SOLEIL performance improvement using optimization based on Genetic Algorithms

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INTRODUCTION

- SOLEIL is the French 3rd generation light source routinely operating since 2007 with a low emittance (3.9 nm·rad) and high intensity (430 mA) beam.

Energy [GeV]	2.75
Circumference [m]	354.1
Nominal current [mA]	430 (multibunch)
Horizontal emittance [nm .rad]	3.91
Emittance coupling (adjusted)	1%
Betatron tunes	(18.18,10.23)
RF frequency [MHz]	352.2

SOLEIL current standard machine parameters
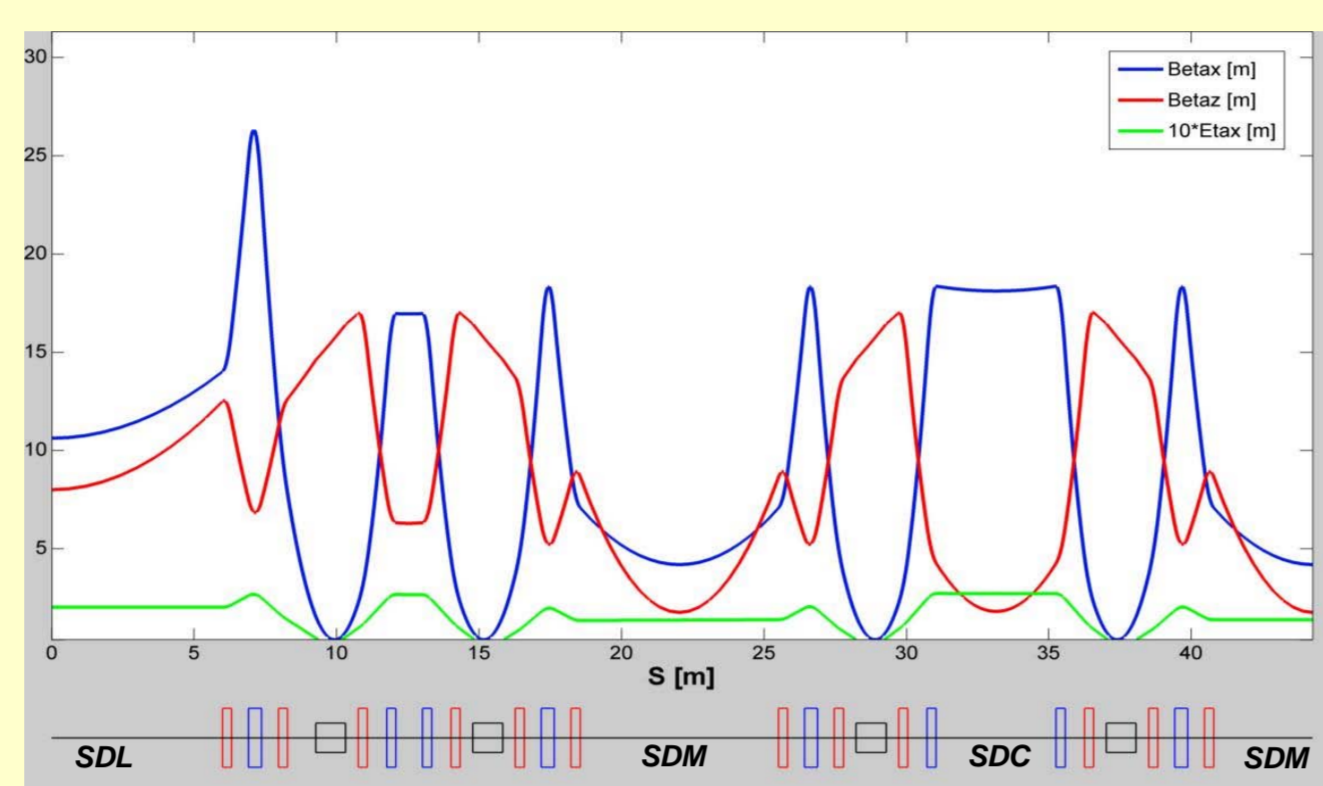
SOLEIL original lattice functions over 1/8th of the ring showing long (SDL), medium (SDM) and short (SDC) straight sections

- The purpose of the application of Multi-Objective Genetic Algorithms (MOGA) is to optimize the linear and non-linear beams dynamics and to search for unexplored solutions.

GENETIC ALGORITHMS

- The need of sextupoles in synchrotron light sources to correct the chromaticities introduces non-linear effects. These non-linear effects reduce the Dynamical Aperture (DA) and the Momentum Aperture (MA) responsible for the injection efficiency and the Touschek lifetime respectively.

- The complexity of the synchrotron light sources has increased over time. For example, the Advanced Light Source (ALS) of Berkeley (USA) had only 3 families of quadrupoles and 2 families of sextupoles in 1993. Today, SOLEIL have 12 families of quadrupoles (163 different power supplies) and 12 families of sextupoles.

- Genetic Algorithms (GA) is a computational method to search the best solutions of multi-objectives problems using techniques inspired in natural evolution like crossover, mutation and evolution.

- Appling GA, the best solutions (Pareto front) are find among all the possible solutions (Pareto optimal set) under a number of constraints [1].

THE OPAC NETWORK

- This PhD project is enrolled in **O**ptimization of the **P**erformance of any **P**article **Ac**celerator (**OPAC**) since December of 2012. OPAC is a new network that trains the next generation of researchers in accelerator science and technology in the Framework of Marie Curie Actions. Today, OPAC have 22 students distributed in Europe.

- List of network partners

  University of Liverpool, UK
  CELLS-ALBA, Spain
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  COSYLAB d.d., Slovenia
  Computer Simulation Technology, Germany
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  GSI Helmholtz Centre for Heavy Ion Research, Germany
  Instrumentation Technologies, Slovenia
  Royal Holloway University of London, UK
  Société Civile Synchrotron SOLEIL, France
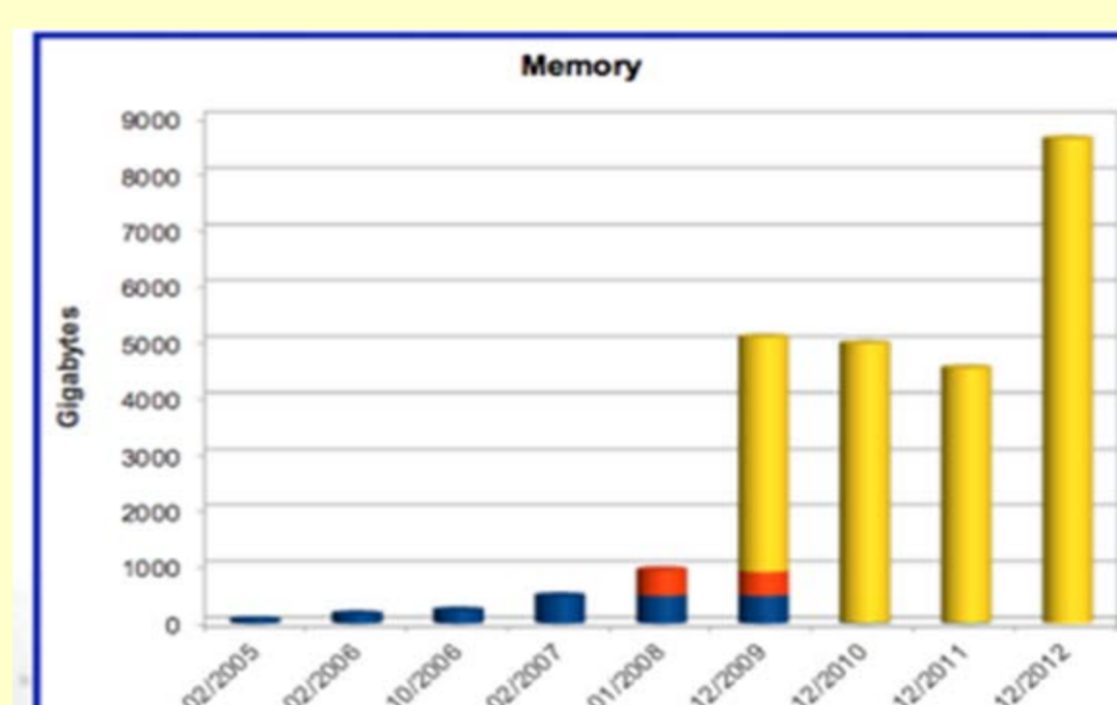 Universidad de Sevilla / Centro Nacional de Aceleradores, Spain

TOOLS

- Tracking codes: BETA [2], TRACY III [3] (long term tracking and FMA)
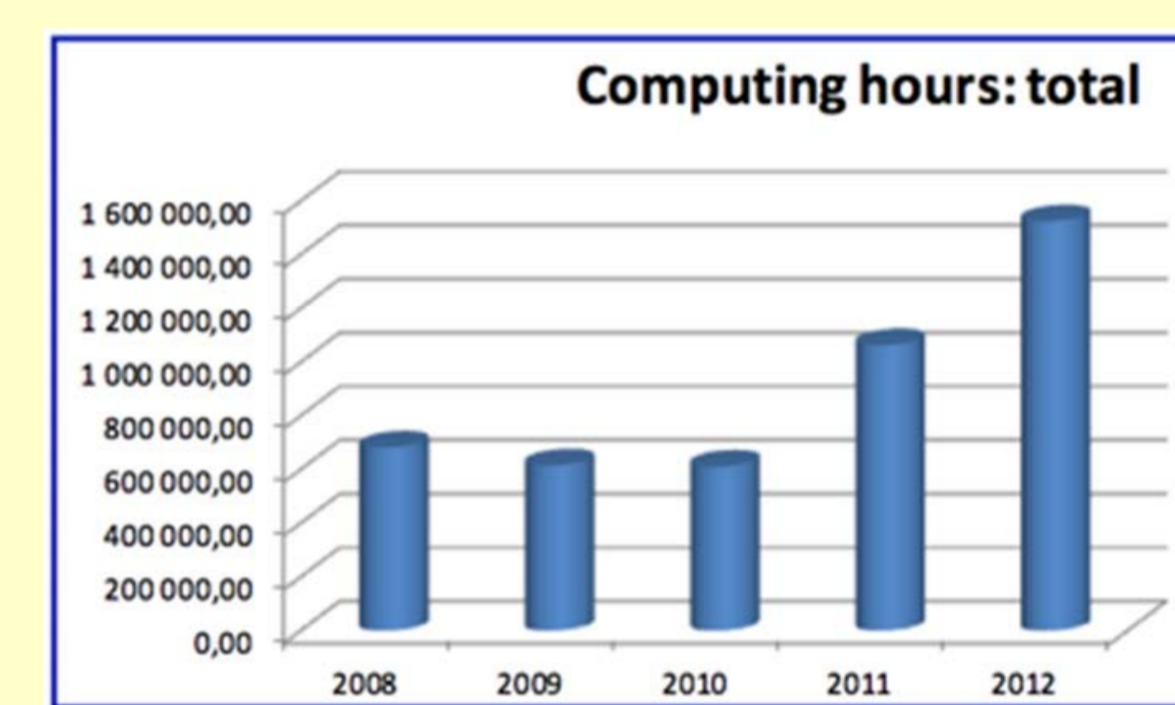- ELEGANT [4] for introduction to MOGA

SOLEIL CLUSTER

- 1072 processors => 11.4 Tflops
- 97% used by Beamlines staff, associates and users
- Adding an interactive node (idai) in 2012 => 8.64 TBytes available
- Intel MPI library for parallel computation

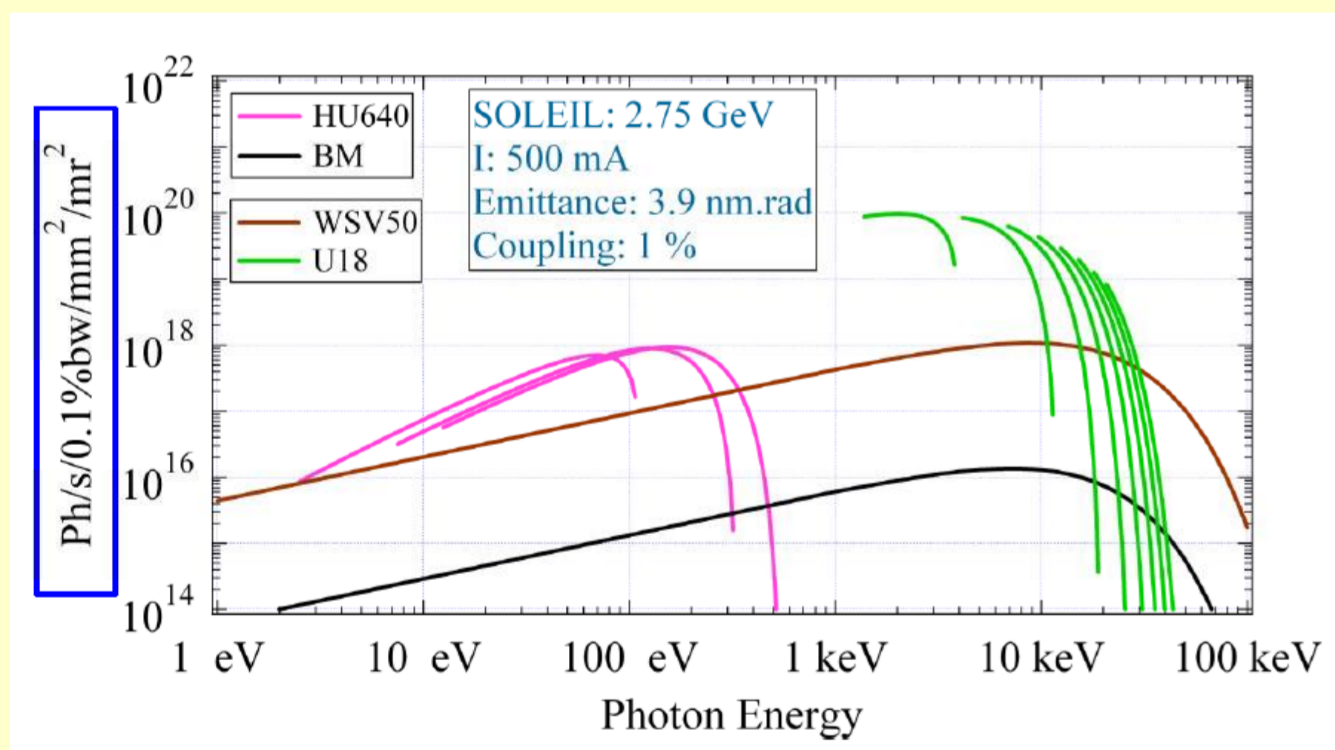*Increase of the memory used since the creation of the Synchrotron SOLEIL*

Increase of the computing hours used in the Synchrotron SOLEIL

OBJECTIVES OF THE PHD PROJECT

- Increase the **Brightness** $B \sim \dfrac{1}{\varepsilon_x \varepsilon_z}$ ⟶ Decrease the horizontal **emittance** ε_x

$$\varepsilon_x = C_q \frac{\gamma^2}{J_x} \frac{\oint (H(s)/\rho^3)\,ds}{\oint ds/\rho^2}$$

$C_q = 3,832 \times 10^{-13} m$
γ relativistic factor
$H(s)$ curly-H function
ρ dipole radius
J_x damping factor

Strong focusing by quadrupoles

Produce large **natural chromaticities**

$$\xi_{x,z}^{nat} = \frac{1}{4\pi} \oint \beta_{x,z}(s)\kappa ds$$

$\beta_{x,z}(s)$ betatron functions in both planes
κ focusing strength

Use of strong **sextupoles** to correct the natural chromaticities

Introduction of **non-linear beam dynamics**: the beam is unstable close to **resonances lines**

Reduction of the MA: reduction of the **beam lifetime**

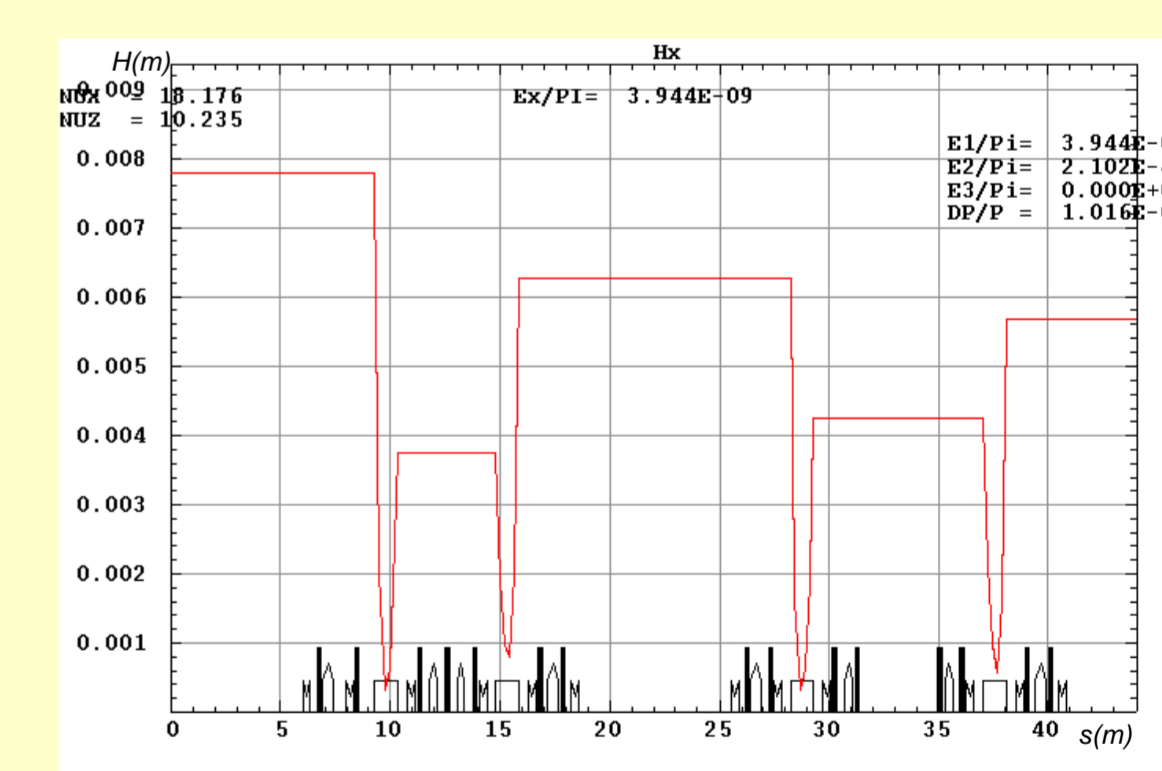Use of Frequency Maps Analysis (FMA)

Reduction of the DA: out of the this area the beam is unstable and the **injection** efficiency is reduced

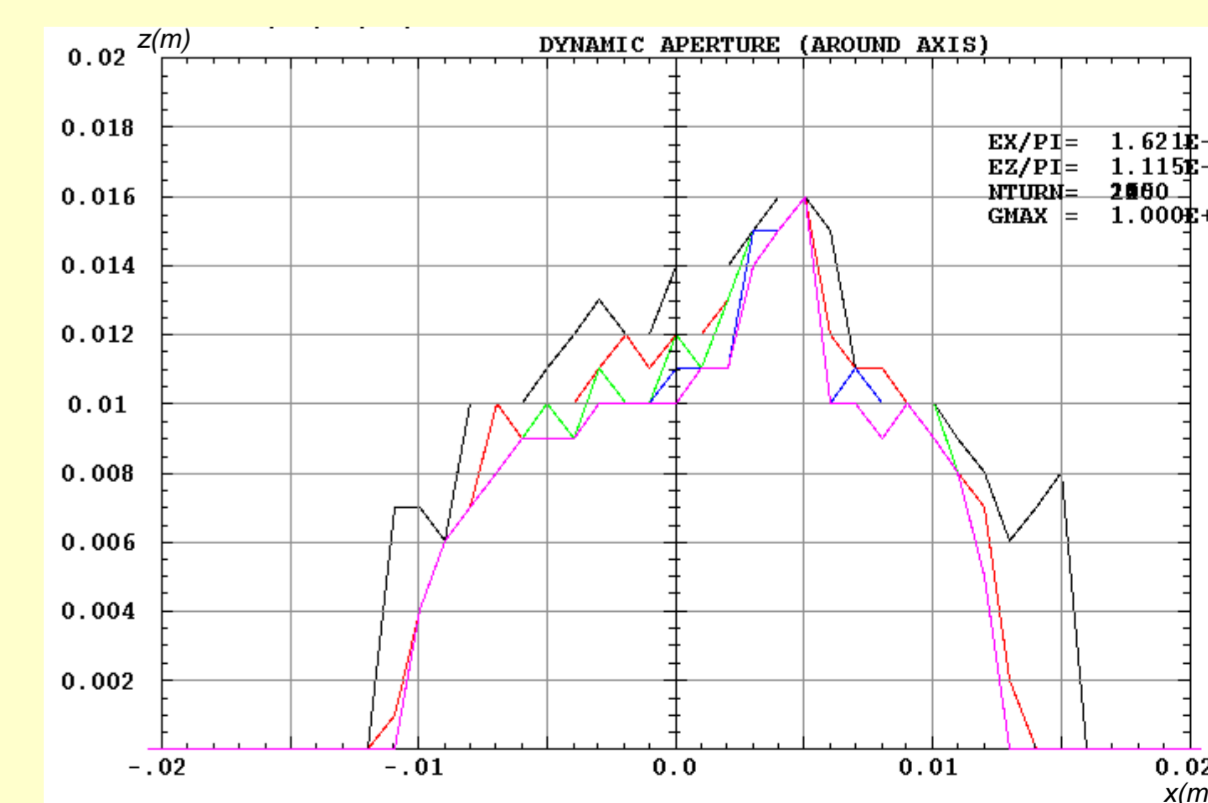*Brightness spectrum of SOLEIL*
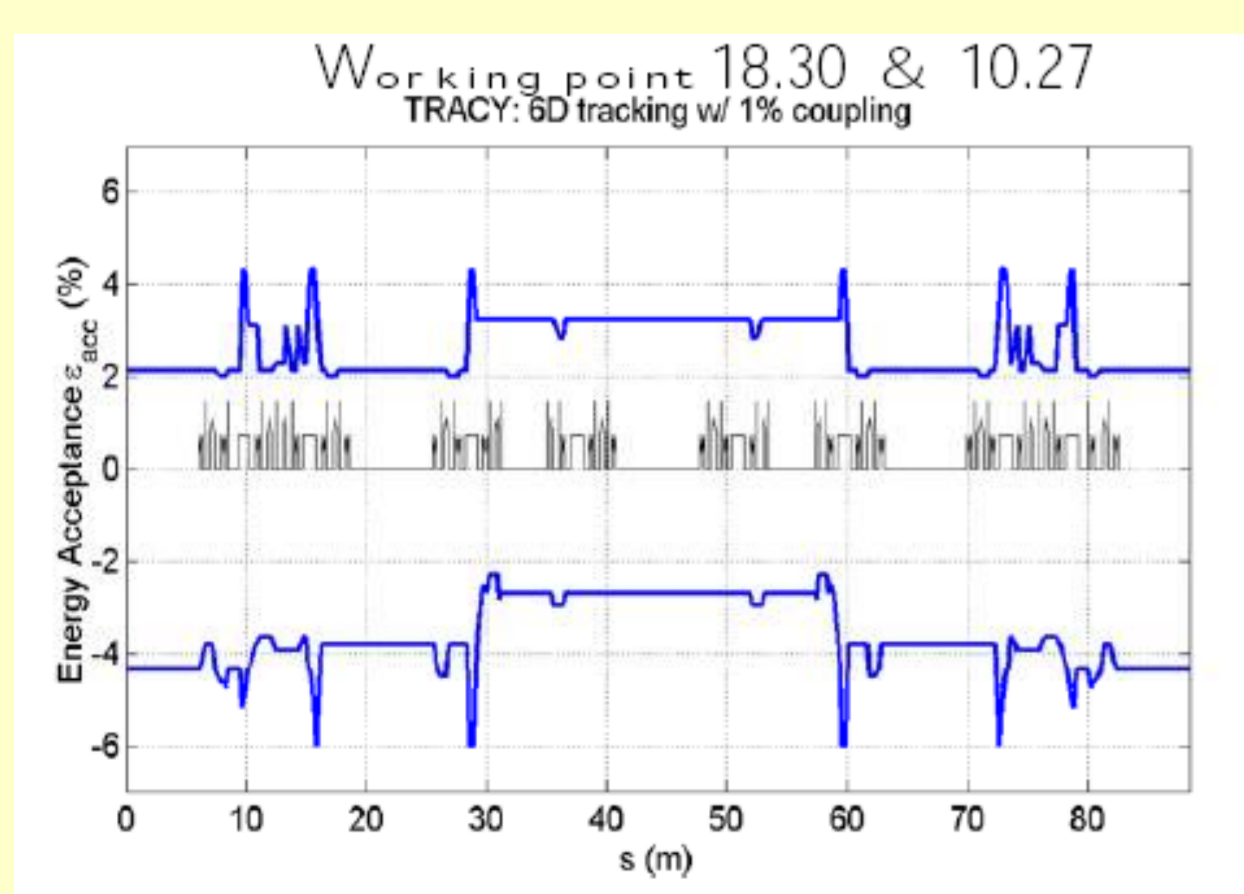
Calculated Momentum Acceptance of SOLEIL using TRACY III code
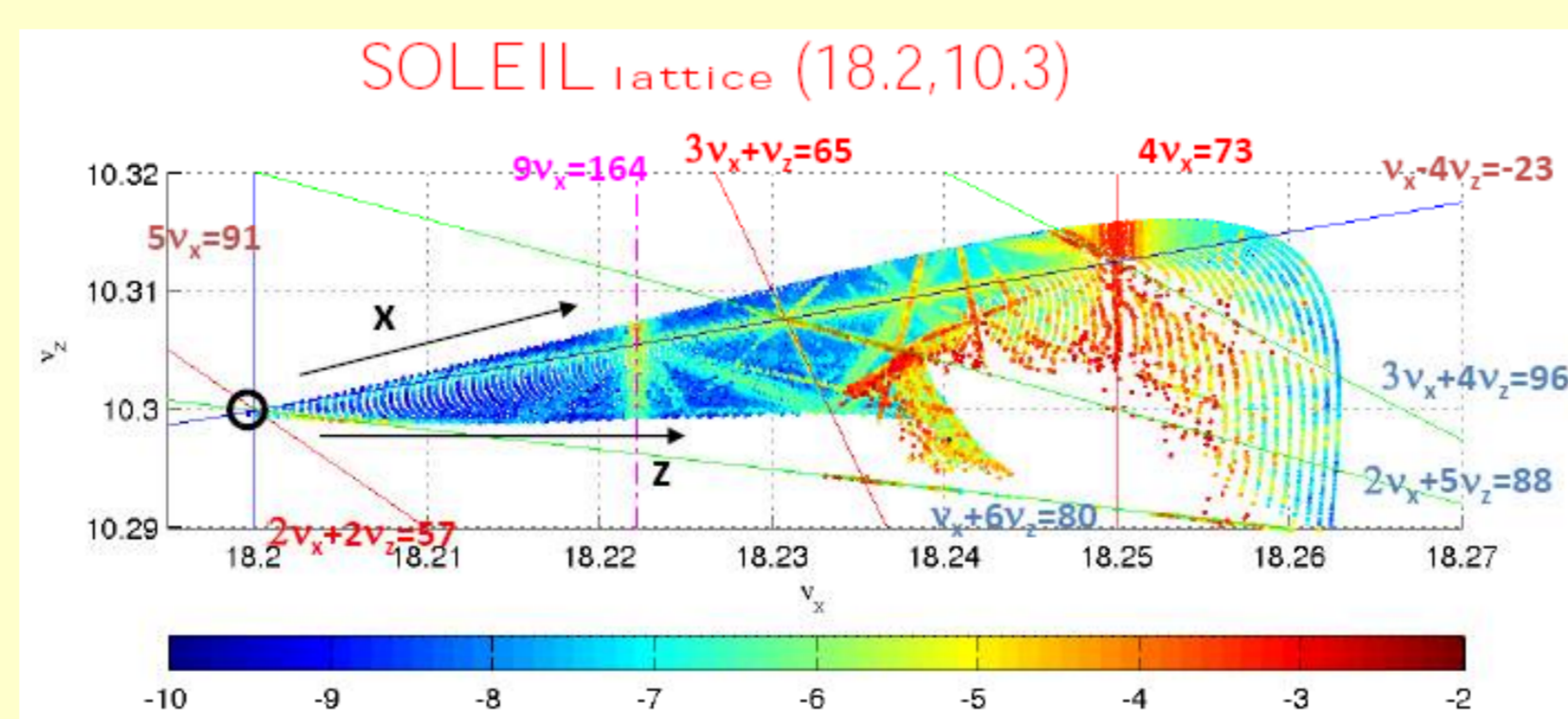
FMA of SOLEIL. The colour difussion reveals the resonances in the frequency map

Curly-H function of SOLEIL lattice. H(s) depends of magnetic structure

Dynamical Aperture of SOLEIL with different number of turns using BETA code: the DA is reduced increasing the number of turns (100, 250, 500 ,1000 and 2000 successively)

- Explore new challenging optics for reducing the effective horizontal emittance of SOLEIL by at least a factor 2 while keeping a large enough beam lifetime and injection efficiency.
- Apply experimentally these new findings for the beamlines of SOLEIL: propose a set of experiments in order to check the benefits of lower horizontal emittance lattices based on photon flux, brightness, and spectral property measurement.
- Evaluate exotic optics to reach sub nanometric horizontal effective emittance. The output of this work will propose directions for large modifications of the design of the storage ring lattice.

REFERENCES: [1] A. Konak, D. W. Coit, A. E. Smith, "Multi-objective optimization using genetic algorithms: A tutorial", 2006. [2] CEA-Saclay. Beta-LNS V5.0 User's Guide, 1999. [3] J. Bengtsson, É. Forest, and H. Nishimura. Tracy User's Manual. [4] M. Borland, "elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation," Advanced Photon Source LS-287, September 2000.