Insertion Devices activity at SOLEIL

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Longitudinal dynamics : R. Nagaoka
A. Nadji

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Vacuum group : N. Bechu, M. H. NGuyen, C. Herbeaux
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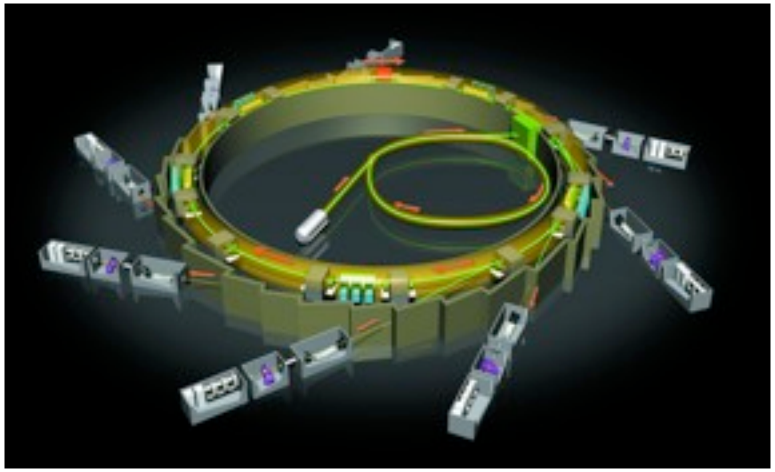
ECA/ICA : N. Leclerq, Y. M. Abiven, F. Blashe

O. Chubar, C. Kitegi (BNL)
J. M. Filhol (Fusion to Energy)

SOLEIL Accelerator complex

Energy	GeV	2.75
RF frequency	MHz	352.197
Betatron Tunes		18.202 / 10.317
Natural Chromaticities		-53 / -19/ Operation with 2 and 2.6
Momentum Compaction α_1 / α_2		4.55×10^{-4} / 4.30×10^{-3}
Emittance H	nm.rad	3.70 ± 0.2
Energy spread		1.0×10^{-3}
Coupling, $\varepsilon_V/\varepsilon_H$	%	0.11
Current Multibunch mode	mA	500 (qualified, operation 2011), 400 in operation now)
Average Pressure	mbar	7×10^{-10}
Beam Lifetime	h	18-11 h depending on IDs, top up mode for the users
Single bunch current	mA	20

100 MeV Linac, Booster synchrotron, 2.75 GeV storage ring



The ID life ...

User request

(spectral range, polarization, taper, aperiodicity)

Conception

radiation : SRW

ID type : EM/PPM/hybrid, end magnets, in vacuum RADIA; OPERA/TOSCA 3D /ELEKTRA 3D

effect on the e. beam : TRACY-II, BETA, RADIA

mechanics CATIA/ motorization-power supplies

Construction

Magnetic measurements (B(x, s) ∫Bds, ∬Bdsds' Gn Gs, multipolar terms, phase error

Corrections (sorting, magnet exchange, adjustement) : IDBuilder

Field/helicity variation

Tests with the electron beam

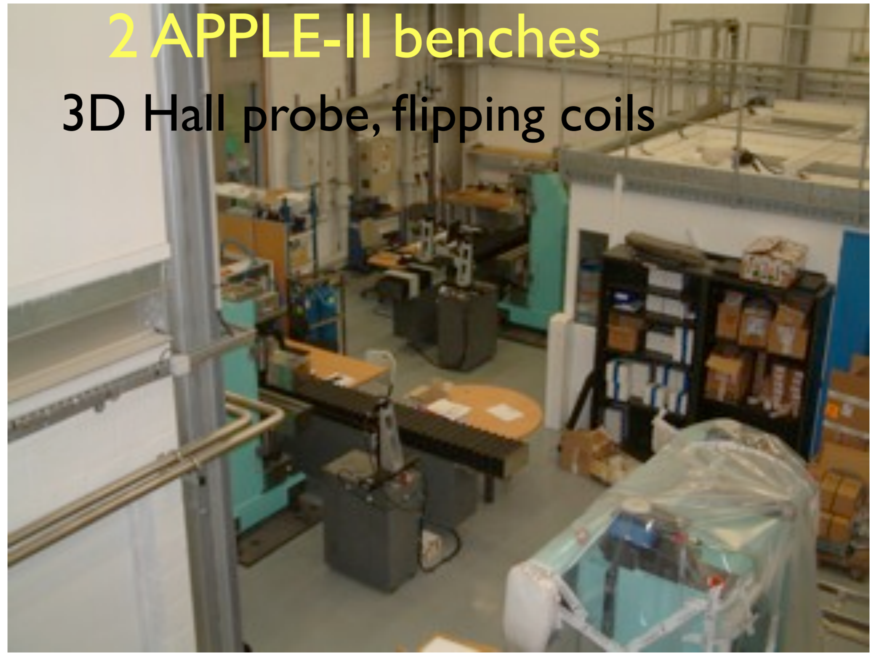
vacuum, orbit, tunes, chromaticities, coupling => ∫Bds, ∬Bdsds' Gn Gs

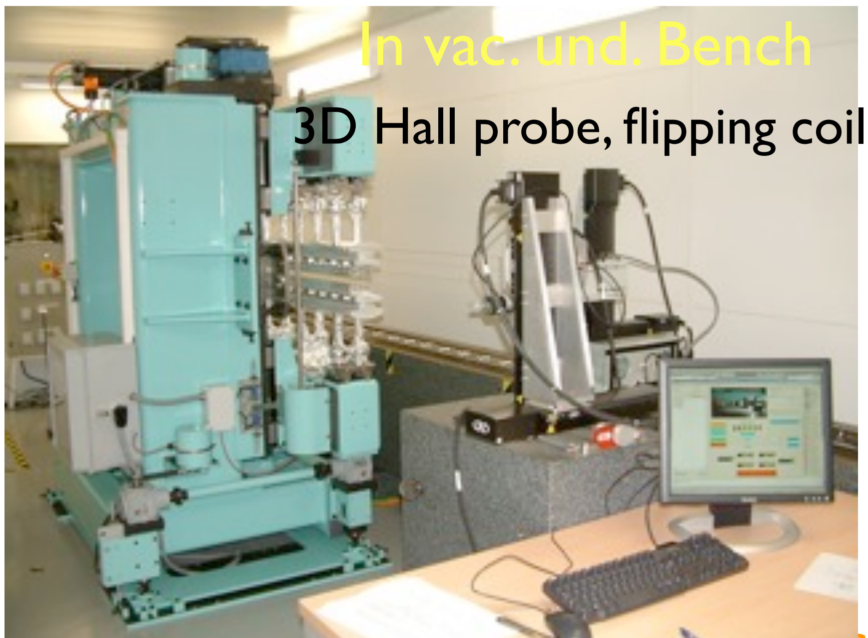
Tests with the photon beamline

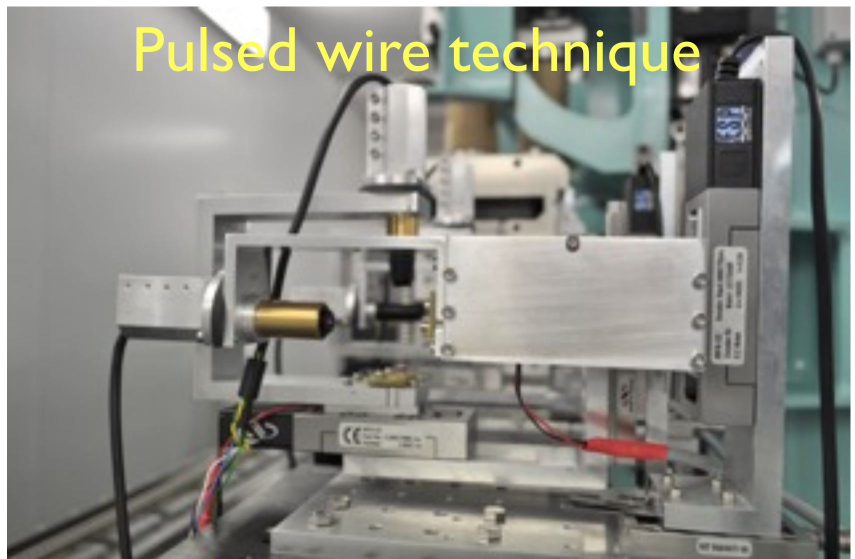
spectra vs. Gap/I, pol. => B, intensity,phase error

I- General presentation of SOLEIL insertion devices

The tools : Magnetic measurement benches







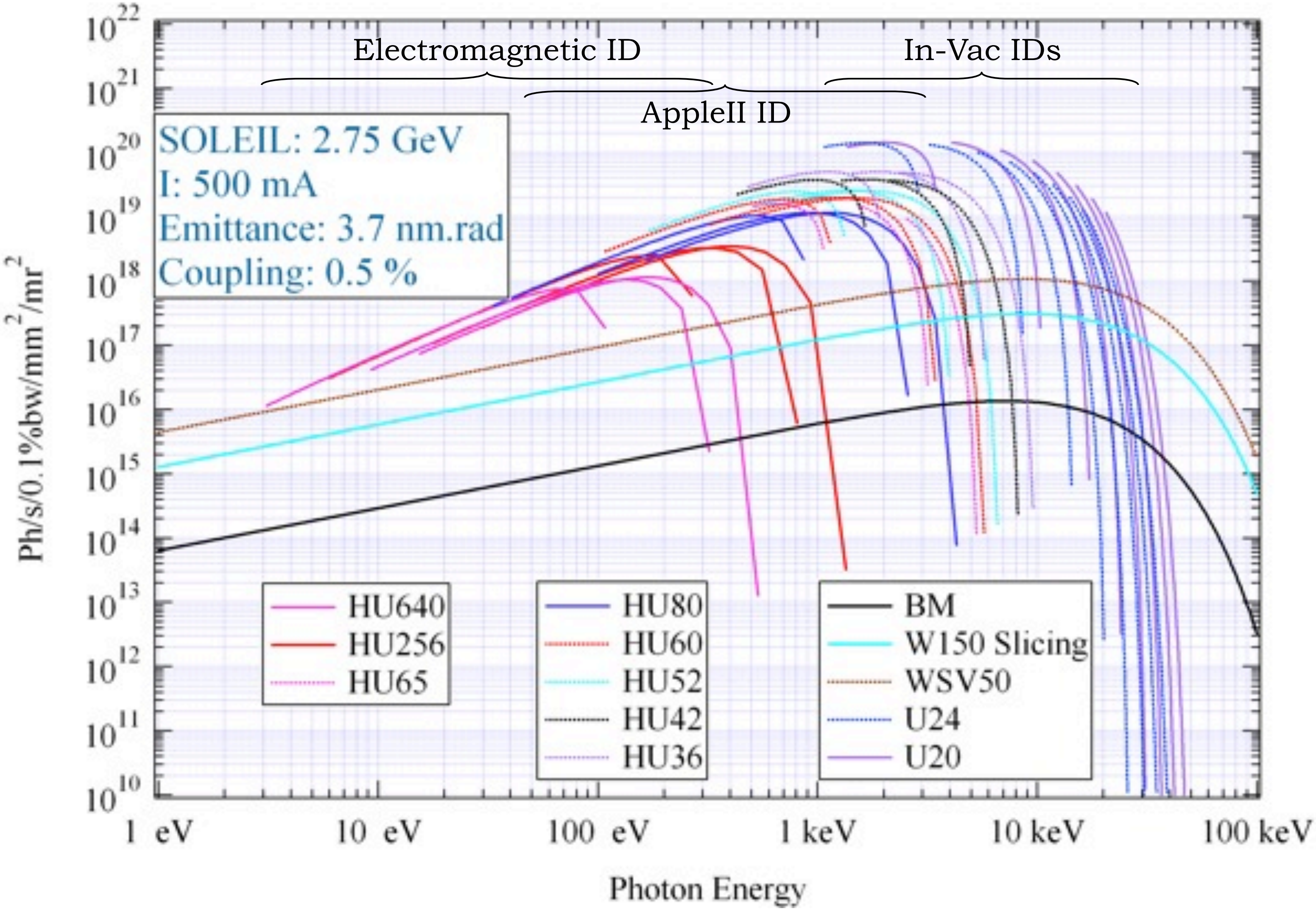
SOLEIL EPU

	HU640	HU256	HU80	HU65	HU64	HU60	HU52	HU44	HU42	HU36
Number	1	3	3	1	1	2	2	2	1	1
Energy (keV) z	0.005- 0.04	0.01-1	0.08-1.5	0.35-0.9	0.1-4	0.1-4	0.5-6	1-8	1-8	2-10
Type	Und.	Und..	Und..	Und..	Und..	Und..	Und..	Und..	Und..	Und..
Technology	EM	EM	Apple-II	EMPHU	Apple-II	Apple-II	Apple-II	Apple-II	Apple-II	Apple-II
Polarization	C, LH, LV var.	C, LH, LV, LHA, LVA	C, LH, LV	C, LV	C, LH, LV	C, LH, LV	C, LH, LV	C, LH, LV	C, LH, LV	C, LH, LV
Periodicity	P	A	1Q-2P	P	Q	P	P	P	P	P
K (T)	5.4/6.6	7.9/10.6	5.7/6.4	1.46	3.7/5.2	3.1/4.5	2.6/3.7	1.7/2.6	1.4/2.2	1.8/2.5
$B_{x\,max}$(T) $B_{z\,max}$(T)	0.09 0.11	0.33 0.44	0.76 0.85	0.24 0.24	0.62 0.86	0.6 0.8	0.53 0.76	0.41 0.64	0.37 0.58	0.53 0.74
N Period number	14	12	19		25		31			
SS	L	M	M	M	M	M	M	M	M	C
Beamline	DESIRS	CASSIOPÉE PLÉIADES ANTARES	TEMPO PLÉIADES SEXTANT	DEIMOS	HERMES	CASSIOPÉ E ANTARES	DEIMOS LUCIA	TEMPO SEXTANT	HERMES	SIRIUS
Installed	y	y	y	y, Feb. 2012	y May. 2011	y	y	y	y Jan. 2011	y

SOLEIL in vacuum undulators and wigglers

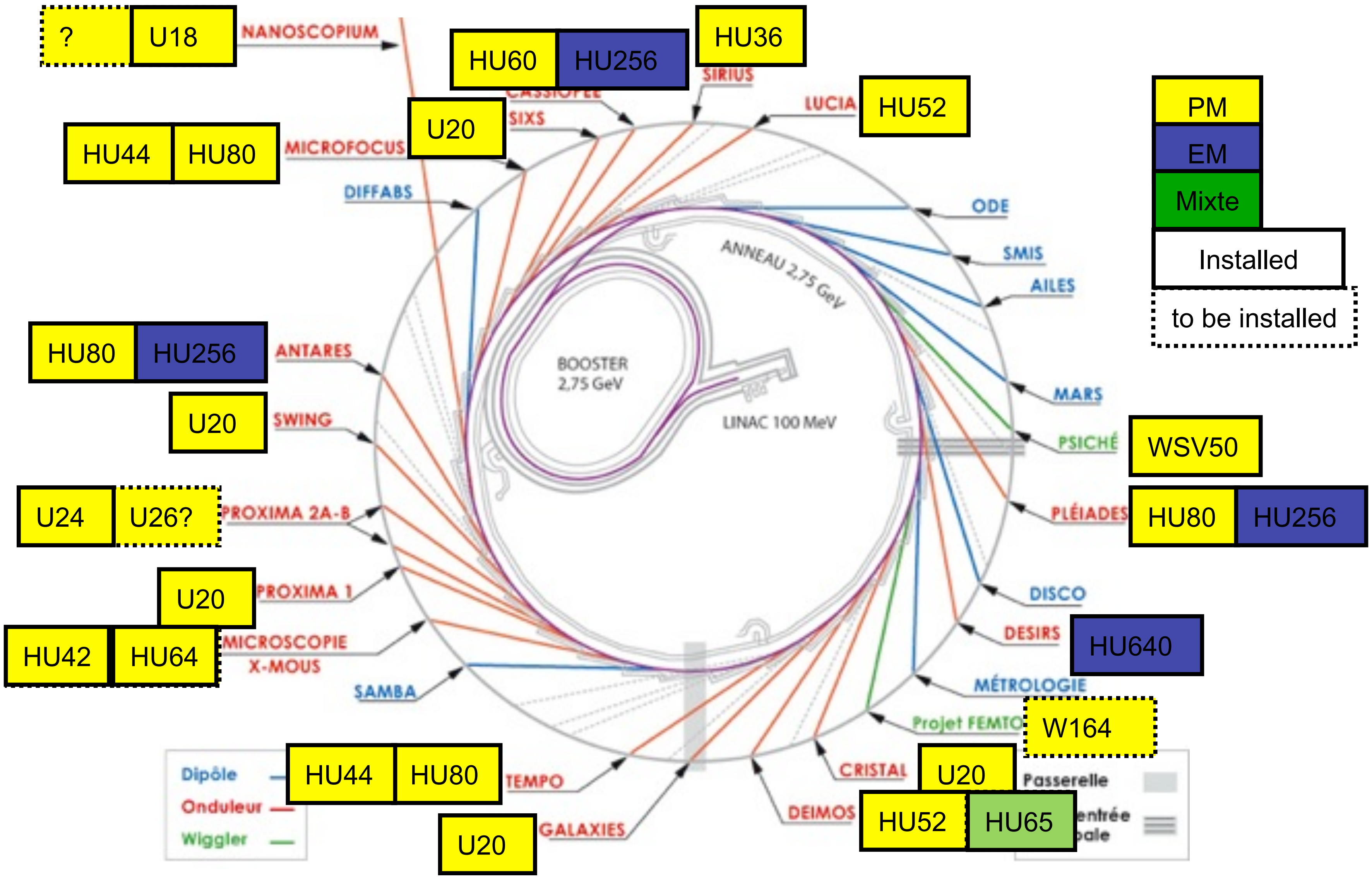
	U24 NdFeB	U20 SmCo	U20 NdFeB	U18cryo	WSV50	W164
Number	1	5	2	1	1	1
Énergy (keV)	5-15	3-20	3-25	1-30	10-50	5-80
Type	Und.	Und.	Und	Und.	In vac. Wiggler	Wiggler
Technology	SV	SV	SV	SV cryo	SV	SV
Polarisation	L	LH	L	L	L	L
Periodicity	P	P	P	P	P	P
K (T)	1.88	1.79	1,96	1.95	9.9	27.6
$B_{x\,max}$(T) $B_{z\,max}$(T)	0.84	0.96	1.05	1.16	2.1	1.8
N		98	98			20
SS	M	5 C, 1 M	1L, 1 S		C	M
Beamline	PX2	*PX1* *CRISTAL* *SWING* *SIXS* *GALAXIES*	NanoSCOPIUM Galaxies n°2	R&D (NanoSCOPIUM)	PSYCHÉ	PUMA
Installed	y	*y*	?/ Aug2012	Aug. 2011	y	Aug. 2013

Brilliance



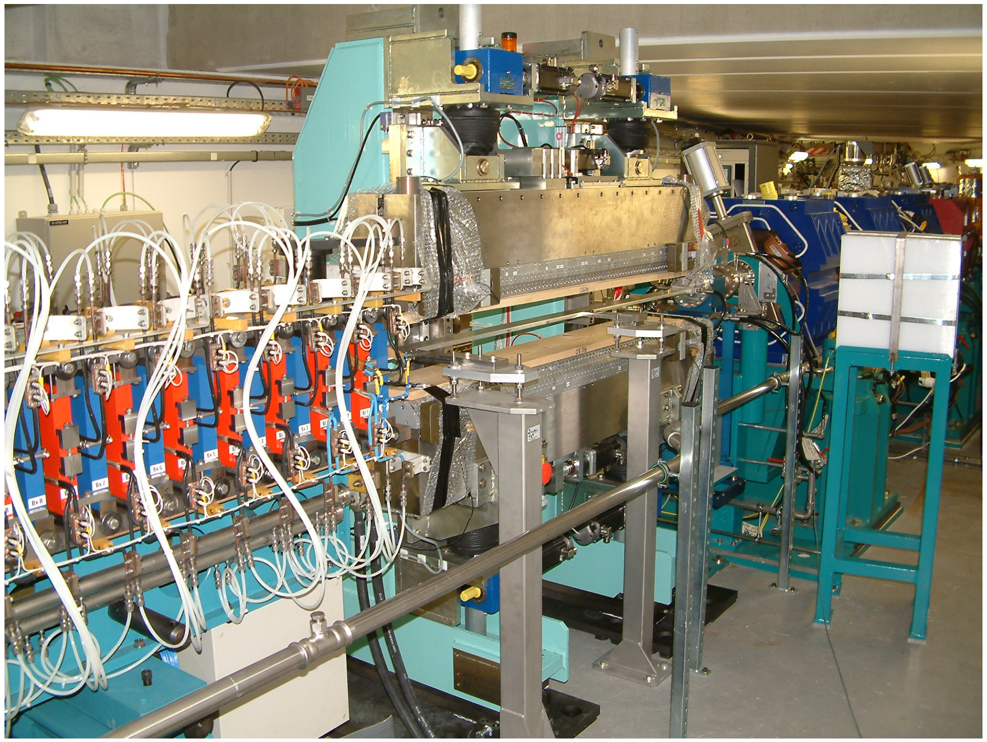
SRW software
O. Chubar, P. Elleaume, Proc. EPAC-98, 1177.
O. Chubar et. al., Proc. SPIE 4143 (2000) 48; SPIE 4769 (2002) 145.

Implementation of the IDs



Medium and long straight section

Two different IDs for a wider spectral range / fast switching



Ex of PLEIADES with its two IDs

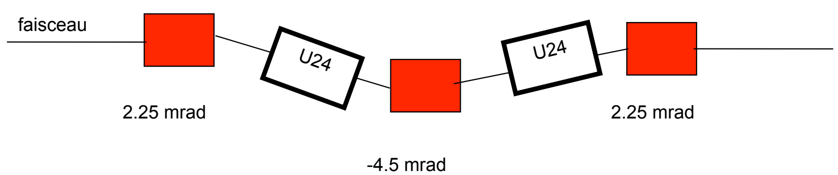
Ex of HU44 and HU80 on TEMPO

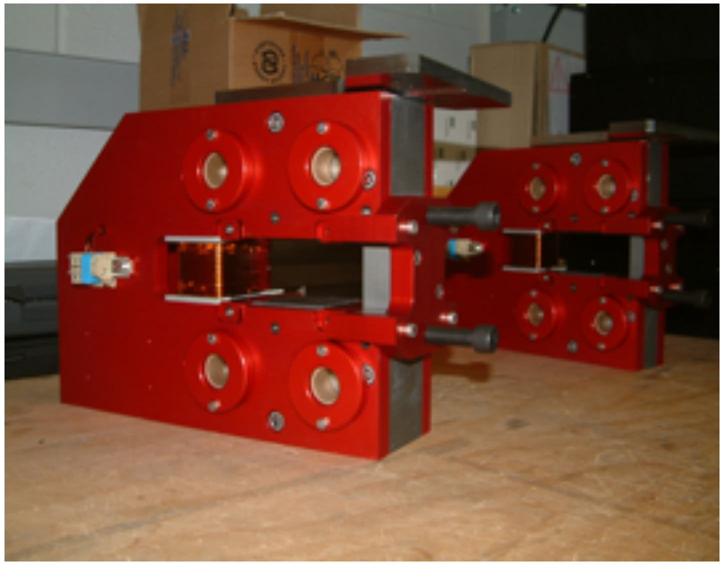
Case of Cassiopée, TEMPO, HERMES, DEIMOS ..

Medium and long straight section

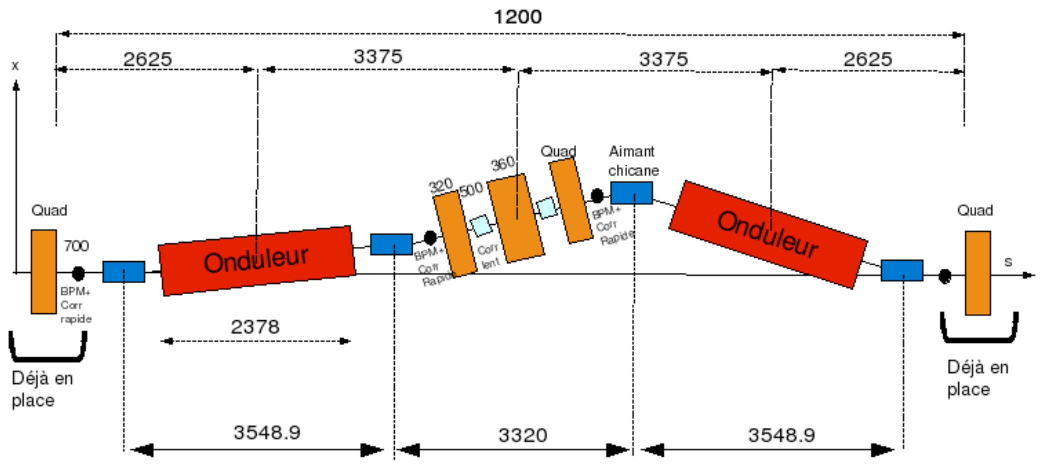
Canted undulators with a magnetic chicane

Example : PXII-A/ PX-IIB





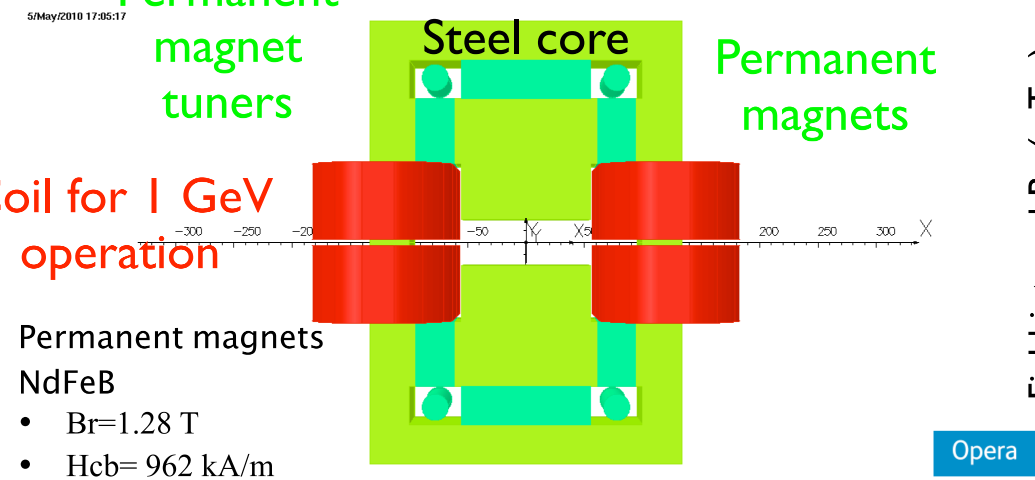
Ex of Nanoscopium/ Nanotomography



	angle (mrad)	Field integral 2.75 GeV (mTm)	Field integral 1 GeV (mTm)
dipole 1	0.5	4.57	1.67
dipole 2	5,38	49,12	17,93
dipole 3	11,88	108,46	39,6
dipole 4	6	54,78	20

Permanent magnet chicane

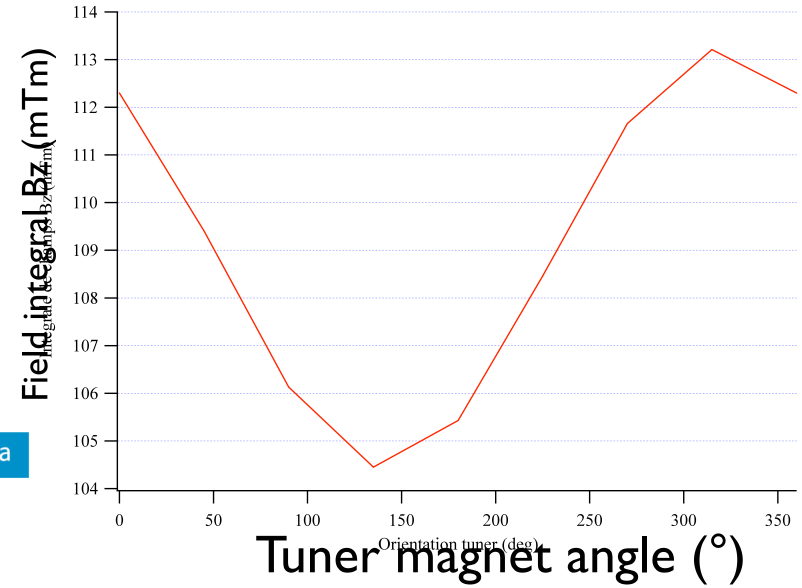
Example of the Dipole 11.88 mrad
Length : 138 mm



Permanent magnets NdFeB

- Br=1.28 T
- Hcb= 962 kA/m
- Hcj=1800 kA/m
- BHmax=400 kJ/m^3

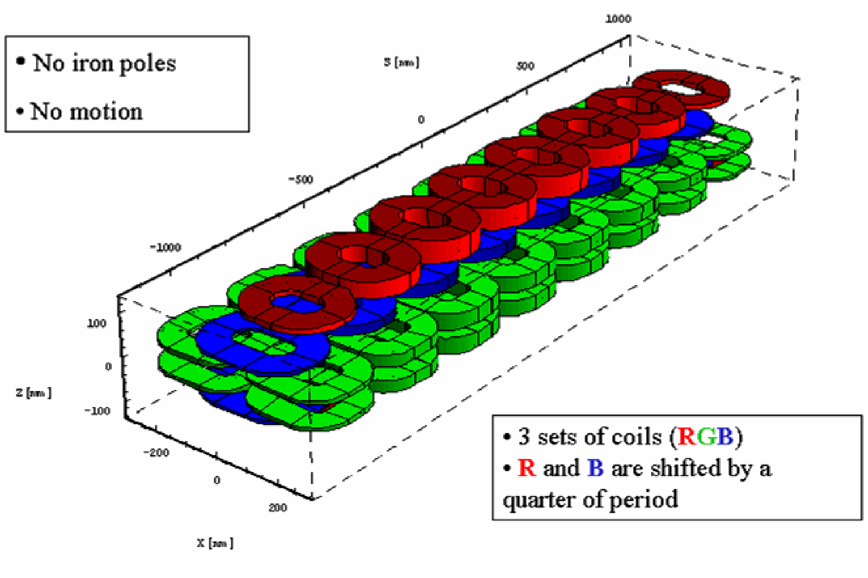
Gap : 36 mm



Dipole 0.5, 5.38 and 6 mrad :
69 mm length

3- EPU and fast polarisation switching

Electromagnetic undulators : HU640



Radia code: http://www.esrf.fr

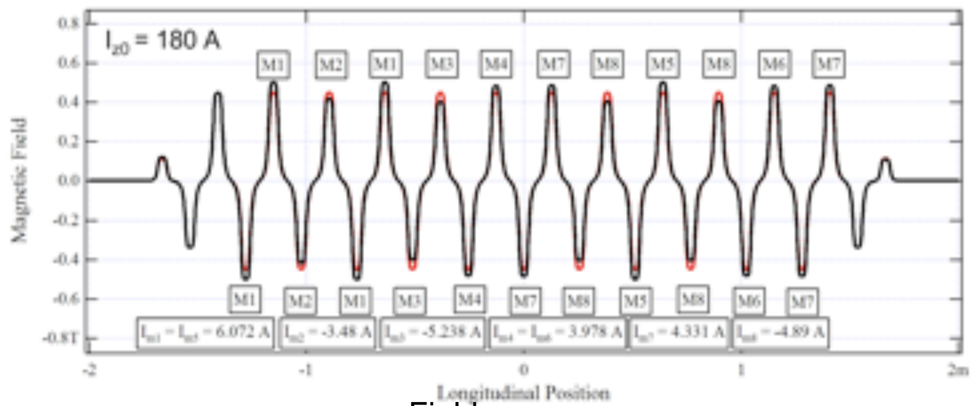
$B_z(s)=B_B.\cos[2\pi s/\lambda_o]+B_R.\sin[2\pi s/\lambda_o]=B_{zo}.\cos[2\pi s/\lambda_o+f]$

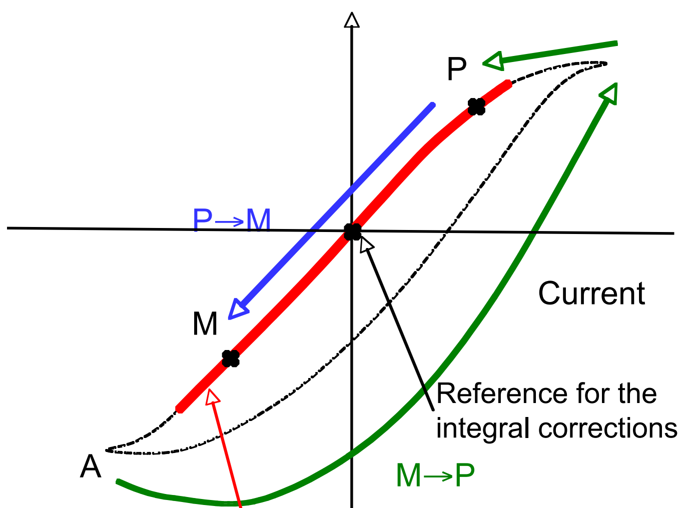
Fast switching : 1 Hz : 270 ms for switching -±600 A on PS1, 300 ms flat top for data acquisition

SOLEIL conception- Realisation Danfysik, Magnetic measurements SOLEIL

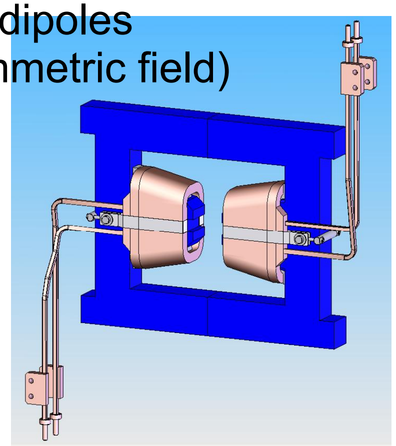
Electromagnetic undulators : HU256

Linear H,V, + Quasi periodic,
Circular
Coll. BINP

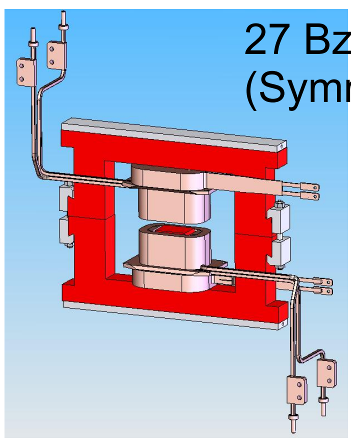




28 Bx dipoles
(Asymmetric field)



27 Bz dipoles
(Symmetric field)

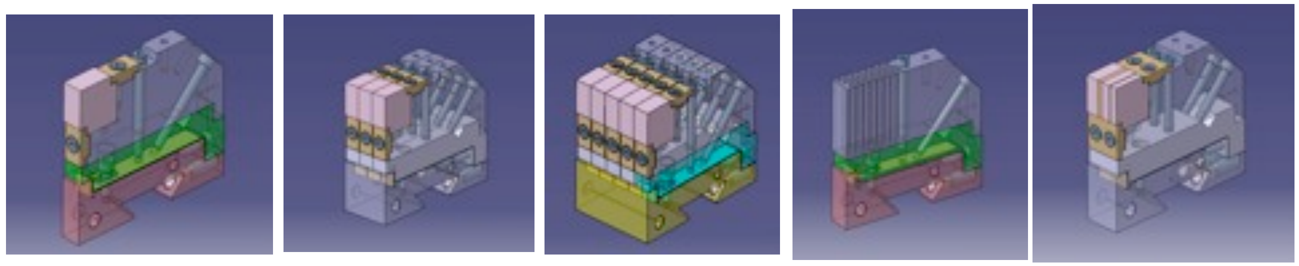


3- EPU and fast polarisation switching

APPLE-II

Total : 12 (3HU80, HU64, 2 HU60, 2 HU52, 2HU44, HU42, HU36)

2 Built in coll. with ELETTRA and 10 by SOLEIL
+ one spare HU60 under construction at SOLEIL

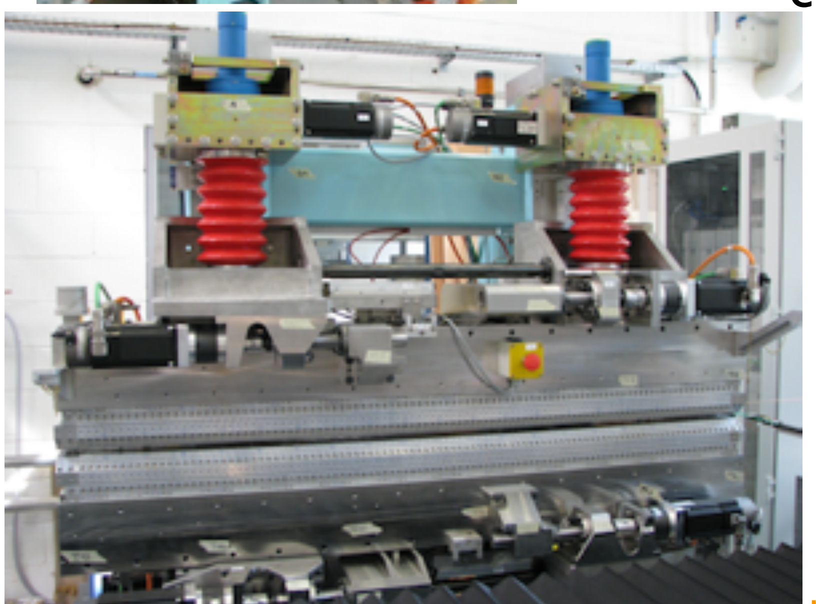


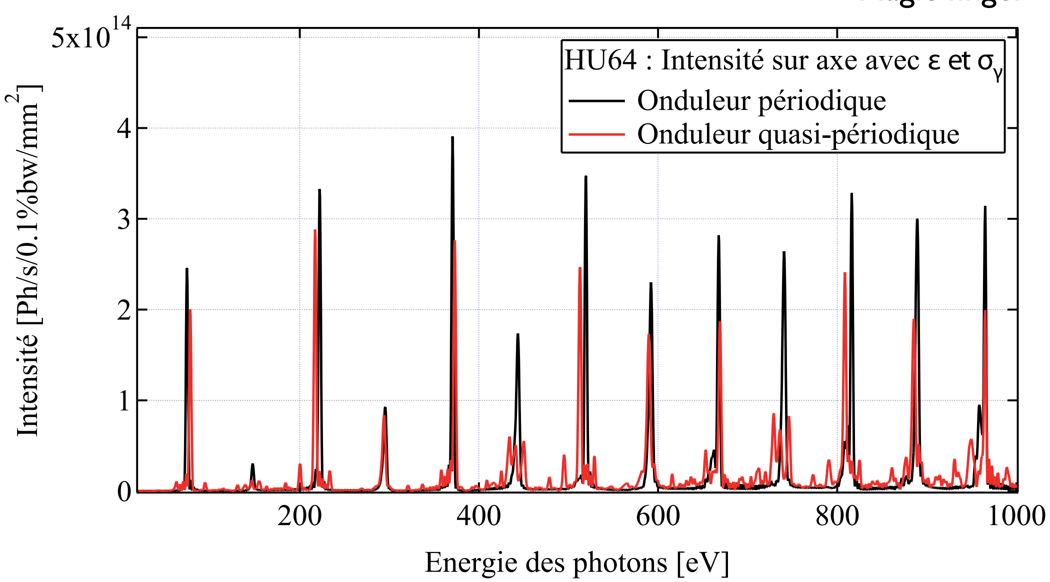
6 axes

8 axes

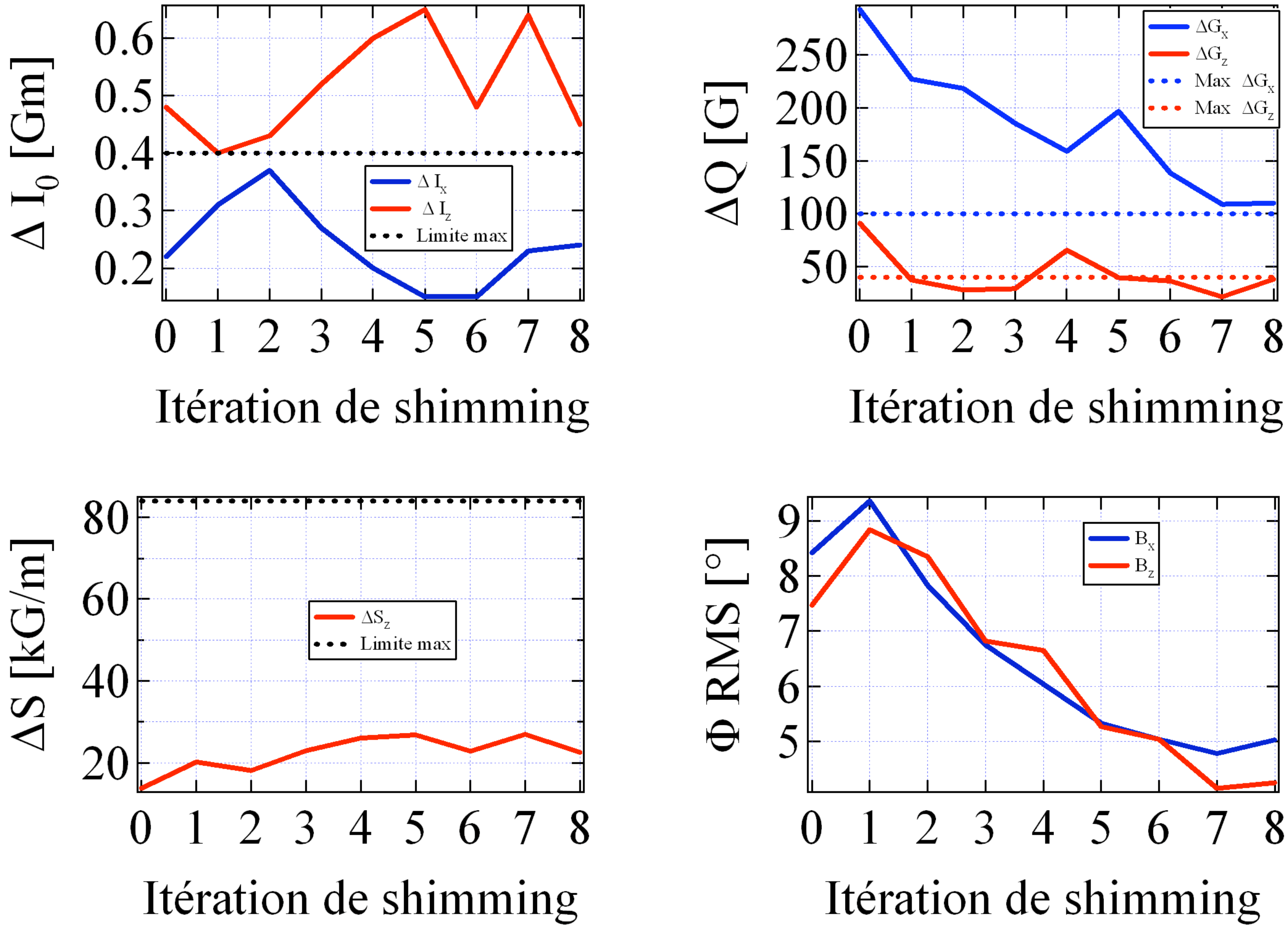
phase and gap variation
aperiodicity
taper
correction coils

Pre sorting, Assembly in modules
Modules measurements
Module assembly with iterative sorting
ID builder and measurement
Shimming
Magic finger





Example of ID-Builder optimisation



HU44 SEXTANT

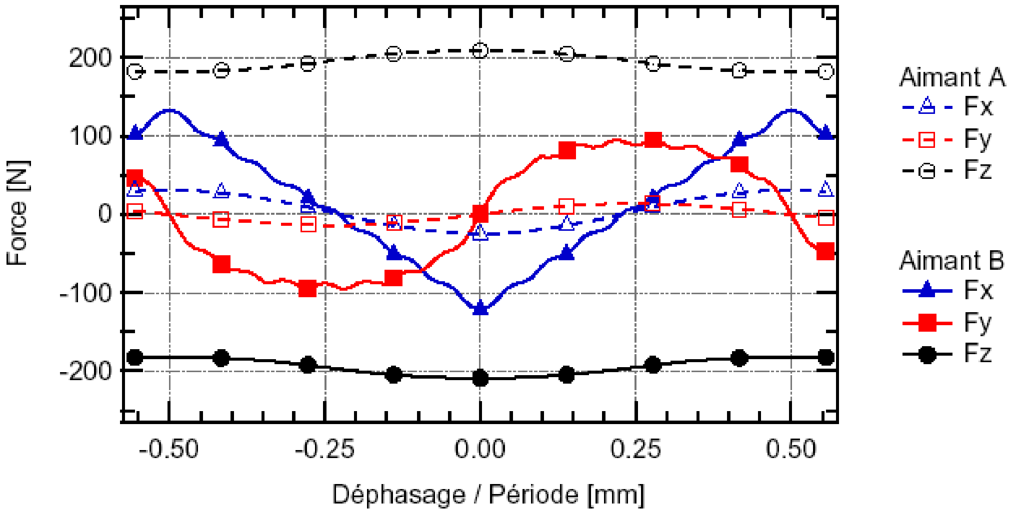
ID Builder, Genetic Algorithm, O.Rudenko and O.Chubar, Proc. of 9th Int. Conf. on PPSN IX, p.362 (2006)

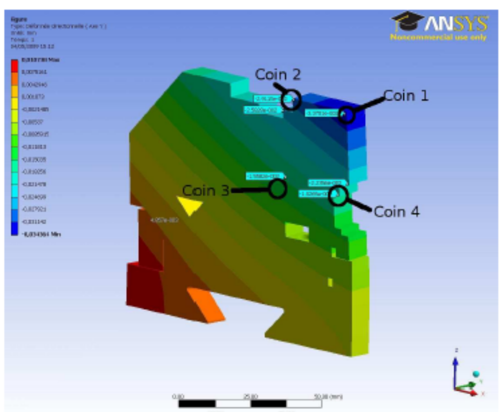
2- EPU and fast polarisation switching

Short period APPLE-II HU36

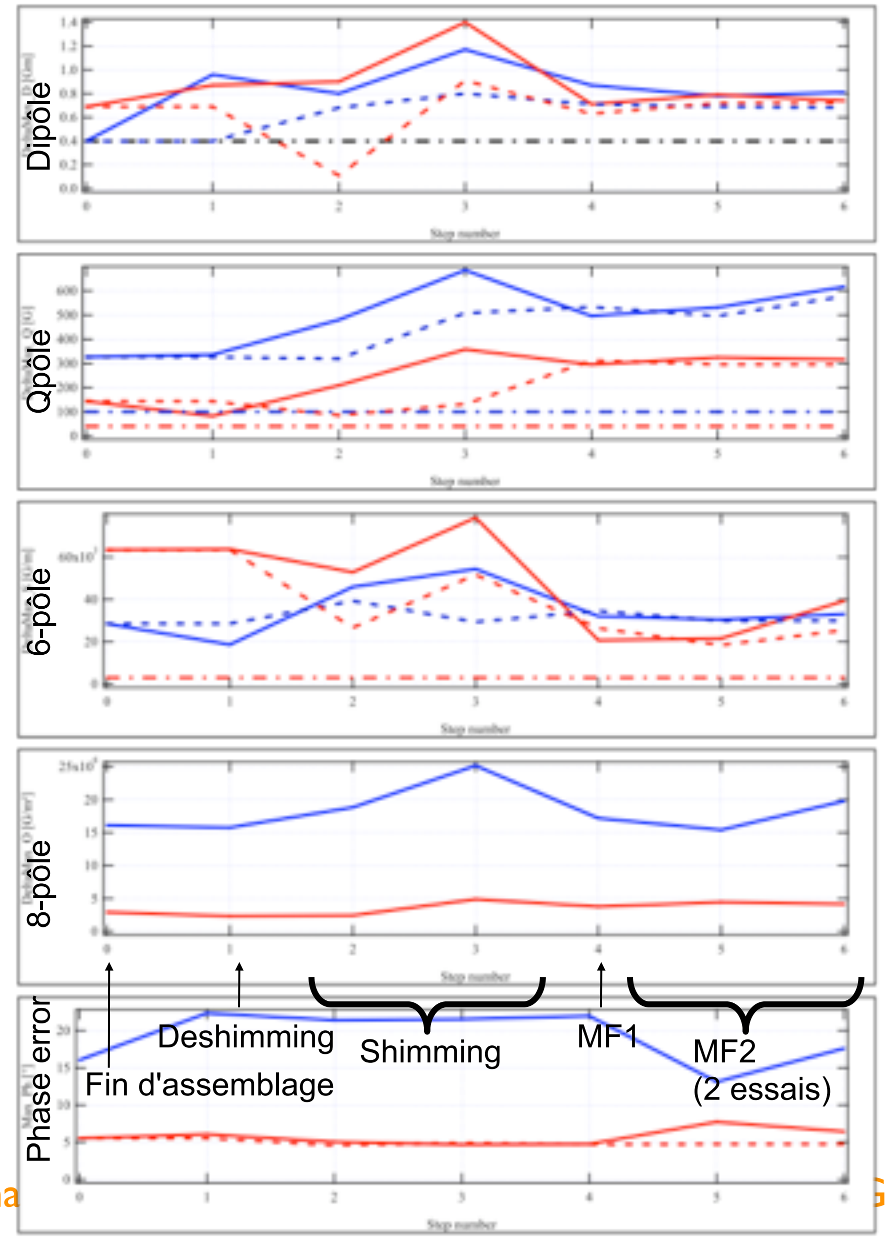
First assembly with Al magnet holders : deformation of the holders because of the magnetic forces during a phase change

=> Mechanical hysteresis

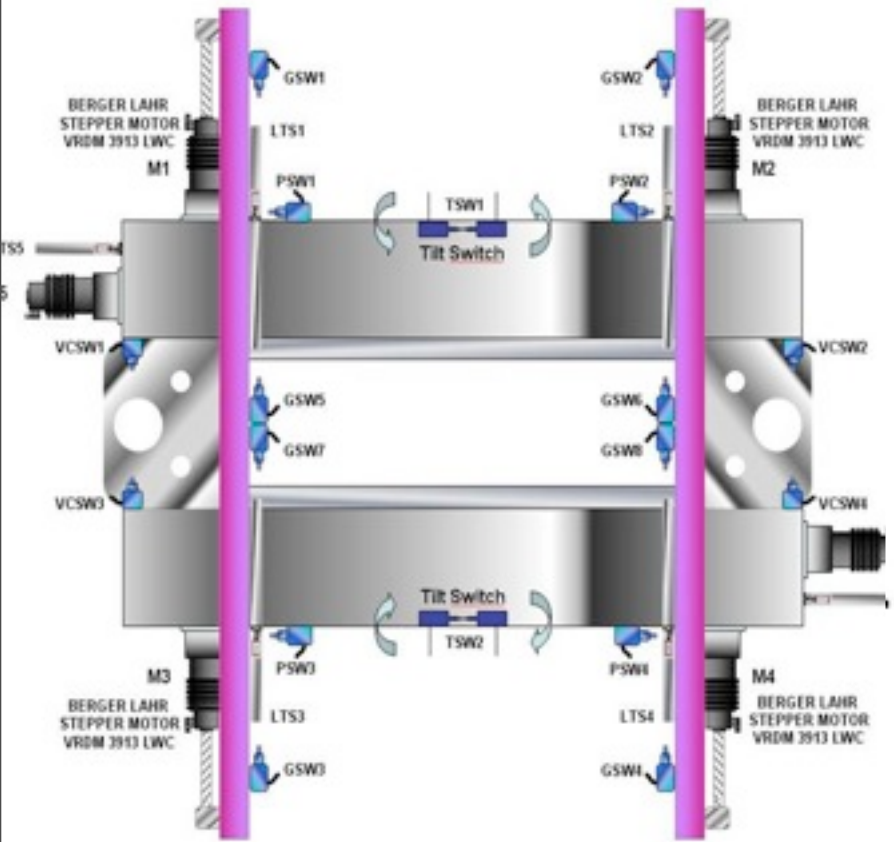


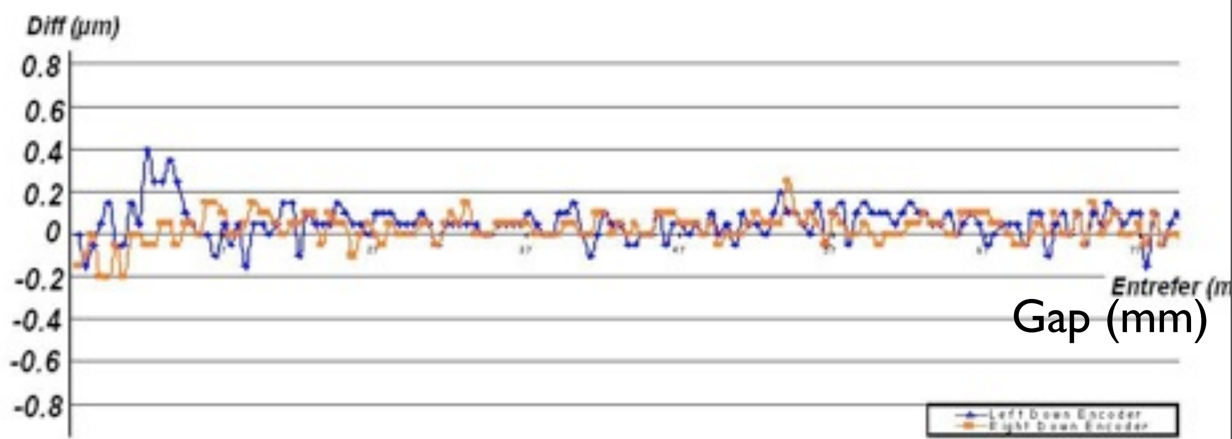


Change to magnet holders in stainless steel, low permeability, assembly with comparators



Motorization





Encoder difference at zero phase per girder

3- EPU and fast polarisation switching

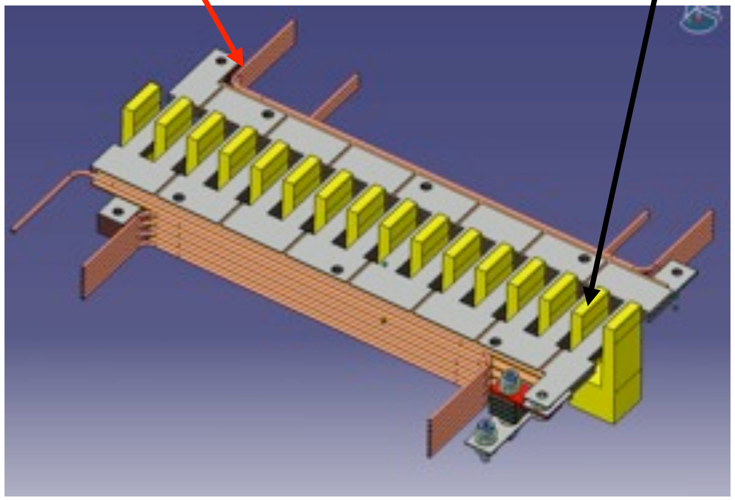
EMPHU

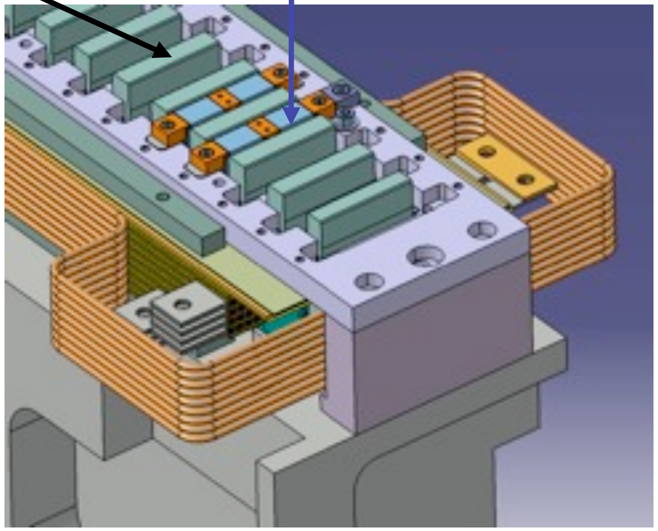
Polarisation switching in 60 ms

Cu foils ⇔ coils : B_z

Steel : core and poles

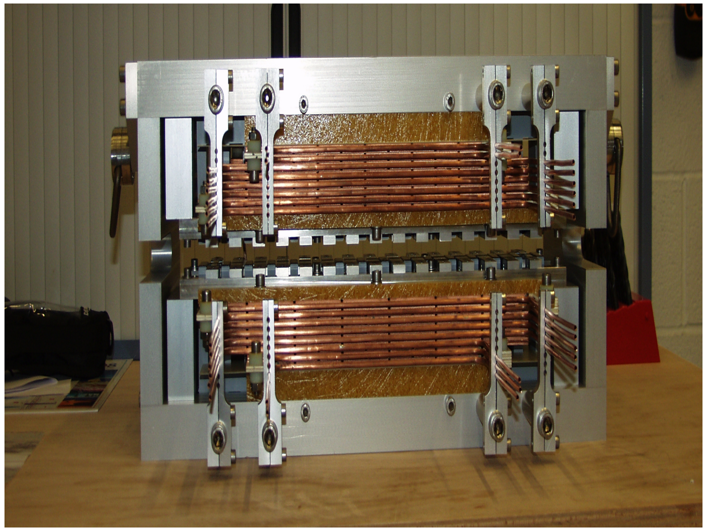
Permanent magnets : B_x

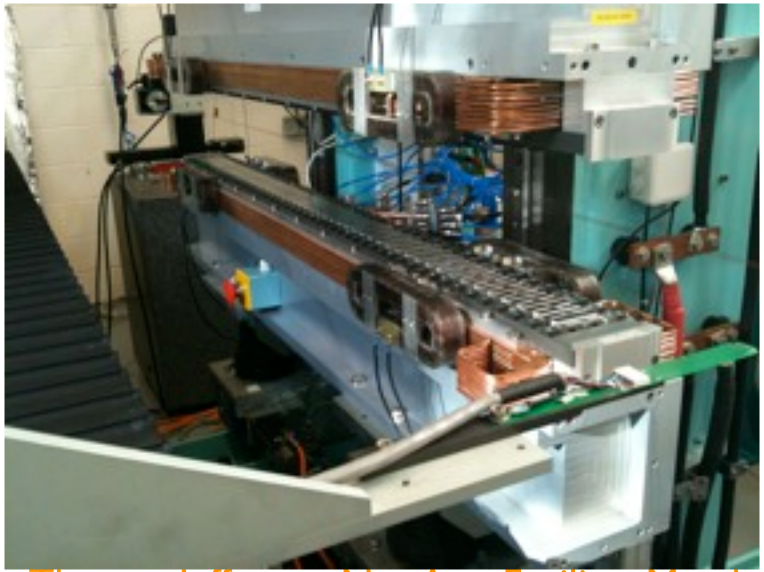




$Bx=Bz=0.24$ T

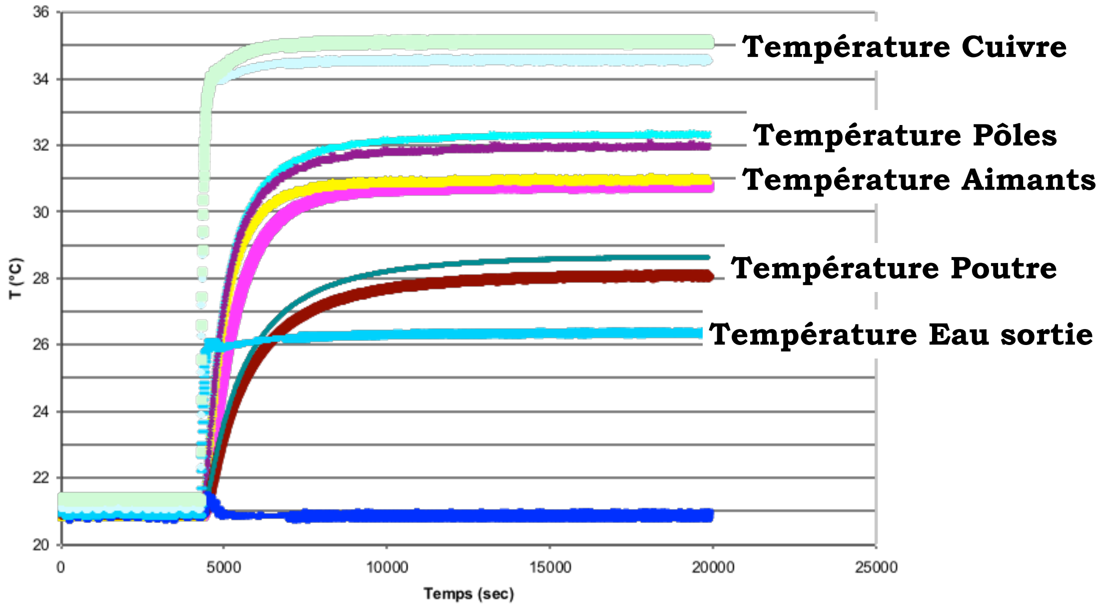
Prototype (SEF)

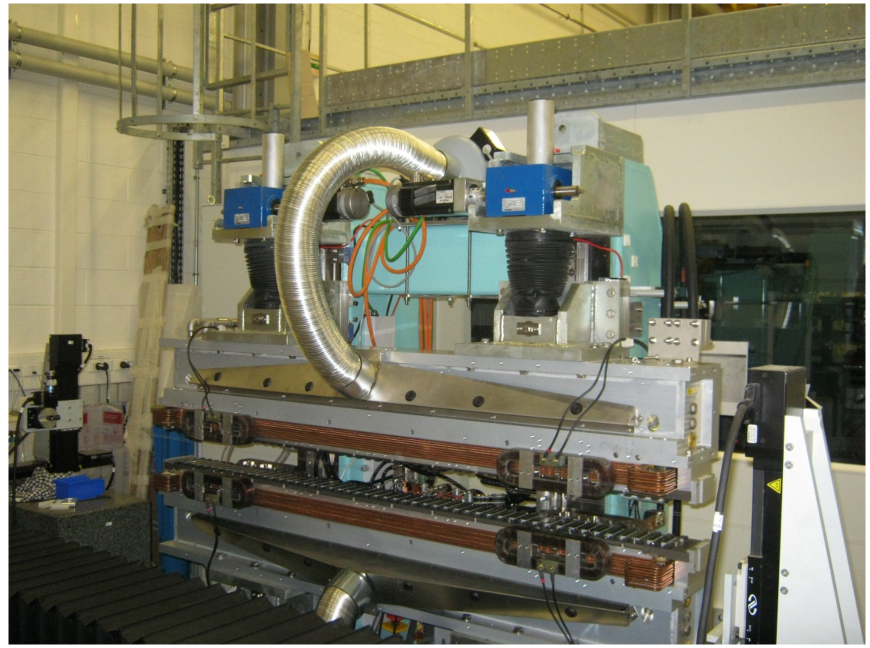


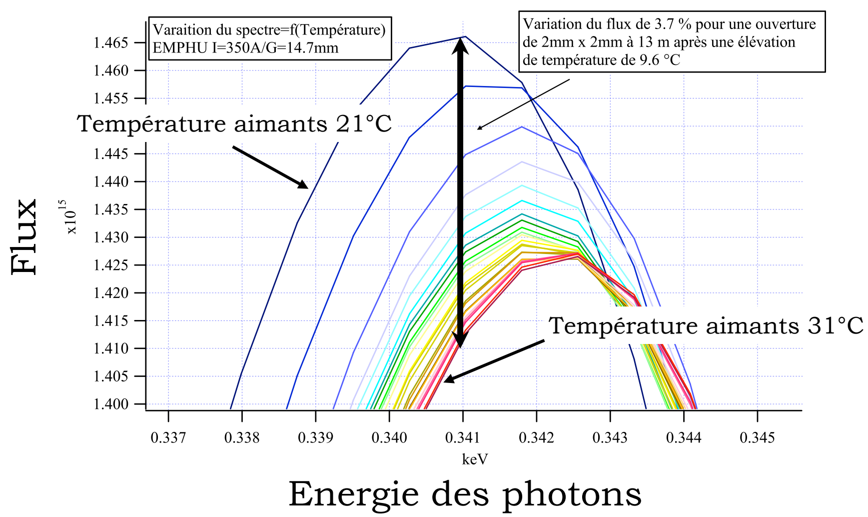


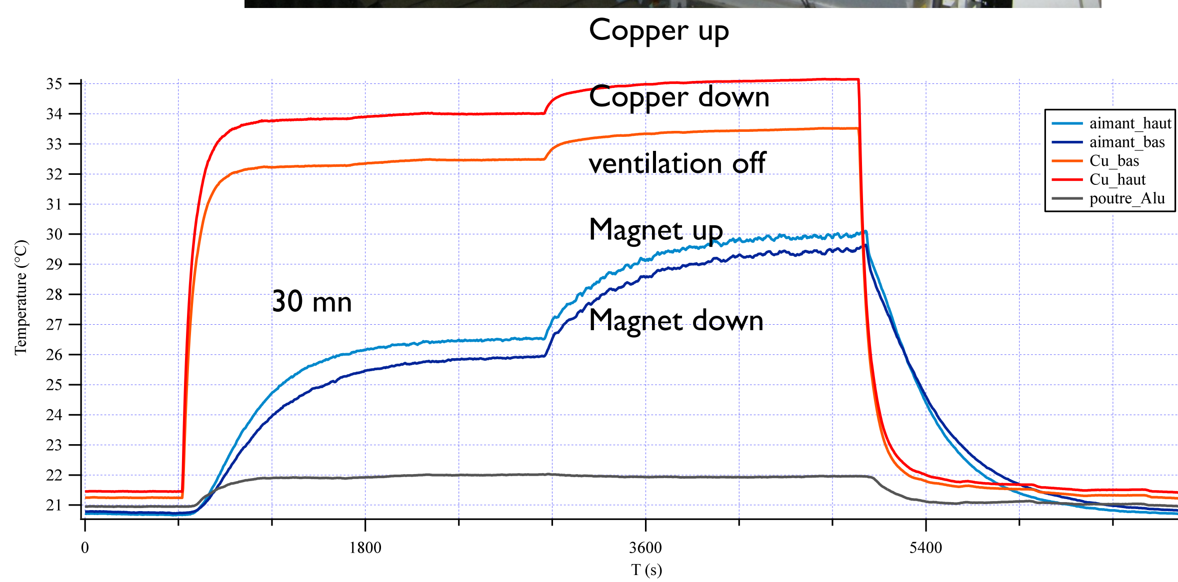
3- EPU and fast polarisation switching

EMPHU





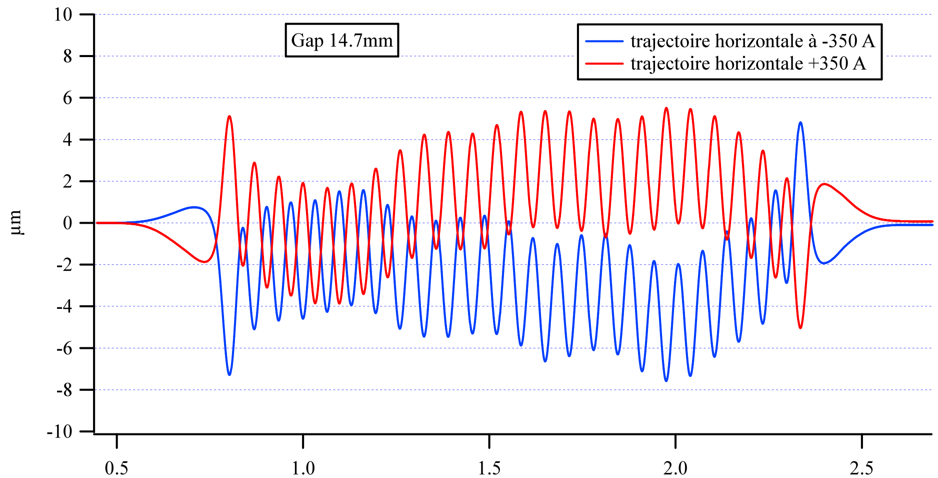




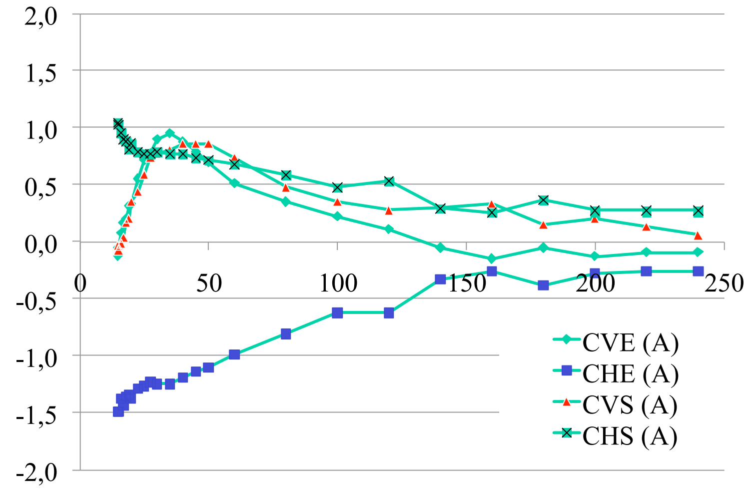
3- EPU and fast polarisation switching

EMPHU

Static measurements

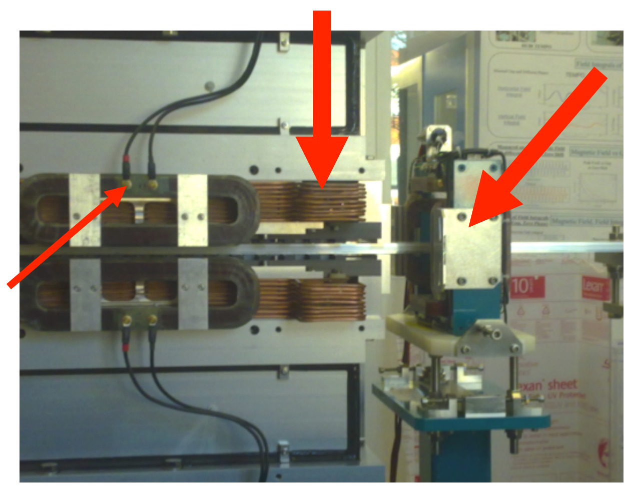


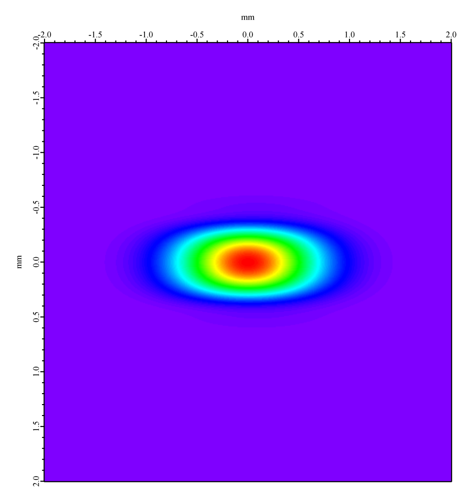
Corrector IP50 : exit position adjustment



Corrector CHE-CHS: field integral adjustment

Corrector HUE-HUS : pointing adjustment



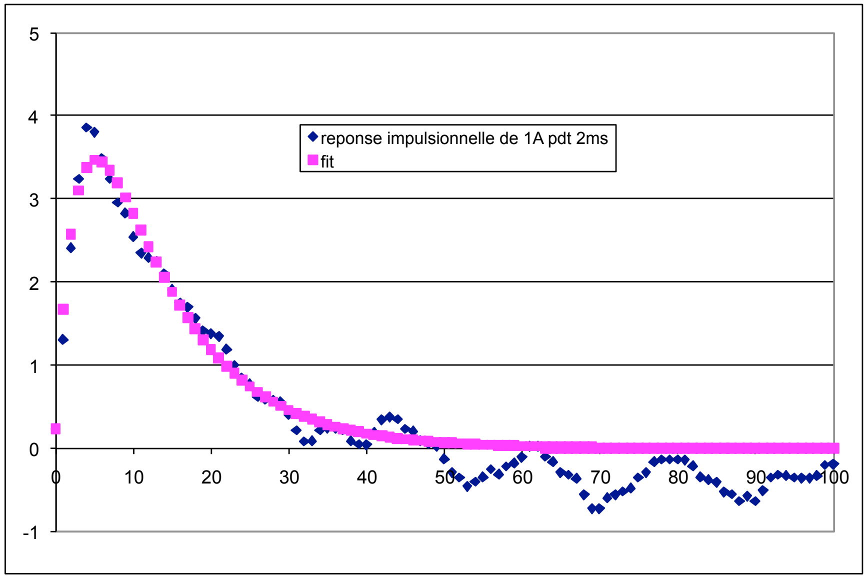


3- EPU and fast polarisation switching

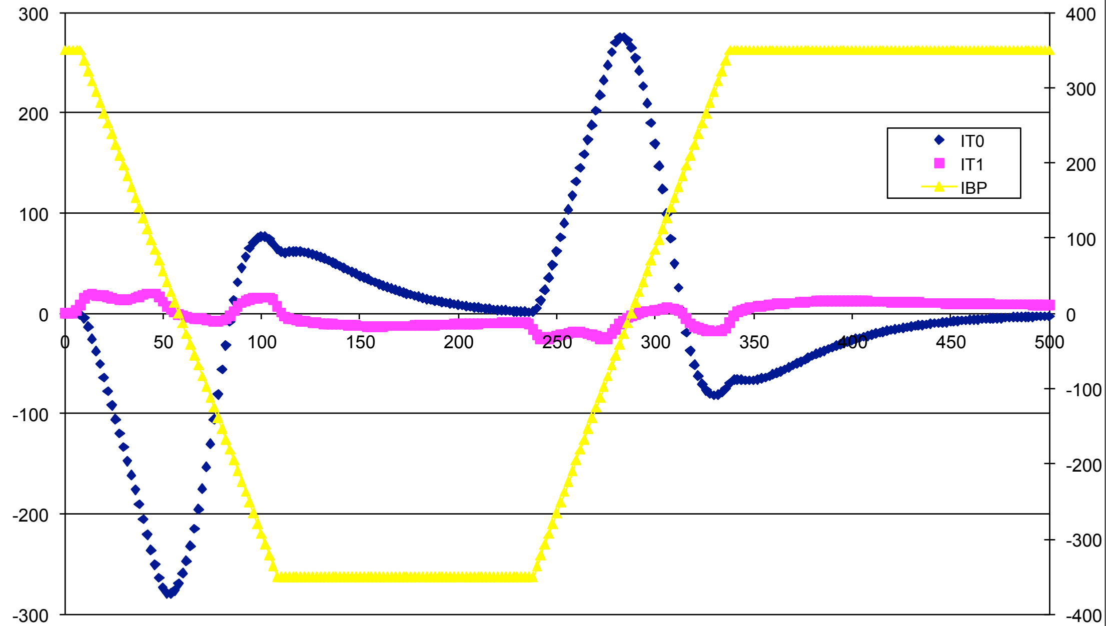
EMPHU

Dynamical measurements

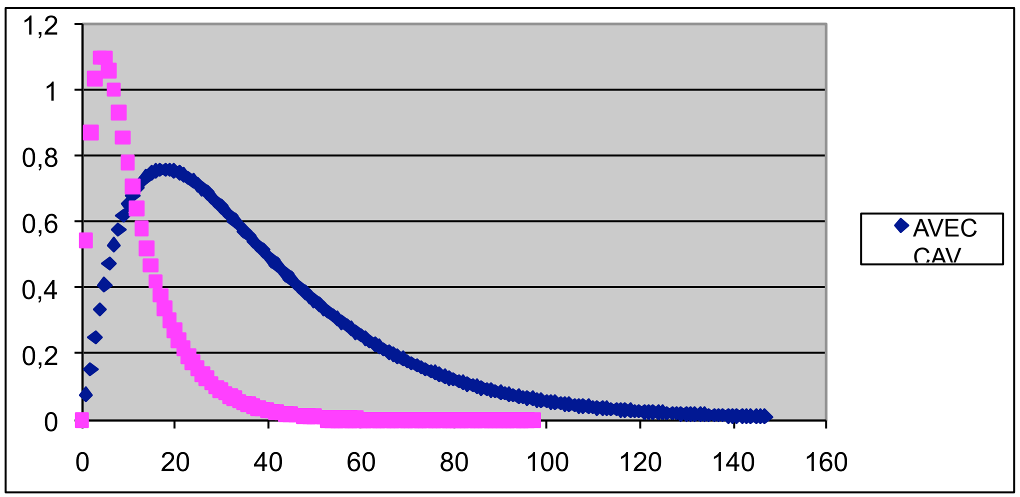
Pulse response without vacuum chamber

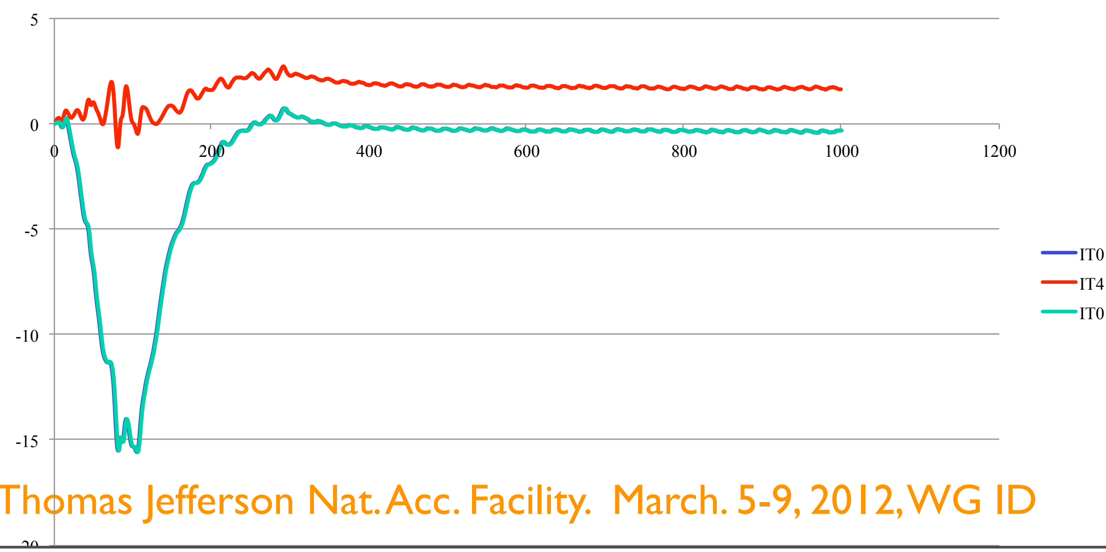


Matlab iterative correction



Pulse response with vacuum chamber



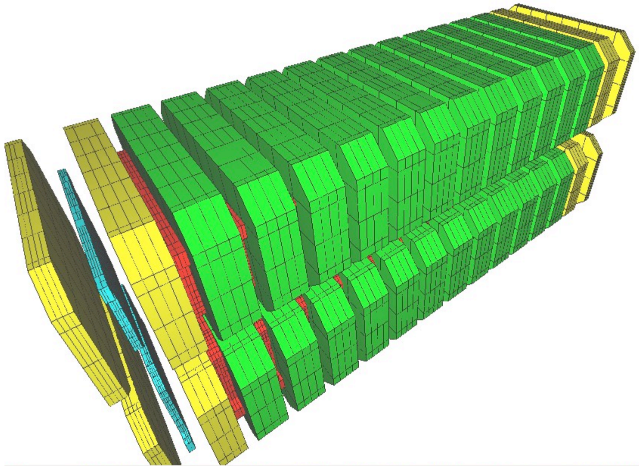


4- In vacuum undulators

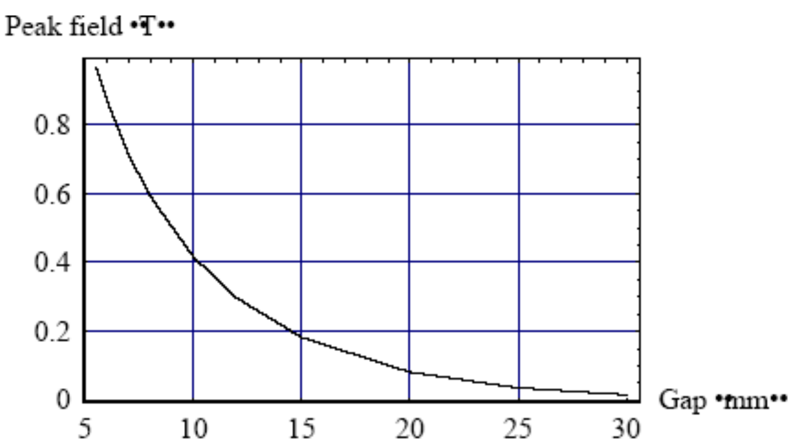
Magnetic and mechanical design

Hybrid technology

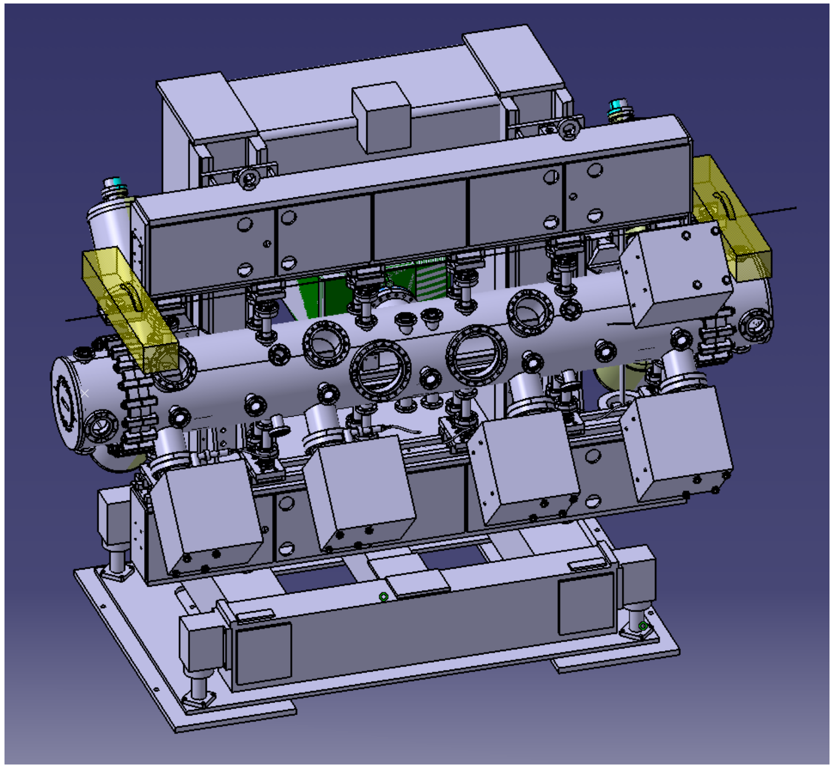
First series SmCo magnets,
second : NdFeB magnets
Vanadium Permendur poles



RADIA design

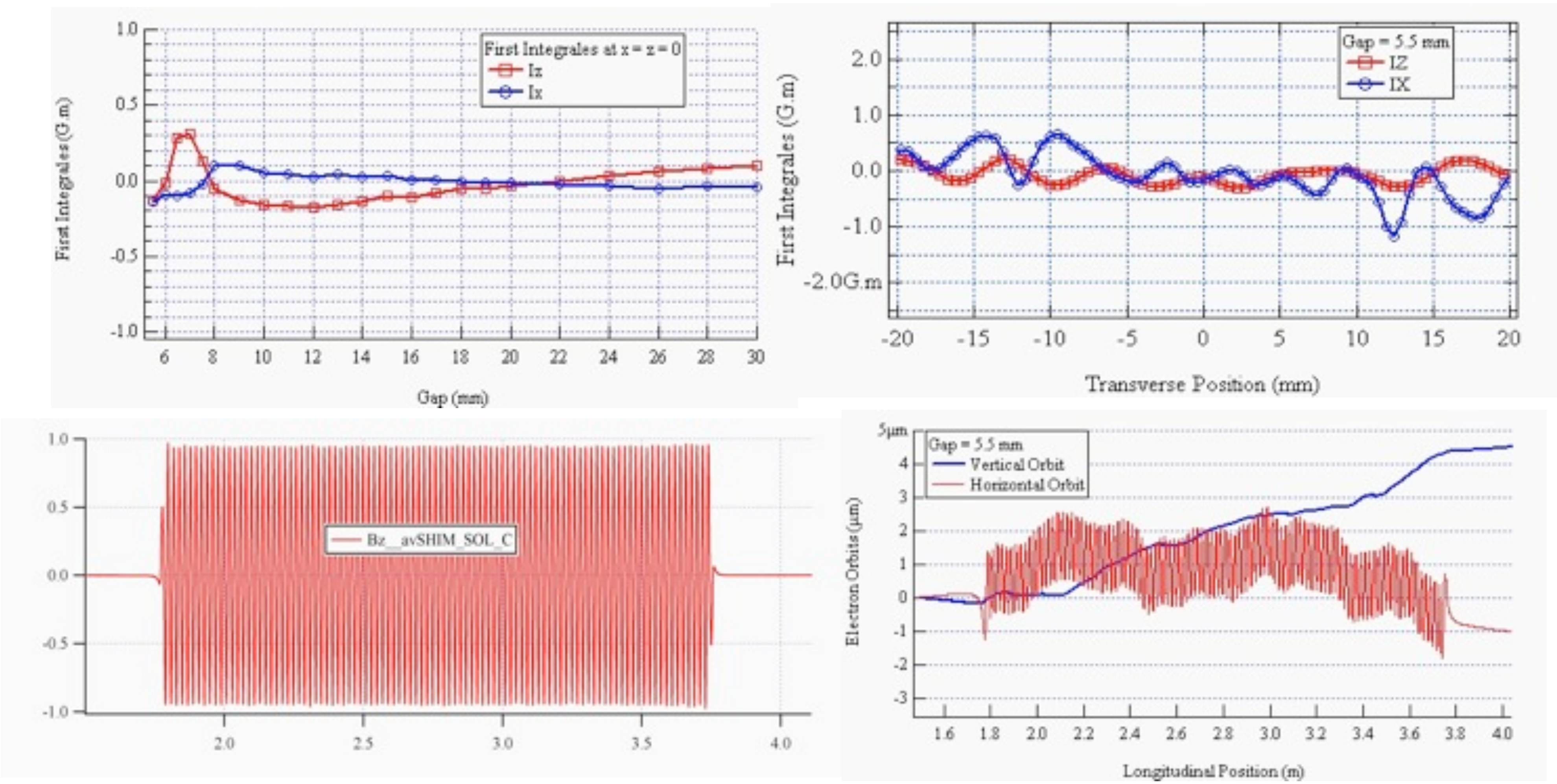


Mechanical design



Magnetic measurements

SWING

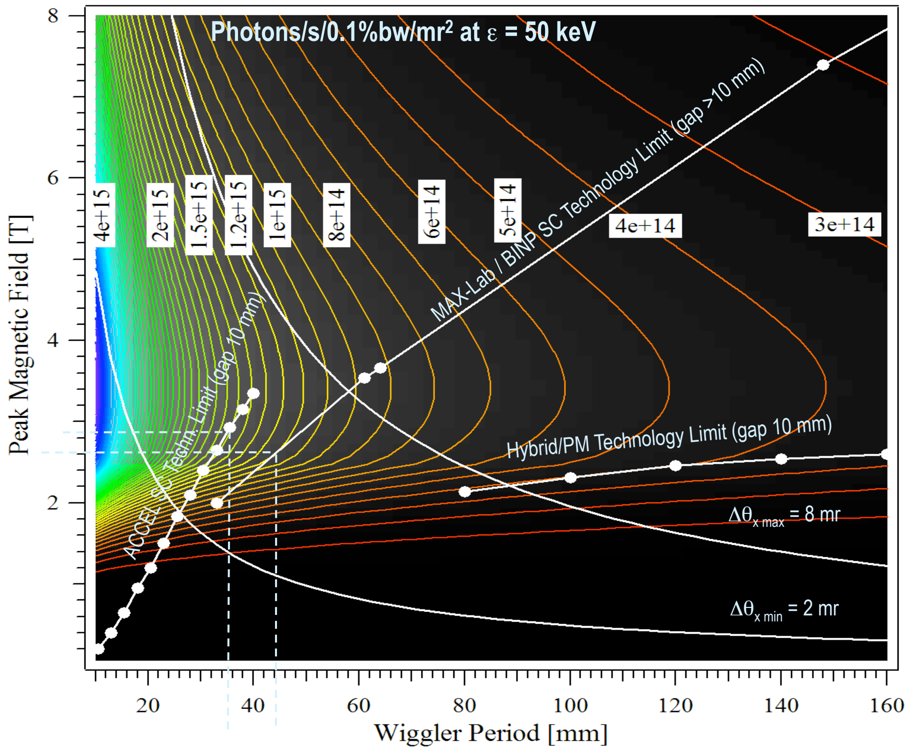


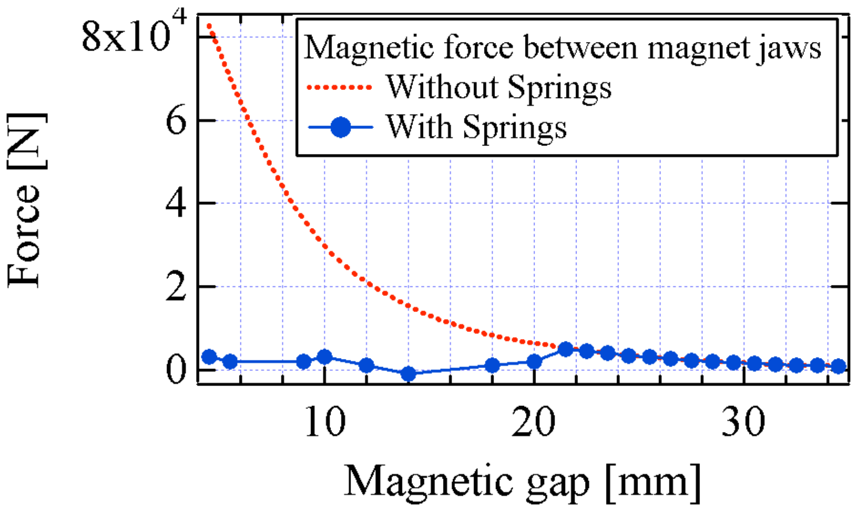
Phase error (Rms) = 2.5^0

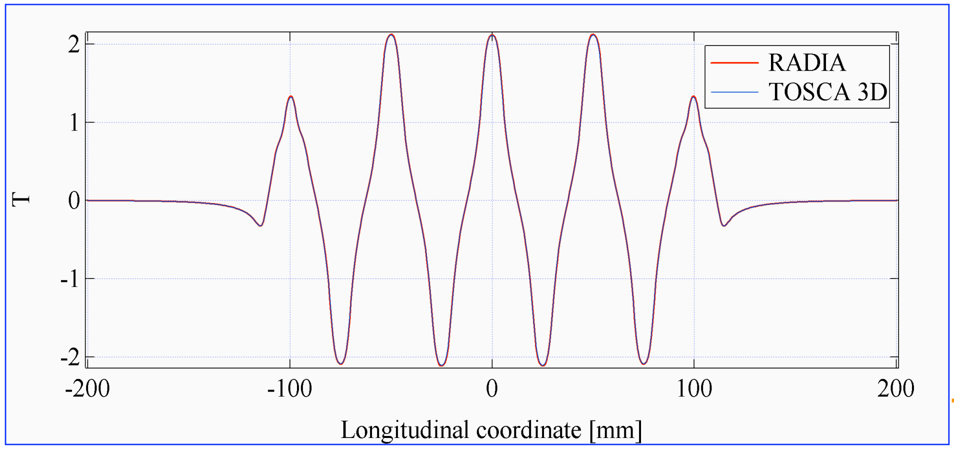
5- Wigglers

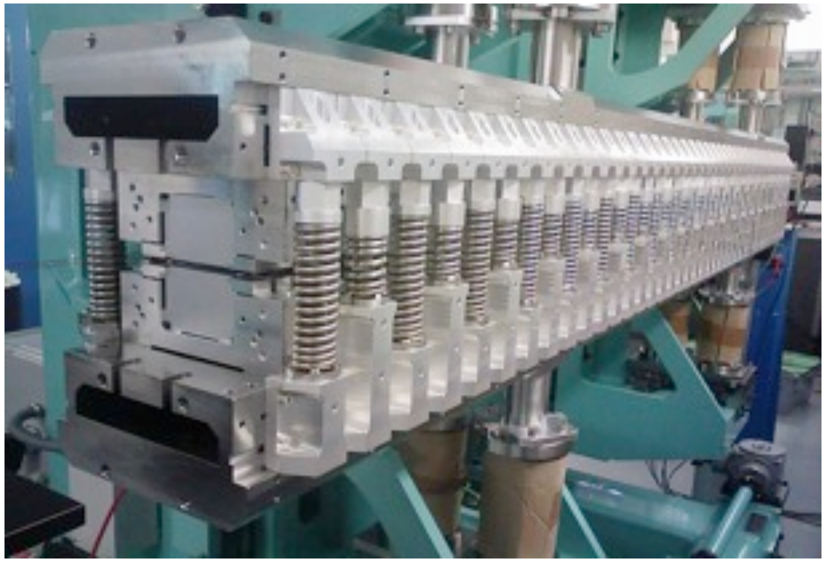
In vacuum wiggler

Choice of an in vacuum wiggler rather than a superconducting wiggler



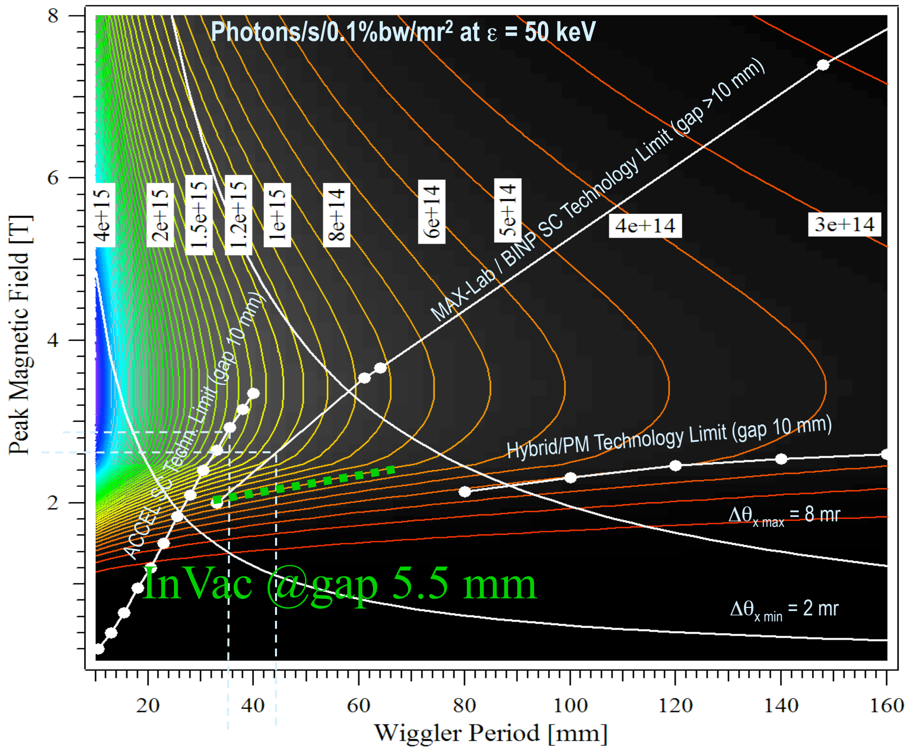


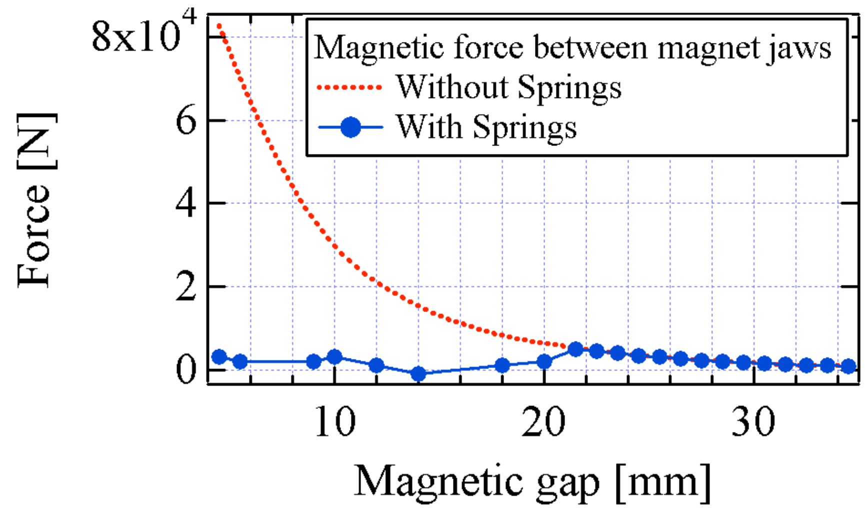


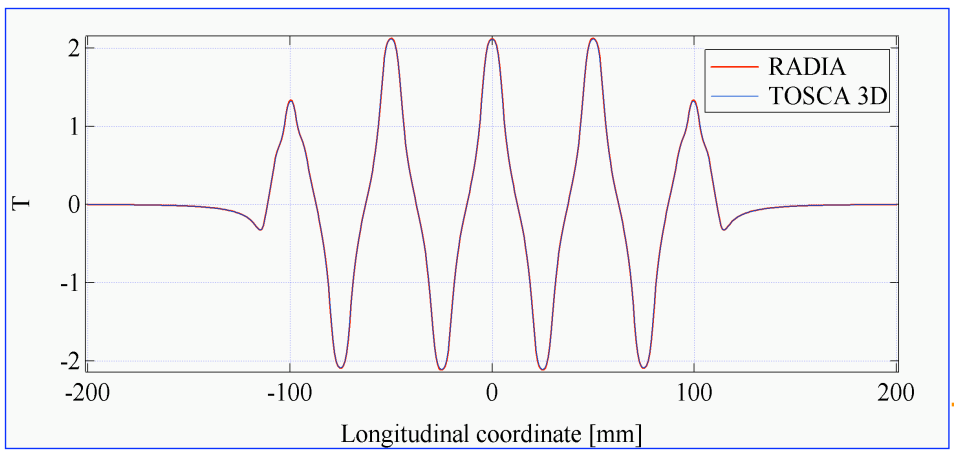


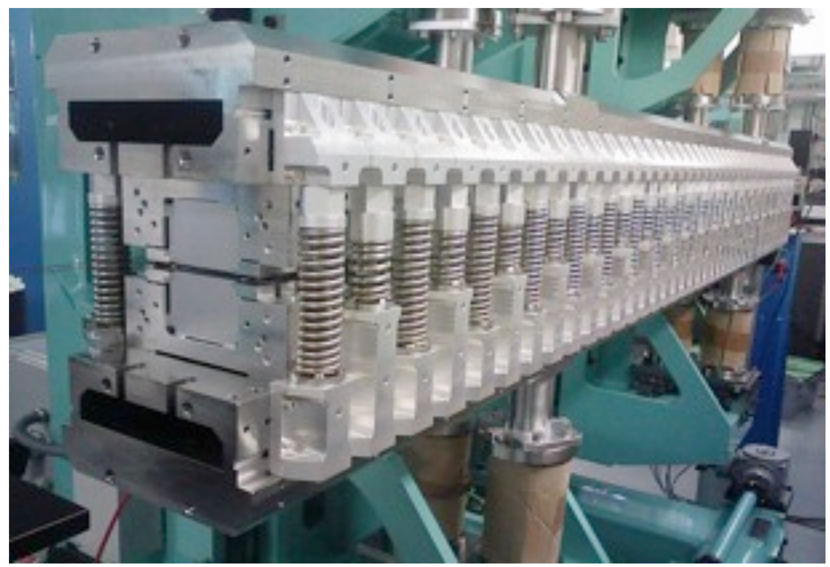
In vacuum wiggler

Choice of an in vacuum wiggler rather than a superconducting wiggler

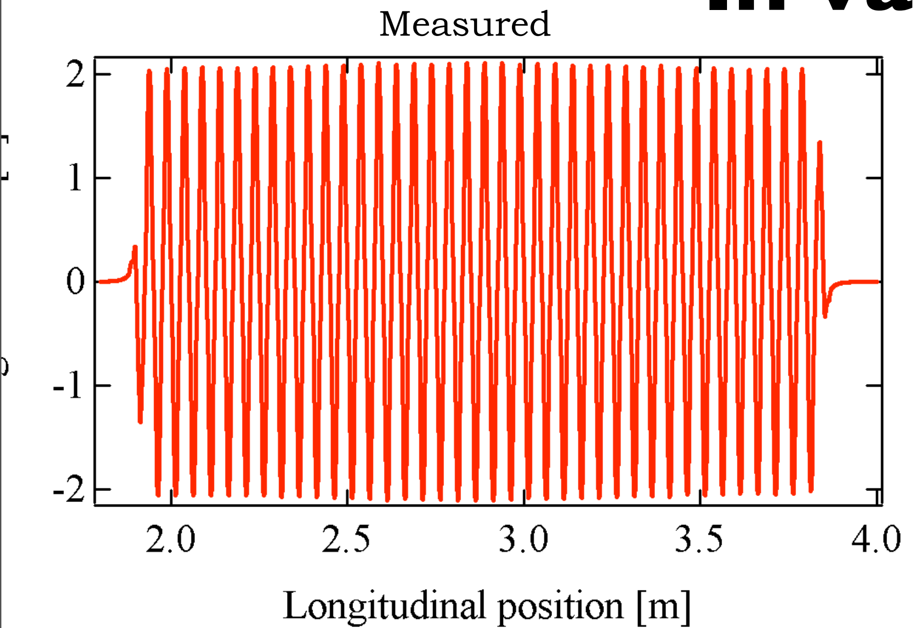


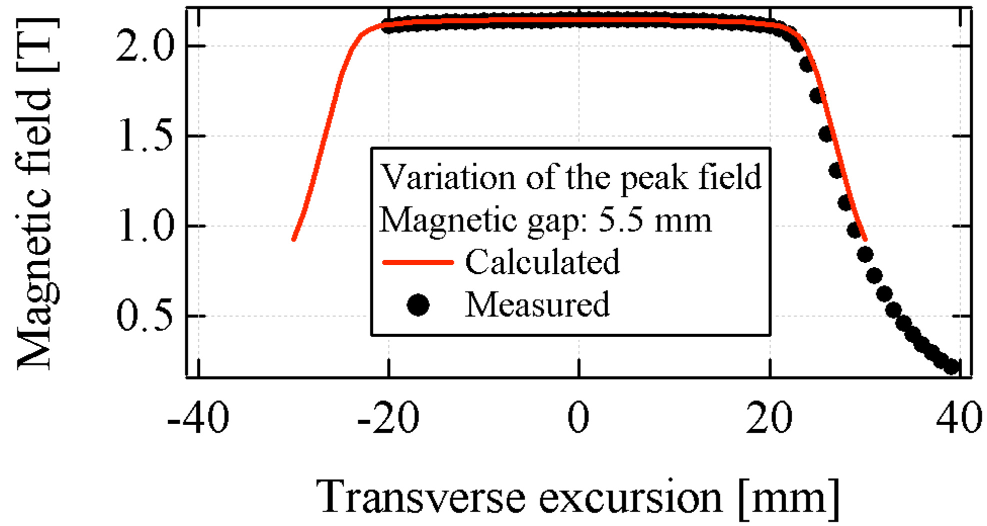






In vacuum wiggler

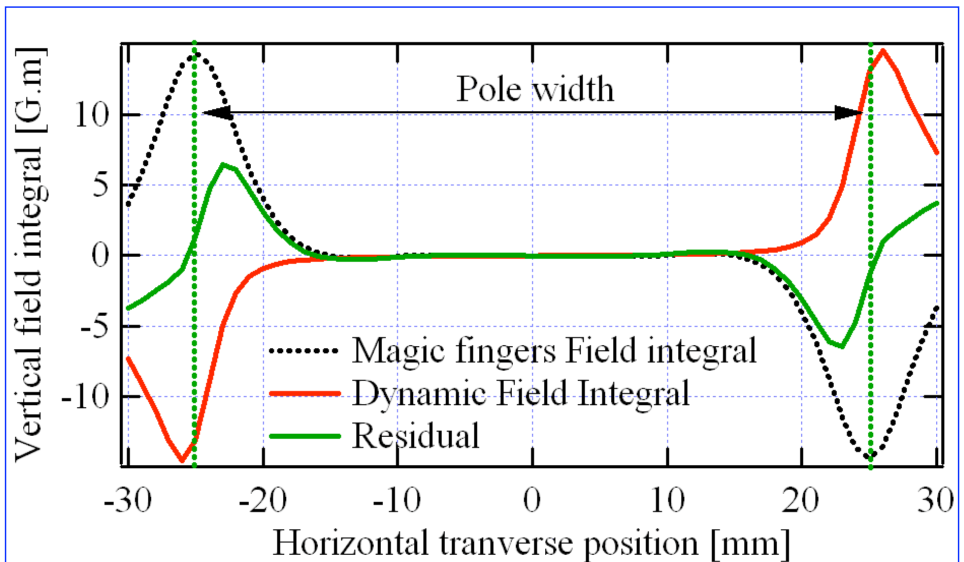


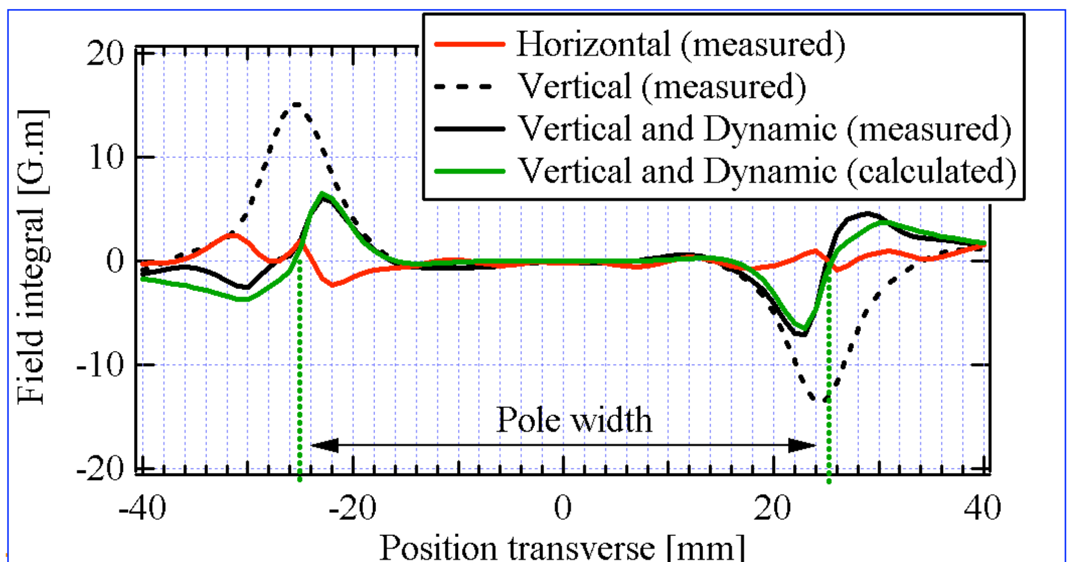


Compensation of the dynamic integral by magic fingers

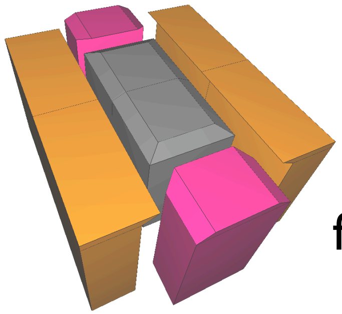
O. Marcoullé et al, IPAC 2011, 3236

J. Safranek et al, Phys. Rev. Special Topics (2002), Vol. 5, 010701, pp. 1-7

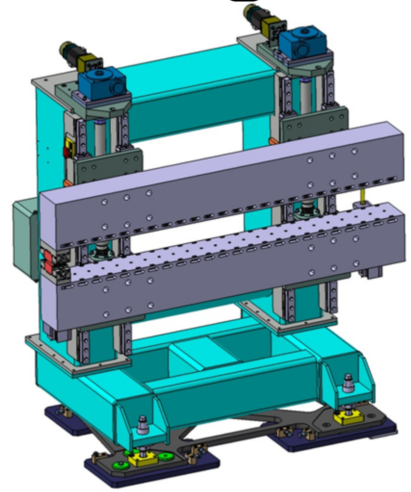


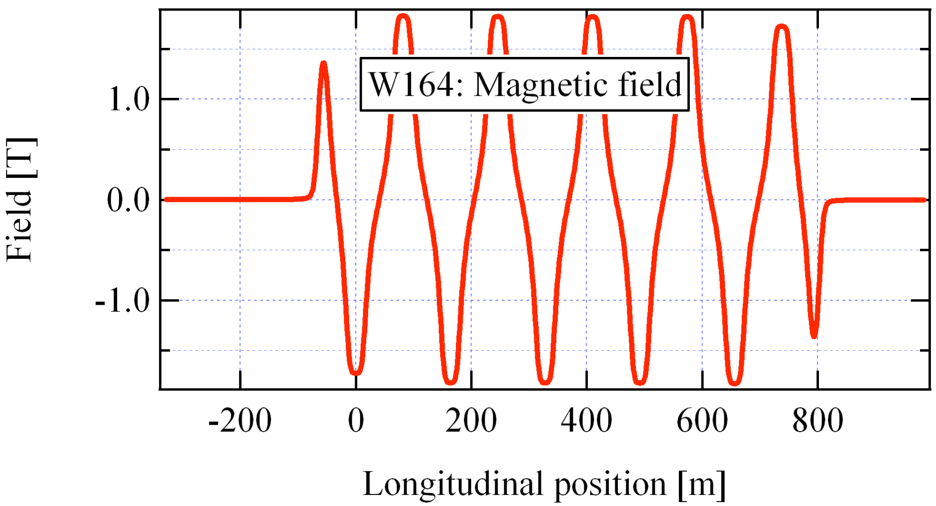


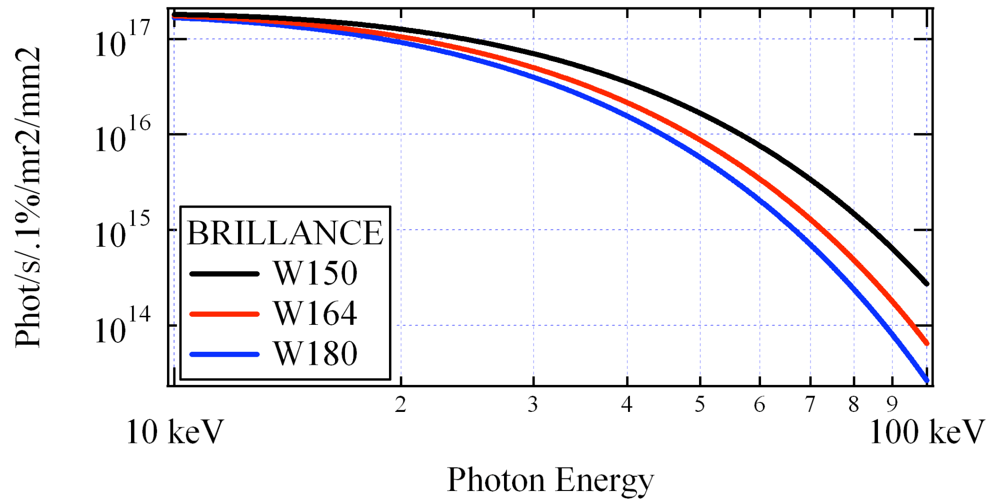
Out of vacuum wiggler for the slicing and PUMA beamline

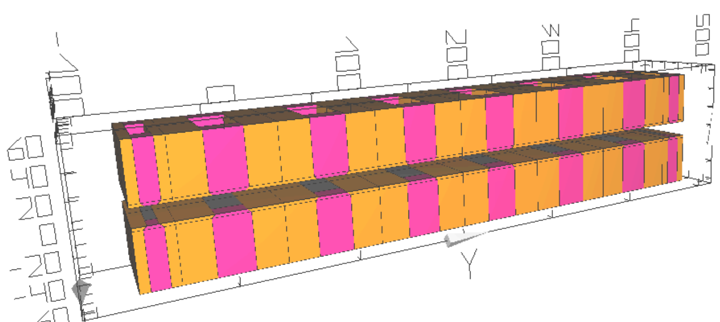


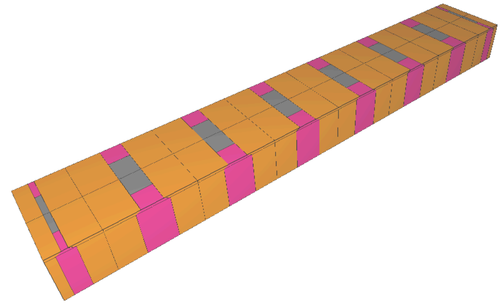
164 mm period, B= 1.8 T at 15 mm
for the slicing project, interaction with the laser at 800 nm
for PUMA, wiggler radiation











Br= 1.37 T, Bs=2.35 T

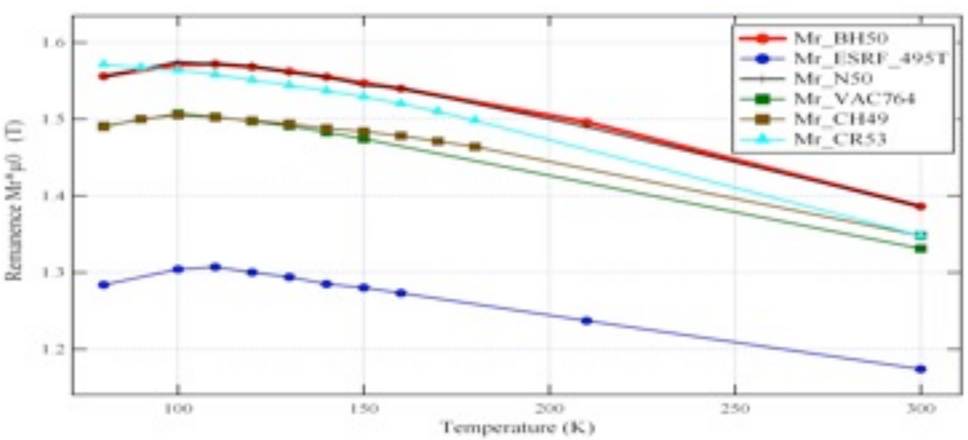
Magnetic measurements on sample magnets

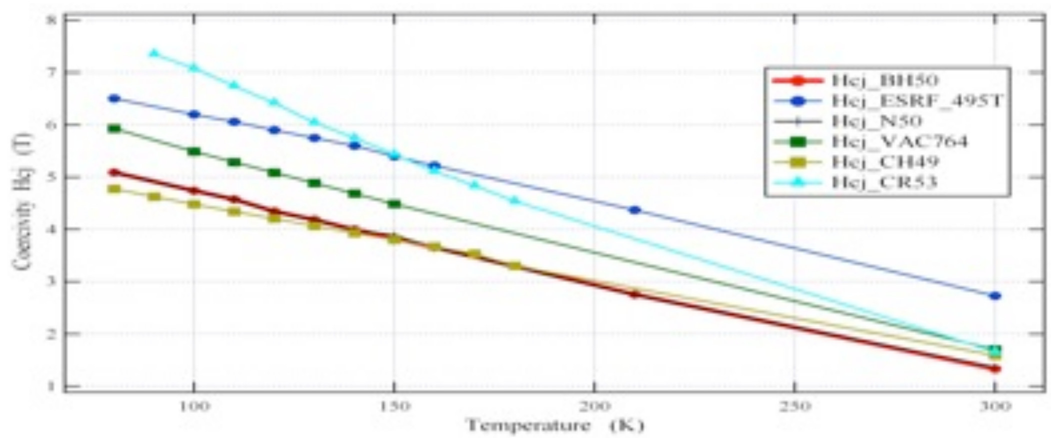
- Test Bench with NdFeB and PrFeB magnets

- Full scale undulator with PrFeB magnets, operation temperature of 77 K

=> Variation of the susceptibility vs T

Characteristics	CR53	BH50	CH49	VAC764	N50
Company	Hitach-Neomax			VAC	Atlas-Yunshen
Type of magnet	$Pr_2Fe_{14}B$	$Nd_2Fe_{14}B$	$Nd_2Fe_{14}B$	$Nd_2Fe_{14}B$	$Nd_2Fe_{14}B$
Remanence Br (T)	1.35	1.40	1.39	1.37	1.40
Coercivity Hcj (T)	1.65	1.39	1.63	1.63	1.38
Temp. Coef ΔBr (%/°C)	0.11	0.11	0.11	0.12	0.11
Temp. Coef ΔHcj (%/°C)	0.58	0.58	0.58	0.70	0.60
Dimensions (mm^3)	4x4x4	4x4x4	4x4x4	4x4x4	4x4x4

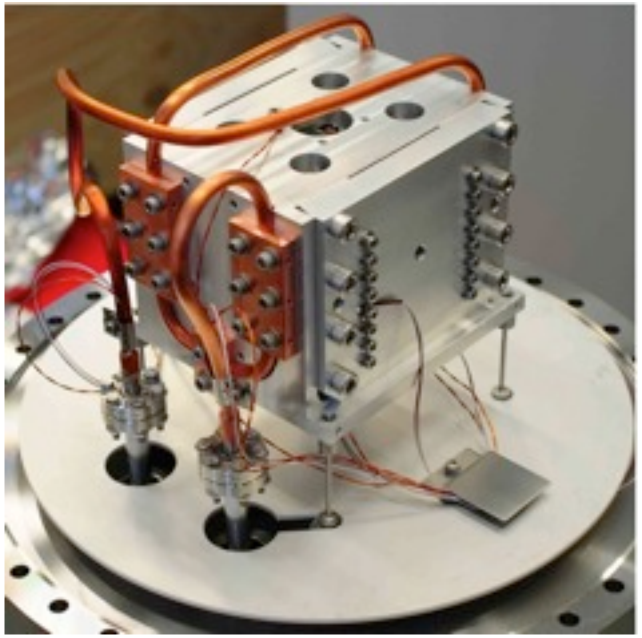


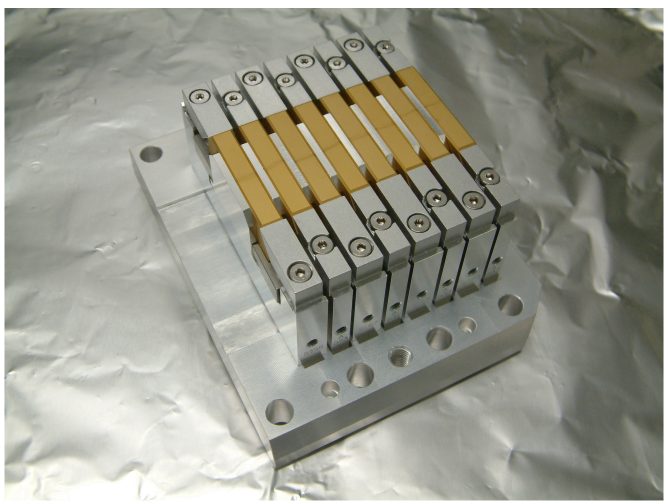


SOLEIL SYNCHROTRON

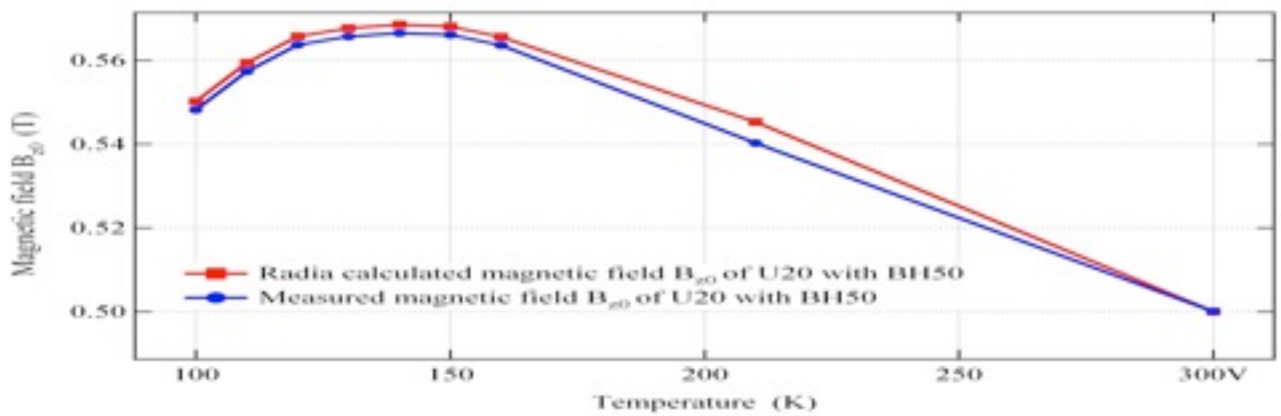
6- R&D cryogenic undulator

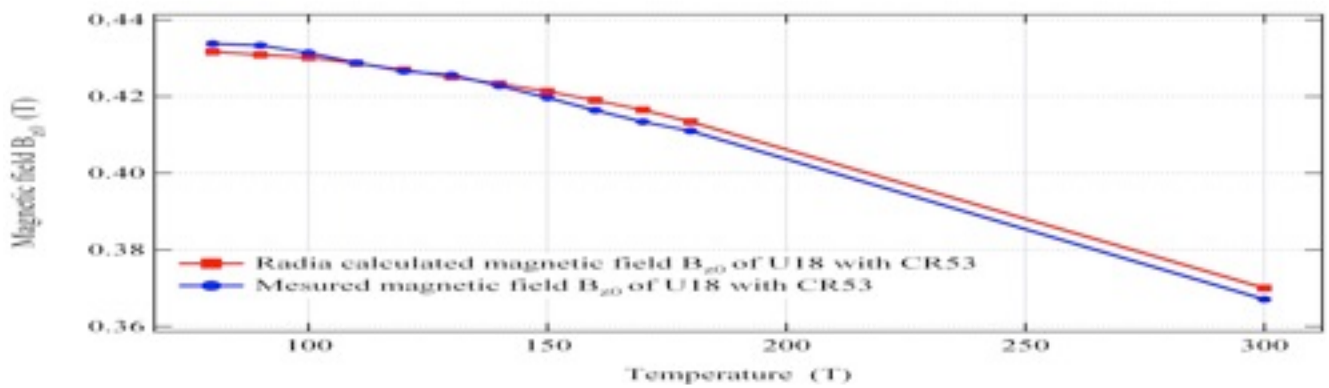
NdFeB and PrFeB 4 periods Test Benches





Validation of magnetic model at low temperature





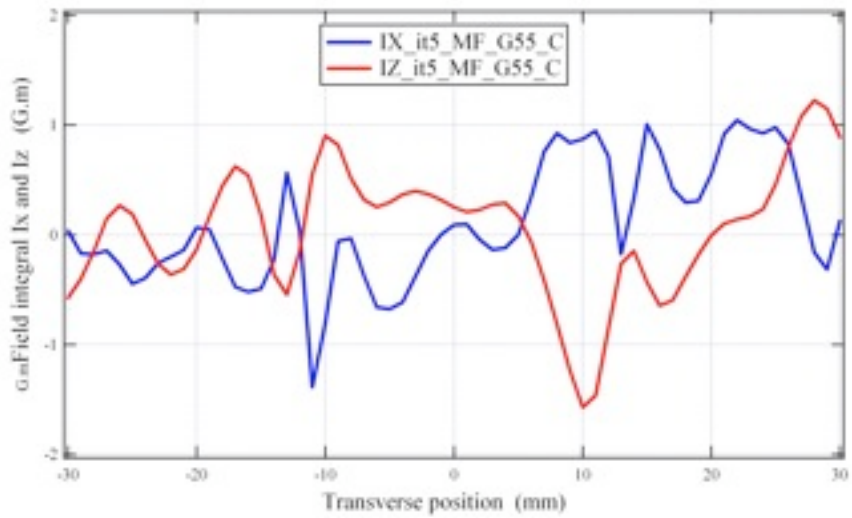
$Nd_2Fe_{14}B$ and $Pr_2Fe_{14}B$ magnets characterisation and modelling for cryogenic permanent magnet undulator applications, C. Benabderrahmane, P. Berteaud, M. Valléau, C. Kitegi, K. Tavakoli, N. Béchu, A. Mary, J. M. Filhol, M. E. Couprie, Nuclear Instruments and Methods in Physics research A 669 (2012) 1-6

6- R&D cryogenic undulator

Room temperature assembly

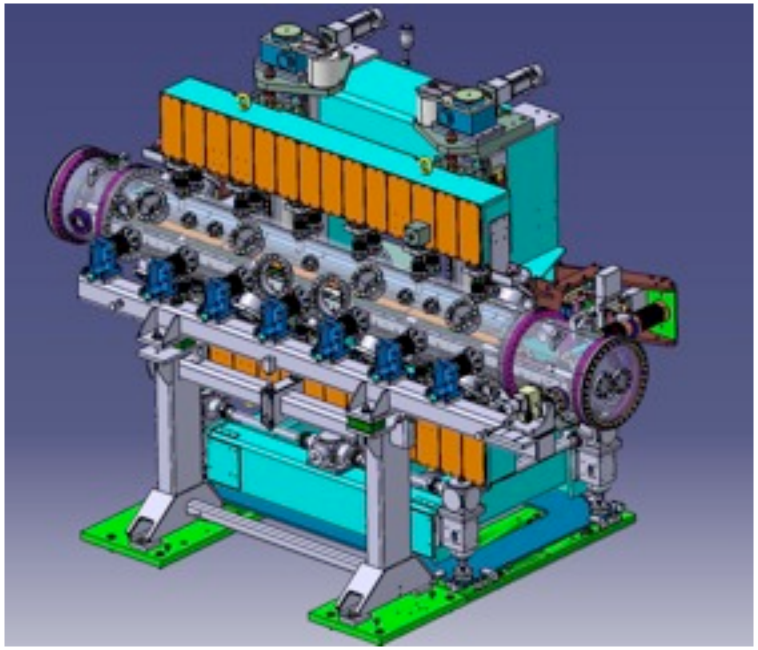
PM	$Pr_2Fe_{14}B$
Pole	Vanadium P
Period:	18 mm
N° periods:	107
Bz_0:	1.15 T à 77 K
K:	1.9
Gap min:	5.5 mm

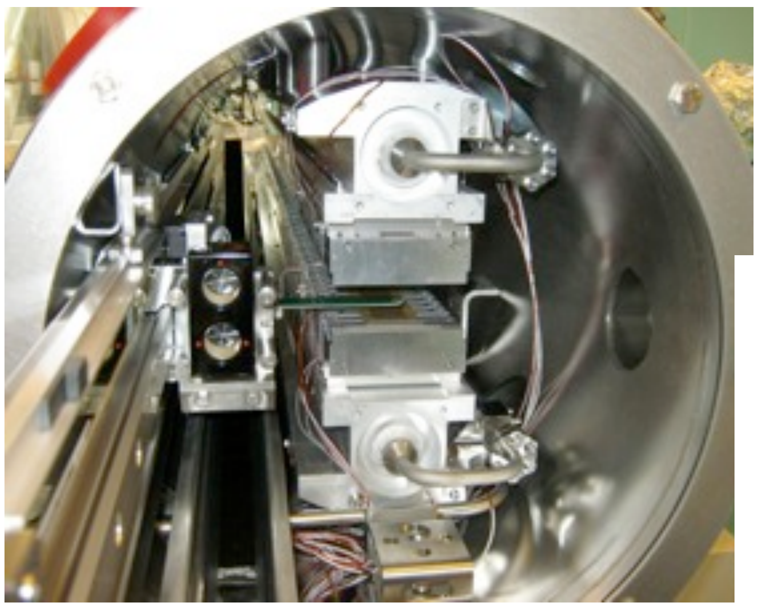
phase error : 3.2 °



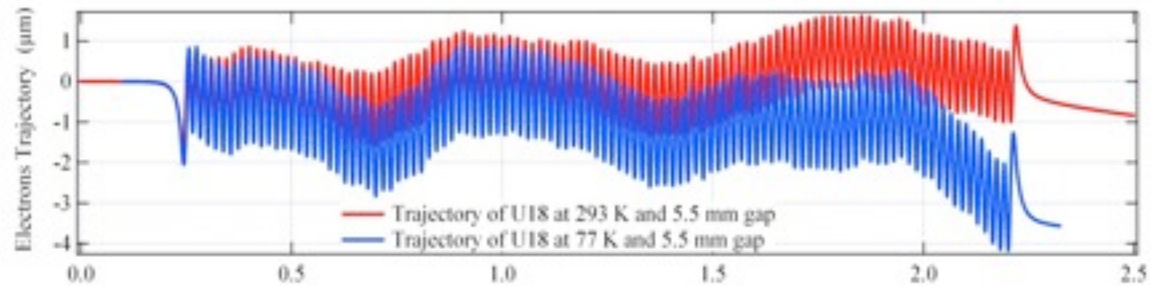
6- R&D cryogenic undulator

Low temperature measurements at 77 K

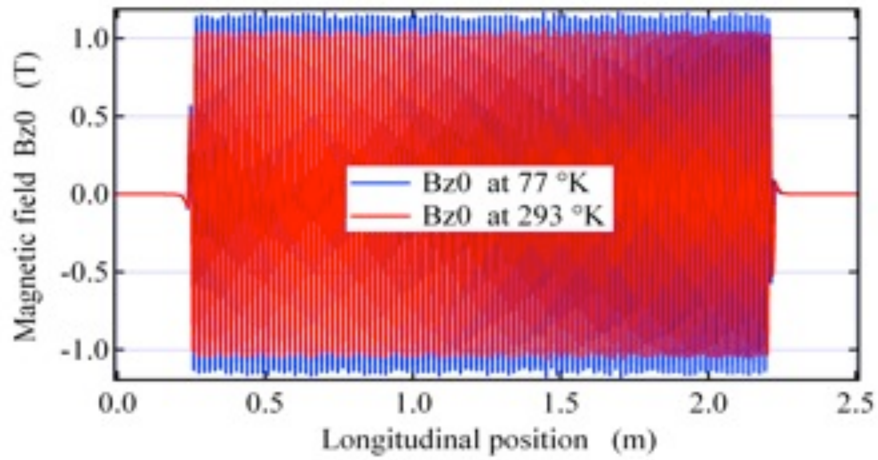


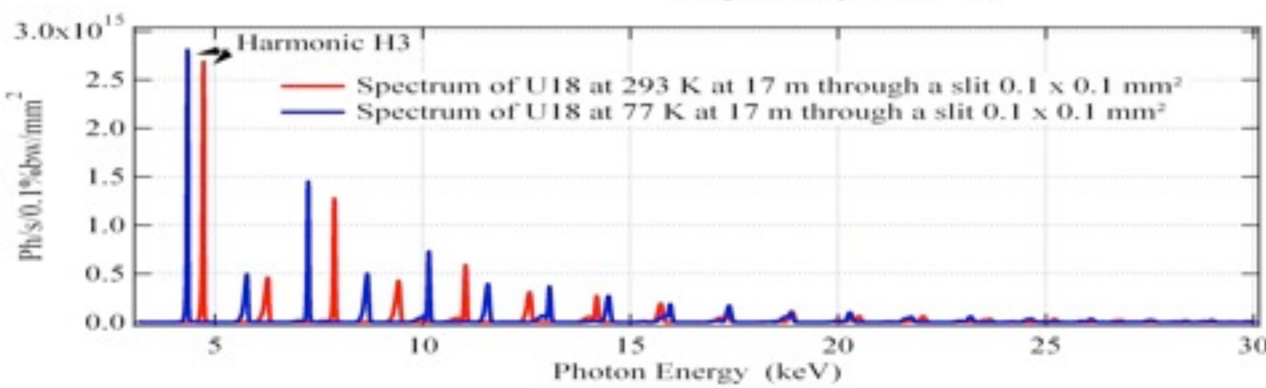


Gain of 10% on the peak field
Phase error at 77 °K is 3.2° Rms

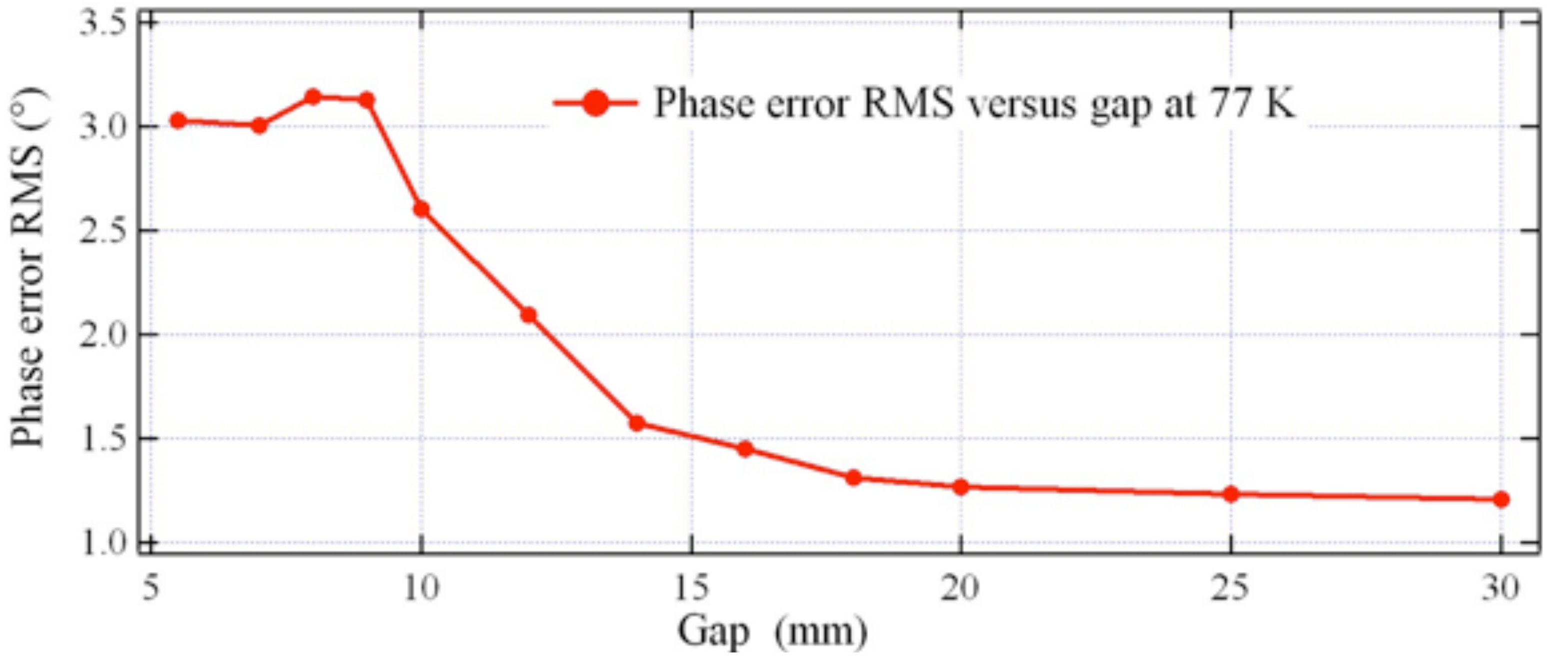


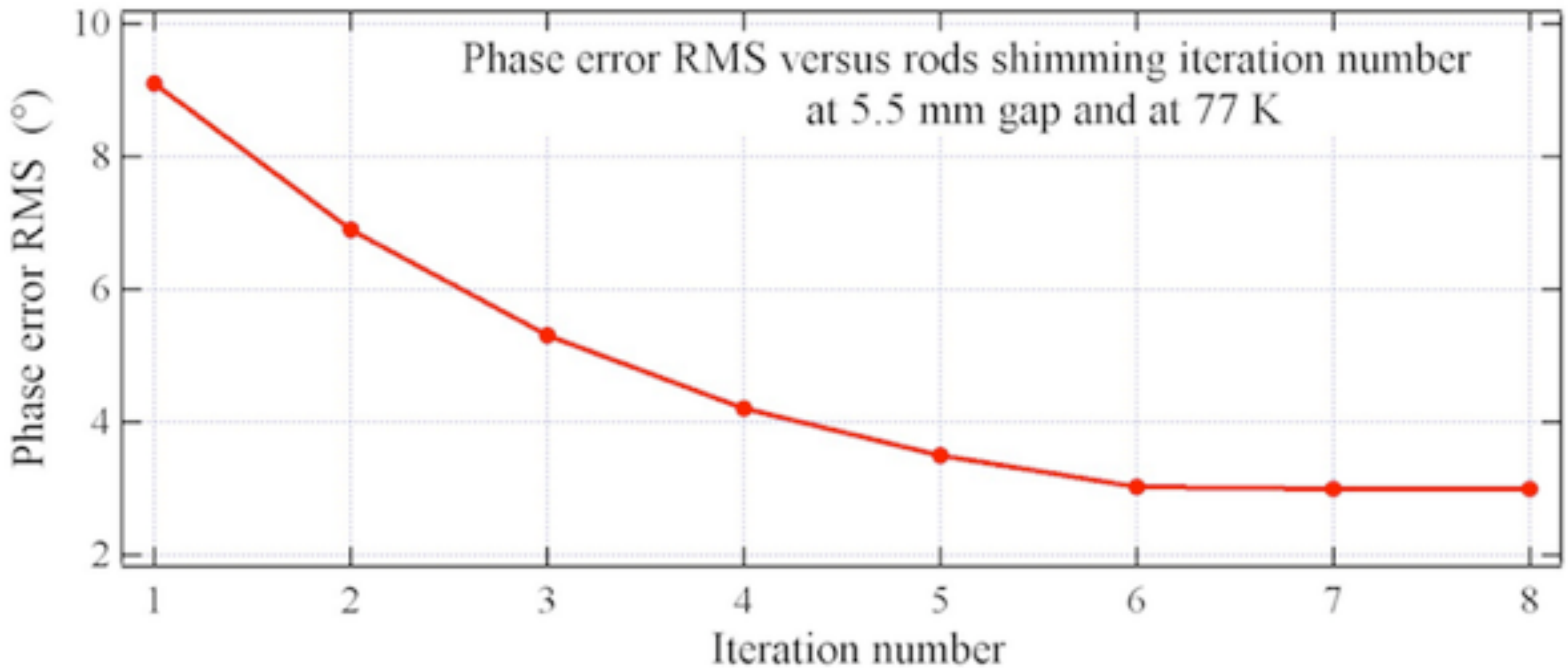
No baking
B= 1.16 T (1.05 T U20 NdFeB, 0.96 T U20 SmCo)





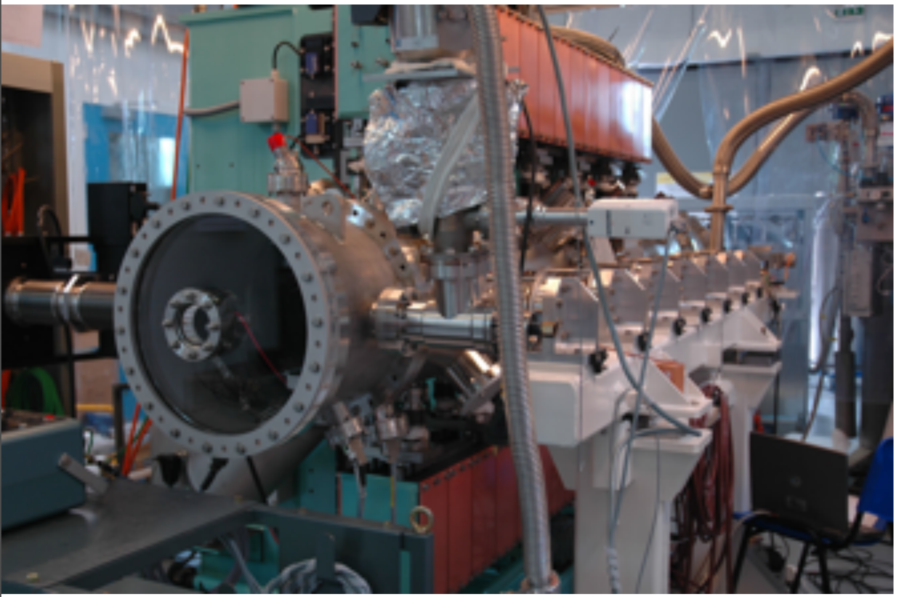
Low temperature measurements at 77 K

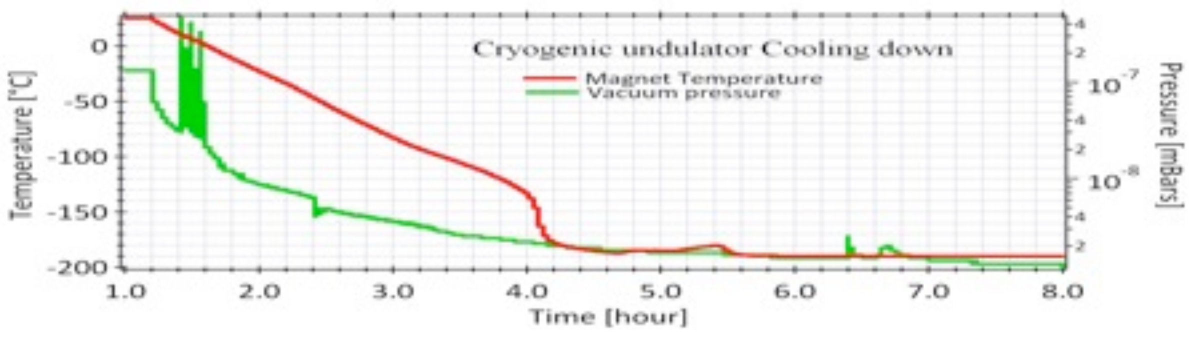




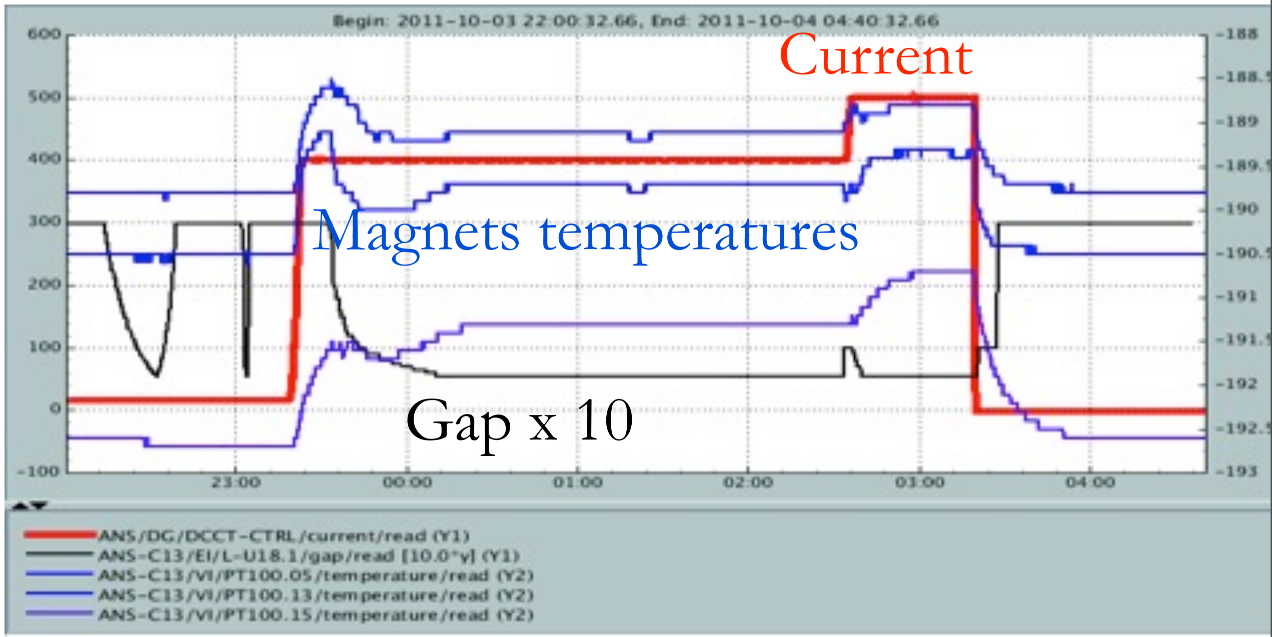
6- R&D cryogenic undulator

Cooling to 77 K

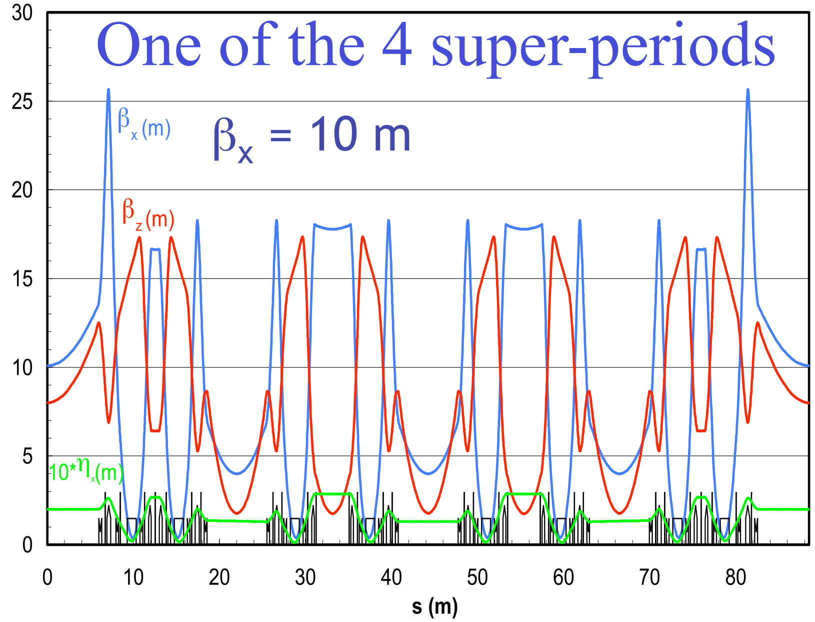


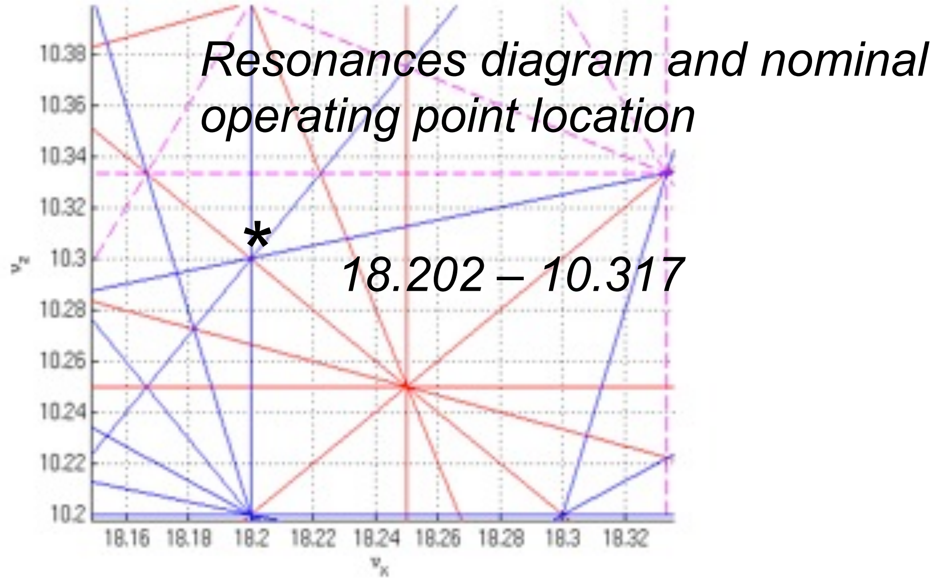


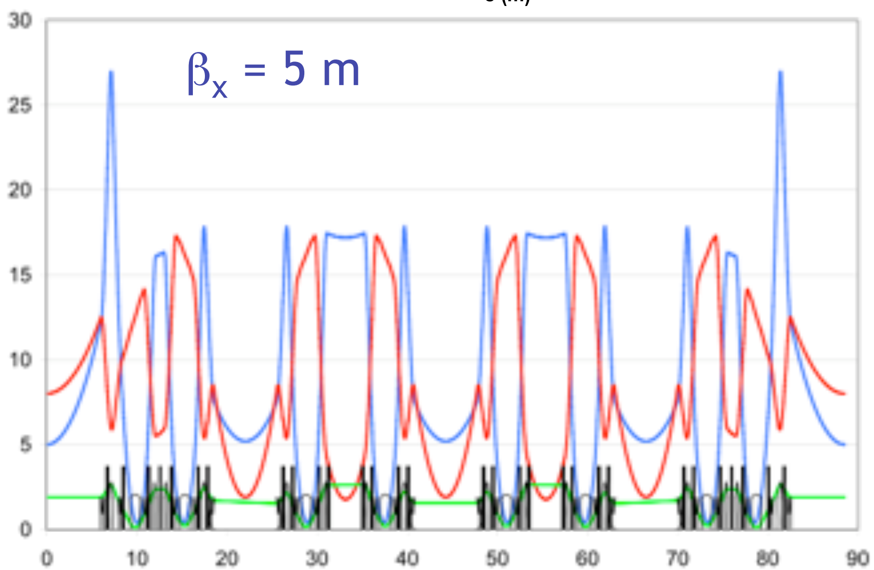
Cryo Cooler: Power 2000 W (<300 W), Liquid LN2,
Pump : 30 to 90 Hz (40 Hz), Flow : 1 to 30 l/mn (5 l/mn)

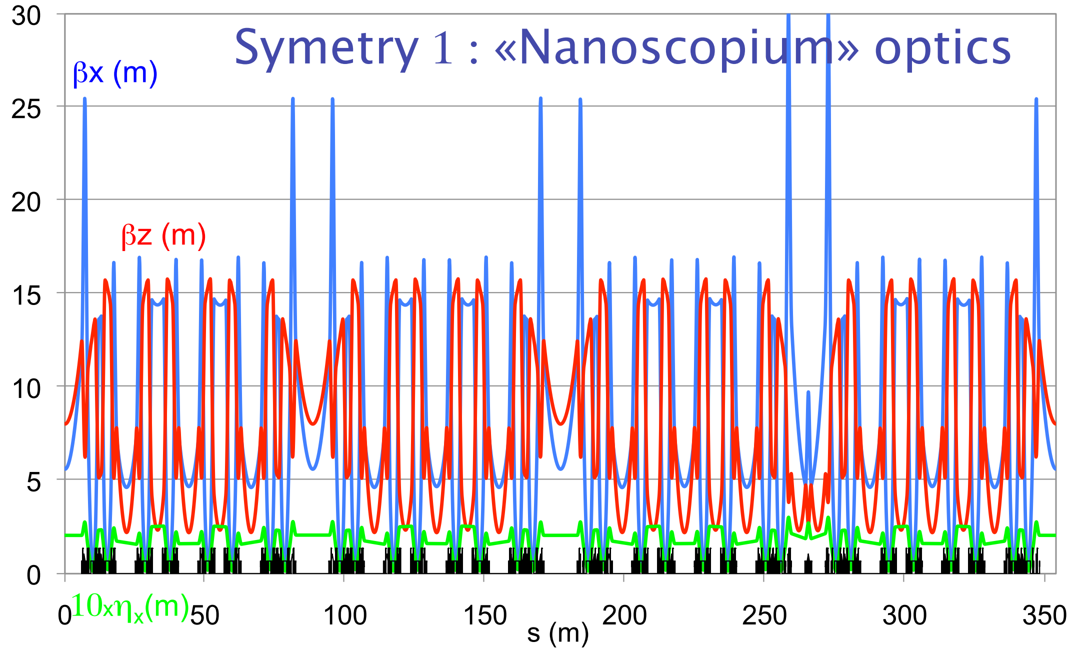


SOLEIL lattice



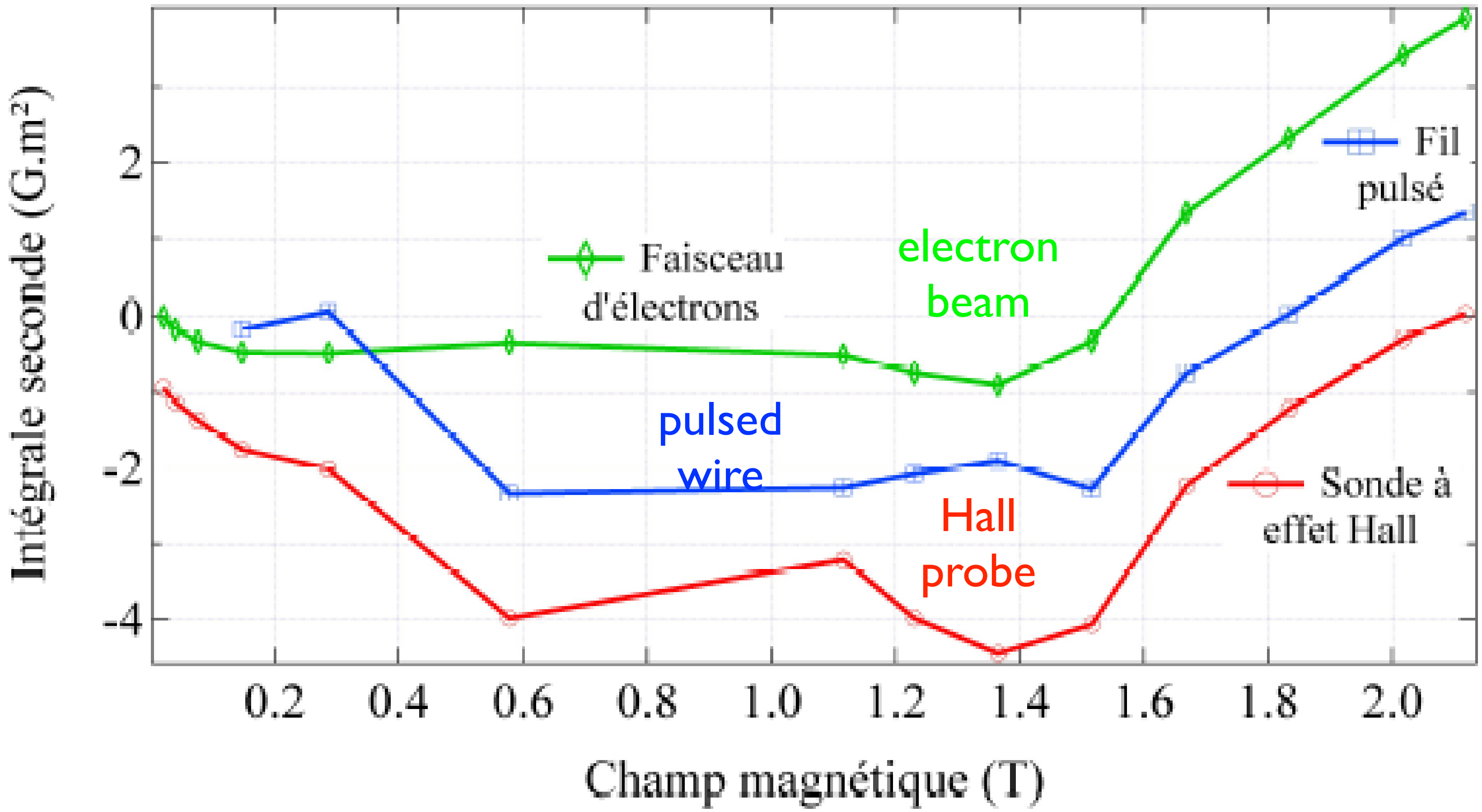






Dipolar terms : field integrals

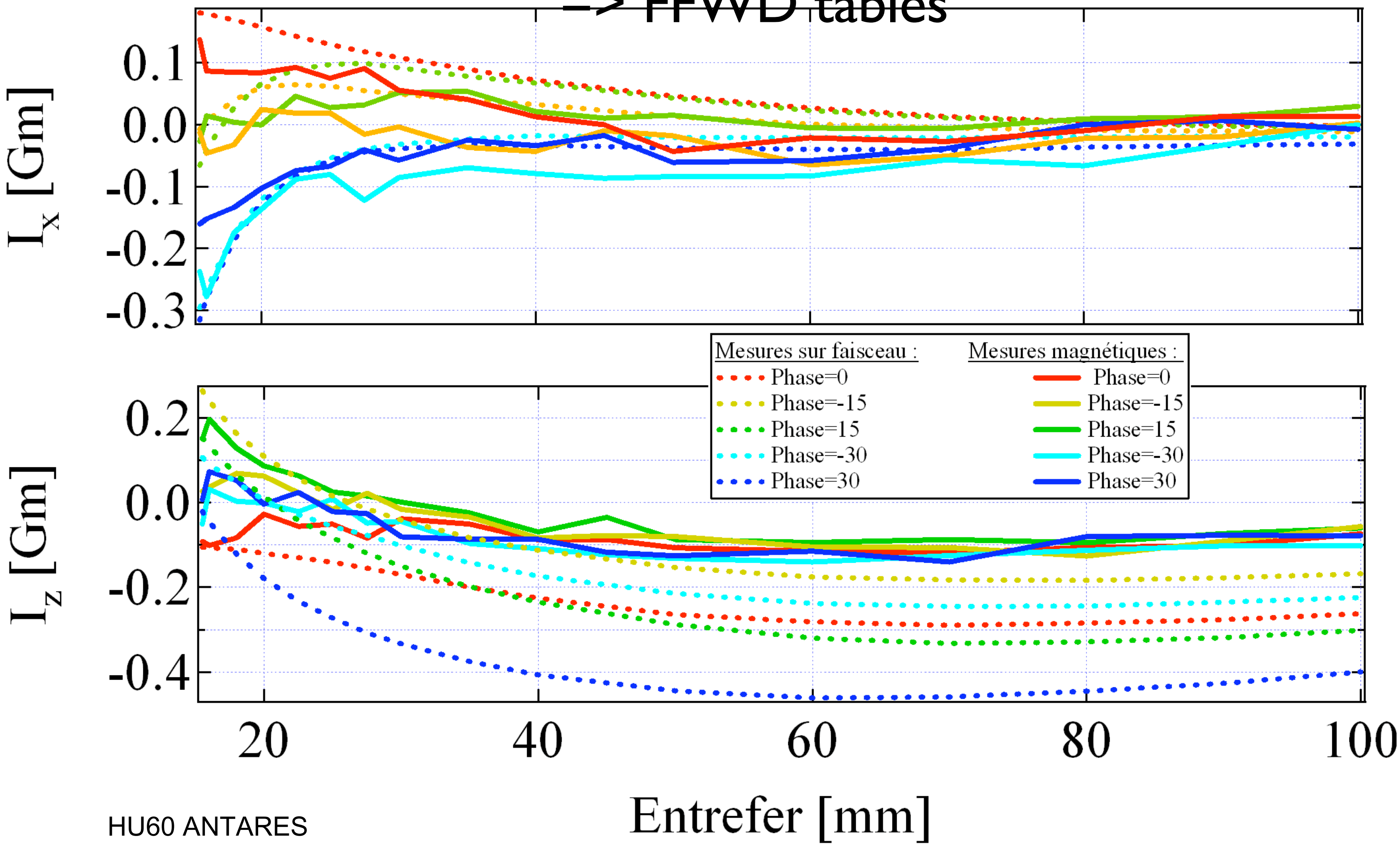
Comparison magnetic measurement hall/ electron beam



In vacuum wiggler

Dipolar terms : field integrals

Comparison magnetic measurement hall/ electron beam
=> FFWD tables



HU60 ANTARES

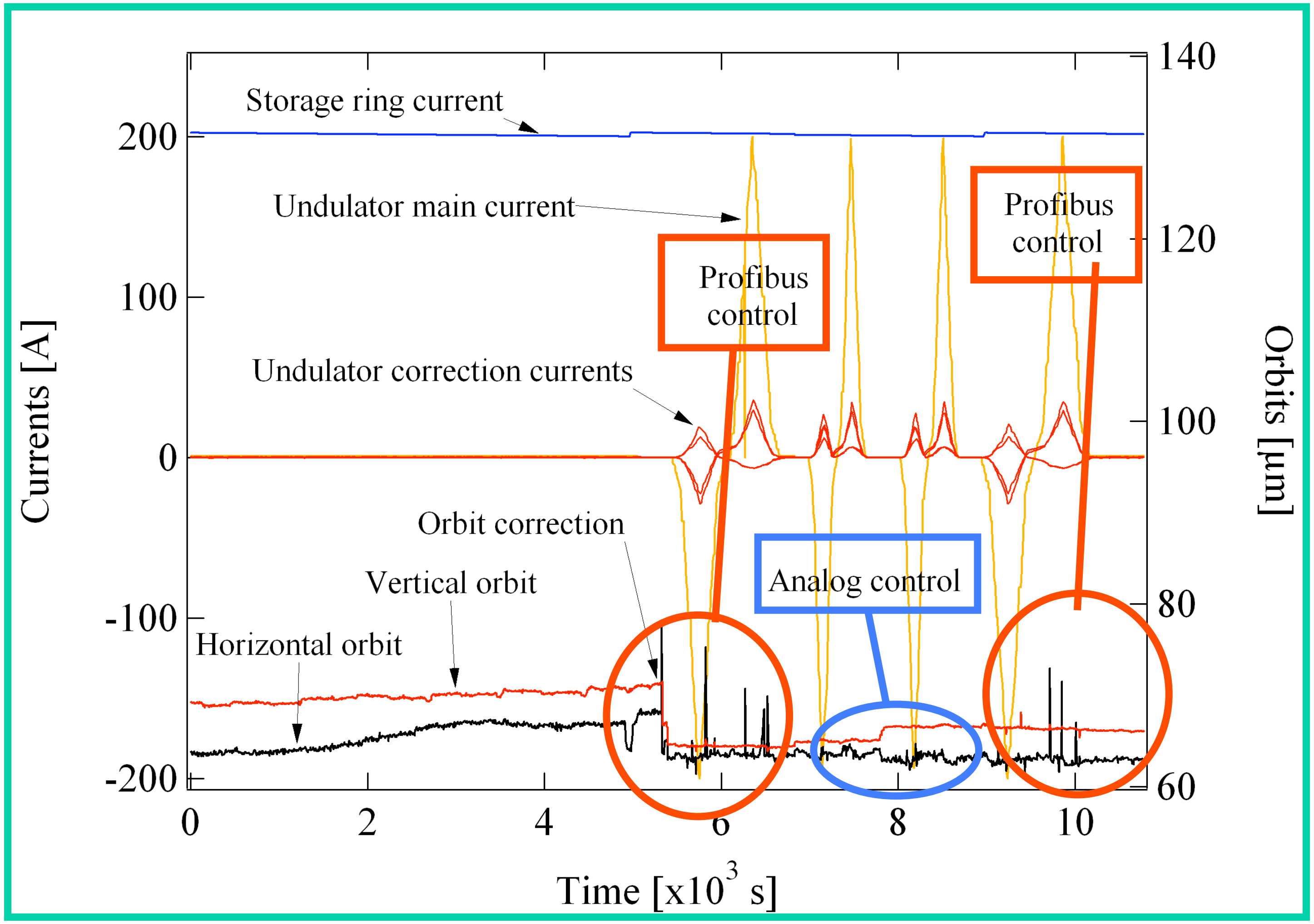
Analog FFWD for EM IDs

Reduction of the spikes due to unperfect synchronisation between main and correction power supplies, via SPI controller

Ex HU256 Cassiopée, on production.

Test on HU256 (Dec)

For HU65 EMPHU : Mid 2011



Increase of the electron orbit length due to some IDs

$$\Delta x(s_i) = -\frac{\eta_x(s_i)}{\alpha} \cdot \frac{K^2 L_u}{4\gamma^2 C}$$

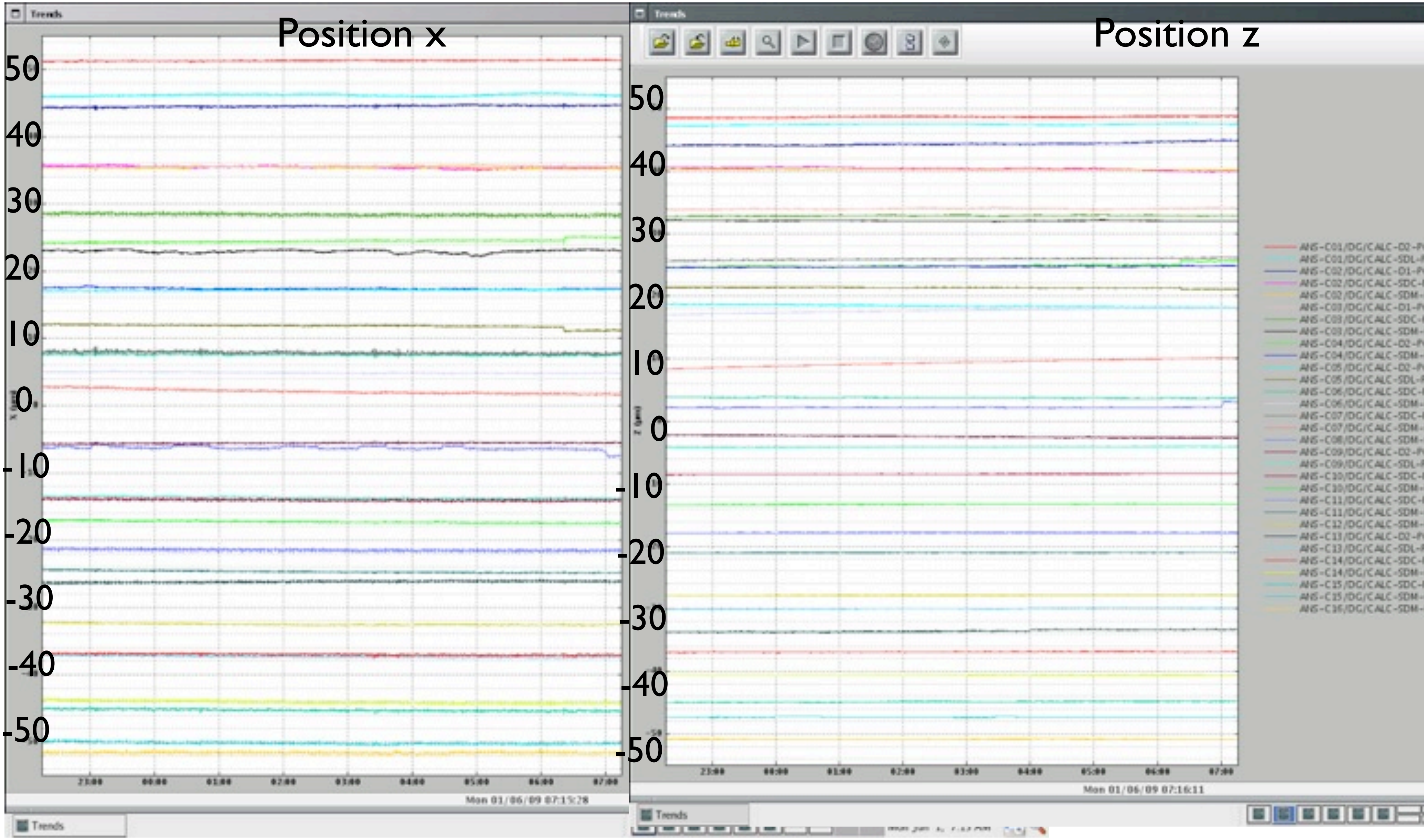
	HU640	HU256	HU80	WSV50	U20
K_{max}	8.87	9.56	7.1	9.8	1.8
L_u [m]	10	3.5	1.6	1.9	1.9
η ond [m]	0.2	0.13	0.13	0.28	0.28
<Δx> [μm] **predicted**	**8.6**	**2.25**	**0.57**	**2.27**	**0.08**

Transverse shift of the orbit up to 10 μm
=> Change of the RF frequency joined to the FFWD tables

7- SOLEIL beam operation in presence of the IDs

Resulting source point stability

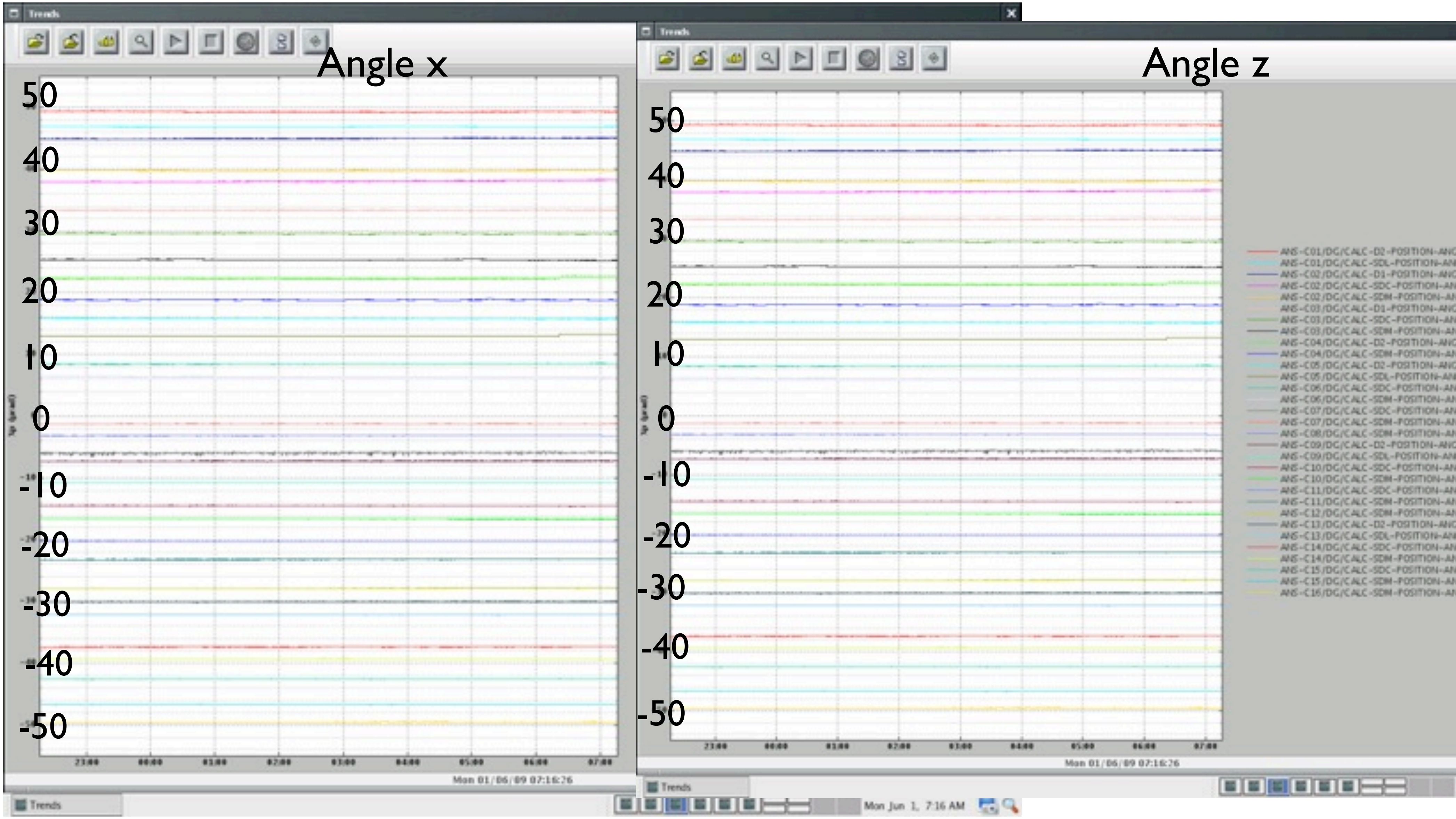
FFWD tables with Slow and Fast Orbit Feedback



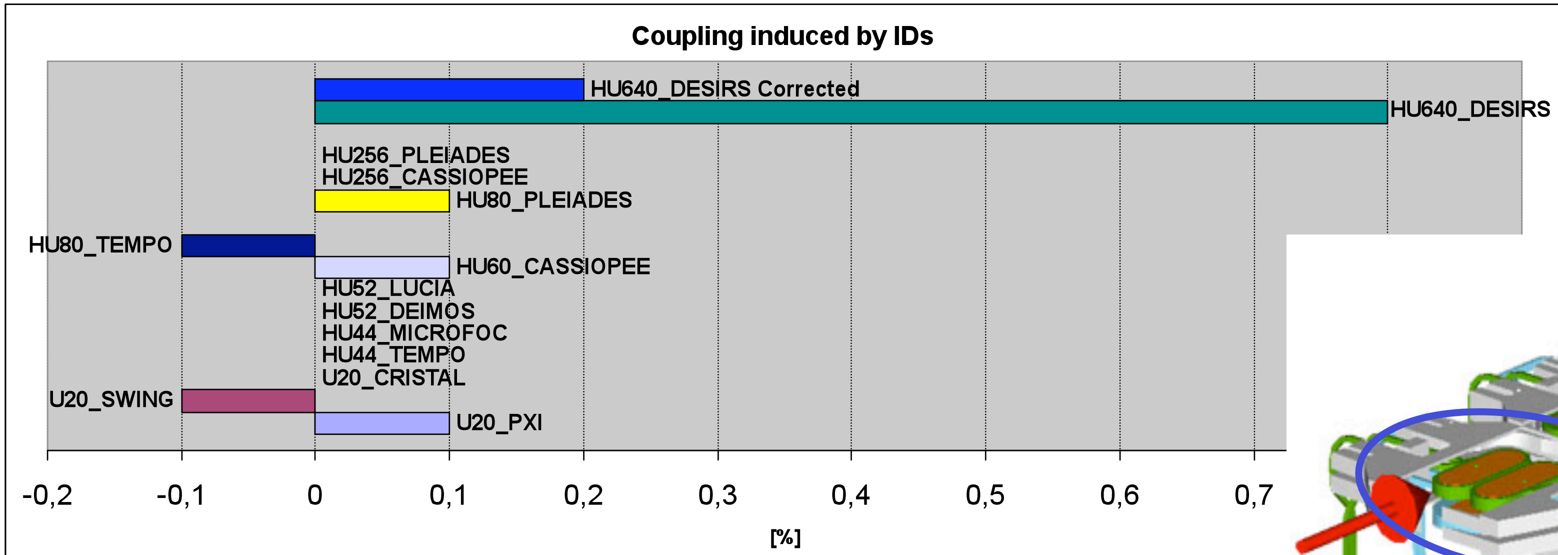
7- SOLEIL beam operation in presence of the IDs

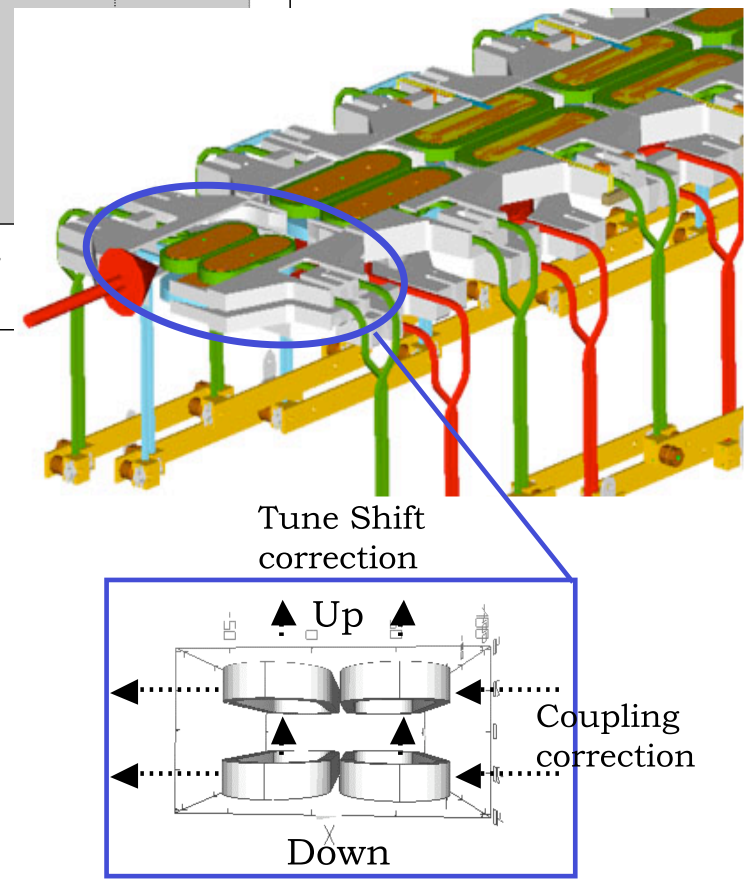
Resulting source point stability

FFWD tables with Slow and Fast Orbit Feedback



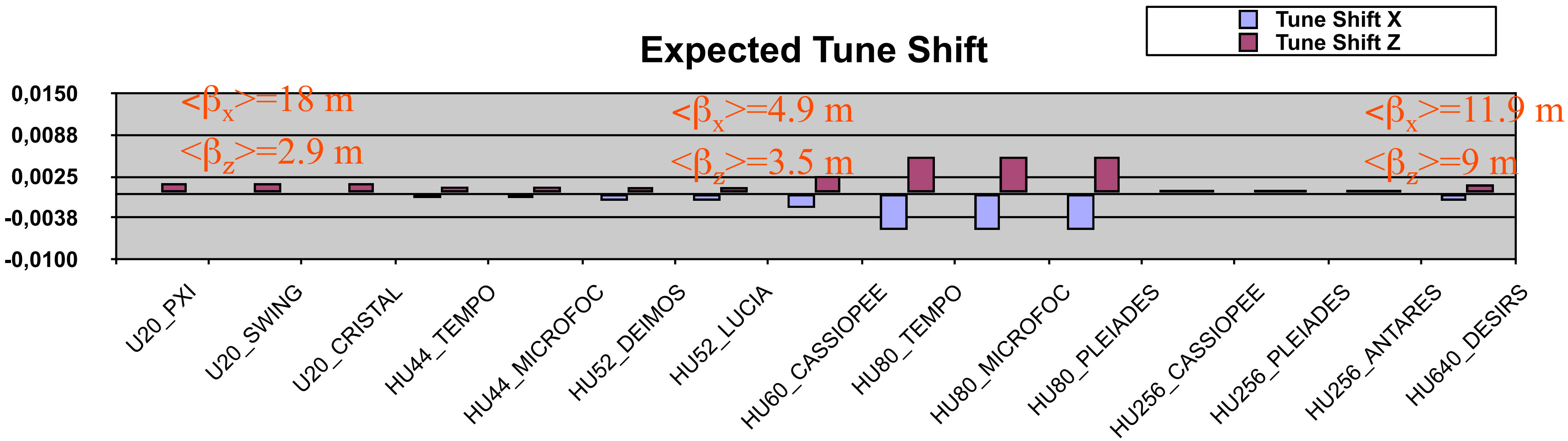
Skew quadrupole : Coupling

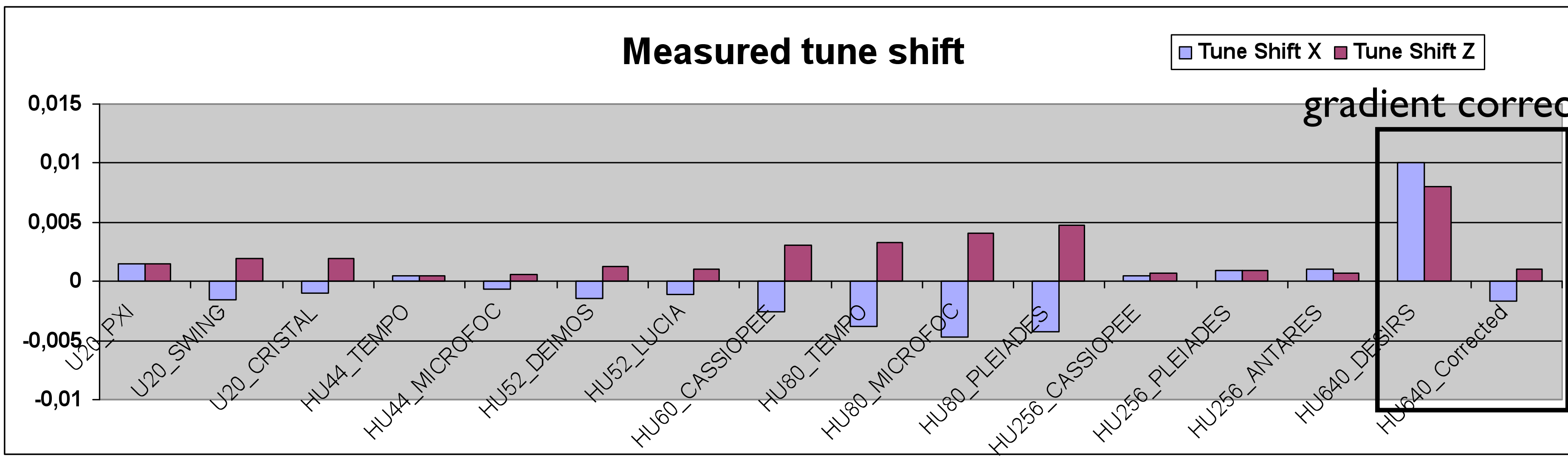




Strong coupling induced by HU640 reduced by modification of the coil position

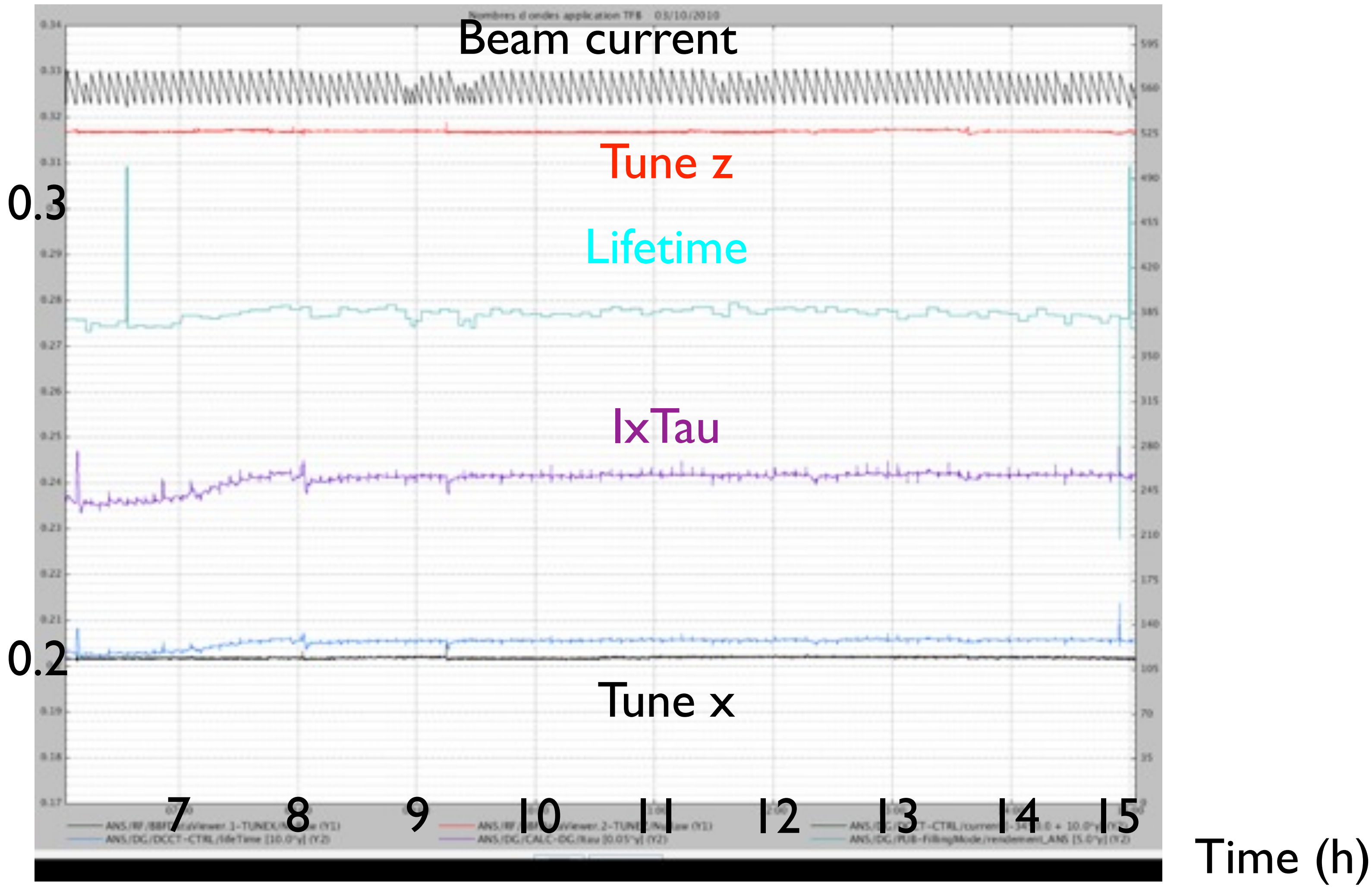
Quadrupolar terms : tune shifts





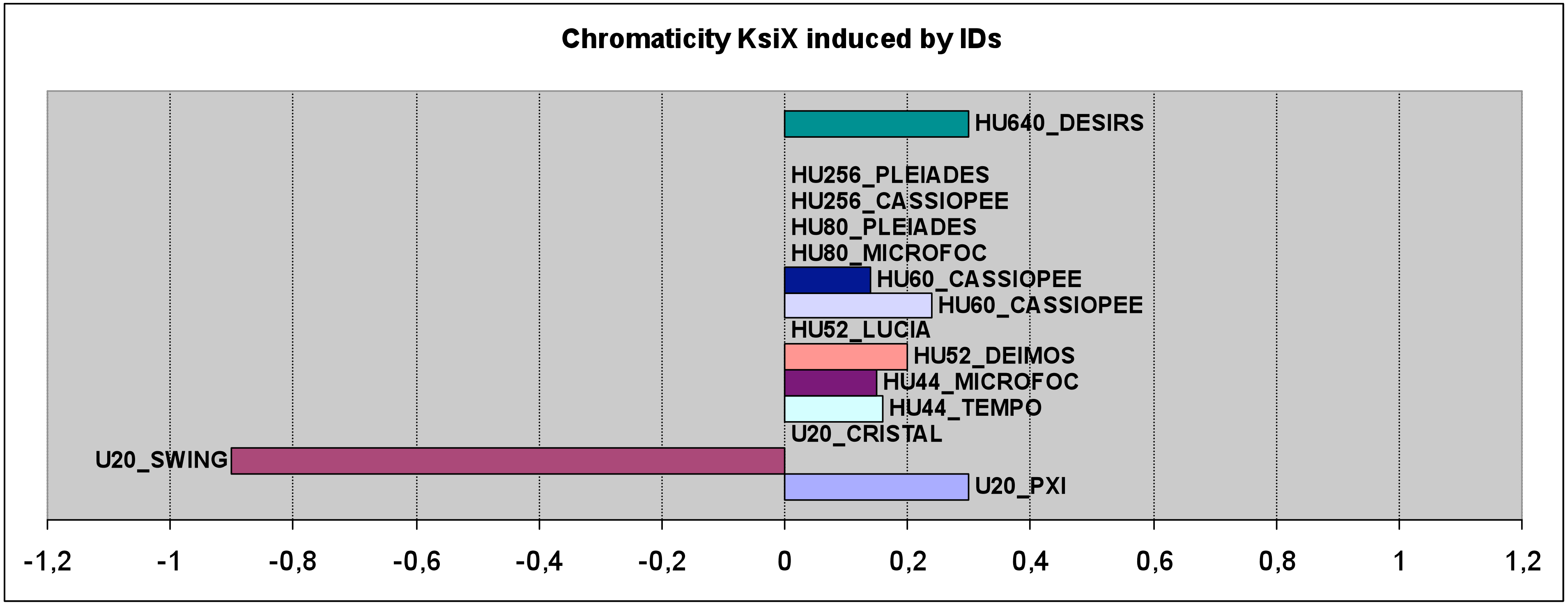
Quadrupolar terms : tune shifts compensation

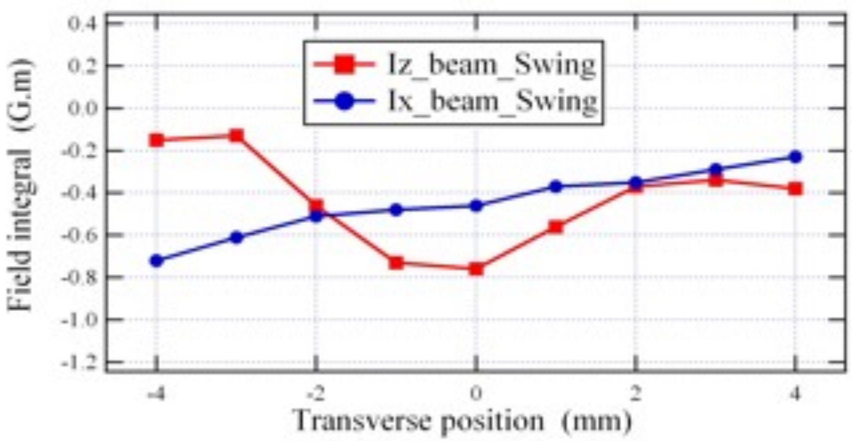
Global Tune Feedback (2 Quad families)



6- SOLEIL beam operation in presence of the IDs

Sextupolar terms : chromaticity





- Chromaticity in X induced by U20_SWING
- No chromaticity induced in Z plane

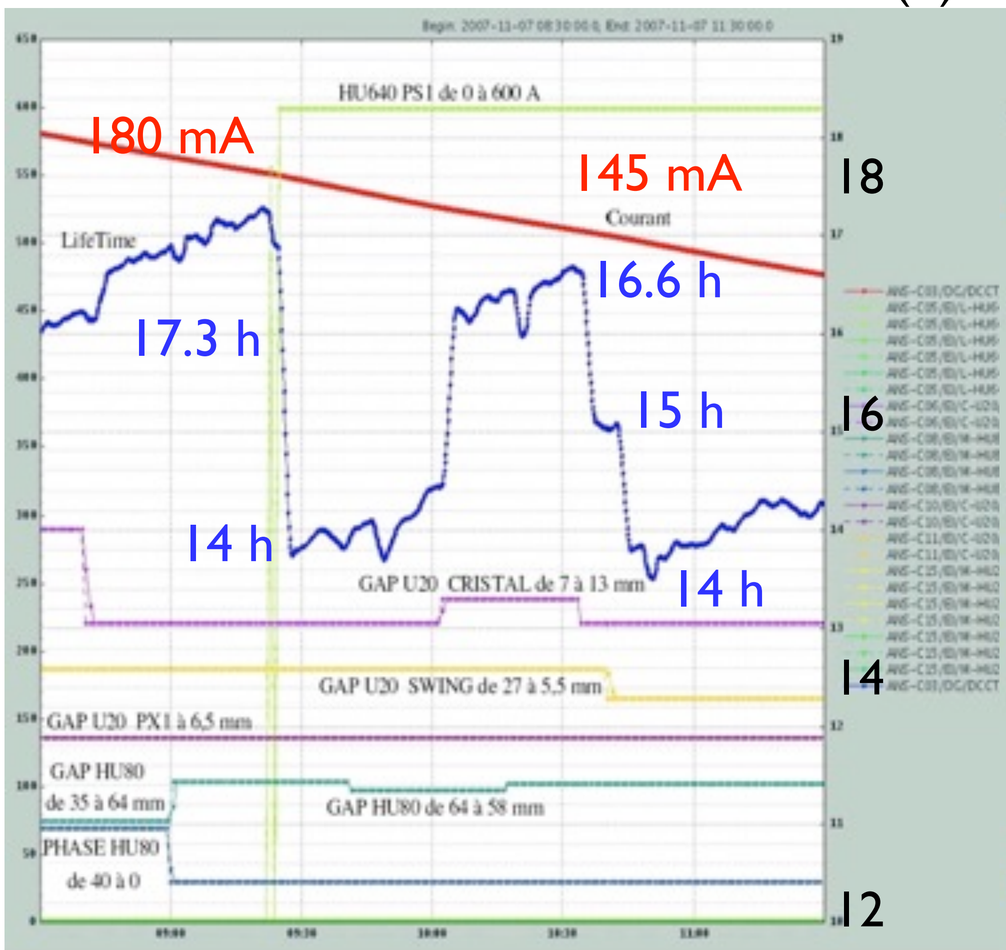
7- SOLEIL beam operation in presence of the IDs

Effect on lifetime

High value of bebatron functions + initial
high energy acceptance (6 %) at SOLEIL

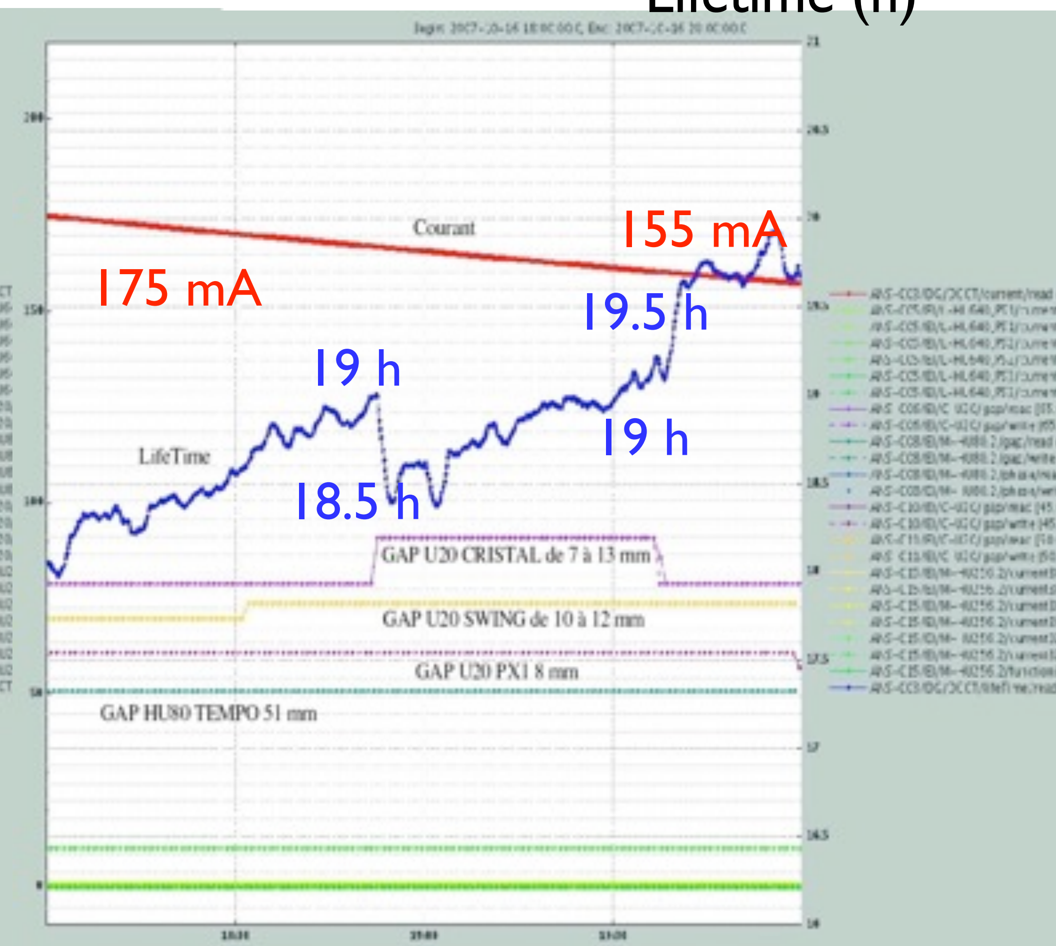
PS1 (HU640)

Lifetime (h)



In vacuum ID

Lifetime (h)



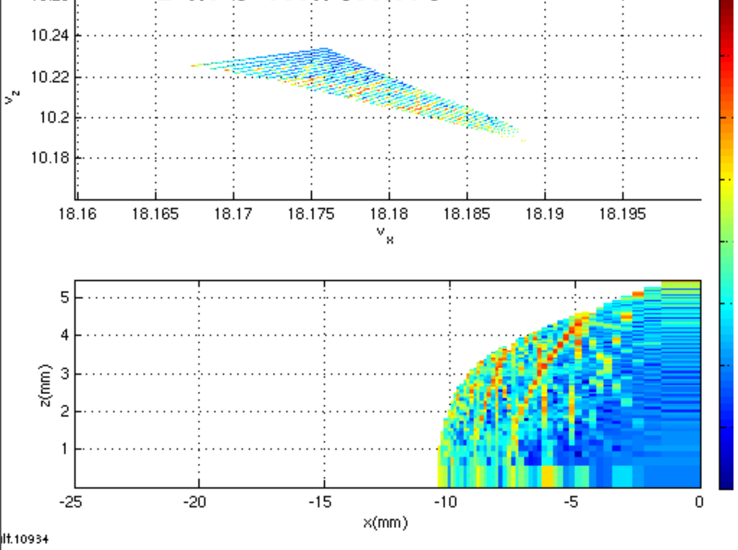
Modelisation with field maps

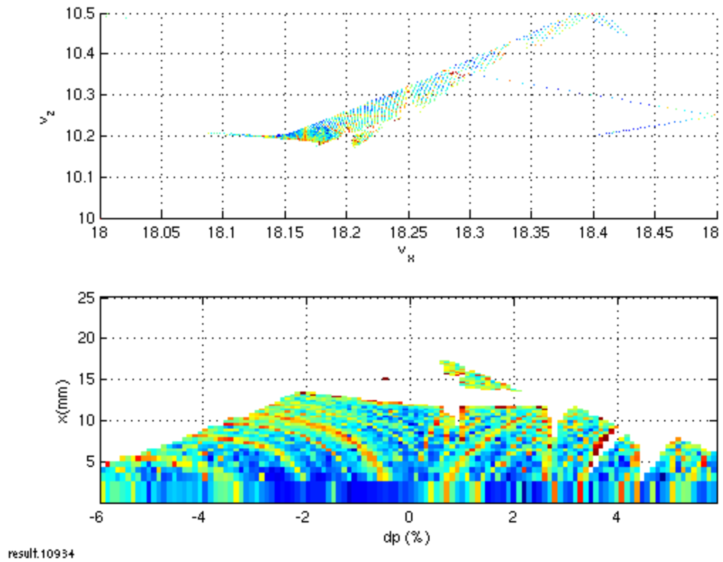
WI64

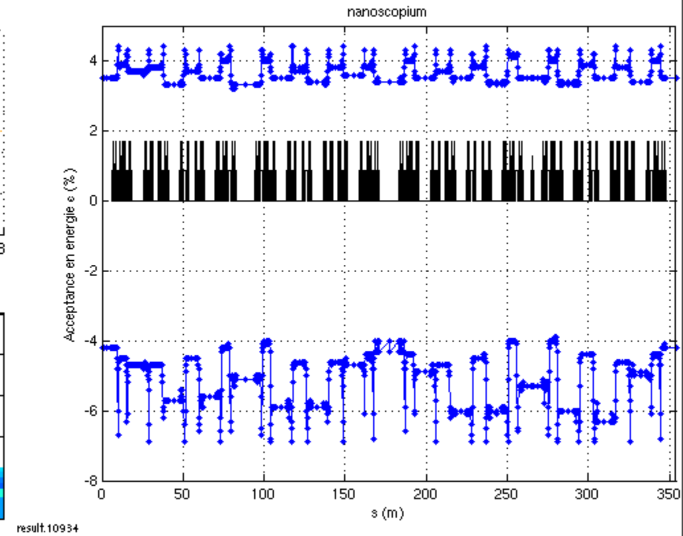
On-momentum dynamics – injection efficiency
(tunes at 18.176; 10,234)

Off-momentum dynamics
(tunes at 18.176: 10.234)

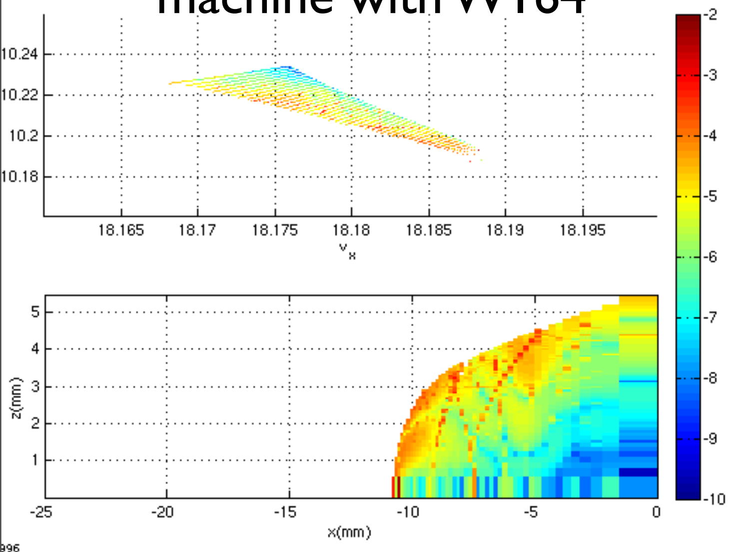
Bare machine

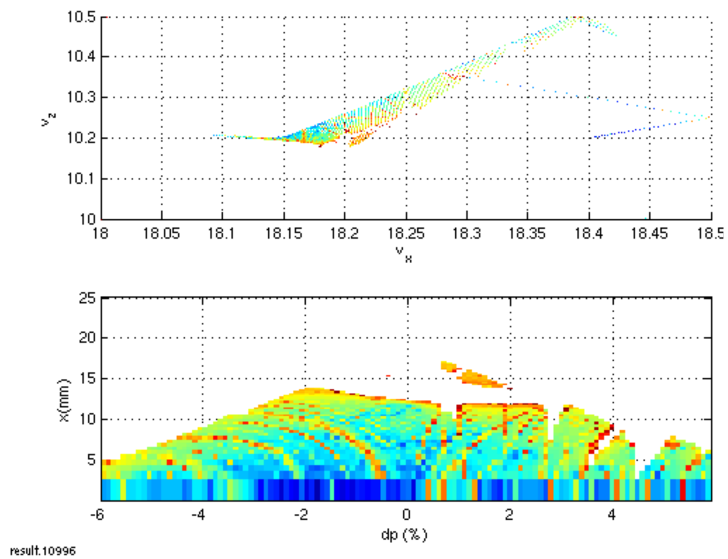


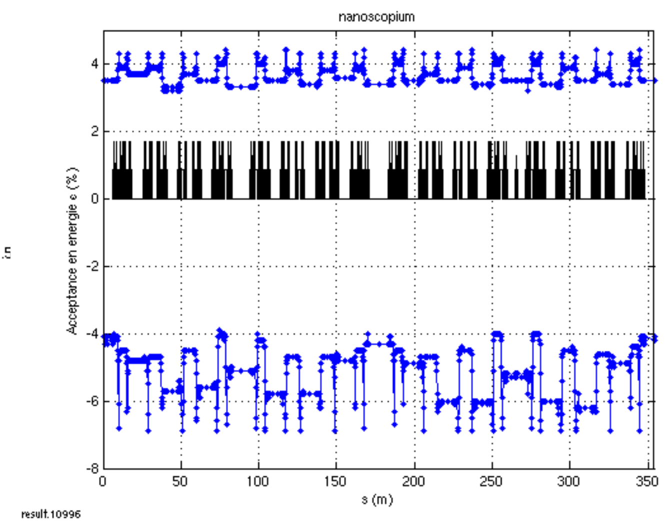




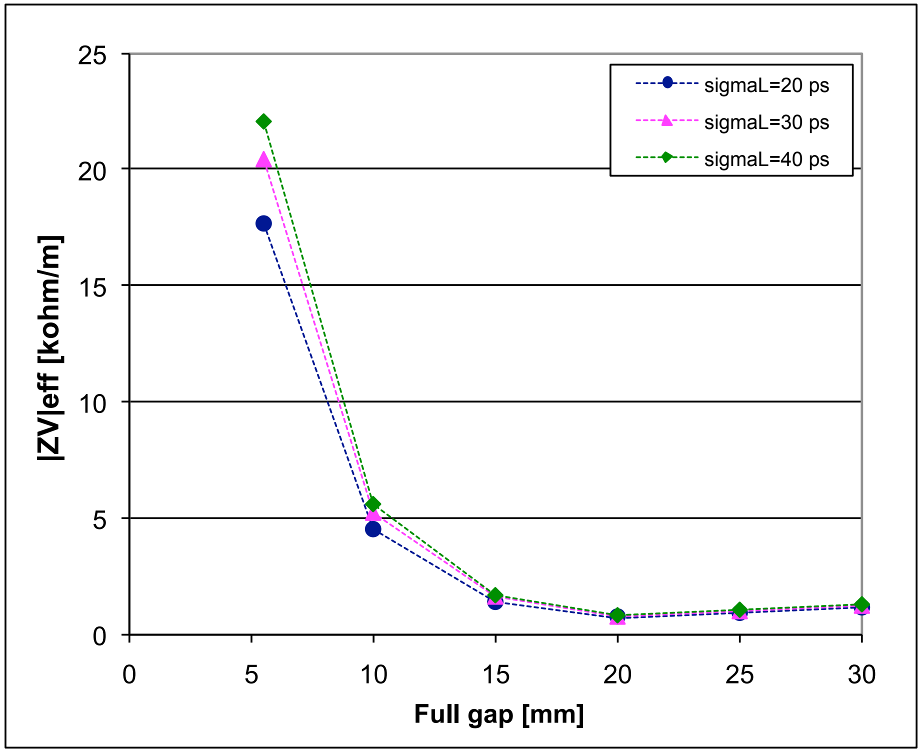
machine with W164

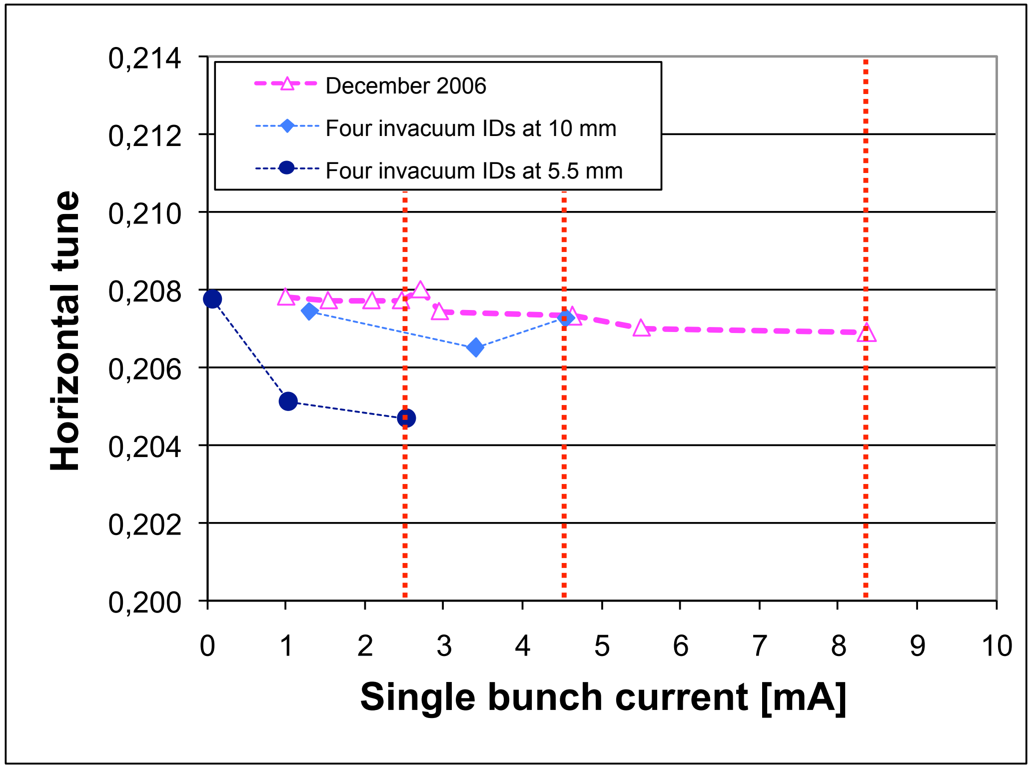






Transverse Mode Coupling Instability Threshold





Conclusion

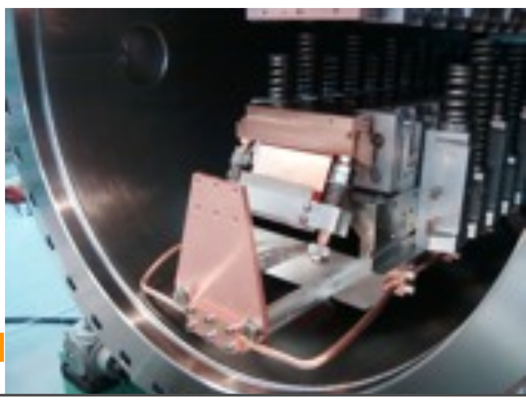
Conclusion

Beam commissioning of SOLEIL with aldready several ID installed

Active construction of ID at SOLEIL : 25 (4 EM, 12 APPLE-II, 1 EMPHU, 7/8 in vacuum undulators, 1 cryogenic undulator, 1 in vacuum wiggler, 1 wiggler to be built)
=> Wide variety of systems

Study of the effect on the stored beam and comparison of magnetic measurements, further correction with magic fingers
Modification of APPLE-II carriages : 180° phase variation
Renewal of CLIO FEL undulator

R&D : - PrFeB cryogenic undulator
- Robinson wiggler
- other



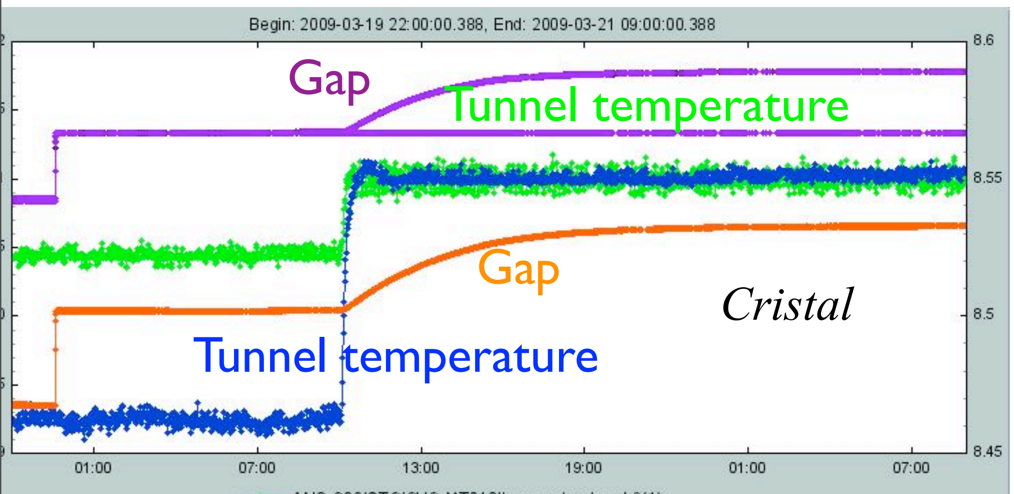
6- SOLEIL beam operation in presence of the IDs

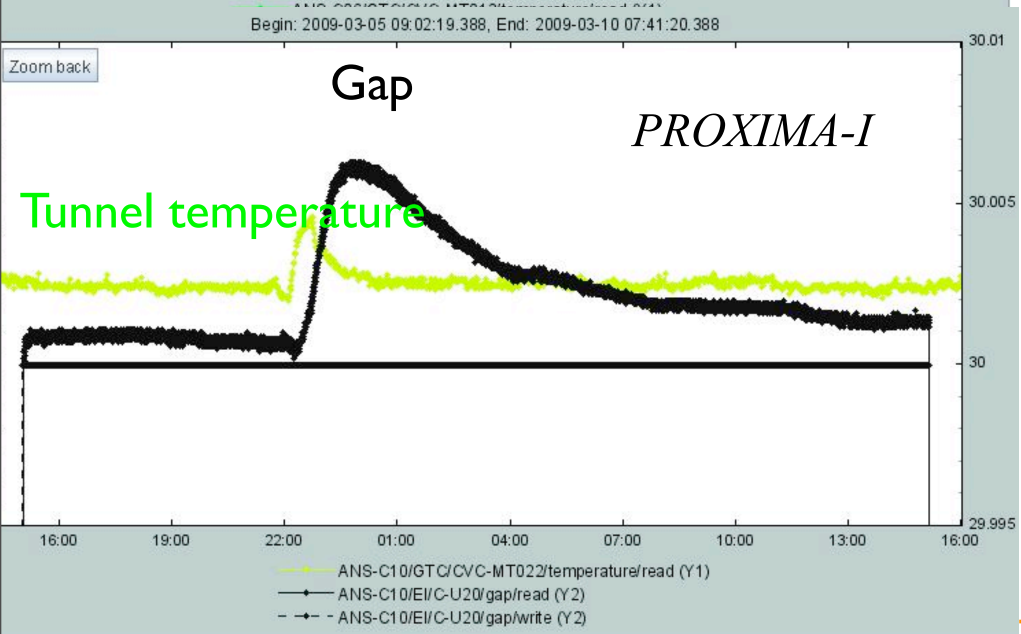
Maintenance of installed IDs

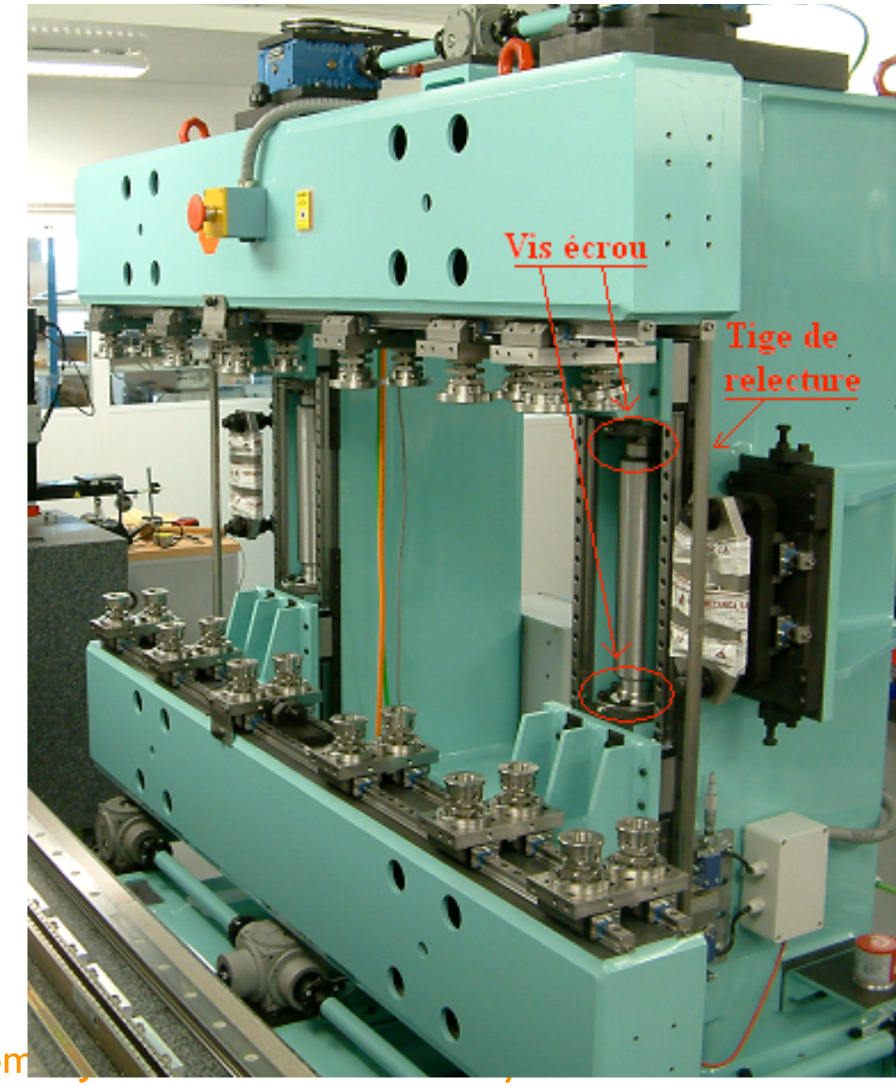
- Encoder change

- Beamline Energy drift due to gap change induced by temperature variation

ΔT= 2 °C, Δgap ~ 25 microns







SOLEIL sizes and divergences at source points

Horizontal emittance 3.7 nm.rad

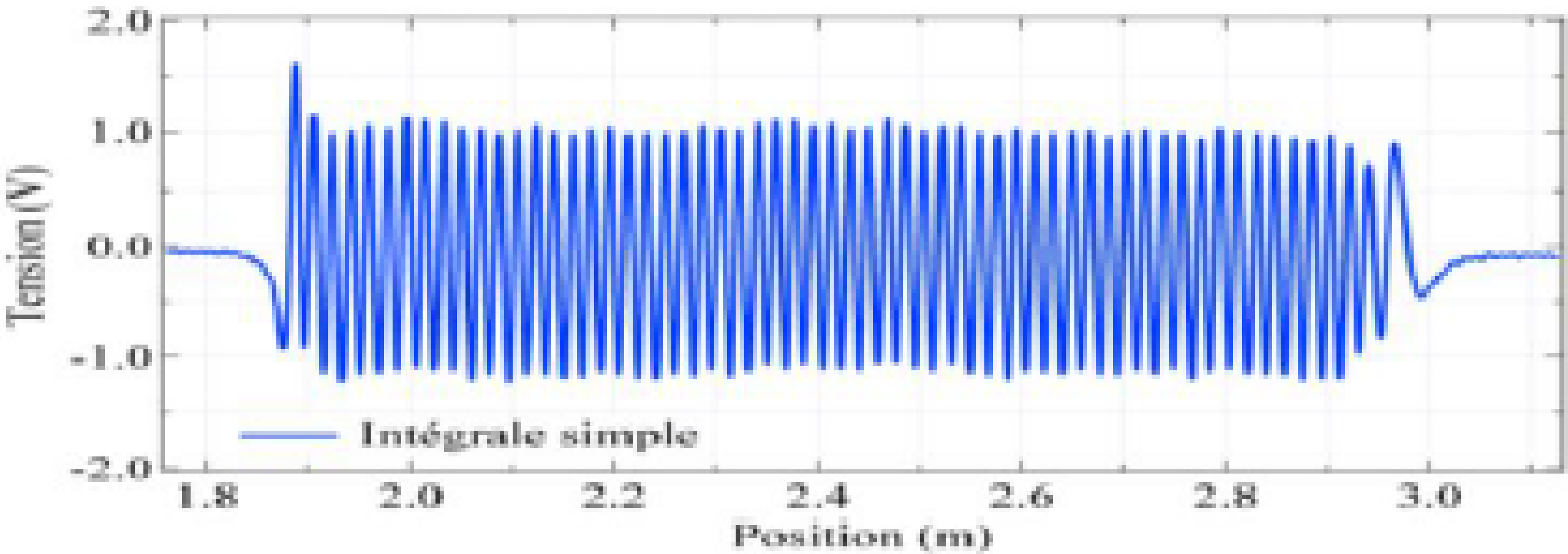
	BetaX m	EtaX m	H Size **SigmaX µm**	H Divergence **Sigma XP µrad**	Effective Emittance H
Short straight	17,8	0,285	**388**	**14,5**	5,61 nm.rad
Medium straight	4,0	0,133	**182**	**30,5**	5,56 nm.rad
Long straight	10,1	0,200	**281**	**19,2**	5,40 nm.rad
Dipole 4°	0,38	0,021	**43**	**107,0**	

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**

The tools : Magnetic measurement benches

Example of field integral measured with the pulsed wire technique



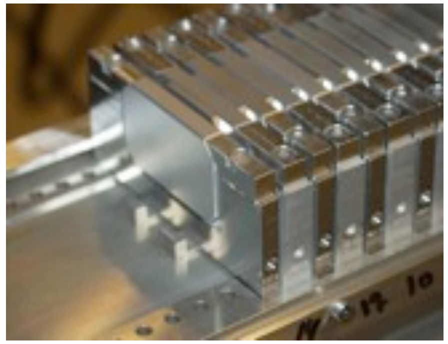
Pulse 4.5 A Δt=10 μs
Measurement of an 1 T, 18 mm period, 2 m long undulator
Signal/Noise : 26.02 dB

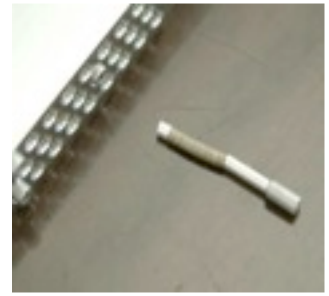
CuBe wire : 125 μm diameter, 10 N, sag : 65 μm
5 A 2 μs bipolar pulse generator developed in house
Photodiode for vibration detection

Measurement of the wire velocity
Wiener filtering

Magnetic and mechanical design

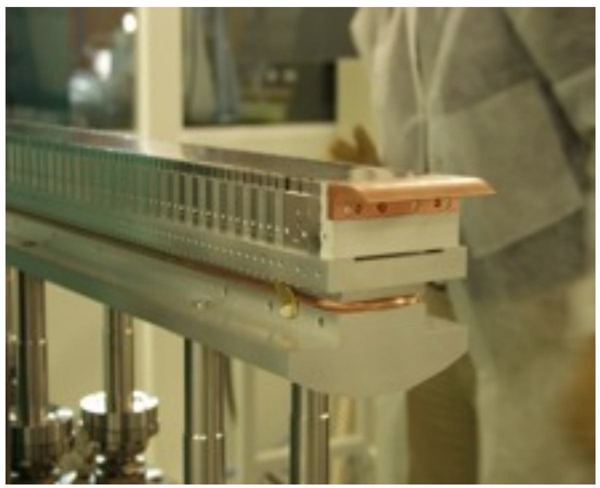
First in vacuum undulator purchased to Danfysik
Per sorting, Assembly in modules
Modules measurements
Module assembly with iterative sorting ID builder (genetic algorithm) and measurement
Shimming, Magic finger





After assembly

Liner

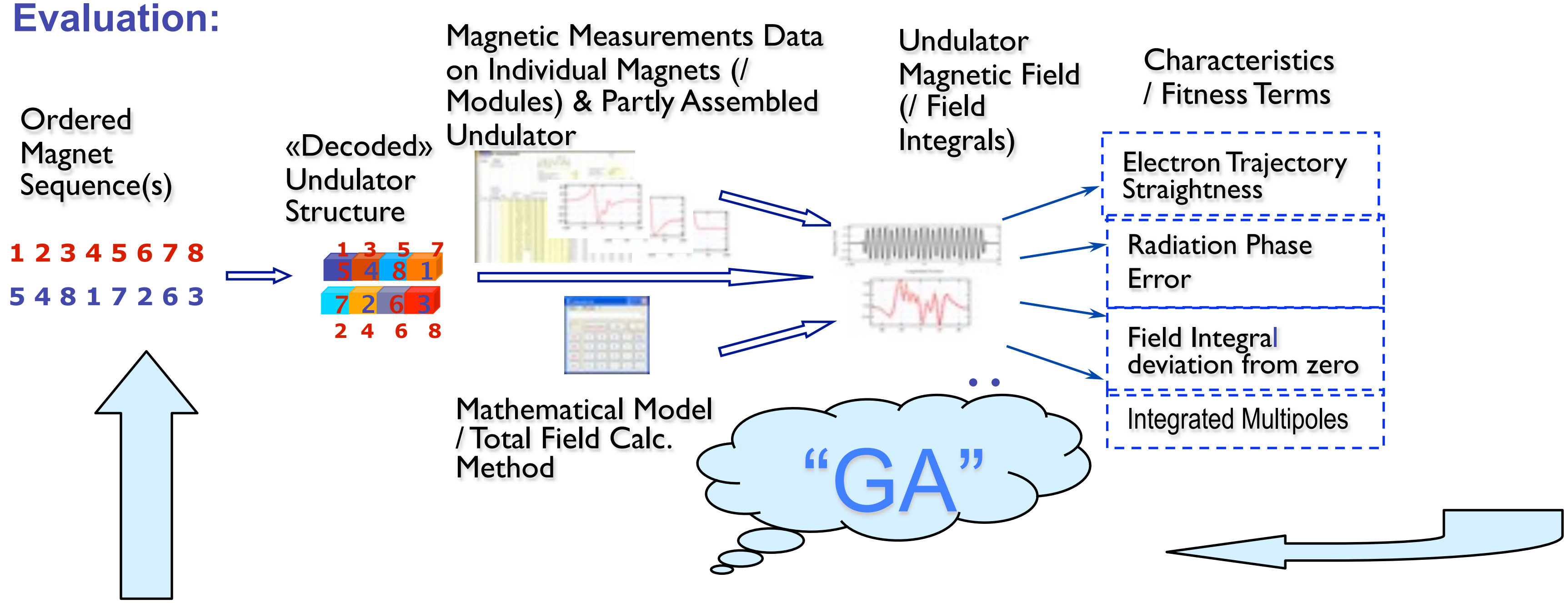


Chamber installation

Genetic algorithm based ID Builder

O.Rudenko and O.Chubar, Proc. of 9th Int. Conf. on PPSN IX, p.362 (2006)

Evaluation:



Variation Operators for Permutations:

Mutation : - e.g. swap items (magnets) at two randomly chosen positions - [5 4 8 1 7 2 6 3] ⟹

Crossover : - e.g. «order 1» - [1 2 3 4 5 6 7 8] [3 5 6 8 1 2 7 4] ⟹ [? ? ? 4 5 6 7 ?] ⟹

Advantages : object function, arbitrary search space, search from ap population, mutation and cross-over => global optimum, multi-modal/multi-objet

SOLEIL Machine status

500 mA (in 312 or 416 buckets), with two cryomodules, used for beamline radioprotection, 400 mA for user shifts, top-up, few shifts in temporal structure mode or hybrid mode