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BEAMLINE ENGINEERING OVERVIEW FOR THE APS UPGRADE*

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Abstract

The Advanced Photon Source (APS) is currently in the process of upgrading to a 4th generation high-energy light source. A new multi-bend achromat storage ring will provide increased brightness and an orders-of-magnitude improvement in coherent flux over the current facility. To take advantage of these new capabilities, we will be building nine new feature beamlines and implementing numerous additional beamline enhancements, all while ensuring the compatibility of existing programs. Clear challenges exist in advancing state-of-the-art optics and developing nanoresolution instrumentation. We also need to recognize and address project scheduling, labor resources, existing infrastructure, bending magnet parameters, and possible modifications to radiation shielding in order to achieve project success.

APS-U Overview

The APS-Upgrade (APS-U) will transform the APS into a next-generation synchrotron light source, exceeding the performance of today's storage ring by up to three orders of magnitude in brightness and coherent flux.[1]

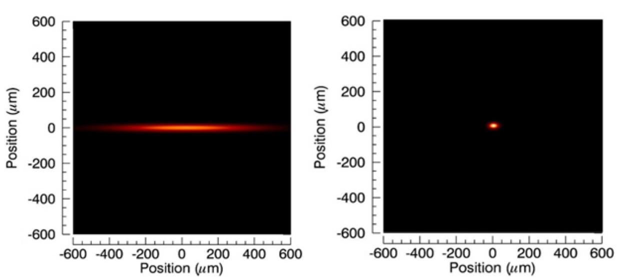

Figure 1: APS electron beam before and after upgrade.

The new storage ring will also produce a much smaller, more coherent beam (Fig 1). Currently we are in the planning and design phase of the project with the main installation planned for 2023 with one year of scheduled dark time.

Feature Beamlines

To take full advantage of the higher brightness and higher energy of the new storage ring, nine "feature" beamlines have been chosen to showcase these capabilities and provide world class scientific programs. Preliminary designs for each beamline have been completed along with detailed cost estimates and project schedules. Table 1 shows the list of feature beamlines that will be either brand new or greatly modified.

Table 1: Summary of APS-U Feature Beamlines

Sector	Name	Title
4-ID	POLAR	Polarization modulation spectroscopy
8-ID	XPCS	X-ray Photon Correlation Spectroscopy Beamline
9-ID	CSSI	Coherent Surface Scattering Imaging
19-ID	ISN	In Situ Nanoprobe
20-ID	HEXM	High-Energy X-ray Microscope
25-ID	ASL	Advanced Spectroscopy & LERIX
28-ID	CHEX	Coherent High-Energy X-ray Sector for In Situ Science
33-ID	Ptycho	Ptychography/ Spectromicroscopy
34-ID	3DMN/ ATOMIC	3D Micro & Nano Diffraction/ High-Resolution Atomic Imaging

Beamline Enhancements

In addition to the nine feature beamlines, another seventeen beamlines will see major enhancements to their optics and end station instrumentation to greatly enrich the capabilities of their current programs. Proposals for beamline enhancements were submitted in February of 2017. Beamlines were chosen based on scientific impact, degree of benefit to the general user program, and alignment with upgraded APS capabilities and APS strategic plans (high energy, coherence, etc.) Enhancements include new and upgraded mirrors, monochromators, and refractive lenses, along with station modifications and end station instrumentation and detectors. These smaller beamline enhancements essentially provide value and many can be completed before the main shutdown to free up resources during the main installation period.

Long Beamlines

In order to achieve extremely small focal sizes and make the best use of the improved beam coherence, two "long" beamlines will be developed which will extend beyond the current APS building footprint. The In Situ Nanoprobe (ISN), and High Energy X-ray Microscope (HEXM) beam-

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lines, at sectors 19 and 20-ID, will extend 220 and 180 meters respectively. With both beamlines being adjacent to each other, the end stations will be in relative close proximity to one another which will allow them to share the same out-building and enable the building to be as small as possible. Final preliminary designs for this new building are complete and we are conducting studies to maximize stability and reduce vibration. The longer of the two beamlines will employ a 101 mm diameter, 146 meter long shielded transport pipe. Vacuum conductance calculations for this section have been done assuming 3x10-10 mbar*L/s/cm2 outgassing rate (conservative for stainless steel), and we've determined that four 200 L/s pumps equally spaced along this span, with a 100 L/s pump at each end will be sufficient even if two of the pumps fail. These results were compared to calculations for the LCLS-XTOD Tunnel Vacuum System with similar results.

IDEA Beamline

Currently the APS Upgrade (APS-U) does not have a suitable testing location for X-ray optics and components (there is one station located on a bending magnet beamline at Sector 1 (1-BM-B) that is used for optics testing, but it does not provide the necessary flux to simulate the planned brightness of the APS-U source). The Instrumentation Development, Evaluation, & Analysis (IDEA) Beamline is currently being built at 28-ID which is one of the last two remaining empty sectors at the APS. Eventually becoming the CHEX beamline after the upgrade, this sector will in the meantime be used to test new undulator designs (SCUs, Revolvers, etc.), evaluate monochromator and mirror stability (thermal, vibrational, positional), including Kirkpatrick-Baez (KB) mirror systems, zone plates, compound refractive lenses (CRLs), and to verify thermal performance of photon masks. Additionally, new detector designs can be developed with vendors over a period of time prior to the completion of the APS upgrade, tested, and performance verified with pre-purchase units. In order to save money and design time, much of the beamline will be built using existing shutters and various other components that we have on hand. The contract for the shielded enclosures for 28-ID was awarded to Enterprise Caratelli and construction will begin in October of 2018. Beamline commissioning should be completed in spring of 2019.

Beamline Design Process

Initial preliminary layouts for the feature beamlines were created working with the beamline scientists based on their optical requirements, existing infrastructure constraints, and radiation safety parameters. Two-dimensional beamline ray trace diagrams were generated to determine the safety envelope, shielding positions, and ultimate component specifications for photon delivery components; i.e. photon absorbers & shutters, Bremsstrahlung collimators, general support structures, and vacuum equipment. Once all of these parameters are known, components will be designed using PTC/Creo 3D CAD software. The APS has a large library of standard time-tested designs which will be leveraged for the upgrade project.

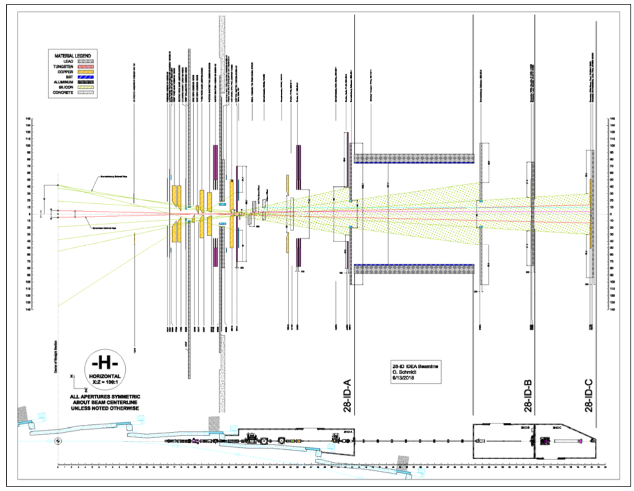

Figure 2: Example raytracing diagram.

Working groups have been established to address Nano positioning, vibrational stability, and high heat-load optics performance. Some of the more complex beamline instrumentation may be designed in-house, however it will be more efficient to specify and purchase most of our optical components from outside vendors. A few of these items have already been purchased as part of an early procurement plan to allow for testing and evaluation at various beamlines including IDEA.

Project Management

From our preliminary beamline layouts, as well as leveraging subject matter experts, we've developed a detailed list of components, hardware, and infrastructure requirements. Using recent purchase requisitions and vendor quotes, we've systematically compiled a very good basis of estimate (BOE) for overall beamline costs. Labor estimates for all resource allocations are based on previous experience and recent beamline upgrades and improvements. The work breakdown structure (WBS) for each beamline consists of Overall Design, Photon Delivery Integration & Assembly, Installation, Optical Components, Non-Optical Components, Diagnostics, Supports, Shielded Transports, Vacuum Systems, Detectors, and End Station Instrumentation, Shielded Enclosures, Mechanical Utilities, Electrical Utilities, Safety Interlocks, Beamline Controls, and Network Infrastructure. All of this information has been loaded into Primavera version 6 project management software (P6), and detailed schedules have been worked out. This is a powerful tool which will allow us to track schedule and cost variances over the life of the project.

Challenges

The new APSU storage ring will establish new source parameters that define our synchrotron and bremsstrahlung radiation safety envelopes. Since these changes will affect all ID and BM beamlines, all existing ray tracing (Fig. 2) diagrams will need to be redrawn and approved by the Radiation Safety Committee. We have achieved a great deal in standardizing our ray tracing techniques over the years and have recently developed a new template that will make

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the process much more efficient. Work is presently underway to bring all of the beamlines up to the current standard, which will make this task much more manageable in the end.

ID beamlines will remain in the same locations with respect to beamline source, however the new storage ring parameters will require the re-alignment of all bending magnet beamlines. The current estimate is a lateral translation of 36mm inboard with a possible rotation of up to 0.75 mrad may be necessary.

The reuse of existing components and infrastructure will be key to lowering the cost and meeting the overall schedule. Identifying components, ensuring that they still have a usable service life, and then tracking and refurbishing them during the main installation period will take significant effort.

Conclusion

The Advanced Photon Source (Fig. 3), at Argonne National Laboratory, is a high energy synchrotron light source in operation since 1995. The upgrade of this facility to a 4th generation light source will ensure many more years of world class science and innovation.

References

[1] M. Borland *et al.*, "The Upgrade Of The Advanced Photon Source," in *Proc. 9th International Particle Accelerator Conf. (IPAC2018)*, Vancouver, BC, Canada April-May 2018, paper THXGBD1.

Figure 3: Bird's eye view of the Advanced Photon Source, Argonne National Laboratory.