Collaborative capabilities of the ASC/NHMFL for the Development of HTS Fusion Technologies

INFUSE Innovation Network for Fusion Energy

The ASC is a Division of the National High Magnetic Field Laboratory, a National User Facility with the highest DC fields in the world (45 T) in a hybrid superconducting and resistive magnet pair.

David C Larbalestier

on behalf of the Fusion Team at FSU (PIs DCL, Tak Kametani and Lance Cooley (Teaching Faculty in the FAMU/FSU College of Engineering) are supported by DOE-OFES and by PPPL – our laboratories are in the National High Magnetic Field Laboratory, Florida State University, Tallahassee, FL, USA

Key Themes – we are an academic education and research program

- Our central thrust is to develop HTS conductor AND magnet technology in an integrated manner in an academic environment training students and postdocs (recent PhDs Maxime Matras CERN), Charlie Sanabria (LBL, now CFS), Michael Brown (Bruker-OST), Chris Segal (CERN), Dan Davis and Yavuz Oz (postdocs ASC-NHMFL)

- We emphasize both REBCO and Bi-2212 conductor and magnet technologies
  - REBCO R&D targets conductor characterization and UHF test coils (45.5 T world record)
  - Bi-2212 targets UHF lab and NMR magnet use and recently (in collaboration with LBL) Rutherford Cable test coils – driving a reliable conductor and reaction technology

- Many very unusual or unique testing capabilities
  - Large bore 14 T/160 mm bore superconducting (SC) magnet for 7 kA cable and magnet tests
  - Resistive small-bore magnet (31 T in 38 mm cold bore) for UHF coil tests
  - YateStar (in-field transport, in ∥ and ⊥ field with 2 cm resolution AND Hall Probe array
  - Multi-mode microscopies: Magneto-Optical, Light, Confocal, SEM, TEM

REBCO is present plan A for compact fusion but Bi-2212 may be better for rapid ramping central solenoids

Our 10 kA/160 mm bore 14 Tesla test facility (details below)

14 T - large bore - high current - LTS Test Bed

- 10 kA bus, 6 x 1.2 kA power supplies
  - Enables individual cable and cable magnet testing
- 128 ppm uncorrected homogeneity (1 cm DSV)

Goals

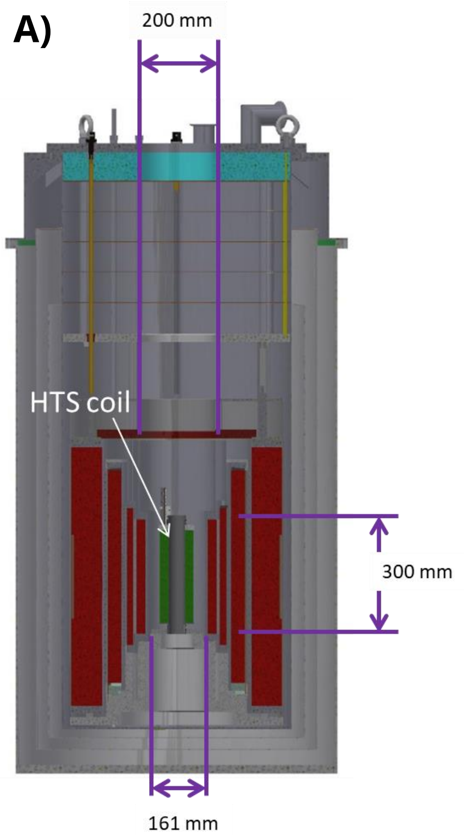
- To explore field generation and mechanical limits in strand-wound and cable wound coils
- To add additional means to improve field homogeneity (e.g., compensation coils, shims etc.)
- Implement novel HTS quench management

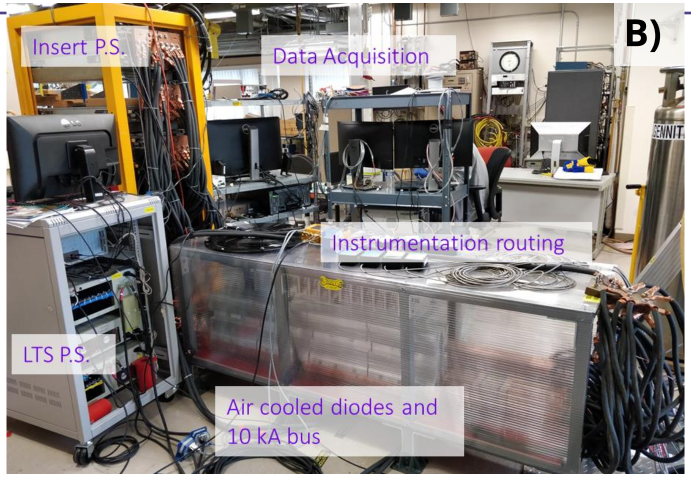
Quench Detection

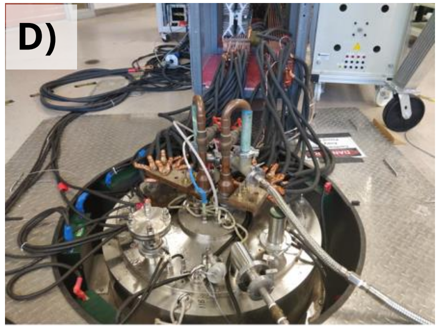
- Successfully implemented FPGA Control Program “QUENCH” : FPGA increases software quench detection speed down to 20 µs steps

Features:

- Signal filter, voltage threshold detection, contactor and P.S. shutdown capability, detection bypass (for p.s. startup voltage fluctuations or other predicted non-quench events)
- Implements real-time signal offset reduction (inductance compensation, signal drift) of quench voltage and current signals with no drop in the monitoring rate.







In operation: Baby-Ruth Test

A) Schematic of the 14 T LTS (red) magnet with a 200 mm probe access and a 161 mm cold bore for HTS insert (green); **B)** Picture of the LTS & HTS support systems; **C)** Picture of the 14 T magnet cryostat with external protection elements; **D)** Picture of the top plate of the 14 T magnet during HTS Bi-2212 Rutherford cable solenoid test.

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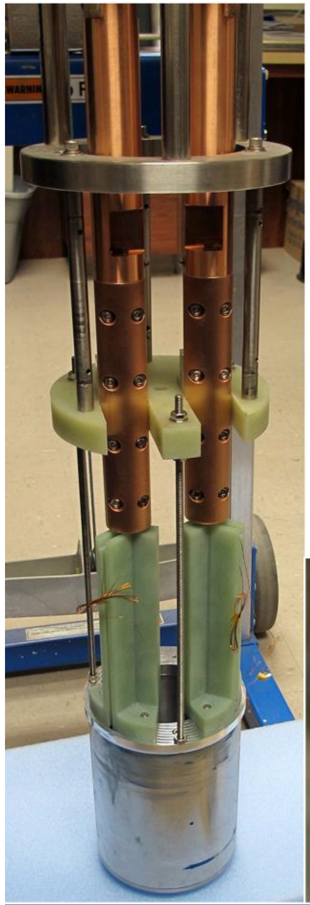
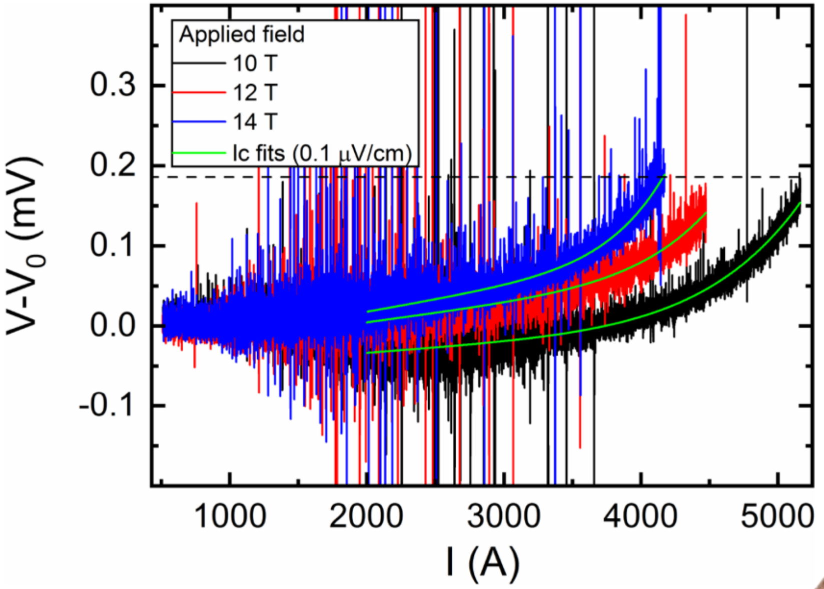
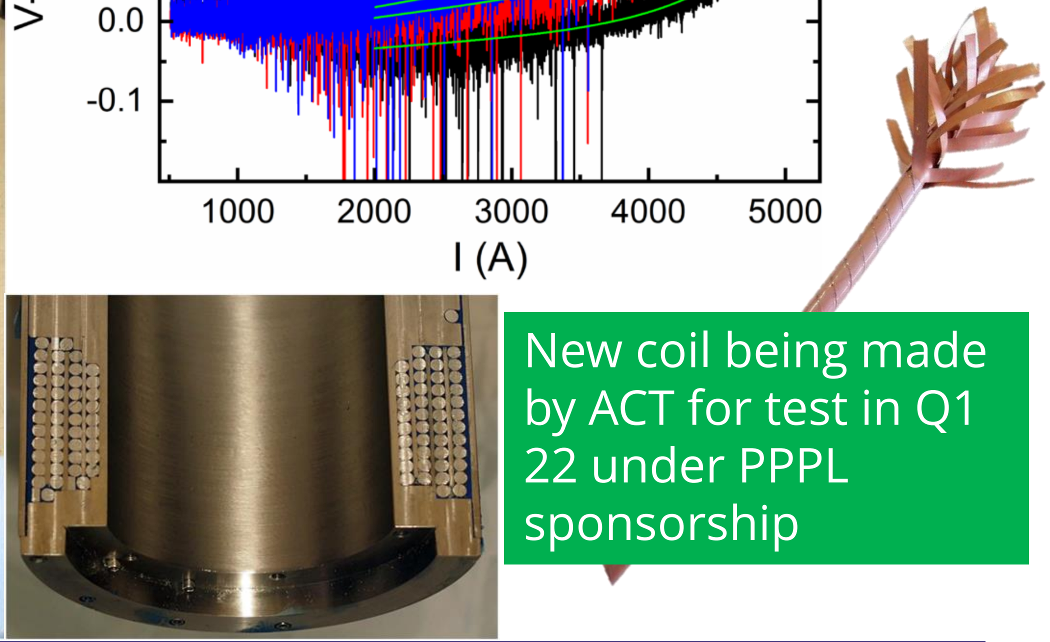
Both REBCO and Bi-2212 Cable solenoid coils have been tested – both firsts – some issues seen.....

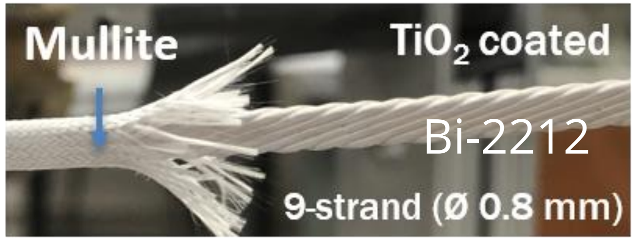


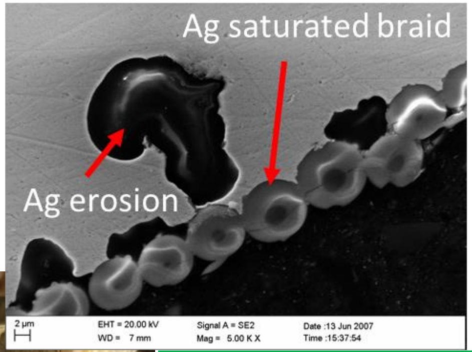


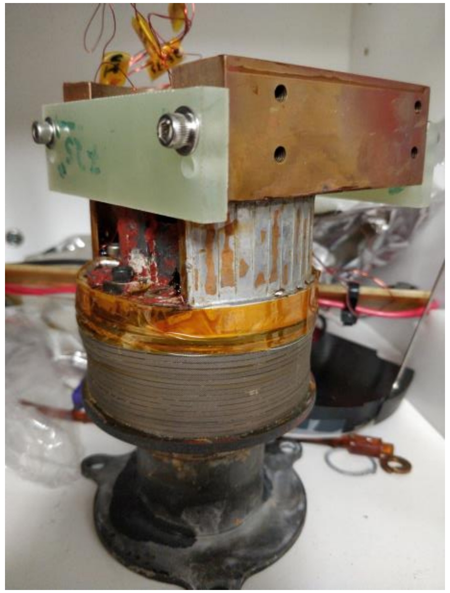


New coil being made by ACT for test in Q1 22 under PPPL sponsorship

CORC Cable Model Coil achieved 15.6 T total field – safely driven into the resistive transition (ACT-FSU SBIR collaboration)







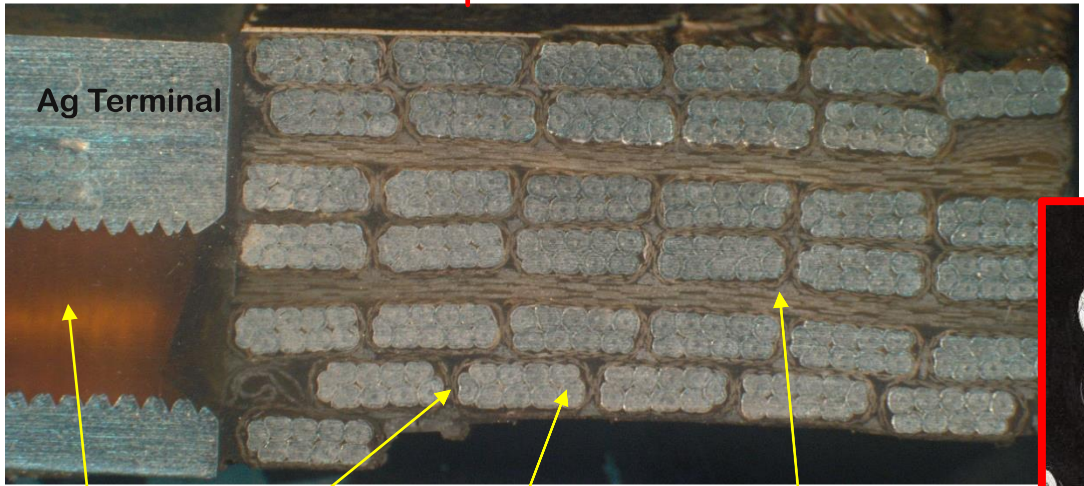
Ag reacts with alumino-silicate braid and causes erosion of the matrix material and promotes leakage – fix being developed

LBNL collaboration with Tengming Shen

Rutherford cable (9-strand) -
Conductor leakage after OPHT caused major loss of Ic (~40% of short sample, 1650 A, 440 A/s ramp rate, 1.6 T, in 8 T background,)

We Post Mortem our Coils – single strand and cables

Diamond Saw Cut - Unpolished Radial Cross-section

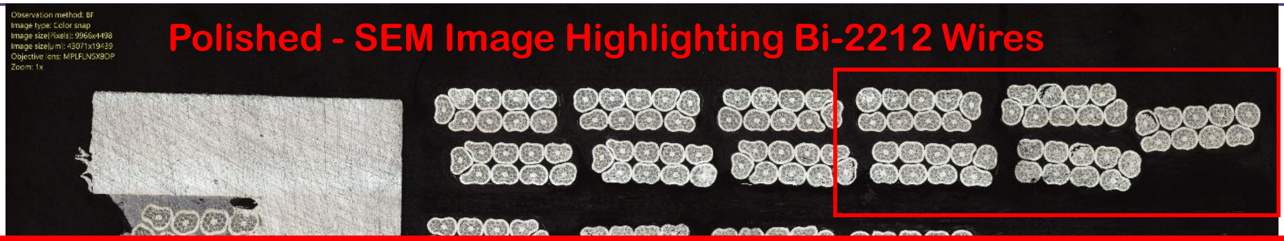


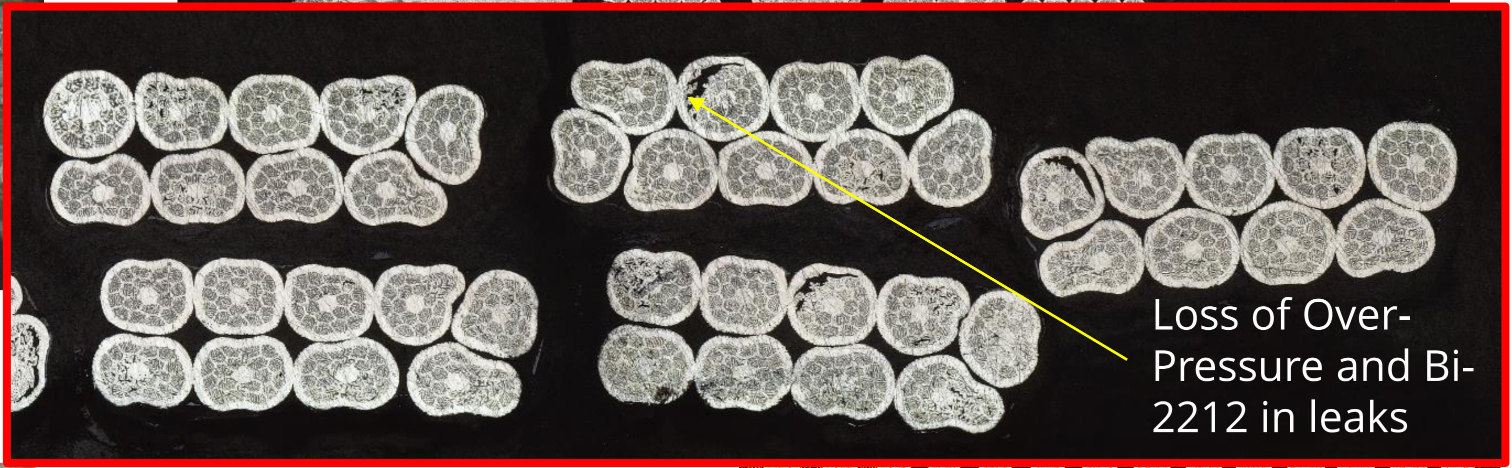
Glass-fiber filled epoxy

Insulation

Bi-2212 Rutherford Cable

Reinforcement



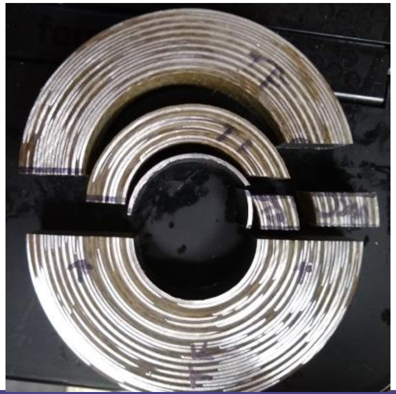


Diamond Saw Cut – Azimuthal Cross-section

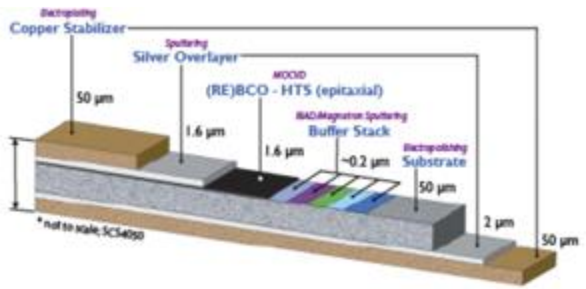
Unpolished

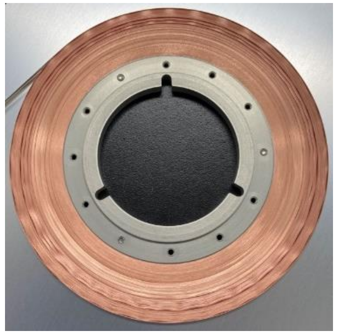
Polished

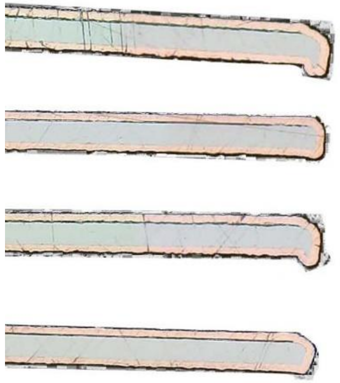
Single-strand Solenoid – Pup-9

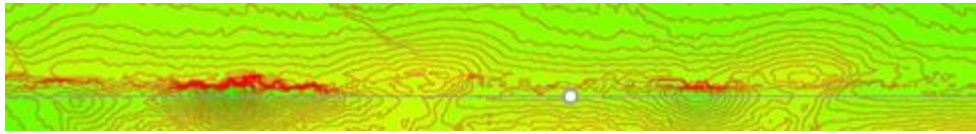


REBCO conductor: do we really know Jc(H,Θ,T) where you need to? NO! Is it stable with length? NO! Are the dimensions stable? NO! Are there defects from slitting? YES!



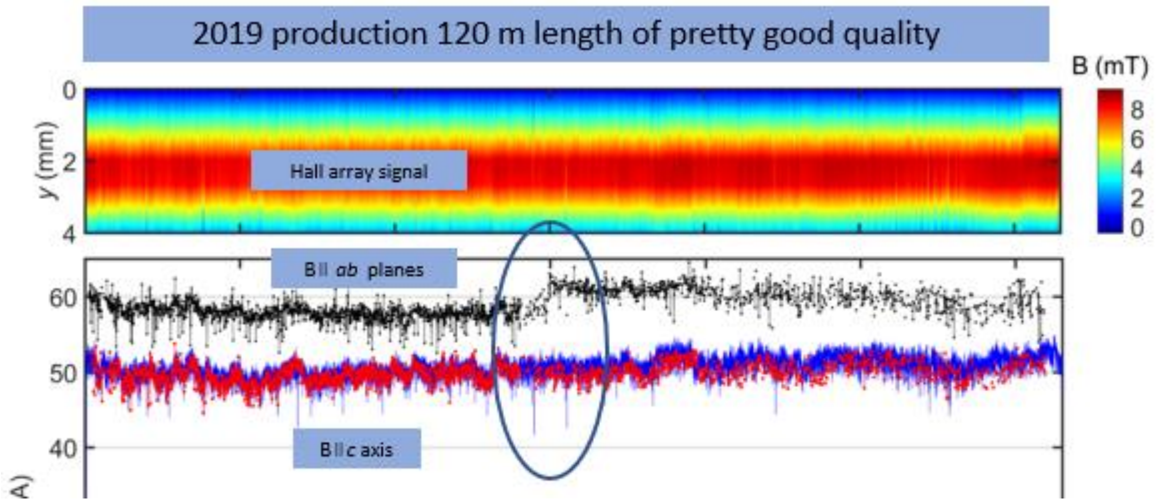






Regular deliveries from more than 1 mfr. have shown edge defects incompatible with our 30-45T test coil windings

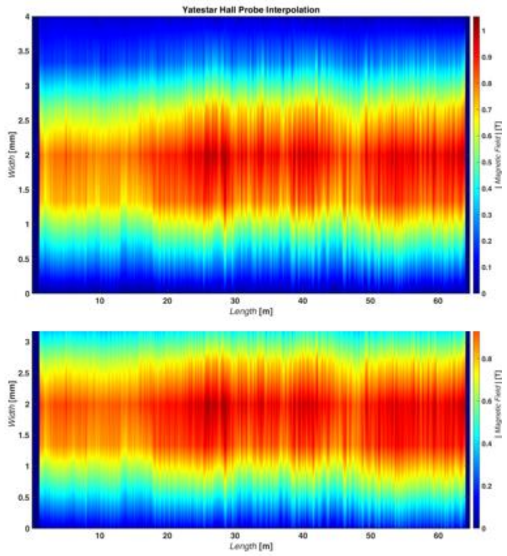
The cartoon – sometimes the reality is different…



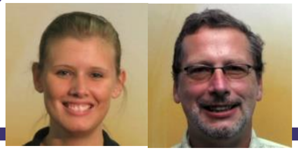
And now to vendor 2…

Hall array scan was run both ways to confirm the chaotic Ic(length) scan

Conductors are not yet uniform!



Growth REBCO fluctuations prevent simple Jc(B,T,θ) lift factor predictions –torque magnetometry is a huge new capability

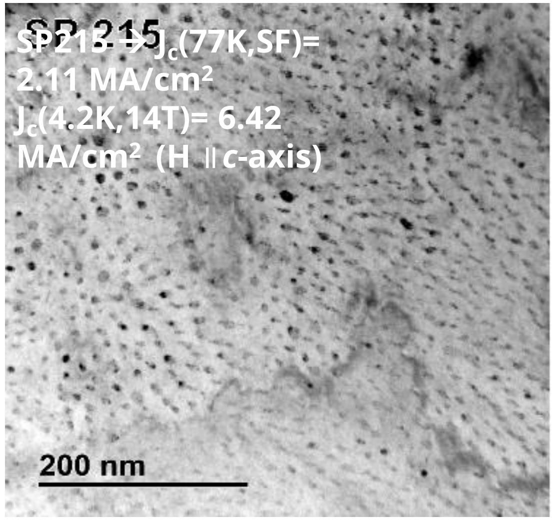


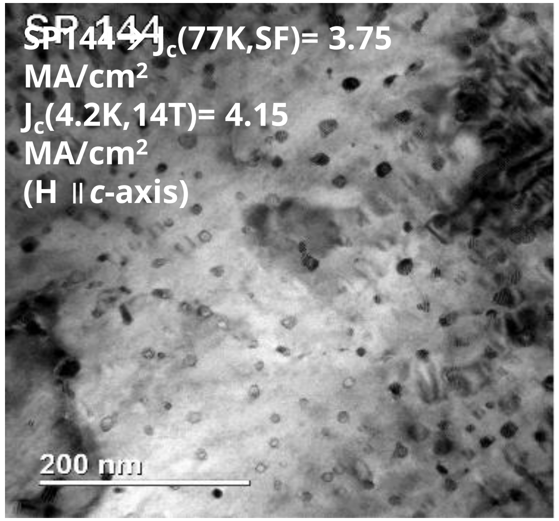
- Most vortex pinning studies address *c*-axis pinning centers – see J_c at right
- But we use the CC with B much closer to *ab*-plane

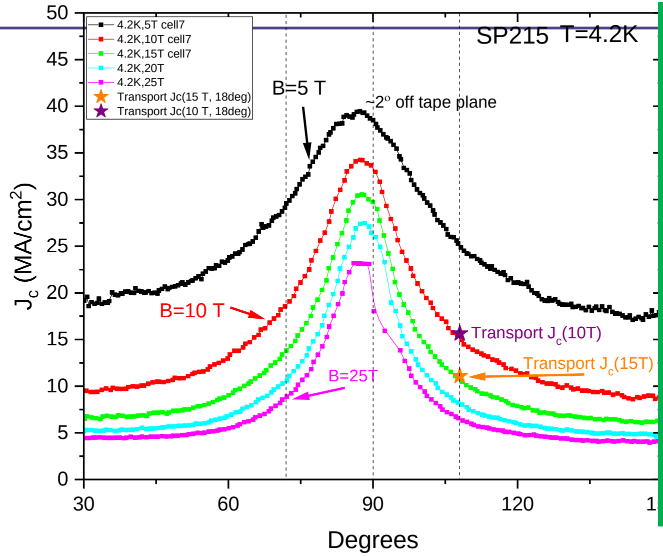
Tape number	BZO diameter (nm)	BZO spacing (nm)	Vol% BZO
SP144	8-12	35-40	4.6
SP215	5-6	11-13	6.9

Principal messages:

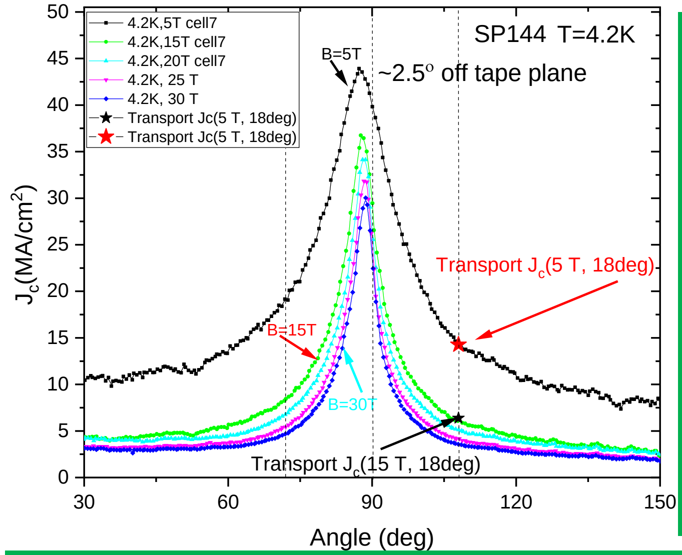
1. Tapes made to the same specification can have very different Jc characetristics
2. Ratio of *ab*-plane and *c*-axis properties is variable
3. Lift factors are unreliable even for tapes made to same specification







SP215 → J_c(77K,SF)= 2.11 MA/cm²
J_c(4.2K,14T)= 6.42 MA/cm²
(H ‖ *c*-axis)
But H ‖ *ab*-plane is 25 MA/cm² at 20 T

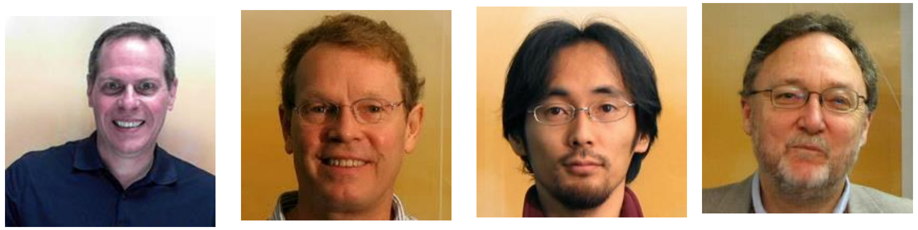


SP144 → J_c(77K,SF)= 3.75 MA/cm²
J_c(4.2K,14T)= 4.15 MA/cm²
(H ‖ *c*-axis)
But H ‖ *ab*-plane is 34 MA/cm² at 20 T

Jaroszynski Torque magnetometer

People: Teaching faculty, research Faculty, Postdocs, PhD, MS and Undergrads working on HTS at ASC/NHMFL/FAMU-FSU

Teaching Faculty



Thank you – any questions?
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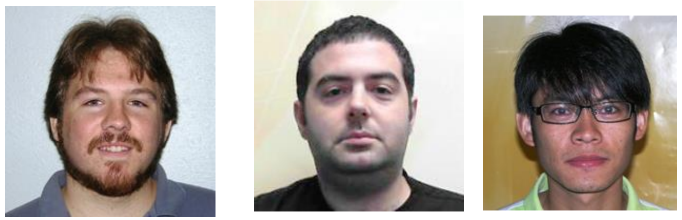
Research Faculty

Postdocs



Dedicated engineers

PhD students