LBNL High-Field Core Program

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LBNL

EuCard Workshop on High Energy LHC
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Mission and Accomplishments
In Nb_3Sn and HTS conductor

Critical contributions to high field magnet technology:

- *Engineering properties of superconducting wires*
- *Cabling of traditional and advanced wires*
- *Pioneered the "wind-and-react" coil fabrication technology*
- *New concepts for mechanical support and magnet assembly*
- *Advances in modeling capabilities and diagnostic tools*

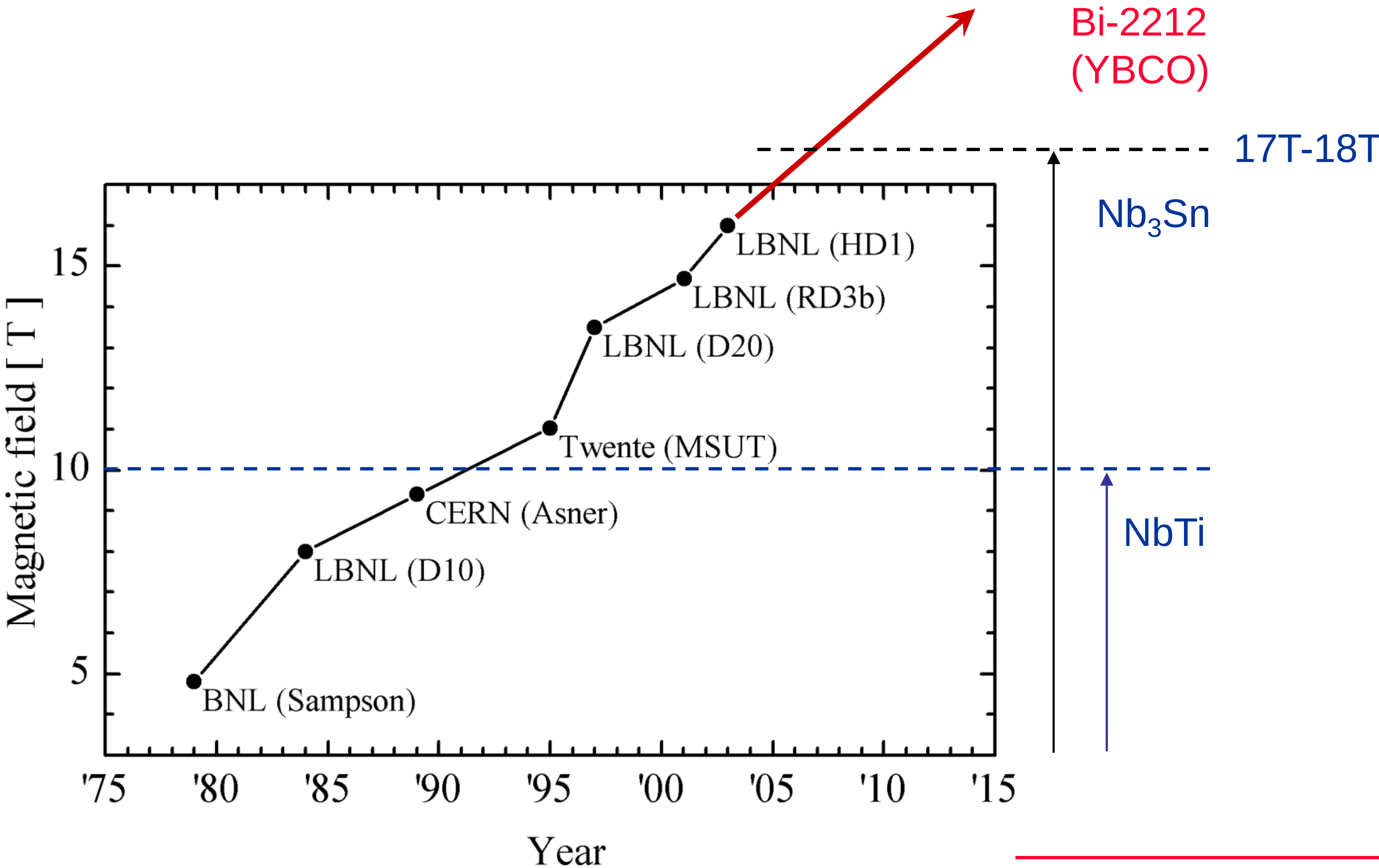
$\Rightarrow$ Pushing the technological limits of accelerator magnets

Impact on the HEP community:

Technology to advance the energy/ luminosity frontier of the LHC

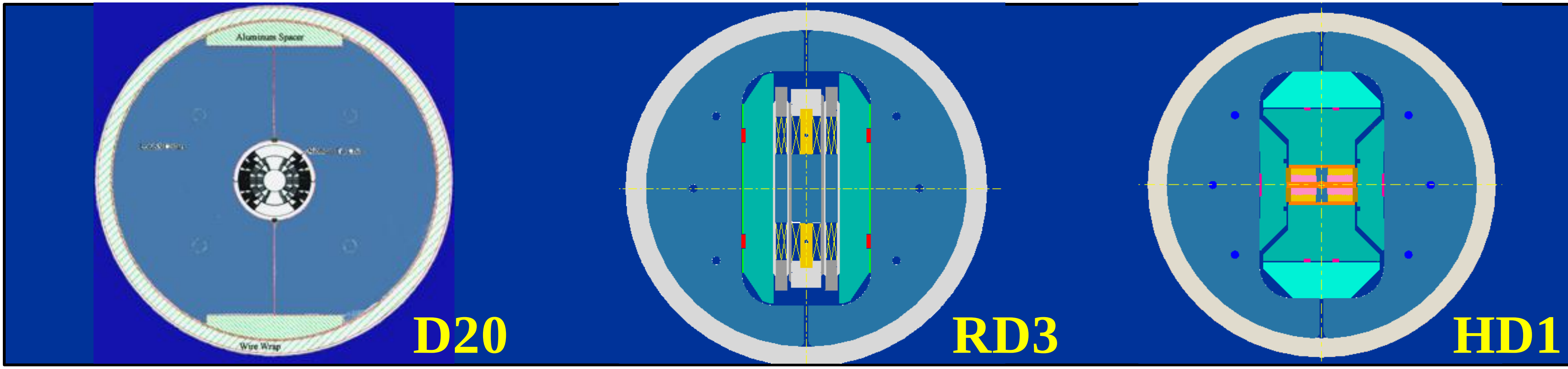
*LBNL has been working almost entirely on Nb_3Sn and HTS for the past 20 years

Progress in High Field Dipoles



Tests of three different types of High Field Dipoles

“cos-theta” “common-coil” “block”



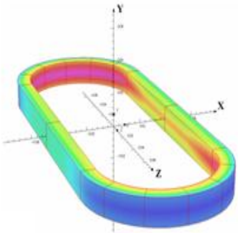
13.8T, 1997
50mm bore

14.5T, 2001

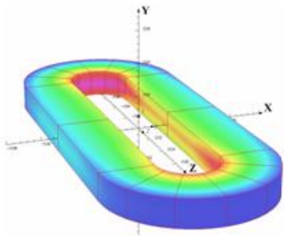
16T, 2003

Sub-scale Coil Test Configurations

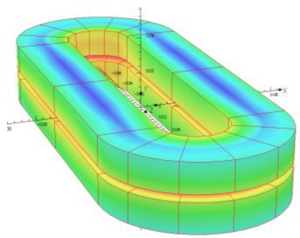
6-turns



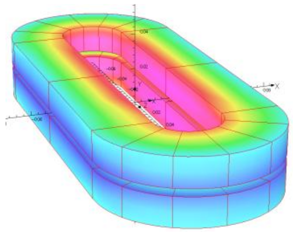
19-turns



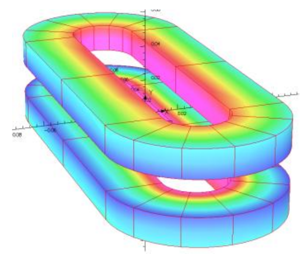
Common coil

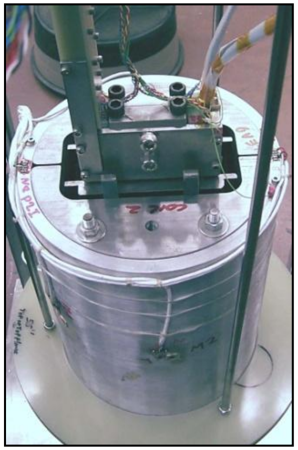


Block

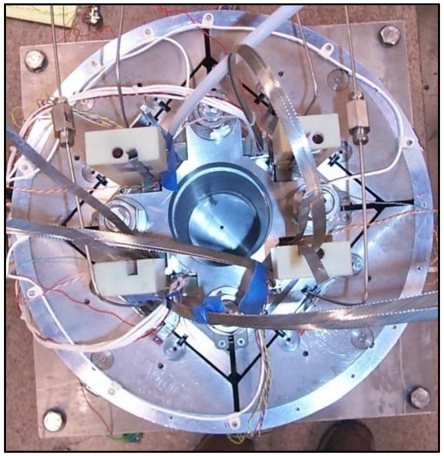


Hybrid

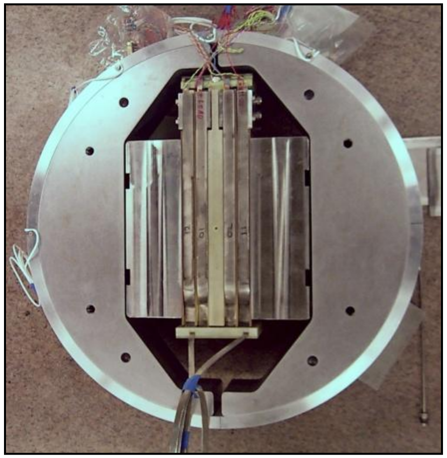




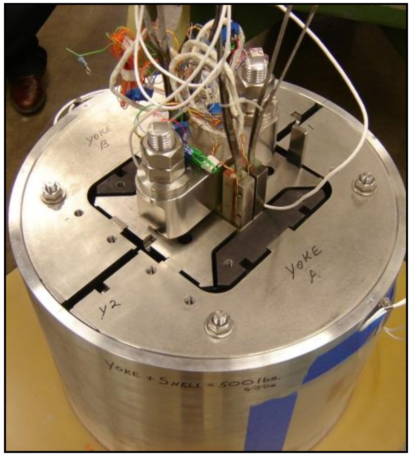
SM
Low field
Low stress



SQ
High stored energy
High Axial forces



NMR
4-coil layout
High field



SD
High field
High stress

HEP Conductor Development (CDP)

Coordinating National Labs, University, Industry

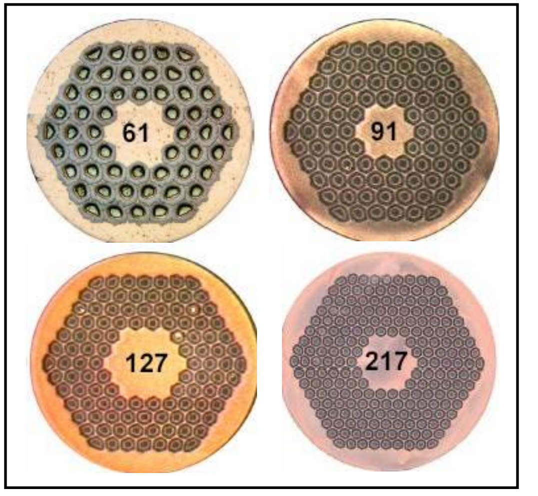
Achievements:

- *Doubled the critical current density of Nb_3Sn*
- *Improved process uniformity & piece length*

Current focus:

- Continue to improve critical current density
- Explore methods to reduce sub-element size

From 2007, CDP supported Bi-2212 development

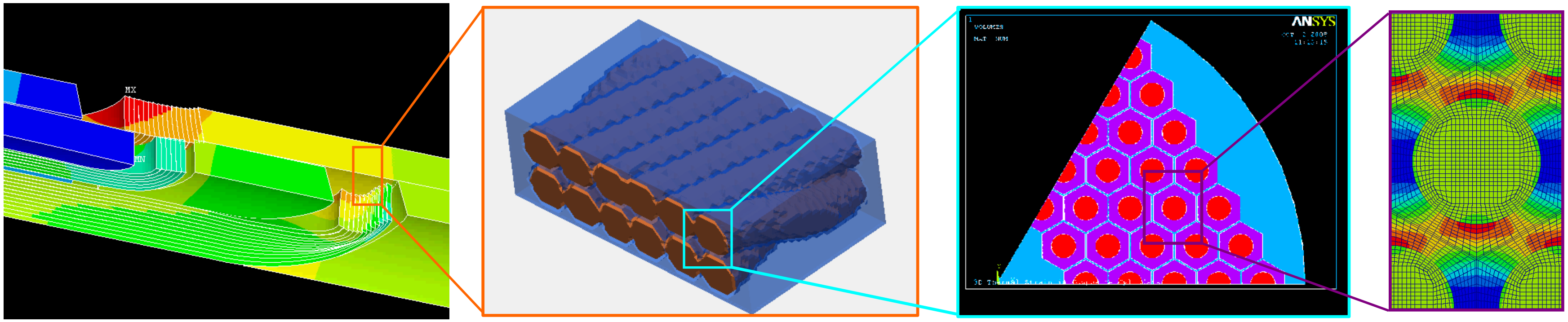


Sub-element designs
Current focus on the 217 sub-element stack

Nb_3Sn	Full qualification in Accelerator configurations
Bi-2212 YBCO	Demonstration in simple configurations

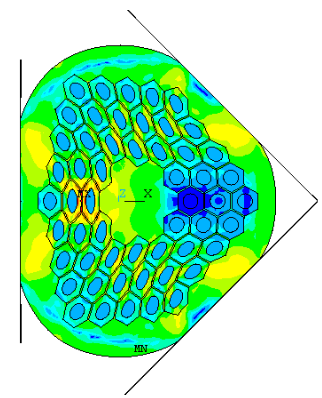
Hierarchical Modeling of Strain State

Magnet/Coil **Cable** **Strand** **Filament**



<u>Goal</u>: Understand relations between conductor state at the different scales

Requires developing, validating and correlating models at each scale



- Nonlinear Properties into Hierarchical Models of Nb_3Sn Strands
- Find J_c in Nb_3Sn magnets due to macroscopic loads
  - Compute strain at the filament level
  - Compute stress in micro-scale due to macro loading
  - Nonlinearity, finite deformation
- Cool-down effects

W&R Bi-2212 Technology Development

Beyond 16 T dipole fields

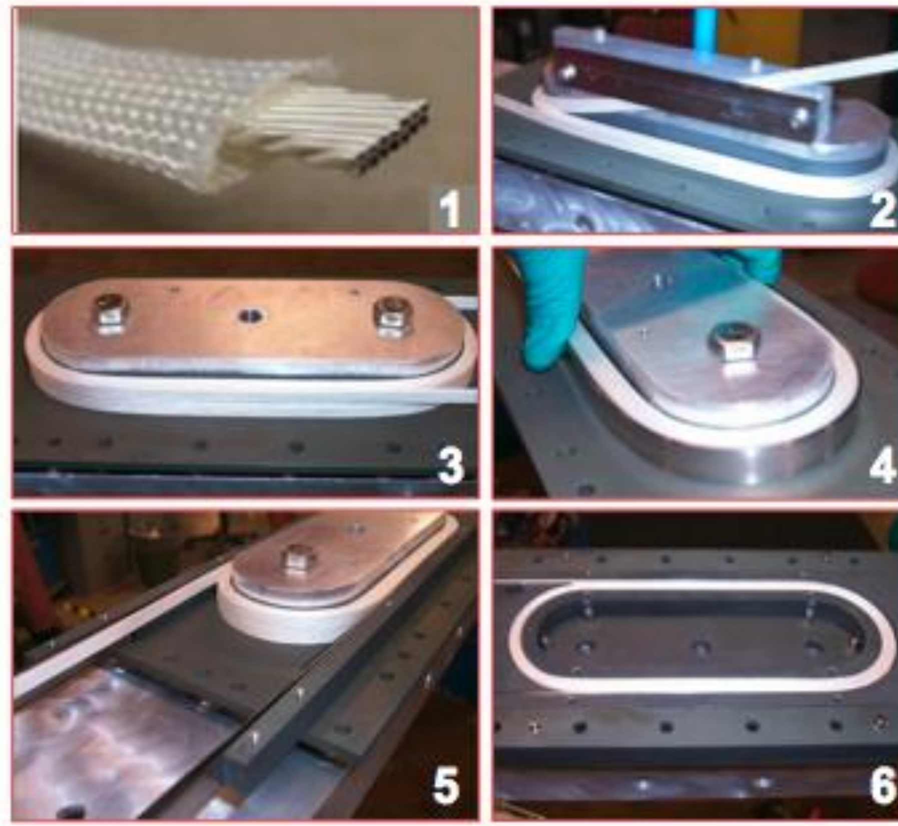
- Optimize Nb_3Sn

- Develop W&R Bi-2212
  - Collaborations
    - **SWCC** Showa Cable Systems Co. Ltd.
    - **OST** Oxford Instruments - Superc. Technology
    - **VHFSMC** U.S. National Program on Bi-2212
  - LBNL: Magnet technology
    - Cabling
    - Compatibility
    - Wire, cable, and coil tests
    - Mechanics
    - Reactions
    - Quench
    - Define conductor requirements

- YBCO, Bi-2223

Subscale coil manufacture

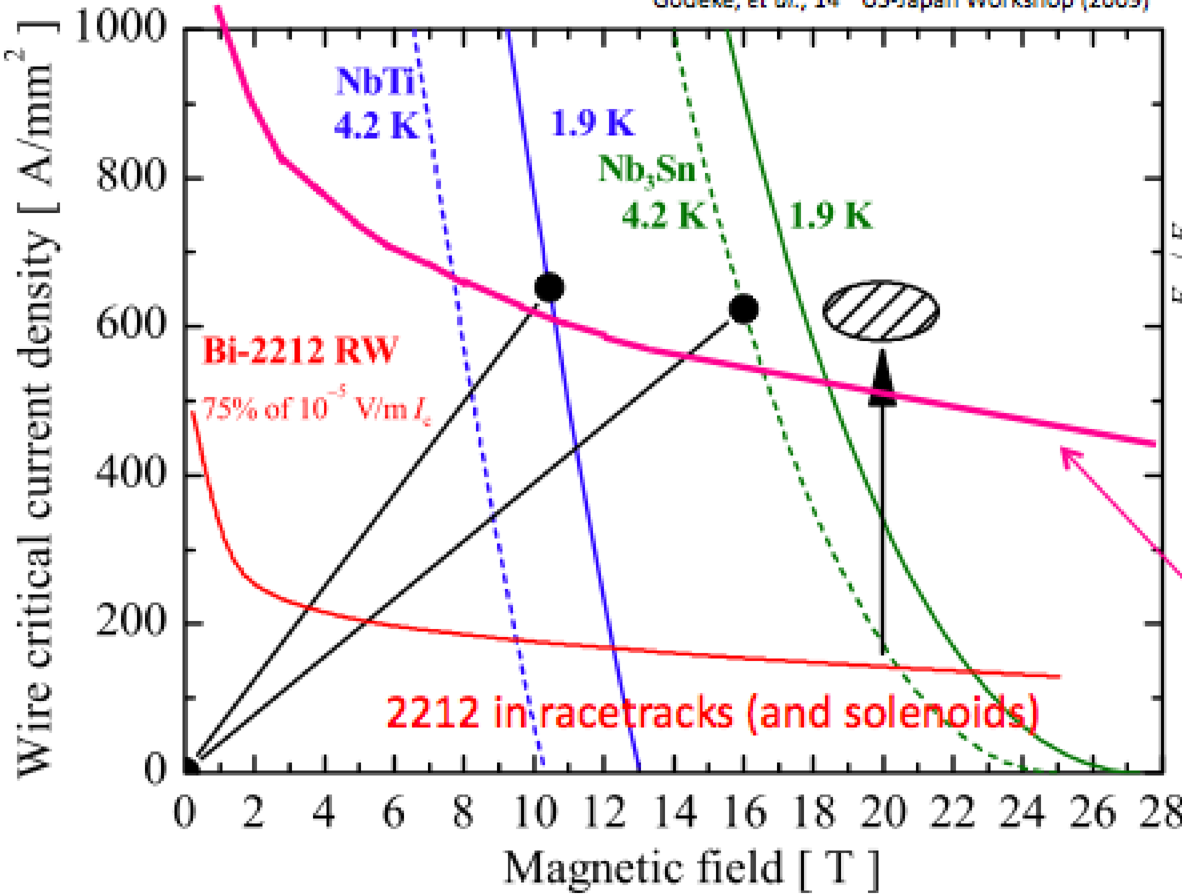
- Purchase wire, make and insulate cable
- Wind coil on Inconel 600 reaction holder
- React, pot, test

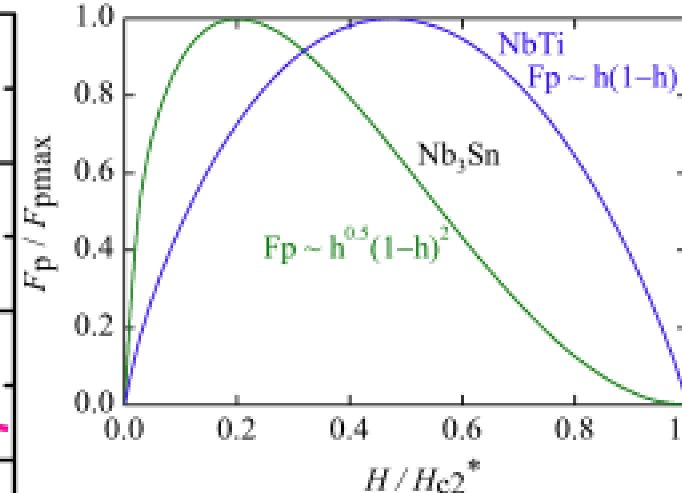


Performance compared to LTS

- **How does R&W Bi-2212 compare to record NbTi, Nb_3Sn?**

Godeke, *et al.*, 14th US-Japan Workshop (2009)





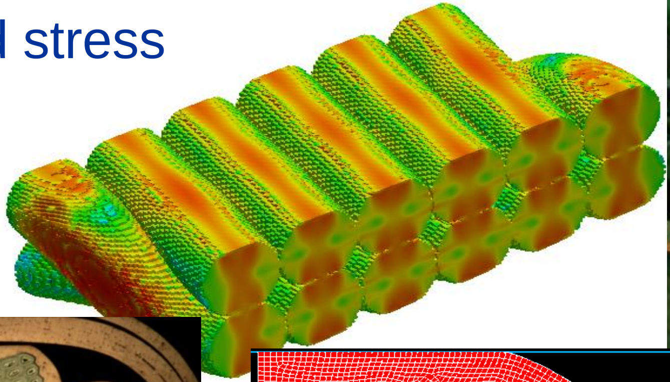
OST published data
1 m, 0.1 uV/cm
Original process with 521
TAS V17 p.2262 2007

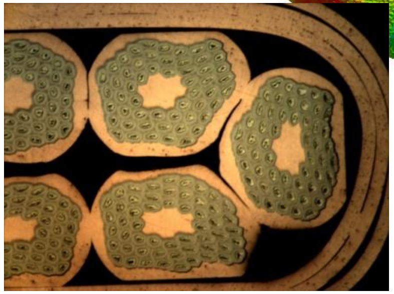
Precursor, Leakage, cabling?

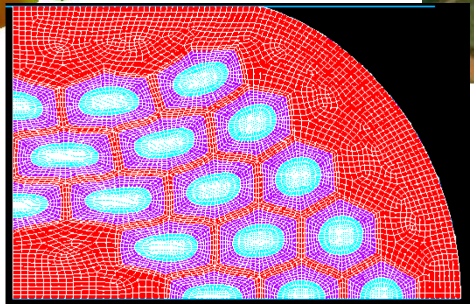
- **A factor 3 – 4 in J_E is needed to become competitive with LTS**
  - Process modified with respect to 'Original' (leakage, cabling), and precursor variance

Cable R&D

- Optimizing cable parameter space
- wide cables (60 strands)
- Fabrication for all LARP magnets
- Critical currents measurements
- Mechanical properties
- Study of strand strain under applied stress





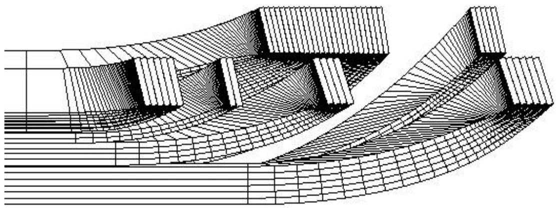


Sub-element deformation

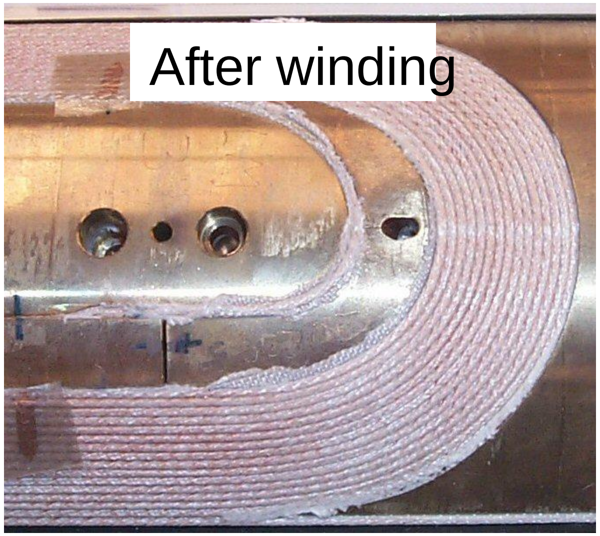
Nb_3Sn challenges

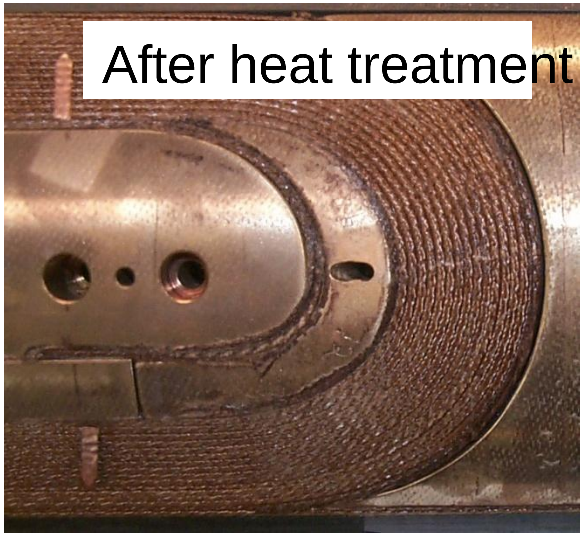
- **After winding:**
  - **Formation of Nb_3Sn at 650 °C**
  - **Epoxy impregnation**
  - **Magnet assembly and pre-load**
  - **Cool-down to 1.9 K and excitation**
- **Strain status of the superconductor**

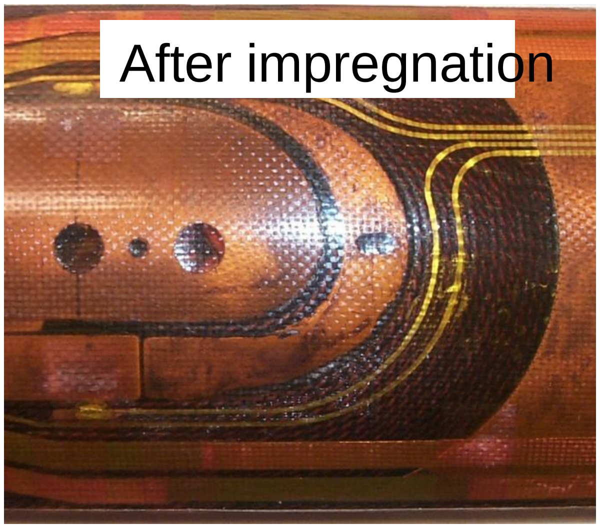
Program BEND



Winding tests w/RP parts

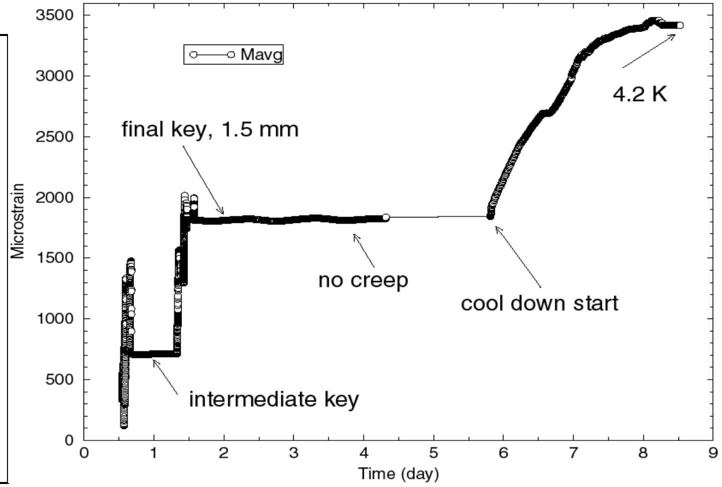






Assembly and Pre-Stress

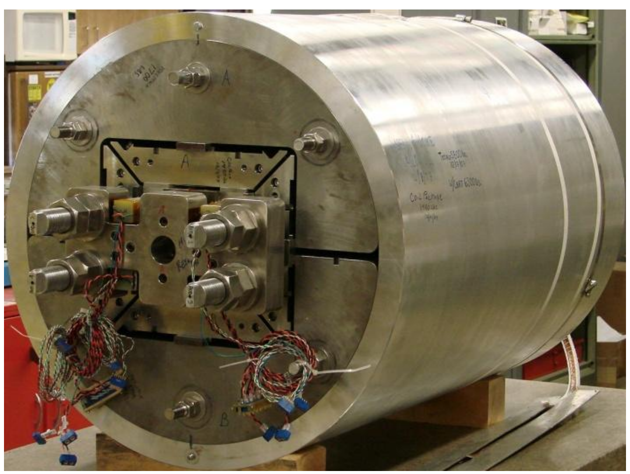
- Support structure that minimizes conductor motion and risk degradation
- Key and bladder technology to control pre-stress
- Applied force is provided by an outer shell or skin



HD2

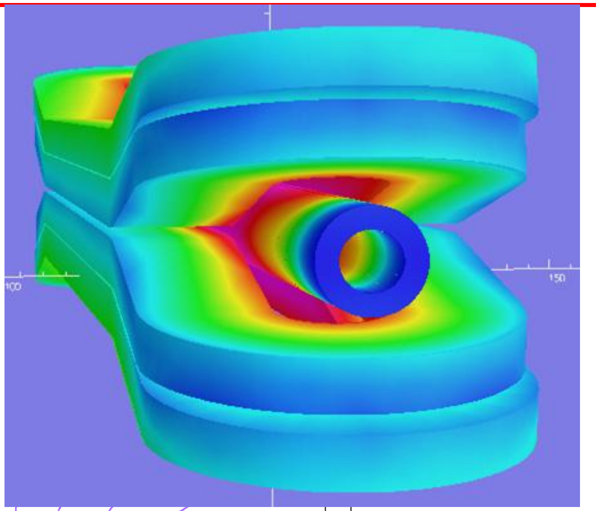
HD1

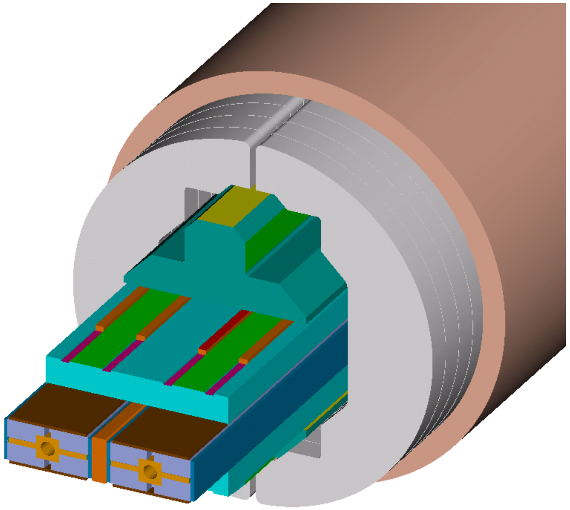
TQ

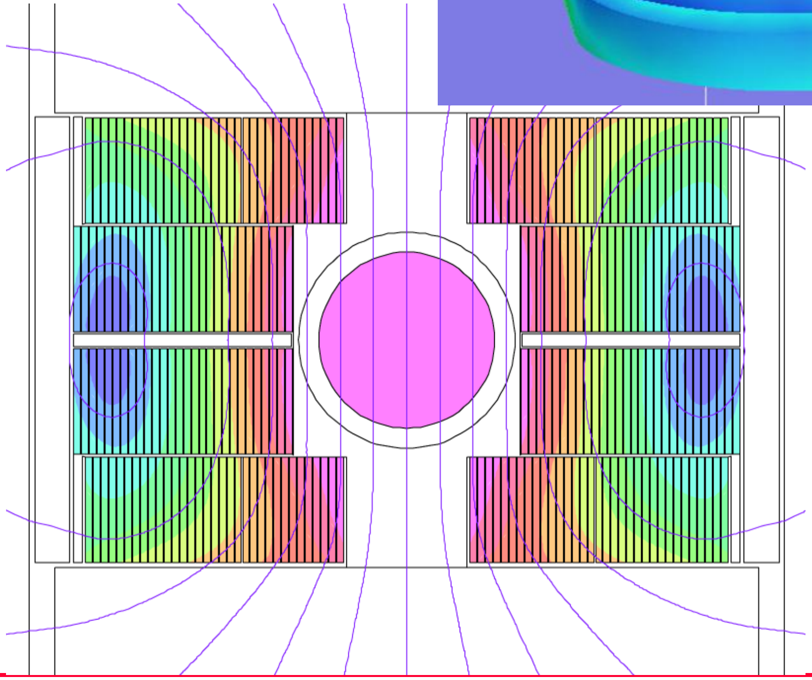


HD2 Dipole

- Target dipole field: **15.6 T** (16.5 T coil field)
- Clear bore 36-43 mm
- Coil design: block-dipole with flared ends
- Designed for accelerator field quality
- Easy to configure in two-aperture layout



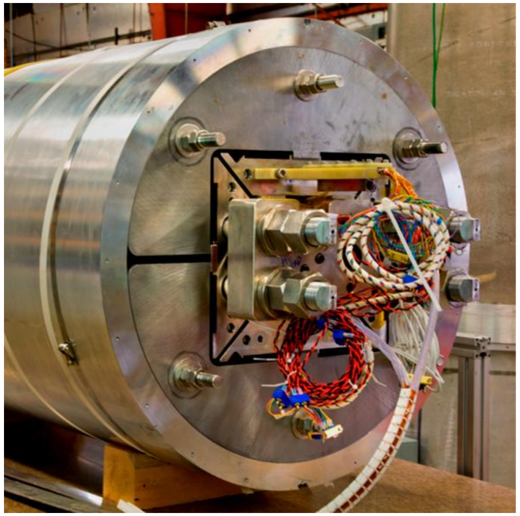


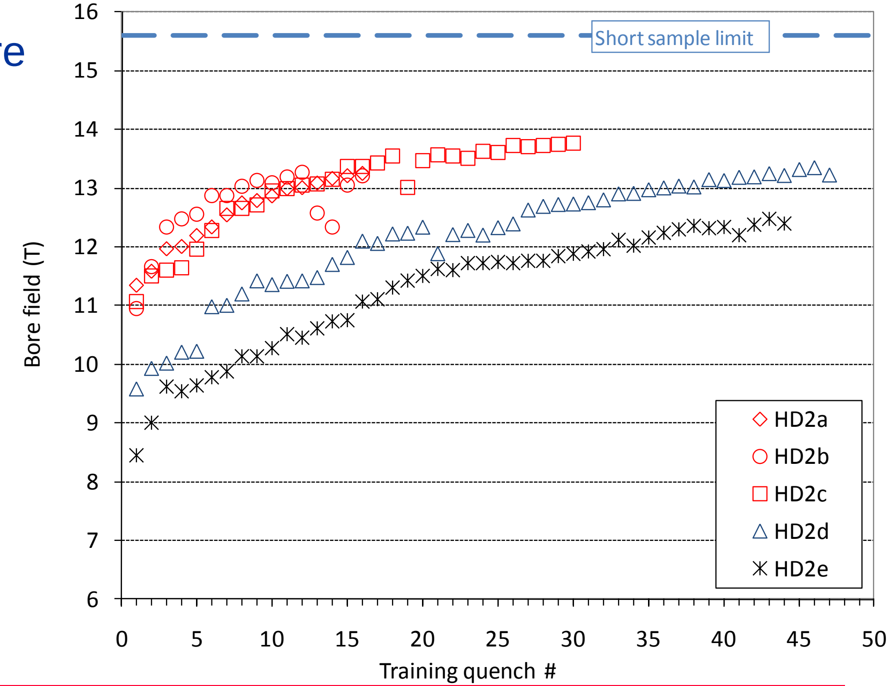


HD2 Dipole

Short sample current I_{ss} at 4.3/1.9 K	kA	18.1/20.0
Bore field at 4.3/1.9 K I_{ss}	T	15.6/17.1
Coil peak field at 4.3/1.9 K I_{ss}	T	16.5/18.1

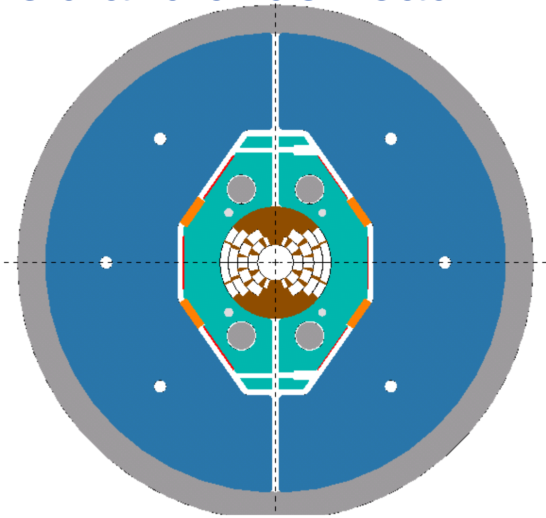
At short-sample the field at the conductor is 1 T more



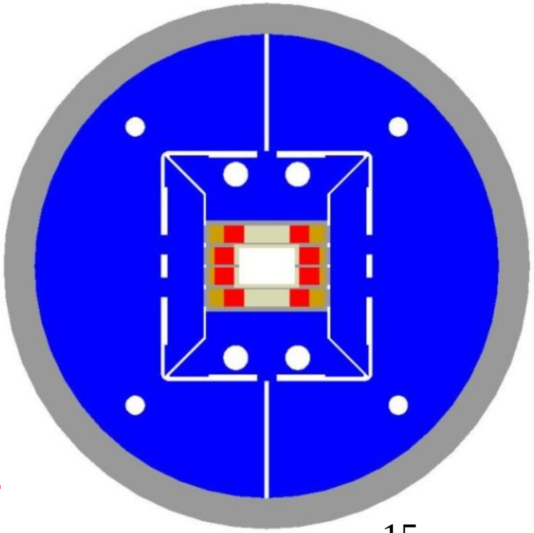


Large Dipole Test Facility (LDF)

- Goal: Testing of cables and inserts in high transverse field and under load
- Relevant to LHC luminosity and the Muon Collider
- Received ARRA support:
  - Conductor orders (placed)
  - Magnet design (underway)
  - Facility for coil fabrication (underway)



clear aperture of 144 mm in the horizontal and
94 mm in the vertical



Short sample current I_{ss} at 4.5 / 1.9 K	**kA**	**16.3 / 18.2**
Bore field at 4.5 / 1.9 K I_{ss}	**T**	**15.5 / 17.0**
Coil peak field at 4.5 / 1.9 K I_{ss}	**T**	**16.8 / 18.6**

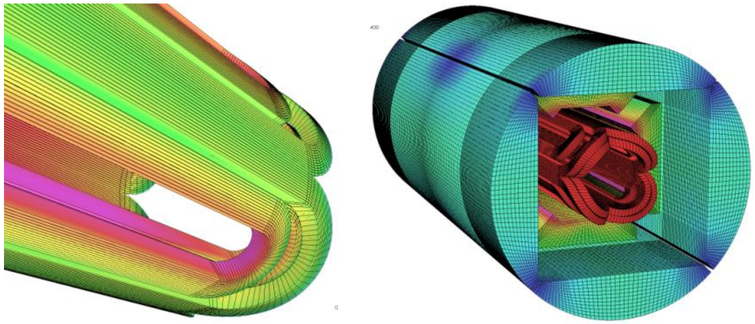
Integrated modeling:

- Full CAD model for drawings and part fabrication

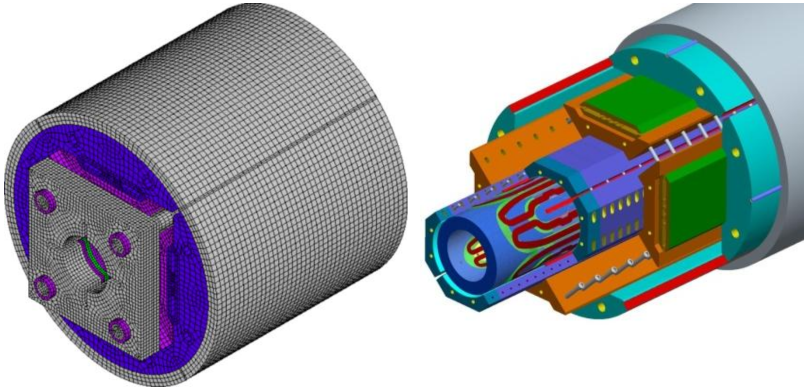
- 3D magnetic model
  - Iron 3D design
  - Conductor peak field
  - Field quality of end regions

- 3D mechanical model
  - Support structure
  - End support system
  - Mechanical and thermal analysis from assembly to operation

Roxie, TOSCA 3D magnetic model

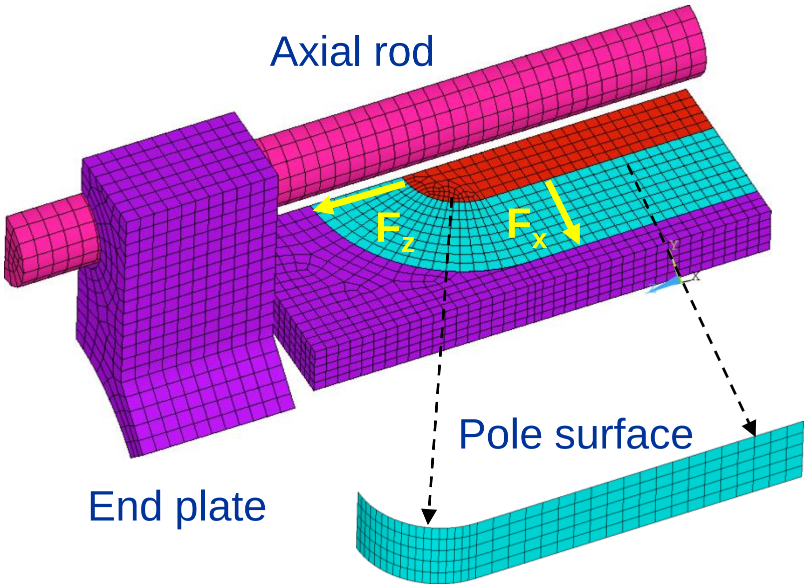


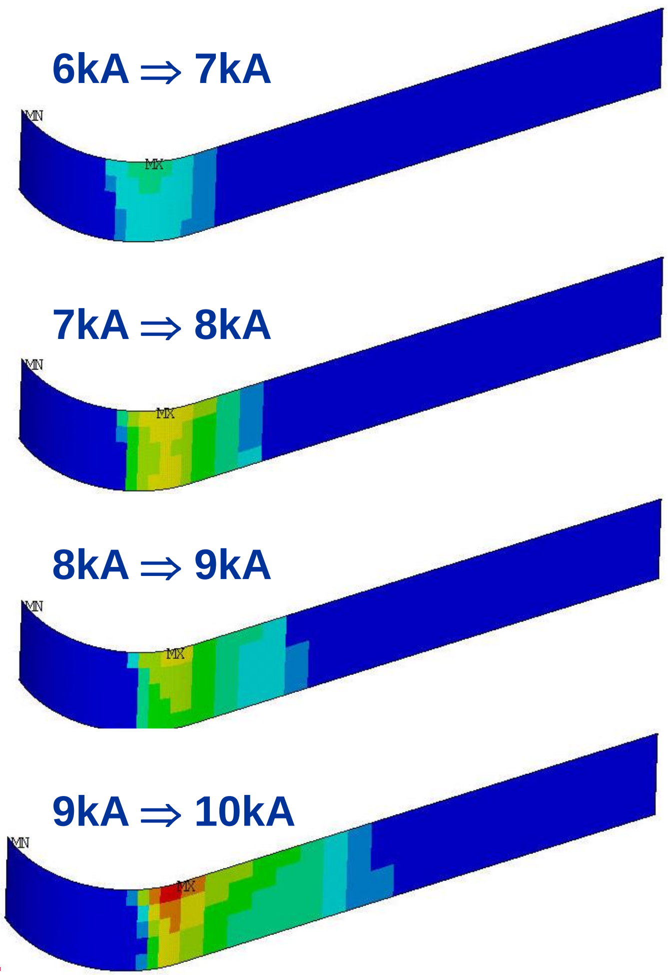
ANSYS, ProE 3D mechanical model



Frictional Energy and Training

Pole-turn sliding under friction models quench patterns & training

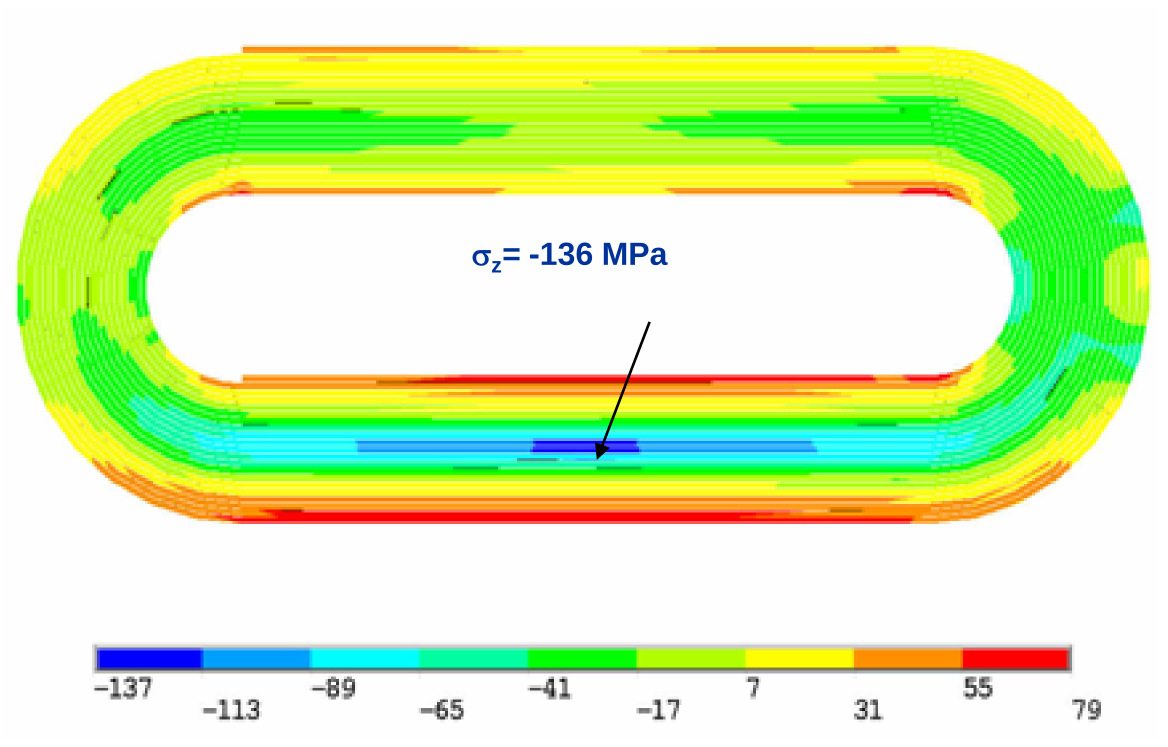




- Analysis of irreversible coil displacements during excitation cycles (ratcheting)
- Evaluation of frictional energy dissipation during excitation cycles

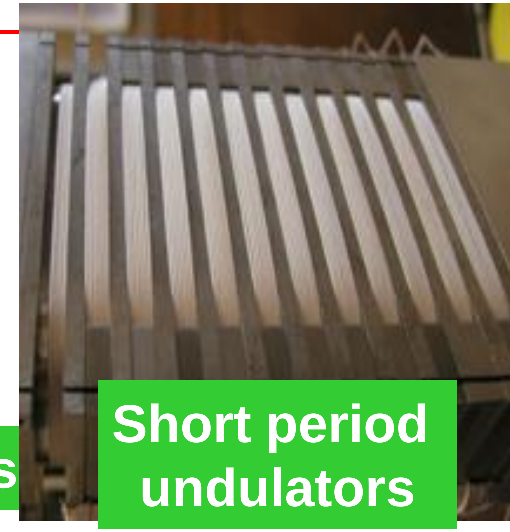
Modeling quench propagation, computation of the thermal stress

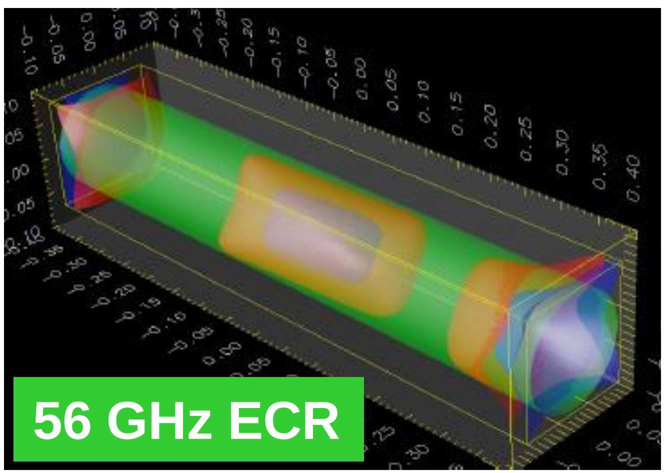
Thermo-mechanical transients

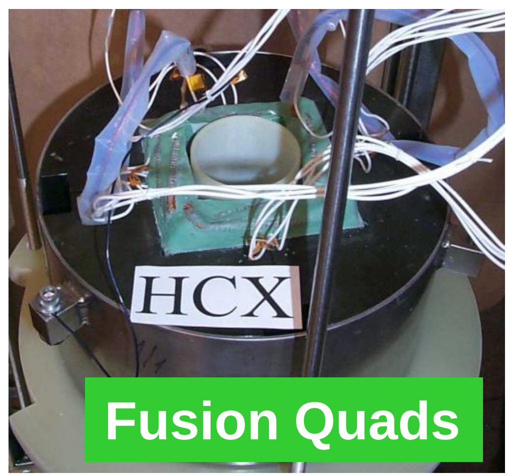


Axial & turn to turn velocity;Temp. & voltage

Contributions to nuclear physics, fusion energy, light sources







Summary

- *Modeling of superconducting wires - Nb_3Sn and HTS*
- *Cable fabrication and modeling of advanced wires*
- *Magnet design and coil fabrication*
- *Magnet assembly and mechanical support structure*
- *Advances in modeling capabilities and diagnostic tools*

- *Reached 13.8T, 14.5T and 16T in three types of dipoles*

- *Introducing accelerator features – bore and field quality*

⇒ Pushing the technological limits of accelerator magnets

LBNL Superconducting Magnet Team

- D. Arbelaez, B. Bingham, S. Caspi, D. Cheng, B. Collins, D. Dietderich, H. Felice, A. Godeke, R. Hafalia, J. Joseph, J. Krishnan, J. Lizarazo, M. Marchevsky, S. Prestemon, G. Sabbi, C. Vu, X. Wang.

- P. Bish, H. Higley, D. Horler, S. King, C. Kozy, N. Liggins, J. Swanson, P. Wong

- D. Pickett, J. Smithwick, G. Thomas, K. Miho