SOLEIL performance improvement using optimization based on Genetic Algorithms

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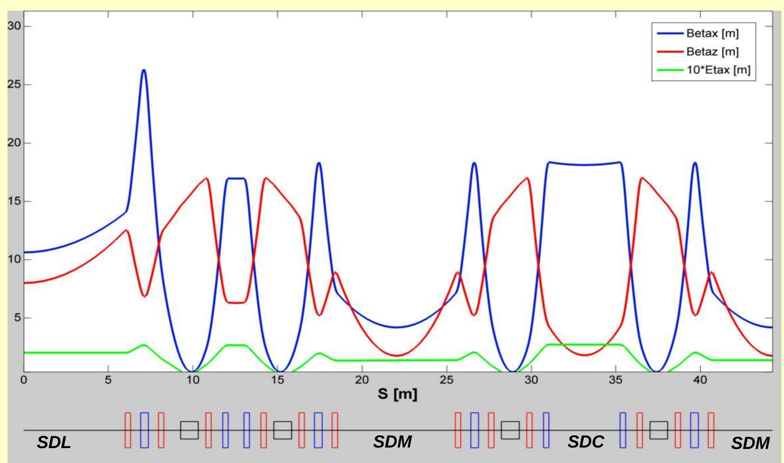
INTRODUCTION

- 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) responsable 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 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
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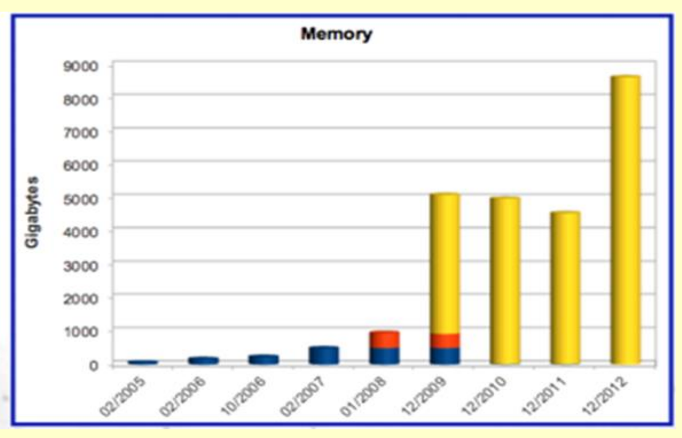
  Instrumentation Technologies, Slovenia
  Royal Holloway University of London, UK
  Société Civile Synchrotron SOLEIL, France
  Universidad de Sevilla / Centro Nacional de Aceleradores, Spain

TOOLS

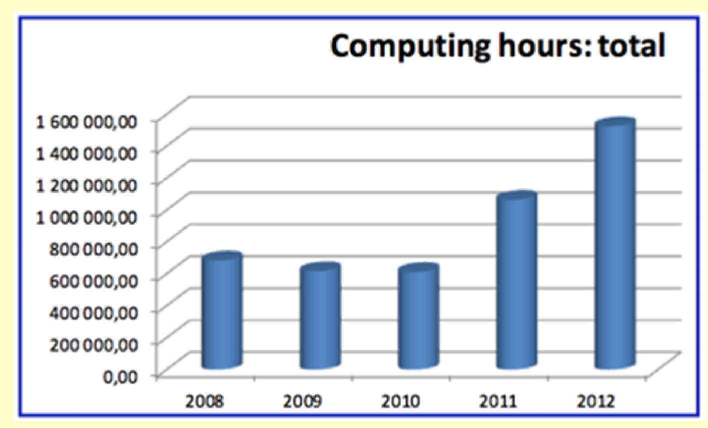
- Tracking codes: BETA [2], TRACY III [3] (long term tracking and FMA)
- ELEGANT [4] for introduction to MOGA

SOLEIL CLUSTER

- 1072 processors => 11.4 Tflops
- 97% used by Beamline 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 Synchrotron SOLEIL



Increase of the computing hours used in Synchrotron SOLEIL

OBJECTIVES OF THE PROJECT

- Increase the **Brightness** $B \sim \frac{1}{\varepsilon_x \varepsilon_z}$

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

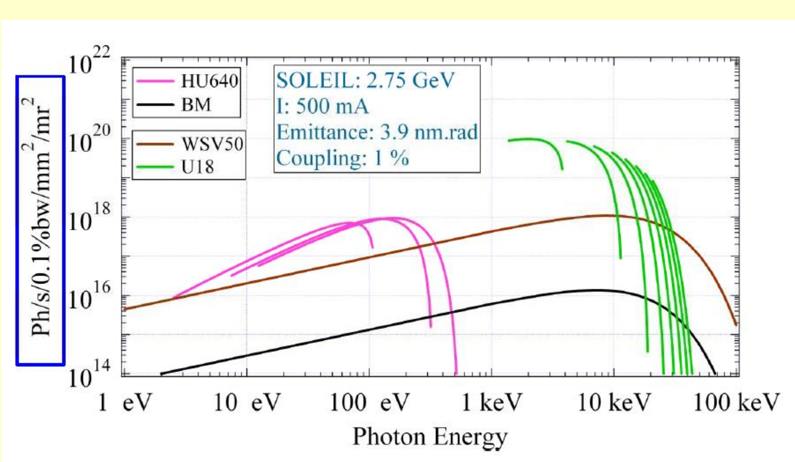
Use of strong **sextupoles** to correct the natural chromaticities

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

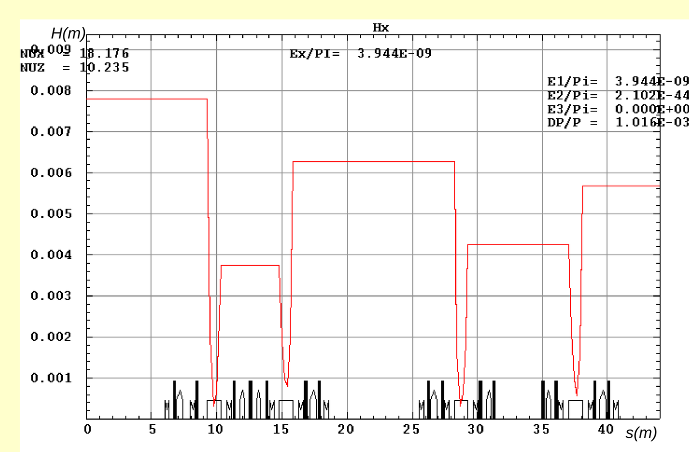
Reduction of the MA: reduction of the **beam lifetime**

Use of Frequency Maps Analysis (FMA)

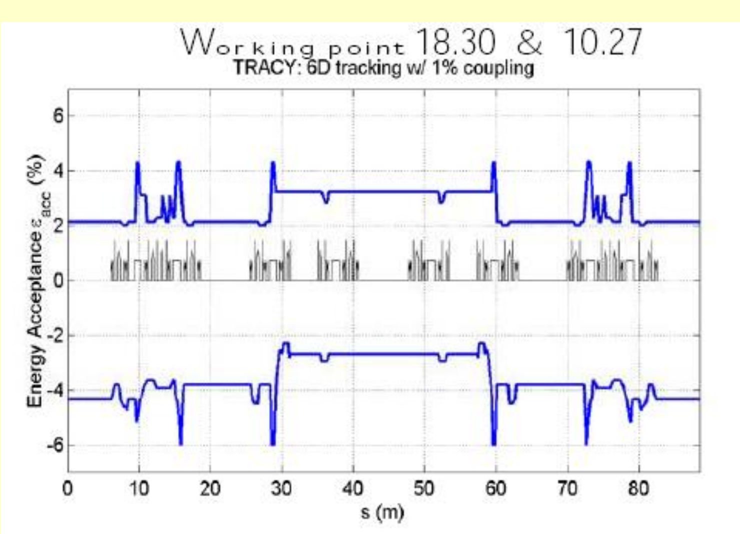
Reduction of the DA: out of the this area the beam is unstable and the **injection** efficiency is reduced



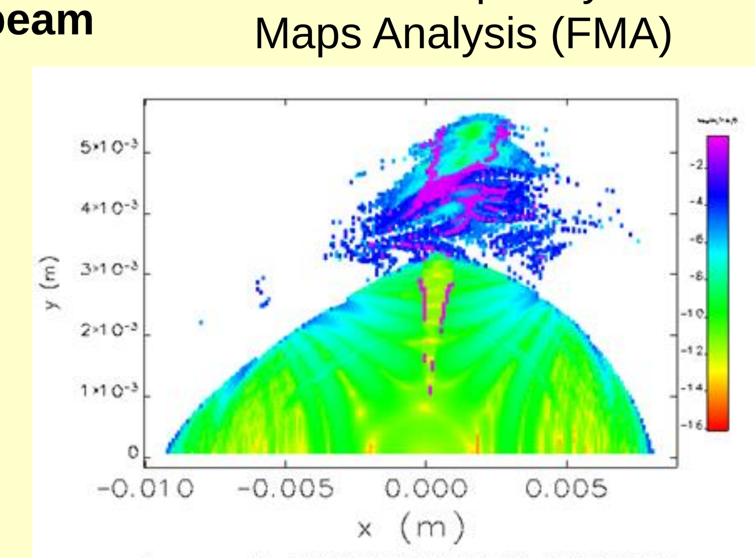
Brightness spectrum of SOLEIL



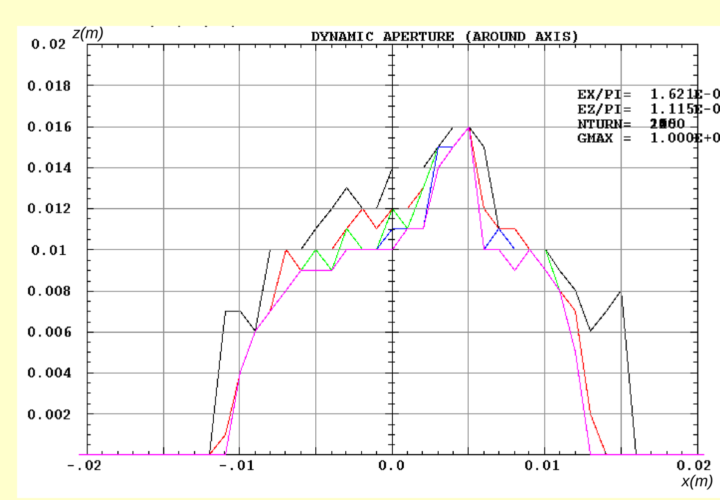
Curly-H function of SOLEIL lattice. H(s) depends of magnetic structure



Calculated Momentum Acceptance of SOLEIL using TRACY III code



DA of SOLEIL using ELEGANT. The colour encodes the diffusion rate and reveals the non-linear beam dynamics at high amplitude or close to resonances.



DA 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.

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