Advanced Photon Source Upgrade (APS-U) Beamline Engineering Overview

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MEDSI
MECHANICAL ENGINEERING DESIGN OF SYNCHROTRON RADIATION EQUIPMENT AND INSTRUMENTATION
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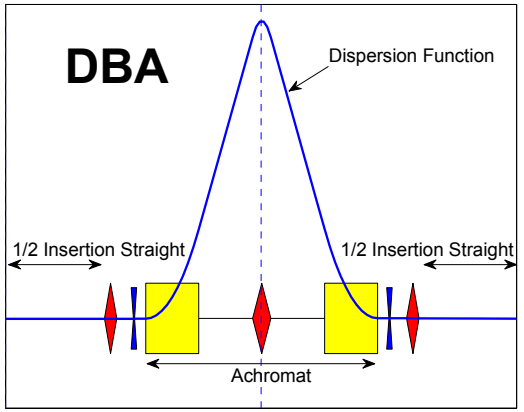
Advanced Photon Source Upgrade (APS-U)

- 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.

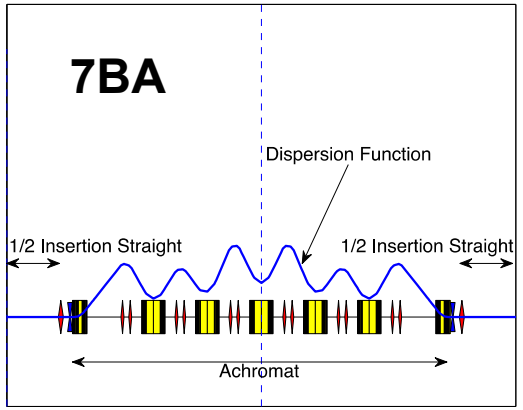
Multi Bend Achromat

ach·ro·mat·ic lens
noun
noun: **achromatic lens**; a lens that transmits light without separating it into constituent colors.

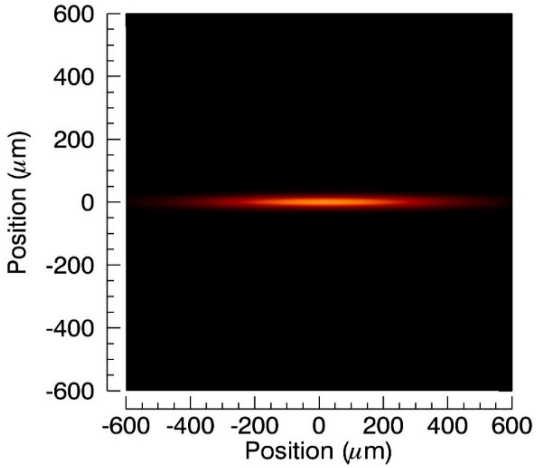
APS Today

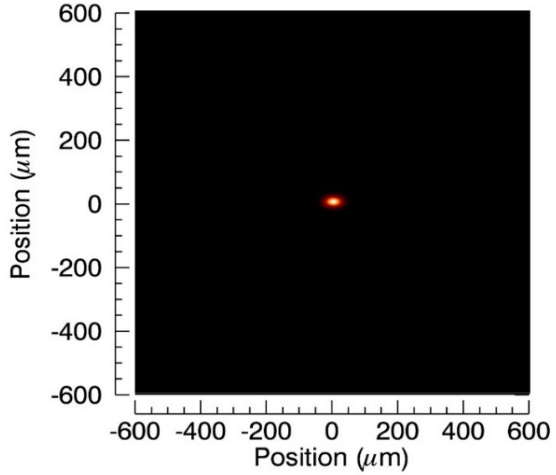


APS-U



D. Einfeld *et al.*, Proc. PAC 95, Dallas TX





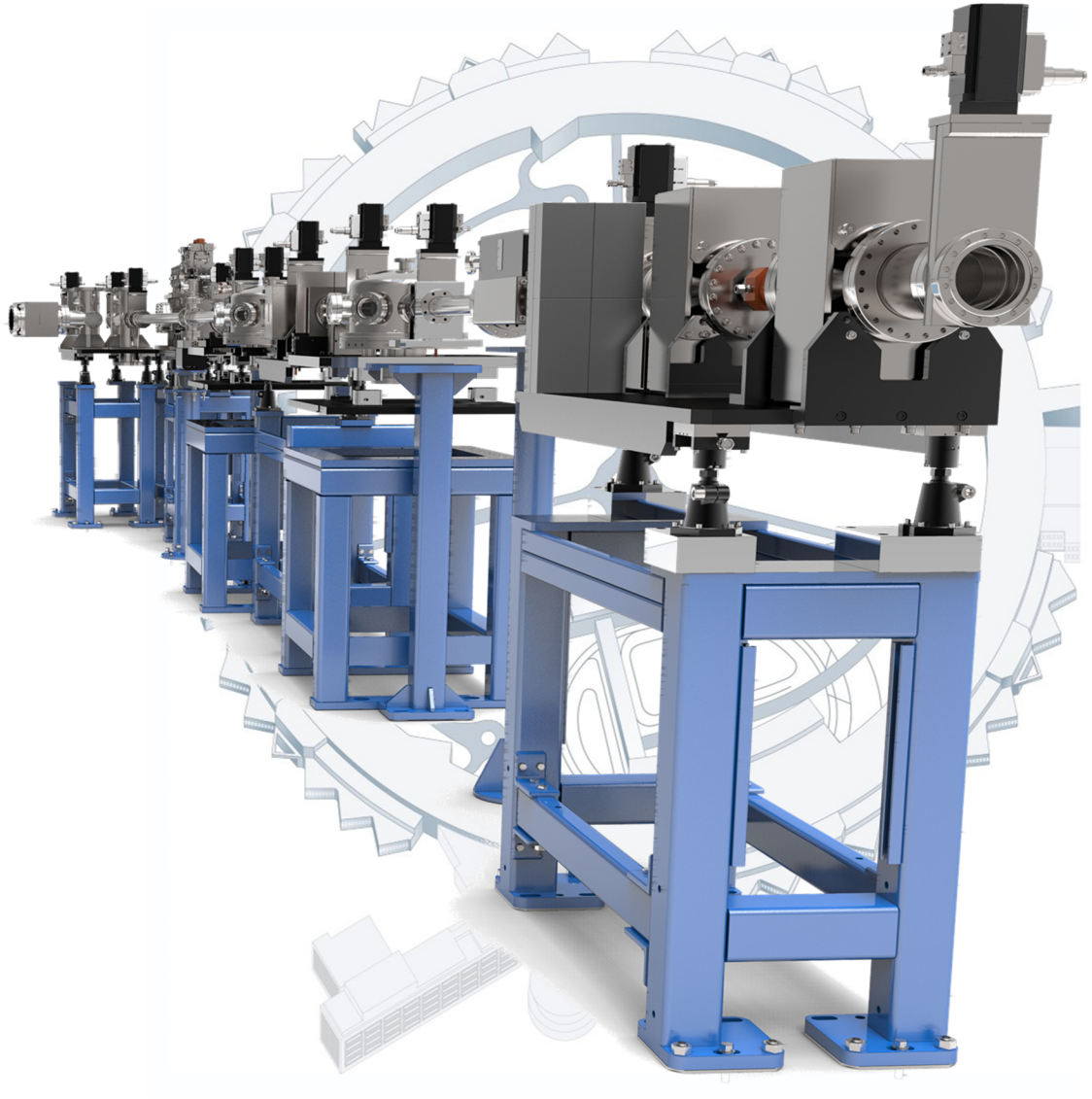
APS-U by the Numbers

	APS-U Timing Mode	APS-U Brightness Mode	APS Now	Units
Beam Energy	6	6	7	GeV
Beam Current	200	200	100	mA
Number of Bunches	48	324	24	
Emittance	32	42	3100	pm-rad
Emittance Ratio	1.0	0.1	0.013	
Horizontal Beam Size (rms)	12.6	14.5	274	μm
Horizontal Divergence (rms)	2.5	2.9	11.3	μrad
Vertical Beam Size (rms)	7.7	2.8	10.8	μm
Vertical Divergence (rms)	4.1	1.5	3.7	μrad
Brightness - 20 keV	154	325	0.6	10^{20} ph/sec/0.1%BW/mm^2/mrad^2
Pinhole Flux - 20 keV	186	217	20.1	10^{13} ph/sec/0.1%BW/in 0.5x0.5 mm^2
Coherent Flux - 20 keV	148	312	0.6	10^{11} ph/sec/01.%BW
Single-Bunch Brightness - 20 keV	321	100	2.6	10^{18} ph/sec/0.1%BW/mm^2/mrad^2

APS-U Feature Beamlines

- To take full advantage of the higher brightness and higher energy of the new storage ring, 9 “feature” beamlines have been chosen to showcase these capabilities and deliver world class scientific programs.

- 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.)

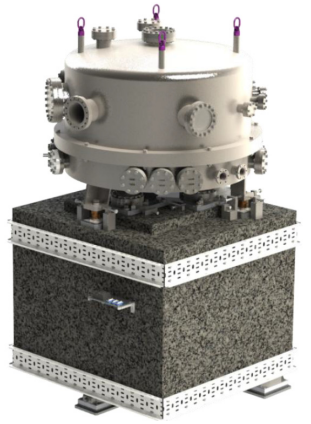


APS-U Feature Beamlines

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

Beamline Enhancements

In addition to the nine feature beamlines, another 17 beamlines will see major enhancements to their optics and end station instrumentation to greatly enrich the capabilities of their current programs.



X-ray Optics	Beamline
CRL Systems with Transfocators	6-ID, 11-ID, 12-ID,15-ID, 32-ID
High- and ultra-precise focusing KB mirrors	2-ID, 3-ID, 7-ID, 13-ID
High-heat-load mirrors	26-ID
Zone plates or multi-layer Laue Lenses.	2-ID, 26-ID
High-energy bent-crystal monochromator	1-ID, 11-ID
Multi-layer optics	25-ID, 32-ID
Mirror repolishing or replacement	2-ID, 5-ID, 13-ID, 15-ID, 32-ID
Ultrahigh-resolution monochromators	27-ID, 30-ID

Station Modifications	Beamline
1-ID-E SAXS/TXM station extension	1-ID
Penetration for long SAXS tube to extend between C and D stations	12-ID

Beamline Enhancements….continued

Endstation Instrumentation	Beamline
Added tilt stage, Hexapod positioner	1-ID
• HDCM, High-stiffness fast-scanning sample stages • BNP: Polycapillary detector collimator, Upgrade scanning stages, Upgrade rotation stage, Upgrade laser interferometer system, Vacuum chamber, Delta tau control system, and High-resolution and high-efficiency zone plate optics	2-ID
• Long in-vacuum SAXS flight-tube • Major revision of the main Bonse-Hart USAXS instrument	12-ID
Table upgrade for stability	13-ID
Moveable LERIX analyzers	25-ID
High-speed high-range nanoprobe scanning capabilities	26-ID
Diffractometer sphere of confusion upgrade	27-ID
Precision slits, Nano-CT stack with high speed air bearing rotation stage, Granite table	32-ID

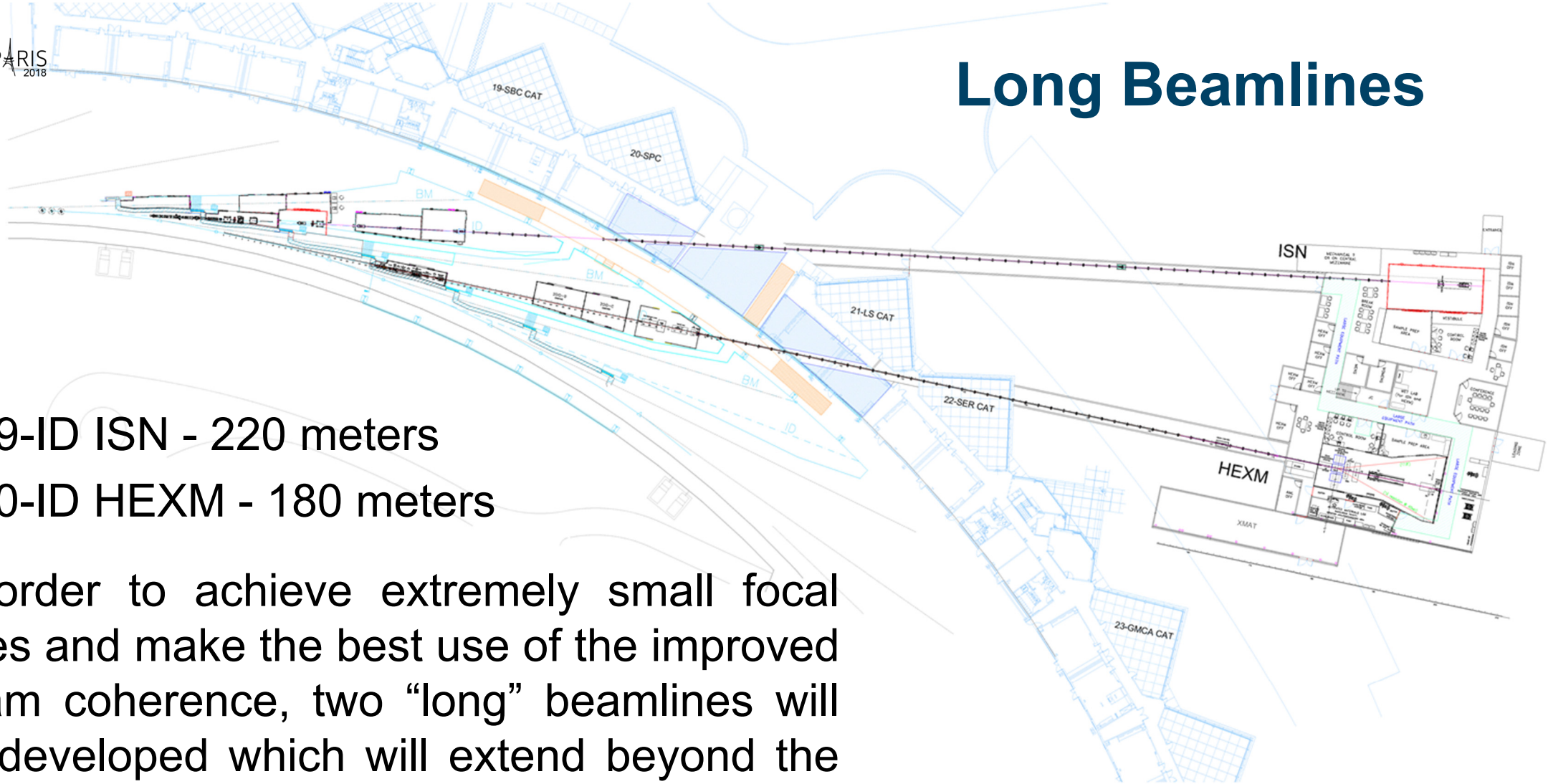
Conversion to Canted Layout	Beamline
Currently splitting the beam from two in-line undulators	11-ID
Enables novel dual-beam experiments (currently has two in line undulators)	32-ID

Overall APS-U X-ray Optics Needs

Optics	Featured/Enhanced Beamlines
High-quality wavefront-preserving CRLs and transfocators	**CHEX, CSSI, XPCS, HEXM**, 6-ID, 11-ID, 12-ID, 32-ID, 15-ID
High- and ultra-precise focusing KB mirror systems	**3DMN, ATOMIC, CSSI, ISN, Polar, XPCS**, 2-ID, 3-ID, 13-ID, 32-ID
High-heat load mirrors	**3DMN, ATOMIC, CSSI, ISN, Ptychoprobe, XPCS**, 2-ID, 7-ID,
New single mirror systems	15-ID, 32-ID
Mirror upgrade, repolishing, or replacement	5-ID, 13-ID, 26-ID
New horizontal HHL double-crystal monochromators	**3DMN, ATOMIC, CHEX, CSSI, ISN, Polar, Ptychoprobe, XPCS**, 2-ID
Upgrade existing vertical HHL double-crystal monochromators	5-ID, 13-ID, 26-ID, 30-ID, 32-ID
Non-silicon monochromators	**CHEX, Polar**
High-energy bent-crystal Laue monochromator	**HEXM,** 1-ID, 11-ID
Zone Plates	**Ptychoprobe**, 26-ID, BNP-ID
Multi-layer optics	**ATOMIC, CSSI, ISN, XPCS**, 25-ID, 32-ID
Ultrahigh-resolution monochromators	27-ID, 30-ID

- Execution of LLP Optic purchases allows the APS-U to better understand vendor capabilities such that our needs are best met and beamline downtime is minimized.

Long Beamlines



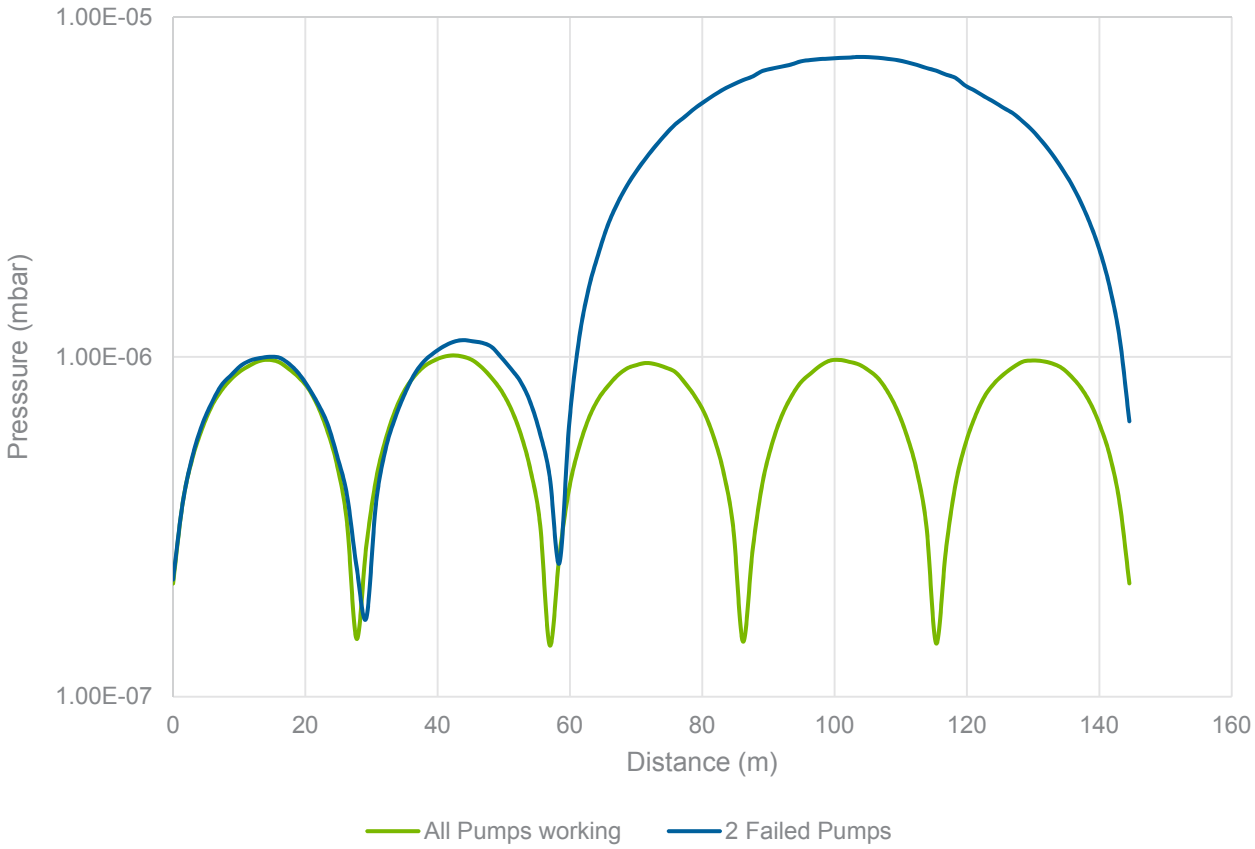
- 19-ID ISN - 220 meters
- 20-ID HEXM - 180 meters

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.

Long Shielded Transport

Vacuum Conductance Analysis run in MolFlo - Tim Clute (AES-MOM Vac)

- ISN Shielded Transport Dimensions
  - 146 meters
  - 4 inch inner diameter
- Assumptions:
  - $3x10^{-10}$ mbar*L/s/cm^2 outgassing rate
  - (Conservative for stainless steel)
- Determination:
  - 4x 200 L/s pumps equally spaced along beamline with 100 L/s pumps at either end
- Compared to LCLS - XTOD Tunnel Vacuum Transport System (XVTS) Final Design Report
  - Similar results and assumptions

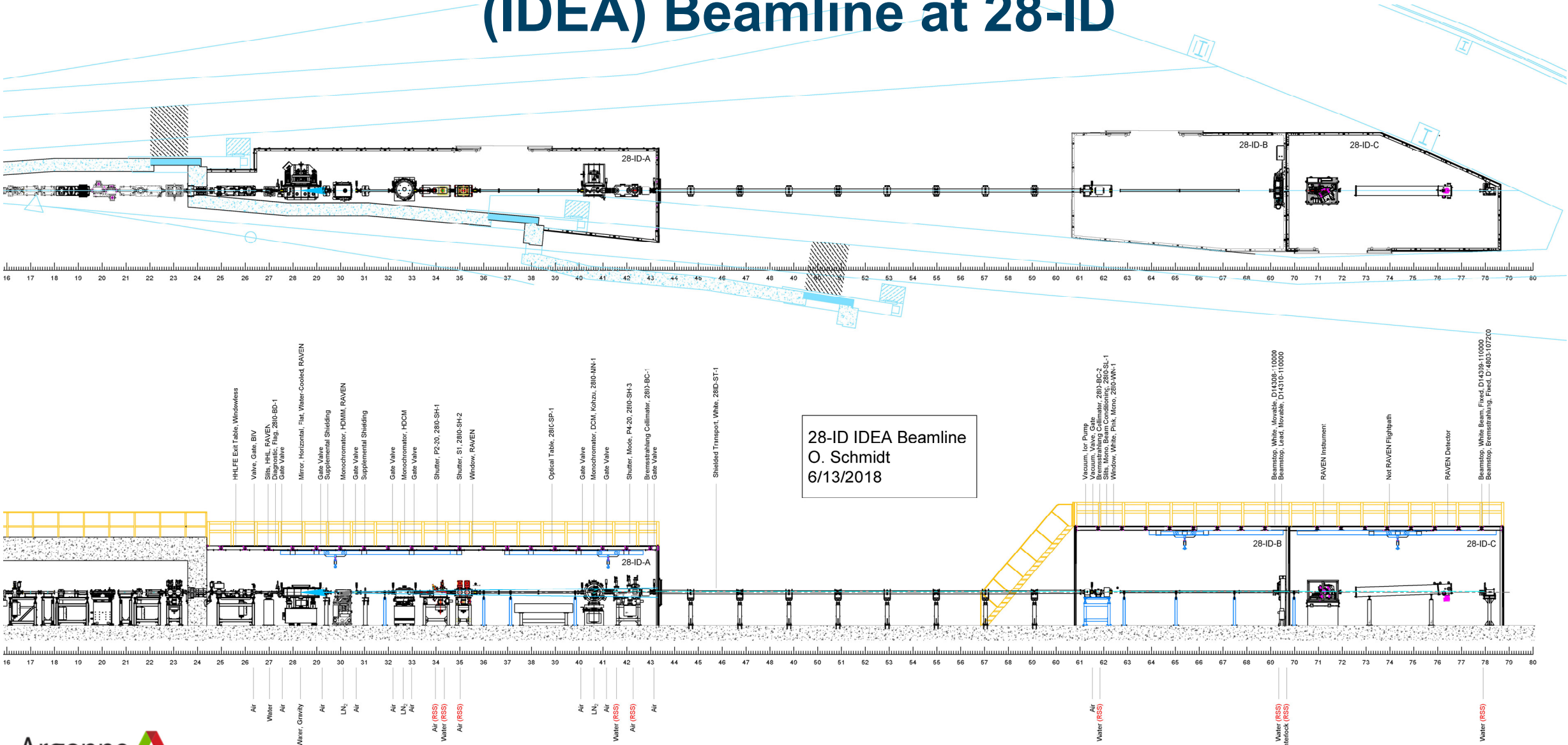


Instrumentation Development, Evaluation, & Analysis (IDEA) Beamline at 28-ID

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). Some of the optics and devices that will need testing are the below:

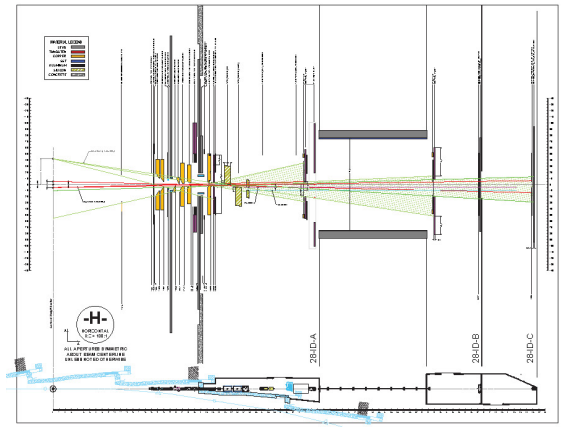
- Testing of new undulator designs (SCUs, Revolvers, etc.)
- Monochromator stability (thermal, vibrational, positional)
- Optics testing (including Kirkpatrick-Baez (KB) mirror systems, zone plates, compound refractive lenses (CRLs), etc.)
- Verification of thermal performance of beamline optics and photon masks
- Proposed detector systems can be tested and the performance can be verified with loaner units from vendors prior to purchase. New detector designs (from vendors) can be developed over a period of time prior to the completion of the APS upgrade.

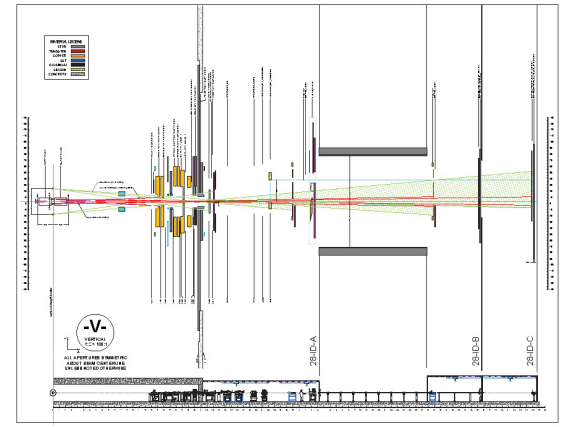
Instrumentation Development, Evaluation, & Analysis (IDEA) Beamline at 28-ID

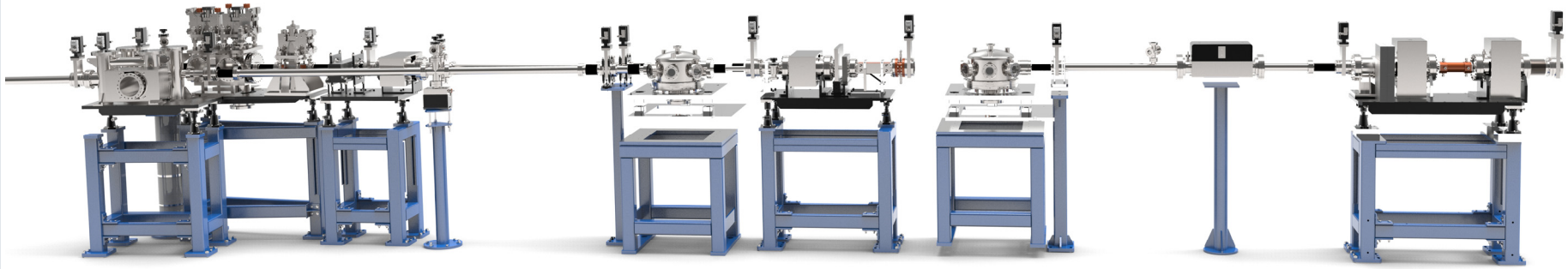


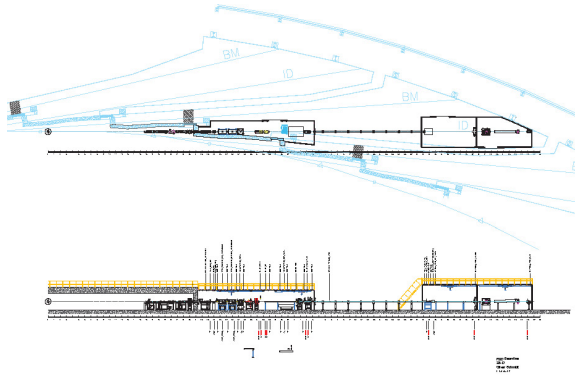
Design Process

- Optical layouts defined by physics requirements
- Beamline Layout / Raytracings produced in AutoCAD to determine shielding locations and apertures
- Individual component designs / fabrication drawings created in PTC/CREO
- Process optimized through experience with past beamline upgrades



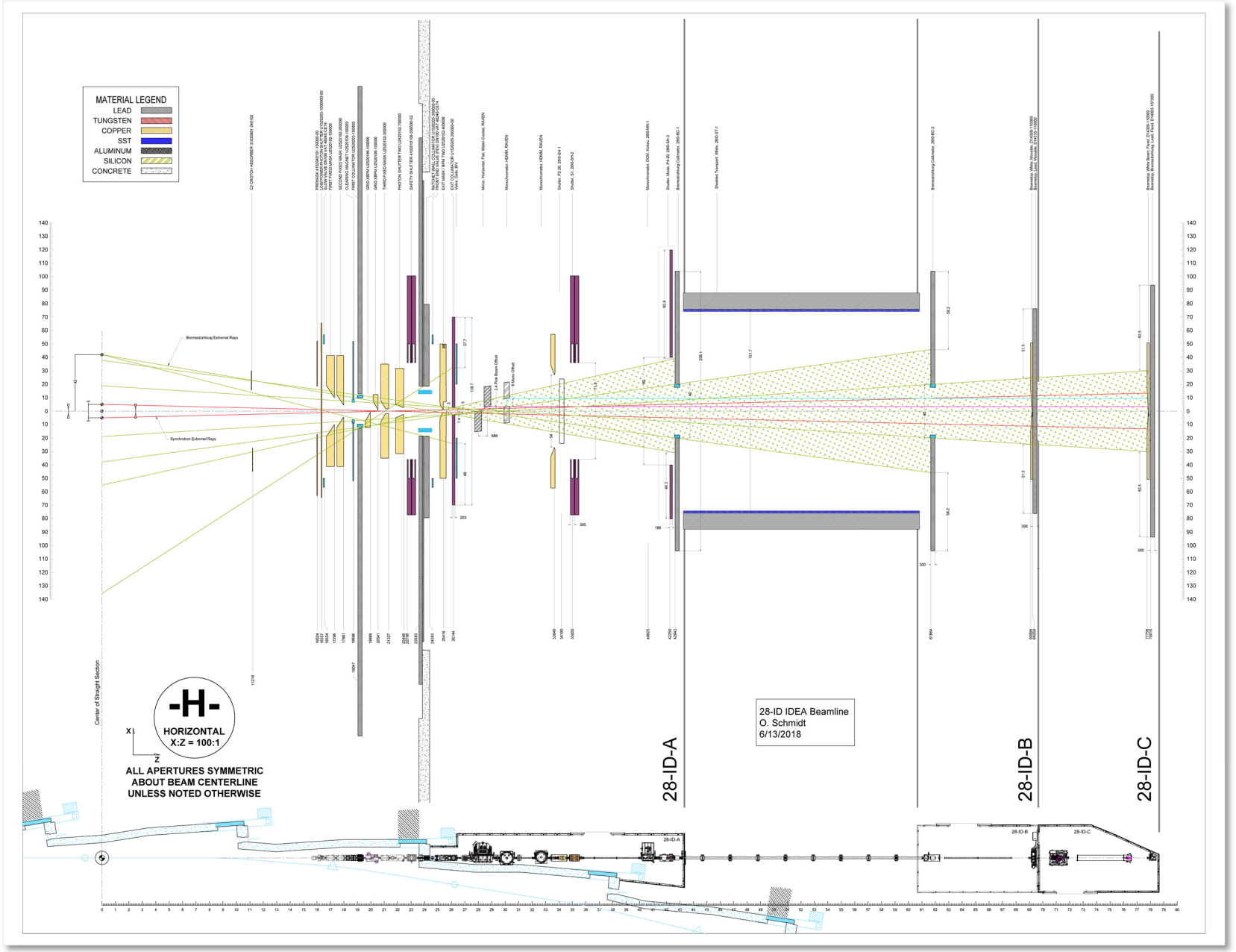






Beamline Raytracings

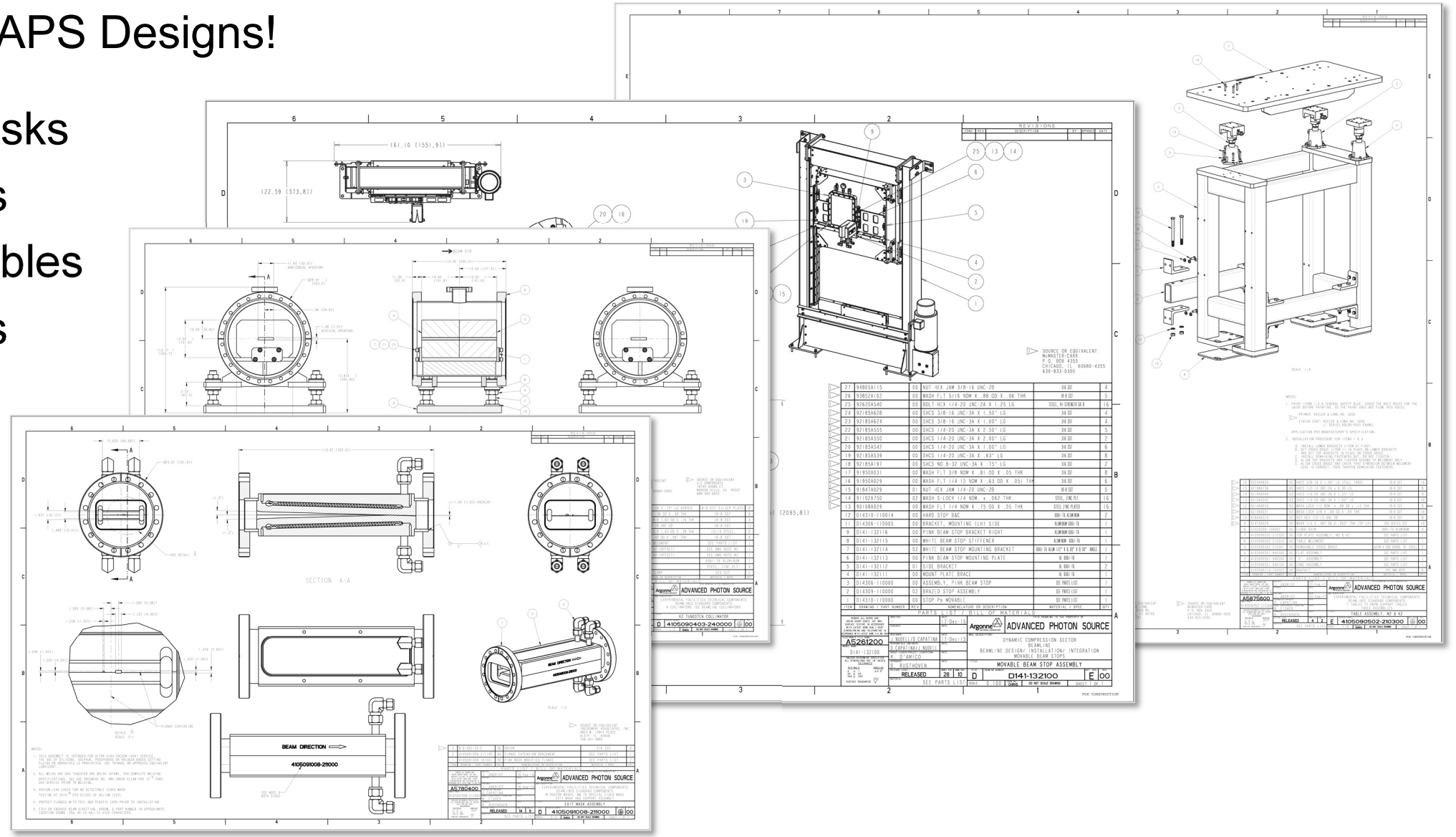
- Define radiation shielding requirements
- Standardized template
- Process refined and simplified
- New source parameters will require all existing beamlines to be re-drawn and approved



Standard Beamline Components

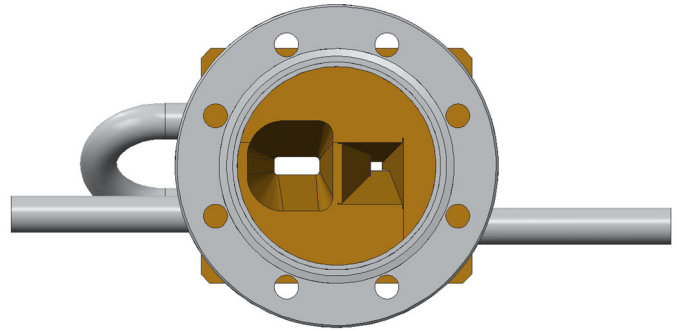
Time Tested APS Designs!

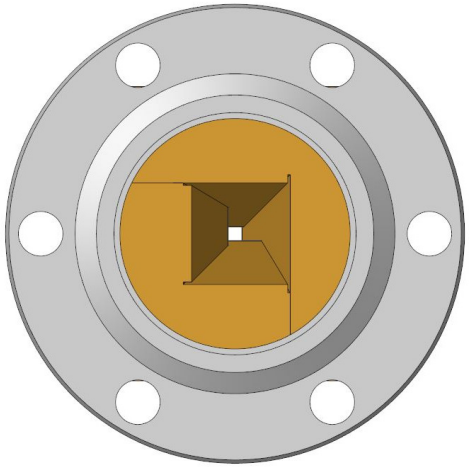
- Photon Masks
- Collimators
- Support Tables
- Beamstops
- Windows
- Shutters
- Bellows

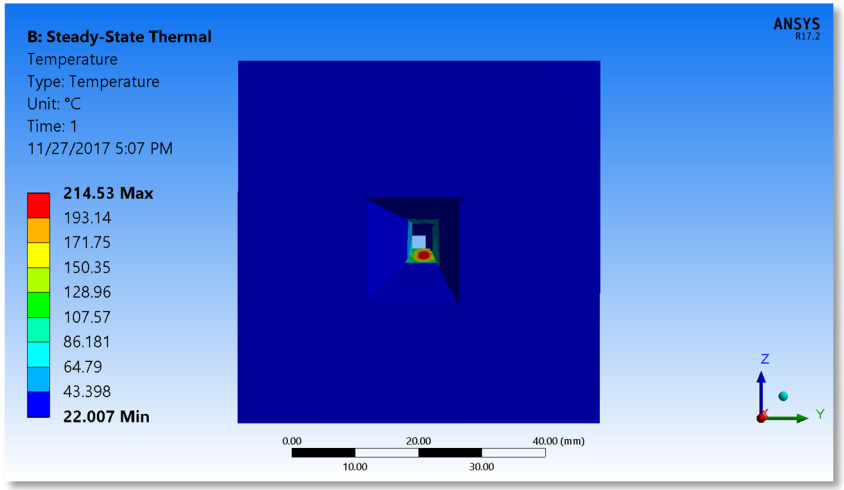


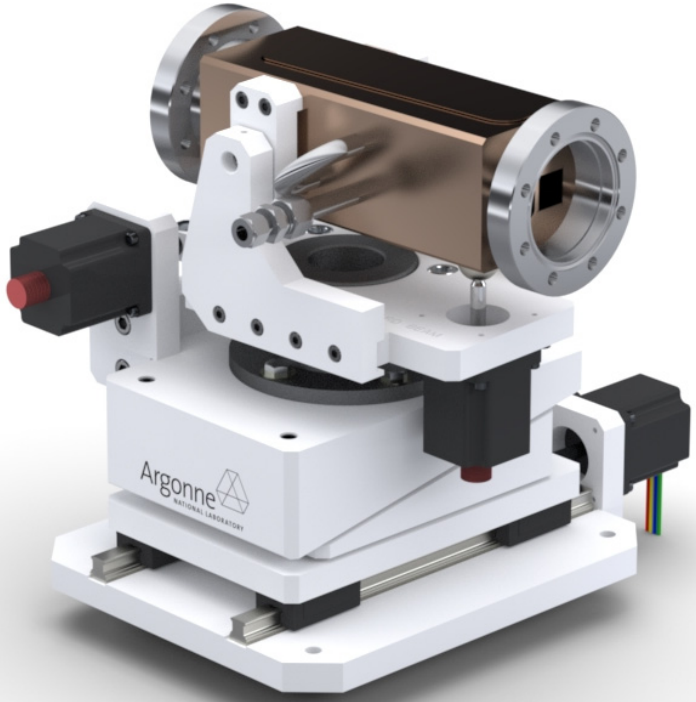
White Beam Slits

- Pivoting variable aperture design
- Canted undulator version in operation since 2010
- Single photon absorber can control both vertical and horizontal aperture saving valuable space
- New High Heat-Load HHL version being developed
  - Initial thermal analysis with two collinear SCUs shows well within safe operating limits



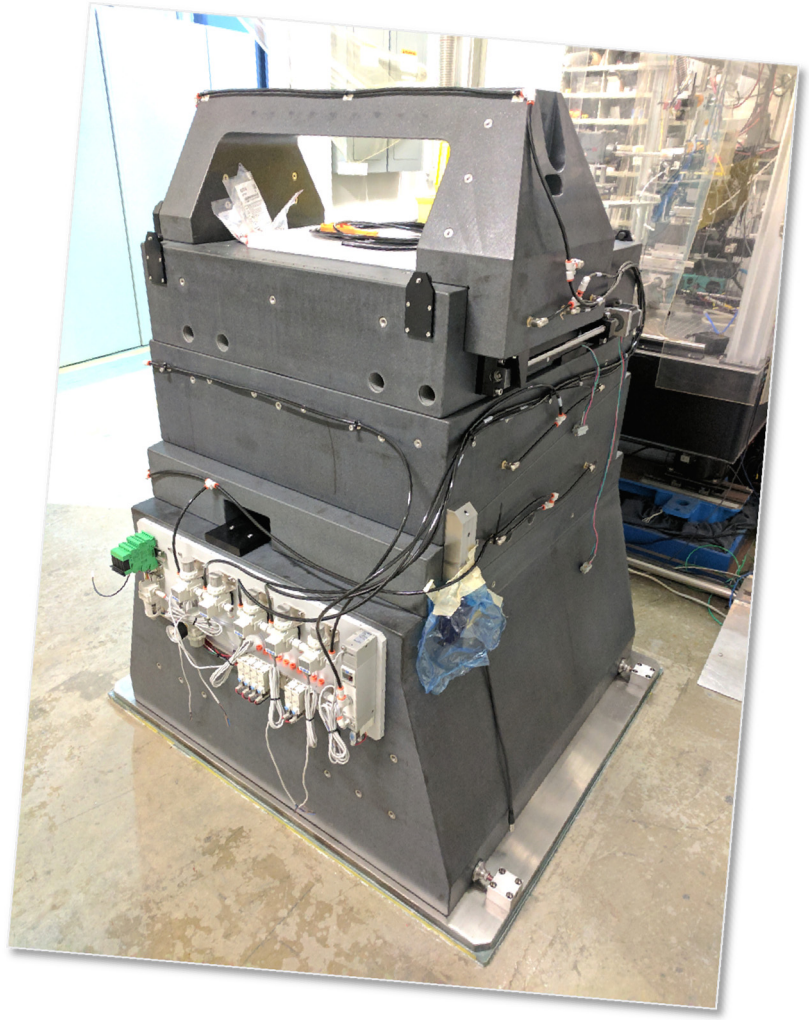






Challenges

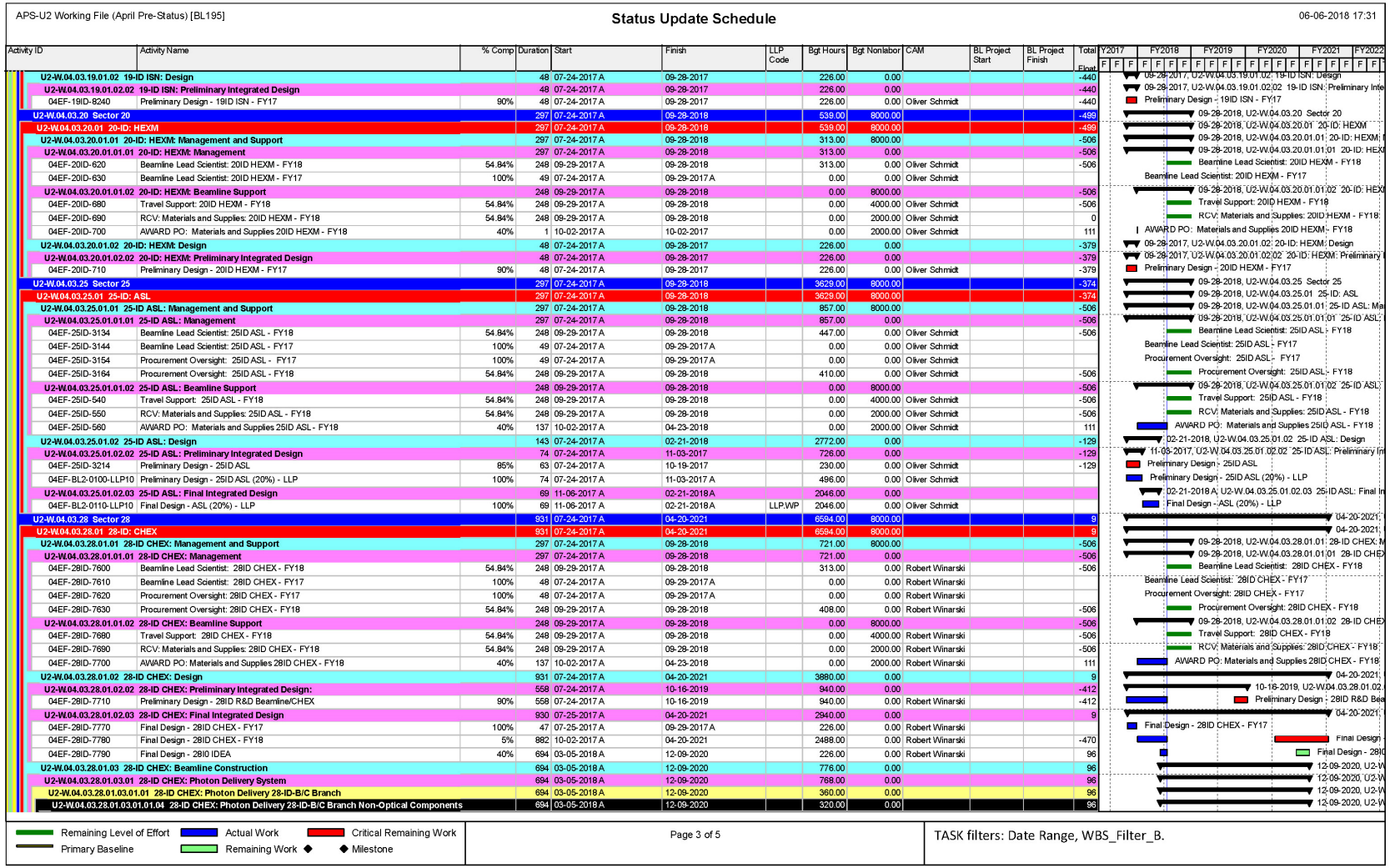
- Most of the beamline design process is routine
  - Standard component designs mature and meet APS-U requirements
- Working Groups
  - High temperature optics
  - Vibration and stability
  - Nano positioning
  - Custom Instrumentation
- Re-alignment of all bending magnet beamlines!
  - The current estimate is a lateral translation of 36mm inboard with a possible rotation of up to 0.75 mrad may be necessary.
- Beamline preparation, staging, installation



Velociprobe at 2-ID

Project Management

- Hundreds of detailed cost estimates compiled from vendor quotes, previous requisitions, wild guesses, based on preliminary designs
- Basis of Estimate values assigned
- Costs escalated/de-escalated to 2016 dollars
- Subject Matter Experts (SME)
  - Safety Interlocks, PSS, BLEPS
  - Mechanical Utilities
  - Electrical Utilities
  - Vacuum Systems
  - Shielded Enclosures
  - Nano Positioning
  - Facilities Construction,
  - Architects
- NSLS-II Thanks!



APS-U2 Working File (April Pre-Status) [BL195] — Status Update Schedule — 06-06-2018 17:31

Activity ID	Activity Name	% Comp	Duration	Start	Finish	LLP Code	Bgt Hours	Bgt Nonlabor	CAM	BL Project Start	BL Project Finish	Total Float
U2-W.04.03.19.01.02	19-ID ISN: Design		48	07-24-2017 A	09-28-2017		226.00	0.00				-440
U2-W.04.03.19.01.02.02	19-ID ISN: Preliminary Integrated Design		48	07-24-2017 A	09-28-2017		226.00	0.00				-440
04EF-19ID-8240	Preliminary Design - 19ID ISN - FY17	90%	48	07-24-2017 A	09-28-2017		226.00	0.00	Oliver Schmidt			-440
U2-W.04.03.20	Sector 20		297	07-24-2017 A	09-28-2018		539.00	8000.00				-499
U2-W.04.03.20.01	20-ID: HEXM		297	07-24-2017 A	09-28-2018		539.00	8000.00				-499
U2-W.04.03.20.01.01	20-ID: HEXM: Management and Support		297	07-24-2017 A	09-28-2018		313.00	8000.00				-506
U2-W.04.03.20.01.01.01	20-ID: HEXM: Management		297	07-24-2017 A	09-28-2018		313.00	0.00				-506
04EF-20ID-620	Beamline Lead Scientist: 20ID HEXM - FY18	54.84%	248	09-29-2017 A	09-28-2018		313.00	0.00	Oliver Schmidt			-506
04EF-20ID-630	Beamline Lead Scientist: 20ID HEXM - FY17	100%	49	07-24-2017 A	09-29-2017 A		0.00	0.00	Oliver Schmidt			
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04EF-20ID-680	Travel Support: 20ID HEXM - FY18	54.84%	248	09-29-2017 A	09-28-2018		0.00	4000.00	Oliver Schmidt			-506
04EF-20ID-690	RCV: Materials and Supplies: 20ID HEXM - FY18	54.84%	248	09-29-2017 A	09-28-2018		0.00	2000.00	Oliver Schmidt			0
04EF-20ID-700	AWARD PO: Materials and Supplies 20ID HEXM - FY18	40%	1	10-02-2017 A	10-02-2017		0.00	2000.00	Oliver Schmidt			111
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U2-W.04.03.20.01.02.02	20-ID: HEXM: Preliminary Integrated Design		48	07-24-2017 A	09-28-2017		226.00	0.00				-379
04EF-20ID-710	Preliminary Design - 20ID HEXM - FY17	90%	48	07-24-2017 A	09-28-2017		226.00	0.00	Oliver Schmidt			-379
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U2-W.04.03.25.01.01	25-ID ASL: Management and Support		297	07-24-2017 A	09-28-2018		857.00	8000.00				-506
U2-W.04.03.25.01.01.01	25-ID ASL: Management		297	07-24-2017 A	09-28-2018		857.00	0.00				-506
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04EF-25ID-3144	Beamline Lead Scientist: 25ID ASL - FY17	100%	49	07-24-2017 A	09-29-2017 A		0.00	0.00	Oliver Schmidt			
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04EF-25ID-540	Travel Support: 25ID ASL - FY18	54.84%	248	09-29-2017 A	09-28-2018		0.00	4000.00	Oliver Schmidt			-506
04EF-25ID-550	RCV: Materials and Supplies: 25ID ASL - FY18	54.84%	248	09-29-2017 A	09-28-2018		0.00	2000.00	Oliver Schmidt			-506
04EF-25ID-560	AWARD PO: Materials and Supplies 25ID ASL - FY18	40%	137	10-02-2017 A	04-23-2018		0.00	2000.00	Oliver Schmidt			111
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U2-W.04.03.25.01.02.02	25-ID ASL: Preliminary Integrated Design		74	07-24-2017 A	11-03-2017		726.00	0.00				-129
04EF-25ID-3214	Preliminary Design - 25ID ASL	85%	63	07-24-2017 A	10-19-2017		230.00	0.00	Oliver Schmidt			-129
04EF-BL2-0100-LLP10	Preliminary Design - 25ID ASL (20%) - LLP	100%	74	07-24-2017 A	11-03-2017 A		496.00	0.00	Oliver Schmidt			
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U2-W.04.03.28.01	28-ID: CHEX		931	07-24-2017 A	04-20-2021		6594.00	8000.00				9
U2-W.04.03.28.01.01	28-ID CHEX: Management and Support		297	07-24-2017 A	09-28-2018		721.00	8000.00				-506
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04EF-28ID-7600	Beamline Lead Scientist: 28ID CHEX - FY18	54.84%	248	09-29-2017 A	09-28-2018		313.00	0.00	Robert Winarski			-506
04EF-28ID-7610	Beamline Lead Scientist: 28ID CHEX - FY17	100%	48	07-24-2017 A	09-29-2017 A		0.00	0.00	Robert Winarski			
04EF-28ID-7620	Procurement Oversight: 28ID CHEX - FY17	100%	48	07-24-2017 A	09-29-2017 A		0.00	0.00	Robert Winarski			
04EF-28ID-7630	Procurement Oversight: 28ID CHEX - FY18	54.84%	248	09-29-2017 A	09-28-2018		408.00	0.00	Robert Winarski			-506
U2-W.04.03.28.01.01.02	28-ID CHEX: Beamline Support		248	09-29-2017 A	09-28-2018		0.00	8000.00				-506
04EF-28ID-7680	Travel Support: 28ID CHEX - FY18	54.84%	248	09-29-2017 A	09-28-2018		0.00	4000.00	Robert Winarski			-506
04EF-28ID-7690	RCV: Materials and Supplies: 28ID CHEX - FY18	54.84%	248	09-29-2017 A	09-28-2018		0.00	2000.00	Robert Winarski			-506
04EF-28ID-7700	AWARD PO: Materials and Supplies 28ID CHEX - FY18	40%	137	10-02-2017 A	04-23-2018		0.00	2000.00	Robert Winarski			111
U2-W.04.03.28.01.02	28-ID CHEX: Design		931	07-24-2017 A	04-20-2021		3880.00	0.00				9
U2-W.04.03.28.01.02.02	28-ID CHEX: Preliminary Integrated Design:		558	07-24-2017 A	10-16-2019		940.00	0.00				-412
04EF-28ID-7710	Preliminary Design - 28ID R&D Beamline/CHEX	90%	558	07-24-2017 A	10-16-2019		940.00	0.00	Robert Winarski			-412
U2-W.04.03.28.01.02.03	28-ID CHEX: Final Integrated Design		930	07-25-2017 A	04-20-2021		2940.00	0.00				9
04EF-28ID-7770	Final Design - 28ID CHEX - FY17	100%	47	07-25-2017 A	09-29-2017 A		226.00	0.00	Robert Winarski			
04EF-28ID-7780	Final Design - 28ID CHEX - FY18	5%	882	10-02-2017 A	04-20-2021		2488.00	0.00	Robert Winarski			-470
04EF-28ID-7790	Final Design - 28I0 IDEA	40%	694	03-05-2018 A	12-09-2020		226.00	0.00	Robert Winarski			96
U2-W.04.03.28.01.03	28-ID CHEX: Beamline Construction		694	03-05-2018 A	12-09-2020		776.00	0.00				96
U2-W.04.03.28.01.03.01	28-ID CHEX: Photon Delivery System		694	03-05-2018 A	12-09-2020		768.00	0.00				96
U2-W.04.03.28.01.03.01.01	28-ID CHEX: Photon Delivery 28-ID-B/C Branch		694	03-05-2018 A	12-09-2020		360.00	0.00				96
U2-W.04.03.28.01.03.01.01.04	28-ID CHEX: Photon Delivery 28-ID-B/C Branch Non-Optical Components		694	03-05-2018 A	12-09-2020		320.00	0.00				96

FY2017 FY2018 FY2019 FY2020 FY2021 FY2022

Remaining Level of Effort | Actual Work | Critical Remaining Work | Primary Baseline | Remaining Work | Milestone

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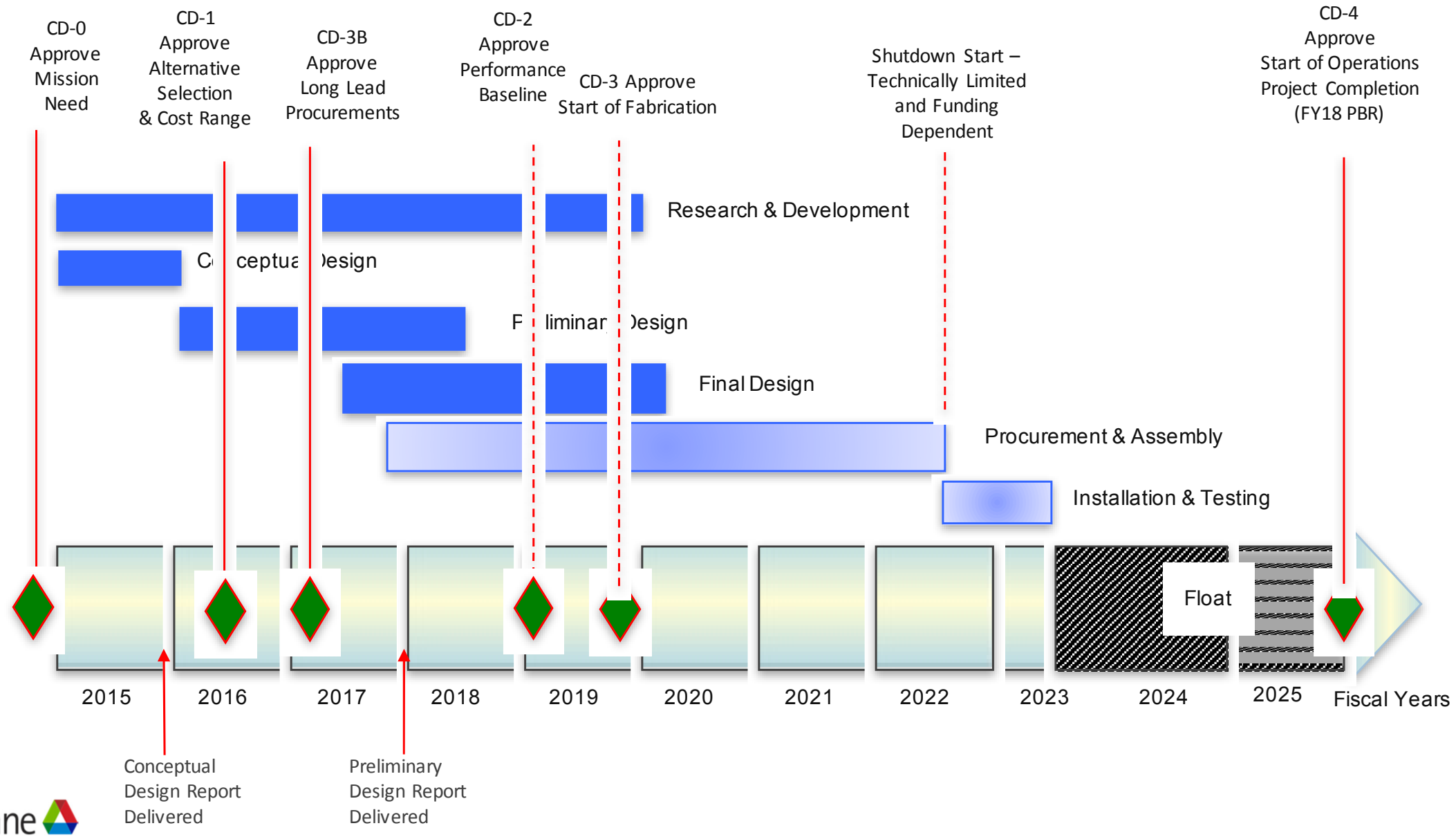
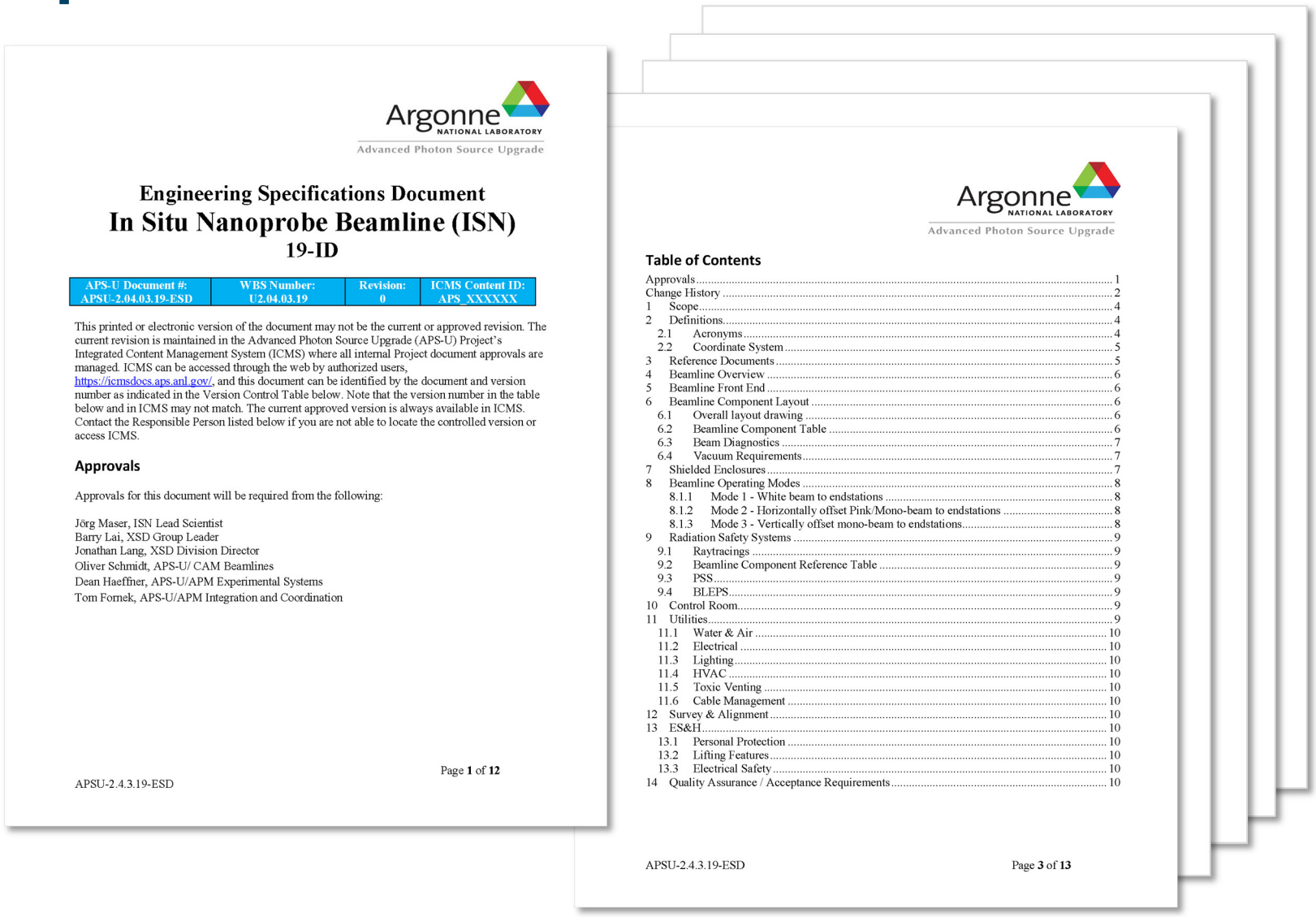
TASK filters: Date Range, WBS_Filter_B.

APS-U Project Schedule



Engineering Specifications Documents - ESDs

- Drafts/outlines complete
- Single source for technical beamline information
- Information compiled as we develop final designs
- Links to separate individual ESDs for larger, more complex components
- Contains info required for radiation safety / technical reviews



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Advanced Photon Source Upgrade

Engineering Specifications Document
In Situ Nanoprobe Beamline (ISN)
19-ID

APS-U Document #:	WBS Number:	Revision:	ICMS Content ID:
APSU-2.04.03.19-ESD	U2.04.03.19	0	APS_XXXXXX

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Approvals

Approvals for this document will be required from the following:

Jörg Maser, ISN Lead Scientist
Barry Lai, XSD Group Leader
Jonathan Lang, XSD Division Director
Oliver Schmidt, APS-U/ CAM Beamlines
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Advanced Photon Source Upgrade

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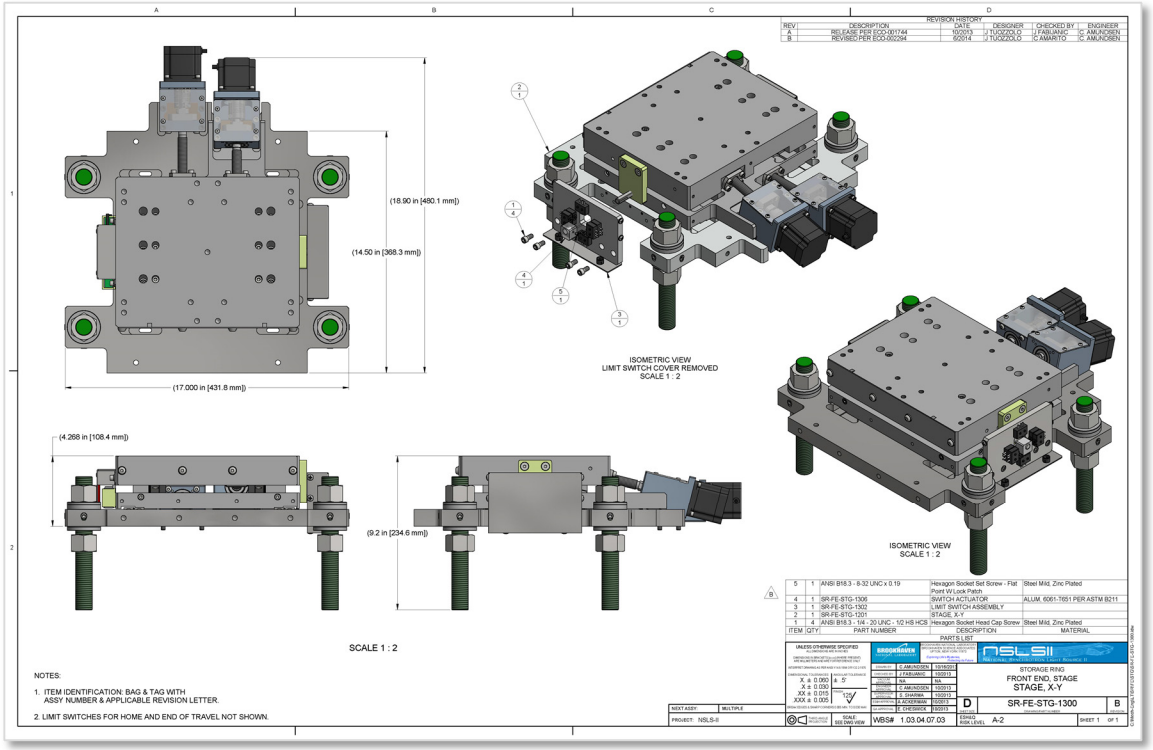
Value Engineering - EVMS

How can we get the most for our money?

- Utilize time tested APS Standard Component designs
  - Photon masks, collimators, tables, shutters, slits, stands, windows, diagnostics, etc…
  - Installation/maintenance experience, technician familiarity
- Vendor supplied components whenever possible
  - Larger design projects; mirrors, monochromators, beamline instrumentation, etc…
  - Ease load on engineering resources
- Reuse existing infrastructure / components
- Evaluate possible alternative materials
- Leverage designs from other laboratories
  - NSLS-II Precision X-Y Stages
  - Economical Design
  - Many Applications
  - Currently building set for use with white beam slits



Beamline Engineering Team

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Future Person

Yifie Jaski

Oliver Schmidt

OVER 130 YEARS OF BEAMLINE DESIGN EXPERIENCE!

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If you know this person

- Tell him the APS will be on the lookout for experienced beamline engineers.
- Great Benefits!
  - Chicago Style Pizza
  - Sunny Beaches
  - Beer is free
- Visit our website:

http://www.anl.gov/careers

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Summary

- Beamline engineering for the APS Upgrade is organized and on track!
  - CD2 review in October 2018
  - CD3 in April 2019
- Preliminary designs are complete, final designs started
- All major components have been identified
- Engineering team is in place