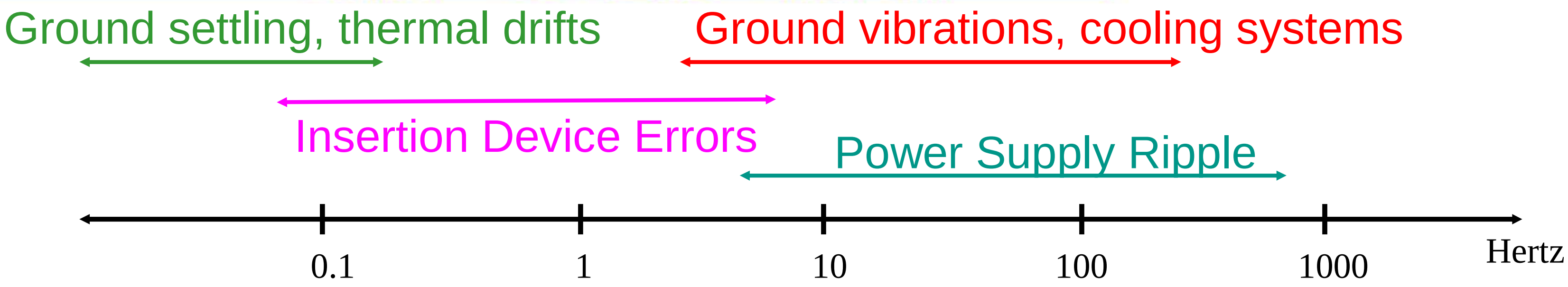
CONTENT

Lecture 4 :

- Beam position stability
- Insertion devices
- Technological aspects
- Time structure
- Conclusions

Position stability disturbances and requirements



Beam stability should be better than :

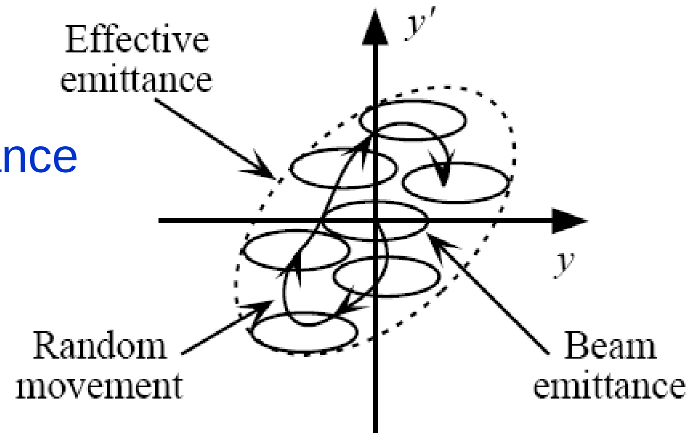
10% of the beam size

10% of the beam divergence

} 20% of beam emittance

up to 100 Hz

but some beamlines have tighter requirements (InfraRed,..)



Electron beam sizes and divergences at Source points (SOLEIL)

Horizontal emittance 3.7 nm.rad

	BetaX m	EtaX m	H Size **SigmaX µm**	H Divergence **Sigma XP µrad**	Effective Emittance H
Short straight	17,8	0,285	**388**	**14,5**	5,61 nm.rad
Medium straight	4,0	0,133	**182**	**30,5**	5,56 nm.rad
Long straight	10,1	0,200	**281**	**19,2**	5,40 nm.rad
Dipole 4°	0,38	0,021	**43**	**107,0**	

Vertical emittance 37 pm.rad (1% coupling)

	BetaZ m		V Size **SigmaZ µm**	V Divergence **SigmaZP µrad**
Short straight	1,75		**8,1**	**4,6**
Medium straight	1,77		**8,1**	**4,6**
Long straight	8,01		**17,3**	**2,2**
Dipole 4°	16,01		**24,5**	**2,1**

Search for the best stability

for 3rd generation light sources this implies **sub-μm stability** (vertical plane)

⇒ identification of sources of orbit movement

⇒ passive damping measures

⇒ orbit feedback systems

It concerns :

⇒ Site and building aspects

⇒ Storage Ring Girder design

⇒ Insertion devices effects

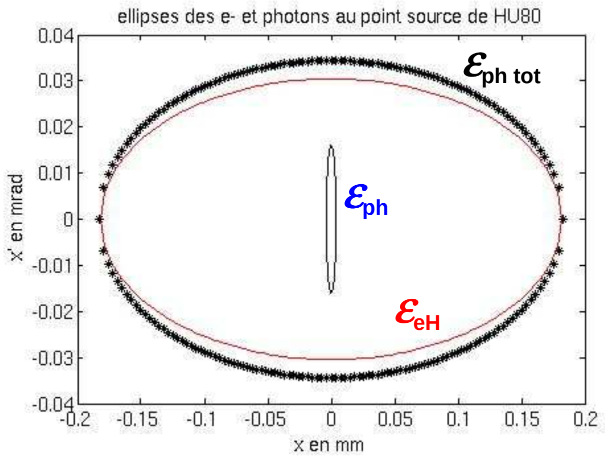
Search for the best stability

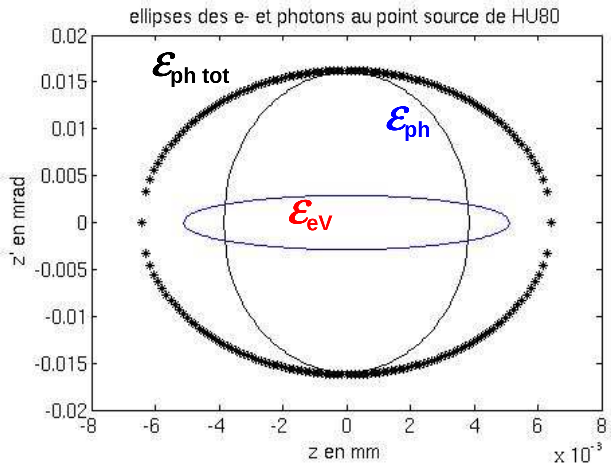
The stability criteria holds for photon beam stability.

⇒ It depends on the Energy of the photons used at the beamline

⇒ More critical for **hard X-ray beamlines** than for VUV soft X-ray beamlines

Exemple SOLEIL : Soft X-ray Beamline « TEMPO » at 1.6 keV





	Electrons beam dimensions		Photons beam dimensions	
	σ_e µm	σ'_e µrad	σ_{tot} µm	σ'_{tot} µrad
Plan H	182	30.4	183	34
Plan V	5.1	2.9	6.5	16

In the Vertical plane :

$\varepsilon_{electron}$ = 15 pm.rad

ε_{photon} = 100 pm.rad

Building design (SOLEIL)

Buildings were designed for optimum position stability :

All potential sources of vibrations in a separate technical building :
All pumps for different cooling circuits + supported on damping material
Compressor for the cryogenic source

Synchrotron building :
Storage Ring and Experimental Hall slabs isolated from the other parts of the building

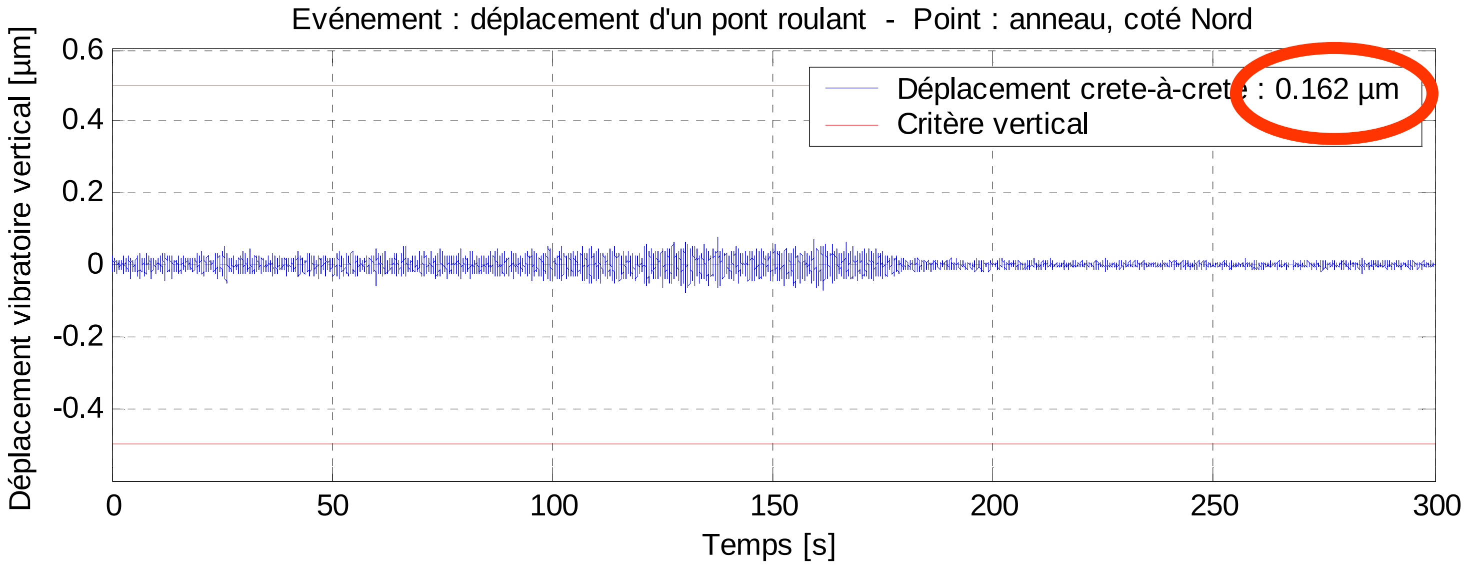
Exp. Hall : => Air temperature regulated at 21 °C ± 1.0 °C
Storage Ring Tunnel : => Air temperature regulated at **21 °C ±0.1 °C**
=> Water cooling circuit regulated at **21 °C ±0.1 °C**

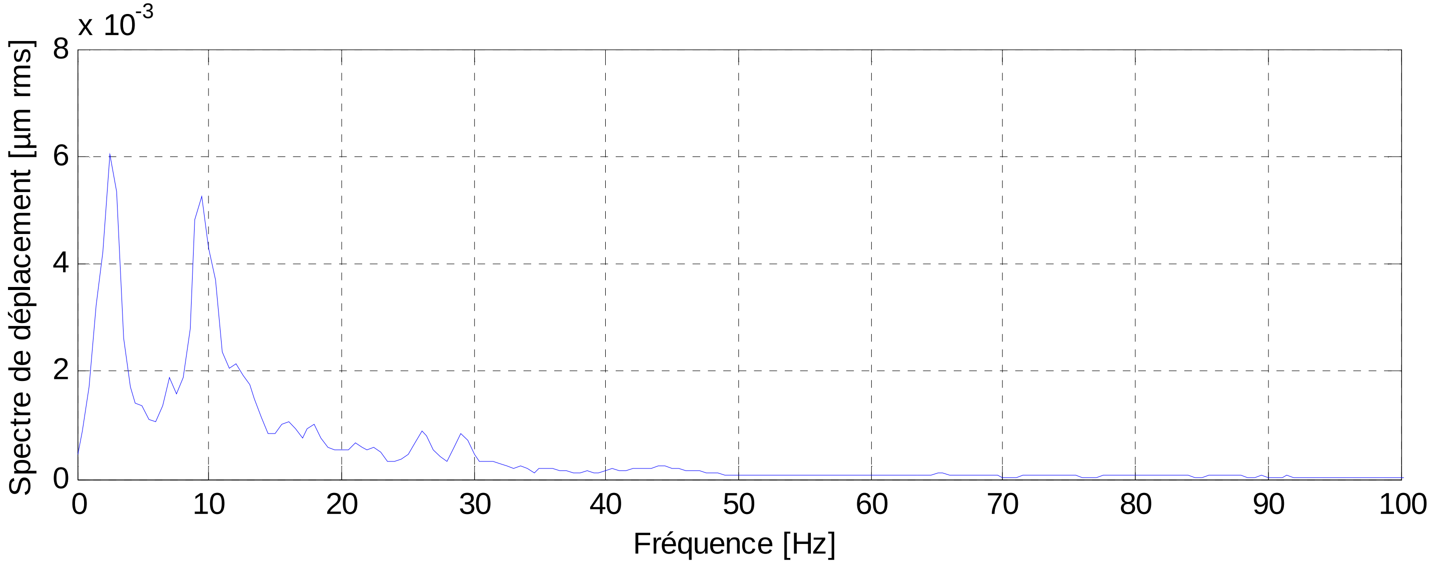
External perturbations
The surface of the 2 roads adjacent to the site were smoothen to minimize perturbation from cars and trucks

Buildings


Technical buildings
Synchrotron building
Restaurant
Central building

Vibrations measurements :
Effect of the crane on the storage ring slab

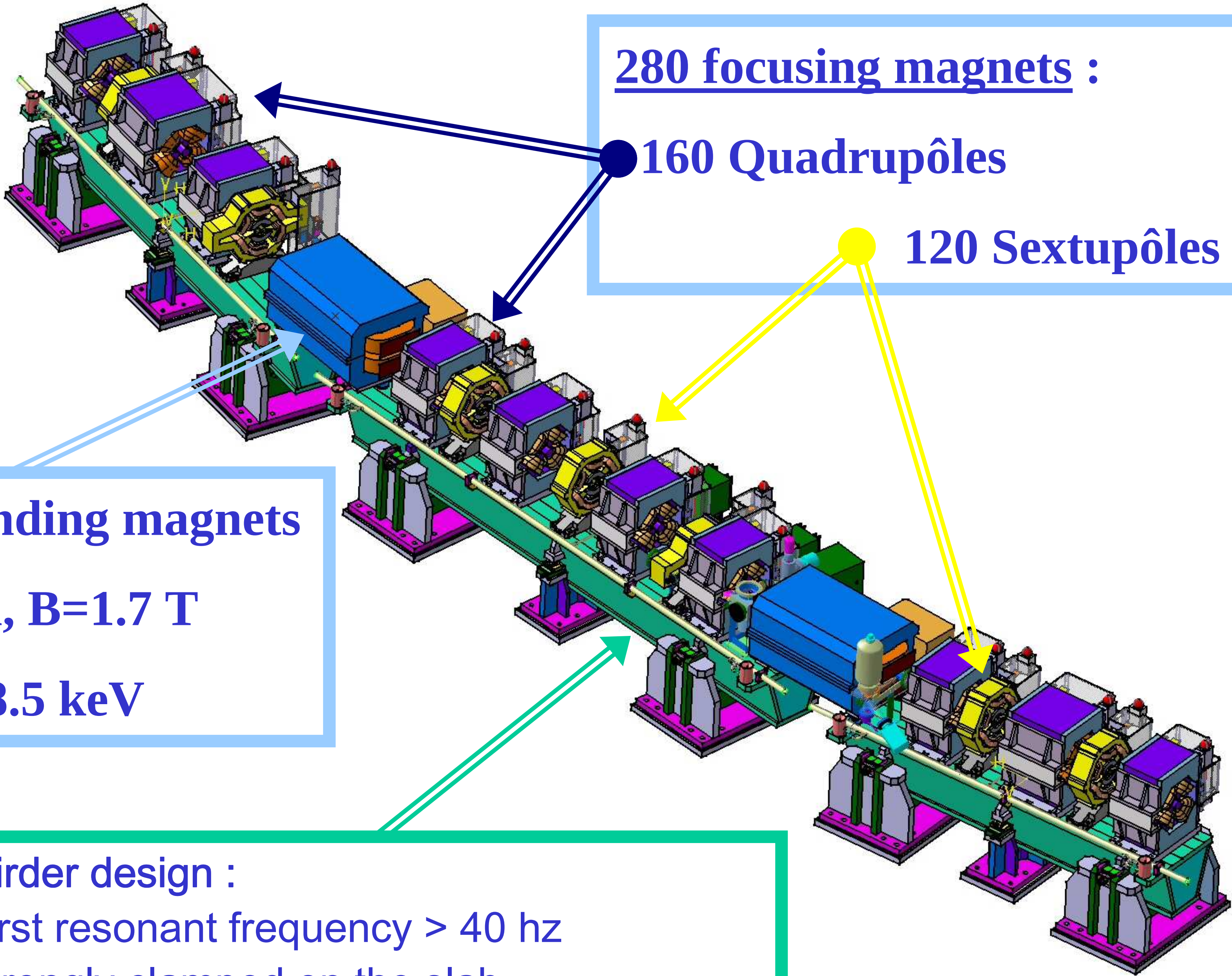




Search for the best stability

Storage Ring :

- Specific design of the girders supporting the magnets (1st eigen mode > 40 Hz)
- High resolution Beam Position Monitors (< 1 µm)
- Fast position feedback (1-100 Hz) implemented in 2007
- Minimize effects of ID gap changes (magnetic measurements)



280 focusing magnets :

- 160 Quadrupôles
- 120 Sextupôles

32 bending magnets

L=1m, B=1.7 T

Ec = 8.5 keV

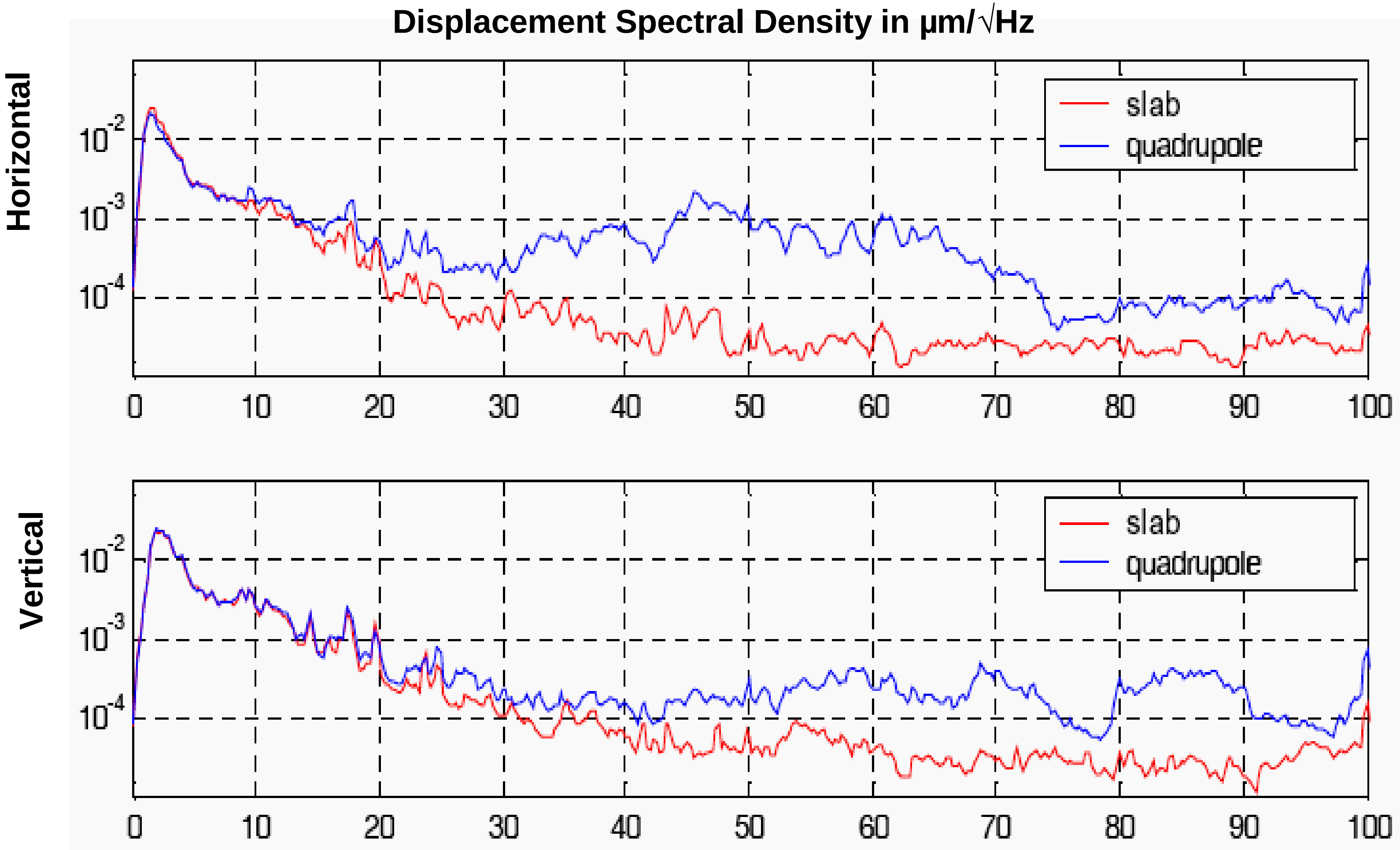
Girder design :

First resonant frequency > 40 hz

Strongly clamped on the slab

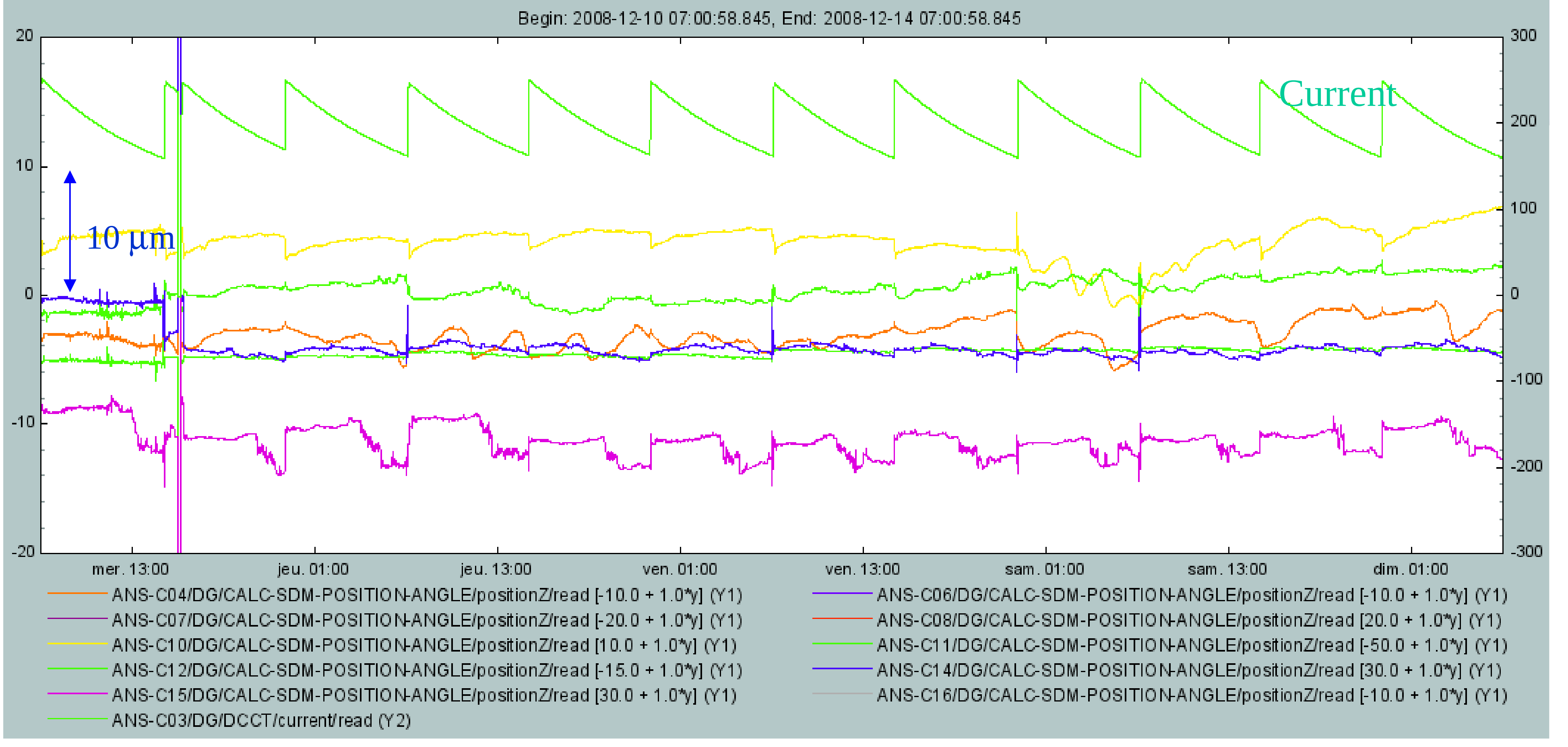
Vibration measurements on SR girders

Residual levels with all utilities ON (cooling, ventilation,..)



No amplification at low frequency (< 30 Hz)

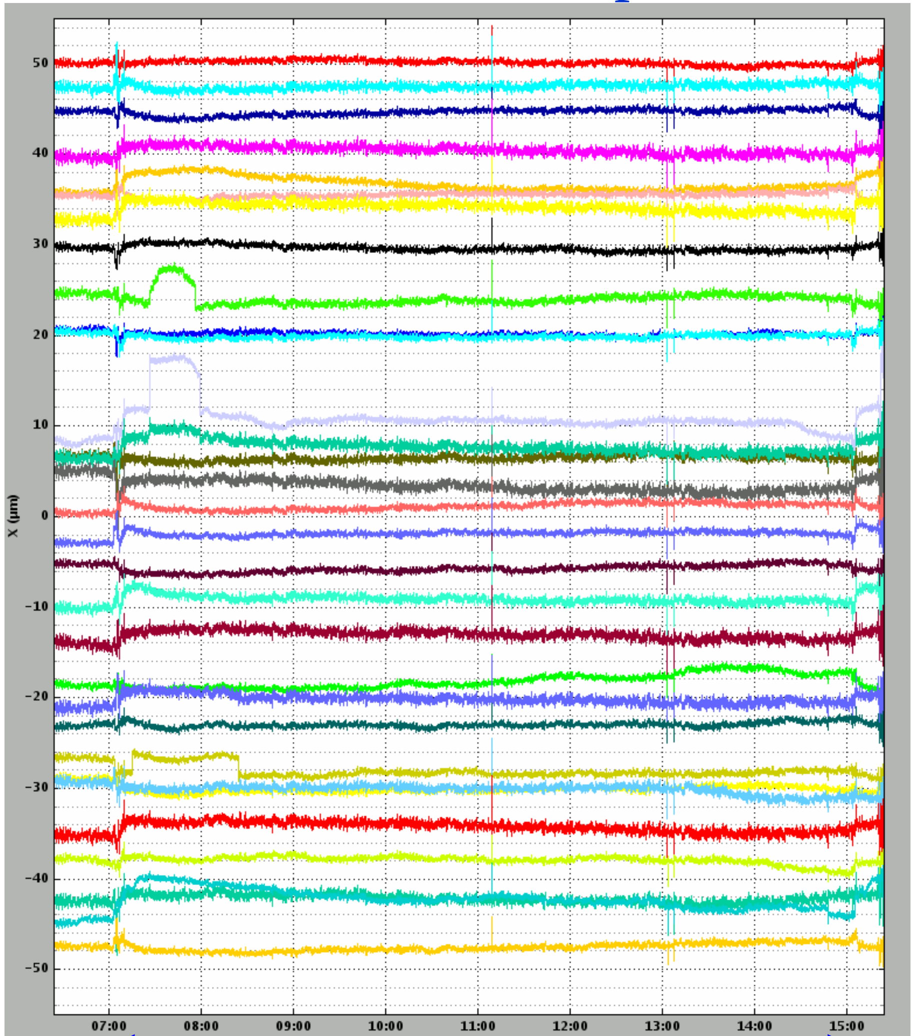
Vertical position stability (1 week) On Medium Straight Sections



Closed orbit corrections performed with as many correctors as BPM (DIAMOND), or with less correctors than BPM (SVD algorithm, SOLEIL, ESRF,…)

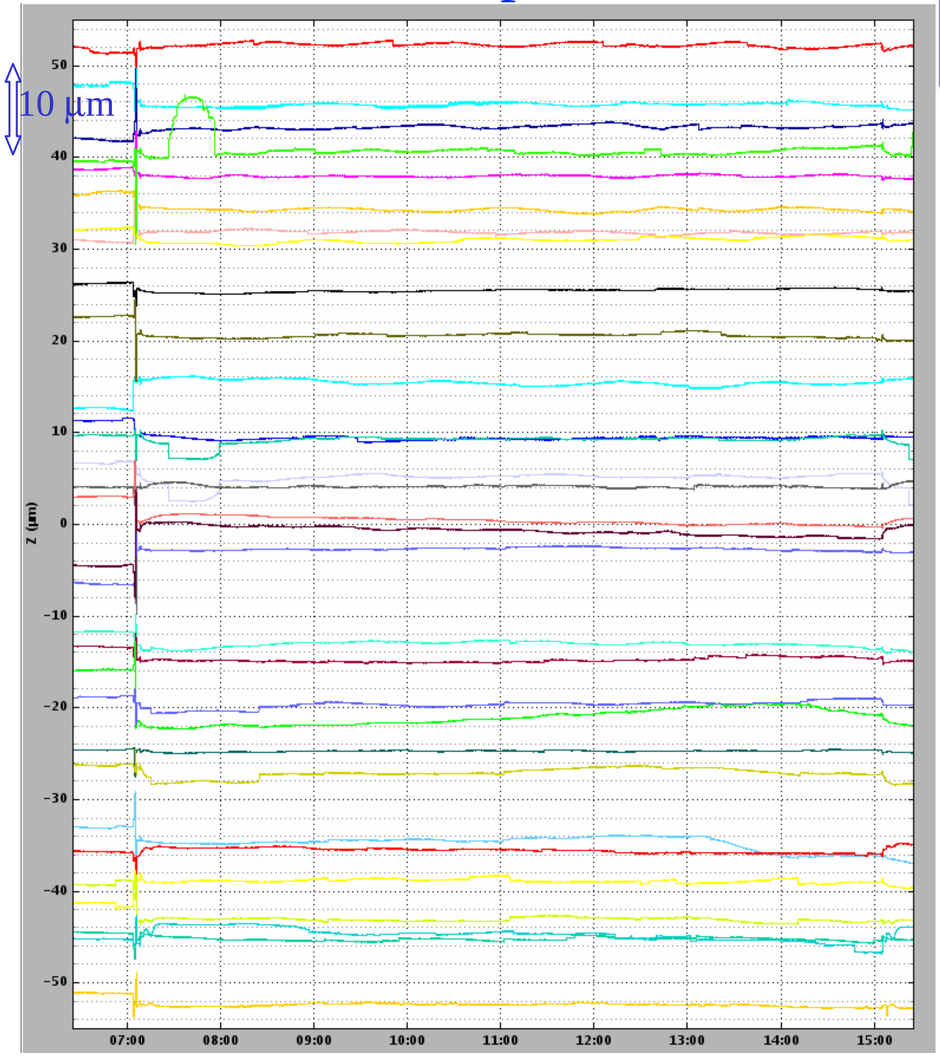
Beam position stability, over 8 hours

Horizontal plane

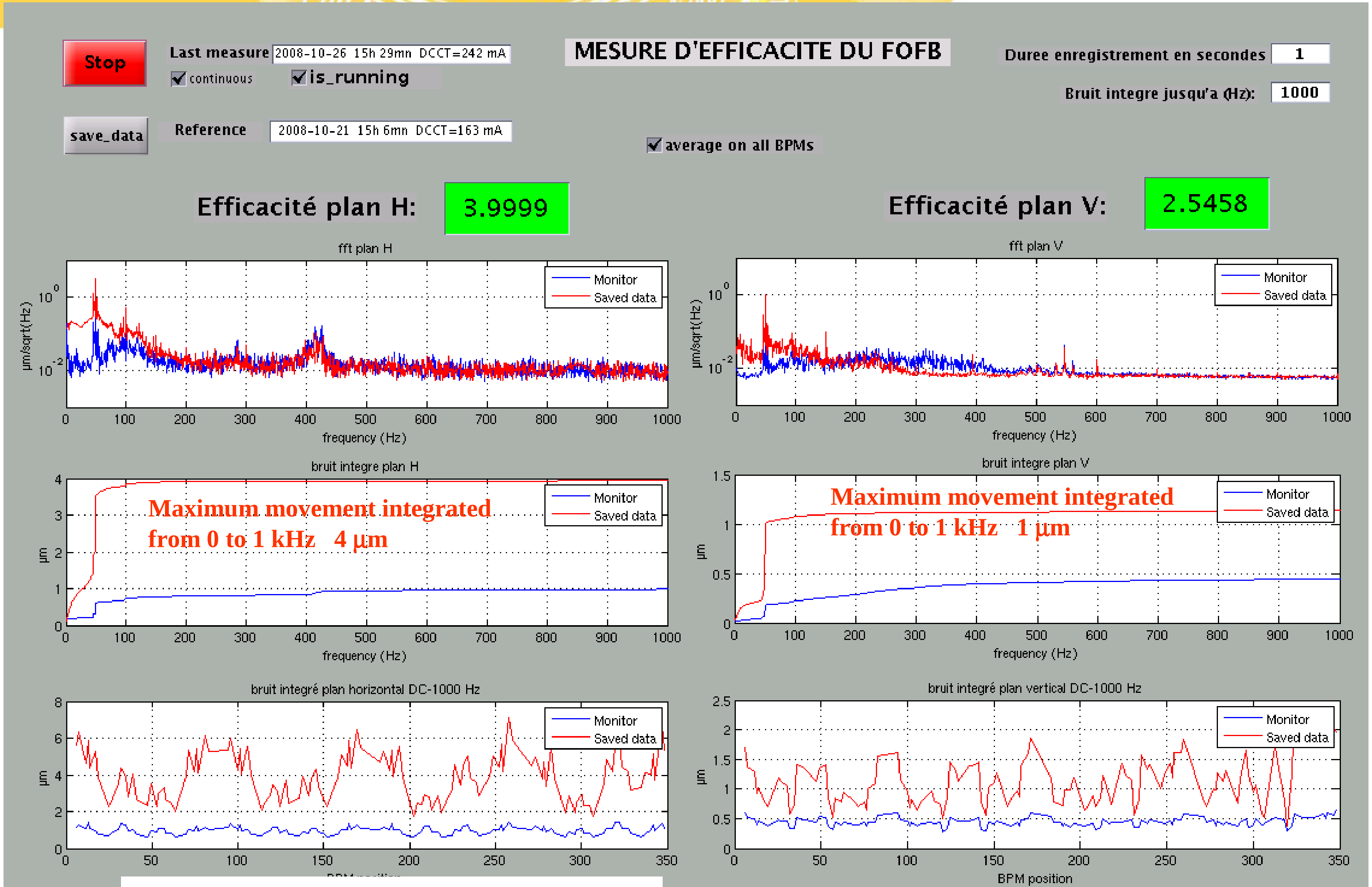


8 hours

Vertical plane



Efficiency of the Fast Orbit feedback (0.01 to 200 Hz)



Feedback OFF (red) Feedback ON (blue)

Overview of fast orbit feedback performance

Summary of integrated rms beam motion (1-100 Hz) with FOFB and comparison with 10% beam stability target

	FOFB BW	Horizontal	Vertical
ALS	**40 Hz**	**< 2 µm in H (30 µm)***	**< 1 µm in V (2.3 µm)***
APS	**60 Hz**	**< 3.2 µm in H (6 µm)****	**< 1.8 µm in V (0.8 µm)****
Diamond	**100 Hz**	**< 0.9 µm in H (12 µm)**	**< 0.1 µm in V (0.6 µm)**
ESRF	**100 Hz**	**< 1.5 µm in H (40 µm)**	**~ 0.7 µm in V (0.8 µm)**
ELETTRA	**100 Hz**	**< 1.1 µm in H (24 µm)**	**< 0.7 µm in V (1.5 µm)**
SOLEIL	**100 Hz**	**< 0.8 µm in H (20 µm)**	**< 0.2 µm in V (0.6 µm)**
SLS	**100 Hz**	**< 0.5 µm in H (9.7 µm)**	**< 0.25 µm in V (0.3 µm)**
SPEAR3	**60Hz**	**~ 1 µm in H (30 µm)**	**~ 1 µm in V (0.8 µm)**

Trends on Orbit Feedback :

- restriction of tolerances w.r.t. to beam size and divergence
- higher frequencies ranges
- integration of XBPMs

* up to 500 Hz

** up to 200 Hz

Efficiency of the Fast Orbit feedback (Electromagnetic undulator HU640)

With Fast Orbit feedback 2 microns in V plane

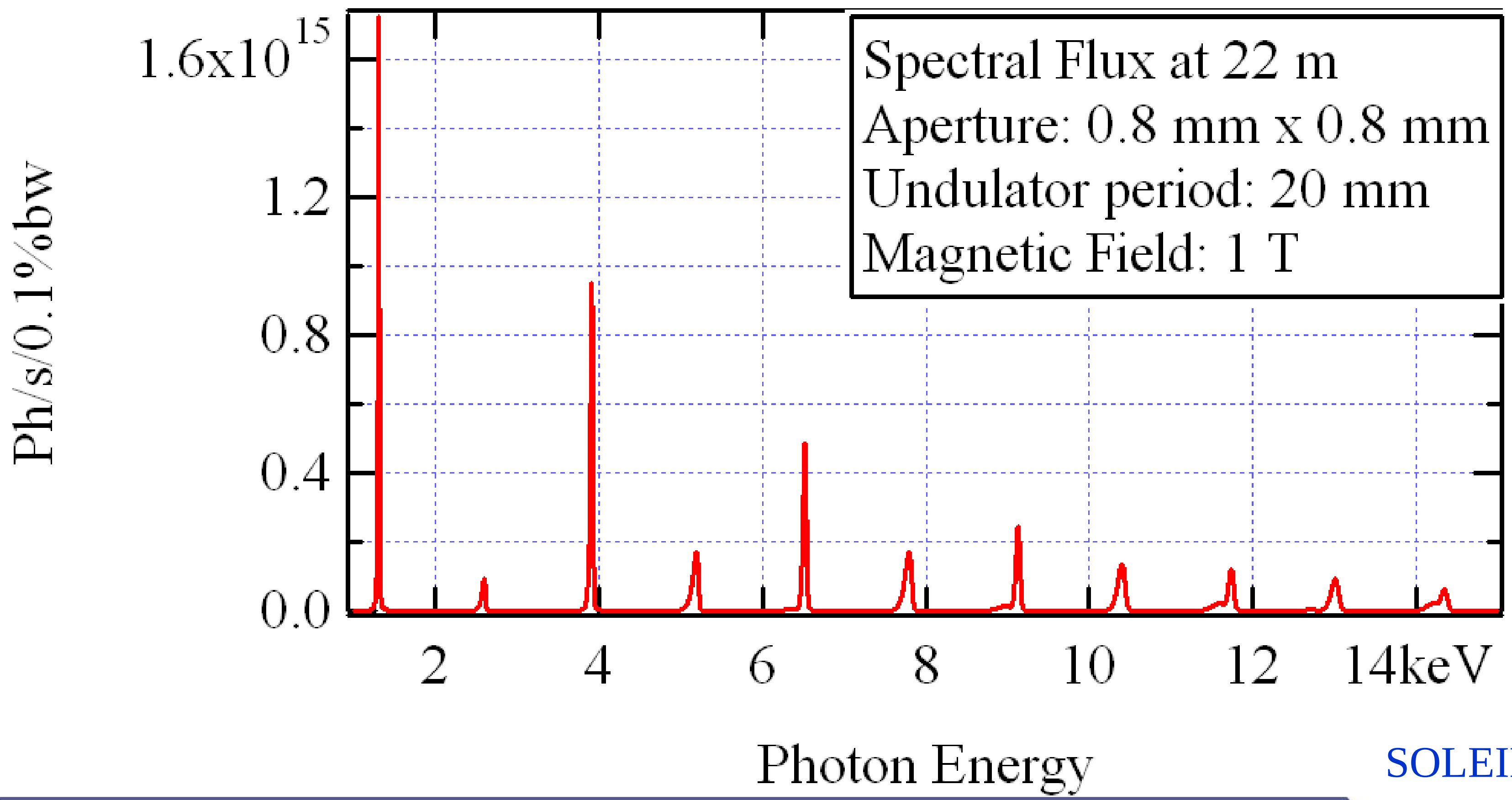
CONTENT

Lecture 4 :

- ❑ Beam position stability
- ❑ Insertion devices
- ❑ Technological aspects
- ❑ Perspectives

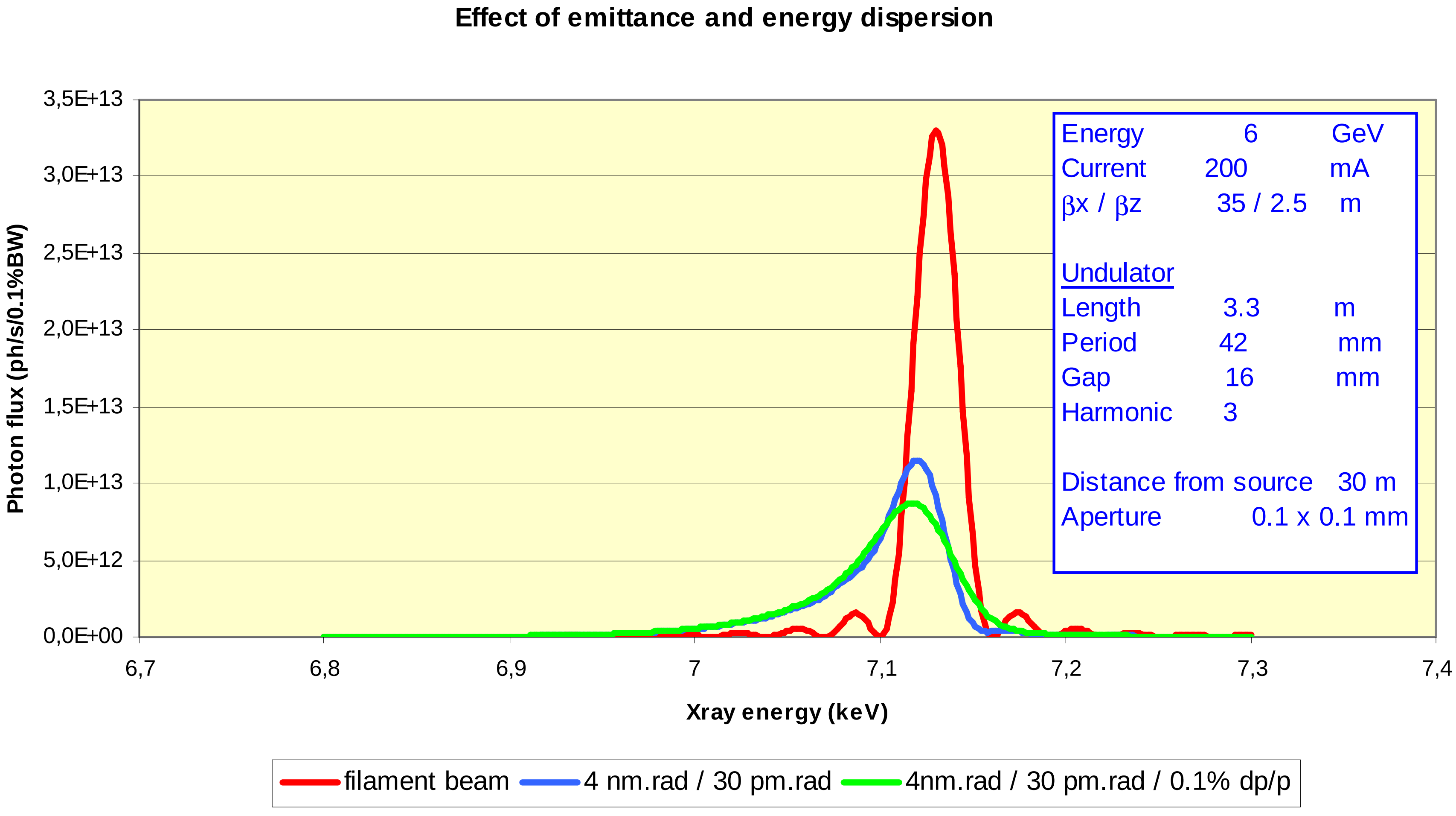
Insertion devices

To get a good separation of the harmonics, observation must be performed using a small aperture



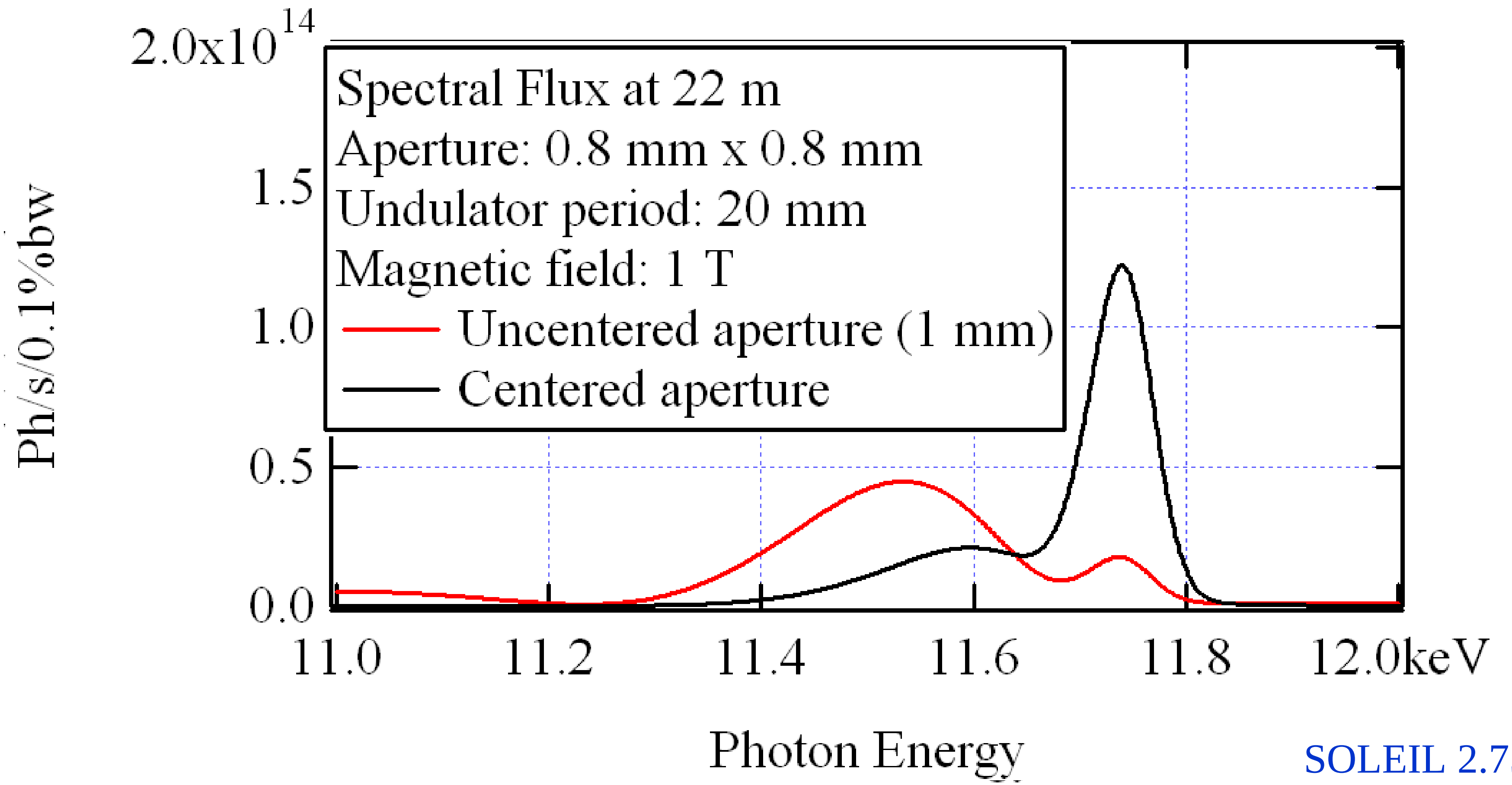
SOLEIL 2.75 GeV
500 mA

Flux reduction due to emittance and energy dispersion



Insertion devices

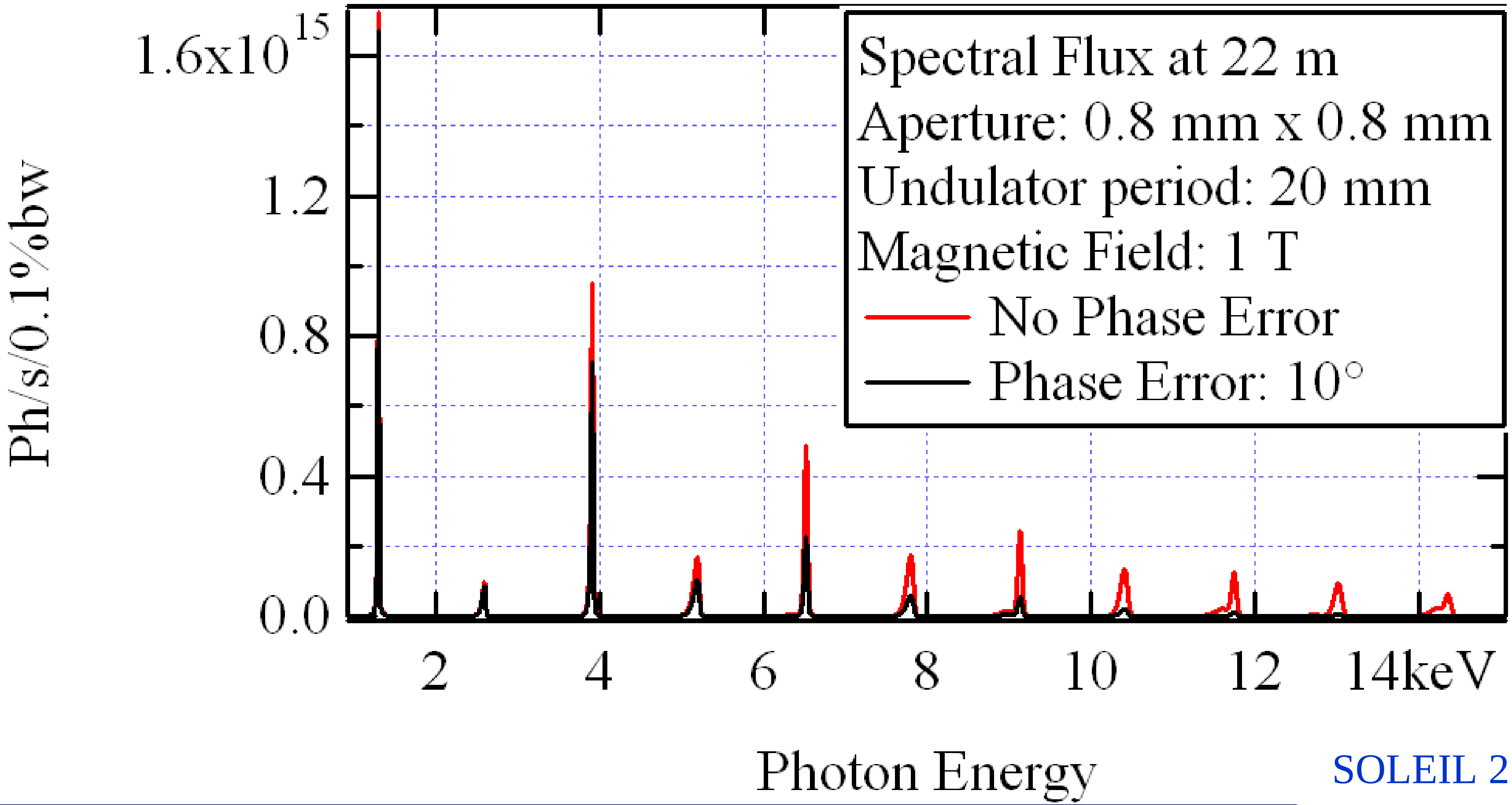
Flux reduction in case of misalignment (harm 9)



SOLEIL 2.75 GeV
500 mA

Insertion devices

Flux reduction due to phase error in the sinusoidal field



SOLEIL 2.75 GeV
500 mA

Insertion Devices construction
From specifications to photons

Specifications set with the beamline responsibles :

Insertion type, spectrum range, polarisation, taper, quasi periodicity,..

Magnetic design using software codes :

- SRW (radiation) and RADIA (magnetic configuration)
- CATIA (mechanical design)
- TRACY-II, BETA (effects on beam)

Construction and assembling

Magnetic measurements : B(x,z,s), ∫Bds, ∬Bdsds',Gn Gs, phase
Shimming : sorting, magnet swapping, magnet moving : IDBuilder
Changing field and polarization : Gap changes, or Current changes

Tests on electron beam

vacuum, beam position, tunes => ∫Bds, ∬Bdsds' Gn Gs phase
Correction of residual field integrals with embedded correctors + machine correctors (feedforward + slow orbit feedback)

Photon beam characterization on the beamline

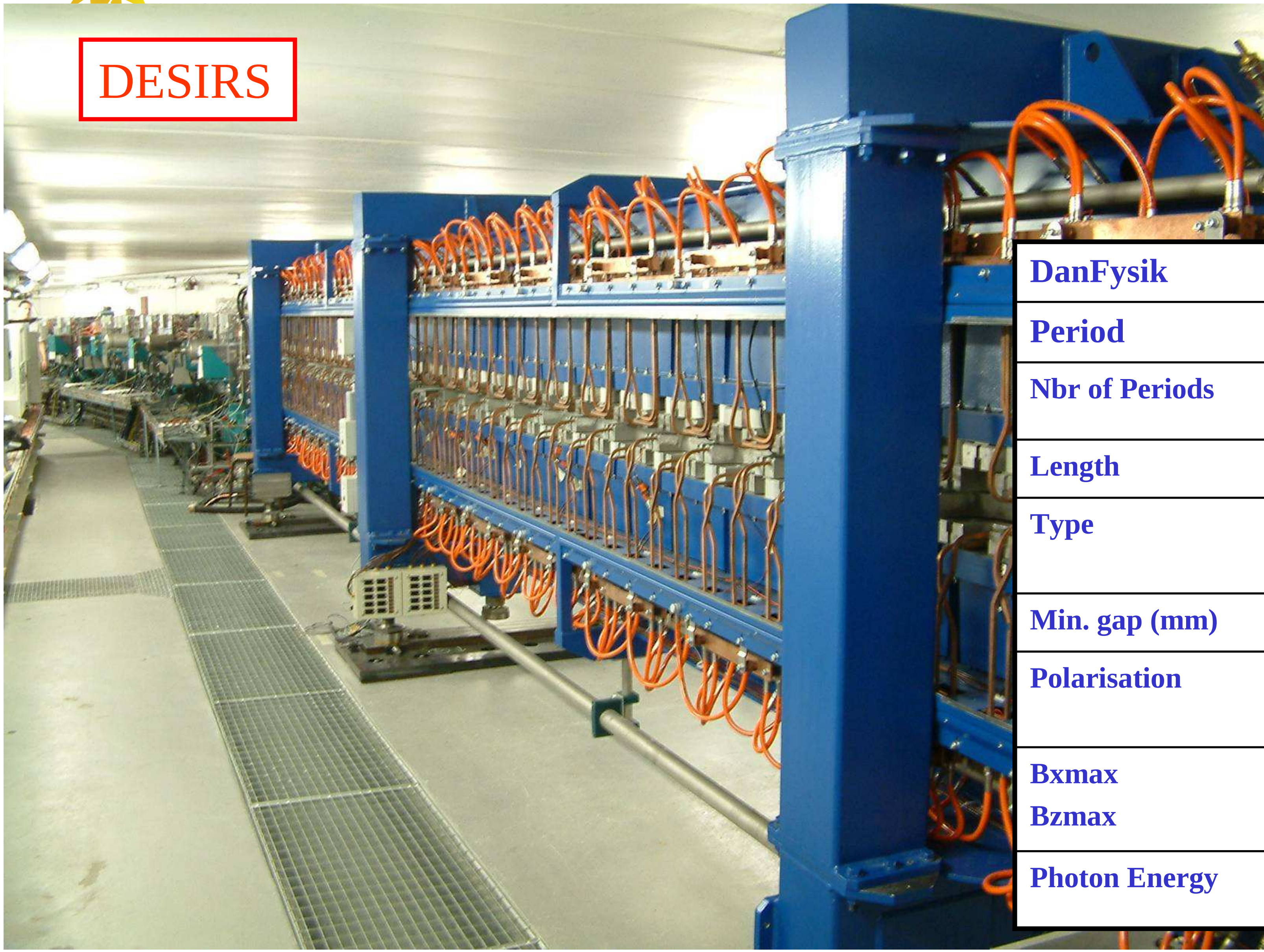
Energy spectrum and calibration. => B, flux, emittance, e- beam energy disp.

SOLEIL Insertion devices

There exists a large variety of insertions devices to match at best the specific requirement of any beamline

BL Name	Resp. Ligne	Energy	Source	Location	Magnetic length (m)	Polarization/ Switch time	Periodic	Technology	Status
phase 1									
DESIRS	Nahon	5 – 40 eV	HU640	I 05-L	10	Circ./lin/phasevar	Yes	HU640	*Installé*
TEMPO #1	Sirotti	45 – 1500 eV	HU80	I 08-M	1,6	Circ./lin.	QP	APPLE II	*Installé*
PROXIMA1	Thompson	4 – 30 keV	U20	I 10-C	1,96	Lin.	Yes	Hybrid in vacuum	*Installé*
SWING	Perez	4 – 30 keV	U20	I 11-C	1,96	Lin	Yes	Hybrid in vacuum	*Installé*
CASSIOPEE #1	Taleb	10 – 1000 eV	HU256	I 15-M	3,1	Circ./lin.	QP	HU256	*Installé*
CRISTAL	Ravy	4 – 30 keV	U20	I 06-C	1,96	Lin	Yes	Hybrid in vacuum	*Installé*
phase 2									
PLEIADES #2	Miron	10 – 1000 eV	HU256	I 04-M	3,1	2 s	QP	HU256	*Installé*
PLEIADES #1	Miron	35 – 1500 eV	HU80*	I 04-M	1,6	Circ./lin.	QP	APPLE II	*Installé*
ANTARES #1	Ascencio	10 – 1000 eV	HU256	I 12-M	3,1	Circ./lin.	QP	HU256	*Installé*
DEIMOS #1	Ohresser	500 eV – 6 keV	HU52	I 07-M	1,6	Circ./lin.	Yes	APPLE II	*Installé*
LUCIA	Flank	500 eV – 6 keV	HU52	I 16-M	1,6	2 s	Yes	APPLE II	*Installé*
SIXS	Garreau	4 – 30 keV	U20	I 14-C	1,96	Lin	Yes	Hybrid in vacuum	*Installé*
TEMPO #2	Sirotti	1 – 5 keV	HU44	I 08-M	1,6	2 s		APPLE II	*Installé*
MicroFOC #2	Sacchi	1 – 5 keV	HU44	I 14-M	1,6	2 s	Yes	APPLE II	*Installé*
CASSIOPEE #2	Taleb	100 eV – 4 keV	HU60	I 15-M	1,6	2 s		APPLE II	*Installé*
MicroFOC #1	Sacchi	*45 – 1500 eV*	*HU80*	*I 14-M*	*1,6*	*Circ./lin.*	*QP*	*APPLE II*	*ready*
GALAXIES	Rueff	4 – 30 keV	U20	I 07-C	1,96	Lin	Yes	Hybrid in vacuum	*ready*
ANTARES #2	Ascencio	100 eV – 4 keV	HU60	I 12-M	1,6	2 s		APPLE II	févr.-09
SIRIUS	Fontaine	2 – 10 keV	HU36	I 15-C	1,6	2 – 4 keV	Yes	APPLE II	avr.-09
PROXIMA2 #1	Shepard	5 – 15 keV	U24	I 11-M	1,96	Lin.	Yes	Hybrid in vacuum	juin-09
MicroXmou #1	Belkou	100 eV – 2 keV	HU64	I 10-M	1,6	Circ./lin.	QP	APPLE II	août-09
PSICHE	Itie	10 – 50 keV	WSV50	I 03-C	2,0	Lin	Yes	Wiggler in vacuum	août-09
DEIMOS #2	Ohresser	350 – 900 eV	HU65	I 07-M	1,6	0,2 s/ 5Hz-10Hz	Yes	EMPHU	oct.-09
MicroXmou #2	Belkou	1.5 – 3 keV	HU40	I 10-M	1,6	Circ./lin.	Yes	APPLE II	janv.-10
MicroScopium	Somogyi	4 – 30 keV	U20 ?	I 02-C	1,96	Lin.	Yes	Hybrid in vacuum	sept.-10

Electromagnet Helical Undulator HU640

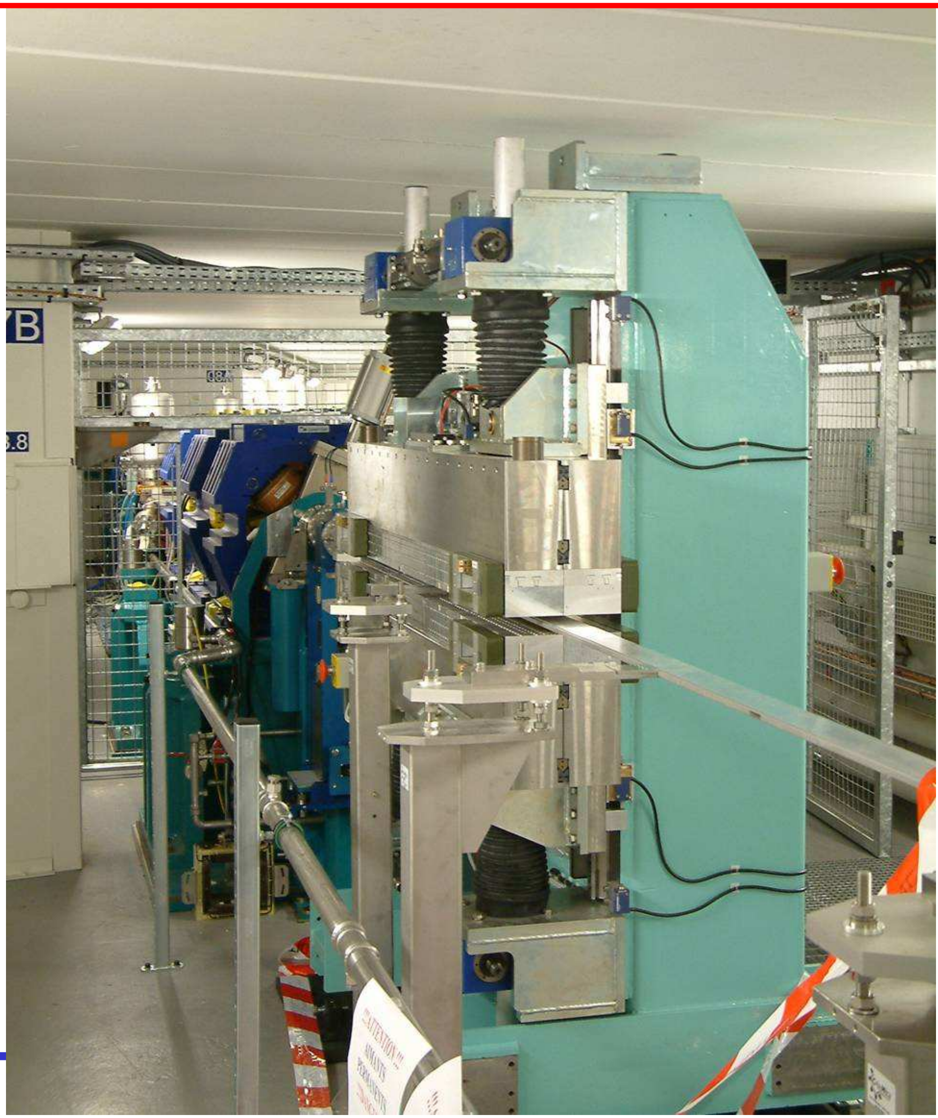


DanFysik	HU640
Period	640 mm
Nbr of Periods	14
Length	10.0 m
Type	Electro-magnetic
Min. gap (mm)	19
Polarisation	Circ./Lin. adjustable
Bxmax Bzmax	0.09 T 0.11 T
Photon Energy	5 – 40 eV

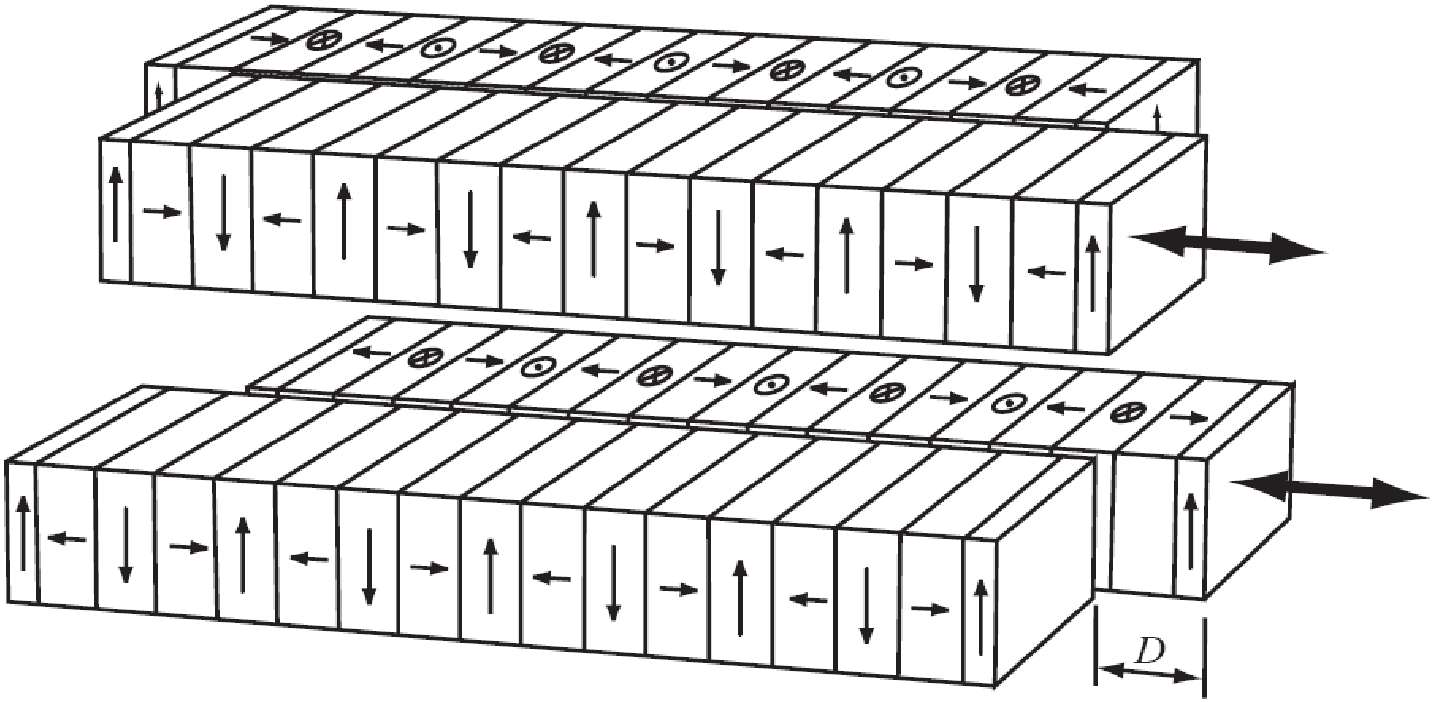
Apple-II Type Helical Undulator HU80

TEMPO, PLEIADES, MICROFOCUS

ELETTRA/SOLEIL	3 x HU80
Period	80 mm
Number of Periods	19
Length	1.65 m
Type	Apple-II
Minimum gap (mm)	15 to 250
Polarisation	Circ./Lin.
Bxmax Bzmax	0.76 T 0.85 [1.0] T
Photon Energy	80 [35] – 1500 eV



Apple-II Type Helical Undulator



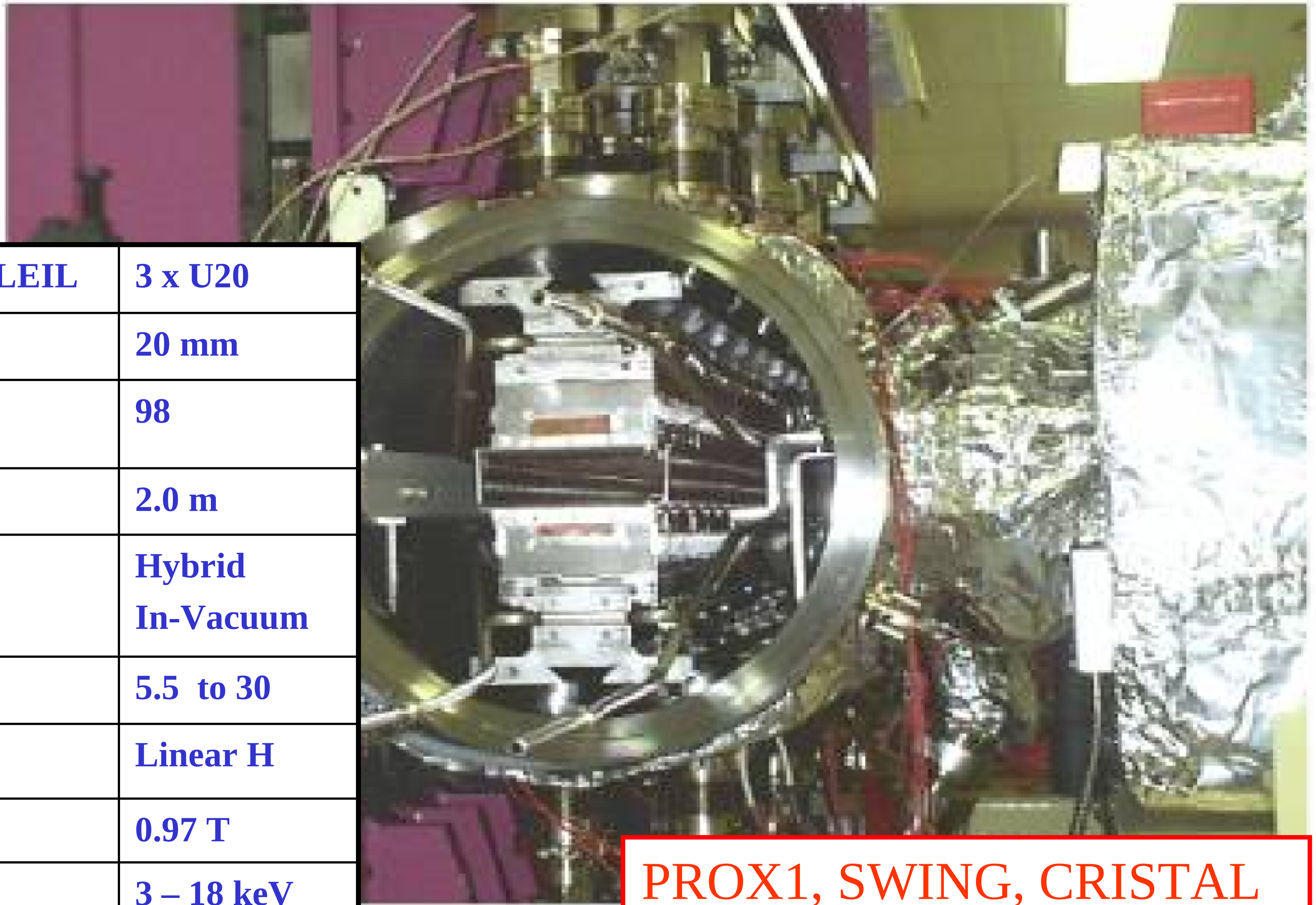
Can create H field, or V field or both, with four independent arrays of permanent magnets

Diagonally opposite arrays move longitudinal, all arrays move vertically

Sliding the arrays of magnetic pole it is possible to control the polarisation of the radiation emitted

In-Vacuum undulator U20

DANFYSIK/SOLEIL	3 x U20
Period	20 mm
Nbr of Periods	98
Length	2.0 m
Type	Hybrid In-Vacuum
Min. gap (mm)	5.5 to 30
Polarisation	Linear H
Bzmax	0.97 T
Photon Energy	3 – 18 keV



PROX1, SWING, CRISTAL

Superconducting Wigglers

Superconducting wigglers are used when a high magnetic field is required 3 - 10 T

They need a cryogenic system to keep the coil superconductive

Nb_3Sn and NbTi wires

SCMPW60 at Diamond

3.5 T coils cooled at 4 K

24 period of 64 mm

gap 10 mm

Undulator K = 21

Cryogenic undulator

The permanent magnet remanent field increases when the magnet is cooled down to 120°K.

⇒ Possibility to get higher field (~ +20%)

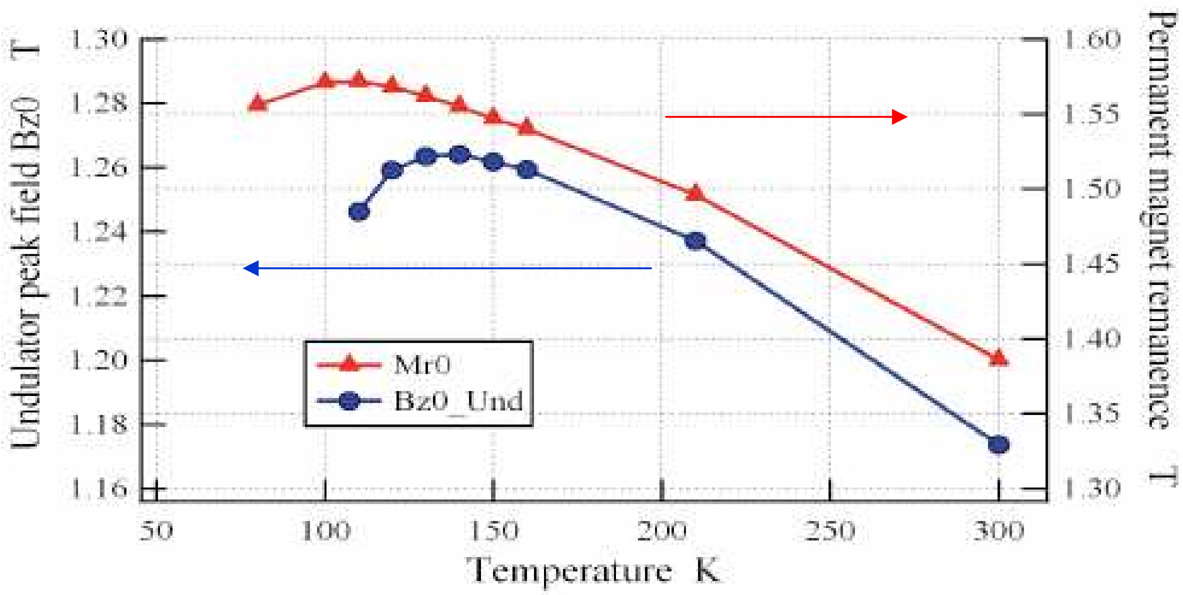
⇒ Harder X-Ray from in-vacuum undulator

Difficulties : => magnetic measurements at 120°K

=> Minimizing RF losses induced by the beam

Prototype tested on the ESRF ring.

Others under construction for SLS, DIAMOND and SOLEIL



Effect of insertion devices on beam dynamics and cures

- Principal effects of undulators and wigglers on beam dynamics
- Closed orbit distortion
- Betatron Tune shift
- Optics variation (β - beating)
- Dynamic aperture reduction
- Variation of damping times; Emittances; Energy spread (wigglers)

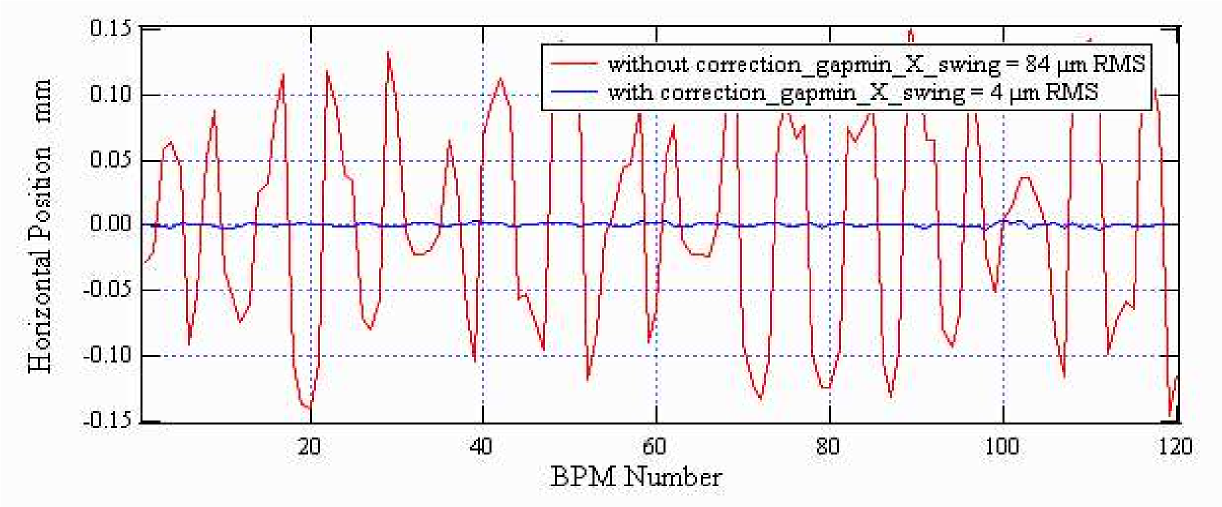
- Remedies => improving field qualities
- Correction of the field integral + Trim coil for closed orbit distortion
- Wide transverse gap (reduced roll-off) for linear optics
- "Magic fingers" to decrease the multipole component of the wiggler

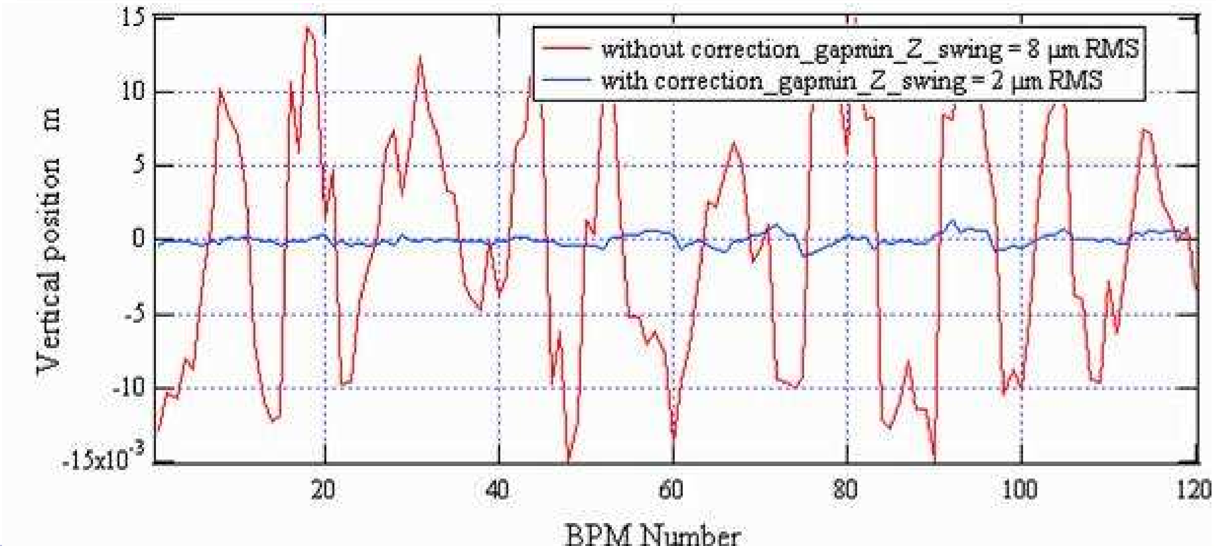
- Remedies => using beam optics methods
- Feed forward tables for trim coil orbit corrections
- Local correction of optics functions (alpha matching schemes, LOCO)
- Non-linear beam dynamics optimisation with wiggler

Compensation of closed orbit distortion

Field integrals can't be corrected < ~100 G.cm in the lab

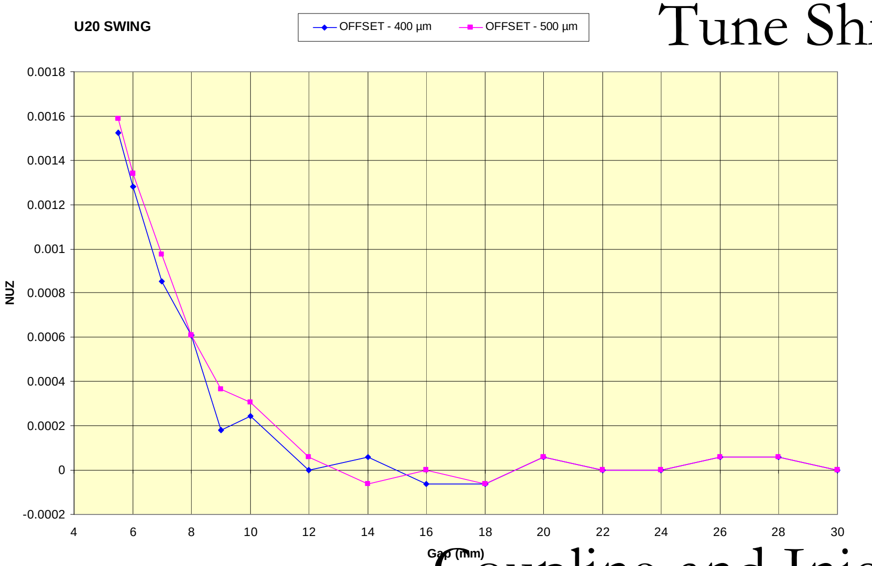
⇒Final correction with beam: feedforward on dedicated steerers = f(gap)

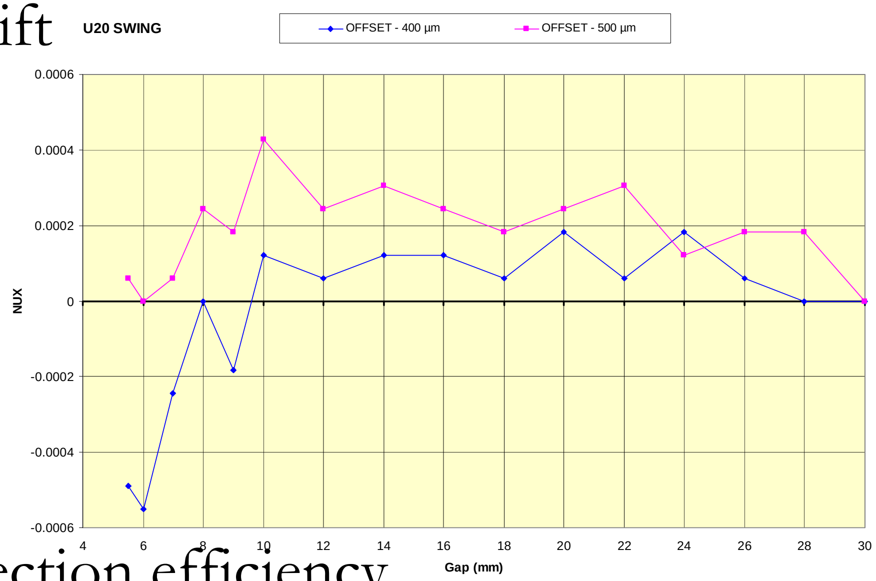




Effects on beam dynamics

Tune Shift





Coupling and Injection efficiency

Undulator	Injection efficiency at 5.5 mm gap	Coupling effect
PROXIMA1	75%	0.1%
SWING	82%	- 0.1%
CRISTAL	88%	0%
3 U20	60 % (85%)	0%

No vertical scraping effect but effect of non linear fields (roll-off)

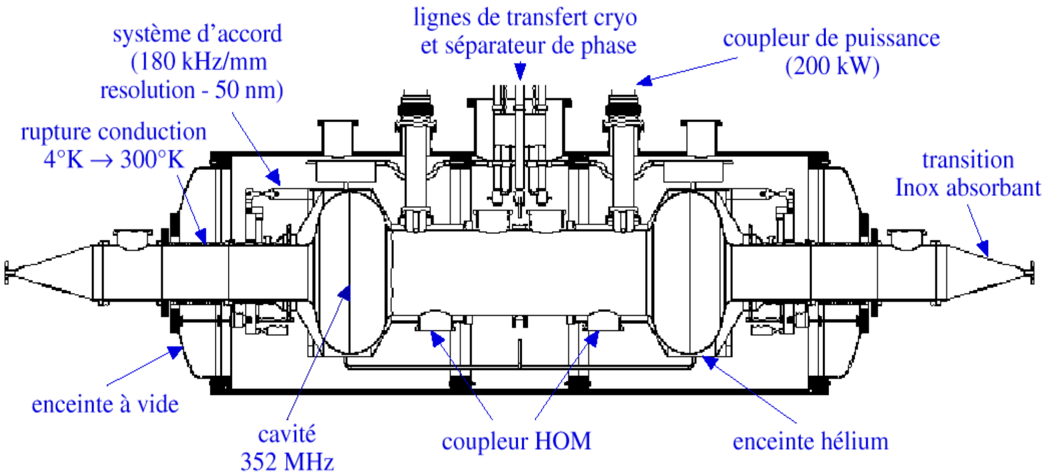
CONTENT

Lecture 4 :

- ❑ Beam position stability
- ❑ Insertion devices
- ❑ Technological aspects
- ❑ Perspectives

RF SYSTEMS : cavities

Superconducting RF cavities : SOLEIL



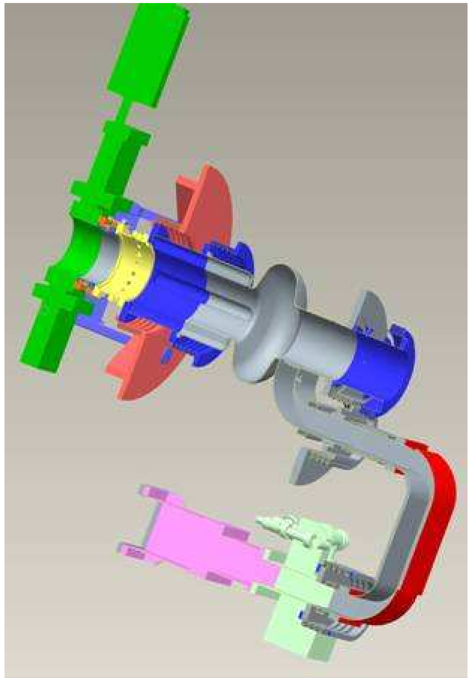
- → 2 cavities @ 352 MHz
- → 150 kW per cavity (LEP type coupler)
- → 2MV per cavity
- → 2 cryomodules installed
- →few problems with the cold tuning system

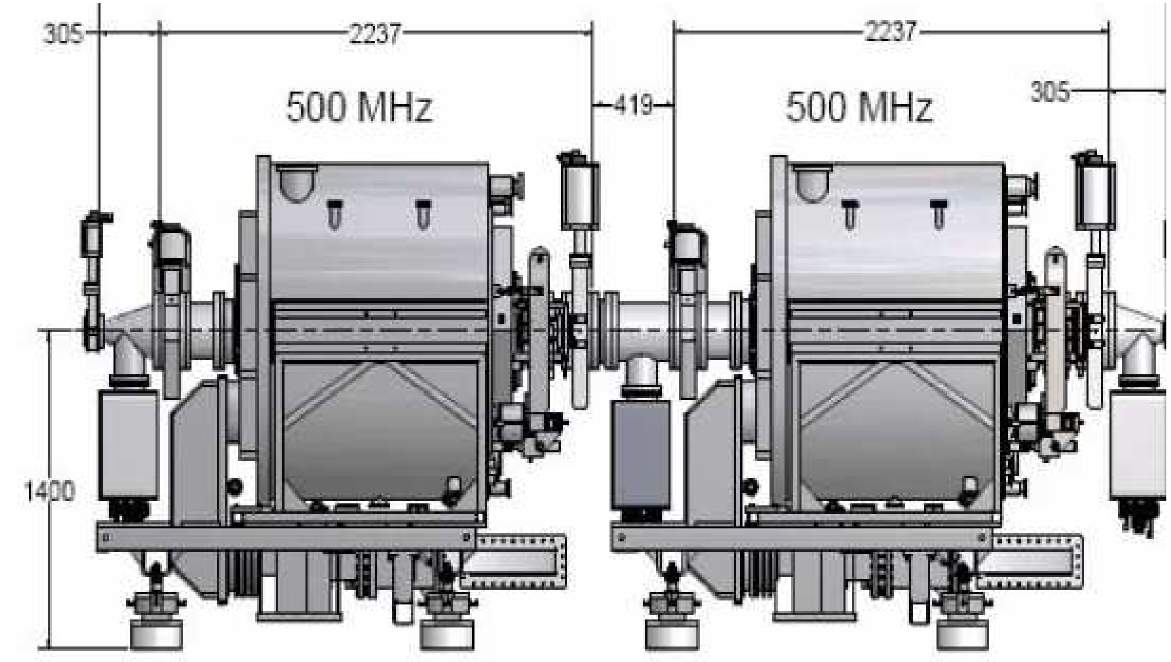
(Collab CEA/CERN/SOLEIL/ESRF)

RF SYSTEMS : cavities

Superconducting RF cavities : CESR-B

(Cornell, CLS, Taiwan, Diamond)





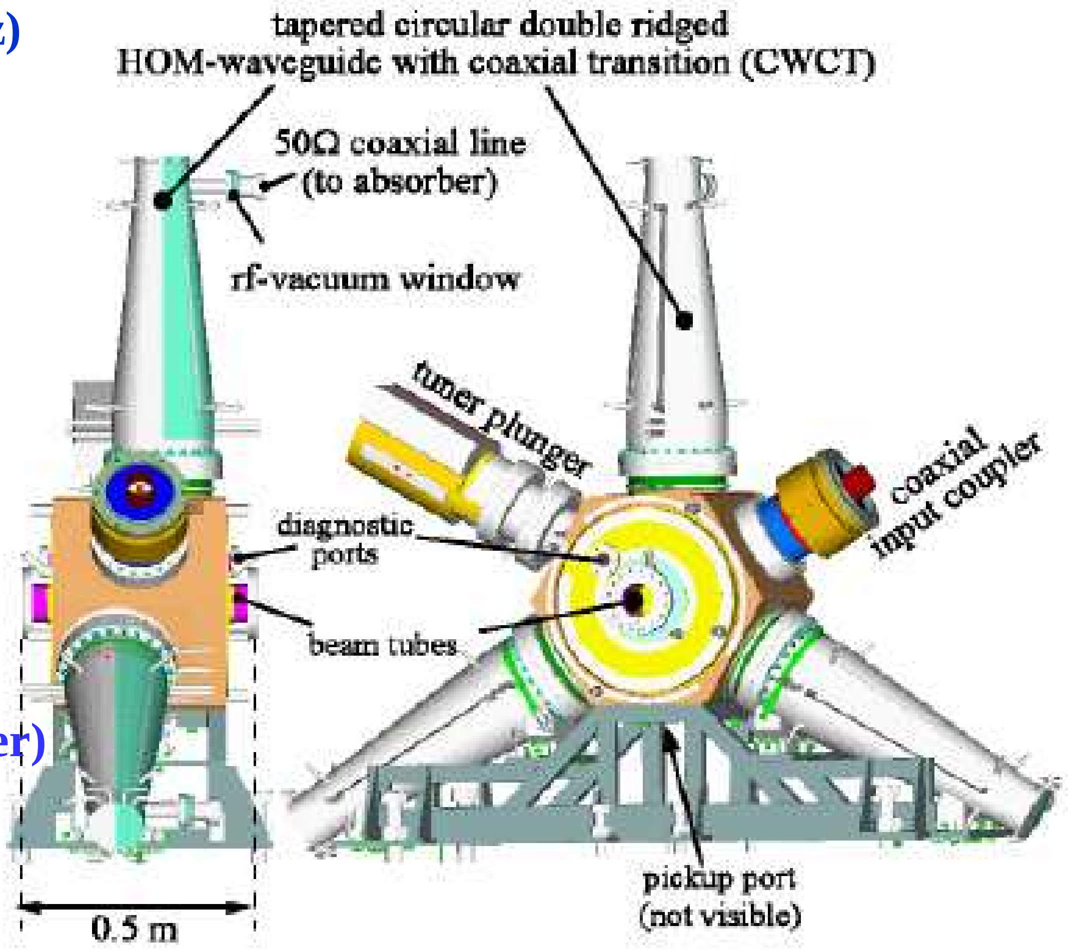
→ **500 MHz**
→ **250 kW per cavity (Waveguide coupling)**
→ **2.4 MV per cavity (8 MV/m)**

RF SYSTEMS : cavities

HOM damped RF cavities : BESSY "WILLI VIEN" cavity

(ALBA, and coming ESRF at 352 MHz)

EU Collaboration



- → 500 MHz
- → 150 kW per cavity (Coaxial coupler)
- → 0.6 MV per cavity
- → Rshunt = 3.1 MΩ
- → Q_0 = 26 700

RF SYSTEMS : Transmitters

IOT's : ELETTRA, DIAMOND, ALBA,..

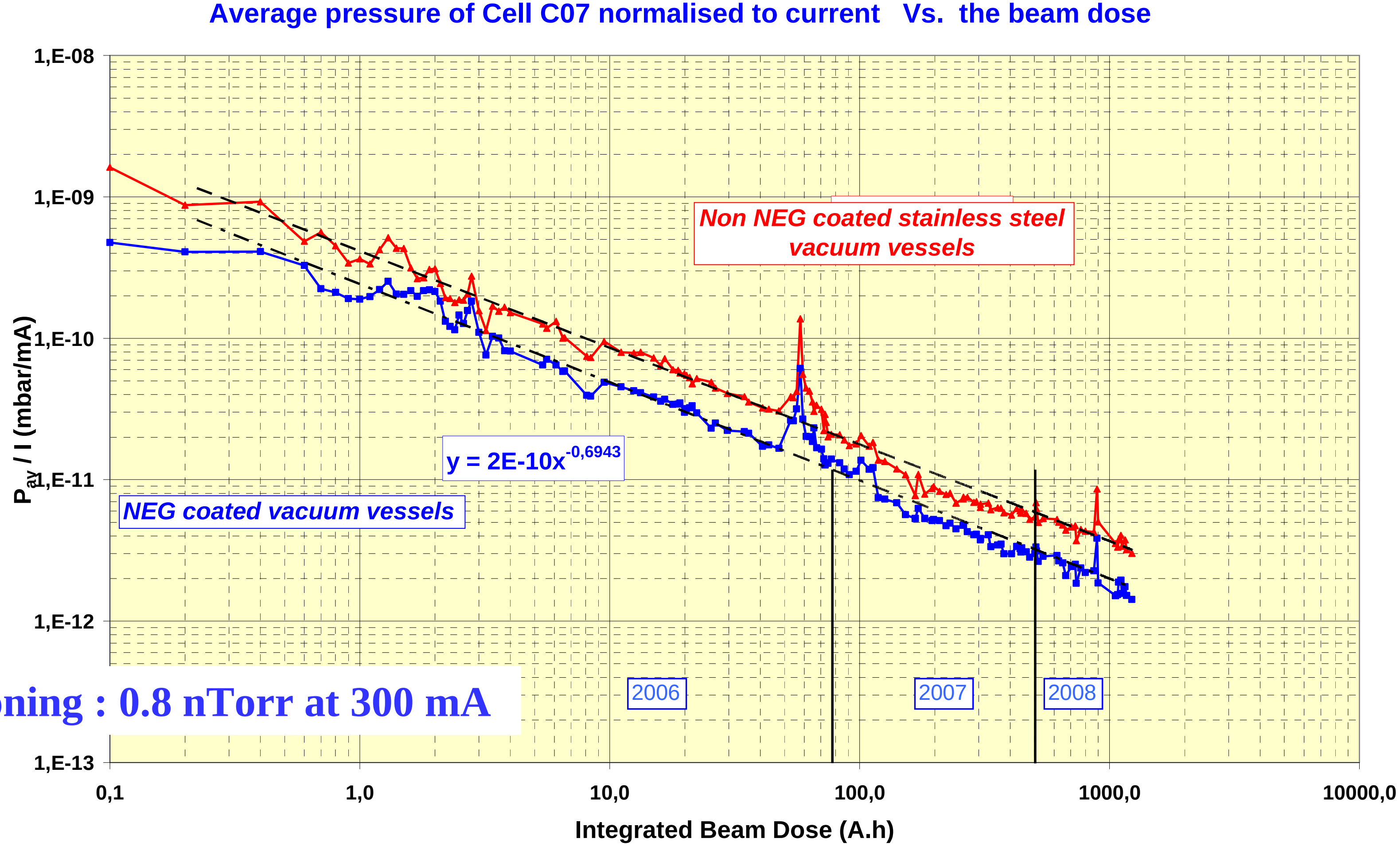
Solid state amplifier : SOLEIL and soon ESRF

- → **4x190 kW @ 352 MHz**
- → **Smooth operation**
- → **Excellent reliability**

VACUUM SYSTEMS

NEG coating (developped at CERN) => for low gap ID vessels at many facilities

More generalised use at SOLEIL (56% of the ring) and MAXLAB



Fast conditioning : 0.8 nTorr at 300 mA

BPM SYSTEMS

LIBERA BPM digital electronics provide sub micron resolution, and also :

⇒ simultaneous turn by turn measurement

⇒ slow orbit data

⇒ fast orbit feedback data, and processing

⇒ with low current dependence

In use at Diamond, SOLEIL, ELETTRA, ASP, ALBA, ESRF, PETRA3,…

TOP-UP Operation

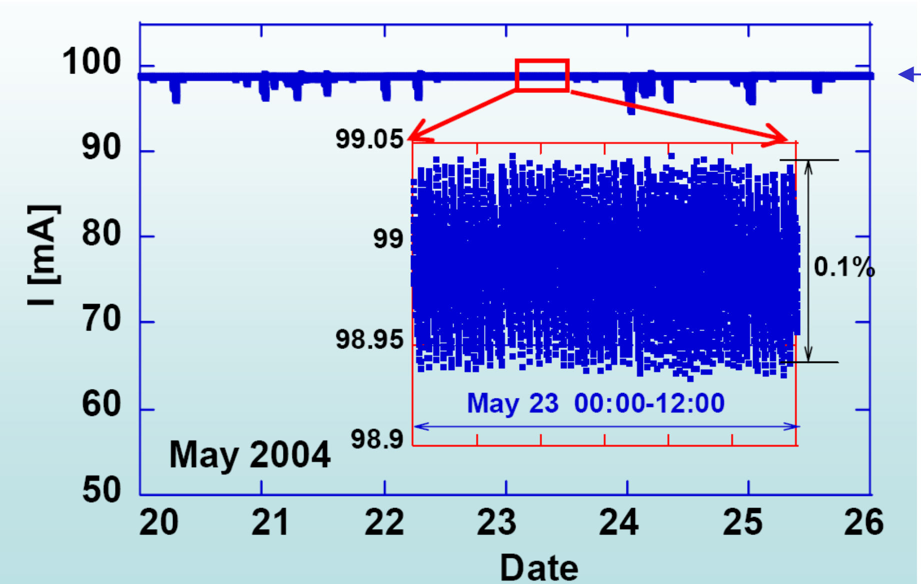
Top-Up operation consists in the continuous (very frequent) injection to keep the stored current constant

Already in operation at APS, SLS, SPring8, TLS, DIAMOND

SOLEIL will operate Top-Up soon

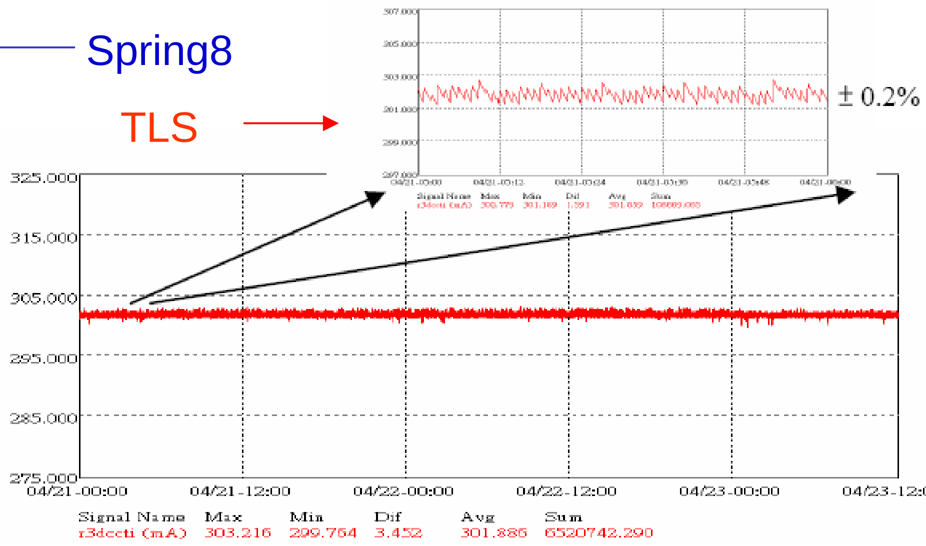
Operating modes are machine (or beamline) specific (frequency of injection, # of shots, charge)

$\Delta I/I \sim 10^{-3}$



Spring8

TLS



TOP-UP Operation

Advantages of Top-Up Operation: stability

Top-Up improves stability:

• constant photon flux on the beamline optics and detectors

• higher average current

• constant thermal load on components

BPMs block stability measured at SLS (M. Boge)

• without Top-Up ~ 10 µm

• with Top-Up < 1 µm

Top-Up is crucial to achieve long term sub- µm stability

Time structure

Many facilities provide specific filling pattern to enable time structure experiments

ESRF : Single bunch, 16 bunch, Hybrid mode (Camshaft),..

SOLEIL : 8 bunch, hybrid mode

Bunch length are of 10-20 ps (rms)

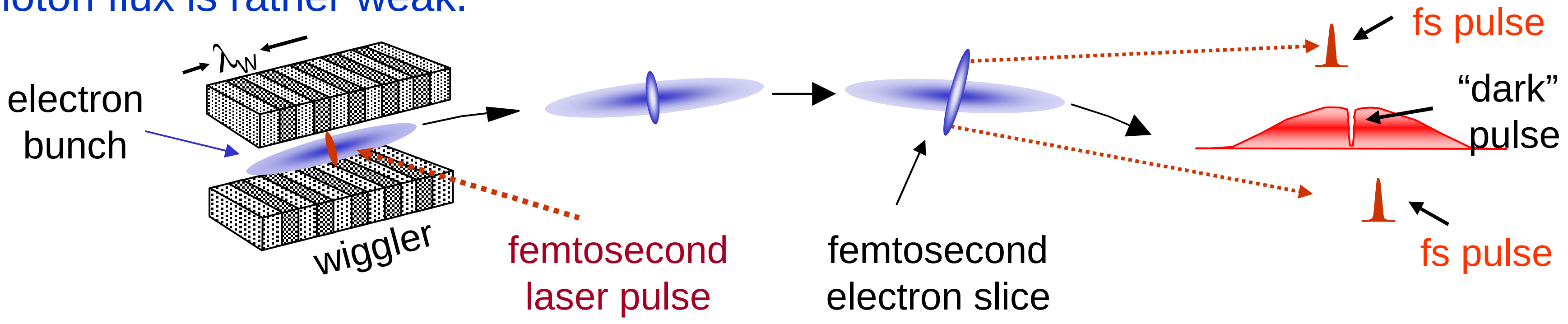
$$\sigma_z = \frac{\alpha c}{2\pi f_s}\sigma_\varepsilon \propto \sqrt{\frac{\alpha \gamma^3}{dV_{RF}/dz}}$$

Request to get shorter bunches

⇒Low alpha lattices provide ps bunch length at very low current per bunch (BESSY II, ANKA, ELETTRA, SPEAR3, SOLEIL)

$$\alpha = \frac{1}{L}\oint \frac{D_x}{\rho} ds \approx 10^{-6}$$

⇒ Femto slicing enables to produce 100fs bunch “slices” using an energy modulation induced by a laser (ALS, SLS, BESSY, and soon SOLEIL). The photon flux is rather weak.



CONCLUSIONS

⇒**Third generation light sources are very reliable source of high brightness, which provide very stable X-rays.**

⇒ **They operate ~5000 hours/year, with > 95% beam time availability**

⇒ No evidence of under subscription: the demand from the User's community and the number of beamlines per facility is still increasing

⇒ The agreement with model is excellent for the linear optics and improvements can be foreseen for the nonlinear optics

⇒**Future developments will target**

➢higher brightness	=> even lower emittance < 1 nm, lower coupling
➢higher stability	=> Top-Up, sub-µm over few hundreds Hz
➢short pulses	< 1 ps
➢higher current	~ 500 mA
➢larger capacity	=> more undulator per straights (canted undulators)