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

- **Motivation for High Field HTS SMES**
- **Design Analysis and Updates**
- **Construction and Test Results**
- **Quench Protection (next talk by Piyush Joshi)**
- **High Priority tasks to meet budget challenge**
- **Status of Milestones and Accomplishments**
  - Magnet division did not have any Q5 milestone

Motivation for High Field HTS SMES

In our field, we are exposed to devices with large stored energy

- Accelerator detector in service
  CMS: 2.66 GJ (4 T NbTi)
- ITER: 6.4 GJ (13 T Nb_3Sn)

Energy $\propto$ Field^2

HTS keeps carrying high currents at high fields for storing large energy:

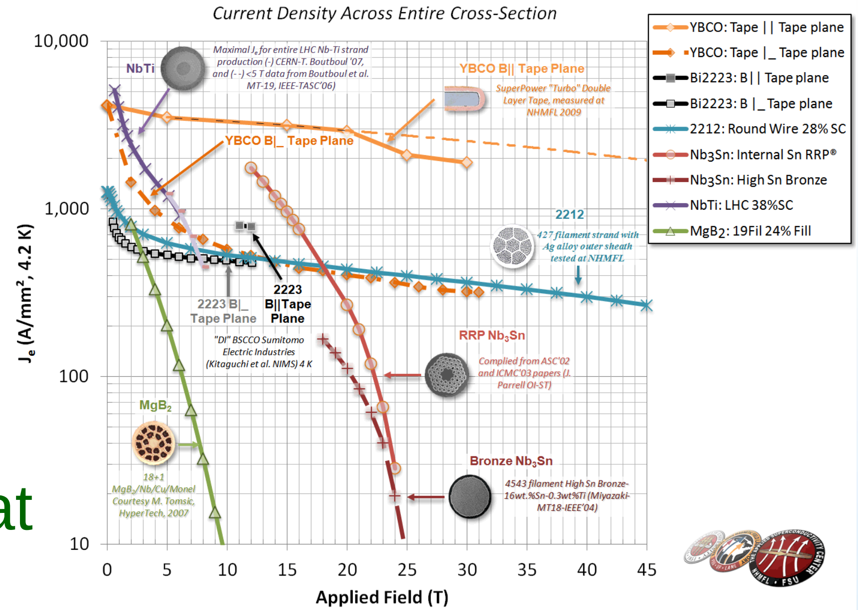
✓ 10X/7X field=> 100X/50X Energy

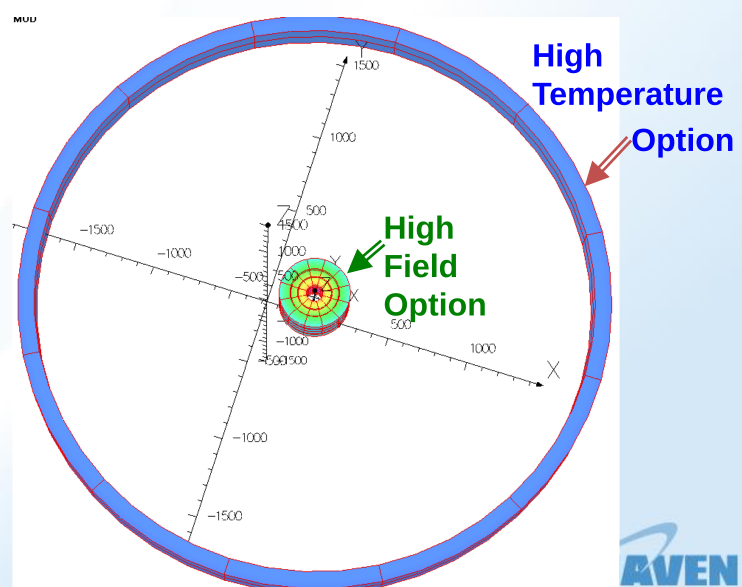
- Q.: Can one achieve ~25T, 30T or more & that too in a large device?
- No one has ever been close to it...

➢ **High field HTS SMES:**

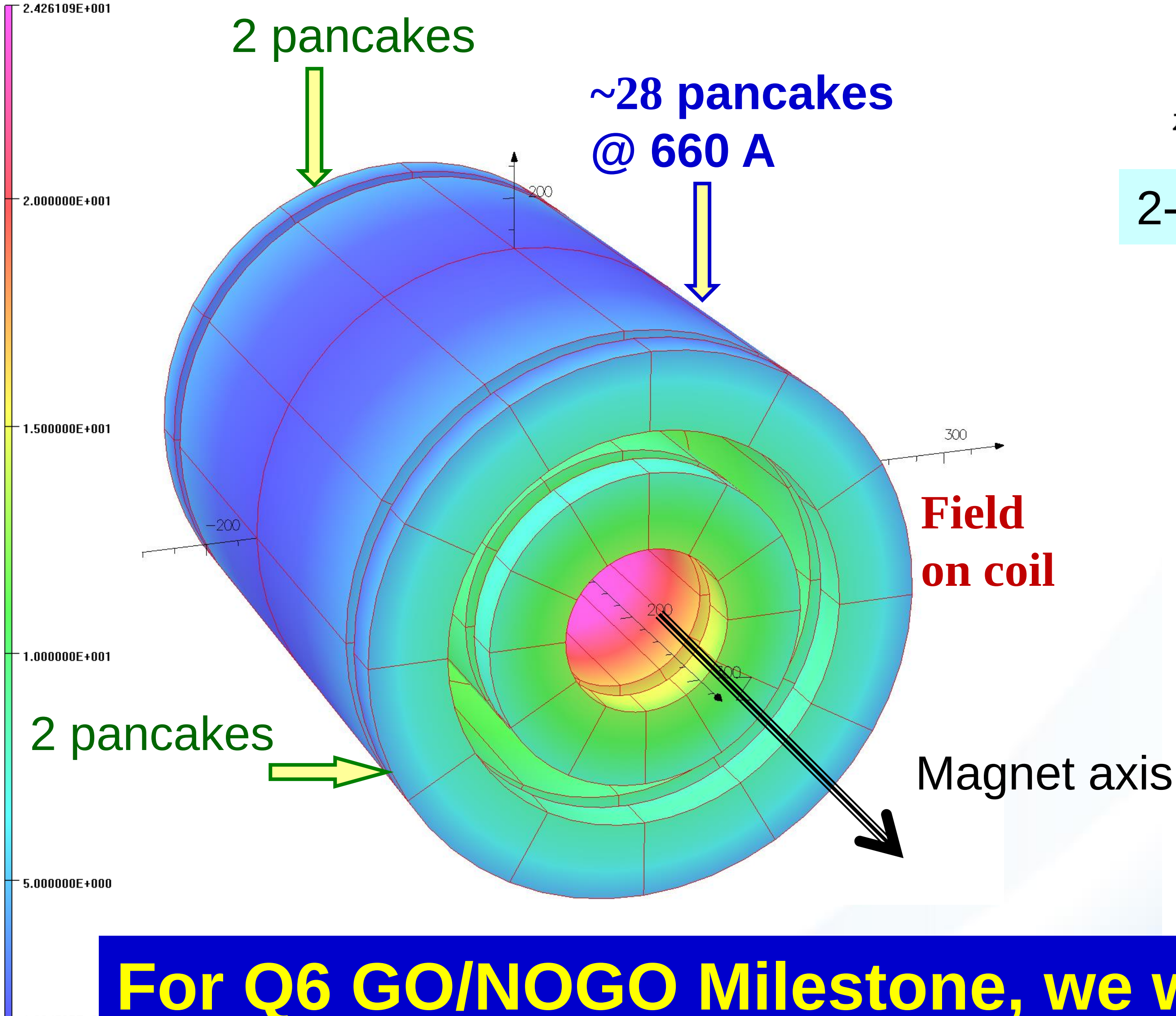
- a transformational technology

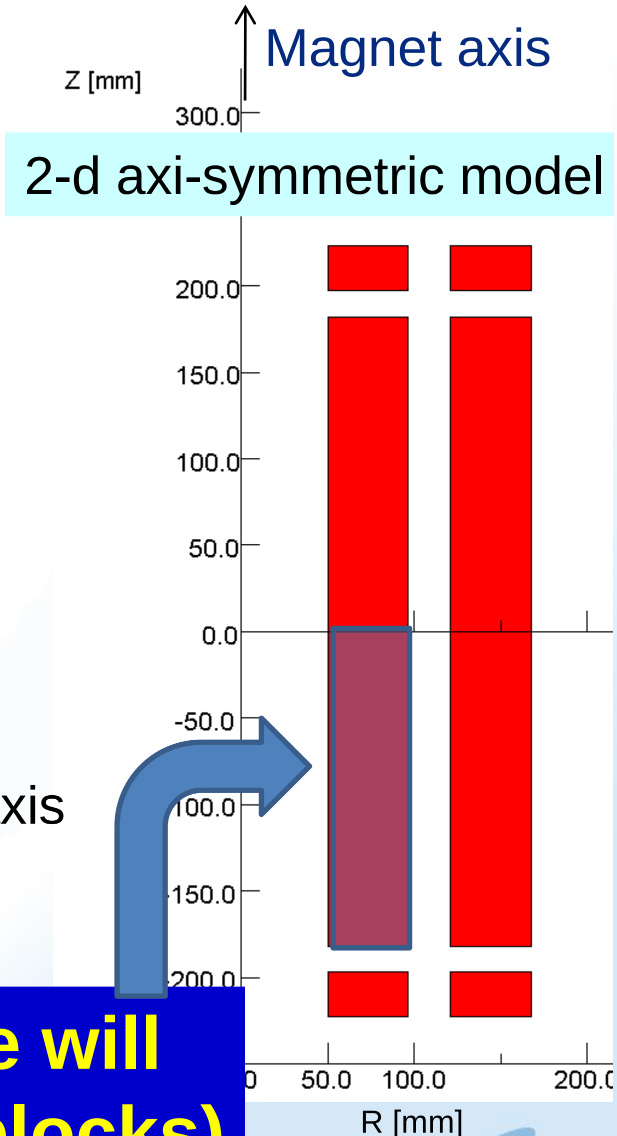
SMD@BNL is in a unique position with a wide range of programs (highest field HTS magnet)





Basic Magnetic Design of the Coil





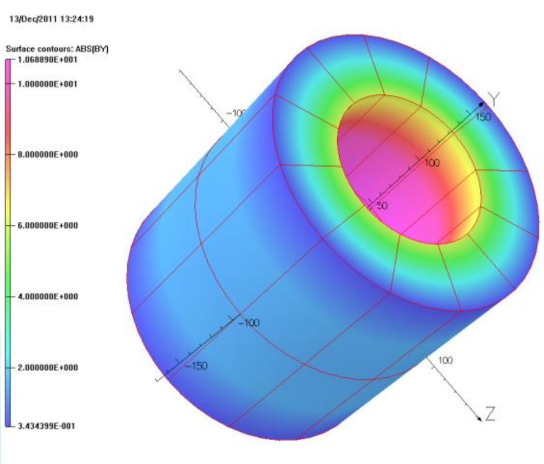
For Q6 GO/NOGO Milestone, we will build & test half inner (no end blocks)

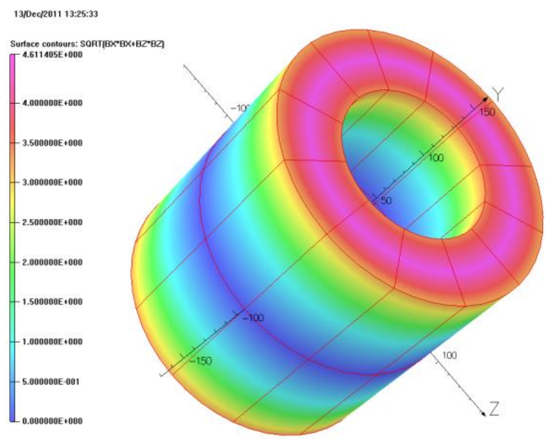
Q6 GO/NO GO Coil (GOAL > 10 T)

Q6 GO/NOGO Design:

- Six double (12 inner single) pancakes
- >10 T (~10.6 T) @ design current of 640 A

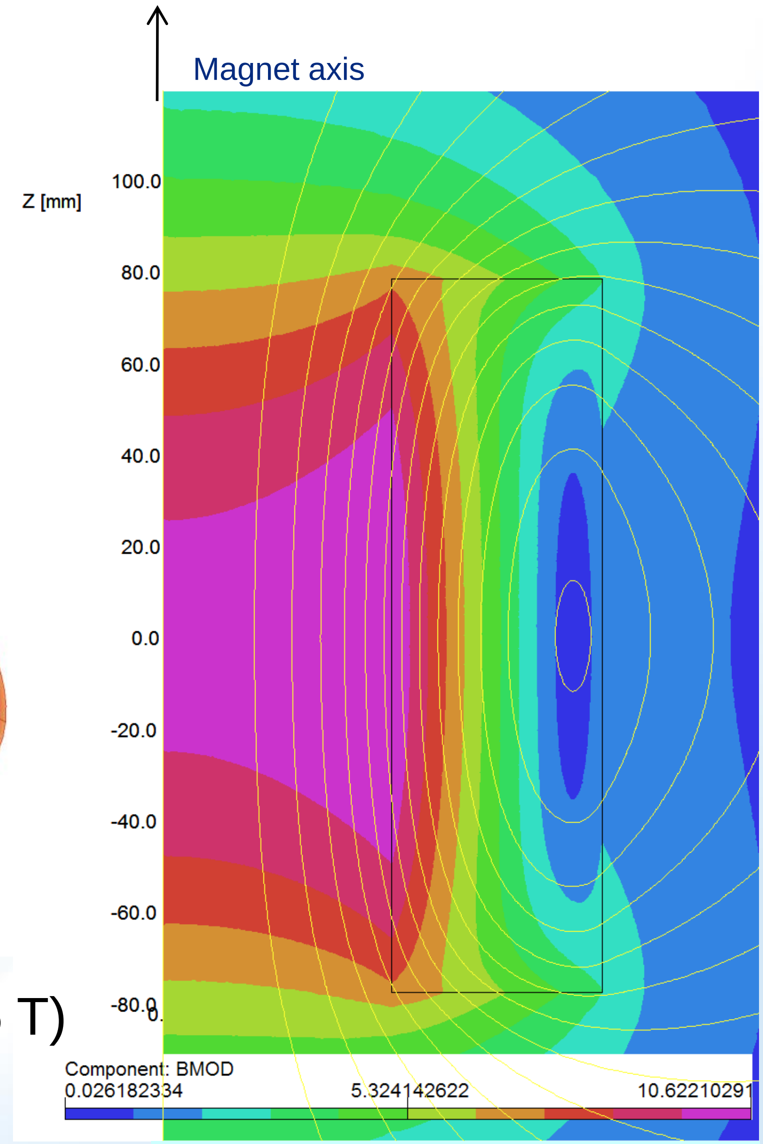
  --- should reach higher due to lower field





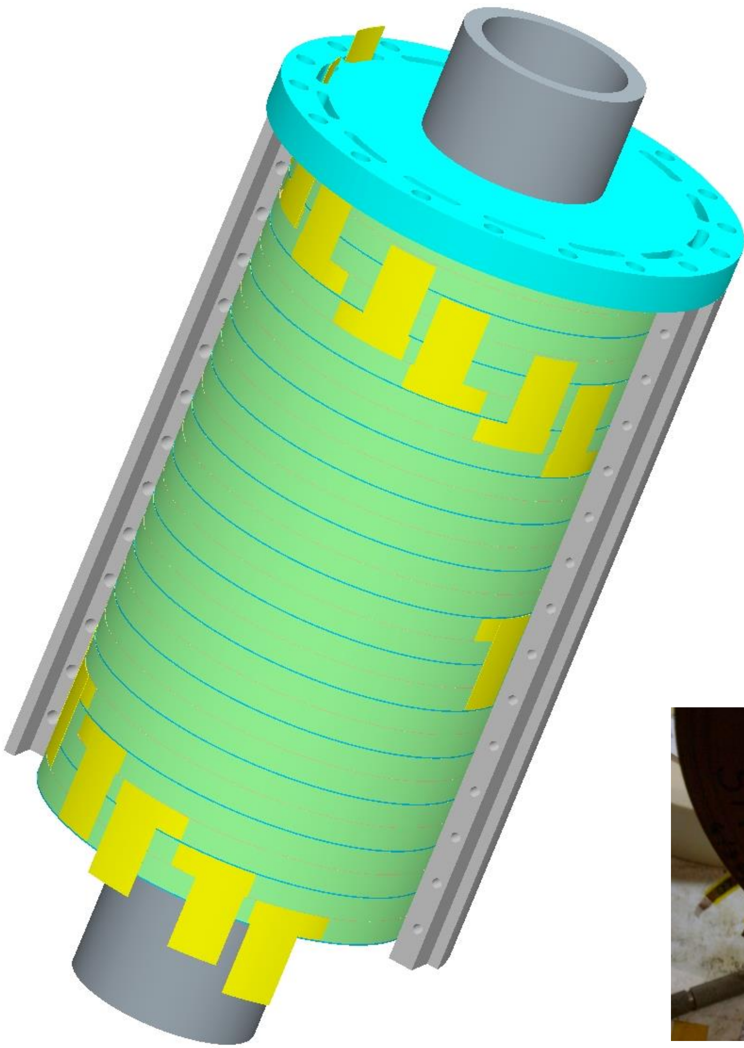
Field perpendicular (4.6 T)

Field parallel/magnitude (10.6 T)

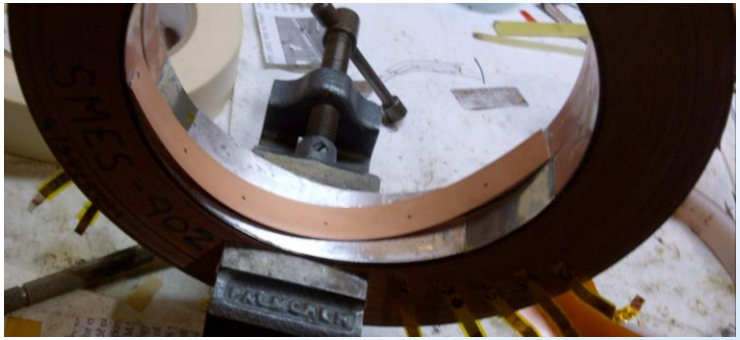


2-d axi-symmetric model

Inner Coils in Support Structure for Q6



- Six double pancake coils are planned to be assembled together to meet Q6 goal
- A number of leads will be taken out for quench protection purpose
- Each double pancake will be made with two single pancakes with a new type of splice at coil inner radius



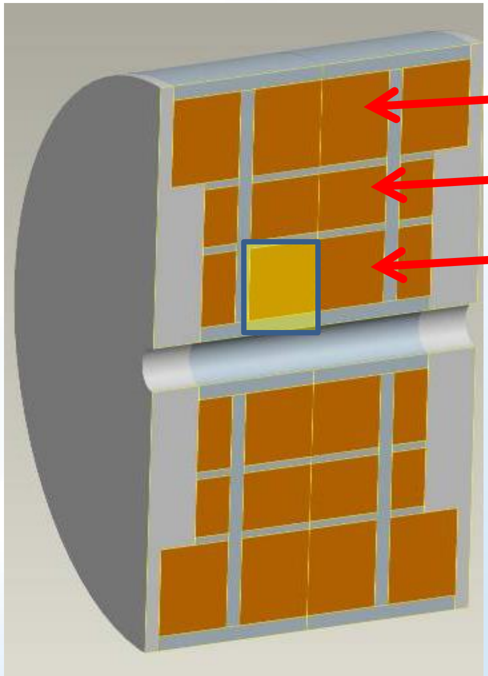
Internal splice in a double pancake coil

Simplified Structures

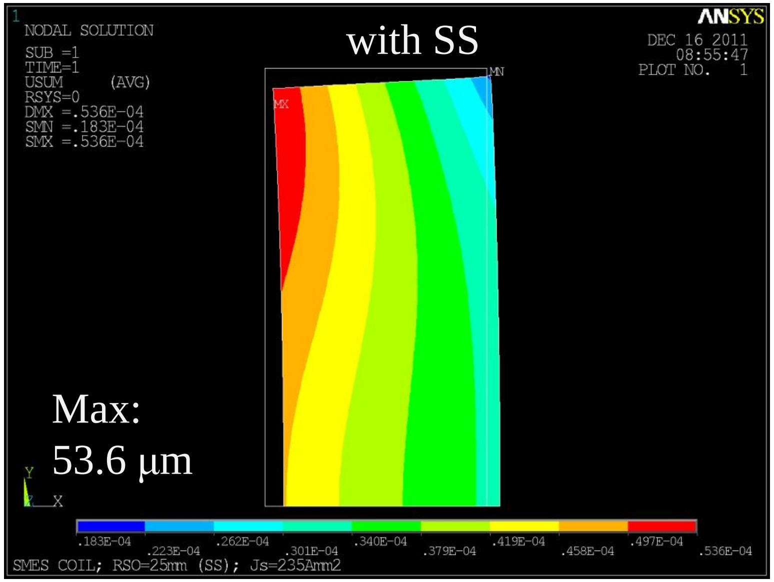
Instead of building a complex support structure between inner and outer coils, we plan to build a simpler structure to test half inner in Q6.

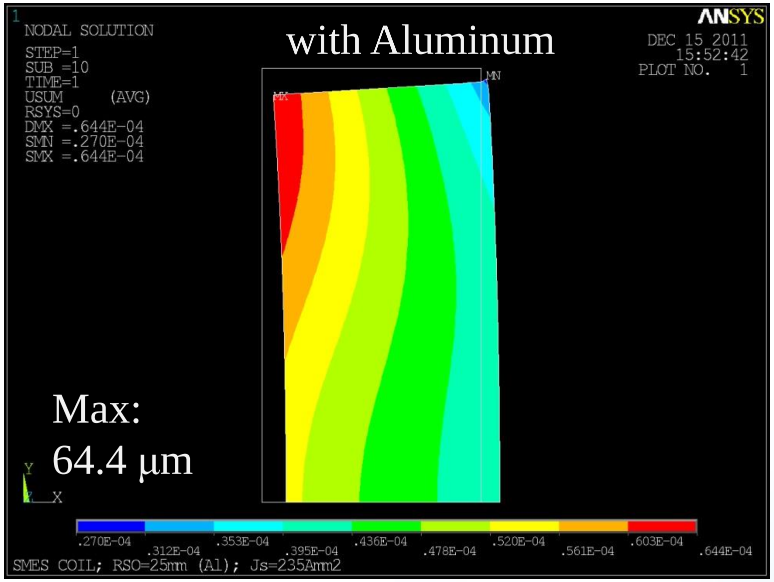
<u>Possible options for structure:</u>

- Stainless Steel Clamp or Tube
- Aluminum Clamp or Tube
- Stainless steel tape with fiberglass/kevlar overwrap

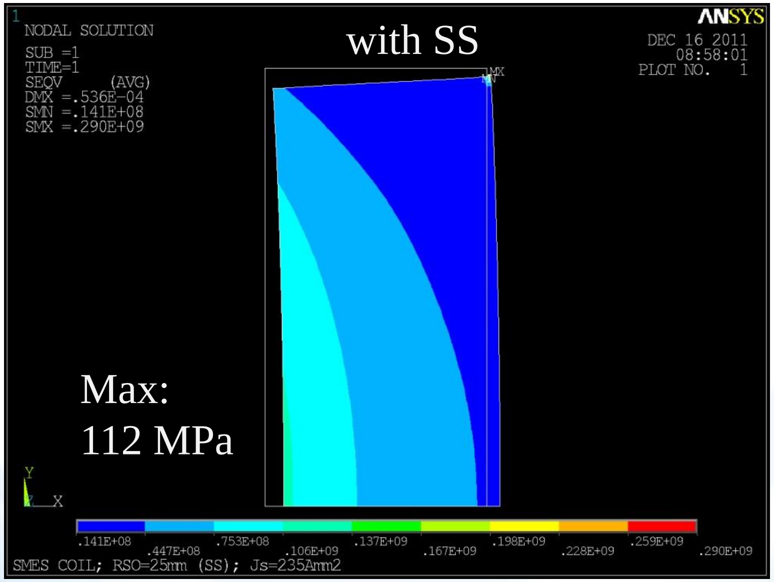


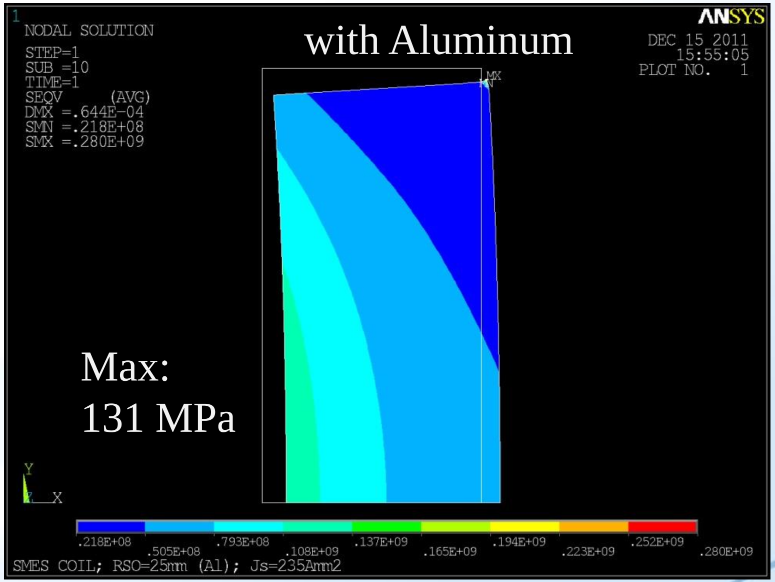
TOTAL DEFORMATION IN HTS COIL





EQUIVALENT STRESS IN HTS COIL

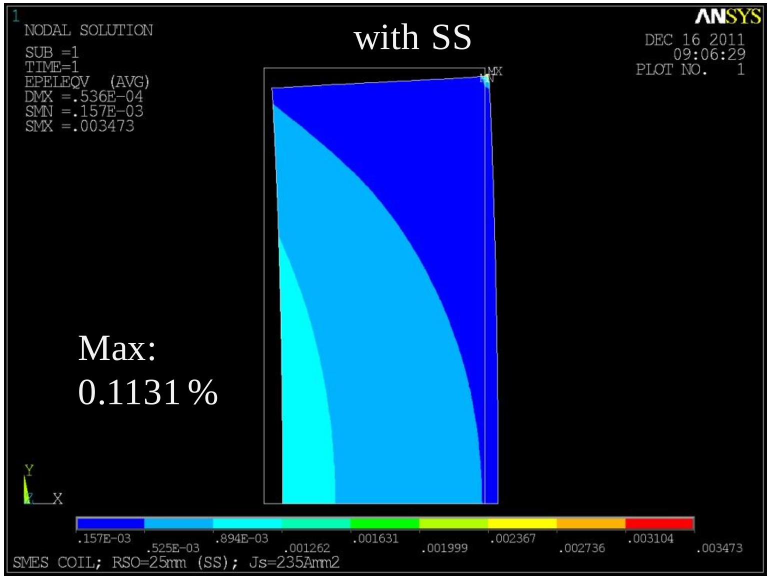


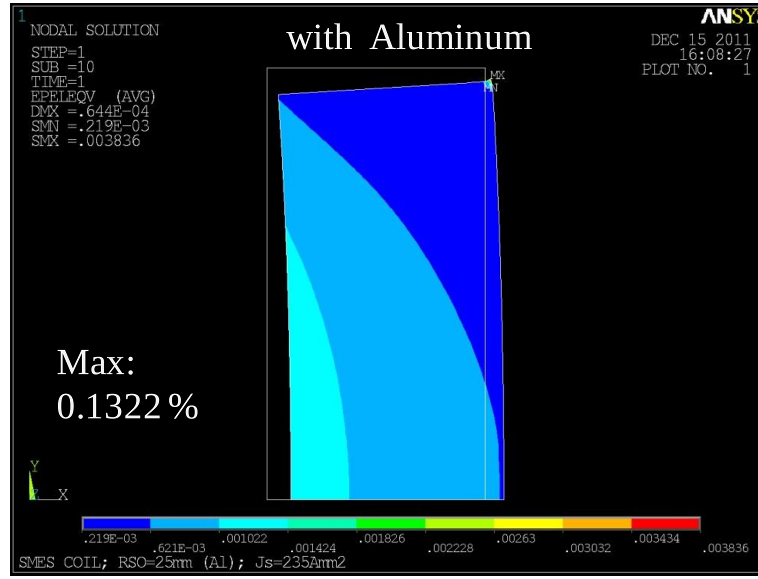


BOTH ARE WITHIN ACCEPTABLE LIMIT

Calculations performed by S. Lakshmi (Post-doc)

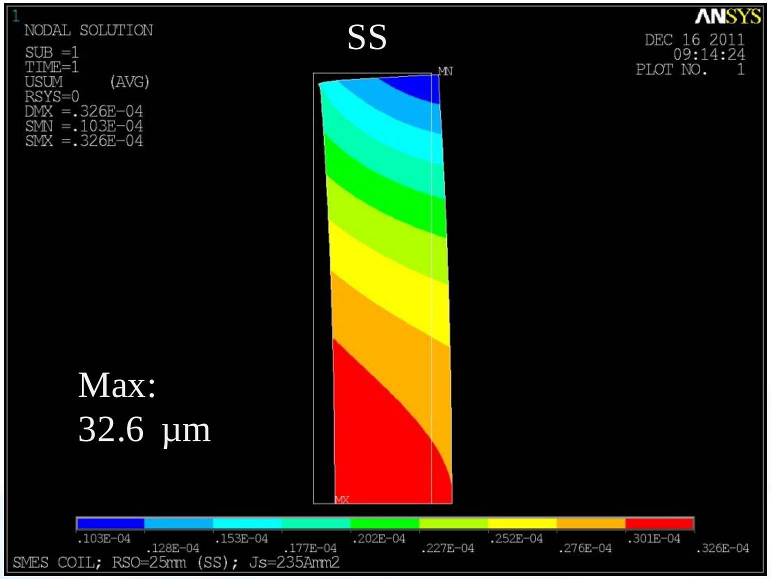
EQUIVALENT STRAIN IN THE HTS COIL

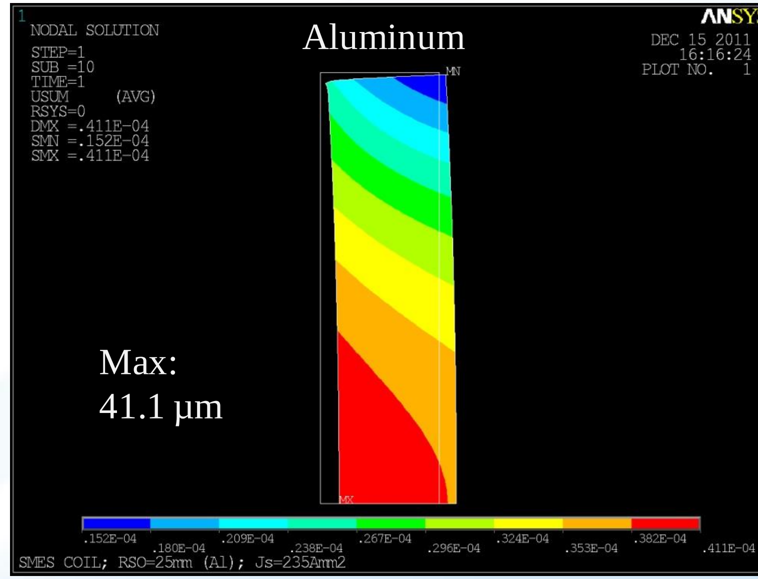




BOTH ARE WITHIN ACCEPTABLE LIMIT

TOTAL DEFORMATION IN THE OUTER SUPPORT STRUCTURE





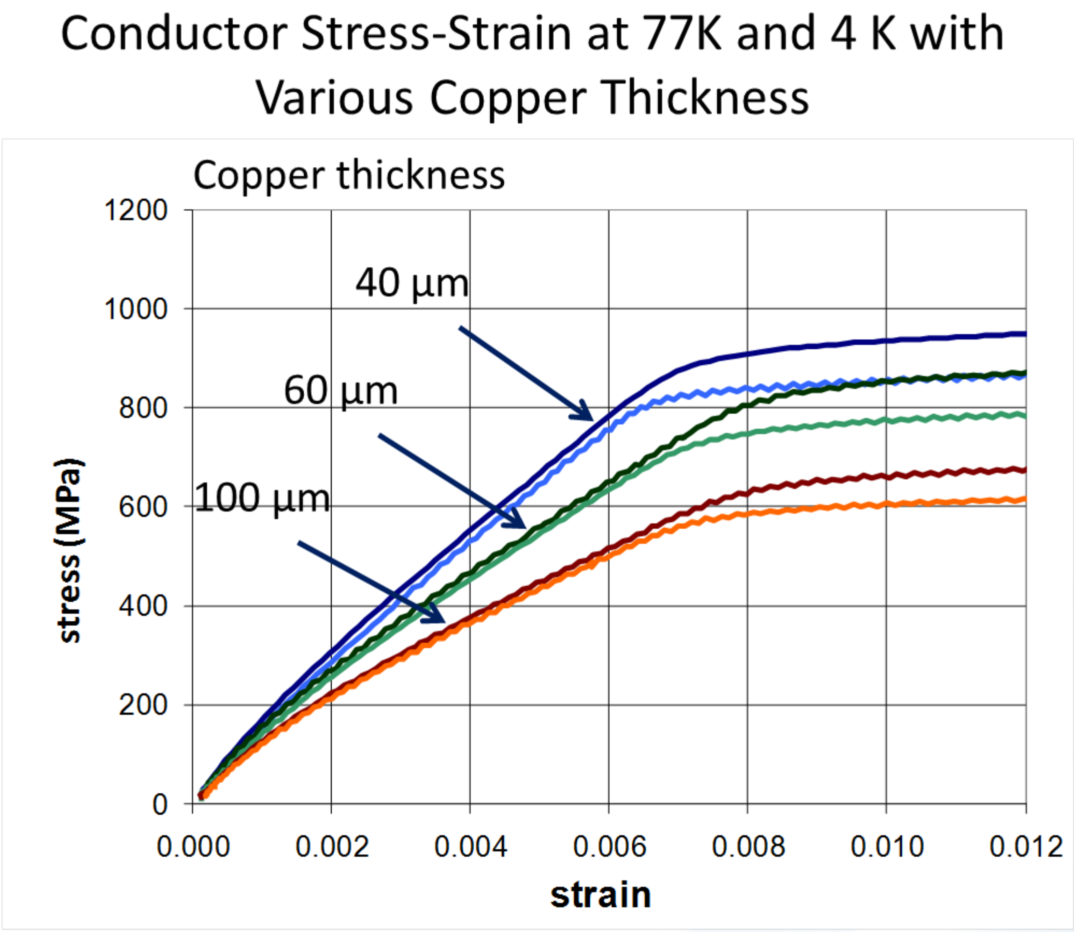
Calculations performed by S. Lakshmi (Post-doc)

SUPPORT STRUCTURE

- We have an acceptable design of the structure that can be made with either Stainless Steel or Aluminum.
- Making it out of Aluminum for Q6 is simpler, faster and cheaper.
- A vendor has been identified who can deliver the desired size tube within a week.
- This Aluminum tube can be easily replaced later with a higher strength Stainless Steel structure (if needed) when energized with outer coil in a large Lorentz force/stress environment
- Option to use stainless steel tape overwrap with Kevlar/Fiberglass is still open (may be with Aluminum tube).

Recent Mechanical Tests of Conductor with Different Amount of Copper

From Drew Hazelton (test at Florida)



Question: Is more copper (used to provide higher stability) really better or really needed?

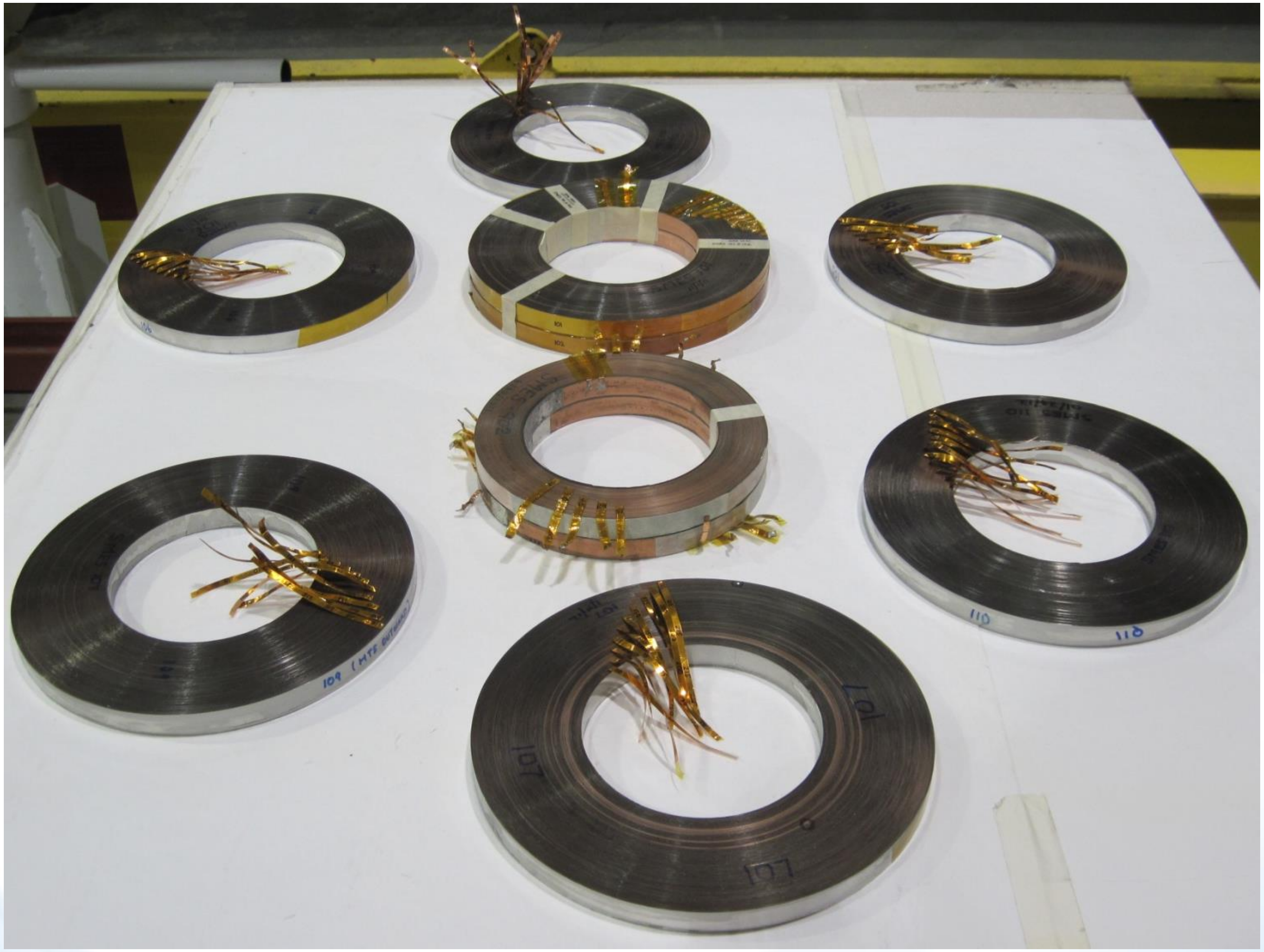
Recent tests show that high modulus coils with ~45 micron copper may be better.

Discussion with Drew Hazelton (SuperPower) to adjust the copper for remaining shipment to make coil more robust.

Significant softening of the stress-strain curve with added copper due to reduced modulus and yielding of the copper.

CONSTRUCTION AND TEST RESULTS

HTS COILS

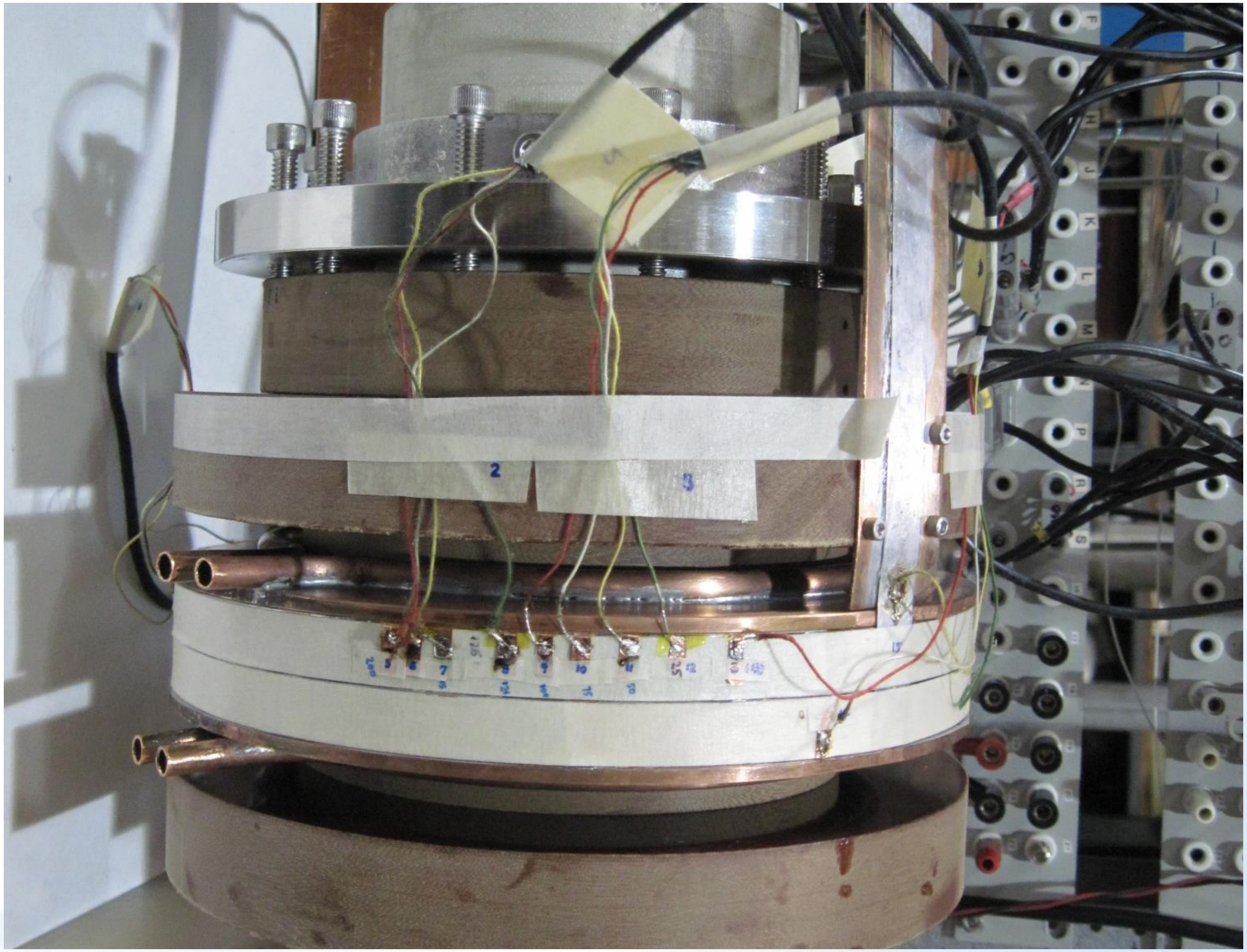


Q6 design needs a minimum of 12 coils.

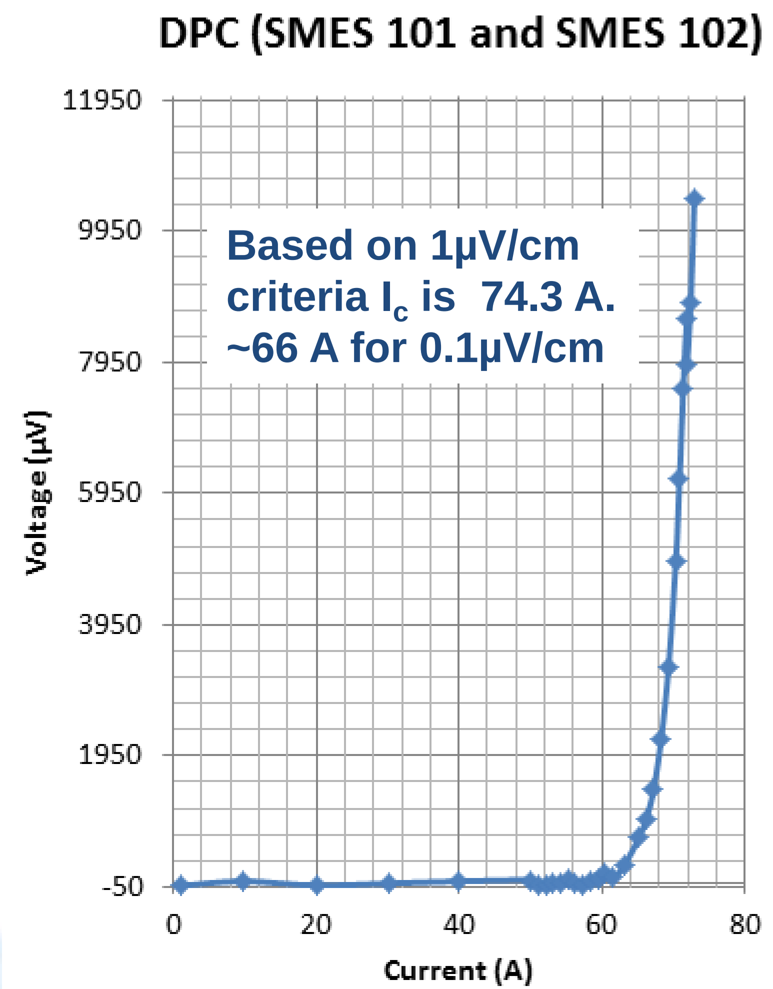
We have already made 11.

We plan to make 14 to 16 to allow sorting/selection.

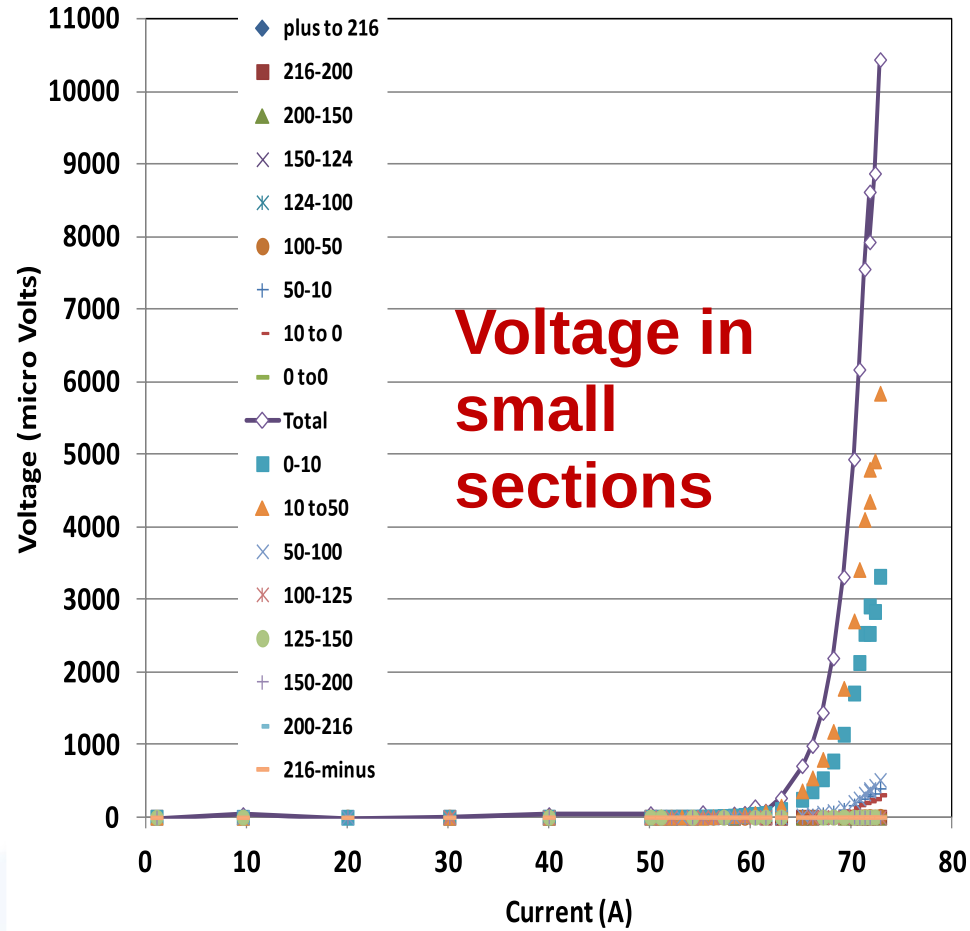
Double Pancake Coil in Test Fixture (ready for 77 K QA test)



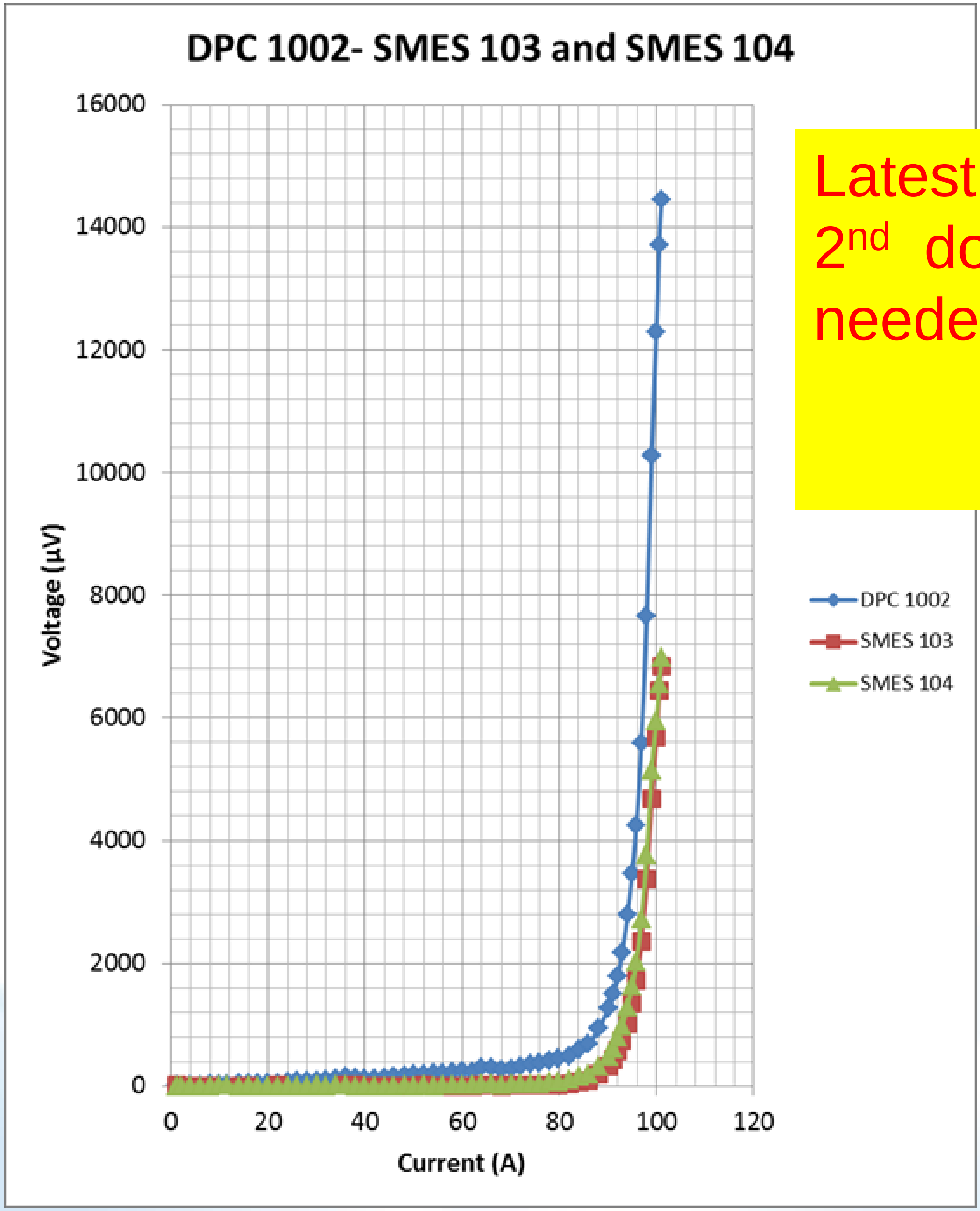
Test Results of 1st Full Size SMES Inner DoublePancake @77K



Detailed analysis



- ✓ **COIL Passes QA Test**
  - ❑ **Good coils, good joint**



Latest Results (7pm yesterday):
2nd double-pancake (of six total needed for Q6) was tested @77K

✓ It (coils + joint) passed QA test too...

Based on 1 µV/cm criteria

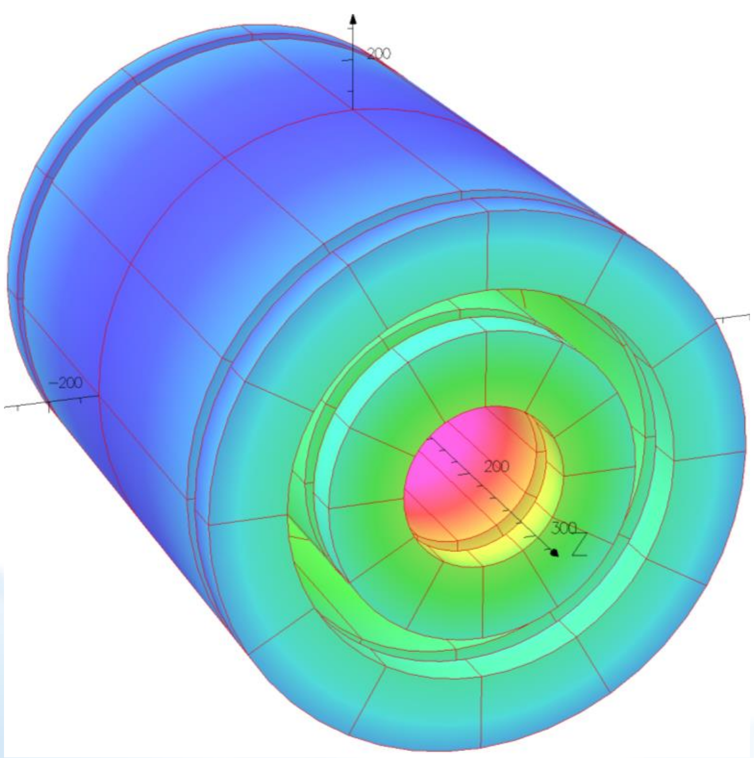
SMES103: 102.5 A

SMES104: 102.5 A

A Summary of Proposal for Future Tasks (that can be performed within the budget)

➢ **SMD has enormous volume of task in the current plan**

We propose to do the following within the budget allocated:



- Wind all coils – inner and outer
- Test SMES system at 4 K with all inner coils included in a simplified support structure
- 4 K high energy/field partial test with one complete double-pancake coil segment (“inner+outer”)
- 77 K test of whole SMES system in a simplified support structure

Summary of Milestones and Accomplishments

- Magnet Division does not have any Q5 milestone
- We are on track to meet Q6 GO/NOGO milestone
- Q6 Milestone needs 6 double pancakes coils. We plan to make more for sorting, as we don't want to take the tested unit apart for re-sorting
- This is a very challenging undertaking as no one has any thing close to this before. BNL Superconducting Magnet Division is in a unique position to take this challenge because of its expertise in this area and feedback from other similar programs.
- Technically, the project is moving well in a step by step manner. We are performing intermediate tests (budget and schedule permitting) to minimize the impact of unknowns with this major new technology.

Major Accomplishments (Q4 Review in Nov 2011)

- **Coil technology is demonstrated to well beyond the Q4 milestone:**
  - **Tests performed to 4 K (milestone required only 77 K)**
  - **Coils tested to 1140 A (design required only ~650 A)**
- **Basic quench protection is demonstrated in detecting small resistive voltage in presence of large noise and in protecting coil well beyond the design current**
- **The basic joint technology is successfully applied to real coils. Joint construction has been found robust in high current 4 K tests. Joint with a resistance of ≤ 1 nΩ built and tested (specification ≤ 5 nΩ)**