APS Upgrade Overview and Status

Stuart Henderson

Director, APS Upgrade Project

APS Users Organization/Partner User Council Joint Meeting

July 9, 2014

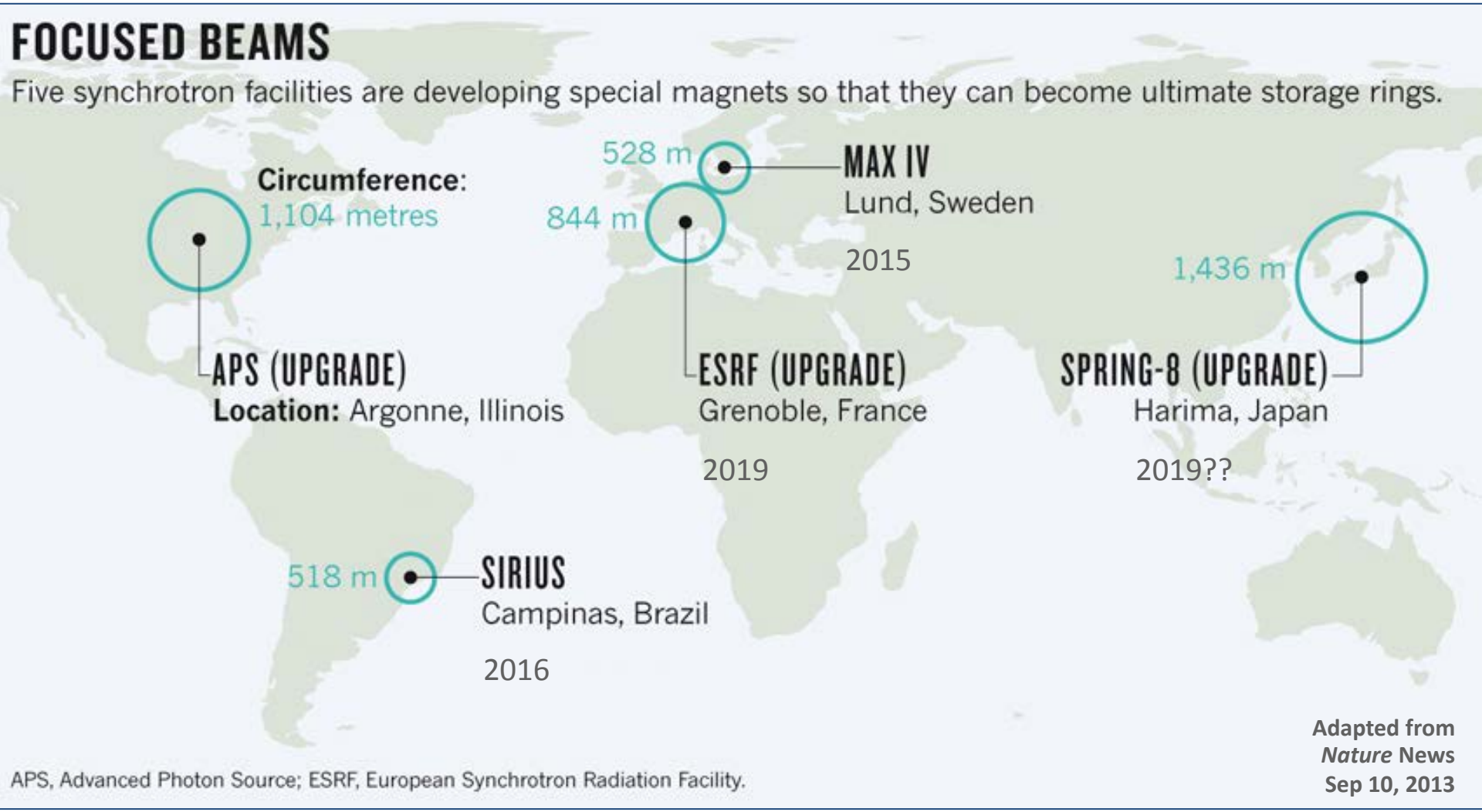
Outline

- Upgrade Context
- APS Upgrade Strategy
- Multi-bend Achromat Concept
- Project Status
- Next Steps

Upgrade Context

The International Light Source Community is Growing and Highly Competitive

International Competition in DLSR Capabilities



Adapted from *Nature* News Sep 10, 2013

Competitive Landscape

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4 July 2014 Last updated at 06:33 ET

Share

Upgrade for Europe's big X-ray light source

By Jonathan Amos
Science correspondent, BBC News

- ESRF Press Release:
  - "The ESRF Council has expressed unanimous support for the implementation of the second phase of the ESRF Upgrade Programme…the objective is to deliver, by 2022, a fully renewed facility for the benefit of scientific users from around the world, and to enable the ESRF to remain the global leader in synchrotron X-ray science."
  - "The current plans aim to maintain user operation with the existing X-ray source uninterrupted until October 2018 and to open the new storage ring source to users in June 2020, after some 20 months of shutdown. By 2022, four new state-of-the-art beamlines will be delivered along with breakthrough improvements in detectors and big-data infrastructures across the whole ESRF, allowing scientists to take full advantage of the new X-ray source."
- SPRING-8
  - Capable of upgrading in 2020 timeframe
- MAX-IV
  - Construction underway now
  - The inauguration of the facility is scheduled for June 21st 2016
- SIRIUS
  - Under construction, aiming for completion 2015-2016

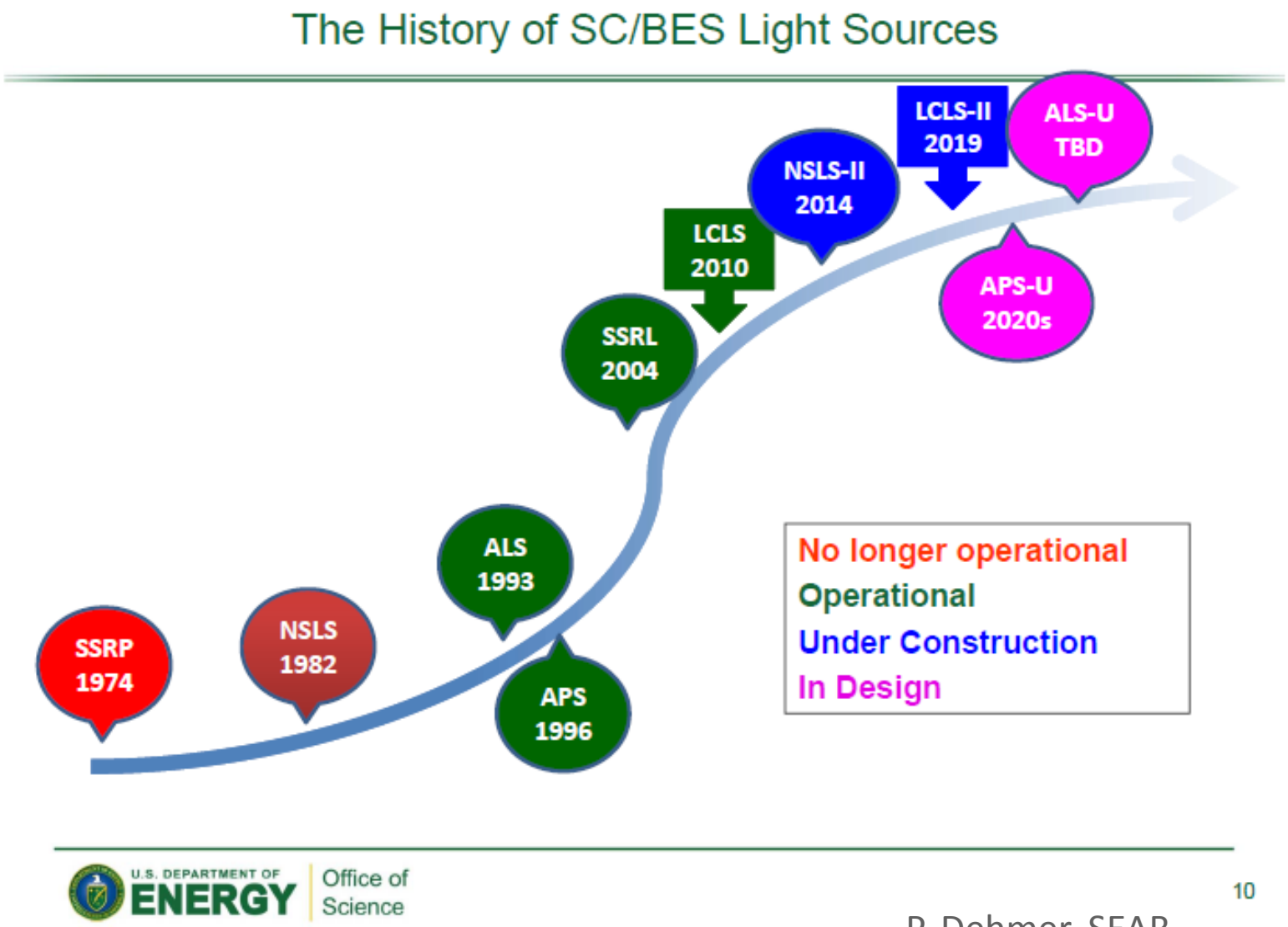
BESAC Report (July 2013) and Response

- The U.S. position within the competitive landscape was a central theme in the July 2013 BESAC Report:
  - "…**present plans for upgrades** of U.S. storage rings **will leave the U.S. behind** the international community…"
  - "…The Office of Basic Energy Sciences should ensure that U.S. storage ring x-ray sources **reclaim their world leadership position**…"
  - "…It is **essential that the facilities** this science community [storage ring users] relies on **remain internationally competitive in the face of the innovative developments…in** other countries.
  - "…developments include **diffraction limited storage rings with beamlines, optics and detectors** compatible with the 10^2 – 10^3 increase in brightness…"

- Following the BESAC report, the APS Upgrade Project immediately began to study the incorporation of an MBA lattice into the project scope
- Rapid progress has been possible due to the DLSR expertise at Argonne and within the larger accelerator science community in the U.S. and world-wide

Our plans for the APS Upgrade enable the U.S. to establish a world leadership position in storage-ring x-ray sources

Domestic Context



P. Dehmer, SEAB Presentation, June 2014

APS Upgrade Strategy

APS Upgrade Goal and Strategy

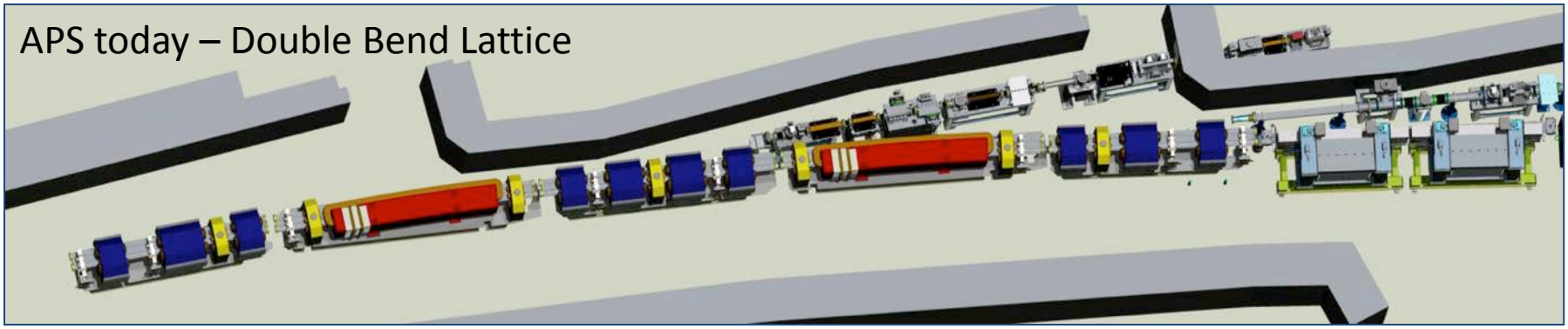
- APS Upgrade Goal: Build the **world's leading high-brightness hard x-ray storage ring**, incorporating advanced beam line, optics, detector and data technologies to enable breakthrough mesoscale science and the ability to explore real systems in real time in real environments.

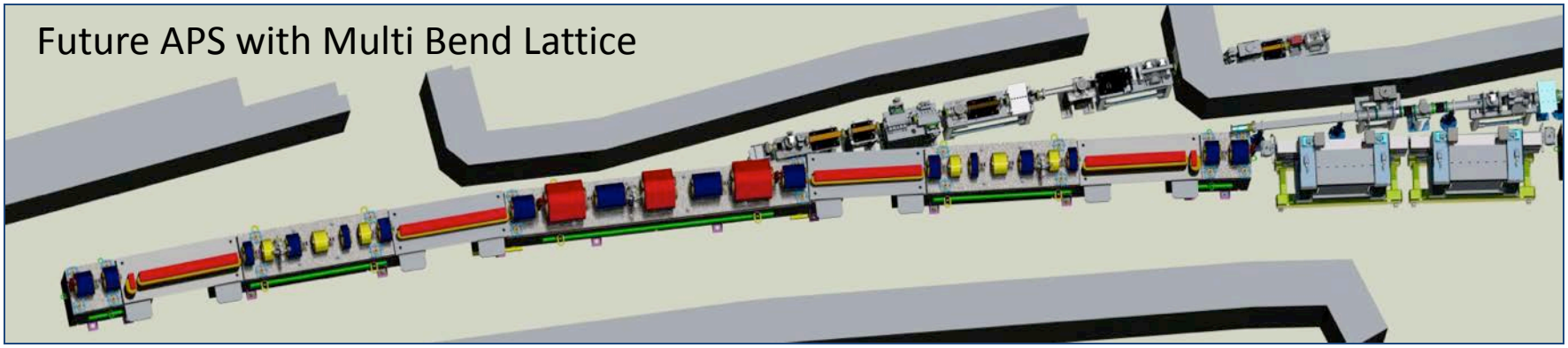
- Strategy: Upgrade the APS with **state-of-the-art technology to maintain world leadership**
  - Rebuild the storage ring with a multi-bend achromat design and high stability to provide the U.S.'s first 4th generation storage ring X-ray source
  - Deploy next-generation undulators to produce the highest x-ray brightness from the low storage ring emittance
  - Develop advanced beamlines that fully exploit the high-brightness source

- MBA Lattice delivers a **generational leap in storage ring performance**, with a factor of 100-1000 increase in brightness and coherent flux

The Upgrade strategy builds upon APS strengths, extending APS capabilities to serve a broad user community, with > 70 simultaneous experiments, with improved stability

APS Upgrade Multi Bend Achromat Lattice Concept





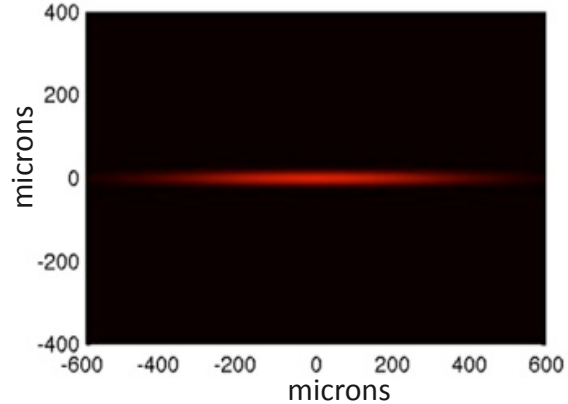
$$\varepsilon_x \sim \frac{E^2}{{N_d}^3}$$

N_d = Number of dipoles per sector (N_d = 7 for APS MBA)
E = Beam energy (E = 6 GeV for APS MBA)

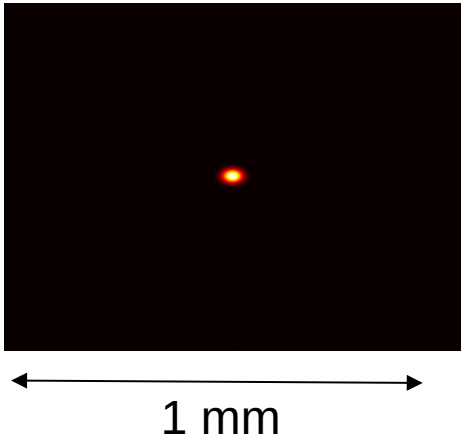
Implementation of an MBA lattice and optimized IDs dramatically enhances APS performance as a hard x-ray source

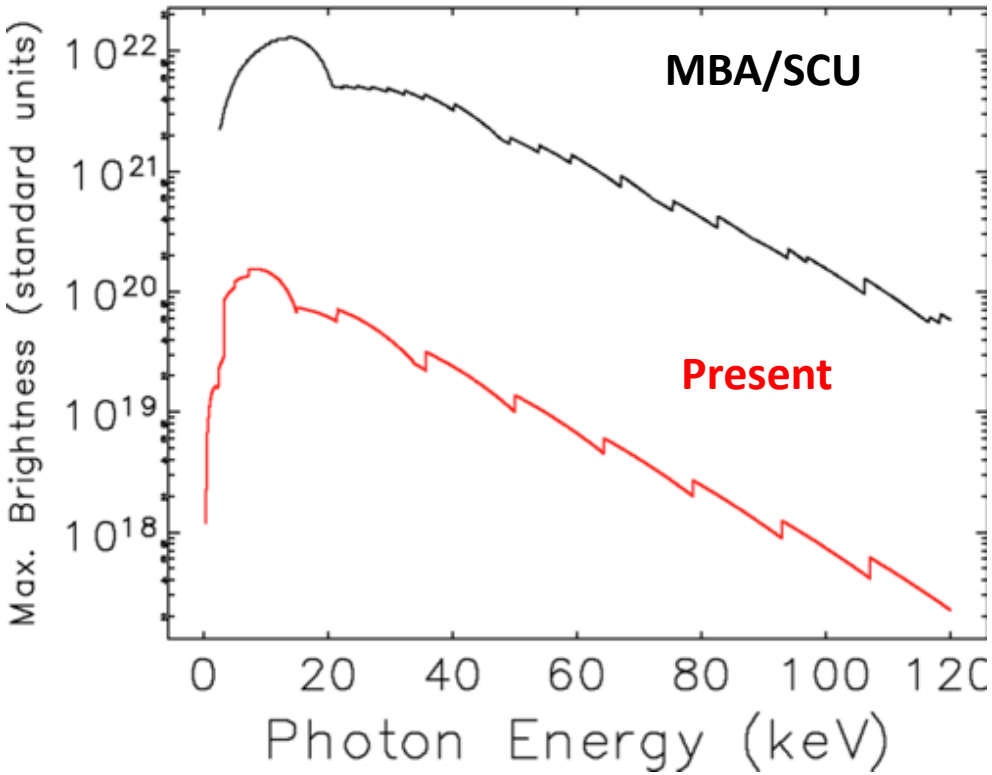
Particle Beam Profiles

APS Now



APS MBA





Scientific Community Engagement

- Important to emphasize: the APS Upgrade is a Science Project, not only an accelerator upgrade. The Project must deliver greatly enhanced scientific capability from the end-user perspective

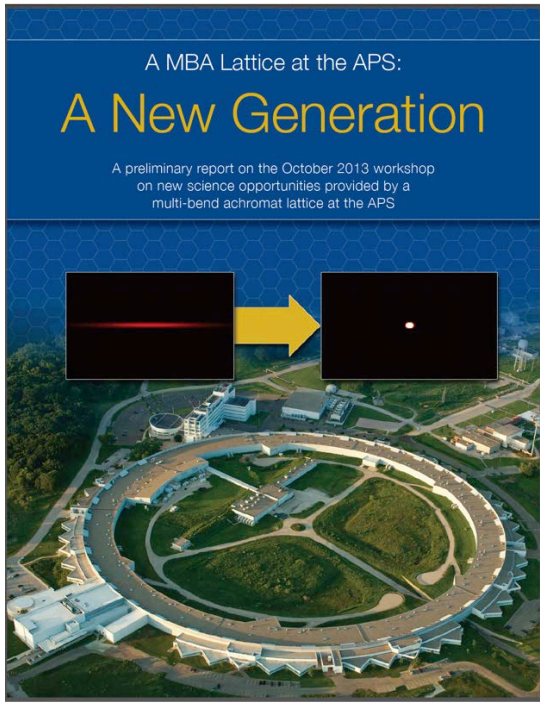
- Scientific community engagement is essential to
  - Explore capabilities of a next-generation source
  - Develop the Scientific Opportunities enabled and articulate their importance
  - Plan for beam lines to best make use of MBA source properties
  - Explore impacts associated with installation period and resumption of routine operation

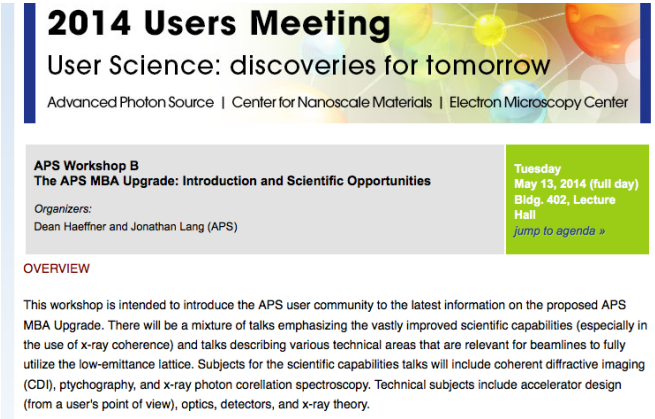
- A compelling Science Case with enthusiastic user community support is a requirement for the APS Upgrade to go forward

Your support is greatly appreciated!

We are Actively Engaging the Scientific User Community

- Activities:
  - Workshop on New Science Opportunities Provided by a MBA lattice at the APS
    - October 21-22, 2013 workshop was a tremendous success: ~400 participants
    - Report posted at www.aps.anl.gov/Upgrade/Workshops/2013/MBA-Technology/
  - 2014 User's Meeting workshops on APS MBA upgrade
  - Regular meetings with stakeholders
- Upcoming:
  - Seminar series
  - Satellite one day workshop at Intl. Workshop on Phase Retrieval and Coherent Scattering, "Coherence", Sept. 7, 2014
  - DLSR Workshop, Fall 2014





2014 Users Meeting

User Science: discoveries for tomorrow

Advanced Photon Source | Center for Nanoscale Materials | Electron Microscopy Center

APS Workshop B
The APS MBA Upgrade: Introduction and Scientific Opportunities

Organizers:
Dean Haeffner and Jonathan Lang (APS)

Tuesday
May 13, 2014 (full day)
Bldg. 402, Lecture Hall
jump to agenda »

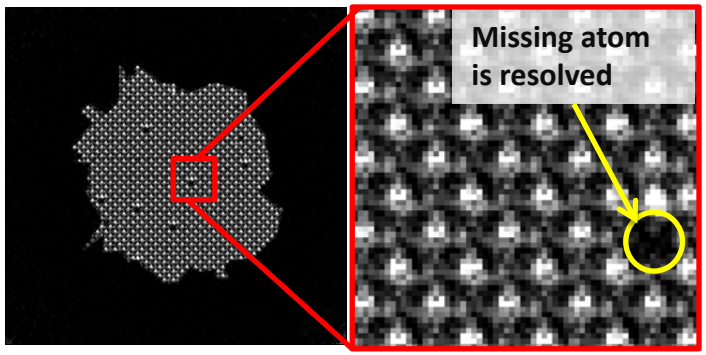
OVERVIEW

This workshop is intended to introduce the APS user community to the latest information on the proposed APS MBA Upgrade. There will be a mixture of talks emphasizing the vastly improved scientific capabilities (especially in the use of x-ray coherence) and talks describing various technical areas that are relevant for beamlines to fully utilize the low-emittance lattice. Subjects for the scientific capabilities talks will include coherent diffractive imaging (CDI), ptychography, and x-ray photon corellation spectroscopy. Technical subjects include accelerator design (from a user's point of view), optics, detectors, and x-ray theory.

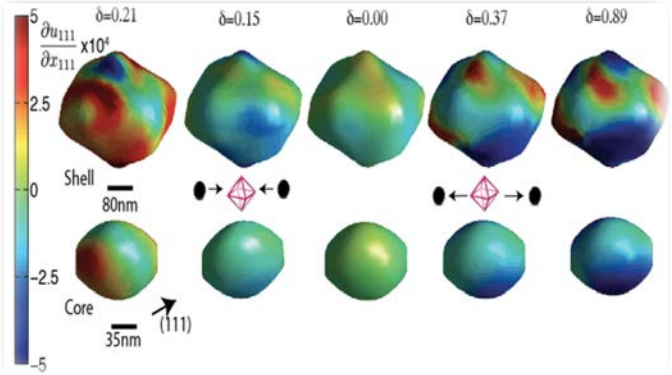
MBA Source Properties Provide Greatly Enhanced Capabilities

- Factors of 100-1000x in brightness directly leads to factors of 100-1000x in coherence based techniques; enables revolutionary capabilities
  - Coherent Diffractive Imaging/Ptychography
    - "Hero" experiments today, applied to ideal systems -> Routine experiments, applied to real world systems
  - X-ray Photon Correlation Spectroscopy
    - Sensitive to the brightness squared -> 10,000X to 1,000,000X
- Low emittance beam is much better match for micro/nano focusing optics
  - Ability to efficiently focus X-rays to nanometer spots
  - Efficiency of focusing improved by x10 or more
- Today's coherent flux levels available at 8 keV will be available at 40 keV
  - Buried systems and In situ environments
- Flux enhancement helps all experiments at the APS
  - Faster data acquisition, more parametric studies
  - Flux can generally be traded for focusing
  - Particularly strong increase at high energies due to SCUs

Simulated reconstruction of nanocrystal with atomic vacancies, using Bragg coherent diffraction imaging



***In operando* Coherent Diffraction Imaging Will Allow Strain Mapping at the Nanometer Scale**



Science Case Development

- Building upon the successful New Science Opportunities workshop (Oct. 2013) and User's Meeting workshops on the APS MBA upgrade (May 2014), we have formed (or are forming) several task forces along scientific themes to sharpen the scientific case and hone the message.

- We have reached out to a number of leading experts:
  - Biology and Life Sciences: Bob Fischetti, Keith Moffat and Soichi Wakatsuki
  - Condensed Matter Physics: Oleg Shpyrko, Mark Sutton, Paul Evans and Peter Abbamonte
  - Advanced Materials/Mesoscale Engineering: Tony Rollett, Bob Suter, Paul Fuoss and Jon Almer
  - Soft Materials: Paul Nealey and Jin Wang
  - Extreme Conditions: Russell Hemley, Guoyin Shen and Yogi Gupta

- Task Force Goal: Articulate a long-term vision for the compelling science directions within the thematic area, which will be addressed by the MBA-upgrade. The science questions being addressed should not be incremental, and should require a revolutionary application of the capabilities of the MBA-upgrade.

- Once the task forces have complete their work, we will
  - Seek your advice and comment on the articulation of the Science Case
  - Work toward community consensus in a follow-on workshop, and
  - Seek advice from our external advisory bodies

Multi-Bend Achromat Concept

APS-MBA High-Level Performance Goals

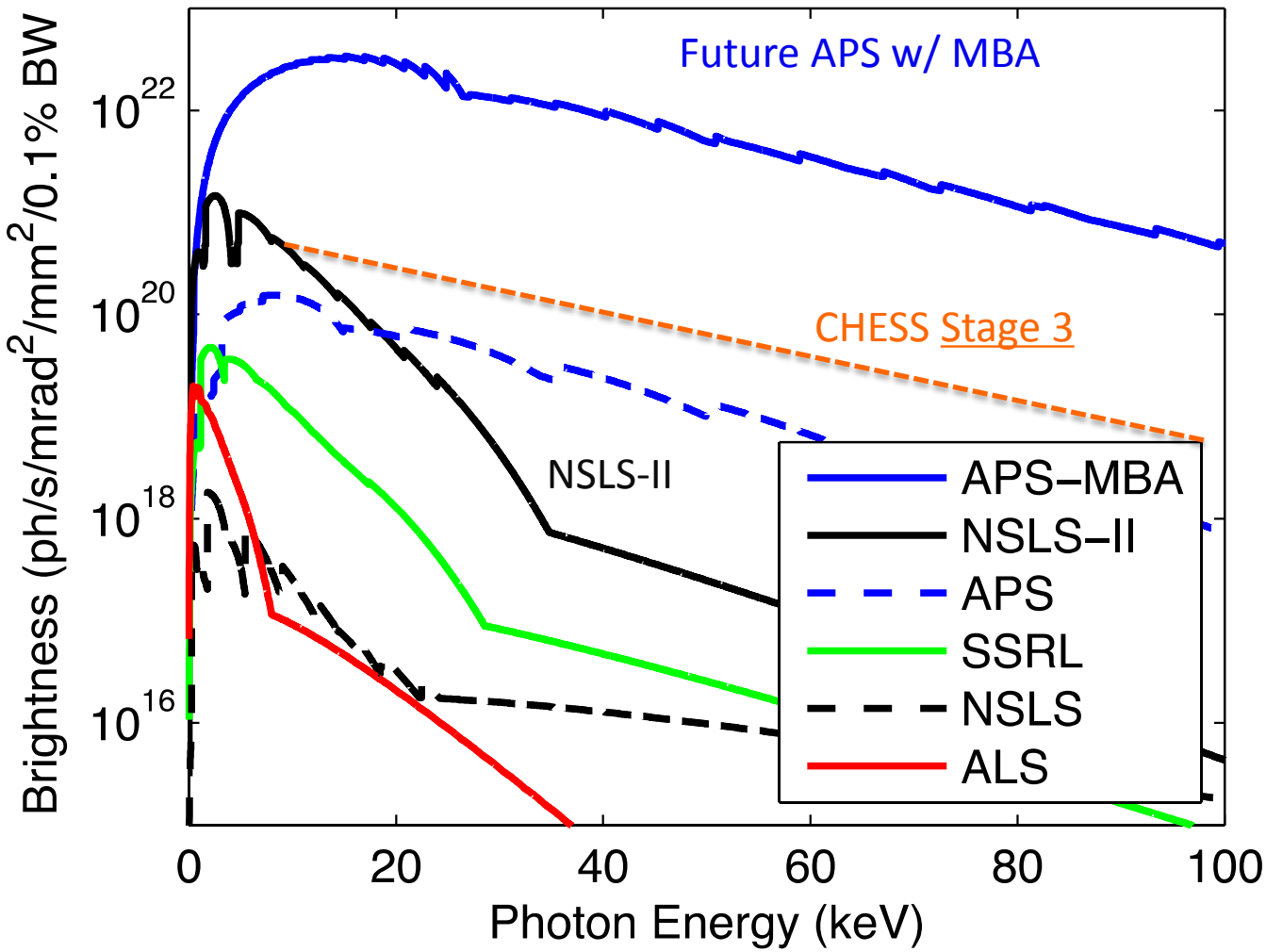
- More than two orders of magnitude increase in brightness at ID sources over a wide range of hard x-ray energies
- Significant improvement in coherent x-ray flux
- All insertion device beamlines supported
- All BM beamlines supported, potentially with greater flux and harder x-rays using three-pole wiggler source
- At least a factor of 2 increase in hard x-ray flux (BM and ID)
- 48 to 324 uniformly-spaced bunches supported

Parameter comparisons: APS today vs APS MBA Upgrade*

Quantity	Symbol	Units	APS Now	APS MBA Timing Mode	APS MBA Bright. Mode
Beam Energy	E	GeV	7	6	6
Beam current	I	mA	100	200	200
Number of bunches	N_b		24	48	324
Bunch duration	σ_t	ps	34	70	18
Bunch spacing	T_b	ns	153	77	11
Bunch rep. rate	f_b	MHz	6.5	13	88
Emittance ratio	$K = \epsilon_y / \epsilon_x$		0.013	1.0	0.1
Horizontal emittance	ϵ_x	pm	3100	46	65
Horizontal beam size	σ_x	μm	275	17.8	21.2
Horizontal beam divergence	σ_x'	μrad	11	2.6	3.1
Vertical emittance	ϵy	pm	40	46	7
Vertical beam size	σ_y	μm	10	10.2	4.0
Vertical beam divergence	$\sigma_{y'}$	μrad	3.5	4.3	1.6

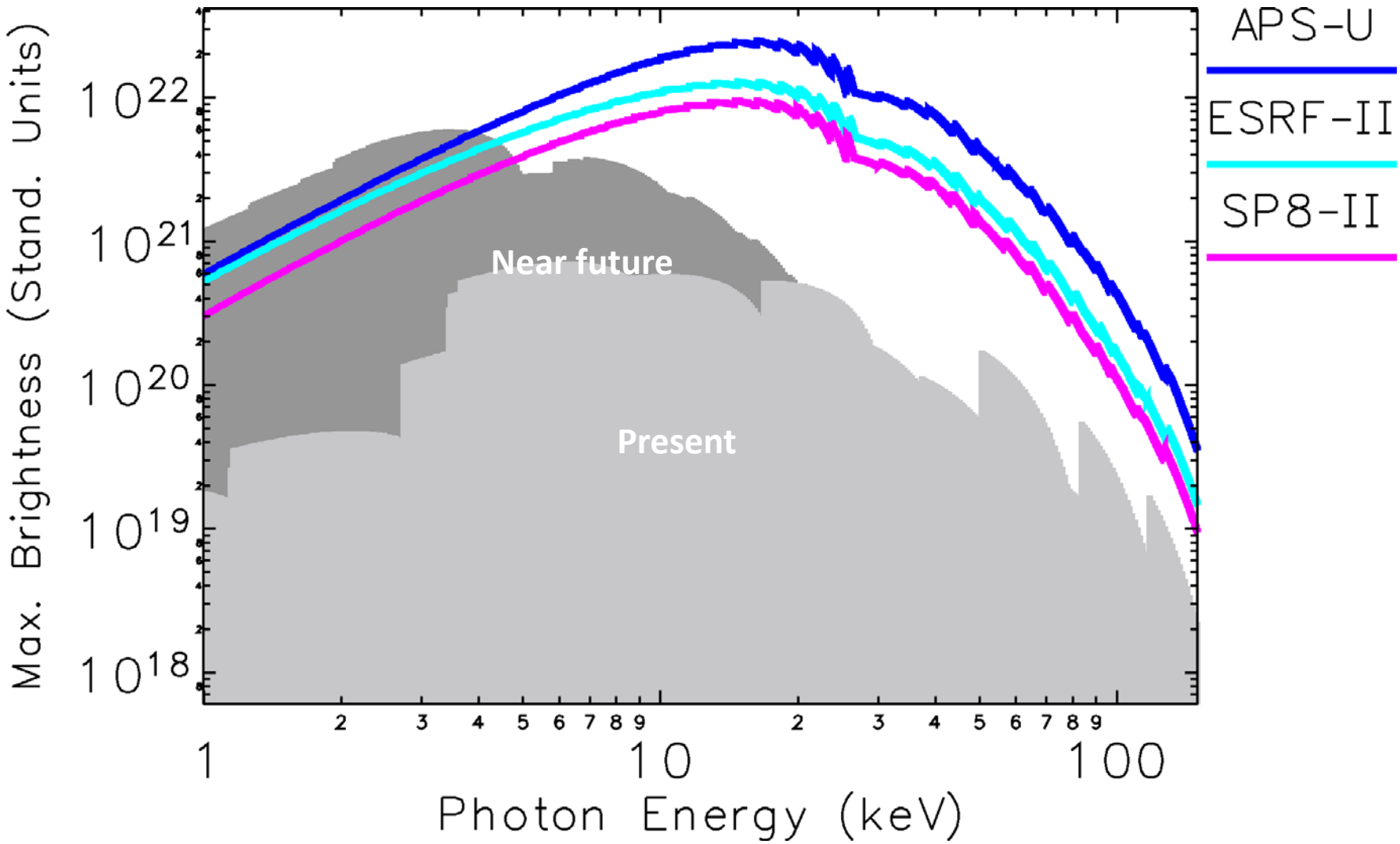
*H7BA-TwoSector-nux95-nuy36-3PW-Version4
Courtesy M. Borland

APS: High energy star in US x-ray facility constellation



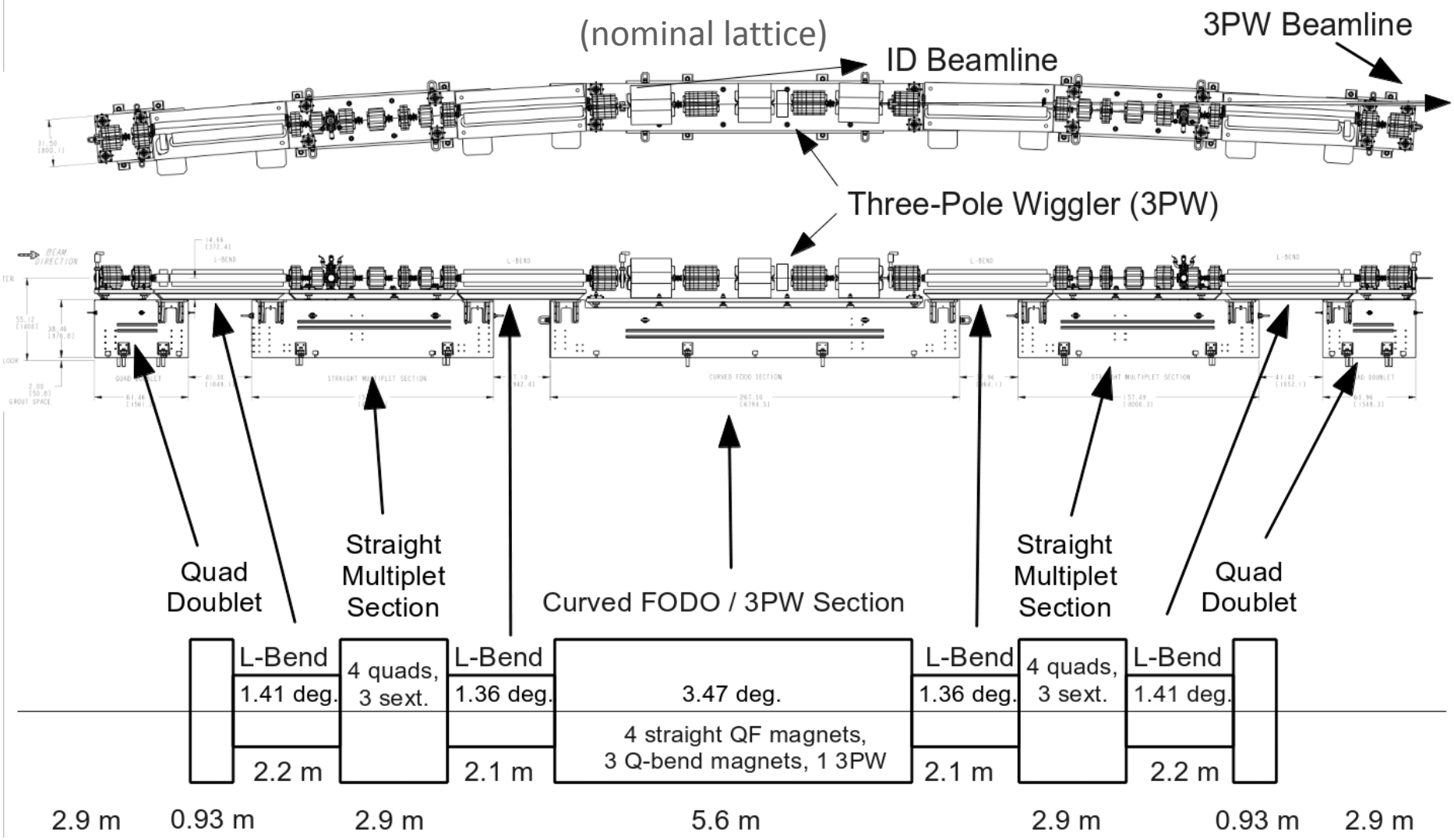
Brightness vs. x-ray energy at top beamlines among BES synchrotron facilities, including approximate CHESS Stage 3 upgrade per Cornell's web page

APS-U Will Deliver World-Leading Performance

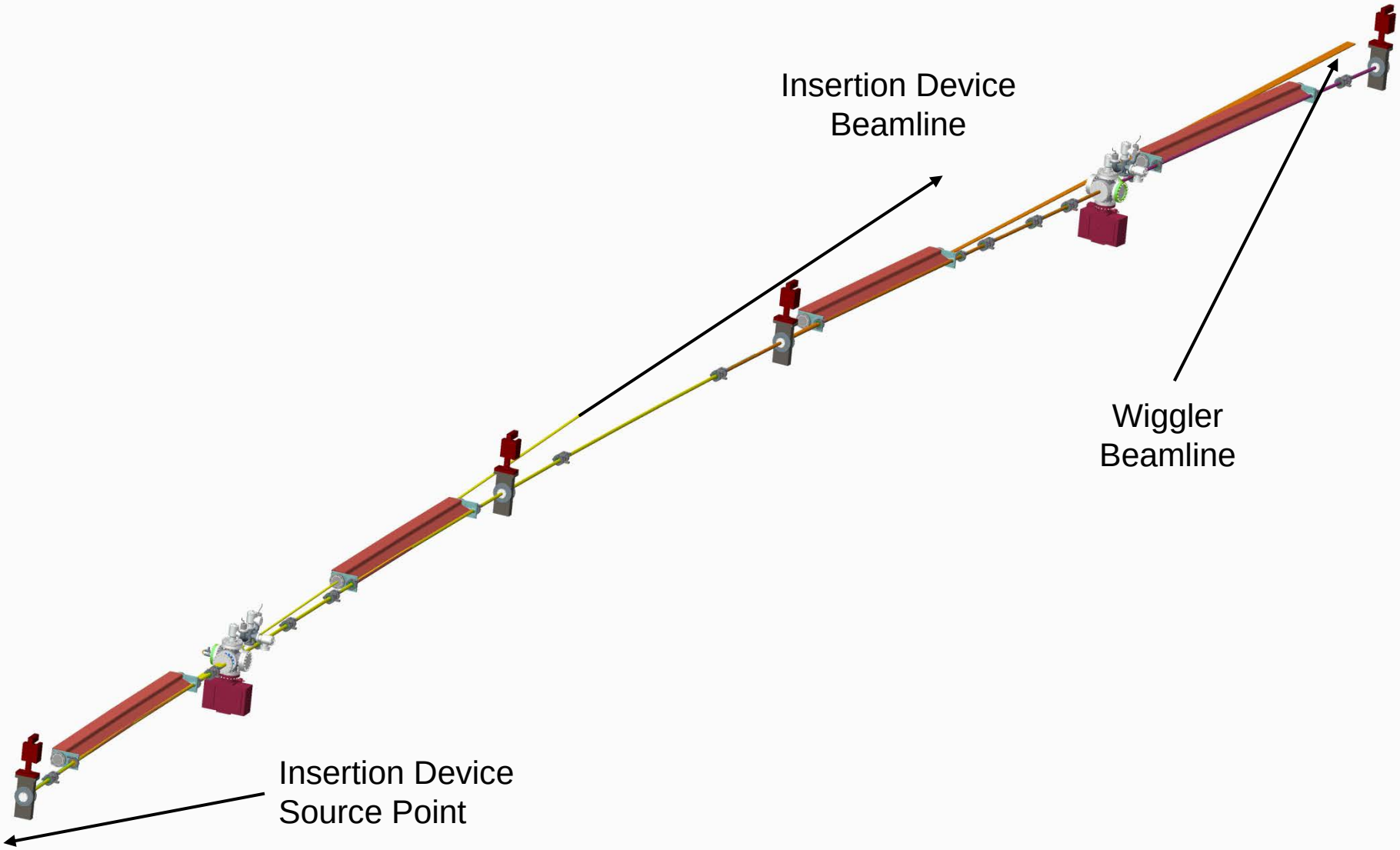


Curves for APS, ESRF and SP8 upgrades based on present designs, and assume identical undulators

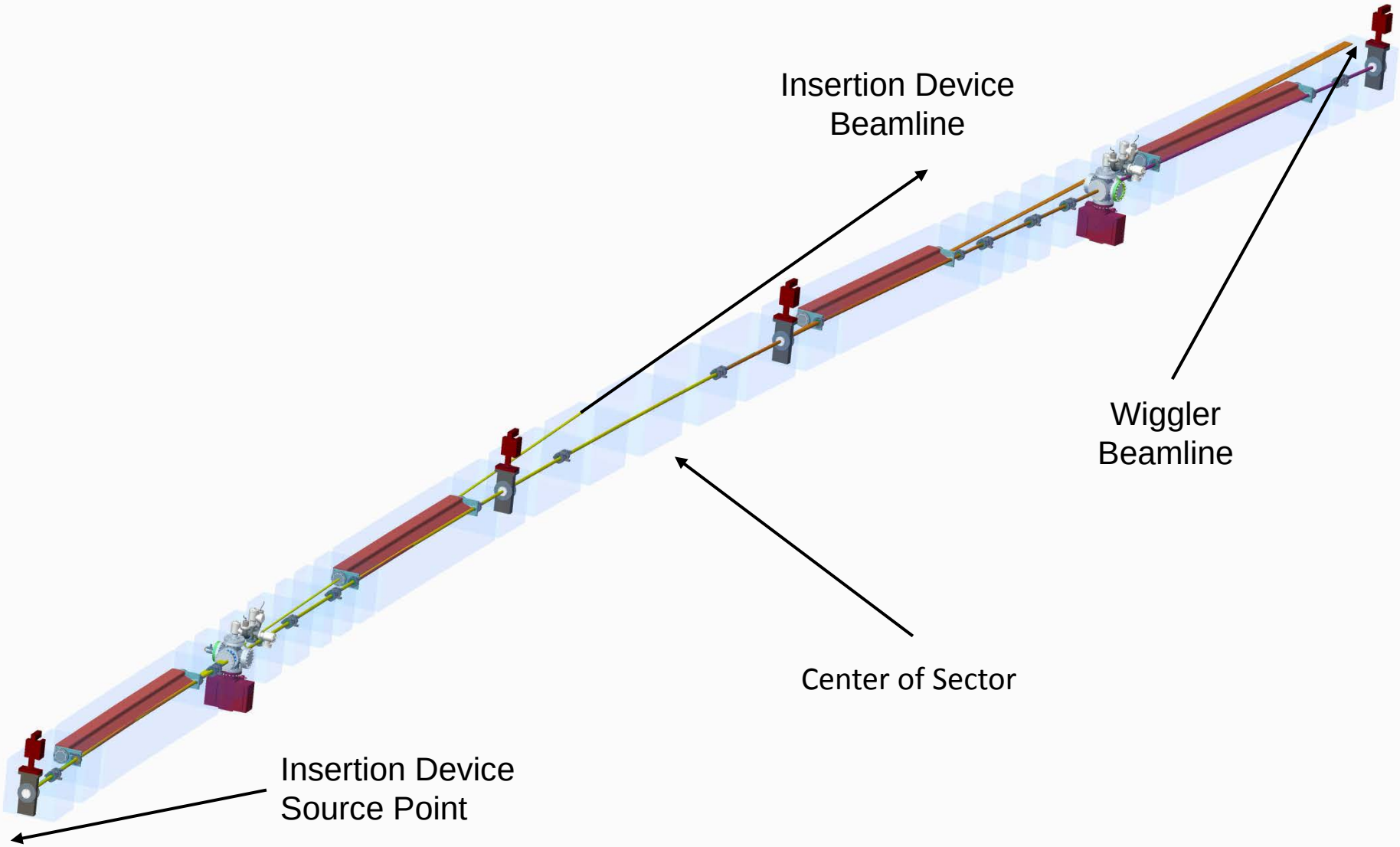
APS MBA Accelerator Implementation



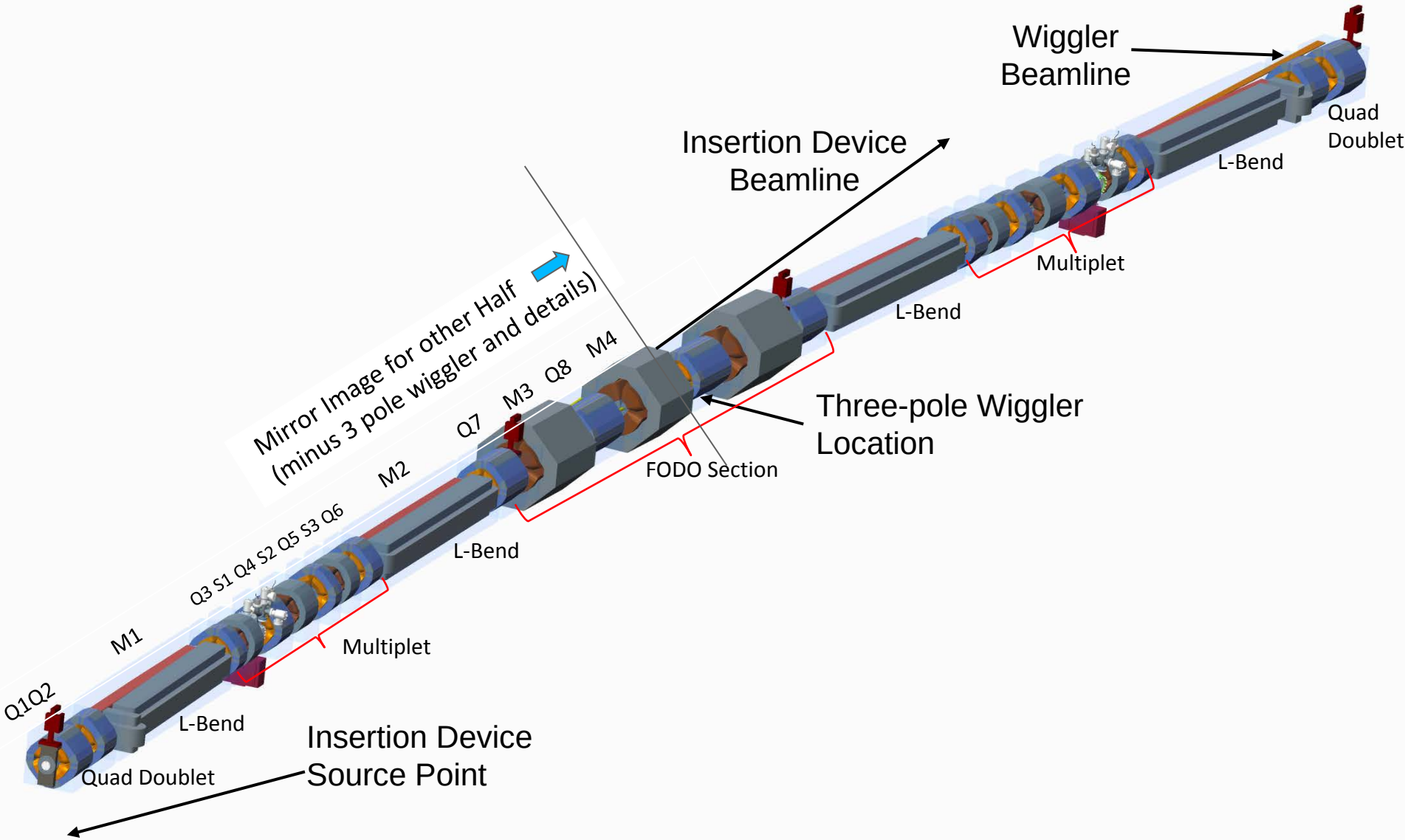
APS MBA Design Development – One Sector Vacuum



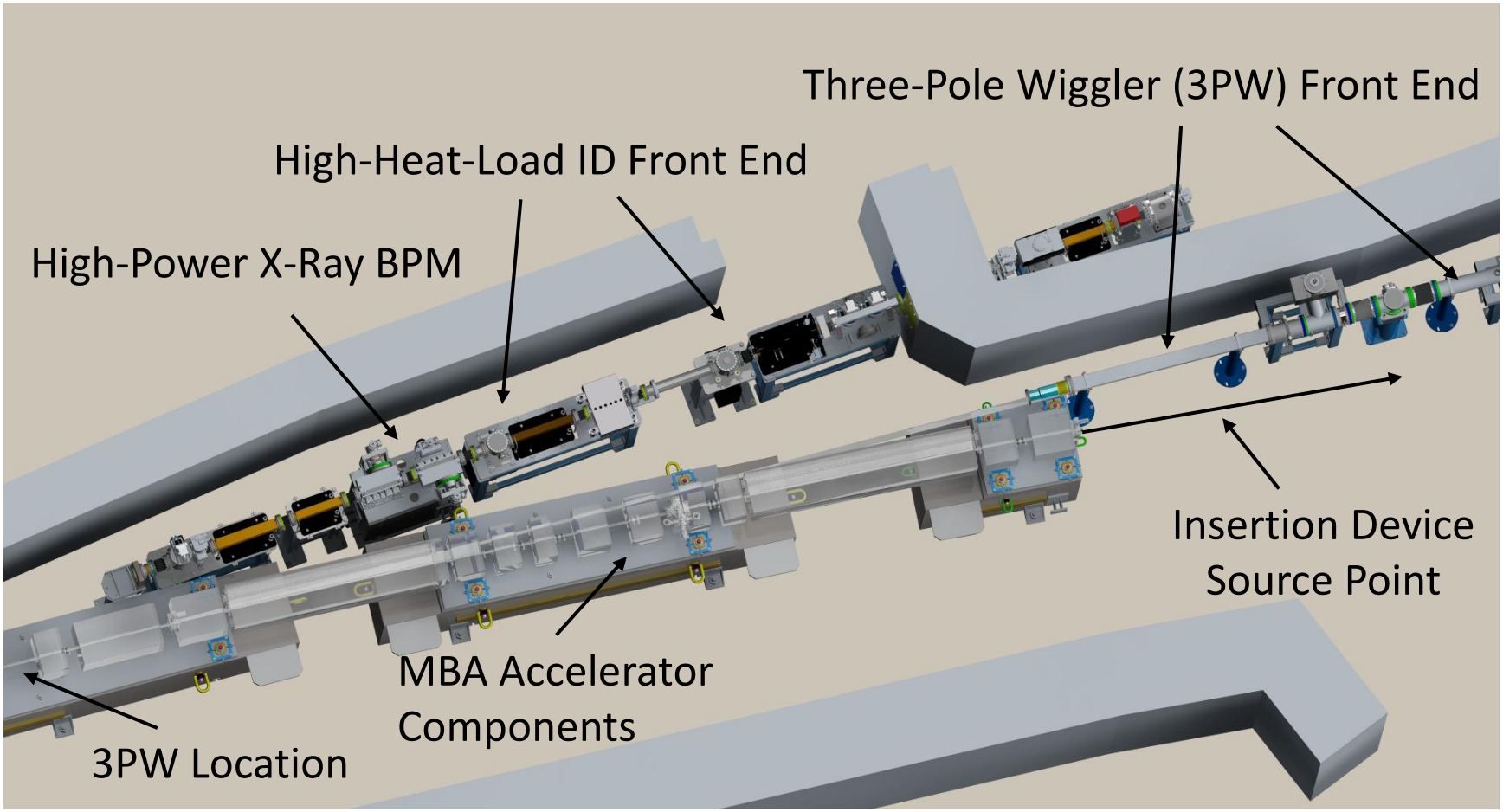
MBA Sector Vacuum / Magnet Integration



Sector Layout: 3D



In-Tunnel Arrangement of Components



APS-U Project Status

Preliminary Consideration of Project Scope

- New, 4th generation multi-bend achromat storage ring lattice in the existing tunnel
- Doubling of the ring stored beam current
- New insertion devices for 35 ID sectors optimized for brightness and flux
  - Round beam created by MBA lattice enables great flexibility in undulators for high brightness
- Replacements of all Front-Ends
- A suite of new beamlines designed for best-in-class performance with MBA source properties
- Optics for remaining beamlines to take full advantage of MBA source properties
- Improved beam stability
- **Well-defined** installation and testing period is a **key deliverable**
  - **External review found the present ~one-year plan achievable**
  - Given central importance of minimizing APS unavailability, will require a very different approach from that taken in typical installations

All beamlines will realize significant benefits

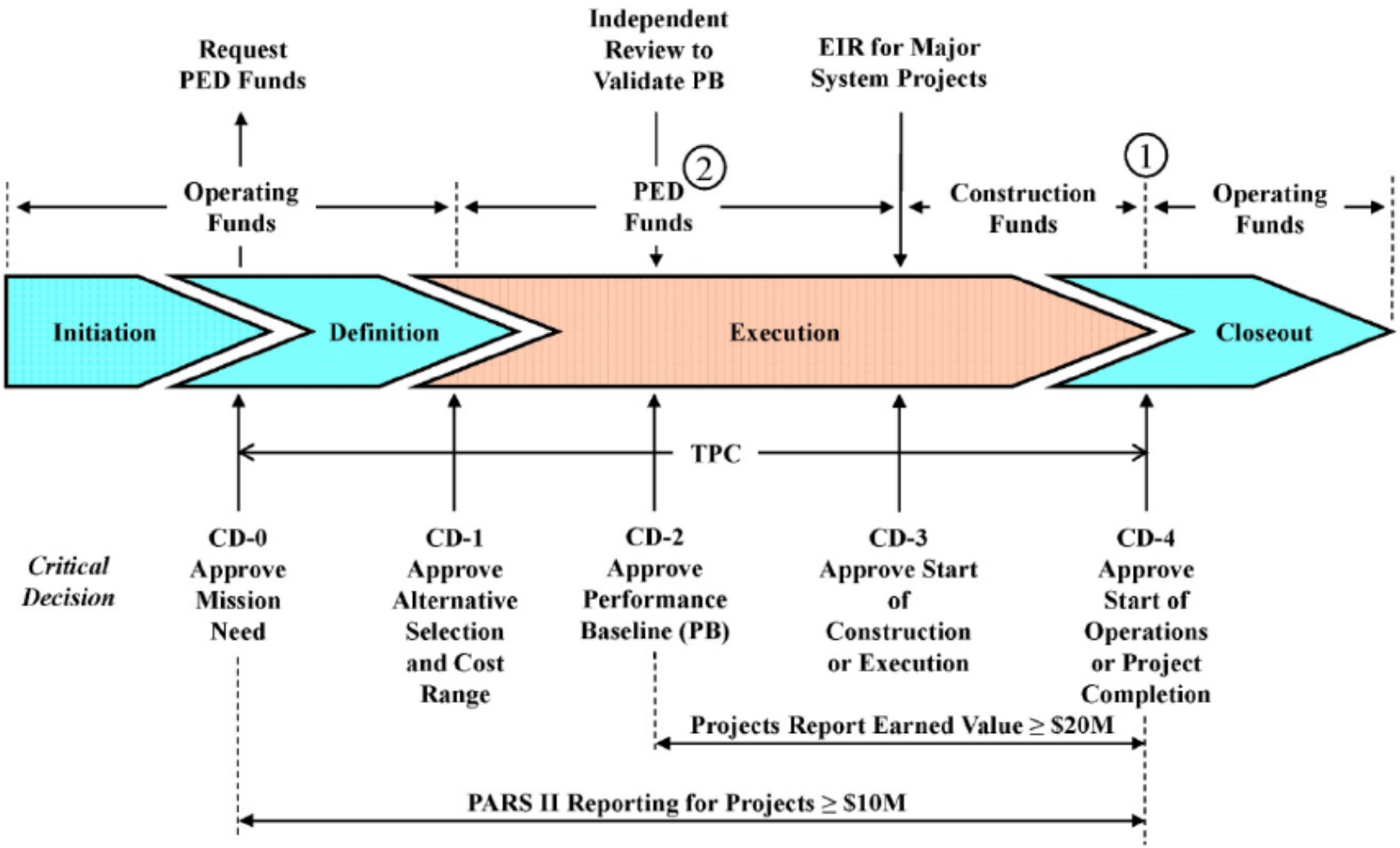
Important to emphasize: the APS Upgrade is a Science Project, not only an accelerator upgrade. The Project will deliver greatly enhanced scientific capability to the User Community

Project Cost and Funding

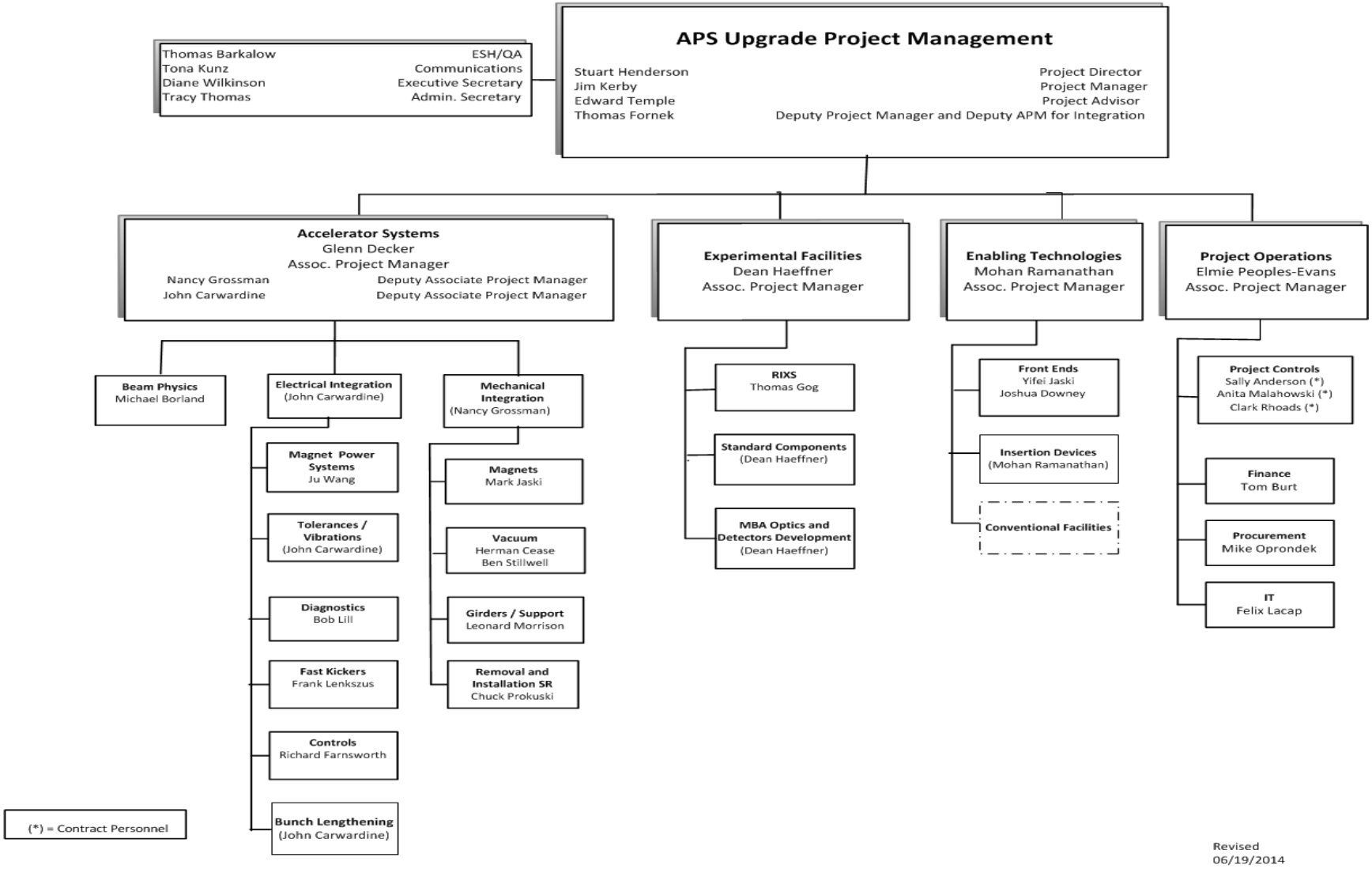
- Project Cost:
  - Pat Dehmer indicated at the Feb. 2014 BESAC meeting APSU cost of very approx. $550M
  - The Project is assembling a bottoms-up cost estimate right now

- Funding
  - FY14 budget: $20M – Fully funded
  - President's FY15 request: $20M
  - Will work closely with BES to determine overall funding and timeline

Schedule will be determined by funding and the DOE Project Process



APS Upgrade Organization Chart



We have a strong team in place ready to execute the Project

Argonne NATIONAL LABORATORY

Advanced Photon Source Upgrade Project

MBA Working Group > Pages > Home

MBA Working Group | APS-U Project | Reviews | Management

Home

Libraries
- Shared Documents

Lists
- Links
- Tasks

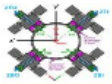
Pictures

General References
- Working » Main Assumptions Document | Lattice File
- MBA Beam Physics » NGSR Wiki
- MBA Contacts and Meetings
- Assumptions Meetings
- Cost Basis (restricted)
- Other Similar Storage Rings
- APS References and Photos

Decommissioning | Chuck Prokuski
- Specifications
- Recent Presentations and Meeting Notes
- References » Documents | Links

Magnets | Mark Jaski
- Specifications
- Recent Presentations and Meeting Notes
- References » Documents | Links

Magnet Power Supply | Ju Wang
- Specifications
- Recent Presentations and Meeting Notes
- References » Documents | Links



Diagnostics | Bob Lill
- Specifications
- Recent Presentations and Meeting Notes
- References » Documents | Links

Bunch Lengthening Systems
- Specifications
- Recent Presentations and Meeting Notes
- References » Documents | Links

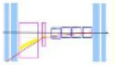
Beamline Related
- Insertion Devices
- Front Ends
- Beamlines

System Integration and Engineering
- Tom Fornek (mechanical) | John Carwardine (electrical) | Nancy Grossman
- Interface Control Documents
- Recent Presentations and Meeting Notes
- Internal Documents (restricted)
- Infrastructure » Space Planning | Utilities
- Supply Chain | Mechanical Support

Installation | Tom Fornek
- Specifications
- Recent Presentations and Meeting Notes
- References » Documents | Links

Vacuum | Herman Cease
- Specifications
- Recent Presentations and Meeting Notes
- References » Documents | Links

Controls | Richard Farnsworth
- Specifications
- Recent Presentations and Meeting Notes
- References » Documents | Links



Fast Injection Kickers | Frank Lenkszus
- Specifications
- Recent Presentations and Meeting Notes
- References » Documents | Links

Tolerances
- John Carwardine | Vadim Sajaev
- Specifications
- Recent Presentations and Meeting Notes
- References » Documents | Links

Injector

Project Status

The Project Team efforts are focused on

- Development of the APS-U concept:
  - Developing the MBA beam physics design and technical system conceptual designs
  - Validation of the MBA physics and technical system conceptual designs via focused technical reviews:
    - 8 independent reviews since Feb. 2014. Bottom line: The APS MBA effort is overall at a level consistent with Conceptual Design; excellent technical progress has been made; very challenging technical requirements are seen as achievable
  - Assembly of generic planning packages for beamlines
    - Ultimate selection will be carried out via a thorough and open process
- Performing key R&D activities:
  - Development and execution of the R&D Plan focused on critical technology
  - Prototyping challenging components for the accelerator (magnets, power supplies, …) and beamlines (detectors)
- Preparing for CD-1 readiness:
  - Preparation of the Conceptual Design Report
  - Preparation of the CD-1 point estimate, cost range, and schedule
  - Preparation of Project Documentation

Technical Design Reviews To Date

Review Title	Date	Reviewers		
MBA Beam Physics	February 13-14, 2014	Weimin Guo - BNL Richard Walker - Diamond Simon Leeman – MAX Lab	Christoph Steier – LBNL (Chair) Ryutaro Nagaoka – SOLEIL Pantaleo Raimondi – ESRF	✔
Diagnostics / Controls (CDR)	March 20-21, 2014	David Gurd – SNS Jim Sebek – SLAC (Chair) Barry Lai – ANL Mark Rivers - UofC		✔
Vacuum Systems Review (CDR)	March 25, 2014	Alex Chen – FNAL H.C. Hseuh – BNL (Chair)	Roberto Kersevan – CERN Dean Walters - ANL	✔
Storage Ring Installation	March 27-28, 2014	Sushil Sharma – BNL (Chair) Greg Fries – BNL Joseph Harkins – LBNL	B. Alan Tatum – ORNL Dave Augustin – FNAL	✔
Magnets and Mechanical Supports (CDR)	April 1-2, 2014	Sushil Sharma – BNL Ramesh Gupta – BNL	Martin Johansson – MAX Lab (Chair) Gael Le Bec - ESRF	✔
Power Supplies (CDR)	April 3-4, 2014	Howard Pfeffer – FNAL (Chair) Bob Lambiase – BNL Fernando Rafael - SLAC		✔
Pulsed Injection Systems (CDR)	April 8, 2014	John Byrd – LBNL (Chair) Chris Jensen – FNAL Wu (Arlene) Zhang - BNL		✔
Bunch Lengthening System (CDR)	May 21, 2014	Louis Emery – ANL (Chair) John Byrd – LBNL Slava Yakovlev - FNAL		✔

Challenges

Technical:

- Integration of engineering design: complicated and compact magnetic lattice
- Challenging magnet designs: combined function/gradient magnets
- On-axis injection
- Development of beamlines, optics and detectors to take full advantage of MBA source properties
- Stability in all its manifestations

Execution:

- Installation: present ~12 month plan for removal/installation/testing with beam
- Space Planning
  - Due to aggressive installation goal, need adequate space for staged equipment and removed equipment, in addition to receiving, testing, fabrication space
- Integration of the APS-U efforts with existing operations and the matrixing of staff

R&D is quite important for this Project. The plan will focus on these challenges:

- Prototyping critical components (magnets, vacuum system, power supplies) leading to full sector mockup

Installation Planning

- **A well-defined** installation and testing period is a **key deliverable**

- Given central importance of minimizing APS unavailability, installation and testing will require a very different approach from that taken in typical installations
  - Need all equipment delivered, tested and staged prior to start of installation
  - Need adequate space for removed material coming out, staged components going in
  - Will use multiple technical crews simultaneously for two shifts per day (5 days/week)
  - Mock-ups will be utilized to train crews to achieve necessary efficiency

- This approach is more expensive and requires more people resources

- We are evaluating resource needs for storage ring removal and installation in 9 months, followed by ~3 months of testing with beam

- An external review committee validated this approach for removal/installation:
  - "…the committee members believe that the Storage Ring equipment removal and installation plans are well developed and achievable…"

Storage Ring Equipment Removal

Material to be Removed: Estimate

Item Description	Weight [tons]	Volume [cu yd]	Type of Waste	Quantity	Type of Containers
Girder assemblies	1761	1449	30% Low level rad	196	B-25 bin
			70% Richardson suspension	45	40 cu yd dumpster
Power cables	73	22	100% Richardson suspension	4	20 cu yd dumpster
DC Converter electronics	27	40	Electronics recycling	4	40 ft semi-trailer
Other electronics	24	88	Electronics recycling	8	40 ft semi-trailer
Totals	1885	1599			
NOTE: Number of bins, dumpsters, and semi-trailers was calculated by volume and adjusted by weight capacity.					

Space Needs

Initial estimate from Jacobs; APSU discussing possibilities with Laboratory, other labs, and off site rental space

Current Summary of Space Needs

*models shown to scale

	Disposition Facility		ID Processing Building	MRAS Building	CRATS Building
	Enclosed	Outdoor			
Square Footage	6,060 ft²	40,550 ft²	15,860 ft²	55,025 ft²	19,400 ft²
10% un-programmed contingency space	606 ft²	4,055 ft²	1,586 ft²	5,503 ft²	1,940 ft²
Total Square Footage	**6,666 ft²**	**44,605 ft²**	**17,446 ft²**	**60,528 ft²**	**21,340 ft²**
Potential Buildings	367		314	New Flex Bldg	335, ?
Available Area					

*400A to be used for staging

Tom Fornek Removal and Installation Plan Introduction March 27-28, 2014 20

Next Steps

Summer 2014

- Complete R&D Plan, Draft Conceptual Design Report
- Complete initial cost roll-up and resource estimate
- Complete draft Science Case document for review
- Brief DOE SC/BES/OPA August 27
- Develop Scientific Community engagement plan

Fall 2014

- Stand-up advisory committee structure and utilize to evaluate Project's concept, cost and schedule in its entirety
- Complete required Project documentation for CD-1
- Continue to make progress on the conceptual design
- Continue to make progress on critical R&D
- Complete CDR
- Complete Science Case document

Summary

- Our plans for the APS Upgrade enable the U.S. to establish a world leadership position in storage-ring x-ray sources, responding to recent BESAC recommendations
- Excellent technical progress continues to be made on the MBA lattice design
  - Technical reviews so far have validated our approach
- Preliminary considerations of scope ensures greatly enhanced scientific capabilities from the end-user perspective
- We are working hard to get "CD-1 ready" by Q2 FY15
- The most challenging issues have been identified and evaluated and will be addressed via the R&D program, which is our near-term focus

APS-U: the world's leading high-brightness hard x-ray storage ring

Finally….

WE WANT YOU!

- Your advice and support is extremely important to us
- We will be counting on your support as we continue to make the case that an upgraded APS is an essential 21st century tool for 21st century science

High-Level Machine Properties

	APS Now	MBA
Beam Energy	7 GeV	6 GeV
Beam Current	100 mA	200 mA
Single Bunch Current	> 16 mA	> 4.2 mA
Effective Emittance	3100 pm-rad	65 pm-rad
Sectors	40	40
Circumference	1104 m	1104 m
RF Frequency	352 MHz	352 MHz
Minimum Bunch Spacing	11.4 ns	11.4 ns
Energy Spread	0.096%	0.095%
Dipoles / Sector	2	7
Quads / Sector	10	16
Sext. / Sector	7	6
Fast Correctors / Sector	1 to 2 / plane	4 / plane