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Advances in superconducting Bi-2212 conductor and accelerator magnet development

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U.S. DEPARTMENT OF ENERGY

U.S. MAGNET DEVELOPMENT PROGRAM

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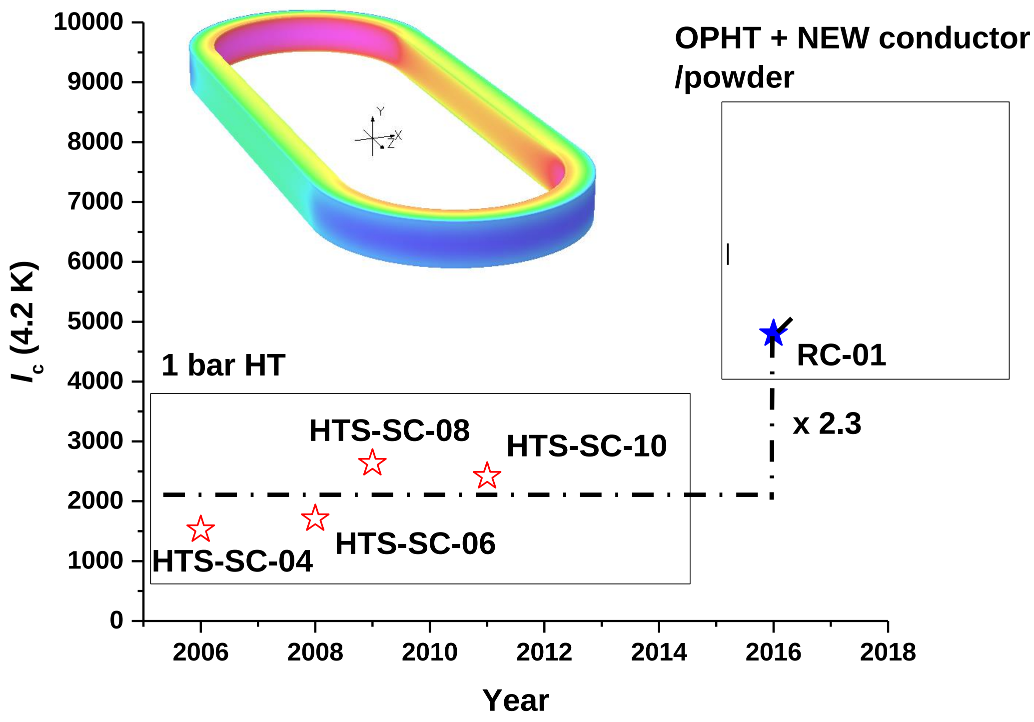
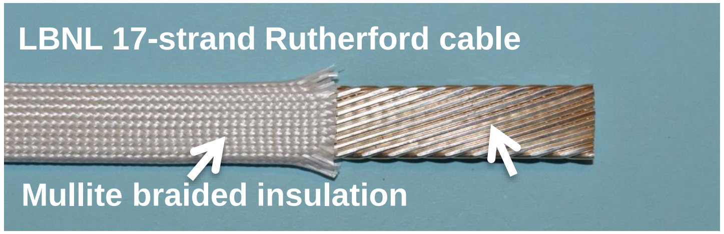
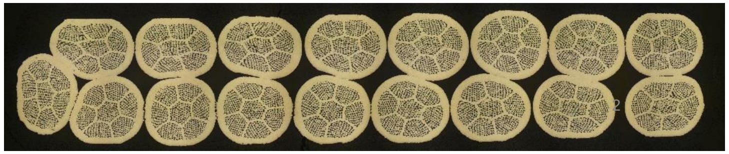
LBNL HTS (2212) subscale magnet program topped with new RC-05 results

Subscale coils allow fast-turnaround test of cable and magnet-relevant technologies.







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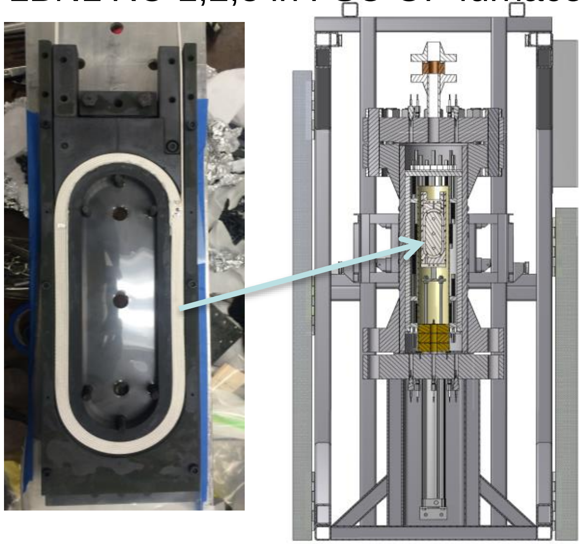
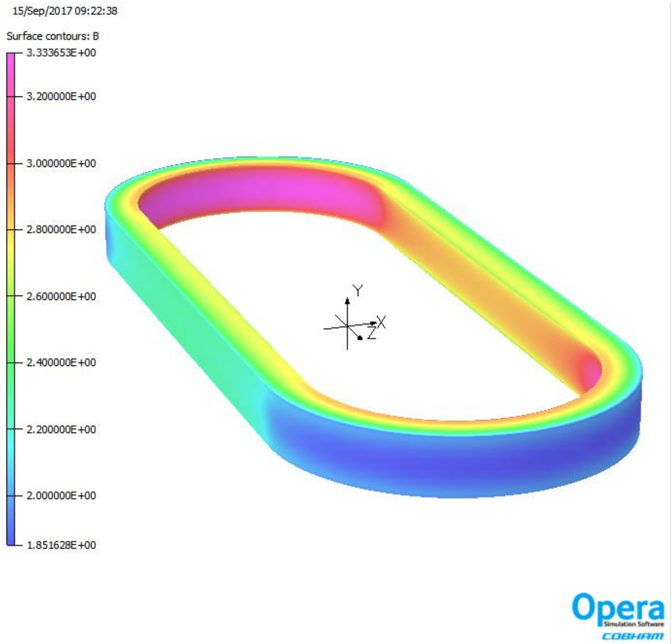
LBNL RC-1,2,5 in FSU OP furnace



Parameters of LBNL HTS-SC and RC coils show Bi2212 is now a very relevant high-field conductor

RC5 – peak field – 3.33 T



2-layer x 6-turn racetrack coil based on 17-strand Rutherford cable (1.44 mm x 7.8 mm, strand diameter = 0.8 mm)

140 m conductor, 8 m cable

18 lbs coil thermal mass, 37 cm x 12 cm x 3.1 cm.

50 bar OPHT (@FSU) for RC coils.

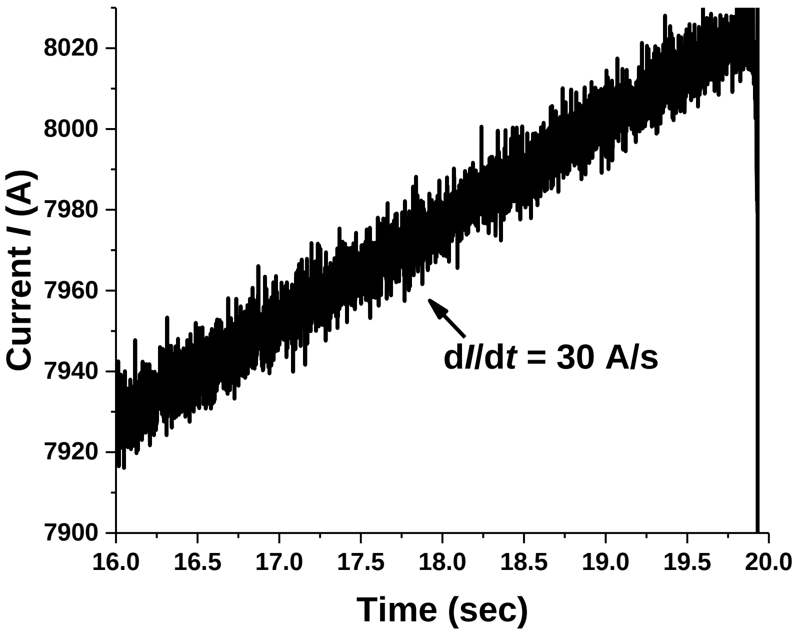
RC-01 (4.8 kA, 80% peak SS J_c, (effective) J_{cable}=430 A/mm², (effective) wire J_e=540 A/mm².), wax impregnation

RC-02 (5.7 kA, 80% peak SS J_c, (effective) J_{cable}=507 A/mm², (effective) wire J_e=644 A/mm².), wax impregnation

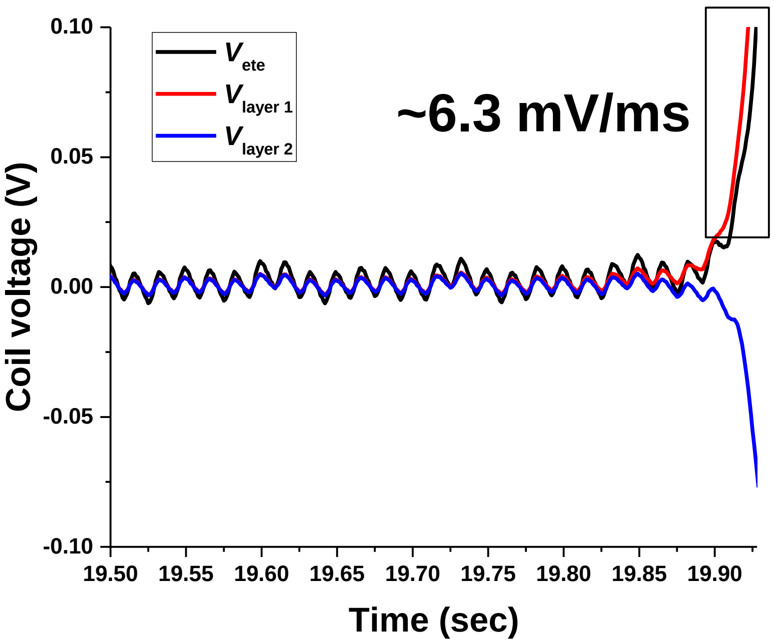
RC-05 (8.2 kA, <73% peak SS J_c, (effective) J_{cable}=730 A/mm², (effective) wire J_e=930 A/mm².), CTD101-K impregnation

RC5 reached 8.2 kA and were safely protected. $J_{e,cable}$=730 A/mm^2 and $J_{e,strand}$=930 A/mm^2 (at 3.33 T) are practical current densities for applications

- (Extrapolated to 20 T) $J_{e,cable}$=408 A/mm^2 and $J_{e,strand}$=529 A/mm^2
- Coil was safely protected against quenches.

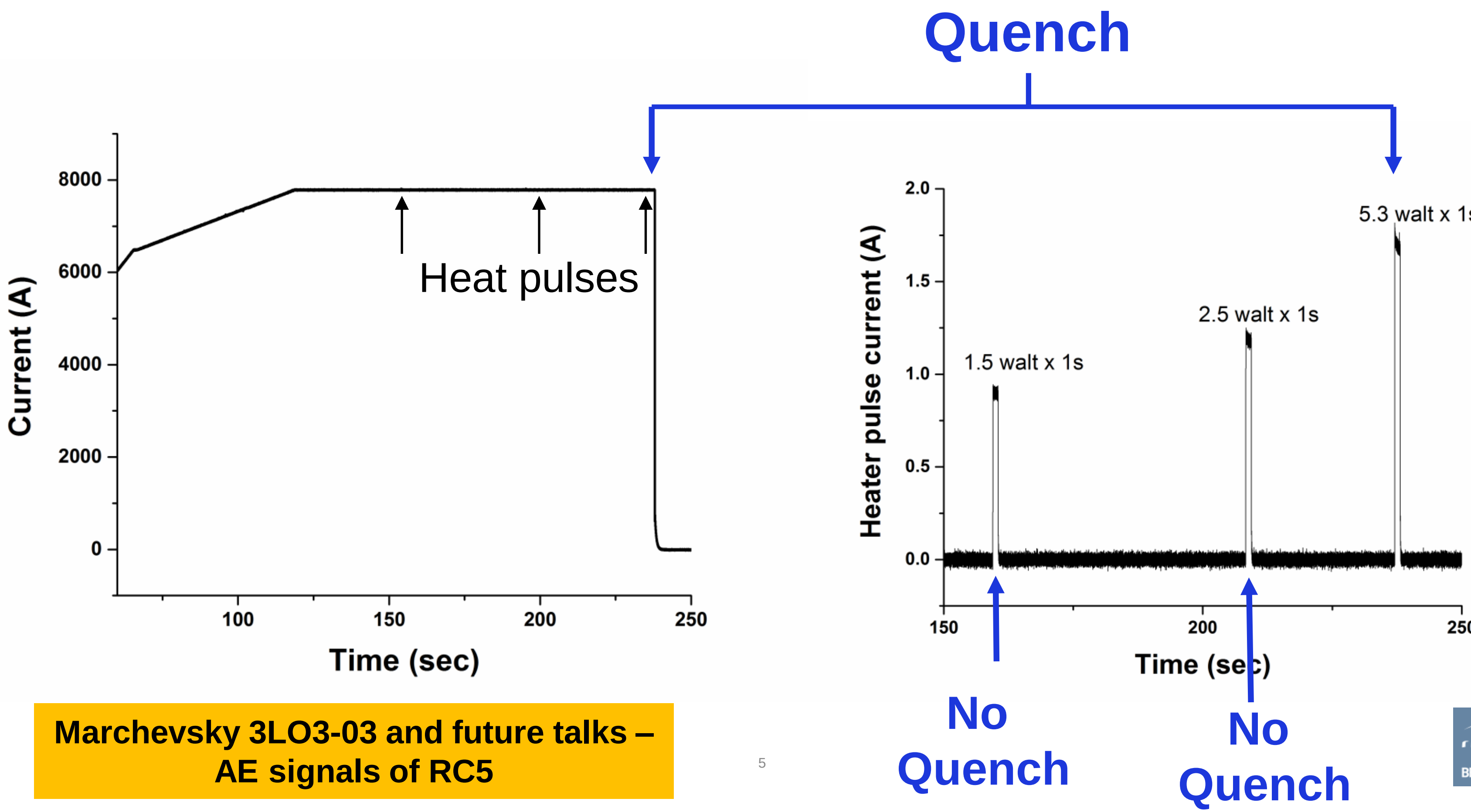


- A thermal run-off.



RC5 is quite stable against disturbances, even at 7800 A => robust against training

- No quench against heater pulses at 1.5 W for 1 s, and 2.5 W for 1 s. Finally quenched at 5.3 W for 1 s.
- Heat pulse applied at the turn #1 (straight section, B≈2.5 T).



Marchevsky 3LO3-03 and future talks – AE signals of RC5

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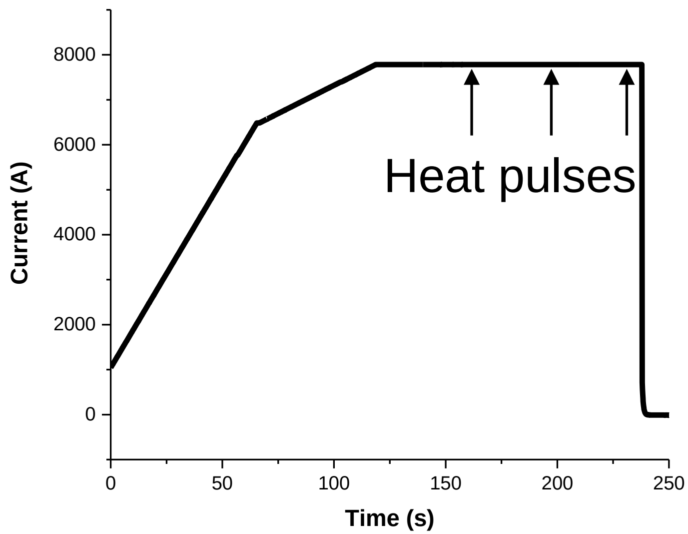
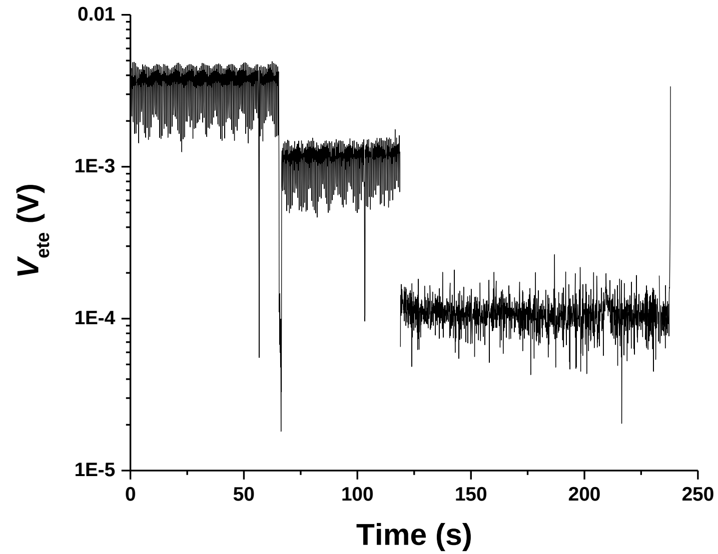
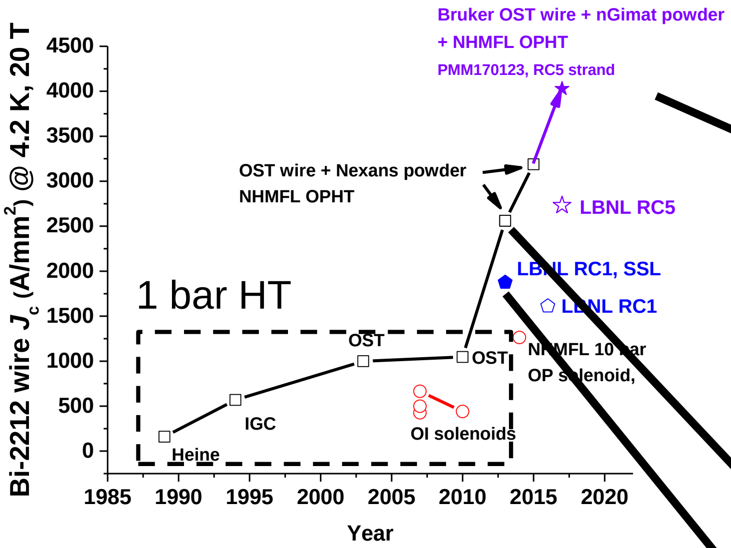
RC5 is quite, without signs of internal dissipation when dwelling at 7800 A



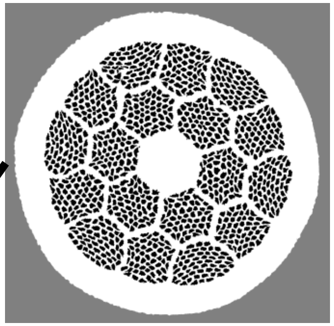


RC5 is possible because of advances in powder, wire, cable, and OPHT technologies,

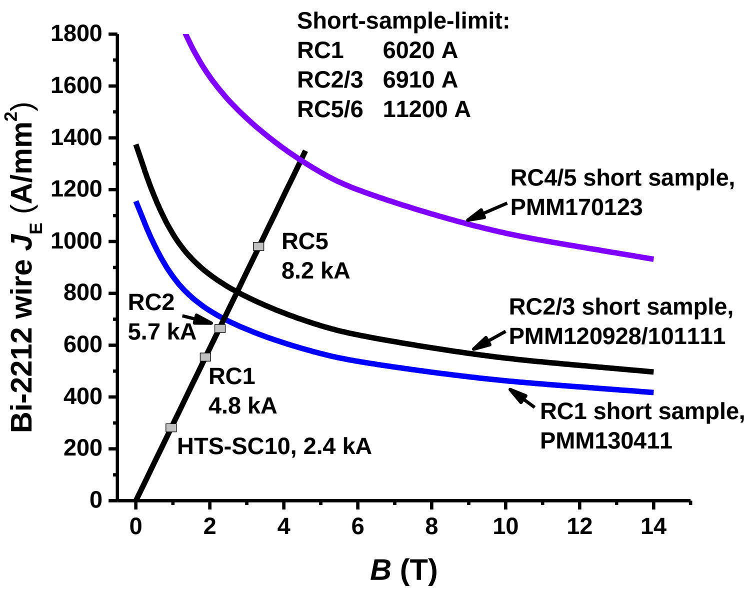
and it also verifies progresses and technological readiness on these fronts.

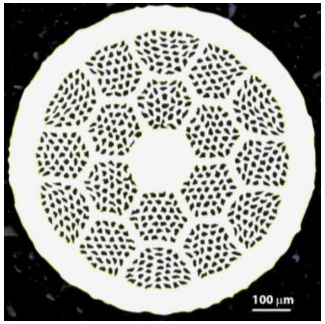


Relevant conductor talk – J. Jiang, 4MO1-03.
DC Larbalestier MT25, Y. Huang 3MP4-02

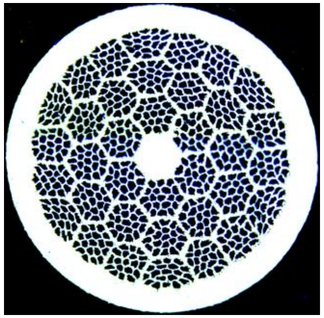


PMM170123, 55x18, nGimat power LXB-52
Conservative short sample J_E used.
See Larbalestier, MT25 talk





PMM101111, 36x18, Nexans powder 77



PMM130411, 19x36, Nexans powder 77

Contributors – RC5 is a product of successful collaboration between U.S national lab, university, and industries.

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- **K. Zhang**, **H. Higley**, A. Lin, L. Garcia Fajardo, J. Taylor, M. Turqueti, T. Shen

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- **E. Bosque**, J. Jiang, U.P. Trociewitz, E.E. Hellstrom, D.C. Larbalestier

The LBNL RC5 was made from the wire PMM-170123, fabricated by Bruker OST with new Bi-2212 powder developed by nGimat LLC (DOE SBIR support) and donated to LBNL.

BRUKER

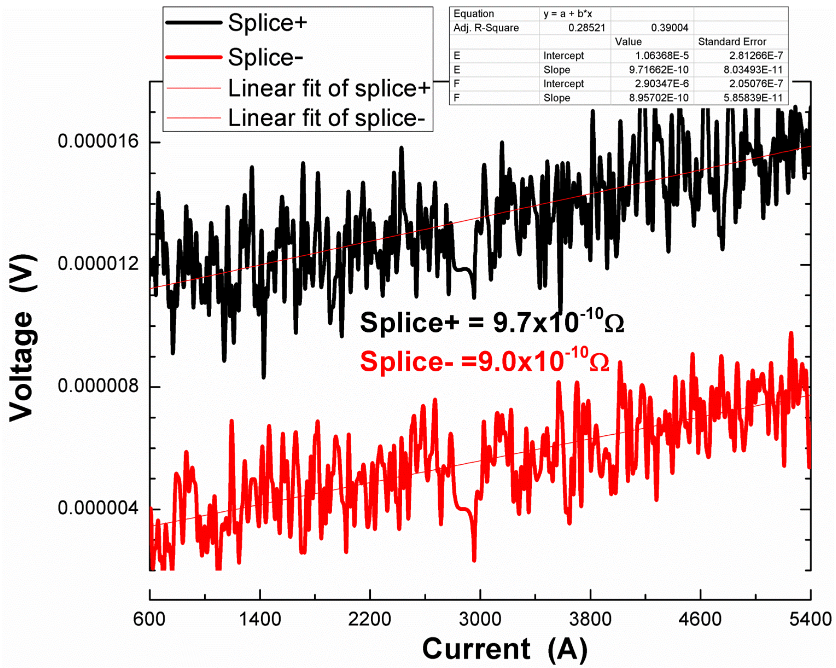
- H. Miao, Y. Huang

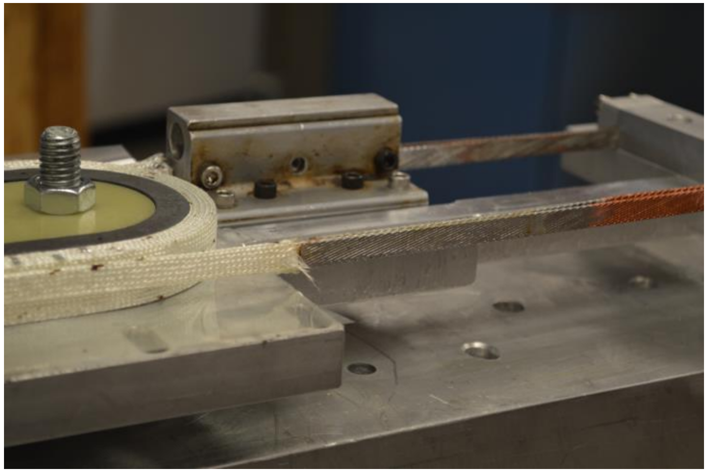
nGimat™ nanoEngineered Materials™

- **M. White**, R. Nesbit, A. Xu, A. Hunt

Other crucial aspects of magnet technology
(1) easy joints

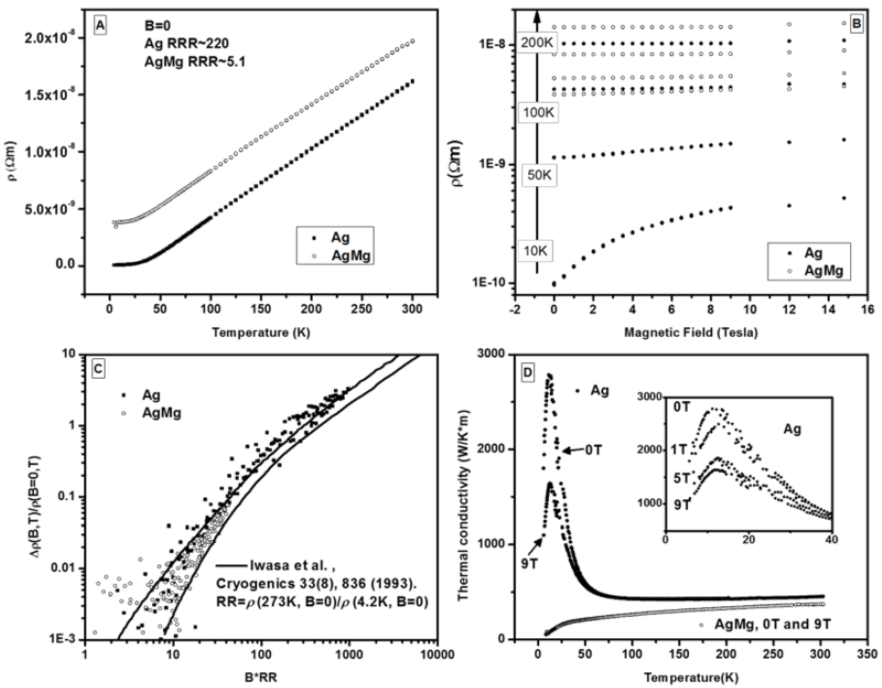
Simple lap joints with contact resistance - 12.5 nano-ohm·cm²



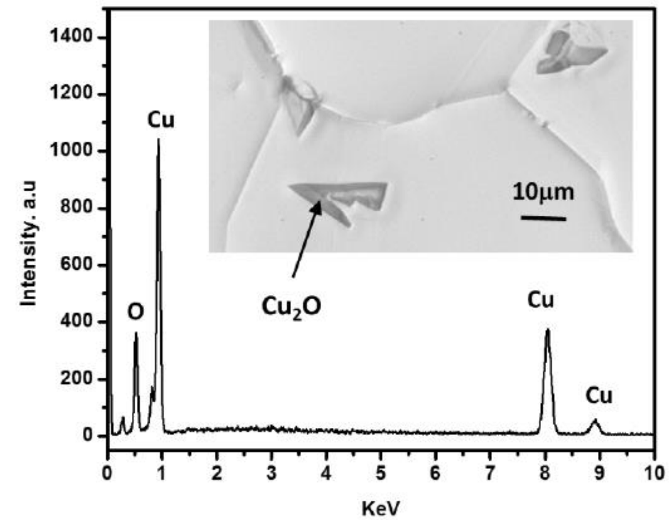


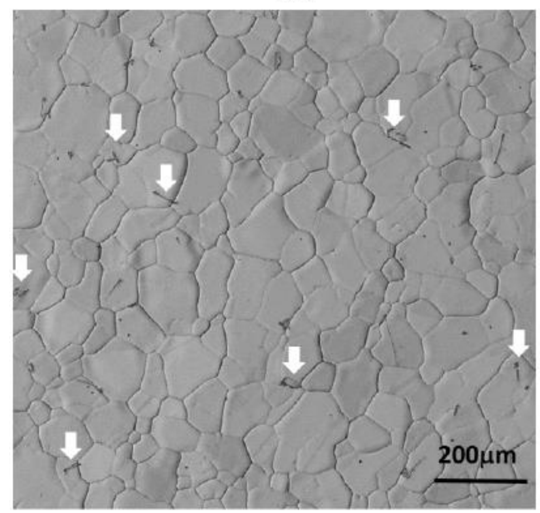
Other crucial aspects of magnet technology
(2) high *RRR* with no diffusion barriers

*Li, Ye, Jiang, Shen, IOP Conf. Series: Materials Science and Engineering **102** (2015) 012027*



Cu in filaments diffuses out but forms Cu_2O on wire surface after reaction





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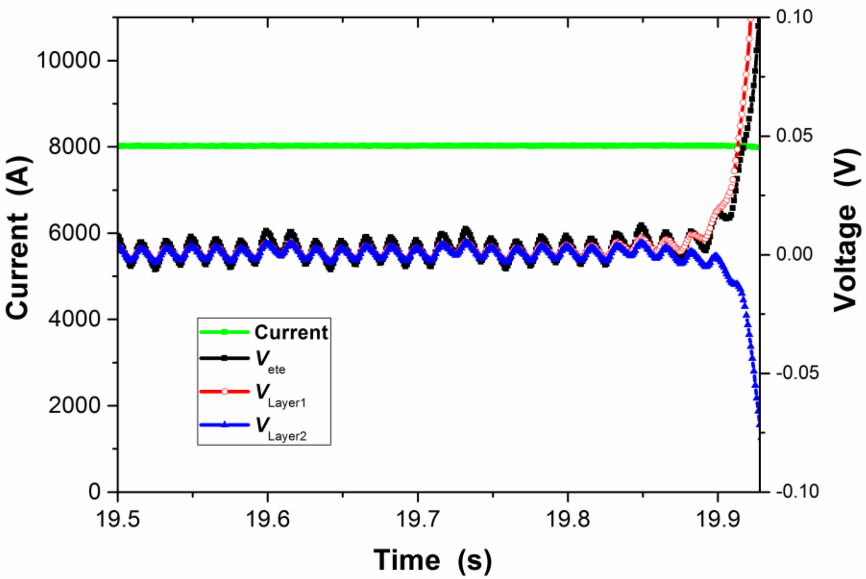
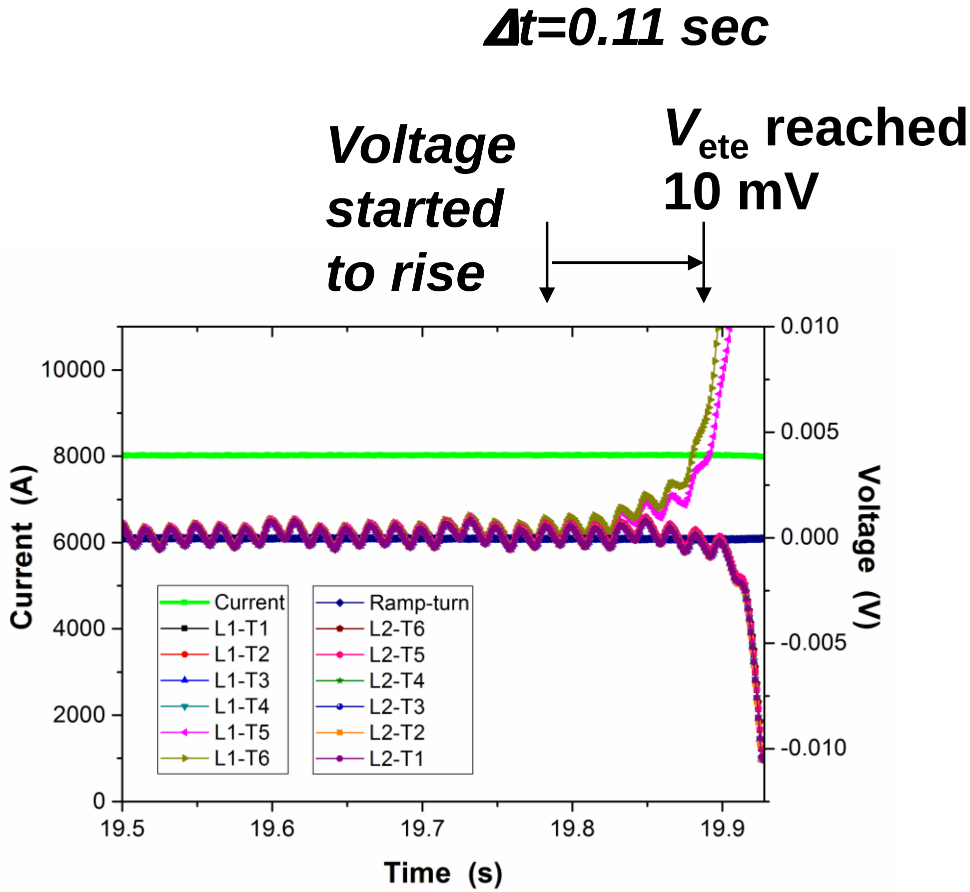
Other crucial aspects of magnet technology

(3) Feasible quench detection using voltage taps and quench protection using dump resistor at wire J_o of 910 A/mm^2

Advanced quench detection:

- **M. Marchevsky, 3LO3-03, acoustic thermometry**
- **E. Ravaioli, 3LP4-23, capacitance measurement**
- **F. Scurti, 3LO3-05, fiber optics**





t=19.782 s, *Voltage taking off.*

t=19.895 s, V_{ete} = 0.011 V

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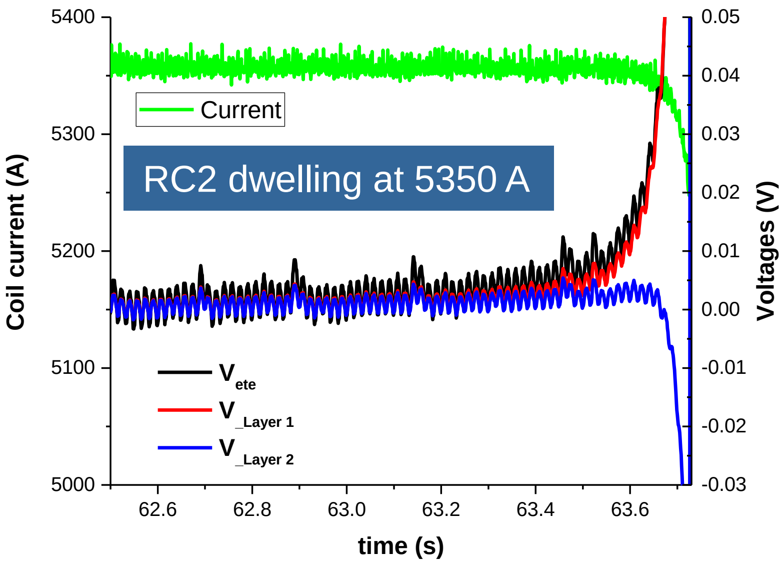
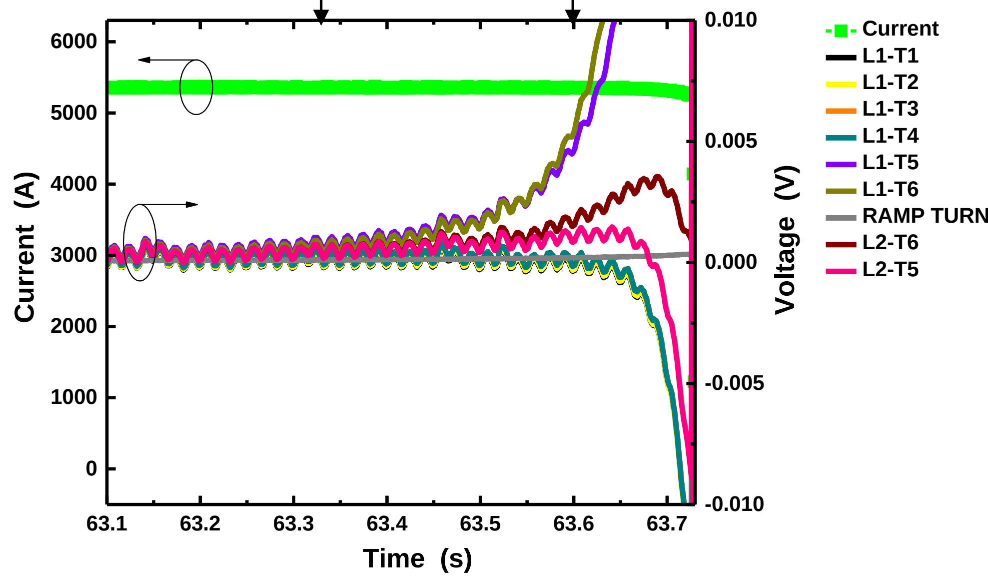
Feasible voltage-based quench detection and quench protection at a lower current – wire J_o=600 A/mm^2

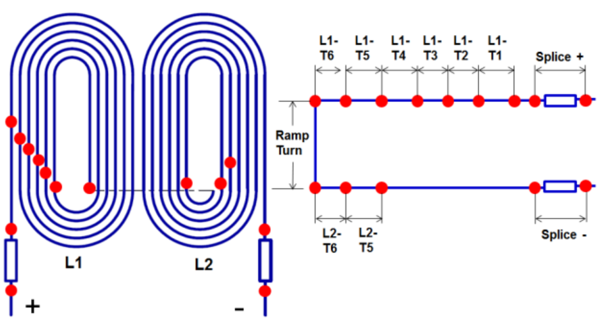


Voltage started to rise

Δt=0.28 sec

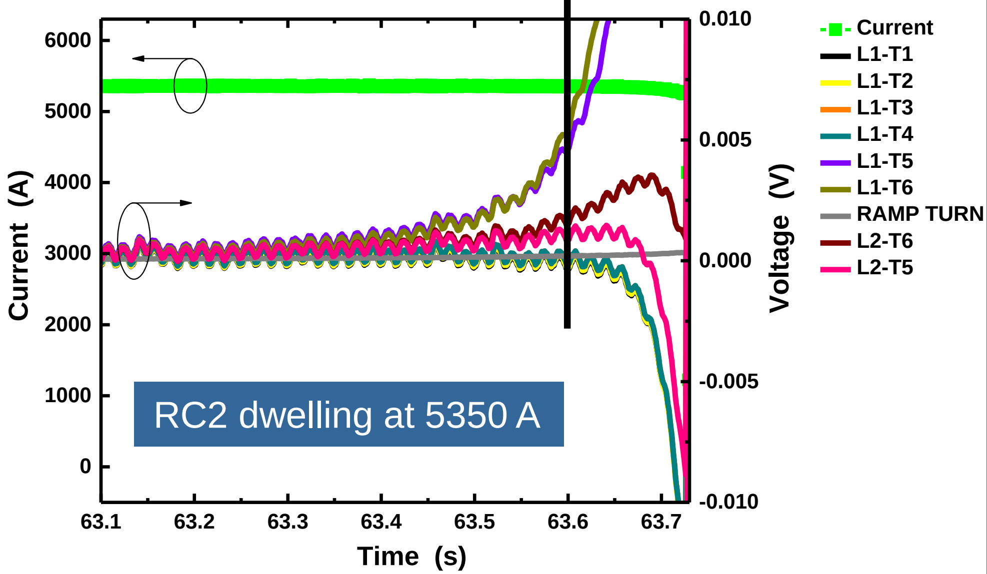
V_{ete} reached 10 mV

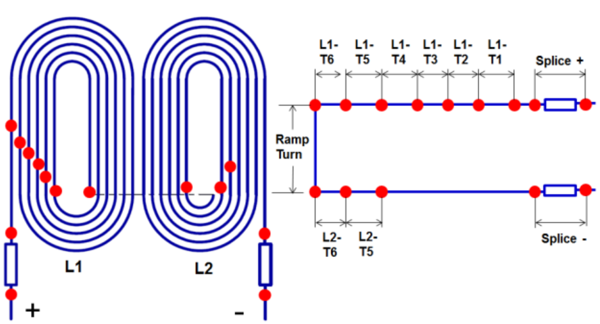


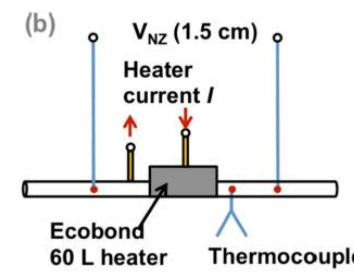


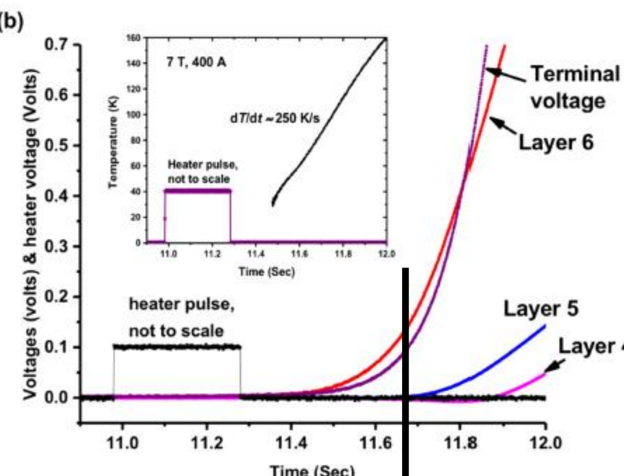
Feasible voltage-based quench detection is perhaps because quenching doesn't occur with a single, localized hot spot, rather with multiple hot spots with several turns

V_{ete} reached
10 mV – normal zones at four turns









Shen et al. *Supercond. Sci. Technol.* 29 (2016) 08LT01

V_{ete} reached
100 mV – normal zone in one layer

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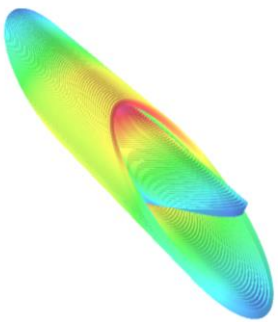
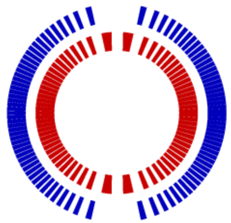
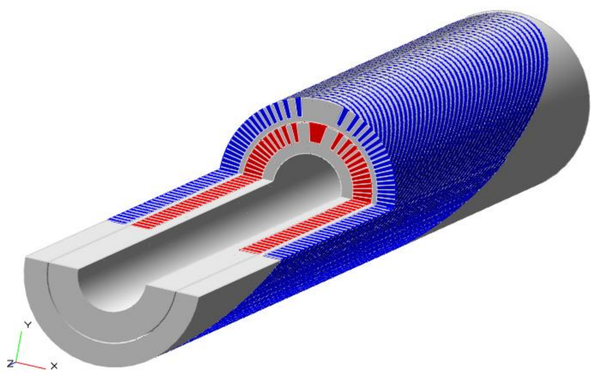
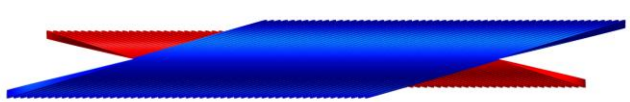
Redefine what is possible: A route to 20 T dipole - Extending CCT to 2212

L. Garcia Fajardo, L. Brouwer









Design 1: 19-strand Rutherford cable, 0.8 mm strand, bore=40 mm, OD=98.4 mm

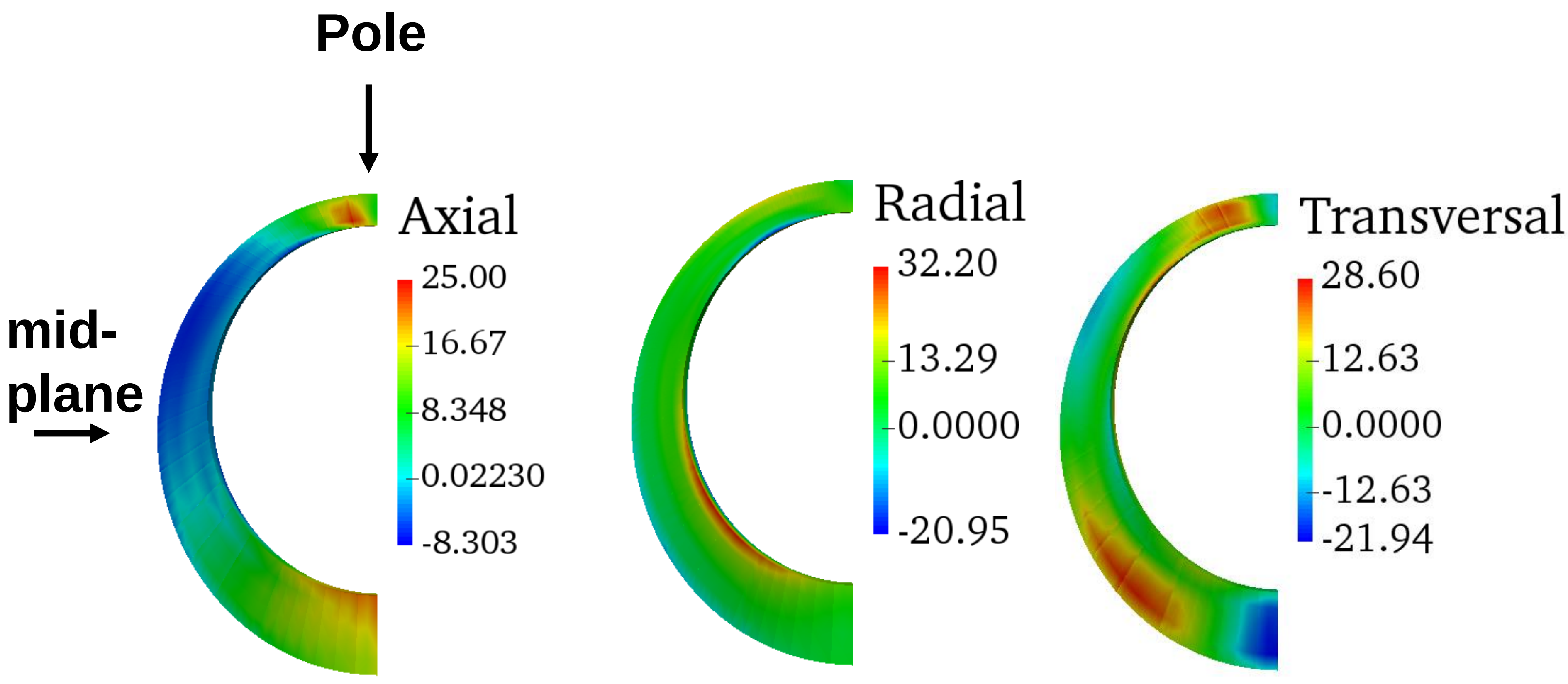
Background field (T)	PMM170123 strand (90% SSL assumed)	
	I–Design (kA)	Dipole field in the bore (T)
0	9.8	**5.4**
15	7.0	**18.9**

Design 2: 13-strand Rutherford cable, 0.8 mm strand, bore=40 mm, OD=81 mm

Background field (T)	PMM170123 strand (90% SSL assumed)	
	I–Design (kA)	Dipole field in the bore (T)
0	7	**4.0**
15	4.9	**17.8**

CCT technology is effective at managing stresses in Bi-2212 coils within limits, even at 20 T

L. Garcia Fajardo, L. Brouwer



Stress in one-half turn of Bi-2212 cable for design 1 at 18.9 T

Key messages – 2212 conductors are ready for magnets (D.C. Larbalestier MT-25)

- **Quadrupled performance in RC5 (3.33 T) – wire J_e – 930 A/mm^2, cable J_e - 730 A/mm^2, cable I_q -8200 A, stable at 7800 A.**

- **Feasible voltage tap based quench detection.**

- **Redefine what is possible – 20 T dipole with 2212 CCT technology.**