Comparison of the APS Upgrade to ERL@APS

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Outline

• **ERL@APS**
  – Performance predictions
  – Concerns

• **APS upgrade**
  – Features and performance predictions
  – Concerns

• **Future of hard x-ray sources at ANL**
• **Conclusions**
Why Upgrade the APS?

• APS has been in operation since 1996
  – ~98% availability
  – ~70 hour MTBF
  – Thousands of users per year
• Source performance meets the demands of most users
  – 7 GeV
  – Very stable beams
  – ~80% of time in top-up
  – 100 mA
  – Various bunch patterns to support timing experiments
  – 3.1 nm horizontal emittance
  – ~35 pm vertical emittance
• APS is presently satisfying users, but can’t do so indefinitely
  – New rings, ERLs, and FELs promise higher coherence, brightness, and/or flux
  – An upgrade in the not-too-distant future is needed to stay relevant.
An “Ultimate” ERL@APS Concept

- Design exercise to show the best an ERL could deliver as an upgrade
- 7 GeV linac
  - Two-pass linac shown as cost-reducing measure
- Large 7 GeV turn-around for new beamlines
  - Accelerate away from APS to put highest-quality beam into TAA
- TAA has nine 50-m straight sections
  - Accommodates 48-m undulators
- Assume “high coherence” beam parameters
  - 0.1 micron normalized emittance
  - 25 mA
  - 0.02% energy spread

M. Borland et al., Proc. PAC09, MO3PB101.

TAA Optics

Optimum beta functions for brightness and coherence

15 TME cells per superperiod

48m undulator

Booster cavity
Transverse Coherence

\[ F_c = \frac{\langle \lambda/4\pi \rangle^2}{\langle E_x E_y \rangle} \]

- ERL TAA 48m
- ERL APS 8m
- APS now

Photon Energy (keV)
Brightness from S2E Tracking

Computed with sddsbrightness (H. Shang, R. Dejus, M. Borland).
Flux from S2E Tracking

Computed with sddsfluxcurve (M. Borland, R. Dejus).
Major Concerns for ERL@APS

- Likely to be very expensive and have long development time
- Flux is unremarkable for 25 mA mode unless undulators are long
  - Present canted beamlines can't have long undulators
  - Only a minority of beamlines with have 48m undulators
- Phasing and trajectory control for very long undulators
  - Harder than undulator for x-ray FEL\(^1\)
- Beam loss in the arcs must be few PPM
  - Beam halo is not well understood
  - Need to understand how to perform effective collimation
- Short-range wakes may eat up the entire energy spread budget\(^2\)
  - Need explicit wake computation, exploration of cures
  - May force a reduction in bunch charge (and average current)

\(^1\)E. Moog, private communication.
\(^2\)M. Billing, ERL09, contribution #35.
Major Concerns for ERL@APS

• Production of ultra-low emittances
  – High DC gun voltage still a challenge
  – Can rf gun provide required beam?
• Seems to be no suitable cathode technology for sustaining 25~100 mA for a major user facility
• High wall-plug power for linac and cryoplant
  – Requires significant advances in RF technology and cryogenics
• Reliability will probably be poor
  – I.e., like CEBAF rather than APS
• What will start-to-end jitter simulations reveal?
APS Upgrade

• APS is anticipating a significant upgrade to begin in the next few years
  – Much less ambitious than ERL@APS
• Details are still being worked out, but may include
  – Beamline improvements, new beamlines
  – Short pulse x-rays using Zholents' scheme
    80 ps FWHM $\rightarrow$ 2 ps FWHM
  – Short-period superconducting undulators
  – Long straight sections
    4.8m $\rightarrow$ 7.7 m
  – Higher current
    100 mA $\rightarrow$ 150 mA (200 mA long term)
  – Lower coupling
    35 pm $\rightarrow$ 8 pm
  – Improved long-term beam stability
Zholents' Transverse Rf Chirp Concept

Cavity frequency is harmonic $h$ of ring rf frequency

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

Pulse can be sliced or compressed with asymmetric cut crystal

(Adapted from A. Zholents' August 30, 2004 presentation at APS Strategic Planning Meeting.)

$^1$A. Zholents et al., NIM A 425, 385 (1999).
• Intrinsic divergence of the photon beam increases as photon energy decreases
• Assumed 2.4-m ID: variously used U18, U33, and U55 devices

X-ray flux is 1% of nominal level

\[ \Delta t_{70} \text{ (ps) } \]

\[ \text{Photon Energy (keV) } \]

\[ 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \quad 7 \quad 8 \quad 9 \quad 10 \]

\[ 0.0 \quad 0.5 \quad 1.0 \quad 1.5 \quad 2.0 \quad 2.5 \quad 3.0 \quad 3.5 \quad 4.0 \]

\[ 24B \quad \text{Hybrid} \]

\[ \text{M. Borland, OAG-TN-2008-016, April 16, 2008.} \]
APS 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
  - Evaluate issues such as heat load from beam

Courtesy ASD-MD group.
Brightness Improvement from SCU

• Add a graph here.
•
Long straight section 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
A Few LSS Placement Options for APS

- **8LSS**: 8LSS mockup performed well in experimental studies.
- **4x2LSS**
- **8RandomLSS**: Presently commissioning 8R-LSS mockup.
Concerns for APS-U

• Short pulse x-rays
  – No light source presently operates with crab cavities
  – Collaboration with JLab, prototypes look good so far
  – Sextupole tuning required for emittance preservation
  – Tight tolerances on rf phase and voltage

• Superconducting undulator
  – To test heat loads, prototype to be installed in 2011
  – For best performance, need to use better superconductor (e.g., NbSn$_3$)

• Maintaining present single bunch limit (~22 mA)
  – Need improved tapers and impedance modeling
  – Need transverse feedback system
    • Prototype already looks good

• Tuning non-linear dynamics in non-symmetric lattice
  – Textbooks say breaking symmetry is a bad idea
  – We'll test mockups before we commit to anything
Concerns for APS-U

• 200 mA not an issue
  – We've already run at 250 mA
  – Would need improved higher-order-mode dampers
  – High heat-load front end design exists

• Lower coupling
  – Top-up should accommodate lifetime reduction
  – Can convert unused correctors to skew quads
Brightness Comparison

• APS: 2.4m U27, 100mA, 3.1nm emittance, 1% coupling
• APS-U: 5.5m SCU20 (NbSn₃ wire, R. Dejus), 200mA, 3.1nm emittance, 0.3% coupling
• ERL-APS: 5.5m SCU20, high-coherence parameters
• ERL-TAA: 48m SCU20, high-coherence parameters
Flux Comparison

- APS: 2.4m U27, 100mA, 3.1nm emittance, 1% coupling
- APS-U: 5.5m SCU20, 200mA, 3.1nm emittance, 0.3% coupling
- ERL-APS: 5.5m SCU20, high-coherence parameters
- ERL-TAA: 48m SCU20, high-coherence parameters
Future Hard X-ray Sources at ANL

- APS-U is not likely to be the final word in x-ray sources at ANL
- Argonne's strategic plan recognizes the central place of hard x-ray sources in ANL's future
- Calls for continued R&D into three options
  - Ultimate storage ring
  - XFEL Oscillator
  - ERL
- Of these, only the ERL is likely to be an upgrade of APS itself
- Whether an ERL@APS will eventually be built depends on how technology develops in the next decade
- APS-U does nothing to preclude ERL@APS
Conclusions

• APS-U is a cost-effective approach to improving APS
  – Short pulse x-rays
  – Higher flux and brightness, particularly for hard x-rays
  – Improved beam stability
  – Improved beamlines, new beamlines
  – Cost of accelerator improvements is ~120 M$
  – Relatively low risk

• ERL@APS makes spectacular promises, but
  – Multiple show-stoppers possible
  – Significant R&D program required
  – Not much enthusiasm from APS users
  – Cost of accelerator portion is ~2 G$, excluding R&D

• APS-U does nothing to preclude ERL@APS
• ANL also keeping XFEL-O and USR in mind