Technology development at LBNL with the subscale magnet program

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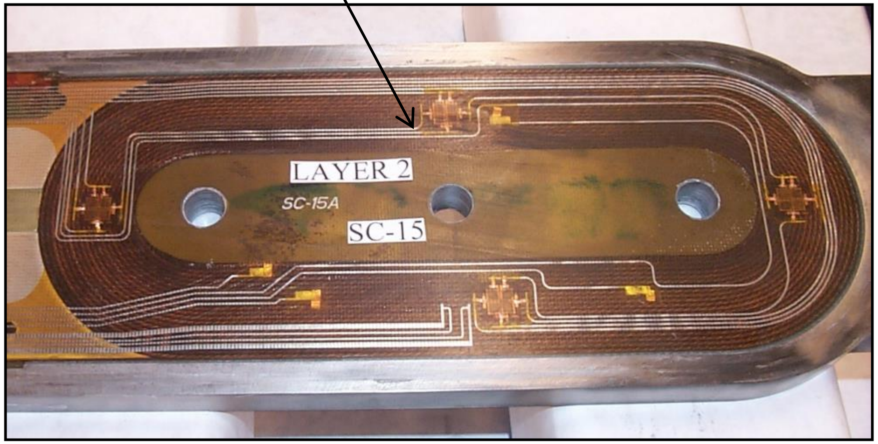
Subscale magnet – small yet complete

“麻雀虽小，五脏俱全”

“Small as the sparrow is, it possesses all the vital organs”

- Cost-effective, rapid turn-around tools for technology development
- Broad R&D topics: conductor, cable, mechanics, materials, fabrication procedures

Instrumentation traces



Nb_3Sn subscale coil, 30 cm long

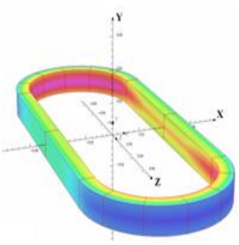
Nb_3Sn program

- Develop and demonstrate key magnet technologies
  - Verify conductor performance in magnet configuration
  - Validate mechanical structure and preload strategy (calculation and measurement)
  - Understand magnet quench behavior (temperature limits, stress effects)
  - Develop and test new instrumentation

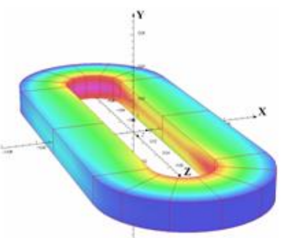
- Establish solid technology base for full-scale magnets
  - Shell-based structure is the baseline for the Nb_3Sn quadrupole for the Hi-Luminosity LHC interaction region

Various subscale magnet configurations

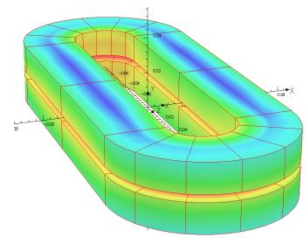
6-turns



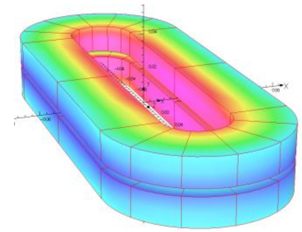
19-turns



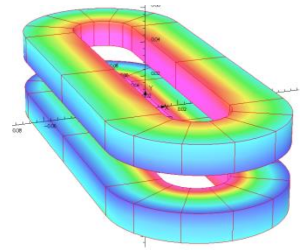
Common coil



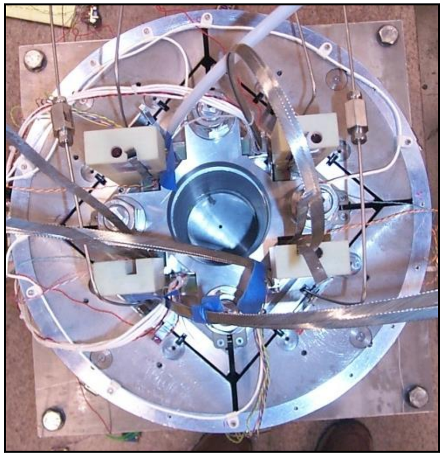
Block



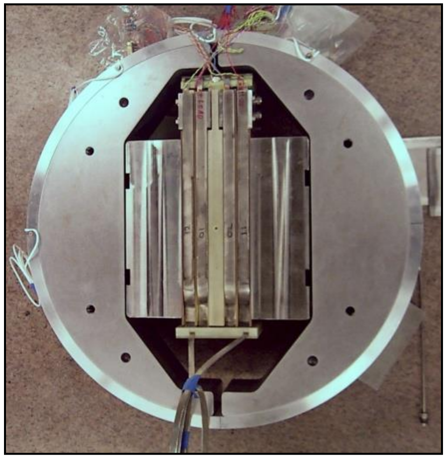
Hybrid



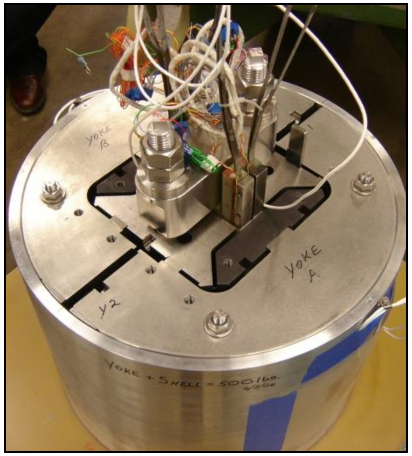
SM
Low field
Low stress



SQ
High stored energy
High Axial forces



NMR
4-coil layout
High field



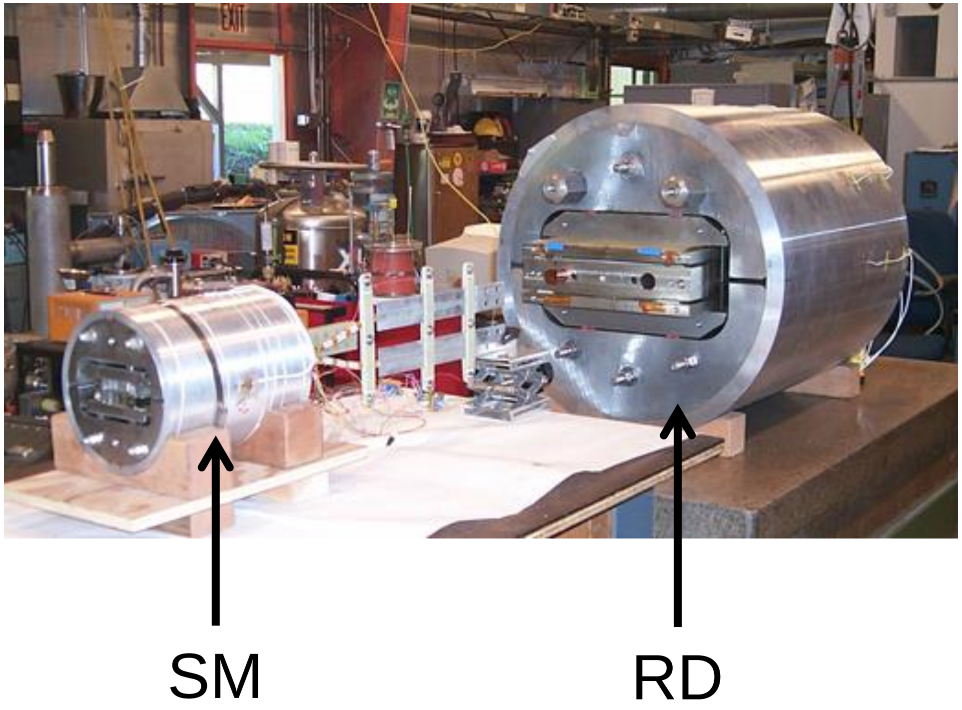
SD
High field
High stress

Subscale common coil

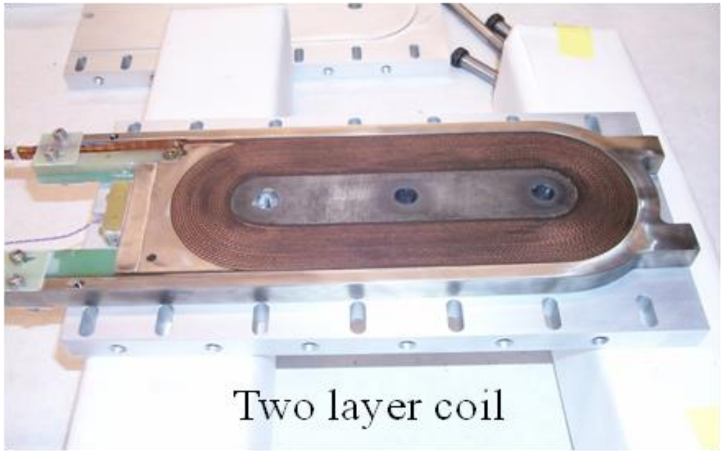
• SM series: first step of the LBNL sub-scale program (~2001)

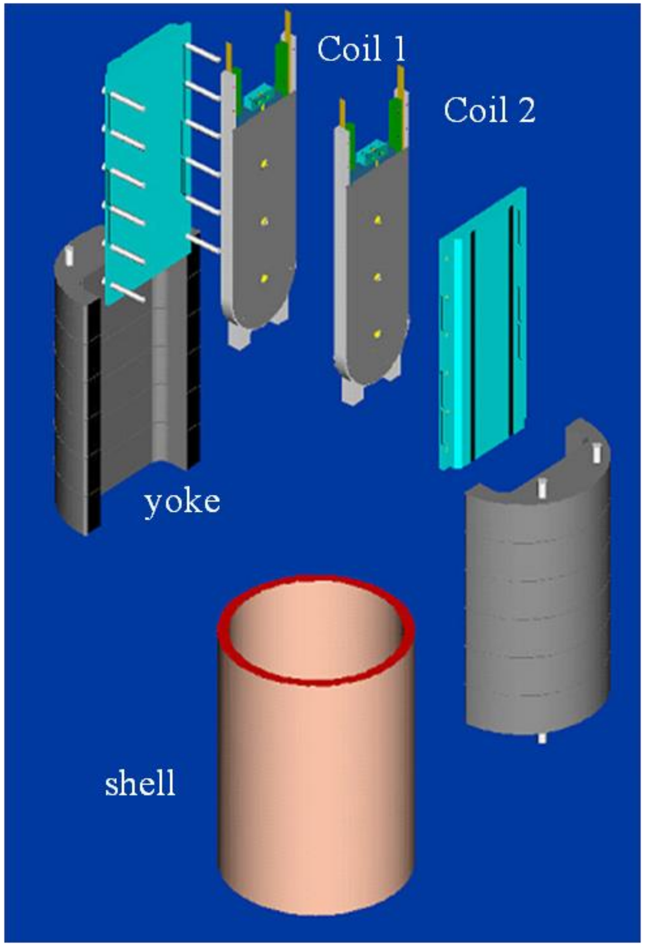
Main features:

- Scaled version of RD (common coil) magnet, about 1/3 scale
- Field range: 9 – 12 T
- Two-layer racetrack coils, 5 kg of material per coil
- Test in small dewar
- Full instrumentation



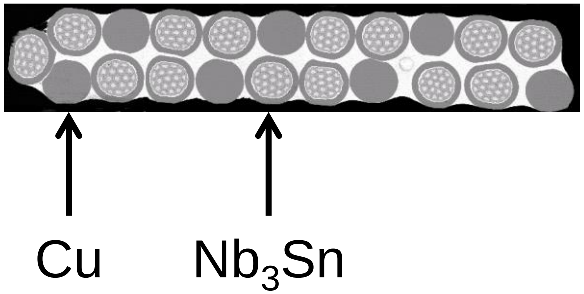
Coil and structure components





We learned a lot from SM magnet

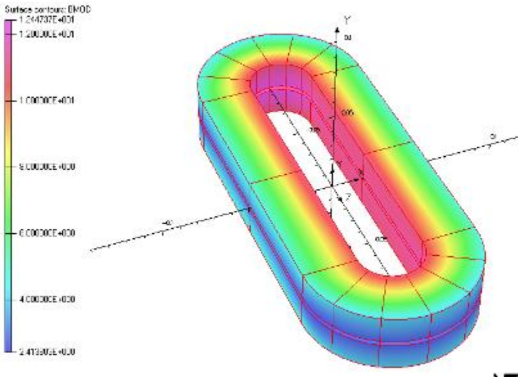
- SM-01: preload strategy
  - Reached the conductor limit at 11.9 T
- SM-02/03: mixed-strand cable
  - Low quench performance observed
  - Mixed strand cable not very appealing for HEP accelerator magnets



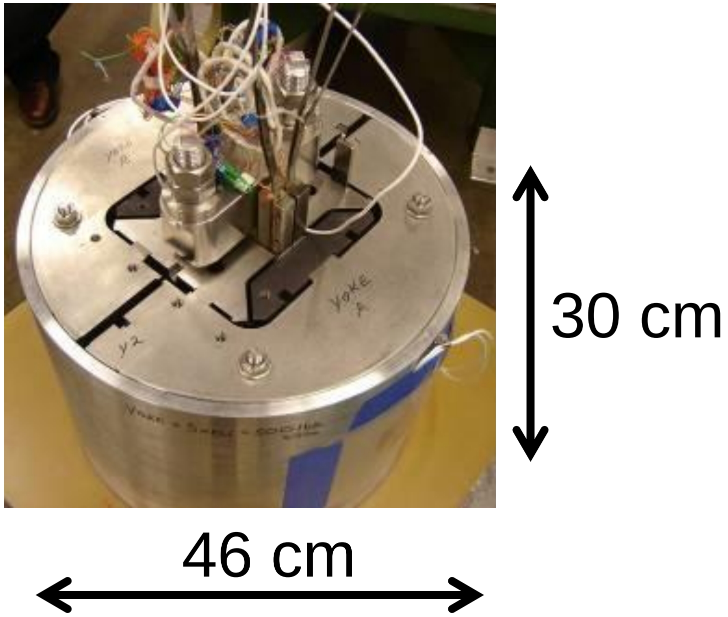
- SM-04: CTD ceramic insulation system
  - Excellent quench performance achieved
- SM-05: quench protection limits
  - First experimental results on Nb_3Sn magnets

Subscale dipole

- Collaboration with CEA/Saclay
- Two racetrack coils
- Magnet 23 cm radius, 30 cm long
- Reached 98% of conductor limit at 4.5 K

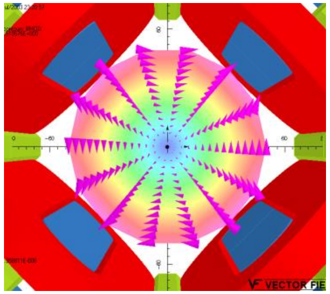


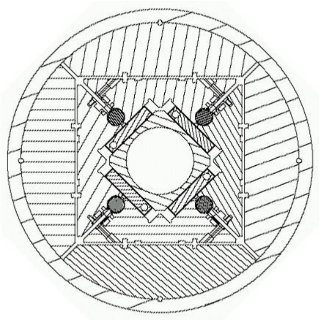
- Implemented the first shell-based dipole structure
- Verified analysis models
- Studied the impact of preload on magnet performance



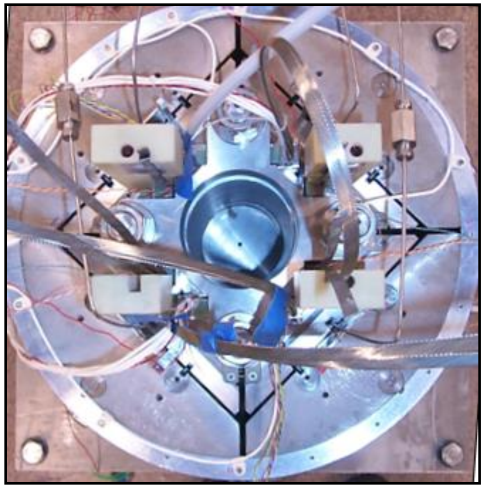
Subscale quadrupole

- Part of LARP collaboration
- Four racetrack coils, square bore
- 13 cm aperture, 30 cm long
- Two models tested at LBL & FNAL



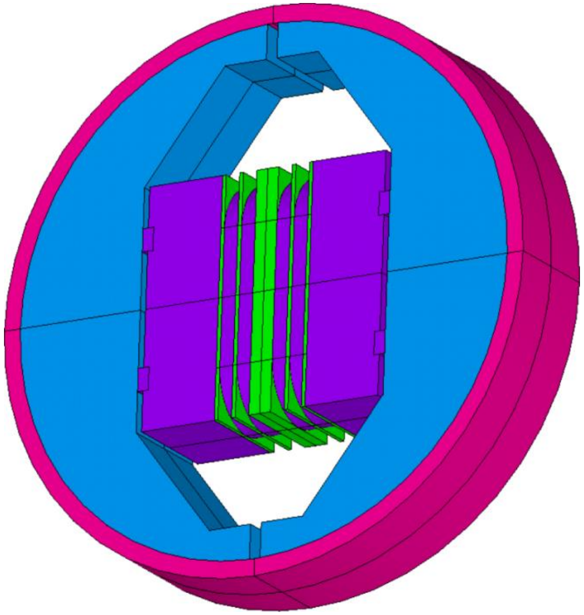


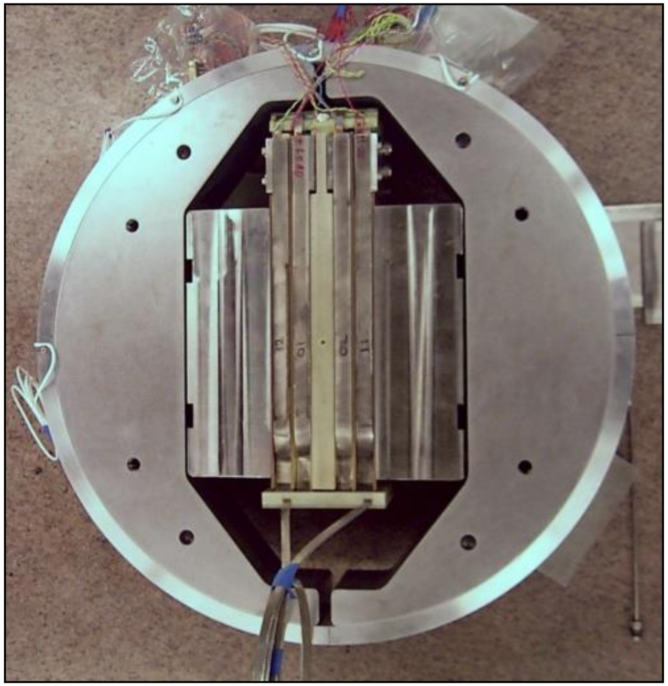
- Verified conductor performance
- Implemented the first shell-based quadrupole structure
- Verified mechanical support structure
- Analyzed quench propagation



Nested coil configuration

- Developed for "ex-situ" NMR studies
- Allows testing of coils in a background field
- Low conductor stress (protected by winding pole)





HTS subscale magnet program

- Develop Bi-2212 and YBCO high-field accelerator insert
- Use subscale coils to address challenges

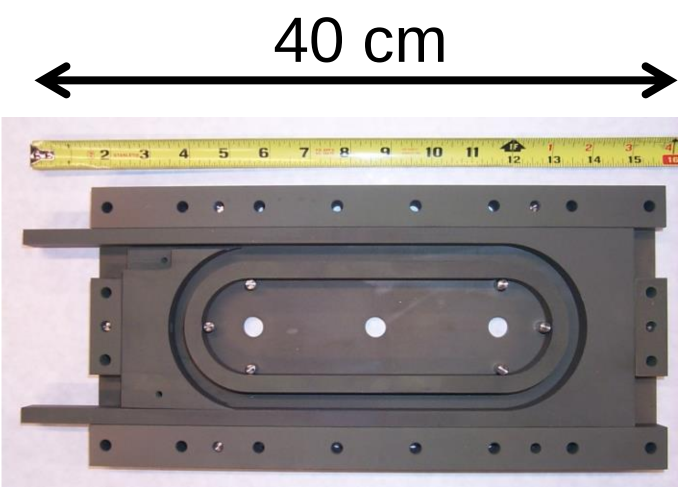
- Challenges for Bi-2212
  - Heat treatment for high conductor performance
  - Material compatibility
  - Mechanical strength and stress limit in background field

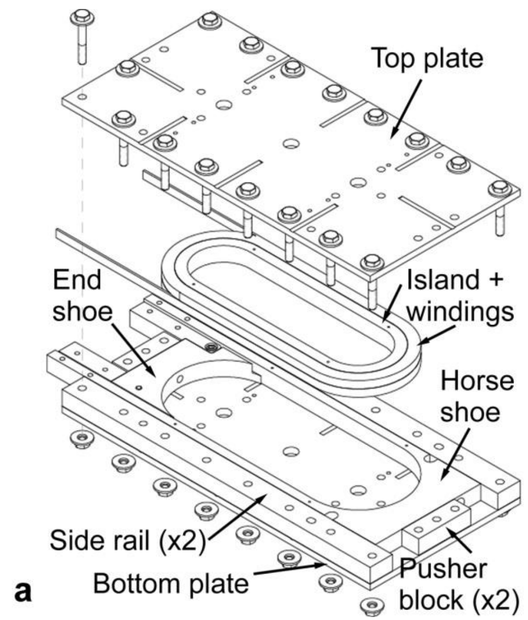
- Challenges for YBCO
  - Cabling and coil fabrication
  - Correlation between short-sample and coil performance

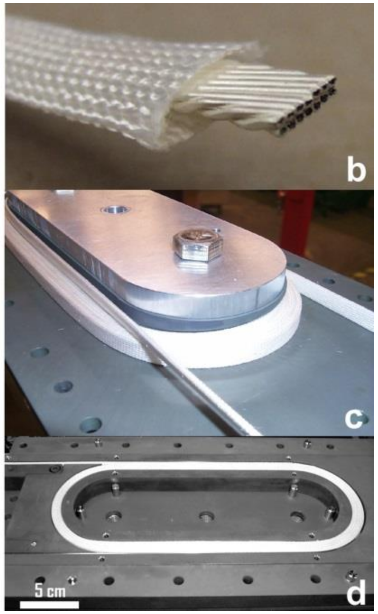
- Shared issues
  - Quench detection and protection
  - Interaction with oursert coils

Bi-2212 racetrack program

- Develop coil fabrication technology
- Racetrack geometry, see Dr. Dietderich's talk for the canted cosθ (CCT) geometry
- 17-strand Rutherford cable







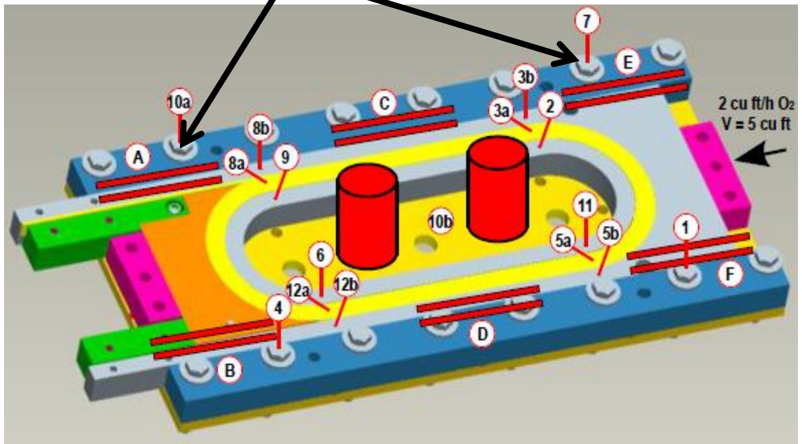
Courtesy of Arno Godeke

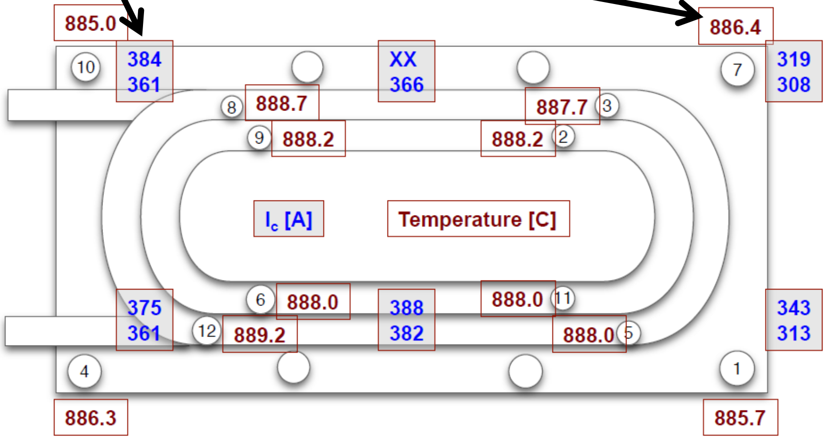
Detailed thermometry during reaction

- Subscale coils allow extensive instrumentation
- Measure and correlate the temperature profiles with coil performance

Thermocouples

I_c and temperature data





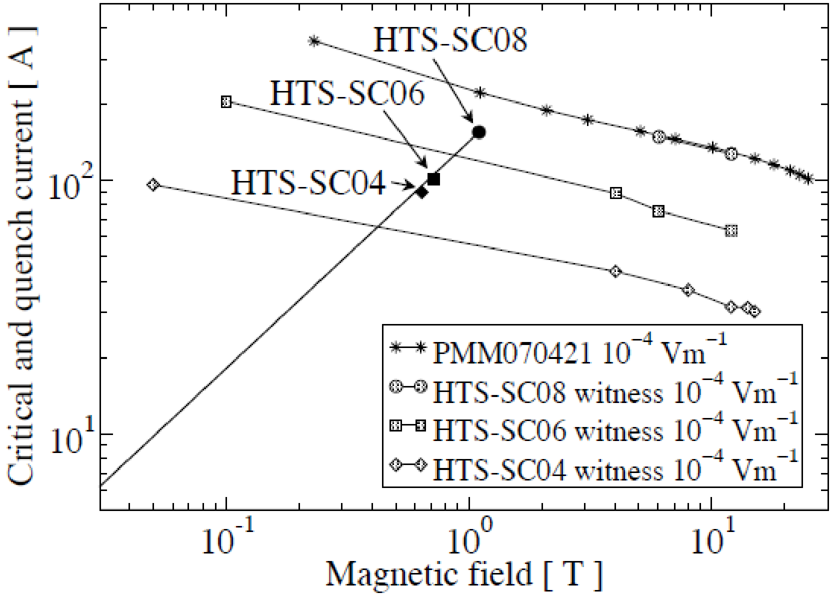
Courtesy of Arno Godeke

Achievements with subscale program

- 13 coils fabricated and tested
- Established the fundamental coil technologies: conductor/cable, insulation, structure, reaction settings

- Record racetrack performance
- Bi-2212 technology is viable for high-field accelerator magnet

Godeke, *et al.*, *Supercond. Sci. Techn.* **23**, 034022 (2010)

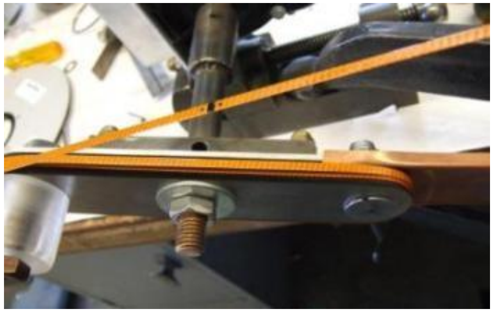


Courtesy of Arno Godeke

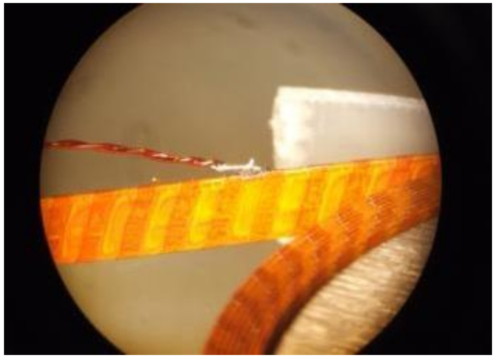
YBCO program

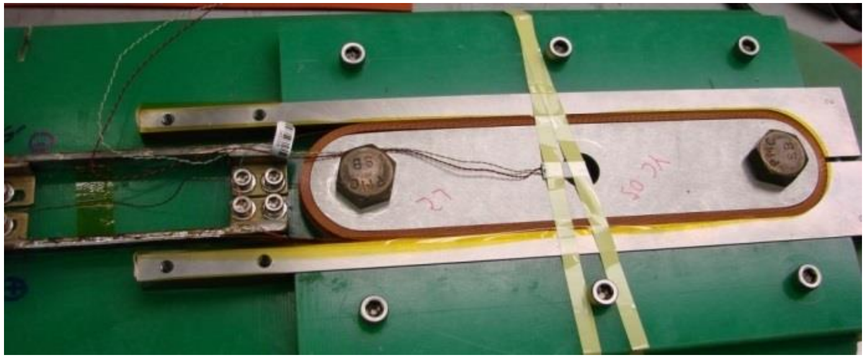
- Correlate the short-sample and coil performance to evaluate coil fabrication technology
    - 2-layer racetrack, single conductor

Coil winding



Voltage tap





Coil performance at 77 K and 4.3 K

- Predict the coil performance based on short-sample behavior
- Reached at least 74% of expected performance

Expected performance: short sample and coil

	77 K	4.3 K	gain
Single conductor	180	1255	7.0
2D 2 × 3-turn coil	156	1078	6.9
2D 2 × 10-turn coil	121	837	6.9

Measured coil performance, similar gain as expectation

Coil	Layer	Turn	Structure	77 K	4.3 K	gain
YC04	2	3	G10 bars	129 (83%)	910 (84%)	7.1
YC05	2	10	Splitted SS horseshoe	90 (74%)	644 (77%)	7.2

Fruitful collaboration and technology transfer

CEA Saclay	Study of preload on Nb_3Sn coil in a dipole configuration
Fermilab	Conductor studies (modified design)
Brookhaven National Laboratory	Technology transfer (identical design, LBNL tooling/parts)
KEK-JAPAN	Application to Nb_3Al, using LBNL provided Nb_3Sn coils
中国科学院高能物理研究所 Institute of High Energy Physics, Chinese Academy of Sciences	The next one?

Summary

- Efficient tool for technology development
  - Cost-effective, rapid turn-around
  - Suitable for broad R&D topics
    - Conductor, cable, mechanics, materials, fabrication procedures, magnet behavior

- Enabled fruitful collaboration and technology transfer
  - Proved model for high-field magnet R&D collaboration