The APS Upgrade Project

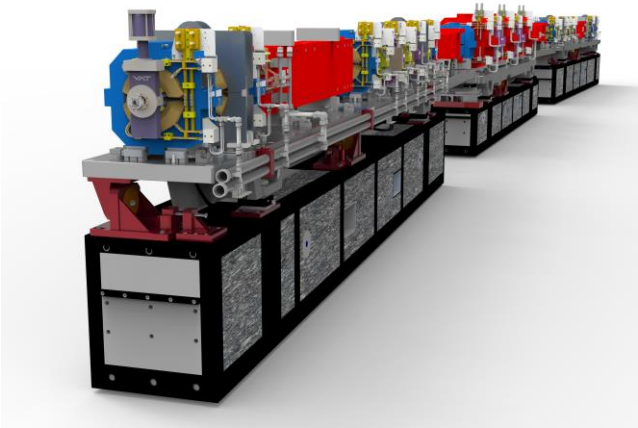
Robert Hettel, APS Upgrade Project Director

BESAC Meeting

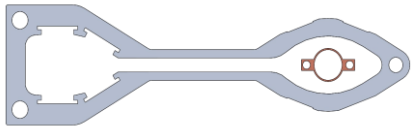
Bethesda North Marriott Hotel and Conference Center, Rockville MD

March 7, 2019

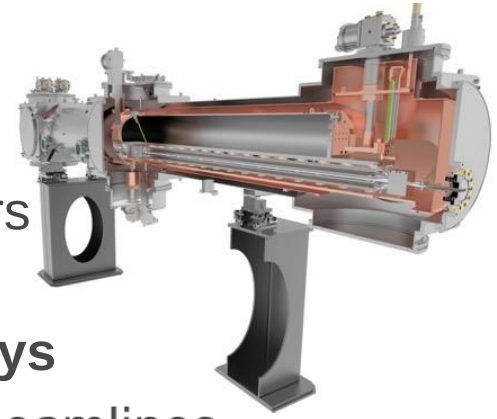
APS-U, a 4th generation storage ring light source, is underway

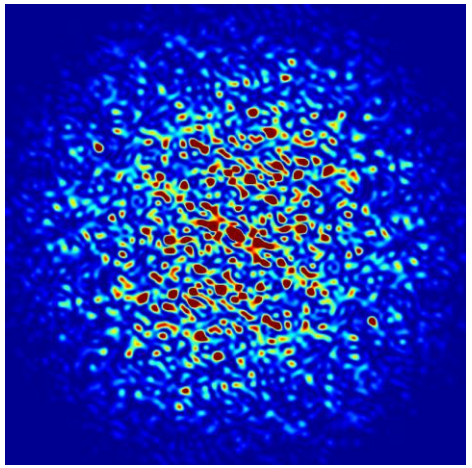


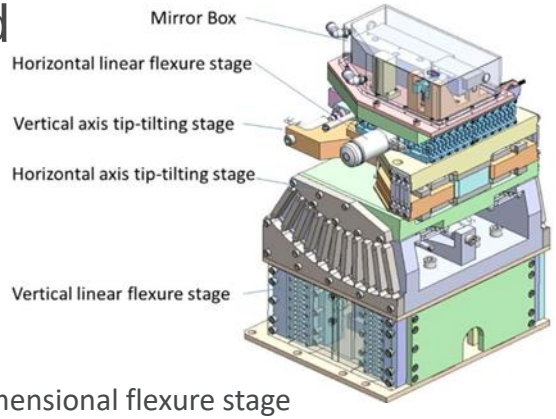
- 6 GeV, 200 mA , 1100 m circumference
- 42 pm-rad emittance
  - diffraction limit for 5.3 Å/2.3 keV
  - first hybrid 7BA lattice with reverse bends
  - on-axis swap-out injection
  - ~32 x 30 pm-rad round beam possible
- 9 superconducting and rebuilt PM planar undulators
- **100x – 1000x increase in brightness and coherence of Ångstrom and sub-Ångstrom X-rays**
- 9 new high performance beamlines, 15 enhanced beamlines
- Coherence preservation in beamlines (advanced optics simulation and characterization tools)
- Stability!
- High-performance computing and AI for experiment control and data analysis
- Utilizes ~1.5 B$ of existing infrastructure



APS and APS-U chambers







Multidimensional flexure stage for <50-nm hard X-ray focusing.

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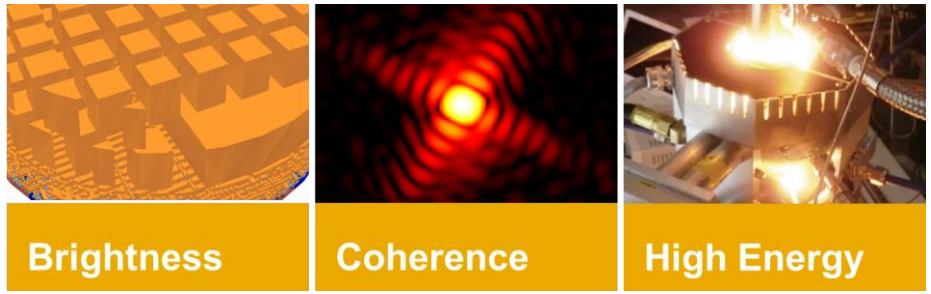
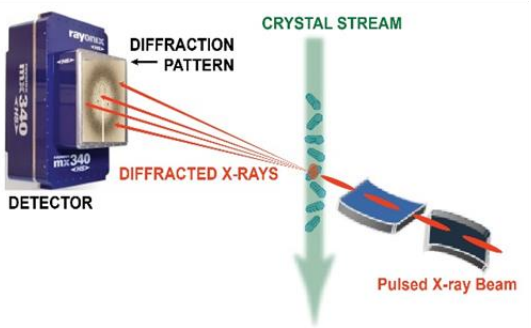
APS-U enables pivotal research across disciplines



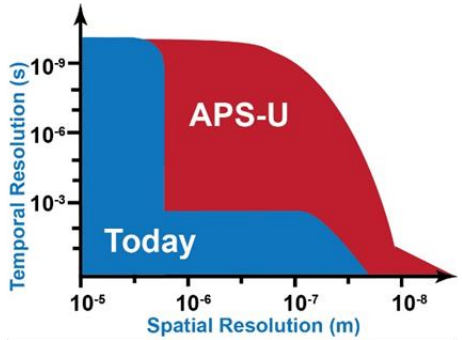
Small-Beam Scattering & Spectroscopy

- Nanometer imaging with chemical and structural contrast; few-atom sensitivity
- Room-temperature, serial, single-pulse pink beam macromolecular crystallography



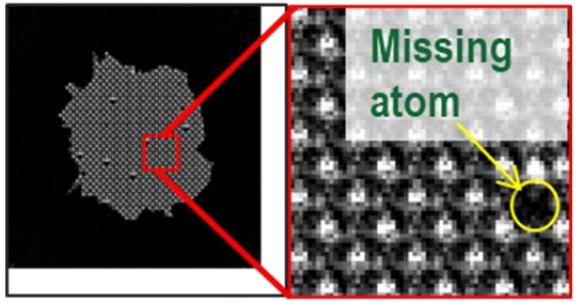
Resolution with Speed

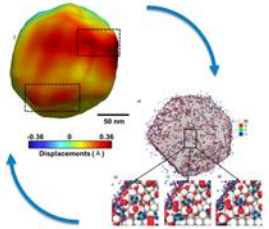
- Mapping all of the critical atoms in a cubic millimeter
- Detecting and following rare events
- Multiscale imaging: enormous fields of view with high resolution



Coherent Scattering & Imaging

- Highest possible spatial resolution: 3D visualization; imaging of defects, disordered heterogeneous materials
- XPCS to probe continuous processes from nsec onward, opening up 5 orders of magnitude in time inaccessible today,





Exploit high performance computing, artificial intelligence

Automatic control of experiments, high volume data acquisition, analysis and reconstruction

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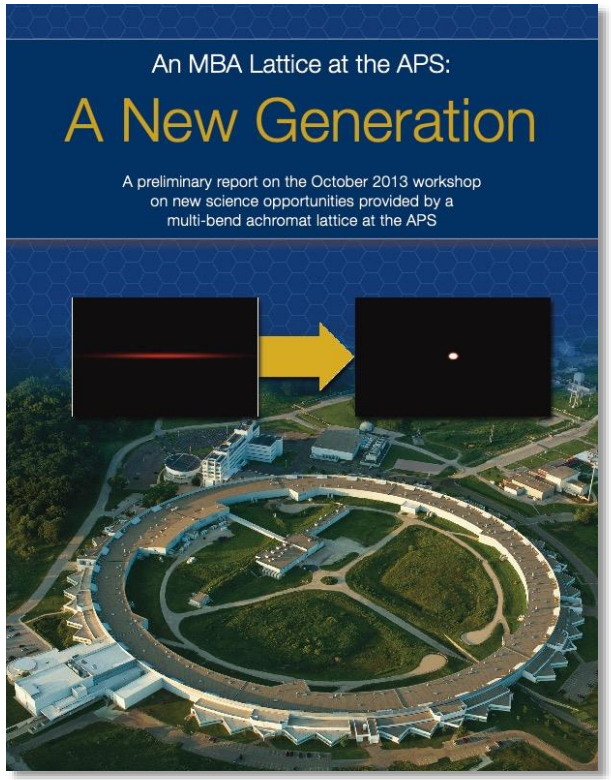
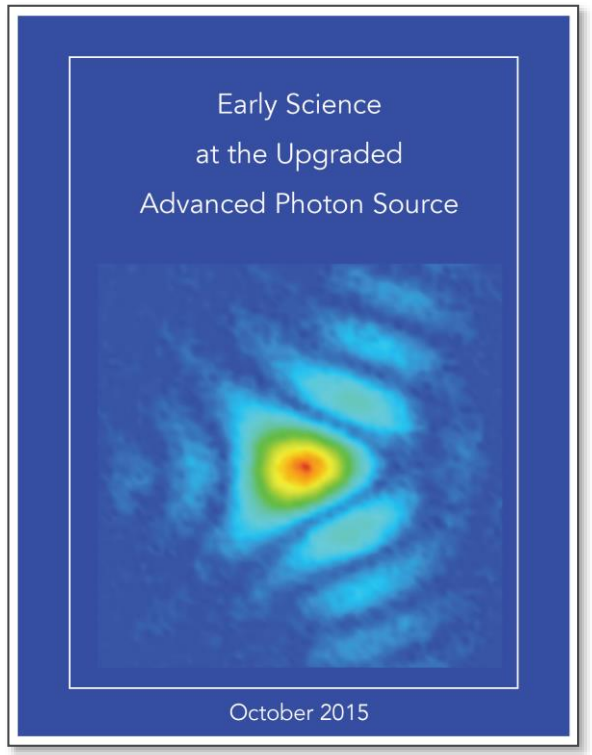
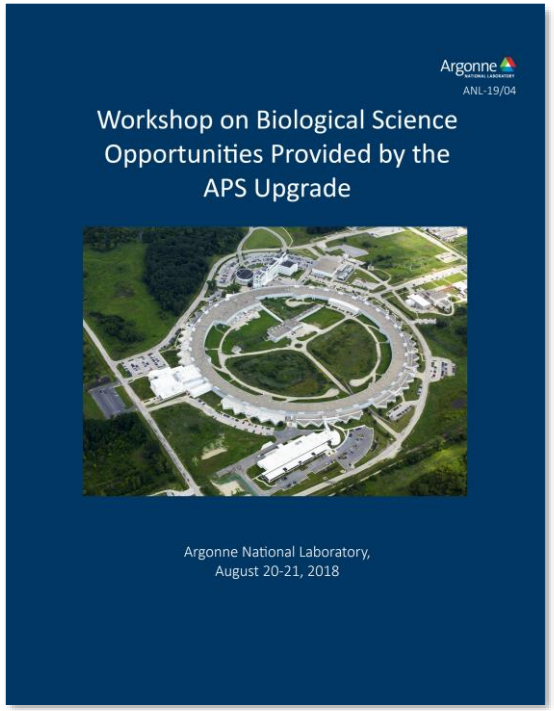
APS-U science workshops







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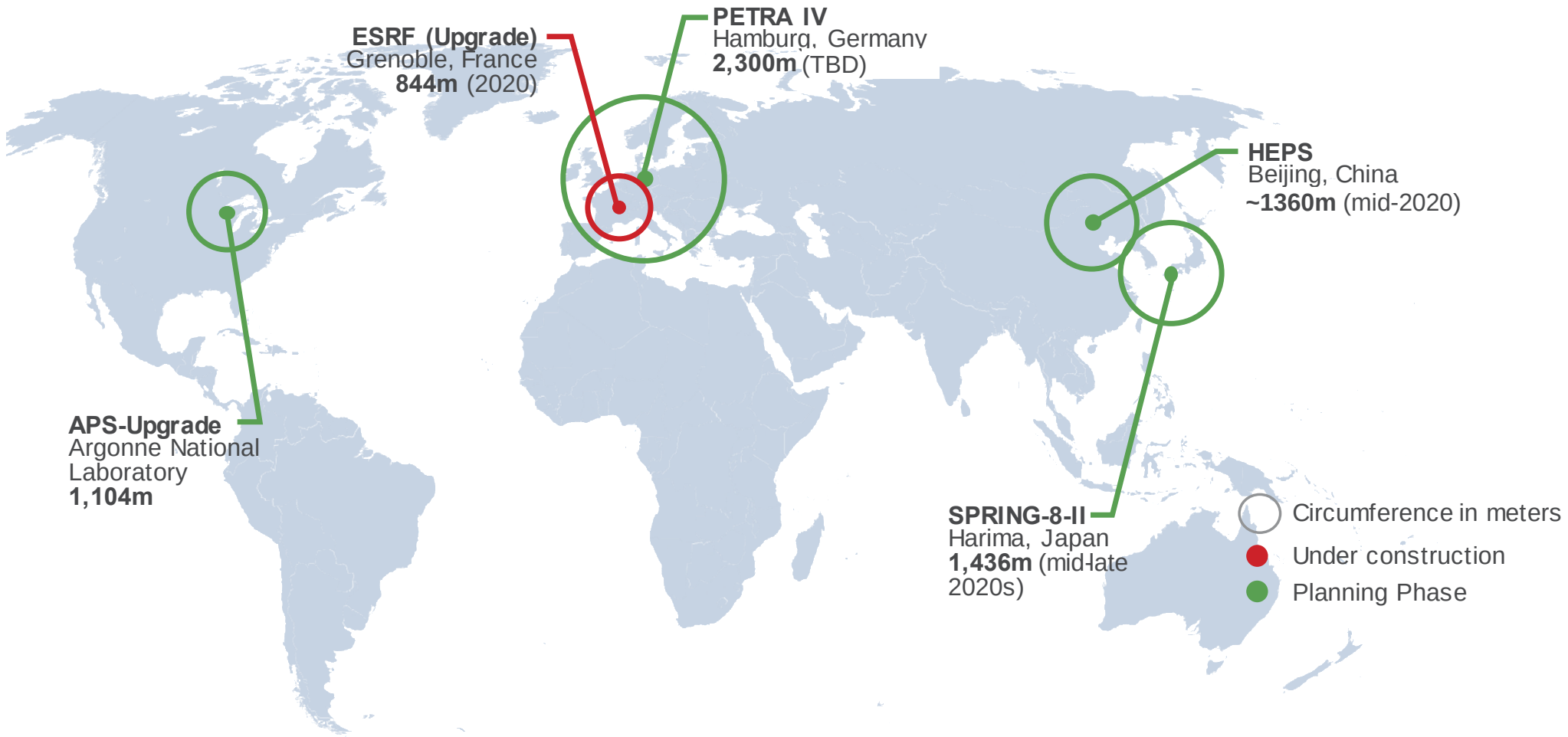
U.S. remains a leader in high energy X-ray science with the APS-U



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APS-U new beamlines and capabilities

Loc.	Name	Title	Technique	Key Science Example
8-ID	XPCS	Small-Angle XPCS Beamline for Studying Dynamics in Soft Matter Wide-Angle XPCS and Time-Resolved Coherent X-Ray Scattering	Small angle XPCS Wide angle XPCS	Understanding soft matter assembly and dynamics, Glass hierarchical dynamics for super-strong materials, Fluid/solid interfaces, …
28-ID	CHEX	Coherent High-Energy X-ray Sector for In Situ Science	In situ, high energy coherent scattering	Real-time imaging of film-growth for higher performance energy-to-light conversion, power transmission, and novel materials
33-ID	Ptycho	PtychoProbe	Sub-5 nm imaging with chemical contrast, extended further w/ lensless imaging to 1 nm and potentially below	Nano-architectured electrochemical structures & Defect engineering for devices, improved materials for infrastructure, buildings, …
4-ID	Polar	Polarization modulation spectroscopy – Electronic Matter: Inhomogeneity, tunability, and discovery at extreme conditions	Magnetic Spectroscopy, combining nanofocusing w/ x-ray polarization,high pressure/low T/high field	Probe mesoscale electronic/magnetic ordering and excitations with resonant diffraction and inelastic scattering
34-ID	ATOMIC	Extremely high resolution coherent imaging of atomistic structures	Bragg coherent diffractive imaging, combining high spatial, temporal and strain resolutions.	Image active catalytic materials approaching atomic resolution
	3DMN	3D Micro & Nano Diffraction	3D nano-diffraction with significantly improved sensitivity	Mapping single defects in nano-crystalline materials to improve thermoelectric devices, structural integrity of mechanical components…

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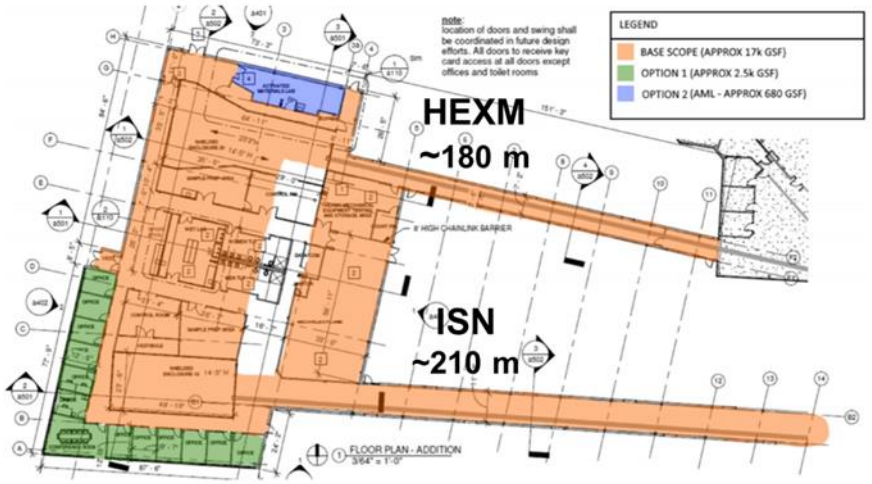
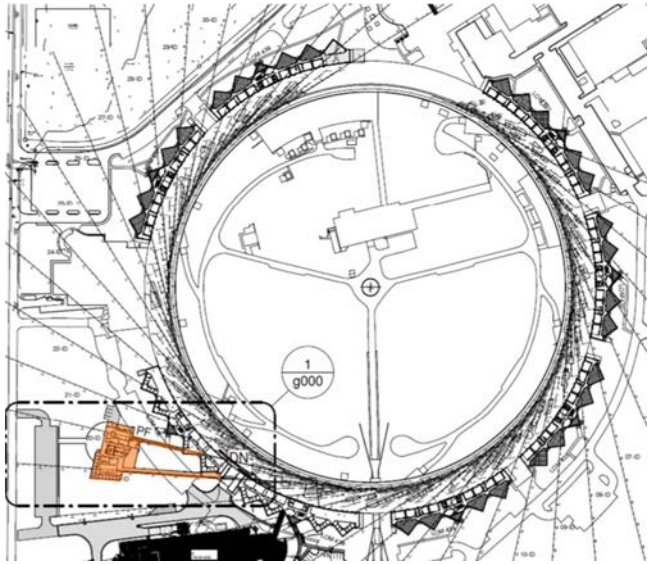
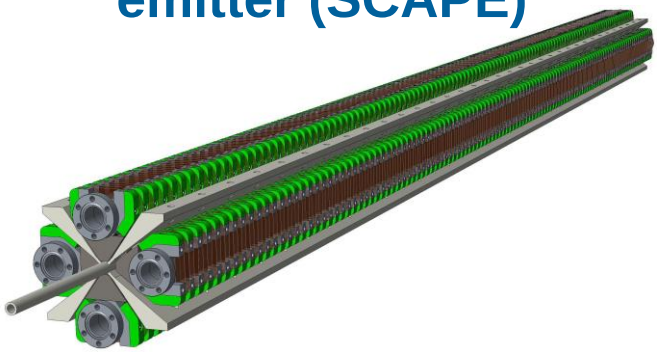
New beamlines and capabilities – cont.

Loc.	Name	Title	Technique	Key Science Example
9-ID	CSSI	Coherent Surface Scattering Imaging for Unraveling Mesoscopic Spatial-Temporal Correlations	Coherent GISAXS, XPCS	Visualizing nano-structured metamaterials in 3D for development of novel photonic materials and improved control of light-matter interaction
20-ID	HEXM	A High-Energy X-ray Microscope	High energy, high resolution diffraction microscopy and high energy CDI	Mesoscale grain dynamics under real conditions to develop new, more durable materials
19-ID	ISN	In Situ Nanoprobe	In-situ trace element, chemical state and structural imaging at 20 nm spatial resolution	Operando studies of element dependence of transport phenomena in new energy harvesting materials, catalytic processes, …





Provision for future SC arbitrary polarizing emitter (SCAPE)



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APS-U Key Performance Parameters

Key Performance Parameter	Thresholds (Performance Deliverable)	Objectives
Storage Ring Energy	> 5.7 GeV, with systems installed for 6 GeV operation	6 GeV
Beam Current	≥ 25 mA in top-up injection mode with systems installed for 200 mA operation	200 mA in top-up injection mode
Horizontal Emittance	< 130 pm-rad at 25mA	≤ 42 pm-rad at 200mA
Brightness @ 20 keV[1]	$> 1 \times 10^{20}$	$> 1 \times 10^{22}$
Brightness @ 60 keV[1]	$> 1 \times 10^{19}$	$> 1 \times 10^{21}$
New APS-U Beamlines Transitioned to Operations	7	≥ 9

[1]photons/sec/mm^2/mrad^2/0.1%BW

+ "Transition to Operations Parameters" for 9 new beamlines (brightness measurements)

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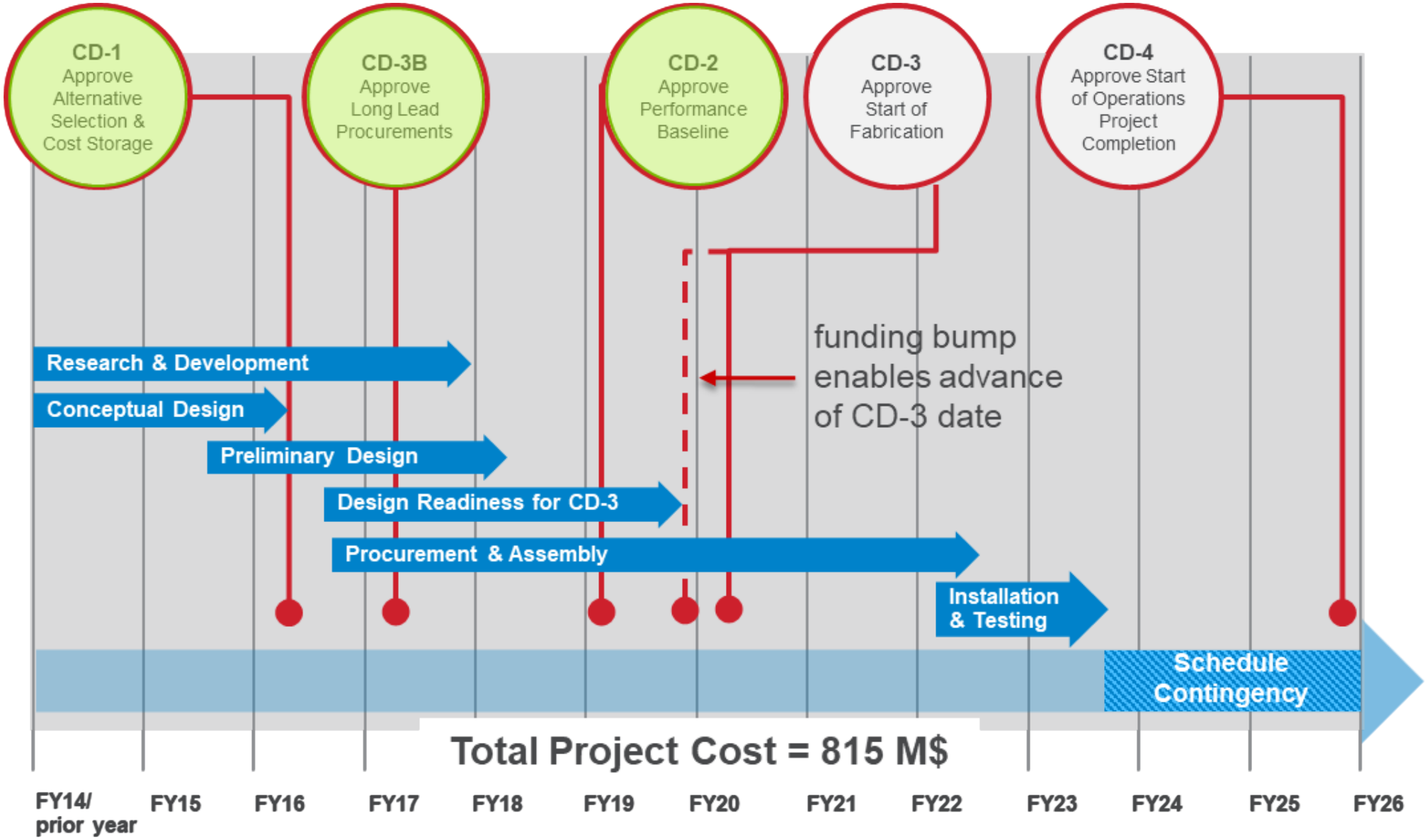
APS-U project is on schedule



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APS-U project is on schedule

Funding bump in FY18 and FY19:

- Enabled long lead procurement spending and early production of magnets, plinths, vacuum chambers, beamline components, power supplies, bunch lengthening system, etc.
- Enabled the project to really take off.

Production Q1 quadrupoles

Look ahead over next 12 months:

- Long beamline building civil construction under way
- Magnet measurement lab complete
- 1321 storage magnets on order
- All large power supplies on order
- Plinths and supports on order
- First experimental hutch built
- Most beamline beam delivery systems and hutches on order
- And much more

SC bunch lengthening cavity cryo-vessel

SC bunch lengthening cavity

Shielded enclosure panels

ID chamber extrusions

Photon stoppers

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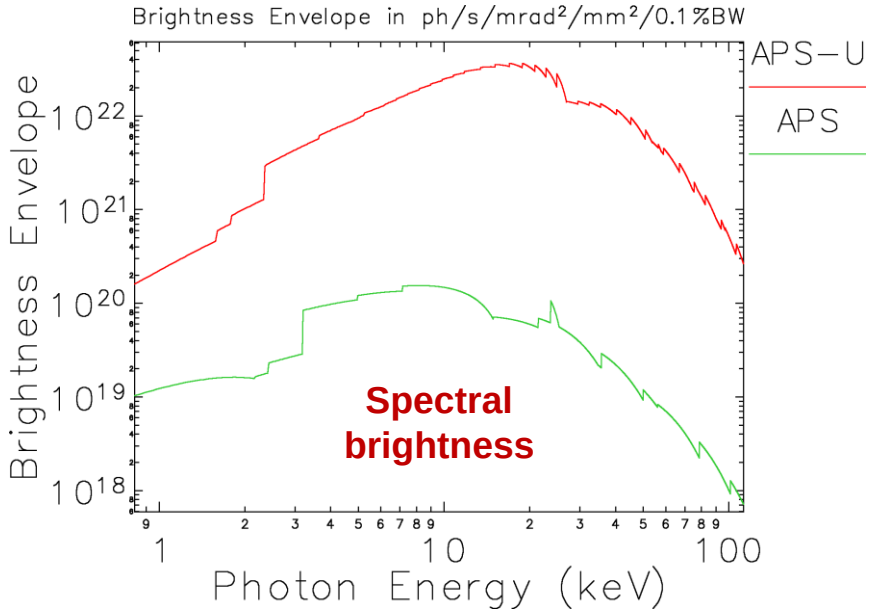
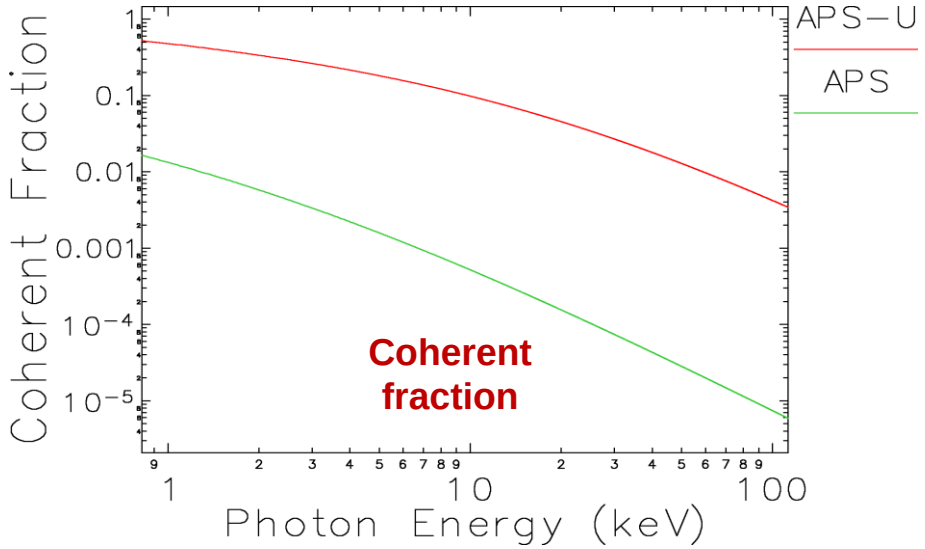
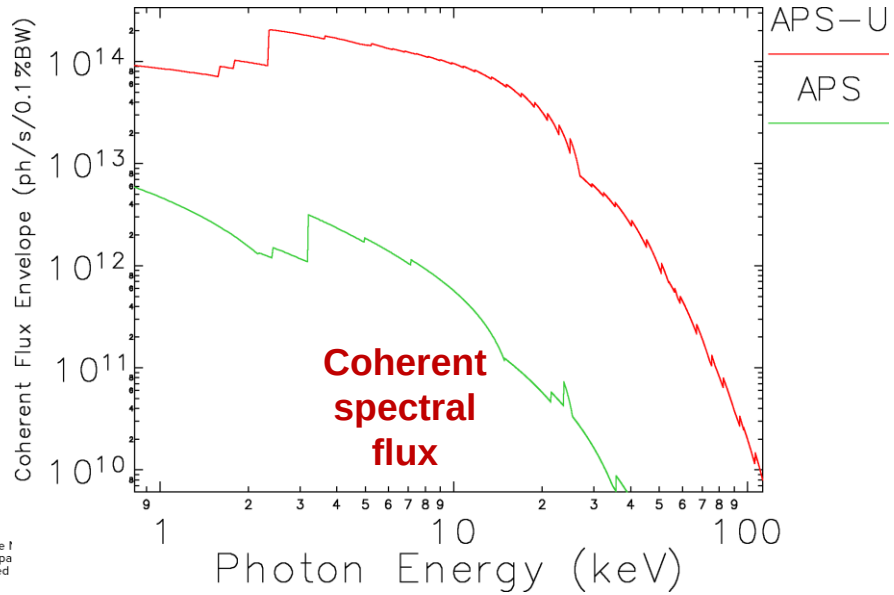
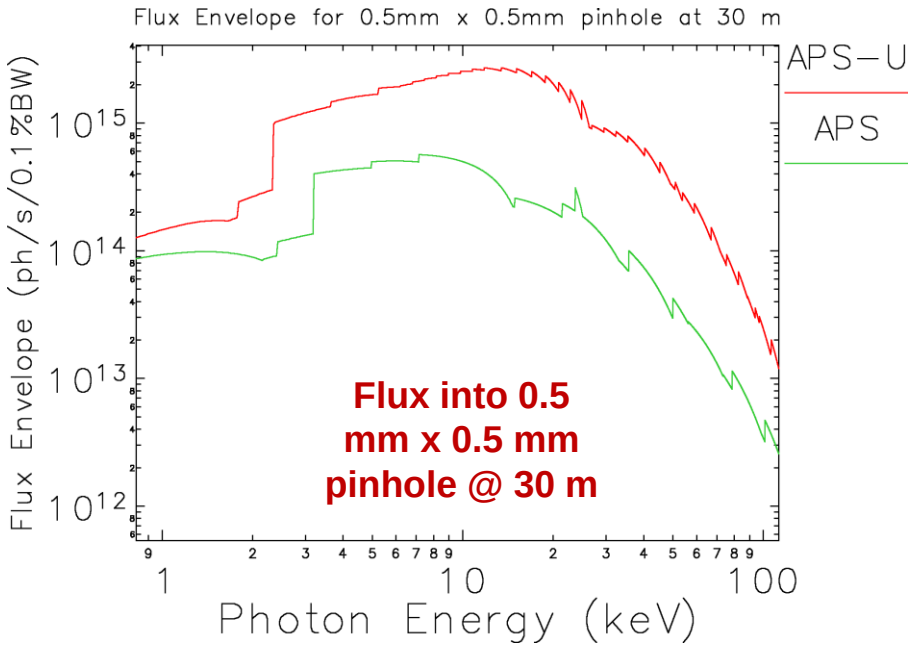
back-up

APS-U Brightness and Coherence



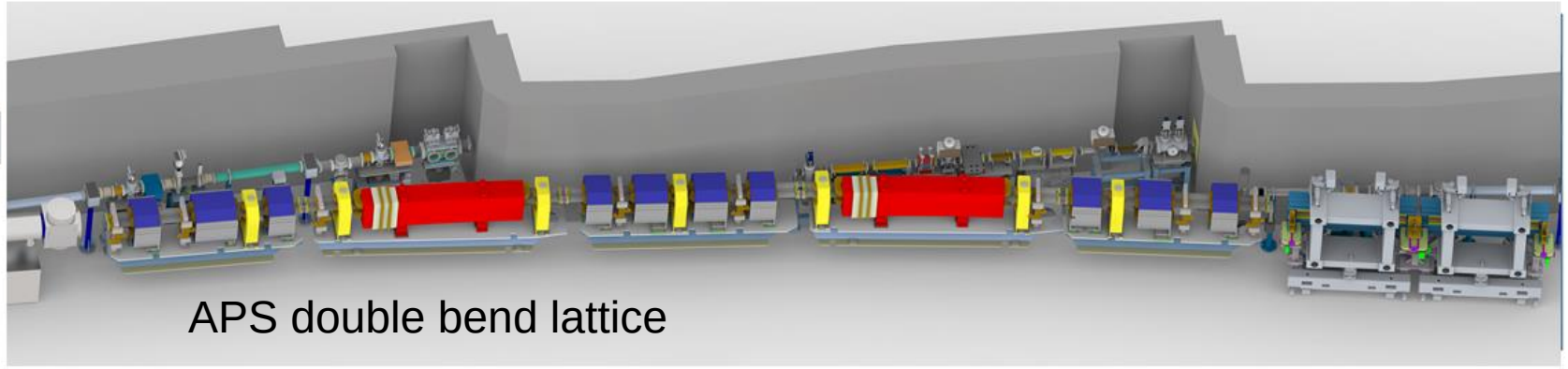


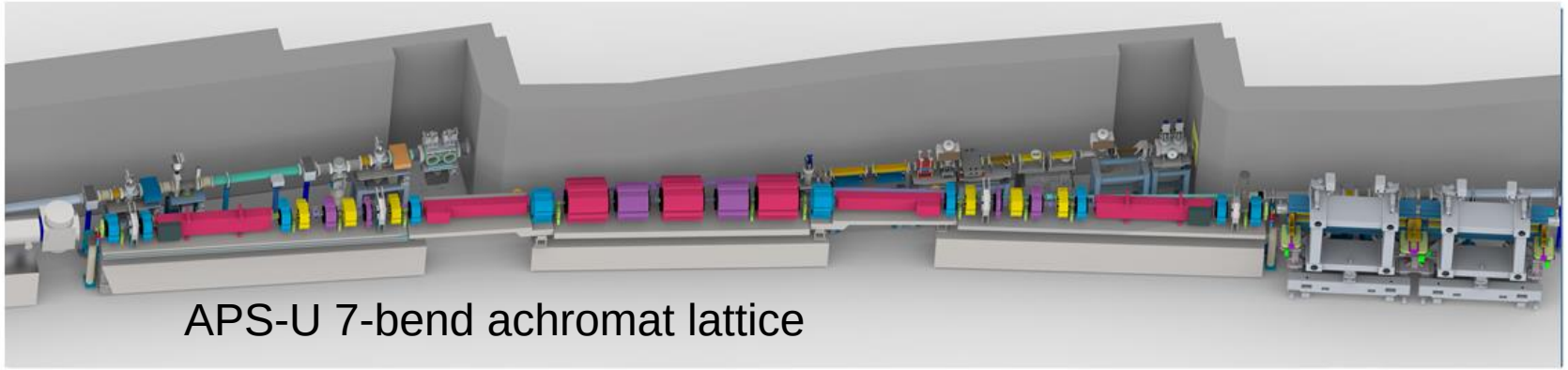




APS-U – High brightness storage ring lattice

~70-fold reduction in horizontal emittance





Hybrid 7BA lattice with longitudinal gradient, transverse gradient and reverse bend dipoles

$$\varepsilon \propto \frac{E^2}{(N_D N_S)^3}$$

N_D = # dipoles/sector
N_S = # sectors