

# Part 1

## The Manufacture of SCU0

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ASD

ASD Seminar  
March 4, 2013

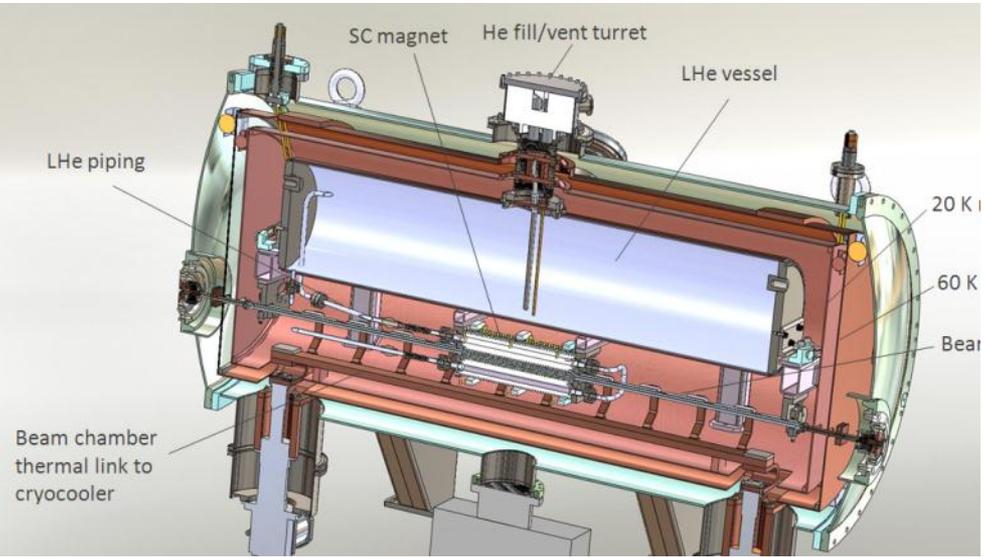
# Outline

- Introduction
- Assembly Planning and Pre Assembly
- Notable Testing During Manufacture
- Cryogenic Operation and Testing
- Opportunities Provided By The Beam Chamber Modification
- Conclusion

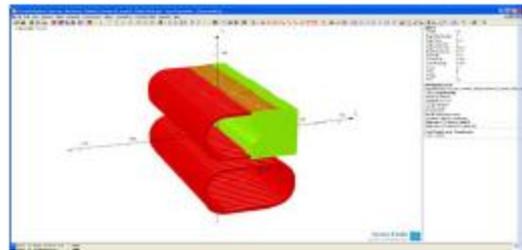


# SCUO Design

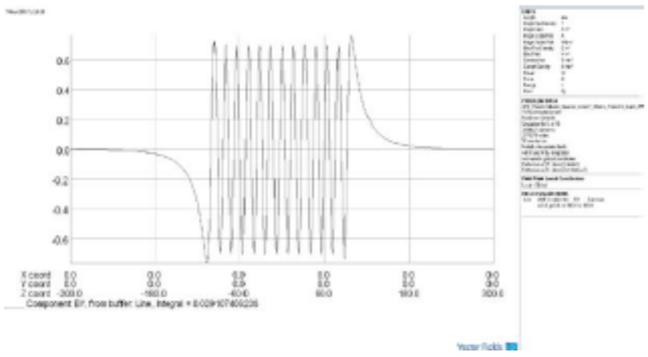
- Over five years of design and testing, involving many different disciplines.



Planar undulator winding scheme



On-axis field in a planar undulator



# SCU0 Component Fabrication

Many components making up the SCU0 were fabricated both at the APS / ANL, and by outside manufacturers or vendors from APS design and specification. Many of these outside components required considerable interaction with the vendors.

## Examples of APS/ANL Fabrication

- The wound and epoxy impregnated superconducting magnet coils
- The braided thermal links for the beam chamber
- Numerous small machined parts, along with many modifications to received machine parts or components.
- The beam chamber weldments.
- The Kevlar cold mass support system

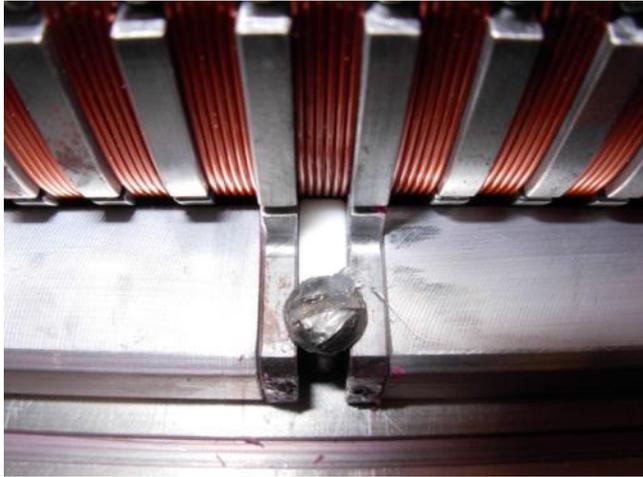
## Examples of Vendor Fabrication

- The carbon steel magnet cores
- The cryostat vacuum SS vessel, Cu thermal shields and Bimetallic LHe reservoir
- The SS cold mass support frame
- Current lead assembly machined parts of copper and stainless steel

# Superconducting Magnet Coil Winding



# Coil Epoxy Impregnation



# Commercially Purchased Components

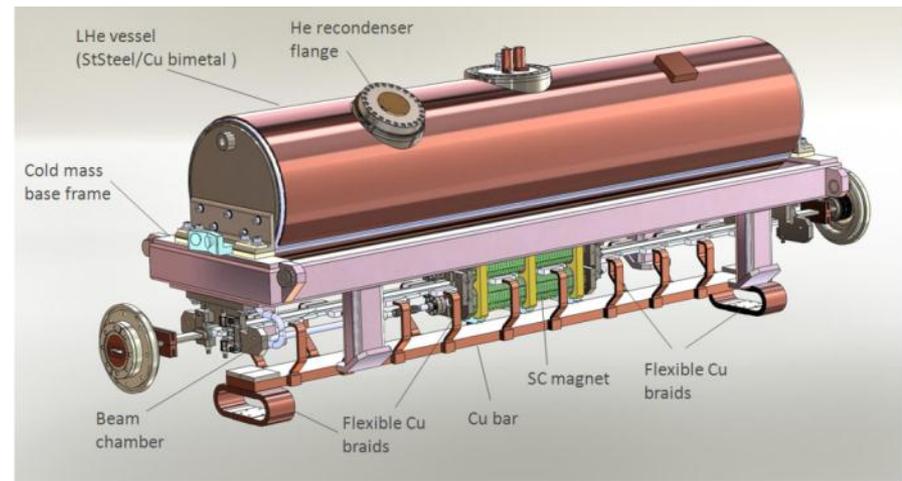
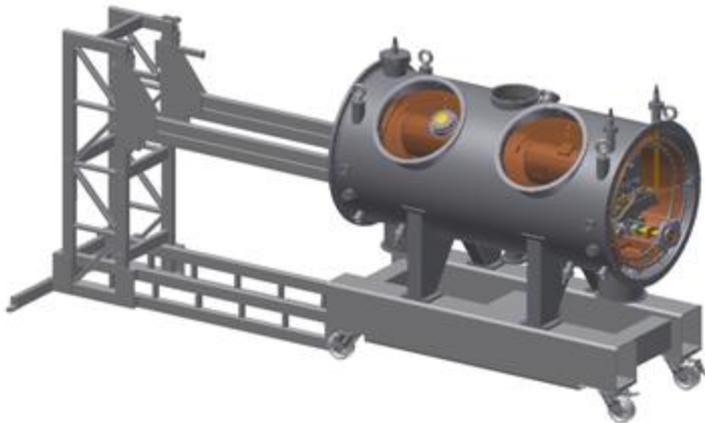
Many components are standard off the shelf or built to specification commercially available components.

## Examples

- Sumitomo Cryocooler Systems
- HTS Magnet Current Leads
- Copper 60K and 20K Thermal Links
- Vacuum Flanges and Components
- Magnet Power Supplies
- Thermometry and Readouts
- Pressure Sensors and Readouts
- LHe Monitoring System
- Lab VIEW Control Software and Components

# Assembly Planning and Pre Assembly

- Ongoing Review Of Drawing Packets
- Additional Assembly Tooling and Fixtures Designed and Built As Needed
- Most Assemblies Pre Assembled Prior to Installation Within The cryostat vacuum vessel
- Thermometry and Instrumentation Mounted and Tested During Pre Assembly
- He Mass Spec Leak Testing of Individual Components and Sub Assemblies



# Major SCU0 Sub Assemblies



60K Shield Assembly With Thermal Links and MLI Installed

# Major SCU0 Sub Assemblies



Cold Mass Assembly

Support Frame, SC Magnets, LHe Reservoir, Beam Chamber, Instrumentation

# SCU Cold Mass Assembly Installation Into Cryostat Vacuum Vessel



# Current Lead / Cryocooler Sub Assembly Testing

- During the review of the drawing packages the complexity and number of parts making up the current lead/cryocooler assemblies was noted. It was decided that it would be worthwhile to assemble the units to gain familiarity with their mechanical buildup prior to the final assembly and installation.
- As the units were being assembled, it was also decided to operate the cryocoolers and test the assemblies.
- The 100 A and 500 A assemblies were tested up to their nominal operating currents utilizing parts of the SCU vacuum vessel for a test cryostat, with the cryocoolers being powered by an installed He compressor previously used for earlier SCU test programs.
- The initial testing indicated that the thermal and electrical contact resistance of the assemblies was higher than desired.
- Several test runs were completed, incorporating a series of design improvements that greatly reduced both the thermal contact resistance and electrical contact resistance.

# Current Lead / Cold Head Assemblies Assembly and Test

## 100 A Current Lead / Cold Head Assembly Complex

- 53 Parts
- 198 Individual Pieces
- 8 Thermally Coupled But Electrically Isolated Joints
- 8 Critical Electrical Joints

REVISION HISTORY						
ZONE	REV	DESCRIPTION	BY	APPROVED	DATE	
33	00A-0275	CP GASKET		CPHC	Copper	2
32	00958A130	M6 PLAIN WASHER			Stainless Steel	12
31	00475K211	M6 BELLEVILLE WASHER			Stainless Steel	16
30	0021150703	02 3/4 CP FLANGE ASSEMBLY			Stainless Steel	2
29	02060327013	00 5/2 PIN CIRCULAR FEED-THROUGH			Stainless Steel	2
28	03808A103	PLAIN WASHER M5			Stainless Steel	6
27	03808A105	M5 HEX HEAD CAP SCREW			Stainless Steel	6
26	00475K215	M5 BELLEVILLE WASHER			Stainless Steel	6
25	02200A132	HSKCS M6 X 30			Stainless Steel	6
24	04130A195	HEX NUT M6			Stainless Steel	6
23	02200A190	SHCS M4 X 30			Stainless Steel	16
22	02111A190	M6 PLAIN WASHER			Stainless Steel	6
21	02477A191	M6 BELLEVILLE WASHER			Stainless Steel	6
20	04130A190	HEX NUT M5 X 0.8 X 4			316 Stainless Steel	8
19	0211150740	00 100A BRACKET FOR CURRENT LEAD			Titanium	2
18	02200A146	HSKCS M4 X 16			Stainless Steel	4
17	0021150729	00 100A COIL HOLDER			ALUMINUM OXIDE (ALOX)	4
16	0021150736	00 100A HOLDER			Copper 100 OPI	4
15	0021150738	00 100A COIL BRACKET 1			Copper 100 OPI	4
14	0021150727	00 100A COIL BRACKET 2			Copper 100 OPI	4
13	0021150728	00 100A CONNECTOR FOR CORRECTION COIL			Copper 100 OPI (100")	4
12	0021150734	00 OVAL THREADED STUD			304 Stainless Steel	8
11	02200A134	HSKCS M4 X 16			Stainless Steel	8
10	00958A130	M6 PLAIN WASHER			Stainless Steel	8
9	02111A148	M6 X 1 X 45			Stainless Steel	12
8	02111A130	M3 X 9 X .7 WASHER			316 Stainless Steel	12
7	04130A126	M3 HEX NUT			Stainless Steel	12
6	0021150730	00 CORRECT ION COIL CLAMP			Titanium	12
5	0021150729	00 100A BRACKET FOR CURRENT LEAD LINK			Titanium	4
4	0021150719	00 100A LEAD ROD BUSHING			PEEK	4
3	0021150726	00 100A LEAD ROD BUSHING			Copper 100 OPI	2
2	0021150726	00 100A ROK CLAMP THREADED CLAMP			Titanium	4
1	0021150727	00 100A ROK CLEANANCE CLAMP			Titanium	4
00	0206030210030	M5 110S CURRENT LEAD				4
19	0021150720	00 100A CURRENT LEAD LINK ASSEMBLY				4
18	0021150714	00 HEAD LEAD ROK SOXA ASSEMBLY				1
17	0021150718	00 CURRENT LEAD SAPPHIRE DISK			ALUMINUM OXIDE (ALOX)	12
16	0021150717	00 CURRENT LEAD LINK NUT			017 CARBIDE	4
15	02-V285	00 VITON O-RING I.D. 14.364 X .139			VITON	1
14	0021150716	00 100A BUSHING			PEEK	6
13	0021150715	00 100A W/ HEAD BLOCK			Copper 100 OPI	1
12	ROK-41502	00 SUNETCHO 4.26 COLD HEAD				1
11	0021150710	00 CURRENT LEAD 100A ASSEMBLY				4
10	02-V285	00 VITON O-RING I.D. 5.809 X .139			VITON	1
9	0021150709	00 TURRET STANDOFF 2			304 Stainless Steel	2
8	0021150708	00 TURRET STANDOFF 1			304 Stainless Steel	2
7	0021150704	00 ST ANDOFF 1 SLIDING			304 Stainless Steel	4
6	0021150706	00 100A FEED THRU NUT			Beryllium Copper C17000	2
5	02-V318	00 O-RING .975 ID X .210			VITON	4
4	0021150705	00 100A FEED THRU INSULATOR			PEEK	8
3	0021150704	00 WELDED FEED THRU 100A			304 Stainless Steel	2
2	0021150702	00 FLANGE 100A			304 Stainless Steel	1
1	0021150701	00 TURRET SUPPORT BRACKET			304 Stainless Steel	1

ITEM	PART NUMBER	REV	PARTS LIST	DESCRIPTION	MATERIAL	QTY
1	0021150701	00	TURRET SUPPORT BRACKET	304 Stainless Steel	1	
2	0021150702	00	FLANGE 100A	304 Stainless Steel	1	
3	0021150704	00	WELDED FEED THRU 100A	304 Stainless Steel	2	
4	0021150705	00	100A FEED THRU INSULATOR	PEEK	8	
5	02-V318	00	O-RING .975 ID X .210	VITON	4	
6	0021150706	00	100A FEED THRU NUT	Beryllium Copper C17000	2	
7	0021150704	00	ST ANDOFF 1 SLIDING	304 Stainless Steel	4	
8	0021150708	00	TURRET STANDOFF 1	304 Stainless Steel	2	
9	0021150709	00	TURRET STANDOFF 2	304 Stainless Steel	2	
10	02-V285	00	VITON O-RING I.D. 5.809 X .139	VITON	1	
11	0021150710	00	CURRENT LEAD 100A ASSEMBLY		4	
12	ROK-41502	00	SUNETCHO 4.26 COLD HEAD		1	
13	0021150715	00	100A W/ HEAD BLOCK	Copper 100 OPI	1	
14	0021150716	00	100A BUSHING	PEEK	6	
15	02-V285	00	VITON O-RING I.D. 14.364 X .139	VITON	1	
16	0021150717	00	CURRENT LEAD LINK NUT	017 CARBIDE	4	
17	0021150718	00	CURRENT LEAD SAPPHIRE DISK	ALUMINUM OXIDE (ALOX)	12	
18	0021150714	00	HEAD LEAD ROK SOXA ASSEMBLY		1	
19	0021150720	00	100A CURRENT LEAD LINK ASSEMBLY		4	
20	0206030210030		M5 110S CURRENT LEAD		4	
21	0021150727	00	100A ROK CLEANANCE CLAMP	Titanium	4	
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24	0021150719	00	100A LEAD ROD BUSHING	PEEK	4	
25	0021150729	00	100A BRACKET FOR CURRENT LEAD LINK	Titanium	4	
26	0021150730	00	CORRECT ION COIL CLAMP	Titanium	12	
27	04130A126		M3 HEX NUT	Stainless Steel	12	
28	02111A130		M3 X 9 X .7 WASHER	316 Stainless Steel	12	
29	02111A148		M6 X 1 X 45	Stainless Steel	12	
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35	0021150736	00	100A HOLDER	Copper 100 OPI	4	
36	0021150738	00	100A COIL BRACKET 1	Copper 100 OPI	4	
37	0021150729	00	100A COIL HOLDER	ALUMINUM OXIDE (ALOX)	4	
38	02200A146		HSKCS M4 X 16	Stainless Steel	4	
39	0211150740	00	100A BRACKET FOR CURRENT LEAD	Titanium	2	
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44	04130A195		HEX NUT M6	Stainless Steel	6	
45	02200A132		HSKCS M6 X 30	Stainless Steel	6	
46	00475K215		M5 BELLEVILLE WASHER	Stainless Steel	6	
47	03808A105		M5 HEX HEAD CAP SCREW	Stainless Steel	6	
48	03808A103		PLAIN WASHER M5	Stainless Steel	6	
49	02060327013	00	5/2 PIN CIRCULAR FEED-THROUGH	Stainless Steel	2	
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51	00475K211		M6 BELLEVILLE WASHER	Stainless Steel	16	
52	00958A130		M6 PLAIN WASHER	Stainless Steel	12	
53	00A-0275		CP GASKET	CPHC Copper	2	

SOURCE OR EQUIVALENT  
 PROCTER-CARR  
 P.O. BOX 4280  
 CHICAGO, IL 60640-4280  
 616-863-8300

SOURCE OR EQUIVALENT  
 ROY T. LINDER  
 P.O. BOX 30 QUAKERTON, PA  
 15052-0030  
 800-245-4586

SUNETCHO (SUN)  
 CRYTECHNICS OF AMERICA  
 3823 MALDEN STREET  
 ALLENTOWN, PA 18033  
 (610)796-4931

OPI ASSOCIATES, INC.  
 455 INDUSTRIAL ROAD  
 SAN CARLOS, CA 94060  
 (800)860-4242

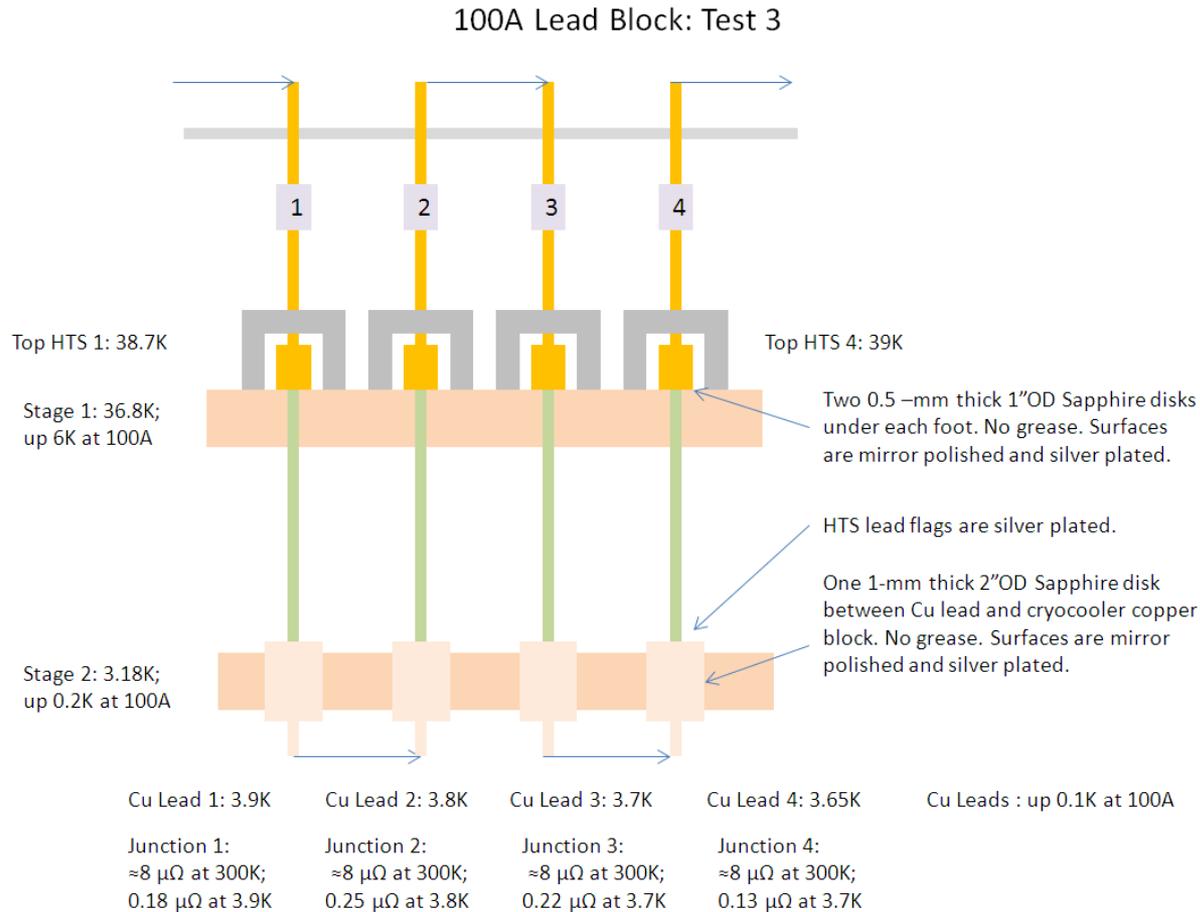
MADE IN CHINA AND  
 NEW ZEALAND  
 NEW ZEALAND 001 642 340 100  
 CHINA 0086 201 502 1000  
 001 642 340 100

DATE: 10/19/2011  
 BY: B. BUFTINGTON  
 D. SCHAPOPOULOS  
 E. TRAKHTENBERG  
 J. FLUERST

10/19/2011  
 4101-150700

ADVANCED PHOTON SOURCE  
 EXP. FACILITIES-TECH COMPONENTS  
 INSERTION DEVICES SYSTEM  
 SUPERCONDUCTING UNDIULATOR SCU 0  
 100A POWER SUPPLY ASSEMBLY  
 POWER SUPPLY 100A ASSEMBLY  
 4101-150700

# Current Lead / Cold Head assembly Testing 100 I Final Configuration

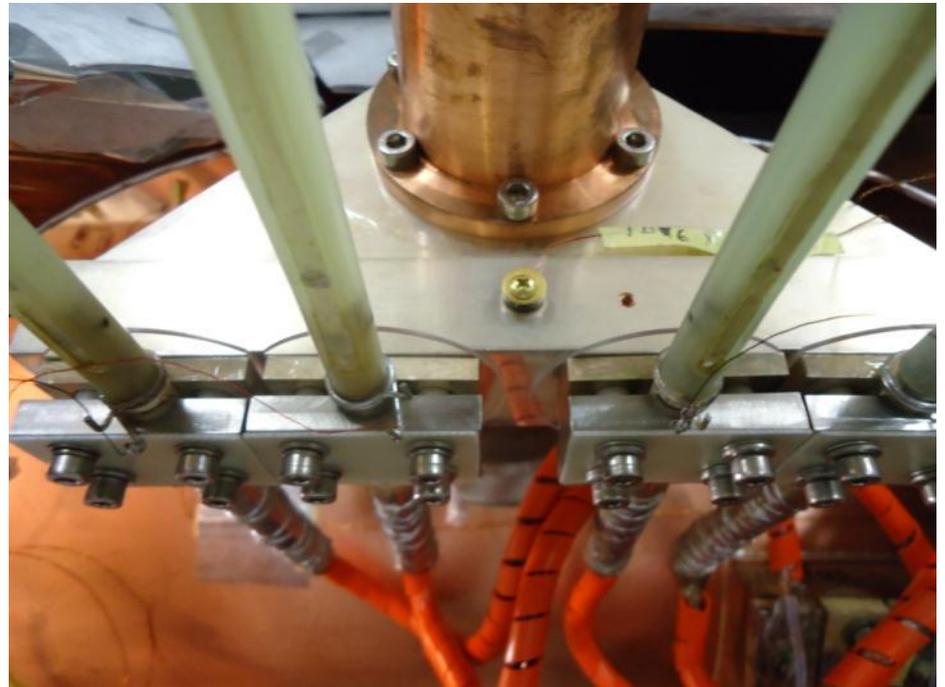


# Current Lead /Cryocooler Assembly

**Initial Assembly**



**Final Plated, Polished, Optical Sapphire Assembly**



# Cryogenic System Overview

The SCU0 cryogenic system utilizes four two stage cryocoolers to refrigerate the superconducting magnets, the beam chamber and the cryostat thermal shields.

- The upper RDK 415 units (Top US and Top DS) 1<sup>st</sup> stages are coupled to the warm magnet current leads, the top of the HTS current leads and the cryostat 60K thermal shield. The second stages of these units are coupled to the bottom of the HTS current leads, the superconducting magnet current leads, the copper jacketed LHe reservoir and a re-condensing bulb within the system LHe reservoir.
- The lower RDK 408 units (Bot US and Bot DS) 1<sup>st</sup> stages are also coupled to the cryostat 60K thermal shield. The 2<sup>nd</sup> stages of these units are coupled to the cryostat 20K thermal shield and to the beam chamber.
- The superconducting magnets are cooled by LHe passing through their iron cores from the system LHe reservoir via a thermal syphon.

# Cryogenic Testing

## Initial Commissioning and Operation

### Sequence

1. System cooldown with cryocoolers only to  $< 10\text{K}$
2. LHe transfer to establish specified inventory.
3. System Stability With No Current or Loads
4. System Behavior During Magnet Conditioning And Measurement
5. System Tolerance To Beam Chamber Heat Loads

### Results

- The system cooled down as anticipated on the cryocoolers
- The system stabilized, and was ready for operation in  $\sim 72$  hrs. The thermal shield and beam chamber temperatures operate below their design temperatures.
- System stable with Zero He boil-off at nominal magnet currents and above, with no additional LHe being added during the several week test program.
- The system He pressure increases with a magnet quench ( $\sim 60$  Torr), but recovers in  $\sim 30$  min.
- Operated with nominal 500 A in magnet coils and 45 W beam chamber heat load.

# Cryogenic Testing

## Non Standard Operation and Upset Modes

### Test and Mode

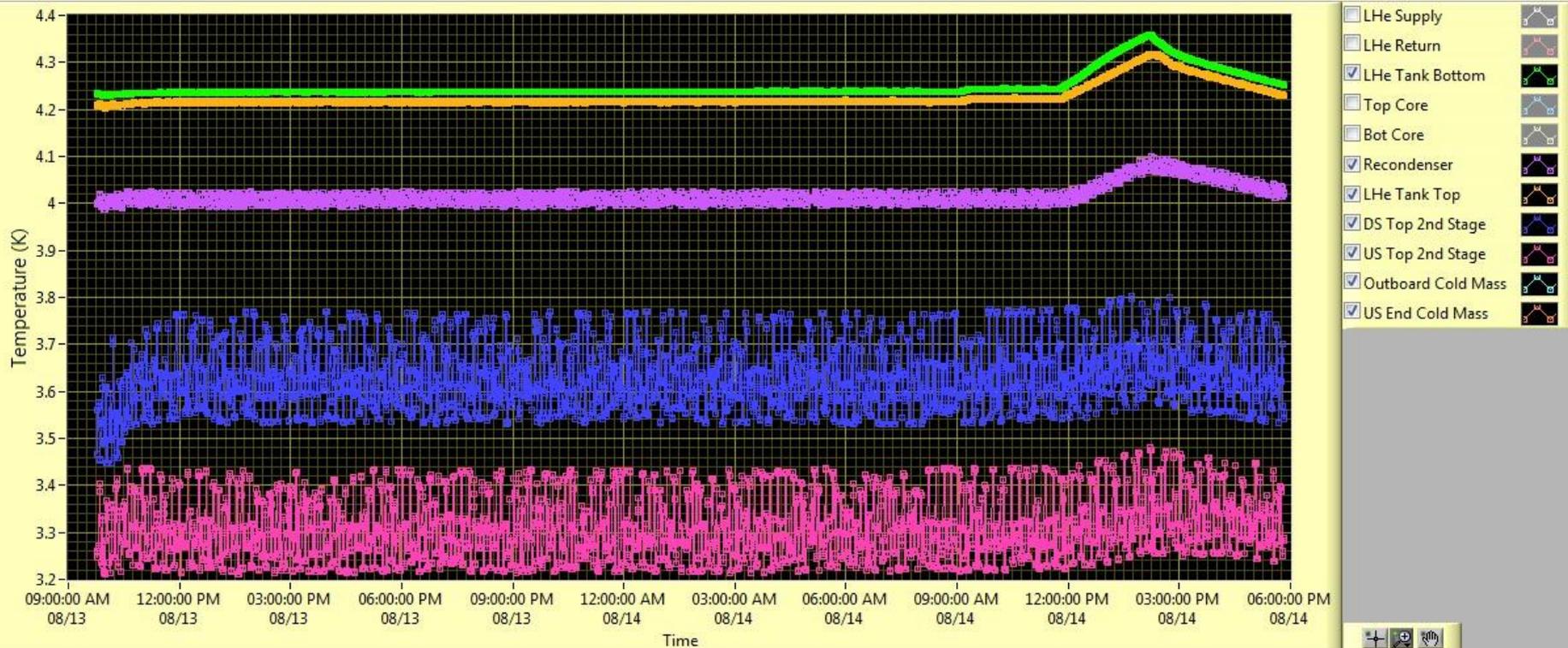
1. Is The System Capable Of Condensing Added He Gas
2. Minimum Achievable Temperature
3. Cryocooler Shutdowns
4. Thermal Cycle Tests, Warm Up and Repeat Cool down

### Results

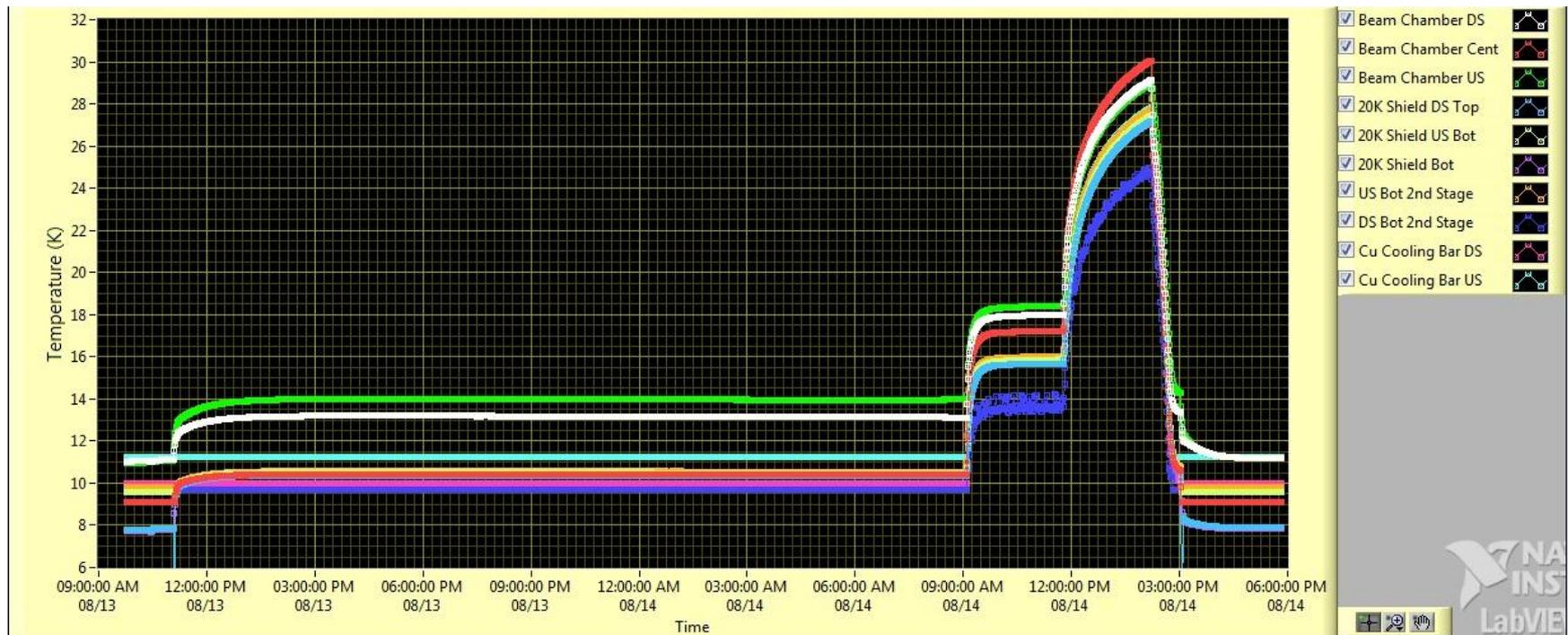
- Successfully increased the LHe inventory with added He gas. (Static heat load only)
- Allowed the HE system to go sub atmospheric, LHe tank stabilized at  $\sim 3.8\text{K}$ . system tolerated
- System stabilized with one lower cryocooler shutdown, 500A operating current and 10 W applied to the beam chamber. 20 W applied to the beam chamber caused a slow increase in system He pressure. (Limited duration test)
- Shutting down each of the upper cryocoolers caused an increase in He system pressure as expected, 40 and 50 Torr in an hour.
- All the cryocoolers restarted uneventfully, and the system recovered.
- System warmed to ambient, the 2<sup>nd</sup> cool down cycle mirrored the 1<sup>st</sup> cool down.



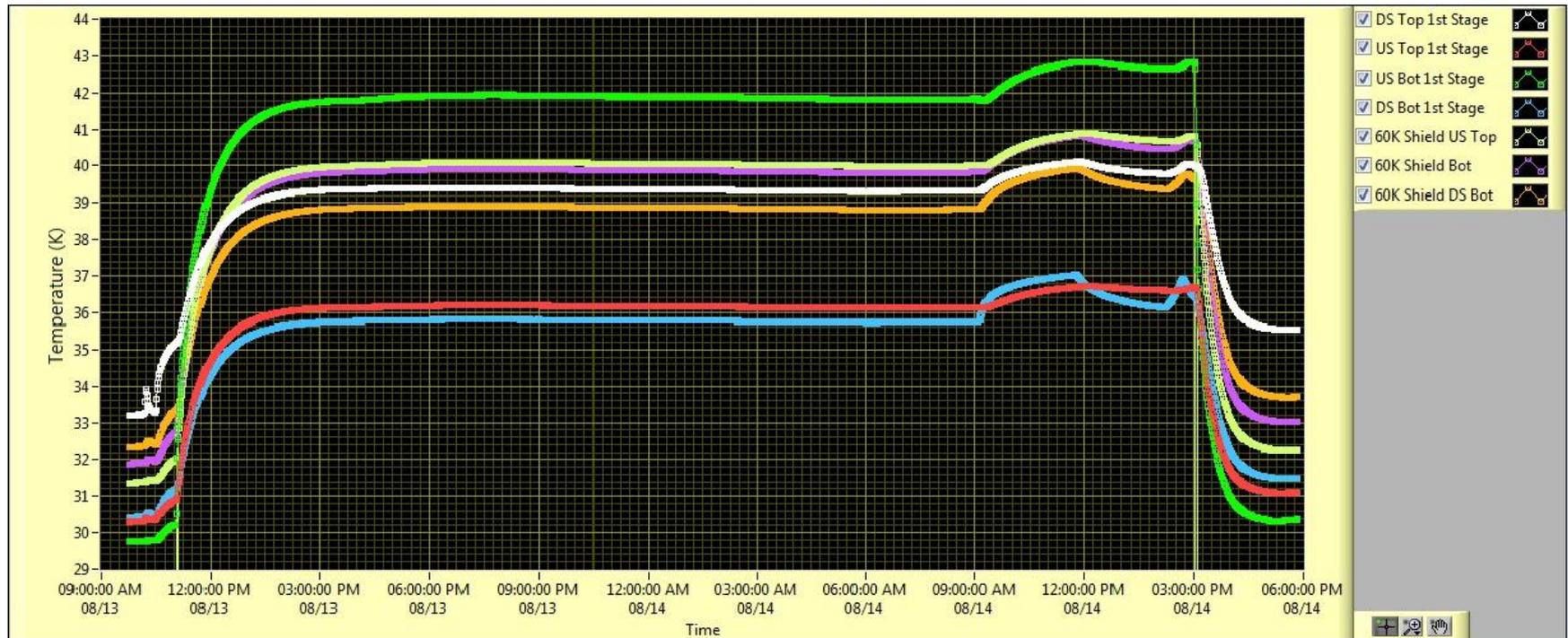
# Representative Cryogenic Data US 408 Cryocooler Shutdown



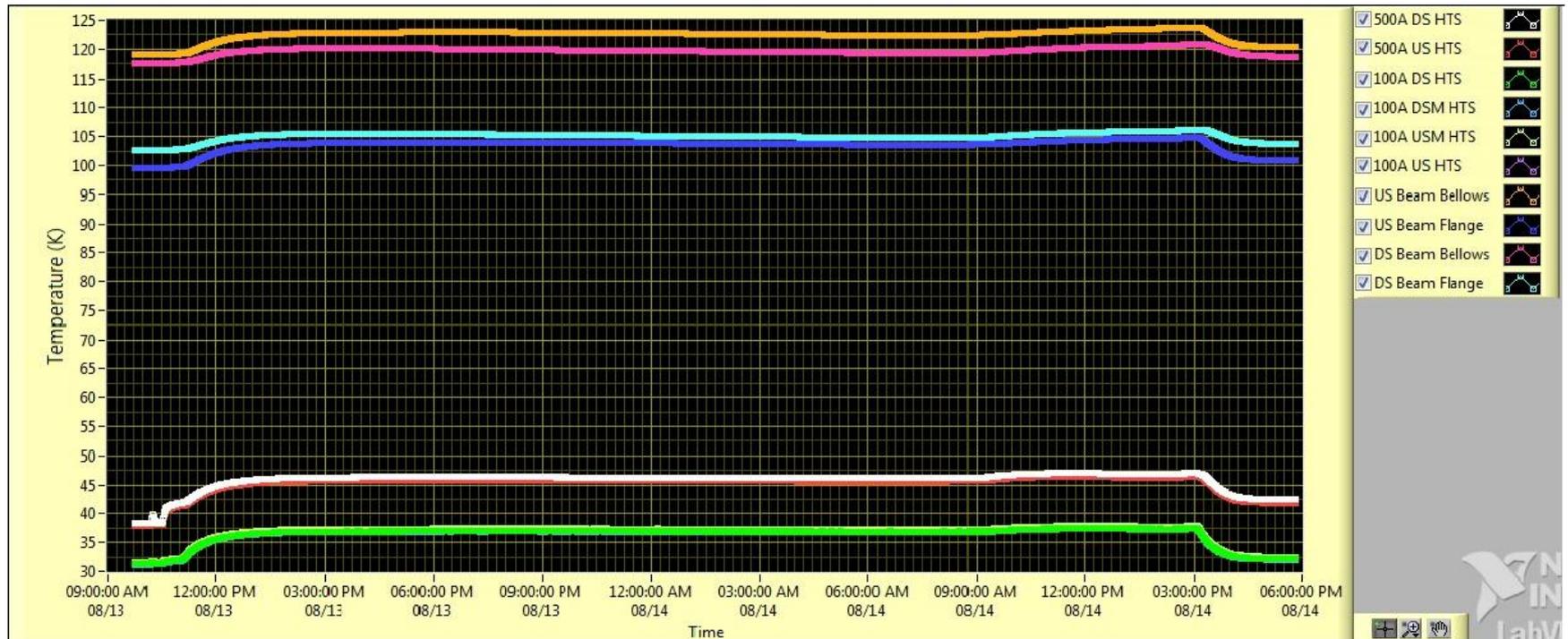
# Representative Cryogenic Data US 408 Cryocooler Shutdown



# Representative Cryogenic Data US 408 Cryocooler Shutdown



# Representative Cryogenic Data US 408 Cryocooler Shutdown



# Cold Mass Alignment

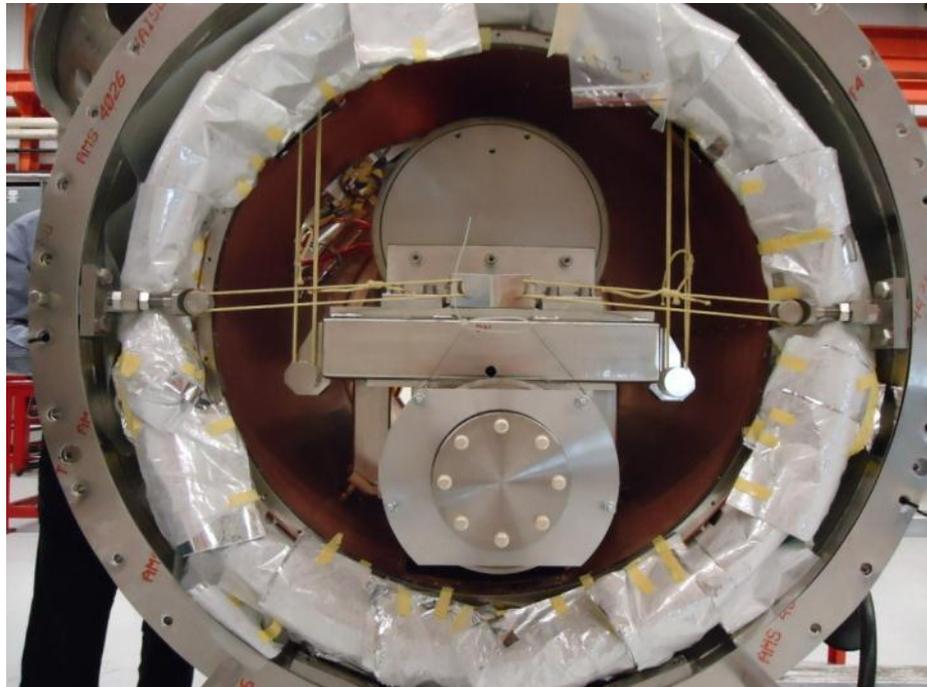
An important parameter that required pre-planning and appreciable time in both the assembly of the cold mass/beam chamber assembly and cold mass to cryostat vacuum vessel assembly. Following warm assembly alignment and cryostat leveling by the APS Survey and Alignment Group the alignment was monitored as the cryostat cooled to operating temperature.

Notable Aspects And Findings:

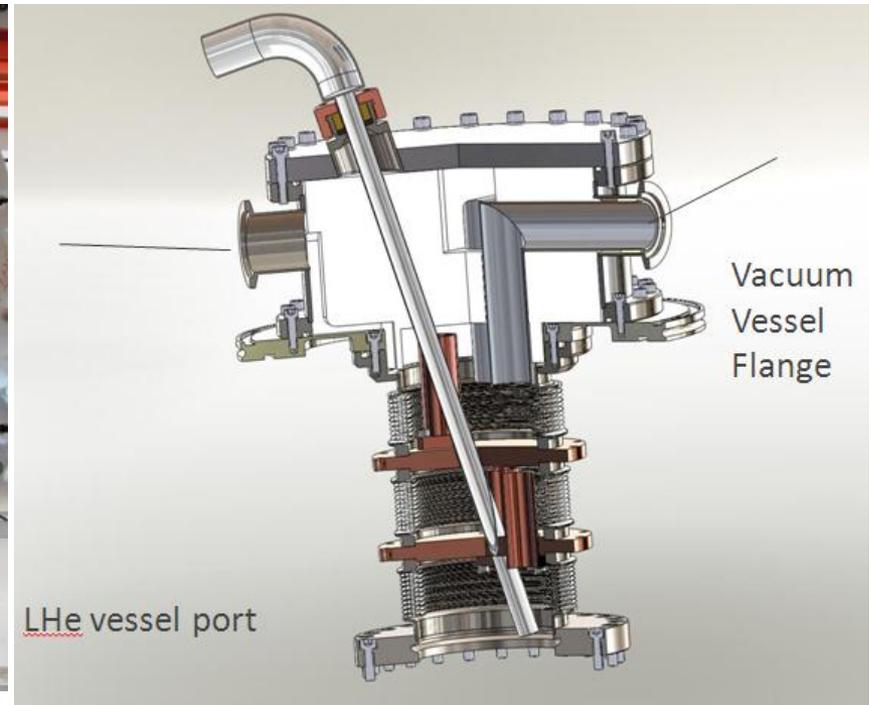
- The vertical position of the suspended cold mass lowered within the cryostat vacuum vessel changed by  $\sim -900 \mu\text{m}$  and a pitched  $\sim 200 \mu\text{m}/\text{m}$  as the cryogenic system cooled to operating temperature. A position change was anticipated due to the cryogenic properties of Kevlar.
- An unanticipated component of this change that was noted and verified was the vertical position of the warm atmospheric pressure cold mass within the cryostat vacuum vessel changed as vacuum was established within the cryostat. This change of  $\sim -300 \mu\text{m}$  and pitch of  $\sim 100 \mu\text{m}/\text{m}$  results from the pressure differential across and through the LHe cryogenic neck bellows assembly.

# Cold Mass Alignment Components

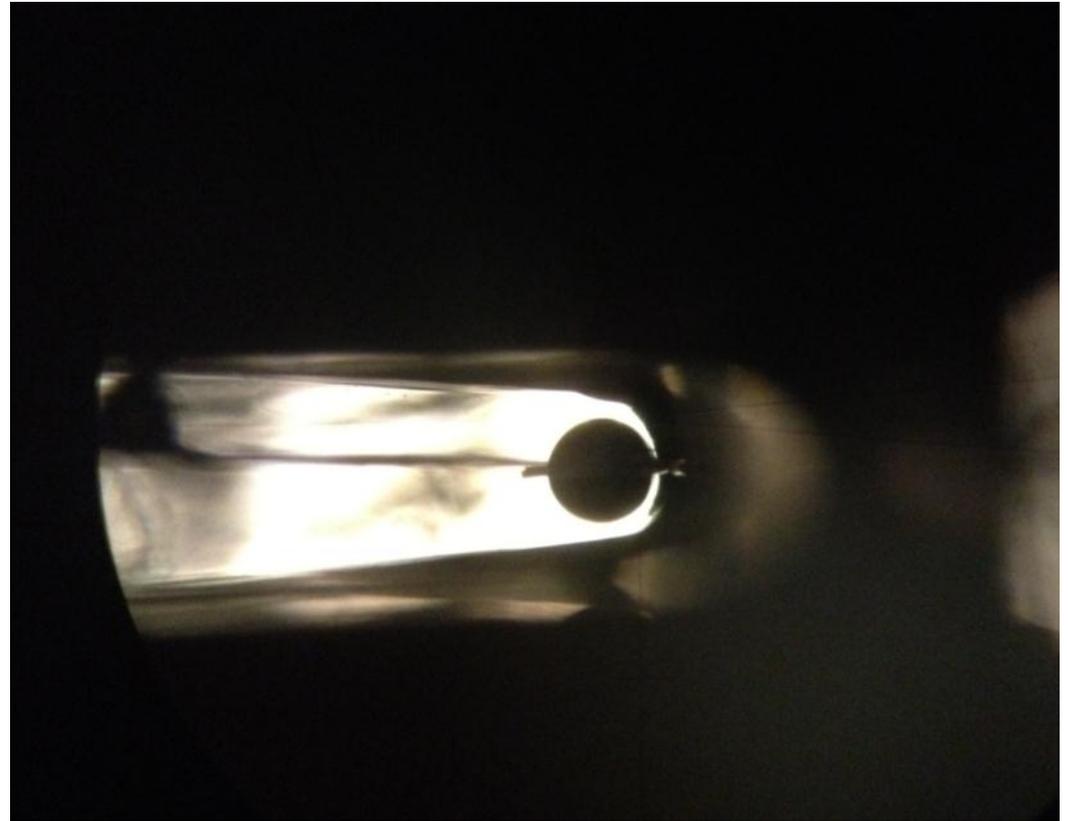
- Kevlar Cold Mass Supports



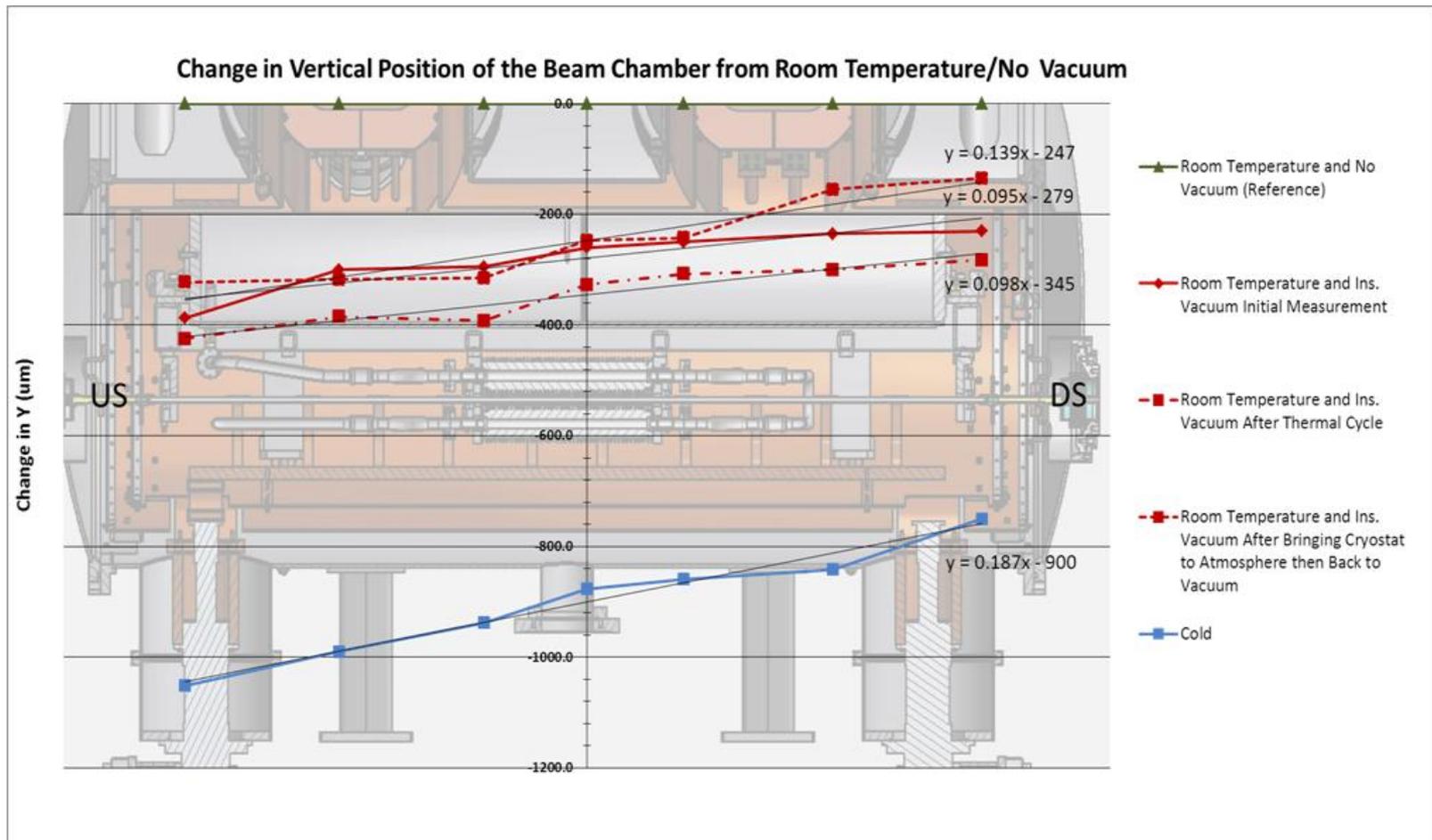
Cold Mass LHe Vessel  
Cryogenic Kneck



# Cold Mass Alignment Measurement



# Cold Mass Alignment Plot



# Improvements Incorporated During The Beam Chamber Replacement

- “Bottomed Out” and suspect thermal sensors were replaced.
- The mounting of thermal sensors on the cold mass were improved for better thermal contact.
- Additional thermometry added to the new beam chamber assembly.
- Cold mass suspension modified to compensate for thermal expansion
- Improved assembly methods utilized from lessons learned on initial assembly.
- Transport support pins modified and tested prior to transport to the S.R.

# Conclusion

After several years of calculation, design, and testing a successful Superconducting Planar Undulator, SCUO, has been built at the APS.

SUO has been installed and is operating in Sector 6 of the APS storage ring, where it is being utilized by the user, with studies on the SCUO itself ongoing.

Along with the dedicated SCU team and the Magnetic Devices group of ASD, many other groups and individuals have contributed to this success.

- The APS Vacuum Group
- The APS Survey and Alignment Group
- The APS Controls Group
- The ANL/APS Machine Shop
- The ANL Weld Shop
- The APS Optics Shop