APS-U Beamlines and Other Experimental Systems

Dean R. Haeffner
Associate Project Manager
Argonne National Laboratory

Three-way Meeting
DESY
September 15, 2016
APS-U Beamline Basics

- Beamlines are a big part of the APS-U
  - 29% of budget
  - Another 14% is front ends and insertion devices
- Reuse of much existing beamline infrastructure
- Key aspects:
  - High brilliance
  - High flux
  - High photon energy
APS-U Beamline Basics (cont.)

- **Current APS**
  - 33 of 35 ID ports are in use
  - 19 of 35 Bending Magnets
    - Several ID and BM ports split into multiple beamlines
    - Approximately $\frac{1}{2}$ of beamlines run by the APS, $\frac{1}{2}$ by CATS

- **Guiding principles for the APS-U**
  - New beamlines and major upgrades will result in world-leading capability that utilize the key aspects of the APS-U storage-ring improvements
  - Other Beamlines Enhancements
    - Minor upgrades that are essential in order to be able to utilize beam from the APS-U – “Do no harm”
    - Further upgrades that are desirable to be able to make the most out of the APS-U
Major Challenges

- **Organizational/Political**
  - Separate organizations for APS Ops, APS-U
    - Matrixed personnel
    - Complicated communications
  - Selection of new beamlines, major upgrades

- **Project**
  - Budget usage
  - Minimize the dark period
  - Scope pile up
  - Managing partners (Other labs, CATs)

- **Technical**
  - Optics
  - Nanopositioning
  - Vibrations/Stability
  - Detectors
  - Bending magnet sources
Experimental Facilities Org Chart

- **Effort from**
  - XSD/AES Engineering
  - XSD Optics
  - XSD Detectors

- **Beamline proposal effort from all XSD groups**
  - Science Case
  - White Papers
  - Full PDR proposals

- **Matrixed XSD staff being added to manage individual beamline effort**
Beamline Selection – Basic Principles

- Budget allows for selection of approximately 6 “new” beamlines and 2 major beamline upgrades

- Guiding Selection Principle
  - New beamlines and major upgrades with resultant world-leading capability that utilize the key aspects of the APS-U storage-ring improvements

- Goals
  - Solicit the best ideas from the community
  - Open and transparent process
  - Meet relevant DOE CD deadlines
  - Effectively use APS & APS-U advisory committees
  - Scope selection that meets the overall strategic needs of the APS
    - “Managed process”
APS-U Beamline Selection

Many workshops, etc. over the last decade
Early science workshops in May 2015
> 200 participants

Guide that underlies beamline development plans
Beamline Selection Process

- **Call** for White Papers for possible beamlines for inclusion in the APS-U Project
  - 10 pages maximum
  - 36 Submitted

- **Review** of White Papers
  - APS-U Beamline Review Committee
  - Followed by APS/APS-U Management Review/Feedback
  - Discussion with APS Scientific Advisory Committee (SAC)

- **Call** for Full APS-U Beamline Proposals from the approved White Papers
  - 30 pages maximum
  - 14 proposals requested

- **Review** of Full APS-U Beamline Proposals
  - APS-U Beamline Review Committee
  - APS/APS-U Management Prioritization/Selection
  - Presentation of Prioritization/Selection to the APS SAC for comment

- **Finalization** of the Prioritization/Selection by APS/APS-U Management

- **Roadmap** – siting of beamline scope at the APS

- Selected Proposals developed to DOE Preliminary Design level
## Selected Beamline Proposals

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEX</td>
<td>Coherent High-Energy X-ray Sector for In Situ Science</td>
<td><em>In situ</em>, surface high-energy coherent scattering</td>
</tr>
<tr>
<td>Polar</td>
<td>Polarization modulation spectroscopy</td>
<td>Magnetic spectroscopy</td>
</tr>
<tr>
<td>HEXM</td>
<td>A High-Energy X-ray Microscope</td>
<td>High-energy microscopies &amp; CDI</td>
</tr>
<tr>
<td>WAXPCS</td>
<td>Wide-Angle X-Ray Photon Correlation Spectroscopy and Time-Resolved Coherent X-Ray Scattering Beamline</td>
<td>Wide-angle XPCS</td>
</tr>
<tr>
<td>Ptycho</td>
<td>PtychoProbe</td>
<td>Ultimate resolution, forward scattering ptychography/spectromicroscopy</td>
</tr>
<tr>
<td>InSitu</td>
<td>In Situ Nanoprobe Beamline</td>
<td><em>In situ</em>, forward scattering ptychography/spectromicroscopy Long working distances</td>
</tr>
<tr>
<td>CSSI</td>
<td>Coherent Surface Scattering Imaging Beamline for Unraveling Mesoscopic Spatial-Temporal Correlations</td>
<td>Coherent GISAXS, XPCS</td>
</tr>
<tr>
<td>Atomic/3DMicroNano</td>
<td>3D Micro &amp; Nano Diffraction Atomic – A beamline for extremely high resolution coherent imaging of atomistic structures</td>
<td>Diffraction microscopy &amp; CDI Bragg CDI Upgrade of current 34-ID</td>
</tr>
</tbody>
</table>
Beamline 1 for R&D

- Need
  - Currently, no APS ID beamline is available for significant APS-U R&D
  - Optics & detector test beamline (1-BM) useful, but does not have ID capabilities for coherence or heat loads

- Use of one of the open APS ID ports for a temporary R&D beamline
  - 25-ID or 28-ID
  - Post Beamline Selection/Roadmap process for final choice
  - Phase I – Build enclosures, infrastructure appropriate for eventual scientific program
  - Goal is to award enclosure(s) contract in 1Q CY17
  - Designed so that FOE and other basic infrastructure would useful for R&D program
  - Turn over to scientific program prior to the start of the storage-ring shutdown for Phase II (completion of beamline)
Beamline 1 for R&D (continued)

- Available for R&D for at least 1.5, possibly 2+ years
- Used for
  - Optics testing
  - BPM testing, calibration
  - Heat-load component testing
  - Undulator testing
- Reduces installation time/risks

<table>
<thead>
<tr>
<th>Phase</th>
<th>Beamline #1</th>
<th>Preliminary Design</th>
<th>Final Design</th>
<th>Procurements</th>
<th>Assemble Test</th>
<th>Install</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I</td>
<td>FY16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FY17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FY18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FY19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FY20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FY21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FY22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FY23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase II</th>
<th>Begin Dark Period</th>
<th>End Dark Period</th>
<th>Design</th>
<th>Procurement</th>
<th>Assembly &amp; Test</th>
<th>Installation &amp; Check Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Beamline Enhancements

- Improvements to all beamlines not involved in the Beamline Selection process
  - Minor upgrades that are essential in order to be able to utilize beam from the APS-U
    - “Do no harm”
  - Upgrades that are desirable to be able to make the most out of the APS-U
    - “Bang for the buck”
    - Do as much as the budget will allow

- Meetings between APS-U staff and beamline staff for every beamline
  - Data gathering
  - 36 meetings in all

- Top down budget developed
- Detailed scope will be determined in the next year
Possible Thermal Issues with HHL Monochromators and Mirrors

- Due to the reduction in storage ring energy from 7 to 6 GeV, all beamlines will require a new insertion device with shorter period to maintain current tuning range.
- The storage ring current will be increased from 100 to 200 mA.
- An APS-U 27.5 mm period is equivalent to the current APS undulator A that has a 33 mm period.

<table>
<thead>
<tr>
<th>Source</th>
<th>Maximum K</th>
<th>Minimum Energy (keV)</th>
<th>Power (W) 3x2 mm² aperture at 30 m</th>
<th>Power (W) 1x1 mm² aperture at 30 m</th>
<th>Power Density (W/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>APS* 33</td>
<td>2.598</td>
<td>3.2231</td>
<td>897.1</td>
<td>164.4</td>
<td>171.1</td>
</tr>
<tr>
<td>APSU 27.5</td>
<td>2.37</td>
<td>3.2642</td>
<td>1306.5</td>
<td>234.5</td>
<td>241.6</td>
</tr>
<tr>
<td>APSU 29.5</td>
<td>2.731</td>
<td>2.4505</td>
<td>1326.5</td>
<td>237.3</td>
<td>245.1</td>
</tr>
</tbody>
</table>

All ID are 2.4 m long  
APS*: 7 GeV 100 mA  
APSU : 6 GeV 200 mA
Possible Thermal Issues with HHL Monochromators and Mirrors

- The horizontal size of the central cone at a typical monochromator or mirror location (30 m) is smaller
- Allows smaller front-end mask aperture
- Total power incident on the optic is significantly less than with the current source
- The peak power density is higher but is not considered unreasonable for a LN$_2$ cooled Si monochromator
- Side-cooled mirrors are good up to 700 W total power
- Monochromator crystal-cooling geometries may need updating

<table>
<thead>
<tr>
<th>Source</th>
<th>Maximum K</th>
<th>Minimum Energy (keV)</th>
<th>Power (W) 3x2 mm$^2$ aperture at 30 m</th>
<th>Power (W) 1x1 mm$^2$ aperture at 30 m</th>
<th>Power Density (W/mm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>APS* 33</td>
<td>2.598</td>
<td>3.2231</td>
<td>897.1</td>
<td>164.4</td>
<td>171.1</td>
</tr>
<tr>
<td>APSU 27.5</td>
<td>2.37</td>
<td>3.2642</td>
<td>1306.5</td>
<td>234.5</td>
<td>241.6</td>
</tr>
<tr>
<td>APSU 29.5</td>
<td>2.731</td>
<td>2.4505</td>
<td>1326.5</td>
<td>237.3</td>
<td>245.1</td>
</tr>
</tbody>
</table>

All ID are 2.4 m long  APS*: 7 GeV 100 mA  APSU : 6 GeV 200 mA
Thermal Distortions in Cryogenically Cooled Monochromators

Performance limits of direct cryogenically cooled silicon monochromators – experimental results at the APS

Wah-Keat Lee,* Patricia Fernandez and Dennis M. Mills
Advanced Photon Source, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439, USA. E-mail: wklee@aps.anl.gov

U27.5 Si (111) Darwin width should show < 10 µrad thermal distortion

- Extinction lengths for a Bragg diffracted beam in silicon are on the order of 10 µm
- Calculate the average power from the incident white beam absorbed in the first 10 µm and assume that this causes crystal distortions

Based on this criteria APS-U undulator U2.75 is well within the good region of this plot
Three-pole Wiggler Bending Magnet Beamlines

- Higher critical energy
  - Current Source 19.5 keV
  - APS- U 3PW source up to 27.9 keV
  - More Flux

- Thermal considerations
  - Current source 87 W/mrad with a power density of 1.61 W/mm² at 22 m
  - APS- U 3PW-1.075T source 279 W/mrad with a power density of 3.96 W/mm² at 25 m
  - Probably will require cryogenically cooled monochromator crystals

- Complicated source

Flux Density @ 25 m (ph/s/mrad^2/0.1%bw)

- X (mm)
- Energy (keV)

APS-U Experimental Facilities R&D Update

- R&D is coordinated with APS Ops and LDRD
- Currently funded by the APS-U
- **U2.02.02.02.01** High Speed Detector Development
  - FASPAX v1.0 ASIC chips have arrived and initial tests are promising
  - Carrier boards and DAQ electronics to test full chip in fabrication
  - Silicon sensors (N-in-N) from BNL have arrived
  - CdTe sensors from Acrorad have arrived.
  - ASICs and sensors will be sent for bump bonding soon
- **U2.02.02.02.02** Nano-focusing Optics Development
  - 4 zone plates with 40-nm outer zone width were stacked and achieved expected gains in efficiency while retaining focal size
  - 3 zone plates with 20 nm outer zone width were fabricated and prepared for stacking tests scheduled in the next few months
  - Currently developing the atomic layer deposition capability for Pt deposition at CNM. This is the final process for 16 and 20-nm zone-width zone plates to achieve the focal spot size goal.
  - Developed fabrication processes for zone plates with zone width down to 16 nm and greater than a 15 aspect ratio
Summary

- The Experimental Facilities scope includes
  - New beamlines,
  - Upgraded beamlines,
  - Global beamline support (Beamline Enhancements/detectors), and
  - R&D associated with beamlines
- The Beamline Selection has selected beamline scope. Roadmap process is underway.
- Many challenges exist, but all appear to be manageable
- We need to hire additional good people, so let us know of good students, postdocs, etc. looking for positions
- Anyone interested in a visiting scientist position should contact me
- We are eager to collaborate on R&D. Beamline 1 presents interesting possibilities.
Conclusion: APS-U – The Future Looks Very Bright

High Energy
Penetrating bulk materials and operating systems
- World’s brightest source of hard x-rays
- 3D mapping deep inside samples
- X-ray cinematography in previously inaccessible regimes

Brightness
Providing macroscopic fields of view with nm-scale resolution
- Multi-scale imaging connecting nanometer features across macroscopic dimensions
- Fast sampling with chemical, magnetic, electronic sensitivity

Coherence
Enabling highest spatial resolution even in non-periodic materials
- Extends lens-less imaging to hard x-ray domain, with resolution down to <1 nm, localizing atoms
- Increases phase contrast for fast full-field imaging
- Correlation methods improve by 10,000x-1,000,000x

CuAsW
100 nm

Steel Cylinder
Cracks