

AFTER THE UPGRADE: SURVEY & ALIGNMENT ACTIVITIES AT THE ADVANCED PHOTON SOURCE



William Jansma, Dusan Banjanac, Davide Bianculli, Joshua Downey, Keith Knight
Advanced Photon Source
Argonne National Laboratory



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Photon Source

- Argonne & The Advanced Photon Source (APS)
- APS Survey & Alignment Section
- APS Upgrade Completed
- Survey Sync Database
- Hydrostatic Level Systems
- Terrestrial Laser Scanning
- RF Electron Guns

- Superconducting Undulators
- In-House Tracker Evaluations
- Etalon System Acquired
- Cavity based X-ray free electron laser (CBXFEL)
- Collinear Wakefield Accelerator R&D
- Vintage Metrology Exhibit
- Acknowledgements

APS SURVEY & ALIGNMENT SECTION



Joshua Downey (Section Leader) , Nemanja Arsic, Keith Knight, Spiro Skiadopolous, Kristine Mietsner, William Jansma, Roberto Lopez, Dusan Banjanac, Cody Holz, Davide Bianculli, Davor Pavlovic, James Brown

ADVANCED PHOTON SOURCE UPGRADE



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Argonne National Laboratory

- First US National Laboratory, chartered July 1, 1946.
- 2026 marks Argonne's 80th Anniversary
- Multi-disciplinary facility operated by UChicago-Argonne, LLC for the U.S. Department of Energy
- Focus on basic science research, energy storage and renewable energy, environmental sustainability, and national security.



ADVANCED PHOTON SOURCE

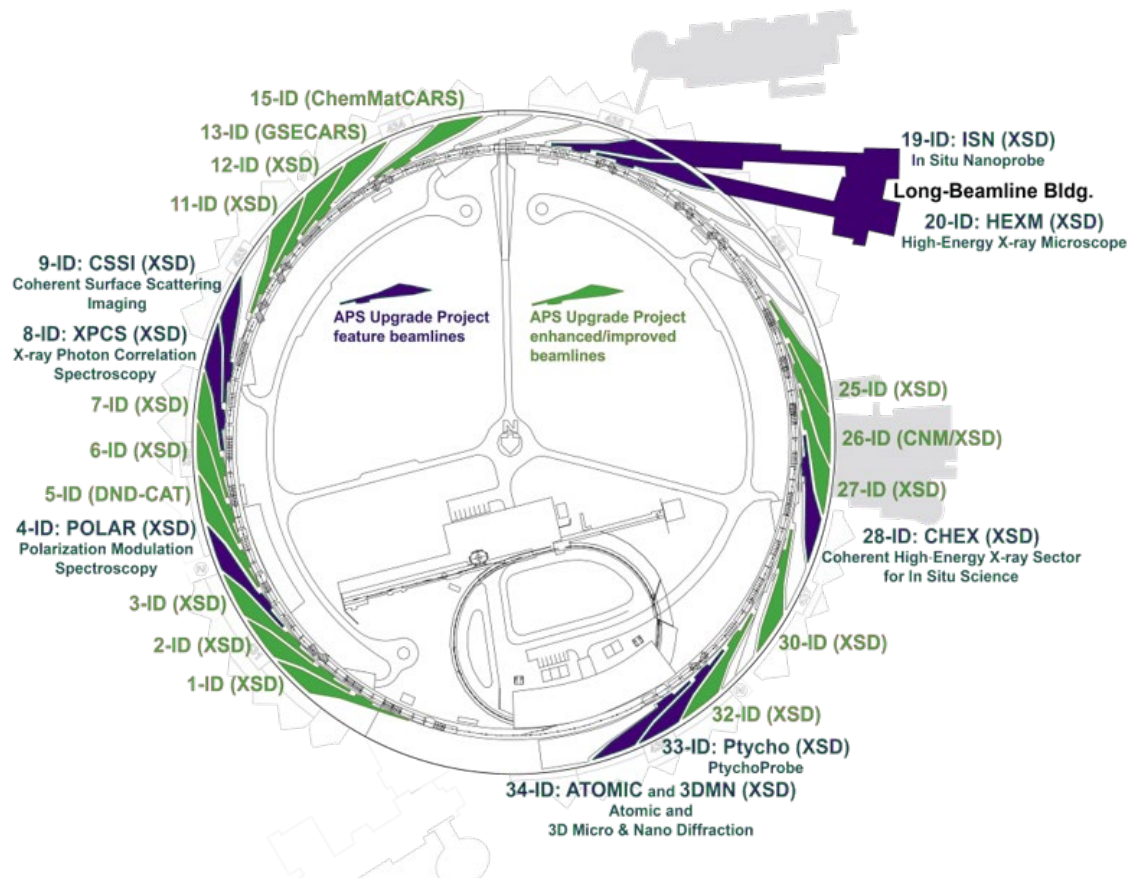
In operation since 1996, APS is the Premier National User Facility in the Western Hemisphere, hosting ~3,500 Scientists Per Year

- Accelerator and X-ray R&D
- Biological Science
- Materials Science
- Chemical Science
- Geoscience
- Environmental Science
- Nanoscience (Center for Nanoscale Materials)
- Pharmaceutical Research
- Atomic, Molecular and Optical Physics



THE APS UPGRADE IS NOW COMPLETE !

The Advanced Photon Source Upgrade project received its final approval in January 2026, having delivered on its full scope on budget and ahead of schedule. The upgraded facility is now fully operational and user experiments are underway.



BEAMLINE COMMISSIONING PROGRESS

SEPTEMBER 14, 2026

KEY 1 Installation Ongoing 2 Installation Complete 3 Ops Commissioning 4 Technical Commissioning 5 Scientific Commissioning and Early Experiments 6 Restart of General User Program

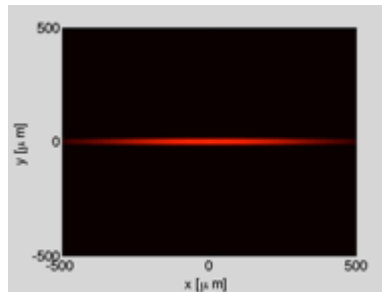
RESTART STATUS		RESTART STATUS		RESTART STATUS		RESTART STATUS																		
1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6							
1-BM-B,C XSD						10-BM-B MR-CAT						16-ID-D,E HPCAT-XSD						25-ID-D,E:ASL XSD						
1-ID-B,C,E XSD						10-ID-B MR-CAT						17-BM-B XSD						26-ID-C CNM/XSD						
2-BM-A,B XSD						11-BM-B XSD						17-ID-B IMCA-CAT						27-ID-B XSD						
2-ID-D XSD						11-ID-B XSD						18-ID-D Bio-CAT						28-ID-B,C XSD						
2-ID-E XSD						11-ID-C XSD						19-BM-D XSD						28-ID-D,E XSD						
3-ID-B,C,D XSD						11-ID-D XSD						19-ID-E:ISN XSD						28-ID-F XSD						
4-ID-B,G,H:POLAR XSD						12-BM-B XSD						20-BM-B XSD						28-ID-G:CHEX XSD						
5-BM-B DND-CAT						12-ID-B XSD						20-ID-D,E:HEXM XSD						29-ID-C,D XSD						
5-ID-B,C,D DND-CAT						12-ID-E XSD						21-ID-D LS-CAT						30-ID-B,C XSD						
6-BM-A,B COMPRES/XSD						13-BM-C GSECARS						21-ID-F LS-CAT						31-ID-D LRL-CAT						
6-ID-B,C XSD						13-BM-D GSECARS						21-ID-G LS-CAT						31-ID-E XSD						
6-ID-D XSD						13-ID-C,D GSECARS						22-ID-D SER-CAT						32-ID-B,C XSD						
7-BM-B XSD						13-ID-E GSECARS						22-ID-E SER-CAT						33-BM-C XSD						
7-ID-B,C,D XSD						14-ID-B BioCARS						23-ID-B GM/CA-XSD						33-ID-C:PTYCHO XSD						
8-ID-E,I:XPCS XSD						15-ID-B,E ChemMatCARS						23-ID-D GM/CA-XSD						34-ID-F:ATOMIC XSD						
8-BM-B XSD						15-ID-C,D ChemMatCARS						24-ID-C NE-CAT						34-ID-E:3DMN XSD						
9-ID-D: CSSI XSD						16-BM-B,D HPCAT-XSD						24-ID-E NE-CAT						35-ID-B,C,D,E DCS						
9-BM-B,C XSD						16-ID-B HPCAT-XSD						25-ID-C XSD												

54 of 71 beamlines are fully commissioned and accepting users

STORAGE RING EMITTANCE

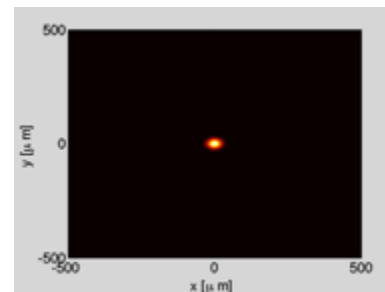
The 2025 peer-reviewed measurements reported 44 ± 3 pm·rad horizontal in low-coupling operation and 28 ± 3 pm·rad horizontal under full coupling; the corresponding storage-ring model values were 44 and 31 pm·rad.

APS

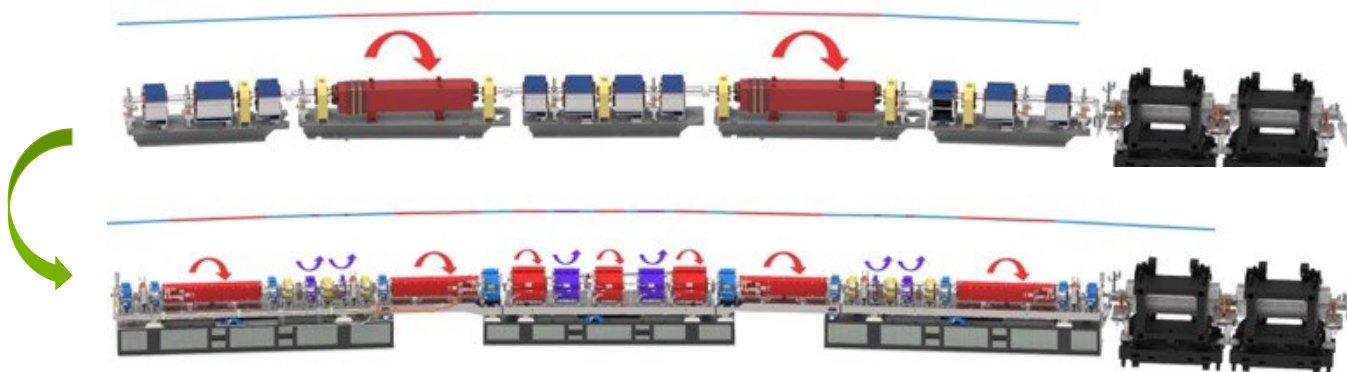


$$\varepsilon_o = 3100 \text{ pm}$$

APS Upgrade



$$\varepsilon_o = 42 \text{ pm}$$



APS

80 bends total

APS-U

520 bends total

240 reverse bends



S&A ACTIVITIES AFTER THE UPGRADE



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SURVEYSYNC — WHY IT WAS DEVELOPED

Turning post-upgrade survey data into repeatable, traceable machine knowledge

DATA FRAGMENTATION

Alignment results lived across spreadsheets, SA jobs, reports and local workflows.

The same engineering steps were repeatedly reconstructed.

STANDARDIZATION

Local sector and module measurements needed consistent transformation into the APS global coordinate system.

Frames, references and reporting had to be repeatable.

TRACEABILITY

A measurement only remains useful when it stays connected to the correct component, nominal definition, drawing and revision.

MEASURE



TRANSFORM



VALIDATE



REPORT



RECORD

Core objective: reduce one-off processing and preserve the engineering context behind every alignment result.

SURVEYSYNC — LEARNING CURVE & DIRECTION

The project evolved from a calculation tool into an engineering integration platform

1 LEARNING CURVE

The mathematics and transformations were only the first layer.

The harder problem became defining provenance, coordinate frames, nominals, tolerances and authoritative sources.

2 CAPABILITIES

- Global coordinate transformation
- Best-fit & residual analysis
- Nominal / actual comparison
- Automated QA and reporting
- CDB machine / asset context
- ICMS / EDCC record linkage
- Windchill / Creo context

3 FUTURE DIRECTION

Establish a canonical alignment definition and connect survey results directly to the as-built lifecycle.

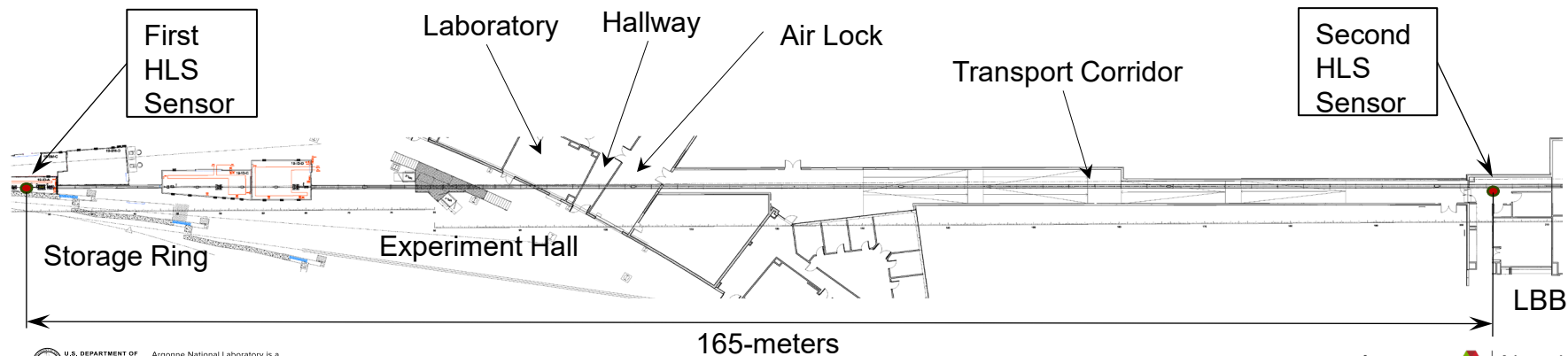
Extend the machine-centric data layer to configuration management, RSS and maintenance workflows.



Engineering intent → installed asset → measurement → as-built → maintenance → engineering feedback

LBB-HLS

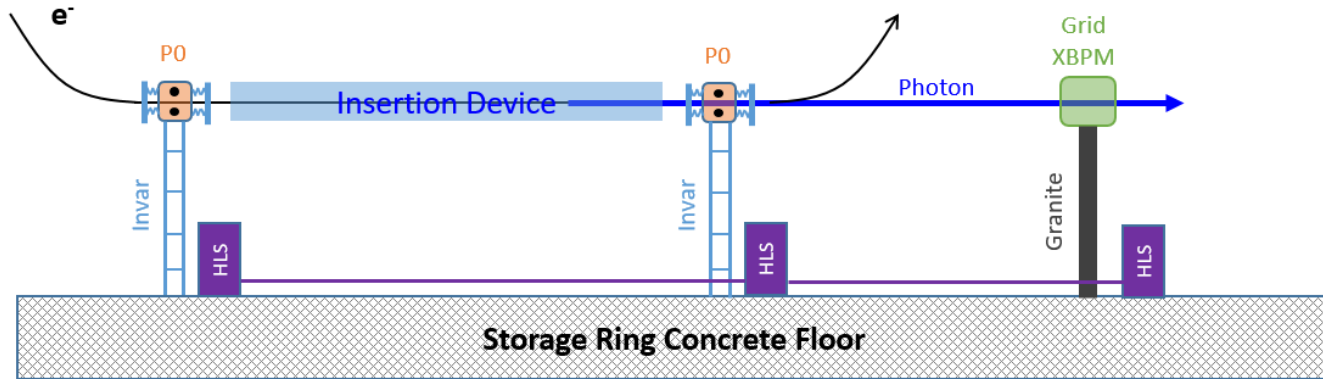
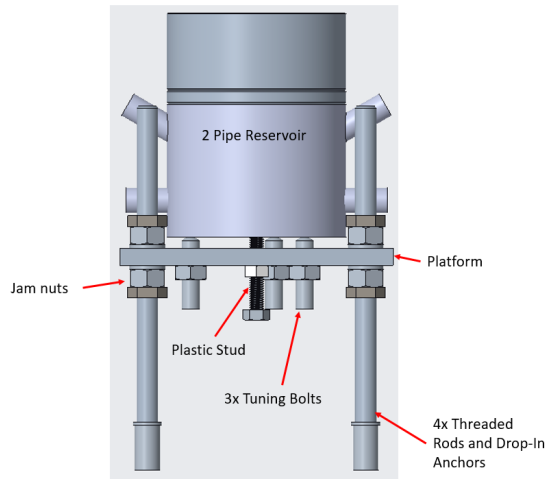
Hydrostatic Level System for Elevation Transfer from Storage Ring to Long beamline Building



STORAGE RING HLS SYSTEM

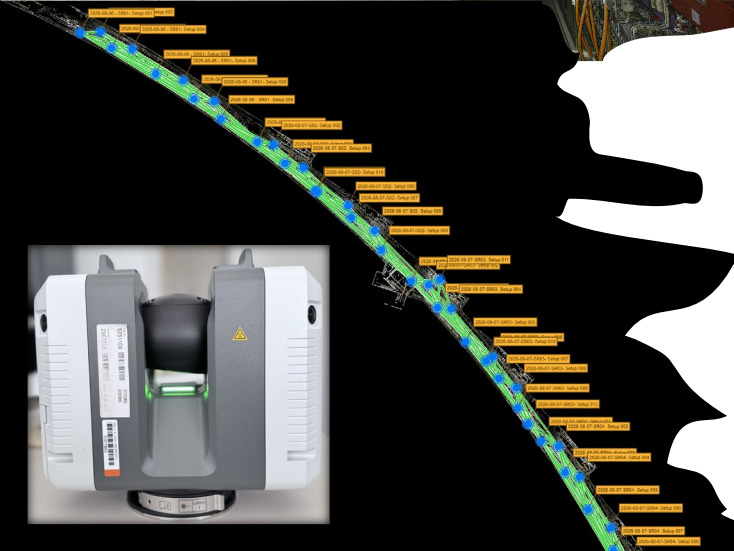
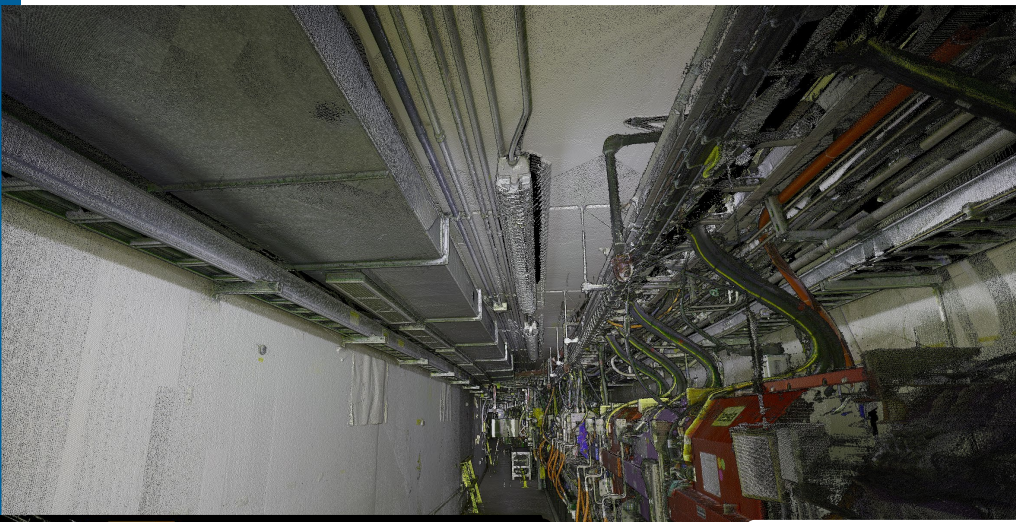
Diagnostic tool to monitor and eventually improve the long-term beam stability.

- 3 sensors per Insertion Device Frontend - 35 ID beamlines
- 5 extra sensors in RF and Injection Area
- Total **110 HLS** sensors



TERRESTRIAL LASER SCANNING

- Entire APS Upgrade storage ring scanned for as-built reference
- Enable designers to extract measurements without ring access



Full APS Storage ring 1.1 km length 3D laser scanning completed in two weeks.

Scope: reverse engineering and TrueView virtual reality

Leica RTC360 - resolution 3 mm @10 m with HDR pictures

433 setups

Post-processing registration and editing with Cyclone Register 360 Plus

27 billion points

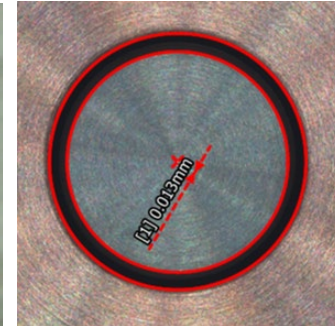
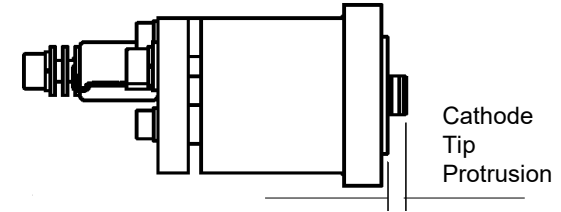
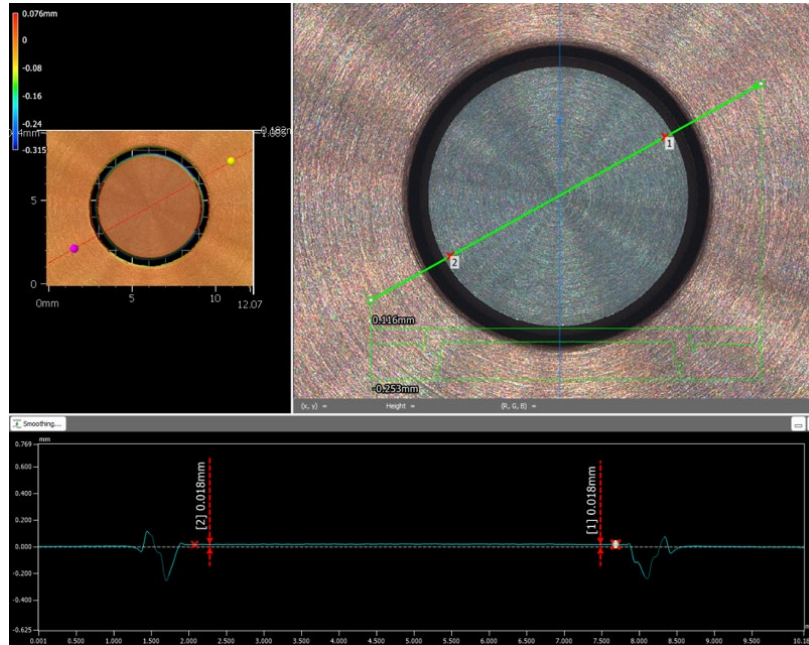
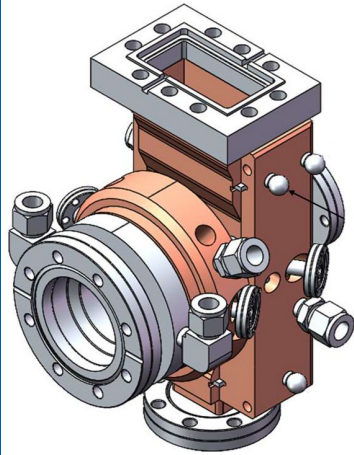
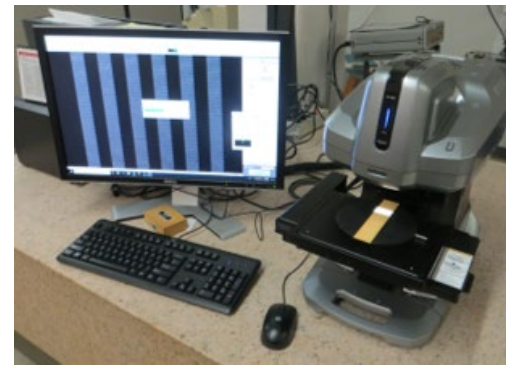
Mean error cloud-to-cloud for each sector = 1.346 mm

Control points mean error for each sector = 1.109 mm

Total space in hard drive = 668 GB

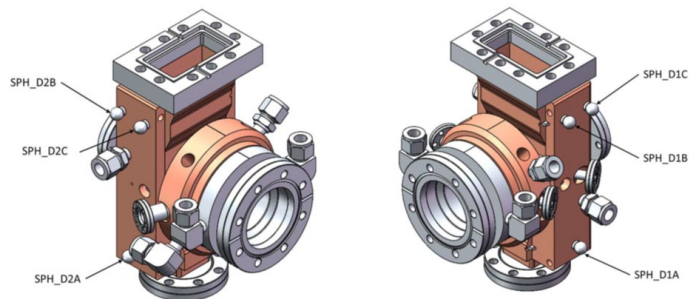
RF ELECTRON GUNS

- APS Upgrade included new RF e^- gun sources developed in collaboration with Radia Beam
- Alignment of cathode protrusion to optimize e^- emittance. Optimal protrusion unknown – experimenting with different alignments.
- New guns installed in LINAC and are operational; optimization continues.



RF GUN ALIGNMENT: METHOD

LINAC RF Gun | Alignment performed 08/28/2026 | Instrument: Leica AT960 with T-Probe



Gun body with survey spheres SPH_D1A–C and SPH_D2A–C

Key question: can the gun be aligned without stressing the RF flange? In past installs it was aligned before the waveguide was attached, then moved out of alignment to make the connection.

1. Reference Beamline Direction

Three downstream/upstream quadrupoles are used as the geometric reference. No dedicated fiducials are available on the quadrupoles.

2. Establish Quadrupole Reference Line

The external yoke of each quadrupole is measured; a cylinder is best-fitted to the measured surface. Cardinal points are calculated and a line is best-fitted through all three quadrupoles.

3. Relate RF Gun to the Reference

Gun fiducials are measured and reported in the gun-origin frame relative to the established beamline/reference direction.

4. Alignment Decision

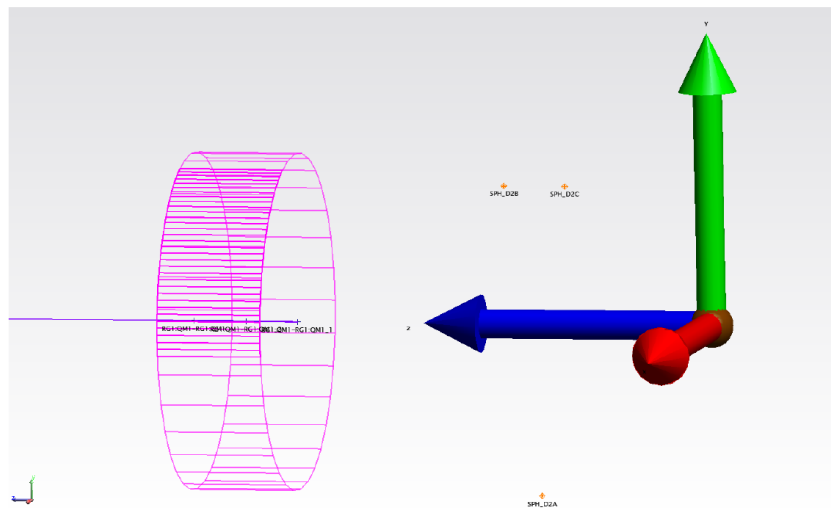
Because the RF flange connection can be sensitive to movement, the goal is to improve alignment as much as practical without applying significant force to the adjustment rods.

FINAL ALIGNMENT RESULT AND DECISION

Report of 08/28/2026: Gun measured vs. nominal, reported in Gun Origin frame

Alignment Result (Accepted by Physics Group):

The final measurement shows residual X/Y/Z and rotational offsets relative to the nominal gun frame. Per the scientists' guidance, alignment should be improved only to the extent that it can be achieved without significant force on the adjustment rods or undue stress at the RF/vacuum connection. Vacuum leak is the main risk. If additional steering is required during operation, downstream steering magnets are available to redirect the beam.



(gun serial number) 20250815::Gun Origin (transformed)					
Reported in(gun serial number) 20250815::Gun Origin::Frame					
	Nominal	Actual	High Tol	Low Tol	Delta
X (mm)	0.000	0.990	0.250	-0.250	0.990
Y (mm)	0.000	0.517	0.250	-0.250	0.517
Z (mm)	0.000	-0.408	5.000	-5.000	-0.408
Rx (deg)	-0.000	0.254	0.057	-0.057	0.254
Ry (deg)	-0.000	-0.419	0.057	-0.057	-0.419
Rz (deg)	-0.000	-0.595	0.057	-0.057	-0.595

Alignment report snapshot

SUPERCONDUCTING UNDULATORS (SCU)



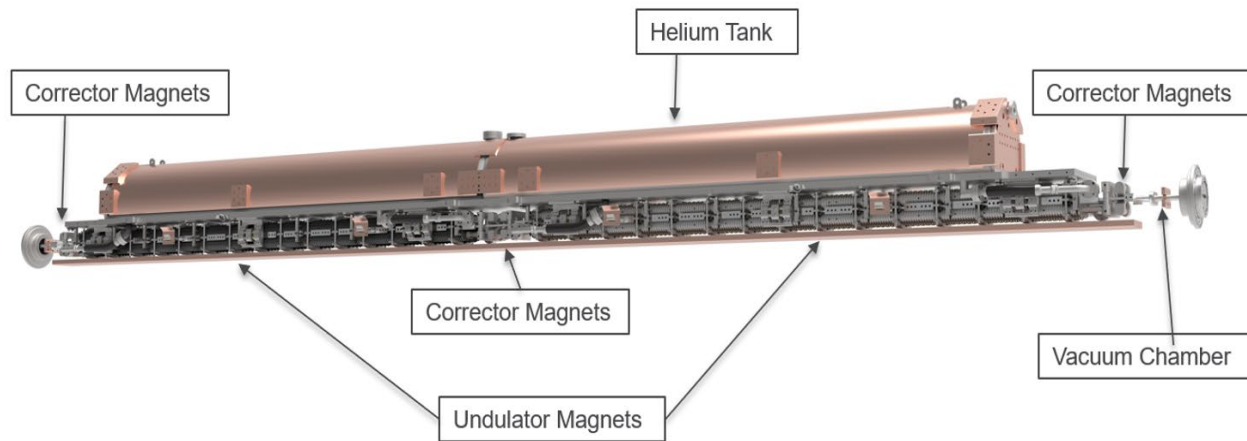
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SCU COLD MASS ALIGNMENT



- **Cold mass:** liquid helium reservoir, beam chamber and undulator magnets
- **Beam chamber:** suspended between the magnets on support points on the reservoir
- **Vertical support:** 4 points at the ends
- **Optional straightness adjustment:** 2 extra supports in the center cube of the cryostat

- **Cold-mass alignment defined at operating temperature**

Warm positioning is intentionally biased to compensate for cooldown contraction, support compliance, and gravity effects so the magnetic axis is correct in the cold state.

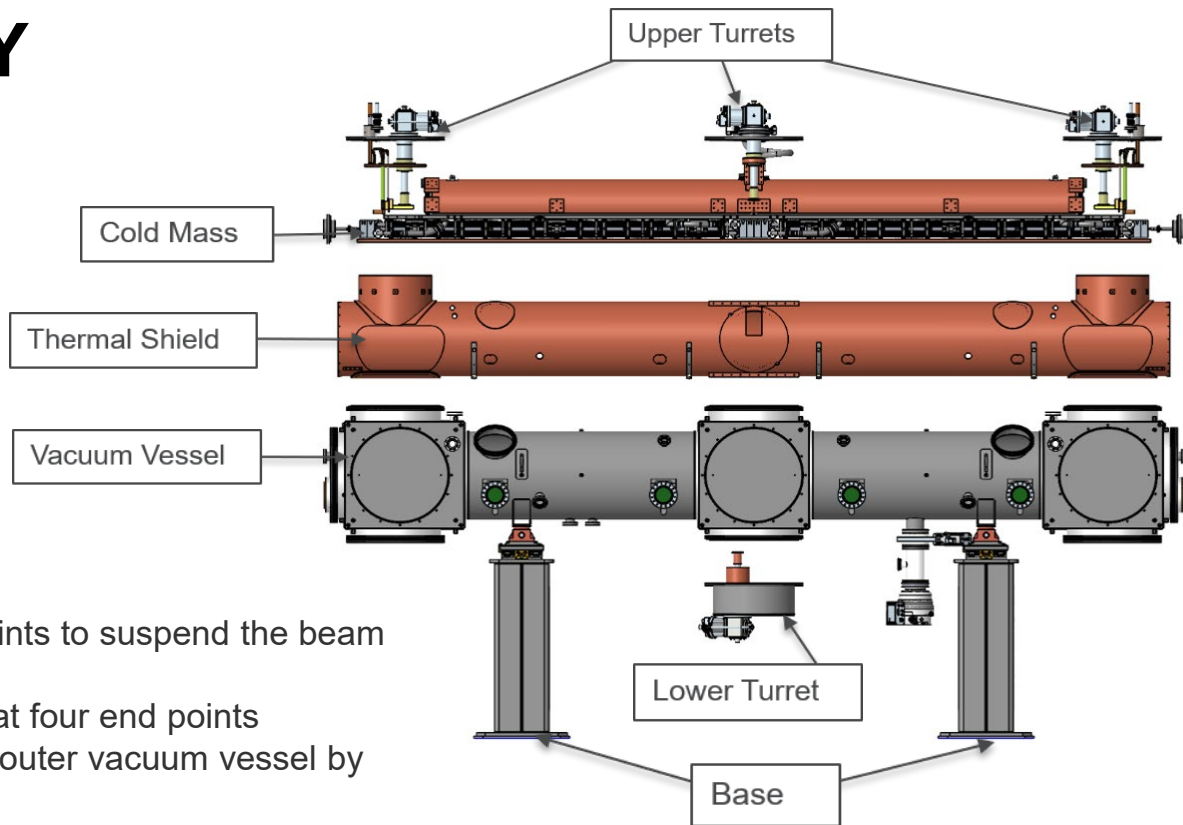
- **For this SCU, the undulator magnets are installed with a room-temperature pitch corresponding to an 800 μm end-to-end offset.**

This warm pre-pitch is applied to account for the predicted cold shift and to bring the cold mass into alignment after cooldown.

SCU ASSEMBLY ALIGNMENT

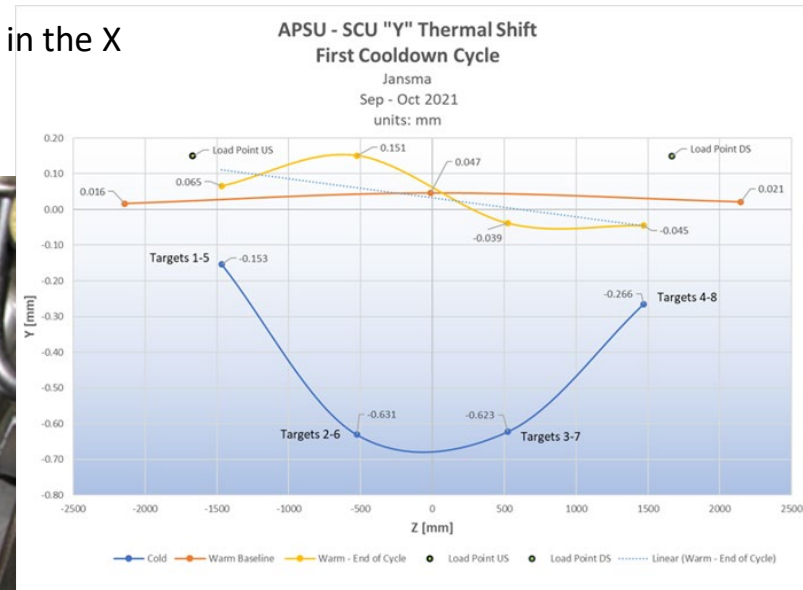
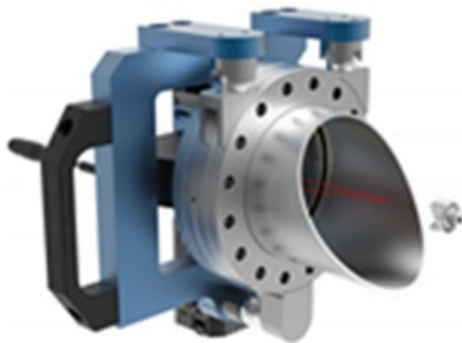
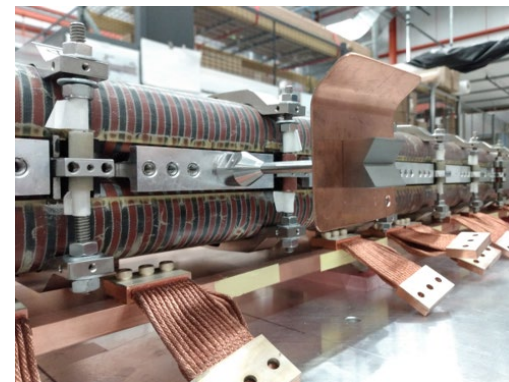
- Main components
 - Vacuum Vessel
 - Thermal Shield
 - Cold Mass
 - Turrets
 - Base

- Liquid helium reservoir support points to suspend the beam chamber between the magnets
- Cold mass is vertically supported at four end points
- Cold mass is suspended from the outer vacuum vessel by adjustable feed-throughs
- Adjustable feed-throughs provide final alignment capability
- Feed-throughs also compensate for movement or misalignment during cool-down



SCU THERMAL DISPLACEMENT

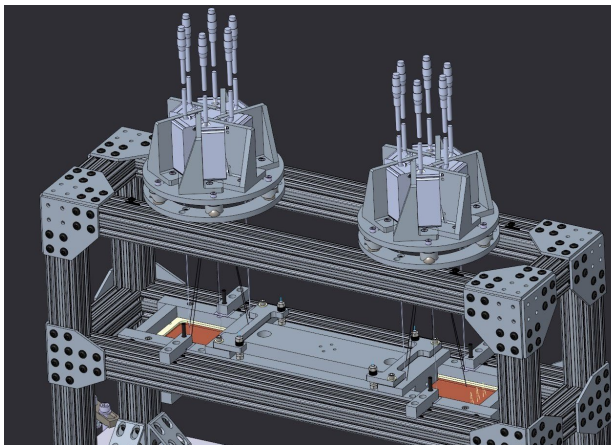
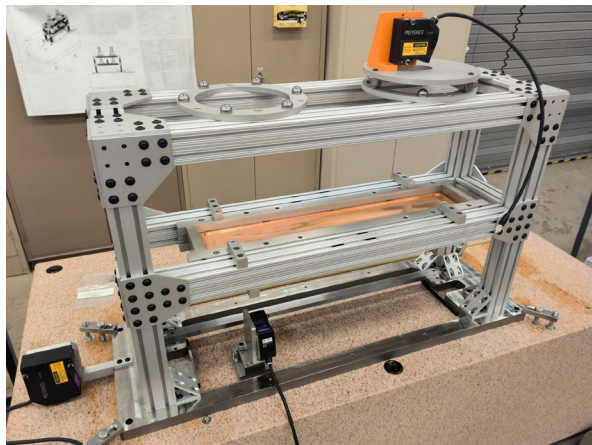
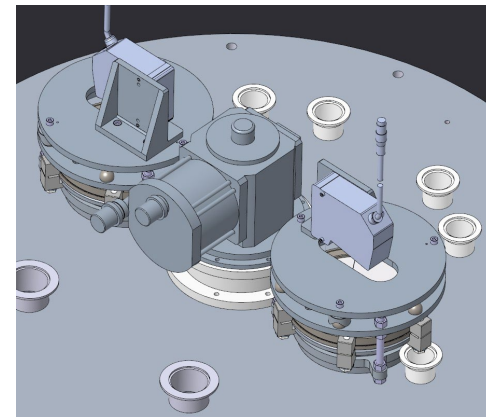
- 2D laser scanning technique measures V-shaped targets mounted to the vacuum chamber.
- Measured through vacuum viewports modified with kinematic hardware
- Displacement between the fixed external cryostat position and the cold mass suspended within it
- Baseline measurement set recorded prior to cooldown with the cold mass precisely aligned within the cryostat.
- Thermal displacement determined by the measured differences in the X and Y target positions from the baseline position.



SCU VACUUM CHAMBER R&D

Measurement Inside a Test Cryostat

- Laser displacement sensor (LDS) mounted to kinematic couple
- Two kinematic bases affixed to cryogenic test chamber
- Movable plate enables measurement of vertical displacement at 12 positions in 2 locations – 6 magnet surface; 6 chamber surface
- LDS resolution is $\sim 2\text{-}\mu\text{m}$
- External fiducials on lid to measure displacement due to vacuum forces



INSTRUMENTS AND CALIBRATION



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IN-HOUSE LASER TRACKERS EVALUATION

14 Laser trackers annually yearly for QA

#6 Leica AT403; #6 Leica AT930; #1 Leica AT500; #1 Leica AT960-LR

ADM offset compensation and Axes Compensation in Tracker Pilot

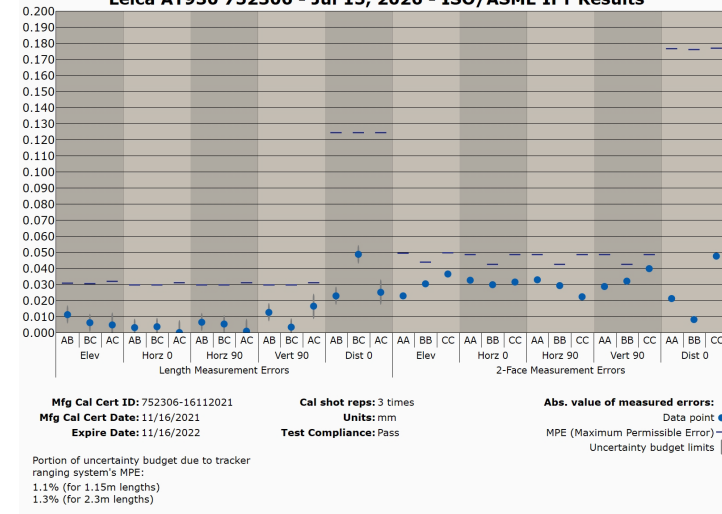
Method: Brunson KinAiry Field Test

Procedure is compatible with ISO 10360:2021 International Standard

Benefits: cost and time saving wrt sending out instruments to Hexagon metrology certified lab, if maintenance not required



Leica AT930 752306 - Jul 15, 2026 - ISO/ASME IFT Results



ETALON SYSTEM ACQUIRED



- APS S&A section recently acquired an Etalon Absolute Multiline Interferometry System (64 channels)
- Integrated short-range Attocube laser system
- Working with **μRay** (Heinrich Schwenke) to update software and activate system – October 2026
- Future application possibilities include:
 - Cryostat cold mass displacement monitoring for Superconducting Undulators
 - Traceable length standard for S&A equipment calibration
 - FEL R&D
 - Beamline component displacement monitoring
 - Low frequency vibration monitoring
 - Establish virtual scale bars for control networks

APS R&D ACTIVITIES



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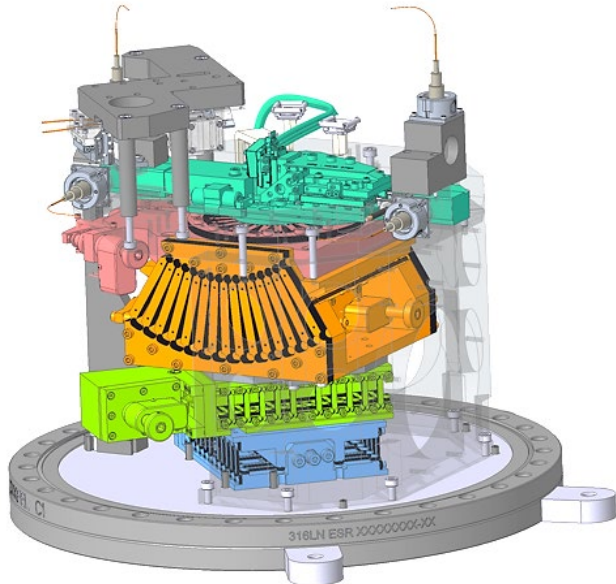
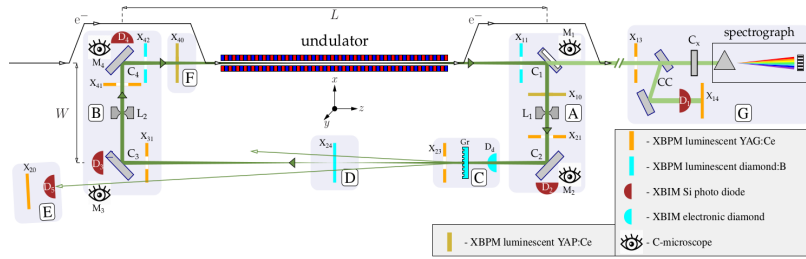
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CBXFEL – CAVITY BASED X-RAY FREE ELECTRON LASER



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ACCELERATOR
LABORATORY

RIKEN

Collaboration between Argonne, SLAC and Riken

Argonne responsible for design, manufacturing, assembly and testing of chambers

Metrology performed at Euclid Techlabs by Argonne

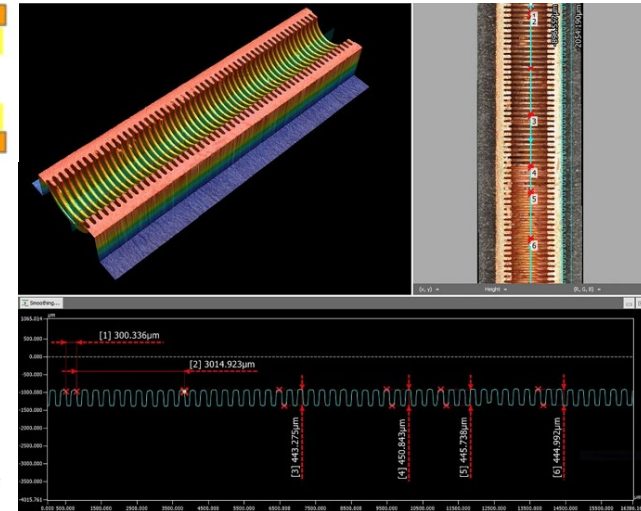
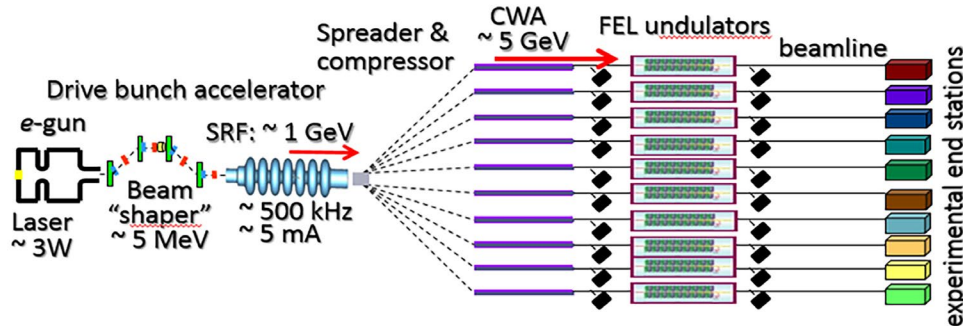
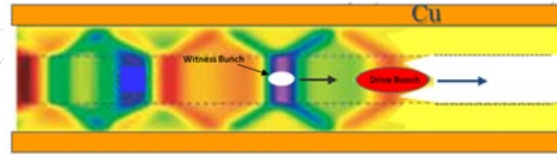
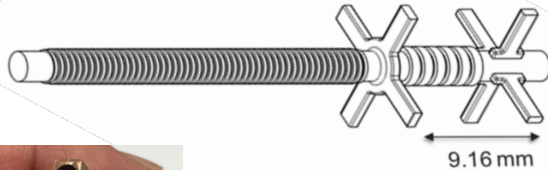
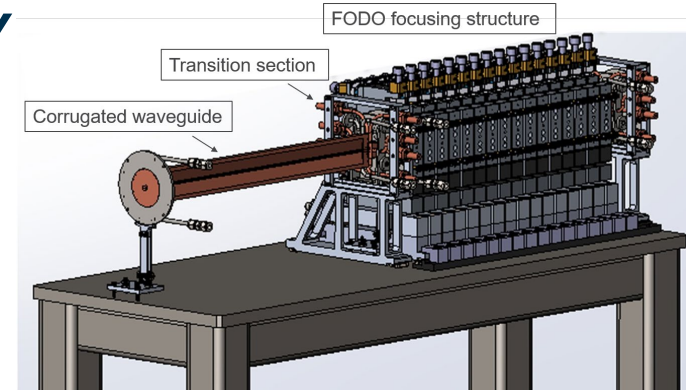
8 fully equipped chambers delivered to SLAC by end of 2025

Installation completed @LCSL II (SLAC) and commissioning undergoing

Dedicated oral presentation by D. Bianculli @ IWAA 2026

COLLINEAR WAKEFIELD ACCELERATOR R&D FOR A COMPACT MULTI-USER FEL FACILITY

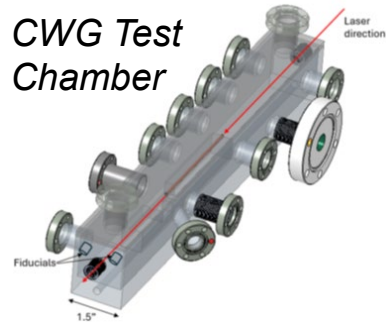
- Inspect fabrication techniques for 2-mm ID internally corrugated waveguide
- Electroformed waveguide structure – so far only 100-mm maximum length
- Alignment of test assembly for waveguide beam studies
- How to achieve $<5\text{-}\mu\text{m}$ alignment over 0.5 meters?



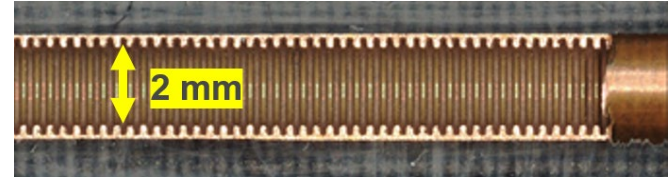
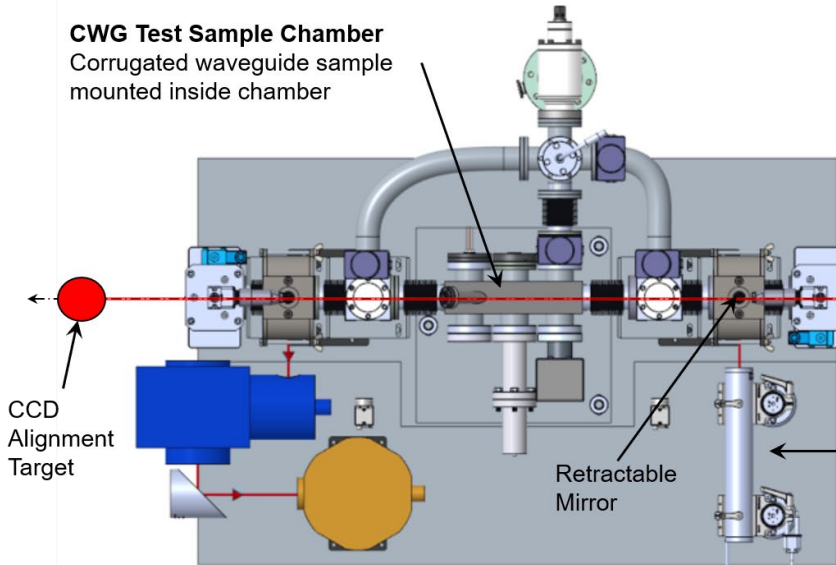
COLLINEAR WAKEFIELD ACCELERATOR R&D FOR A COMPACT MULTI-USER FEL FACILITY

Corrugated Waveguide Breakdown Test

- Sub-assembly Fiducialization
- LEA in-tunnel alignment within control network
- Laser alignment verification for sample swaps



CWG Test Sample Chamber
Corrugated waveguide sample mounted inside chamber



LEA Alignment Laser
Laser aligned collinear with e^- beam
Verify CWG sample alignment WRT electron beam

Retractable Mirror

CWG Test Assembly Laser
Verify alignment of CWG sample WRT test assembly

VINTAGE METROLOGY EXHIBIT



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VINTAGE METROLOGY EXHIBIT



- In cooperation with the Argonne Institutional Partnerships / STEM Outreach Program for Argonne's 80th Anniversary Open House
- Goal to educate students and lab visitors on alignment, metrology and precision measurement history at Argonne and enhance the impact of the existing historical IPNS accelerator control room exhibit in the Learning Center.



Acknowledgements

The preceding was made possible through the extraordinary effort of the APS Survey & Alignment team in cooperation with many other APS staff and personnel.

Sincere appreciation and thanks to everyone who contributed to this work.

S&A Engineering Staff

Dusan Banjanac
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Michael Bosek*
James Brown
Cody Holz
Roberto Lopez
Kris Mietsner
Davor Pavlovic
Spiro Skiadopolous

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