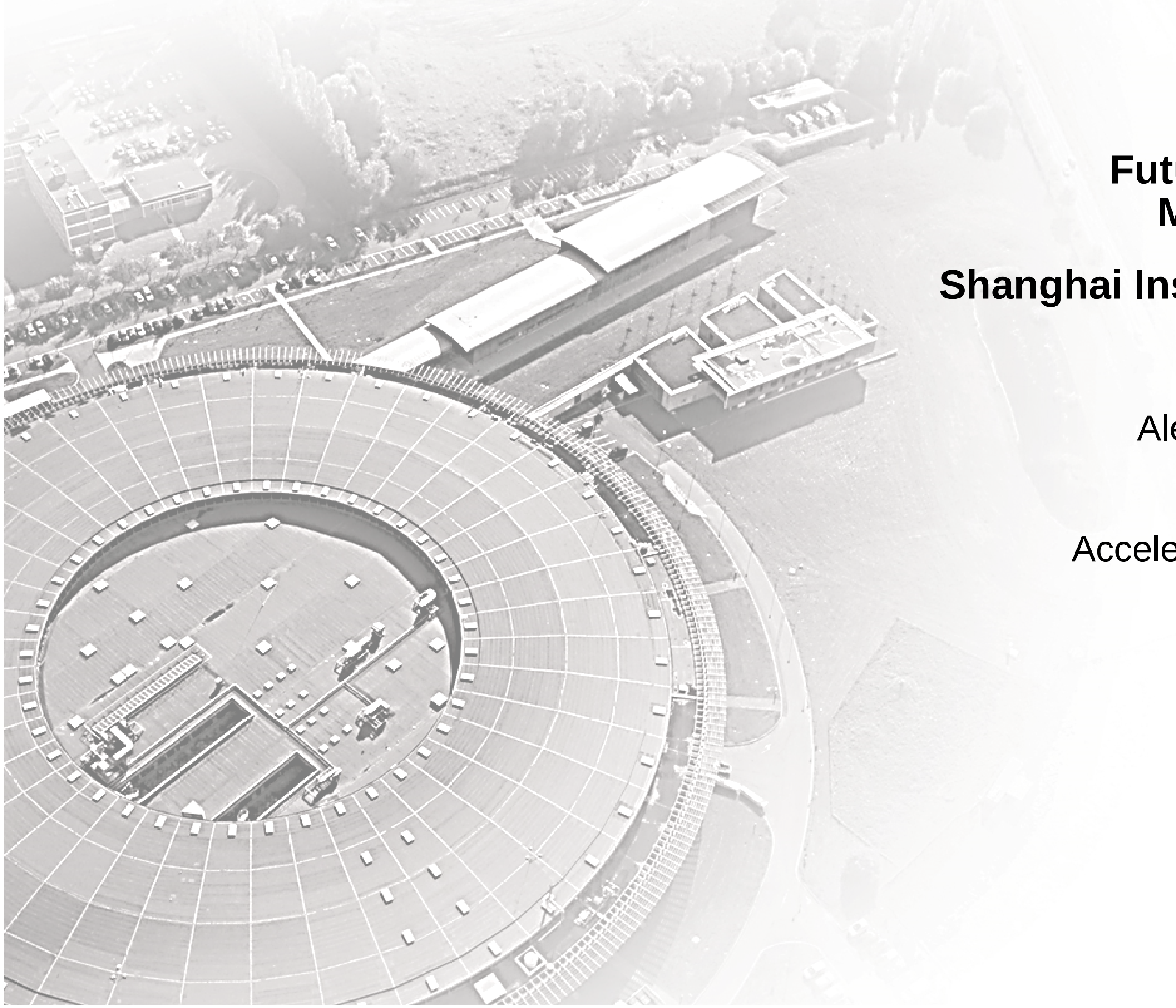
BASELINE LATTICE
FOR THE UPGRADE OF SOLEIL



Future Light Source
March 5-9 2018

Shanghai Institute of Applied Physics

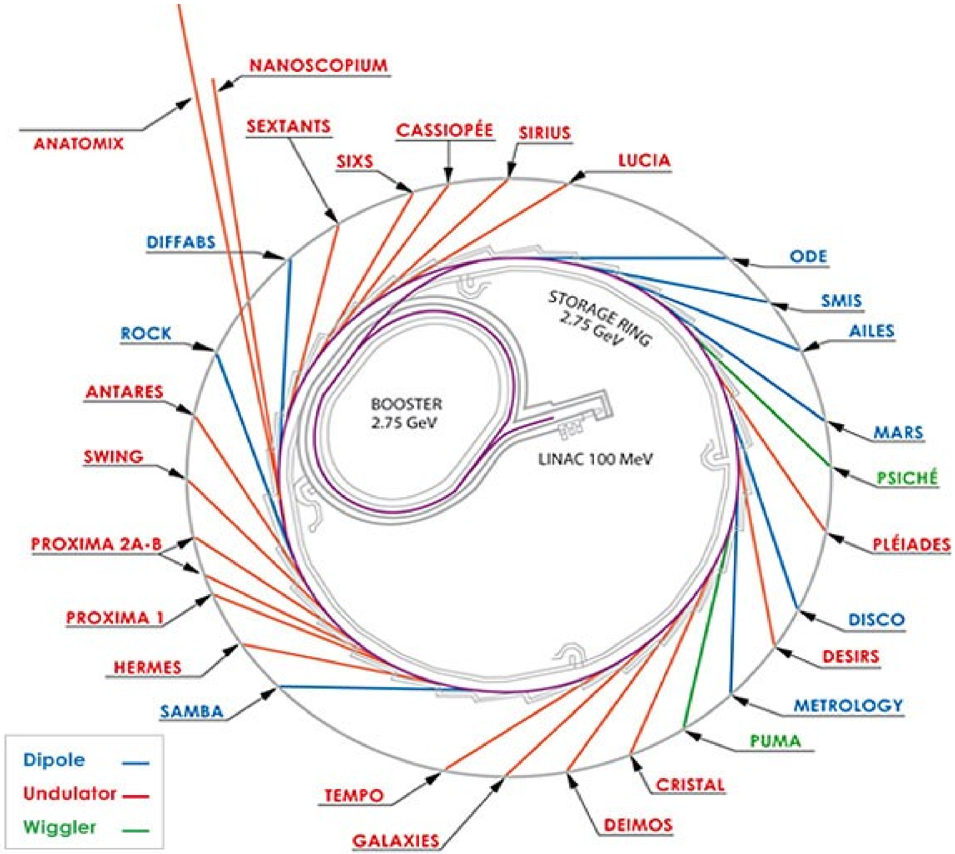
Alexandre Loulergue

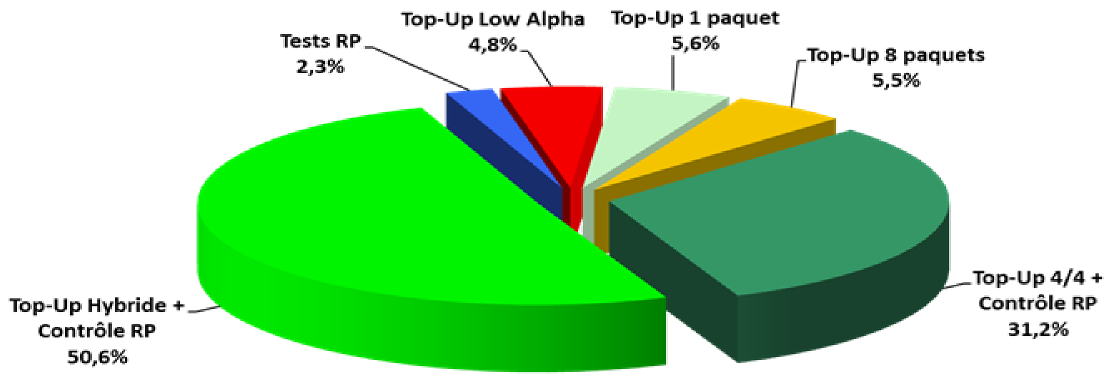
On behalf of the
Accelerators and Engineering
Division

Upgrade Lattice Outline

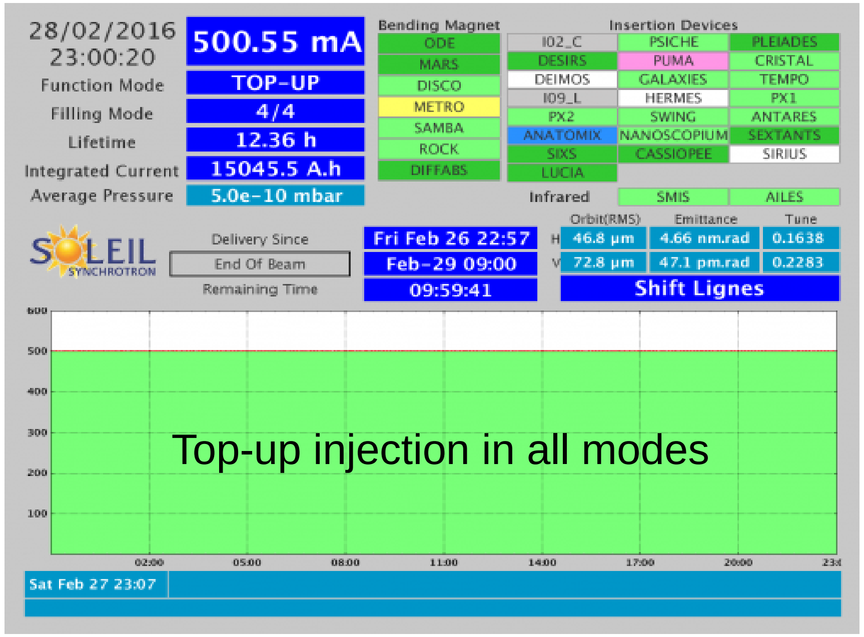
- 2016 proposition 200 – 250 pm.rad
- 2017 baseline 72 pm.rad
- Injection investigation
- Tunnel investigation
- Timeline

SOLEIL Today





5 modes of operations

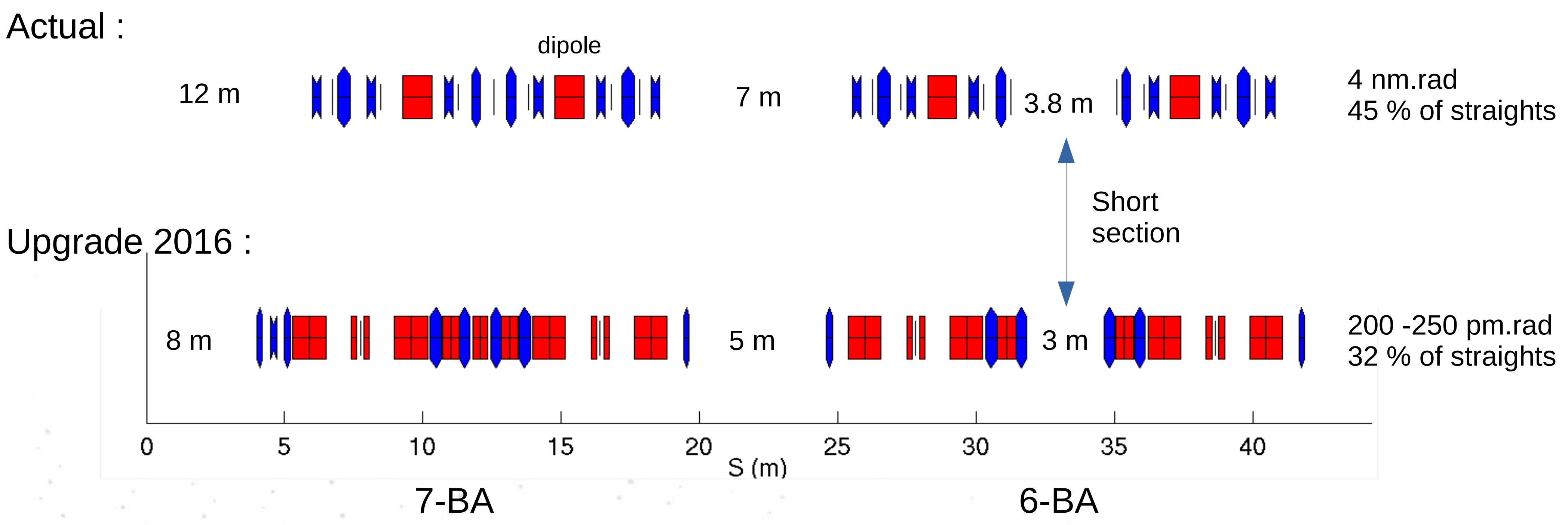


2008 : Open to users
2009 : Top-up operation
2018 : 29 beamlines
(2 under commissioning)

Upgrade Lattice Evolution

C=354 m   16 cells of 2 kinds

1/8 of the ring here
2.75 GeV



L. Farvacque et al. , A Low-Emittance Lattice for the ESRF, Proceedings of IPAC (2013)

Upgrade Lattice Evolution

To push further the emittance reduction and to maximize the photon flux in the soft X-rays photon energy up to 3 keV :

We increased the number of cells from 16 to 20 without short straight sections giving 20 straights of length of 4.4 m (25% of the circumference). The natural emittance is then reduced down to 72 pm.rad (or 50 pm.rad at full coupling)

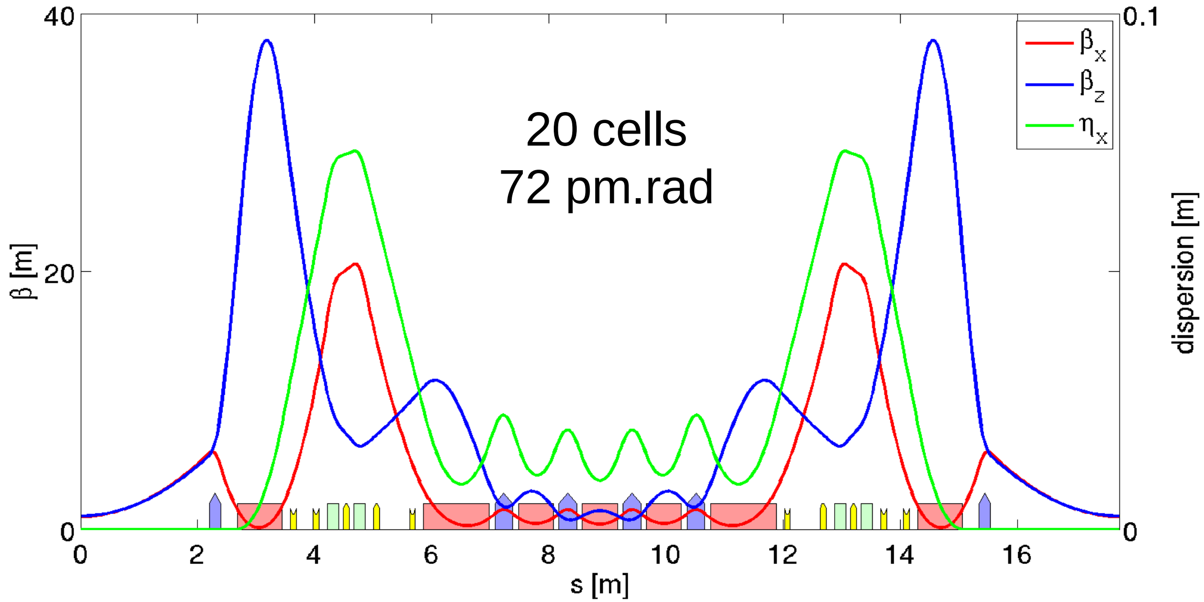
The optics also includes low beta function (~ 1 m) at straight center for electron-photon matching

Magnets are stronger :

– Sext < 2000 T/m2
– Quad < 100 T/m
– Dip ~ 0.6 T & 40 T/m

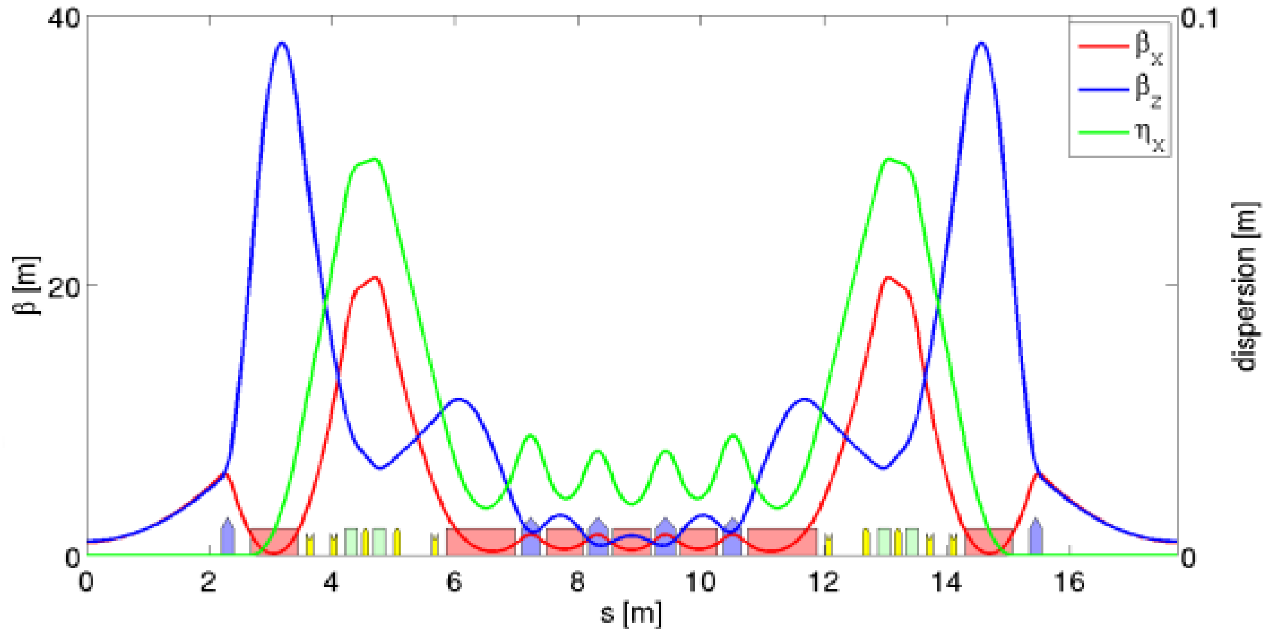
Without Long. Grad. in Bend

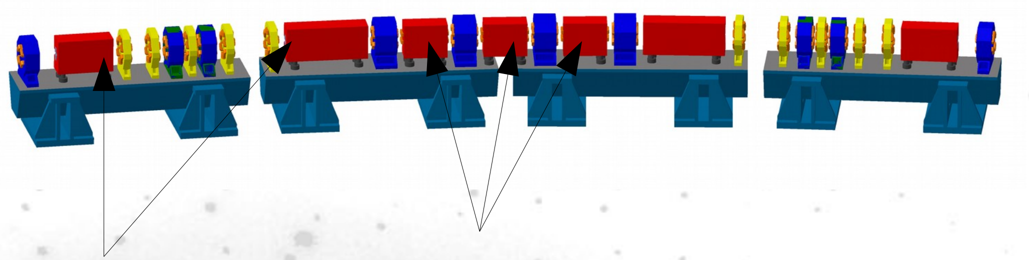
Nat. Chro. = -6.7 / -6.3 per cell
= -135 / -125 total



Upgrade lattice baseline

20 cells 72 pm.rad





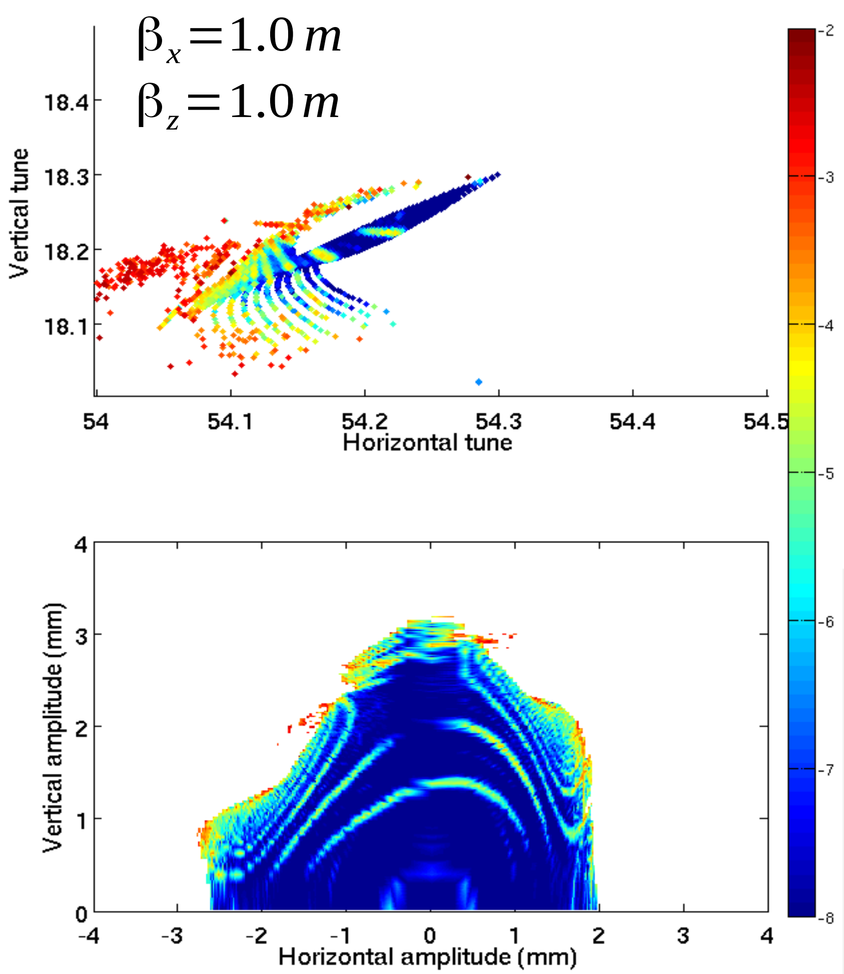
Small extra quadrupole for tuning to be added

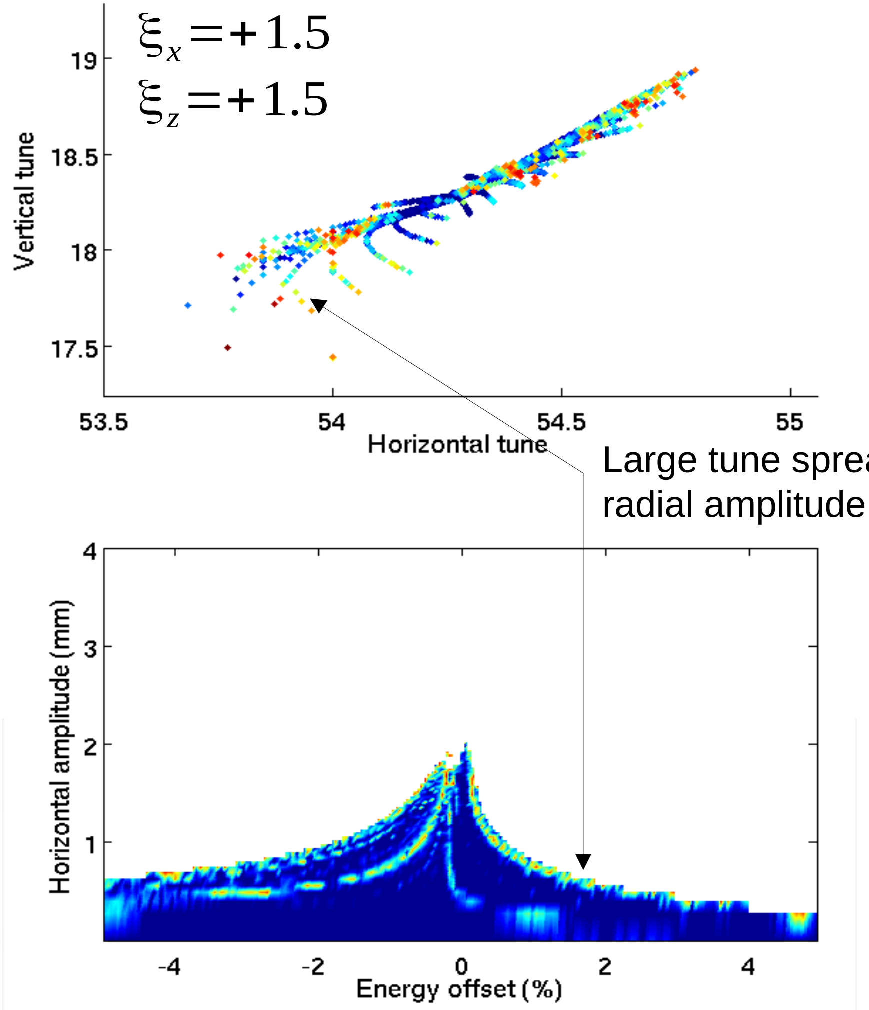
Combined dipole & quadrupole with independent variation of few %

Circumference	C (m)	354.2
Energy	E (GeV)	2.75
Working point	ν_x ν_z	54.3, 18.3
Nat. Chrom.	ξ_x ξ_z	-134, -125
Mom. Comp. Fact.	α_1	1.5 10^{-4}
Nat. Emittance	ε_{x0} (pm.rad)	72
Energy spread	σ_E / E	8.6 10^{-4}
Energy loss / turn	U_0 (keV)	310
Damp. times	$T_{x,z,s}$ (ms)	10, 21, 24

Ring FMA

Perfect lattice
4D tracking
TRACYIII





Large tune spread with radial amplitude

Taken at straight center

Ring beam dynamics

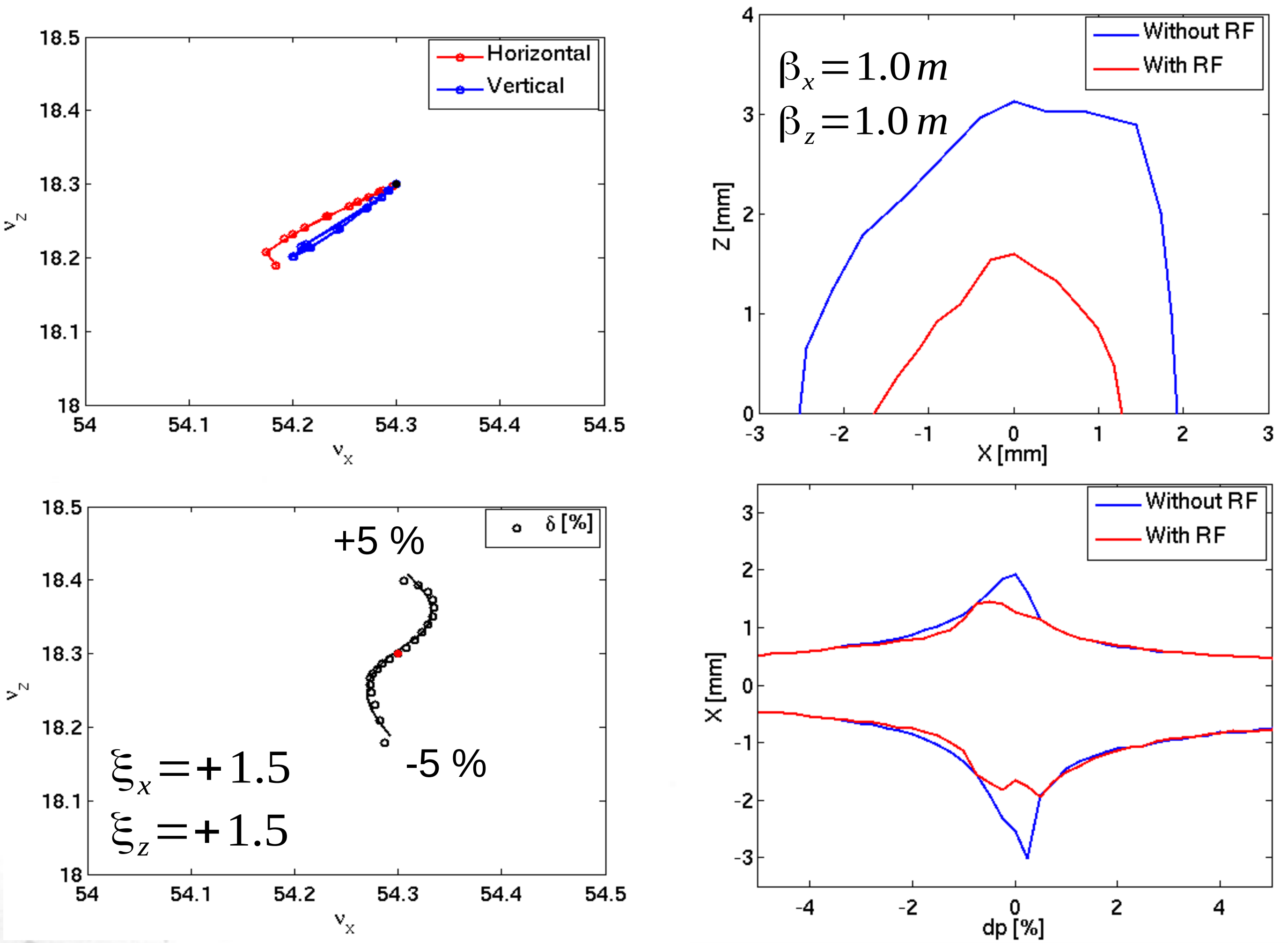
Perfect lattice
4D-6D tracking
AT2.0

4 sextupoles and 2 octupoles families are used here

On momentum DA is reduced by ~2 with the RF

4D Tune footprints are kept ±0.1 over 1 turn

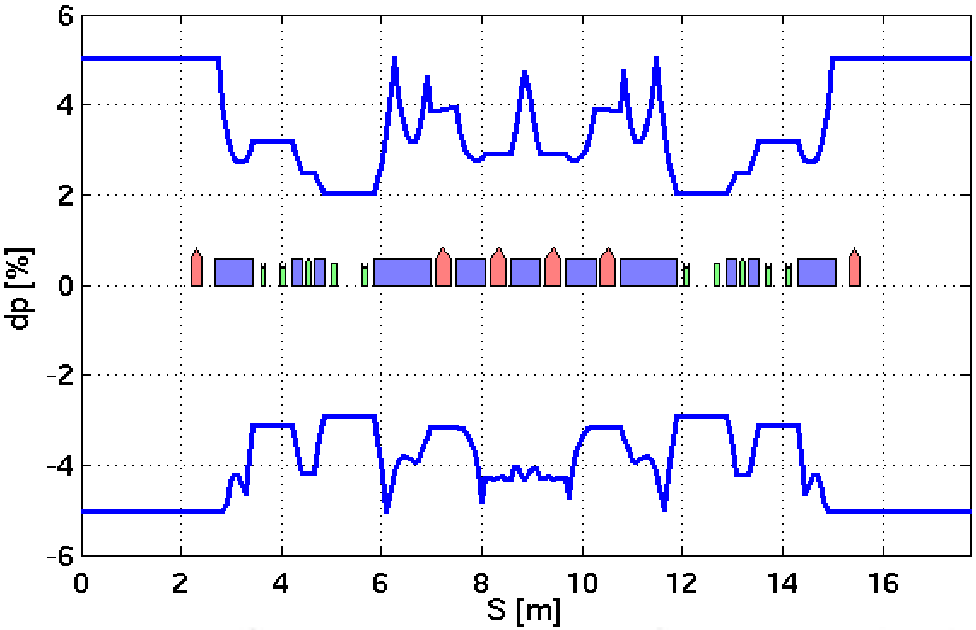
Fast drop of the amplitude with energy
Larger tune shift with amplitude when off momentum

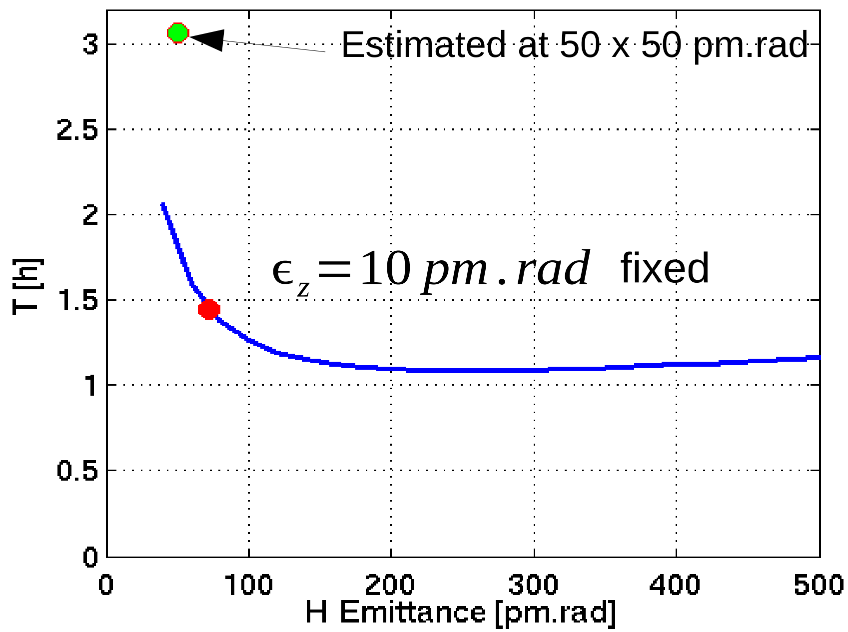


Touschek Lifetime

Perfect lattice
AT2.0

Momentum acceptance





Beam pipe diameter of 16 mm
RF Voltage of 1.1 MV
Natural bunch length of 3.7 mm RMS

With 72 in H and 10 in V pm.rad the beam lifetime is about 1.5 h at 500 mA (1.4 nC per bunch)

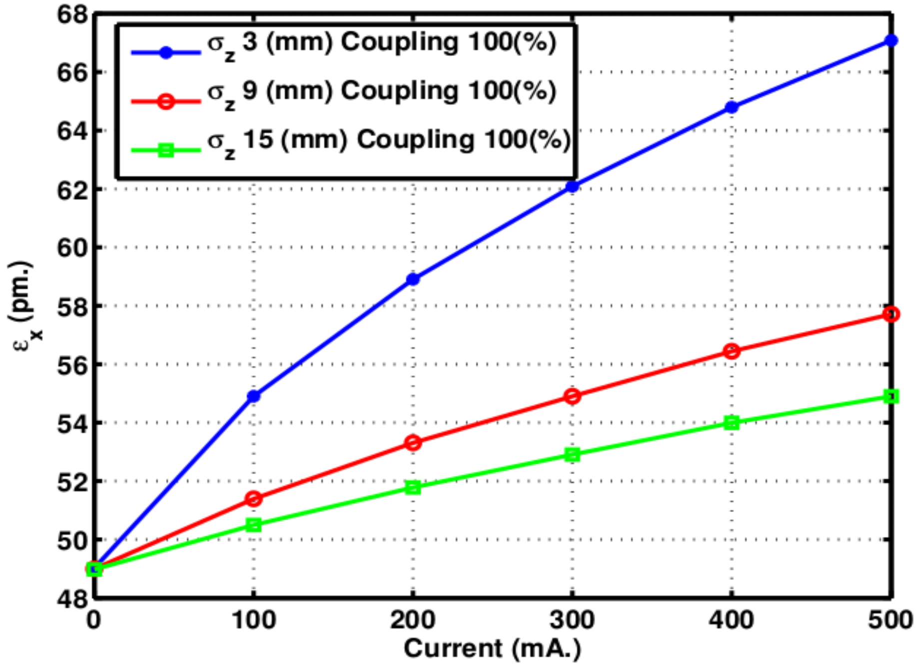
Up to 3 h at full coupling (50 x 50 pm.rad)

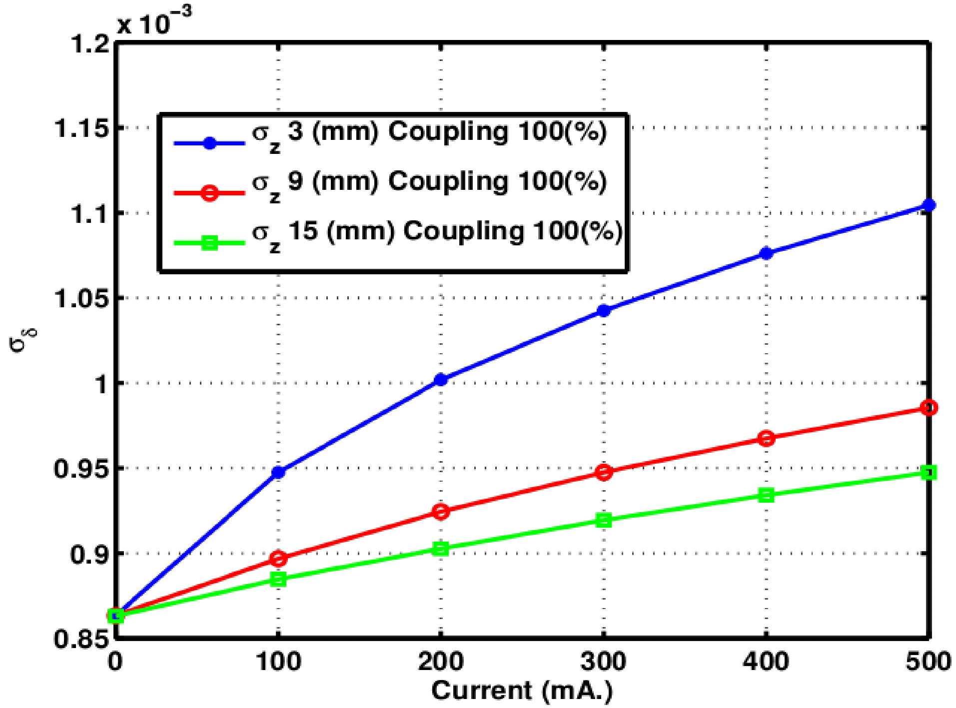
Simple horizontal emittance scan
Seems to be on the good side !

No bunch lengthening by means of third harmonic here

IBS emittance increase

Courtesy of K. Manukyan, SESAME



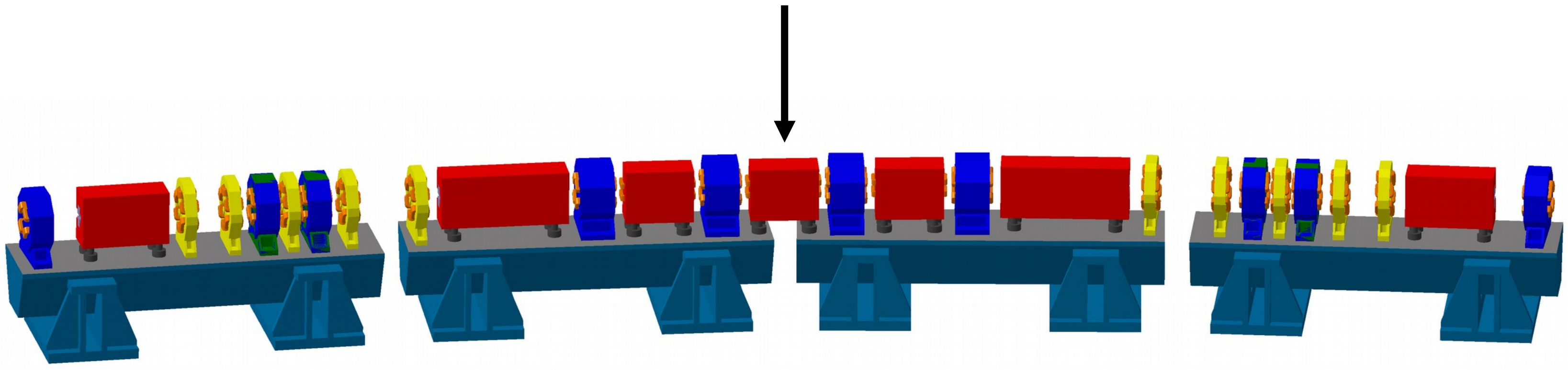


Preliminary IBS effect computed with Elegant code :
Simple Gaussian distribution model

ZAP code gives equivalent values

Emittance increase by 30 % with natural RMS bunch length (3.7 mm / 0 mA)
Limited to 10 % with RF harmonic bunch lengthening (x 5)

3T super-bend

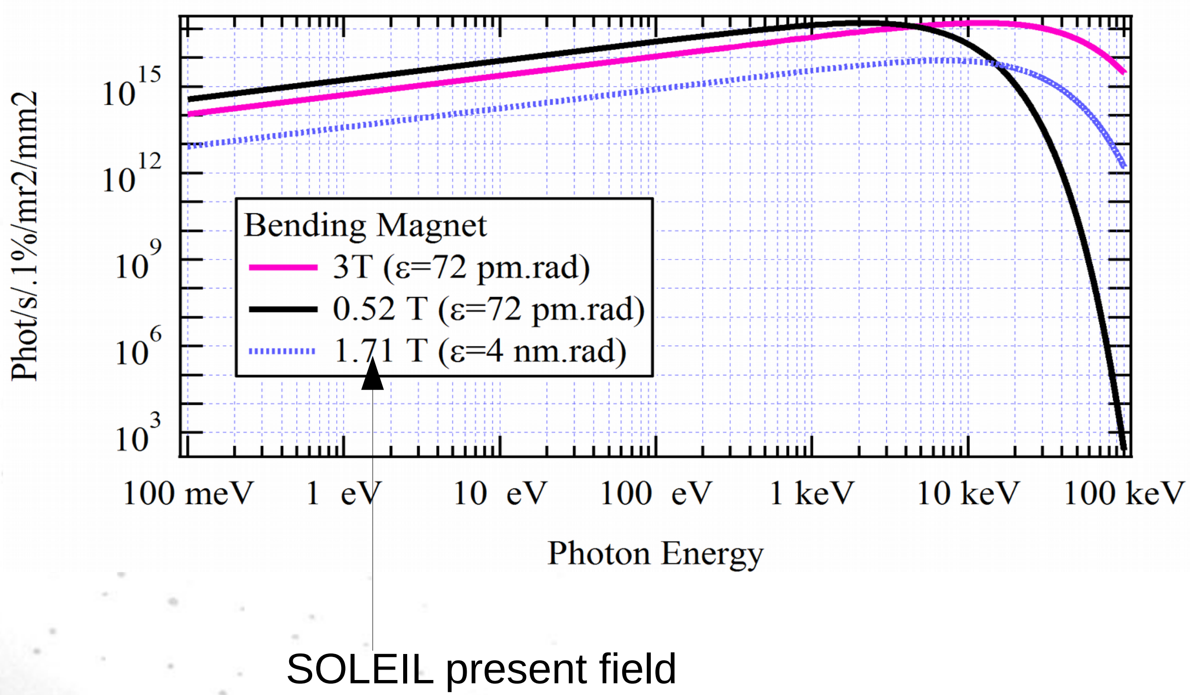


Insertion of 3T super-bend in the central magnet of the cell

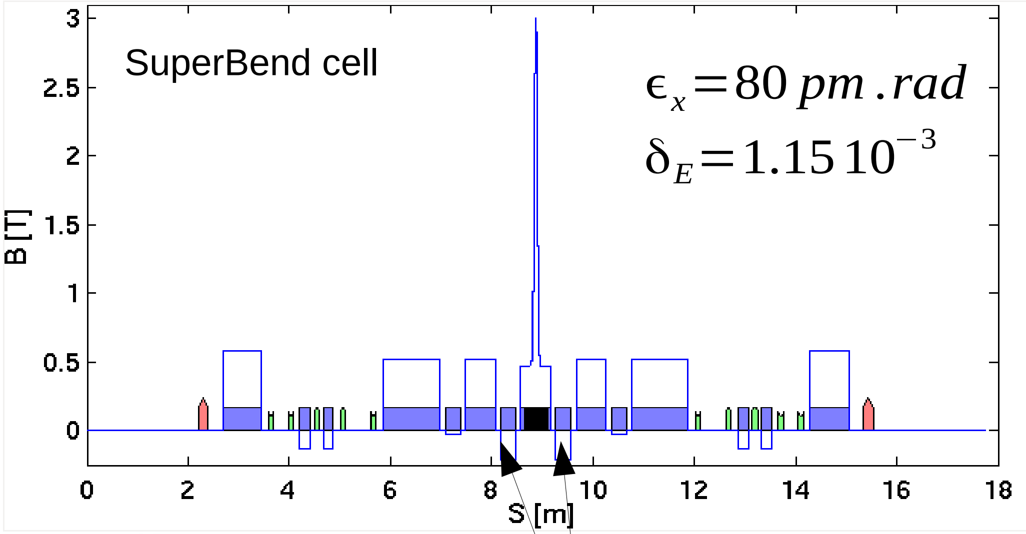
To increase the photon flux above 10 keV

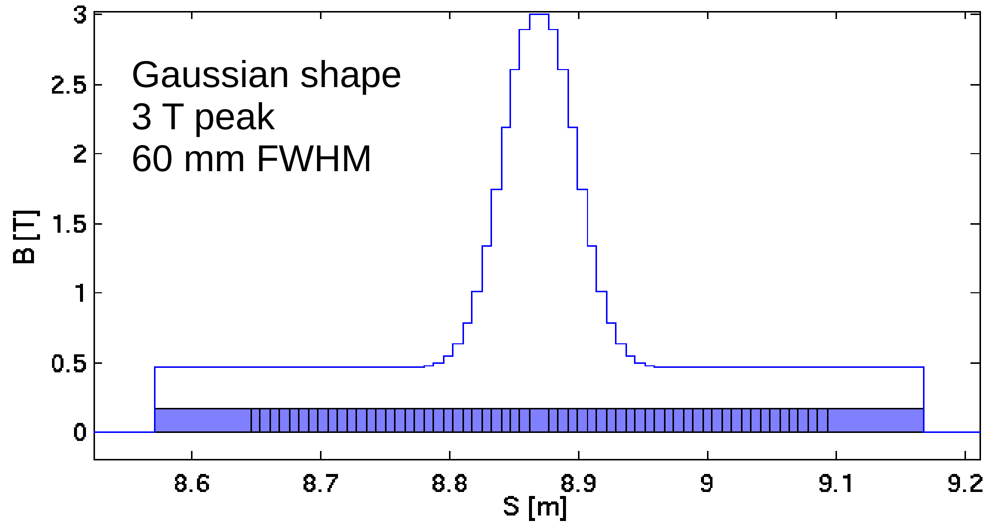
4 are foreseen, one each 5 cells

Emittance impact is not negligible
The present H-function is not well suited



3 T super-bend





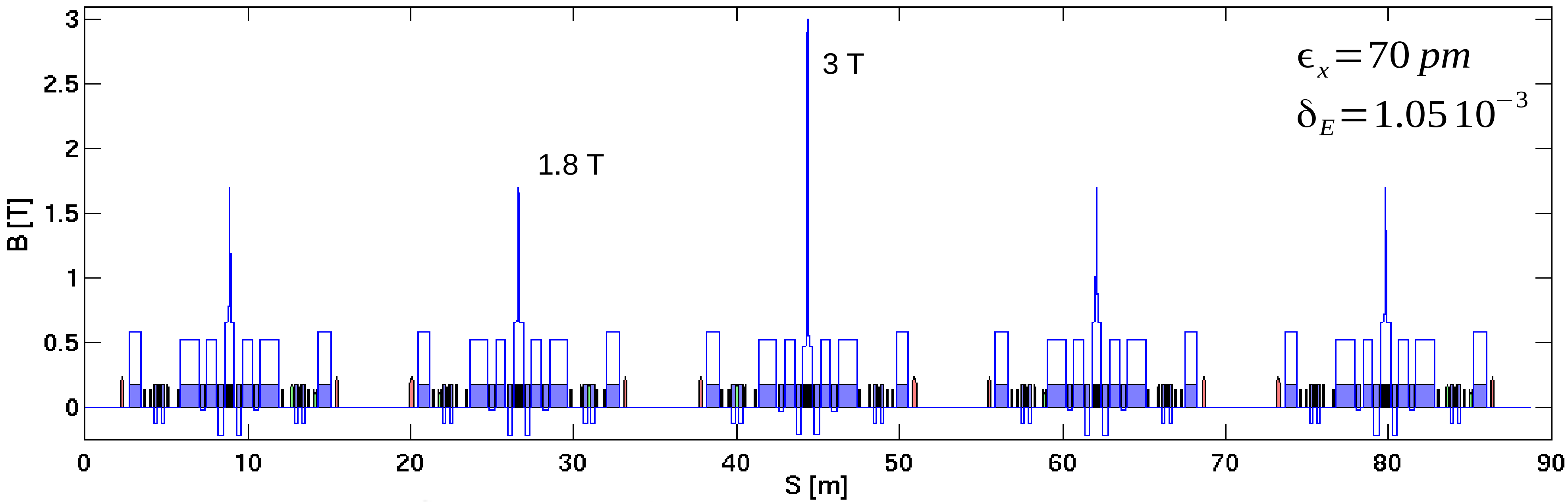
Reverse-bend

Shifted quadrupoles by ~1.3 mm to reduce the H-function and limit the emittance increase (here from 72 to 80 pm.rad)

A. Streun, The anti-bend cell for ultralow emittance storage ring lattices NIMA, 737 (2014)

3 T super-bend + 1.8 T

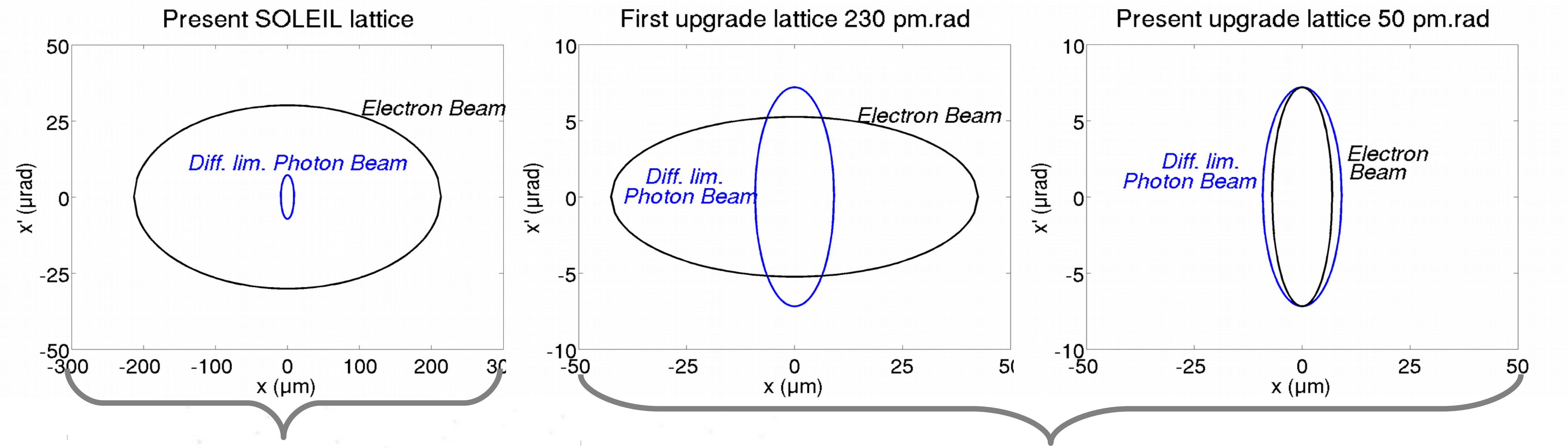
1/4 of the ring



Add 1.8 T on central bend of other cells to reduce back the emittance ~ 70 pm.rad

Possibility to reduce the emittance down to ~60 pm.rad by pushing further the reverse bend but at the cost of a larger energy spread and a lower momentum compaction ...

Electron-Photon Matching



Actual ID length

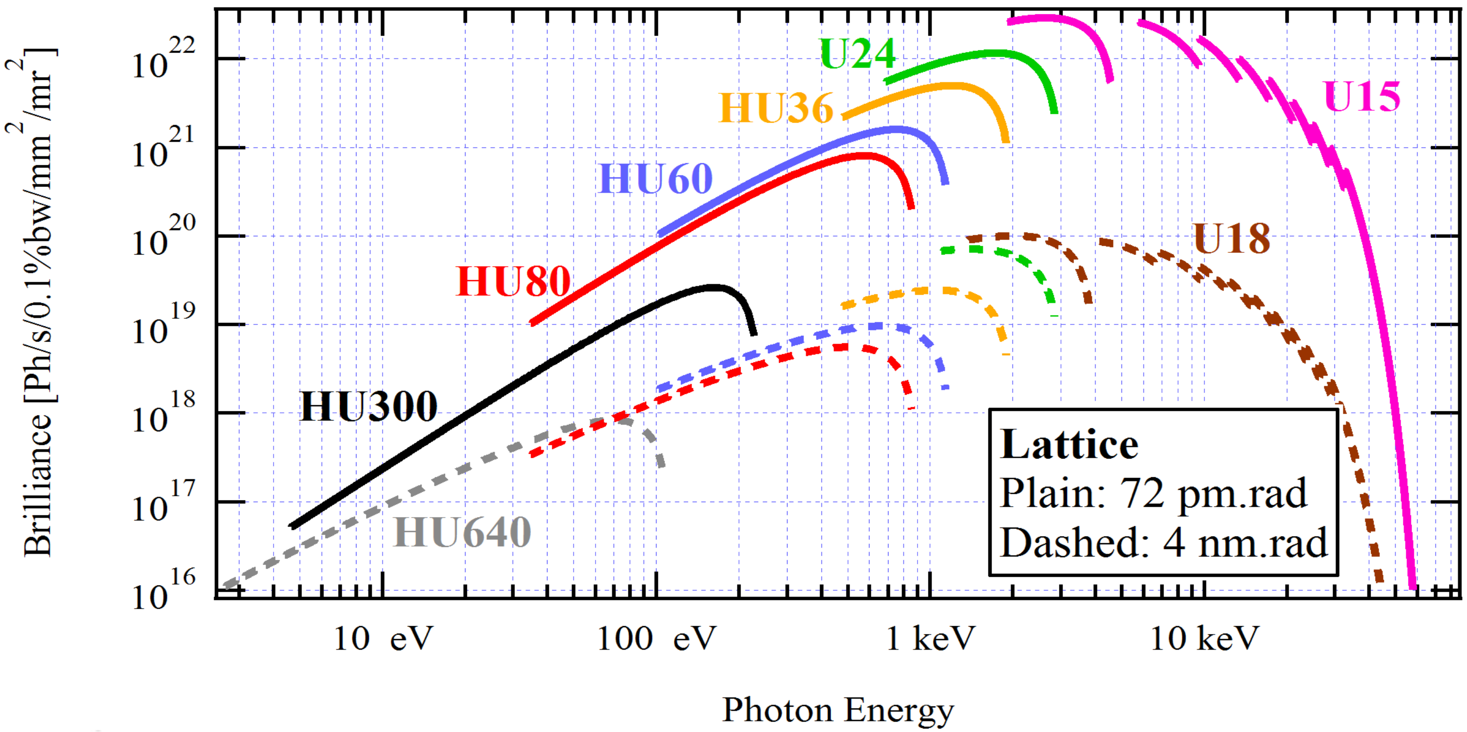
4m ID length

Diffraction limited photon beam emittance is 65 pm.rad at an energy of 3 keV

$\beta_{matched} = L/\pi \approx 1.27\,m$ for a undulator of 4 m

With 50 pm.rad and $\beta = 1\,m$ the beam size is 7 µm and 7 µrad RMS in divergence in both planes at source.

Photon Brilliance Comparison

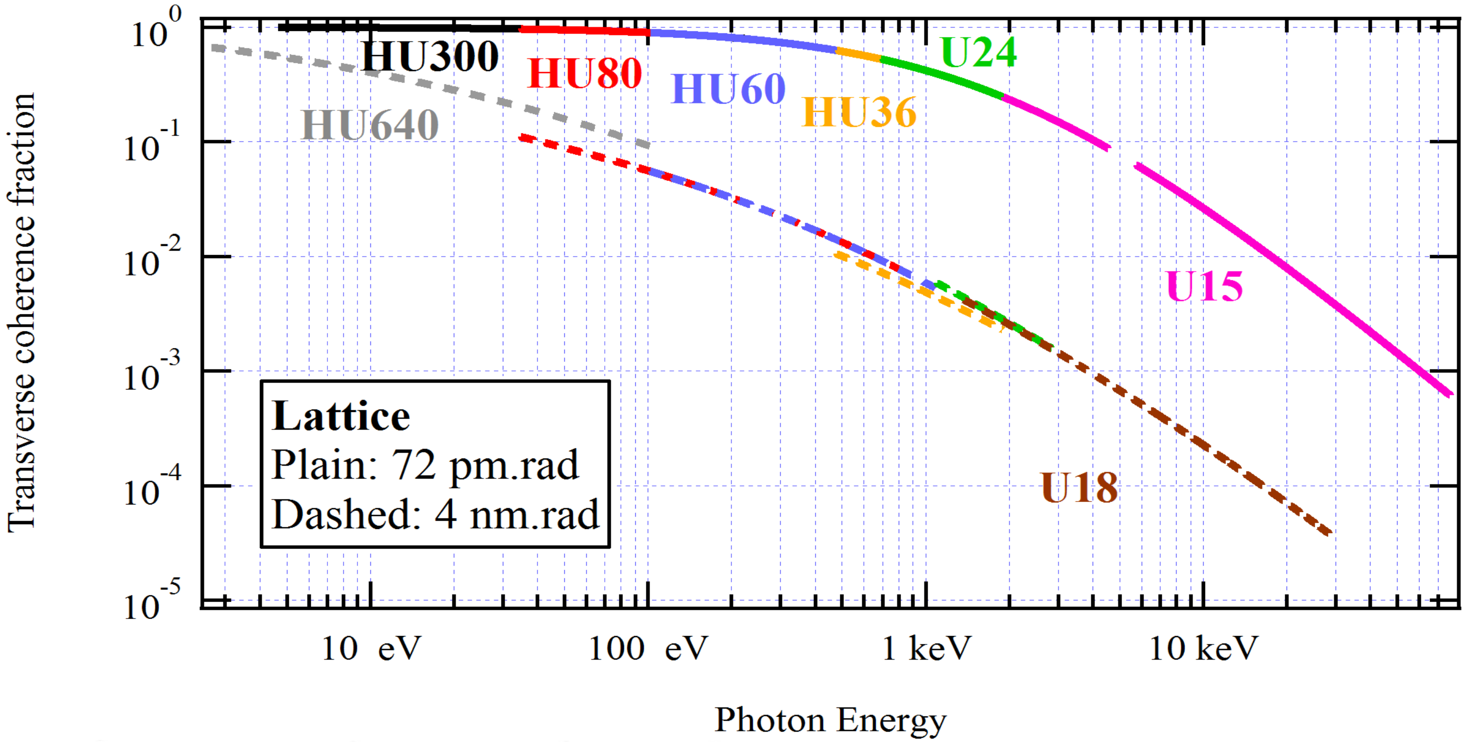


The brilliance increase reach two orders of magnitude in the region of interest:

Between 1 to 3 keV, exceeding a value of 10^{22} photons/s/mm2/mrad2/0.1%b.w

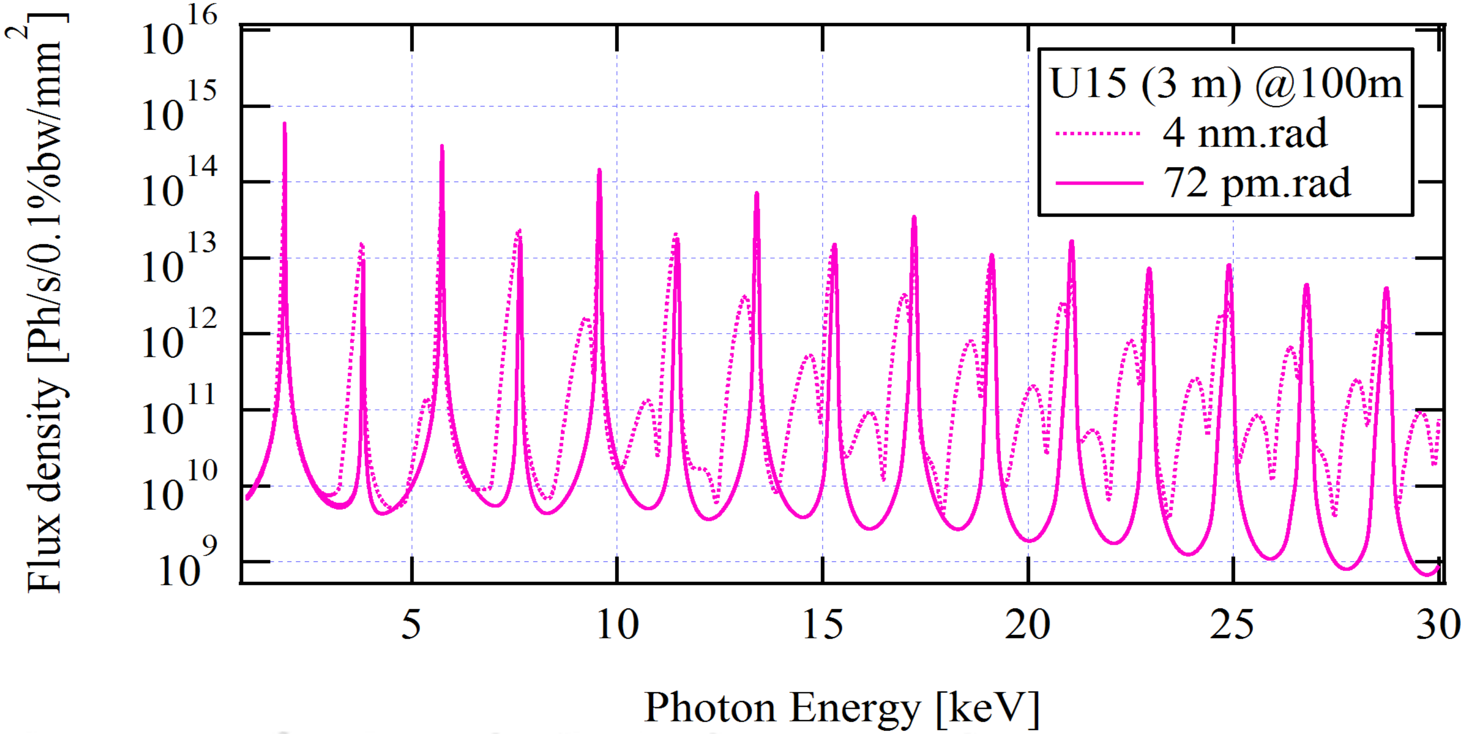
It can exceed 10^{20} photons/s/mm2/mrad2/0.1%b.w at 40 keV,

Transverse Coherence Fraction Comparison

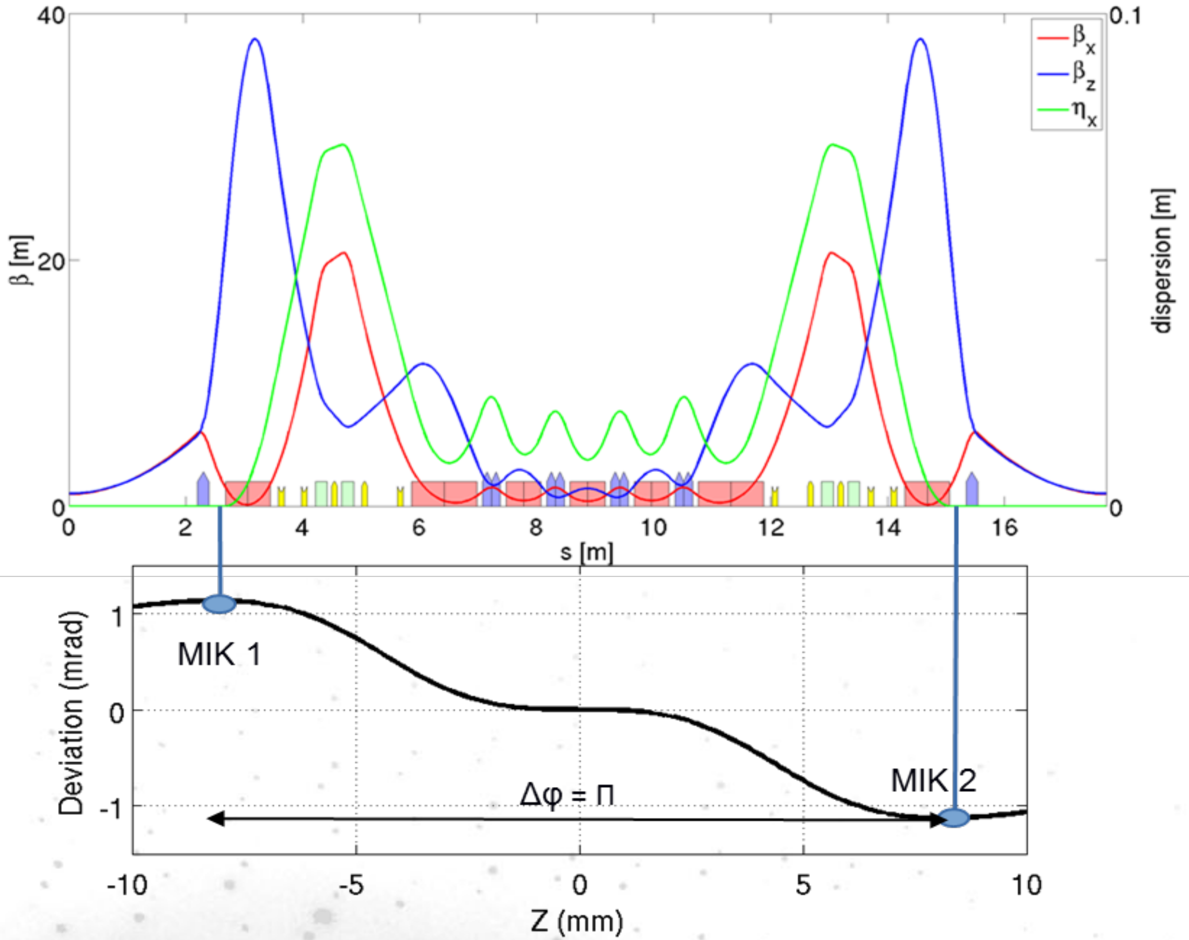


The photon beam should be fully coherent up to almost 200 eV, exeeding 40 % at 1 KeV
And reaching 14 % at 3 KeV

Undulator Spectral Purity Comparison



Try Vertical Injection With Non Linear Kicker (NLK)



Take advantage of the phase to use two small NLK

Off axes to accumulate

Keep the lattice symmetry

Take advantage of the large vertical beta function

Take advantage of the natural small vertical emittance of the booster

But : vertical betatron oscillation versus low gap ID …

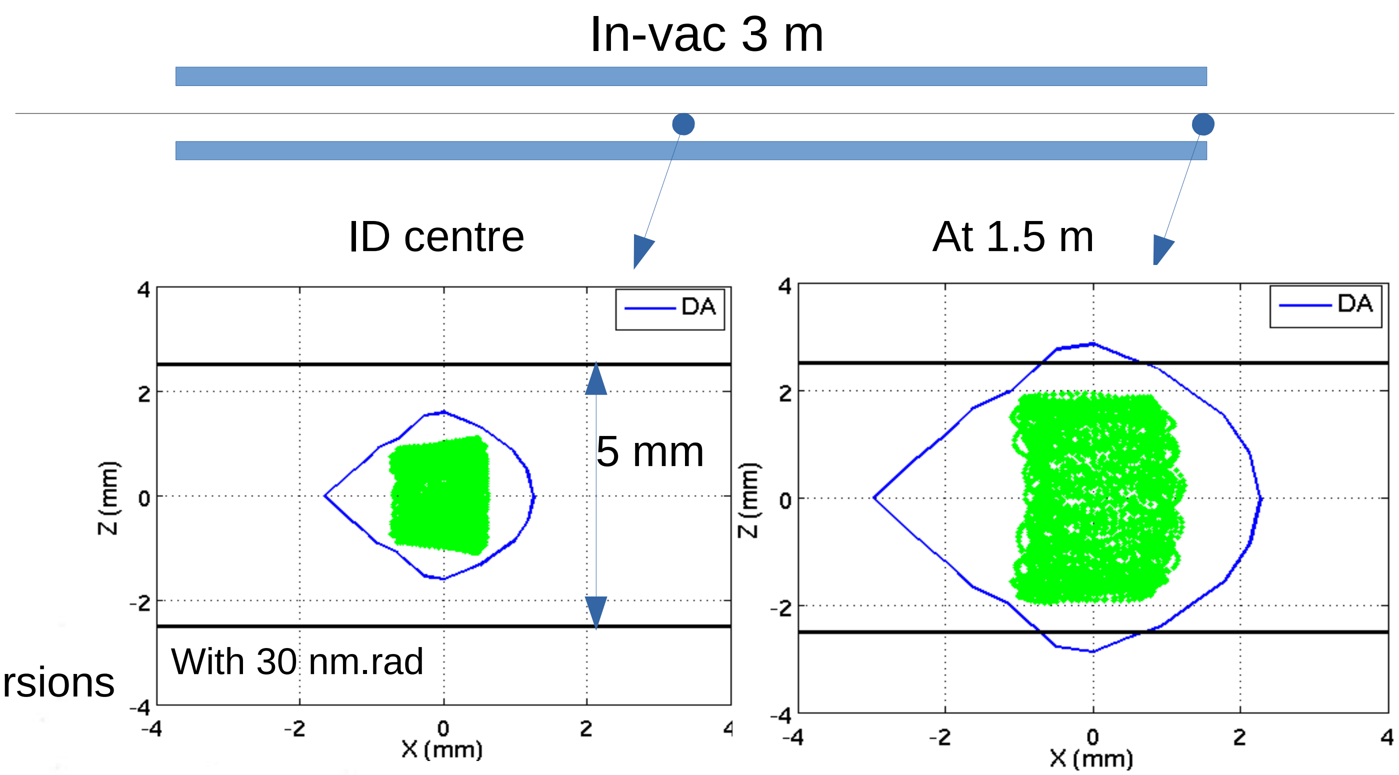
Try Vertical Injection With Non Linear Kicker

Tracking with emittance (9 rms):

- With present 130 nm.rad from the booster

  First cell large orbit and strong sextupoles enlarge the particle vertical excursions and reach the 5 mm ID gap

- With only 30 nm.rad, vertical excursions are reduced



Perfect lattice

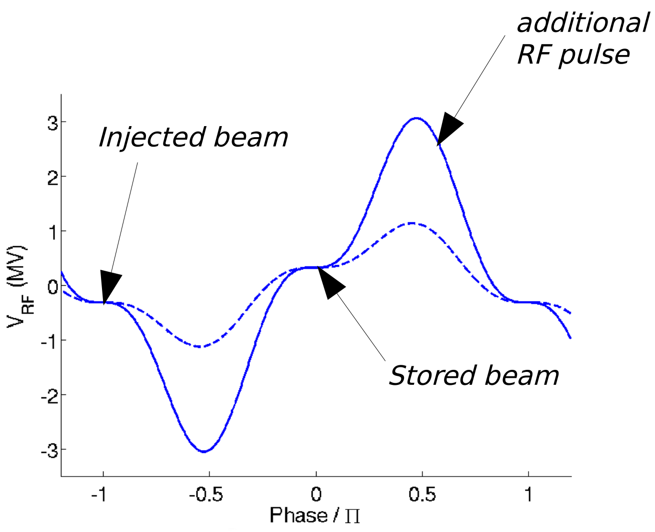
We envisage to upgrade the booster too :

=> Doubling the number of cells
   gives 30 nm.rad
=> Reuse ring quad and sext ?

The booster emittance of 130 nm.rad became rather large as compared to low emittance acceptance lattices ...

Longitudinal Injection on Chromatic Orbit With a NLK and an Extra RF Pulse

	Main RF (MV)	Harm. 3 (MV)
Normal	0.9	0.3
+ injection	+1.4	+0.47



Derived from :

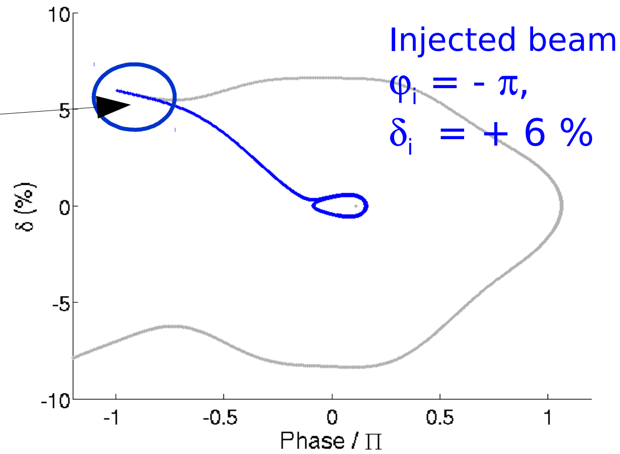
M. Aiba et al., Longitudinal injection scheme using short pulse kicker for small aperture electron storage rings, Phys. Rev. ST Accel. Beams 18, 020701 (2015).

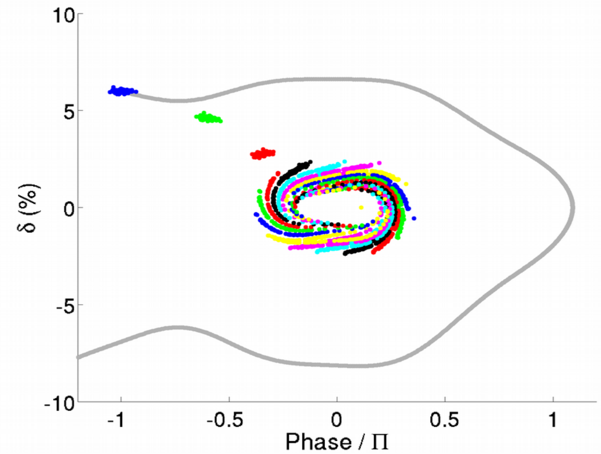
Tracking with a booster emittance of 30 nm.rad gives 100 % efficiency on a perfect baseline lattice

Beam injected on a chromatic orbit by mean of an NLK located in the dispersion bump at an energy offset of + 6%

200 turns

NLK accomodation still under investigation ...

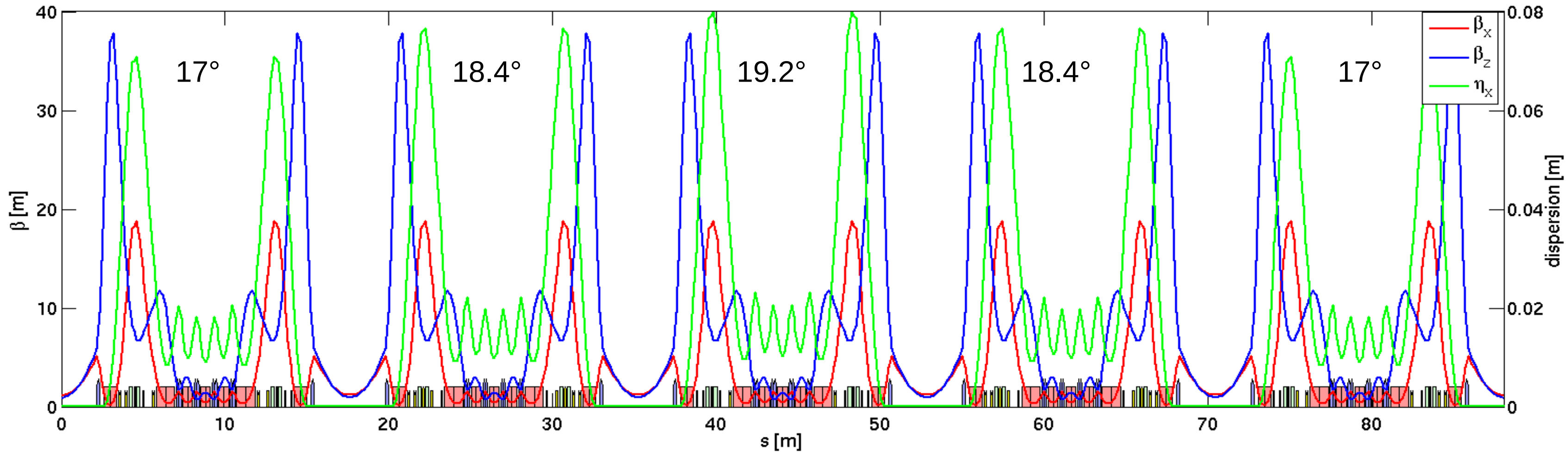




Fitting the Tunnel and Beamline Positions

The 20 cell symmetry gives a “round” geometry that doesn't perfectly fit the present tunnel with long and short straight sections. Modulating the deviation per cells (initially 18°) :

5 cells : 1/4 of the ring

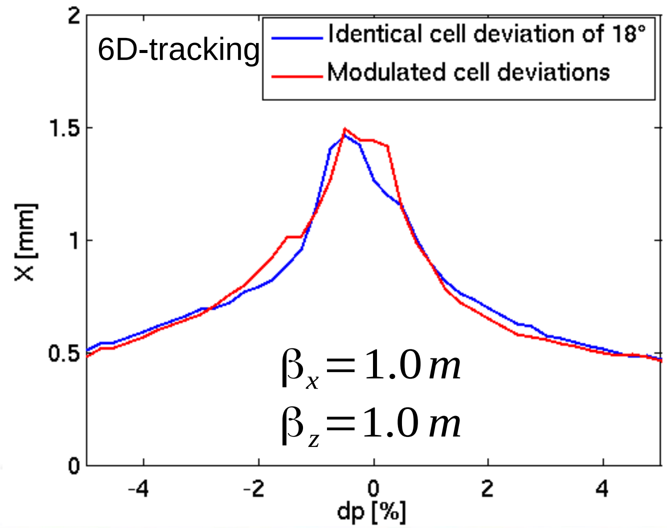


Keeping sextupole and octupole strengths, the beam dynamics is ~unchanged.
Emittance increase is marginal

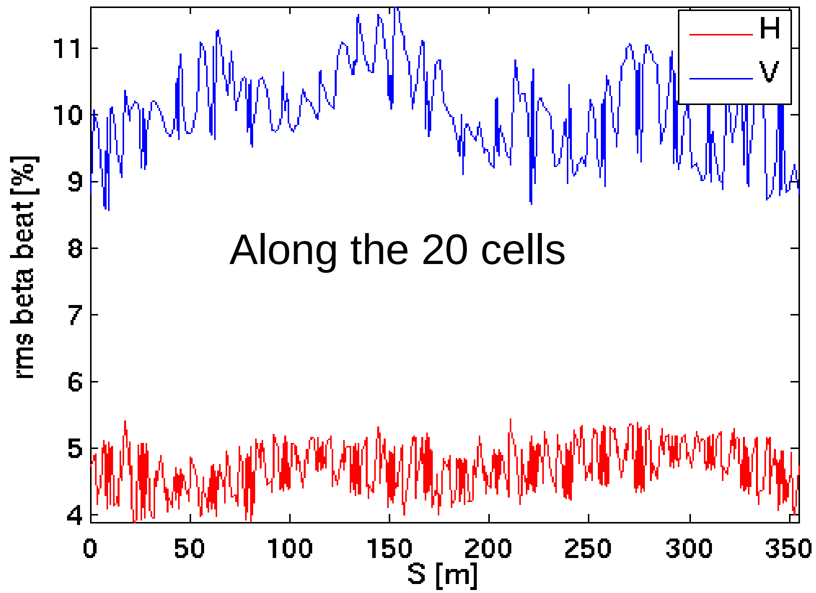
But enlarge the number of dipole magnet types (± 7 % in dipolar field)

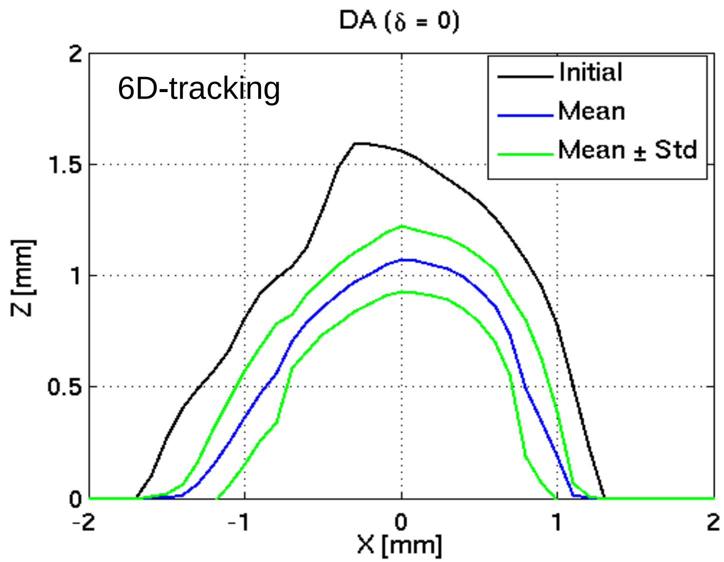
Nevertheless, 8 ratchet walls will have to be also slightly changed to have :

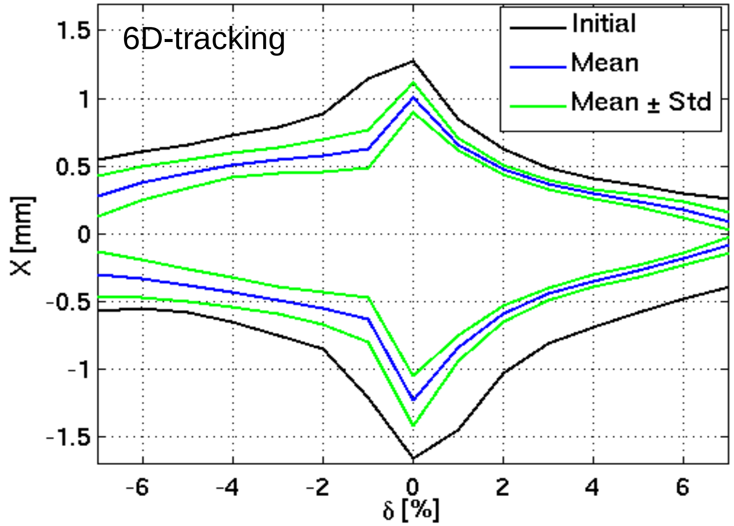
- The 20 straight line sources (17 identified for experiments)
- The 4 3T bend sources available



Quadrupole Strength Errors







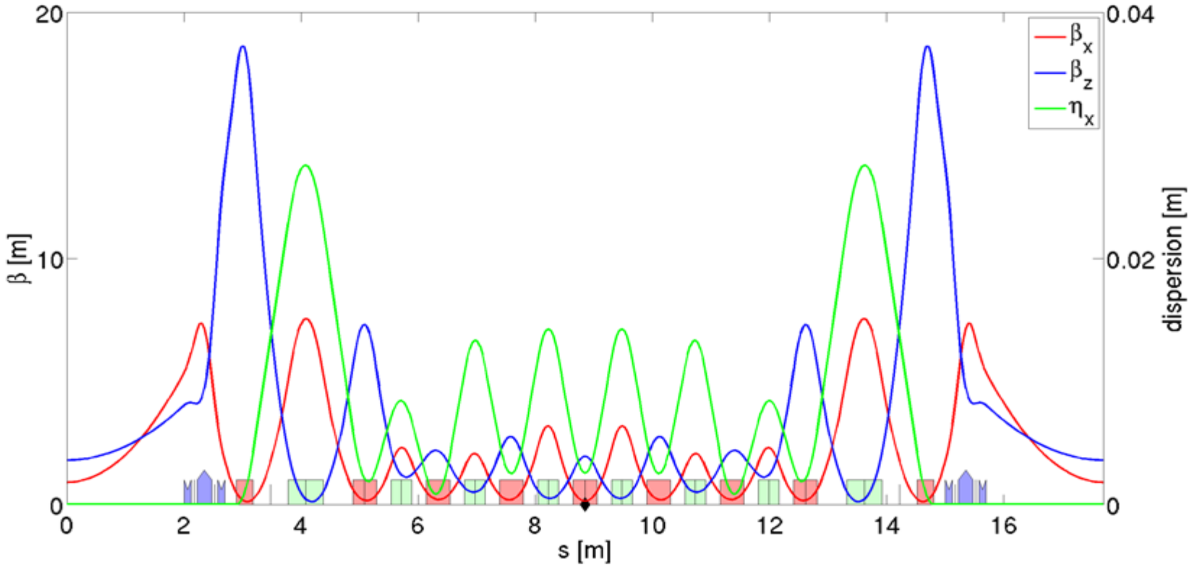
Simple error quad strength by 1‰ rms, 500 trials

Large beta beat of few percents

DA drops from 1.5 to ~1.2 mm

Lower Emittance With On Axes Injection

As a possible candidate ...



9 BA variation giving a natural emittance of 32 pm.rad
Also 20 cells for one turn

On momentum DA is limited but has a rather large off momentum DA
Intensive MOGA optimization
On axis injection / off momentum

Temporal Structure and Short Bunches

Temporal structure

- As today : Hybrid/Camshaft mode, 1 bunch, 8 bunches
- Possibility of Pseudo Single Bunch

C. Sun et al. Realization of Pseudo Single Bunch Operation with Adjustable Frequency., Proceeding of IPAC 2015

Short pulse option

Use of two harmonic cavities of different frequencies «à la BESSY VSR» to shape the longitudinal phase space producing short and long bunches

SOLEIL	f_{RF} (GHz)	V_{RF} (MV)	V'_{RF} (MV. GHz)
Nominal RF SC cavity	0.352	1	2π 0.35
First harmonic SC cavity (n=5)	1.760	10	2π 17.6
S[nd] harmonic SC cavity (n=5+1/2)	1.936	9.1	2π 17.6
Even fixed points			2π 35
Gain			35/0.35 = 100
Theoretical bunch length reduction			$\sqrt{100} = 10$

→ From 24 to 2.4 ps FWHM (at 0 mA)

G. Wüstefeld et al., Simultaneous Long and Short Electron Bunches in the BESSY II Storage Ring, Proceedings of IPAC 2011.

Jankowiaket al., The Bessy VSR Project For Short X-Ray Pulse Production, *Proceeding of IPAC 2016*

Timeline

Date	Phase
Dec. 2016	Council meeting, presentation of the first proposal for an upgrade.
2017 - 2019	Discussions regarding the definition of the project (beamlines and storage ring); definition of objectives. Baseline Lattice defined.
2018 - 2019	Continuation of discussions and prototyping to assess feasibility of key options.
2019	**Decision to launch a Conceptual Design Report (CDR).**
2019-2020	CDR based on preliminary studies and prototyping.
2020	**Decision to launch a Technical Design Report (TDR).**
2020-2022	Technical Design Report.
2022	**Decision to start the project.**
2022-2025	Reconstruction of storage ring and beamlines.
2026	Restart of user operation.

Conclusion

The present SOLEIL upgrade lattice baseline achieve a low natural emittance of 72 pm.rad or 50 x 50 pm.rad at full coupling.

Including a third harmonic cavity should guarantee a correct beam lifetime as well as a limited emittance increase from IBS.

Low beta function at straight level for a good electron-photon matching up enabling a very high brilliance in the 1 to 3 keV region (SOLEIL scientific case target).

Injection is still under investigation while keeping the high lattice symmetry enabling a more comfortable beam dynamics acceptance.

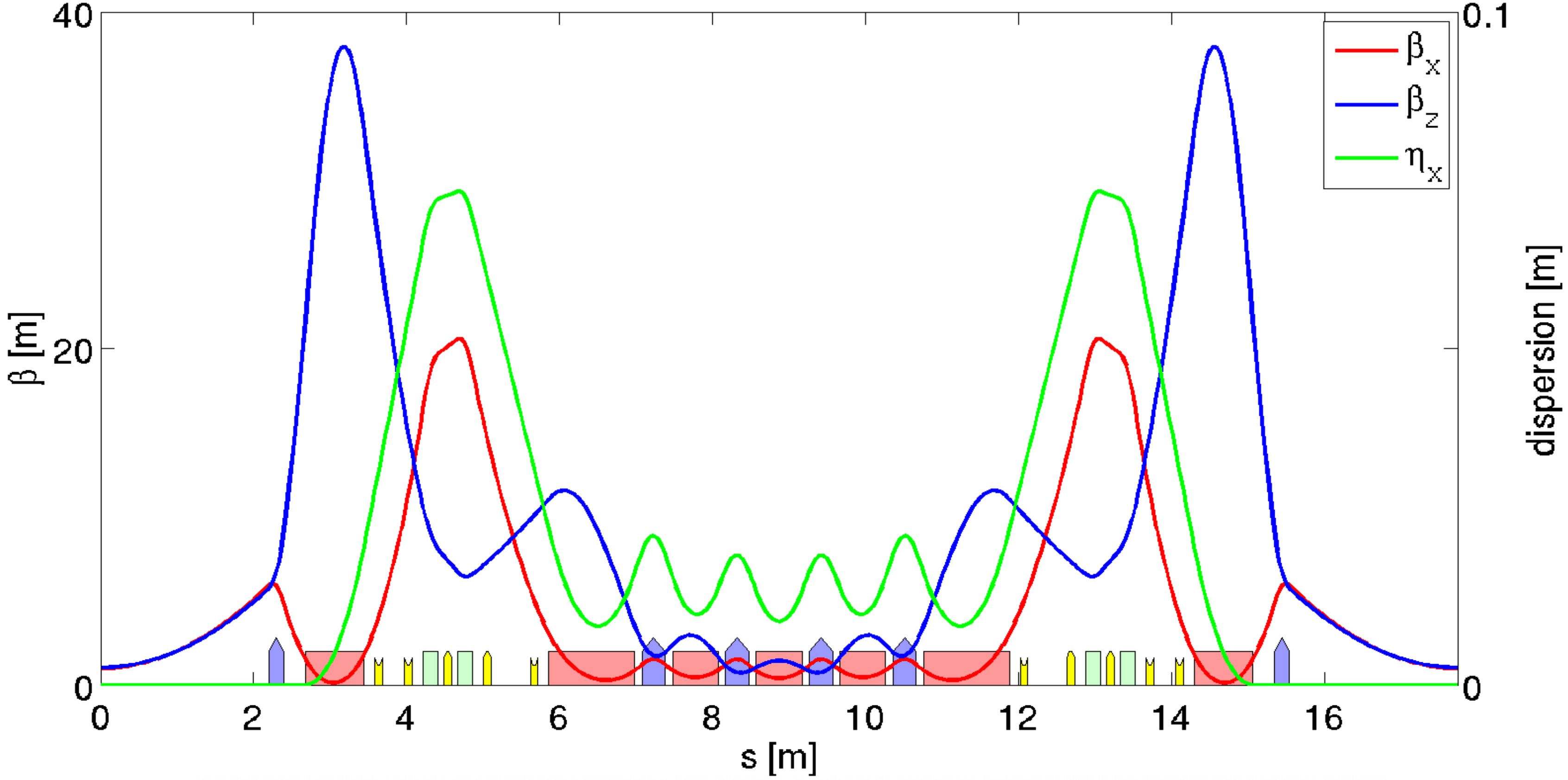
Additional changes (under investigation) :

- Beamlines redistribution
- Injector upgrade with much lower emittance from the booster (130 down to ~30 nm.rad)
- Super-Conducting to warm main RF system (no space anymore and lower voltage needed)
- 8 ratchet walls to be slightly modified

Ongoing task :

- Extensive errors analysis
- Magnet design and pulsed elements feasibility just started

Thank you for your attention


40
20
0
0.1
0
0
2
4
6
8
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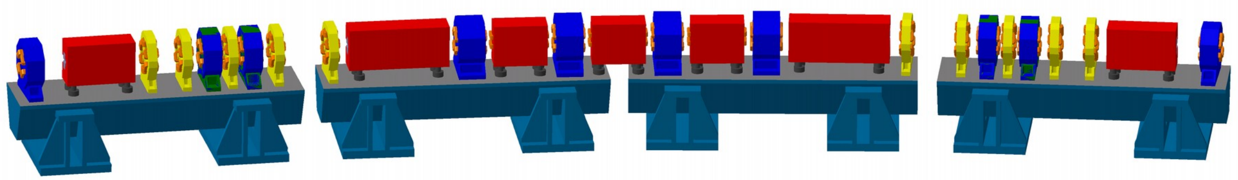
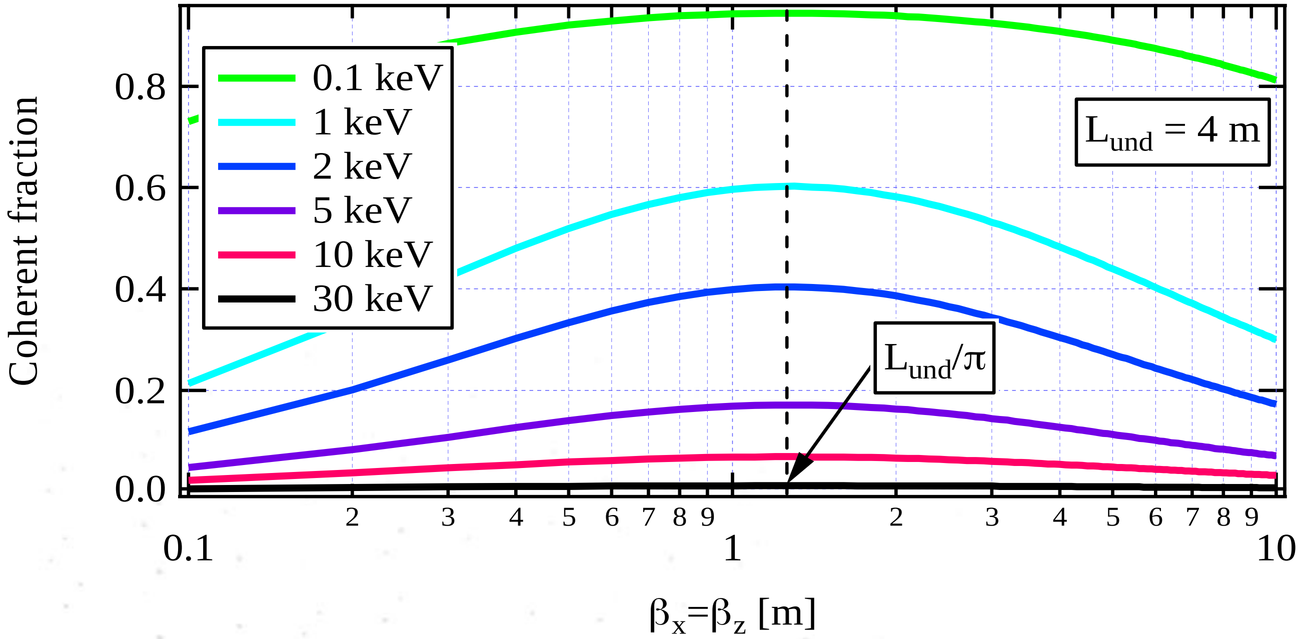
12
14
16
s [m]
β [m]
dispersion [m]
β_x
β_z
η_x





$$TCF = \frac{\left[\frac{\lambda}{2\pi}\right]^2}{\Sigma_x \Sigma_z \Sigma_x{}' \Sigma_z{}'}$$

For a undulator of 4 m, the matched beta function is : $\beta \simeq \frac{L_{und}}{\pi} = 1.27\,m$

Increase the number of FODO-cell by 2 by splitting the long dipole

1/8 of the ring

<u>Actual optics</u>

Natural emittance : 140 nm.rad
110 nm.rad at minimum

<u>Possible upgrade :</u>

Splitting the long 32 dipoles with 32 additional quadrupoles

Natural emittance is 30 nm.rad

Keep RF and injection/extraction section as there are.