LEL 2022 - 3rd Workshop on Low Emittance Lattice Design

26-29 June 2022 , ALBA

7BA-4BA HOA lattice developed for the SOLEIL upgrade

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SOLEIL Upgrade Project Objectives

While maintaining the broad spectrum of photons ranging from far IR to hard X-rays, the SOLEIL UPGRADE project aims at maximizing the intensity of coherent photon flux (highest brilliance and transverse coherence possible) arriving at the beamlines especially in the soft to tender X-rays photon energy range.

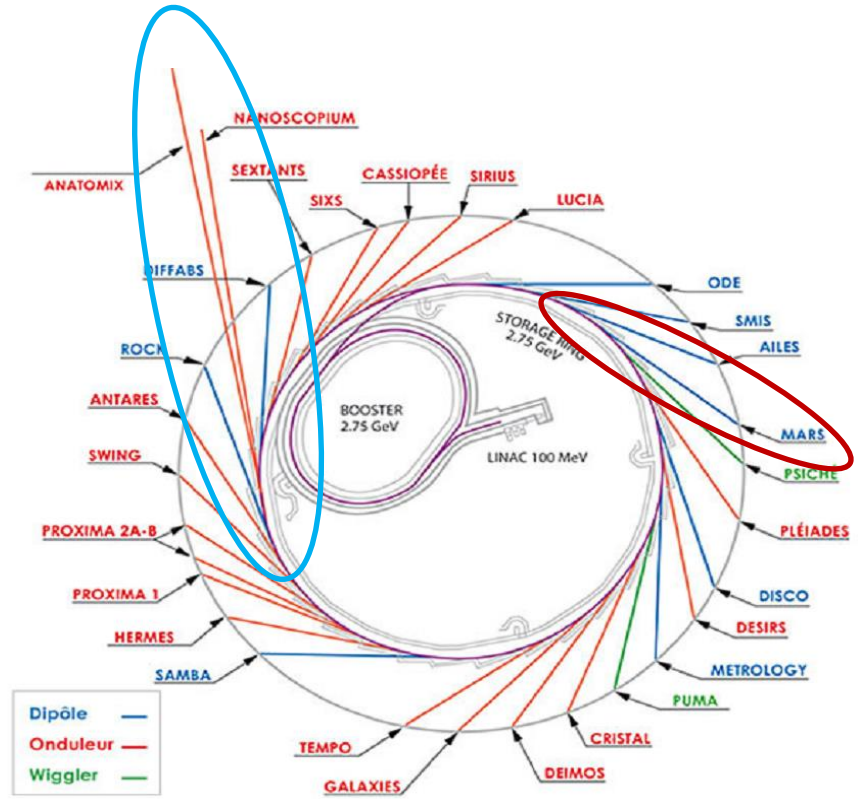
Three objectives are the key guiding principle for the optimization of the NEW LATTICE.

1) Lowest electron beam emittance possible < 100 pm.rad.
2) ID β-functions close to the matching value.
3) New IDs well optimized (benefit the most from the New Lattice)

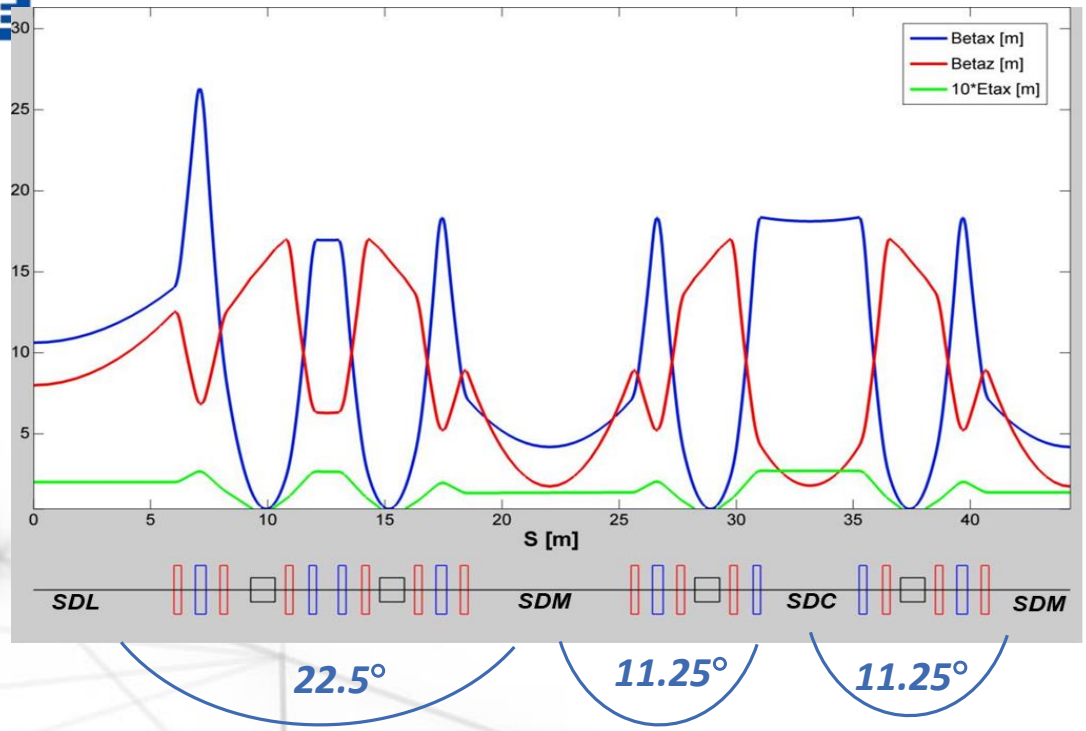
+) With the highest electron beam current possible (500 mA)

Geometry of the new lattice must allow:

- Keeping the source point of **MARS BL** (treating radioactive sources) unchanged
- **Two long BLs NANOSCOPIUM and ANATOMIX** to conserve their current hutches by using new canted in-vacuum IDs with shorter magnetic periods
- Impact on the positions of other existing BLs must be minimised as much as possible



SOLEIL ring today and its boundary conditions



1/8th of the present SOLEIL lattice

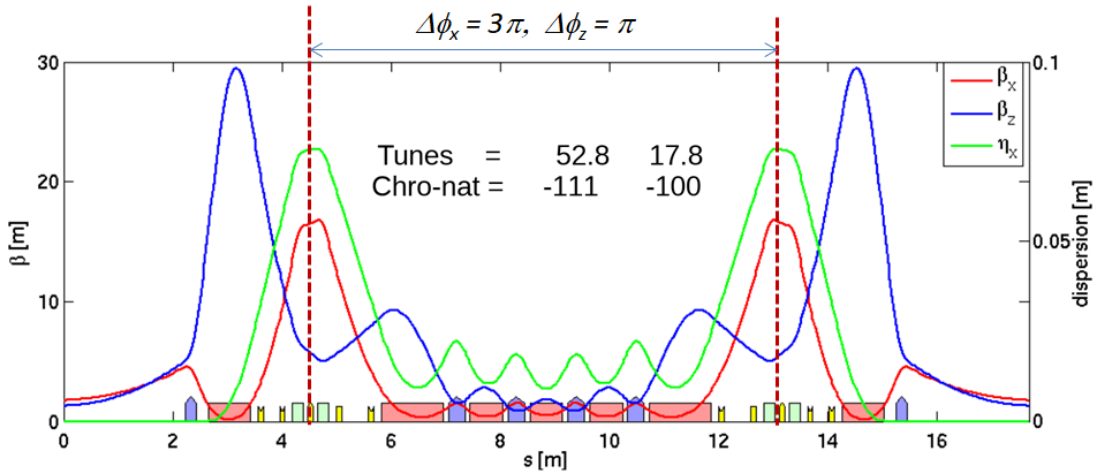
Energy	2.75 GeV
Circumference	354.097 m
Lattice type	Double Bend
Number of cells	16
Number of straight sections	4×12 m, 12×7 m, 8×3.8 m
Magnet sections length	8×12.5 m, 16×5.73 m
Ratio of straight sections length to circumference	46%
Horizontal natural emittance ε_x	3.91 nm·rad
Adjusted emittance ratio	1%
Betatron tunes (ν_x, ν_z)	(18.17, 10.23)
Natural chromaticities (ξ_x, ξ_z)	(-52.55, -21.24)
Momentum compaction	4.49×10^{-4}
RMS energy spread	1.016
Horizontal damping partition number J_x	0.9953
Radiation damping times (τ_x/ τ_z/ τ_s)	(6.92/6.88/3.43) ms
Dipole field	1.71 T
Radiation loss per turn (w/o IDs)	943.8 keV
Nominal current	500 mA (multibunch mode), 450 mA (hybrid mode), 8×12 mA (8-bunch mode), 1×16 mA (1-bunch mode)
RF frequency f_{RF}	352.2 MHz
RF voltage (typical)	4× 650 kV

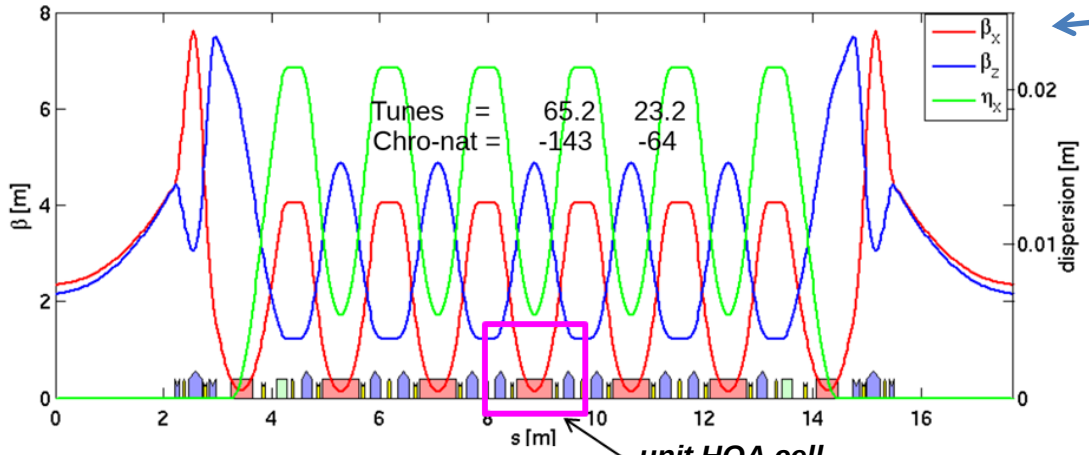
<u>Major characteristics of the present SOLEIL ring</u> (a 16 Double Bend cell ring)

- Half of them integrates a SS (Straight Section) of 3.8 m in between the two dipoles
- Long SS of 12 m introduced symmetrically at 4 locations
- Ring's original symmetry: Four with 24 SSs (consisting of 3 different lengths):
- Beam filling: 5 modes including multibunch at 500 mA, single bunch at 16 mA and low α

20×(7BA ESRF hybrid) versus 20×(7BA HOA)

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





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

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

Hybrid 7BA (ESRF-EBS type) symmetry 20:
ε_x = 75 pm.rad, $\tau_{Touschek}$ ~ 4 h

HOA 7BA (SLS-II type) 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

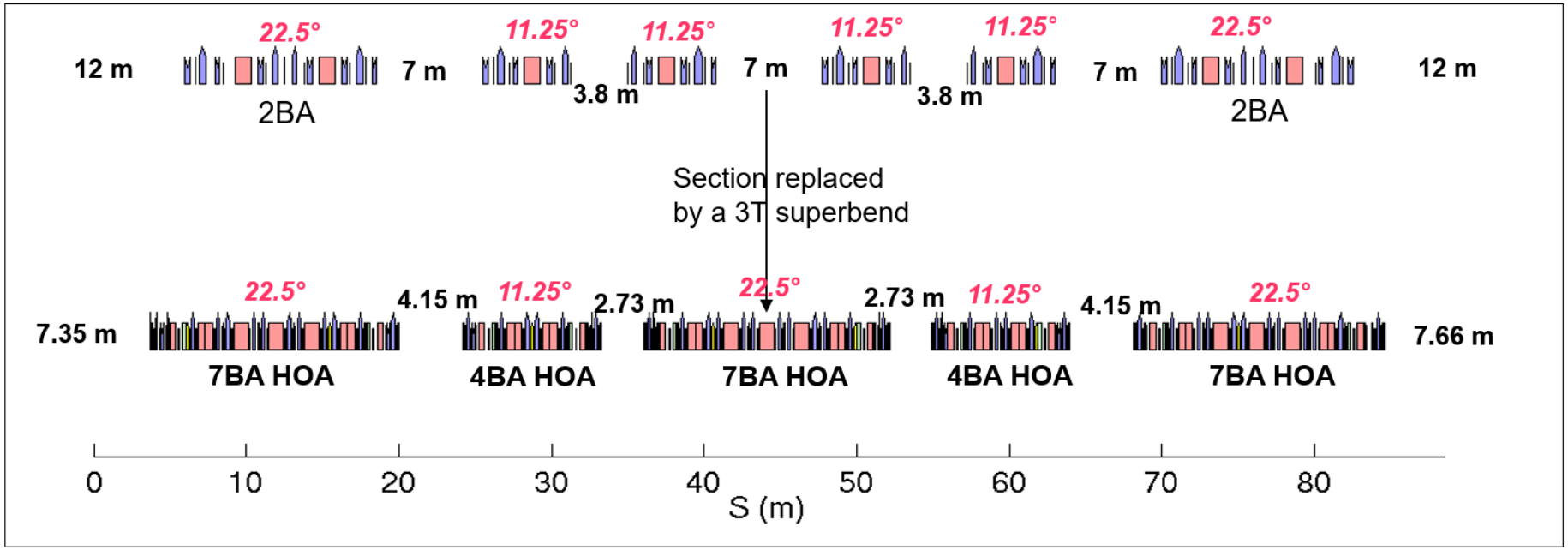
7BA-4BA HOA to overcome the geometric mismatch

- **Symmetry-4** 20-cell 7BA hybrid lattice **with 4×6 m + 16×4 m** straight sections developed (ε_x = 74 pm.rad, $\tau_{Touschek}$ = 1.8 h)
  → Positive results obtained for longitudinal on-axis injection using one of the peaks of η_H as well as inclusion of canted and double waist optics in one long straight sections

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 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

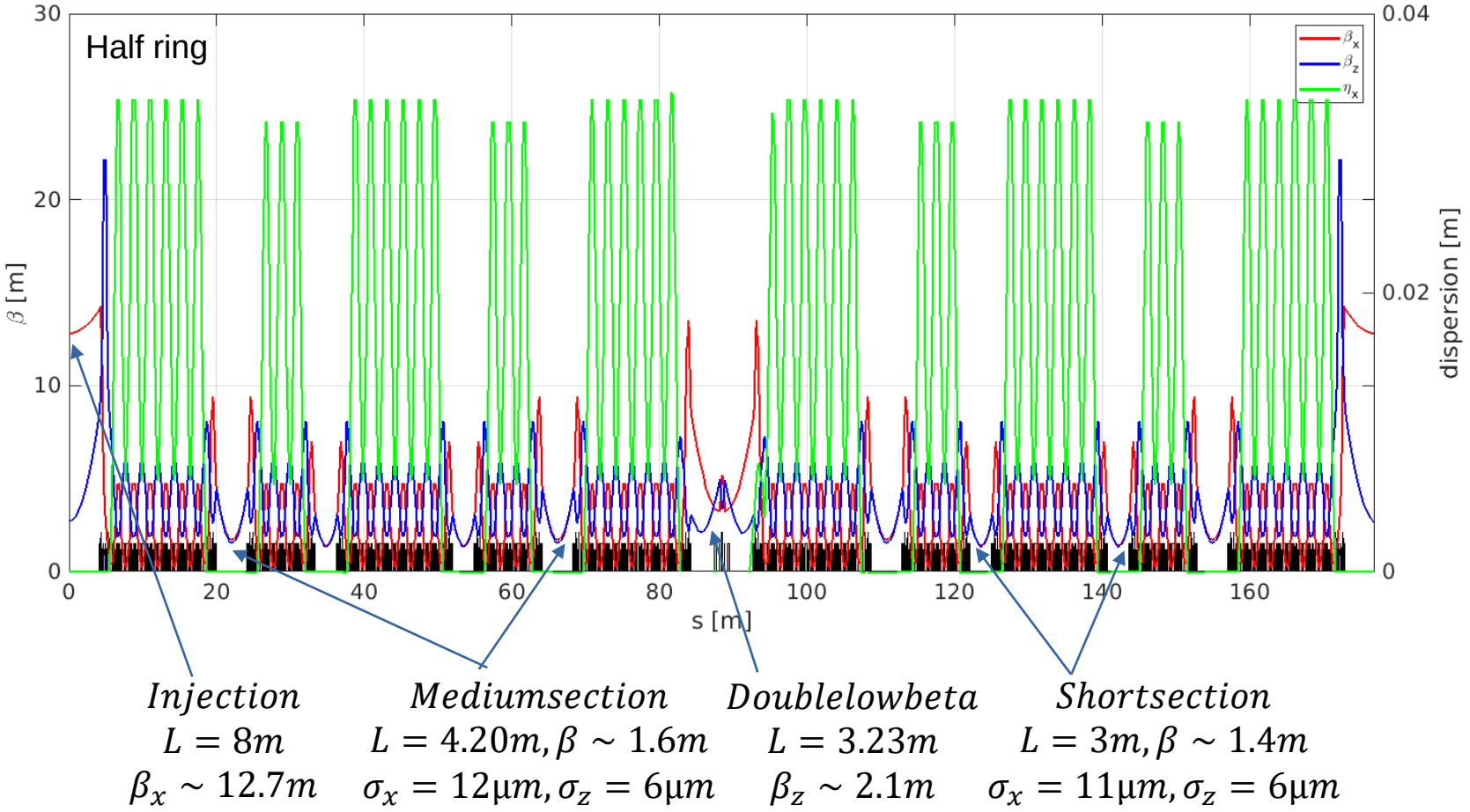
⇨ **20 cells 7BA-4BA HOA** (V0313) defined in the CDR phase as the SOLEIL upgrade reference lattice



Relation between the present ring and 20 cells 7BA-4BA HOA for 1/4th of the ring

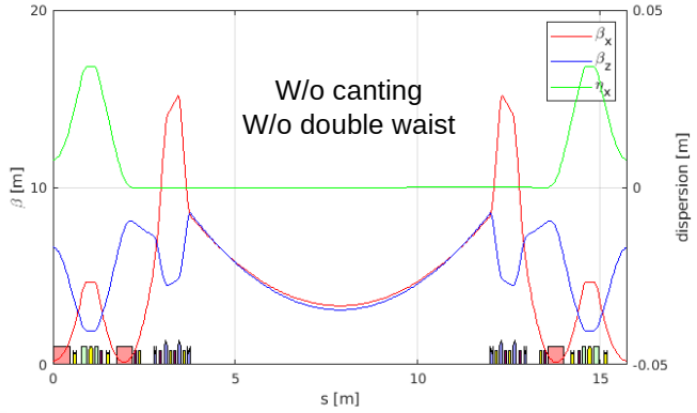
Main parameters and optical functions

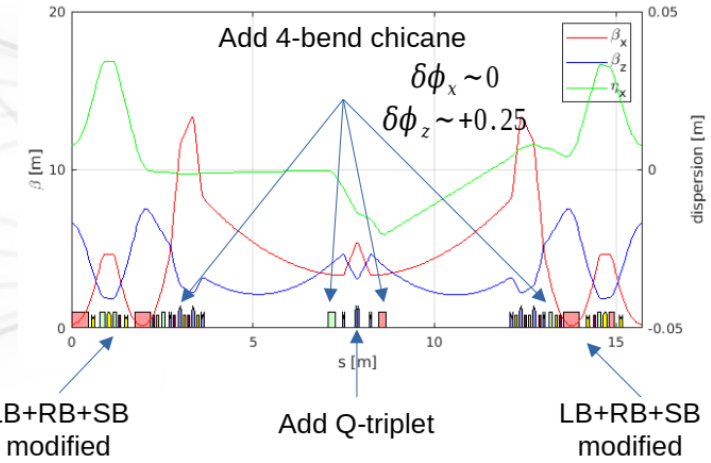
Lattice		TDR : V0356
Symmetry	-	2
Energy	GeV	2.75
Circumference	m	353.92
Natural H. emittance	pm.rad	84.4
V. Emittance (30%)	pm.rad	25.3
Energy spread	%	0.091
RMS Natural Bunch length	ps	8.5
Harmonic number	-	416
Main RF frequency	MHz	352.382
Energy loss per turn W/o ID	keV	458.5
RF Voltage	MV	1.8
MCF	-	1.04E-04
Synchrotron frequency	kHz turns	1.8 500
Damping times	ms	7.7 / 14.4 / 12.2
Nominal tunes	-	54.2 / 18.3 / 0.002
Natural chromaticities	-	-108 / -65
Corrected chromaticities	-	+1.6 / +1.6

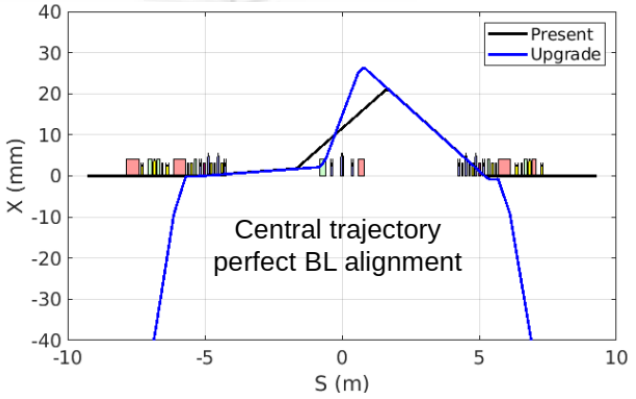


- Main parameters, optics as well as the beamline positioning are rather similar to the CDR case
- Straight section ratio : 25% of the total circumference.

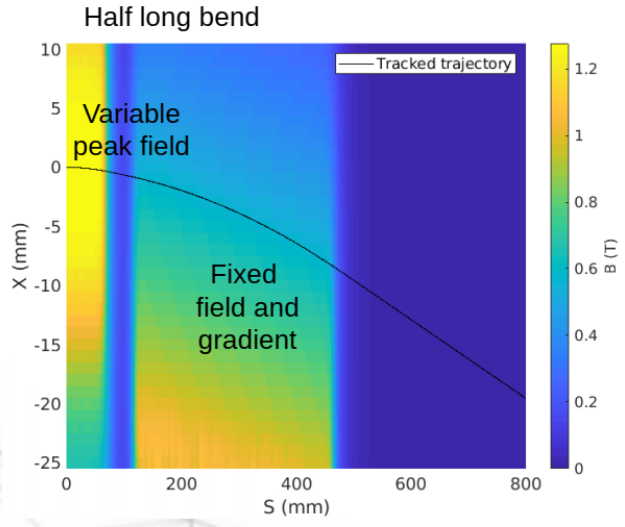
Some further developed lattice characteristics

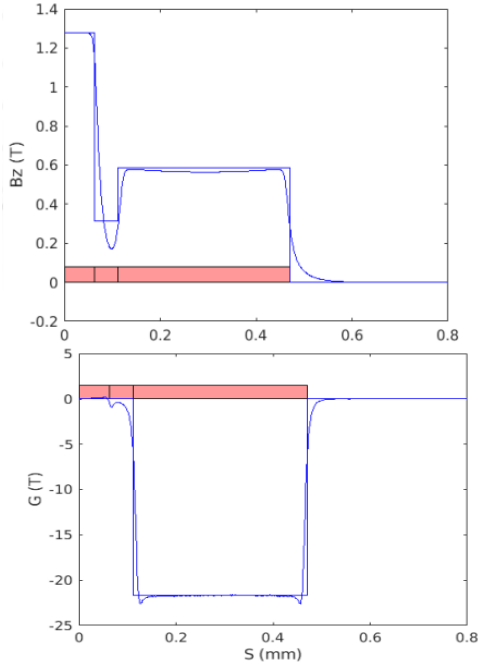




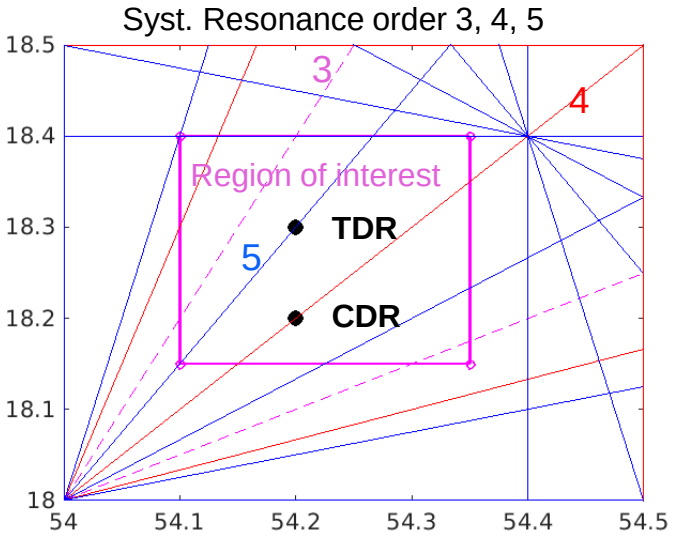


Magnet type	Nbr	
Permanent Bend	116	With gradient ~ 20 T/m
Permanent reverse bend	192	Shifted quad by ~ - 2.5 mm
Permanent Quadrupoles	164	G_{fix} = 120 T/m
Sextupoles	412	S_{max} = 8000 T/m^2 + dip. corr. H & V
Octupoles	216	O_{max} = 100000 T/m^3 + quad and skew quad corr.
Quadrupolar correctors	196	GL = 0.6 T
Total	1296	





Working Point scan



CDR WP on coupling resonance and betatron injection based on non-linear dissonance was risky to control.

TDR WP is then changed out of the resonance toward (54.2, 18.3)

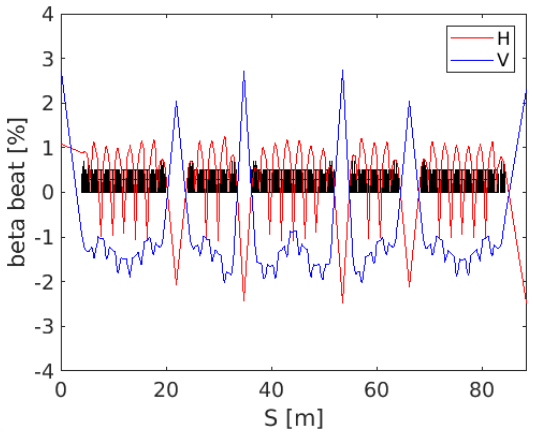
This lattice being based on permanent magnet bends and quadrupoles, 412 quadrupolar correctors are present to manage : WP change, Super-Bend side effect, ID's compensation and lattice errors.

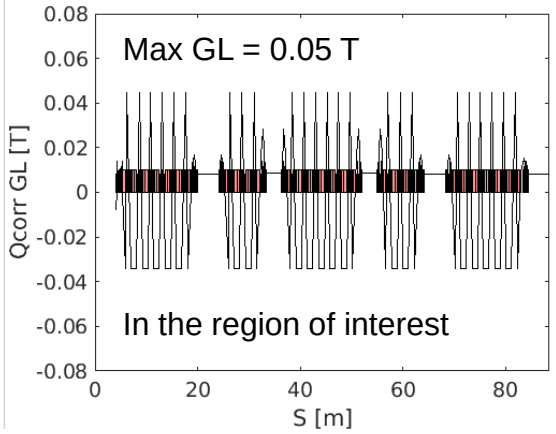
To scan the tunes:

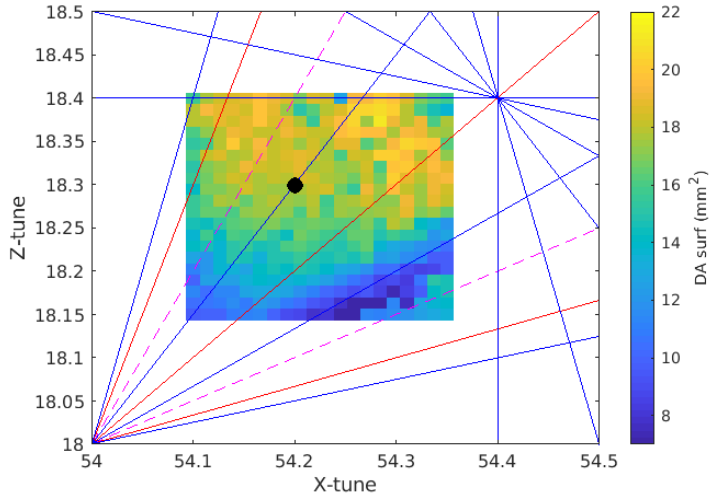
All the arc quadrupole correctors are used.

To minimize the beta beat:

α_x and α_z are set to zero at each straight section center with quad. corr. in the matching sections.

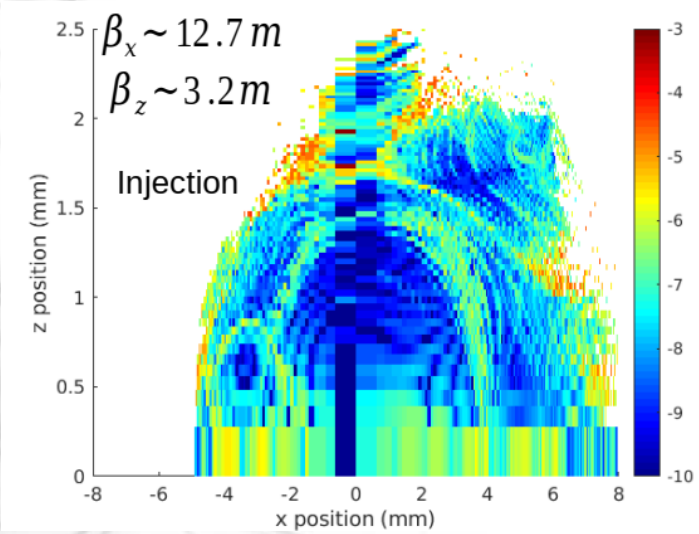


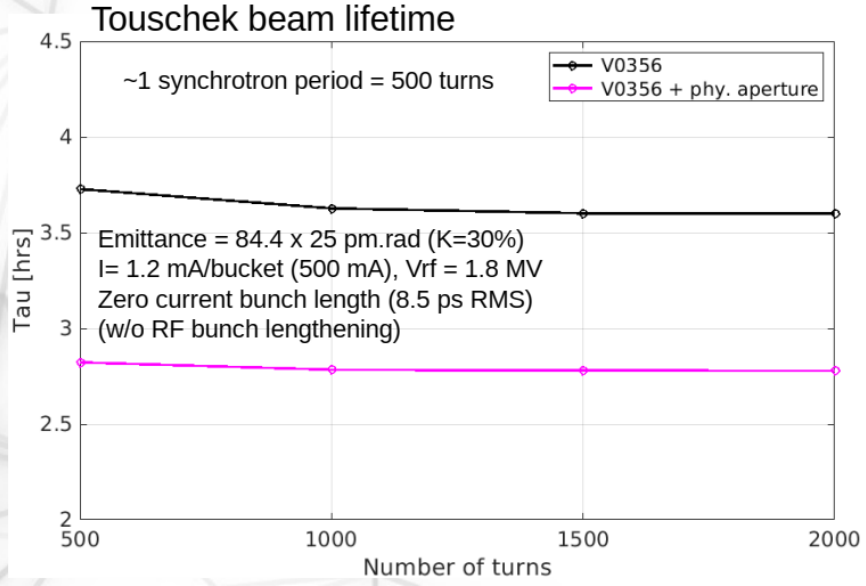


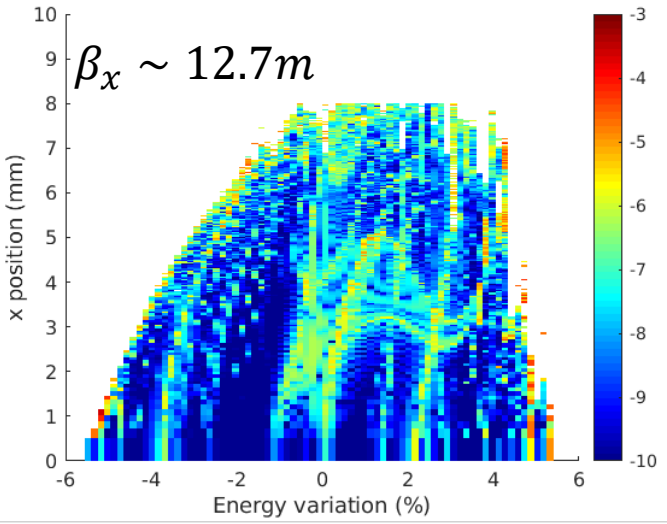


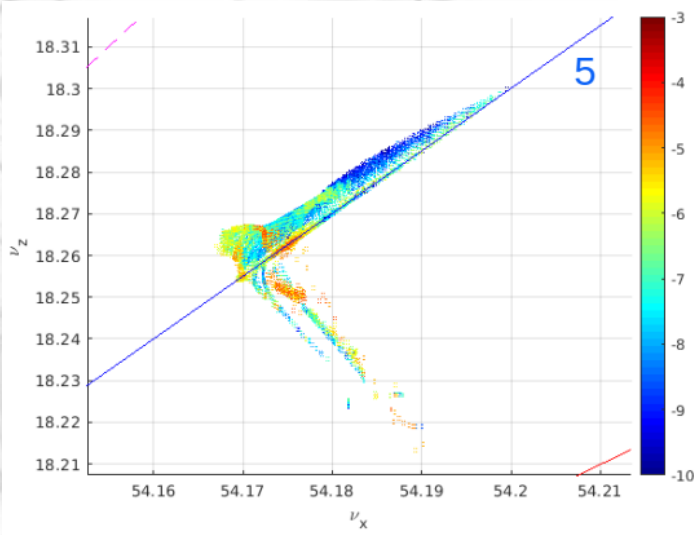
DA surface not much impacted with WP scan w/o non-linear re-tuning

Ideal lattice beam dynamics





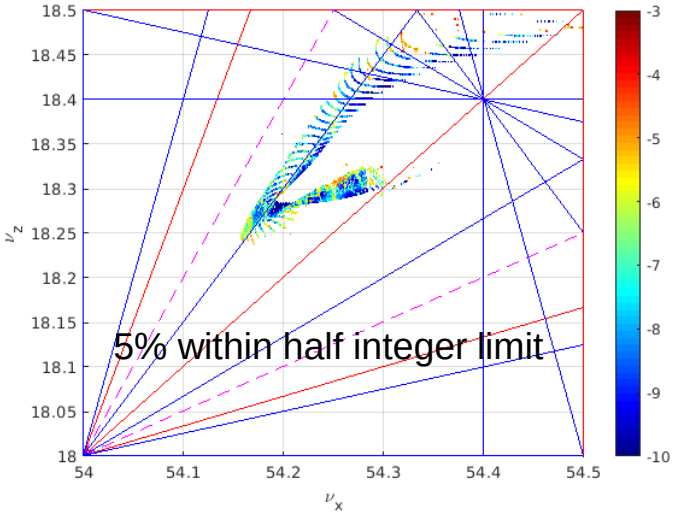




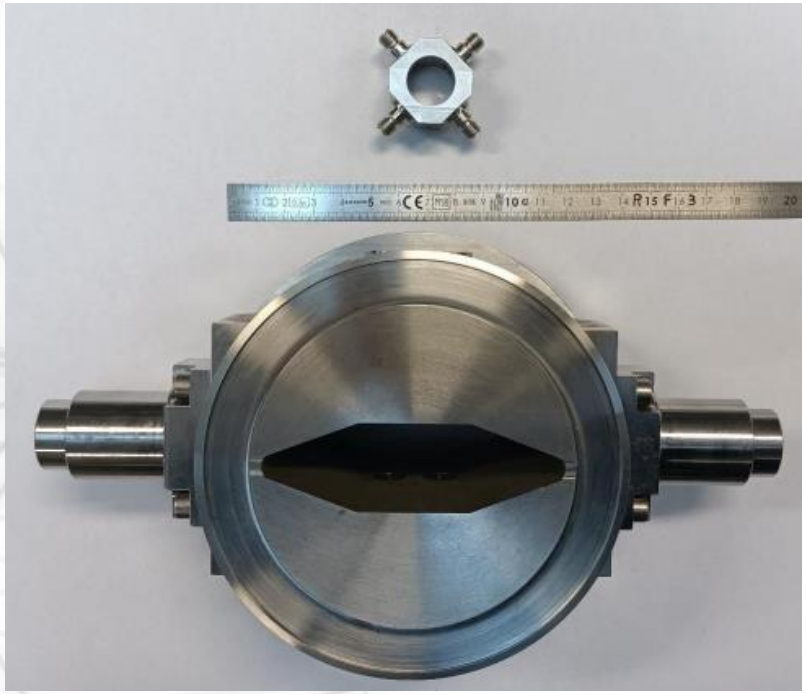
Physical aperture has a non-negligible impact, to be included in the optimization (scraper and collimators not included).

RF HC bunch lengthening (by ~3) to mitigate the beam lifetimes.

Target pressure at 100 A·h is 10^{-9} mbar at 500 mA.
Considering 100% nitrogen, the vacuum lifetime in about 20 hrs.



Miniaturization



BPM prototypes for SOLEIL (bottom) and SOLEIL Upgrade (top)

Upgrade Permanent magnet quadrupole prototype (top)
Present Electromagnet quadrupole (bottom)

TDR Milestones (*tentative*)

TDR Master Schedule

N°	Nom de la tâche	Milestone
1	**TDR**	
2	Accelerators Program	05/07/2024
3	Sub Projects studies and prototyping	
4	New reference lattice	31/03/2022
5	MAC 1	18/05/2022
6	Notification for proof of concept vacuum chambers ("marché innovant")	30/06/2022
7	Decision on the number of girders in the storage ring	30/06/2022
8	Decision on harmonic cavity	05/07/2022
9	Notification for Validation's Sextupole ("marché innovant")	15/07/2022
10	Booster lattice feasibility	01/09/2022
11	Beamline photon sources selection (1st version)	30/09/2022
12	Purchase mechanical parts for the quadrupole #2	10/10/2022
13	Call for tender for girder prototype	15/11/2022
14	MAC 2	November 22
15	Design review pulsed magnets	01/12/2022
16	Notification for Validation's Long Dipole ("marché innovant" ?)	01/12/2022
17	Notification for Validation's Octupole ("marché innovant")	09/01/2023
18	MIK first production validation	01/03/2023
19	MAC 3	May 23
20	BPM and electrodes validation on the current Machine	30/06/2023
21	Decision for full monitoring of the storage ring with HLS	15/08/2023
22	Call for tender for thin septum prototype for SR injection	01/09/2023
23	Bipolar power supplies prototype ready	02/10/2023
24	MAC 4	November 23
25	Validation of Priority equipment specifications for accerators program: magnets, vacuum system, girders, radiofrequency cavities, BPM electrode	01/12/2023
26	MIK prototype V2 validation	01/03/2024

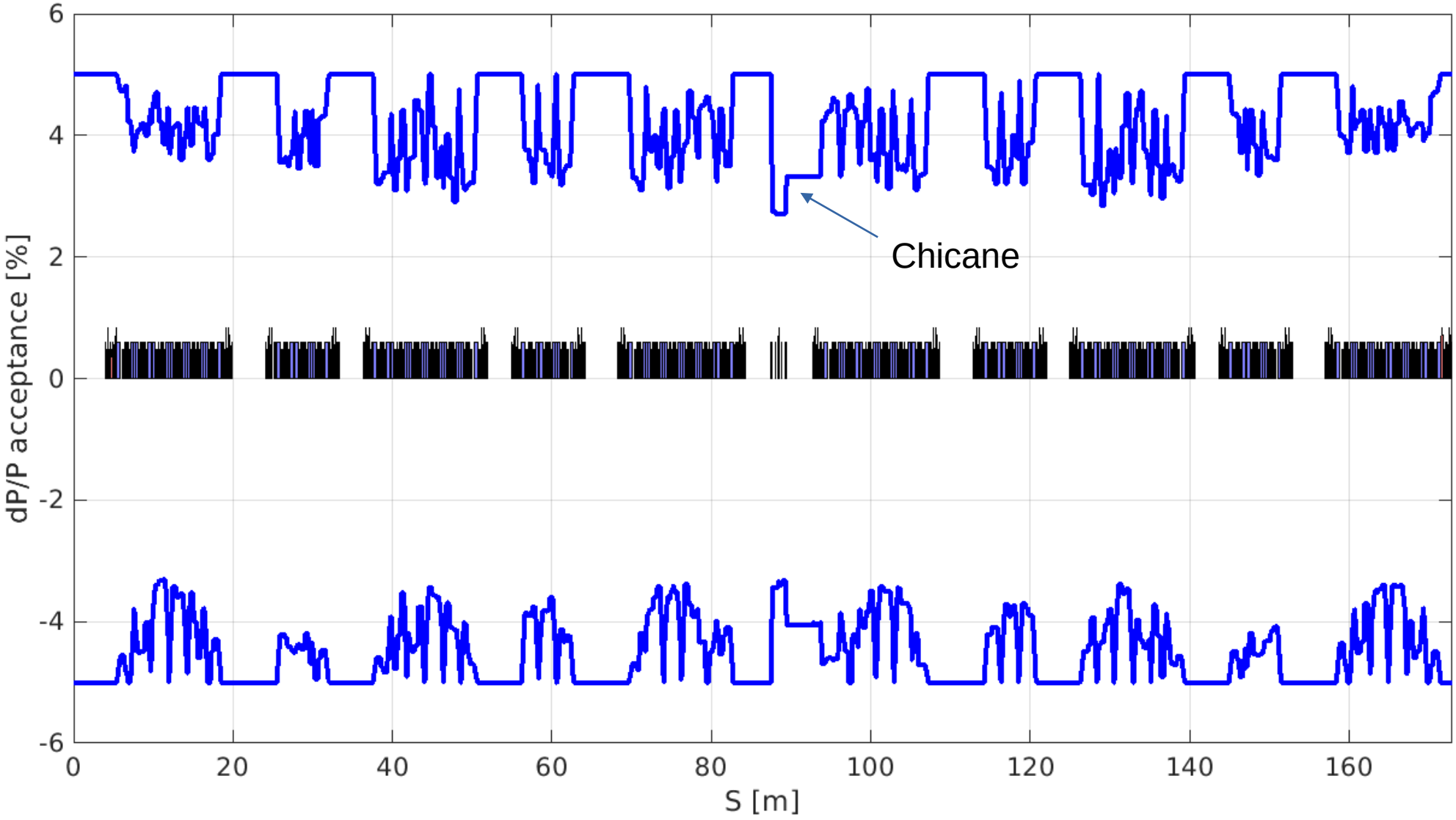
Summary and conclusion

- The extended DB lattice (half of the 16 DB cells having short straight sections in between the two dipoles) of the present SOLEIL ring has set a non-trivial starting point for its upgrade.
- The ESRF hybrid type and HOA lattices were compared by symmetrizing the ring with 20 cells. Satisfactory solutions with $\varepsilon_{x0} < 100$ pm·rad found for both lattices along with their characteristics.
- Using the "modularity" of HOA lattices, an alternating 7BA and 4BA HOA cells allowed us to construct a 20-cell HOA ring that matches to a good extent most existing source points including the canted two long BLs and achieving $\varepsilon_{x0} < 100$ pm·rad with reasonable lifetime. However, the symmetry of the ring is limited to 2.
- A number of physically & technically challenging designs have been integrated (permanent magnets for the main dipoles and quadrupoles, internally $\phi = 12$ mm NEG coated chambers as the basis, use of very strong sextupoles and octupoles, DA barely enough for off-axis injection, …)

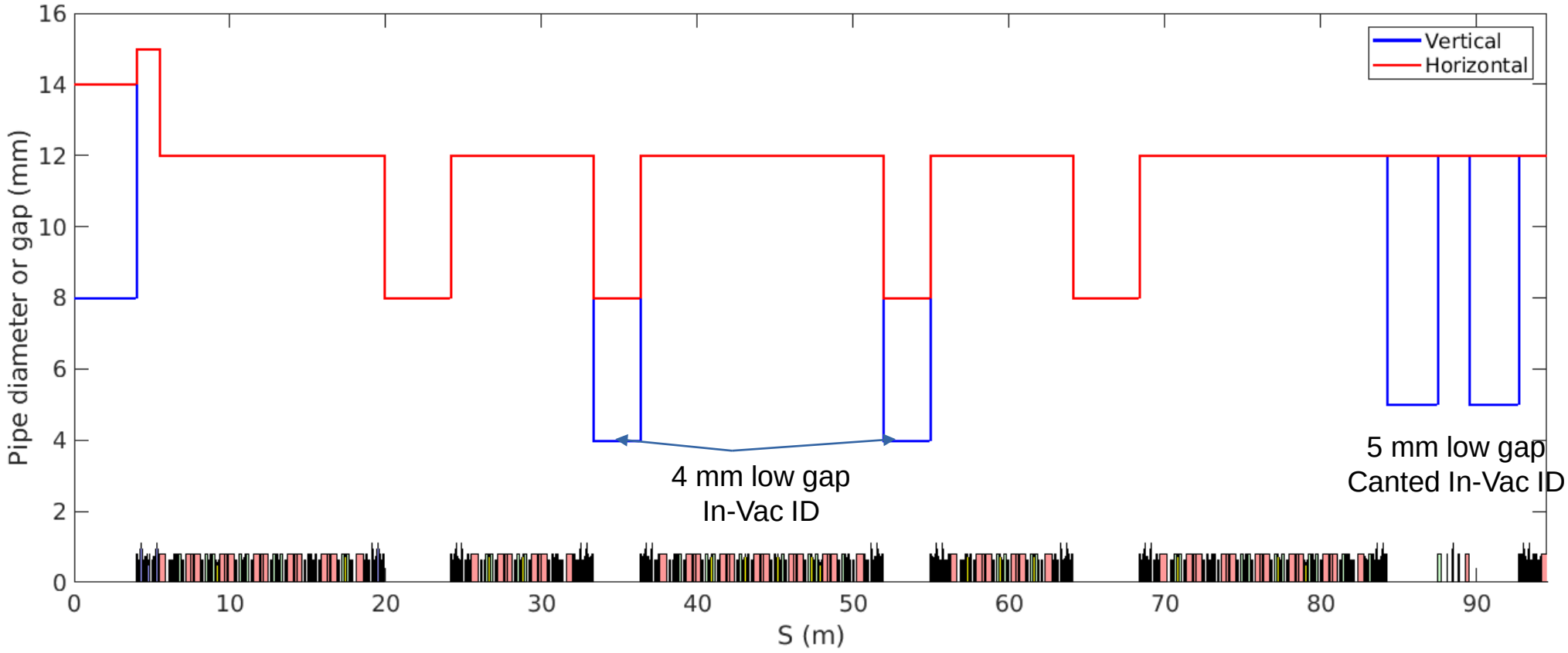
  ➔ No show-stoppers identified, but issues and risk assessment are to be made rapidly to ensure and further improve the performance

Additional materials

TDR V0356 Energy acceptance

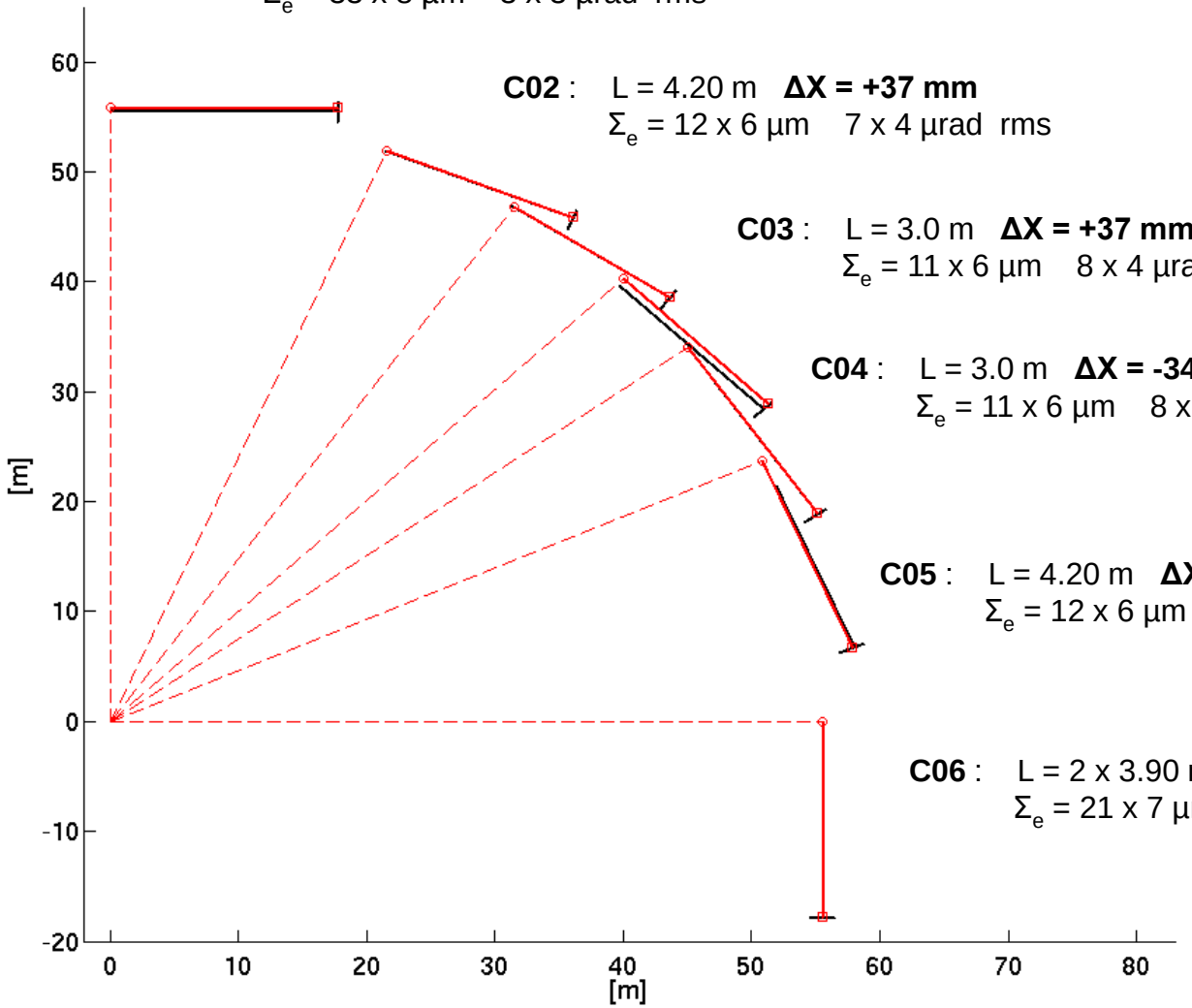


TDR V0356 Physical aperture



Detailed lattice configuration

C01 : L = 8.0 m ΔX = +260 mm
Σ_e = 33 x 8 µm 3 x 3 µrad rms



C02 : L = 4.20 m **ΔX = +37 mm**
Σ_e = 12 x 6 µm 7 x 4 µrad rms

C03 : L = 3.0 m **ΔX = +37 mm**
Σ_e = 11 x 6 µm 8 x 4 µrad rms

C04 : L = 3.0 m **ΔX = -34 mm**
Σ_e = 11 x 6 µm 8 x 4 µrad rms

C05 : L = 4.20 m **ΔX = -103 mm**
Σ_e = 12 x 6 µm 7 x 4 µrad rms

C06 : L = 2 x 3.90 m **ΔX = 0 mm**
Σ_e = 21 x 7 µm 5 x 3 µrad rms