Testing of Superconducting Magnets

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BNL – 2nd International Magnet Test Stand Workshop

8th May 2018

Content

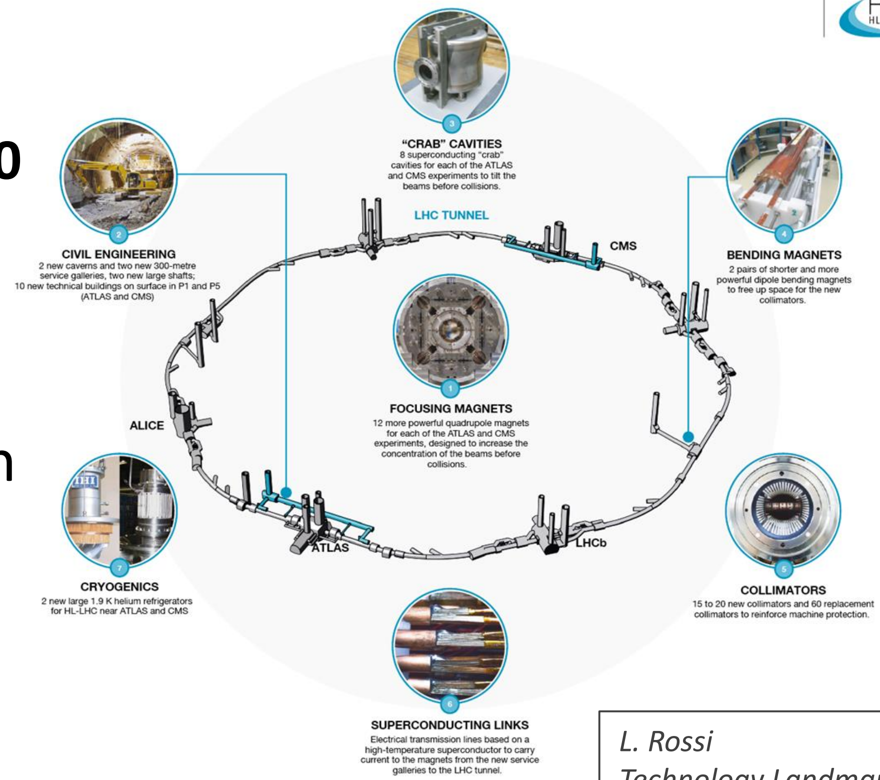
- Where are we ?
- Where are we going in the near-future?
- What's beyond our near-future destination ?

Necessity of Testing

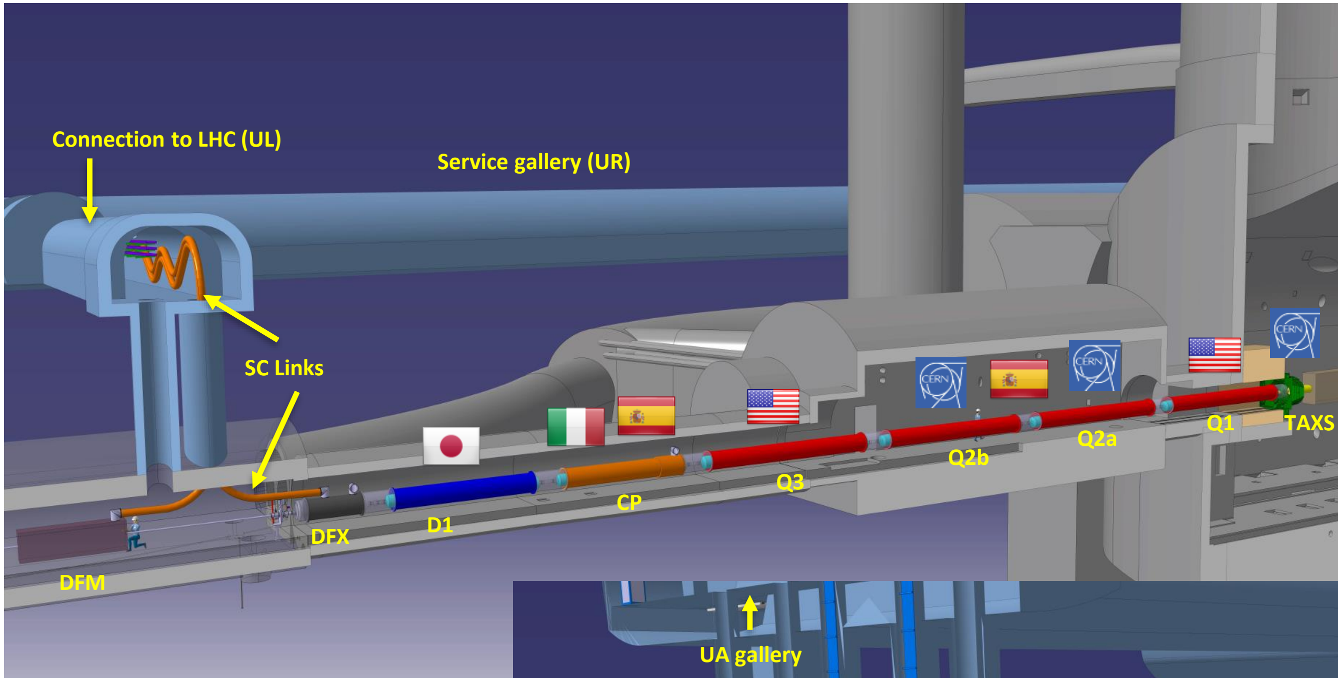
- Testing equipment to performance level before installation is a major risk reduction approach to construction of unique facilities such as accelerators
  - Replacing a magnet during commissioning or operation of an accelerator facility is typically more expensive/time-consuming (not to talk about the disruption to the research program) than catching a non-performing element before installation.
  - Advantage of accelerator field versus one-of-a-kind applications such as fusion or magnets for experiments.
- Testing of magnets has been a routine effort for all accelerators based on NbTi technology (Tevatron, RHIC, HERA, LHC, …)
- Existing Testing capabilities extensively described at “2016 1st International Workshop of the SC Magnet Test Stands”

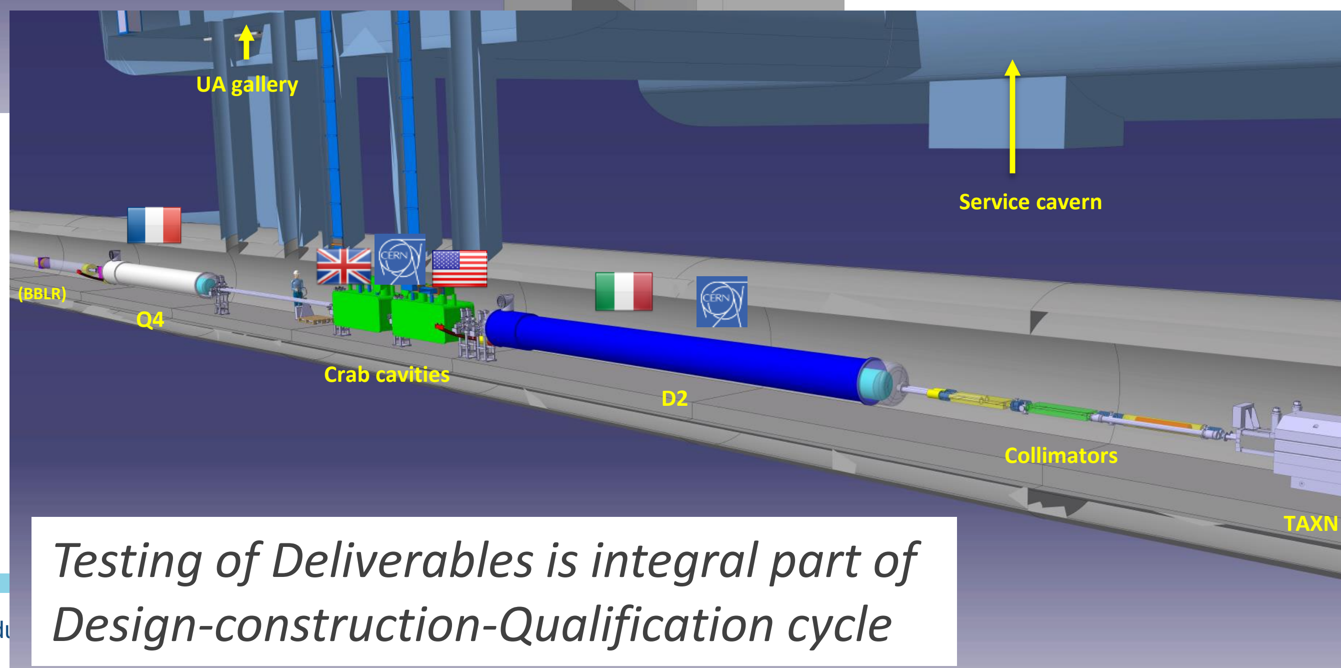
Big Elephant in the Room – HL-LHC & Nb_3Sn Technology

- A peak luminosity of L_{peak} = **5 × 10^{34} cm^{-2}s^{-1} with levelling**, allowing:
  - An integrated luminosity of **250 fb^{-1} per year**, enabling the goal of **L_{int} = 3000 fb^{-1}** twelve years after the upgrade.
- This luminosity is more than ten times the luminosity reach of the first 10 years of the LHC lifetime.



L. Rossi
Technology Landmarks

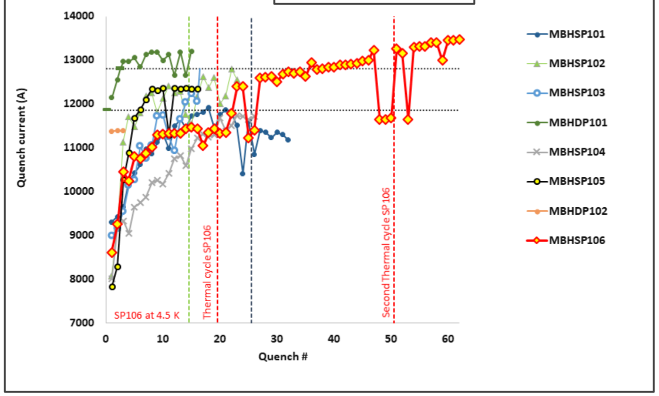




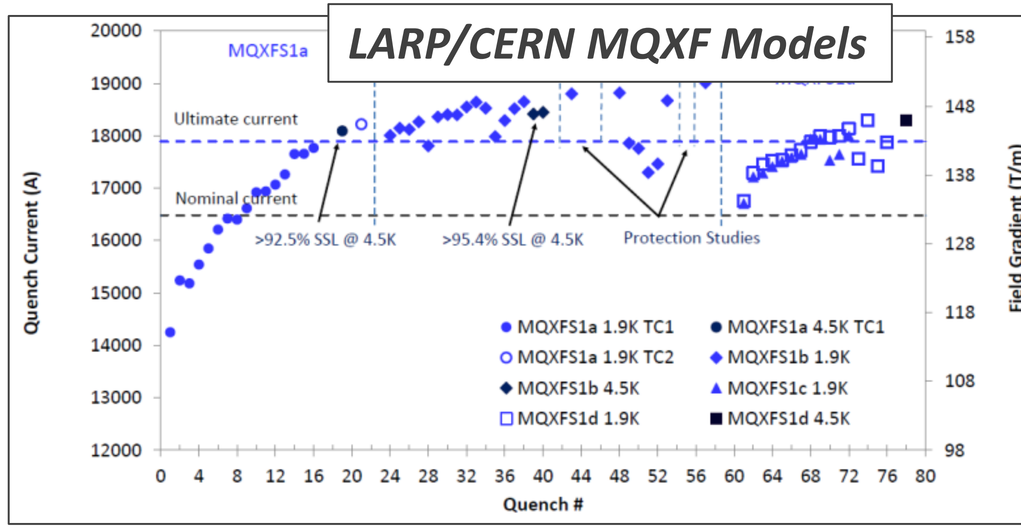
Testing of Deliverables is integral part of Design-construction-Qualification cycle

Testing Experience on Nb_3Sn (*for Project Managers*)

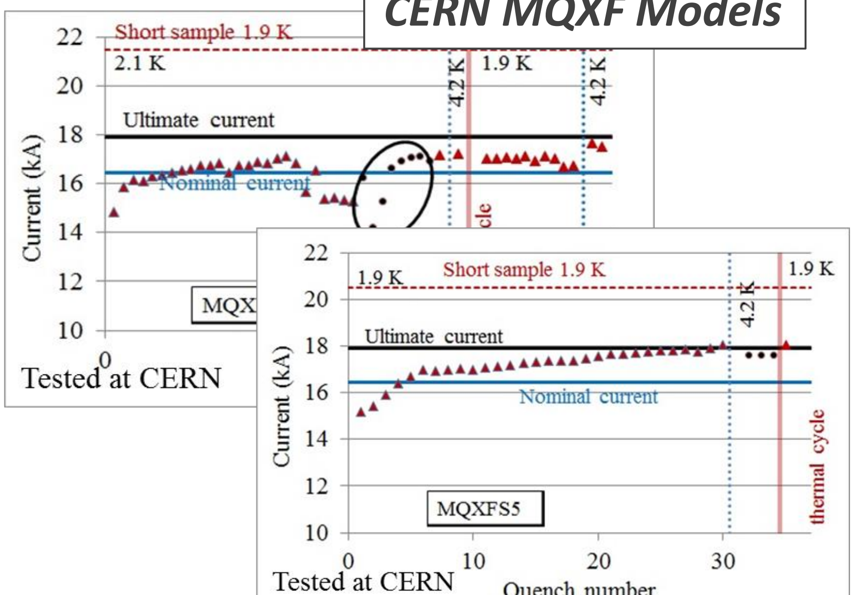
11 Tesla



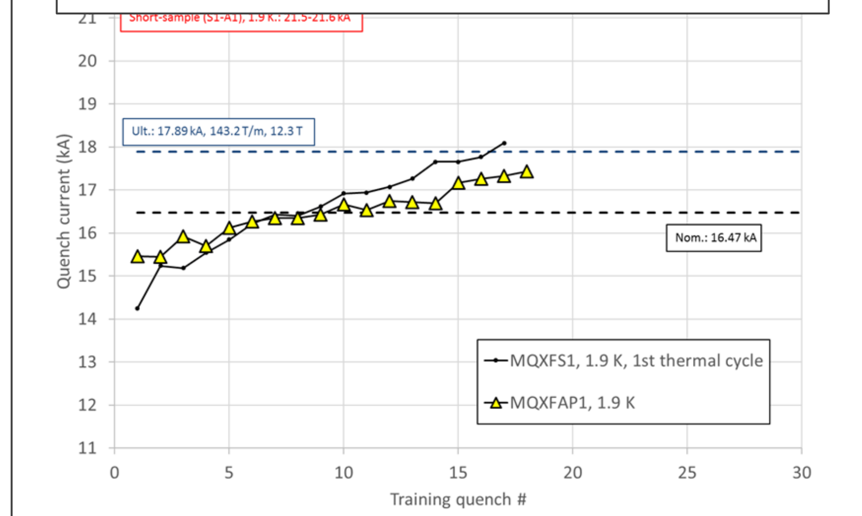
LARP/CERN MQXF Models



CERN MQXF Models



LARP/HL-LHC AUP MQXFA Prototype



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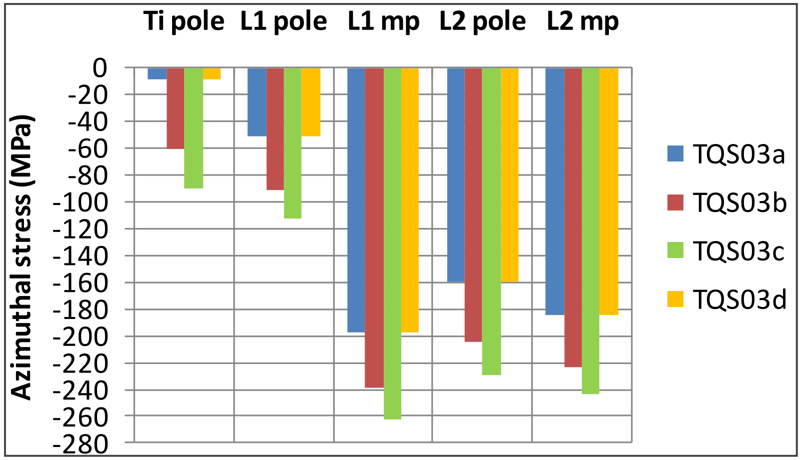
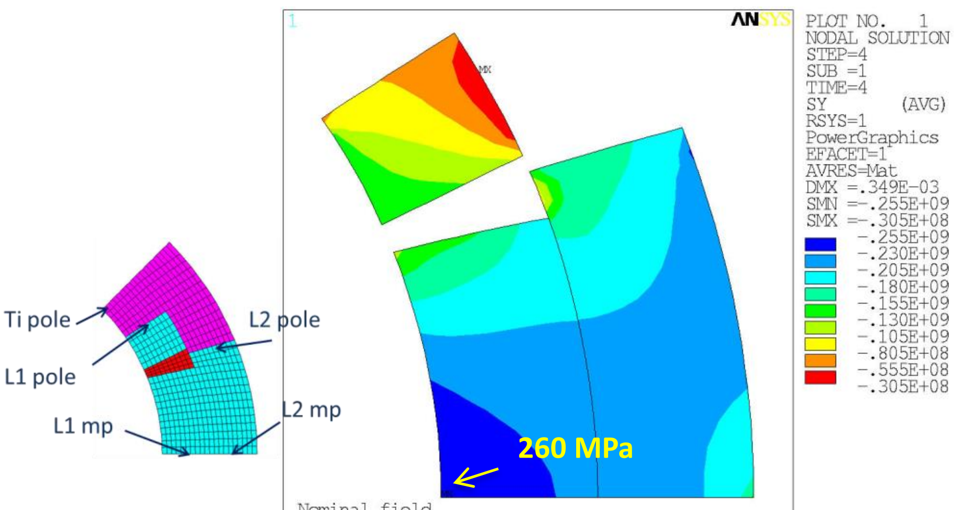
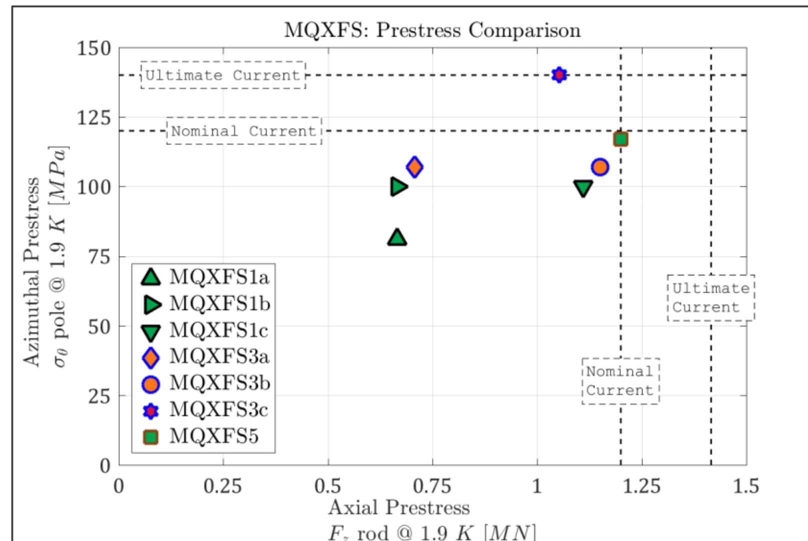
Testing Experience on Nb_3Sn (*for Magnet Developers*)



12 kA (achieved quench level)
Check for permanent or reversible degradation

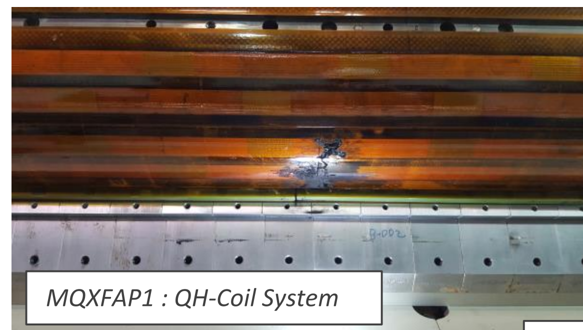




from G.Ambrosio - LARP

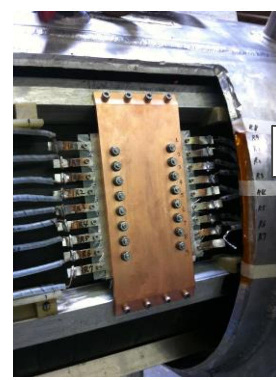
Non-standard Configurations: i.e. *when s#%@ happens*

- MQXFAS1: Burned Negative SC lead
  - a quench detection cable connected to the wrong receptacle, followed by mis-identification of quench detection signal anomalies in the standard checkout data
- MQXFAP1: Short QH-to-coil progressed to a Coil-to-GND short
  - Hipot after exposure to He, possible mis-identification of unexpected GND currents during early quenches
- MICE Spectrometer Solenoids
  - Burnt lead, probably caused by failure of connection to internal diode pack during quench.
- Critical questions for this workshop:
  - ***What can be inferred from deep scrutiny of all data at test facility ?***
  - ***Database of "lessons learned" from all regions ?***



MQXFAP1 : QH-Coil System

GND Insulation between Coil and Mechanical Structure



MICE SSD: Cpoil Lead pack

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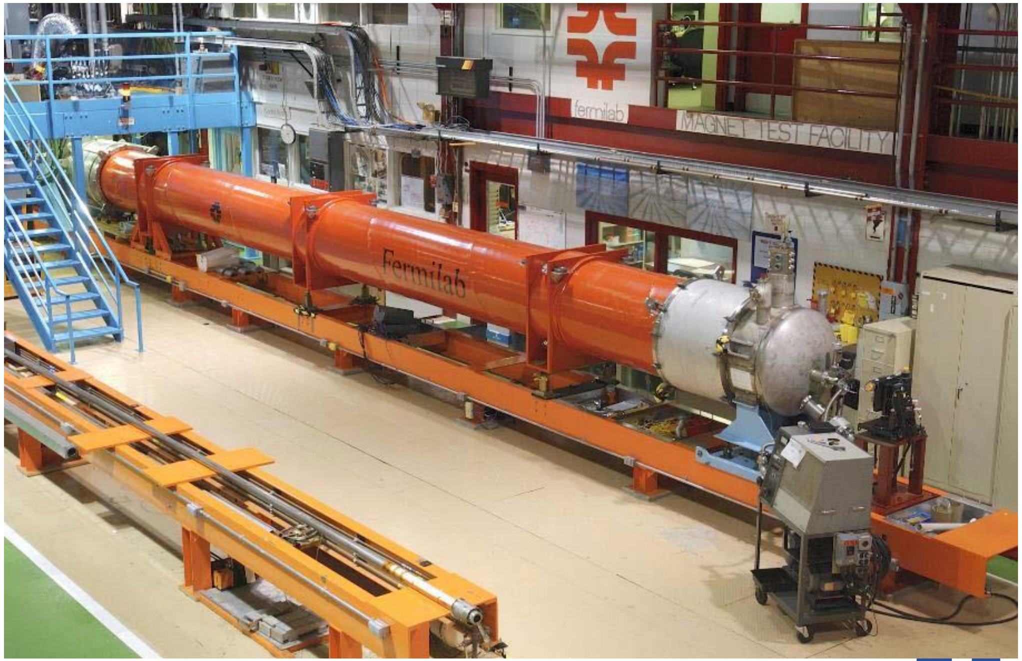
Total Numbers to be Tested and Schedule

- HL-LHC (2019-2023):
  - CERN/FREIA/LASA/CIEMAT/CEA:
    ~10 Quads + ~12 Dipoles Nb_3Sn
    ~80 NbTi Magnets
    Sc Links and HTS Current Leads
  - BNL/FNAL: ~20 Quads Nb_3Sn
  - GSI: ~400 NbTi Magnets
- Magnets R&D (2019-2023)
  - CERN/CEA/FNAL/LBNL/BNL: ~few/year/location
- Other Machines (2020-2026)
  - IEC (Ion Electron Collider)@BNL/JLAB: likely NbTi
  - PIP-II@FNAL: few dozens NbTi focusing solenoids
  - …

US Strategy for HL-LHC Magnets and Testing

- Test at BNL (single magnet in vertical configuration) and at FNAL (2 magnets assembled in Cold Mass and Final cryostat).
  - Few challenges, but overall risk reduction is expected to speed-up execution of HL-LHC AUP Project
  - *Functional Requirement Specs* and *Acceptance Criteria* to define **what** and **how** measurements are performed



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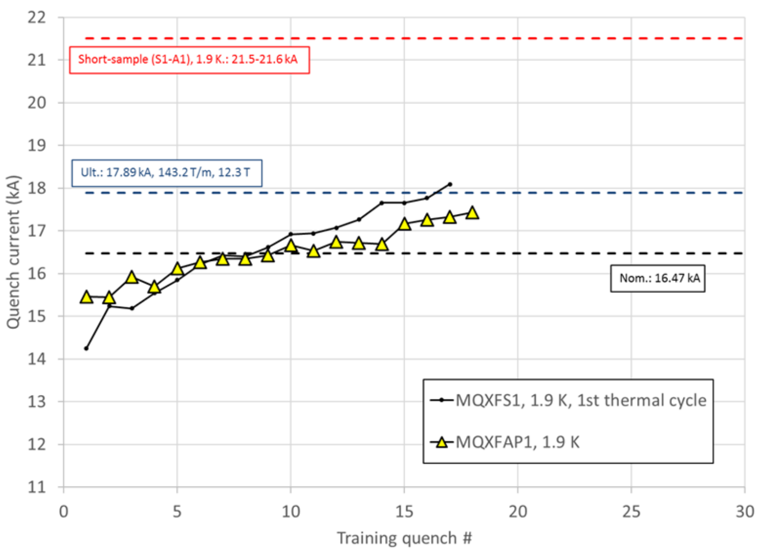
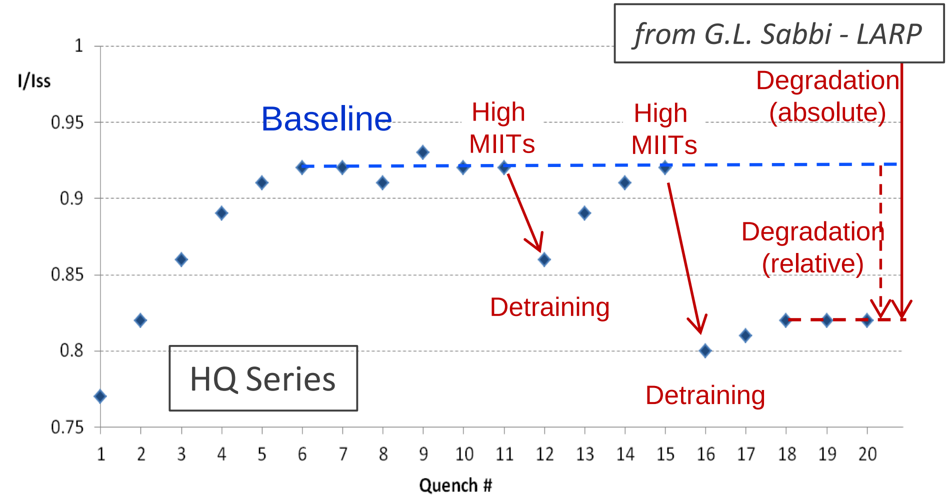
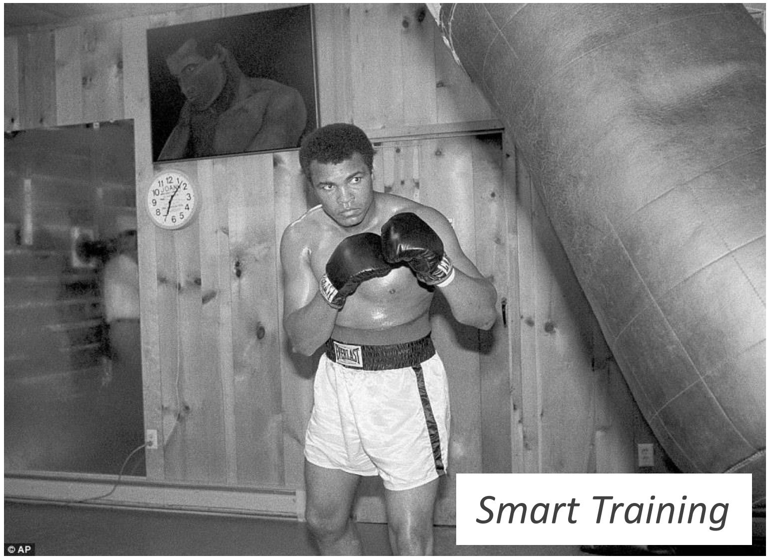
Training appears to be a constant feature of Nb_3Sn Magnets





- Extended training (~20 quenches to nominal) is ~viable for low quantities of magnet (HL-LHC), not for larger endeavors such as FCC
- (So far) No magic bullet for a "train-less" magnet
  - Personal hunch: coil assembly/materials might reserve surprises, but solutions based on mechanical structure might not be the proper venue to pursue
- More worrisome, at high current values "detraining" (high MIITs) appears to be a feature of Nb_3Sn magnets as well

Nb_3Sn Magnet Training

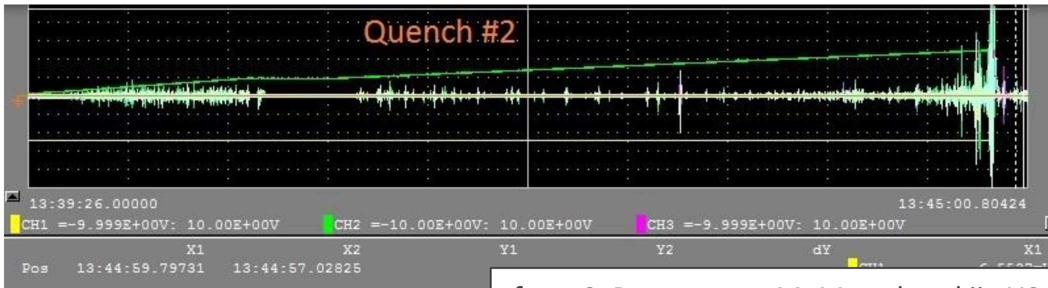


I hated every minute of training…

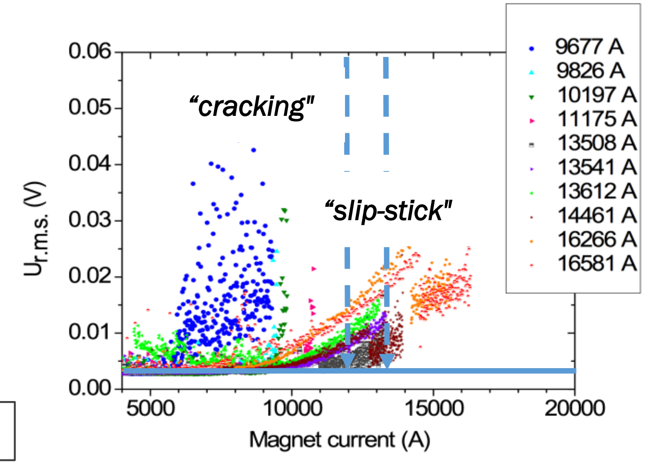
Muhammad Ali

LBNL-MDP Technology

- Acoustic sensors



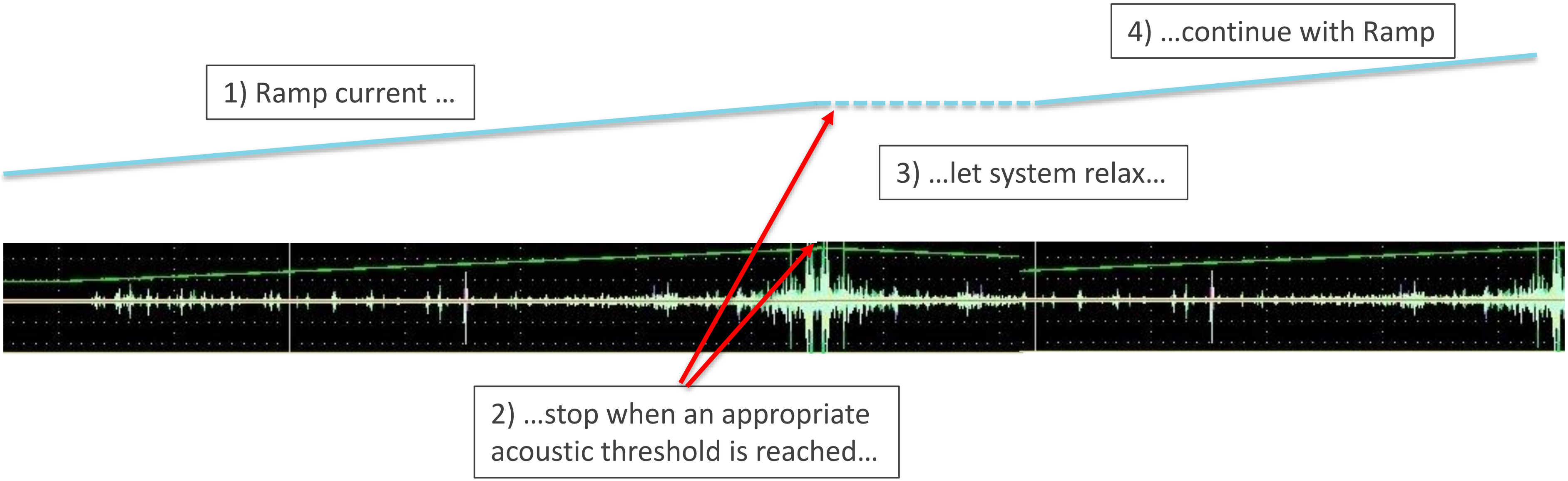
from S. Prestemon - M. Martchevskii US MDP



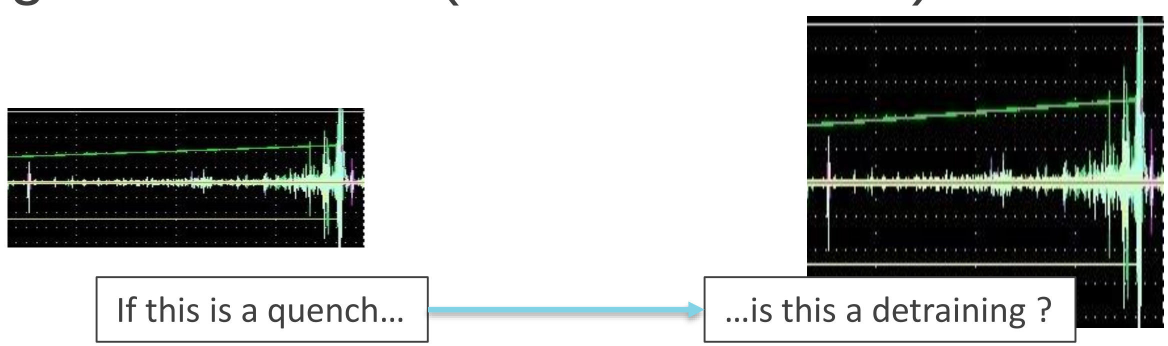
- What happens if current ramp is stopped once a critical acoustic threshold is achieved, and magnet is left to "relax" ?
  - Can we avoid quenches and speed-up training ?
  - Can we eliminate one set of points from the plot (i.e. "slip-stick") ?
  - More important, can we identify "detraining" events (high MIITs) and avoid them ?

Ideal Experiments in the "ideal" Test Stand

- Training ramp driven by acoustic sensors



- Detraining identification (and avoidance !)



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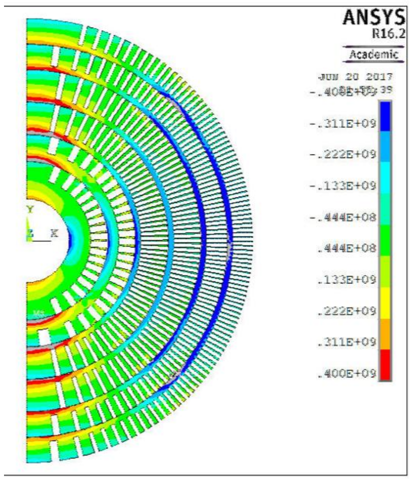
Other venues for Magnet Test Systems

- Test of Hybrid Magnets
- Multiple-leads top and λ-plates
- *Detection and Quench protection in coupled-magnet systems*

Parameter	Existing VMTF	Proposed HFVMTF
Operating Temperature	1.8K	1.8-1.9K
Maximum Current (1st PS)	30 kA	30 kA (re-use existing)
Maximum Current (2nd PS)	Not available	Incl. 10 to 15 kA (to test hybrid magnets)
Helium Vessel Diameter	25.8 inches (655 mm)	42 inches (1066 mm)
Maximum Length of Test Object	3750 mm	>2000 mm (funds limited)
Maximum Diameter of Test Object	630 mm (MQXFS1 with skin)	1000 mm
Crane Capacity	10 tons	25 tons (existing)

First look at Hybrid designs
Caspi, Brouwer, et al



	I0 (kA)	By-bore	Bmod (HTS)	Bmod (CCT)	Bmod (CT)
ANSYS	11	19.5	19.66	16.94	15.5
Opera2D	11	19.716	19.87	17.08	15.89
%diff		1.10	1.06	0.82	2.45
Poisson (Neumann boundary)	11	20.600	20.77	17.96	16.90
Poisson (parallel boundary)	11	19.370	19.58	16.80	15.82
Poisson (Average)		19.985	20.18	17.38	16.36
%diff		1.35	1.51	1.73	2.87

Conclusions

- We have a lot of magnets to test
- Recent progress in monitoring/diagnostic techniques extremely promising
- HL-LHC AUP with several (~few dozens) identical magnets could be an ideal deployment ground for monitoring & diagnostic equipment to inform world community on behavior of Nb_3Sn magnets
- HTS magnets can be tested in stand-alone today, however hybrid magnets of the future will require development of new test stands equipment and/or technology (quench protection) when viable future models (~20T) will start hitting the testing facilities
- Benefits of database of “lessons learned” on Magnet Test Facilities