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SLS2 Fast Orbit Feedback (FOFB) Overview

DLS2-SLS2 Exchange Meeting on BPMs & Feedbacks, Nov. 30, 2020, PSI

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- **Introduction**
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- **SLS2 FOFB**
- **Summary**

Introduction & Strategy

Present SLS1 BPM & Feedback Electronics (Orbit, Multibunch, ...):

- Technology from year ~2000:
- Few spares, limited performance

-> Need upgrade (soon) anyway (with/without SLS2)

Activities at SLS1 until 2023:

- Upgrade SLS1 BPM & feedback electronics & software already before dark period. Motivation:
  - Reduce SLS2 commissioning time
  - Verify at SLS1 that new systems meet SLS2 requirements
- Keep old SLS1 kickers, magnets & magnet power supplies (PS) until dark period

Dark Period & SLS2:

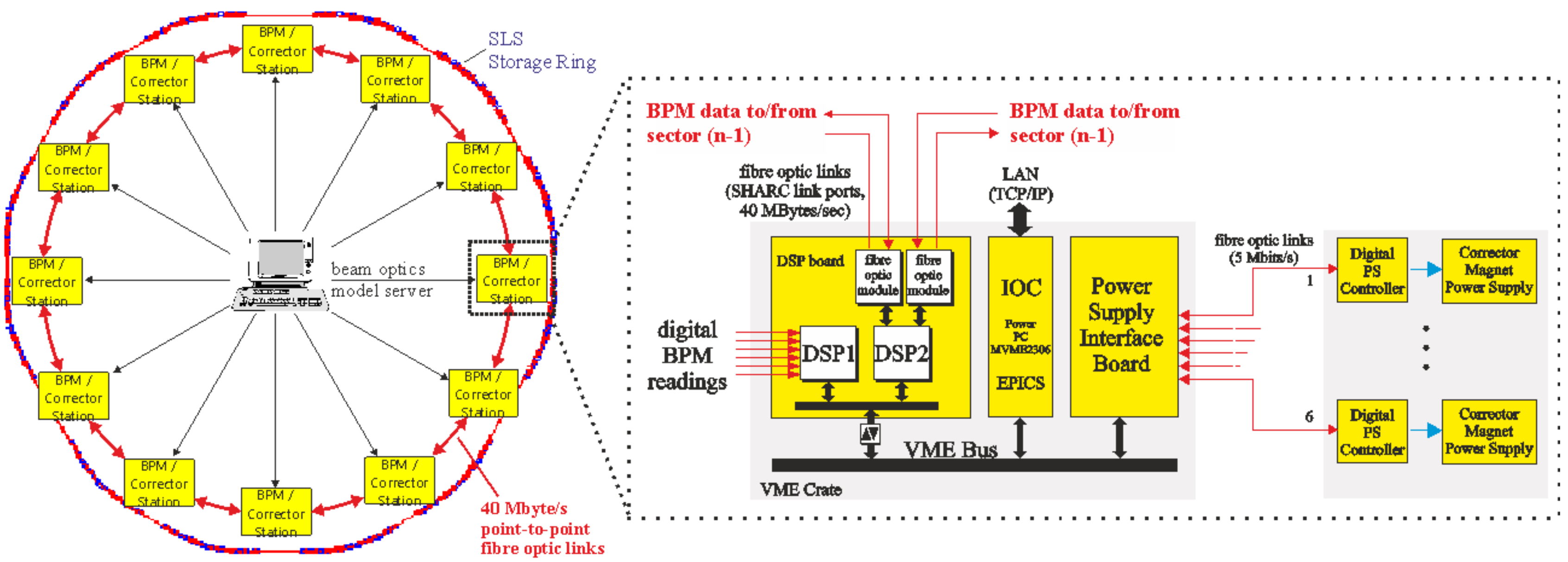
- New ring beam pipe & BPM pickups (more than SLS1)
- New corrector magnets & power supplies
- New MBFB kickers
- Add more BPM electronics (SLS2 has more BPMs)
- New/larger orbit feedback network, new power supply interface, ...

Present (Old) SLS BPM & FOFB System

SLS1 storage ring: 12 "BPM/FOFB" VME crates, each with:

- 2 VMEbus EPICS IOCs (1 BPM, 1 Magnet) + Event Receiver
- 1 DSP Board (BPM position calculation, FOFB algorithm, ...)
- 6-7 BPM digitizer cards ("QDRs") with DDC ASICs
- 2 Hytech boards for corrector PS interface

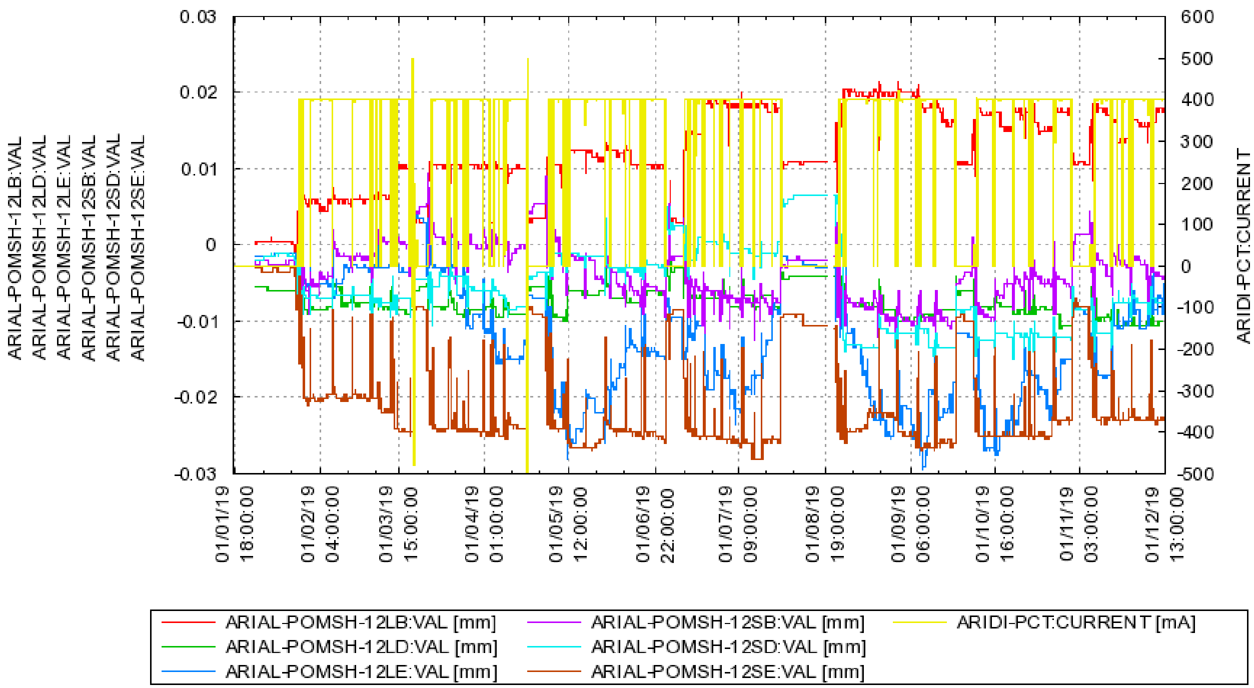
BPM RF Front-Ends (RFFEs): In separate VME crate, slow gain control interface to DSP



SLS1 Beam Pipe Motion @ BPMs

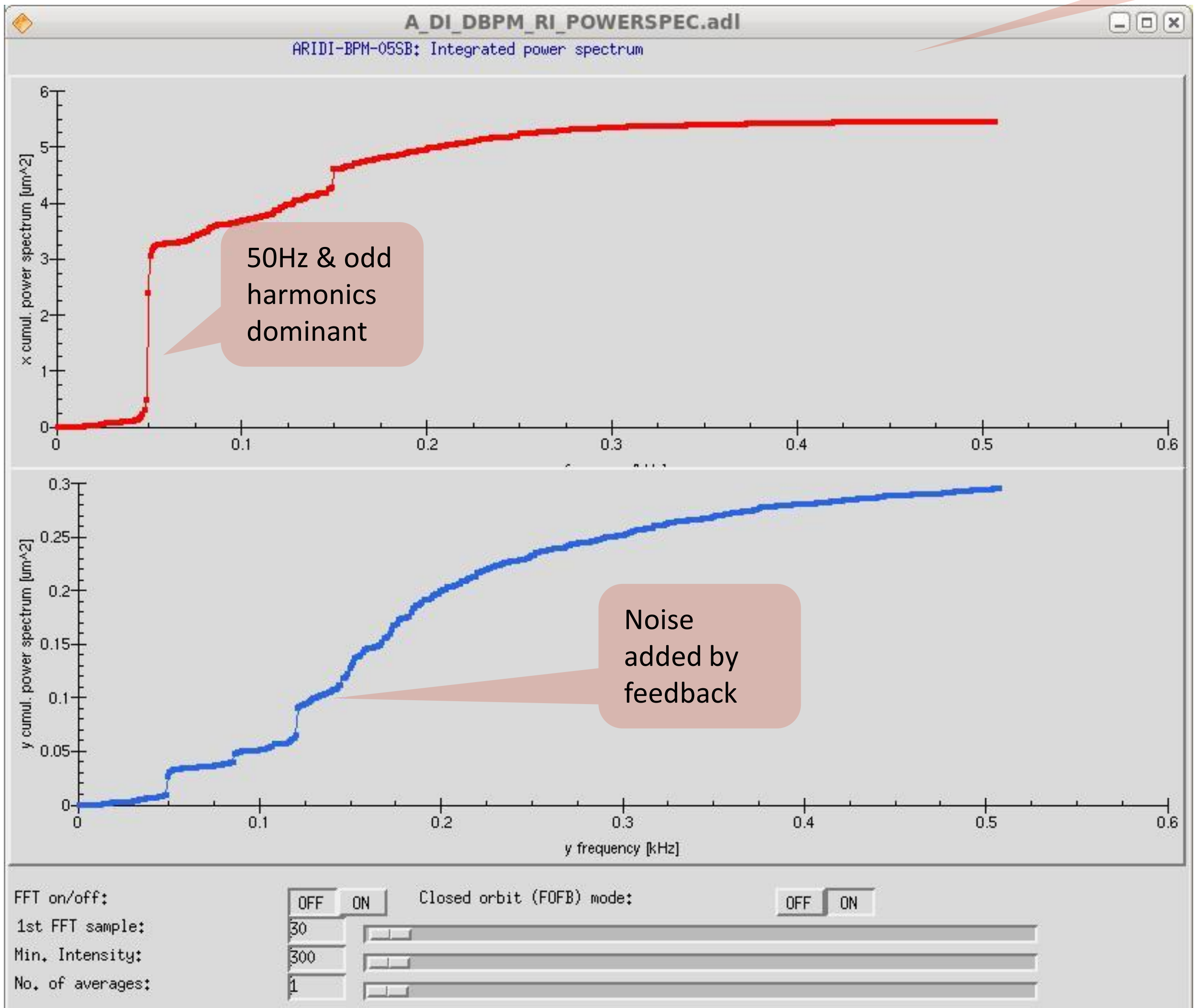
January-December 2019, POM reading in one of 12 SLS1 sectors:

- 0 <-> 400mA: ~10um motion
- Jumps visible after periods without beam: Hysteresis of beam pipe position, or of position encoder?
- SLS1 encoders not used for/by feedback. Using BBA instead.



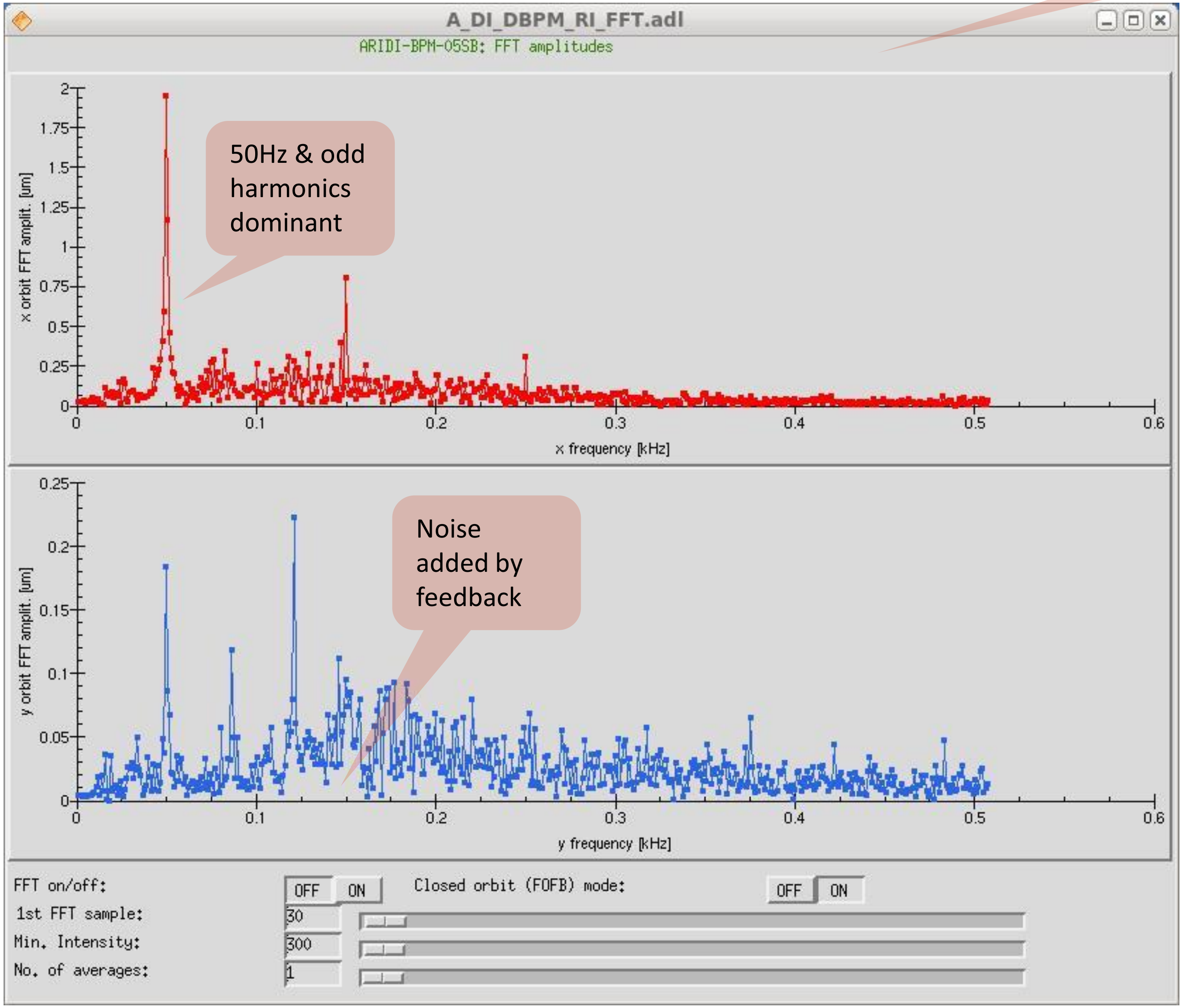
SLS1 BPM Power Spectral Density

3.9.2020, 9:43, 400mA, active feedback



SLS1 BPM FFT

3.9.2020, 9:43, 400mA, active feedback

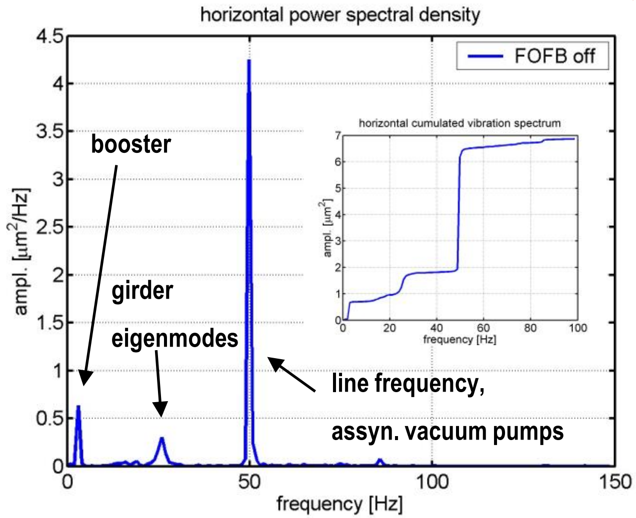


SLS1 FOFB Performance

Power Spectral Density

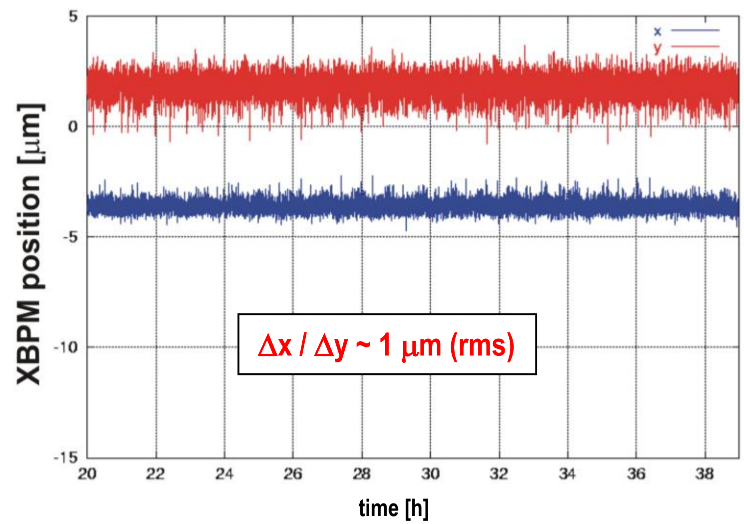
Horizontal, measured at RF BPM outside of FOFB loop (β_x = 11 m).

Older data...



Medium / Long Term Stability

Photon BPM signals at ID 06S, ~ 10 m from source point. Data points integrated over 1 s.



SLS Orbit Stability with FOFB

- **Horizontally (1 - 100 Hz):** $0.38\ \mu m \cdot \sqrt{\beta_x}$
- **Vertically (1 - 100 Hz):** $0.27\ \mu m \cdot \sqrt{\beta_y}$

Examples:
tune BPM (β_y = 18 m) ⇨ Δy = 1.2 μm
ID 06S (β_y = 0.9 m) ⇨ Δy = 0.25 μm

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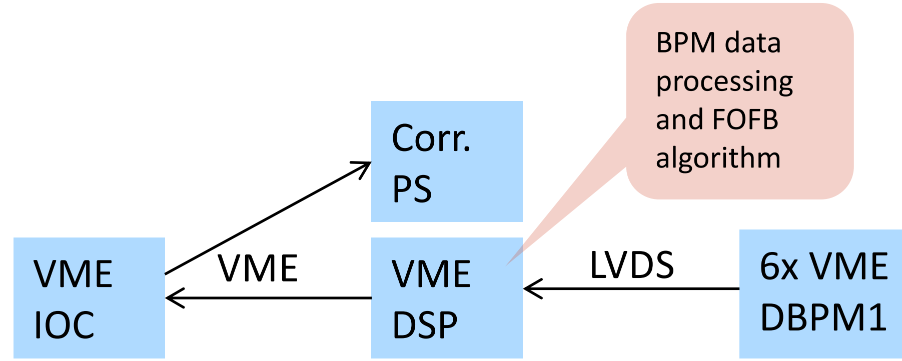
SLS FOFB Upgrade Steps

	SLS1 (year 2000 - now)	SLS1 (until 2023)	SLS2 (2024+)
Network Topology	Ring	Tree (Small)	Tree (Large)
FOFB Algorithm	Distributed (4kHz) SVD + PID	Centralized (4kHz) Regularized SVD + ...	Centralized (20+kHz) + adap. Feed-forward + ...
FOFB Electronics	12 DSP cards	1 DBPM3 (Zynq U+)	
BPM Platform	DBPM1 (VME)	DBPM3 (Zynq U+)	
FOFB Software	Assembler Code	C++ & VHDL (Basic Features)	C++ & VHDL (Advanced)
Magnet PS	PSI Design (~500 Hz BW)		PSI Design (~5 kHz BW)*
Magnet PS Interface	VME		Fiber
Corrector Beam Pipe	2mm Steel		1mm Steel + 5µm Cu
Corrector Magnet	Combined (Sextupole + Dipole Corrector)		Dedicated
Crossover Frequency	100 Hz		>300 Hz*
Target Loop Latency	1.6ms		<0.2ms*
Short-Term Stability	<25% of beam size	<5...10%	<5%

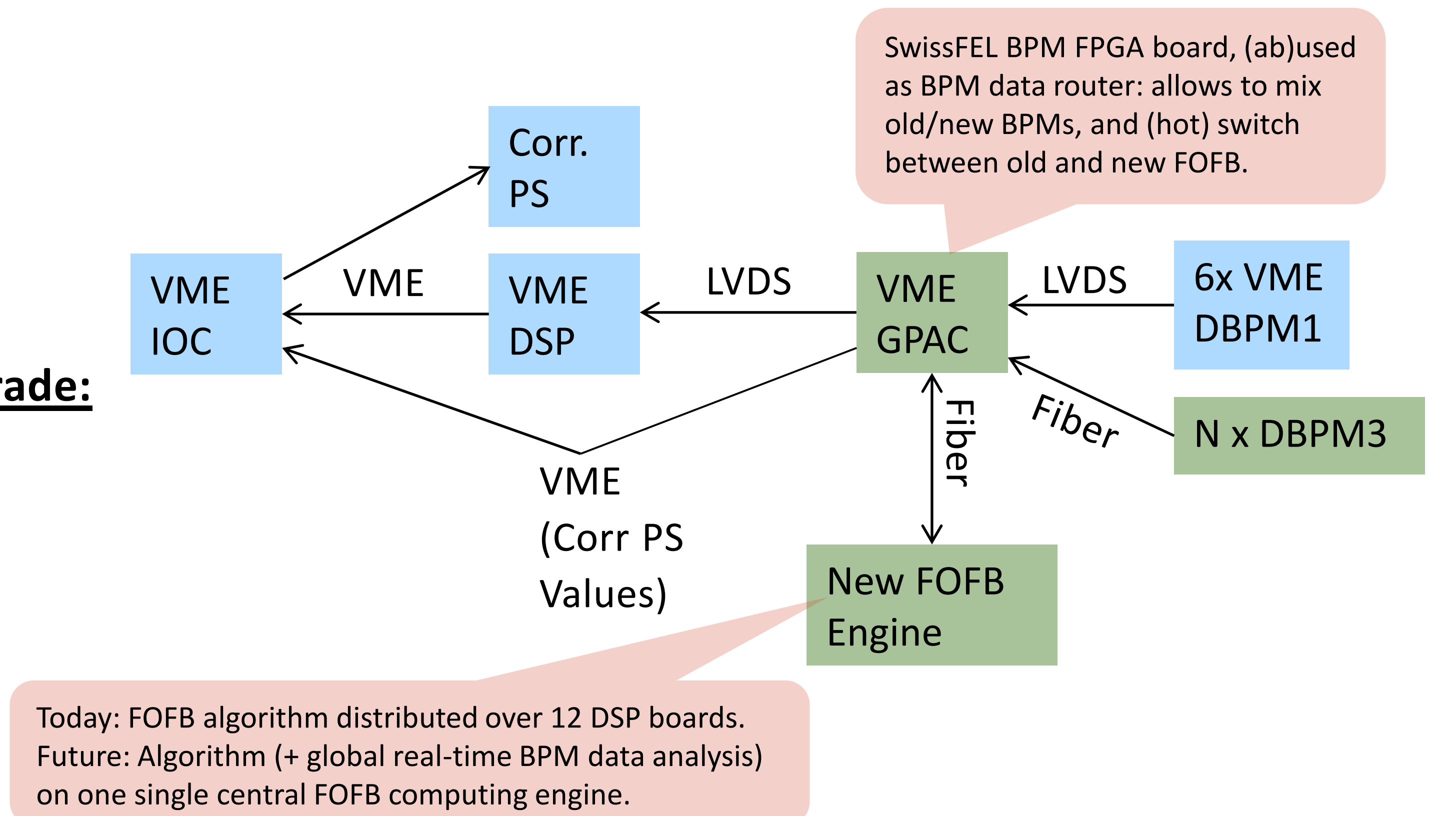
*BPM & corrector bandwidth & latency depend (also) digital filters & parameters that are programmable -> can be configured/changed during operation. Optimal bandwidth depends on beam perturbation spectrum: Trade-off between adding noise to beam and suppressing perturbations (SLS2: Expect not much >> 100 Hz ...).

Incremental SLS1 BPM/FOFB Upgrade

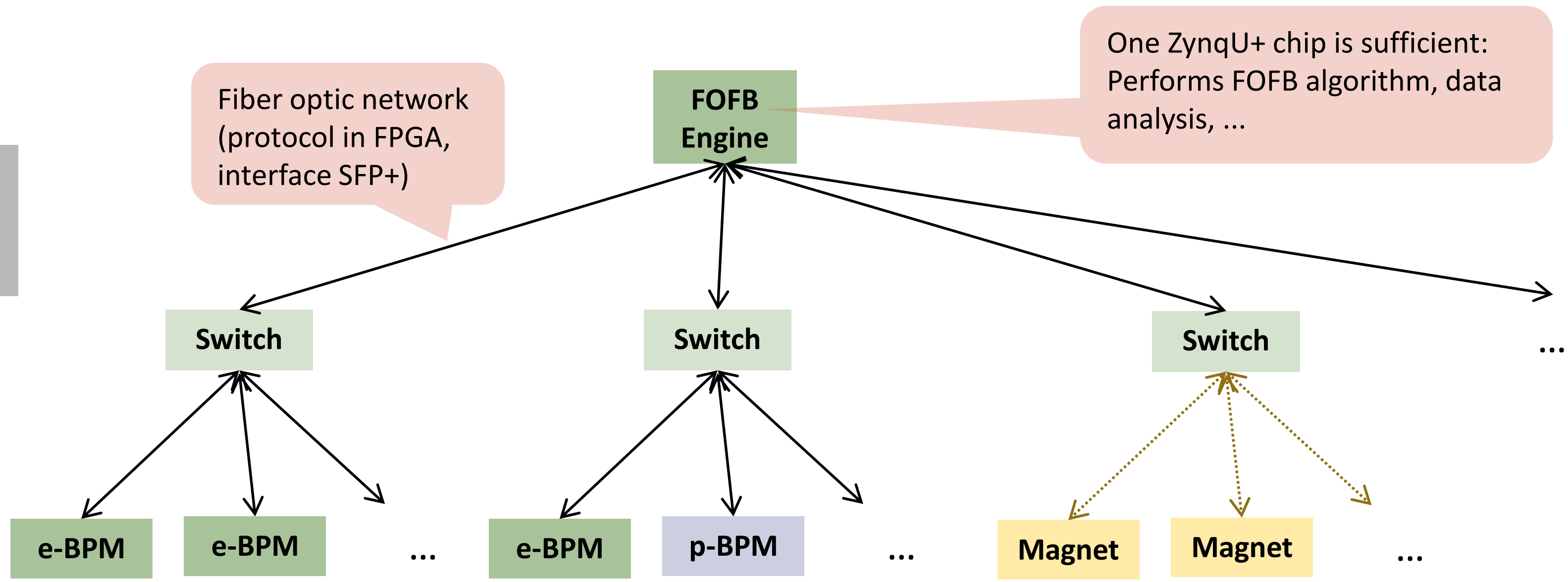
Now (one of 12 sectors):



SLS1 Upgrade:



Final SLS2 FOFB System



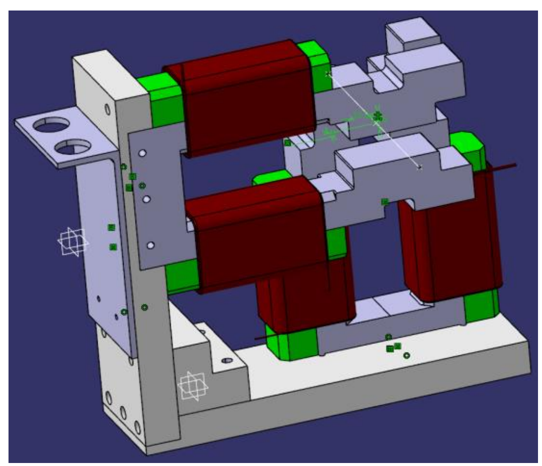
<u>Real-time network (BPM + corrector data, > 20 kHz correction rate): Tree topology</u>

- Fiber optic links (50MBaud POF for magnet PS, multi-gigabit SFP+ for everything else)
- Can be scaled/extended (size, performance)
- Allows mixing of different monitors & actuators (e-BPM, photon BPM, magnet PS, ...)
- e-BPM, Switch & FOFB Engine can use same FPGA board (Zynq U+ SoC).
- Timing system has same topology -> common fiber cable bundles (like SwissFEL)
- Communication protocol TBD, several options (use/improve existing ones, ...)

SLS2 Orbit Corrector Magnets

SLS1 & SLS2

- Similar number of BPMs and nearby corrector magnets (near quads)
- Only fast correctors (good experience at SLS1)
  - Strong enough to enable expected static corrections at startup
  - Weak enough not to add significant noise onto the beam
  - Additional coil winding can be added during commissioning -> more kick
  - Power supply: Digital "Pre-emphasis" can reduce impact of eddy currents in magnet & beam pipe (for smaller current variations ...)
  - Magnets: 0.5m or 0.35mm lamination (being simulated/discussed ...)



Courtesy Magnet Section

SLS BPM & FOFB Components & Features

Subsystem	SLS1 Now	SLS1 2023	SLS2 Day1	SLS2 Final
Electron BPM Pickups & Mechanics	Old	Old	New	New
BPM Electronics Hardware	Old	New	New	New
BPM Electronics Firmware/Software	Old	New	New*	New*
Fast Orbit Feedback DSP Hardware	Old	New	New*	New*
Fast Orbit Feedback DSP Software	Old	New	New*	New*
Fast Orbit Feedback Magnet Power Supplies	Old	Old	New	New
Fast Adaptive / ID Gap Feed-Forward	-	-	New	New
Timing System Interface	Old	New	New*	New*
Control System Interface	Old	New	New*	New*
Slow Photon BPM Based Orbit Feedback	Old	Old	New	New
Fast Photon BPM Based Orbit Feedback	-	-	-	New
Operator/Expert High-Level Applications	Old	Mix	New	New
Slow Orbit Feedback (Backup for Fast Feedback)	Old	Old	New	New
Physics / Beam Optics Applications	Old	Mix	New*	New*
Fast First-Fault Detection/Archiving	-	-	New	New
Automated/Pro-Active Fault Detection	-	-	-	New

- *Significant adaptations for SLS2 (different from SLS1) needed (optics, lattice, performance, number of elelements, data rates, control & timing system, ...)*

Contents

Summary & Outlook

- Aiming to replace SLS1 BPM/FOFB electronics (excl. magnets, PS, network) until 2023
- Full upgrade for SLS2 until 2025
- Just started working on new system. Next steps:
  - Modelling/simulation & (more) detailed specification of new SLS2 system (stability goal: <5% of X/Y beam size 1Hz-1kHz):
    - SLS1 & and SLS2 Y beam size similar now (min. ~2µm)
    - SLS1 X/Y coupling now much smaller than ~20 years ago ...
    - SLS2: BPM geometry factor 2x smaller -> resolution 2x better
  - Bandwidth & noise analysis & optimization:
    - Magnet lamination thickness
    - Beam pipe thickness
    - Test of power supply with magnet & pipe, ...
  - Now preparing hardware needed for mixing old and new BPM/FOFB electronics (prototype tested & OK) -> beam test at SLS1 with new BPMs & FOFB electronics can start soon ...

Thank you for your attention!

Thanks to all other supporting PSI colleagues and groups, including:

- **Marek Palka (SLS2 MPSoC FOFB engine algorithms, ...)**
- **Jonas Purtschert (GPAC3 FPGA firmware)**
- **Goran Marinkovic (FPGA/SoC system expert & consulting)**

Supplementary Slides