HiLumi
HL-LHC PROJECT

Magnet Test Facility at LBNL

M. Marchevsky and the MTF Team,
Lawrence Berkeley National Laboratory
Berkeley, CA U.S.A.

EuCARD²

1st Intl. Workshop of the Superconducting Magnets Test Stands,
CERN, June 13-14, 2016

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The Team

<u>Berkeley Center for Magnet Technology (BCMT)</u>

Steve Gourlay

<u>BCMT Magnet Test Chair</u>

GianLuca Sabbi

<u>Magnet Test Facility</u>

Physicist / PI: **Maxim Marchevsky**

Electronics Engineer: **Marcos Turqueti**

Liquid He plant operator: **Paul Bish**

Electronics Technician: **Jordan Taylor**

Cryogenic / Mechanical Tech

<u>Short Sample Test Facility</u>

Physicist / PI: **Xiaorong Wang**

Physicist: **Tengming Chen**

Postdoc: **Lyiang Ye**

Electronics/Mechanical/CryoTech: **Hugh Higley**

<u>Mechanical Engineering and Tech Support</u>

Mechanical Engineers: **Ray Hafalia, Dan Cheng**

Tech lead: **Tom Lipton**

Mechanical Technicians: **James Swanson, Matt Reynolds, Ahmet Pekedis**

Role of the MTF

- An essential tool for efficient, reliable and safe characterization of magnet performance: **training, quench locations, quench propagation dynamics, ramp-rate behavior, strain distribution, mechanical instabilities, protection limits, and field quality**
- An array of diagnostic tools to study and understand magnet behavior and provide feedback to the magnet designers
- A platform for testing new ideas, concepts and instrumentation, allowing us to keep a leading edge in magnet technology and expand into new areas

Magnets tested recently:

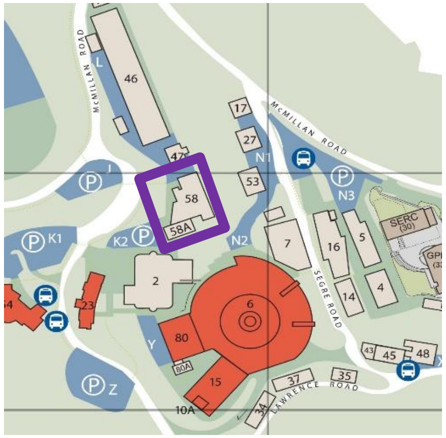
- *HQ01a (5/2010), HQ01b (6/2010), HQ01c (9/2010), HQ01d (4/2011), HQ01e3 (12/2012)*
- *HD3a (12/2011), HD3b (4/2013)*
- *CCT1 (12/2013), CCT2 (05/2014), CCT3a (03/2016)*

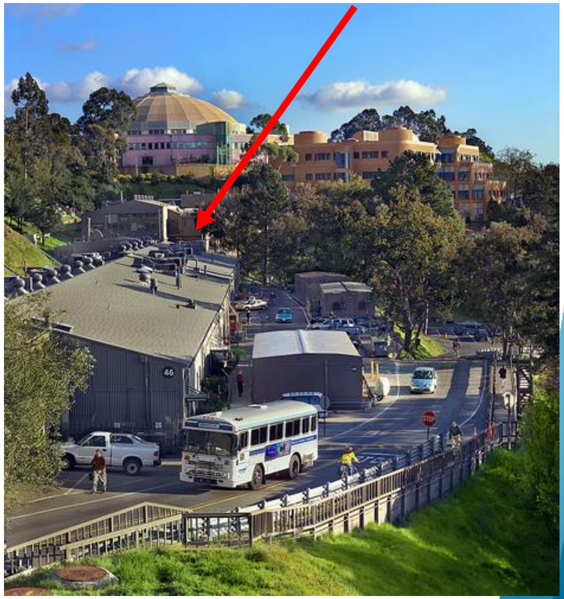
LBNL's versatile magnet test facility can be operated with a smaller group of people, greater flexibility, faster turnaround, some unique instrumentation capabilities, and at a lower cost.

Location

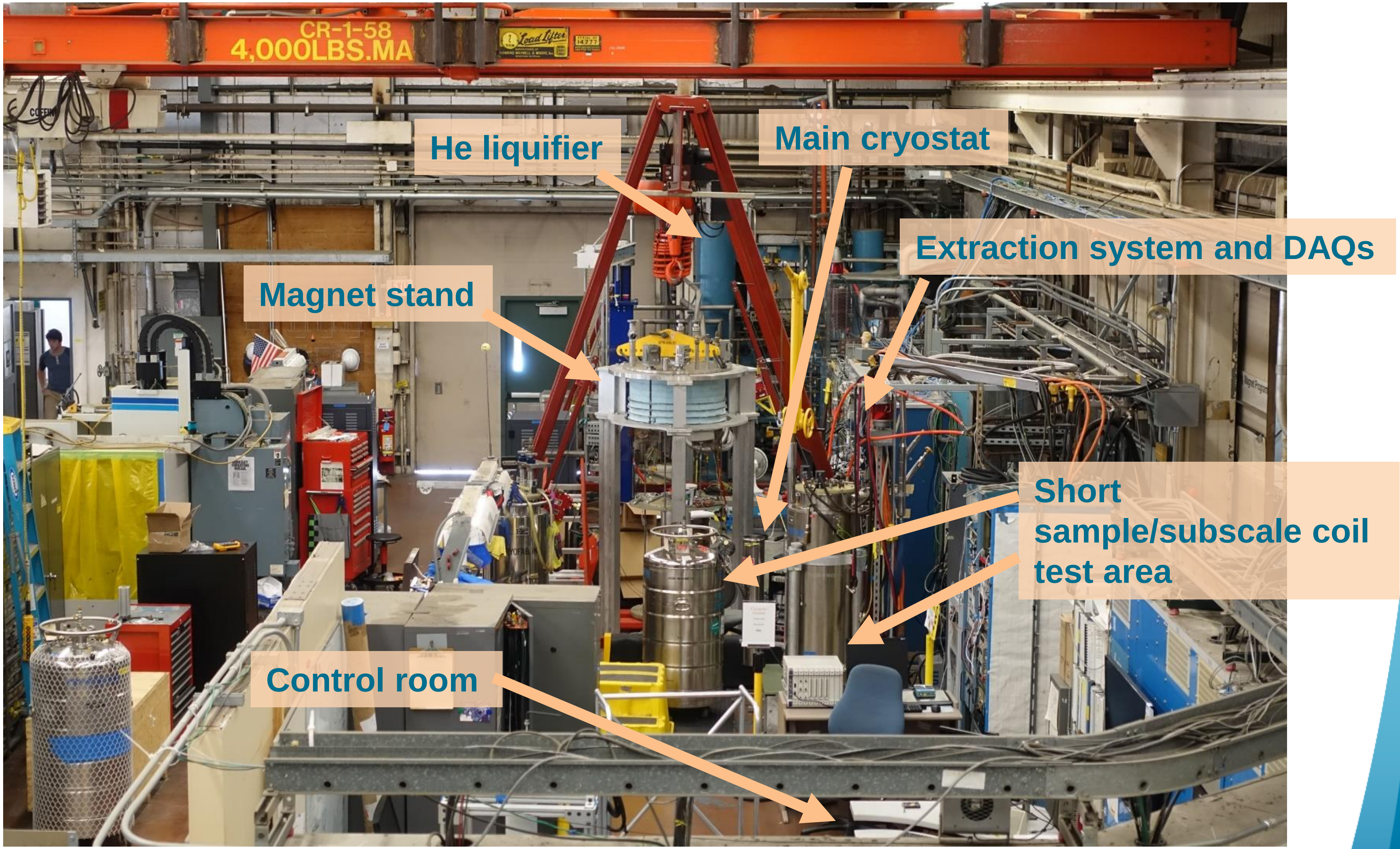
- Berkeley, CA

- LBNL Bldg. 58



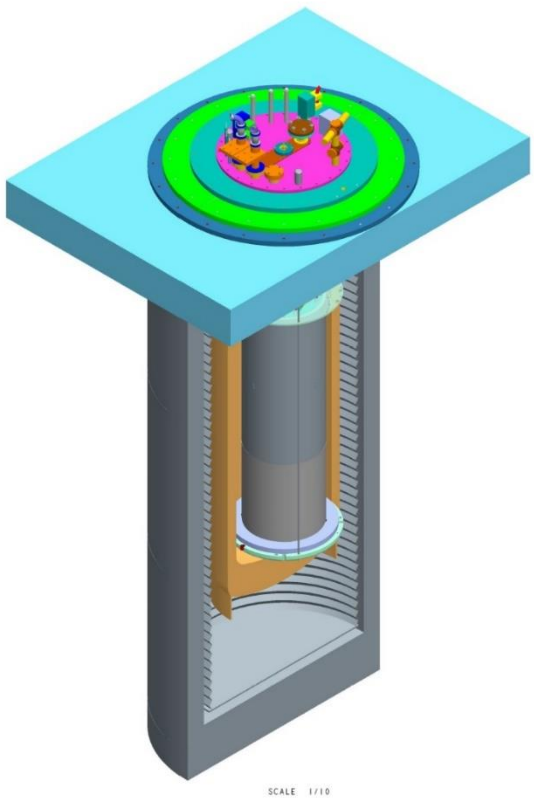


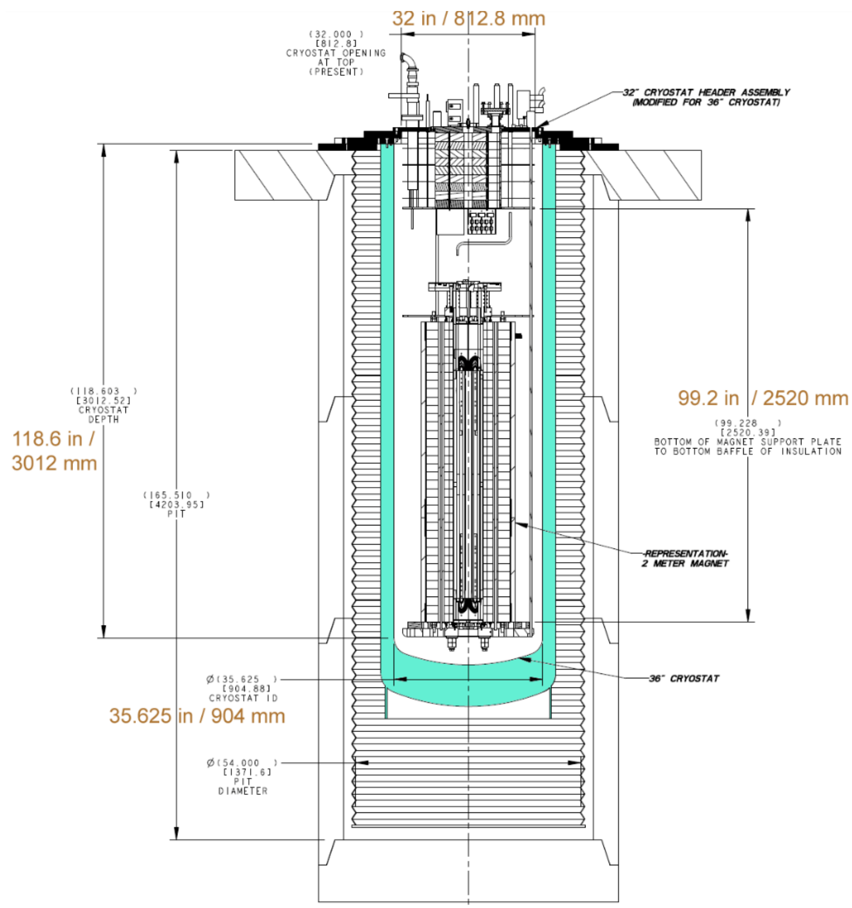
Look inside bldg. 58



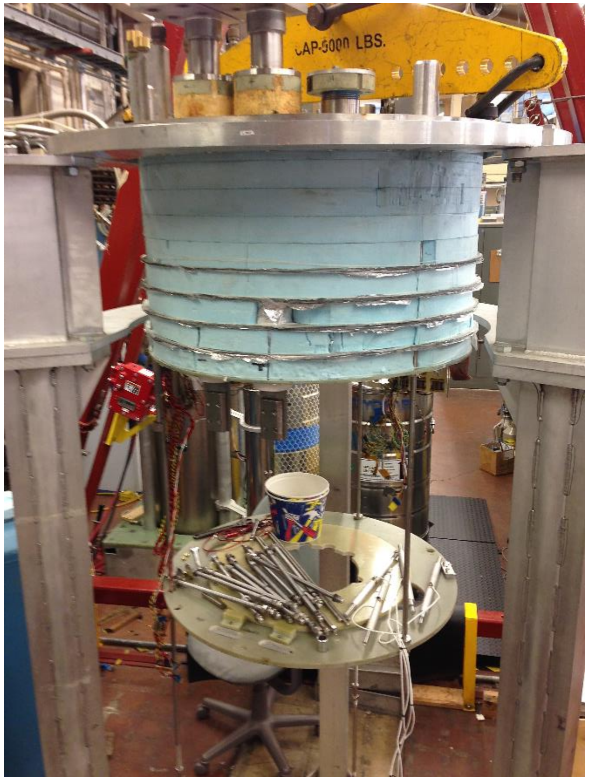
Main cryostat

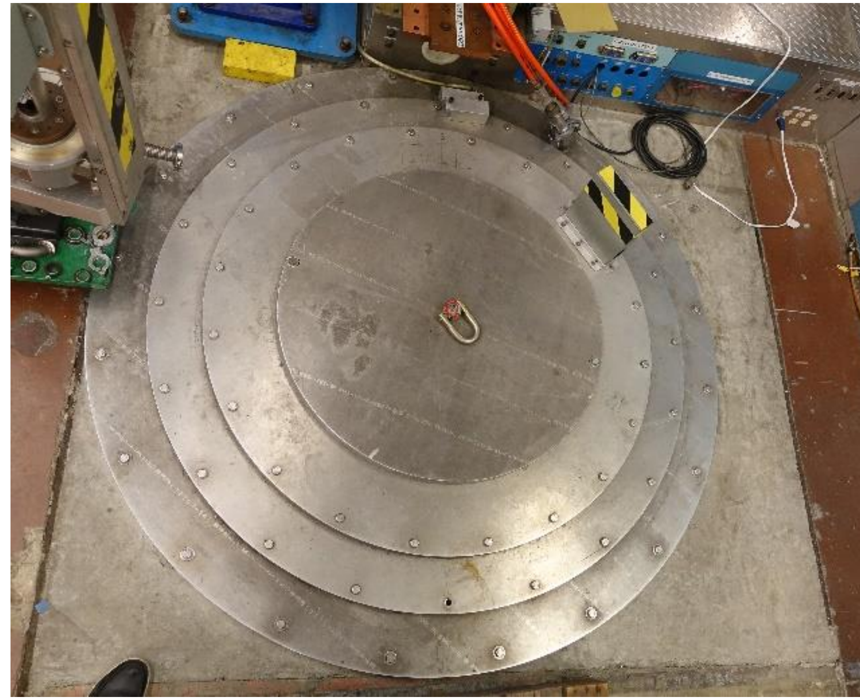
- ~ 3 m long stainless cryostat (made by Precision Cryogenics)
- ~ 1600 L fill capacity (empty); typically ~ 500-800 L with the magnet
- Max. operational pressure: 13 psi
- ~ 0.9 m ID (adjusted with top plate rings to 0.8 m header diameter
- 4.2 K base temperature





Magnet header & stand surface



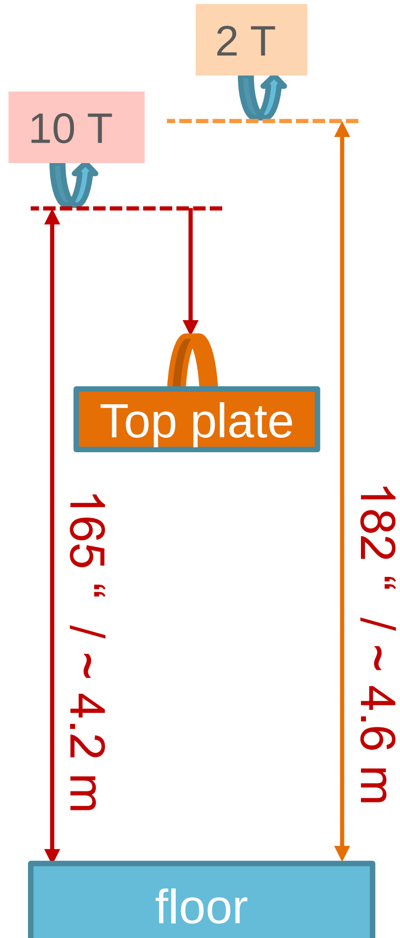


- Ring-adjustable top plate ID

- Maximal magnet height ~ 2.2 m
- Maximal magnet weight: 3000 kg (tested)
- Header weight: 340 kg
- Maximal magnet diameter ~0.8 m

Handling cranes (10 T, 2 T)

10 T crane (covering the magnet stand area)
coverage)



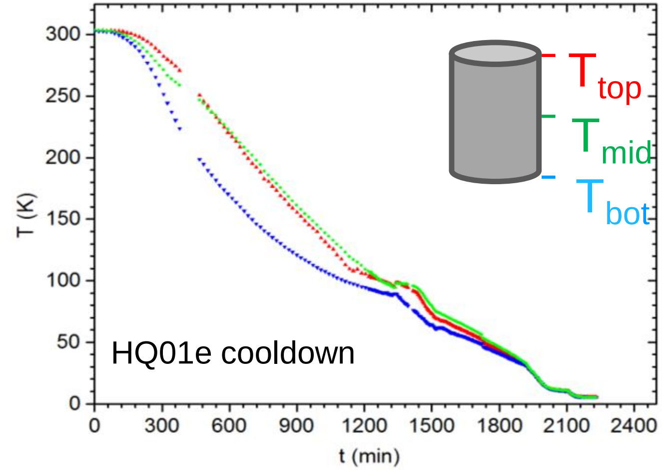
2 T crane (covering the entire building)

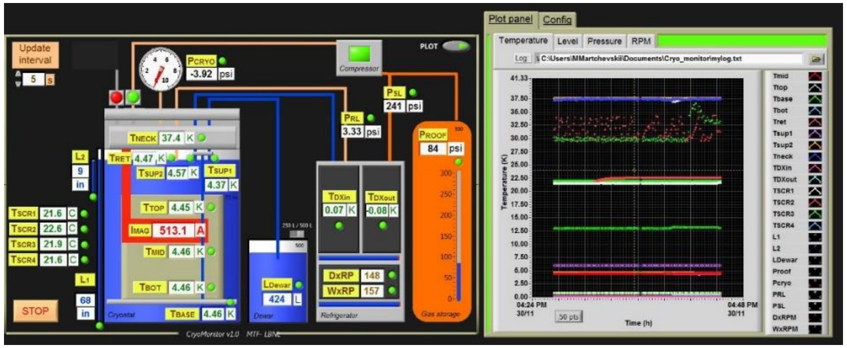
Helium liquifier and cryo-monitoring

- 200 W
- In operation since the 1980, and still running strong
- Liquid Helium production rate: 40 l/h
- Typical cooldown period from room temperature to 4.2 K: ~1.5 days

Liquifier control panel

Inlet and return He lines





Monitoring is available remotely, and on mobile devices

Compressor and Helium gas storage

- Sullair series C20L oil flooded screw compressor with 400 HP 60 Hz 480 V Westinghouse motor
- Nominal output pressure to the coldbox: 240 psi

- Storage capacity: ~1500 L (liquid equivalent).
- Storage pressure: up to 245 psi
- Additional roof storage 500 L equivalent

LBNL-supported Cryo Upgrade

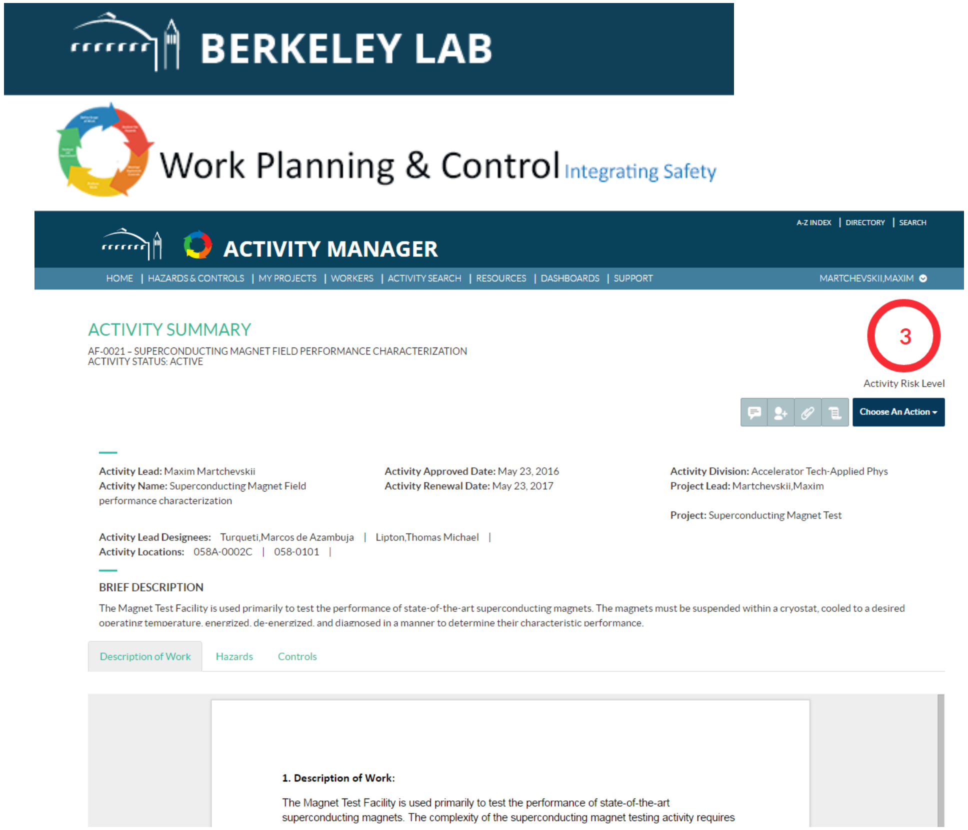
	Linde (M1630)
Capacity	218 W @ 4.6 K, 70 L LHe/h
LN2 Consumption	80 L/h
Electrical Power	80 kW
Cost	$ 1 M

- With additional expenses on recovery system, piping, instrumentation, civil engineering, support utilities and labor, the net planned upgrade figure is **~ $ 2,500,000**

Control room

- Many “legacy” indicators & controls on the panels… but these days the test is controlled exclusively through the LabView / LabWindows interfaces (to PS, DAQs & quench detection) over Ethernet network.
- Analog QDS system and lead over-voltage indicators are still used for redundancy and included in the power supply interlock loop.

Safety

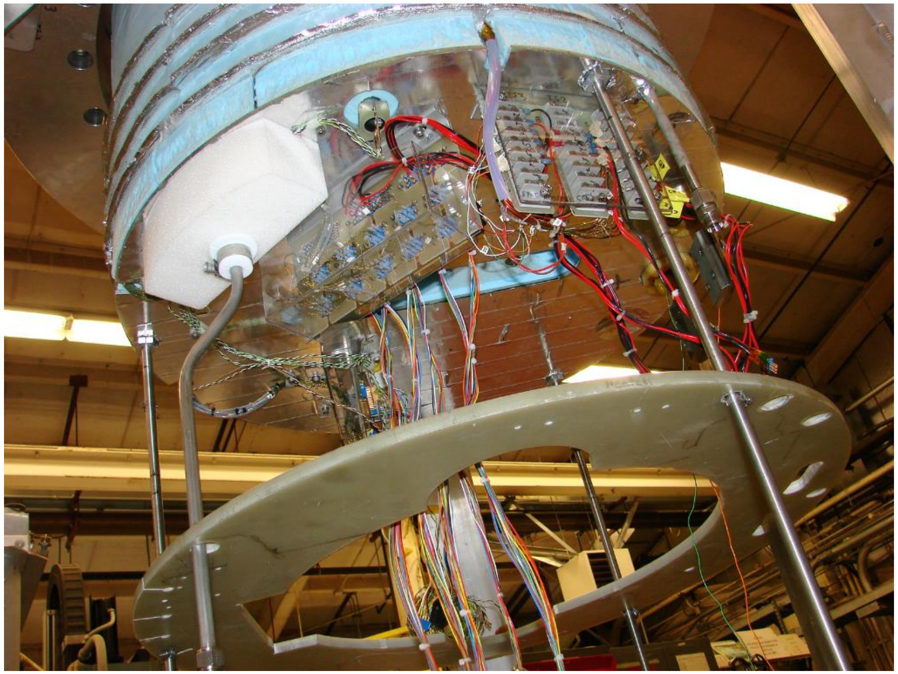


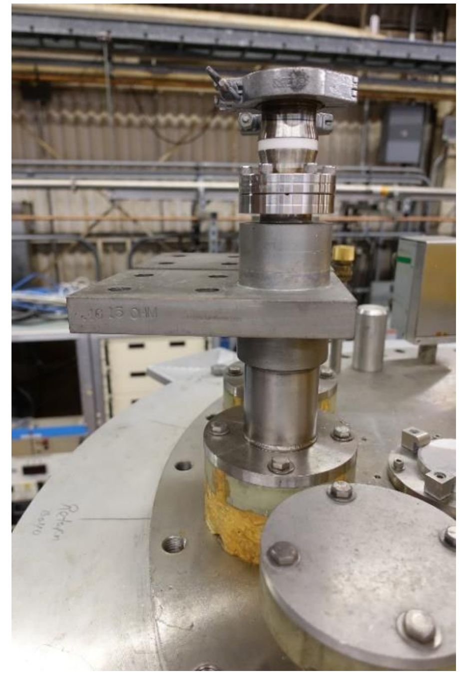
- Power supply, extraction system, and magnet leads are protected with interlocked doors
- Emergency stop buttons
- Cryogenic safety rules and PPE
- Limited area access during testing

- WPC (Work Project Control) database
- LOTO (LockOut - TagOut) procedures for the power supply and extraction system
- Regular Safety Training of the facility personnel
- Interlocks (mechanical and electrical) on all major systems and access doors

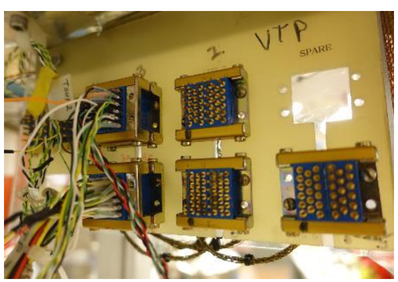
Header electrical interfaces

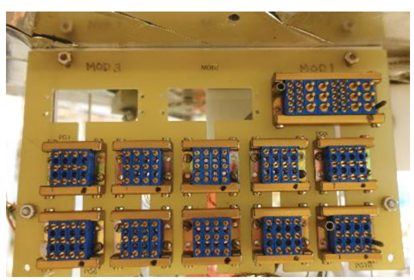
- **Sufficient amount of signal lines available to accommodate any magnet**





- Vapor-cooled current leads (tested to 17.5 kA)
- Voltage monitored



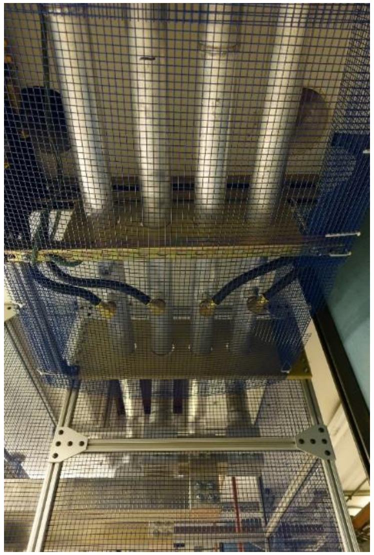


- 200+ Hypertronic connector interface wire lines available
- Bronze twisted pair wiring
- Vtap wiring hipoted to 1 kV at room temperature and at 4.2 K

Power supply and DC current lines

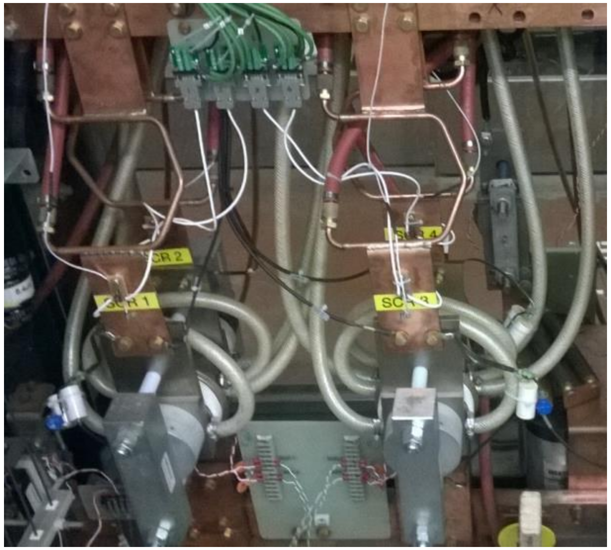
- **New main power supply has been installed and fully commissioned in 2015.**

To the test area



- Made by Alpha Scientific
- Maximal current: 25 kA (limited to 23.5 kA by voltage drop on the lines + SCRs balance resistors); current is monitored via voltage across the internal shunt.
- Maximal voltage: 20 V
- Remotely controlled from the MTF control room via Ethernet interface (dedicated network line)
- Current regulation accuracy: 200 ppm

Energy Extraction System



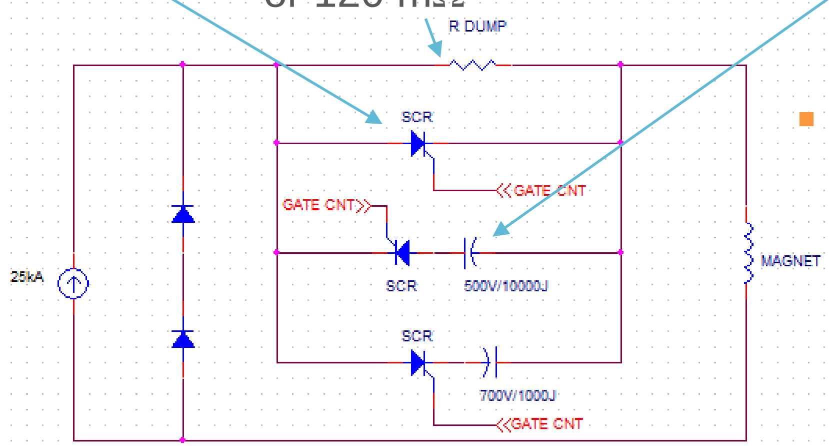
4xN5946FC220 SCRs

- 6000A @ 55C each
- Max voltage 1800V
- Min extraction time 1 ms

Dump Resistor

- Adjustable: 20,24,30,40,60, or 120 mΩ

Capacitor Bank



- Extraction upgrade with IGBTs is planned in 2017

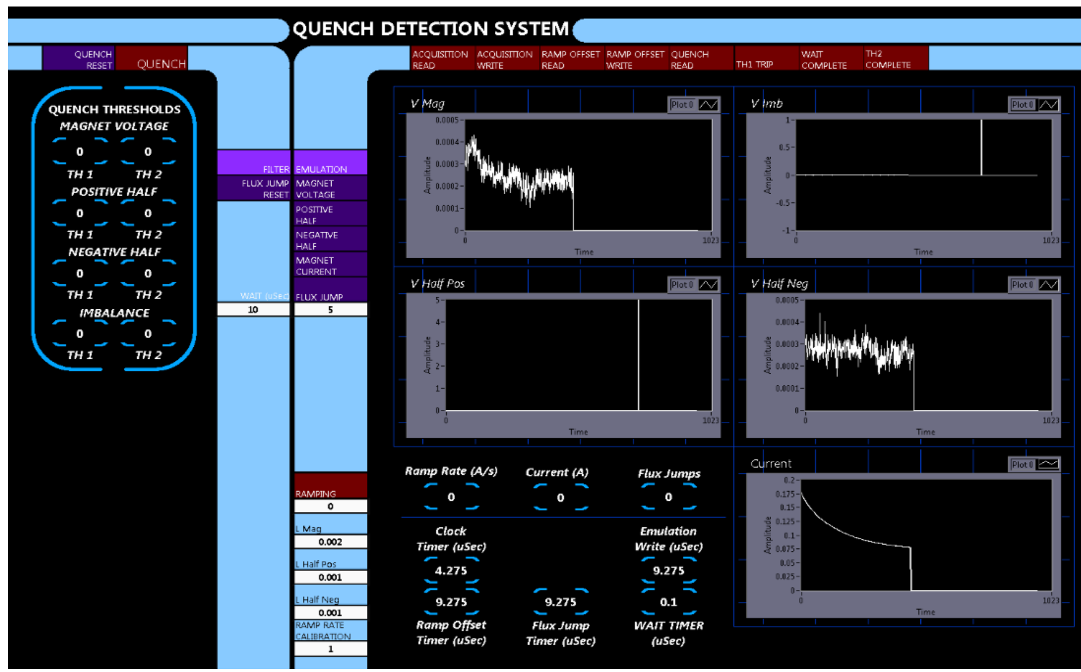
Magnet protection

- Four protection heater lines and 4 spot heater lines available on the header
- Four interlocked MTF Protection Heater circuits
- Newly designed and built HFUs

- 4 HFU units (+2 spare); each has 2 independently controlled outputs
- Support for 8 independent protection heater circuits
- IGBT-based; switching time < 0.1 ms
- Maximal voltage 350 V
- Internal capacitors 5 mF

FPGA-based quench detection system

- 2 µs response time (with internal 40MHz clock)
- Programmable signal recognition capability
- Flux jump identification and counting
- Data 1 MSPS four channels data logging
- Programmable digital delay line for extraction
- Programmable heater firing sequencer
- Inductive voltage automatic compensation



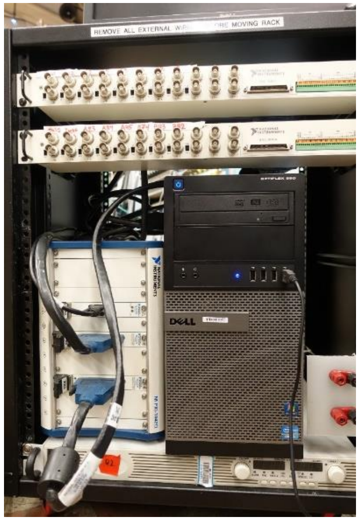
Auxiliary DAQs and software

➢ Flexibility in choosing data acquisition options

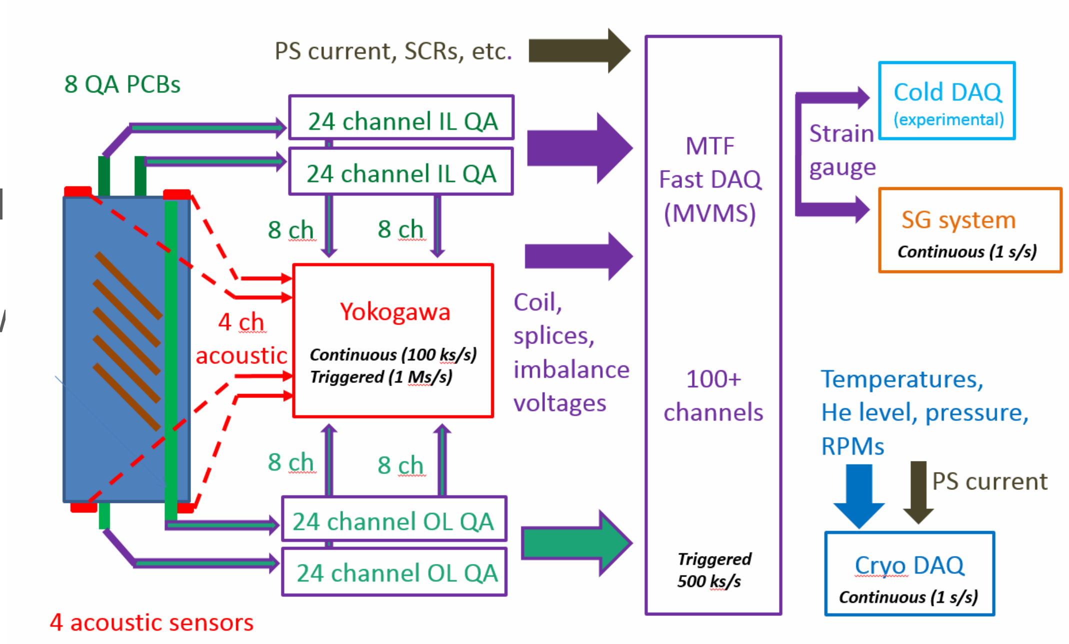
Yokogawa WE7000

- 4 channels at 1 MHz
- 32 channels at 100 kHz
- Proprietary acquisition & viewer software; data are exportable into Labview waveforms and CSV formats

2x **NI PXI-6123**

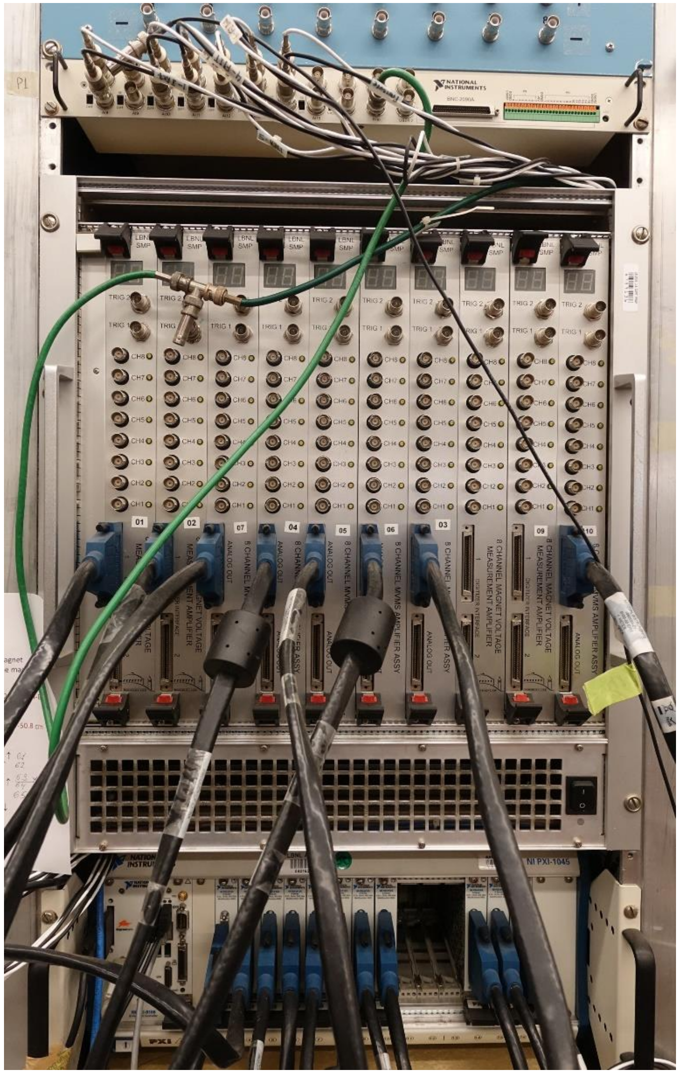


- 16 channel at 500 kHz
- NI Labview acquisition analysis software



Signal flowchart for a typical magnet test

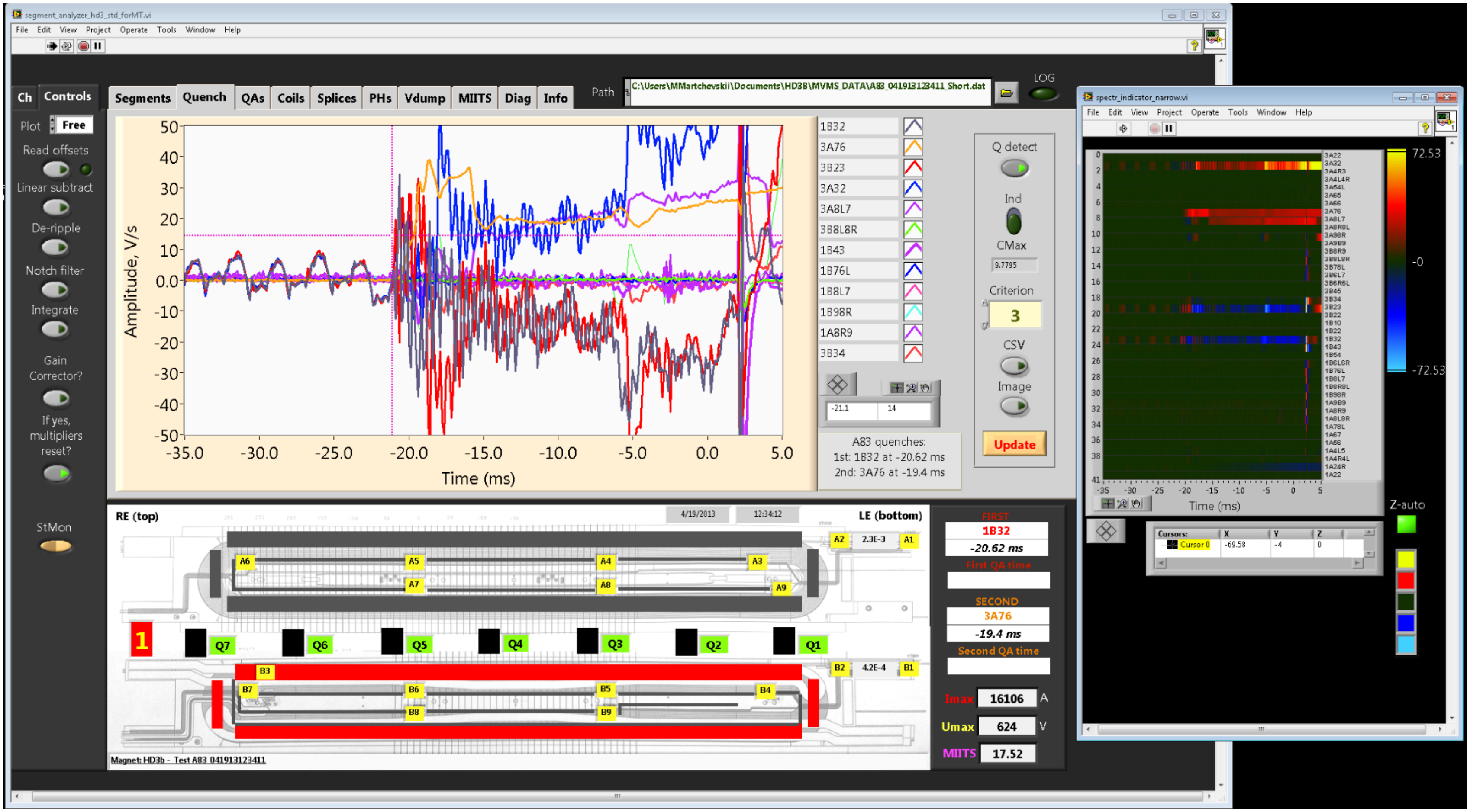
DAQ cards and software



- 160+ DAQ channels at 500 kHz
- National Instruments PXI-6123 cards interfaced to remotely programmable custom built HV (1000 V to ground) buffer amplifiers.
- NI LabWindows-based acquisition and viewing software; using custom data format. Data are exportable to NI waveform / Diadem formats, and to CSV.
- Additional LabView-based signal analysis software for automated threshold based quench localization, MIITs calculation, and extraction diagnostics

Instant data analysis

- Automated data analysis for quench localization

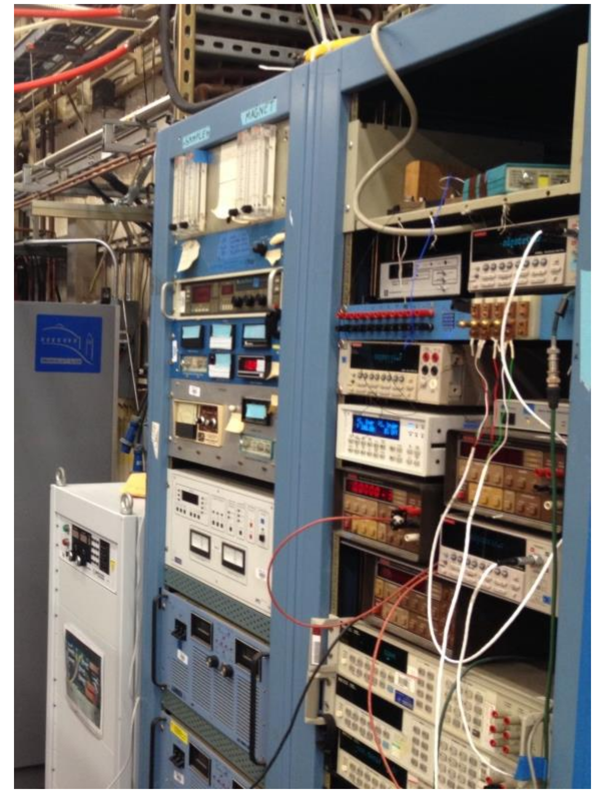


Short sample & subscale coil test facility

➤ **A versatile system accommodating short samples as well as subscale coils**

15 T solenoid SC magnet

- J_c testing as a function magnetic field, strain, and temperature
- 15 T background field at 4.2 K
- 4.5 kA single power supply
- 25 kA SC transformer
- Variable-temperature insert
- U springs for strain dependence
- RRR measurement of extracted strands
- Cryogen-free system with high measurement throughput
- Tested NbTi and Nb_3Sn samples, HTS coils, Nb_3Sn undulators



Instrumentation

Xiaorong Wang

Magnetic measurement capability

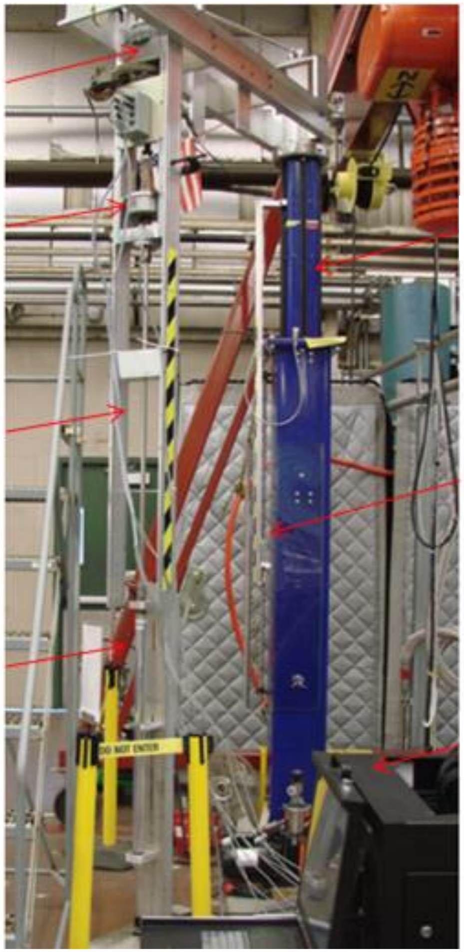
- **High resolution and sampling rate**

Rotation drive

Encoder

Shaft

Harmonic coil



Linear drive

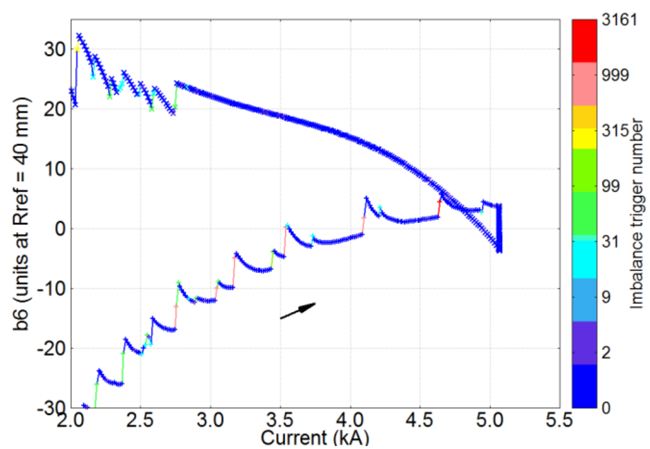
Displacement sensor

DAQ

Magnetic measurement setup

High performance and measurement throughput:

- 24-bit resolution (10^{-5} – 10^{-6} of main field amplitude depending on the probe radius)
- 100 kHz sampling rate
- Probe rotation speed 1.5 Hz



Multipole fluctuation correlated to flux jump in the magnet

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Field quality studies

Study of high-field Nb_3Sn superconducting magnets

- Reproducibility and uniformity of field quality during magnet assembly and operation. Correction of geometric field error
- Persistent current effect from high-J_c conductor and its correction
- Dynamic effect due to inter-strand/inter-filament coupling
- Magnet field quality as a system behavior. Multipole fluctuation due to the interaction between magnet (flux jump) and power supply

Measurement and diagnostics development

- Development of high-performance measurement system based on rotating coils for warm and cold measurements
- Probe and system calibration in collaboration with FNAL (J. DiMarco)

Analysis

- Use of standard software (Opera, Roxie) and development of in-house code
- Strand/cable stack measurement data as input to the model in collaboration with Ohio State University (M. Sumption)

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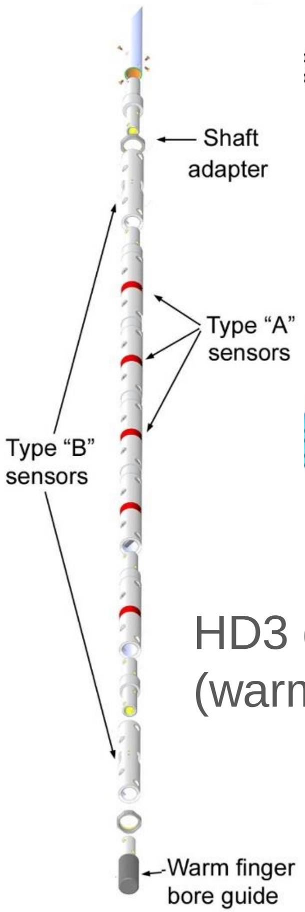
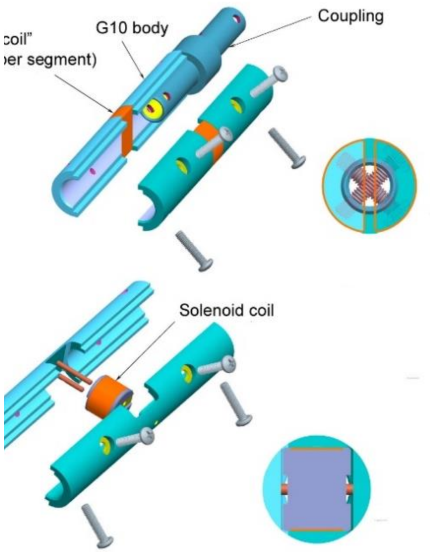
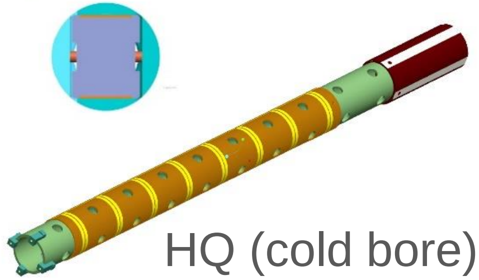
Inductive quench antennas



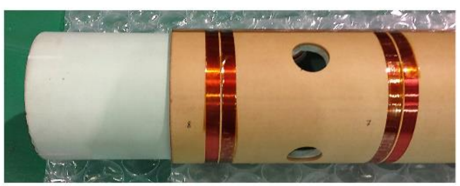


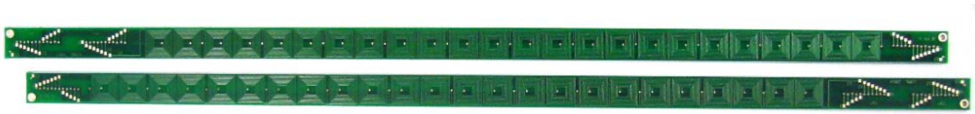
HD3 dipole (warm bore)



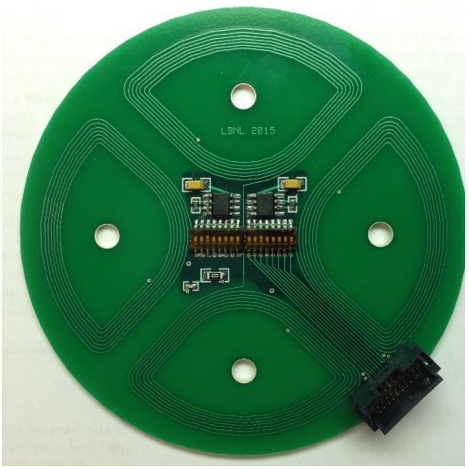
HQ (cold bore)

b.

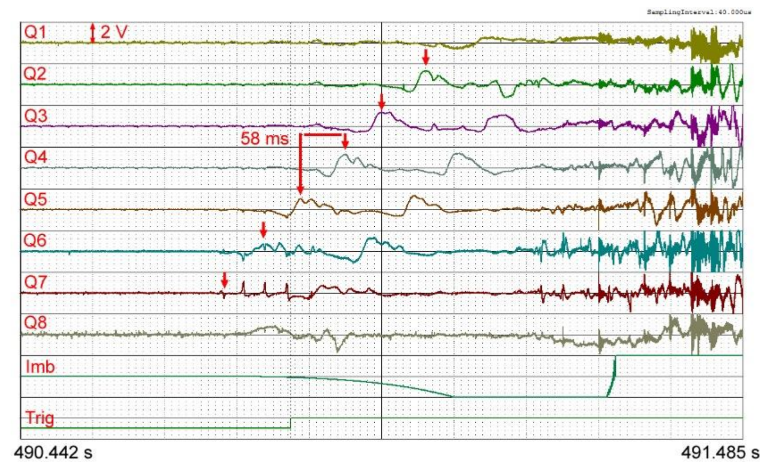




CCT2 linear arrays

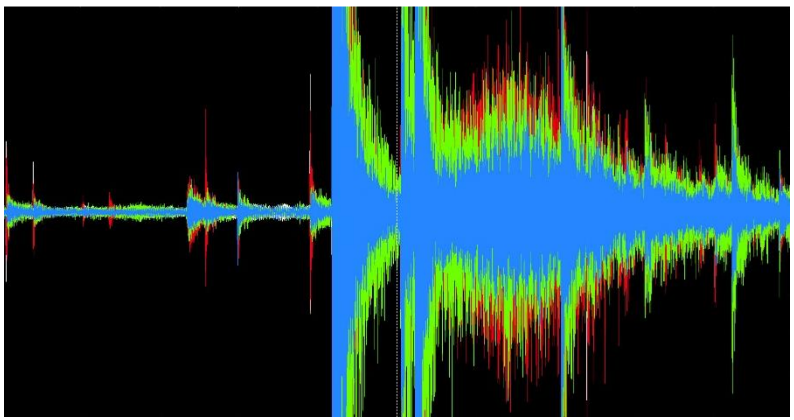


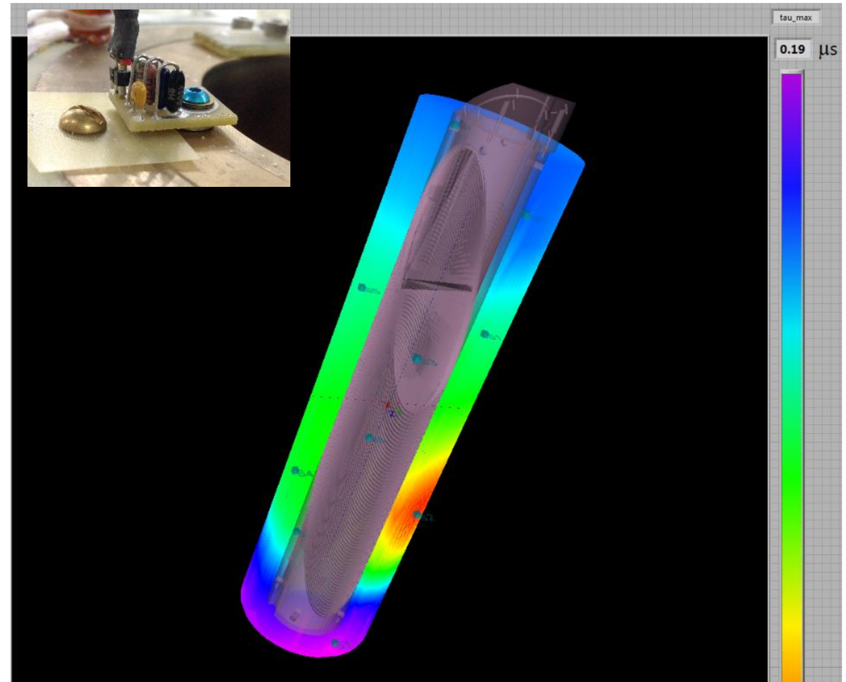
MQXF (warm bore)



Development and propagation of a slow quench in HQ02b at 6 kA recorded by the quench antenna

Acoustic emission sensor system

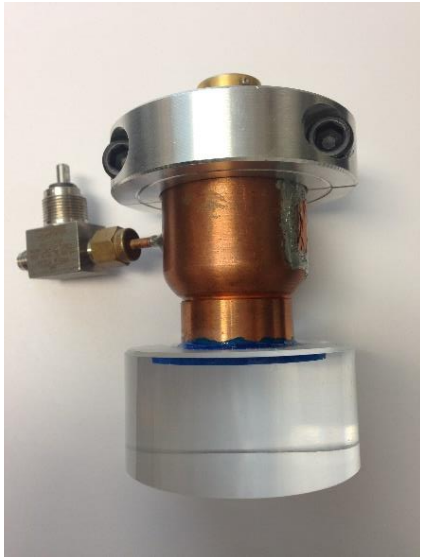




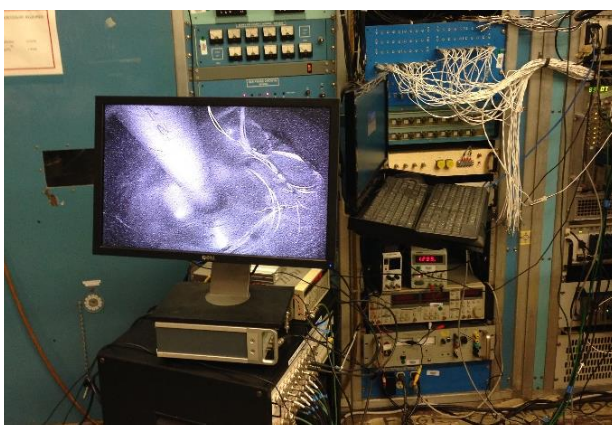
Mechanical disturbance in CCT3 triangulated using acoustic emission sensors (colormap of arrival times)

- Acoustic emission detection / triangulation system using in-house developed cryogenic amplified sensors (up to 16 sensors); 5 cm quench triangulation accuracy
- Data acquired with either Yokogawa or NI DAQ sub-system
- Location triangulation using in-house developed software (LabView-based)

Cryogenic video camera

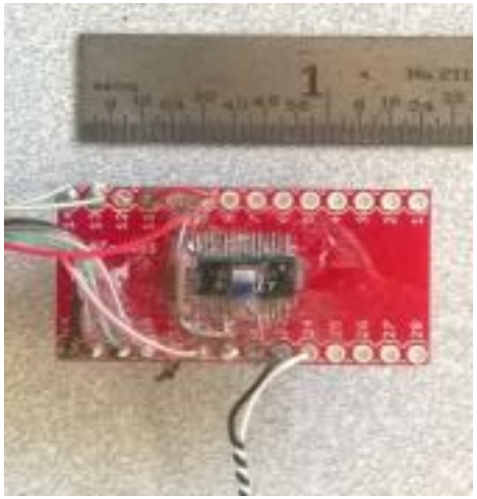


Quench in the CCT3 dipole



Live top view of the CCT3 magnet at 4.2 K in helium bath

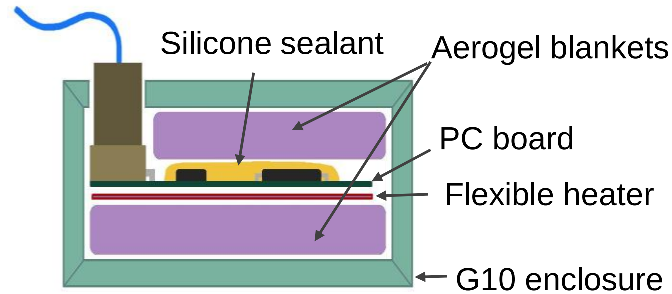
Cryo-electronic interfaces



Analog to Digital Converter

- 4.2 K operation
- 16 channels
- 24 bits
- 500 μW
- 6.25 kSPS (per channel)
- Design for Strain Gauge measurements

M. Turqueti



- 16 multiplexed differential inputs
- Built-in a gain x50 amplifier
- 60 kSPS (per channel)
- 30 K operation
- 4.2 K operation using built-in heater

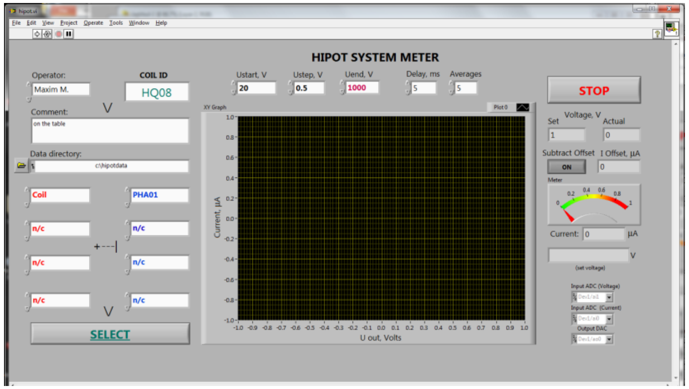
Quality control tools

Hipot Sytem

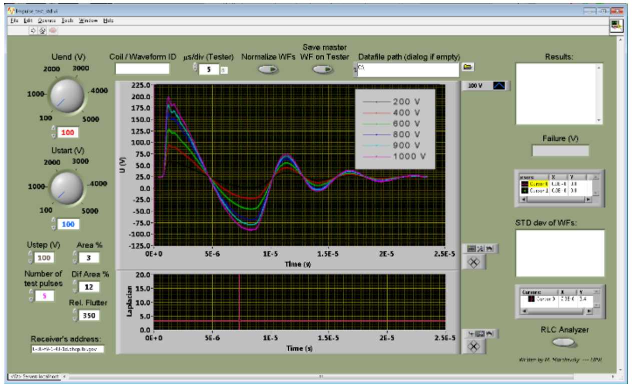
- Based on Bertan 0-5 kV analog power supply
- Current thresholds: 0.8, 8, 80 and 800 µA

Impulse Tester

- ECG Kokusai model DSW-05
- 0-5 kV, 100 V step
- 0.01 mF internal capacitance



- Variable ramp rate, thresholds
- Data saved as CSV and images



- Controls all tester parameters
- Data saved as CSV and images

Test Facility Summary

- 1 large cryostat (1800 l / 0.9 m diam. / 3 m long), in-ground pit
- 1 smaller cryostat with 15 T superconducting solenoid
- Several smaller sized cryostat for short sample and subscale coil studies
- Two handling cranes (10 T and 2 T capacity)
- Liquid He plant with 40 l/h productivity
- 4.2 K base operating temperature
- 25 kA (23.5 kA usable) main DC power supply
- 4.5 kA secondary power supply (short sample & subscale tests)
- 200+ simultaneous acquisition channels (500 & 100 kHz) in 3 independent DAQs
- SCR-based extraction with 20-120 mΩ dump resistor
- 4 heater lines powered with IGBT-controlled HFUs (5mF / 300 V)
- Digital FPGA-based QDS system
- Magnetic measurement system
- Strain gauge measurement system
- Quench antenna arrays
- Acoustic emission / triangulation sensors (up to 16)
- Cryogenic video camera for real-time magnet view
- Cryo-electronic magnet interfaces (DAQ, FPGA, multiplexer) operating at 4.2 K
- Automated electrical QA tools (hi-pot and impulse tests)

Thank you!