SOLEIL UPGRADE IDEAS

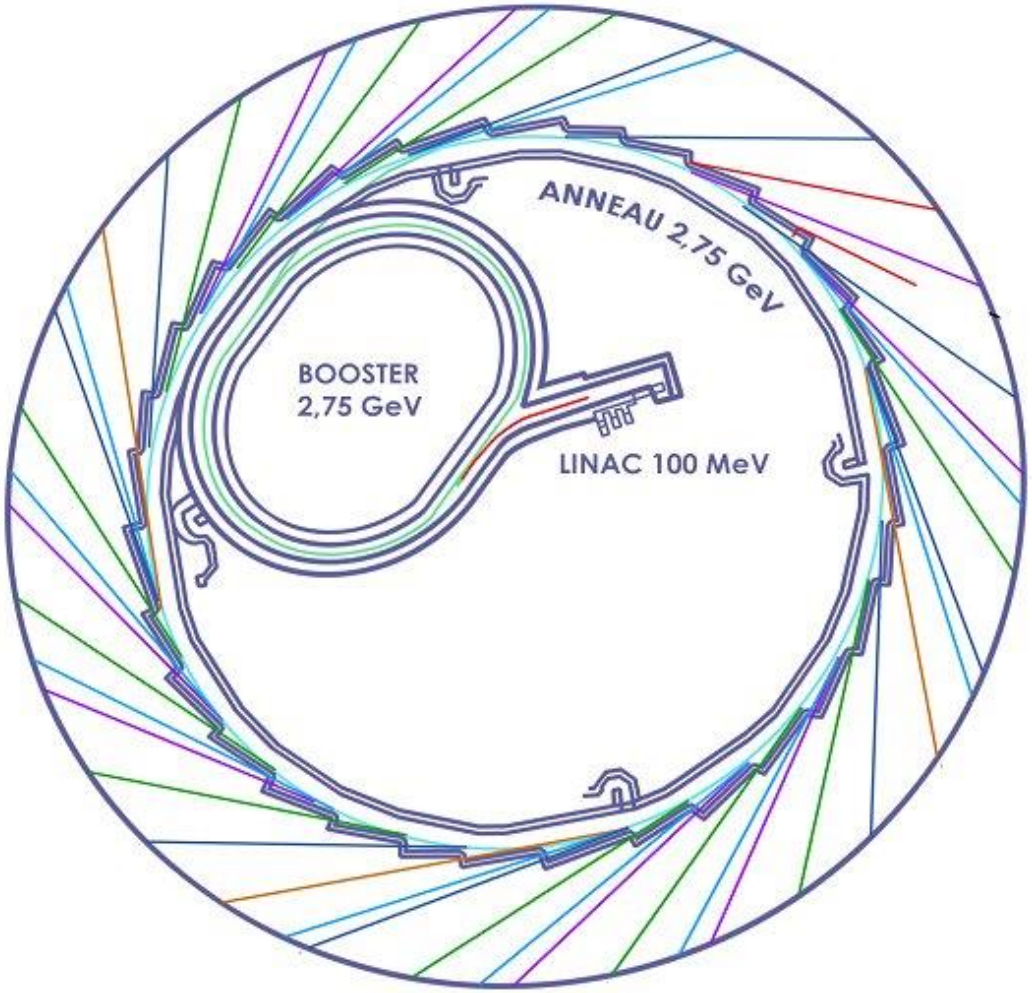
Amor Nadji

On behalf of Synchrotron SOLEIL team

PLAN

- Key features of the current lattice
- Beamlines (distribution, photon spectrum and brilliance)
- Modes of operation and performances
- Current short term projects
- First thoughts about a major upgrade
  - Strategy
  - Constraints and challenges
  - First ideas
- Summary

SOLEIL: 3rd Generation Synchrotron Light Source



Storage Ring Main Parameters

Parameters	Values
Energy (GeV)	2.75
Circumference (m)/RF frequency (MHz)	354.097 / 352.202
Betatron Tunes	18.1580 / 10.2280
Momentum Compaction α_1 / α_2	4.5×10^{-4} / 4.6×10^{-3}
Emittance H (nm.rad)	3.9
Energy spread	1.016×10^{-3}
Coupling, $\varepsilon_V/\varepsilon_H$	1%
Current Multibunch mode (mA)	500
Average Pressure (mbar)	5×10^{-10}
Beam Lifetime (h)	**12 h**

- **Commissioning of the Storage Ring: June-December 2006**
- **First external users: January 2008.**

DBA | High ratio SS/C | 3 SS types | Compact

SOLEIL lattice

Circumference: **354 m**

4 superperiods

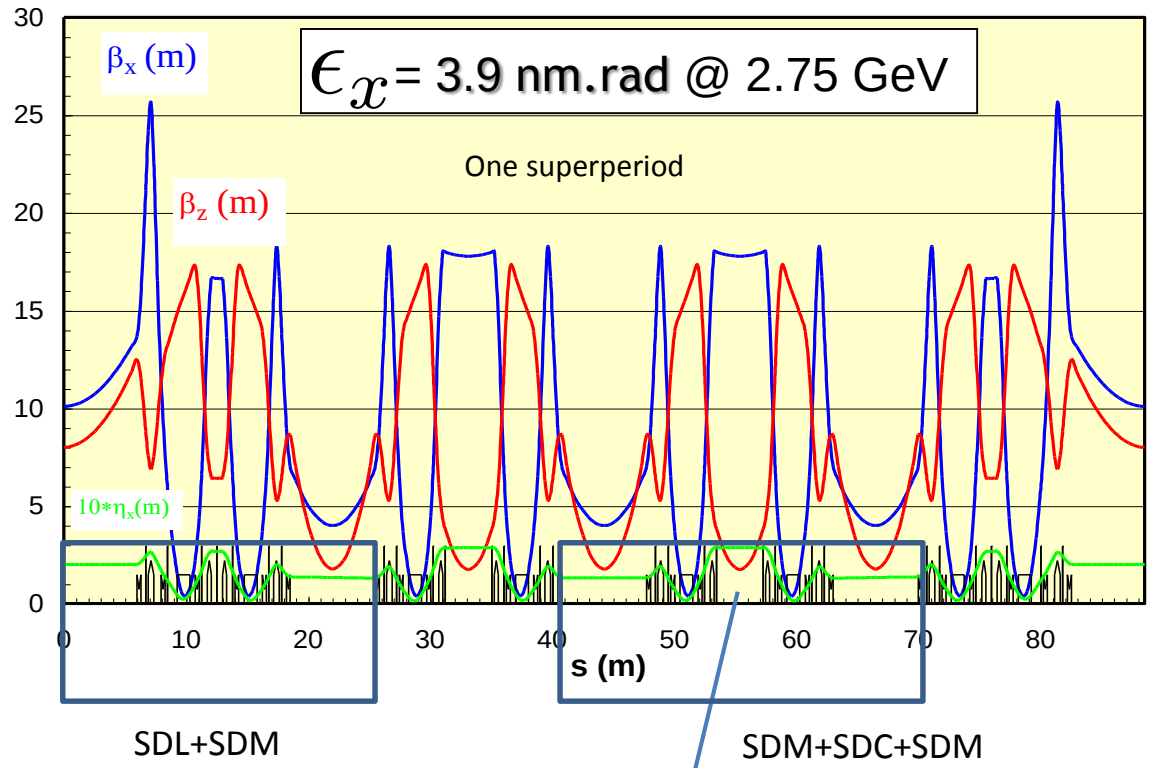
24 straight sections

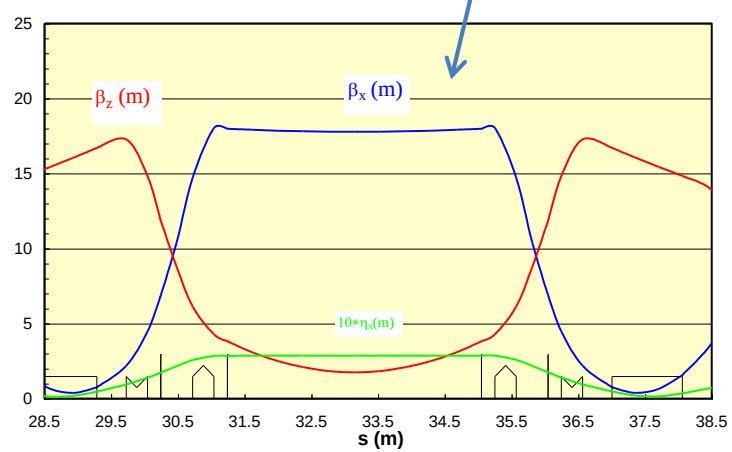
(**21** dedicated to IDs)

4 x 12 m
12 x 7 m
8 x 3.6 m

45% of the circumference available for straight sections

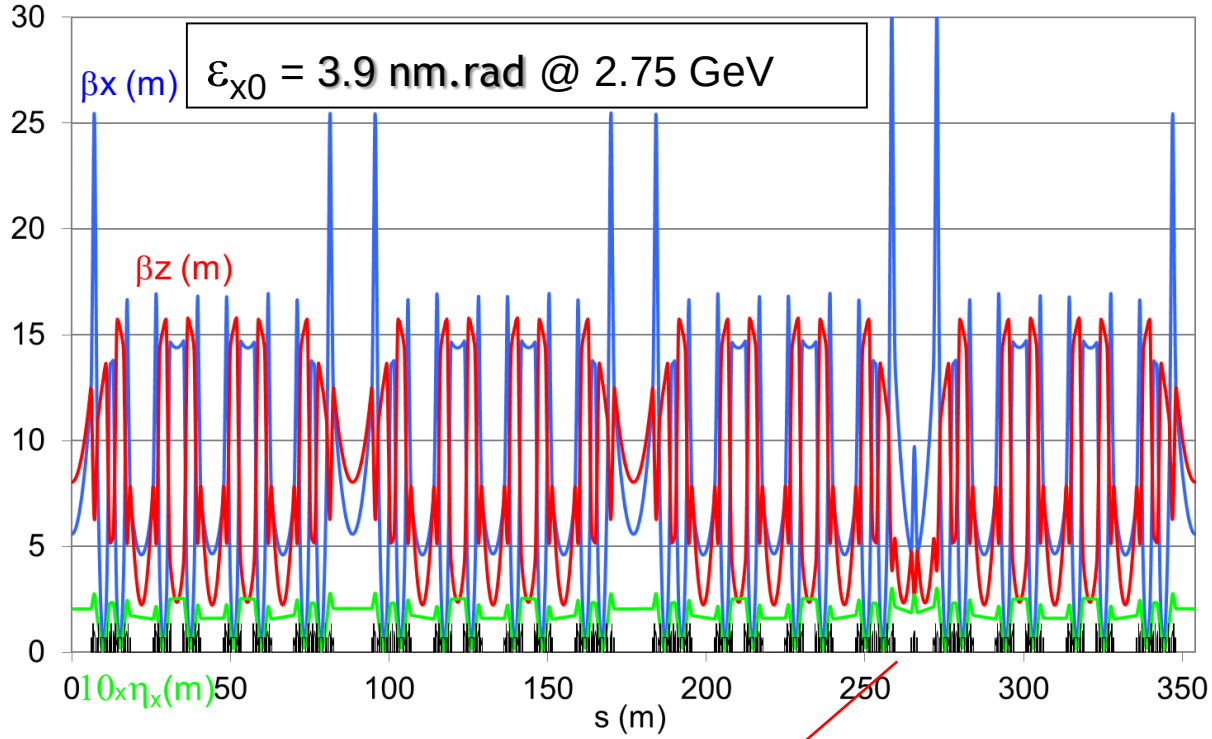
Different β functions in straight sections

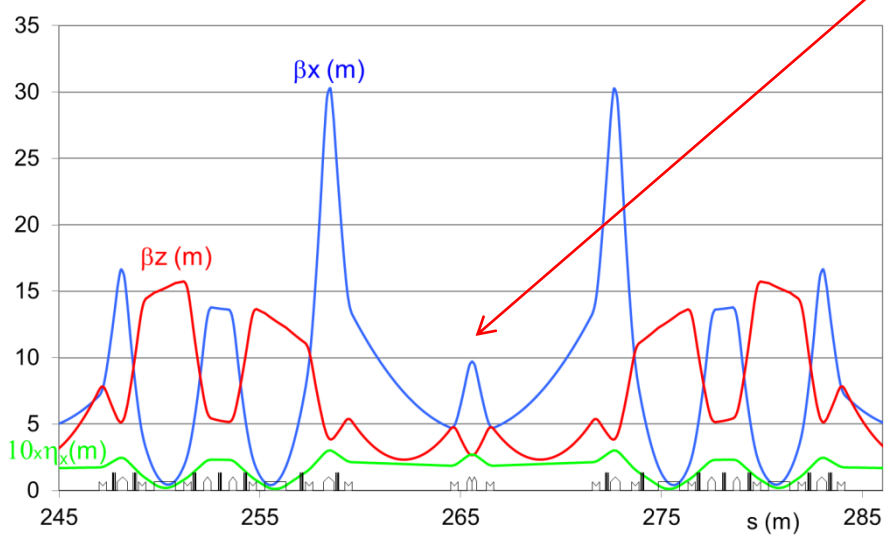




SDL: Long straight section
SDM: Medium straight section
SDC: Short straight section

SOLEIL lattice since January 2012

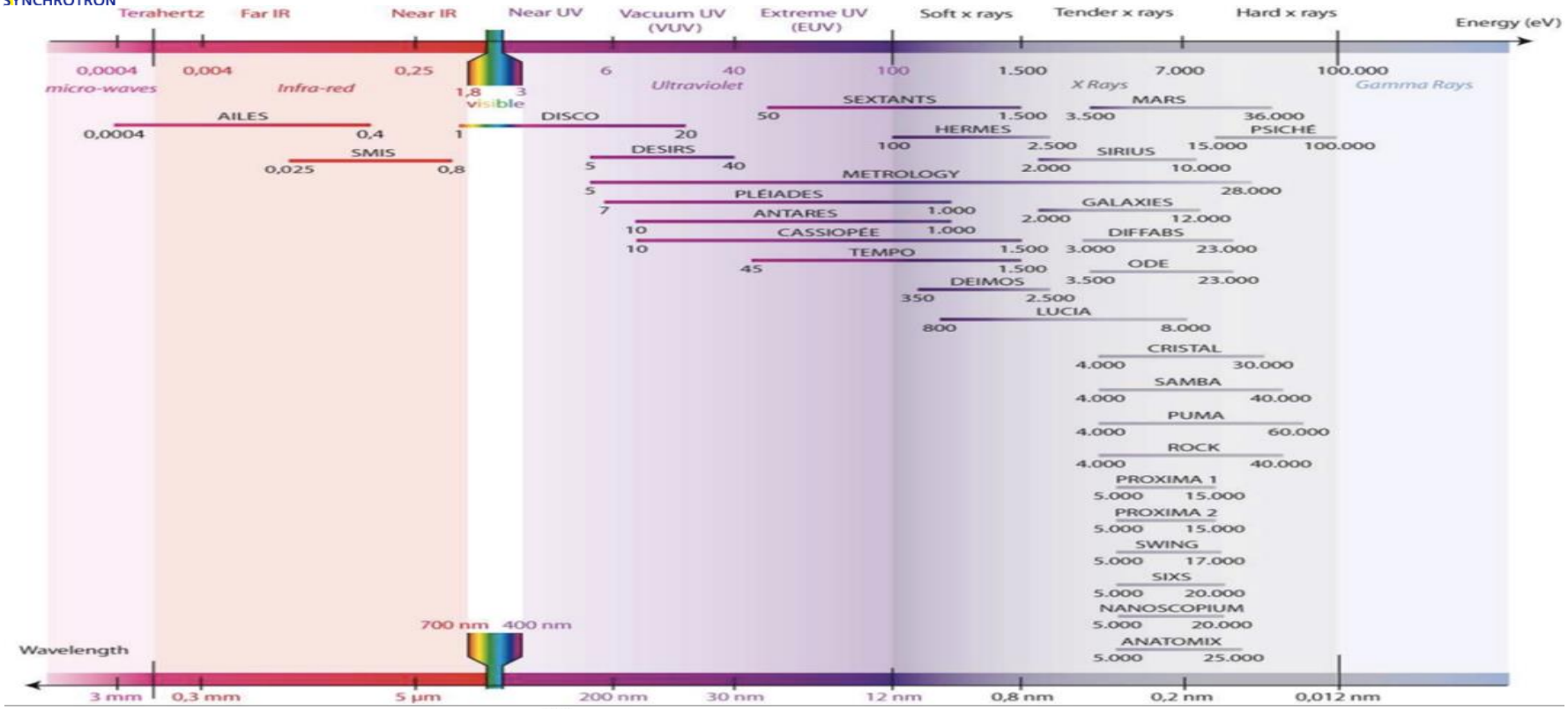




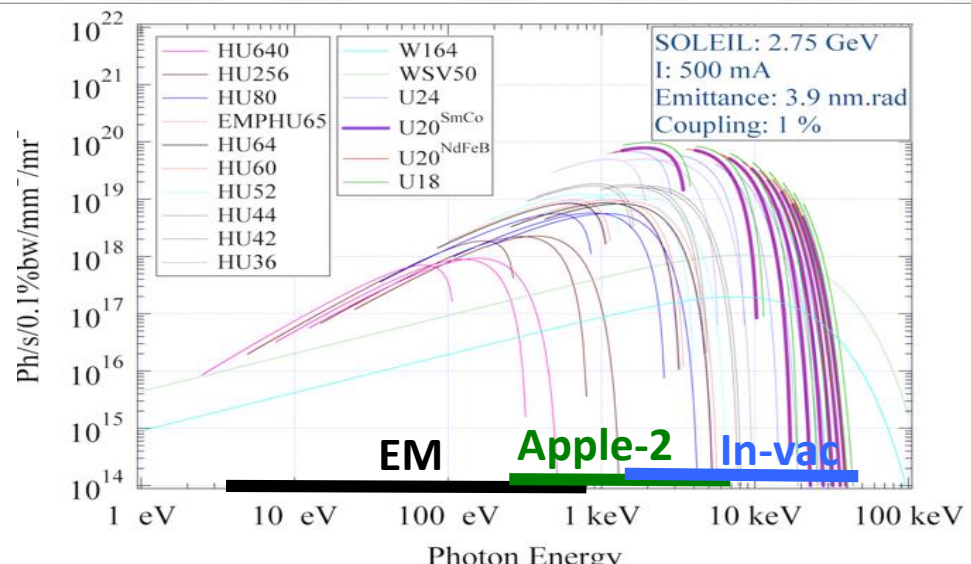
Upgrade of one long straight section (SDL)

- 2 canted in-vacuum undulators of 5.5 mm minimum gap
- 2 long beamlines (~180 m).

Beamlines, brilliance and photon energy spectrum

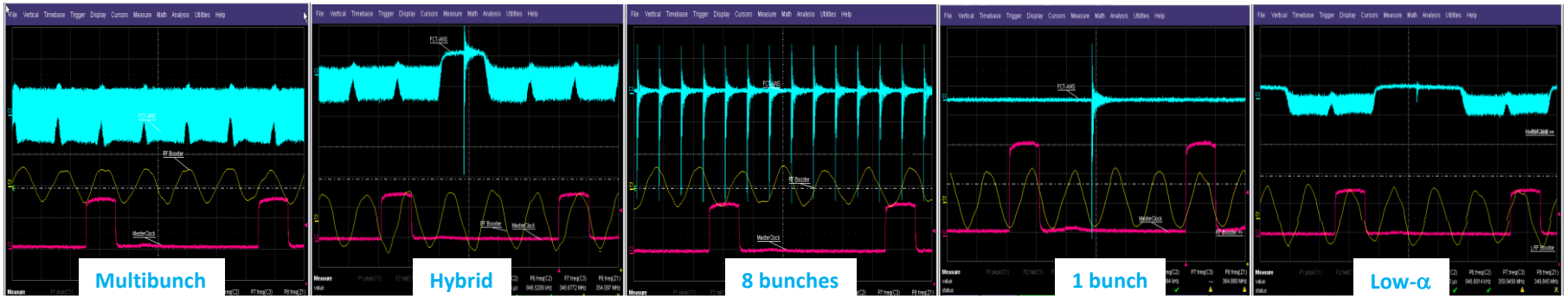


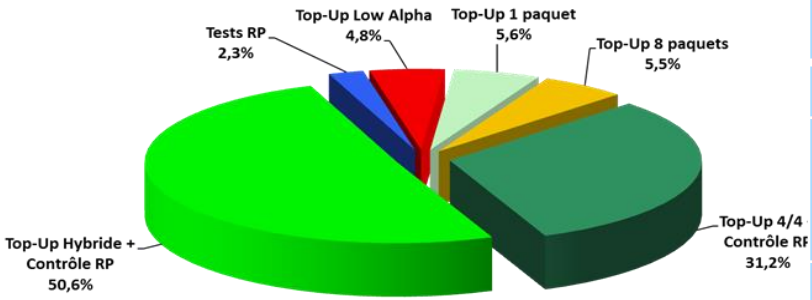
- 29 beamlines
- 3 beamlines are under commissioning
- Will be open to users on January 2017



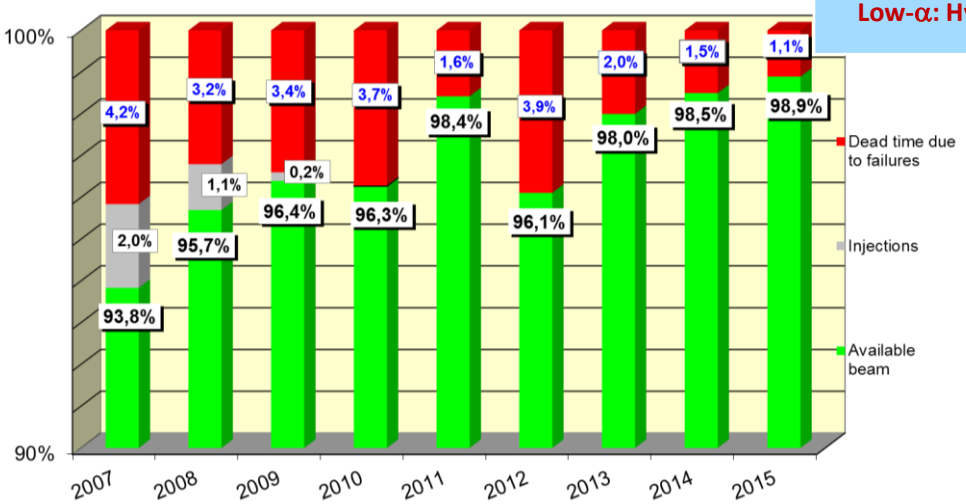
OPERATION

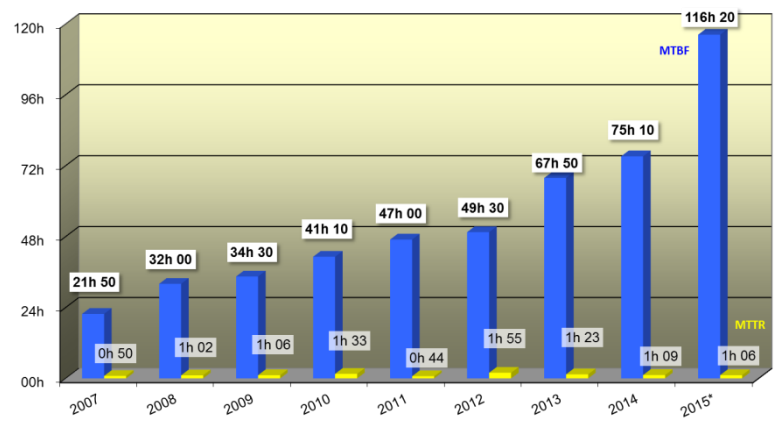
5 modes of operation, all in Top-up mode.





Mode of operation Bunch filling patterns	User Operation in 2016	Ultimate performance achieved
Multibunch	500 mA	500 mA
Hybrid/camshaft mode	425 mA + 5 mA	425 mA + 10 mA
	+ Slicing on high intensity bunch	Slice length < 200 fs FWHM
8 bunches	100 mA	110 mA
1 bunch	16 mA	20 mA
Low-α: Hybrid mode	4.7 ps RMS for 65 µA	< 3.2 ps RMS for 15 µA

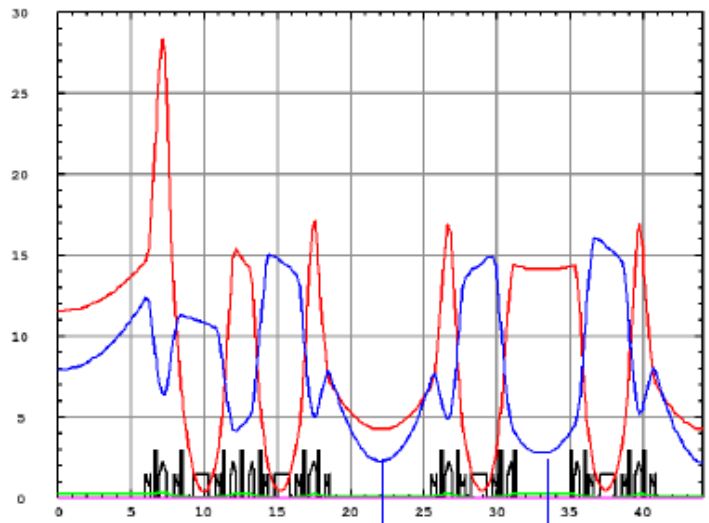




Current short term projects

- Better matching in straight sections hosting high photon energy undulators (β_z ~1m).
- Booster RF upgrade (shorter bunch length).
- Design and construction of a Multipole Injection Kicker (collaboration with MAX IV).
- Local round and ultra low emittance electron beam (collaboration with MAX IV).
- Theoretical and experimental instabilities studies at MAX IV (collaboration with MAX IV).
- Test with users at lower coupling (~ 0.2 %, ε_z ~ 8 pm.rad).

New optics with lower vertical beta in medium and short straight sections



Actual

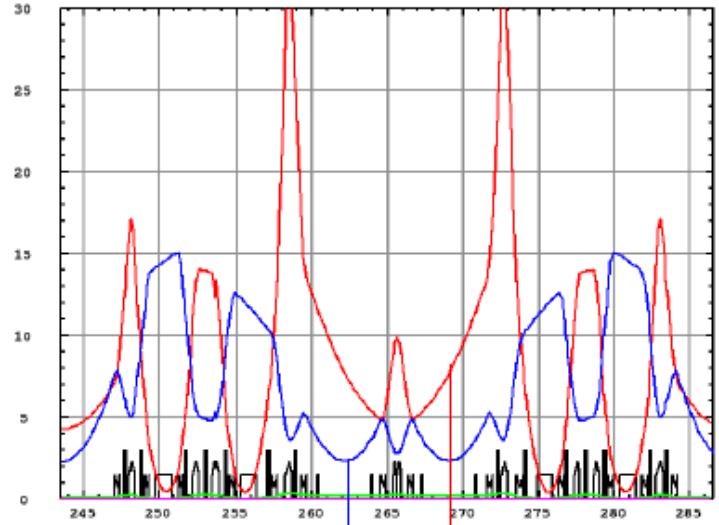
β_z

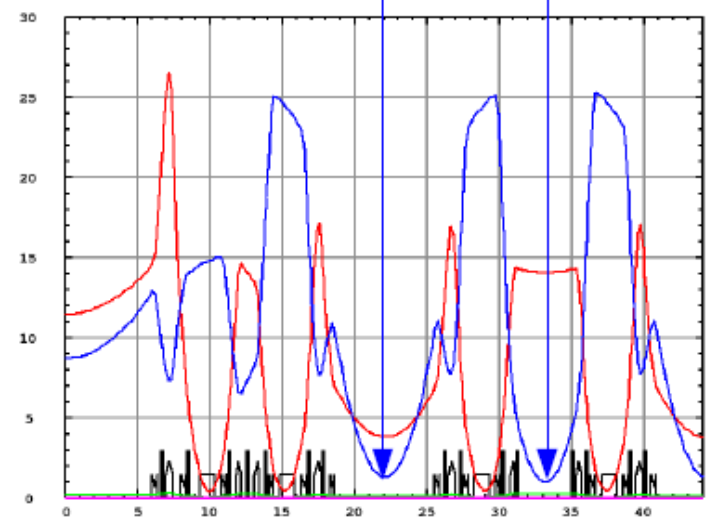
SDC 2.7 m
SDM 2.3 m
SDL13 2.3 m

β_x

SDL13 8 m
High divergence

SDL13





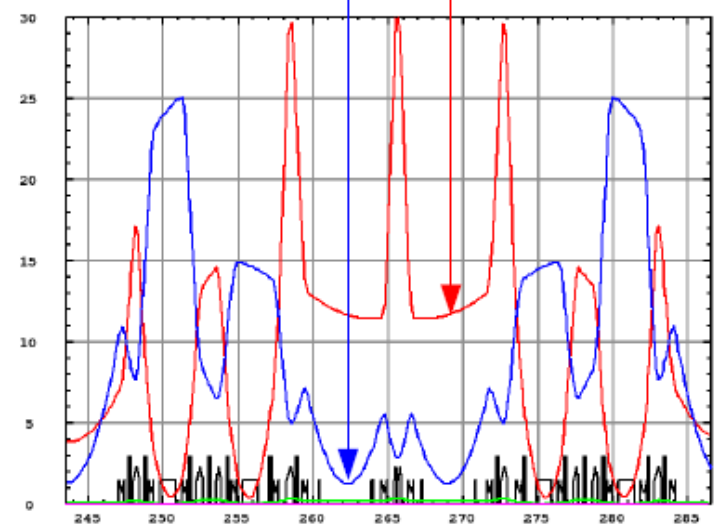
New

β_z

SDC 1.0 m
SDM 1.3 m
SDL13 1.3 m

β_x

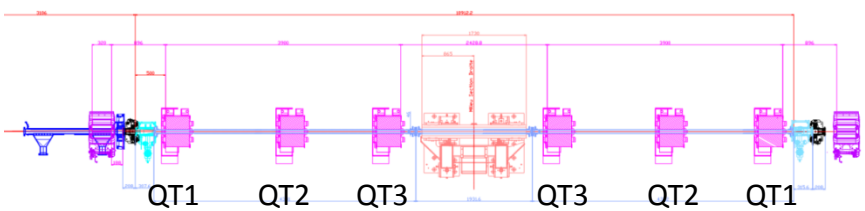
SDL13 12 m
low divergence in horizontal asked by users



Local round and low emittance beam

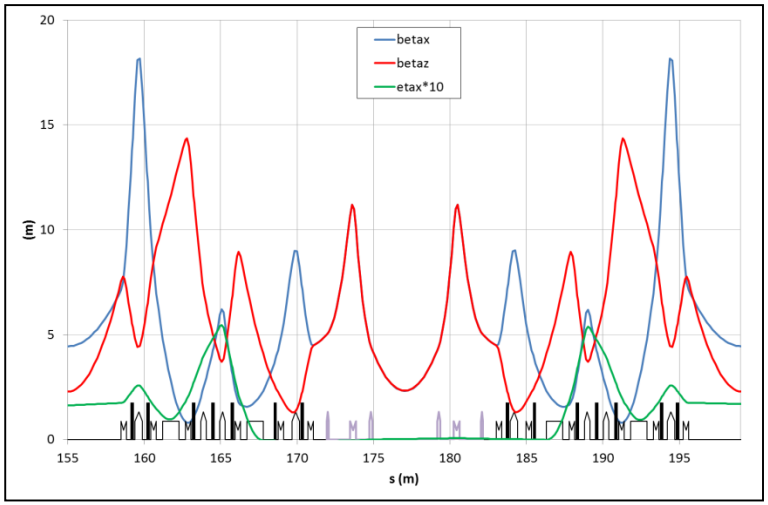
A. Chao and P. Raimondi (SLAC-PUB-14808)

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



- *Skew quadrupole length : L = 0.14 / 0.39 / 0.20 m*
- *Skew quadrupoles gradient < 40 T/m*
- *1 quadrupole of the ring reach gradient > 20 T/m*

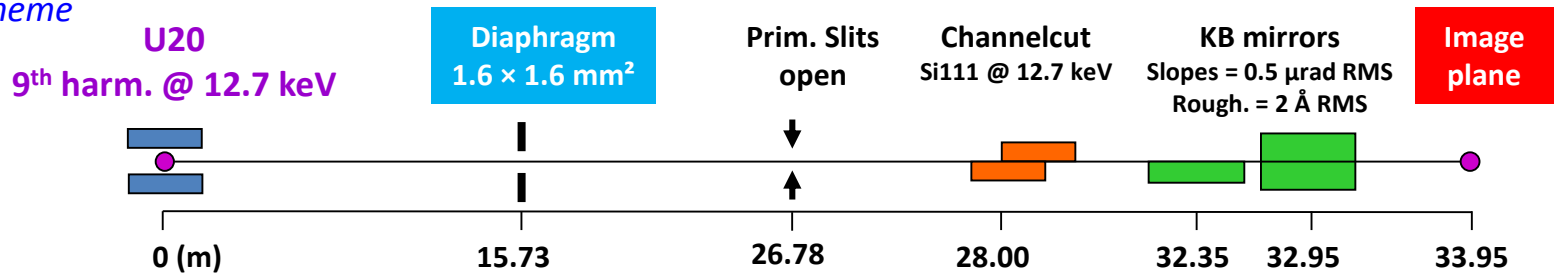
Optics with 4.2 m available for the solenoid



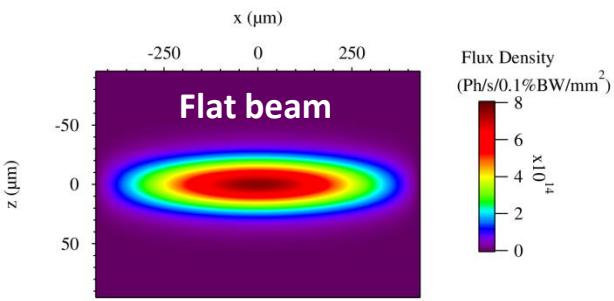
RMS Beam Size and Divergence at source point (Coupling = 0.01)	
	WITH Solenoid 10 T ; 60 T
Horizontal emittance (pm.rad)	400
Vertical emittance (pm.rad)	400
H-size (µm)	60.3 ; 24.6
H-divergence (µrad)	6.6 ; 16.2
V-size (µm)	60.3 ; 24.6
V-divergence (µrad)	6.6 ; 16.2

Local round and low emittance beam:
Application to the bio-crystallography beamline PX2 (SOLEIL)

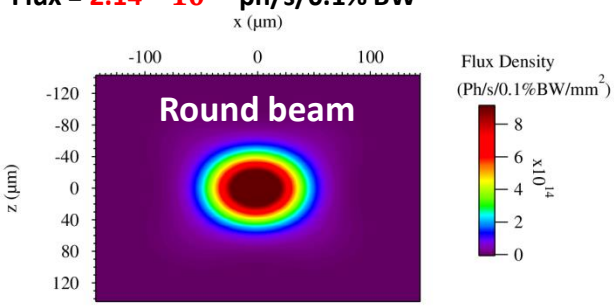
Sideview scheme



Source

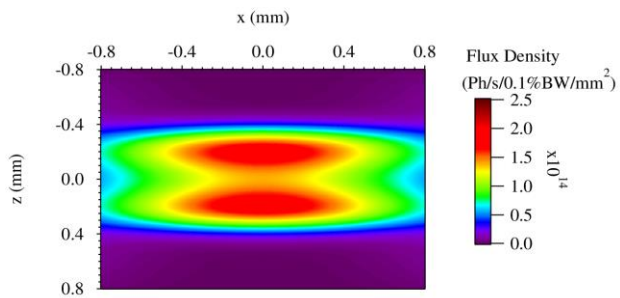


$\Sigma_{x,z}$ = 204.92 × 14.23 µm² (H ×V)
Flux = 2.14 · 10^{14} ph/s/0.1% BW

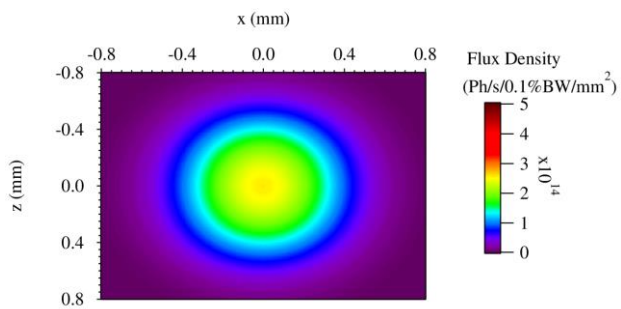


$\Sigma_{x,z}$ = 25.60 × 26.40 µm² (H ×V)
Flux = 1.84 · 10^{14} ph/s/0.1% BW

Diaphragm: SRW, Wave Propagation*

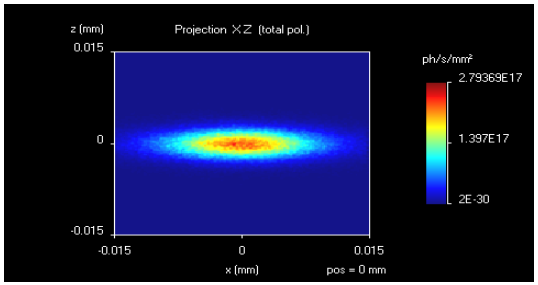


FWHM Sizes = 1.45 x 0.68 mm² (H ×V)
Flux = 1.43 · 10^{14} ph/s/0.1% BW

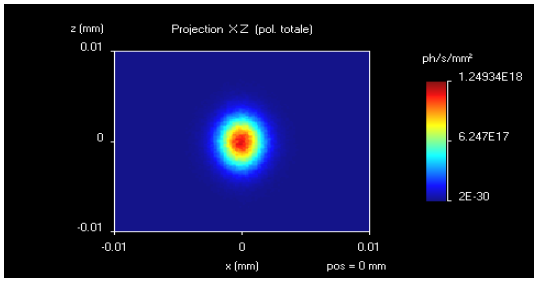


FWHM Sizes = 0.67 x 0.81 mm² (H ×V)
Flux = 1.56 · 10^{14} ph/s/0.1% BW

Sample : SPOTX**



FWHM Sizes = 14.8 × 3.8 µm² (H ×V)
Flux = 1.51 · 10^{13} ph/s



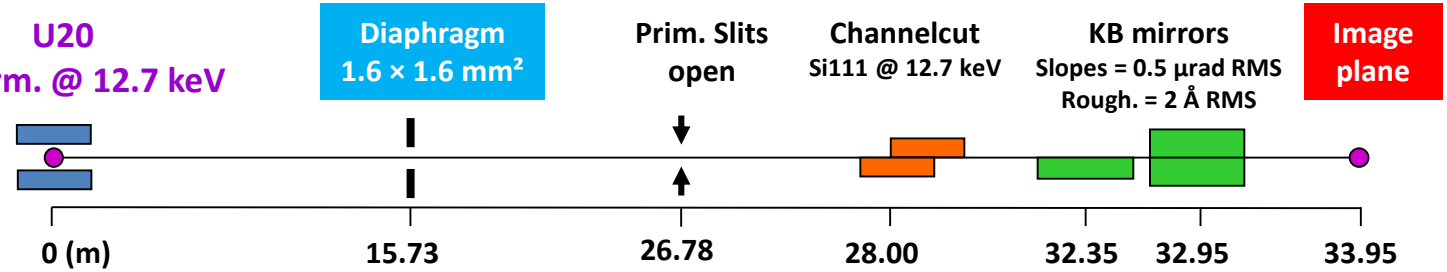
FWHM Sizes = 2.8 × 4.5 µm² (H ×V)
Flux = 1.67 · 10^{13} ph/s

** José-Miguel Luque-Raigon (post-doc in Accelerator Physics group at SOLEIL)*

*** Moreno, T. & Idir, M., (2001). J. Phys. IV France **11**, 527–531*

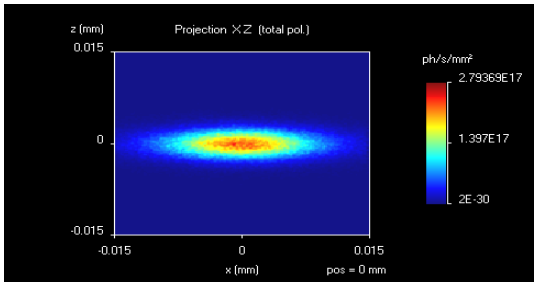
Local round and low emittance beam:
Application to the bio-crystallography beamline PX2 (SOLEIL)

Sideview scheme



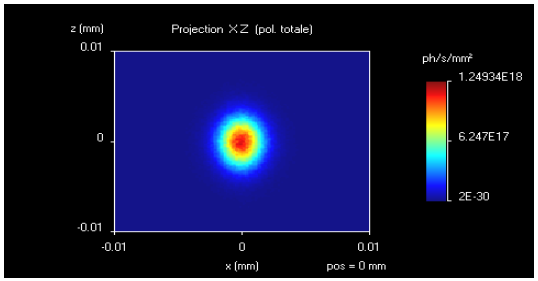
Sample : SPOTX**

Flux Density (ph/s/mm^2) = 2.7 10^{17}



FWHM Sizes = 14.8 × 3.8 µm^2 (H ×V)
Flux = 1.51 · 10^{13} ph/s

Flux density at the sample is increased by a factor of 5



Flux Density (ph/s/mm^2) = 1.3 10^{18}

FWHM Sizes = 2.8 × 4.5 µm^2 (H ×V)
Flux = 1.67 · 10^{13} ph/s

** José-Miguel Luque-Raigon (post-doc in Accelerator Physics group at SOLEIL)*

*** Moreno, T. & Idir, M., (2001). J. Phys. IV France **11**, 527–531*

Towards a test with users at lower coupling (~ 0.2% ε_z ~ 8 pm.rad).

- Global feedback by means of a modulated vertical dispersion wave : **Done**
- Local ID (high frequency) coupling feedforward, to cancel ID contribution to the coupling : **in progress**
- Re-alignment of the storage ring : **in progress**
- Local ID focusing feedforward, to cancel ID contribution to the beta beating : to be foreseen in order to make reliably the online measurement of emittance and energy dispersion at pinholes.
- Optimization of Transverse Feedback parameters versus current at minimum coupling .

First thoughts about a major upgrade:

- Strategy
- Constraints and challenges
- First ideas

Strategy

Development of Scientific case

Scientific Sections				
Surfaces-Interfaces-Nanosystems	Atomic and molecular Physics	Biology and Health	Physical Chemistry of soft condensed matter	Physical Chemistry of hard condensed matter

User community representatives

Started October 2015, first draft available from 1 section.

Presentations :
r f
c ities
: ges in
your domain ».
Refined scientific case per subject domain.

Starting March 2016

vision
o
beamline representatives.
Refined requirements.

Started early 2015.

e
improvements.
Optimise source

Provisional cost and time scale estimates => Upgrade Plan version 1 (November 2016 for the SAC and December 2016 for the council)

Consultation

Strategy

- **The Final requirements should derive from future science goals.**

- **Target date: 2025**

- **First directions:**
  - Higher brilliance and coherence fraction.
  - Short « intense » pulses.

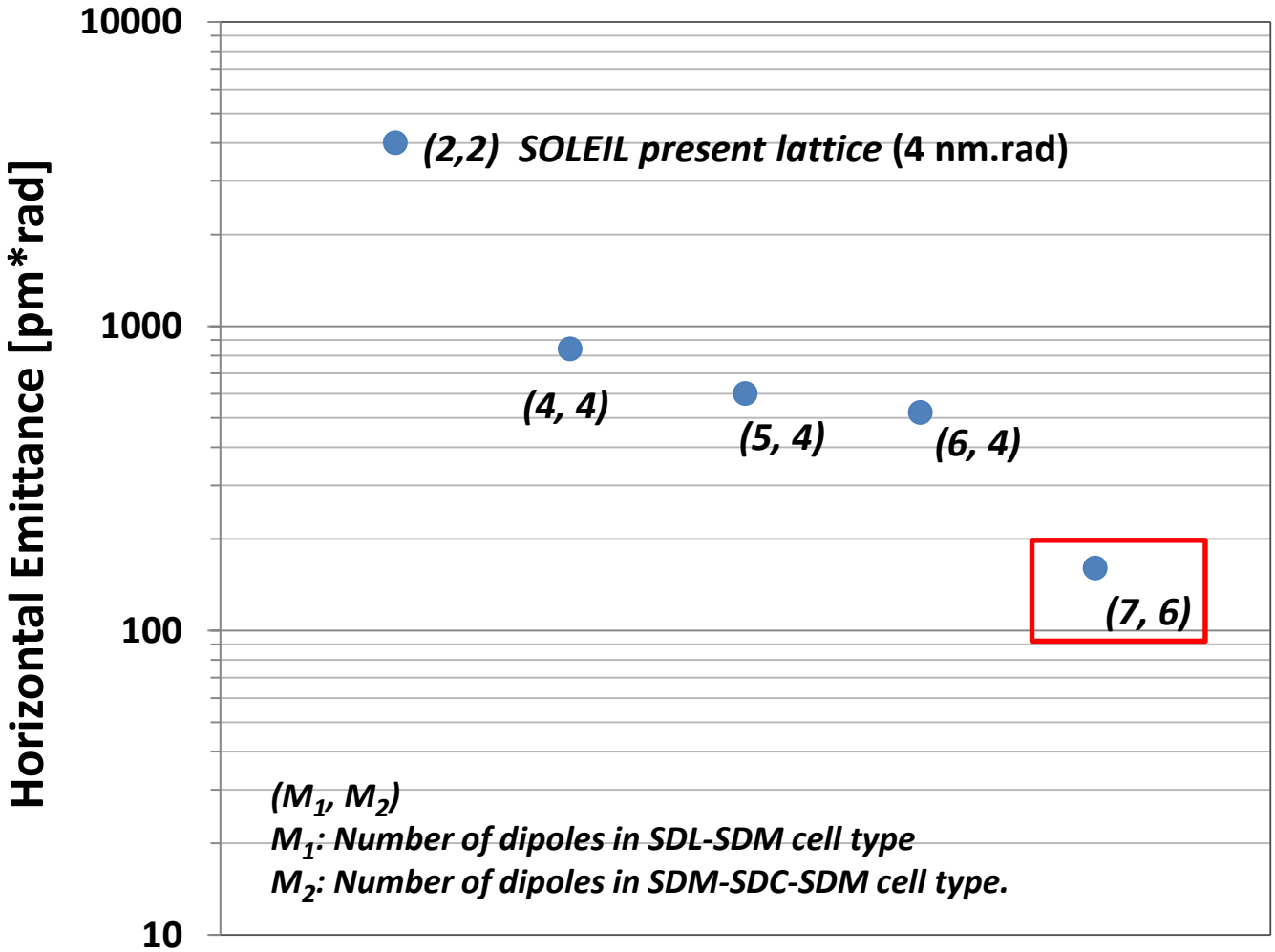
Constraints and Challenges

- Constraints
  - Get more than a factor 10 lower H-emittance (< 400 pm.rad).
  - Keep circumference, tunnel & hall.
  - Keep beamlines source points.
  - **Serves very broad photon energy range: from IR to 30 keV on undulators and to 80 keV on wigglers.**
  - Re-use injector: Linac & booster.
  - Radiation shielding.

- Main challenges:
  - Small circumference (354 m).
  - Presence of short straight sections.
  - Versatile communities.

First Ideas

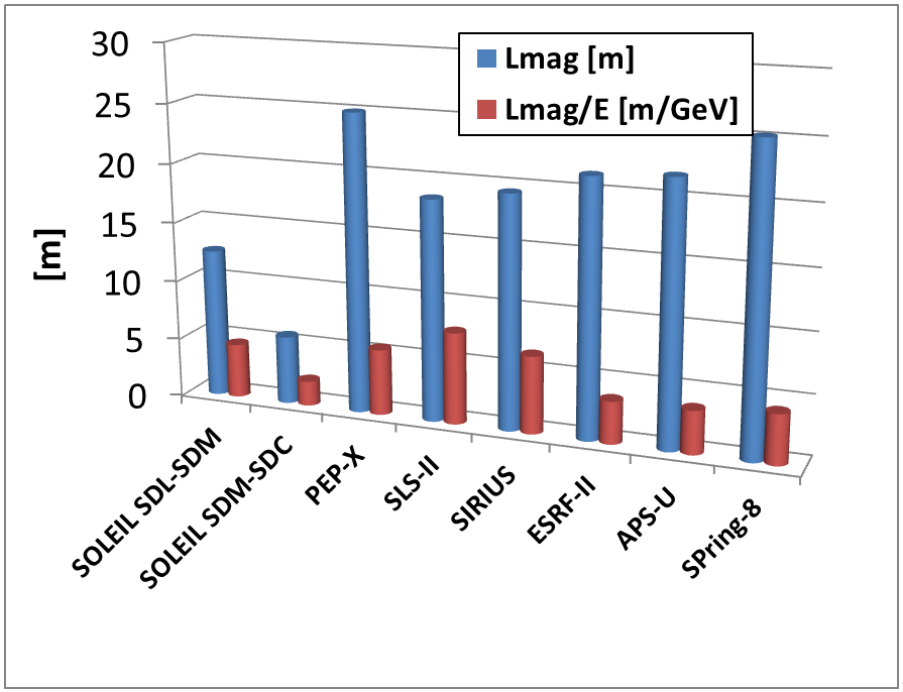
Use MBA structure to reduce the horizontal emittance



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

- Lengths of the magnet sections are quite limited in the current SOLEIL configuration:

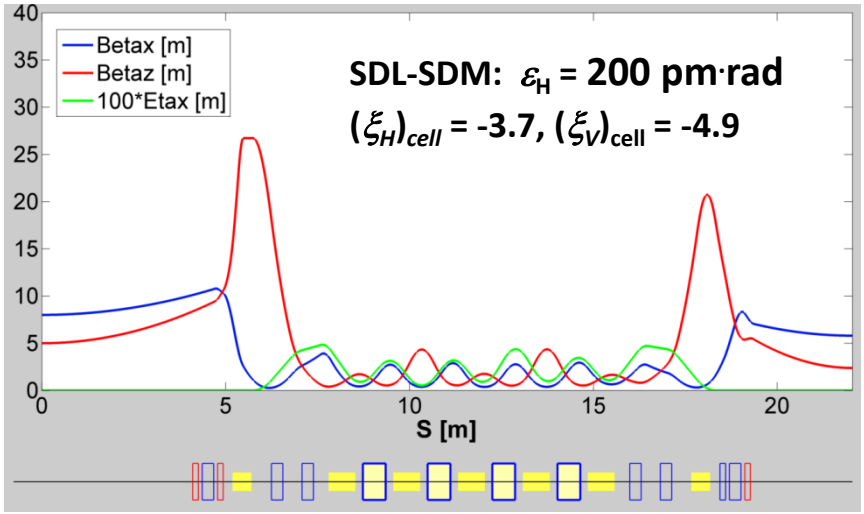
  12.5 m (SDL-SDM) and 5.73 m (for each side of SDM-SDC-SDM)

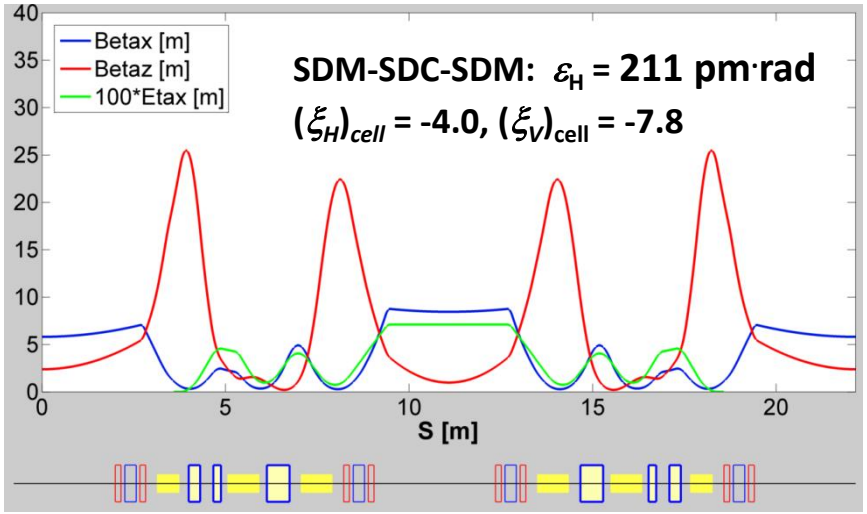


- Preliminary results (presented at IPAC2015) indicate that;
  - Horizontal emittance in the 100 ~ 200 pm.rad range appears reachable.
  - However, the required focusing strengths and chromaticities “blow up” as expected.

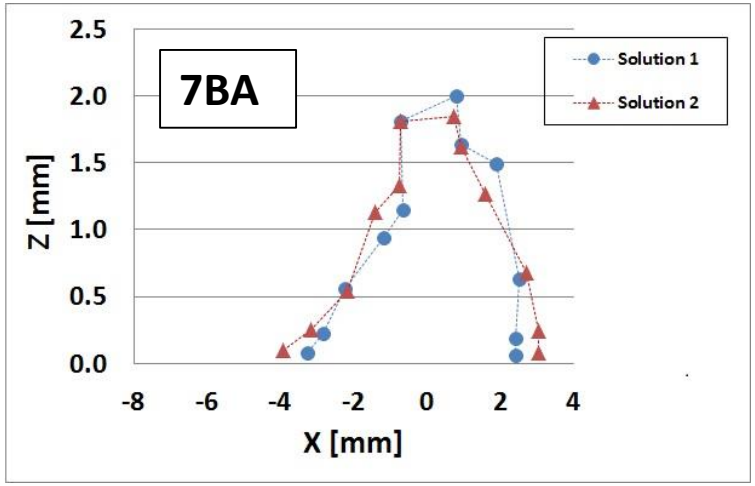
Ongoing studies on 7BA-6BA lattice

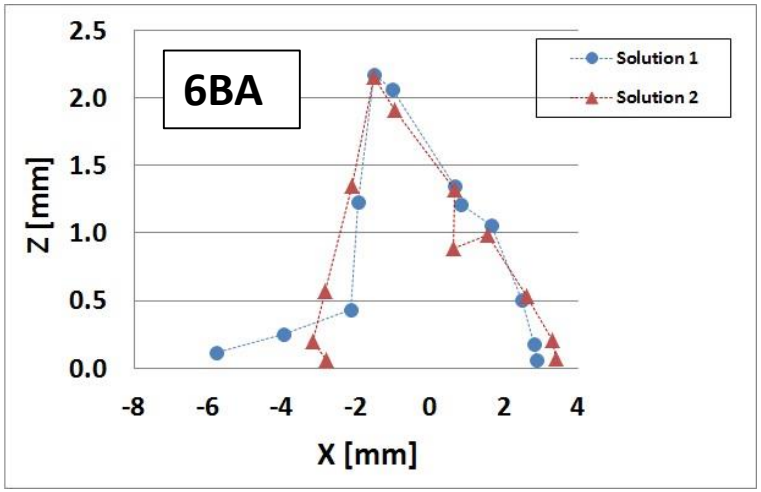
- **Solution with increased magnet sections, lower dipole fields (0.8 T) and integrating anti-bends in focusing quadrupoles.**



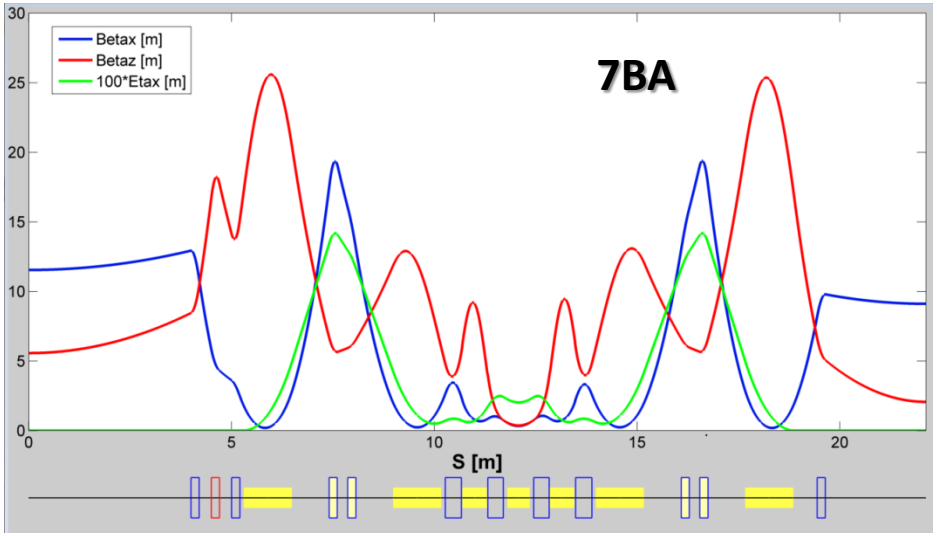


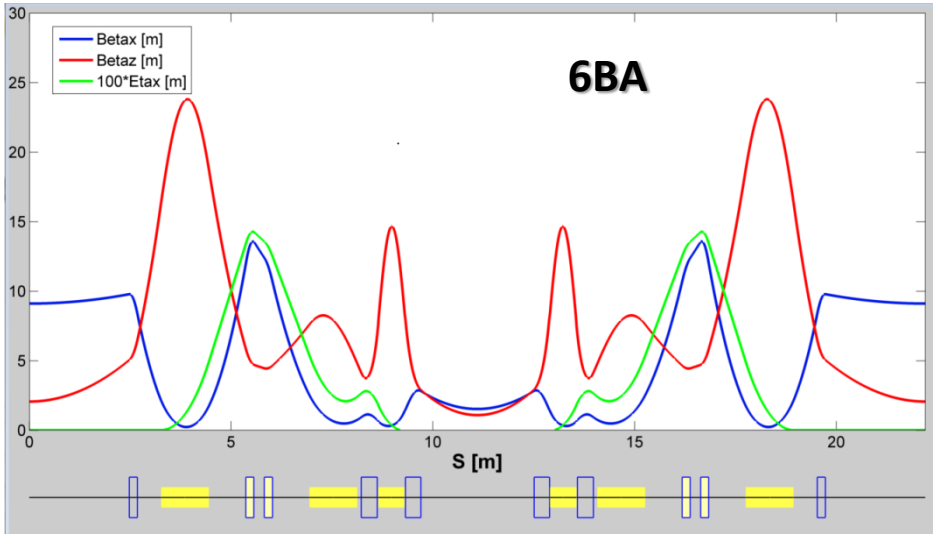
⇒ **SDL = 9 m instead of 12 m; SDM= 5 m instead of 7 m and SDC= 2.8 m instead of 3.8 m.**

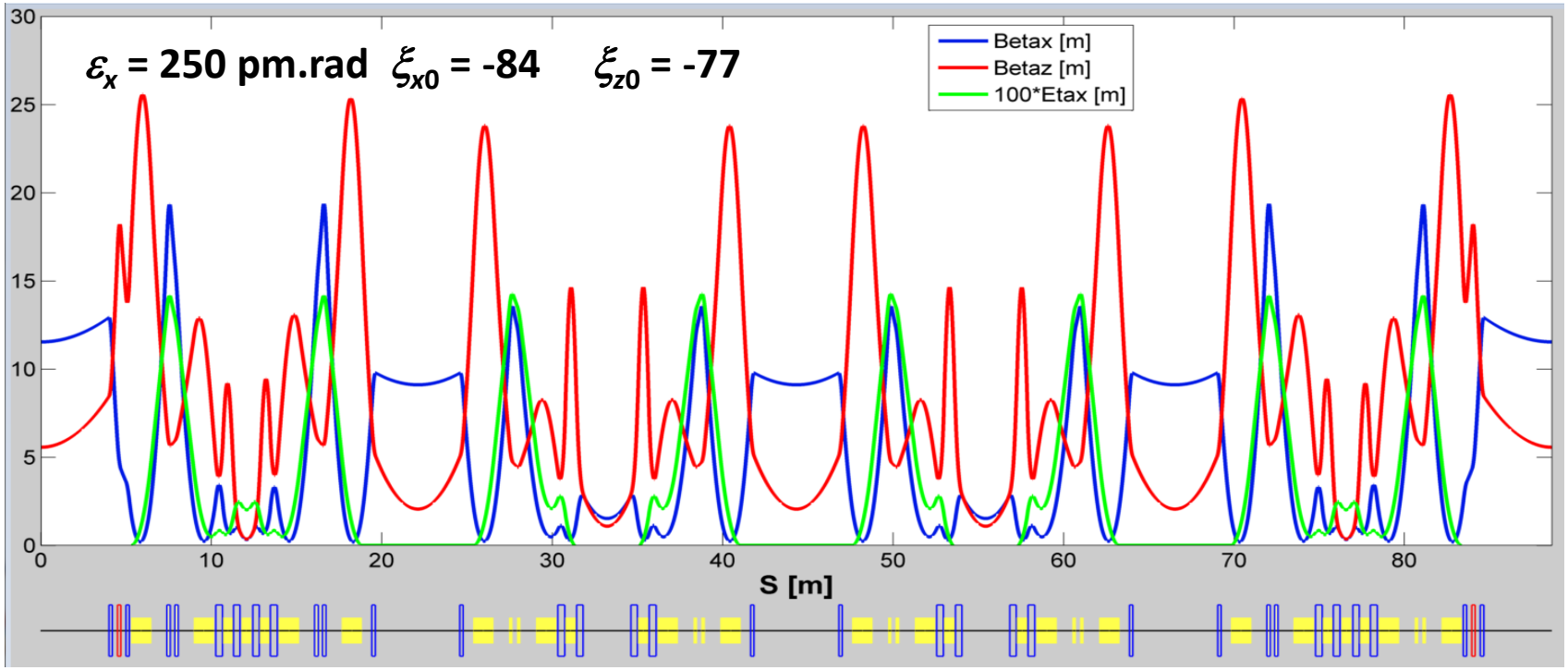




Lattice based on 7BA (à la ESRF) and 6BA (à la Diamond)

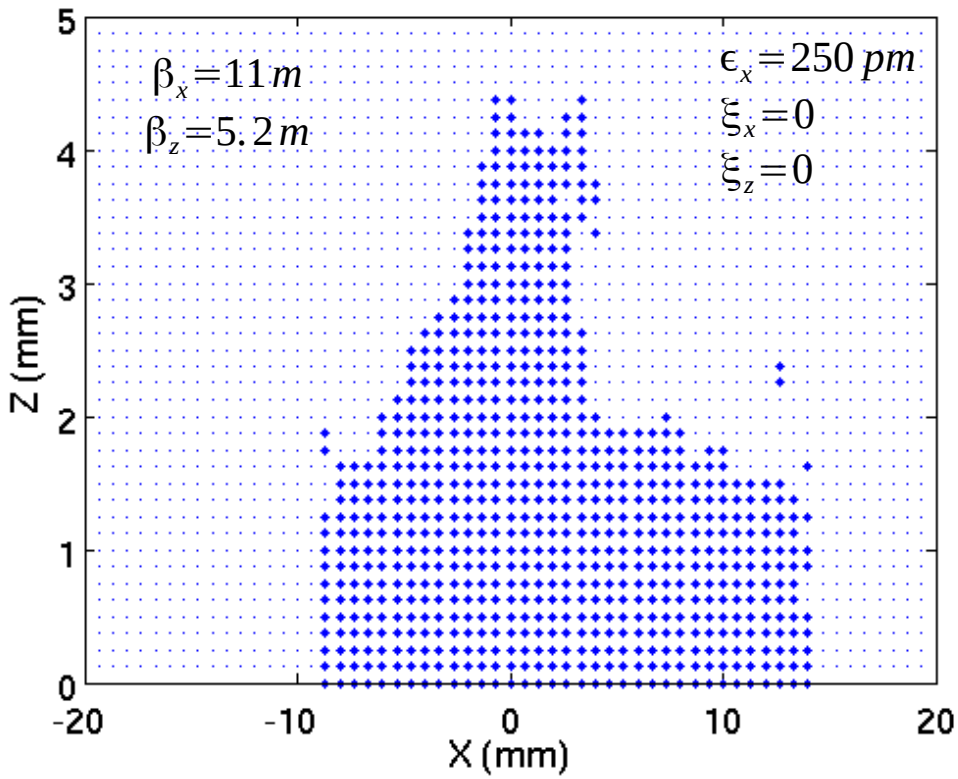






Lattice based on 7BA (à la ESRF) and 6BA (à la Diamond)

- Optics : - I transformation phase shift and sextupoles optimisation
- Straight sections: SDL = 8 m, SDM = 5 m and SDC = 2.8 m
- Gmax = 80 T/m and SLmax = 160 T/m (integrated)
- Off momentum aperture not good yet



Schematic Layout of Today Proposal for the Storage Ring Upgrade

SDL 1

7 BA + 6 BA

Nominal operation :

ε_x ~ 200 pm.rad
ε_z ~ 8 pm.rad
I = 500 mA
σ^*_l > 45 ps (RMS)

SDL 4

SDL 2

Short bunch operation :**

ε_x ~ 600 pm.rad
ε_z ~ 50 pm.rad
I = 100 mA
σ_l ~ 1 ps (RMS)

SDL : long straight section (12 m)

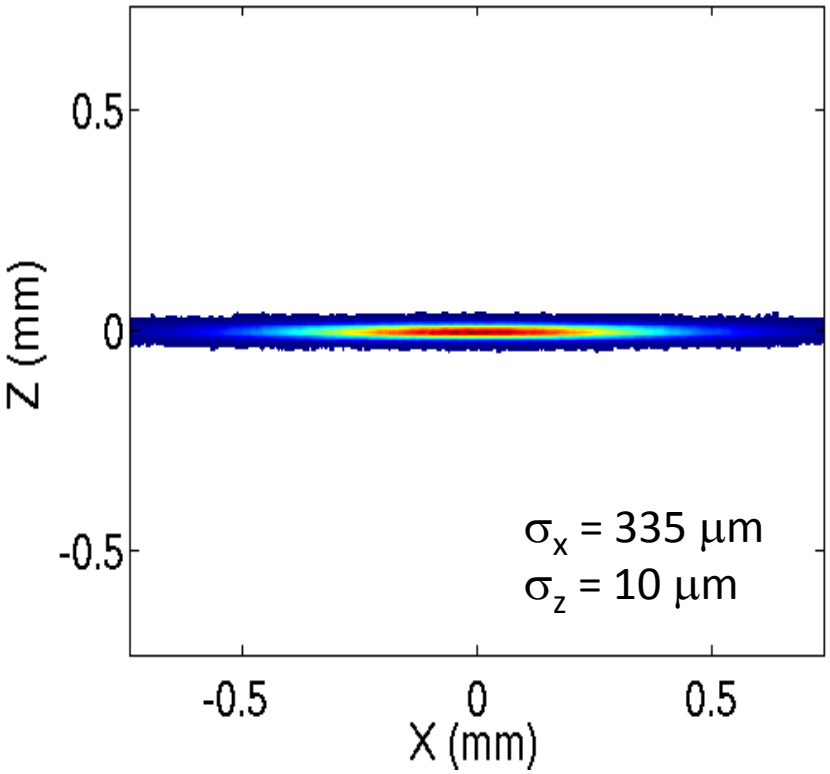
: nominal RF frequency (352 MHz) + additional cavities (either like VSR project or using Crab cavities)

SDL 3

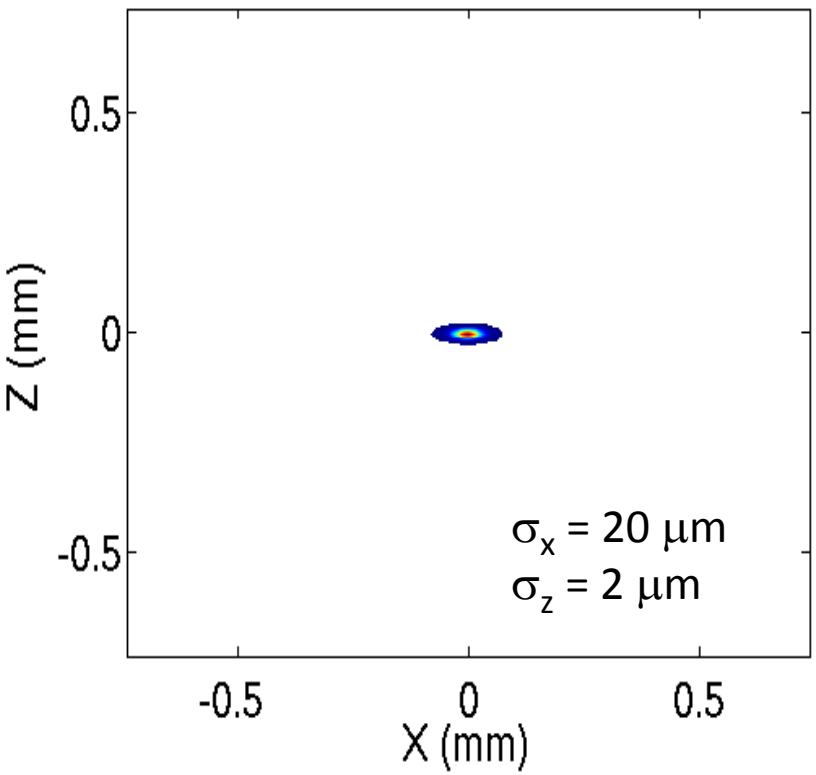
***: obtained with a harmonic cavity tuned to lengthen the bunch (> x 3).**

Electron Beam size comparison

SOLEIL today



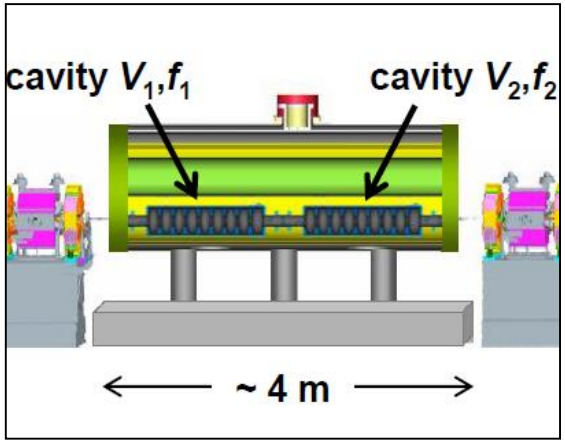
SOLEIL tomorrow



Calculation performed in a short straight section with ε_x = 250 pm.rad

Simultaneous short and long bunches

- Shaping the longitudinal phase space by high gradient SC systems.
- BESSY VSR project : **use of two harmonic cavities with two different frequencies.**
- Substantial challenges: high gradient "HOM free" SC cavities, stability requirements, lifetime, …



SOLEIL	f_{RF} (GHz)	VRF (MV)	V'_{RF} (MV. GHz)
Nominal RF SC cavity	0.352	2.5	2π x 0.88
First harmonic SC cavity (n=5)	1.760	25	2π x 44
Second harmonic SC cavity (n=5+1/2)	1.936	22.7	2π x 44
Even fixed points			2π x 88
Gain			88/0.88 = 100
Bunch length reduction			$\sqrt{100} = 10$

(very preliminary)

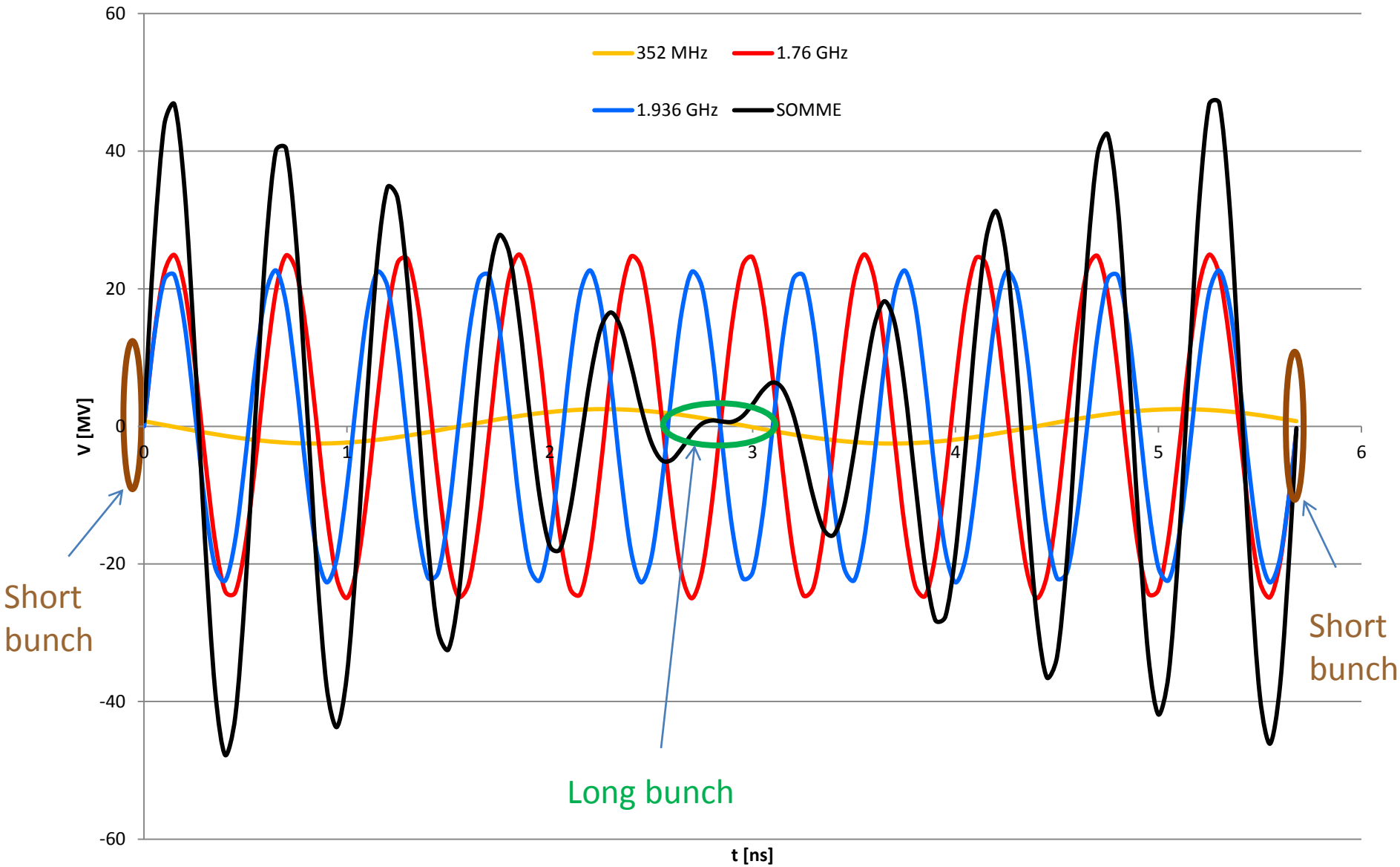
$$\sigma_l \propto \sqrt{\frac{\alpha}{V'}}\,\sigma_E$$

$$V' = \frac{dV}{dt} = 2\pi\, f_{RF}\, V_{RF}$$

Nominal bunch length ≈ 15 ps RMS
short bunch of 15/10 ≈ 1.5 ps RMS

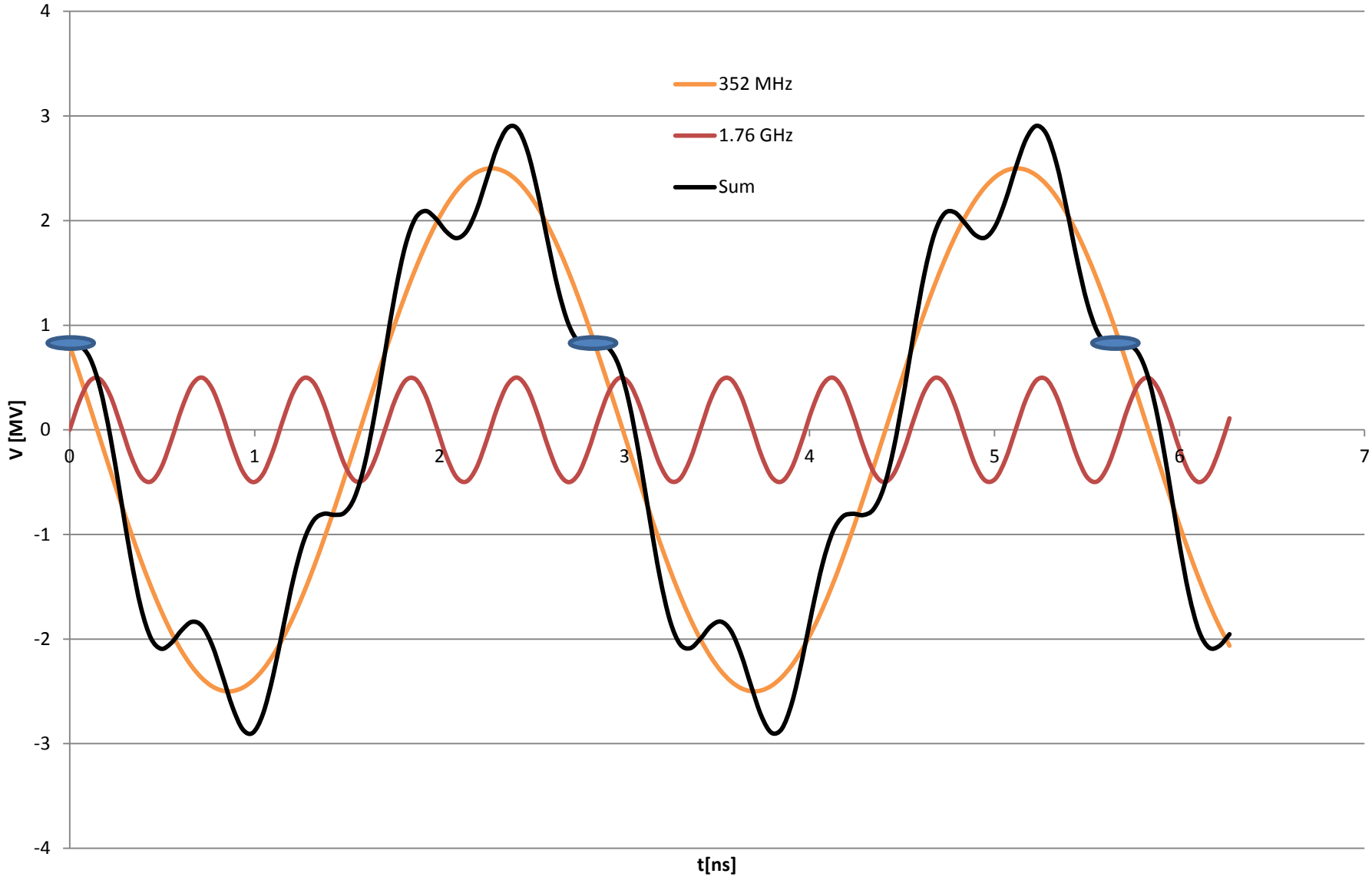
G. Wüstefeld et al.
Proceedings of IPAC2011, San Sebastian, Spain

Simultaneous short and long bunches

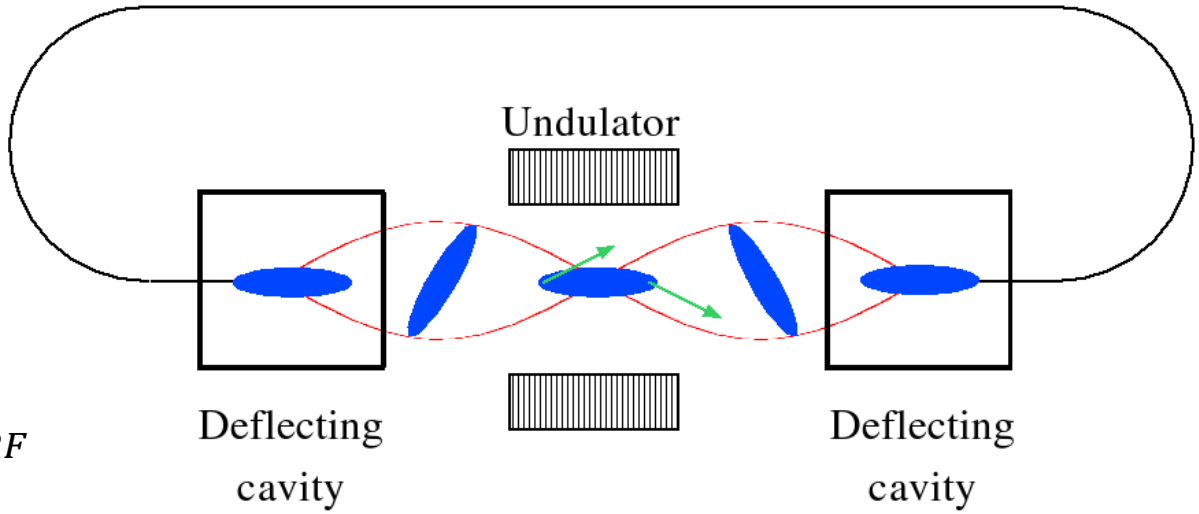


present cavity + SC cavities 1 + 2

Longer bunches



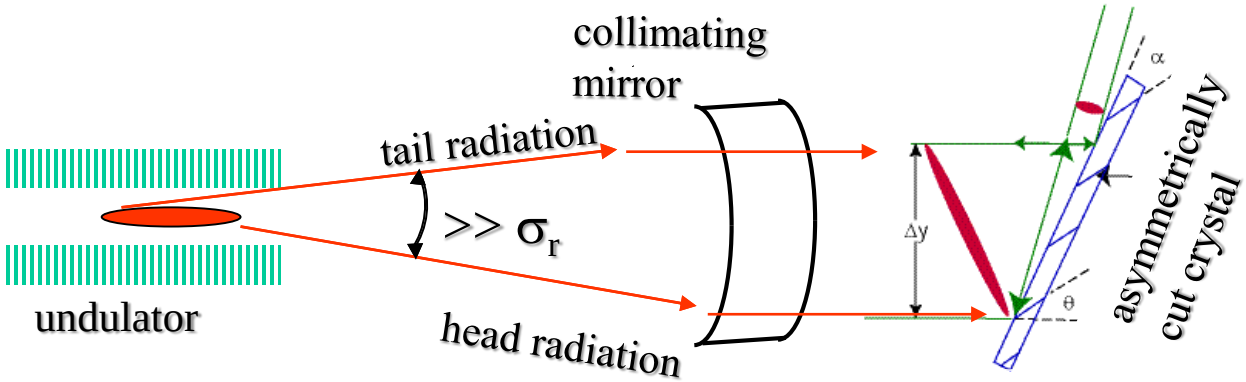
Short bunch using a time dependent radio frequency orbit deflection



$$f_1 = h\, f_{RF}$$

$$f_2 = \frac{hm \pm 1}{m} f_{RF}$$

$$\delta y'(\hat{z}) = \frac{eU_1}{E_b} \sin(2\pi f_1 \sigma_\tau \hat{z}) - \frac{eU_2}{E_b} \sin(2\pi f_2 \sigma_\tau \hat{z})$$



*) Zholents, Heimann, Zolotorev, Byrd, *Nucl. Instr. Meth. A* 524, 385(1999).

*) A. Zholents, *Nucl. Instr. Meth. A 798*, 111(2015).

Numerical application to SOLEIL

$$\sigma_{x-ray} \approx \sigma_\tau \frac{\sqrt{\sigma_{y\prime}^2 + \sigma_\theta^2}}{y\prime(1)} \approx \frac{E_b}{eU_1} \frac{\sqrt{\frac{2\epsilon_y}{L_u} + \frac{\lambda_x}{\pi L_u}}}{2\pi f_1} |\sin(\pi\nu)|$$

Parameters used:

E = 2.75 GeV

V = **4** MV

h = **8** (f_{RF0} = 352 MHz and f_1=2.8GHz)

ε_y = 50 pm.rad

L_u = 2 m

Photon energy	700 eV	12 keV
Bunch length (RMS)	0.7 ps	0.3 ps

SUMMARY

- 26 beamlines are open to the users, 3 are under commissioning, to be opened by January 2017 .
- 5 modes of operation (all in Top-up) + FemtoSlicing operation (since 14/03/2016).
- Good availability of the beam (98.9 % in 2015) and good MTBF (105 h in 2015).
- Short term projects towards improvement of the storage ring operation.
- First thoughts for a major upgrade of the facility to satisfy science goals.
  - Horizontal emittance ~**200 pm.rad** → MBA
  - Short "intense" pulses ~**1 ps** → High gradient SC RF systems or deflecting RF kicks.