Recent CORC® Progress

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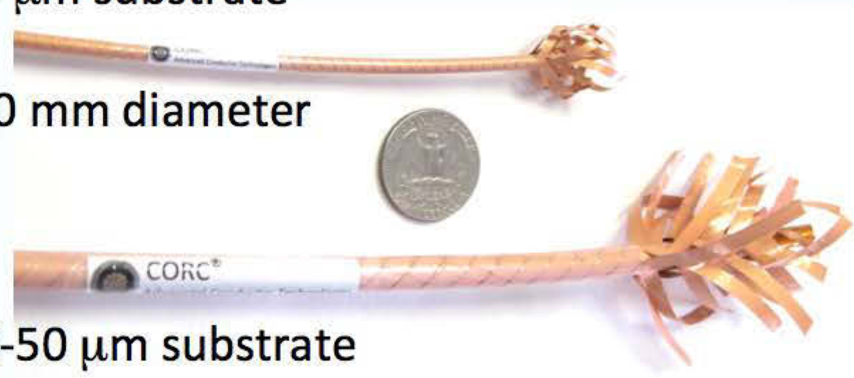
LTSW, Jacksonville, FL, February 14, 2018

CORC® magnet cables and wires



CORC® wires (2.5-4.5 mm diameter)

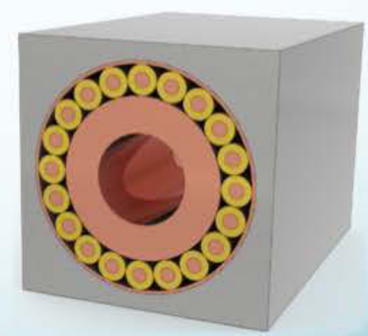
- Wound from 2-3 mm wide tapes with 30 μm substrate
- Typically no more than 30 tapes
- Highly flexible with bending down to < 50 mm diameter

CORC® cable (5-8 mm diameter)

- Wound from 3-4 mm wide tapes with 30-50 μm substrate
- Typically no more than 50 tapes
- Flexible with bending down to > 100 mm diameter

CORC®-Cable In Conduit Conductor (CICC)

- Performance as high as 100,000 A (4.2 K, 20 T)
- Combination of multiple CORC® cables or wires
- Bending diameter about 1 meter



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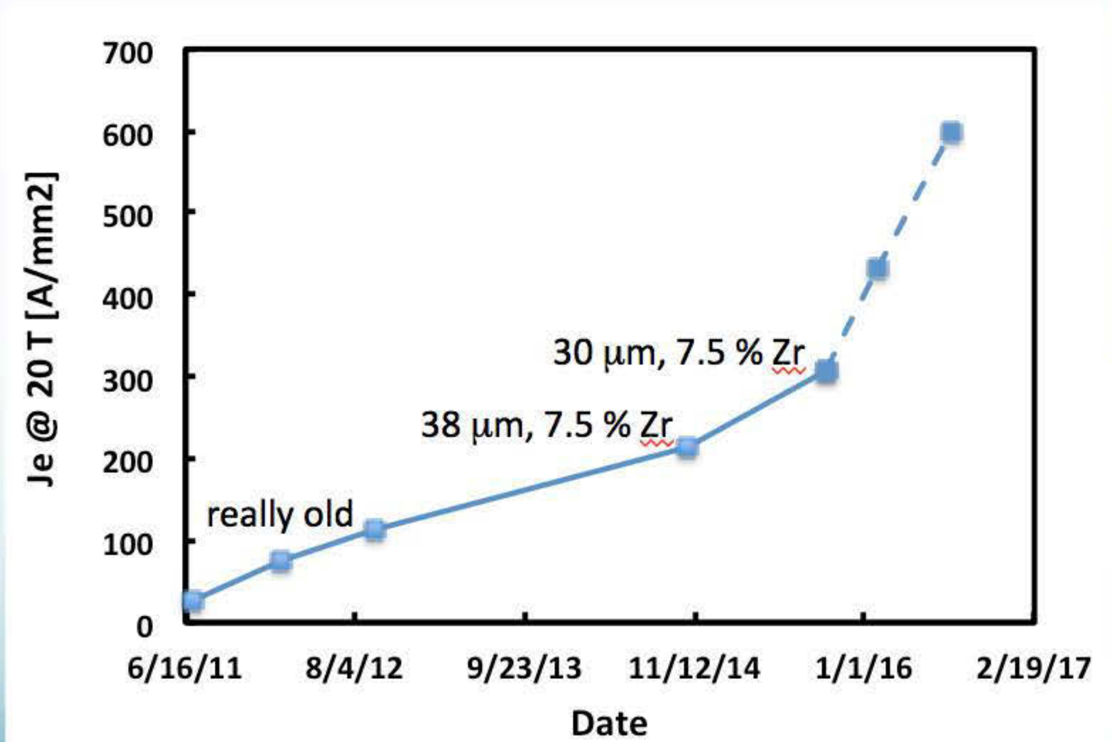
J_e in CORC® accelerator cables: current and future

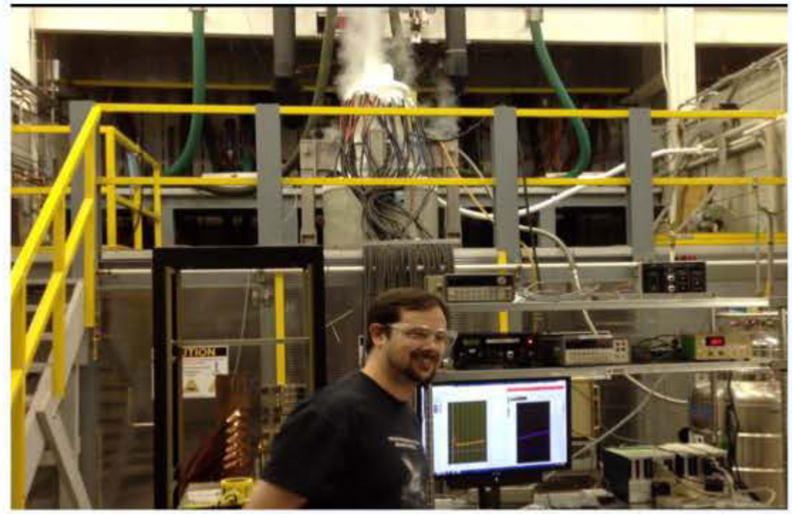
CORC® cable J_e on track to 600 A/mm^2 at 20 T

- .....
- J_e of 309 A/mm^2 at 20 T achieved in Oct. 2015



In-field CORC® cable testing @ 100 mm

- Large bore magnet at NHMFL (17 T)



Problems!

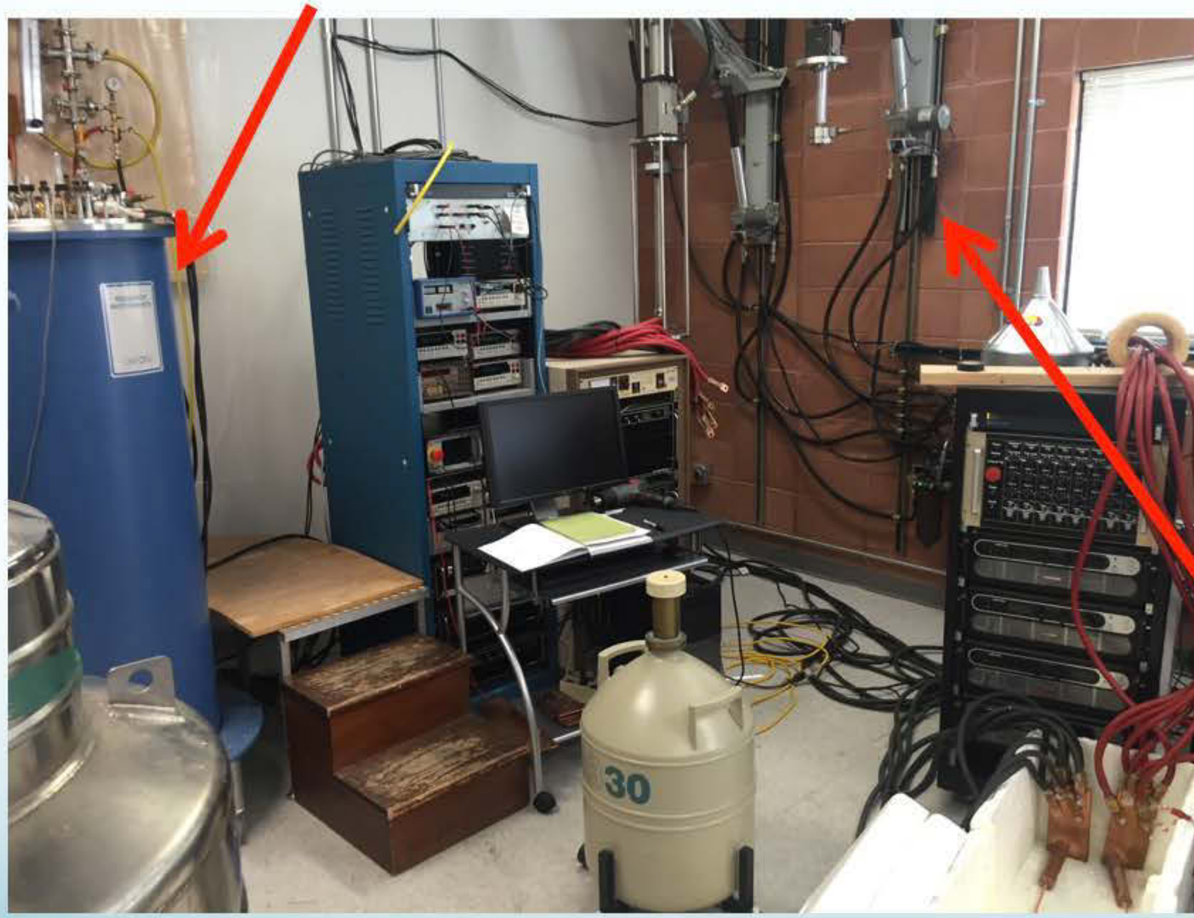
- NHMFL magnet decommissioned

Tests now need to be performed in-house!

In-house test facilities Univ. of Colorado

In-field cable test setup

- Several magnets: 12 T (80 mm cold bore), 14.5 T (56 mm bore)
- Currents exceeding 16 kA dc and fast ramping (> 1 MA/s)



Design and picture
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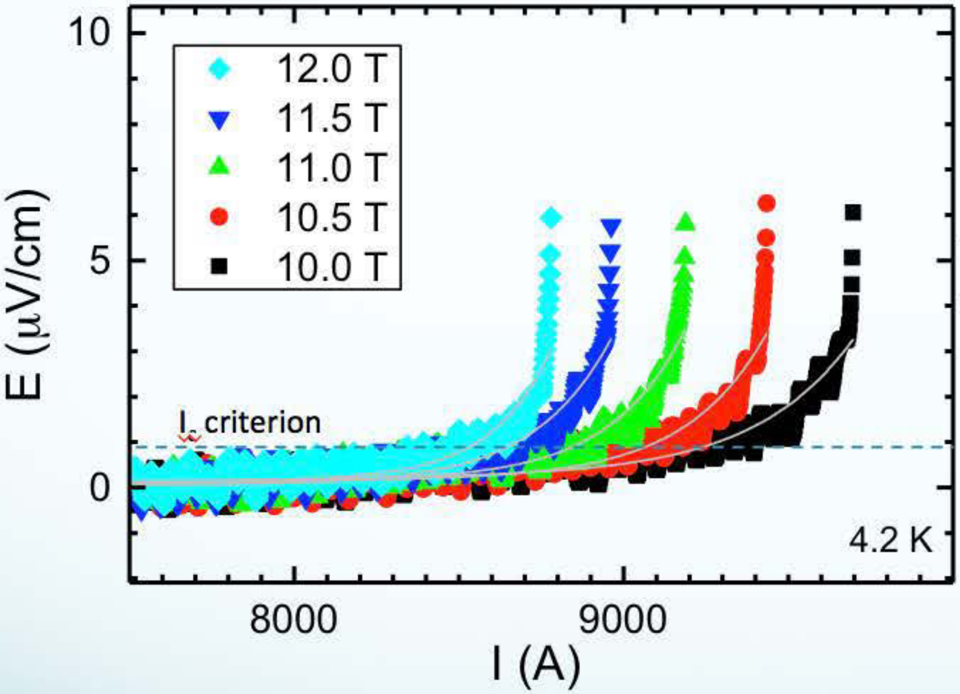
Mechanical testing setup

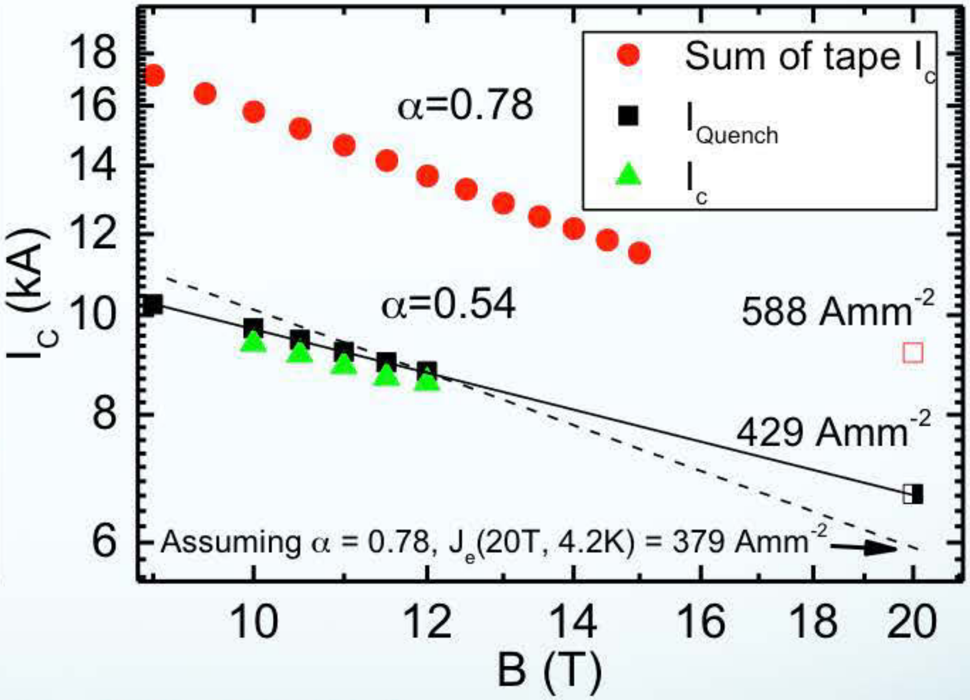
- Transverse compression
- Axial tension
- Loads up to 10,000 lbs
- Including stress cycling >100,000 cycles

Record CORC® magnet wire performance

High-J_e CORC® wire layout

- 50 tapes, 2-3 mm wide, 30 μm substrate
- 4.46 mm CORC® wire diameter
- 67 mm hairpin





- I_c = 8,591 A (4.2 K, 12 T, 1 μV/cm)
- **Projected J_e(20 T) between 379 and 429 A/mm²**
- Projected I_c(20 T) = 6,500 A

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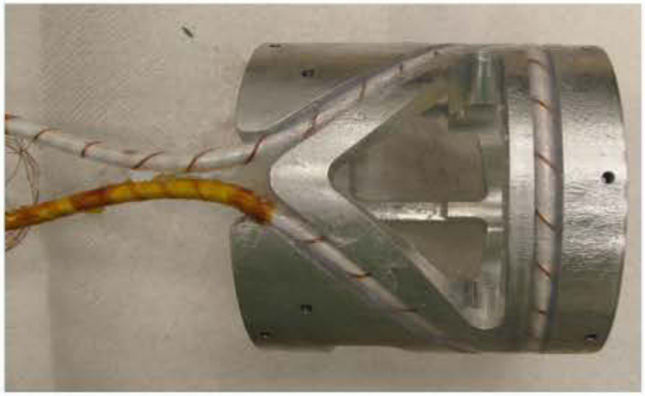
CORC® magnet cable and wire performance

CORC® cable tested at 100 mm diameter (2011 – 2015)



CORC® wire tested at 60 mm diameter (2016 –)

Design and picture
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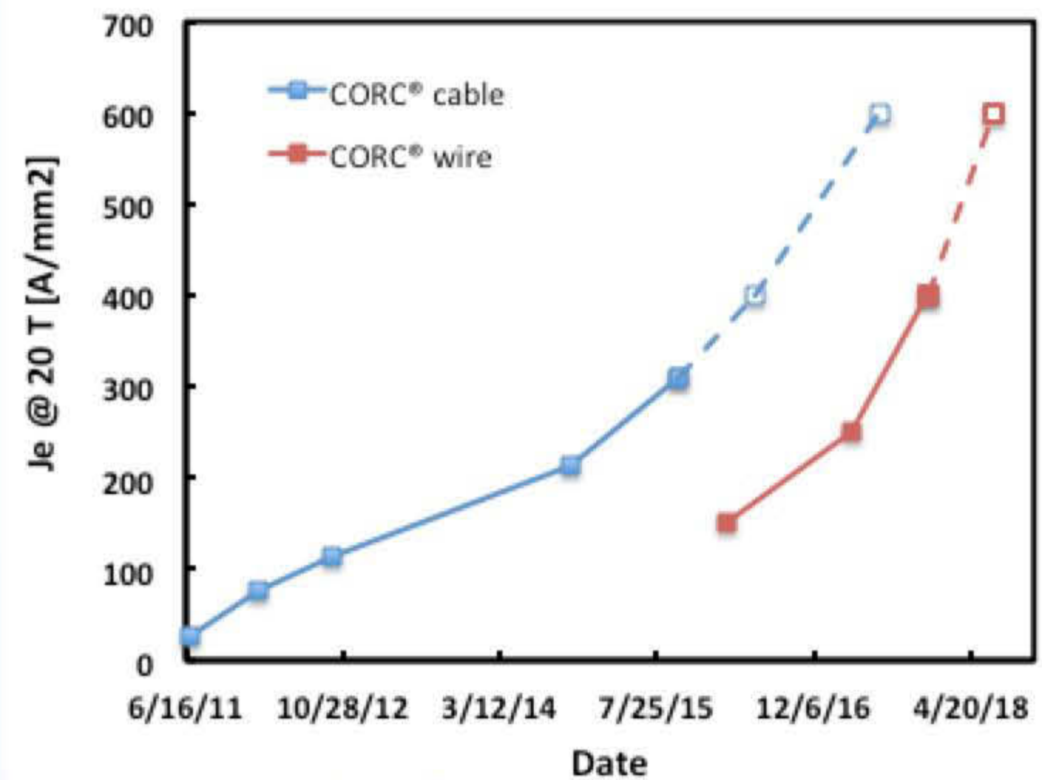


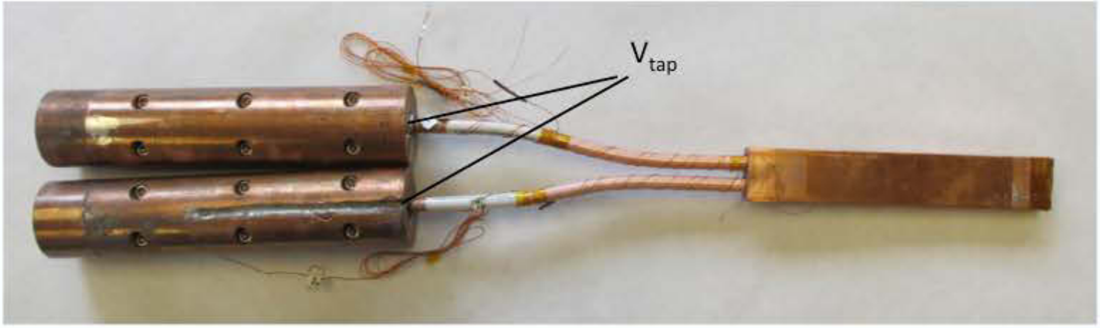
Closing in on J_e > 600 A/mm^2 goal

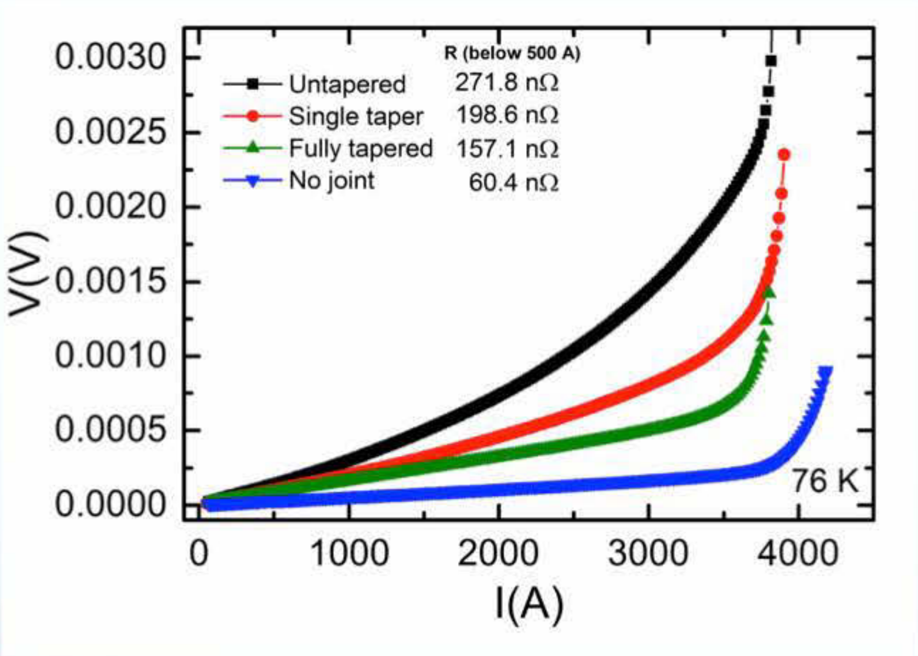
- J_e (20 T) now exceeded 400 A/mm^2 in CORC® wire
- Combined with I_{opp}(20 T) > 6,500 A
- Next step is thinner substrates 20 – 25 μm
- **More details in Jeremy's talk later today**

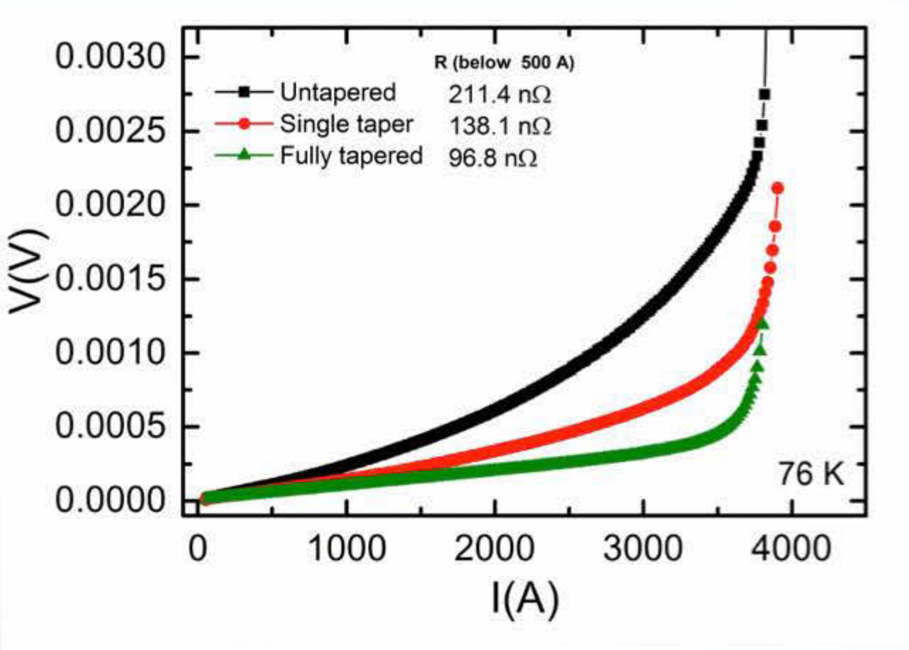
CORC® cable joint resistance 76 K

CORC® cable joint

- 38 tapes, 10 layers
- 15 cm long joint, 100% In
- Different number of tapers





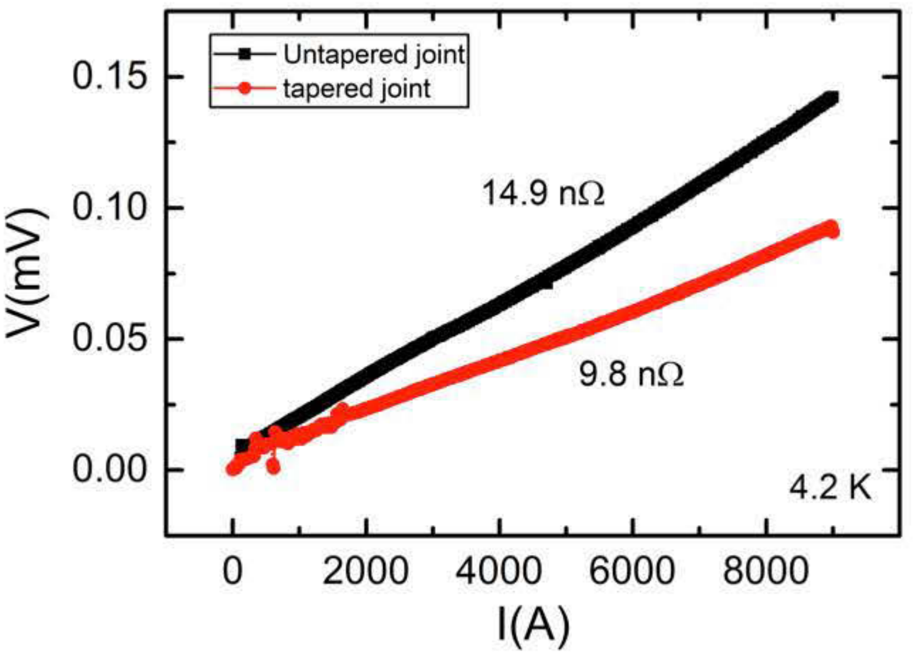


- **Contact resistance lowest at full taper**
- **Joint R(76 K) = 96.8 nΩ**

CORC® cable joint resistance 4.2 K

CORC® cable joint tested at 4.2 K

- Current up to 9,000 A
- Measured in self-field

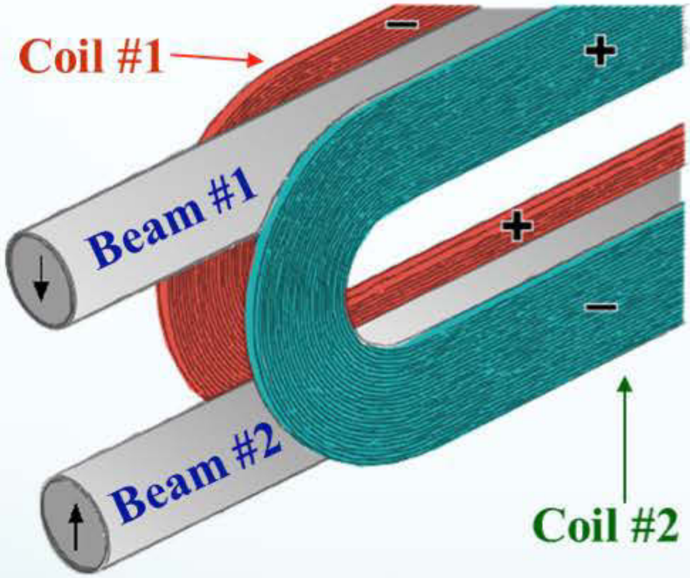


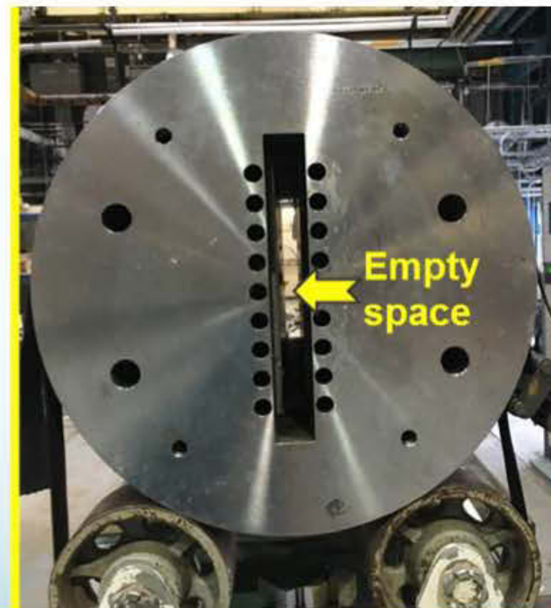
- Contact resistance lowest at full taper
- **Joint R(4.2 K) = 9.8 nΩ**
- **Factor of 10 lower than at 76 K**
- **CORC®-CICC (6 cables) suggest R=1.5 nΩ**
- Further reduction possible

Common coil magnet from CORC® cables (SBIR Ph. I)

Magnet program with Brookhaven National Laboratory (Ramesh Gupta)

- Combine CORC® insert with 10 T LTS common coil outsert
- CORC® cable with expected J_e(20 T) 500 A/mm² delivered
- Operating current 10 kA connected in series with LTS outsert





Common coil benefits

- Only large bending diameters required
- Allowing CORC® cables to be used
- Allowing use of highest J_e cables

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BROOKHAVEN NATIONAL LABORATORY

The road to 21 T in CORC®-CCT magnets (SBIR Ph. 2)

Magnet program with Lawrence Berkeley Nat. Lab. (Xiaorong Wang)

- Develop a canted-cosine theta CORC® insert magnet
- Generate 5 T in a 16 T background field
- **More details by Xiaorong Wang later today**

Step 1: 2-Layer, 40-turns CCT magnet (C1)

- Generate **1 T in self-field**
- CORC® wire $J_e(20\ T) = 150\text{-}200\ A/mm^2$
- Learn to wind and protect CORC®-CCT magnets

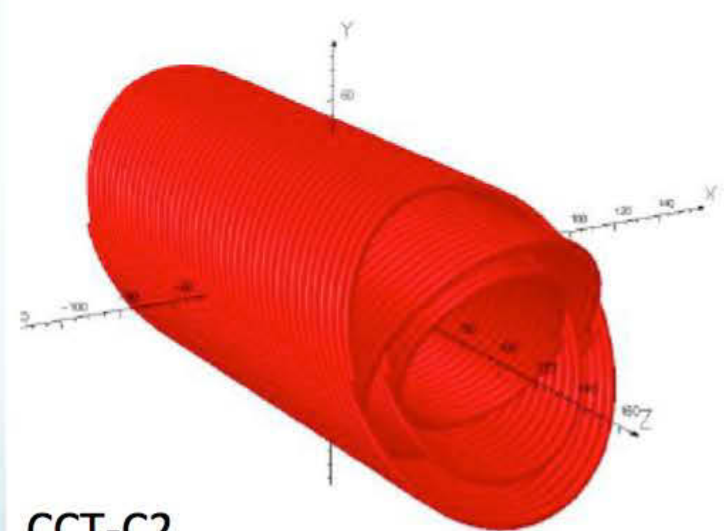
CCT-C1

Step 2: 4-Layer, 40-turns magnet (C2)

- Generate **3 T in self-field**
- CORC® wire $J_e(20\ T) = 200\text{-}300\ A/mm^2$
- CORC® wire bendable to 60 mm diameter

Step 3: 6-Layer, 40-turns CCT magnet (C3)

- Generate **5 T in self-field**
- CORC® wire $J_e(20\ T) = 300\text{-}400\ A/mm^2$
- CORC® wire bendable to 30 mm diameter



CCT-C2

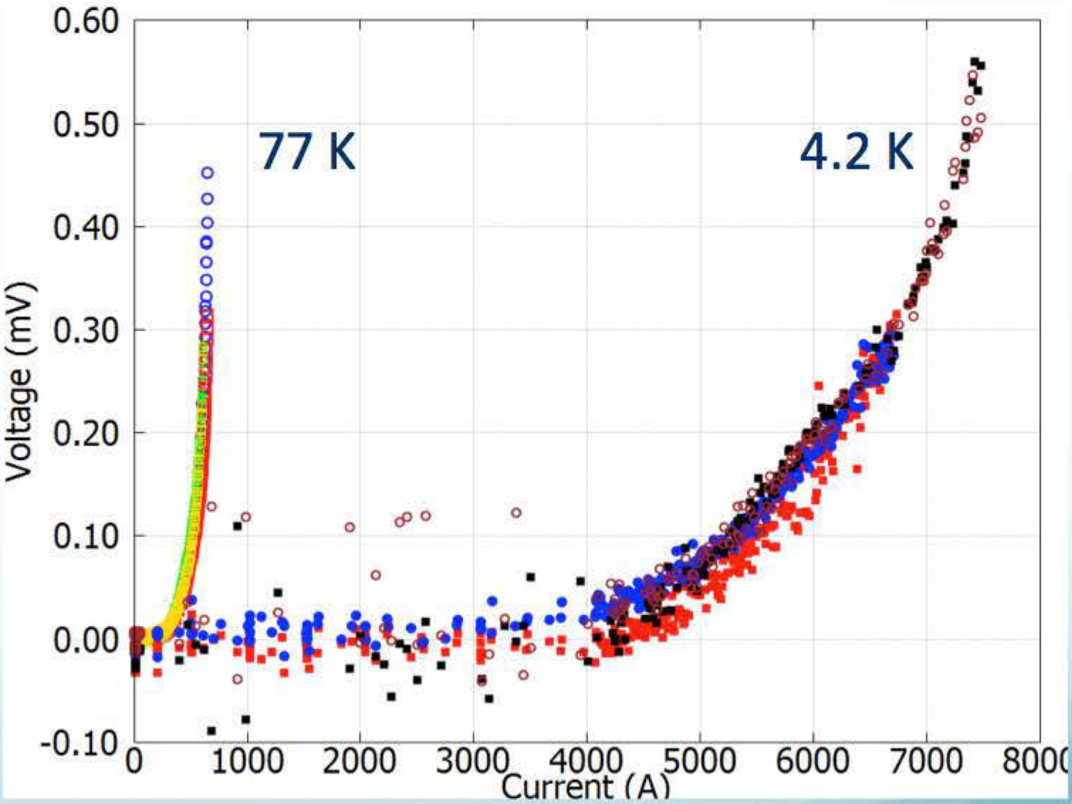
Baby coil C0a: CORC® wire test for CCT-C1

CCT C0a: CORC® wire with 16 tapes

- 2 Layers
- 3 Turns per layer
- Inner layer I.D. 70 mm
- Minimum bending diameter 50 mm

CCT C0a performance

- I_c (77 K) = 646 A (layer A) and 675 A (layer B)
- I_c (4.2 K) = 6,700 A (both layers)

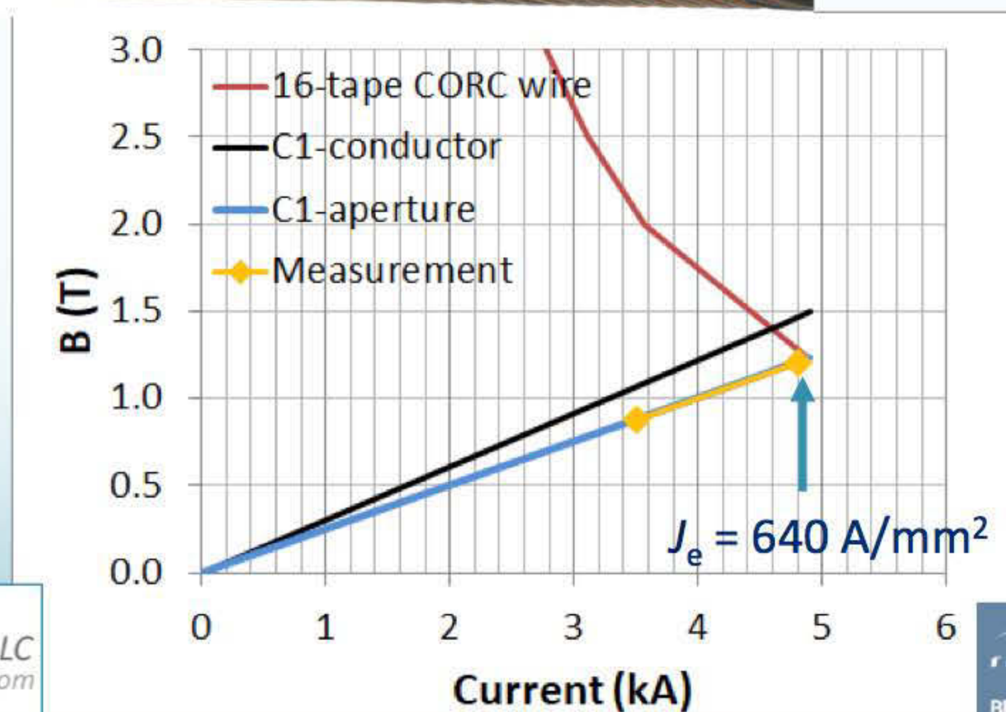


CORC® CCT-C1

CCT-C1 Magnet wound at LBNL

- 2 Layers, 40 turns per layer
- LBNL ordered 50 m of CORC® wire in 2016
- CORC® wire contains 16 tapes, J_e (20 T) = ~150 A/mm^2

CCT-C1 generated 1.2 T at 4,800 A (104 % of expected performance)



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BERKELEY LAB

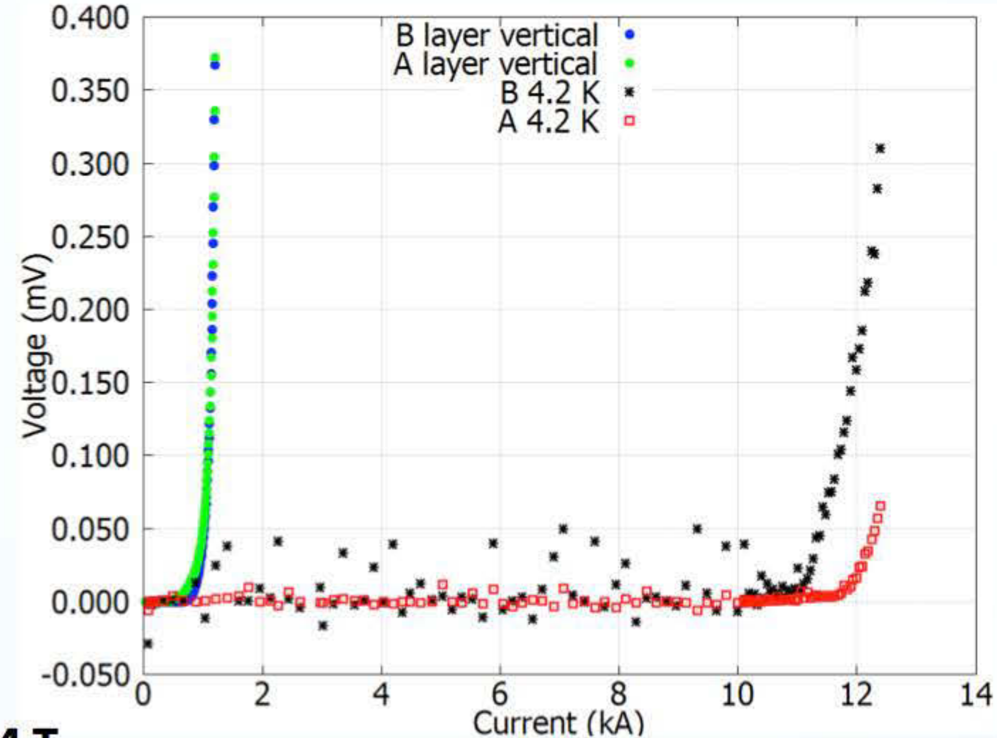
Baby coil C0b: CORC® wire test for CCT-C2

CCT C0b: CORC® wire with 29 tapes

- 3-turn per layer
- Inner layer I.D. 85 mm
- CORC® wire J_e (20 T) = ~300 A/mm²

CCT C0b performance

- I_c (77 K) = 1.092, 1,067 A (layer A, B)
- I_c (4.2 K) = 12,141, 11,078 A (layer A,B)
- Dipole field 0.68 T (4.2 K)
- Peak J_e(4.2 K) = 1,198 A/mm²
- **Expected field of CCT-C2 (40 turns) ~3-4 T**

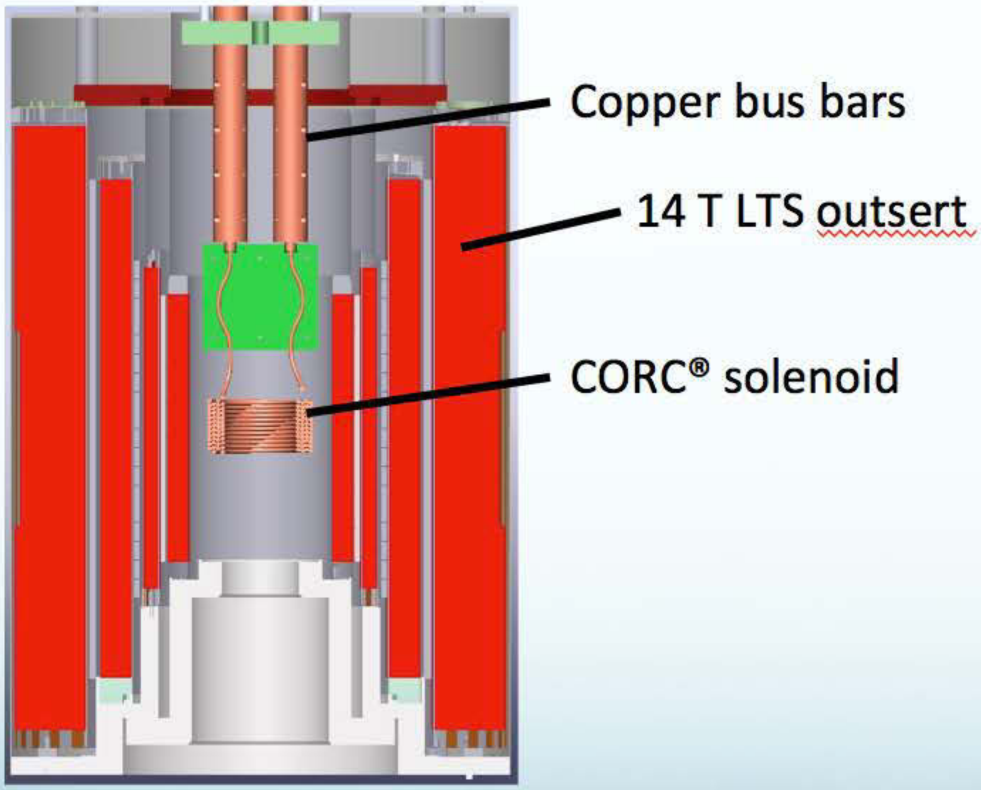


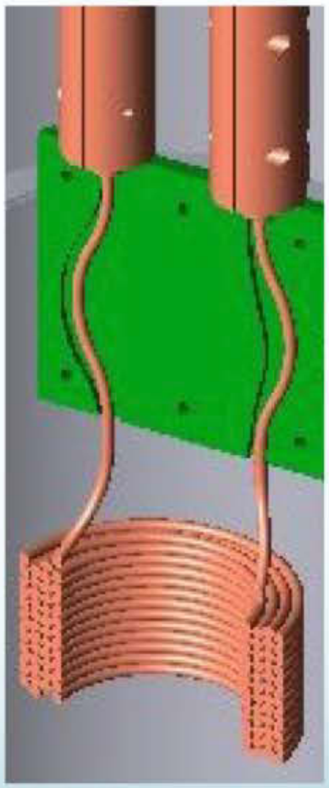
- **Order for 75 m of high-J_e CORC® wire received from LBNL**
- **Full-size coil C2 expected to be wound in Q2 2018**

CORC® high-field insert solenoid (SBIR Ph. 2)

Magnet program with ASC-NHMFL (David Larbalestier, Dima Abraimov, Huub Weijers)

- Develop high-field insert solenoid wound from CORC® wires
- Test insert magnet at 14 T background field at ASC-NHMFL
- Aim for added field of at least 2-3 T, maybe 5 T depending on tape performance





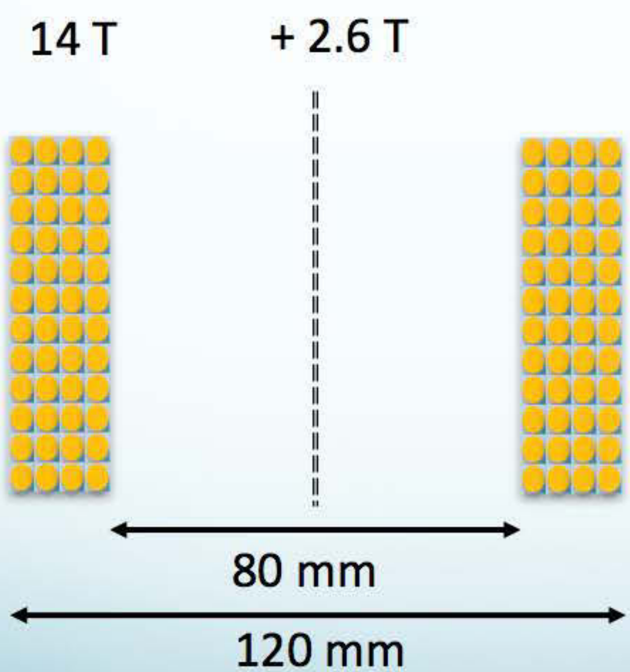
CORC® insert wire details

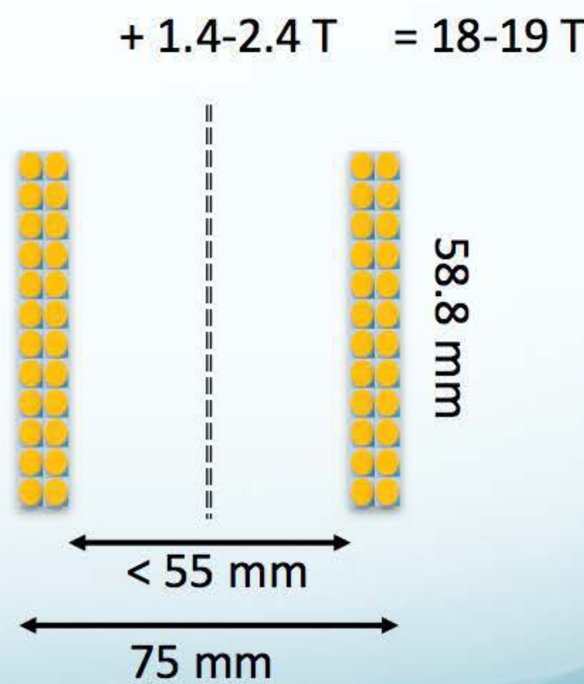
Coil 1 (Q2 2018)

- Wound form ~17 meters of CORC® wire
- I_{opp}(16 T) about 5,000 A
- J_e(20 T) about 250 A/mm^2
- Total of 48 turns in 4 layers
- Field generated 2.6 T in 14 T background

Coil 2 (After coil 1)

- Wound form 6-10 meters of CORC® wire
- Connected in series with Coil 1
- Goal is to generate 1.4-2.4T





Summary

Univ. of Colorado in-house cable test facility up and running

- Cable testing at up to 14.5 T and currents of 16 kA
- Mechanical testing up to 10,000 lbs, including cyclic loads

CORC® cables and wire performance

- In-house facility demonstrated J_e(20 T) = 400 A/mm² in 67 mm bending diameter
- J_e(20 T) = 600 A/mm² on the horizon
- CORC® cable joint resistance now < 100 nΩ at 76 K and < 10 nΩ at 4.2 K

CORC® cables and wires going into magnets

- Common Coil at Brookhaven Nat. Lab. (SIBR Phase I)
  - 500 A/mm² J_e(20 T) CORC® cable delivered
- CCT 5 T (self-field) magnet at Lawrence Berkeley Nat. Lab (SIBR Phase II)
  - CCT-C1 (2x 18 meters CORC® wire): completed and tested at 1.2 T
  - CCT-C2 (4x 18 meters): CORC® wire in production
  - CCT-C3 first order design ready
- Insert solenoid magnet at the ASC-NHMFL (SIBR Phase II)
  - Coil 1 design complete: I_{app} (16 T) = 5 kA
  - CORC® wire design complete and tested (J_e (20 T) = 250 A/mm²)
  - Coil test anticipated Q2 2018 (magnet pit needs digging!)