LARP

Model Quadrupoles results and next steps

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LBNL

LARP Collaboration Meeting – CM14
FNAL
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Outline

- *The LARP Model Quadrupole Program*
  - *TQ magnet highlights*
  - *HQ magnet highlights*
- *Next Step*
- *Summary*

LARP – Model Magnet Program Goals

Magnet Goals:

- Demonstrate that Nb_3Sn technology is a viable option for the LHC phase II upgrade.

TQ -Technology Quad Goals:

- Maintain and develop Nb_3Sn technology in US Labs
- Demonstrate that a 200 T/m gradient can be reached in a 90mm bore
-

HQ -Technology Quad Goals:

- Maintain and develop Nb_3Sn technology in US Labs
- Demonstrate accelerator quality and performance in a 120mm bore

Collaboration

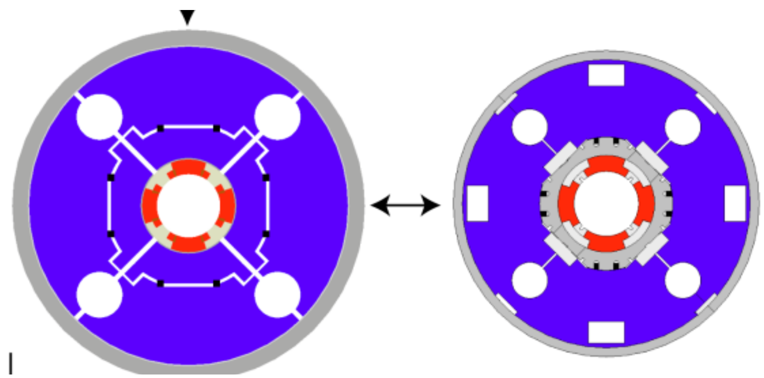
- BNL – Coil reaction and impregnation, conductor testing
- FNAL – Magnet design and analysis, conductor testing, coil parts design and fabrication, coil winding, curing, reaction, impregnation, instrumentation, assembly, testing.
- LBNL – Magnet design and analysis, conductor testing, coil winding, curing, reaction, impregnation, instrumentation, assembly and testing..
- CERN – Magnet assembly and testing

LARP – Model Quadrupoles

1. Nb_3Sn Technology - TQ

- *Conductor studies*
- *Coil fabrication*
- *Mechanical support*
- *Modeling tools*
- *Quench protection*

Technology Quadrupoles
TQS, TQC
1 m long
90 mm bore

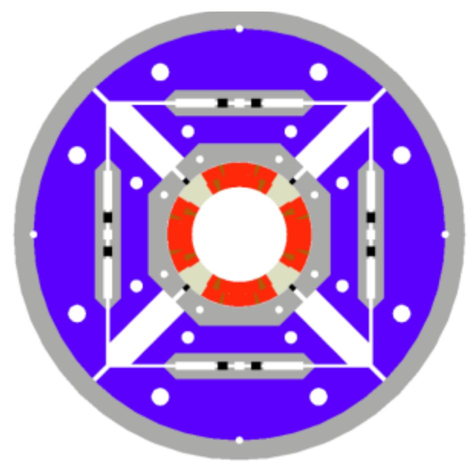


Reached 238 T/m

2. Design optimization - HQ

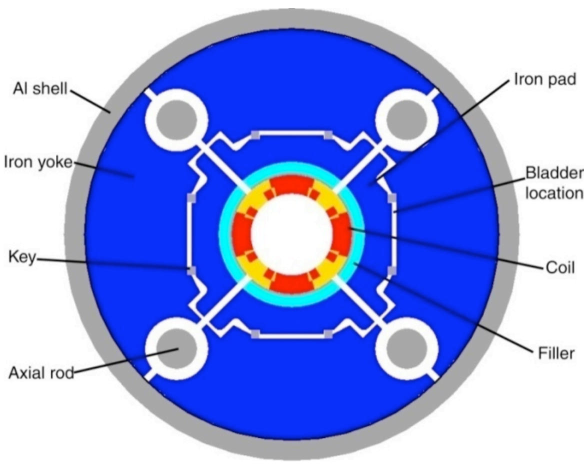
- *Larger aperture*
- *higher energy and forces*
- *Accelerator quality*

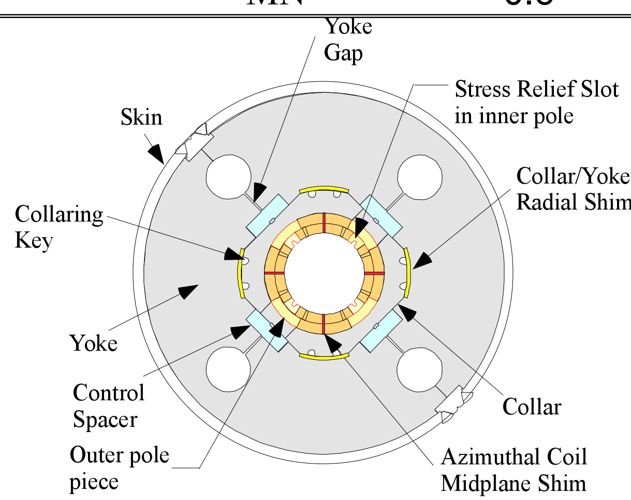
High Field Quadrupole
HQ
1 m long
120 mm bore

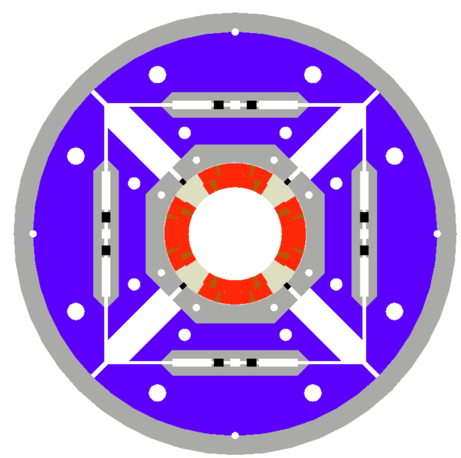


TQ and HQ Parameters

		TQ	HQ
Coil aperture	mm	90	120
Overall magnet diameter	mm	500	570
Jc 12T, 4.2 K, RRP 54/61 or 108/127	A/mm^2	3000	3000
Maximum gradient 4.4 K/1.9 K	T/m	239/262	199/219
Maximum current 4.4 K/1.9 K	kA	13.6/14.9	17.7/19.5
Peak field 4.4 K/1.9 K	T	12.25/13.4	13.9/15.2
Max. stored energy 1.9 K	MJ/m	0.6	1.4
Max F_θ forces 1.9 K, IL/OL	MN/m	-2/-2.1	-1.92/-3.2
Maximum axial force per end	MN	0.6	1.4



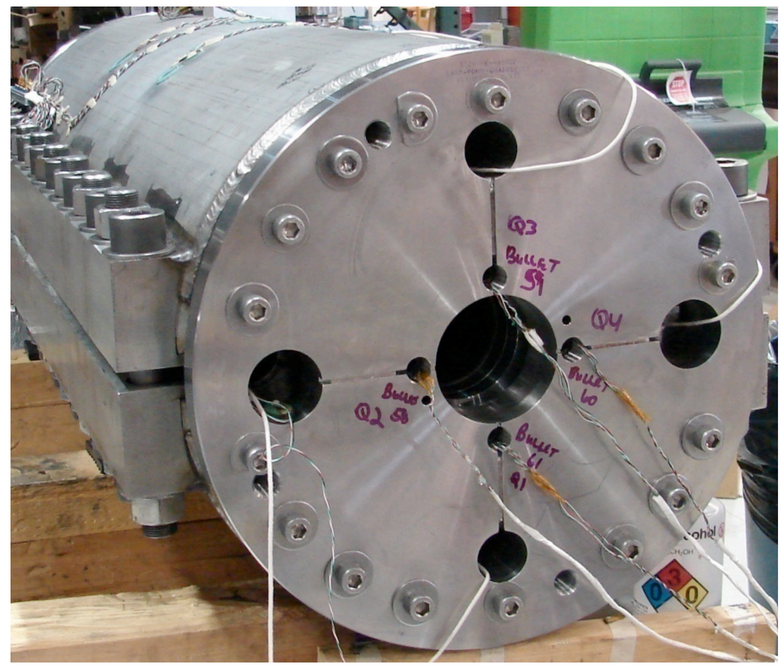




TQ Technology Quadrupole – TQS, TQC

TQS

TQC



The TQ Program

The TQ program has been the longest LARP magnet program (since 2004) and is now virtually completed.

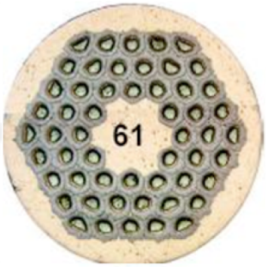
The program built a total of 33 coils 4 of which were practice coils (12%), 5 had issues (15%) and 24 (73%) were working coils.

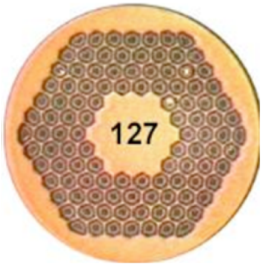
There were total of 16 tests, 5 (~1/3) were with virgin coils and 11 (~2/3) were with replaced or reused coils.

The completed program has coils and 2 different structures that can still be used in the future.

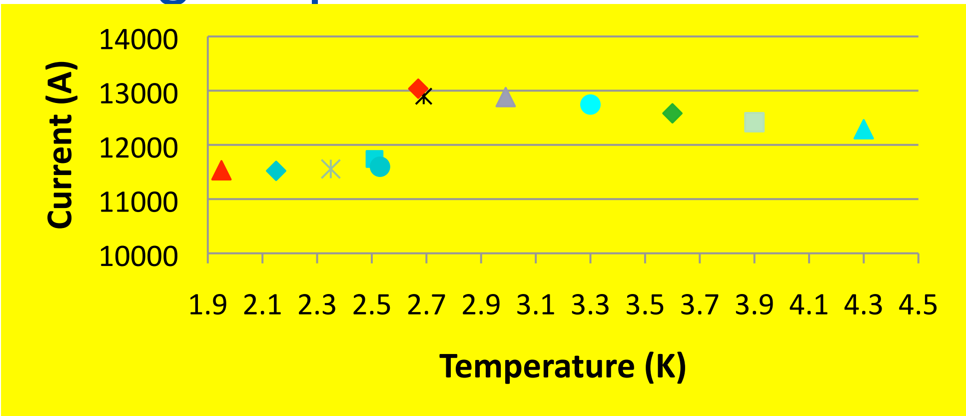
Lesson learned - Conductor

- Magnet performance using Nb_3Sn conductor with 54/61 filaments was unstable below ~ 2.5 K (quench current at 4.4 K is higher than 1.9K)



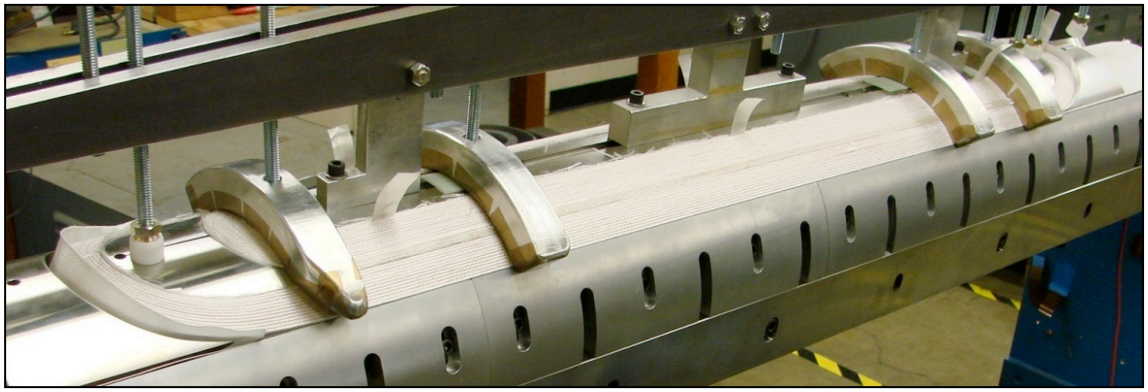


- Replacing the 54/61 conductor with 108/127 filaments magnet performance remained stable down to 1.9 K

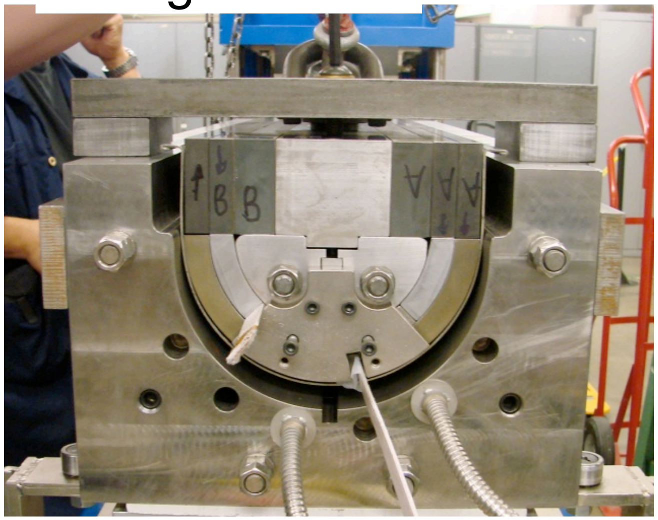


Nb3Sn Technology – Coil Winding and Curing

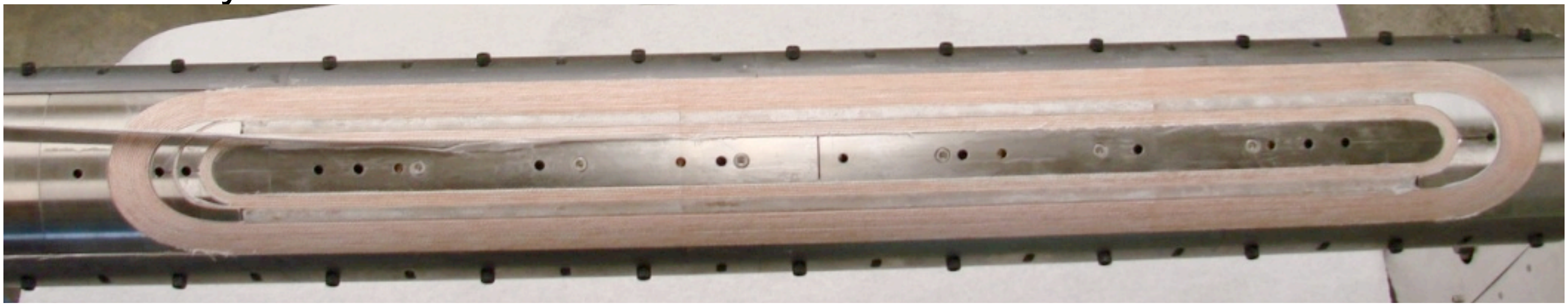
Coil Winding



Curing

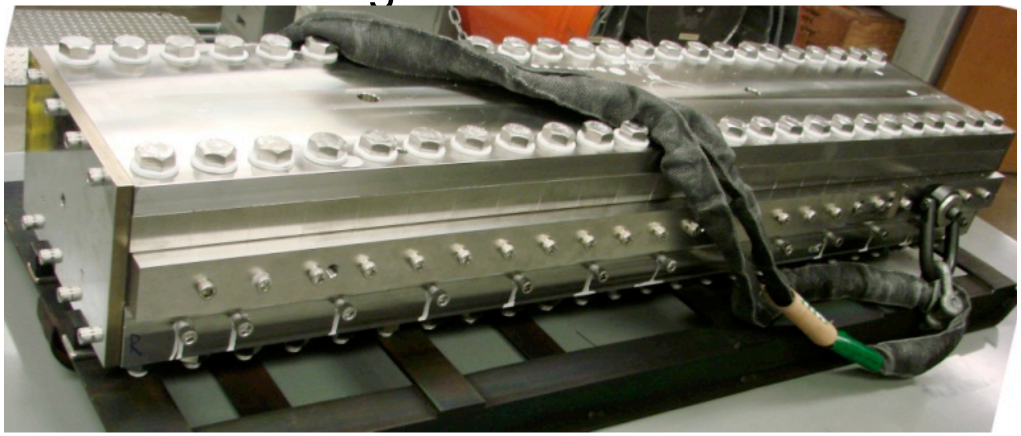


Cured Layer 1



Nb3Sn Technology - Reaction and Impregnation

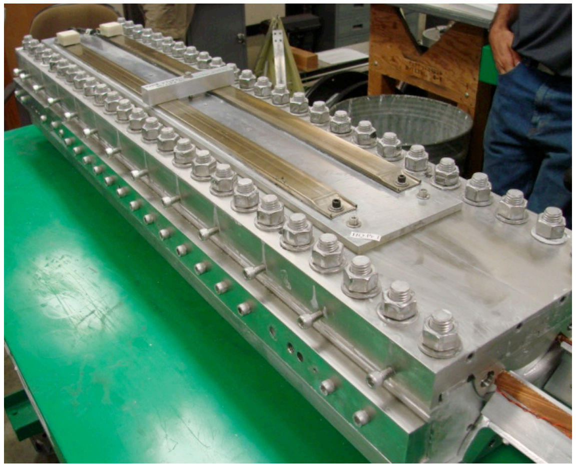
Reaction Tooling



•72 hr at 210 C

•48 hr at 400 C

•48 hr at 665 C



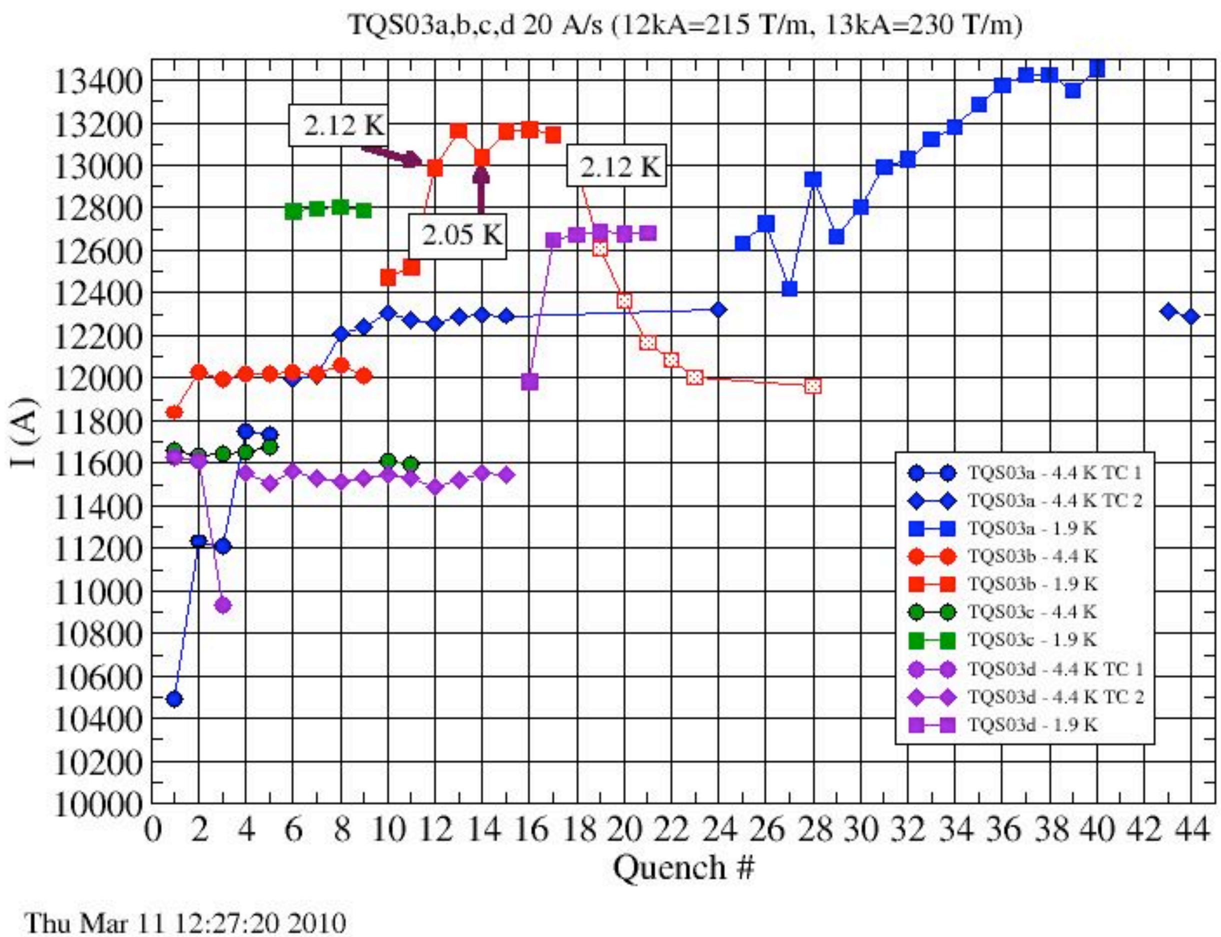
Post Reaction: NbTi Leads, VT, SG.

Impregnation Tooling

Lesson learned – assembly

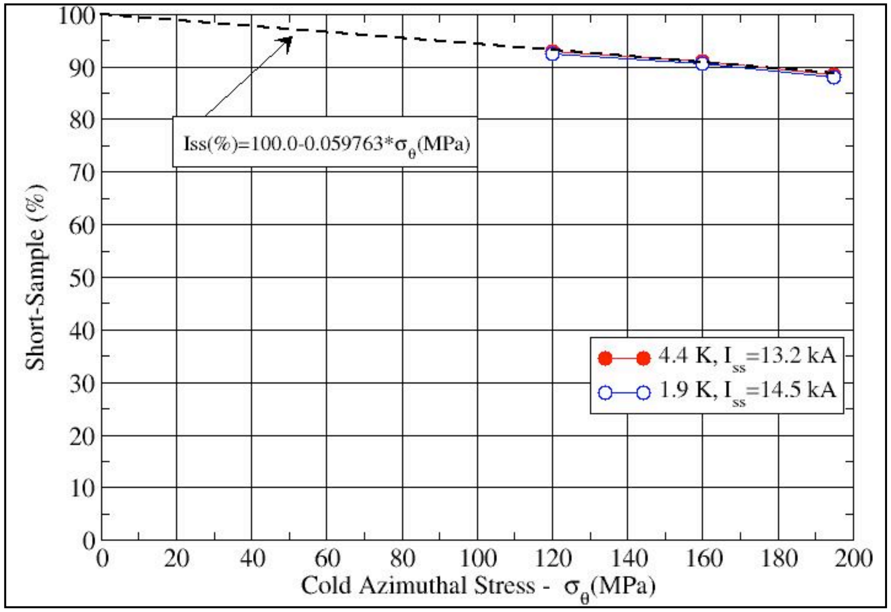
- Applied force is provided by an outer shell or skin (not collars)
- Assembly and coil compression is a delicate operation with a sensitivity of ~32MPa/100 microns of displacement.
- Key and bladder technology or a split and bolted outer skin is a way to control pre-stress (not welding)

Magnet Training



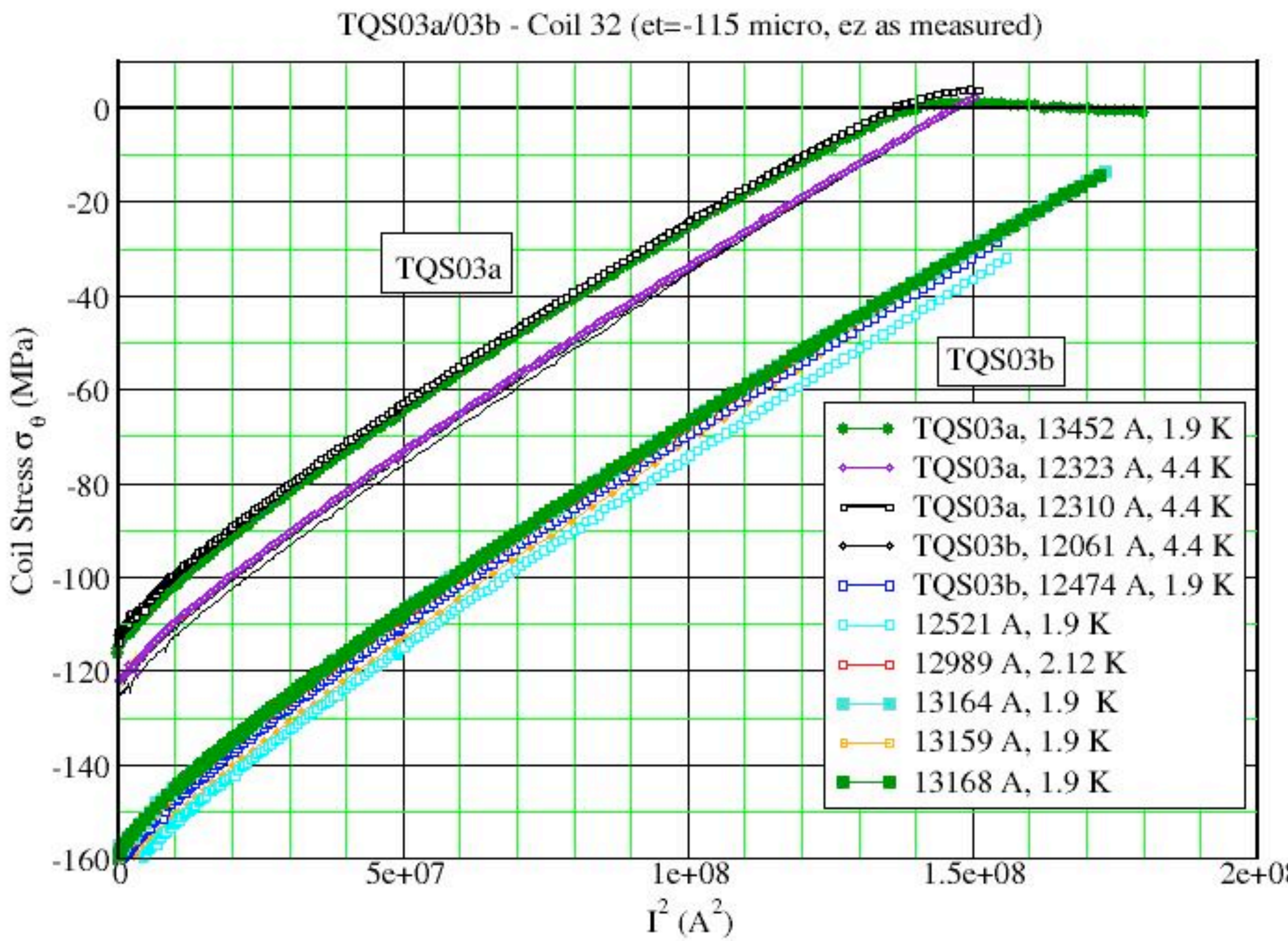
Lesson learned – Pre-stress

- 150 MPa is not a hard limit for magnet performance.
- Impact of pre-stress on current plateau not too sensitive to stress (but still limited by strain).



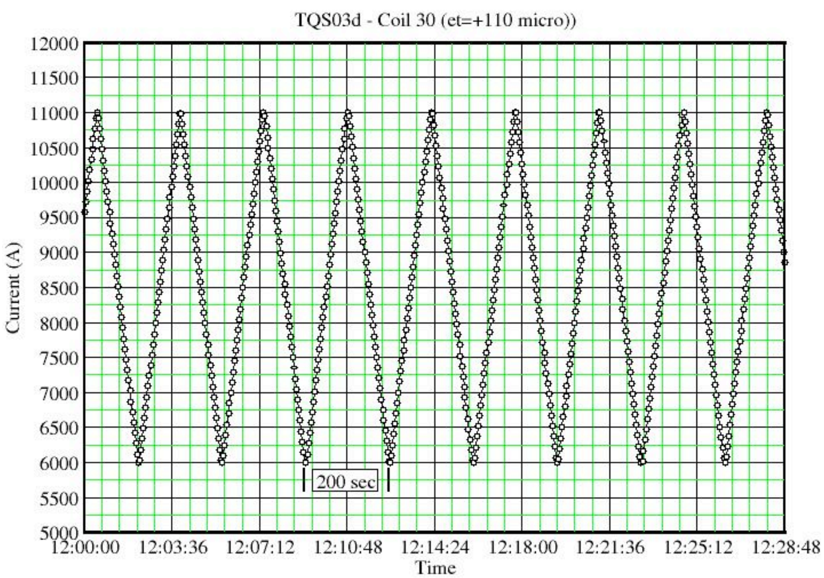
Lesson learned – Magnet Performance …

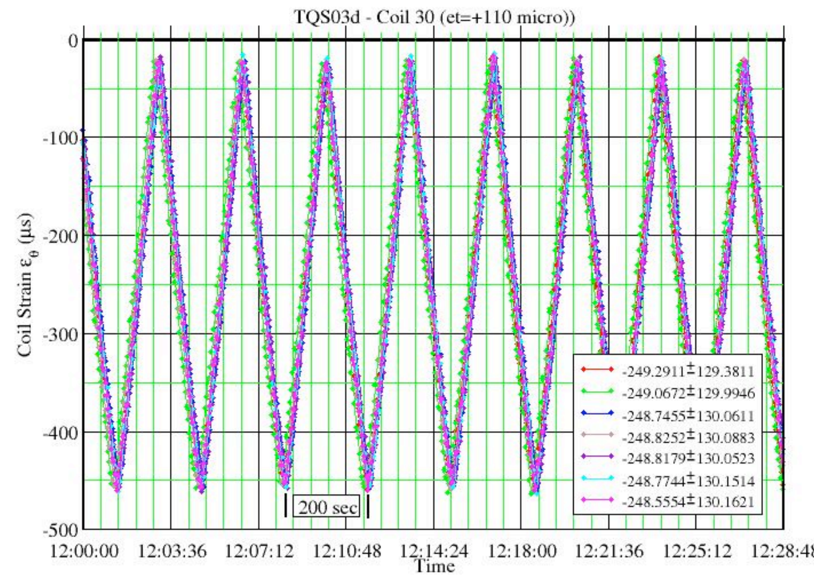
Increase pre-stress from 120MPa to 160Mpa



Lesson learned – Magnet Performance

- No degradation up to 1000 cycles





6000A-11000A

0 – 450 με (70-0 Mpa)

The HQ Program

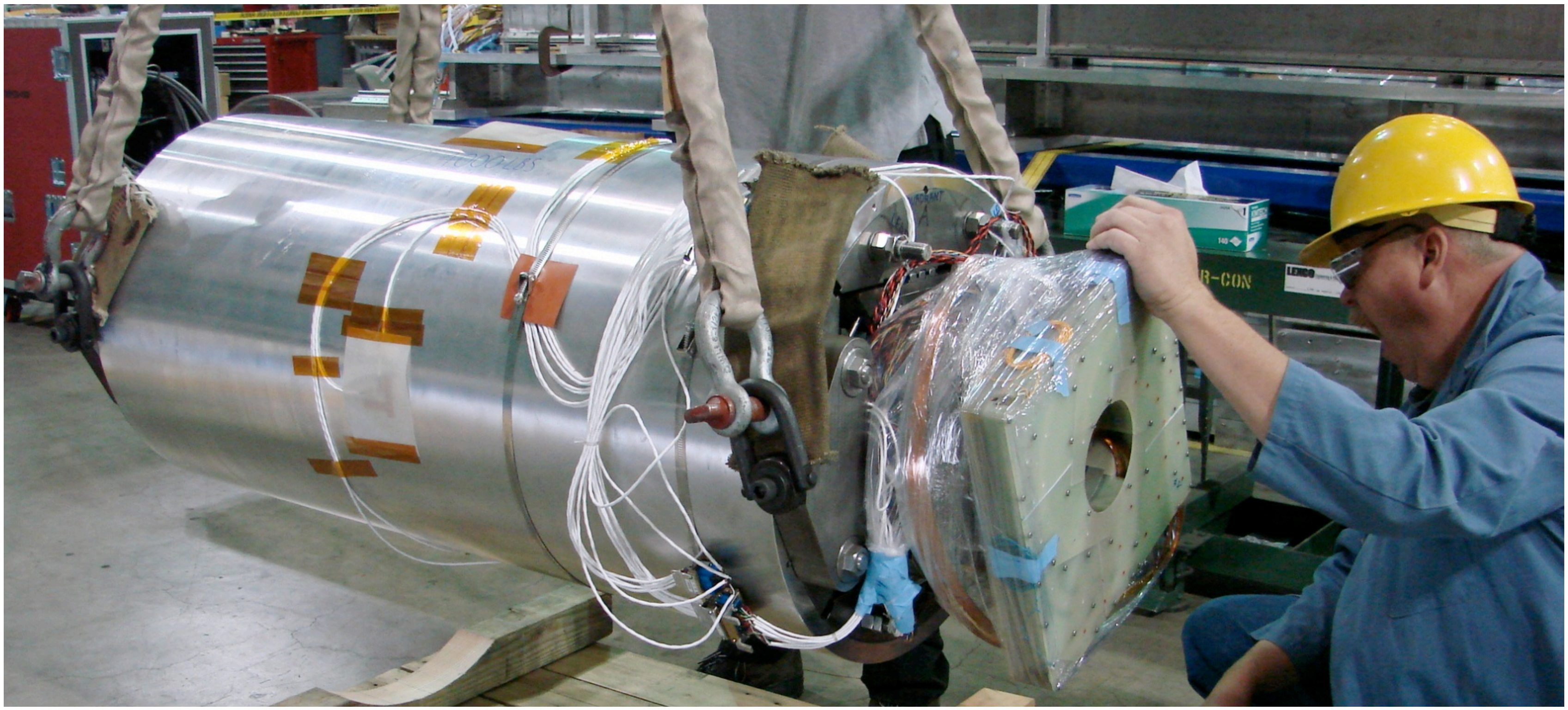
The HQ program will finish 12 coils by the end of 2010

All coils are considered working coils.

Based on the TQ statistical model we expect to have ~6 test, 2 with all virgin coils and 4 with replaced or reused coils.

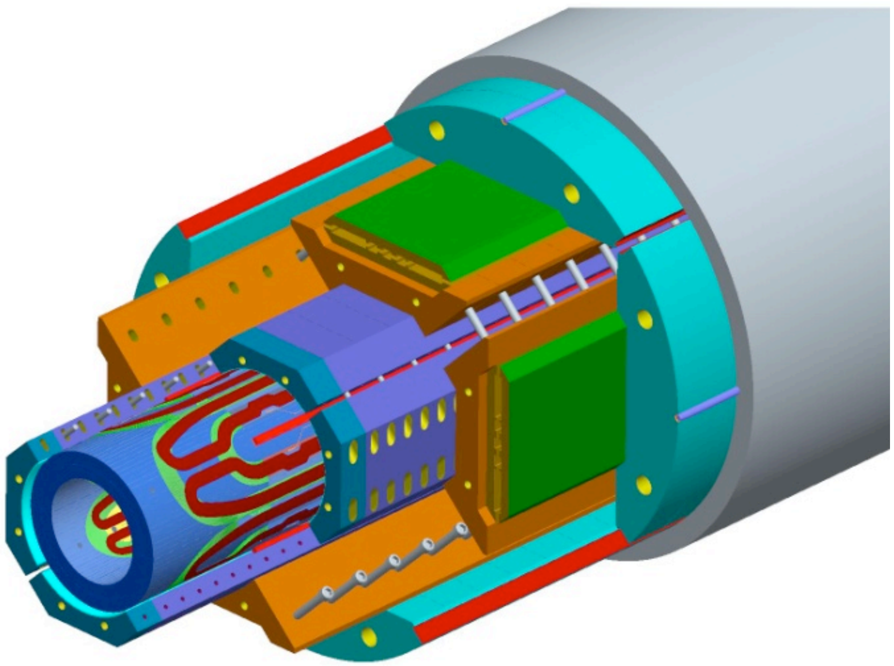
The first HQ test is underway. The magnet is now at 4.4K and expected to have the first quench this week.

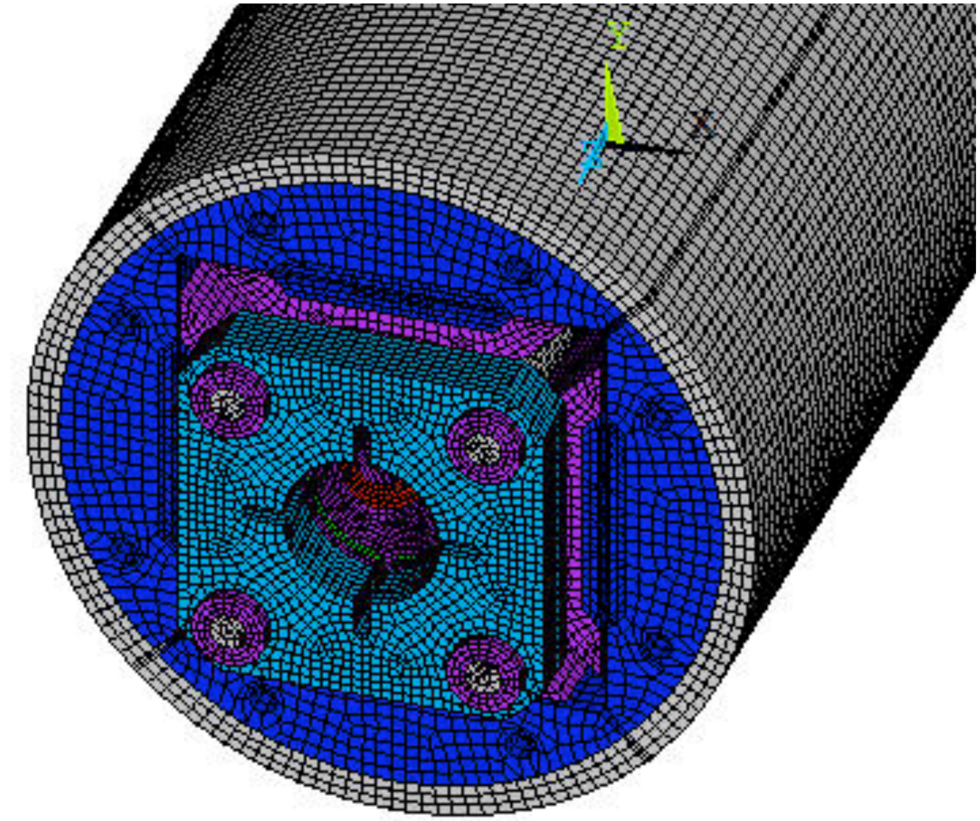
HQ01a



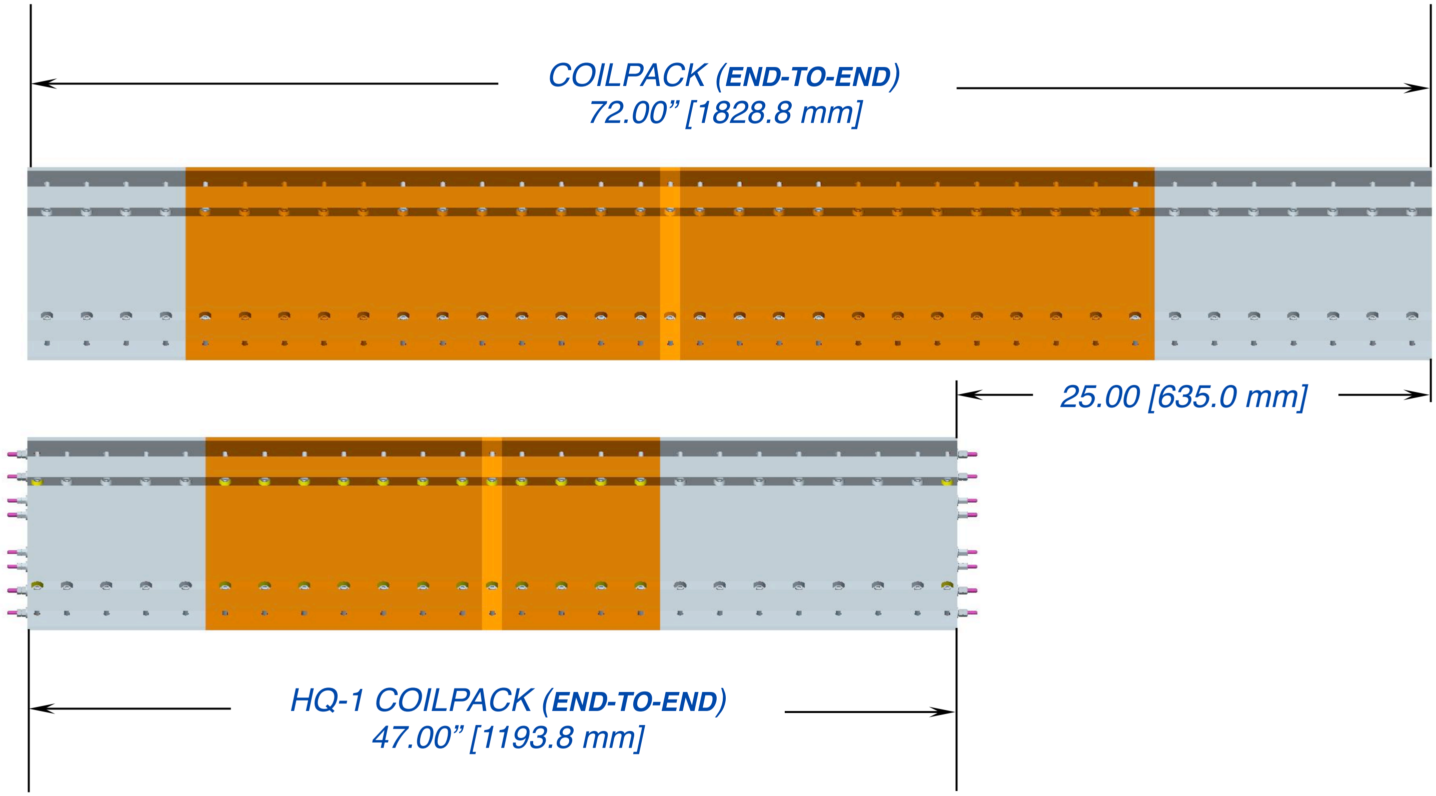
Lesson learned – Analysis

1. Modeling
2. Properties
3. Friction
4. Azimuthal & Axial pre-load





Next Step - Longer HQ Magnet, HQ-2



TQ Summary

- Nb3Sn technology - winding, curing, impregnation, instrumentation, protection.
- RRP 54/61 [Jc (12 T, 4.2 K) 2925 A/mm2] is unstable below 3K
- RRP 108/127 [Jc (12 T, 4.2 K) 2770 A/mm2] is stable down to 1.9K
- Pre-stress 195Mpa, Iss~88% (TQS03c)
- TQ exceeded 200 T/m goal (237 T/m at 1.9K)
- Reduced training (< 5 quenches, TQS03a)
- No re-training (TQS03b)
- 1000 cycles 6-11kA

HQ Summary

- A 120 mm bore, Nb_3Sn quadrupole for Phase II is under construction
- With a current density conductor of 3000 A/mm^2 (12 T, 4.2 K) the magnet is expected to reach 15 T at 1.9 K (219 T/m)
- The magnet is optimized for alignment and field quality
- Assembly and pre-stressed with an outer Aluminum shell and “key and bladder” technology.
- First test last week of April 2010