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Status of a Single-Aperture 11 T Nb_3Sn Demonstrator Dipole for LHC Upgrades

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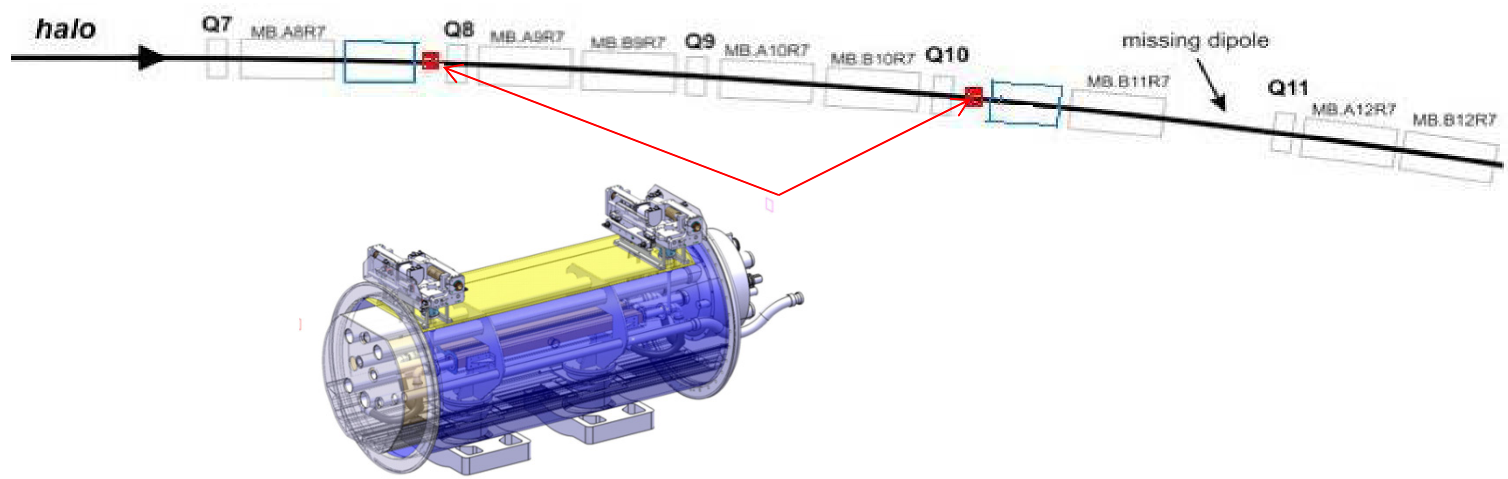
Outline

- Program goals, approaches and phases
- 11 T demonstrator magnets design and parameters
- Single-aperture demonstrator magnet construction
- Test objectives
- Conclusions

LHC Collimation Upgrade

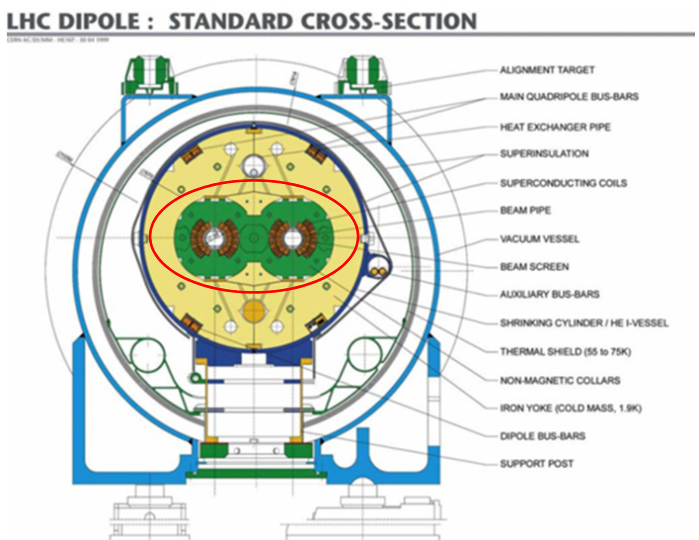


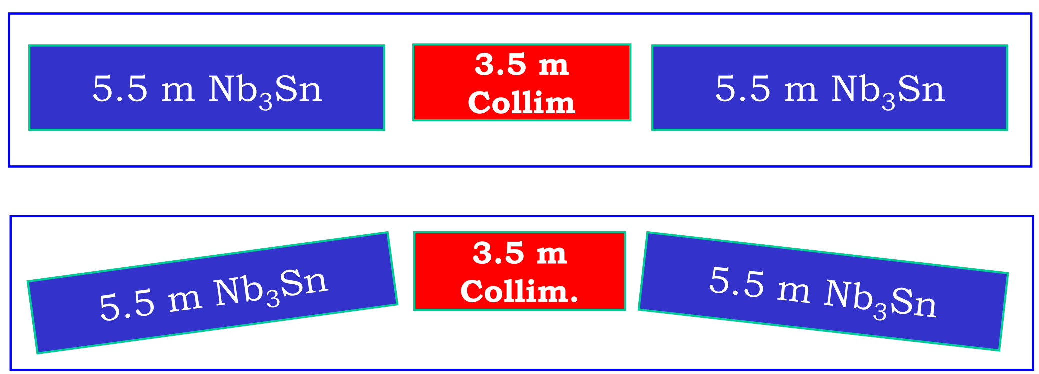
- ❖ CERN is planning to upgrade the LHC collimation system
  - o additional collimators in DS regions around points 2, 3, and 7
  - o IR 1 and 5 as part of the HL-LHC
- ❖ The required space ~3.5 m can be provided by stronger (11 T) and shorter (11 m) dipoles
  - o Nb_3Sn technology

Details in THPPD009

General Design Approach

- Coil aperture 60 mm
  - accommodate the beam sagitta and avoid the additional complication of curved Nb_3Sn coils
- 5.5 m long coils, separate collared coils
- Modified 550 mm iron yoke from the LHC main dipole
  - compatibility with LHC main systems
- 11 m long magnet combines two 5.5 m long cold masses
  - arrangement flexibility





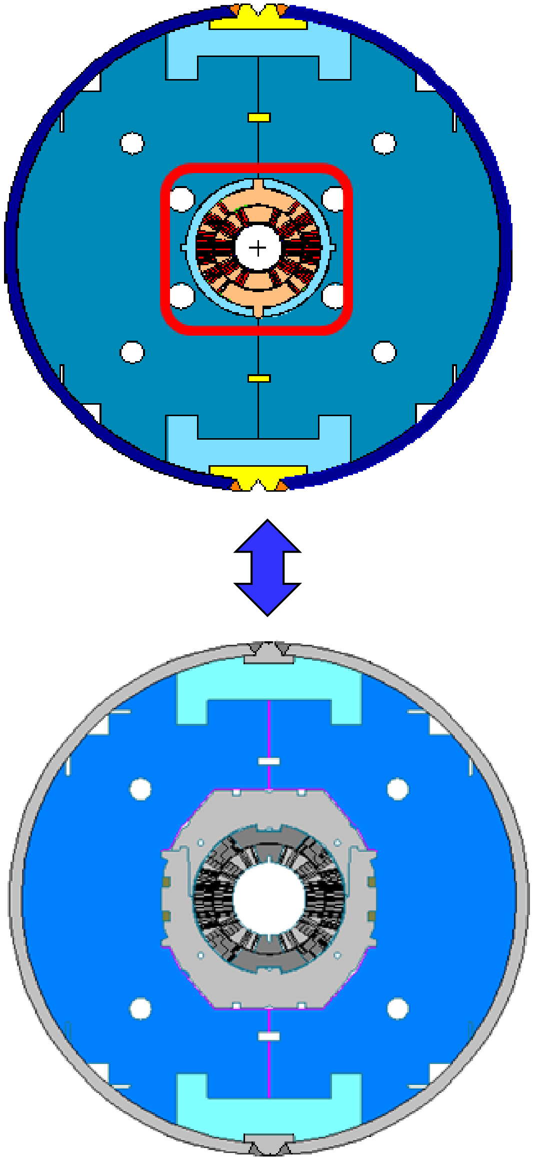
Magnet Development Plan

- CERN and FNAL have started in October 2010 a joint R&D program to demonstrate feasibility and build a twin-aperture 11 T, 5.5 m long Nb_3Sn dipole prototype by the end of 2014.
- Program phases and goals:

Date	Description	Length	Remarks	Goals
Jun 2012	Single-aperture demonstrator dipole	2 m	Design and construction: FNAL	• Collared coil design & technology • Quench performance, margin
Jun 2013	Twin-aperture demonstrator dipole #1	2 m	Collared coils: FNAL Cold-mass: CERN	• 2-in-1 structure • Quench performance • Field quality • Quench protection • Reproducibility
Dec 2013	Twin-aperture demonstrator dipole #2	2 m	Collared coils: CERN Cold-mass: CERN	
Dec 2014	Twin-aperture prototype	5.5 m	Collared coil 1: FNAL Collared coil 2: CERN Cold mass and cryostat: CERN	• Design & technology scale up • Cryostat • Accelerator performance

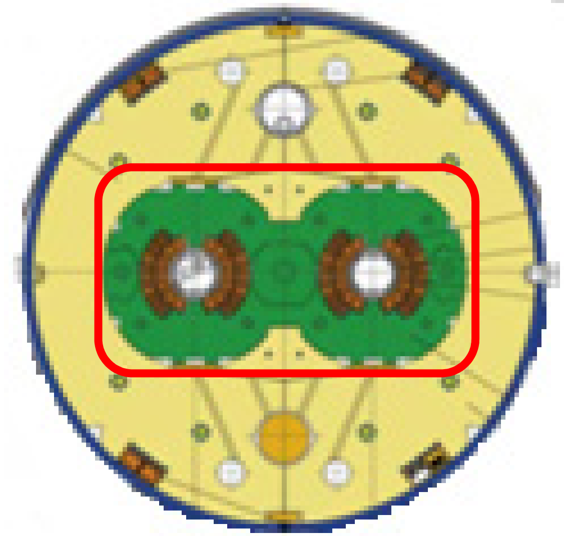
Single-Aperture Demonstrator

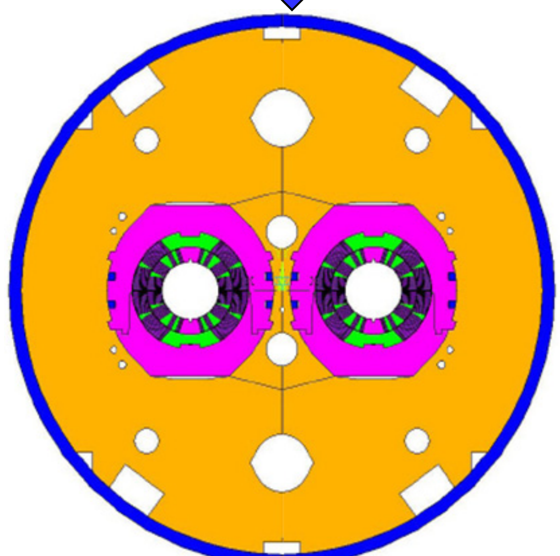
- Modified structure of HFDA dipole.
- Two-layer 6-block coil design
- Stainless steel collar
- 400 mm vertically split iron yoke
- Al clamps to control yoke gap
- 12 mm thick stainless steel skin
- 50-mm thick end plates



- Coil azimuthal pre-stress ~130 MPa
  - coil under compression up to 12 T
- Mechanical structure optimized to maintain the coil stress <165 MPa
  - safe for brittle Nb_3Sn coils

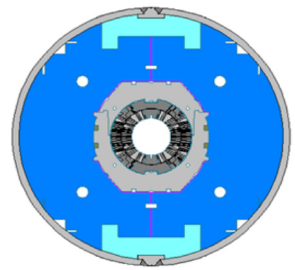
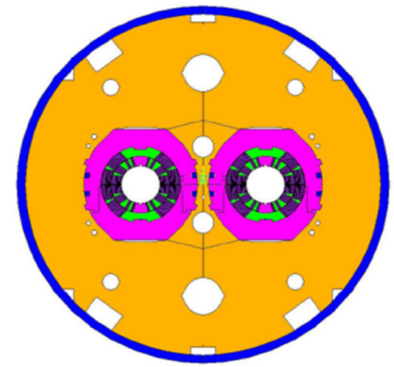
Twin-Aperture Demonstrator



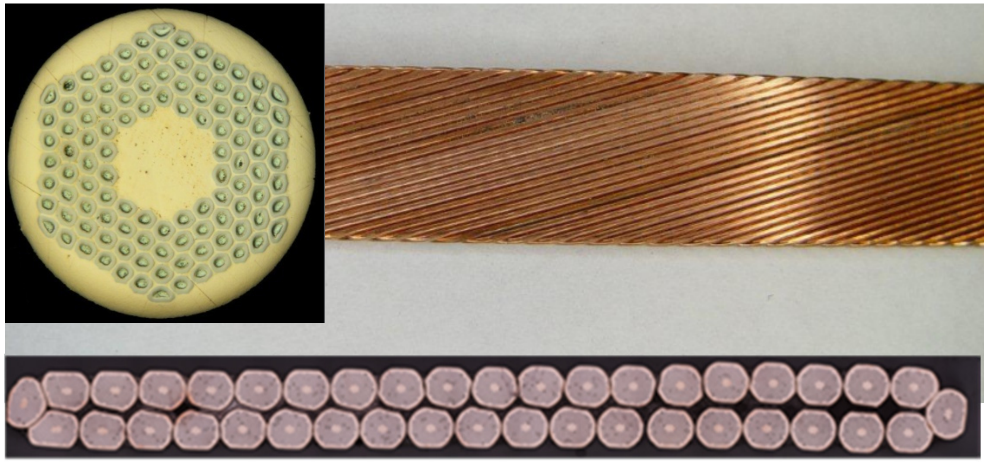


- Modified MB yoke with separate collared coils
- Electromagnetic design challenges
  - matching the MB transfer function
  - control the magnetic cross-talk between apertures
  - minimization of the unwanted multipoles in the current cycle
- Mechanical design challenges
  - first twin-aperture Nb_3Sn dipole
  - Lorentz force management
  - Poles under compression and coil stress <165 MPa
- Quench protection challenges
  - Larger stored energy

Demonstrator Dipole Parameters

Parameter	Single-aperture 	Twin-aperture 
Aperture	60 mm	
Yoke outer diameter	400 mm	550 mm
Nominal bore field @11.85 kA	10.88 T	11.23 T
Short-sample bore field at 1.9 K	13.4 T	13.9 T
Margin B_{nom}/B_{max} at 1.9 K	0.81	0.83
Stored energy at 11.85 kA	424 kJ/m	969 kJ/m
F_x per quadrant at 11.85 kA	2.89 MN/m	3.16 MN/m
F_y per quadrant at 11.85 kA	-1.58 MN/m	-1.59 MN/m

Strand and Cable



Strand (OST):

- Nb_3Sn RRP-108/127
- 0.7 mm diameter
- high-J_c, stable

Cable (FNAL/CERN):

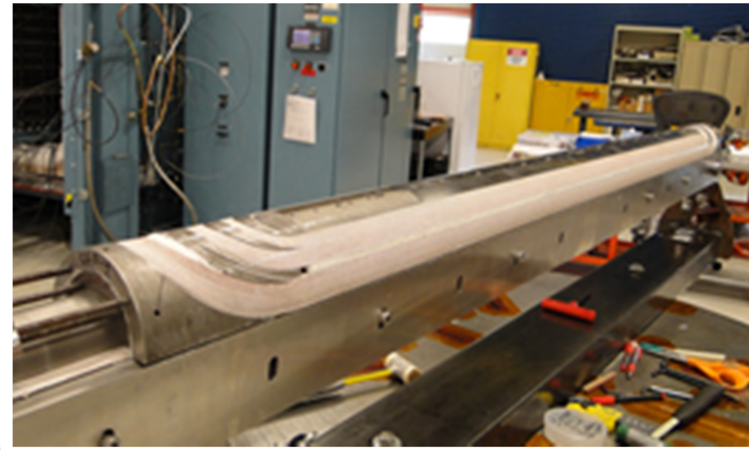
- 40 strands
- 15-mm wide, 1.25 mm thick
- Low degradation, <4%

Cable production:

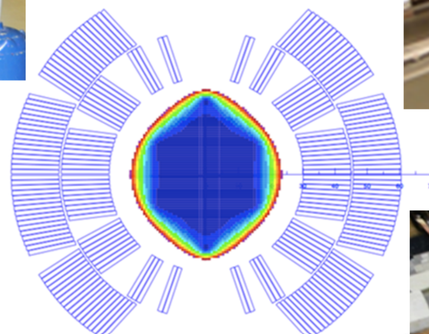
- 440 m long piece for 2 main coils (FNAL)
- 210 m long piece for spare coil (CERN)
- R&D cable with stainless steel core

Coils

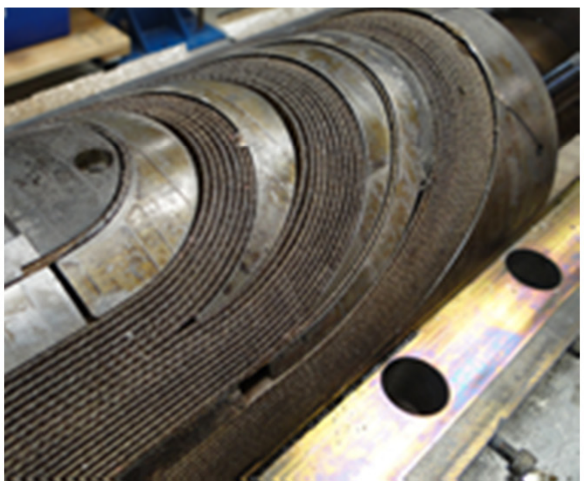
Coil winding



Coil after curing at 150°C



- 6-blocks
- 56 turns
- Ti poles
- Stainless steel wedges and end spacers



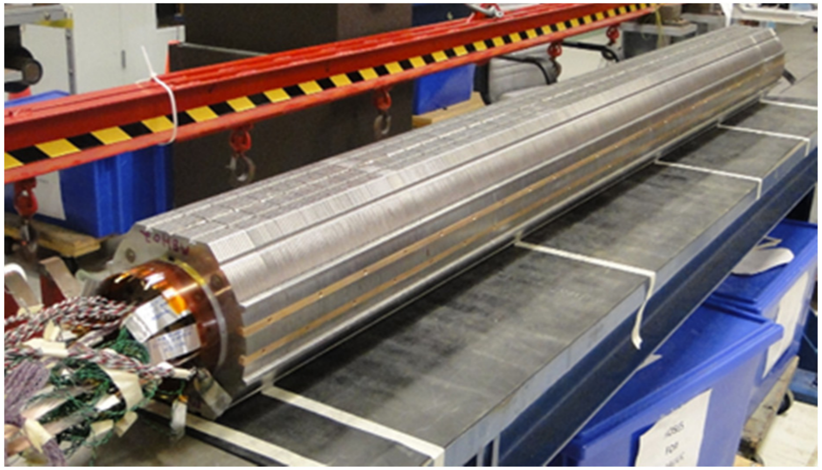
Coil after reaction at 640°C

Coil after impregnation with epoxy

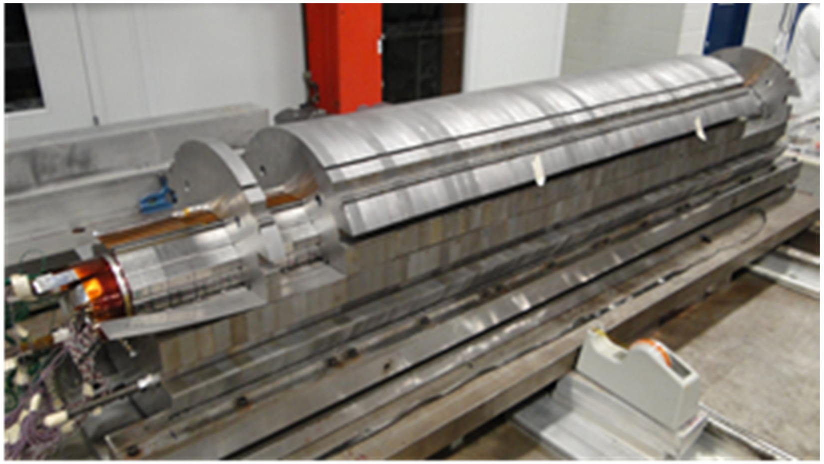
2 main coils + spare coil (reacted, being epoxy impregnated).

Magnet Assembly

Assembly of two instrumented coils



Collared coil

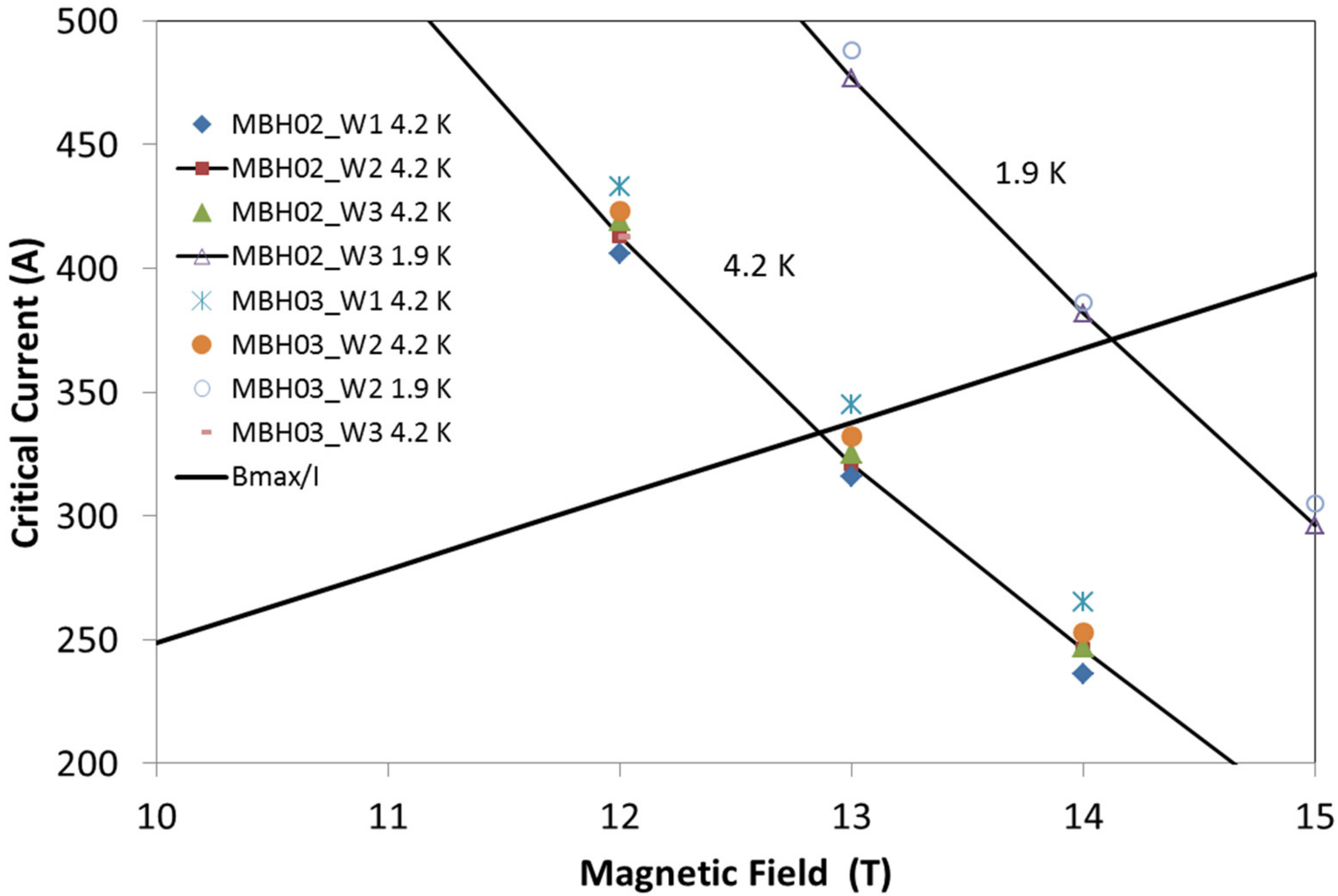


Collared coil assembly with iron yoke

2 m long cold mass

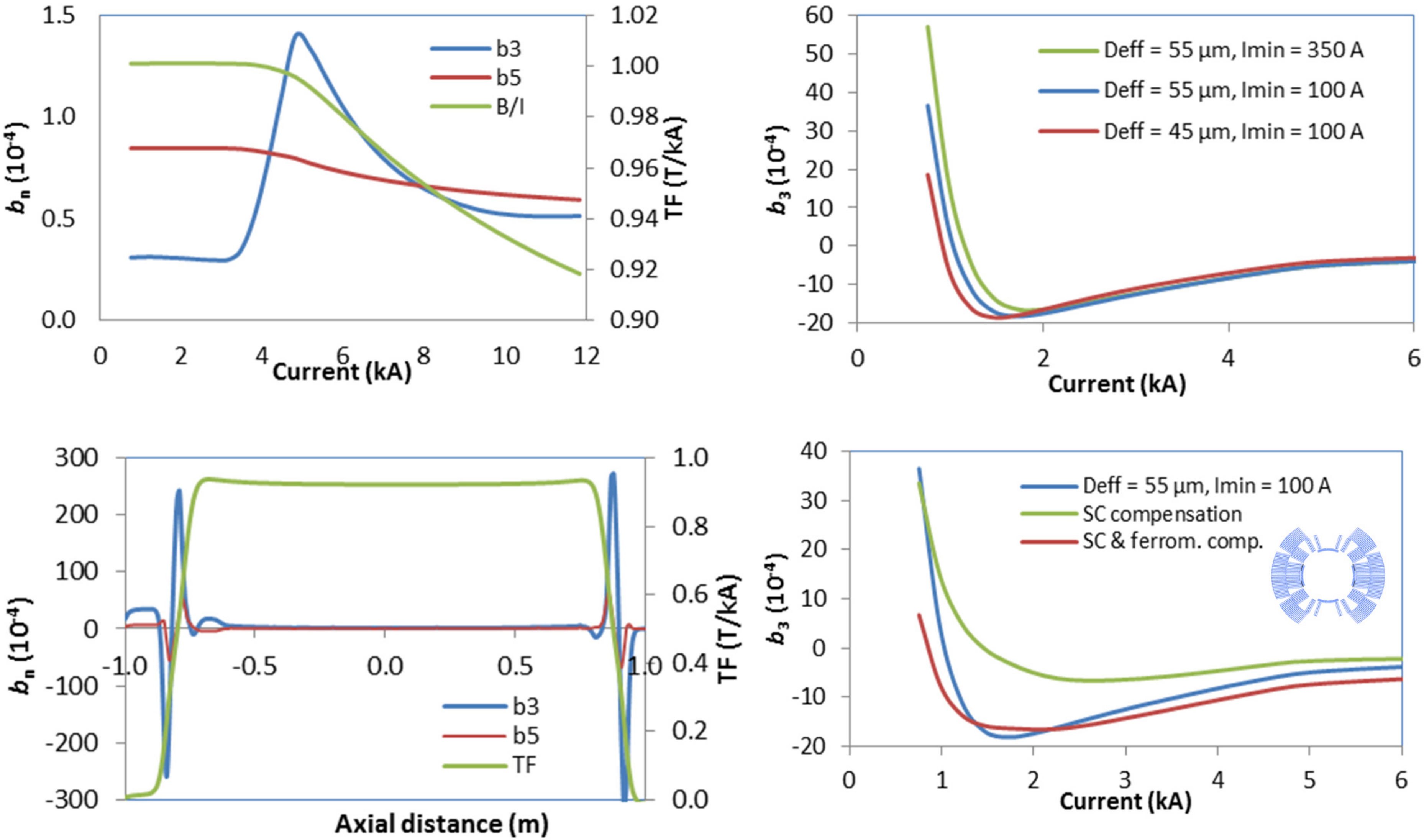
❖ Magnet assembly completed, magnet test in June.

Maximum Field and Margin



SSL: I_{max} (4.2/1.9K)=13.3/15.0 kA B_{max}(4.2/1.9K)=12.7/13.4 T.

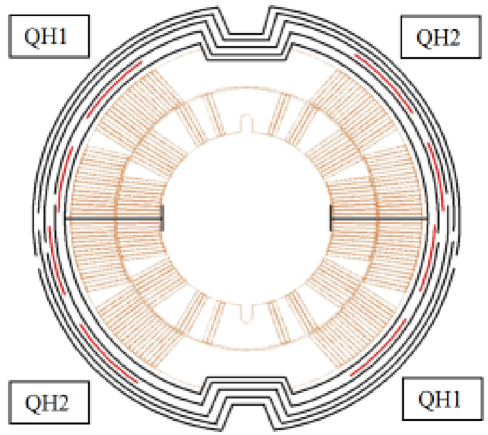
Field Quality Analysis

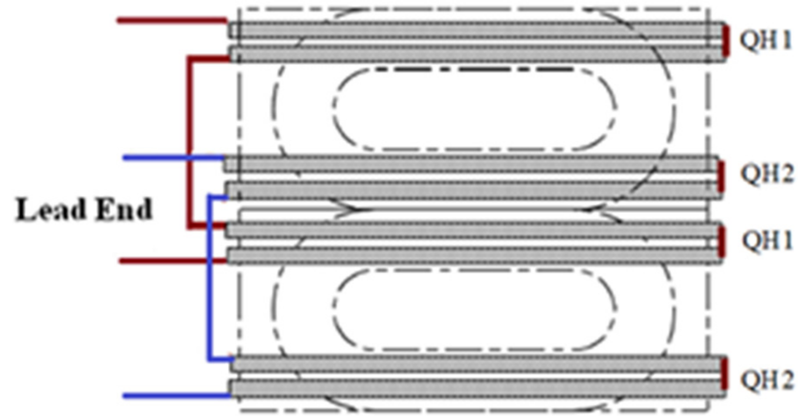


Details in THPPD039

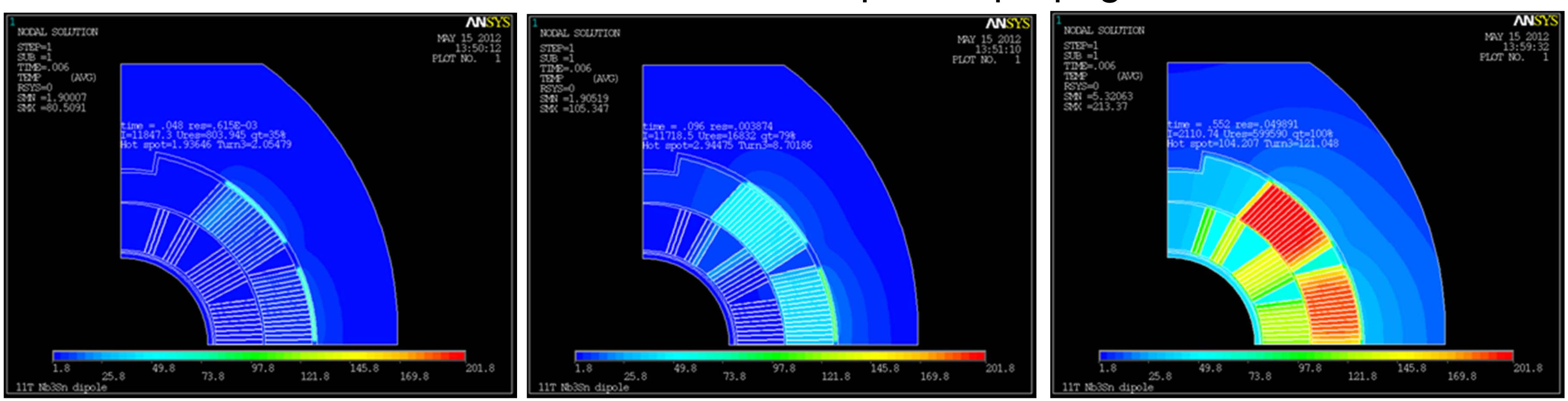
Quench Protection

Quench heater position and electrical connection





Simulation of transverse quench propagation



Details in THPPD040

Conclusions

- 11 T Nb_3Sn demonstrator dipole magnets for possible use in accelerators in particular for the LHC upgrades are being developed by FNAL/CERN collaboration.
- The first single-aperture 2 m long demonstrator magnet is complete and being prepared for test at FNAL
- Test objectives:
  - demonstrate the quench performance, nominal field, and operation margin
  - field quality and quench protection study
- Passive correctors will be fabricated and tested with the 11 T demonstrator magnet.
- A 1 m long model with RRP-150/169 strand and stainless steel core is being fabricated at Fermilab and will be tested later this year.

Acknowledgements

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