US MDP Bi-2212 Canted-Cosine-Theta (CCT) magnets at LBNL

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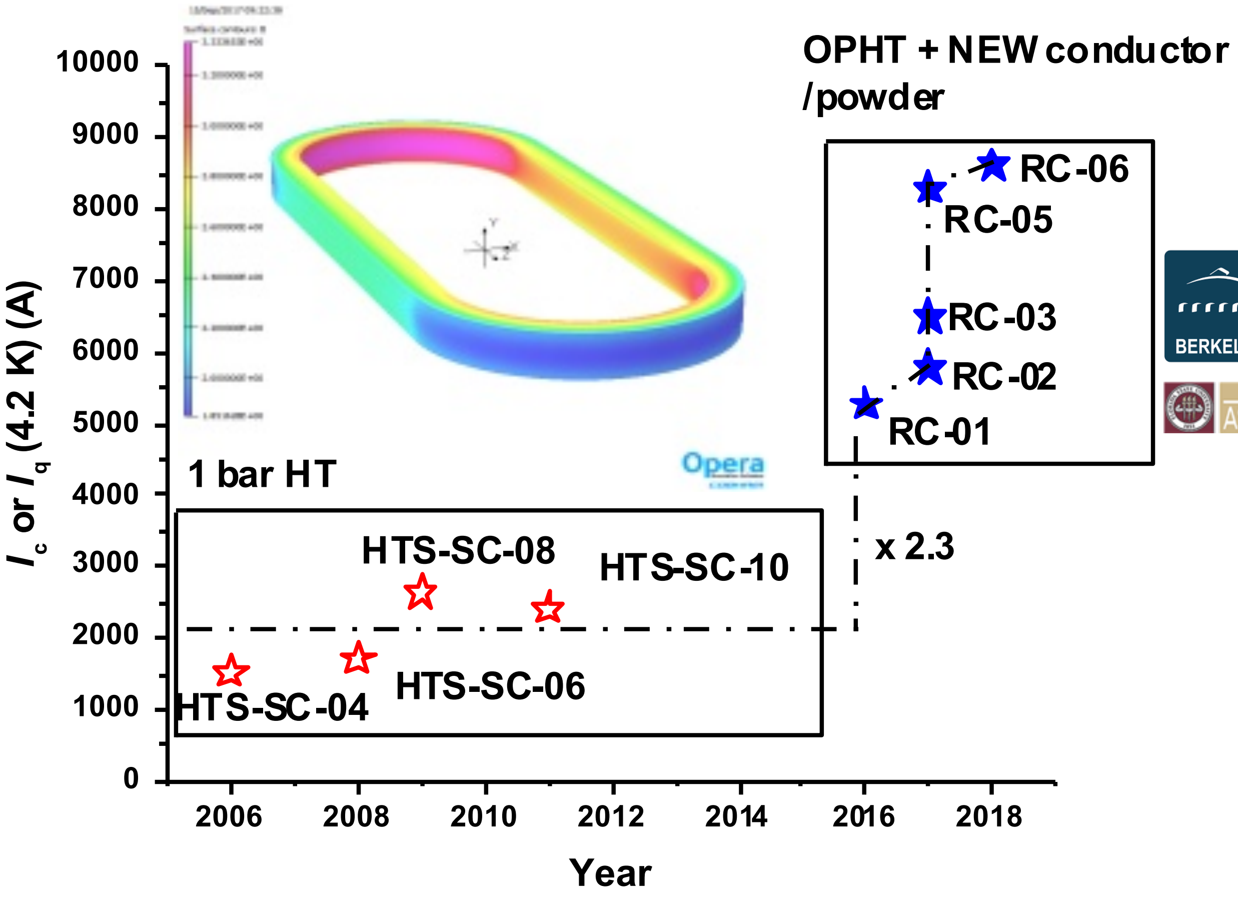
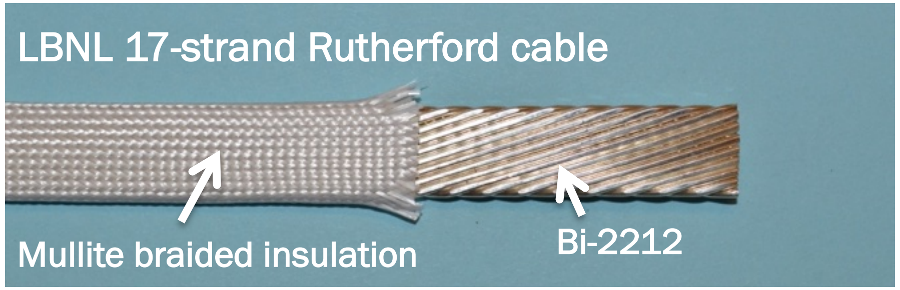
For the LBNL Supercon group and the US MDP 2212 WG
2024/04/30

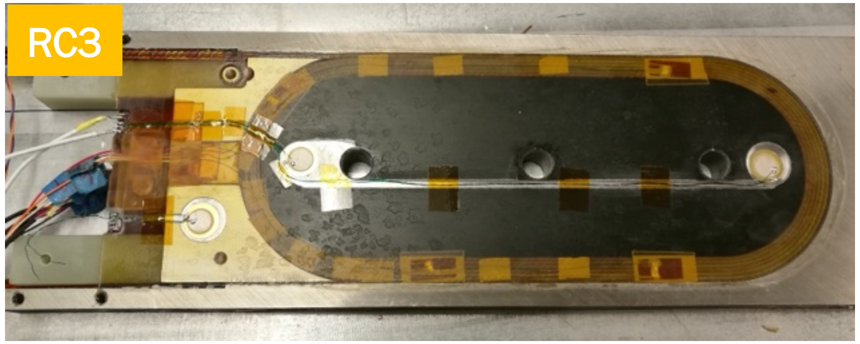
Outline

- **Bi-2212 is the only multifilamentary, round wire HTS conductor with high critical current carrying capability above 20 T.**
- **A short history of Bi-2212 magnets at LBNL: From VHFSMC to MDP**
- **The current program, status overview, challenges, lessons learned.**

(2015-2018): Single racetrack coils as a technology R&D vehicle for verifying heat treatment, materials compatibility, insulation, cable parameters

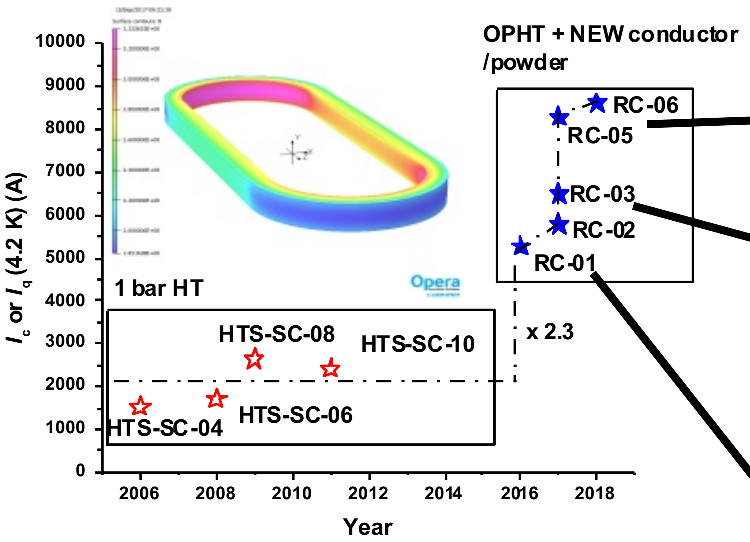


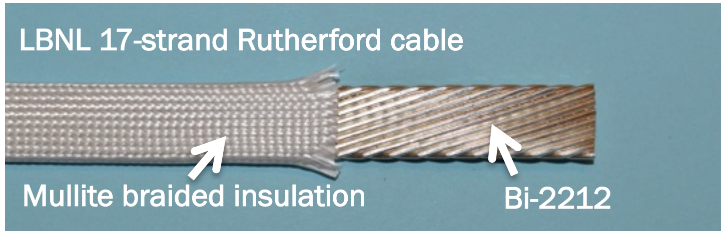


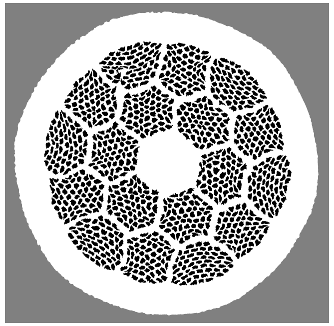


Shen et al., Scientific Reports volume 9, Article number: 10170 (2019)
Zhang et al Supercond. Sci. Technol. 31 105009 (2018)

(2015-2018): Single racetrack coils as a technology R&D vehicle for incorporating the best conductors available and benchmarking their coil performance

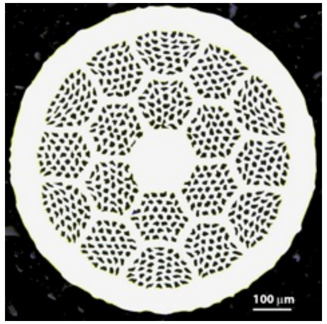




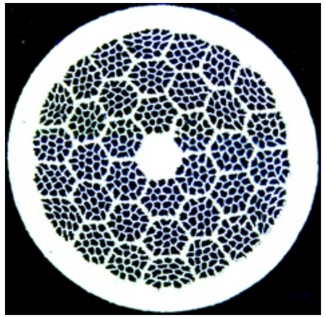


PMM170123, 55x18, nGimat powe LXB-52

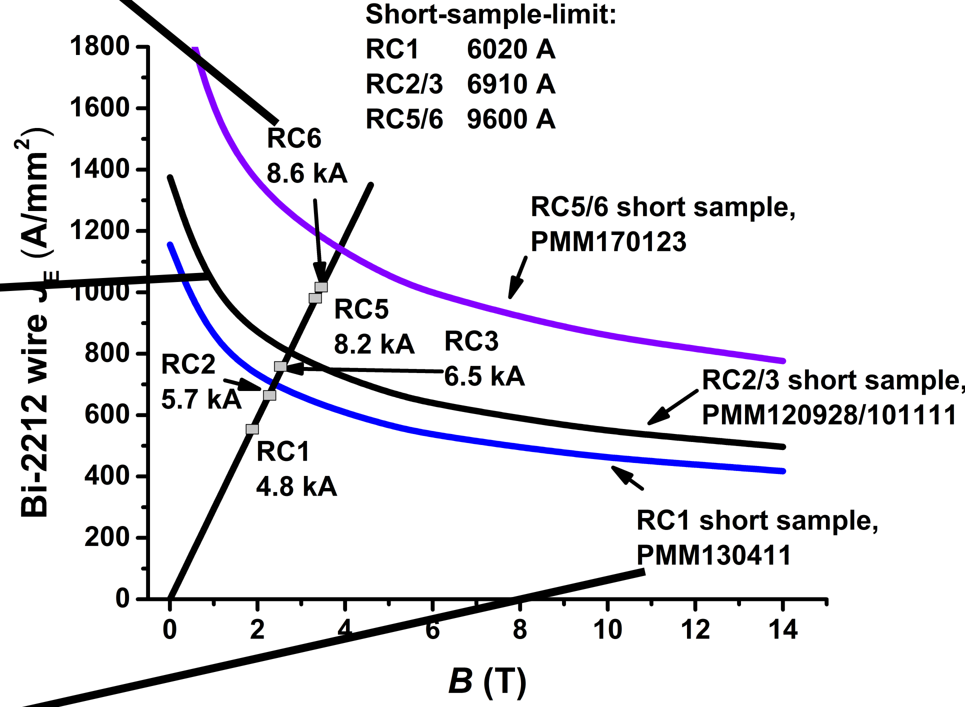
SBIR strand



PMM101111, 37x18, Nexans powd 77

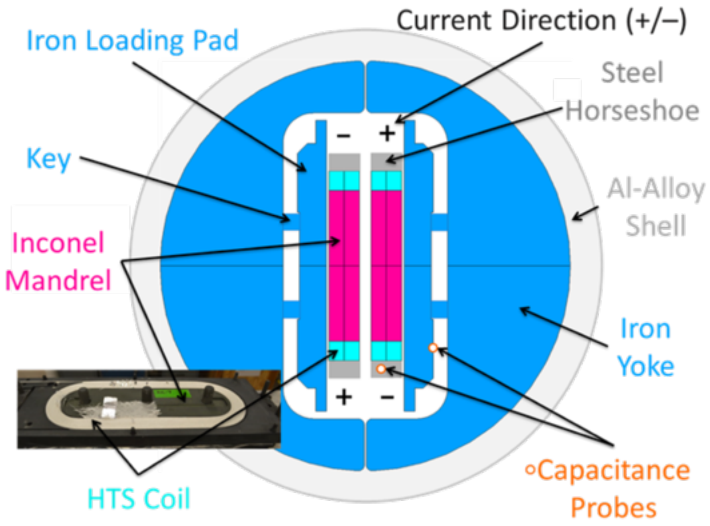


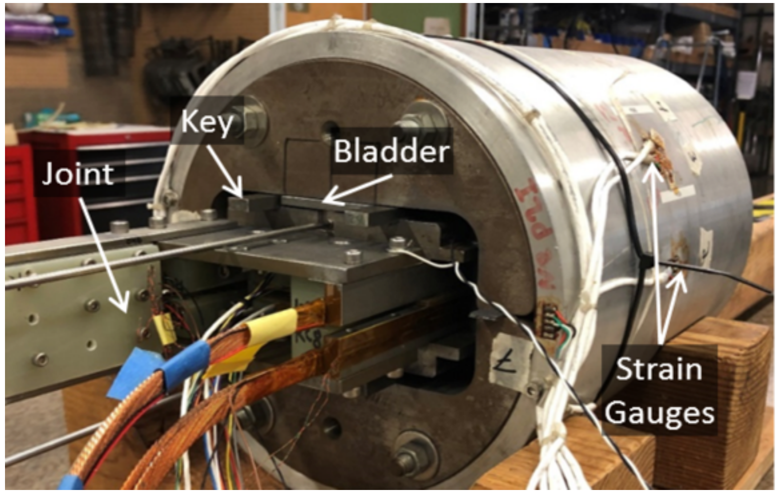
PMM130411 19x36, Nexans powder 77



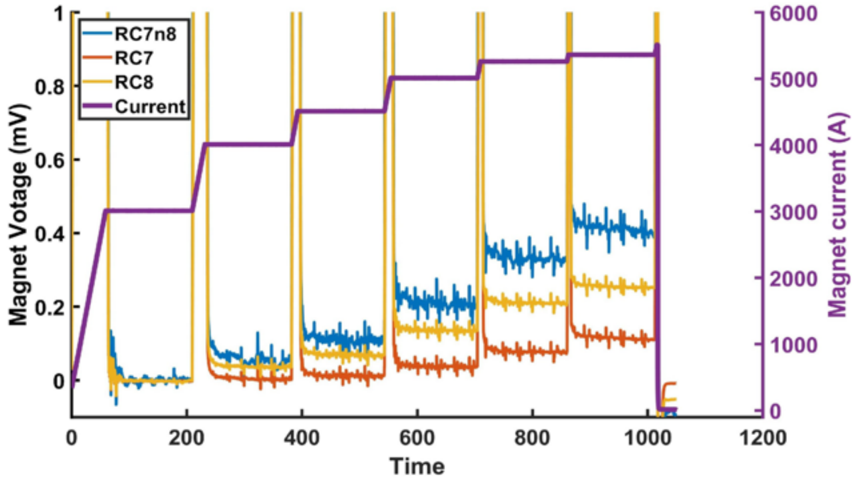
Shen et al., Scientific Reports volume 9, Article number: 10170 (2019)
Zhang et al Supercond. Sci. Technol. 31 105009 (2018)

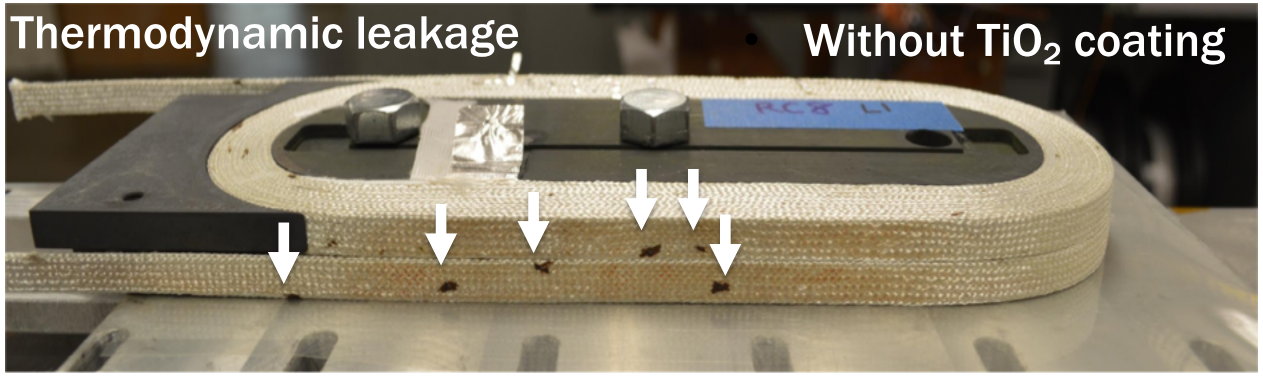
(2015-2018): A 4.7 T common coil dipole magnet (without a clear bore)

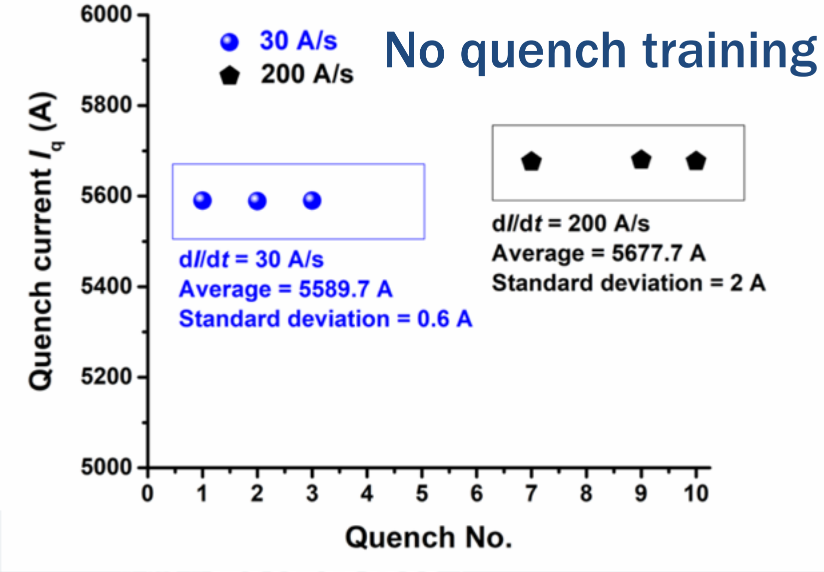




Precursor for predicting incoming quench

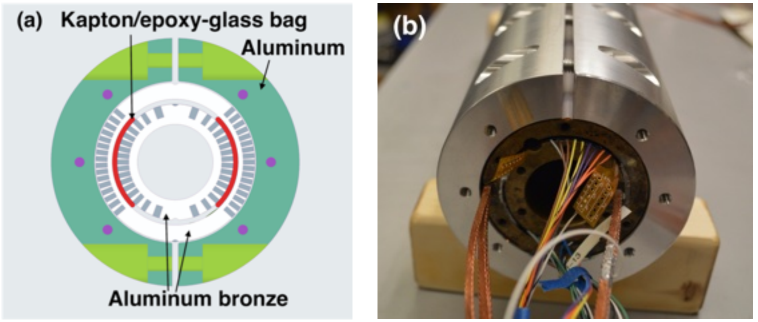






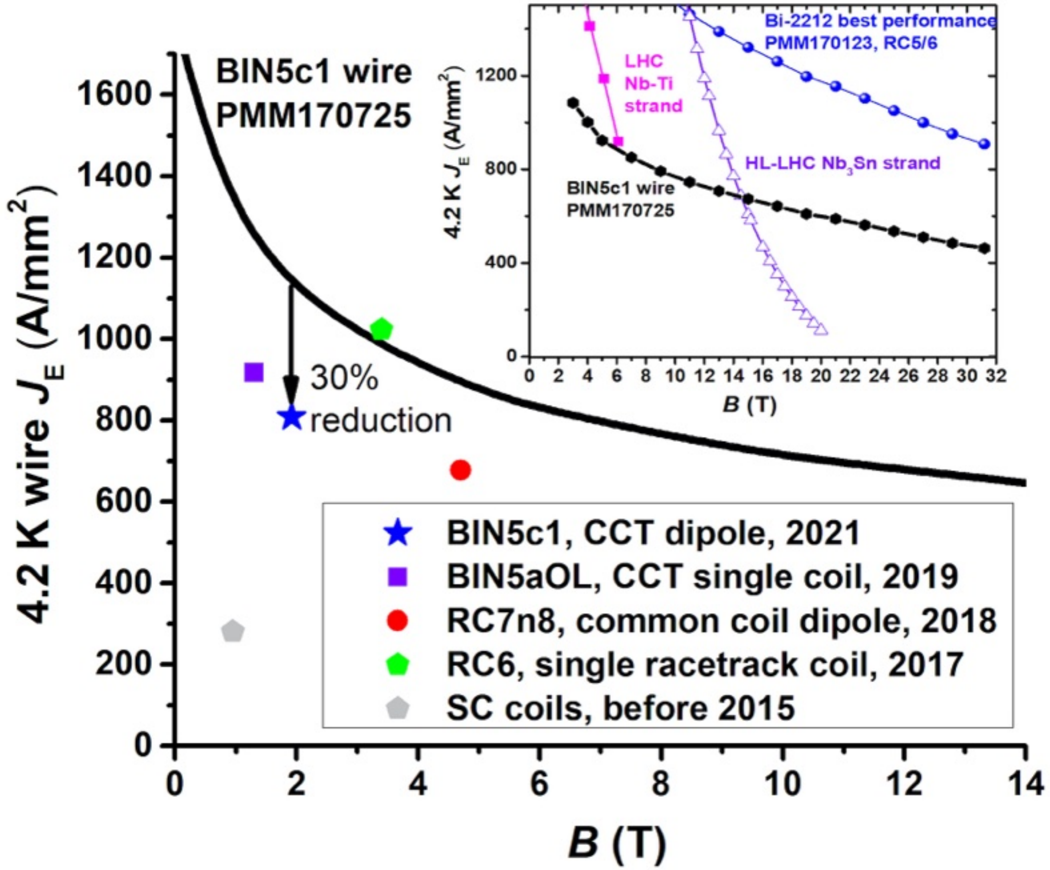
D. Davis, PhD thesis.

(2019-2022) Subscale Bi-CCT coils and the first Bi-2212 dipole magnet with bore (1.64 T, 31 mm bore)



- Material compatibility with 954 Al-bronze mandrel
- Methods of winding and insulating with TiO_2 and mulltie sleeve insulation
- 9-strand Rutherford cable, 4.0 mm x 1.44 mm, with 0.8 mm strands twisted during cabling
- No quench training. No degradation due to quenches or thermal cycles.
- Only 40 cm long.
- A technology R&D vehicle and useful for verifying performance of new SBIR conductors.

- 15-30% J_c gap from strand to coil



Bi-2212 CCT magnet development overview

Needs hybrid magnet test facility (R. Teyber talk)

BIN5/CCT5 hybrid

BIN5
2.4T SSL standalone

- 8 coils made

Bi-CCT1
~5T SSL standalone

- 3 coils wound

Bi-CCT2
~7.3T SSL standalone

- Cable to be fabricated

Bi-CCT1/CCT6 hybrid

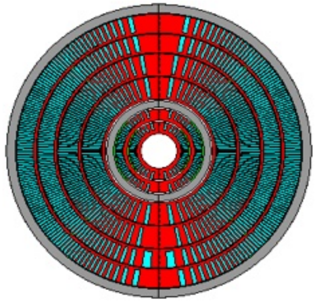
Bi-CCT2/CCT6 hybrid

1m long. Needs RENEGADE (D. Davis talk)

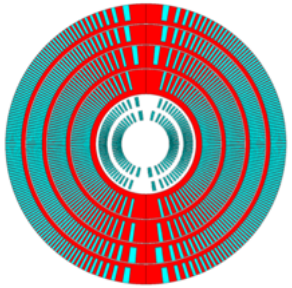
Cable design:

	Strand dia (mm)	Cable dimensions (mm x mm)	No. Strands
BIN5	0.8	4 x 1.4	9
Bi-CCT1/RC	0.8	7.8 x1.4	17
BI-CCT2	1	12 x 1.8	22 or 23

CCT6-Bi-CCT1



CCT6-Bi-CCT2

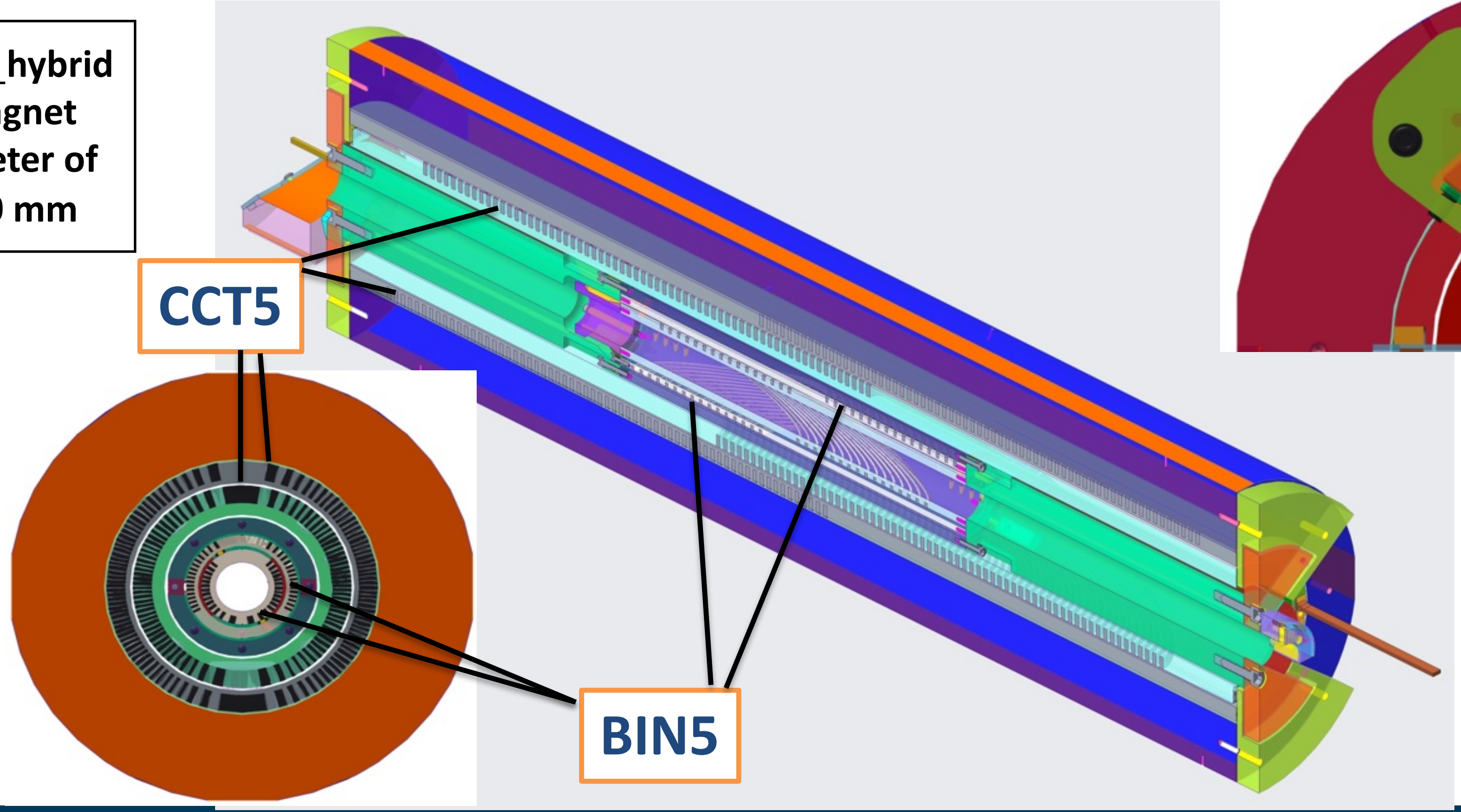


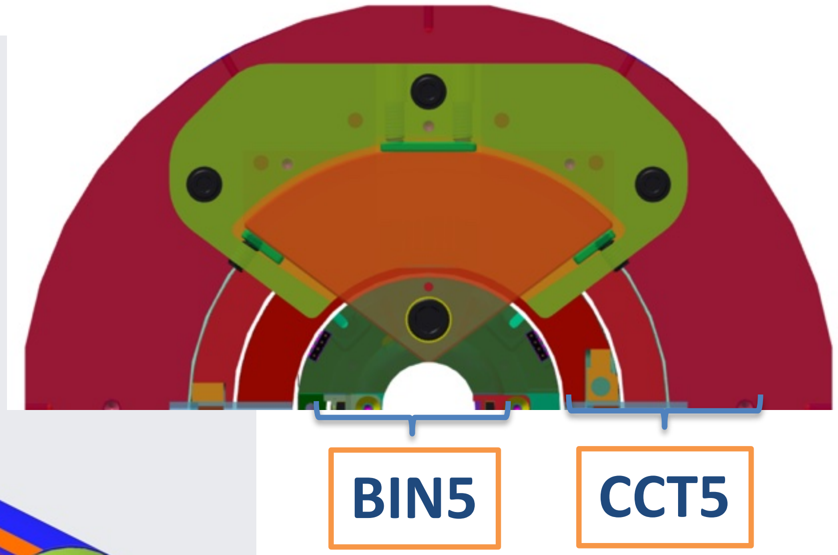
Science of strand/cable/coil fabrication
Improve/optimize magnet design

Further design and analysis of CCT5-BIN5 hybrid magnet

- LBNL (hybrid) magnet test facility upgrade with a hybrid magnet header and two power circuits (R. Teyber talk)
- BIN5 insert assembly ready.

CCT5/BIN5c hybrid dipole magnet
Bore diameter of CCT5 is 90 mm

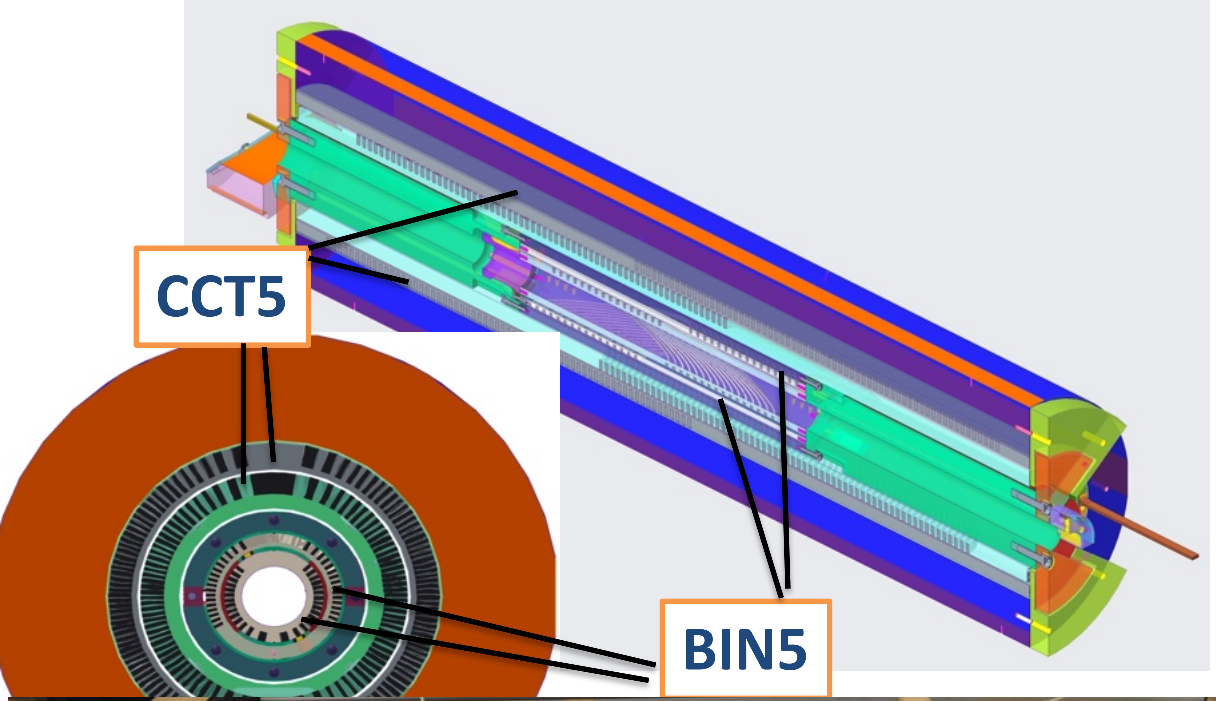


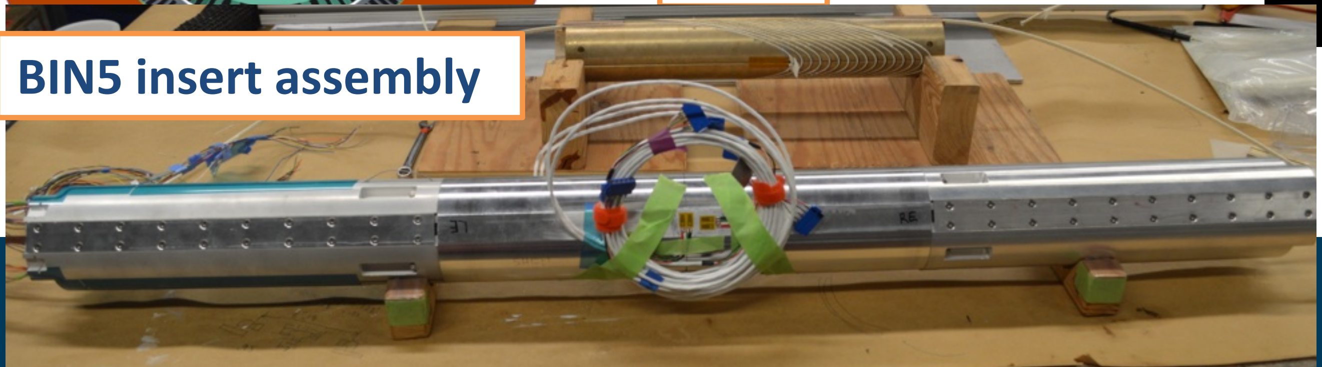


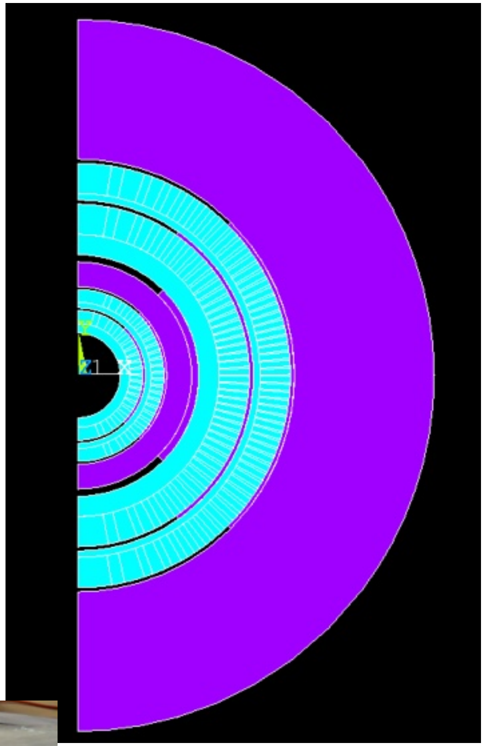
Mechanical integration of BIN5 and CCT5 and handling of special events

CCT5/BIN5c hybrid dipole magnet

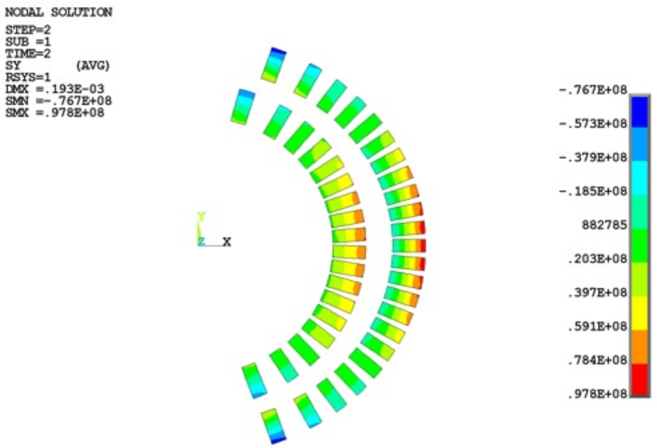
- CCT5 or CCT5w?
- Add smart shim between CCT5 and BIN5?





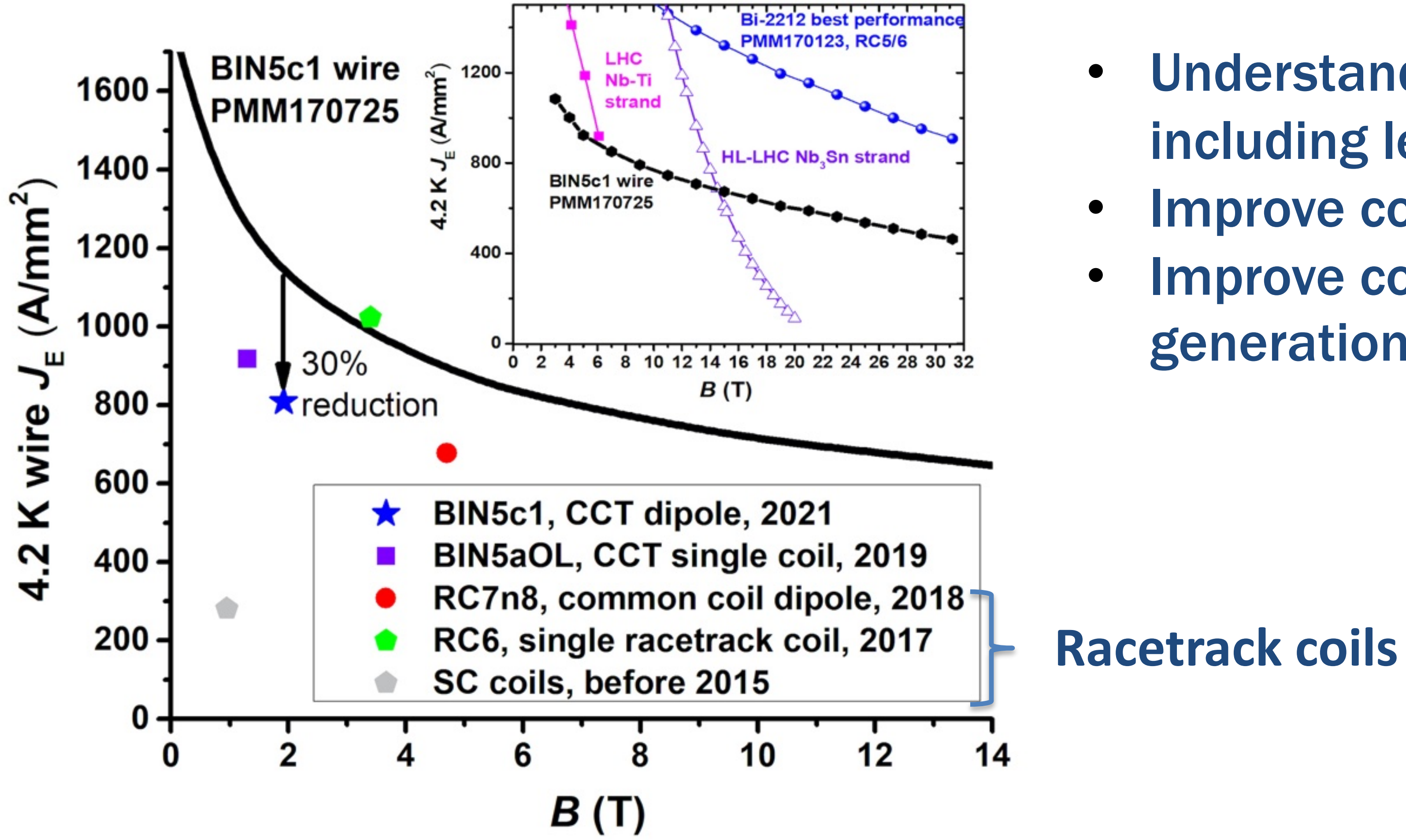


1) Eddy current during quench protection & force analysis, L. Brouwer
2) Mech safety analysis by LG Fajardo
3) Hybrid stress analysis, D. Arbelaez



Peak azimuthal stress during energization
- 98 MPa with smart shim.

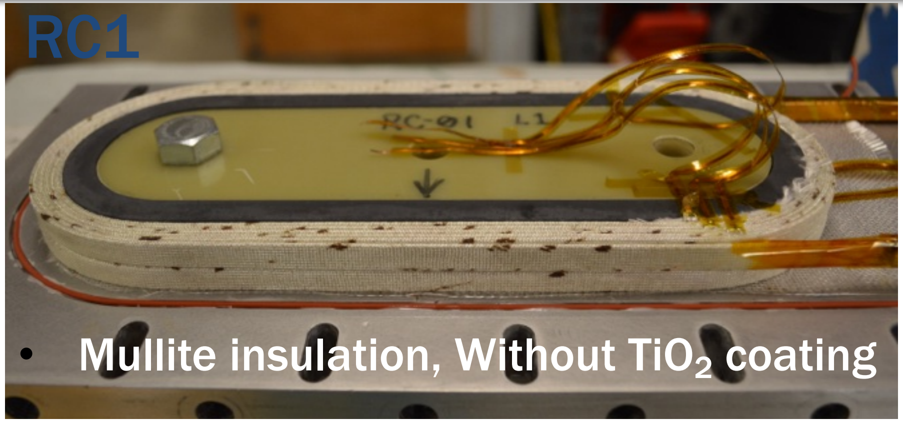
Back to this plot - how to further improve magnet performance?



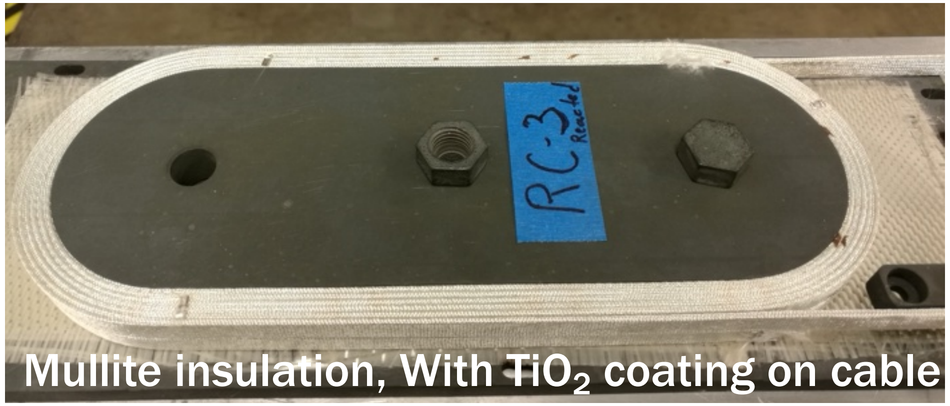
- Understand and remove sources including leakage.
- Improve conductor performance.
- Improve coil fabrication and field generation efficiency.

Leakage observation – racetrack coils

RC1

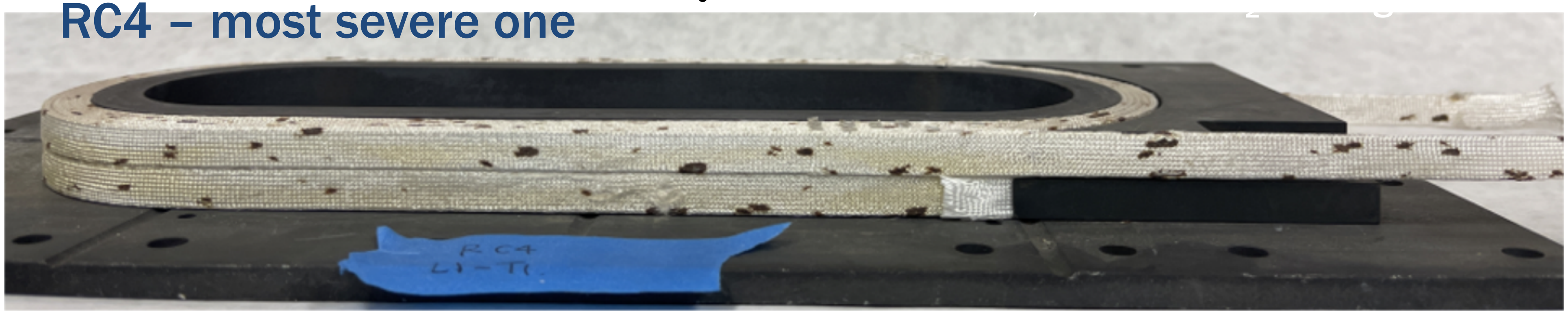


- Mullite insulation, Without TiO_2 coating



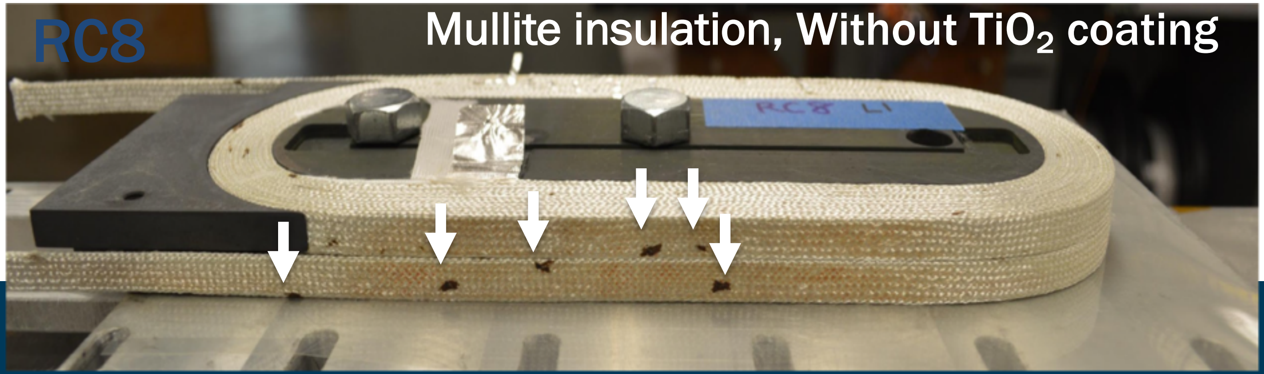
Mullite insulation, With TiO_2 coating on cable

RC4 – most severe one



RC8

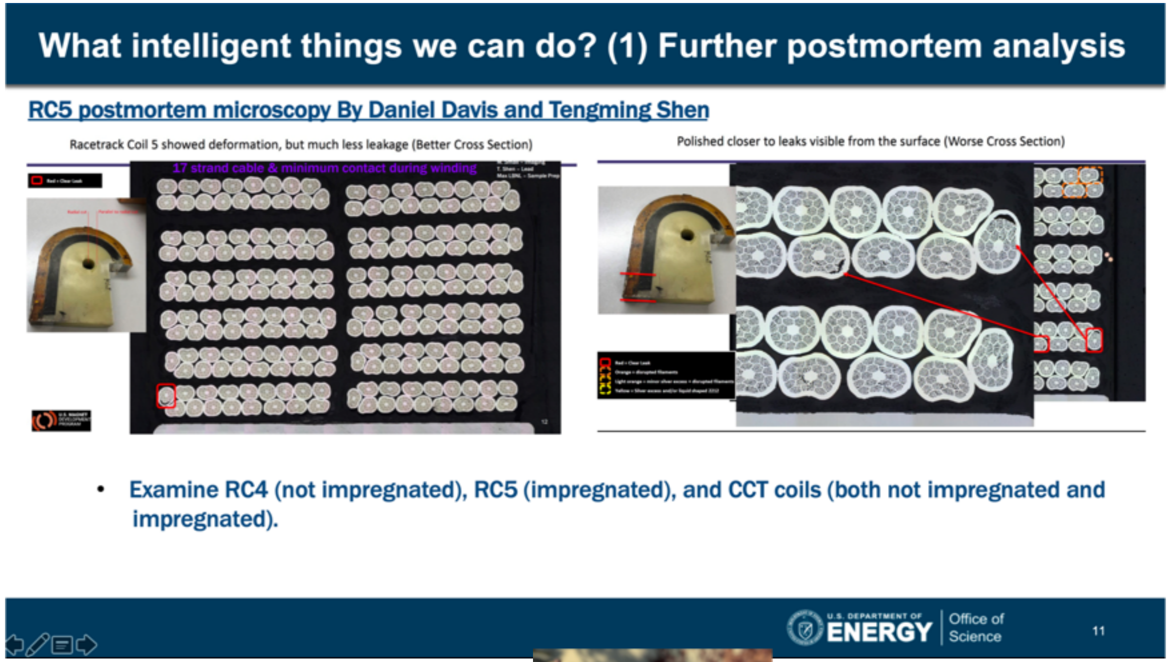
Mullite insulation, Without TiO_2 coating



Questions towards leakage

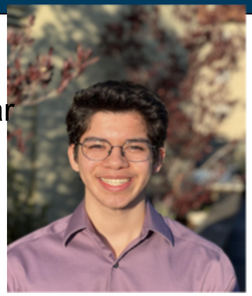
- OPHT was expected to remove leakage. Indeed this is the case in the round strand solenoids.

- Why leakage in OPHTed, Rutherford cable coils?
- How much an impact does it make in reducing coil performance?
- What is the extensiveness of the leakage in CCT coils where each cable is encased in a mandrel?



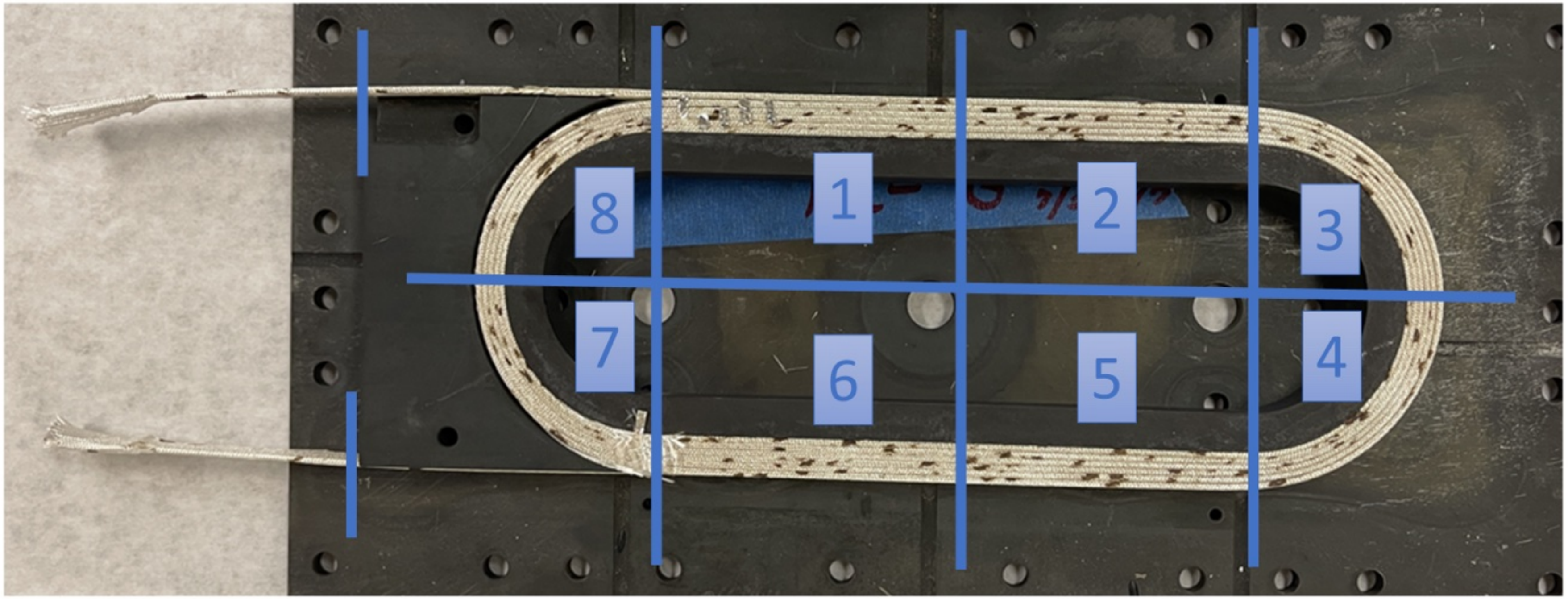
Jean-Francois Croteau, Chris Escobar

Chris Escobar, UC Berkeley engineering, undergraduate



Leakage observation in a racetrack coil (RC4)

Dissection details

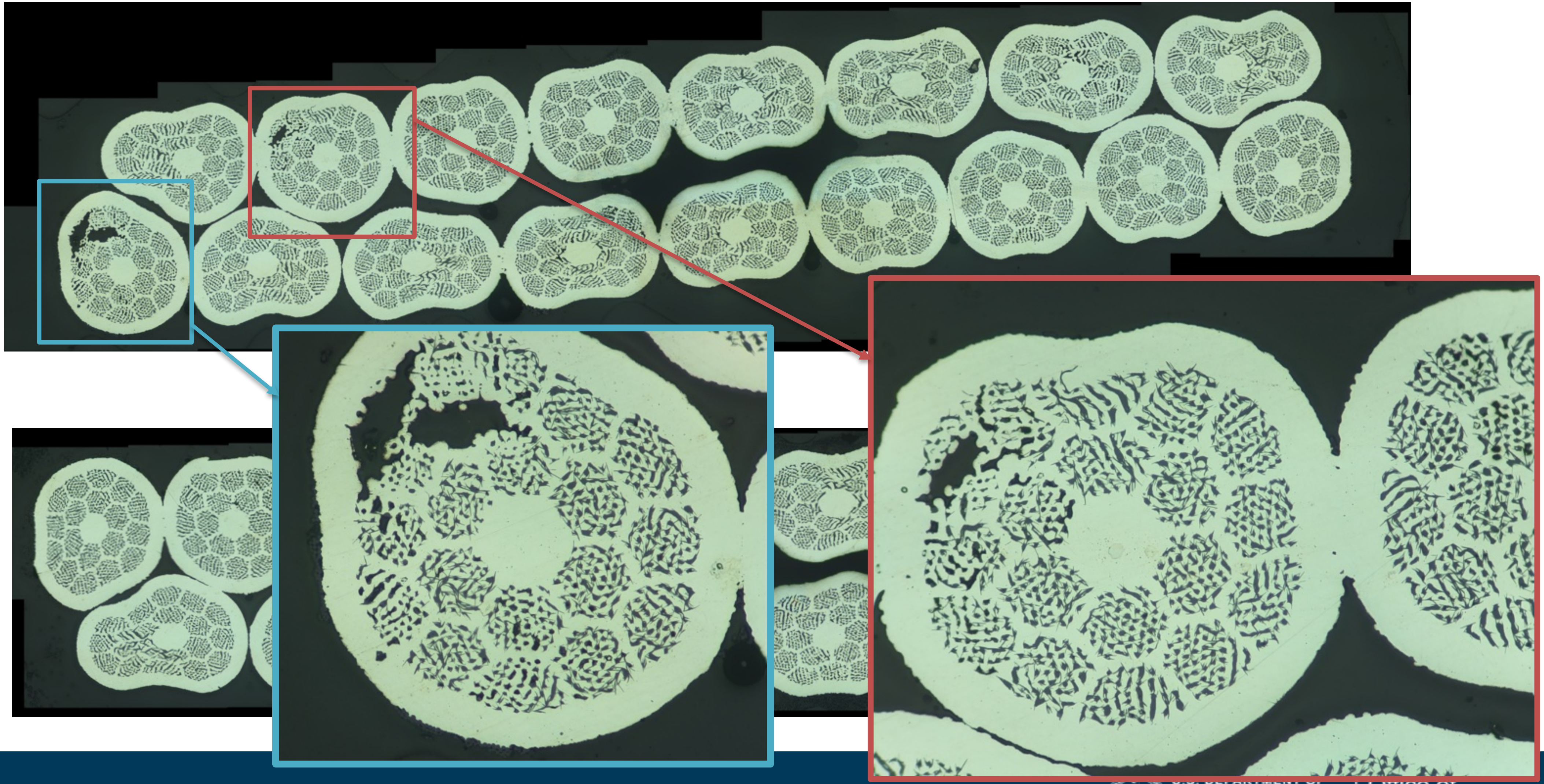


Coil cut along blue lines as shown above. It was cut into 8 segments and the leads, which extend to the left, were cut in half and labeled separately.

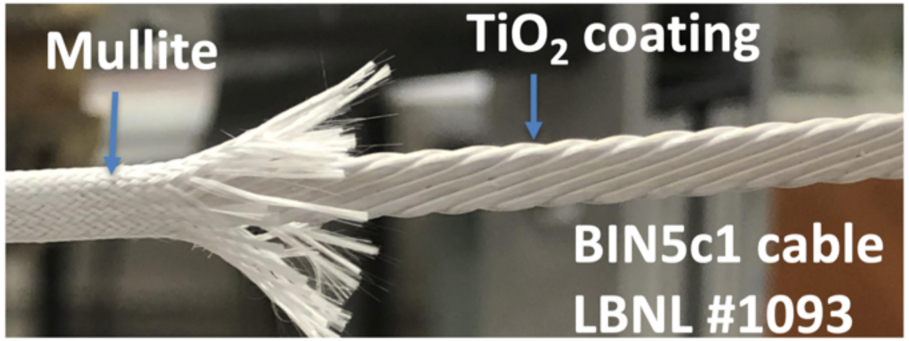
Leakage observation in a racetrack coil (RC4)

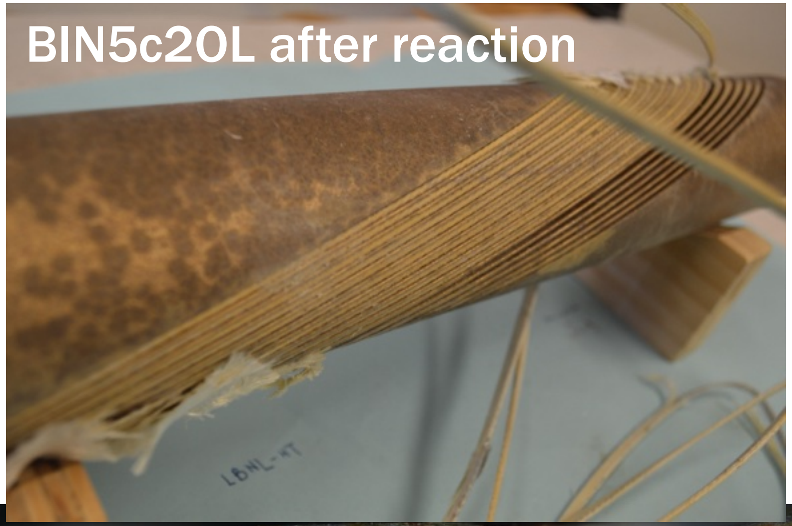
L1-T6-2

Jean-Francois Croteau, Chris Escobar



Leakage observation in a CCT coil (CCT BIN5c2OL)





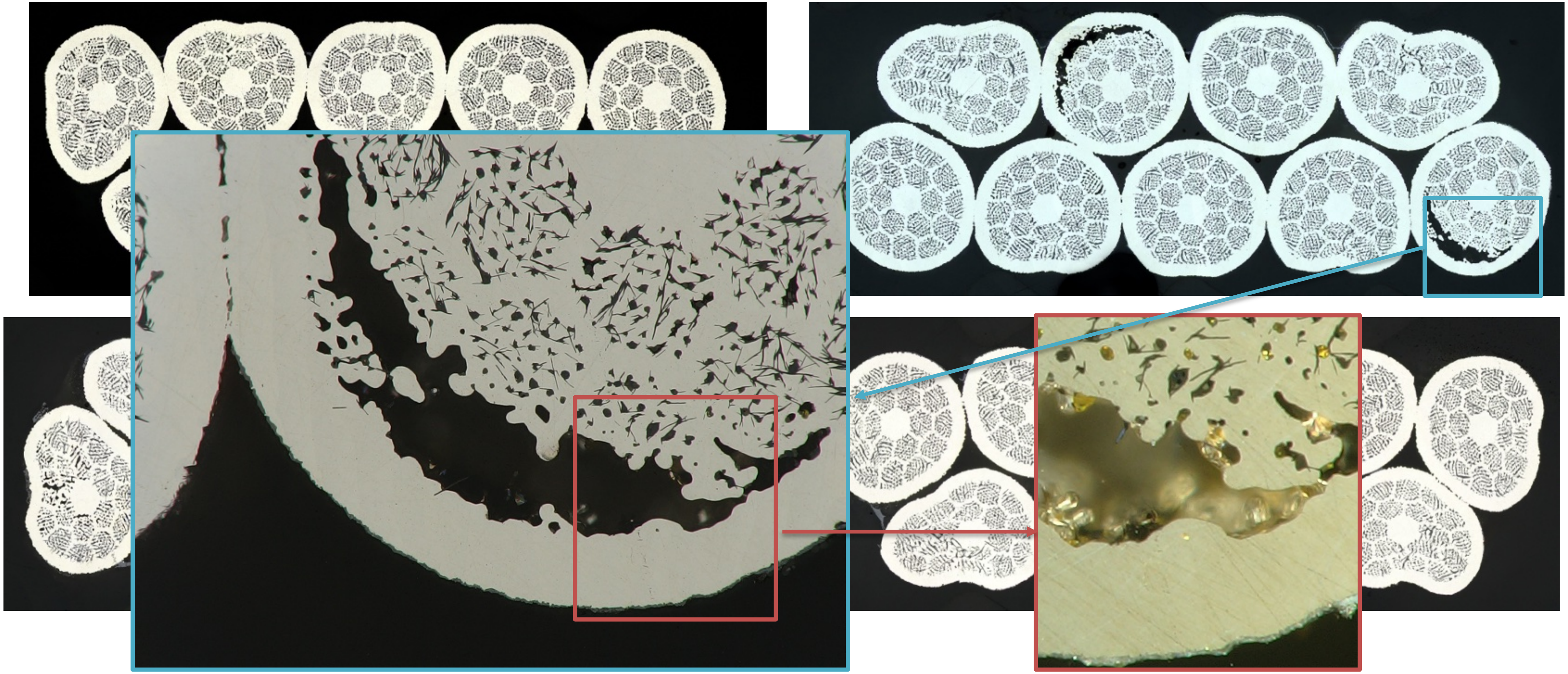
Cable broad face

Jean-Francois Croteau, Chris Escobar

Cable edge

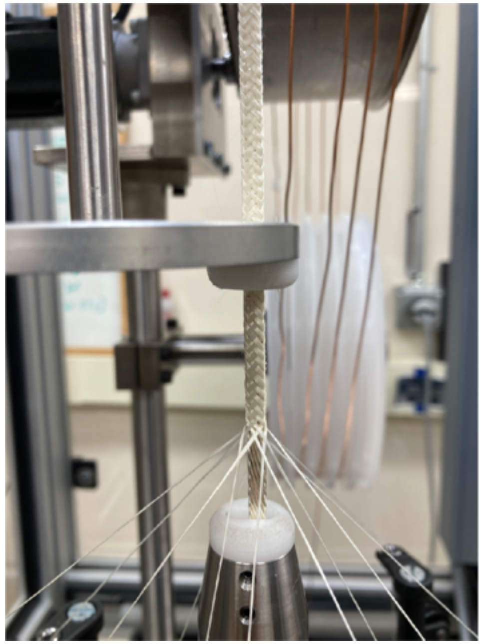
Leakage observation in a CCT coil to quantify its impact

Jean-Francois Croteau, Chris Escobar



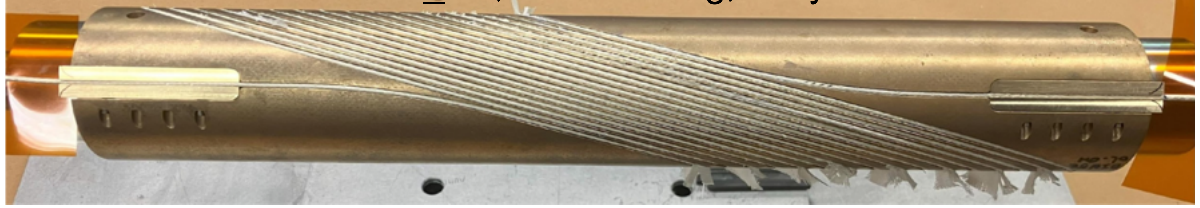
A new CCT coil with new insulations (pure alumina, BIN5E) has been wound

- **Coil fab additionally supported by ARDAP.**
- **Wound. Reaction soon.**
- **Will serve as a backup to BIN5C.**



By Youngjae Kim, FSU et al.
FSU task led by D. Davis

ARDAP CCT coil BIN5E_OL, after winding, not yet reacted.



- CCT ARDAP coil BIN5E:
  - Outer layer coil wound. No electrical shorts.
  - Have to use TiO_2 slurry to “repair, reinforce and lubricate” alumina fibers.

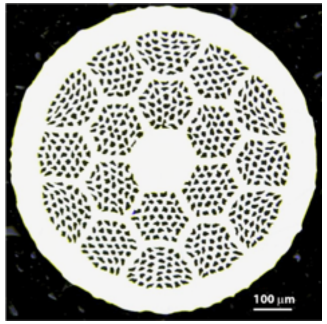
- CCT ARDAP coil BIN5E:
  - Inner layer coil wound. No electrical shorts.
  - NEW: Use **Al_2O_3 slurry** to “repair, reinforce and lubricate” alumina fibers. (courtesy of Dr. Jun Lu, NHMFL)

A fast-turnaround experiment to check various hypothesis and test methods of removing leakage

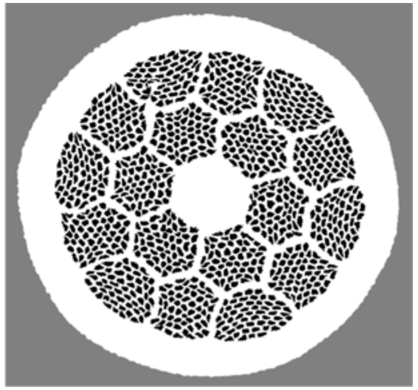
Insulation scenarios for Bi-2212 Rutherford cable CCT coils

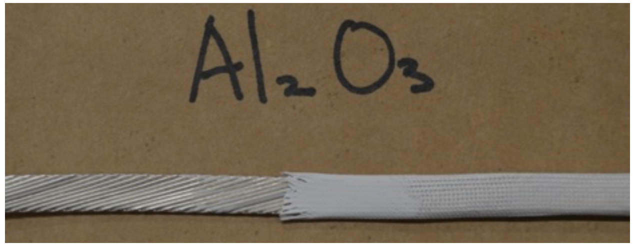
Scenerios	Coating on Bi-2212 cables	Painting on insulation sleeves	Insulation sleeves
1	TiO_2	No	No sleeves
2	No	No	Mullite (2Al2O3 - SiO2)
3	No	No	Pure alumina
4	TiO_2	TiO_2	Mullite (2Al2O3 - SiO2)
5	Al_2O_3	Al_2O_3	Mullite (2Al2O3 - SiO2)
6	TiO_2	TiO_2	Pure alumina
7	Al_2O_3	Al_2O_3	Pure alumina
8	Other	Other	Pure alumina/mullite

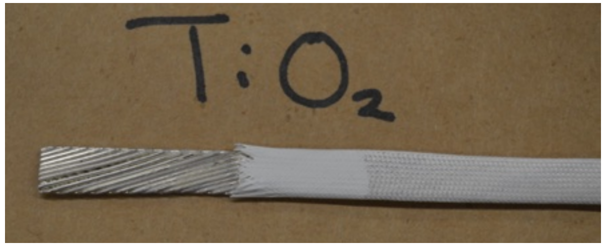
37 x <u>18</u>



55 x <u>18</u>







- Does leakage in Rutherford cable coils reduce in conductors with thicker Ag-Mg alloy like 1.0 mm diameter strands? (E. Barzi)

Summary/next steps

- Long length Bi-CCT1 coils await for RENGEGADE facility @ NHMFL.
- Bi-CCT2 (small bore, 12 mm wide cable) cable fabrication is moving forward and fabrication tests will be conducted to finalize the design.
    - Improve understanding of science of achieving high J_c in Bi-2212 Rutherford cables. (ARDAP talk)
- BIN5 is ready to be assembled into CCT5 to be tested as a CCT5/BIN5 hybrid in coming months. Back up BIN5E coils fabricated with new pure Alumina insulation.
- Improve understanding of the leakage with analysis of both racetrack coils and CCT coils, and a dedicated tester is started.

Coming next

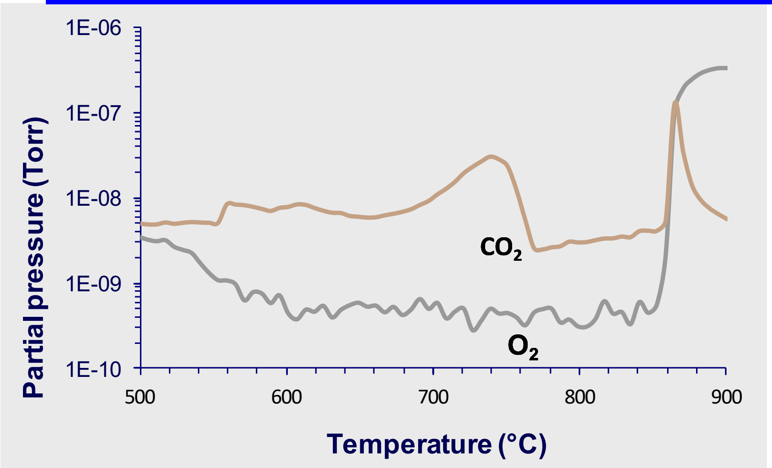
Thank you for members of MDP 2212 WG and international collaborators.

Status of Bi-2212 CCT magnets *Alvin Tollestrup Auditorium , IARC*	*Tengming Shen* 10:45 - 11:05
Status of Bi-2212 SMCT magnets *Alvin Tollestrup Auditorium, IARC*	*Alexander Zlobin* 11:05 - 11:25
Commissioning the RENEGADE overpressure processing furnace *Alvin Tollestrup Auditorium, IARC*	*Daniel Davis* 11:25 - 11:45
Status of Bi-2212 solenoid magnet development including cable solenoids *Alvin Tollestrup Auditorium, IARC*	*Daniel Davis et al.* 11:45 - 12:00
Transverse pressure dependence of Bi-2212 Rutherford cables *Alvin Tollestrup Auditorium, IARC*	*Anna Kario* 12:00 - 12:20
An ARDAP Project on Enhancing Domestic Production of Bi-2212 wires for High Field Magnets *Alvin Tollestrup Auditorium, IARC*	*Tengming Shen* 12:20 - 12:35
Addressing test challenges and conductor needs *Alvin Tollestrup Auditorium, IARC*	*Emanuela Barzi* 13:20 - 13:30
Highlights of LTSW2024 Bi-2212 session (David Larbalestier) *Alvin Tollestrup Auditorium, IARC*	*David Larbalestier* 13:30 - 13:45

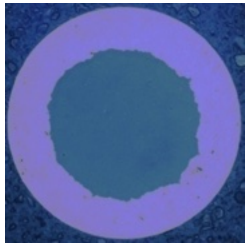
- **Canted-Cosine-Theta**
- **Stress Management Cosine-Theta**
- **A crucial facility.**
- **International collaboration.**
- **A key technology question.**
- **New conductor science and advances.**

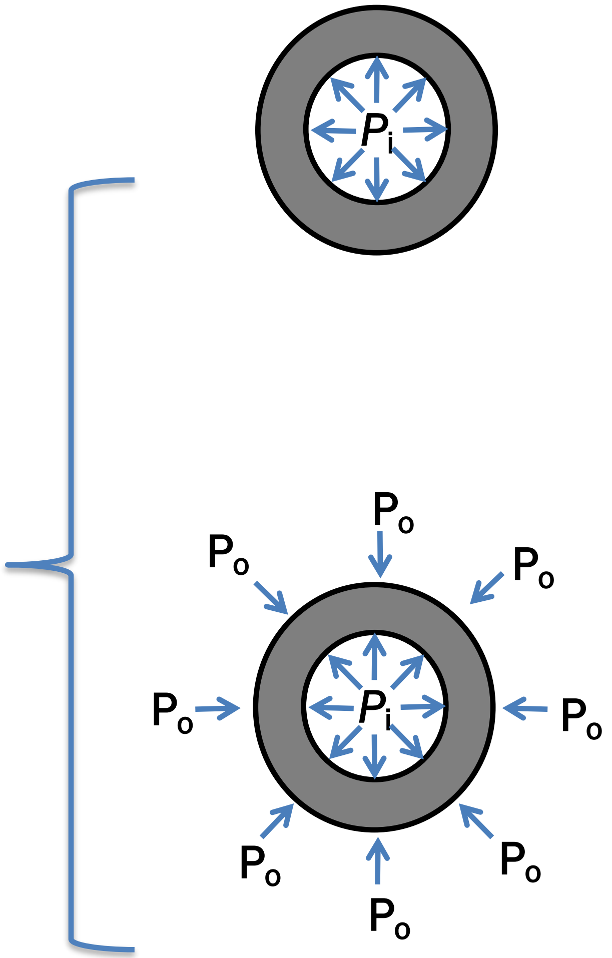
What causes ceramic leakage?

Gas species detected by a residual gas analyzer while heating Bi-2212 wires at 180 °C/h in vacuum.



Like a pressure vessel at high-temperatures.





Conventional 1 bar heat treatment

Ag creeps outward -> creep rupture of Ag-Mg

Overpressure processing

Ag creeps inward -> densification