SOLEIL SYNCHROTRON

How it all started; hardware perspective

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Libera workshop; Smartno April 25, 2013

Outline

1. How did it start?
   a. Background
   b. Specifications
   c. Libera-electron concepts
   d. The people
2. Future BPM systems for Light Sources
   a. Photon beam position and angle
   b. SOLEIL stability
   c. Specifications for SIRIUS, the Brazilian machine
3. Conclusion

The BL (Before Libera ☺) History

- ☼ 1972-75: For DCI BPM system in Orsay, I used for the first time the concept of 4 electrodes switched to a single channel. The detector was analog but a 10 µm stability over about 1 hour allowed to bring the four DCI beams into interaction.

- ☼ 1981 to 2001: 11 more BPM systems designed and built, 6 of them together with Rok.

- ☼ October 2001: SOLEIL construction is officially approved.

SOLEIL BPM System Specifications

	Closed orbit correction	Global Feedback	First turns	Turn-by-turn for machine studies
Number of BPMs	120	48	120	120
measurement resolution (rms)	< 0.2 µm in 1 second	< 0.2 µm (residual on beam with 100 Hz feedback BW)	< 500 µm in a single measurement	< 1 µm in 60 seconds
Absolute accuracy with respect to quad	< 200 µm	×	< 500 µm	< 200 µm
Absolute accuracy after beam based alignment	< 50 µm	×	×	×
Measurement rate	> 1 per second	~ 1 KHz for 100 Hz feedback BW	1 per second	every 60s
Dynamic range	M: 200 → 600 mA T: 20 → 120 mA	M: 200 → 600 mA T: 20 → 120 mA	0.4 → 4 mA	4 → 100 mA
Current dependence within a 10 dB range	< 5 µm (< 1µm after calibration)	< 5 µm (< 1µm after calibration)	< 500 µm	×
8-h and 1-month drift at constant current	< 1 µm in 8 h < 3 µm in 1 month	< 1 µm in 8 h < 3 µm in 1 month	< 500 µm	×
Reproducibility versus bunch pattern	< 10 µm (< 1µm after calibration)	< 10 µm (< 1µm after calibration)	< 500 µm	< 500 µm

Guiding Concepts

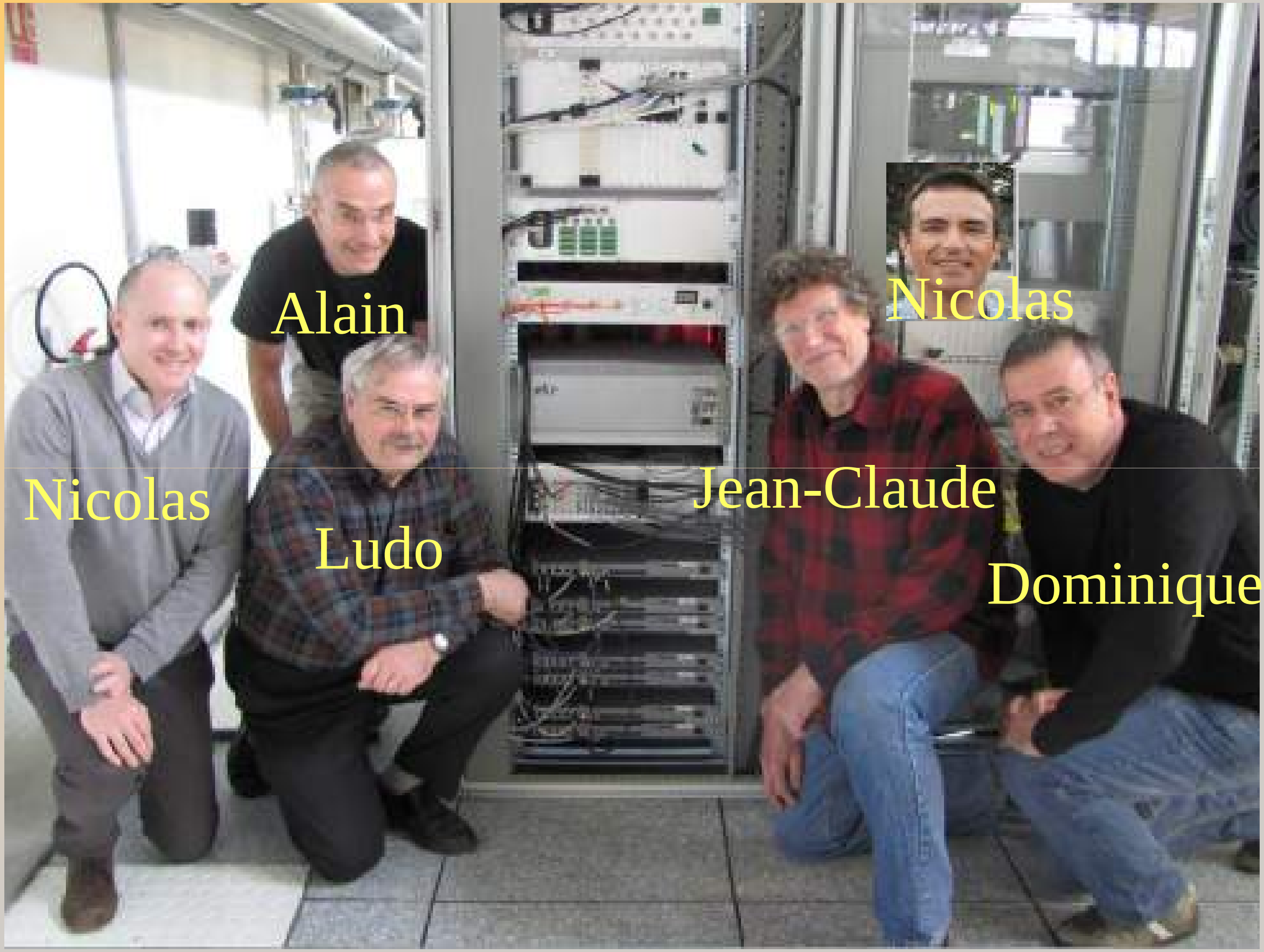
- Four Electrodes switched to 1 channel: Old DCI concept is the best for photon delivery, but not OK for turn-by-turn measurements required by machine physicists.

- Brain storming session in Orsay (mid 2002): J. Darpentiny proposed 4 electrodes switched to 4 channels. That combines the high stability switching scheme for photon delivery and turn by turn capability for machine physics studies.

- Digital electronics developed for SLS is better than the previous analog ones

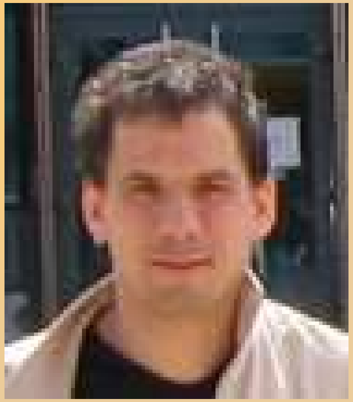
- Reliability: for a MTBF (Mean Time Between Failures) better than 3 months on the global feedback system with 120 BPMs, one needs an individual MTBF better than 30 years on each BPM (that actually scared us!)

The actors: SOLEIL in France



The actors: IT in Slovenia

Rok Ursic



Andrej Kosicek

Peter Paglovec

Mojca Franceskin

Uros Mavric

Borut Repic

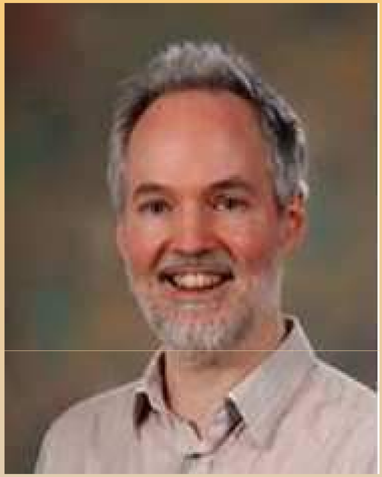
Sassa Bremec

Borut Solar

Some Development Steps

- European tender procedure ended up with only Instrumentation Technologies having good chances to meet the specifications.
- Design Review at SOLEIL
  - Guenther Rhem from Diamond was invited
  - July 2003: Diamond chose the Libera for their BPM system
- March 2004: Prototype acceptance tests in Nova Gorica (SOLEIL + IT)
  - A near 2-year cycle of weekly phone conferences (SOLEIL & IT) with written report started in March 2004. Andrej for IT, JC, Ludo, Nicolas H. and Dominique for SOLEIL.
- December 2004: Booster Commissioning SOLEIL with Andrej & Peter from IT.
- May 2006 storage Ring commissioning with Andrej & ? Form IT.
- The BPM system (1st turn capability) was the major diagnostic for storing the beam in a very short time.
- A lot of work remained in 2006, especially to commission the interlock feature.

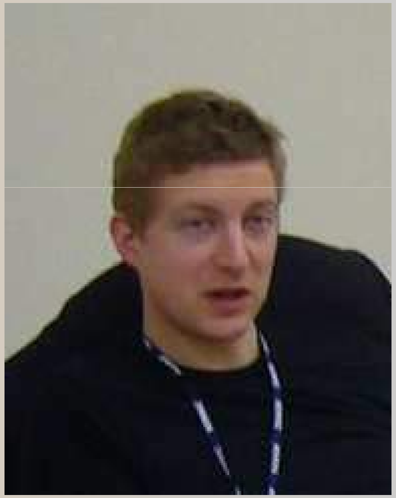
The actors: Diamond in UK



Michael Abbott

Guenther

Isa Uzun



James Rowland

2007-2013: Following versions of Libera

- Libera Brillance: actually achieved the submicron stability
- Libera Photon extended fast orbit feedback capability to photon BPMs

+ many new members join the Libera family

2013-2020: Future Light Sources, Ultimate Storage Rings (USR)

New 3rd generation light sources with very low emittance are in contruction: NSLSII (Brookhaven, USA), MAXIV (Lund, Sweden), SIRIUS (Campinas, Brazil)

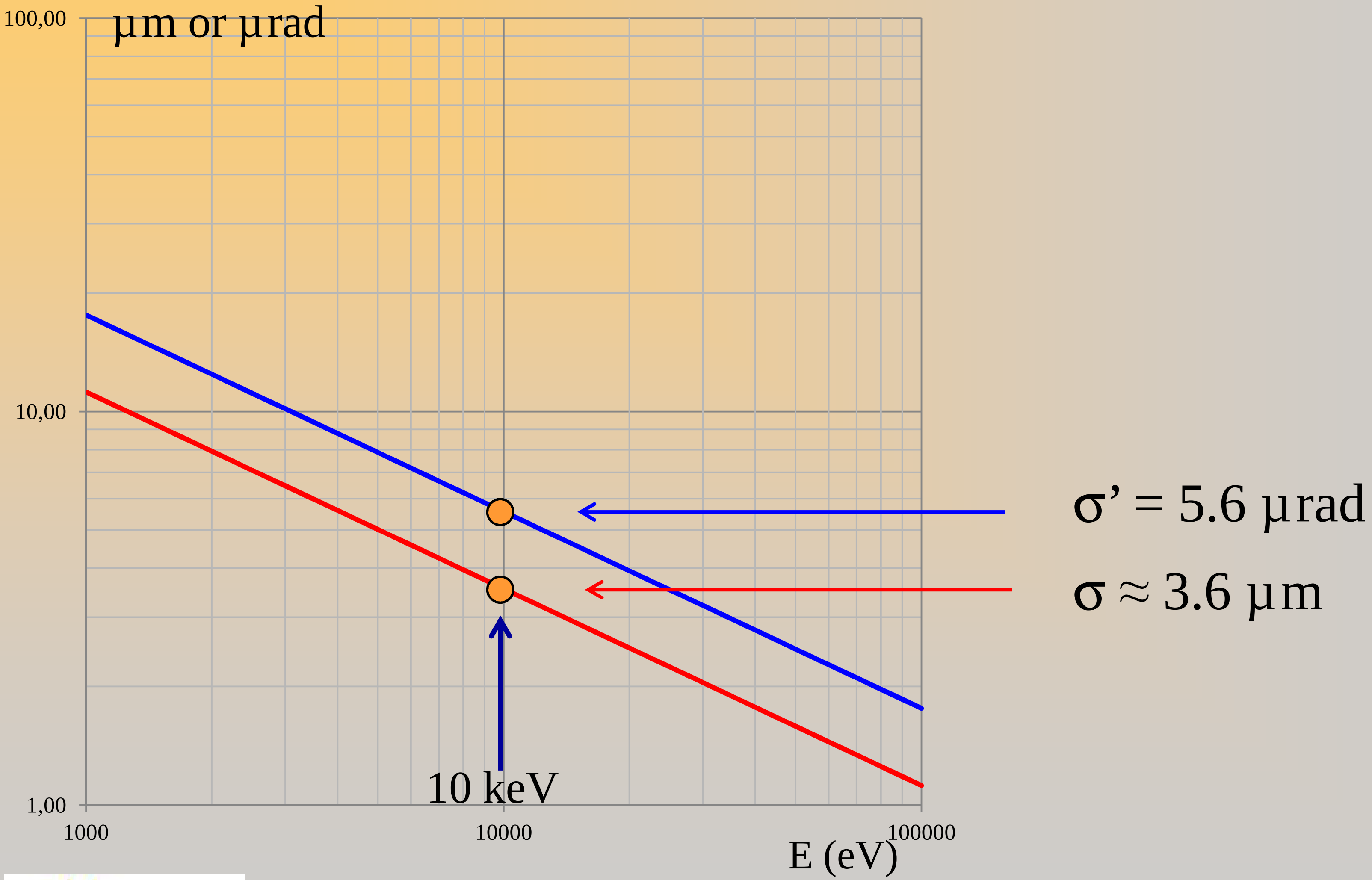
or nearly funded: BAPS (Beijing, China)

Photon beam emittance ε = source point size * divergence

Diffraction limit of 10 keV photons corrresponds to ε =10 pm.rad

Machine	ESRF, SOLEIL	NSLS II	MAX IV	SIRIUS	BAPS
Emittance H in pm.rad	~4000	2000 to 500	320	280	~10

Size and Divergence limits of 10 keV Photon Beam from a 2m undulator



Stability Requirements of BPMs & Electronics

- Orbit Feedback locks the beam on the BPM center
- Beam stability cannot be better than BPM stability
- BPM stability requirements are usually:
  - beam position stability better than photon beam size /10
  - beam angle stability better than photon beam divergence / 10

We need numbers:

- Let's take the smallest source point size and divergence of 10 keV photons out of a 2 m long undulator

Divergence = 5.6 µrad

Size ≈ 3.6 µm

Beam Position & Angle Stability Requirements for Sirius, the Brazilian New Machine

- Standard requirements of 1/10 beam size and divergence in
  - for undulator length = 2 m
  - vertical plane: size and div. = 10 keV diffraction limit

$\sigma_y/10 \approx 360$ nm $\sigma_y'/10 \approx 560$ nrad

Angular resolution of a pair of BPMs = SQRT(2)*σ_{BPM} / BPM separation

Then, $\sigma_{BPM} \leq$ BPM separation /SQRT(2)

Then vertical BPM resolution < 360 nm

  - Horizontal plane: Electron beam size and divergence are dominant

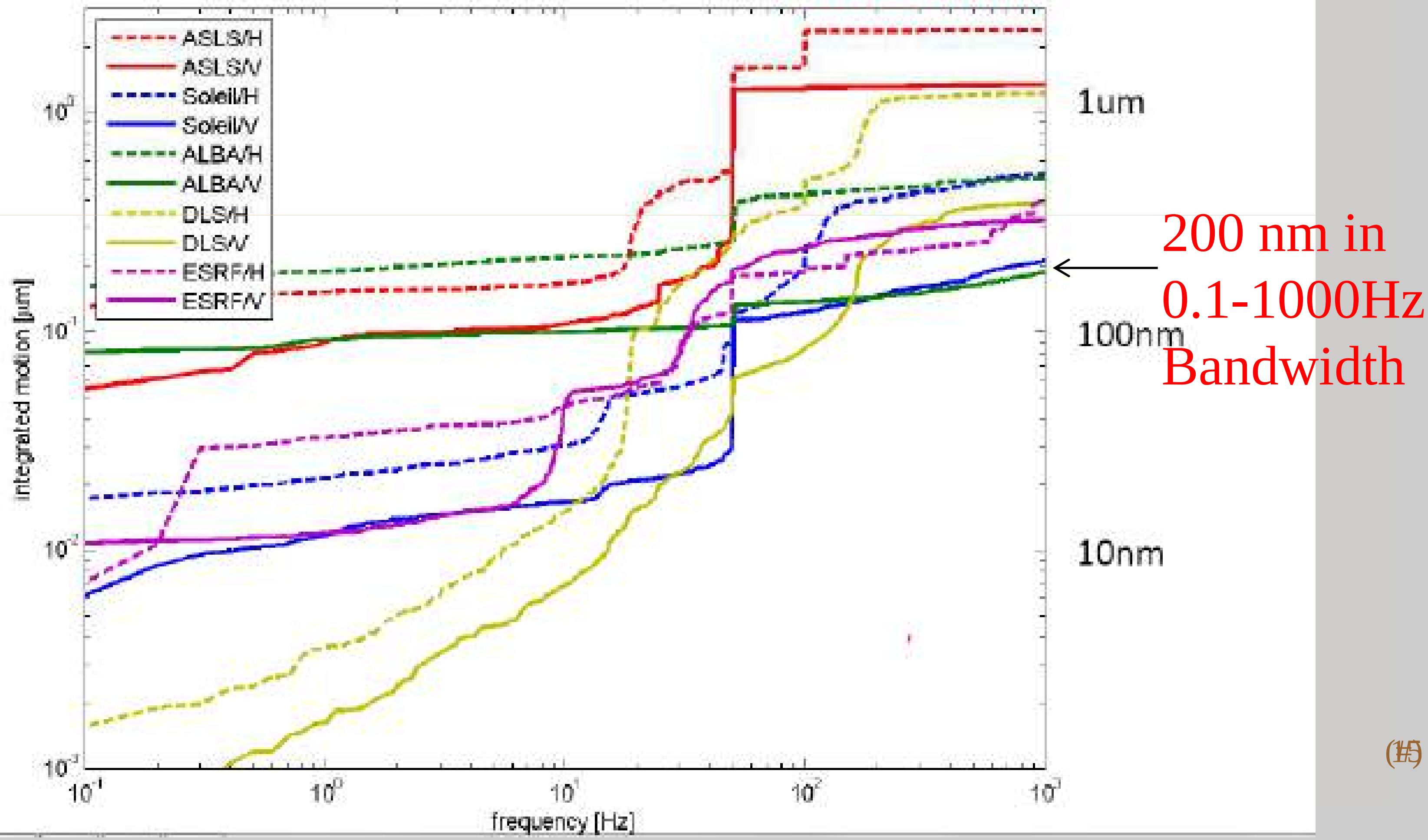
$\sigma_x/10 \approx 3$ µm

$\sigma_x'/10 \approx 0.4$ µrad requires ~1 µm resolution for a 3 m BPM separation

Then Horizontal BPM resolution < 1 µm

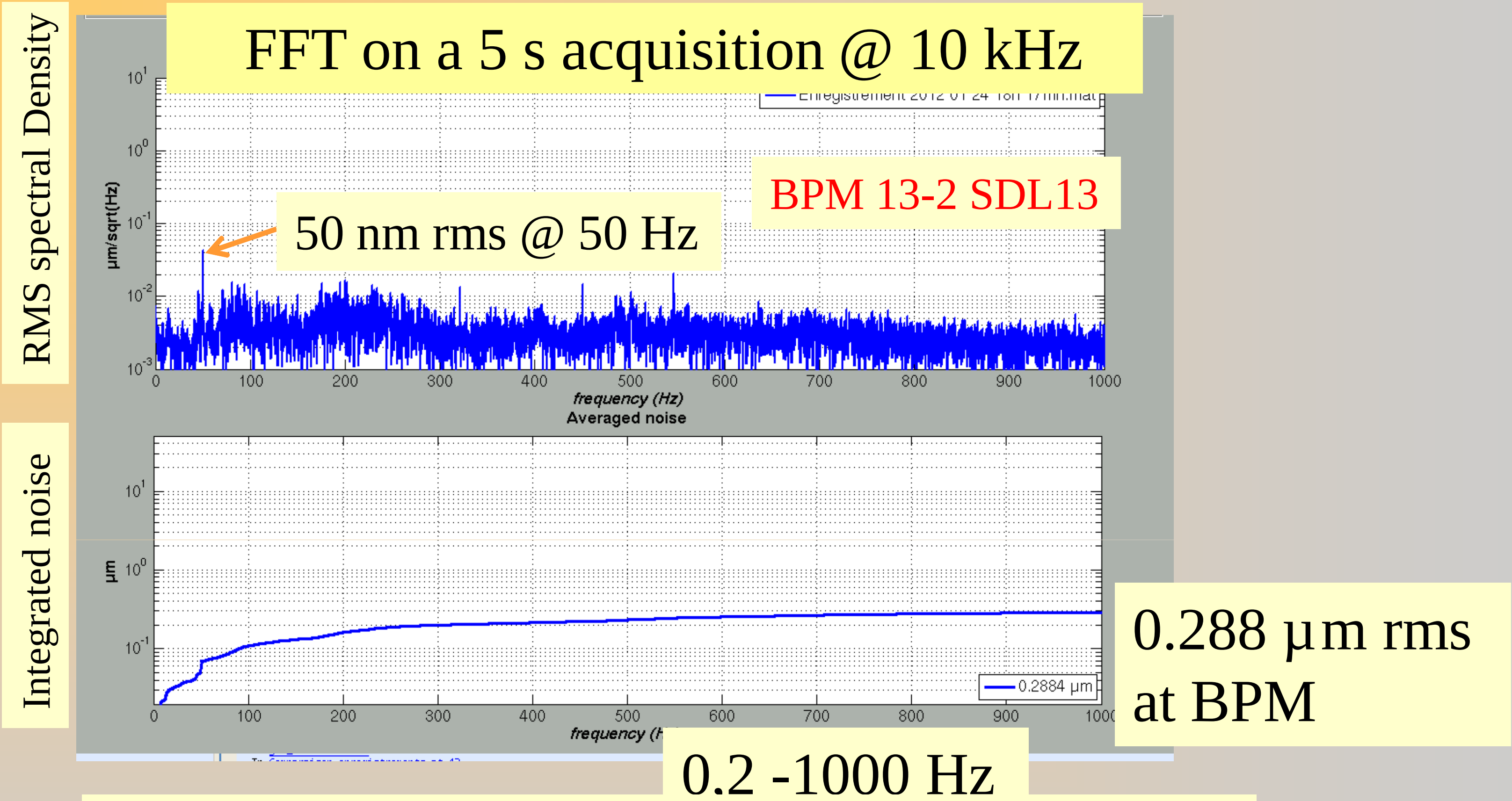
Courtesy G. Rehm, SRI2012

A snapshot of beam stability at various 3rd generation light sources



Example of short term stability (SOLEIL)

FFT on a 5 s acquisition @ 10 kHz



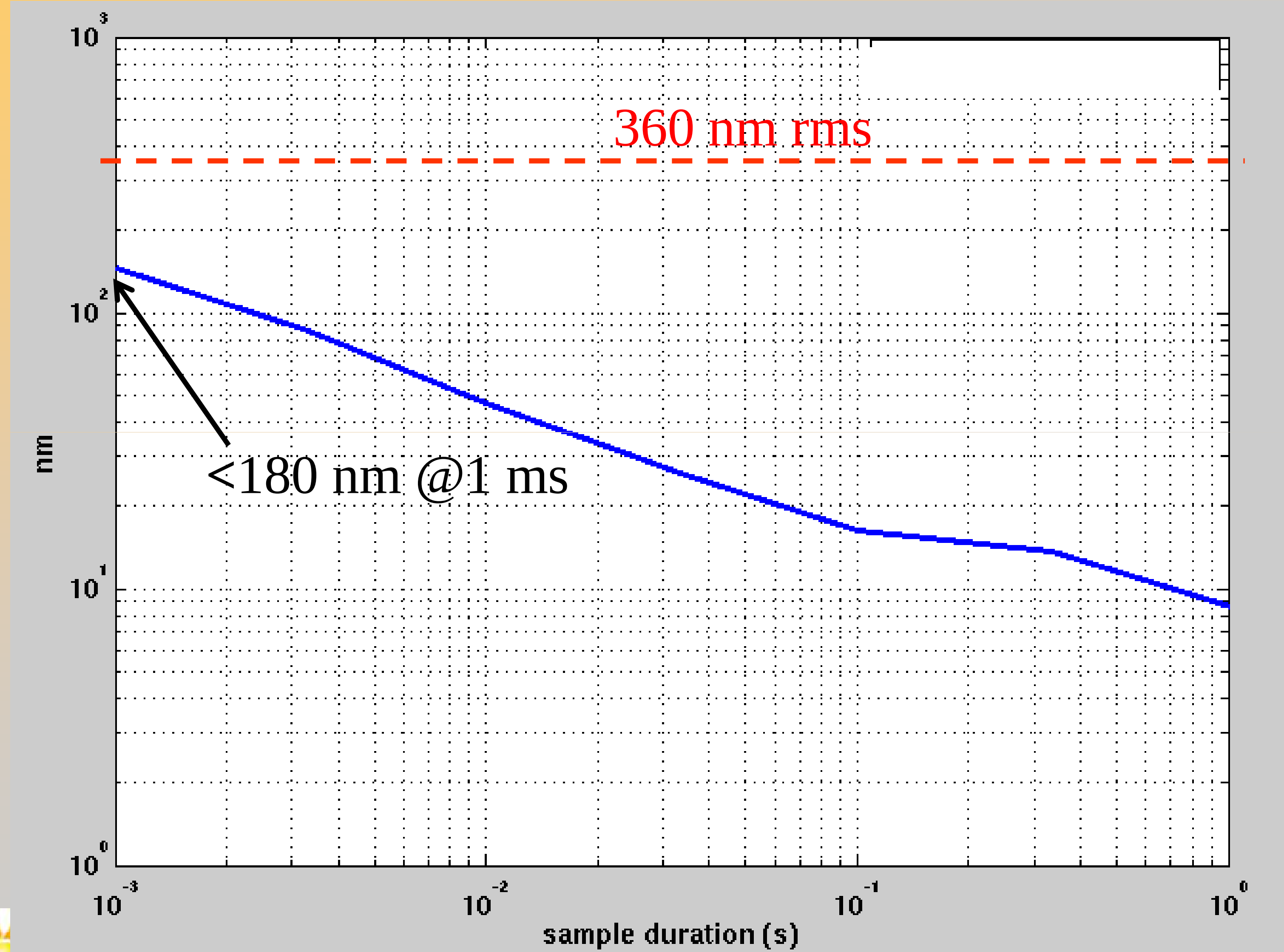
Vertical noise

Measured on BPM 13-2: 0.288 μm

Undulator beamline source pt: < 0.200 μm

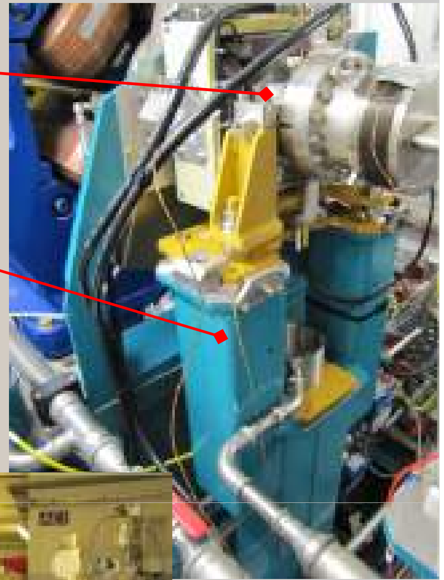
Bending magnet beamlines < 0.500 μm

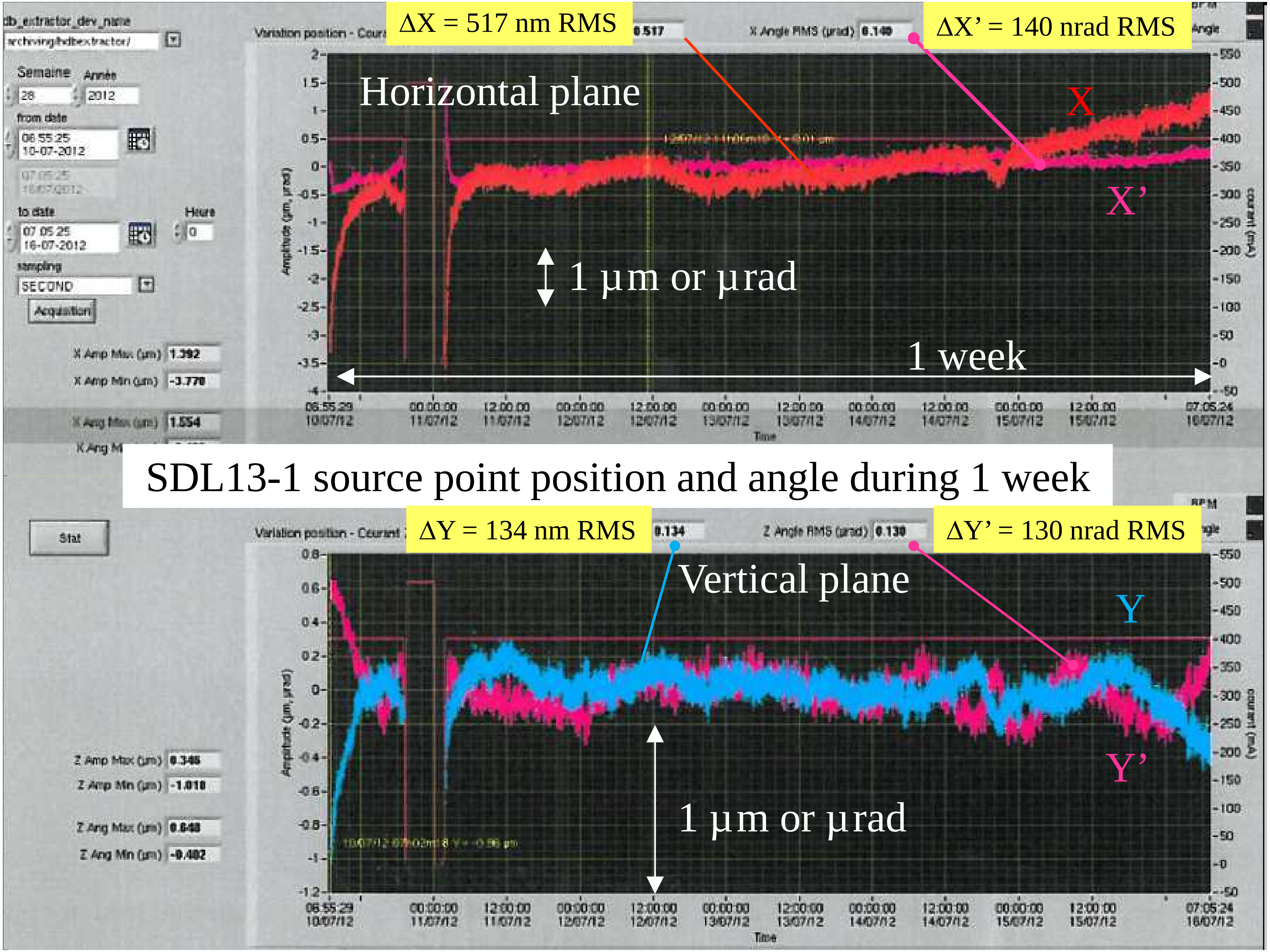
RMS Short Term Stability Versus Acquisition Time (position is averaged during that time)



Special Invar BPM and XBPM Stands for two long Beamlines: Anatomix and NanoScopium

- 4 Invar BPM stands and cradles for Reliable measurements of long term beam stability (at each end of the two undulators)
- 1 XBPM and its stand in Invar on NanoScopium Frontend (FMB design with Invar vacuum chamber).
- XBPM came in operation last October, but a local stability problem prevented evaluation of the machine stability based on that key source point
- The machine stability evaluation comes from BPMs on the Nano-tomography straight section (it cannot be checked with an XBPM yet)





SDL13-1 source point position and angle during 1 week

Beam Quality Criteria for Beam Stability at SOLEIL

- We recently defined the Beamline useful beam time : It is the Percentage of Beam Time that fulfills the Beamline requirements.
- A realistic number must be > 90%
- All source points of the ring are archived.
- In this way, we can estimate the Useful Beam Time for future Beamline by checking the time their requirements would have been met in 2012, for example.
- Then, we discuss again the requirements and/or the possible machine improvements, an/or possible beamline improvements.

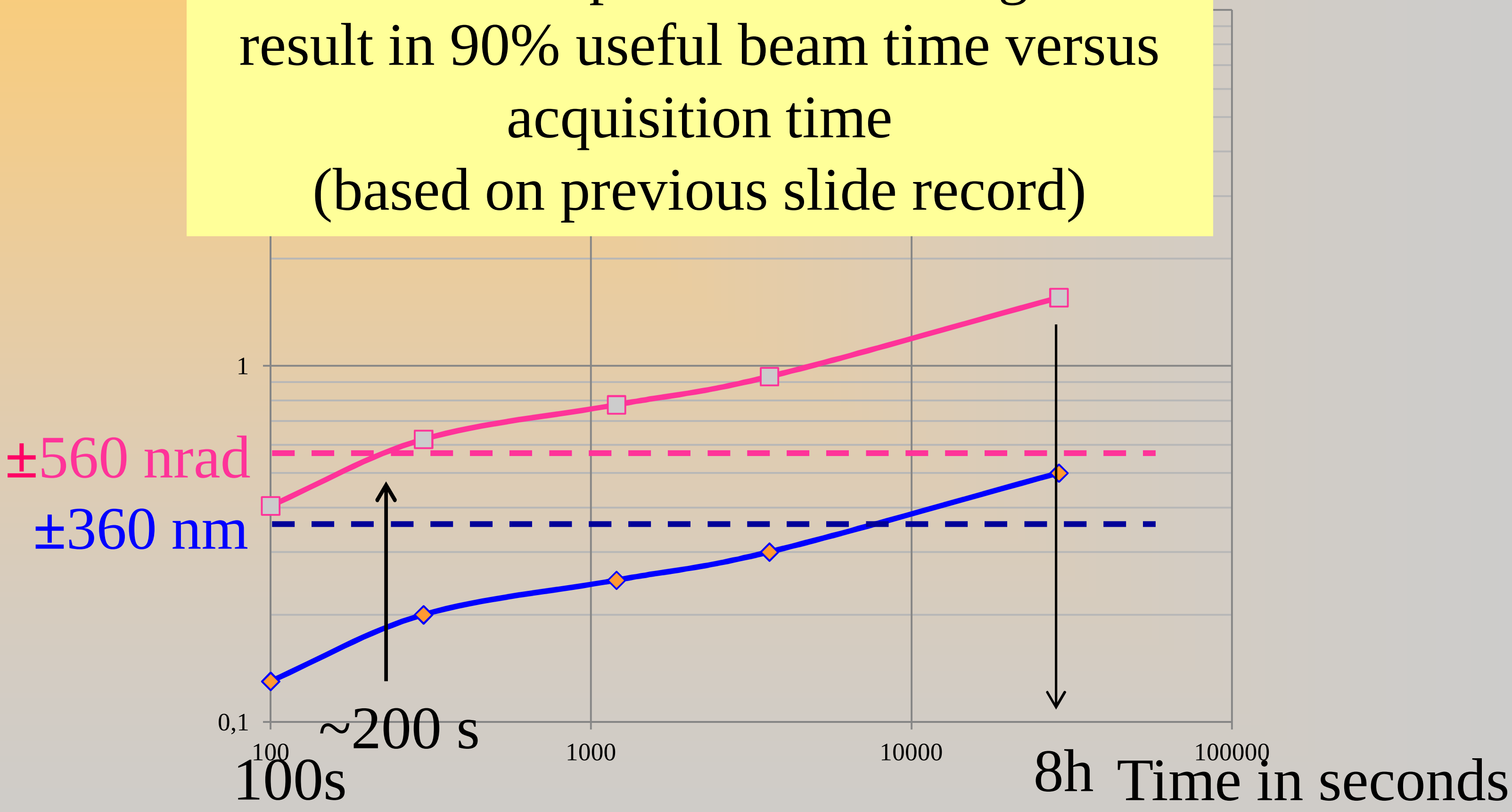
SOLEIL Most Critical Beamline Stability Requirements (updated 22/04/2013)

paramètre ↓	PX1	PX2	Anatomix	Nano scopium	Tightest wrt Beam size
Temps acq.	5 mn	de 10 à 30 mn (90% et 10% des utilisations)	10mn (pos. & ang); 6h (σ, σ')	8 hours	
Position H	35 µm rms	30 µm rms	± 12 µm	± 5 µm	$\sim\sigma_x/125$ *
Angle H	3 µrad rms	4 µrad rms	± 4 µrad	± 5 µrad	$\sim\sigma'_x/15$ *
Position V	1 µm rms	1.3 µm rms	± 1 µm	± 1.5 µm	$\sim\sigma_z/25$ *
Angle V	±1.5 µrad	1 µrad rms	±1 µrad	± 1.5 µrad	$\sigma'_z/14$ *
Taille	/	/	± 5% en 6h***	± 2% (besoin info pour acquisitions « stop and go »)	
Divergence	/	± 10%	± 5% en 6h (99% manips)	± 2%	
% de faisceau utile**	100%	99%	95%	?	

* σ is the beam size and σ' the divergence of the PHOTON Beam at its source point and the highest user energy. Equivalence: ± 2.5 µm (or µrad)≈ 1 µm rms (or µrad rms)
** mesured on archived data of week 2012/37
*** tolerates 1% of acquisitions out of tolérances in a 6h lo of data.

~1-minute-to-8-hour Beam Stability Versus Acq. Time

± tolerances in position AND angle that result in 90% useful beam time versus acquisition time
(based on previous slide record)



USR Orbit Feedback Systems

- Probably similar to existing systems
  - Bandwidth extension to 500 Hz or more would supress better the 50Hz spectrum lines of the mains an its harmonics (60 Hz in Americas)
  - Vacuum chamber space with thin stainless steel walls or ceramic gaps need to be reserved for fast correctors
  - If a square correction matrix is not possible, the correction algorithm should favor the few beamlines with tightest stability requirements. This is done with different « weights » depending on the BPM.
  - Beam Instrumentation and feedback systems should go to the Beamlines too.

SOLEIL Feedback Characteristics

Parameters (H,V)	SOFB	FOFB
BPM #	122, 122	122, 122
Corrector #	57, 57 **(in arcs)**	50, 50 **(in straight sections)**
Sing. Value #	57, 57	46, 47
Corrector maximum strength	1.0, 0.7 mrad	**28, 23 µrad**
Correction rate	0.1 Hz	10 kHz
Bandwidth	0-0.05 Hz	0-200 Hz
Efficiency	IDs and arcs	Mostly IDs

SIRIUS BPM electronics specifications - Last update: 2013-March-22

BPM system specifications	Fast acquisition or slower (users operation)	Turn by turn (machine studies)	Single-Pass (commisssioning)	comments
absolute accuracy wrt alignment references	Does not depend on the BPM system	N/A	< 0.5 mm before BBA	BPM mechanical alignment references & BBA & BCD & BPD
Resolution (rms position fluctuations 0.1 to 1000 Hz)	< 0.14 µm	< 3 µm	N/A	Beam current > 50 mA, multi bunch mode, 3/4 filling pattern
Resolution for 1st turns and single-pass	N/A	N/A	< 0.5 mm	200 ns bunch train, 1.5 nC total charge
1 hour stability	< 0.14 µm	N/A	N/A	sigma/10, centered and 0.5 mm off-center beam
1 week stability	< 5 µm	N/A	N/A	Minimum time between 2 BL realignments, centered and 0.5 mm off-center beam
Beam Current Dependence before top-up (BCD)	< 1 µm	N/A	N/A	Centered or 0.5 mm off-center beam & 30% beam current decrease; 50 mA < Ib< 200 mA
Beam Current Dependence with top-up (BCD)	< 0.14 µm	N/A	N/A	Centered and 0.5 mm off-center beam; 50 mA<Ib<500 mA
BCD for BBA from 20 to 500 mA	10 to 15 µm	N/A	N/A	BBA current = 20 mA ?; defined by vacuum group (crotch absorber?)
Bunch Pattern Dependence (BPD)	< 5 µm	N/A	N/A	Minimum time between bunch pattern changes = 1 week
H to V coupling (DY for DX=1mm)	< 10 µm	< 10 µm	N/A	BPM block + electronics

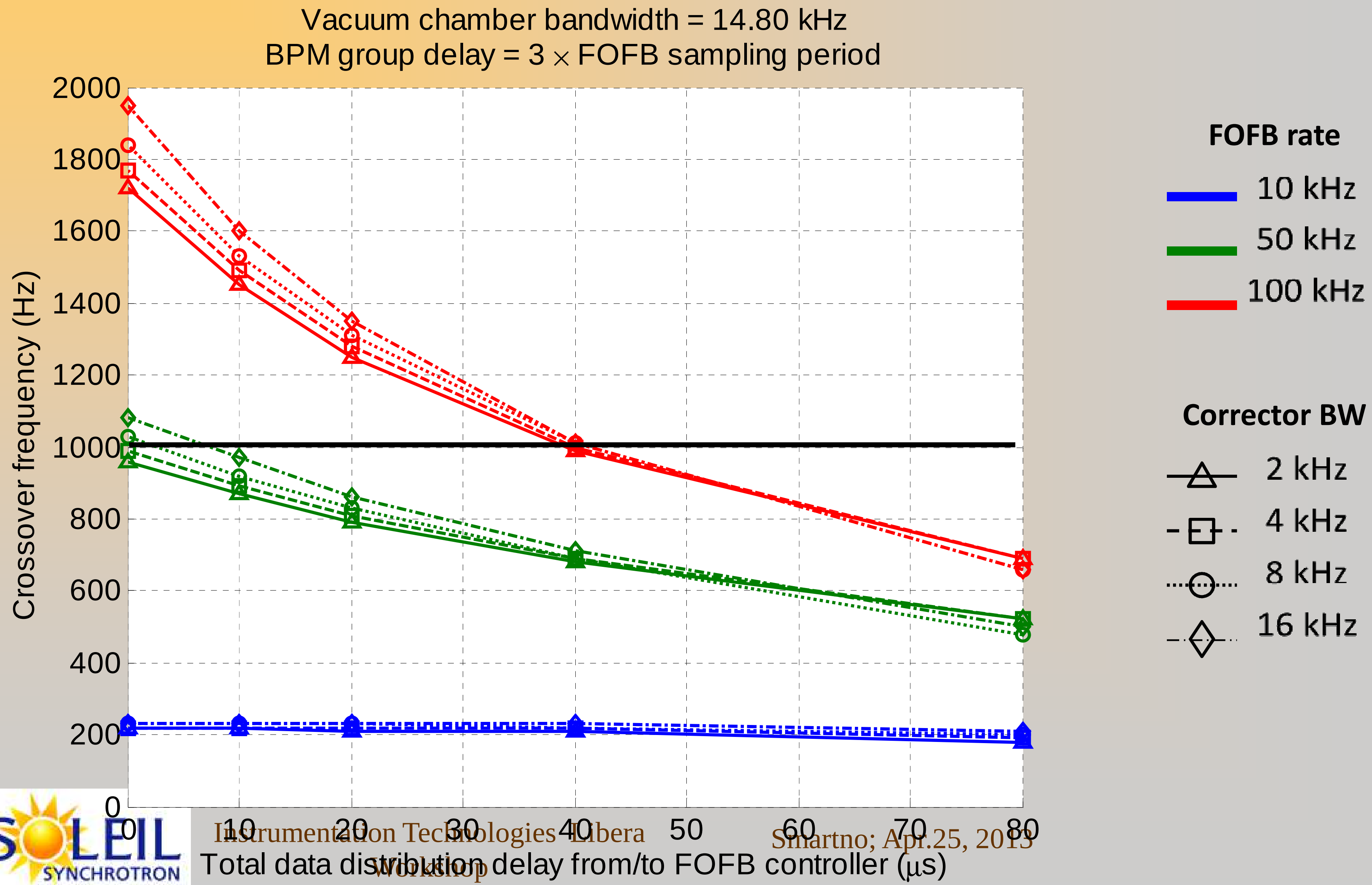
Comment 1: all the mentioned beam offsets are wrt the BPM electrical offset

Simulations for SIRIUS Fast Orbit Feedback (Courtesy Daniel Tavares)

- **Closed-loop specifications:**
  - PI controller
  - Stability: phase margin > 50^0
  - Peak disturbance amplification < 5 dB (≈ factor 1.8)

- **Fixed parameters:**
  - Vacuum chamber bandwidth (7.4 kHz and 14.8 kHz)
  - Orbit correction calculation latency (1 FOFB period)
  - BPM digital filter latency (3 FOFB periods)

SIRIUS FOFB Simulations (Courtesy Daniel Tavares)



Tentative specifications for SIRIUS (D. Tavares)

- Vacuum chamber bandwidth?

  Tentative answer: 7.4 kHz (50 µm copper coating on ceramic chamber)

- Power + magnets bandwidth?
- Data distribution network delays?
- Orbit correction calculation algorithm period?

  Tentative answer: 5 µs (full parallel Matrix multiplication + PI on FPGA)

- BPM filters group delay?

  Answer: 30 µs @ 100 kHz update rate

- FOFB sampling rate?

  Tentative answer: 100 kHz

Conclusions

- We are all very proud to have contributed to the BPM electronics that is presently the state of the art.
- People from labs and from industry showed they can team-up and design a product that benefits the whole community.
- Trust in each others has been the key for success.
- The present performance is not far from what is needed in the next one or two decades.
  - Stability should reach ~ 0.2 to 0.1µm in one hour
  - Reduced delay for wider FOFB bandwidth can be achieved with higher switching electrode rates (100 kHz at SIRIUS).
  - The reliability is a very important parameter. The whole system MTBF including FOFB should be > 3 months and each failure quickly fixed.