Fast Orbit Feedback at the SLS

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Outline

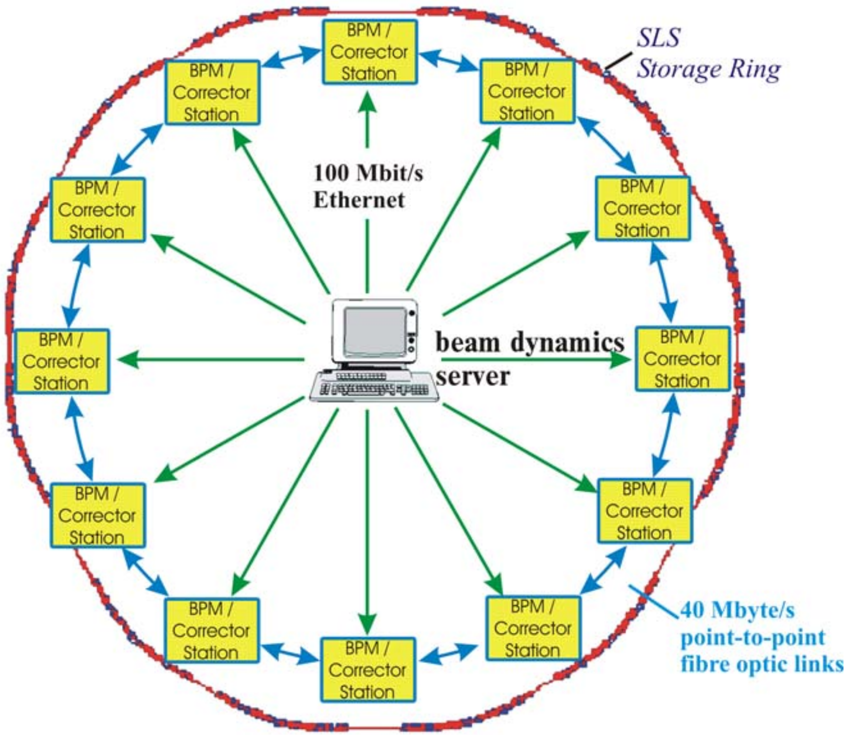
- (Initial) Stability Requirements
- Orbit Feedback Layout
- Fast Orbit Feedback Results
- Experiences / Limitations / Extensions

Stability Requirements

- **Angular stability:** **$\Delta\Theta_{beam} < 1\ \mu rad$ ***
  *** typical < 10 μm at the experiment**
- **Position stability:**
  σ/10 at Insertion Devices (ID)
  → low beta ID: vertical beam size ~10 μm (1% coupling)
  → **1 μm RMS in vertical plane**
- **suppression** of orbit distortion up to 100 Hz by factor of >5
- fast compensation of orbit distortions due to **ID gap changes**

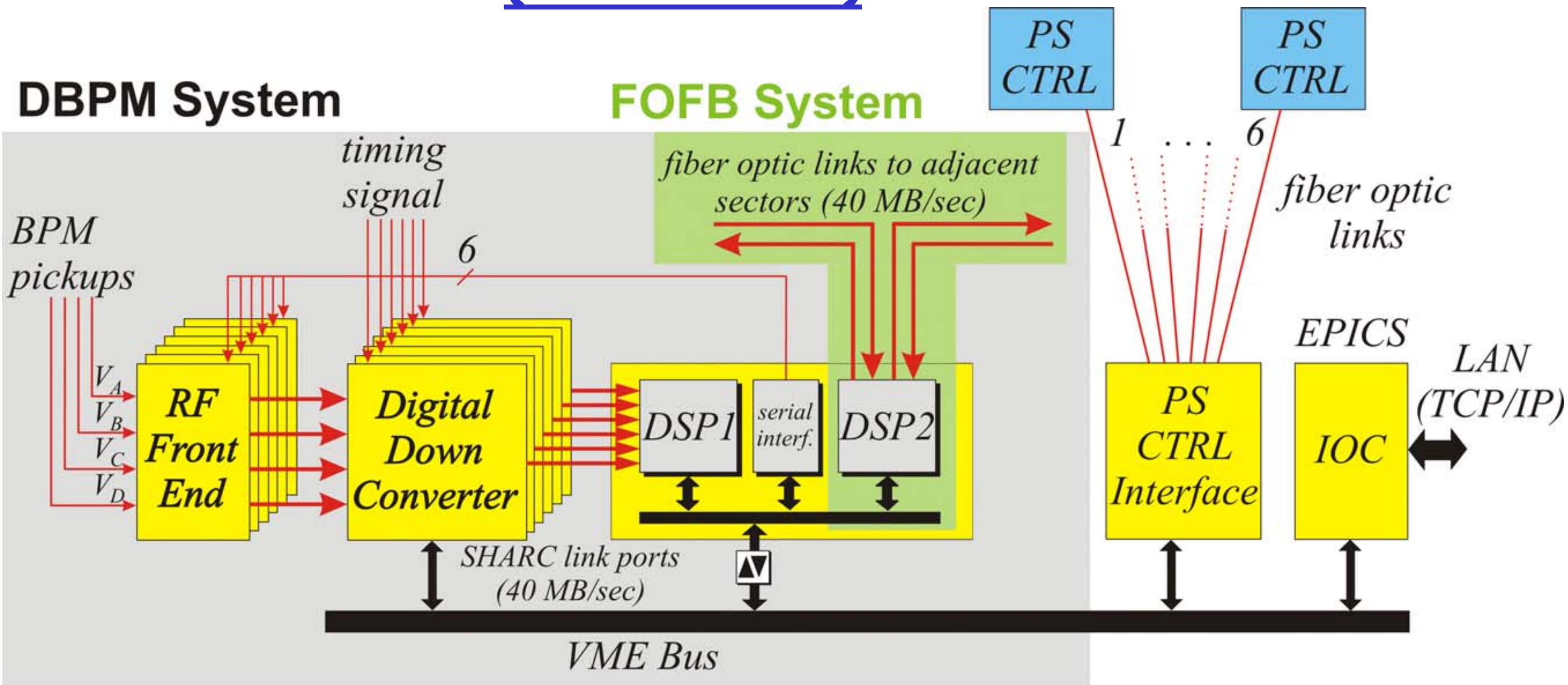
Fast Orbit Feedback Layout

- only one feedback
- 6 BPMs / 6 corrector magnets in each plane, 12 sectors
- **decentralized** data processing
- sampling and correction rate: 4 kHz
- point-to-point fiber optic ring structure for global data exchange
- initialization and control by beam dynamics application (BD server)



- Femto project: additional BPM(s) and corrector magnet(s)

DBPM / Fast Orbit Feedback Hardware Layout (sector view)



- DSP processor: ADSP2106x (on the market since Sep. 1994)
- DDC: Intersil HSP50214 (on the market since ~1997)

FOFB: A highly sophisticated system

Required Subsystems:

- 72 DBPMs
- fast network for real time data exchange (24 modules)
- power supplies (144 PS + 24 VME interface boards)
- timing system (12 boards + …)
- network
- control system (vxWorks, EPICS, Linux, Oracle DB)
- beam dynamics services
- “operator…” ☺

A failure in any subsystem will result in failure of the FOFB…

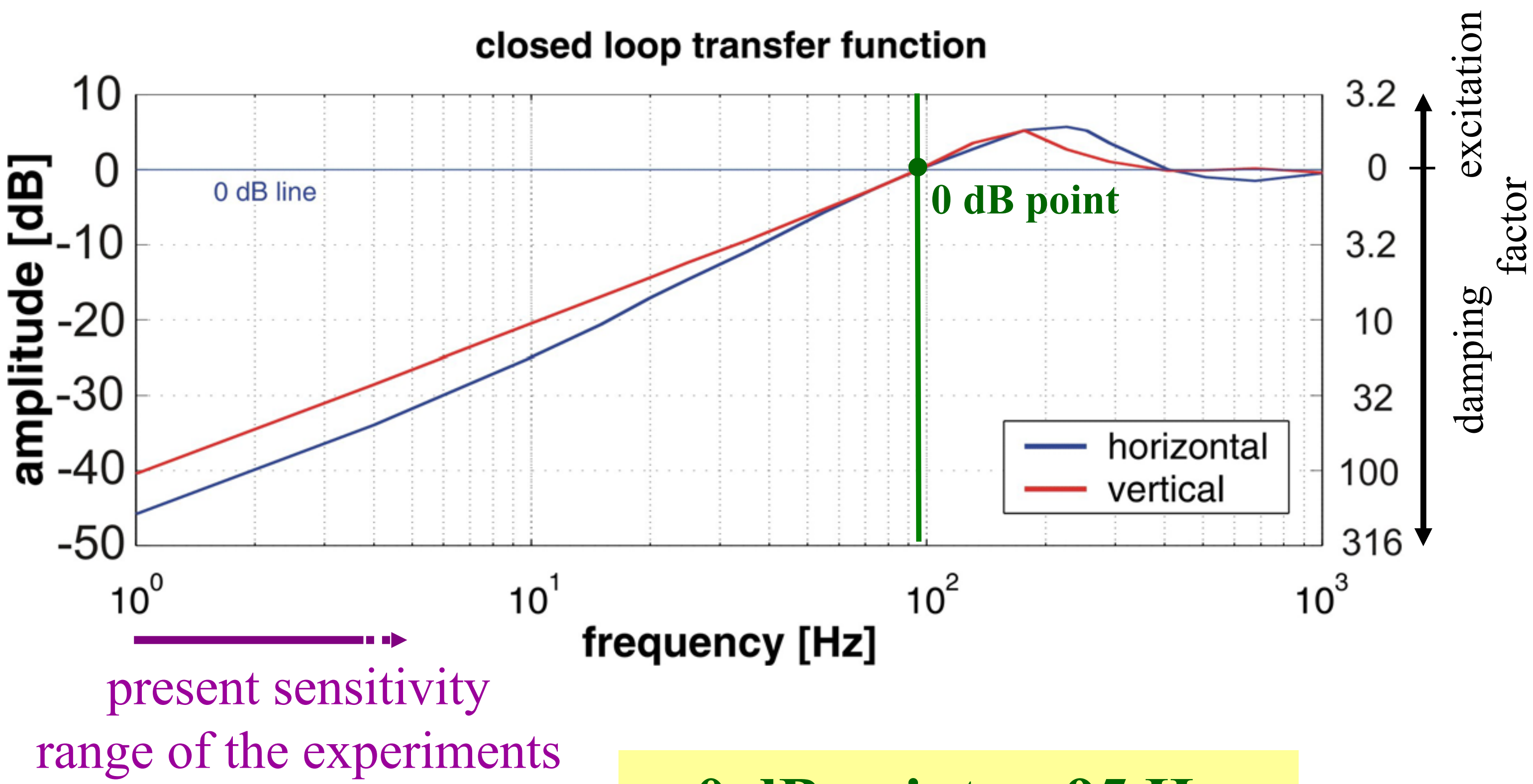
Performance: Stability Frequency Ranges

- **short term stability**: ~ 6 ms – 1 s (1 Hz – 150 Hz)
  mainly limited by
  - BPM resolution
  - corrector magnet resolution
  - system latency
  - eddy currents in vacuum chambers

- **long term stability**: 1 s – days (run period)
  mainly limited by
  - reliability of hardware components
  - systematic errors of BPMs
  - thermal equilibrium of the machine (→ top-up)

Performance: Short Term Stability

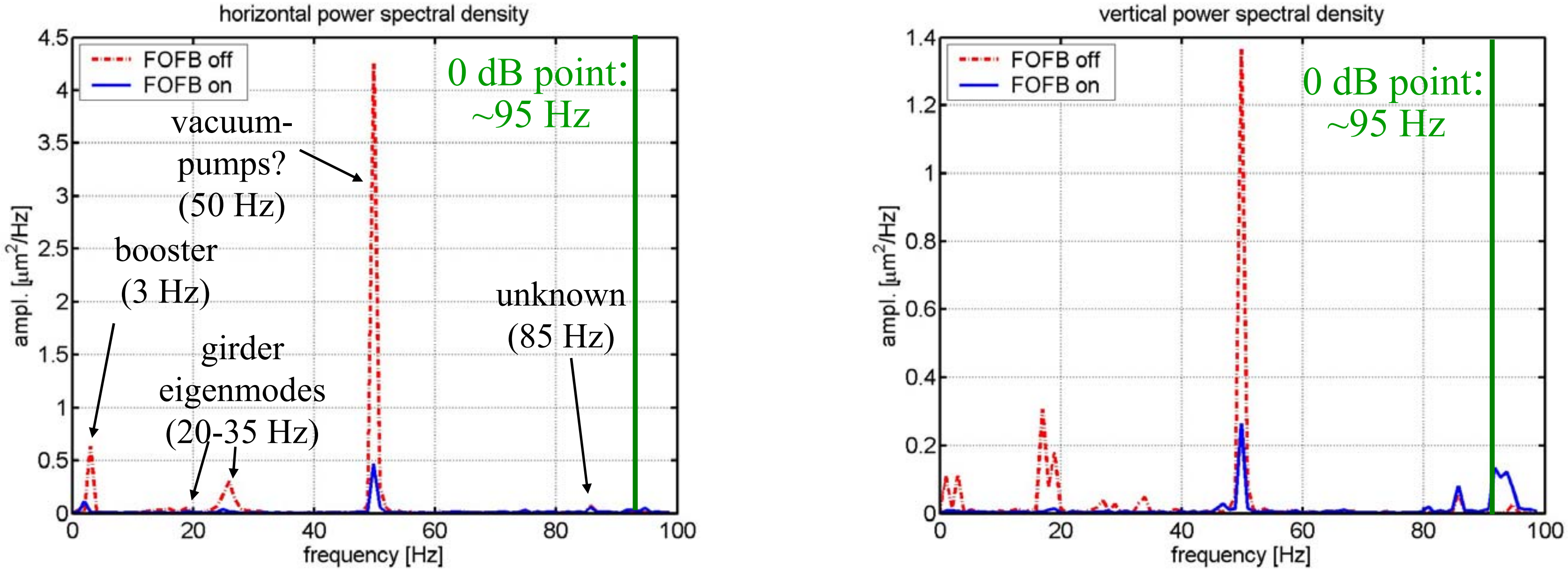
transfer function measurement



0 dB point: ~ 95 Hz (in both planes)

FOFB: spectral power density (1-100 Hz)

Fast Orbit Feedback off/on
(without any ID gap change)



horizontal vertical

(measured at tune BPM, outside of the feedback loop, β_x=11 m, β_y=18 m)

FOFB: Cumulated Power Spectral Density (1-150 Hz)

	horizontal		vertical	
FOFB	off	on	off	on
1- 100 Hz	**0.83 μm · $\sqrt{\beta_x}$**	**0.38 μm · $\sqrt{\beta_x}$**	**0.40 μm · $\sqrt{\beta_y}$**	**0.27 μm · $\sqrt{\beta_y}$**
100-150 Hz	0.08 μm · $\sqrt{\beta_x}$	0.17 μm · $\sqrt{\beta_x}$	0.06 μm · $\sqrt{\beta_y}$	0.11 μm · $\sqrt{\beta_y}$
1-150 Hz	0.83 μm · $\sqrt{\beta_x}$	0.41 μm · $\sqrt{\beta_x}$	0.41 μm · $\sqrt{\beta_y}$	0.29 μm · $\sqrt{\beta_y}$

RMS values to be scaled with $\sqrt{\beta}$ at desired location

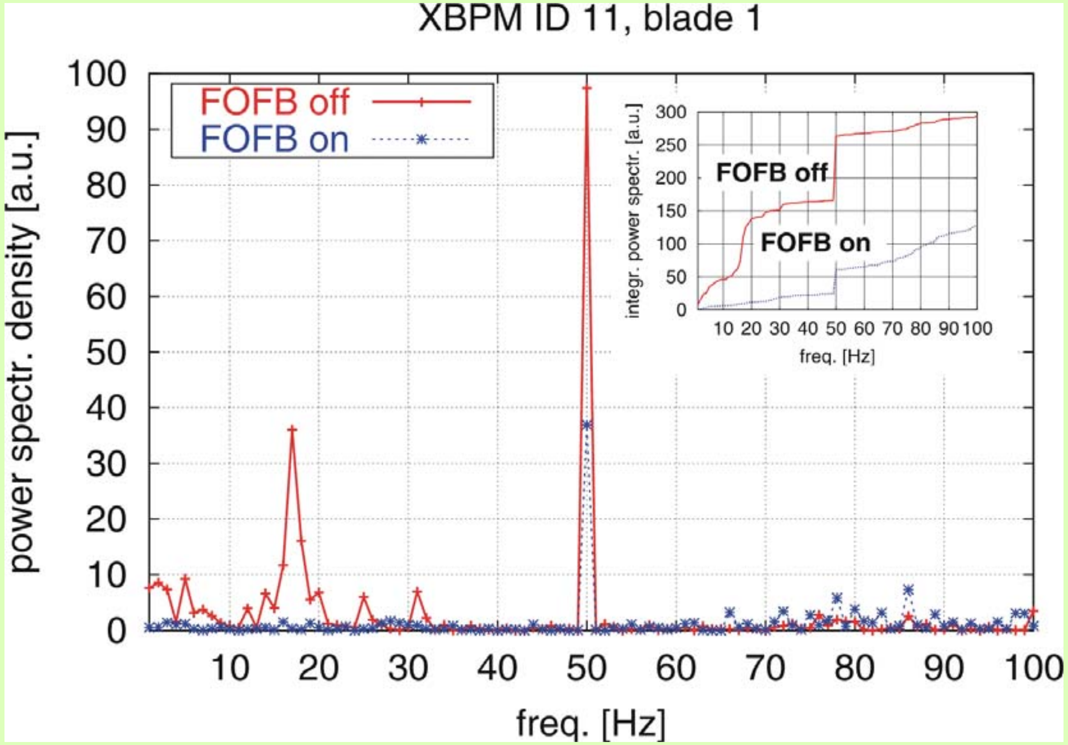
Examples (with FOFB):

Tune BPM (β_y=18 m): $\sigma_y = \sqrt{18} \cdot 0.29$ μm **= 1.2 μm** (1 – 150 Hz)

Source point at ID 6S (β_y=0.9 m): $\sigma_y = \sqrt{0.9} \cdot 0.29$ μm **= 0.28 μm** (1 – 150 Hz)

Performance: Short Term Stability (external reference: Photon BPM at beamline 11M)

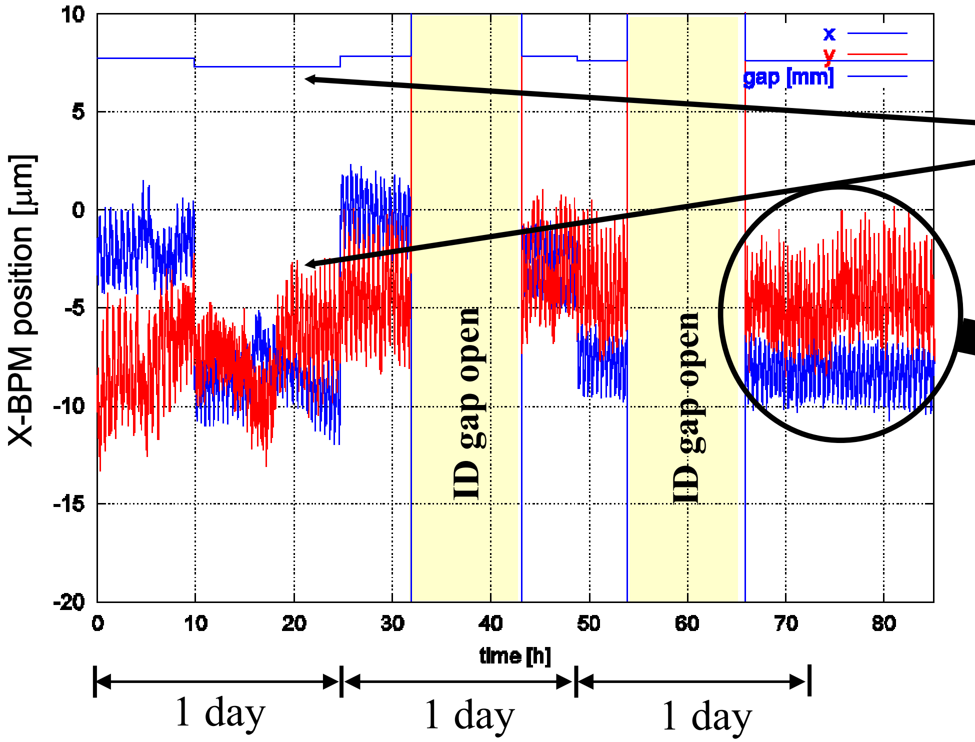
- power spectral density @ single PBPM blade
- no synchronous readout of all 4 blades yet to determine hor./ver. PSD



(meas. in Sept. 2003, 0 dB @ 60 Hz)

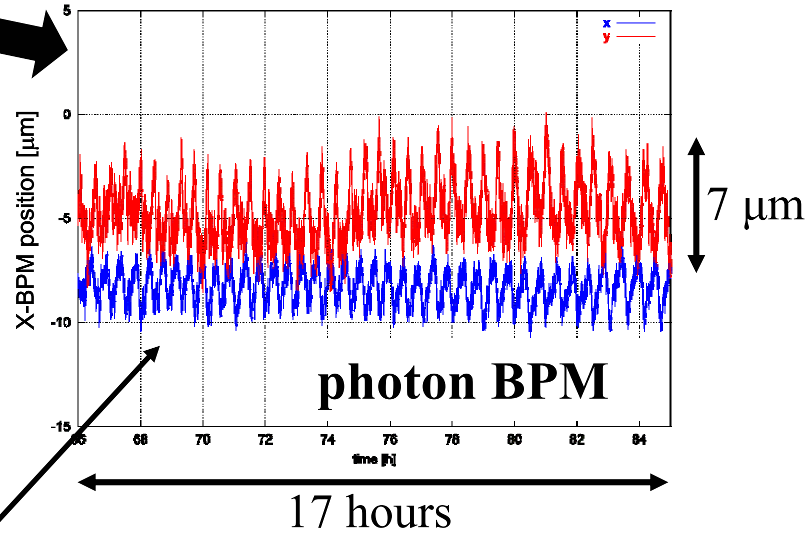
⇒ **successful suppression of noise sources originating from the electron beam**

Performance: Long Term Stability (external reference: PBPM at beamline 6S)



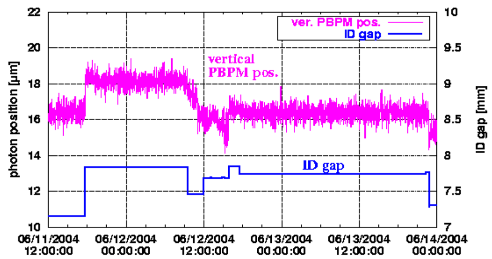
each sample: average over 1 s

gap dependency of photon BPMs → calibration necessary



<u>but</u>: photon BPMs show
systematic effects of the RF BPMs

Performance: Long Term Stability



Strategy:

- if photon BPMs are reliable enough
  - ⇒ used to minimize systematic effects of RF BPMs, girder drifts, temperature drifts, etc.
  - ⇒ slow PBPM feedback which changes reference orbit of FOFB (asymmetric bump)
  - ⇒ keep photon beam position constant at first PBPM

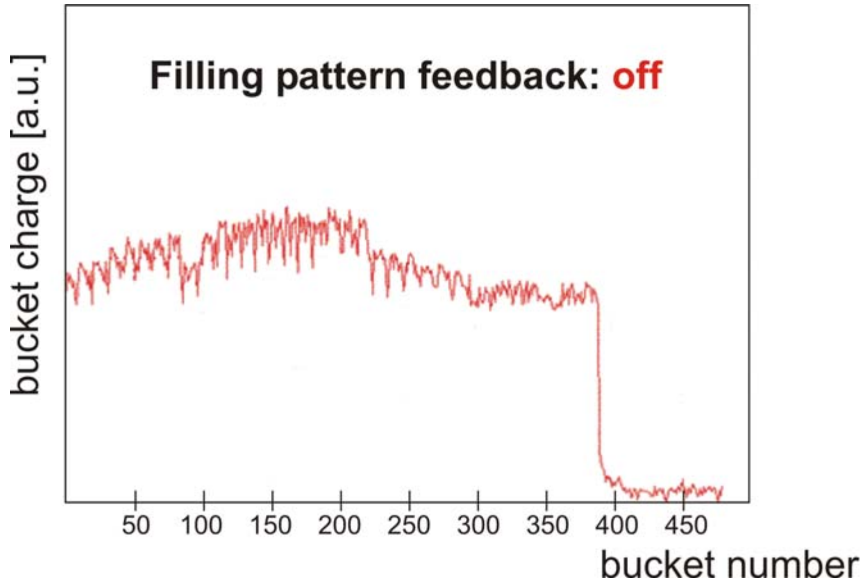
- so far: only one PBPM at ID beamline 4S and 6S is reliable enough and understood to be integrated in PBPM feedback

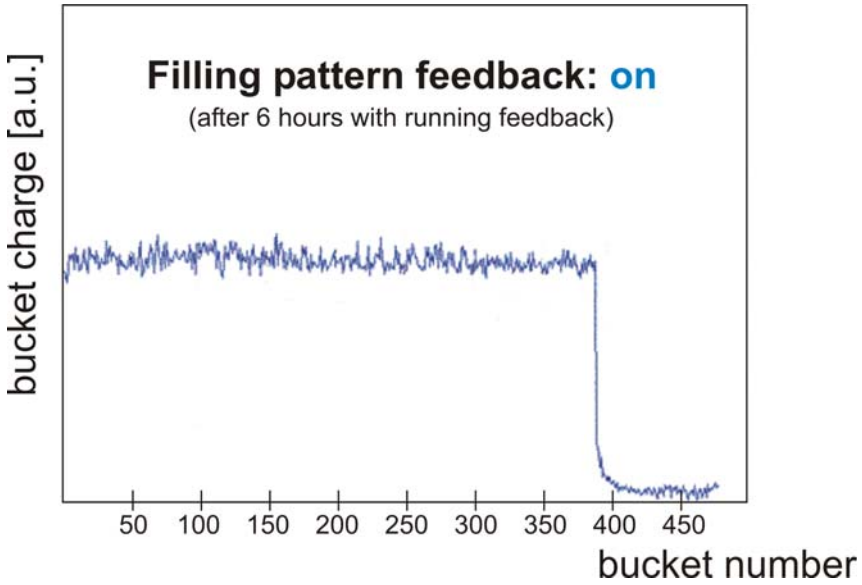
- filling pattern feedback to keep bunch pattern constant

Filling Pattern Feedback

Standard SLS filling pattern:

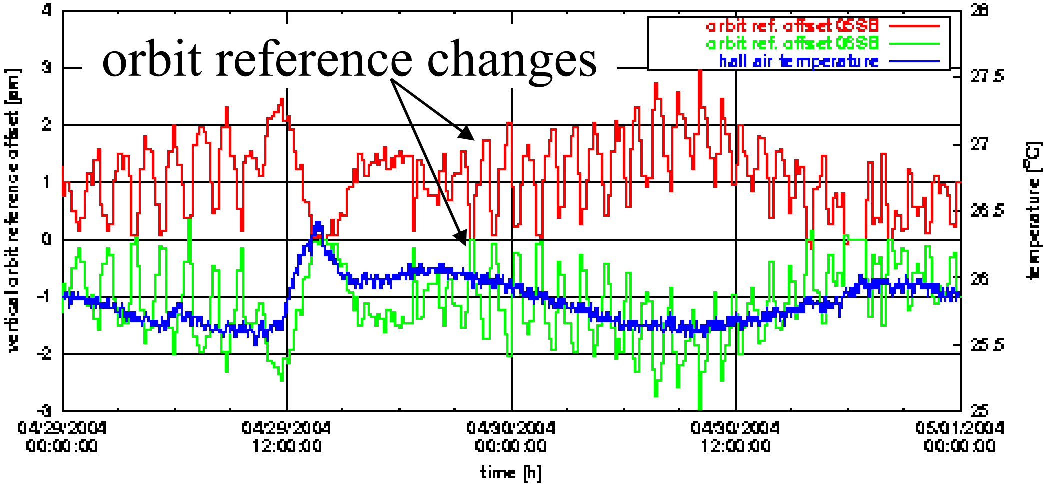
- 390 buckets filled
- gap of 90 buckets



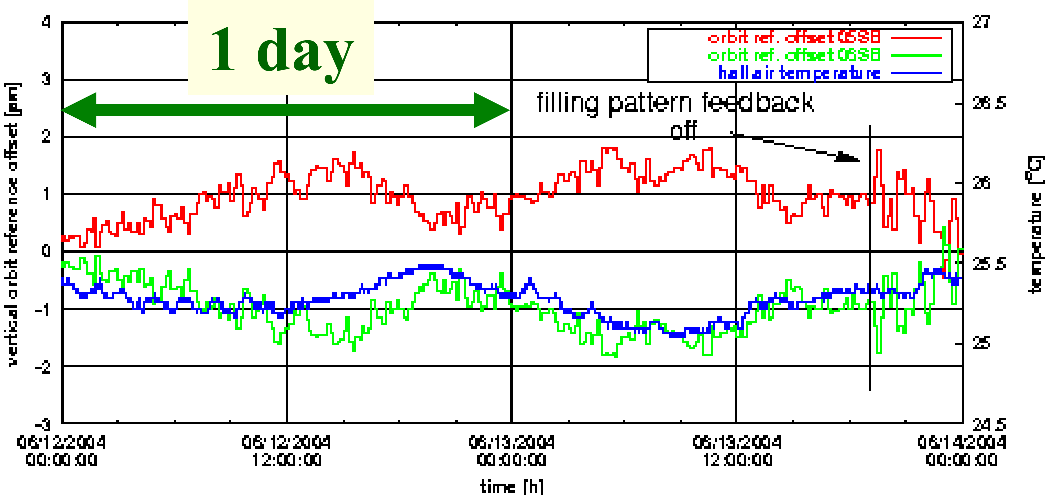


Performance: Long Term Stability @ ID 6S

- without filling pattern feedback



- with filling pattern feedback



⇒ ref. orbit changes:
< ±1 µm
over 1 day period

FOFB: Experiences / Limitations

- arbitrary orbits possible (→ allows simple PBPM feedback)
- bigger feedback loop delays than expected (sample period: 250 μs)
  - data transfer from DSP to PSC via IOC: ~100 μs
  - substantial group delay in digital filters: ~600 μs

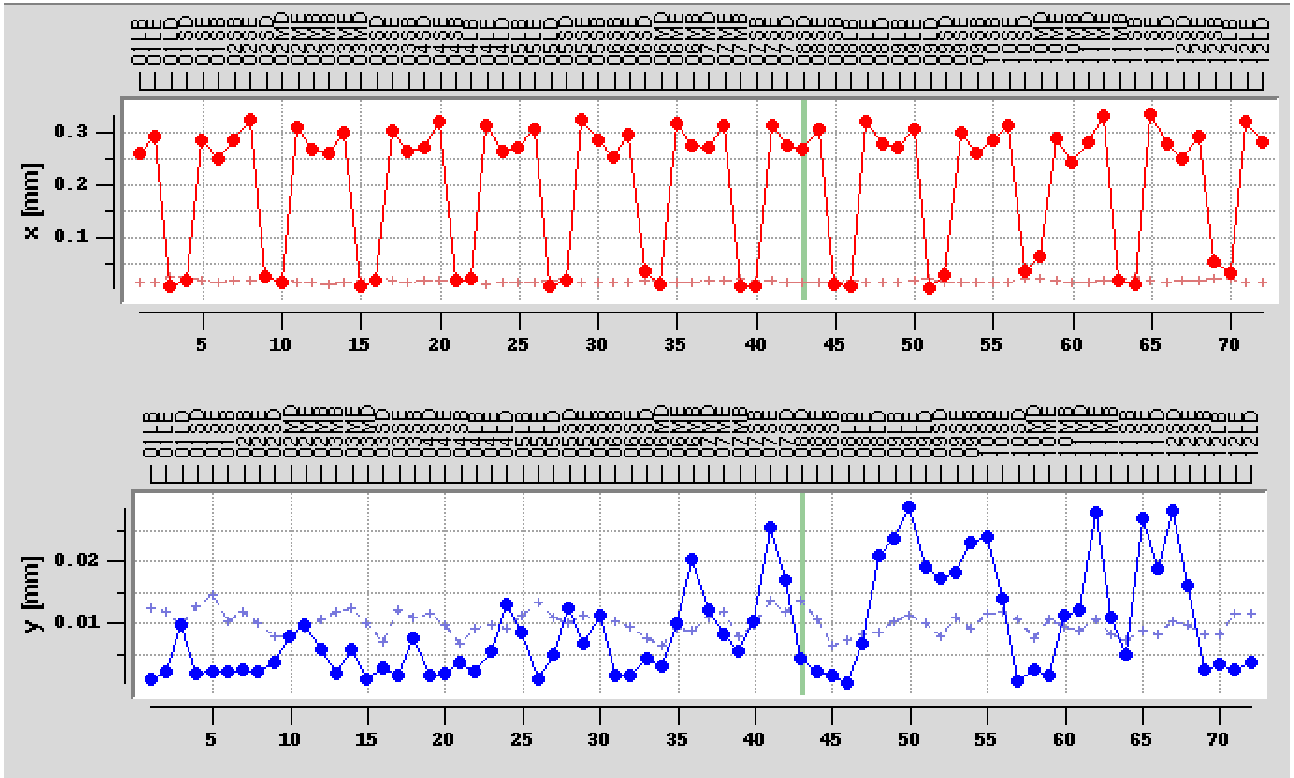
→ total loop delay of 1.5 ms

→ slightly lower bandwidth than envisaged (0 dB @ 95 Hz)

but: no dominant excitation lines in noise spectrum @80-100 Hz

- Mean Time Between Failures
  - hardware (DBPM/FOFB): **1** failure/month
  - ctrl sys./network/user/operator: **1-3** failures/month
- "RF glitches" while adjusting the main RF frequency (IEEE interface of RF generator)

RF frequency change:



300 µm

dispersion orbit corresponds to
~ 500 Hz
freq. change
(ΔE/E~2 ‰)

timescale: 30-40 ms

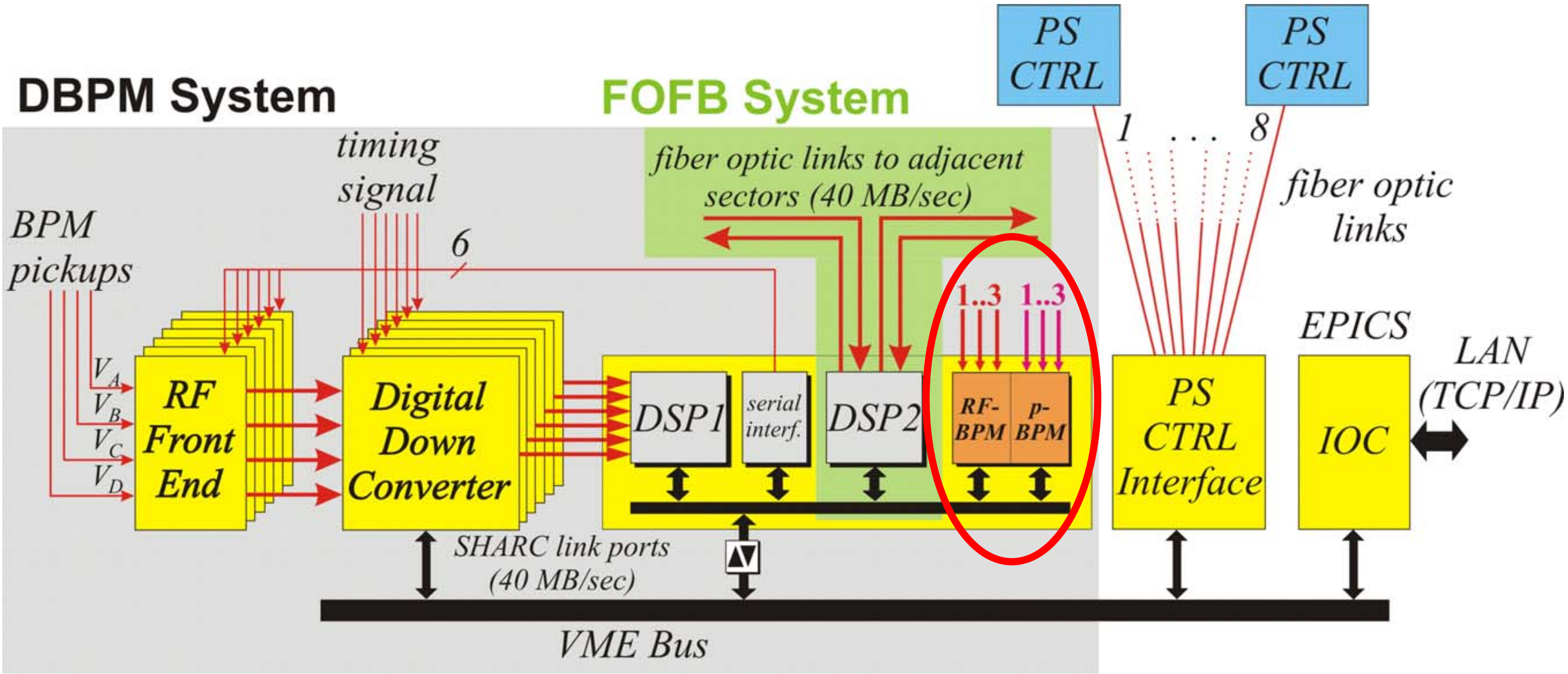
(peak offset values with respect to ref. orbit)

⇒ change of frequency requires different strategy (?)

(→ frequency modulation input of RF generator instead IEEE interface?)

FOFB: Extensions

- **Femto project**: requires additional BPM/corrector magnets in ID straight to guarantee the required orbit stability (Jul. 05)
- integration of photon BPMs into FOFB (→IR beamlines)



Summary

- very flexible and reliable FOFB system
- suppressions of orbit distortions up to 95 Hz
- global orbit stability (1 – 150 Hz): horizontal 0.41 $\mu m \cdot \sqrt{\beta_x}$, vertical 0.29 $\mu m \cdot \sqrt{\beta_y}$
- power spectral densities of photon BPMs: still to be measured
- residual variations of photon beam @ PBPM 6S: $\leq 7\ \mu m_{pp}$ (long term)
- PBPM feedback @ beamline 4S, 6S → < ±1 µm (long term)
- filling pattern feedback minimizes systematic errors of RF-BPMs, remaining systematic errors due to temperature dependency of RF-BPM electronic **< ±1 µm/day** @ RF-BPM
- substantial improvements for "easy usability"
- upgrade/extension for additional RF-BPMs (Femto) & photon BPM integration

SPring8: "Maybe we don't need a fast orbit feedback."

ALS: "The users didn't request a fast orbit feedback but we knew that we can do better…"

SLS: "We already have a stable beam and we need a fast orbit feedback to preserve it."