NSLS-II Current Projects & Plans for a Future Upgrade

5th Workshop on Particle Accelerator Upgrade Removal and Installation
May 4-8, 2026

Gregory Fries, Brookhaven National Laboratory

Brookhaven National Laboratory

Outline

- NSLS-II Overview
- Beamline Construction Projects
  - NEXT-II
  - PQIM
  - NEXT-III
- Obstacles from Recent Beamline Install
- Reliability & Ultimate Performance Plan
- Initial Plans and Development for NSLS-IIU

Gregory Fries

NSLS-II Accelerator Division

Deputy Director for Projects

- At NSLS-II for 17 years
- Coordinated NSLS-II accelerator installation
- CAM for accelerator infrastructure for new beamline construction
- Manage accelerator projects, staffing & budget
- NSLS-II work control manager

Brookhaven Lab Today

Relativistic Heavy Ion Collider, future Electron-Ion Collider

Physics

Instrumentation

Computational Science

Northeast Solar Energy Research Center

Chemistry

Biology, More

Interdisciplinary Science Bldg. for Energy

Center for Functional Nanomaterials

Lab for BioMolecular Structure (Cryo-EM)

National Synchrotron Light Source II

Environment, Nonproliferation, and More

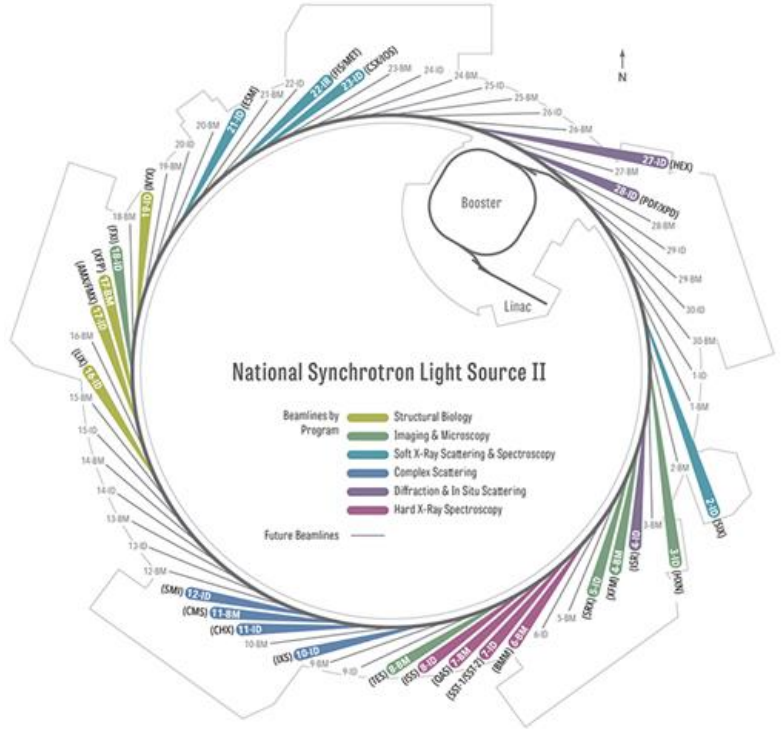
Plus Much, *Much* More!

Long Island Solar Farm

National Synchrotron Light Source II

U.S. Department of Energy Facility

- Hosts peer reviewed science and technology research
- Serves scientific, industrial and education communities



Competitive brightness on the world stage

- 3 GeV electron beam energy
- 792m in circumference
- Designed for current up to 0.5A
- Can host ~ 60 Beamlines; currently 29 in user operations
- 4 beamlines in construction
- 5 more on the drawing board

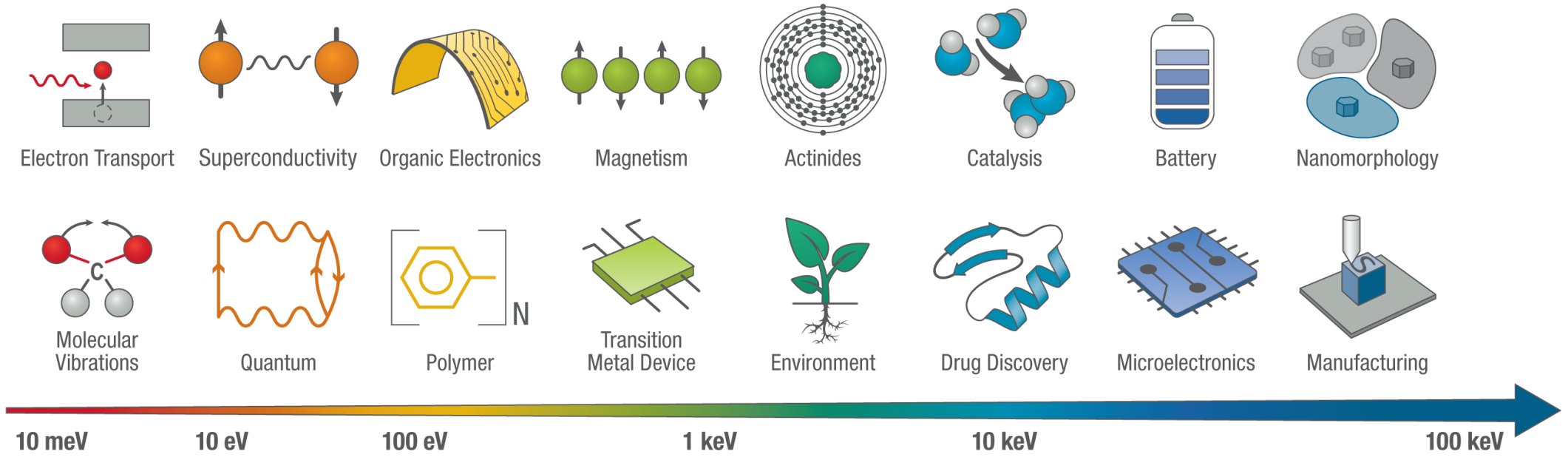
Quick ramp-up

- Accelerator installation 2011-2014
- First light October 2014
- GU ops started July 2015

Brookhaven National Laboratory

NSLS-II Mission

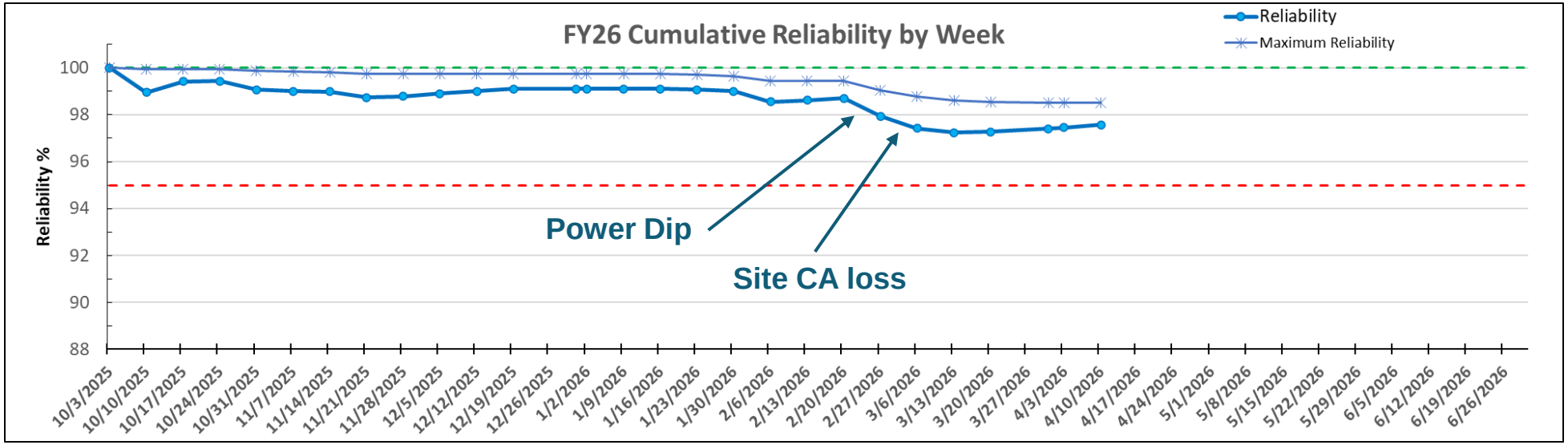
To develop and operate a premier user facility that embraces diversity to safely and efficiently deliver high-impact and cutting-edge science and technology for the benefit of society



- The challenges of today are complex and multiscale and require a multimodal approach enabled by an advanced data infrastructure
- To achieve its mission, NSLS-II must remain a competitive facility delivering cutting-edge science across a wide range of photon energies

Operations & Reliability

- Operations goal is 500mA and 30pm-rad with >97% reliability for ~5000 hours
  - Scheduled for 4800 hours in FY26 & 4900 hours in FY27



- Many installation & testing activities are dependent upon operating schedule
- Major installation activities occur during machine shutdowns
- Three machine shutdowns per year (~4 weeks each)
- Two-day maintenance period every 3 weeks
- Studies period 2-3 times per month

Operating Schedule

May 2026						
Day	Half Shifts					
	0-4	4-8	8-12	12-16	16-20	20-24
1	D	D	D	D	D	D
2	D	D	D	D	D	D
3	D	D	D	D	D	D
4	D	D	D	D	D	D
5	D	D	D	D	D	D
6	D	D	D	D	D	D
7	D	D	D	D	D	D
8	D	D	D	D	D	D
9	D	D	D	D	D	D
10	D	D	D	D	D	D
11	D	D	D	D	D	D
12	D	D	D	D	D	D
13	D	D	D	D	D	D
14	D	D	D	D	D	D
15	D	D	S	S	S	S
16	S	S	S	S	S	S
17	S	S	S	S	S	S
18	S	S	S	S	S	S
19	S	S	O	O	O	O
20	O	O	O	O	O	O
21	O	O	O	O	O	O
22	O	O	O	O	O	O
23	O	O	O	O	O	O
24	O	O	O	O	O	O
25	O	O	O	O	O	O
26	O	O/M	M	M	M	M
27	M	M	M	M	M/S	S
28	S	S	O	O	O	O
29	O	O	O	O	O	O
30	O	O	O	O	O	O
31	O	O	O	O	O	O

June 2026						
Day	Half Shifts					
	0-4	4-8	8-12	12-16	16-20	20-24
1	O	O	O	O	O	O
2	O	O	O	O	O	O
3	O	O	O	O	O	O
4	O	O	O	O	O	O
5	O	O	I	I	S	S
6	S	S	S	S	S	S
7	S	S	S	S	S	S
8	S	S	O	O	O	O
9	O	O	O	O	O	O
10	O	O	O	O	O	O
11	O	O	O	O	O	O
12	O	O	O	O	O	O
13	O	O	O	O	O	O
14	O	O	O	O	O	O
15	O	O	O	O	O	O
16	O	O/M	M	M	M	M
17	M	M	M	M	M/S	S
18	S	S	O	O	O	O
19	O	O	O	O	O	O
20	O	O	O	O	O	O
21	O	O	O	O	O	O
22	O	O	O	O	O	O
23	O	O	O	O	O	O
24	O	O	O	O	O	O
25	O	O	O	O	O	O
26	O	O	I	I	S	S
27	S	S	S	S	S	S
28	S	S	S	S	S	S
29	S	S	O	O	O	O
30	O	O	O	O	O	O

July 2026						
Day	Half Shifts					
	0-4	4-8	8-12	12-16	16-20	20-24
1	O	O	O	O	O	O
2	O	O	O	O	O	O
3	O	O	O	O	O	O
4	O	O	O	O	O	O
5	O	O	O	O	O	O
6	O	O	O	O	O	O
7	O	O/M	M	M	M	M
8	M	M	M	M	M/S	S
9	S	S	O	O	O	O
10	O	O	O	O	O	O
11	O	O	O	O	O	O
12	O	O	O	O	O	O
13	O	O	O	O	O	O
14	O	O	O	O	O	O
15	O	O	O	O	O	O
16	O	O	O	O	O	O
17	O	O	I	I	S	S
18	S	S	S	S	S	S
19	S	S	S	S	S	S
20	S	S	O	O	O	O
21	O	O	O	O	O	O
22	O	O	O	O	O	O
23	O	O	O	O	O	O
24	O	O	O	O	O	O
25	O	O	O	O	O	O
26	O	O	O	O	O	O
27	O	O	O	O	O	O
28	O	O/M	M	M	M	M
29	M	M	M	M	M/S	S
30	S	S	O	O	O	O
31	O	O	O	O	O	O

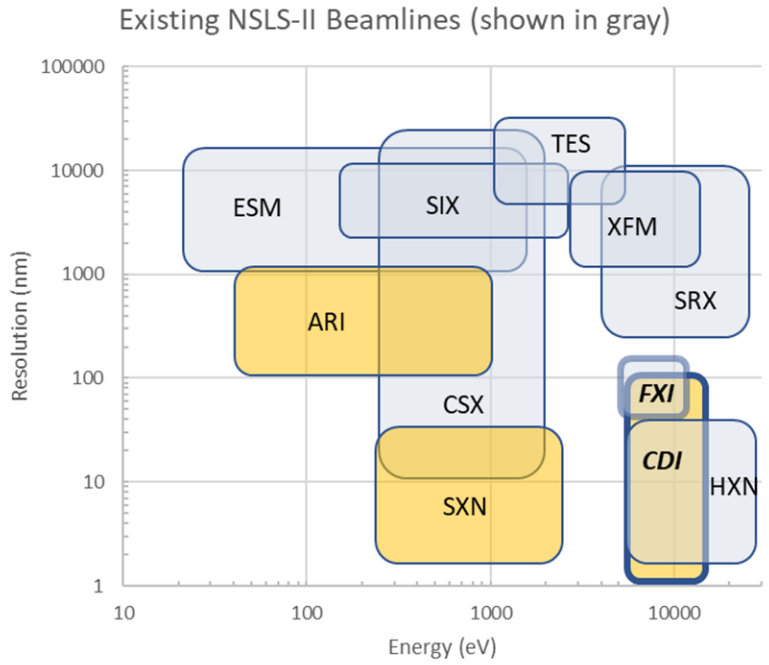
August 2026						
Day	Half Shifts					
	0-4	4-8	8-12	12-16	16-20	20-24
1	O	O	O	O	O	O
2	O	O	O	O	O	O
3	O	O	O	O	O	O
4	O	O	O	O	O	O
5	O	O	O	O	O	O
6	O	O	O	O	O	O
7	O	O	I	I	S	S
8	S	S	S	S	S	S
9	S	S	S	S	S	S
10	S	S	D	D	D	D
11	D	D	D	D	D	D
12	D	D	D	D	D	D
13	D	D	D	D	D	D
14	D	D	D	D	D	D
15	D	D	D	D	D	D
16	D	D	D	D	D	D
17	D	D	D	D	D	D
18	D	D	D	D	D	D
19	D	D	D	D	D	D
20	D	D	D	D	D	D
21	D	D	D	D	D	D
22	D	D	D	D	D	D
23	D	D	D	D	D	D
24	D	D	D	D	D	D
25	D	D	D	D	D	D
26	D	D	D	D	D	D
27	D	D	D	D	D	D
28	D	D	D	D	D	D
29	D	D	D	D	D	D
30	D	D	D	D	D	D
31	D	D	D	D	D	D

Operation Status Legend

O	Accelerator Operations
S	Studies
M	Maintenance
C	Commissioning
I	Interlock Certification
D	Shutdown

NEXT-II Project

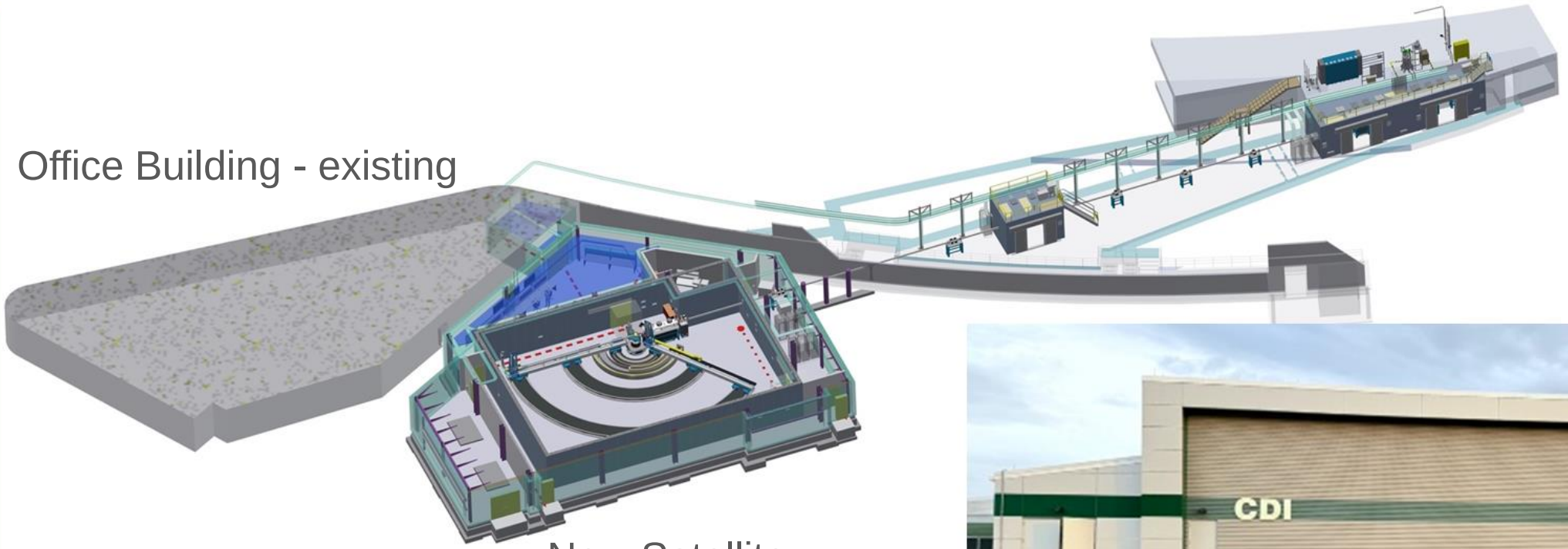
- 3 new beamlines selected from Strategic Planning Workshop in 2015
- These beamlines address science opportunities in quantum information science, energy storage and catalysis and fill capability gaps in NSLS-II portfolio.
- CD-2/3 in Oct. ‘21
- CDI – Coherent Diffractive Imaging
  - Accelerator Readiness Review (ARR) in Sept. ‘25
  - In beamline commissioning
- ARI – ARPES & RIXS – Spectroscopy & X-ray Scattering
- SXN – Soft X-ray Nanoprobe
  - ARI/SXN share a straight & canted front end
  - Joint ARR in July ‘26



CDI Beamline

NSLS-II - existing

Office Building - existing



New Satellite
Endstation Building

CDI Satellite Building Construction

Obstacles overcome:

- Vendor start delayed by improper submittals
- Discovery of approx. 600 yards of unsuitable soil that required mitigation
- Steel sub-contractor in financial trouble delayed work for months, eventually replaced
- Design issue with concrete aggregate vs. spacing between rebar in roof beams
- Design issue with steel frame resulting from change in roof from curved to flat
- Supply chain issues with metal siding material
- GC relationship with sub-contractors added to delays

September 2022, CDI SEB soil remediation

May 2023, CDI SEB roof formwork and rebar

Courtesy of J. Hawkes

CDI Hutches

Obstacles overcome:

- Two unsuccessful RFPs. The market could not support both project cost and schedule.
  - Forced first-time hybrid self-performing effort
- Unsuccessful procurement of design work forced in-house design effort.
- Existing vendor models and drawings were incomplete and had errors.
- Learning curves for in-house engineers, first-time fabricator, and first-time BNL installers
- Design or fabrication issues resulted in re-work delays.
- Supply chain issue with lead sub-contractor

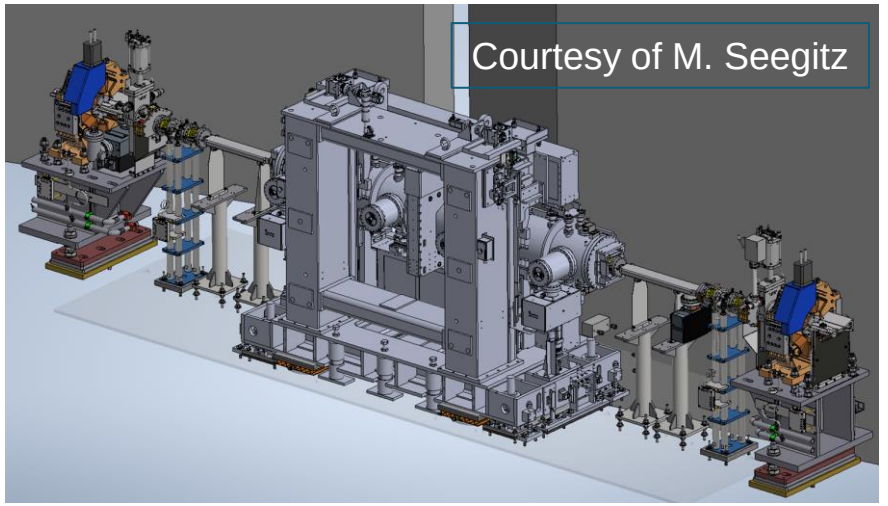
April 2024, 9-ID-B hutch installed

Courtesy of J. Hawkes

CDI Accelerator Scope

- CDI Source (Insertion Device)
  - One In-Vacuum Undulator (IVU18) – 18mm period length
  - 2.4m long with tapering function; 4.63mm minimum gap; 1.15T peak magnetic field
- Straight Section
  - RF BPMs with high stability stands
  - Vacuum equipment & spool pieces
- Front End
  - Non-canted front end with an X-BPM

- All scope is very similar to existing IVU beamlines
- New design work was greatly minimized
- Extensive experience with similar installations

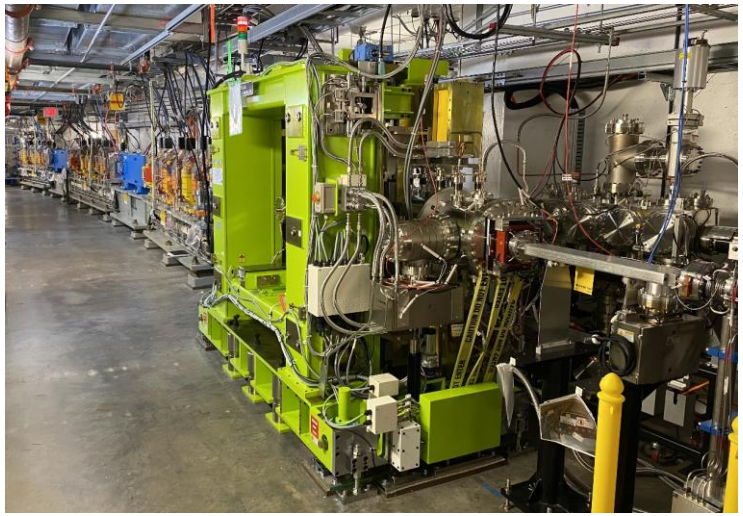


CDI IVU Straight Layout

CDI IVU Measurement, Testing & Install

- Spring ‘24 shutdown
  - Cable tray installation
- Summer ‘24 shutdown
  - Tunnel floor preparation
- Sept. ’24 – Dec. ‘24
  - IVU arrived at BNL from vendor
  - Magnetic measurements, tuning & controls testing
  - IVU bake out (in lab)
- Winter ‘24 shutdown
  - IVU installed & surveyed in SR tunnel (gap LOTO’d open)
  - Straight reconfiguration & bake out
  - Control rack installed on SR mezzanine
  - Cables pulled & terminated; tie-in to EPS
- Spring ’25 shutdown
  - IVU integration testing

IVU in lab



IVU in installed

CDI IVU Obstacles

Obstacles overcome:

- Interference with adjacent Front End
- Vendor was sold during contract negotiations
- Vendor fell behind schedule immediately and delayed each review
- PPM issued a Notice to Cure to get vendor back on track
- Delay required airfreighting at significant cost which BNL split with the vendor
- Cost of airfreighting was less than cost of delaying the ARR by 3 months

September, 2022 9-ID straight section with clashing elements of 8-BM

September, 2023 9-ID straight section reworked

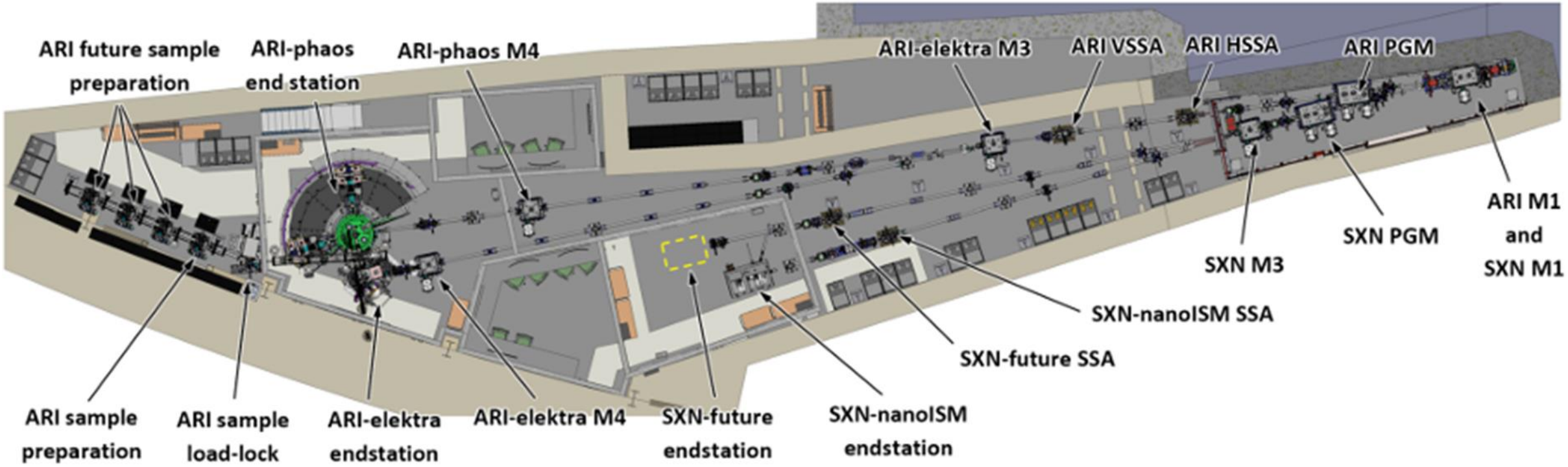
CDI Front End Install

- Summer ‘23 shutdown
  - Exit pipe (from SR to FE) installed & cell 9 bake out
- Winter ‘23 shutdown
  - Cable tray installation & cable pulling
- Spring ‘24 shutdown
  - Front end stands installed
- Summer ‘24 shutdown
  - Vacuum, electrical & mech. utility connections made
  - Ratchet wall collimator installed (shutters LOTO’d closed)
- Winter ‘24 shutdown
  - Bake out & final survey
- Spring ’25 shutdown
  - Integration testing & tie-in to PPS

FE before connections

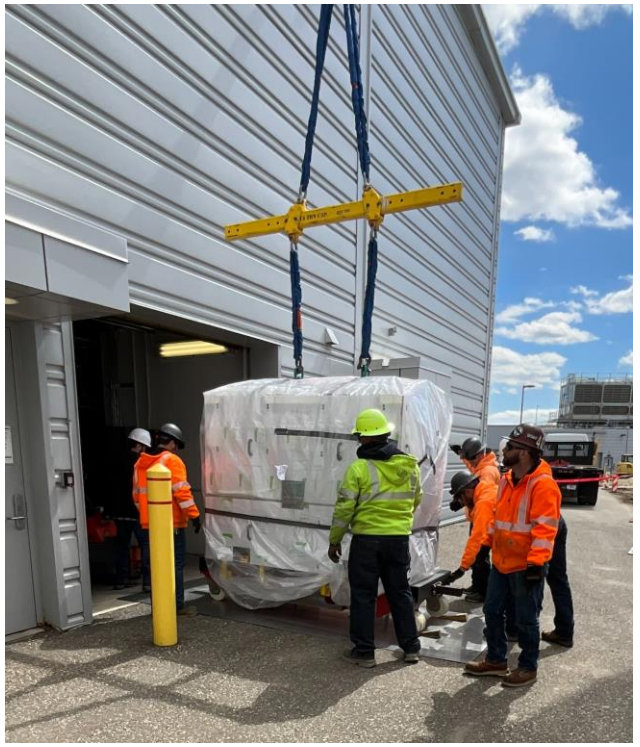
FE after connections

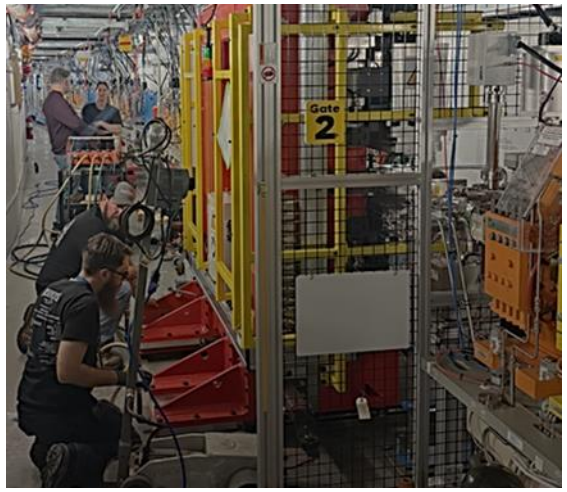
ARI & SXN Beamline



ARI & SXN EPU Transport

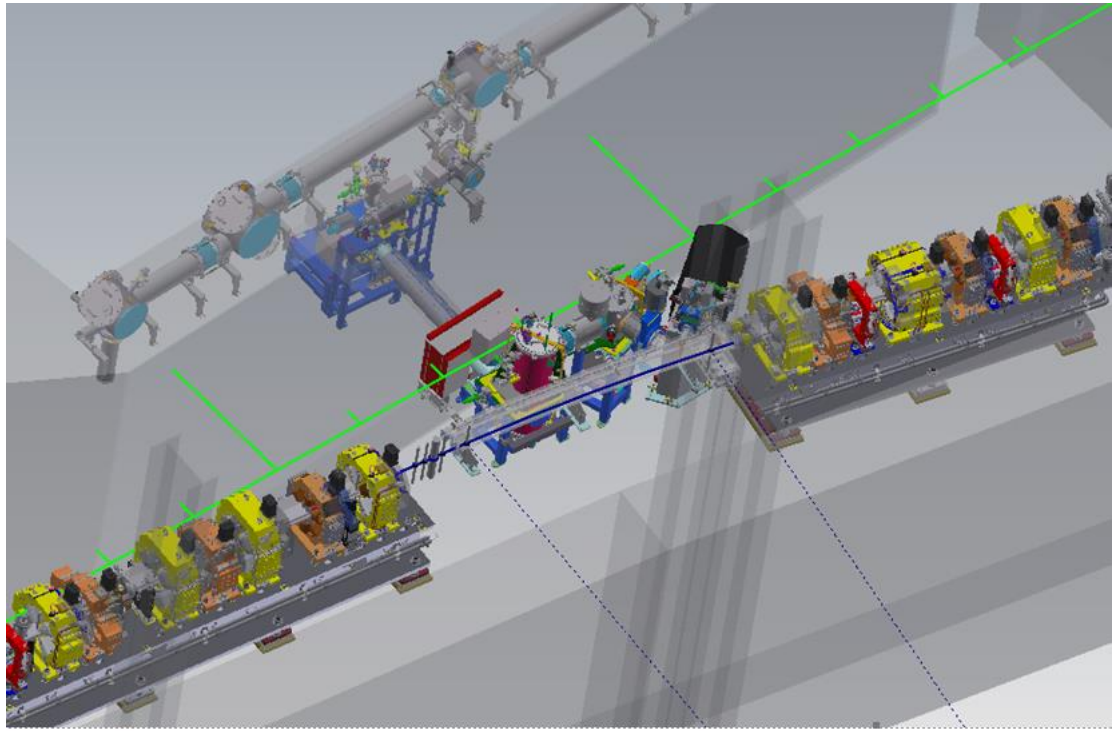
- Two Elliptically Polarizing Undulators
  - ARI EPU installed in Winter ‘25
  - SXN EPU installed in Spring ’26
- Use building crane in measurement lab to load onto flatbed truck
- Use mobile crane in accelerator courtyard to unload
- Use casters & tugger to move into service bldg.
- Use air casters to move into SR tunnel
- Finishing wiring & starting testing to prepare for ARR in July





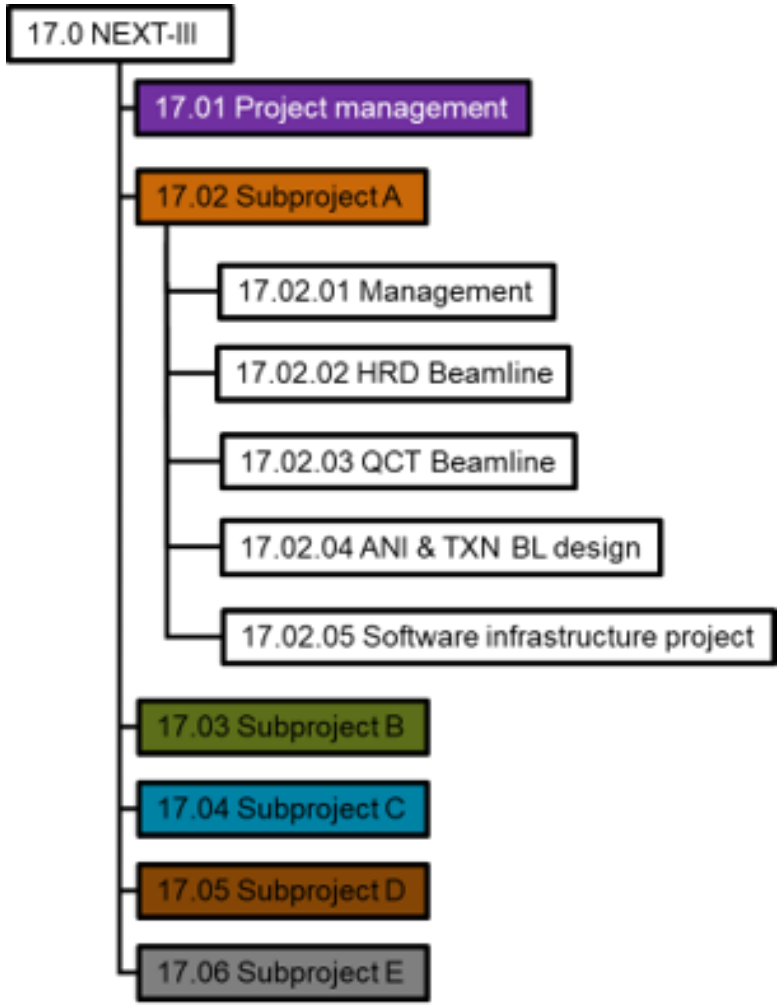
PQIM Project

- Probes for Quantum Information Materials
- Includes Infared beamline at NSLS-II
- Need to swap dipole vacuum chamber & install mirrors in SR tunnel
- Significant supplement shielding required
- Core drilled & backfilled ratchet wall in preparation
- Installation to start in Summer ‘26
- ARR planned for Oct. ’27
- See Mike Seegitz’s poster for additional details



NEXT-III Project

- 8-12 new beamlines executed in staged subjects
- Includes infrastructure updates to support new beamlines
- Each subproject to include ~2-4 beamlines
- Each subproject ~1-2 years apart
- CD-1 received in Sept. ‘24
- CD-2/3 for Subproject A in Oct. ’26
  - QCT – Quantitative Cellular Tomography
  - HRD – High Resolution Diffraction
  - ANI/TXN – Advanced Nanoscale Imaging & Tender X-ray Nanoprobe (Design Only)
- Subproject B kicked off in May ’25
  - ANI-TXN – Build
  - AMP – Advanced Materials Process
- Beamlines for Subproject C to be chosen this year
- Subprojects D & E to follow

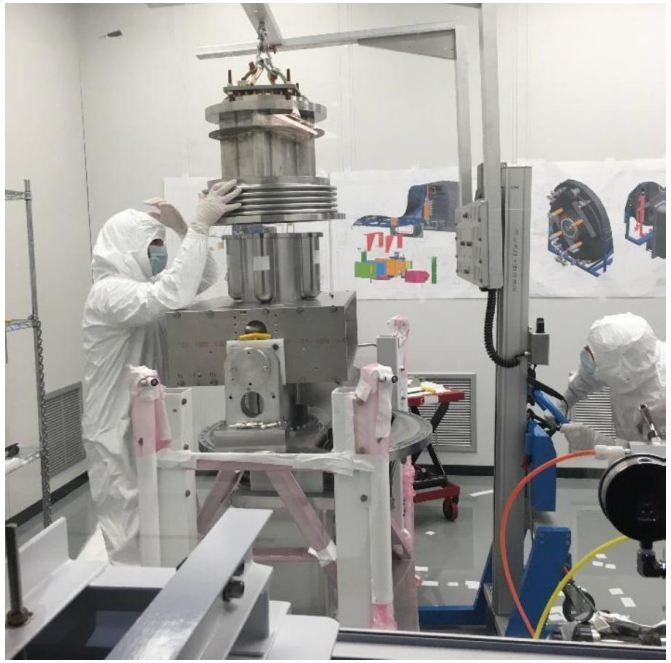


Reliability and Ultimate Performance (RUP) Plan

- Plan to reach NSLS-II design goal of 500mA with diffraction-limited emittance of 8 pm-rad while maintaining >97% reliability
- Scope includes:
  - Spare 500 MHz RF cryo module
  - Spares not in hand (critical & intermediate)
  - Redundant 850 W RF cryo plant
  - Solid state amplifier (SSA) - to replace klystron transmitter
  - Measures against utility interruptions for cryogenic plan
  - Backup injector & storage ring dipole power supply
  - 2 Third harmonic 1.5 GHz cavities
  - 4th 500 MHz RF system with cryo module & SSA
  - Addressing obsolescence (ex. BPMs, PS & RF controllers, VFDs)
- ~10-year plan that started in 2019
- Strong focus on single points of failure & redundancy

RUP Plan – Spare RF Cryo Module

- A spare cavity has been completed to allow fast replacement of failed unit to support full 500 mA operations.



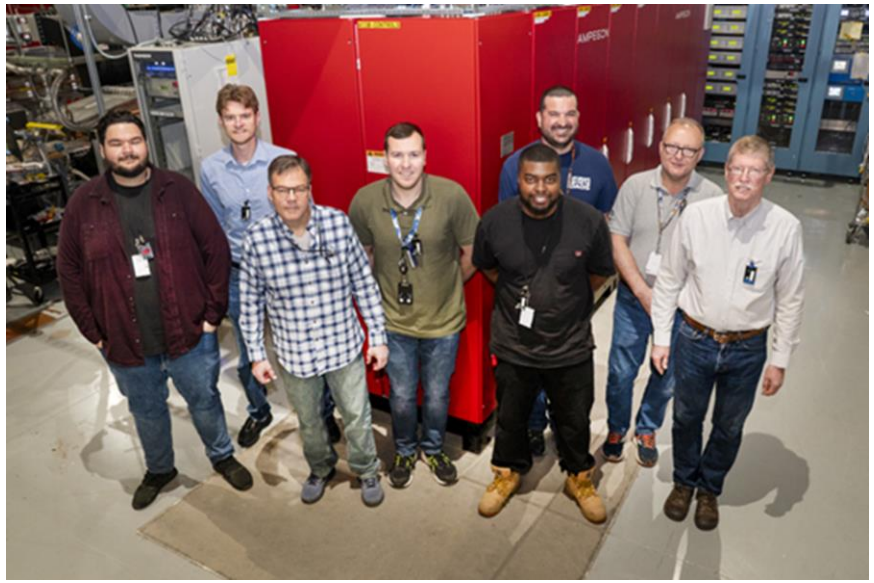
Assembly of niobium cavity in cleanroom

Testing in RF blockhouse

Courtesy of J. Rose

RUP Plan – Second Solid State Amplifier

- 300 kW klystrons are getting harder to source. It only has one vendor in Europe, plus the lead time is 1.5-2 years.
- A 2nd solid-state amplifier (SSA) has been purchased and installed to replace a klystron-based transmitter. In addition to more reliable operation this provided an additional spare for our remaining klystron transmitter.

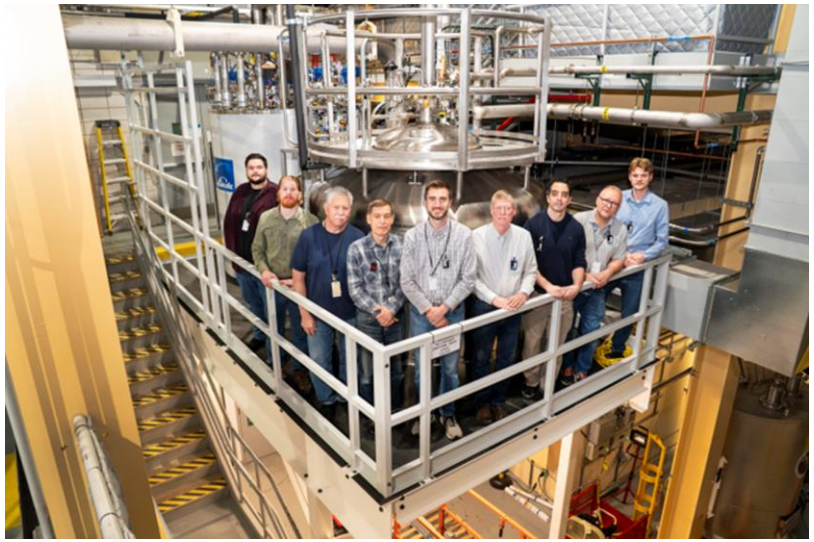


SSA Installed with RF team

Courtesy of J. Rose

RUP Plan – Second Cryogenic Plant

- A 2nd cryo plant has been installed along with its dedicated dewar providing a second system which alternates with primary to allow maintenance and refurbishment of the standby unit as well as a spare in the event of a failure of the other.
- Redundant system lessens downtime from a cold box trip from days to hours.
- A new mezzanine was constructed in the RF bldg. house the new system.



2nd Cryo Plant Installed with Cryo team

Courtesy of J. Rose

RUP Plan – Upcoming & In-process Projects

- Back-up SR dipole power supply
  - Installation is complete & integrated testing in process
- Measures against power & compressed air interruption
  - Power dip ride-thru capacitor bank complete
  - Back-up diesel generator delivered; install starting
  - Back-up air compressors installed
- Purchasing of spare & replacement parts in ongoing
- Work on harmonic cavities & back-up injector dipole power supply is starting
- 4th RF system in FY28-FY30
  - Required as more beamlines are added
  - Provides redundancy

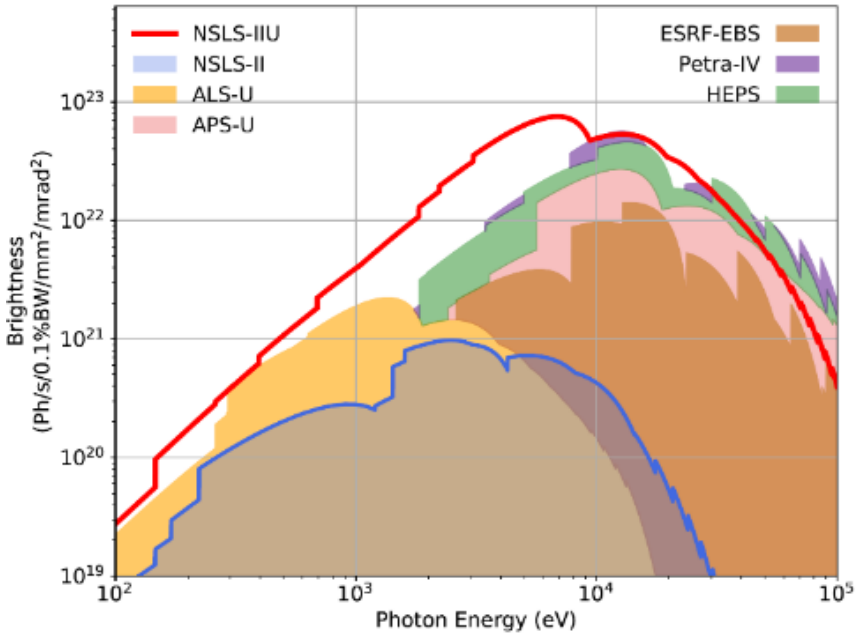
Back-up SR Dipole PS

Back-up Generator

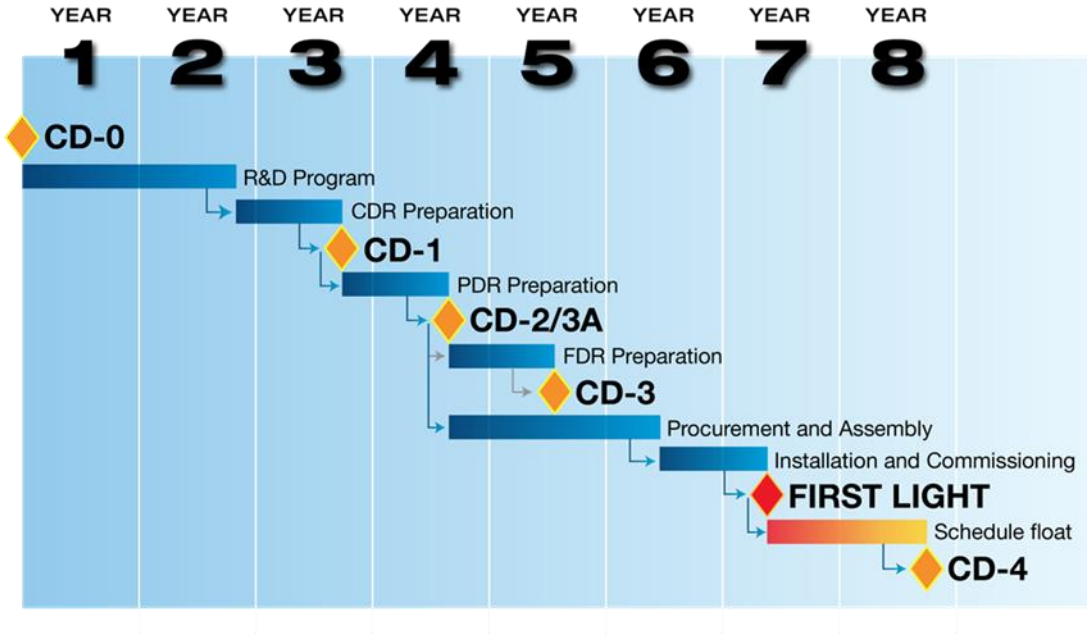
Courtesy of J. Rose

NSLS-IIU Introduction

- Initial plans for a full upgrade to NSLS-II underway
  - Proceeding through development projects and prototyping
- Retreat held in ‘23 to review upgrade options
  - High brightness + beam energy upgrade chosen
- CD-0 as soon as next year
- Complex bend concept
  - Relying on permanent magnet technology
- Triple complex bend achromat lattice
- Upgrade goals:
  - x120 in brightness at 10 keV, x15 at 1 keV
  - Preserve present source location
  - Utilize advanced insertion devices
  - Minimize power consumption
  - Increase reliability
  - Dark time <1 year

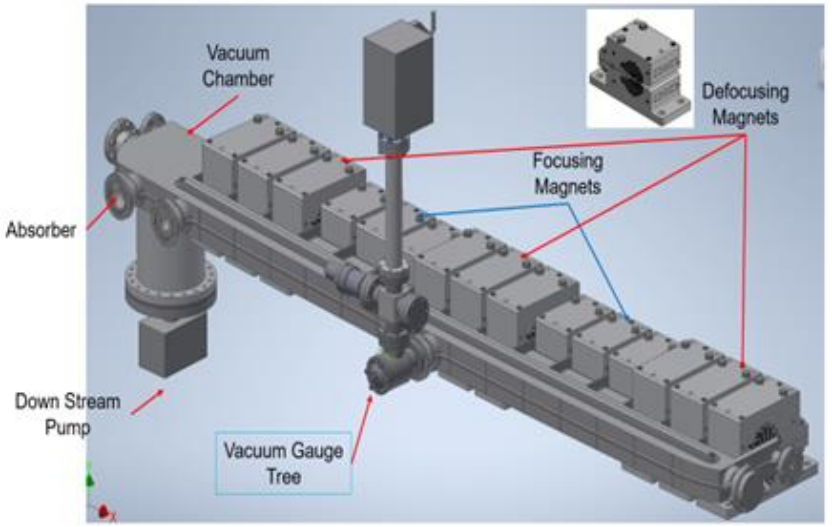


D. Hidas for NSLS-IIU proposal

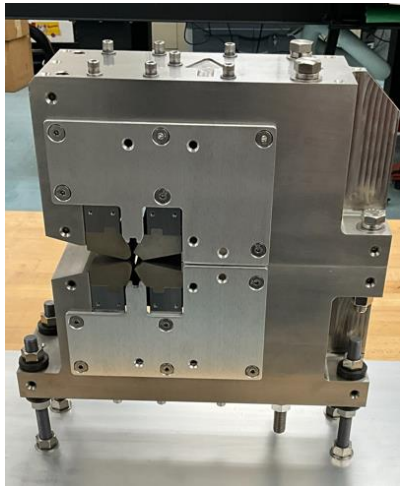


NSLS-IIU Benefits & Requirements

- Would include removal of existing ring, install of ~180 CB assemblies & 100 quads, testing & commissioning
- Benefits of complex bend approach
  - Supports low emittance lattice
  - No coils, power supplies, controls and DI water
  - Facility magnets energy consumption reduced by ~75%
  - Compact and cost-effective design
- Requirements
  - Fit in the current tunnel
  - Maintain source points
  - No realignment for ID beamlines
  - BM beamlines likely to be moved
  - Reusing super-conducting RF & injector



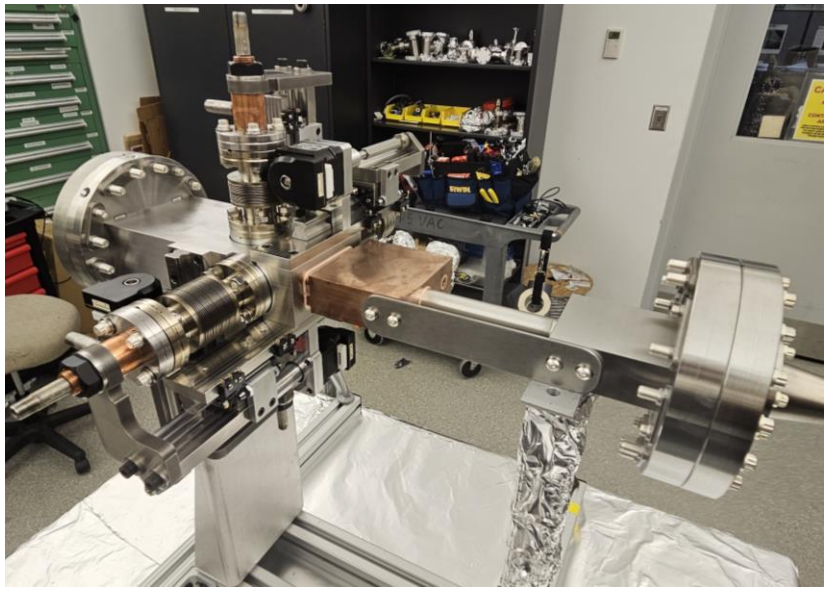
Complex Bend Model


Hybrid PMQ prototype

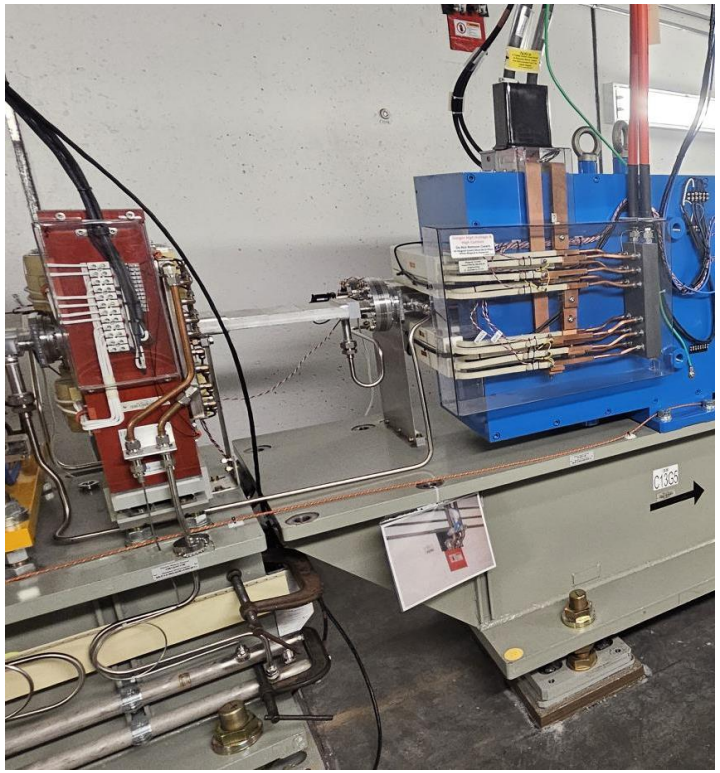
Complex Bend Array Prototype

XY Scraper

- 4-channel beam scraper installed to vary local aperture
- To determine minimum aperture with acceptable beam lifetime & injection efficiency
- Installed in April ‘26



Scraper in lab



Location in SR tunnel

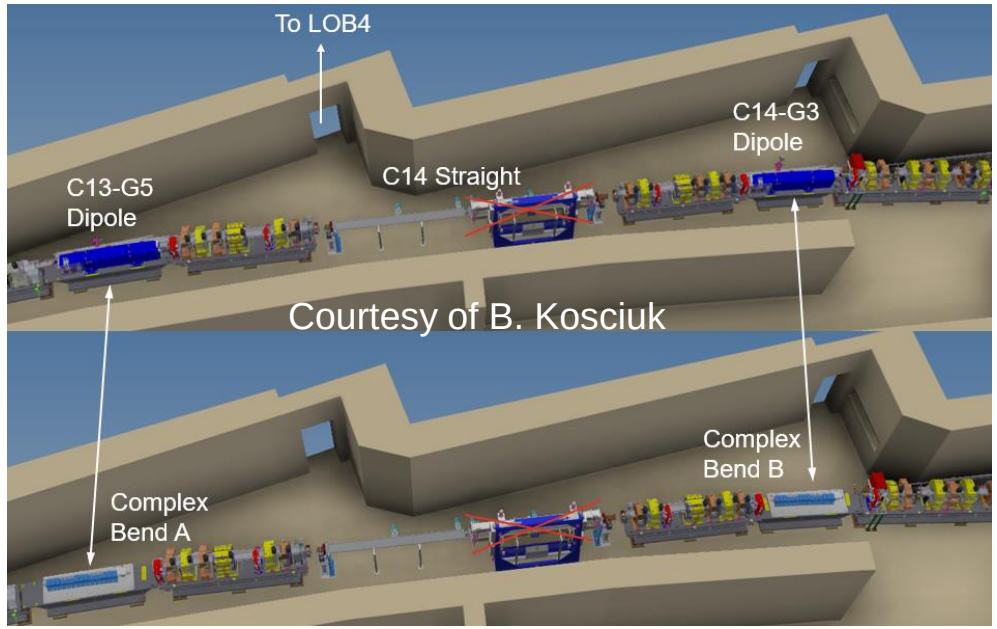
Installed in SR tunnel

Courtesy of B. Kosciuk

Brookhaven National Laboratory

Modifications to NSLS-II storage ring lattice

R&D funded project to replace two 2.62 m NSLS-II dipoles with complex bends (CBs)



Existing Dipole

Courtesy of T. Shaftan

- Project goals:
  - Develop and demonstrate accelerator design of CBs and their model in the NSLS-II ring lattice.
  - With beam study program predict major impact of the mechanical and magnetic constraints on the ring lattice. Use the scraper and the 8-pole magnets to simulate changes imposed by CBs in the ring.
  - Build and characterize two CBs and demonstrate the required specifications using mechanical and magnetic measurement benches.
  - Install these CBs in the tunnel and prepare the ring for operations within a single shutdown. Planned for 2027.
  - Fully characterize the performance of CBs and performance of the modified ring lattice.
- Constraints/requirements of lattice design:
  - Keep beam entry and exit CB coordinate unchanged.
  - Match CB local optics to the NSLS-II ring lattice while maintaining nearby quadrupole gradients within limits.
  - Maintain storage ring sufficient DA and MA for off-axis injection and good beam lifetime.
  - Tolerant to magnets field and misalignment errors.

Summary

- After over 10 years, NSLS-II continues operations with high reliability to support a robust user program
- Multiple projects are in process to continue build-out of experimental beamlines
- RUP plan to increase performance, reliability, add redundancy, and address obsolescence making excellent progress
- Plans for NSLS-IIU underway proceeding through development projects and prototyping