APS Upgrade Options

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for the APS Upgrade Team

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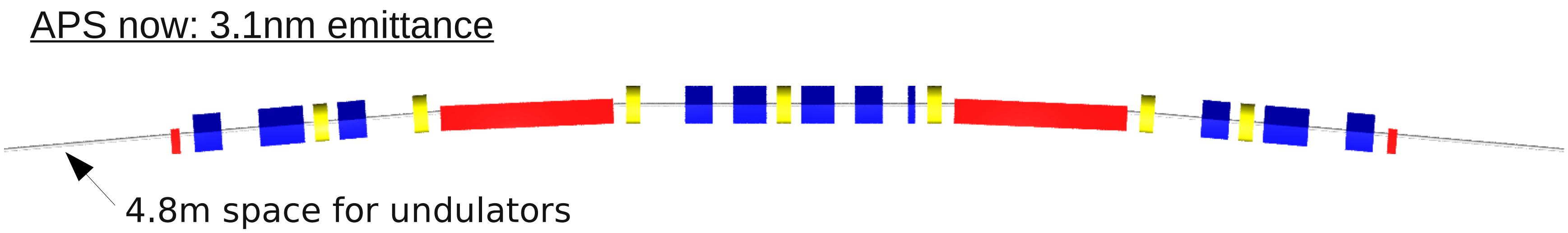
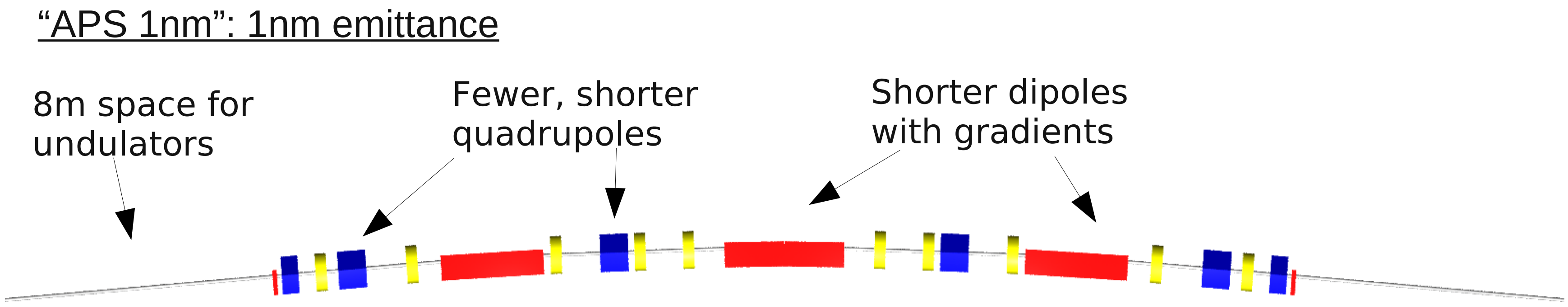
ERL@APS[1]

- Single-pass 7 GeV linac with 7 GeV turn-around
  - Short-pulse x-ray facility expansion
  - Arc supports expansion w/new beamlines
- High-coherence mode[2]: ~140-fold boost in brightness and transverse coherent fraction
  - 0.06 nm emittance in both planes
  - 0.02% energy spread
  - 25 mA with 1.3 GHz bunch rate
- Long undulators give even higher brightness
- Drawbacks include cost, size, environmental impact, low flux
- Technical risk is very high
  - Ultra-low emittance gun
  - High average current gun
  - Parts-per-billion beam loss control
  - Very high Q cavities

[1]M. Borland, G. Decker, A. Nassiri, Y. Sun, M. White, NIM A 582 (2007) 54-56.
[2]G. Hoffstaetter, "Status of the Cornell ERL Project," FLS2006 workshop.
[3]I. Bazarov et al., Proc. PAC 2001, 230-232 (2001).

APS 1nm Replacement Ring Design[1]



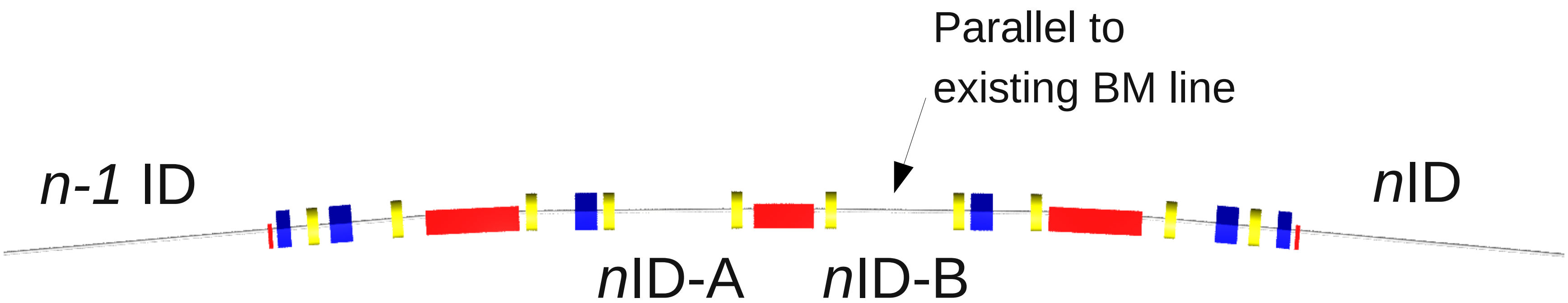


- With 200 mA and 8m optimized IDs, about 40-fold brightness increase
  - Transverse coherent fraction improves ~5-fold
  - Flexible bunch patterns as in APS today[2]
- Main drawbacks: 1 year dark time for installation, disappointing transverse coherence improvement
- Moderate technical risk, related to control and correction of magnet and alignment errors

[1] A. Xiao, M. Borland, V. Sajaev, Proc. PAC07, 3447-3449.
[2] Y. Chae, Y. Wang, A. Xiao, Proc. PAC07, 4330-4332.

APSx3 Replacement Ring Design[1]

- Evolved from APS1nm design following user feedback
  - 1.7 nm effective emittance
  - Main straight accepts 8m ID (increased from 4.8m)
  - Two short straight sections per sector with ~1m available for ID
    - *One is parallel to present BM beamline*
    - *Three-pole wiggler option for bending-magnet-like source*
- Performance midway between APS today and APS1nm
- Drawbacks: 1 year dark time for installation, disappointing transverse coherence improvement
- Moderate technical risk



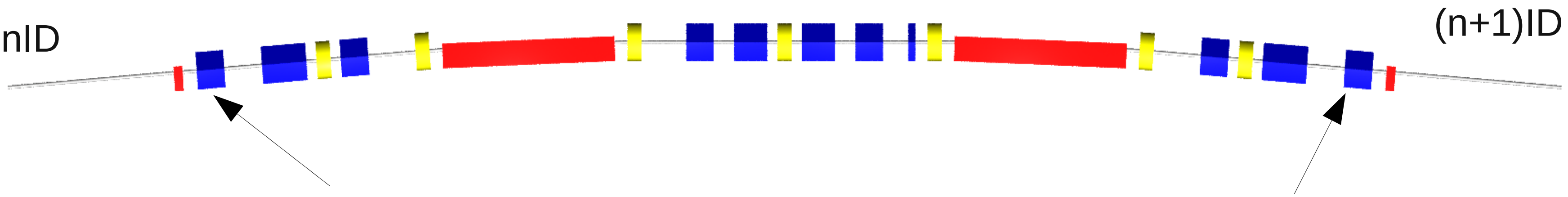
[1]V. Sajaev, M. Borland, and A. Xiao, Proc. PAC07, 1139-1141.

cAPS: APS with sector-by-sector customization

- This option capitalizes on flexibility built into APS
  - Individual quadrupole and sextupole power supplies
  - Trim windings on all dipoles
- Customizations could include
  - Long straight sections (LSS), perhaps 11 m for IDs
  - LSS (8m for IDs) with reduced horizontal beamsize (120 microns instead of 280)
  - Reduced horizontal beamsize, perhaps down to 40 microns[1]
  - Split dipoles to turn BM beamline into ID beamline (1m device)[2]
  - High-field dipoles for harder bending magnet radiation[3]
- Drawbacks
  - Emittance will go up depending on what's requested
    - *Not hard to imagine ending up at 4~5 nm*
- Technical risk is low to moderate
  - Broken symmetry can lead to poor lifetime and injection efficiency
  - Crotch absorber redesign needed; may limit improvements, beam current

[1] Y.-C. Chae, ASD/APG/2008-01, March 6, 2008.
[2] M. Borland, OAG-TN-2008-010, April 1, 2008.
[3] M. Borland, OAG-TN-2004-003, Feb. 9, 2004.

APS-LSS: Ring with all Long Straight Sections



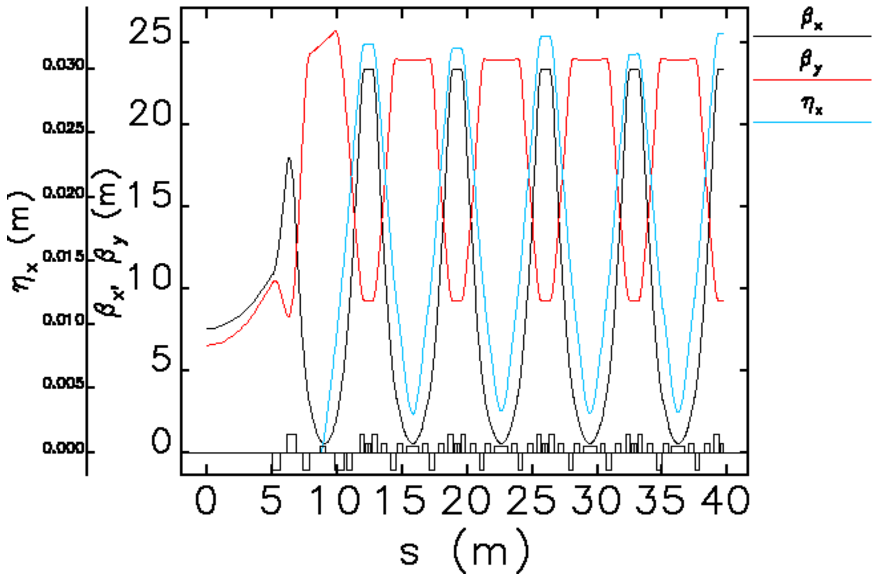
Removing these quadrupoles plus two steering magnets gives space for 7.7-m-long IDs

- In this option, we lengthen every straight section by 2.9m
- Emittance increase from 3.1 to 3.4 nm[1] (probably more)
- Drawbacks
  - Reduced flexibility for lattice functions
    - *May choose to leave a few sectors unaltered*
- Technical risk is very low
  - Can be mocked up prior to any hardware changes by just turning off the Q1 quadrupoles
  - Actual mechanical changes can be staged
- More about LSS options in R. Gerig's talk tomorrow.

[1]V. Sajaev, "Post ERL Ring Lattice," ASD/APG/2007-06.

USR7: Ultimate Storage Ring at 7 GeV

- Preliminary 40-sector, ten-bend-achromat design shows promise[1]
  - 3.1 km circumference
  - 0.016 nm emittance in both planes (fully coupled)
    - *Could go lower with damping wigglers*
  - Space for 8m insertion devices
  - Higher brightness and flux than ERL@APS, assuming 200 mA
  - ~80-fold increase in transverse coherent fraction
- Drawbacks:
  - Cost and size
  - ~4000 bunches
  - Doesn't use existing beamlines
- Technical risk appears moderate
  - Conventional magnet technology
  - Must use "swap-out" operation to replace depleted bunches[2]
  - Errors must be well controlled to achieve acceptable lifetime, injection



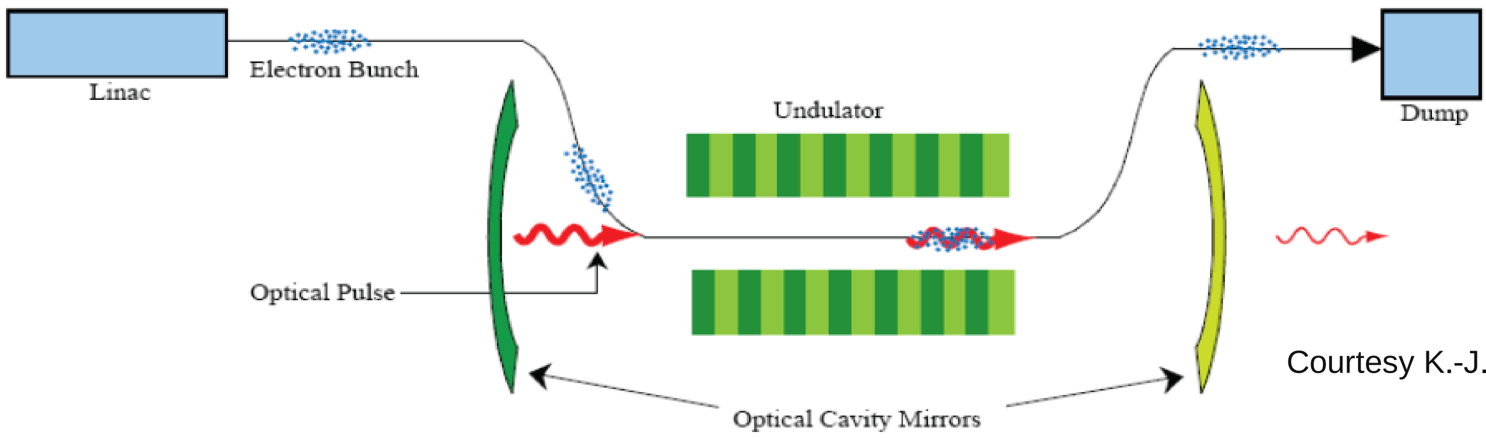
[1]M. Borland, "Ultimate Storage Ring Light Sources," Workshop on Enabling Grand Challenge Science, LSU, January 2008.
[2]M. Borland, "Can APS Compete with the Next Generation?", APS Strategic Retreat, May 2002.

XPS: eXtreme Photon Source in APS Tunnel

- Attempt to design the lowest-emittance 7-GeV, 40-sector ring that will fit in the APS tunnel
- Six-bend achromat concept[1]
  - 0.2 nm emittance
  - Space for 8m insertion devices
- Drawbacks:
  - Requires long dark time for installation
  - Inflexible bunch patterns (fill most buckets)
- Technical risk is very high
  - Sextupole strengths unrealistic, no solution evident
    - *Alignment tolerances correspondingly difficult*
  - Many quadrupole magnets must have sextupole component
  - Dynamic aperture adequate only for on-axis injection (swap-out mode)

[1]M. Borland, "A 0.2 nm Lattice for APS Upgrade with Long Straights," OAG-TN-2006-022.

XFEL-O: X-ray FEL Oscillator[1,2]



Courtesy K.-J. Kim

- Use Bragg mirrors to make x-ray cavity for oscillator FEL at 3~30 keV
  - Promises >10^5 times average brightness of other proposed sources
  - Need same high beam quality as ERL@APS, but low average current
  - 10-GeV four-pass superconducting linac with few MHz beam rate
- Drawbacks: size, cost, single- or few-user facility
- Technical risk is high
  - Ultra-low emittance electron beam required
  - Very high timing stability (20 fs)
  - Development of sufficiently stable, efficient x-ray cavity

[1]K.-J. Kim, “1A FEL Oscillator with ERL-Like Beams,” April 2008, Shanghai.
[2]K.-J. Kim, Y. Shyd'ko, S. Reiche, “An X-ray Free-Electron Laser Oscillator with an ERL,” submitted to PRL.

Summary of Options

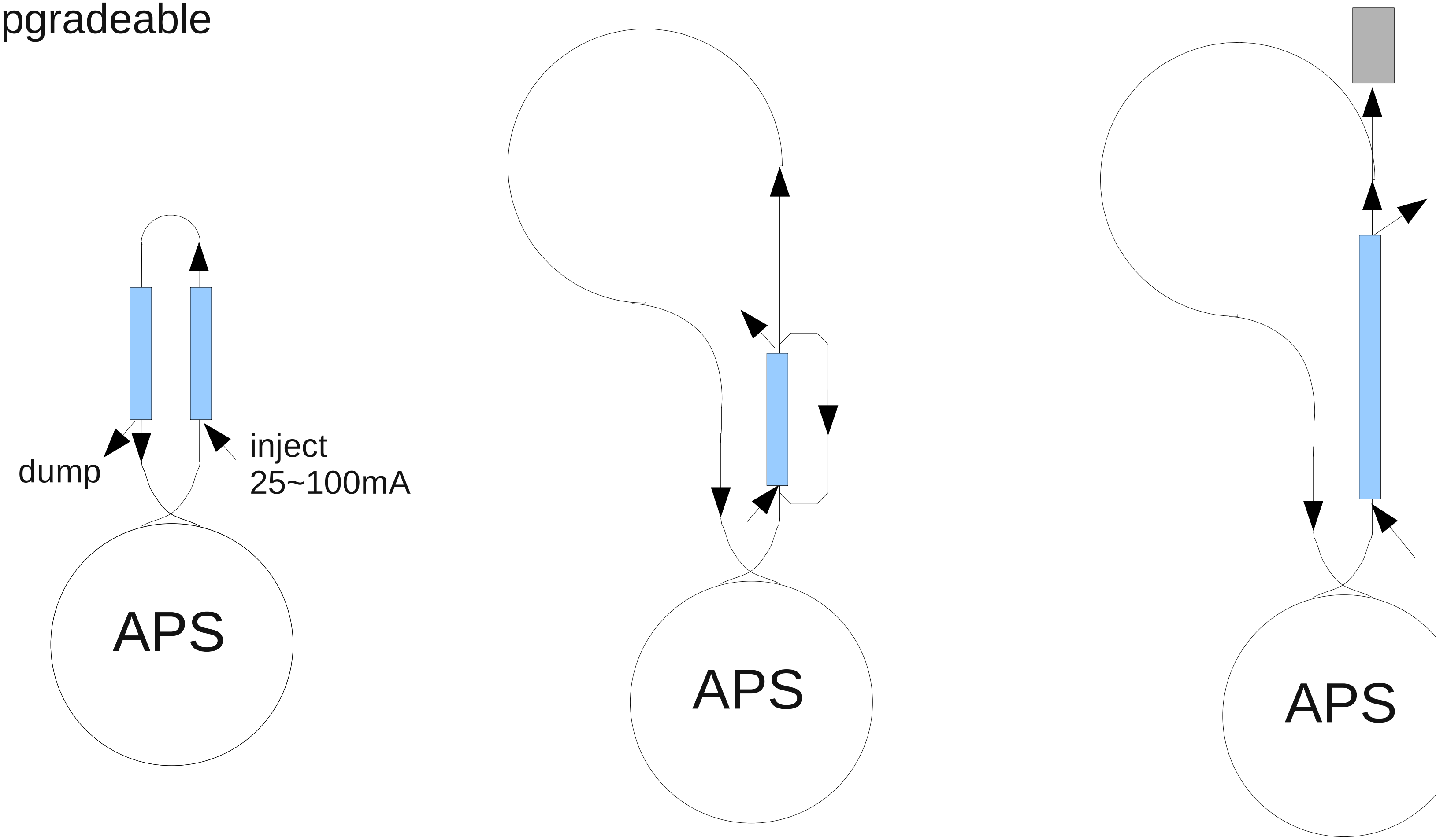
Option	Flux (relative)	Max. Ave. Brightness (relative)	Time Required	Approximate Dark Time	Cost	Technical Risk
APS today	1	1 (2.4m U33)	N/A	N/A	N/A	N/A
ERL@APS	0.5	140 (4.8m U33)	10 years, including R&D	6 months	$$$	Very high
APS 1nm	7	40 (8m U33)	5 years, including R&D	1 year	$	Moderate
APSx3	7	18 (8m U33)	5 years, including R&D	1 year	$	Moderate
cAPS	3	2 (8m U33)	5 years, including R&D	0 (use periodic shutdowns)	$	Moderate
APS-LSS	3~7	4~10 (8m U33~special ID)	6 years	0 (use periodic shutdowns)	$	Very low
USR7	7	400 (8m U33)	5 years, including R&D	N/A	$$$$	Moderate
XPS	7	75 (8m U33)	7 years, including R&D	2 years	$$	Very high
XFEL-O	1 to 100	10^7 to 10^9	5 years, including R&D	N/A	$$	High

A Few Configuration Options for ERL@APS

Basic: Two 3.5 GeV linacs, budget turn-around system; upgradeable

Better: Two-pass linac, new 7GeV user arc; upgradeable

Best: 7 GeV linac, new user arc, straight-ahead hall



Based on ideas from M. Borland, G. Decker, N. Sereno

What are ESRF and SPring-8 Considering?

- ESRF[1]
  - Pursuing something very similar to APS-LSS
    - *Have already implemented new optics in operation*
    - *Will remove quadrupoles and replace chambers as needed*
  - Also pursuing reduced vertical emittance (factor of 2.5) and higher beam current (300mA)
  - Long term, looking into TBA replacement ring or damping wigglers to reduce emittance below 1 nm
- SPring-8
  - X-ray FEL under construction
    - *Considering coupling linac to ring, but benefit is unclear*
  - Have design for 0.08-nm emittance replacement ring[2]
    - *Eliminates half the straight sections*
    - *Remaining straights accommodate 5-m undulators*
  - Also have design for 6 GeV ultimate storage ring at new site[3], comparable to USR7

[1] ESRF Science and Technology Program 2008-2017, volume 1, Sept. 2007.
[2] K. Tsumaki, N. Kumagai, Proc. EPAC06, 3362-3364.
[3] K. Tsumaki, N. Kumagai, NIM A 565 (2006) 394-405.