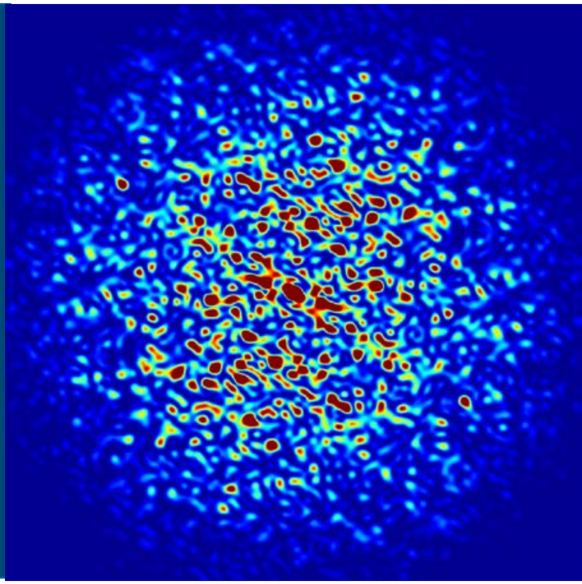
The APS Upgrade Project Status



Robert Hettel
Director, APS Upgrade Project
Argonne National Laboratory

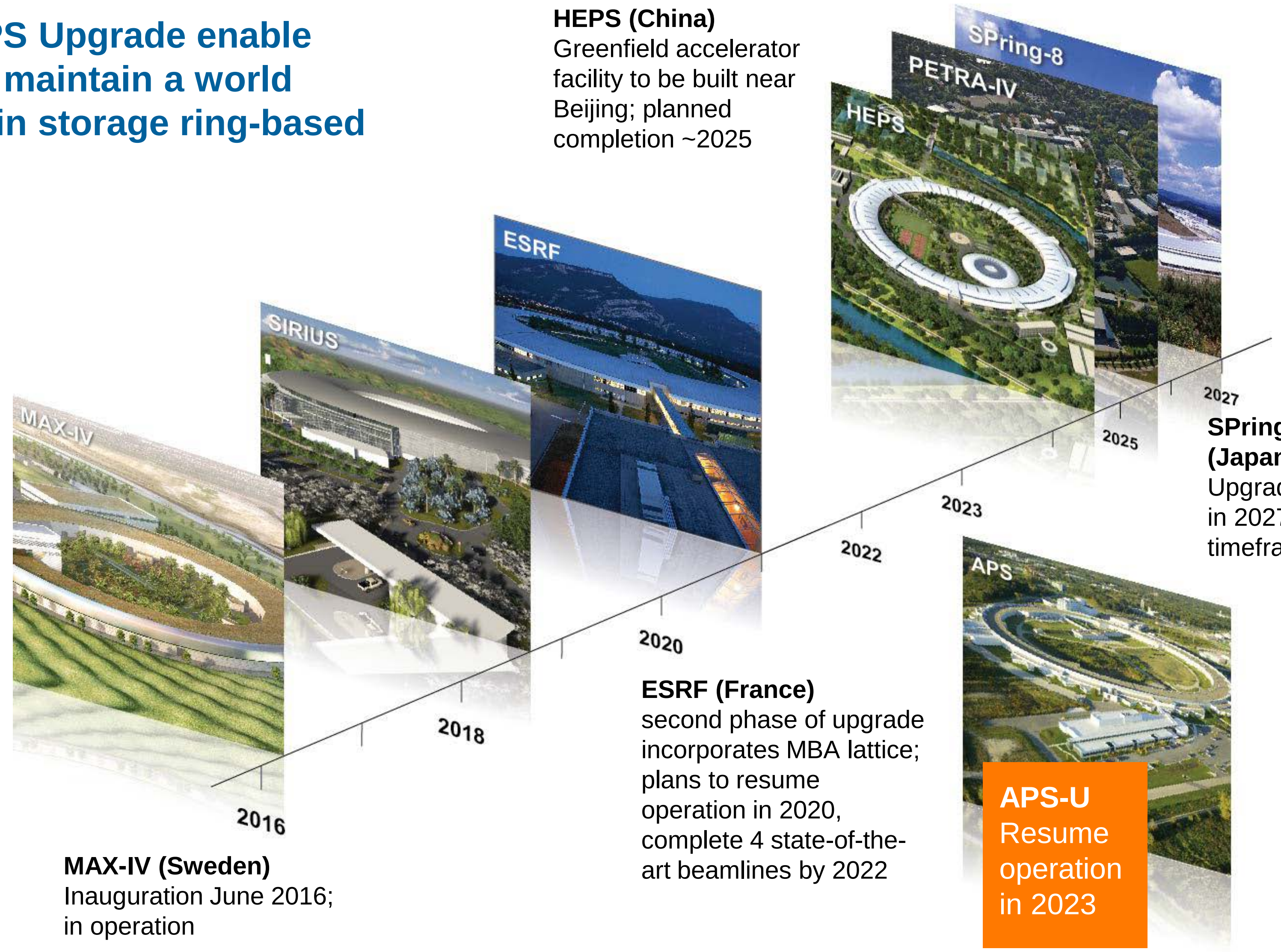
APSUO/PUC Meeting

October 24, 2018

International High Energy 4GSR Development

Our plans for the APS Upgrade enable the United States to maintain a world leadership position in storage ring-based x-ray sources

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



SPring-8 (Japan)
Upgrading in 2027 timeframe

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

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

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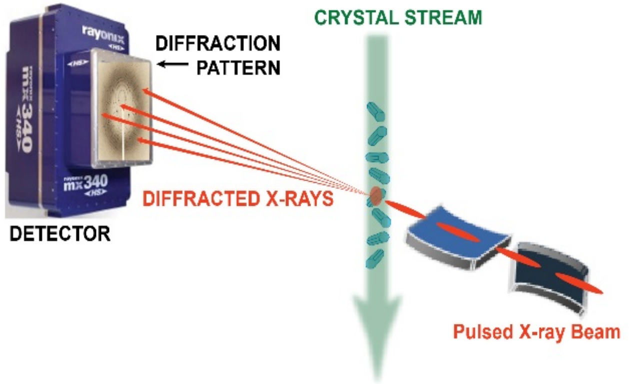
THE APS Upgrade:
building a world-leading hard X-ray facility

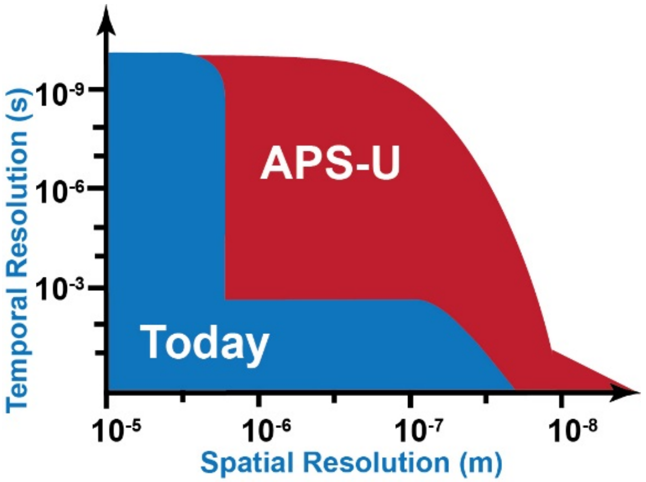
Small-Beam Scattering & Spectroscopy

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



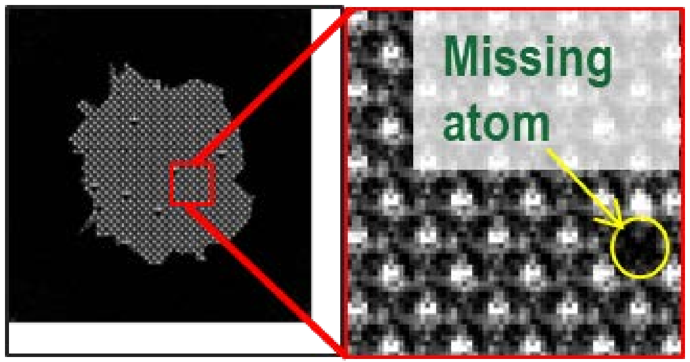
Resolution with Speed

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

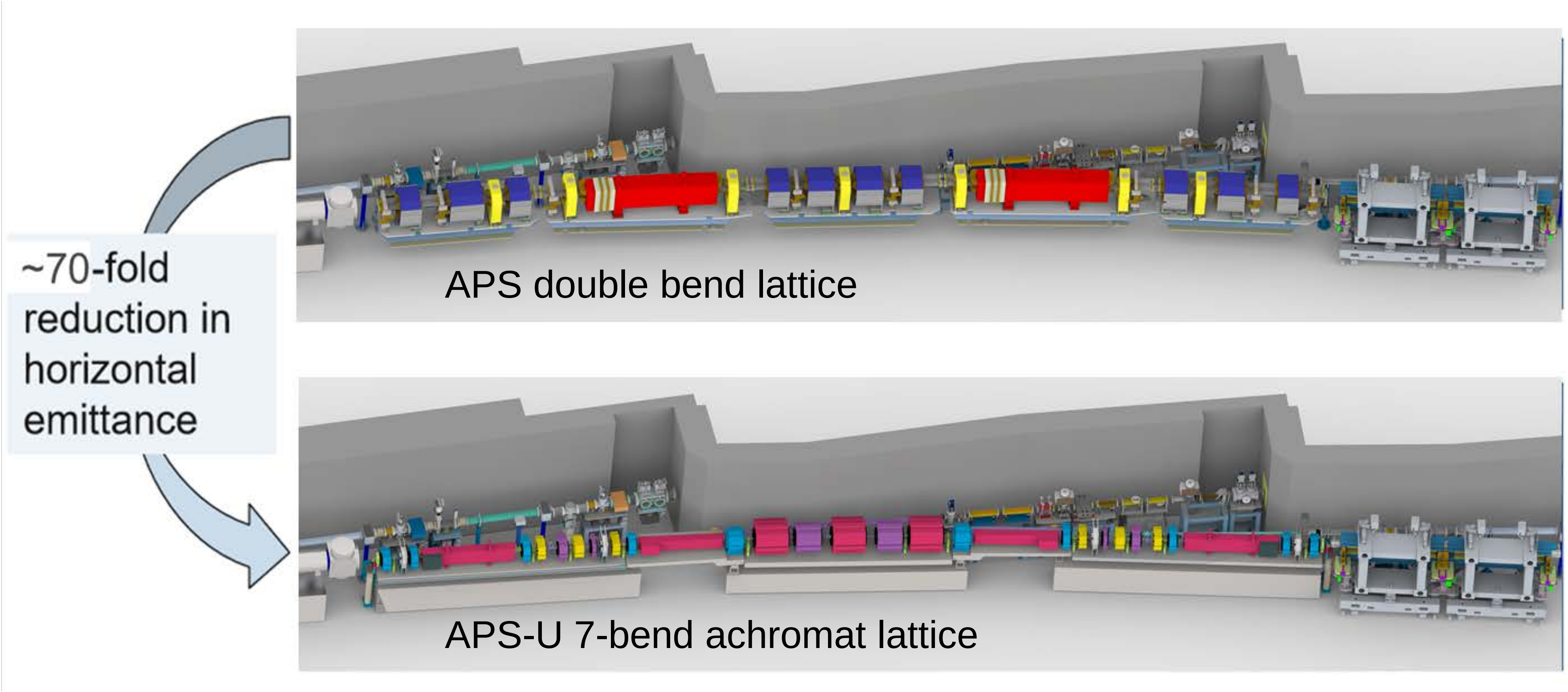


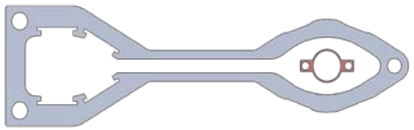
Coherent Scattering & Imaging

- 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,



APS-U – High Brightness Storage Ring Lattice



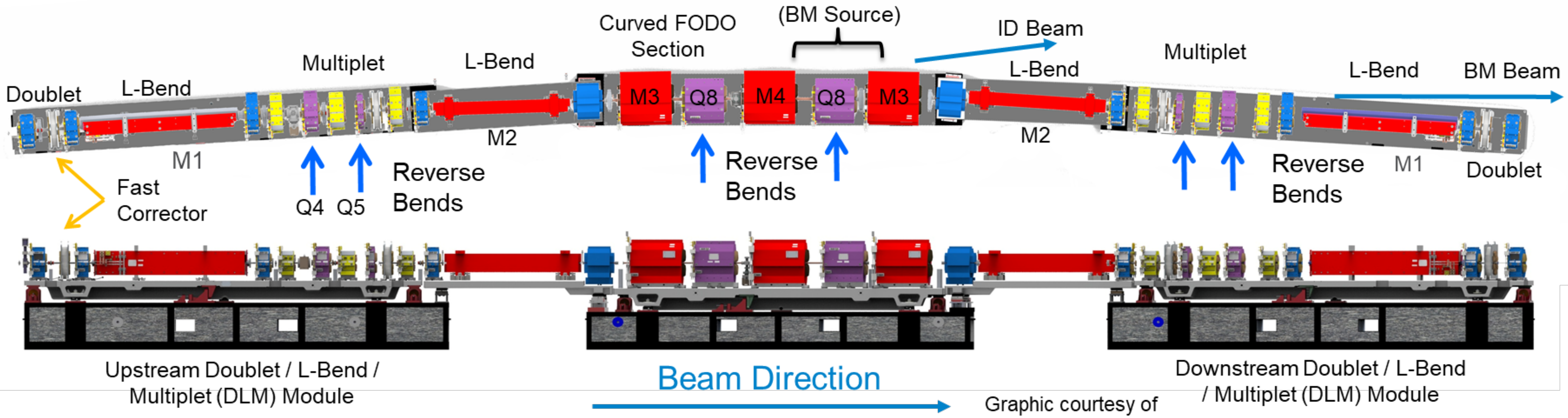


APS and APS-U chambers

100x – 1000x increase in brightness and coherence of Ångstrom and sub-Ångstrom X-rays

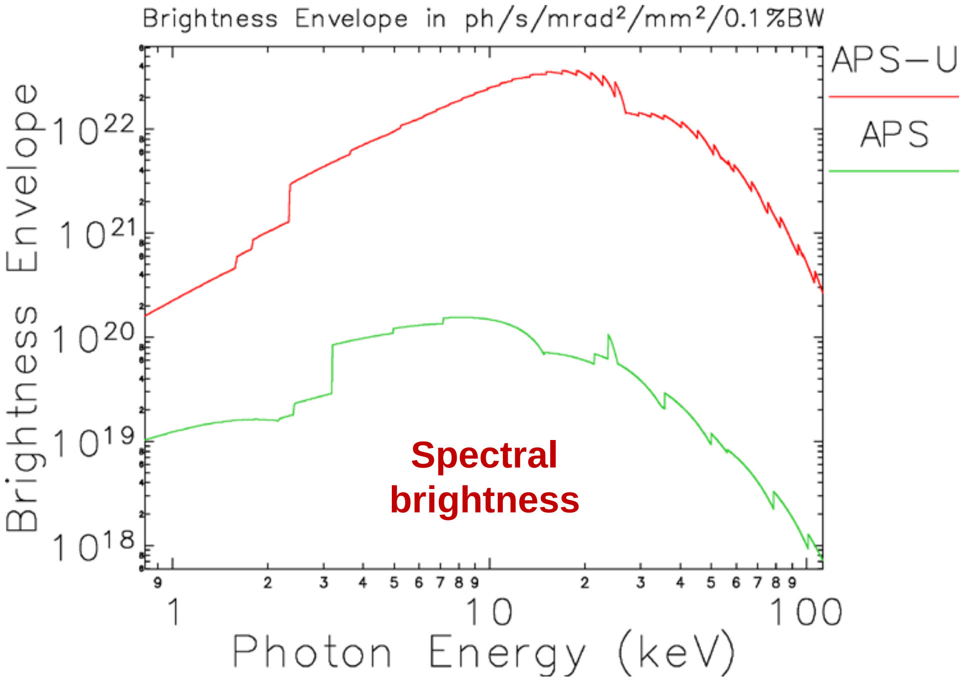
APS-U Lattice

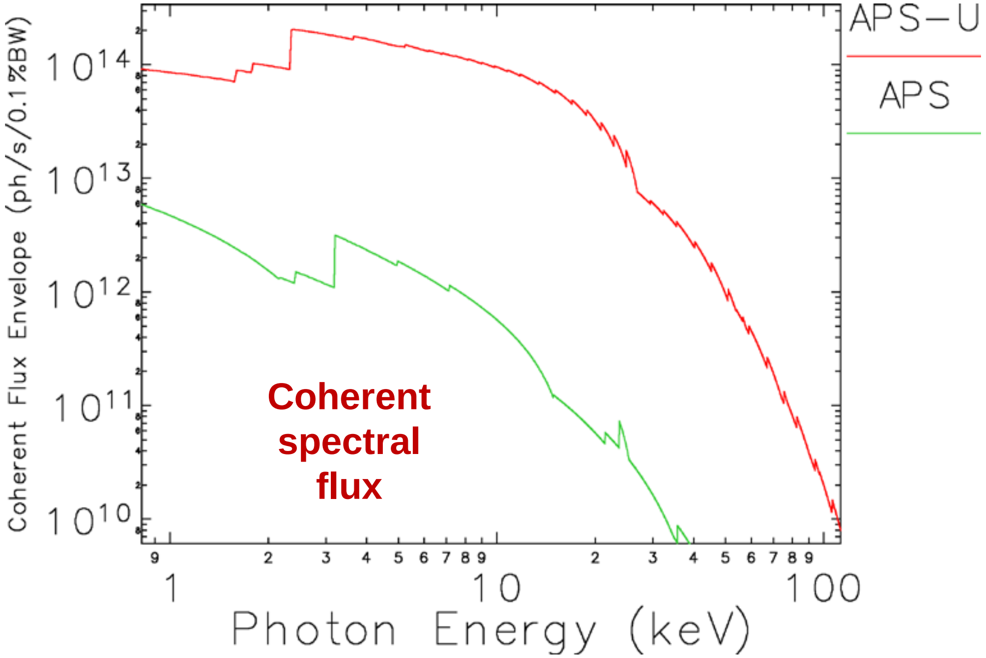
- Storage ring consists of 40 Sectors. Each with 33 arc magnets; 27.6 meters / sector
- Each sector is hybrid 7BA (Raimondi et al., ESRF) with longitudinal bends and reverse bends (Streun et al., PSI). (First standard 7BA built for MAX-IV.)
- Vacuum systems integrated with magnets, supports, insertion devices, front ends

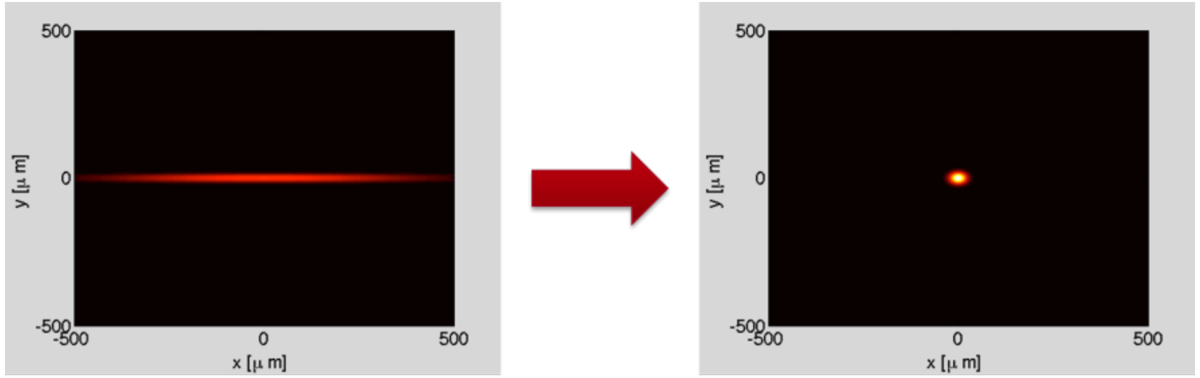


Graphic courtesy of J. Nudell, AES-MED

APS-U ensures that the United States maintains world leadership in light sources







APS-U Parameters

Quantity	APS Now	APS MBA Timing Mode	APS MBA Brightness Mode	Units
Beam Energy	7	6	6	GeV
Beam Current	100	200	200	mA
Number of Bunches	24	48	324	
Bunch Duration (rms)	34	104	88	ps
Energy Spread (rms)	0.095	0.156	0.130	%
Bunch Spacing	153	77	11	ns
Emittance Ratio	0.013	1	0.1	
Horizontal Emittance	3100	31.9	42.2	pm-rad
Horizontal Beam Size (rms)	275	12.6	14.5	μm
Horizontal Divergence (rms)	11	2.5	2.9	μrad
Vertical Emittance	40	31.7	4.2	pm-rad
Vertical Beam Size (rms)	10	7.7	2.8	μm
Vertical Divergence (rms)	3.5	4.1	1.5	μrad

APS-U Preliminary Design Report, September 2017

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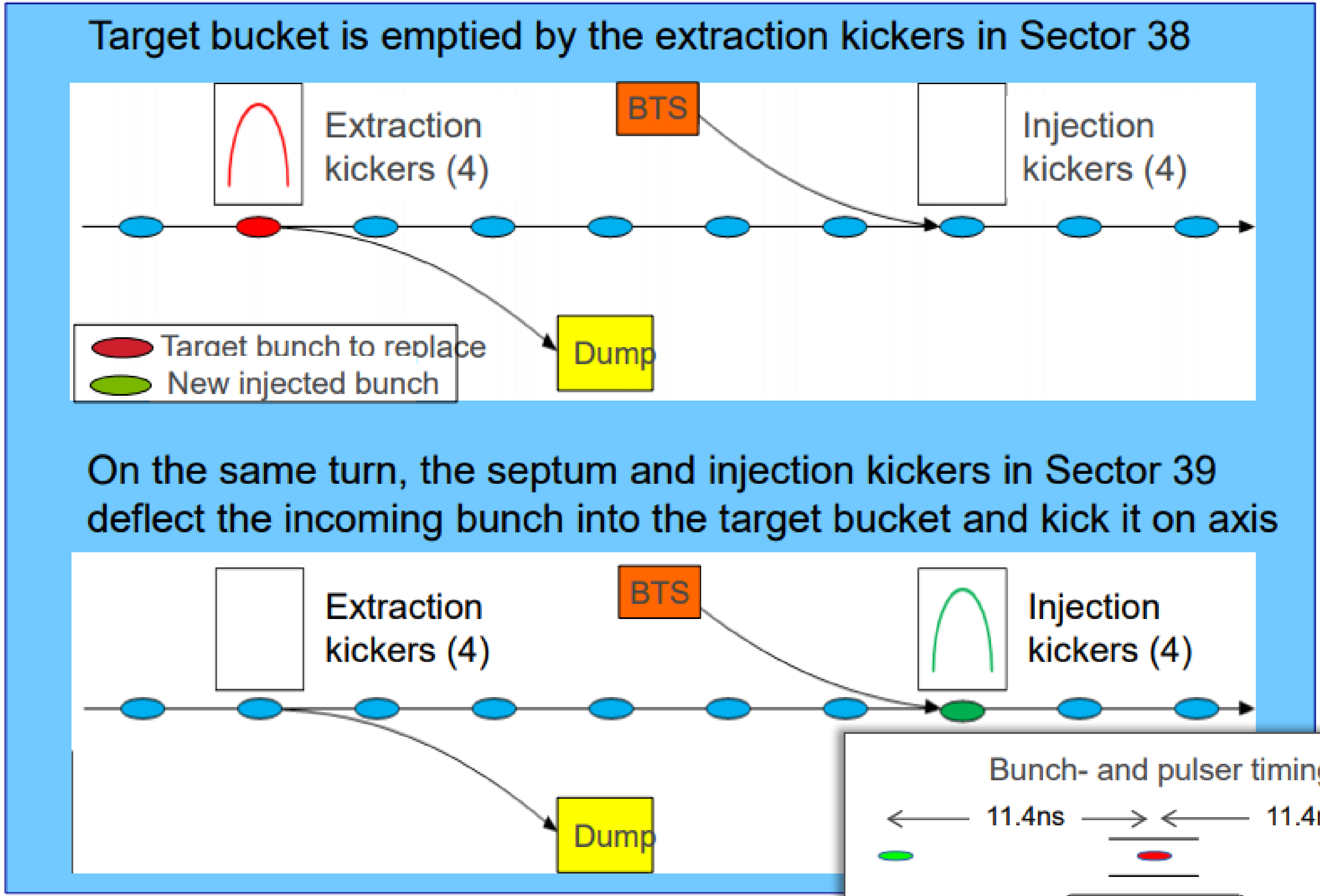
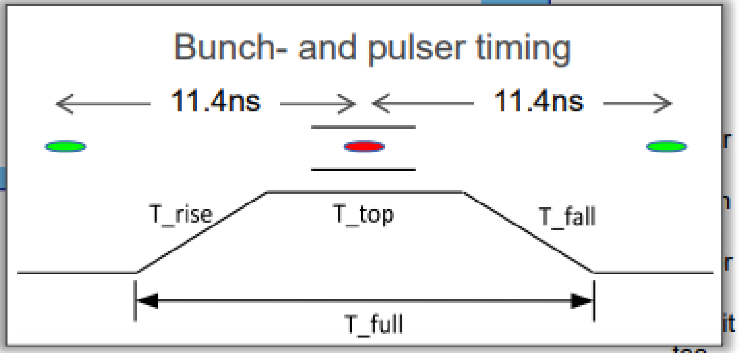
Bunch Swap-Out Injection

Emery and Borland, 2003

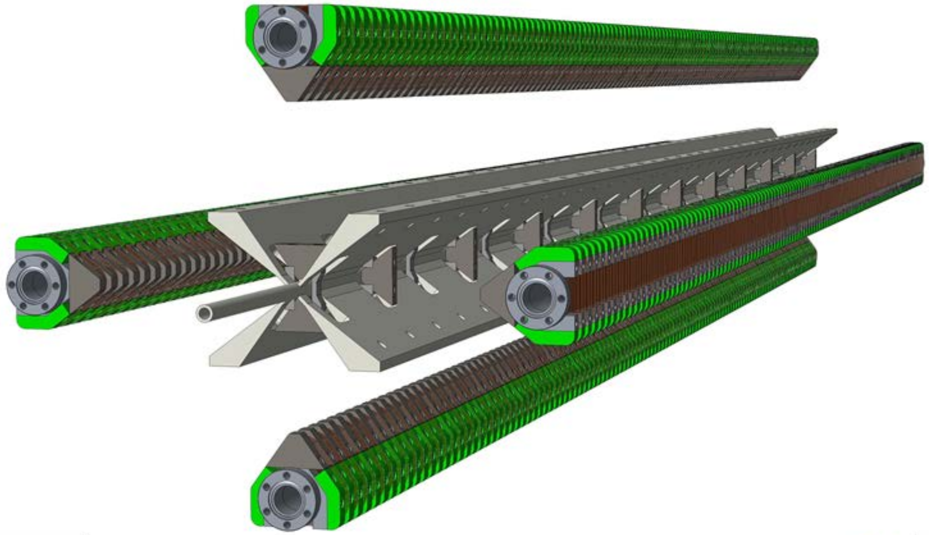
- Requires 2 nC per shot for 372-bunch, 200-mA high brightness mode
- Requires 16 nC per shot for48-bunch, 200 mA timing mode – a challenge for the Injector at the moment

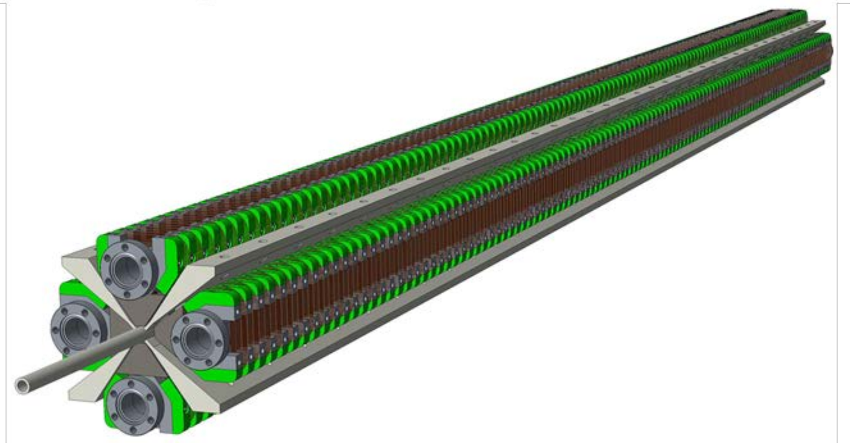




Novel Insertion Devices – SCAPE
(NOT INCLUDED IN PROJECT)

- APS-U small, round vacuum chambers (6 mm diam)
  - Novel polarizing SCUs
  - Superconducting Arbitrary Polarizing Emitter → **SCAPE**
- Polar beamline
  - Significant upgrade to 4-ID
  - Goal is fast switching circular or linear polarization
  - *In situ* experiments on magnetic materials
- Does not impact KPPs



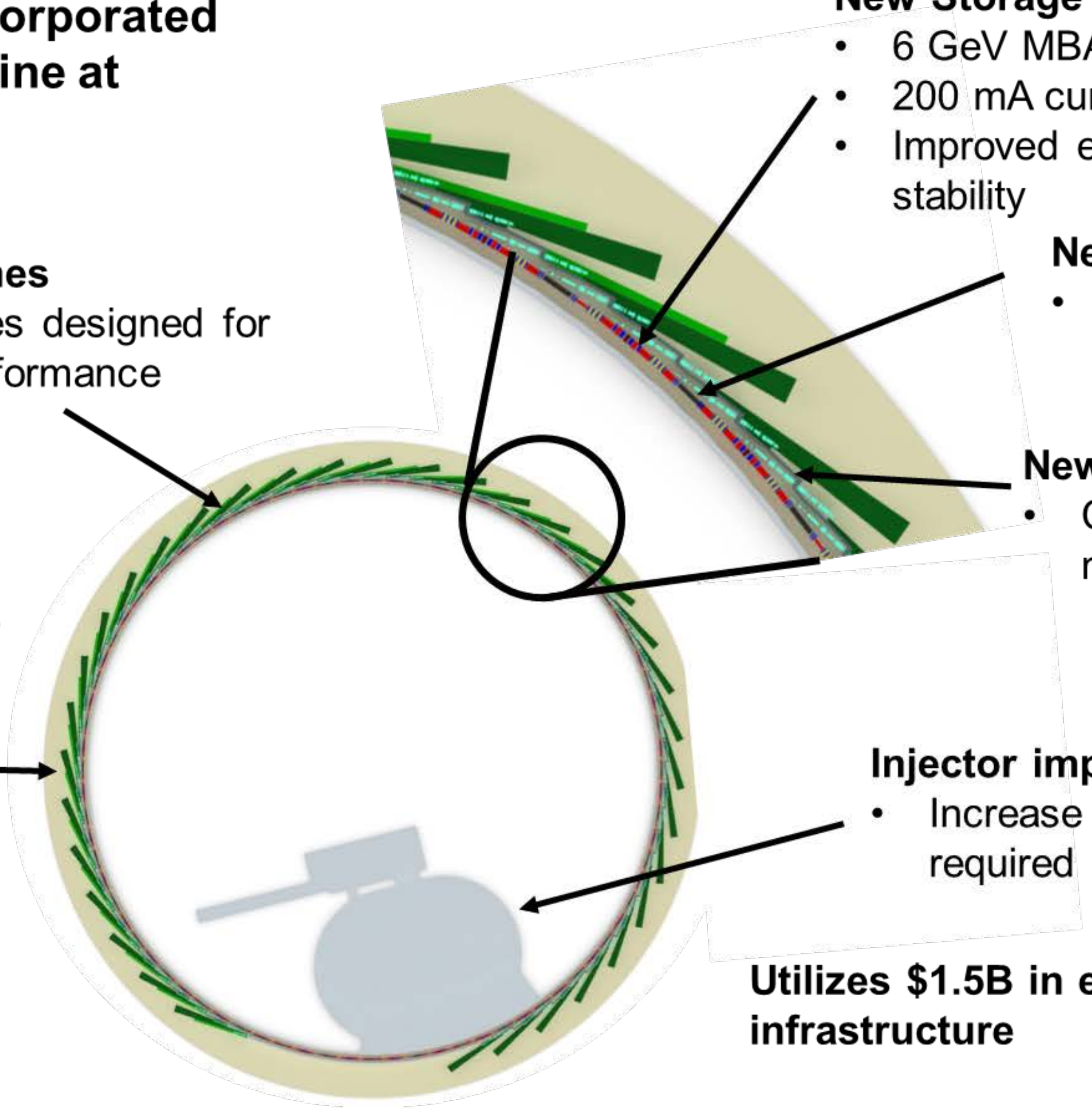


APS-U Project Scope

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"



New Storage Ring
- 6 GeV MBA lattice
- 200 mA current
- Improved electron/photon stability

New Insertion Devices
- Incorporate SCUs on selected beamlines

New/upgraded Front-ends
- Common design for maximum flexibility

Injector improvements
- Increase performance as required to meet APS-U needs

Utilizes $1.5B in existing infrastructure

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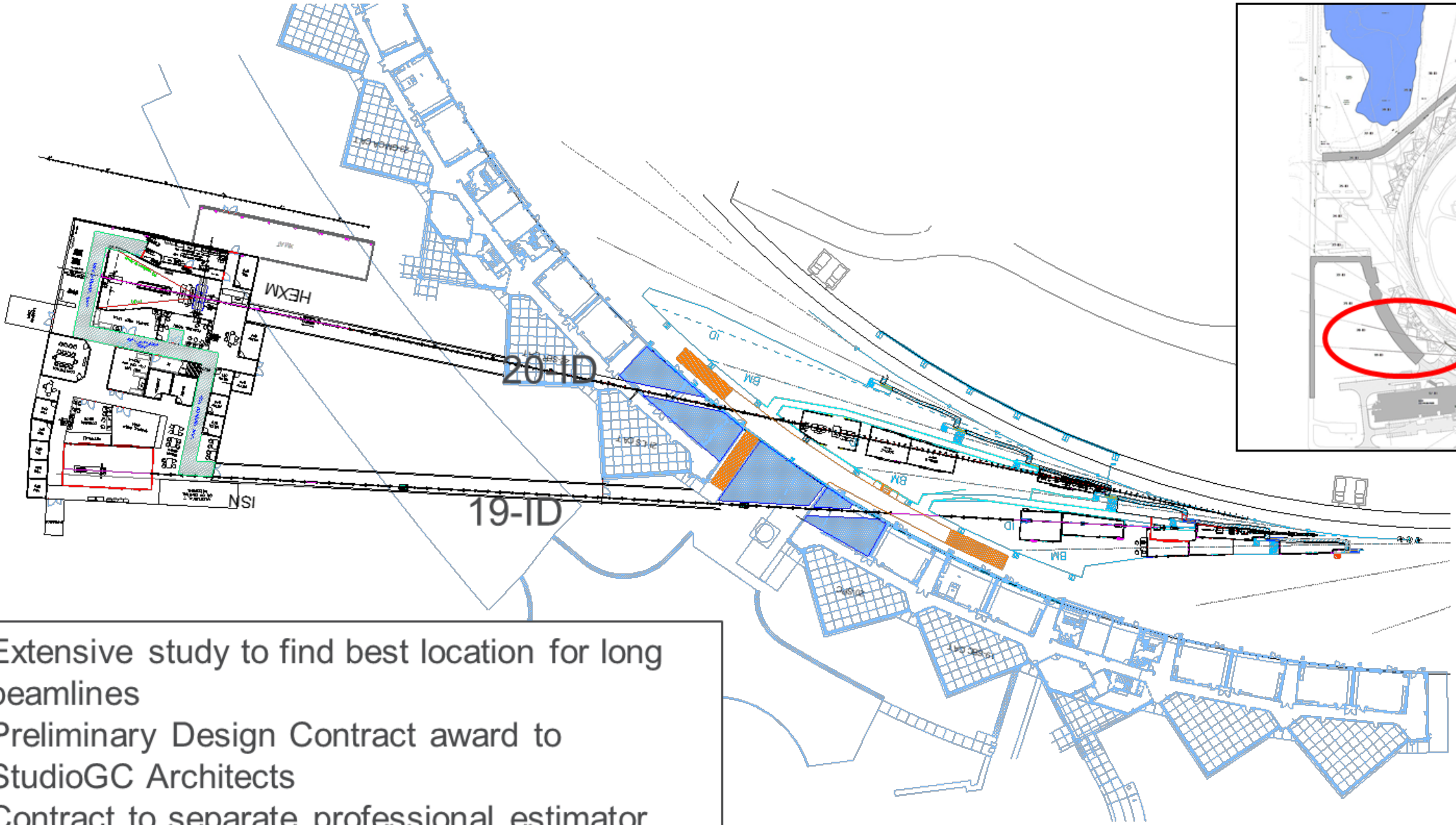
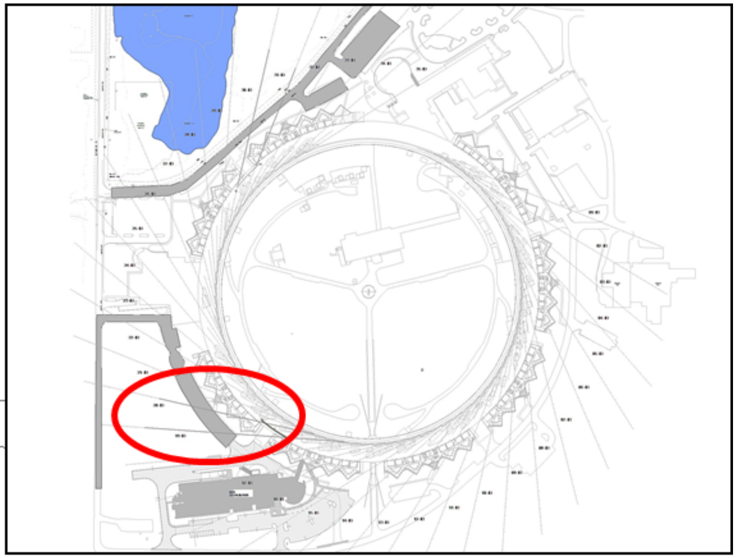
APS-U Feature Beamlines

Location	Name	Title	Science Lead	Technique
28-ID	CHEX	Coherent High-Energy X-ray Sector for In Situ Science	Robert Winarski Brian Stephenson	*In situ*, surface high-energy coherent scattering
4-ID	Polar	Polarization modulation spectroscopy	Daniel Haskel	Magnetic spectroscopy
20-ID	HEXM	A High-Energy X-ray Microscope	Sarvjit Shastri Jon Almer	High-energy microscopies & CDI
8-ID	XPCS	Development of a Small-Angle X-ray Photon Correlation Spectroscopy Beamline for Studying Dynamics in Soft Matter Wide-Angle X-Ray Photon Correlation Spectroscopy and Time-Resolved Coherent X-Ray Scattering Beamline	Suresh Narayanan Alec Sandy	Small-angle XPCS Wide-angle XPCS
33-ID	Ptycho	PtychoProbe	Volker Rose	Ultimate resolution, forward scattering ptychography/spectromicroscopy
19-ID	ISN	InSitu Nanoprobe Beamline	Jörg Maser	*In-situ*, forward scattering ptychography/spectromicroscopy Long working distances
9-ID	CSSI	Coherent Surface Scattering Imaging Beamline for Unraveling Mesoscopic Spatial-Temporal Correlations	Jin Wang Jiang Zhang	Coherent GISAXS, XPCS
34-ID	ATOMIC 3DMN	Atomic – A beamline for extremely high resolution coherent imaging of atomistic structures 3D Micro & Nano Diffraction	Ross Harder Jon Tischler	Diffraction microscopy & CDI Bragg CDI Upgrade of current 34-ID

+ enhancements of X-ray optics, instrumentation and end station components for many existing beamlines

Long Beamline Building Conceptual Design





- Extensive study to find best location for long beamlines
- Preliminary Design Contract award to StudioGC Architects
- Contract to separate professional estimator will be awarded soon

Photon Transport Simulation Tools

Levels of simulation: accuracy vs efficiency

Analytical method

- Mathematica/Excel
- Gaussian beam profile
- Optics acceptance
- Focusing condition using geometric magnification and diffraction formula
- Fast optimization of the beamline layout with reasonable accuracy

Numerical method

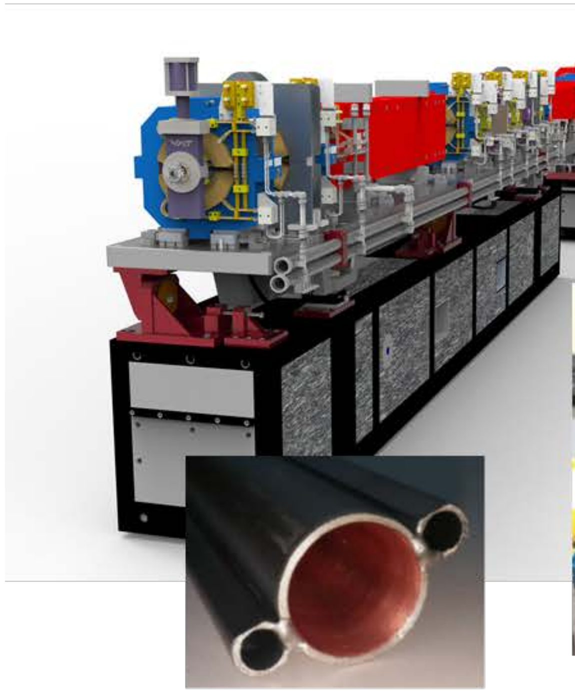
- *SHADOW*, Ray, McXtrace, xrt
- ***HYBRID*** (add diffraction)
- SRW, Phase
- More accurate source profile
- Effects of non-ideal optics
- Effects of optics vibration and misalignment
- Beam intensity, spot size, divergence, and energy spectra
- Optics specification and mechanical requirements

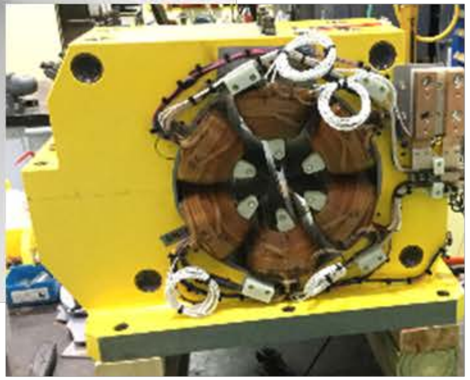
Mutual coherence

- **The Mutual Optical Intensity (MOI) model**
- Multi-electron SRW
- Coherent mode decomposition method
- Comsyl
- Partially coherent source and propagation through optics
- Local coherence and wavefront

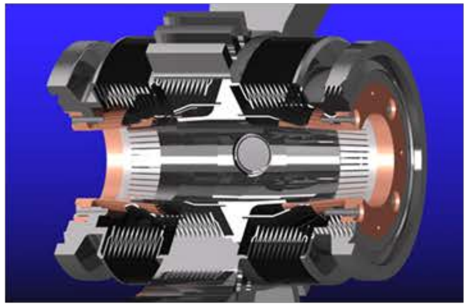
Cohberent wavefront preservation

APS-U Accelerator Technology

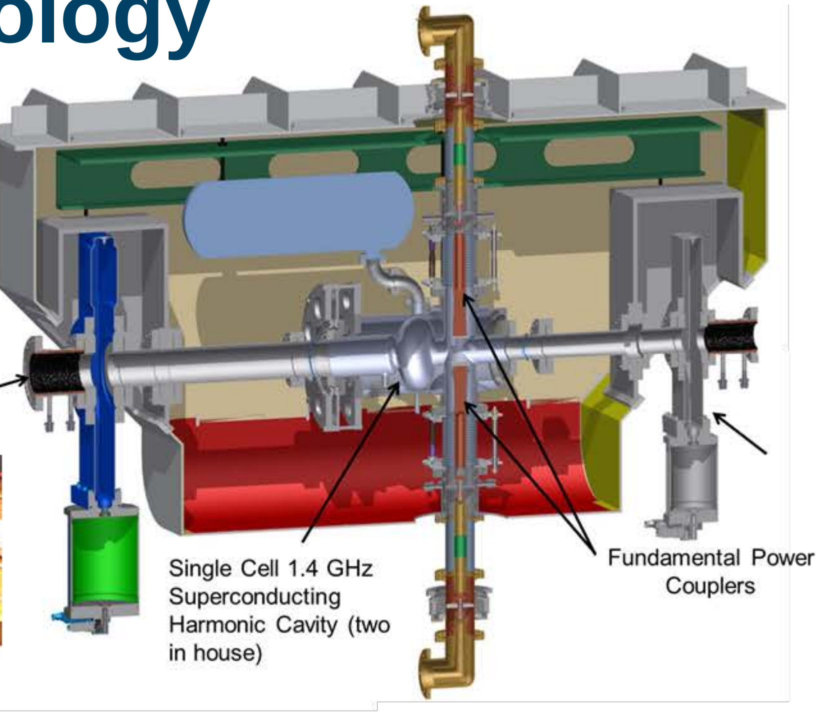


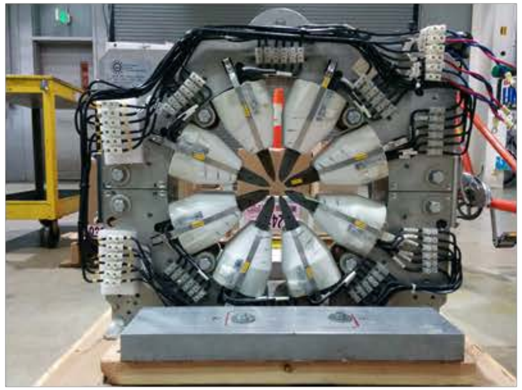


Sextupole



In-House Design
Fast Bipolar Power Supply*

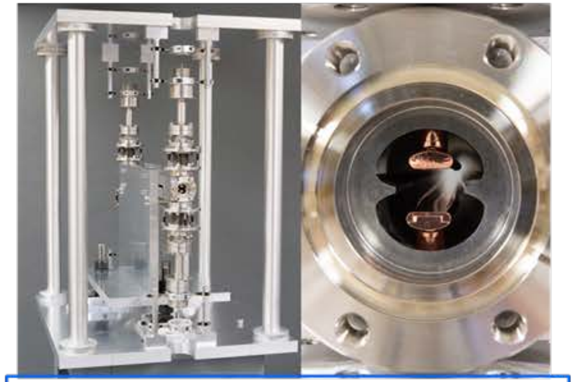




8-Pole Corrector

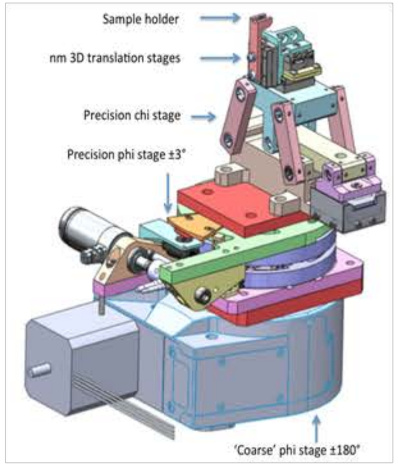
Q-Bend Magnets M3,M4

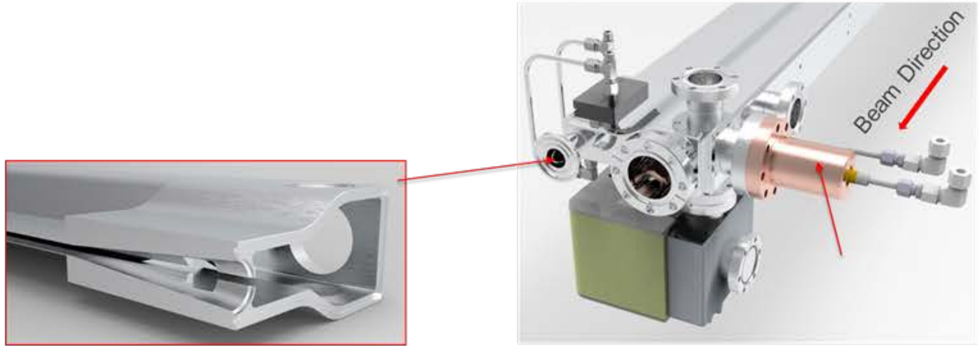
M1 Longitudinal-Gradient Dipole



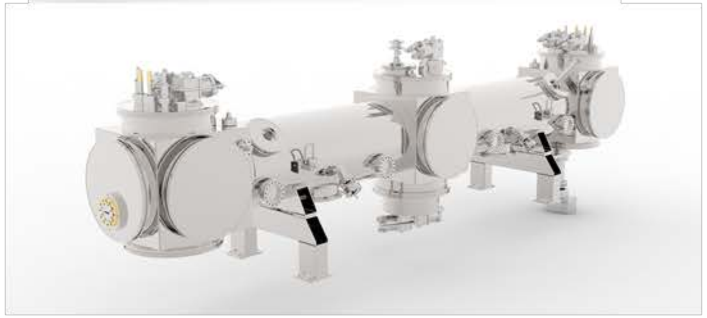
Prototype Stripline Kicker used for successful BTX Beam Tests

APS-U Beamline and ID Technology

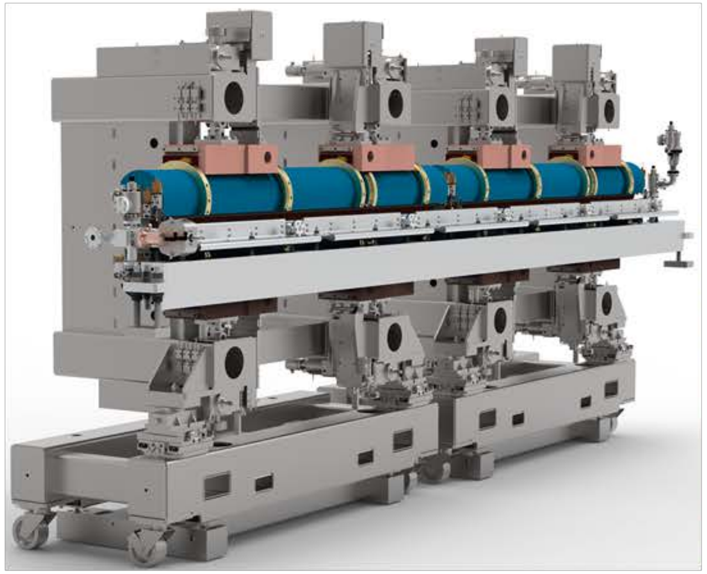




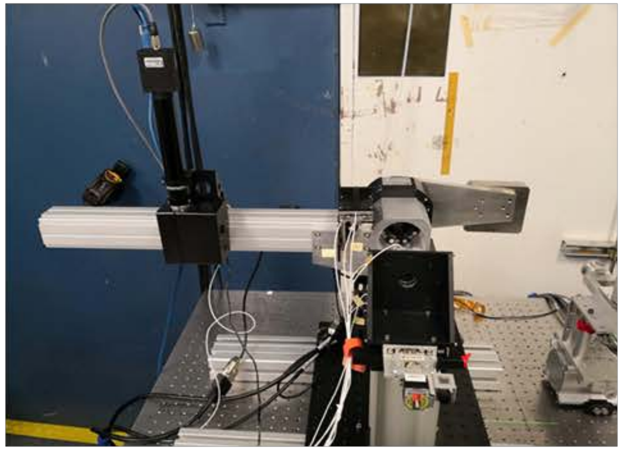

superconducting ID




Velociprobe: fast scanning nano-probe


revolver IDs


high heat load front end


prototype compact wavefront sensor

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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	$\geq$ 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	$\leq$ 42 pm-rad at 200mA
Brightness @ 20 keV[1]	> 1 x 10^{20}	> 1 x 10^{22}
Brightness @ 60 keV[1]	> 1 x 10^{19}	> 1 x 10^{21}
New APS-U Beamlines Transitioned to Operations	7	$\geq$ 9

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

A Transition to Operations Plan is being developed

Beamline Transition to Operations Parameters

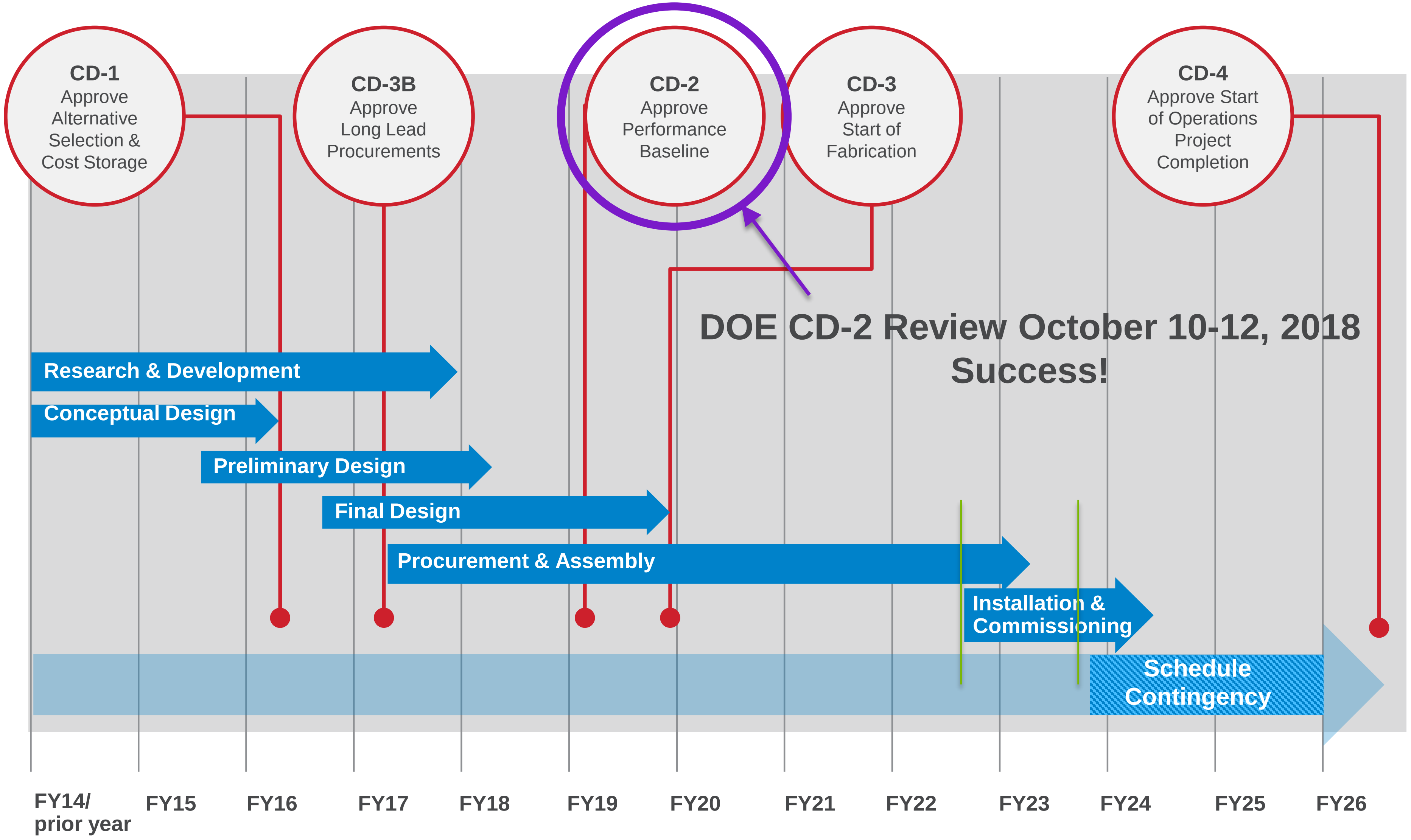
Beamline	TTOP Brightness[1] Thresholds	TTOP Brightness[1] Objectives	TTOP Energy (keV)	Energy Range (keV)	Description
Polar	> 5.7 x 10^{19}	> 8.4 x 10^{21}	9	2.75 – 27	Magnetic spectroscopy beamline with polarization control for studies of electronic materials at extreme conditions. Beamline can take full advantage of novel polarizing undulators developed for the APS-U storage ring.
XPCS	> 1.0 x 10^{20}	> 7.5 x 10^{21}	20	8 – 25	X-ray photon correlation spectroscopy beamline with instruments for small- and wide-angle scattering designed for the study of dynamic heterogeneity in complex materials.
CSSI	> 5.0 x 10^{19}	> 3.8 x 10^{21}	20	6 – 30	Coherent surface scattering imaging beamline to explore the structure and dynamics of low dimensional, mesoscale, heterogeneous systems.
ISN	> 5.0 x 10^{19} Focus[2] < 50 nm	> 7.5 x 10^{21} Focus[2] < 20 nm	20	4.8 – 30	A scanning nanoprobe optimized for large working distances and in situ experiments
HEXM	> 1.0 x10^{19}	> 2.2 x10^{21}	60	35 – 120	High-energy x-ray microscope for experiments on in situ environments for materials science and engineering applications.
CHEX	> 4.5 x 10^{19}	> 3.3 x 10^{21}	20	5 – 60	One tunable and three fixed-energy beamlines designed for coherent, high-energy x-ray in-situ diffraction studies of materials synthesis and chemical transformations.
Ptycho	> 1.5 x 10^{20} Focus[2] < 50 nm	> 1.8 x 10^{22} Focus[2] < 5 nm	10	5 – 30	Ultimate spatial resolution, ultra-fast scanning nanoprobe with ptychography for extremely high-resolution structural measurements.
ATOMIC	> 4.5 x 10^{19}	> 3.4 x 10^{21}	20	5 – 30	Bragg coherent diffraction imaging to study materials with spatial resolution of one nm or better. Zoom optics allow variable spot sizes so that the x-ray probe can be matched to the needs of individual experiments.
3DMN	> 2.9 x 10^{19}	> 2.5 x 10^{21}	20	5.3 – 30	3D diffraction nanoscope using both pink and monochromatic x-rays to study materials structure and mechanical behavior.

- Brightness measurement required for each new beamline.
- For completion of beamline transfer to operations: Threshold TTOP must be met or exceeded; key equipment is verified to be in place and working

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

[2] FWHM

APS-U Project Schedule



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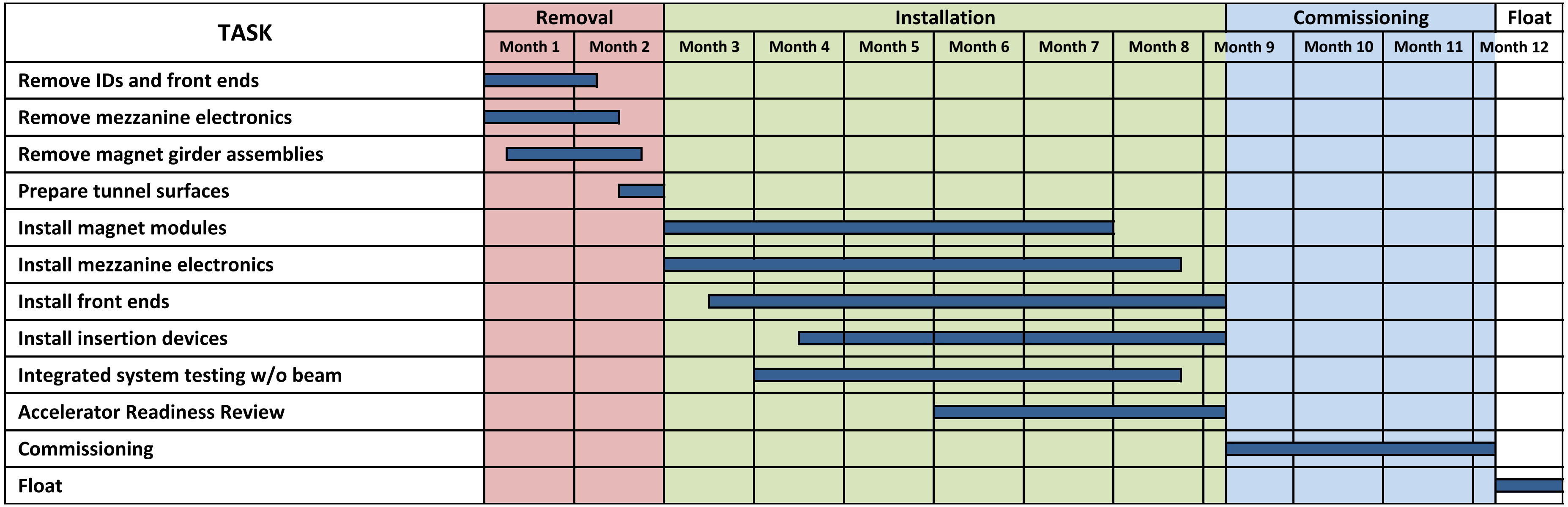
Removal, Installation, and Commissioning Schedule



- The plan was developed from the bottom up.
- The plan has been reviewed multiple times.
- Consensus: The plan is achievable

APS-U Budget and Funding Profile for CD-2

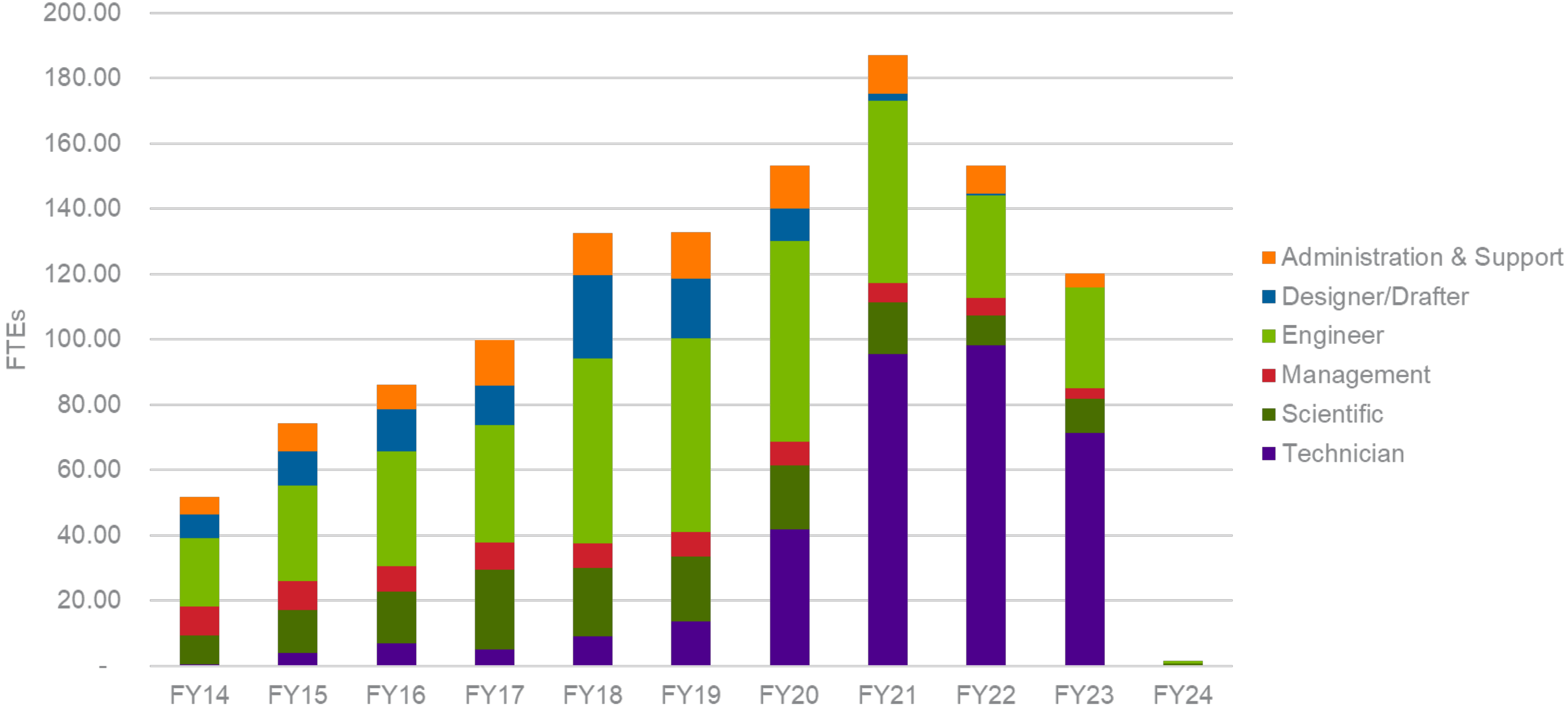
WBS Element	WBS Description	Total Estimated Cost ($M)
	Total Estimated Cost (TEC)	
U1	**APS Upgrade Project – previous scope costs**	**35.4**
U2	**APS Upgrade Project – Multi Bend Achromat**	**610.7**
U2.01	Project Management	57.9
U2.02	Conceptual Design and Development	49.4
U2.03	Accelerator Systems	250.0
U2.04	Experimental Facilities	186.2
U2.05	Front Ends and Insertion Devices	67.2
	Contingency(TEC)	**150.4**
	Sub-total (TEC)	**796.5**
	Other Project Cost (OPC)	
U1	**APS Upgrade Project – previous scope OPC**	**8.5**
U2	**APS Upgrade Project – MBA OPC**	**7.1**
	Contingency (OPC)	**2.9**
	Sub-total (OPC)	**18.5**
	Total Project Cost	**815.0**

- **30% cost contingency**
- **28 months schedule contingency**
- **scope contingency under evaluation**
- **long lead procurements in process (CD-3b)**

Funding (BA) in Millions of Dollars (Then-year Dollars)

	All Prior Years	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	Total
OPC	8.5									5.0	5.0	18.5
TEC	40.0	20.0	20.0	20.0	42.5	93.0	130.0	150.0	159.8	121.2		796.5
Total	48.5	20.0	20.0	20.0	42.5	93.0	130.0	150.0	159.8	126.2	5.0	815.0

FTEs by Resource Type



- Ramping up Project staff as proceed to CD-3
- APS Operations-funded staff will participate in accelerator and beamline commissioning

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Safe practices are an utmost priority for ANL and the APS-U project

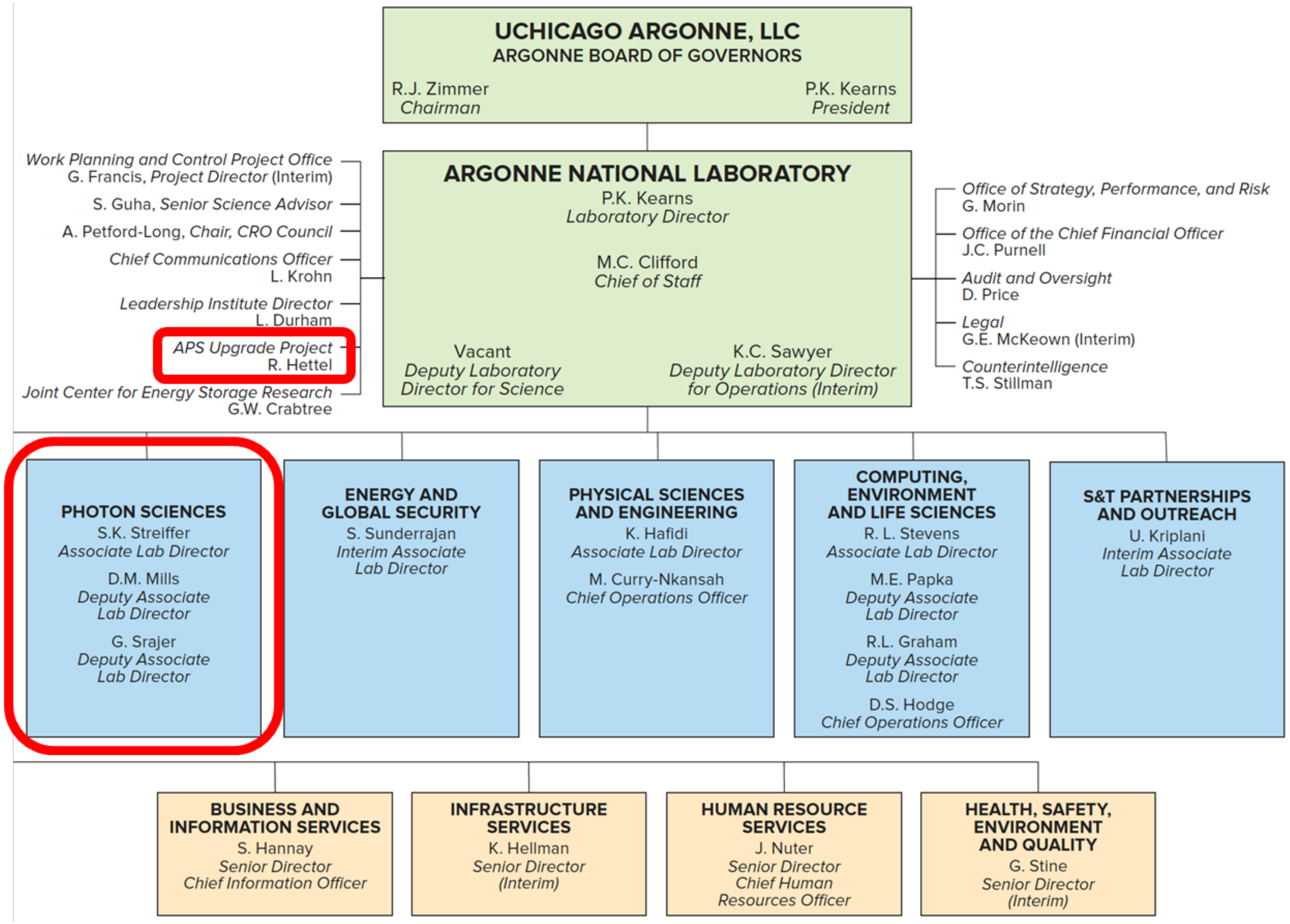
Worker Safety

- Exemplary ES&H performance is essential for the successful execution and completion of this project
- We are committed to a strong Integrated Safety Management approach for the Project; we strive to prevent all accidents and injuries

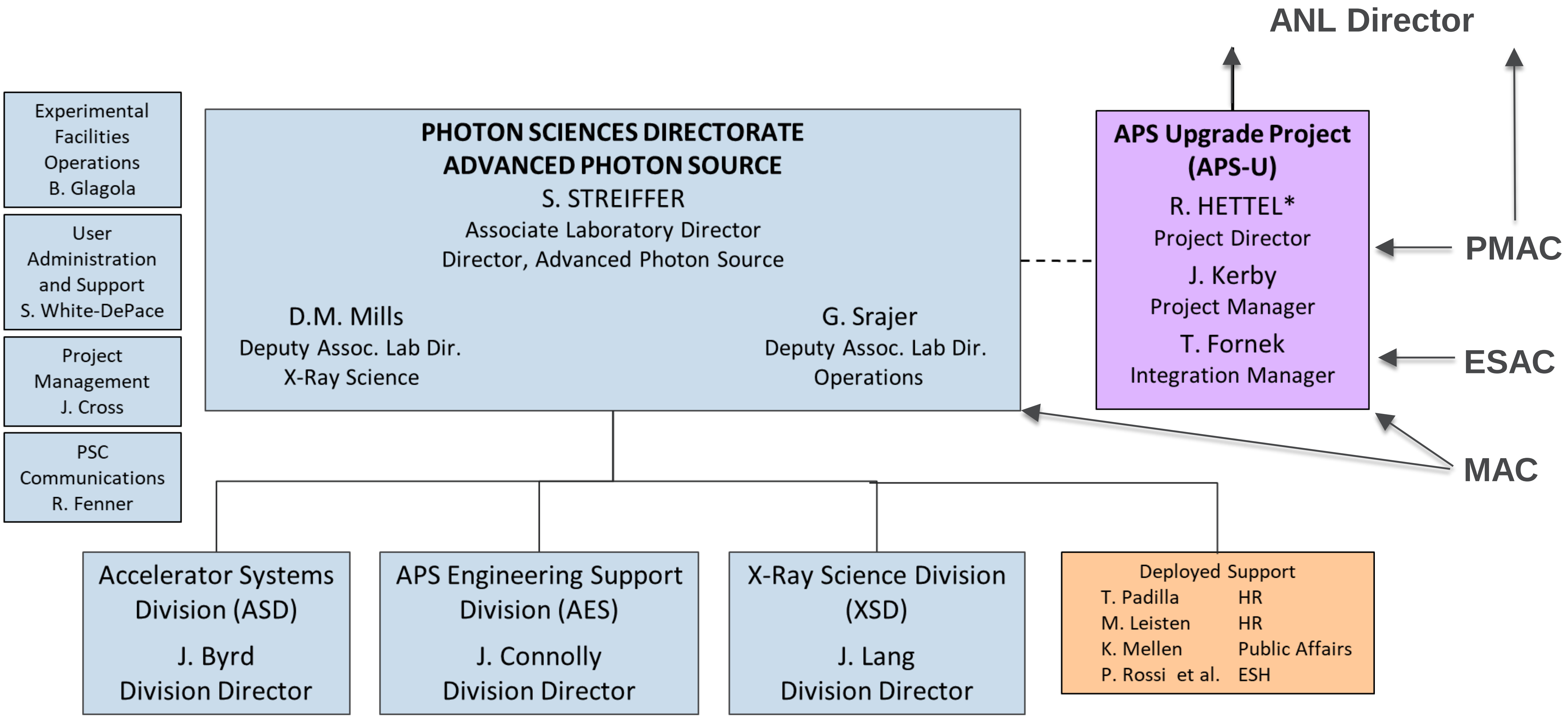
Accelerator and Beamline Safety

- Well-integrated and well-planned Accelerator Readiness Review (ARR) process is essential for the successful execution and completion of this project
- We are fortunate to be able to build upon a strong culture of operational rigor and discipline and a well-developed radiation safety program at the APS

High Level Organization for ANL



High Level Organization for APS and APS-U



APS-U project management team is in place and ready to deliver the project

Jim Kerby
Project Manager

Robert Hettel
APS Upgrade Project Director

Tom Fornek
Integration Manager

Elmie Peoples-Evans
Project Operations

Glenn Decker
Accelerator Systems

Mohan Ramanathan
Front-ends and IDs

Dean Haeffner
Experimental Systems

Summary

- The APS-U enables the United States to maintain a world leadership position in storage-ring x-ray sources
- The APS-U project is well underway with many designs in an advanced stage; contracts for many components have already been issued
- Accelerator and experimental system R&D programs have been successful
- A long-lead procurement program has been initiated to reduce project risks with a prioritized sequence of purchases
- Conducting the project in a safe manner is a high priority
- Approach to dark time + dark time + commissioning will be disruptive
- **Working diligently on reaching CD-3 in FY19**