

# Fabrication and testing at 77 K of large-aperture REBCO pancake coils for a high-field SMES solenoid

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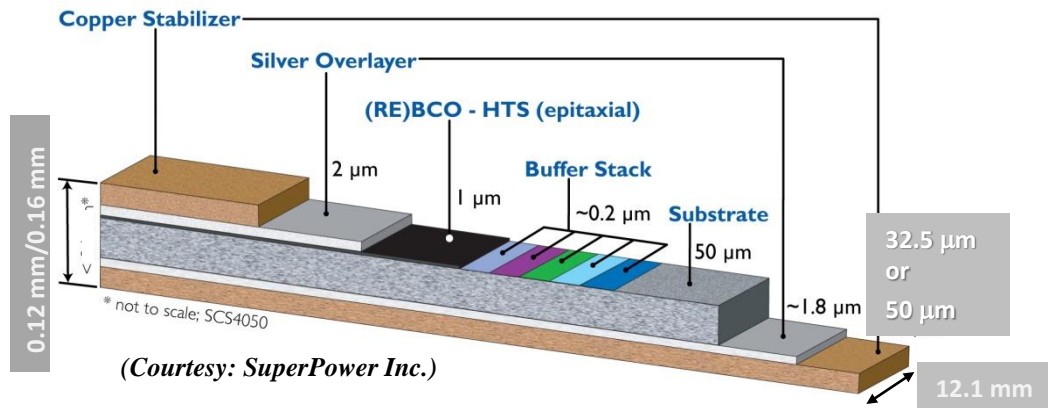
*This work is supported by ARPA-E via a CRADA between BNL and ABB Inc. and by Brookhaven Science Associates, LLC under the contract no. DE-AC02-98CH10886 with the U.S. Department of Energy*

## Presentation outline

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- Specification of REBCO tape
- Coil Parameters
- Fabrication of the single pancake coils
- Preparation of the double pancake assembly
- Test results of double pancake coils at 77 K
- Summary

# Specification of REBCO tape

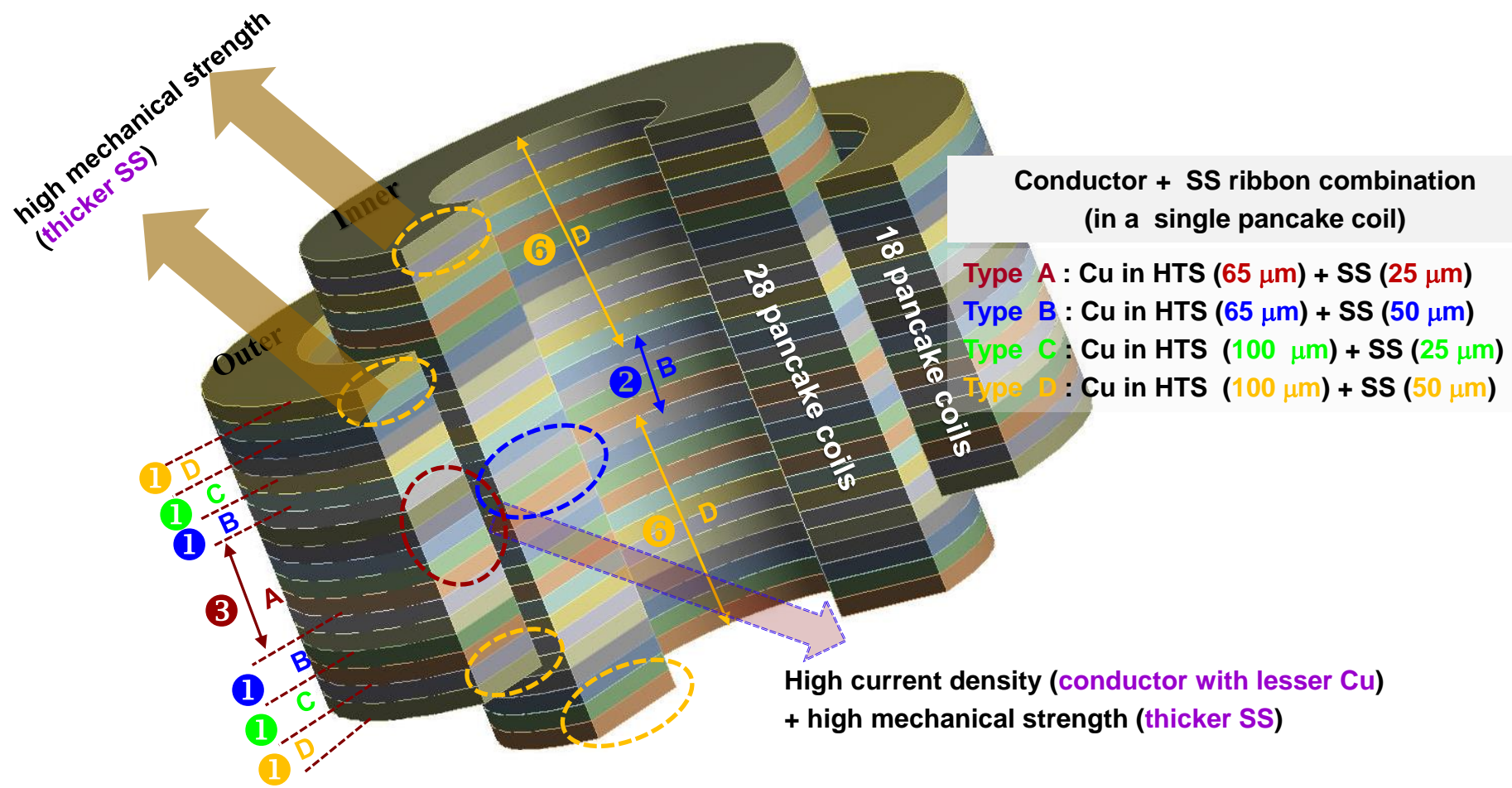


**Tape architecture**

- Type: SCS12050-AP
- Total length of the tape: ~ 7 km
- Width of the tape : 12.1 mm
- Thickness of Hastelloy substrate : 50 μm
- Thickness of copper stabilizer : 65 μm or 100 μm
- Thickness of the tape : 0.12 mm or 0.16 mm (depending on the thickness of the copper stabilizer)
- Piece length: 50 m to 400 m (may include multiple number of factory-made splices)
- Transport properties at 77 K, self field : **Minimum  $I_c > 300$  A ; Average  $I_c > 320$  A**

# Lay-out of the coils in the solenoid assembly

☞ Coils are graded to improve maximum field strength and mechanical stability margin.



# Coil parameters



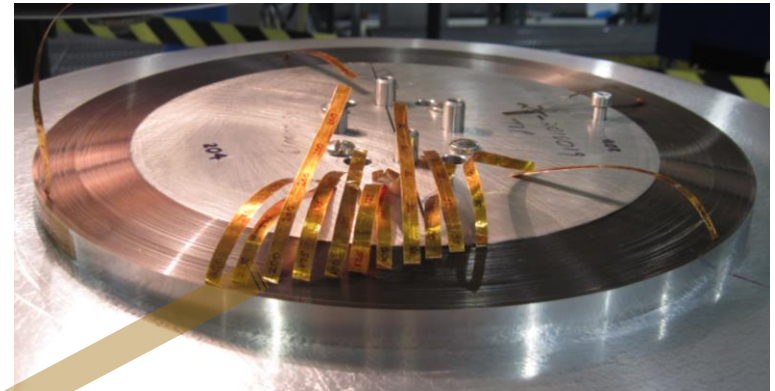
Number of inner coils : 28			
Type of the coil	B	D	
Thickness of Cu in the tape ( $\mu\text{m}$ )	65	100	
Thickness of SS ribbon ( $\mu\text{m}$ )	50	50	
Number of coils	4	24	
Nominal number of turns per coil	270	215	
Nominal length of tape per coil	125	100	



Number of outer coils : 18				
Type of the coil	A	B	C	D
Thickness of Cu in the tape ( $\mu\text{m}$ )	65	65	100	100
Thickness of SS ribbon ( $\mu\text{m}$ )	25	50	25	50
Number of coils	6	4	4	4
Nominal number of turns per coil	258	220	208	182
Nominal length of tape per coil	211	180	170	149

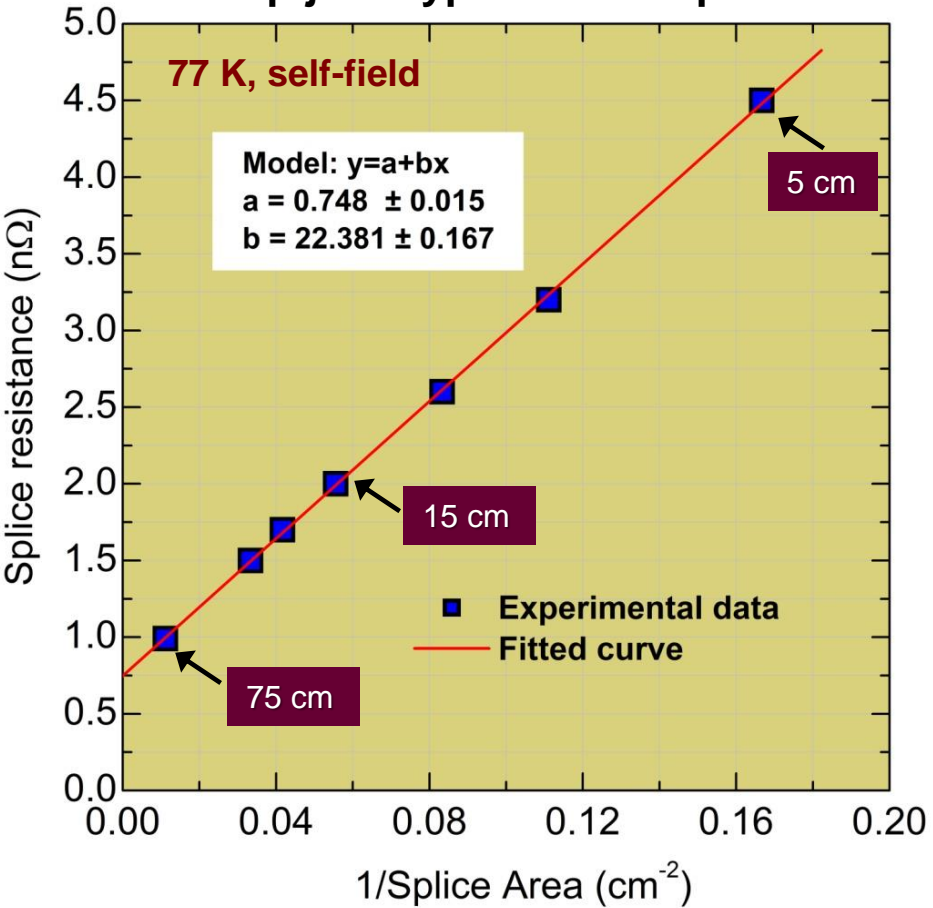
# Pancake coil winding

- In each pancake coil, the HTS layer of the tape faces inward towards the winding bobbin
- Spools of REBCO tape and SS ribbon were loaded with low tension during the winding process
- Tape was visually inspected during the coil winding (first measure of quality assurance of the coils).
- Multiple voltage taps (after first 10 turn and then after 25, 50 75 turns etc..) were installed for the detailed diagnostics of the coil sections at 77 K.
- Thin layer of epoxy painted on the top and bottom coil surfaces keeps the coil layers physically intact.



# Technology for low resistance HTS splices

Lap joint type REBCO splice

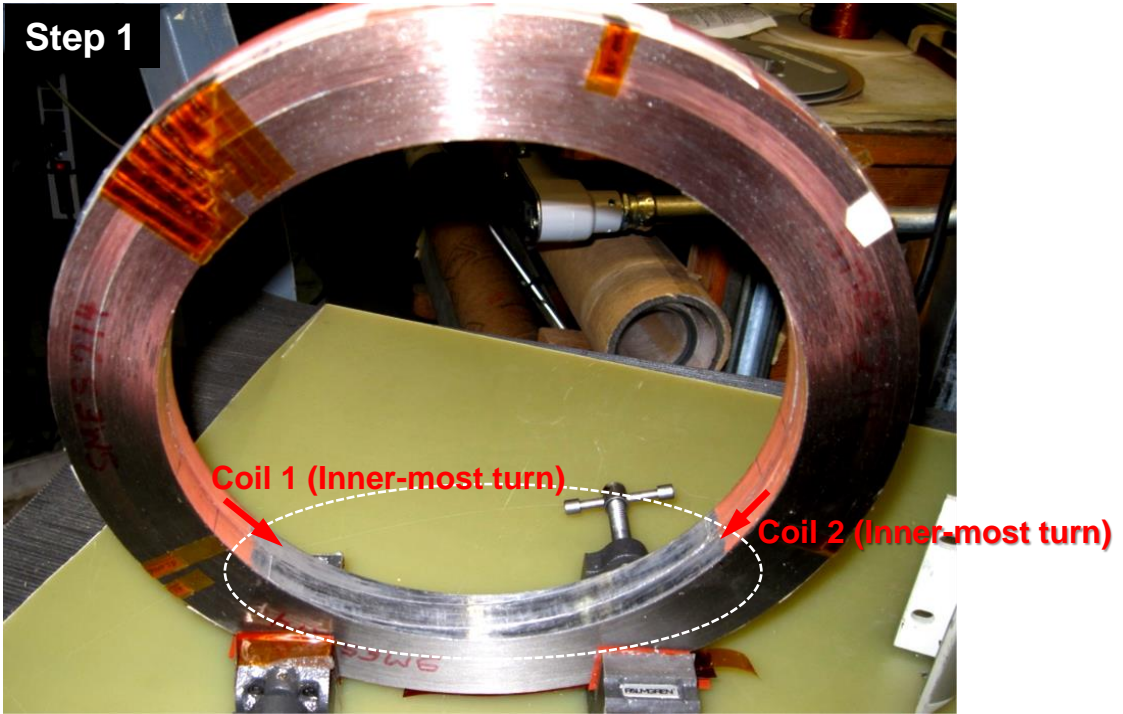


☞ Demonstrated a technology for low resistance REBCO splices for application to HTS magnets

☞ Implemented it in the construction of the pancake coils and in the magnet assembly

“ Low resistance splices for HTS devices and Applications”  
L. S. Lakshmi *et.al.* *Supercond. Sci. Techno.* (Manuscript to be submitted)

# Preparation of a double pancake coil

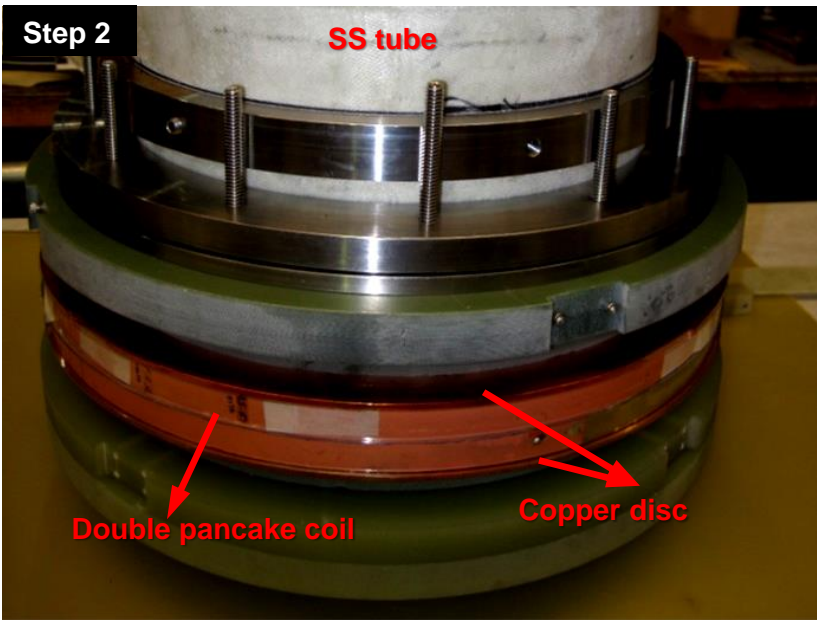


**Double pancake coil assembly  
(after installing spiral shaped splice)**

- Mylar spacer (~127  $\mu\text{m}$  thick) provides an electrical insulation between the pancake coils
- Spiral shaped splices placed on the inner surface connects a pair of coils in the double pancake coil assembly
- Splice overlap length : 15 cm (inner double pancake assembly)  
: 20 cm (outer double pancake assembly)

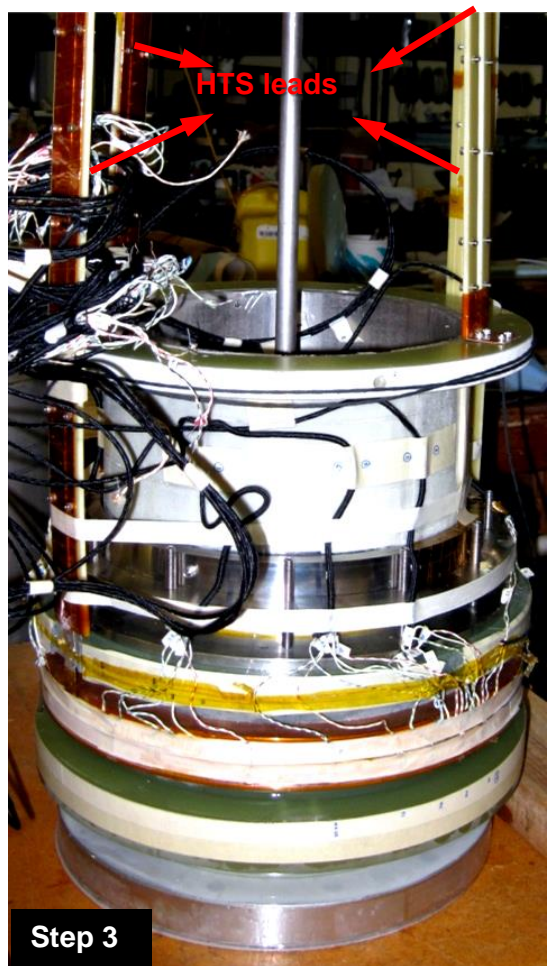


# Preparation for the 77 K test



**Double pancake coil assembly**  
(clamped between a pair of G-10 discs)

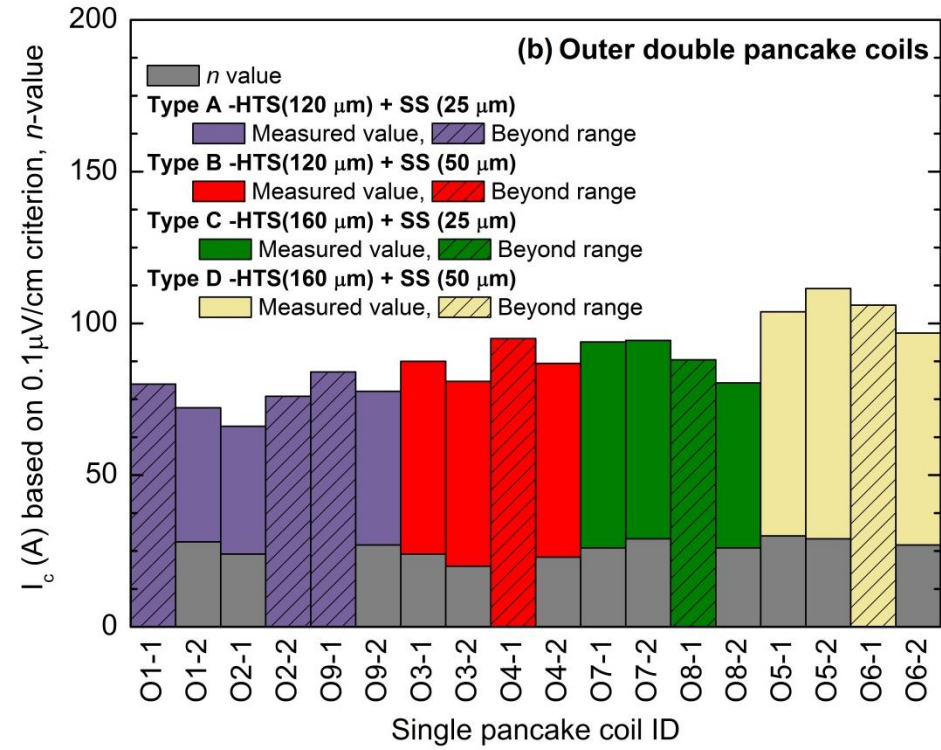
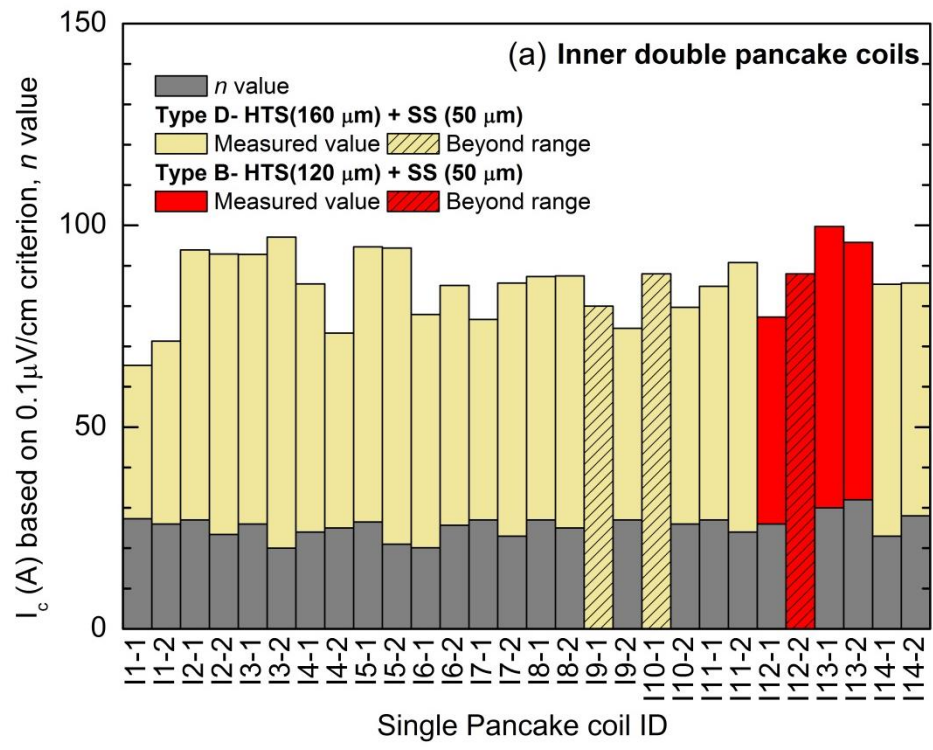
- DPC unit is mounted to an electrically insulated SS tube
- 3 mm thick Cu disk placed on the top and bottom of the DPC enables thermal conduction



**Double pancake coil assembly**  
(after securing multiple voltage taps)

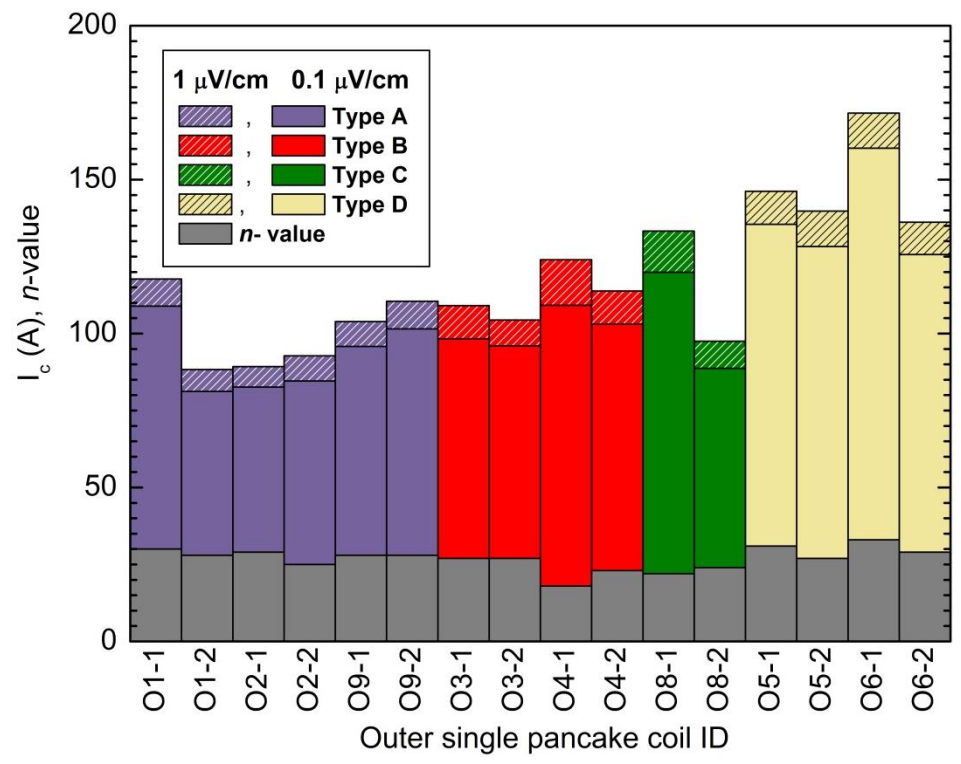
# Test results at 77 K : double pancake coils

Two pancake coils are connected in series



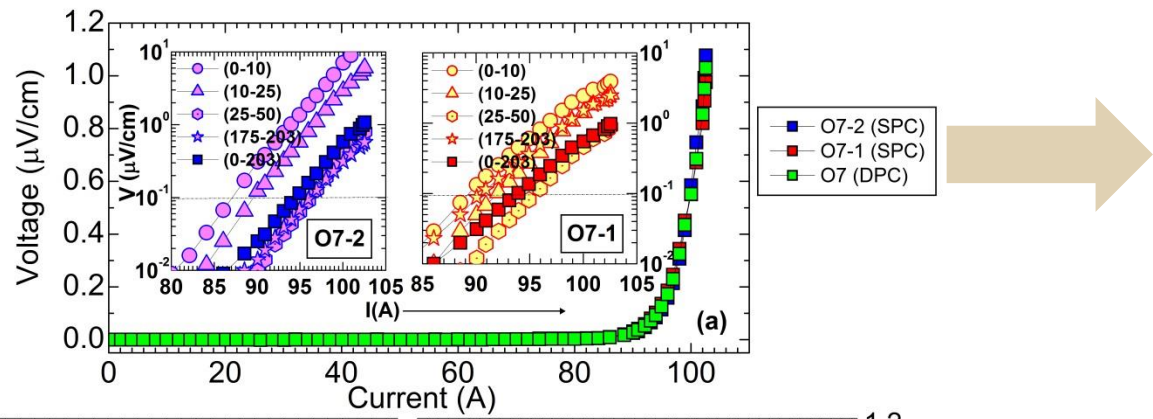
- $I_c$  of the companions coils range from 70 A to 100 A for the inner DPC assemblies and 75 A to 110 A for the outer DPC assemblies.

# Test result at 77 K of a series of outer single pancake coils

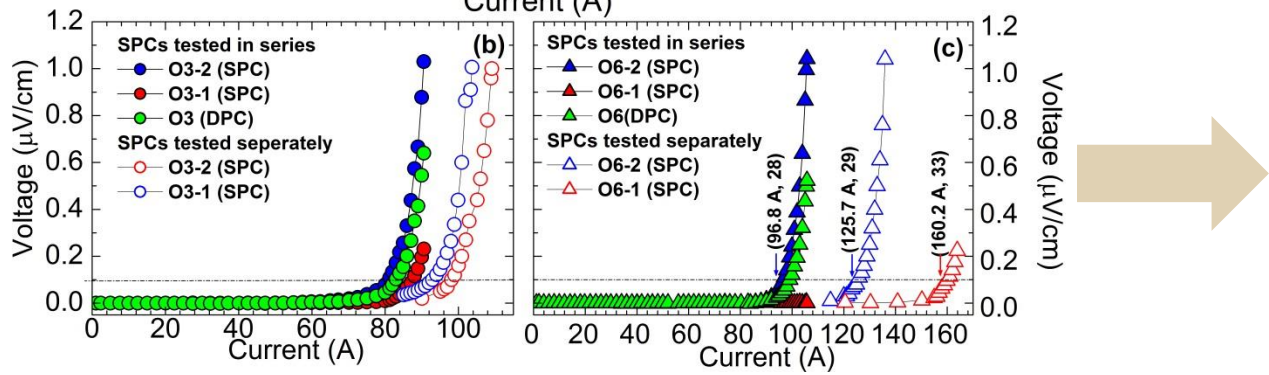


- No correlation exists between the  $I_c$  of the coil and the tape(s) constituting coil at 77 K.

# Highlights of the 77 K test results



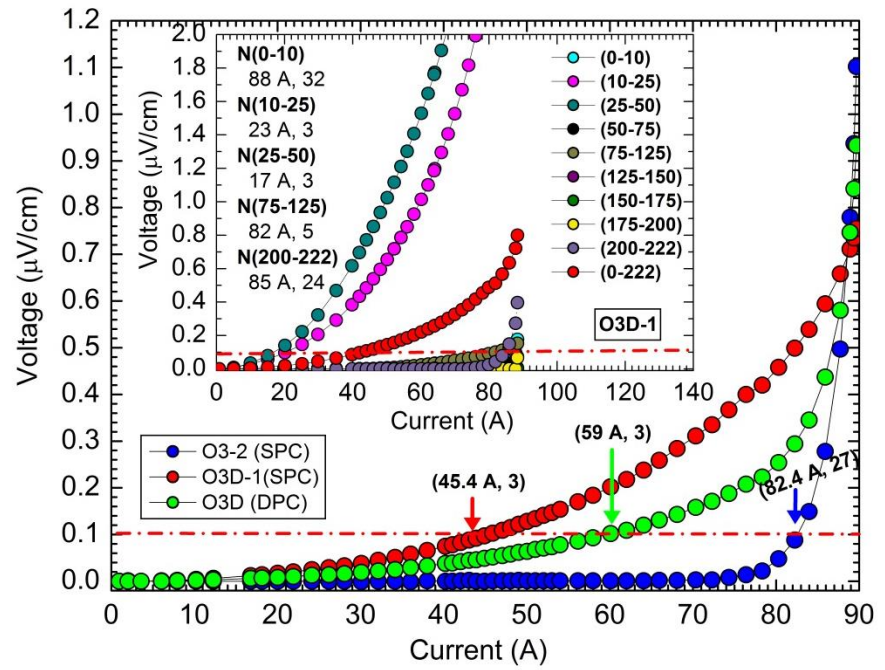
**Type 1:**  
companion coils with identical electrical characteristics at 77 K




**Type 2:**  
Performance of a DPC is limited by one of the companion coils.

Higher  $I_c$  at 77 K of the coils does not translate into an identical coil performance at 4 K

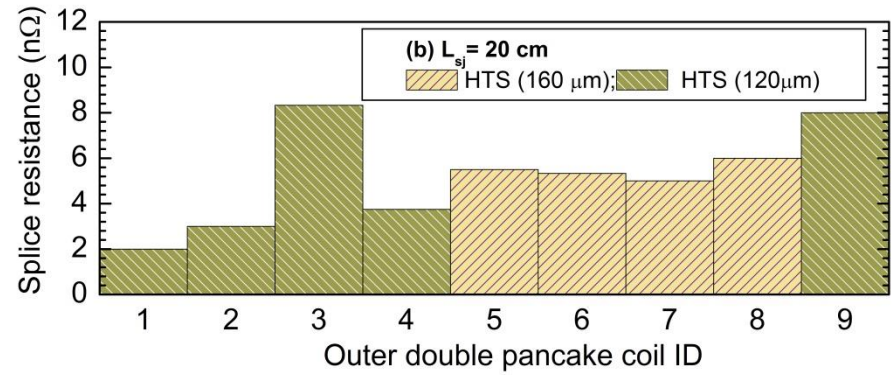
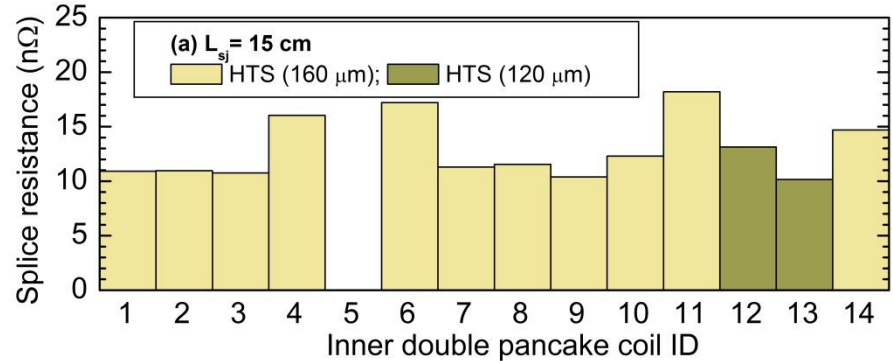
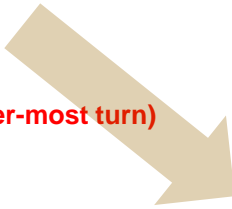
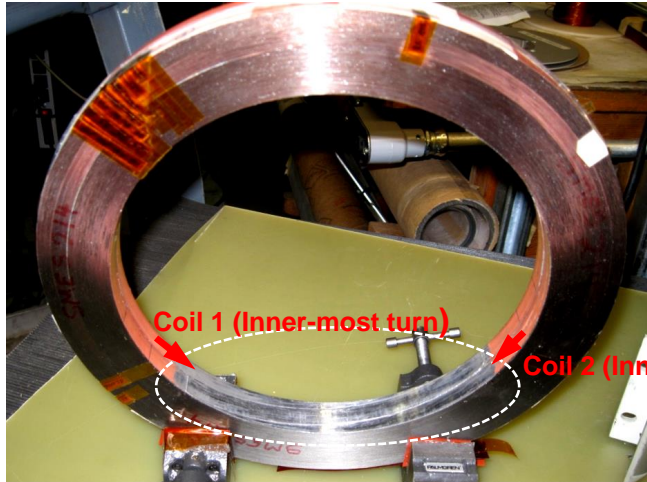
# Significance of 77 K test of SMES coils



**Type 3:**  
Inferior performance of the DPC is due to the bad sections in one of the companion coil

 Detailed diagnosis of the coil sections played a critical role to ensure the quality of tapes and the winding and assembly process of the pancake coils.

# Test results at 77 K of the spiral splices



- Resistance per splice is less than 7.5 nano-ohms
- Splice resistance is seemingly sensitive to the surface conditions of tapes of different production batches and contact resistance between the layers constituting the tape.
- Splice resistance is practically not sensitive to the resistance of the stabilizer layer

## Summary

- Forty six pancake coils, including twenty eight inner coils and eighteen outer coils were built.
- These coils were assembled into twenty three double pancake coil units and tested successfully at 77 K.
- 77 K tests played a crucial role in the QA process for the prototype ~ 24 T solenoid magnet.
- The technology for the low resistance lap joint and spiral shaped splices has been demonstrated and successfully implemented in the construction of the coils.
- The detailed diagnosis of the coil sections provides an additional check on the quality of tapes, winding and assembly process of the coils.

# Acknowledgement

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We acknowledge the contributions by our technical staffs, especially Glenn Jochen, J. D. Ambra, Eric Evangelou and Anthony Sorrentino.