SLS Status and Development of an SLS2 Upgrade

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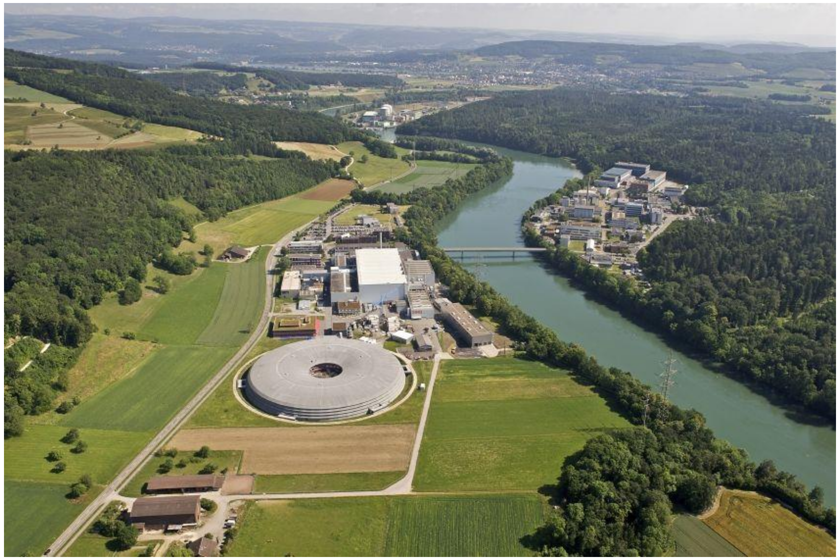


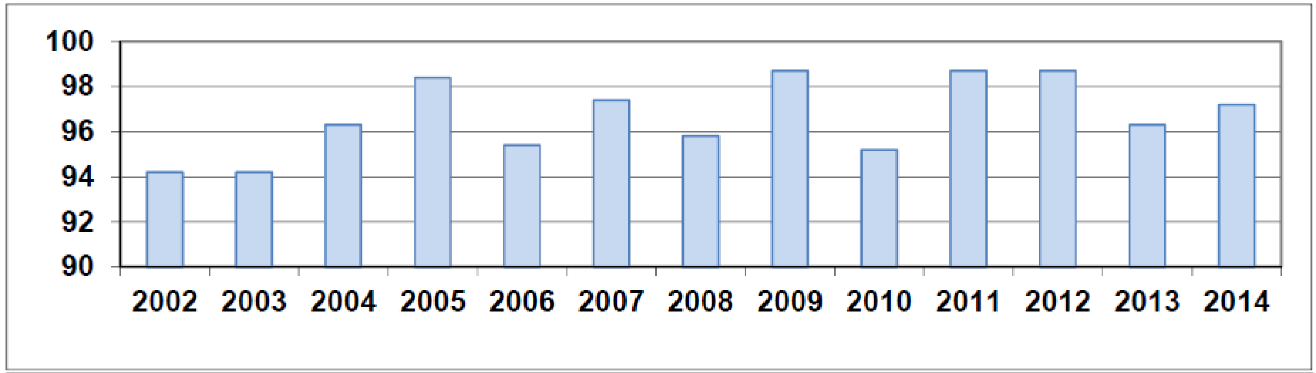
ESLS XXII meeting, Grenoble, Nov. 2014

Operation

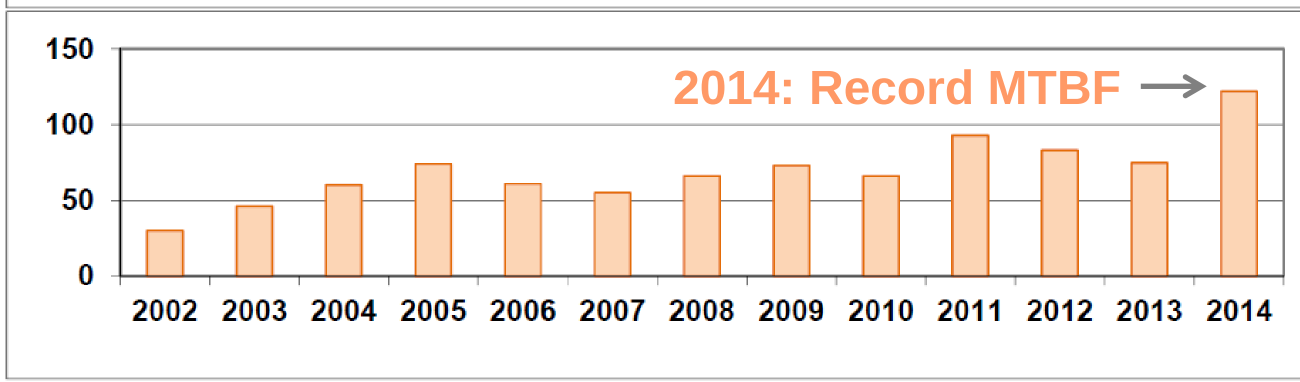
SLS in 13th year of user operation: 18 beam lines

Performance 2014 (Jan.-Oct.)

Availability
97.2 %



MTBF
122 h



Two Major Incidents:

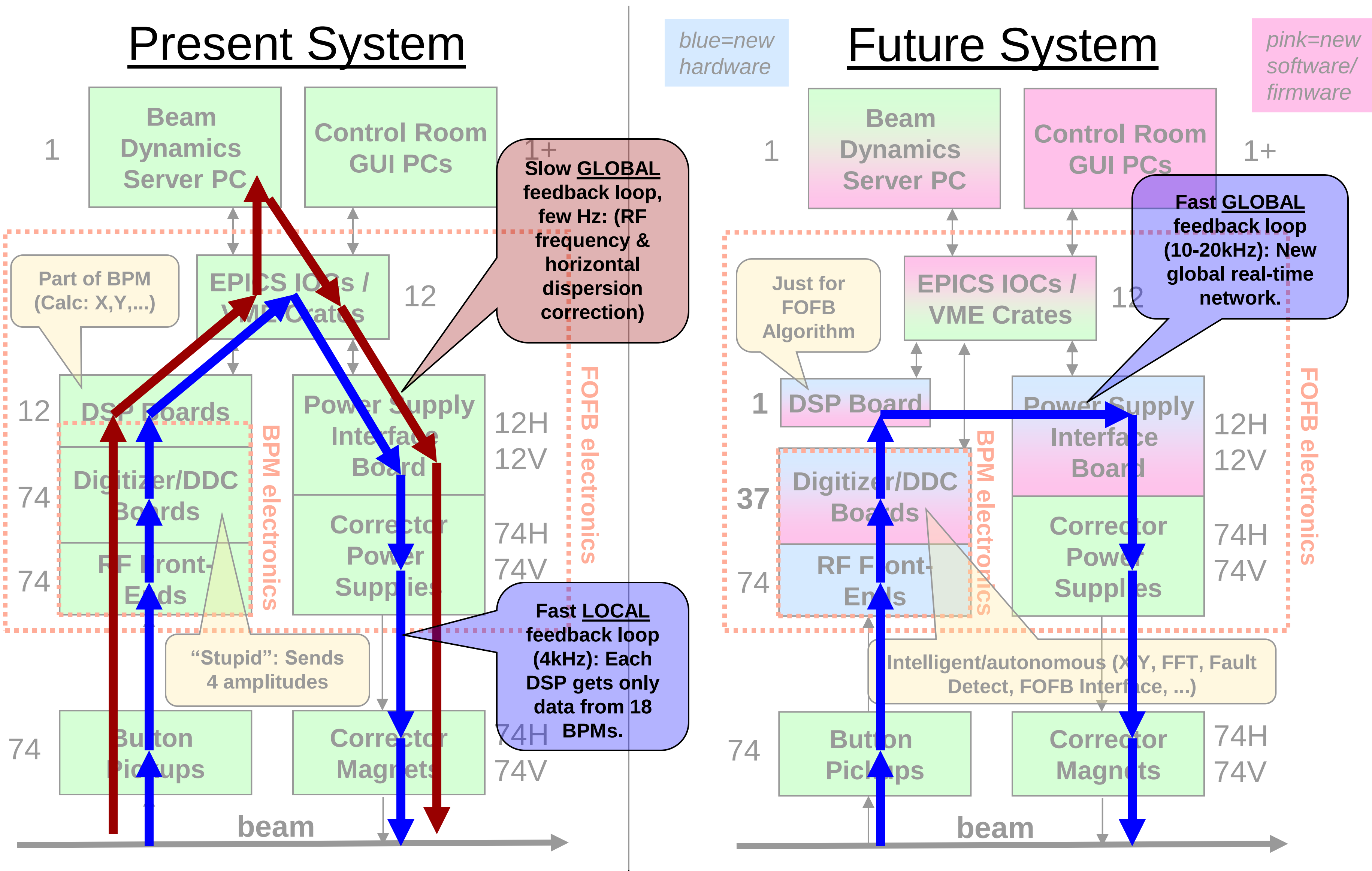
- U14 Broken Taper Foil, 76 hrs downtime
  - Located by activation
- 1-Second power outage, 65 hrs downtime
  - Helium compressor shut-off, partial warming of 3HC.

BPM system replacement[1]

- New SLS BPM electronics
  - In-house design
  - Synergy with SwissFEL & E-XFEL (BPM FPGA board hardware, firmware, software, etc.)
  - Prototype: <100nm RMS noise at 2kHz BW (k=10mm geometry factor).
- New FOFB
  - Global BPM data transfer, one feedback engine (present system: 12 sector FBs communicating with adjacent sectors, 4KHz correction rate), more robust.
  - All feedback algorithms implemented low-level (DSP/FPGA) with ~10kHz correction rate (now: dispersive correction & photon BPM FB on high-level PC with few Hz correction rate).
  - Feedback algorithm in high-level language (presently: DSP assembler) provides better performance and allows adding new features:
    - Integration of coupling correction in FOFB: "2nd order orbit correction".
    - Fast polarization switching for PolLux and PEARL. Now: Slow reference to FOFB & feed forward for coupling.
- Schedule
  - Replacement 2016/17 (team presently busy with SwissFEL & E-XFEL BPMs & feedbacks).

[1] "Development of New BPM Electronics for the Swiss Light Source", W. Koprek, IBIC2012

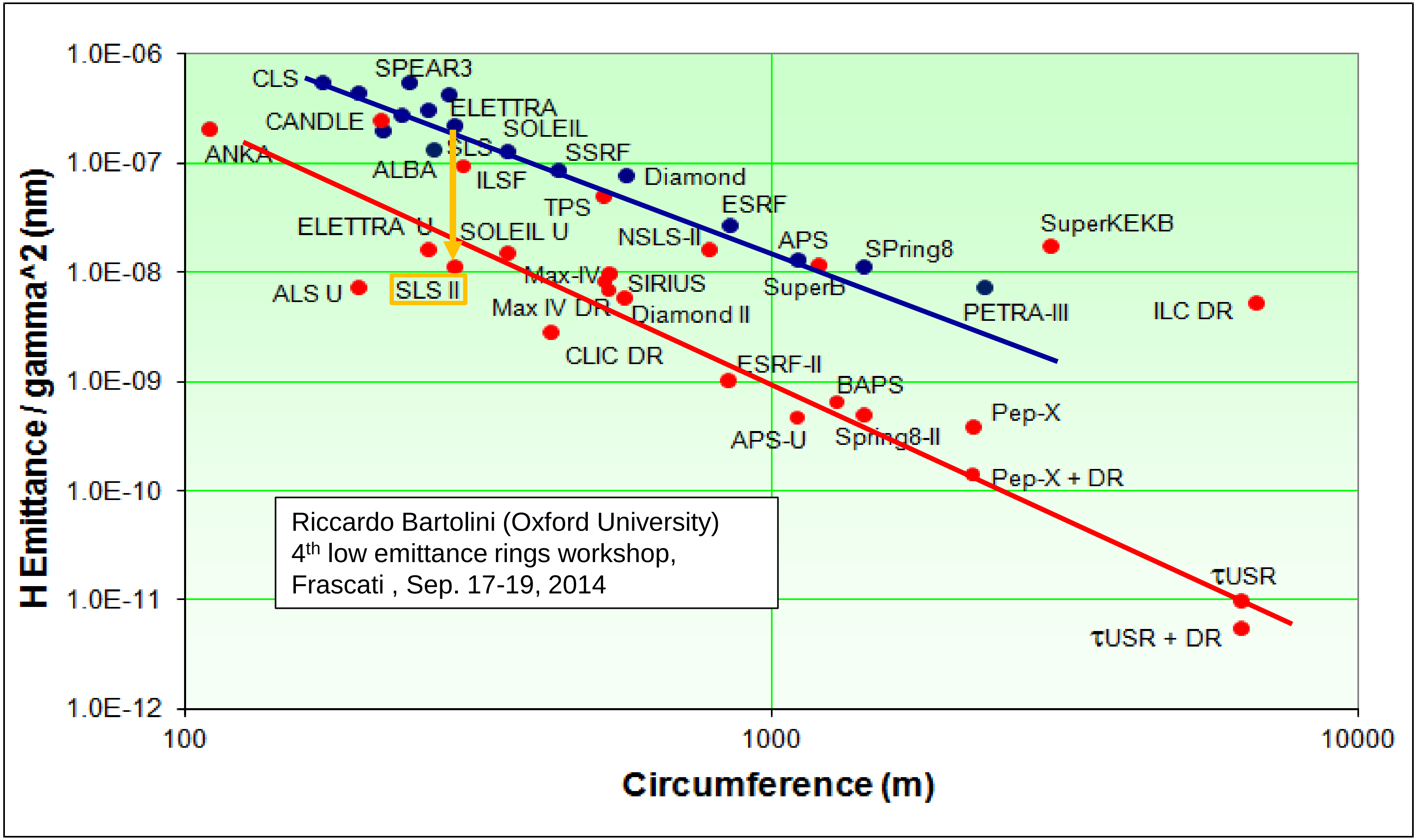
SLS FOFB: Feedback Loops[1]



Motivation for an SLS2 Upgrade

- SLS commissioned in 2000
  - Serving 18 beamlines with >97 % uptime
  - 5.5 nm x 5 pm emittance beams at 400 mA
- New, state-of-the-art machines coming online
  - MAX-IV, NSLS2, ESRF Upgrade, PETRA 3, et. al.
- Need to stay competitive
- Project Goals
  - Replace SLS with significantly lower emittance design
  - Maintain existing building, injector, beam lines
  - Minimize downtime and impact to users
  - Moderate budget (<100 MCHF)

The storage ring generational change



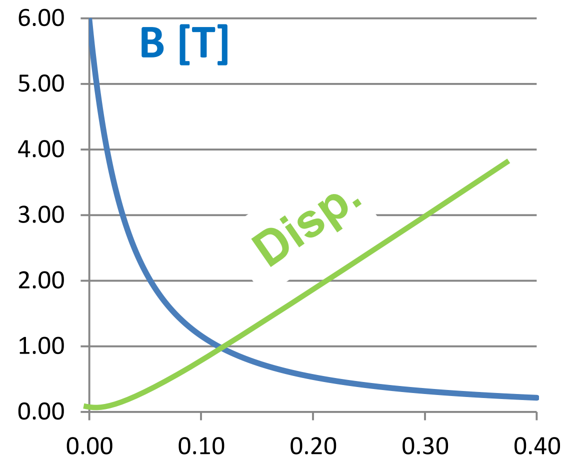
Storage rings in operation (•) and planned (•).
The old (—) and the new (—) generation.

SLS-2 design constraints and the main challenge

- Constraints
  - keep circumference: hall, tunnel.
  - re-use injector: booster, linac.
  - keep beam lines: avoid shift of source points.
  - limited "dark time" for upgrade.
- Challenge: small circumference
  - Scaling MAX IV to SLS size and energy gives $\varepsilon \approx 1$ nm.
  - Multi bend achromat: $\varepsilon \propto (\text{number of bends})^{-3}$
  - Damping wigglers (DW): $\varepsilon \propto \frac{\text{ring}}{\text{ring} + \text{DW}}$ radiated power
  - Low emittance from MBA and/or DW requires space !

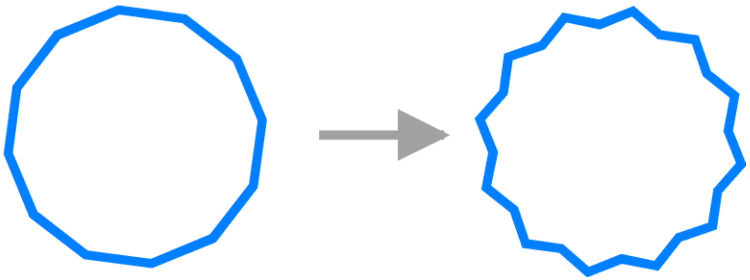
Compact low emittance lattice concept

- Longitudinal gradient bends (LGB): field variation B = B(s)
  - $\varepsilon \propto \int (\text{dispersion}^2 \ldots) \times (\text{B-field})^3 \, ds$
  - $\rightarrow$ high field at low dispersion and v.v.
- Anti-bends: B < 0
  - matching of dispersion to LGB



⇨ factor ≈ 5 lower emittance

compared to a conventional lattice



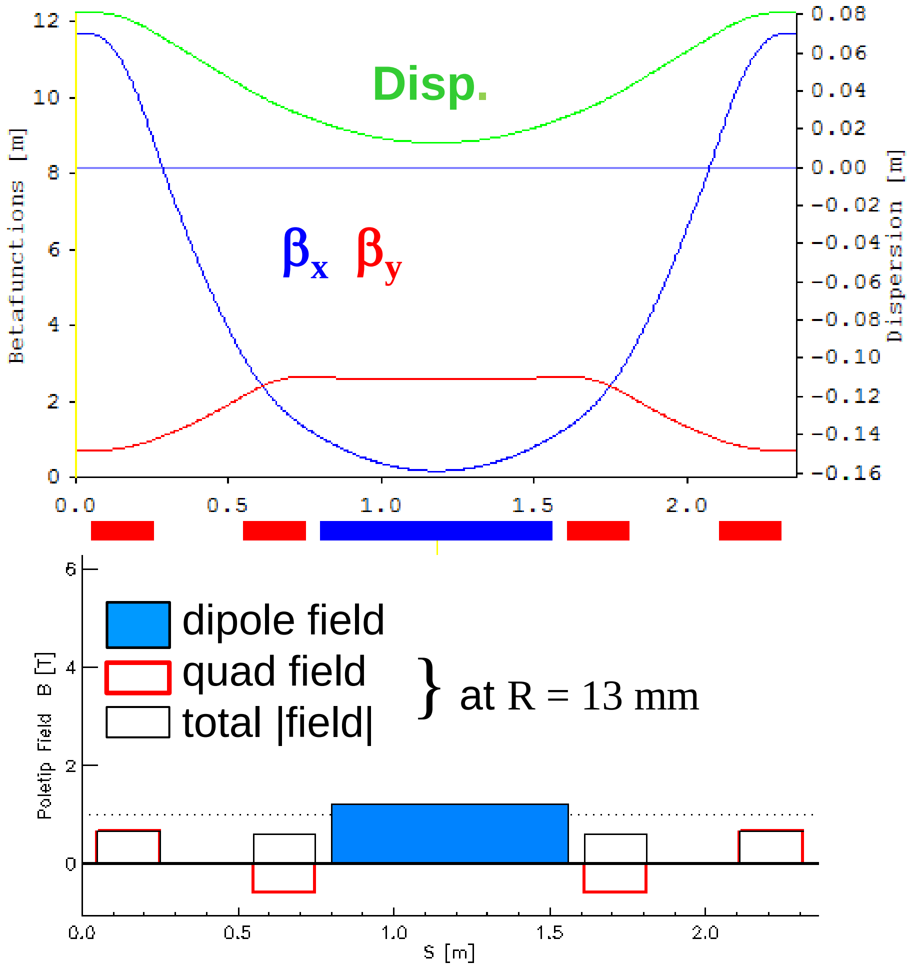
- Additional benefits
  - Hard X-rays (≈ 80 keV) from B-field peak (≈ 5 Tesla)
  - ε-reduction due to increased radiated power from high field and from Σ|angle|>360° ("wiggler lattice")

AS & A. Wrulich, NIM A770 (2015) 98–112; AS, NIM A737 (2014) 148–154

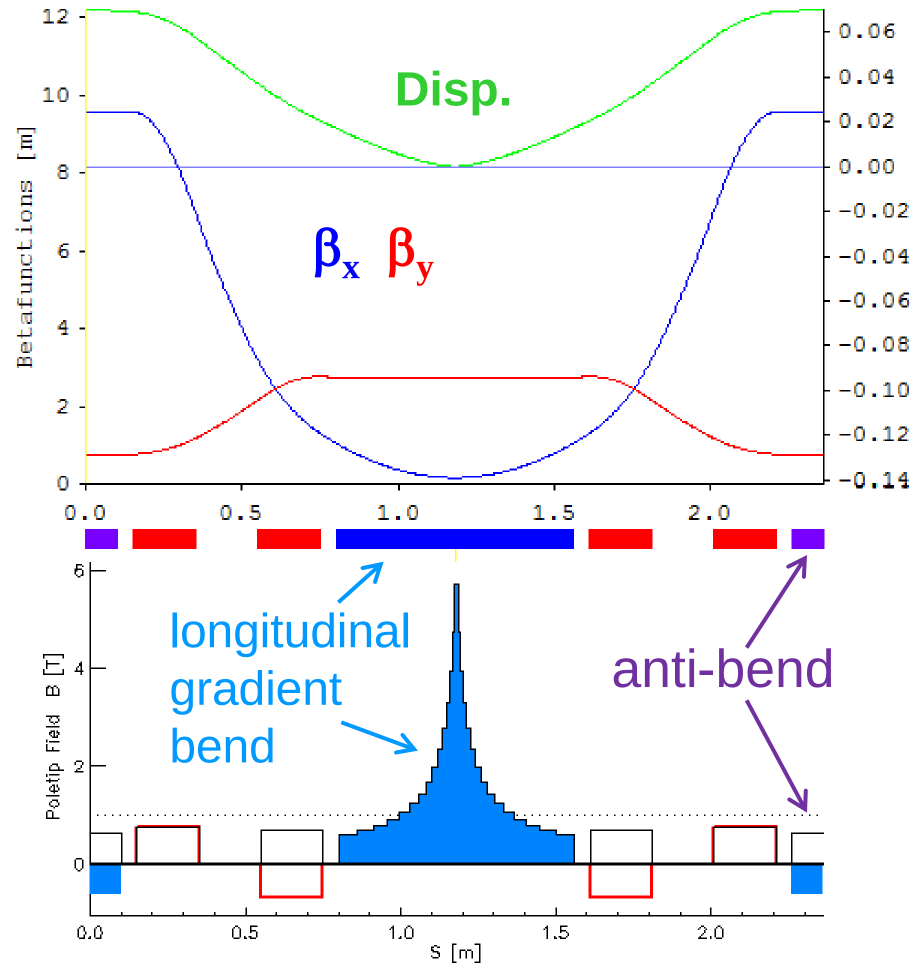
A compact low emittance cell

- Conventional cell vs. longitudinal-gradient bend/anti-bend cell
  - both: angle 6.7°, E = 2.4 GeV, L = 2.36 m, $\Delta\mu_x$ = 160°, $\Delta\mu_y$ = 90°, $J_x \approx 1$

conventional: ε = 990 pm

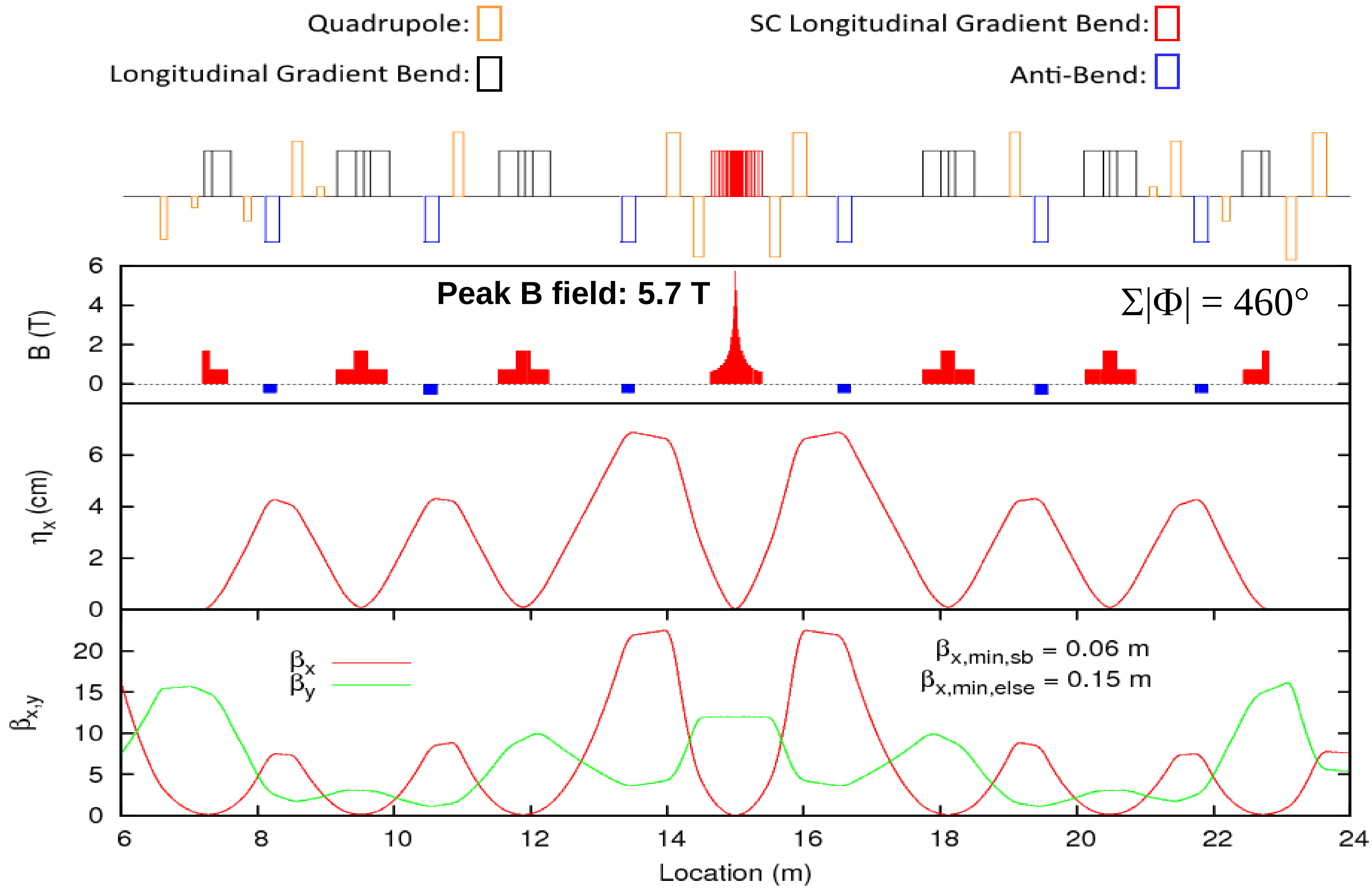


LGB/AB: ε = 200 pm



Lowest emittance Prototype

- Maximal application of longitudinal gradient bend/anti-bend cell concept



Comparison

	NSLS 2	PEP-X	MAX-IV	SLS	SLS2 (concept)
E_0 (GeV)	3	4.5	3	2.411	2.4
Circ. (m)	780	2199	528	288	288
ε_x (pm)	550	11	320	5000	72
ν_x	32.35	113.23	42.2	20.43	39.42
ν_y	16.28	65.14	14.28	8.74	10.76
α_p	$3.7\ 10^{-4}$	$5.0\ 10^{-5}$	$3.1\ 10^{-4}$	$6.0\ 10^{-4}$	$-5.4\ 10^{-5}$
ξ_x	-100.	-162.3	-49.8	-67.3	-154.7
ξ_y	-41.8	-130.1	-43.9	-22.2	-46.4
$-\xi_x/\nu_x$	3.1	1.2	1.2	3.3	3.9
$-\xi_y/\nu_y$	2.6	2.0	3.1	2.5	4.3

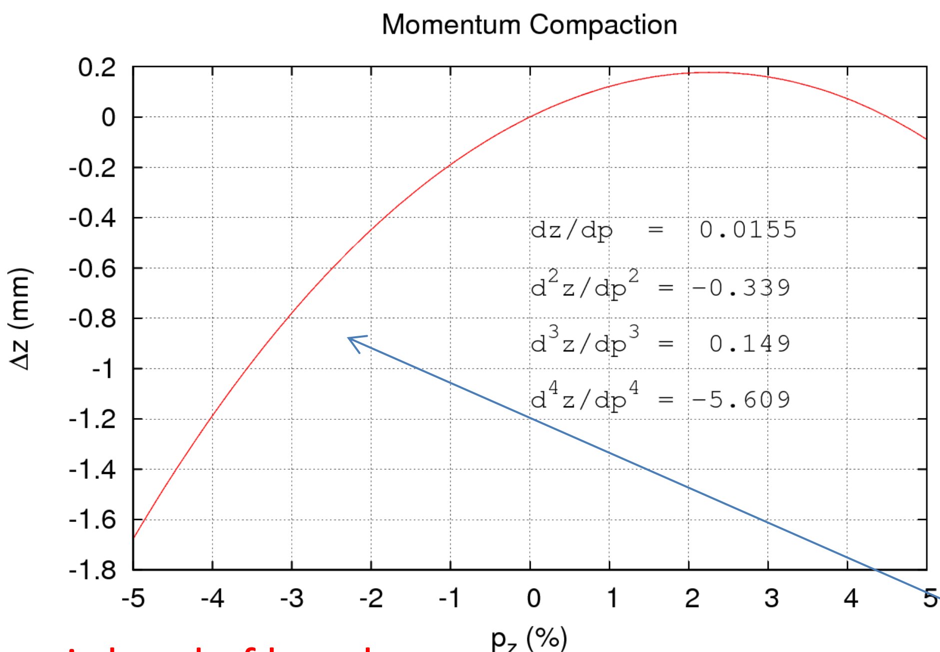
Impressive emittance reduction

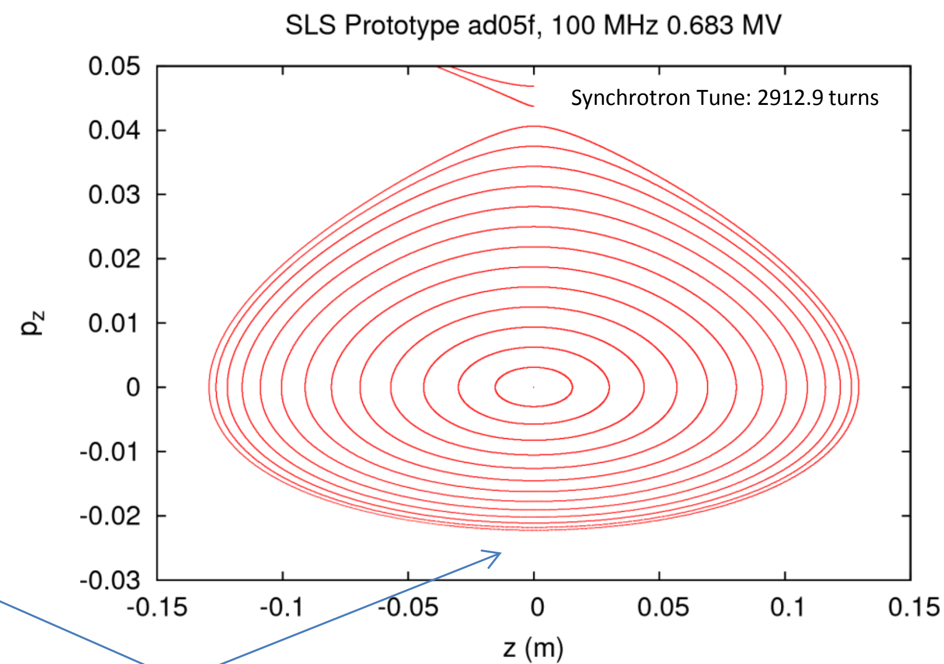
Momentum compaction non-linear

Challenging nonlinearities

- Nonlinear momentum compaction makes this cell unfit for the SLS2 upgrade.

Longitudinal Dynamics





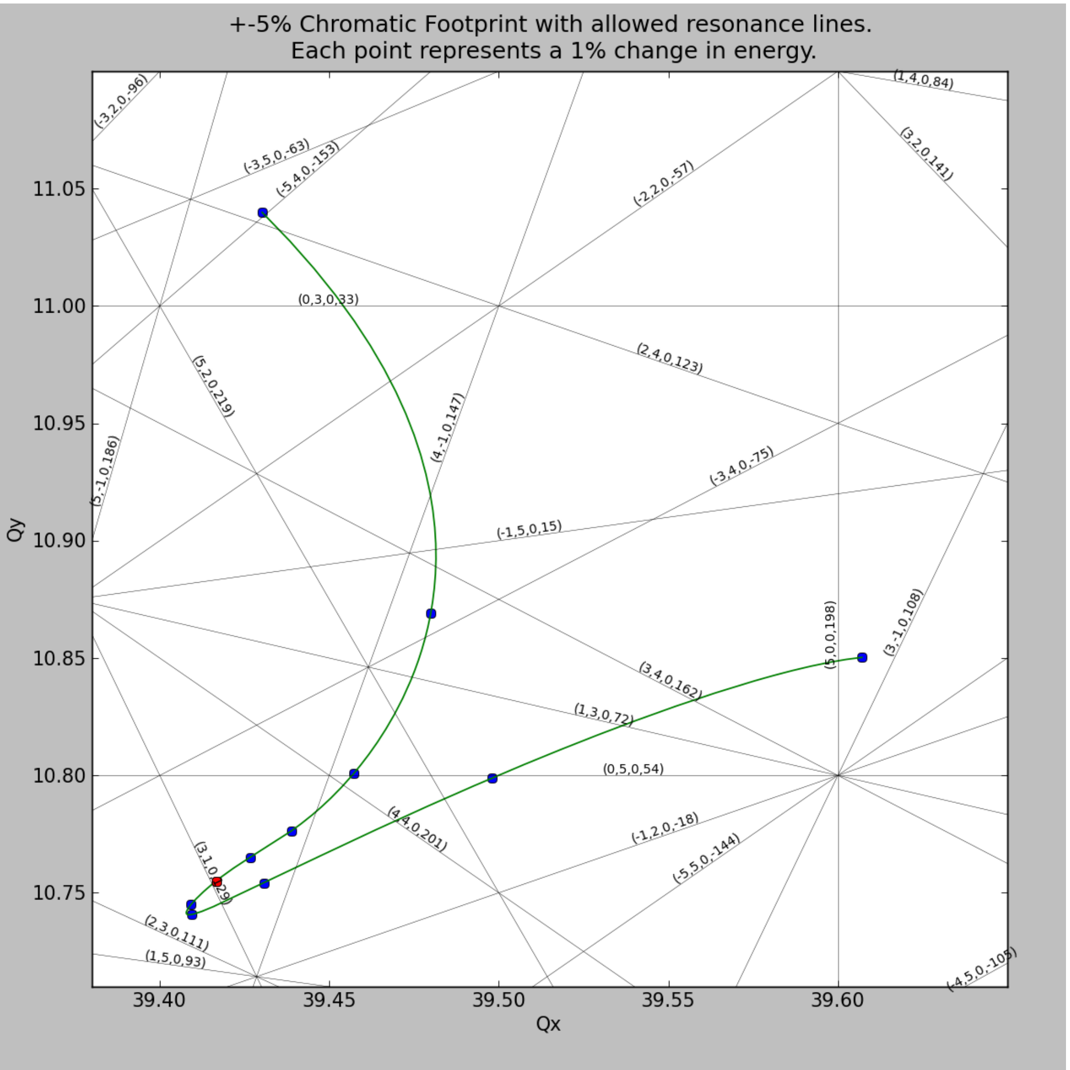
+z is head of bunch

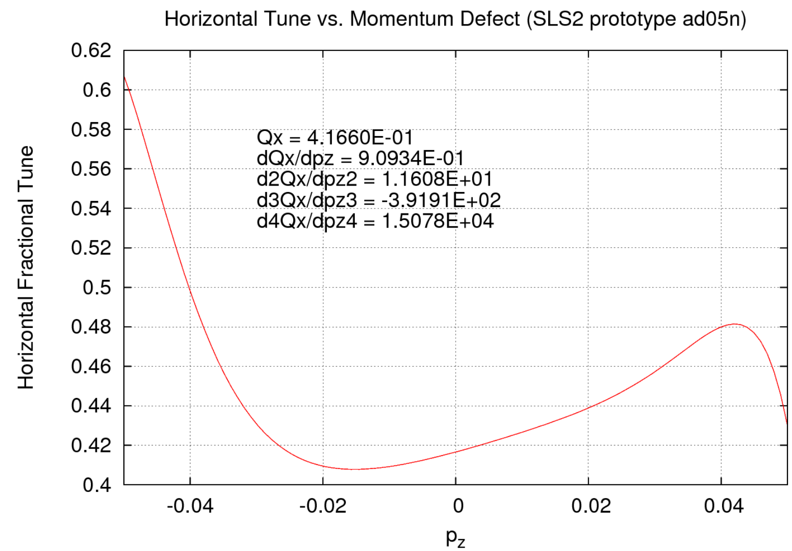
Bucket size limited by non-linear roll-off in momentum compaction

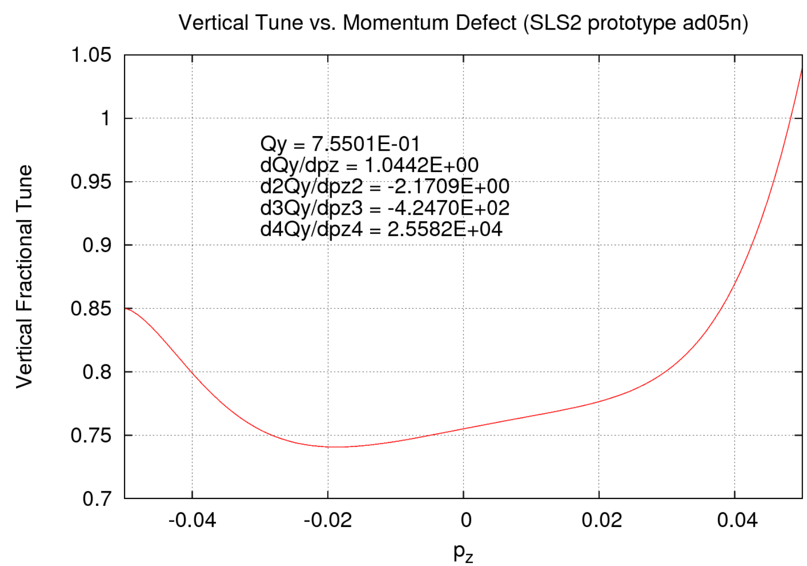
- Lattice is below transition.
- Momentum compaction is dominated by nonlinear terms.
- Goal: ±5% bucket.
- Limits injection scheme options.
- Manipulation of momentum compaction by multipoles seems to always require too large a sacrifice in DA.

Large Chromatic Tune Shifts

- Sextupole scheme that yields acceptable on-momentum DA, results in a large chromatic tune footprint.

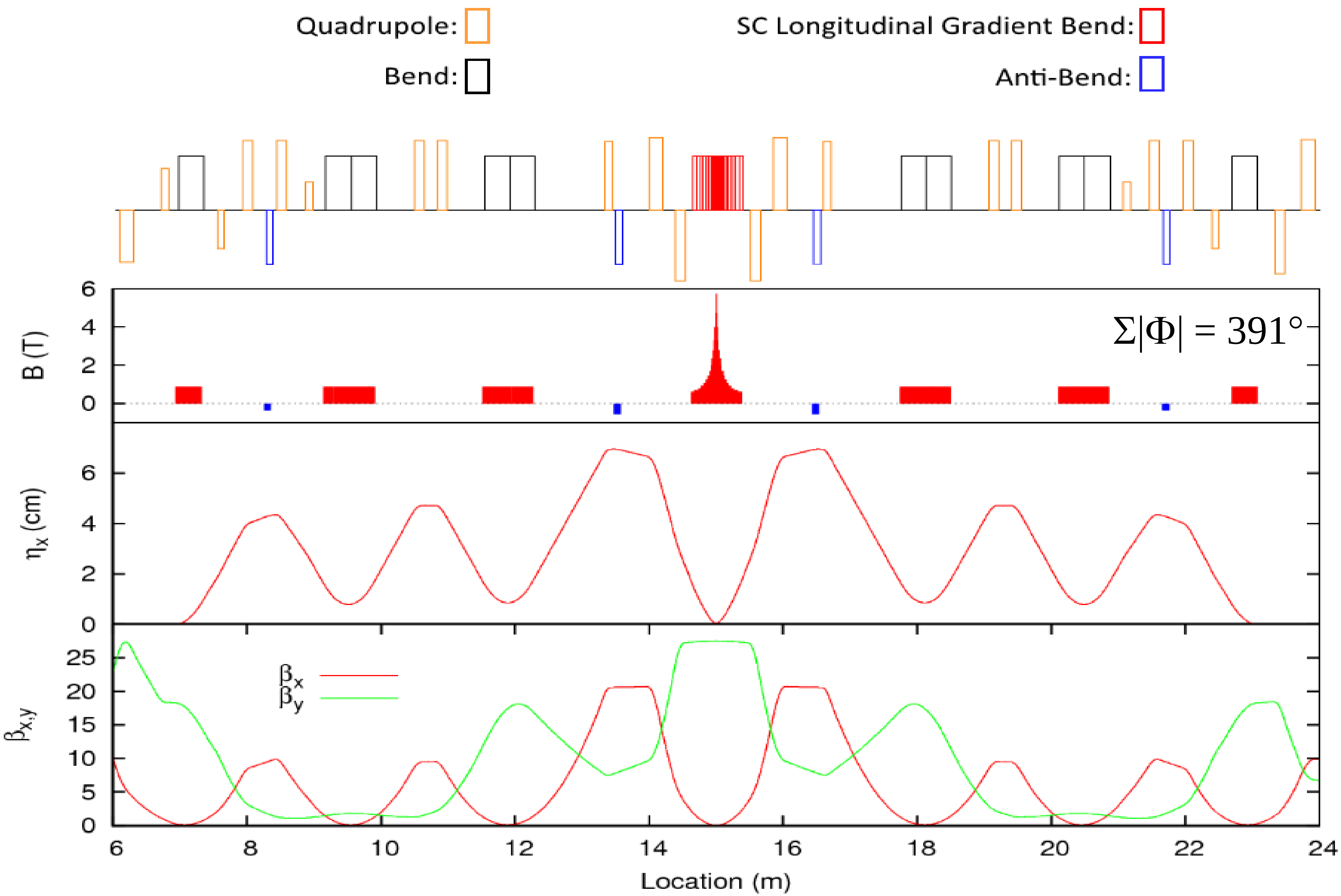






Large Positive α_p Prototype

- Adjust optics for finite dispersion in ordinary bends to generate large positive α_p.



Comparison

	NSLS 2	PEP-X	MAX-IV	SLS	SLS2 (concept)	SLS2 ($\alpha_p >> 0$)
E_0 (GeV)	3	4.5	3	2.411	2.4	2.4
Circ. (m)	780	2199	528	288	288	288
ε_x (pm)	550	11	320	5000	72	183
ν_x	32.35	113.23	42.2	20.43	39.42	39.39
ν_y	16.28	65.14	14.28	8.74	10.76	10.76
α_p	$3.7\ 10^{-4}$	$5.0\ 10^{-5}$	$3.1\ 10^{-4}$	$6.0\ 10^{-4}$	$-5.4\ 10^{-5}$	$1.3\ 10^{-4}$
ξ_x	-100.	-162.3	-49.8	-67.3	-154.7	-163.7
ξ_y	-41.8	-130.1	-43.9	-22.2	-46.4	-70.46
$-\xi_x/\nu_x$	3.1	1.2	1.2	3.3	3.9	4.2
$-\xi_y/\nu_y$	2.6	2.0	3.1	2.5	4.3	6.5

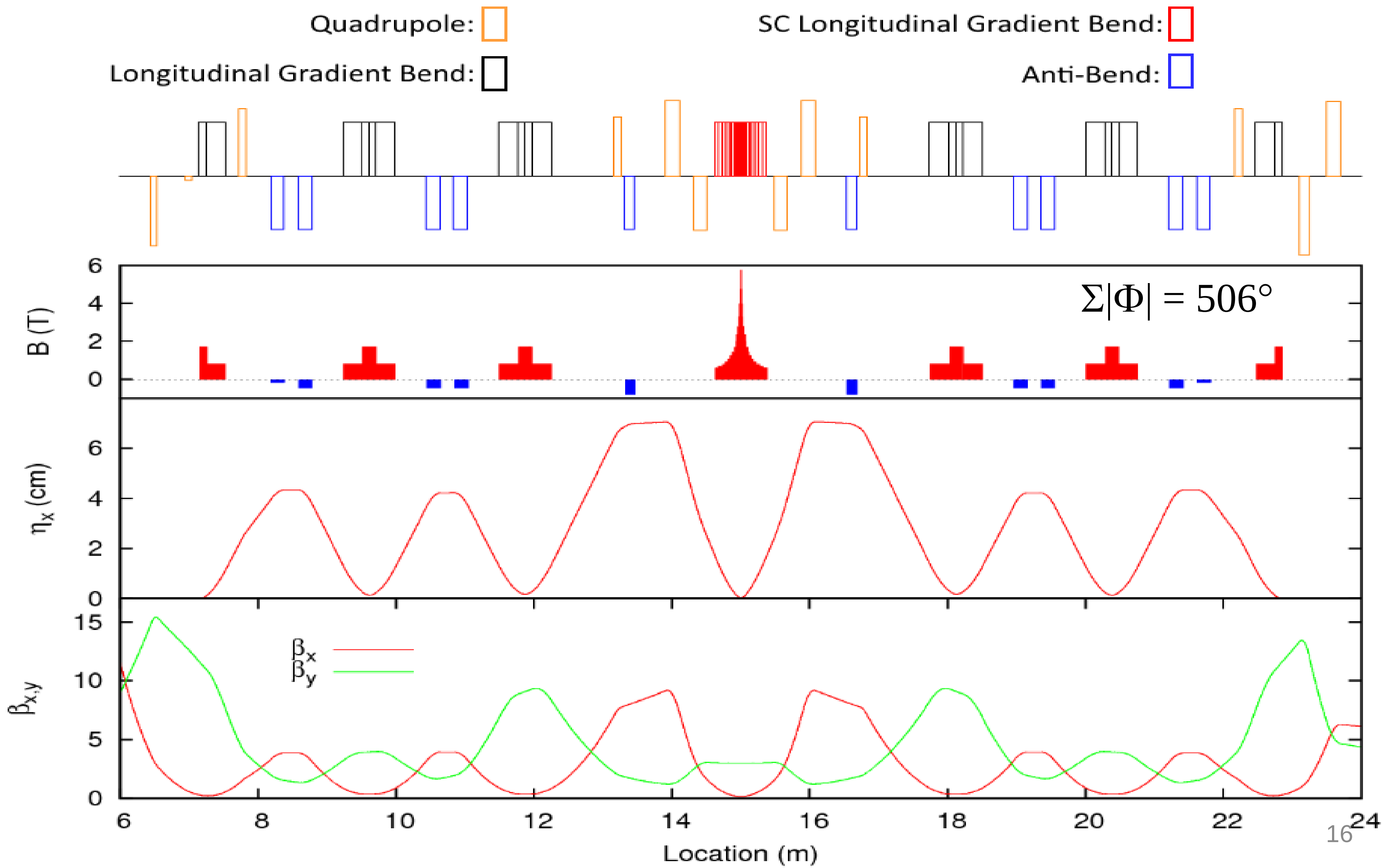
Emittance reduction not as impressive

α_p is better

Challenging nonlinearities

Large Negative α_p Prototype

- Large dispersion in anti-bends generates large negative α_p.



Comparison

	NSLS 2	PEP-X	MAX-IV	SLS	SLS2 concept)	SLS2 (α_p >> 0)	SLS2 (α_p << 0)
E_0 (GeV)	3	4.5	3	2.411	2.4	2.4	2.4
Circ. (m)	780	2199	528	288	288	288	288
ε_x (pm)	550	11	320	5000	72	183	162
ν_x	32.35	113.23	42.2	20.43	39.42	39.39	35.58
ν_y	16.28	65.14	14.28	8.74	10.76	10.76	13.86
α_p	$3.7\ 10^{-4}$	$5.0\ 10^{-5}$	$3.1\ 10^{-4}$	$6.0\ 10^{-4}$	$-5.4\ 10^{-5}$	$1.3\ 10^{-4}$	$-1.0\ 10^{-4}$
ξ_x	-100.	-162.3	-49.8	-67.3	-154.7	-163.7	-73.0
ξ_y	-41.8	-130.1	-43.9	-22.2	-46.4	-70.46	-40.6
$-\xi_x/\nu_x$	3.1	1.2	1.2	3.3	3.9	4.2	2.1
$-\xi_y/\nu_y$	2.6	2.0	3.1	2.5	4.3	6.5	2.9

better ε_x

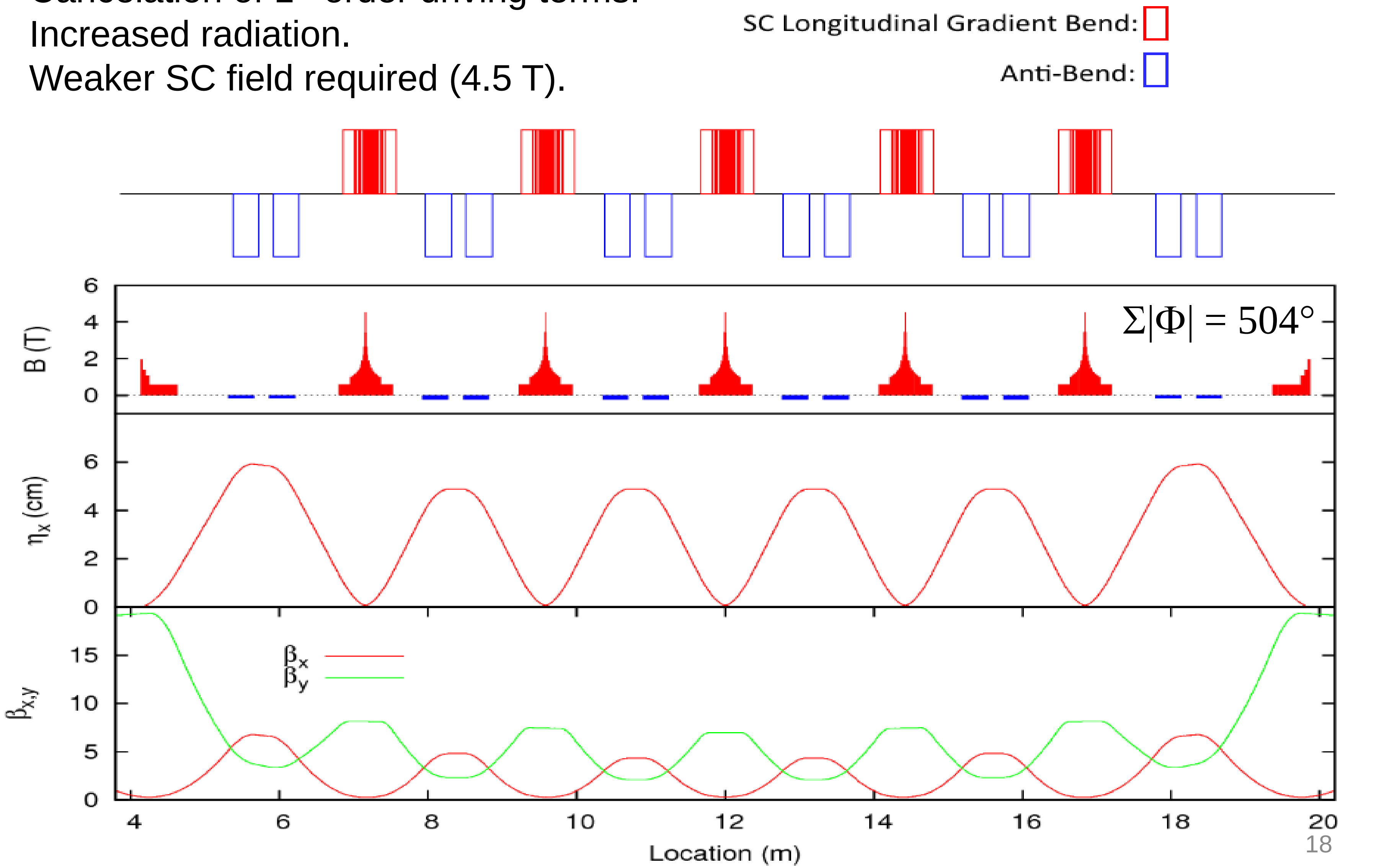
α_p is linear

Relaxed optics

- Acceptable DA & tune shifts not found when using local optimizer on NDTs.
- Off-momentum DA is esp. important (+/- 5%).
- Now working with multi-objective genetic optimizer.

7BA Superbend Cell (preliminary)

- 7BA constructed of superbends and antibends.
- Cancelation of 1st order driving terms.
- Increased radiation.
- Weaker SC field required (4.5 T).



Comparison

	NSLS 2	PEP-X	MAX-IV	SLS	SLS2 (concept)	SLS2 (α >> 0)	SLS2 (α << 0)	SLS2 (7BA)
E_0 (GeV)	3	4.5	3	2.4	2.4	2.4	2.4	2.4
Circ. (m)	780	2199	528	288	288	288	288	288
ε_x (pm)	550	11	320	5000	72	183	162	131
ν_x	32.35	113.23	42.2	20.43	39.42	39.39	35.58	37.38
ν_y	16.28	65.14	14.28	8.74	10.76	10.76	13.86	9.26
α_p	$3.7\ 10^{-4}$	$5.0\ 10^{-5}$	$3.1\ 10^{-4}$	$6.0\ 10^{-4}$	$-5.4\ 10^{-5}$	$1.3\ 10^{-4}$	$-1.0\ 10^{-4}$	$-1.1\ 10^{-4}$
ξ_x	-100.	-162.3	-49.8	-67.3	-154.7	-163.7	-73.0	-63.7
ξ_y	-41.8	-130.1	-43.9	-22.2	-46.4	-70.46	-40.6	-45.1
$-\xi_x/\nu_x$	3.1	1.2	1.2	3.3	3.9	4.2	2.1	1.7
$-\xi_y/\nu_y$	2.6	2.0	3.1	2.5	4.3	6.5	2.9	4.9

- 7BA Superbend cell is very preliminary.
- 60 superbends will be more expensive than 12.

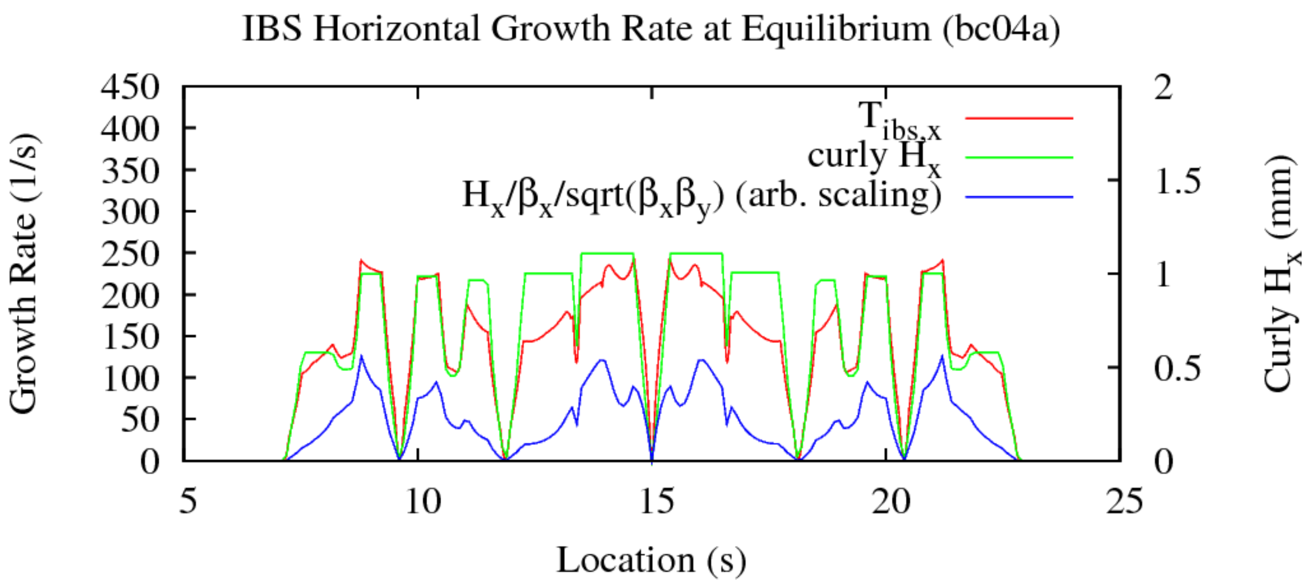
Better ε_x
Good α_p
Relaxed linear optics
Vertical nonlinearities challenging

IBS in Anti-Bend LGB Cell

- IBS is nonlinear, but for high-γ, a rough scaling is[1]:

$$\frac{1}{\tau_{\mathrm{IBS},\perp}} = \frac{\mathcal{H}_x}{\beta_x\sqrt{\beta_x\beta_y}}$$

- Can be mitigated by round beam scheme (1/2 the emittance).



- Only weakly dependent on RF, due to current requirements.

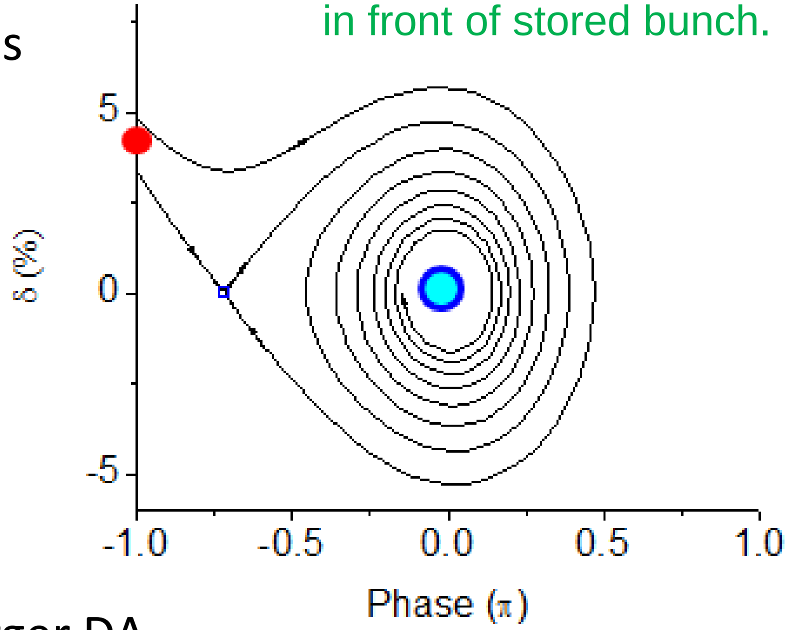
Prototype Lattices	Zero Current Radiation Only ε_x	5 mA, 100 MHz 5% Bucket, 3HC (2x BL) 10 pm ε_y ε_x	1 mA, 500 MHz 5% Bucket, 3HC (2x BL) 10 pm ε_y ε_x
Concept	73 pm	110 pm	95 pm
α << 0	183 pm	210 pm	202 pm
α >> 0	162 pm	200 pm	187 pm
LGB 7BA	131 pm	157 pm	143 pm

[1]A. Fedotov. "Comments on simplified treatment of intrabeam scattering using plasma approach.", 2004

Injection Schemes

- Goals:
  1. Minimize user impact during top up
  2. Compact layout
  3. Minimize DA requirements
- "4 kicker" scheme meets none of these goals
- Longitudinal injection
  - Potentially meets all three goals.
  - Challenges
    - Requires "golf club" acceptance
    - Requires big momentum acceptance
    - Technological hurdles if 500 MHz used
- Multipole kicker injection
  - Possible solution, but off-axis, requires larger DA
- Investigating hybrid approach
  - Use multipole kicker to kick off-momentum particle onto dispersive closed orbit.
  - Near-on-axis, off-momentum.

Bunch injected on-axis, but onto "golf club" shaft in front of stored bunch.



SLS-2 Design Research

- Find cell design that gives sub-200 pm emittance and allows for acceptable DA and tune shifts.
- Design & prototyping of SC Superbends.
- Study machine impedance, decide on RF system.
  - Perhaps negative chromaticity with negative momentum compaction will also suppress head-tail & coupled bunch.
- Explore round beam schemes.
  - Split the emittance, makes IBS negligible
  - Round beam desired by most users.
- Develop orbit feed-back based on photon BPMs.
  - Carry over from SLS BPM Upgrade Project.
  - Lattice too dense for placing RF-BPMs at all locations.
- Explore on-axis injection schemes.
- MOGA and PSO for direct optimization of dynamic aperture.
  - Assisted by NDT calculations.

Conclusion

- SLS-2 design is constrained by comparatively small ring circumference.
- New LGB/AB cell provides a solution for compact low emittance rings.
- An emittance of 100-200 pm seems possible with contemporary magnet technology.
- But feasibility has not yet been proven.
- Project is in Concepts & Research phase.
- A conceptual design report is planned for 2016.