BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

arpa·e CHANGING WHAT'S POSSIBLE

High Field HTS SMES Solenoid

Part I : Relevance, Overview & Lessons Learned

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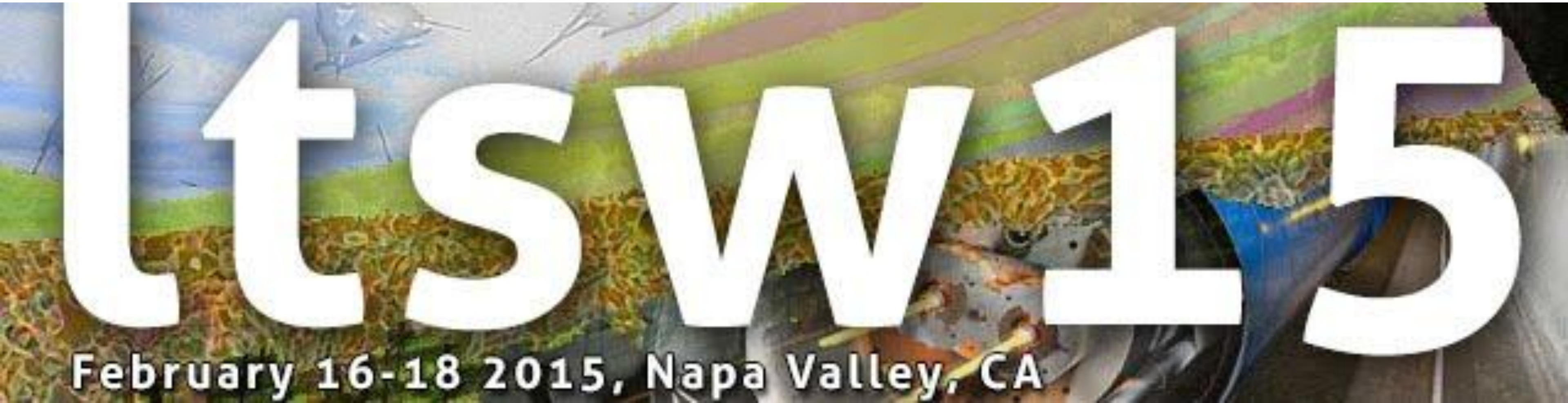
Part II : Coil Construction & 77 K Test (Lakshmi)



Relevance of SMES Solenoid to HEP High Field Magnet Program

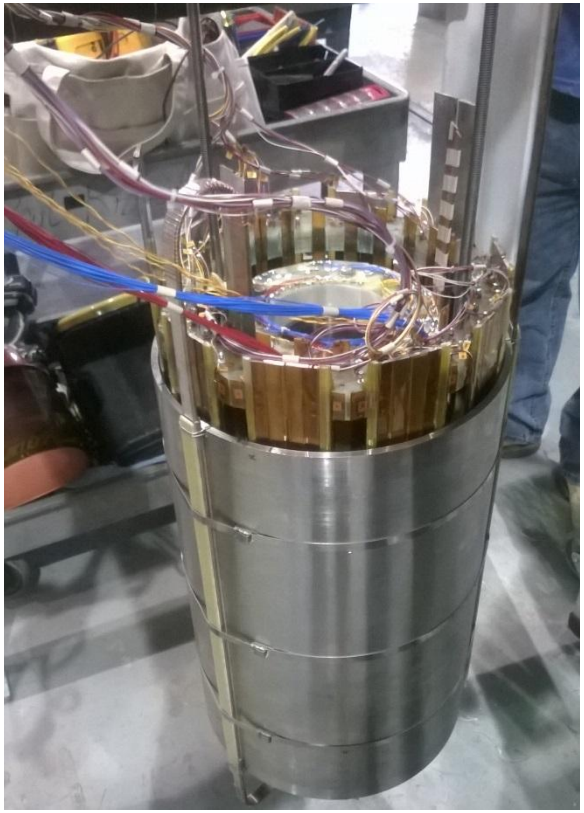
- High field: 25 T
- Large aperture: 100 mm
- Large stresses: 400 MPa
- Large number of coils: 48
- Significant HTS per coil: 100 m to over 200 m
- Large use of HTS: over 6 km, 12 mm wide
- Associated technology: quench protection, etc.

Large aperture high field all HTS magnet

- **There has been no such HTS magnet project in the past**
- **Aggressive parameters – BNL/SMD appreciated that – but didn't want to miss the chance of learning from this major opportunity**
- **Significant portion of the technology developed & lessons learned are directly applicable to very high field magnets for HEP, etc...**

Parameters of HTS Solenoid

Stored Energy	1.7	MJ
Currrent	700	Amperes
Inductance	7	Henry
Maximum Field	25	Tesla
Operating Temperature	4.2	Kelvin
Overall Ramp Rate	1.2	Amp/sec
Number of Inner Pancakes	28	
Number of Outer Pancakes	18	
Total Number of Pancakes	46	
Inner dia of Inner Pancake	102	mm
Outer dia of Inner Pancake	194	mm
Inner dia of Outer Pancake	223	mm
Outer dia of Outer Pancake	303	mm
Intermediate Support	13	mm
Outer Support	7	mm
Width of Double Pancake	26	mm

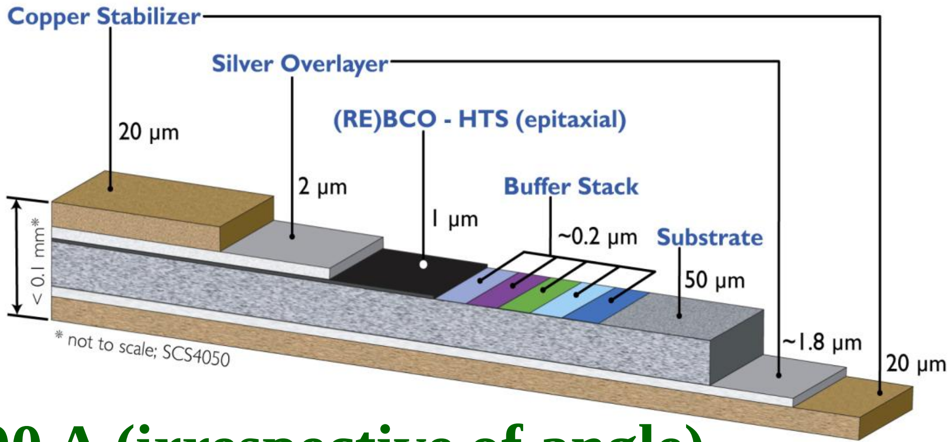


High field and big radius create large stresses (~400 MPa)

Conductor Specifications

SuperPower Inc. A Furukawa Company

12 mm wide



- ❑ **Formal specs at 77 K**
- ❑ **Informal specs at 4 K (mutually agreed upon)**
  - **Minimum I_c (@4K, 8T) : 700 A (irrespective of angle)**
  - **Ends of each cut saved for 4 K, in-field measurements**

Insulation: SS Tape
25 µm and 50 µm

Cu: 65 µm and 100 µm

➢ **for electrical and mechanical grading**

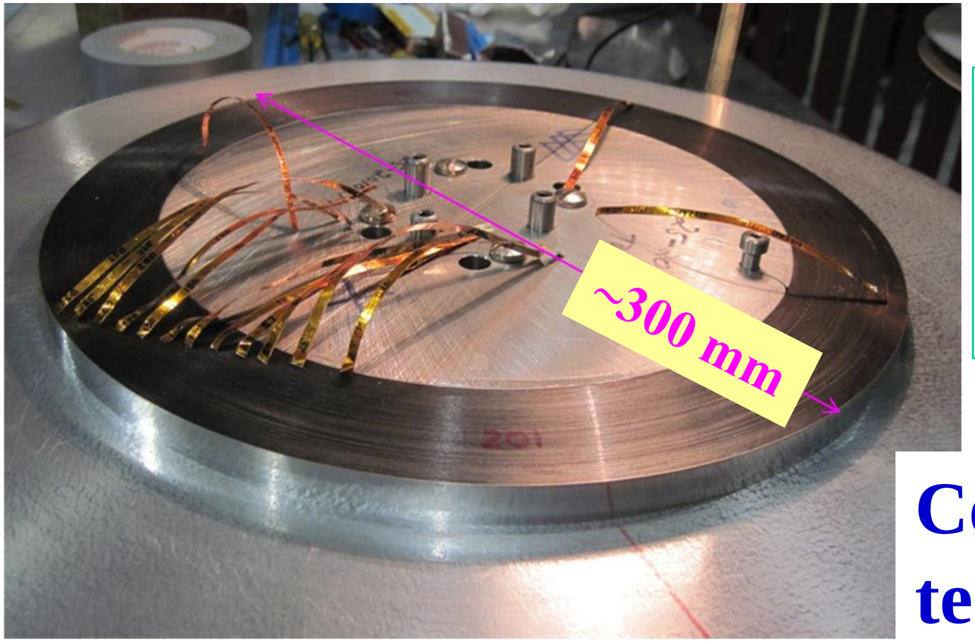
Hastelloy: 50 µm

Quality Assurance (QA) Used in Conductor and Coil

HTS is not a production conductor yet and was treated that way

- ➢ **Conductor inspected physically during the coil winding**

❑ **Each coil was tested at 77 K with many v-taps to find weak links**

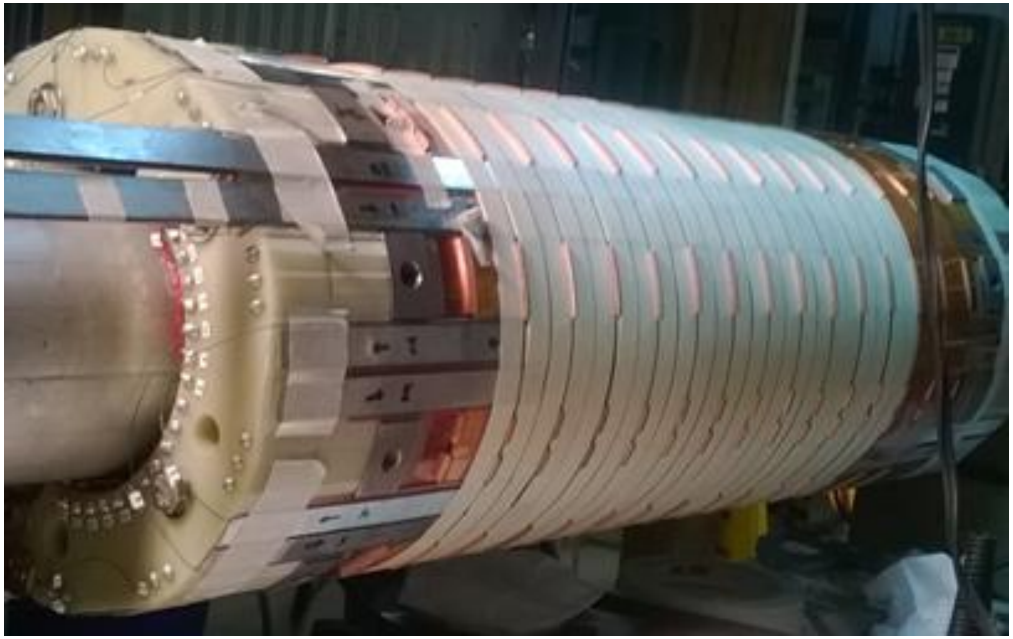


Outer: ~210 meter (258 turns)

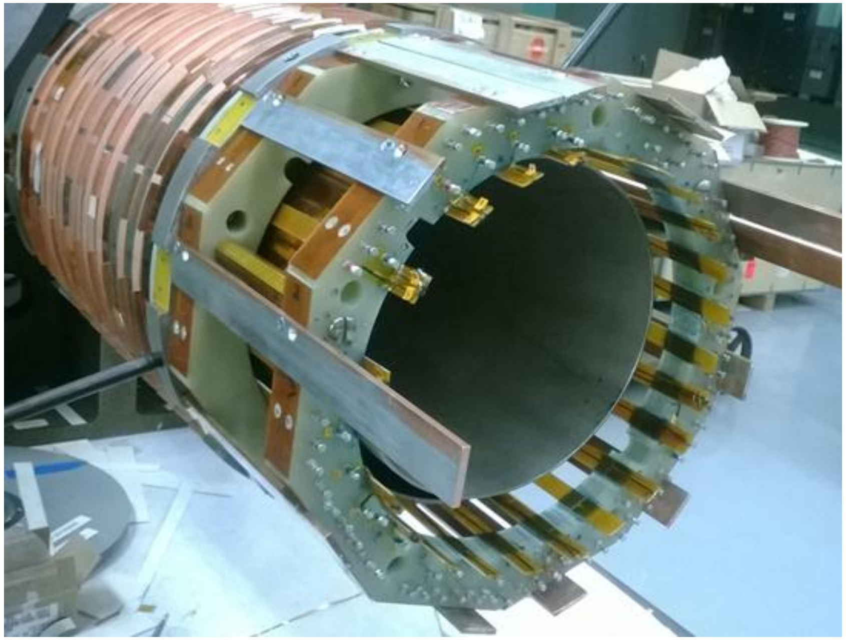
Few issues were discovered and decision was made on the case by case basis

Coil construction and 77 K tests in the next presentation

Inner and Outer Coils



Inner Coil (28 pancakes)
102 mm id, 194 mm od



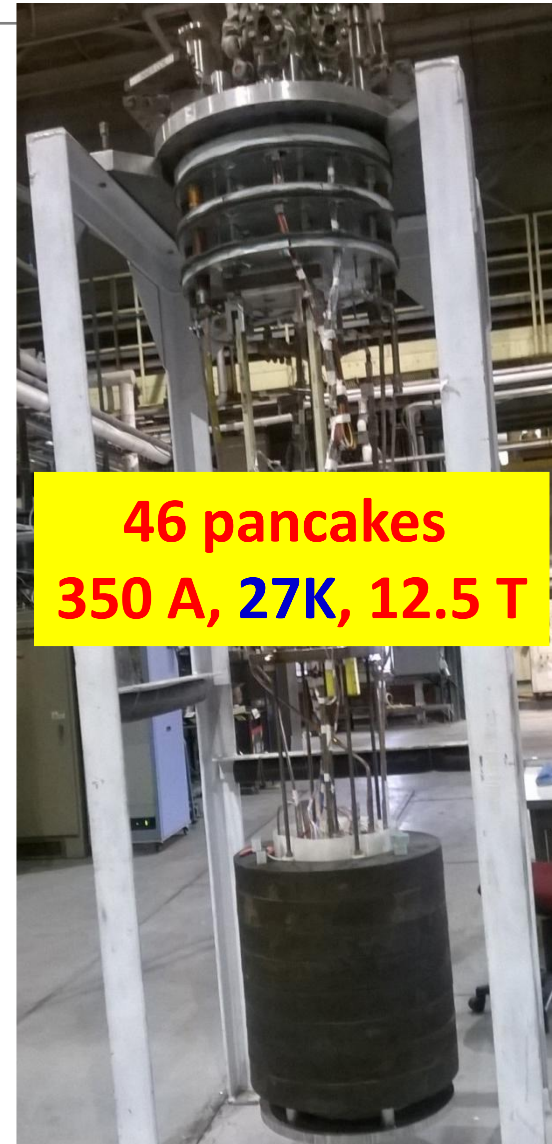
Outer Coil (16 pancakes)
223 mm id, 303 mm od

Multiple leads to bypass weaker or defective pancakes (plan for the worst case scenario: only one test run)

High Field HTS Magnet Test Results
100 mm bore, 12 mm ReBCO SMES Coil

2 pancakes
1140 A, 4K

12 pancakes
760 A, 4K, 11.4 T

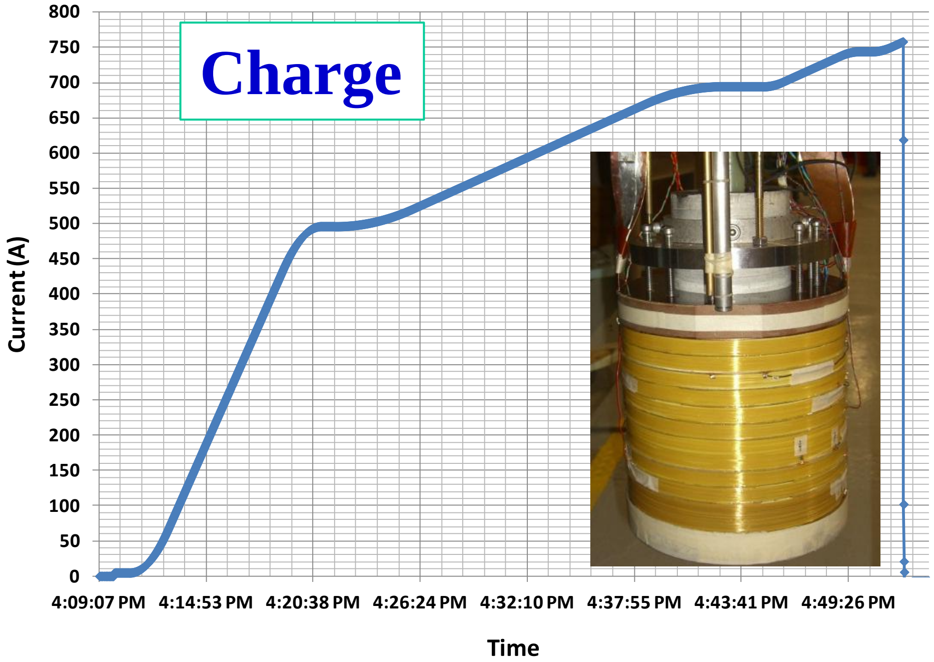


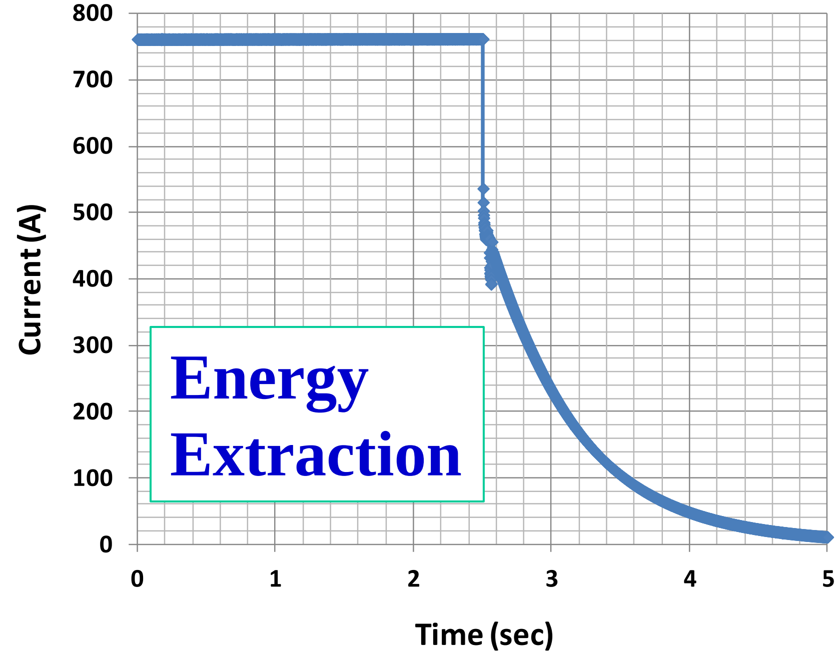
46 pancakes
350 A, 27K, 12.5 T

Peak fields higher

100 mm bore HTS Solenoid (4K Test)

12 pancakes, each made with 100 meter of 12 mm wide ReBCO Tape





- Reached ~ 11.4 T at 760 A
- Energy extracted and dumped in the external resistor
- 77 K re-test showed no degradation in coil performance

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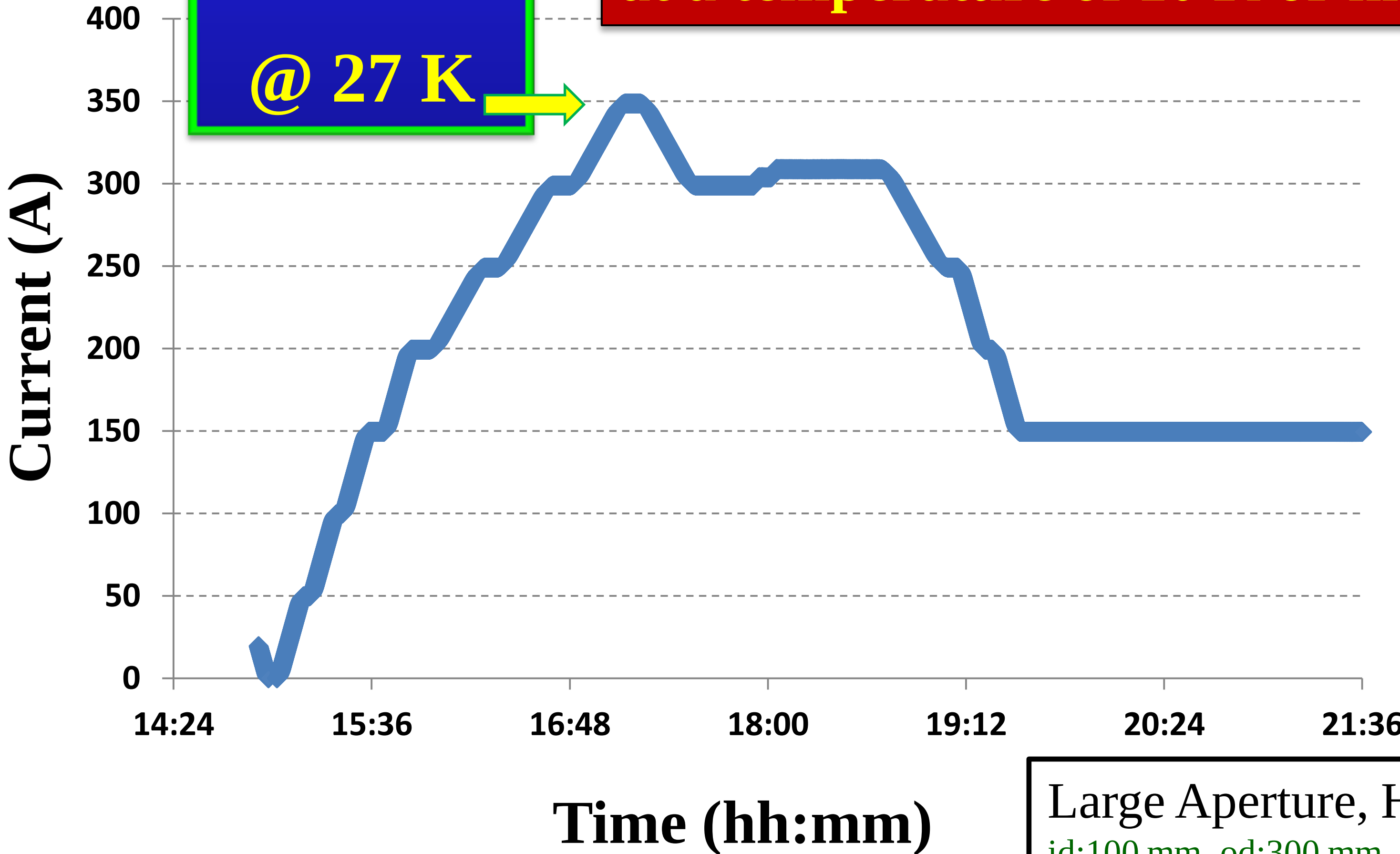
Last High Field SMES Coil Test at BNL

350 Amp
12.5 Tesla
@ 27 K

Record field in a superconducting magnet at a temperature of 10 K or higher



➢ The Event

Large Aperture, High Field Coil
id:100 mm, od:300 mm, >6 km of 12 mm tape

The Event

- We tested the solenoid at several temperatures between 20-80 K, including the 350 Amp (12.5 T) test run
- During one such test, the system tripped due to a data entry error at ~165 A – well below the current reached earlier
- The trip resulted in large resistive voltage in a few sections of the inner coil, together with the loss of most instrumentation

➢ Differences in opinion on what should be the next step

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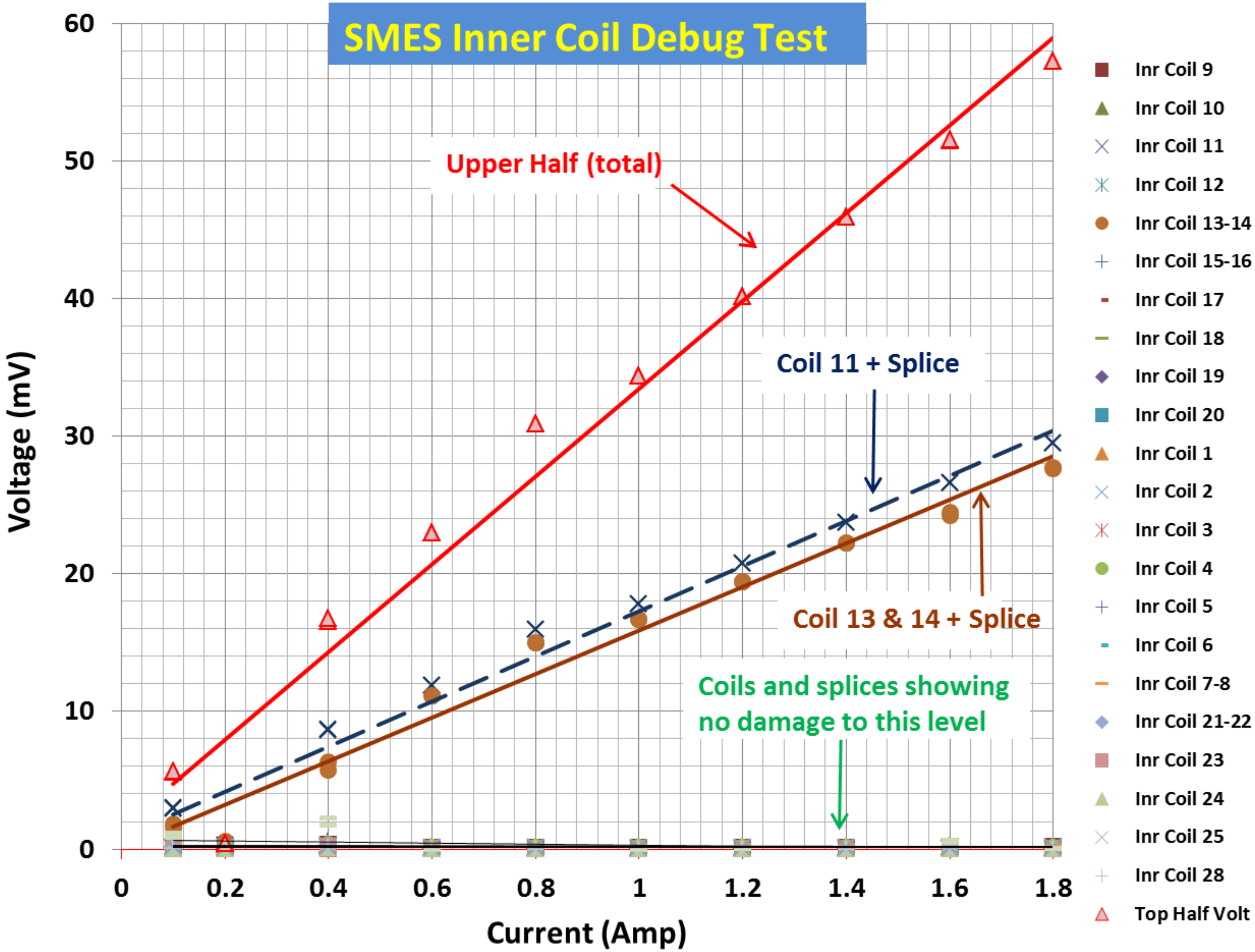
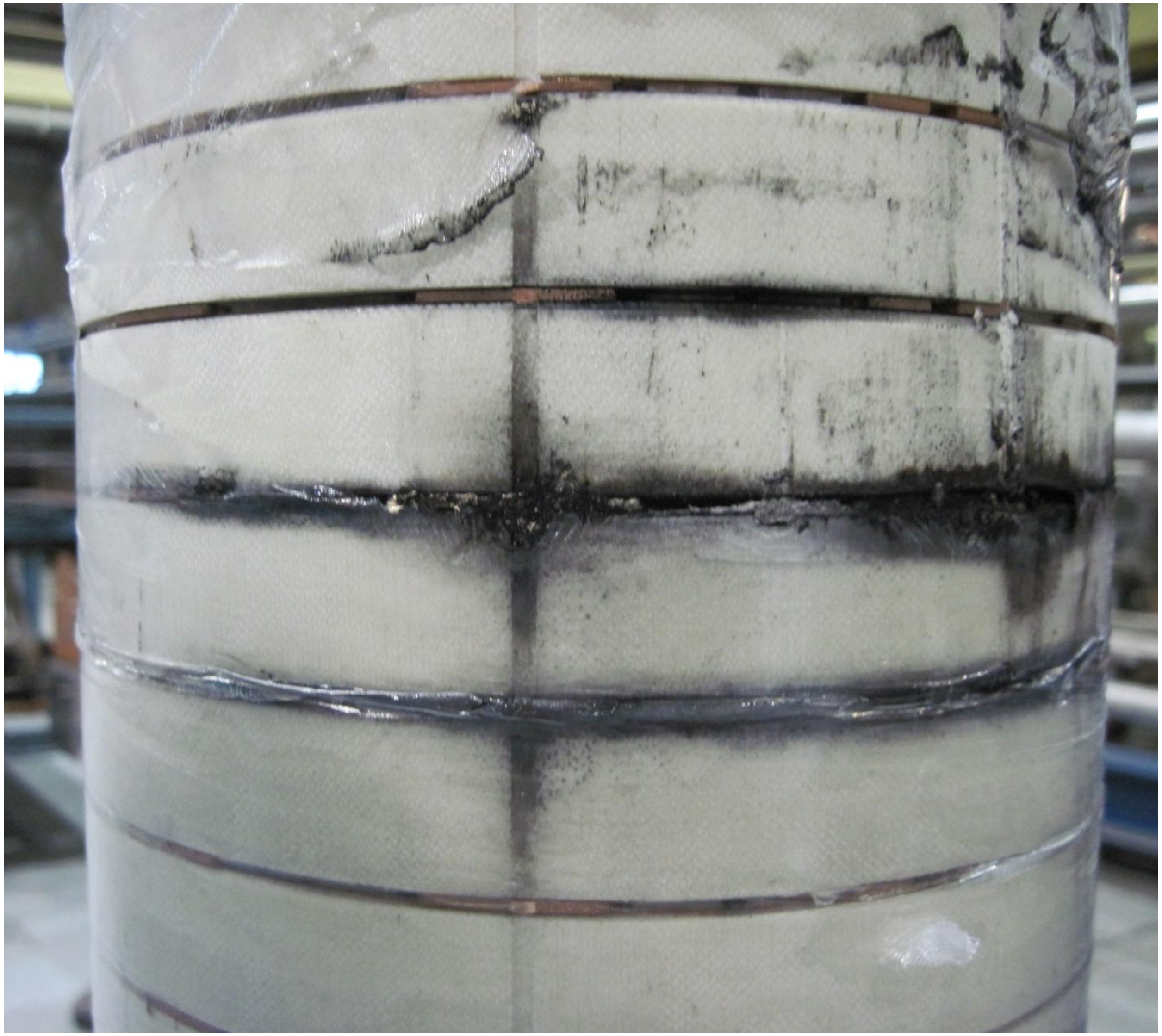
Low Current Superconducting Test (after the event, using back panel, etc.)



Major issues with the two sections consisted of "leads, splices and pancake coil(s)"

Physical Inspection of the Inner



Lessons Learned (personal thoughts)

- Technical reviews with subject matter experts are important
- In superconducting magnets (particularly demanding magnets with a new technology), more than one test and iterations are required. They must be part of the program
- The team that constructs the device is usually in the best position, at least in the first round, to debug and fix it before the magnet is out
- Above statements may be obvious but are important. Such reasoning should be understood and explained to collaborators and funding agencies - irrespective of the reasons
- Multiple failures, either real or perceived, in devices made with new material is not good for anyone, and may be detrimental to the field

SUMMARY

- **Even though the design goals - high field (25 T), big aperture (~100 mm), new conductor (ReBCO), large hoop stresses (~400 MPa) - were much to aggressive to be achieved in first attempt, the R&D opportunity was beneficial in advancing the technology.**
- **Demonstration of 12.5 T at 27 K is a significant milestone and is a demonstration of the potential of ReBCO.**
- **This is the first time that such a large amount of HTS (over 6 km of 12 mm wide tape) has been used in a high field application.**
- **From a pure scientific perspective, there is still lot to learn from the device made - setbacks are part of R&D, shouldn't be the end. However, the experience and several aspects of technology developed should be relevant to high field magnets for FCC.**