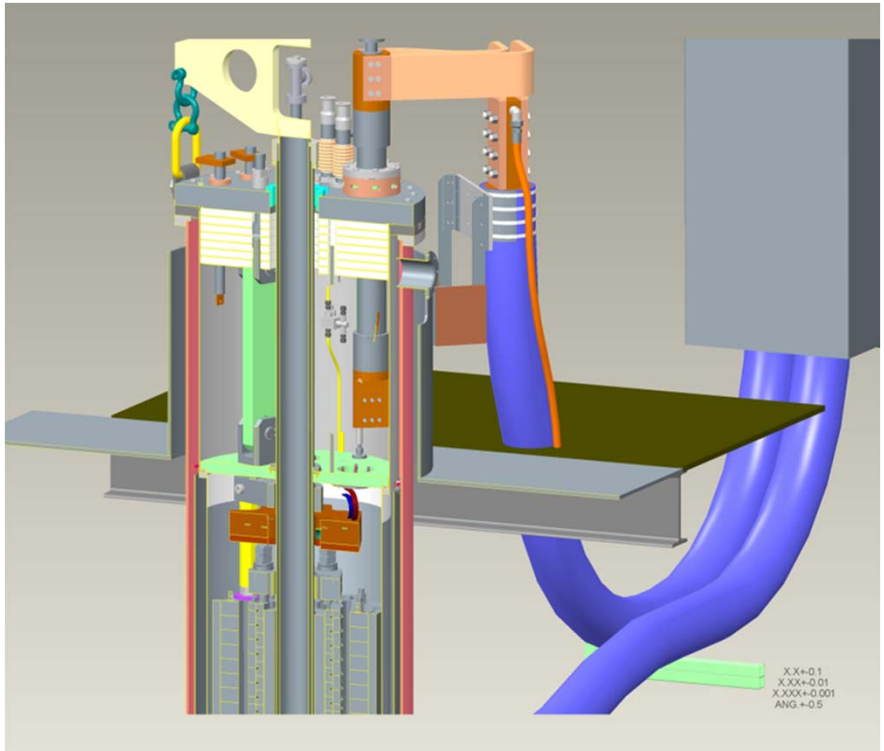
# BNL LHC Hi-Lumi
# QXF Vertical Test Facility Status

M. Anerella

On behalf of H. Hocker, P. Joshi, P. Kovach & A. Marone

May 19, 2016



# Outline

Introduction

Cryogenic Infrastructure

Power Supply

Data Acquisition

Test Dewar

Schedule to Completion

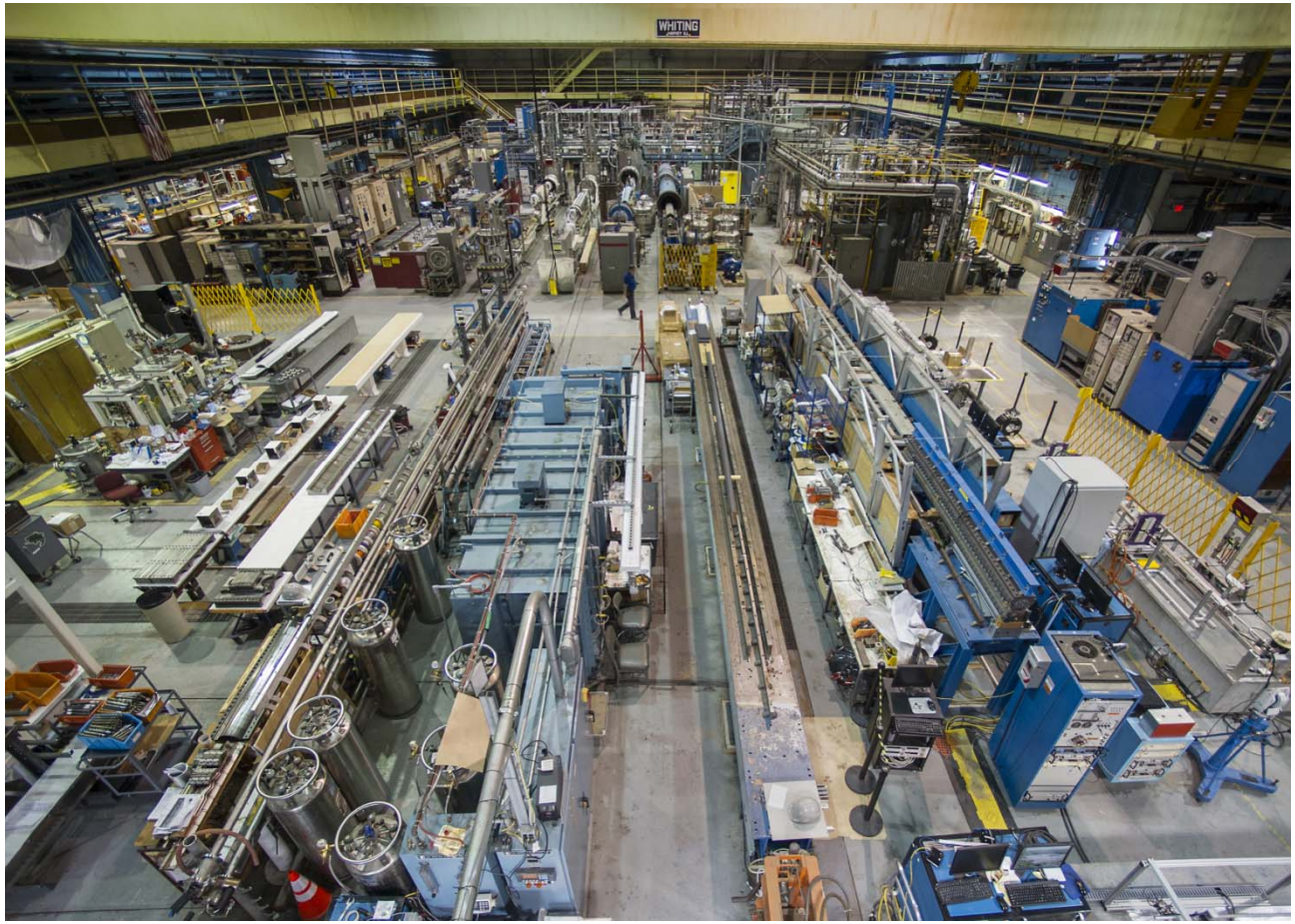
# Introduction – the Challenge for HiLumi

New for the BNL Cryogenic Test Facility:

- 24KA (21KA max. required, mirror) in magnet testing (previously 10KA for magnets; are now modifying a 30KA power supply previously utilized for cable sample tests)
- 1.9K in magnet testing (previously 4.5K for magnets, but 1.9K has been achieved for cable sample tests)

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

## Test Facility in Background



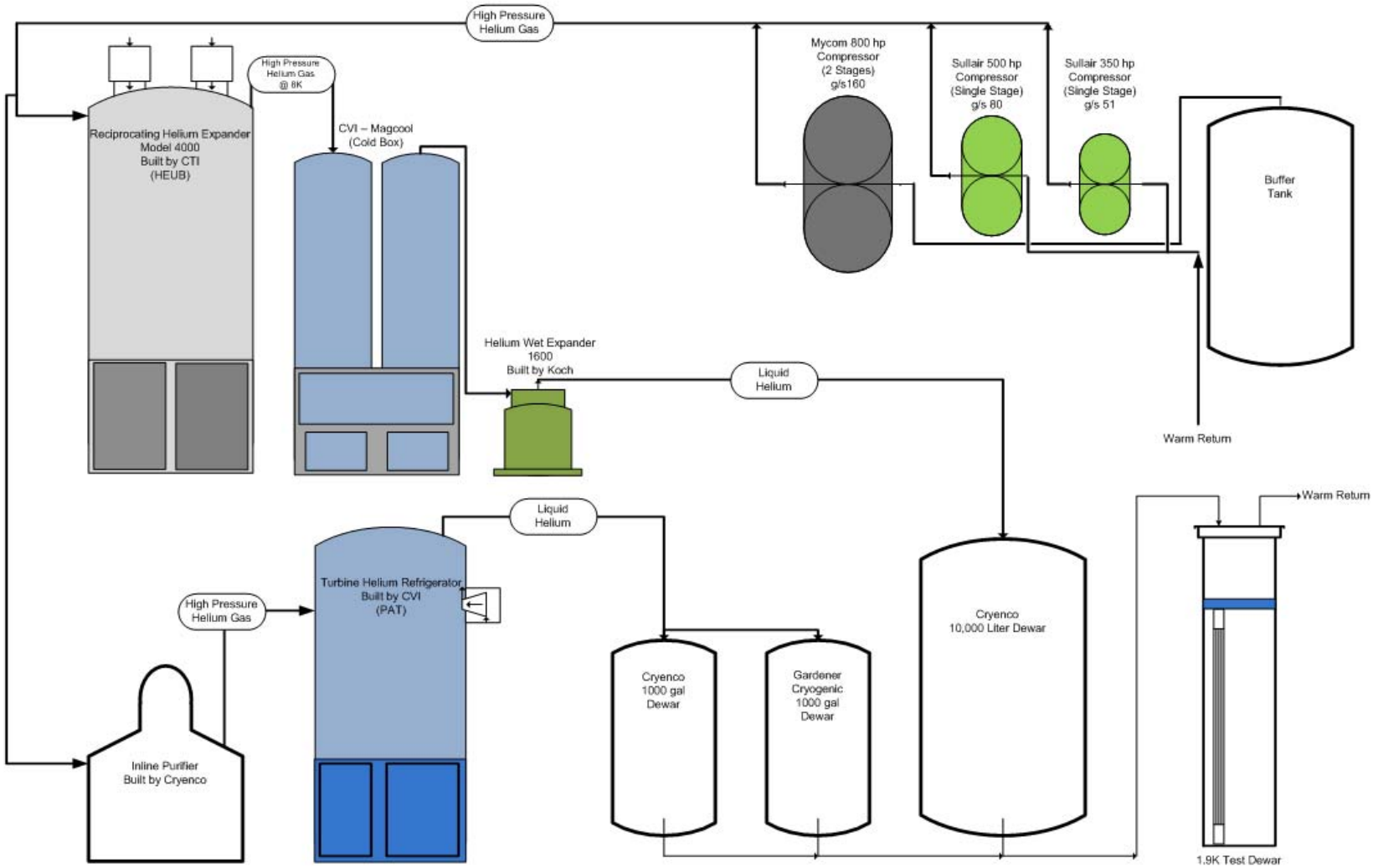
# Cryogenic Facility Overview
# "the challenge for HiLumi"

- BNL has a large infrastructure of cryogenic test equipment, but:
  - 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

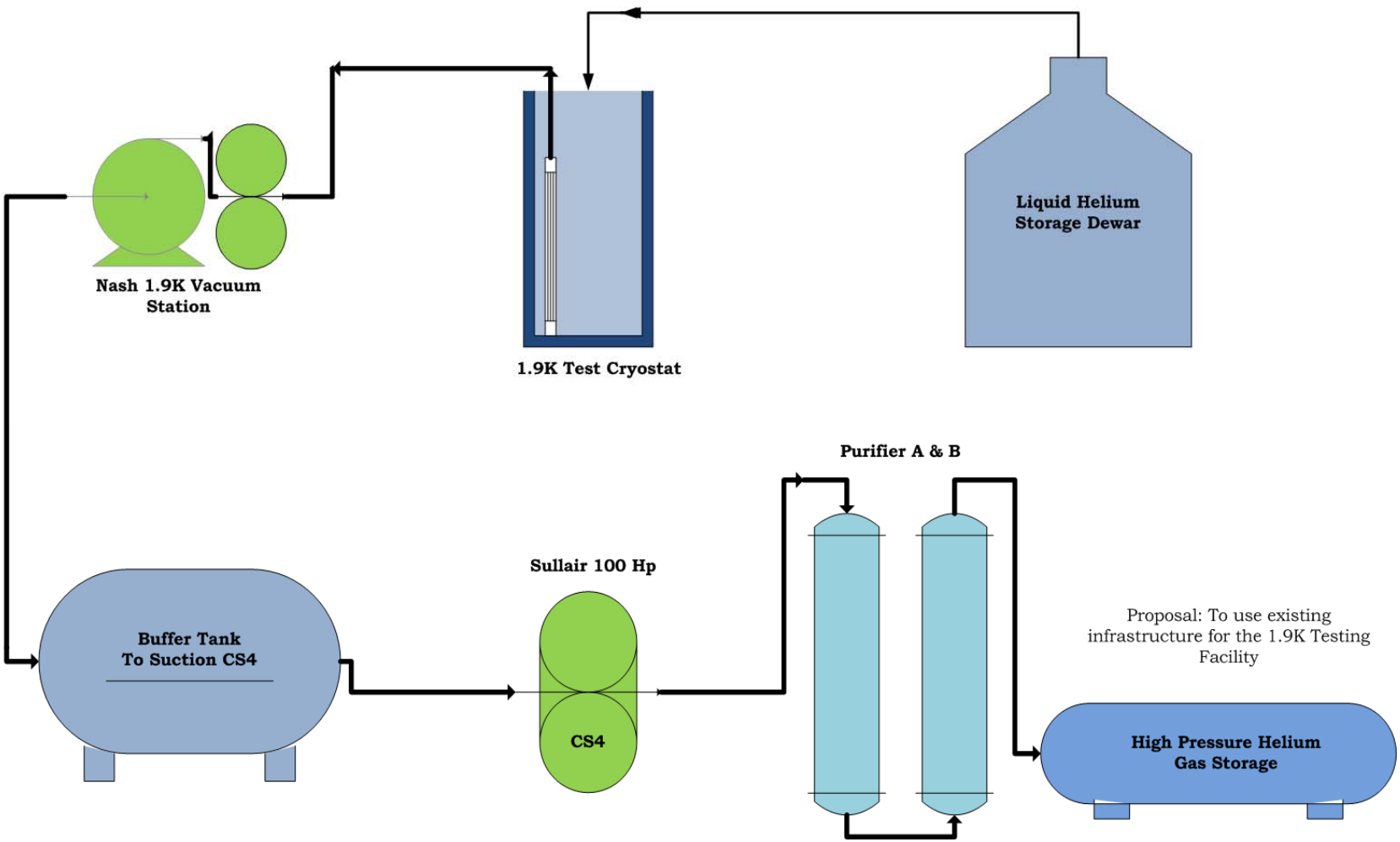
    → BNL management supported funding the purchase of critical spares, preventive maintenance of critical components, and installation of backup systems to improve reliability and reduce risk for the Hi-Lumi production magnet testing program

- Previous 1.9K testing was limited to superconducting cable samples (some years ago), not magnets

# Cryogenic Facility Schematic

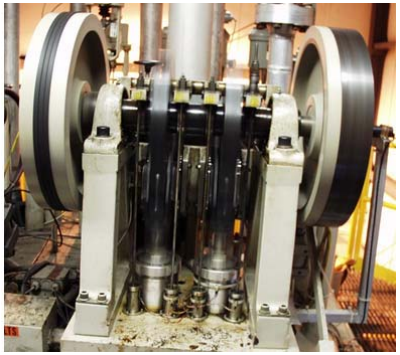


# 1.9K Cooling Schematic

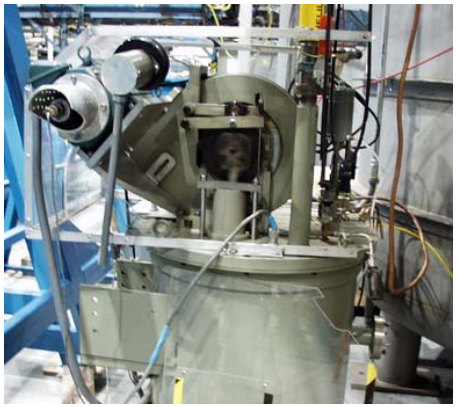


# Cryogenic Facility p.1
# Main Refrigeration Units

1. CTI Model 4000 refrigerator (primary unit, 320 l/hr. uses (2) reciprocating engine expanders)
   - ✓ Rebuilt expander in 2013
   - ✓ Unit in good working condition



2. Koch Model 1600 Wet Expander
   - ✓ Unit in good working condition
   - ✓ Seals, O-rings, other parts replaced / maintained



# Cryogenic Facility p.2
# Secondary Refrigerator

- CVI Refrigerator* (2 turbines, 160 l/hr)
  - ✓ Replaced (1st stage nitrogen-helium) heat exchanger
  - ✓ Replaced turbine chilled water heat exchanger
  - ✓ Replaced temperature sensors
  - ✓ Updated control system

* backup unit, risk mitigation against CTI Refrigerator failure

Note: all this work is BNL funded

# Cryogenic Facility p.3
# Compressors

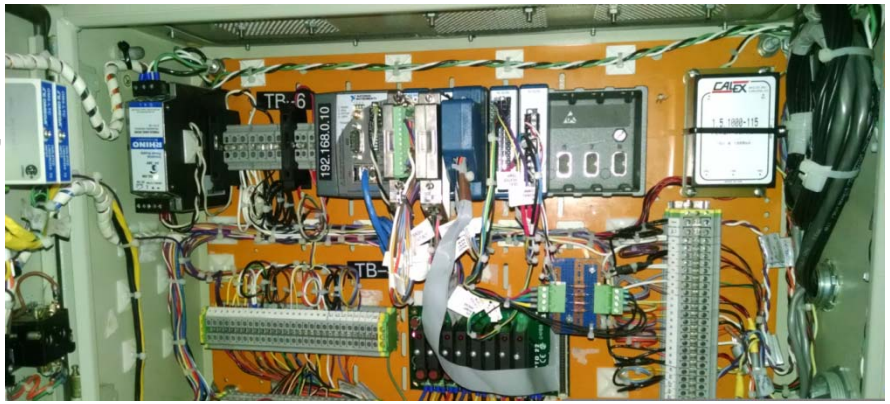
- Mycom Compressor (primary unit, 2 stage, 800 hp, 160 g/s)
  - ✓ Purchased & received critical spares:
    - ✓ new 2nd stage compressor head
    - ✓ new 400 hp motor
    - ✓ new oil heat exchanger
    - ✓ new helium heat exchanger
  - ✓ Maintenance items completed:
    - ✓ Installed new oil filter & seals
    - ✓ Repaired oil leaks
    - ✓ Replaced oil line clamps
    - ✓ Refurbished & resealed heat exchanger

- Sullair 350 Compressor (single stage, 350 hp, 51 g/s)
  - ✓ Purchased & received critical spares:
    - ✓ new compressor screw
    - ✓ new oil pump

Note: all this work is BNL funded

# Cryogenic Facility p.4
# Nash Helium Vacuum Pump

- Nash Vacuum Pump (2.7 g/s @ 1.8K)
  - ✓ Purchased (BNL funded) new 100 hp Sullair compressor
  - ✓ Connected helium exhaust gas line to 110 hp compressor and inline purifier, to reclaim helium gas (was previously routed to dirty gas facility)
  - ✓ Replaced legacy soldered copper water lines with welded stainless steel
  - ✓ Purchased new booster and liquid ring vacuum pumps
  - ✓ Refurbished existing / purchased new (BNL funded) spare chilled water heat exchangers
  - ✓ Replaced drive belts
  - ✓ Repaired service air supply line
  - ✓ Updated control system
  - ✓ Installed new vacuum jacketed transfer line, valve to test dewar



# Cryogenic Facility p.5

- 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

"before" legacy copper lines & valves

"now"

Note: all this work is BNL funded

# Cryogenic Facility p.6

## 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

# Cryogenic Facility p.7

(FY17)*

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

* Pending final budget authorization

# Electrical Systems Overview
# "the challenge for HiLumi"

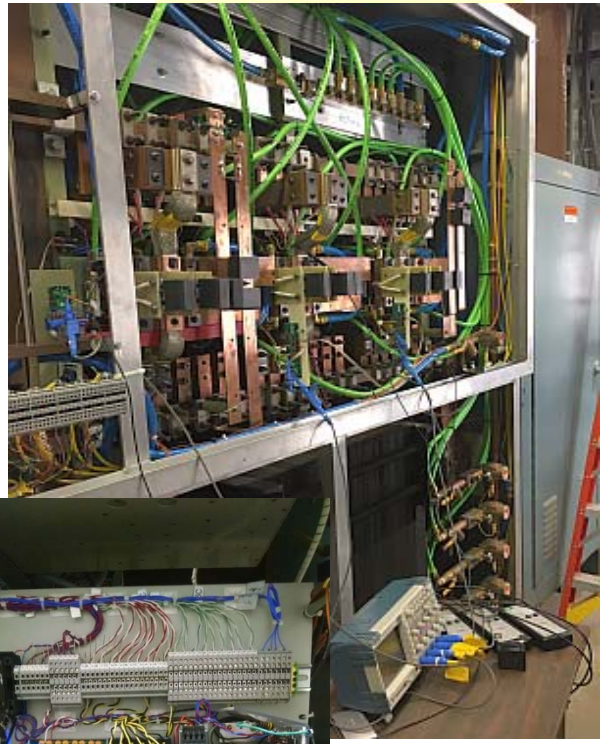
- 24KA
- Intensive data acquisition
- 5 MJ energy extraction

# Power Supply Energy Extraction Switch

- 24KA IGBT Based Energy Extraction Switch:
  - Switch consist of 2 modules each with six high power IGBTs in parallel
  - First module - Design and tuning of snubber circuit components to absorb high voltage switching transients is complete in one module. Tested so far up to 9KA.
  - Tuning and testing of second module in progress. Tested up to 5.4KA
  - Stray and mutual inductances in the power supply circuit generated much higher switching transients than expected.
  - Reconfiguration of snubbers caused some delays.
  - 40 channel IGBT Switch data monitoring and logging system for each module: Lab View program debugged and tested.

- 24KA water cooled cables : Finished DI water cooling circuit, installed drain outlet and verified flow (>18GPM) and pressure drop.

IGBT Switch

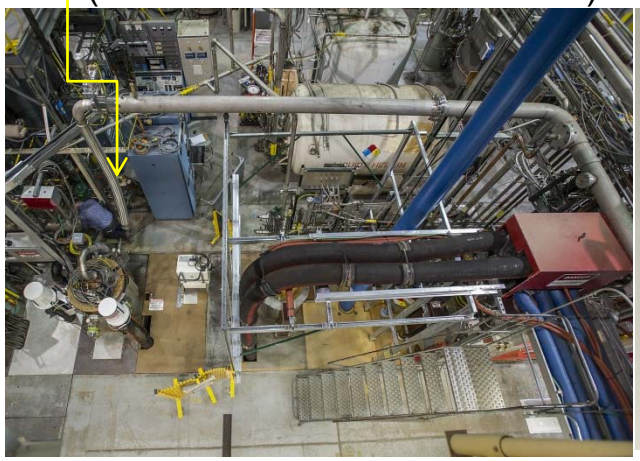


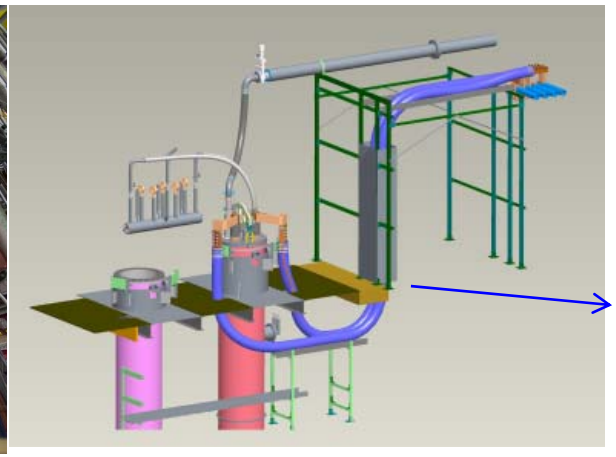
IGBT Data logger

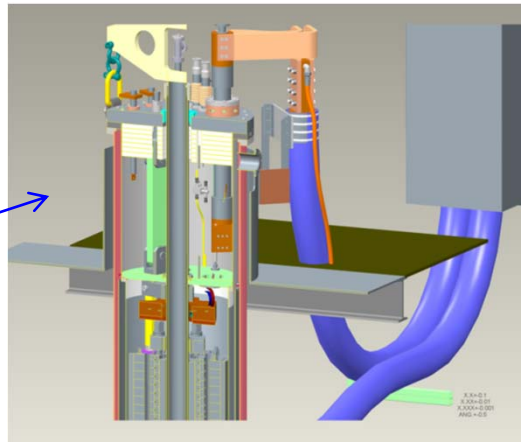
# Power Supply Status, continued

Water cooled cable (from 24KA IGBT cabinet terminal to dewar) installation is complete

(Note also helium vacuum line)







# Data Acquisition and Controls

Voltage Taps monitoring system:

- 128 Channels Fast logger: Assembled and tested
- 64 Channels Slow logger: Assembled and tested
- 64 Channel Strain gage logger: 32 Channels tested, remaining channels to be assembled
- 8 Channel Quench Detector: Assembled & 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

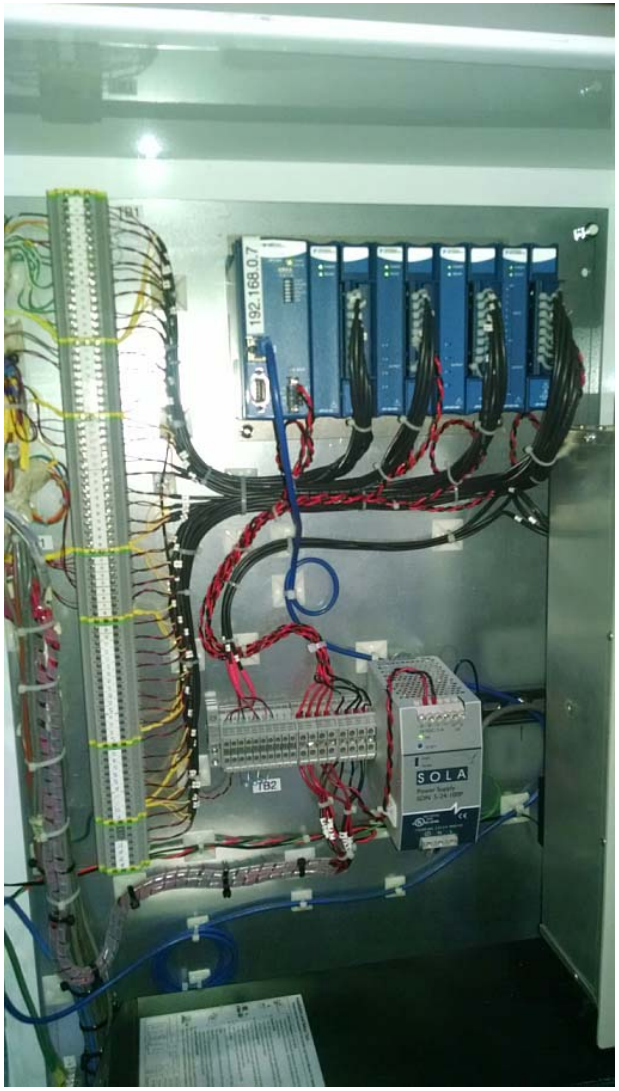
64 Ch Slow Logger

Quench Detector

128 Ch
Fast Logger

# Cryogenic Controls

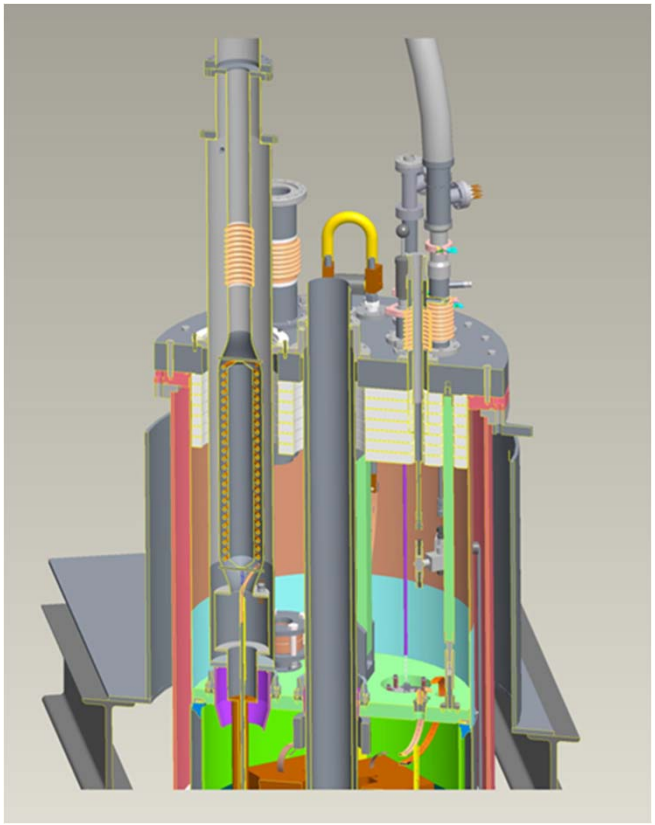
- Nash Vacuum Pump Controls : New lab View based controls tested for remote and local operation
- Finished hardware and software debugging of the new Lab View based Inline Helium purifier and its associated valve system.
- Helium Recovery compressor: Retrieved vendor programmed ladder logic code for 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.



# Vertical Dewar Overview
# "the challenge for HiLumi"

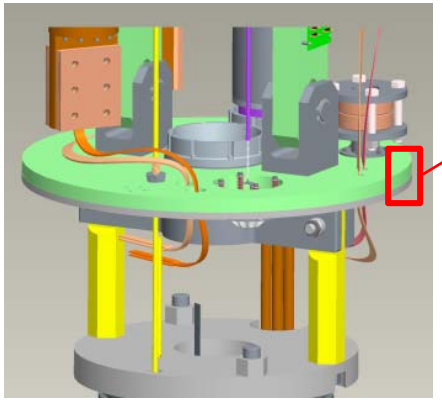
- Existing vertical test dewars operate at 4.5K; no capacity for 1.9K heat exchanger
- Existing available dewar consists of Ø 610 mm helium vessel in ~ Ø 810 mm vacuum vessel (HiLumi magnet = Ø 630 mm)
- Total helium dewar length = 6.1 m
- Total hook height above dewar flange ~ 6.7 m

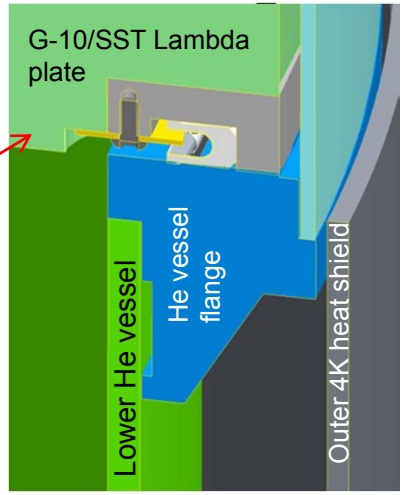
# Test Dewar
# Overall Design

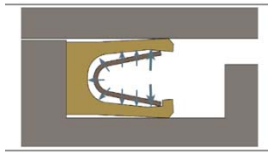


Upper dewar assembly:

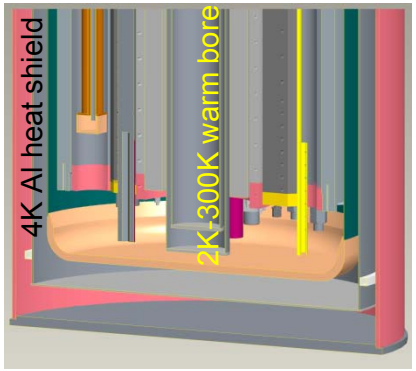
- Vent *and* burst disc in lambda plate (for Safety Approval)
- Gravity seal at lambda plate





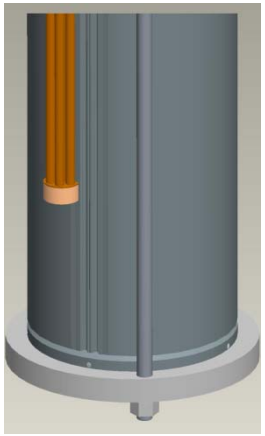



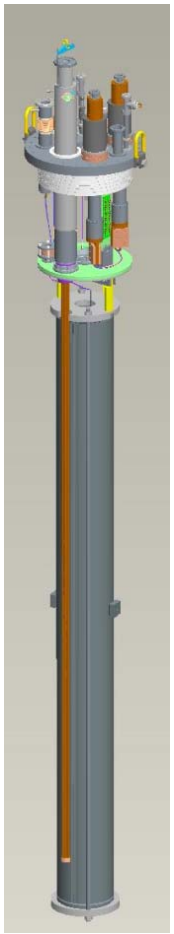
Lambda plate sealing detail




+200 mm extended helium dewar bottom

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

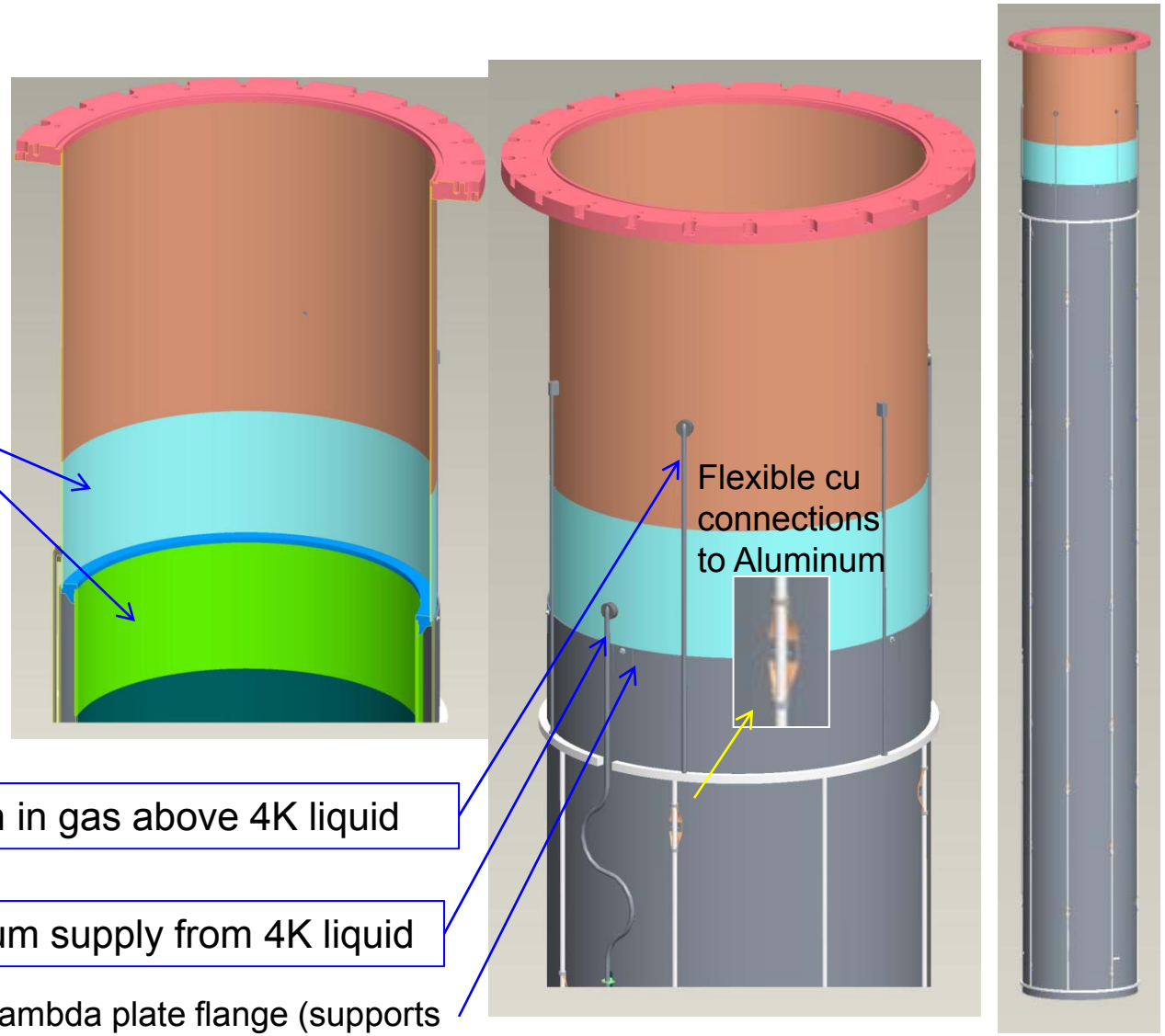




Overall hanging assembly (mirror shown)

# Helium Dewar & Outer 4K Heat Shield Design Details

"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 4K liquid

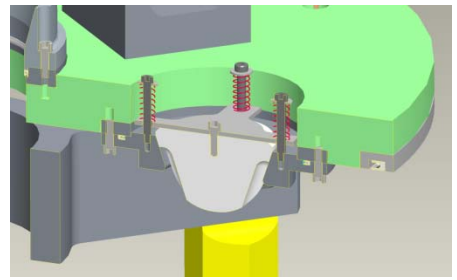
Helium supply from 4K liquid

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

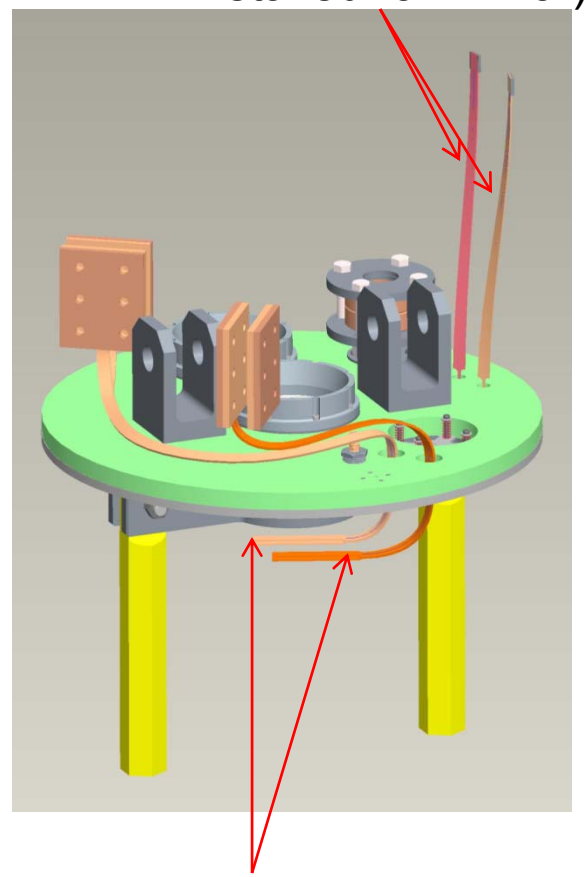
SST manifolds, pipes

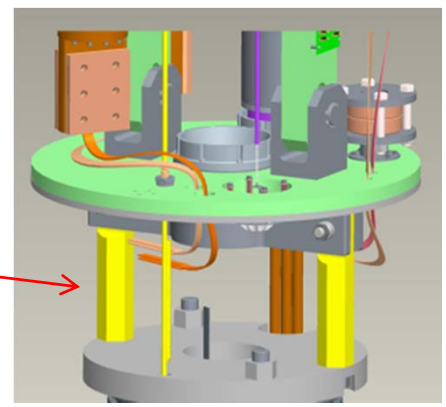
# Lambda Plate Design Details

- Pressure relief valve with "backflow" poppet (not shown)



CLIQ leads (not installed for Mirror)



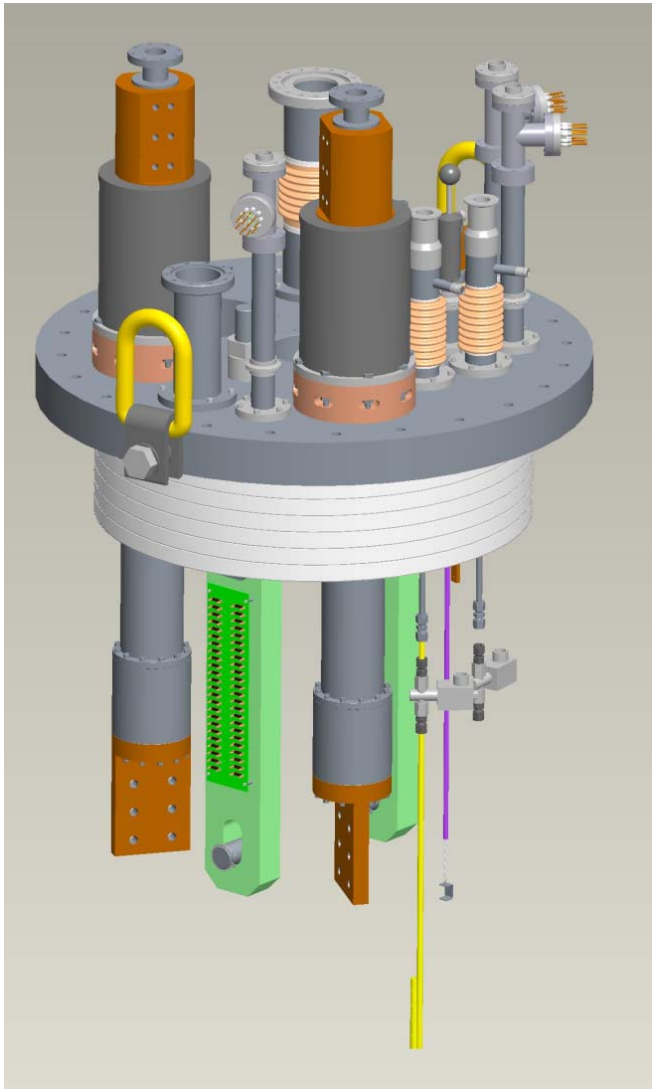


Note: exiting magnet leads will be cut to ~ 300 mm past splice box; is this acceptable for production magnets?

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

# Top Hat Design Details

- (2) 24KA main coil vapor cooled leads
- (2) 1KA CLIQ vapor cooled leads; port for 3rd lead provided
- (3) instrumentation wiring ports
- (2) helium fill lines
- Heat exchanger ports, manifiolds & solenoid valves under plate
- Warm bore port
- Helium vent port

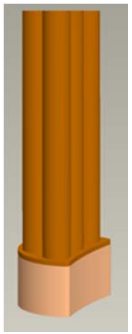


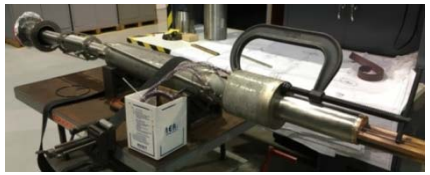
# Test Dewar Status p.1
# 2K Heat Exchanger Assembly

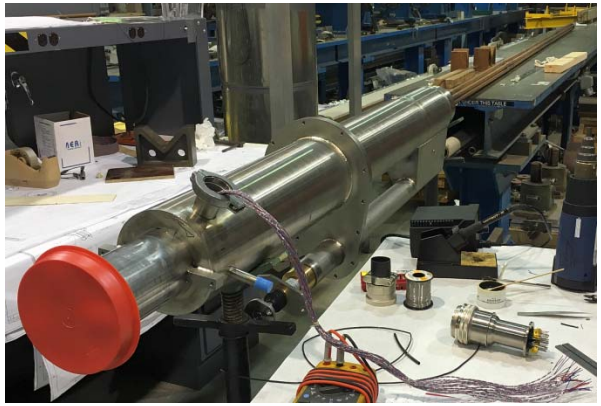
ASSEMBLY COMPLETE

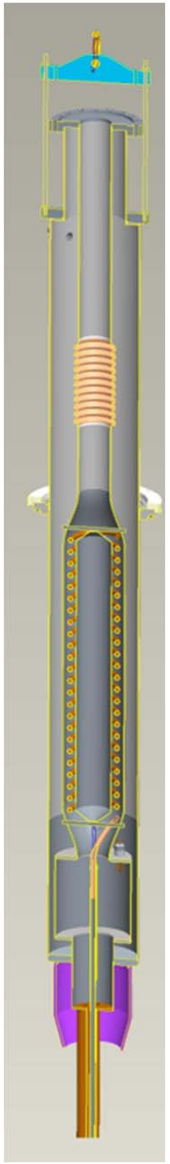
top hx end

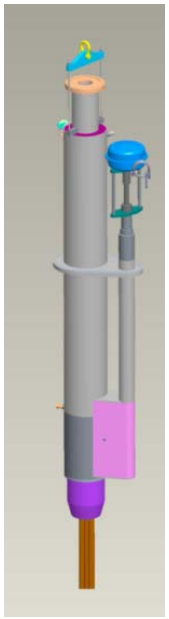
bottom hx end











# Test Dewar p.2
# Helium Dewar & Outer 4K Heat Shield Status

2/10/16 - Contract placed with Ability Engineering;

- Heat shield delivered 5/5/16
  - Assembly work started (welding of stainless steel cooling lines)

Heat shield (at BNL)

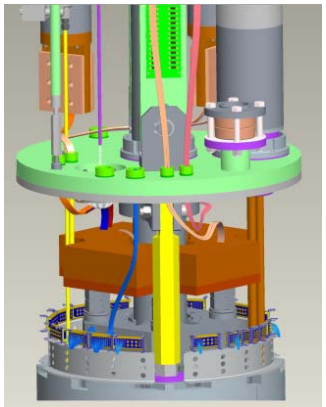
- Fabrication complete, testing underway
  - Delivery expected 5/20

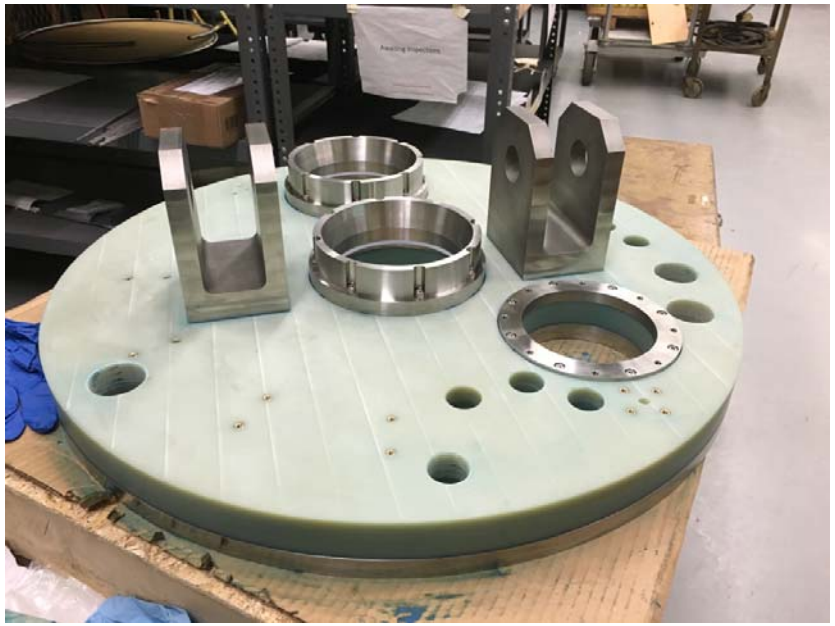
Stainless steel vessel in leak check (at vendor)

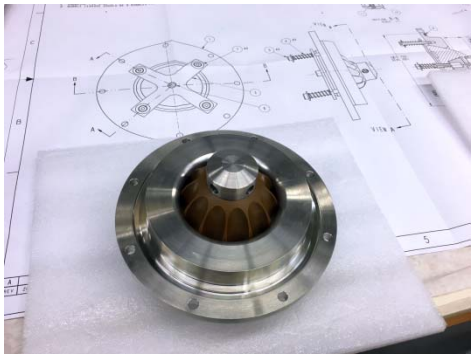
# Test Dewar Status p.3
# Lambda Plate

Assembly underway

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

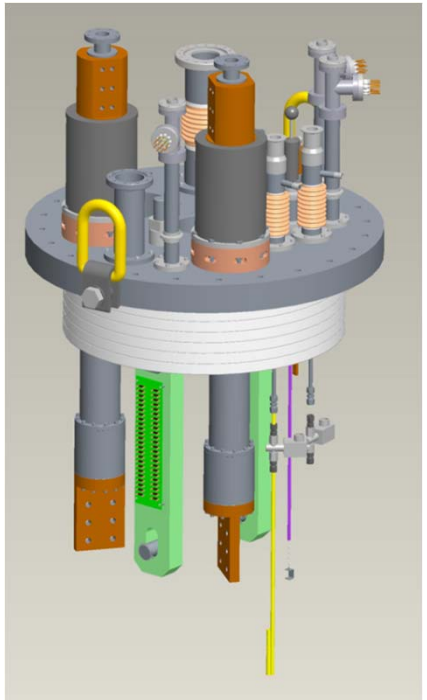


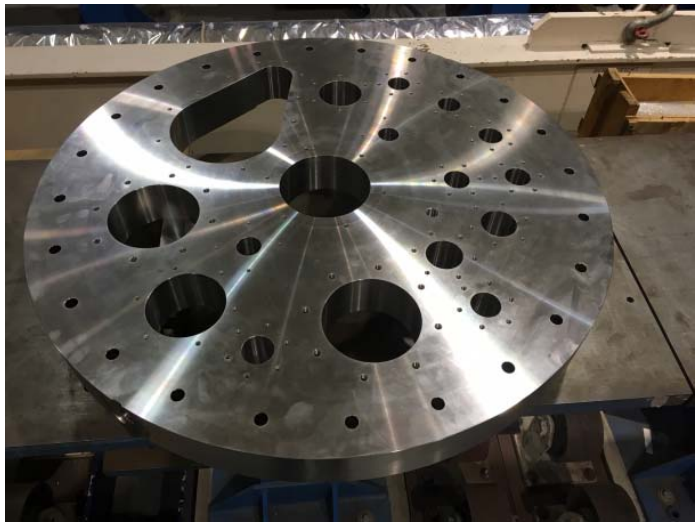




# Test Dewar Status p.4
# Top Hat Assembly

- 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

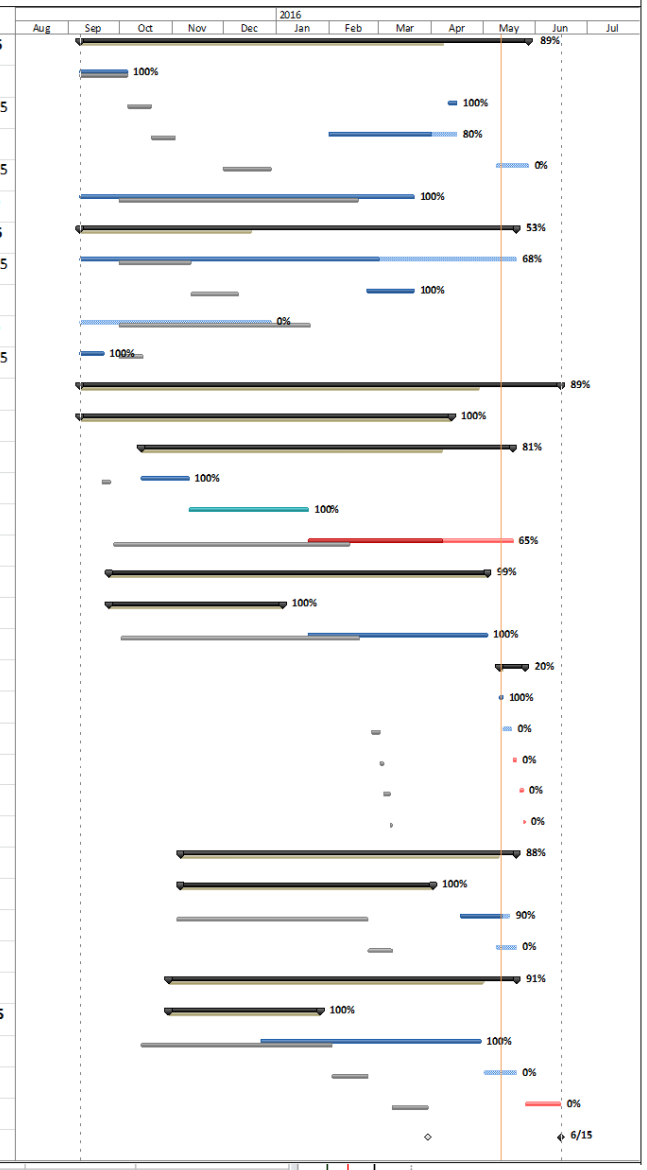




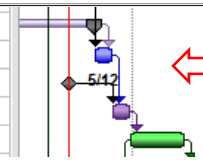
# Schedule To Completion

LARP vertical test facility FY16 051216.mpp

| ID | | Task Mode | Task Name | Duration | Start | Finish | Baseline Start | Baseline Finish |
|---|---|---|---|---|---|---|---|---|
| 1 | | | **cryogenic facility** | **189 days** | **Tue 9/8/15** | **Fri 5/27/16** | **Tue 9/8/15** | **Wed 2/17/16** |
| 2 | ✓ | | install new quench vent lines and valves | 20 days | Tue 9/8/15 | Mon 10/5/15 | Tue 9/8/15 | Mon 10/5/15 |
| 3 | ✓ | | complete wet expander maintenance | 5 days | Mon 4/11/16 | Fri 4/15/16 | Tue 10/6/15 | Mon 10/19/15 |
| 4 | | | turn on / commission Nash pump | 55 days | Mon 2/1/16 | Fri 4/15/16 | Tue 10/20/15 | Mon 11/2/15 |
| 5 | | | turn on / commission CVI refrigerator | 15 days | Mon 5/9/16 | Fri 5/27/16 | Tue 12/1/15 | Mon 12/28/15 |
| 6 | ✓ | | buy, install transfer line from Nash to dewar | 140 days | Tue 9/8/15 | Mon 3/21/16 | Thu 10/1/15 | Wed 2/17/16 |
| 7 | | | **power supply** | **184 days** | **Tue 9/8/15** | **Fri 5/20/16** | **Thu 10/1/15** | **Wed 1/20/16** |
| 8 | | | assemble, test (2) 15KA IGBT cabinets | 184 days | Tue 9/8/15 | Fri 5/20/16 | Thu 10/1/15 | Wed 11/11/15 |
| 9 | ✓ | | complete DAQ etc. wiring installations | 20 days | Tue 2/23/16 | Mon 3/21/16 | Thu 11/12/15 | Wed 12/9/15 |
| 10 | | | design, assemble spike detector & quench antenna systems | 80 days | Tue 9/8/15 | Mon 12/28/15 | Thu 10/1/15 | Wed 1/20/16 |
| 11 | ✓ | | install water-cooled 22KA power cables | 10 days | Tue 9/8/15 | Mon 9/21/15 | Thu 10/1/15 | Wed 10/14/15 |
| 12 | | | **Test Dewar** | **202 days** | **Tue 9/8/15** | **Wed 6/15/16** | **Tue 9/8/15** | **Tue 3/29/16** |
| 13 | ✓ | | **heat exchanger assembly** | **156 days** | **Tue 9/8/15** | **Tue 4/12/16** | **Tue 9/8/15** | **Thu 3/10/16** |
| 17 | | | **helium dewar** | **156 days** | **Wed 10/14/1** | **Wed 5/18/16** | **Mon 9/21/15** | **Fri 2/12/16** |
| 18 | ✓ | | release drawings (13 details, 1 assembly) | 20 days | Wed 10/14/1 | Tue 11/10/15 | Mon 9/21/15 | Fri 9/25/15 |
| 19 | ✓ | | vendor search | 50 days | Wed 11/11/1 | Tue 1/19/16 | NA | NA |
| 20 | | | fabricate parts | 86 days | Wed 1/20/16 | Wed 5/18/16 | Mon 9/28/15 | Fri 2/12/16 |
| 21 | | | **outer 4K heat shield** | **158 days** | **Fri 9/25/15** | **Tue 5/3/16** | **Fri 9/25/15** | **Thu 2/25/16** |
| 22 | ✓ | | **release drawings (16 details, 1 assembly)** | **72 days** | **Fri 9/25/15** | **Mon 1/4/16** | **Fri 9/25/15** | **Thu 10/1/15** |
| 27 | ✓ | | fabricate parts | 75 days | Wed 1/20/16 | Tue 5/3/16 | Fri 10/2/15 | Thu 2/18/16 |
| 28 | | | **assemble & install helium dewar & heat shield** | **11 days** | **Wed 5/11/16** | **Wed 5/25/16** | **Fri 2/26/16** | **Tue 3/8/16** |
| 29 | ✓ | | weld, install cooling lines | 2 days | Wed 5/11/16 | Thu 5/12/16 | NA | NA |
| 30 | | | wrap heat shield in MLI | 3 days | Fri 5/13/16 | Tue 5/17/16 | Fri 2/26/16 | Tue 3/1/16 |
| 31 | | | install heat shield to helium vessel | 2 days | Thu 5/19/16 | Fri 5/20/16 | Wed 3/2/16 | Thu 3/3/16 |
| 32 | | | weld supply & return lines | 2 days | Mon 5/23/16 | Tue 5/24/16 | Fri 3/4/16 | Mon 3/7/16 |
| 33 | | | **install in dewar** | **1 day** | **Wed 5/25/16** | **Wed 5/25/16** | Tue 3/8/16 | Tue 3/8/16 |
| 34 | | | **top hat** | **141 days** | **Fri 11/6/15** | **Fri 5/20/16** | **Fri 10/2/15** | **Tue 3/8/16** |
| 35 | ✓ | | release drawings (46 details, 1 assembly) | **106 days** | **Fri 11/6/15** | **Fri 4/1/16** | **Fri 10/2/15** | **Tue 11/3/15** |
| 39 | | | fabricate parts | 21 days | Mon 4/18/16 | Mon 5/16/16 | Wed 11/4/15 | Tue 2/23/16 |
| 40 | | | assemble | 10 days | Mon 5/9/16 | Fri 5/20/16 | Wed 2/24/16 | Tue 3/8/16 |
| 41 | | | **lambda plate & magnet supports** | **146 days** | **Fri 10/30/15** | **Fri 5/20/16** | **Mon 9/28/15** | **Tue 2/23/16** |
| 42 | ✓ | | release drawings (24 details, 1 assembly) | **63 days** | **Fri 10/30/15** | **Tue 1/26/16** | **Mon 9/28/15** | **Tue 10/13/15** |
| 46 | ✓ | | fabricate parts | 93 days | Wed 12/23/1 | Fri 4/29/16 | Wed 10/14/1 | Tue 2/2/16 |
| 47 | | | assemble | 15 days | Mon 5/2/16 | Fri 5/20/16 | Wed 2/3/16 | Tue 2/23/16 |
| 48 | | | **commissioning tests** | 15 days | Thu 5/26/16 | Wed 6/15/16 | Wed 3/9/16 | Tue 3/29/16 |
| 49 | | | **TEST FACILITY OPERATIONAL** | 0 days | Wed 6/15/16 | Wed 6/15/16 | Tue 3/29/16 | Tue 3/29/16 |




| | | | | |
|---|---|---|---|---|
| **MQXFP Mirror assembly** | **77 days** | **Fri 2/12/16** | **Tue 5/31/16** | **189,418,396** |
| Shipment to BNL | 2 wks | Wed 6/1/16 | Tue 6/14/16 | 419,420 |
| BNL Test facility commisioned | 0 days | Thu 5/12/16 | Thu 5/12/16 | |
| Test prep | 2 wks | Wed 6/15/16 | Tue 6/28/16 | 426,425 |
| Mirror test | 6 wks | Wed 6/29/16 | Wed 8/10/16 | 427 |

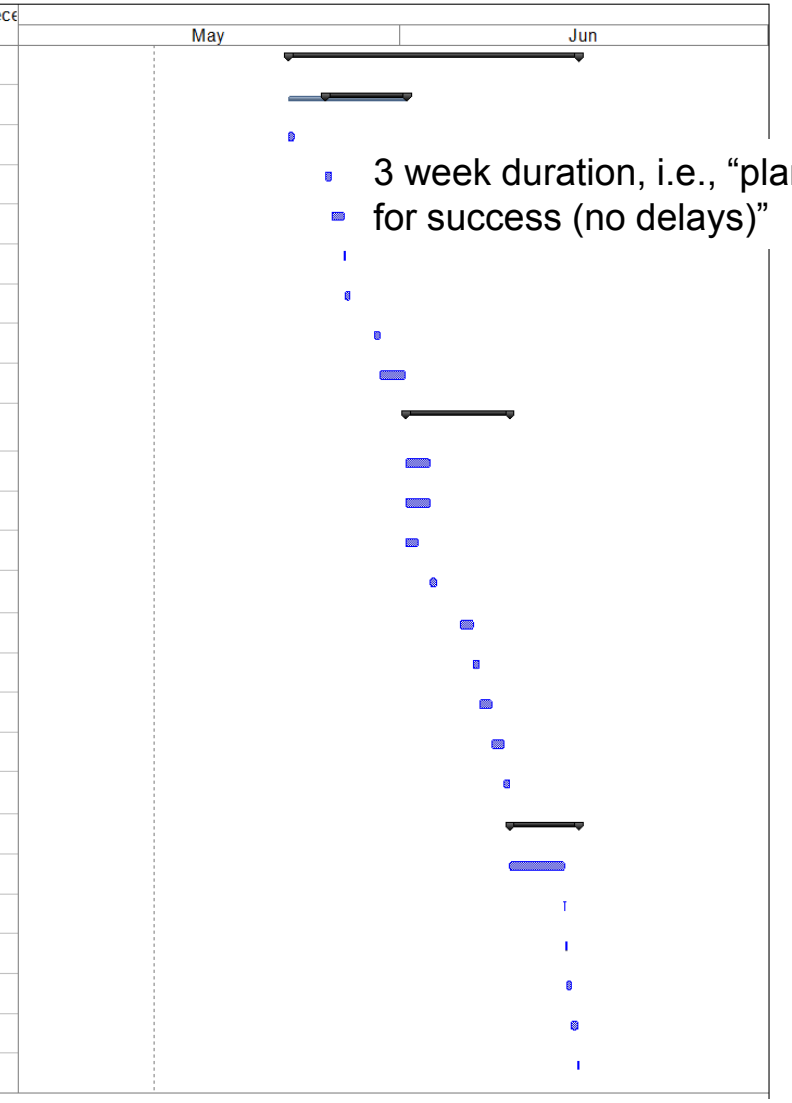



6/15/16 Commissioning Completion agrees with latest LARP Mirror Test Schedule

G. Ambrosio, MQXF_160502.MPP

# Test Facility Commissioning

| ID | Task Name | Duration | Start | Finish | Predece |
|---|---|---|---|---|---|
| 1 | **LQXF Cold Test Cycle** | **17.75 days** | **Mon 5/23/16** | **Wed 6/15/16** | |
| 2 | **prepare for test** | **4.75 days** | **Thu 5/26/16** | **Wed 6/1/16** | |
| 3 | install top hat / lambda plate on wiring stand | 0.25 days | Mon 5/23/16 | Mon 5/23/16 | |
| 4 | solder test leads | 0.5 days | Thu 5/26/16 | Thu 5/26/16 | 3 |
| 5 | 300K electrical checkout | 1 day | Thu 5/26/16 | Fri 5/27/16 | 4 |
| 6 | move to dewar | 0.25 days | Fri 5/27/16 | Fri 5/27/16 | 5 |
| 7 | connect lambda plate to 1.9K vessel | 0.25 days | Fri 5/27/16 | Fri 5/27/16 | 6 |
| 8 | lower vessel into dewar | 0.25 days | Mon 5/30/16 | Mon 5/30/16 | 7 |
| 9 | connect power leads, Nash, vacuum, inst., etc. | 2.25 days | Mon 5/30/16 | Wed 6/1/16 | 8 |
| 10 | **Cold Test (includes 1 thermal cycle)** | **6.5 days** | **Wed 6/1/16** | **Thu 6/9/16** | |
| 11 | turn on Nash pump | 2 days | Wed 6/1/16 | Fri 6/3/16 | 9 |
| 12 | turn on refrigerator / make liquid | 2 days | Wed 6/1/16 | Fri 6/3/16 | 9 |
| 13 | 300K electrical checkout | 1 day | Wed 6/1/16 | Thu 6/2/16 | 9 |
| 14 | cool to 4.5K | 0.5 days | Fri 6/3/16 | Fri 6/3/16 | 13,12 |
| 15 | start Nash Pump / cool to 1.9K | 1 day | Mon 6/6/16 | Mon 6/6/16 | 14 |
| 16 | 1.9K electrical checkout | 0.5 days | Tue 6/7/16 | Tue 6/7/16 | 15 |
| 17 | current ramp tests | 1 day | Tue 6/7/16 | Wed 6/8/16 | 16 |
| 18 | warmup | 1 day | Wed 6/8/16 | Thu 6/9/16 | 17 |
| 19 | final electrical checkout | 0.5 days | Thu 6/9/16 | Thu 6/9/16 | 18 |
| 20 | **breakdown test** | **3.75 days** | **Fri 6/10/16** | **Wed 6/15/16** | |
| 21 | disconnect power leads, Nash, vacuum, inst., etc. | 2.25 days | Fri 6/10/16 | Tue 6/14/16 | 19 |
| 22 | raise vessel from dewar | 0.25 days | Tue 6/14/16 | Tue 6/14/16 | 21 |
| 23 | detach lambda plate from 1.9K vessel | 0.25 days | Tue 6/14/16 | Tue 6/14/16 | 22 |
| 24 | move to wiring stand | 0.25 days | Tue 6/14/16 | Tue 6/14/16 | 23 |
| 25 | unsolder leads | 0.5 days | Wed 6/15/16 | Wed 6/15/16 | 24 |
| 26 | remove top hat / lambda plate | 0.25 days | Wed 6/15/16 | Wed 6/15/16 | 25 |




3 week duration, i.e., “plan for success (no delays)”

# Summary

- Considerable progress has been made
- Many more important tasks are to be completed in the next ~ 1-2 weeks
- Considerable resources are engaged (engineers, technicians, machinists, welders)
- No “showstoppers” yet

Thank you for your attention