



Can round wire Bi-2212 become a viable new high field magnet technology?

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On behalf of
**Very High Field Superconducting Magnet
Collaboration (VHFSMC)**

EUCARD2 Video Meeting

Hosted by Lucio Rossi, July 26, 2011





Six tasks and their leaders

Task 6: Can we leverage industry to make 2212 a viable magnet technology?

- Ken Marken (LANL) and Arup Ghosh (BNL)

Task 1: What controls J_c and can we raise it substantially?

- Eric Hellstrom (NHMFL-FSU) and Terry Holesinger (LANL)

Task 2: How does stress degrade J_c and how do we inhibit it?

- Najib Cheggour (NIST-Boulder) and Arno Godeke (LBNL)

Task 3: Can robust 2212 cable be made?

- Emanuela Barzi (Fermilab) and Al McInturff (TAMU)

Task 4: Can magnets be protected given slow conductor quench velocities?

- Justin Schwartz (NCSU) and Soren Prestemon (LBNL)

Task 5: Can we get 2212 conductors and cables into magnets without excessive degradation?

- Arno Godeke (LBNL) and Ulf Trociewitz (NHMFL-FSU)

Tasks 1 and 6 were agreed to be primary because magnets require high J_c in industrially fabricable conductors

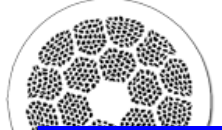


Task 6. Industrial partnering

Ensuring the conductor supply

\$1million, 25 % of VHFSMC funding spent in industry (1/2 in each year)

- **9 qualification billets**
 - 2 manufacturers used 3 different powders from two sources and 2 billet configurations to deliver 3,400 m of wire
 - This has been the prime study of VHFSMC
- **Additional production billets from Oxford Superconducting Technology (OST) serve coil and cable development goals**
 - 2 billets using Nexans 521-powder (not readily available any longer)
 - 330 m of 0.8 mm cable strand & 130 m of 1.2 mm for solenoids
 - 6 billets using Nexans 521-granulate powder (readily available)
 - 1200 m at 0.8 mm, 260 m at 1.2 mm
- **Year 1: OST proposed R&D aimed at increasing J_c through reduced filament porosity, improved filament uniformity, and reduced 2212 leakage.**
 - 8 billets 1800 m of wire delivered for use and evaluation
- **Year II: a 2nd R&D Proposal from OST has been funded.**



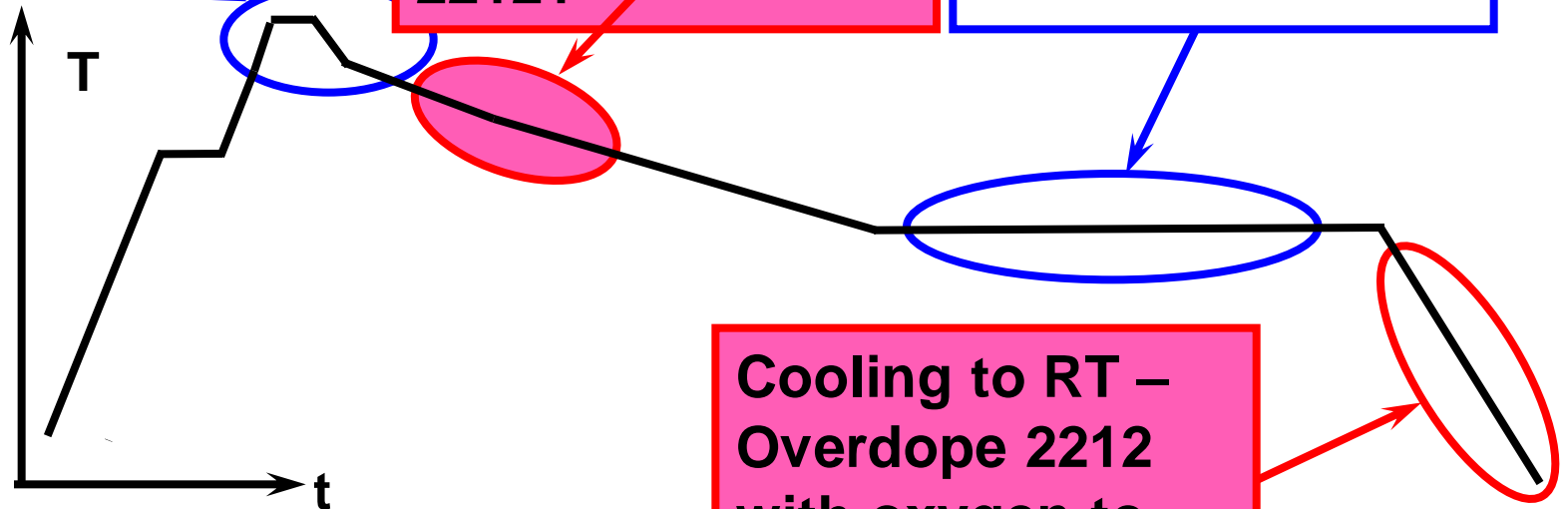
Task 1: HT for high J_c is complex: what is really going on?

Melt region – Why does J_c vary with T_{max} ?

How can we eliminate bubbles?

2212 formation region – How to form more and better connected 2212?

Annealing step – Needed to increase J_c , but do not know what occurs.



New understanding on these steps obtained in VHFSMC

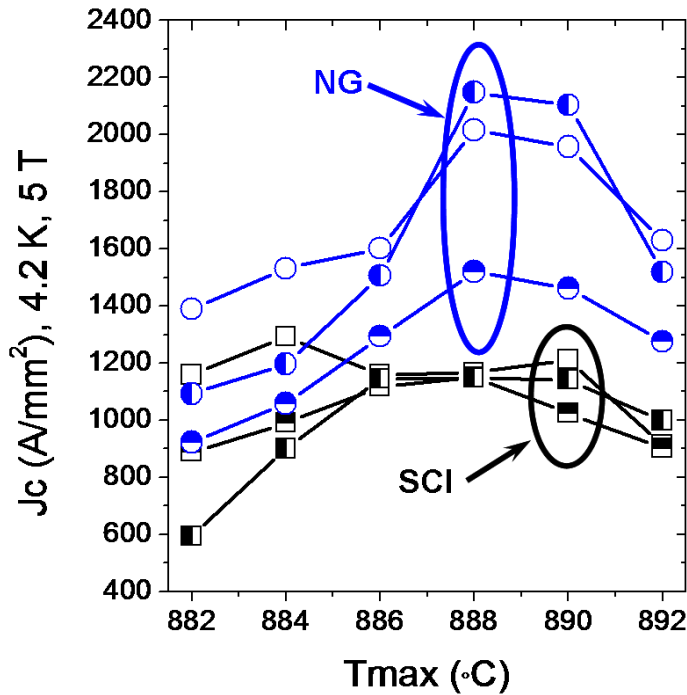
Cooling to RT – Overdope 2212 with oxygen to increase pinning and J_c .



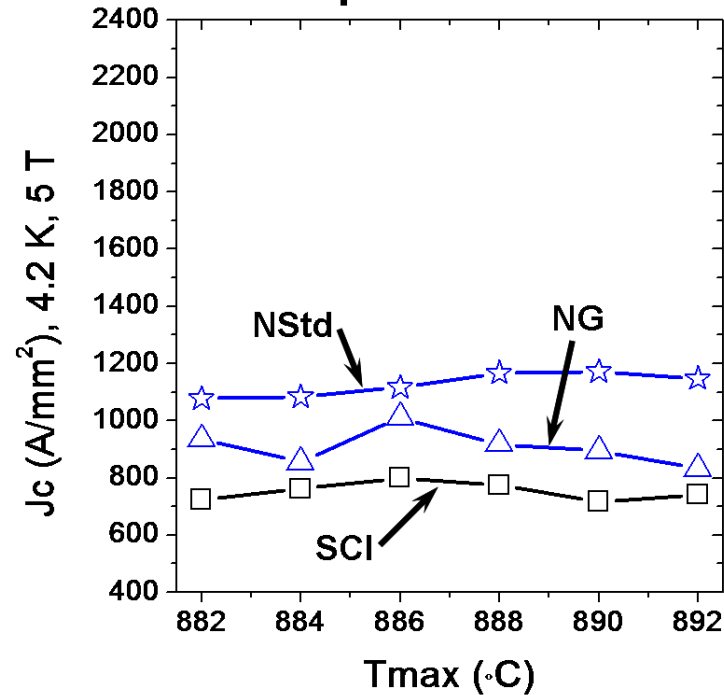


Tasks 1 and 6: Wide variation in J_c with standard HT- process does NOT define J_c

OST Wires



Supercon Wires



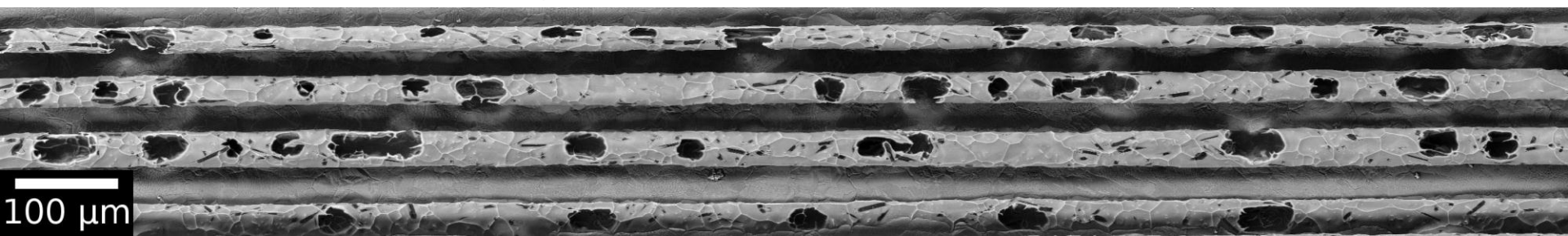
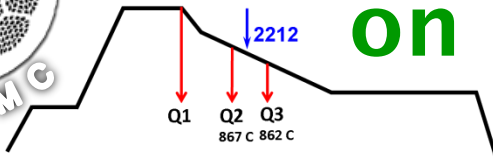
- NG = Nexans granulate
- NStd = Nexans standard powder
- SCI = SCI Engineered Materials

- Nexans granulate powder produces highest J_c
- OST has 2x higher J_c than Supercon for same powder
- Wires with higher J_c appear more sensitive to T_{max}
- Possible causes of variation – differences in powder morphology, C content, wire fabrication, architecture, filament packing density, packing atmosphere

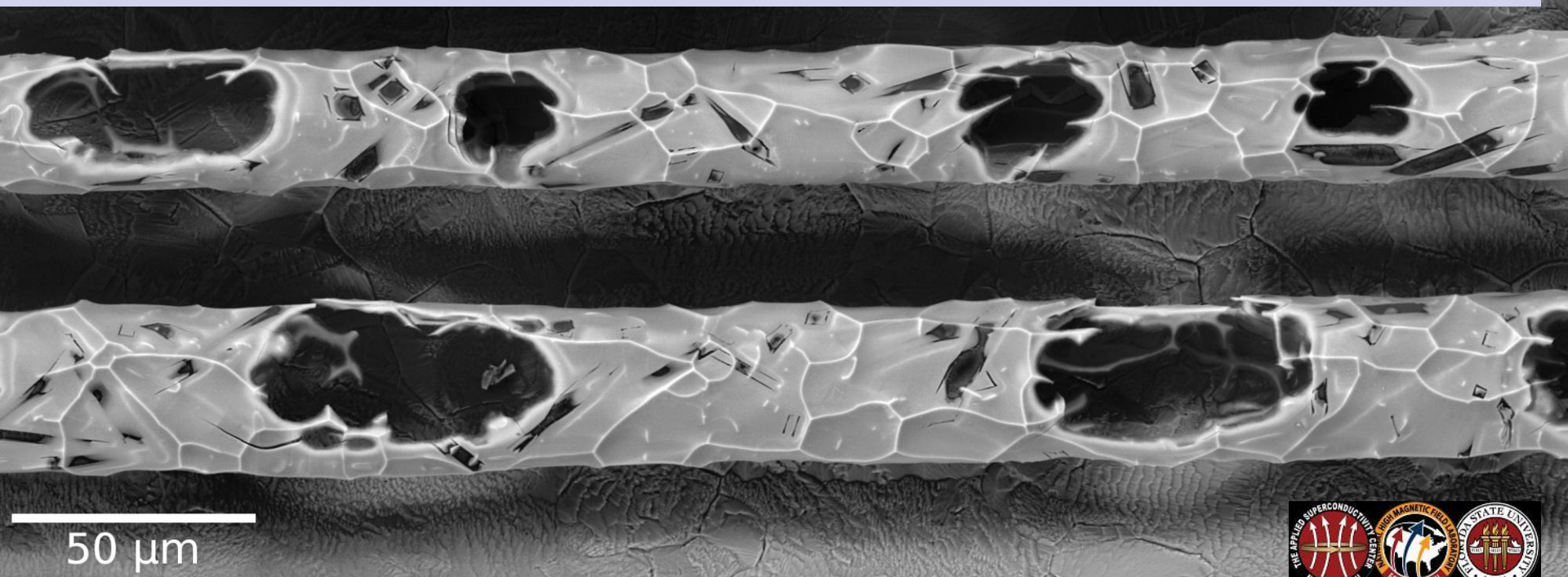




Quench 1: Large bubbles form on melting and holding at T_{\max}

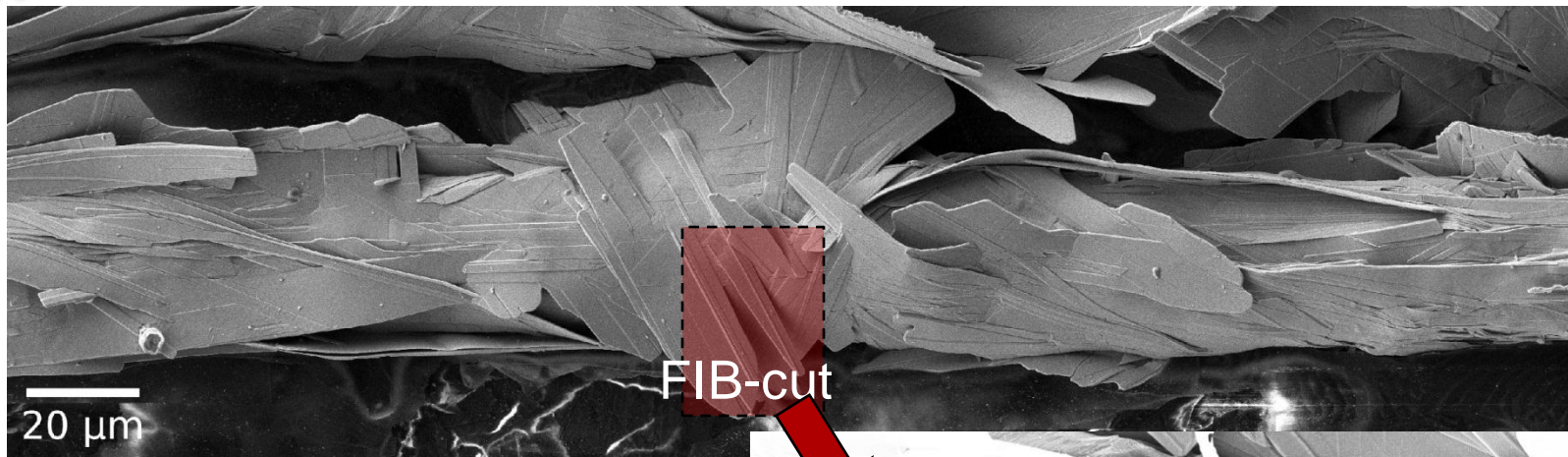


F. Kametani et al., "Bubble formation within filaments of melt-processed Bi2212 wires and its strongly negative effect on the critical current density," *Superconductor Science and Technology*, 24, 075016 (2011).



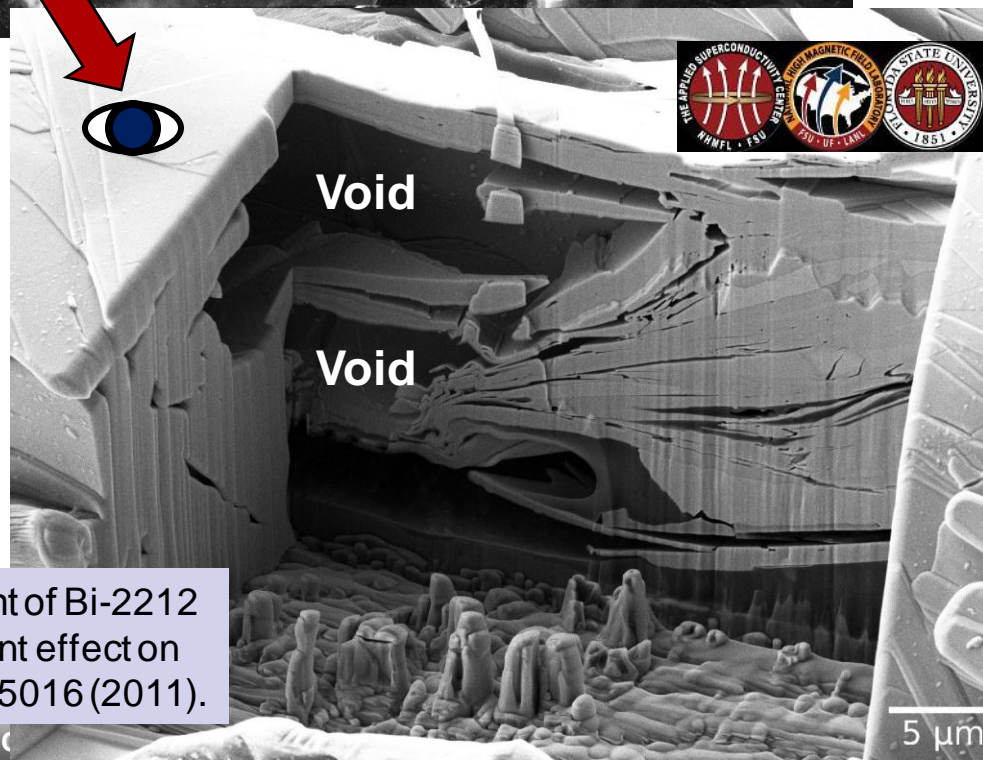


Large voids in filaments block current in fully-processed wire



Bubbles can be partially filled on resolidification and 2212 reformation – but many voids remain

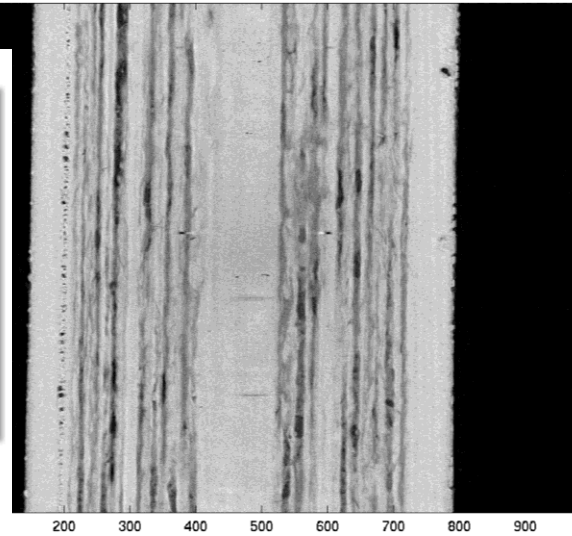
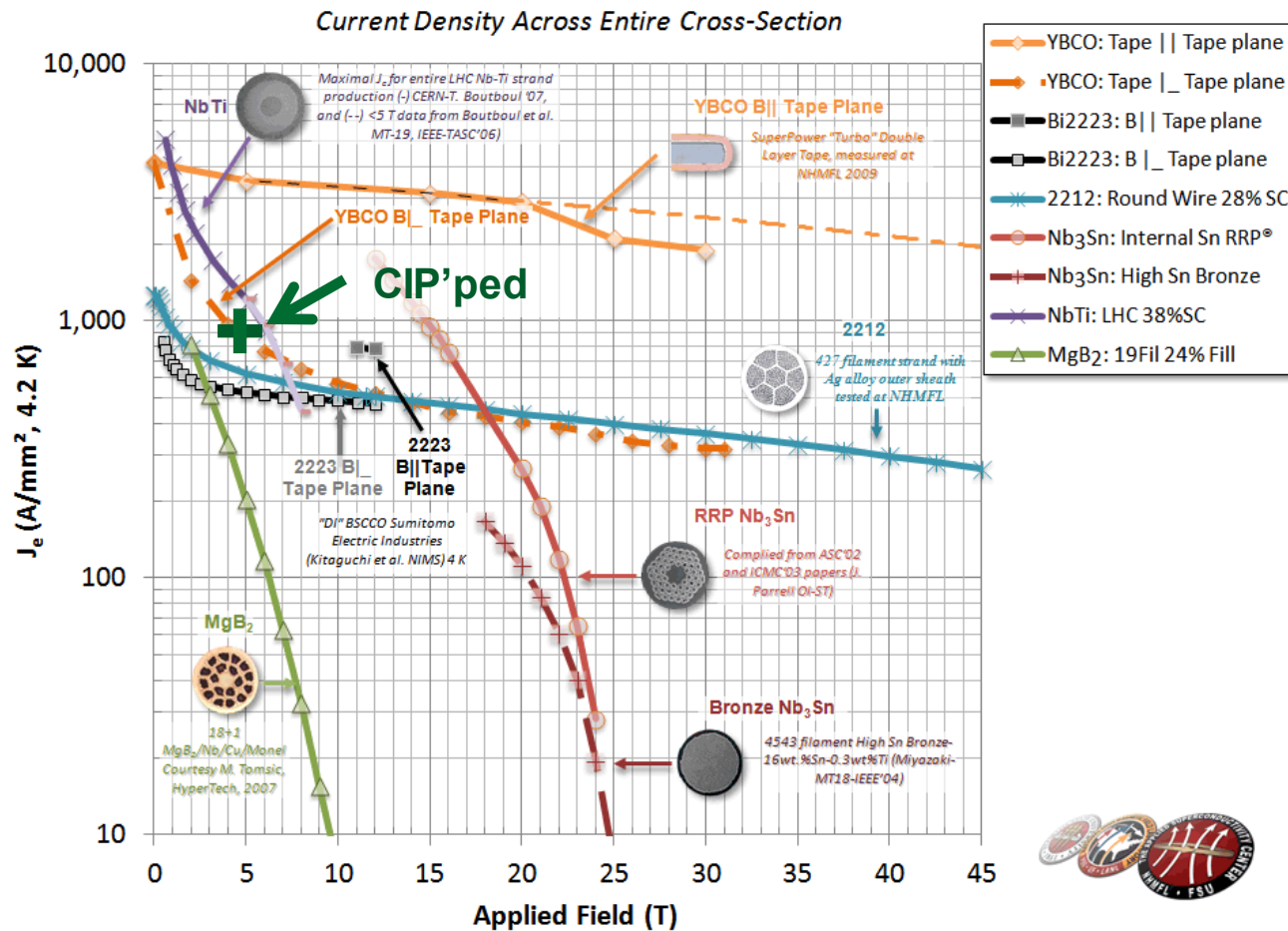
Bubbles cause long range motion of 2212 and help cause the length dependent J_c and I_c



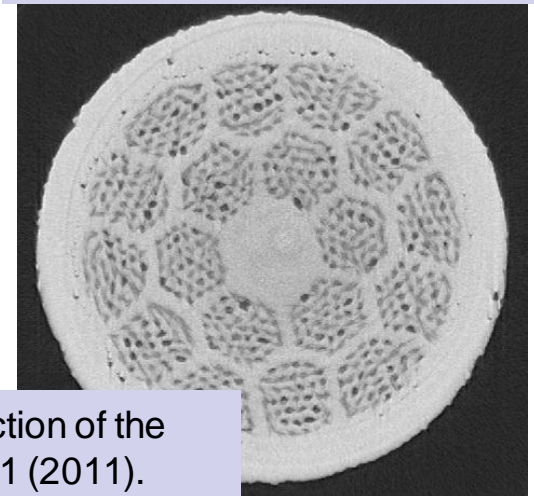
A. Malagoli et al., "Evidence for long range movement of Bi-2212 within the filament bundle on melting and its significant effect on J_c ", *Superconductor Science and Technology*, 24, 075016 (2011).



Bi-2212 breakthrough – remove bubbles



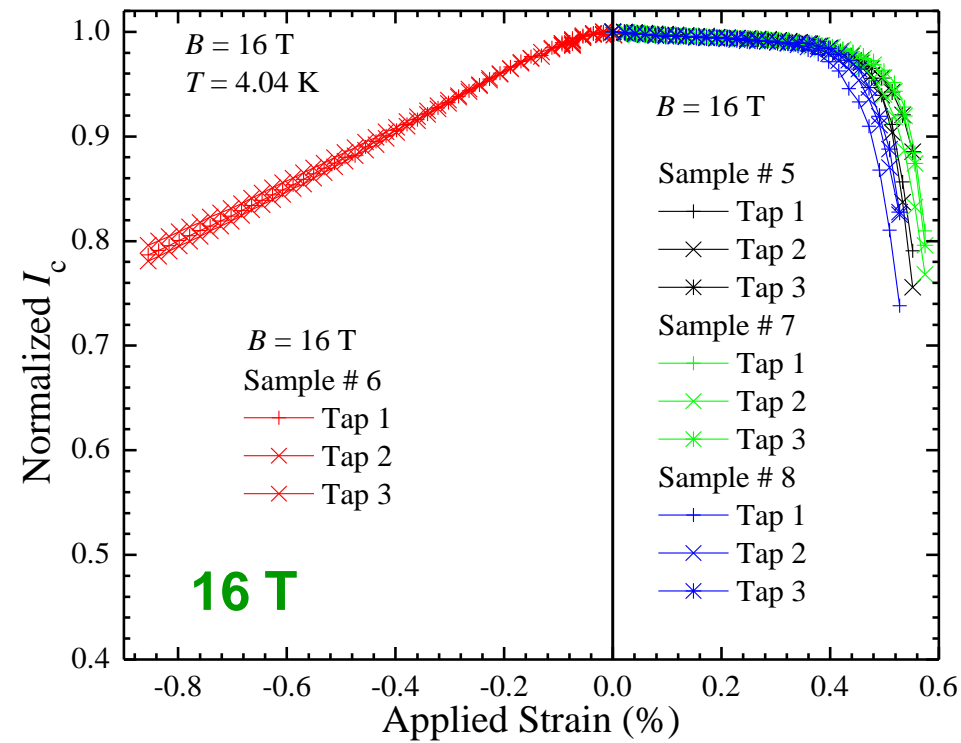
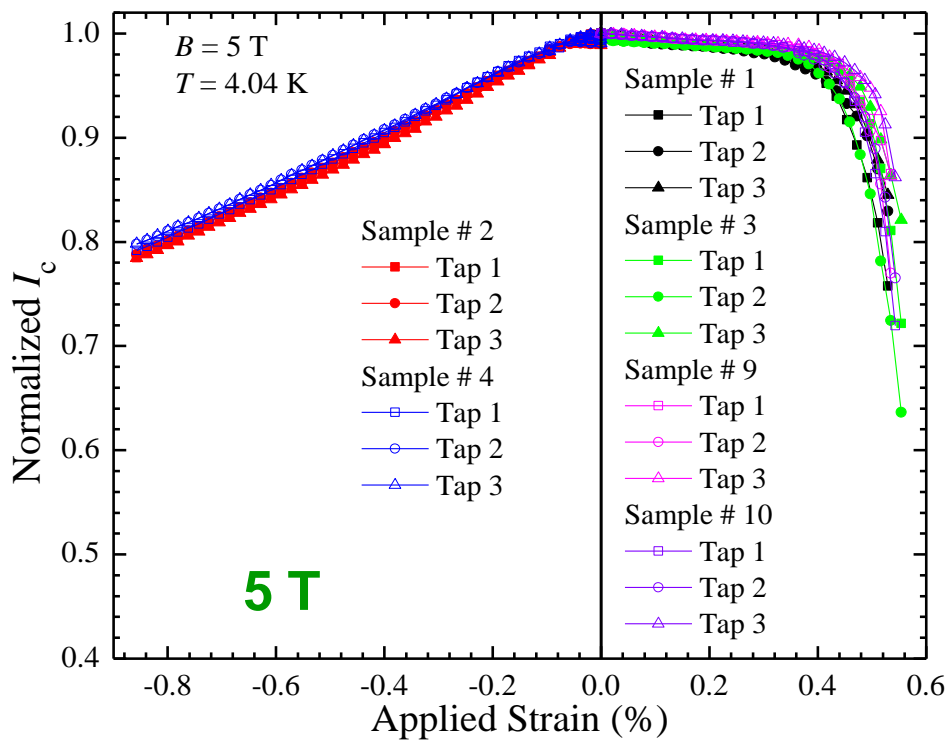
Tomograms of CIPped and NHMFL reacted wires by C. Scheuerlein (CERN)



J. Jiang et al., "Doubled critical current density in Bi-2212 round wires by reduction of the residual bubble density," *Superconductor Science and Technology*, 24, 082001 (2011).



Task 2: How does stress degrade J_c and how do we inhibit it?



Tension: $I_c(\text{strain})$ shows a slight negative slope and reversibility before the sharp I_c drop

Compression: $I_c(\text{strain})$ shows a almost linear behavior but no reversibility

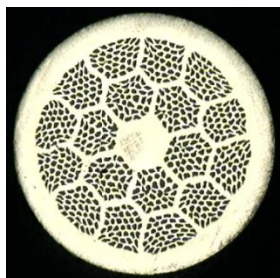
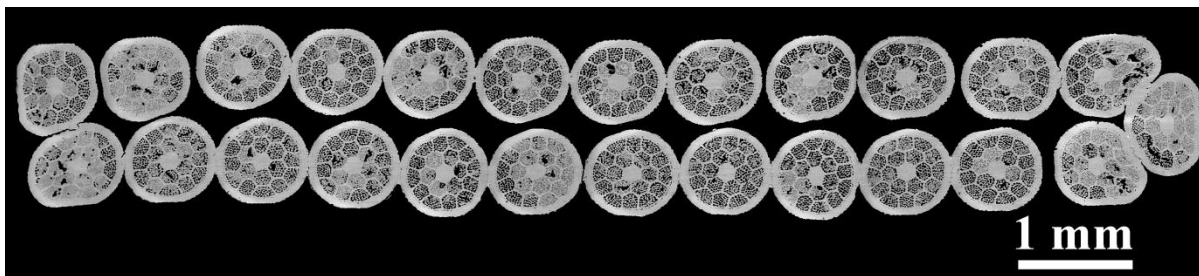
Nearly universal $I_c(\text{strain})$ dependence and very similar between 5 T and 16 T (at 4 K)

X F Lu, N Cheggour, T C Stauffer, et al., "Electromechanical characterization of Bi-2212 strands" *IEEE Trans. Appl. Supercond.* 21 3086-9 (2011)

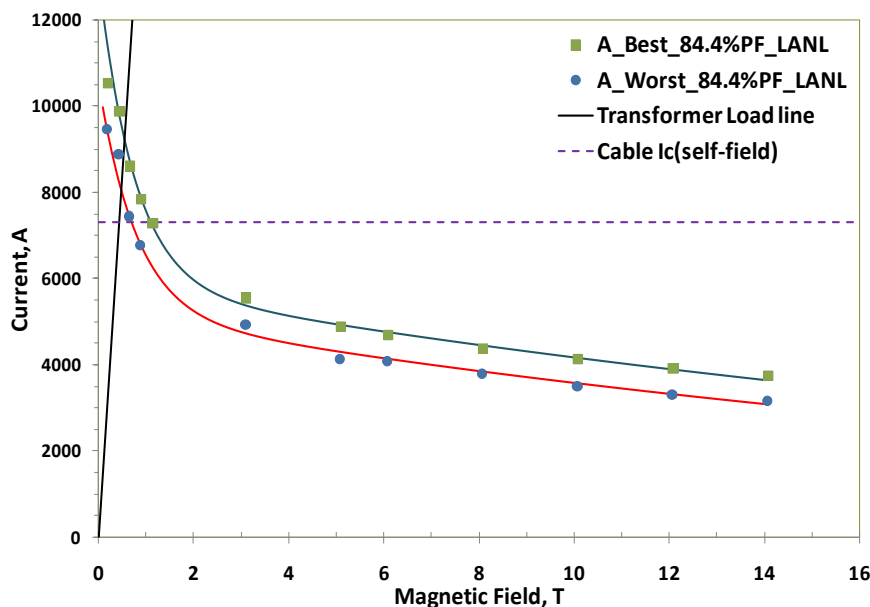




Task 3. Can good cables be made and maintain properties after reaction?



OST wire
0.8 mm using
Nexans
precursor



Cable I_c test results showing 90% of predicted value

Cable and witness samples reacted at LANL

Yes: Rutherford cables with reasonable compaction can be readily fabricated with cabling degradation that is < 20%.

E. Barzi et al., "BSCCO-2212 Wire and Cable Studies", IEEE TAS. 21,. 2335 (2011).





Task 4: Can magnets be protected given slow conductor quench velocities?

Tests made on 6 layer, 14 turn per layer coil

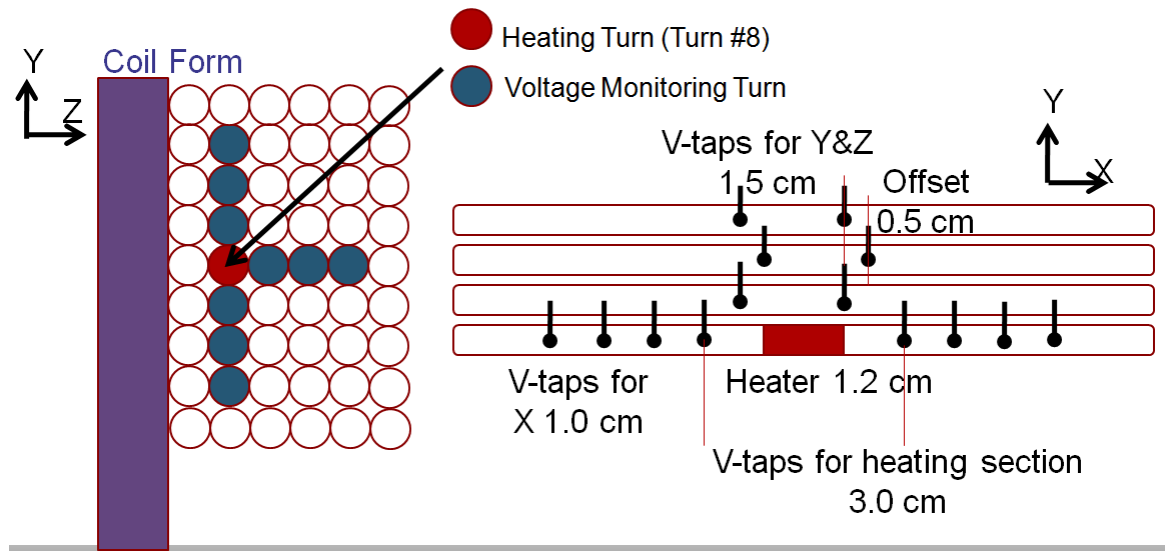
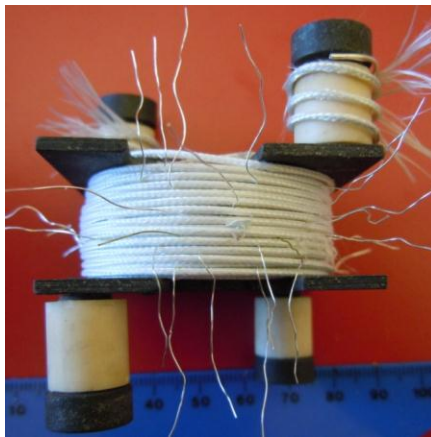
- Wind-and-react 0.8 mm diameter strand
- Epoxy impregnated



3-D Quench behavior studied up to 20T at the NHMFL

Configuration for 3-D quench measurement

Before heat treatment



D. Arbelaez, "Numerical investigation of the quench behavior of $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$ wire," *IEEE Transactions on Applied Superconductivity* 21(3) 2787-2790 (2011)





Task 5: Small Bi-2212 Round Wire Test Coils on Inconel 600

Both coils: “regular”
HT, no visible leaks

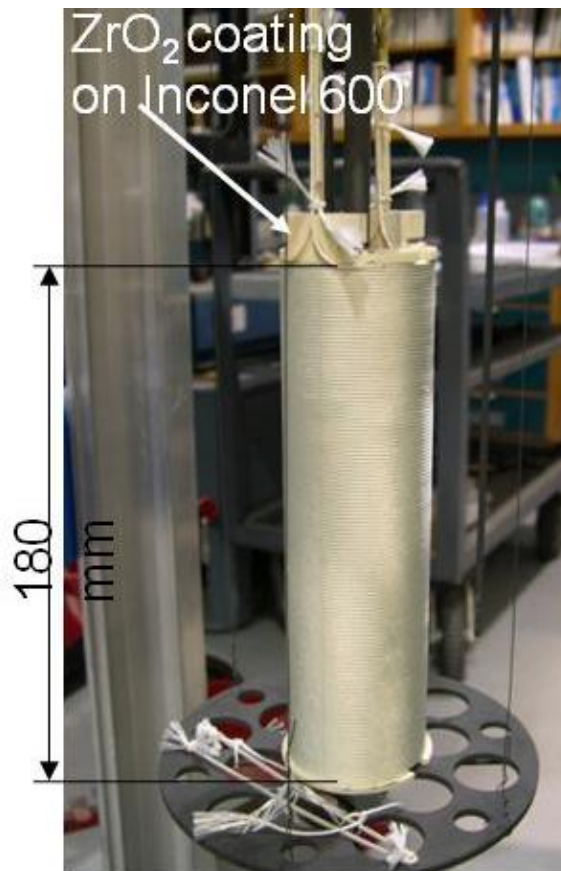


Coil specs:

- 10 layers/750 turns, $L \sim 3$ mH
- $ID = 15$ mm, $OD = 38$ mm
- height = 100 mm
- conductor length ~ 66 m
- $DB = 1.1$ T at 31 T
- winding $J_w = 80$ A/mm² at 31 T
- (90 – 70 A/mm² in previous 5 T magnet at 20 T)
- no mechanical degradation

• first HTS wire-wound coil
to go beyond 30 T (32.1 T in
31 T background)

ZrO₂ coating
on Inconel 600



Coil specs:

- 10 layers/135 turns, $L = 14.9$ mH
- $ID = 32.4$ mm, $OD = 57.4$ mm
- height = 180 mm
- conductor length ~ 220 m

- **Field generated: 2.3 T in self-field and 1.2 T at 20 T**
- **Early voltage transition in innermost layers**
⇒ **Ic degraded due to bore-tube/strand /insulation interaction**



Trociewitz and Myers



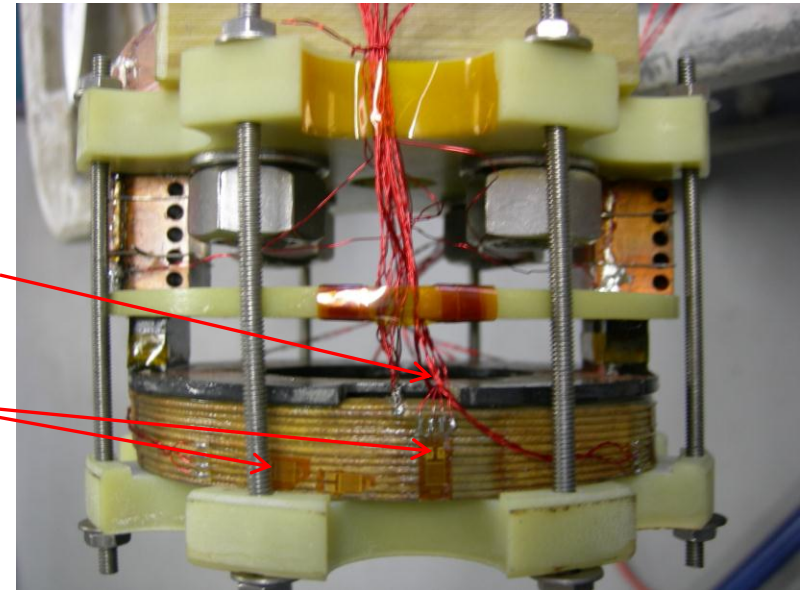
Can Bi2212 Coils operate at high stresses ?

Coil specifications:

- 1.03 mm OD wire
- ID = 92.5 mm
- OD = 118.5 mm
- 10 layers, 10 turns
- Bore tube less
- epoxy impregnated
- $\Delta B \sim 0.2$ T at 20 T

Voltage
Taps

Strain
gauges



- Coil dimensions represent section of type “C” coil of 7 T design
- Coil did not degrade at $I_c(20T)$, effective load sharing by epoxy impregnation
- At stress levels of ~ 92 MPa assuming fully coupled layers, coil reached max. strain level of $\sim 0.16\%$

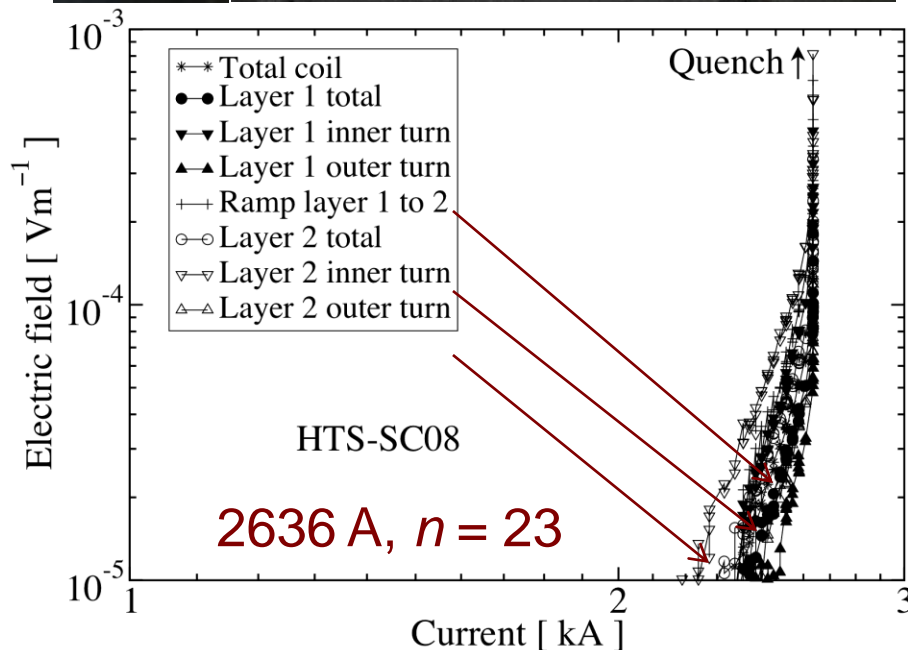
• Conductor fairly robust in epoxy impregnated winding pack





Status of Bi-2212 Race-track Coils

HTS-SC08 – uses 17 strand cable



Coil performance

- Coil achieves 75% of round wire witness
- Limited by inner turns and ramp

Pending issues

- Increase engineering J_E by factor 3 – 4
- Critical current gradients
- Stress-strain sensitivity Bi-2212
- Leakage

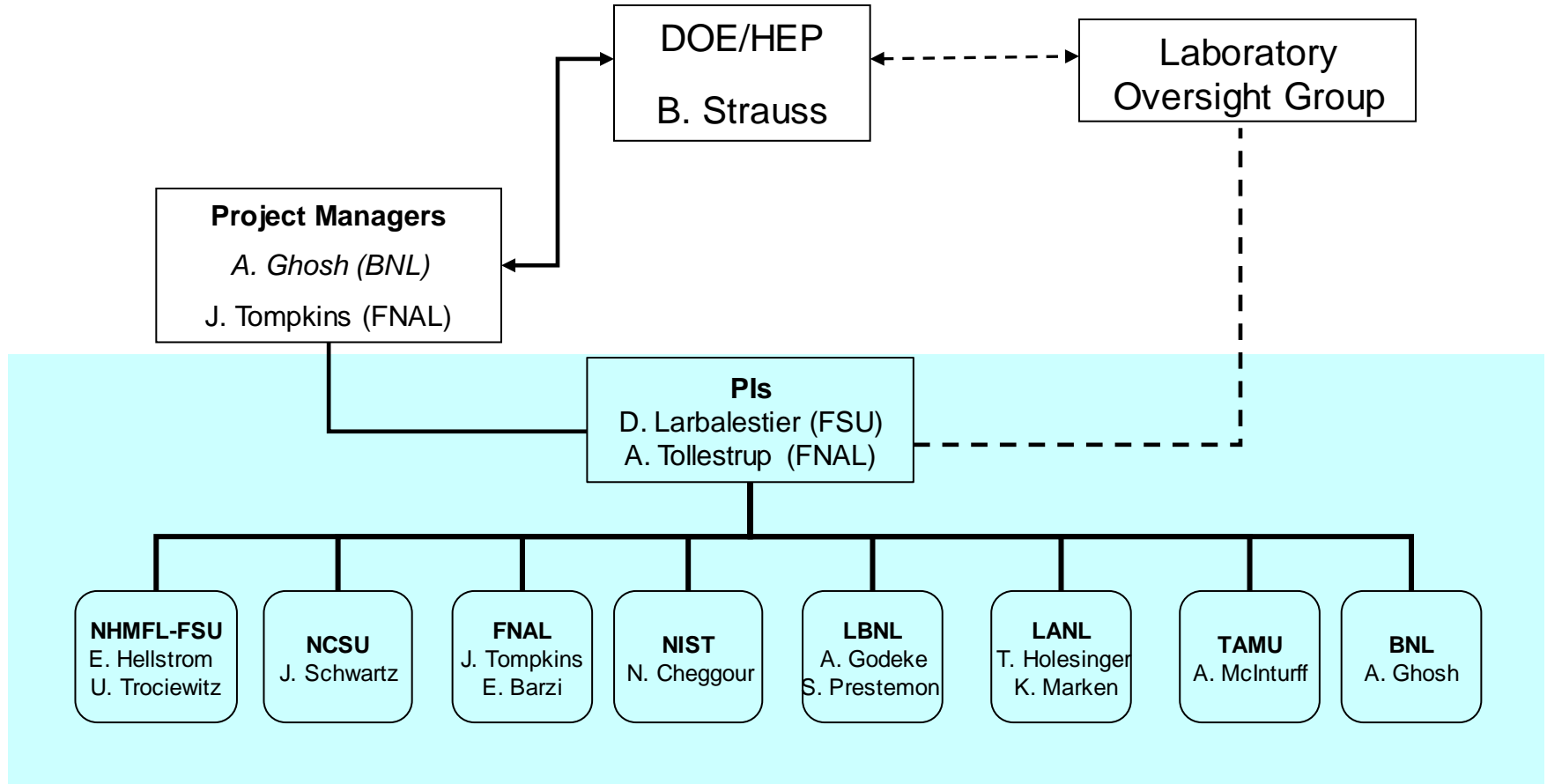
W&R Bi-2212 is realistic!

A. Godeke et al., "Supercond. Sci. Tech. 23, 034022 (2010),





VHFSMC is multi-lab and multidisciplinary



VMFSMC Organizations and Relationships



Summary: Approach and Project Management

- **The Technical Committee (TC) meets monthly for 3-4 hrs by video, and twice yearly face-to-face.**
 - Forum for all technical presentations and discussions and develops the tasks and budgets.
 - Oversees progress, discusses technical and collaboration issues, sets up *ad hoc* sub-groups to examine key technical issues ...
- **Project manager takes input from the TC, drafts the initial FWP, submits budget to DOE, and sends periodic progress reports to the DOE based on reports from the individual task leaders.**
- **The 'Executive Committee' composed of PI's and PM coordinates activities, responds to program needs, and provides short-term guidance between Technical Committee meetings. It meets by weekly phone call of about 1-1.5 hours.**
 - Current members: A. Ghosh, BNL; D. Larbalestier, FSU-NHMFL; A. Tollestrup, J. Tompkins, L. Cooley, FNAL; A. Godeke, LBNL



Post ARRA Plans

- VHFSMC is an ARRA-funded effort for two years only. The funds formally terminate June 30, 2011, but “no cost” extensions through December 31 may allow a short term extension.
- The ongoing collaboration will shrink to about half the ARRA contract value, requiring leverage by those with base programs that can sustain the ongoing 2212 effort and work in a synergistic manner without conflicting industrial interactions



VHFSMC publications: 2010-2011

Task 1 - publications

- T. Shen, J. Jiang, F. Kametani, U.P. Trociewitz, D.C. Larbalestier, J. Schwartz and E.E. Hellstrom, "Filament to filament bridging and its influence on developing high critical current density in multifilamentary $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8-x}$ round wires" *Supercond. Sci. Technol.* 23 (2010) 025009
- M. Rupich and E. E. Hellstrom, "Bi-Ca-Sr-Cu-O HTS Wire", Chapter 11.4 in 100 years of Superconductivity, Editors Horst Rogalla and Peter Kes, Chapman & Hall // CRC of the Taylor & Francis Group (2011).
- A. Malagoli, F. Kametani, J. Jiang, U.P. Trociewitz, E.E. Hellstrom and D.C. Larbalestier, "Evidence for long range movement of Bi-2212 within the filament bundle on melting and its significant effect on J_c ", *Superconductor Science and Technology*, 24, 075016 (2011).
- F. Kametani, T. Shen, J. Jiang, C. Scheuerlein, A. Malagoli, M. Di Michiel, Y. Huang, H. Miao, J.A. Parrell, E.E. Hellstrom and D.C. Larbalestier, "Bubble formation within filaments of melt-processed Bi2212 wires and its strongly negative effect on the critical current density," *Superconductor Science and Technology*, 24, 075016 (2011).
- J. Jiang, W.L. Starch, M. Hannion, F. Kametani, U.P. Trociewitz, E.E. Hellstrom and D.C. Larbalestier, "Doubled critical current density in Bi-2212 round wires by reduction of the residual bubble density," *Superconductor Science and Technology*, 24, 082001 (2011).
- T. Shen, J. Jiang, F. Kametani, U.P. Trociewitz, D.C. Larbalestier and E.E. Hellstrom, "Heat treatment control of $\text{Ag-Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8-x}$ multifilamentary round wire: Investigation of time in the melt," under review at *Superconductor Science and Technology*, 24, xxxxxx (2011).
- C. Scheuerlein, M. Di Michiel, M. Scheel, J. Jiang, F. Kametani, A. Malagoli, E.E. Hellstrom, and D.C. Larbalestier, "Void and phase evolution during the processing of Bi-2212 superconducting wires monitored by combined fast synchrotron microtomography and X ray diffraction," to be submitted to *Supercon. Sci & Tech* July 29, 2011..



VHFSMC publications: 2010-2011

- X F Lu, N Cheggour, T C Stauffer, C C Clickner, L F Goodrich, U Trociewitz, D Myers, and T G Holesinger, "Electromechanical characterization of Bi-2212 strands" *IEEE Trans. Appl. Supercond.* 21 3086-9 (2011)
- N Cheggour, X F Lu, T G Holesinger, T C Stauffer, J Jiang, and L F Goodrich, "Reversible effect of strain on transport critical current in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+x}$ superconducting wires: A modified descriptive strain model", submitted to *Superconductor Science and Technology*.

Task 3

- E. Barzi, V. Lombardo, D. Turrioni, F. J. Baca, and T. G. Holesinger, "BSCCO-2212 Wire and Cable Studies", *Trans. Appl. Sup.*, V. 21, No. 3, p. 2335 (2011).
- E. Barzi, V. Lombardo, A. Tollestrup, D. Turrioni, "Study of Effects of Transverse Deformation in BSCCO-2122 Wires", *Trans. Appl. Sup.*, V. 21, No. 3, p. 2808 (2011).

Task 4

- D. Arbelaez, S.O. Prestemon, D.R. Dietderich, A. Godeke, L. Ye, F. Hunte and J. Schwartz, "Numerical investigation of the quench behavior of $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$ wire," *IEEE Transactions on Applied Superconductivity* 21(3) 2787-2790 (2011)

Task 5

- H.J. Weijers, U.P. Trociewitz, W.D. Markiewicz, J. Jiang, D. Myers, E.E. Hellstrom, A. Xu, J. Jaroszynski, P. Noyes, Y. Viouchkov, and D.C. Larbalestier, "High Field Magnets With HTS Conductors", *IEEE Trans. Appl. Supercond.*, 20, 576 (2010)
- A. Godeke, P. Acosta, D. Cheng, D. R. Dietderich, M. G. T. Mentink, S. O. Prestemon, G. L. Sabbi, M. Meinesz, S. Hong, Y. Huang, H. Miao, J. Parrell, "*Supercond. Sci. Tech.* 23, 034022 (2010),