Part1
The Manufacture of SCU0

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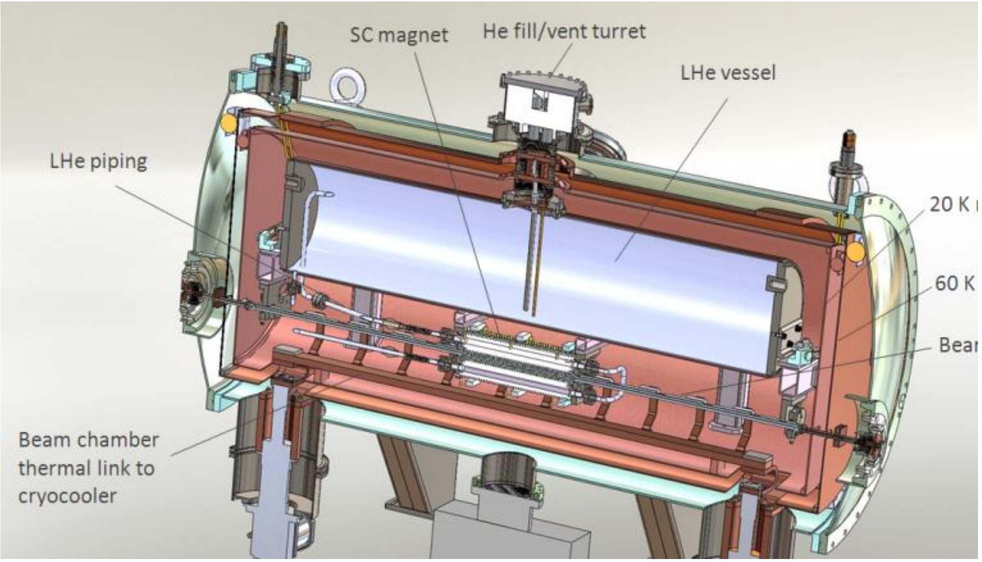
Outline

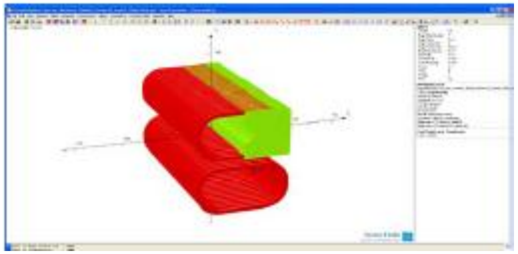
- Introduction
- Assembly Planning and Pre Assembly
- Notable Testing During Manufacture
- Cryogenic Operation and Testing
- Opportunities Provided By The Beam Chamber Modification
- Conclusion

SCUO Design

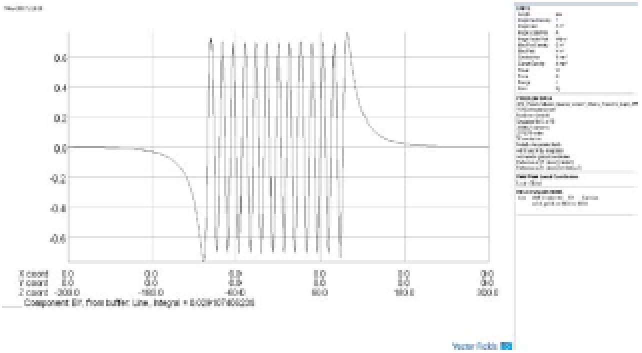
- Over five years of design and testing, involving many different disciples.



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.

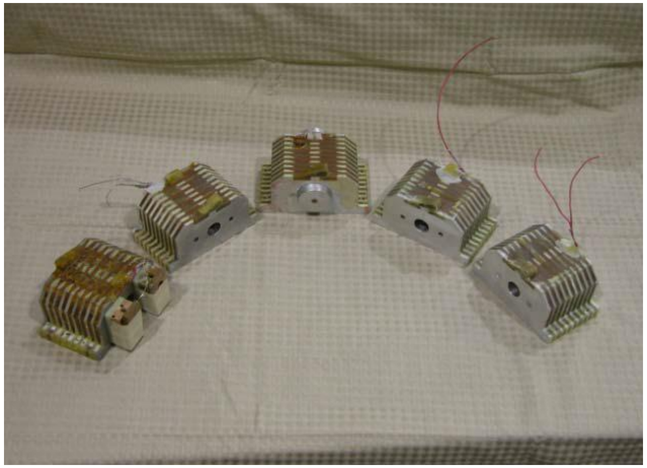
Examples of APS/ANL Fabrication

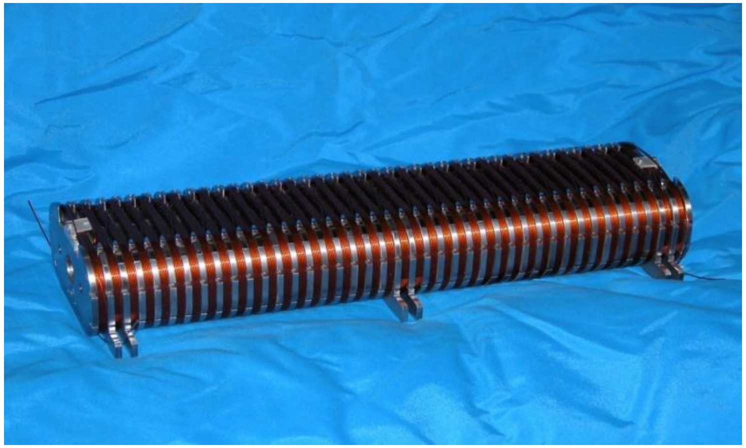
- The wound and epoxy impregnated superconducting magnet coils
- The braided thermal links for the beam chamber
- Numerous small machined parts, along with many modifications to received machine parts or components.
- The beam chamber weldments.
- The Kevlar cold mass support system

Examples of Vendor Fabrication

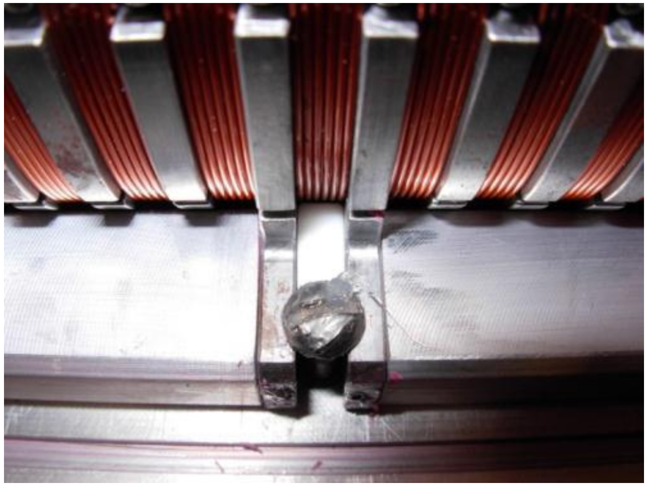
- The carbon steel magnet cores
- The cryostat vacuum SS vessel, Cu thermal shields and Bimetallic LHe reservoir
- The SS cold mass support frame
- Current lead assembly machined parts of copper and stainless steel

Superconducting Magnet Coil Winding





Coil Epoxy Impregnation



Commercially Purchased Components

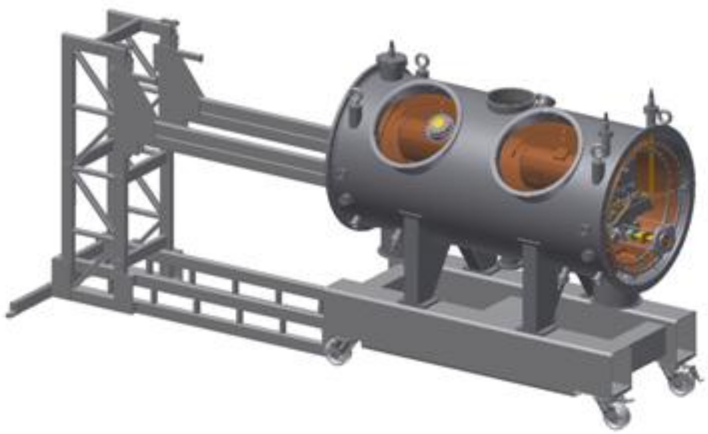
Many components are standard off the shelf or built to specification commercially available components.

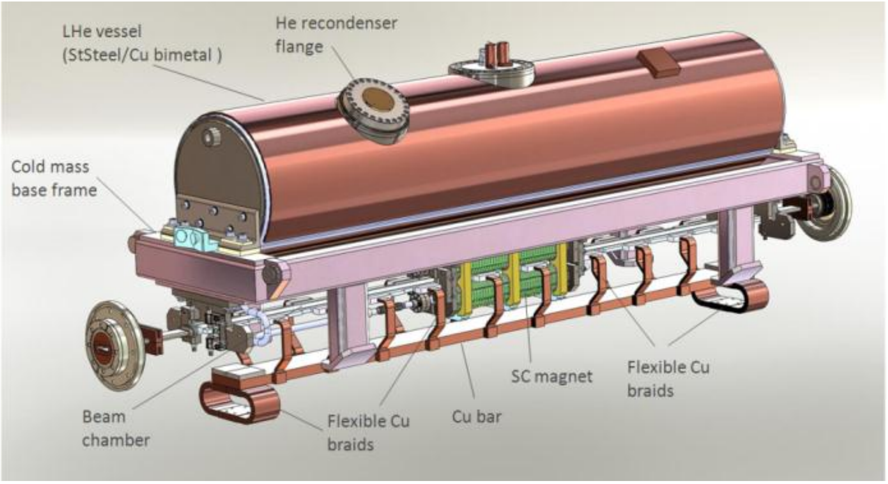
Examples

- 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

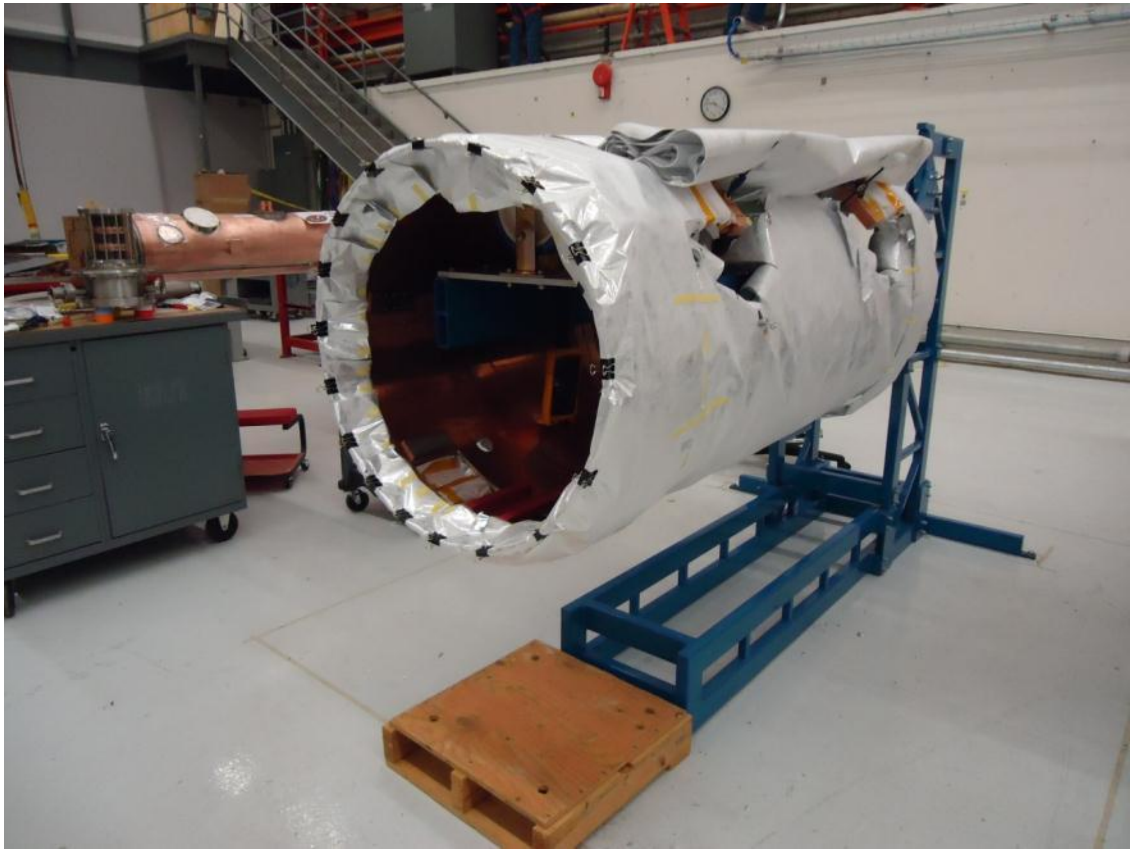
Assembly Planning and Pre Assembly

- 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



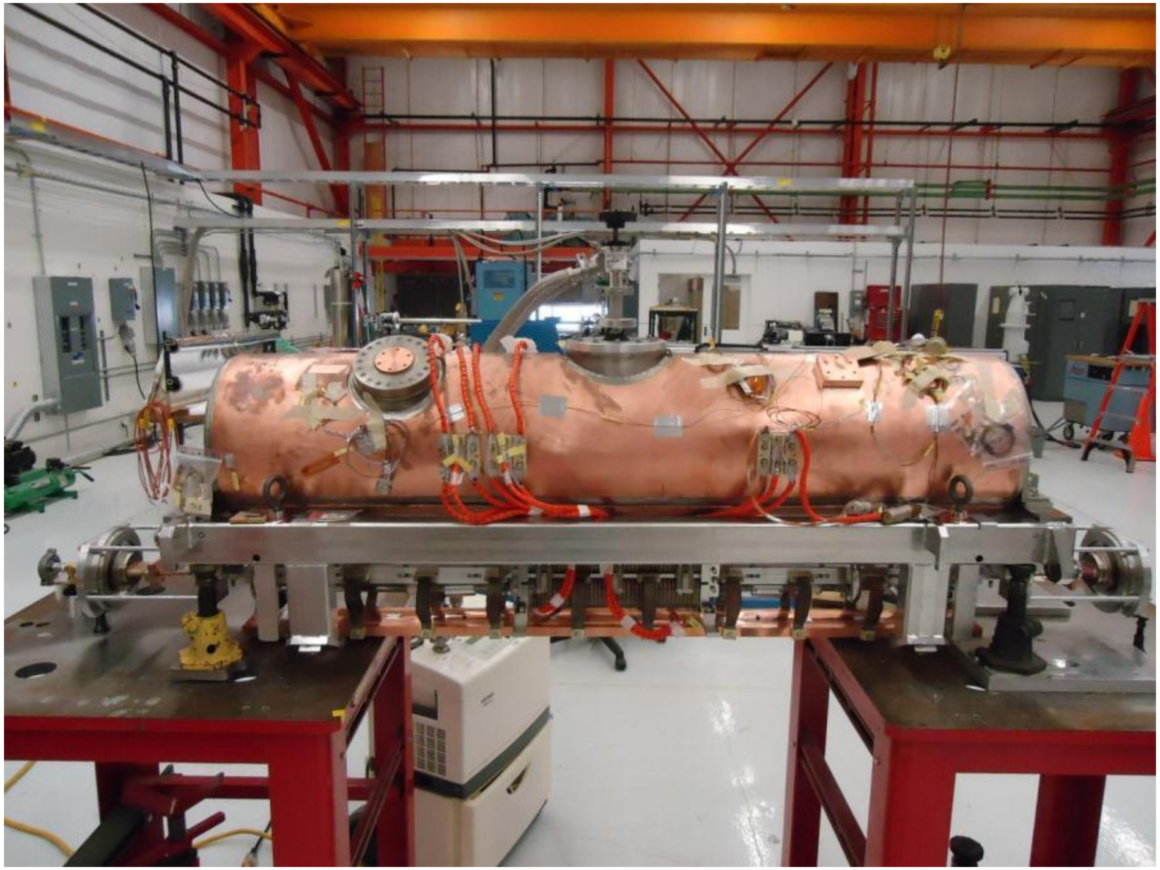


Major SCU0 Sub Assemblies



60K Shield Assembly With Thermal Links and MLI Installed

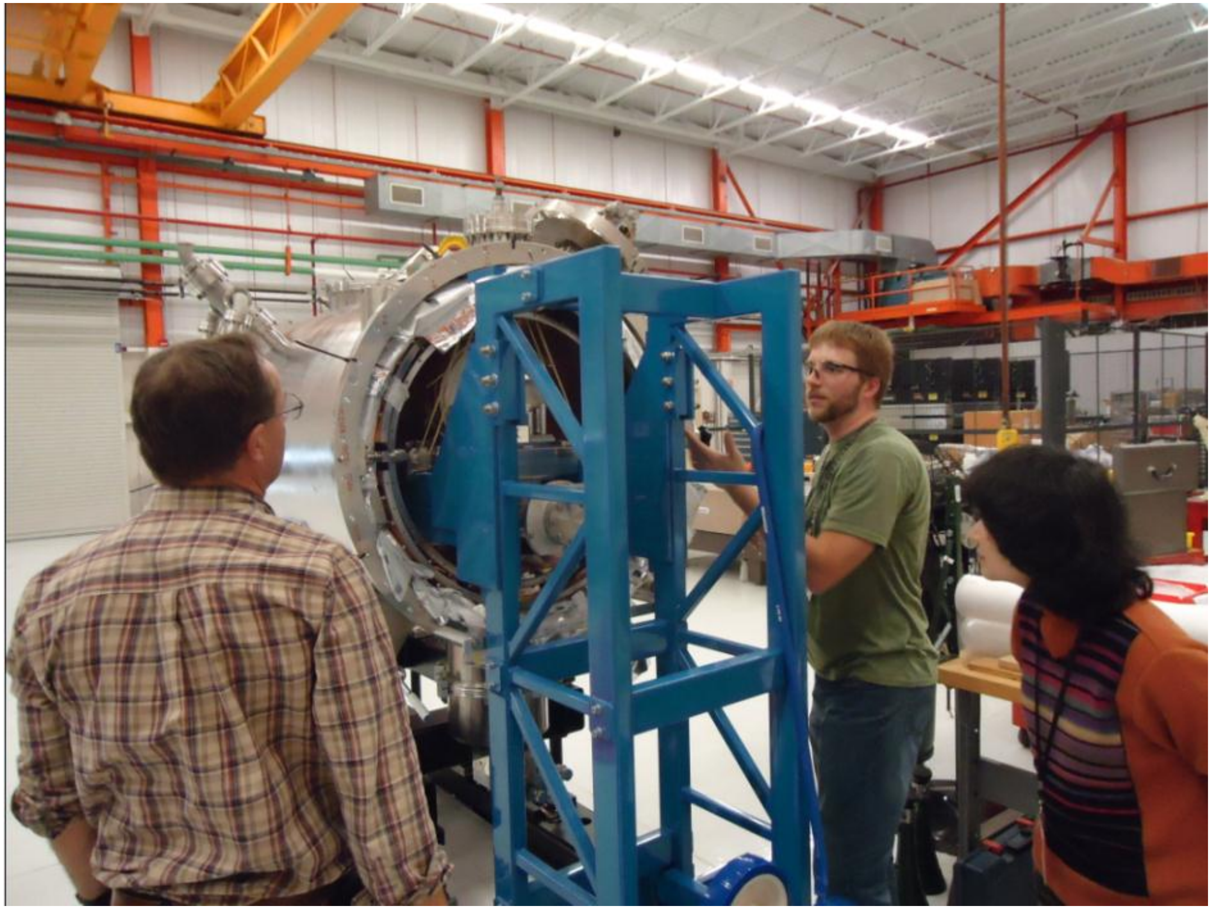
Major SCU0 Sub Assemblies



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 /

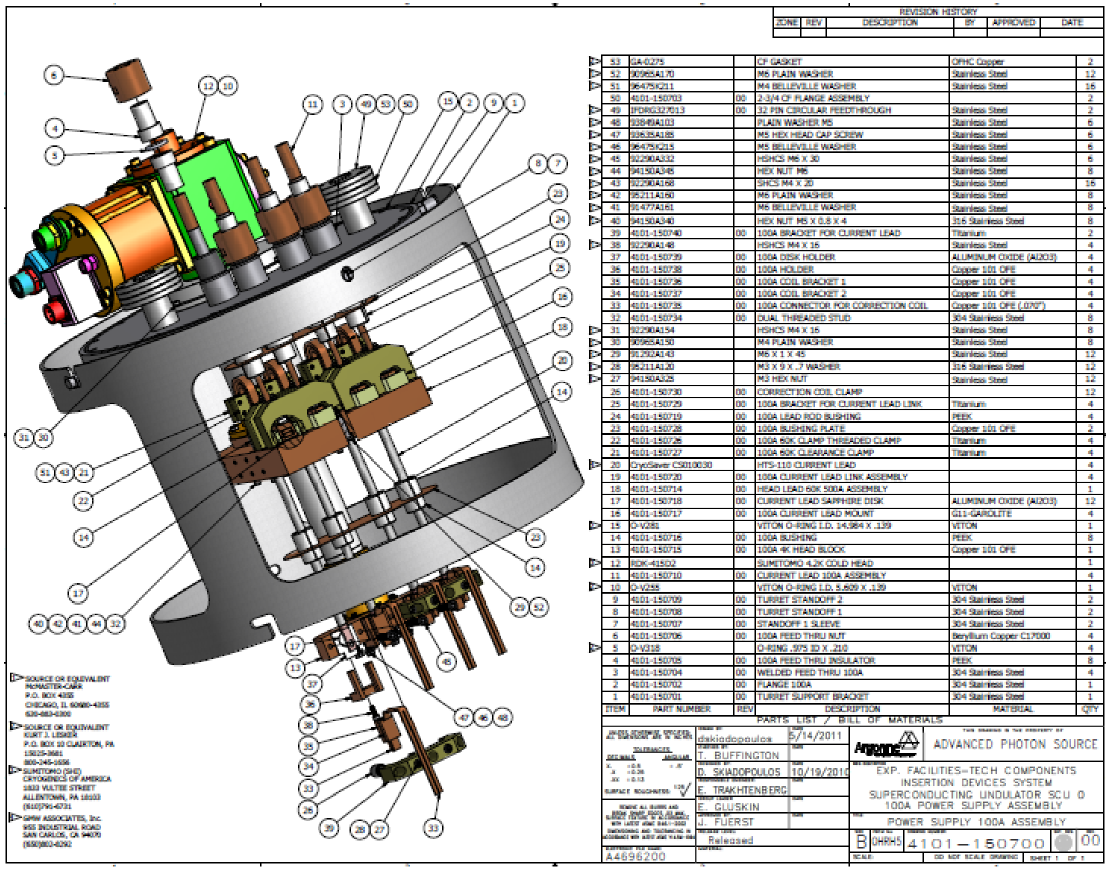
Cold Head Assembly

Complex

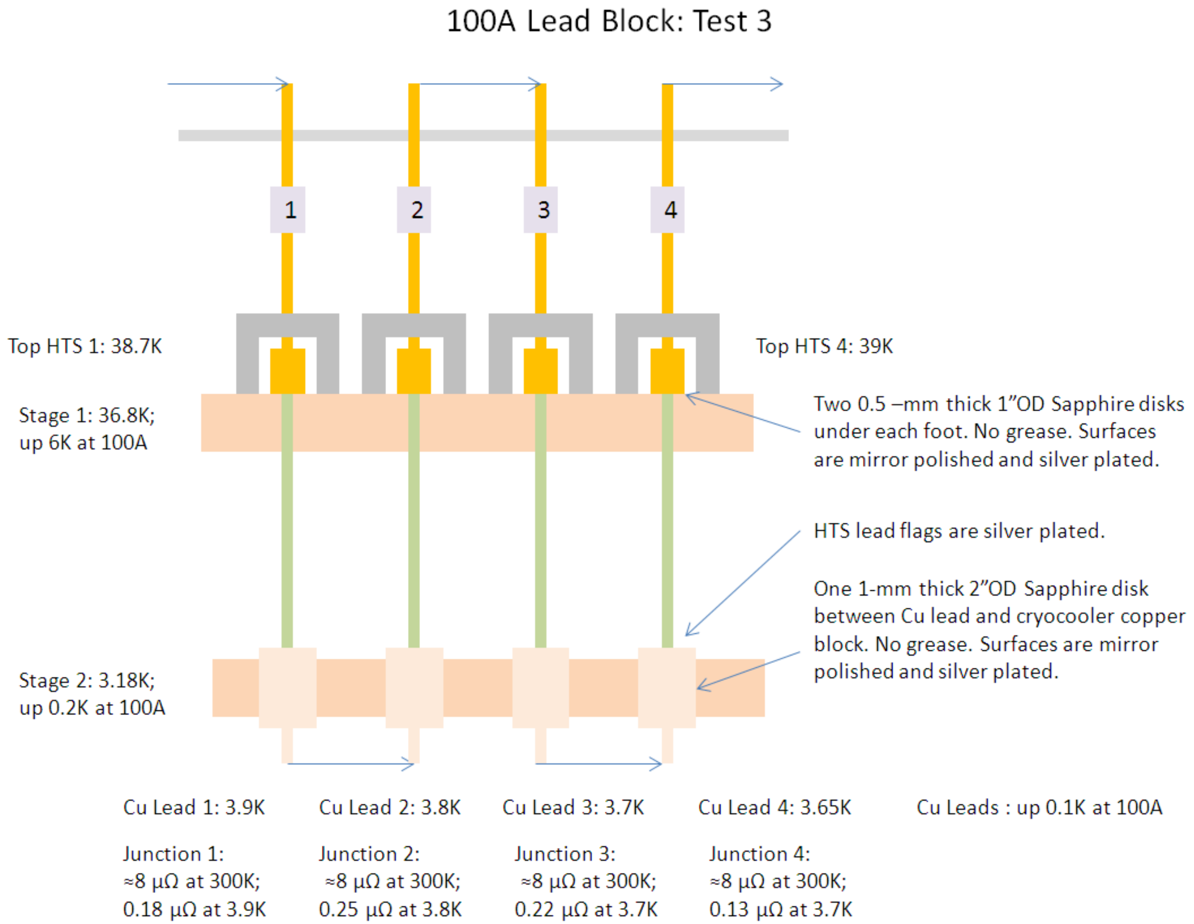
- 53 Parts
- 198 Individual Pieces

Critical

- 8 Thermally Coupled But Electrically Isolated Joints
- 8 Critical Electrical Joints

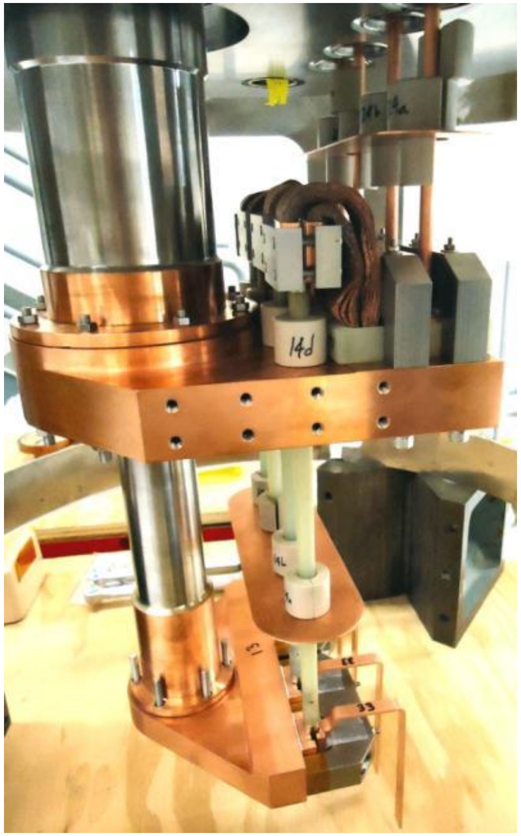


Current Lead / Cold Head assembly Testing 100 I Final Configuration

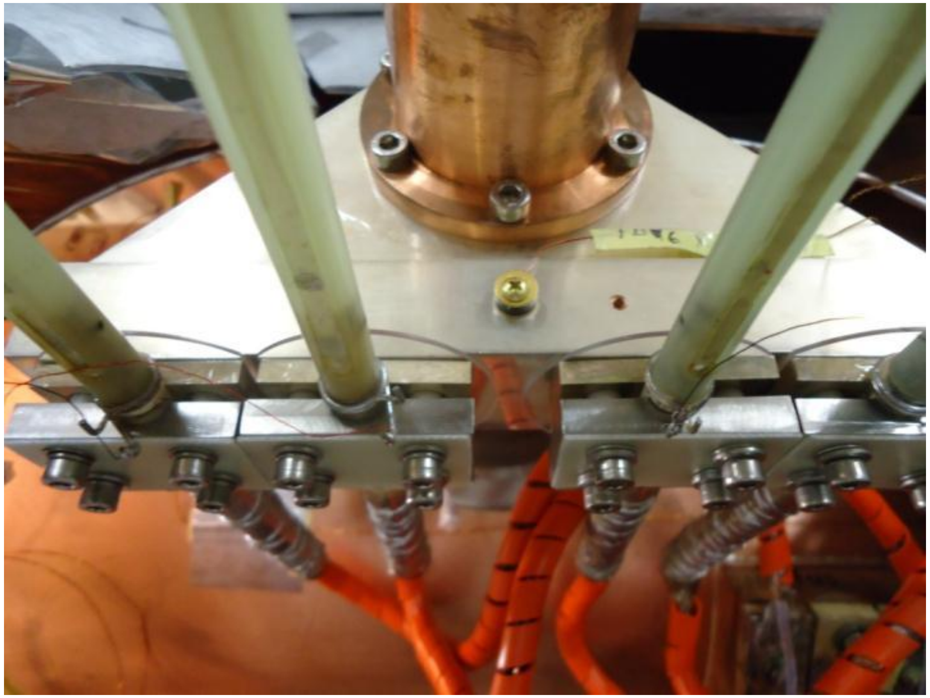


Current Lead /Cryocooler Assembly

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) 1st stages are coupled 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) 1st stages are also coupled to the cryostat 60K thermal shield. The 2nd 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 < 10K
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 cryoccolers
- The system stabilized, and was ready for operation in ~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 (~60 Torr), but recovers in ~30 min.
- Operated with nominal 500 A in magnet coils and 45 W beam chamber heat load.

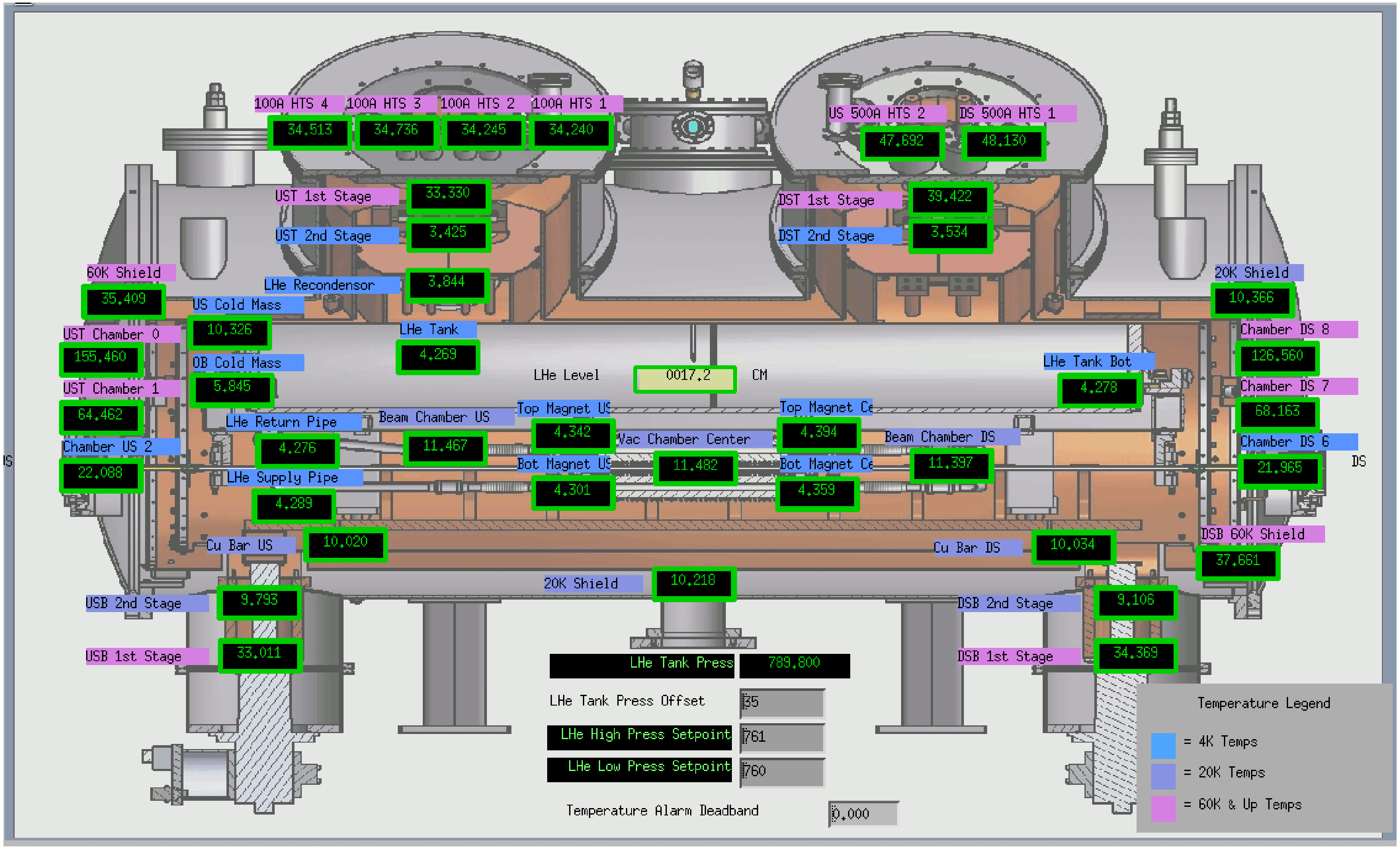
Cryogenic Testing
Non Standard Operation and Upset Modes

Test and Mode

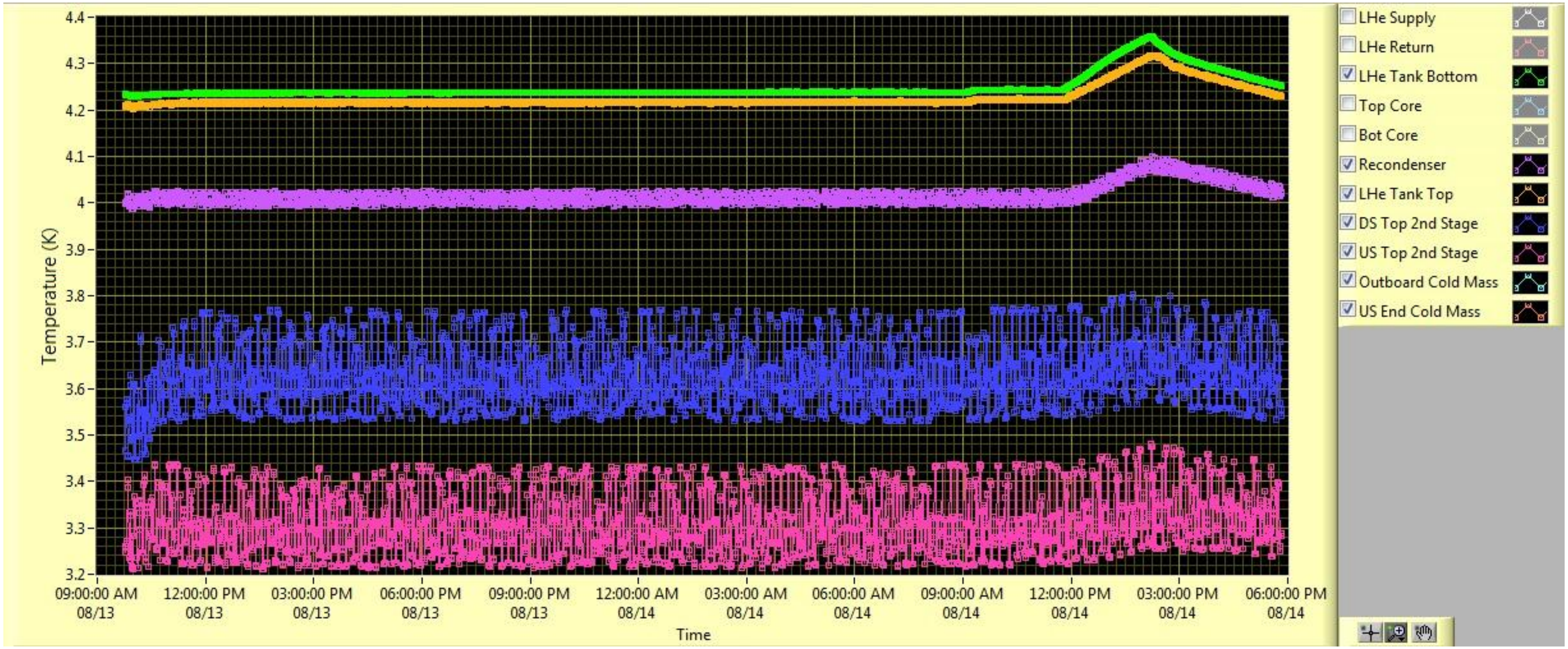
1. Is The System Capable Of Condensing Added He Gas
2. Minimum Achievable Temperature
3. Cryocooler Shutdowns
4. Thermal Cycle Tests, Warm Up and Repeat Cool down

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 ~3.8K. ystem 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 2nd cool down cycle mirrored the 1st cool down.


100A HTS 4
34.513
100A HTS 3
34.736
100A HTS 2
34.245
100A HTS 1
34.240
US 500A HTS 2
47.692
DS 500A HTS 1
48.130
UST 1st Stage
33.330
UST 2nd Stage
3.425
DST 1st Stage
39.422
DST 2nd Stage
3.534
60K Shield
35.409
LHe Recondensor
3.844
US Cold Mass
10.326
20K Shield
10.366
UST Chamber 0
155.460
LHe Tank
4.269
OB Cold Mass
5.845
LHe Level
0017.2
CM
LHe Tank Bot
4.278
Chamber DS 8
126.560
UST Chamber 1
64.462
Chamber DS 7
68.163
LHe Return Pipe
4.276
Beam Chamber US
11.467
Top Magnet US
4.342
Vac Chamber Center
11.482
Top Magnet Ce
4.394
Beam Chamber DS
11.397
Chamber US 2
22.088
Chamber DS 6
21.965
US
DS
LHe Supply Pipe
4.289
Bot Magnet US
4.301
Bot Magnet Ce
4.359
Cu Bar US
10.020
Cu Bar DS
10.034
DSB 60K Shield
37.661
20K Shield
10.218
USB 2nd Stage
9.793
DSB 2nd Stage
9.106
USB 1st Stage
33.011
DSB 1st Stage
34.369
LHe Tank Press
789.800
LHe Tank Press Offset
35
LHe High Press Setpoint
761
LHe Low Press Setpoint
760
Temperature Alarm Deadband
0.000
Temperature Legend
= 4K Temps
= 20K Temps
= 60K & Up Temps

Representative Cryogenic Data
US 408 Cryocooler Shutdown



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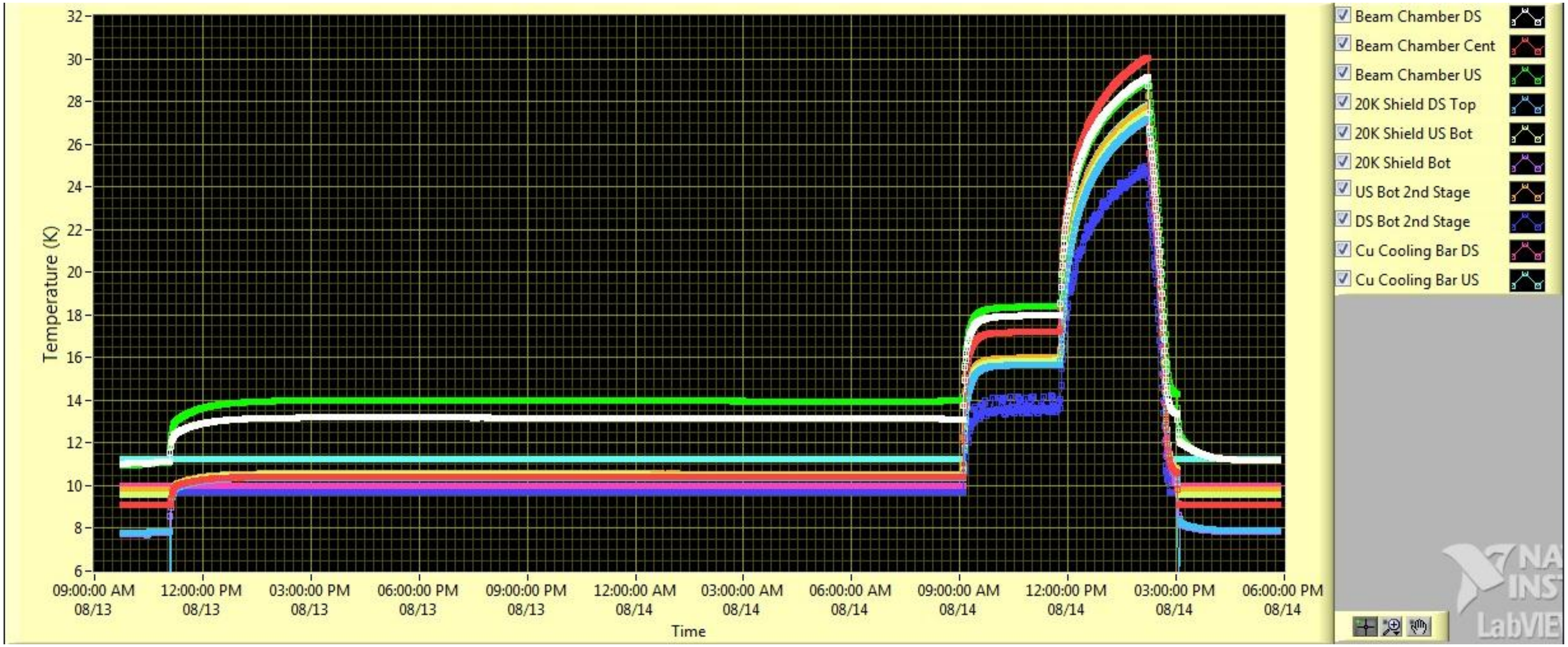

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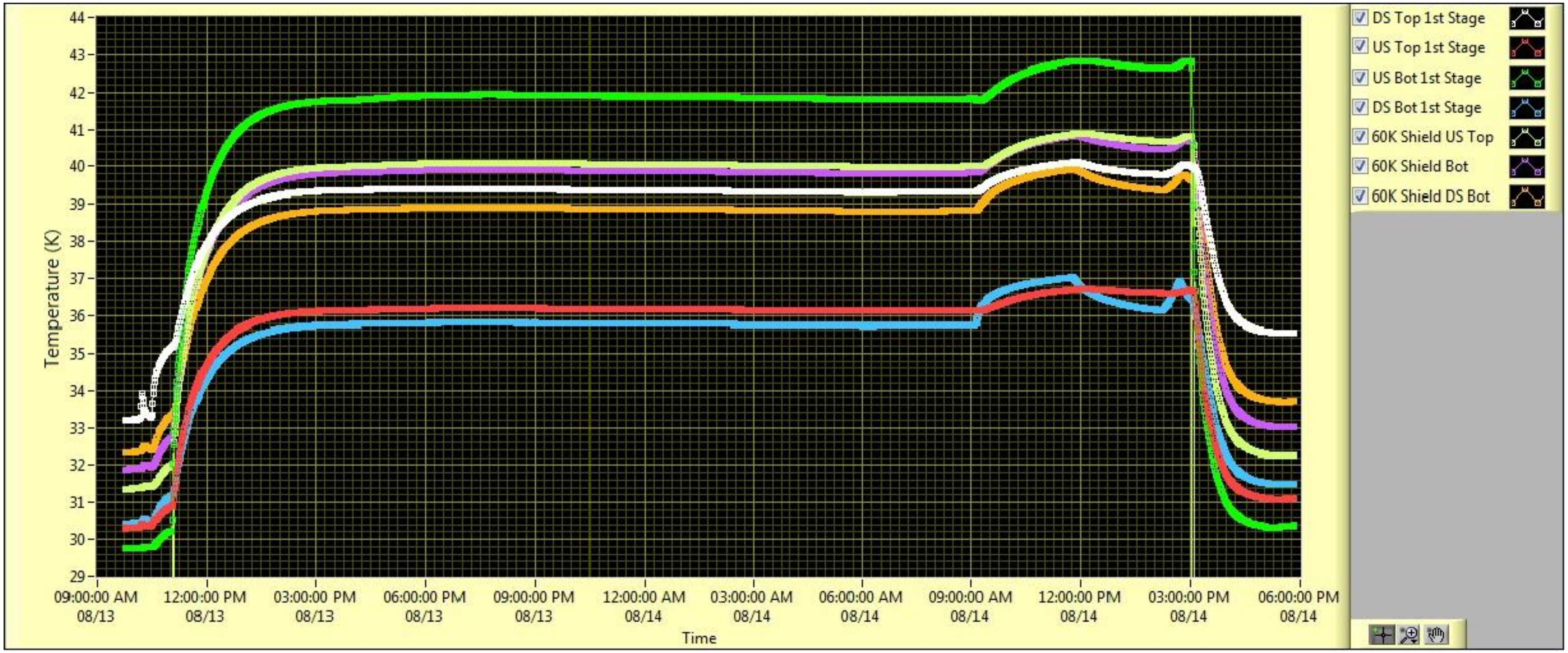

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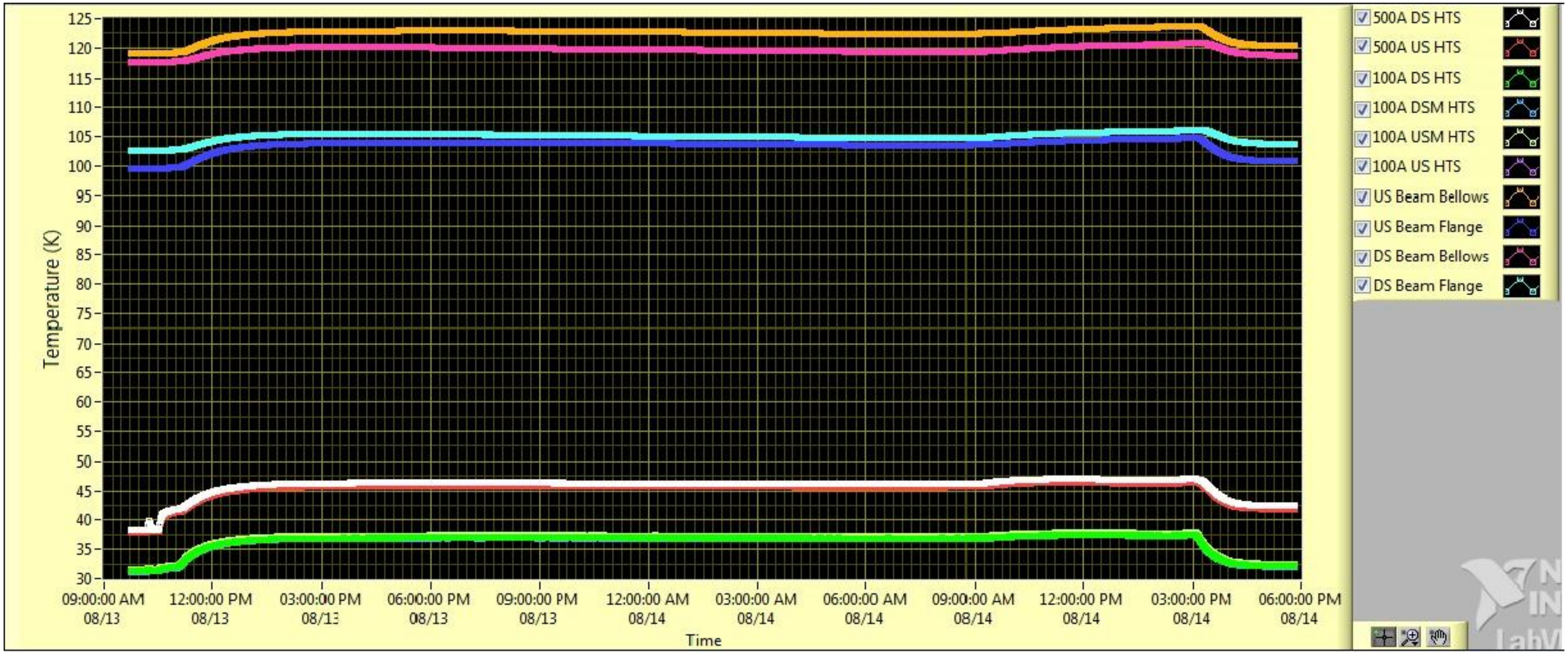


Cold Mass Alignment

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:

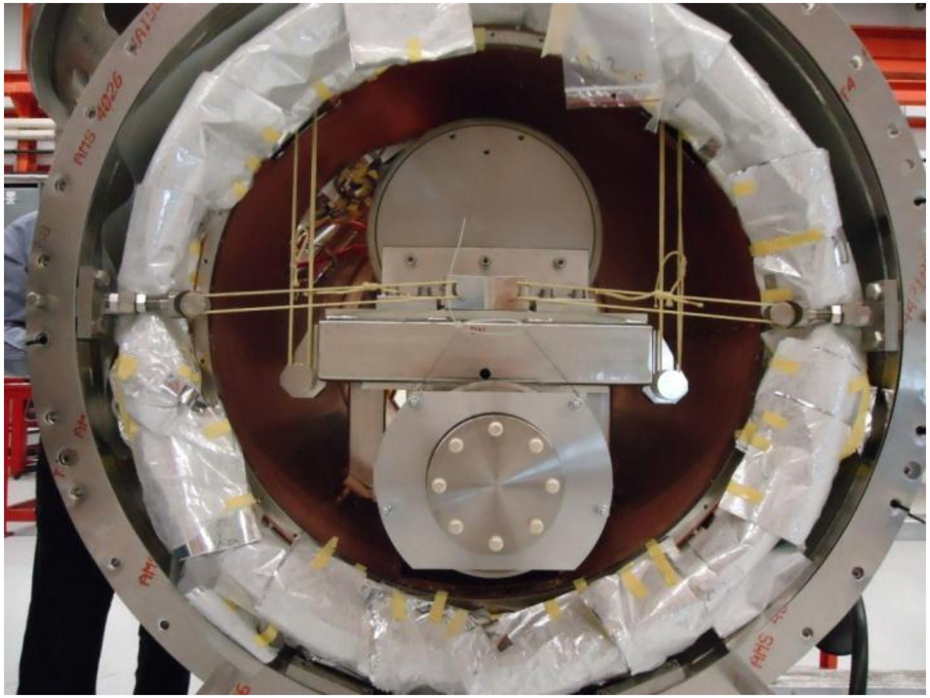
- The vertical position of the suspended cold mass lowered within the cryostat vacuum vessel changed by ~-900 µm and a pitched ~200 µm/m as the cryogenic system cooled to operating temperature. A position change was anticipated due to the cryogenic properties of Kevlar.
- An unanticipated component of 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 ~-300 µm and pitch of ~100µm/m results from the pressure differential across and through the LHe cryogenic neck bellows assembly.

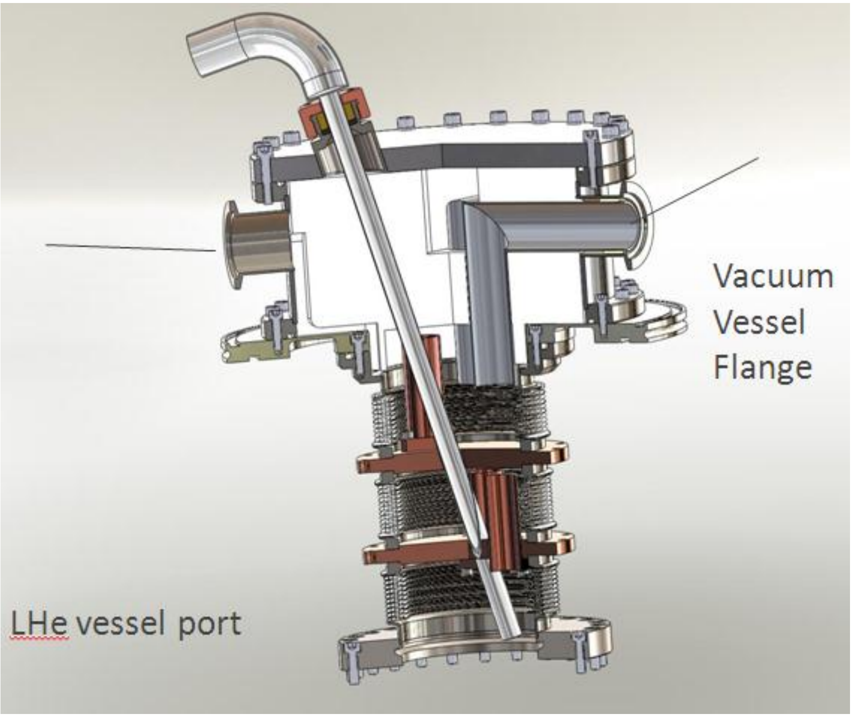
Cold Mass Alignment Components

- Kevlar Cold Mass Supports

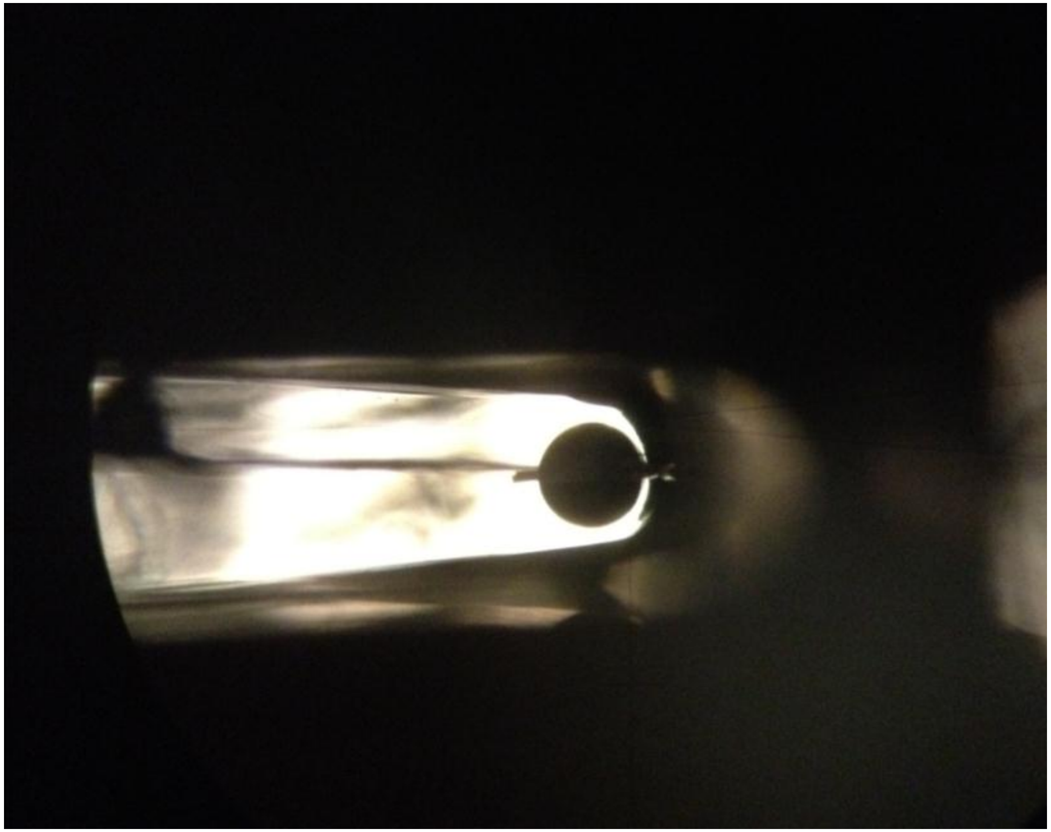
Cold Mass LHe Vessel

Cryogenic Kneck

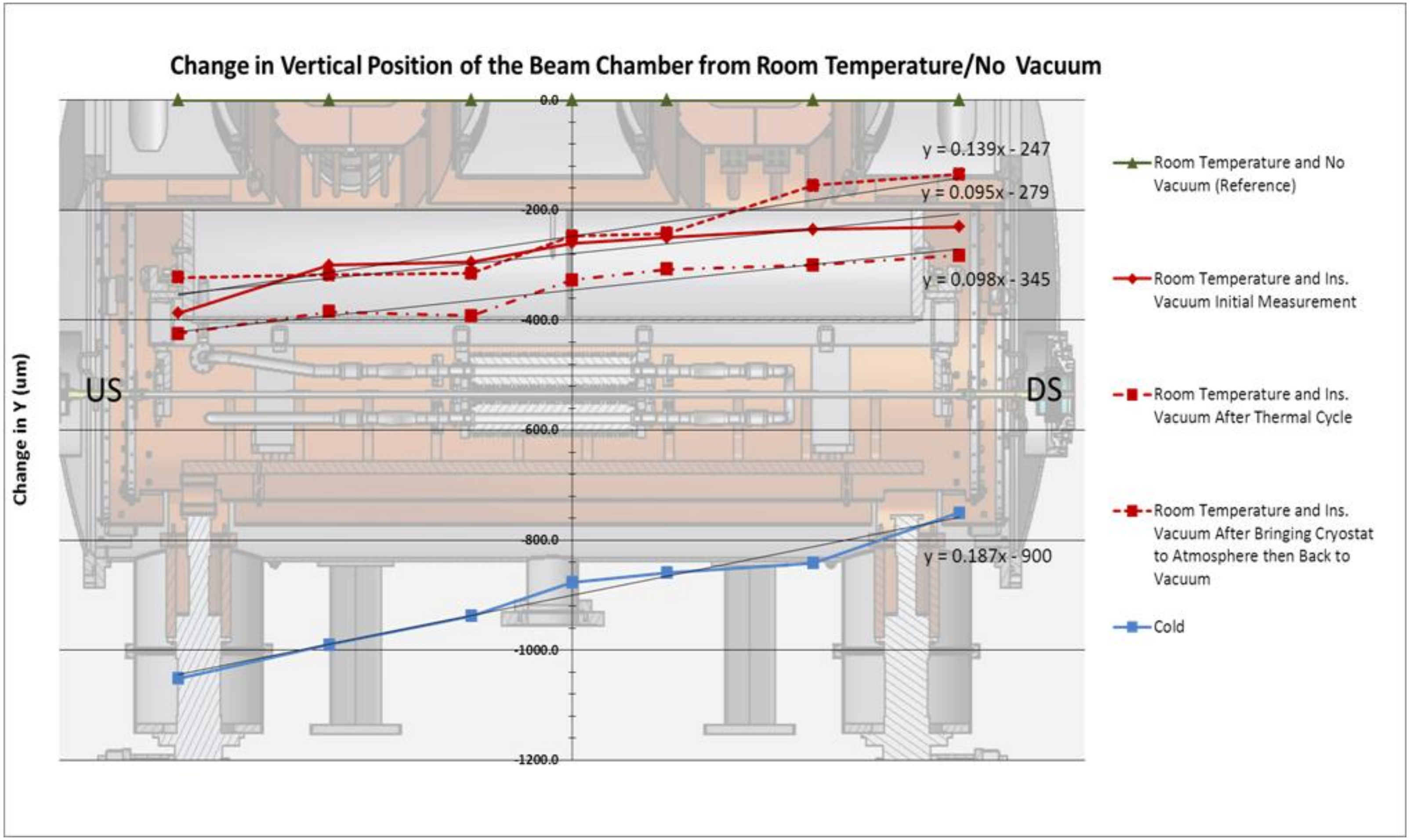




Cold Mass Alignment Measurement



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, SCU0, has been built at the APS.

SU0 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