SLS Diagnostic Devices and Orbit Feedback Control

Tri-centre workshop on beam position monitors for medium energy synchrotron sources

29th-30th September 2003
Orsay, France
T. Schilcher

Outline

- Stability Requirements for SLS
- Sources for Orbit Distortions
- Diagnostic Devices to Measure Orbit Distortions
- Orbit Feedbacks

Stability Requirements

- photon source fluctuations one order of magnitude below resolution of experimental stations
- angular stability: $\Delta\Theta_{beam} < 1\ \mu rad$
- position stability:

  1/10th of vertical beam size at location of insertion devices

  → low beta ID: vertical beam size ~10 μm (1% coupling)

  → **1 μm RMS in vertical plane**

- suppress oscillations up to 100 Hz by factor of 5
- fast compensation of orbit distortions due to user controlled ID movements

Sources for Orbit Drifts and Distortions

1. **Long term motions** (weeks-years):
   - ground settlements
   - seasonal ground motions
2. **Medium** (minutes-days) and **short term motions** (milliseconds-seconds):
   - thermal drifts of storage ring components (girders, magnets, vacuum chambers…)
   - RF drifts
   - ground vibrations, cooling water
   - injector operation
   - ID gap changes
3. **High frequency motions** (sub-milliseconds):
   - single and multi-bunch instabilities, synchrotron oscillations
   - pulse power sources

Orbit Stabilization

1. **Long term motion:**
   → realignment of storage ring

2. **Medium and short term motion:**
   - temperature stabilization of tunnel and experimental hall
   - top-up operation

   → minimizing thermal transients

   - slow and/or fast orbit feedback on electron beam position

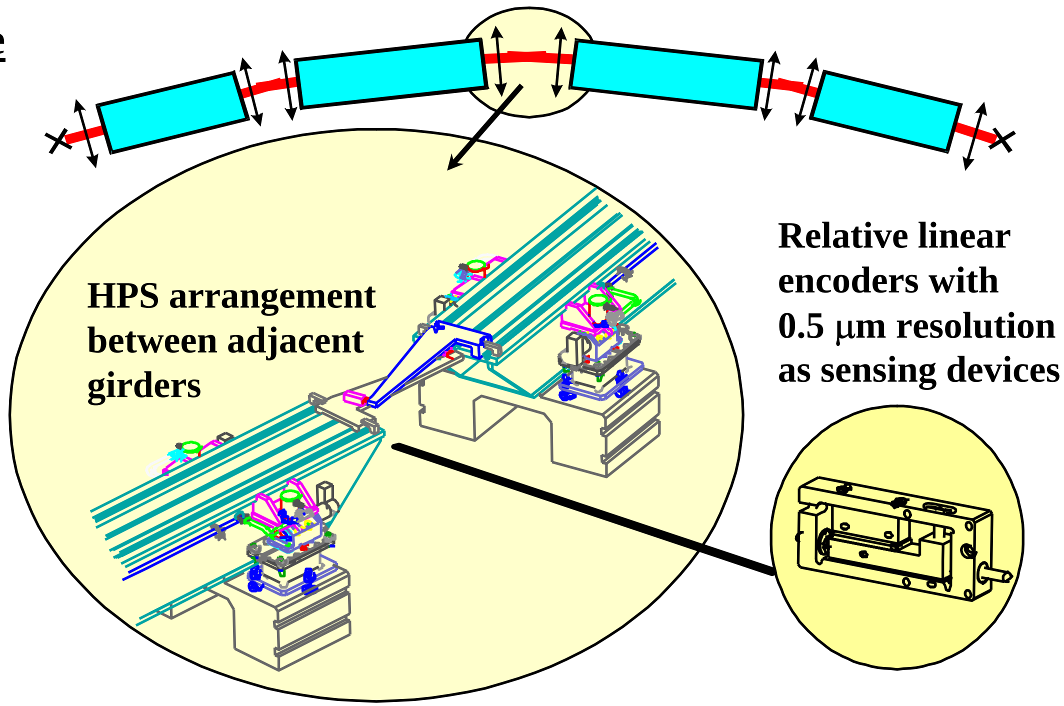
(3. **High frequency motions:**
   → multi-bunch feedback systems, 3rd harmonic cavities)

Orbit Stabilization: Long Term Motions

SLS: measurement of girder positions

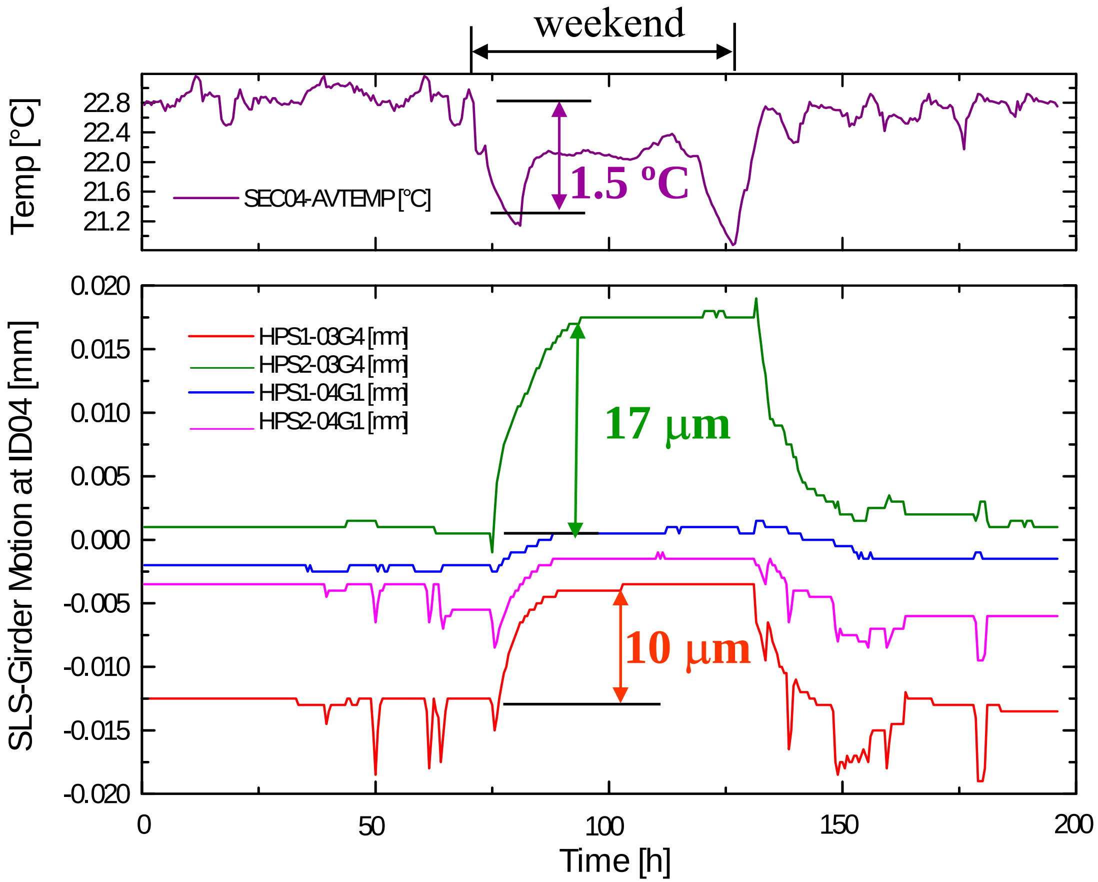
- hydrostatic leveling system (HLS)
- horizontal positioning system (HPS)

"Train link" over one storage ring sector



Horizontal Positioning System

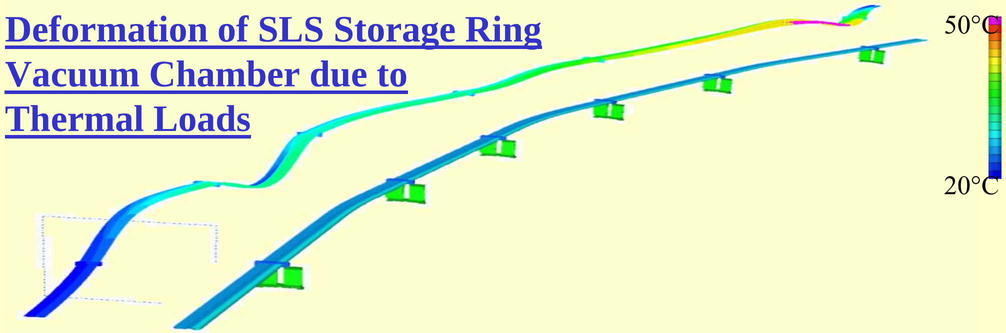
Girder Motion at ID04 as a Function of SR Tunnel Temperature



- storage ring operation stopped over weekends in the early days of SLS commissioning
- tunnel temperature set-point changes have direct influence on beam orbit due to alignment changes
- realignment possible by means of girder movers

Orbit Stabilization: Medium Term Motion (1)

Deformation of SLS Storage Ring Vacuum Chamber due to Thermal Loads

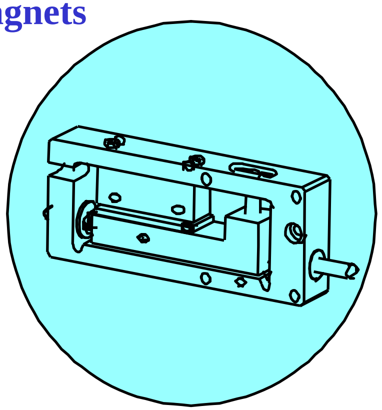


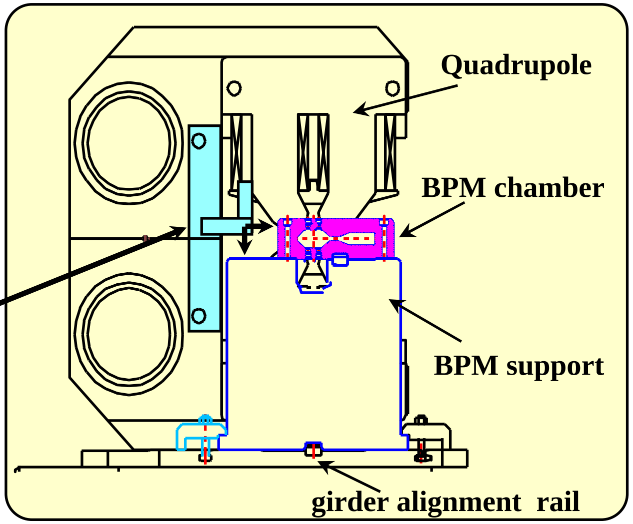
FEA-simulations indicate movements of up to 2 µm/°K in the transverse plane at the positions of the BPM blocks

→ top-up operation

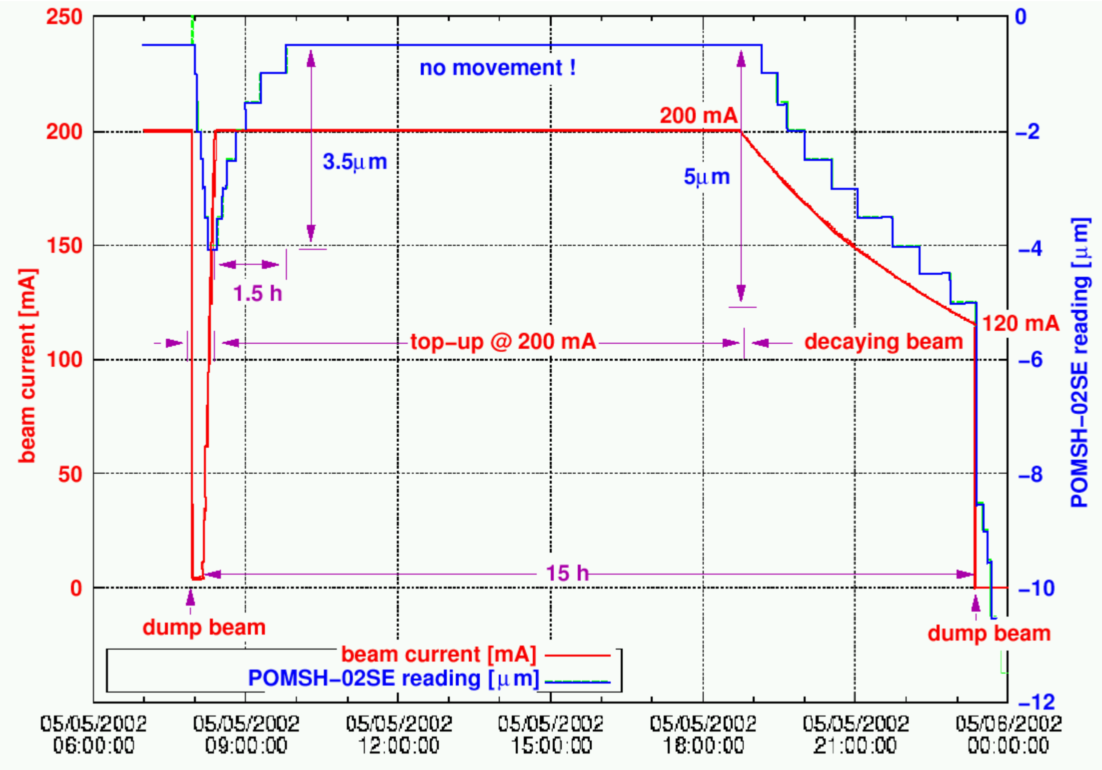
Mechanical Position Monitoring System (POMS)

Dial gauges equipped with linear encoders as sensing devices attached to quadrupole magnets





Position Monitoring System (POMS)



- top-up:
  beam current stabilized at 200 mA with 0.5 mA deadband ($\tau \sim 12h$)
- POMS:
  linear encoders on all BPM stations measuring offset between BPMs and adjacent quadrupoles
  (POMS resolution: 0.5 µm)

No movement during top-up! Machine in thermal equilibrium!

Orbit Stabilization: Medium and Short Term Motion (2)

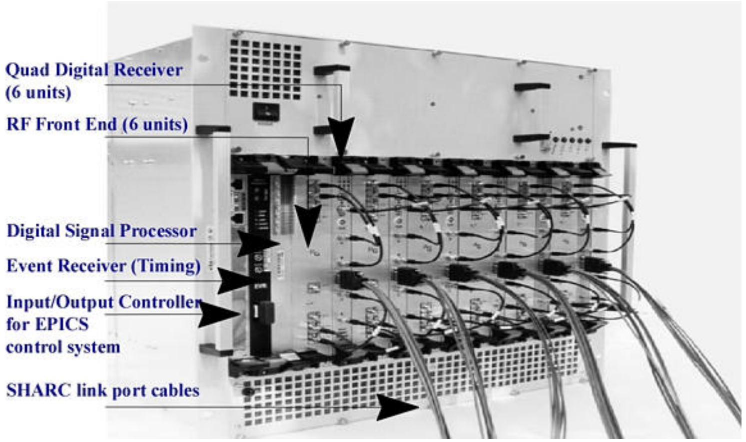
correct any remaining orbit drifts and distortions by **orbit feedback**

but:

feedback on electron beam position requires

- high resolution of position sensor (BPM)
  ↔ max. achievable orbit stability
- "long" term stability of BPM readout electronics
- reliable position readings
- definition of reference
  (magnetic center, ground floor, ID BPMs…)

Digital Beam Position Monitors



- 72 BPMs in the SLS storage ring
- 12 BPM electronics stations,
  6 BPMs each
- 4 channel system
- modular system
  - RF front end
    (down conversion to IF)
  - Quad Digital Receiver
    (digital down conversion to base band)
  - Digital Signal Processing (position calculation)
- pilot signal in all four channels
  → calibration of electronics by individual gain settings,
  self-test capability

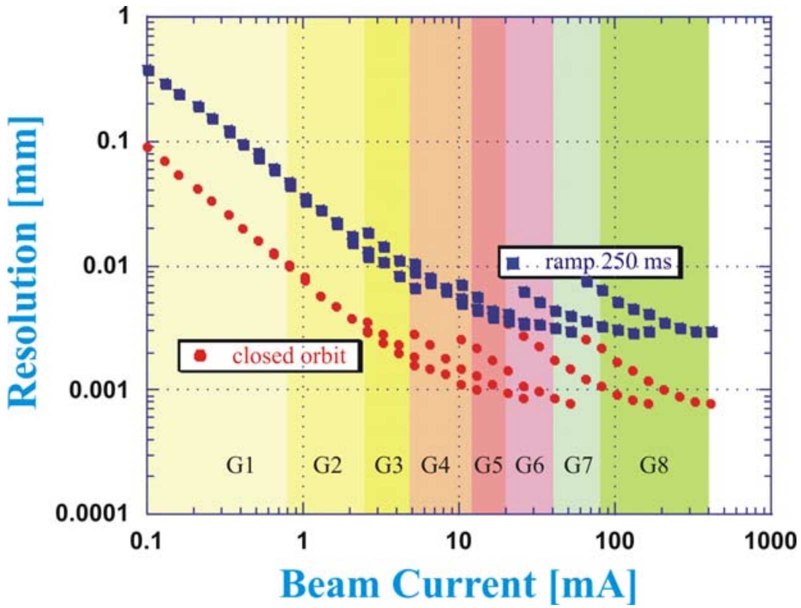
Digital Beam Position Monitors: Specifications

some important BPM parameters for storage ring operation

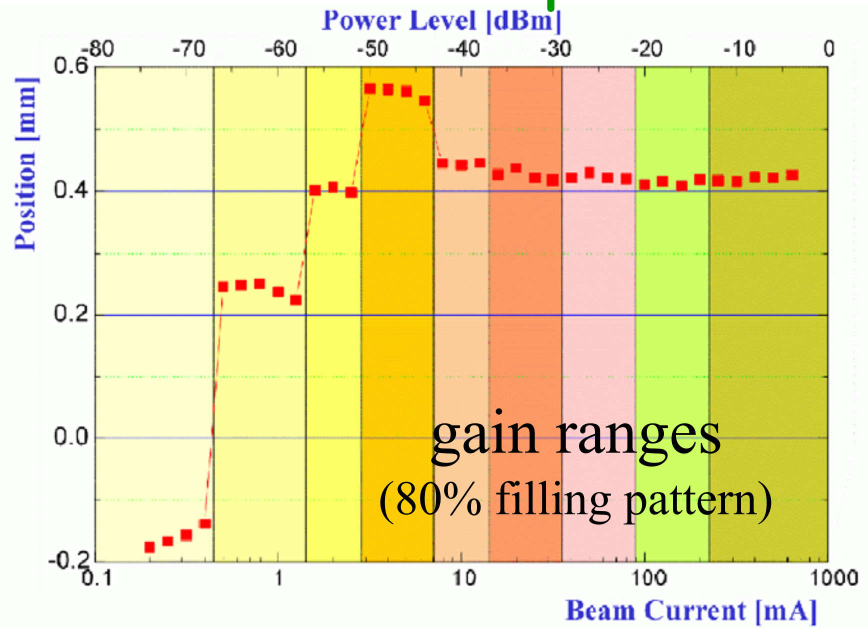
Parameter	Closed Orbit and Feedback Mode
Dynamic Range	1 – 500 mA
Beam Current Dependence full range	< 100 µm
Resolution	< 1 µm
Bandwidth	> 2 kHz

Digital Beam Position Monitors: Performance (1)

Resolution



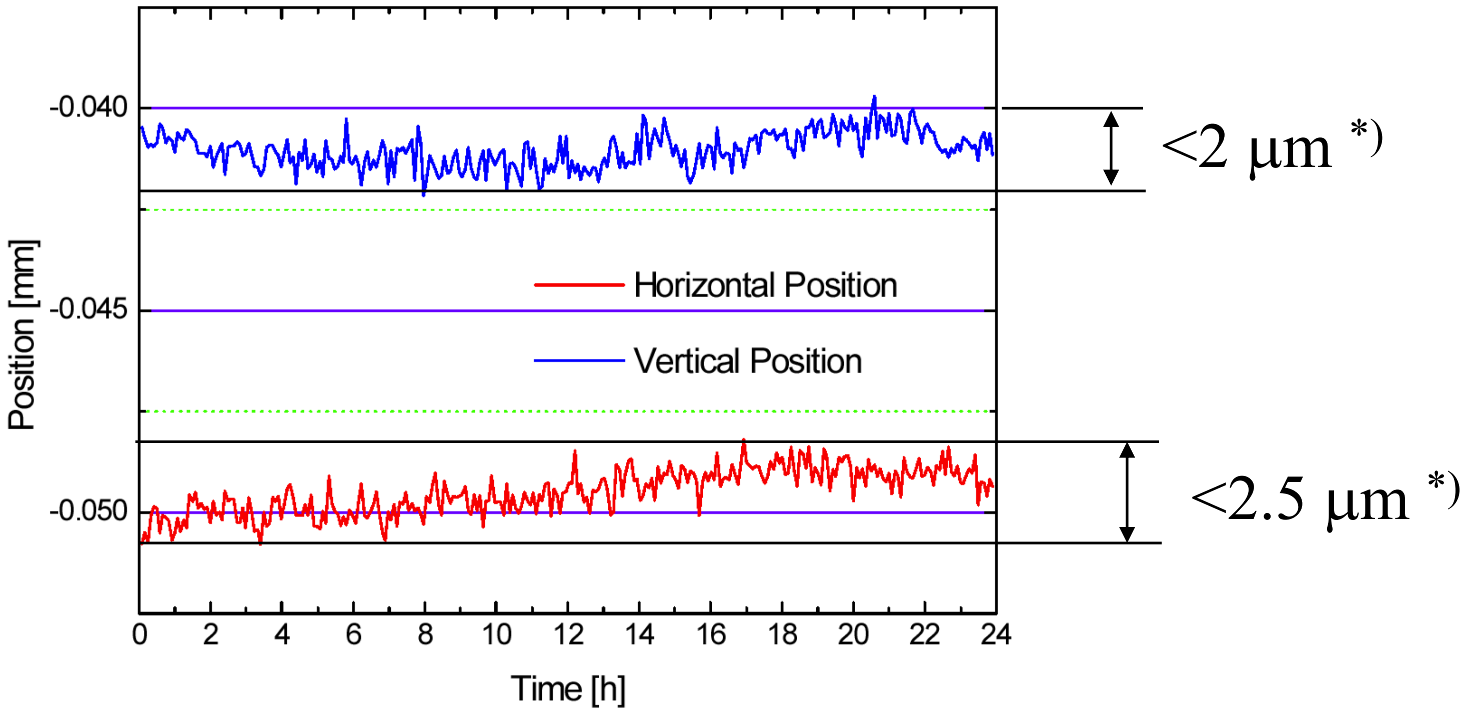
Beam Current Dependence



- DBPM resolution at working point: ~0.8 µm
- top-up operation: minimal influence of beam current dependency
- orbit correction only for I_{beam} > 20 mA
- systematic effects of gain changes could be compensated – if required

Digital Beam Position Monitors: Performance (2)

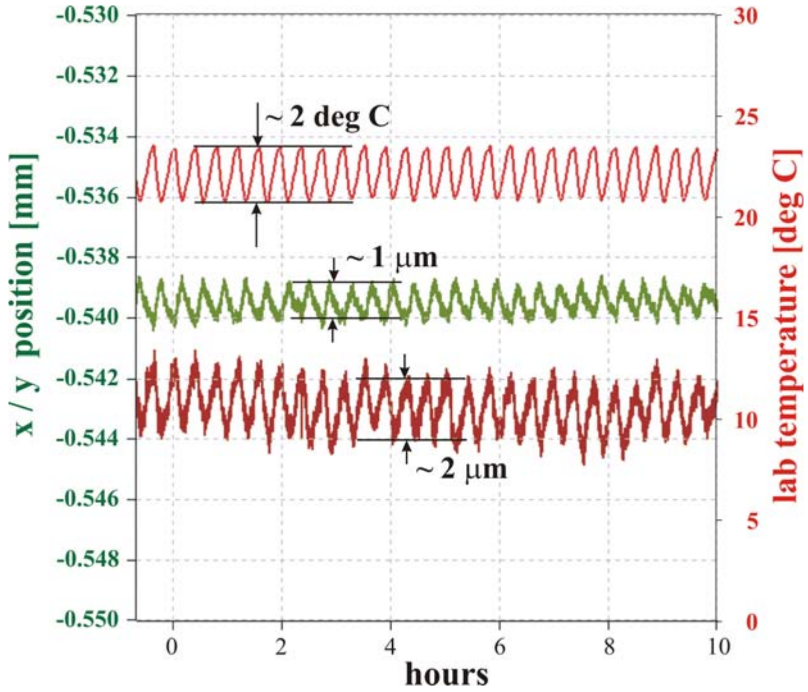
Stability long term stability measurement in technical gallery (with RF signal generator):



*) hall temperature (technical gallery) regulated < ±1 ºC (spec)

Digital Beam Position Monitors: Performance (3)

Stability: Lab Measurements



- due to hot summer 2003:
  → "relaxed" setting in cooling system
- air conditioning system in lab shows a strong 2 ºC swing now
- "small" temperature reservoir in lab compared to technical gallery hall

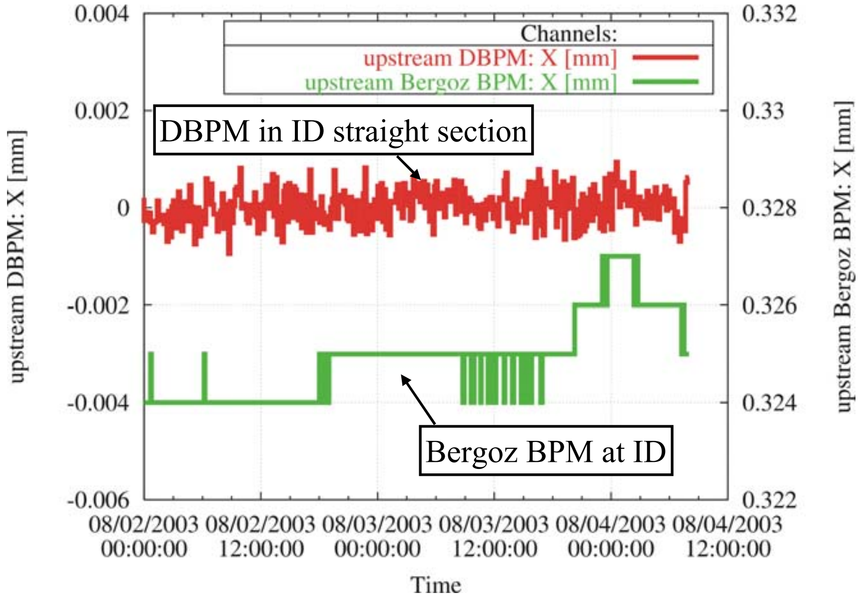
upgrade plans:
measure air temperature at BPM crates and correct for systematic temperature effects

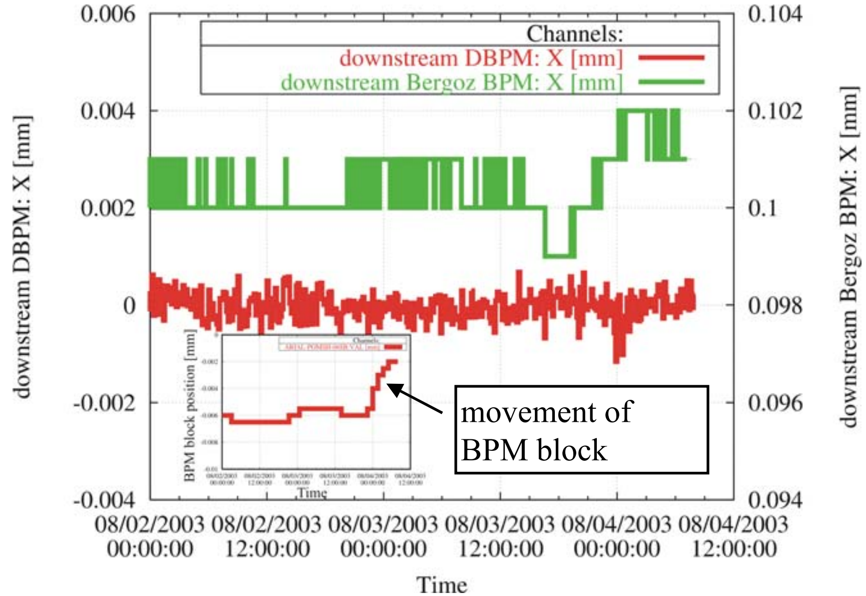
→ **orbit stability will profit from planned cooling system upgrades**

Digital Beam Position Monitors: Performance (4)

Stability: at ID U24 (Protein Crystallography Beamline)

- Bergoz BPM position readings limited by readout electronics
- presently: LSB ↔ 1 μm





upgrade plans:

- improved readout electronics of Bergoz BPMs (→ higher resolution)
- combination of DBPM, POMS and X-BPMs

DBPM Low Level Security Software

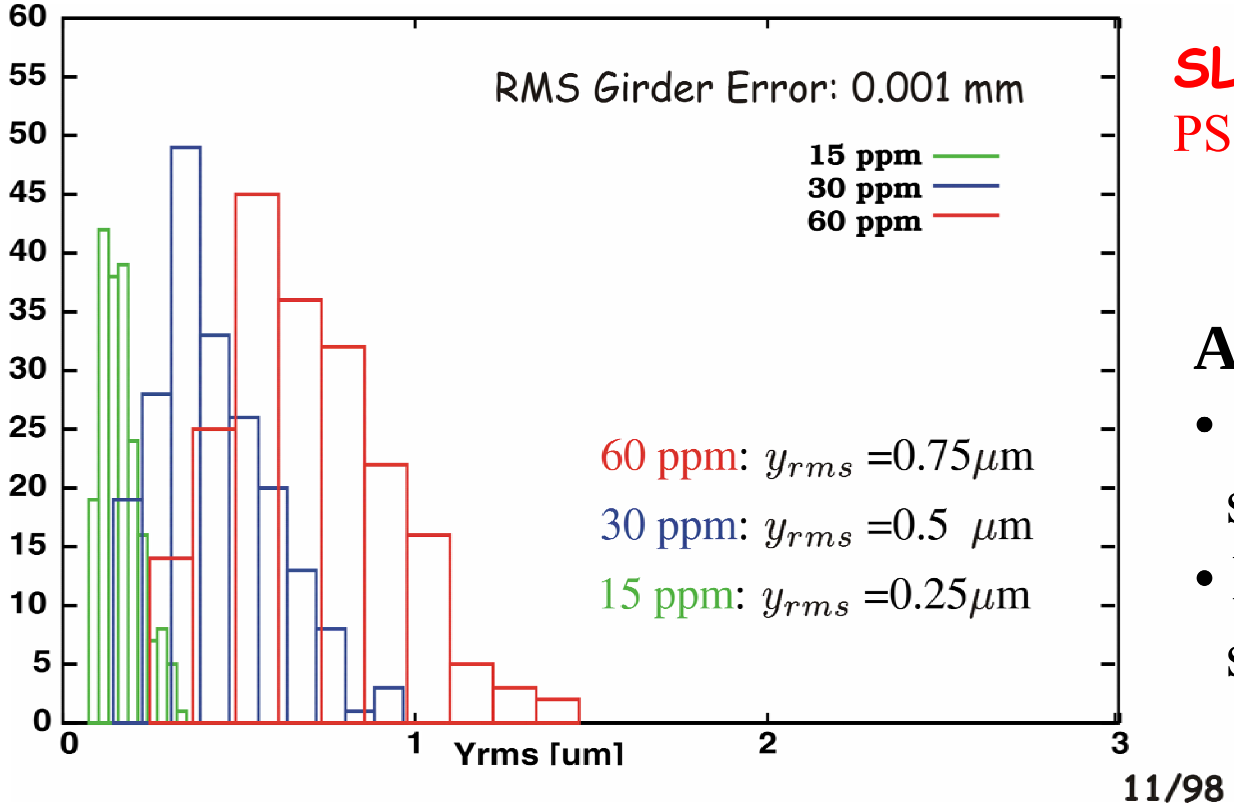
- digital BPM system provides access to all system data
  - → possibility to make BPM software “intelligent”
  - → data integrity checks before passing on erroneous data to orbit feedback / operator / interlocks etc.

- closed orbit / feedback mode (4 kSamples/s):
  cross check of pick-up raw values $V_A + V_C \approx V_B + V_D$

- since implementation of security package:
  no beam loss due to faulty BPMs !

Power Supply Resolution / RMS Orbit Distortion

TRACY estimated residual vertical RMS orbit after orbit correction as seen by the monitors: (histogram for 200 seeds introducing girder misalignment of 1 µm)



SLS requirement:

PS with 15 ppm resolution

Achieved:

- Short term (<60s) stability < 10 ppm
- Long term (1000h) stability < 30 ppm

Feedback Implementation

phase 1:

- Slow Orbit Feedback (SOFB), high level application
- use all 72 BPMs and all 72 correctors in each plane
- RF frequency correction for path length changes
- test correction scheme and sub-system performance
- in operation since August 2001

phase 2:

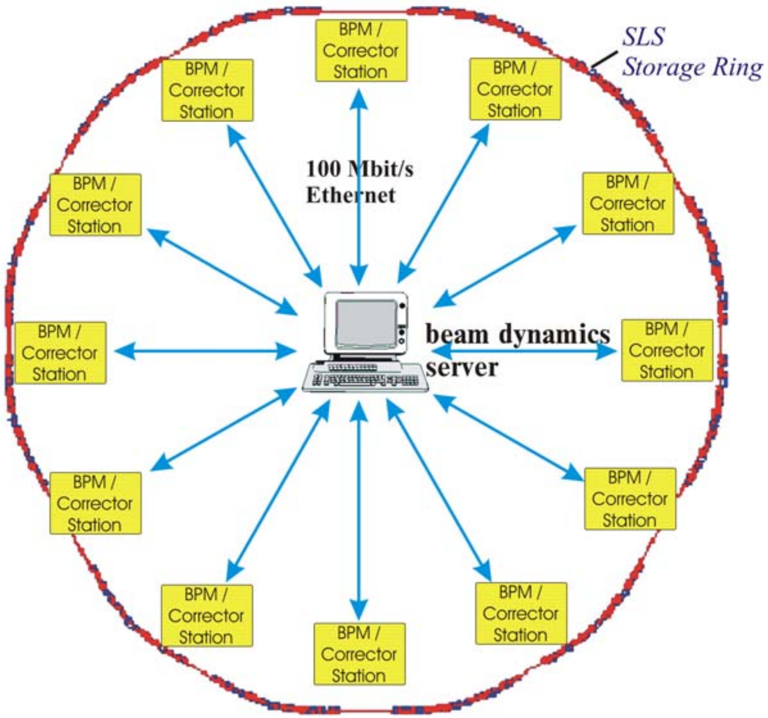
- Fast Orbit Feedback (FOFB), low level application
- same scheme as SOFB, replaces SOFB,
  only **one** global orbit feedback!
- SOFB is used to correct initial orbit within a
  few µm to the reference orbit, FOFB takes over then
- RF frequency correction still carried out by SOFB
- FOFB under commissioning since spring 2003 (machine shifts)
- planned operation during user shifts: beginning 2004

Phase 1: Slow Orbit Feedback

central processing unit:
- calculate inverted response matrix (SVD)
- read all BPM values
- calculate correction
- set new corrector settings
- use control system network
- runs up to 2 Hz update rate
- standard operation:

  toggles correction between horizontal and vertical plane

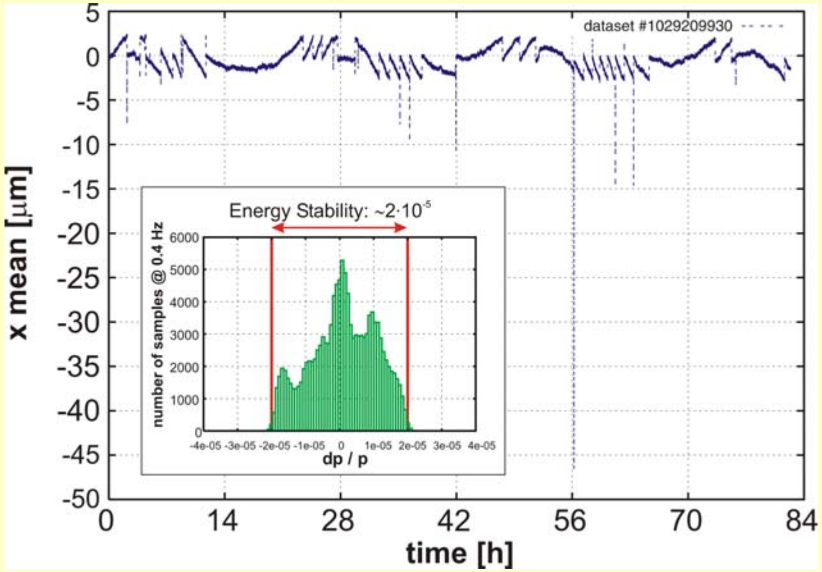
  → full correction cycle <3 s (~0.4 Hz)



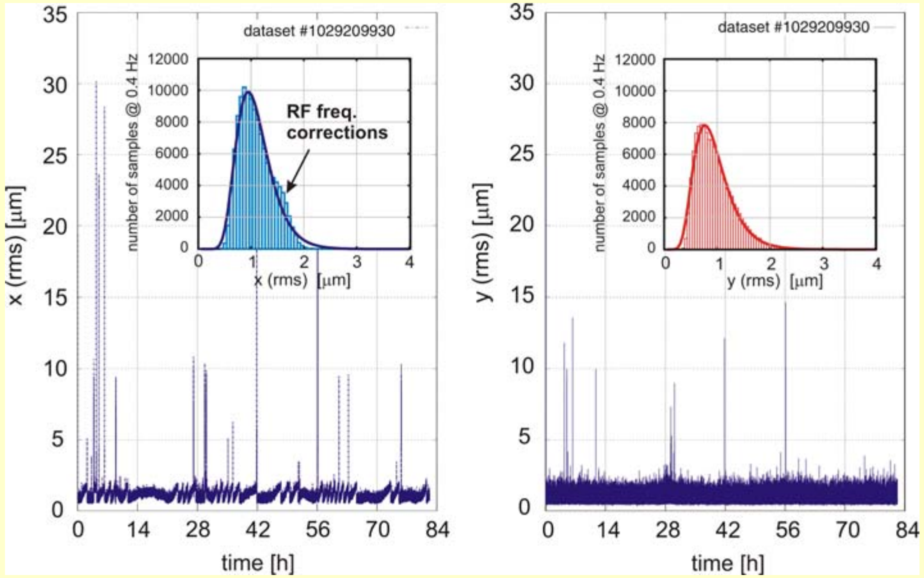
Slow Orbit Feedback: Performance (1)

example: 3 days run, 13 August – 16 August 2002

horizontal orbit mean position



orbit RMS in both planes



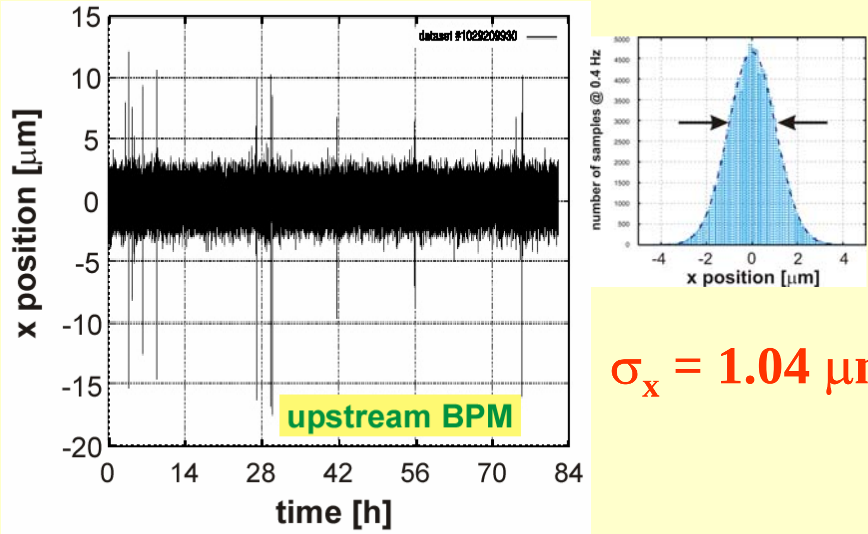
remaining predominant orbit distortions:

1. RF frequency changes
2. ID gap changes

Slow Orbit Feedback: Performance (2)

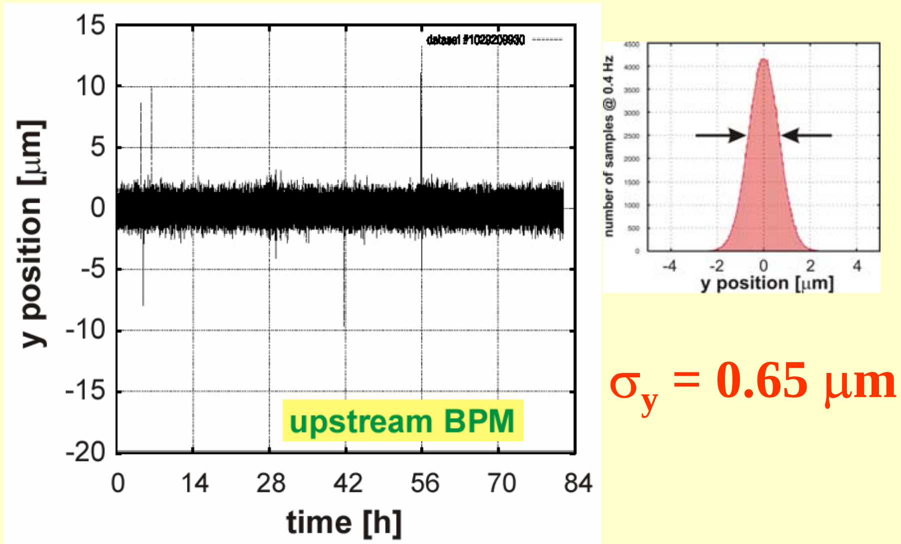
adjacent DBPM to ID U24 (protein crystallography):

upstream BPM: horizontal



$\sigma_x = 1.04\ \mu m$

upstream BPM: vertical



$\sigma_y = 0.65\ \mu m$

downstream BPM: horizontal

$\sigma_x = 0.98\ \mu m$

downstream BPM: vertical

$\sigma_y = 0.64\ \mu m$

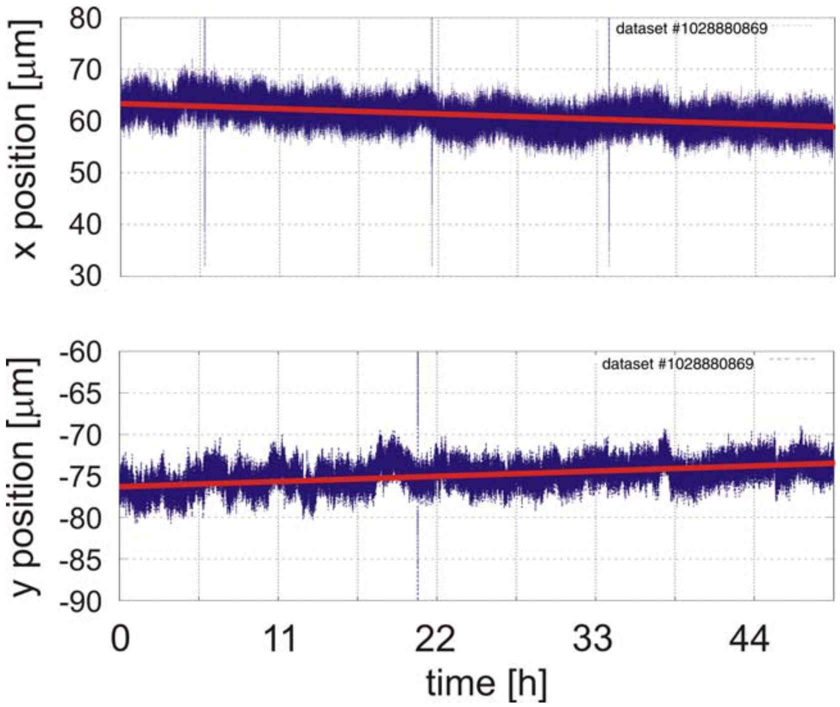
→ calculation of angular stability at ID:

$\sigma_{\Delta\Theta}$ (hor.) = 0.29 µrad

$\sigma_{\Delta\Theta}$ (ver.) = 0.19 µrad

Orbit Stability: SOFB

X-BPM at protein crystallography beamline (~ 8.6 m from ID U24)



- single X-BPM does not allow to resolve angle and position of radiation source point!
- X-BPM:

  $\sigma_x \approx 2.7$ μm (drift: 2.3 μm)

  $\sigma_y \approx 1.5$ μm (drift: 1.7 μm)

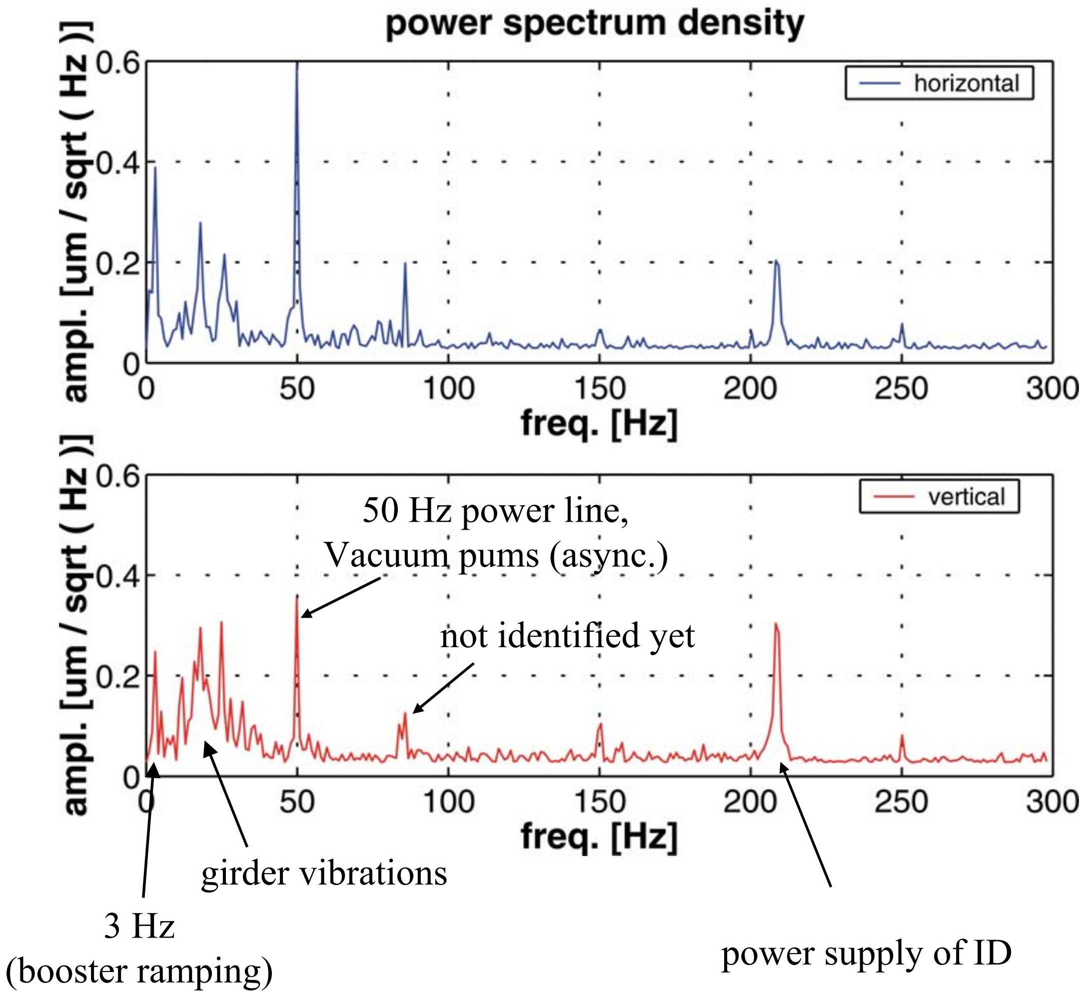
- estimated maximal angle error:

  $\sigma_{x'} \approx 0.31$ μrad @ source point

  $\sigma_{y'} \approx 0.18$ μrad @ source point

first results in Aug. 2002 (J. Krempasky)

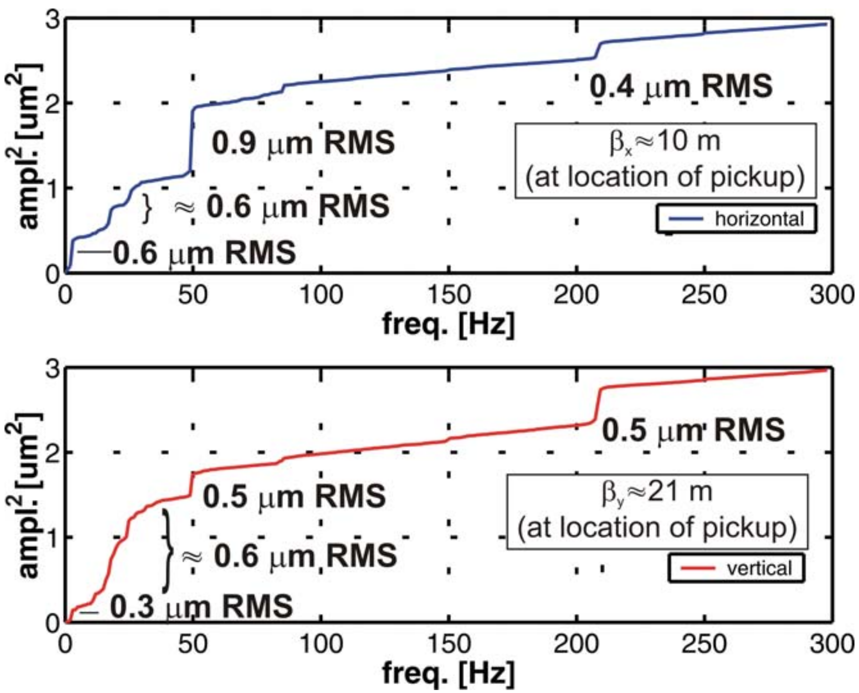
Noise Sources at SLS: 0.5 - 300 Hz



conditions:

- spectra measured with DBPM system
- normal work day
- booster ramping with 3 Hz for top-up operation
- no ID movements

Integrated Noise Spectrum
(0.5 - 300 Hz)



	horizontal	vertical
total RMS (incl. sensor noise)	1.7 μm RMS	1.8 μm RMS
Beam osc. globally @ BPM	1.7 μm (scaled with $\sqrt{\beta_{x(mean)}/\beta}$)	1.4 μm (scaled with $\sqrt{\beta_{y(mean)}/\beta}$)

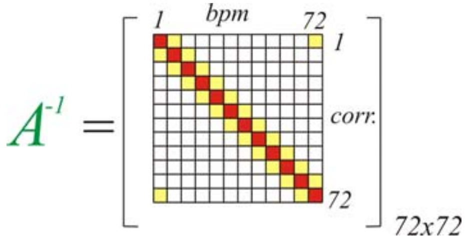
β_x(mean) ≈ 10 m

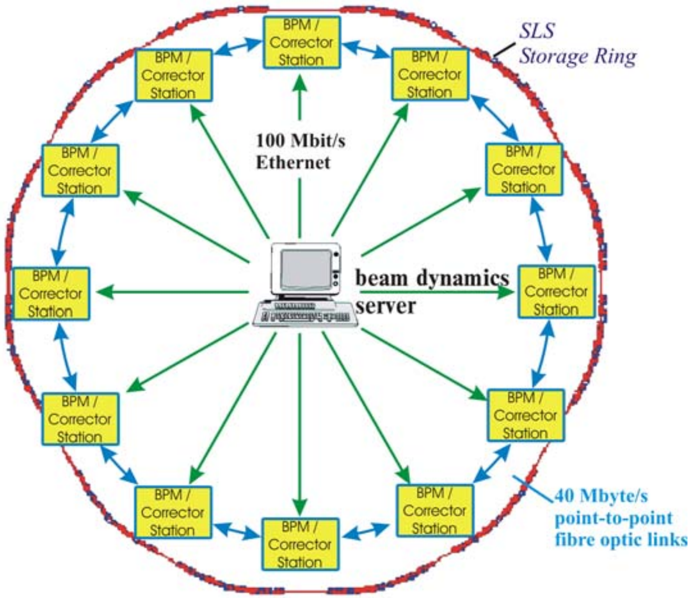
β_y(mean) ≈ 11 m

short straights ID: $\beta_x = 1.4$ m

$\beta_y = 0.9$ m

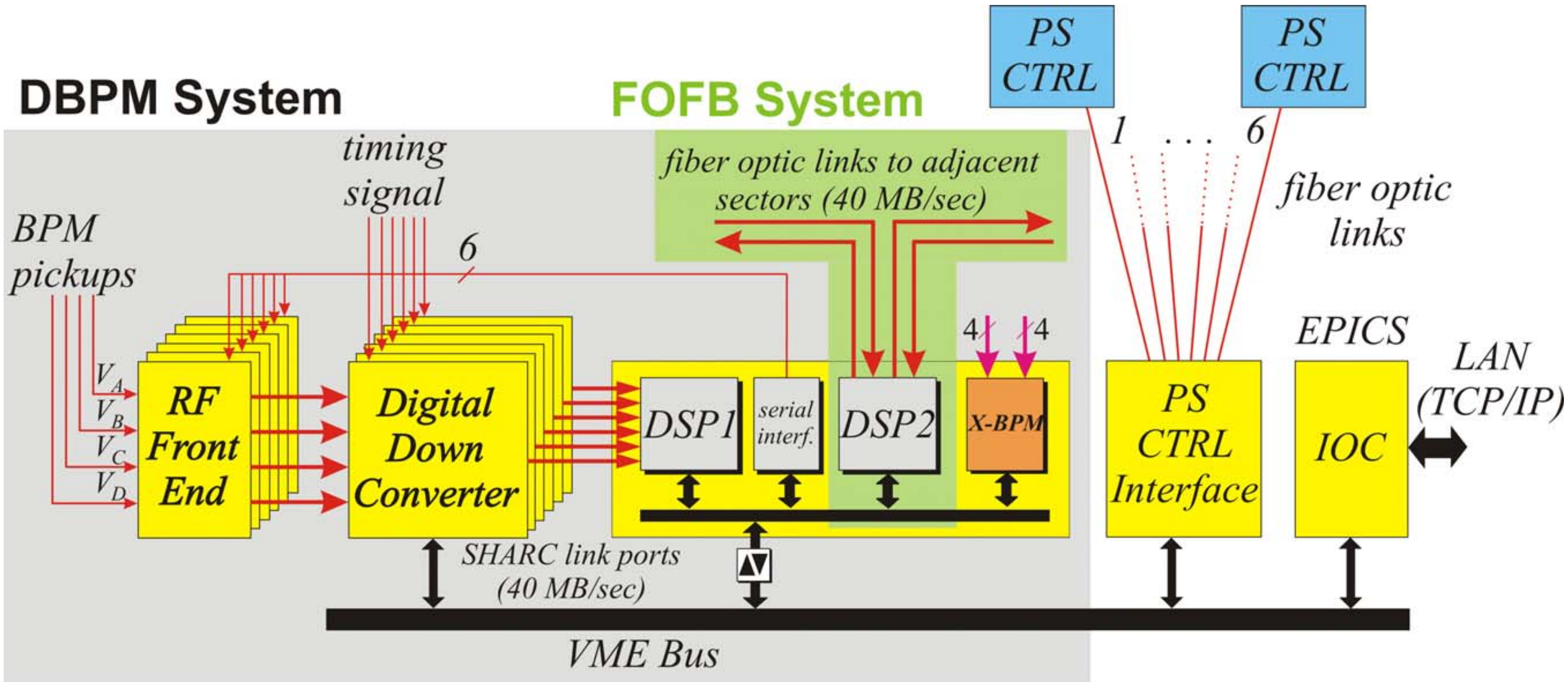
Phase 2: Fast Orbit Feedback





- 6 BPMs and 6 corrector magnets per station
- 4 kSamples/s update rate
- processing decentralized and integrated in the 12 BPM stations
- decentralized structure of feedback → can continue to run even if not all BPM data are available for the current cycle (link breakdown etc...)

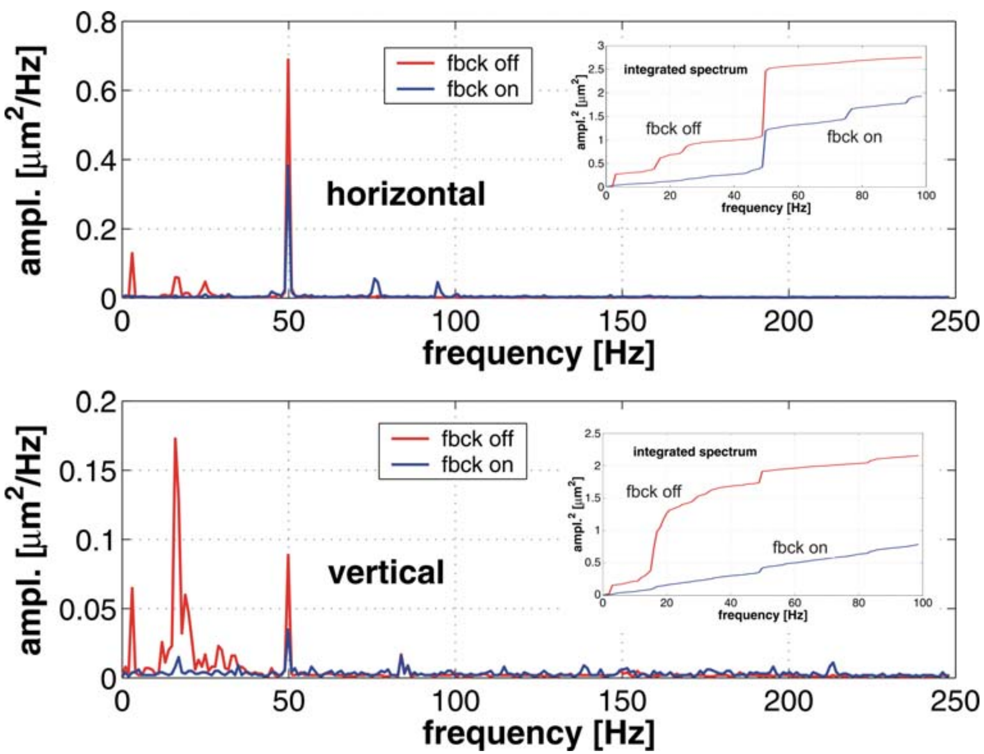
DBPM / Fast Orbit Feedback Hardware Layout



Integration of 2 X-BPMs on DBPM hardware

→ **Integration in Fast Orbit Feedback possible**

FOFB: First Results



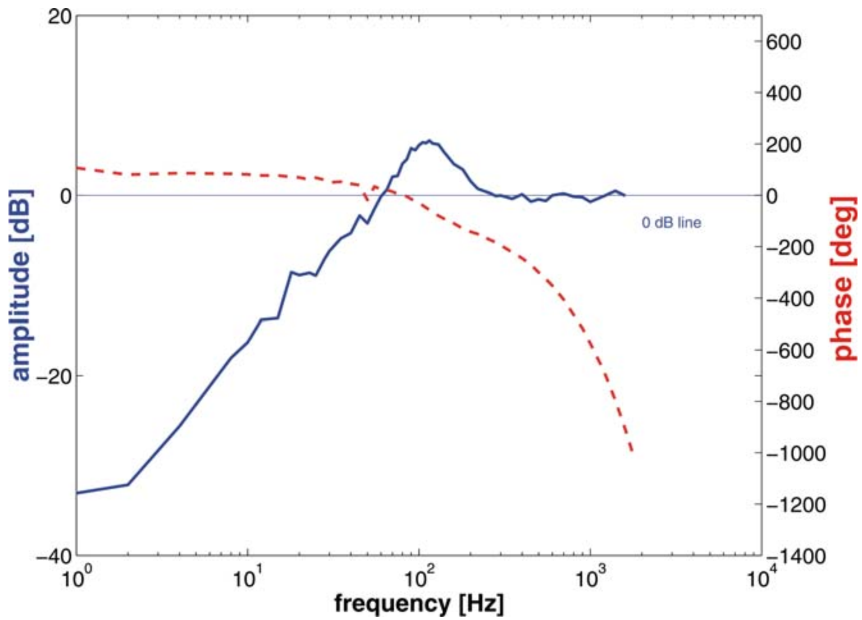
	horizontal		vertical	
FOFB	off	on	off	on
0.5-100 Hz	1.7 µm	1.4 µm	1.5 µm	0.9 µm
100-400 Hz	0.95 µm	1.1 µm	0.95 µm	1.2 µm

(measured at tune BPM which is not in the feedback loop)

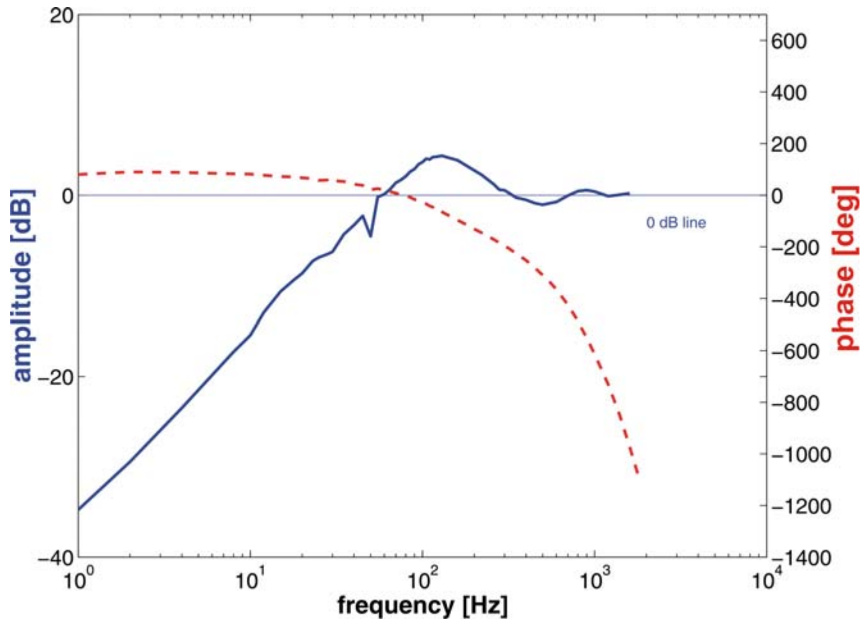
still to be measured: photon position stability at experiments…

Transfer Function Measurements

horizontal closed loop transfer function



vertical closed loop transfer function



Time Delays:

- Quad Digital Receiver Settings: ~600 µs
- position calculation (DSP1): ~ 60 µs
- "global" data exchange: ~ 8 µs
- feedback alg. + SVD matrix calc.: ~70 µs (DSP2)
- data transfer to PS controller: ~150 µs
- asynchronous mode of QDR: <250 µs

Conclusions

- temperature stabilization of storage ring tunnel and experimental hall is vital if orbit has to be stabilized to the (sub-)micron level
- top-up operation guarantees thermal equilibrium of machine and simplifies the operational conditions of diagnostic devices
- Slow Orbit Feedback system stabilizes the orbit to the micron level globally; Fast Orbit Feedback system is under commissioning which will replace SOFB
- Integration of X-BPM absolutely necessary and probably the only way to stabilize the photon beam at the experiments any further