Progress on 25 T Design and Subscale Coil Tests with Bi-2212 Inserts

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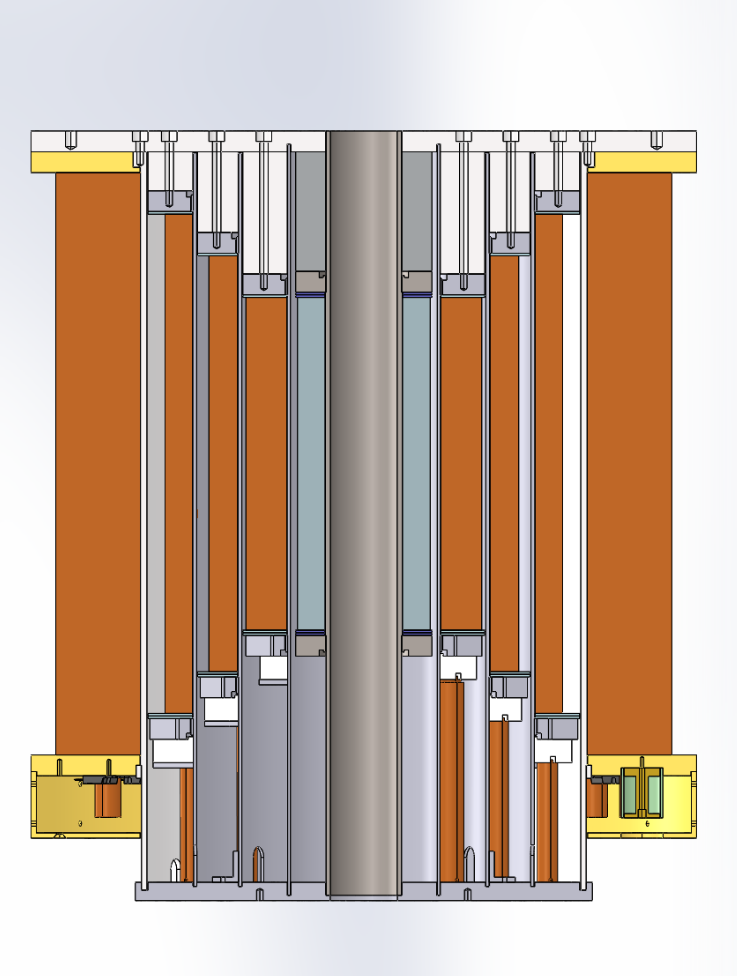
OVERVIEW

- Cryomagnetics received a 2018 DOE STTR Phase I and a 2019 DOE STTR Phase II award to design a viable 25 T all superconducting magnet using an 8 T Bi-2212 insert inside of a 17 T LTS background coil, suitable for commercial use
- The 17 T background coil is based on a magnet already built by Cryomagnetics, currently in the field at a customer site
- Cryomagnetics is collaborating with the team at ASC to design the 25 T
- Two subscale coils have been built for preliminary testing, another is currently under construction, and more are planned for the near future

25 T All Superconducting Magnet

- 25 T design consists of
  - 8-Tesla Bi-2212 insert
  - Three Nb3Sn coils generating 2-3 Tesla each
  - NbTi coil generating 9 Tesla
- Cold bore of 40 mm
- Quench protected and strain mitigated



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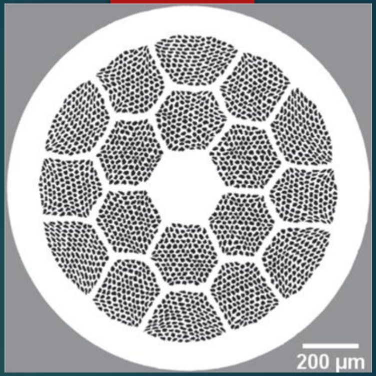
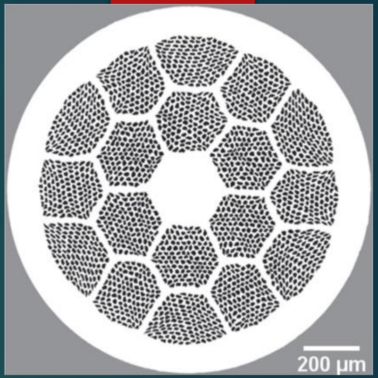
Bi-2212 Wire



- 0.8 mm wire appears to be the smallest diameter wire that can be presently trusted to perform reliably
- Even so, 0.8 mm wire has mostly been used in Rutherford cables, where single-strand defects are not as critical as they are in a solenoid configuration
- Solenoids made by ASC typically consist of >1.0 mm wire
- While the initial 25 T design will use separate power supplies for the HTS and LTS portions, one goal of Cryomagnetics is to have a series-connected system, so small diameter wire is desirable

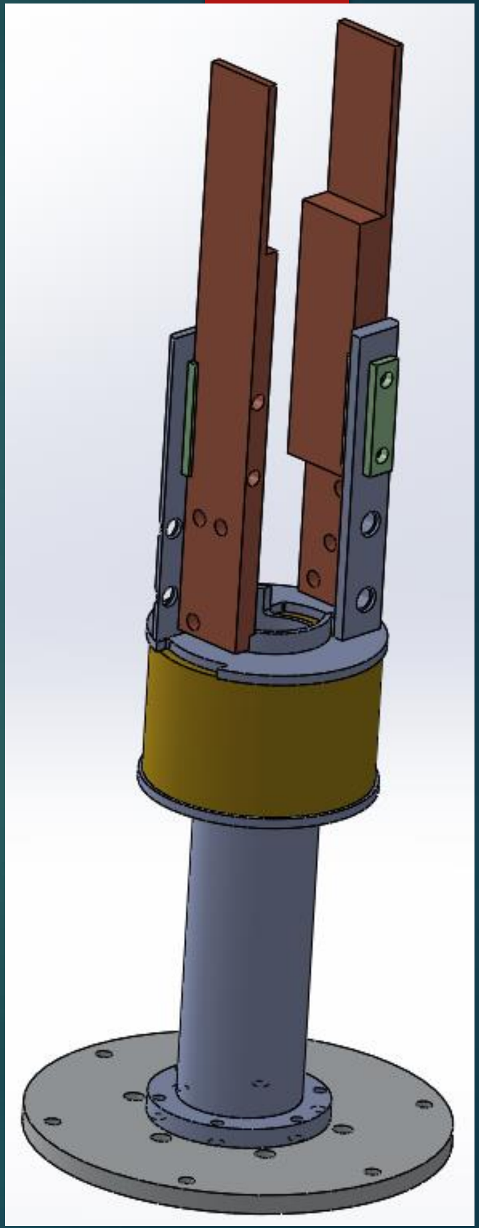
Bi-2212 Wire



- Y. Huang at Bruker-OST provided data that shows that the Bi-2212 filament diameter stays at a consistent 15 μm over a wide range of wire diameters, including down to 0.8 mm
- However, as mentioned, a single serious wire defect will render an entire solenoid unusable
- 0.8- and 0.9-mm subscale coils were made and tested, and a 1.0 mm coil is currently under construction, all produce ~5 T
- The subscale coils are small (~20 mm bore, ~4 cm length) and are used to characterize the performance of the Bi-2212 wire to aid us in the design of the 25 T magnet

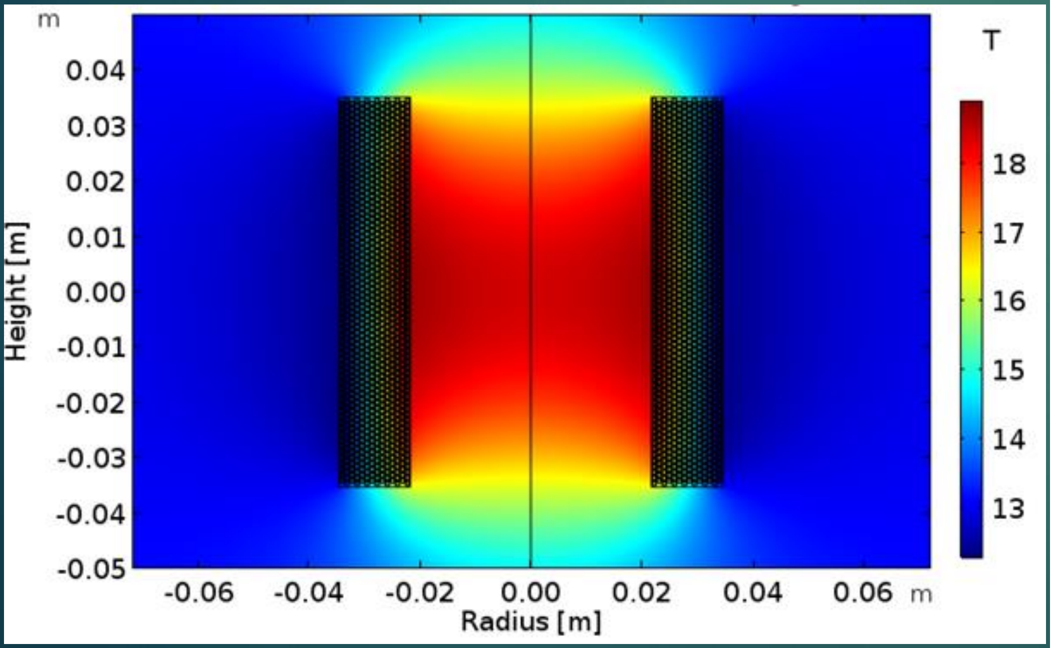
Subscale Coil Design

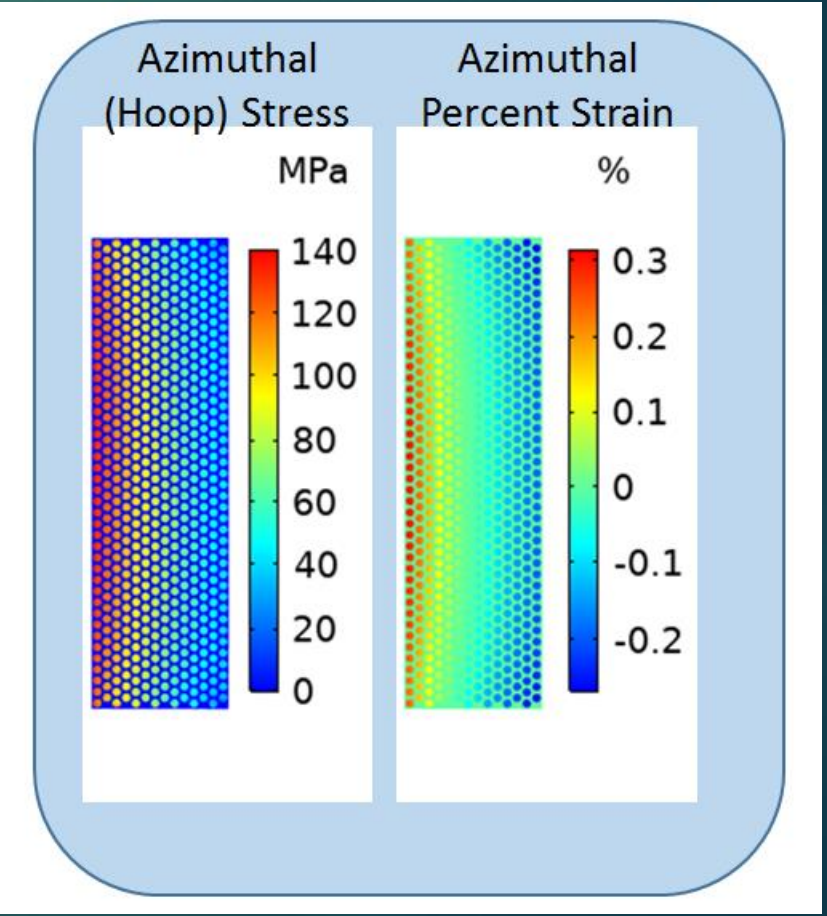
- Two subscale Bi-2212 coils, one with 0.8 mm wire, and one with 0.9 mm wire, were created in collaboration between Cryomagnetics and ASC
- The 0.8- and 0.9-mm coils are complete, and were tested in a 13 T background coil at Cryomagnetics, and a 14 T background coil at ASC
- A 1.0-mm subscale coil is underway, testing expected later this year



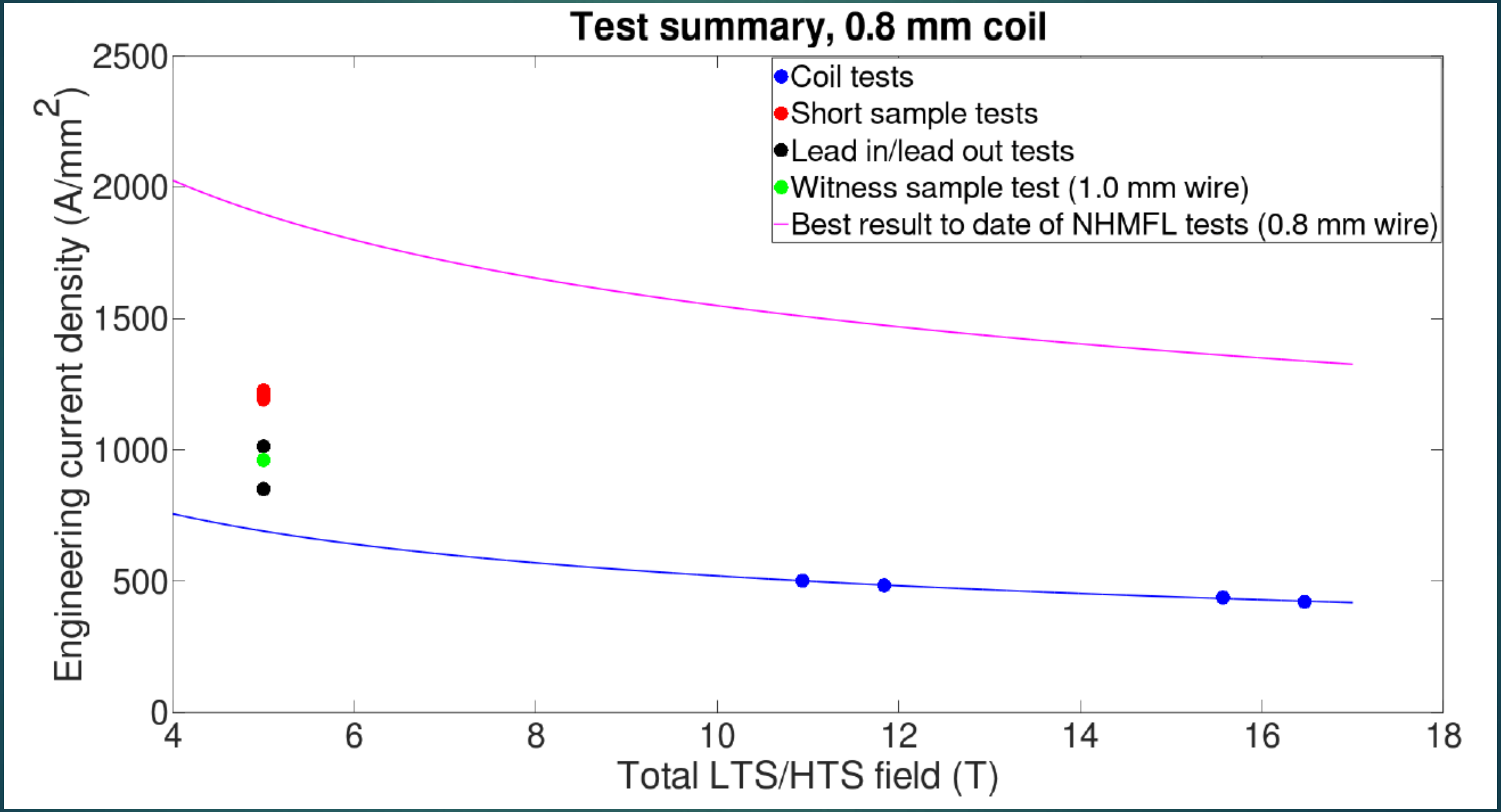
0.9 mm Subscale Coil Design

- The design has both J_E and strain within safe margins
  - < 800 A/mm^2 @ 18 T
  - < 0.4 % peak strain

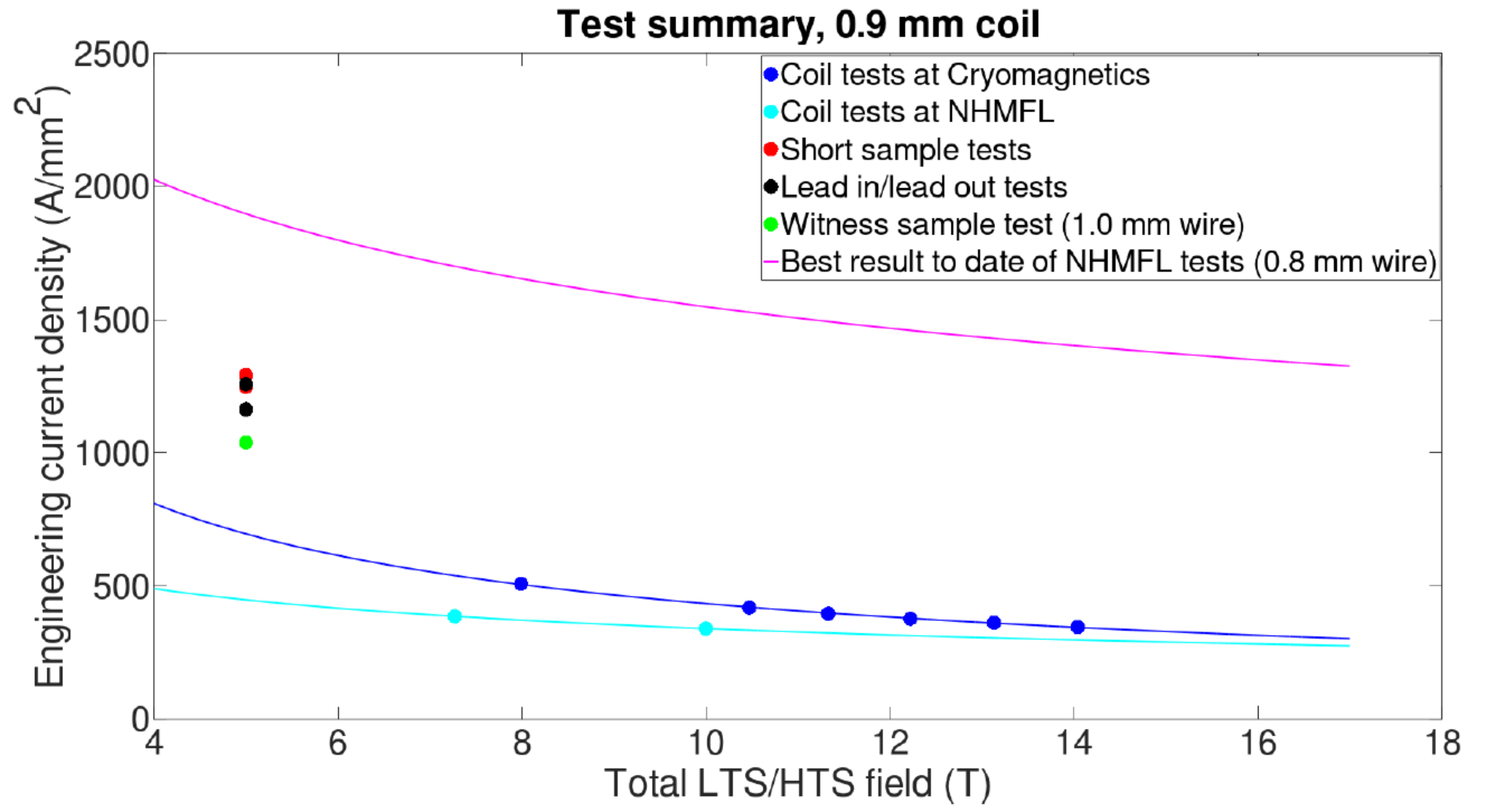




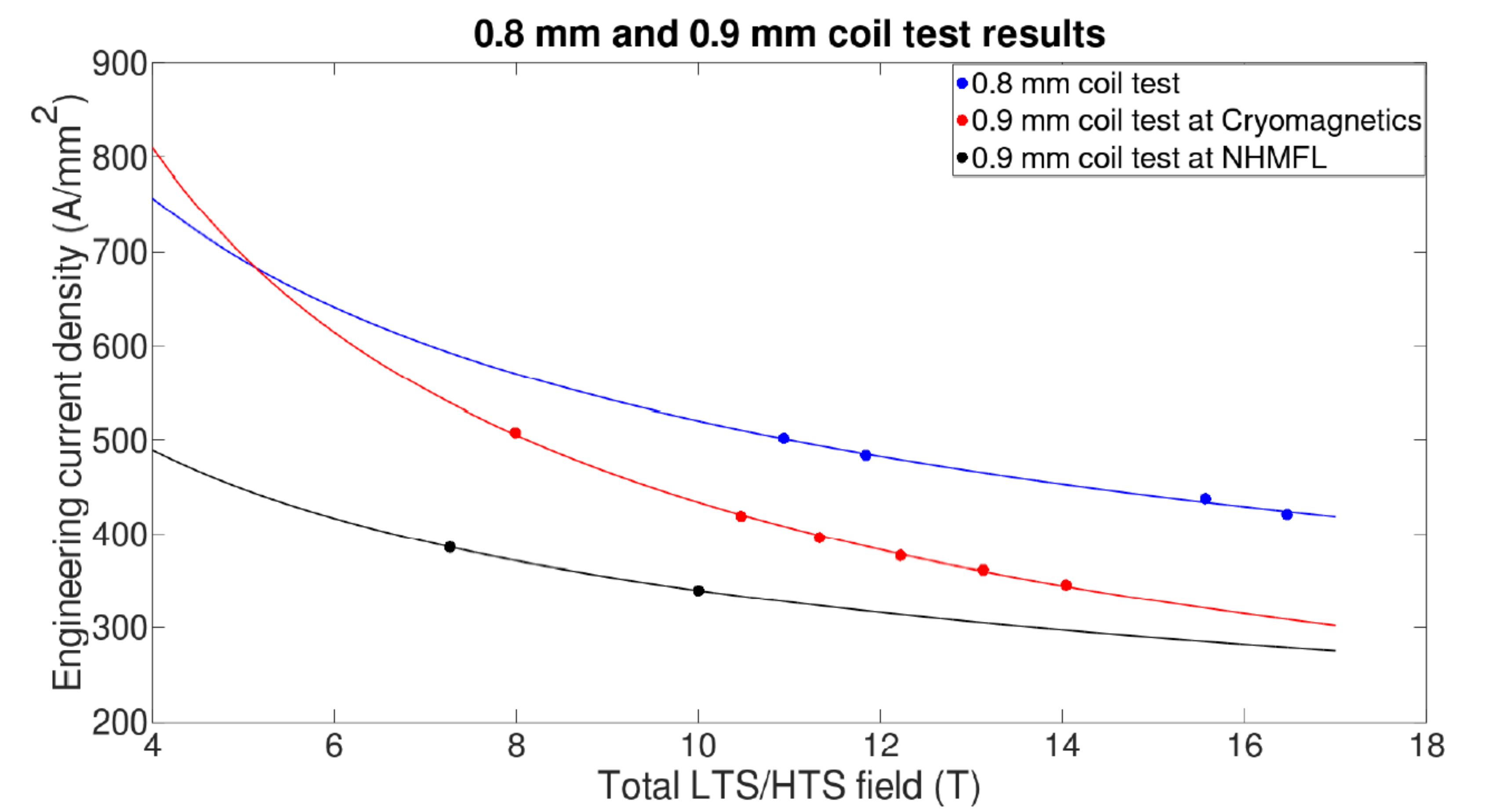
Test results for 0.8 mm coil



Test results for 0.9 mm coil



Full subscale coil results



0.8- and 0.9-mm Subscale Coil Cryomagnetics Test Notes

- The background magnet was charged to a range of field levels (5-12 Tesla) and the Bi-2212 coil was charged until a voltage was detected, when a dump resistor was switched in
- The power supply we used on the Bi-2212 runs (not a Cryomagnetics supply) did not allow precise control over the ramping rate, so consistency was challenging
- One of the Bi-2212 quenches (at 8 T background) caused the LTS magnet to quench, and the Bi-2212 coil survived with no degradation despite significant inductive coupling (i.e. successful passive quench protection)

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Why was 0.8 mm coil not tested at Cryomagnetics?

Shipping damage occurred in transit from ASC to Cryomagnetics

Unforeseen surprises are the rule in science, not the exception. –Leonard Susskind

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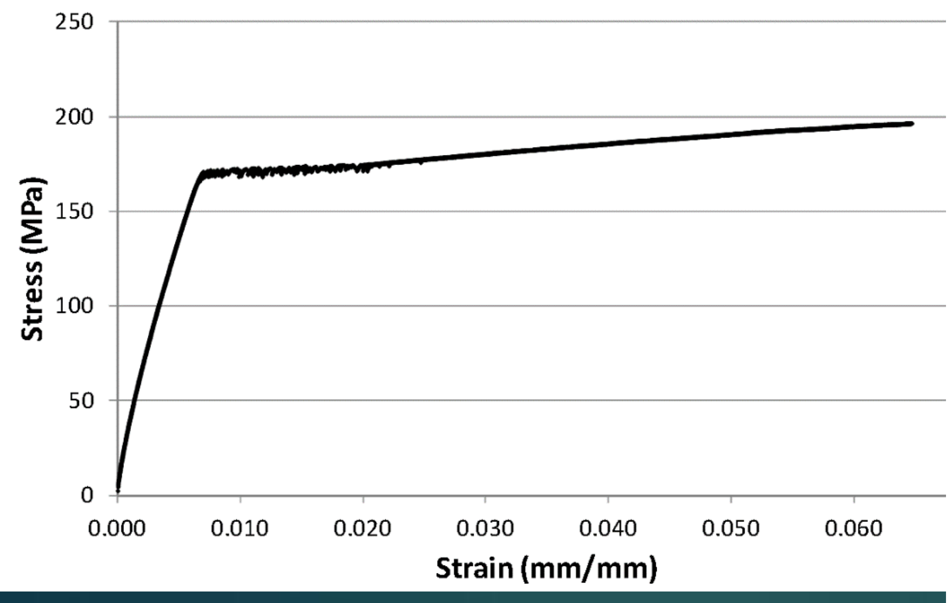
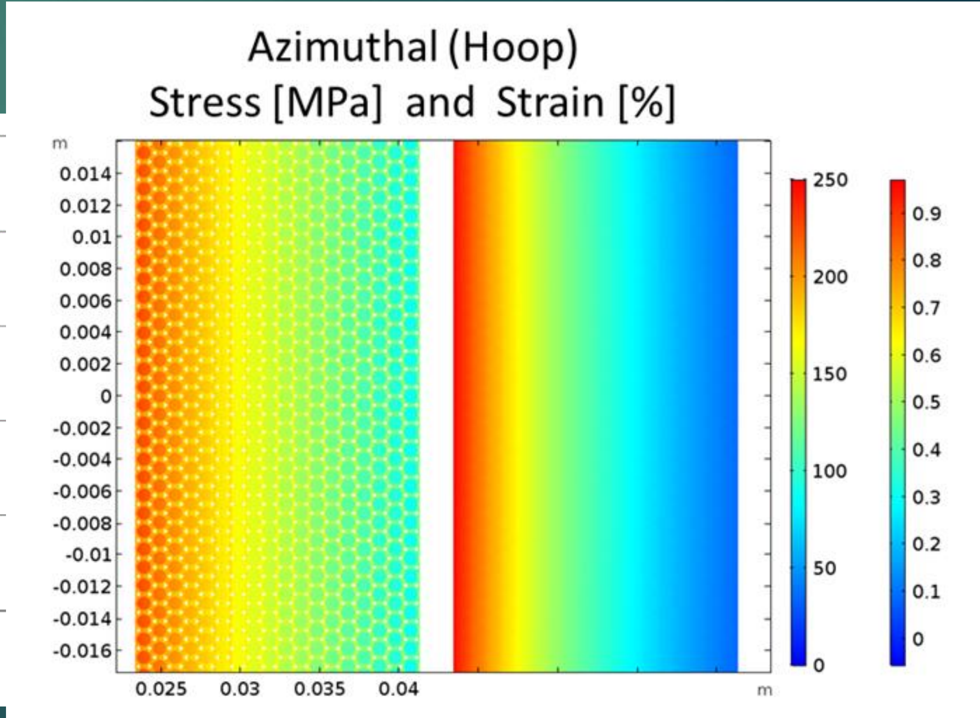
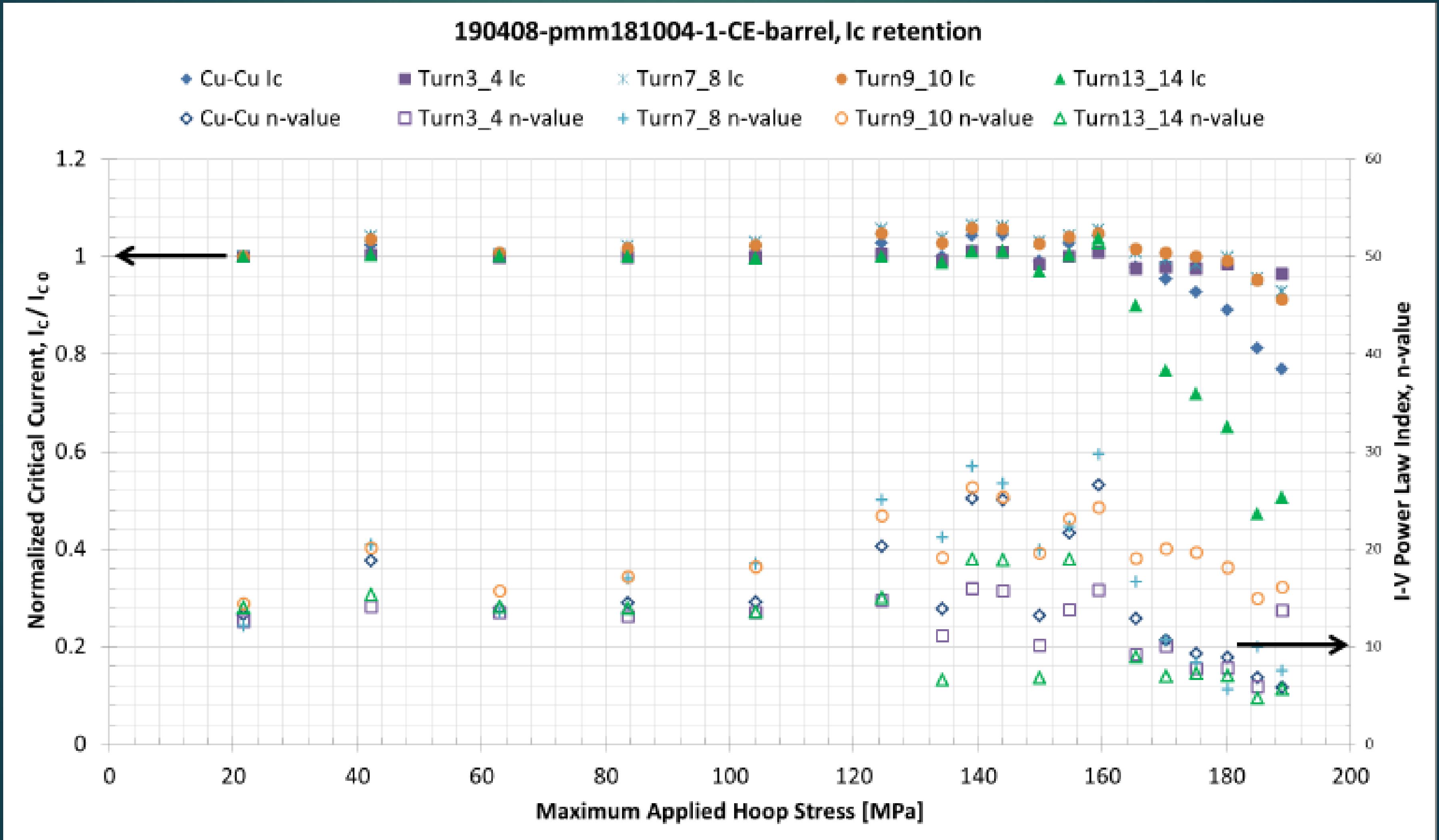
25 T Magnet Design: Strain Considerations

- While there's a desire to use Bi-2212 wire with the smallest diameter possible, achieving high J_E with moderate currents, and helping to ultimately lead to a series-connected HTS/LTS design, strain mitigation is crucial, and grading will be necessary

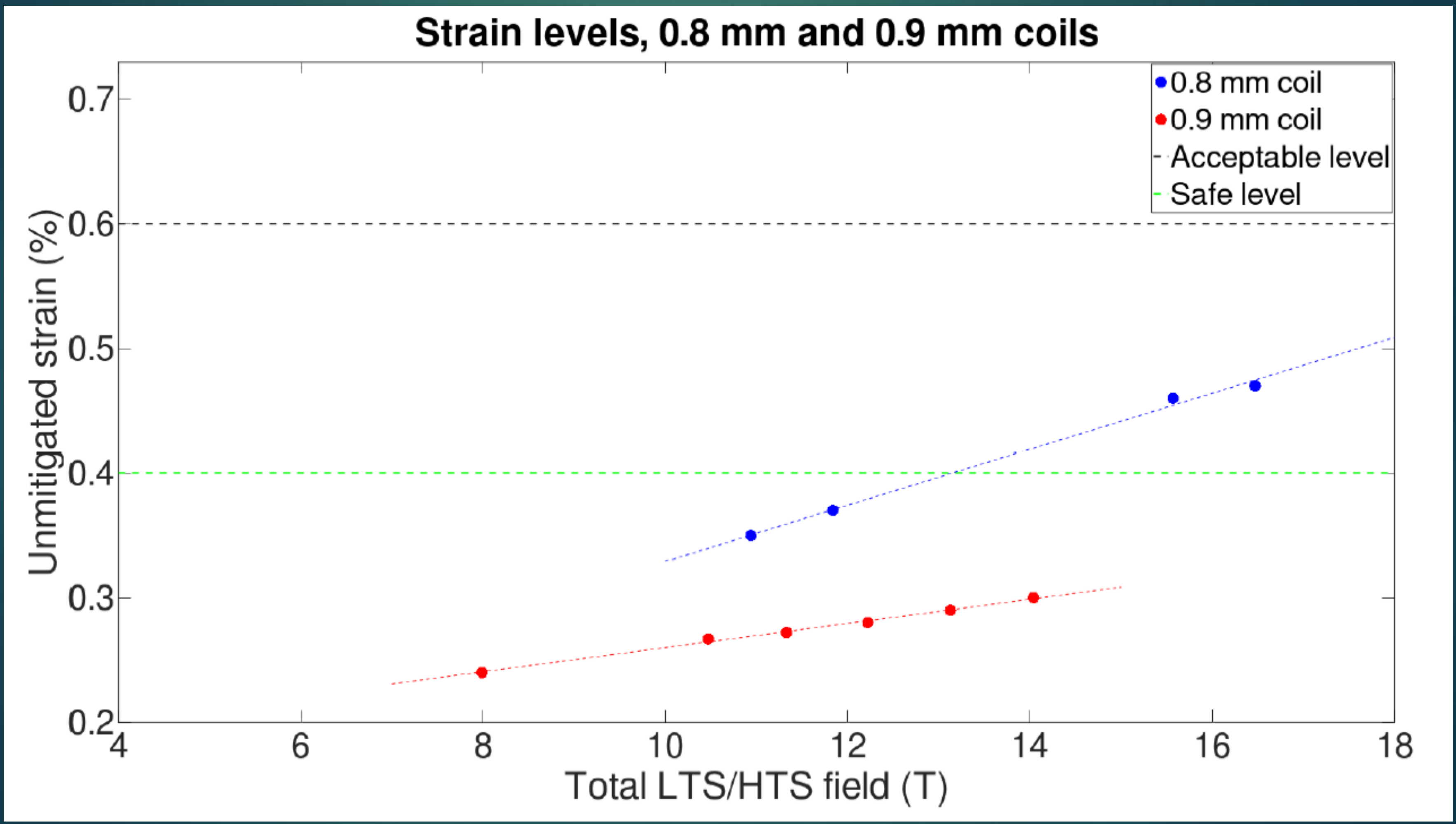




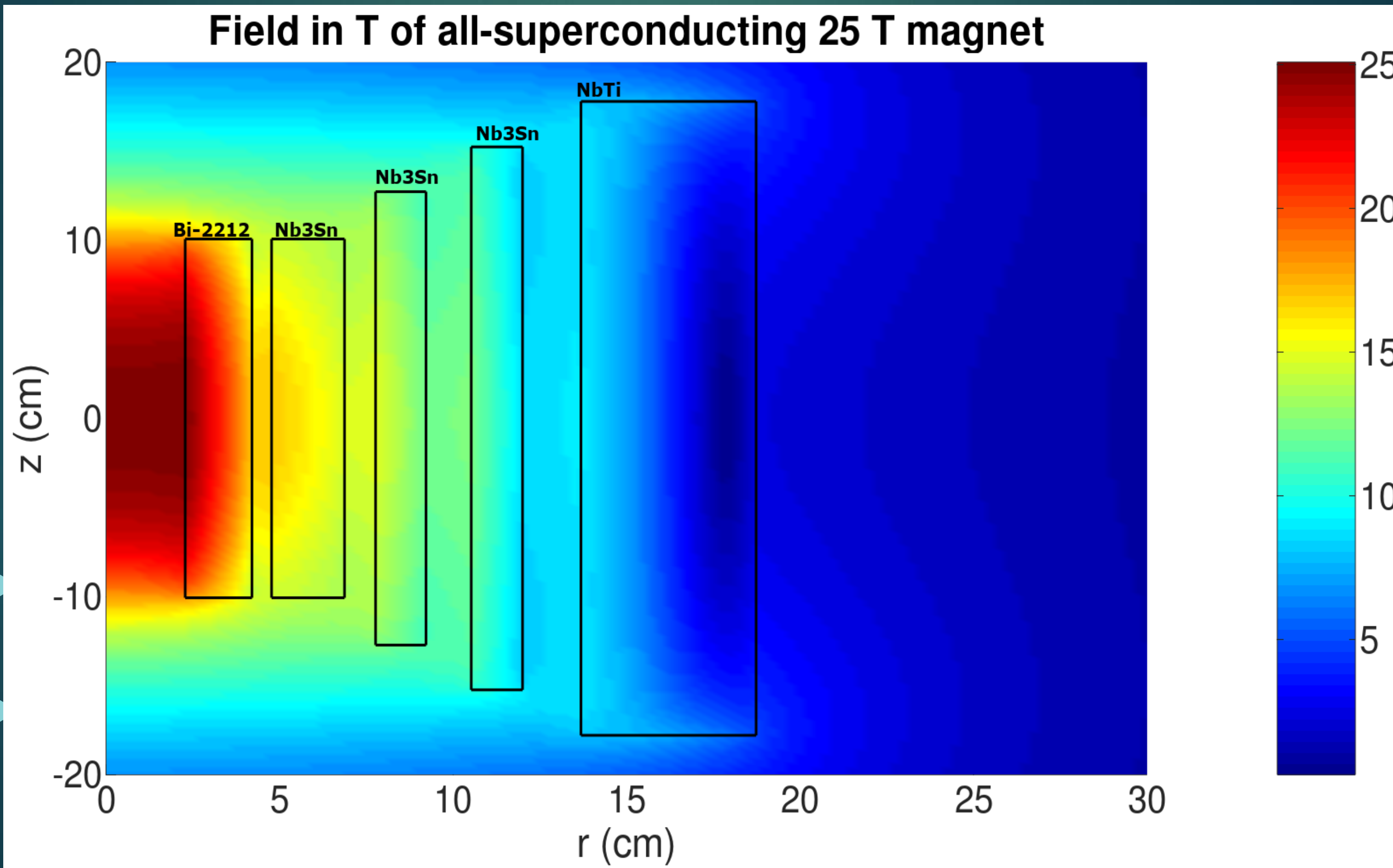
25 T Magnet Design: Strain considerations



Unmitigated strain of existing subscale coils



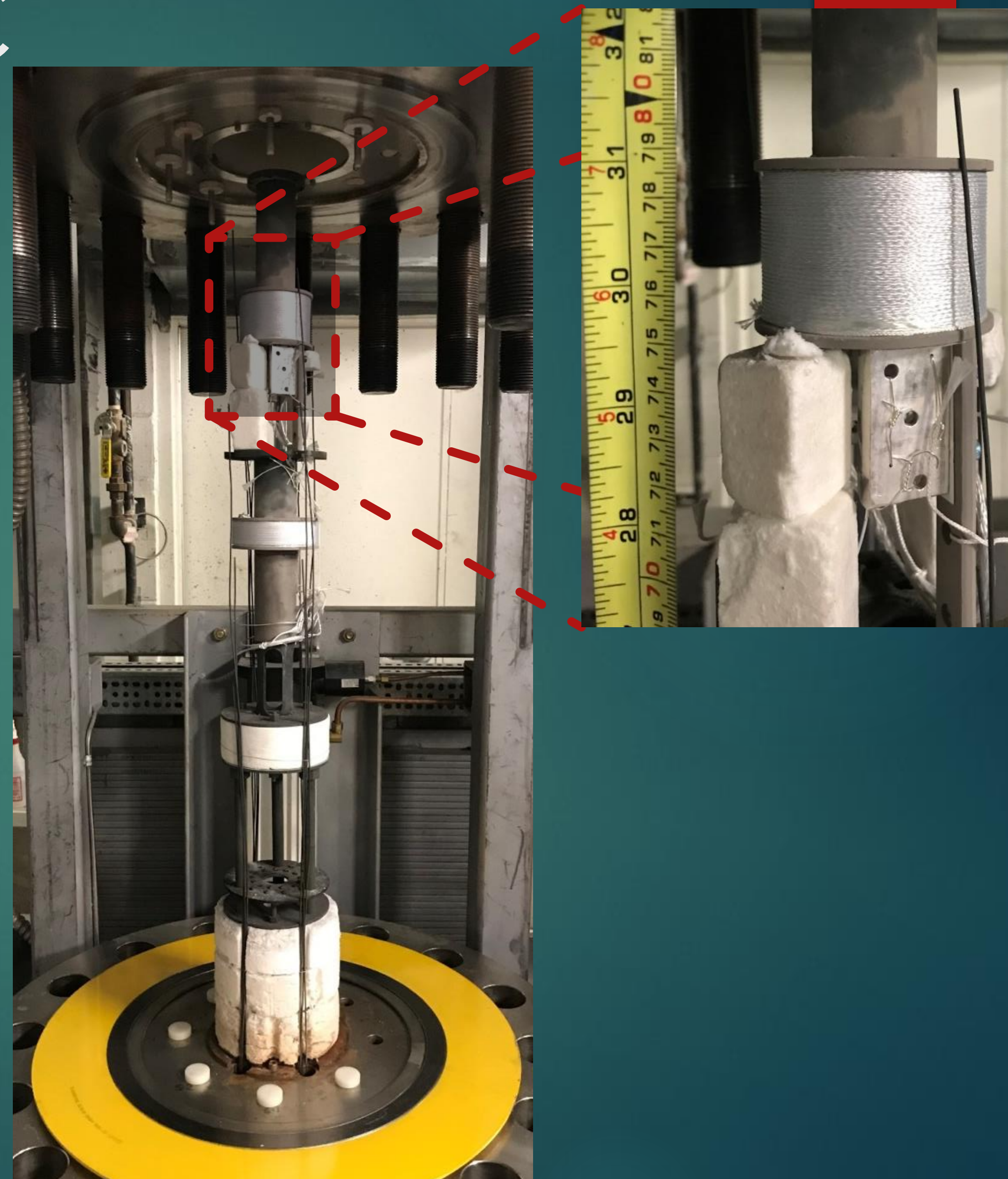
25 T Magnet Design: J_E considerations



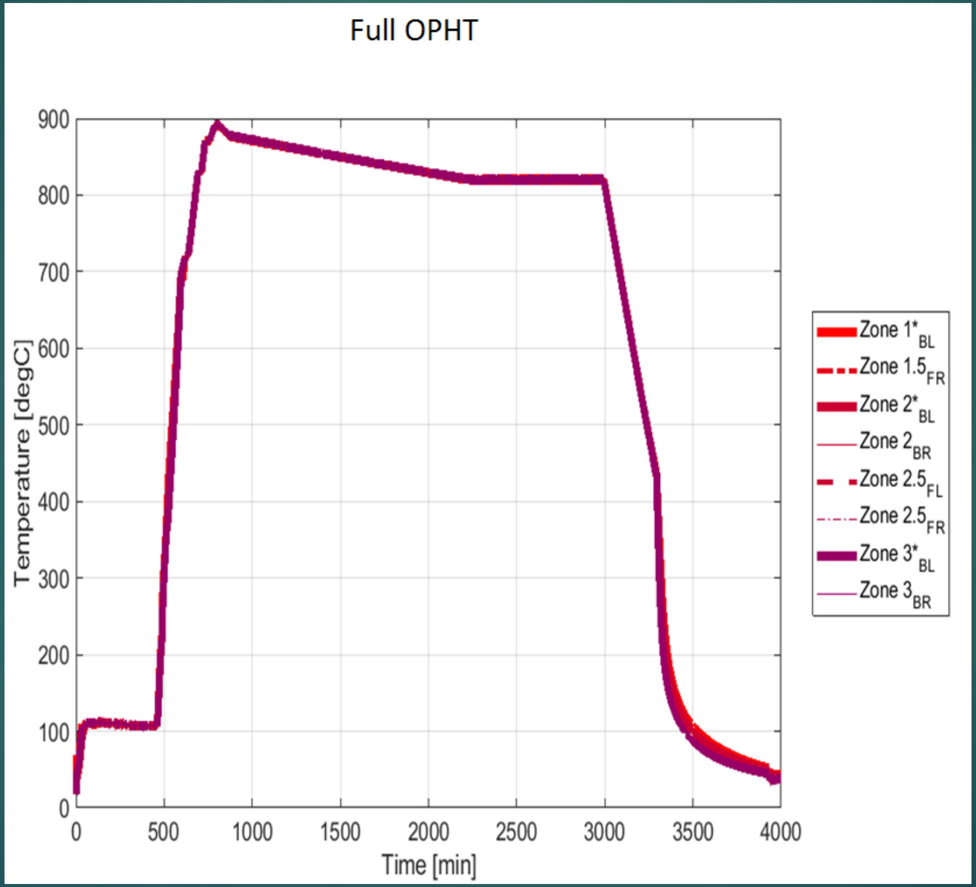
25 T Magnet Design: J_E considerations

- 1.0 mm wire
  - J_E = 485 A/mm^2
  - 47% of P. Lee's 2017 plot, 42% of ASC record sample
  - 61% load line (w.r.t Lee 2017)
- 0.9 mm wire
  - J_E = 600 A/mm^2 (lower than barrel test results)
  - 52% of Lee 2017 plot, 50% of ASC record sample
  - 67% load line
- 0.8 mm wire
  - J_E = 760 A/mm^2 (on par with barrel test results)
  - 61% of Lee 2017 plot, 40% of ASC record sample
  - 73% load line

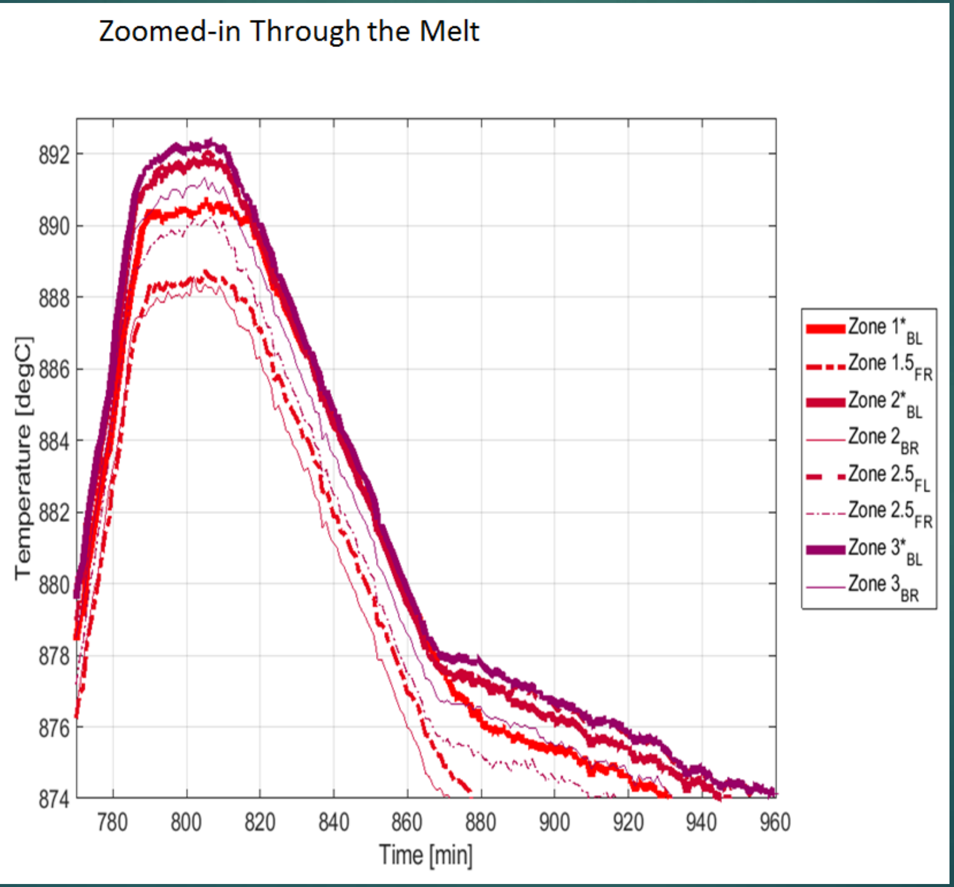
OPHT at ASC



OPHT at ASC Full Heat Treat



OPHT at ASC
Melting Phase Detail



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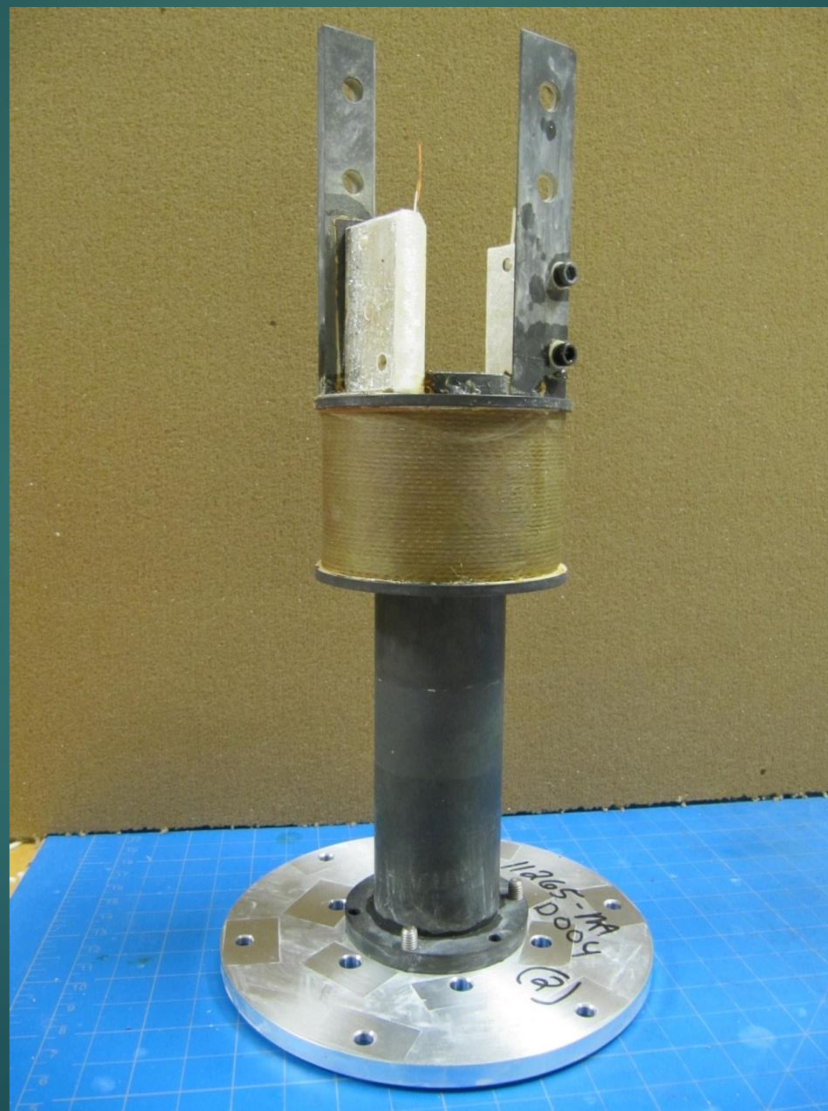
0.9 mm Subscale Coil—Finished Product



Conclusions

- The J_E values achieved in the 0.8- and 0.9-mm subscale coil tests were low (~1/3 of ideal J_E), but we believe we have found and isolated an issue and it will not arise in future coils, including the 1.0 mm subscale coil currently under construction
- The full-scale 25 T magnet design takes all expertise from ASC, as well as all results from Cryomagnetics' and ASC's full battery of tests on the subscale coils, into account
- Construction of the 25 T magnet will be performed in Year 2 of the STTR period, paving the way for commercial very high field magnets

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