Neutron X-ray Summer School, August 16, 2023

Synchrotron Radiation User Facilities

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Advanced Photon Source
Argonne National Laboratory

UChicago Argonne, LLC

U.S. DEPARTMENT OF ENERGY

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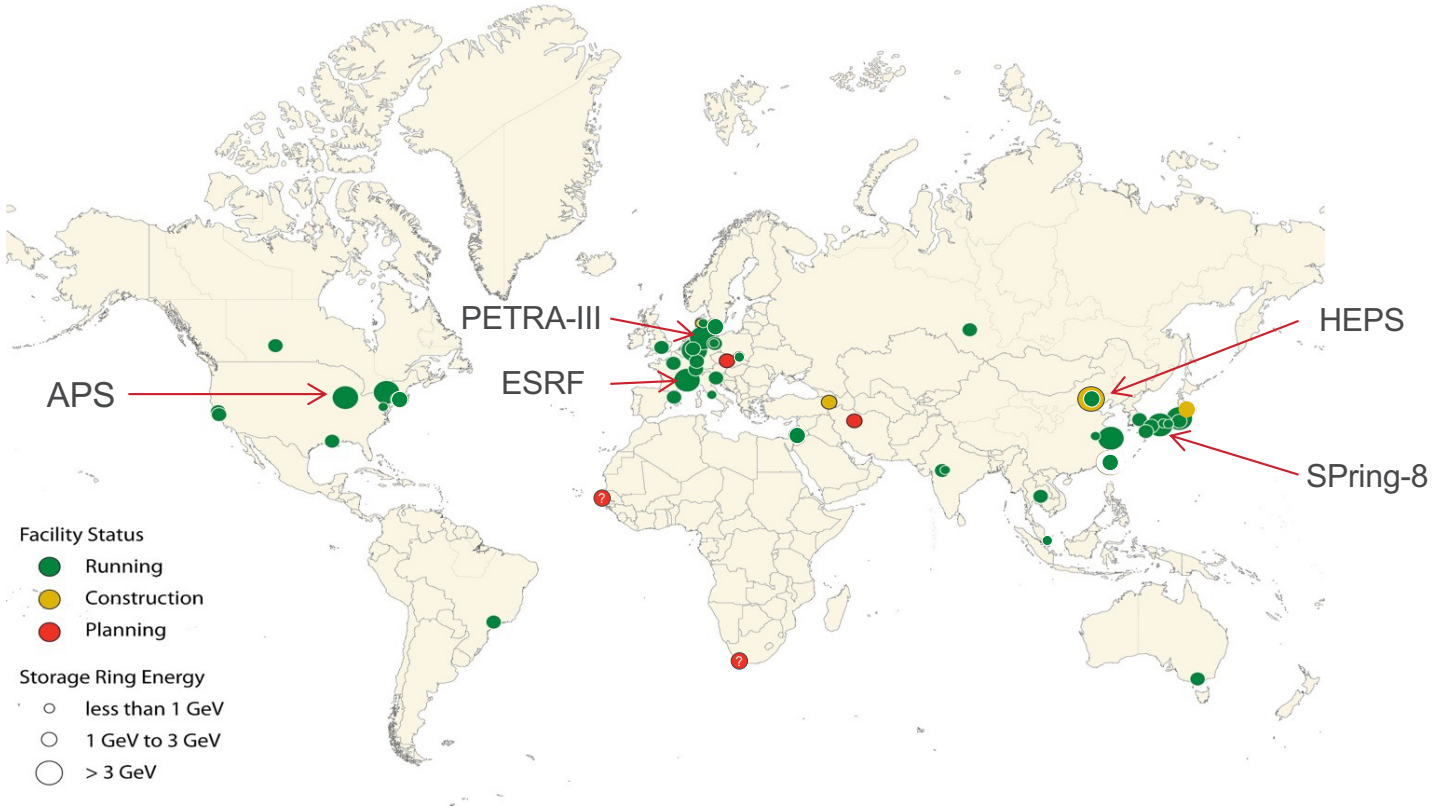
SYNCHROTRON FACILITIES AROUND THE WORLD

Over 40 synchrotron light-source facilities world-wide



Approximately 50,000 scientists use one of these facilities each year.
Five are large-circumference high-energy (>5 GeV) high-brilliance (<3nm-rad) storage rings

SYNCHROTRON LIGHT SOURCES IN NORTH AMERICA

8 light sources; 5 DOE US; 1 NSF US; 1 State US; 1 Canadian

2.9 GeV; 18.1 nm

Canadian Light Source (CLS)
University of Saskatchewan

7 GeV; 3 nm

1.9 GeV; 2 nm

Advanced Photon Source (APS)
Argonne National Laboratory

6 GeV; 27 nm

Advanced Light Source (ALS)
Lawrence Berkeley National Laboratory

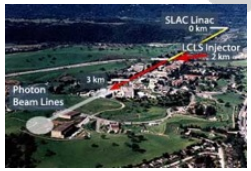
Cornell High-Energy Synchrotron Source (CHESS)
Cornell University

NSLS-II
Brookhaven National Laboratory

3 GeV; 0.75 nm

Stanford Synchrotron Radiation Laboratory(SSRL)
Linac Coherent Light Source (LCLS)
Stanford Linear Accelerator Center

3 GeV; 10 nm



CAMD
Louisiana State University

1.3 GeV; 200 nm

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LIGHT SOURCE PARAMETERS

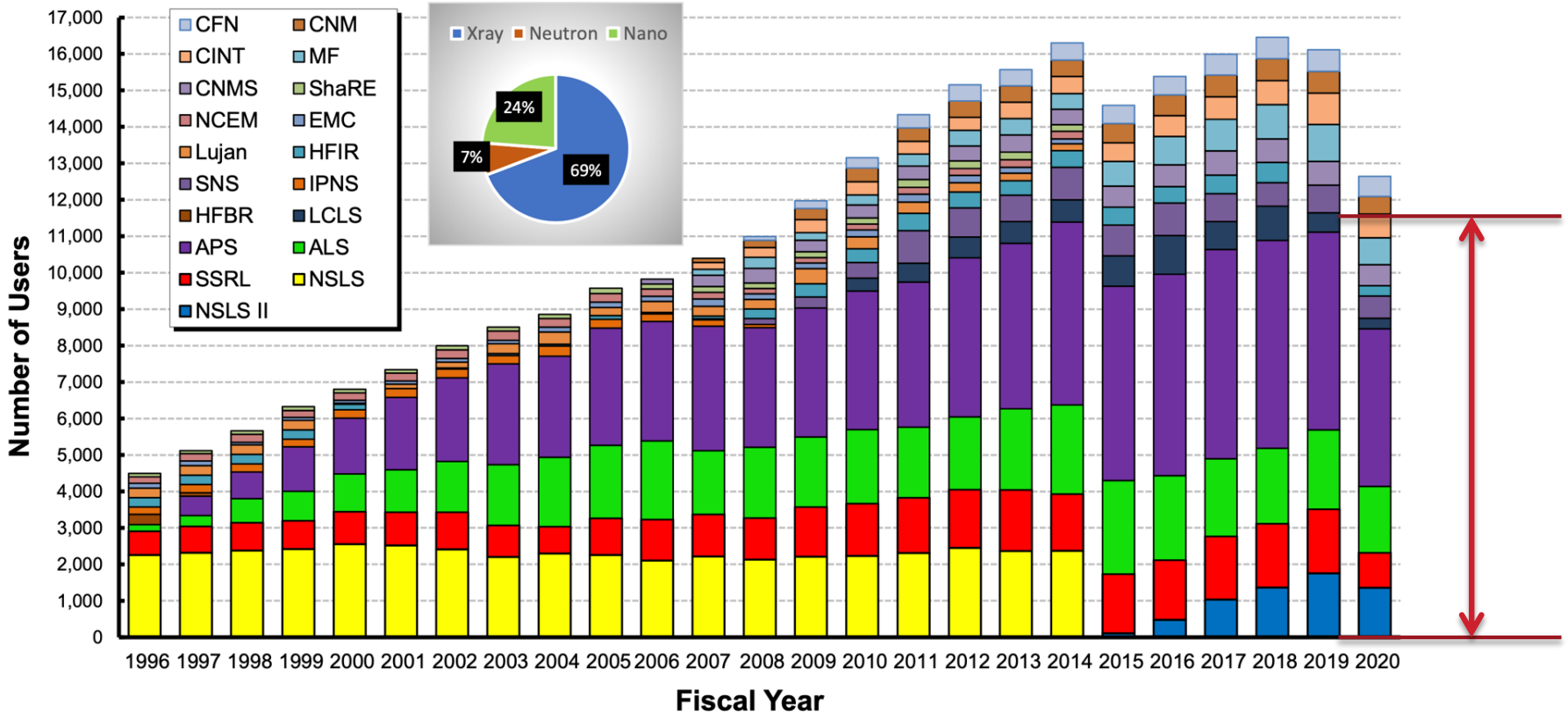
Source	Energy	Current	Circum.	Emittance	# Beamlines
APS	7.0 GeV	100 mA	1104m	3.0 nm-rad	67 (47 ID)
APS-U	6.0 GeV	200 mA	1104m-δ	0.042 nm-rad	70 (54 ID)
NSLS-II	3.0 GeV	400 mA	792m	0.75 nm-rad	30 (22 ID)
SSRL	3.0 GeV	500 mA	234m	10 nm-rad	27 (18 ID)
ALS	1.9 GeV	500 mA	199m	2.0 nm-rad	46 (17 ID)
CHESS	6.0 GeV	200 mA	768m	27 nm-rad	8 (8 ID)
CLS	2.9 GeV	250 mA	170m	18.1 nm-rad	20 (13 ID)
CAMD	1.3 GeV	200 mA	55m	200 nm-rad	15 (3 ID)

Most important: Energy, emittance, & does it have a beamline for what I want to do

*LCLS – X-ray free electron laser accelerator, so parameter don't easily correlate

DOE SCIENTIFIC USER FACILITIES

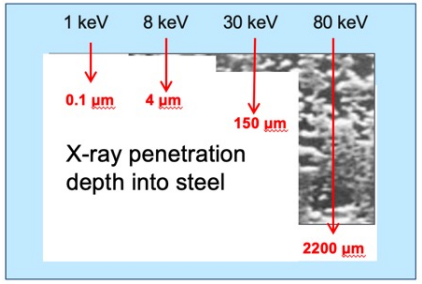
More than 11,000 unique users use one of the DOE light sources each year; Canadian Light Source ~1000; CHESS ~1000 users

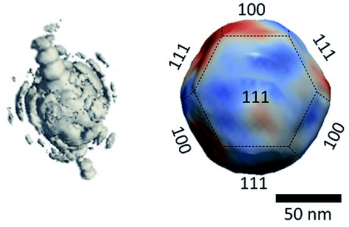


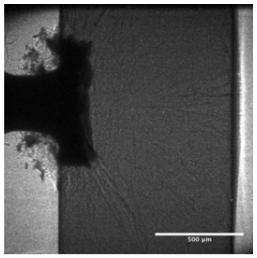
WHY CHOOSE PARTICULAR FACILITY?

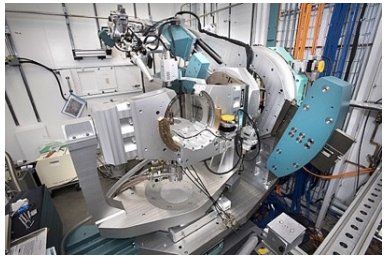
Considerations for your experiment

- Energy range of x-rays
  - Higher energy storage rings generate ”harder” x-rays
    - Penetration, complex environments, in-situ/operando, …
  - Lower energy rings – light elements, electronic and magnetic sensitivity, ..
- Brightness
  - Enables smaller focal spots & coherence measurements
- Timing structure
  - Pulse structure suitable if doing ultra-fast experiments
    - Pump-probe; high-speed imaging
- Specialized capabilities
  - Unique measurements (e.g. beam polarization, magnetic field, stress/strain equipment, furnaces, laser heating, gas handling, …
  - Ancillary labs capabilities (e.g. electrochemistry, high pressure, …)
- Location
  - Similar capabilities for some techniques (e.g. XAS, SAXS, …)
  - Easier to transport your own equipment.









Remote Access

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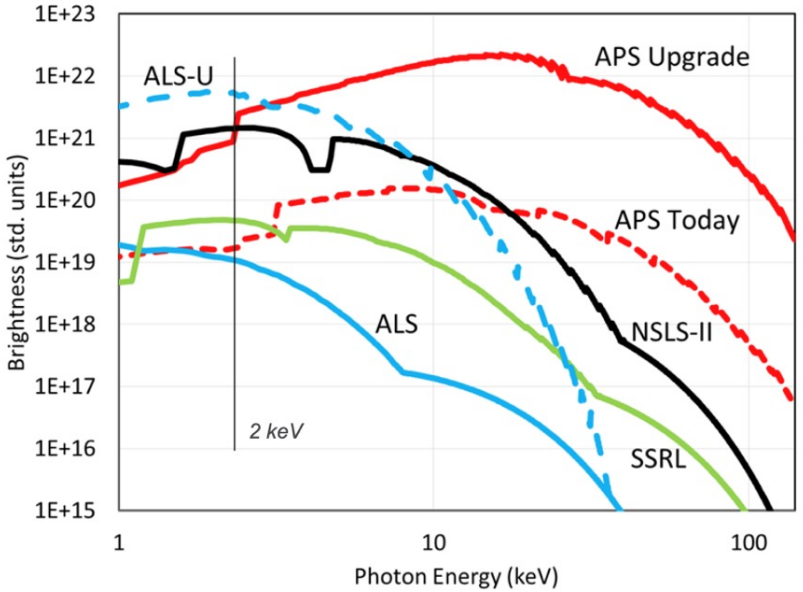
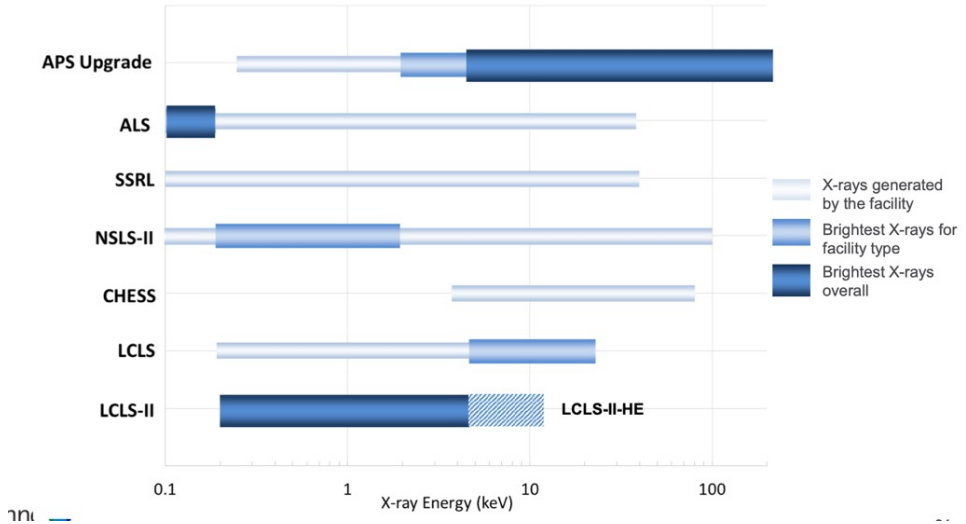
DOE LIGHT SOURCE FACILITIES

Light sources optimized* for particular energy ranges



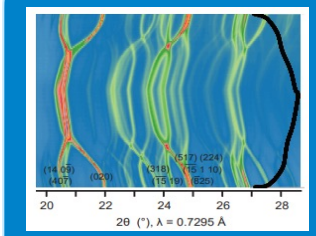


- Harder x-rays contain significant power in the x-ray beam
- Lower energy ring can go to higher current without heat load mitigation

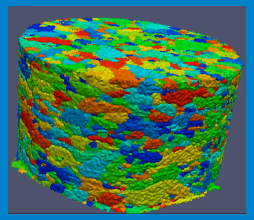
LIGHT SOURCE FACILITIES

Spectral range

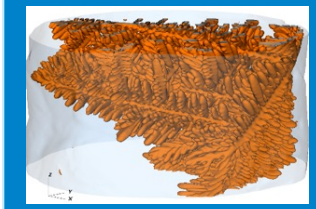
Hard X-ray (>20 keV)



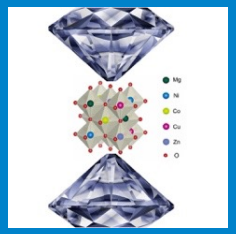
In-operando XRD



HighE Diff. Micro.



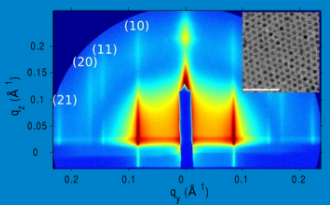
Dynamic Tomography



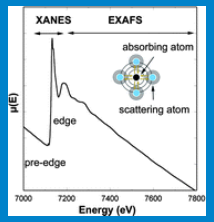
High-Press. XRD

PDF, HEDM, XRD, High Press., Tomography, ….

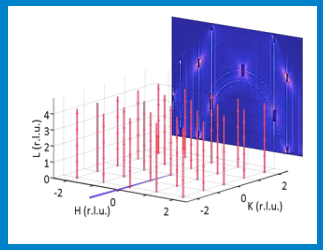
X-rays (5-20 keV)



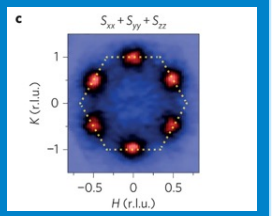
GI-SAXS



XAS



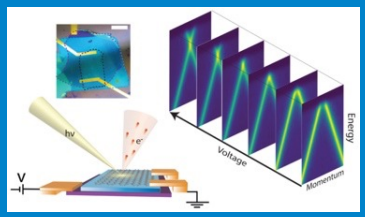
Surface Diffraction



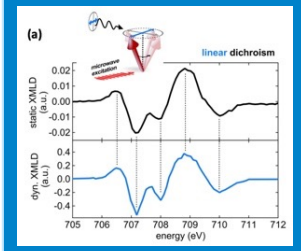
RIXS (3d K, 5d L)

SAXS, XAS, Diffraction, XRF, Spectro-microscopy, ….

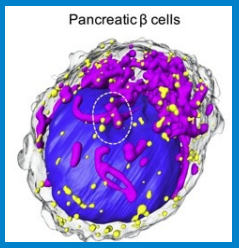
Soft X-ray (<3 keV)



Angle Resolved Photoemission



XMCD

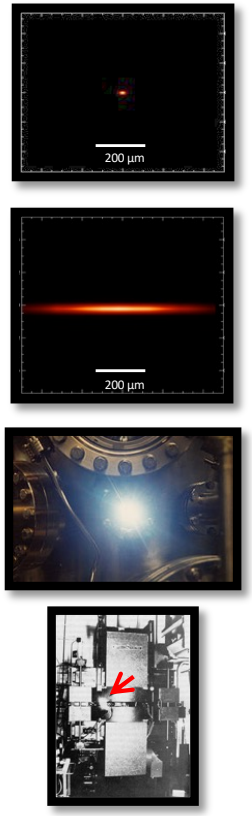


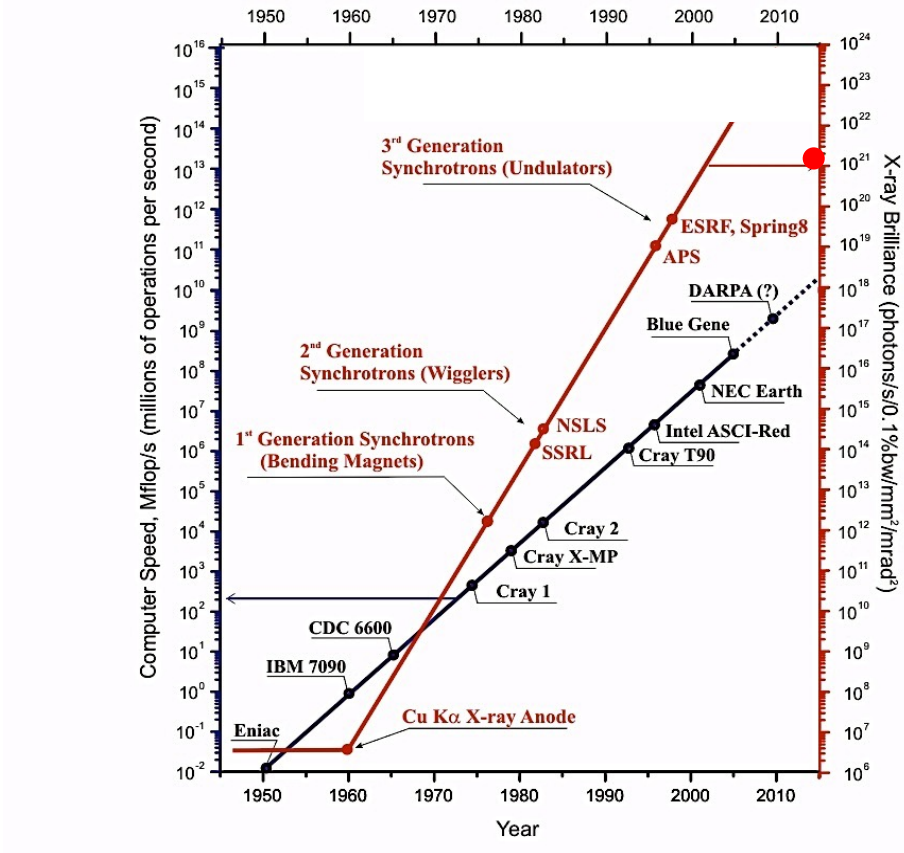
Imaging

ARPES, XMCD, Imaging, Light elements, …

Facilities will offer range of capabilities even outside their “sweet” spot.

EVOLUTION OF SYNCHROTRON BRIGHTNESS



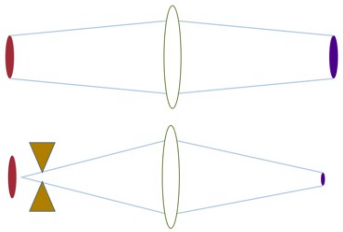


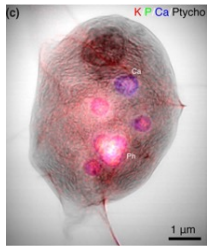
≥ 2 orders of magnitude increase in brightness between generations

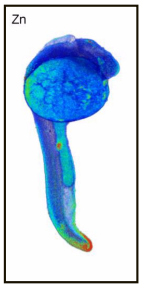
DOE SCIENTIFIC USER FACILITIES

Brightness & Beam Coherence

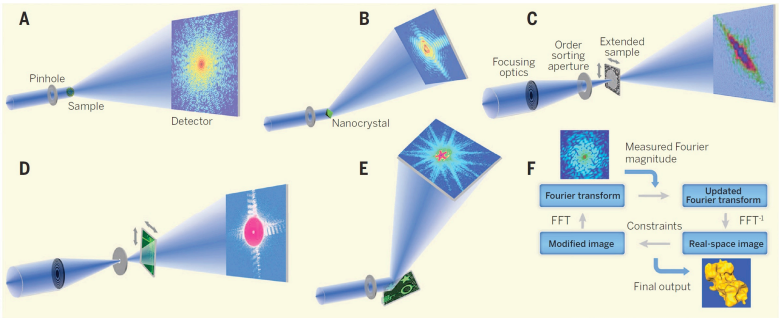
Focusing of x-ray beam





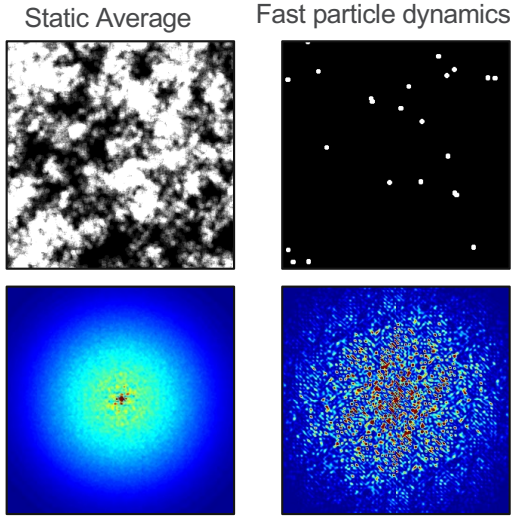


Coherent (lensless) imaging



J. Miao *et al., Science* **348**, 530 (2015)

X-ray Photon Correlation Spectroscopy



Simulation courtesy of Z. Jiang (APS)

Brightness enables focusing of all x-rays into nanometer scale focal spots

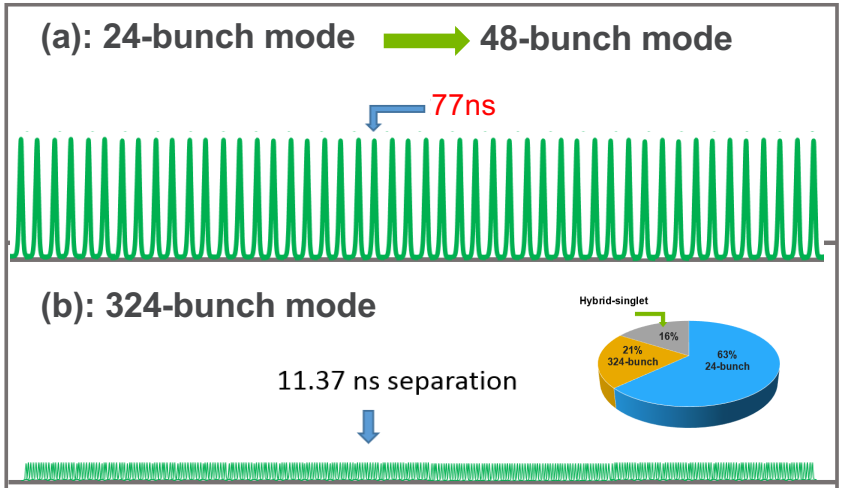
Enables lensless imaging & studies of dynamics using correlation methods

See talks by Chris Jacobsen, Stefan Hruszkewycz (Tuesday) & Larry Lurio (today)

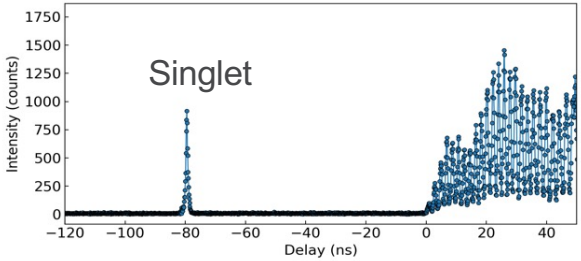
LIGHT SOURCE FACILITIES

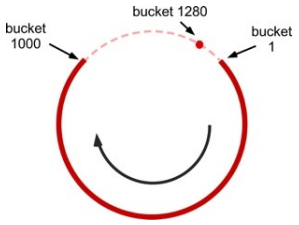
Timing modes

APS operates majority of the time (~80%) in a fill pattern that enables pump-probe (and other) timing studies



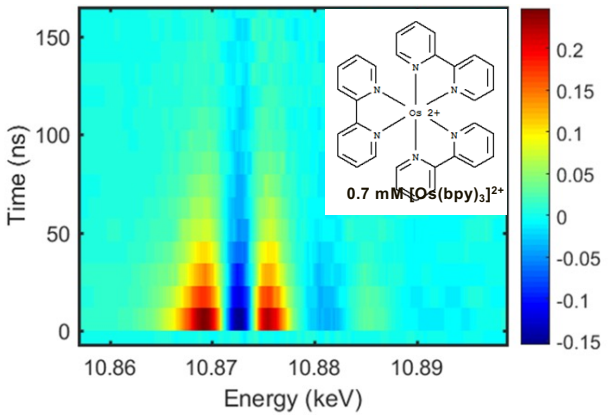
NSLS-II 1320 Buckets; 1056 filled; *2 ns separation*





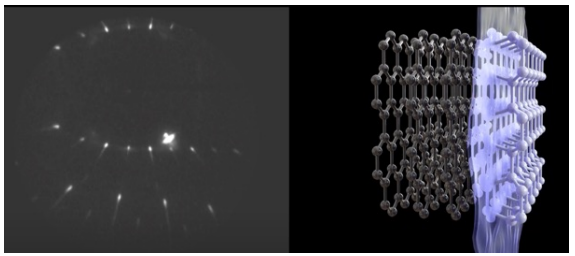
Time-Resolved X-ray Absorption

Os L_{III} edge difference XAS



E. Kinigstein *et al., Rev. Sci. Instrum.* **92**, 085109 (2021)

Single pulse x-ray diffraction @ APS 35-ID

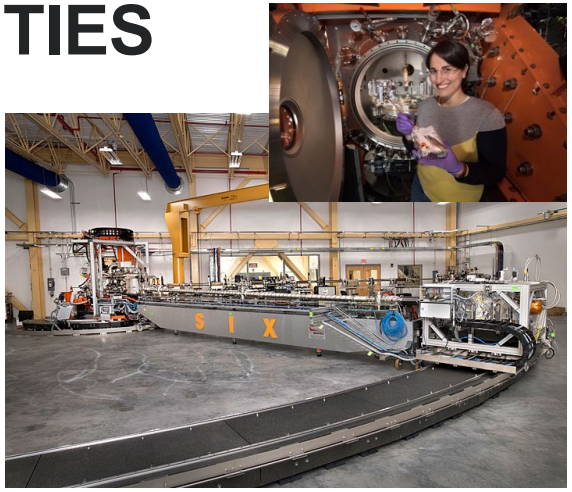


See talks by Ann Marie March (today) & Paul Fouss (Monday)

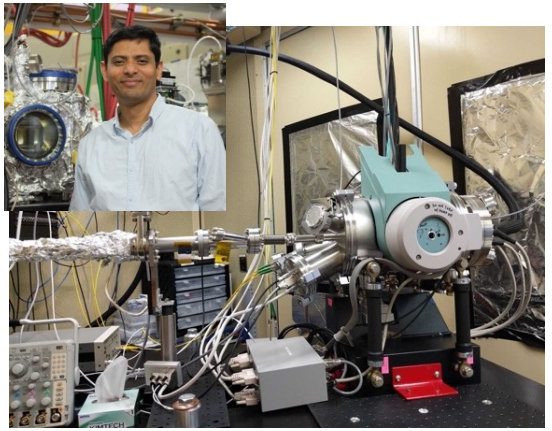
LIGHT SOURCE FACILITIES

Beamline capabilities

Nanoprobe @ APS

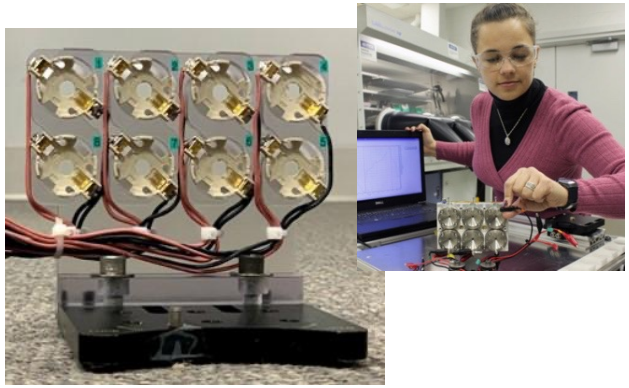


Soft X-ray RIXS @ NSLS-II

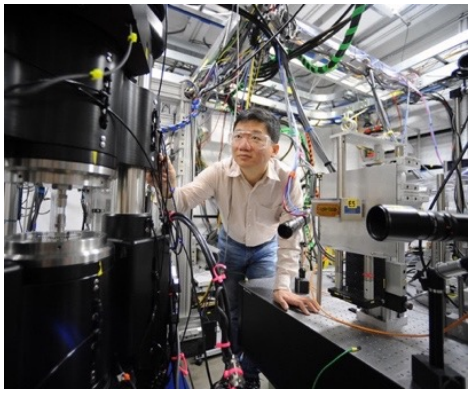


COSMIC imaging @ ALS

MEC instrument @ LCLS



AMPIX electrochemical cells @ APS



RAMS instrument @ APS

- Ancillary capabilities at each beamline typically given on web pages

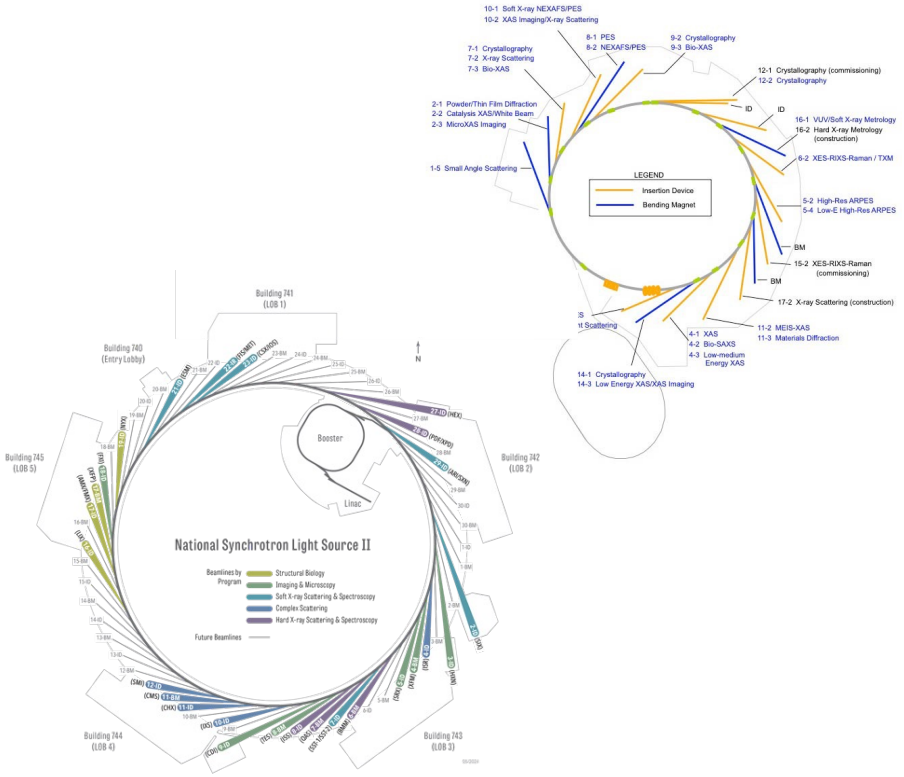
LIGHT SOURCE FACILITIES

Beamline capabilities information

Beamlines Directory

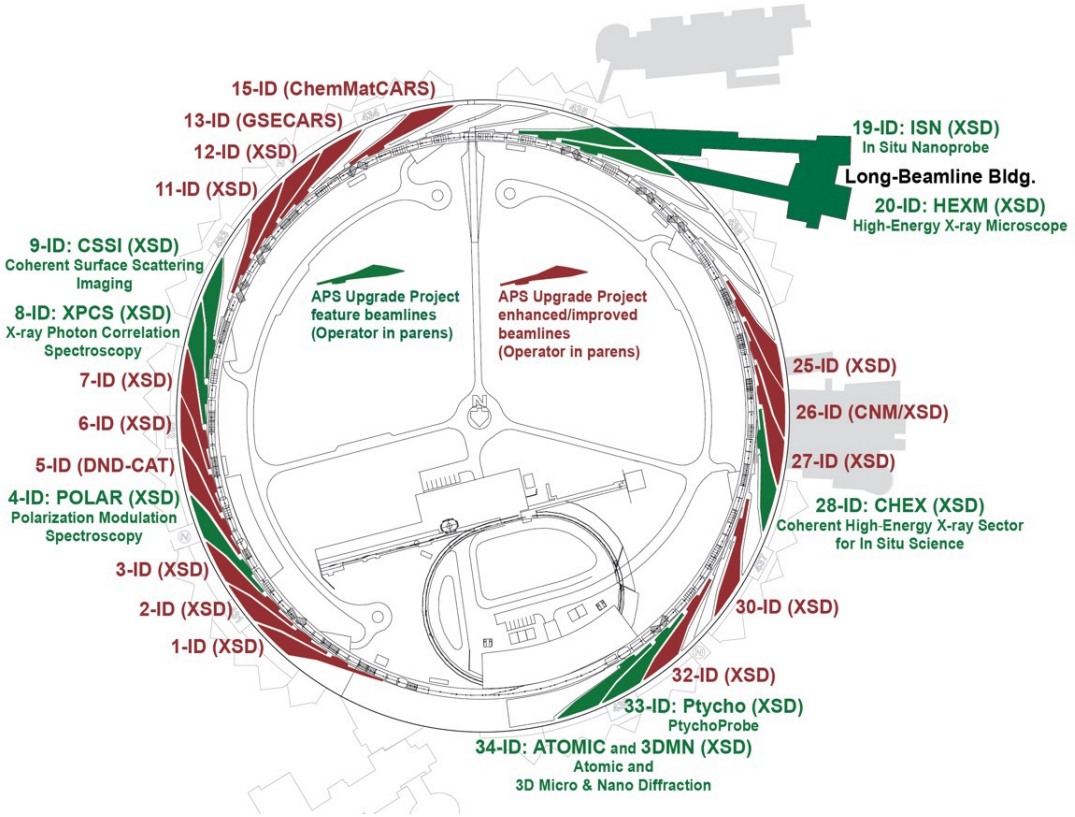
Information on APS Operations and General User Programs During the COVID Pandemic. To determine what access modes are available to general users at this time, check the operational status of the APS - Read More

Beamline	Disciplines	Techniques	Energy Range	Access	Operator	Status
1-BM-B,C	• Materials Science • Physics	• Optics testing • Detector testing • Topography • White Laue Single Crystal Diffraction	• 6-30 keV • 50-120 keV	• On-site	XSD	
1-ID-B,C,E	• Materials Science • Physics • Chemistry • Life Sciences	• High-energy x-ray diffraction • Tomography • Small-angle x-ray scattering • Fluorescence spectroscopy • Pair distribution function • Phase contrast imaging	• 41-136 keV • 45-116 keV	• On-site	XSD	
2-BM-A,B	• Physics • Life Sciences • GeoScience • Materials Science	• Tomography • Phase contrast imaging	• 10-170 keV • 11-35 keV	• On-site	XSD	
2-ID-D	• Life Sciences • Materials Science • Environmental Science	• Microfluorescence • Micro x-ray absorption fine structure • Nano-imaging • Ptychography	• 5-30 keV	• On-site • Remote • Mail-in • Beamline Staff	XSD	
2-ID-E	• Life Sciences	• Microfluorescence	• 5-20 keV	• On-site	XSD	



- Types of measurements supported at beamlines typically given on web pages
- Contact local beamlines staff with questions

APS UPGRADE PROJECT



- $815M upgrade; Reuses ~$1.5B in infrastructure
- Split ~½ accelerator & ~½ beamlines

APS Today

ε_o = 3100 pm

APS Upgrade

ε_o = 42 pm

- New storage ring and new updated insertion devices yields brightness increases of **up to 500x**
- Project includes 9 new feature & 15 enhanced beamlines to optimally exploit this brightness increase
- Exploit high performance computing, AI/ML for data analysis

44 Petaflops

On-line 22'

~2 Exaflop (2000 Petaflops)

Coming Fall 23'

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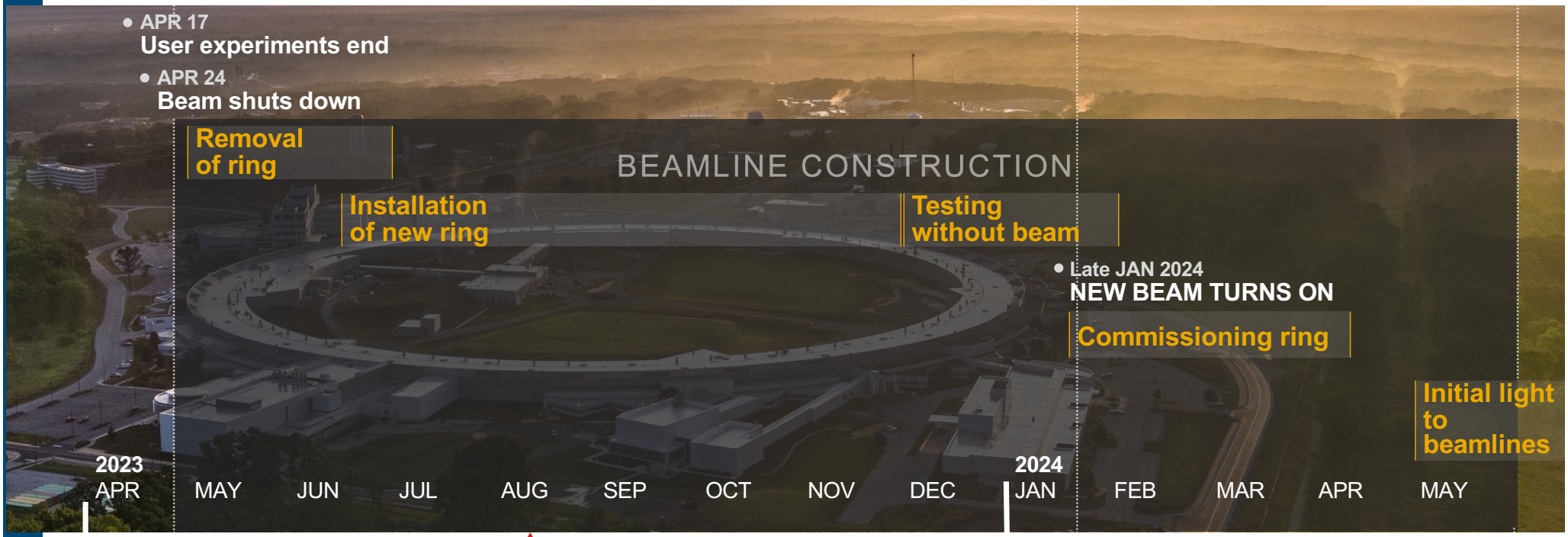
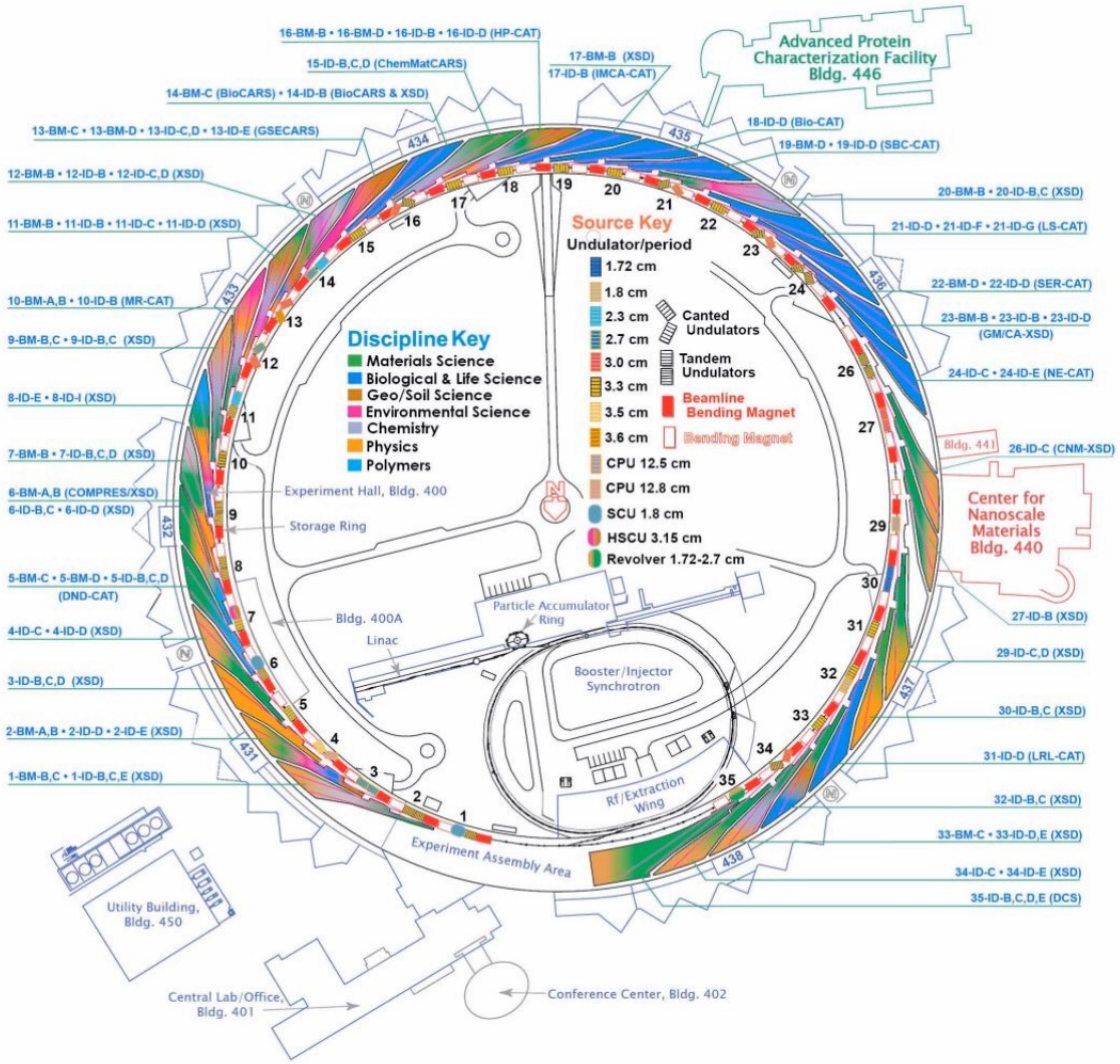
APS-U DARK TIME SCHEDULE



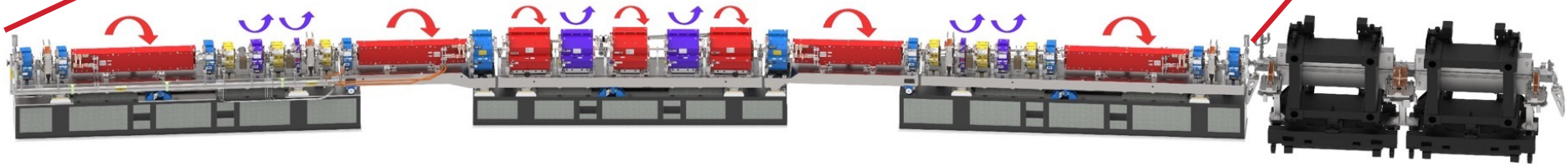
Today: Accelerator installation & beamline work

Initial light from APS-U expected onto experimental hall floor in May ‘24 (~9 months from now)


16-BM-B • 16-BM-D • 16-ID-B • 16-ID-D (HP-CAT)
15-ID-B,C,D (ChemMatCARS)
14-BM-C (BioCARS) • 14-ID-B (BioCARS & XSD)
13-BM-C • 13-BM-D • 13-ID-C,D • 13-ID-E (GSECARS)
12-BM-B • 12-ID-B • 12-ID-C,D (XSD)
11-BM-B • 11-ID-B • 11-ID-C • 11-ID-D (XSD)
10-BM-A,B • 10-ID-B (MR-CAT)
9-BM-B,C • 9-ID-B,C (XSD)
8-ID-E • 8-ID-I (XSD)
7-BM-B • 7-ID-B,C,D (XSD)
6-BM-A,B (COMPRES/XSD)
6-ID-B,C • 6-ID-D (XSD)
5-BM-C • 5-BM-D • 5-ID-B,C,D (DND-CAT)
4-ID-C • 4-ID-D (XSD)
3-ID-B,C,D (XSD)
2-BM-A,B • 2-ID-D • 2-ID-E (XSD)
1-BM-B,C • 1-ID-B,C,E (XSD)
17-BM-B (XSD)
17-ID-B (IMCA-CAT)
Advanced Protein Characterization Facility Bldg. 446
18-ID-D (Bio-CAT)
19-BM-D • 19-ID-D (SBC-CAT)
20-BM-B • 20-ID-B,C (XSD)
21-ID-D • 21-ID-F • 21-ID-G (LS-CAT)
22-BM-D • 22-ID-D (SER-CAT)
23-BM-B • 23-ID-B • 23-ID-D (GM/CA-XSD)
24-ID-C • 24-ID-E (NE-CAT)
Bldg. 441
26-ID-C (CNM-XSD)
Center for Nanoscale Materials Bldg. 440
27-ID-B (XSD)
29-ID-C,D (XSD)
30-ID-B,C (XSD)
31-ID-D (LRL-CAT)
32-ID-B,C (XSD)
33-BM-C • 33-ID-D,E (XSD)
34-ID-C • 34-ID-E (XSD)
35-ID-B,C,D,E (DCS)
Source Key
Undulator/period
1.72 cm
1.8 cm
2.3 cm
2.7 cm
3.0 cm
3.3 cm
3.5 cm
3.6 cm
Canted Undulators
Tandem Undulators
Beamline Bending Magnet
Bending Magnet
CPU 12.5 cm
CPU 12.8 cm
SCU 1.8 cm
HSCU 3.15 cm
Revolver 1.72-2.7 cm
Discipline Key
Materials Science
Biological & Life Science
Geo/Soil Science
Environmental Science
Chemistry
Physics
Polymers
Experiment Hall, Bldg. 400
Storage Ring
Bldg. 400A
Linac
Particle Accumulator Ring
Booster/Injector Synchrotron
Rf/Extraction Wing
Experiment Assembly Area
Utility Building, Bldg. 450
Central Lab/Office, Bldg. 401
Conference Center, Bldg. 402

APS-U SECTOR IN OFFSITE WAREHOUSE

Sector Mockup



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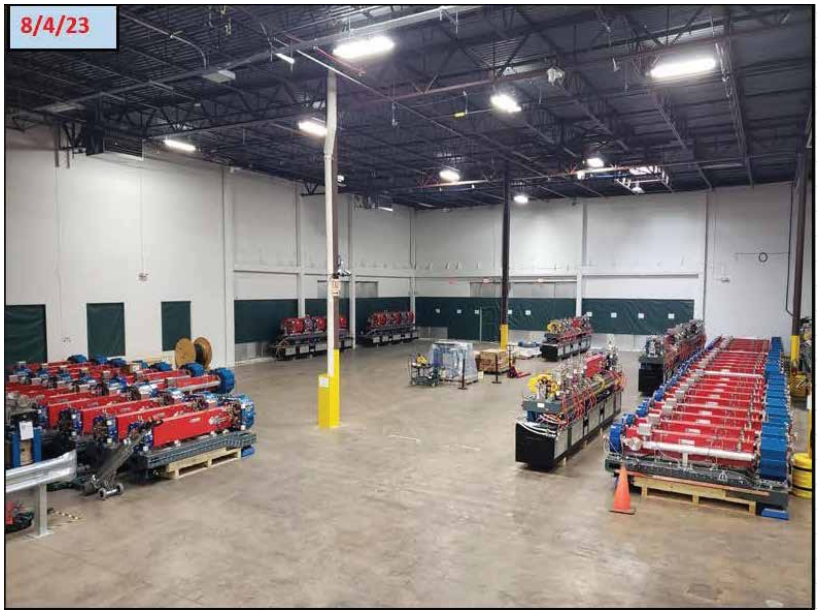
OFFSITE WAREHOUSE

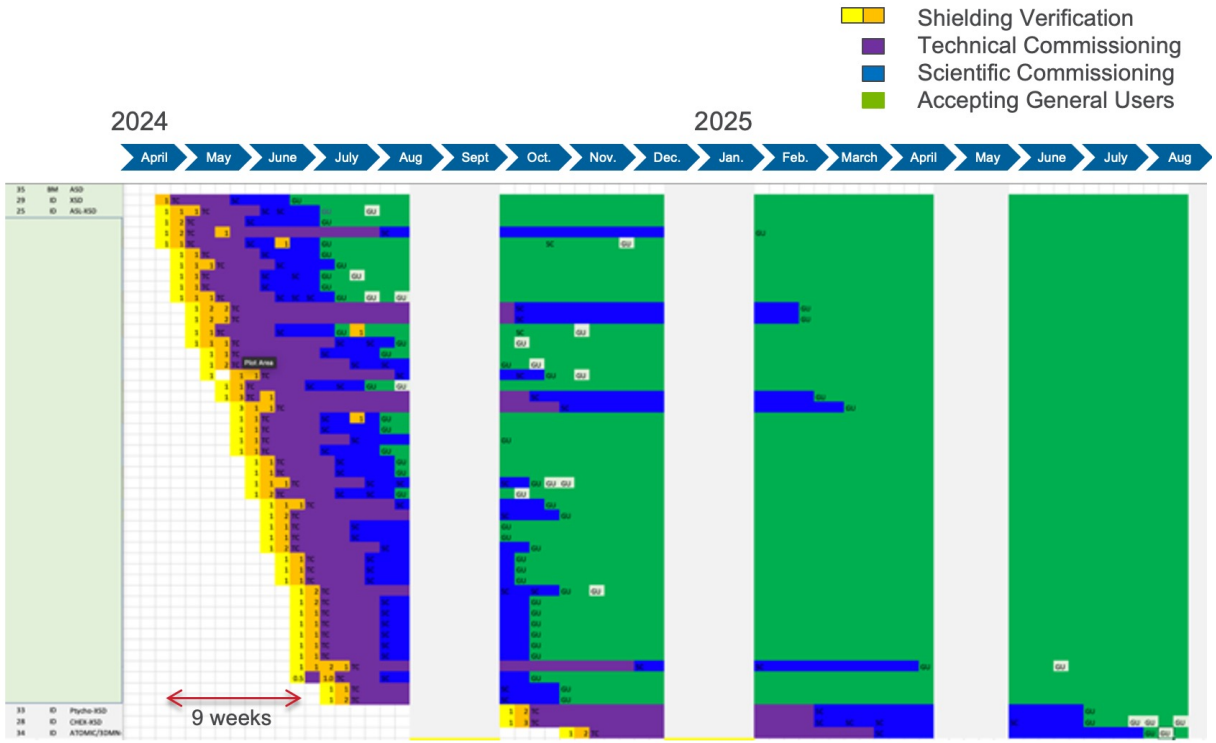
Emptying out fast



APSU BEAMLINE STARTUP NOTIONAL TIMELINE

Time increments in weeks

- Resume operations in ~May 2024
  - All stations need shielding verification performed before can start x-ray work. Will take ~9 weeks to go through all 54 ports (canted beamlines same time)
  - Technical commissioning: Check if all systems are working properly with x-rays (~1 month for beamlines with no/modest upgrades; ~ 3 months for new beamlines)
  - Scientific commissioning: First demo experiments (pre-scheduled)

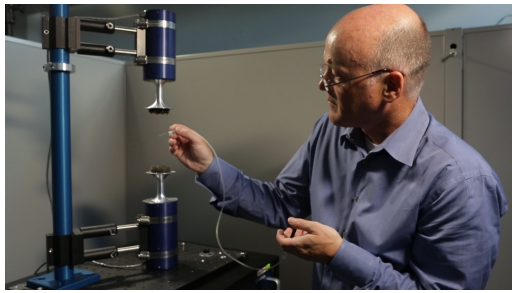


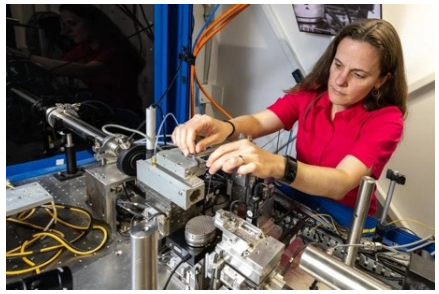
Expect nearly all beamlines to be accepting general users by Oct. ‘24

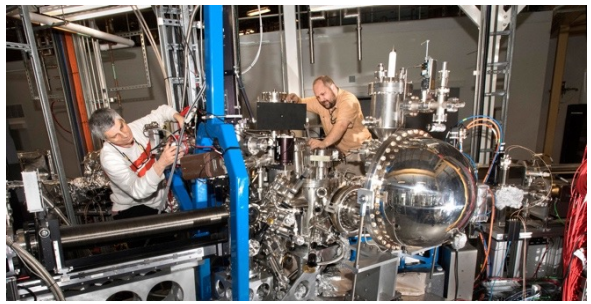
SUMMARY

Lots of considerations when choosing a beamline/facility
Can be daunting task.

- Energy range for measurement?
- Brightness needs?
- Timing structure important?
- Specialized sample/measurement capabilities needed?
- Location
  - Remote or Mail-in capabilities offered?







Staff at the facilities there to help you make the most effective use of your time.
Talk to them, they can help guide you towards the best choice beamlines

QUESTIONS

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