Role of the frequency map analysis in the choice of the working point of SOLEIL

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PhD position (10/2001-10/2004)

Contents

1. Effects of coupling

- Frequency maps for optics 1 (18.3, 10.27)

- Frequency maps for optics 2 (18.2, 10.3)

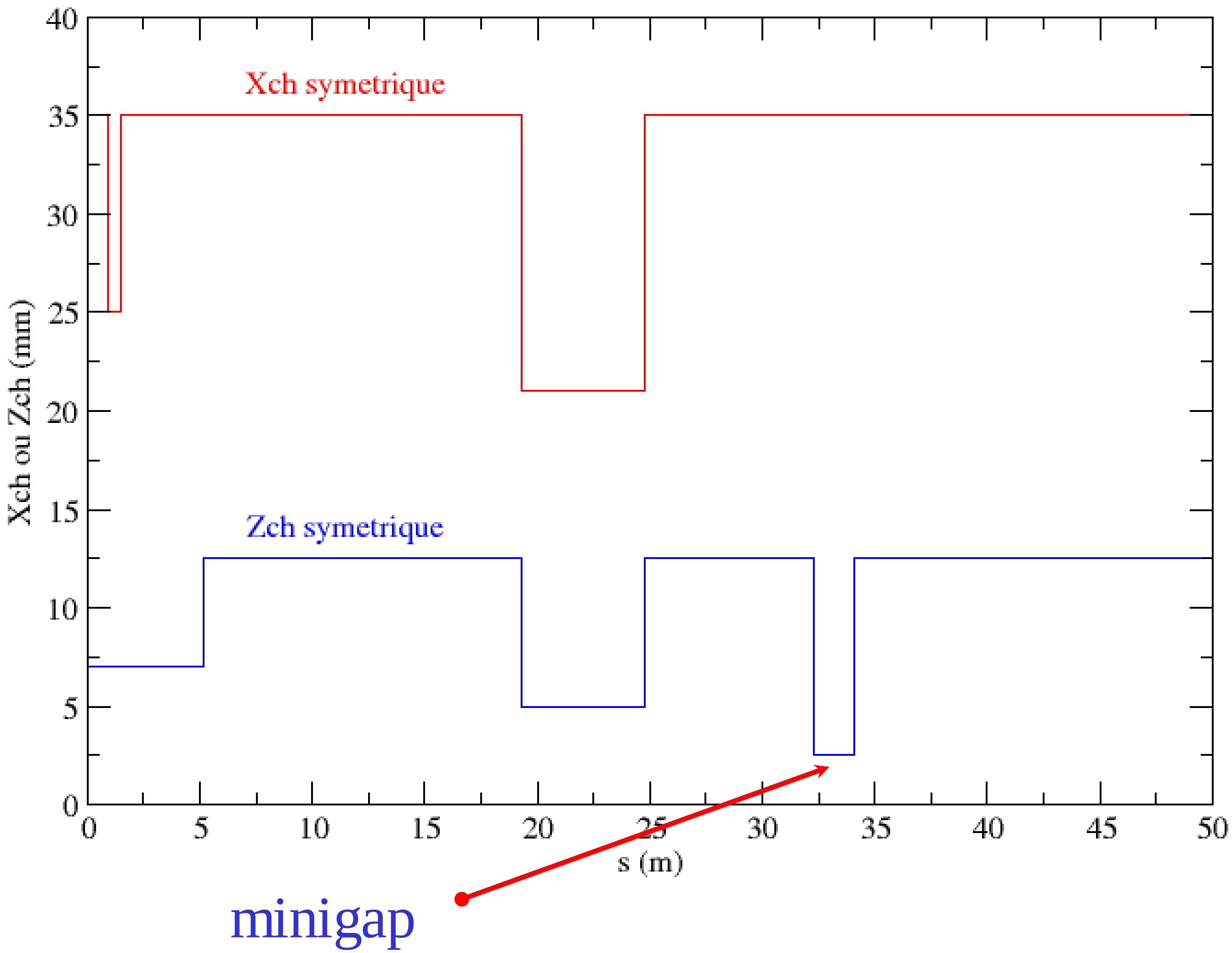
* Recommandations for the working point (18.2, 10.3)

2. Conclusion

Working conditions

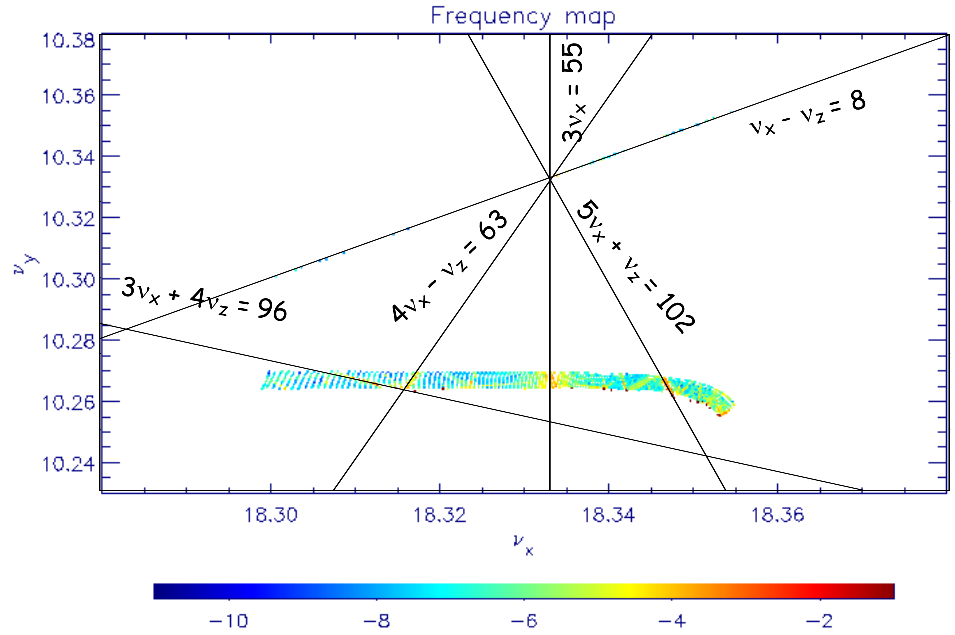
- Tracking over 1026 turns (damping time ~ 5600 turns) using DESPOT (or TRACY II) + NAFF routine
- ▶ vacuum chamber in DESPOT = stability test at the entrance of the machine: 25mm : half horizontal aperture (septum)
  7mm : half vertical aperture (insertion device vessel)
  ▶ vacuum chamber in TRACY = stability test along ½ a super-period with a symetrical chamber in horizontal and in vertical
- Coupling = rotating randomly the 160 quadrupoles of the machine (1% in DESPOT read from BETA and 1.88% in TRACY).
- Lattices with zero chromaticities
- Entrance of the machine (β_x=10.64m, β_z=8m, η_x = 20cm)

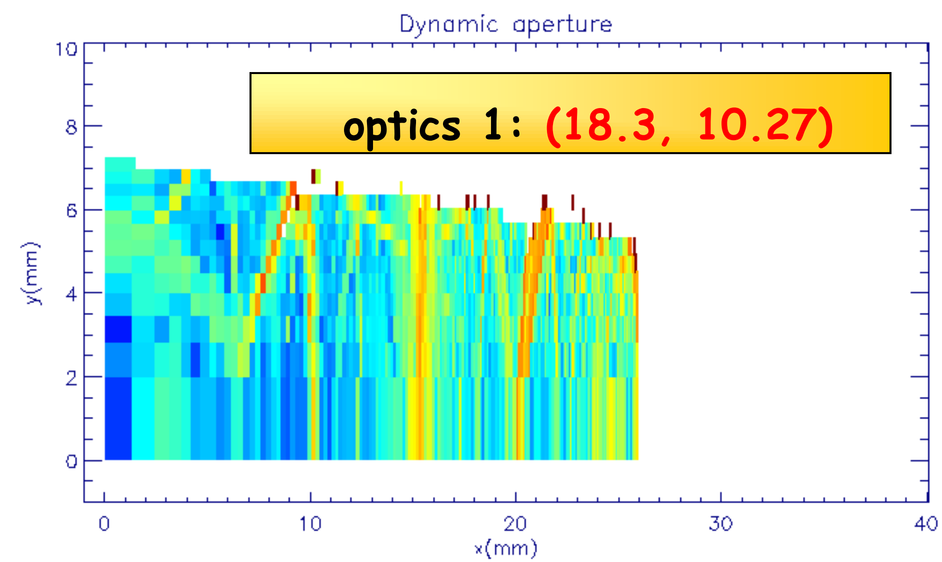
The vacuum chamber introduced when using TRACY for frequency maps and lifetime calculations (symetric in both planes)



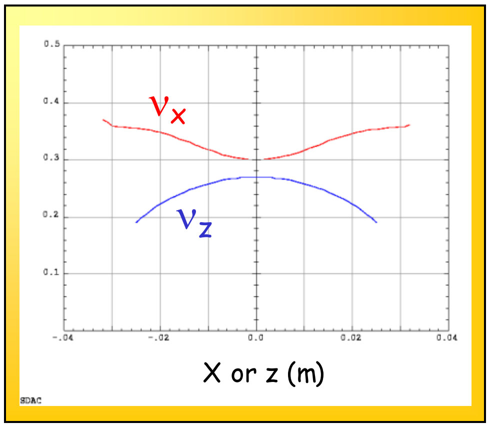
Optics 1:(18.3, 10.27)

* Can reach $3\nu_x = 55$ at large amplitude
* Close to $\nu_x - \nu_z = 8$ ($\Delta\nu = 0.03$)
* Crossing between the tunes at certain energy deviations.

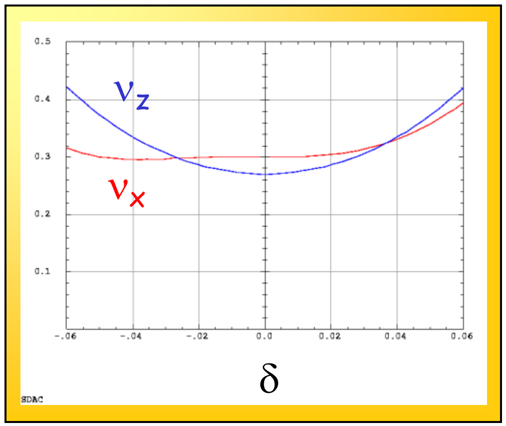




on momentum particles



Tune shift with amplitude

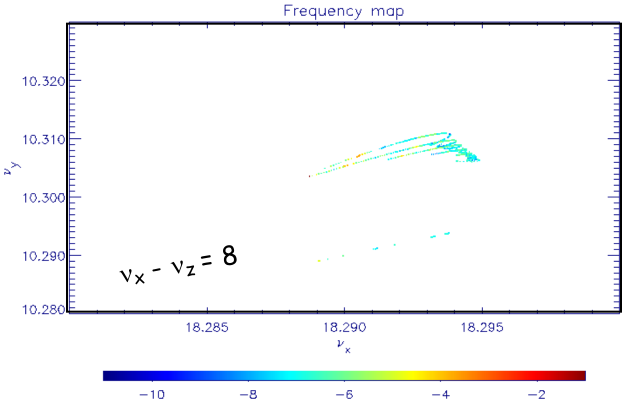


Tune shift with energy

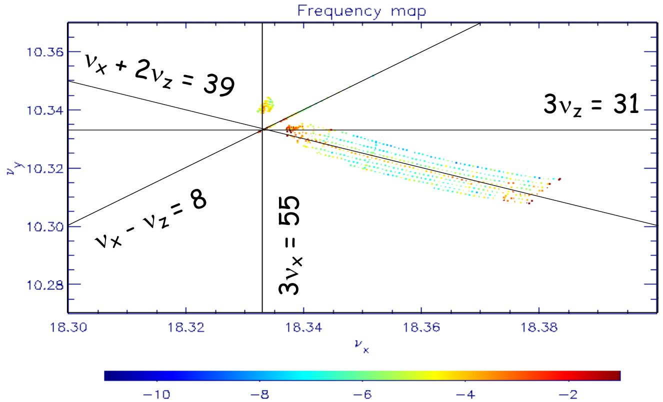
off momentum particles

optics 1: (18.3, 10.27)

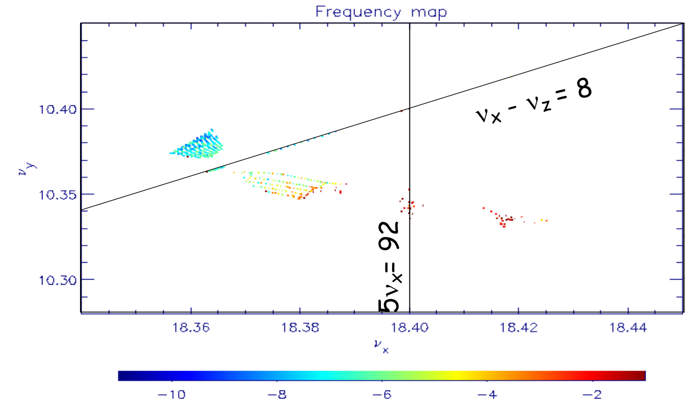
δ = -3%

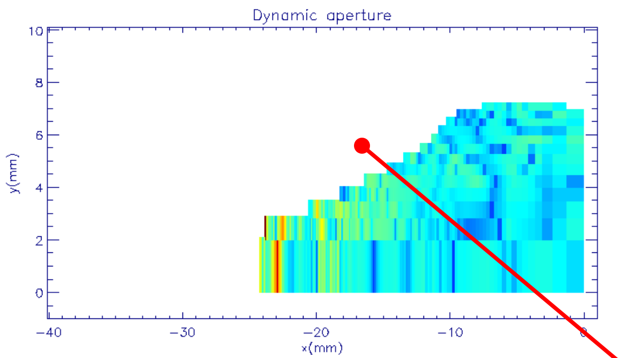


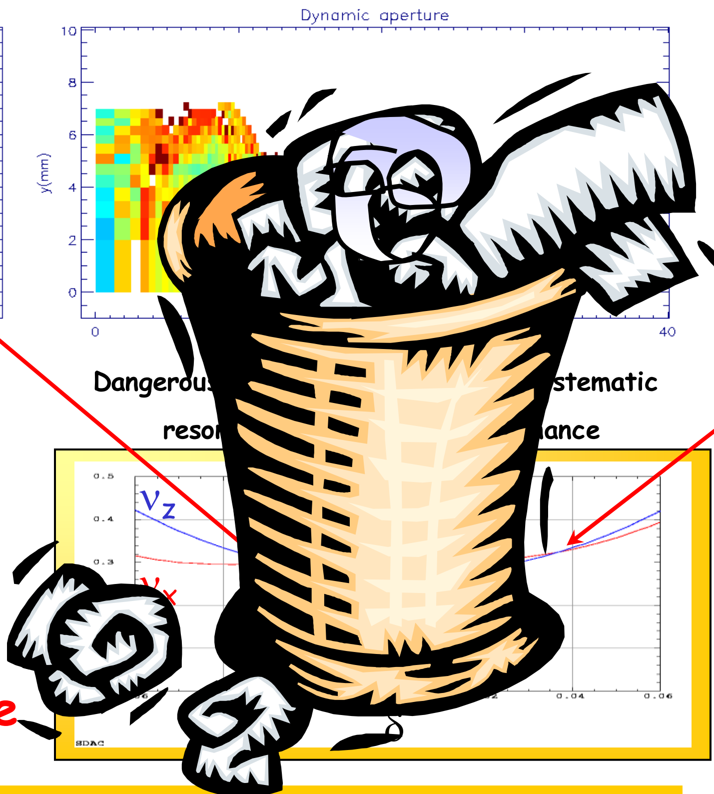
δ = 4%

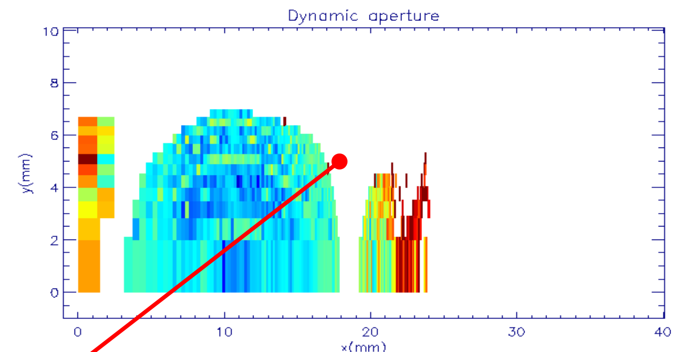


δ = 5%









Dangerous ... stematic

reso... ance

The dynamics is dominated by the coupling resonance

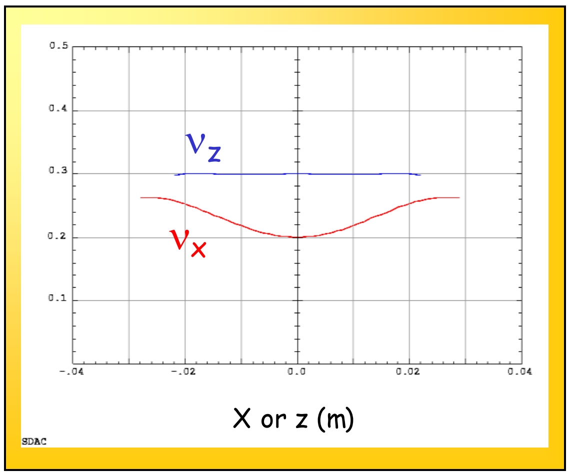
The coupling resonance splits the stability domain.
The dynamics is quasi non-existent

Optics strongly affected by the coupling resonance

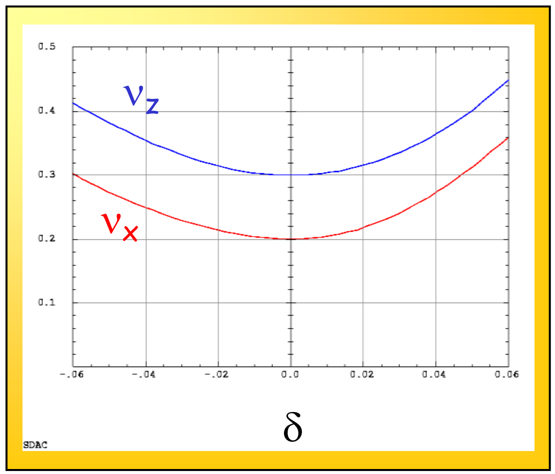
* The 0 for the amplitudes = the center of the machine

Optics 2:(18.2, 10.3)

* far from 3rd order resonances.
* far (enough) from coupling resonance $\nu_x - \nu_z = 8$ ($\Delta\nu = 0.1$).
* no Crossing between the tunes



Tune shift with amplitude



Tune shift with energy

THE STRATEGY TO BE ADOPTED IS TO MAKE THE DYNAMICS OF TOUSCHEK PARTICLES FREE OF THE COUPLING RESONANCE EFFECTS

Good On-momentum dynamics

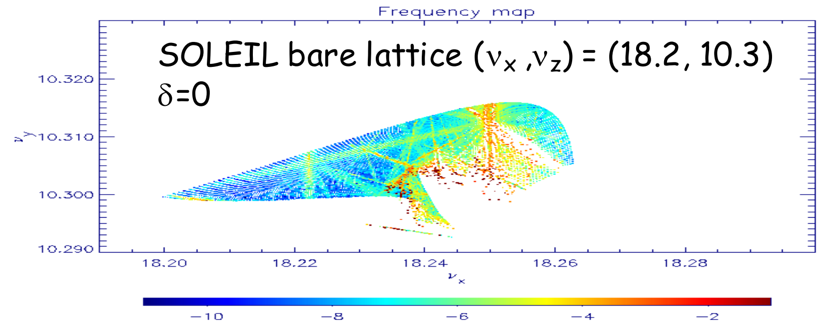
⟶ Good Injection rate

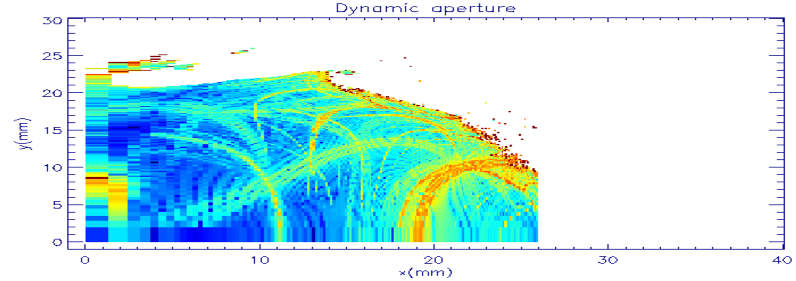
Good Off-momentum dynamics

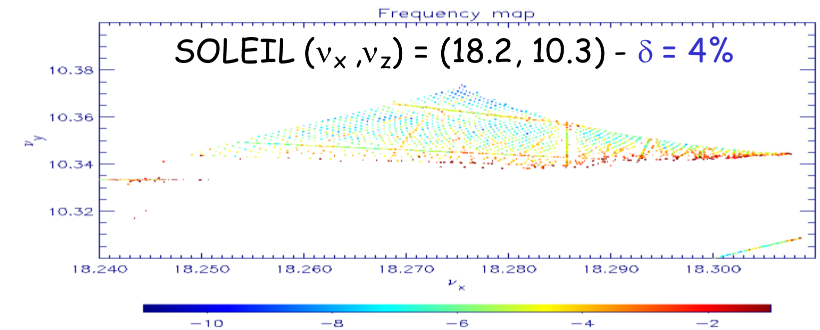
⟶ Good Lifetime

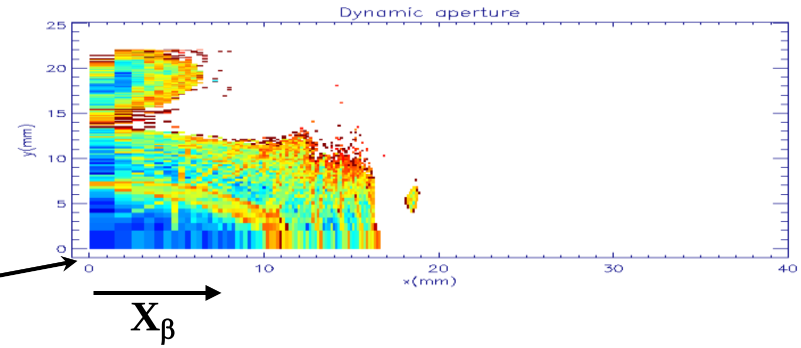
(Touschek dominant in

3rd generation light sources +
dispersion distributed everywhere)









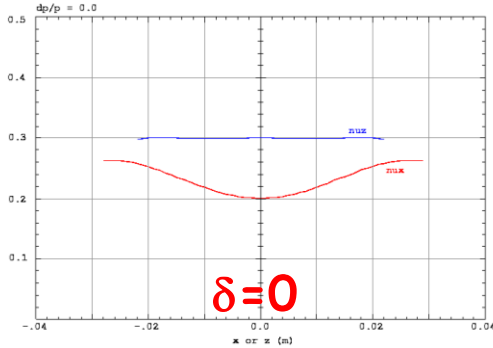
Touschek particles = change of energy +
horizontal betatron oscillation (induced amplitude)

* The 0 here = the closed orbit

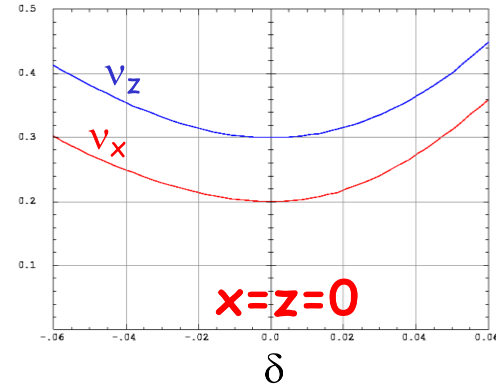
SOLEIL SYNCHROTRON

SOLEIL

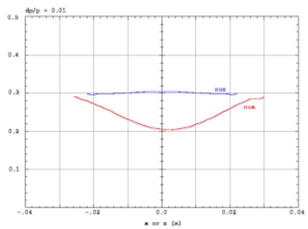
Tune shift with amplitude



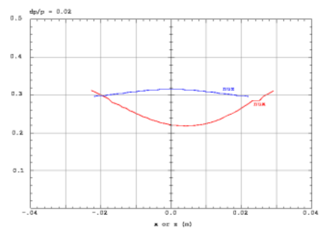
Tune shift with energy



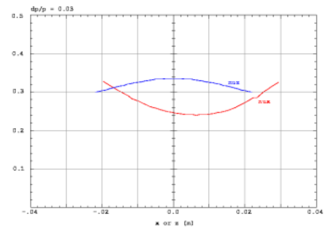
Off momentum with positive energy deviations



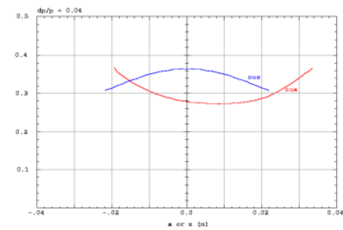
$\delta=1\%$



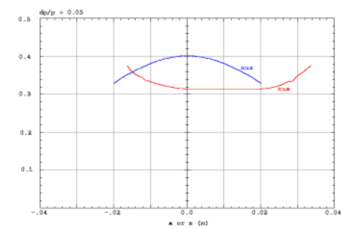
$\delta=2\%$



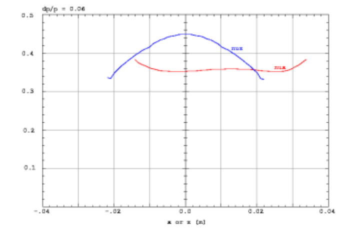
$\delta=3\%$



$\delta=4\%$

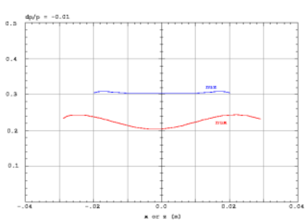


$\delta=5\%$

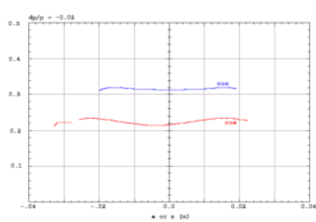


$\delta=6\%$

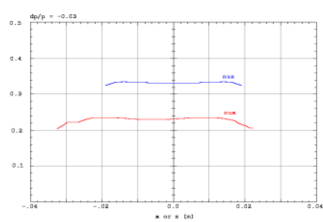
Off momentum with negative energy deviations



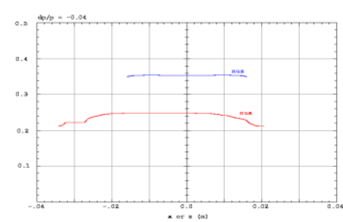
$\delta=-1\%$



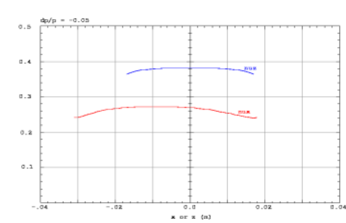
$\delta=-2\%$



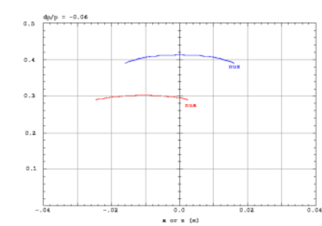
$\delta=-3\%$



$\delta=-4\%$



$\delta=-5\%$



$\delta=-6\%$

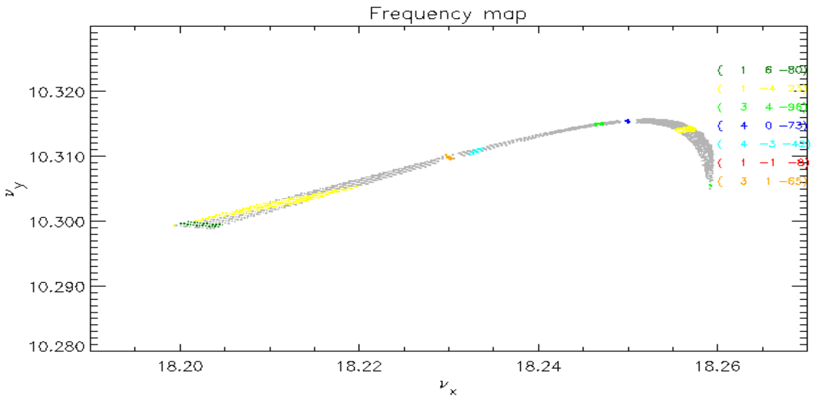
$(\nu_x, \nu_z)=(18.2, 10.3)$ $(\xi_x, \xi_z)=(0,0)$ $(\beta_x, \beta_z)=(10.6m, 8.0m)$

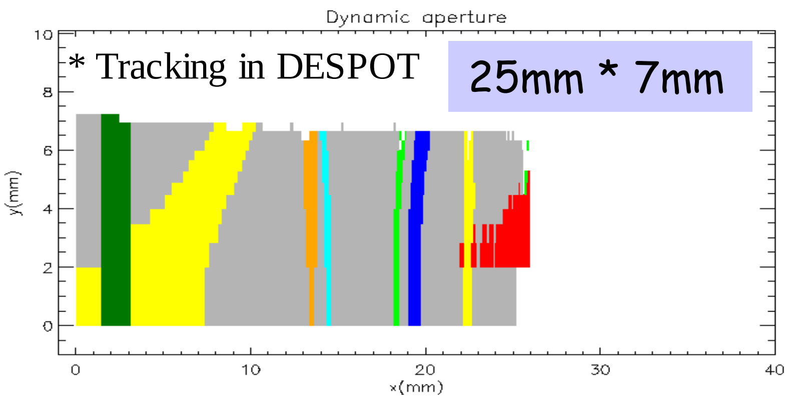
Stability on 1026 turns

Optics 2: (18.2,10.3)

On-momentum

With 1% coupling + vacuum chamber at s=0





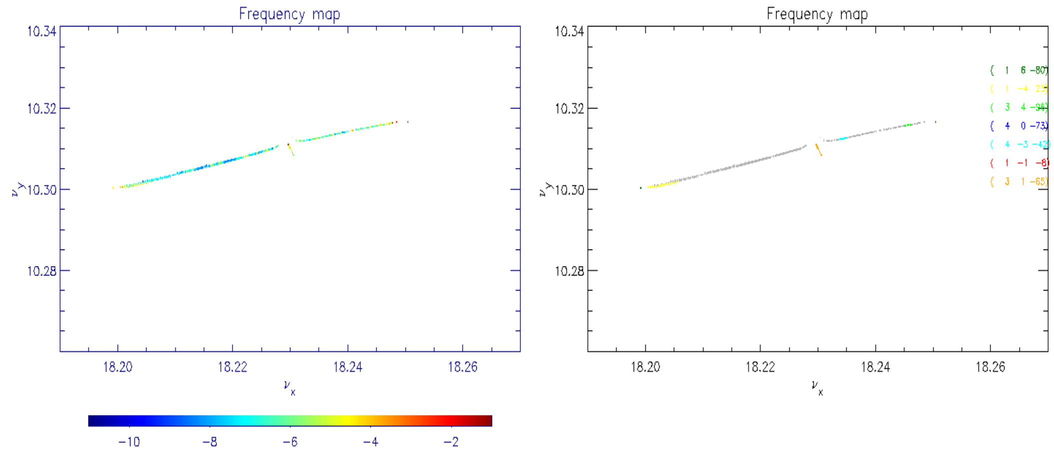
$\nu_x - 4\nu_z = -23$

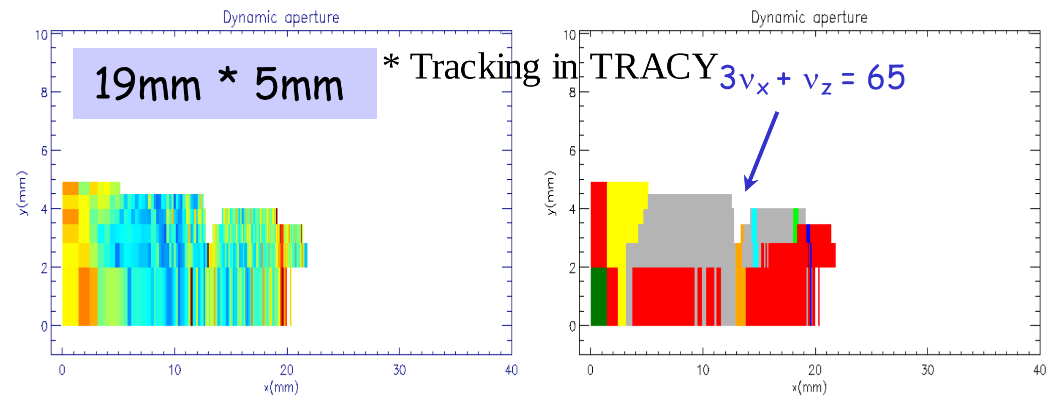
$\nu_x + 6\nu_z = 80$ $\quad 2\nu_x + 5\nu_z = 88$

$9\nu_x = 164$ $\quad 4\nu_x = 73$

Confined high order or non-systematic resonances

With 1.88% coupling + vacuum chamber on ½ super-period





$\nu_x - 4\nu_z = -23$ $\quad 3\nu_x + \nu_z = 65$

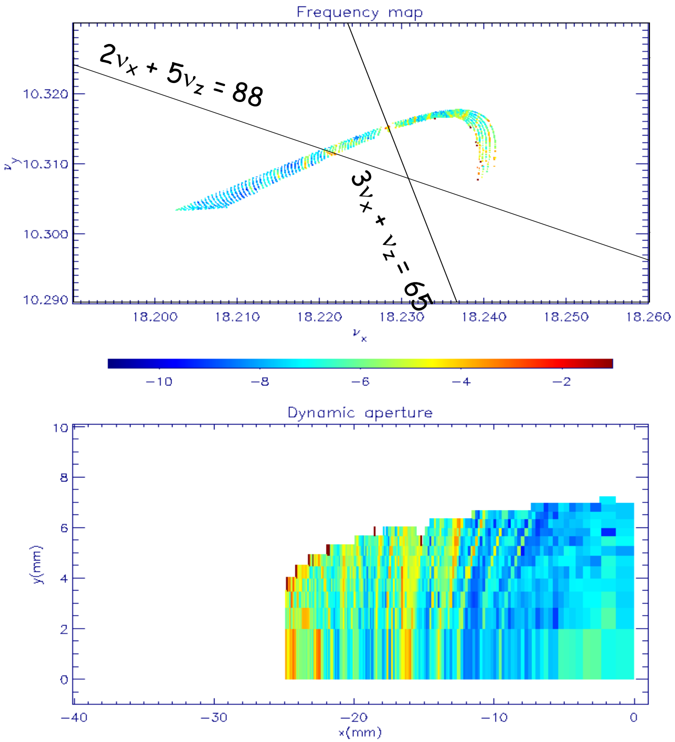
$\nu_x + 6\nu_z = 80$ $\quad \nu_x - \nu_z = 8$

Linear and non linear coupling resonances can be limitative

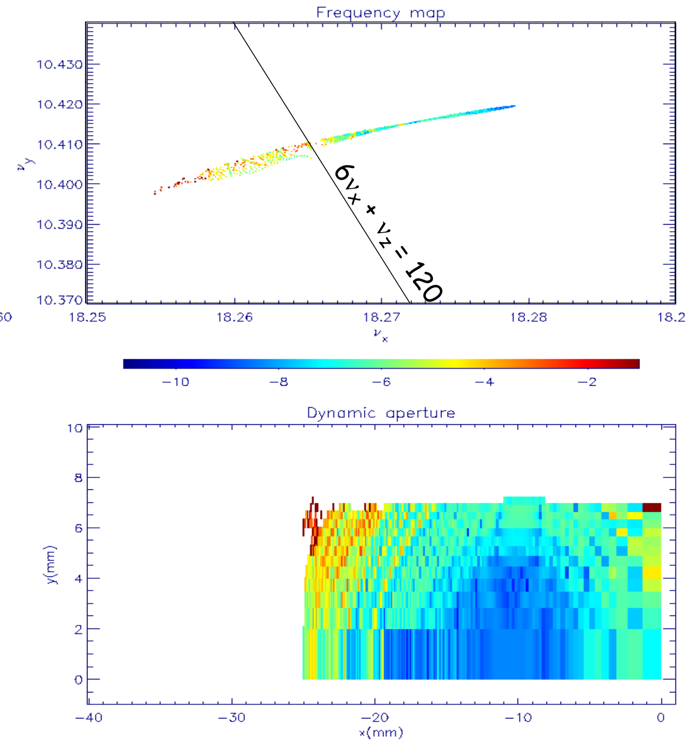
off momentum particles

optics 2: (18.2, 10.3)

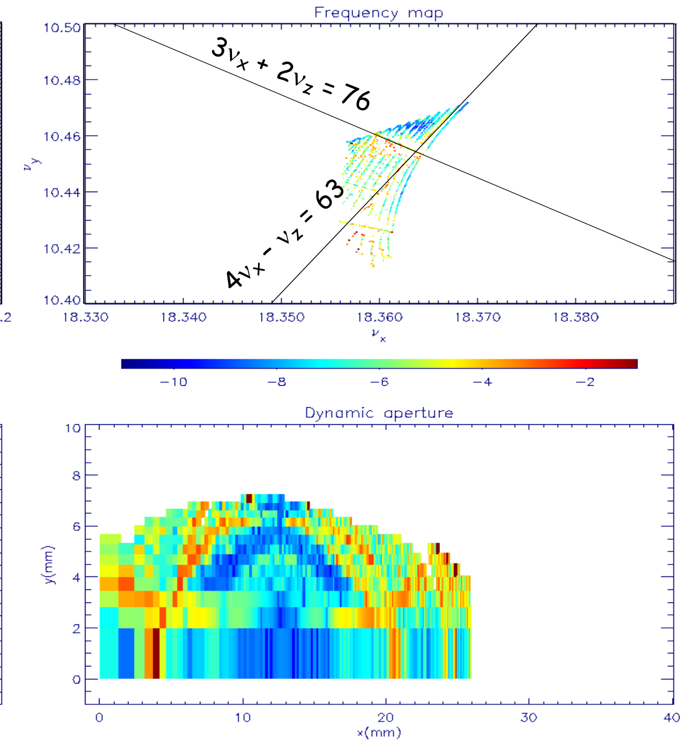
δ = -1%



δ = -6%



δ = 6%



Stable dynamics till -25mm in Horizontal

Stable dynamics except beyond

$6\nu_x + \nu_z = 120$ where it starts to be chaotic

The dynamic aperture can be reduced both in vertical and horizontal because of the diffusion on the 5th order node

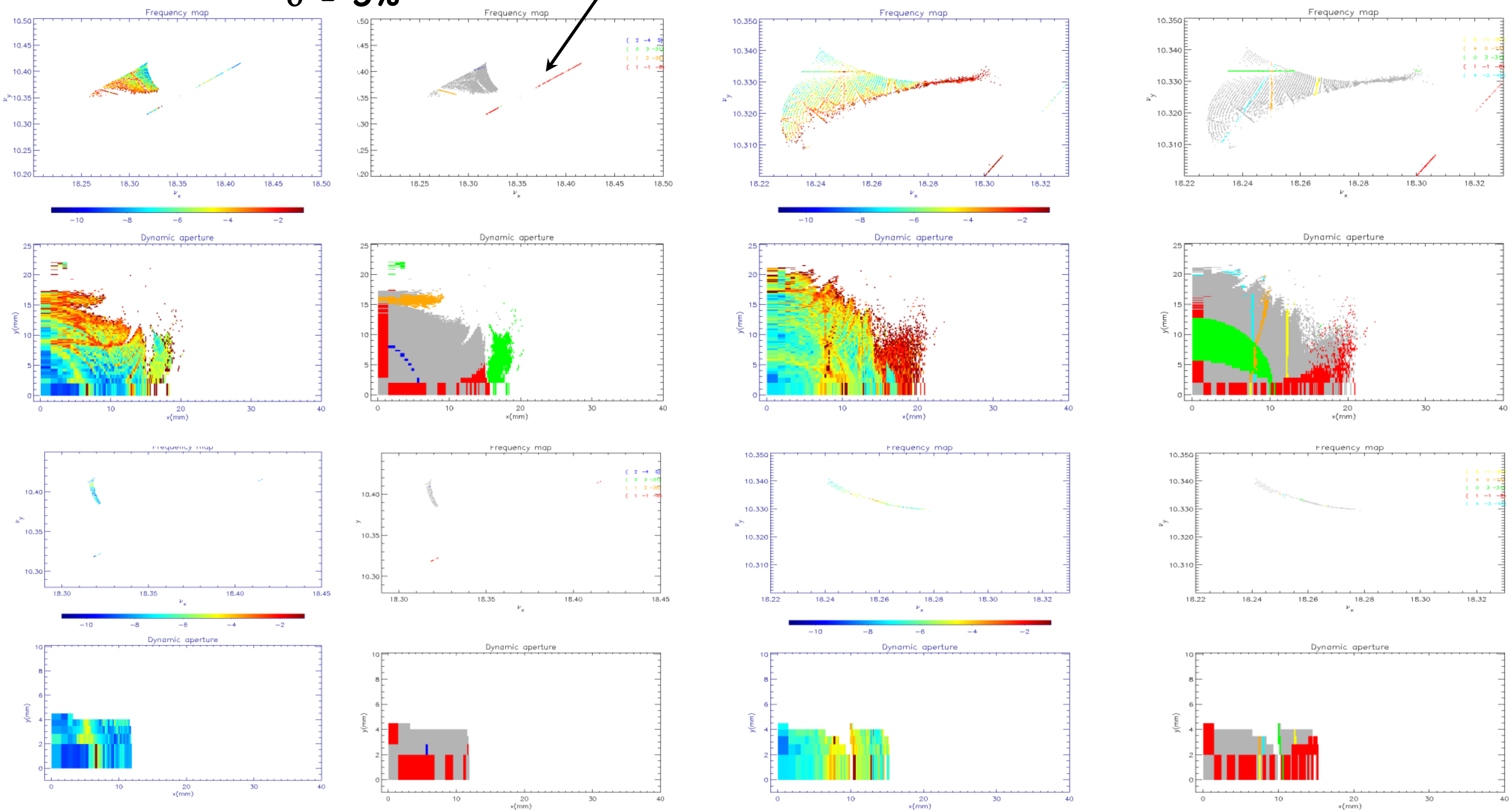
* Tracking in DESPOT

* The 0 for the amplitudes = the center of the machine

optics 2: (18.2, 10.3)

$\nu_x - \nu_z = 8$

δ = 5% δ = 3%



* Tracking in TRACY

* The 0 for the amplitudes = the closed orbit

Nothing remains above the crazy $3\nu_z = 31$

SOLEIL SYNCHROTRON

Multipolar components

A set of 56 H Correctors, 56 V correctors and 32 QT is activated to correct the horizontal closed orbit (without taking into account the residual closed orbit)

The multipolar components (up to 22 pôles) have been defined using the field map generated by TOSCA 3D code

The particles have been tracked when including the worsen set in terms of lifetime among a statistique of ~ 30 sets

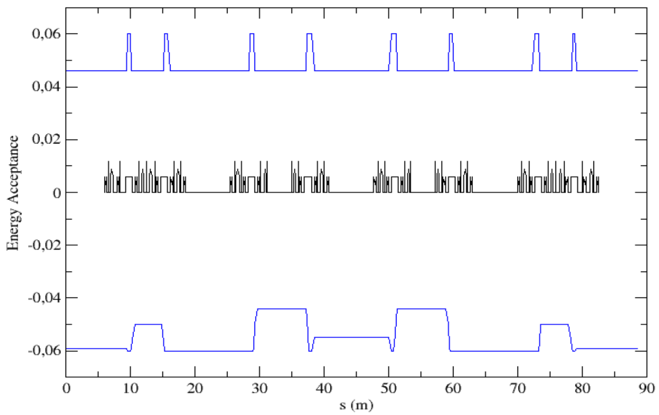
----- Normal -----skew	@35mm ΔB/B
Decapôles	+ 0.043 -
14-pôles	+ 0.063 +
22 pôles	- 0.037 +

For H and V correctors

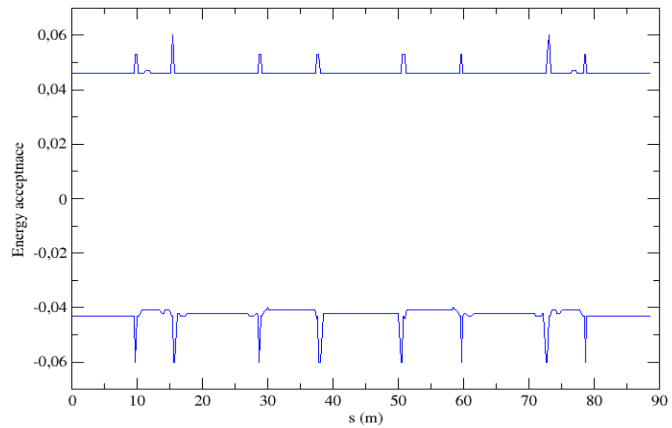
Octupole @35mm ΔB/B
-0.68

For QT

4D Touschek lifetime calculations

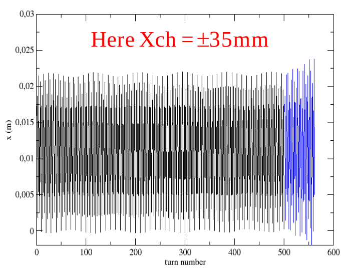


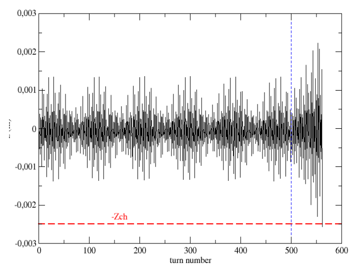
Reference Lattice (without Correctors)

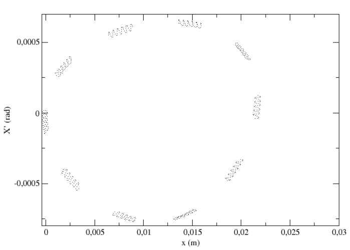


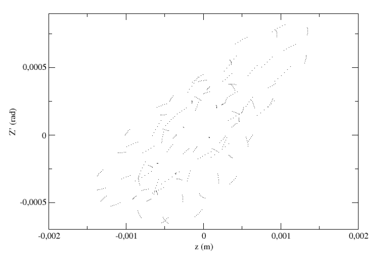
Lattice with the worsen set of correctors

	τ_p(h)	τ_n (h)	τ_{Tot} (h)
without	72	45	55
with	33	43	37



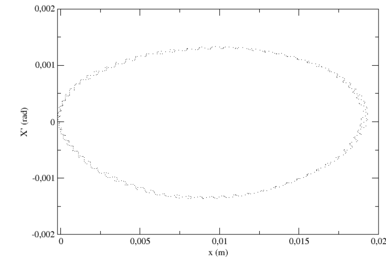


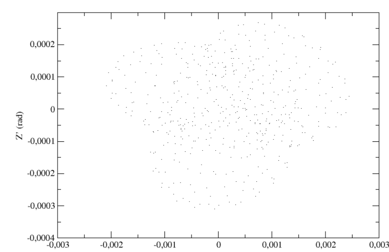




At the loss location (minigap)

At s=0



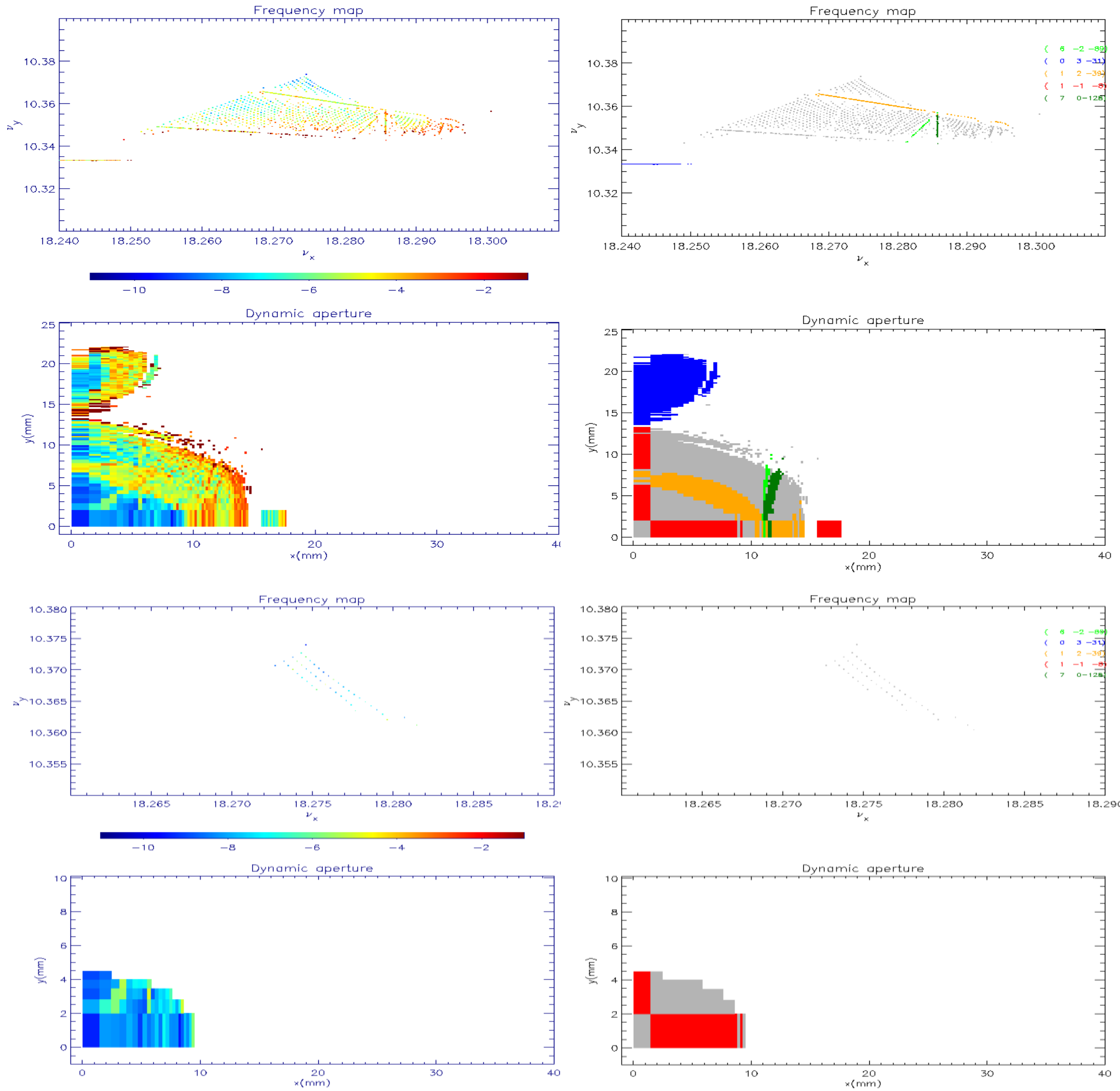


optics 2: (18.2, 10.3)

1.88% coupling +

the worsen set of correctors among 30 sets

$\delta = 4\%$



Nothing remains above the non linear coupling resonance

$\nu_x + 2\nu_z = 39$

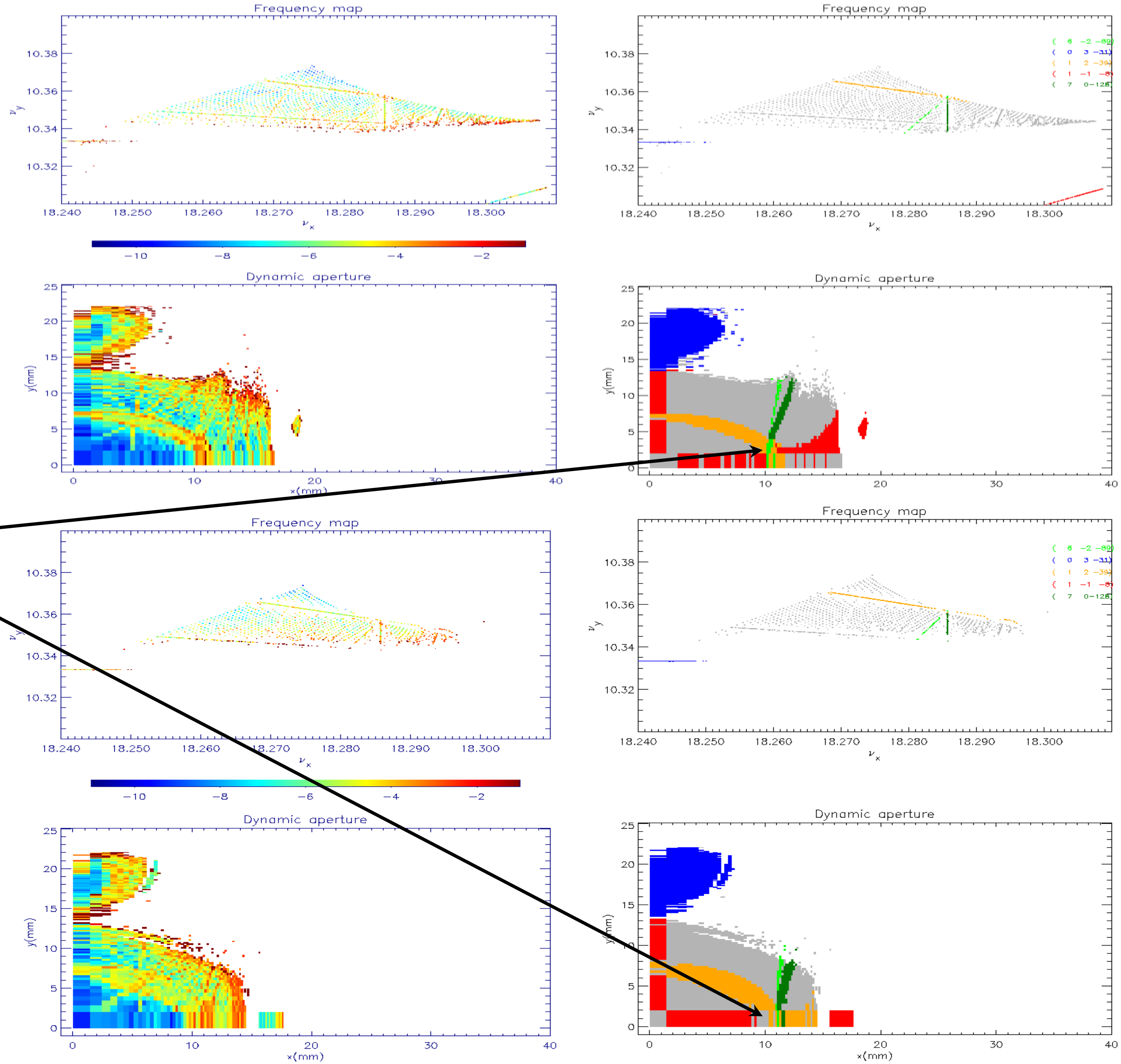
* Tracking in TRACY

* The 0 here = the closed orbit

SOLEIL SYNCHROTRON

$\delta = 4\%$

Without correctors



The node

$6\nu_x - 2\nu_z = 89$ $\nu_x + 2\nu_z = 39$

$7\nu_x = 128$ **is very dangerous**

With correctors

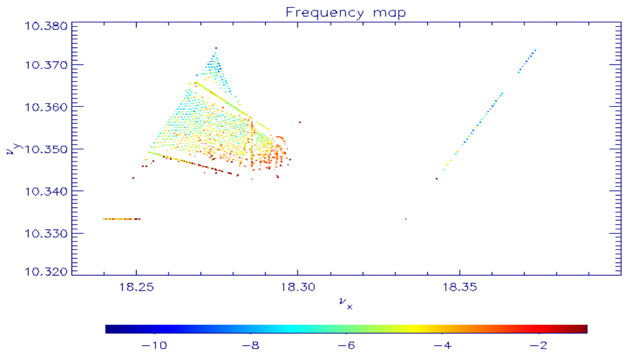
* Tracking in TRACY

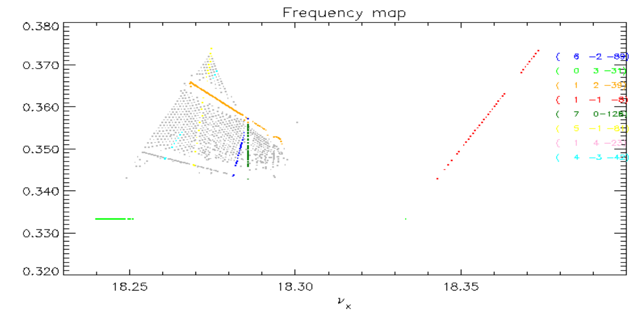
* The 0 here = the closed orbit

SOLEIL SYNCHROTRON

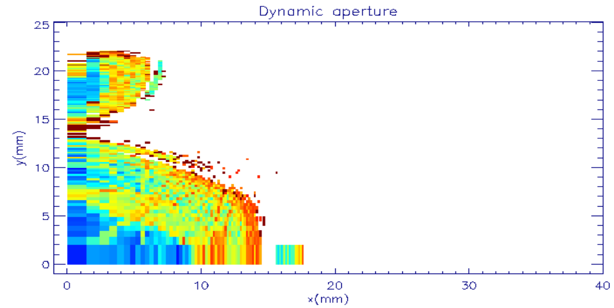
δ = 4.5%

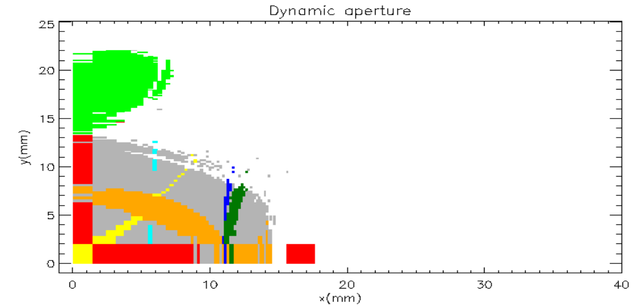
With correctors



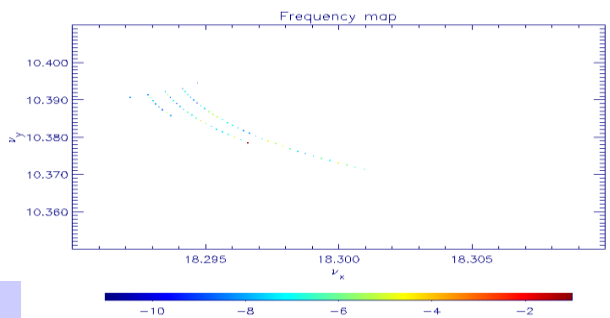


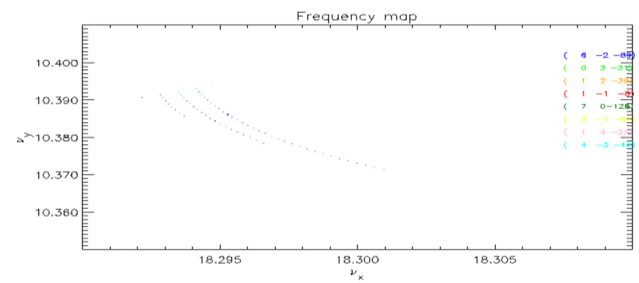
Without vacuum chamber

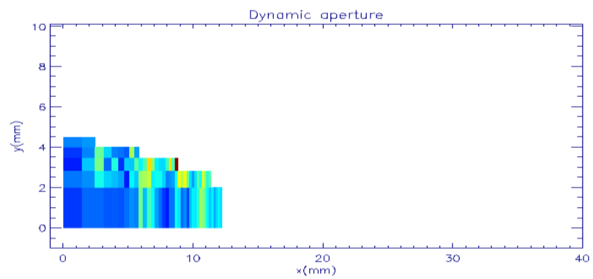


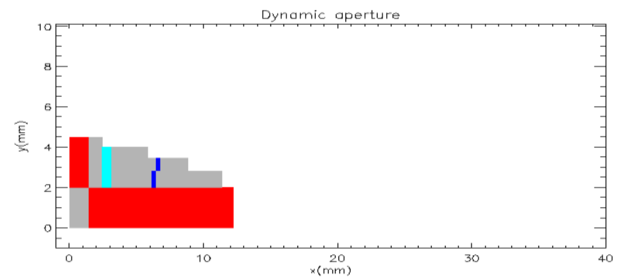


With vacuum chamber









The node

$6\nu_x - 2\nu_z = 89$ $\nu_x + 2\nu_z = 39$

$7\nu_x = 128$ is very dangerous

Nothing remains above the non linear coupling resonance

$\nu_x + 2\nu_z = 39$

* Tracking in TRACY

* The 0 here = the closed orbit

Recomandations for the working point (18.2, 10.3)

Considering only 4D calculations in terms of frequency maps and Touschek lifetime (in the conditions described before), one has to:

* Move slightly the working point in order to avoid the node ($\nu_x - 4\nu_z = -23$ & $\nu_x + 6\nu_z = 80$)

* Try to avoid the $3\nu_x + \nu_z = 65$ for on momentum particles.

* Not consider far enough from third order vertical resonance

* **Not neglect the effects of non linear coupling resonances (especially $\nu_x + 2\nu_z = 39$)**

And by the way:

* Look more carefully at the coupling generated randomly by rotating the quadrupoles in TRACY correct it after verification and repeat the calculations

But one has to note that in 6D calculations where synchrotron oscillations and radiation are taken into account, some resonances which were dangerous in 4D can be avoided and others which were not become dangerous, so this has to be considered when defining a good working point.

SOLEIL SYNCHROTRON

Conclusion

In 3rd generation light sources with dispersion distributed everywhere and low gap insertion devises where Touschek scaterings are dominant

One has to optimise jointly the tune shift with amplitude and with energy such as ν_x =f(x) and ν_z=f(z) for a fix energy deviation δ never cross each other (never encounter the coupling resonance).

The crossing does not occur before the possible induced amplitude at this value of δ.

This has to be verified for all energy deviations δ in the range of the desirable energy acceptance (±6% for example).

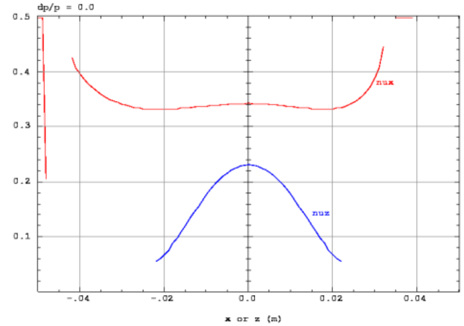
This, of course, does not prevent adverse effects of non linear coupling resonances

Frequency Map Analysis is a powerful tool in the design phase of a machine

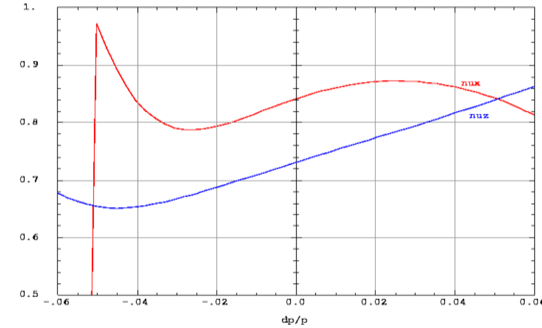
Annexes

SOLEIL SYNCHROTRON

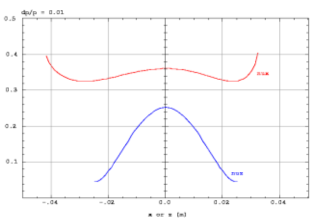
Tune shift with amplitude



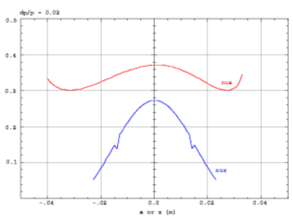
Tune shift with energy



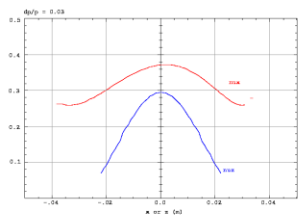
BESSY II



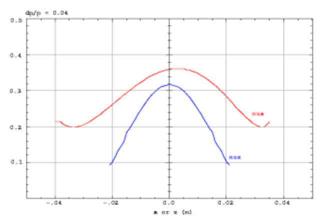
δ=1%



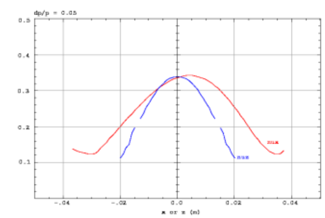
δ=2%



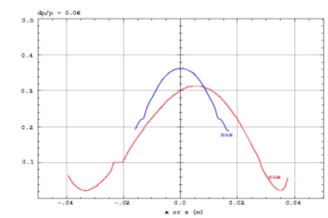
δ=3%



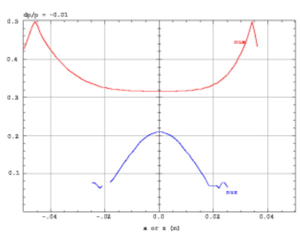
δ=4%



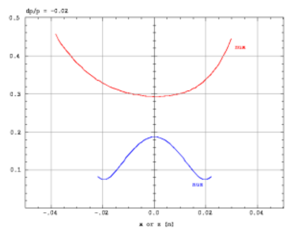
δ=5%



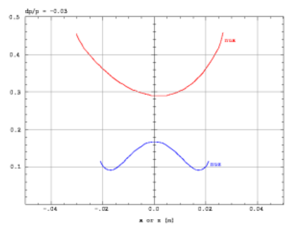
δ=6%



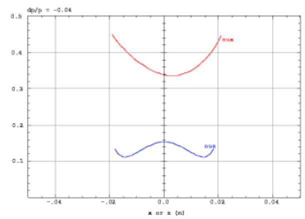
δ=-1%



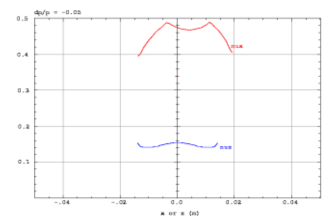
δ=-2%



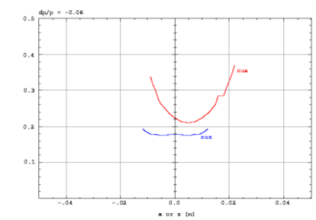
δ=-3%



δ=-4%



δ=-5%



δ=-6%

(ν_x, ν_z)=(17.84, 6.73)

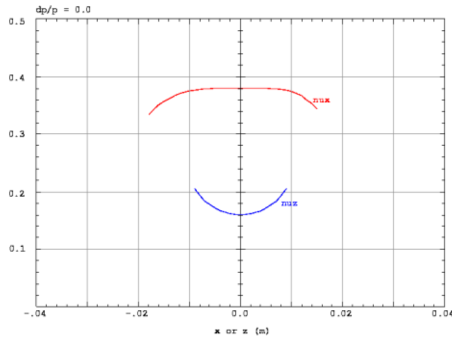
(ξ_x, ξ_z)=(2,2)

(β_x, β_z)=(14m, 3.4m)

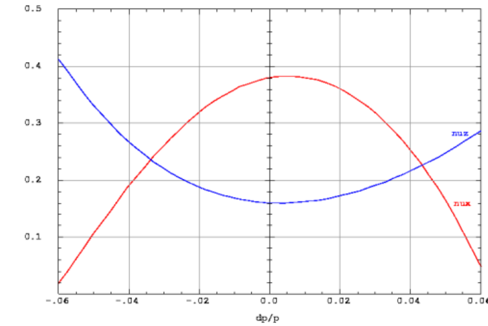
Stability on 1026 turns

SOLEIL SYNCHROTRON

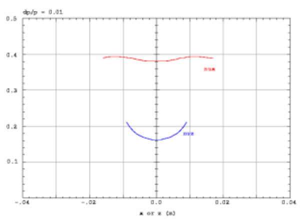
Tune shift with amplitude



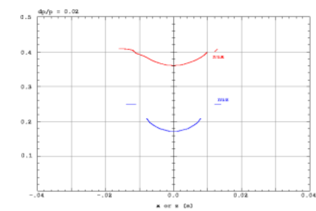
Tune shift with energy



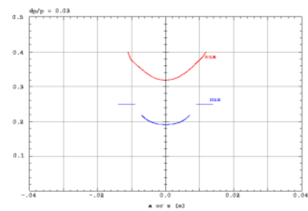
SLS



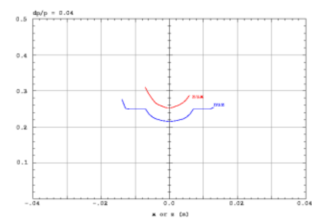
δ=1%



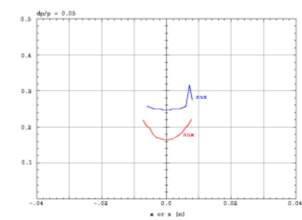
δ=2%



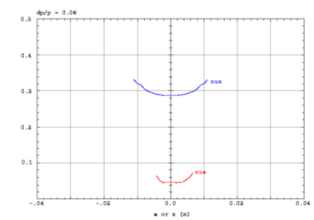
δ=3%



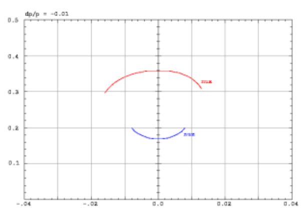
δ=4%



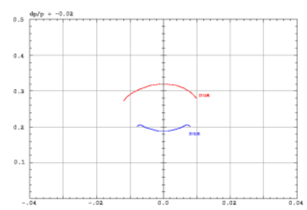
δ=5%



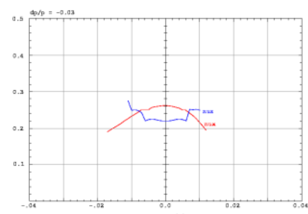
δ=6%



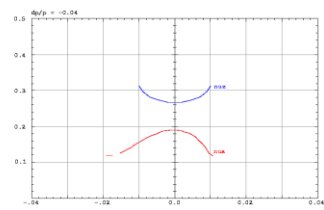
δ=-1%



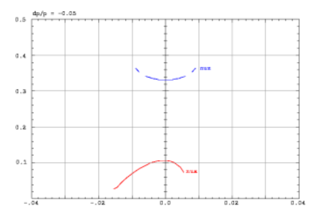
δ=-2%



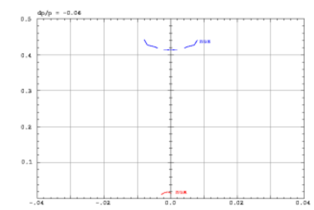
δ=-3%



δ=-4%



δ=-5%



δ=-6%

(ν_x, ν_z)=(20.38, 8.16)

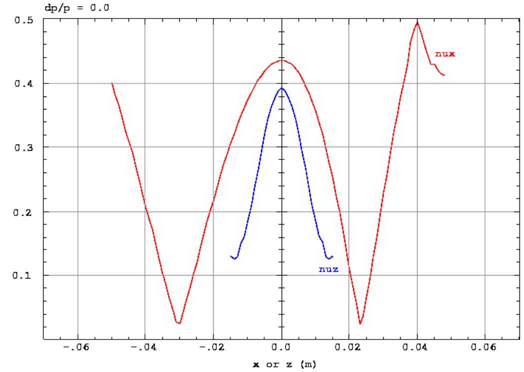
(ξ_x, ξ_z)=(1.06,-0.3)

(β_x, β_z)=(4.56m, 3.73m)

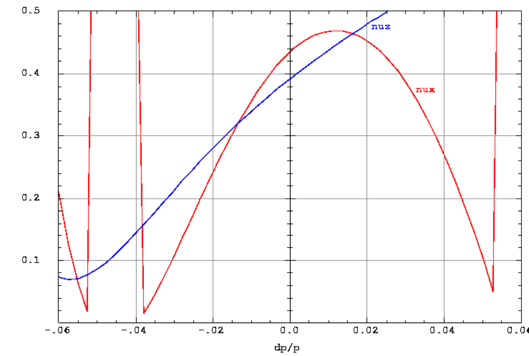
Stability on 1026 turns

SOLEIL SYNCHROTRON

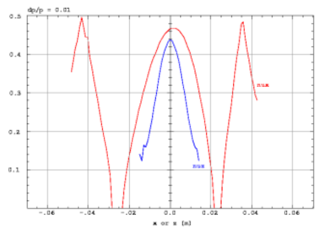
Tune shift with amplitude



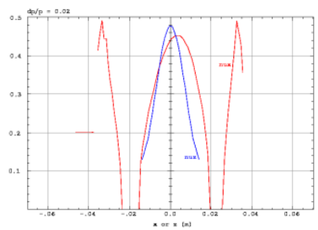
Tune shift with energy



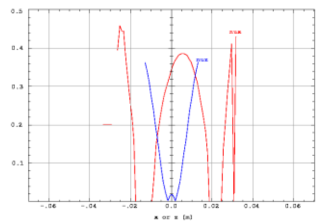
ESRF



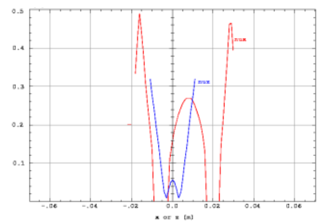
δ=1%



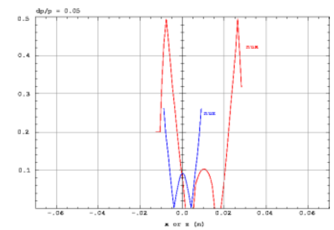
δ=2%



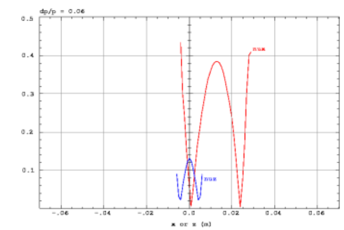
δ=3%



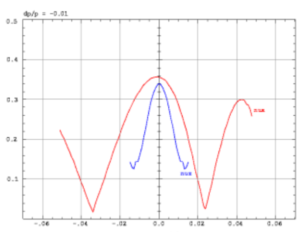
δ=4%



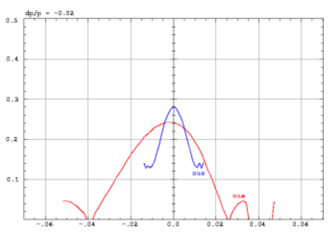
δ=5%



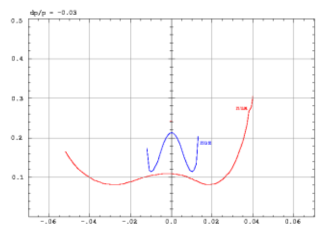
δ=6%



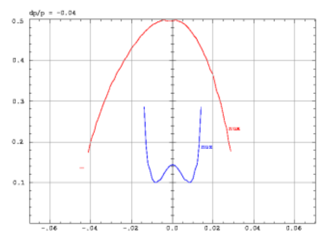
δ=-1%



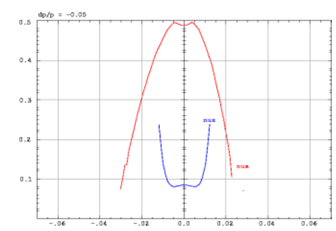
δ=-2%



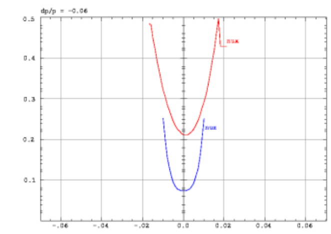
δ=-3%



δ=-4%



δ=-5%



δ=-6%

(ν_x, ν_z)=(36.435, 14.39)

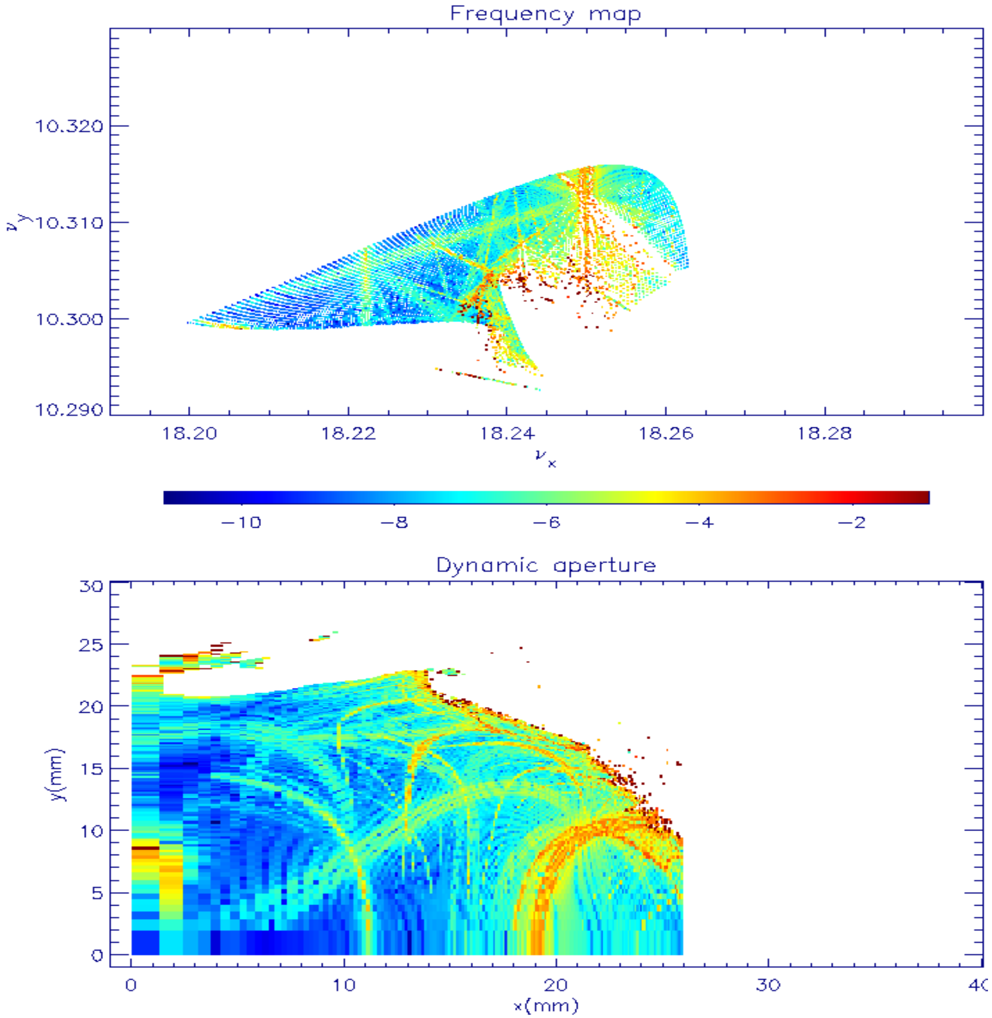
(ξ_x, ξ_z)=(5.6,4.8)

(β_x, β_z)=(35m, 2.5m)

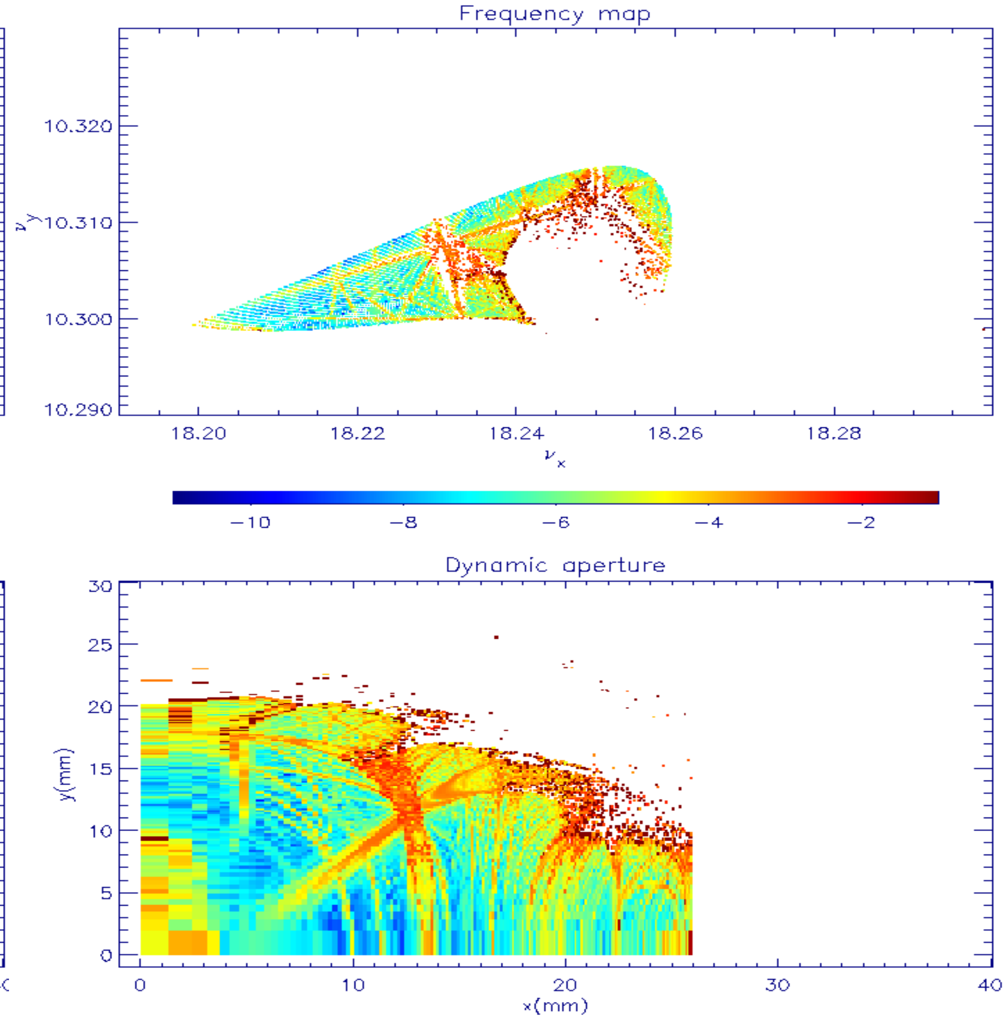
Stability on 1026 turns

Optics 2: (18.2,10.3) On-momentum

Ideal lattice



With 1% coupling



Reduction of the regular regions by enlarging certain existing resonances and by exciting new ones.

Optics 2: (18.2,10.3) On-momentum