SOLEIL Upgrade

Ryutaro Nagaoka, on behalf of the
SOLEIL upgrade conceptual design team

Outline

1. SOLEIL as of today
2. Upgrade lattice study evolution
3. 7BA Hybrid vs 7BA HOA
4. Present CDR reference lattice
5. Injection schemes developed
6. Collective effects
7. RF system
8. Magnets
9. Vacuum, girders
10. SR sources and expected performance
11. Tentative planning and objectives
12. Summary

Acknowledgements

RN thanks all members of the SOLEIL Upgrade Conceptual Design team for their contributions to what presented here

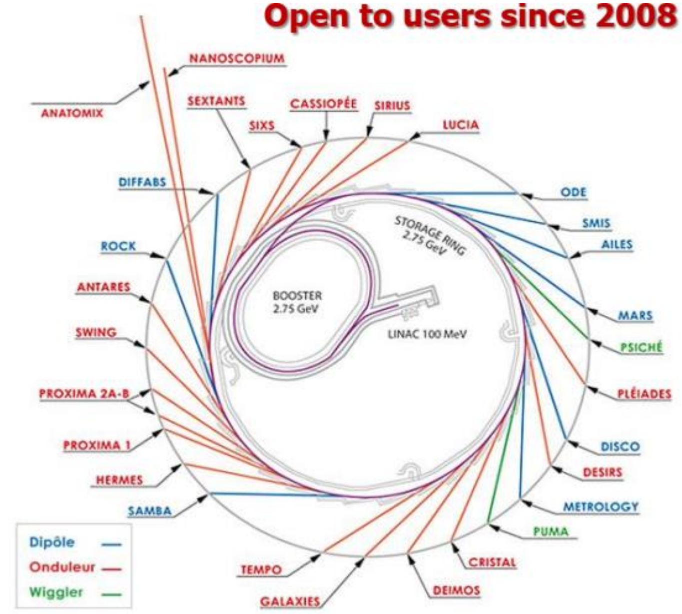
SOLEIL as of today [1/2]

SOLEIL: The French national 3rd Generation Light Source

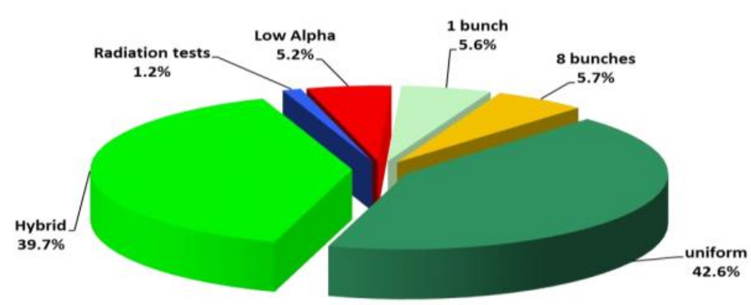
- 29 beamlines operational in 2018.
- ~ 37000 users visits since 2008.
- > 600 articles published yearly.
- Machine availability > 98% and MTBF > 90 hours.
- 5 (to 6) modes of operation.

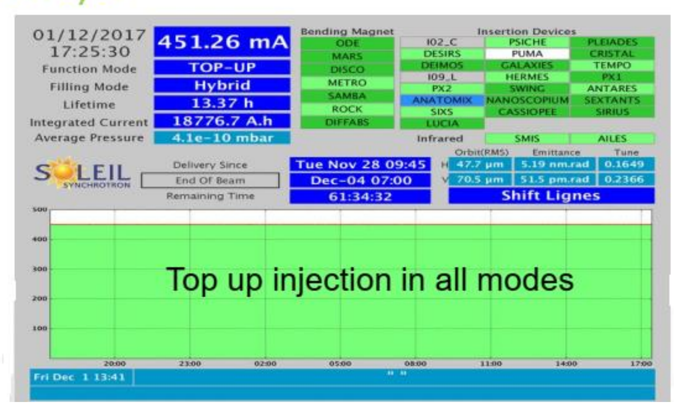
Mode of operation Bunch fill. patterns	User Operation in 2017	Ultimate performance achieved
Multibunch (M2)	500 mA	500 mA
Hybrid/camshaft mode (M)	425 mA + 5 mA	425 mA + 10 mA
	+ Slicing on high intensity bunch	Slice length < 200 fs FWHM
8 bunches (8)	100 mA	110 mA
1 bunch (S)	16 mA	20 mA
Low-α: Hybrid mode (L)	4.7 ps RMS for 65 μA	< 3.2 ps RMS for 15 μA

Open to users since 2008



Broadband spectrum:
9 orders of magnitude from far IR to hard X-rays.





SOLEIL as of today [2/2]

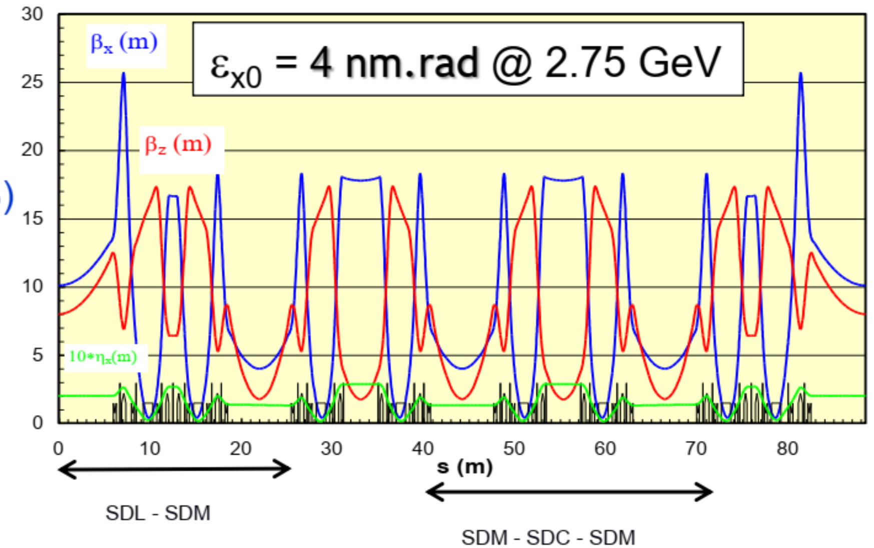
SOLEIL lattice Today and Challenges for its Upgrade

Rather small Circumference: **354 m**

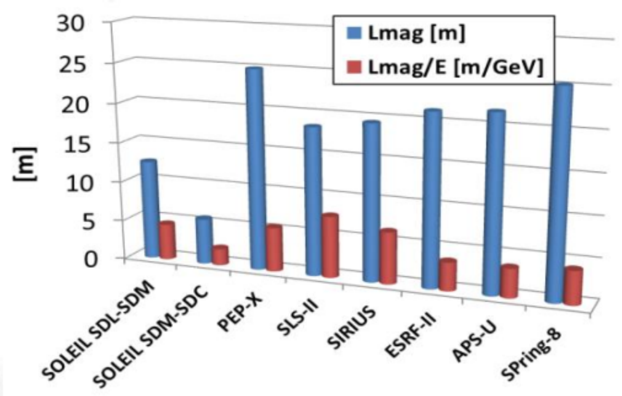
16 cells

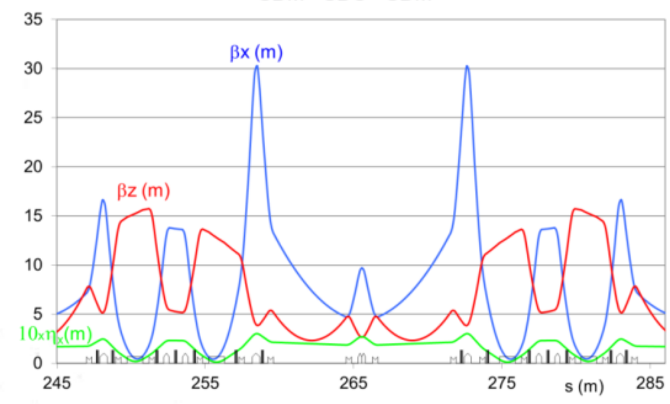
High ratio of free straight sections (~45%)

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



Very compact magnetic structure



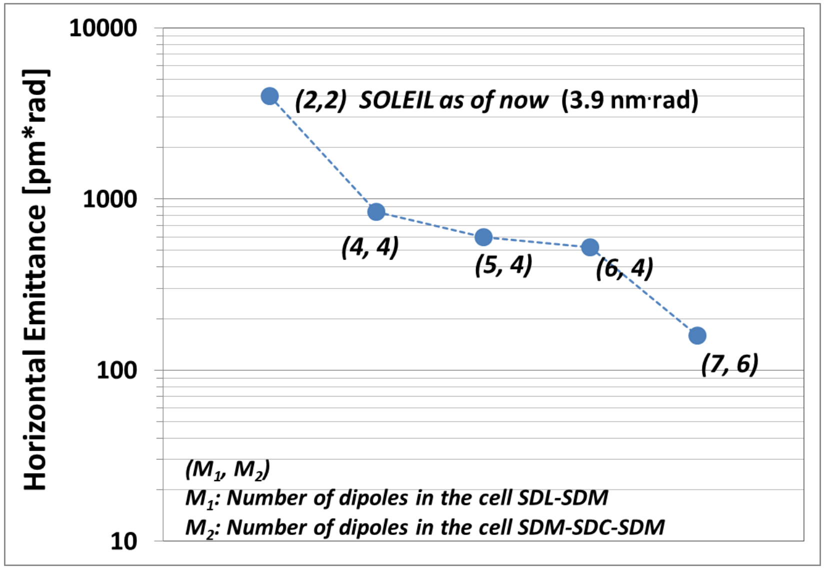


The lengths dedicated to magnets are relatively short; 12.5 m in SDL-SDM and 2 × 5.73 m in SDM-SDC-SDM.

One long straight section (**SDL13**, accommodating 2 long beamlines) **has been modified.**

Upgrade lattice study evolution [1/2]

Lattice	ε_{H0} [pm]	Conference
4BA using LGBs (24 existing straight sections non-altered)	980	IPAC2012
5BA-4BA (24 existing straight sections non-altered)	520	IPAC2013
5BA-4BA (24 existing straight sections non-altered)	440	IPAC2014
7BA-6BA using LGBs (24 existing straight sections non-altered)	145	IPAC2015
7BA-6BA using RBs (24 existing straight sections quasi non-altered)	206	IPAC2016
7BA-6BA using the ESRF hybrid type lattice (24 existing straight sections kept but shortened)	220	IPAC2017
20×(7BA ESRF hybrid type lattice)	72	IPAC2018
20×(7BA Higher-Order Achromat lattice)	76.5	IPAC2019

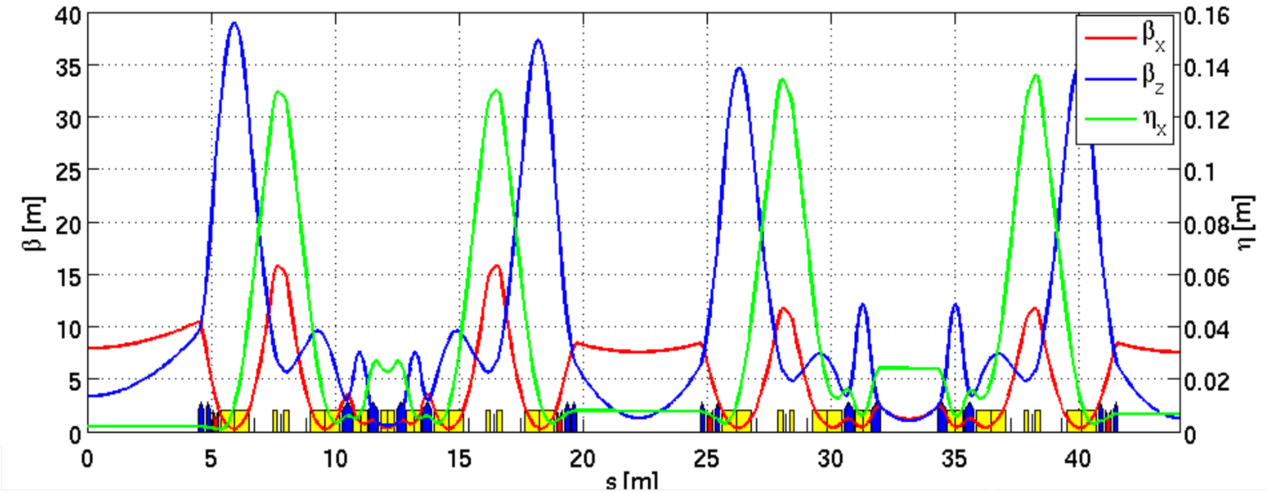


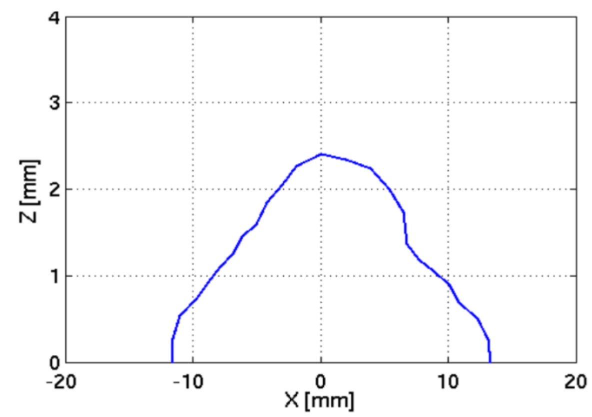
$$\varepsilon_x^{TME} = \frac{1}{8\sqrt{15}}\frac{C_q\gamma^2}{J_x}\theta_0^3 \cdot \left\{ \frac{1}{\left[2+(M_1-2)3^{1/3}\right]^3} + \frac{1}{\left[2+(M_2-2)3^{1/3}\right]^3} \right\}$$

An approximate formula for TME in a ring composed of alternating M_1BA and M_2BA cells.

θ_0 : Total bending angle per cell

Upgrade lattice study evolution [2/2]





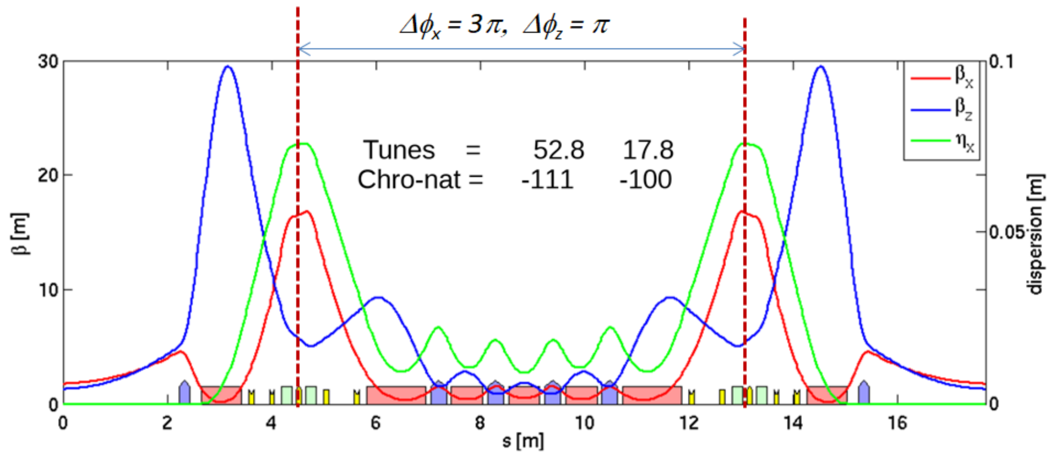
*A **7BA-6BA lattice employing the ESRF hybrid scheme** and keeping the existing SDL, SDM and SDC sections (2017)*

- Inspired by the ESRF hybrid lattice, a 7BA-6BA structure adopting this scheme was studied (7BA in SDL-SDM and 6BA in SDM-SDC-SDM cells)
- Goal was to find a solution allowing the standard off-axis injection with good lifetime, by keeping the existing 24 SSs (Straight Sections) (SDL, SDM and SDC).
- A solution giving the emittance of 220 pm was found by shortening the SSs to some extent: (12 → 9 m, 7 → 5 m, 3.8 → 2.8 m)

⇨ It was concluded that ε_H **= 220 pm is too high** for the effort needed to get this solution

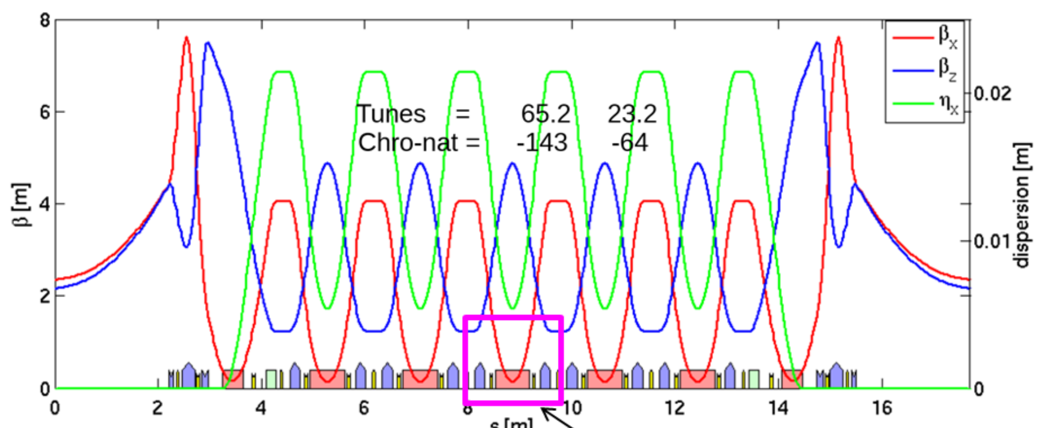
7BA Hybrid versus 7BA HOA [1/2]

Two representative MBA lattices developed and employed in the community that integrate linear and nonlinear optimisations in their structures, were compared for M = 7:



In both cases, the ring is composed of **20 identical cells** with the free straight section length of **4.4 m**

Hybrid 7BA symmetry 20:
ε_x = 75 pm.rad, $\tau_{Touschek}$ ~ 4 h



unit HOA cell
With specific values of
$(\Delta\phi_x, \Delta\phi_z) = 2\pi\cdot(3/7, 1/7)$

HOA 7BA symmetry 20:
ε_x = 76 pm.rad, $\tau_{Touschek}$ ~ 15 h

Both lattice schemes gave satisfactory symmetric 20-cell solutions in terms of
- Emittance
- Dynamic acceptances
- Robustness
- Beam lifetimes

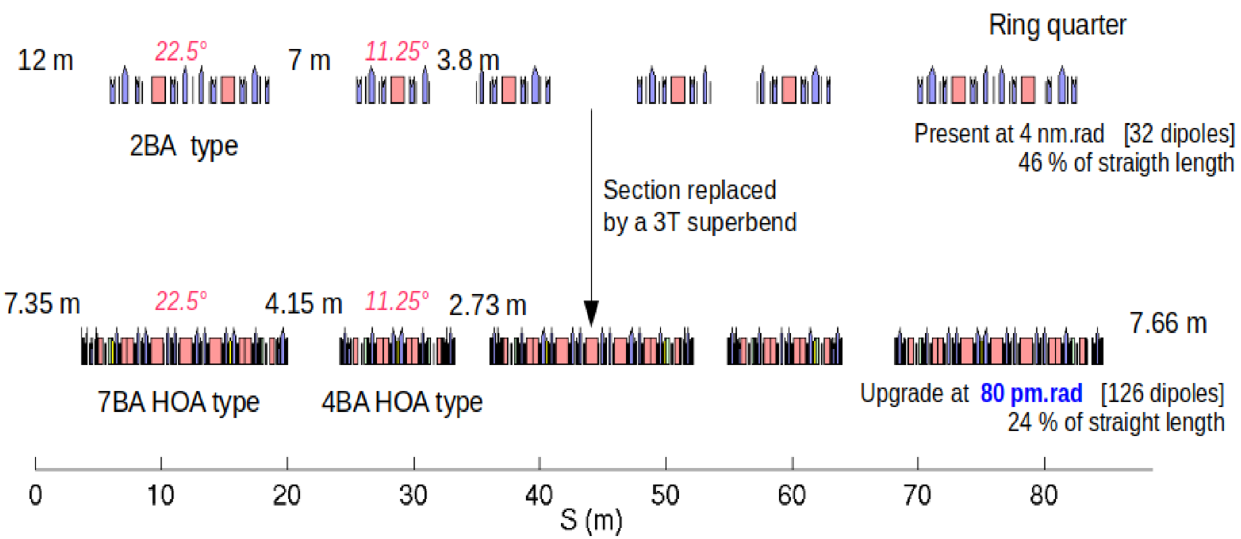
7BA Hybrid versus 7BA HOA [2/2]

- **A 20-cell 7BA hybrid solution** possessing **symmetry 4 with 4×6 m + 16×4 m** straight sections was developed, giving ε_x = 74 pm.rad and $\tau_{Touschek}$ = 1.8 h
- Inclusion of canted and double waist optics in one long straight sections → Results rather promising

However, mechanical engineering studies revealed that there are yet 6 to 8 shielding ratchet walls and as many BLs (out of 24) that are geometrically in a serious mismatch

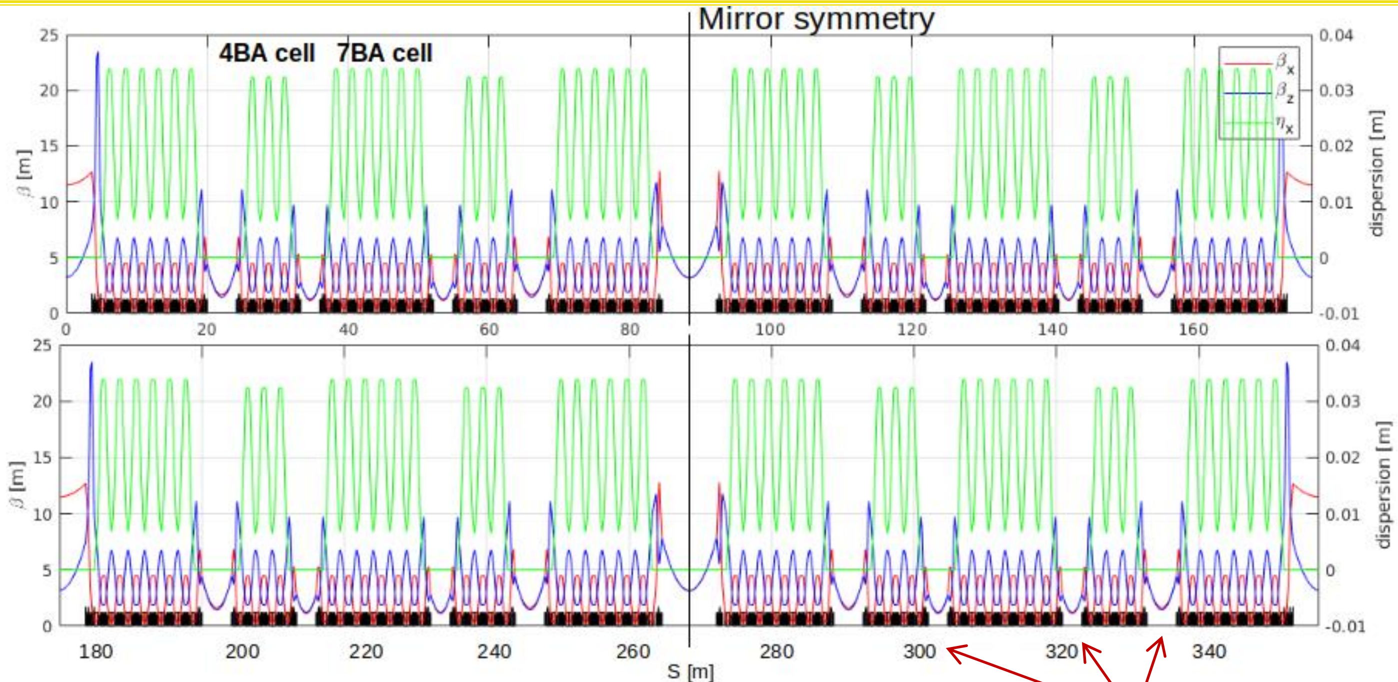
⇨ Using the "***modularity***" of **HOA cells**, studies launched to explore a **20 cells *M*BA-*N*BA HOA** that best matches the geometric constraints and fulfils the performance requirements

⇨ **20 cells 7BA-4BA HOA** defined today as the SOLEIL upgrade CDR reference lattice



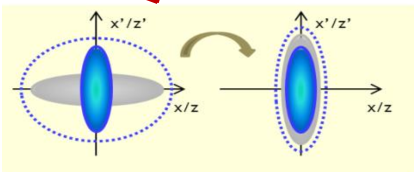
- Symmetry was reduced to **2** with **4** different straight lengths
- A much better beamline (BL) parallel positioning obtained : Offsets : -105, ±35 and 0 mm for the 2 long canted BLs.

Present CDR reference lattice [1/3]



Entire layout of the CDR lattice: "HOA 7BA-4BA symmetry 2"

	L (mm)	B (T)	G (T/m)	No.	Tot	Location
Short bend 7BA cell	400	0.998	-8.013	24	40	Arcs dispersion
4BA cell	400	0.957	-8.013	16		suppressor
Long bend 7BA cell	947	0.696	-15.88	60	76	In the arcs
4BA cell	947	0.668	-15.88	16		
Rev bend 1 7BA cell	200	-0.210	56.34	120	152	In the arcs
4BA cell	200	-0.201	56.34	32		
Rev bend 2 7BA cell	200	-0.178	57.79	24	40	Arcs dispersion
4BA cell	200	-0.171	57.79	16		suppressor
Quadrupoles [B']	Various	-	≤ 110	144	144	Quadruplet in the straights
Sextupoles [1/2 B"] H&V correctors	60/80/110	-	8000 T/m²*	368	368	Both arcs and straights Combined magnet
Octupoles [1/6 B'''] Q correctors	50		3.10^5 T/m³*	176	176	Both arcs and straights Combined magnet
Total					996	

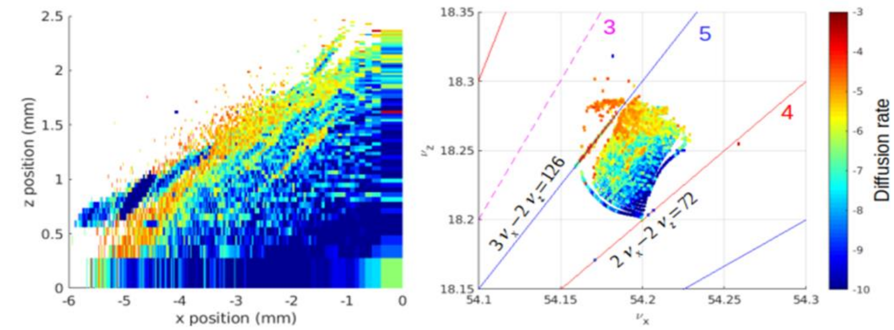


Main characteristics of the magnets used for the CDR lattice

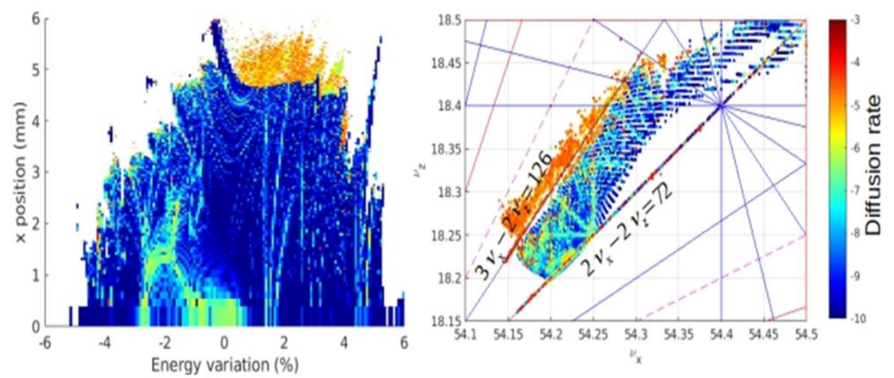
- Permanent magnets for dipoles and reverse bends
- Need of strong sextupoles and octupoles

Present CDR reference lattice [2/3]

Lattice		CDR lattice upgrade	Current lattice
Symmetry		2	1
Energy	[GeV]	2.75	2.75
Circumference	[m]	353.74	354.10
Straight ratio	[%]	24	46
Number of straight secs		20	24
RMS Natural H. emittance	[pm.rad]	81	4000
RMS Coupled H&V Emittance	[pm.rad]	53	
RMS Energy spread	[%]	0.09	0.10
RMS Natural Bunch length	[ps] [mm]	9.182 2.7	15.17
Harmonic number		416	416
Main RF frequency	[MHz]	352.56	352.20
Energy loss per turn W/o ID	[keV]	490	917
RF Voltage	[MV]	1.38	2.9
Momentum compaction factor	[-]	9.12E-05	4.4E-04
Synchrotron frequency	[kHz] [turns]	1.4 600	4.5 190
Damping times (H/V/L)	[ms] [turns]	7.3 / 13.1 / 11.7 6000 / 11000 / 10000	6.9 / 6.9 / 3.5 5800 / 5800 / 2900
Nominal tunes (H/V/L)		54.2 / 18.2	18.16 / 10.22
Natural chromaticities (H/V)		-108 / -65	-53 / -19
Corrected chromaticities (H/V)		+1.6 / +1.6	+1.3 / +2.2



On-momentum Frequency Map Analysis (FMA) at injection point



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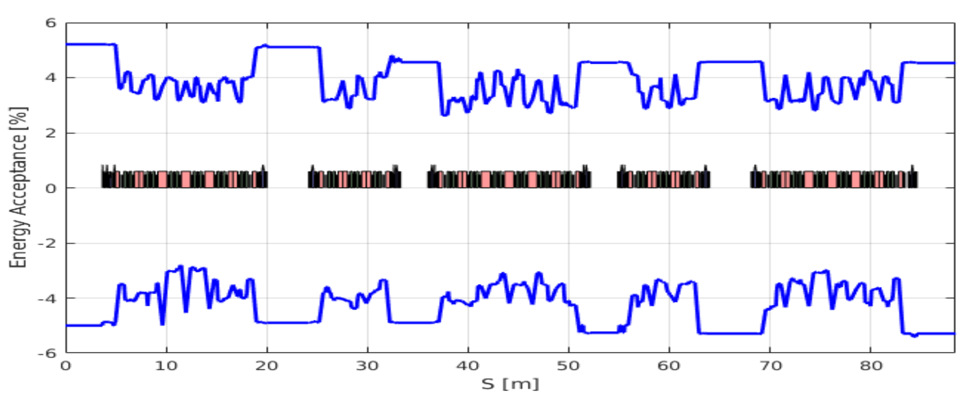
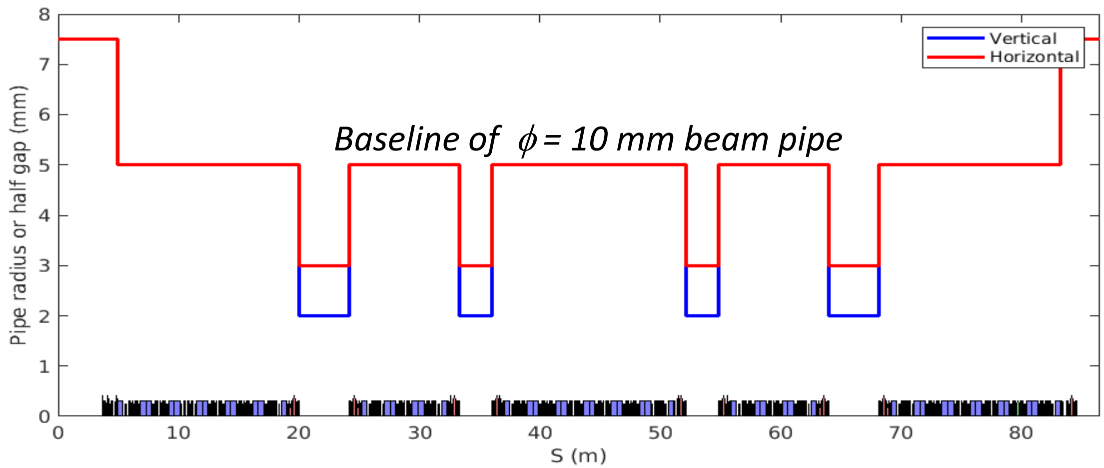


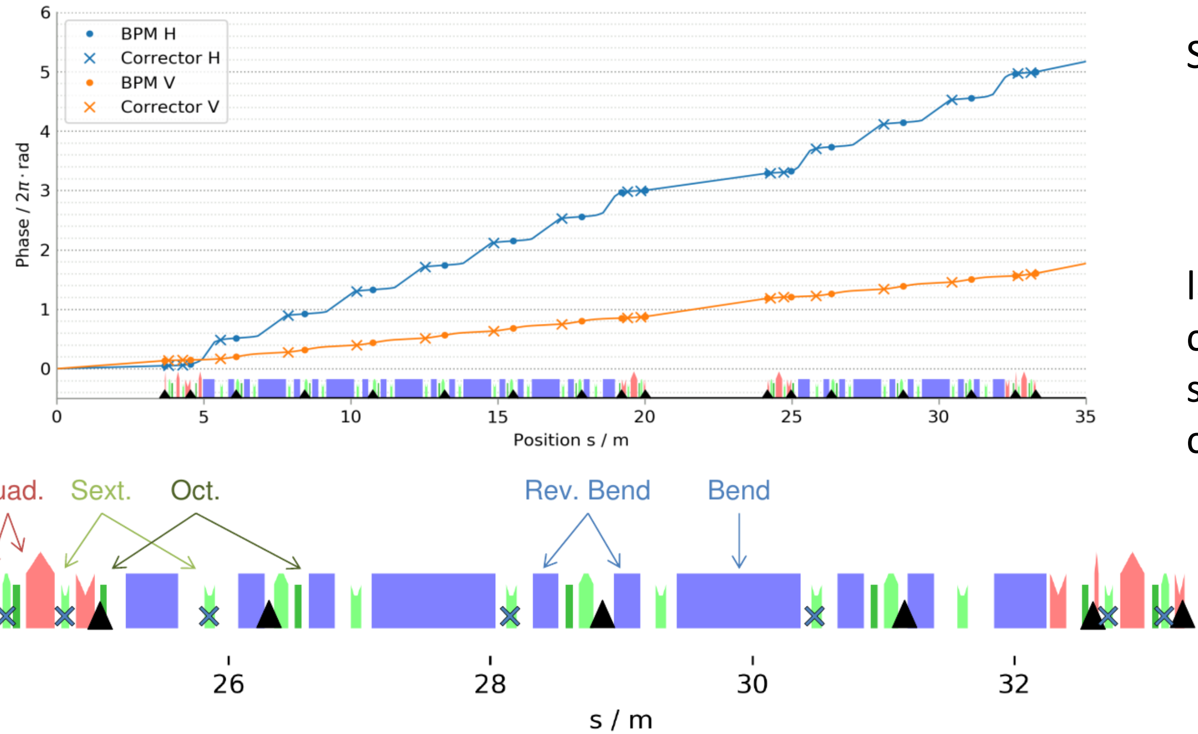
Left: Local energy acceptance along ¼ ring

$(\tau)_{Touschek}$ at 500 mA:
~3.5 hours 100% coupling
~1.5 hour 10% coupling
w/o bunch lengthening

Present CDR reference lattice [3/3]



Half physical aperture along the ring including in-vacuum insertion device gaps



Studies of

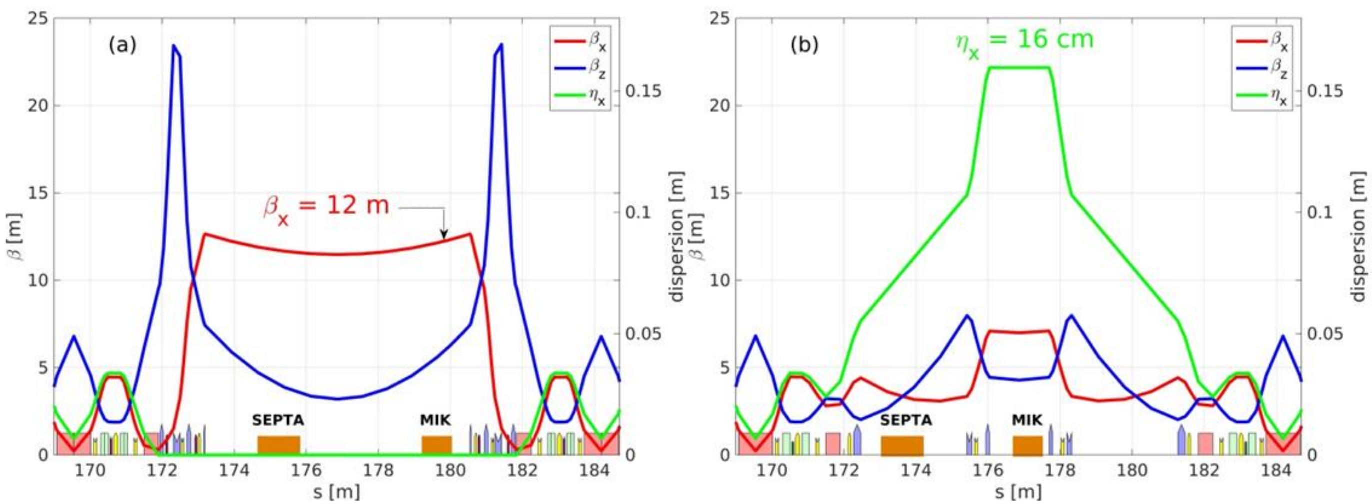
- Lattice tuning flexibility
- 1st-turn steering
- Robustness against errors

launched with specific BPM-correctors (dipolar, normal and skew quadrupolar) configurations

Injection schemes developed [1/2]

SOLEIL SYNCHROTRON UPGRADE

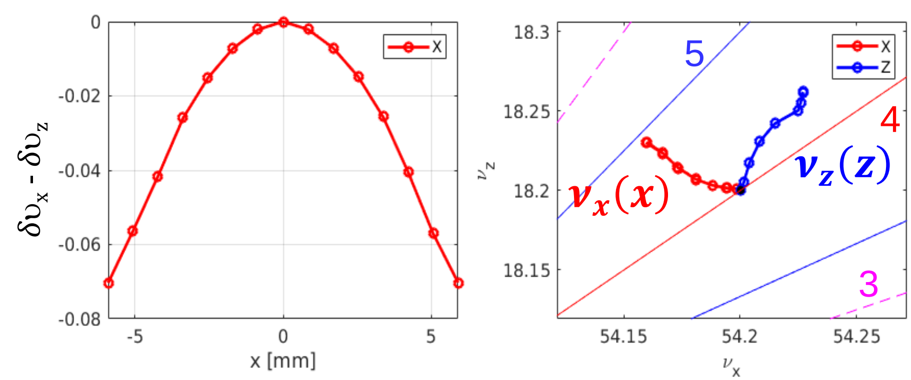
- Two injection schemes are developed and studied at SOLEIL using a MIK (Multipole Injection Kicker), with the experience of developing one which gave success at MAXIV: "**betatron off-axis**" and "**synchrotron on-axis**" injections



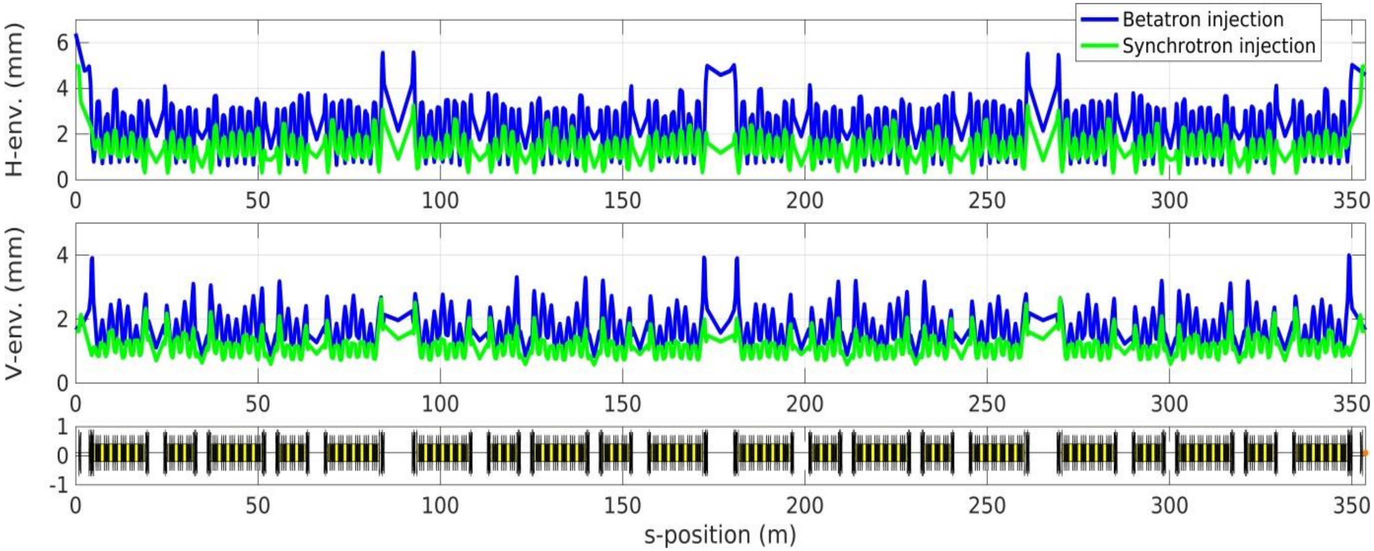
- In both cases, MIK deflection at Δx = -3.5 mm from the stored beam location
- Injected beam at δ = -2% for synchrotron on-axis injection

Left: Horizontal beta bump for betatron off-axis injection with tunes (54.20, 18.20). Right: Horizontal dispersion bump for synchrotron on-axis injection with tunes (54.16, 18.16)

- In both schemes, beam is injected to a ring tuned to a coupling resonance and the stored beam is fully betatron coupled
- In betatron off-axis injection, nonlinear tune shifts with amplitude are adjusted to enable "***dissonance***" for the injected beam



Injection schemes developed [2/2]



H and V beam envelopes over 900 turns after injection for both injection schemes, w/o error at injection nor in storage ring. Ring working point is set at full coupling. $(\varepsilon_H)_{inj} = (\varepsilon_V)_{inj}$ = 5 nm.rad, σ_L = 25 ps for betatron and 35 ps for synchrotron injections

	Positive aspects	Negative aspects
Betatron off-axis	• Allow straightforward implementation in injection straight • Pulse magnets specs comfortable	• Sensitivity to lattice errors • Need of a large DA • Injection beam envelops have smaller margins against ID gaps
Synchrotron on-axis	• Relaxed DA requirement • Less sensitivity to lattice errors • Reduced injection beam envelops	• Explicit lattice modifications with a dispersion bump • Need of larger off-momentum DAs • More demanding MIK specs

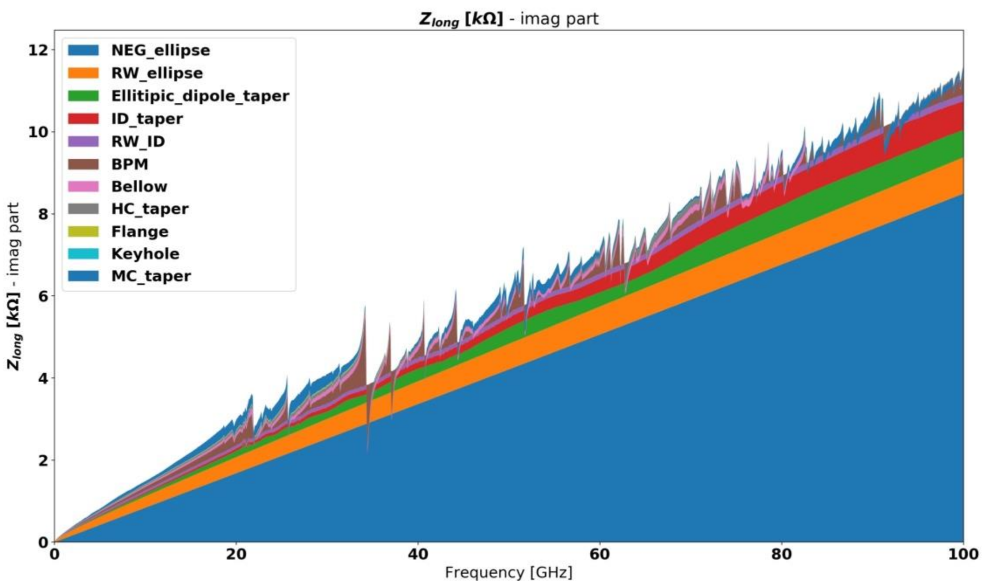
⇨ Both schemes to be pursued further

Collective effects [1/2]

Impedance model considered for the collective effect simulations:

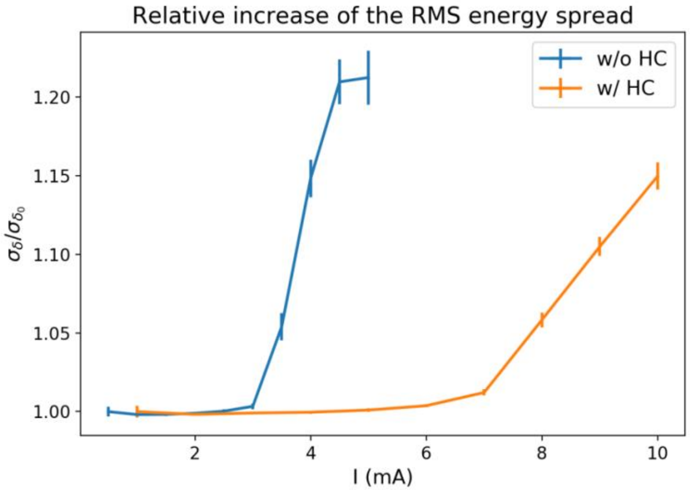
Elements	Number	Remarks
BPM	200	
Keyhole	12	
Bellows	125	"comb" type
Flanges	250	"impedance free" type
Taper Main RF (per pair)	1	L = 250 mm ⇔ 10,2°
Taper Harmonic RF (per pair)	1	L = 100 mm ⇔ 8,5°
Taper dipoles (per pair)	116	L = 43 mm ⇔ 8°
Taper ID under vacuum (per pair)	9	L = 100 mm ⇔ 2° (on vertical plane only)
RW ID (elli. – 80 mm × 3 mm - Cu)	18 m	
RW (elli. - **12 mm** × **10 mm** - Cu)	**336 m**	
NEG	336 m	$\rho_{NEG} \approx 2{,}5 \times 10^{-5}\Omega.m$ $h_{NEG} \approx 1\ \mu m$

Estimated longitudinal impedance (imaginary part)

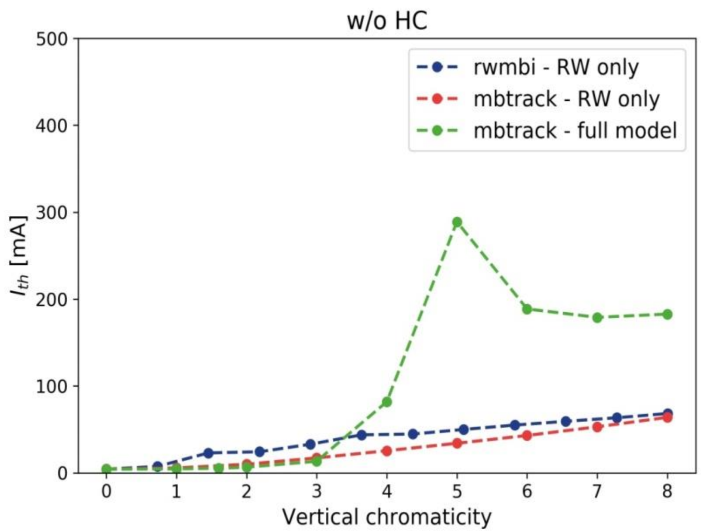


- **Major contributions** (RW, Tapers, …), but there are elements not yet designed and included (Injection, Feedback, …).
- So far, only the **main cavity tapers** and the **BPMs** are on the watch list for heating concerns. Tapers shall be redesigned to reduce its impedance (nonlinear tapers) and a thermal study of the BPM will indicate if the present design is acceptable or not.

Collective effects [2/2]



RMS energy spread versus single bunch current, w/o and with harmonic cavity lengthening



Vertical resistive-wall threshold in multibunch without HC lengthening

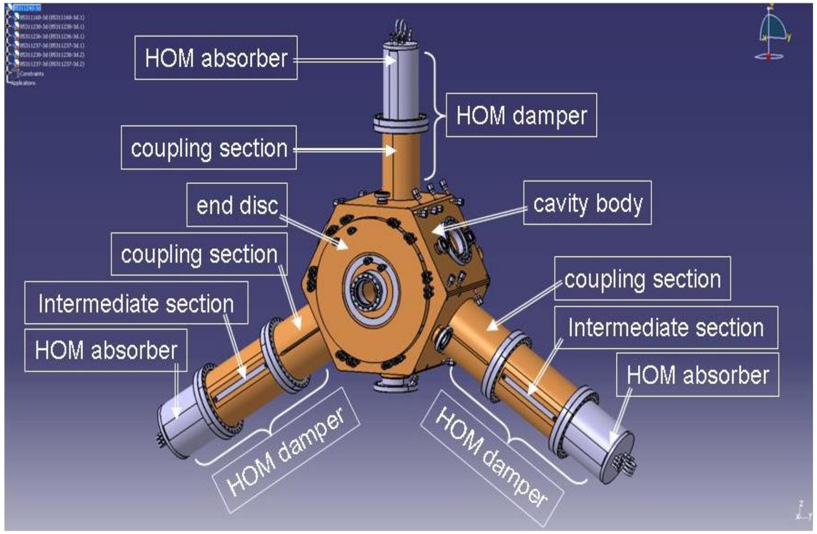
- Microwave thresholds using the obtained Z_{BB} and Z_{CSR} indicate that there are still margins w.r.t. the bunch current needed in multibunch operation. Thresholds are found to rise significantly with HC lengthening

- Thresholds of transverse instabilities (TMCI, headtail and resistive-wall) are found to be very low with small chromaticities (e.g. $(I_{th})_{RW}$ ~7 mA at ξ = 1.6) . However, with several sources of Landau damping (headtail, HC lengthening, optics nonlinearities, …) and transverse feedback, the nominal currents are expected to be reached.

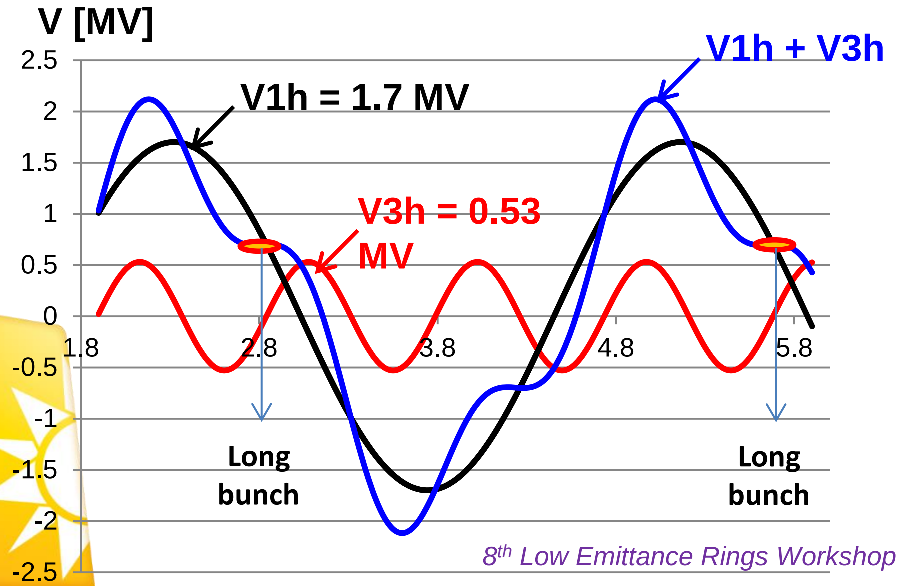
- Studies on HC-driven instabilities shall be presented by Alexis Gamelin later this afternoon

RF system

- **Main RF cavity**: use 4 Normal Cavities (ESRF-EBS type is a good candidate) in a 4.2 m straight → P_{RF} = 4 x 75 kW
- Redundancy : one can easily meet the requirements with only 3 of the 4 cavities in use.



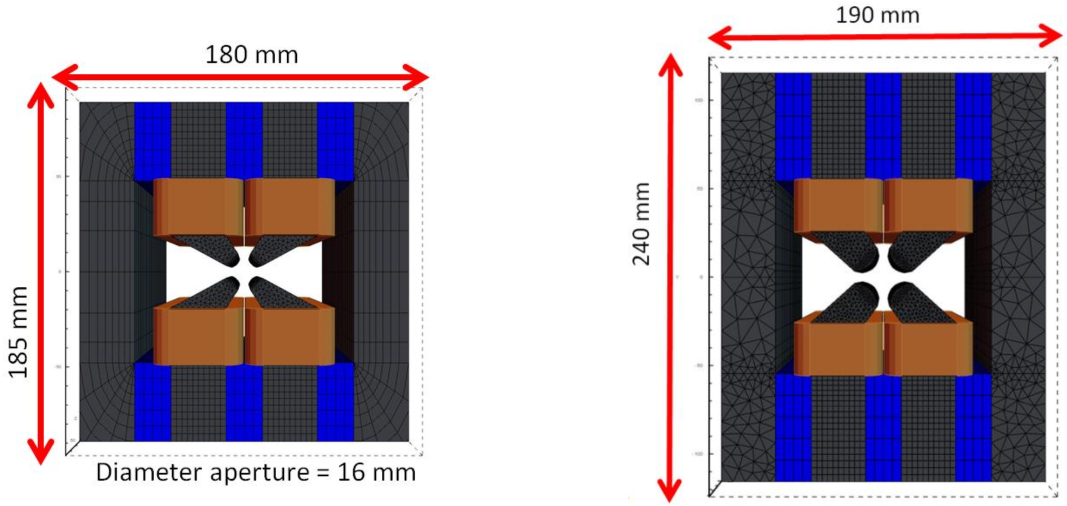
- **Harmonic RF system**: *h* = 3, 4 or 5. The favored one is presently a passive SC system, based on the Super3HC CM.



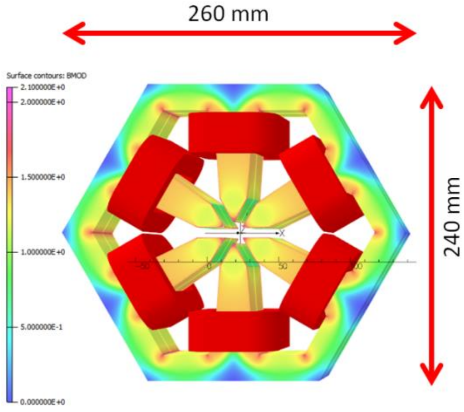
Magnets

- Great challenge imposed on the SOLEIL Upgrade: **Magnet bore diameter of 16 mm** needed for high gradient magnets required for the targeted emittance

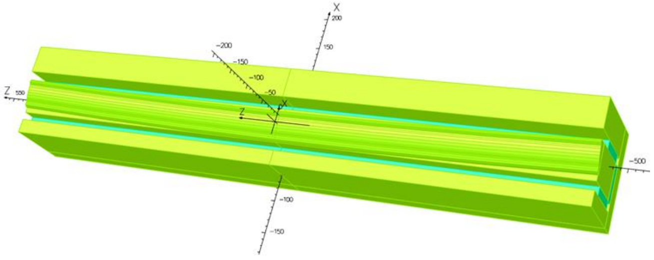
- All dipoles shall be made of permanent magnets
- All reverse bends and most of quadrupoles shall be made of permanent magnets
- Sextupoles and octupoles shall be electromagnets, integrating dipolar (in sextupoles) and quadrupolar (both normal and skew in octupoles) correctors



Quadrupoles (left) and reverse bends (right)

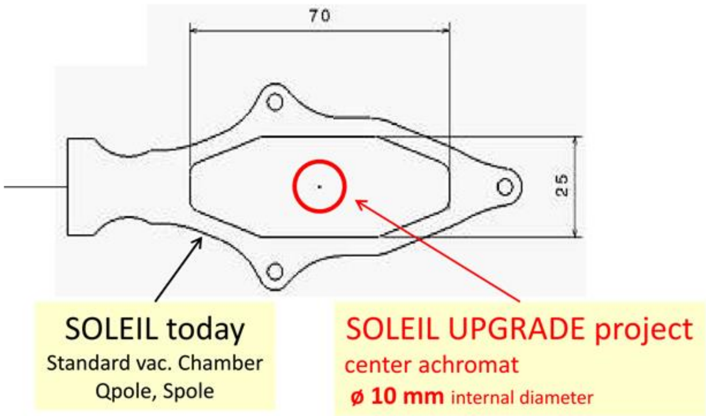


Sextupoles



Combined-function dipoles

Vacuum, girders

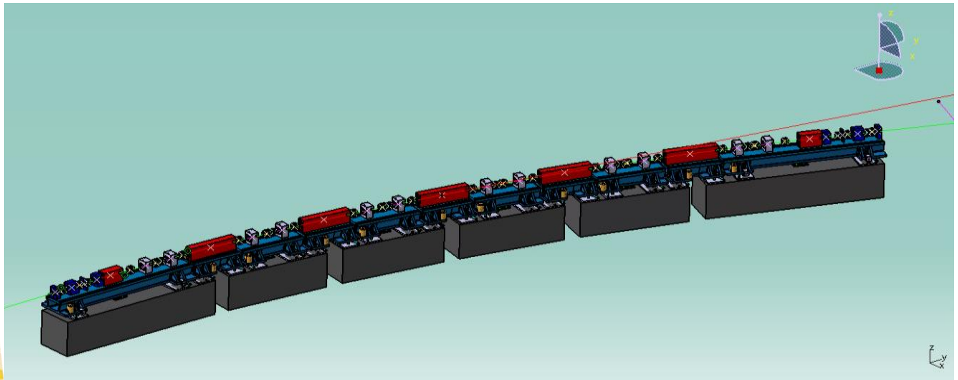


Challenges on the vacuum:

- Traditional linear distributed pumping not possible.
- Less « standard » pumping space available → only few ionic pumps along the ring!
- More than **95 %** of the ring chambers must be NEG coated. **10 mm** inner diameter chambers foreseen along the lattice (not only on straight section)

⇨ Beam-based study launched on the balance between photon-stimulated desorption and NEG pumping speed for a 10 mm diameter chamber

Dedicated talk by Vincent Le Roux on Wednesday at 14:30



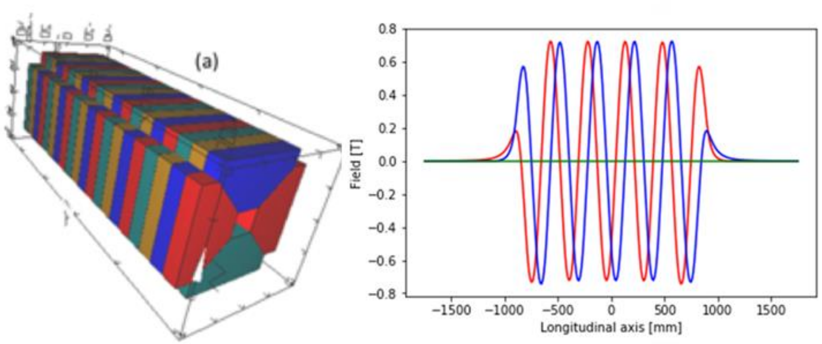
Girder composition for a 7BA cell currently considered

- Several scenarios (compositions) studied for girders and plinths. Currently considered configuration consists of 172 girders
- Tolerances for girder to girder as well as magnets on girder alignment are being studied by beam dynamics and alignment groups

SR sources & expected performance [1/2]

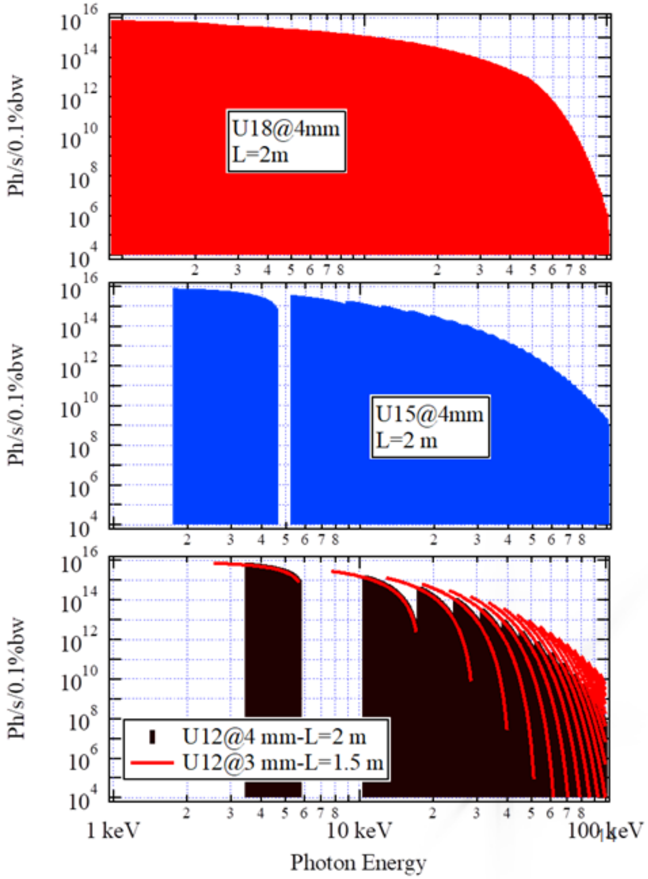
◊ Several specific types of insertion devices (IDs) are developed to enhance their performance in different spectral ranges:

- VUV and Soft X-rays range: Crossed undulators, in-vacuum APPLE II and bi-period undulators
- Hard X-rays: Cryogenic undulators



Crossed undulator for VUV domain (5 – 40 eV), variable polarization, λ = 300 mm

In-vacuum APPLE-III undulator CPMUE32 for soft X-rays domain, a full-scale prototype developed and being tested



Spectral performance of cryogenic undulators (U18, U15 and U12)

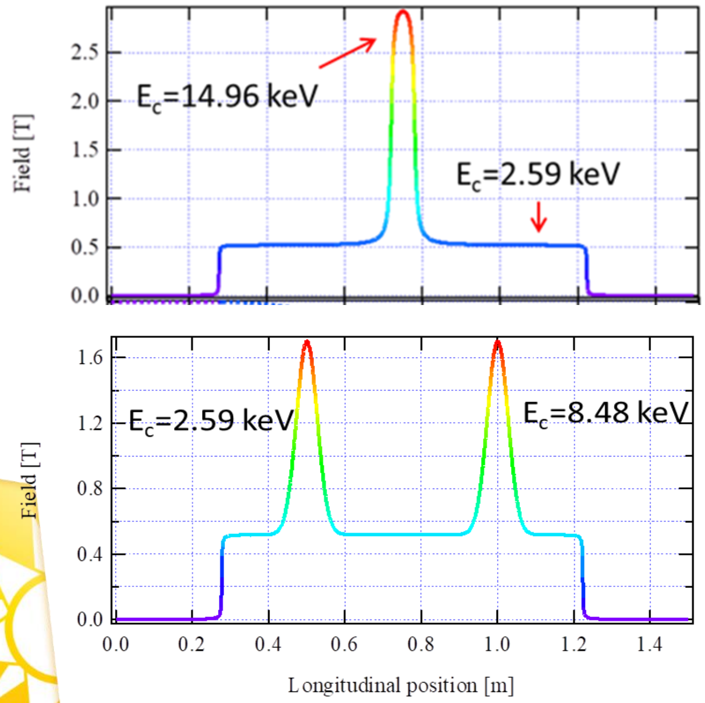
SR sources & expected performance [2/2]

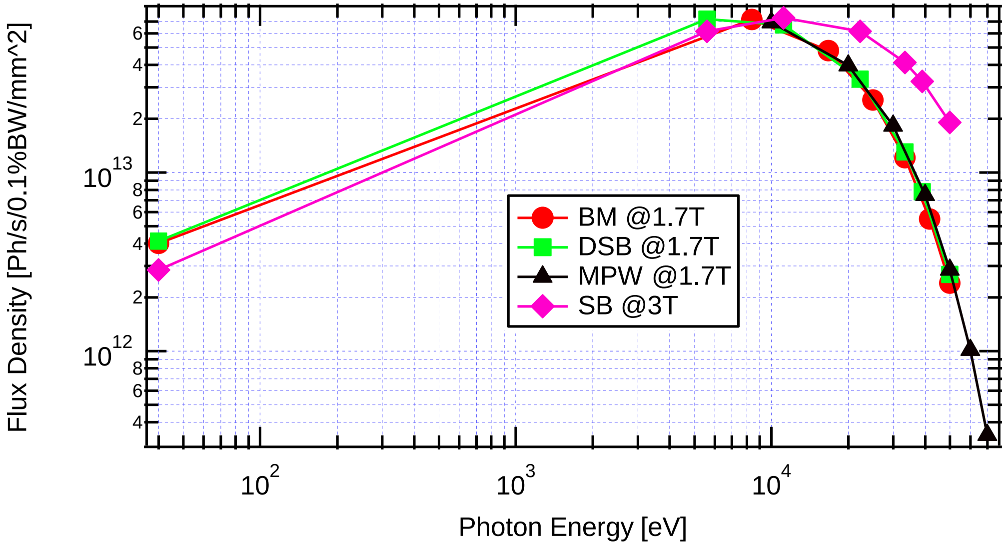
◊ Dipole magnets and other types of radiation sources:

Again, the aim is to cover the wide range of photon energies (IR – hard X-rays), including those that the majority of the present dipole beamlines are using with the 1.7 T dipoles

Studies being made on introduction of;

- 3 T superbends
- 1.7 T double superbends
- 1.7 T 3-pole wiggler
- IR extraction from 0.7 T (long) dipoles





Calculated photon flux densities from dipolar sources

Tentative planning and objectives

December 2018
Council authorization to produce the Conceptual Design Report (CDR)

December 2020
Decision to launch a Technical Design Report ?

2022
Decision on the realization of the SOLEIL Upgrade ?

End 2027
Restart of SOLEIL

2016 - 2018	Jan. 2019 – Dec. 2020	2021 – 2022	2023– 2027
Preparation of the SOLEIL Upgrade project (Documents, etc.)	Writing of the CDR	Writing of the TDR	Implementation of the SOLEIL upgrade

Summary

- With the aim of reducing the horizontal natural emittance ε_{H0} of the SOLEIL ring to below 100 pm.rad, a 7BA-4BA HOA symmetry 2 lattice was developed and defined as the CDR lattice.
- With the modularity of the HOA lattice, the combination of 7BA and 4BA cells allowed fitting the new ring into the existing beamline source points to the extent that no ratchet wall modifications in the storage ring tunnel are needed.
- The choice of HOA however requires strong magnetic fields, which led us to choose the beam pipe of ϕ = 10 mm. All engineering designs (magnet, vacuum, diagnostics, …) are being made accordingly and their feasibility assessed.
- Two injection schemes (off-axis betatron and on-axis synchrotron) developed with the use of a MIK appear promising for the CDR lattice, allowing sitting on a coupling resonance. More to be studied.
- Despite the small beam pipes assumed, first studies on collective effects found no critical issues of beam-induced heating and beam instabilities. Importance of HC bunch lengthening and transverse feedback in mitigating them was confirmed.
- More than a factor of 40 reduction in ε_{H0} along with the ongoing innovative SR source designs (IDs and superbends) resulted in a significant gain (typically more than two orders of magnitude in brilliance) in the SR performance over a wide range of photon energies covered by SOLEIL.

Thank you for your attention