Between Model and Reality II

or why diagnostics are so crucial for running an accelerator facility?

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SOLEIL SYNCHROTRON

Layout

Note: General overview w/o going into details
→ See detailed talks during this diagnostics CAS

- **Introduction**
  - Main focus on circular synchrotron light sources
  - Beam line stability → See S. Hustache's talk on June 5th
- **Example of a 3GLS needs for commissioning (SOLEIL)**
- **Stability requirements for accelerators**
  - Noise sources and solutions
  - Closed orbit stability
  - Tune, chromaticity, coupling stability
- **Collective effects**
- **Other needs for operation**
- **Conclusion**

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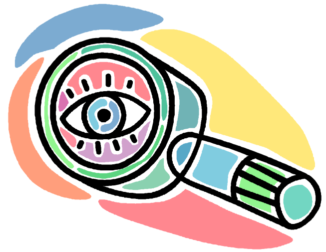
Diagnostics are our ears and eyes in the control room

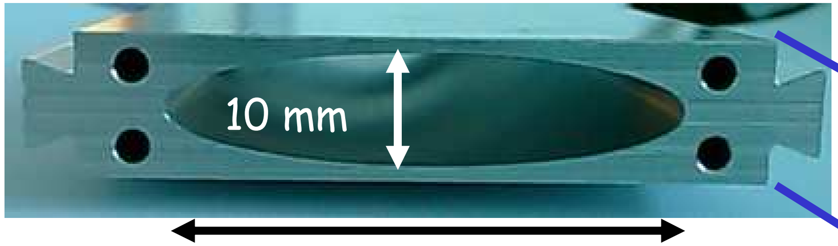
Need to diagnose before acting onto the beam



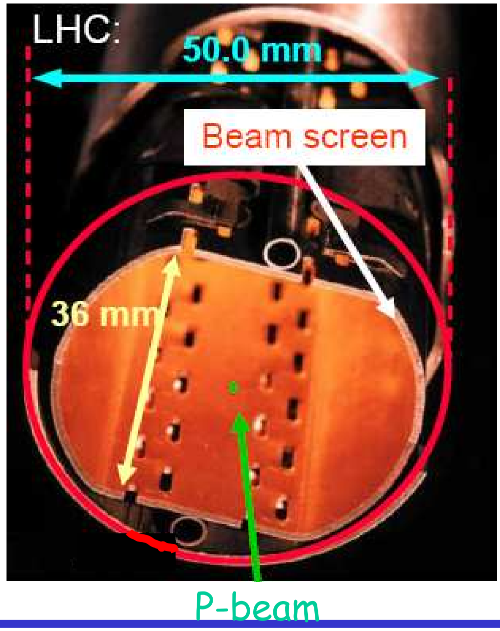
- Follow ultra-relativistic particle beam circulating in an ultra vacuum environment, a vacuum vessel with small dimensions (4-5 mm full gap for in-vacuum undulators at SOLEIL).
- Pencil beam with tiny dimensions: orbit stability requirement a few micrometers for colliders and below micrometer in light sources
  - Active control relying on diagnostics
  - Pushing the performance limit
  - Always more demanding & challenging requirements
- Surveying mission and active control mission

Vacuum chamber dimensions

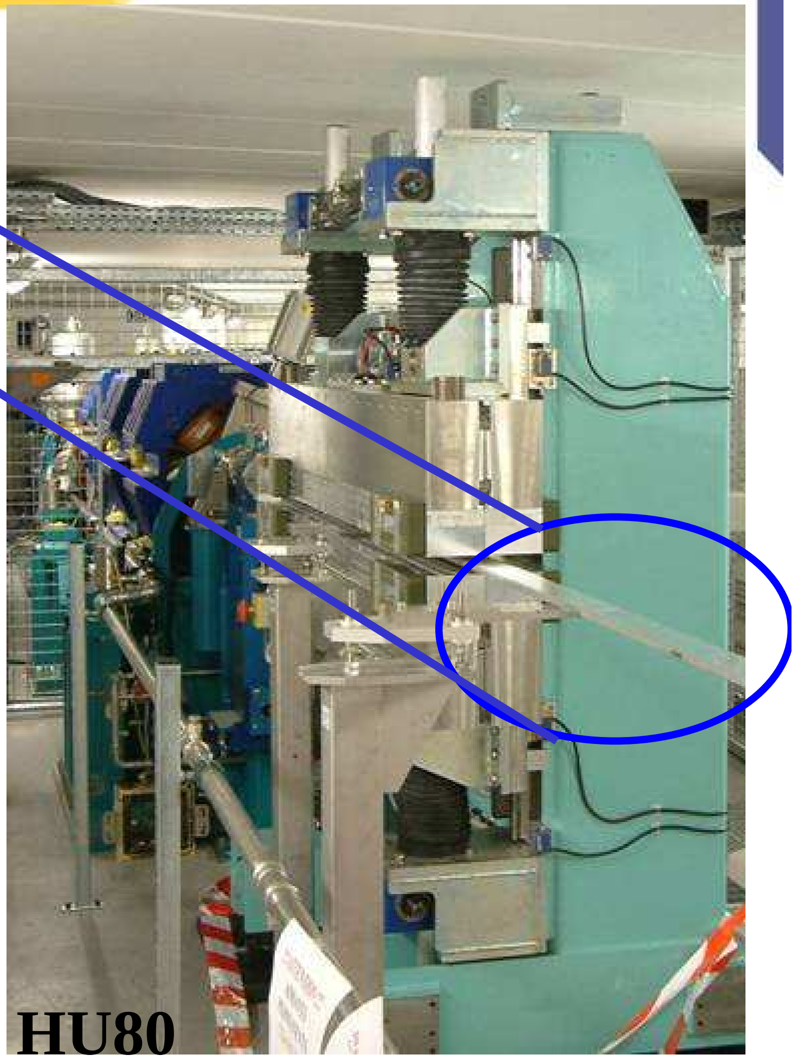
Soleil straight section vacuum vessel



F_{rev} = 847 kHz
Ultra vacuum
2.75 GeV

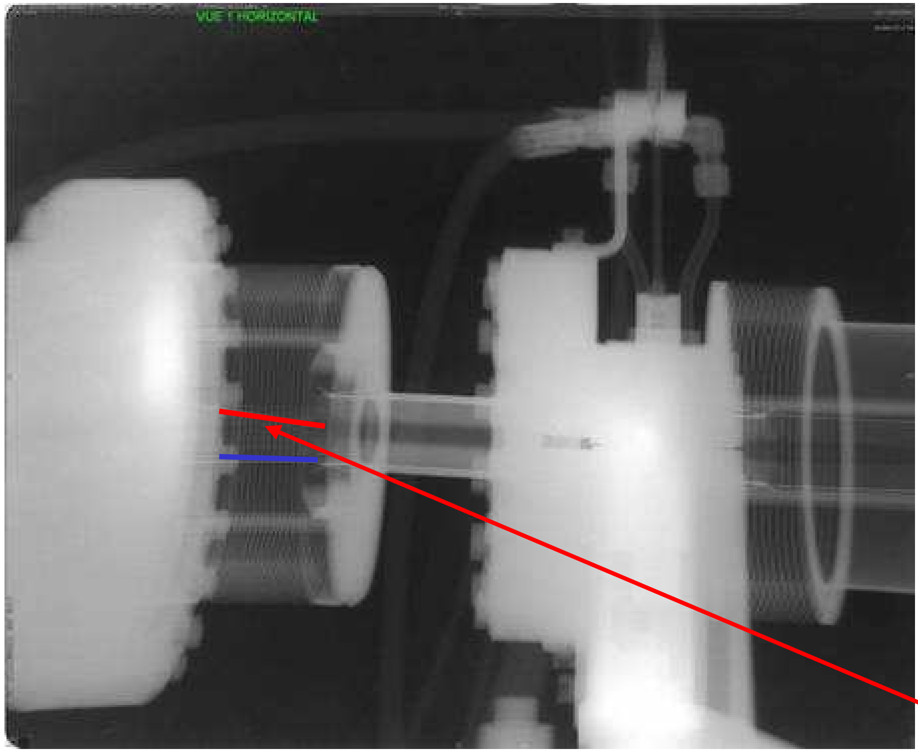


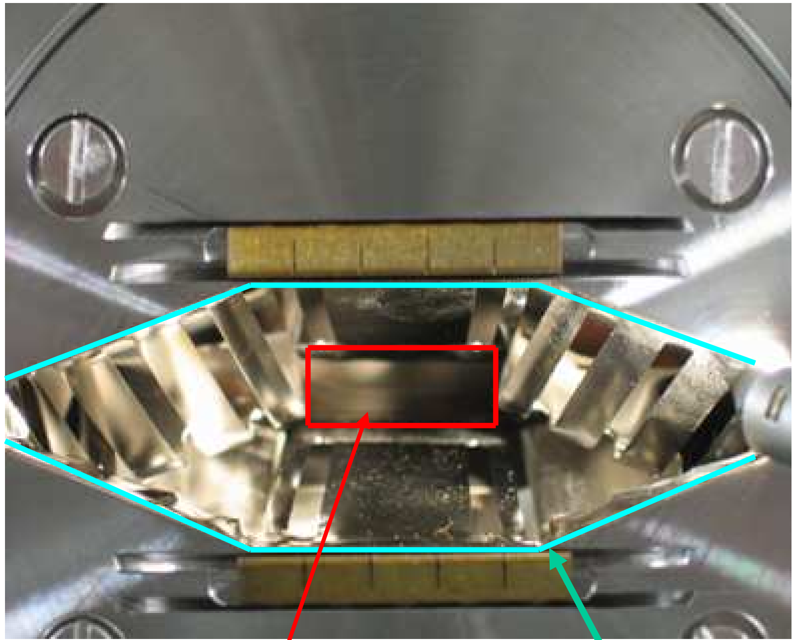
Supra-conductive magnets
Ultra vacuum
7 TeV



Unexpected obstacles (SOLEIL):

Bad mounting of some RF Fingers in short straight section bellows





RF finger at 1.5 mm from beam axis !

"Model" aperture

Available physical aperture

How to localize the issue?

- Beam loss monitors
- Local activation (inside tunnel)
- Orbit bump (BPM)

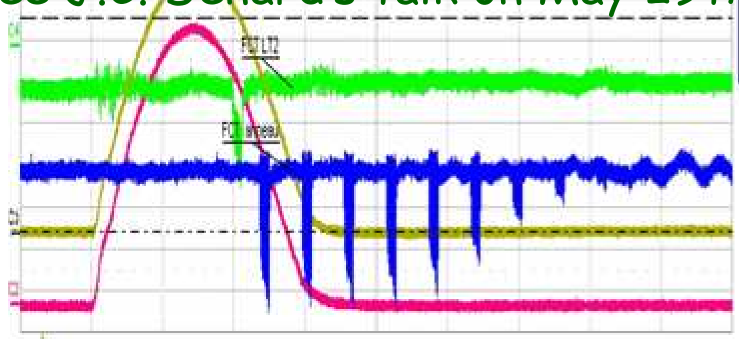
Reality differs all the time from Models

No large accelerator run the first day with nominal performance just by pushing a simple "button".

There are expected and unexpected sources of (static and time variable) perturbations

Commissioning periods
Example for Light sources

See J.C. Denard's talk on May 29th



- First time Beam into the storage ring
  - No accumulation, 1 or a few turns if lucky!
    - Questions arise
      - Where is the beam?
      - Where do losses occur?
      - What is the injected charged before loss?
    - Insertable screens
    - Beam Position Monitors (BPM) providing turn by turn data **synchronized** on the injection time
      - Position (very large amplitude (mm), few 100 µm of resolution)
        - » Nonlinearity when reading large amplitude (asymmetry VAC, …)
      - Location of total & partial beam losses along the ring
      - Compute tunes (through FFT, 4 turn algorithm, …)
    - Measurement of the current on turn by turn basis (FCT)
    - Checking magnet polarity **(> 100 to 1000 magnet polarities)**
  - Accumulation: **How far are we from the modeled accelerator?**
    - Need to determine stored beam energy (10^{-5} for modern light sources)
    - Need to get orbit and correct it (BPM in slow acquisition mode, with high resolution, below 0.2 µm RMS)
      - Very large amplitude (cf. alignment, magnetic errors described on Monday by H. Braun)

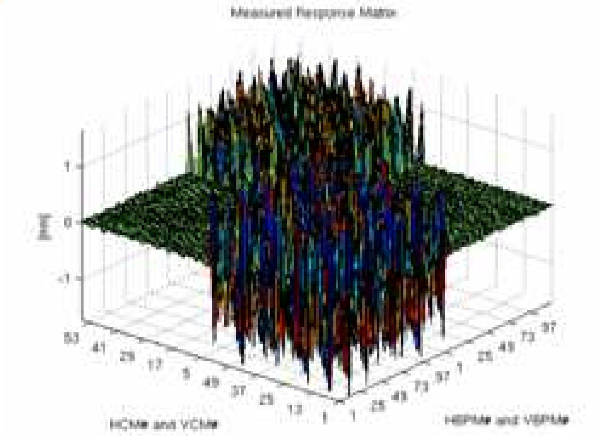
SOLEIL SYNCHROTRON Stacking the beam con't

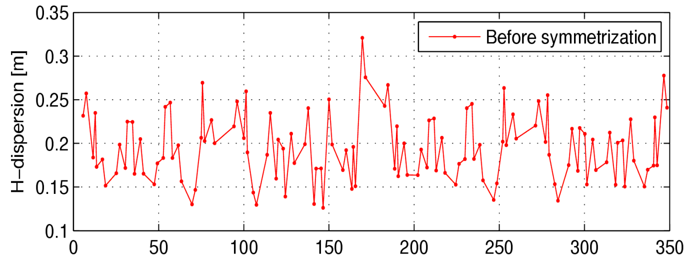
- Need to correct the betatron tunes
  - In general tunes are off by 0.5 to a few units ! (cf. Monday H. Braun's talk)
  - Wrong tunes can prevent good injection efficiency, give large orbit distortion, jeopardize any orbit correction, ….
    - » Measured by excitation of the transverse motion (kicker, shaker, stripline, …)
    - » Analysis of turn by turn data (BPM electronics, FFT)
- Current, lifetime measurement (DCCT, …)
- Need to insure the beam is going through the center of the quadrupole and sextupole magnets
  - Correct for magnetic center determination errors, alignment errors of both magnets and BPM blocks into the tunnel)
  - Standard technique is known as Beam Based Alignment
    - » Use of the BPM to measure the closed orbit for various steerer settings
    - » Low noise BPM electronics to reach center values below micrometer level

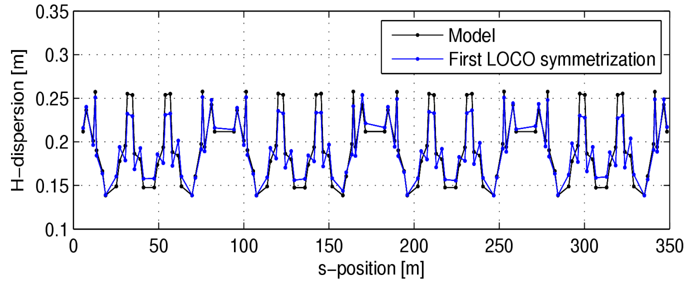
For Lattice measurement, see J. Wenninger's talk on May 31st

Exploring the linear optics

- Emittance, luminosity, lifetime are strongly impacted by optics function asymmetry
  - Need to restore optical symmetry of the storage ring. Before correction, beta beating of a few 10% in horizontal and vertical planes
    - Measure of closed orbit (so called BPM Response Matrices)
    - Dispersion function (energy dependant part of the closed orbit)
    - Use of BPM with a good resolution, steering magnets
  - Need to correction for coupling
    - Natural coupling produced by alignment errors, magnet errors, …
    - Emittance measurement (pinhole techniques, …)
- Need to determine real physical apertures
- Need to be able to scrap the beam in **a safe manner**
  - Scrappers, beam dump, fast kickers

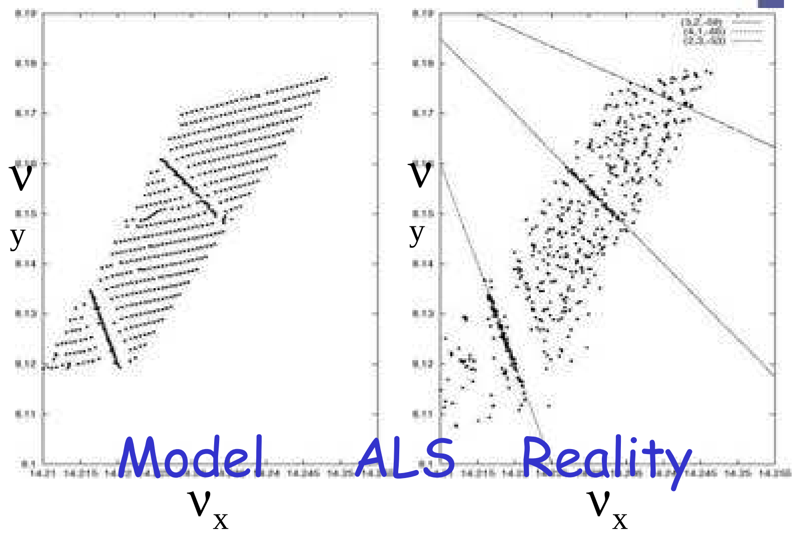






Probing machine non-linearities

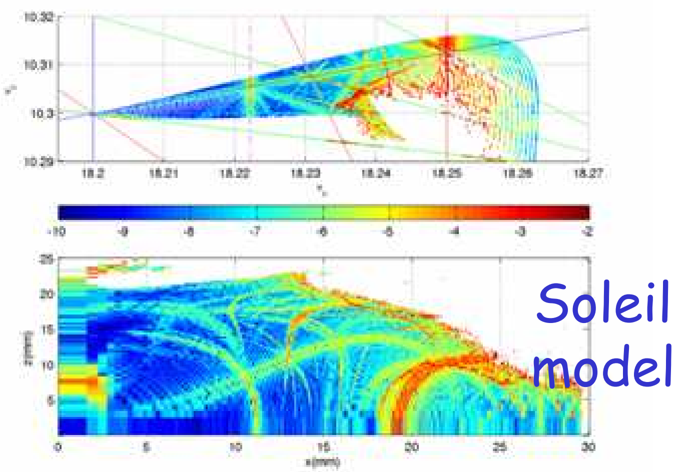
- Non-linear optics
  - Tune foot print (Frequency Map Analysis), resonances
    - Based on **turn by turn data** for large off axis beam position
  - On & off momentum dynamics aperture
  - Information about multipole errors at large amplitude
    - Comparison Model/Reality
  - Non-linear effect introduced by insertion devices and higher order multipolar field from magnets



- Compensation of equipment effects such as insertion devices

- Improvement of the accelerators: new working points, ultra low coupling, different filling patterns

- Exotic machine settings
  - Machine Physicist experiments
  - Low alpha setting, femto-second, crab cavities, ..



Example of a high resolution and multipurpose diagnostics

BPM Electronics Requirements for SOLEIL

	Slow FB	Fast FB	First turns	Turn-by-turn
Absolute accuracy	≤ 20 µm	≤ 20 µm	≤ 500 µm	≤ 200 µm
rms Resolution @ rep. rate	≤ 0.2 µm @ 10 Hz	≤ 0.2 µm in 100 Hz BW	≤ 500 µm @ 847 kHz	≤ 20 µm @ 847 kHz
Measurement rate	10 Hz	≥ 4000 Hz	SR: 847 kHz B: 1.9 MHz	SR: 847 kHz B: 1.9 MHz
Dynamic range	20 - 600 mA	20 - 600 mA	0.4 - 4 mA	4 - 600mA
Current dependence	≤ 1 µm	≤ 1 µm	≤ 500 µm	×
8-h drift	≤ 1 µm	≤ 1 µm	≤ 500 µm	×
1-month drift	≤ 3 µm	≤ 3 µm	≤ 500 µm	×
bunch pattern dependence	≤ 1 µm	≤ 1 µm	≤ 50 µm	≤ 500 µm

See P. Forck's talk today

Stability criteria for different facilities

What are the machine and user requirements?

How to maintain performance for user operation?

How to reach a beam availability larger than 96%?

How to operate without damaging the accelerator facility?

Requirements for colliders

- **Lepton accelerators (LEP, PEPII, KEK-B,…)**
  - Collider luminosity and collision stability
  - Effective Emittance preservation
  - Minimization of coupling (orbit in sextupoles)
  - Minimization of spurious dispersion (orbit in quadrupoles)
  - Tune and orbit feedbacks mostly during energy ramping

- **Hadron colliders (HERA, LHC, RHIC, Tevatron, …)**
  - Keep the beam into the pipe
    - Significant amount of energy stored into the beam
      - Quench superconducting magnets
      - Drill holes into the vacuum vessel and/ or serious damage
  - Capacity to control particle losses in the machine
  - Orbit stability driven by luminosity inside the experimental insertions: 25 μm constraint at collimators for LHC
  - Energy preservation below 10^{-4} at LHC
  - Ramping the beams from injection energy (450 GeV) to collision energy (7 TeV)
    - Synchronization of the magnets
    - Different working point in tune diagram
    - Avoid crossing resonances in tune diagram
    - LHC: $\Delta\nu < 10^{-3}$, $\Delta\xi = 2\pm1$ (ξ changed by >100 units during ramping)
    - → orbit, tune, chromaticity and coupling feedforward/feedbacks

XFEL requirements

Orbit distortions lead to:
- beam centroid motion
- beam shape variations → effects on SASE power and gain length

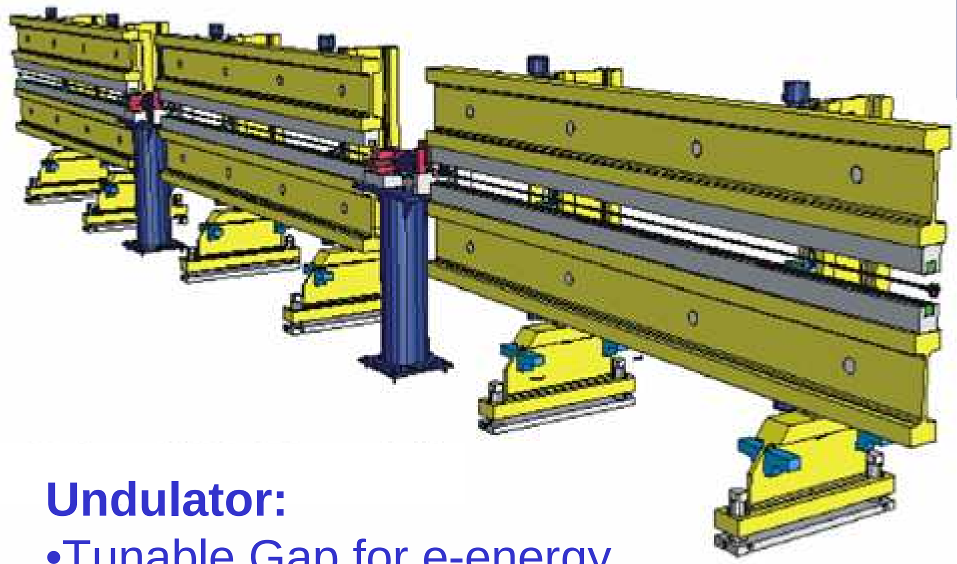
Undulator alignment
- Temperature: < 0.08 °C
- Gap : < 1 μm
- Alignment error : < 100 μm

- Gun charge & emittance fluctuation

- Beam shape variation and bunch density to be maintained for SASE power preservation

- Low emittance, low energy spread

- Position stability: 0.1 σ



Undulator:
- Tunable Gap for e-energy independent wavelength selection
- λ ≈ 40 - 80 mm
- B ≈ 0.5 – 1.3 T
- Gap > 10 mm
- 5 m long segments embedded in 12.2 m long FODO cell
- Total length ≈ 700 m

Third generation Synchrotron Light Sources

- Brilliance preservation
- (Ultra) low emittance
- Constant (large) lifetime
- Sub micron orbit stability (< 0.1 σ)
- Energy stability (< 10^{-4} to 10^{-5}) for spectral resolution   See AS. Mueller's talk on June 3rd
- User freely controlled insertion devices
  - Has to be transparent for all the users
- Tune variations (10^{-3}), low coupling (1-0.1%) and sometime chromaticity preservation

$$B \propto \frac{I}{\varepsilon_x \varepsilon_z} \equiv \frac{I}{\sigma_x \sigma'_x \sigma_z \sigma'_z}$$

Orbit stability

Brilliance reduction

↑

Emittance growth

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Time dependent Orbit Oscillations

↑

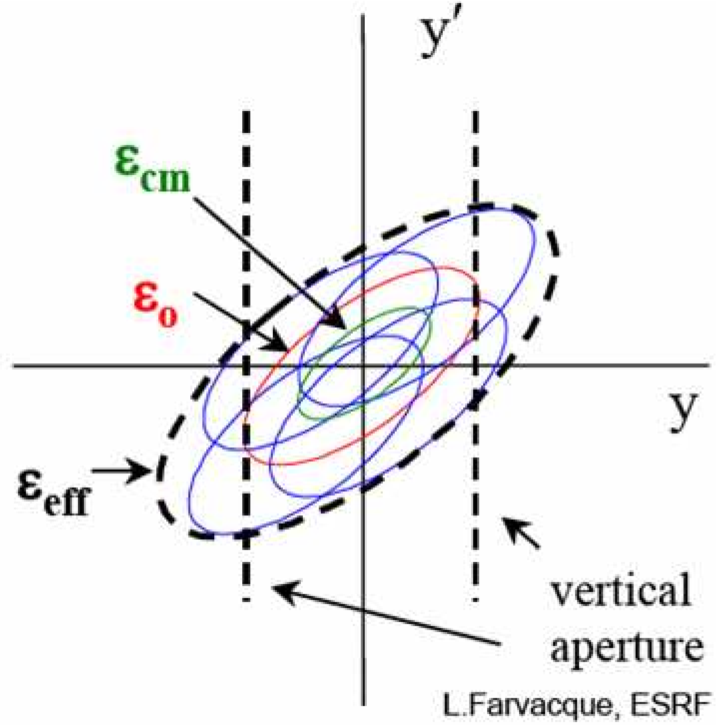
Magnets motion

↑

Girders (support) motion

↑

Ground Vibration



Sources of electron beam instability of position

- **Long term (weeks to years)**
  - Ground settlement (mm)
  - Season ground motion (mm)

- **Medium term (minutes to days)**
  - Diurnal temperature (1-100 μm)
  - Crane motion (1-100 μm)
  - Filling pattern (heating, BPM processing) (1-100 μm)
  - Sun and Moon tides (ΔC = 10-30 μm)
  - River, dam activity, heavy rains (1-100 μm)
  - Current decay (thermal drift, electronics BPM)
  - RF frequency drift (1-100 μm)
  - Startup after shutdown period (thermal effects)
  - Drift of vacuum chamber due to temperature, etc…
  - Ramping in energy or change of machine optics

Sources of noise II

- Short term (milliseconds-seconds)
  - Ground vibration, traffic, trains, construction work, etc
    - Amplification by girder, magnet resonances by lattice (nm becomes μm!)
  - Cooling water, LHe, LN, vibration (μm)
  - Rotating machinery (air conditioners, pumps, chillers, …) (μm)
  - Booster operation (μm)
  - Insertion devices (1-100μm)
  - Transients created by fast switching devices (Eddy current, ..)
  - Power supplies (μm)
  - Injection (1-500μm)

- Very short (High frequencies)
  - 50 or 60 Hz of Sector
  - D/A converter digitization noise
  - Pulsed power sources
  - Switching frequencies of power supplies
  - Synchrotron oscillation (1-100 μm)
  - Single and multibunch instabilities (1-100μm)
  - Electromagnetic interferences (appliances in the lab, radio broadcast mast, …)

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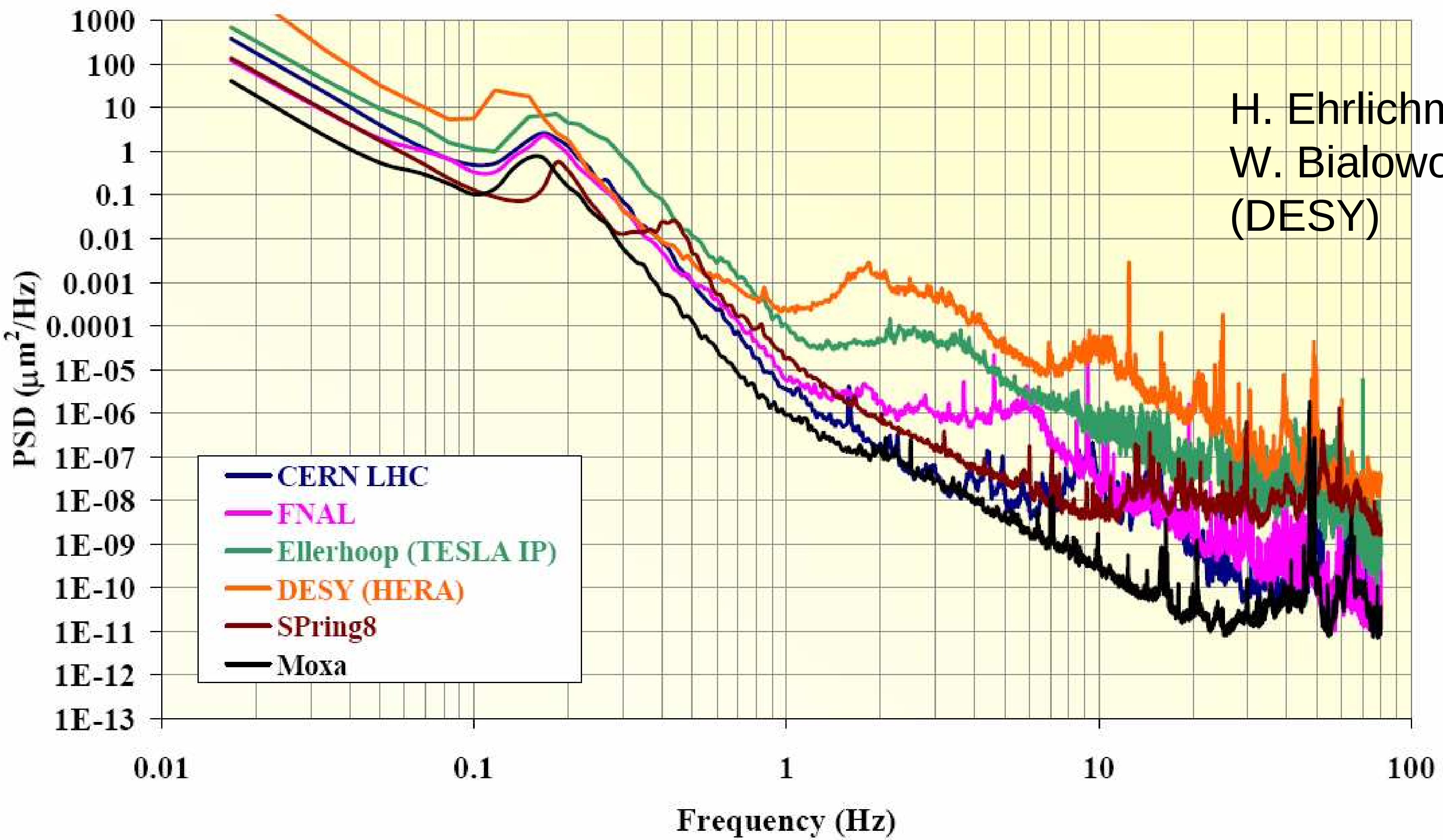
Ground Motion Spectra



H. Ehrlichmann
W. Bialowons
(DESY)

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Solution to reach required stability

- Long term stability: 100 µm / 10 m / year
  - ✓ Building foundation, (Piles, slab)
  - ✓ Alignment, (Girder design to damp or not amplify vibration)
  - ✓ Position survey of girders, BPMs, etc …
- Medium term stability: (24h) ⟷(reference BPM versus beamlines)
  - ✓ Storage ring tunnel (and water cooling): 21 ℃ ± 0.1 ℃
  - ✓ Experimental hall : 21 ℃ ± 1 ℃
  - ✓ Slow Orbit Feedback
  - ✓ Top-up
- Short term stability:
  - ✓ Girder design
  - ✓ Fast Orbit Feedback

$\sigma_{COD} < 0.1\,\sigma_{Beam}$
and
$\sigma'_{COD} < 0.1\,\sigma'_{Beam}$

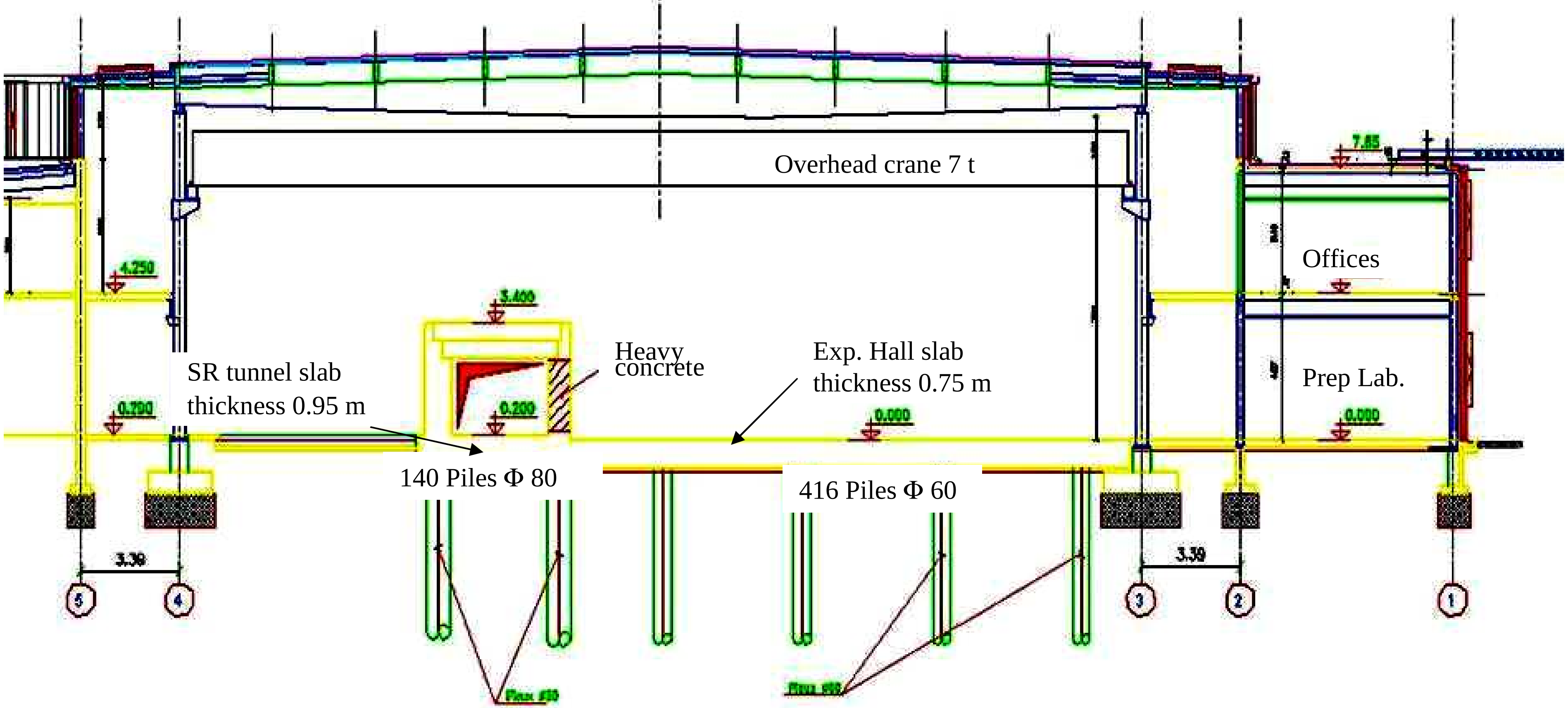
	σ_{COD} (µm)	σ'_{COD} (µrad)
Horizontal	18	3
Vertical	0.8	0.5

(SOLEIL example: for 1% coupling in medium SS)

Sub-micron tolerances

Building design: SOLEIL example

95 cm thick slabs laying on piles for Storage Ring and Exp. Hall



Slab settlement < 50 μm /year

Vibrations amplitude < ± 0.5 μm

Bored piles 16m long anchored in Fontainebleau sand

128 under the ring tunnel

420 under the experimental hall (4*105)

64 under linac and booster with a slab unconnected

Soleil

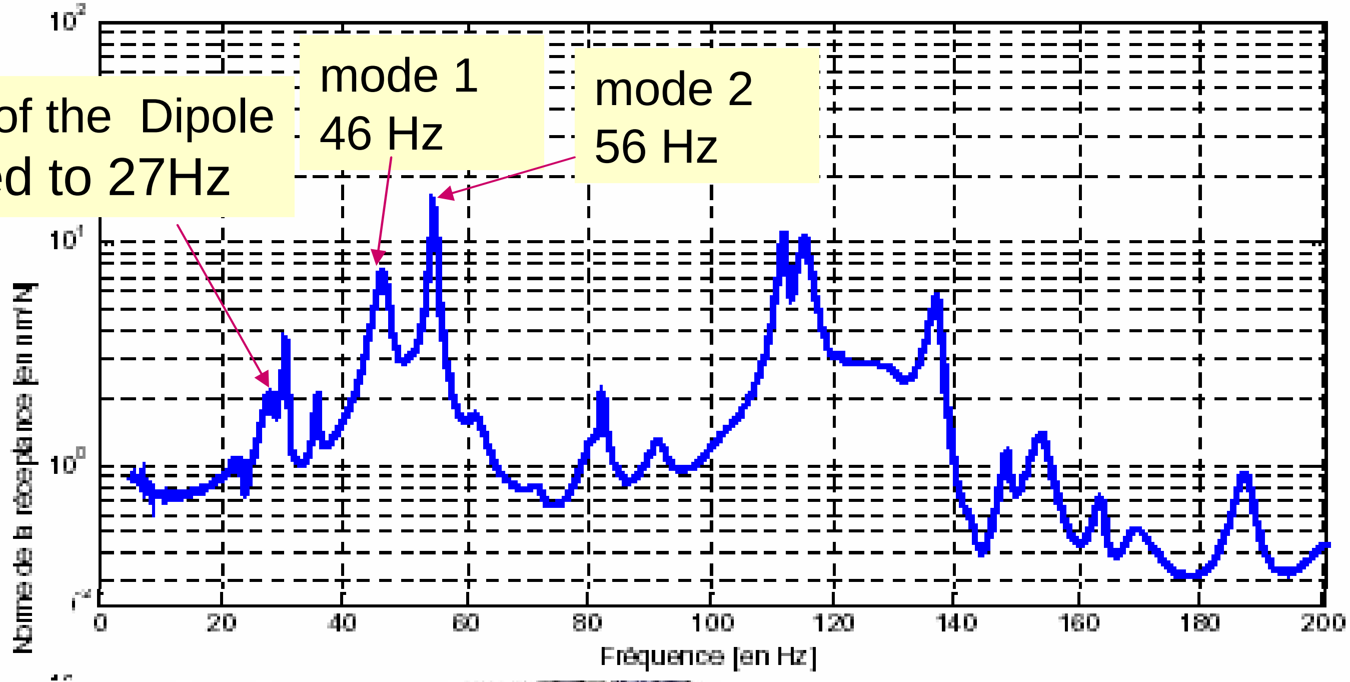
Alignment tolerances for SOLEIL

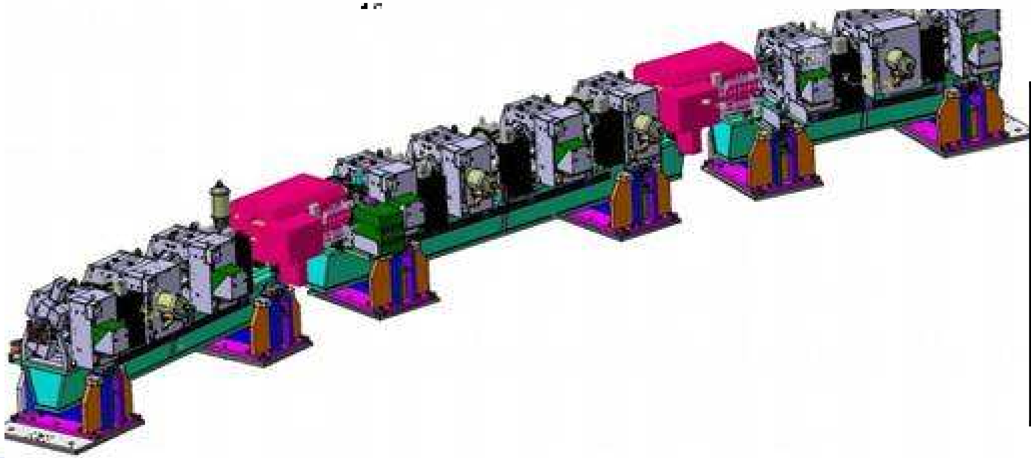
See yesterday's talk by H. Braun

Error type	r.m.s magnitude
Quadrupole transverse displacement x,z	0.03 mm
Girder transverse displacement x,z	0.1 mm
Girder roll error	0.1 mrad
Bending magnet transverse displacement x,z	0.5 mm
Bending magnet longitudinal displacement s	0.5 mm
Bending magnet relative field error	0.001
Bending magnet roll error	0.1 mrad

(BPMs displacement errors: 100 μm r.m.s.)

Use of girders to reduce closed orbit distortion





	Horizontal	Vertical
w/o girders	30	10
w/ girders	16	3
Gain	47%	70%

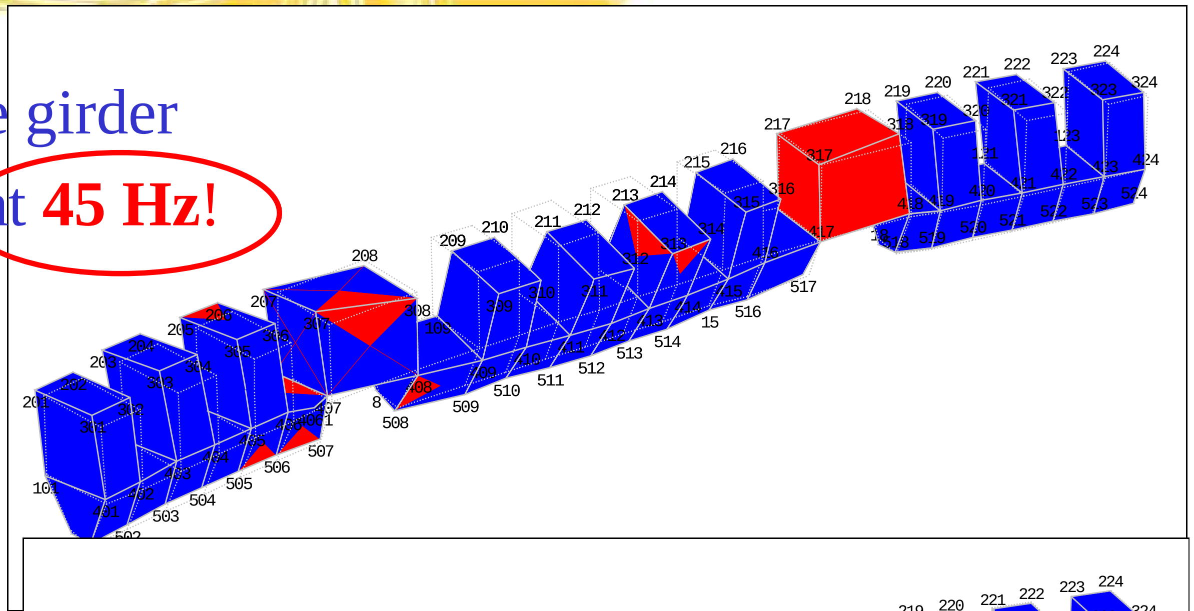
Vibration measurements on SR girders

Experimental Modal Analysis

- 1st mode on quadrupole girder

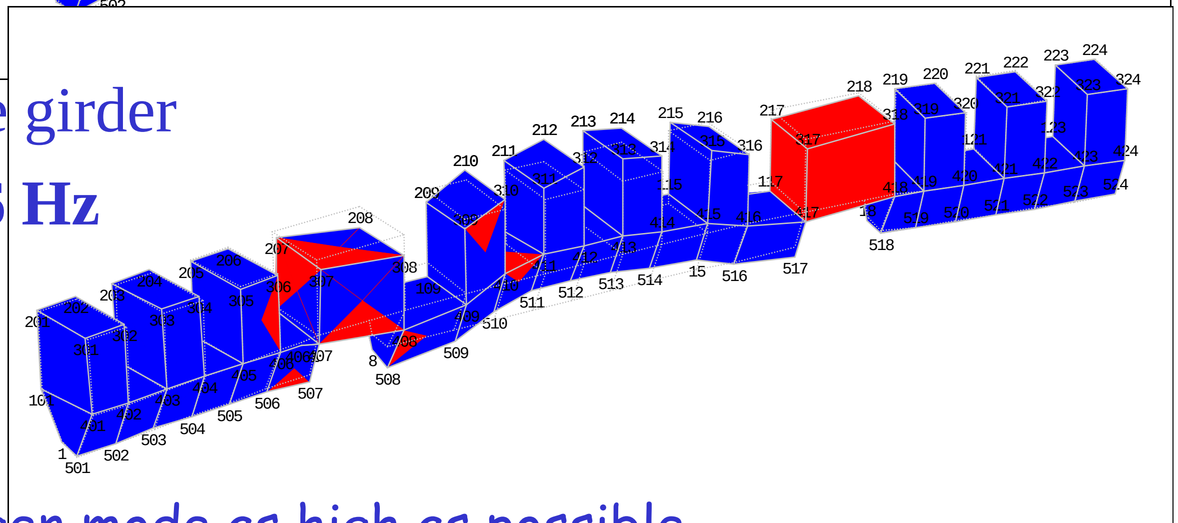
⇒(transversal flexion) at **45 Hz!**

⇒(design value 40 Hz)



- 2nd mode on quadrupole girder

⇒(vertical flexion) at **56 Hz**



Aim to push first eigen mode as high as possible

Survey & evolution & dynamic alignment of girders

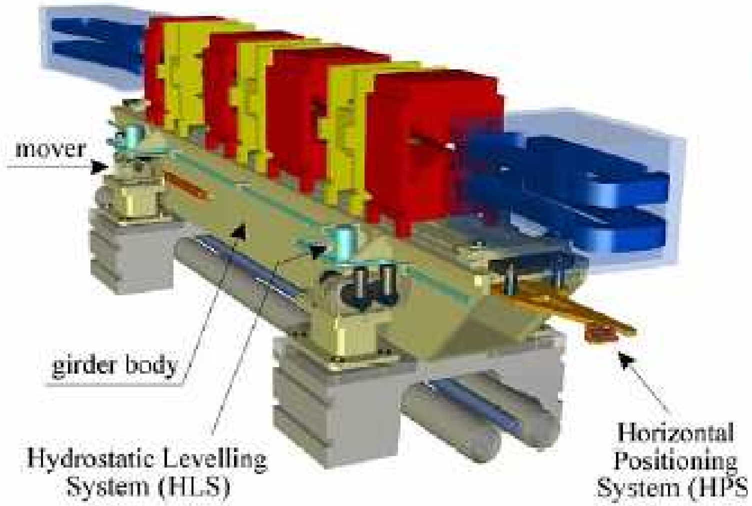


Figure 1: SLS storage ring girder assembly

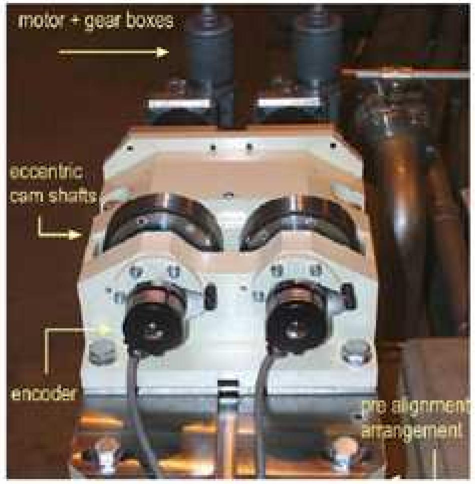


Figure 2: Mover system for SLS storage ring girders

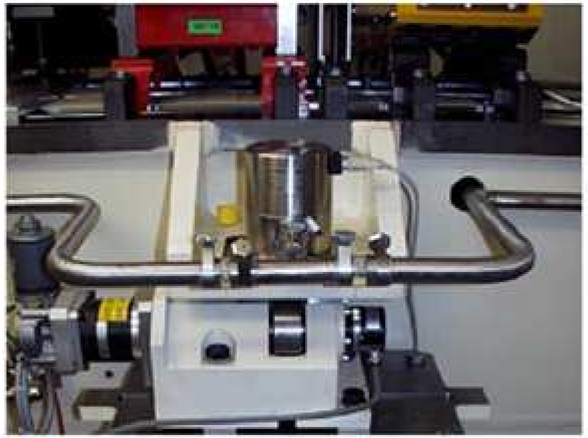


Figure 4: HLS sensor with water pipe connection.

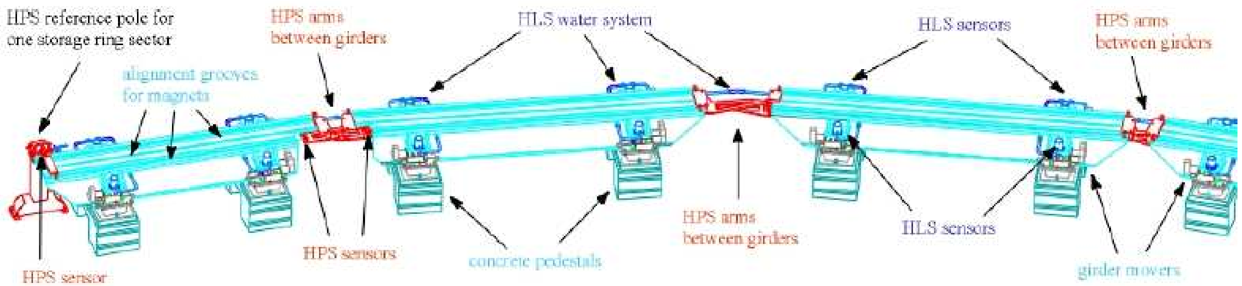


Figure 3: HLS (blue) and HPS (red) systems overview over one sector (corresponds to one TBA) of the SLS storage ring. Magnets and BPMs mounted on the alignment rails at the girder surface are not shown.

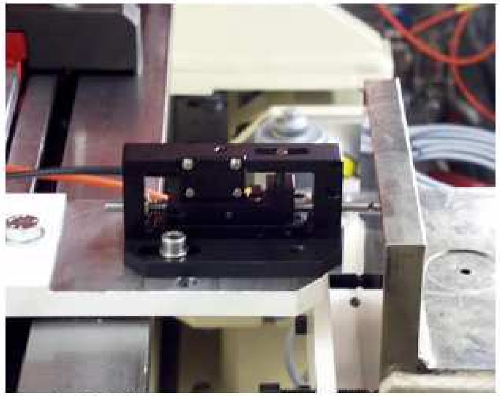


Figure 6: HPS sensor touching reference pole.

See S. Radealli's talk on June 5th

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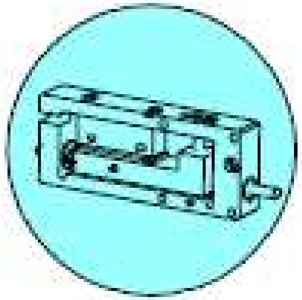
BPM position motion

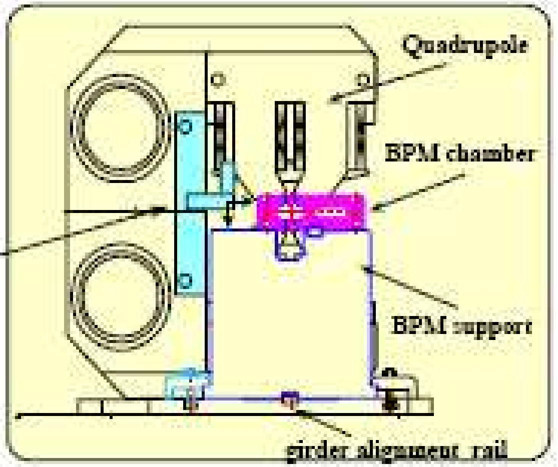
Monitoring of BPM Block Positions

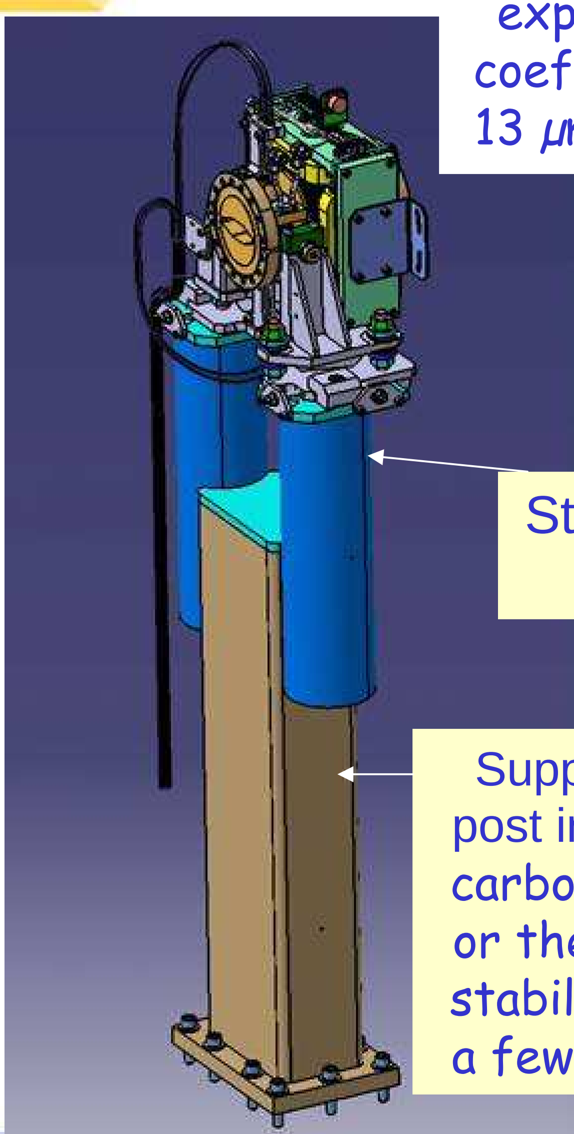
POMS Features

- Dial gauges sense transverse movements of BPM block in reference to adjacent quadrupole magnets.
- Linear encoders of type Renishaw RGH24Z50A00A with 0.5 μm resolution are used as sensing devices.
- Complete integration into EPICS control system through (low cost) serial SSI-interface and 32 channel VME-SSI card.
- POMS data will be used for determination of "real" electron beam positions in DSP part of the DBPM system to maintain a "golden orbit" after BBA.

Two dial gauges per BPM station equipped with linear encoders as sensing devices attached to adjacent quadrupole magnets

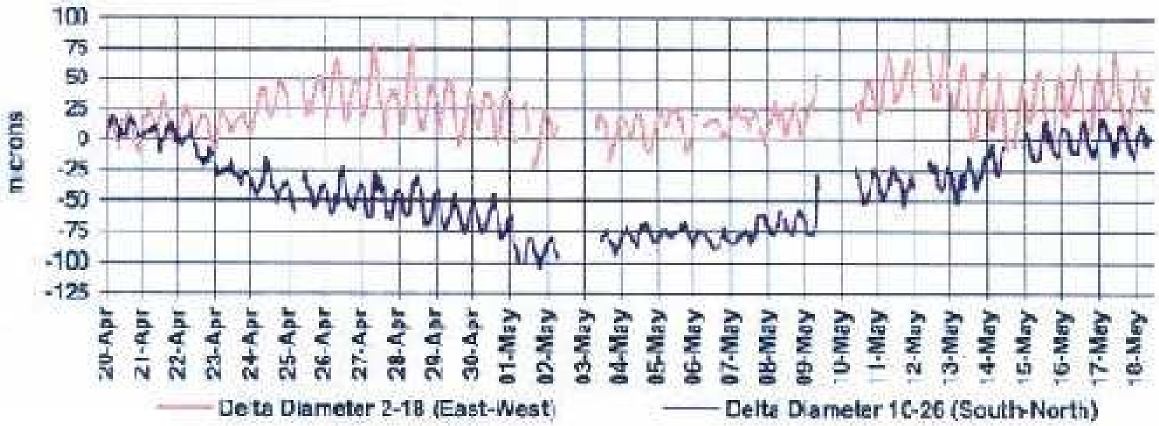


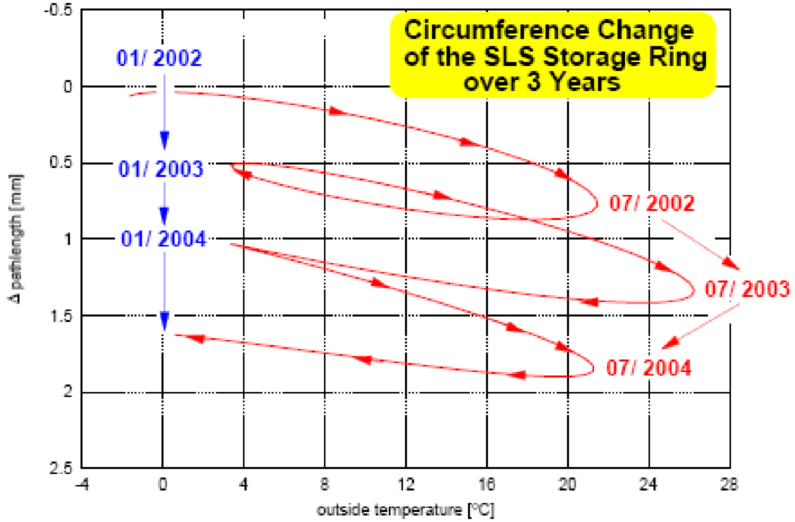




Example of long term noise

Gravitational earth tides due to sun and moon (ESRF)





Solution to reach required stability criteria

- Long term stability: 100 µm / 10 m / year
  - ✓ Building foundation, (piles, slab)
  - ✓ Alignment, (Girder design to damp or not amplify vibration)
  - ✓ Position survey of girders, BPMs, etc …

- Medium term stability: (24h) ⟷ (reference BPM versus beamlines)
  - ✓ Storage ring tunnel (and water cooling): 21 ℃ ± 0.1 ℃
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- Short term stability:
  - ✓ Girder design
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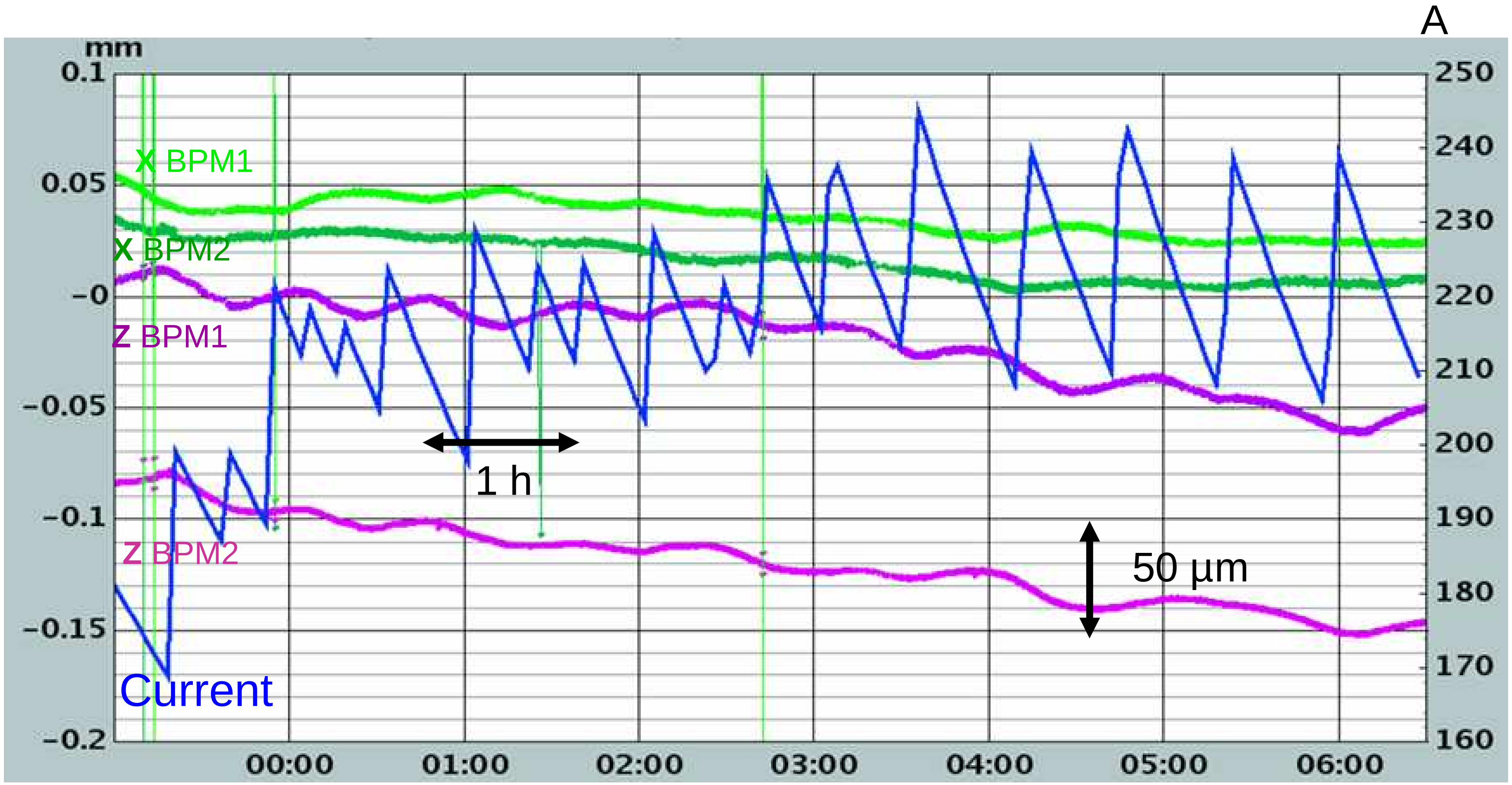
Sub-micron tolerances

	σ_{COD} (µm)	σ'_{COD} (µrad)
Horizontal	18	3
Vertical	0.8	0.5

(SOLEIL example: for 1% coupling in medium SS)

Natural drift of orbit w/o FB



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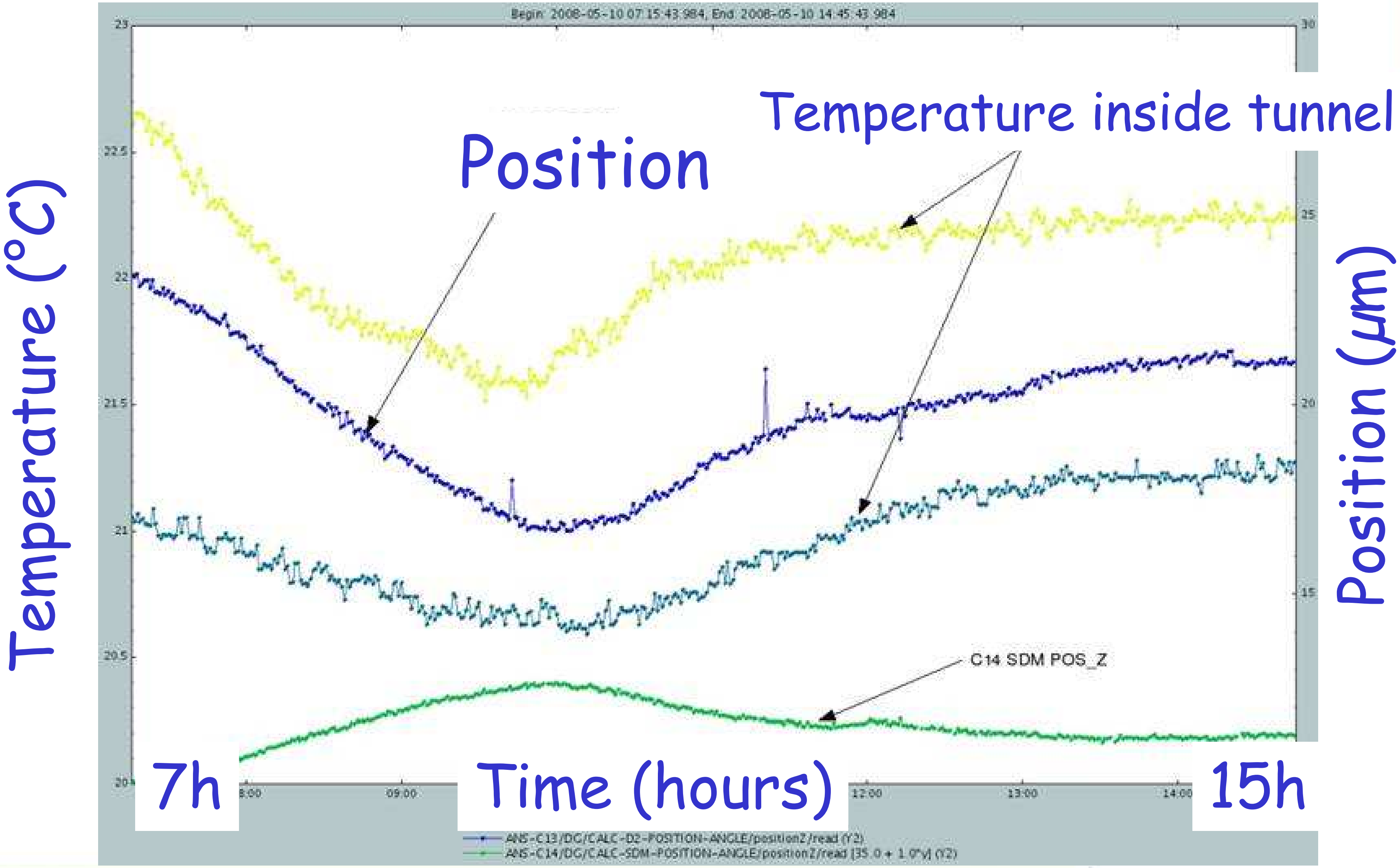
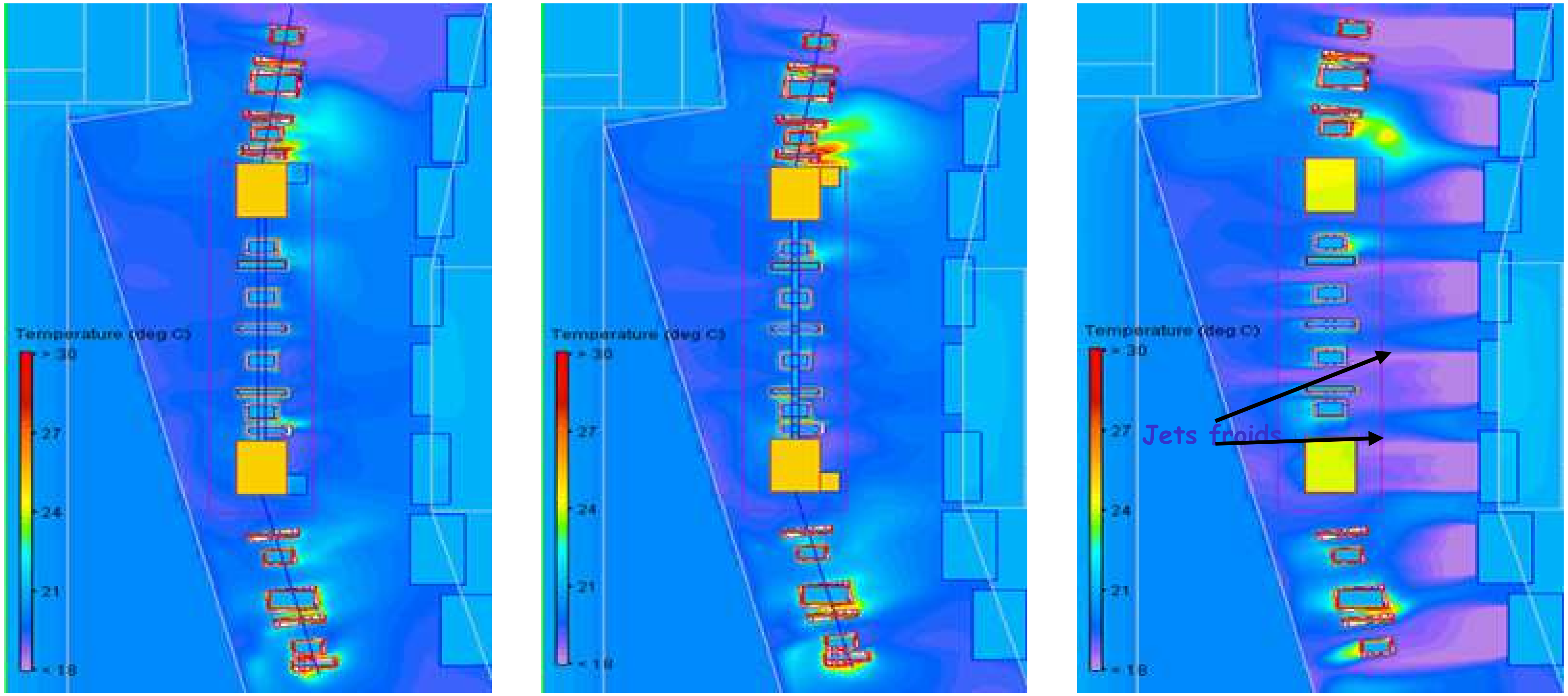
Orbit variation with temperature



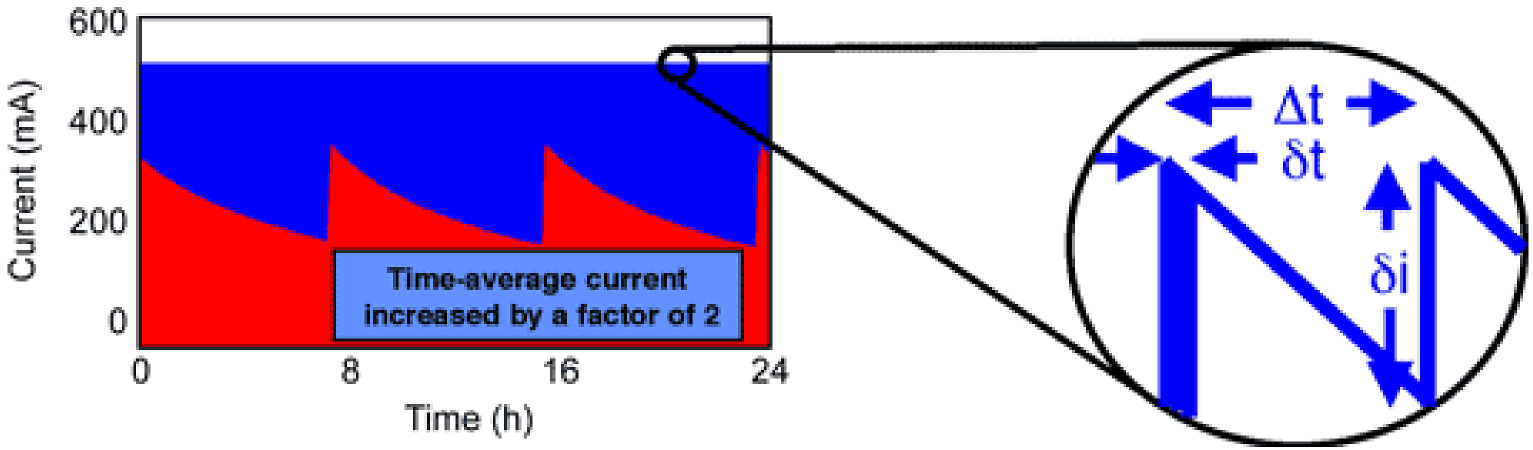
Tunnel temperature regulation

❖ The achieved static (average) air temperature in the area of the girders is of 19.5 ± 0.3 °C in the longitudinal direction. UTA regulation should insure the temporal stability within ± 0.1 °C.



(altimetry) 1 m 1.20 m (Beam axis) 1,48 m (UTA axis)

Top-up injection and light sources



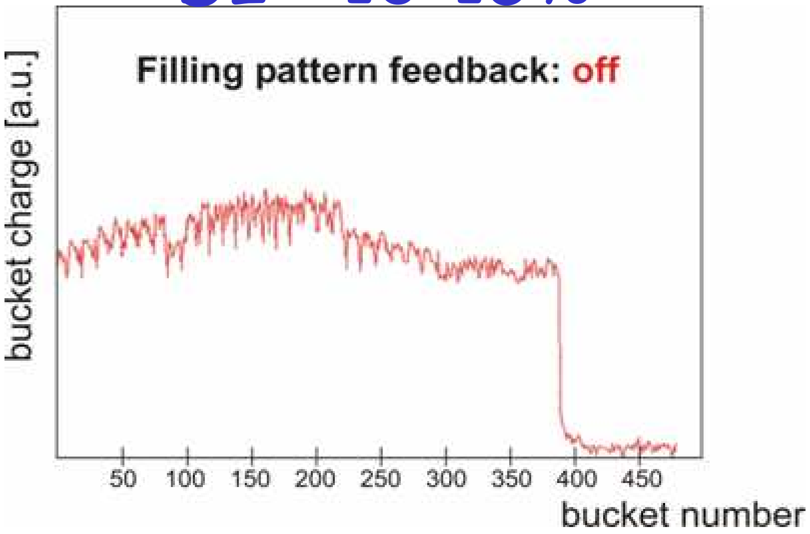
- Constant thermal load on beam-line optics (mirror alignment, thermal optical bumps, …)
- Constant thermal load on accelerator equipments. Reduction of thermal drift on BPM electronics.
- **Only way to reach sub micron stability level**
- **Not suitable for all user needs (long integration time, image scanning, …)**

Filling Pattern Feedback

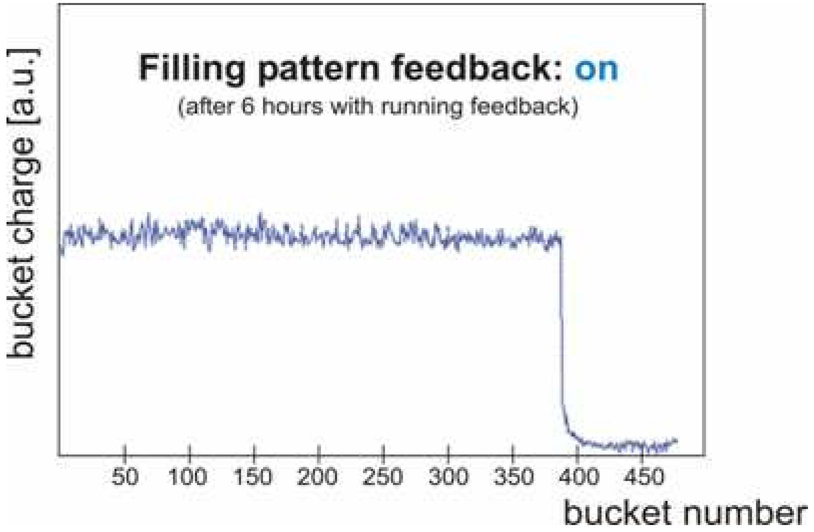
Standard SLS filling pattern:

- 390 buckets filled
- gap of 90 buckets

DI < 10-15%



DI < 1%



Filling pattern Feedback: bunch by bunch current

- Filling pattern preservation (<1% bunch to bunch variation)
  - Electronics stability
  - Useful for beam-line experiments
- For time resolved experiment: need of bunch purity monitor (see K. Wittenburg's talk on June 5th)

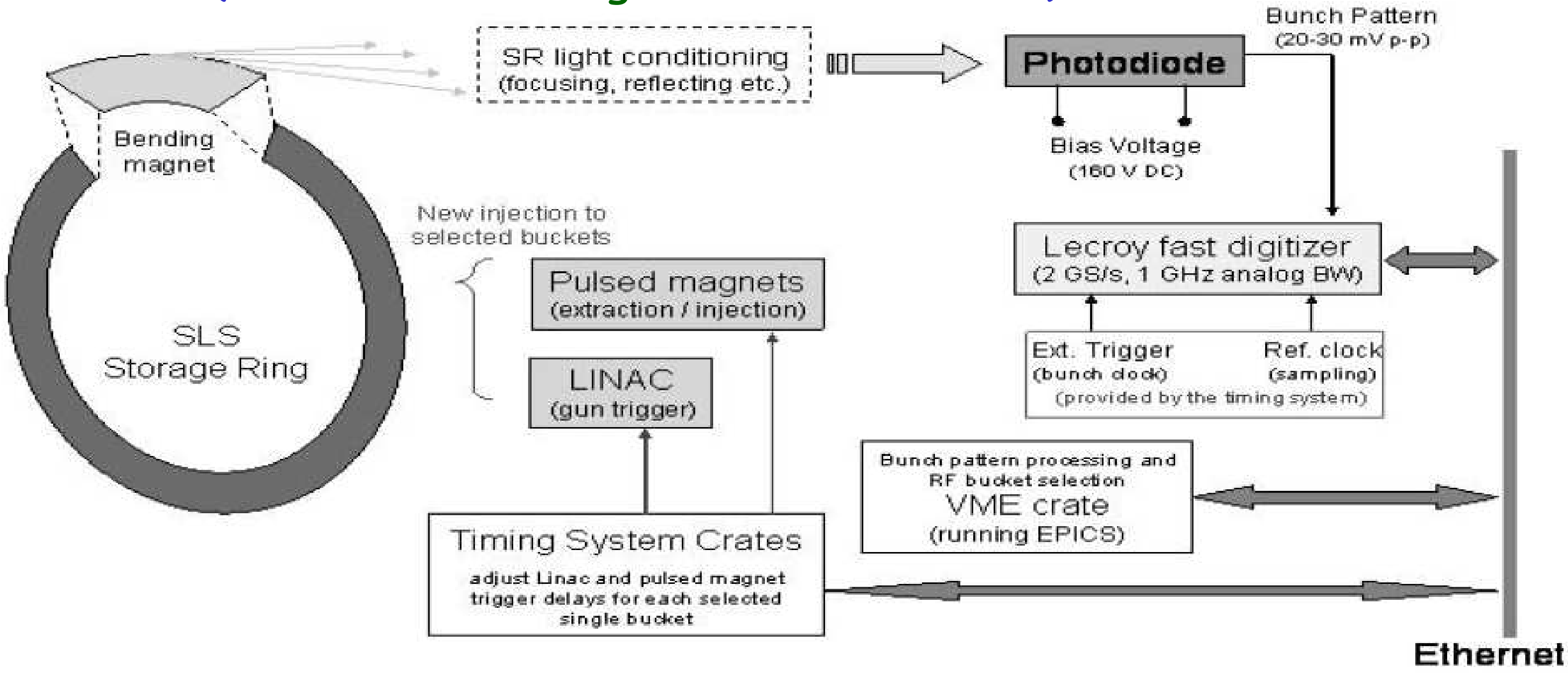


Figure 1: filing pattern feedback loop architecture EPAC'04, Kalantari et al., SLS

Solution to reach required stability criteria

- Long term stability: 100 µm / 10 m / year
  - ✓ Building foundation, (Piles, slab)
  - ✓ Alignment, (Girder design to damp or not amplify vibration)
  - ✓ Position survey of girders, BPMs, etc …
- Medium term stability: (24h) ⟷ (reference BPM versus beamlines)
  - ✓ Storage ring tunnel (and water cooling): 21 ℃ ± 0.1 ℃
  - ✓ Experimental hall : 21 ℃ ± 1 ℃
  - ✓ Slow Orbit Feedback
  - ✓ Top-up
  - ✓ Position survey of girders, BPMs, etc …
- Short term stability:
  - ✓ Girder design
  - ✓ Feedforwards (insertion devices, injection)
  - ✓ Fast Orbit Feedback

Sub-micron tolerances

	σ_{COD} (µm)	σ'_{COD} (µrad)
Horizontal	18	3
Vertical	0.8	0.5

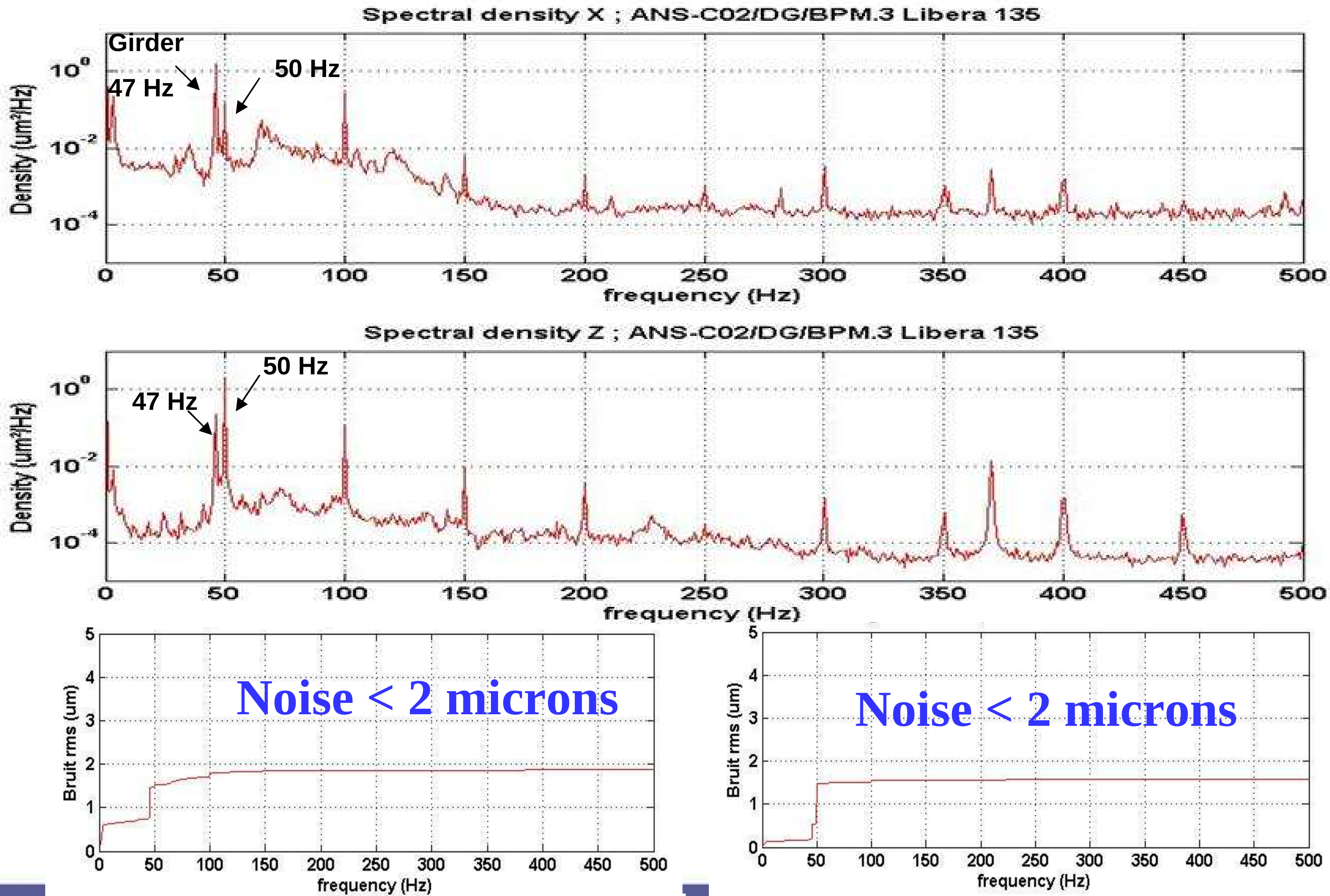
(SOLEIL example: for 1% coupling in medium SS)

Short term stability solutions

- Survey: seismic detectors (geophones, etc), FFT on turn by turn data from XBPMs, BPMs
- Predicable disturbances: feedforwards
- Unpredictable disturbances: slow & fast orbit feedbacks

Geophones

Typical noise spectrum at SOLEIL
BPM + Beam: 0 to 500 Hz



Orbit and RF frequency feedbacks

- Use of BPM and XBPM distributed all around the ring
- Use of dedicated H & V steerers (dipolar magnets)
- Control of master clock frequency (energy feedback)

- One single FB system (SLS)
- 2 FB systems
  - Slow (0-1 Hz) and fast feedbacks (1 – 150 Hz)
  - Frequency dead zones or not in frequency domains (APS, ALS, …)
  - Interaction between feedbacks if frequency overlap
- No introduction of additional noise onto the beam

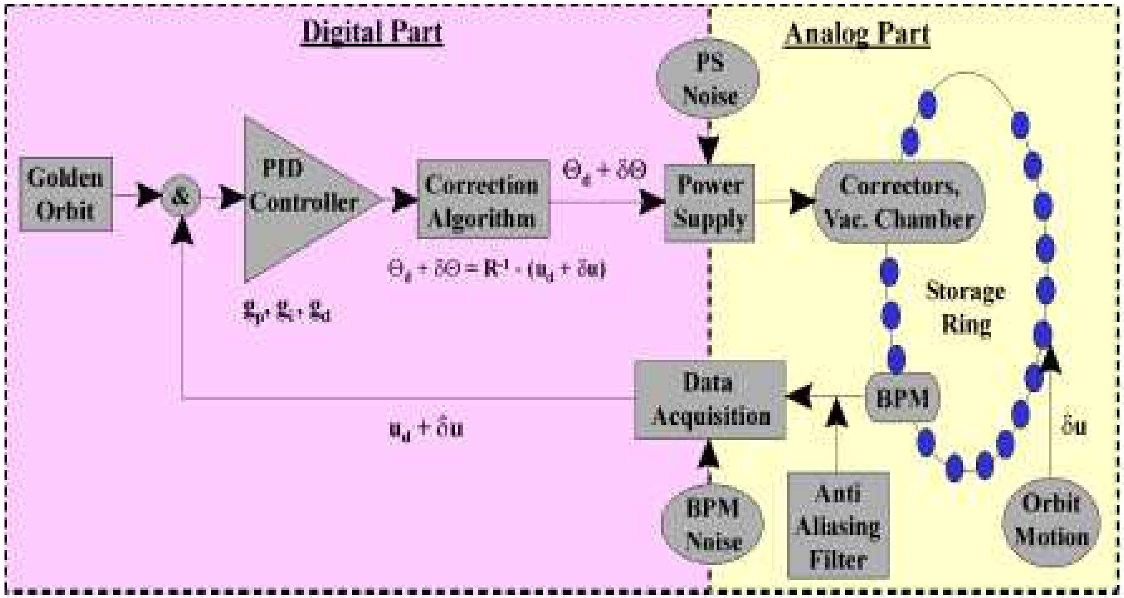
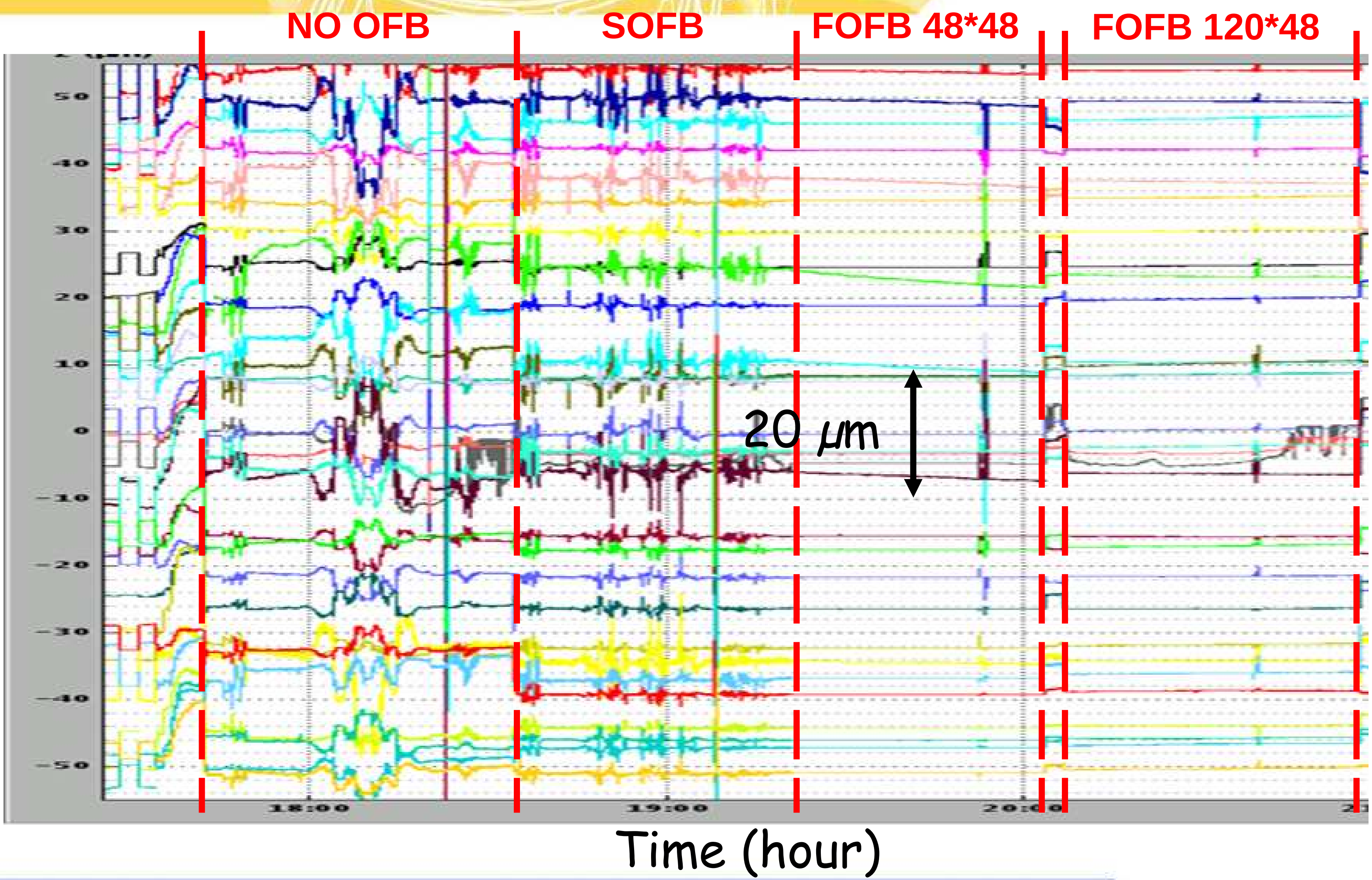


Figure 2: Block diagram of global orbit feedback.

See M. Boege's talk on May 31st

Effect on the perturbations caused by the insertion devices (vertical plane)

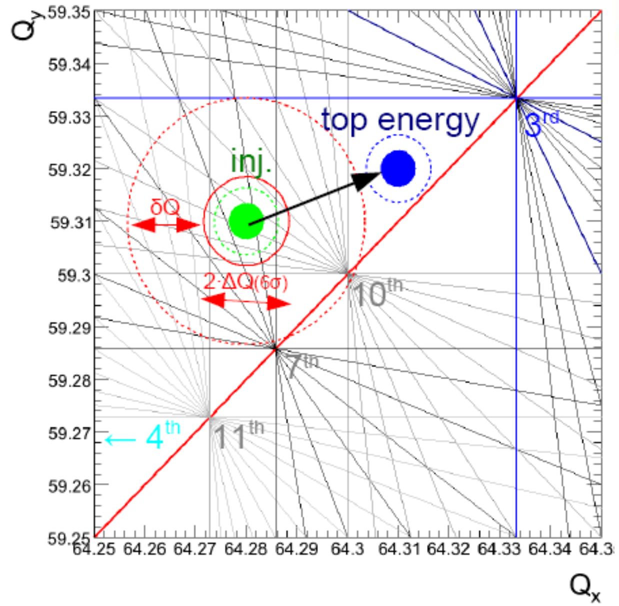


Feedforward systems

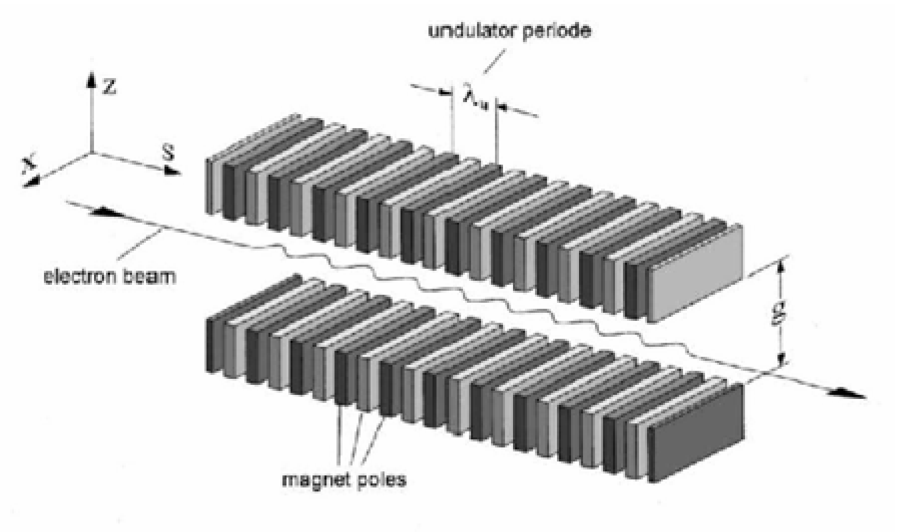
- Well known disturbance prediction either based on model or on beam measurements
  →"Set and forget system"

- Examples:
  - Ramping process (LHC) in the tune diagram
  - Perturbation depending **on insertion device** configurations (gap, phase, velocities): orbit, tune, chromaticities, coupling, beta-beating

- Limitations
  - Beam condition dependence
  - Difficult to get to perfect correction
  - Difficulties to synchronize mechanical jaws/ power supplies for insertion devices
  - Nonlinear interactions between insertion devices
    - Introduce errors on the orbit
    - Residual orbit taken care by feedback systems

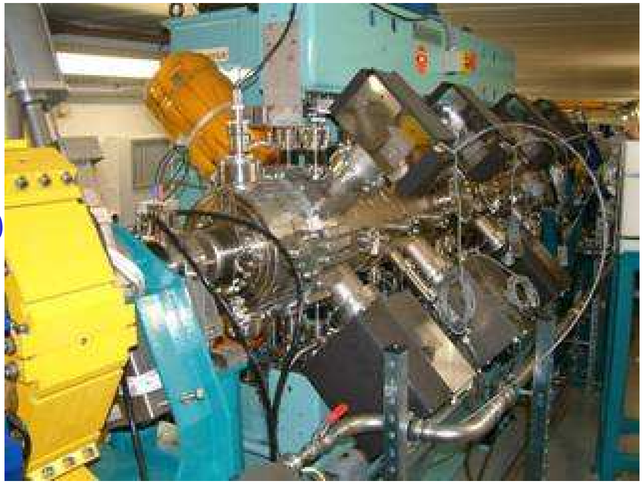


Insertion devices commissioning



Motorized ID
Apple II
(HU80)
Variable
polarization

U20
Low gap



EM ID
HU640
10 m
Fast
switching

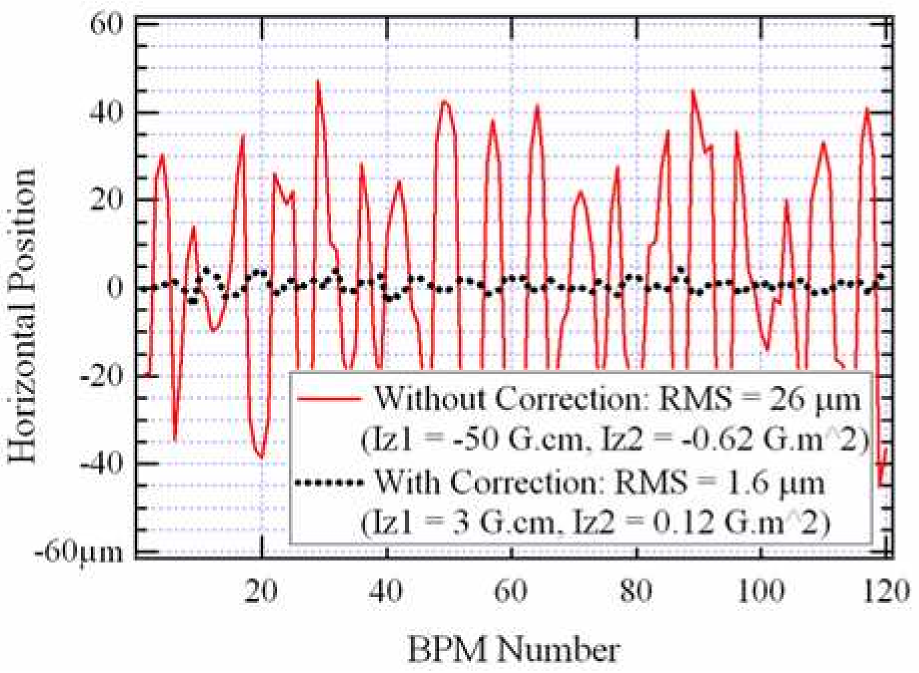
Insertion device based rings

BL Name	Energy	Source	Location	Useful length (m)	Polarization Switch time	Periodic	Technology	Installation
phase 1								
DESIRS	5 – 40 eV	HU640	I 05-L	10	Circ./lin/phasevar	Yes	HU640	*Installé*
TEMPO #1	45 – 1500 eV	HU80	I 08-M	1,6	Circ./lin.	QP	APPLE II	*Installé*
PROXIMA1	4 – 30 keV	U20	I 10-C	1,96	Lin.	Yes	Hybrid in vacuum	*Installé*
SWING	4 – 30 keV	U20	I 11-C	1,96	Lin	Yes	Hybrid in vacuum	*Installé*
CASSIOPEE #1	10 – 1000 eV	HU256	I 15-M	3,1	Circ./lin.	QP	HU256	*Installé*
CRISTAL	4 – 30 keV	U20	I 06-C	1,96	Lin	Yes	Hybrid in vacuum	*Installé*
phase 2								
PLEIADES #2	10 – 1000 eV	HU256	I 04-M	3,1	2 s	QP	HU256	*Installé*
PLEIADES #1	35 – 1500 eV	HU80*	I 04-M	1,6	Circ./lin.	QP	APPLE II	*Installé*
ANTARES #1	10 – 1000 eV	HU256	I 12-M	3,1	Circ./lin.	QP	HU256	*Installé*
CASSIOPEE #2	*45 – 1500 eV*	*HU80*	*I 15-M*	*1,6*	*Circ./lin.*	*QP*	*APPLE II*	*Installé*
DEIMOS #1	500 eV – 6 keV	HU52	I 07-M	1,6	Circ./lin.	Yes	APPLE II	*Installé*
LUCIA	500 eV – 6 keV	HU52	I 16-M	1,6	2 s	?	APPLE II	avr.-08
SIXS	4 – 30 keV	U20	I 14-C	1,96	Lin	Yes	Hybrid in vacuum	mai-08
MicroFOC #2	1 – 8 keV	HU44	I 14-M	1,6	2 s		APPLE II	mai-08
MicroFOC #1	*50– 1500 eV*	*HU80*	*I 14-M*	*1,6*	*Circ./lin.*	*QP*	*APPLE II*	*août-08*
CASSIOPEE #2	100 eV – 4 keV	HU60	I 15-M	1,6	2 s		APPLE II	août-08
GALAXIES	4 – 30 keV	U20	I 07-C	1,96	Lin	Yes	Hybrid in vacuum	août-08
TEMPO #2	1 – 8 keV	HU44	I 08-M	1,6	2 s		APPLE II	sept.-08
PROXIMA2 #1	5 – 15 keV	U24	I 10-M	1,96	Lin.	Yes	Hybrid in vacuum	janv.-09
SIRIUS	2 – 10 keV	HU34	I 15-C	1,6	2 – 4 keV	Yes	APPLE II	janv.-09
ANTARES #2	100 eV – 4 keV	HU60	I 12-M	1,6	2 s		APPLE II	mars-09
DEIMOS #2	350 – 900 eV	HU65	I 07-M	1,6	0,2 s/ 5Hz-10Hz	Yes	EMPHU	avr.-09
MicroXmou	100 eV – 4 keV	HU60 ?	I 06-M	1,6	Circ./lin.	QP	APPLE II	mai-09
HT PRESSION	10 – 50 keV	WSV50	I 03-C	2,0	Lin	Yes	Wiggler in vacuum	juil.-09
MicroScopium	4 – 30 keV	U20 ?	I 02-C	1,96	Lin.	Yes	Hybrid in vacuum	janv.-10

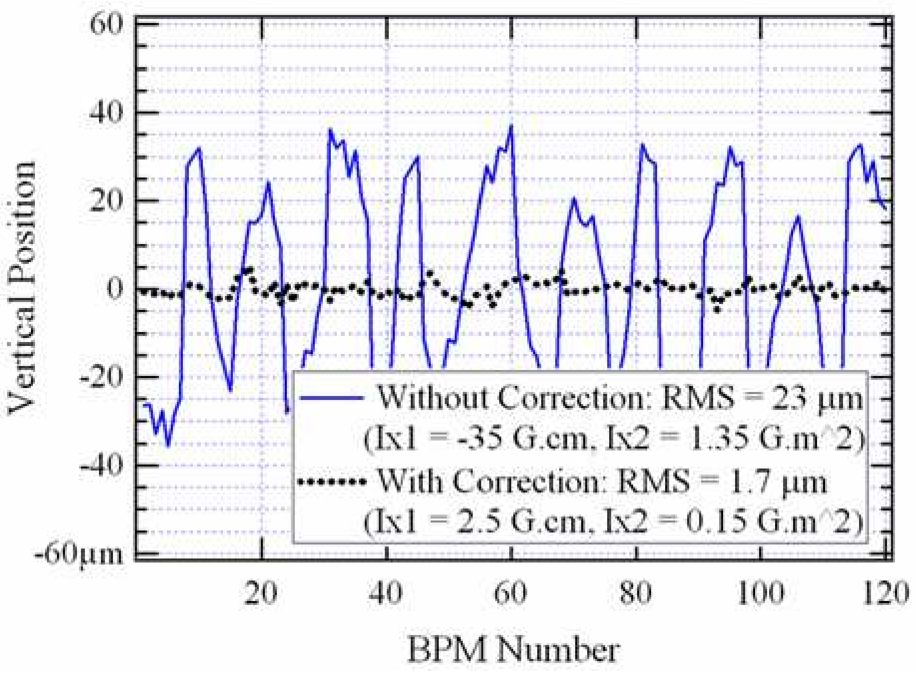
HU80-TEMPO Commissioning: Feed-Forward Correction Test

Minimal Gap (15.5 mm)
Helical Mode (Phase = 20 mm)

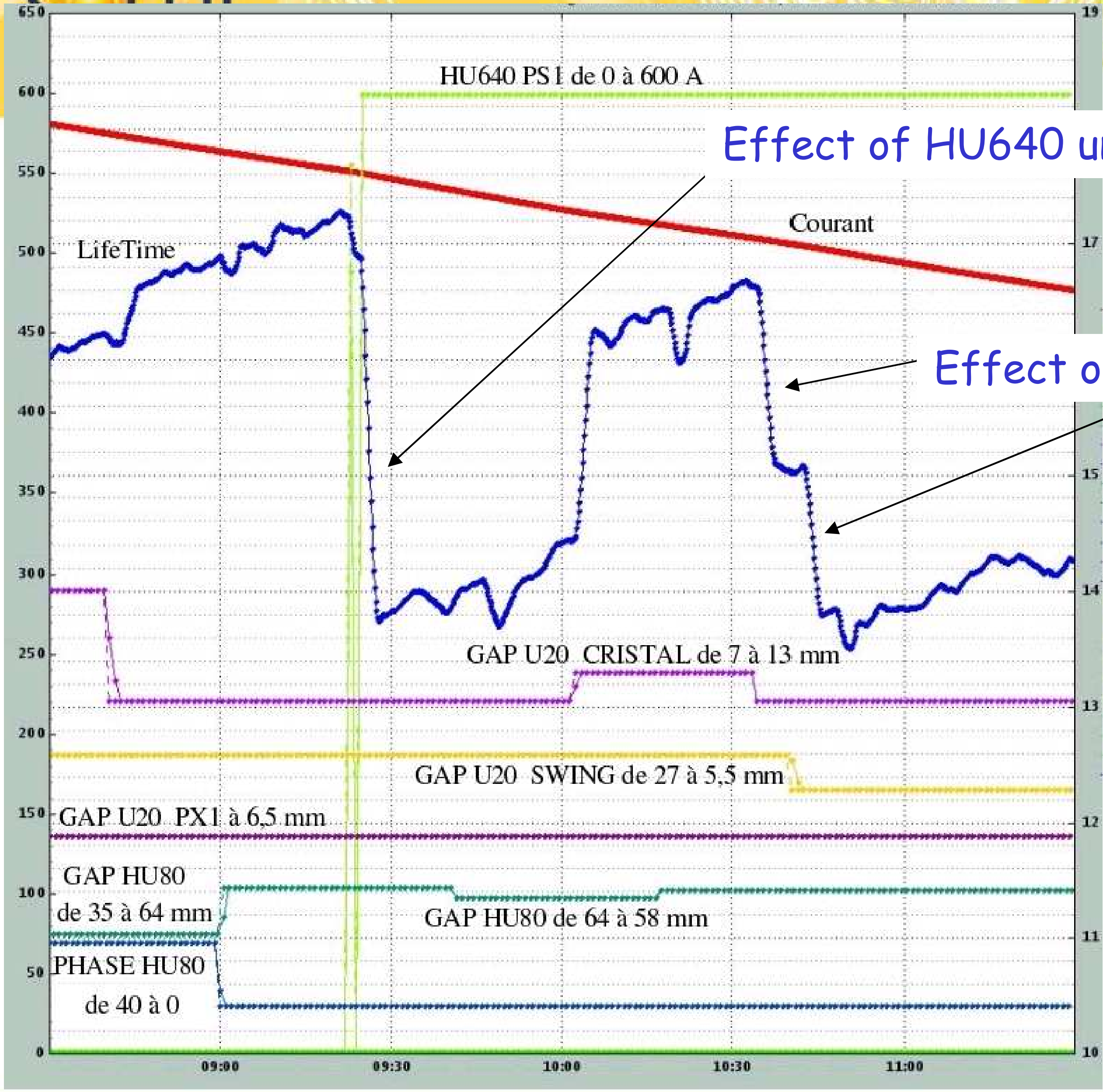
Horizontal BPM Data



Vertical BPM Data



Effects of ID devices



Beam lifetime reduction due to non linear effects from IDs

Tunes, chromaticities, coupling stability

- Feedforward & feedback systems

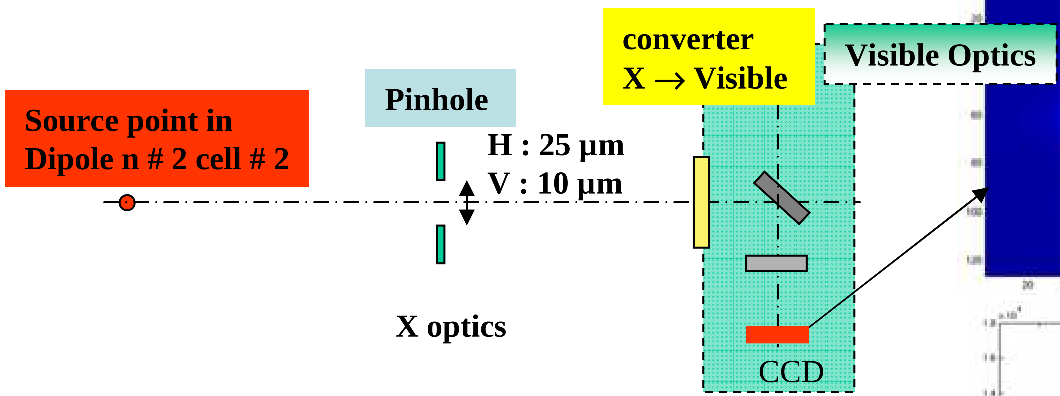
- Perturbation sources:
  - Insertion devices for all synchrotron light sources
  - Tune shift with current per bunch (impedance effect, …)
  - Injection, top-up (KEK, APS)
  - Ramping from one energy to another one (mostly for hadron colliders)

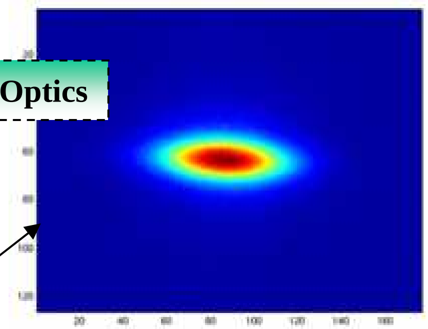
- On line tune measurement:
  - E-machine (excitation possible but has to be transparent for user)
    - Shaker magnets, striplines
    - One bunch excitation using fast transverse feedback (Elettra, SOLEIL, …)
  - Hadron machine: passive measurement since damping very long (LHC = 10^{-3})
    - Schottky detectors (cf. RHIC, LHC, …) See F. Caspers' talk on June 3rd
    - Tune Phase Locked Loop (PLL) with excitation level below 1 μm

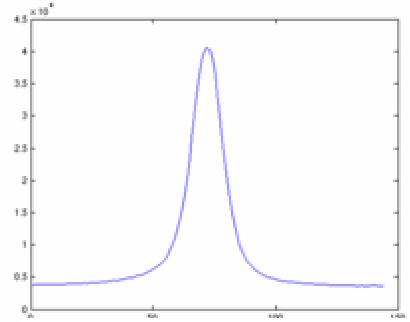
- On line chromaticity measurement

SOLEIL SYNCHROTRON Beam Emittance Measurements

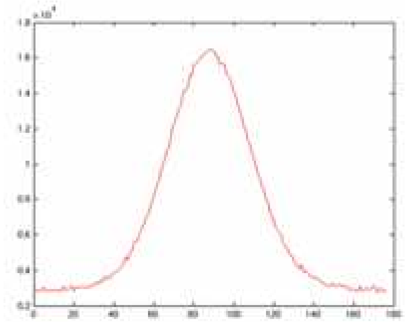
- On line coupling measurement
  - -Coupling Phase locked system (LHC) with excitation level below 1 µm
  - -Pinhole system (light sources) (imaging with no beam excitation)
  - -Use of skew quadrupoles as correctors







Measured Vertical Projection



Measured Horizontal Projection

See H. Braun's talk on June 2nd

Measuring ever smaller emittances

Use of off axis emission of vertical polarized radiation

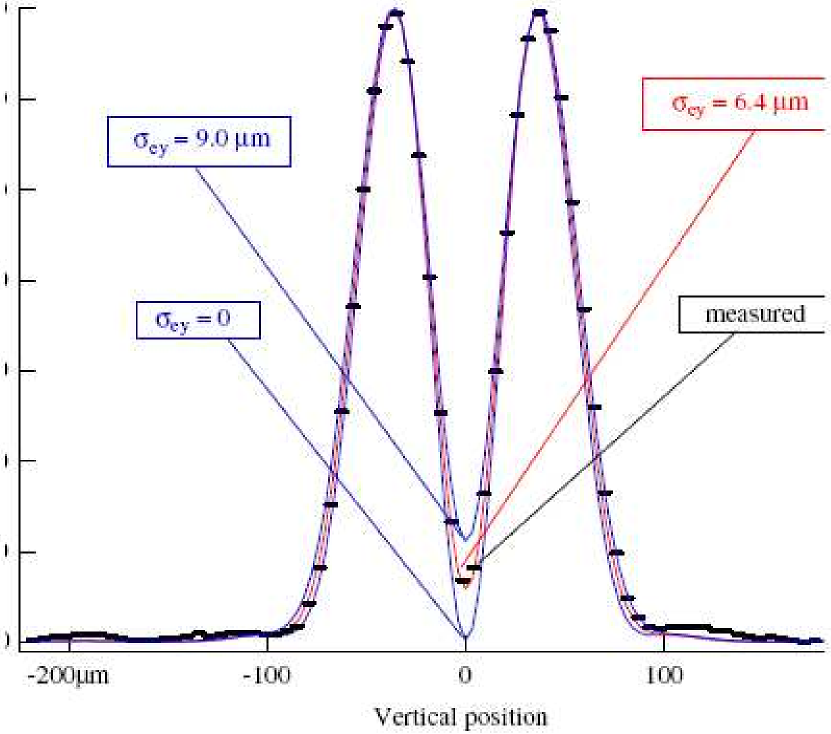
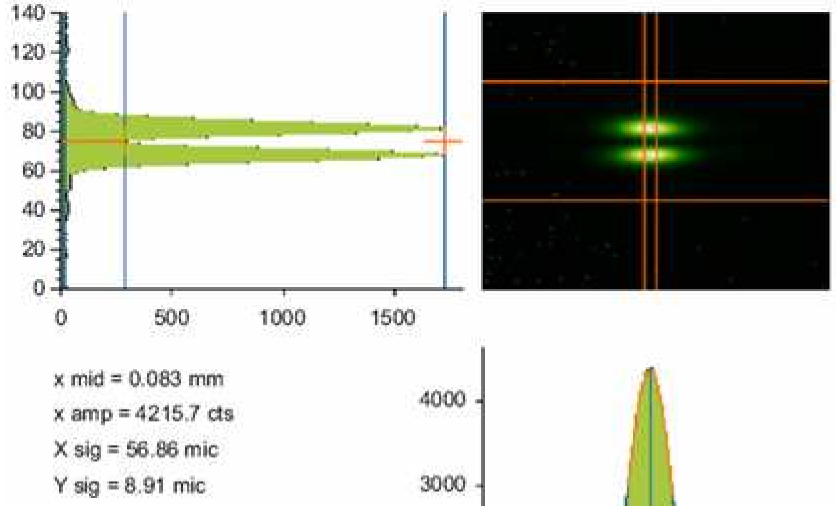
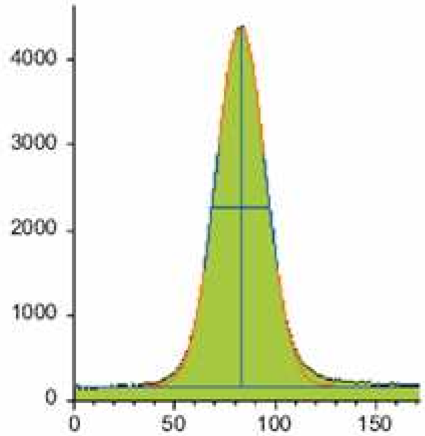


Fig. 8. Measured (marks) and predicted (three solid lines) vertical image profiles. $\lambda = 364\,\mathrm{nm}$; acceptance angles $3.9\,\mathrm{mrad_H}/9.0\,\mathrm{mrad_V}$. Machine conditions: 400 mA in top-up operation; tuned skew quads.





NIM A, in press

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Nested loops at LHC

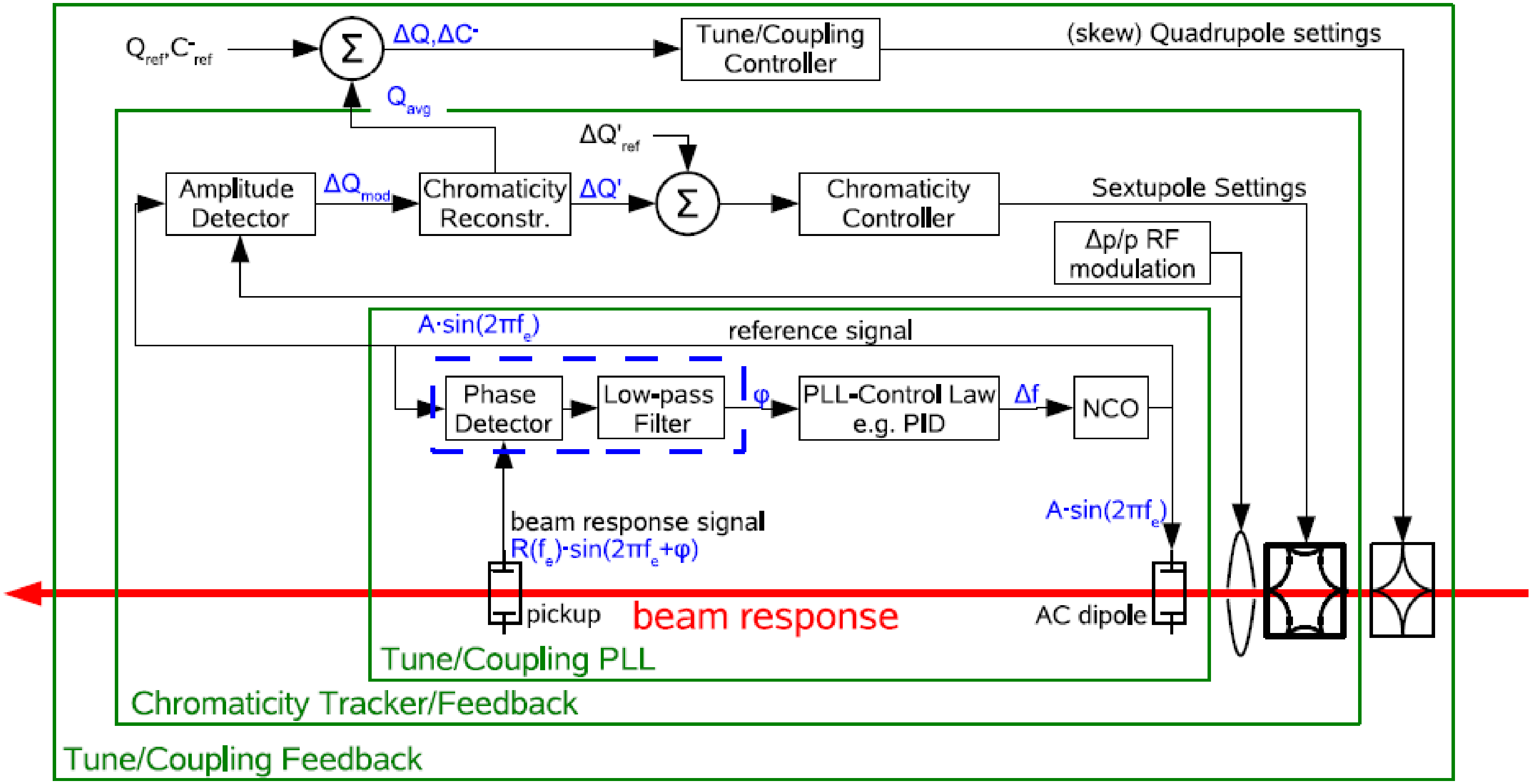


Figure 3: Nested loop scheme required for a coherent control of tune, coupling and chromaticity.

Courtesy of R. SteinHagen, Workshop care Q/Q' 2007

Collective effects: difficult part

See M. Lonza's talk on June 4th

- Interaction of the beam with the vacuum vessel (wake fields, impedance), with the residual gas
  - Trigger instability in transverse and longitudinal planes
  - Trigger single bunch and multi-bunch instabilities
  - Need of dedicated feedbacks, designs, …
- High density of current per bunch induces
  - Bunch lengthening
  - Instabilities (microwave, …) → current threshold
    →Bunch length measurement (streak camera, …)
- Beam/beam effect in colliders
- CSR effects and instabilities, beam break-up, …

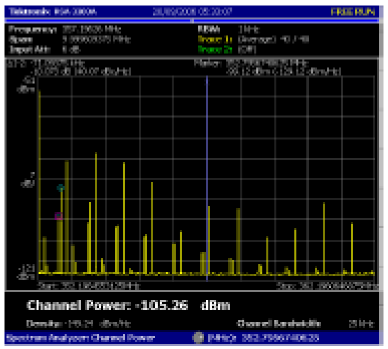
Impedance budget: model vs reality

- Thorough estimation of impedance contribution carried out a SOLEIL during the construction phase. **Measured ImZ a factor 2 larger in H, V & L planes**

Object	Number	Loss factor [V/pC]	$\langle P\rangle$500mA [kW]	$\Sigma\|Z_L/n\|$eff [mΩ]	(ZV)eff [kΩ/m]	$\Sigma\beta_v$*(ZV)eff [kΩ]	(ZH)eff [kΩ/m]	$\Sigma\beta_h$*(ZH)eff [kΩ]
Shielded bellows	176	8.72E-03	**1.17**	**48.30**	(0,03 0,14)	(52,8 246,4)	(0,01 0,06)	(15,8 112,6)
Flange	332	4.67E-04	0.12	11.65	(0,00 0,01)	(0,7 42,3)	(0,00 0,01)	(9,1 46,8)
Dipole chamber	32	1.64E-04	2.63E-03	0.48	(0,00 0,00)	(0,2 0,7)	(0,00 0,03)	(0,1 0,8)
SOLEIL cavity	1	2.20	**1.55**	9.30	(0,29 0,44)	(0,8 1,3)	(0,17 0,44)	(0,8 2,0)
BPM	120	3.31E-03	0.28	12.80	(0,02 0,04)	(22,4 37,2)	(0,0 0,0)	(0,0 0,0)
Medium section tapers	10	1.76E-03	1.24E-02	9.31	(1,35 3,41)	(85,5 215,9)	(0,01 0,56)	(0,4 33,7)
Long section tapers	3	7.32E-04	1.55E-03	1.52	(0,43 1,13)	(14,9 39,2)	(0,00 0,24)	(0,1 9,2)
In-vacuum ID tapers	4	0.25	0.76	**18.92**	(0,50 1,42)	(6,0 17,0)	(0,13 0,50)	(9,4 36,0)
SOLEIL cavity outer tapers	1	0.17	0.13	6.70	(0,49 1,56)	(2,6 8,3)	(0,01 0,29)	(0,0 1,6)
Resistive-wall	-	7.31	**5.17**	**85.50**	(21,8 101,5)	(135,2 743,5)	(7,1 51,7)	(34,8 376,3)
Injection zone	1	1.86E-03	1.42E-03	0.09	(0,00 0,01)	(0,0 0,1)	(0,10 0,72)	(1,2 8,7)
Pumping slots (at quadrupoles)	128	< 1,0E-07	< 1,0E-07	0.01	(0,00 0,00)	(0,0 0,0)	(0,00 0,00)	(0,0 0,5)
Total	-	-	9.20	204.6	-	(321,1 1351,9)	-	(71.7 628.2)

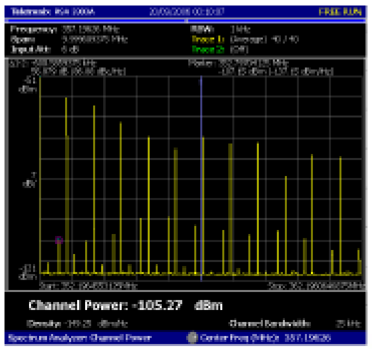
- Characterization of instability in terms of beam spectra

R. Nagaoka, EPAC 2004



← "RW dominated"

→ "Ion-induced dominated"

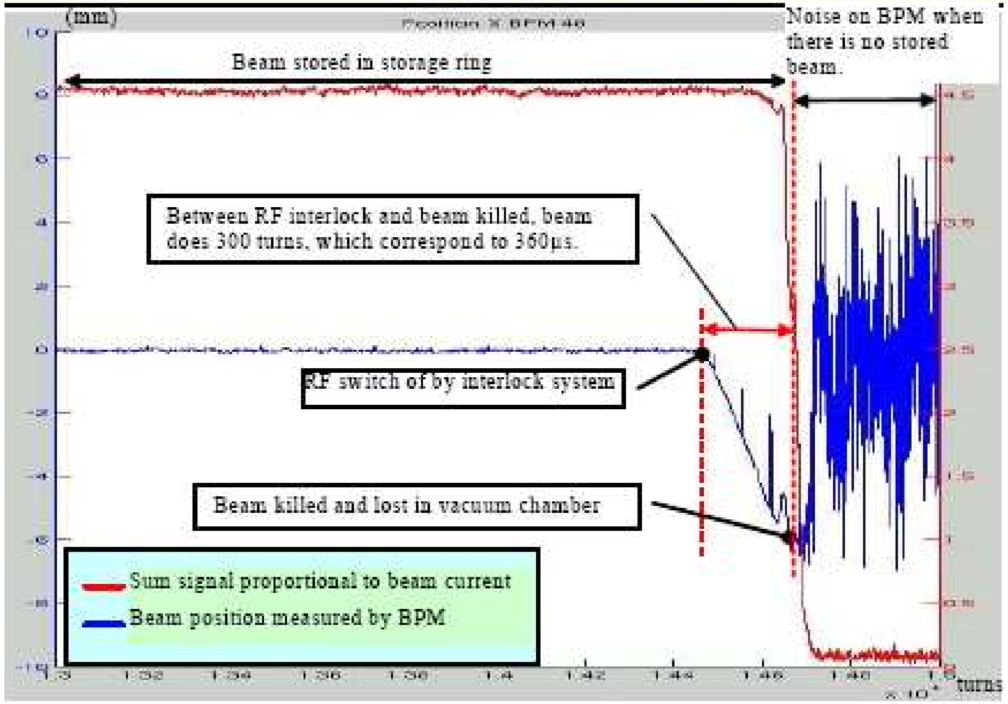


Daily operation

Aim: high beam availability, save operation and steady high performances

- Survey of the beam parameters (closed orbit, tunes, chromaticities, coupling, current decay, luminosity, injection efficiency, instabilities)
- Top-up operation for Light sources
- Dose rate
- Capacity to control and localize beam losses
  - Mandatory for large energy machine (cf. LHC, loosing the beam is forbidden)
    - Too much energy stored into the beam will quench magnets and/or destroy equipments
    - Activation of components, areas
    - Radiation safety issue
  - Machine Protection system See R. Schmidt's talk on June 5th
    - Thermocouple, Instabilities slot, Beam position, Pressure …
    - Limit maximum current stored into the accelerator
    - Beam dumpers

Capacity to understand unexpected beam losses (postmortem systems, Machine Protection system)



Dipac'07, Abiven et al.

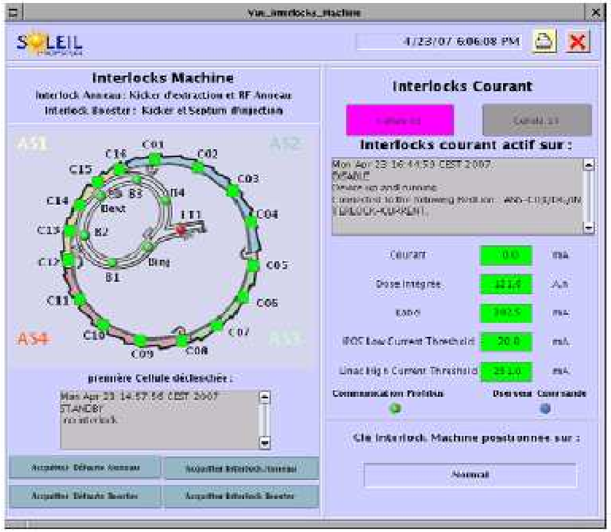


Figure 4 : Interlock Supervision application

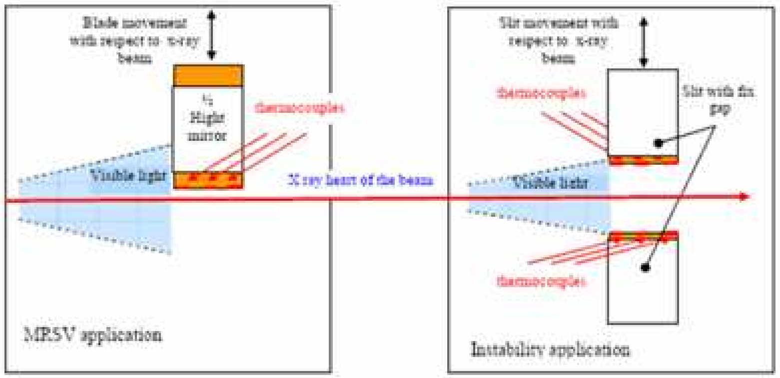


Figure 3 Description of the MRSV and the instability applications.

Systems relying heavily on diagnostics, dealing with thousands of parameters.
Need to have quickly information for decision making

Conclusion

- Model/Reality: a lots of improvements this last 10 years, nevertheless:
  - Difficulties to foresee all aspects
  - Static errors (modeled in a statistical way: impossible to get the real distribution)
  - Dynamical errors

- High number of perturbation sources
  - Known sources
  - Unknown sources

- By pushing so much accelerator performance, parameters become very sensitive to any drift in temperature, in tunes, …

- High performance can be reached only with the heavy help of lots of feedforward and feedback systems.

Fortunately, high performance diagnostics enable us to get a model close to reality

Diagnostics improvements help us to increase performance

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- W. Decking (DESY)
- H. Braun (CERN)