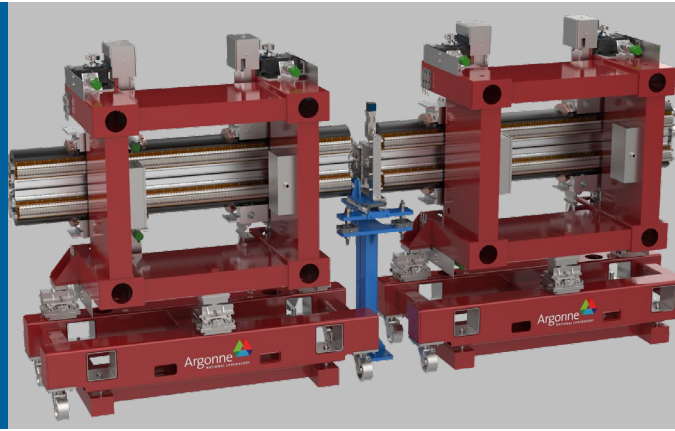
OVERCOMING CHALLENGES DURING THE INSERTION DEVICE STRAIGHT SECTION COMPONENT PRODUCTION AND TUNING PHASE OF THE ADVANCED PHOTON SOURCE UPGRADE



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APS-U Insertion Devices CAM
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July 26, 2021

U.S. DEPARTMENT OF ENERGY
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AGENDA

- Introduction
  - Overview
  - APS-U ID Team
- Hybrid Permanent Magnet Undulator (HPMU)
  - Scope
  - Challenge
  - Solution
- Superconducting Undulator (SCU)
  - Scope
  - Challenge
  - Solution
- ID Vacuum System
  - Scope
  - Challenge
  - Solution
- Summary

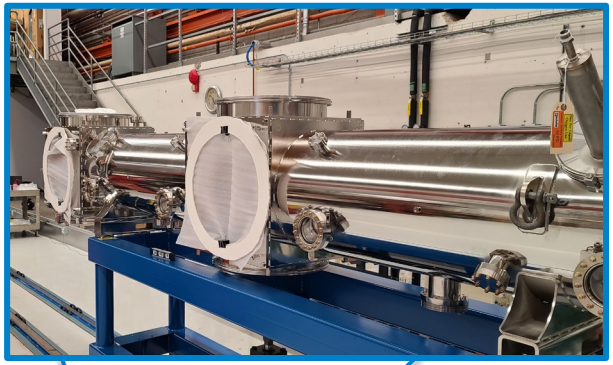
INTRODUCTION: OVERVIEW

- The first 35 of 40 sector straight sections in the storage ring contain Insertion Devices (ID)
  - Hybrid Permanent Magnet Undulators (HPMU)
  - Superconducting Undulators (SCU)
  - Vacuum system (excluding P0 BPM's)

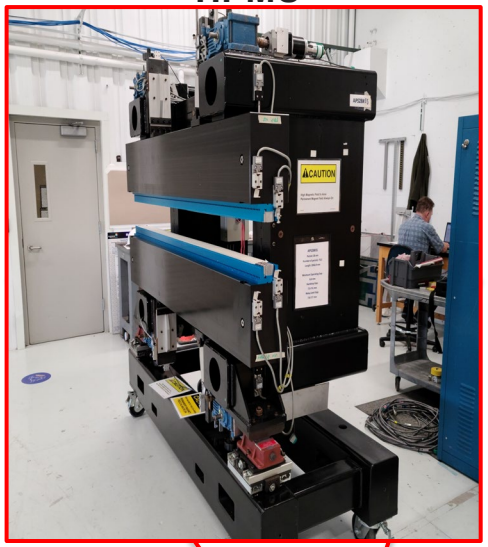
	Period	Period		Period	Period
Sector	ID1	ID2	Sector	ID1	ID2
1	SCU1.65	SCU 1.65	18		Planar 3.3
2	Planar 2.8*	Planar 2.8*	19	Rev 2.5/2.1	Rev 2.5/2.1
3	Planar 2.7	Planar 2.7	20	SCU1.65	SCU 1.65
4	Planar 3.0	Planar 3.0	21	Planar 3.0*	Planar 2.1*
5		Planar 3.0	22	Planar 3.3*	Planar 3.3*
6	Planar 2.3*	Planar2.7*	23	Planar 3.3*	Planar 3.0*
7		Planar 2.8	24	Planar 3.0*	Planar 2.1*
8	Rev 2.5/2.1	Rev 2.5/2.1	25	Planar 2.8*	Planar 2.8*
9	Planar 2.1	Rev 2.5/2.1	26	Planar 2.8	Planar 2.8
10		Planar 3.3	27	Planar 2.5	Planar 2.5
11	SCU1.65*	SCU1.65*	28	SCU1.85*	SCU1.85*
12	Planar 2.8*	Planar 2.8*	29	IEX	IEX
13	Planar 3.3*	Planar 2.7*	30	Planar 1.35	Planar 1.35
14	Planar 2.1	Planar 2.1	31	Planar 3.3*	Planar 3.3*
15	Planar 2.8*	Planar 2.7*	32	Planar 2.8*	Planar 1.35*
16	Rev 2.5*/2.1*	Rev 2.5*/2.1*	33	Rev 2.5/2.1	Rev 2.5/2.1
17		Planar 3.3	34	Planar 2.8*	Rev 2.5*/2.1*
			35	Rev 2.3/1.4	Rev 2.3/1.4

Current APS-U ID Plan

SCU

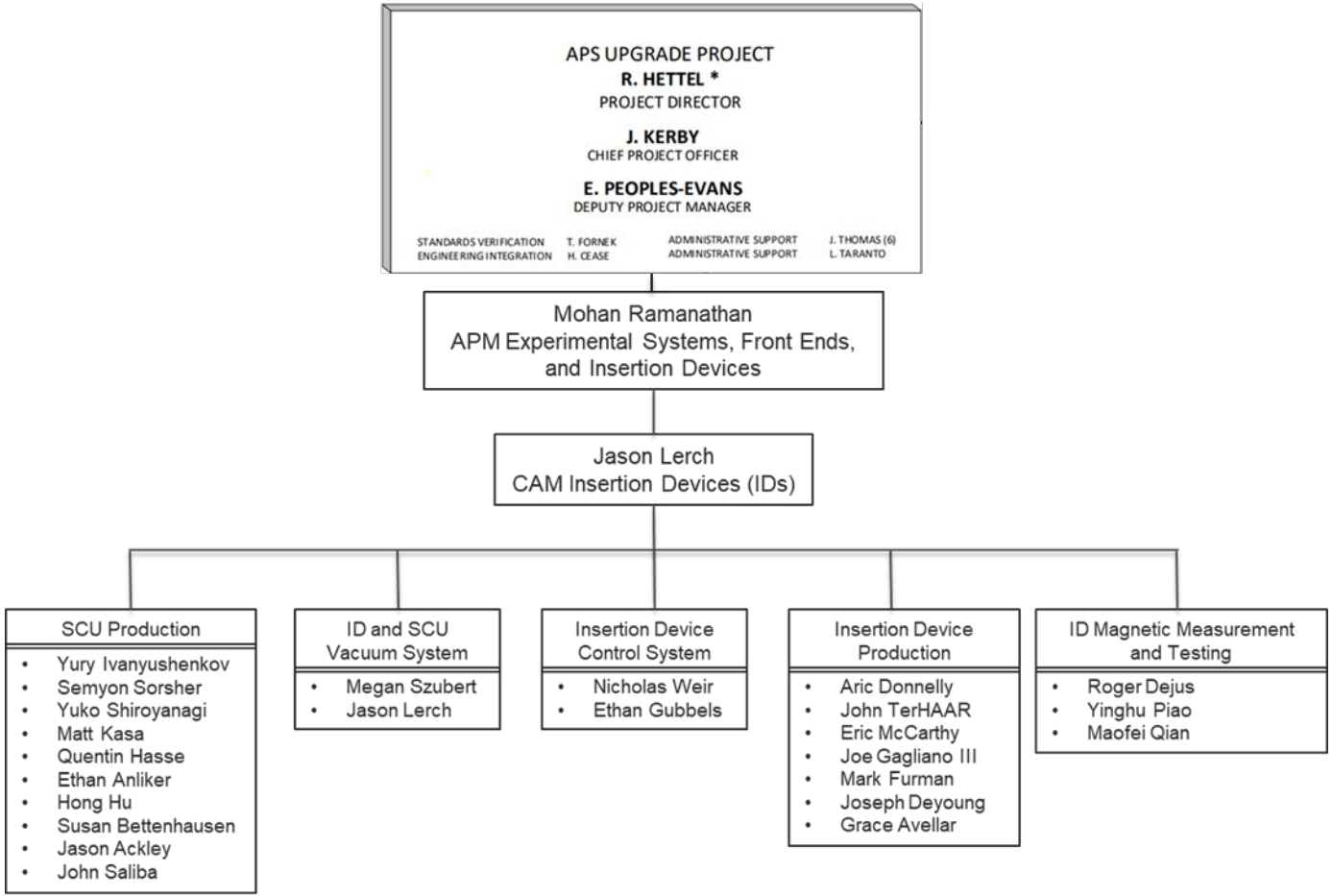


HPMU



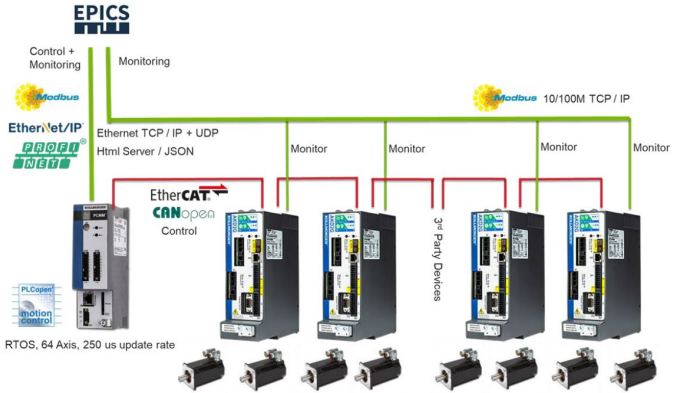
Top view of typical APS-U sector with ID Straights shown in blue (SCUs) and red (HPMUs)

INTRODUCTION: ID TEAM



HPMU: SCOPE

- Hybrid Permanent Magnet Undulators (HPMU)
  - New control system for both revolving and non-revolving HPMU
  - 12 new revolver undulators
  - 5 new and 4 reused magnet periods
  - New monokeeper design for new magnetic period structures
  - 11 new phase shifters (PS)
  - 14 new up, center, and downstream canting magnet (CM) assemblies



New 2.8 cm Period Device with Monokeeper

New Revolver Undulator Frames

New Phase Shifter Assembly

New Center Canting and Corrector Magnet

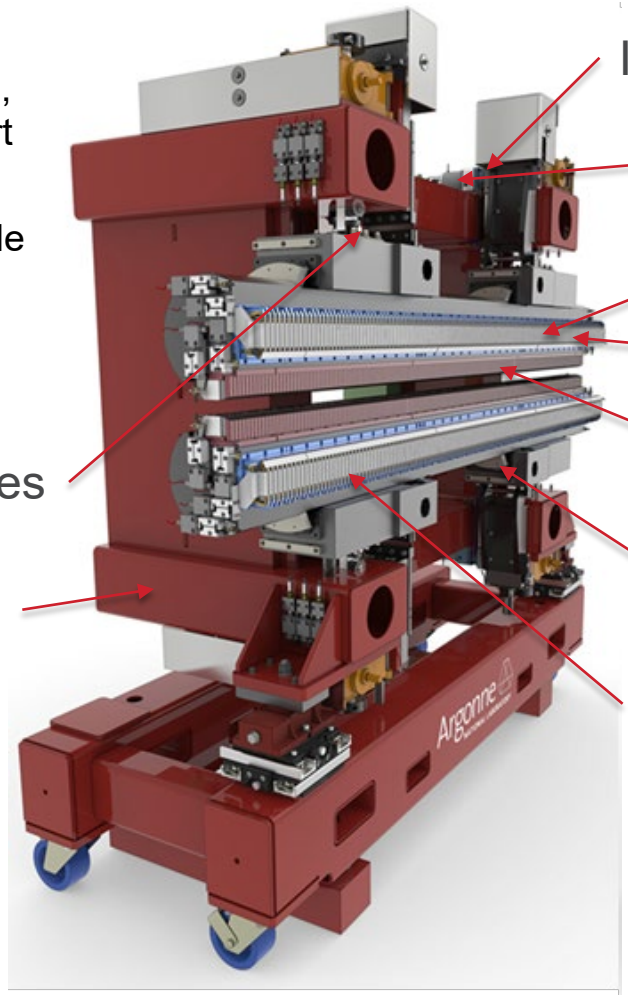
HPMU: CHALLENGE

- Main challenge is assembling, testing, and tuning all devices prior to the start of commissioning

	Current APS ID Layout					APS-U ID Layout			
Sector	GSM ID1	GSM ID2	Current ID1	Current ID2	Sector	GSM ID1	GSM ID2	APSU ID1	APSU ID2
1		4M-W	SCU1.8	Planar 2.3	1			SCU1.65	SCU 1.65
2	STI	STI	Planar 3.3	Planar 3.3	2	4M-W	4M-W	Planar 2.8*	Planar 2.8*
3	4M-W	STI	Planar2.7	Planar2.7	3	STI	STI	Planar 2.7	Planar 2.7
4		STI	CPU	Planar 3.5	4	STI	STI	Planar 3.0	Planar 3.0
5		STI		Planar 3.3	5		STI		Planar 3.0
6	4M-W		Planar 3.3	SCU1.8	6	4M-W	4M-W	Planar 2.3*	Planar2.7*
7	STI		Planar 3.3	HSCU	7		STI		Planar 2.8
8	4M-B	4M-B	Planar 3.3	Planar 3.3	8	4M-R	4M-R	Rev 2.5/2.1	Rev 2.5/2.1
9	4M-W	STI	Planar 3.3	Planar 3.3	9	4M-W	4M-R	Planar 2.1	Rev 2.5/2.1
10		STI		Planar 3.3	10		4M-W		Planar 3.3
11	STI	4M-B	Planar 3.3	Planar 2.3	11			SCU1.65*	SCU1.65*
12	4M-W	4M-W	Planar 3.0*	Planar 2.7*	12	4M-W	4M-W	Planar 2.8*	Planar 2.8*
13	4M-W	4M-W	Planar 3.6*	Planar 3.0*	13	4M-W	4M-W	Planar 3.3*	Planar 2.7*
14	4M-B	4M-B	Planar2.7	Planar 2.3	14	STI	STI	Planar 2.1	Planar 2.1
15		STI		Planar 3.3	15	4M-W	4M-W	Planar 2.8*	Planar 2.7*
16	4M-W	4M-W	Planar 3.0*	Planar 3.3*	16	4M-CR	4M-CR	Rev 2.5*/2.1*	Rev 2.5*/2.1*
17		STI		Planar 3.3	17		4M-W		Planar 3.3
18		STI		Planar 3.3	18		4M-W		Planar 3.3
19		STI		Planar 3.3	19	4M-R	4M-R	Rev 2.5/2.1	Rev 2.5/2.1
20		STI		Planar 3.3	20			SCU1.65	SCU 1.65
21	4M-W	4M-W	Planar 3.3*	Planar 3.0*	21	4M-W	4M-W	Planar 3.0*	Planar 2.1*
22		4M-B		Planar 3.3	22	4M-W	4M-W	Planar 3.3*	Planar 3.3*
23	4M-W	4M-W	Planar 3.3*	Planar 3.0*	23	4M-W		Planar 3.3*	Planar 3.0*
24	4M-W	4M-W	Planar 3.3*	Planar 3.3*	24	4M-W	4M-W	Planar 3.0*	Planar 2.1*
25					25	4M-W	4M-W	Planar 2.8*	Planar 2.8*
26	4M-B	4M-B	Planar 3.3	Planar 3.3	26	STI	STI	Planar 2.8	Planar 2.8
27	4M-W	4M-W	Planar 3.0	Planar 3.0	27	STI	STI	Planar 2.5	Planar 2.5
28	STI	STI	Planar 3.3	Planar 3.3	28			SCU1.85*	SCU1.85*
29			IEX	IEX	29			IEX	IEX
30	4M-W	4M-W	Planar 1.72	Planar 1.72	30	STI	STI	Planar 1.35	Planar 1.35
31		4M-W		Planar 3.3	31	4M-W	4M-W	Planar 3.3*	Planar 3.3*
32	STI	STI	Planar 3.3	Planar 1.8	32	4M-W	4M-W	Planar 2.8*	Planar 1.35*
33		STI		Planar 3.3	33	4M-R	4M-R	Rev 2.5/2.1	Rev 2.5/2.1
34	4M-W	4M-W	Planar 3.0*	Planar 3.3*	34	4M-W	4M-CR	Planar 2.8*	Rev 2.5*/2.1*
35		4M-WR		Rev 2.7/1.72	35	4M-R	4M-R	Rev 2.3/1.4	Rev 2.3/1.4

HPMU: CHALLENGE

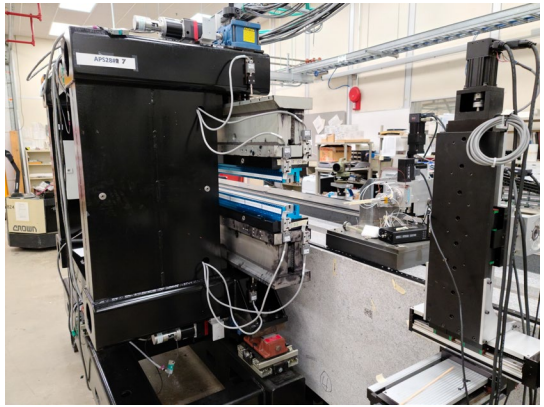
- Main challenge is assembling, testing, and tuning all devices prior to the start of commissioning
- Components are sourced from multiple vendors whose schedules seldom overlap or agree



HPMU: CHALLENGE

- Main challenge is assembling, testing, and tuning all devices prior to the start of commissioning
- Components are sourced from multiple vendors whose schedules seldom overlap!
- These activities started as Covid shutdown the lab

ID Technicians Removing Magnets from Magnetic Structure with Covid Controls in Place

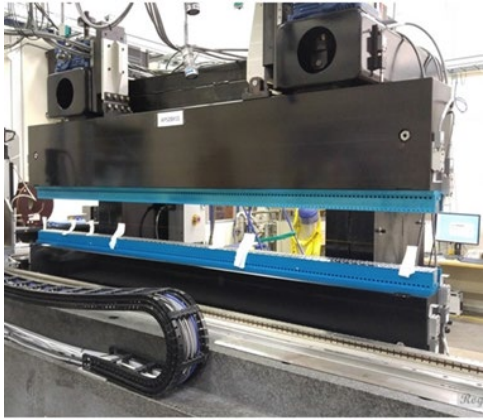


ID Tuning with Minimal Staff; Measurements Taken Remotely

HPMU: SOLUTION

- Hybrid assembly and tuning strategy based on whether assembled device is a new period or reused period
  - Revolver is a special case of a new period assembly
- New Period Devices

Magnetic Structures Assembled onto Spare GSM



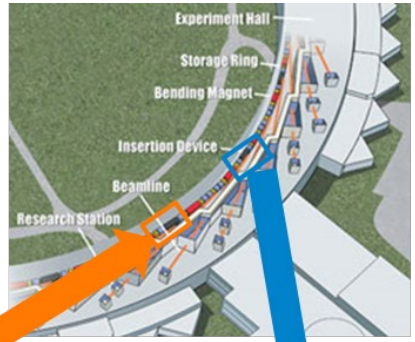
Magnetic Structures "Pre-Tuned"

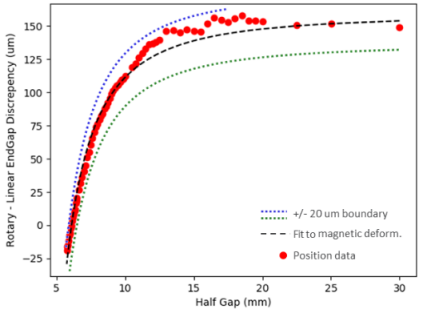
Magnetic structures are then stored in "Pre-Tuned" pairs until dark time when GSM's are removed from storage ring

HPMU: SOLUTION

- Hybrid assembly and tuning strategy based on whether assembled device is a new period or reused period
  - Revolver is a special case of a new period assembly
- New Period Devices
- Reused Periods
  - ID Swap Out
    - Device is removed from storage ring and retrofit with new baseplate or super-strongback
    - The mechanically updated devices are then tuned to accommodate APS and APS-U magnetic specifications
    - The device is then swapped back into the storage ring during the next shutdown and the process restarts

ID Swap Out Schematic



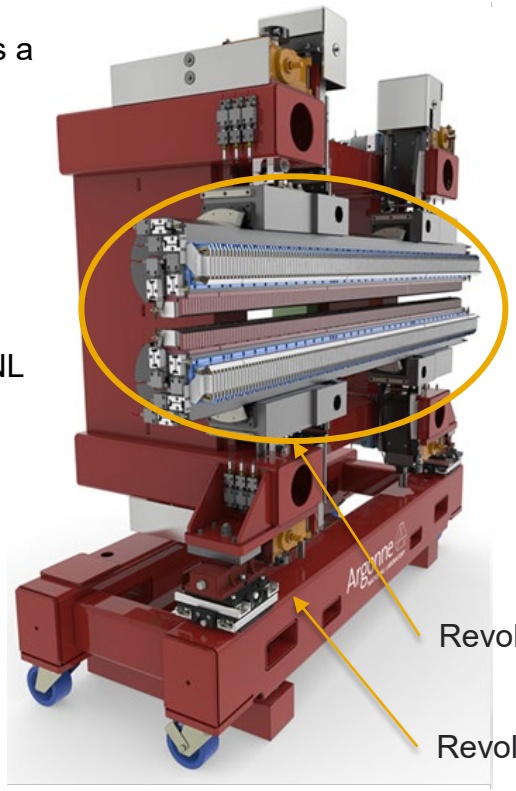


For info on new methods being developed for diagnosing mechanical issues on IDs see N. Weir Poster MOPB13

HPMU: SOLUTION

- Hybrid assembly and tuning strategy based on whether assembled device is a new period or reused period
  - Revolver is a special case of a new period assembly
- New Period Devices
- Reused Periods
  - ID Swap Out
- Revolver Undulator
  - GSM and magnetic structures are new and will be fully assembled at ANL
  - All will be fully tuned prior to the start of dark time

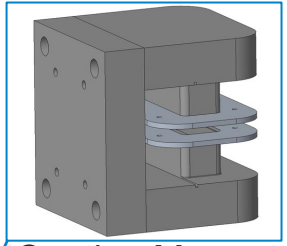
Completed Revolver GSM Frame Assemblies



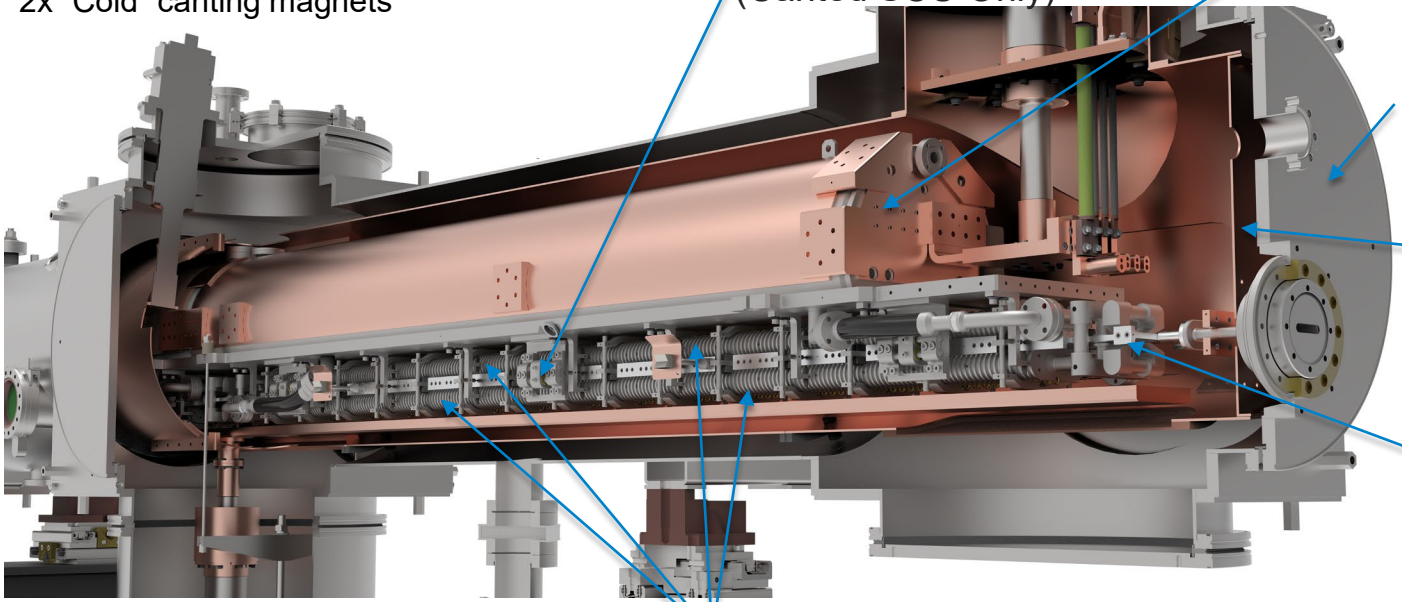
Revolver GSM Upper Stage Frames from Dial

SCU: SCOPE

- Superconducting Undulator (SCU)
  - 4 colinear devices
  - 4 canted devices
  - 2 different periods (18.5mm, 16.5mm)
  - 3 different core lengths (1.9m, 1.5m, 1.3m)
  - 4x4.8m long cryostats
  - 2x “Cold” canting magnets



Canting Magnet
(Canted SCU Only)



LHe tank supplies both undulators

Vacuum Vessel

Thermal Shield

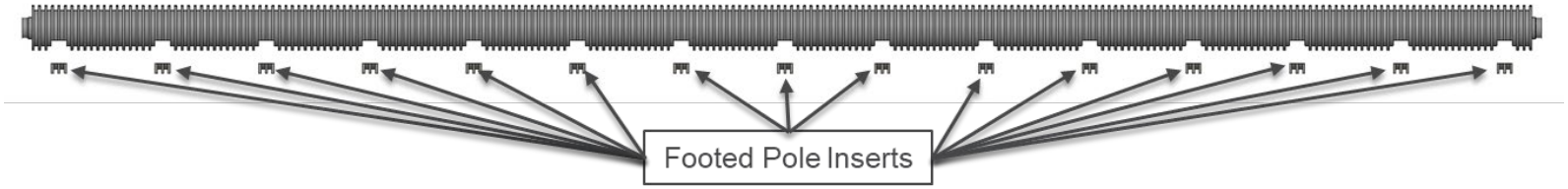
4.8m Long vacuum chamber (T_{OPS}=20K)

Magnet Core (T_{OPS}=4K)

SCU: CHALLENGE

- The new 4.8m long SCU is extremely complicated to assemble
- Magnet cores with footed poles were difficult to fabricate and wind without shorts

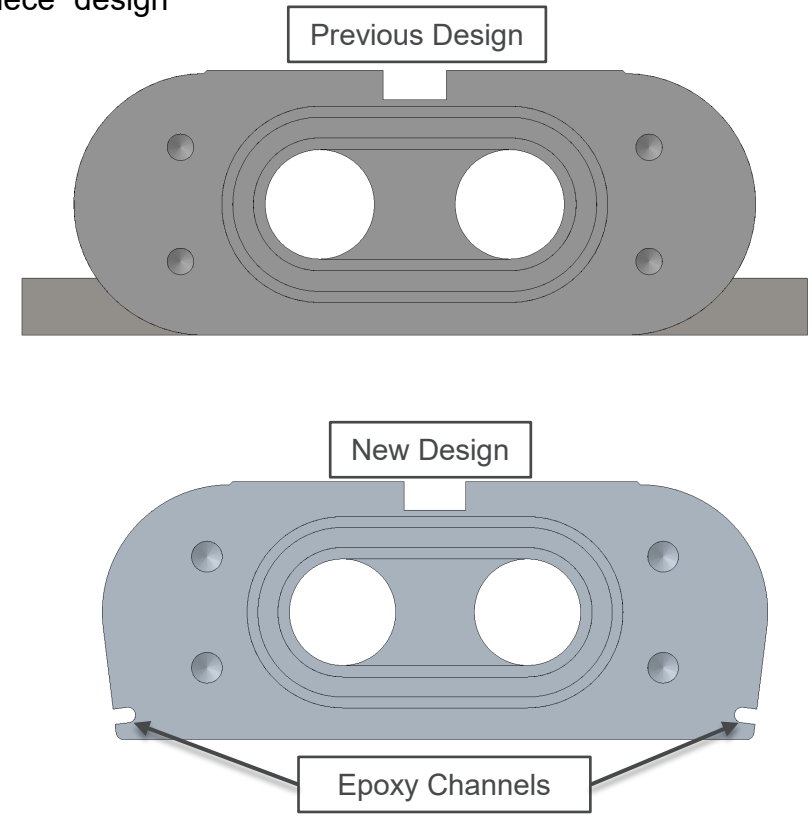
SCU Cold Mass Being Assembled into the Vacuum Vessel

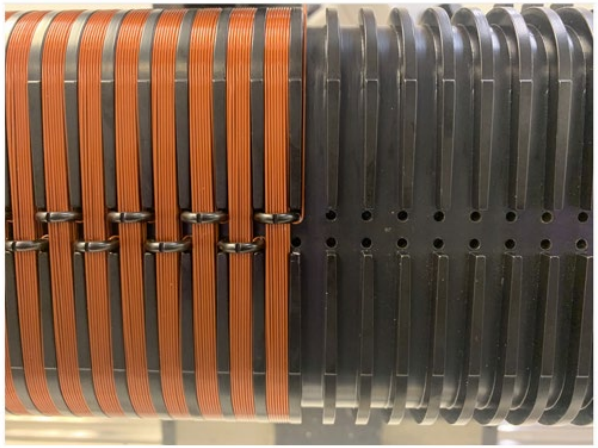


SCU Magnet Core with Footed Poles

SCU: SOLUTION

- Changed design from “footed pole” design to “single piece” design





Magnet Core During Winding Process

*See E. Anliker Poster MOPB09 for more information

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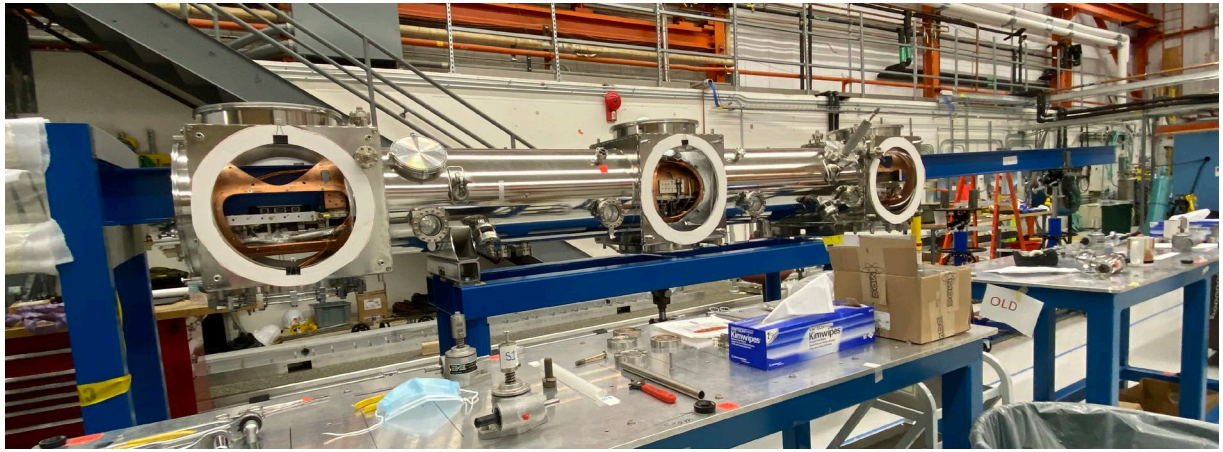
SCU: SOLUTION

- Changed design from “footed pole” design to “single piece” design
- Built an assembly system for inserting the cold mass into the vacuum vessel

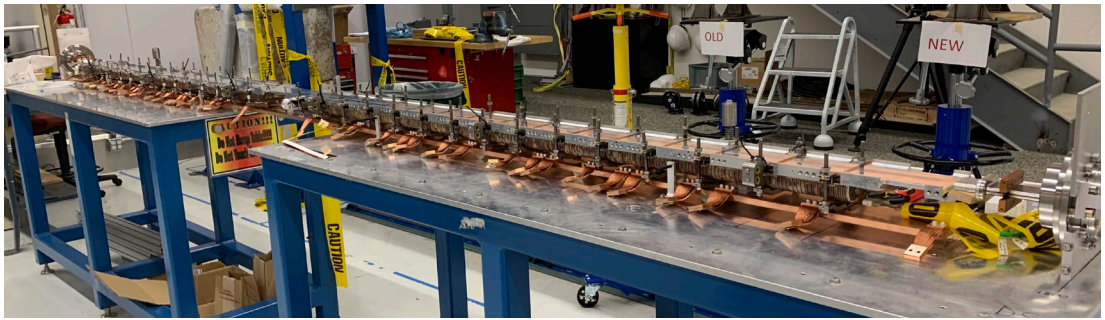


Vacuum vessel being moved over the cold mass assembly

ID VACUUM SYSTEM: SCOPE

- HPMU ID Vacuum Chamber (IDVC)
  - 31x 5.4m long aluminum vacuum chamber
  - Vacuum pumping provided by NEG cartridge and ion pumps
  - Strongback support for continuous support and adjustment across straight section
  - Photon absorber

HPMU IDVC Production Units Prior to Vacuum Testing

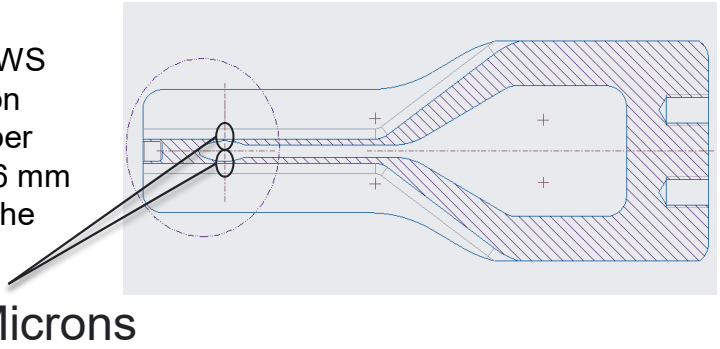


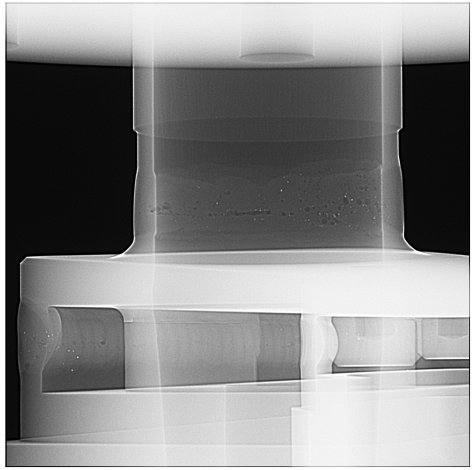
SCU Vacuum Chamber During Cold Mass Assembly

- SCU Vacuum Chamber
  - 4x4.8m long aluminum vacuum chamber for inside cryostat
  - 8xCopper vacuum chamber/absorber for outside cryostat
  - Ion pumps for outside cryostat vacuum pumping

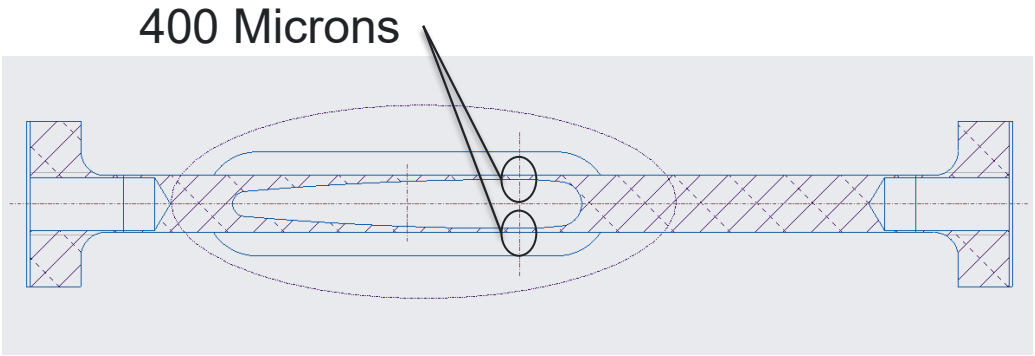
ID VACUUM SYSTEM: CHALLENGE

- HPMU ID Vacuum Chamber
  - Getting aluminum welds to meet AWS D17.1 class B or better specification
  - Machining center section of chamber where nominal wall thickness is 0.6 mm
  - Machining aperture transition into the aluminum extrusion





IDVC Cross Section (Left) and Failed Weld Test (Right)

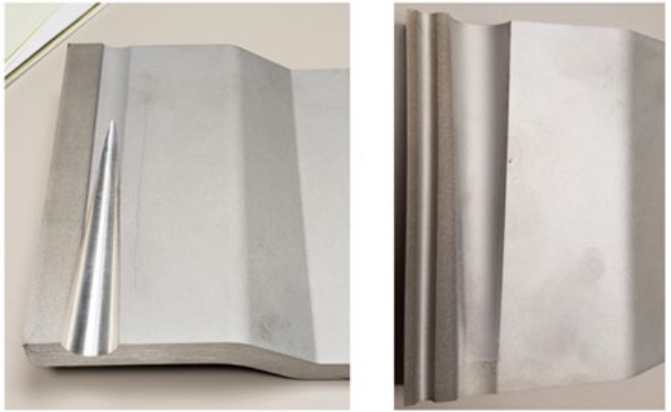


SCU Vacuum Chamber Cross Section

- SCU Vacuum Chamber
  - Welding bi-metal joint without damaging bi-metal interface and meeting AWS D17.1 class B or better specification
  - Machining center section of chamber where nominal wall thickness is 0.4 mm
  - Handling the vacuum chamber during cold mass assembly

ID VACUUM SYSTEM: HPMU IDVC SOLUTIONS

- HPMU ID Vacuum Chamber
  - Work with physics group and manufacturers to come up with best method to machine aperture transition into ends of the chamber
  - Collaboration between ANL weld engineers and vendor vendor weld engineer
  - Collaboration between ANL manufacturing engineers and vendor machinist on how best to achieve thin wall features



IDVS transition cone test pieces; conventional machining (Left) and plunge EDM (right)

IDVC Production Weldment
(Center Region is 7.5 mm tall for reference)

First IDVC Production Unit Welding (Left) and Successful Weld Test (Right)

*See M. Szubert Poster MOPB11 for more information

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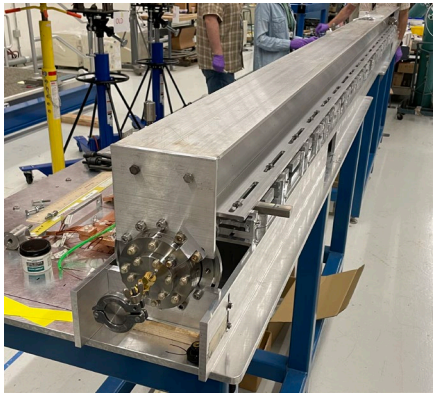
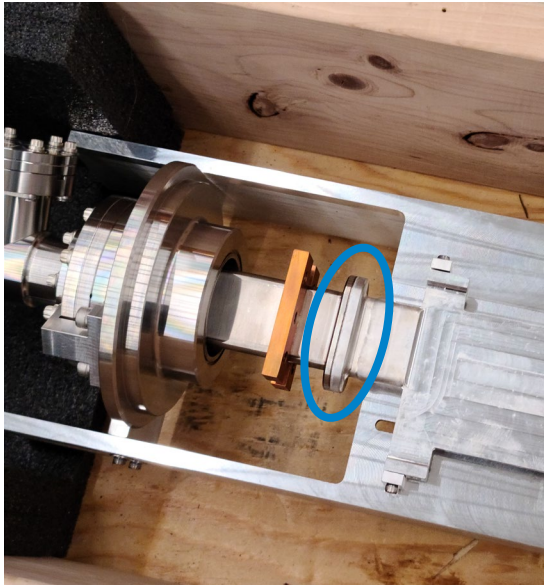
ID VACUUM SYSTEM: SCU VC SOLUTIONS

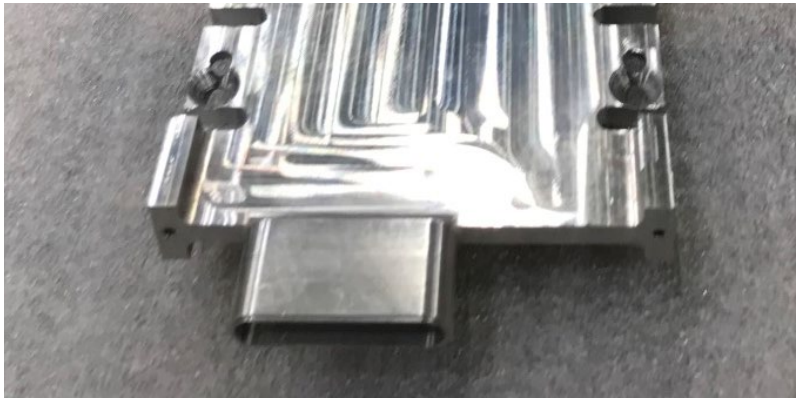
- SCU Vacuum Chamber
  - Collaboration between ANL weld engineers and vendor weld engineer
  - Collaboration between ANL manufacturing engineers and vendor machinist on how best to achieve thin wall features
  - Developed a lifting and assembly strongback for transport and assembly of the SCU VC



SCU VC Lifting and Assembly Fixturing



SCU VC Weldment
(Circled component is bi-metal transition)

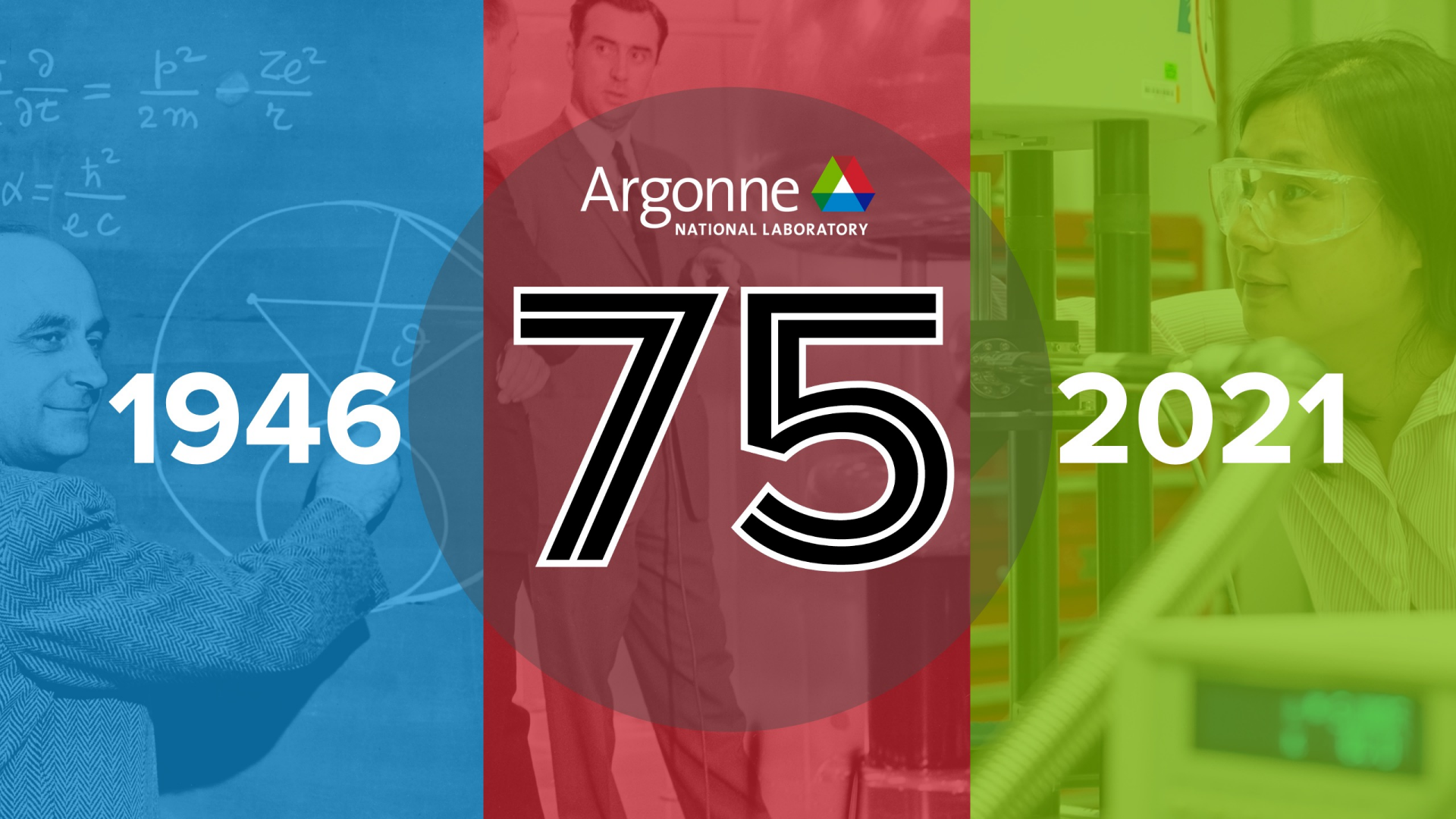


SCU VC Post Machining
(Center Region is 7.1 mm tall for reference)

SUMMARY

- ID Team has an extensive scope
  - Multiple technical areas requiring members with different technical backgrounds
- HPMU's:
  - Assembly and tuning 55 devices in a short time period with limited facilities
  - Working through the pandemic
  - Developed hybrid assembly and tuning plan to tune or pre-tune as many devices as possible
- SCU's:
  - Challenging new design incorporating two undulators into a single cryostat
  - Developed a new core design that simplified manufacturing and assembly
- ID Vacuum System:
  - HPMU ID vacuum chamber has small cross section and thin wall thickness over large areas of the chamber
  - SCU Vacuum chamber has extremely thin wall and is difficult to handle during assembly
  - Both chambers were difficult for our vendors to weld to required specification
  - Developed methods to machine features into vacuum chamber without compromising structural integrity
  - Developed welding processes and procedures with our vendors to ensure welds meet specification

QUESTIONS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