Status of SMES Coil

Ramesh Gupta (BNL PI - SMD)
Piyush Joshi (Electrical Engineer)
Seetha Lakshmi (Post-doc)
Jesse Schmalzle (Mechanical Engineer)
Mike Anerella (Mechanical Engineer)
Peter Wanderer (Division Head)

Superconducting Magnet Division
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BROOKHAVEN NATIONAL LABORATORY
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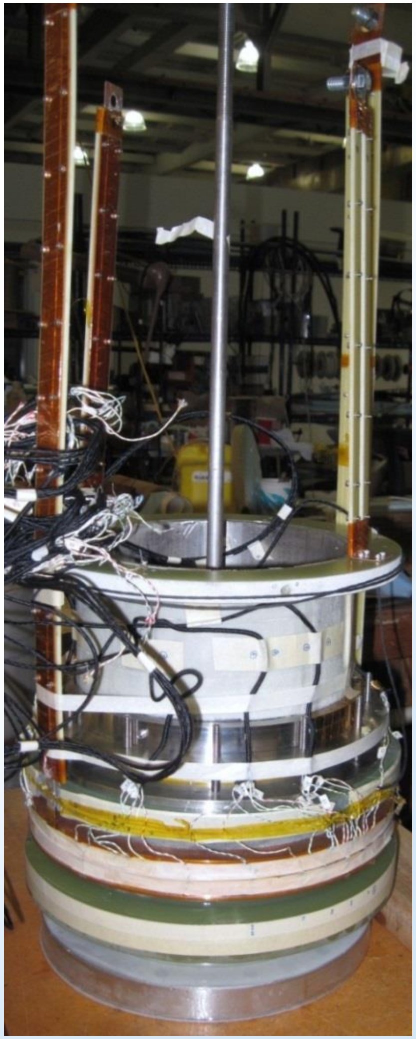
Office of Science
U.S. DEPARTMENT OF ENERGY

Overview of Activities

- **Construction and test results of pancake coils**
- **Status of parts needed for 1.7 MJ SMES**
- **Schedule**
- **Quench protection system update**
- **Summary**

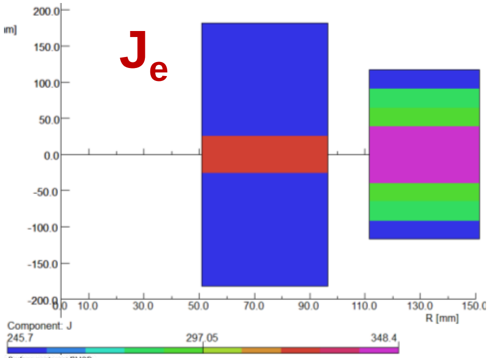
Status of Pancake Coils

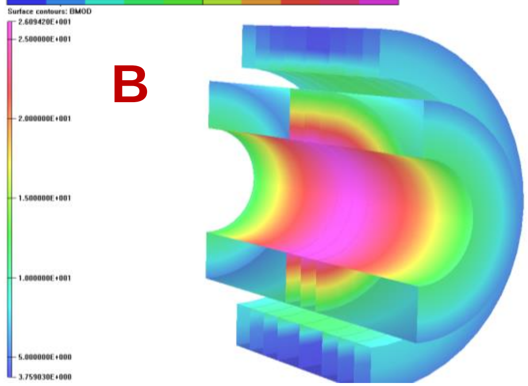
- **Two outer double pancakes dis-assembled (took significant time to do it safely)**
- **Replacement coils built with new conductor**
- **Two replacement double pancake assemblies built (one with good single pancake from previous assembly and one newly wound)**
- **Double pancake assemblies required for 1.7 MJ SMES are ready after having passed rigorous 77 K QA test**
- **A brief summary of overall performance and the latest test results**



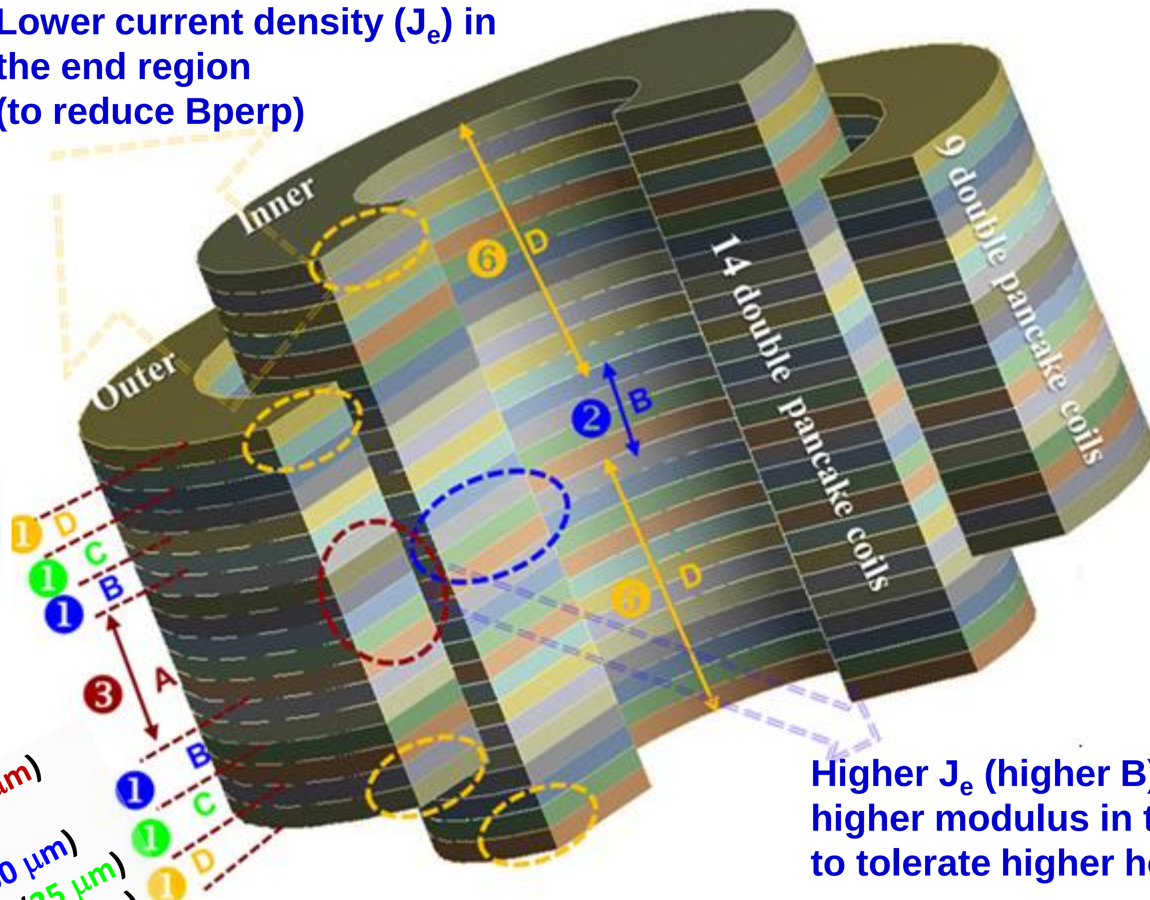
Optimization of Pancake Windings

(see slides in back-up section for actual implementation)





Lower current density (J_e) in the end region (to reduce Bperp)



Higher J_e (higher B) and higher modulus in the middle to tolerate higher hoop stress)

Parameters:

- SS thickness
- Cu (HTS) thickness

Type A : Cu in HTS (65 μm) + SS (25 μm)

Type B : Cu in HTS (65 μm) + SS (50 μm)

Type C : Cu in HTS (100 μm) + SS (25 μm)

Type D : Cu in HTS (100 μm) + SS (50 μm)

Allows higher fields (and higher energy) for the same amount conductor (cost driver)

Caveat: Sorting is based on 77 K measurements (not 4 K)
Large variation seen between "77K, self-field" & "4K, in-field I_c"

77 K QA Test of

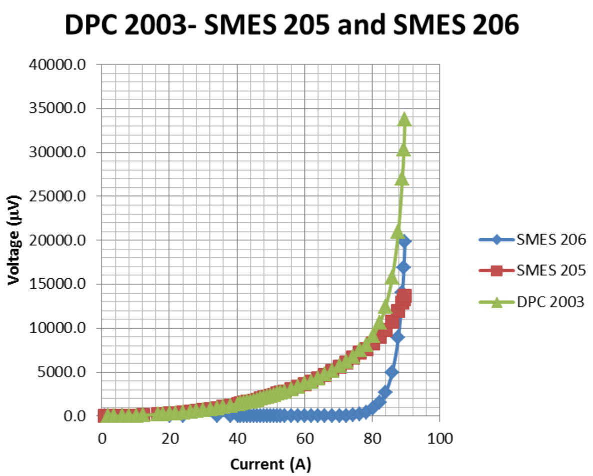
Single and Double Pancakes

(one case discussed, two in back-up section)

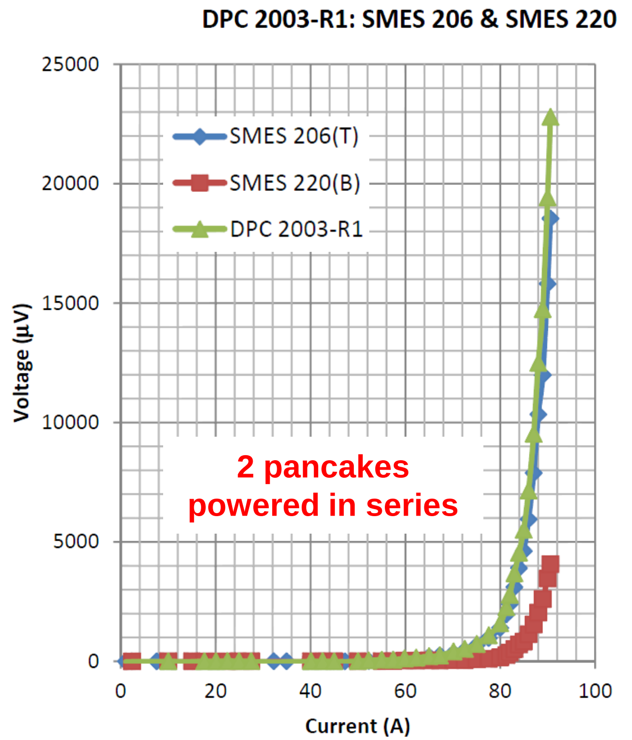
Outer Double Pancake DPC2003 (Repaired)

Single pancake 205 replaced by 220 (206 retained)

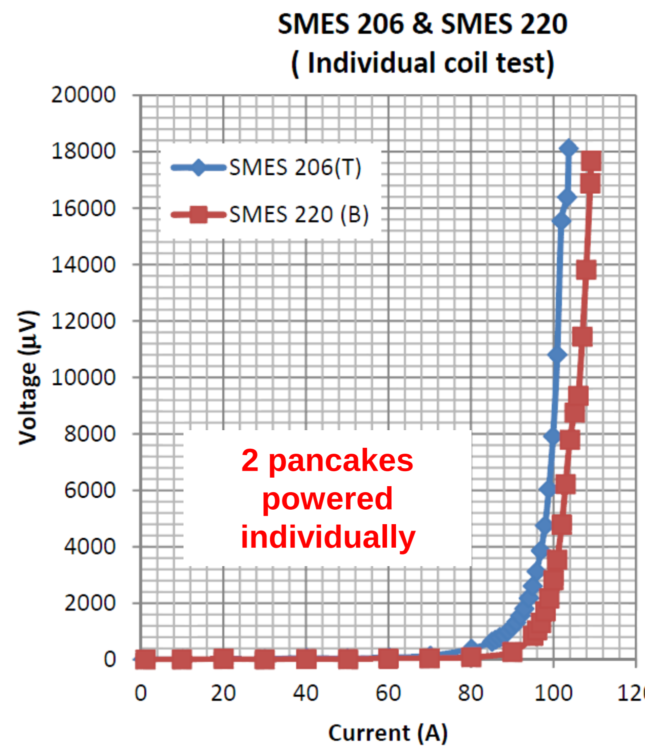
Original assembly (before repair)



(205 had an unacceptable performance)



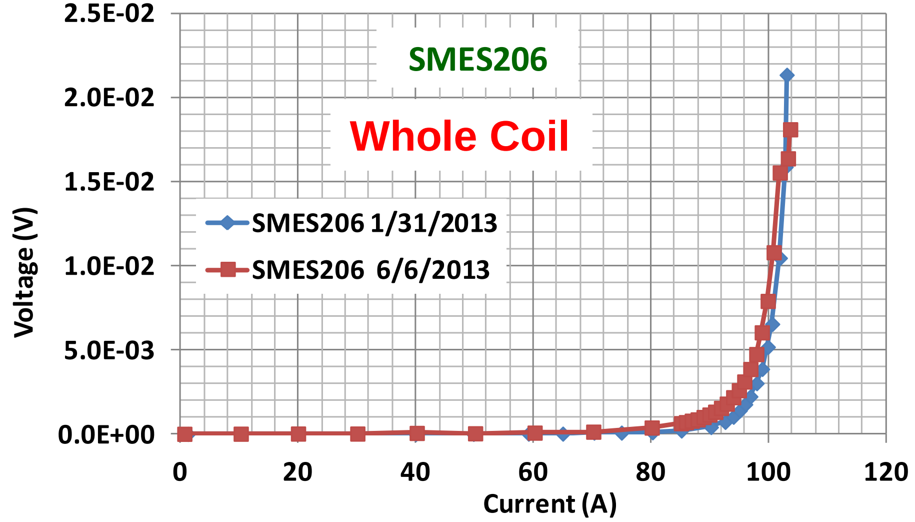
		Ic	
	N	1µV/cm	0.1µV/cm
SMES 206	20	90.6	80.9
SMES 220	24	96.1	87.5
DPC 2003-R1	27	86.5	79.4

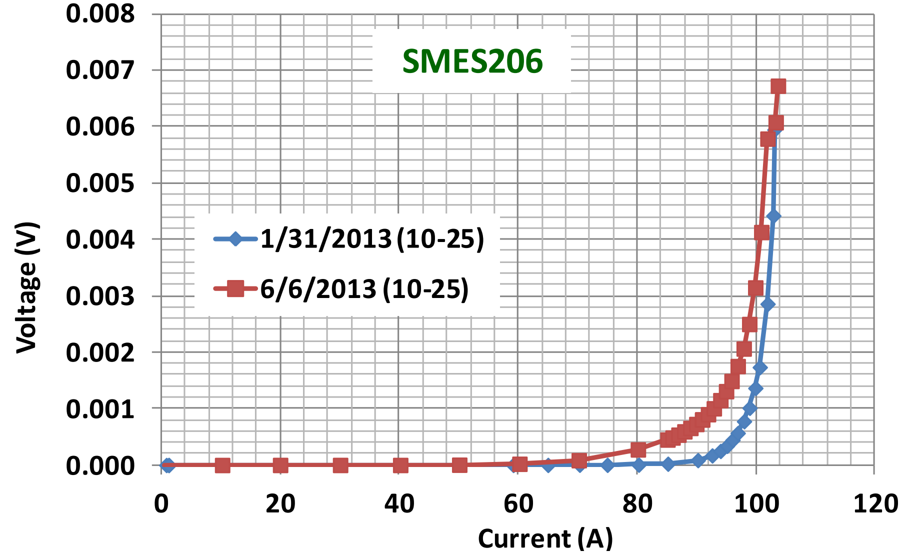


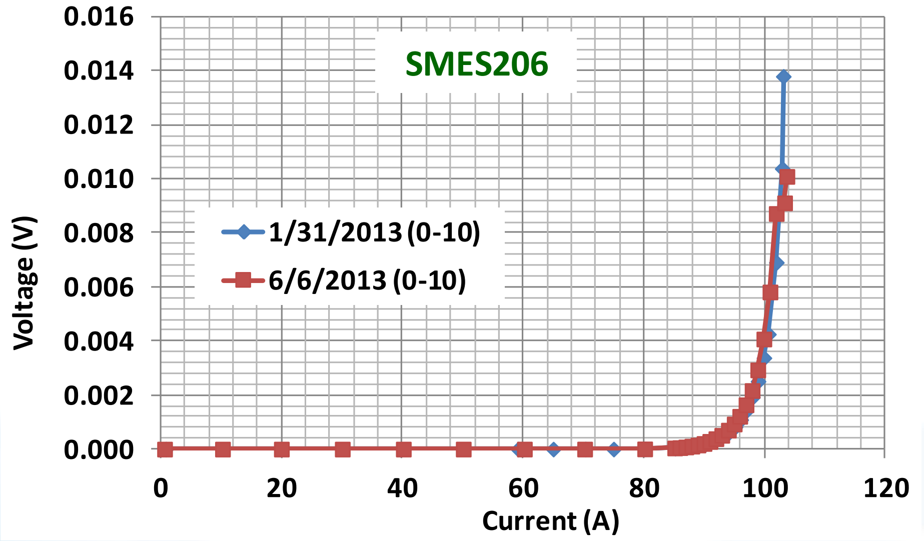
		Ic	
	N	1µV/cm	0.1µV/cm
SMES 206	23	104	94
SMES 220	27	109.1	98.06

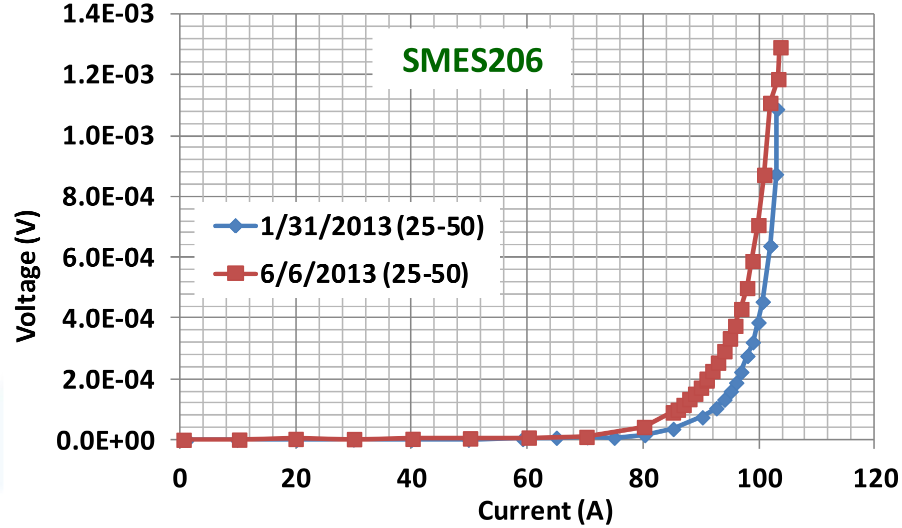
Small Change in the Performance of Pancake SMES206

(Detailed analysis with a number of v-taps --- a part of critical 77 QA test)





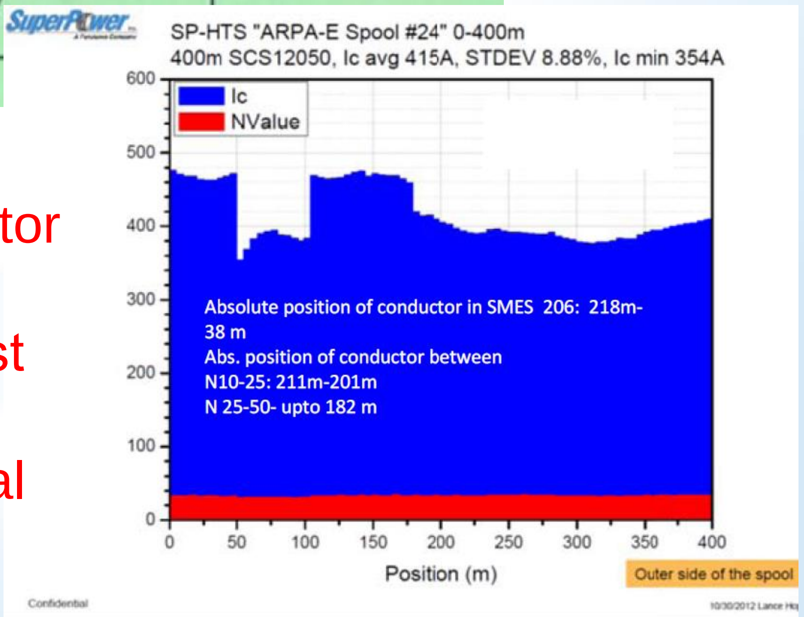




A slight change in performance (seen only because of so many voltage taps installed).
Is it important? Examine construction and conductor data carefully…

Trace-back to Coil Winding and Conductor

OP	Description	Name/Life #	Date	DR
245	Enter 25 in the "Target Turns to Wind" box, click "Wind". Wind turns 11 - 25. set set speed to 250 @ N10 Blemish on HTS (Discoloration) at turn 11.84 Two small dark spots (bumps) on bottom of HTS side at 12.74 small ding (superficial) on top at 14.38 1/2 inch scratch lengthwise on HTS side at 21.87			
250	Install a voltage tap when machine pauses after turn 25.			
255	Enter 50 in the "Target Turns to Wind" box, click "Wind". Wind turns 26 - 50. Small dark bump on Non HTS side at 30.77 3/4 inch scratch at 43.73 on HTS side Small scratch found on Bottom of HTS - slight amount of Grey showing at 48.7			
260	Install a voltage tap when machine pauses after turn 50.			

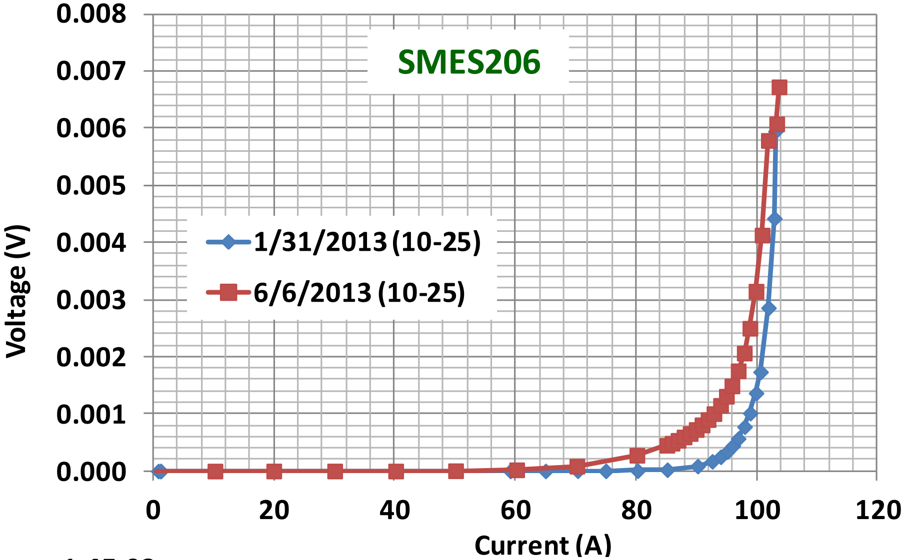


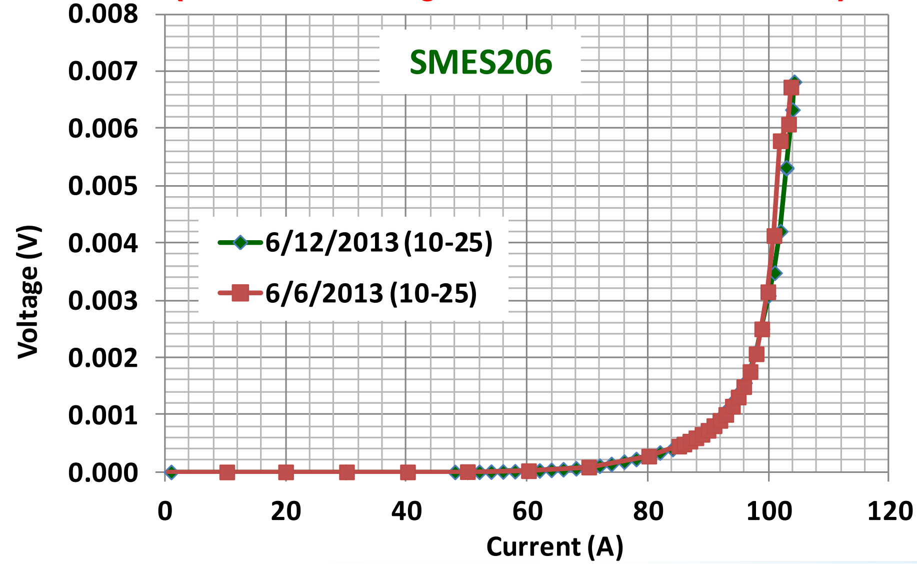
- During the coil winding, technicians noted some blemishes and scratches in the conductor at the turn location in question.
- They didn't produce any signal in the QA test at SuperPower test. But are they critical?
- No signal during the first test but small signal during the next in the turns at that location.
- How about next cycle? Any further change?

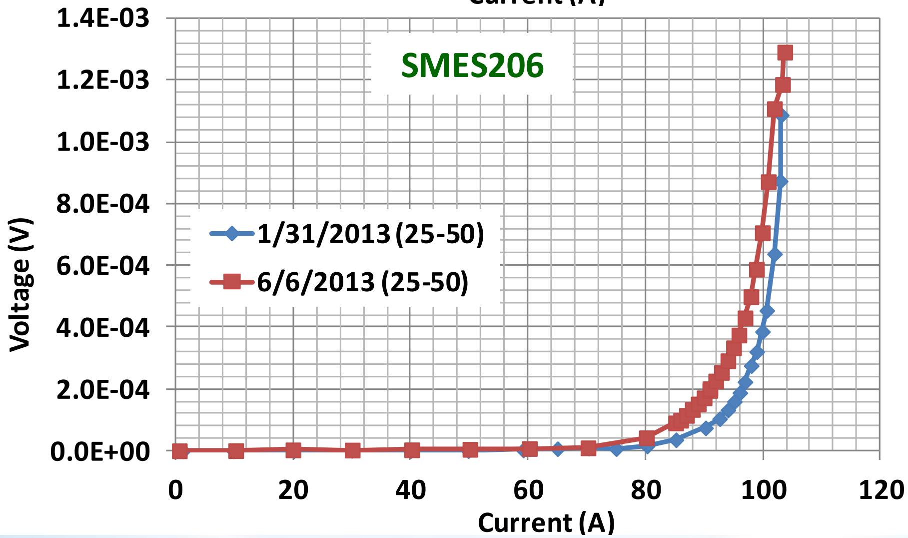
Detailed Study of Coil Performance with Thermal Cycles

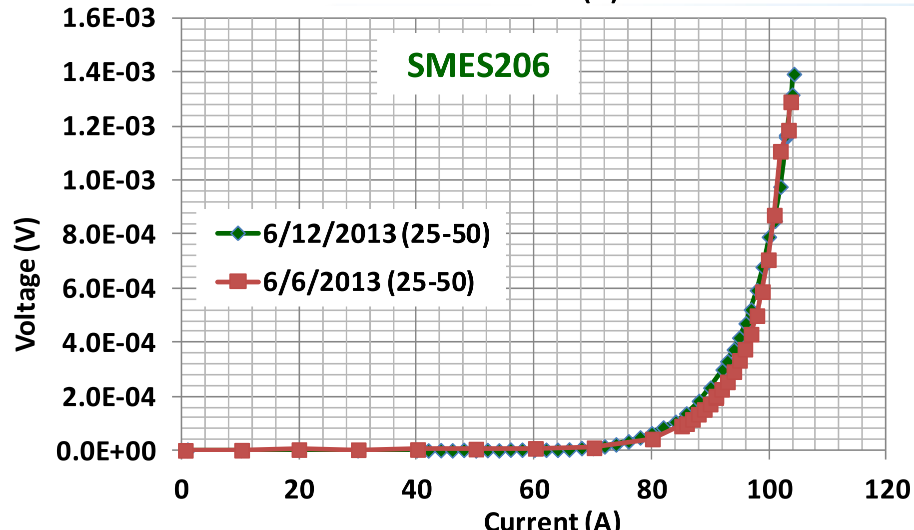
Comparison between first two sets
(slight change in performance between 1/31/13 & 6/6/13)

Comparison between next two sets
(no further change between 6/6/13 & 6/12/13)









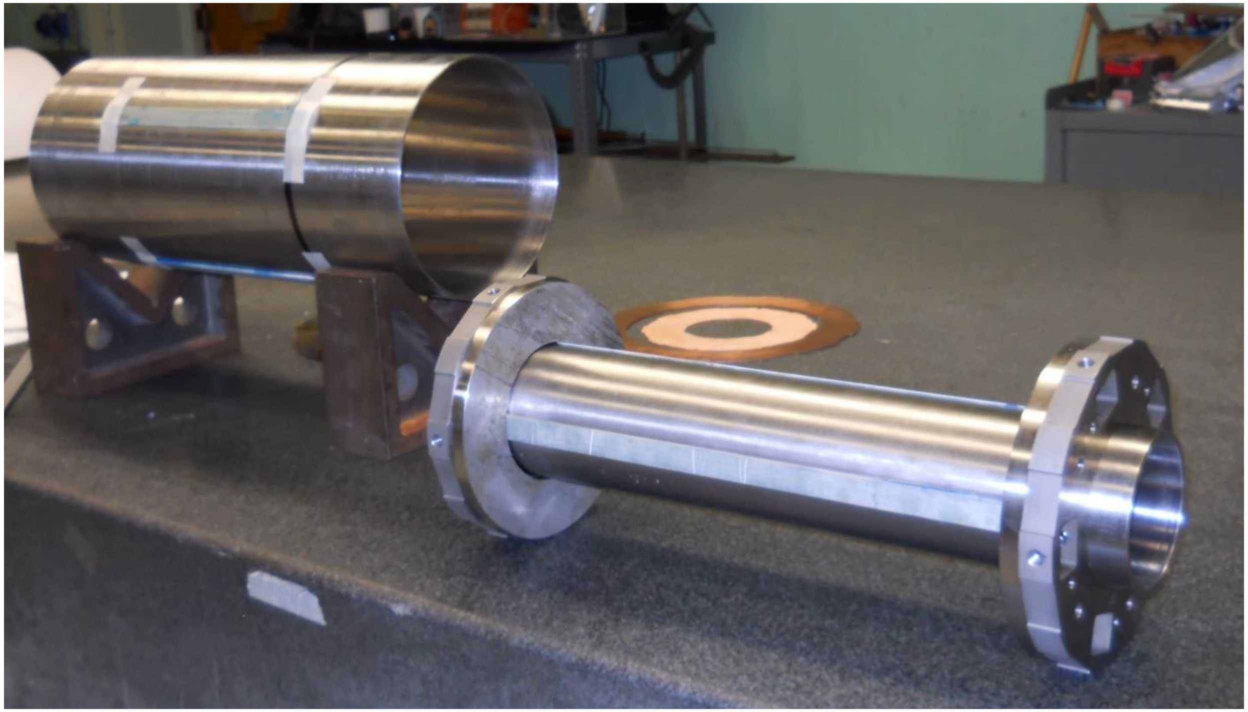
Since no further change, coil accepted

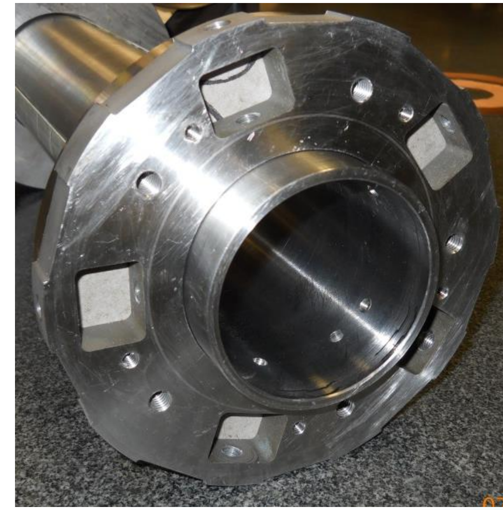
Status of

Parts and Fabrication

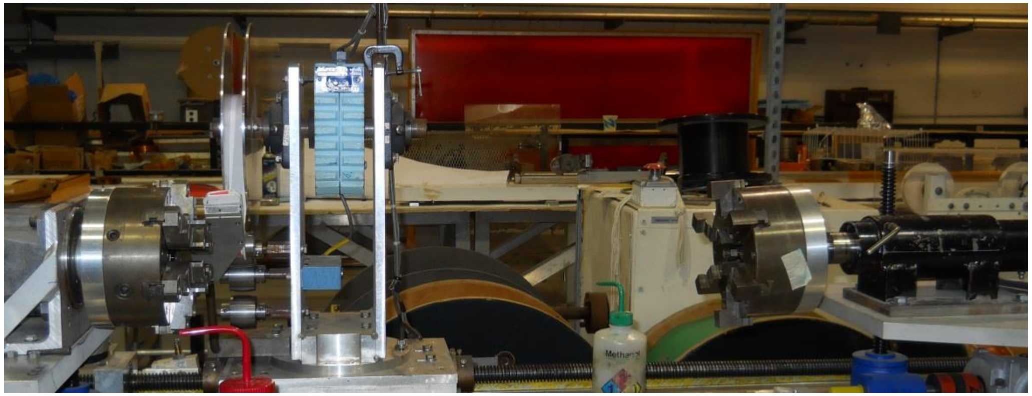
- All parts received from BNL central shops and outside vendors
- Essentially all machining done at magnet division

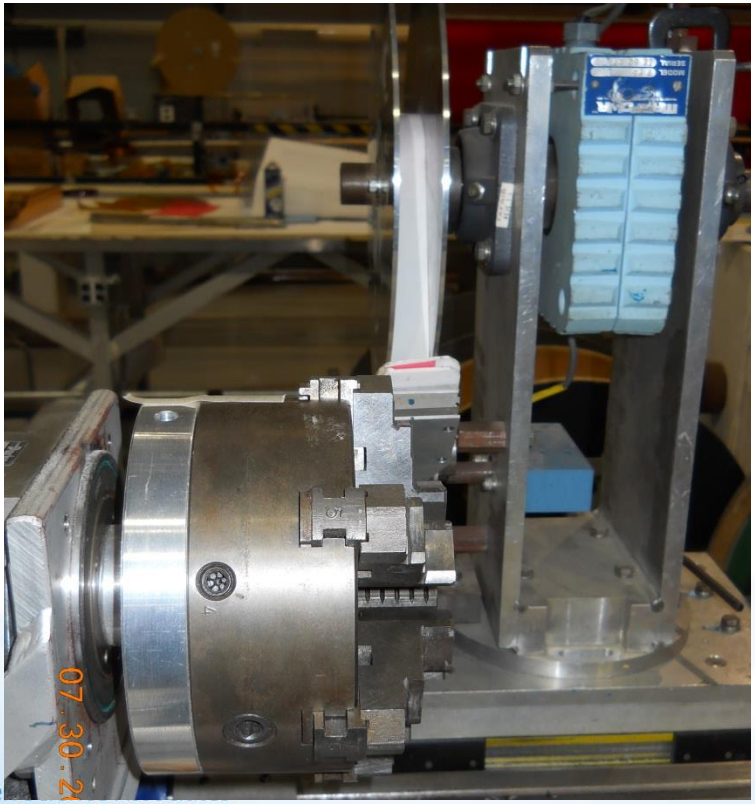
A Few Parts of SMES Structure

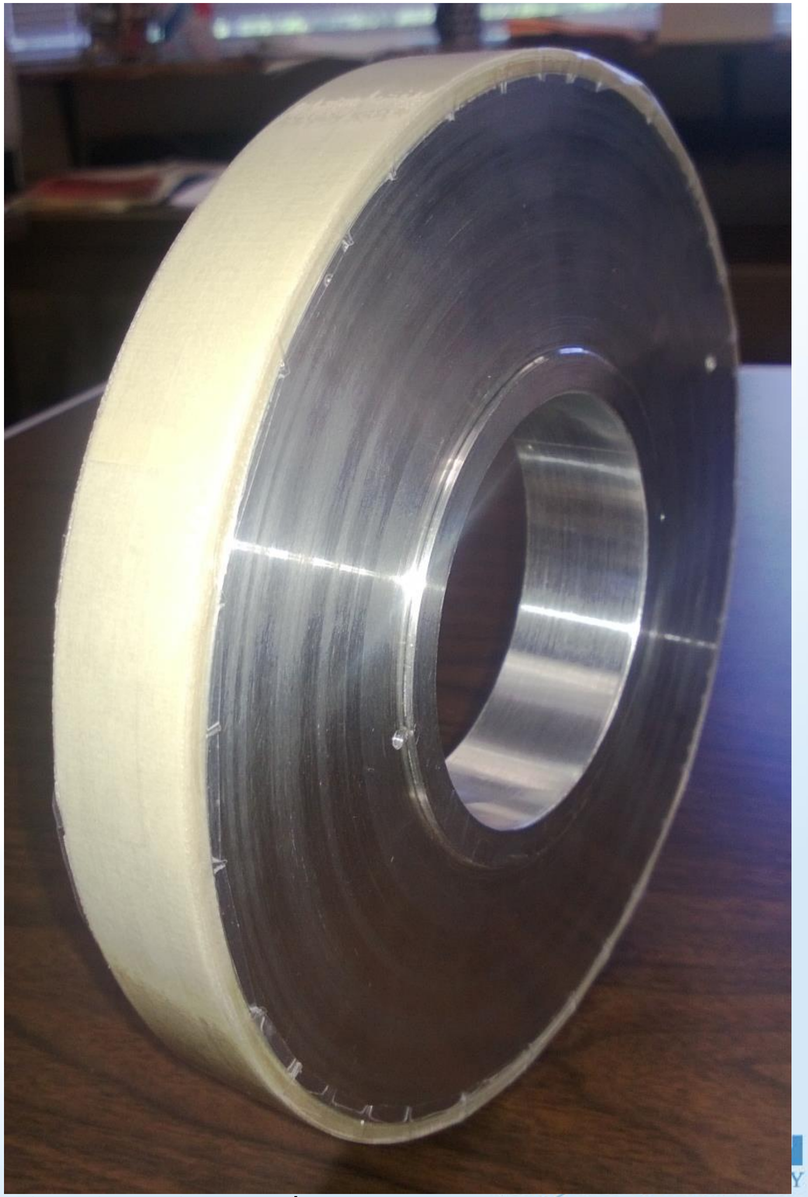




Dry Run for Putting Fiberglass-epoxy tape on the Pancakes (o.d. will be machined to match i.d. of support tube)



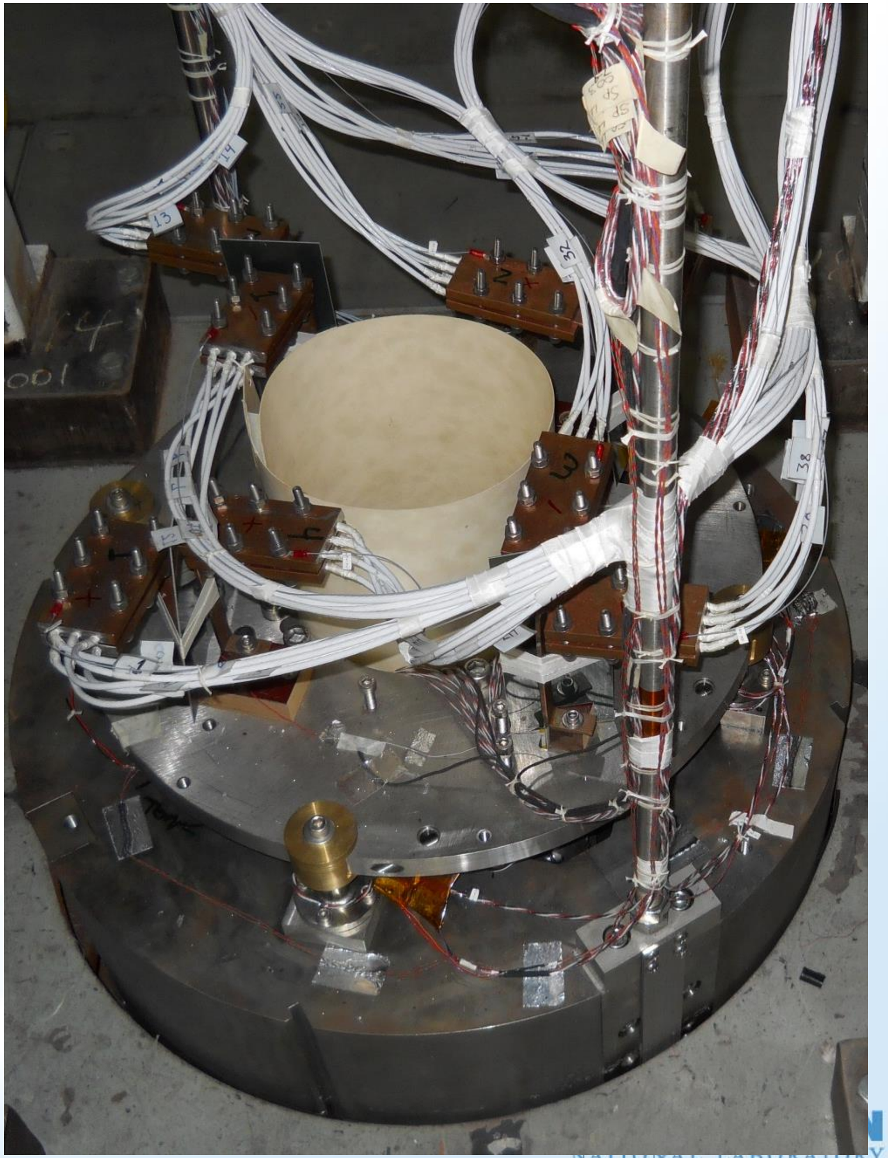




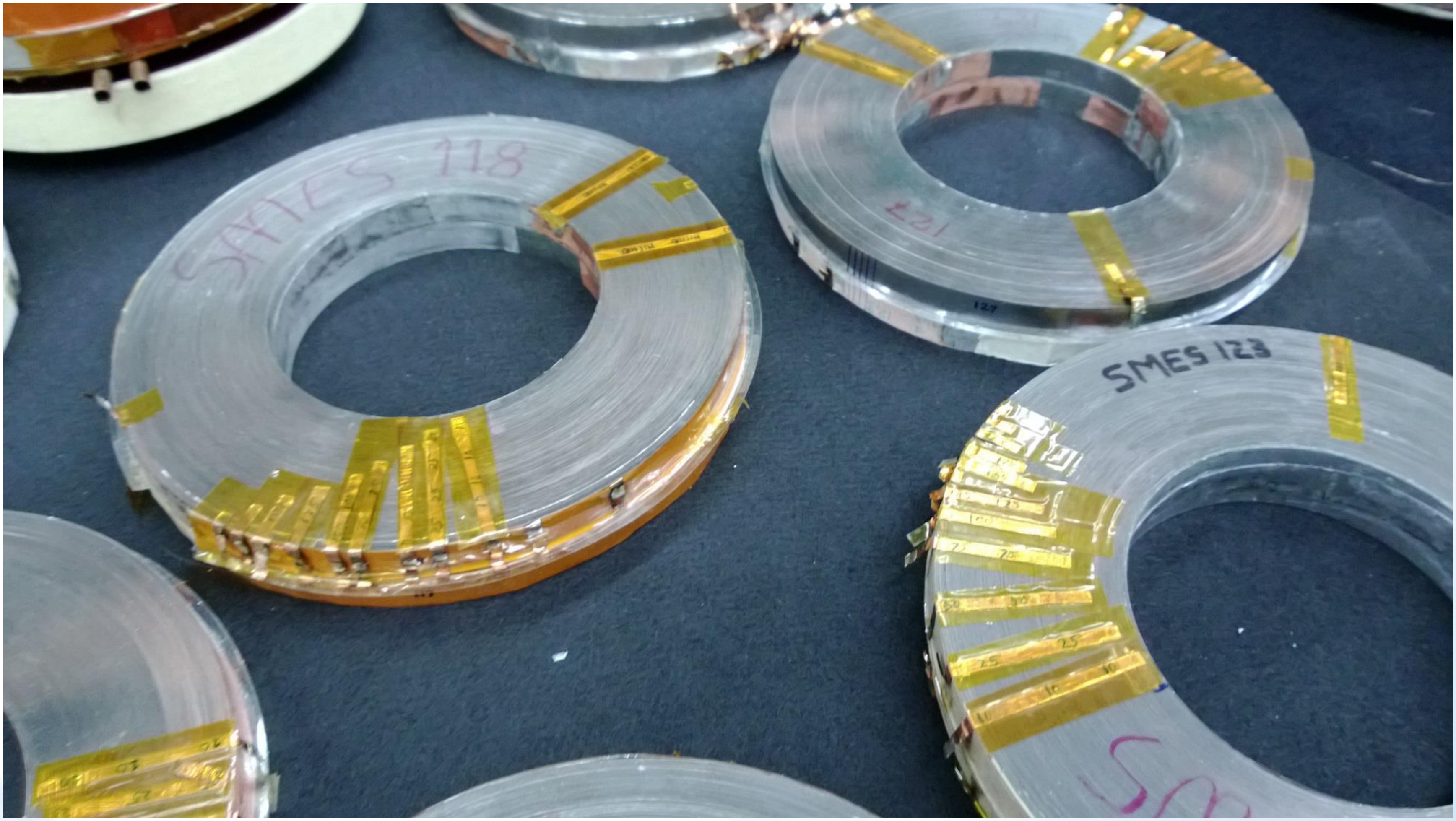
Newly Acquired Tool to Cut Mylar Sheets

(saves significant time while cutting it precisely)

Current Leads for Dividing Coils in 2 Sections
(scheduled to be tested soon with FRIB HTS Quadrupole)

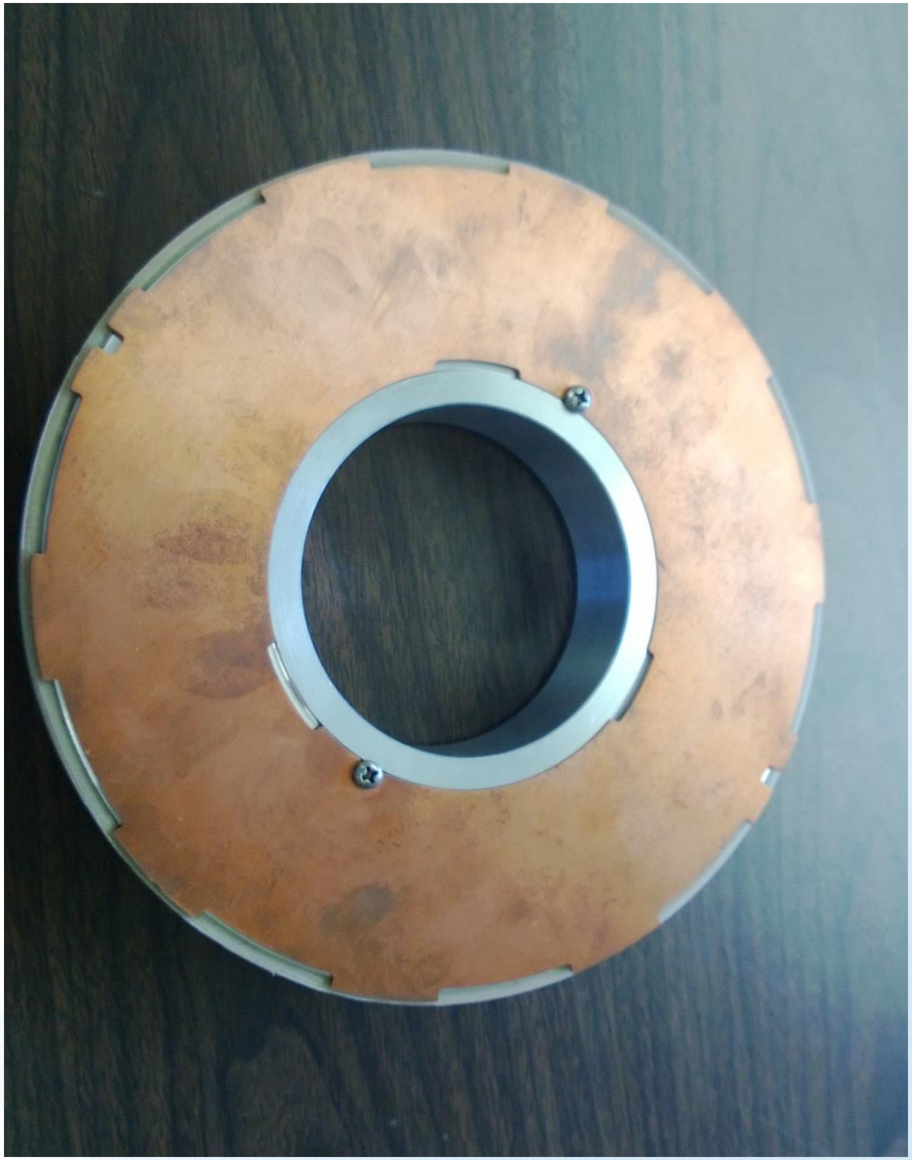


Preparation of Double Pancake Coils for 1.7 MJ Test



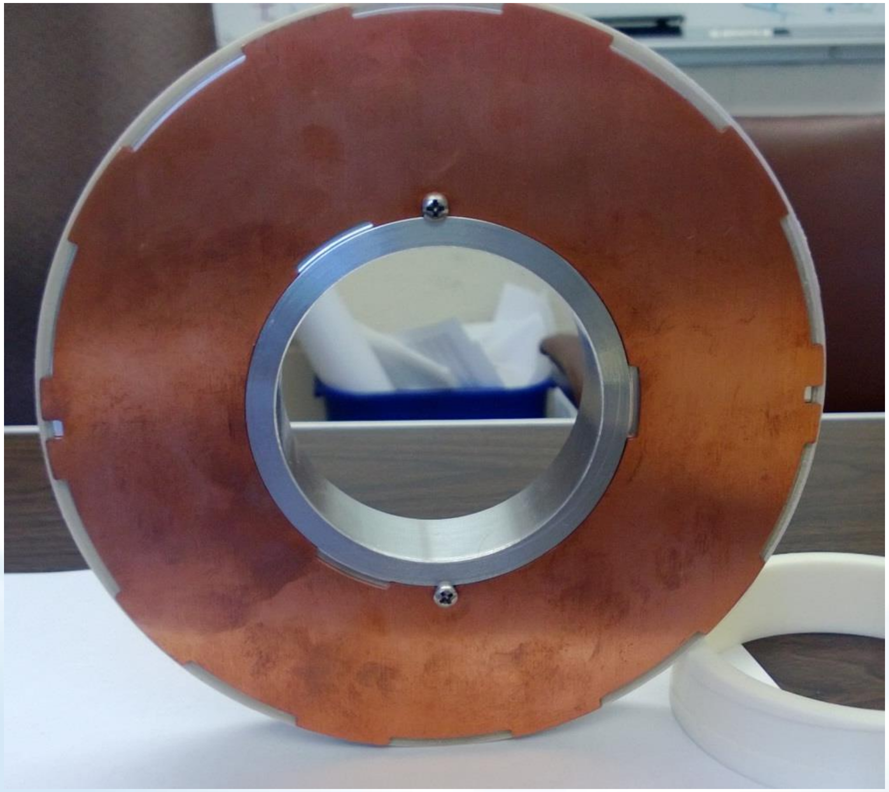
All voltage taps (that were used in 77 K QA test) have to be removed, surface has to be cleaned, mylar sheet has to be attached

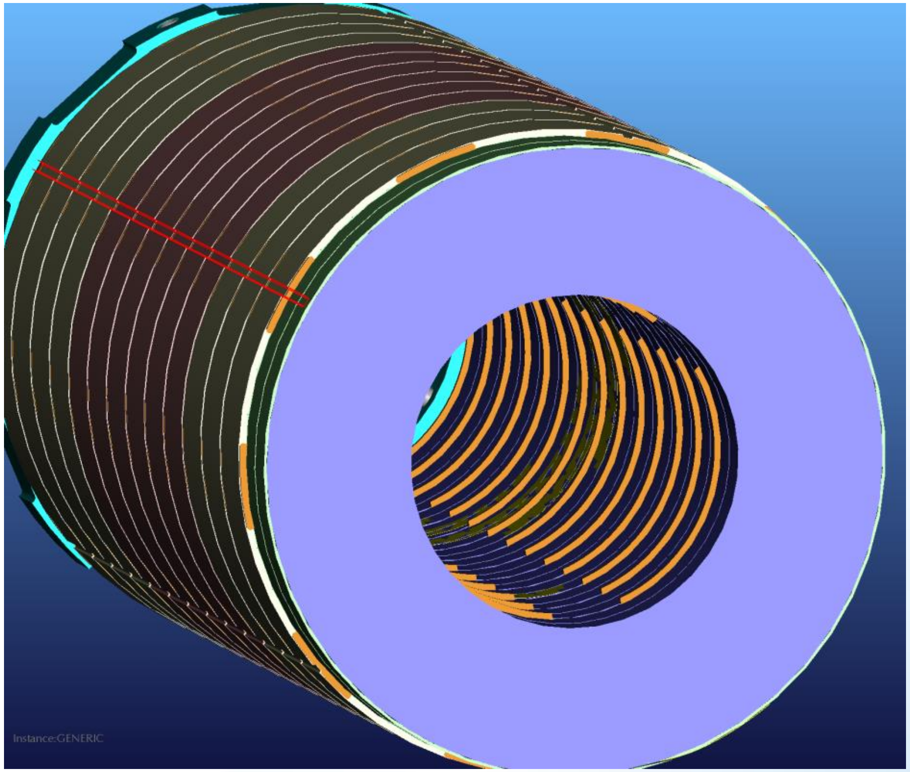
Change in the Shape of Copper Discs to Reduce Thermal Strain on Coil

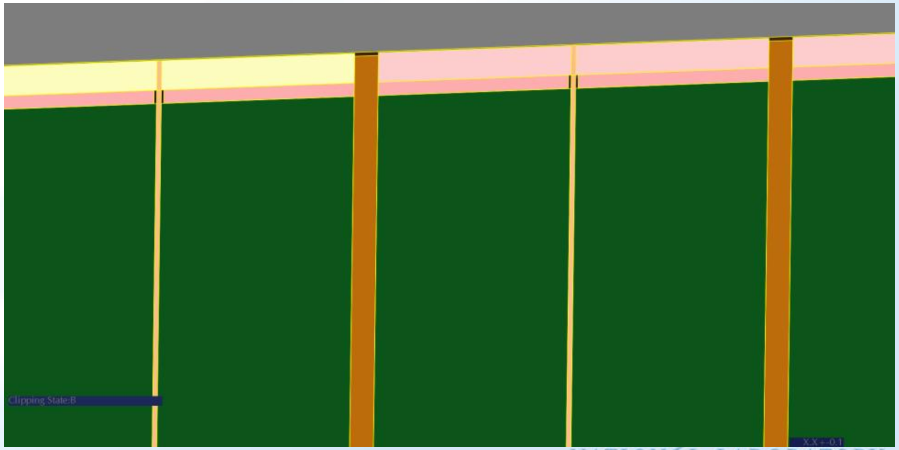


Implementation of Upgraded Thermal Design

- To minimize thermal strain on a large well constrained structure (as needed for high field magnets), copper discs are exposed to helium cooling i.d. and o.d. that spread cooling more uniformly across the pancake
- Cu discs also play role in quench protection
- Large structure is slowly cooled by He only

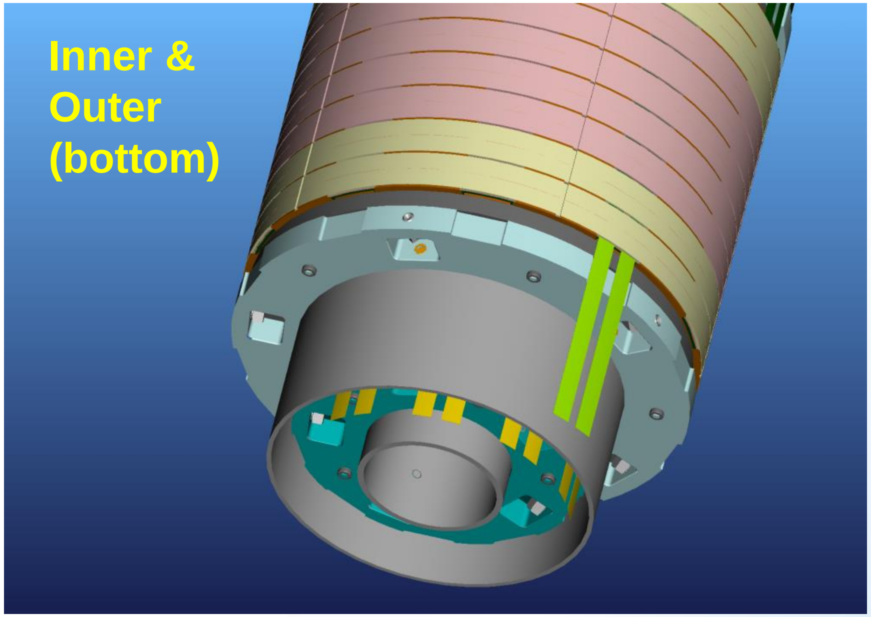


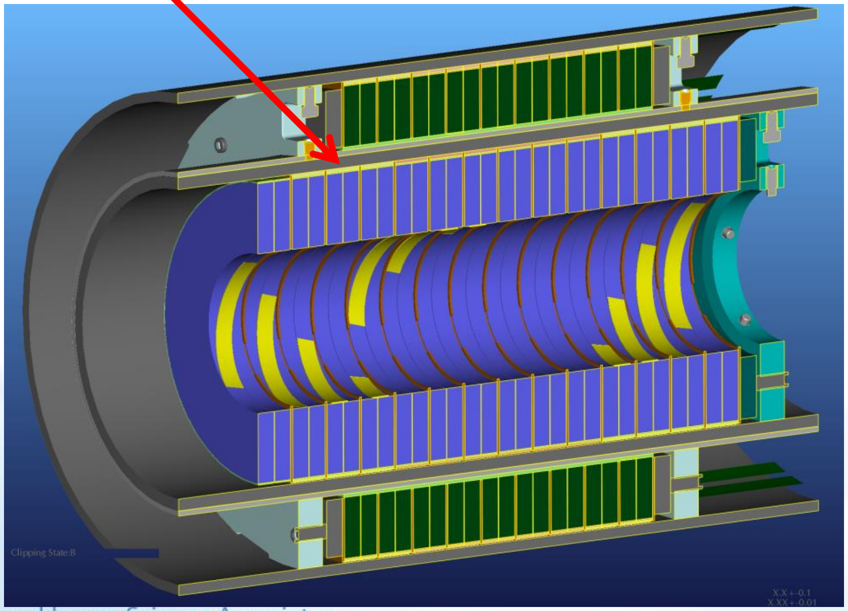


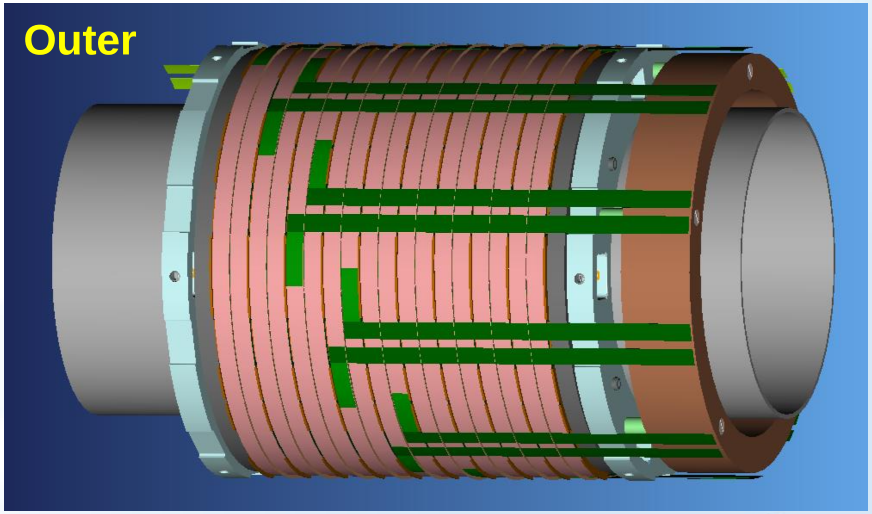


Coil Sections and Current Leads

- The whole coil is divided in two sections – inner and outer
- Leads from each double pancake are brought out to allow better compatibility with ARMY use (higher ramp rate generates higher voltage - will be reduced by making more sections)
- Outgoing leads will be made by joining 4-ply ASC tape (limited to ~1 kA at one location) with SuperPower tape







Detailed Task and Schedule

	Task	Schedule
1	12 T Q6 Structure Disassembled	July 2013
2	Inner and Outer Double Pancakes Prepared for 1.7 MJ	August 2013
3	Inner and outer Assembled in Support Structure	September 2013
4	1.7 MJ SMES Coil Installed in Test Rig	October 2013
5	Quench Protection System Integrated with Coil in Test Rig	October 2013
6	Initial Coil Test at 77 K (Quench Detection and Quench Protection System also tested)	November 2013
7	1.7 MJ (~24 T) Test of Magnet Coil at 4 K (Performed with BNL QD, QP and Power Supplies)	November 2013

Summary

• All pancakes assemblies needed for 1.7 MJ (14 inner and 9 outer) have been assembled, tested and have passed critical 77 K QA test.

• Double pancake coils are being prepared for the final SMES assembly.

• All magnet parts have been delivered.

• Quench protection system is being upgraded (Piyush Joshi) for higher isolation voltage. The QD and QP system is being continuously tested.

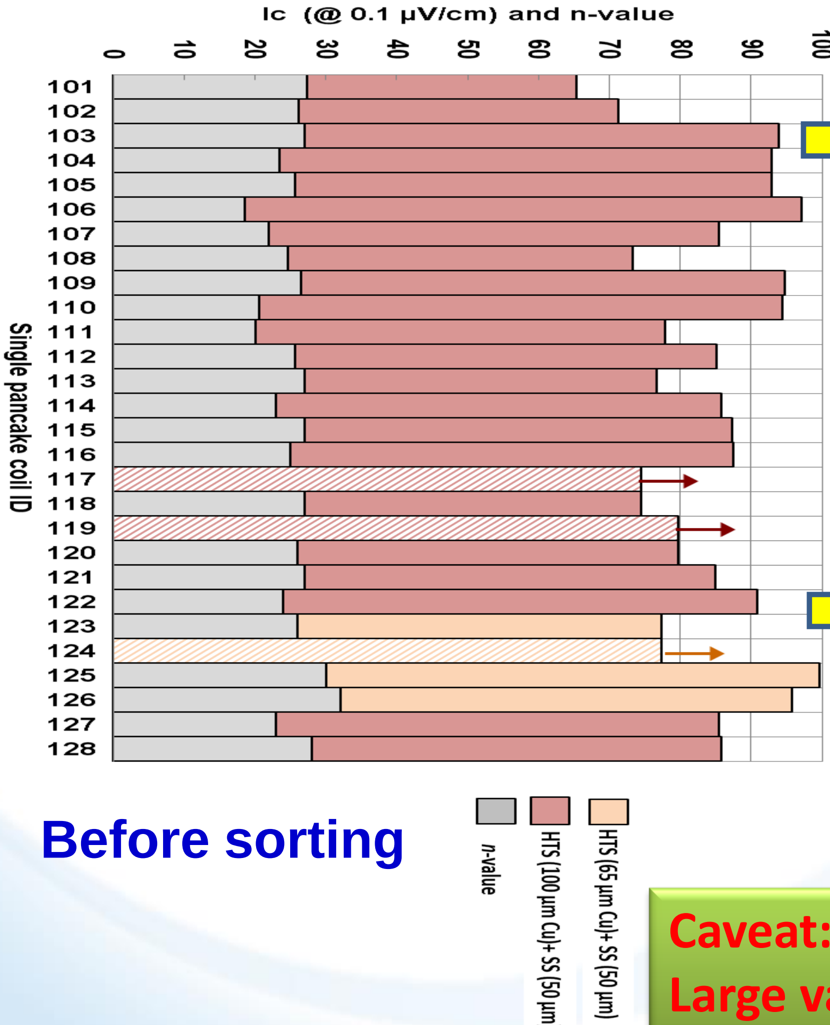
• This is truly a "high risk, high reward" device – highest field, highest stress HTS magnet creating the highest energy density SMES ever built.

• When complete, it will be a significant achievement and the technology developed here will be applicable in many areas – a major contribution of the arpa-e program. We appreciate this opportunity and your support.

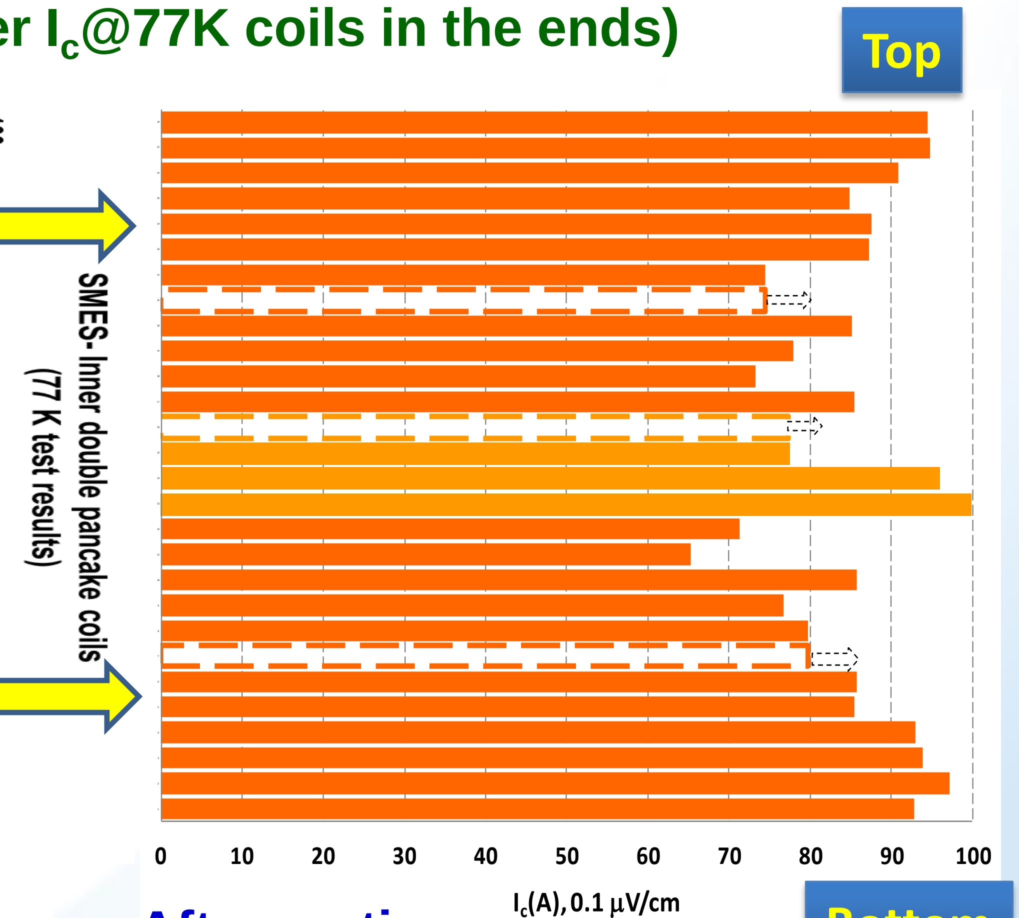
Backup Slides

Placement of Pancakes within Inner Coil

- **First sorting: Mechanical parameters (higher modulus coil in the middle)**
- **Second sorting: Electrical (higher I_c@77K coils in the ends)**



Before sorting

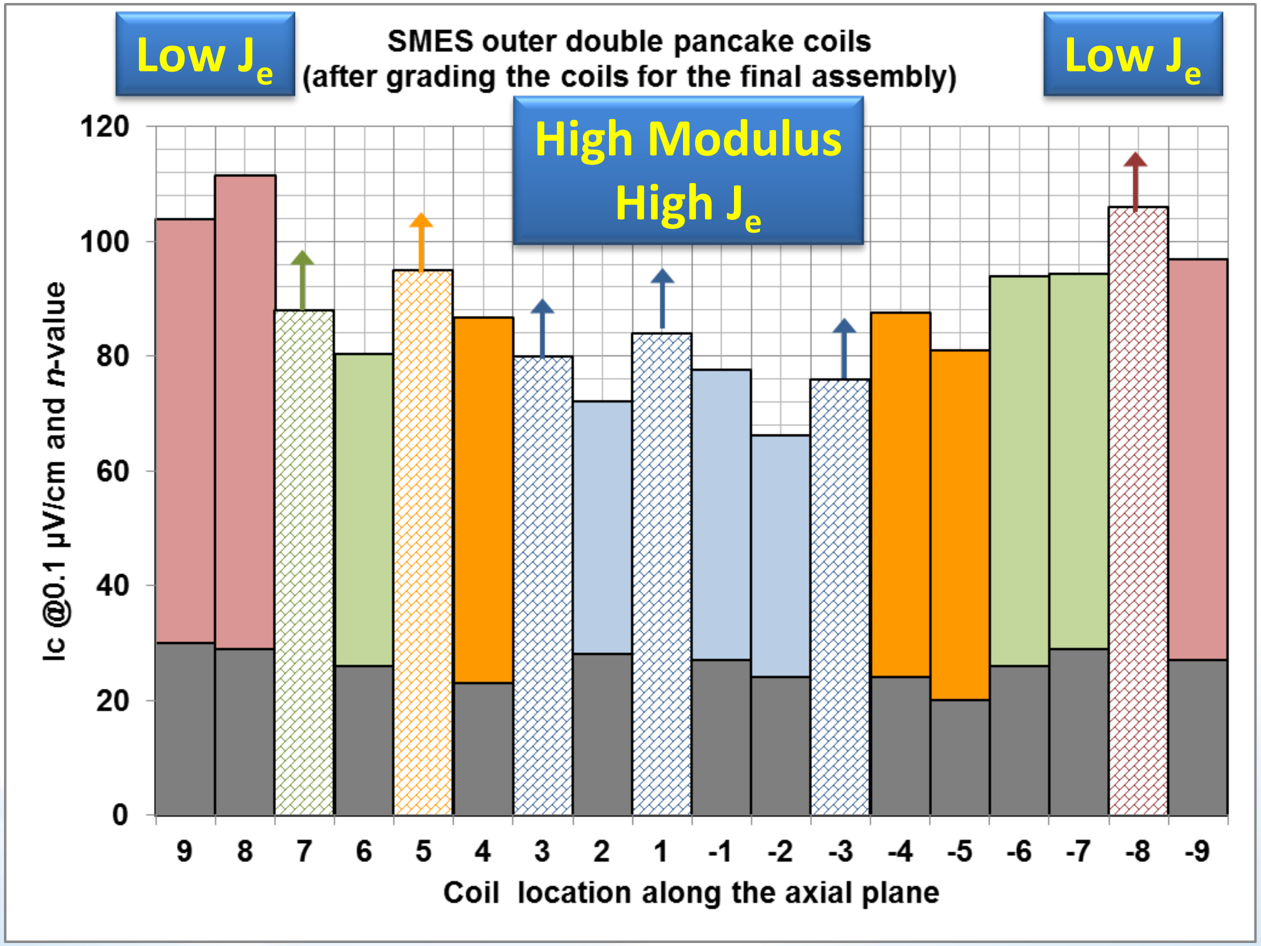


After sorting

Caveat: Sorting based on 77 K (not 4 K)
Large variation seen between 77 K & 4 K, in-field I_c

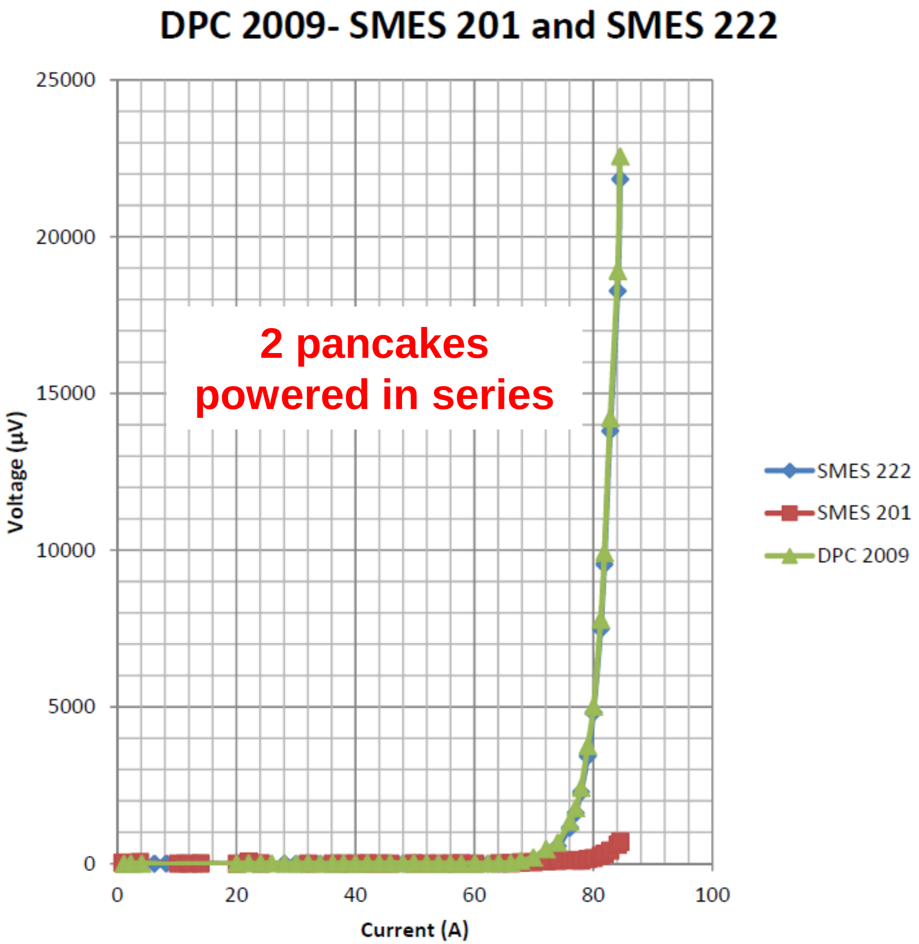
Placement of Pancakes within Outer Coil

- First sorting: Mechanical parameters (higher modulus coil in the middle)
- Second sorting: Electrical (higher I_c@77K coils in the ends)

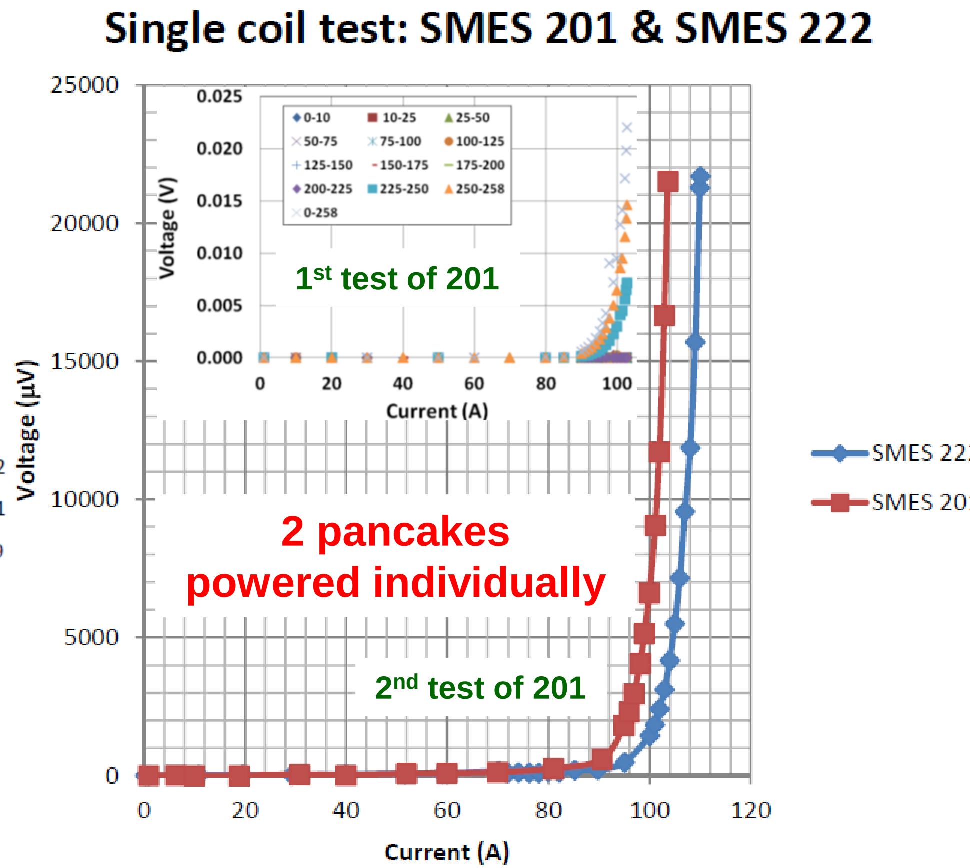


: expected higher I_c (measurement limited by the companion pair)

Outer Double Pancakes DPC2009



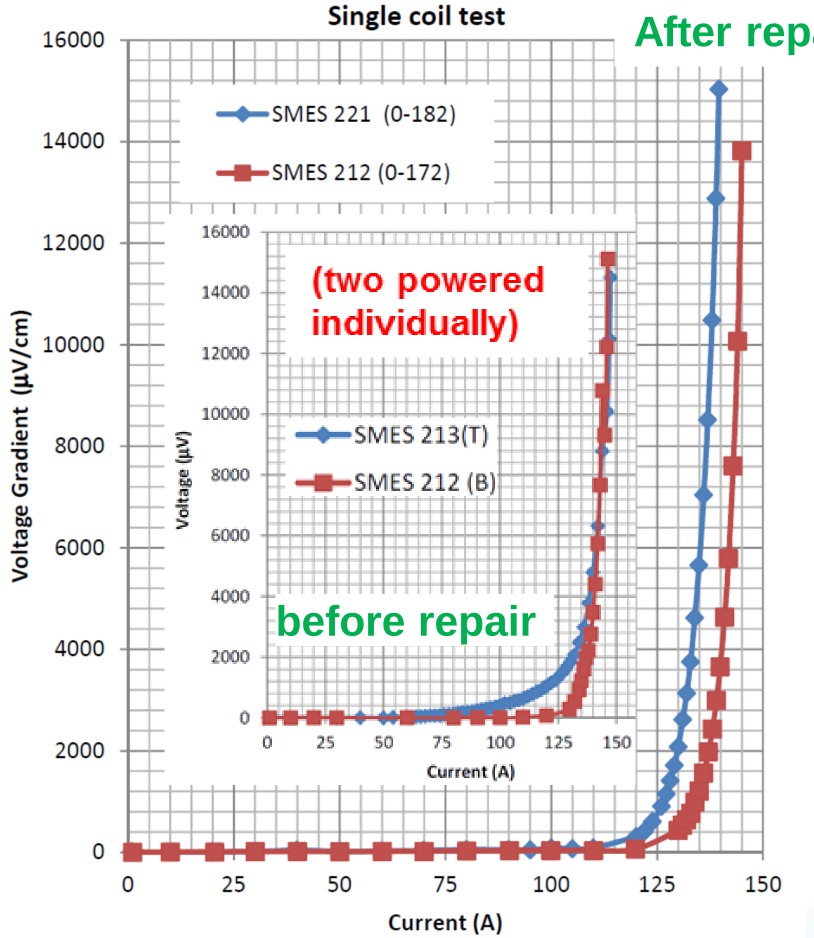
DPC 2009 ASSEMBLY	N	Ic 1µV/cm	Ic 0.1µV/cm
SMES 222	27	84.5	77.6
SMES 201		>84.5	
DPC 2009	27	>84.5	79.4



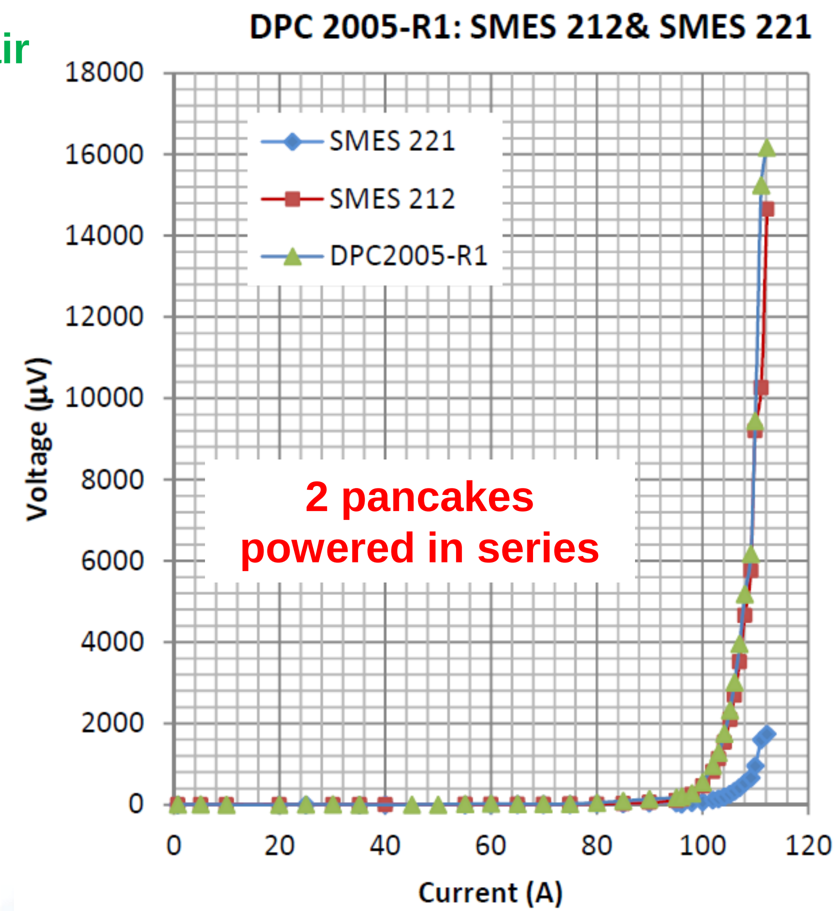
	N	Ic 1µV/cm	Ic 0.1µV/cm
SMES 222	28	110.1	101.5
SMES 201	28	103.9	95.8

Outer Double Pancakes DPC2005 (Repaired)

221 replaces 213

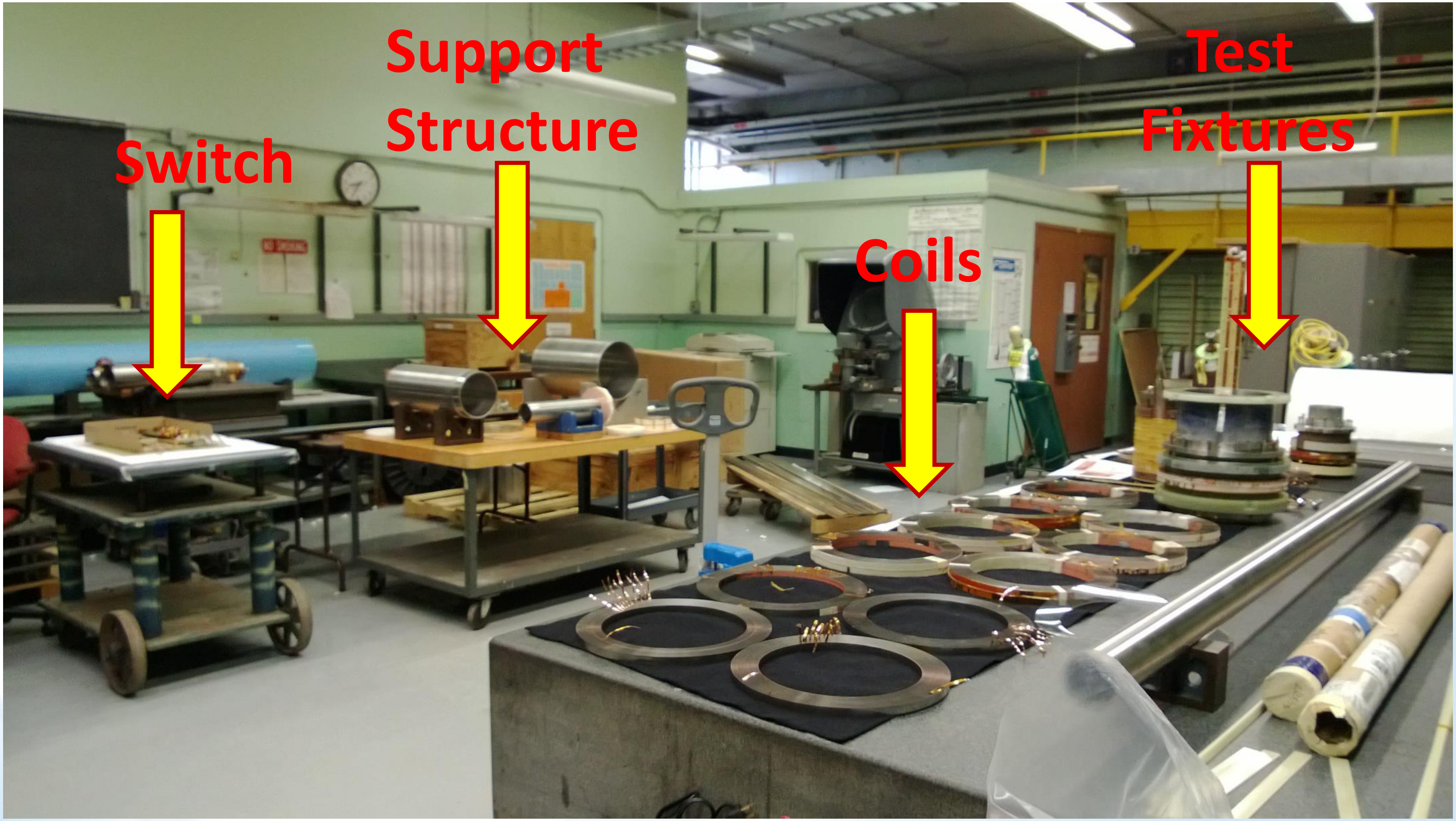


		Ic (A)	
	N	1µV/cm	0.1µV/cm
SMES 221	27	139.8	128.3
SMES 212	31	145.8	135.5

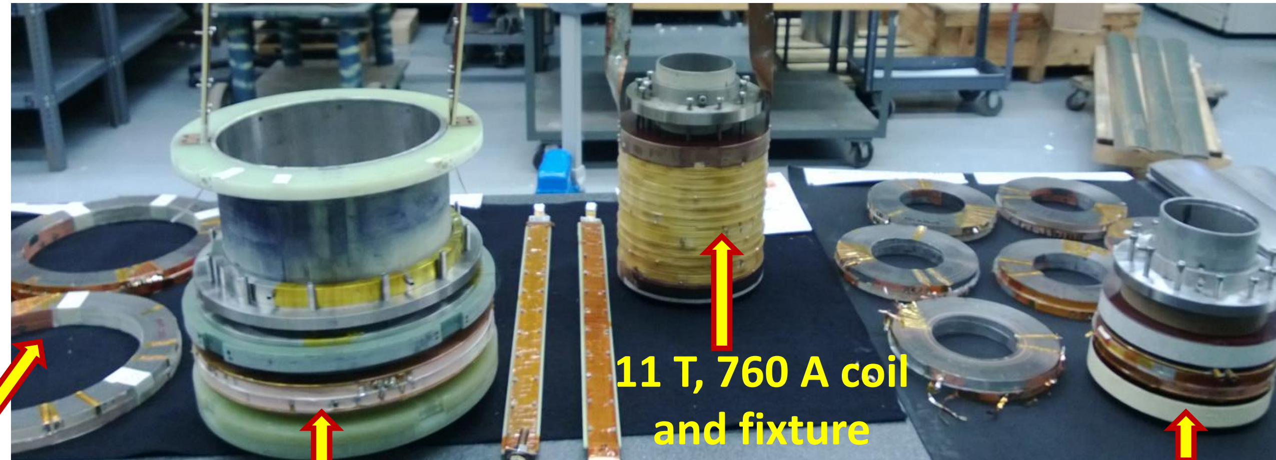


		Ic(A)	
	N	1µV/cm	0.1µV/cm
SMES 221	29	120.7	111.5
SMES 212	30	112.0	103.8
DPC2005-R1	30	114.2	105.8

A Few Parts of SMES Coil Prior to Assembly



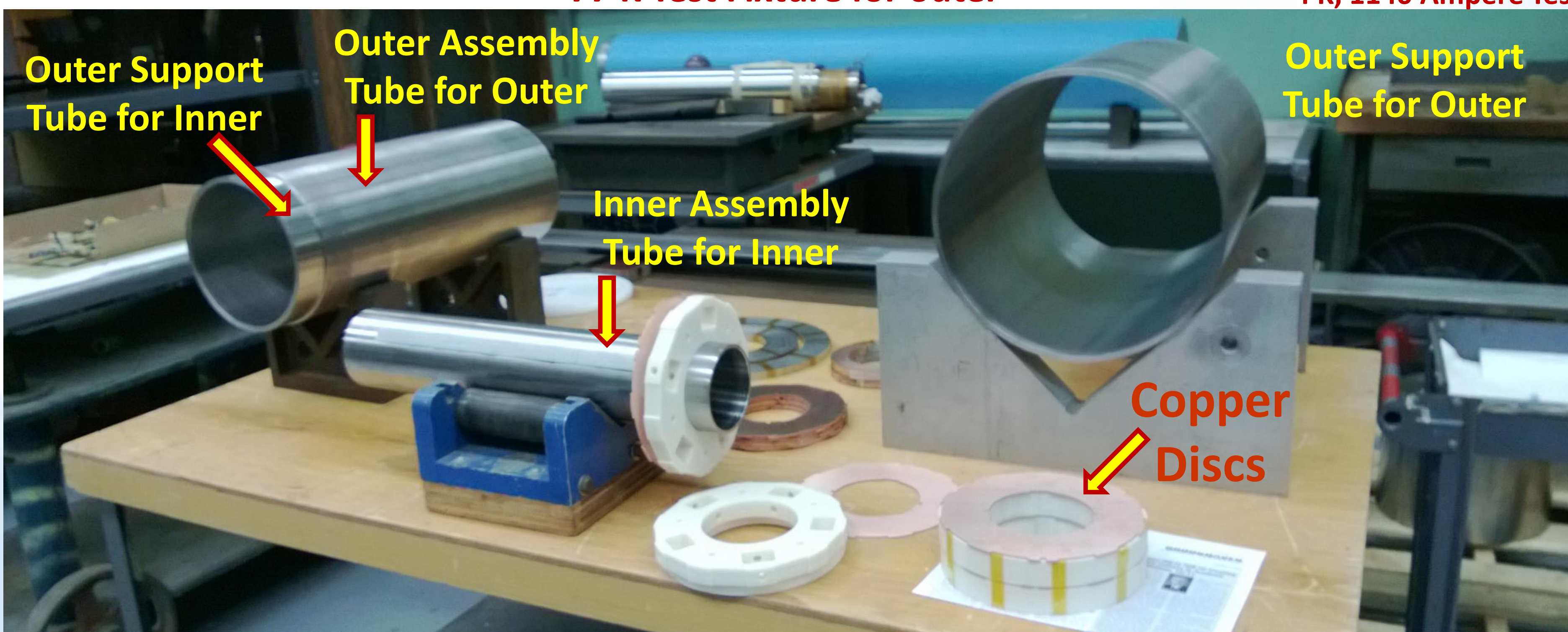
Coils, Test Fixtures and Support Structure



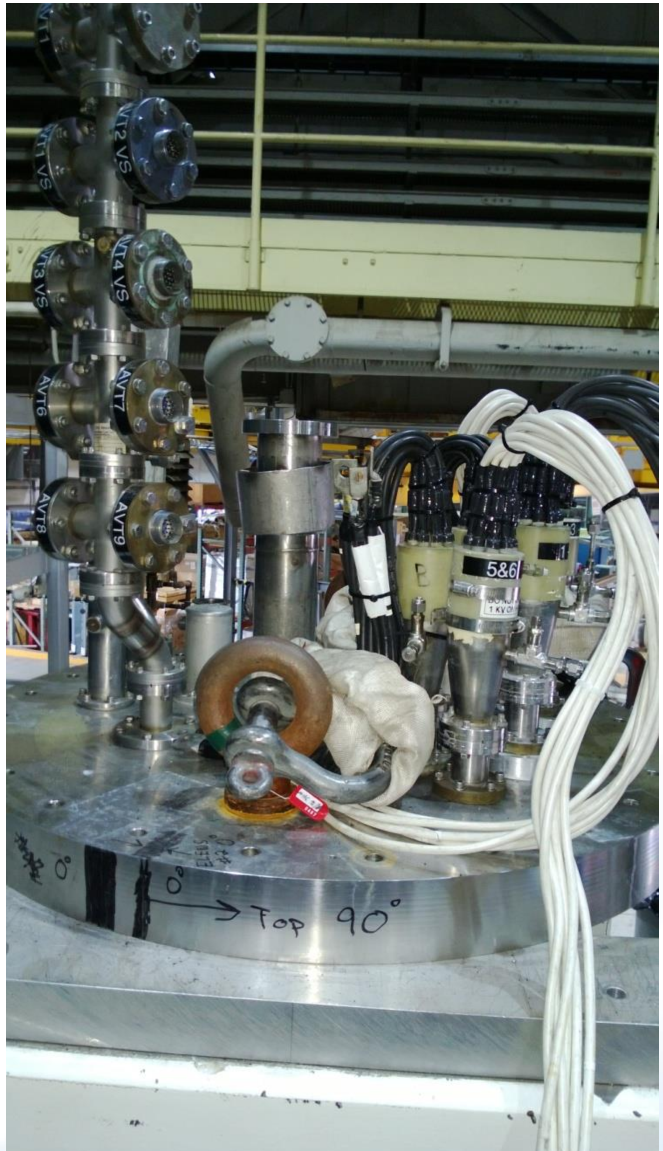
Pancake coils: inner and outer

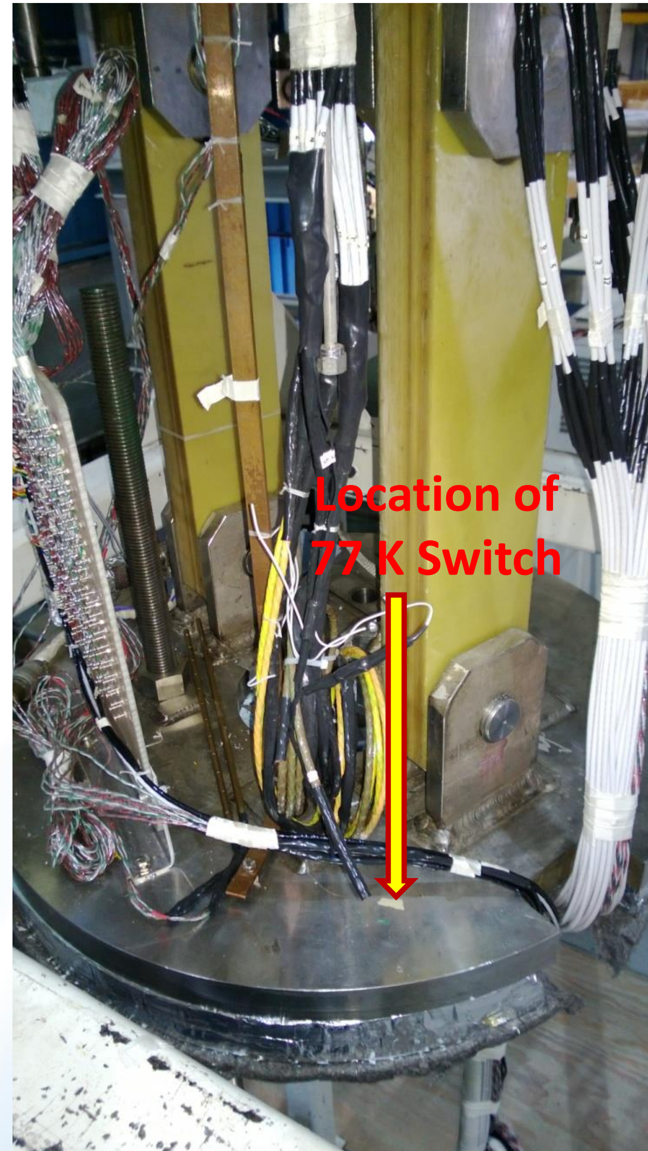
77 K Test Fixture for outer

Inner Double Pancake
4 K, 1140 Ampere Test



Test Fixture for 1.7 MJ Coil



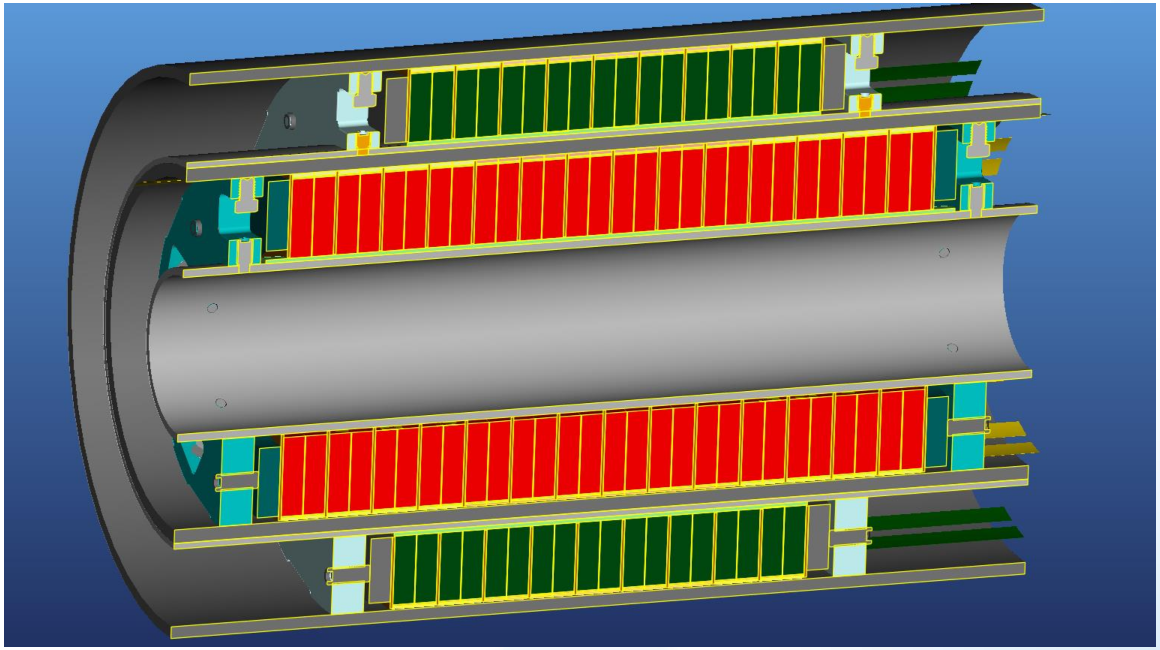


Top Hat with instrumentation panel and current leads

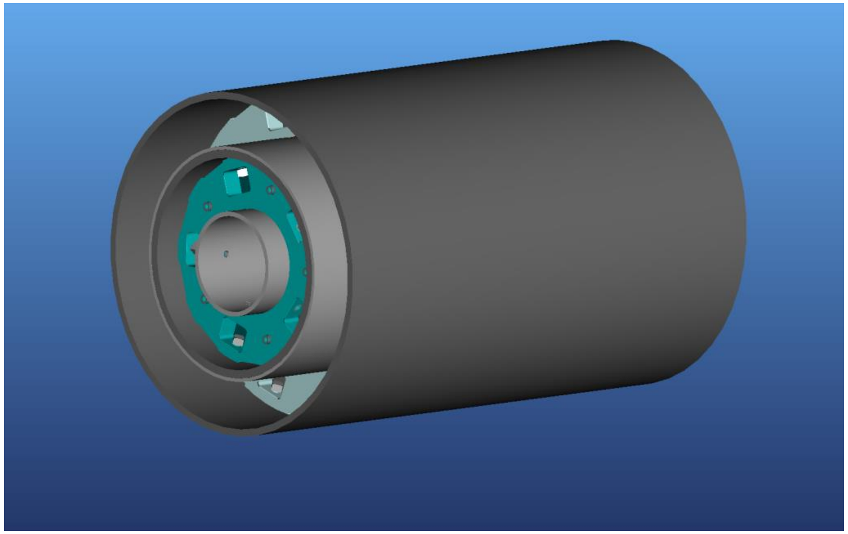
Copper Discs for Inner and Outer Coils

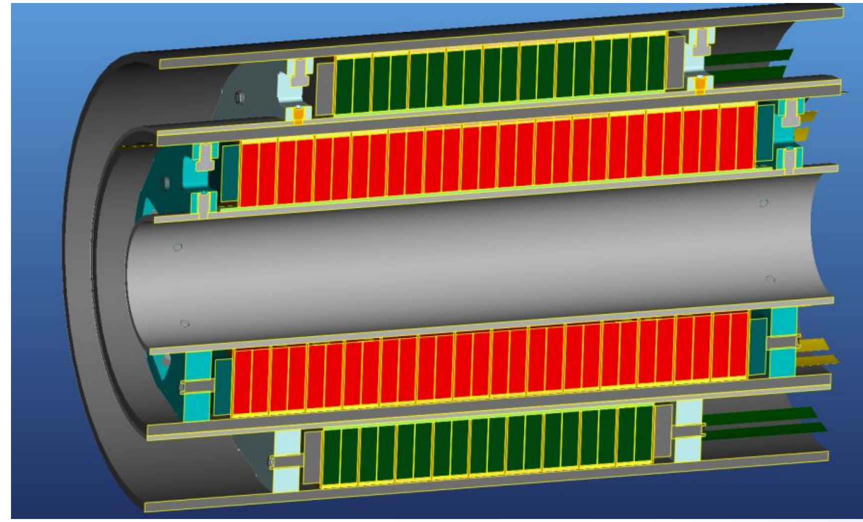
Engineering Design of the 1.7 MJ Coil

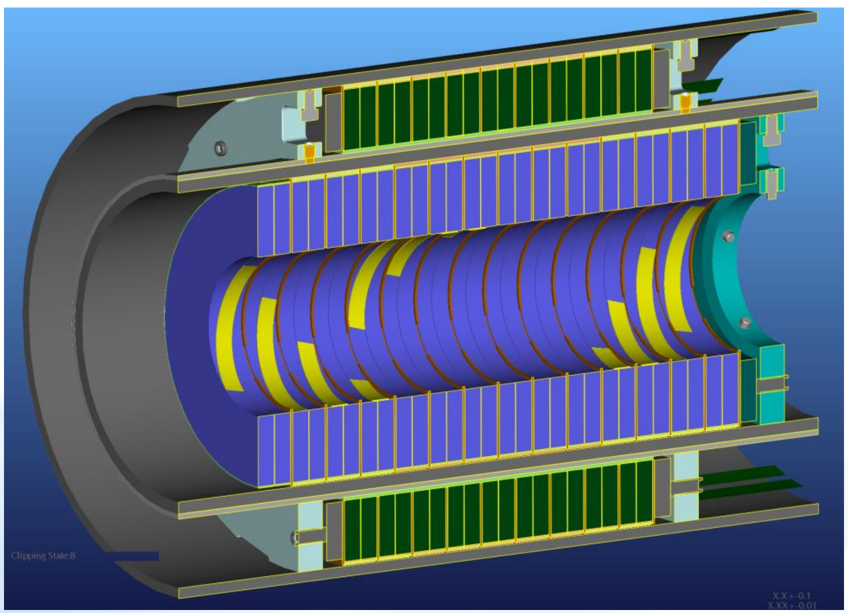
- After getting a final direction on 1.7 MJ choice, a more complete engineering design has been developed (earlier postponed to avoid duplication of 1.7 MJ and 2.5 MJ efforts)

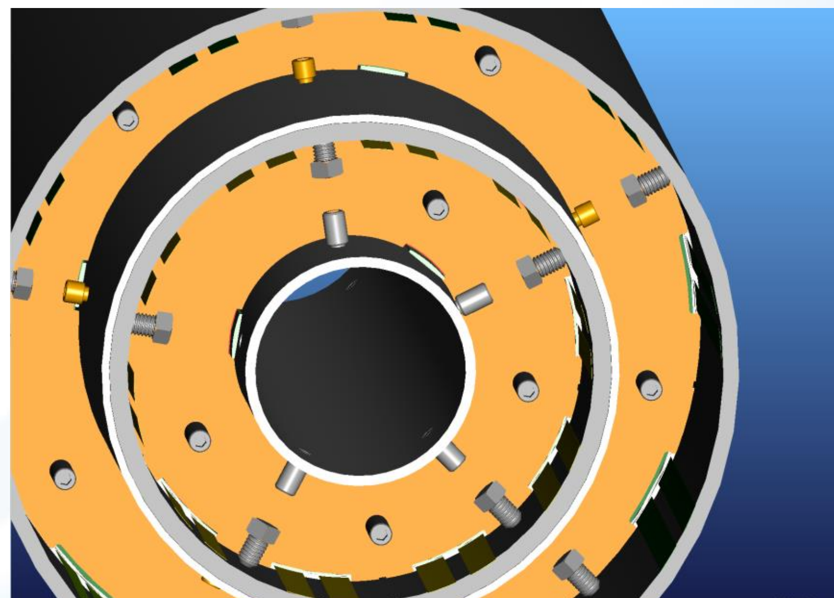


Engineering Design – Magnet Assembly

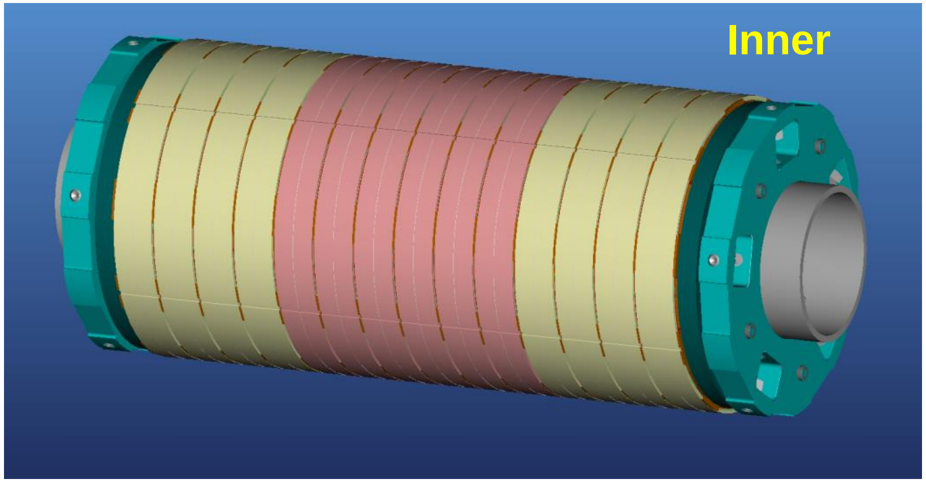








Electrical Connection and Leads



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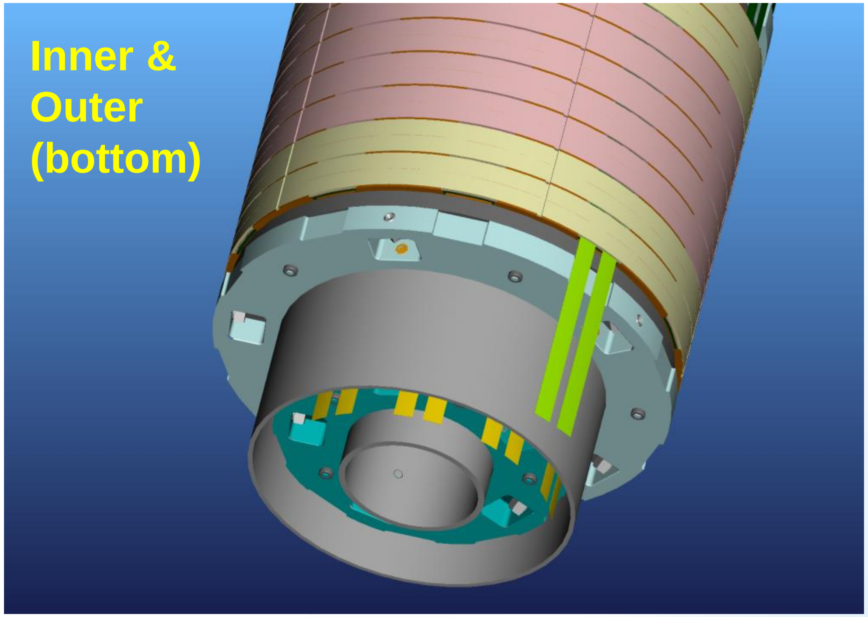

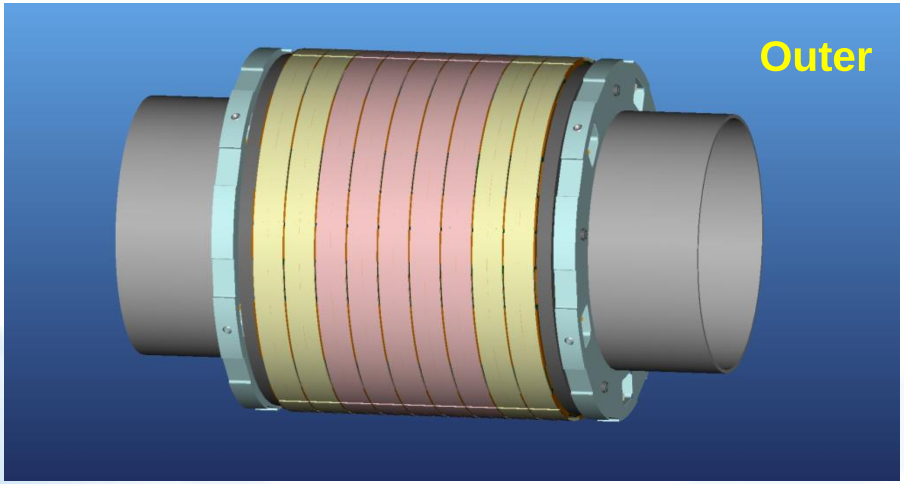

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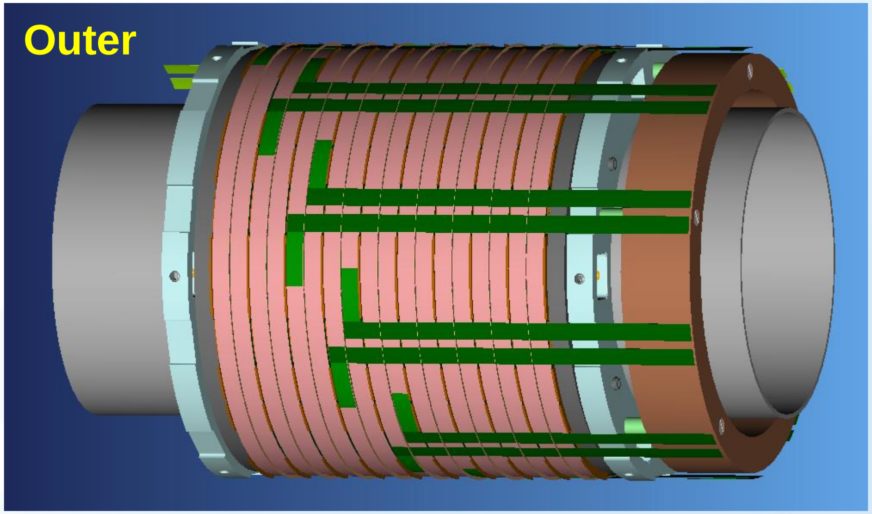
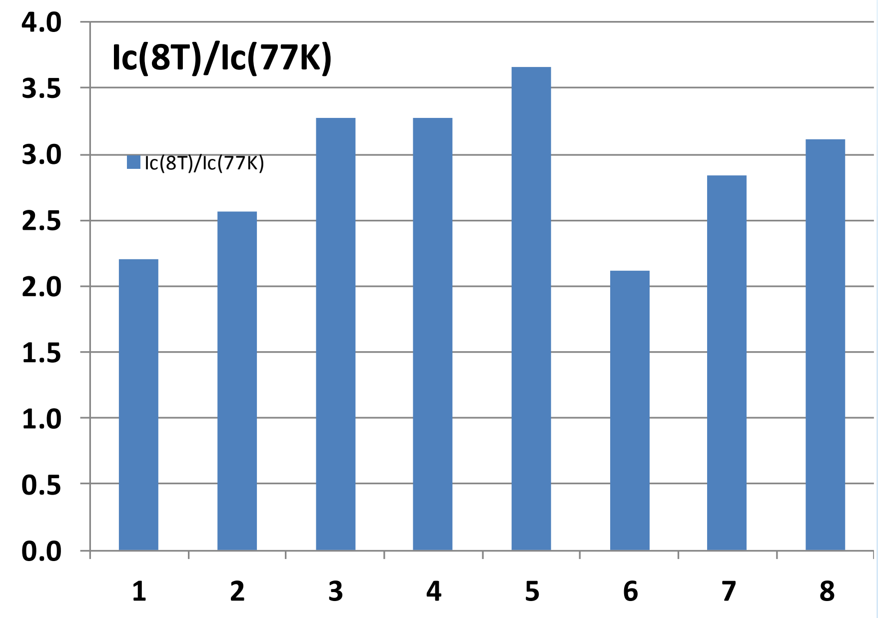


Choosing/Sorting the Locations of Pancakes

- **The agreed I_c specification on wire is >700 A at "(4 K, 8 T)". SuperPower has saved samples from each run. Measured data at "(77 K, self-field)" are available for each run and measured data at "(4K, 8T)" are expected soon from many more.**
- **BNL did its own measurements of several samples since in-field 4 K values are the one that are relevant for this project. We found a large variation in I_c values.**
- **The performance of SMES is likely to be limited by the coils in the end region because of a large anisotropy of I_c in HTS. Therefore we want the best coils there.**
- **In the absence of 4K data, we will sort based on the measured I_c in coils at 77 K.**

Short sample measurements at BNL

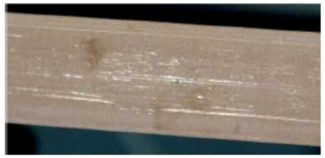
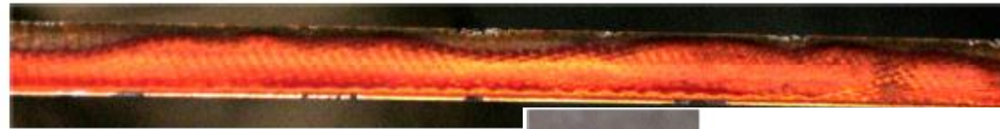
Sample Num	Comments	Tape Width, mm	Ic_Perp(8T)	Ic(77K)	Ic(8T)/Ic(77K)
1	PERP TEST	12	726	330	2.200
2	PERP TEST	12	800	312	2.564
3	PERP TEST	12	1119	341	3.282
4	PERP TEST	12	1324	404	3.277
5	PERP TEST	12	1401	383	3.658
6	PERP TEST	12	773	365	2.118
7	PERP TEST	12	956	337	2.837
8	PERP TEST	12	1369	439	3.118

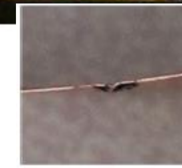


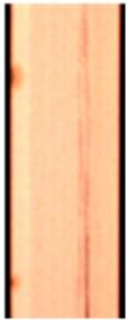
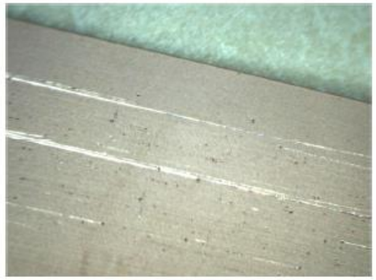
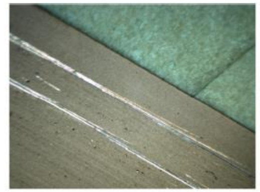
I_c(4K,8T) : 726 A to 1369 A (spec > 700 A)

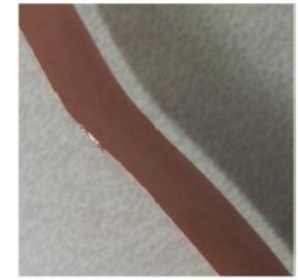
Lift factor 2.1 to 3.7

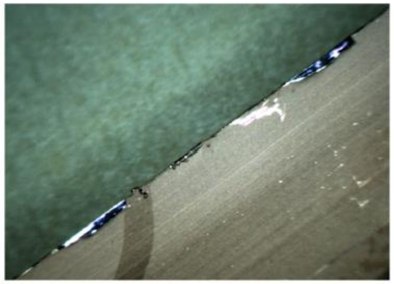
Visual Inspection of Conductor and Splices During Coil Winding (first line of defense in QA)

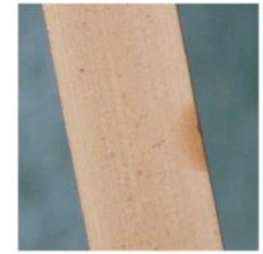




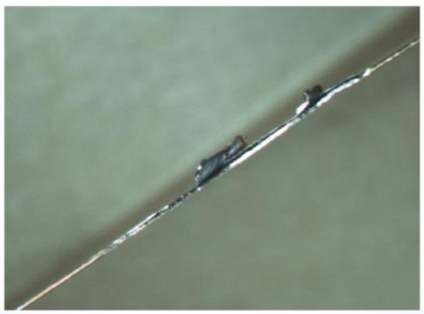





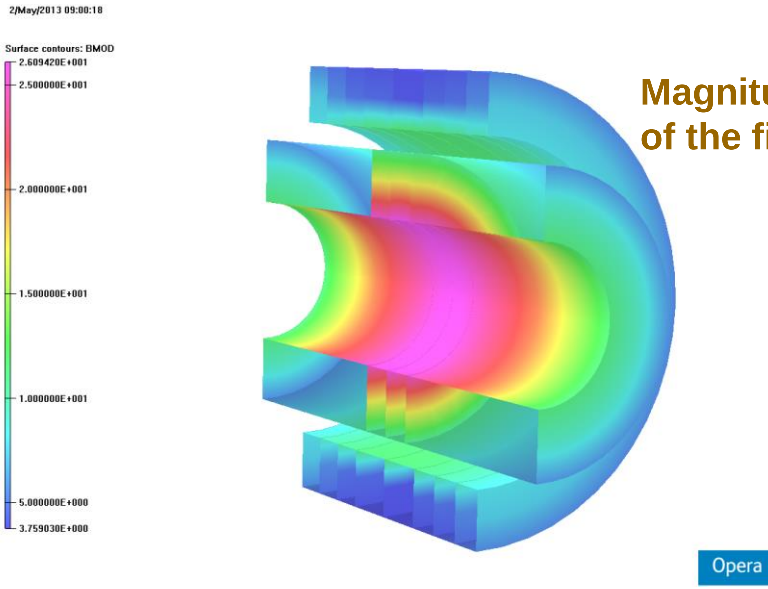





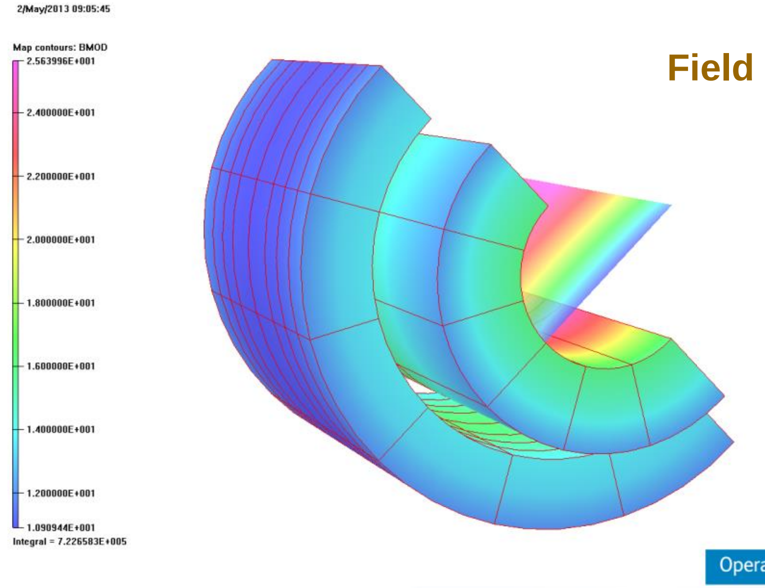
SuperPower has replaced the conductor in these and other cases where we were not sure

Because these defects were present in an extended length or at multiple locations, two coils were replaced. (If the concern is only in a small section, we remove that part, put splice and keep winding.

Magnetic Analysis of the Final Geometry (OPERA)

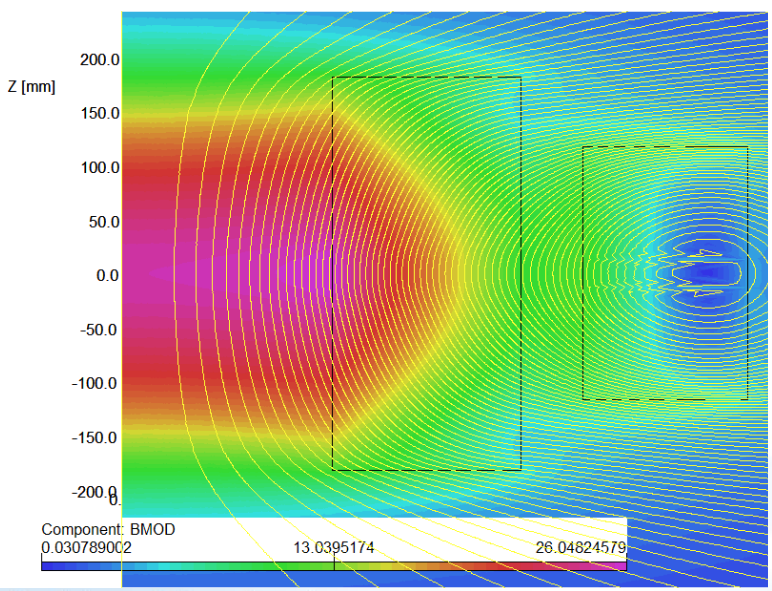


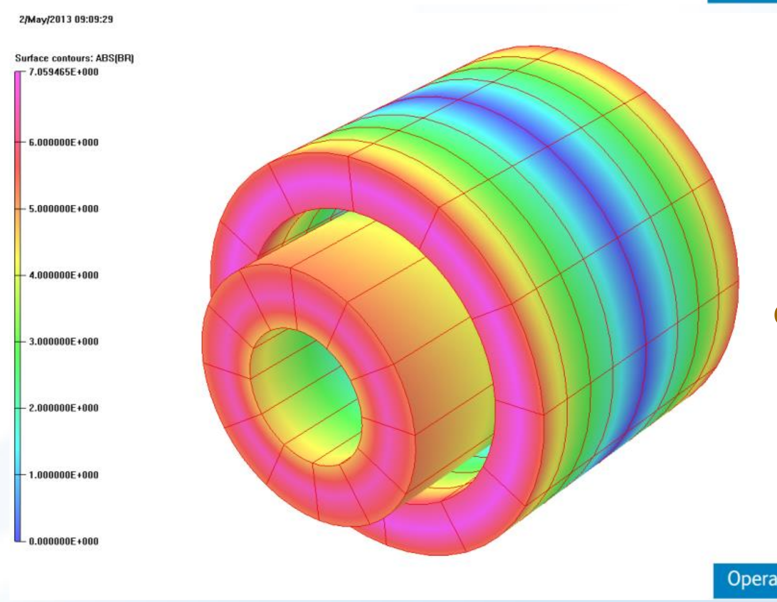
Magnitude of the field



Field on a patch

Field and field lines in cross-section

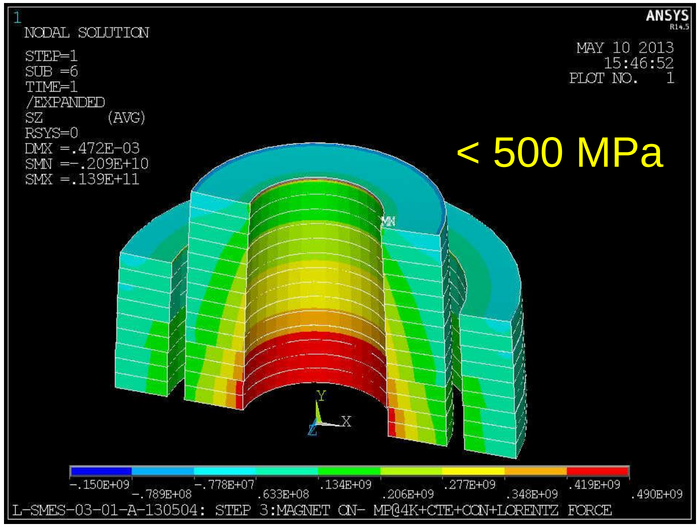




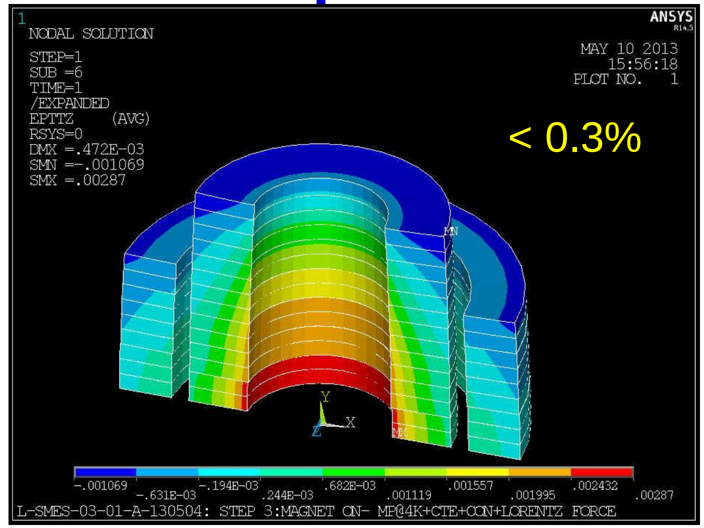
$B_{perpendicular}$ (radial) component of the field

Mechanical Analysis of the Final Geometry (ANSYS)

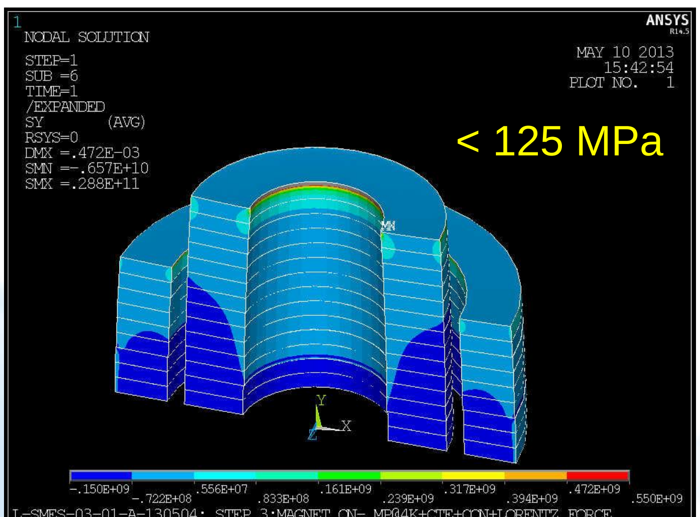
Hoop Stress



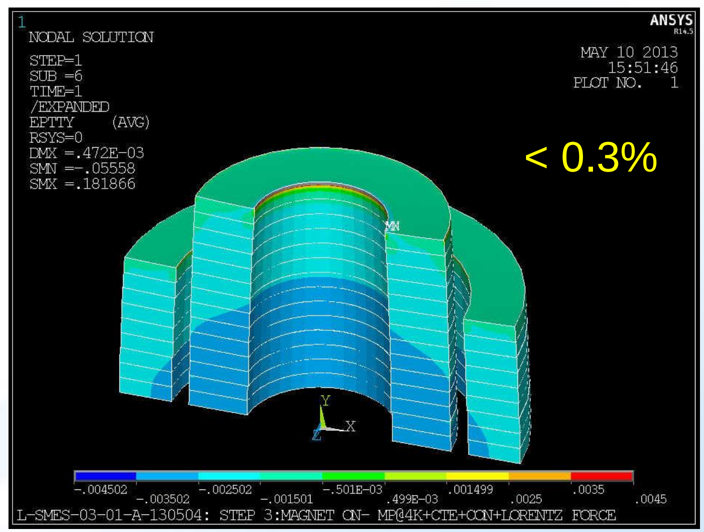
Hoop Strain



Axial Stress



Axial Strain



Coil deformation due to Lorentz forces: ~200 μm