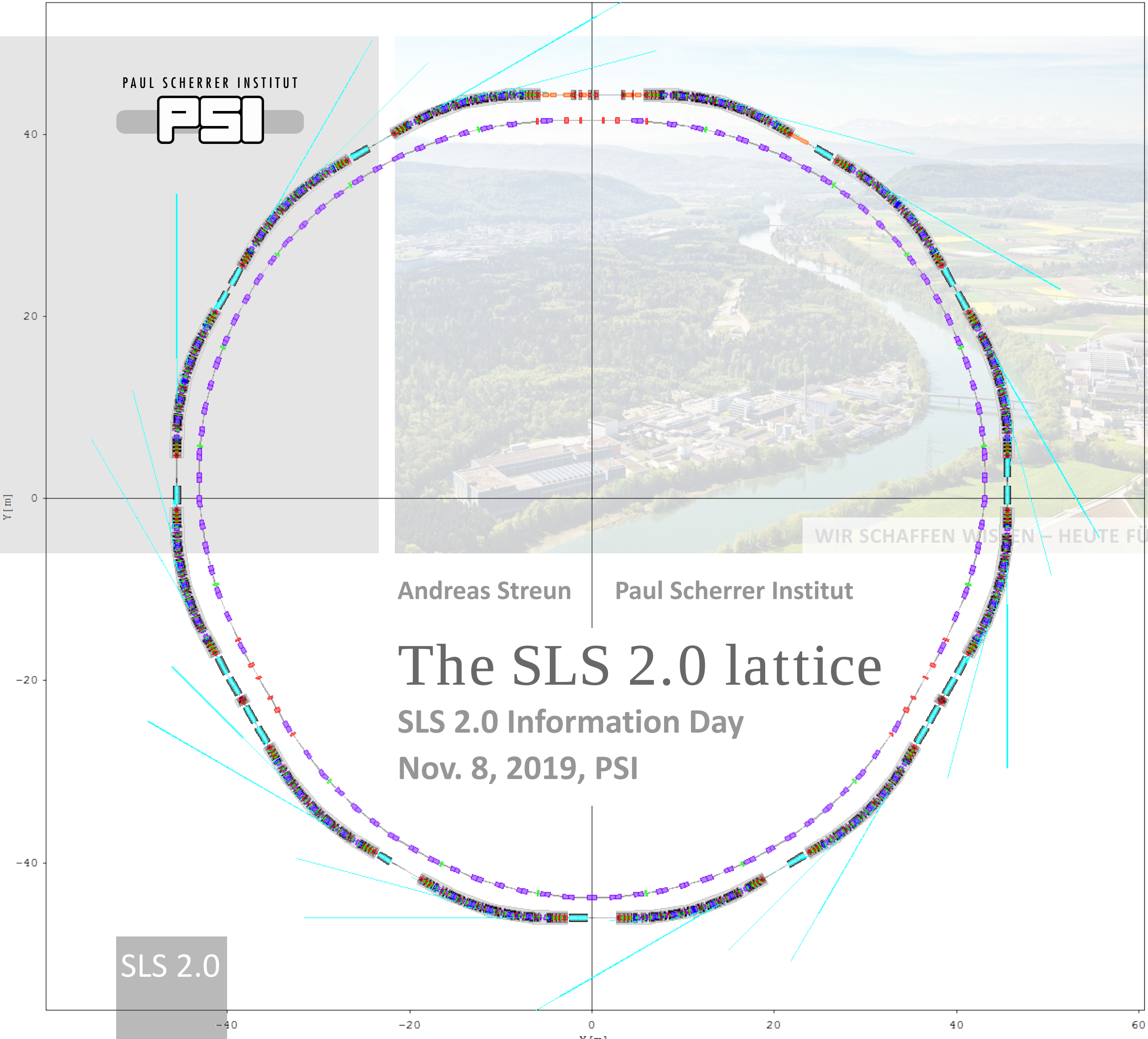
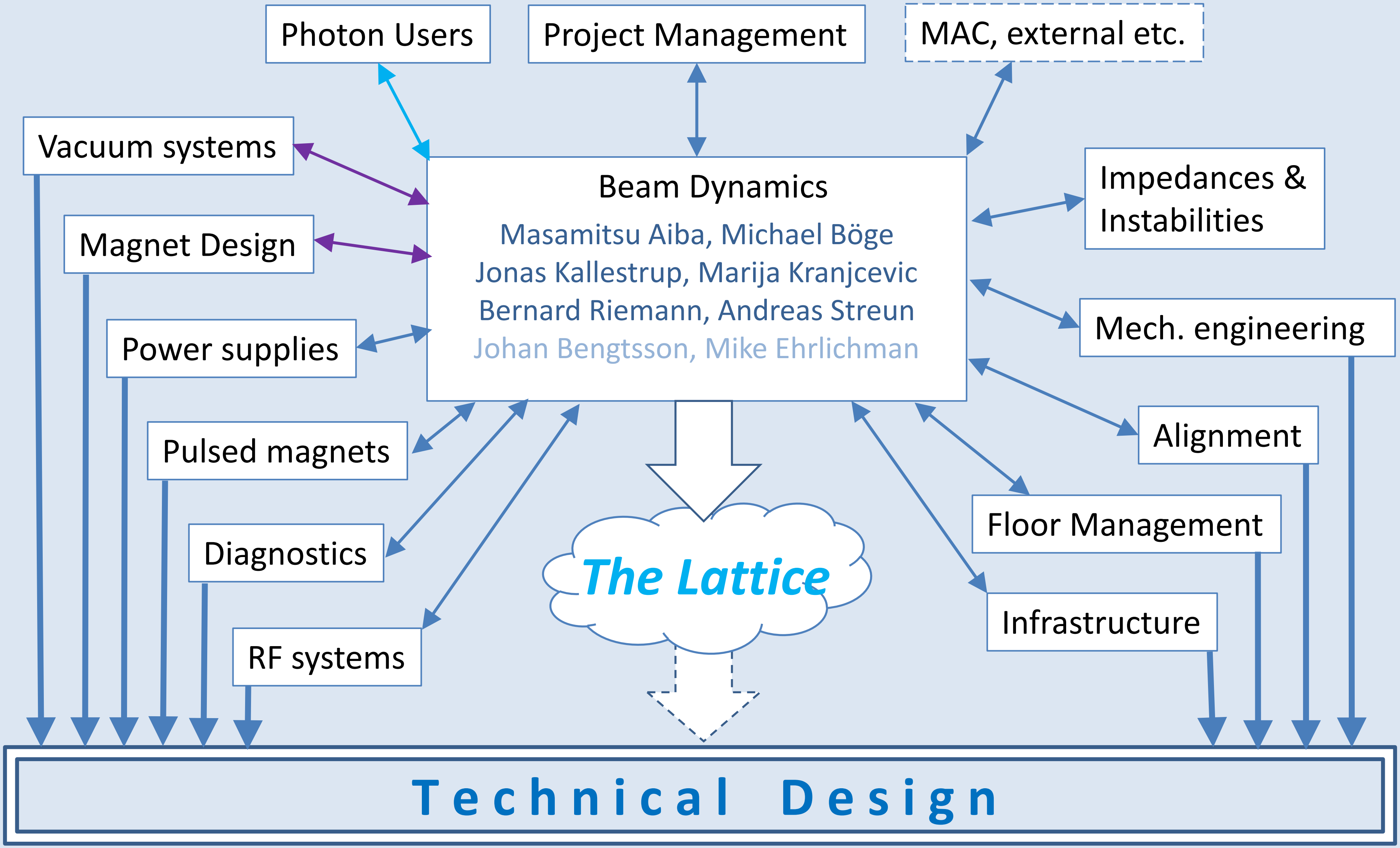


Andreas Streun | Paul Scherrer Institut

The SLS 2.0 lattice

SLS 2.0 Information Day

Nov. 8, 2019, PSI


Photon Users
Project Management
MAC, external etc.
Vacuum systems
Beam Dynamics
Masamitsu Aiba, Michael Böge
Jonas Kallestrup, Marija Kranjcevic
Bernard Riemann, Andreas Streun
Johan Bengtsson, Mike Ehrlichman
Impedances & Instabilities
Magnet Design
Power supplies
Mech. engineering
Pulsed magnets
Alignment
Floor Management
Diagnostics
The Lattice
Infrastructure
RF systems
Technical Design

Why SLS 2.0 ?

- A new generation of light sources
  - Performance (brightness) increase by factor 10…100
  - Pioneer: MAX IV storage ring (Sweden)
  - Key issue: miniaturization of components
  - World-wide new facilities and upgrade projects
  - → SLS upgrade needed to stay competitive

SLS 2.0 History

- First thoughts ~2012
- Letter of Intent 1/2014 ⇨
- Conceptual Design Report 9/2017 ⇨
- Submission to SNF 1/2018
- ETH board: included in “roadmap” 12/2008
- First Machine Advisory Committee meeting 6/2019
- “Final” lattice: 9/2018 (“A”)
  - → 3/2019 (“B”)
  - → 6/2019 (“B+”)

Final lattice → 10/2019 ✓

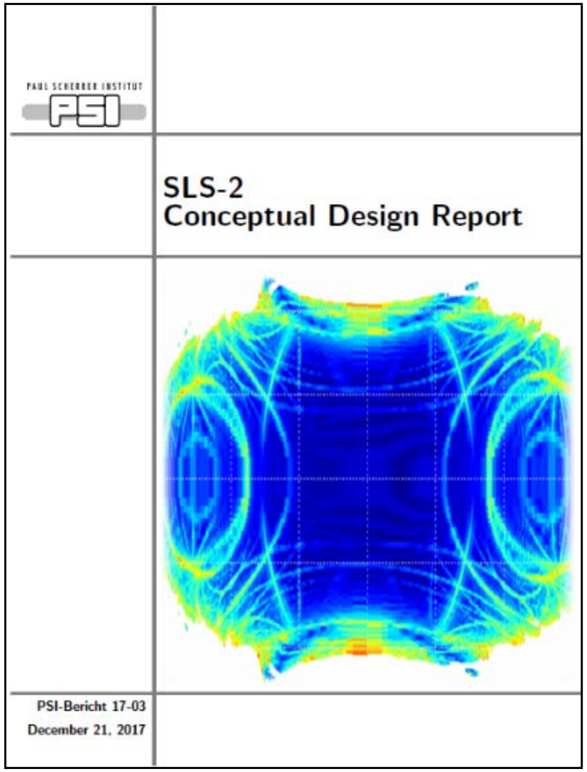
Letter of Intent for Swiss Research Infrastructure Roadmap

January 23, 2014

Swiss Light Source 2.0

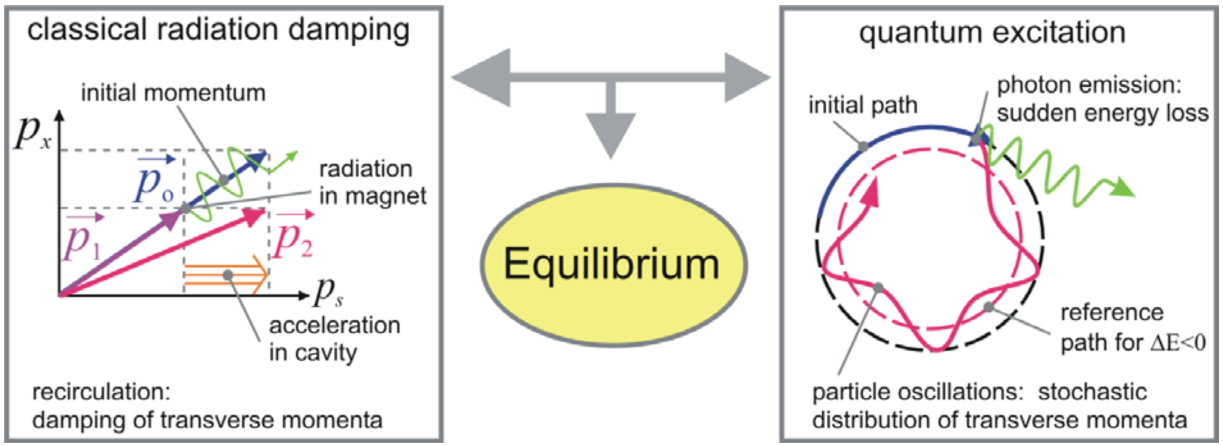
J. Friso van der Veen*, Leonid Rivkin
Paul Scherrer Institut, Villigen, Switzerland

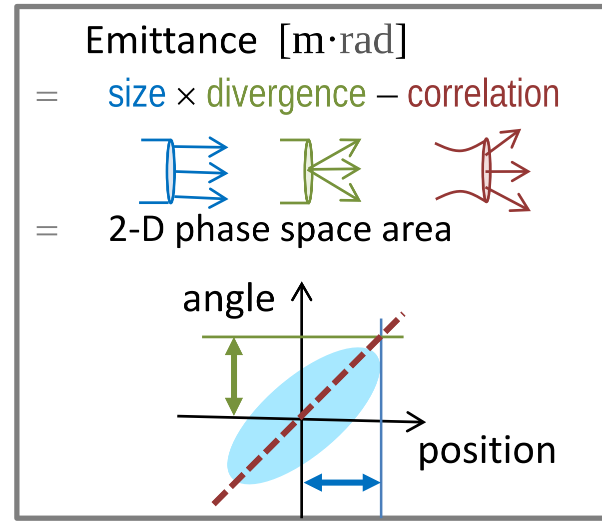
With contributions from:
O. Bunk, T. Garvey, A. Menzel, F. Nolting, V. Schlott, T. Schmitt, M. Stampanoni, A. Streun, V. N. Strocov, M. Wang and A. F. Wrulich



Brightness and Emittance

- Brightness $\propto$ 1/emittance
- Emittance = pure lattice property*





- Emittance $\propto E^2\,\phi^3 \propto\ E^2$ / (circumference)³
  - E = beam energy
  - ϕ = deflection angle *per* bending magnet
    $\propto$ (length of **unit cell** [= 1 bending magnet + focusing]) / **circumference**

* in an electron storage ring

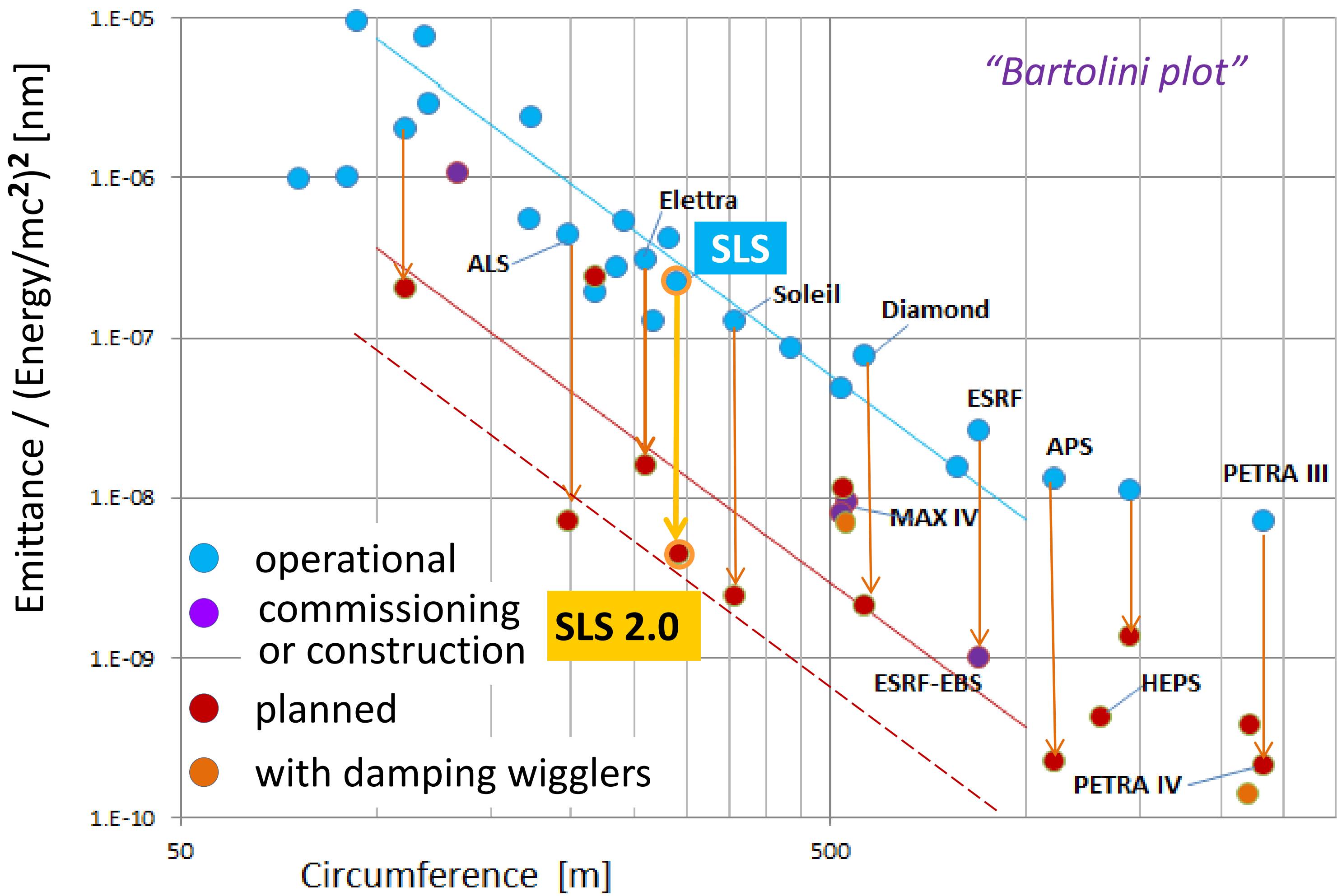
→ reduce unit cell length → miniaturization of components:

  - small aperture vacuum pipe and small bore magnets

SLS 2.0 and the new light sources generation

Emittance normalized to energy vs. circumference

$\varepsilon_x \propto (\text{Energy})^2 / (\text{Circumference})^3$



Theoretical Emittance scaling

$\varepsilon \propto \gamma^2 C^{-3}$

$\ln \frac{\varepsilon}{\gamma^2} = K - 3 \cdot \ln C$

$K \approx 2 \rightarrow \approx -1$

improvement ×20

↓ upgrade projects

SLS 2.0 design charge

- User requirements
  - 30× higher brightness
  - wide spectrum of beam lines: from VUV to hard X-ray
- Challenge: comparatively small circumference
  - Brightness $\propto$ (circumference)^3
- Beam physics feasibility
  - Lifetime and injection efficieny $\rightarrow$ dynamic aperture
  - 400 mA beam current $\rightarrow$ impedances & instabilities
- Technical limitations
  - Magnets and vacuum system
- Civil engineering
  - limited modifications of building and infrastructure

SLS 2.0 Lattice Solution

- Increased number of bending magnets
  - 12 × 7-Bend-Achromat [SLS: 12 × 3-BA] → $(7/3)^3 \approx$ factor 13
- Reduced beam pipe aperture
  - 18 mm diameter [SLS: 65 mm × 32 mm]
- Novel low emittance unit cell
  - Combination of reverse bends and longitudinal gradient bends → optimum suppression of quantum excitation
  - Emittance 123 pm [SLS: 5580 pm] ⇨ factor 45 smaller

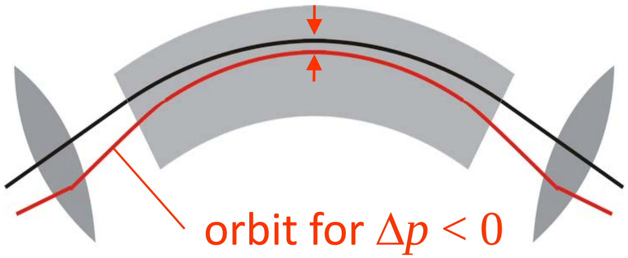
+15…20% emittance increase by intrabeam scattering (IBS)

- Maintain total straight length: ≈ 80 m
  - 3 × long (11.4 m) + 9 × standard (5.4 m)
  - [SLS: 3 × long (11.5 m) + 3 × medium (7 m) + 6 × short (4 m)]
  - all straights to be split at variable ratio
- Avoid tunnel modification
  - symmetry-3 footprint but symmetry-12 dynamics by tuning

The LGB-RB unit cell for lowest emittance

Standard cell = relaxed TME

- quadrupoles to focus dispersion
- dispersion at center > 0

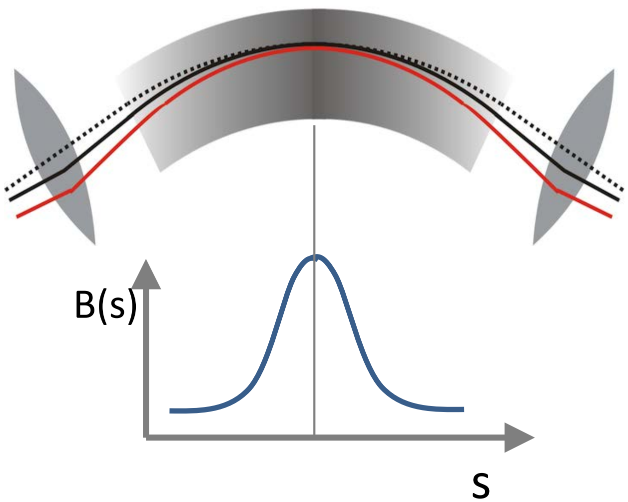


LGB-RB unit cell

Step 1:

decouple dispersion from horizontal focusing !

- displaced quadrupoles
  = **reverse bending magnets (RB)**
  ⇨ dispersion at centre → 0 ✓



Step 2:

exploit small dispersion at centre !

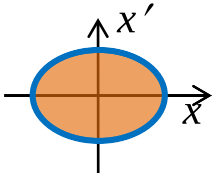
- longitudinal field variation in dipole magnet:
  = **longitudinal gradient bend (LGB)**

LGB needs RB to work properly !

B. Riemann & AS, *Low emittance lattice design from first principles: Reverse bending and longitudinal gradient bends, Phys. Rev. Accel. Beam, 22, 021602 (2019)*

Problems which caused design revisions

- Space conflicts
  - minimum distances between elements
  - feasibility of magnets (short, wide, high fields)
  - feasibility of mounting (magnets, cables, water pipes)
  - free pathways for photon beams
- Insufficient brightness
  - bad matching of electron phase space to diffraction
    - brightness depends on the area of the electron phase space (emittance $\varepsilon_x = \sigma_x \cdot \sigma_{x'}$) ***and*** on its aspect ratio (beta function $\beta_x = \sigma_x / \sigma_{x'}$)

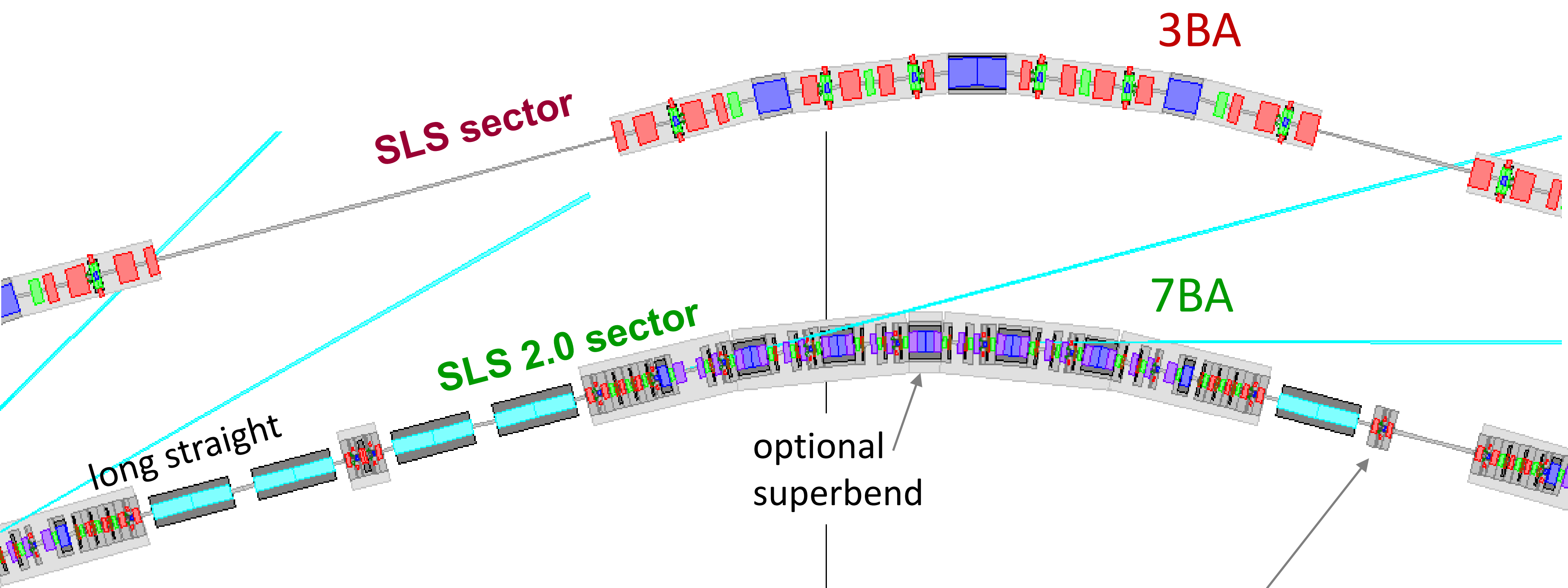


  → split standard straights in mini-beta optics ("completion phase")
- Insufficient dynamic aperture
  - constraints on (dynamic) symmetry and working point
  - development of alternative injection schemes
- Risk of beam instabilities

  GREEN MACHINE

  → switch from "B" to "B+" (side effect: reduced power consumption)

SLS and SLS 2.0 ring sector layout



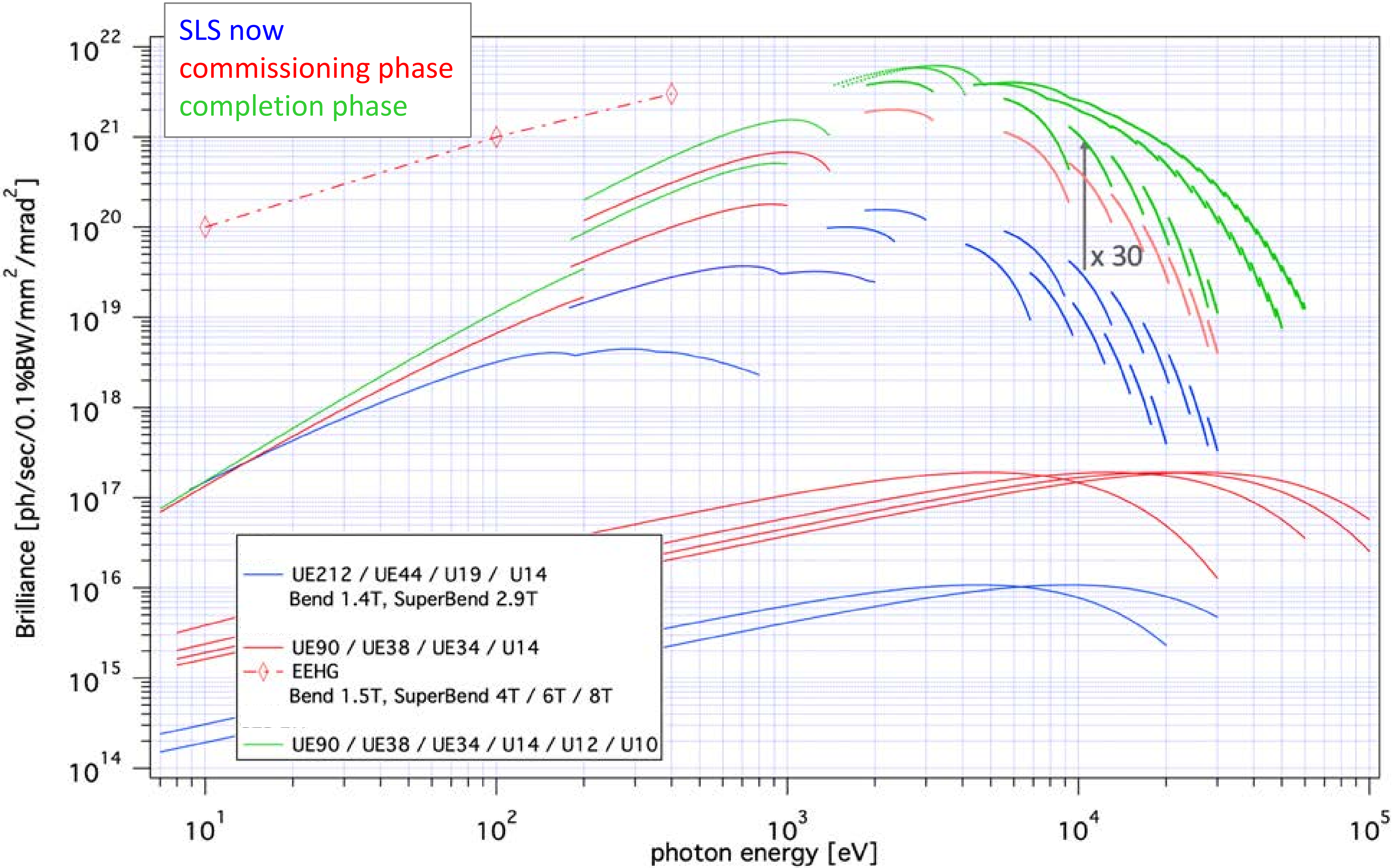
Optional superbends (5T) in arc centers

3 superbends planned in centers of arcs 2,6,10

Long straights 5L/9L split from beginning

Quadrupole doublets for splitting standard straights to be used in completion phase

Performance: brightness



Lattice Parameters

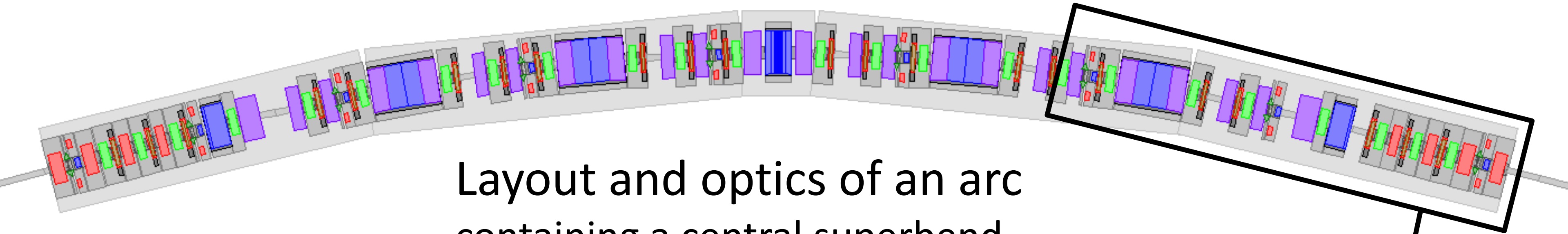
	SLS today	SLS 2.0 commissioning	SLS 2.0 completion
Circumference [m]	288.007'289	288.000'177	280.000'256
Emittance [pm.rad]*#	5579	123	128
Energy spread [10^{-3}]*#	0.874	1.016	1.053
Radiation loss per turn [keV/turn]*	539	432	441
Momentum compaction factor [10^{-4}]	+6.04	+1.02	+1.02
Short straights: number x length [m]	6 x 3.97 3 x 6.97	9 x (2.76+2.11) [a]	
Long straights: number x length [m]	3 x 11.73	2 x (2 x 5.235) [5L, 9L] 1 x (4.28 + 2.80 + 1.66) [1L]	
Working point: tune x/y	20.43/8.74	39.28/15.35	45.30/21.20

* without insertion devices but including superbends

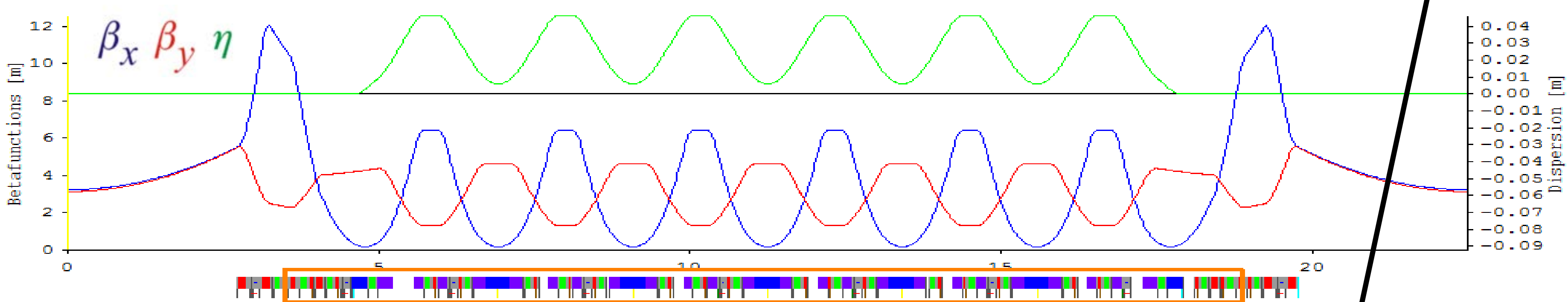
without IBS

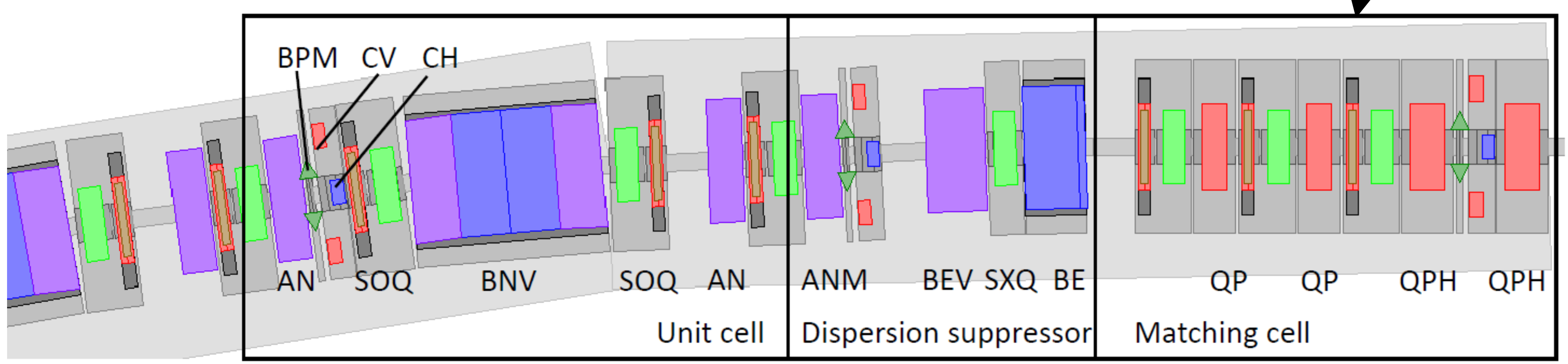
[a] nominal asymmetric split of straights, other splits are possible too.

7BA arc

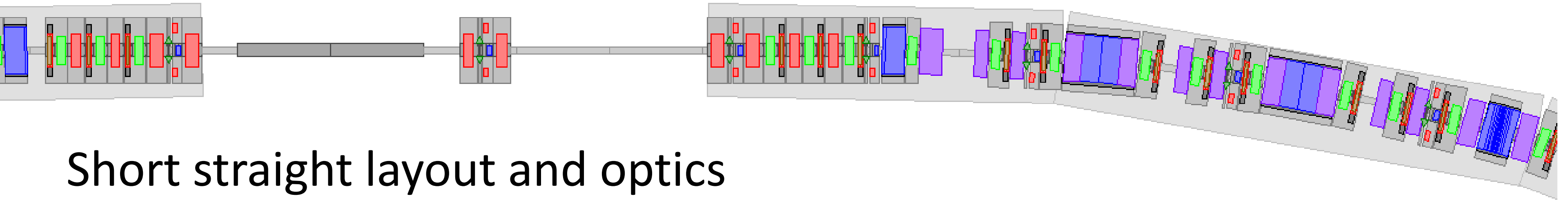


Layout and optics of an arc
containing a central superbend

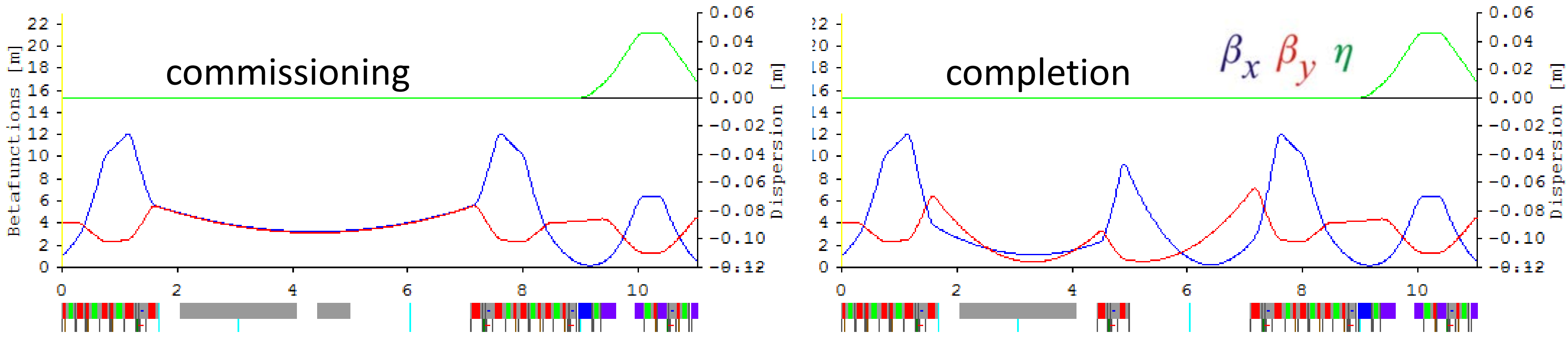




Short straights

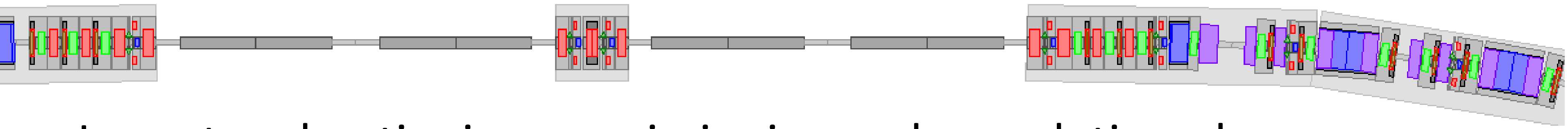


Short straight layout and optics

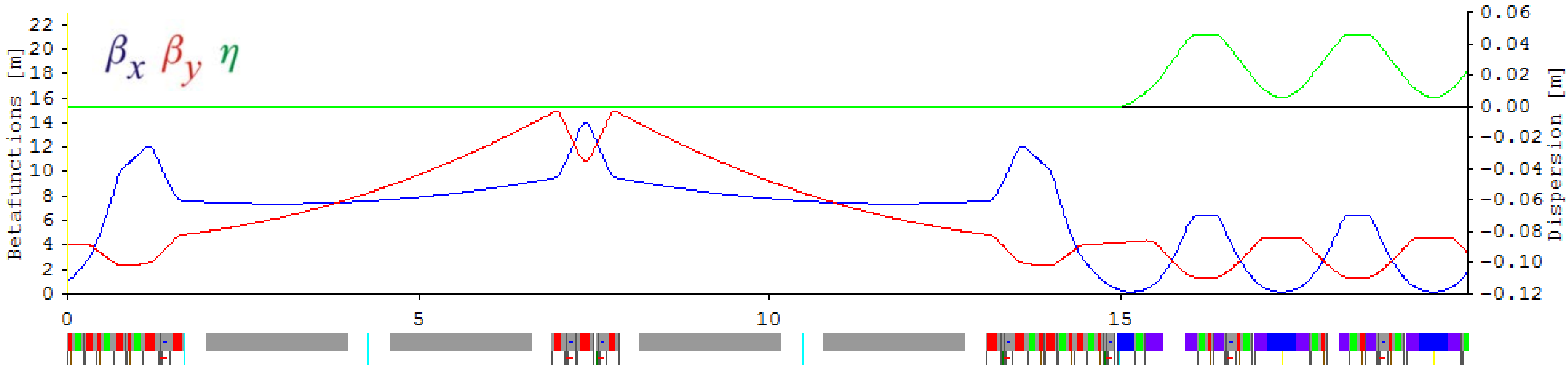


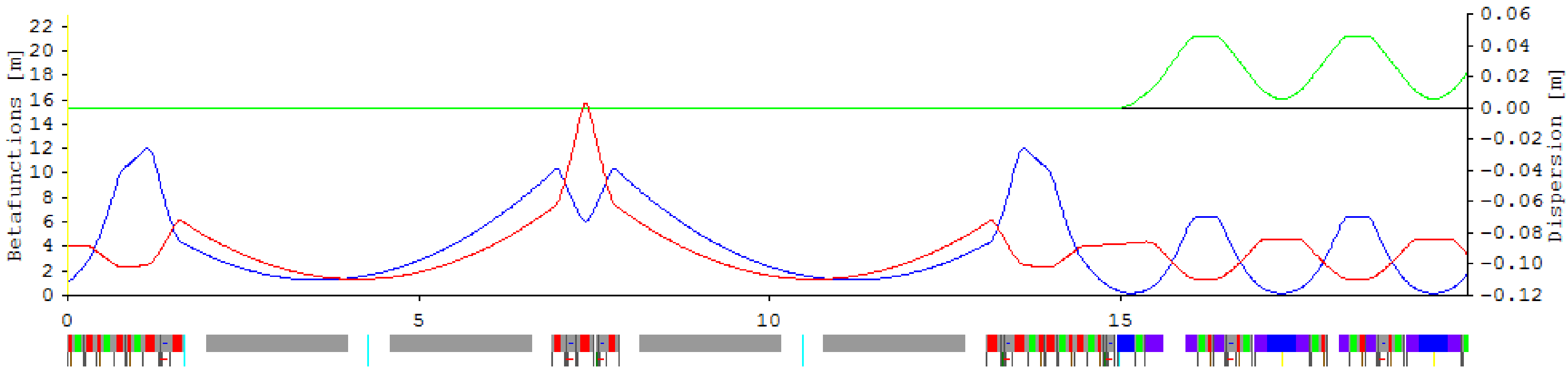
			straight
Phase 2	nominal split	2.76 + 2.11 m	06, 10, 12
	inverse nominal	2.11 + 2.76 m	02, 04
	almost symmetric	2.50 + 2.37 m	03, 07, 11
	very asymmetric	2.90 + 1.97 m	08

Long straights 5L and 9L

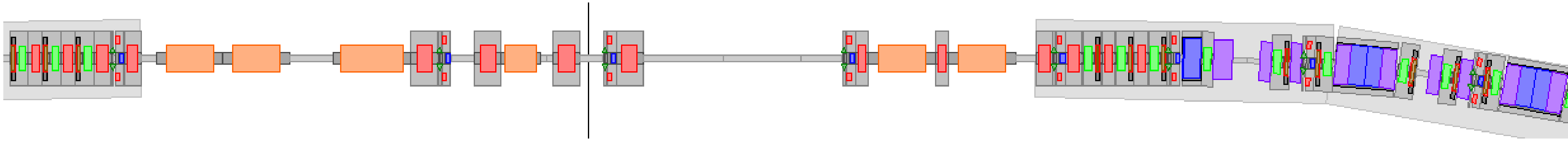


Layout and optics in commissioning and completion phase



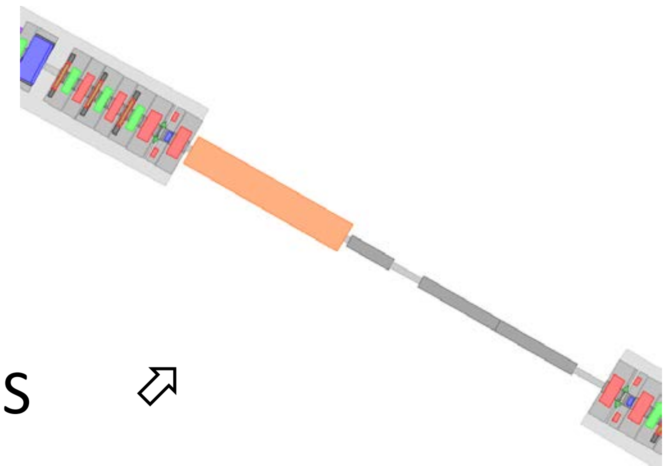


Injection straight 1L



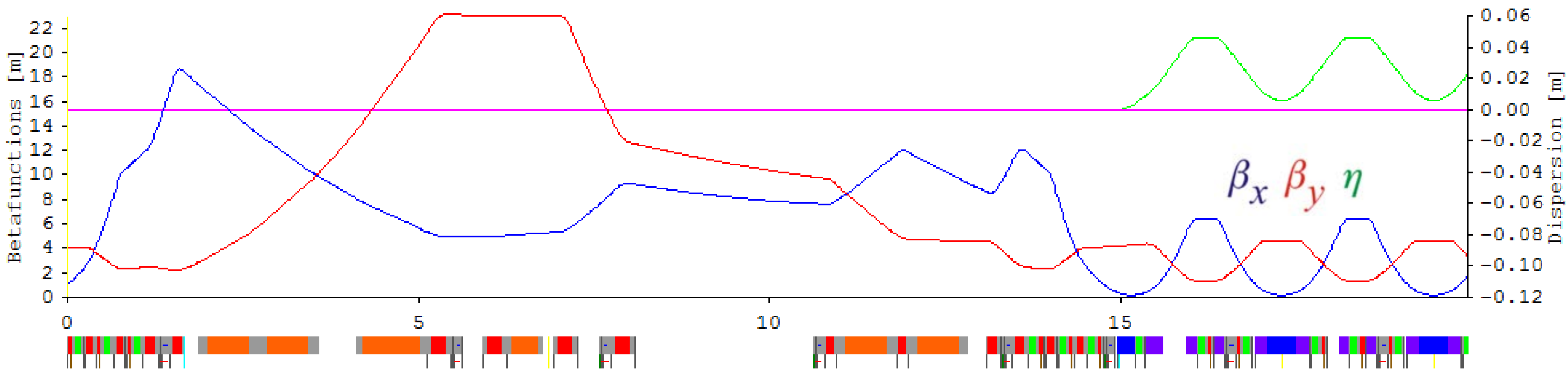
Injection for commissioning phase

Layout ⇧ and optics ⇩ of injection straight 1L



Vertical injection elements:

- 4 bump kickers (re-use SLS)
- Thick septum and thin (1mm) septum
- Fast kicker for pseudo-on-axis injection in 2S ⬀
- 4 large aperture quadrupoles (re-use SLS)



Dynamic aperture (commissioning)

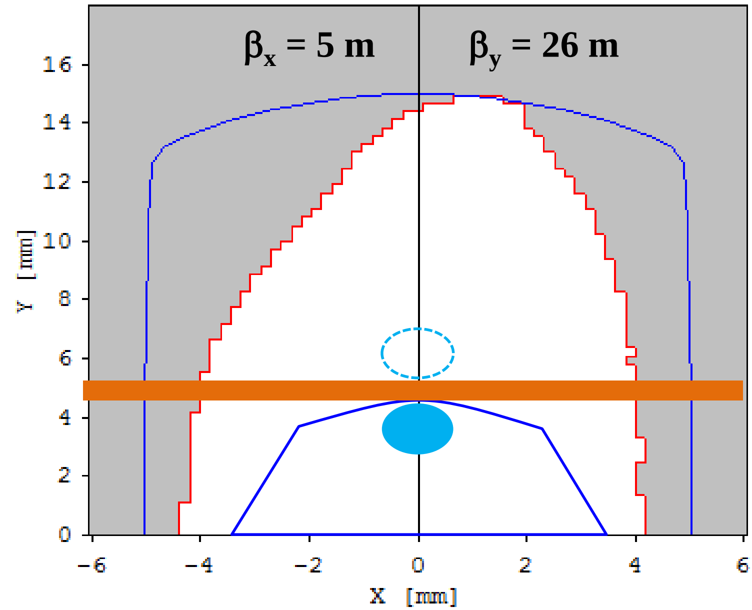
Dynamic aperture (x,y)

physical aperture from (fake) 10 mm × 15 mm beam pipe

approx. physical aperture from real beam pipes including mini-gap undulators

5-sigma beam size of injected beam from booster

1 mm thin septum



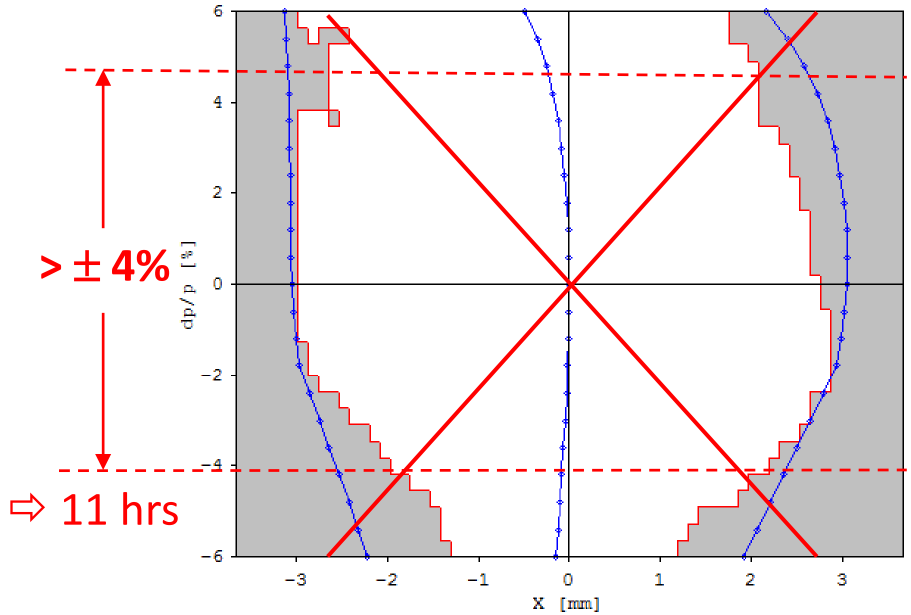
Momentum dependent. D.A.

(x, Δp/p) Range ±6%

max. initial amplitudes of Touschek scattered particles $= (\mathcal{H}_{max}\,\beta_x)^{1/2}\,\Delta p/p$, $\mathcal{H}_{max} \approx 0.45$ mm

eff. momentum acceptance

⇨ Touschek- Lifetime ∝ (mom. acc.)^3



Magnet and power supply inventory

SLS 2.0 288 m circumference = 80 m straights + 208 m arcs

60 long./trans. grad. compound bends, BNV=[VB|BN|VB] 0 (PM)

24 end magnets BE 0 (PM)

144 reverse bends AN 0 (PM)

106 quadrupoles QP 96

288 sextupoles + 264 octupoles [incl. quad+skewquad] 2×48 (?) +2×264

114 twin correctors CHV [CH+CV] 2×114

upgrade: +4 superbends BS [+8 VBS] (-4 BNV), +18 high gradient quads QX,
+9 twin correctors CHVX: +39/-4, +39

➔ **739 magnets** (228 PM, 4 SC), **≥≈ 987 power supplies**

SLS 288 m circumference = 80 m straights + 208 m arcs

36 bending magnets BX, BE 2

174 quadrupoles QA/B/C[W] 174

120 sextupoles SR[W] {sext.+{CH+CV}(72),skewquad(36),aux.sext.(12)} 9+2×72+36+12

upgrade: 3 superbends BXS: +3/-3 bends, +6 PS

upgrade: Femto insertion: +3 bends, +4 quads, +1 corr.H/V, +9

➔ **338 magnets, 392 power supplies**

Commissioning strategy

Commissioning (end 2024 / early 2025)

- small aperture chambers in place (∅ 8 mm)
  - small aperture BPMs already installed
- reduced gap chambers for superbend (10 mm)
  - but PM-bends in place of superbends
- undulators in place but open or off
- Risk: beam threading with small apertures

First year of operation (2025/26)

⇨ installation of 5 T superbends

⇨ beam line commissioning and user operation

⇨ machine development: optics correction, beam based alignment

⇨ installation of high gradient quads to split standard straights

⇨ completion: low beta optics and injection

Conclusions & Outlook

- Achievements
  - emittance reduced by factor > 40 (bare lattice)
  - total straight length maintained: 80 m like SLS
  - confidence in beam stability (NEG, 18 mm beam pipe etc.)
  - tunnel modifications avoided: shifts < 25 cm
  - power consumption reduced (only 2 instead of 4 cavities)
  - ~ 7½ hrs beam lifetime (commissioning phase), ~ like SLS
  - safe injection scheme (vertical, pseudo-on axis)
  - brightness increase ×13 in commissioning optics
  - brightness increase ×30 in final optics (complete)
- ⇨ Next steps
  - Further development of final optics
  - Detailed technical layout

THE END