Study of Lower Emittance Lattice at SOLEIL

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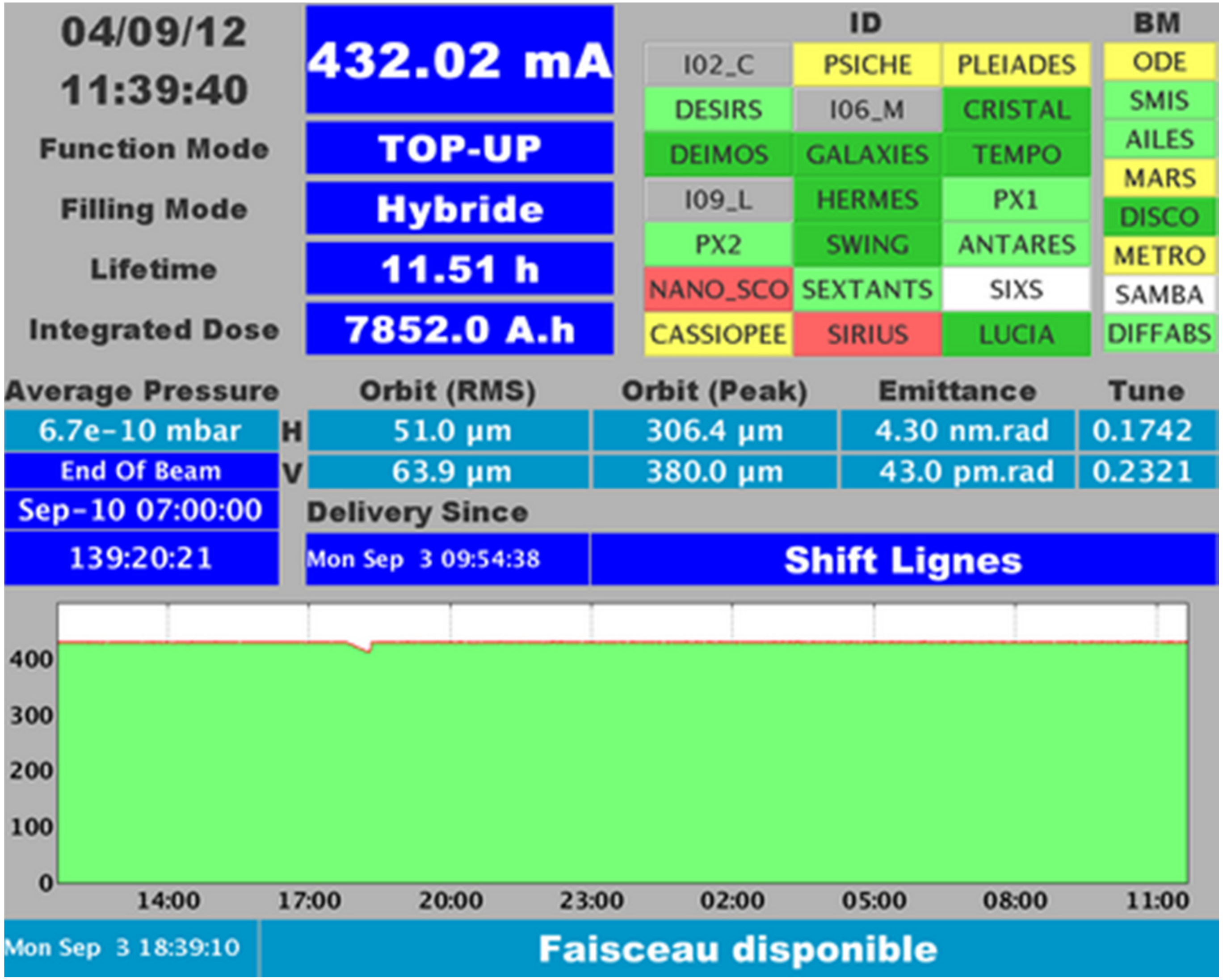
On behalf of the Sources and Accelerators Division

Synchrotron SOLEIL

27 Beamlines have seen the Beam

19 from IDs, 6 from BM + 2 IR



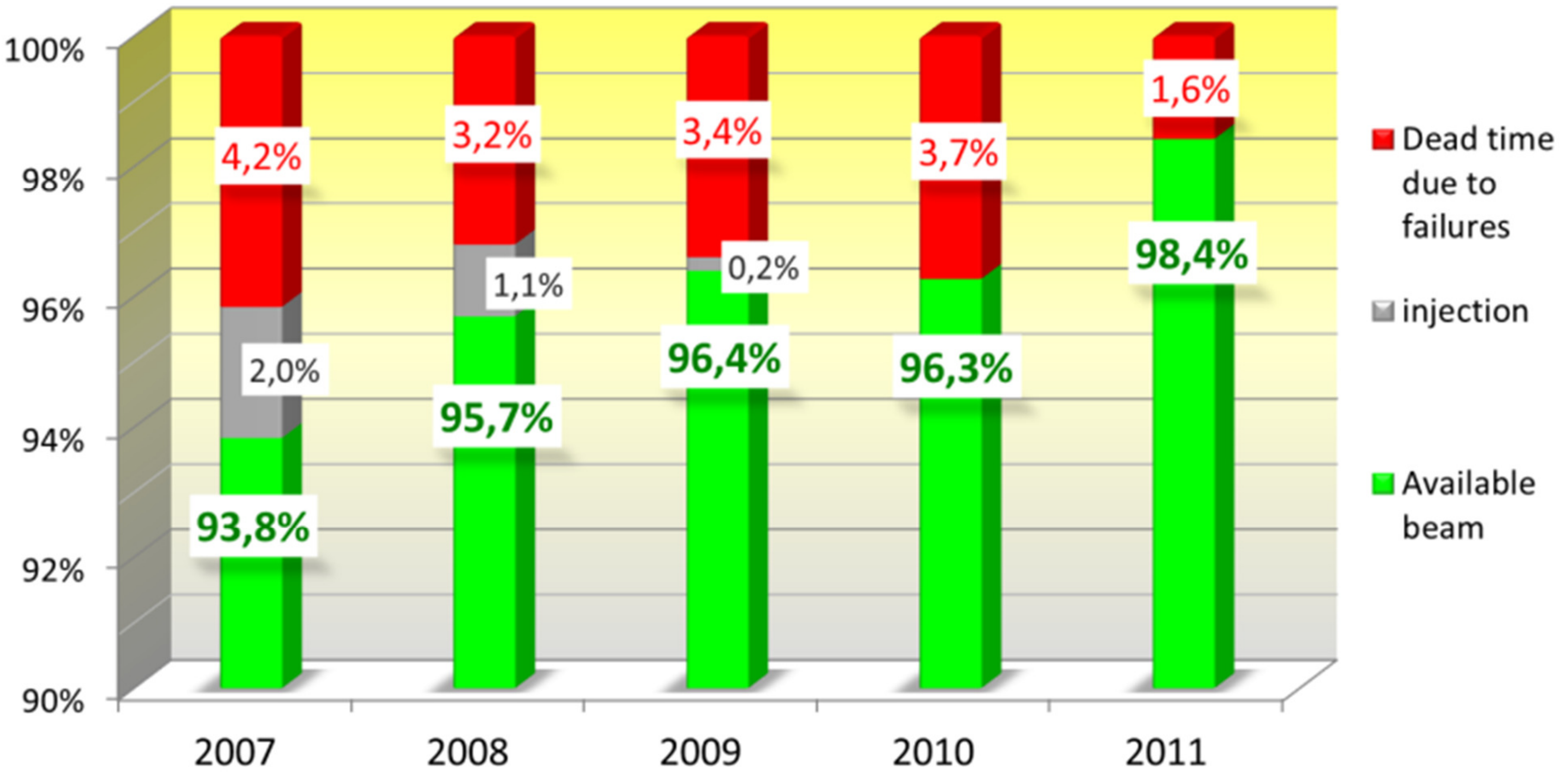
5 Modes of Operation for the USERS

All in Top-up injection

Mode of operation	User Operation	Ultimate performance achieved
Multibunch	430 mA	500 mA
Hybrid	425 mA + 5 mA	425 mA + 10 mA
8 bunch	100 mA	100 mA
1 bunch	12 mA	20 mA
Low α : bunch length and current	4.7 ps RMS and 65 μA per bunch	2.5* ps RMS and 10 μA per bunch

* Not yet measured

Photon beams availability in user operation.



Storage Ring Main Parameters

Energy (GeV)	**2.75**
Emittance H (nm.rad)	**3.7** (up to **4.5** with all IDs closed)
Circumference (m)	**354.097**
Coupling, $\varepsilon_V/\varepsilon_H$ (%)	Minimum achieved ≈ **0.1** Operation (controlled) ≈ **1**
Energy Spread	1.016×10^{-3}
Betatron Tunes H / V	18.1742 / 10.2321
Chromaticities H / V	1.4 / 2.6
Beam Lifetime (h) @ 430 mA (multibunch)	15h – 20h depending on the IDs configuration

SOLEIL Lattice

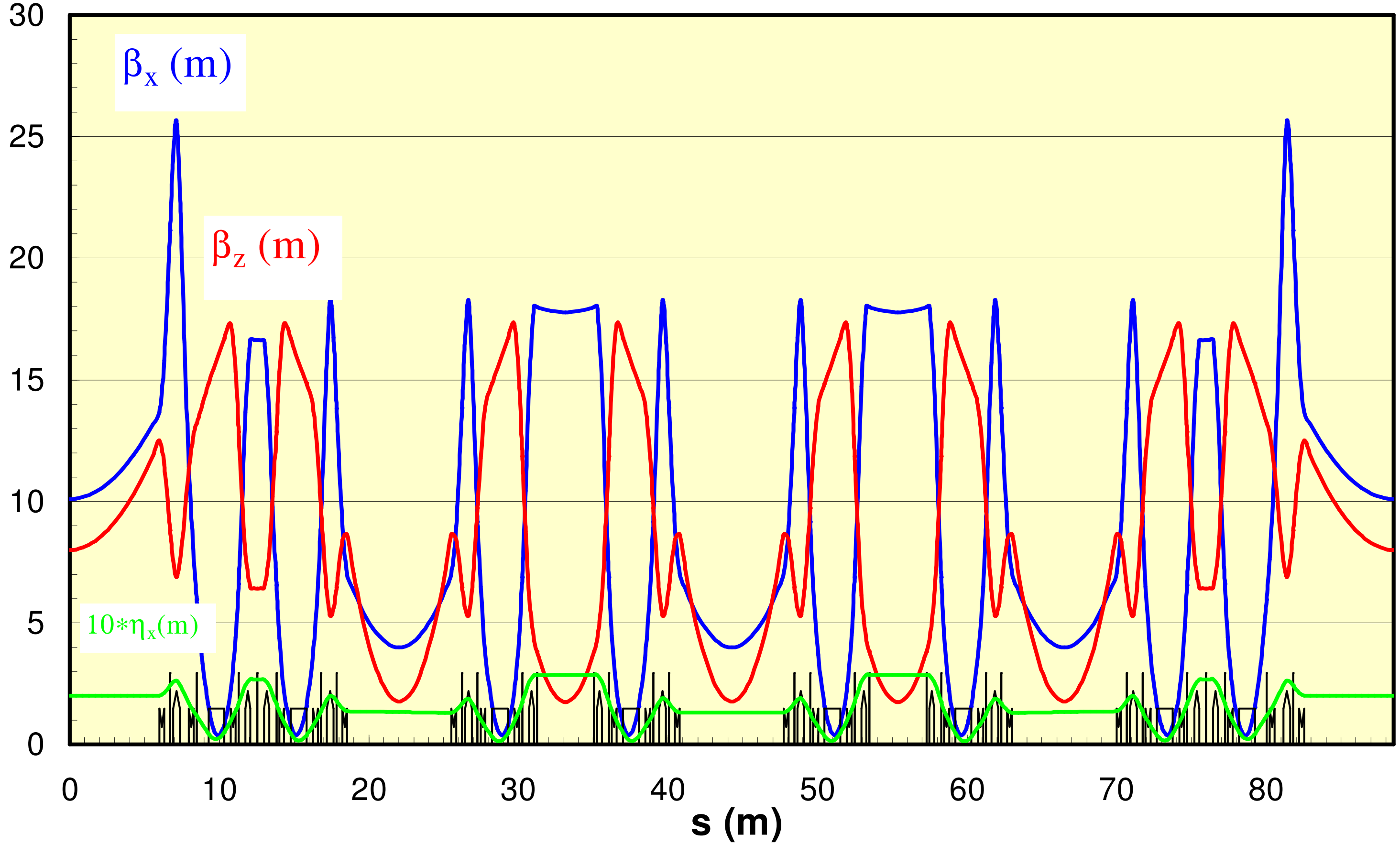
ε_{x0} = **3.7 nm.rad** @ **2.75 GeV**

24 straight sections
4 x 12 m
12 x 7 m
8 x 3.6 m

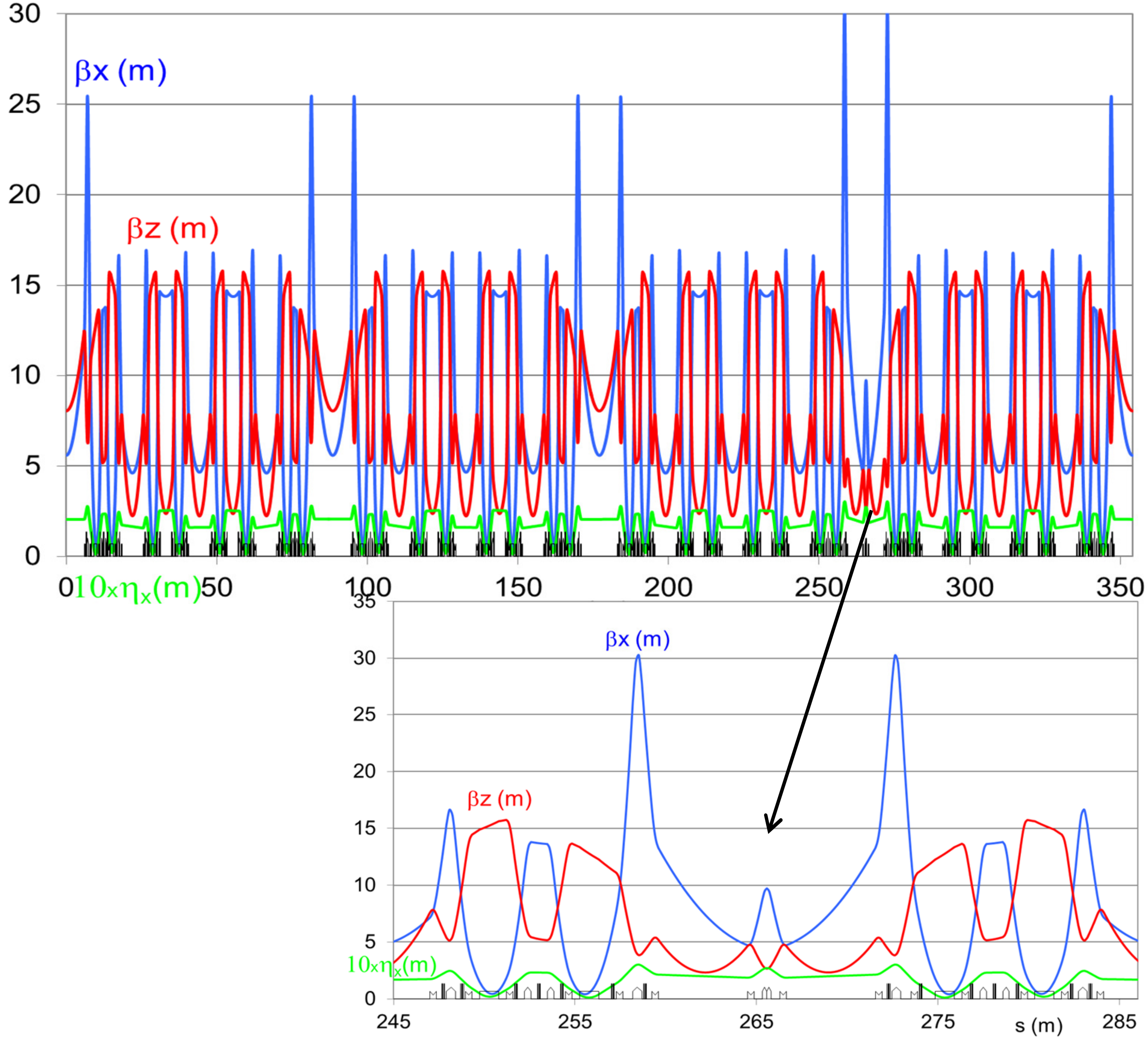
Different β-functions

Finite dispersion
in all straight sections

High ratio (**45%**) of IDs straight sections over a total **354 m** circumference.



SOLEIL Lattice Modified



Operation with a new optics since January 2012

Two canted 5.5 mm gap in-vacuum undulators

SOLEIL SYNCHROTRON

✓ A few possibilities of reaching lower **horizontal emittance** in the Storage Ring are currently investigated at SOLEIL.

❑ Short term path :

- Robinson Wiggler in a non-zero horizontal dispersion straight section.
- Genetic Algorithms to reach unexplored solutions.
- Beam Adapter in the 12 m long straight section.

❑ Long term path :

- Ultimate Storage Ring in the same tunnel with a goal of reducing the horizontal emittance by a factor of 10.

Robinson Wiggler

❖ Horizontal (natural) emittance: $\varepsilon_{x0} = \dfrac{C_q \gamma^2 \langle H \rangle_{dipole}}{J_x \rho_x}$

❖ J_x is related to the damping partition D by : $J_x = 1 - D$

$$D = \frac{\oint \frac{\eta_x}{\rho_x^3} ds + \boxed{\frac{2}{B^2 \rho_x^2} \oint \eta_x B \frac{dB}{dx} ds}}{\oint \frac{ds}{\rho_x^2}}$$

If $D = -1$ ⟹ $J_x = 2$

The horizontal emittance can be divided by a factor 2

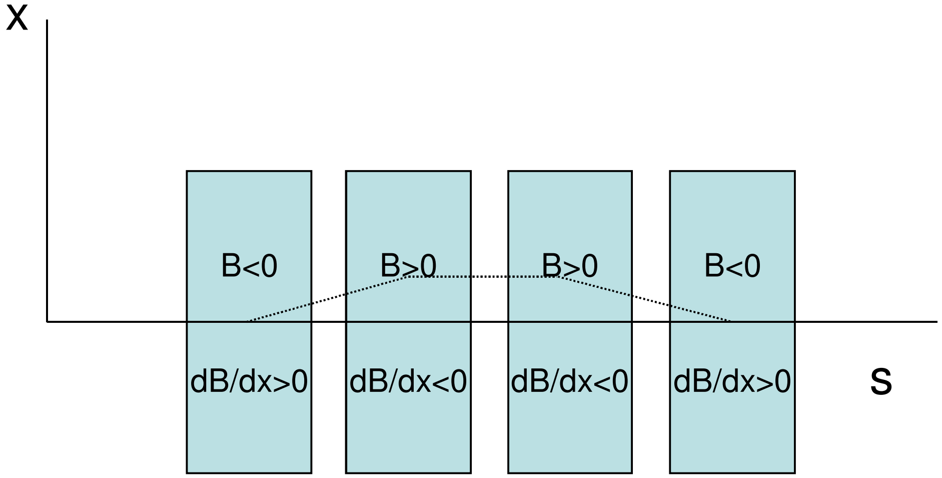
Such as: $J_x + J_z + J_s = 4$ where $J_z = 1$ and $J_s = 1$

A magnetic element introducing the product $B*dB/dx$ in a straight section where the dispersion η_x is **non zero** contributes to the modification of D.

If this magnetic element is such as the field (B) and the gradient (dB/dx) are of opposite sign, this contribution is ***negative*** and consequently we can try to find the conditions to make **D =-1**!

Robinson Wiggler

❖ A gradient wiggler magnet, as proposed by Robinson*, consists of even number of consecutive blocks with field and gradient of opposite signs.



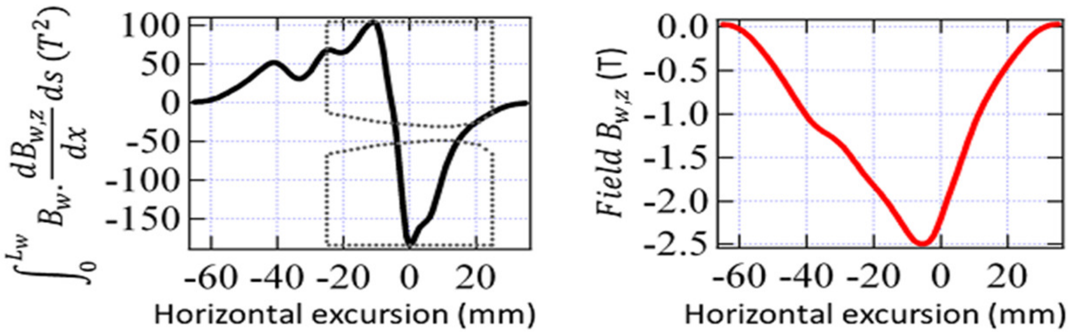
Used on the PS at CERN (in 1983) to counteract the natural horizontal anti-damping → J_x = 3 and D = -2.

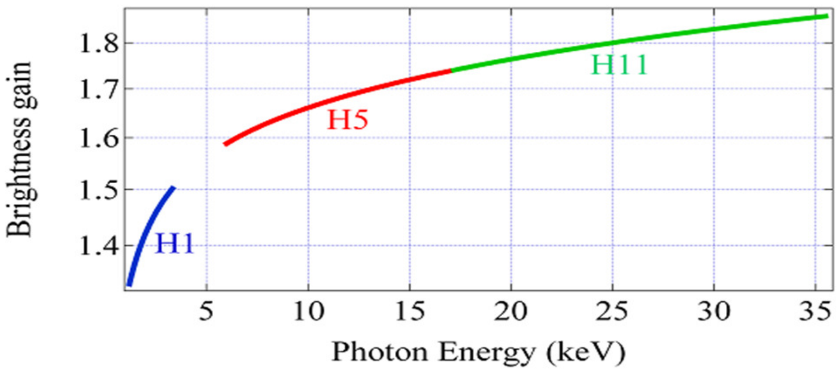
*: K.W. Robinson, Phys. Rev. 3 (1958) 373.

Application to SOLEIL: (work in progress by a PhD student)

❖ In short straight sections of the SOLEIL Storage Ring : $\eta_x = 28$ cm.

$D \approx 5.6\times10^{-3}\left\langle B_w \frac{dB_{w,z}}{dx}\right\rangle L_w$ Where $\left\langle B_w \frac{dB_{w,z}}{dx}\right\rangle L_w \approx 193\, T^2$ and $L_w \approx 2\, m$





(see H. Abualrob et al., IPAC'12)

Drawback and Issues

- Energy dispersion is increased by a factor $\sqrt{2}$

$$\left(\frac{\sigma_E}{E_0}\right)^2 = \frac{2}{2+D}\left(\frac{\sigma_{E,0}}{E_0}\right)^2$$

- Damping in longitudinal plane with $J_s = 1$ (larger damping time constant)

- How to reach such very high gradient?

- Homogeneity of the magnetic field in the electron beam region:
  effect on injection and beam lifetime

- What are the radiation properties?

….

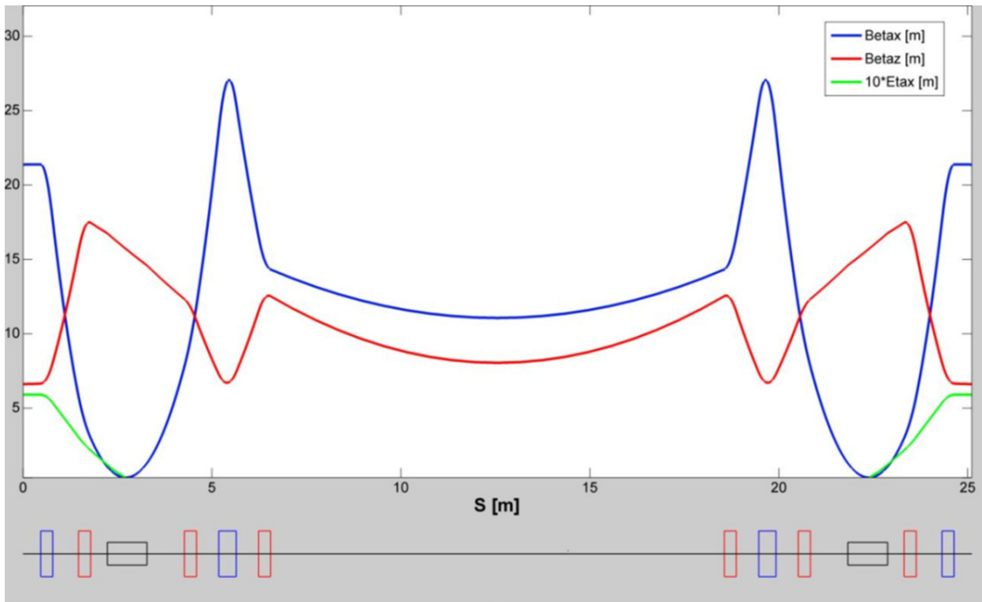
Possibility of Applying the Emittance Adapter to a Long Straight Section

- Application of the round ⇔ flat beam conversion studied by Y. Derbenev et al. in light source rings was proposed by A. Chao and P. Raimondi (cf. FLS 2012).

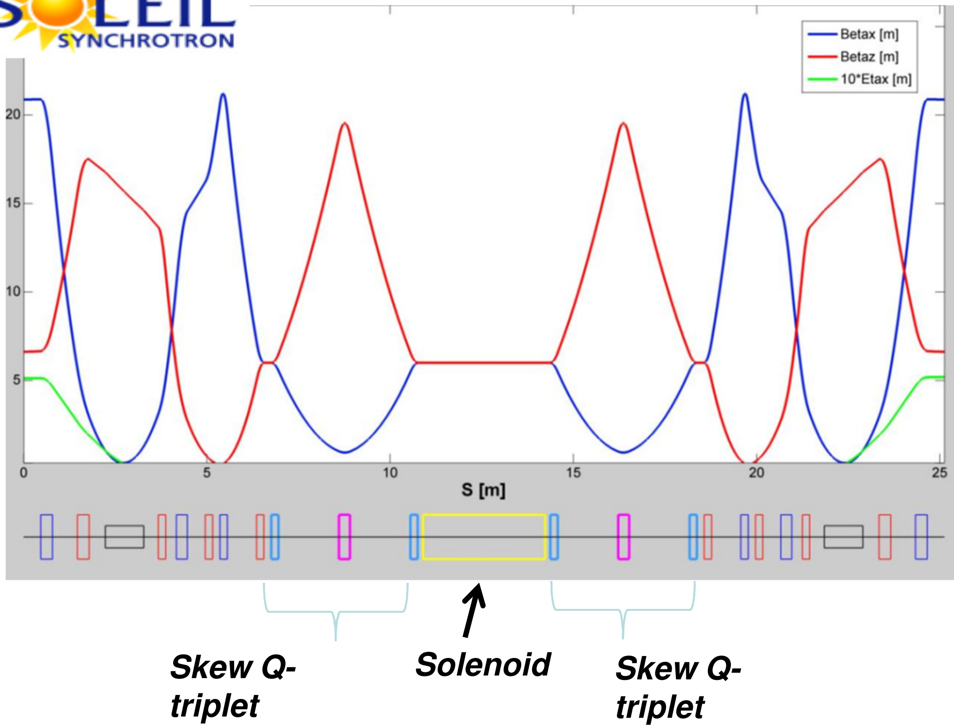
- The scheme consists in a local exchange of the apparent horizontal and vertical emittances using skew quadrupoles and a solenoid;

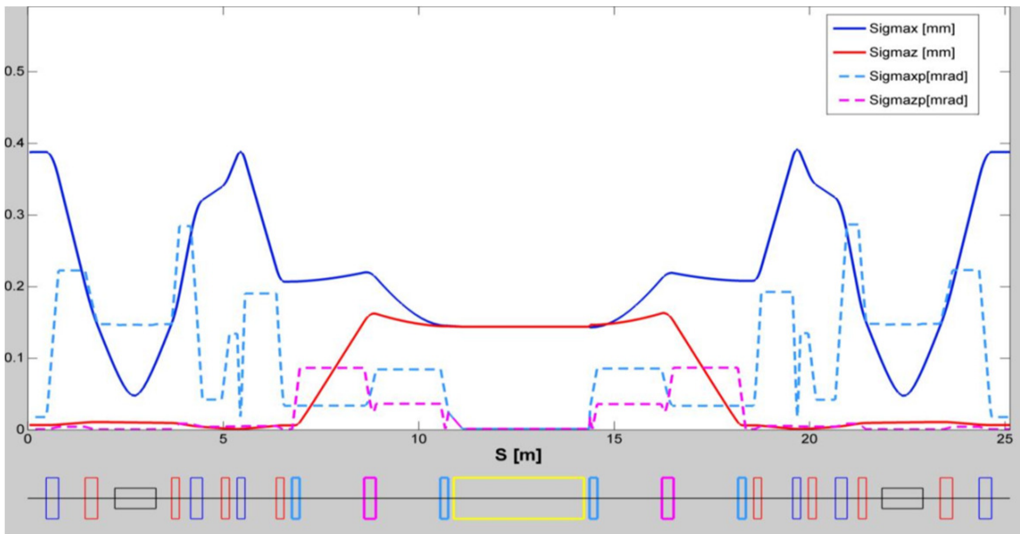
$$(\varepsilon_x)_{apparent} \sim \sqrt{(\varepsilon_x \cdot \varepsilon_z)_{ring}}$$

- As in the SOLEIL storage ring, **a 12 m long straight section is still free**, application of the scheme is of great interest in lowering the horizontal emittance locally.



One of the four 12 m long free straight sections in the dispersion-free optics



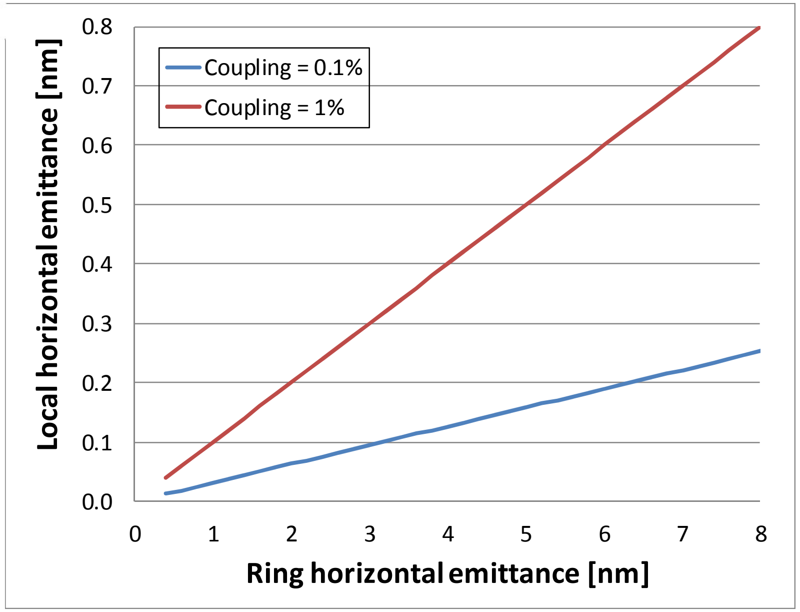


Characteristics of the preliminary adapter solution found :

Straight section	Dispersion-free ($\eta_x = 0$)
At both ends of skew Q-triplets	$\beta_x = \beta_z = 6$ m, $\alpha_x = \alpha_z = 0$
ε_x in the regular cells	7 nm
ε_z in the regular cells	7 pm (0.1% coupling)
ε_x and ε_z in the solenoid	**0.22 nm**

Solenoid length	3.6 m
Solenoid field	3.06 T

Length/skew Q-triplet	4.0 m
Magnet length [m]	Gradient [T/m]
0.2	19.16
0.3	-15.30
0.2	19.26



Range of local horizontal emittance potentially reachable with this scheme

- The emittance adapter seems to work without imposing particular difficulties on the adapter magnets for SOLEIL, as claimed by A. Chao and P. Raimondi, and thus the scheme appears attractive for SOLEIL.

- Optics matching efforts should be continued to maximize the distance available for the solenoid

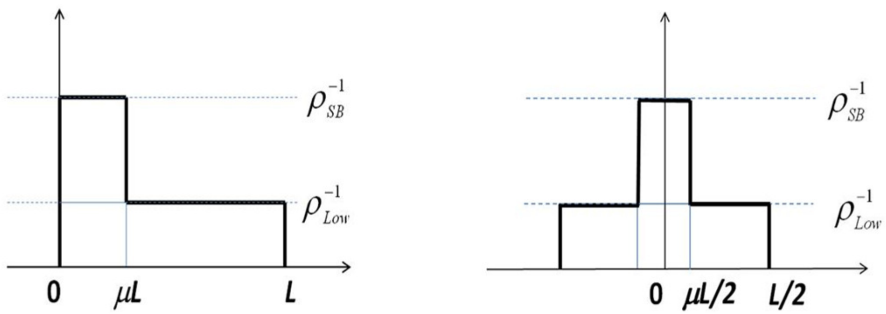
- **Technical challenges for the construction of a compatible insertion device and associated beam dynamics issues must be pursued.**

Long term path : an USR in the same tunnel ?

- The approach taken is to employ whatever methods available to lower the emittance, ***under the constraint of leaving the circumference of the ring as well as the straight sections unchanged.***

- As a first of such study, the use of longitudinal field variation of superbends is attempted, ***since at SOLEIL there are growing interests in the dipole beamlines for such dipoles as means to raise the photon energy.***

Description of a superbend (SB) with the hard-edged model:



Asymmetric and symmetric field profiles

$$\rho_{Low}^{-1} = \frac{1}{1-\mu}\left(\frac{\Theta}{L} - \rho_{SB}^{-1} \cdot \mu\right)$$

Θ: Bending angle
L: Dipole length
$(0 \leq \mu \leq \rho_{SB}\Theta/L)$

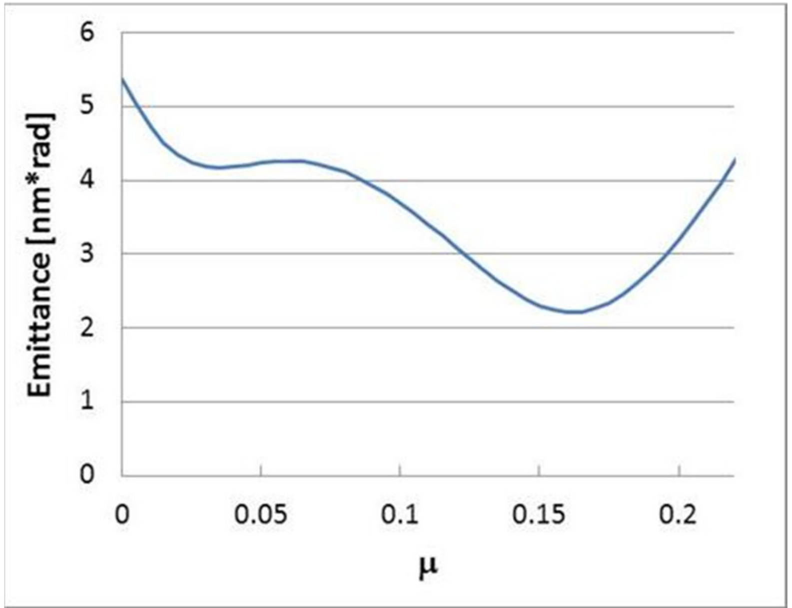
(see R. Nagaoka et al. *IPAC 2012*)

Theoretical Minimum Emittance (TME) for a given dipole profile:

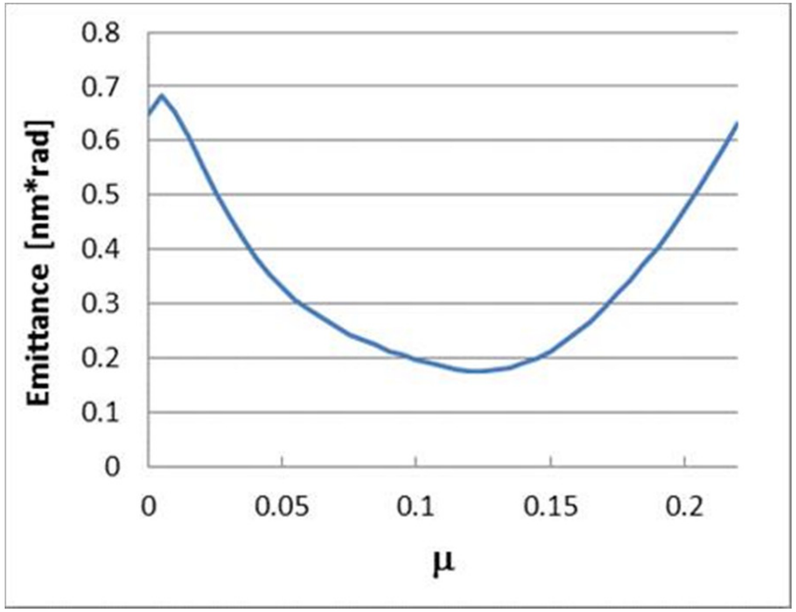
$$(\varepsilon_x)_{\min} = C_q \frac{\gamma^2}{J_x} \frac{2\sqrt{S_{01}(S_{03} - (S_5^2/I_3))}}{\oint \rho^{-2}\,\mathrm{d}s}$$

S_{01}, S_{03}, S_5 and I_3 are specific integrals of dispersion and $\rho(s)$ functions over the dipole

(*cf. R. Nagaoka and A. Wrulich, NIM A575 (2007) 292*)



TME for an asymmetric dipole with the achromat condition (Θ = 11.25°, B_{SB} = 7.2 T)

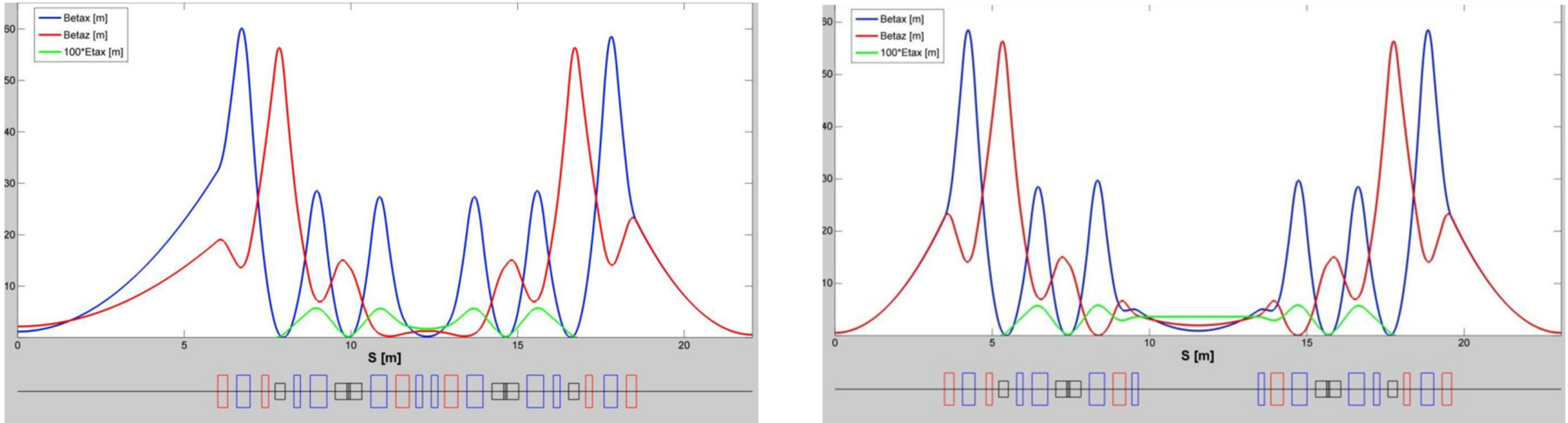


TME for a symmetric dipole without the achromat condition (Θ = 8°, B_{SB} = 7.2 T)

Strategy adopted in the lattice search:

$\eta_x = 0$ in the long (SDL) and medium (SDM) straight sections, due to the inevitable energy spread increase ⇒ Use of dispersion suppressing dipoles

Results obtained using 7 T superbends:



Lattice and optics for the SDL-SDM (left) and SDM-SDC-SDM cells (right), altogether representing 1/8th of the ring

	Cell SDL-SDM	Cell SDM-SDC-SDM
Horizontal emittance [nm·rad]	0.98 [3.85]	0.97 [2.67]
Energy spread	1.94×10^{-3} [1.02×10^{-3}]	1.94×10^{-3} [1.02×10^{-3}]
Momentum compaction	0.983×10^{-4} [4.836×10^{-4}]	0.941×10^{-4} [4.154×10^{-4}]
Betatron tunes	(2.805, 1.368) [1.110, 0.477]	(2.811, 1.717) [1.165, 0.811]
Natural chromaticities	(-29.36, -9.63) [-3.22, -1.15]	(-29.68, -12.25) [-3.34, -1.69]

	Θ [deg]	L [m]	High field			Low field		
			B_{SB} [T]	ρ_{BS} [m]	L_{BS} [m]	B_{Low} [T]	ρ_{Low} [m]	L_{Low} [m]
Superbend	8	0.8	7.2	1.273	0.1	0.8	11.460	0.7
Dispersion suppressor	3.25	0.304	1.71	5.36	0.304			

Summary of the bending magnets used (the field gradients employed are not shown)

	Long straight	Medium straight	Short straight
SOLEIL original optics	5.34	5.55	5.58
SB-QBA	0.98	0.98	2.48
Ratio	**5.5**	**5.7**	**2.3**

$$[\varepsilon_x(s)]_{eff} \equiv \sqrt{\varepsilon_x^2 + H(s)\cdot\varepsilon_x\cdot\sigma_{\Delta p/p}^2}$$

Effective emittance $[\varepsilon_x(s)]_{eff}$ [nm·rad] *in comparison with the original SOLEIL optics*

Summary:

◊ With a QBA (Quadruple Bend Achromat) lattice consisting of 2 superbends and 2 dispersion suppressors, **a solution reaching a sub-nanometer emittance was found for the SOLEIL ring**. The study should therefore be continued in this direction, in addition to other schemes such as a MBA (Multiple Bend Achromat) lattice.

◊ The obtained solution clearly exhibits non-trivial issues (linear and nonlinear dynamics, beam injection, magnet technology, beam lifetime, instability, …), which must be pursued in parallel.