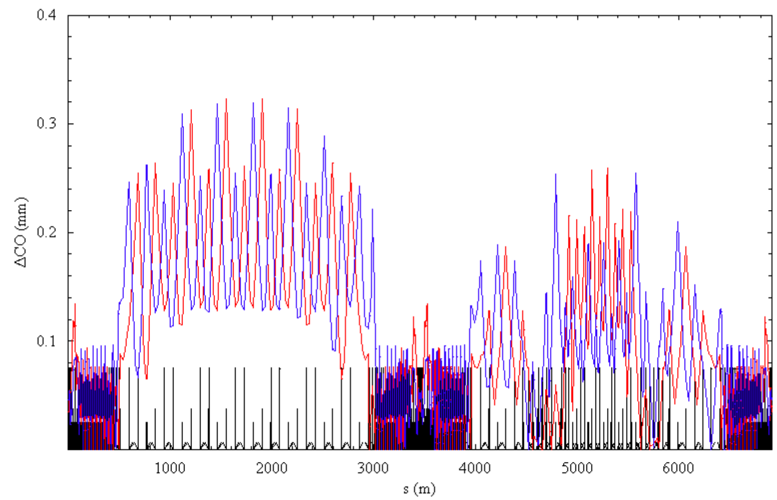
Case without a corrector in the structure



The rms errors on the closed orbit are more than a few millimeters in the arcs and than one centimeter in the straight section. So, correctors and BPM are needed in the structure to compensate the statistic errors in the magnetic elements.

Case 1 : case with a corrector and a BPM at each quadrupole of the arc





Less than 0.15 mm rms in the arcs and 0.3 mm in the structure

Maximum rms angle in a horizontal/vertical corrector : 0.022/0.021 mrad

It corresponds to an rms integrated field of about 0.02 T.m

BUT

71/66 horizontal/vertical correctors and so many BPMs

Enough place in the arcs?

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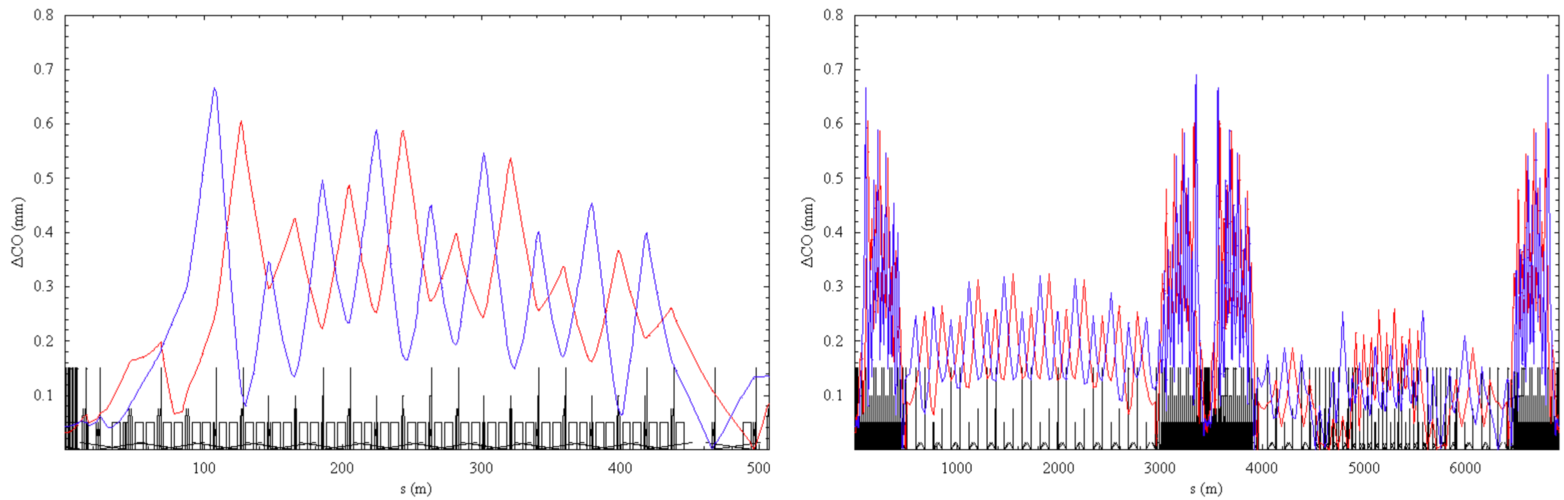
Case 2 : case with a BPM at each quadrupole of the arc but a corrector at each second quadrupole



Less than 0.7 mm rms in the arcs and 0.7 mm in the structure

Maximum rms angle in a horizontal/vertical corrector : 0.03/0.023 mrad

It corresponds to an rms integrated field of about 0.03 T.m

BUT

55/50 horizontal/vertical correctors and 71/66 BPMs

There are less correctors than in the previous case but the errors on the closed orbit strongly increase. If possible, the first case is better.

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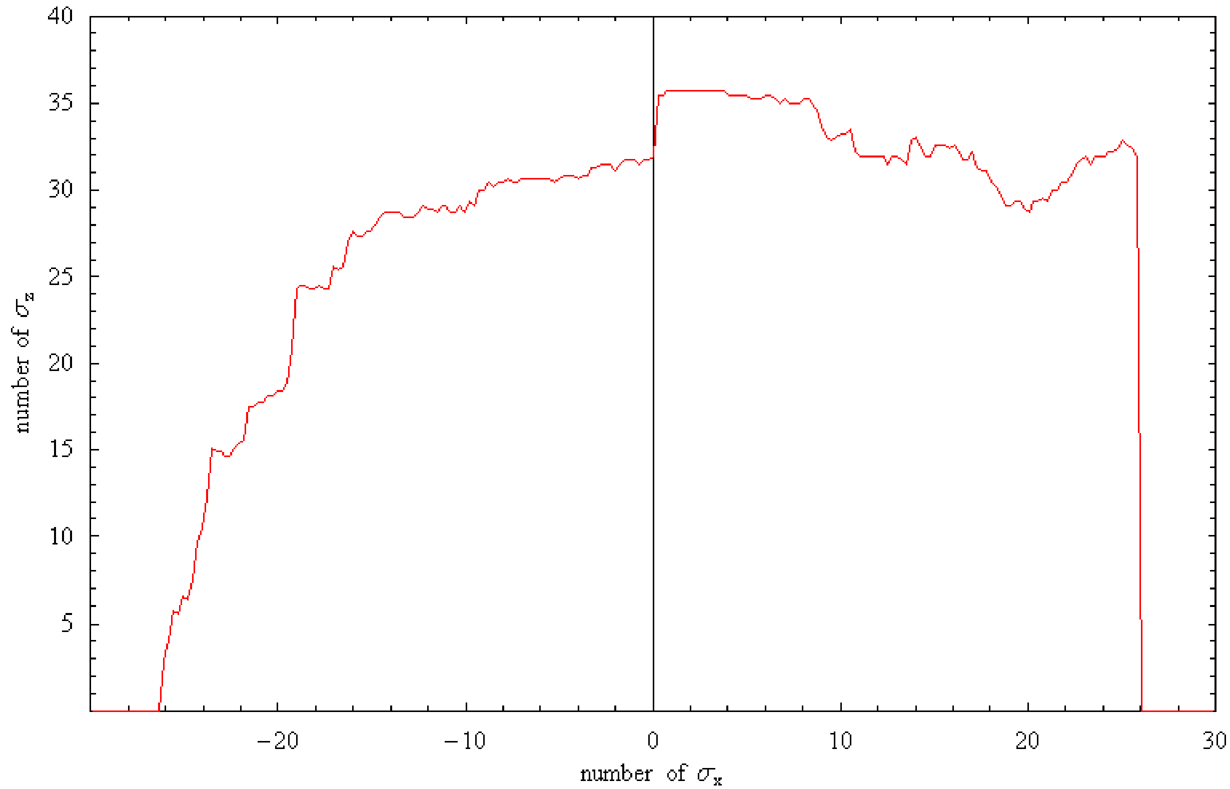
2. Multipolar defects in the dipoles. Effects on the transportation in the decay ring.

Dynamic aperture without a defect in the structure



Neon case

$$\sigma_x = \sqrt{\beta_x \varepsilon_x} \approx 2\ \mathrm{mm}$$

$$\sigma_z = \sqrt{\beta_z \varepsilon_z} \approx 0.9\ \mathrm{mm}$$

$$\varepsilon_x = 0.22\ \mathrm{mm.mrad}$$

$$\varepsilon_z = 0.22\ \mathrm{mm.mrad}$$

After optimization, the obtained dynamic aperture is very large

8 sextupole families are used in the arc

The coupling between the horizontal and vertical planes is very low

The beam shape is almost not deformed by the sextupoles

Systematic multipole defects in the dipoles

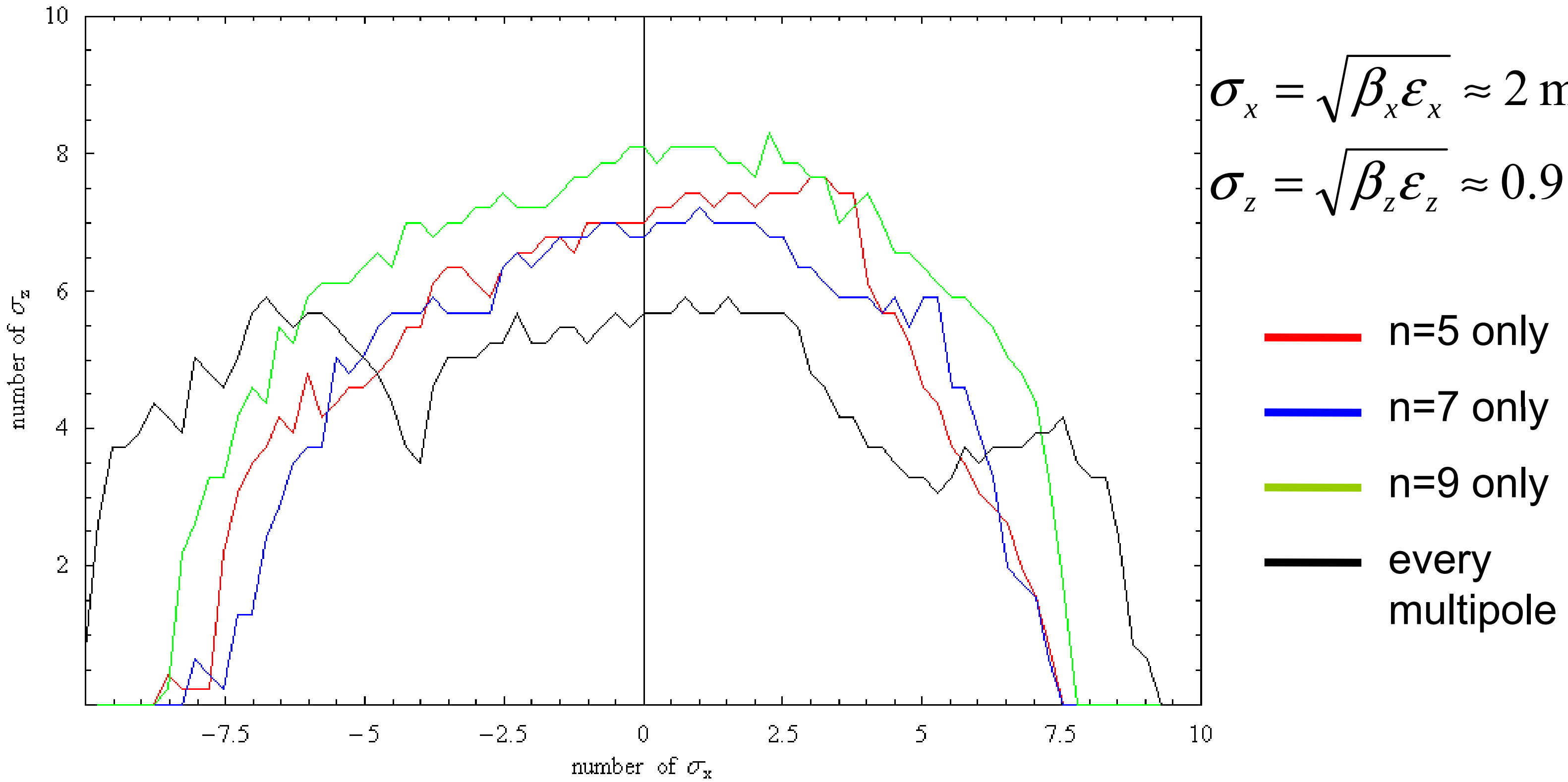
C. Vollinger, E. Wildner

Multipole order n	b_n (10^{-4}) at R = 60 mm	$K_n L = \frac{b_n \theta}{R^{n-1}}$ (m^{1-n})
(fundamental) 1	6.036	2.2 10^{-5}
2	0	0
3	-1.685	-0.00171
4	0	0
5	33.018	9.307
6	0	0
7	-50.123	-3924.5
8	0	0
9	29.583	643400

The dipole field is not perfect and some multipole components exist in the dipoles which will excite the higher order resonances.

How does the dynamic aperture change in presence of these systematic defects?

Effects of the multipole defects on the dynamic aperture



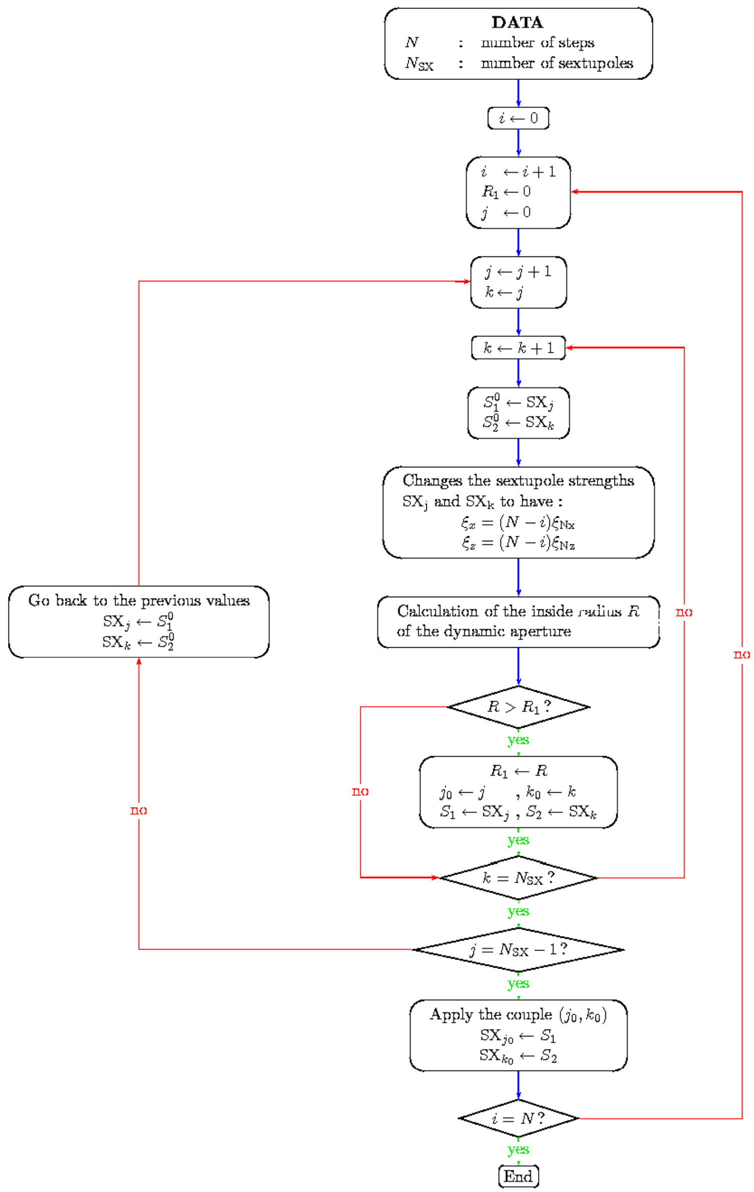
$$\sigma_x = \sqrt{\beta_x \varepsilon_x} \approx 2\ \text{mm}$$

$$\sigma_z = \sqrt{\beta_z \varepsilon_z} \approx 0.9\ \text{mm}$$

The dynamic aperture dramatically decreases because of the high order multipole defects (10 and 14 poles principally)

It is necessary to enlarge the dynamic aperture in presence of multipole lenses.

Algorithm principle to enlarge the dynamic aperture



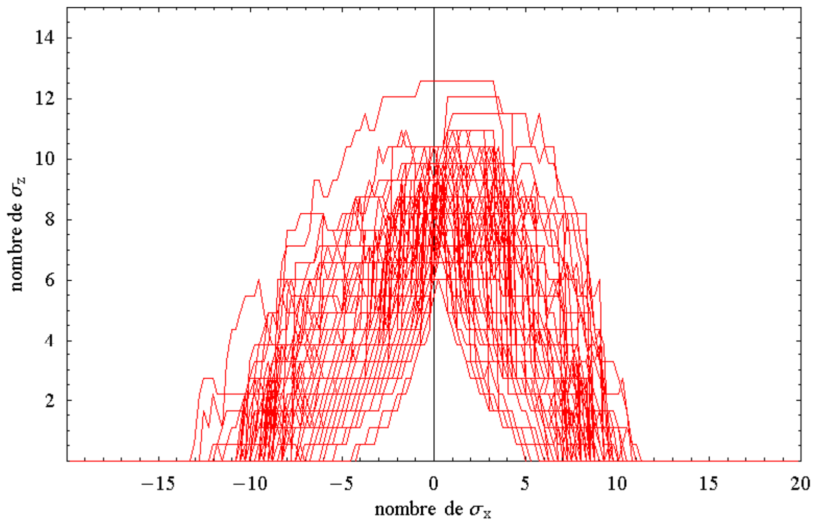
"Algorithm for chromatic sextupole optimization and dynamic aperture increase", E. Lebichev, P. Piminov, EPAC06

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 and the iteration goes to the next step.

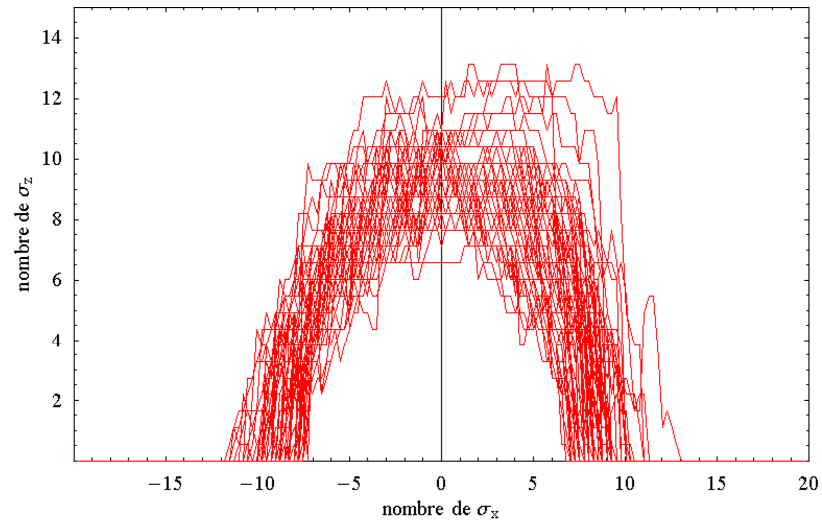
At the end, the dynamic aperture should be larger than initially.

Test of the dynamic aperture automatic enlargement

Before optimization



After optimization

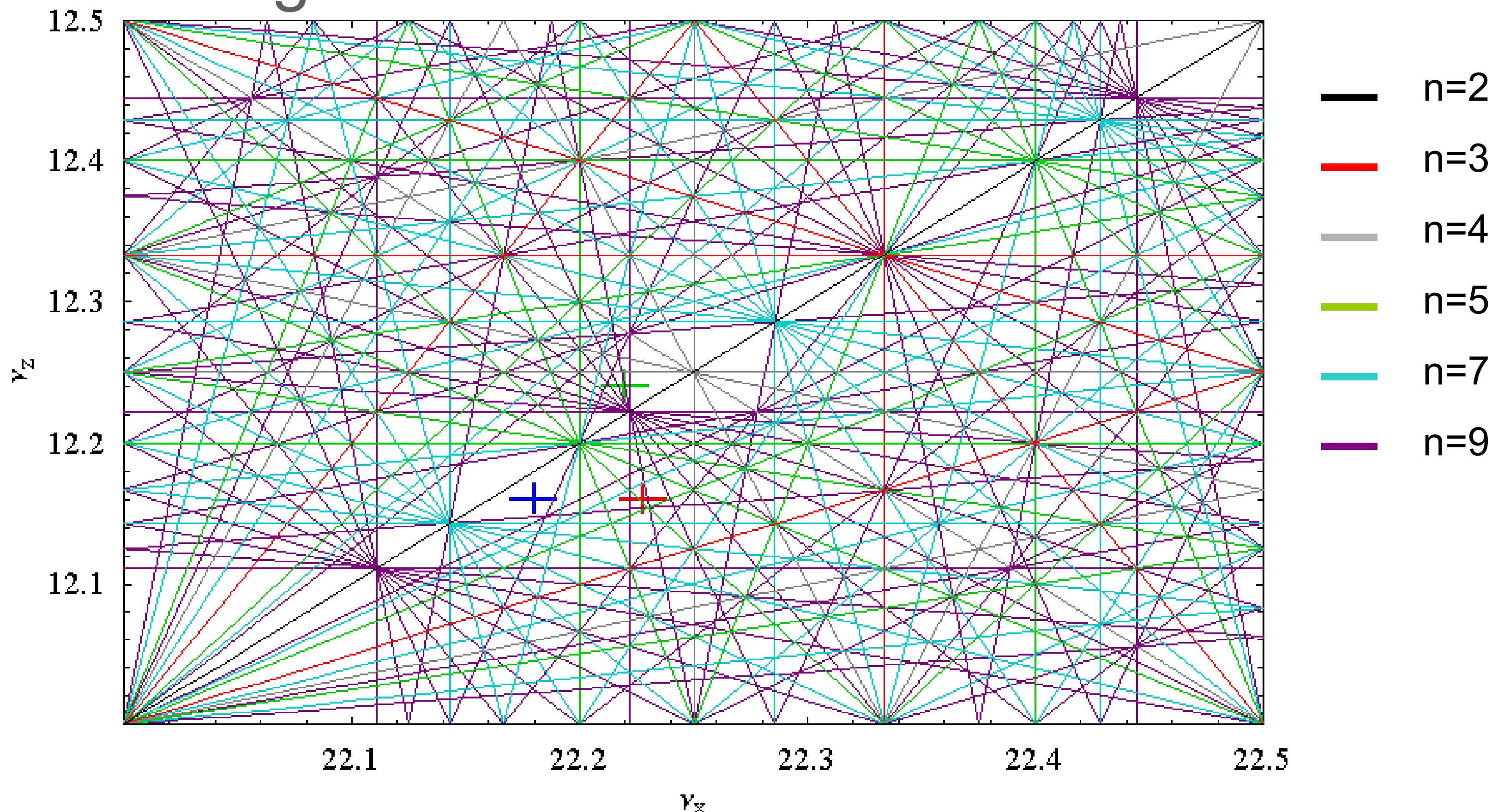


The simulation was made with only decapole lenses in the dipoles.

The rms value of the integrated strength in each dipole was equal to 9.307 m^{-4} and the mean to 0.

The test shows that the dynamic aperture was enlarged thanks to the algorithm and the dispersion on the dynamic aperture reduced.

Tune diagram and resonances



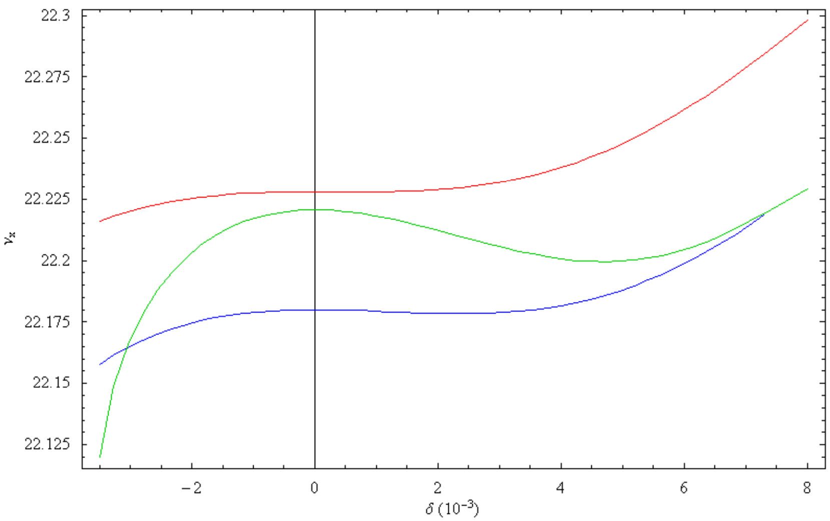
Several working points have been compared to minimize the multipole effects on the transverse stability of the beam

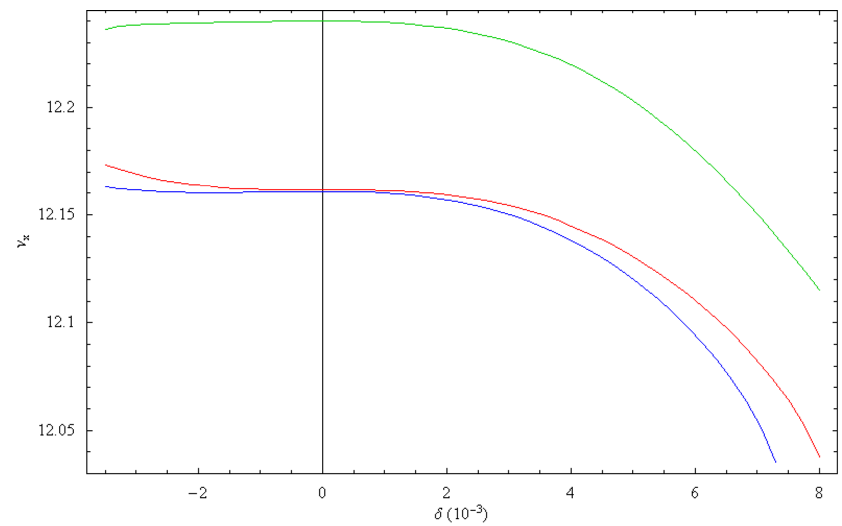
Case 1 $\nu_X = 22.228, \nu_Z = 12.16$

Case 2 $\nu_X = 22.18\ , \nu_Z = 12.16$

Case 3 $\nu_X = 22.22\ , \nu_Z = 12.24$

Variation of the tune with the momentum



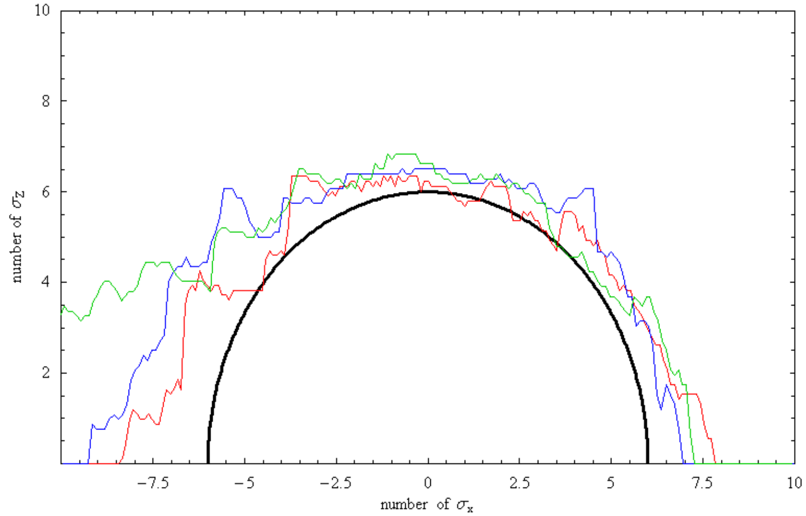


	δ_{min}	δ_{max}
Case 1	-8 ‰	8.2 ‰
Case 2	-5.1 ‰	7.5 ‰
Case 3	-3.5 ‰	8.8 ‰

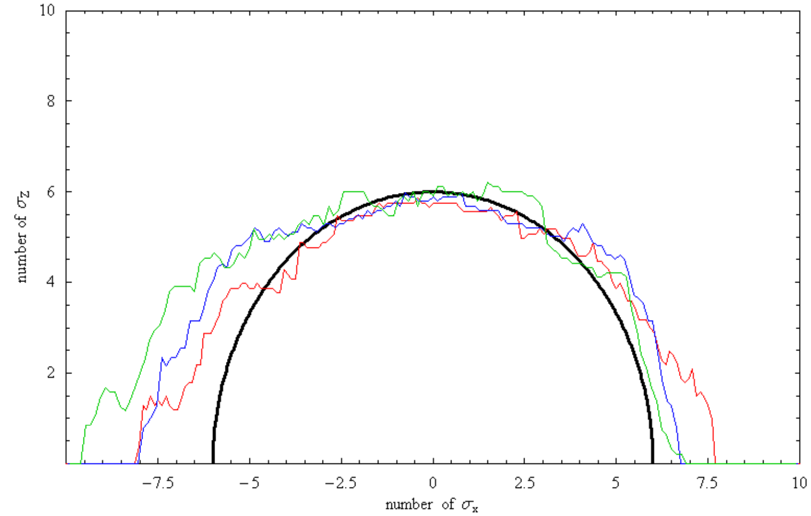
The momentum acceptance in the third case is the smallest. The tune variations are not negligible

Dynamic apertures for the 3 working points at different δ

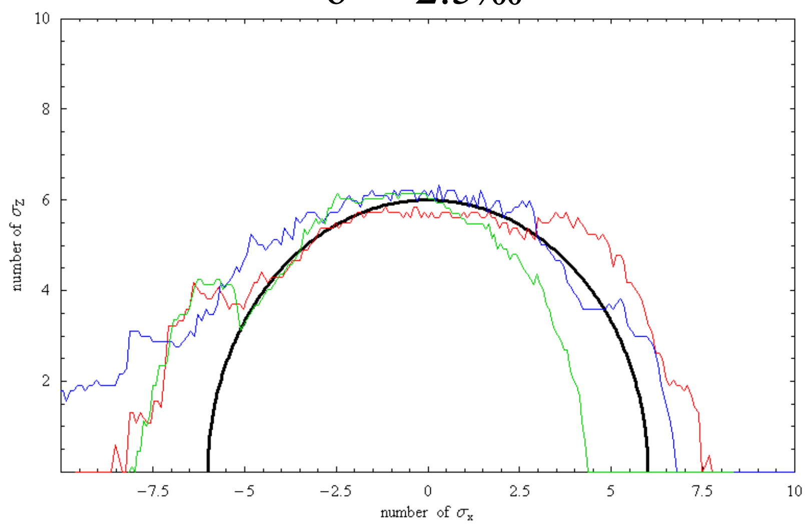
δ = 0‰



δ = 2.5‰



δ = -2.5‰



σ_x / σ_z	δ = 0‰	δ = 2.5‰	δ = -2.5‰
Case 1	1.99 / 0.91	1.92 / 1.01	2.06 / 0.84
Case 2	1.73 / 0.92	1.57 / 1.02	1.95 / 0.84
Case 3	1.82 / 0.92	1.48 / 0.94	2.42 / 0.89

Red: $\nu_x = 22.228, \nu_z = 12.16$

Blue: $\nu_x = 22.18\ , \nu_z = 12.16$

Green: $\nu_x = 22.22\ , \nu_z = 12.24$

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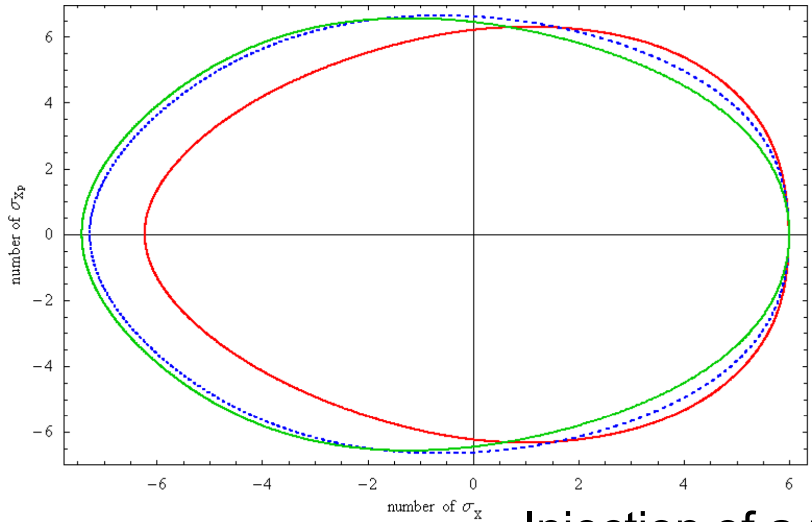
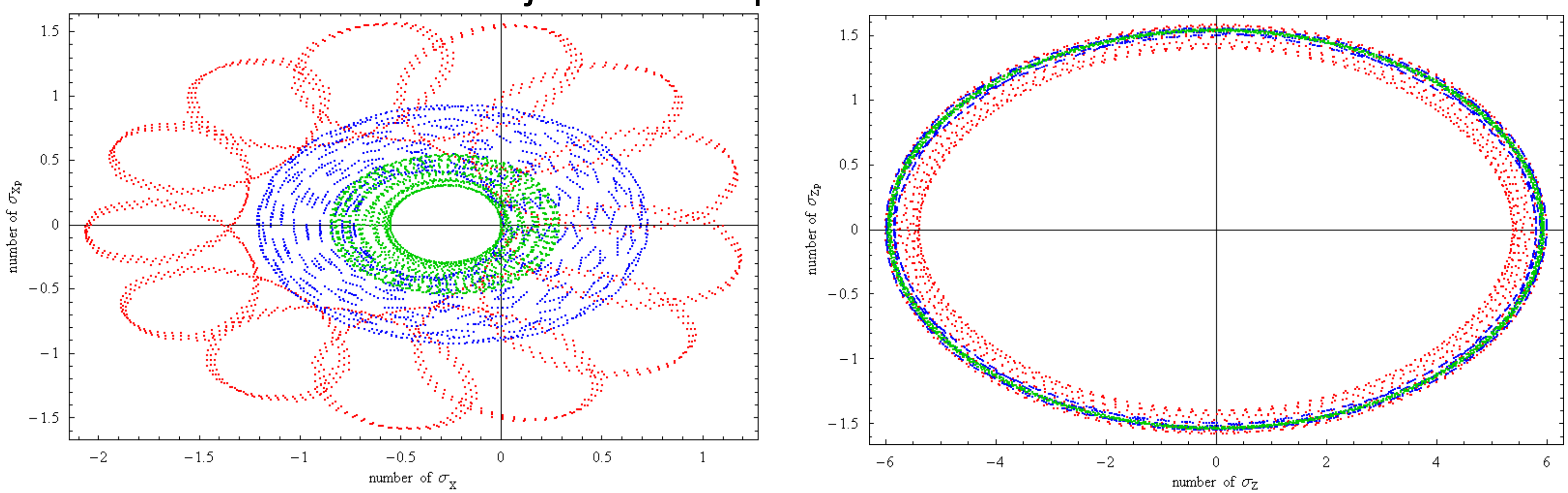
Tracking at 6 σ in the Helium case

Injection of a particle at X=6 σ



The coupling between the horizontal and vertical planes is the most important in the Case 1. High order resonances occur in the decay ring and the beam shape will be very deformed.

Injection of a particle at Z=6 σ



Red: $\nu_X = 22.228, \nu_Z = 12.16$

Blue: $\nu_X = 22.18\ , \nu_Z = 12.16$

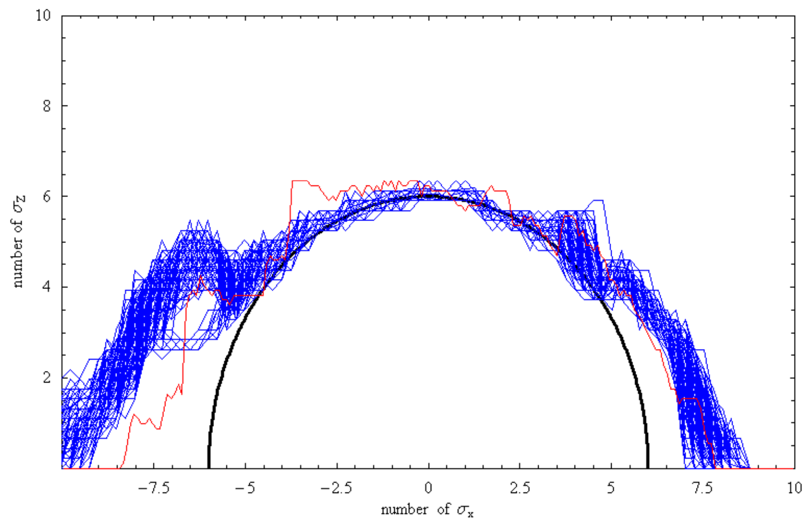
Green: $\nu_X = 22.22\ , \nu_Z = 12.24$

$\varepsilon_x = 0.11\,\text{mm.mrad}$

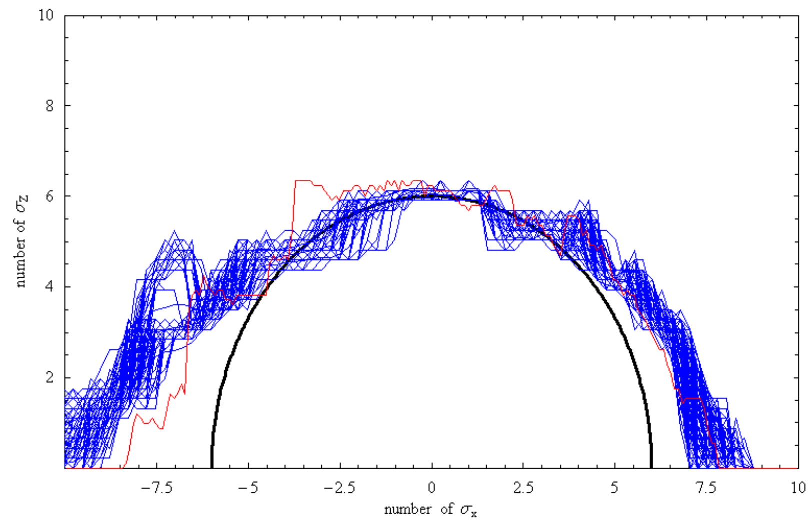
$\varepsilon_z = 0.06\,\text{mm.mrad}$

Random multipole components in the dipoles

n=5



n=7



- The systematic multipole components have been kept in the dipoles
- The random rms error is assumed equal to 10% of the systematic error and we have launched 250 samples
- In the n=5 case, the dispersion on the dynamic aperture is low.
- In the n=7 case, the vertical stability decreases. The Neon beam may be very deformed
- To get a better statistics on the random errors, the use of a MPI code has been enabled

Conclusion

1. The misalignment errors can be corrected by inserting BPMs and correctors in the decay ring. However, to have an acceptable error on the closed orbit, a large number of correctors has to be used

2. The systematic errors in the dipoles have been studied. The n=10 and n=14 defects bring the strongest contribution. To reduce their effects, different working points have been studied. The one which gives the best compromise between momentum acceptance, coupling between the two planes and transverse stability seems to be

$$\nu_X = 22.18 \ , \nu_Z = 12.16$$

3. The multipole defects in the dipoles may be too large for the Neon beam but they are acceptable for the Helium beam. Indeed, the Neon beam emittance was enlarged due to space charge effects. In the FP7 program, the space charge effects are reduced thanks to low values of Z^2/A

4. The random errors around the systematic values do not change the dynamic aperture a lot. Enlarging the dynamic aperture for each random sample may not be needed.

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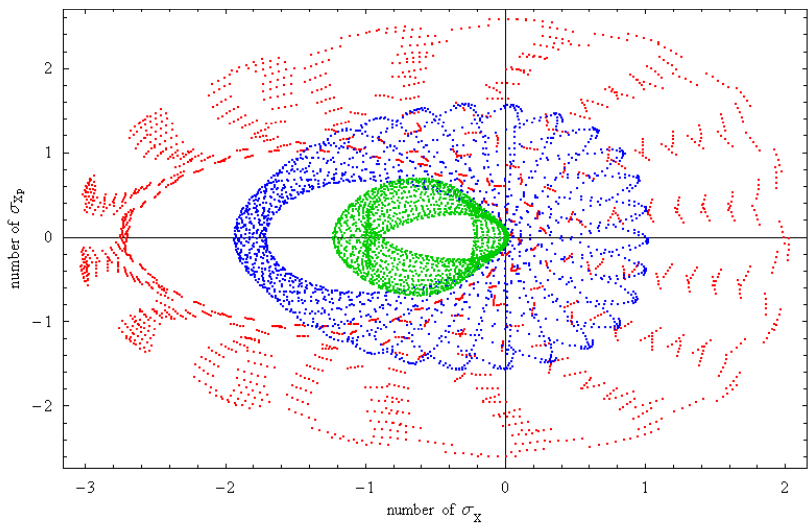
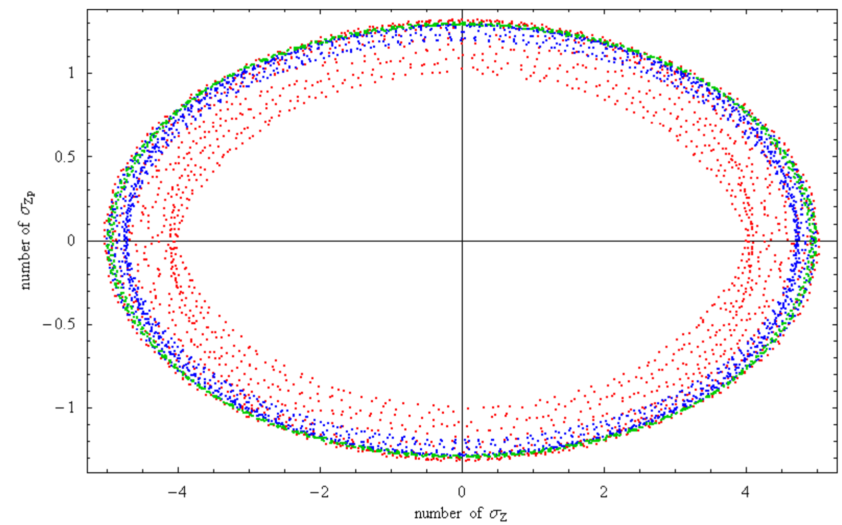
THANK YOU FOR YOUR ATTENTION

Tracking at 6 σ in the Neon case

Injection of a particle at Z=6 σ





A large transfer from the vertical plane to the horizontal plane occurs in the Case 1. In the 2 other case, the coupling resonances are much less excited.