U.S. MAGNET
DEVELOPMENT
PROGRAM

The Canted-Cosine-Theta (CCT) Dipole Program

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CCT Motivation and outline

- “ … *investigate new designs for high field…*”

- “ … *understand and reduce training …*”

- “… *implement HTS materials into high-field magnets* …”

- Status of the Canted-Cosine-Theta magnet program at LBNL

- Challenges and issues

3 CCT tests, 2-Layers 90 mm bore

CCT2

- 5.3 T short-sample dipole
- 23 strd. **NbTi** cable **tested up to 4.7 T**
-

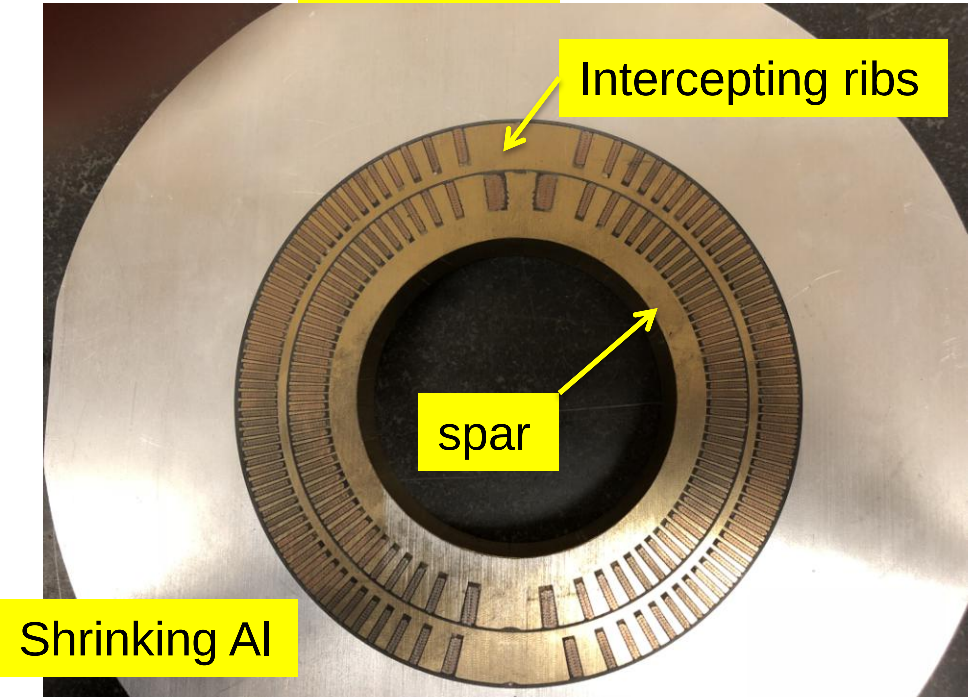
CCT3

- 10.4 T short-sample dipole
- 23 strd. **Nb_3Sn** cable **tested up to 7.4 T**
- Conductor damage suspected (69% of SS limit)

CCT4

- 10.4 T short-sample dipole
- 23 strd. **Nb_3Sn** cable **tested up to 9.1 T**
- Long training but good memory (86% of SS limit)

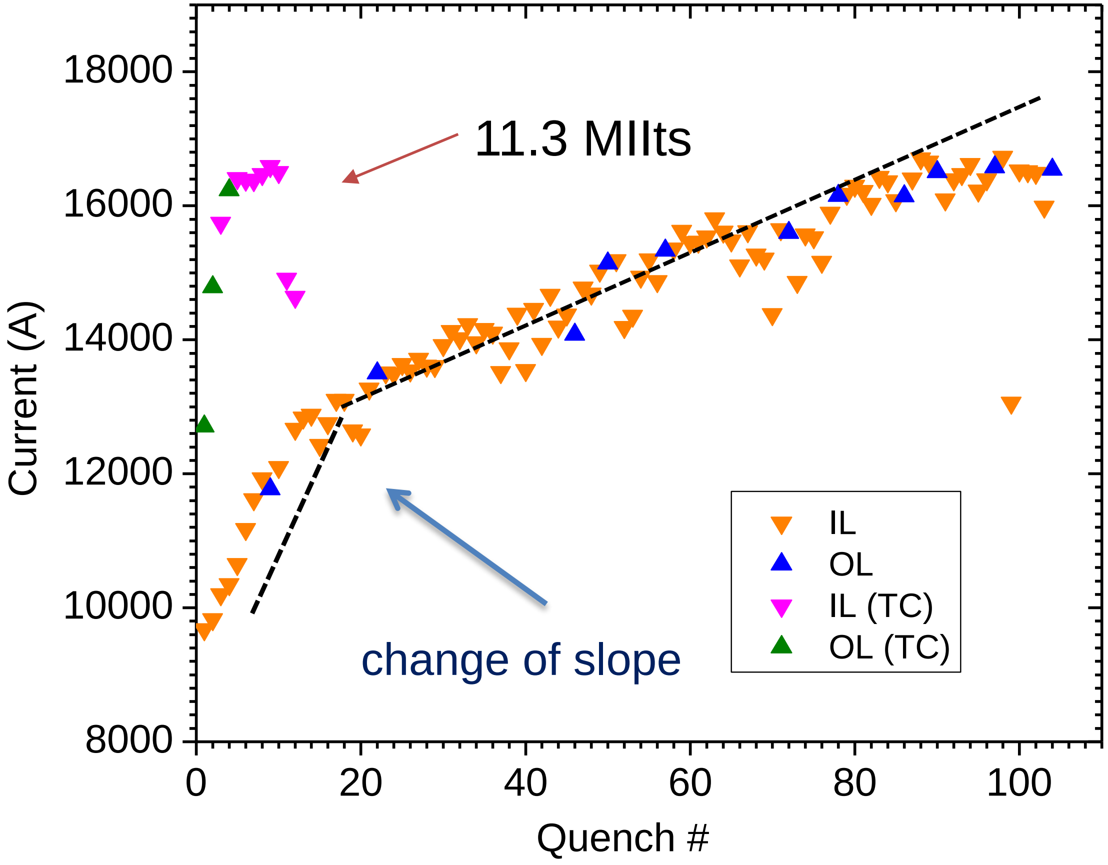
CCT3/4



❖ All layers impregnated
❖ All tests at 4.4 K

CCT4 Test Results

- CCT4 Bore Reached 9.14 T, 16.7 kA, 86% of short sample (90 mm aperture)
- Long training but good memory after thermal cycle
- **Reduction in training is the main focus for CCT5**

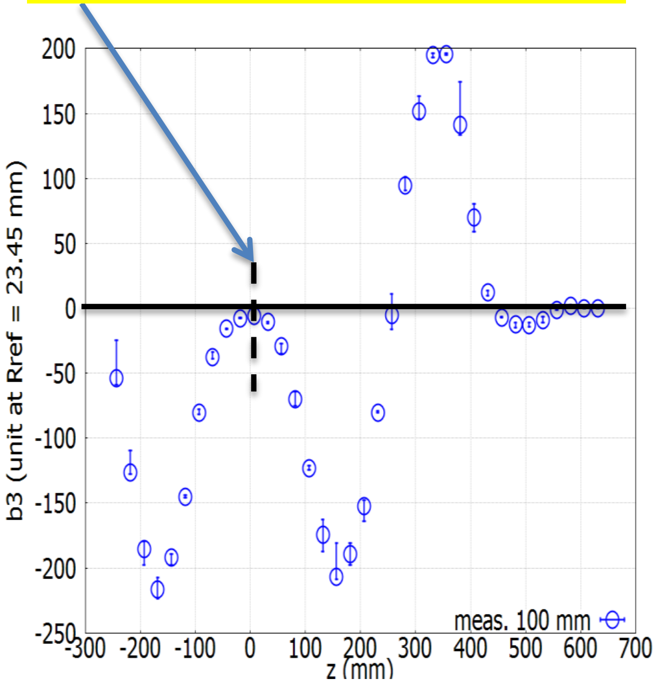


11.3 MIlts

change of slope

❖ Iron for return flux only

Magnet center – mostly ends



Sextupole - from center to "end" integrates to 0

Initial training location form a cluster near the pole then spreads towards the mid-plane

Lessons Learned

Changes Proposed for CCT5 …

1. *Training despite an **inner structure** and reduce conductor stress*
2. *Good memory up to 9 T*

Main suspects/Change:

1. Channel size and cable size
   Pole-gaps in channels (cable follows mandrel during reaction)
2. Stick-slip between layers
   Impregnating layers separately
3. Epoxy cracking
   Replace CTD-101K with FSU Mix-61 epoxy
4. Analysis and FEA studies
   Details and multi-physics

(*Lucas Brouwer)*

5. Two distinct training regimes (Acoustic Emission).
   Acoustic Emission, Reacted cable studies and extracting, sintering, cu etching, visual filament inspection

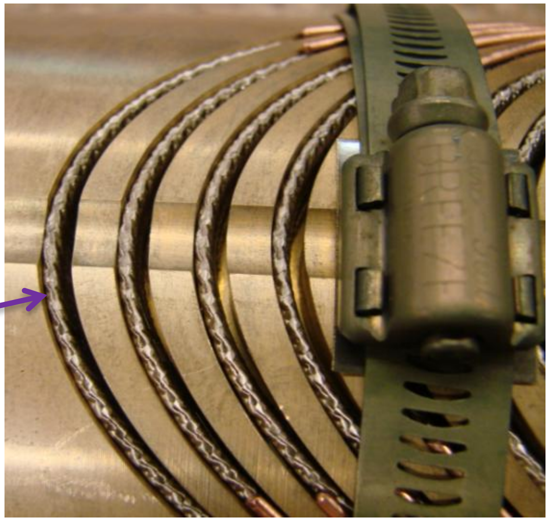
(Maxim Martchevskii
Emelie Nilsson- CERN)

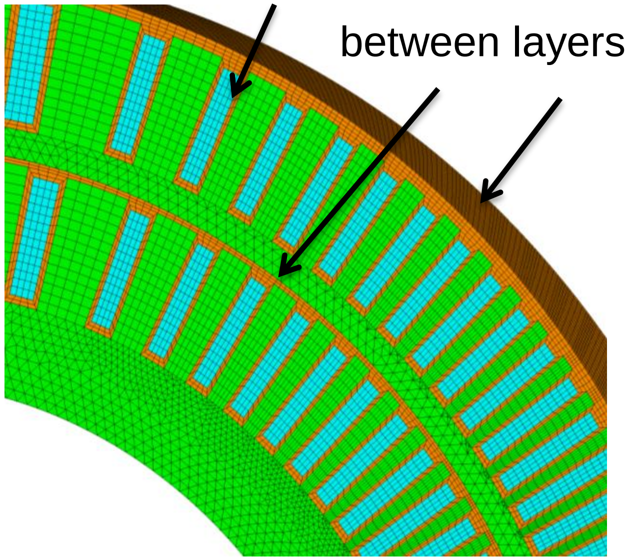
6. ***External structure***
   Utility structure

(Mariusz Juchno)

Assembly:

1. ***Slide layers into each otherby force***
   Slip planes (shims) between layers, "bend & shim" to assemble/disassemble





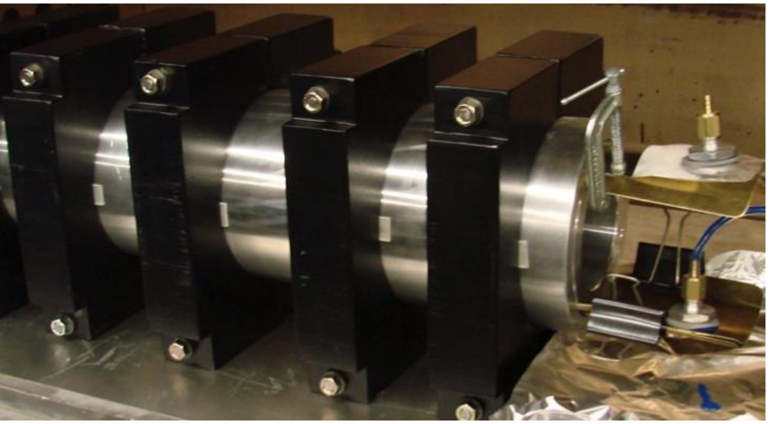
“Bend-Shim” assembly using “Smart-Shims”

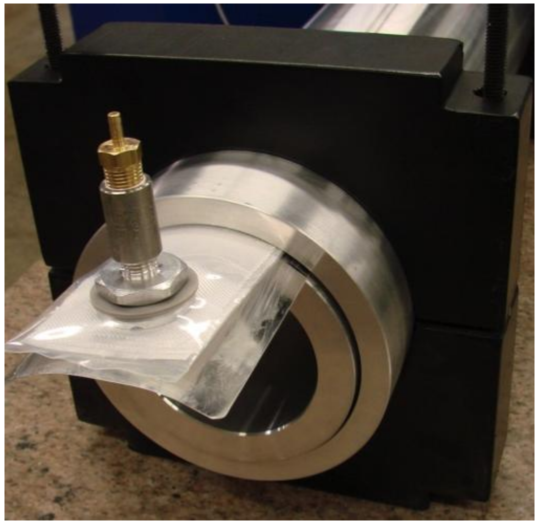
•**Insert layer 1 into layer2** (~1.5 mm radial gap)

• **Bend outer layer, insert “smart-shim”, inject epoxy, cure, remove force, springs back**

•**Taking care of any geometry irregularity**

• **Disassembling by reversing the process**





CCT conceptual High Field design

Magnetics

- **19 T – Lorentz forces**
  - 6 layers
  - Any conductor – Nb3Sn, HTS (carrying the same current)

Internal Structure

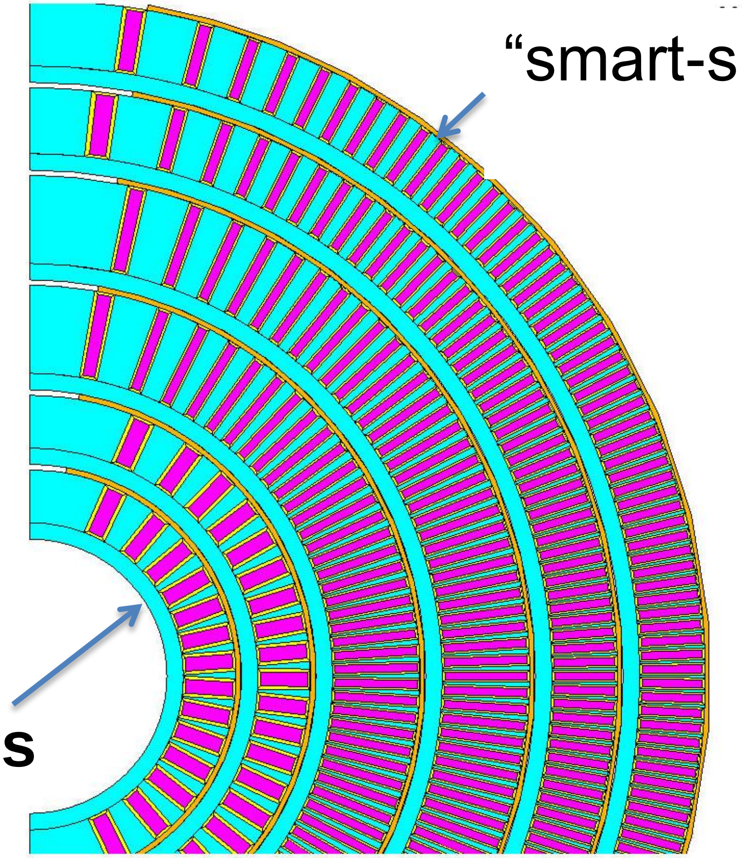
- **CCT spars integrate Lorentz forces**
- **Magnet Assembly/Disassembly using “smart-shims”.**

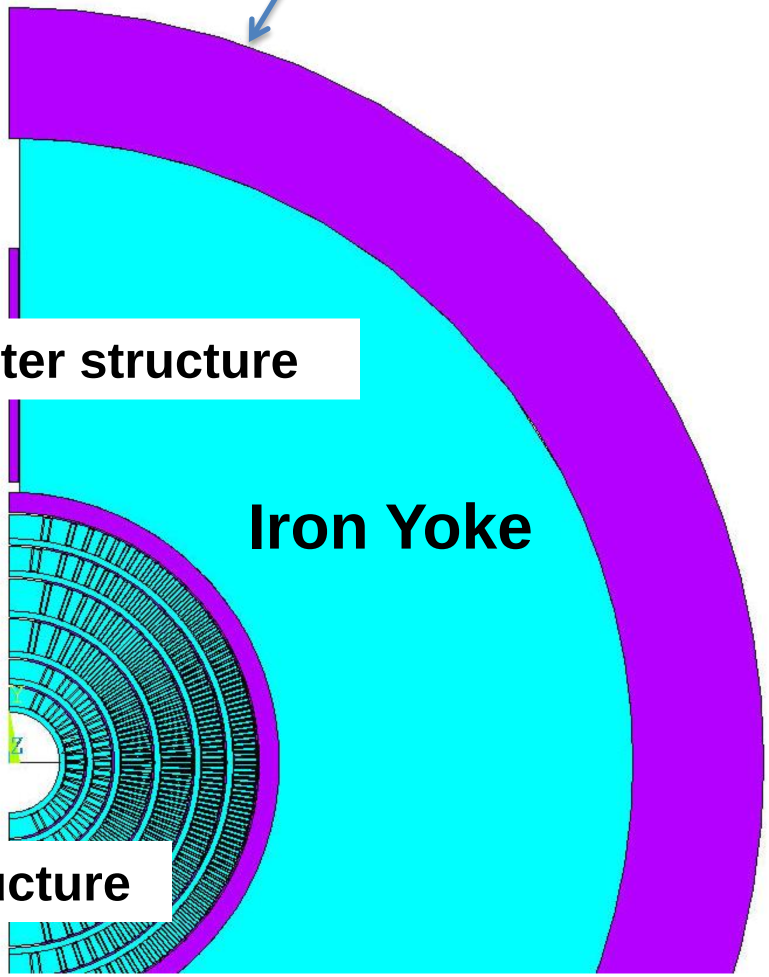
External structure

- **Yoke and Shell structure controlling bending**

Towards High Field CCT Demonstrator 19 T, 14 kA/turn

- 6-Layer CCT Design
  - 2 inner layers HTS + 4 outer layers using Nb_3Sn
  - Assembly using “bend and shim”
  - Outer structure to confine inner structure

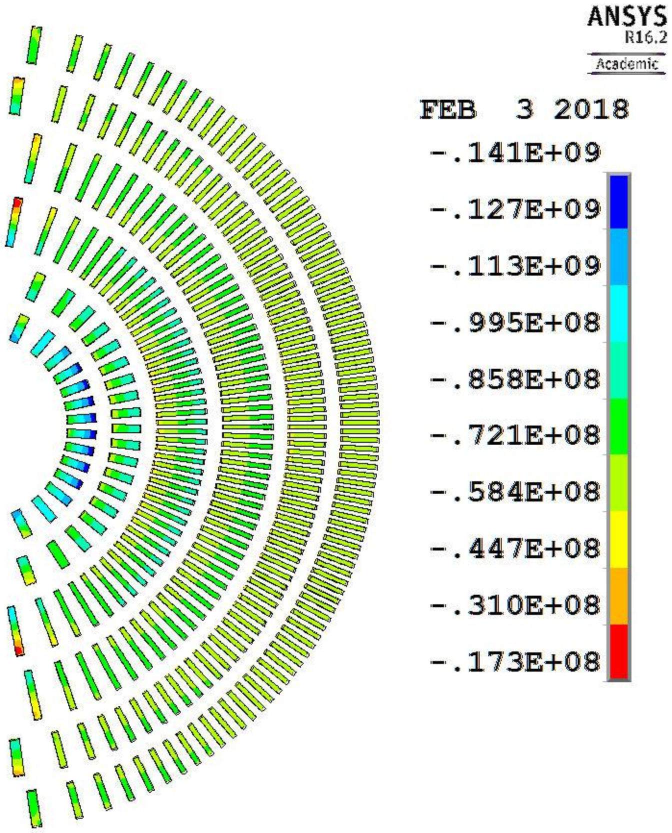




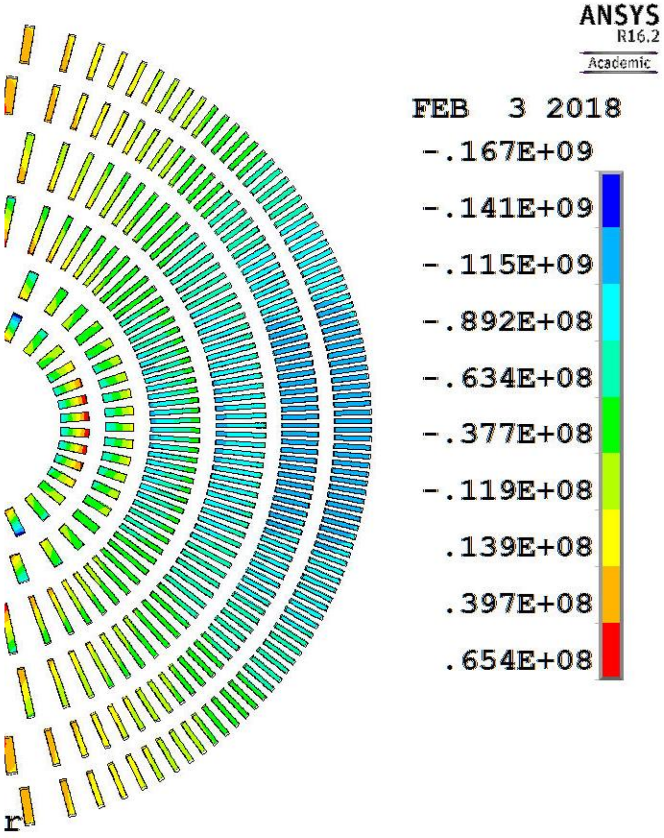
6 layers azimuthally stressed

Assuming Lorentz forces at a 19T level

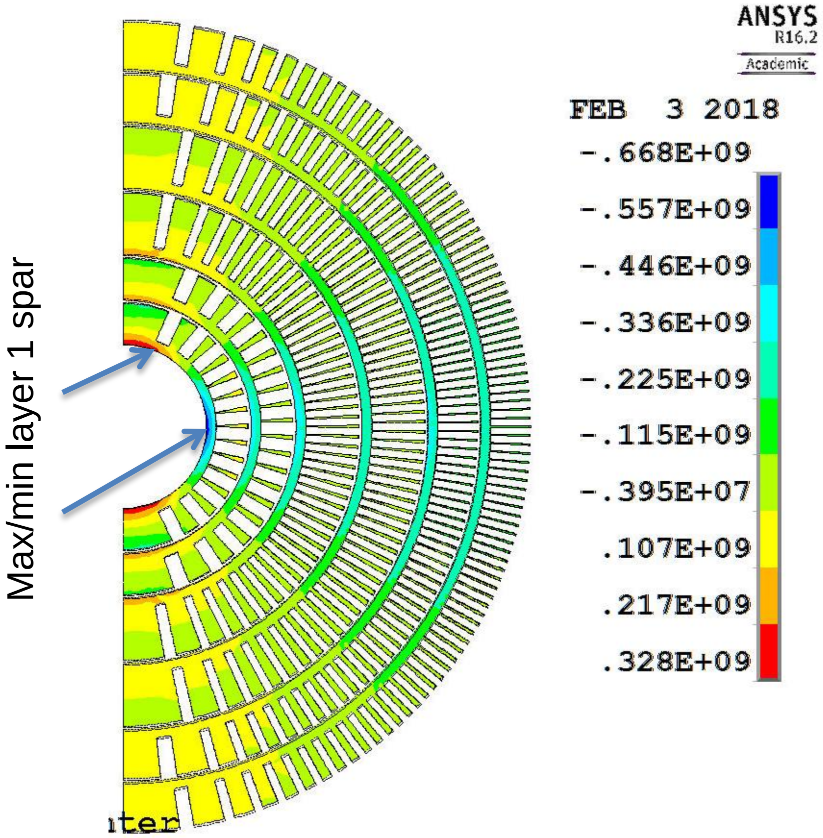
Conductor
Cold
-17 to -141 MPa



Conductor
19 Tesla
+65 to -167 MPa



Bronze mandrel
19 Tesla
+328 -668 MPa



CCT HTS Using CORC® wires

(**Xiaorong Wang** - xrwang@lbl.gov)

CCT HTS Using 2212 wire

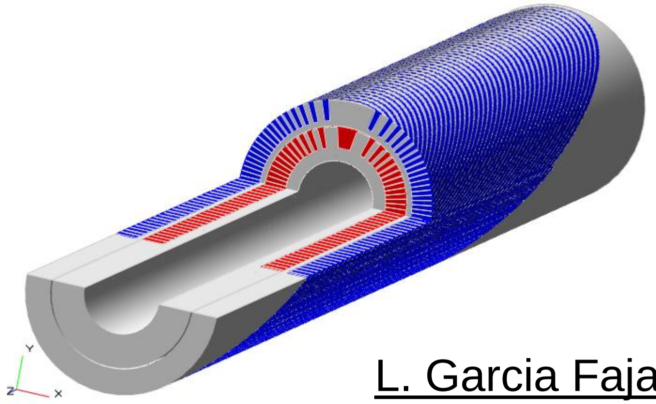
(**Tengming Shen** - tshen@lbl.gov)

HTS Using CORC® wire

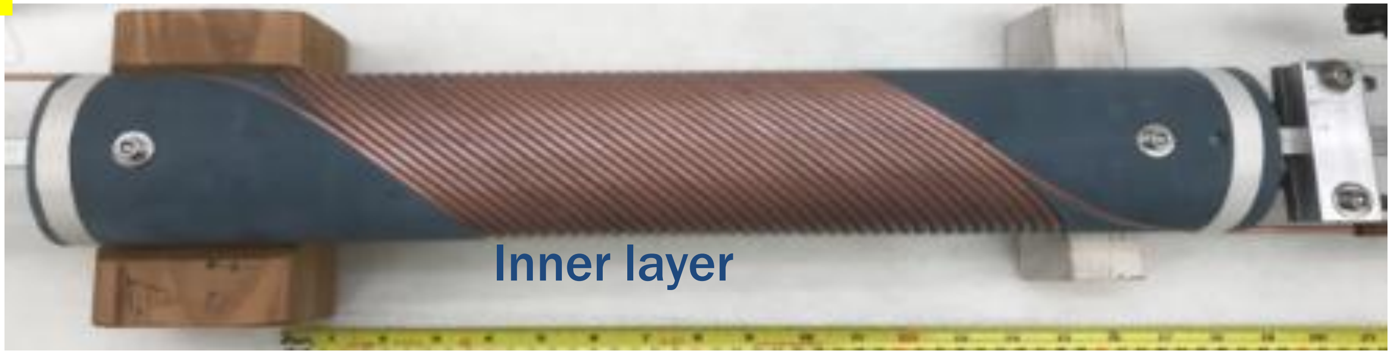
C1 reached 4.8 kA, 1.2 T at 4.2 K, J_e = 640 A/mm^{2,} (reproducible after thermal

Next C2, 4 layers 3 T, 2018

http://iopscience.iop.org/article/10.1088/1361-6668/aaad8f



L. Garcia Fajardo, L. Brouwer



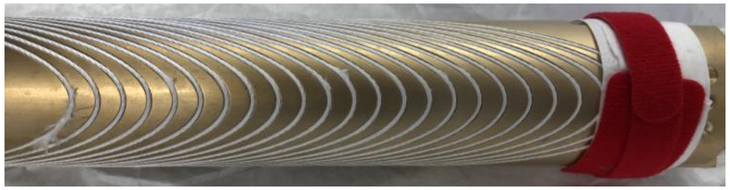
HTS Using 2212 wire

RC5 reached 8.3 kA with wire J_E of 940 A/mm^2 (quench detection shown to be feasible)

Next BIN4, 9 strands, 1 bar, 2018

Next BIN5, 9 strands, 50 bar 2018

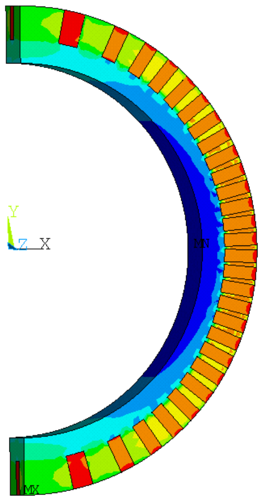
Next BIN7, 19 strands, 2020 – 5.4 T

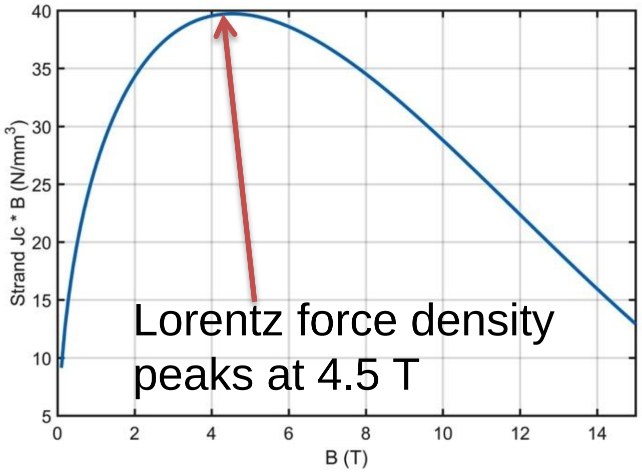


A Subscale 5.2 T Dipole Program

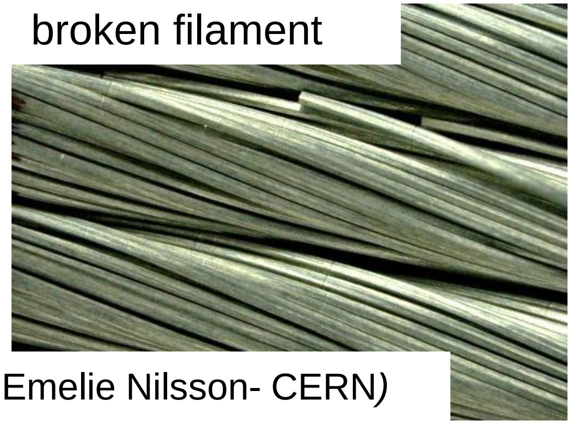
- **Motivation**
  - Faster turn-around to understand CCT behavior
  - Can be tested in small cryostat
- **Better understanding of CCT magnets**
  - Testing of epoxies and interfaces
  - Cable expansion experiments
  - Mandrel deformation during heat treatment
  - Test new instrumentation methods
  - Test new winding method – Wind-React-Wind
    - Cable reacted without insulation
    - Cable extracted
    - Cable placed back into an insulated mandrel

CCT Subscale



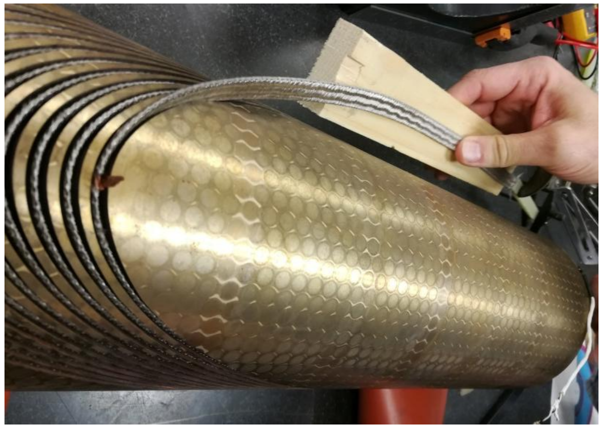


Lorentz force density peaks at 4.5 T



broken filament

Emelie Nilsson- CERN)



Extracted

Etched Cable
No apparent damage

Summary

- Initial CCT R&D technology is advanced through 2-layer models
- A high field 6-layer CCT is in the early design stage
- Issues with conductor damage have been addressed (gaps)
- Next model is focus on reduced training (CCT5 and subscale)
    - Single layer impregnation, mix-61 epoxy, new assembly – Bend and Shim
- CCT using HTS 2212 cable and CORC® wire
- Subscale CCT dipoles to expedite training experiments
- Acoustic Emission studies and new techniques to validate de-bonding