Incoming R&D magnet tests at FNAL and plans for training studies. Milestones

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FNAL

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Current FNAL (IB1) LHe consumers

- SRF (cavity testing)
  - Three test stands
  - R&D and production (like PIP-II)
- Test Stand 4, TS4
  - AUP (HL-LHC) magnets/cryo-assemblies exclusively
- VMTF
  - All R&D magnets

Generally – TS4 and VMTF can not operate simultaneously. Each can operate in coordination with SRF (depending on activities)

Although we have two cryo-plants only one is operating now (for technical reasons) and not at full capacity (contamination; pending cryo-maintenance)

Magnet testing at VMTF – current constraints

- Cryo-maintenance period
  - Starting October 1st
  - Three weeks long
  - Another week for restart and margin

Few scheduled power outages are also on the way, first on September 6th (this can delay us by a day easily)

MT28: Sep 9 – Sep 18 (effectively)

- Test Stand 4, AUP cryo-assemblies
  - Higher priority
  - Testing soon to conclude (started in February/March 2023);
  - Second cryo-assembly cool-down in December/January?

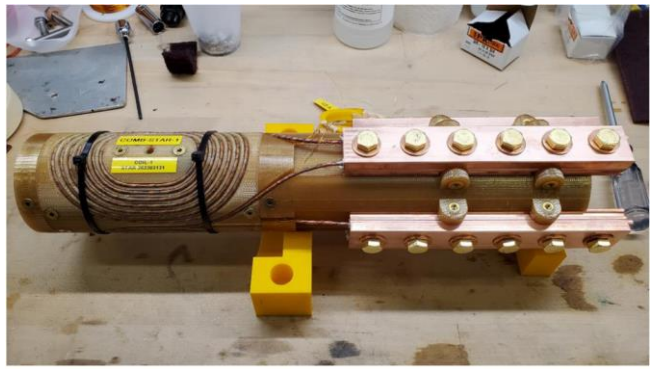
- SRF
  - Overall higher priority (projects)
  - Some days we may not be able to test magnets (quenches particularly)

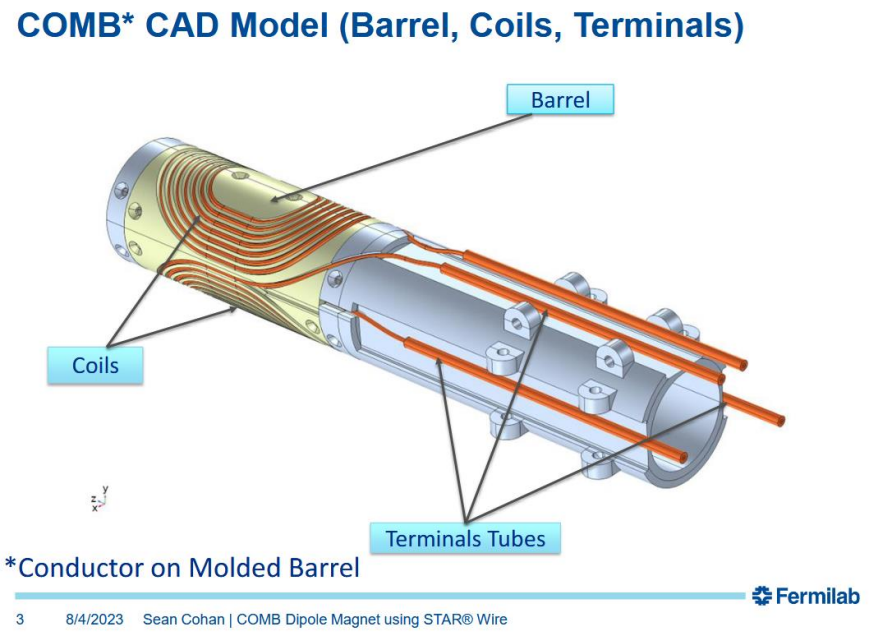
- Funding : see slide 11

R&D Magnets in line to test

- SMCTM1 (stressed managed mirror magnet)
  - In the pit, ready for testing (for the last few weeks), awaiting TS4 “cold” operations
  - All ready (including test plans, Maria in charge for testing), details discussed elsewhere
  - Two thermal cycles (TC) + resplicing (two coils powered): It is possible but extremally unlikely the first TC to end before MT28 and the second TC to end before October 1st; more likely TC1 will be at the end of September and the whole test will finish at the end of November

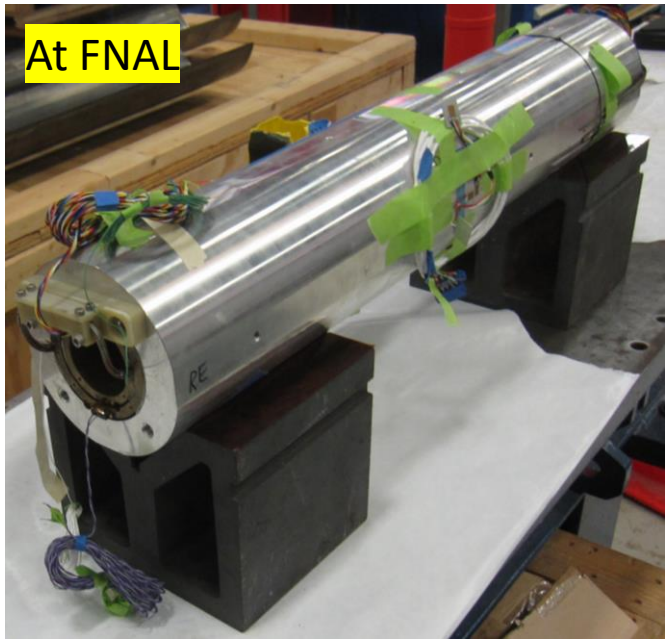
- HTS dipole magnet
  - Vadim’s effort, design and efforts discussed elsewhere
  - The only magnet we can test with a 15 kA-top plate (allows for parallel work) due to limited number of channels
  - Preparations in October for a test in December, we could “swap” with SMCTM1 after its TC2, if needed



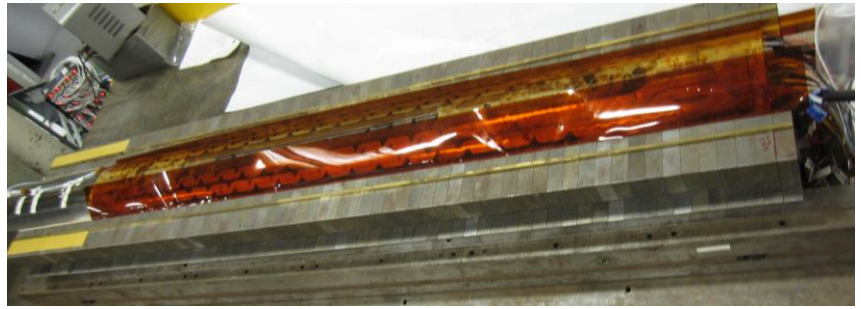


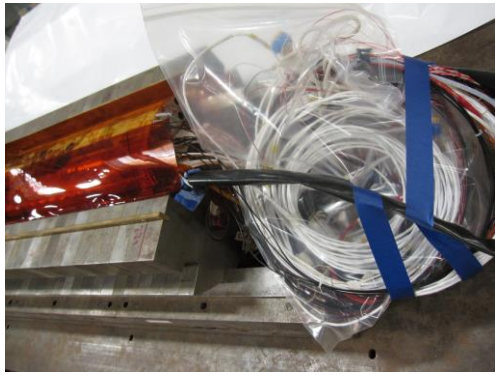
R&D Magnets in line to test (2)

- CCT magnet ("subscale"), from LBNL
  - Available at FNAL since June
  - The test plan is just a draft still, we'll discuss when we are closer to testing
  - Some preparations are needed at FNAL site (instrumentation)
  - Testing depends on TS4 schedule – it is likely to be not earlier than March 2024
  - We had an opportunity to test in May/June 2023 due to inactivity at TS4, we may have other opportunities, so we start preparations in November/December, restart communications in October



- MQXFSM3 (AUP short mirror magnet)
  - Coil instrumented with a lot of diagnostic tools
  - The main goal of testing is not the magnet itself but instrumentation and methods (including QCD)
  - Magnet still in fabrication
  - To test in ~ May 2024, nothing earlier seems realistic





There are other R&D magnets also coming in 2024

HTS dipole magnet

- Instrumentation **discussions** regarding quenches (still not fixed)
  - Optical fibers
    - Fiber-optics location and complexity to be decided on (and some modifications to top plate)
    - Temperature fiber
    - Avoid complicated geometries
  - Quench antenna
    - Use the warm bore and already fabricated QA support (and QA arrays)
    - Will not have ability to locate quenches precisely (if we see them)
    - It is possibly to use other, smaller quench antennas if deemed a better option (plan B)
  - Acoustic sensors
    - Useful features (screw holes, holes) on the outer bore makes it easy to attach several sensors on OD
    - Possibility to also attach to the inner bore, but we have to keep the bore open (for QA, magnetic measurements)
  - “Second” sound
    - In the last several years we had informal conversation in using “second sound” (exploring superfluidity of He and the presence of distinctive “entropy” waves)
    - This technique is regularly used in SRF testing and was generally available for us
    - Some discussions on-going, possibly for CCT as well
  - Quench detection with attached NbTi wire (?)
    - We have a developed instrumentation, and complete DAQ that was used on leads years ago
    - We have to decide on complexity and trade offs

~ November 2023

CCT magnet

~ March 2024

- Planning
  - The main reason CCT is at FNAL is the desire to test it at 1.9 K

    It was suggested some years ago to establish temperature dependence, possibly at 1.9 K, for the purpose of determining quench limitations at training but recently there were interesting results about CCT training behavior at 1.9 K from elsewhere. The interest at 1.9 K now is explicitly on quench training

  - QCD may be tested after some training sequence at 1.9 K, to be discussed
  - We'll plan to converge on the test plan in October
  - Instrumentation considered for now is close to what was mentioned about the HTS magnet, it has differences, but the bore was explicitly left accessible so we can use it at FNAL

    installing a fiber on the magnet ID using a latex bladder / still finalizing a grid design/, but the majority of the bore should be instrumented; second sound transducers for the magnet, with 1 LE and 1 RE to see if we can "hear" the hot spot; 8 acoustic sensors and there is already one power transducer installed;
    flex-QA to be decided (default is the solution for the HTS magnet), we may have a dedicated array designed;
    RF-based detection?

  - We'll restart all work in October

MQXFSM3

- Magnet assembly (follows MQXFSM1 and MQXFSM2)
  - The coil, never used before, was instrumented and ready about an year ago

    ~ May 2024
  - Simone, while still at FNAL at the time, trained Martel on the assembly tasks, in theory

    Martel is the only technician working on the assembly, he never did this before (including during the theoretical training) and is only working on the job when not needed for AUP
  - This work is not affected by funding issues (it is a slow moving negotiated effort)
  - Engineering oversight by Charlie O., Steve and Rodger B. (consulting)

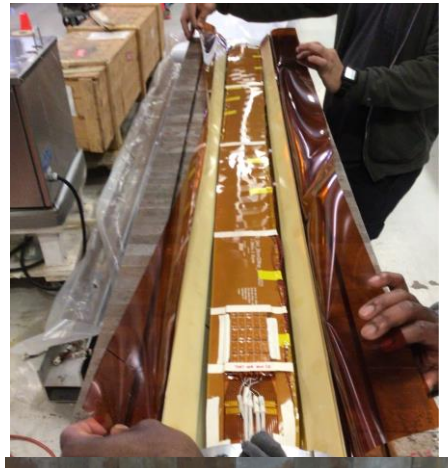
    We have run a preliminary pressing of the coil to validate the shim system and contact conditions.
    It looked fairly reasonable, but we have made some minor changes.
  - We need to troubleshoot issues with fibers (the rest of instrumentation is fine)

    We lost the two fibers on the coil OD, on the return end the fiber seems broken at the end of the coil.
    On the LE there is an issue recognizing the termination which may be recoverable.
  - Assembly continues at pace suitable for people involved (Charlie, Martel in particular)

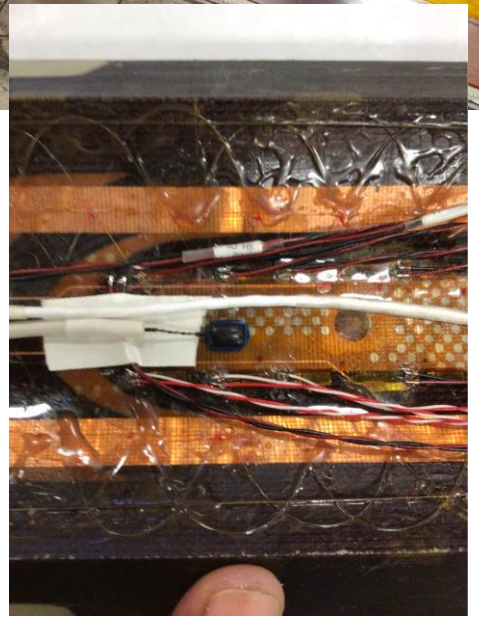
MQXFSM3

Some pictures from work on the magnet

Quench antennas

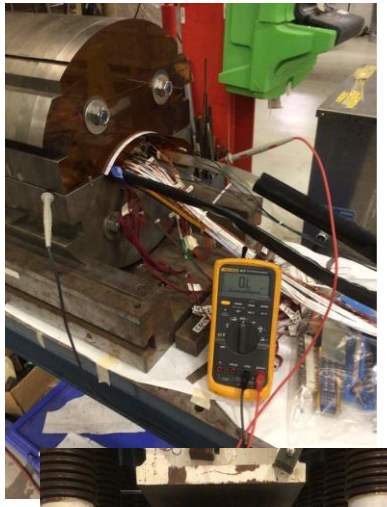


Optical fibers



Wiring

Assembly and pre-stress tests



Fuji paper checks

Training in the four magnets to test

- The SM magnet will probably train and data analyzed as usual
  - V-I measurements may be performed if desired

- HTS magnet is not expected to train or even quench but it will be interesting to start analyzing quench data (if any) and ramp data with available instrumentation
  - V-I measurements and splice resistance may be useful as well

- CCT manet
  - For training related studies explicitly (temperature dependence)
    QCD use is possible as an addition, not decided yet
  - Non-invasive diagnostics techniques applied as needed to help with analysis and extend analysis options

- MQXFSM3
  - QCD will be used explicitly to further explore effect on training
  - Beyond it, ramps and quenches will be used for testing various techniques and appropriate instrumentation
    - ✓ Array of spot heaters, QA (including on SC splices), acoustics, fiber optics, V-I

Milestones

(moved from slide 3; funding was not and is not a constraint for magnet testing)

- Funding
  - In May 2023 we were advised to limit R&D activities due to funds exhaustion
  - In July 2023 we were told to stop R&D activities except if specifically agreed on to continue (no non-urgent activities)
  - Those make us reconsider work arrangements

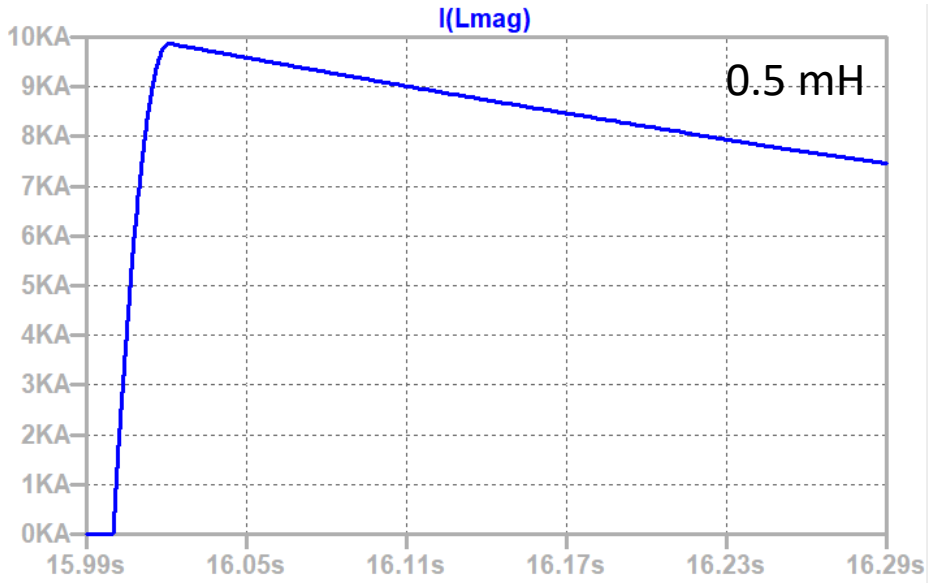
Milestones - QCD

Milestone #	Description	Status *	Updated Target	Comments
		QCD		
AIIIe-M1	Commissioning of QCD	Done		
AIIIe-M4	First magnet test with QCD	Done		
AIIIe-M7	First CCT test with QCD	In progress	Feb-24	QCD testing depends on agreements with LBNL on the test plan, the CCT magnet is at FNAL; timing depends on facility availability
AIIIe-M12	~~QCD preparations and test on a large magnet~~	Obsolete	n/a	~~It should be retired (removed), it is not a realistic option anymore~~

QCD is available for testing, there was no any magnet test at VMTF for more than an year (LHe is not a problem)

An option for the coming CCT test, for instance is to use/discharge QCD without any transport current through it. Half QCD voltage (500 V) is applied in the example.

We'll discuss protection issues (delay times with current) before we decide on any usage.



LTspice simulation (approximation)

SSL@4.5 K ~ 9.4 kA
SSL@1.9 K probably ~10% up, ~10.5 kA

Milestones - vibrations

mechanical vibrations

AIIIe-M10	Design of a dedicated device/technique using vibrational methods	In progress	Sep-24	Activities started but at minimum involvement of an engineer (low burn effort, when resources allow)

Michael Kifarkis applied for an LDRD (at FNAL) and I helped with drafting the application, as a CI. It was not selected.

Project SUMMARY: Superconducting magnets and coils in particular have a complex design with multiple interfaces. It is known that friction between materials in the coil plays an important role for both magnet training and overall performance. Dependencies of friction coefficients on component materials and environmental properties- relevant to magnets, are not well known. The present project has multiple goals addressing this lack of knowledge: (a) investigate friction properties of various interfaces relevant for superconducting coil fabrication; (b) study dependencies on environment characteristics and their correlations (temperature, stress, material); and (c) **develop, introduce, and validate ultrasonic vibrational techniques to change friction of contact interfaces**. These developments will allow Fermilab to have reliable means to predict behavior of magnets based on interface properties. This, in addition to material properties, may pave the way for complete prognostic analysis of magnet operations. Moreover, the project will also introduce a new facility tool for active modulation of friction between interface surfaces. There is well-known scientific evidence that friction depends on vibrational parameters. Such applications for magnets or magnet components have not yet been explored anywhere in the world, to the best of our knowledge.

He was in contact with LBNL colleagues few months ago, there were studies there which seemed useful in the context. We'll continue the studies, he and I will ask for R&D support for FY24.

Milestones – sub-scales

sub-scales

AIIIe-M11	Design of a “cable/stack” testing device and samples	Obsolete	n/a	See Milestone M13a
AIIIe-M13	Fabrication of a “cable/stack” testing device	Obsolete	n/a	See Milestone M13a
AIIIe-M13a	Design and fabrication of a “cable/stack” testing device	Not started	Apr-25	No concrete agreements for support yet (the milestone will move next time if status remains)

This is not expected to progress/change in the next six months