SOLEIL SYNCHROTRON

Comparison between Modeling and Reality at SOLEIL: Beam Transverse Dynamics and Apertures

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On behalf of the
Accelerator Physics Group
Synchrotron SOLEIL

- **Machine w/o IDs**
  - Linear optics
  - Aperture & lifetime
  - FMA
- **Machine w/ IDs**
  - Linear effects
  - Inj. Eff. & Lifetime
  - FMA
- **Conclusion**

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First day optics

Energy tuning

- Measurement with quads turned off and turn by turn BPM: $\Delta E/E$ = - 4 10^{-3}
  - ✓Agreement with the LT2 dipole calibration
  - ✓Agreement with the booster beam extraction time
    - ➢Decision: scaling in energy of all the storage ring magnets: 2.739 GeV

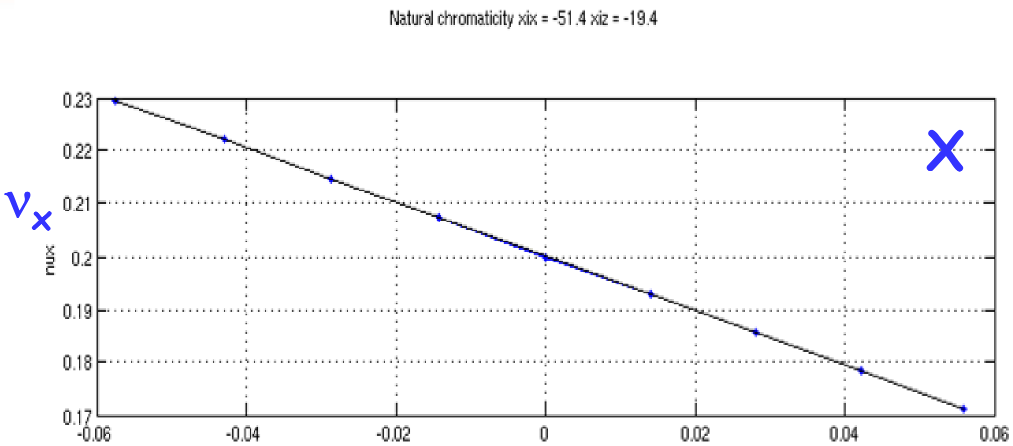
	ν_x	ν_z	ξ_x^{full}	ξ_z^{full}
Model	18.20	10.30	0	0
Machine	17.8	10.1	~-1/-2	~-1/-2

Magnet quad. Bench
Expected abs. calibration: 2 10^{-3}
But e-beam meas: 12 10^{-3}

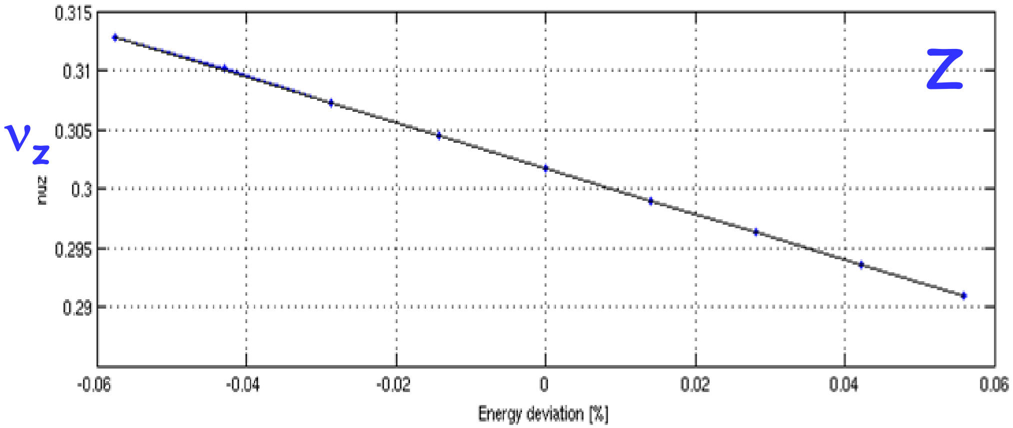
Quadrupole tuning based on tune measurement

- A relative scaling of all quadrupole gradients of **+8 10^{-3} recovers the tunes**
  - ➢Decision: scaling applied to all quadrupole magnets
  - ➢Coherence with nominal lattice and Chasman Green lattice
    - ➢this new calibration gives ν_x = 18.23 and ν_z = 10.31
- ➢**Relative tune difference is proportional to natural chromaticities**
  - ➢Other solution would have been to change dipole field and to retune storage ring injection

Natural chromaticities



Energy offset (%)



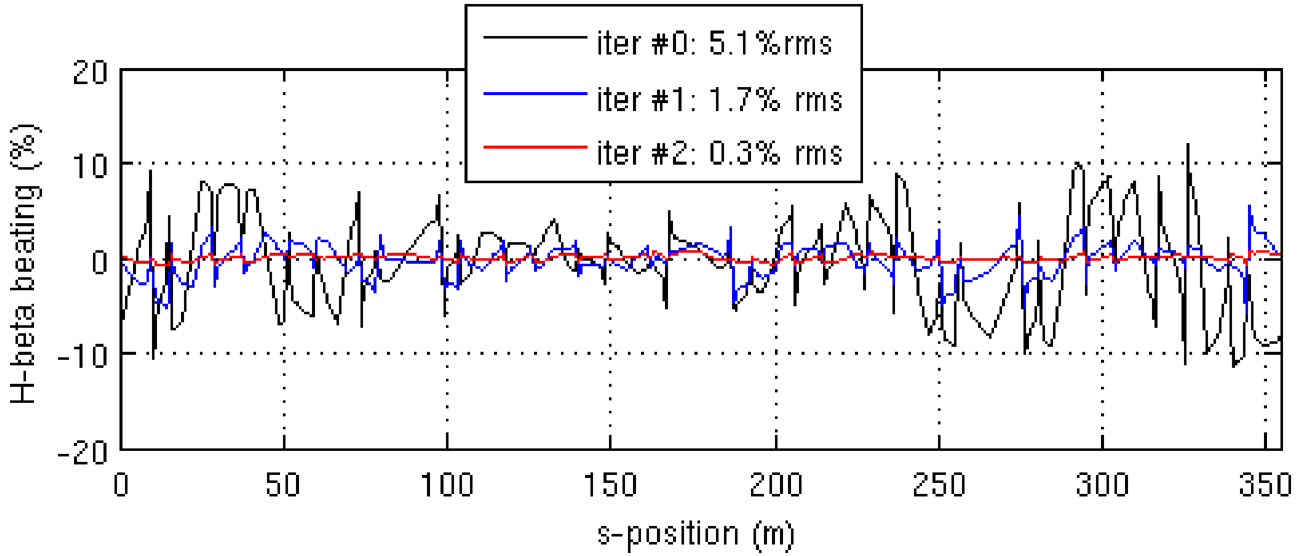
Energy offset (%)

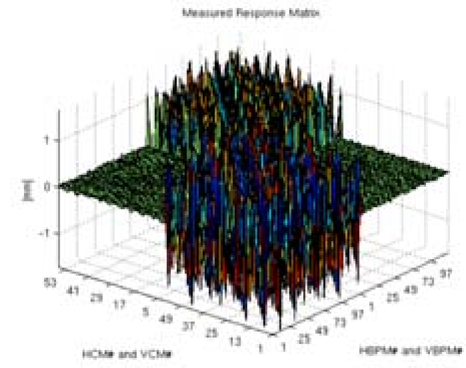
	ξ_x^{nat}	ξ_z^{nat}
Model	-53	-23
Measurement	-51.5	-19.4

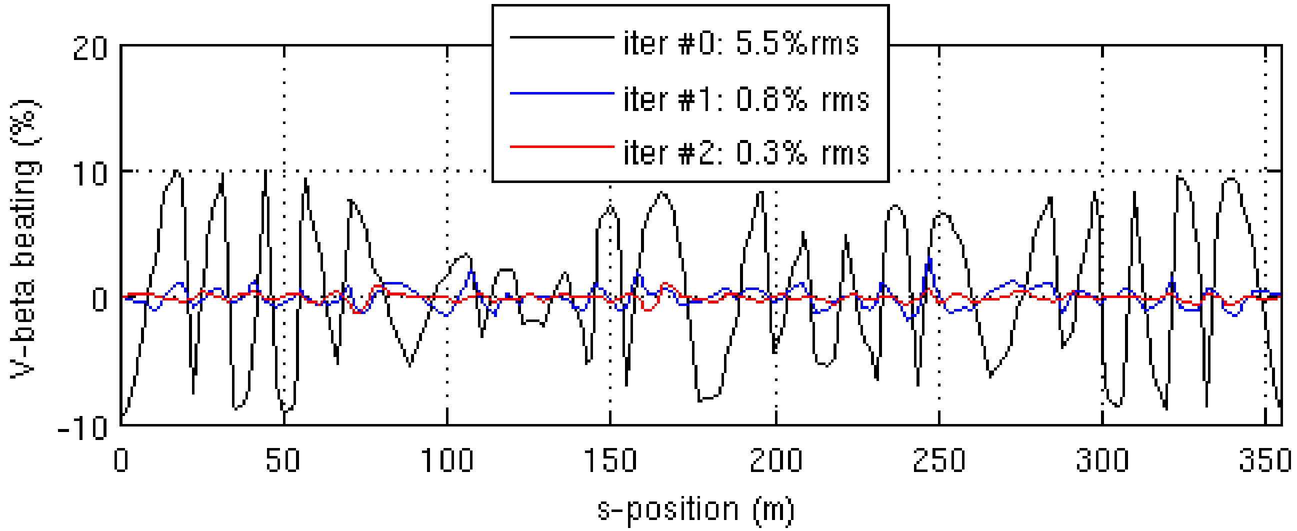
Measurement of dipole field performed using NMR probe.

The difference in the vertical plane is mainly due to the wrong energy dependence of dipole fringe fields in the model.

Reduction of beta-beating using LOCO code



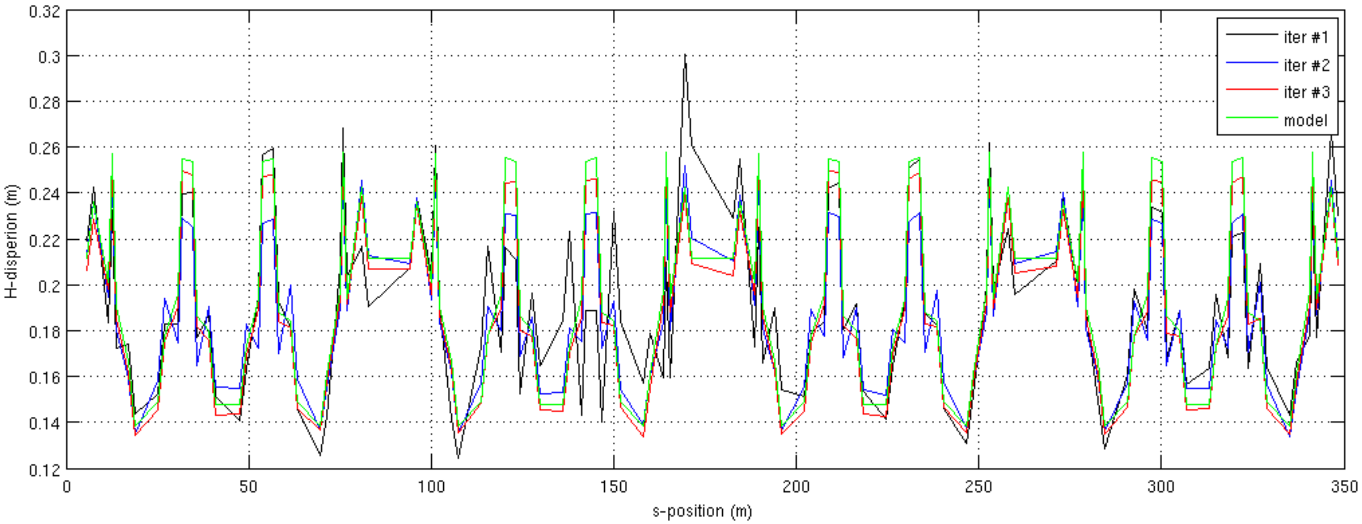




≤ 0.3% rms

BPM noise
H: 220 nm RMS
V: 60 nm RMS

Restoring symmetry of the H-dispersion function

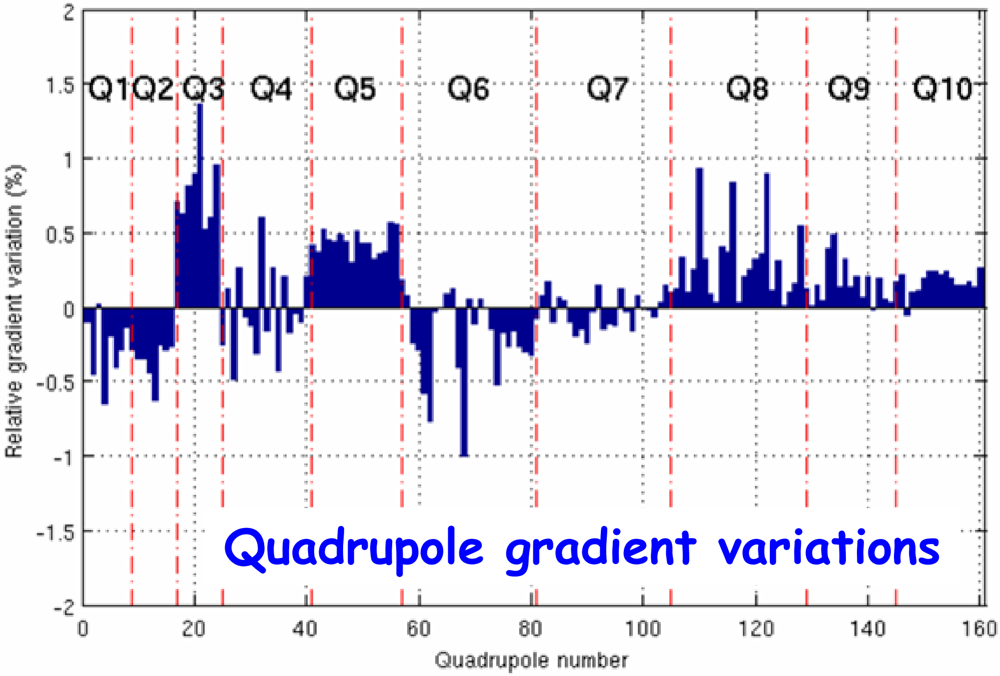


Difficulties using LOCO

- Unrealistic quad values (>>%)
- 120 BPM/160 quad ratio
- Close by quadrupole issues

→Modified version of LOCO w/ constraints on gradient variations (see ICFA newsletter, Dec'07)

→Results compatible with mag. meas. (10^{-3} gradient identity, Brunelle *et al.*, EPAC'06) and internal DCCT calibration of individual power supply



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Linear Model agreement

- Orbit, chromaticity, tune response matrices are very closed to real machine

- **Theoretical values successfully used for**
  - Beam transport matrix for first turn correction (energy calibration, …)
  - Relative tune shifts
  - Relative chromaticity shifts
  - Orbit correction (stable even when using all singular values).

Tune shifts with energy

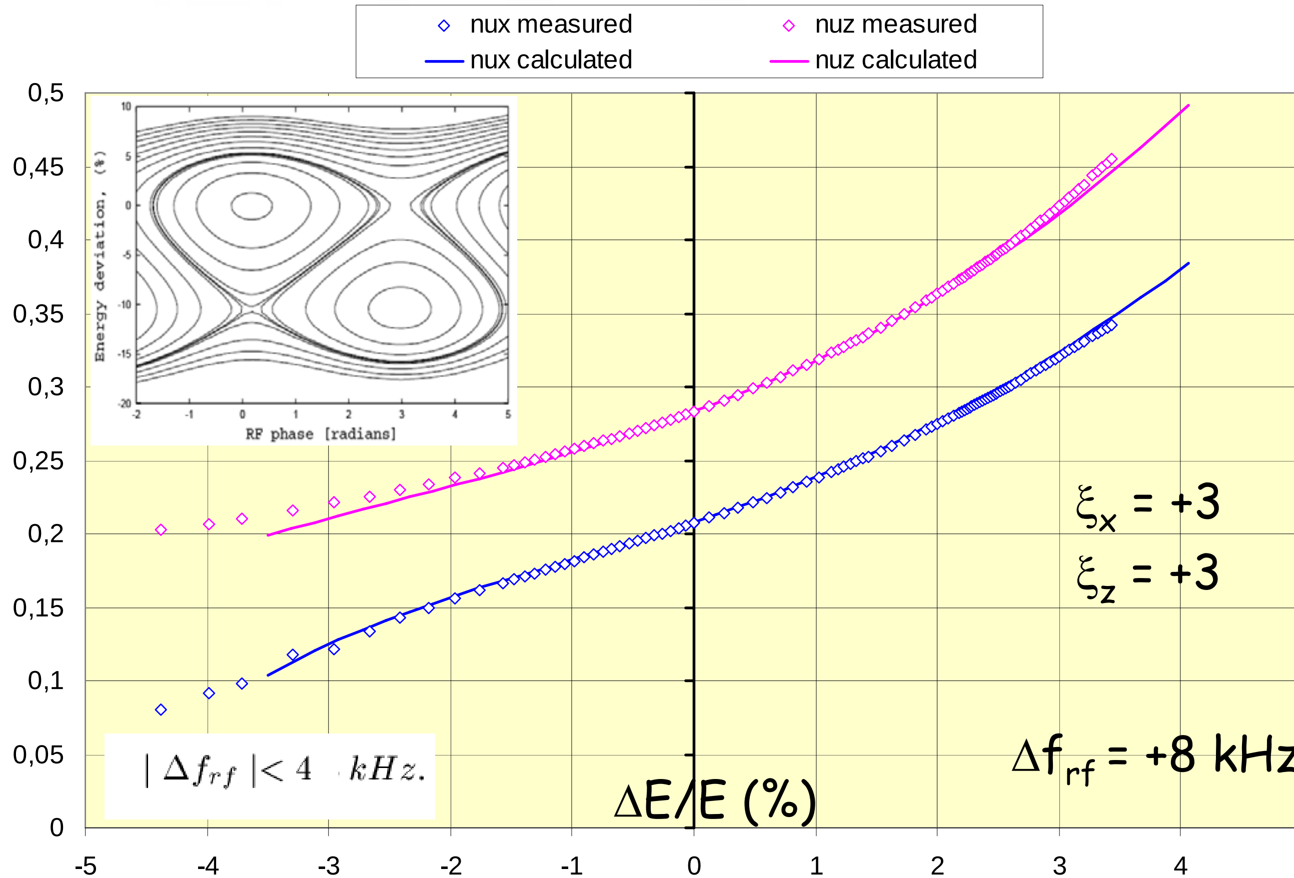
Good Agreement with model

DP/P > 0: loss on half Integer resonance (V-plane, 0.02 wide)

DP/P < 0: loss on longitudinal beam dynamics

$\alpha_1 = 4.5\ 10^{-4}$

$\alpha_2 = 4.6\ 10^{-3}$



$$\delta_{1,2} = -\frac{\alpha_1}{2\alpha_2}\left(1 \pm \sqrt{1 - \frac{4\alpha_2}{\alpha_1^2}\frac{\Delta f_{RF}}{f_{RF}}}\right)$$

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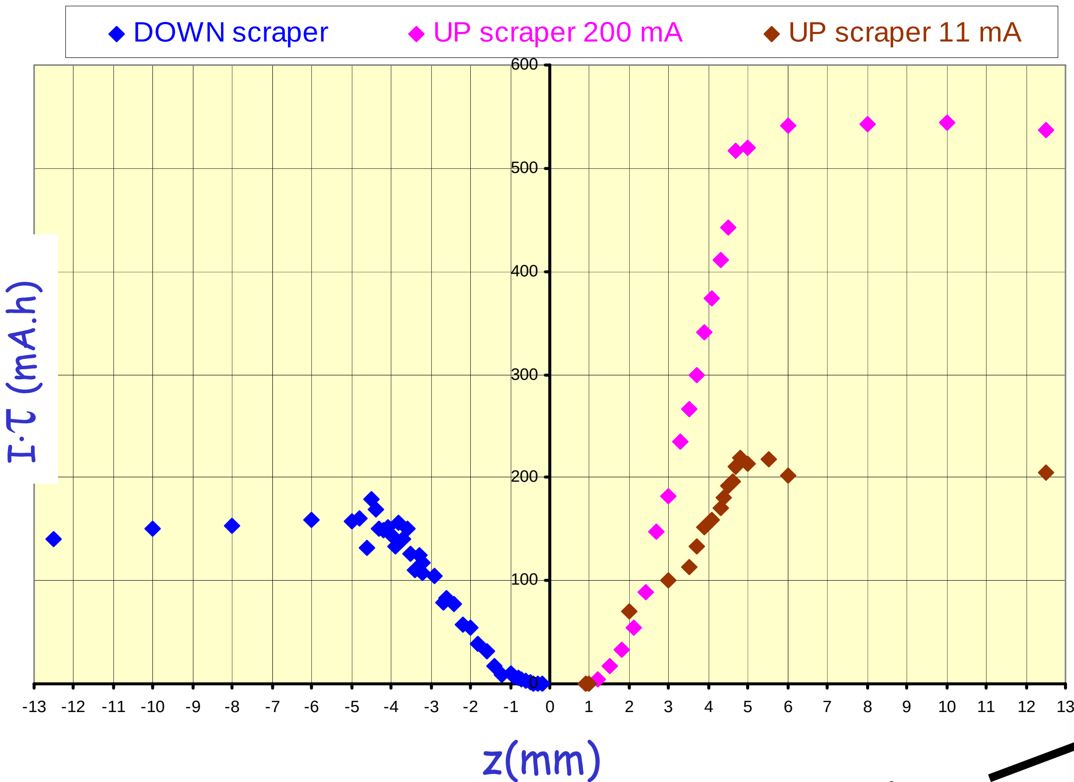
Vertical Acceptance

Measured Ixτ vs. vertical position of scrapers (up and down)

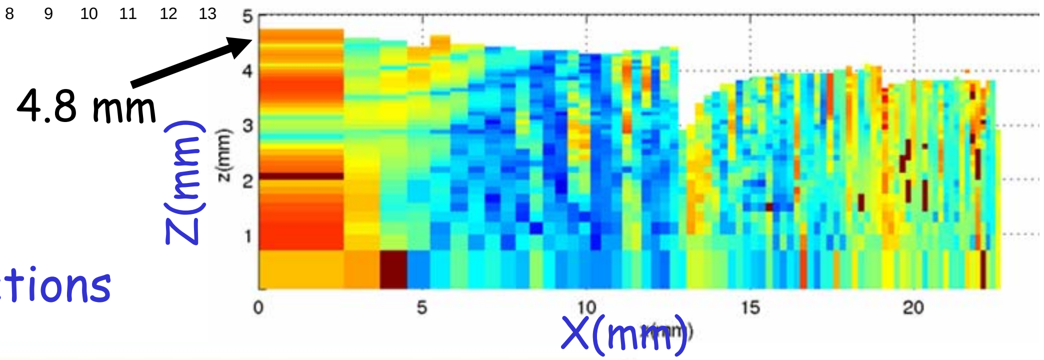


V-scraper is located in a long straight section (200 μm offset)

⇨Measured ~ ± 4.8mm
⇨Expected ± 5.5 mm at scraper position
Validity of used method?

Simulated Dynamic Aperture

(middle of long straight section)



Simulations parameters:

κ = 1%

Zmin = ±5mm in medium straight sections

Lifetime: Reality vs. modeling

8 bunch operation mode

Touschek dominant régime

V_{RF} = 2 MV (1CM, 2.9%)

Experimental conditions

312 bunches, I = 250 mA, κ=0.9 %, V_{RF} = 2.4 MV (1 CM, 3.7%, σ_l =25ps)

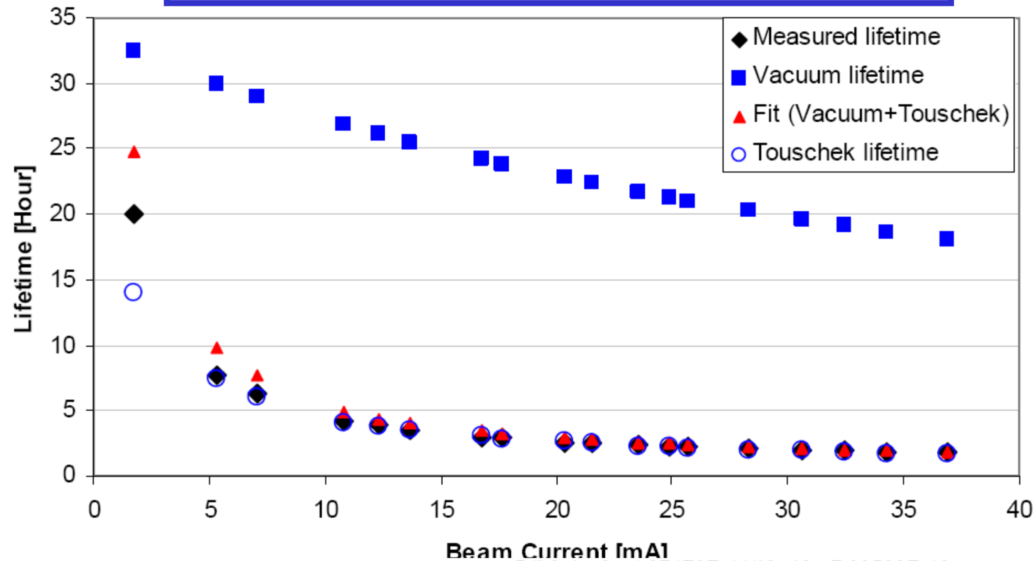
Measurement: 17.3h

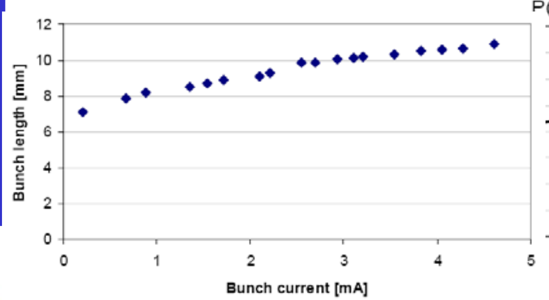
Theory: 16.4 h

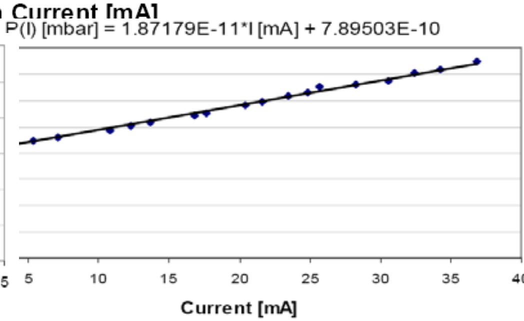
- Touschek (77 h)
- Gas scattering 20 h

→Good agreement

→-4.6% and 3.5% momentum acceptance

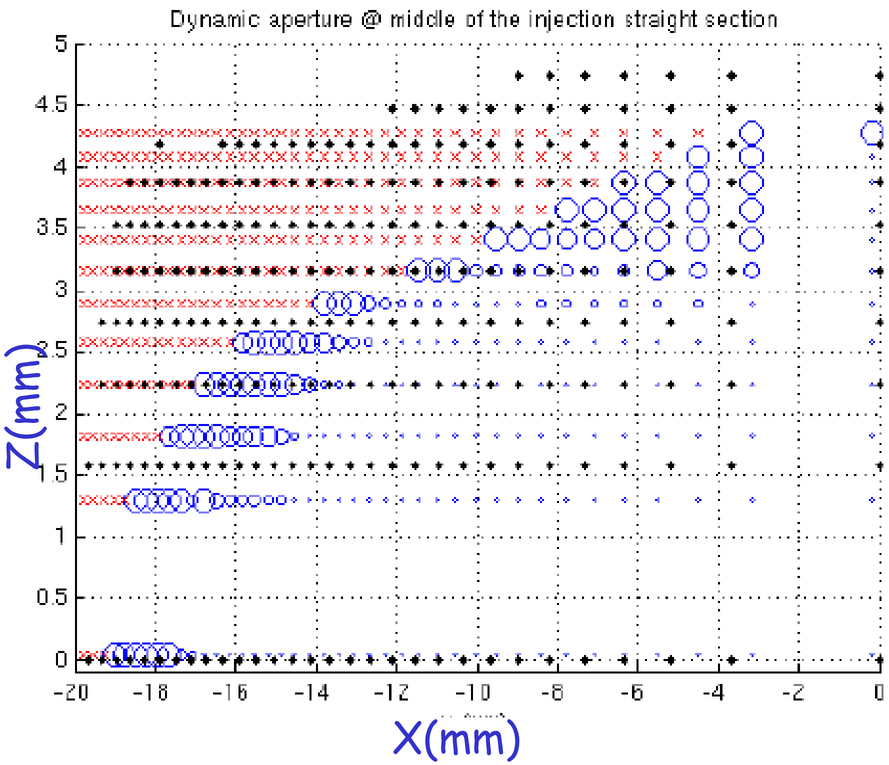


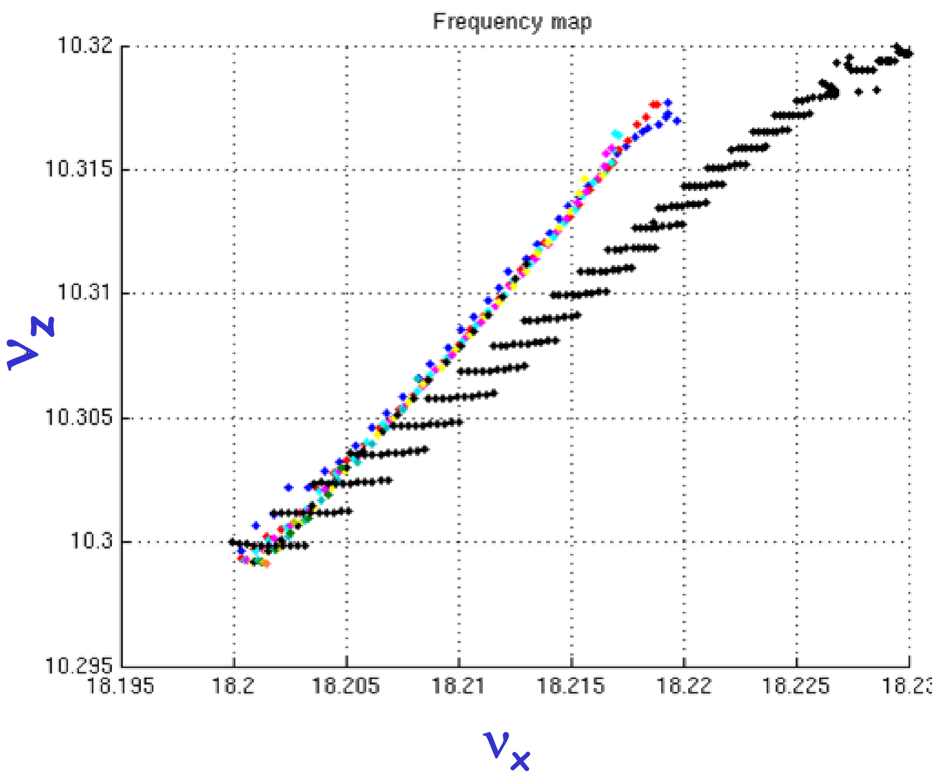




Experimental DA and FMA

Full beam losses @ x = -18.6 mm corresponding to a transverse absorber upstream to U20 (Short SS)





Blue circle size: lost rate
Red: unstable
Black model

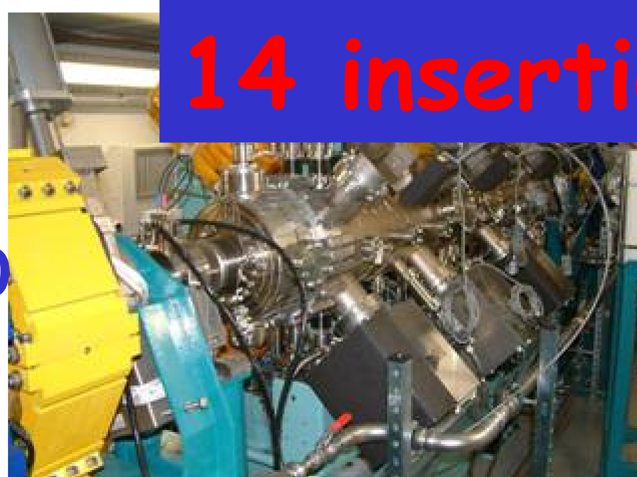
Zero chromaticities

Insertion Device Effects installed and to come

Em
Fast switching
HU640
10 m

Apple II
3+1x HU80
2+1x HU52
1+1x HU44
1xHU34

Full control by users
14 insertion devices



In vac.
4+1x U20
1x U24

Em
Switching
3x HU256

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ID building strategy

- **Tolerances**

$$\int B_x ds = \int B_z ds = \pm 20\, G.cm \qquad \iint B_x dsds' = \iint B_z dsds' = \pm 1\, G.m^2$$

- **A 3 step-process using ID builder (O. Chubar)**
  1. Assembly: Module sorting according to magnetic measurements
     → Minimization of first and second integrals
  2. Shimming: using a merit function
     → Minimization at different gap and phase values with weight factor
     i. On axis first & second integral (angle & position) in H & V plane
     ii. Skew and normal gradient for new IDs
     iii. Phase error < 0.2°
  3. Magic fingers (different gap and phase values with weight factor)
     → Reduction of high field integral for large transverse amplitudes

- **Expected or unexpected effects depending on gap, phase, current values**
  - Orbit distortion (Feedforward)
  - Tune, chromaticity, coupling variations
  - Injection efficiency, lifetime variation (non-linearities, …)

Undulators effects on beam parameters at maximum field

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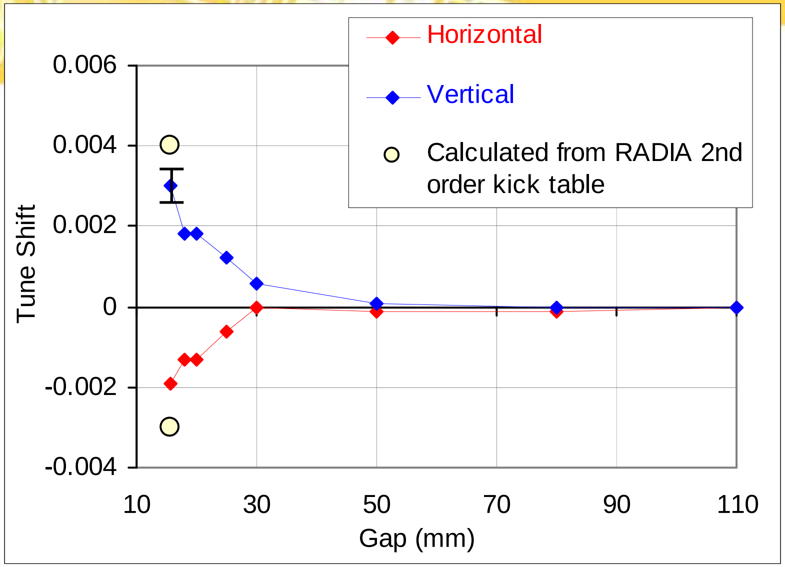
Undulator	Tune shifts ν_x	ν_z	Chromaticity variation ξ_x	ξ_z	coupling (%)
U20 PROXIMA1	+ 0.0015	+ 0.0015	+0.3	0	+0.1
U20 SWING	- 0.0016	+ 0.0019	-0.9	0	-0.1
U20 CRISTAL	- 0.0010	+ 0.0019	0	0	0
HU80 PLEIADES					
Phase 0	+ 0.0016	+ 0.0012	0	0	0
Phase 40	- 0.0050	+ 0.0056	0	0	0
HU256 CASSIOPEE					
Hor. Linear Pola. (LH)	0	+ 0.0007	0	0	0
Vert. Linear Pola. LV	+ 0.0005	0	0	0	0
HU640 DESIRS					
PS1 = + 600A (LV)	- 0.0042	+ 0.0035	0	0	0
PS1 = - 600A (LV)	+ 0.0064	- 0.0045	- 0.3	- 0.3	+ 0.5
PS2 = + 440A (LH)	- 0.0020	+ 0.0013	0	0	0

Additional focusing (1): Apple II type HU80

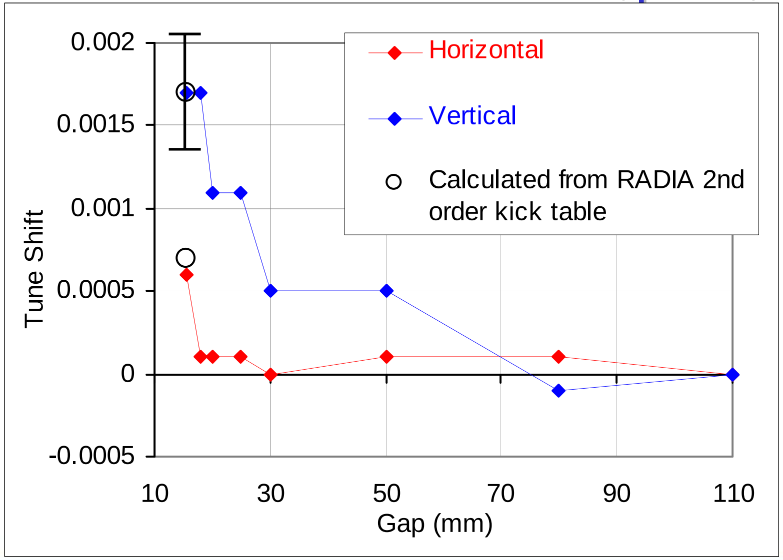
~ Helical Mode

(Phase, ϕ = 20 mm)

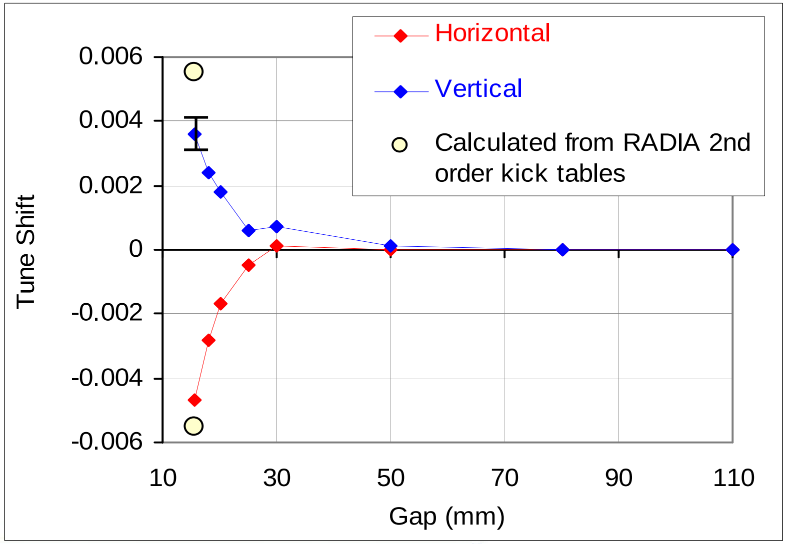


Good agreement with RADIA 2nd order kick map

Lin. Horizontal Polar. Mode (ϕ = 0)



Lin. Vertical Polar. Mode (ϕ = 40 mm)



Additional focusing (2): in vacuum U20

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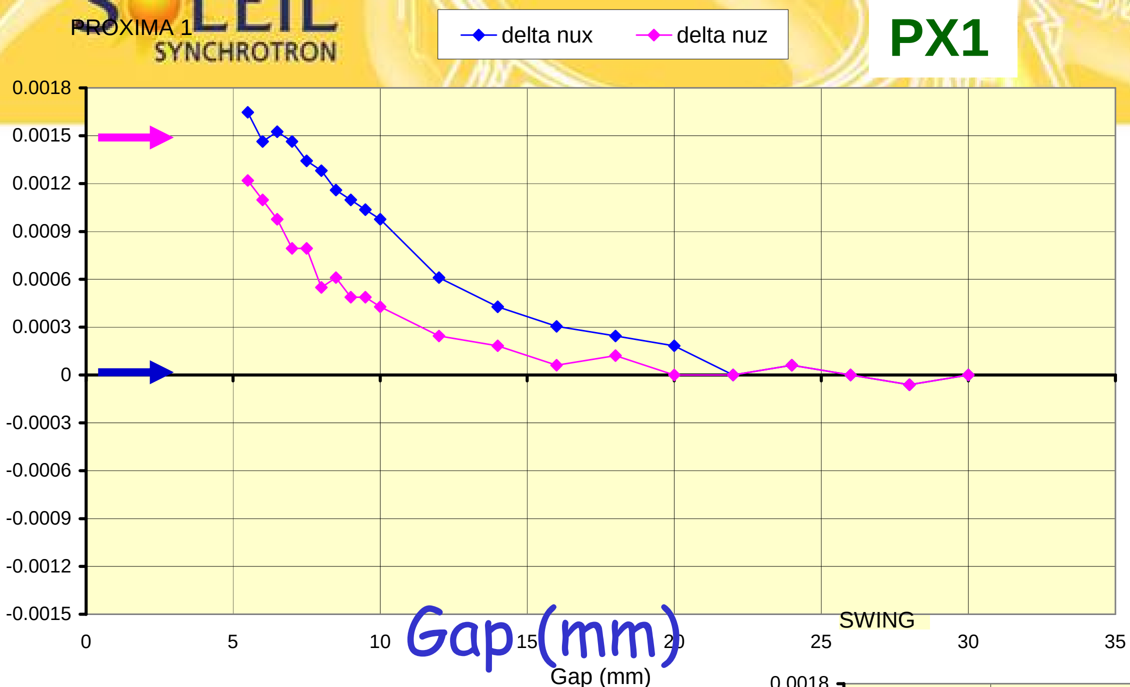
PROXIMA 1

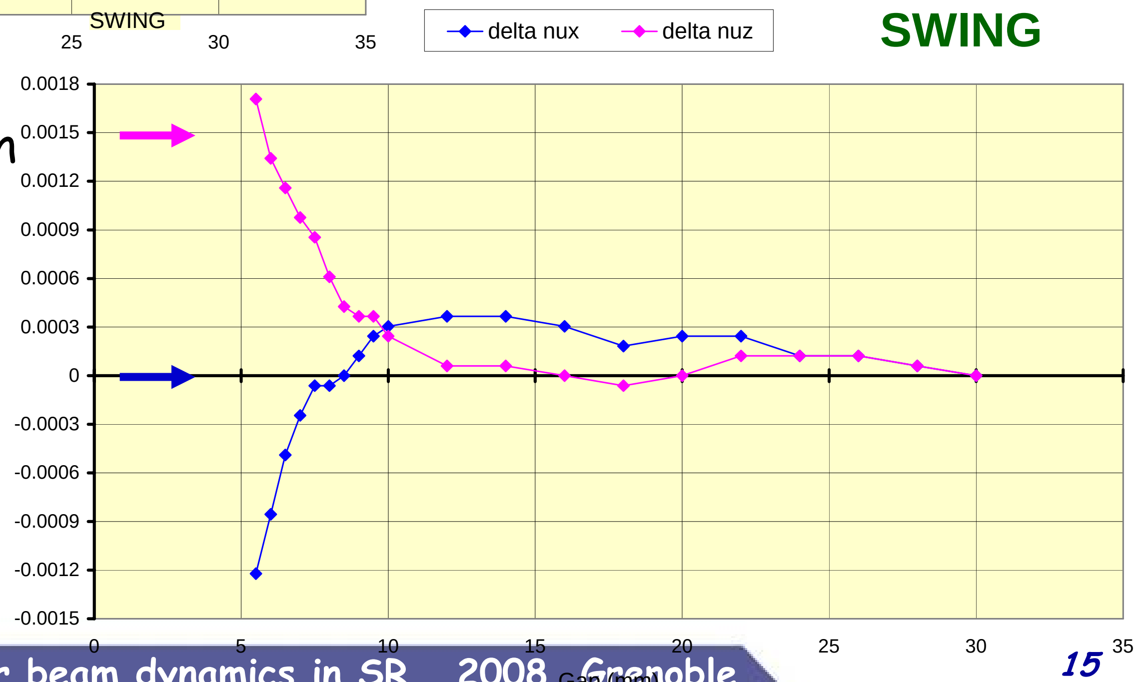
PX1



Gap (mm)

The construction of these two U20 undulators is based on the same design

SWING



Tune shifts expected from design

→ $\Delta\nu_x = 0.00000$

→ $\Delta\nu_z = 0.00169$

Rather large H-tuneshift

$\langle\beta_x\rangle = 18$ m

$\langle\beta_z\rangle = 2$ m

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Effects of undulators on injection efficiency at maximum field

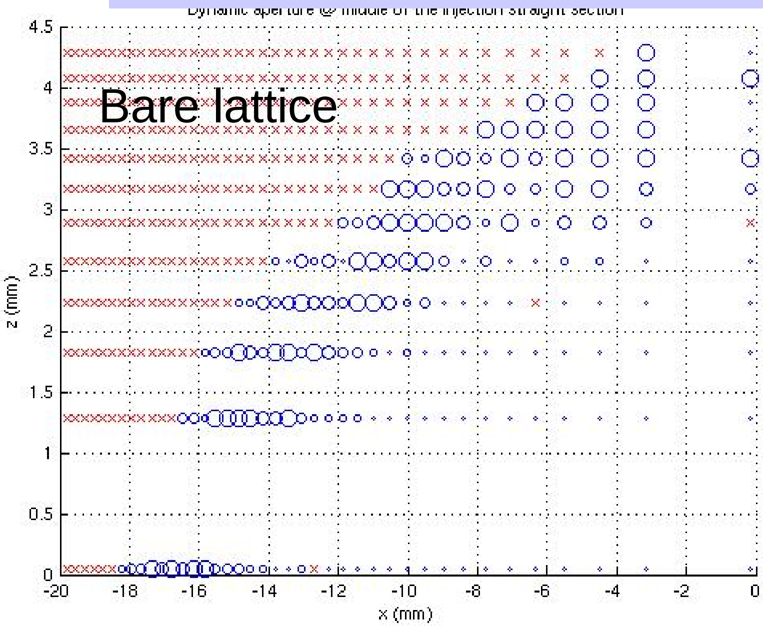
ID configuration	Inj. Efficiency (%)
Bare machine	96
U20 SWING	85
U20 PROXIMA1	74
U20 CRISTAL	88
3 x U20	50
HU80 TEMPO	
Phase 0	90
Phase +/- 40	94
HU80 CASSIOPEE	
Phase 0	95
Phase +/- 40	92
HU80 PLEIADES	
Phase 0	39
Phase +/- 40	95
Phase +/- 20	87
3 x HU80 Phase 0	44

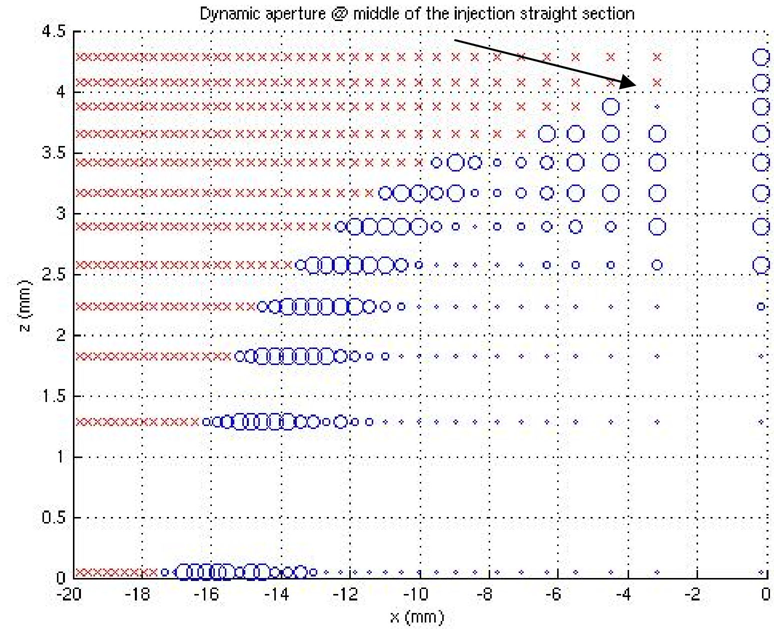
ID. configuration	Inj. Efficiency (%)
Bare machine	96
HU640 mode LV	
PS1= + 600A	76
PS1= - 600A	55
HU256	No significant effect
3 x U20 + 3 x HU80 + 3 x HU256 + HU640 PS1	40
3 x U20 @ 10mm + HU80 Pléiades @ 15.5mm	18.200 / 10.300 40
+ HU640 PS1 @ + 450A	18.206 / 10.318 80

High sensitivity to tune shifts

Strong DA reduction

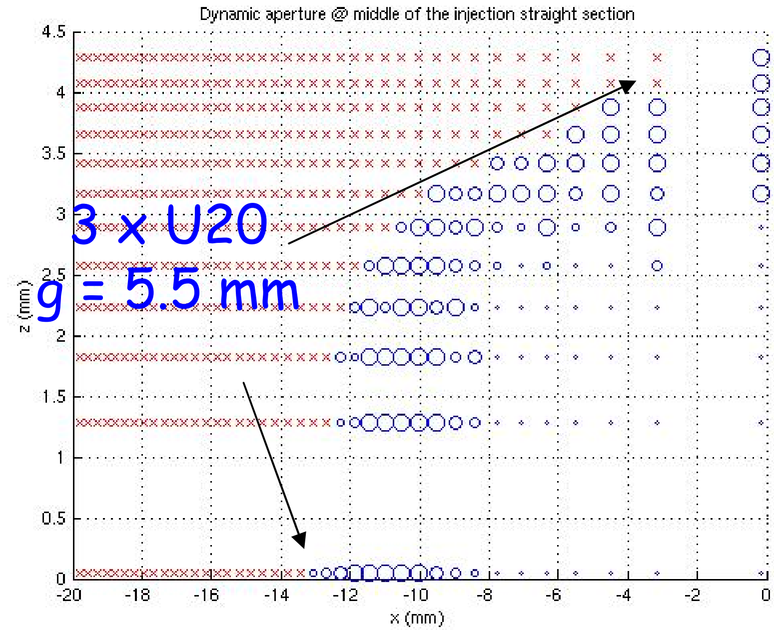
1 x U20 closed at minimum gap





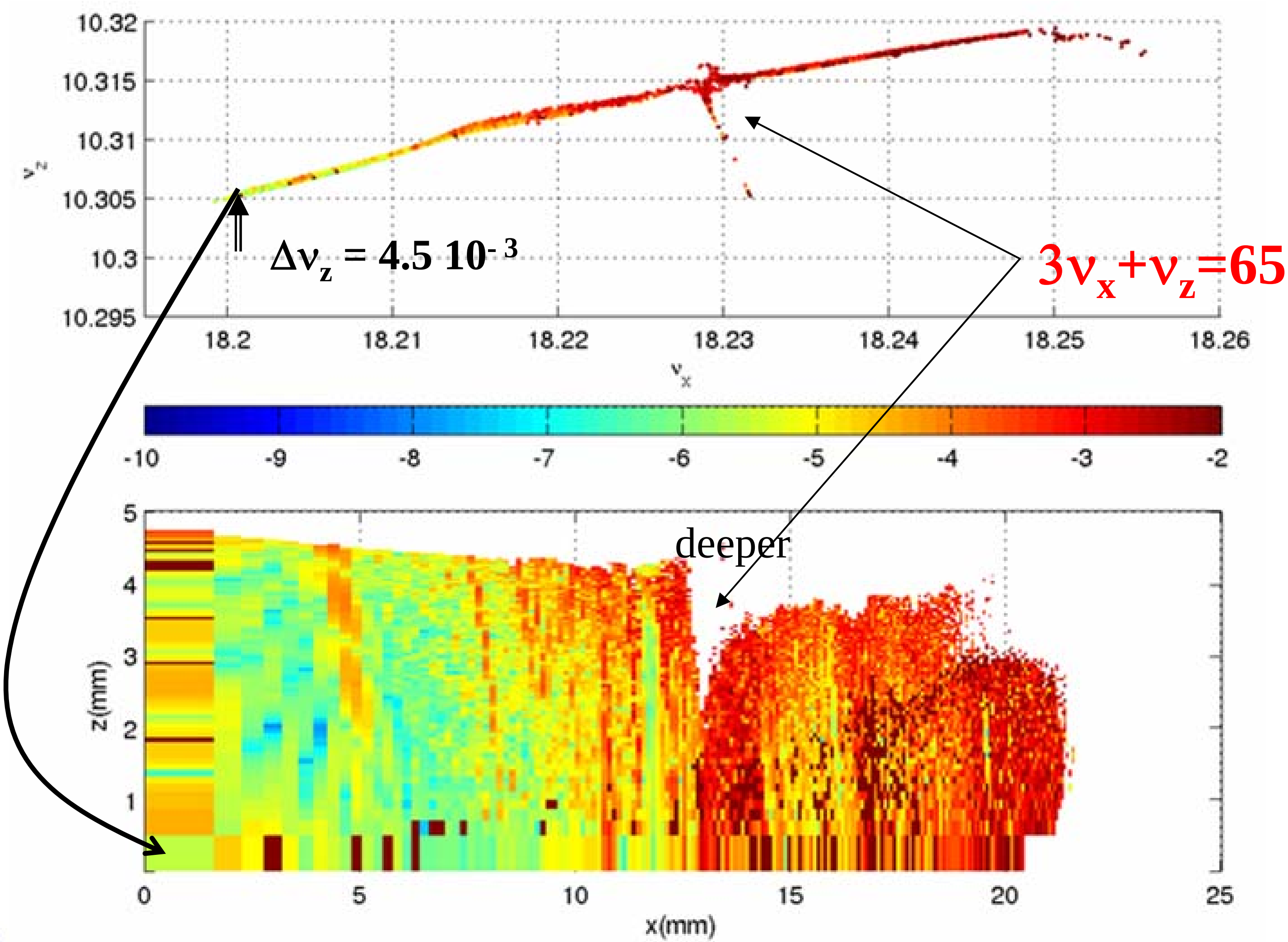
	Bare lattice	1 x U20	3 x U20
Injection Eff. (%)	98	88	**50**
Beam lifetime* (h)	13.1	12.8 (-2.3%)	**8.7 (-33%)**

* Measured for 60mA in 8 bunches
VRF = 2.8 MV ; coupling=6.5%



Effects of 3 in-vacuum IDs

! Good agreement Model/Reality !



Combined Effects of IDs

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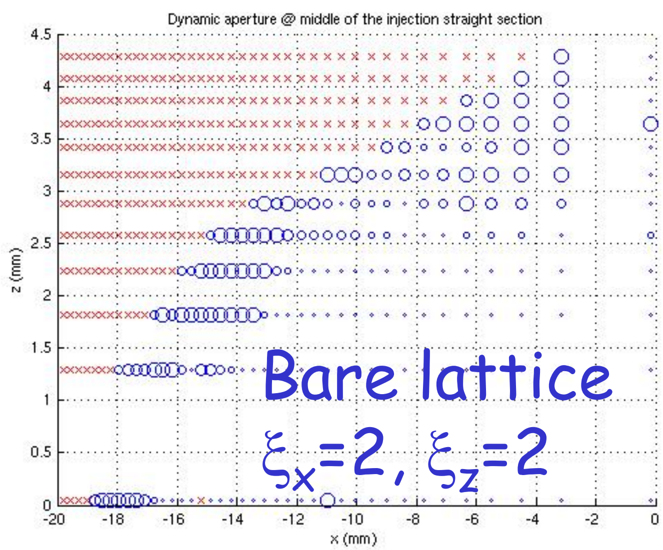
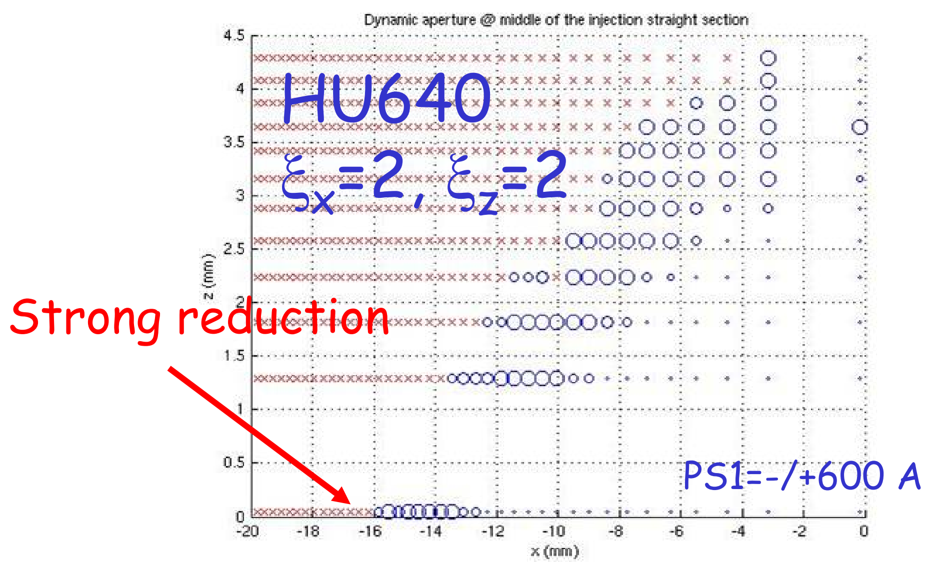
The supposedly perfectly linear 10 m long HU640

- Electromagnetic insertion device with no iron poles
- **According to RADIA (model): no effect on non-linear dynamics**
- Difficulty to ensure high precision magnetic measurement for a 10 m long ID
- Assembly/disassembly of the device
- On the beam
  - Skew terms
  - Strong reduction of injection efficiency
  - Hysteresis (need for cycling), compromise transparent operation
  - Worst configuration: PS1=-600 A (LV mode, fast variable polarization in future)





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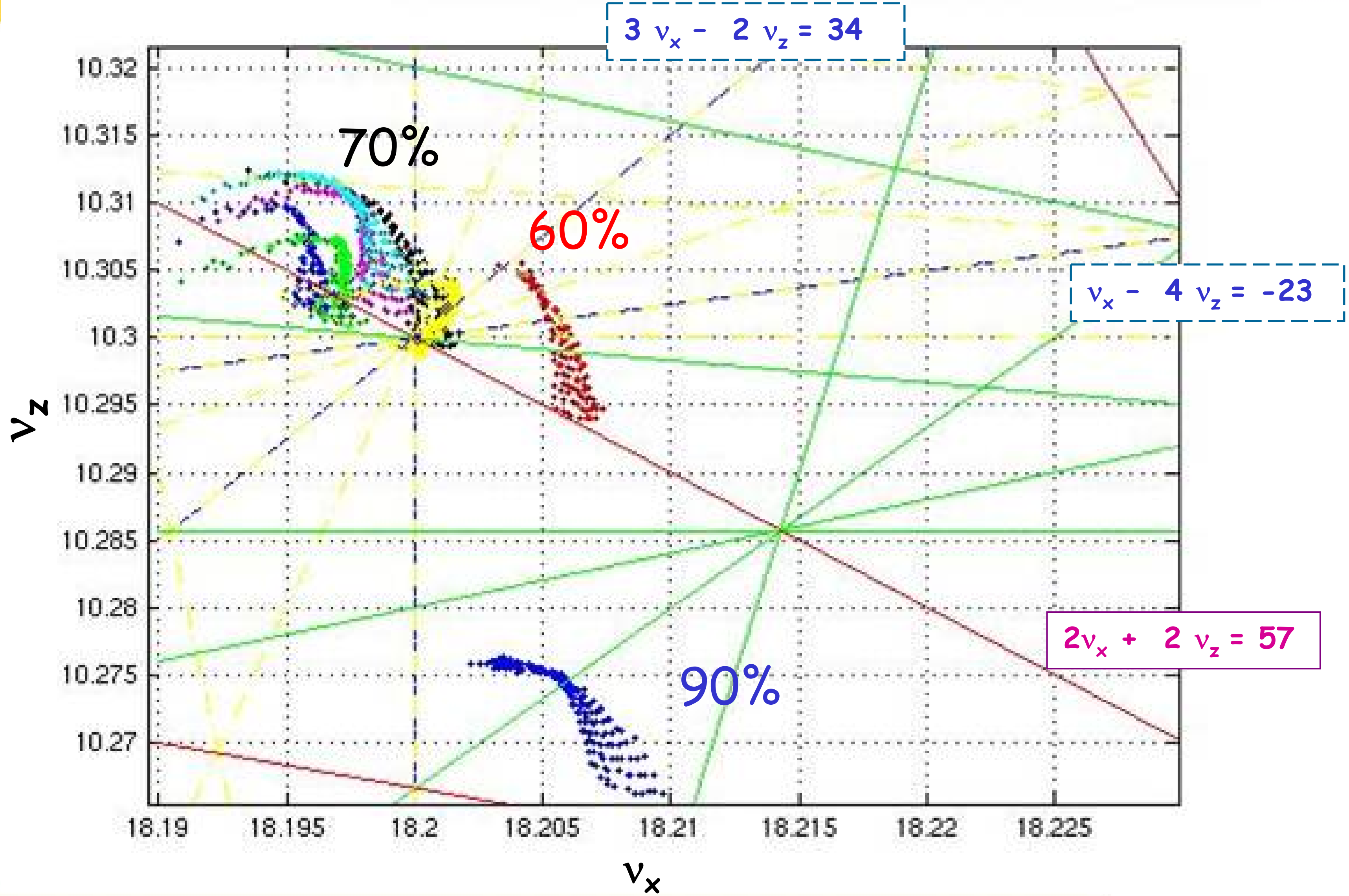
FMA HU640 & injection efficiency
Sensitivity to working point



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Effects of undulators on beam lifetime examples

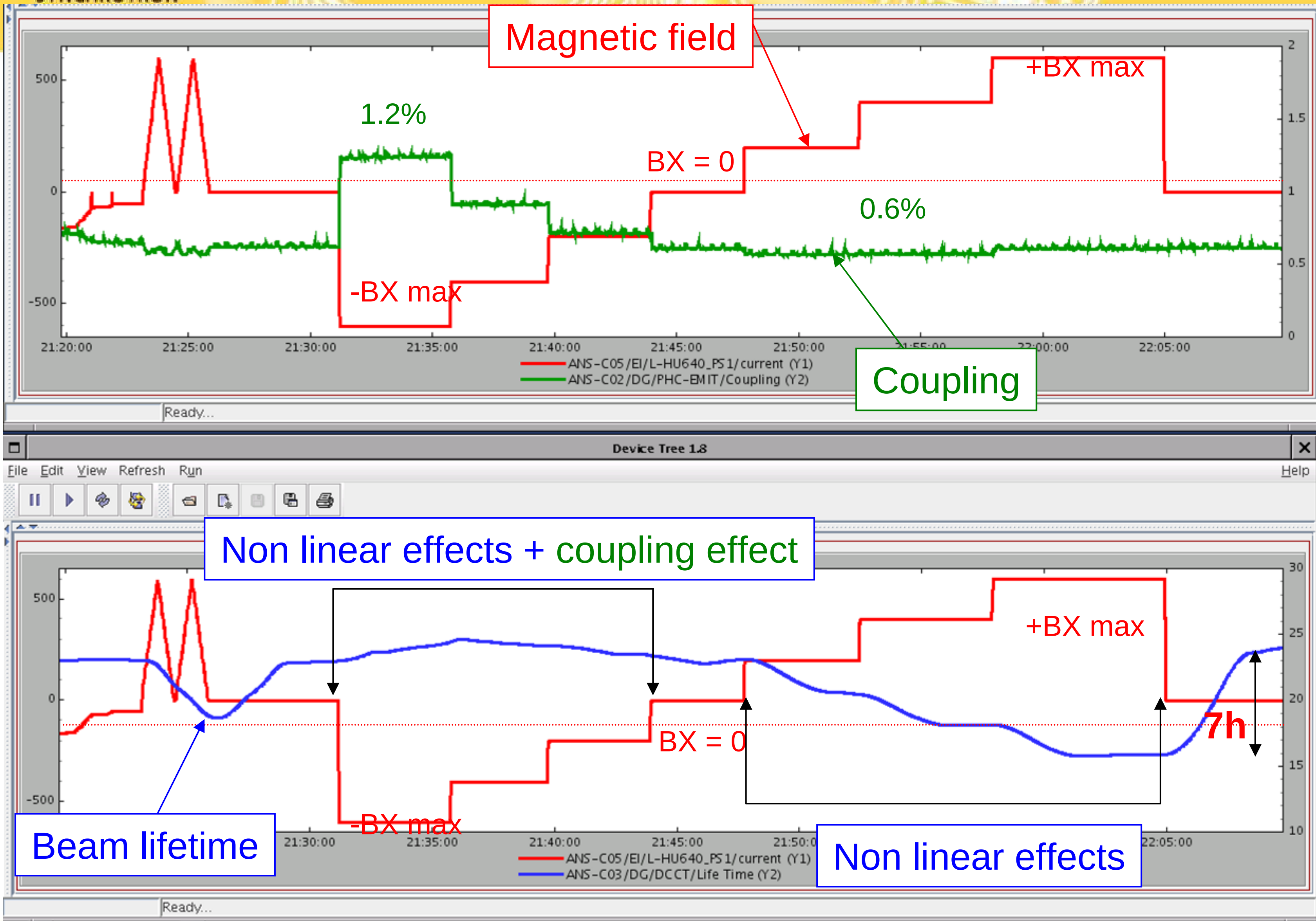
Undulator Configuration	Beam lifetime* (h)
Bare machine	13.1
U20 PX1 U20 PX1 + SWING U20 PX1 + SWING + CRISTAL	12.8 11.2 8.7
U20 PX1 + SWING + CRISTAL + HU80 Pléiades	7.6

Undulator Configuration	Total Coupling (%)	Beam lifetime* (h)
Bare machine	0.6	23
HU640 PS1 (A)		
-200	0.72	23.2
-400	0.90	24.1
-600	1.24	24.2
+200	0.56	20.3
+400	0.57	17.8
+600	0.61	15.4

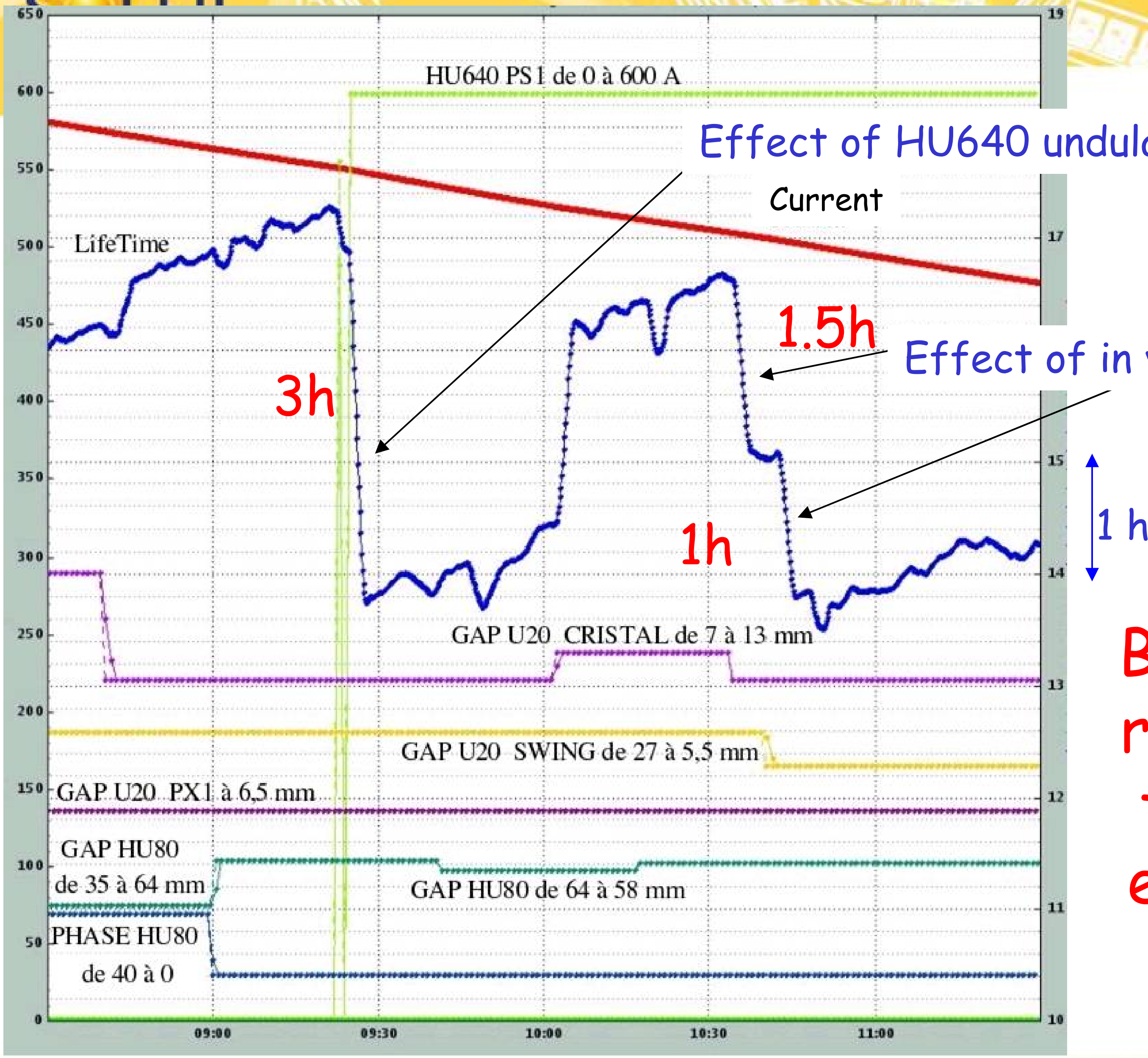
* Measured for 60mA in 8 bunches
VRF = 2.8 MV ; coupling=6.5%

* Measured for 202mA in 312 bunches
VRF = 2.8 MV ; coupling=0.6%

Effect of the HU640 undulator in the LV mode operation



Beam lifetime variation during operation



Beam lifetime reduction due to non linear effects from IDs

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Conclusion & perspectives

- Machine without insertion devices
  - Pretty good agreement with the model (H & V acceptances, DA, lifetime)
  - FMA: first experiments are positive but need further analysis

- Insertion devices: good and bad guys
  - RADIA + tracking simulation codes + magnetic measurement in rather good agreement with e-beam measurements
  - U20: still question about real physical apertures
  - Difficult to anticipate all construction and assembly errors
  - HU640: need to retrofit a model for our simulation
  - Need strong improvement for injection efficiency and lifetime
    - → New working point, coupling correction, feedforward on tunes, FOFB
    - → Preparation for top-up operation soon.