Test Facility Status at FNAL

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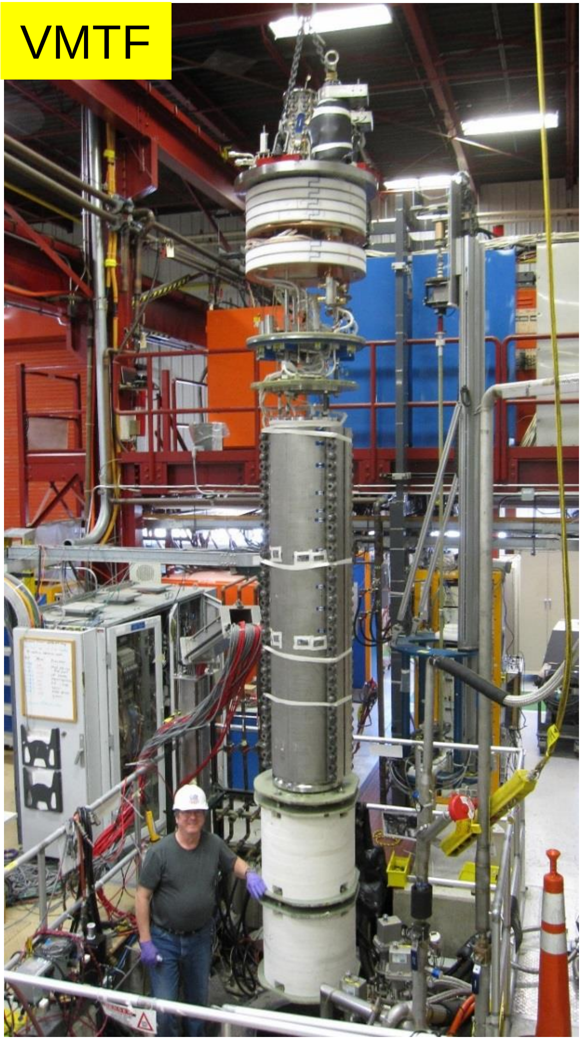
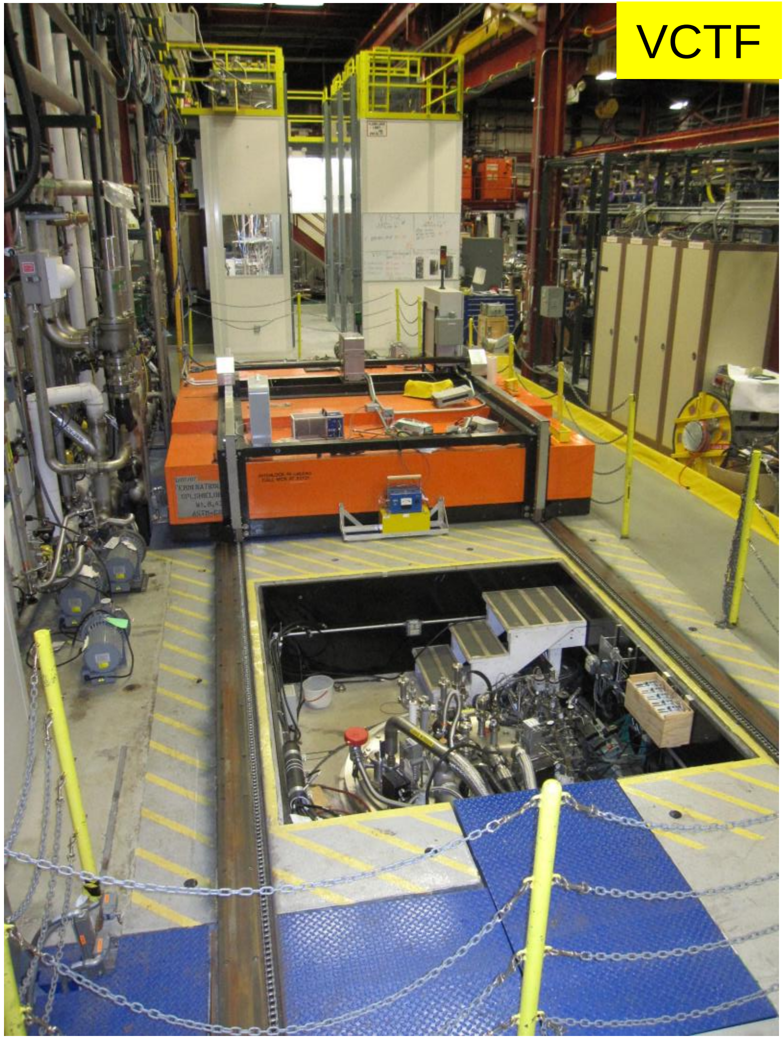
Introduction to Magnet/Cavity Test Facility

- Magnet test facility (MTF) originates from the Main Ring period, when the first main accelerator was built at Fermilab
  - First conventional magnet tests started by the end of the 1960s
- Testing of the first superconducting accelerator magnets started in the late 1970s
  - MTF cryogenic plant in operation since 1978
- Vertical Magnet Test Facility (VMTF) - the main R&D stand for the SC magnets, in operation since 1996
  - LARP magnets – TQ, LQ, HQ, short MQXF model, and many other magnets were tested at VMTF
- Vertical Cavity Test Facility (VCTF) commissioned in 2007 to support the SC RF cavity R&D program at Fermilab
- Currently SC RF cavity and magnet test facilities share all the plant liquefaction capacity

Magnet Test Facility (cont'd)





Cryo-plant Improvements

- Various improvements are planned or already made to improve overall reliability of the cryo-plant
- Already implemented full stream purification system helps to control contamination level
- New liquefier will be procured soon, increasing total LHe make rate to 600 ltr./hour and total liquid storage volume to 14,000 ltr.
  - Current CTI-1500 liquefier with liquefaction rate up to 300 ltr./hour and 10,000 ltr. storage dewar for the LHe
  - New liquefier is expected to be fully operational in 2021
- Combination of higher liquefaction and LHe storage capacities will significantly increase throughput in magnet and SRF cavity testing
  - <u>Practically no downtime due to cryo-plant maintenance</u>

More on Cryo-plant

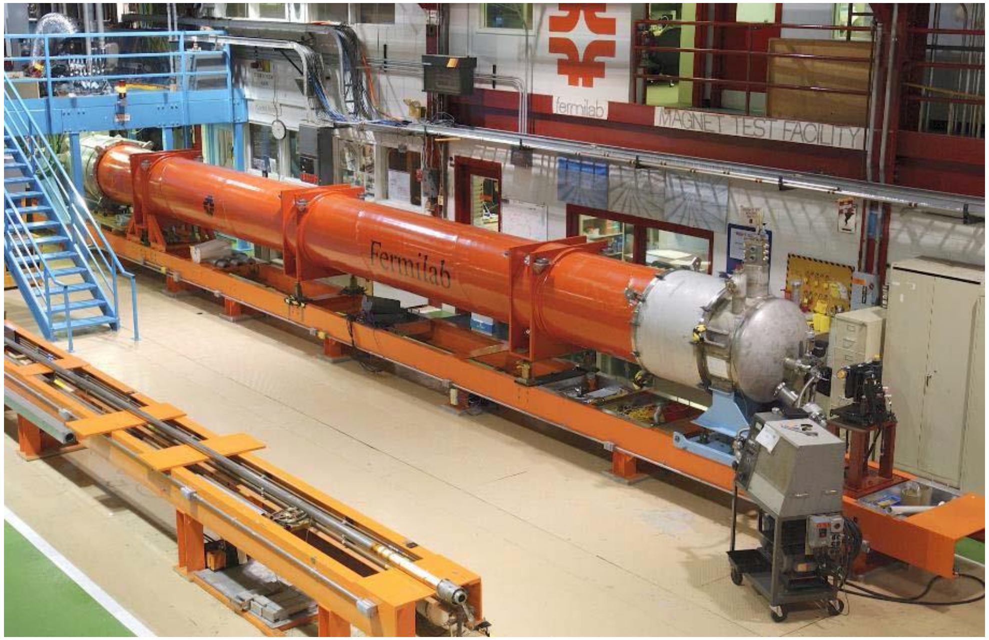
- Five 30,000-Gal (~114 m^3) buffer tanks are used for storage of helium gas

- One 30,000-Gal buffer tank is used for the helium gas recovery after high-current quenches at TS4/VMTF
  - Longer transfer line helps to warm up the GHe

Horizontal Test Stand

- The Horizontal Test Stand (TS4) previously was used for testing the present LHC inner triplet quadrupoles at FNAL in 2001-2006

- Test stand upgrade currently in progress to accommodate new Q1/Q3 cryo-assembly design and meet new test requirements
  - Some of old components will be refurbished and re-used



Old LHC cryo-assembly at the horizontal test stand

Power Systems

- Existing 30 kA power system will be used for Q1/Q3 cryo-assemblies horizontal test
  - 6 PEI-150 (150 kW) power supply units connected in parallel, each delivering 5 kA at 30 V
- New 20 kA rated flexible water-cooled power cables, connecting the solid bus bar to the top plate, were recently installed and tested in a shorted bus configuration
- External energy extraction system based on a solid-state dump switch
  - SCRs mounted in water cooled heatsinks
  - Dump resistor configurations from 2 to 120 mΩ
- No issues are expected with continuous operation at currents up to 25-26 kA
  - 10-15 min or less of continuous operation at currents above 27 kA

Power Systems (cont'd)

150 kW Power Energy Industries (PEI) PS module

Dump Resistor Cabinet

HL-LHC AUP Magnet Tests

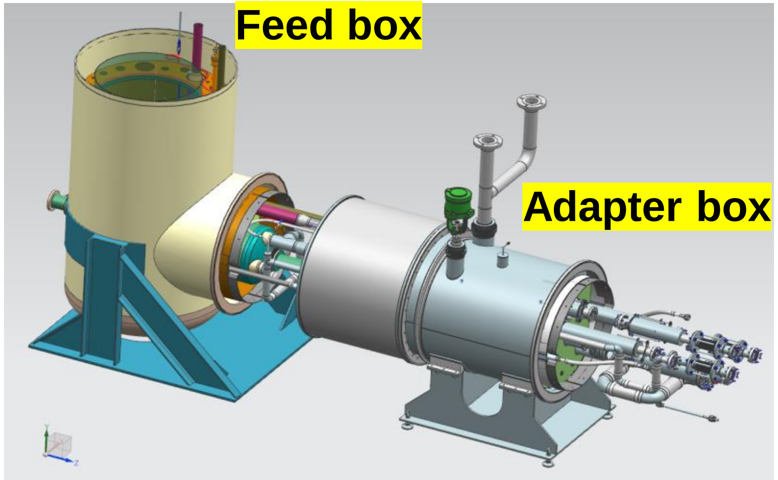
- Q1/Q3 cryo-assemblies with two MQXFA magnets inside will be tested at Fermilab's Horizontal test stand
- Currently project scope is a horizontal test of 12 cryo-assemblies (2 pre-series, 10 production and re-work)
  - MQXFA magnets to be trained at BNL
- 3 power leads at TS4 will allow independent powering of magnets in the cryo-assembly
  - Individual magnet training possible if necessary
  - Independent magnet protection with new CLIQ connection scheme
- Comprehensive magnetic measurements including magnet alignment and harmonics measurements are expected during horizontal tests at Fermilab

Cryo-Mechanical Upgrades

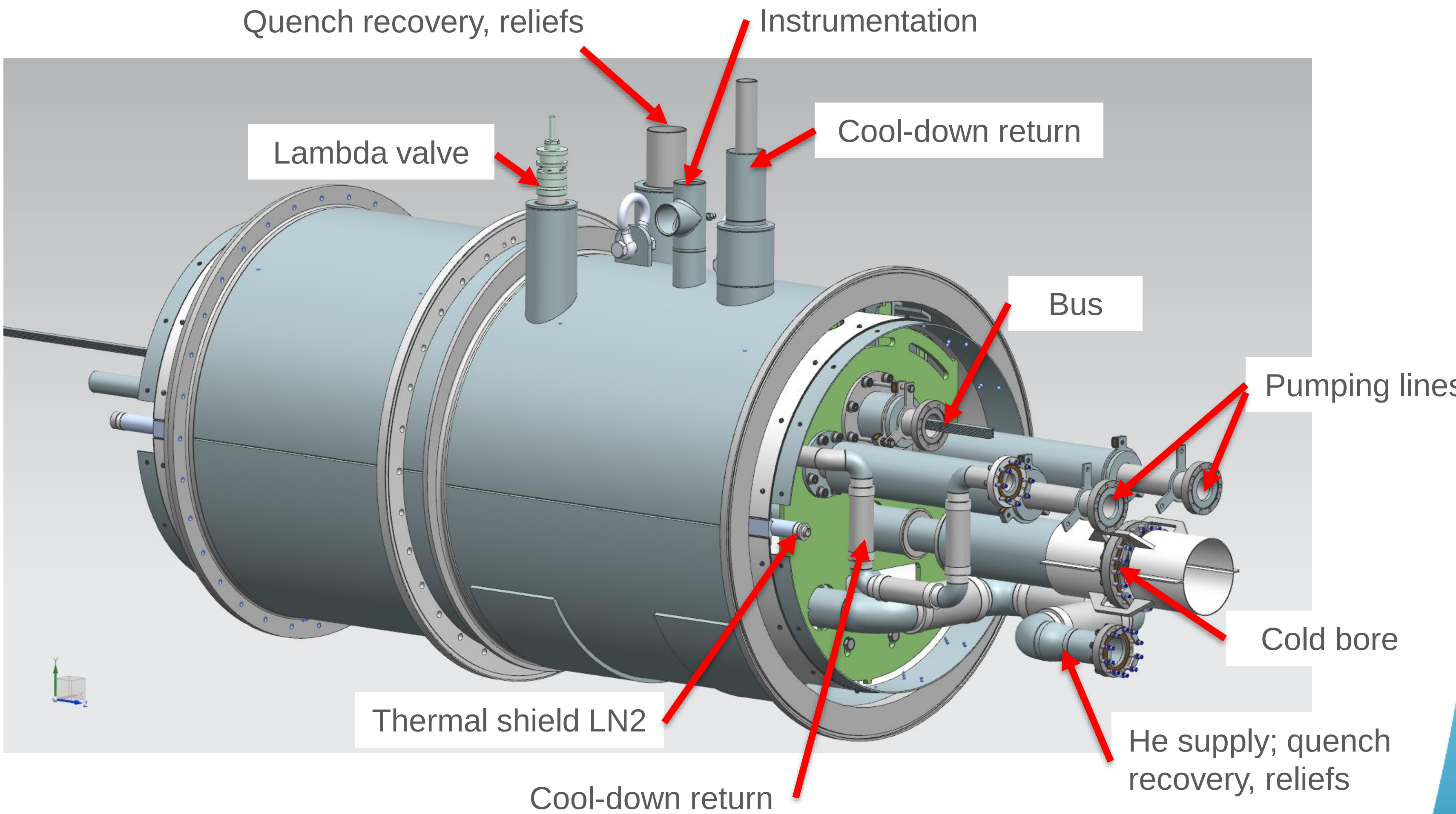
- Various test stand components are under upgrade right now. The plan is to complete most of upgrades in Feb.-March 2020 followed by a zero-magnet test

- Overhead crane upgrade was required for lifting Q1/Q3 cryo-assemblies with two magnets
  - Most cost-efficient solution was to add one more 25 T crane
  - Two cranes in tandem provide a total lifting capacity of 50 T

- New adapter box allows connecting the existing Feed box with the new cryostat



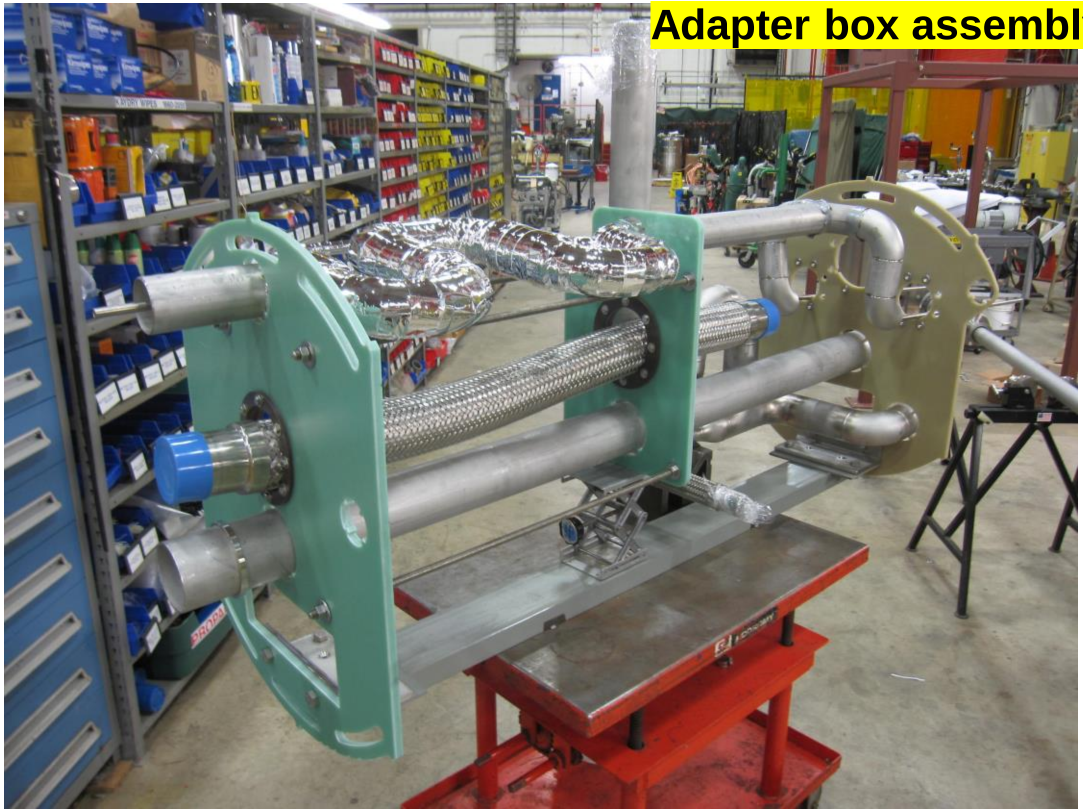
Adapter Box



Quench recovery, reliefs
Instrumentation
Lambda valve
Cool-down return
Bus
Pumping lines
Cold bore
Thermal shield LN2
He supply; quench recovery, reliefs
Cool-down return

Adapter Box Status

- Adapter box assembly currently in progress.
  - Most of (long lead-time) parts/components arrived
  - Expected to be ready for installation at TS4 by the end of this year



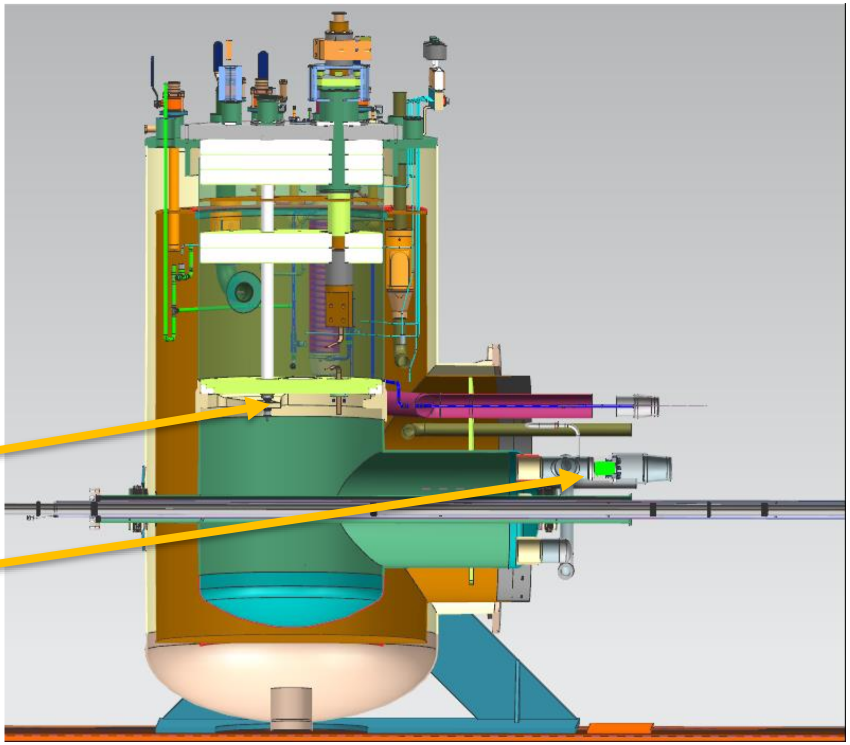
Adapter box assembly in MW9

New location of Lambda plug

- Separation between the 4.5 K and 1.9 K areas moved from the Feed Box to the adapter box (interface between the FB and the cryo-assembly)

- We can test cryo-assemblies at high pressure, i.e. under conditions close to the operation at LHC

- Other obvious advantages
  - Reduced consumption of LHe
  - Fast quench recovery

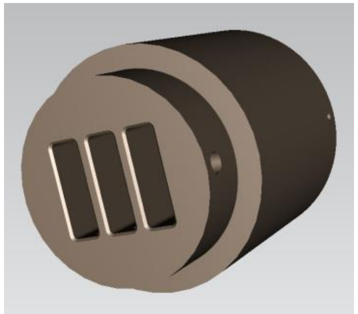


Lambda plate (old location)

New location of lambda plug

Lambda plug

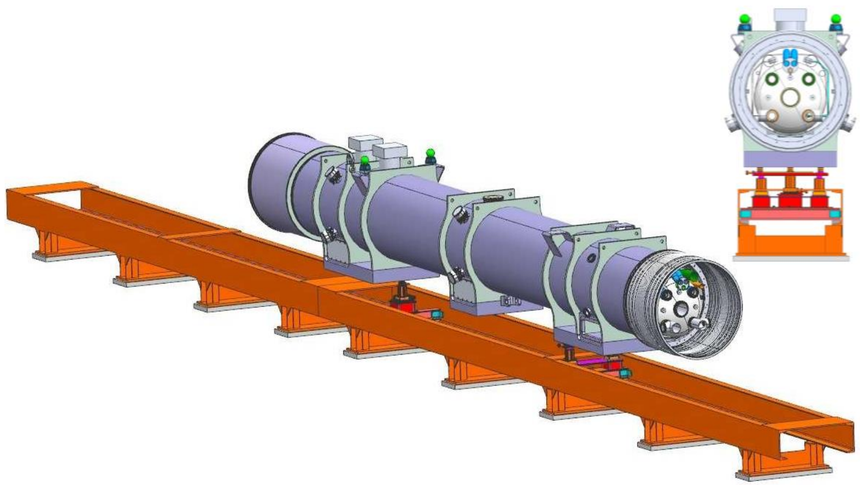
- CERN developed lambda plug design was adopted for Stand 4
  - Lambda plug is made of Ultem 1000
- Lambda plug design at Fermilab is modified to accommodate 3 power leads
- Lambda plug prototype assembly is ready for cold testing in LN2
  - Leak rate check at 300 K and cold
  - ~280 psig pressure drop will be created by GHe supply
  - Several thermal cycles

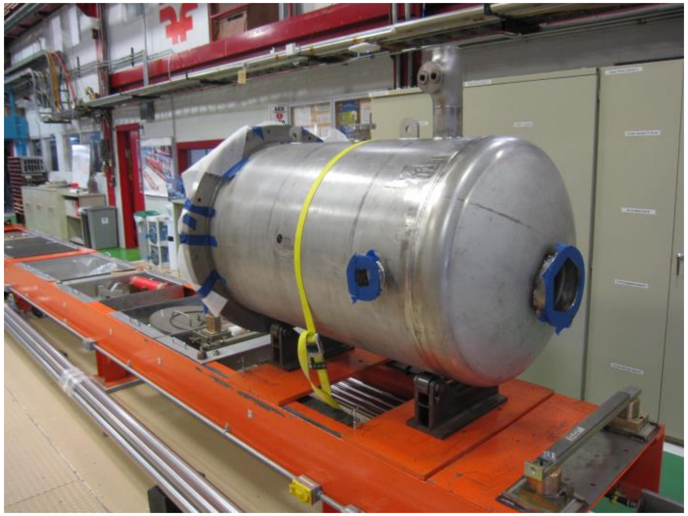


More Cryo-Mechanical Upgrades

- Quench recovery system design and analysis is complete, the required sizing is established
  - Eliminate unexpected and unnecessary venting of helium
  - Quench system was reviewed in Jan. 2019, assembly after the zero-magnet test

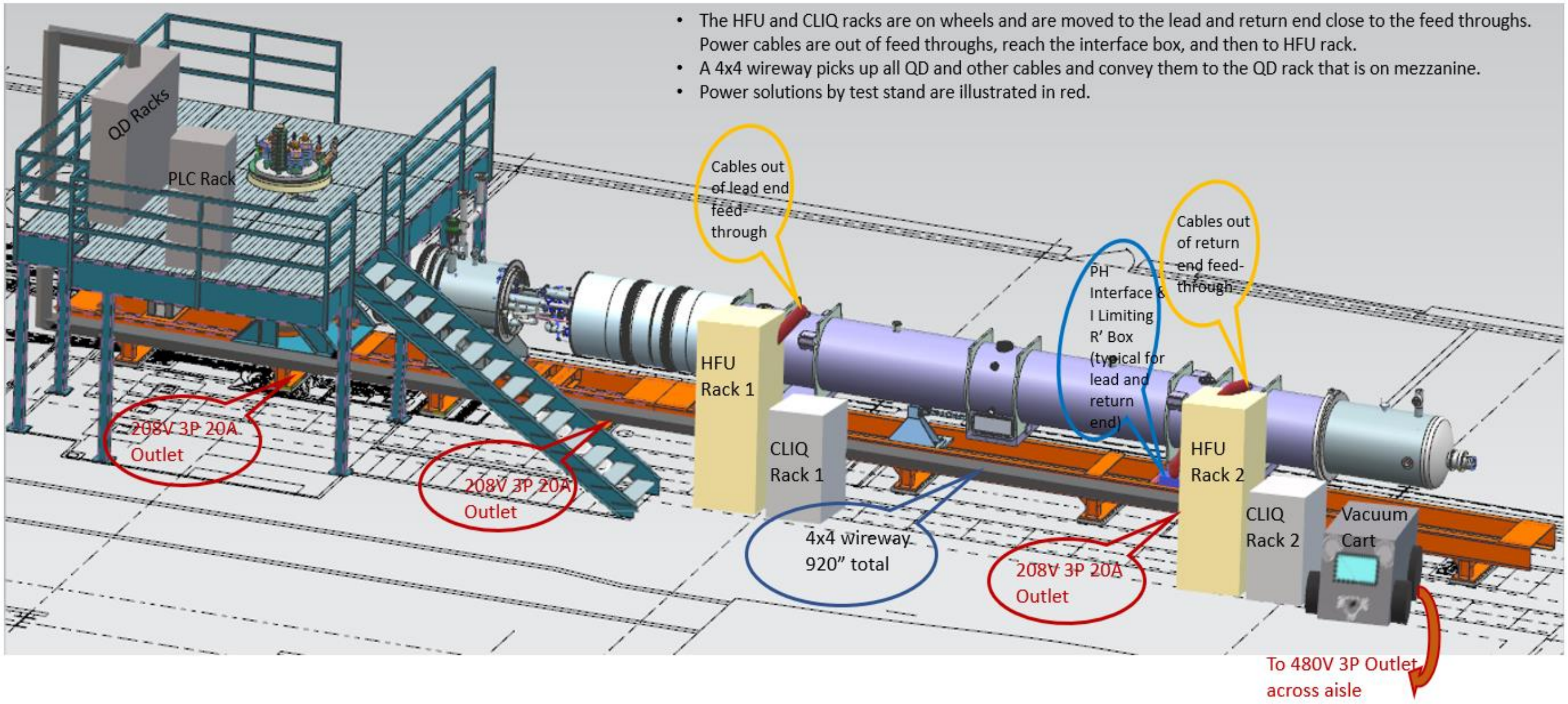
- New Return End box just delivered





- 3-point mounting support system is developed and fabricated
  - CERN designed anchor for axial support will help to restrain the cryo-assembly against the longitudinal forces

Horizontal Test Stand layout



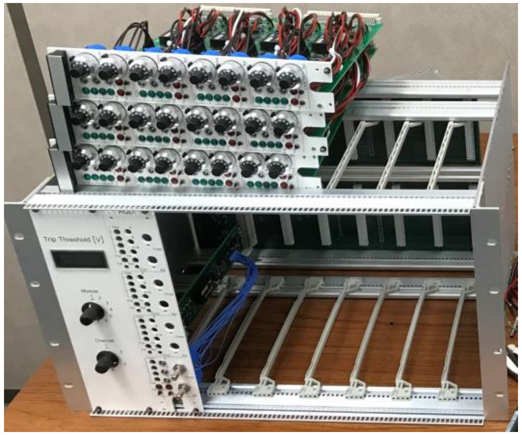
Quench Protection and Monitoring

- QPM Requirements and Specifications are developed
  - A three-tier design will be deployed: Tier 1 – primary QD, Tier 2 – secondary QD, and Tier 3 – System Monitoring and Data Management
- High reliability is achieved with two independent systems: Digital (primary) and Analog (secondary) quench detection
  - Validation time implemented
  - Current dependent thresholds applied to avoid voltage spike trips
- Coupling loss Induced Quench (CLIQ) system is included in the magnet protection along with the quench heaters
  - CLIQ fabrication in progress, delivery in Nov.-Dec. 2019
- Heater Firing Units (HFU) are provided by CERN
  - 4 units arrived, (12 + 2 spares) - to be delivered this year
  - FNAL QP requires additional features: crowbar function, load status, charge status and front panel indicators and manual controls

Quench Detection System Status

- Full chasses of Analog and Digital quench detection modules are assembled
- AQD and DQD final tests in progress. Full integration tests of the AQD, DQD and Tier-III will be done in Nov.-Dec. 2019
- QPM final commissioning during the zero-magnet test in Mar. 2020

AQD (left) and DQD chasis



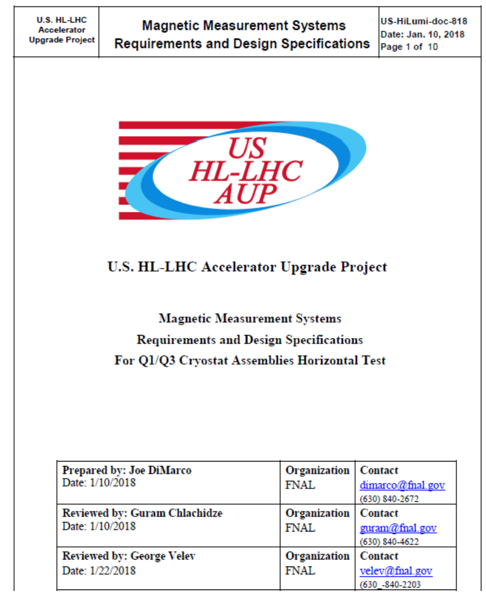
DQD Module

Magnetic measurement systems

- Rotating coil and Single Stretched Wire Systems will be used for alignment, field strength and harmonics measurements

- Measurement system requirements and design specifications were developed in 2018

New SSW system



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U.S. HL-LHC Accelerator Upgrade Project

Magnetic Measurement Systems
Requirements and Design Specifications
For Q1/Q3 Cryostat Assemblies Horizontal Test

Prepared by: Joe DiMarco Date: 1/10/2018	Organization FNAL	Contact dimarco@fnal.gov (630) 840-2672
Reviewed by: Guram Chlachidze Date: 1/10/2018	Organization FNAL	Contact guram@fnal.gov (630) 840-4622
Reviewed by: George Velev Date: 1/22/2018	Organization FNAL	Contact velev@fnal.gov (630_-840-2203

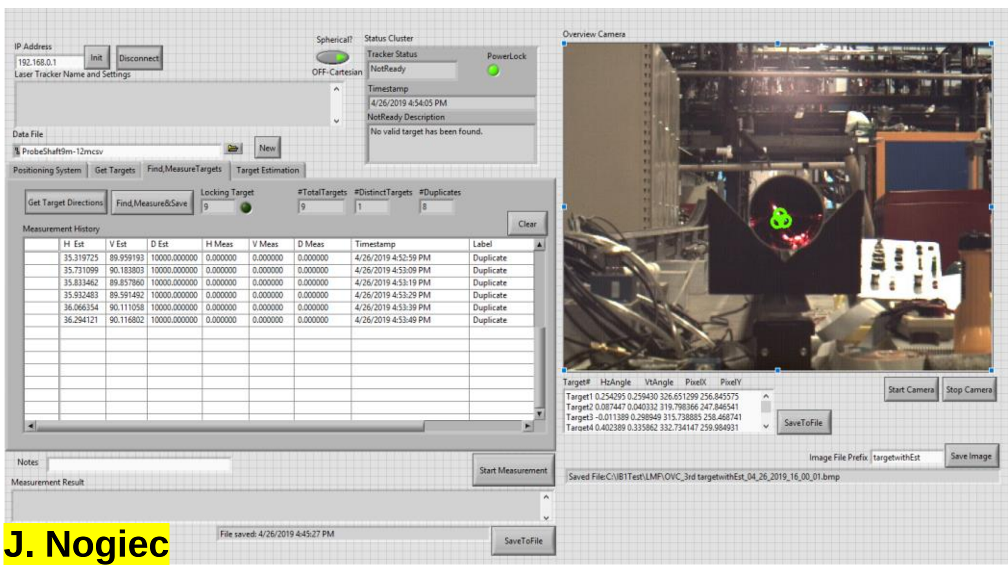
- Single Stretched Wire (SSW) system is already assembled
  - Currently in commissioning
  - Similar systems are successfully used for LCLS-II, Mu2e, etc.

Magnetic measurement systems (cont'd)

- Rotating coil system DAQ was successfully tested with MQXFS1 short model at VMTF
- Fermilab developed PCB measurement probes are used at BNL, LBNL and FNAL
  - Currently dual 110/220-mm and single 440-mm long probes are available.
  - Work on dual 110/110-mm probe in progress.

Precise magnetic measurements at Stand 4

- For accurate measurements of the local magnetic center and field angles we need to know the measurement probe location and orientation inside the magnet with high precision
- Laser tracker will follow and measure 3 targets (reflectors) on a probe
  - Dedicated software developed for finding and measurement of targets
  - Tests currently in progress at magnet test facility



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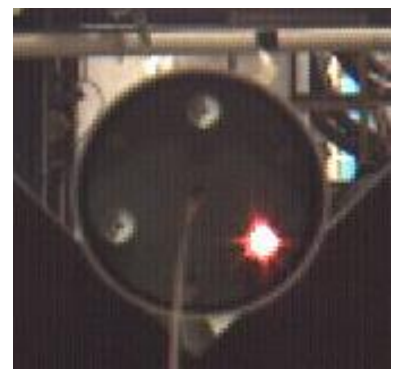


Probe with 3 targets inside the warm bore tube

Process Controls Upgrade

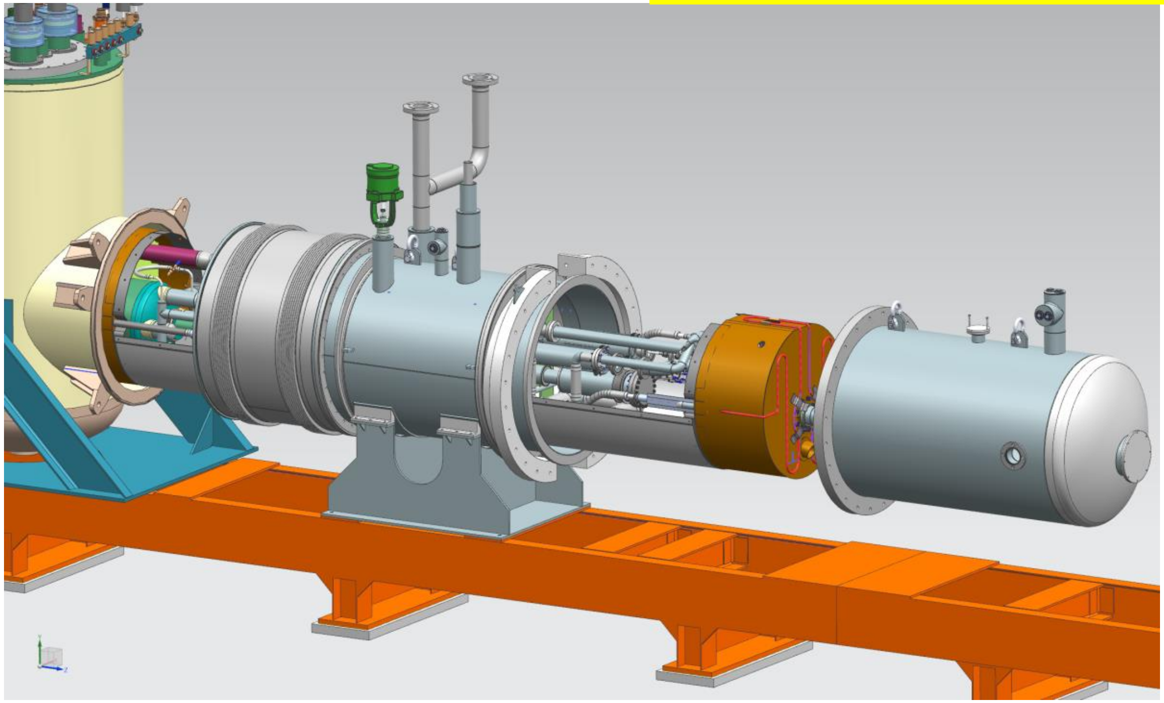
- High level architecture and design has been finalized
- Old PLC cabinets were disconnected and moved out from the platform at Horizontal Test Stand
- Fully populated new (S7/400, Lakeshore and I/O) cabinets are installed, PLC networked
- Work on the PLC programming & integration with iFix in progress
- Terminations of the control instrumentation in Jan. 2020
- New system commissioning is expected in Jan-Feb 2020

New PLC cabinets at TS4

Zero-magnet test

- Zero-magnet test – major milestone for Horizontal Test Stand upgrade
  - Most cryo-mechanical upgrades, power leads, lambda plug, controlled cool-down, as well as new QPM system will be commissioned

Test stand 3D model for zero-magnet test



Summary

- Thanks to experienced and hardworking team Horizontal Test Stand upgrade is on track to meet very important milestone - zero-magnet test in March 2020
- Recent and planned cryo-plant upgrades will allow reliable cryogenic operation of the magnet test stand in parallel with the SRF cavity testing
- Overhead crane capacity at MTF now is adequate for lifting and handling Q1/Q3 cryo-assembles
- Upgrade of various test stand components will be completed soon
  - Adapter box assembly in Nov.-Dec.
  - Lambda plug prototype cold test expected in a week or two
  - New transfer lines/warm piping installations in Nov.-Dec.
- Quench detection integration tests in Dec. 2019
- Preparations for pre-series cryo-assembly test will start immediately after zero-magnet test

Backup Slides

More on Cooling Capacity

- Full stream purification system helps to control contamination level of H_2O, N_2 and O_2 increasing overall cryo-plant reliability

- New Helium compressor skids - 4 Kinney pumps in parallel used for TS4/VMTF and VCTF
  - Total pumping speed of 10 g/s at 12 torr (4.5 K operation) and 15 g/s at 20 torr (1.9 K operation)

- 10,000 Gal LN_2 dewar filled twice a week
  - Dry gas in warm bore
  - 1st stage cooling of the cold box

- Industrial Cooling Water (ICW) system feeds the low conductivity water (LCW) for cooling power supplies or conventional magnets