The APS Upgrade

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APS Upgrade
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The Advanced Photon Source: BES’s largest user facility

- APS is an xray microscope
  - In operation since 1995
  - 7 GeV electron synchrotron
  - 1104m circumference
  - Hard xrays: 1KeV – 100KeV

- 68 simultaneously operating end stations
- 5000 operating hours/year, 98% availability
- FY17: 5700 unique users, 700 institutions
- FY17 operating budget: $134M
To stand still is to lose ground

The push now is for higher brightness and transverse coherence, smaller spot sizes

HEPS (China)
Greenfield accelerator facility to be built near Beijing; planned completion ~2025

MAX-IV (Sweden)
Inauguration June 2016; in operation

ESRF (France)
Second phase of upgrade incorporates MBA lattice; plans to resume operation in 2020, complete 4 state-of-the-art beamlines by 2022

SPring-8 (Japan)
Upgrading in 2027 timeframe

APS-U
Resume operation in 2023

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Brightness and coherence scale inversely with emittance

Reducing emittance from 3100 pm-rad (APS) to 42 pm-rad (APS-U)

⇒ 2 orders of magnitude higher brightness and transverse coherence
⇒ smaller spot size for microprobes
⇒ round beams
⇒ New science capabilities
Emittance scaling

\[ \varepsilon_x = C_L \frac{E^2}{N_D^3} \]

- \( E \) = Beam energy (\( E = 6 \text{ GeV} \) for APS MBA)
- \( N_d \) = Number of dipoles per sector (\( N_d = 7 \) for APS MBA)

**APS - 7 GeV, 2-bend lattice**

- \(~70\)-fold reduction in horizontal emittance

**APS-U replaces this with this**

**APS-U - 6 GeV, 7-bend lattice**
APS-U Project Scope

All existing beamlines incorporated in plans to come back online at conclusion of APS-U

Feature beamlines
Suite of beamlines designed for best-in-class performance

Beamline Enhancements: improvements to make beamlines “Upgrade Ready”

“Do no harm”

New Storage Ring
- 6 GeV MBA lattice
- 42 pm-rad emittance @ 200 mA current
- Improved electron/photon stability

New Insertion Devices
- Incorporate SCUs on selected beamlines

New/upgraded Front-ends
- Common design for maximum flexibility
- Integrated hard x-ray beam position monitors

Injector improvements
- Increased performance (high single-bunch charge)

Utilizes $1.5B in existing infrastructure

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APS-U 42-pm Lattice

- Storage ring consists of 40 Sectors. Each with 33 arc magnets; 27.6 meters / sector
- Each sector is a hybrid 7BA with four longitudinal-gradient dipole bends, three transverse-gradient dipoles, and six reverse bends.
- Vacuum systems integrated with magnets, supports, insertion devices, front ends.
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Fast Bunch Swap-Out Injection

Prototype Stripline Kicker* used for successful BTX Beam Tests

On the same turn, the septum and injection kickers in Sector 39 deflect the incoming bunch into the target bucket and kick it on axis.

Operation demonstrated with beam to 30 kV; double the original requirement.

* Courtesy Z. Conway et al., ANL-PHY
MBA Control System constraints and challenges

- Control system design **retains the underlying APS controls infrastructure**

- Enhancements are driven by APS-U technical system needs
  - Ubiquitous embedded IOCs, FPGA-based controllers, network appliances
  - Substantial increase in number network ports
  - Substantial increase in data volume and throughput requirements

- Commissioning time is short for Controls + Integrated Tests + full MBA
  - Must be completely integrated/tested/debugged very soon after installation
  - All tools must be debugged and ready
  - Requires expedient troubleshooting tools
  - Early deployment of “virtual accelerator systems” with production PV names
  - Early development of integrated tests (using the virtual accelerator and test stands)

- Will need to draw upon the numerous ‘modern’ tools developed by the EPICS community
### Major challenge – 12-month dark-time schedule

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<th>TASK</th>
<th>Removal</th>
<th>Installation</th>
<th>Commissioning</th>
<th>Float</th>
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<tr>
<td></td>
<td>Month 1</td>
<td>Month 2</td>
<td>Month 3</td>
<td>Month 4</td>
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<tr>
<td>Remove IDs and front ends</td>
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<tr>
<td>Remove mezzanine electronics</td>
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<tr>
<td>Remove magnet girder assemblies</td>
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<td>Prepare tunnel surfaces</td>
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<td>Install magnet modules</td>
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<tr>
<td>Install mezzanine electronics</td>
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<tr>
<td>Install front ends</td>
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<tr>
<td>Install insertion devices</td>
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<tr>
<td>Integrated system testing w/o beam</td>
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<tr>
<td>Accelerator Readiness Review</td>
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<tr>
<td>Commissioning</td>
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<tr>
<td>Float</td>
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- 3-month beam commissioning phase begins in Month #9
- Control System will be expected to be ready from the moment it’s needed
- Transferring Controls interfaces from existing technical systems to new will be a daunting task (~500,000 PVs, over 21 new systems)
From PDR

MBA Control System Scope

Control System Engineering
Applications & Services
- Technical System Database (magnet measurements, calibration data, installed equipment, etc)
- Subsystem Integration Tests
- APIs to other toolkits (e.g. Matlab, Octave, python)

EPICS Controls Hardware & Software Infrastructure

Physics Applications & Operation Tools
- Interactive Tools
- Convenience Tools for Operators
- Injection Sequencer
- Alarms
- Long Term Data Logging
- sdds tools

Interface(s) to Technical Equipment

Data Acquisition (DAQ)
Timing, Bulk Data, Maintenance, ...
Accelerator Control

MPS
- Fast Orbit Feedback
- Unipolar Power Supplies
- Bipolar Power Supplies
- Vacuum Systems
- Transverse Feedback System
- Longitudinal Feedback System

Diagnostics
- BPMs
- X-ray Intensity Monitors
- BPLD
- Beam Size Monitors
- Mechanical Motion System
- Current Monitors

Booster / SR 352MHz Sync
Injection / Extraction Timing
Beamline Timing
Water Systems
Cryo Plant
Absorbers
RF Upgrades
RF Bunch Lengthening System

Existing Systems to Remain
- Oscilloscopes
- Video Distribution
- DCCTs
- LNDs
- BACNET
- Top-off Monitor
- Injectors
- PSS/ACIS

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Requirements for high data rates + Time-correlation of data from disparate systems $\rightarrow$ Structured data (EPICS V7) $\rightarrow$ APS-U DAQ

**High-bandwidth data collector**

**Means of processing data**

**Real-time processing workflow**

1. DAQ Setup
2. Start Data Acquisition
3. Stream DAQ Data to Data Collector
4. Save Files to Local Storage
5. Initiate Real-Time Processing Workflow
6a. Process Data
6b. Save Processed Files
6c. Notify SDDS to PV Object Service
7. Convert SDDS Files to PV Objects
8. Update PVA Channels
9. Receive PVA Updates

**“Fifty-thousand-channel” oscilloscope**

**OrbitVectorServices**

[method = ACLockin]
[event = beam-loss]
DAQ Use Case: Monitoring SR Injection

Booster RF Cavity Amplitude (during injection)  
[ 8 chan @ 271KHz ]

SR BPM acquired from Existing Feedback System  
[ 2616 chan @ 1.5KHz ]

SR BPM acquired from APSU Prototype Feedback System  
[ 48 chan @ 22.4KHz ]
The APS orbit feedback system was the first digital truly global fast orbit feedback system to be implemented at a light source – In operation since 1995

- APS-U fast orbit feedback follows the same architecture and design philosophy (it just uses ‘modern’ technology)
APS-U Orbit feedback Integrated R&D

Feedback Controller + 22kHz DAQ

Fast data network node-to-node datalink

Cut-through switch

Corrector power supplies (8 new fast, 8 existing slow)

1.5kHz RTFB DAQ

Libera Brilliance+ BPM electronics (4 units, 16 bpsms total)

J. Carwardine, N. Sereno, N. Arnold
### Fast orbit feedback system parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>APS-U design</th>
<th>‘Datapool’</th>
<th>RTFB</th>
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<tbody>
<tr>
<td>Algorithm implementation</td>
<td>‘Unified feedback’ algorithm</td>
<td>Separate DC and AC systems for slow and fast correctors</td>
<td></td>
</tr>
<tr>
<td>BPM sampling &amp; processing rate</td>
<td>271 kHz (TBT)</td>
<td>10 Hz</td>
<td>1.5 kHz</td>
</tr>
<tr>
<td>Orbit correction update rate *</td>
<td>22.6 kHz</td>
<td>10 Hz</td>
<td>1.5 kHz</td>
</tr>
<tr>
<td>Signal processors (20 nodes) (one node demonstrated)</td>
<td>DSP (320 GFLOPS) + FPGA (Virtex-7)*</td>
<td>EPICS IOC</td>
<td>DSP (40 MFLOPS)</td>
</tr>
<tr>
<td>Num. rf bpsms / plane</td>
<td>570 *</td>
<td>360</td>
<td>160</td>
</tr>
<tr>
<td>Fast correctors / plane</td>
<td>160 *</td>
<td>-</td>
<td>38</td>
</tr>
<tr>
<td>Slow correctors / plane</td>
<td>320 *</td>
<td>282</td>
<td>-</td>
</tr>
<tr>
<td>Fast corrector ps bandwidth</td>
<td>10 kHz</td>
<td>-</td>
<td>1 kHz</td>
</tr>
<tr>
<td>Fast corrector latency</td>
<td>&lt;10 us</td>
<td>-</td>
<td>~250 us</td>
</tr>
<tr>
<td>Closed-loop attenuation bandwidth</td>
<td>DC to 1 kHz**</td>
<td>DC - 1 Hz</td>
<td>1 Hz - 80 Hz</td>
</tr>
</tbody>
</table>

* Highest demonstrated at any light-source to date

** >800 Hz has been demonstrated

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Wrap-up

- The APS-U lattice design has the lowest horizontal emittance of all synchrotron light sources currently under consideration (42 pm-rad)

- APS will continue operating until mid FY2022
- APS-U is due to come on line in FY2023 after a 12-month shutdown

- APS-U R&D program has been very successful (for Controls and others)
- Early procurements are underway (magnets, power supplies, …)

- There are many challenges (for Controls and others)

- We have funding (FY2018 budget = $93M)