Status of SMES Coil

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Superconducting Magnet Division
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BROOKHAVEN NATIONAL LABORATORY

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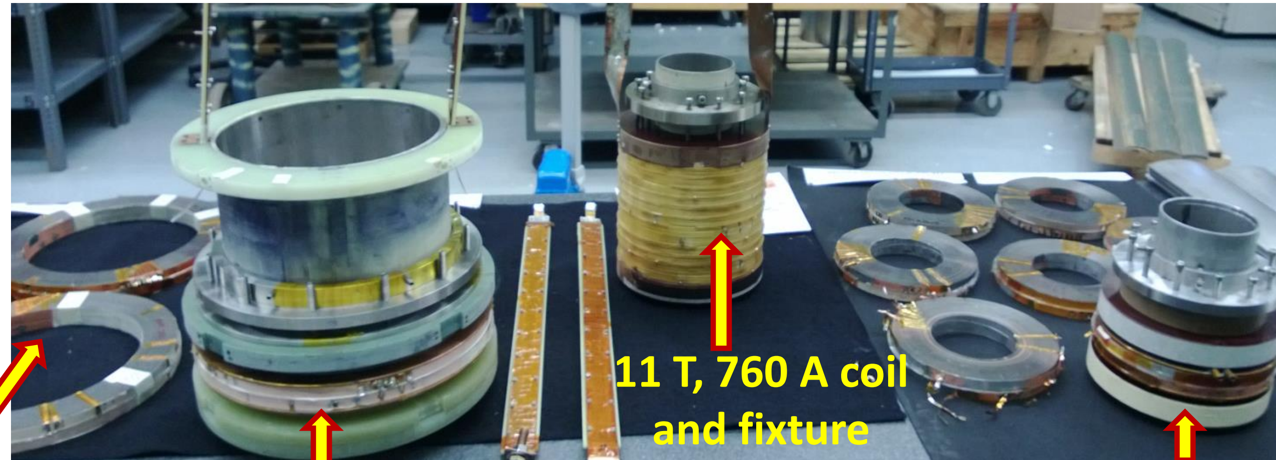
Office of Science
U.S. DEPARTMENT OF ENERGY

Overview of Activities

- **Assembly of inner and outer coils from pancakes**
- **Development of current leads**
- **Progress on Plus-up Work**
- **Quench protection system update (Piyush Joshi)**
- **Field test of quench system in protecting large HTS coil (during an accidental vacuum leak in another program)**
- **Summary**

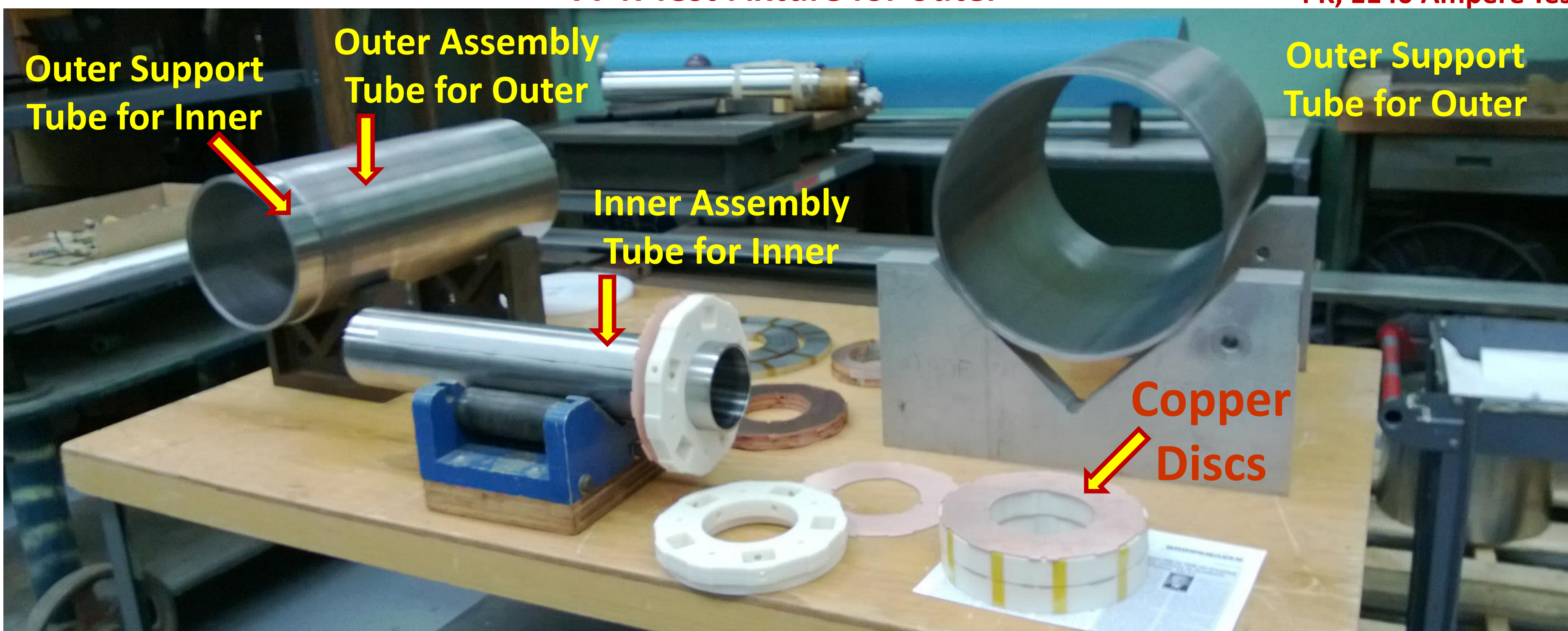
Scattered Parts Shown During the Last Visit (1)



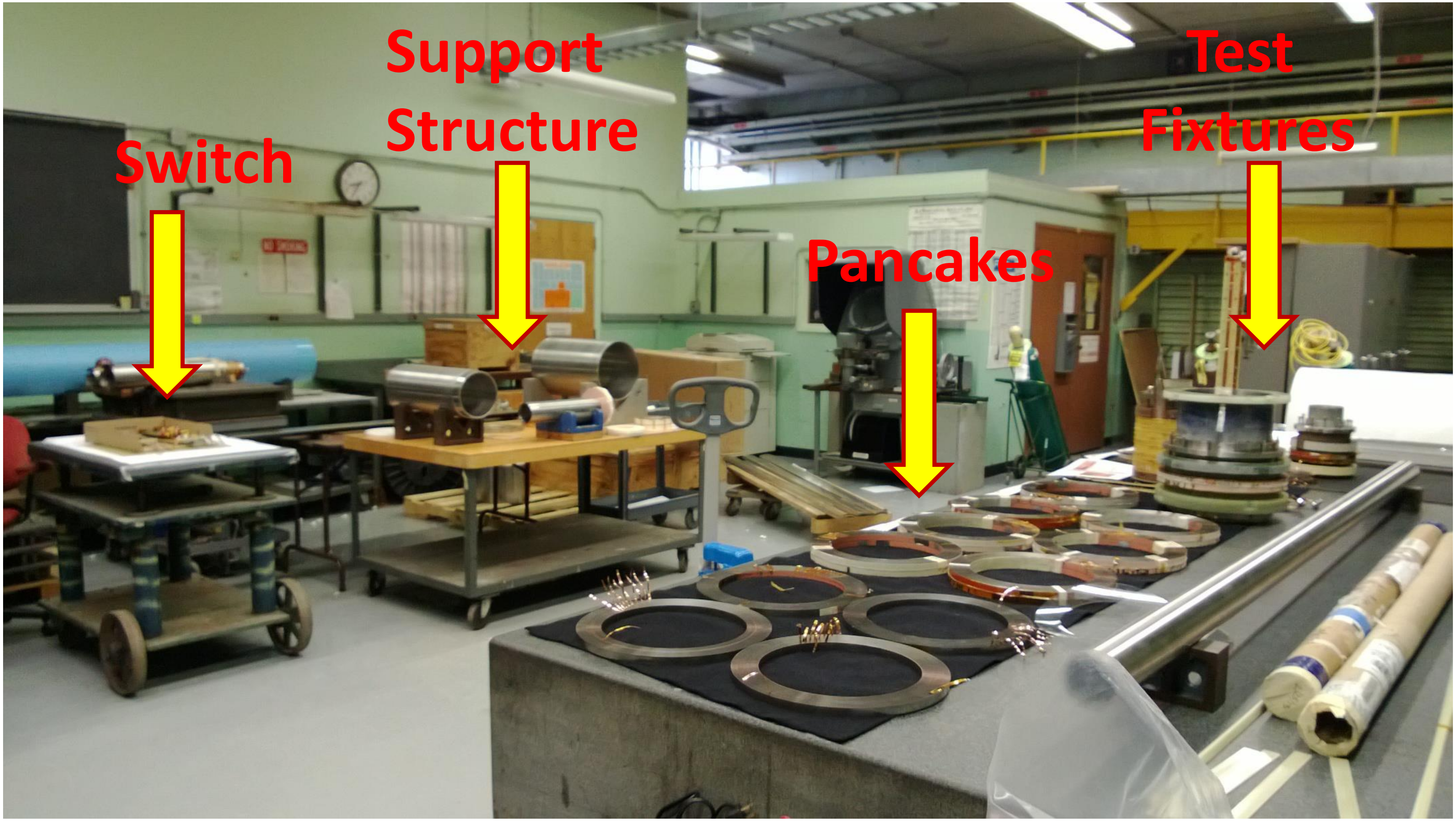
Pancake coils: inner and outer

77 K Test Fixture for outer

Inner Double Pancake
4 K, 1140 Ampere Test

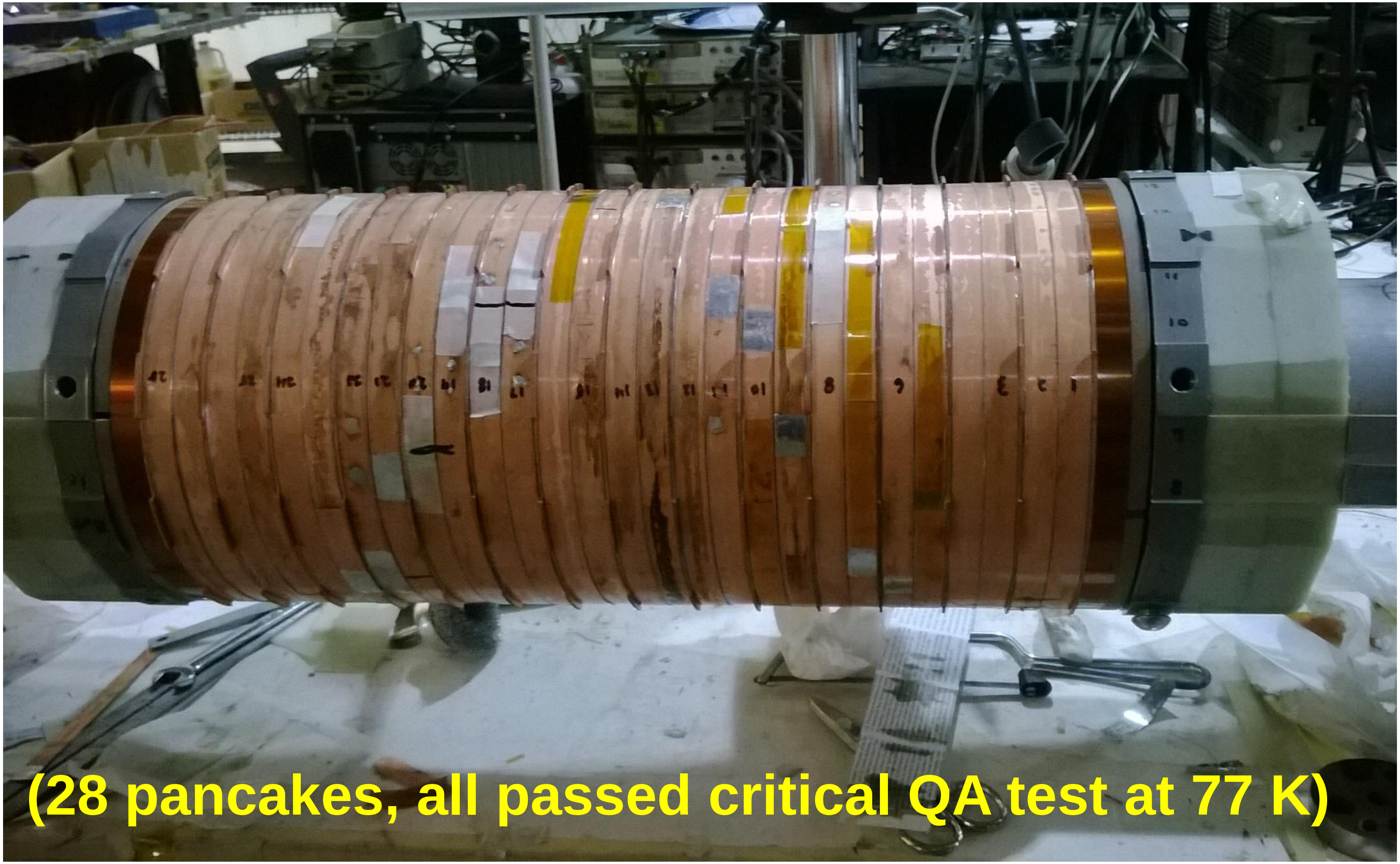


Scattered Parts Shown During the Last Visit (2)



Now pancakes have been assembled in the coils (next 2 slides)

Inner Coil Assembly (NOW)



Outer Coil Assembly (NOW)

Passed High-pot test to over 1 kV

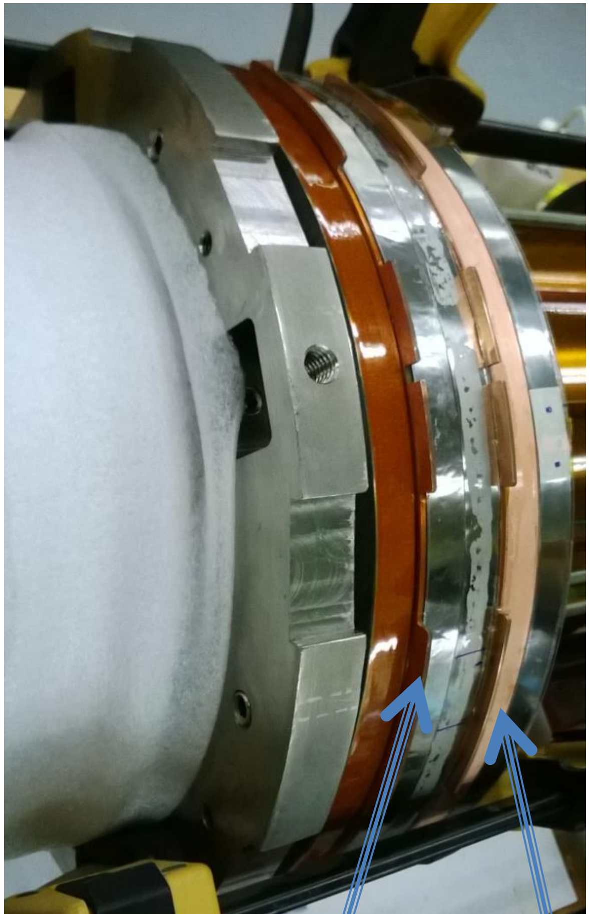
Example of Detailed Work

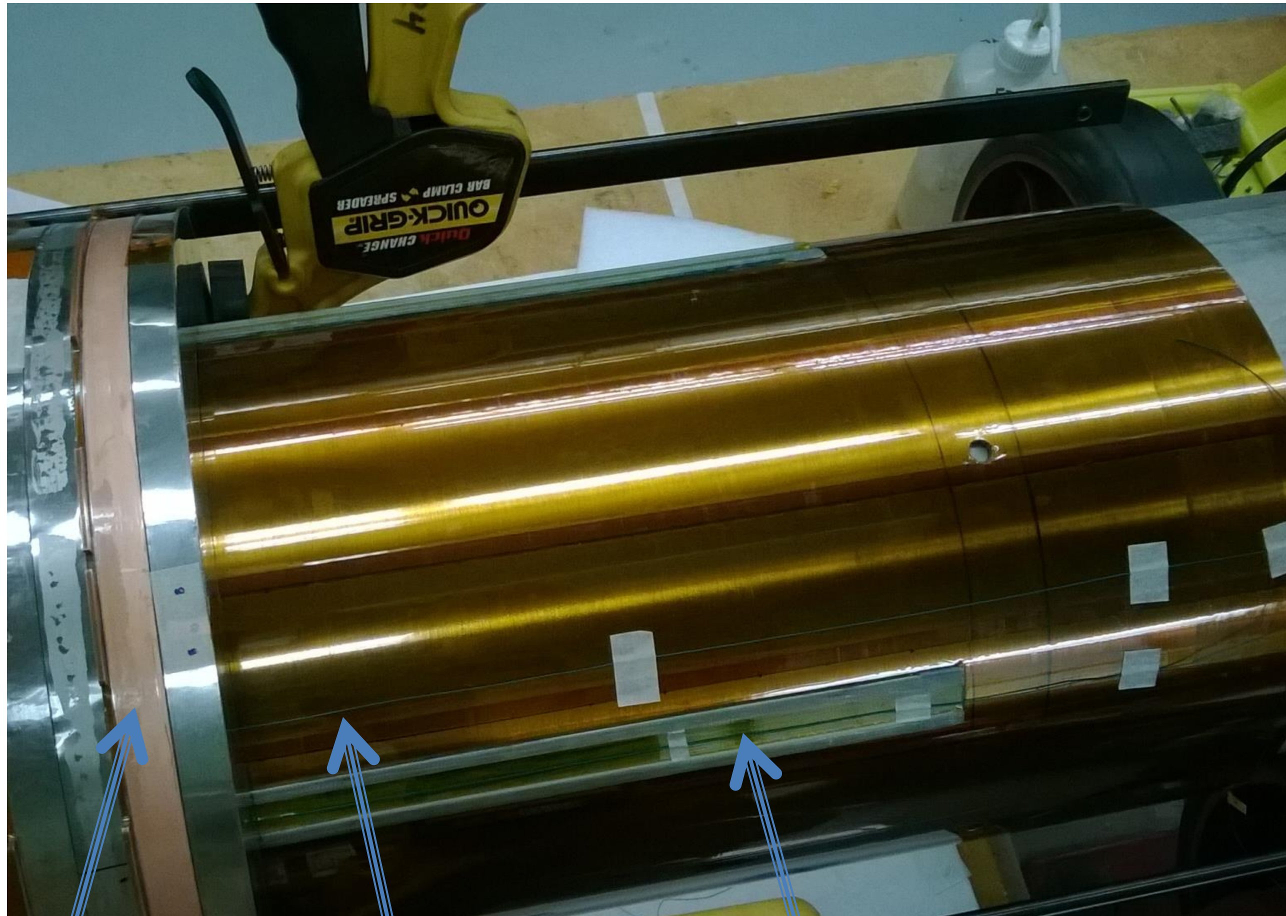
(magnet constructions requires paying attention to a lot of details)

The progress made in October 2013: SMES outer coil assembly (log from S. Lakshmi Lalitha)

	(Oct 3-7)	Carefully secured all inner voltage tap wires on the structure, before installing the push plate and end plate of the magnet assembly.
		Fabrication work
2	Received - October 11	Made additional slots on the inner surface of the push plates and end plates to take the inner voltage tap wires out from the coil assembly (machine –shop work).
3		Brought down the outer dimension of end-plate to match it up with the other component parts including the coil stack (machine-shop work).
4		Trimmed down the slots on the end-plate to match it up with the OD of the copper plate and coil stack (machine shop work)
5	(Oct-8)	Added shim on the push plates: to match the outer dimensions with rest of the components and to reduce the slack on the inner surface in order to achieve the mechanical stability of the current leads and to prevent the possible electrical shorts (hand-made)
6	(Oct 8)	Opened up holes in the end-plate in order to secure the G-10 plate for electrical lead termination (hand-made)
7	Received –Oct 15	A pair of G-10 discs was made to secure individual current leads coming out from G-10 discs. Outer surfaces of the G-10 discs were not flat and co-planar. Additional efforts were needed to get it fixed (machine shop work). This is to prevent strain on the current leads and to ensure that they stay flat, especially outside the coil surface.
8	Oct 18-21	Designed the lay out the voltage tap termination on the G-10 voltage tap board, drilled and tapped holes (hand-made). This can accommodate 110 voltage tap connections in total
9	Oct 16-21	Extra features were made on the G-10 voltage termination disks to secure the voltage tap wires (more than 75) coming out from the magnet assembly (all handmade)
		Coil assembly process
10	**Squeezing the magnet assembly (using torque wrench)** (oct 15-23)	Goal: Achieve a tight fit assembly at room temperature. This was a multi-step process. Systematically increased the torque, squeezed evenly. After each step, checked electrical continuity of all component parts to ensure that squeezing causes no undesirable outcomes. Initially assembly tends to relax every day. The above process was repeated three to four times a day for about fifteen days.
11	Hipot test (Oct 23)	Prepared the coil assembly for the Hipot test Maximum voltage applied : 1500 V, Leakage current is less than 0.1 micro-amps for whole magnet assembly at 1500 V. waiting for the feedback from the Electrical Engineer before installing the individual current leads and the rest of the voltage taps. Observations: an electrical short between a copper disc and coil (fourth coil from the top end of the assembly). The voltage tap (redundancy exist) is found broken, which limits a detailed trouble shooting at this stage
12	(Oct 16-18), Oct 23	Additional copper strips were made for stabilizing the current leads. pre-tinned the Cu bus bars to complete the initial preparation for making the individual current leads from the coil assembly

Coil Construction





Cu Disc

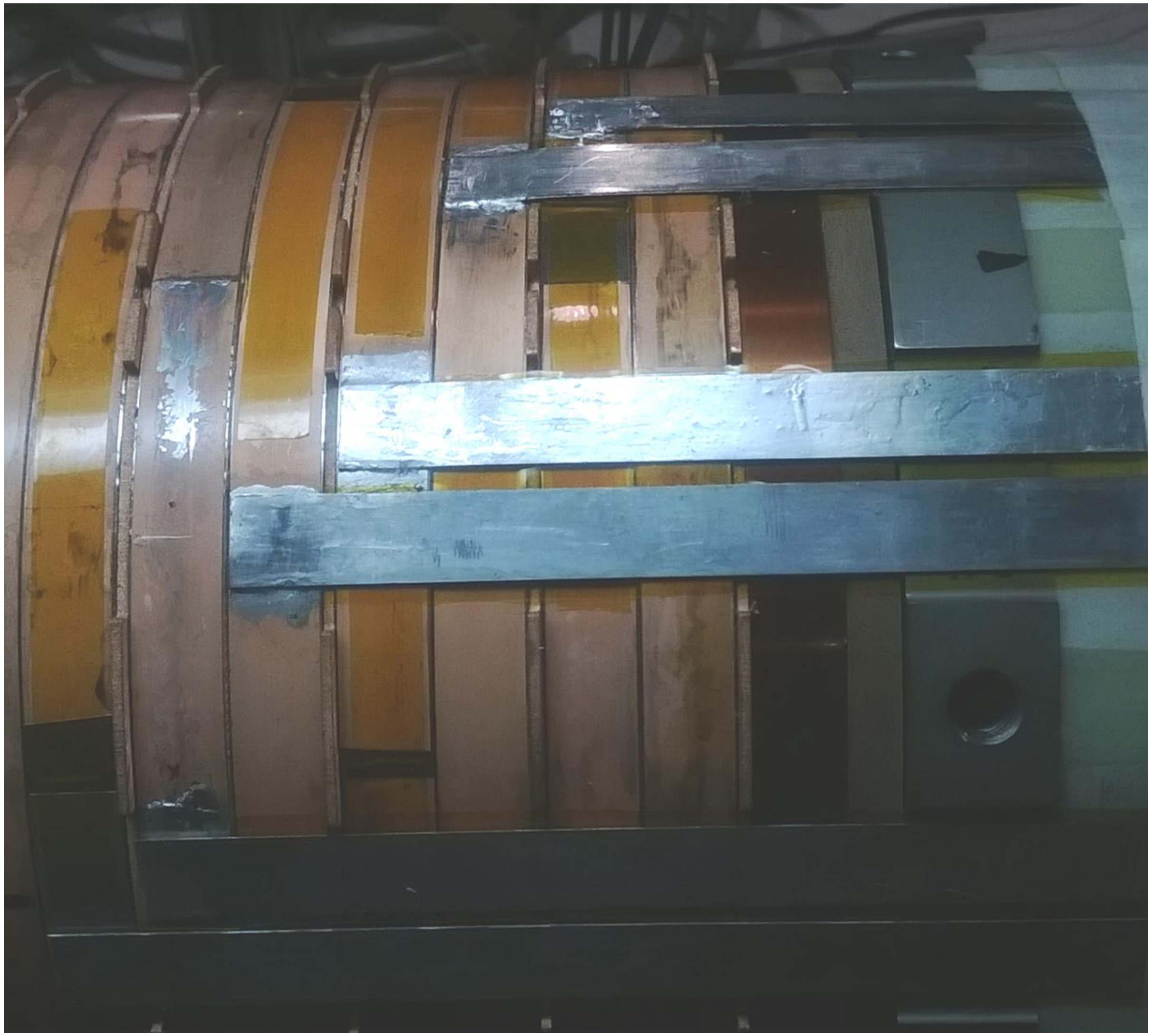
HTS Coil

Insulated Tube

Voltage tap routing (from inside)

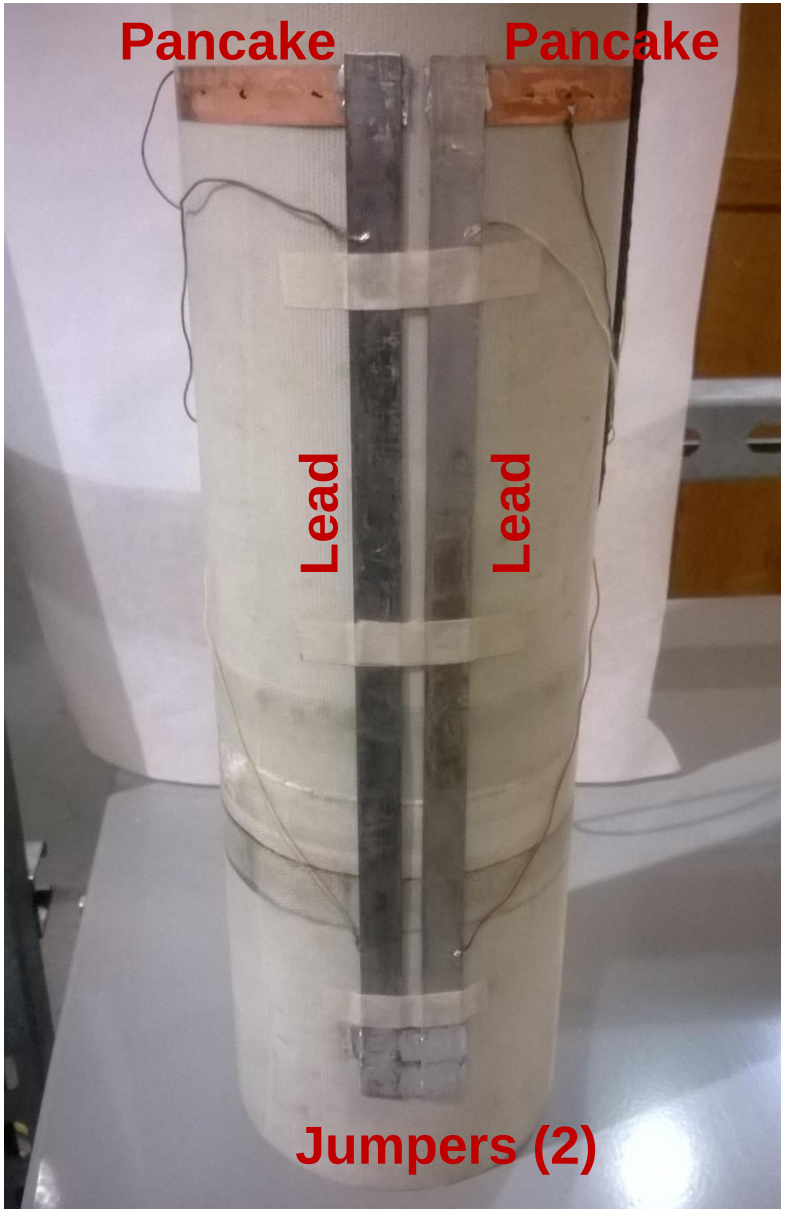
(also included: temperature sensors)

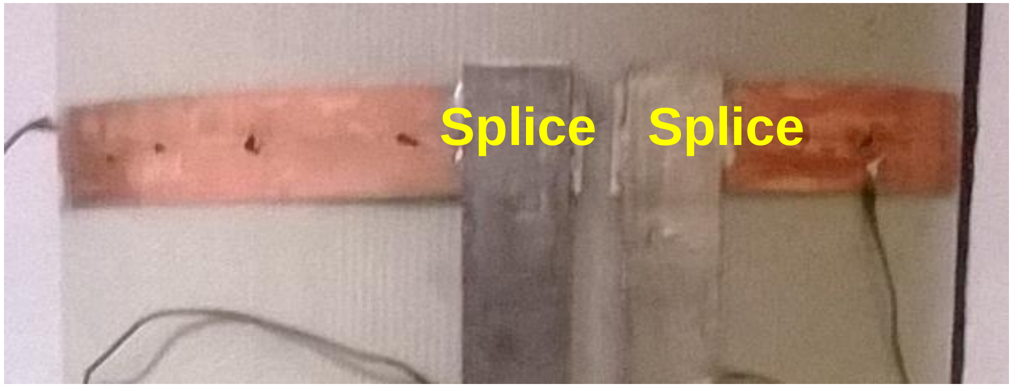
Current Leads and Splices



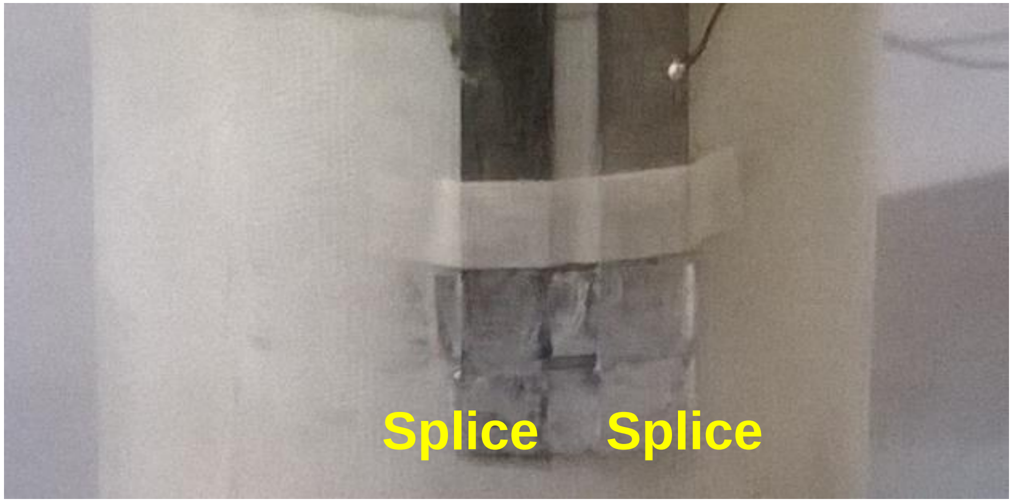
- Current leads and splices need extra attention
- They should be robust and have generous margin
- In addition to base conductor, we use extra conductor

Simulation and 77 K Test of Leads and Splices (1)

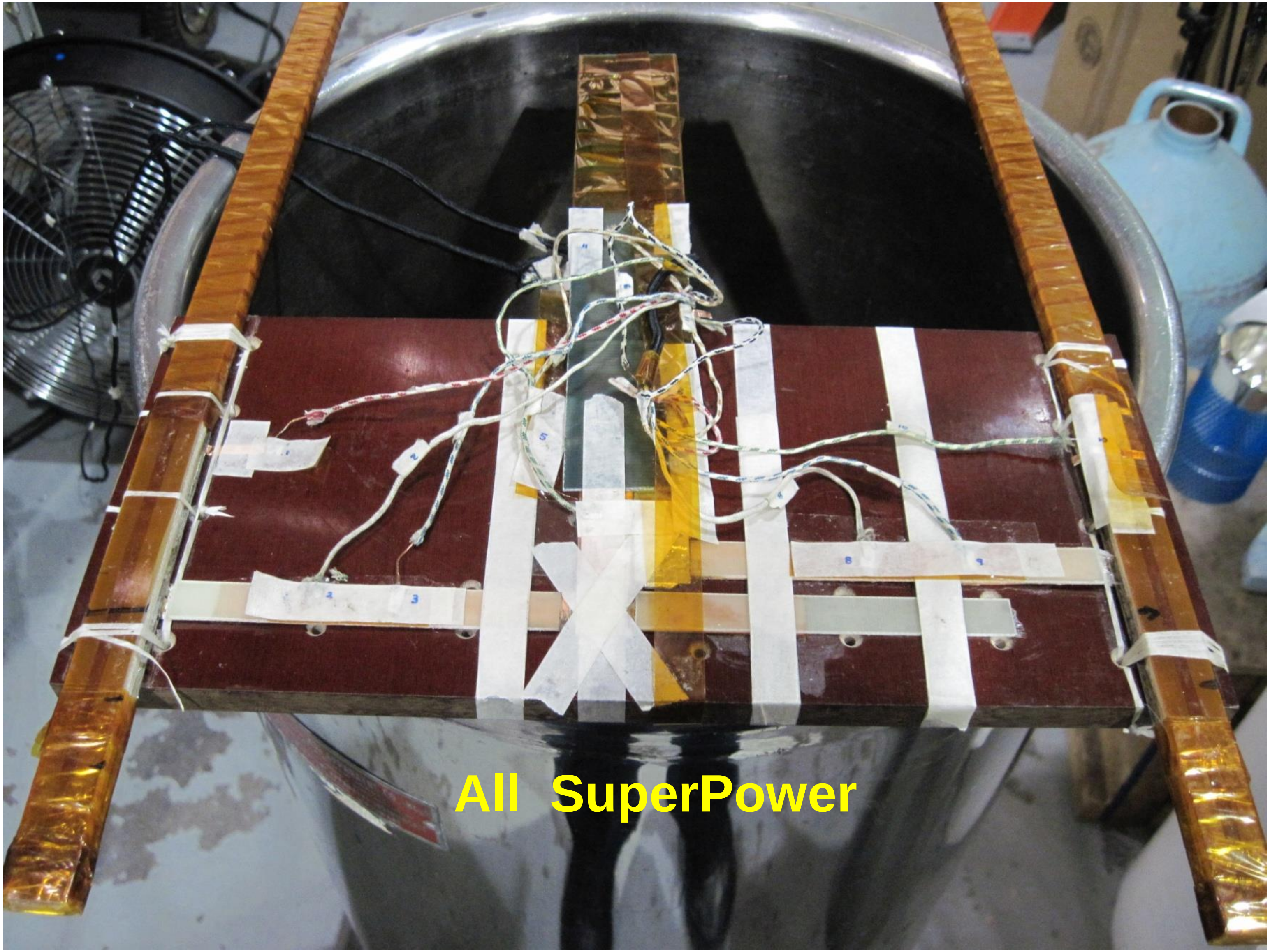




Double HTS tape in addition to single HTS tape used in the coil (total three)

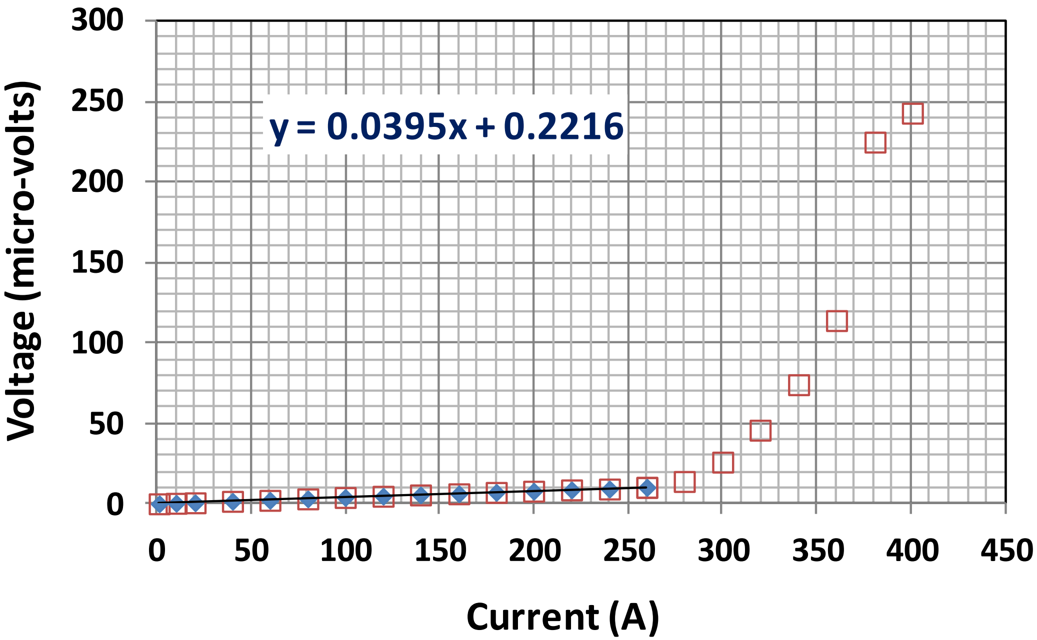


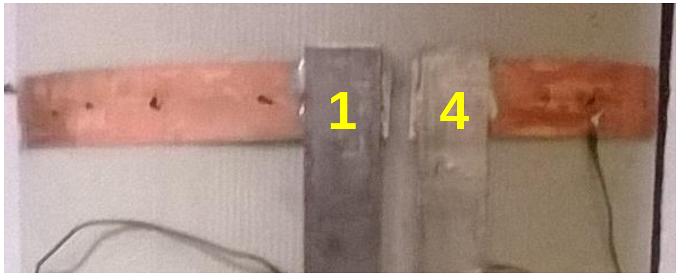
Simulation and 77 K Test of Leads and Splices (2)

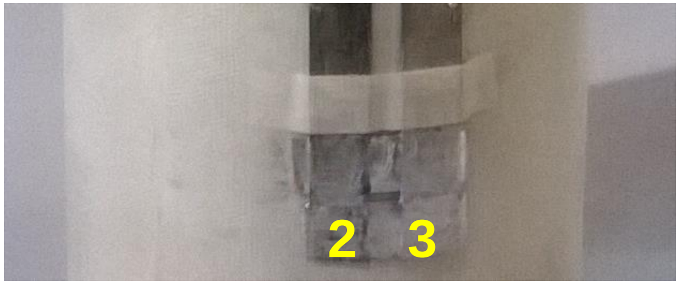


Two HTS single tapes of the type used in the coil + Cu stabilizer tape (total three)

77 K Test Results on Lead Splice (1)







Resistance in nano-ohms (overlap area of a single splice 1.2cmX1.2cm=1.5cm^2)

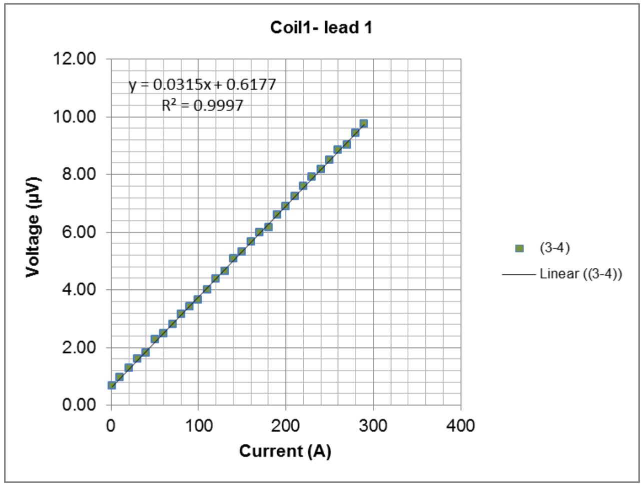
	SP-ASC	2xASC-ASC	SP-ASC
	1	2,3	4
one outer	275	93	307
two outer	295	52	296
one inner	51	99	40
two inner	49	61	40
three inner	49	81	38

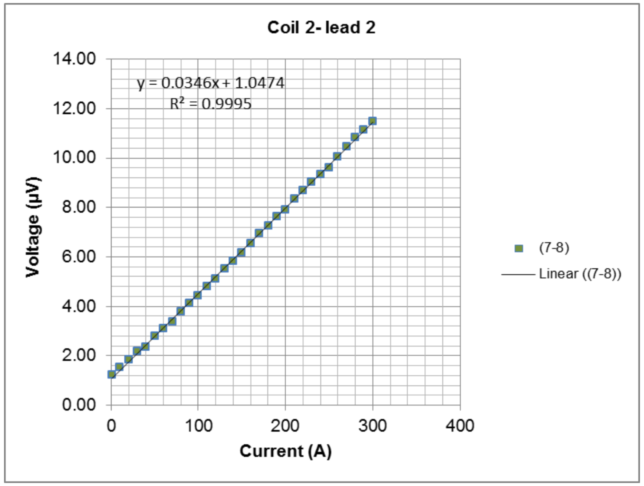
	SP-SP	2xSP-SP	SP-SP
	1	2&3	4
one inner	55	88	69
two inner	55	42	61

Chosen as final configuration (inner)

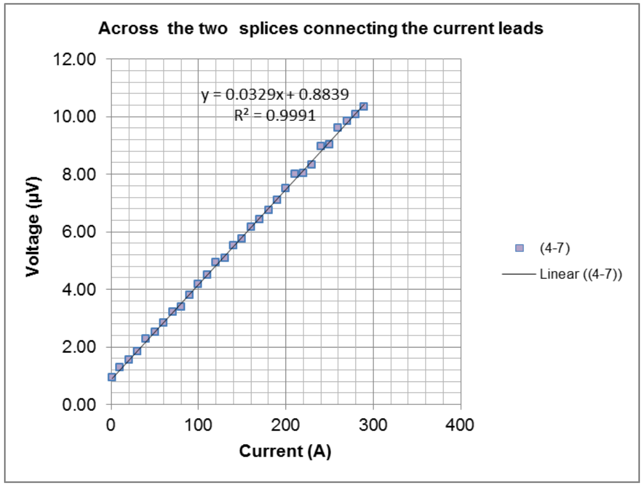
(backing for extra margin and stability: HTS double tape)

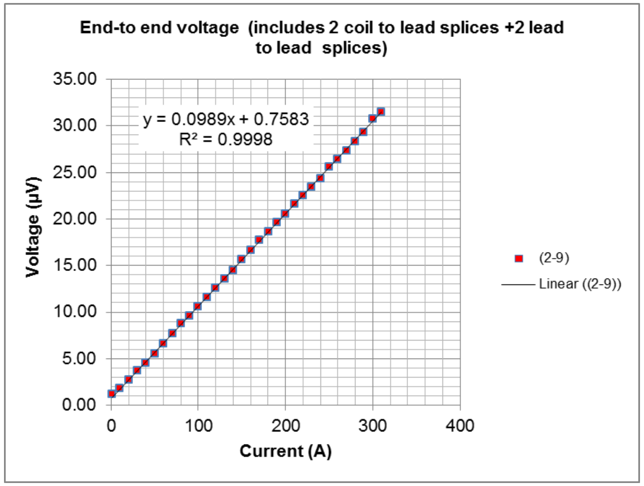
77 K Test Results on Lead Splice (2)





Chosen as final configuration for outer





Extra margin and stability from two HTS tapes plus copper stabilizer tape

Splices	Splice resistance at 77 K
Coil1 (SP)- Current lead 1 (SP)	31.5 nΩ
Current lead 1- Current lead 2 (two interconnecting splices)	32.9 nΩ
Coil 2- Current lead 2 (SP)	32.9 nΩ
Total (coil1- Current lead 1+ Current lead 1- Current lead 2 + Coil2- Current lead 2)	98.9 nΩ

Progress on Plus-Up Work

Funding received in October 2013

BNL SOW for FY 13 “Plus up” funds of $145K
On Superconducting Magnetic Energy Storage (SMES)
For ARPA-E Through CRADA No. BNL-C-11-01 with ABB Inc
July 29, 2013

Status of Work

In September, 2012 BNL submitted Tasks for $145K of Plus up funding. Based on work done since then and knowledge gained thus far, we have updated the tasks as shown below.

Tests at 77K and 4.2K of Magnet Alone

These tests are without switch or converter. Coil is divided into two separate sections for tests of the magnet alone, in order to limit the quench voltage to safe values during tests, while we are pushing the envelope to determine the maximum current (quenching may occur).

a) Complete dividing coil in two sections so that the energy from coils can be extracted in separate sections. Work will take place during the final assembly of the coil. — **Underway**

b) Complete the two enhanced power supply/electronics systems. (Enhance = modify existing system for higher voltages and higher current.) In addition to the power supply, this system contains the quench detection and protection system, the energy extraction, and the dump resistor. Budget estimated from experience with 10T coil test — **Underway**

c) Make four copper leads, modify cryo-test station for leads and instrumentation. — **Completed**

d) Complete the testing 77 K and 4 K testing of the magnet coil, quench detection and quench protection systems. — **Scheduled**

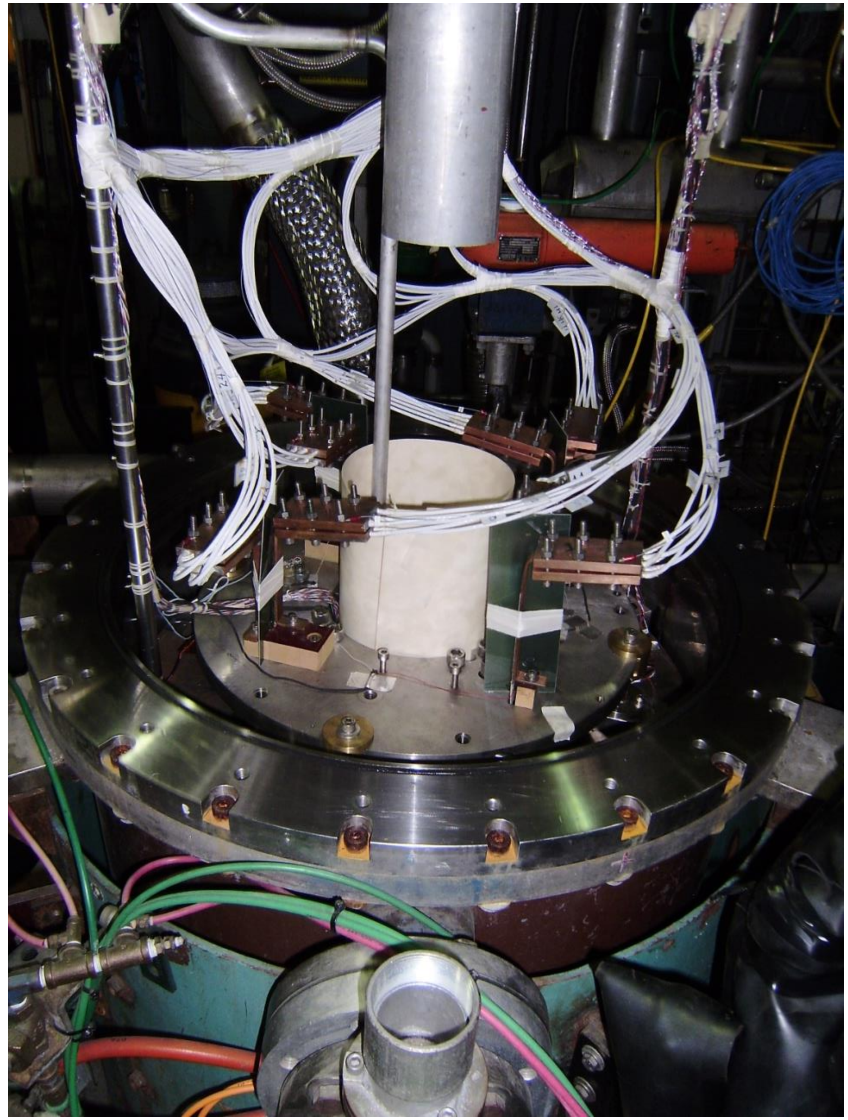
Integration of magnet, switch, and converter

e) System integration for the coil, the superconducting switch, and convertor. Provide preliminary design options for these activities. — **Completed**

The total of the five tasks above from Plus-up funds is: $145k

Plus-up Work: (c) Leads, etc.

Make four copper leads, modify cryo-test station for leads and instrumentation

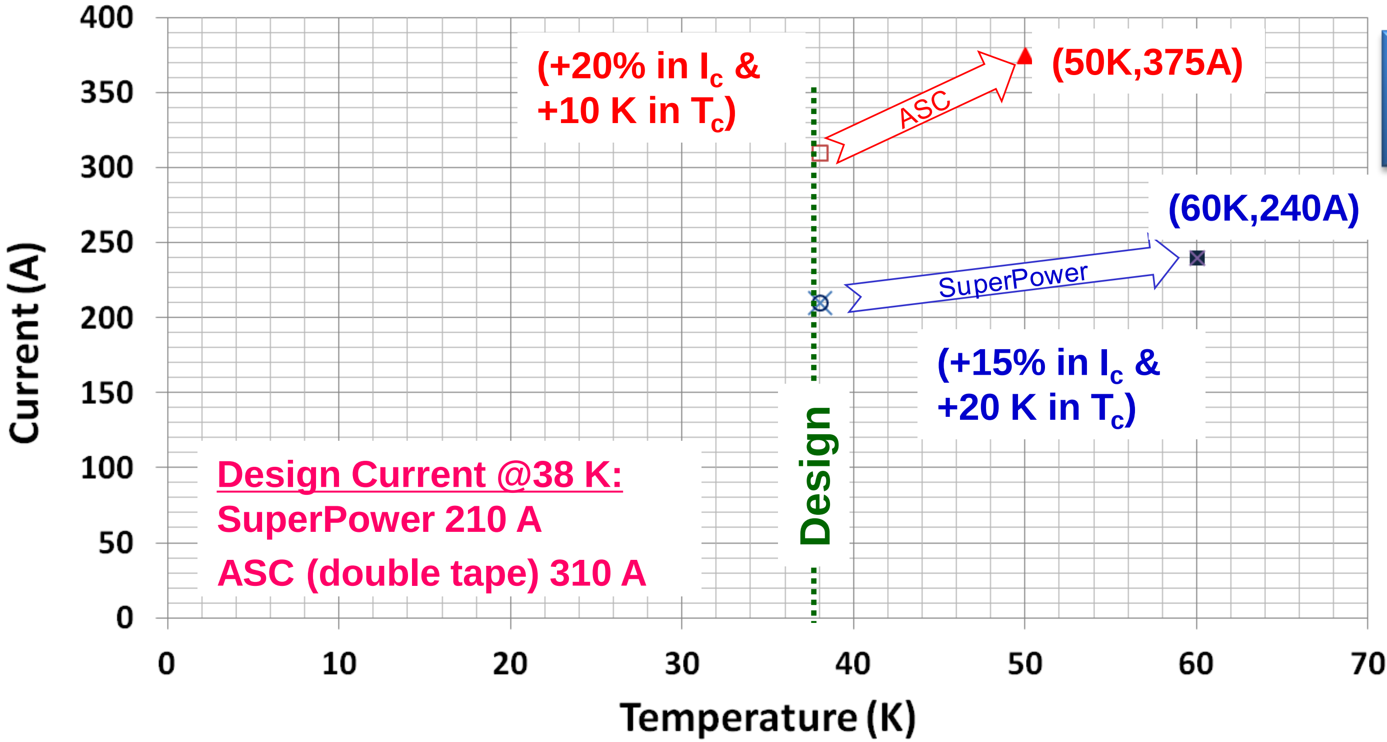


8 Cu leads, 400 A each (double to 800 A)
(He Gas cooled at the top)

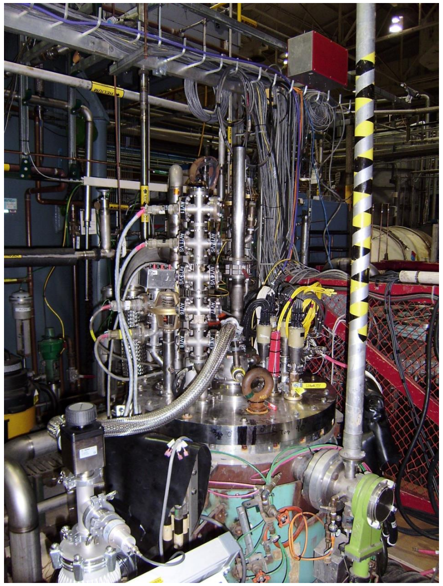
See other instrumentation also

Test of Current Leads (Demo of Plus-up Work)

(proven during the test with a magnet for another project - FRIB)



Proven to work for 2 X 375 = 750 A



- **Relevance to ARMY SMES : Magnet with significant amount of HTS worked well**
- **High temperature operation with unprecedented temperature margin (only possible with HTS)**

Field Test of Quench Protection System

• BNL/BSA is providing a significant amount of funds to develop advanced quench protection system to be used in a variety of HTS magnets.

• This system will be used in protecting SMES coil

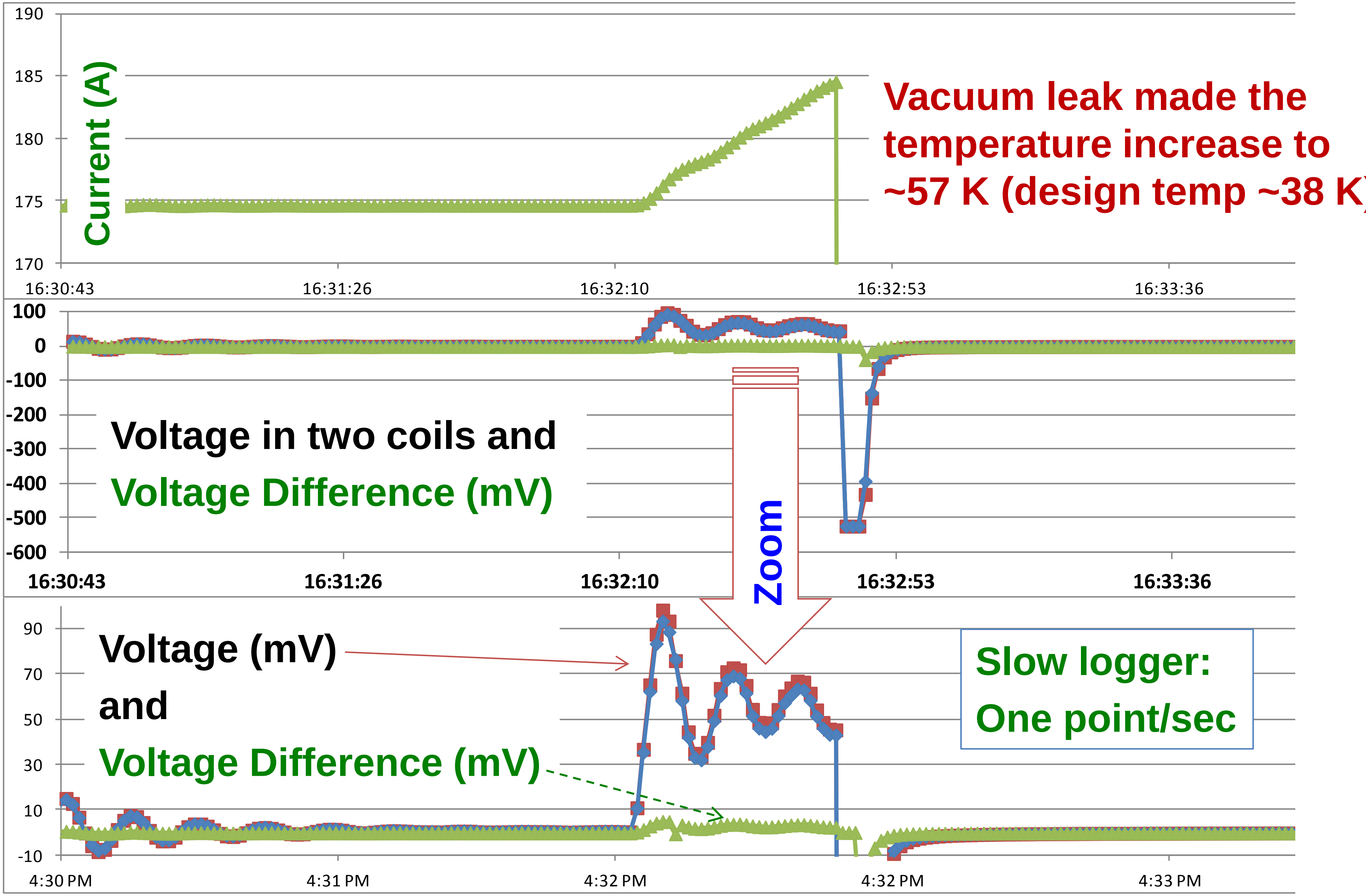
• The system (with fewer channels) was recently tested with another large magnet – HTS quad for FRIB

• During a recent test (September 2013) of FRIB HTS magnet, a vacuum leak developed which forced the HTS coils to quench (thermal runaway)

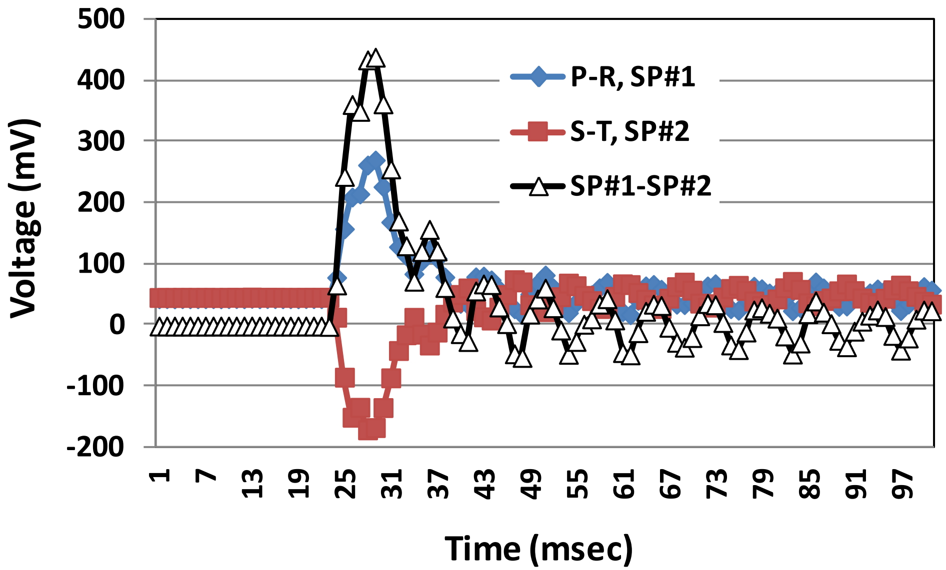
• Such accidents are the real concern and this event provided an unplanned opportunity of the field test of the system

• Following slides show that the quench protection system was able to protect the coil after a quench during the charging phase (most challenging) when the coil was near the design operating current

Event (Quench) During the Ramping of the SuperPower Coils

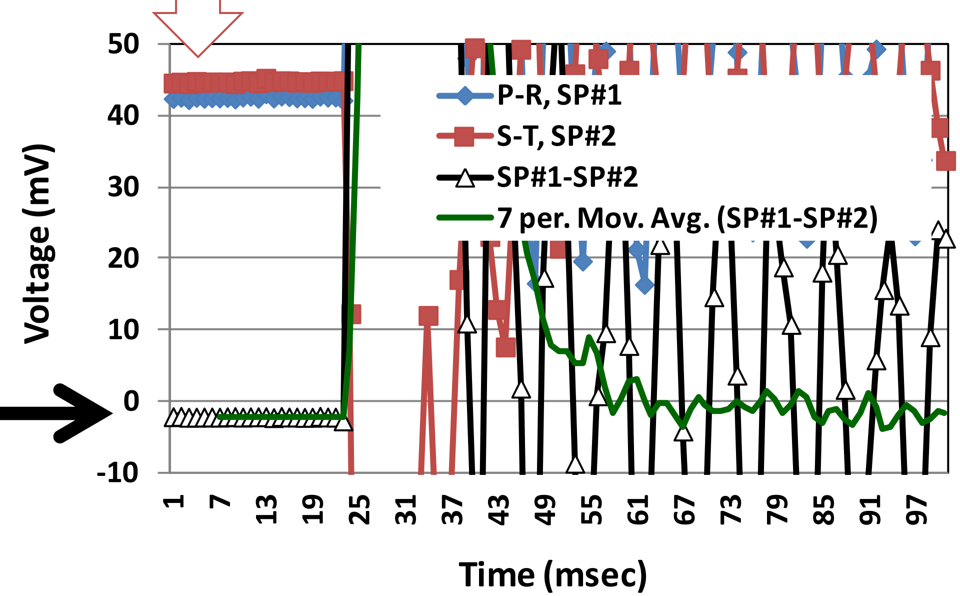


Snap Shot of the Event (Quench) that Triggered the Shut-off



Fast logger: One point/msec

Large inductive voltage in individual coils (ramp)



Low quench detection threshold (2 mV) kept during the ramp by monitoring difference voltage

Status of HTS Coil after the Quench

- HTS coils were thoroughly tested after the event and NO degradation in performance was observed
- This shows that the quench protection system can protect coils against the events like this (this has always been a major concern for HTS magnets)

Summary

• Inner and outer pancakes have been assembled together

• Basic quench protection system has been developed (Piyush Joshi) and was recently successfully tested in a real magnet for 8 channels. Moreover, a test is planned in January where the system will be tested for over for 40 channels in the same configuration as needed for SMES

• Quench protection system was able to protect the HTS coils during an accident – a real field test

• 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

Outer Coil Assembly During Construction

Updated arpa-e SMES Schedule

(R. Gupta, P. Joshi, M. Anerella, P. Wanderer)

November 21, 2013

- Complete leads and instrumentation on inner coil assembly: December 13, 2013
- Complete leads and instrumentation on Outer coil assembly: December 20, 2013
- Complete wrap, cure and machine inner coil assembly: December 20, 2013
- Quench Protection Electronics fully qualified, debugged and tested: December 20, 2013
- Complete wrap, cure and machine outer coil assembly: January 14, 2013
- Complete assembly of inner and outer coils in support structure: January 31, 2014
- Complete installation of SMES coil on top-hat with power leads and instrumentations (v-taps, temp sensors etc.): February 17, 2014
- Complete installation of SMES coil in Dewar to attach and debug power supply and instrumentation at room temperature: February 24, 2014
- Complete ~77 K system test: March 14, 2014
- Complete 4K High Field Test of SMES Coil for 1.7 MJ Stored Energy: March 28, 2014

Second Generation HTS Quad for FRIB*
(higher gradient and operating temperature)

First generation quad was made with the 1G HTS (Bi2223)
Higher performance 2nd generation quad is made with 2G HTS

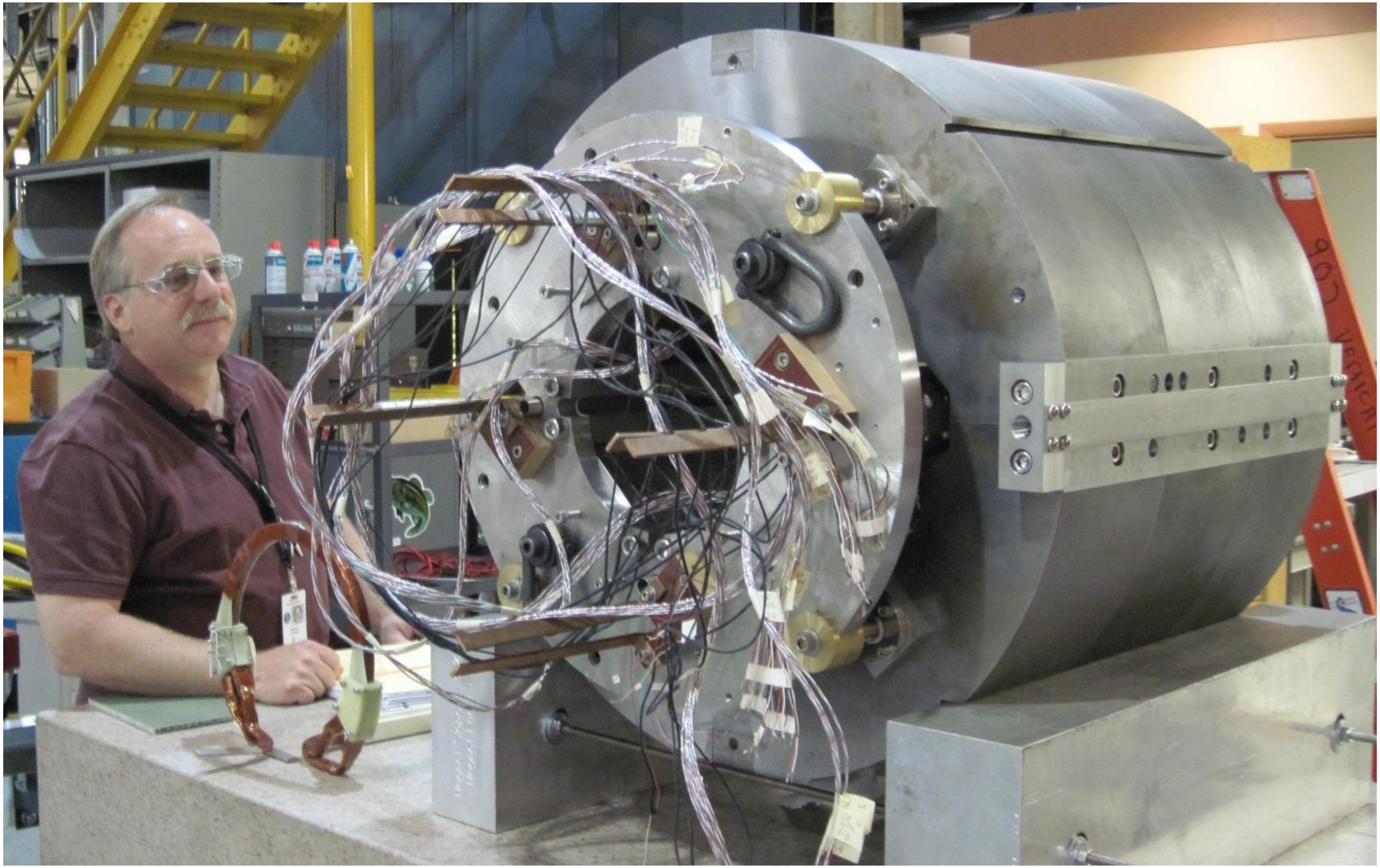
Eight coils wound

Four coils made with double tape:
- ~ 2 X 210 m per coil (420 m total)
- ~2x125 turns

Four coils with single tape:
- ~330 m per coil
- ~213 turns

***Facility for Rare Isotope Beams (FRIB)**

Completed Second Generation HTS Quad for FRIB



Design operating Temperature 38 K (has over 10 K margin)

HTS Magnet at the Test Station