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Update on REBCO accelerator magnet technology development at LBNL and research plan for fusion magnets

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Acknowledgment

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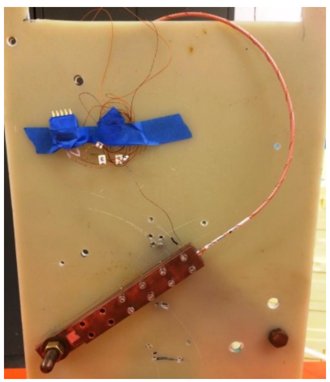
Connecting the conductor developments and accelerator magnet needs

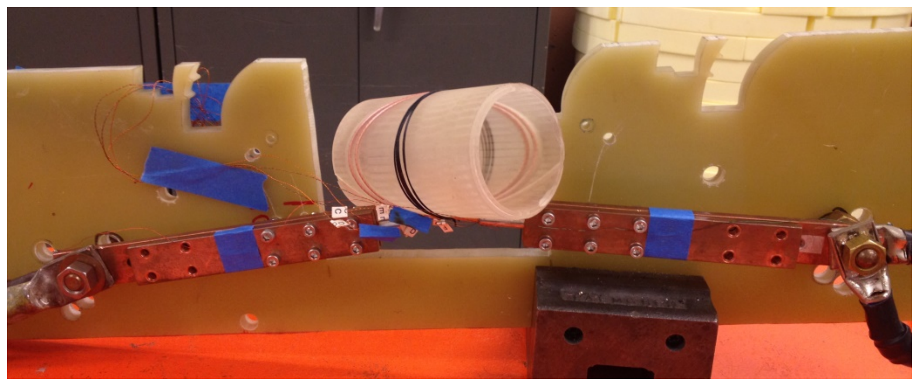
- REBCO conductor has significant potential: J_e and cost
- Two intertwined issues for REBCO accelerator magnets
  - Magnet technologies are under development
  - Guidance on conductor properties based on magnet performance and needs lags

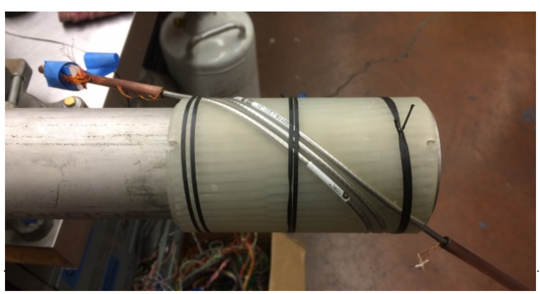
- Evaluating various conductor/cable concepts based on canted cosθ design
  - Conductor on Round Core (CORC®) wire
  - Tape stack (MIT and Roebel)

Working closely with vendor on short sample testing and wire optimization

- ACT has supplied several short samples of different designs for us to test winding on CCT grooves
- Excellent opportunity to learn wire handling

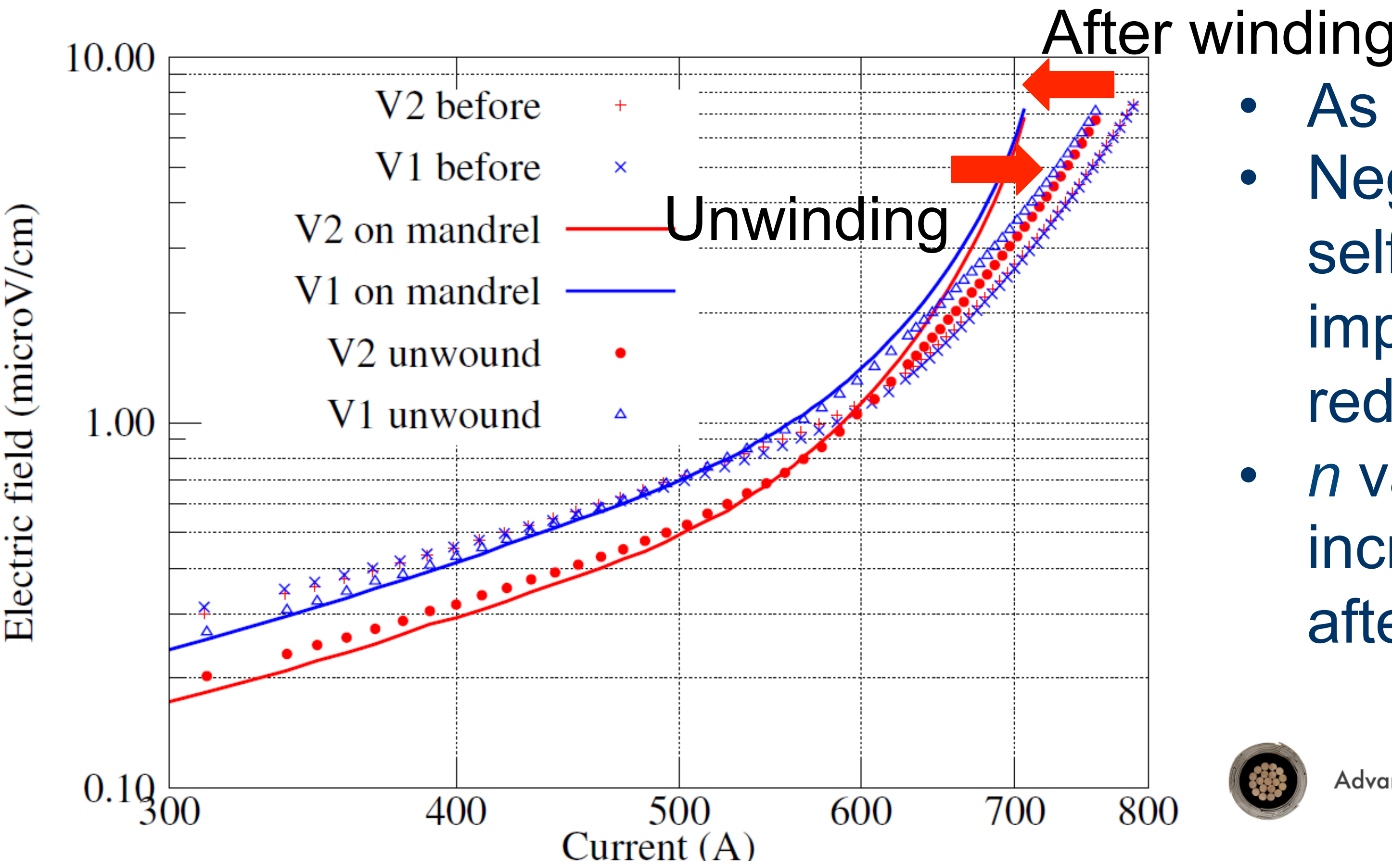






Advanced Conductor Technologies
www.advancedconductor.com

5% - 10% I_c degradation after being wound to the CCT grooves



- As expected
- Negligible self-field impact on I_c reduction
- *n* value increased after winding

Advanced Conductor Technologies
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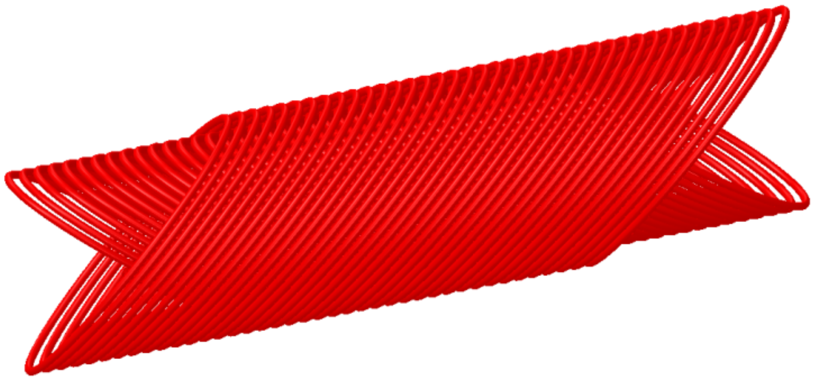
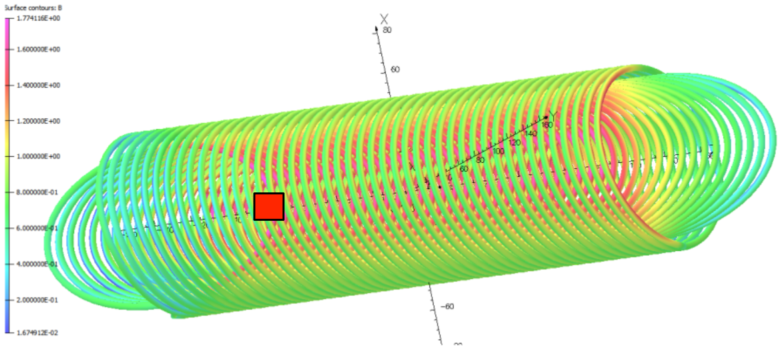
A subscale CORC® CCT dipole magnet

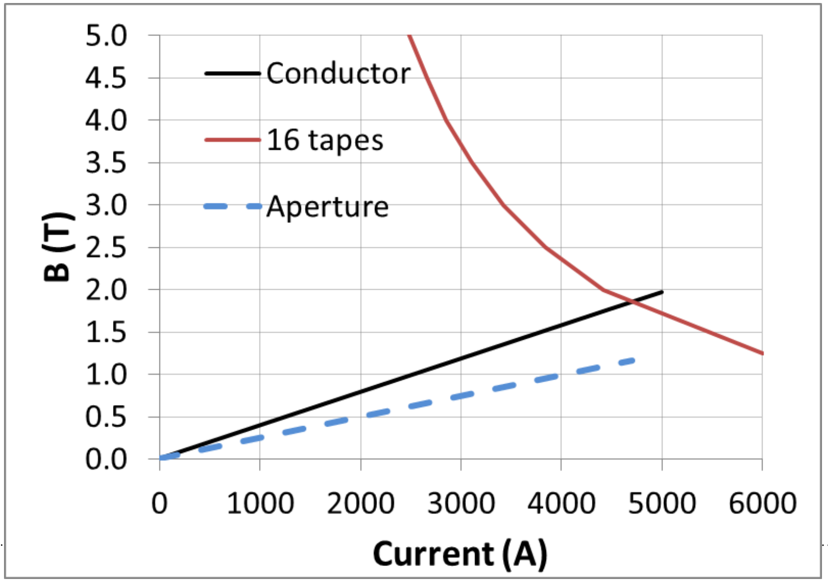
- 2 layers, 40 turns using single CORC® wires
  - 70 mm aperture, 500 mm long, 40 m long conductor
  - Wire minimum bending diameter 46.5 mm (10% I_c degradation)

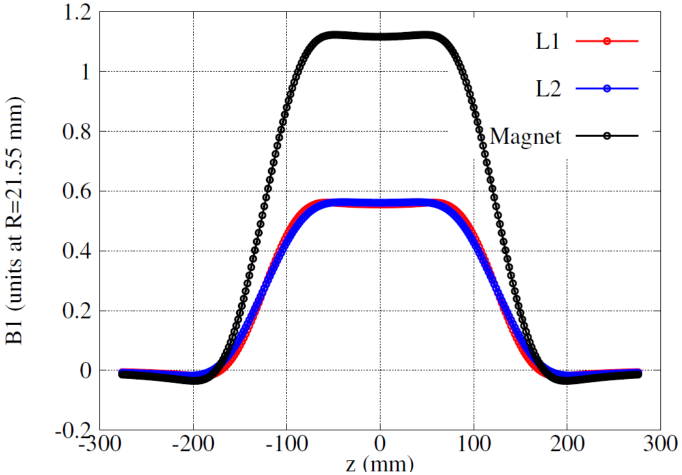


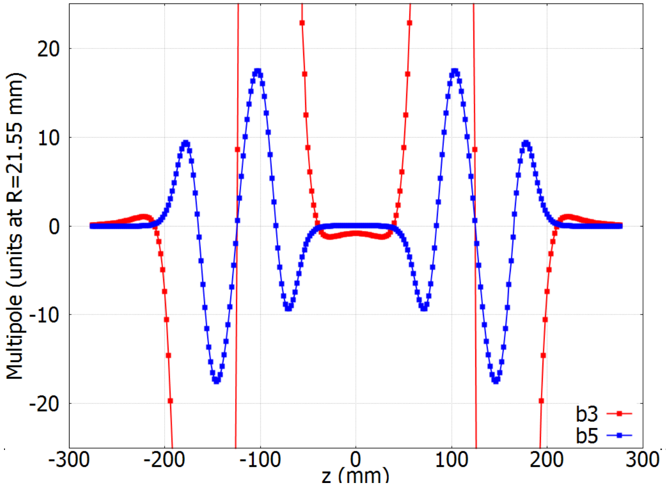
- Establish a magnet platform to provide feedback on conductor development

Moderate 1 T dipole field at 4.2 K

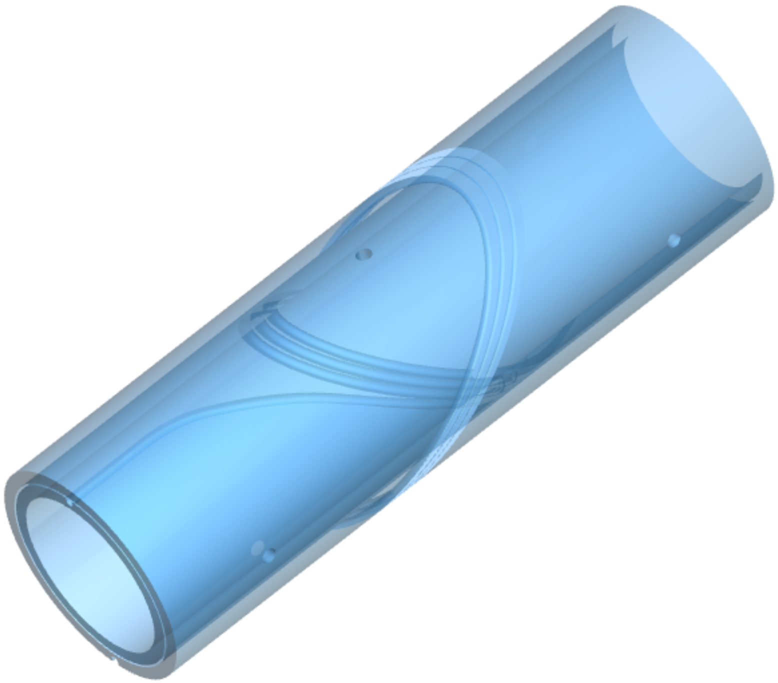






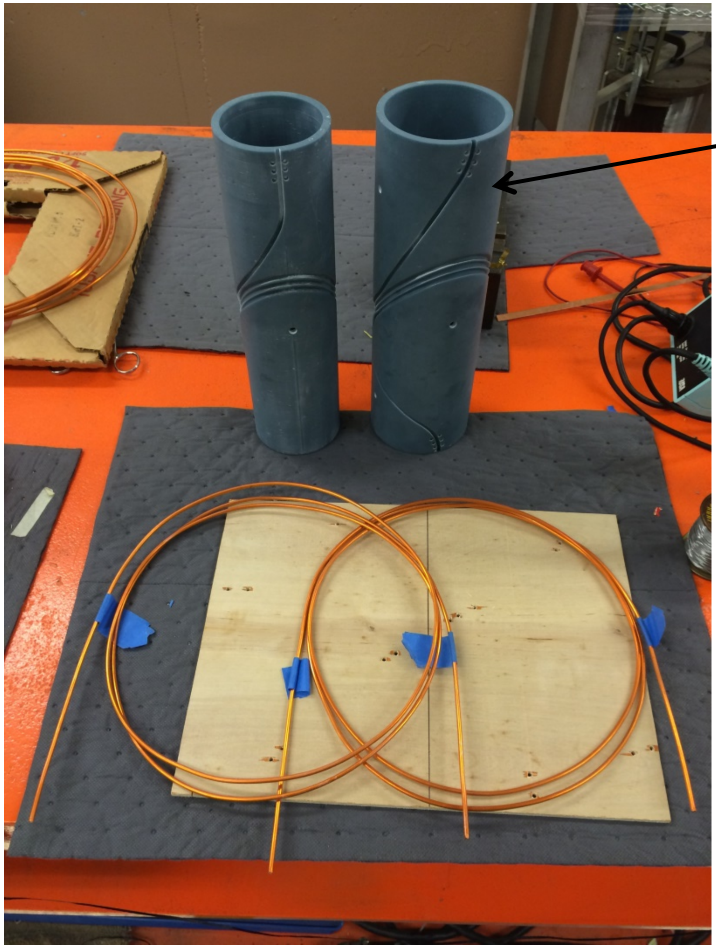


We started with a 2-layer 3-turn mini-coil



- Same design as the subscale except with only 3 turns
- An affordable and quick turn-around vehicle to develop magnet technologies: winding, assembly, joints, impregnation, test and etc.

How it would look like – mandrels and conductors



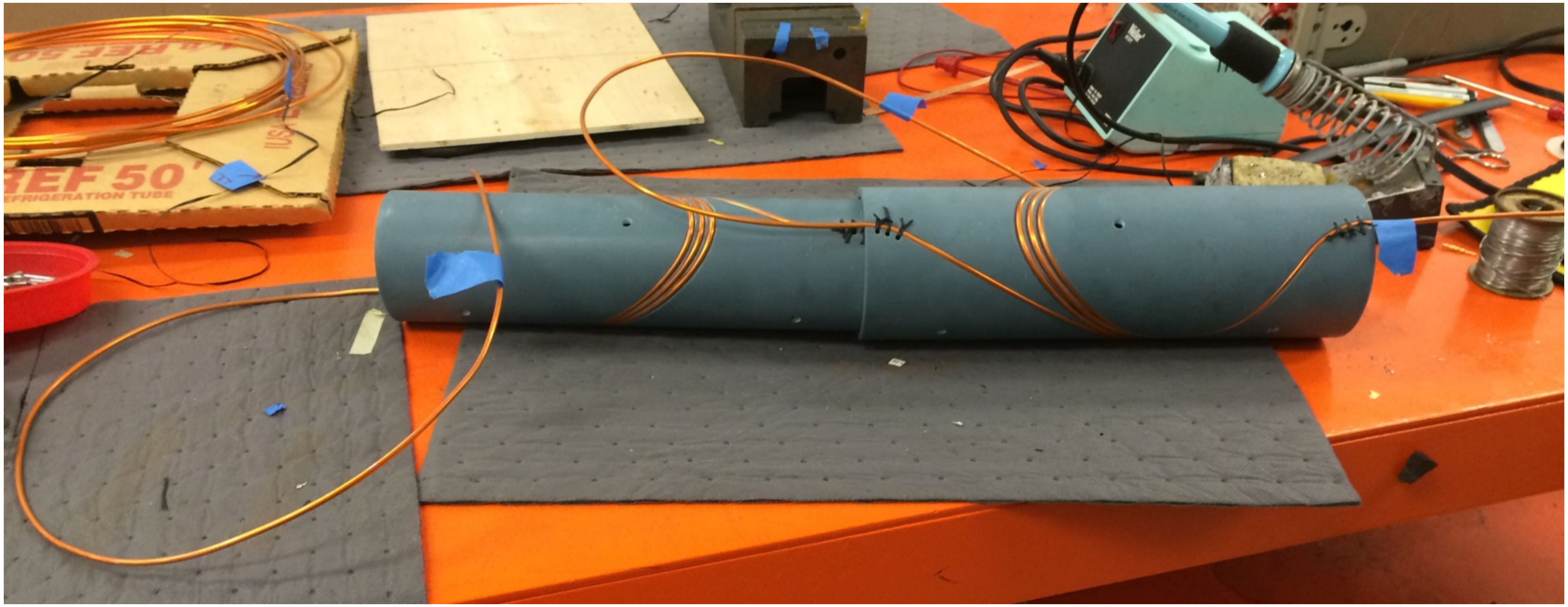
Mandrels printed with Accura® Bluestone

- Quick and inexpensive
- -0.6% contraction from RT to 4.2 K

How it would look like – after winding each layer

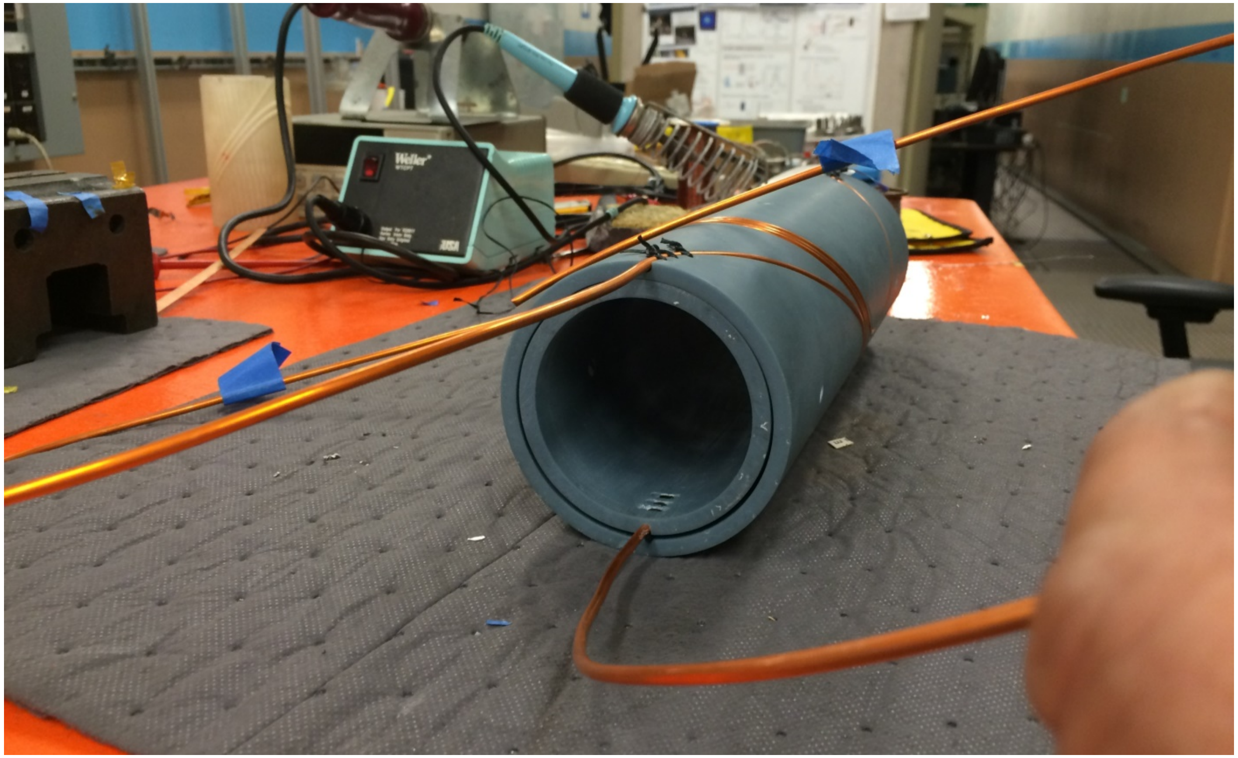
- Joints will be tricky
  - Low resistance. Enough length for current transfer
  - Clear for aperture. Support in background field

How it would look like – assembly



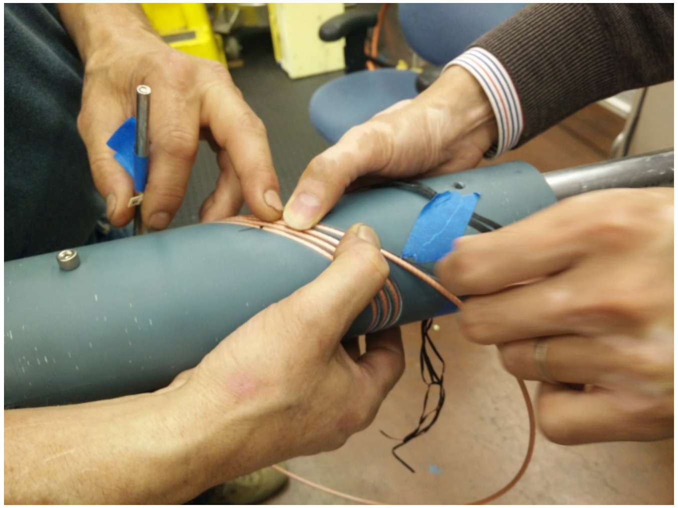
- Clearance and alignment between layers
- Impregnation
- Joint development

How it would look like

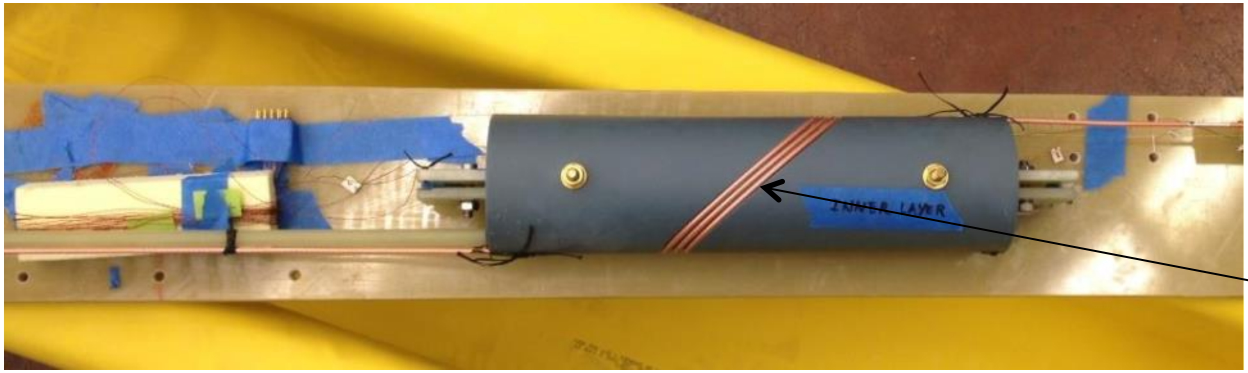


Now let's try the real conductor…

The 3-turn inner layer was wound and tested in LN_2

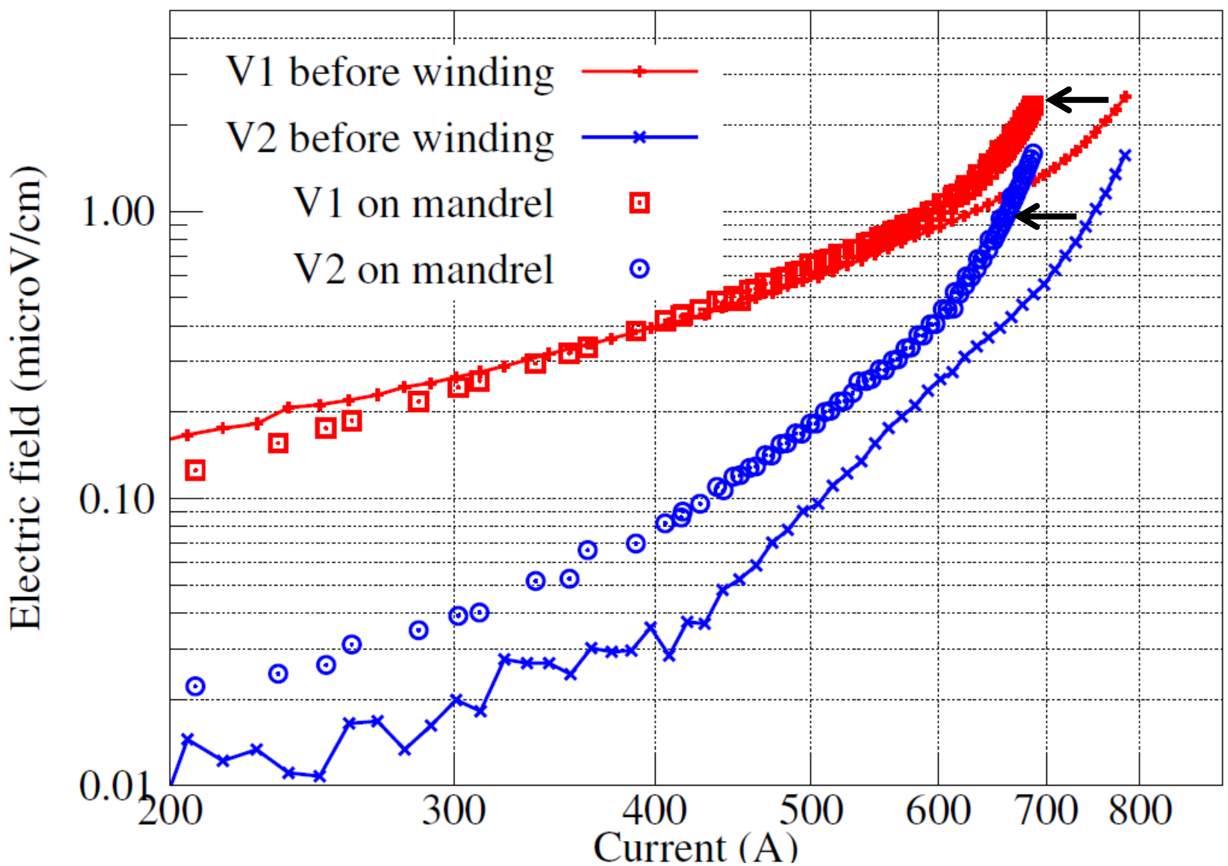


- CORC® wire diameter 3.09 mm
- 8 layer of SuperPower tapes
- Each tape 2 mm wide with 30 µm thick substrate



Hall sensor in the aperture

I_c degraded 11% after winding, consistent with vendor data



- 754 A to 673 A
- n value increased from 9 to 13

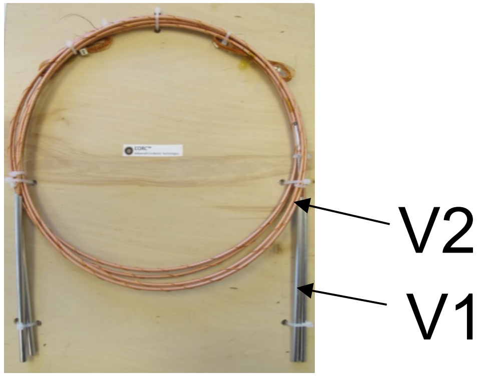
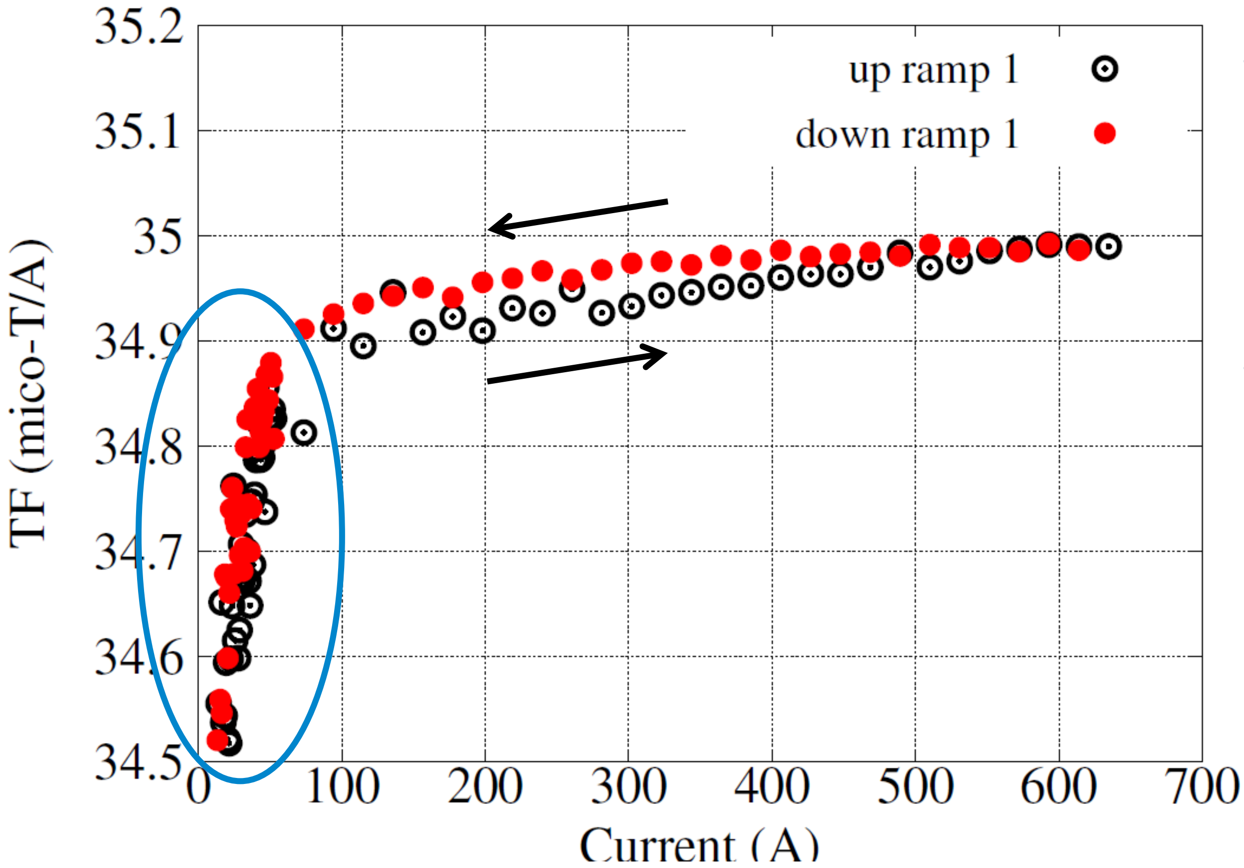


Image courtesy J. Weiss, ACT

Signature of persistent-current effect (screening-current effect)

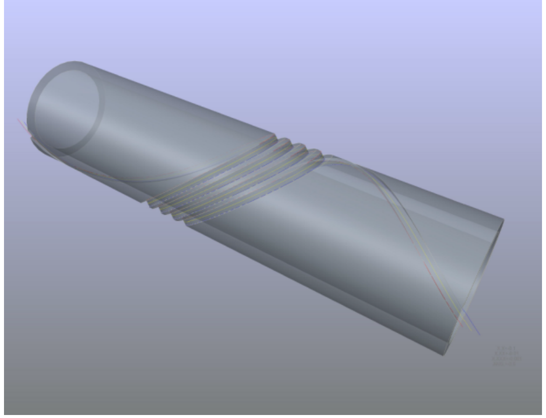


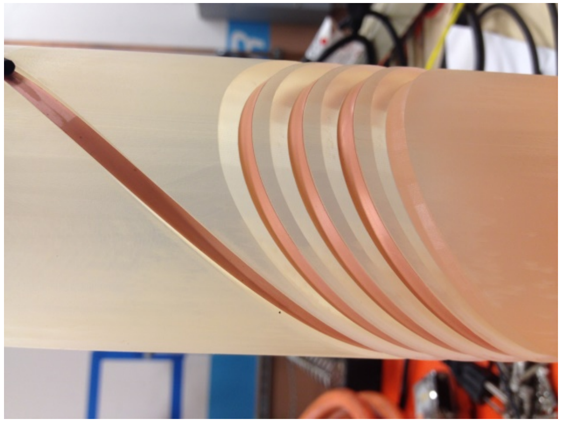
- Hysteresis between up and down ramps
- Non-linear behavior below 100 A

Next steps for the REBCO CCT magnet development

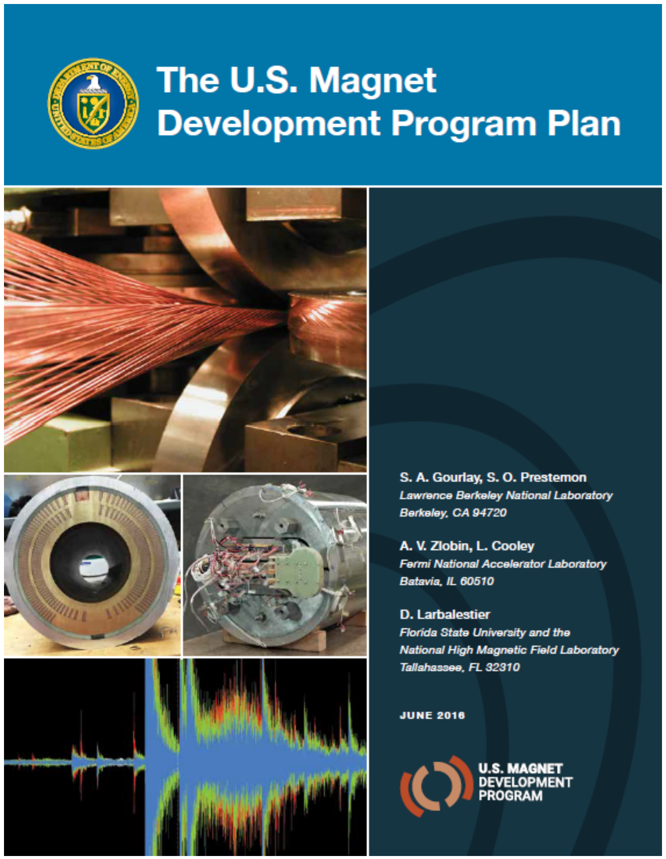
- Complete and test the 3-turn mini-coil at 77 K and 4.2 K
  - Continue to use the 3-turn platform to study the impregnation and other issues
- Develop the 40-turn subscale magnet

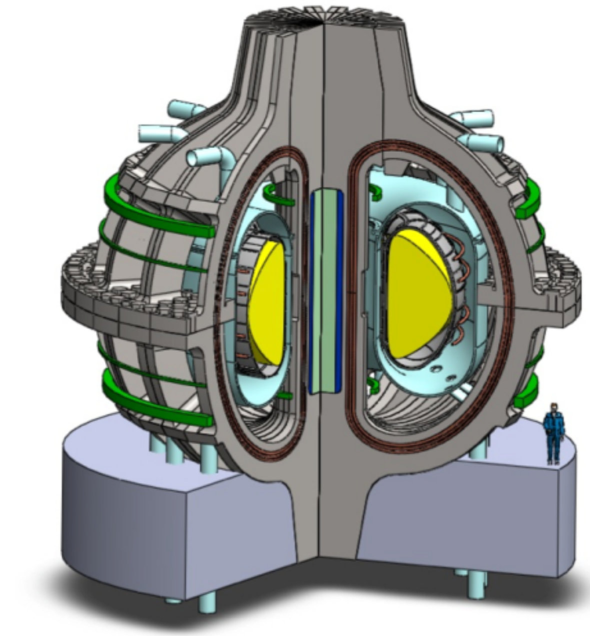
- Develop the tape-stack version





Leverage the HEP REBCO magnet development for fusion applications





- J. Minervini, talk at LTSW, Santa Fe, 2016
- B. Sorbom et al., Fusion Engineering and Design, p. 378 – 405, 2015 (100)

Issues and solution overlap between FES and HEP – conductor and cable

Issues	Remarks	FES/HEP solution overlap
Conductor performance	Critical current, quench behavior and AC loss as a function of strain, temperature and background fields.	High
Cable architecture	Different architectures and requirements for FES and HEP.	Low
Mechanical tolerance	Mechanical load on conductor/cable during winding, cooldown, energization.	High
Quench tolerance	Quench induced conductor degradation.	High
Radiation tolerance	Impact on superconductor, impregnation and insulation materials.	High
AC loss	Sources of AC loss and dependence on the conductor and cable design.	High
Joints	Low loss. FES may also require demountable joints.	High

Issues and solution overlap between FES and HEP – magnet

Issues	Remarks	FES/HEP solution overlap
Design and analysis for high-field magnets	Integrated magnetic, mechanical, thermal design and analysis.	High
Structure materials and fabrication	Mechanical, electrical and thermal properties. Compatibility with HTS conductors. Fabrication method.	High
Coil fabrication technology	Winding of HTS cables, strain induced degradation. Insulation. Impregnation.	High
Cooling mode	Thermal budget and optimal cooling mode	Low
Quench detection and protection	Advanced diagnostics for early detection and scheme for effective energy extraction.	High
Cost analysis	Analysis of cost-driving elements.	High

Evaluate feasibility for high-field HTS fusion magnets, and clarify R&D needs

- Design study of subscale TF and PF coils
- Fabrication and test of subscale coils
- Advanced analysis tools for magnetics and mechanics
- Strategy for quench detection and magnet protection
- Feasibility and R&D plan for high-field HTS fusion magnets

- A "mini-workshop" at Boston in August with MIT, Tufts, and NHMFL/FSU to clarify the R&D issues and how we can coordinate activities to most efficiently and effectively make progress

Summary

- LBNL is developing technologies for REBCO accelerator magnet applications
  - Connecting conductor developments with magnet needs

- Leverage the HEP Magnet Development Program for high-field REBCO fusion magnets
  - Evaluate the feasibility of REBCO fusion magnets
  - Coordinate with partners to identify and address R&D issues