BNL MAGNET TEST FACILITY

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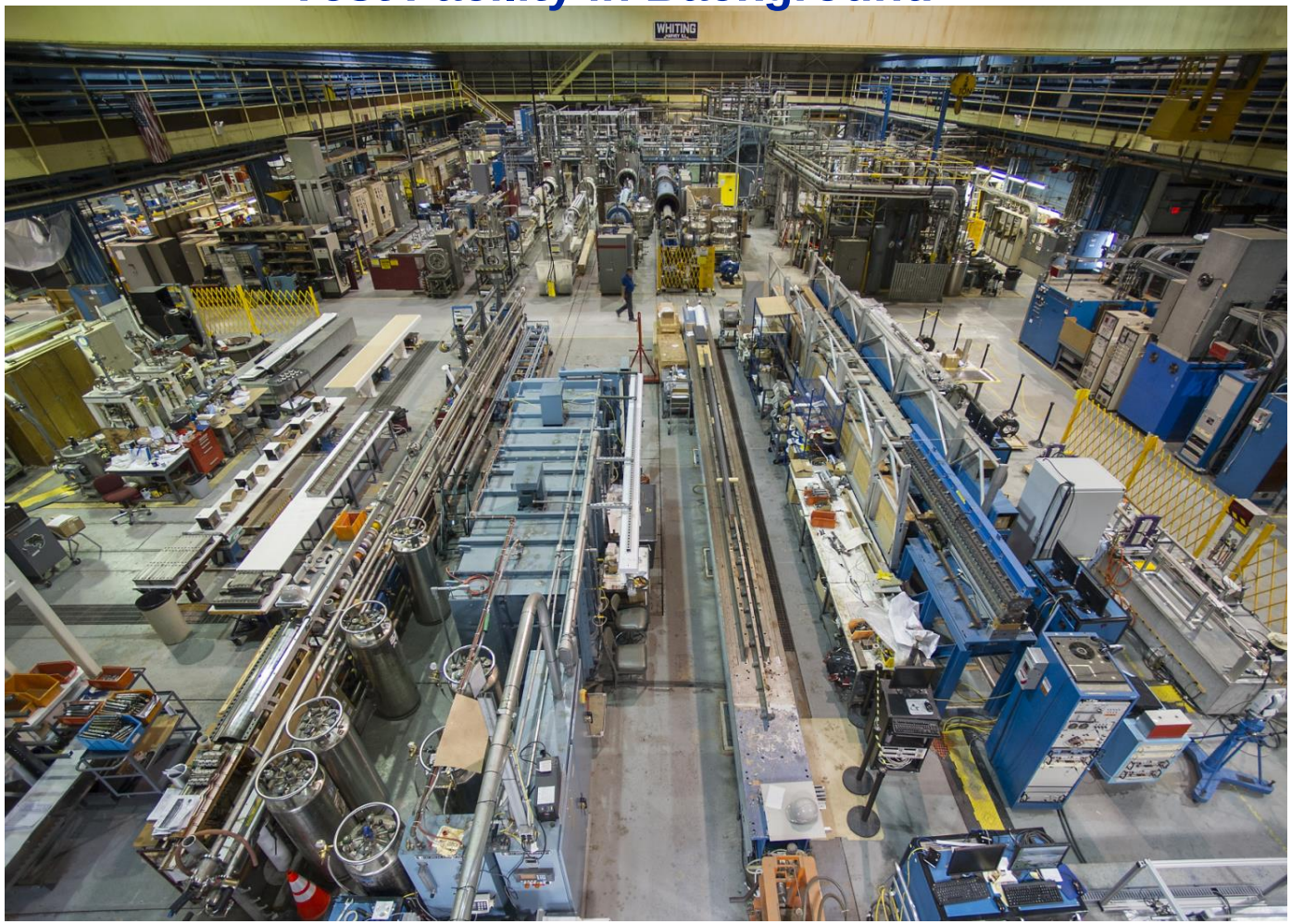
BNL MAGNET TEST FACILITY

1. Cryogenics Facility
2. Power Supplies and Upgrade for MQXF Tests
3. Redesigned Vertical Test Dewar for 1.8 K Magnet Tests
4. Data Acquisition
5. Quench Protection
6. Magnetic Field Measurements

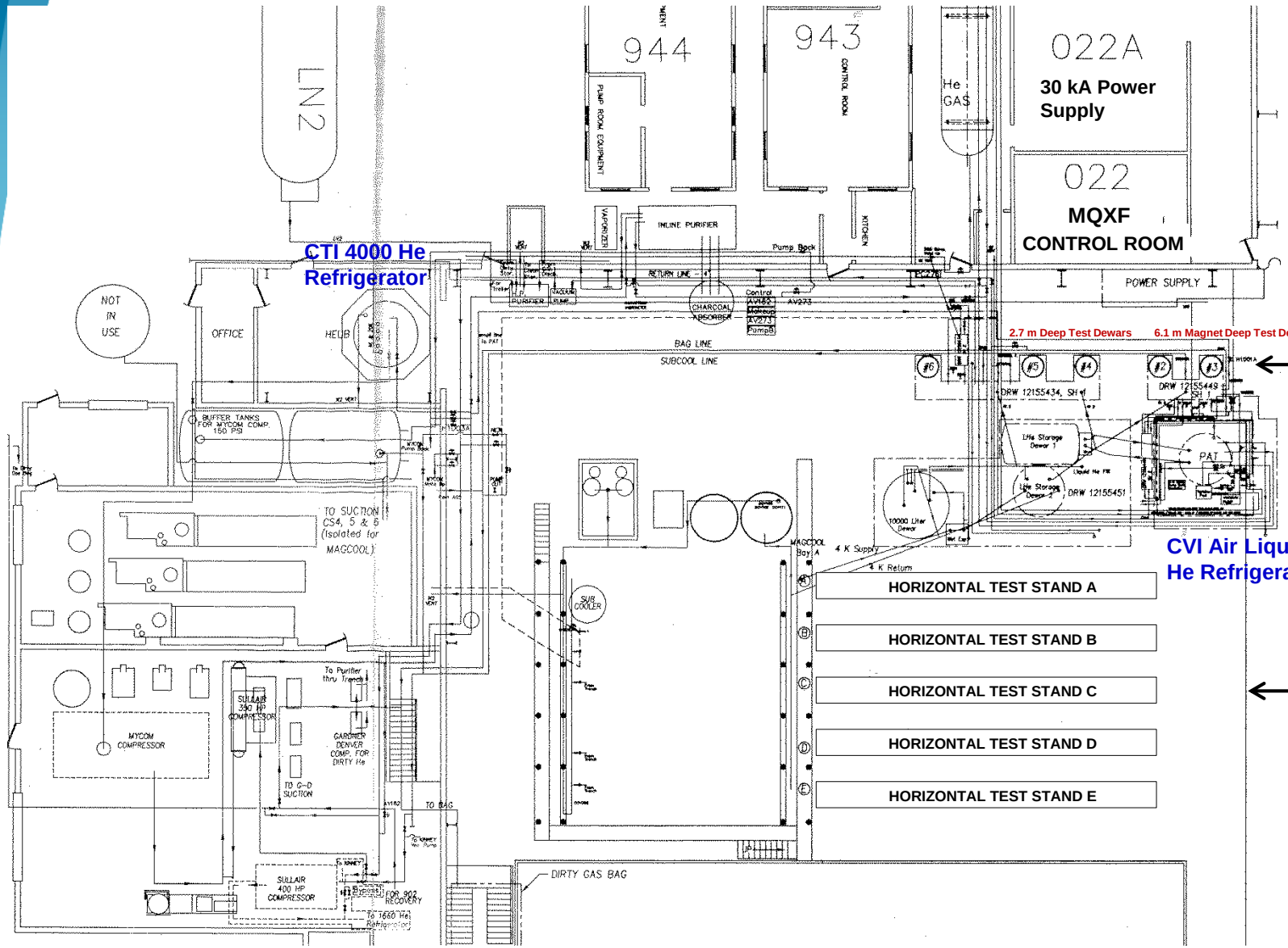
BNL MAGNET TEST FACILITY

BNL Facility North (High) Bay Area (30 t crane)

Test Facility in Background



BNL MAGNET TEST FACILITY



TEST FACILITY UPGRADES FOR MQXF

SUMMARY

• The former cable test 30 kA power supply (2 x 15 kA) reconfigured to test magnets to 24 kA (2 x 12 kA) with new IGBT switch and energy extraction circuits.

• 1.8 K vertical magnet test dewar (4.2 m useful depth) with new 24 kA top plate, newly designed LHe vessel, 4.5 K heat shield, lambda plate, heat exchanger, and 24 kA water-cooled cables

• Diagnostic and monitoring instrumentation with PLC for CTI Model 4000 refrigerator (main liquefier) and CVI refrigerator (backup liquefier), along with hardware upgrades.

• New data acquisition, monitoring, and control software (NI LabVIEW)

• Upgraded data acquisition loggers and scanners for speed and precision

• Added new backup compressors

• New dirty gas compressor and purifier

• Other upgrades

BNL CRYOGENICS FACILITY

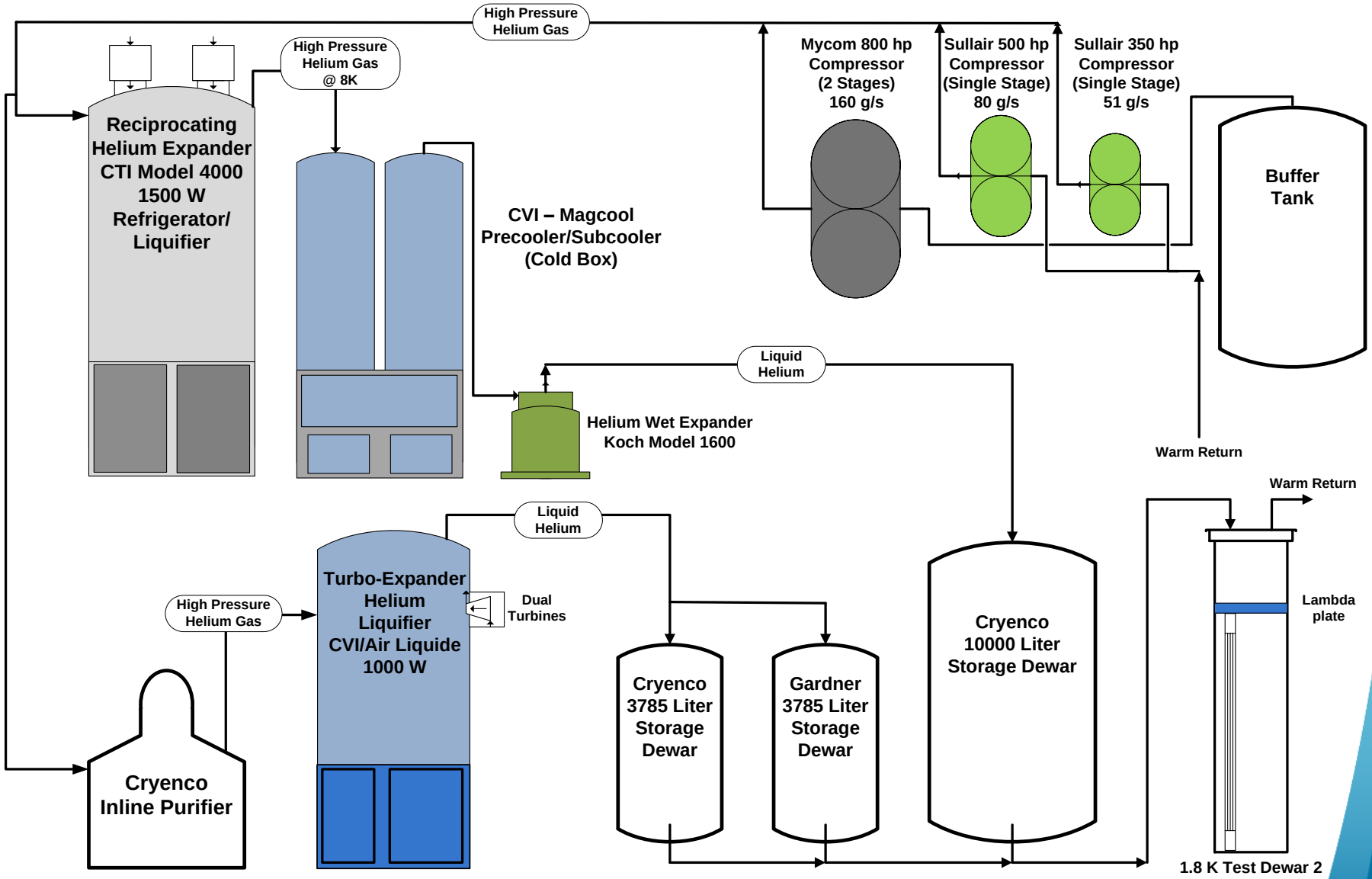
CRYO CHALLENGES

- BNL Magnet Division has a large infrastructure of cryogenic test equipment, but:
  - The cryogenic test facility has been operational and in use since the 1970's, supporting SSC, RHIC, LHC, etc.
  - Despite repairs as needed, equipment reliability decreases with age.

    → BNL management supported funding the purchase of critical spares, preventive maintenance of critical components, and installation of backup systems to improve reliability and reduce risk for the Hi-Lumi production magnet testing program (RISK MITIGATION).

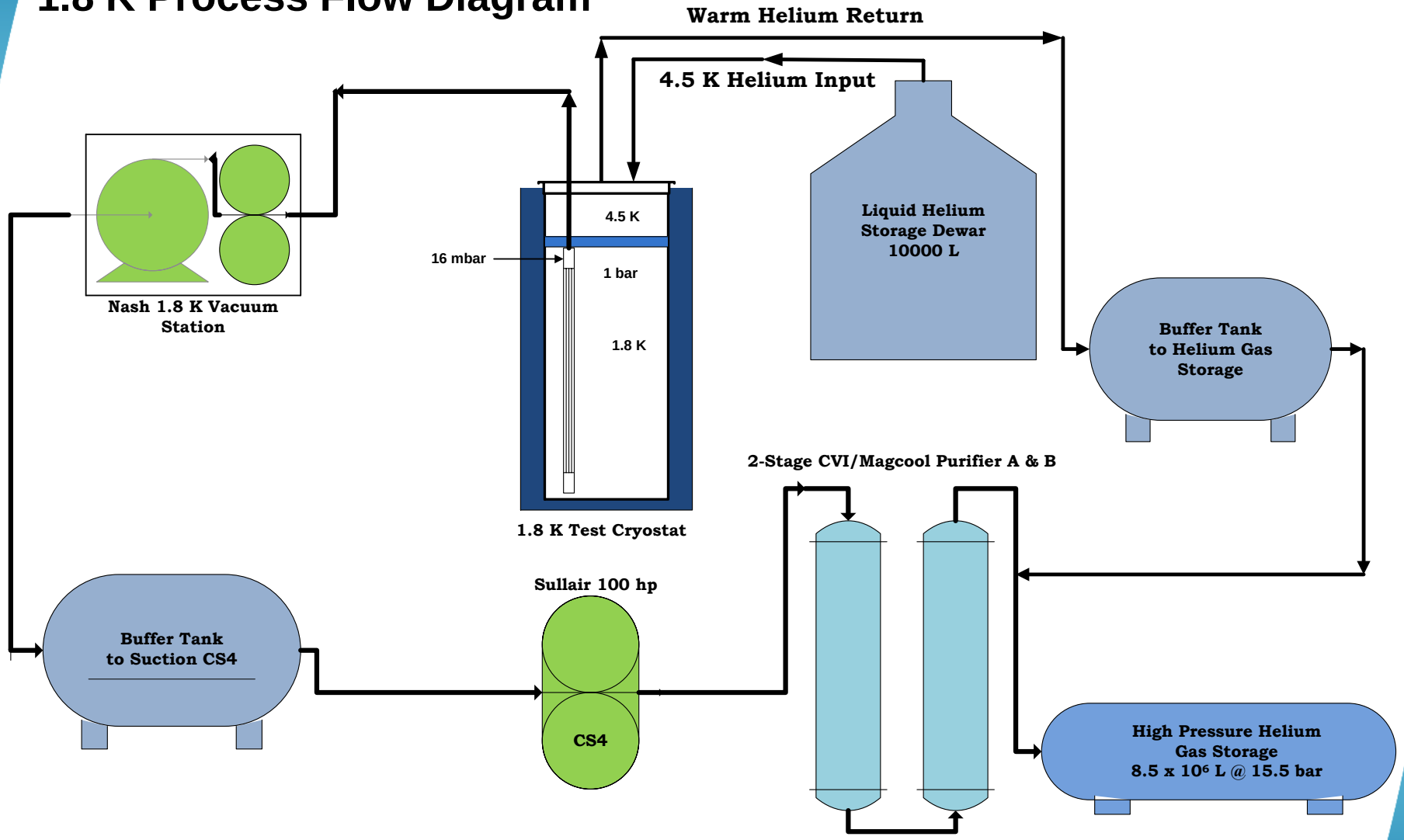
- Previous 1.8 K testing was limited to superconducting cable samples (some years ago), not magnets.

BNL VERTICAL CRYOGENICS FACILITY



BNL VERTICAL CRYOGENICS FACILITY

1.8 K Process Flow Diagram



As proposed: Using existing infrastructure for the new 1.8 K Testing Facility

BNL CRYOGENICS FACILITY

CTI MODEL 4000
REFRIGERATOR/LIQUEFIER
Primary source of liquefaction
1500 W at 4.5K

Two reciprocating expansion engines rated at 250 rpm

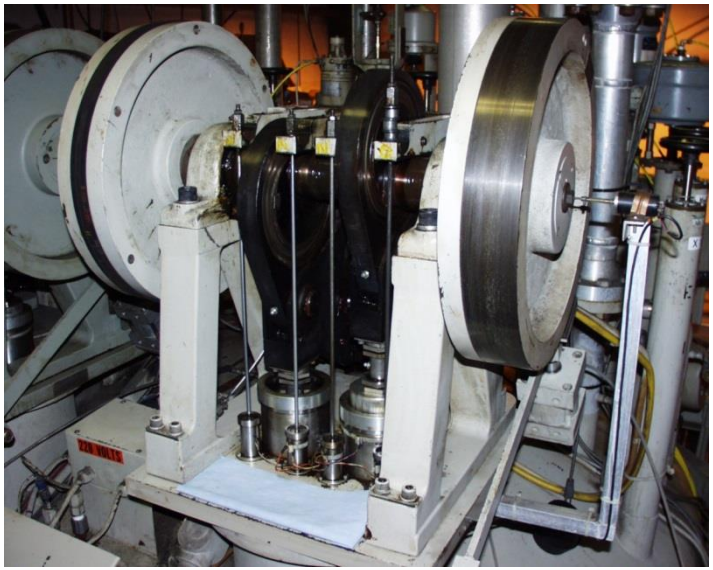
70 g/s (**150g/s** with Creare circulator cold pump) forced flow capacity at 5 - 12 atm in HTF-Magcool

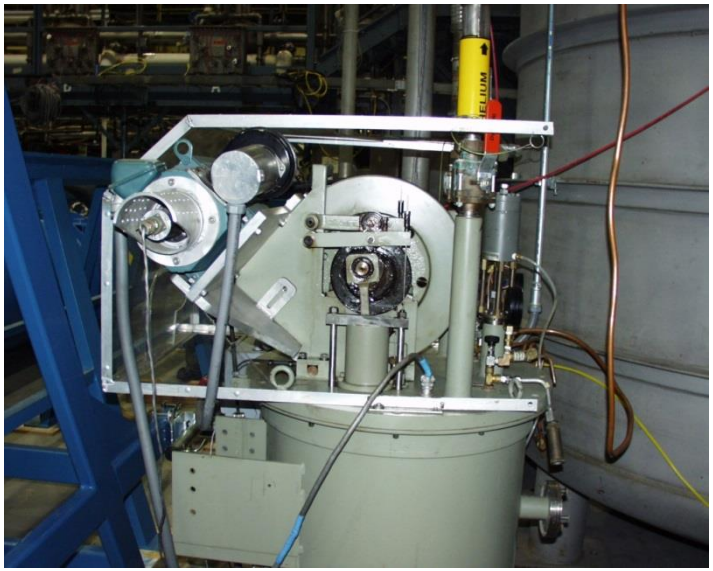
He liquefaction: 320 L/hr (with both expansion engines and a Koch Model 1600 Wet Expander running)

Recently upgraded with a new LN_2 heat exchanger, doubling the number of inline purifiers to four, rebuilt expansion engines, and new diagnostic and control software (LabVIEW).

This work was funded by BNL.

BNL CRYOGENICS FACILITY





CTI Model 4000 Refrigerator
Reciprocating Expansion Engines

250 rpm

Each has two cylinders: 9.1 cm bore; 7.6 cm stroke

Largest in world (we think)

Recently rebuilt.

Koch Model 1600 Wet Expander

Has two cylinders

60 rpm

7.6 cm bore; 5.1 cm stroke

Largest in world (we think)

Recently rebuilt

This work was funded by BNL.

BNL CRYOGENICS FACILITY

CVI – AIR LIQUIDE He LIQUIFIER
Secondary source of liquefaction
1000 W at 4.5K (used at 700 W)

Two turbine expanders rated at 130000 rpm
In-line gas purifier

He liquefaction: 160 L/hr
Total facility LHe rate (both liquefiers): 480 L/hr

Recently upgraded for use as a back-up to mitigate risk in the event of CTI Model 4000 failure:

1) New first stage LN_2 – He heat exchanger
2) New chilled water heat exchanger
3) New and upgraded relief and isolation valves
4) Re-plumbing and new piping to increase efficiency
5) New and refurbished vacuum pumps
6) New instrumentation (including temp sensors and PLC controls) for turbine protection

This work was funded by BNL.

BNL CRYOGENICS FACILITY

COMPRESSORS (Pt 1)

Mycomm 800 (2-Stage)
PRIMARY UNIT

Power = 597 kW
Discharge pressure = 18 bar
Delivers 160 g/s
Purchased critical spares (BNL funded):
New 2nd stage compressor head
New 400 hp motor
New oil heat exchanger
New helium heat exchanger
All maintenance & refurbishment items completed

Can supply either the CTI Model 4000 refrigerator/liquifier and Magcool, or the CVI liquifier

Mycomm and Sullair 350 compressors

Sullair 500

Power = 373 kW
Discharge pressure = 18 bar
Delivers 80 g/s
Provided and installed by BNL funding.

All-purpose; recently installed & can be configured to work with Sullair 350 as a **backup** in the event Mycomm down.

Sullair 500 compressor

Sullair 350

Power = 261 kW
Discharge pressure = 18 bar
Delivers 51 g/s
Purchased critical spares (BNL funded):
new compressor screw
new oil pump

All-purpose; presently configured to work with Mycomm to provide 210 g/s delivery. Can also be used with Sullair 500 as a **backup** in the event that Mycomm is down. (Risk Mitigation)

BNL CRYOGENICS FACILITY

COMPRESSORS (Pt 2)

Gardner Denver 60

Power = 44.7 kW
Discharge pressure = 17 bar
Delivers 213 m^3/hr → 9.65 g/s
New Gardner Denver compressor purchased with BNL funding.

Pumps 'dirty' He gas to dirty gas bag and gas recovery tank.

Sullair 100 (3 units: CS4, CS5, CS6)

Power = 74.6 kW
Discharge pressure = 12 bar = 1.2 MPa
Delivers 20 g/s (80 g/s @ 8 bar input)
New Sullair 100 compressor purchased with BNL funding.

Presently, only CS4 (new unit) being used, for pumping Nash 1.9 K station outlet to high pressure gas storage tanks. All three are used for horizontal testing (Magcool facility).

Linde Model 500A He Gas Purifier

with dedicated compressor
All new system and commissioning contract purchased with BNL funding.

Cleans and recovers 'dirty' gas.

Creare circulator pumps

Presently configured for Magcool operations:
(1) Nitrogen cooldown (Cooldown I)
(2) Warmup
(3) Pump and purge

BNL CRYOGENICS FACILITY

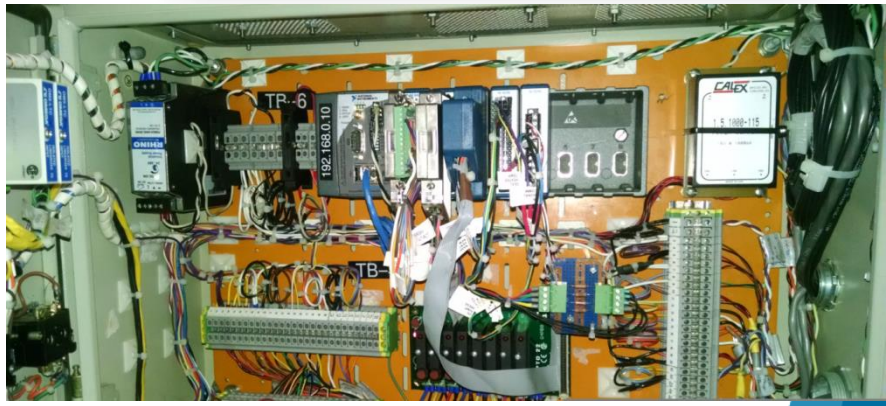
Nash-Kinema Vacuum Pump

Power = Two stages at 74.6 kW each
Suction pressure = 0.0837 bar @ 4.5 K
Discharge pressure = 1.2 bar
Delivers 2.7 g/s @ 1.8 K
Cooling capacity = 40 W @ 1.8 K

Pumps on LHe in heat exchanger - down to 16 mbar for 1.8 K operation.

Upgrades included:

1. Reconfigured exhaust. Connected helium exhaust gas line to new Sullair 100 compressor and inline purifier, to reclaim helium gas (was previously routed to dirty gas facility).
2. Replaced legacy soldered copper water lines with welded stainless steel.
3. Purchased new spare booster and liquid ring vacuum pumps.
4. Refurbished existing / purchased new spare chilled water heat exchangers (BNL funded).
5. Replaced drive belts.
6. Repaired service air supply line.
7. New LabVIEW controls with remote HMI panel.
8. Installed new vacuum jacketed transfer line, valve to test dewar.



BNL CRYOGENICS FACILITY

- **LIQUID HELIUM STORAGE DEWARS**
  - Storage Dewar #1 3785 L
  - Storage Dewar #2 3785 L
  - Storage Dewar #3 10000 L
    - **Total liquid helium storage capacity is 17570 L.**

- Total He gas storage capacity is approximately 8.5×10^6 L.
- Liquid nitrogen storage capacity is approximately 40000 L.

BNL CRYOGENICS FACILITY

VERTICAL TEST DEWARS

DEWAR #	DEPTH m	WIDTH cm	VOLUME L
2	6.1	60.96	1779
3	6.1	71.12	2422
4	2.68	60.96	753
5	2.74	60.96	801
6	2.68	60.96	786

Present Configurations:

Dewars 2 and 3: for longer magnets (4.2m)

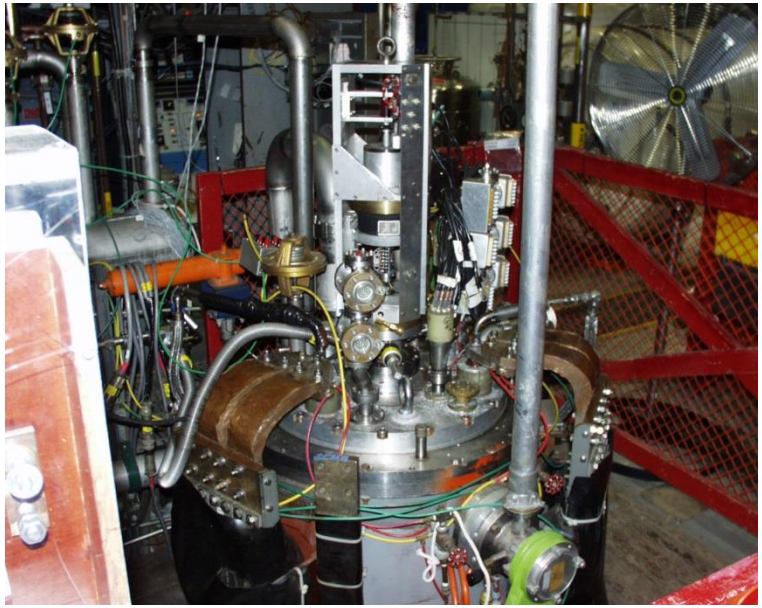
Dewar 2 (610mm): now updated and configured for 1.8 K/1 bar operation with lambda plate, new 24 kA leads and water-cooled cabling, and hanging fixture

Dewar 3: wider (711 mm) for larger magnets 4.5K

Dewar 4: 4.5K cable testing

Dewar 5: 1.8K/1 bar cable testing

Dewar 6: common coil type magnets (Nb_3Sn and HTF) and other short magnets (2m); cable testing



PRIMARY POWER SUPPLIES

(1) 30kA (2 x 15 kA) @ 14VDC Previously cable testing, now configured 24 kA (2 x 12 kA) MQXF operation at 1.8 K

(2) 10kA @ 20VDC "HTF", 10VDC, 30VDC, 40VDC, 50VDC)

(3) 8.5kA (9.2kA) @15VDC "VTF", 30VDC

(4) 8kA @ 12VDC "Short sample test facility magnets"

(5) 10kA @10VDC bipolar

(6) 7.5kA @ 25VDC "Fast Ramp", 50VDC, 100VDC (GSI ramp rates to 7800 A/s)

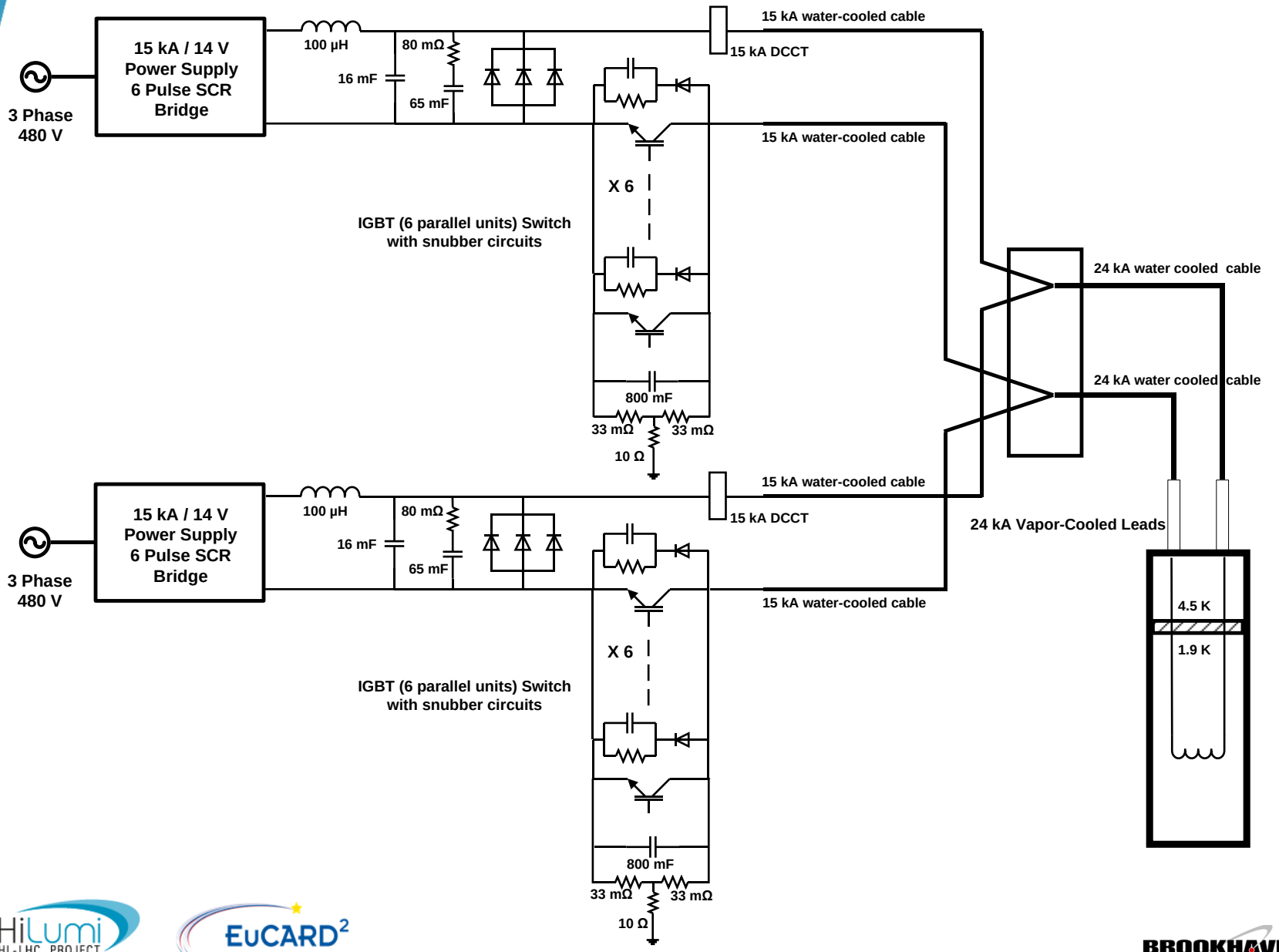
(7) Dual Acme 5500A @ 125V "Room temperature field measurements and calibration magnets for measuring coils"

(8) Variety of trim power supplies (bipolar and unipolar)

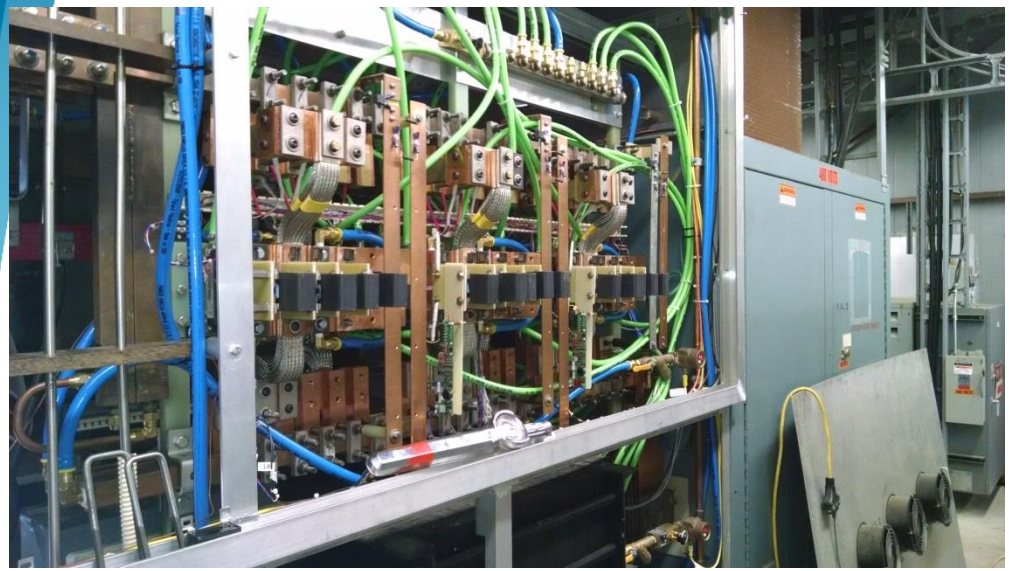
All power supplies can be configured for a wide range of magnet tests.

Energy extraction is available with

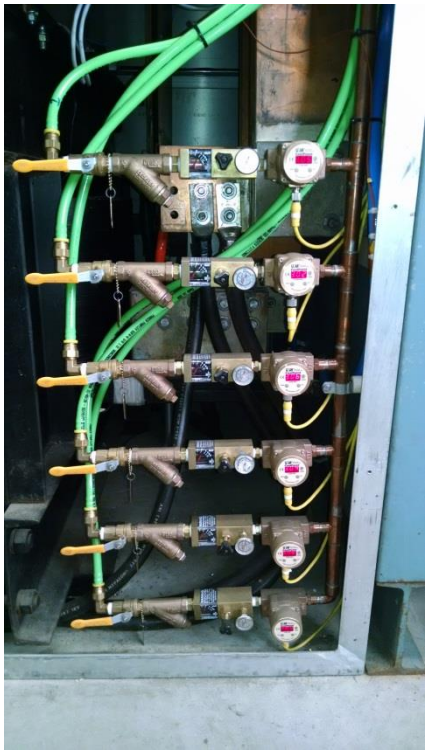
30 kA POWER SUPPLY UPGRADE



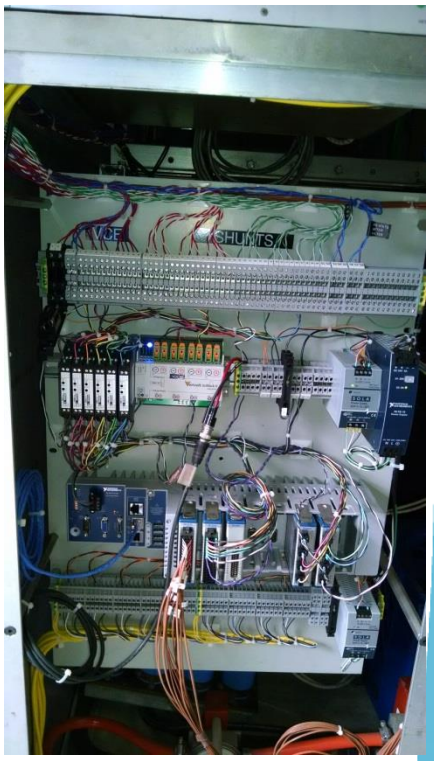
30 kA POWER SUPPLY UPGRADE



15 kA power supply switch cabinet with IGBT and snubber circuits. Each power supply is configured for 12 kA with 6 water-cooled IGBT and snubber circuits, allowing 24 kA magnet operation.



Plumbing and flow gauges with signal acquisition for IGBT water cooling and monitoring.



IGBT data acquisition and instrumentation panel

Existing three water-cooled free-wheeling diodes in parallel.

NEW: Upgrades to previous cable sample 30 kA power supply (two 15 kA in parallel) to operate magnets to 24 kA.

30 kA POWER SUPPLY UPGRADE

Power Supply Energy Extraction Switch

- **24 kA IGBT-based Energy Extraction Switch:**
  - Switch consists of 2 modules, each with six high power IGBTs in parallel. (One module of 6 for each 15 kA power supply.)
  - **IGBT rated to 3600 A per unit & at least 1200 V C-E voltage.**
  - **IGBT current & C-E voltage will be limited 2000 A and 840 V.**
  - Stray and mutual inductances in the power supply circuit generated much higher switching transients than expected.
  - So each IGBT has been equipped with a snubber circuit designed to limit high voltage switching transients to 600 V.
  - 40 channel IGBT Switch data monitoring and logging system for each module: Lab View program debugged and tested.

IGBT
Rated collector current = 3600 A
Max operating current = 2000 A
Max C-E voltage per IGBT = 840 V
(These values are with 66 mΩ dump resistor.)

Energy Extraction
66 mΩ center tapped to ground
Stainless Steel
1 MJ energy absorption rating

Existing all stainless steel 66 mΩ dump resistors will be replaced by new high power ceramic 66 mΩ 10 MJ resistors for MQXF tests.

- **24 kA water-cooled cables**: Finished DI water cooling circuit, installed drain outlet, and verified flow (>68 L/min) and pressure drop. **15 kA water-cooled cables** flow is 30 L/min.

1.8 K TEST DEWAR ASSEMBLY

New Top Plate

New top plate to accommodate lambda plate and fixturing for MQXF 4.2 m quads and 24 kA vapor-cooled leads and heat exchanger for 1.8 K operation.

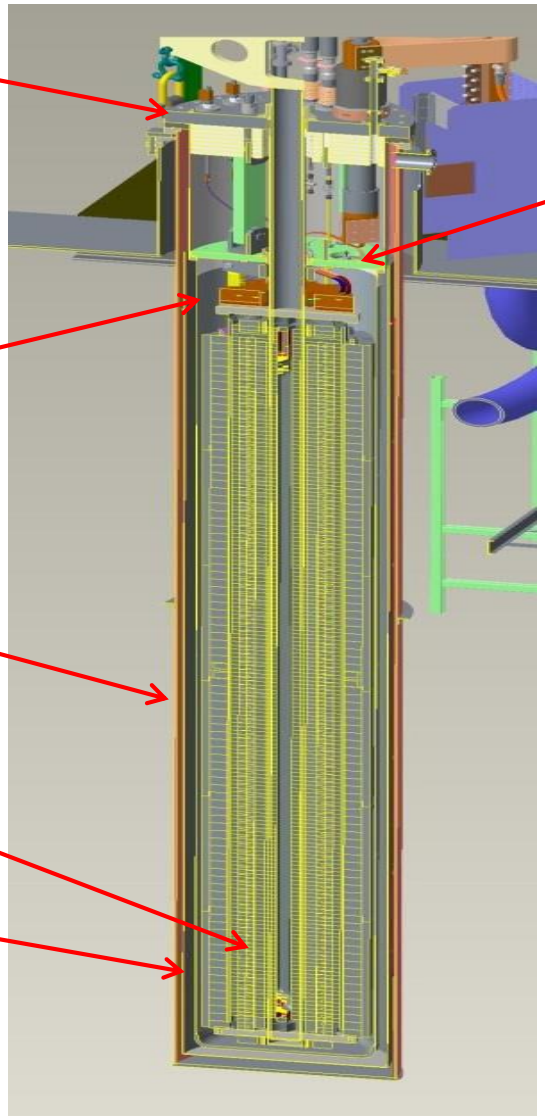
Redesigned Inner He Vessel

Rated at 5.86 bar

Existing Outer Dewar

MQXF Magnet

4.5 K Heat Shield



Lambda Plate

Top is 38.1 mm thick G10 (lower heat load)

Bottom is 19.05 mm thick 304 stainless steel (for added strength and sealing to He vessel interior flange)

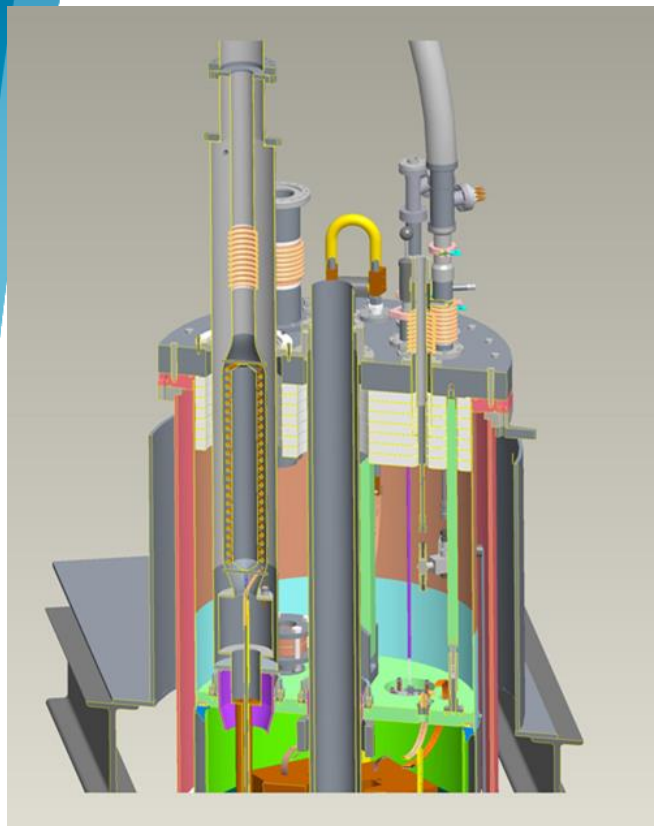
Bonded together with Stycast 2850FT

Total heat load < 1.4 W

Components below lambda plate and internal to heat exchanger are designed for 5.86 bar, above lambda plate for 3.45 bar.

1.8 K TEST DEWAR ASSEMBLY

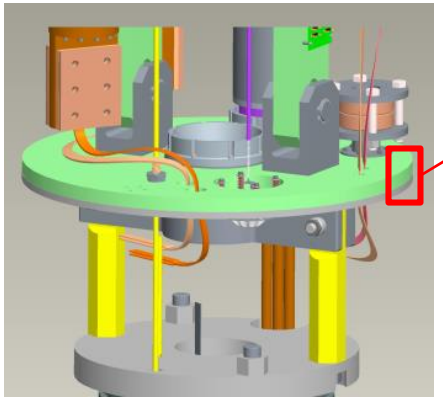
Test Dewar Overview

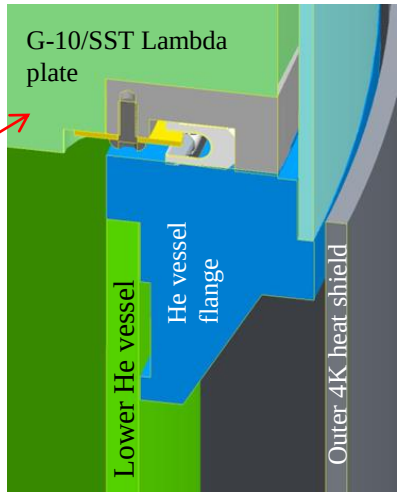


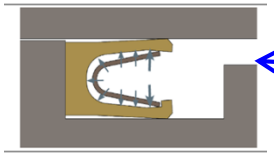
Upper dewar assembly:

- Vent *and* burst disc in lambda plate (for Safety Committee approval)
- Gravity seal at lambda plate

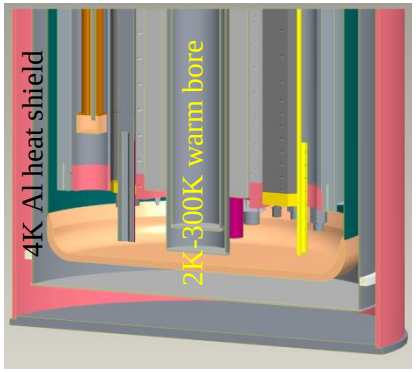
Lambda plate sealing detail





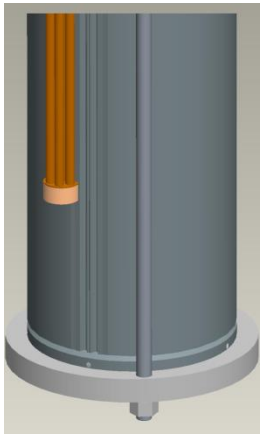


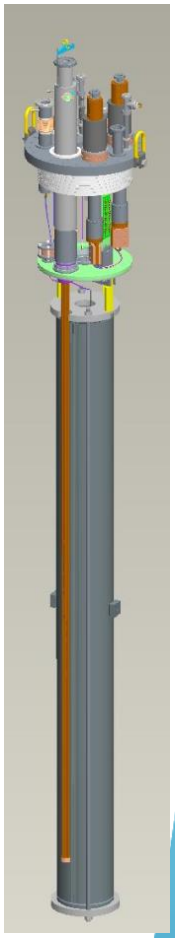
Lambda Plate Spring-Energized Face Seal to He Vessel



+200 mm extended helium dewar bottom

Heat exchanger in magnet helium passage (left) and outside Mirror O.D. (right)





Overall hanging assembly, or insert (mirror shown)

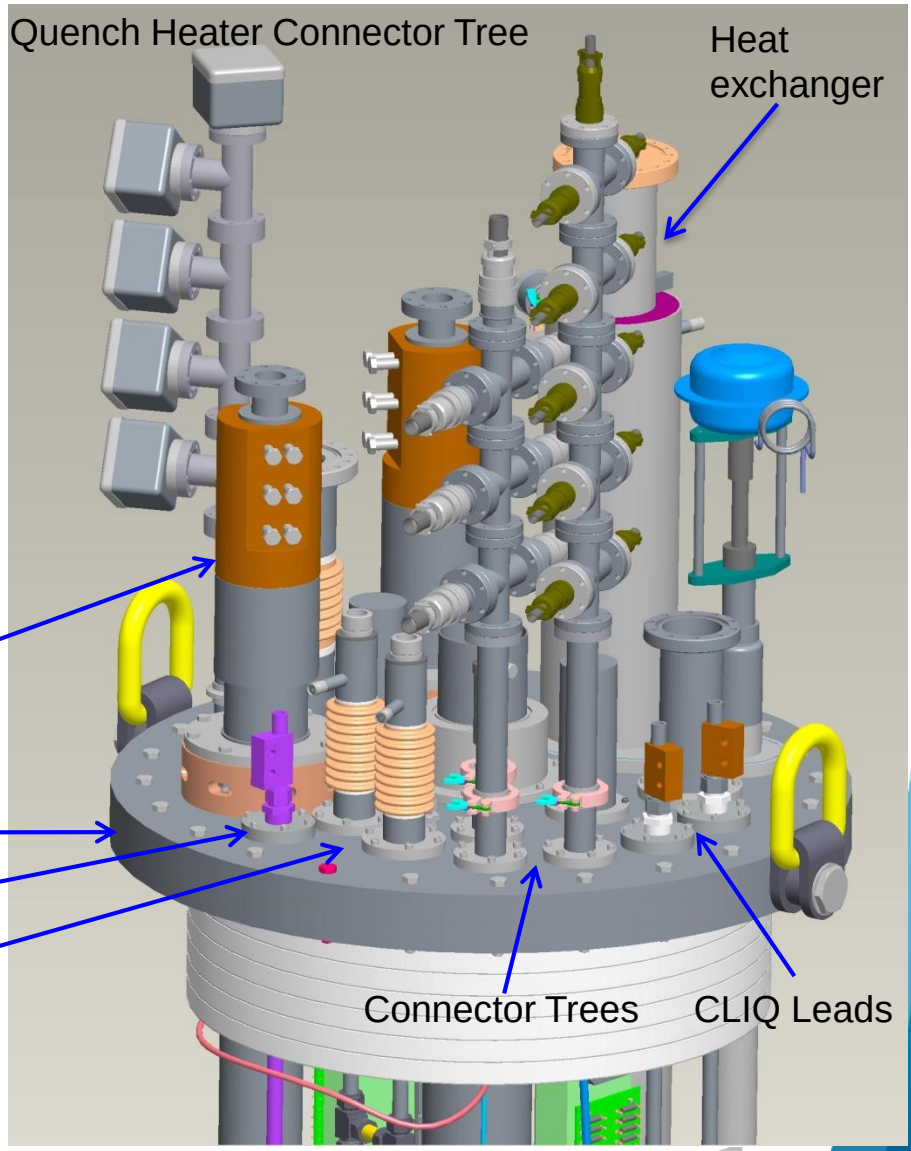
Serviced by 30 t crane with 6.79 m hook clearance height above dewar flange.

1.8 K TEST DEWAR ASSEMBLY

1.8 K Top Plate Details

- (2) 24 kA main coil vapor-cooled leads
- (2) 1 kA CLIQ vapor-cooled leads; port for 3rd lead provided
- (3) instrumentation wiring ports
- (2) helium fill lines

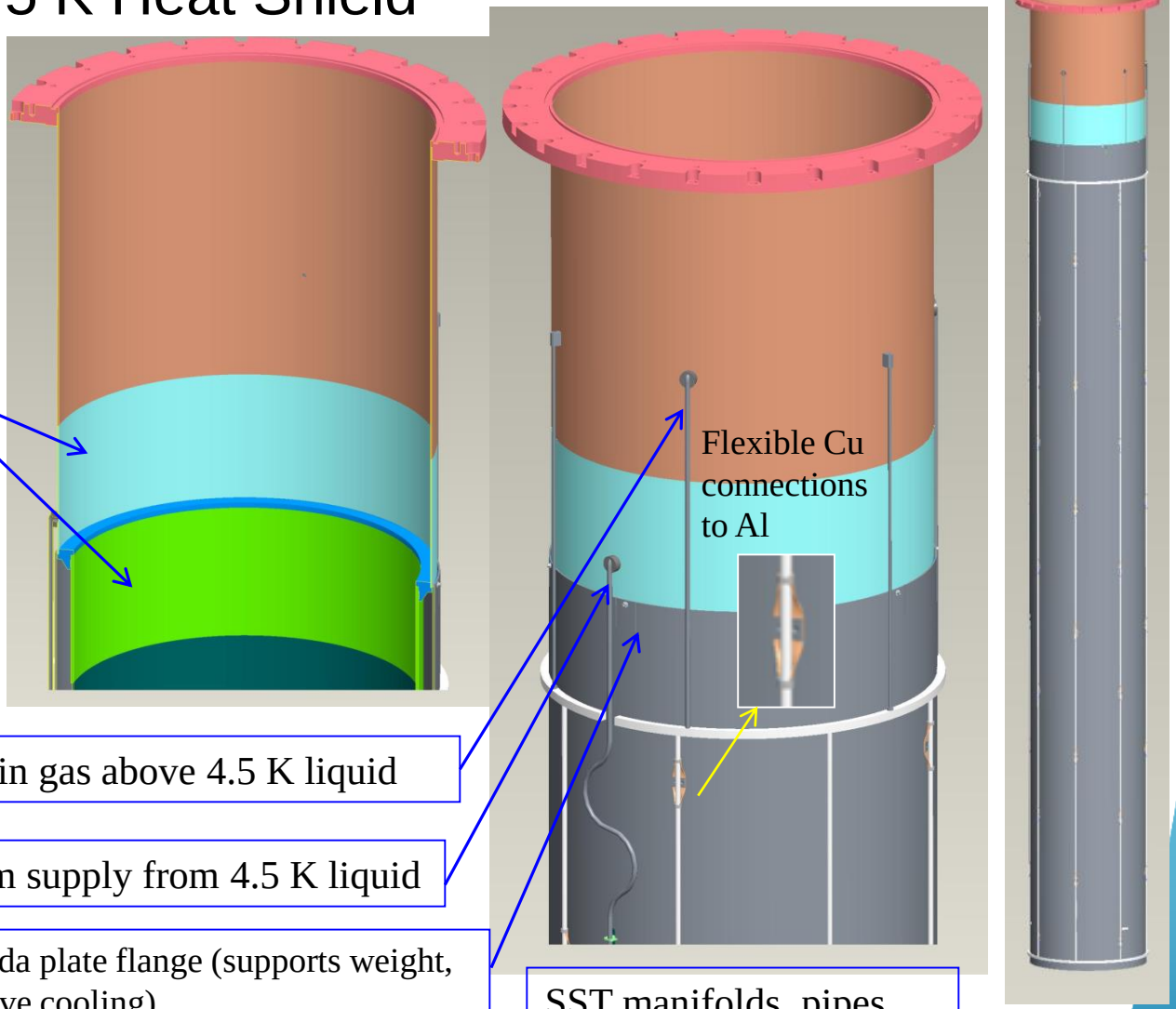
- Heat exchanger ports, manifolds and solenoid valves under plate
- Warm bore port
- Helium vent port



1.8 K TEST DEWAR ASSEMBLY

4.5 K Heat Shield

"blue/green" sections of helium vessel and lambda plate flange welded as a subassembly to permit precise, flat machined surface of lambda plate flange after welding (also locally thicker sections to accommodate bending stresses)



Helium return in gas above 4.5 K liquid

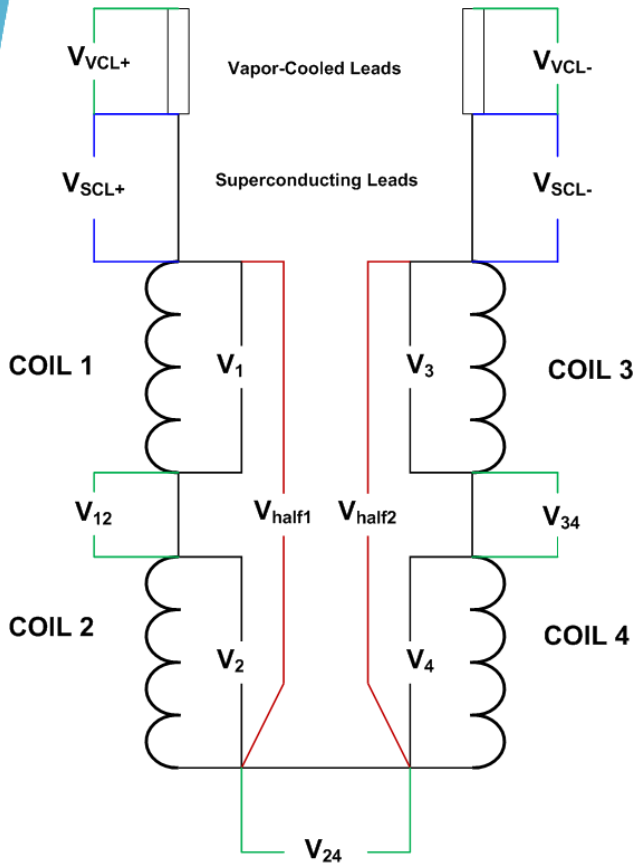
Helium supply from 4.5 K liquid

Heat shield is bolted to outside of lambda plate flange (supports weight, provides conductive cooling)

SST manifolds, pipes

QUENCH PROTECTION

QUENCH DETECTION



The quench detection system is based on a redundant scheme which relies on a number of voltage signals. When any one of the following signals reaches its specified *threshold voltage* after a specified *validation time*, a fast discharge is instigated (current decays through dump resistor). Typical threshold voltages and validation times are listed here.

1)	Half coil voltage V_{half1} - V_{half2}	50-100 mV	10 ms
2)	Quarter coil voltage $V_1 – V_2$	50-100 mV	10 ms
3)	Quarter coil voltage $V_3 – V_4$	50-100 mV	10 ms
4)	Total coil voltage V_{total}	50-100 mV	10 ms
5)	SC lead voltages V_{SCL+} and V_{SCL-}	10-50 mV	5 ms
6)	Splice voltages V_{12}, V_{34}, V_{24}	8-10 mV	5 ms
7)	Current Derivative $V_{total} – L\ dI/dt$	0.1-5 V	10 ms

Note: In Nb_3Sn magnets, current-dependent thresholds as high as several volts at low currents are necessary and are set in the software. This is to avoid false QD trips due to flux jump spikes.

There are also designed into the system a number of interlocks which also rely on various signals which, if they do not meet specified conditions such as *voltage threshold* or *on-off state*, will instigate a slow discharge, with the dump resistor out of the circuit. These include:

1) Vapor-cooled lead voltages 80-100 mV 500-1000 ms
2) Strip heater capacitor bank not charged
3) IGBT switch temperature or voltage too high
4) Others

CONTROL, MONITORING, AND DATA ACQUISITION SOFTWARE

- RECENTLY UPGRADED WITH ALL NEW SOFTWARE
  - POWER SUPPLY CONTROL PROGRAMS (LABVIEW)
  - INSTRUMENTATION CONTROL PROGRAMS (LABVIEW)
  - DATA ANALYSIS PROGRAMS (LABVIEW / DIADEM) include:
    - DATA HANDLING, PLOTTING, AND ANALYSIS
    - MULTIPLE SIGNALS DISPLAYED
    - SIGNAL MANIPULATION
    - WAVEFORM CALCULATOR
    - $\int(I^2\,dt)$ CALCULATION

DATA ACQUISITION SYSTEMS

FAST DATA LOGGER DAQ

National Instruments PXIe-4300 (16 Units)
Number of channels = 8 differential, simultaneous sampling
Analog input = ±10 V, ±5 V, ±2 V, ±1 V
ADC resolution = 16 bit
Sampling rate = 250 kHz max per channel
Time scale resolution = 10 ns
TOTAL CHANNELS = 128 differential, simultaneous sampling
Usage = fixed (main) voltage taps and configurable (auxiliary) voltage taps
Status: Assembled and Tested

128 Channel Fast Logger

SLOW DATA LOGGER DAQ

National Instruments PXI-6289 (4 Units)
Number of channels = 16 differential
Analog input = ±10 V, ±5 V, ±2 V, ±1 V, ±0.5 V, ±0.2 V, ±0.1 V
ADC resolution = 18 bit
Sampling rate = 500 kHz max multichannel (31.25 kHz max)
Time scale resolution = 50 ns
TOTAL CHANNELS = 64 differential
Usage = monitoring of vapor-cooled lead voltages, splice voltages, SC lead voltages, temperatures, LHe levels, and other instrumentation
Status: Assembled and Tested

64 Channel Slow Logger

DATA ACQUISITION SYSTEMS

QUENCH DETECTOR DAQ

National Instruments PXIe-6356 (1 Unit)
Number of channels = 8 differential, simultaneous sampling
Analog input = ±10 V, ±5 V, ±2 V, ±1 V
ADC resolution = 16 bit
Sampling rate = 1.25 MHz max per channel
Time scale resolution = 10 ns
TOTAL CHANNELS = 8 differential, simultaneous sampling
Usage = signals used for quench detection, such as half coil and quarter coil voltage differences, SC lead voltages, etc.
Status: Assembled and Tested

8 Channel Quench Detector

STRAIN GAUGE LOGGER DAQ

Agilent 34970A Data Acquisition/Switching Unit (2 Units)
Number of channels = 60 differential, scanning
ADC resolution = 22 bit max
Scan rate = 250 ch/s max
TOTAL CHANNELS = 120 differential, scanning
Usage = strain gauges

Note: For mirror test, a portable Cytec scanner system will be used. All 64 channels have been assembled and tested.

MAGNETIC FIELD MEASUREMENT

Existing inventory of over 60 ***magnetic field measuring coils***, with variety of lengths and radii:

External drive coils, various radii and lengths, some with warm bore tubes

Moles, 1 m long and smaller, various radii, with electric (warm) or gas-driven (cold) motors

Example: Coils 84 and 86 shown below are external drive coils suited for 8 cm aperture magnets

2 radial dipole bucking windings

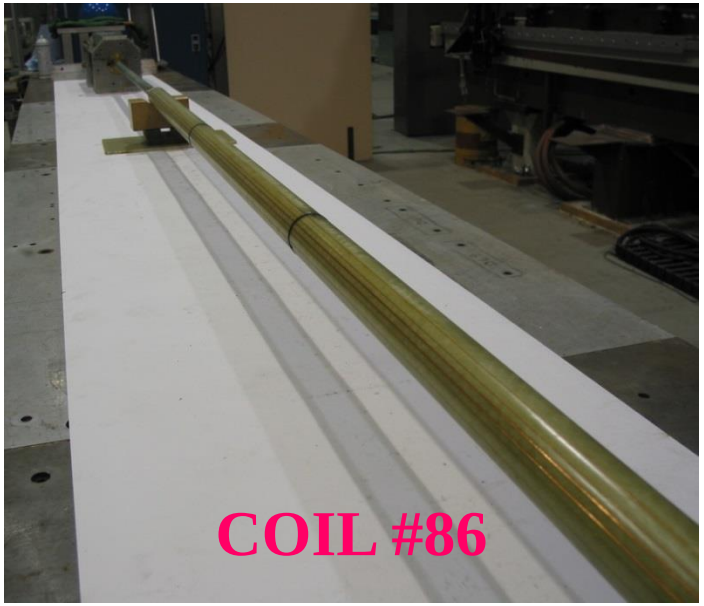
2 radial quadrupole bucking windings

1 tangential winding

digital bucking

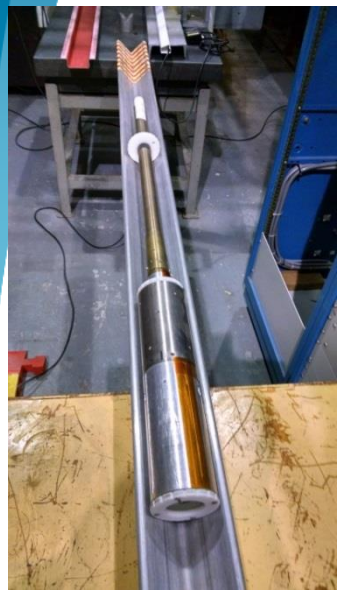
Other devices: Hall probes, fluxgate magnetometers, vibrating wire

Magnetic field measuring probe designed for MQXF will not be needed for the upcoming mirror test but will be available for the testing of the prototypes starting in Feb 2017.



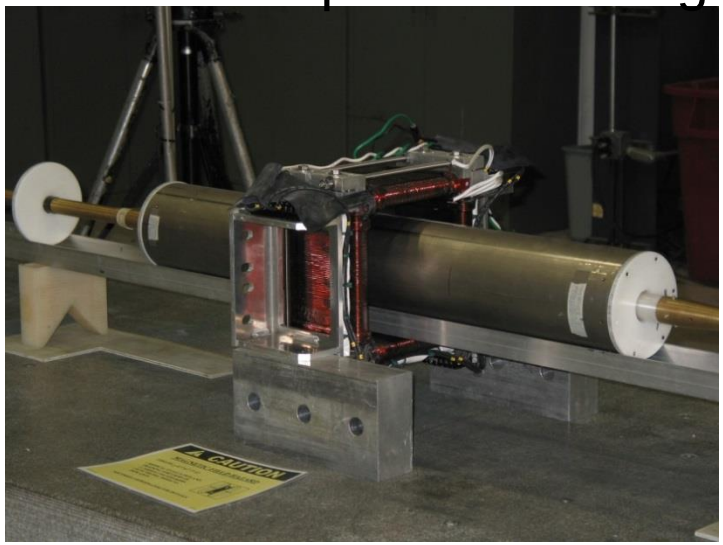
MAGNETIC FIELD MEASUREMENT

More examples of existing measuring coils

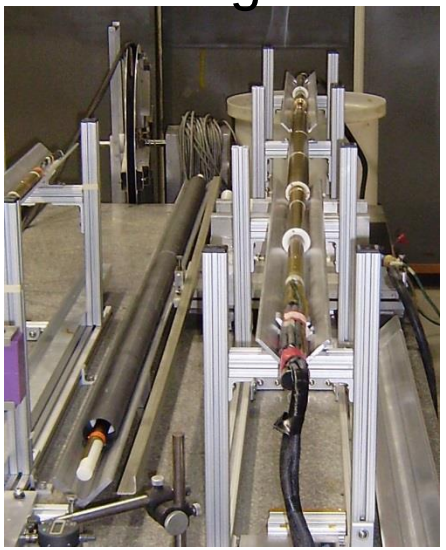


Mole RA-7

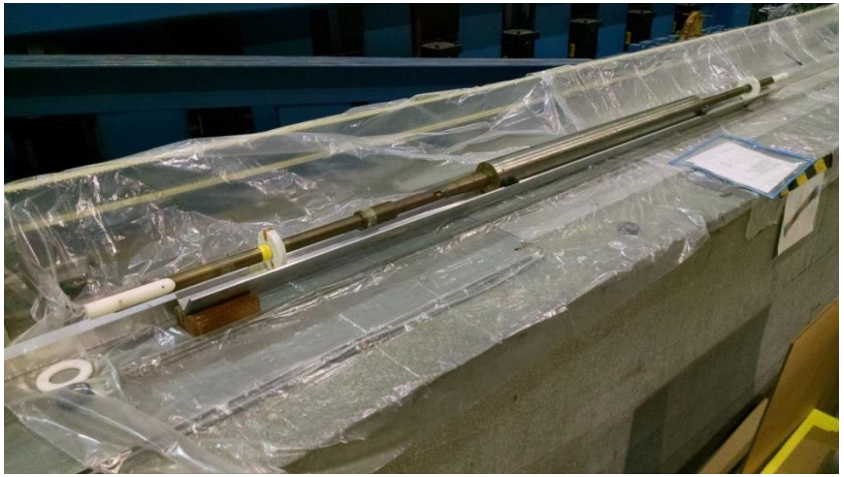
External Drive Coil 76 8 cm



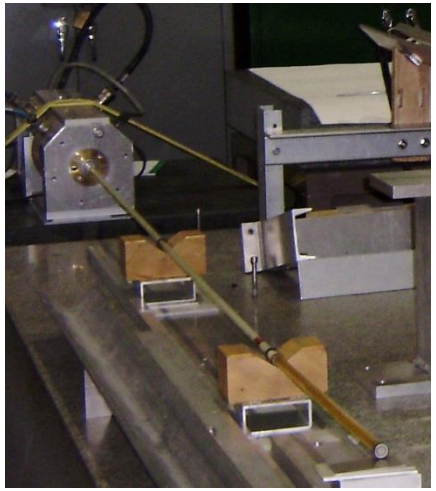
Warm DX Mole in AGS Corrector Magnet



Mole RA-3



D0 Warm Mole 13 cm



Coil 96 2.54 cm

Coil 203 9-Windings 30 cm

SUMMARY

• The cryogenics facility refrigerators, compressors, and other peripheral devices have been refurbished and re-configured to test MQXF quadrupoles at 1.8 K and 1 bar (nom).

• New compressors, purifiers, critical spare parts, and other updates were provided with BNL funding. These items have been purchased to provide backup systems and mitigate risks in the event of equipment failure.

• The Magnet Division 30 kA power supply (formerly used for cable testing) and peripheral systems such as energy extraction and quench heater firing units are being converted to test magnets to 24 kA and at 1.8 kA.

• A completely new and redesigned vertical test facility (in an existing outer vacuum vessel) is being built to accommodate 1.8 K testing of MQXF magnets, with new inner helium vessel, 4 K heat shield, 1.8 K heat exchanger, lambda plate, new top plate with 24 kA Cu leads, and 24 kA water-cooled cables to test dewar.

• The old data acquisition systems have been replaced by completely modernized and improved NI hardware and LabVIEW-based software.

•The updated and reconfigured 1.8 K vertical test facility commissioning will be done with a short sample of Nb3Sn cable instrumented with taps and a spot heater. The mirror magnet will be present on the hanging fixture but not connected to the power leads until the cable test has been successfully completed.

• Magnetic field measuring probe, spike detector system, and quench antenna data acquisition system are yet to be built, but will not be needed for the upcoming mirror magnet test.

SUMMARY

• Cryogenics refrigerators, compressors, and other peripheral devices can be configured to provide for a variety of testing scenarios, including forced flow supercritical He or liquid He testing, and testing down to 1.8 K.

• Magnet Division power supplies cover a wide range of testing applications for loads of various inductances and resistances, current and voltage levels, current ramp rates, and quench protection requirements.

• Data acquisition systems are designed for flexibility to accommodate many magnet and instrumentation configurations.

• There is a large inventory of magnetic field measuring coils of different sizes and design for a wide variety of applications.

• Further upgrades of facility systems are in progress.

THANK YOU FOR YOUR ATTENTION

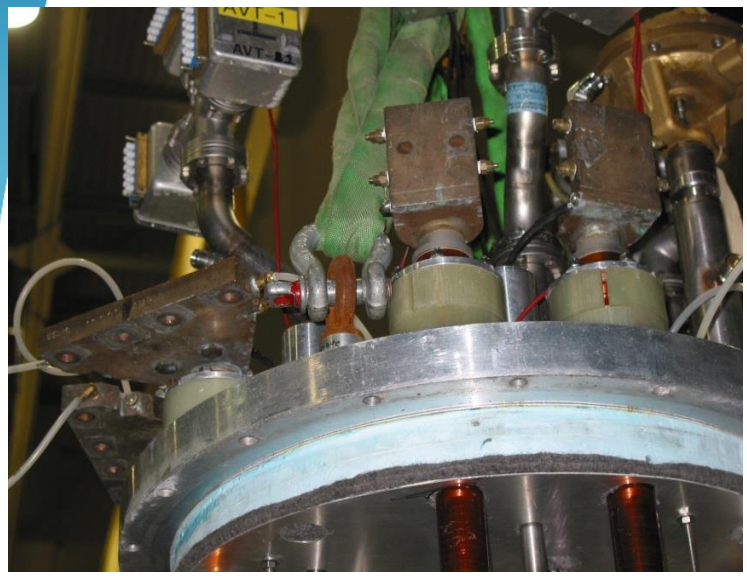
Acknowledgements for contributions to this presentation: Mike Anerella, Sebastian Dimaiuta, Piyush Joshi, Paul Kovach, Andy Marone, Bill McKeon, Jesse Schmalzle, Dan Sullivan

EuCARD²

BROOKHAVEN NATIONAL LABORATORY

BACK UP SLIDES

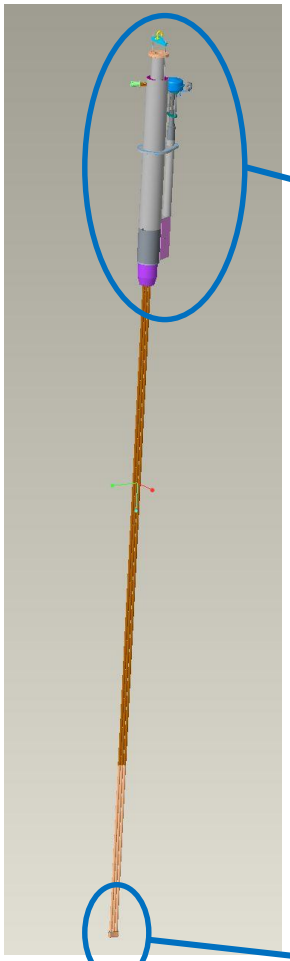
BNL VERTICAL TEST FACILITY

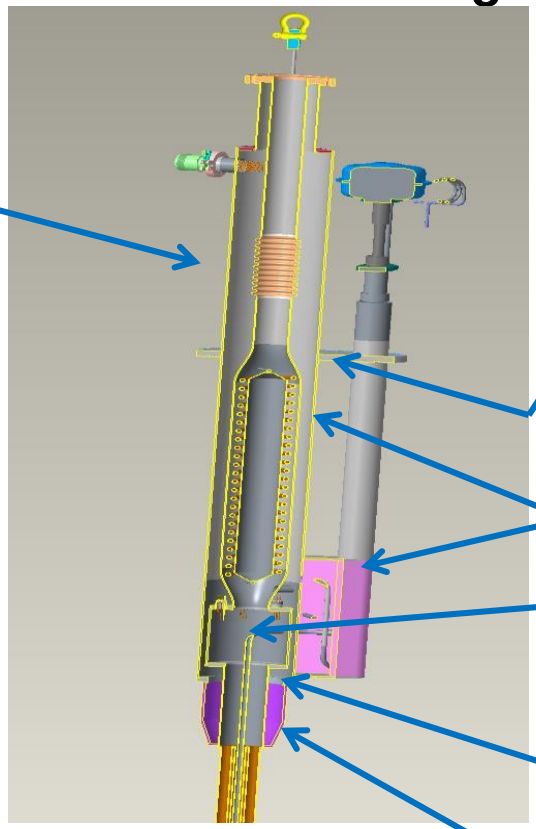


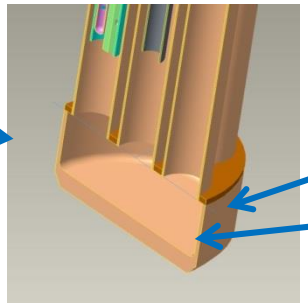
- **VERTICAL DEWAR TOP PLATES**
  - **New top plate to accommodate MQXF 4.2 m LHC Inner Triplet quads and 24kA leads and lambda plate/fixture for 1.8K**
  - **Magnet hanging fixtures and parts for a wide range of magnet types**
  - **Variety of feedthroughs and instrumentation connector assemblies**
  - **Gas-cooled and liquid-injection power leads for various power applications**
  - **Associated temperature sensors and level probes with each top plate**
  - **Presently eight top plates of various configurations available**

1.8 K TEST DEWAR ASSEMBLY

1.8 K Heat Exchanger







Top Plate Interface

Outer vacuum jacket above lambda plate designed for 50 psi (3.45 bar) external pressure.

All internal volume components designed for 85 psi (5.86 bar).

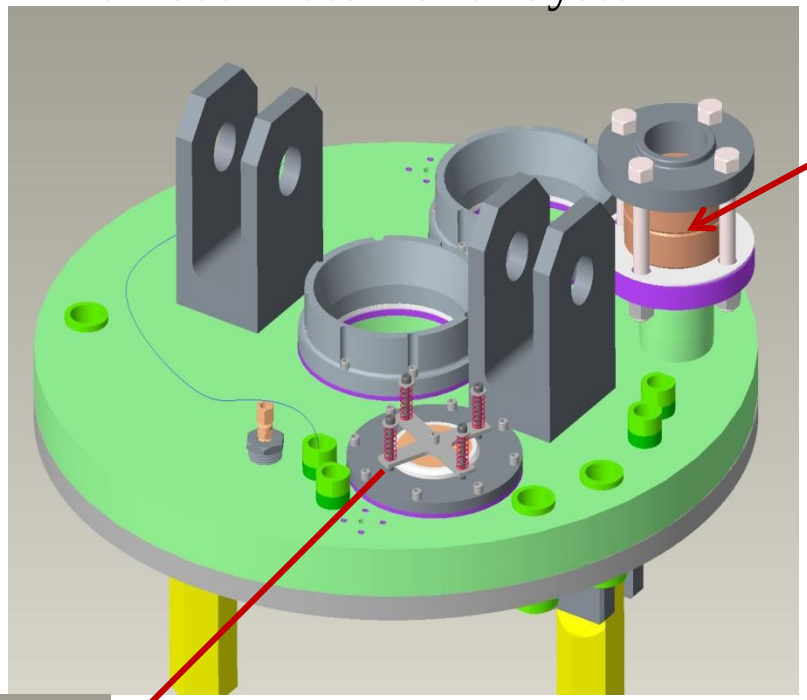
Lambda Plate Interface

Components below Lambda plate are designed for 85 psi (5.86 bar) external pressure.

Crescent-shaped bottom cup

1.8 K TEST DEWAR ASSEMBLY

Lambda Plate Relief System

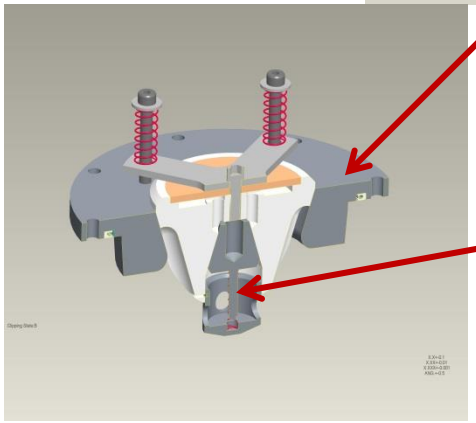


2” Fike burst disc designed for subcritical flow (API 520). Venting 4150 g/s helium at 5.86 bar to 3.45 bar backpressure.

Required area is 14.8 cm^2. Provided area is 20.0 cm^2.

Certified by Fike: 2.2 bar @ 74.8 K (lowest they can certify to). Calculated allowance to LHe temperature.

Relief conditions:
3.45 bar above lambda plate
5.86 bar below lambda plate



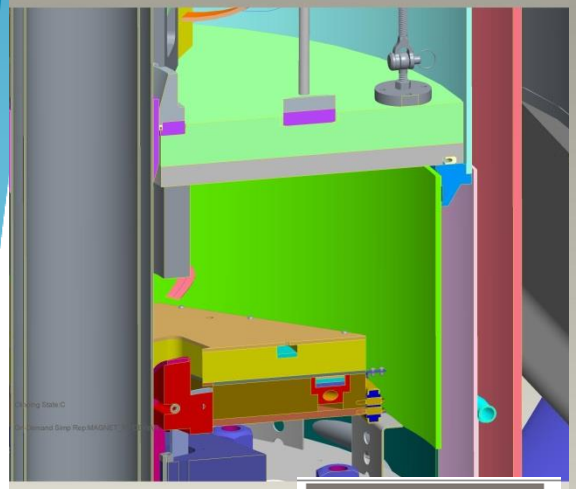
Service (Quench) Valve

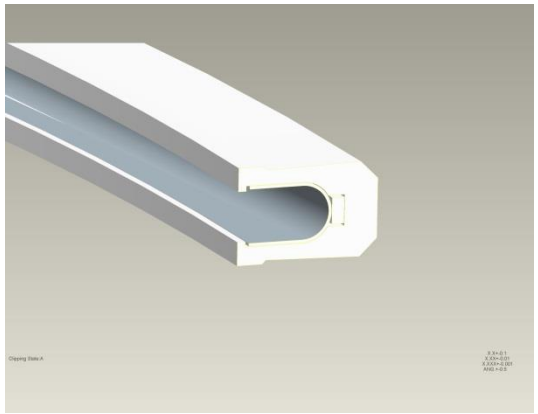
- Designed for 750 g/s with a pressure rise of under 0.34 bar @ operating conditions (approx. 1.2 bar).
- Contains internal 1.8 K make up valve, to eliminate low pressure vapor under lambda plate.

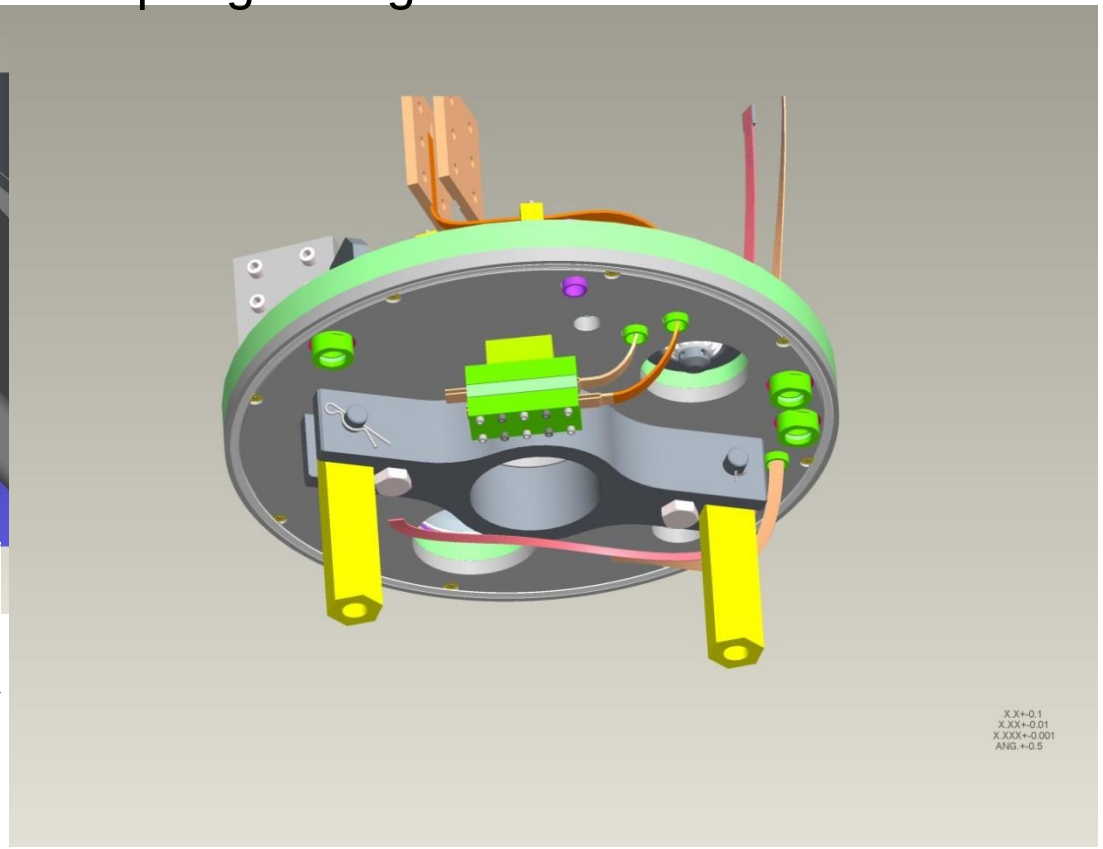
1.8 K TEST DEWAR ASSEMBLY

Lambda Plate Spring-Energized Face Seal to He Vessel

Lambda plate sealing detail







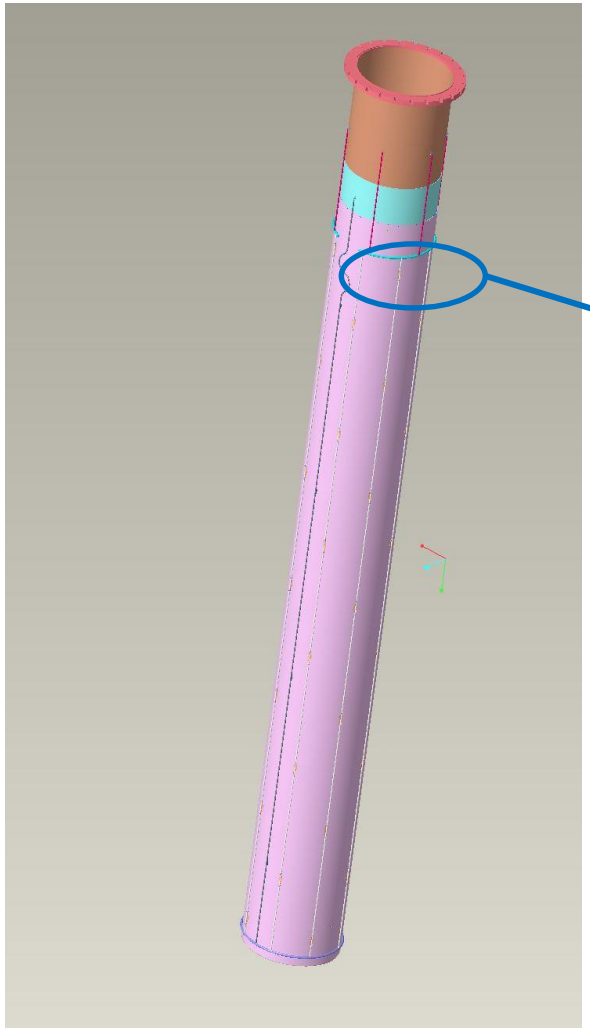
MATERIAL: SEAL JACKET - PTFE
CANTILEVER SPRING - ELIGOY/CRYOGENIC SERVICE
CONTINUOUS CONTACT SPRING FORCE: 60 LBS/LINEAR INCH MAX.
OPERATING DIFFERENTAIL PRESSURE: 5 PSID MAX.
MAXIMUM (NON-OPERATING) PRESSURE DIFFERENTIAL: 85 PSIG
OPERATING MEDIA: LIQUID AND GASEOUS HELIUM
OPERATING TEMPERATURE RANGE: 2° K-300° K.
LEAK RATE: BUBBLE TIGHT AT 5 PSID.

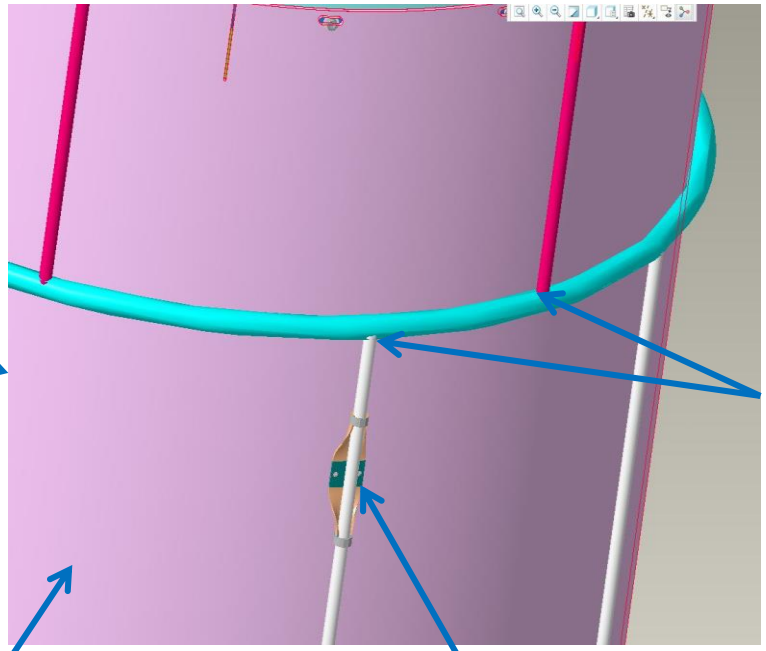
ADVANCED EMC TECHNOLOGIES, LLC

"The load required to completely compress the seal is approximately 50-60 lbs per linear inch. That's about 4200-5100 lbs. …….the difference in height between a completely compressed seal and one in the relaxed state is large enough to handle gaps if the parts are not completely flat or if the seal is not completely compressed." P. Kovach, designer.

1.8 K TEST DEWAR ASSEMBLY

4.5 K Heat Shield





1/16” fillet welds (TYP)

⅛” aluminum Shell

Flexible copper attachments

Vertical tubes (white & red) ⅜” X .028” wall, seamless 304 Stainless Steel.

Header tubes (Blue) ⅝” X .065” wall, seamless 304 stainless steel.

QUENCH PROTECTION

Quench Protection Heater Firing Units (HFU)

PRESENT HFU SYSTEM

Number of capacitor banks	4
Number of capacitors per bank	15 units
Capacitor voltage rating	450 V
Capacitance per unit	3100 μF
Total capacitance per bank	46500 μF

Maximum energy density that can be delivered vs capacitance with present system

Number Capacitors	C (μF)	R (Ω)	RC (ms)	time (ms)	E (J)	inner energy density (J/cm^2)	outer energy density (J/cm^2)
1	3100	3	9.3	42.828	313.9	0.5	0.8
2	6200	3	18.6	85.656	627.8	1.0	1.5
3	9300	3	27.9	128.484	941.6	1.5	2.3
4	12400	3	37.2	171.312	1255.5	2.0	3.1
5	15500	3	46.5	214.140	1569.4	2.5	3.8
6	18600	3	55.8	256.968	1883.3	3.0	4.6
7	21700	3	65.1	299.797	2197.1	3.5	5.4
8	24800	3	74.4	342.625	2511.0	4.1	6.2
9	27900	3	83.7	385.453	2824.9	4.6	6.9
10	31000	3	93.0	428.281	3138.8	5.1	7.7
11	34100	3	102.3	471.109	3452.6	5.6	8.5
12	37200	3	111.6	513.937	3766.5	6.1	9.2
13	40300	3	120.9	556.765	4080.4	6.6	10.0
14	43400	3	130.2	599.593	4394.3	7.1	10.8
15	46500	3	139.5	642.421	4708.1	7.6	11.5

Number Capacitors	C (μF)	R (Ω)	RC (ms)	time (ms)	E (J)	inner energy density (J/cm^2)	outer energy density (J/cm^2)
1	3100	2	6.2	28.6	313.9	0.5	0.8
2	6200	2	12.4	57.1	627.8	1.0	1.5
3	9300	2	18.6	85.7	941.6	1.5	2.3
4	12400	2	24.8	114.2	1255.5	2.0	3.1
5	15500	2	31.0	142.8	1569.4	2.5	3.8
6	18600	2	37.2	171.3	1883.3	3.0	4.6
7	21700	2	43.4	199.9	2197.1	3.5	5.4
8	24800	2	49.6	228.4	2511.0	4.1	6.2
9	27900	2	55.8	257.0	2824.9	4.6	6.9
10	31000	2	62.0	285.5	3138.8	5.1	7.7
11	34100	2	68.2	314.1	3452.6	5.6	8.5
12	37200	2	74.4	342.6	3766.5	6.1	9.2
13	40300	2	80.6	371.2	4080.4	6.6	10.0
14	43400	2	86.8	399.7	4394.3	7.1	10.8
15	46500	2	93.0	428.3	4708.1	7.6	11.5

DATA ACQUISITION SYSTEMS
STATUS SUMMARY

DAQ SYSTEMS STATUS:

- 128 Channel Fast logger: Assembled and tested.
- 64 Channel Slow logger: Assembled and tested.
- 64 Channel Strain Gauge logger: 32 Channels tested, remaining channels to be assembled.
- 8 Channel Quench Detector: Assembled and tested.
- Cable end connector assembly complete on dewar end.
- Acquisition software written/debugged/tested.
- All isolators / pre-amplifiers assembled, calibrated & tested.

(FY16) - Spike Detector & Quench Antenna Data Acquisition System to be designed & built.

64 Channel Slow Logger

8 Channel Quench Detector

128 Channel Fast Logger

DAQ-isolation amplifier cabinet

BNL CRYOGENICS FACILITY

- Inline Purifiers
  - ✓ Replaced Polyflow lines
- Valve Boxes
  - ✓ Replaced Polyflow lines
- Quench Tank
  - ✓ Replaced valve & legacy soldered copper lines with stainless steel welded pipe; rerouted quench recovery line to improve flow
  - ✓ Replaced legacy soldered copper small diameter return manifold piping with large diameter welded stainless steel
  - ✓ Purchased & installed new return manifold valves

Note: all this work is BNL funded

"before" legacy copper lines & valves

"now"

BNL CRYOGENICS FACILITY

Sullair 500* (500 hp, 94 g/s) Installation

* backup unit, risk mitigation against Mycom compressor failure

- 4160V transformer relocated into place – conduit/wiring installation complete
- Sullair skid modified for new location
  - Electrical panel removed
  - Frame cut/shortened/re-welded
- All electrical & plumbing installations are complete
- Waiting for turn-on
- Cost underrun! Surplus funds approved for use in commissioning helium dirty gas purifier system (Linde contract)

Note: all this work is BNL funded

BNL CRYOGENICS FACILITY

(FY17)*

- Re-commission Kinney Vacuum Pump (backup to Nash Pump, 2.0 g/s He @ 1.8K)

* Pending final budget authorization

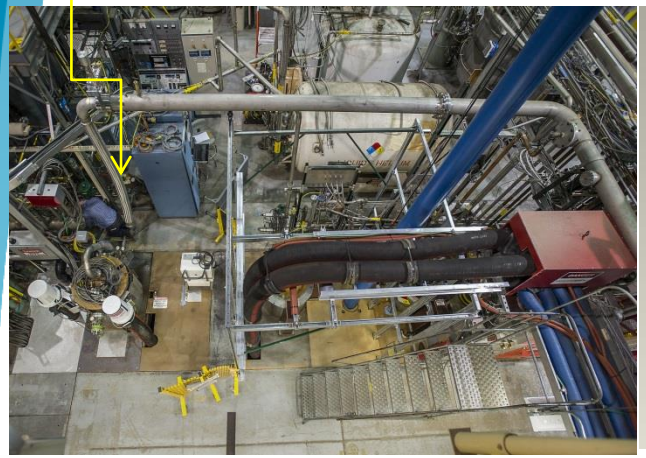
BNL CRYOGENICS FACILITY

Cryogenic Controls

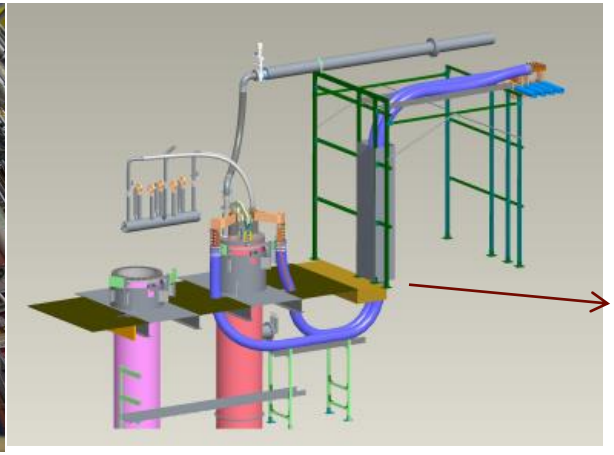
- Nash Vacuum Pump Controls : New lab View based controls tested for remote and local operation
- Finished hardware and software debugging of the new Lab View based Inline Helium purifier and its associated valve system.
- Helium Recovery compressor: Retrieved vendor programmed ladder logic code for modification and addition of remote control logic. initial testing revealed damaged pressure sensor (as received). Replacement ordered.
- New Lab View based controls for Quench recovery valve system being tested.
- Monitoring system and controls for various level sensors, temperature sensors, heaters, vacuum sensors etc. are in process of being calibration and testing.

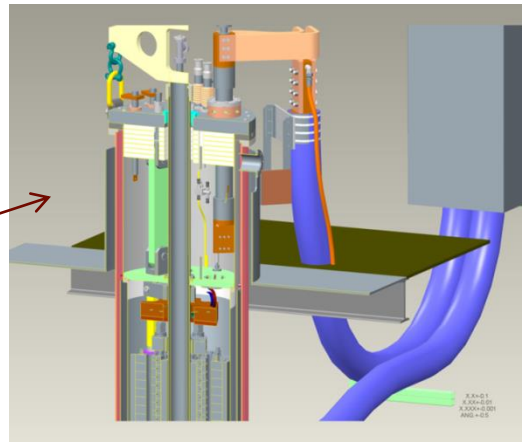
30 kA POWER SUPPLY UPGRADE

24 kA water-cooled cable to dewar installation is complete



(Note also helium vacuum line)

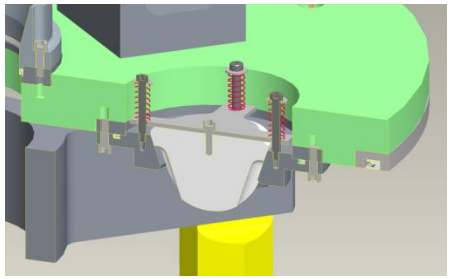


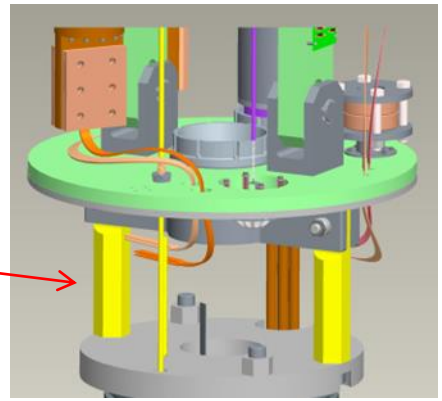


1.8 K TEST DEWAR ASSEMBLY

Lambda Plate Design Details

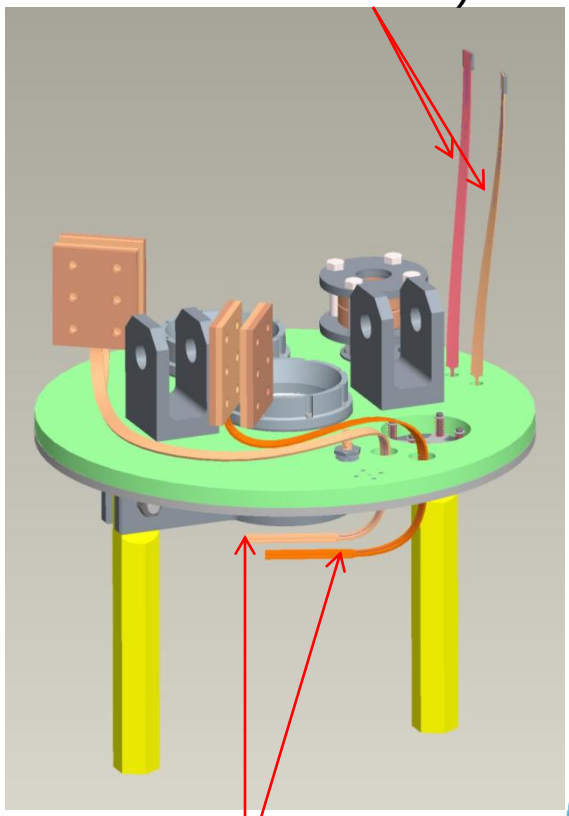
- Pressure relief valve with “backflow” poppet (not shown)





Note: exiting magnet leads will be cut to ~ 300 mm past splice box; is this acceptable for production magnets?

CLIQ leads (not installed for Mirror)

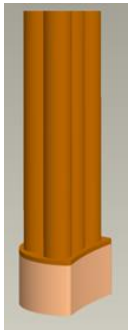


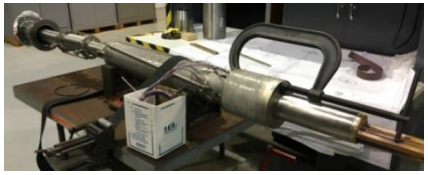
Main current lead connections to 24KA vapor cooled leads (not shown)

1.8 K TEST DEWAR ASSEMBLY

Test Dewar Status p.12K Heat Exchanger Assembly

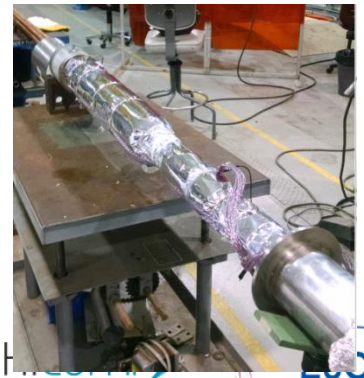
ASSEMBLY COMPLETE

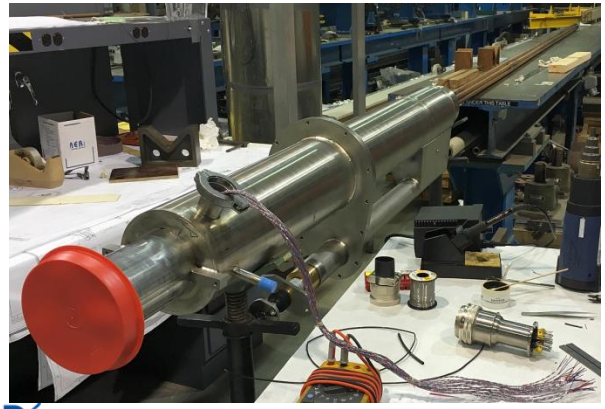


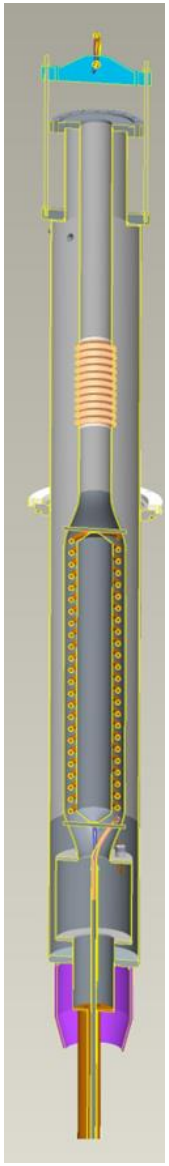


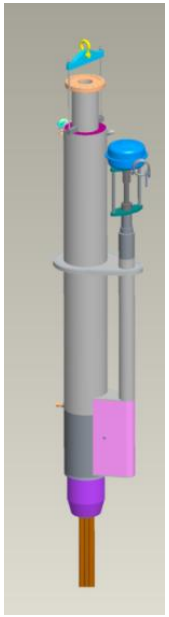
top hx end

bottom hx end









1.8 K TEST DEWAR ASSEMBLY

Helium Dewar & Outer 4K Heat Shield Status

6/10/16 –
Heat shield welded to helium vessel.
Insulation blanket installed.

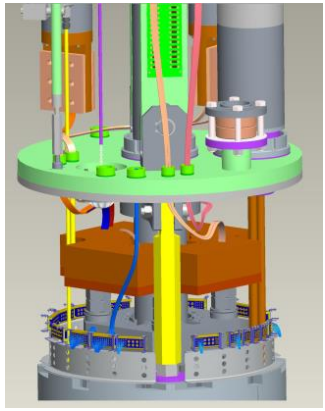
Heat shield (at BNL)

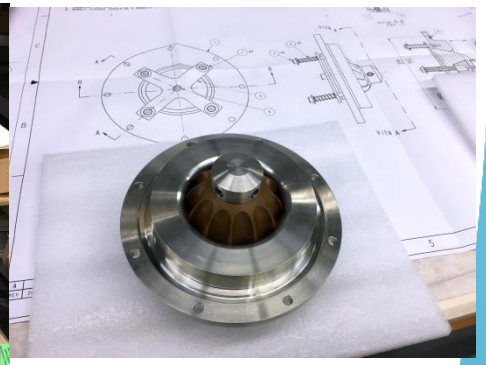
1.8 K TEST DEWAR ASSEMBLY

Test Dewar Status p.3 Lambda Plate

Assembly underway

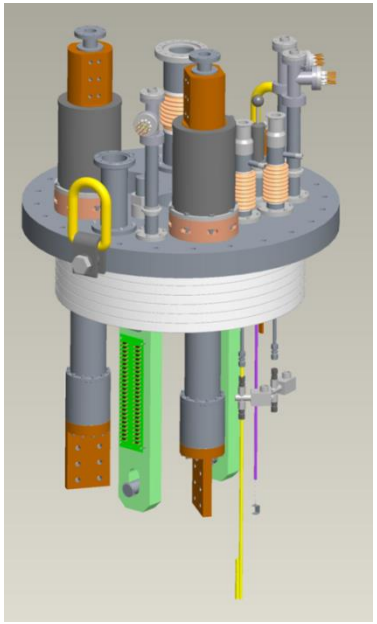
- G-10 & stainless steel plates potted with Stycast epoxy
- Components being installed

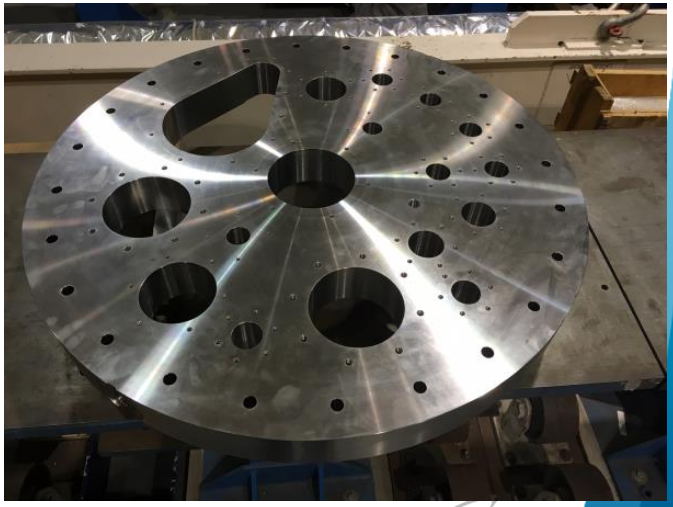




1.8 K TEST DEWAR ASSEMBLY

- top hat detail parts being fabricated:
  - 24KA vapor cooled leads received
  - Top hat received, being inspected
  - (3) Instrumentation towers assembled
  - Wiring harnesses being assembled
  - Most parts promised 5/16
  - Delivery issue with Ultem 24KA lead insulators, material sent to 2nd vendor, parts due 5/19





MAGNETIC FIELD MEASUREMENT

Coil #	RN #	Type	Diameter	Length	Warm Finger	WF O.D	In Use	G.S	Stored	Comment's	# of Coils
29,30,31		External drive Cold					No	No	Inst Lab roof	Dipole (Drive in Trailer)	6
32,33,34		External drive Cold					No	No	Inst Lab S.B	Drives in Trailer	
35,36		External drive Quad					No	No	Inst Lab S.B	RHIC Quad (**No drive**)	
37		9" Baby RHIC	2.195"	9"	NO	NO	No	No	Inst Lab	Coil on Stick	
40		Booster Coil			N/A	N/A	No	No	Inst Lab	Analog	
41		Booster Integral			N/A	N/A	No	No	Inst Lab	Made with Litz wire	1
42		Mole D1			N/A	N/A	No	Yes			
43		Mole D2			N/A	N/A	No	Yes			
44		Mole D3			N/A	N/A	No	Yes		Turned into a Piezo Electric	
45		RHIC Mole									
46		Booster			N/A	N/A	No	No	Dipole Cal Mag	Analog	
47		LBL									
48		Mole FE1			N/A	N/A	N/A	Yes	Fermi Lab	Sent to SSC 6-10-92	5
49		Mole FE2			N/A	N/A	N/A	Yes	N/A	Sent to SSC 8-19-92	5
50		Mole FE3			N/A	N/A			Cal Lab		5
51		Mole FE4			N/A	N/A	No	Yes	Trailer		5
52		Mole FE5			N/A	N/A	N/A	Yes	N/A	Sent to SSC 10-15-92	5
53		Mole FA1			N/A	N/A	N/A	Yes	N/A	Sent to SSC 8-1-92	5
54		Mole FA2		2"	N/A	N/A		Yes	Trailer	Coil is Ceramic	5
55		Mole FA3			N/A	N/A		Yes	Trailer	No G.S drive G.S drifts	5
56		Mole FA4			N/A	N/A		Yes	Inst Lab	**(No Drives)**	5
57		Mole FA5			N/A	N/A		Yes	Inst Lab	No Coil drive	5
58		Mole FA6			N/A	N/A			Fermi Lab		5
59		Mole FA7			N/A	N/A		Yes	Trailer	No Coil drive	
60		FP1			N/A	N/A	No	Yes	Inst Lab		
61		FP2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Never Built	
69		Mole RA2			N/A	N/A	Yes	Yes	Cal Area		5
70		Mole RE2 /RA1 ********			N/A	N/A		Yes	1-2 In Box	Mole became RE2 10/93	5
71	RN17	NSK drive Cold	1.950"	1 Meter	Yes S.S		Yes	No	High Bay	Fast Rotating, brass sleeve	
72		Mole RA3			N/A	N/A	Yes	Yes	Cal Area		5
73		Mole RA4 DO cold			N/A	N/A	No	No	Inst Lab	DO Vertical Mole	5
74		Mole RA5 DX Cold	5.710"		N/A	N/A	Yes	No	Cal Area	DX Vertical Mole	5
75	RN1	NSK drive Cold	3.25"	109 3/8	Yes	4.00"	Yes	No	High Bay	13cm Quad	
76		Mole RE1			N/A	N/A					5
77		Mole RE3/REA3			N/A	N/A			Annex	Used in tunnel coil is Air powered	5
78		Mole RE4			N/A	N/A			Cal Area		5
79		Mole RE5 DO Warm	3.2"		N/A	N/A	Yes	Yes	Cal Area		5
80	RN2	NSK drive Cold	1.95"	141"	Yes		NO Drive	No	Inst Lab	RHIC CQS Overheater in dewar	5
81	RN3	NSK drive Warm	1.95"	141"	No		Yes	No	High Bay	RHIC CQS #2	5
82		Mole RE6 DX Warm	6.050"		N/A	N/A	Yes	Yes	Annex		5
83		Mole RA6 Snake	2"		N/A	N/A	Yes	No	Cal Area	Snake Vertical Mole	5
84	RN 6	NSK drive Cold			No		No	Yes	Annex	8cm warm Rhic Still on tracks	
85	RN7	NSK drive Cold			S.S sleeve		No	No	Annex	8cm warm Rhic G.S Removed	5
86	RN8	NSK drive Cold	1.91"	80"	Yes	2.63" S.S	Yes		High Bay	8cm Long RHIC, brass sleeve	5
87	RN9	NSK drive Cold	1.91"	80"	Yes	2.63" S.S	Yes		Annex	8cm Long RHIC, brass sleeve	5
90	RN12	NSK drive Cold							High Bay	13cm Long RHIC Vertical	5
91	RN13	NSK drive Cold			AL Tube		No	No	Annex	13 cm Short RHIC (**no drive**)	5
92	RN14	NSK drive Cold			AL Tube	5.505"	No	Yes	Annex	13cm Long RHIC	5
94	SN1	NSK drive Cold			No		No	No	Inst Lab	SNS Dipole (**no drive**)	5
95	SN2	External drive Warm			No		Yes	Yes	Annex	21cm SNS Quad	5
96	RN16	APT			No		No	No	Inst Lab	Los Alamos (**no drive**)	5
97	SN3	External drive Warm			No	N/A	In Calibrat	Yes	Cal Area	26cm Quad Coil	5
98		NSK drive Cold			Yes G-10		Yes	No	Cal Area	Bio-Med	16
99		NSK drive Cold			Yes G-10		In Const	No	Inst Lab	GSI	16
201		NSLS 30mm	2.480"	80"	S.S sleeve				Annex		9
202		CAD Fast Ramp			G-10 Sleeve				Cal Area	Tube from BIO-Med Coil is old#84	4
203		NSLS	2.364"	60"	S.S sleeve				Annex		9

Inventory of measuring coils