XXIV ESLS Meeting
Lund 2016

SOLEIL Status and Upgrade Proposals

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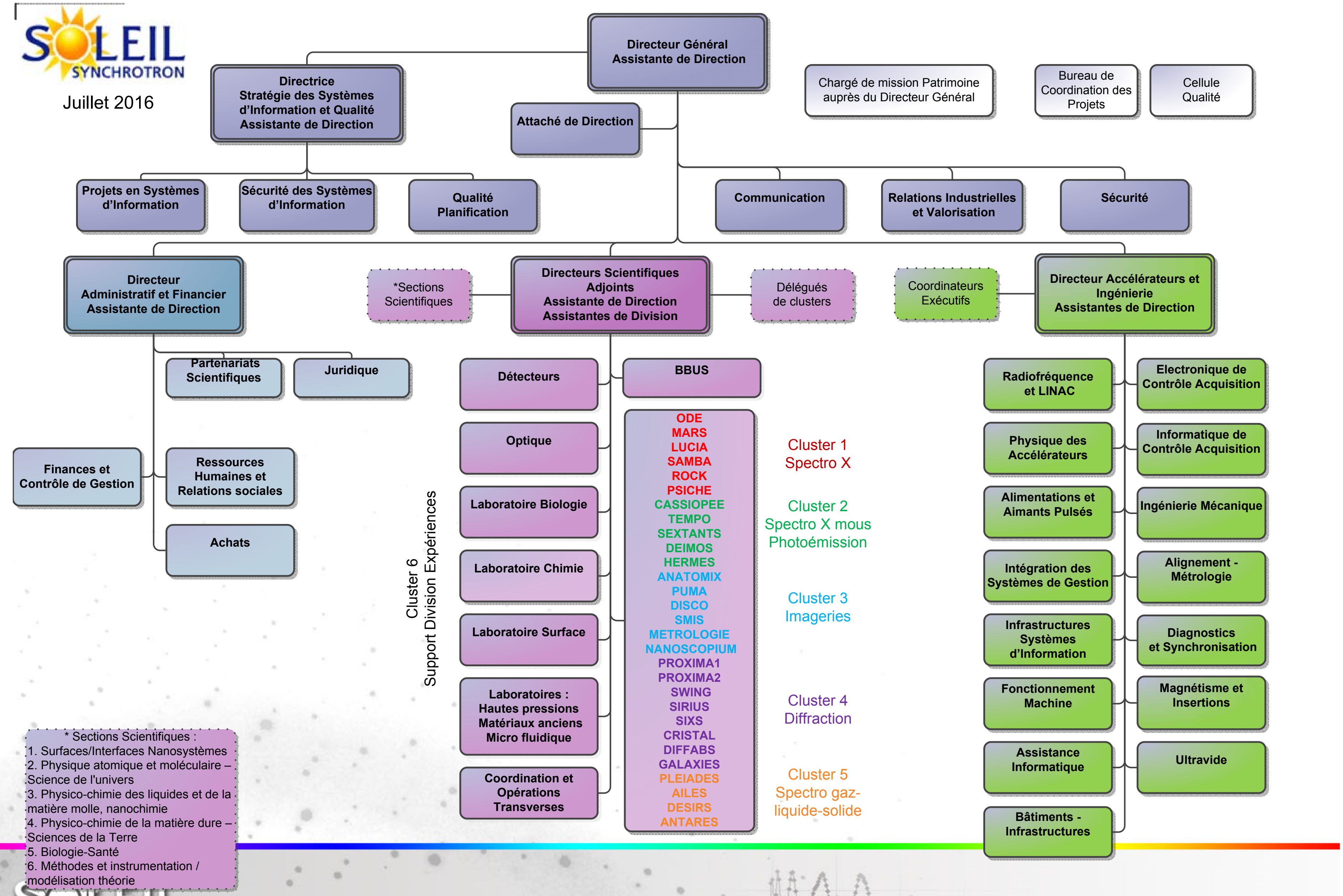
Synchrotron SOLEIL
Accelerator Coordinator
On behalf of the Accelerators and Engineering Division

New Organization Chart



Content

- Operation performance in 2016 (RUN 1 to 4 out of 5)
  - Metrics
  - Failure gallery
  - A selection of on-going projects
- First upgrade proposal for SOLEIL
  - Constraints
  - First lattice explorations

Operation Performance in 2016 (RUN 1 to 4 out of 5)

Beam time schedule in 2016

5100 hours for the beamlines.

janv 2016			
ven 01	.	.	.
sam 02	.	.	.
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mar 19	.	.	.
mer 20	.	.	A
jeu 21	A	A	A
ven 22	A	A	A
sam 23	A	A	A
dim 24	A	A	A
lun 25	A	A	A
mar 26	B	B	B
mer 27	M	M	M
jeu 28	M	M	M
ven 29	M	M	M
sam 30	M	M	M
dim 31	M	M	M

févr 2016			
lun 01	A	A	Tv
mar 02	Cp	B	B
mer 03	M	M	M
jeu 04	M	M	M
ven 05	M	M	M
sam 06	M	M	M
dim 07	M	M	M
lun 08	A	A	Tv
mar 09	Cp	B	B
mer 10	M	M	M
jeu 11	M	M	M
ven 12	M	M	M
sam 13	M	M	M
dim 14	M	M	M
lun 15	A	A	Tv
mar 16	Cp	B	B
mer 17	M2	M2	M2
jeu 18	M2	M2	M2
ven 19	M2	M2	M2
sam 20	M2	M2	M2
dim 21	M2	M2	M2
lun 22	A	A	Tv
mar 23	Cp	B	B
mer 24	M2	M2	M2
jeu 25	M2	M2	M2
ven 26	M2	M2	M2
sam 27	M2	M2	M2
dim 28	M2	M2	M2
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ven 11	A	A	A
sam 12	A	A	A
dim 13	A	A	A
lun 14	A	A	A
mar 15	B	B	B
mer 16	M	M	M
jeu 17	M	M	M
ven 18	M	M	M
sam 19	M	M	M
dim 20	M	M	M
lun 21	A	A	Tv
mar 22	Cp	B	B
mer 23	M	M	M
jeu 24	M	M	M
ven 25	M	M	M
sam 26	M	M	M
dim 27	M	M	M
lun 28	A	A	Tv
mar 29	Cp	B	B
mer 30	M2	M2	M2
jeu 31	M2	M2	M2

avr 2016			
ven 01	M2	M2	M2
sam 02	M2	M2	M2
dim 03	M2	M2	M2
lun 04	A	A	Tv
mar 05	Cp	B	B
mer 06	M2	M2	M2
jeu 07	M2	M2	M2
ven 08	M2	M2	M2
sam 09	M2	M2	M2
dim 10	M2	M2	M2
lun 11	A	A	Tv
mar 12	Cp	B	B
mer 13	M	M	M
jeu 14	M	M	M
ven 15	M	M	M
sam 16	M	M	M
dim 17	M	M	M
lun 18	A	A	Tv
mar 19	8	8	8
mer 20	8	8	8
jeu 21	8	8	8
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jeu 19	S	S	S
ven 20	S	S	S
sam 21	S	S	S
dim 22	S	S	S
lun 23	A	A	Tv
mar 24	Cp	B	B
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jeu 26	M	M	M
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sam 28	M	M	M
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mar 31	Cp	B	B

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mar 07	Cp	B	B
mer 08	M	M	M
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lun 13	A	A	A
mar 14	L	L	L
mer 15	L	L	L
jeu 16	L	L	L
ven 17	L	L	L
sam 18	L	L	L
dim 19	L	L	L
lun 20	A	A	Tv
mar 21	Cp	B	B
mer 22	M	M	M
jeu 23	M	M	M
ven 24	M	M	M
sam 25	M	M	M
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sam 09	M	M	M
dim 10	M	M	M
lun 11	A	A	Tv
mar 12	Cp	B	B
mer 13	M	M	M
jeu 14	M	M	M
ven 15	M	M	M
sam 16	M	M	M
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lun 18	A	A	Tv
mar 19	Cp	B	B
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jeu 25	A	A	A
ven 26	A	A	A
sam 27	A	A	A
dim 28	A	A	A
lun 29	A	A	A
mar 30	B	B	B
mer 31	M	M	M

sept 2016			
jeu 01	M	M	M
ven 02	M	M	M
sam 03	M	M	M
dim 04	M	M	M
lun 05	A	A	Tv
mar 06	Cp	B	B
mer 07	M	M	M
jeu 08	M	M	M
ven 09	M	M	M
sam 10	M	M	M
dim 11	M	M	M
lun 12	A	A	Tv
mar 13	Cp	B	B
mer 14	M2	M2	M2
jeu 15	M2	M2	M2
ven 16	M2	M2	M2
sam 17	M2	M2	M2
dim 18	M2	M2	M2
lun 19	A	A	Tv
mar 20	Cp	B	B
mer 21	M2	M2	M2
jeu 22	M2	M2	M2
ven 23	M2	M2	M2
sam 24	M2	M2	M2
dim 25	M2	M2	M2
lun 26	A	A	Tv
mar 27	Cp	B	B
mer 28	M	M	M
jeu 29	M	M	M
ven 30	M	M	M

oct 2016			
sam 01	M	M	M
dim 02	M	M	M
lun 03	A	A	Tv
mar 04	Cp	B	B
mer 05	M	M	M
jeu 06	M	M	M
ven 07	M	M	M
sam 08	M	M	M
dim 09	M	M	M
lun 10	A	A	Tv
mar 11	8	8	8
mer 12	8	8	8
jeu 13	8	8	8
ven 14	8	8	8
sam 15	8	8	8
dim 16	8	8	8
lun 17	A	A	A
mar 18	L	L	L
mer 19	L	L	L
jeu 20	L	L	L
ven 21	L	L	L
sam 22	L	L	L
dim 23	L	L	L
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sam 05	A	A	A
dim 06	A	A	A
lun 07	A	A	A
mar 08	S	S	S
mer 09	S	S	S
jeu 10	S	S	S
ven 11	S	S	S
sam 12	S	S	S
dim 13	S	S	S
lun 14	A	A	Tv
mar 15	Cp	B	B
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dim 20	M2	M2	M2
lun 21	A	A	Tv
mar 22	Cp	B	B
mer 23	M2	M2	M2
jeu 24	M2	M2	M2
ven 25	M2	M2	M2
sam 26	M2	M2	M2
dim 27	M2	M2	M2
lun 28	A	A	Tv
mar 29	Cp	B	B
mer 30	M	M	M

déc 2016			
jeu 01	M	M	M
ven 02	M	M	M
sam 03	M	M	M
dim 04	M	M	M
lun 05	A	A	Tv
mar 06	Cp	B	B
mer 07	M	M	M
jeu 08	M	M	M
ven 09	M	M	M
sam 10	M	M	M
dim 11	M	M	M
lun 12	A	A	Tv
mar 13	Cp	B	B
mer 14	M	M	M
jeu 15	M	M	M
ven 16	M	M	M
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mar 17	.	.	.
mer 18	.	.	A
jeu 19	A	A	A
ven 20	A	A	A
sam 21	A	A	A
dim 22	A	A	A
lun 23	A	A	A
mar 24	B	B	B
mer 25	M	M	M
jeu 26	M	M	M
ven 27	M	M	M
sam 28	M	M	M
dim 29	M	M	M
lun 30	A	A	Tv
mar 31	Cp	B	B

févr 2017			
mer 01	M	M	M
jeu 02	M	M	M
ven 03	M	M	M
sam 04	M	M	M
dim 05	M	M	M
lun 06	A	A	Tv
mar 07	Cp	B	B
mer 08	M2	M2	M2
jeu 09	M2	M2	M2
ven 10	M2	M2	M2
sam 11	M2	M2	M2
dim 12	M2	M2	M2
lun 13	A	A	Tv
mar 14	Cp	B	B
mer 15	M2	M2	M2
jeu 16	M2	M2	M2
ven 17	M2	M2	M2
sam 18	M2	M2	M2
dim 19	M2	M2	M2
lun 20	.	.	.
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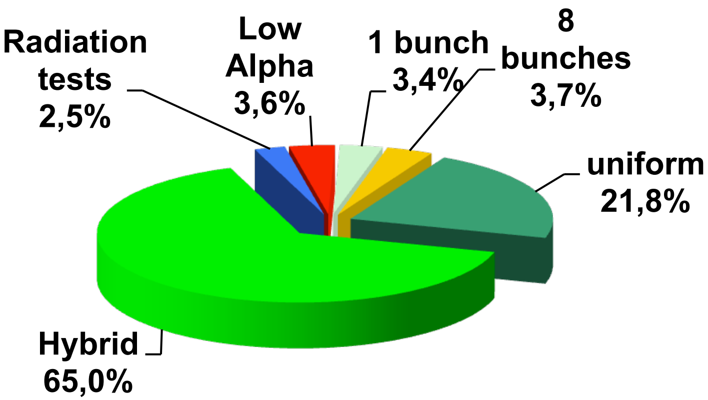
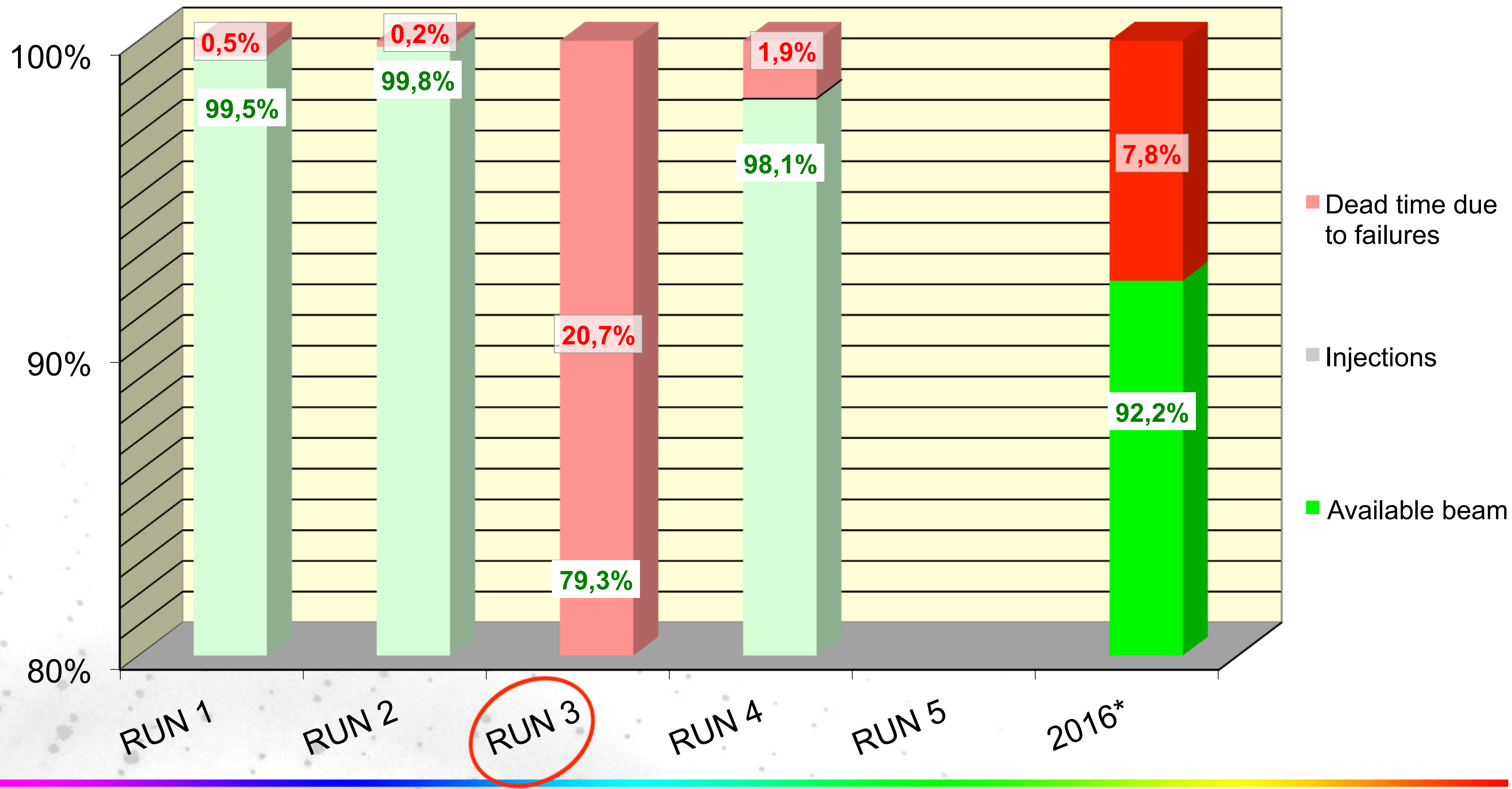
mar 28	.	.	.



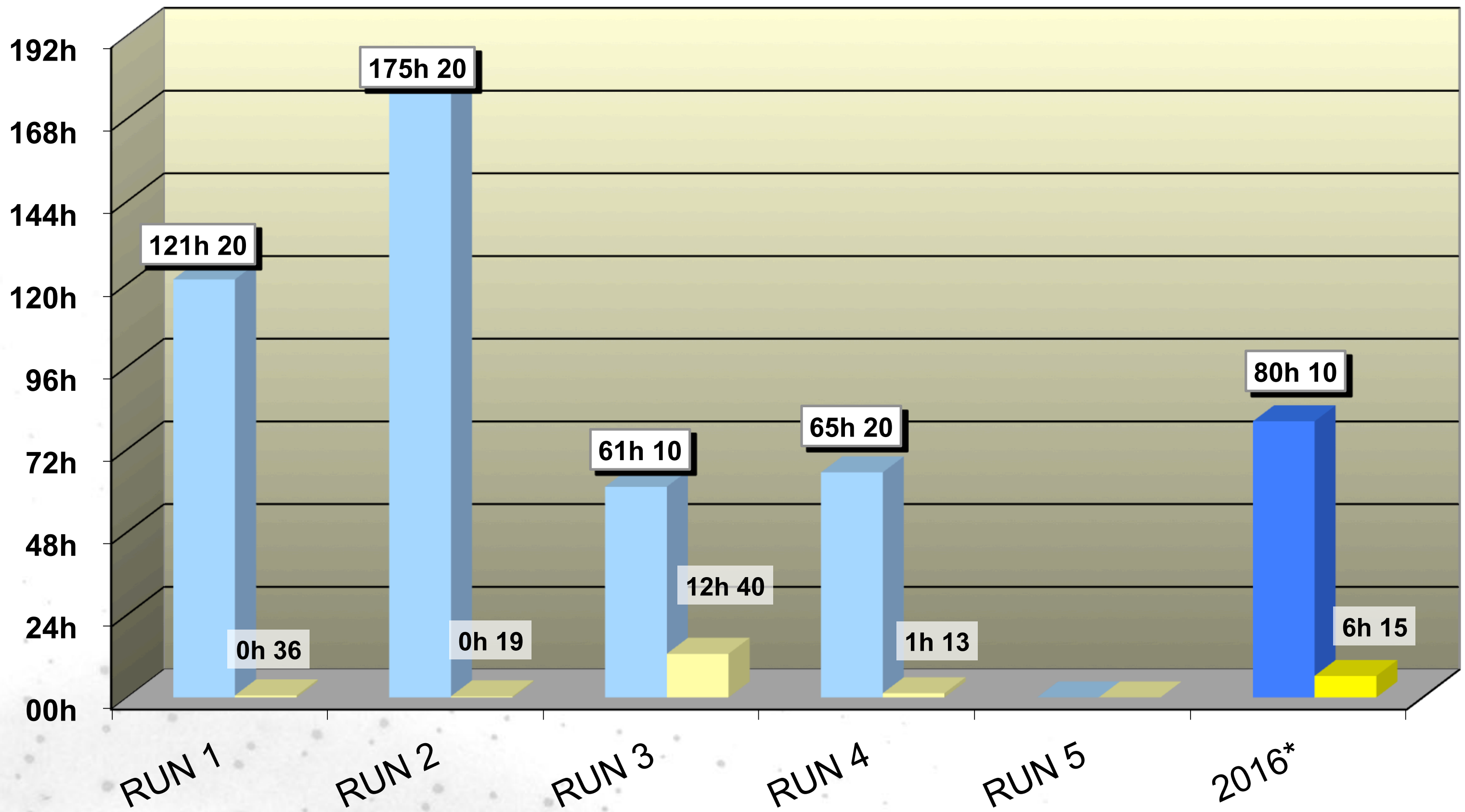
Mode of operation Bunch fill. patterns	User Operation in 2016	Ultimate performance achieved
Multibunch (M2)	500 mA	500 mA
Hybrid/camshaft mode (M)	425 mA + 5 mA	425 mA + 10 mA
	+ Slicing on high intensity bunch	Slice length < 200 fs FWHM
8 bunches (8)	100 mA	110 mA
1 bunch (S)	16 mA	20 mA
Low-α: Hybrid mode (L)	4.7 ps RMS for 65 µA	< 3.2 ps RMS for 15 µA

Photon Beam Availability
(2016: Run1 to Run4 out of 5)

represents a beam availability of 92.2 %



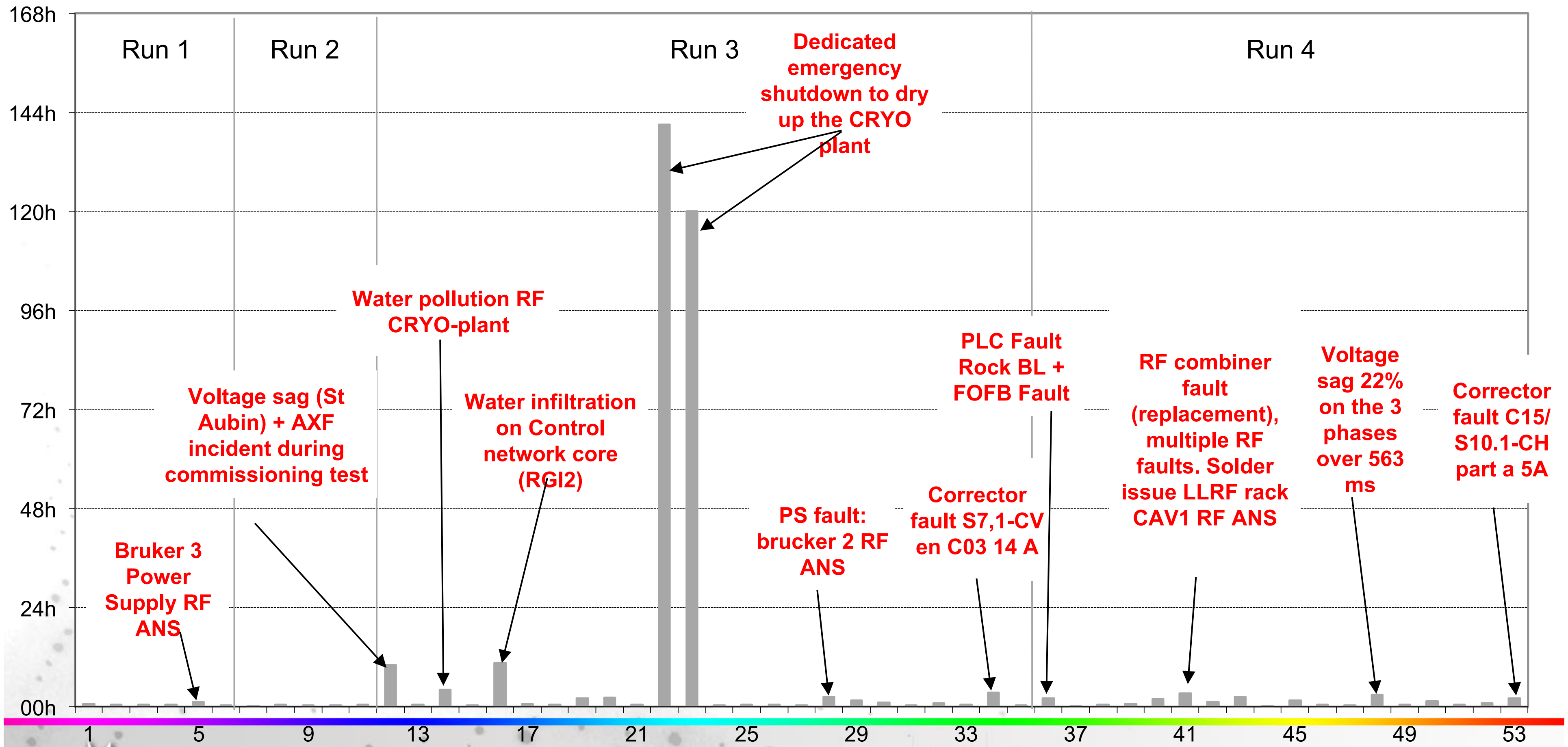
MTBF (MeanTime Between Failures) & MTTR (MeanTime To Recovery) during beamlines and RP sessions in 2016 (Run1 to Run4)



Duration of every interruption (Run 1 to 4)

Time duration of the 53 beam interruptions (beam losses or equipment failures) impacting the beamline or Radiation Safety Tests

Total 331:33
Min 00:02
Max 141:00
Mean 06:15
RMS 25:00



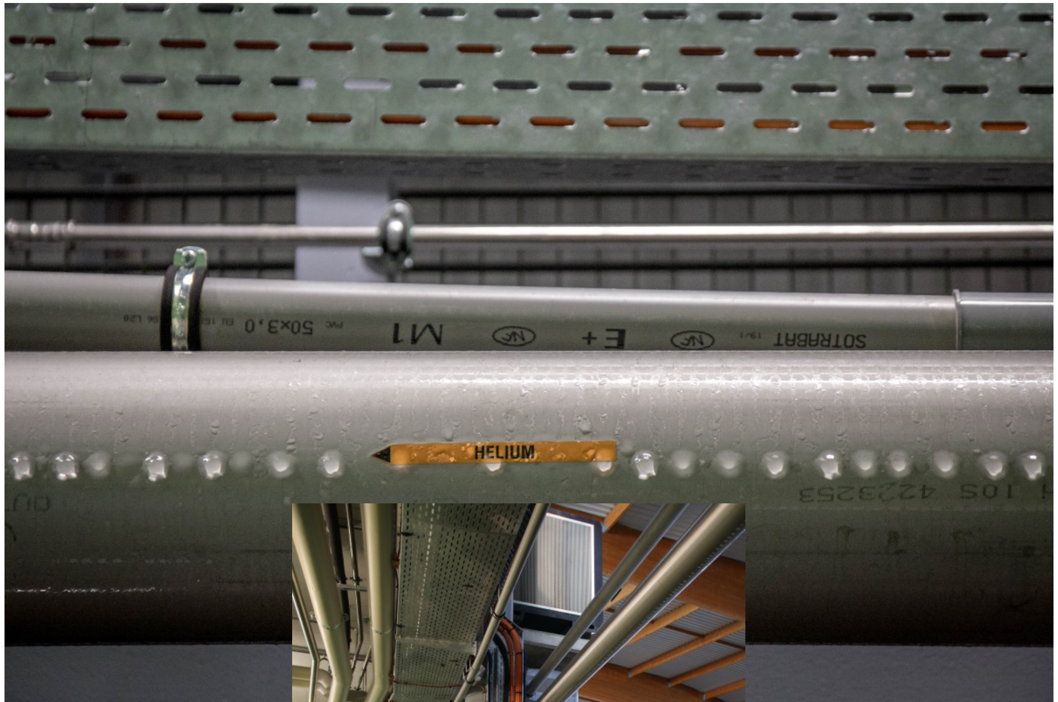
Two examples:

Cryogenic water pollution

Water infiltration

DISASTER GALLERY

Cryogenic plant: Water pollution of the first exchanger of the coldbox
Water condensation extending with time along the HP He pipe
Loss of efficiency



Storage Ring cryogenic system breakdown of June 2016 (RUN3)

- End of May, beam loss due to a "nitrogen pre-cooling" fault on the cryogenic system
- Investigations revealed a loss of efficiency on the first heat exchanger of the Helium liquefier due to a **water deposition** on the Helium side

- Emergency situation → emergency action:

  State evaluation and risk level for cryogenic system

  ⇒ Interlock strap allowing nitrogen pre cooling, power recovery and nominal storage ring current

- Short term action:

  Unanimous expert opinion: **Significant risk of turbo expenders destruction**

  ⇒ one week stop during "low alpha" operation to dry the first heat exchanger

  Existing drying process capability not suited with large water contamination

  ⇒ water spread all over cryogenic system, which required a deep drying action
  - 4 days lost and 8 extras!
  - large volume of pure Helium gas (500 m^3) and liquid (2000 liters) supplies for 6 days
  - large amount of involved human resources: over a full week, 2 x 8 hours a day ~ 20 man.week overall

- Long term action:

  With help from expert consultant, we came to the conclusion that, despite close loop operation, for continuous operation over long periods, water accumulation can reach critical level and therefore **desiccation is needed**. The possibility of applying for SOLEIL the hardware solution adopted by CERN, which was concerned with similar experience, is being studied.

Cryogenic: activated charcoal replacement, drying up all the HE circuit from the cold-box to the compressor room during 2 weeks!

Two examples:

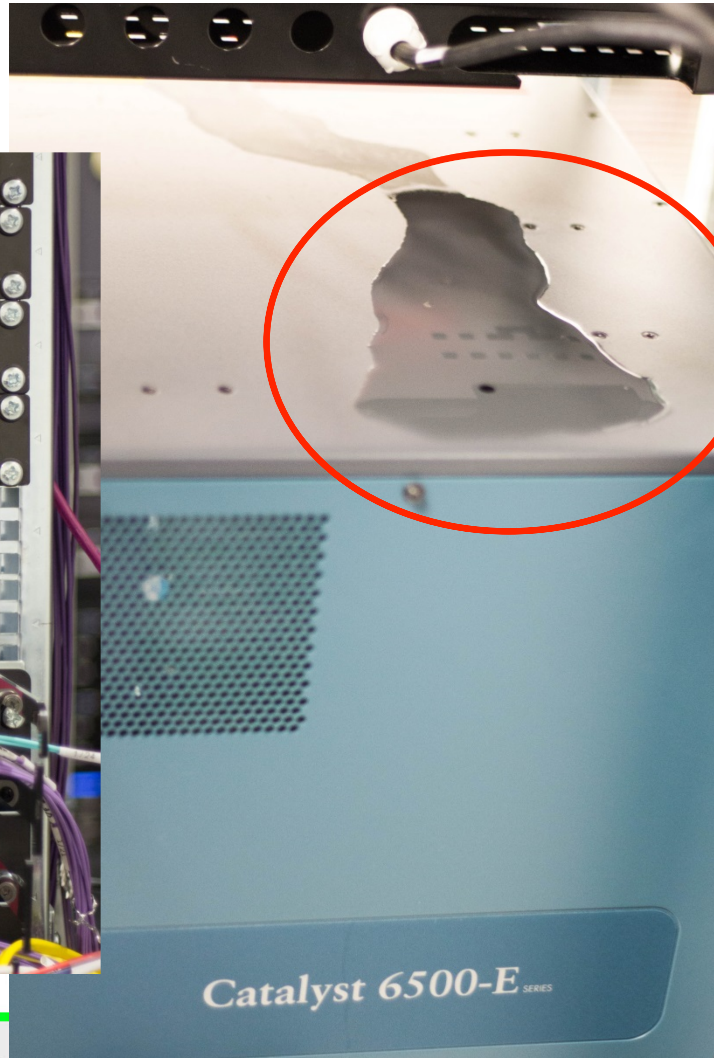
- Cryogenic water pollution
- **Water infiltration**

DISASTER GALLERY

Heavy rains in 31 May 2016. Flooding nearby SOLEIL, infiltration of water from the roof
Right into the main computer room

Network core out of order (not waterproof)

Secondary control room not able to take over (cabling non redundant for a few central equipment)



Task force to build a temporary network core using piles switches

10h30 beam interruption for users

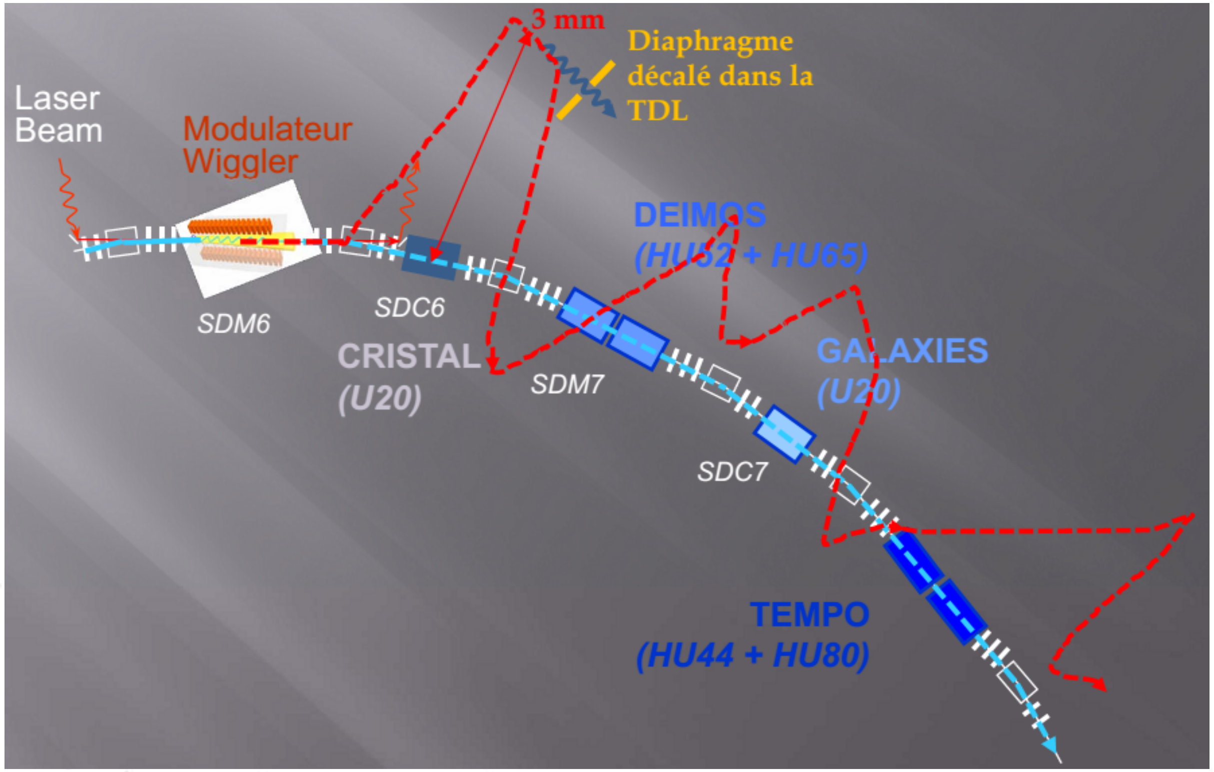
A selection of on-going projects

Femto-Slicing: Photons on CRISTAL beamline

<u>Laser 2.5 kHz, 800 nm, 50 fs</u>

- 2.5 mJ in Wiggler
- 0.5 mJ CRISTAL beam-line

Wiggler 164 mm, 3.5 m



Sliced beam can be used by several beamlines simultaneously

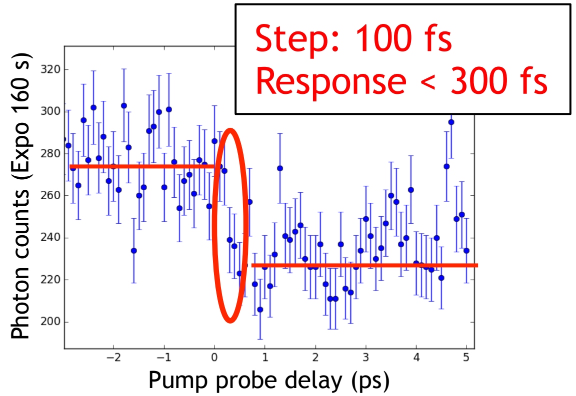
Femto-slicing operation

❑ 5 weeks of operation from June 16 to Feb. 17:

- Use of the natural dispersion of the lattice
- Transparent operation for users, except:
  - The THz beamline (lines @ rep. rate of laser and harmonics) → still in investigation.
  - The PUMA beamline (in commissioning) with source point @ W164 wiggler, closed to the specific slicing gap.

❑ First evidence of photon short bunch length on the **hard x-ray beamline** CRISTAL

Intensity of the (111) Bragg reflection of a 40 nm Bismuth thin-film.



❑ Commissioning of the second **soft x-ray beamline** TEMPO

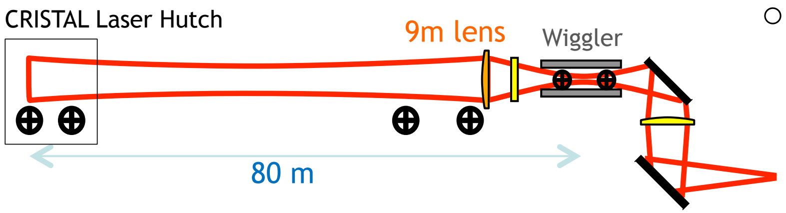
- Installation and commissioning of the adjustable chicane
- First photons foreseen in December 2016 ?

3 magnet chicane of a few mrad, to adjust the photon beam at center of the first beamline mirror.

Femto-slicing operation

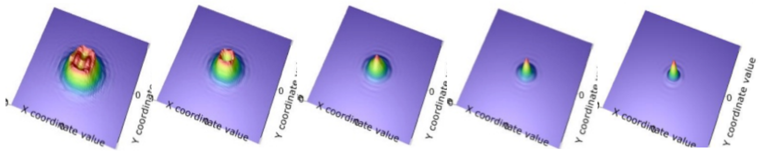
❑ Improvement of performances:

- Laser beam transport and quality:



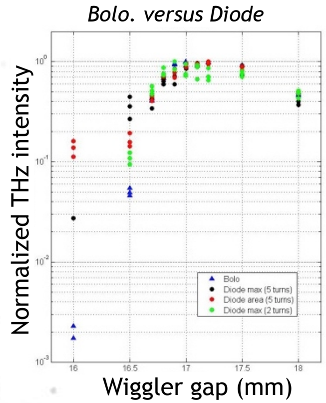
- ○ Using the electron beam as a probe, we assessed a wrong longitudinal position of the laser beam waist in the wiggler → change in position of the 9 m lens.

- ○ New method of minimization of the frequency chirp
- ○ Modeling of the laser beam with real transport and machine apertures (OpticStudio)



Understanding of the effect on focus in wiggler of a large laser beam through apertures.

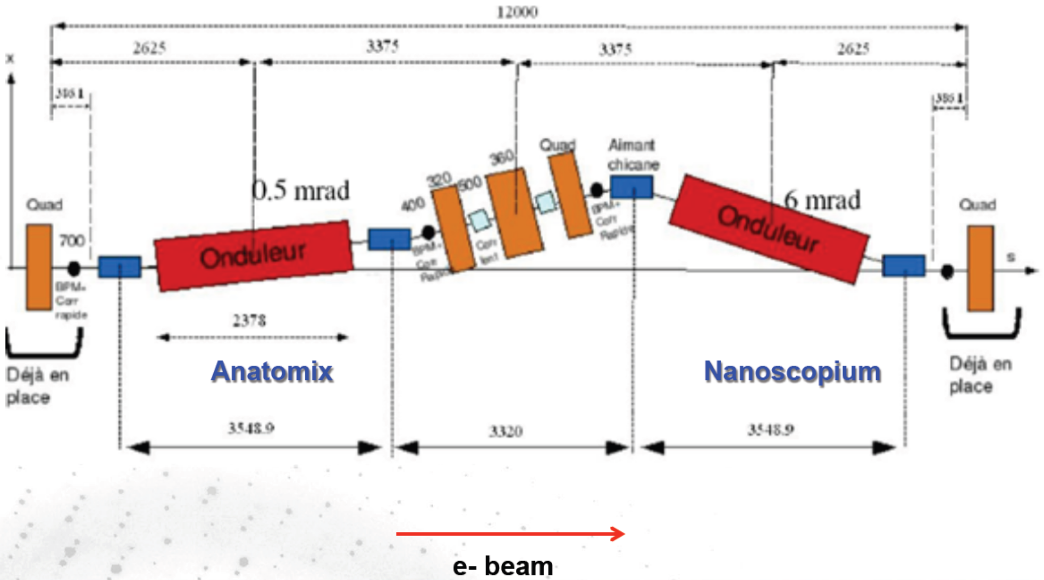
- Commissioning of a THz diode (ACST) to supplement the bolometer (IR Labs)

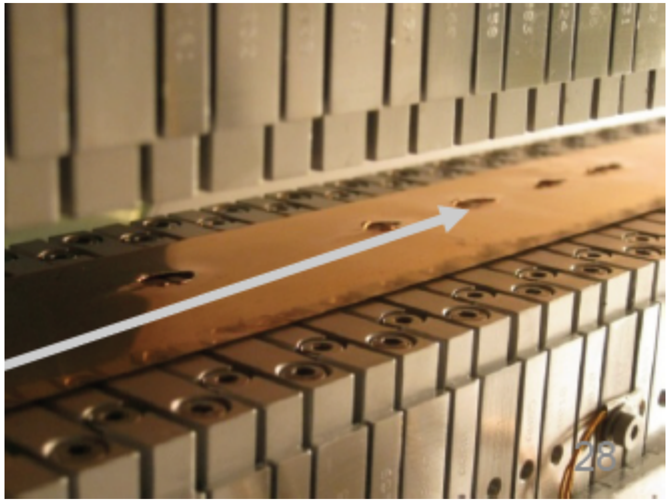


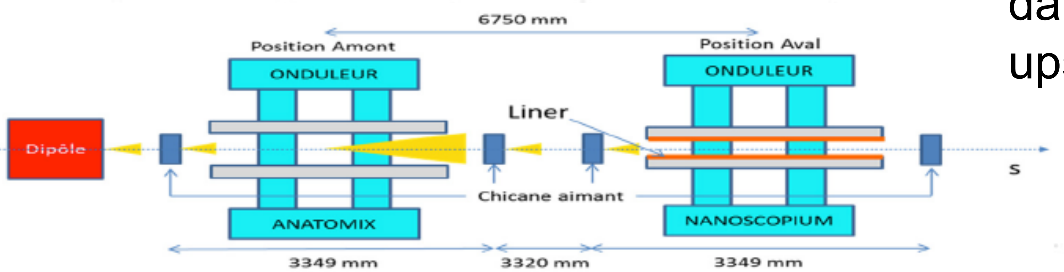
- Upgrade of laser foreseen in 2017: 1 kHz, 5 mJ ⇒ 5 kHz, 5 mJ

→ Increased number of photons @ CRISTAL beamline by a factor 4:
$8.6\ 10^4$ ph/s @ E = 7.15 keV (bandwidth $\Delta E/E = 2.4\ 10^{-4}$)
laser: 2.8 W inside wiggler, 1kHz

Operation with two in-vacuum canted undulators in a single straight section







Liner of the downstream U20 ID was damaged by radiation emitted in the upstream ID during September 2011

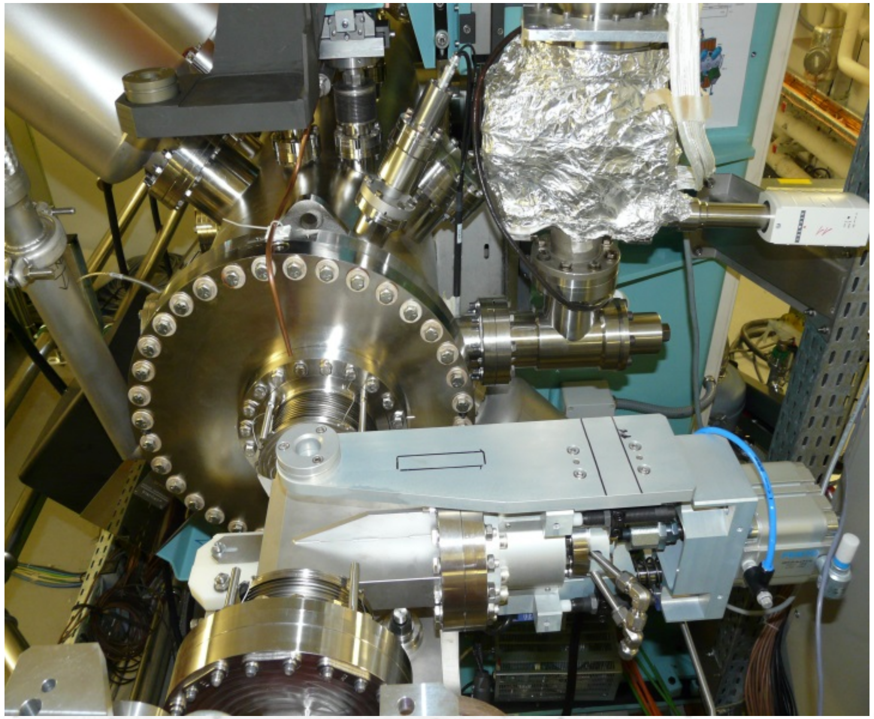
Peak power: 400 mW/mm^2

SDL13: simultaneous operation at 5.5 mm

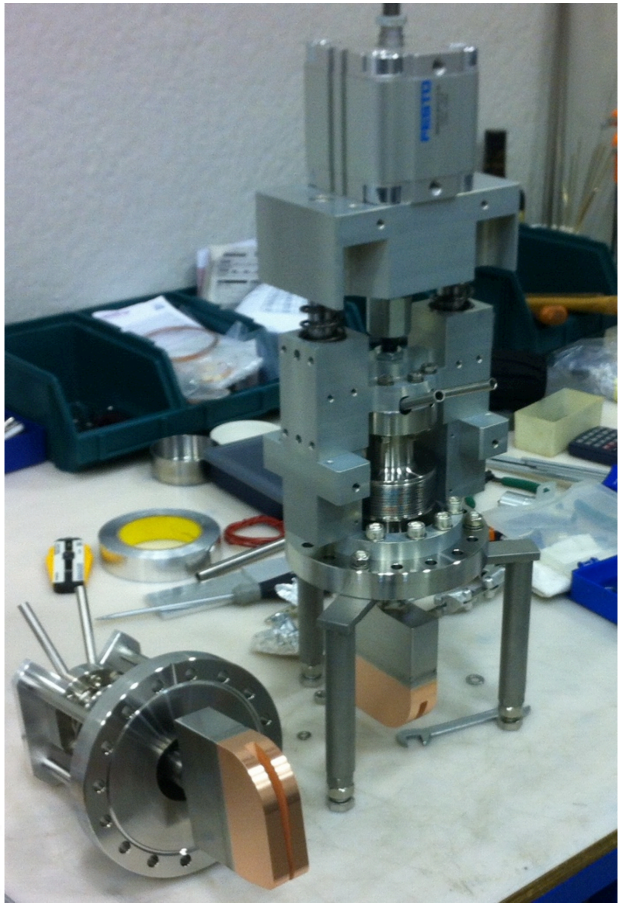
January 2016

Mobile absorber upstream of second undulator
Fast angle interlock on the e-beam of the upstream undulator

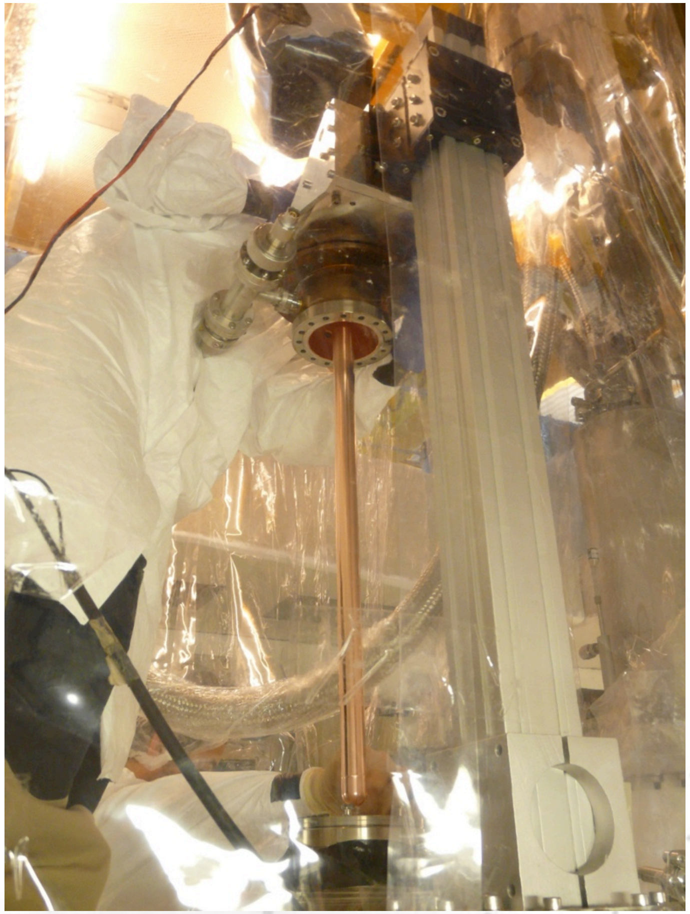
Anatomix BL in-vacuum undulator **5.5 mm**
Nanoscopium in-vacuum undulator **5.5 mm**



Installation of the absorber in Jan'16



Project progress



3rd RF power coupler installed in January 2016

New vertical fast kicker for injection tuning Summer 2016 and new position for vertical collimator

PROPOSALS FOR A SOLEIL UPGRADE

Boundary Conditions and Constraints

- In the current discussion, the lattice study of the upgraded storage ring should be performed with the following requirements:

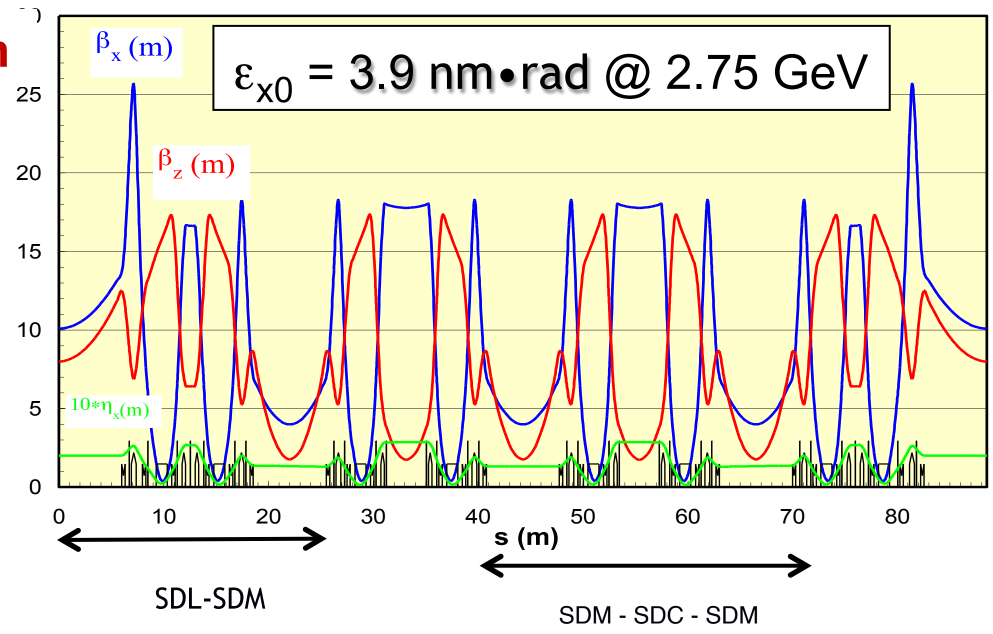
- Reduce by more than a factor 10 the horizontal electron beam emittance (< 400 pm•rad).
- Reuse of the existing tunnel and its radiation shielding wall.
- Keep the same energy of 2.75 GeV.
- Maintain the existing insertion device source points.
- Preserve the very broad photon energy range.
- Preserve a current of 500 mA in multibunch filling pattern.
- Preserve time structure and time resolved operations.
- Reuse of the injector complex: Linac and booster.
- Reuse much of the technical infrastructure.
- Limit downtime to a maximum of two years
- Minimize operation costs, in particular the wall-plug-power
- Preserve Infra Red (IR) beamlines
- Provide alternative radiation sources for the existing bending magnet based beamlines.

Today's SOLEIL Lattice and main Challenges

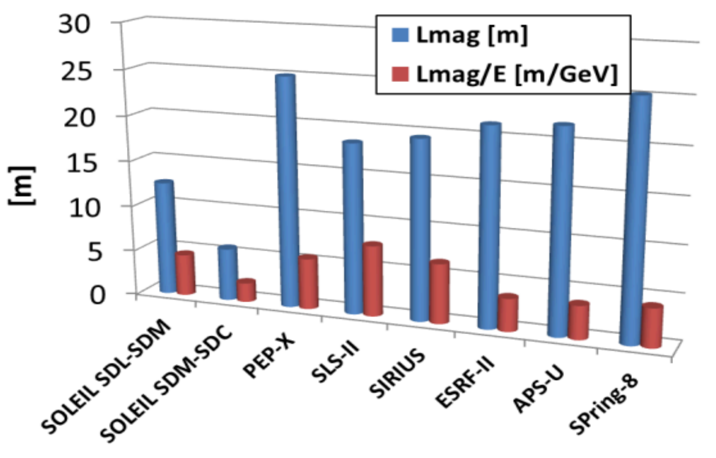
Rather small Circumference: **354 m**

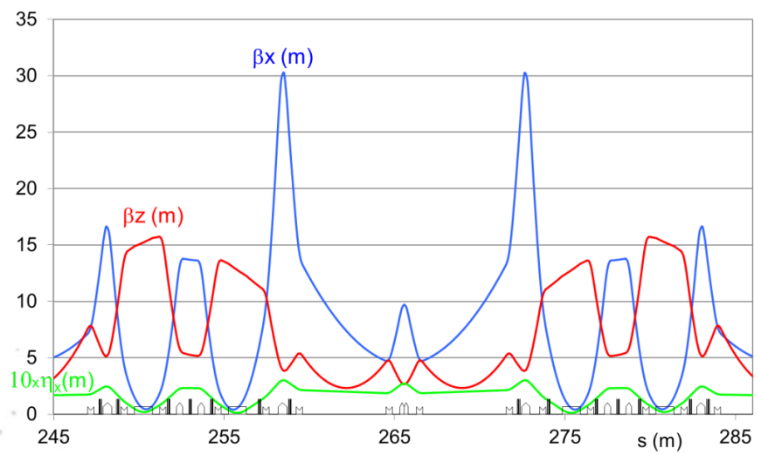
High ratio of free straight sections

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



Very compact magnetic structure



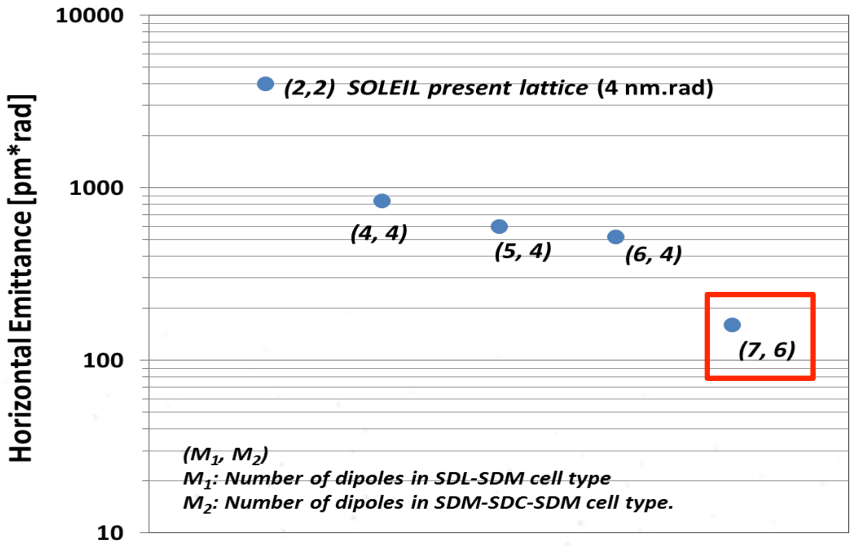


The lengths dedicated to magnets are relatively short; 12.5 m in SDL-SDM and 2 × 5.73 m in SDL-SDC-SDM.

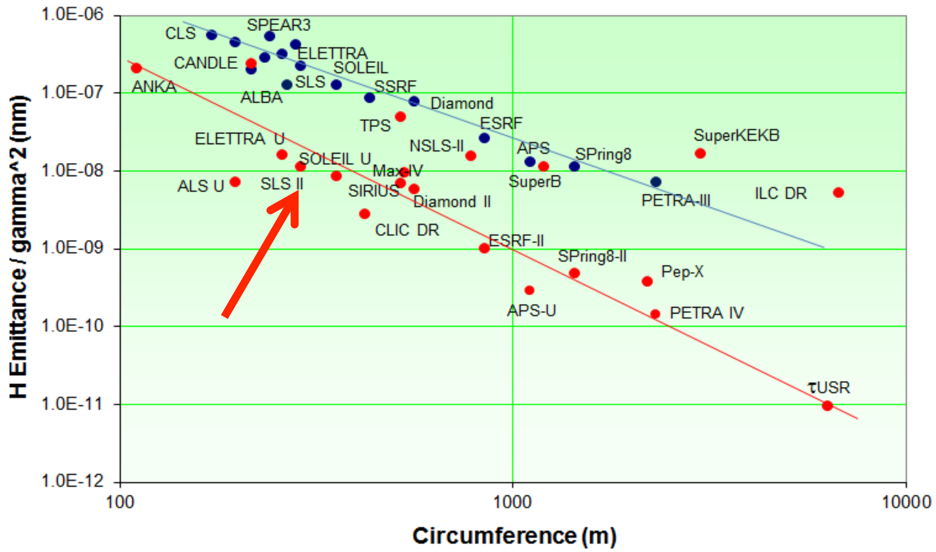
One long straight section (**SDL13**, accommodating 2 long beamlines) **has been modified.**

STRATEGY

Using Combination of Multi Bend Achromat structure



Courtesy of R. Bartolini

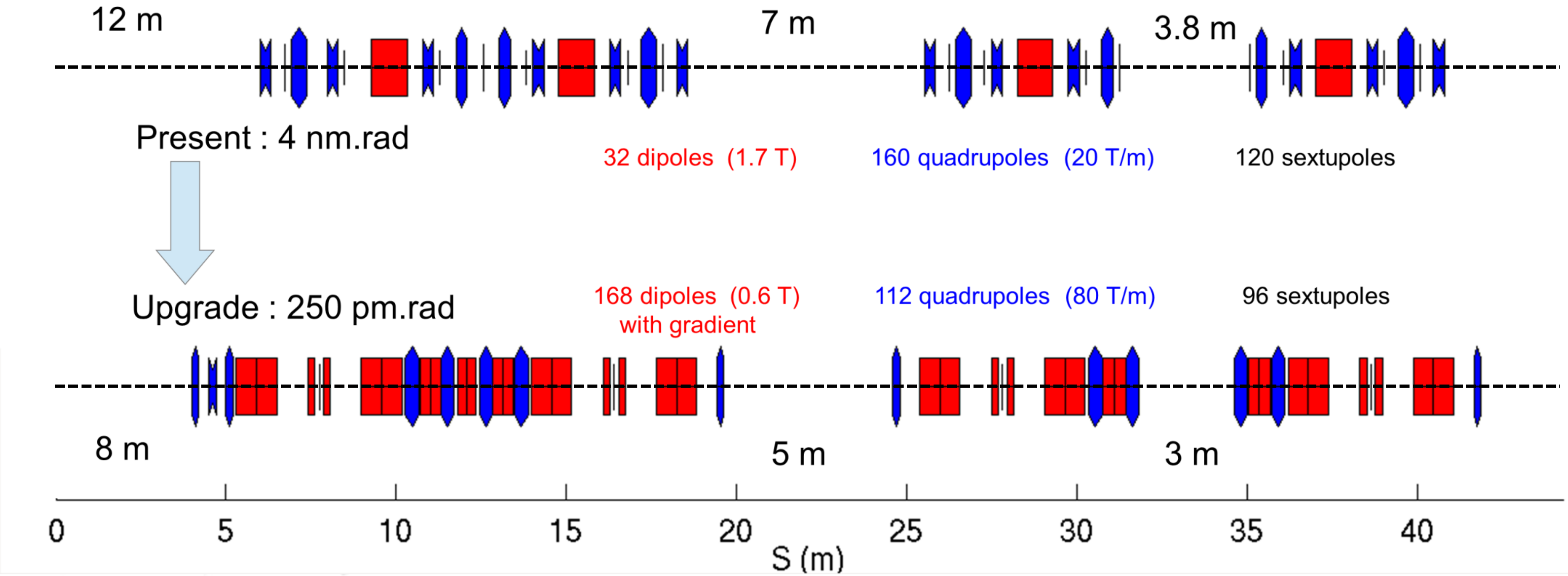


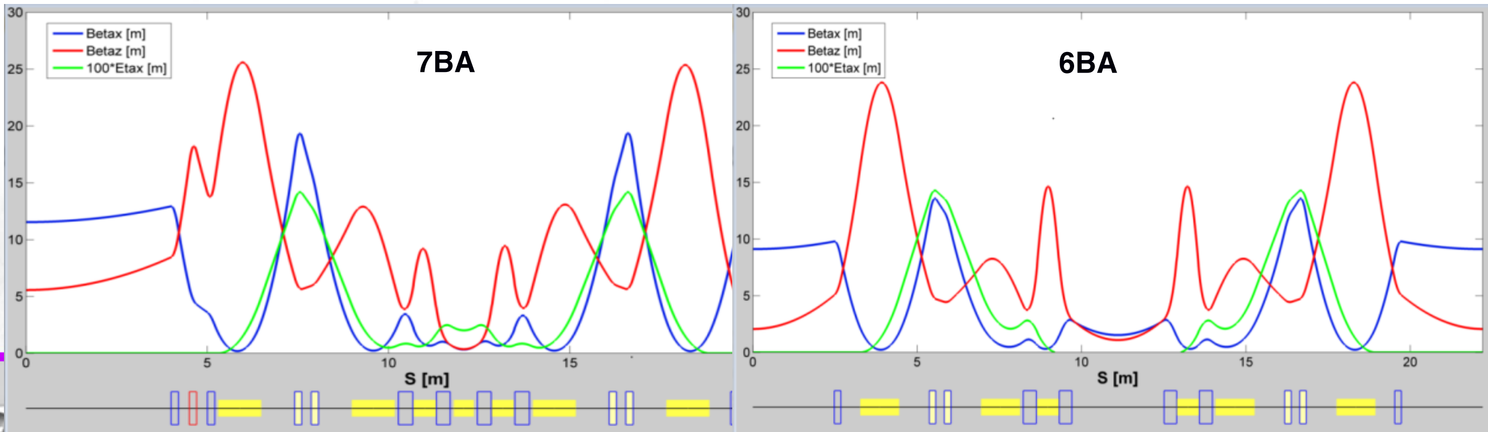
$$(\varepsilon_x^{Combined\ MBA})_{\min} = \frac{1}{8\sqrt{15}}\frac{C_q\gamma^2}{J_x}\theta_0^3 \cdot \left\{\frac{1}{\left[2+(M_1-2)3^{1/3}\right]^3} + \frac{1}{\left[2+(M_2-2)3^{1/3}\right]^3}\right\}$$

An emittance of around 200 pm•rad could be reached if a combination of **7BA** and **6BA** is considered.

For SOLEIL, calculation is performed with an emittance of **250 pm•rad**.

Baseline Lattice: emittance 250 pm•rad with Off-axis injection

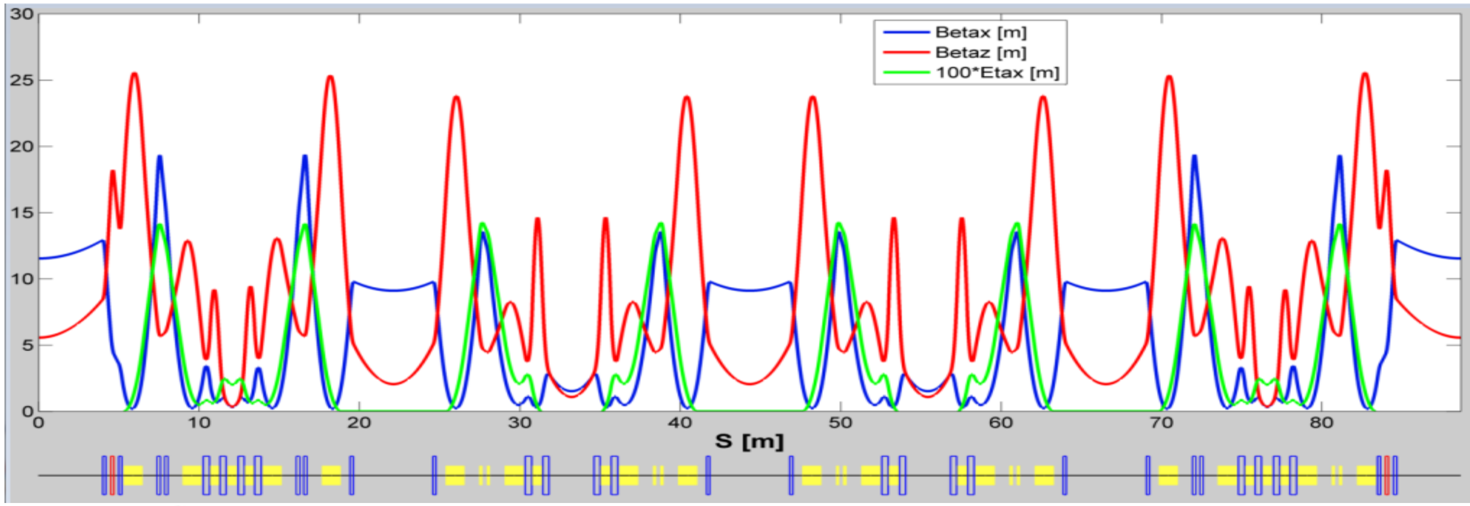




Optical functions

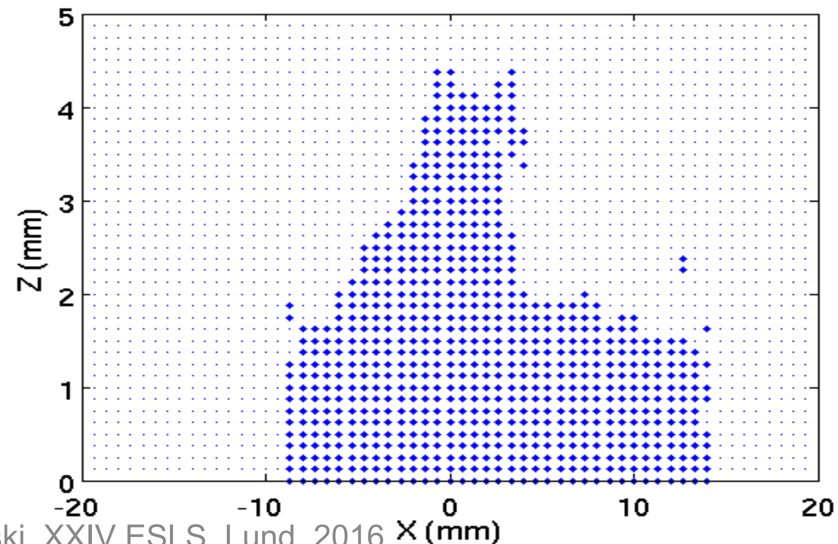
Baseline Lattice (version 1): 250 pm•rad

ε_x = 250 pm•rad ξ_{x0} = -84 ξ_{z0} = -77



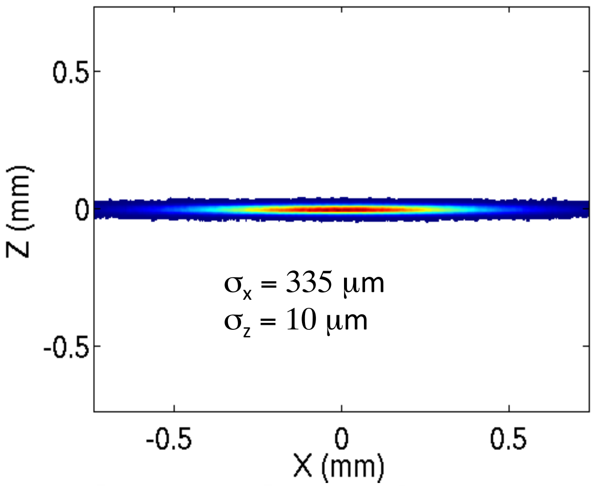
On-momentum dynamic aperture large enough for off-axis injection.

Bared "idealized" lattice

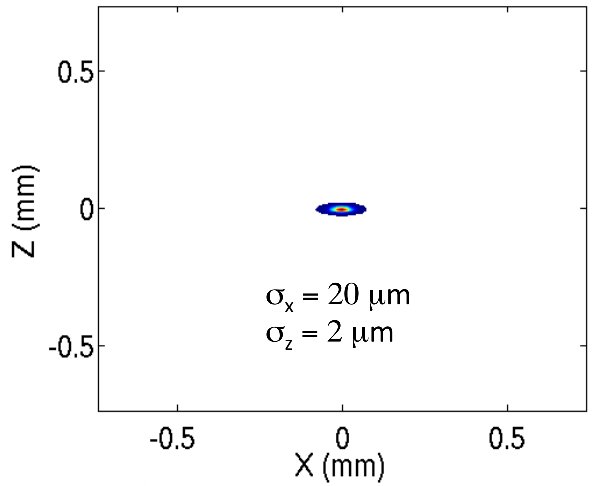


Photon Source Properties

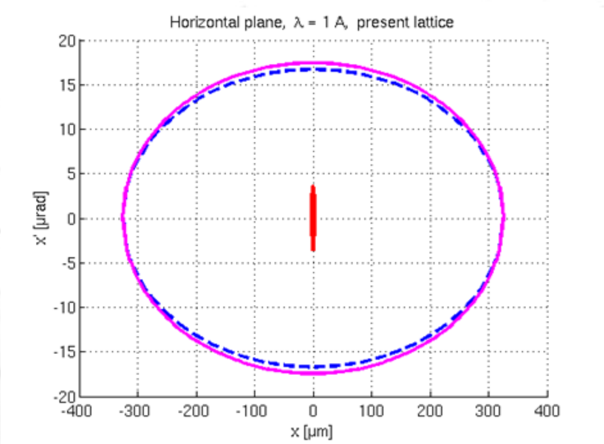
Present

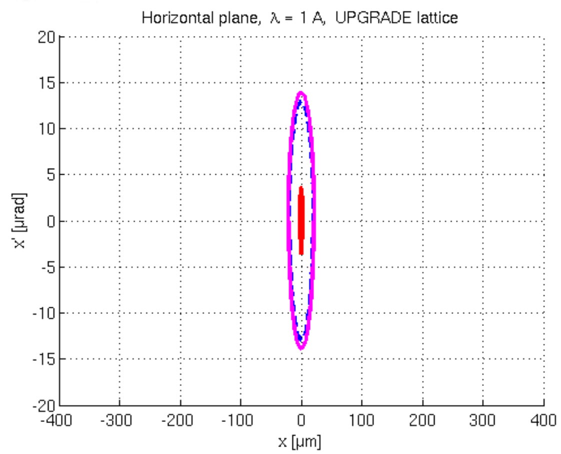


Upgrade



Transverse electron beam profiles of SOLEIL and SOLEIL upgrade baseline lattice in a short straight section.





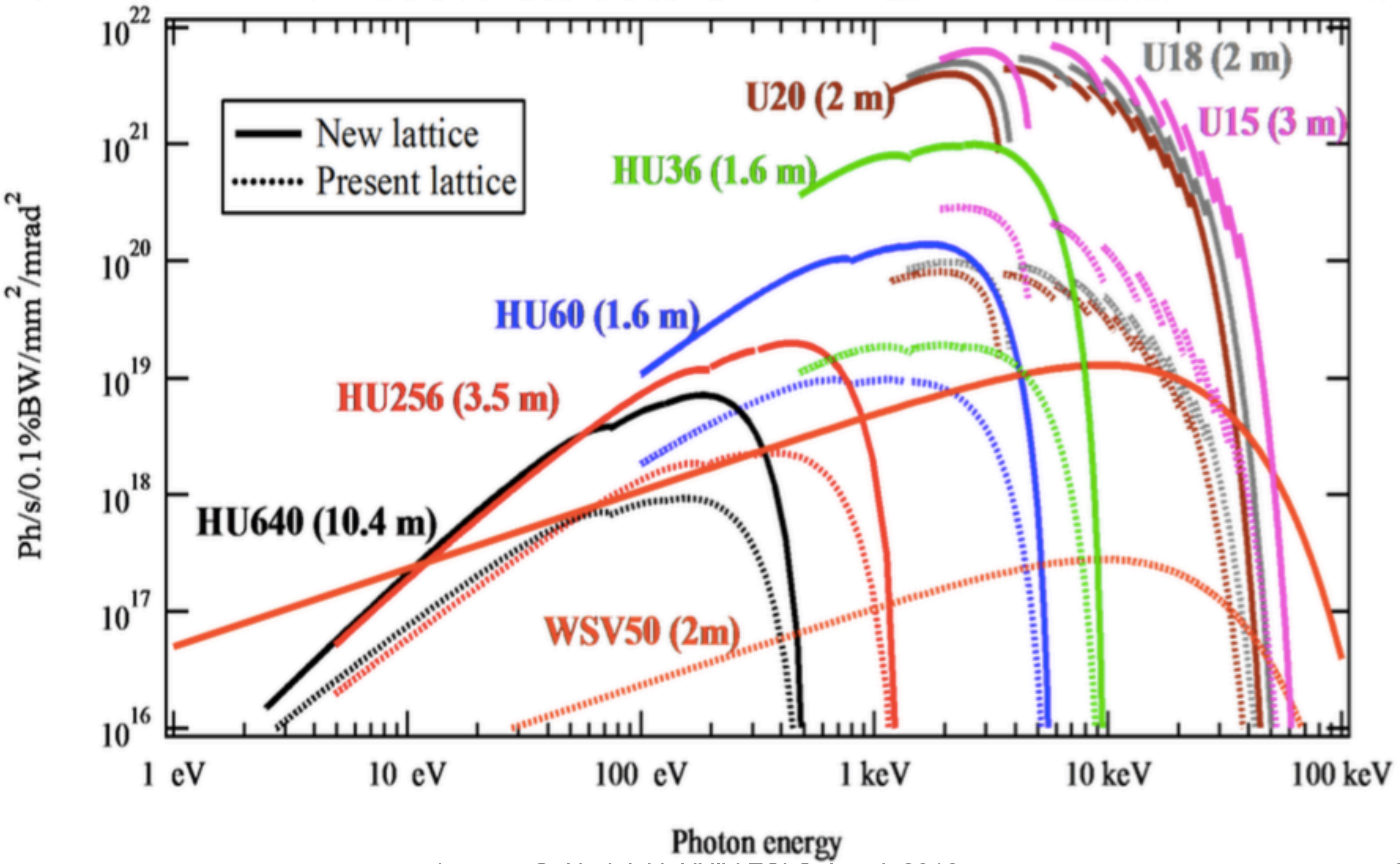
electron beam (dashed blue), single electron @ 1 Å (red) and convoluted photon beam (magenta) at in-vacuum undulator source point.

Present

Upgrade

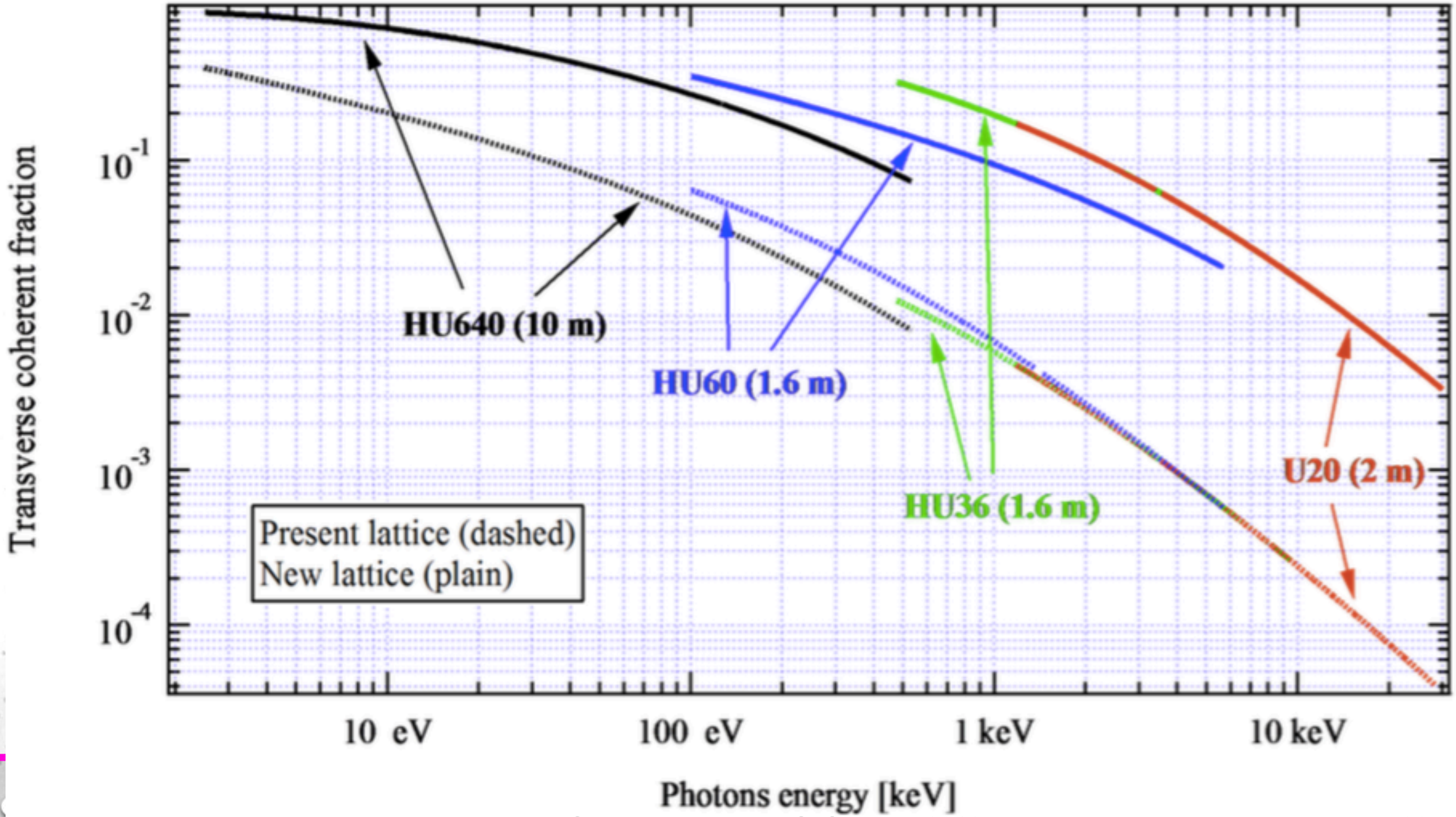
Photon Source Properties

Brilliance for the present and the new baseline lattice



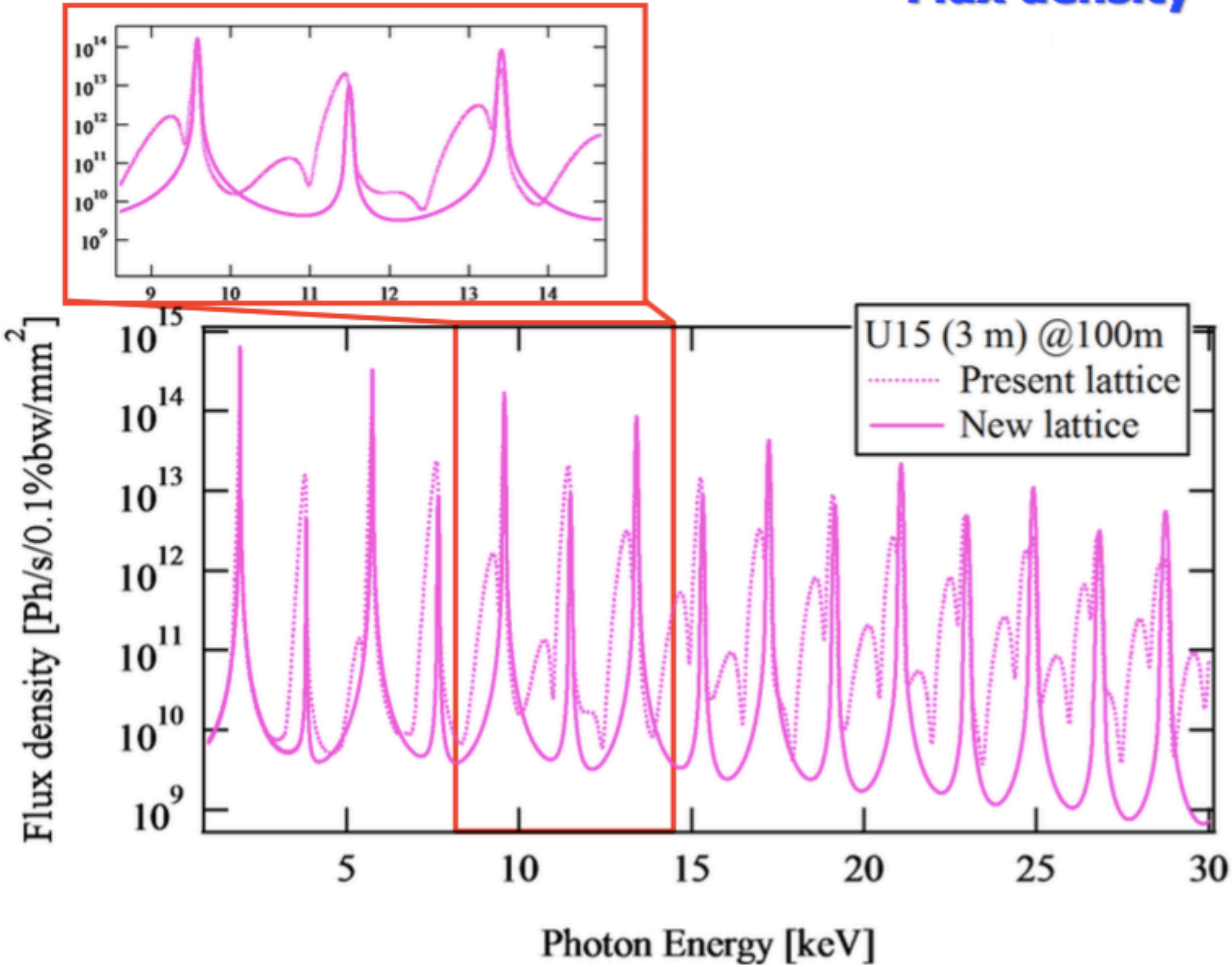
Photon Source Properties

Coherent fraction for the present and new baseline lattice



Photon Source Properties

Flux density



Bending Magnet Sources

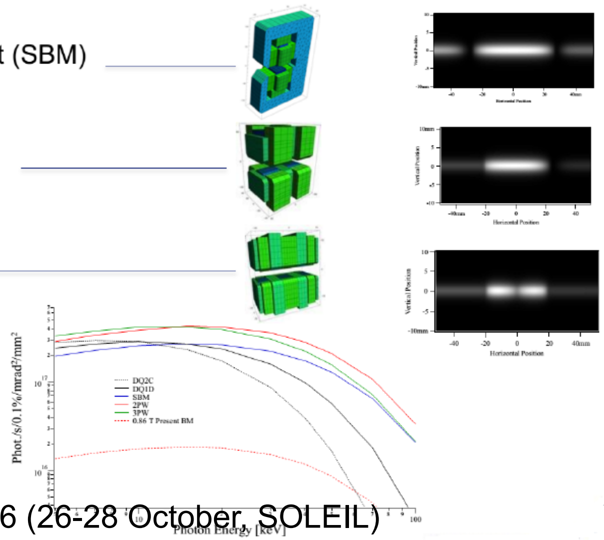
- The increase number of dipoles from 2 to 6 or 7 conducts to lower dipole field of **0.6 T** instead of **1.7 T** of the present lattice.
- Consequent reduction of critical energy from **8.6 keV** to **3.0 keV.**
- We might anticipate that for IR up to soft X-ray dipole beamlines, this will have a marginal effect while for the <u>hard X-ray dipole beamlines</u>, this will correspond to a <u>reduction of the available flux.</u>

➡ an upgrade to a <u>multipole wiggler</u> would be beneficial.

- This option is being considered in the ESRF-EBS with different number for the wiggler poles.

3 different options available for each beamlines 0.86 T Peak field

1. Insertion of a Short Bending Magnet (SBM)
   - 2 mrad X-ray fan
2. Insertion of a 2 Pole Wiggler (2PW)
   - 1.7 mrad x-ray fan
   - 2 possible configurations
3. Insertion of 3 Pole Wiggler (3PW)
   - 1.6 mrad fan



(J. Chavanne (ESRF) at LER2016 (26-28 October, SOLEIL)

➡ Other projects are considering the possibility of introducing "<u>superbend</u>" like in SIRIUS (3.2 T) or like SLSII project with a superconducting Longitudinal Gradient Bend (LGB) "superbend" of 5-6 T.

- Due to the much reduced apertures of the vacuum chamber in the arc, extraction of <u>**IR radiation**</u> is expected to be more difficult.

Electron bunch length manipulation

- Part of the scientific case requires high repetition and very stable short and intense **(~1 ps)** pulses for time resolved experiments.

- **Low-alpha** and **Femtoslicing** operations are expected to be very difficult to realize in such a structure. In addition, the first causes difficulty in obtaining high bunch current, to the extent that the total stored current is typically reduced significantly and the low photon flux obtained by the second may be problematic for many experiments.

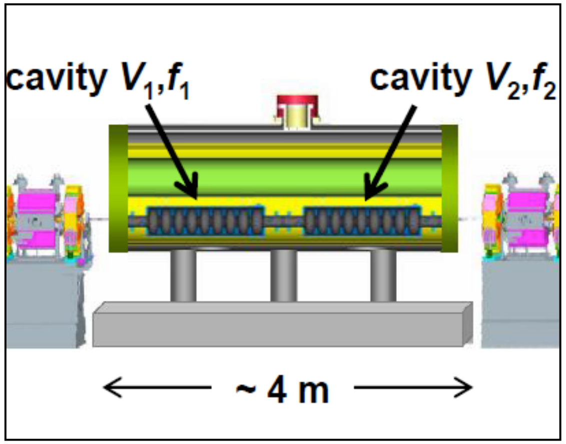
> **Two promising new possibilities** are under investigations: both are based on the use of harmonic RF cavities:

  - **High gradient RF-voltage** using the **superconducting multi-cell cavities "*à la* BESSY-VSR“.**

  - A pair of **RF deflecting cavities** (Crab cavities) with slightly different frequencies

Simultaneous short and long bunches

- 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)	V_{RF} (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
2nd 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			$\sqrt{100} = 10$

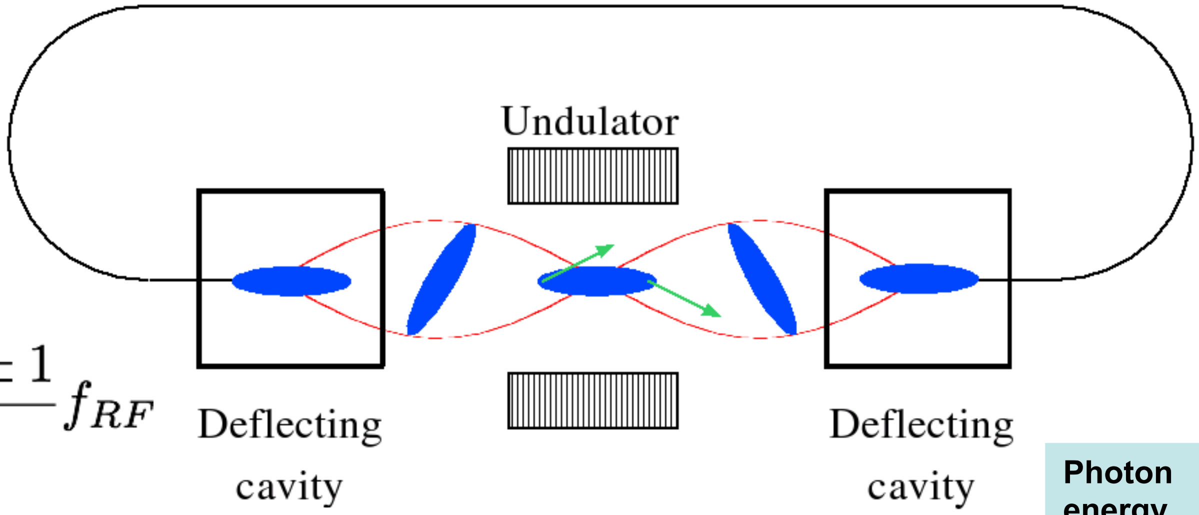
$$\sigma_l \propto \sqrt{\frac{\alpha}{V'}}\,\sigma_E$$

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

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

Short bunch using a time dependent radio frequency orbit deflection

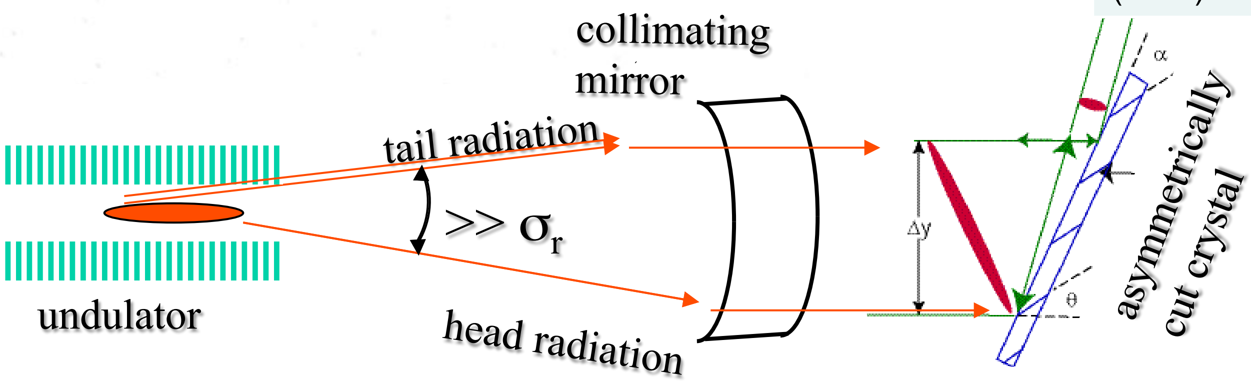


$$f_1 = h f_{RF}$$

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

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

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



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

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

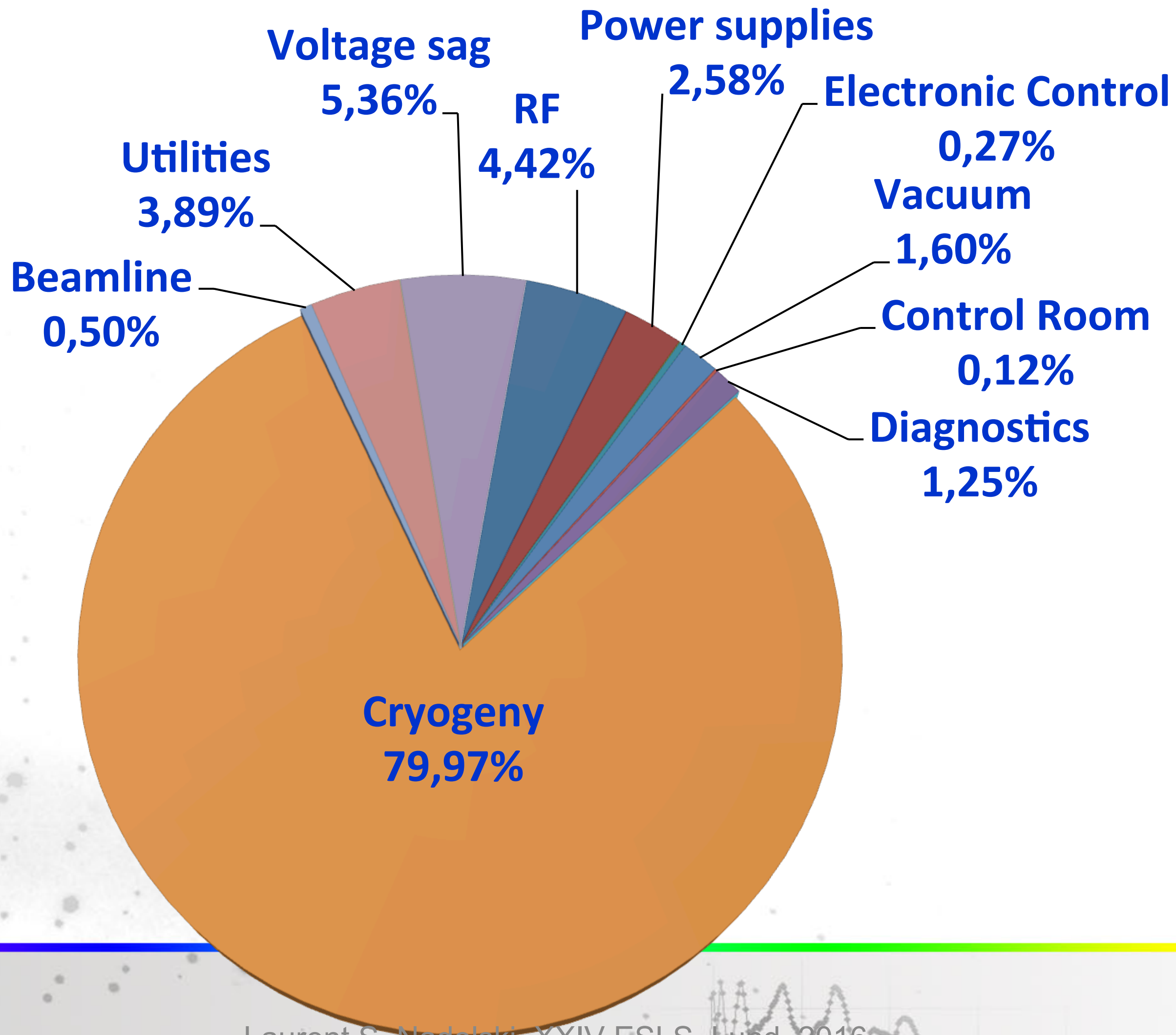
Conclusion

- SOLEIL operation
  - 10 year old facility with 29 beamlines
  - A challenging year to maintain high standard performance
  - Chapter of obsolescence and aging components is being opened

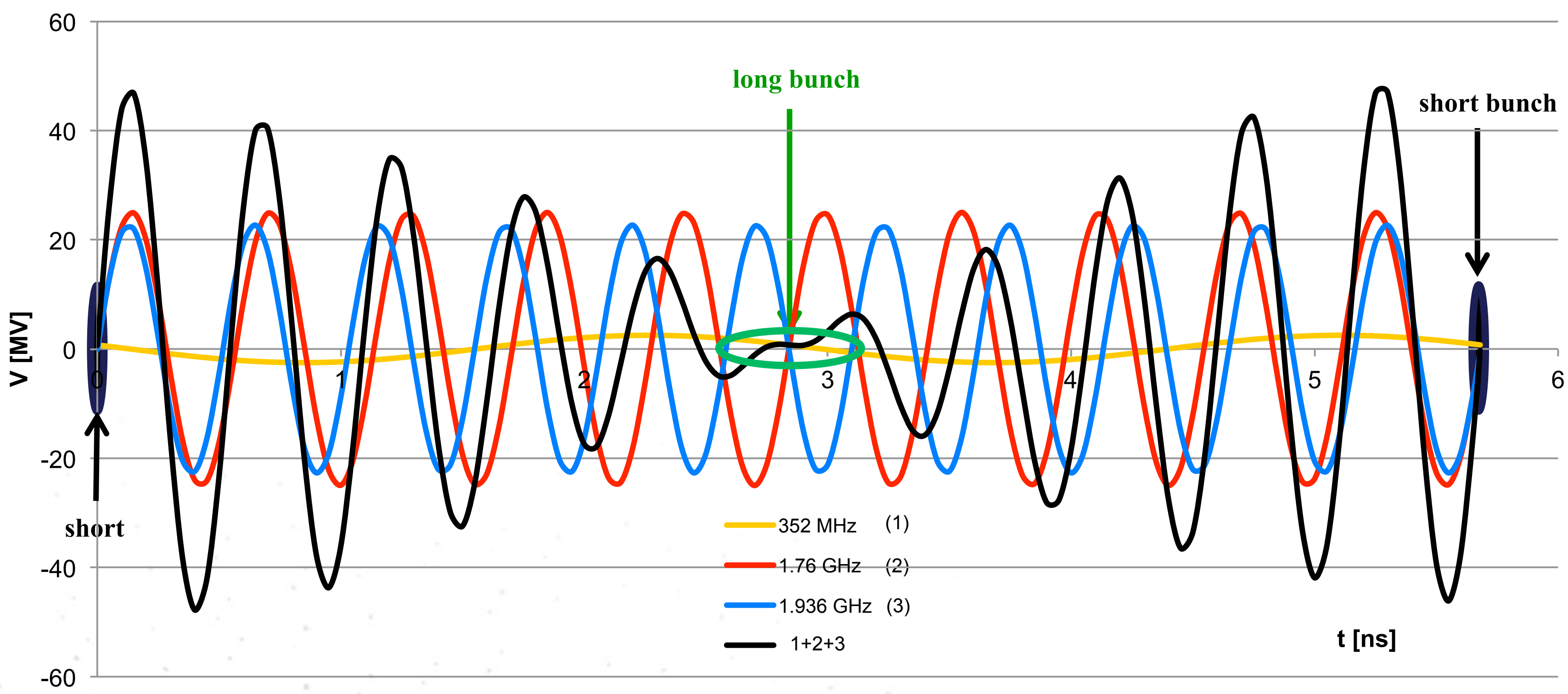
- SOLEIL follows the general trend for DLSR
  - Intense discussions with scientific community
  - Preserving the present specificities
  - Baseline emittance 250 pm•rad 6BA/7BA compact lattice

BACKUP SLIDES

Origin of the 332 hours Beam time LOST in 2016 (RUN1 to RUN4)



Simultaneous short and long bunches



- Alternately long (15 ps) & short (1.5 ps) bunches along the train, obtained by adding 2 harmonic systems, h_1 = 5 and h_2 = 5.5

→ Replace one of the actual 352 MHz CMs by another one containing a pair of SC cavities of each frequency, either passive or powered with 10 kW SSA's @ 1.76 and 1.94 GHz **?**

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