Accelerator Options for the APS Renewal

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Outline

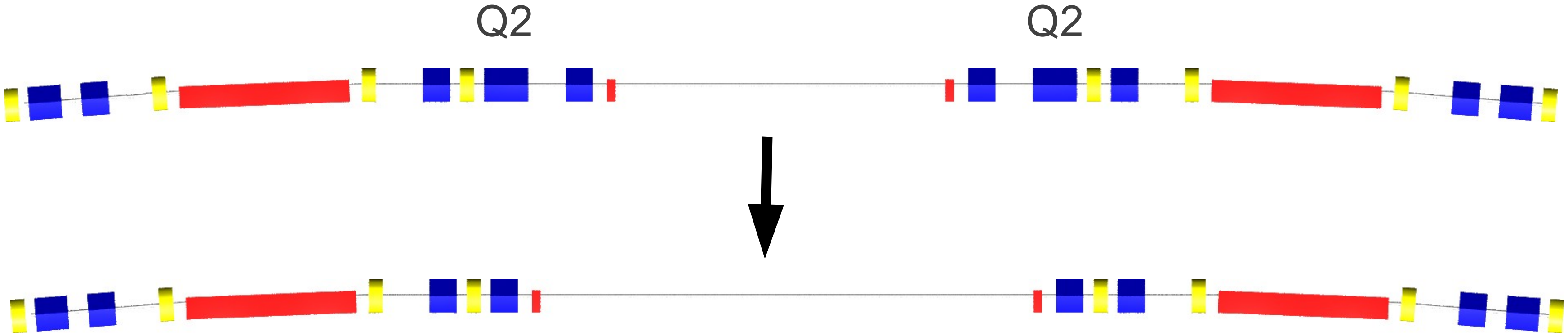
- Lattice changes
- Short-pulse x-rays
- Higher current
- Beam stability
- Insertion devices

Lattice changes

- Primary lattice change will be long straights
- Other options include
  - Stronger dipole magnets
  - Split dipole magnets for additional IDs
  - Alternating high/low beamsize
- Concerns with any lattice change
  - Loss of flexibility
    - E.g., ability to provide RHB
  - Increased emittance
    - Lattice is optimized for low emittance so this is almost inevitable
  - Decreased injection efficiency and lifetime
  - Decreased single bunch current limit
    - Can result from, e.g., increased beta functions at ID transitions
  - Ability to accurately predict the above

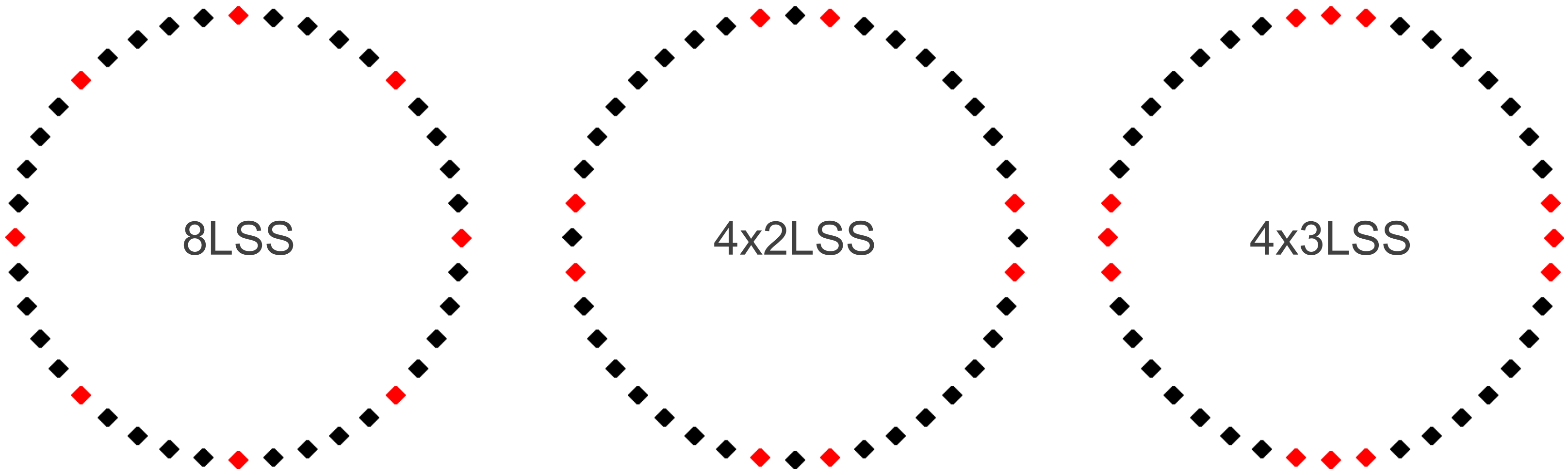
LSS scheme

- LSS can be implemented at APS with a simple scheme
  - Remove the Q2 magnets on either side of SS
  - Remove the adjacent correctors
  - Remove the adjacent BPMs
  - Slide other components away from the ID



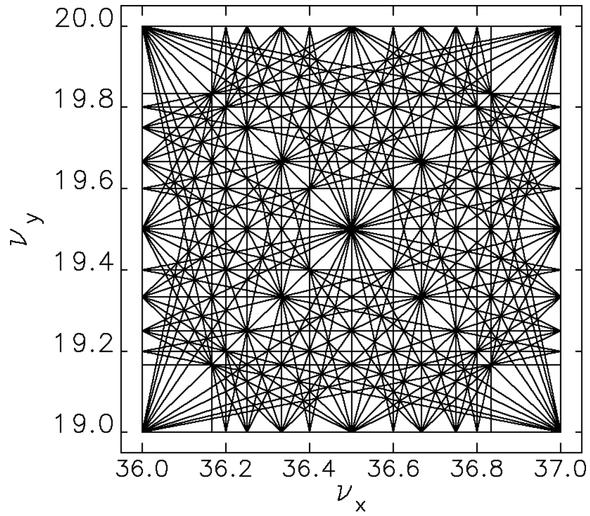
- Increases space available for ID from 4.8 to 7.7m
- Most cost-effective option for LSS

Options for symmetric LSS placement

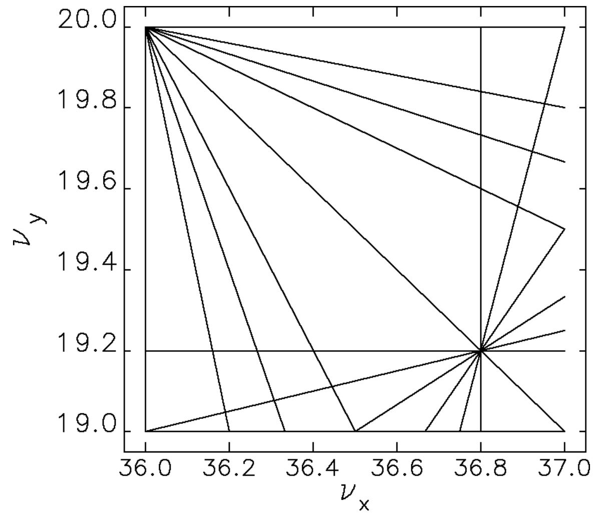


- Can implement gradually by making use of independent power supplies
- E.g., if we want to modify Sector 10, we can turn off Q1 magnets in Sector 30 to make it look quasi-symmetric

Importance of symmetry



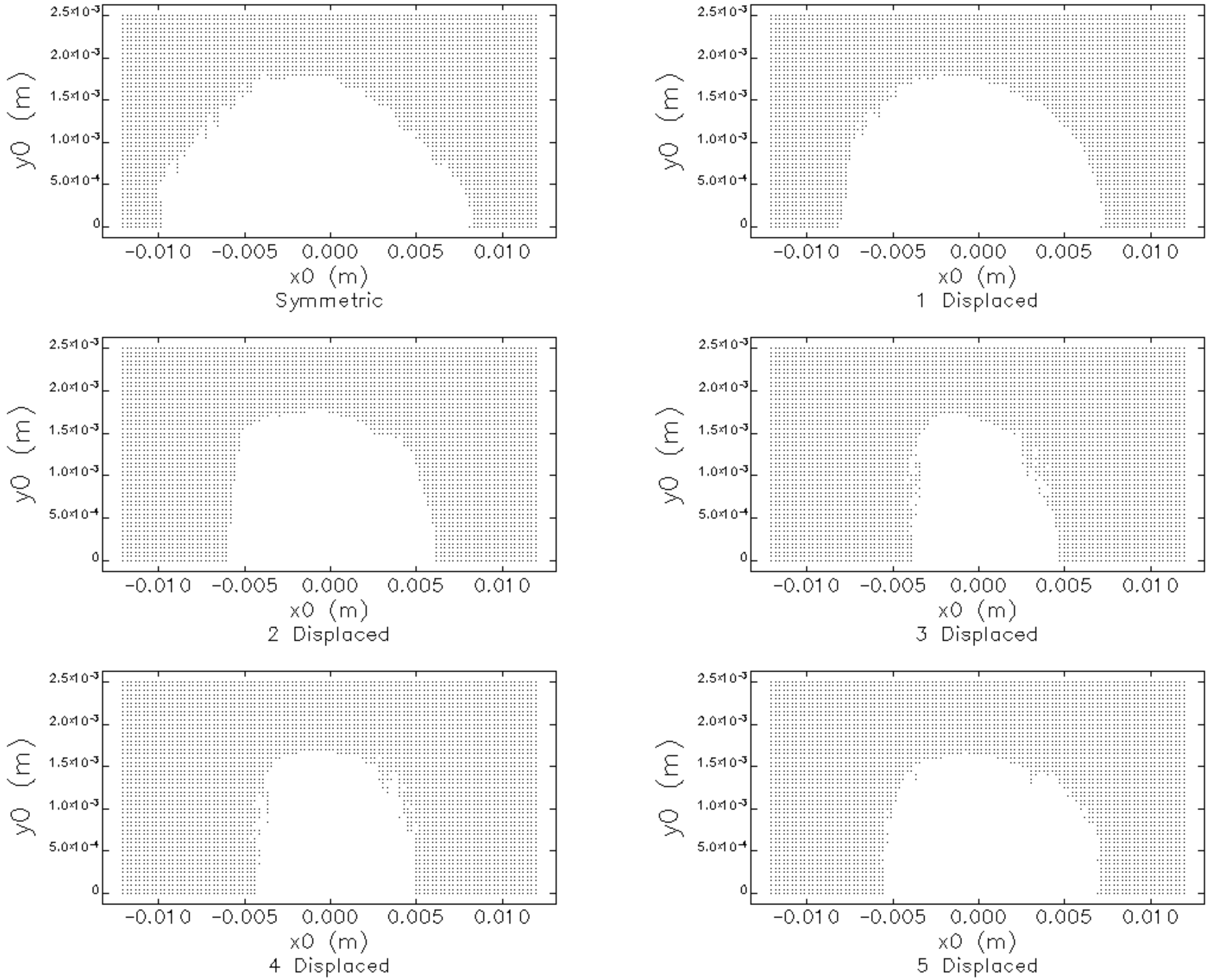
S=1



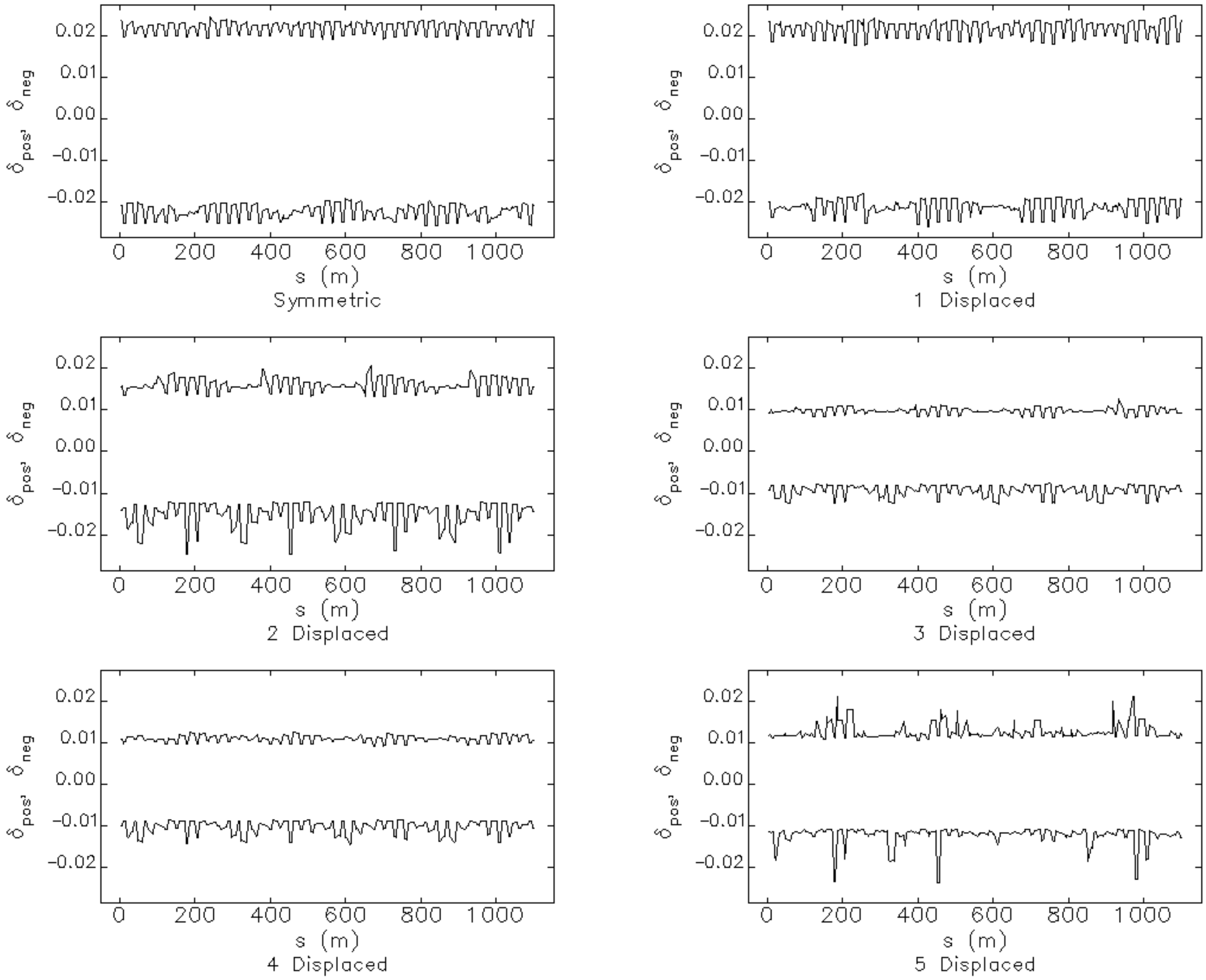
S=8

- Accelerator lattices are subject to resonances that can make particles unstable
- Reduced lattice symmetry implies
  - Denser resonances
  - Lower-order resonances
  - Stronger resonances
- This makes the accelerator more sensitive to errors
  - Difficult injection
  - Shorter lifetime

Importance of symmetry: dynamic apeture



Importance of symmetry: momentum aperture



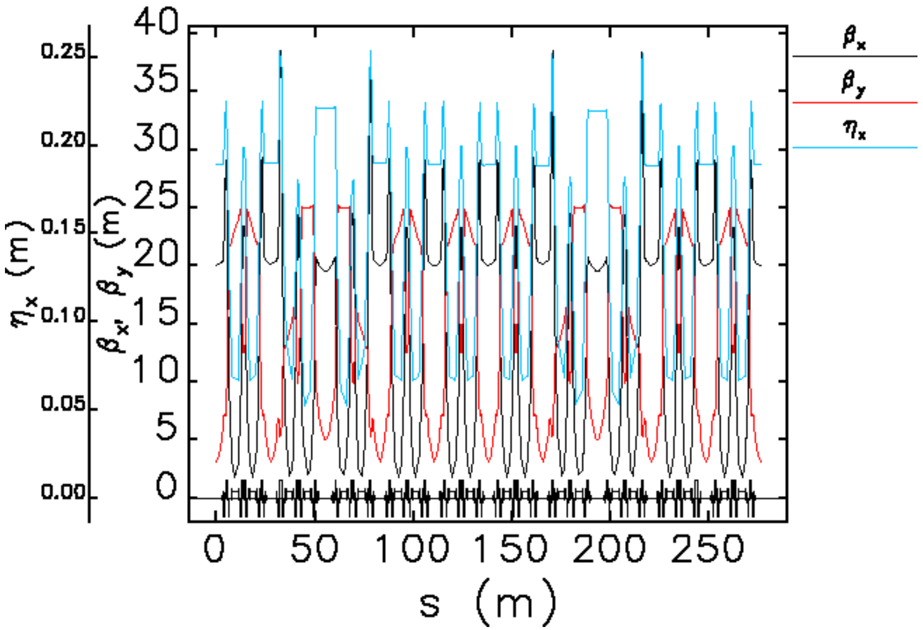
Status of lattice development

- Have developed numerous configurations
  - Fully tested in simulation: 2xLSS, 4xLSS, 8xLSS
  - Test pending, but should work: 10xLSS, 4x2LSS, 4x3LSS
  - Not workable so far: 20xLSS
- An 8xLSS mock-up was tested[1]
  - Same injection efficiency as regular lattice
  - 30% better lifetime
  - Breaking reflection symmetry of sextupole strengths was key
- 40xLSS is attractive since no beamlines have to move
  - Would be too costly if implemented literally
  - Another option[2]
    - Can mock up all non-LSS sectors (turn off Q1s)
    - Might allow arbitrary placement of real LSS sectors
  - Work on this idea is on-going
  - May have issues with single-bunch limit
    - Can be easily mocked up in machine studies

[1]M. Borland *et al.*, PAC09, TH6PFP062
[2]R. Gerig, private communication.

Parameters of NxLSS lattices

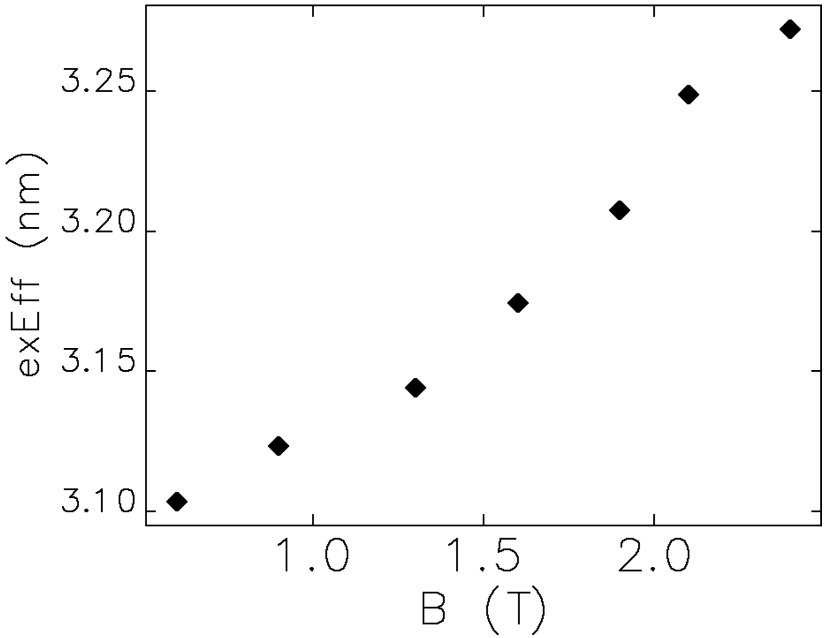
Quantity	Now	2xLSS	4xLSS	8xLSS
Short straights:				
Effective emittance (nm)	3.14	3.23	3.20	3.36
ID betax (m)	19.49	19.90	20.10	20.20
ID betay (m)	2.90	3.05	3.10	3.06
Long straights:				
Effective emittance (nm)	3.14	3.48	3.45	3.60
ID betax (m)	19.49	19.20	20.00	19.60
ID betay (m)	2.90	5.08	5.00	5.03
Max. betax (m)	28.85	37.00	37.00	37.30
Max. betay (m)	27.80	25.90	25.60	25.70

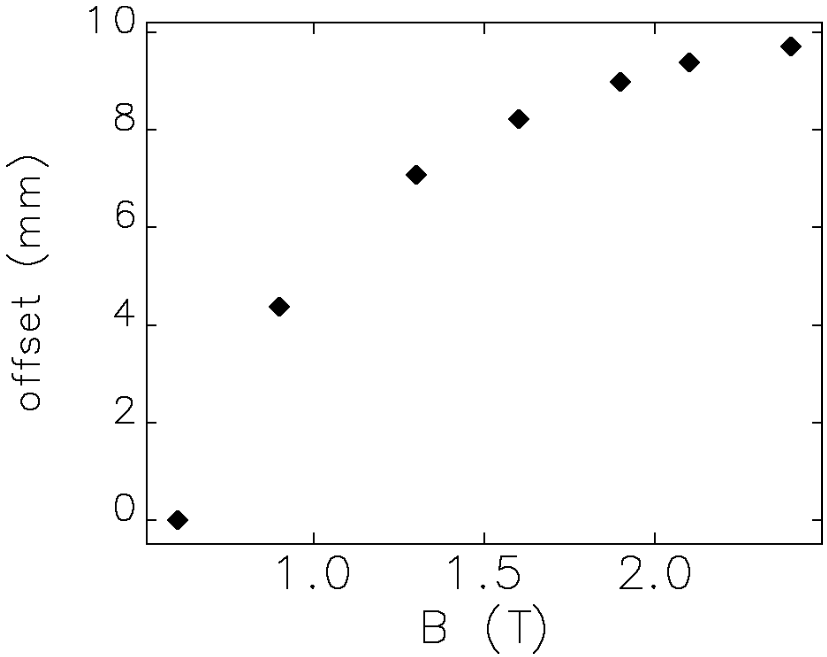


Lattice functions for a portion of the 8xLSS lattice

Strong dipole option[1]

- APS has relatively weak, 0.6T dipoles giving E_{crit}=20 keV
- Replacing individual dipoles with stronger dipoles is an option
- For 1.3T, effects are modest
  - Emittance increases by about 0.05 nm/dipole
  - Transverse offset of photon beam by ~7mm
- Will require improved absorbers, particularly for >100 mA

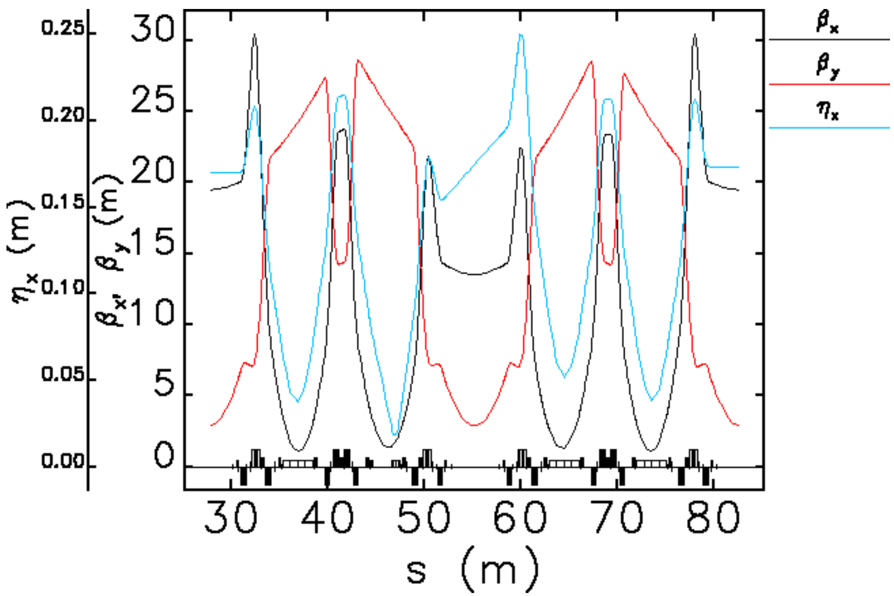




[1] M. Borland, OAG-TN-2004-003.

Split dipole option[1]

- A similar option is to split a dipole and insert a short ID
  - Dipoles will be 1.35 T and 1.73 T
    - Angles are such that new ID sends radiation down old BM line
    - Issues with absorbers, particularly for >100 mA
    - Pollution of x-ray BPMs for new ID
  - About ~2m space between dipoles allows ~1m for ID
  - Minimum chamber gap of 12mm
  - Can do four of these with ~12% emittance increase
  - Lattice for downstream device not ideal



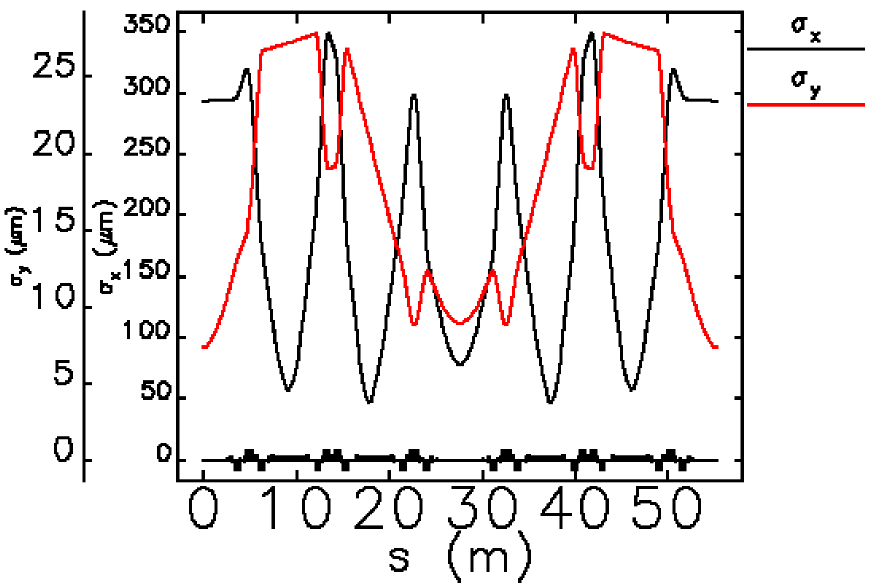
Divergence is 30% higher for downstream ID.

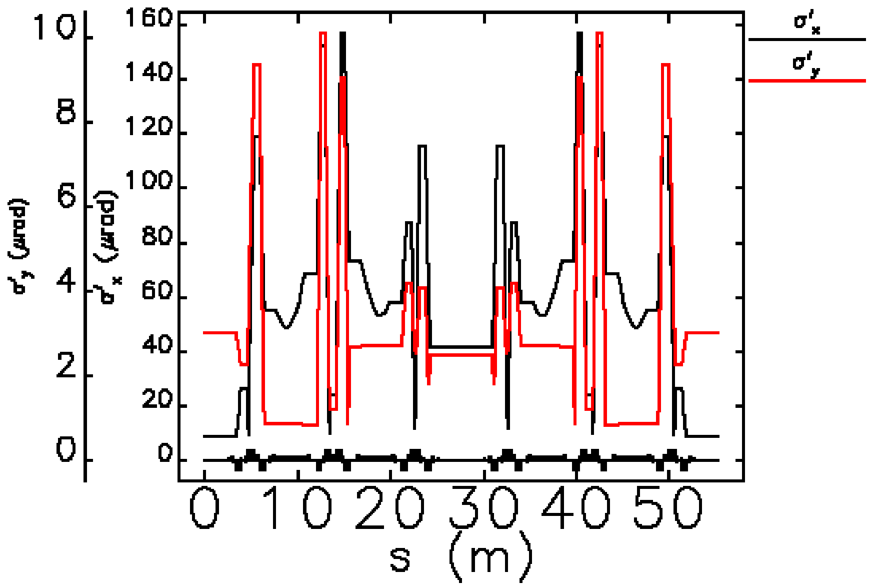
Effective emittance is 15% higher.

[1]M. Borland, APS LS-316, 4/2008.

Alternating Beamsize

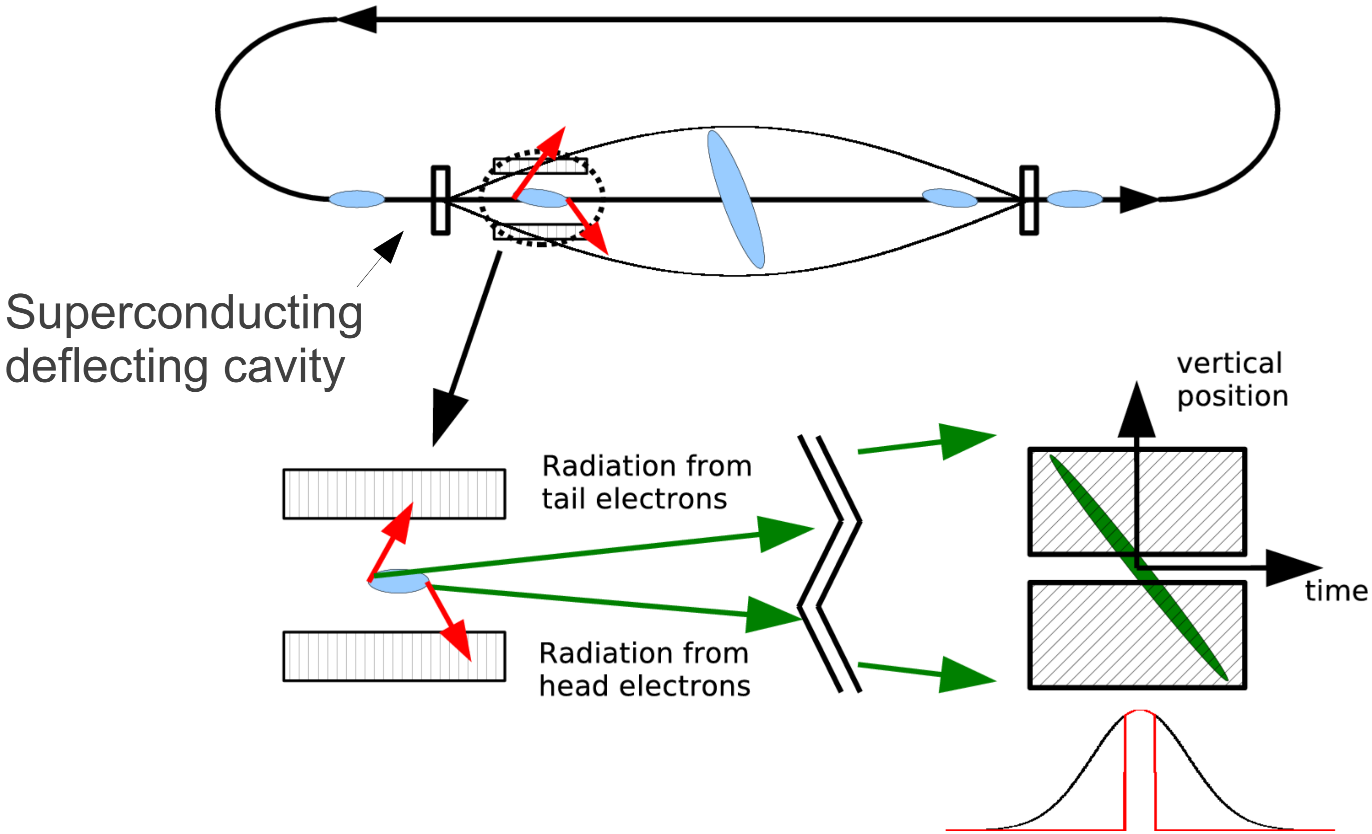
- ESRF has a lattice with alternating horizontal beamsize
- A similar lattice was developed for APS[1]
  - 2.5 nm effective emittance at high-beta straights
  - 3.2 nm effective emittance at low-beta straights
- Might be able to implement this with 20 LSS at either high- or low-beta straights





[1]M. Borland, APS LS-317, 12/2004.

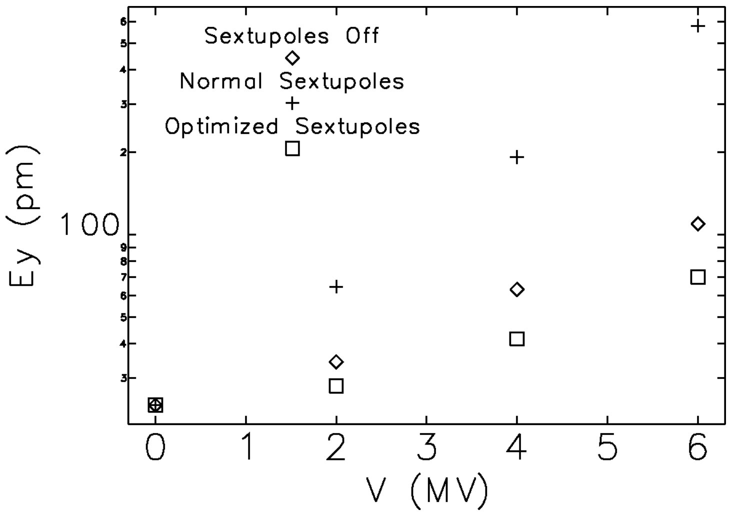
Short-pulse x-rays using Zholents' scheme[1,2]

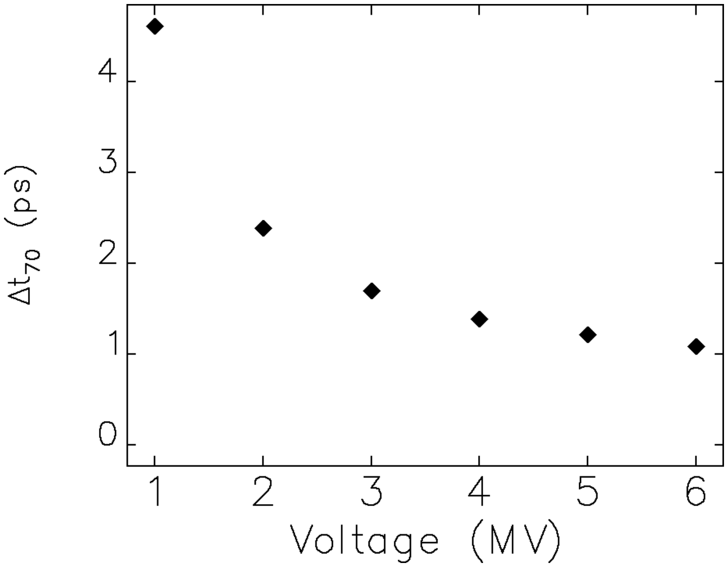


$$\sigma_t \approx \frac{E}{h\omega_a V}\sqrt{\frac{\epsilon_y}{\beta_y} + \frac{\lambda}{2L}}$$

[1]A. Zholents *et al.*NIM A 425, 385 (1999).
[2]M. Borland, Phys. Rev. ST Accel Beams 8, 074001 (2006).

Effects of crab cavities





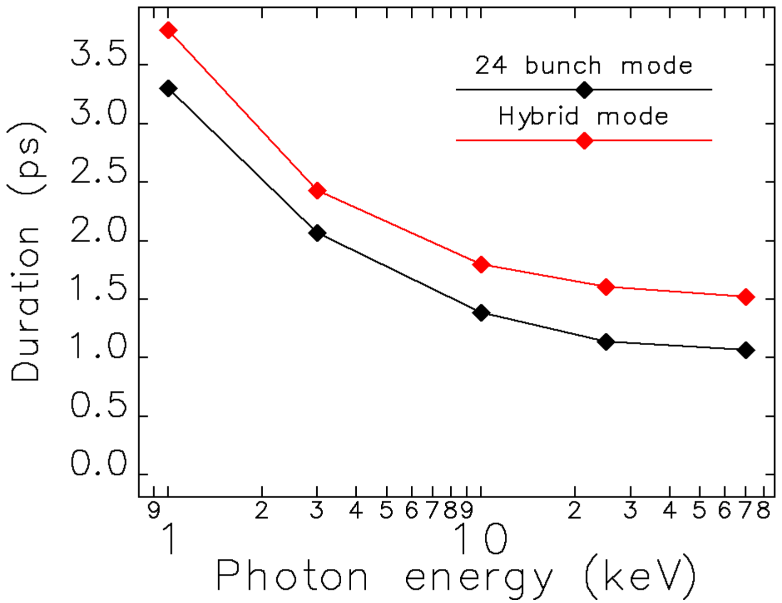
- Existence of sextupoles between crab cavities results in significant vertical emittance growth[1]
- Optimization of these sextupoles can control the growth[2]
- Has implications for dynamic and momentum aperture

- Achievable pulse duration shows diminishing returns vs voltage due to emittance increase

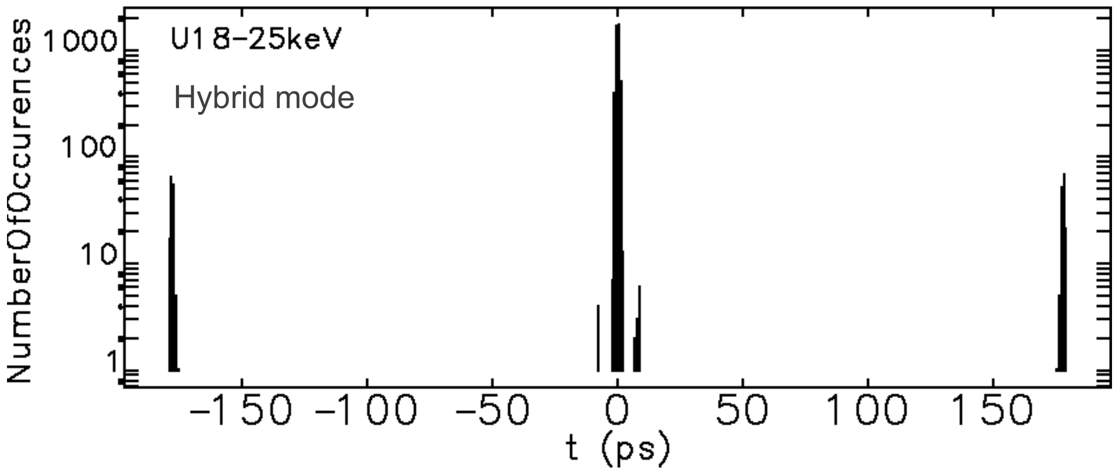
[1]M. Borland, Phys. Rev. ST Accel Beams 8, 074001 (2006).
[2]M. Borland and V. Sajaev, PAC05, RPAE072.

Predicted performance (4MV)

- Curves show duration for 1% transmission through slits
- Pulse duration worse for low photon energies due to large opening angle
- Hybrid mode worse because of increased emittance degradation due to longer bunch



- Time structure is complicated by two effects
  - 2nd harmonic radiation
  - Reversal of rf voltage



[1]M.Borland *et al.*, OAG-TN-2008-026.

SPX status and R&D

Courtesy P. Kneisel, JLab

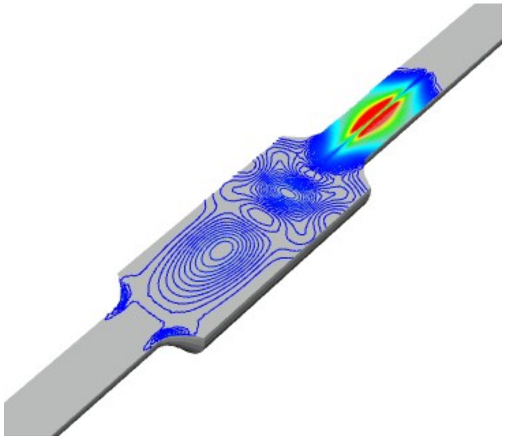
- Cavity prototyping effort
  - Exploring single- and multi-cell cavity concepts
  - Several prototypes built in collaboration with JLab
- HOM/LOM management
  - Must extract unwanted cavity modes to ensure beam stability
  - Lower-order modes are particularly difficult to extract
  - One approach is on-cell dampers which are very compact
- Cryomodule
  - Cryomodule design is challenging due to large number of waveguide penetrations (perhaps 10 cells/cryostat)
  - Must also carefully shield cavity from stray magnetic fields
- Rf control
  - Tolerances on rf fields are tight: ~0.1% amplitude and ~0.05° phase
  - R&D is needed to develop a suitable low-level rf system
- Beam dynamics and operations methods
  - Need to develop tolerances for steering in nearby sextupoles
  - Need detailed diagnostics plan for tune-up and operation

Higher beam current

- Higher beam current has advantages
  - Higher flux and brightness
  - Compensate shorter undulators used in canted sectors
- Also has several challenges
  - Front end and beamline power limits
    - Most front ends and beamlines will need to be upgraded
    - Upgrades more extensive and expensive for 200mA compared to 150mA
  - Heating of components by beam fields

$$P \sim I_b^{4/3}$$

(~150% higher)



Deposition of energy from passing through an ID transition (courtesy Y. Chae).

The vertical scraper has an issue with beam heating and needs to be replaced.

Higher beam current

- Additional challenges
  - Longer bunch

$$\sigma_z \sim I_b^{1/3}$$ (~25% longer)

    There is not much we can do about this

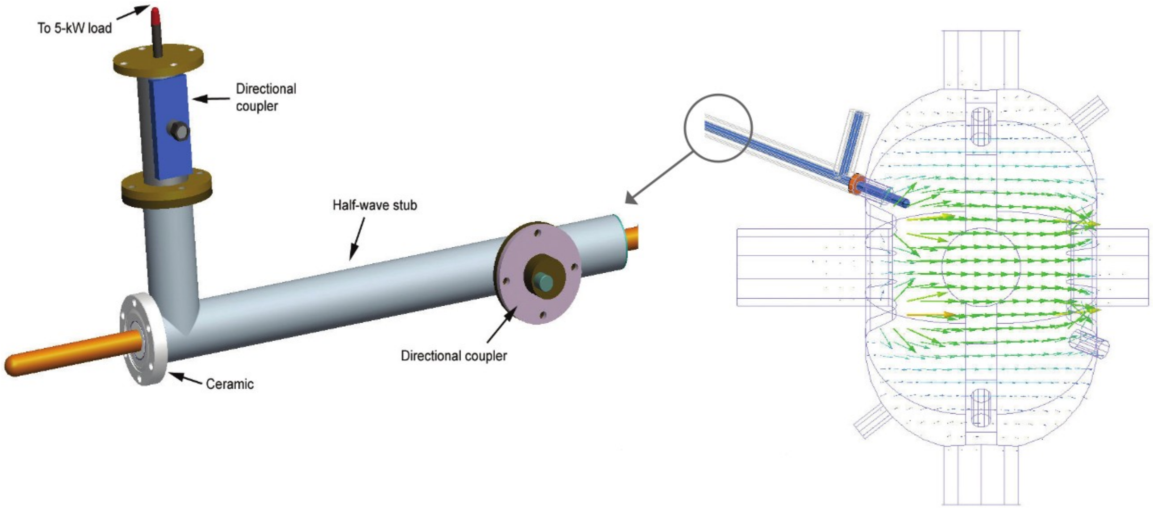
  - Shorter beam lifetime

$$\tau \sim 1/I_b^{2/3}$$ (~40% shorter)

    - This can be addressed by faster topup (e.g., 60s interval)
    - Would rather improve the lifetime
      - Upgrade as many ID transitions as possible to reduce impedance
      - Allows reducing the chromaticity without destabilizing the beam
      - Results in larger momentum aperture, higher Touschek lifetime
      - If nothing else, install improved transitions for LSS and small gap chamber (sector 4)
      - May be needed in any case due to beta function changes at LSS
  - Coupled-bunch instability due to cavity HOMs
    - Need upgraded dampers

Upgraded HOM dampers

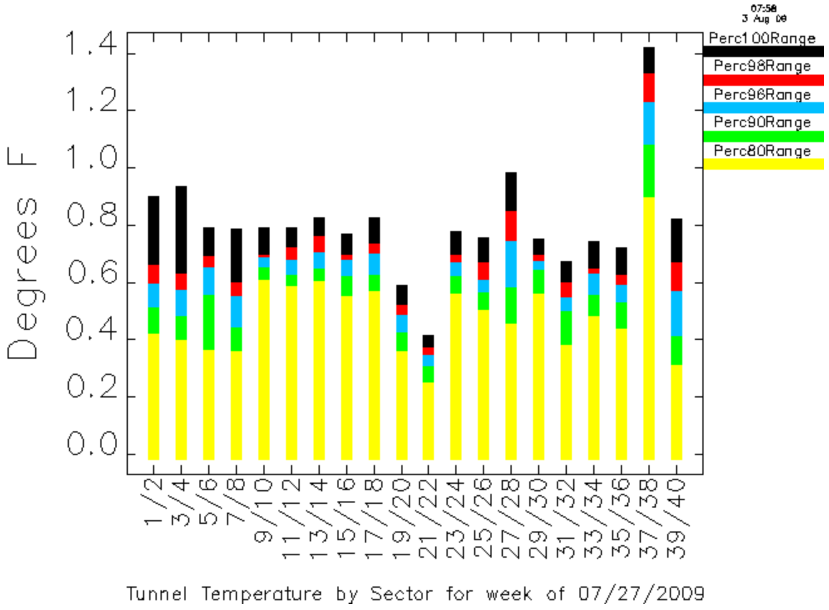
- HOM dampers are used to control higher-order modes in the rf cavities
  - Needed to control coupled-bunch instabilities
- Presently
  - Dampers only exist in 4 of 16 cavities
  - Dampers do not have sufficient power handling capability for 200 mA in 24 bunch mode
- New damper design concept exists[1] and will be implemented in 8 of 16 cavities



[1]G. Waldschmidt, private communication.

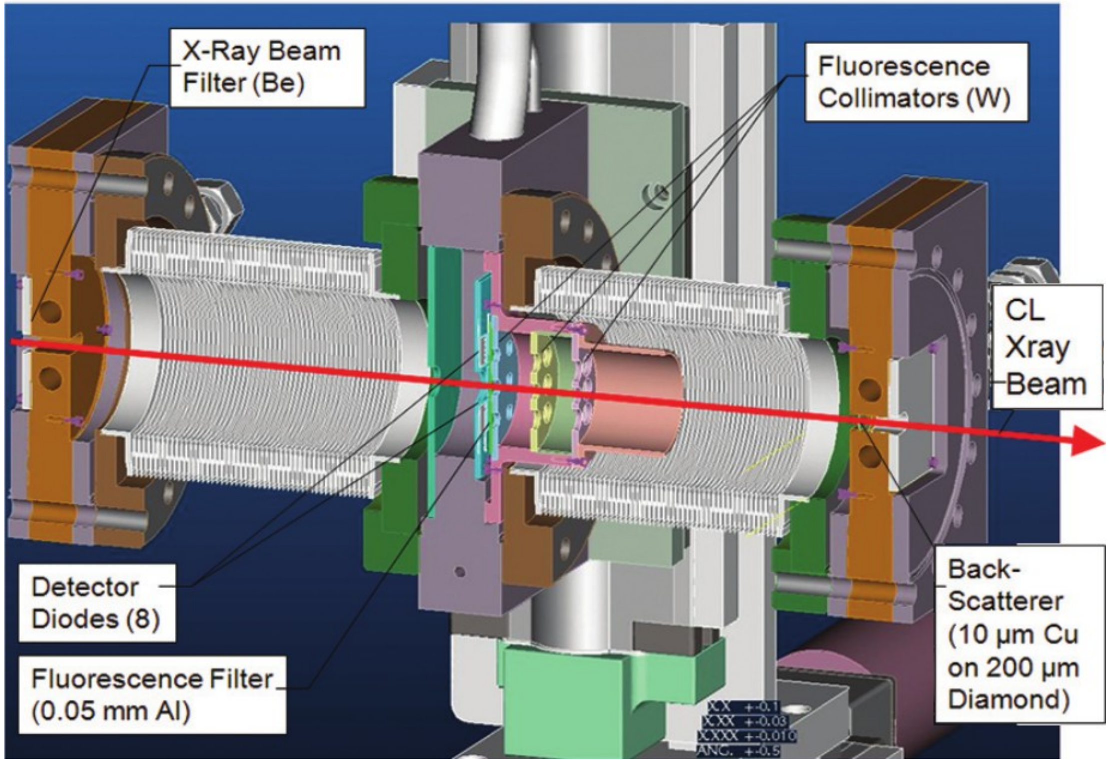
Beam stability

- Improved beam stability benefits most experiments
  - Reduces noise and artifacts in experimental data
  - Allows more challenging experiments to be performed
  - Supports use of long beamlines
- Photon beam stability on hour-to-day scales is thermally-driven
  - Expansion of BPM supports
    - Stabilization at ± 0.2°F level would give 0.5 μrad stability for ~1 week time scales
    - Alternatively, can rebuild stands using material with low thermal expansion
  - Fluctuation in tunnel temperature
    - Major global component of long-term drift
  - Most cost-effective mix of global and local improvements is under investigation



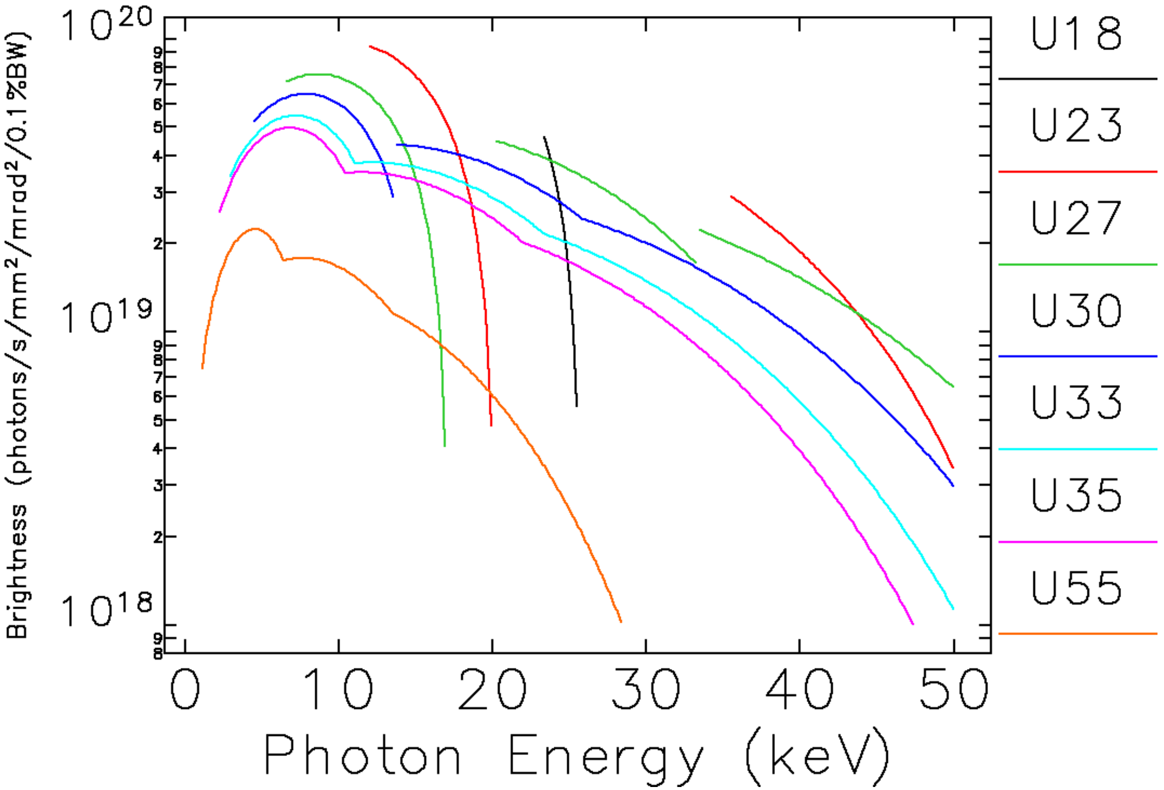
X-ray BPMs

- Current x-ray BPMs use “fringe” radiation from the x-ray beam
  - Subject to systematic problems as gap varies
  - Interference from stray radiation from other magnets
- Developing hard x-ray BPMs to be used for on-demand alignment and diagnosis
- A concept has been successfully tested at 35ID
  - Based on copper fluorescence
- Emphasis at present is to simplify the design and reduce insertion length



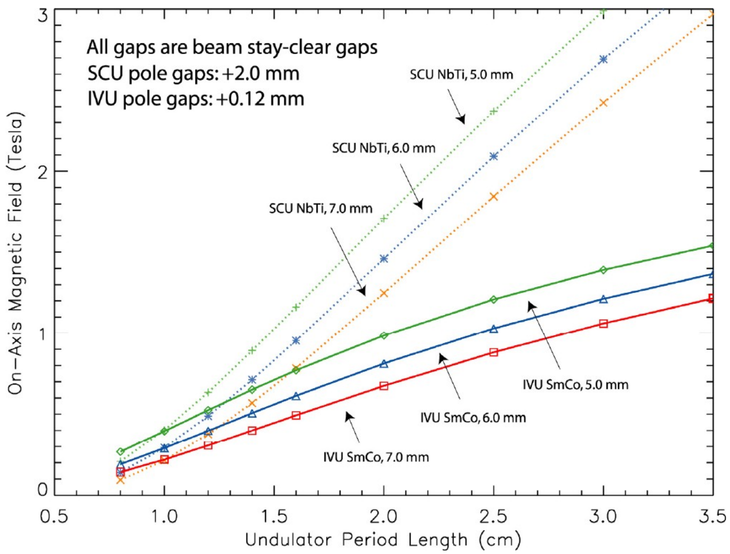
Insertion devices

- Presently 45 insertion devices installed, mostly planar
- Using the short-period devices gives higher brightness for shorter wavelengths
  - Tuning range is reduced
  - Anticipate that most general-purpose U33 devices will be replaced



In-vacuum devices for APS?

- In vacuum devices are used at ESRF, Spring8, etc.
- Beam impedance of IVUs is large[1]
  - For fixed impedance, IVU gives no improvement
  - We could benefit from IVUs *if* we restricted gaps during hybrid mode
- Superconducting undulator seems a better approach
- Intriguing options
  - Variable quasi-periodicity
  - Switchable period length[3], e.g., 15mm and 30mm



For the same beam stay clear and period > 10mm, SCU is superior[2].

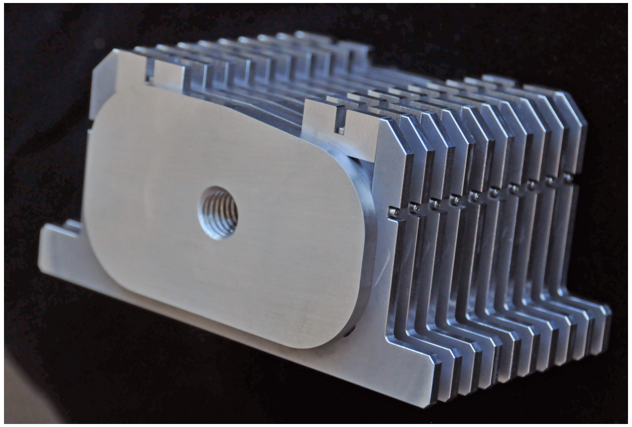
For fixed performance, SCU has 2mm aperture advantage.

N.B.[1]: Impedance ~ $1/g^{2.5}$

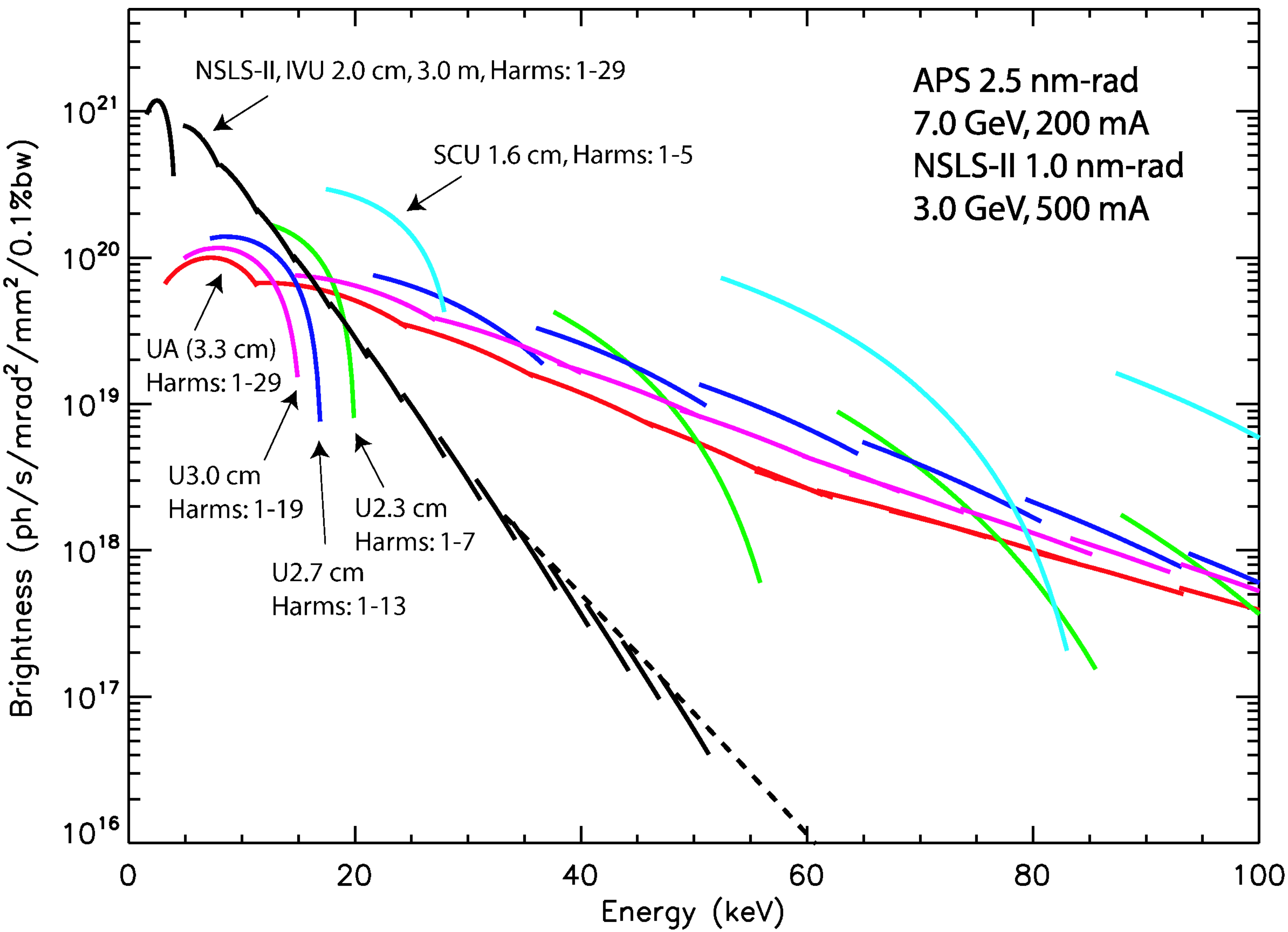
[1] Y. Chae, AOP-TN-2009-011.
[2] R. Dejus et al., MD-TN-2009-004.
[3] A. Bernhard *et al.*, EPAC08, WEPC100.

SCU R&D program

- APS has an on-going program to develop a SCU
  - Targeting 20~25 keV first harmonic
  - Using 16mm period with NbTi wire
- Several 10- and 42-pole prototype cores created and tested
  - 25 keV level (200 A) easily achieved, ~3 deg rms phase error
  - Need 500A for 20 keV operation, achieved 720 A after training
    - ~7 degree rms phase error
    - Original spec for APS U33 is 8 deg rms error
  - Inadvertent taper partly responsible for phase errors
- Proceeding with plans to install a 42-pole prototype in 2011
  - Test critical issues such as heat load from beam

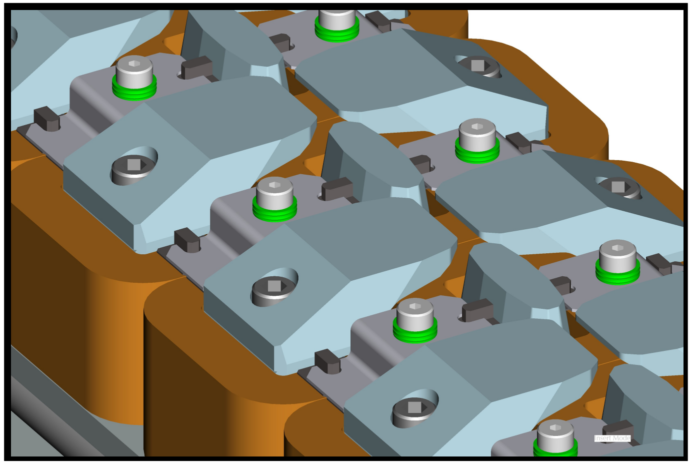


SCU keeps APS at the brightness frontier

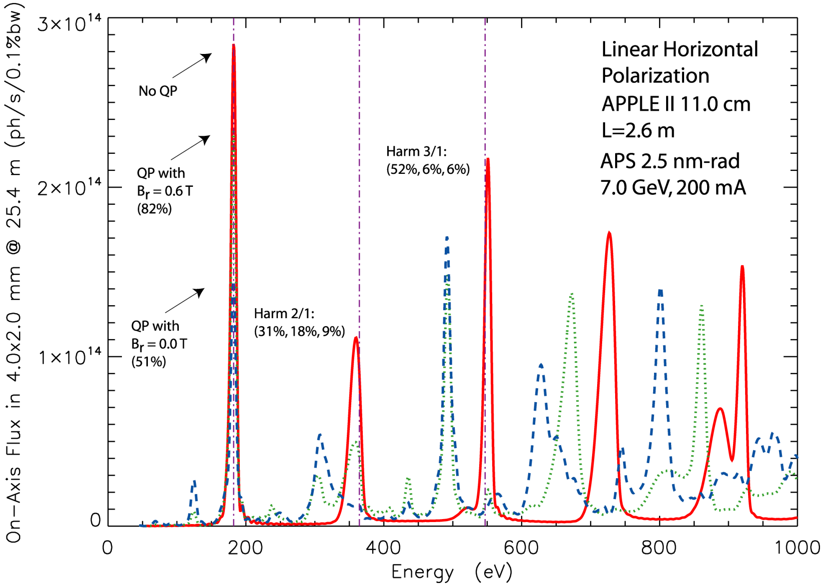


Other ID plans

- Several types of specialized undulators are under consideration for polarization control
  - APPLE-type devices
  - Electromagnetic devices
- APPLE devices also attractive for experiments that need to eliminate on-axis higher-harmonics
- Quasi-periodic devices are being considered for the same reason



IEX prototype device half-jaw, courtesy M. Jaski (APS).



Effect of quasi-periodicity for linearly polarized radiation

Ensuring that we "do no harm"

- To make extensive changes, we must have trusted modeling of
  - Single-particle beam dynamics
  - Collective beam dynamics
  - Rf cavities, including beam dynamics effects
  - Insertion devices, including their effect on the beam
- High level of confidence in single-particle dynamics
  - E.g., 8LSS mock-up showed expected behavior
  - Planning further quantitative benchmarking
  - Code testing collaboration with other light sources
    - Particularly interested in modeling effects of unusual IDs
  - Considering installing "bad" prototype IEX device for beam dynamics experiments
- High level of confidence in collective beam dynamics
  - Quantitative predictions of thresholds, bunch lengthening based on calculated impedances
- Rf cavity modeling is reliable, backed-up by prototyping and careful measurement
- Targeted R&D and prototyping used for ID development as needed

Conclusion

- A significant upgrade of the APS storage ring is anticipated as part of the renewal
- Several lattice options
  - Long straights
  - Stronger dipoles
  - Split dipoles for extra IDs
  - Alternating beamsize
- SPX promises to deliver <2 ps FWHM pulses with 1% intensity
- Accelerator changes to support 200 mA are well understood
- Improvements to long-term beam stability are planned
- Many of the remaining U33 devices will likely be replaced with optimized devices
  - Customized period length gives higher brightness
  - APPLE devices and quasi-periodic devices
  - SCU for ultimate brightness
- We will proceed cautiously to ensure smooth operation at every step