First studies on a possible SLS upgrade

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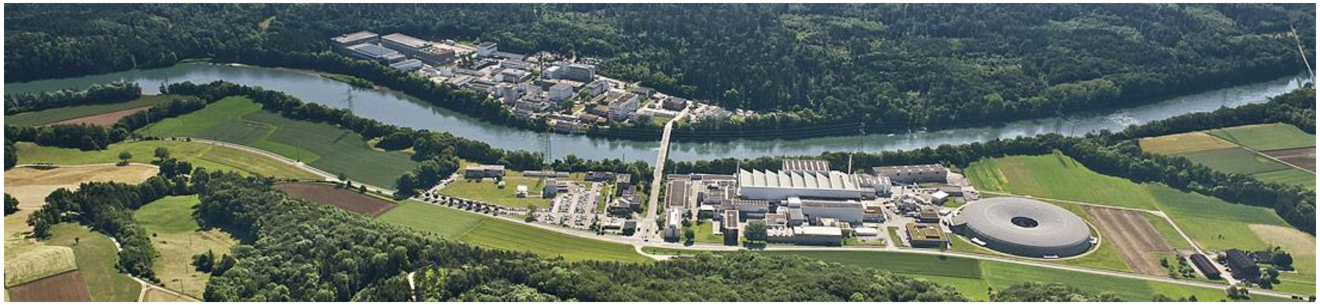
Paul Scherrer Institut



Overview

1. Motivation for an SLS Upgrade
2. Describe SLS2 project scope
3. Introduce upgrade concepts
4. Studies on SLS2 prototype based on maximal exploitation of those concepts.
5. Discuss challenges and program directions
6. Recap and conclude

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Motivation

- SLS commissioned in 2000
  - Serving 18 beamlines with >99 % uptime
  - 5.5 nm x 5 pm 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)

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Existing SLS

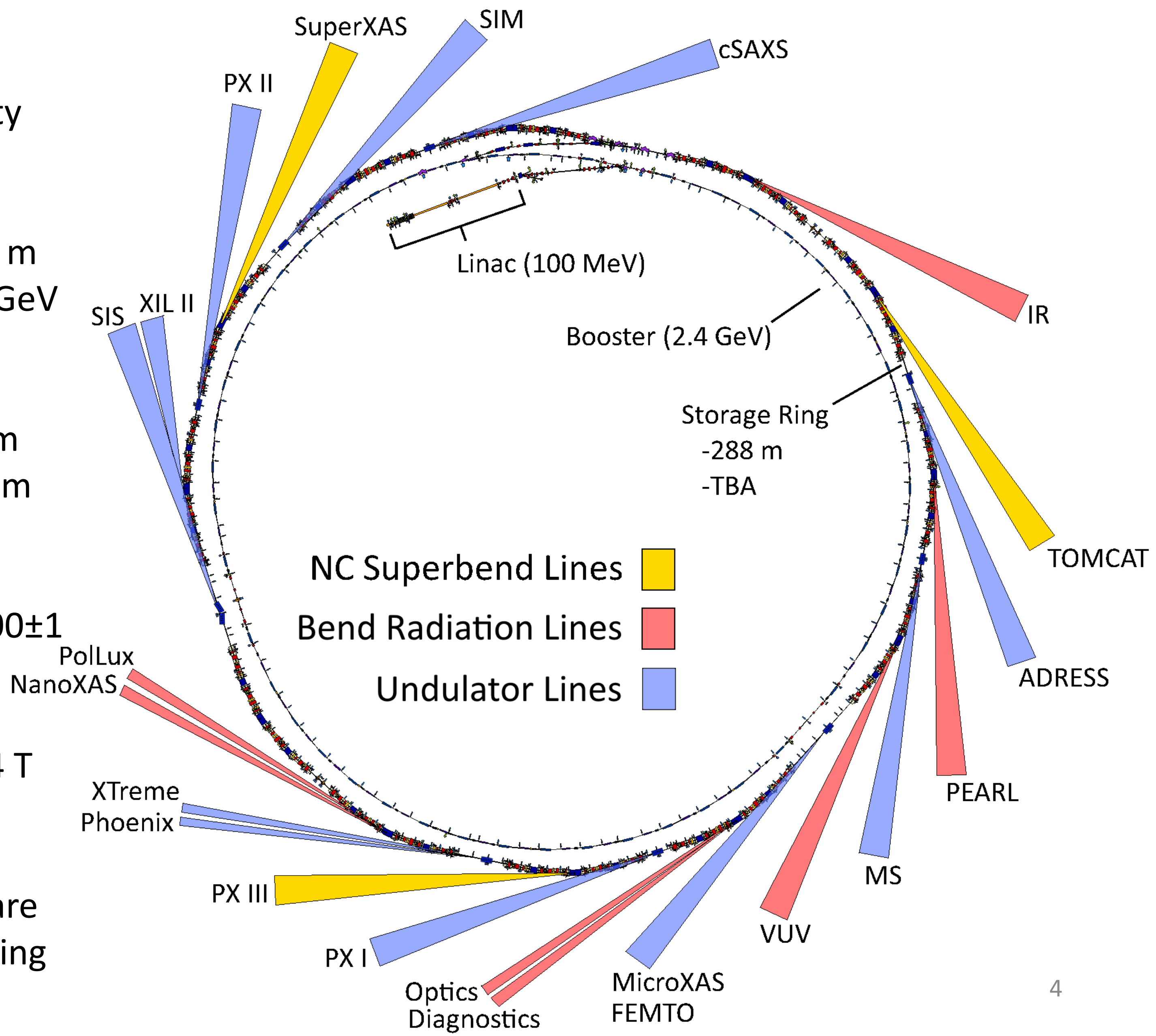
- TBA Design
  - 12 x 8°+14°+8°
- 3-fold basic periodicity
- Q_x = 20.43
- Q_y = 8.74
- Compact Lattice: 288 m
- Medium Energy: 2.4 GeV

- Emittance
  - horizontal 5.6 nm
  - nominal vert 5 pm
  - LET vert ~1 pm

- Top-up operation: 400±1 mA

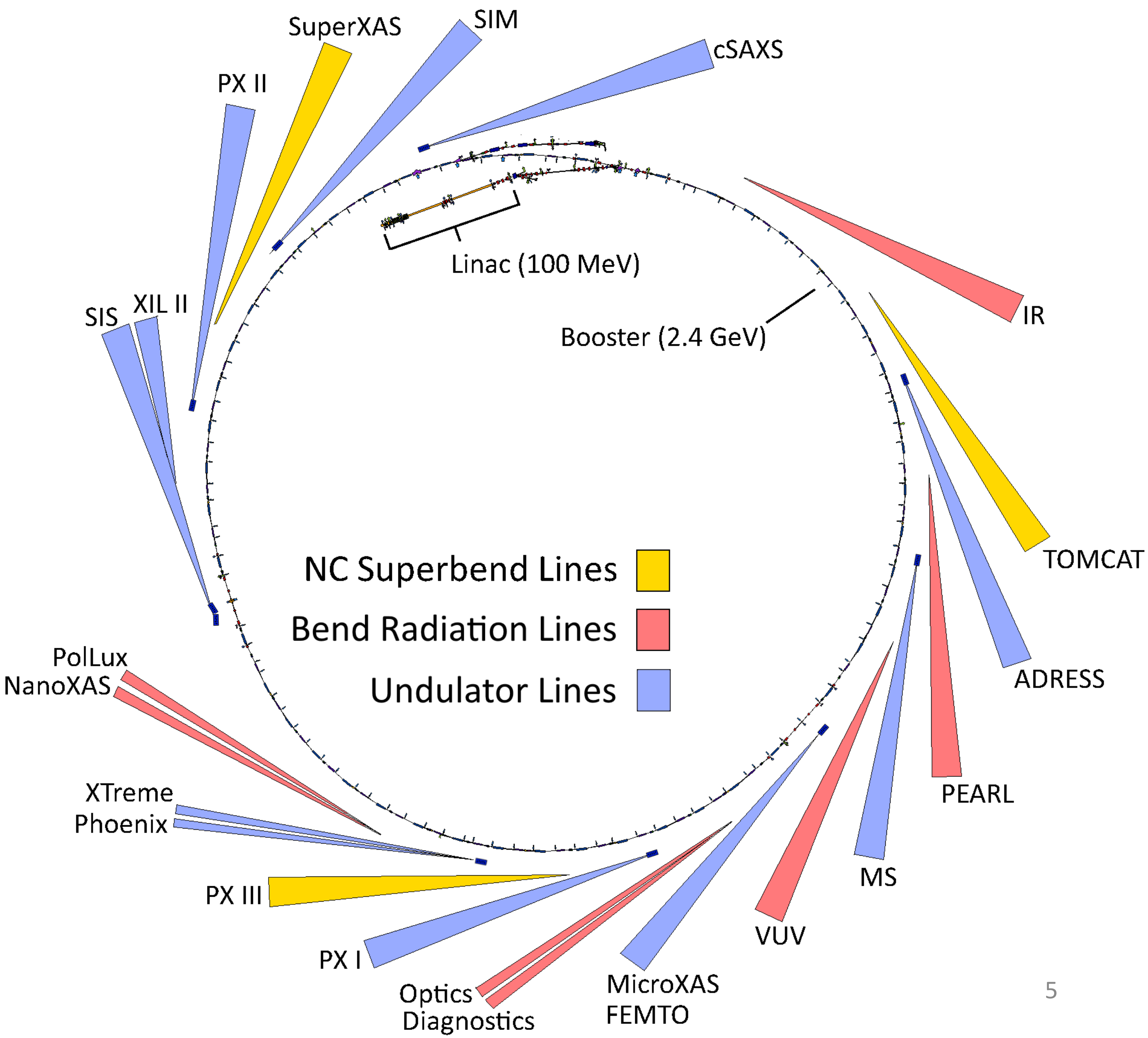
- Normal bends are 1.4 T electromagnets

- Existing superbends are 2.9 T normal conducting super-ferric magnets.



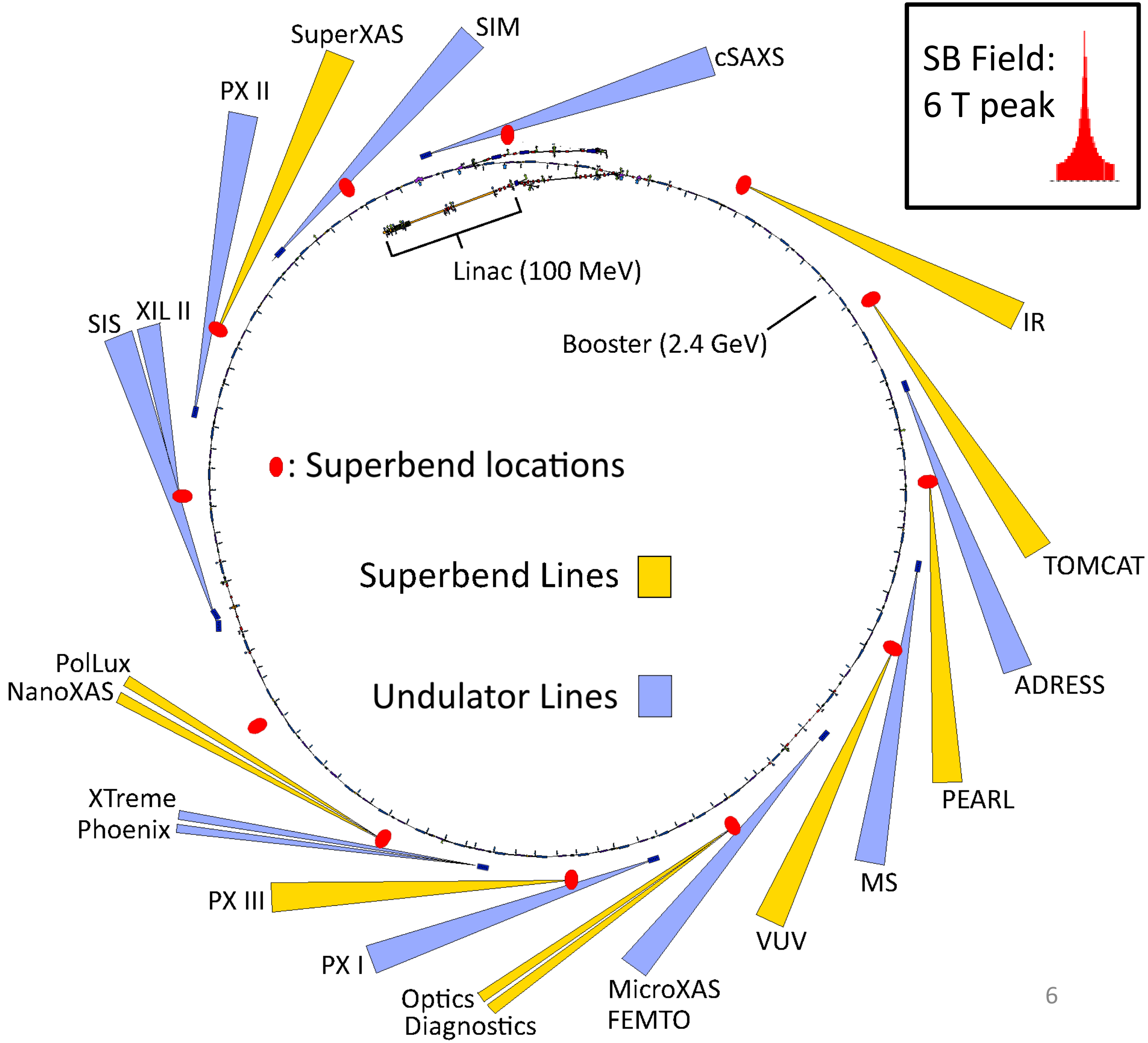
Preserve Existing Facilities

- Preserve:
  - Building
  - Beamlines
  - Undulators
  - Linac & booster
- Booster:
  - 3 Hz
  - Inject at:
    - 10/2 nm rad
    - 0.08% dp
    - 1 mA
    - Near 100% eff.
- Cost constraints
  - Asking for 83 MCHF
  - Includes 20 MCHF for beam line updates
- Early 2020s



12 SC Superbends Installed

- "Standard" MBA design would yield only ~1 nm
- Propose MBA utilizing superbends, longitudinal gradient bends, and anti-bends
  - Yields ~100 pm or less
- Bend radiation users benefit from higher photon flux & higher photon energy
  - Photons up to 100 keV from a 2.4 GeV ring



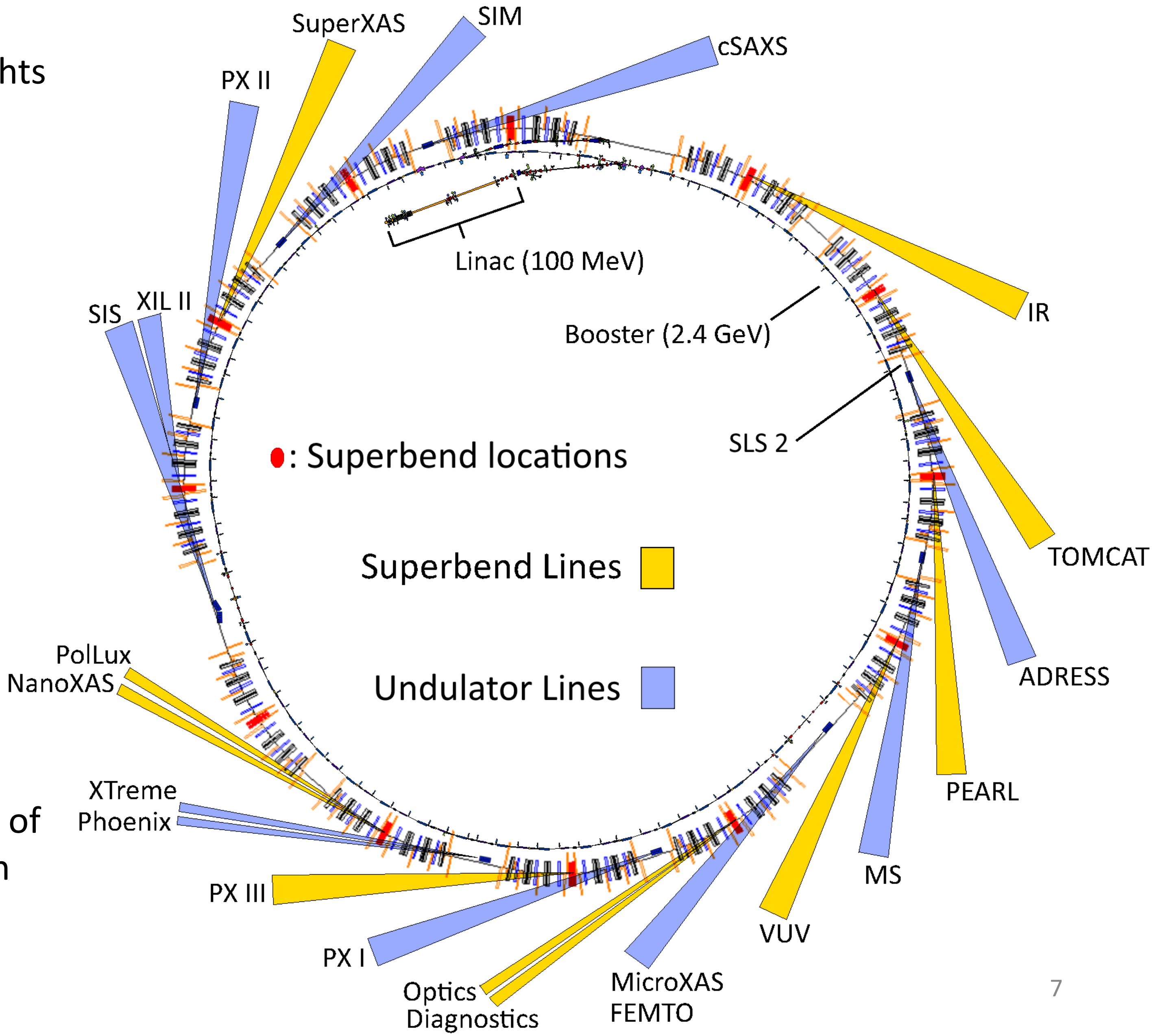
Prototype Lattice

- 12 MBA cells.
- Dispersion-free straights
- J_x ~ 1.3

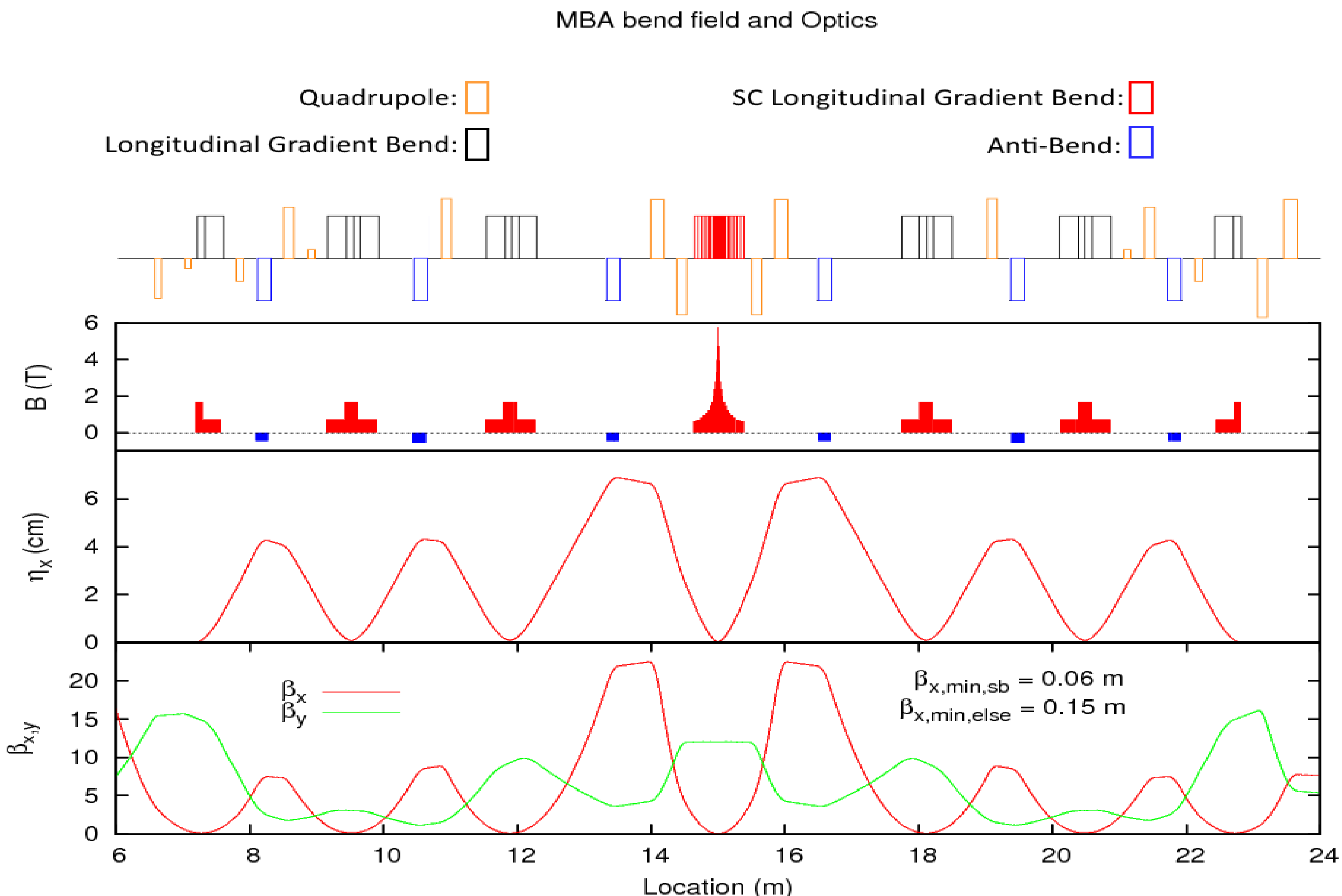
- Longitudinal gradient bend field and anti-bends minimize I_5 integral
- 73 pm horizontal emittance

- Q_x = 39.417
- Q_y = 10.755
- σ_e = 0.11 %

- Initial design: 1-order of magnitude increase in brilliance for photons above 100 eV.



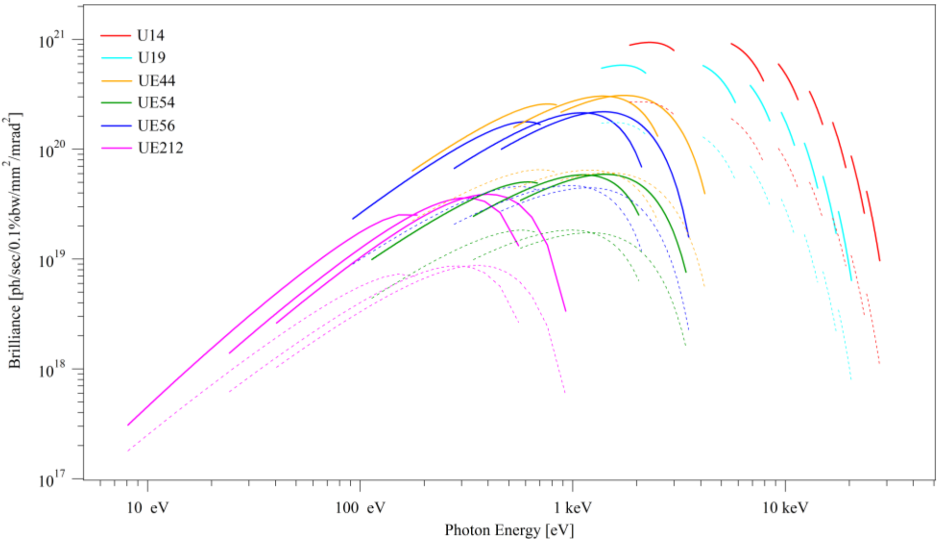
SLS2 Prototype Linear Optics*



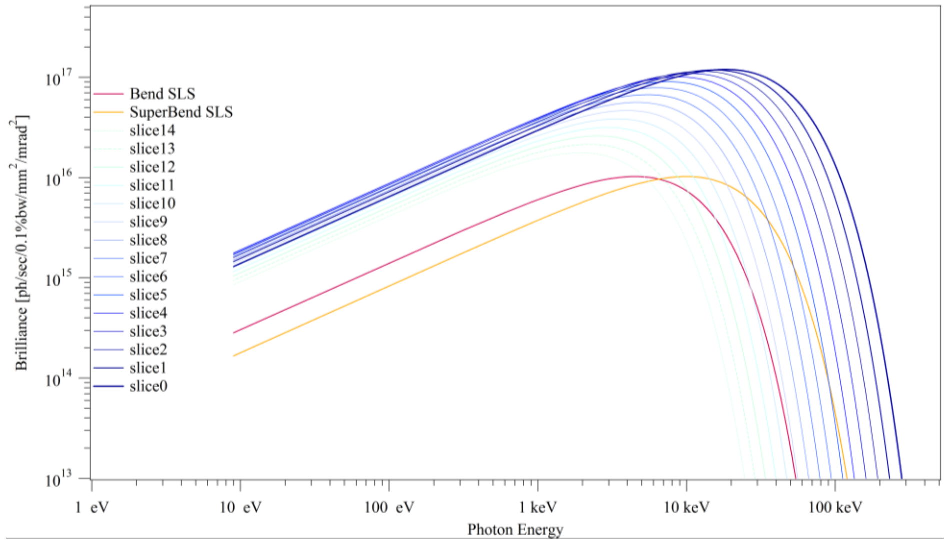
*See Thursday Morning talk by Andreas Streun for details!

Undulator & Superbend Brilliance

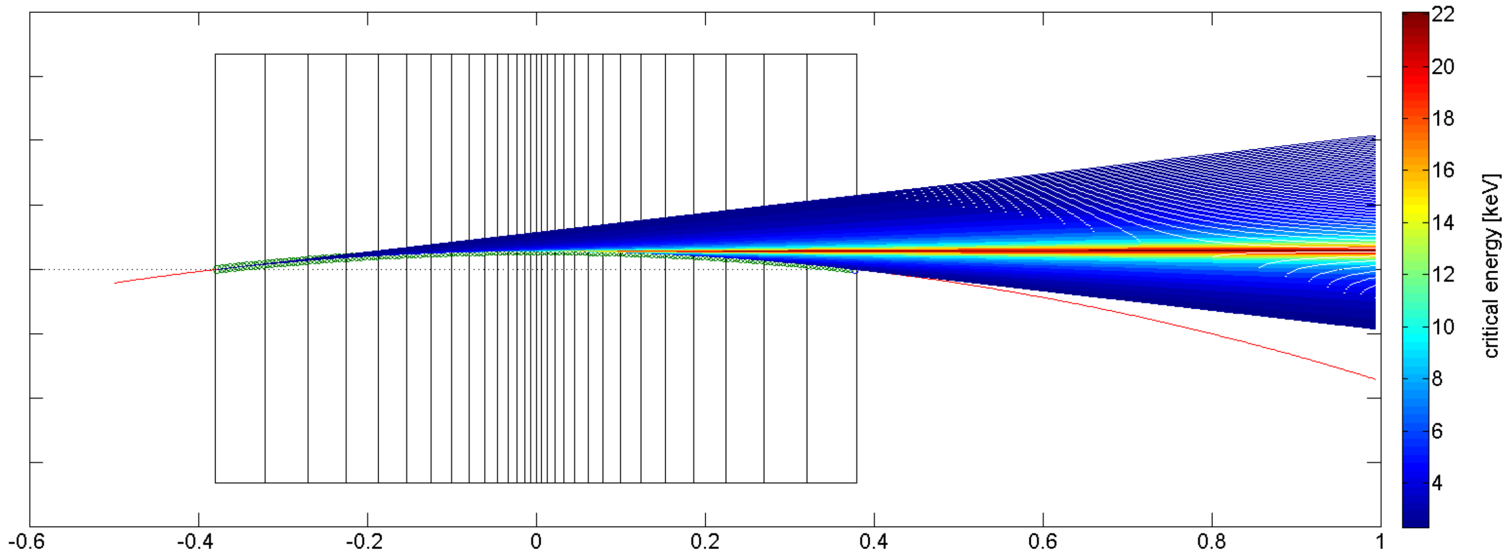
SR for all ID (SLS dashed lines, SLS2 cont. lines)



SR for BM (SLS: bend and superbend, SLS2 slices with different field for longitudinal gradient bend)



In a longitudinal gradient bend horizontal spectrum is not homogeneous! Every slice emits with a different Ec (up to 1 order magnitude difference!). Possible position monitor based on this property



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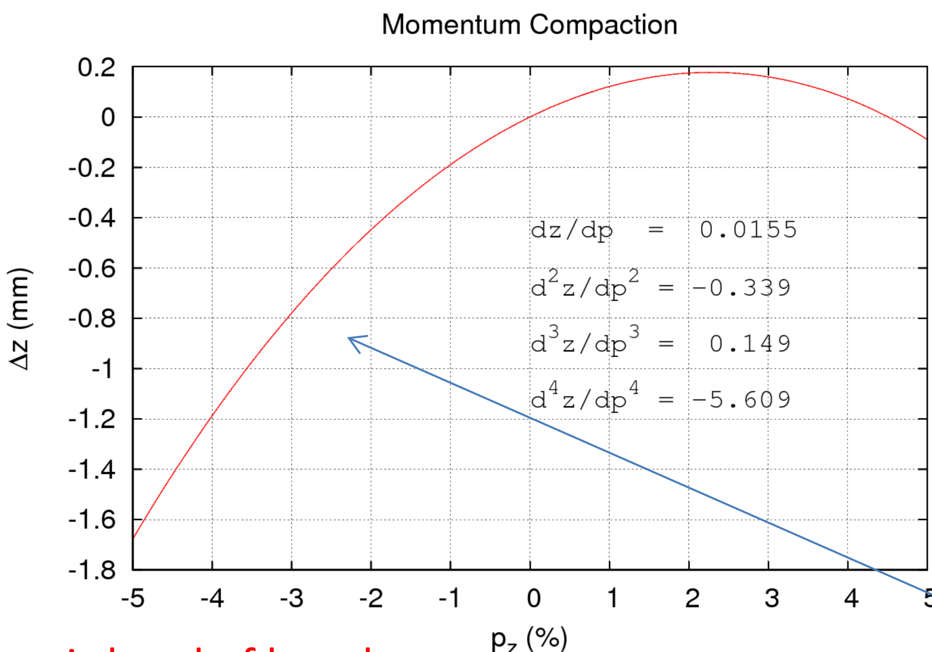
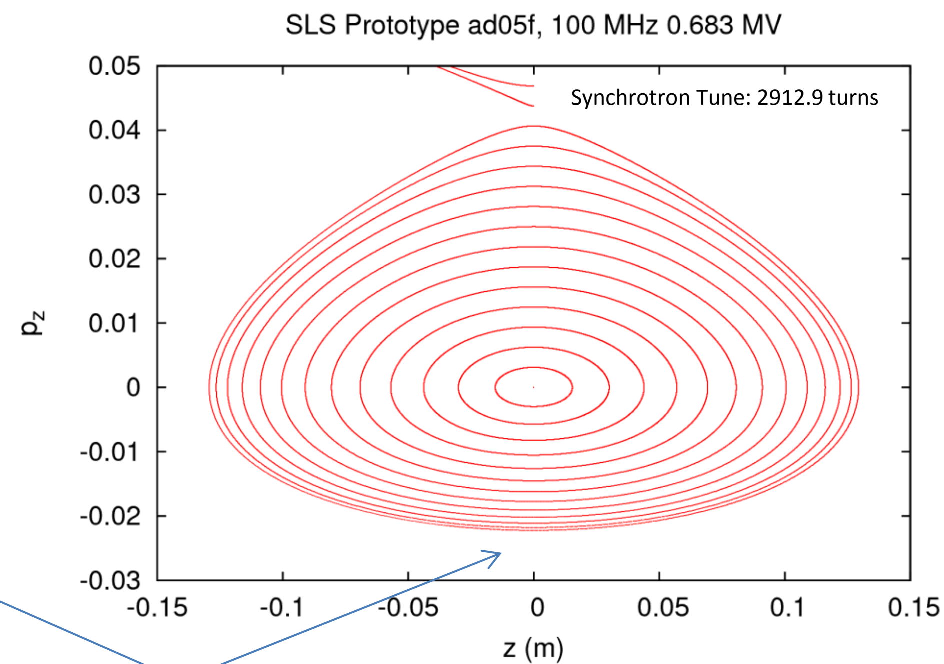
Comparison To Other Contemporary Designs

	SLS2 (low ε prototype)	NSLS 2	PEP-X	MAX-IV
Energy (GeV)	2.4	3	4.5	3
Circumference (m)	288	780	2199	528
Horizontal Emittance (pm)	72	550	11	320
ν_x	39.4155	32.35	113.23	42.2
ν_y	10.7550	16.28	65.14	14.28
α_p	$-5.38\ 10^{-5}$	$3.7\ 10^{-4}$	$4.96\ 10^{-5}$	$3.07\ 10^{-4}$
ξ_x	-154.715	-100.	-162.3	-49.8
ξ_y	-46.445	-41.8	-130.1	-43.9
$-\xi_x/\nu_x$	3.9	3.1	1.2	1.2
$-\xi_y/\nu_y$	4.3	2.6	2.0	3.1

- Small linear momentum compaction makes non-linear momentum compaction important.
- High ratio of chromaticity to tune indicates non-linearities will be significant.

Longitudinal Dynamics



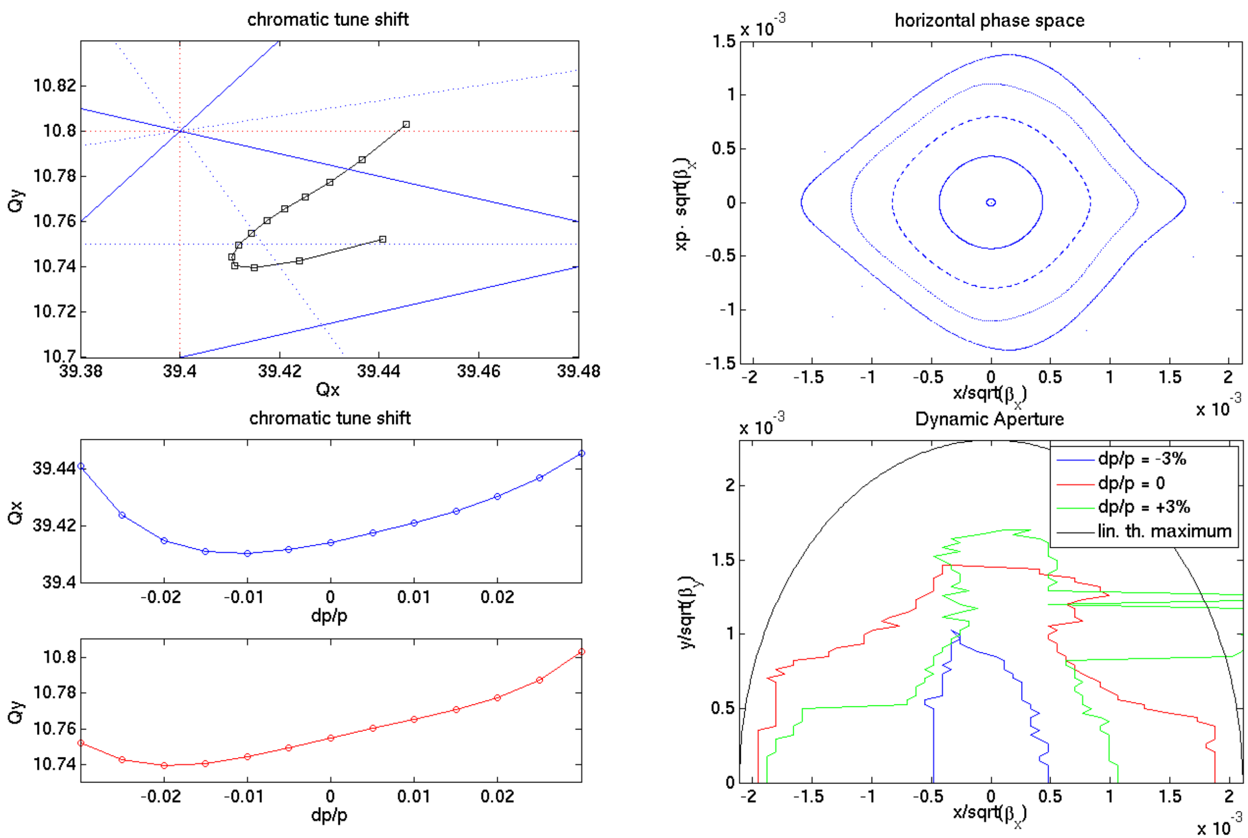


+z is head of bunch

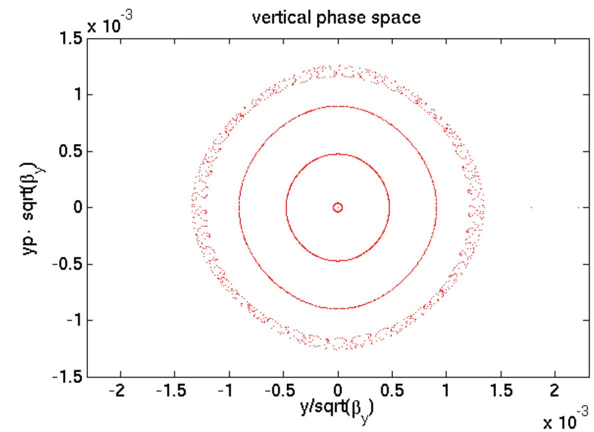
Bucket size limited by non-linear roll-off in momentum compaction

- Lattice is below transition
- Higher orders of momentum compaction calculated using TPSA.
- Goal: ±5% bucket.
- Possible solution: use multipoles to manipulate nonlinear momentum compaction to widen bucket.

Nonlinearities & Dynamic Aperture



- 1000 turns tracked for dynamic aperture
- 2d tracking



- On-momentum DA is acceptable.
- Off-momentum DA at ±3% is too small
  - -3% does not actually exist, due to RF bucket

Nonlinear Optimization

- First pass optimizes 3rd and 4th order (in phase space coordinates) driving terms represented in the Lie exponential format and also tune shifts.
  - 25 quantities to optimize
  - 9 sextupole families, 4 octupole families
- Development work
  - SLS1 techniques not adequate for SLS2
  - Including higher order terms in optimization
    - Manipulate higher order compaction to enlarge bucket
    - Manipulate non-linearity chromaticity to limit tune footprint
  - Global optimizers that exploit TPSA
  - Weighting
  - Engineering Tolerances
  - Direct optimization methods

Misalignments, girders, correction schemes

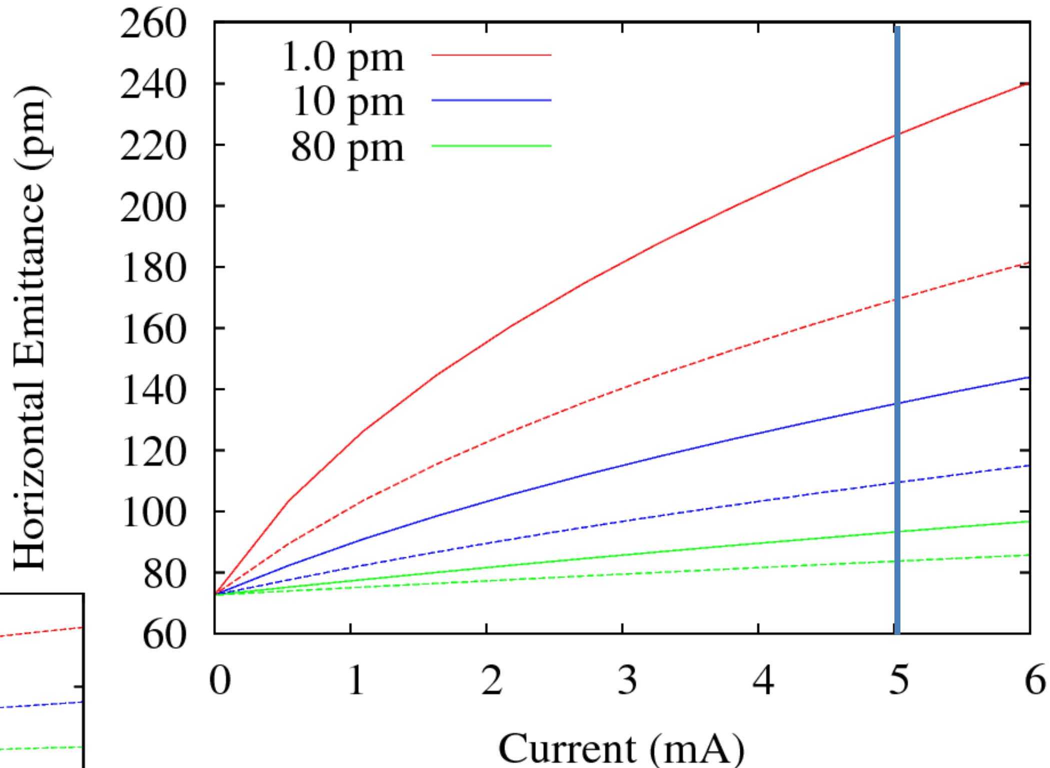
- Initial tracking studies on misaligned & orbit-corrected lattices suggest following "closed orbit on day-1" tolerances:
  - 25 µm absolute girder displacement (SLS1: 300 µm)
  - 10 µm girder-to-girder displacement (SLS1: 100 µm)
  - 7.5 µm element-to-girder displacement (SLS1: 50 µm)
- Correction scheme:
  - 192 button BPMs
  - 60 x-ray BPMs at center of bends
  - 192 Correctors
- Beam-based girder alignment during commissioning.

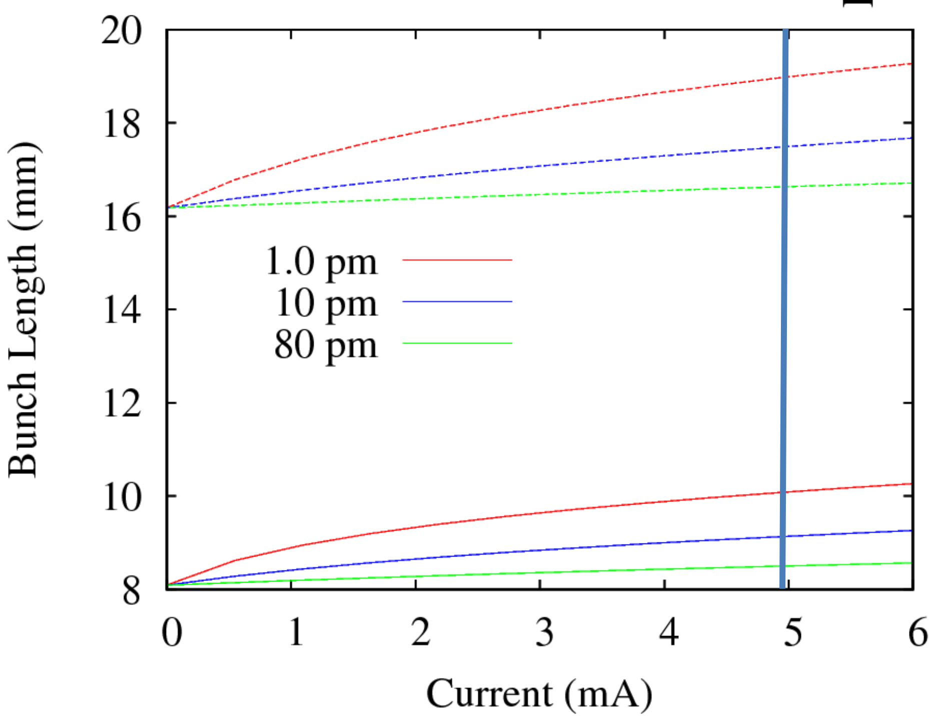
Intrabeam Scattering

- 100 MHZ RF with and without 3HC for various vertical emittance situations.

- Solid: w/o 3rd Harmonic Cavity
- Dotted: with 3rd Harmonic Cavity

- 100 MHz RF had 1/5 number of buckets, requires 5 mA/bunch





- In low emittance conditions, 66% of emittance generated by IBS
  - Necessitates round beam scheme

- Note: bunch length assumes linear RF bucket

Intrabeam Scattering

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
“First”	86.7 pm	126.3 pm	113.6 pm
“Improved”*	72.8 pm	109.4 pm	95.4 pm
“Positive Compaction”	182.6 pm	209.7 pm	201.5 pm
“Large Negative Compaction”	162.0 pm	199.2 pm	187.2 pm

- IBS is strong for low-ε lattices, but can be dealt with using coupling scheme
- Working on an adjustable skew-quad based scheme for obtaining round beams

*The “Prototype Lattice” shown in presentation

Impedance Effects & RF System

- Low emittance, short bunches, and small chamber have strong impact on impedance effects
- RF decisions driven by impedance effects
- 100 MHz or 500 MHz RF
  - We have 500 MHz NC RF already, and could adapt for SLS2
  - 100 MHz RF gives longer bunches
  - Other cavity designs could be purchased or developed in-house
- 3rd Harmonic Cavity for lengthening
  - Have passive, may go driven
- Small & negative momentum compaction could impact impedance instabilities
- Hiring post doc to examine these effects

Direction of SLS2 Development

- Nonlinearities, Low & Nonlinear momentum compaction perhaps make lowest emittance prototype lattice un-workable.
  - By strengthening or weakening anti-bends, momentum compaction can be made positive or large & negative
    - Trade off is larger emittance
  - Possibly use nonlinear momentum compaction to enlarge bucket
- Design coupling scheme for round beams
  - Strong coupling would impact all aspects of SLS2 (IBS, nonlinearities, operation, etc.)
- And much more …
  - impedance studies, feedback, correction, …

Recap and Conclusion

- SLS wishes to upgrade and remain a competitive light source.
- "Standard" MBA would not be a significant upgrade.
  - 5.5 nm -> 1.0 nm
- Lattice based on LGB and anti-bends may offer a low-emittance solution within the given constraints.
  - Potential for sub-100 pm
- Preserve much of existing facilities.
- Construction early 2020s.
- Prototype lattice evaluated, challenges identified, proposed solutions.