PAUL SCHERRER INSTITUT

V. Schlott for the "SLS 2.0 Project Team"

SLS 2.0 Status and Diagnostics Considerations

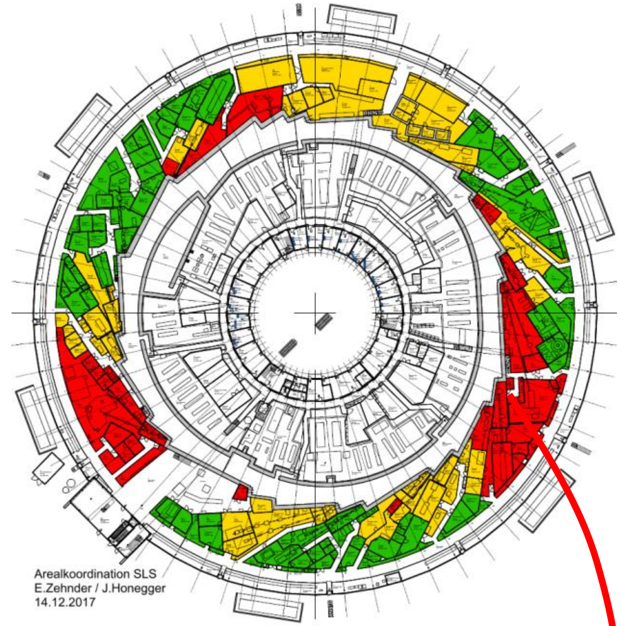
TW-DULER WS

DLS, April 20th, 2018

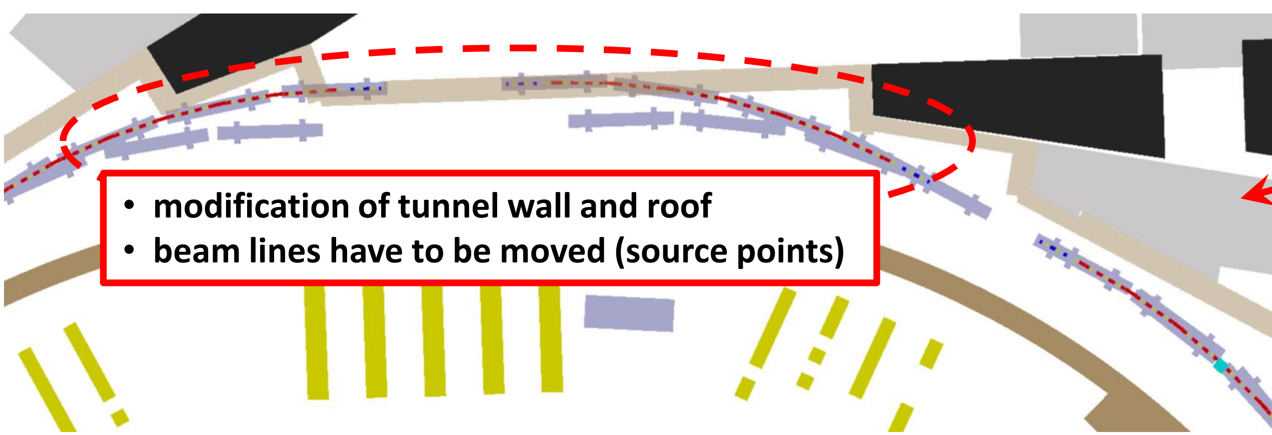
SLS 2.0 – Some Key Parameters

The SLS 2.0 Upgrade includes…:

- new storage ring lattice: 12 x «7-bend achromat»
  - → 40 – 50-times lower emittance (~ 100 pm @ 2.4 GeV)
  - → 290.4 m circumference (SLS: 288 m)
  - → 12 identical ID straights with length of 5 ½ m



- Use of novel technologies
  - → compact and high field permanent magnets (LGBs)
  - → NEG-coating for vacuum chambers with 20 mm diameter
  - → Upgrade of insertion devices (cryo-undulators)
  - → new girders, renewed infrastructure, CS electronics and feedback loops
  - → improvements of beam lines and experimental stations (optics, detectors…)
  - → many more systems, which are required for a state-of-the-art SRLS user facility…!!!



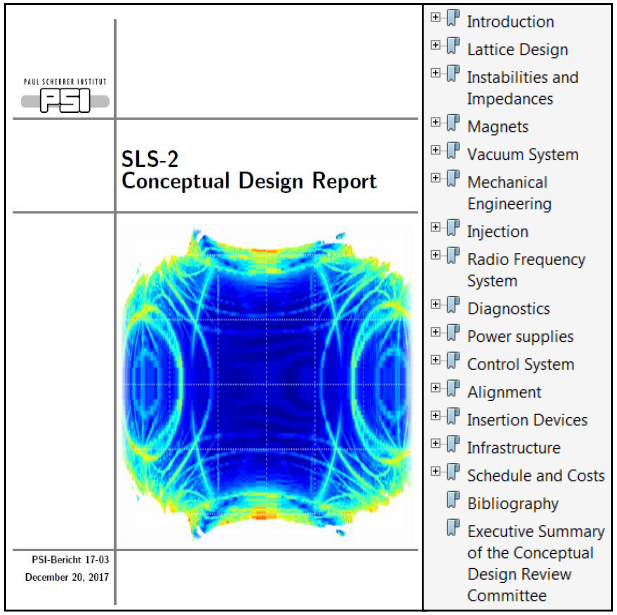
SLS 2.0 – Project Proposal (Jan. 2018)

- **Positive evaluation of the SLS 2.0 Conceptual Design Report by an external review committee in September 2017**

- **Project Proposal (Swiss Research Infrastructure Roadmap 2021 – 2024) has been submitted to Swiss funding agencies in January 2018**

- **Project costs have been estimated to 100 MCHF (machine and beam lines without salaries)**

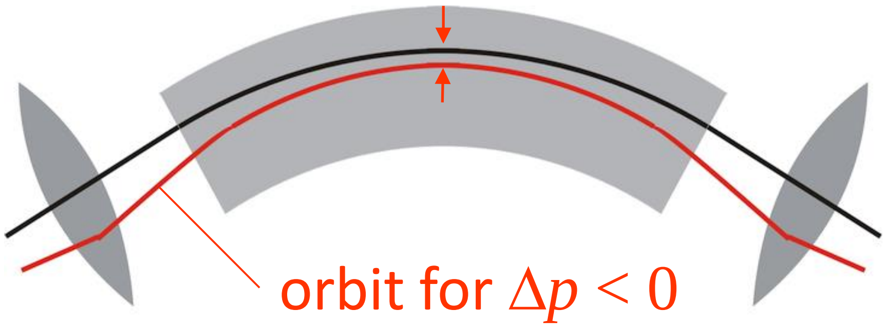
- **Upgrade program has to be realized in parallel:**
  - → **BPM, FOFB and MBFB systems**
  - → **high power and low level RF systems**
  - → **injector complex and electrical infrastructure**
  - → **CS electronics and safety systems**
  - → **cooling and cryogenics systems**
  - → **building and its infrastructure**



www.lib4ri.ch/archive/nebis/PSI_Berichte_000478272/PSI-Bericht_17-03.pdf

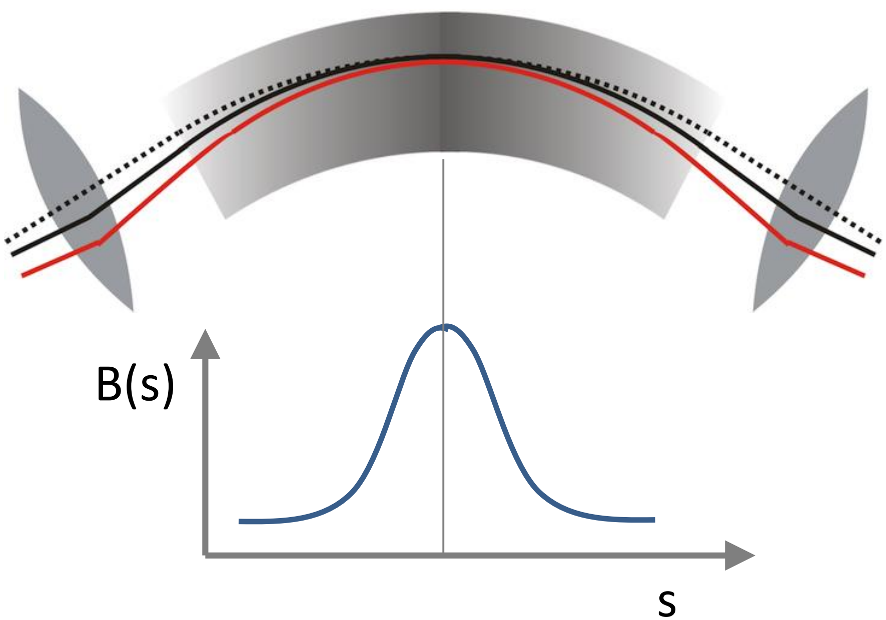
Novel low emittance lattice concept

slide by Andreas Streun



Standard periodic cell

- quadrupoles (lenses) to focus dispersion
- dispersion at center > 0



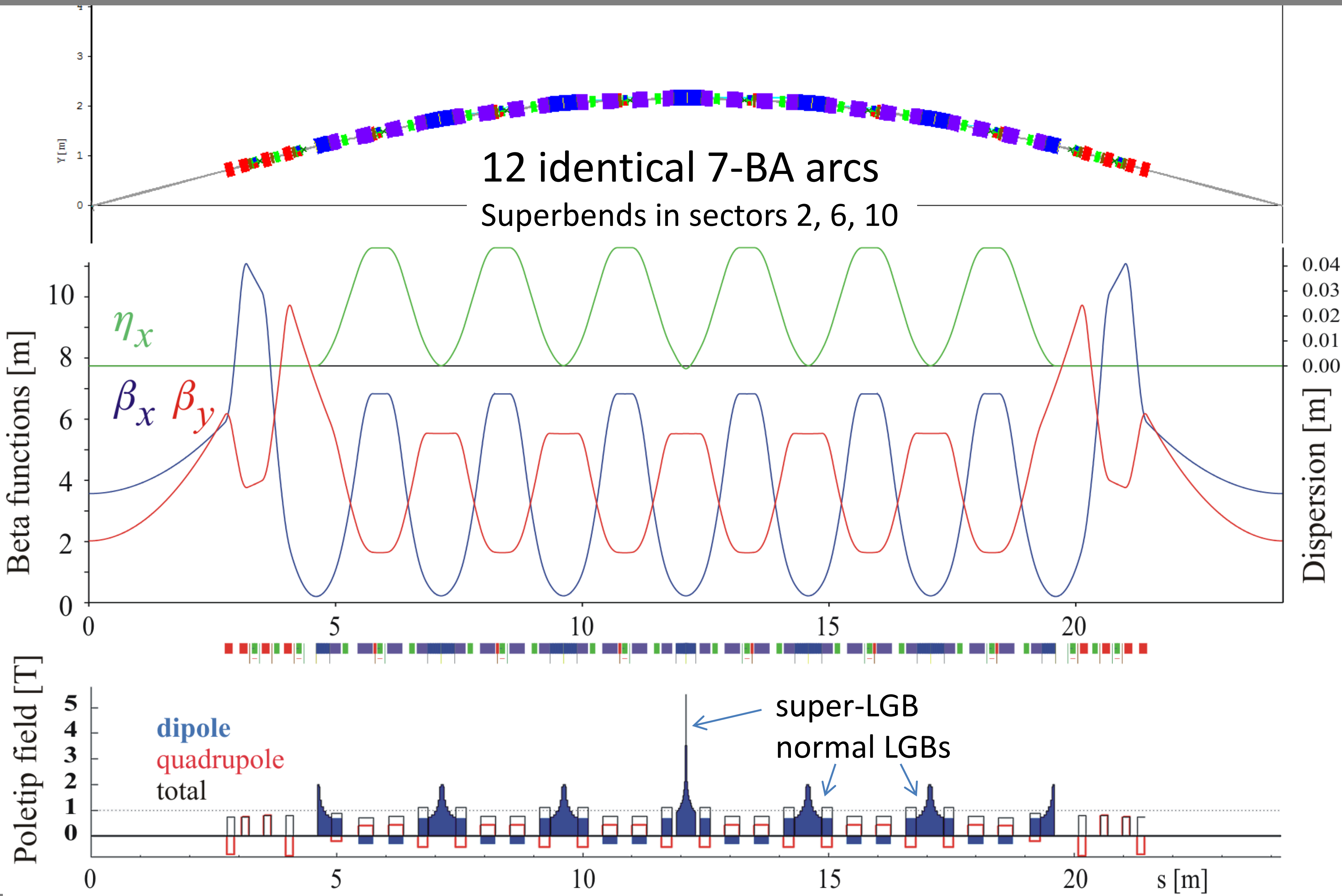
Modified periodic cell

- displaced quadrupoles = **reverse bending magnets (RB)**
- dispersion at centre $\rightarrow 0$
  (suppression of quantum excitation)
- longitudinal field variation in dipole magnet: max. B at center = **longitudinal gradient bend (LGB)**

⇨ 5× lower emittance than conventional cell

SLS 2.0 7-bend achromat

slide by Andreas Streun



Beam size

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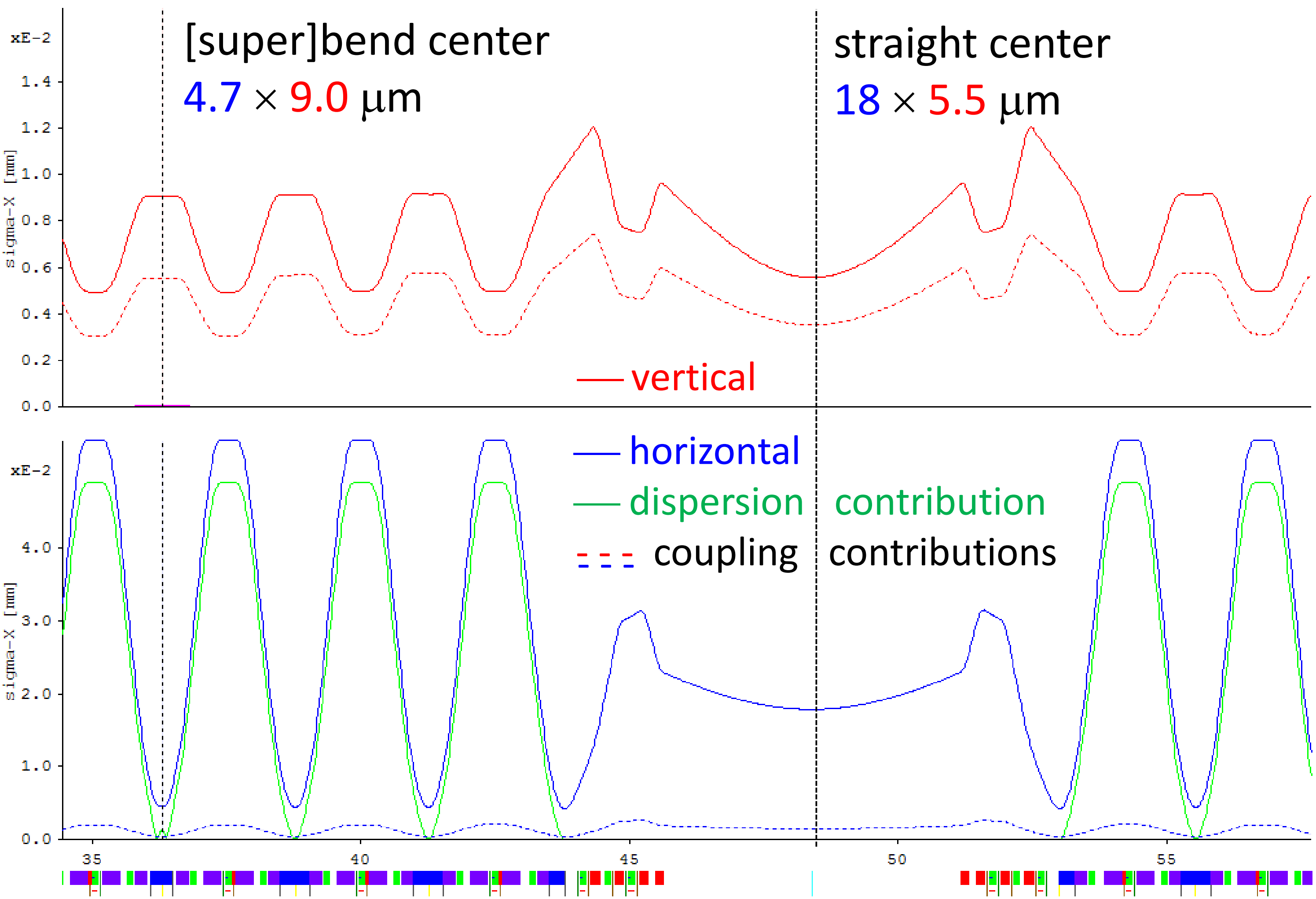
rms envelopes for 10% emittance coupling (no IBS)

emittances 98 pm / 10 pm



Periods			3
Length	[m]		290.400
Angle	[deg]		360.000
AbsAngle	[deg]		561.600
TuneA			39.19298
TuneB			15.30746
ChromA			0.000
ChromB			0.000
Alpha	[xE-3]		-0.133
JA			1.66685
JB			1.04354
Energy	[GeV]		2.400
EmitA	[nm rd]		0.098
EmitB	[nm rd]		0.010
dE/turn	[keV]		554.4
Espread	[xE-3]		1.036
TauA	[ms]		5.031
TauB	[ms]		8.036
TauE	[ms]		6.503
Location			BSOM
Position	m		36.300
BetaA	m		0.209
AlphaA			0.0000
BetaB	m		5.318
AlphaB			0.0000
Disp X	m		-0.0012
Disp'X	rad		0.0000
Disp Y.	m		0.0000
Disp'Y	rad		0.0000
PhiA/2pi			4.8989
PhiB/2pi			1.9134
curly H	m		(to do)
Orbit X	mm		0.0000
Orbit X'	mrad		0.0000

Lattice parameters

slide by Andreas Streun

Name	SLS*)	SLS 2.0#)
Emittance at 2.4 GeV [pm]	5069	102 → 126♦)
Lattice type	12×TBA	12×7BA
Circumference [m]	288.0	290.4
Total *absolute* bending angle	360°	561.6°
Working point $Q_{x/y}$	20.43 / 8.22	39.2 / 15.30
Natural chromaticities $C_{x/y}$	–67.0 / –19.8	–95.0 / –35.2
Optics strain[1)]	7.9	5.6
Horizontal damping Partition J_x	1.00	1.71
Momentum compaction factor $[10^{-4}]$	6.56	–1.33
Radiated Power [kW] [2)]	208	222
rms energy spread $[10^{-3}]$	0.86	1.03 → 1.07♦)
damping times x/y/E [ms]	8.9 / 8.9 / 4.4	4.9 / 8.4 / 6.5

1) product of horiz. and vert. normalized chromaticities C/Q
2) assuming 400 mA stored current, bare lattice without IDs
*) SLS lattice before FEMTO installation (<2005)
#) SLS 2.0 with 3 superbends

♦) including intra-beam scattering for 1 mA bunch current (400 mA in 400 of 484 buckets; 500 MHz), 10 pm vertical emittance, 1.4 MV RF voltage, 3rd harmonic cavity for 2.2×bunch length.

Challenges for a low emittance ring in a very limited space

- **Dynamic Acceptance:** sufficient life time and injection efficiency
  → can be achieved with discrete correctors (not combined with sextupoles)
- **Beam current:** stability with regard to impedances
  → probably ok for 500 nm NEG-coating (still under investigation)
- **Magnets:** field strength, compactness and field quality
  → permanent and electro magnet designs under consideration
  handicapped by space restriction → iterative lattice design
- **Girder System:** positioning accuracy and stability
  → can be achieved with modern design tools and mineral cast technique
- **Vacuum System:** compactness, pressure and impedance
  → establishment of NEG-coating technique for 20 mm chamber diameter
- **Injection:** efficiency and reliability in off-axis top-up injection
  → modified 3-bump scheme using anti-septum

Overview of SLS 2.0 Diagnostics

Diagnostics System	#	Remarks	Status
Beam Position Monitor (BPM)			
- Storage Ring Pick-Up	144	120 storage ring BPM pick-ups plus 24 ID interlock BPMs	dark period
- Storage Ring Electronics	144	consists of RF front ends and digital back ends (BPM electronics under design)	2021 +
- Injector Electronics (SLS-2.0 upgrade program)	63	55 for booster, 9 for LINAC and TLs (same BPMs as for the SLS 2.0 storage ring)	dark period
Current Monitor (NPCT)	2	incl. NPCT vacuum chambers , comm. Bergoz NPCT transformer and electronics	dark period
Filling Pattern Monitor (FPM)	1	requires synchrotron radiation port from LGB without front end components	dark period
Time Structure / Streak Camera	1	upgrade / renewal of existing dual-sweep synchro-scan streak camera	dark period
Profile Monitor (SRPM) (π-polarization method)	2	requires SR-port from LGB with front end components and diagnostics hutch	dark period
"in-Air" Position (and Profile) Monitor (XBPM)	24	using hard X-ray radiation (> 10 keV) through bending magnet absorbers for position and possibly profile (local coupling) measurements (2 per sector)	to be designed
Screen Monitor (SCM)	2	beam profile meas. in storage ring injection straight for injection optimization	dark period
Long. Beam Loss Monitor (LBLM) (optical fiber along BTR line)	1	monitors and locates beam losses in the BTR and the storage ring injection area	SwissFEL ?
Beam Loss Monitors (BLM)	48	4 BLMs (scintillator rods and photo multipliers) per sector	SwissFEL ?
ID-Photon BPM (PBPM)	18	Diamond quad-PBPM for hard x-ray beam lines. Gas-based PBPMs for low energy beam lines (SwissFEL-type, R&D ongoing). DAQ integrated in FOFB.	to be developed
BTR Diagnostics Upgrade			
- Screen Monitor	3	SwissFEL-type of SCM for beam observation / matching	SwissFEL
- Synch. Radiation Monitor	3	new camera system and optics	SwissFEL
- Charge Monitor	1	Bergoz Turbo-ICT for improved S/N	dark period
Injector Diagnostics Upgrade	All	electronics and CS-upgrade of diagnostics systems	dark period

Some Stability-related Issues for SLS 2.0

- **Alignment Specifications**

  → absolute girder alignment: 60 μm
  → girder to girder alignment: 20 μm
  → elements on girder alignment: 30 μm

- **Assumptions & Strategy**

  → small girder-to-girder and elements on girder tolerances due to small maximum corrector strengths of ± 400 μrad (for ± 5 A PS)

  → PS noise ~ 5 ppm in amplitude (matching noise contribution to BPMs: 50 nm rms @ 1 kHz)

  → beam-based girder and BPM alignment to reduce corrector strengths

  → allow for deliberate beam steering and fast feed forwards
  (e.g. polarization bumps of up to 300 μrad max. @ 10 Hz for individual beam lines)

  → vertical source point stability: 100 nm (50 nrad)
  from days to 100 Hz for σ/10 of beam size in ID straights: sqrt (1 pmrad x 1.7 m) ≈ 1.3 μm

  → source point reproducibility: run to run < 1 μm (500 nrad) / SDs < 10 μm (4 μrad)

  → emittance / betatron coupling stability to 1% (10 mrad) @ 100 Hz to be controlled by dedicated skew quads and to be monitored by (fast) beam size measurement

SLS 2.0 – Standard Diagnostics Systems

- **Storage Ring Current, Transmission Efficiency and Lifetime**
  - → use of commercially available NPCT monitors and front end electronics
  - → use of standardized PSI read-out and processing electronics (new HW platform)

- **Filling Pattern and Top-Up Control**
  - → use of visible SR from LGB measured with APD (e.g. AD230-8-TO52-S1 APD & trans-impedance amp.)
  - → use of fast (GS/s) ADC and filling pattern / top-up control via SLS 2.0 event system

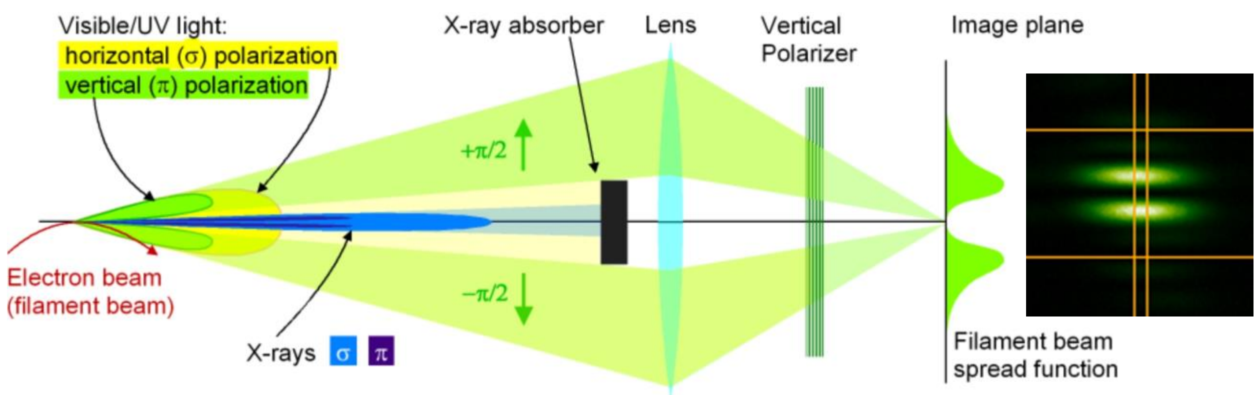
- **Beam Loss Monitoring** (developed for SwissFEL but not yet implemented at SLS)
  - → long. loss monitor (organic scintillator fiber, BCF-12) in BTR and injection straight for determination of beam loss locations (< 0.5 m resolution) during injection
  - → localized loss monitors (e.g. Cerenkov or gamma-scintillators) in storage ring sectors for turn-by-turn beam loss detection
  - → SwissFEL BLM electronics (PSI-design) or LIBERA-BLM (commercial) for read-out

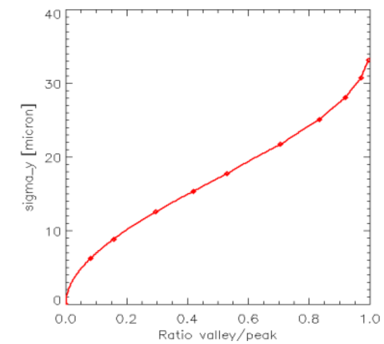
- **Injection Diagnostics**
  - → screen (YAG:Ce) monitors in BTR and injection straight and SR monitors in BTR
  - → re-use of SwissFEL screen monitor design and camera read-out system
  - → Turbo-ICT for higher resolution and improved S/N

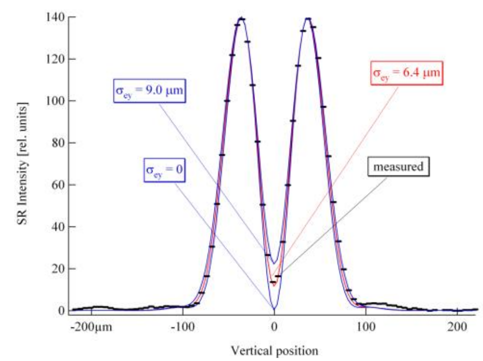
Synchrotron Light Monitor – Coupling and Emittance Determination

…application of π-polarization (vertical) and interferometric method (horizontal) by using visible / UV SR from LGB bending magnets allows the determination of the small SLS 2.0 beam sizes, which are in the order of 5 µm (σ_h and σ_v)

Example: Principle of π-Polarization Method







- Å. Andersson, et al., *Determination of Small Vertical Electron Beam Profile and Emittance at the Swiss Light Source,* NIM-A 592 (2008) 437-446
- T. Mitsuhashi, *Spatial Coherency of the SR at the Visible Light Region and its Application for Electron Beam Profile Measurement,* Proc. PAC 1997, Vancouver, p. 766
- O. Chubar & P. Elleaume, *Accurate and Efficient Computation of Synchrotron Radiation in the Near Field Region,* EPAC 1998

- **re-use of components from SLS-1 X08DA and X09DA beam size monitors (cost savings)**
- **efficient out-coupling of light in (single?) beamline hutch (easy maintenance)**

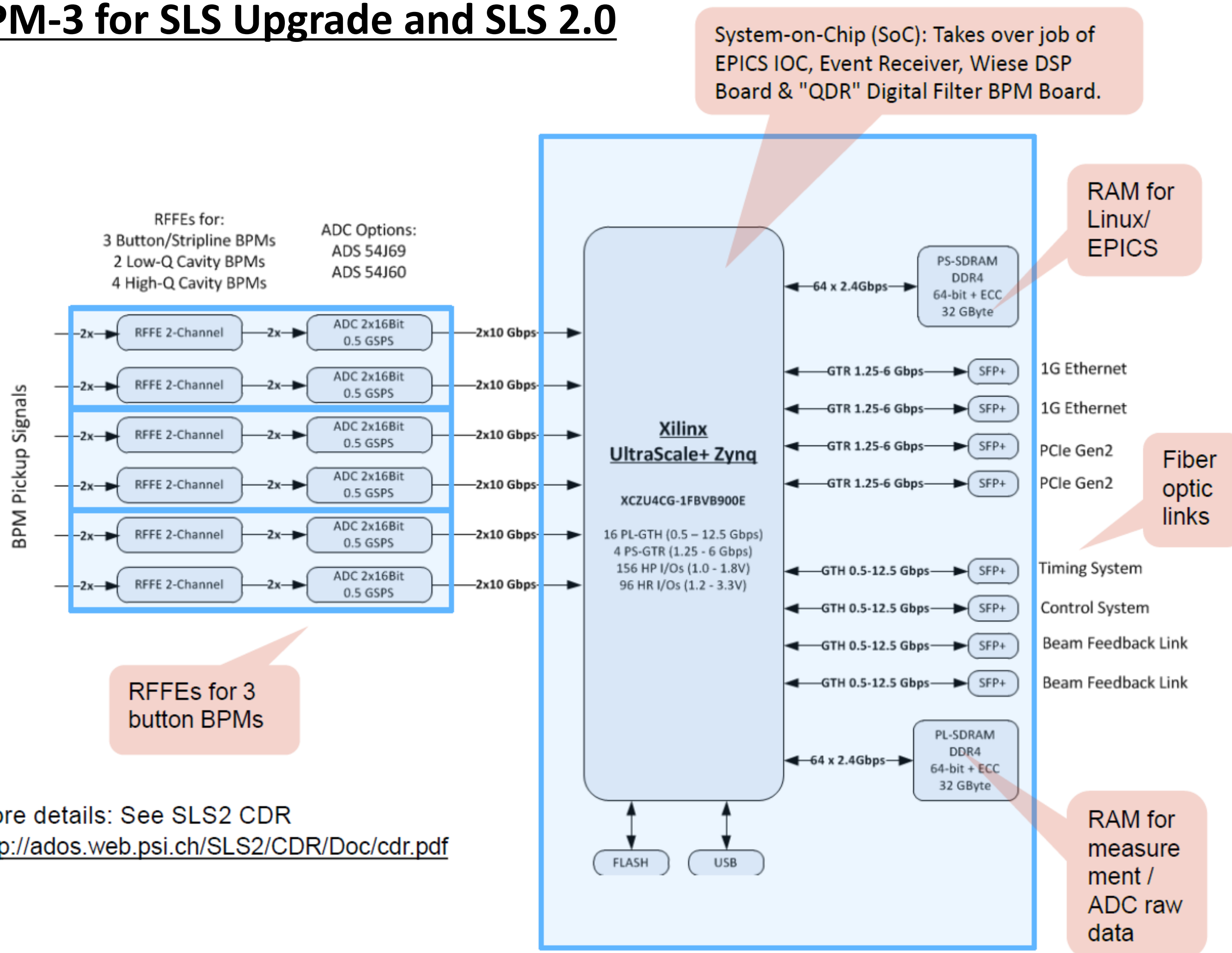
SLS 2.0 – Improved Diagnostics Systems

- **Present SLS BPM and FOFB System (DBPM-1)**
  - → BPMs "end of lifetime" (failure rate still ok, but no spares, obsolete HW and FW)
  - → non-scalable FOFB ring topology and obsolete DSP programming with assembler

- **Upgrade of SLS BPM / FOFB System** (SLS 2.0 BPM / FOFB System)
  - → aiming for cost-effective and least complex and scalable solution
  - → Zynq UltraScale+ System on Chip
  - → cost optimized housing (no VME) with single 12 V supply (optional redundancy)
  - → RFFE and ADC on the same PCB
  - → ADCs with multi-gigabit serial links (JESD204B)
  - → form factors are driven by application requirements
    (system is open for other possible PSI applications e.g. HIPA and SwissFEL BPMs)
  - → Optional: LINUX and EPICS running on BPM (may be added later)
  - → direct timing system interface

- **Status** (PSI (AEK) Electronics Governance Board decision is still pending)
  - → design has been started with goal of replacing present SLS system by 2021

DBPM-3 for SLS Upgrade and SLS 2.0



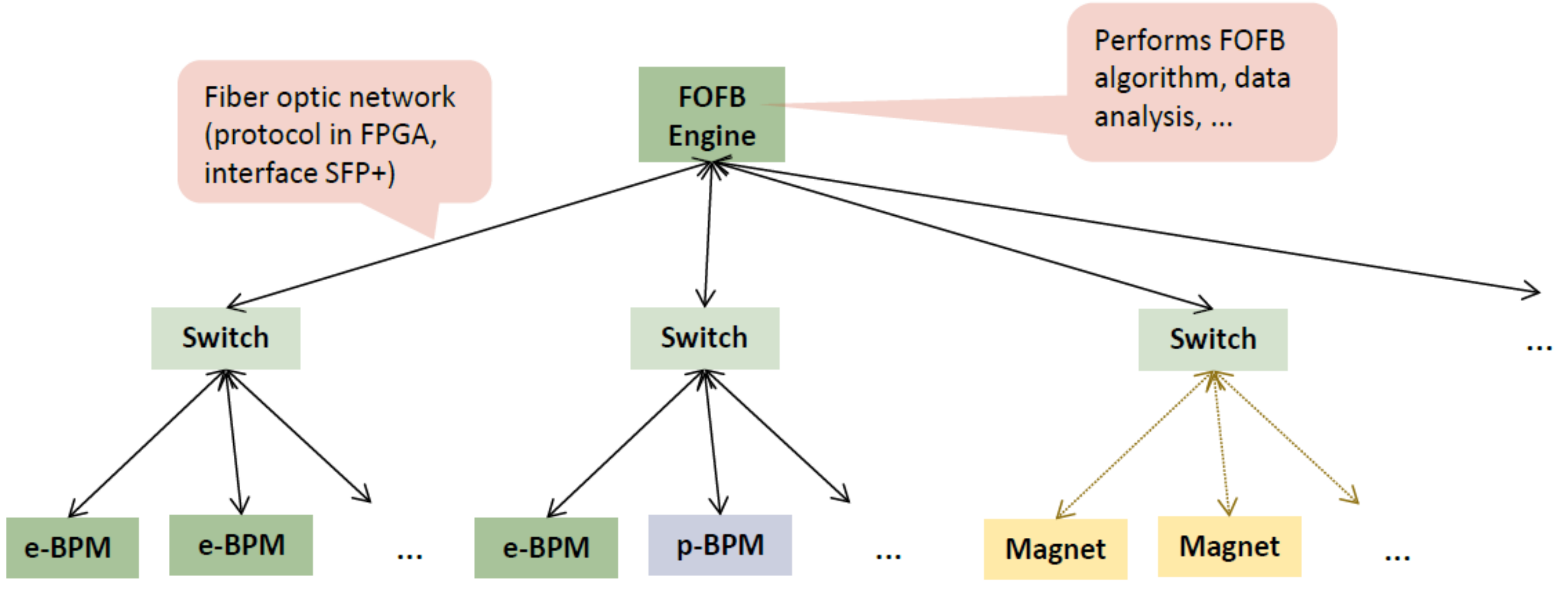
More details: See SLS2 CDR
http://ados.web.psi.ch/SLS2/CDR/Doc/cdr.pdf

DBPM-3 Specifications

Parameter	Value	Beam Current / Filling Pattern
Position Noise (1 kHz BW)	<50 nm RMS	nominal
Position Noise (0.5 MHz BW)	<1000 nm RMS	nominal
	<50 um RMS	1mA single bunch
Position Drift (for constant beam current and filling pattern), electronics only	<100 nm / hour	nominal
	<400 nm / week	nominal
	<1000 nm / year	nominal
Position Drift (mechanics only, for top-up operation mode and standard tunnel temperature stability)	<100nm / hour	nominal
	<400nm / week	nominal
	<1000 nm / year	nominal
Beam current dependence for constant filling pattern	<100nm / 1%	nominal

See SLS2 CDR
http://ados.web.psi.ch/SLS2/CDR/Doc/cdr.pdf

Fast Orbit Feedback Topology



Data transfer from / to FOFB-engine through “tree topology”

- → **size and performance is scalable / extendable**
- → **allows the mix of different monitors and actuators (e-BPM, p-BPM, magnet PS,…)**
- → **uses fiber optic links (50 Mbaud POF for magnet PS, else: multi-gigabit SFP)**
- → **e-BPM, Switch and FOFB-engine can use the same FPGA board (Zynq U+ SoC)**

Summary and Conclusions

- SLS 2.0 Upgrade Project has been proposed to funding agencies
  - → positive recommendation on CDR
  - → project planning and lattice refinement (for freezing system specs) is ongoing
- 7-BA and novel technologies allow emittance reduction by factor 40 -50
- SLS accelerator tunnel has to be modified and source points (beam lines) need to be moved
- "Dark Period" should be as short as possible (complicated logistics!)
- Critical feasibility issues (systems) are identified presently worked-out
- Diagnostics specifications are achievable with state-of-the-art systems
  - → standard diagnostics available
  - → stability criteria and stabilization strategy worked out
  - → BPM and FOFB systems in design (MBF possibly included)
  - → beam profile monitoring should be feasible with π-polarization technique