Accelerator Aspects of the Advanced Photon Source Upgrade

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2011 Particle Accelerator Conference, New York City, NY
March 29th, 2011

Five Areas of Upgrade

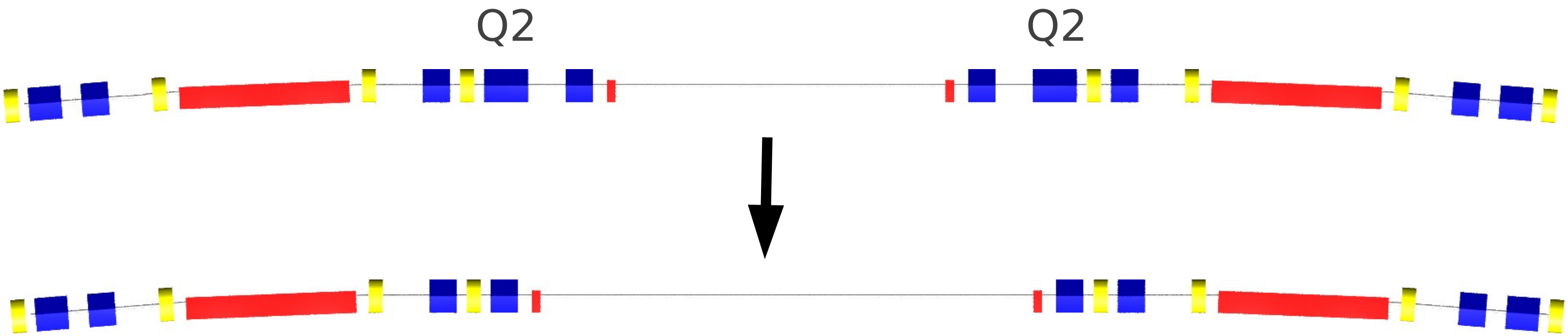
- Long Straight Sections
- Beam stabilization
- Optimized insertion devices
- Deflecting cavities
- Higher current

Requirements

- Beamline capacity
- Canted undulator
- Higher brightness and flux
- More demanding experiments
- Short-pulse x-ray
- Maintain present bunch patterns

Long straight section (LSS) scheme

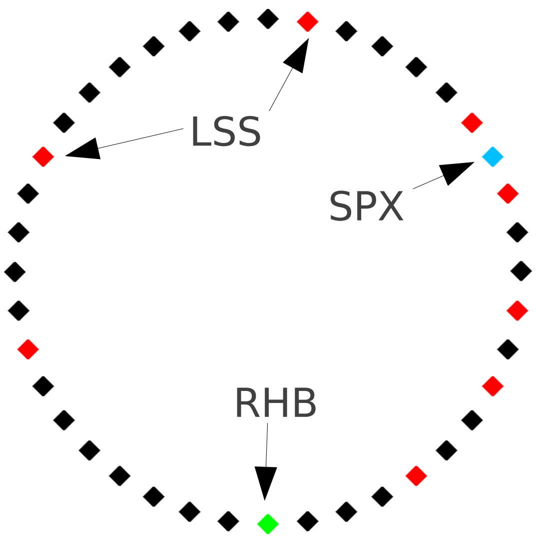
- LSS can be implemented at APS with a simple scheme
  - Remove the Q2 magnets on either side of SS
  - Remove the adjacent correctors
  - Remove the adjacent BPMs
  - Slide other components away from the ID



- Increases space available for ID from 4.8 to 7.7m
- Most cost-effective option for LSS
- Can use existing spare magnets for installation

Non-symmetric LSS Placement

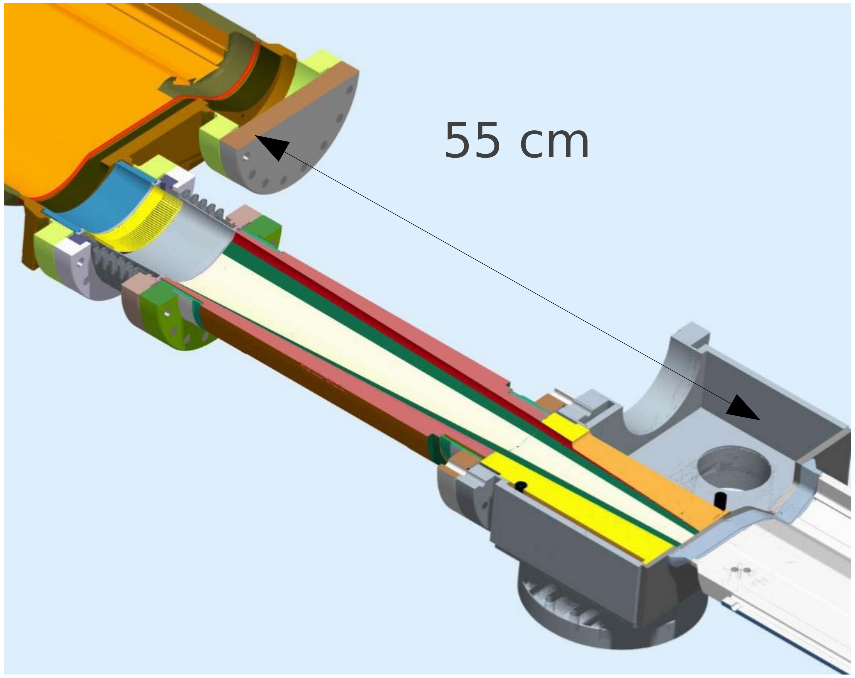
- Multi-objective genetic algorithms used to develop lattices with reduced symmetry, directly tuning for
  - Large Touschek lifetime
  - Large dynamic aperture
  - Adequate chromaticity
- Variables include tunes and 25+ sextupole knobs
- APS and ANL computing resources (fusion, intrepid) invaluable
- Lattices developed include
  - 8 non-symmetric LSSs
  - 8NLSS + SPX in sector 6 or 7*
  - 8NLSS + SPX(7) + RHB in sector 20
- THP125 "Multi-objective Optimization of a Lattice for Potential Upgrade of the Advanced Photon Source"



*Original position, since moved to sector 6.

Long Taper Development

- LSSs will increase effective vertical impedance
  - Longer chamber and larger beta functions
  - Single bunch limit 16 mA → 12 mA
  - Exacerbated by problems obtaining very high chromaticities
- Longer (linear) tapers will reduce impedance
- Tapers will use “accelerator real estate”
- APS-U involves replacing tapers at LSS and 4ID (small-gap chamber)



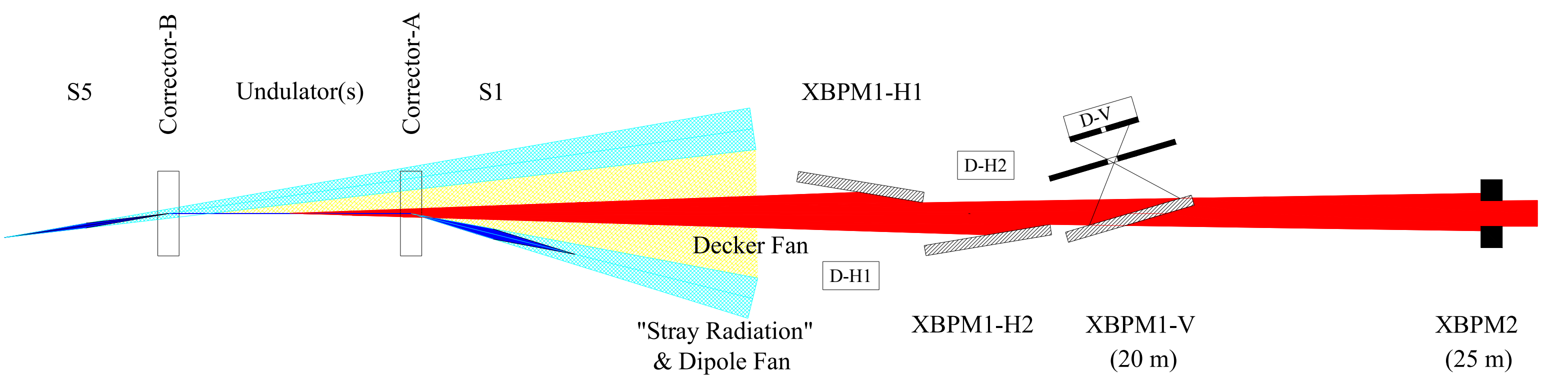
Beam Stabilization

- APS users continually demands improved beam stability
  - Improved beam stability is like a brightness upgrade
  - Targeting a two- to four-fold improvement
- Components of the beam stability upgrade
  - New BPM electronics
  - Front-end hard x-ray BPMs
  - Real-time feedback system upgrade
  - Tunnel temperature regulation improvements
  - BPM position sensing
  - Vacuum chamber microwave mode dampers

		AC rms Motion, 0.1-200 Hz		**Long-term drift (One Week)**	
		μm rms	μrad rms	μm rms	μrad rms
Horizontal	Present	5.0	0.85	7.0	1.4
	Upgrade	3.0	0.53	5.0	1.0
Vertical	Present	1.6	0.80	5.0	2.5
	Upgrade	0.42	0.22	1.0	0.5

Hard X-ray BPM (GRID XBPM)

- Photo-emission BPMs have residual 10~20 micron gap-dependent errors
- New BPM concept based on X-ray fluorescence (MOP188-9)
  - Uses grazing incidence to improve power handling
  - Immune to soft bending magnet radiation background
  - In-air prototype tested at 35ID



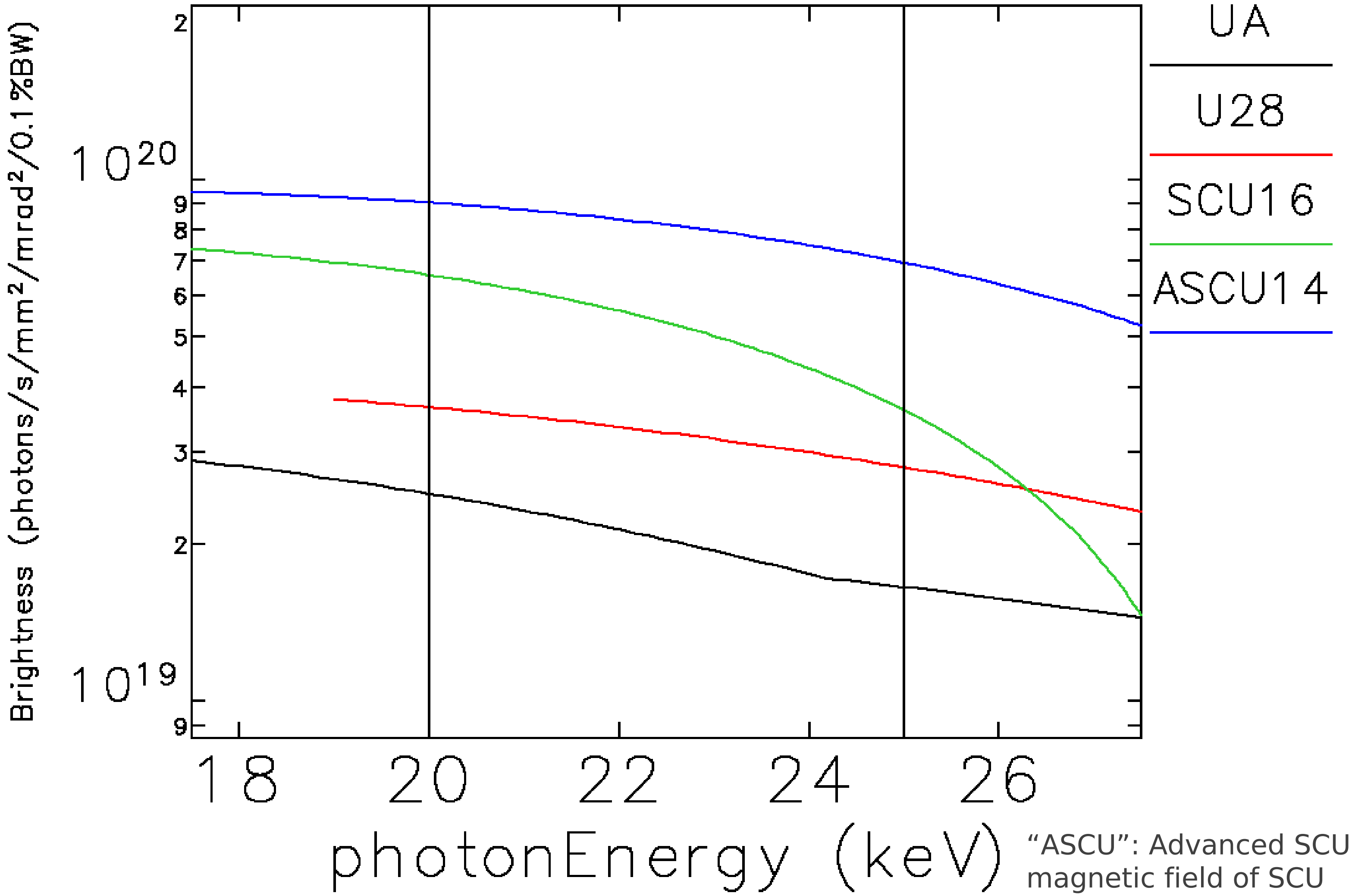
Real-time feedback system upgrade

- Originally commissioned in 1997
- Limited to 1.5 kHz sample rate ⇒ 60 Hz closed-loop bandwidth
- Scope:
  - Complete replacement of existing DSPs & reflective memory system
  - Double the number of BPMs interfaced to the system
  - Double the number of fast steering correctors (relocate and interface to existing correctors)
- Benefits:
  - Increase closed-loop bandwidth to 200 Hz
  - Improve AC stability four-fold
  - Improve feedforward system that mitigates top-up disturbance

Optimization of Source Brightness

- 30 APS “Undulator A” (U33) devices still in use
  - 33 mm period, 2.4 m long, with K<2.75
  - General-purpose device for 3~30 keV
- Also a selection of other periods in use
  - 18, 23, 27, 30, and 55 mm
- Options for brightness improvement, in rough order of cost per beamline
  - Customized period
  - Revolver
  - Higher current ($ mostly for new front ends)
  - Longer device (in LSS)
  - Superconducting device
- Goals
  - Maximize brightness in specific energy band(s)
  - Find path to competitive brightness well into the future

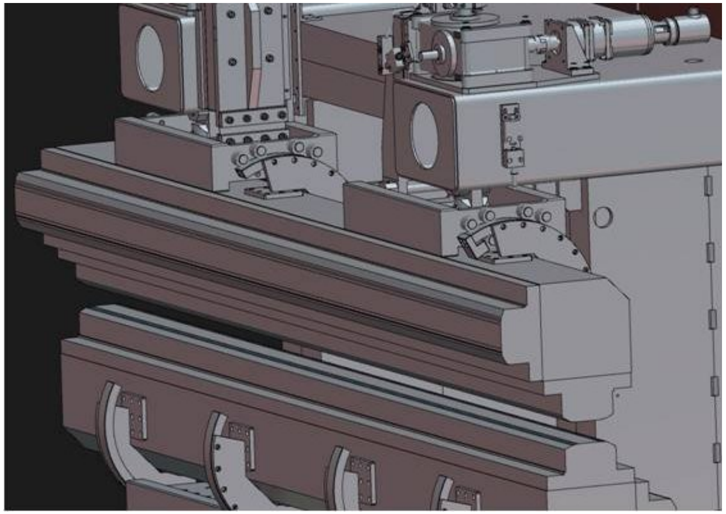
Example: 20-25 keV, 100 mA, 2.4-m Total Length

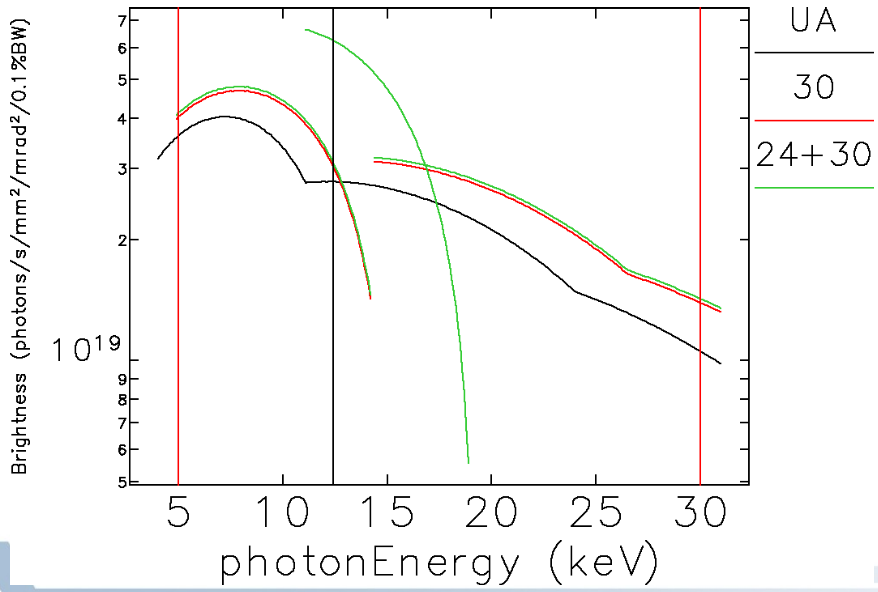


"ASCU": Advanced SCU with 2x magnetic field of SCU (future development potential)

Revolver Undulators

- Revolvers have of two or more magnetic structures, one support
- In use at, e.g., ESRF, SPRing-8
- More space-efficient than multiple in-line devices
  - Obviates need for more LSS
- Brightness gains relative to single devices

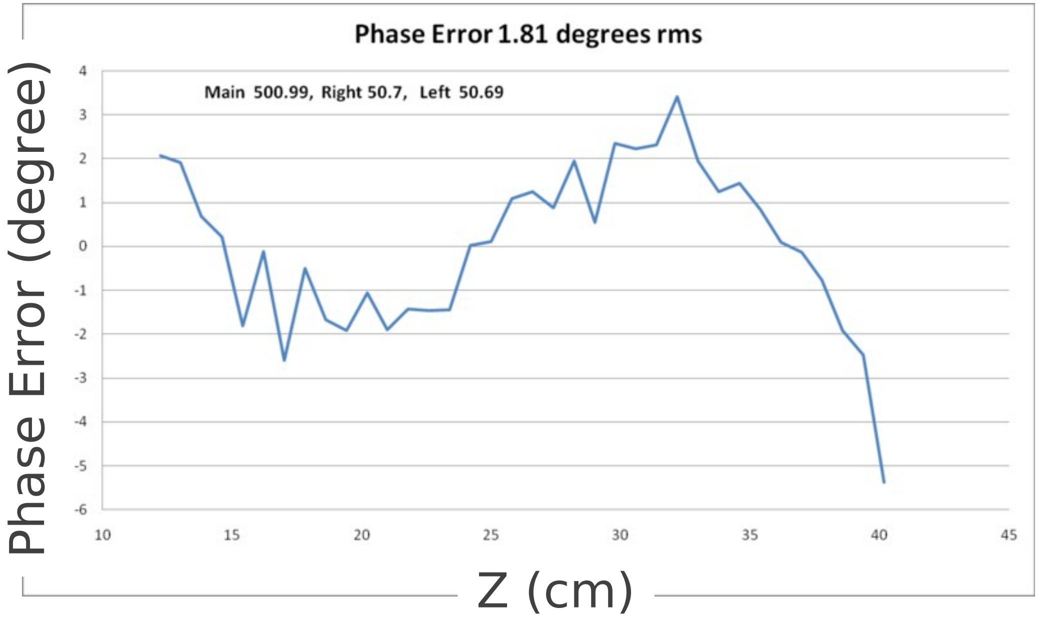




- Undulator periods selected on the basis of
  - Coverage of spectral range
  - Single energy
- Satisfies users' typical spectral usage

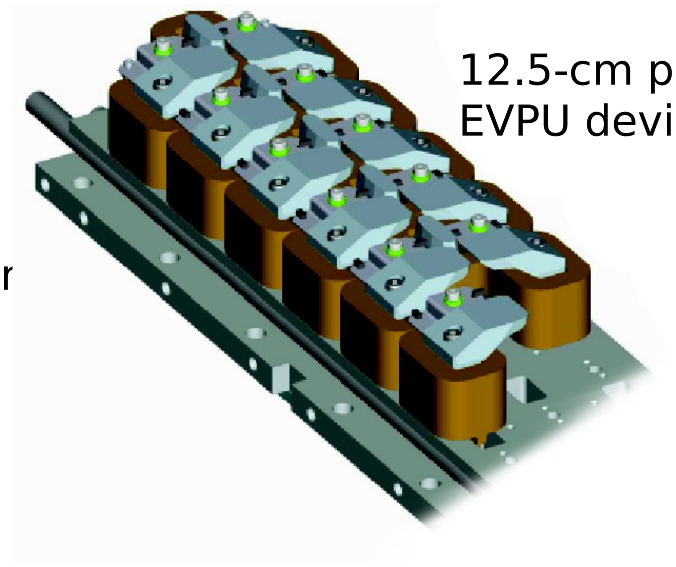
Superconducting Undulator Status

- Prototyping 16 mm period device with NbTi wire
  - Targeting 20~25 keV first harmonic
- 42-pole (0.34 m) test assemblies manufactured and tested(TUP161, TUP219, TUP241, TUP242, TUP243, TUP245)
- Design field of 0.61 T reached for 500 A current
  - Gives 20.5 keV
- Quench at ~700 A
- Rms phase error only 2 deg w/o shimming
  - Comparable to HPM devices
  - Good performance for 3rd and 5th harmonics
- Eventual device will be about 2m long

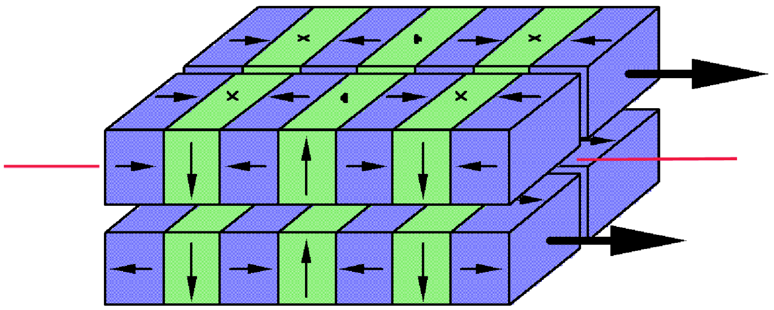


Other Types of Devices

- EMVPU undulator
  - Electromagnetic, variable polarization, variable quasi-periodicity (TUP188, TUP240, TUP244)
  - Optimized for low energy:
    250 eV horizontal polarization,
    440 eV circular polarization
  - Primary concerns are optics, beam dynamics effects (WEP064)
  - For APS-U, plan to develop version with faster switching
- APPLE-II undulators
  - Requested by two groups
  - Interest in reduction of higher-harmonic contamination and use of polarization



12.5-cm period
EVPU device

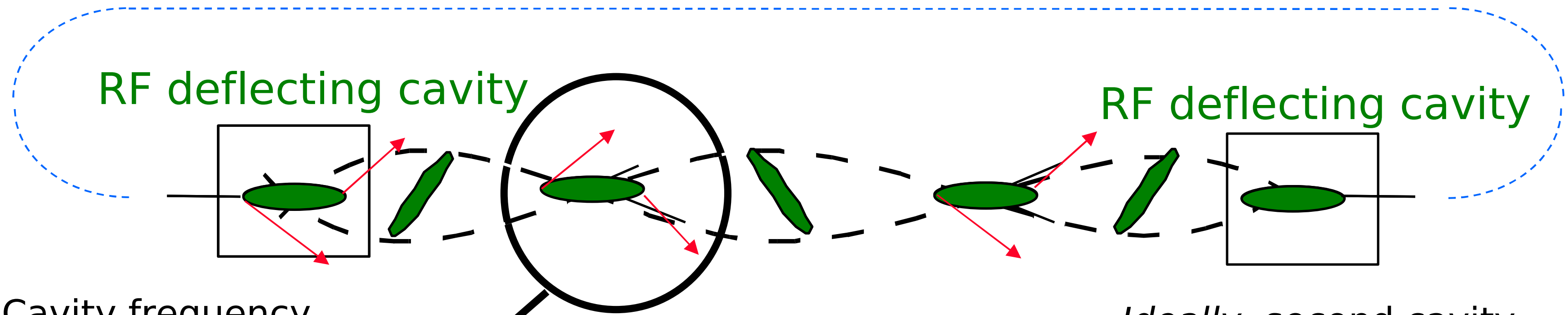


Schematic of an APPLE-II undulator

Short-Pulse X-rays (SPX)

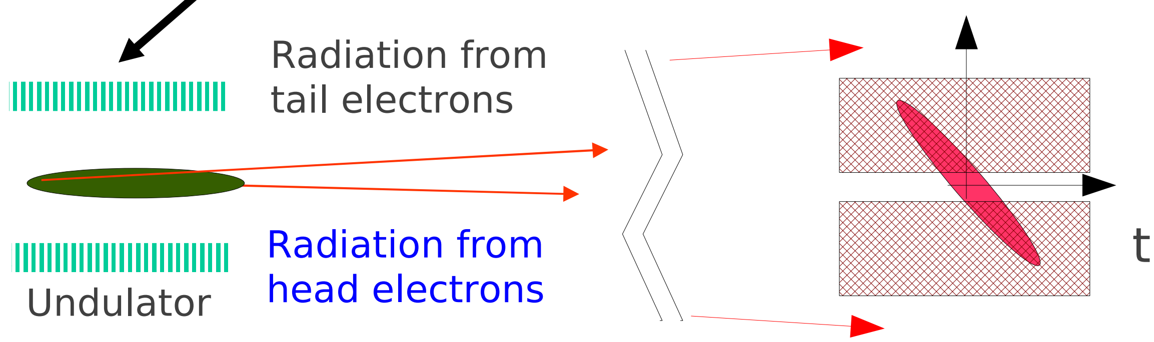
- Timing studies are an important aspect of APS user program
  - Timing fill mode used 75% of time
  - Timing studies will increase in importance
- Providing short-pulse x-rays addresses a mission need and a weakness of storage rings and an area of significant interest
- Several possible schemes
  - Superconducting deflecting cavities
  - Laser slicing (THP126 "Obtaining Sub-picosecond X-ray Pulses in the Advanced Photon Source using Laser Slicing")
  - Low-alpha operation
  - Rf phase modulation
  - Harmonic cavity
- Only the first two are really viable
  - Compatible with normal APS operations at 100+ mA
  - Reach to few ps regime or shorter
- Deflecting cavities give much higher average flux

Zholents' Transverse Rf Chirp Concept[1]



Cavity frequency is harmonic *h* of ring rf frequency

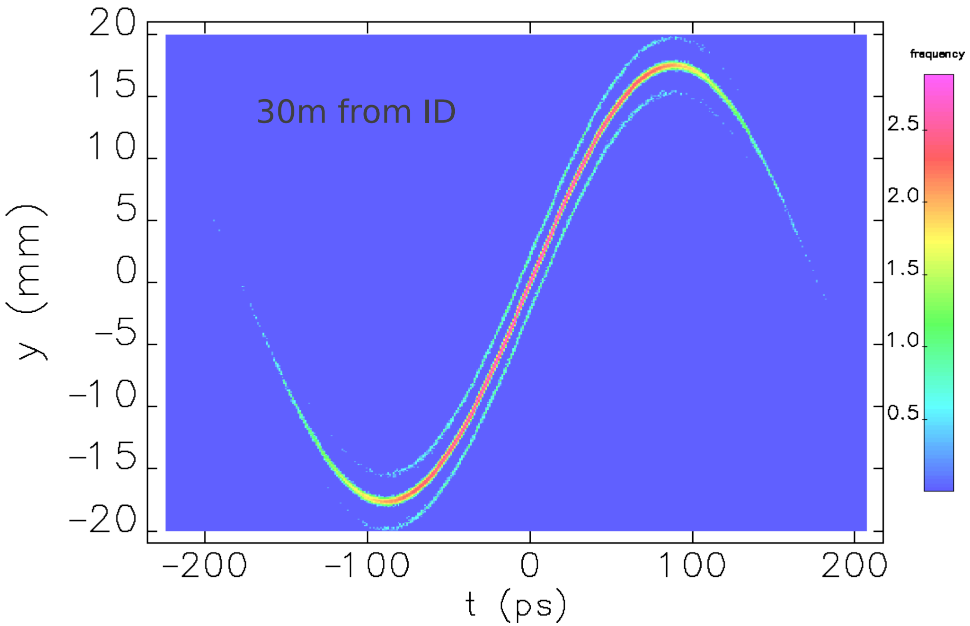
Ideally, second cavity exactly cancels effect of first if phase advance is n*180 degrees

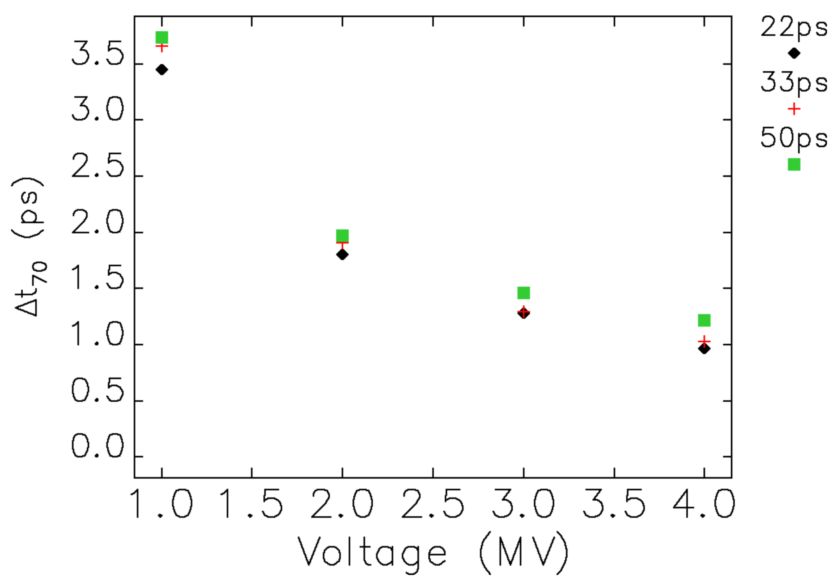


Pulse can be sliced or compressed with asymmetric cut crystal

[1]A. Zholents *et al*., NIM A 425, 385 (1999).

Predicted Pulse Duration (10 keV, 2.4-m U33)





- Assumes slits set for 1% transmission
- Limitations on voltage (related to LSS)
  - 4 MV requires increasing part of 7ID chamber gap by ~3.5mm[1]
  - 2 MV possible with standard ID chambers
- Calculations neglect effect of ID fields on beam dynamics

[1]V. Sajaev, AOP-TN-2010-017, 8/16/10.

Other

- Tolerance study of voltage and phase control
  - Differential phase tolerance particularly challenging
- R&D plan under way for SC cavity (THP212), cryogenics, beam dynamics, LLRF
- Planning installation in ring of test system
  - Pair of cavities in sector 5
  - Addresses many risks that may impact overall success
  - When operating, will provide first look at chirped x-ray pulses
- More details at A. Nassiri's talk Wednesday 11:30 (WEOBS5) "Status of the Short-Pulse X-ray Project (SPX) at the Advanced Photon Source"

Higher Current (THP124)

- Accelerator is presently capable of 150 mA operation in all fill modes
  - Recent tests show that only 2 klystrons are needed
- 150 mA operation requires beamline/front-end upgrades
- 200 mA operation is taken as a long-term goal, but is not in scope
  - All APS-U changes must be 200 mA-compatible
  - Impact on ID optimization needs to be carefully considered
- 200 mA operation requires several upgrades
  - Replacement of HOM dampers (four cavities) to improve power-handling capability
  - Modest upgrade of controls to improve stability for four-klystron operation