NEWS Mid-Term REVIEW – March 4-6, 2019

NEWS Work Package 7

Advanced Superconducting Technologies for Particle Accelerators

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WP7 Tasks

***T6.1**: <u>Build and install the superconducting modules of the Mu2e Transport Solenoid (INFN, FNAL)</u>. The modules are in construction at the ASG Superconductors in Italy under a FNAL contract, with the active collaboration and supervision of INFN personnel.*

***T6.2**: <u>Design and build</u> a 16 T Nb_3Sn accelerator dipole (FNAL, INFN). This includes coil design studies, magnetic analysis, design of mechanical structure for the 4-layer coils, and coil stress analysis at the three stages of magnet operation.*

***T6.3**: Optimize state-of-the-art electrochemical techniques (US patent pending) for Nb_3Sn thin layer deposition on Nb and on Cu (POLIMI, FNAL, Faraday). <u>Applications</u> include performance improvement of superconducting Nb_3Sn wires for High Field Magnets, Radio-frequency cavities, superconducting magnetic shields.*

WP7 Milestone & Deliverables

MS9 : Mu2e Transport Solenoid Constructed [Month No. 20 = February 2019]

D7.1 : 16 Tesla Dipole Designed [Month No. 24 = June 2019]

Verify the design studies, magnetic analysis, mechanical structure design, coil stress analysis at the three stages of magnet operation (i.e. room temperature, after cooling down at the temperature of operation of 4 K, and at nominal magnetic field operation).

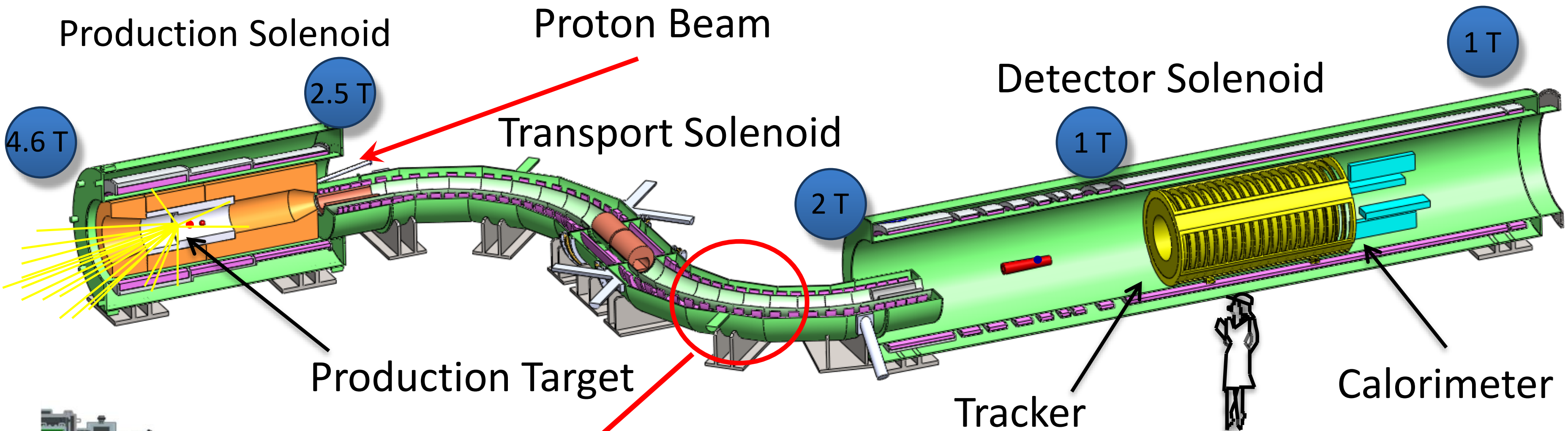
D7.2 : Nb_3Sn Deposition Technique Optimized on Niobium and Copper [Month No. 36 = June 2020]

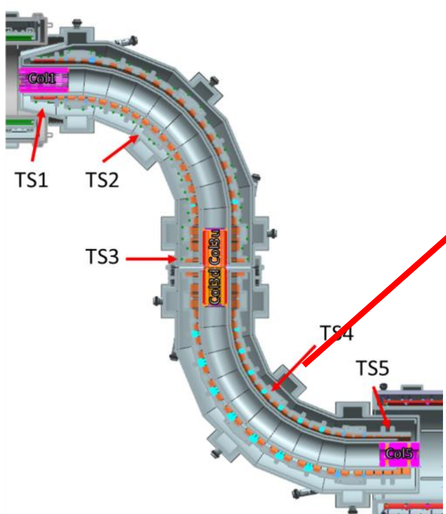
State of the art electrochemical techniques will be optimized to achieve the best uniformity of the deposit across the surface, the best purity and improve the adhesion of the film. Samples will be experimentally characterized.

Mu2e TS Status (T6.1)

(Pasquale Fabbricatore, INFN-Genova)

The TS solenoid of Mu2e experiment is composed of 52 superconducting coils integrated into 27 modules constituting the TS serpentine.

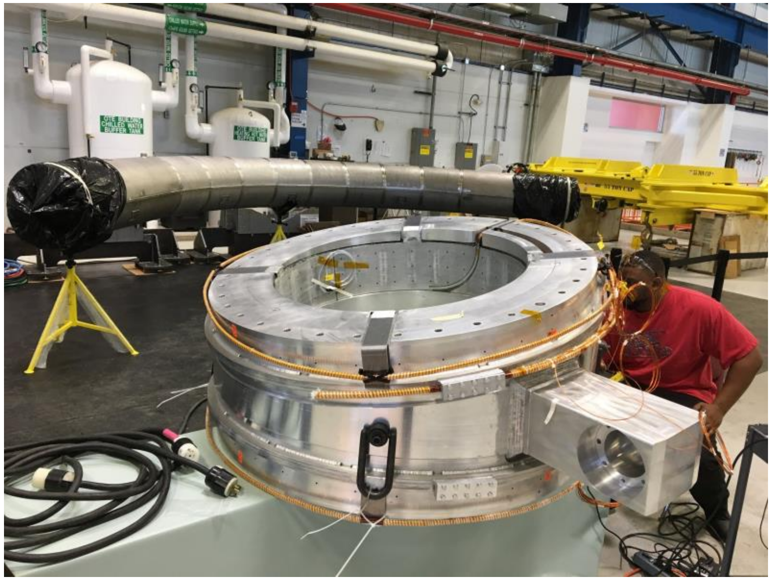




The TS module design was validated through prototype module development in the framework of a collaboration Fermilab-INFN.

Industrial contract for the module construction

The contract for the construction of the 27 modules, to be later assembled and integrated into the cryostat at Fermilab, was awarded by Fermilab to ASG Superconductors in Genova. The construction plan has been delayed due to some design changes and some difficult procurements of the Al-alloy mechanical structures. Most of the units will be tested in second half of 2019 and (mainly) 2020 (Secondments at Fermilab planned now for 2020).

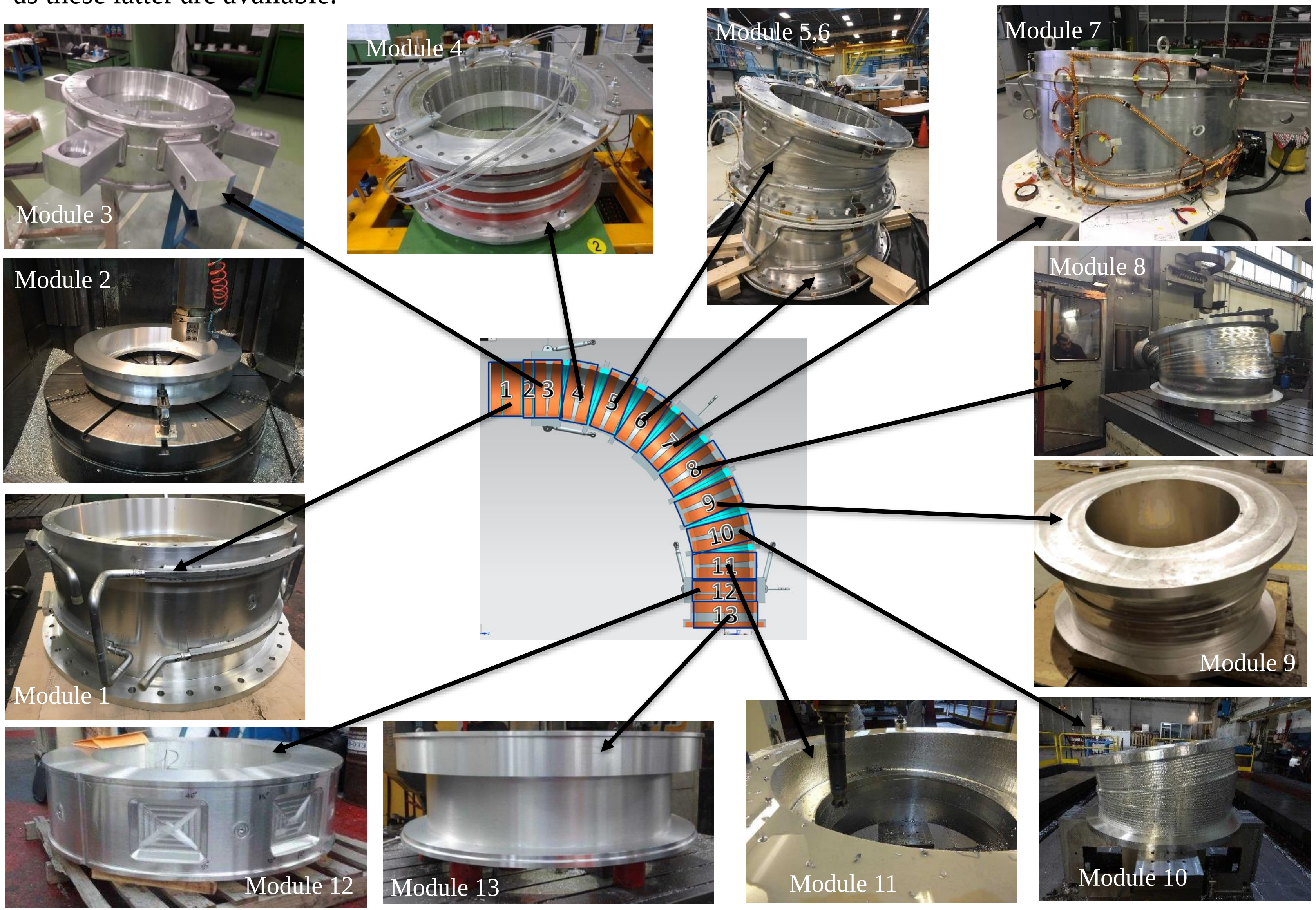


The first unit (composed of a single module) was delivered to Fermilab and successfully tested in 2018.

The second unit (2 modules) is now at Fermilab under preparation for the cryogenic test.

Update of the TS cold mass construction

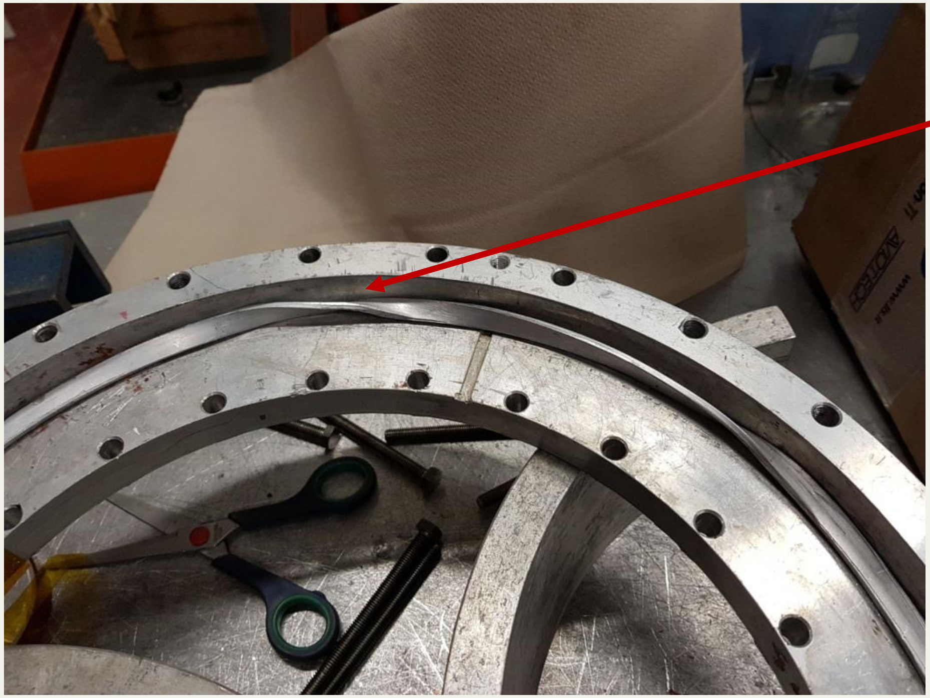
All the 52 coils of the TS have been constructed. They are integrated into the Al-alloy mechanical structures, as these latter are available.



Conductor characterization at INFN, Genova

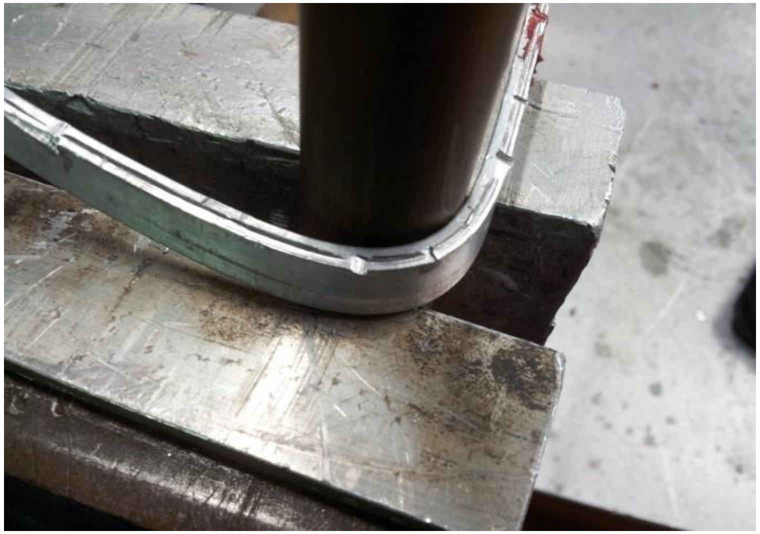
The critical currents of cables (more than 40) from Mu2e solenoids (PS, TS and DS) were measured with a Direct Transformer Method up to 5 Tesla and 100 kAmpere.

INFN Genova has also performed studies for evaluating the impact of conductor deformation during construction (bending and twisting) on electrical transport properties.

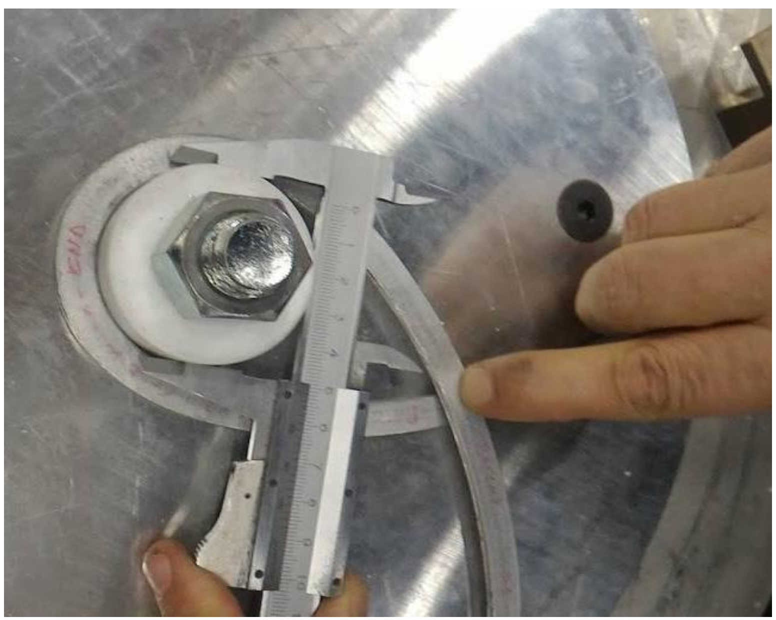


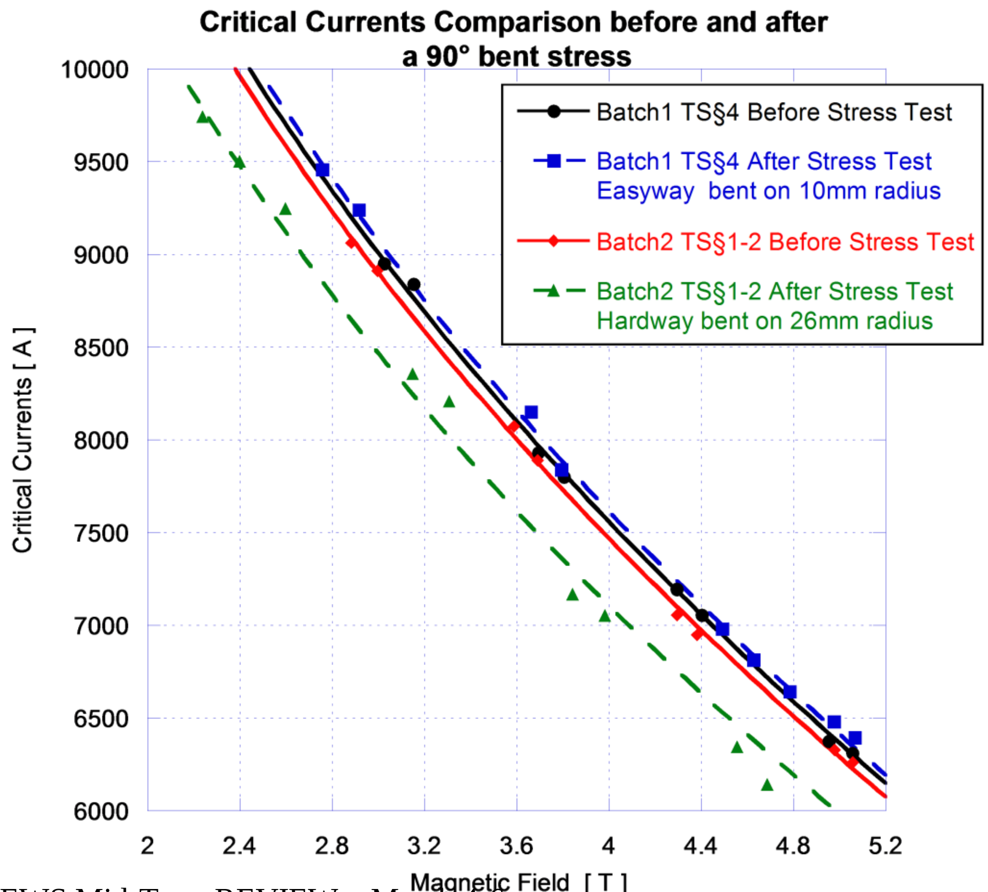
As an example, a double twisting of the TS conductor does not cause any degradation of the critical current.

Conductor characterization at INFN, Genova (cont.)



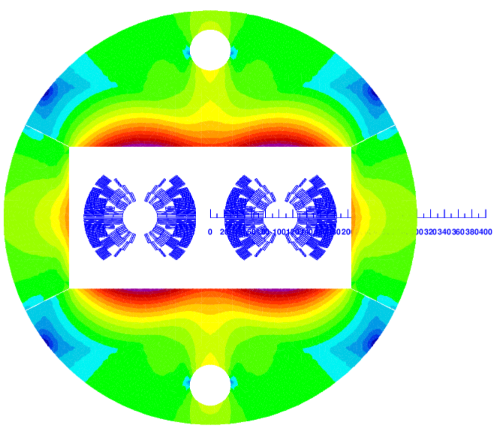
The bending of the TS conductor could cause some limited degradation if the bending radius is too small (see hard way bending on 26 mm radius)

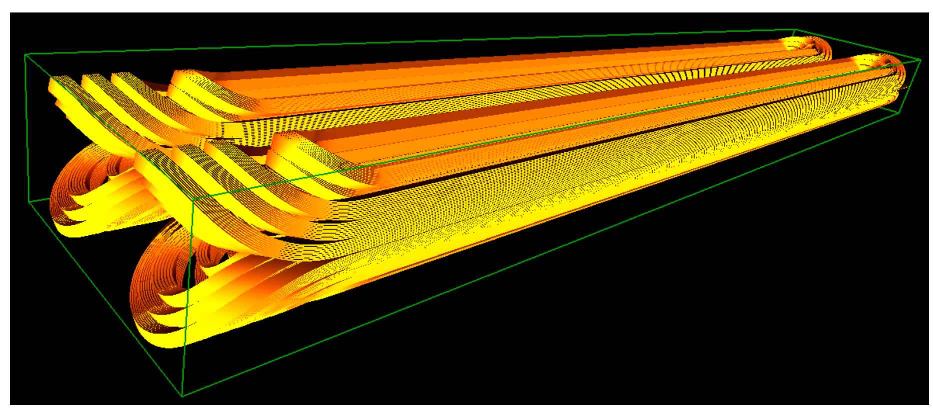




FNAL-INFN 16 T Accelerator Dipole (T6.2)

- **The challenge for high field Nb_3Sn superconducting magnets is to push the <u>design limit</u> of these magnets to their superconducting potential (or <u>Short Sample limit</u>). To design and build a 16 T Nb_3Sn superconducting dipole, *the design limit needs to be at least 17 T*.**
- **Within the *cos-theta* magnet geometry, i.e. the same design used in the Tevatron @ Fermilab and at LHC @ CERN, a number of strain management options will be investigated.**

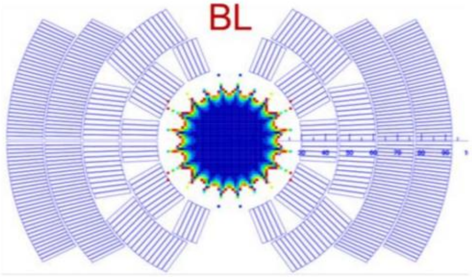




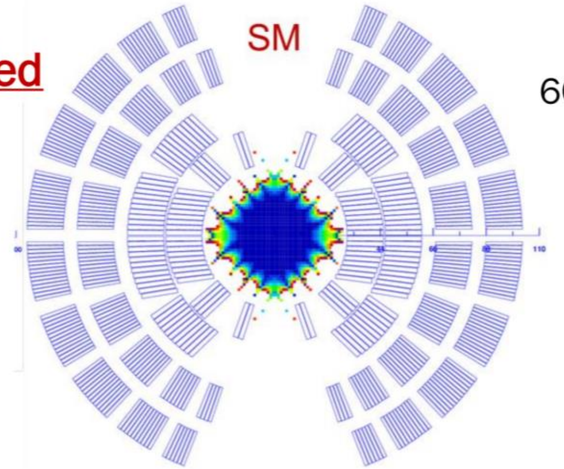
Conceptual Design and Analysis of 4-layer 16 T Cos-theta Dipole Complete

1. Conceptual design studies are complete including magnetic and mechanical analysis

60 mm aperture
B_{des}~15 T



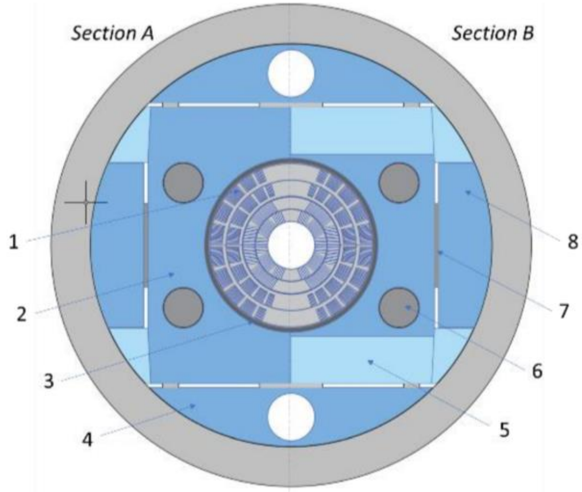
SM is needed



60 mm aperture
B_{des}~17 T

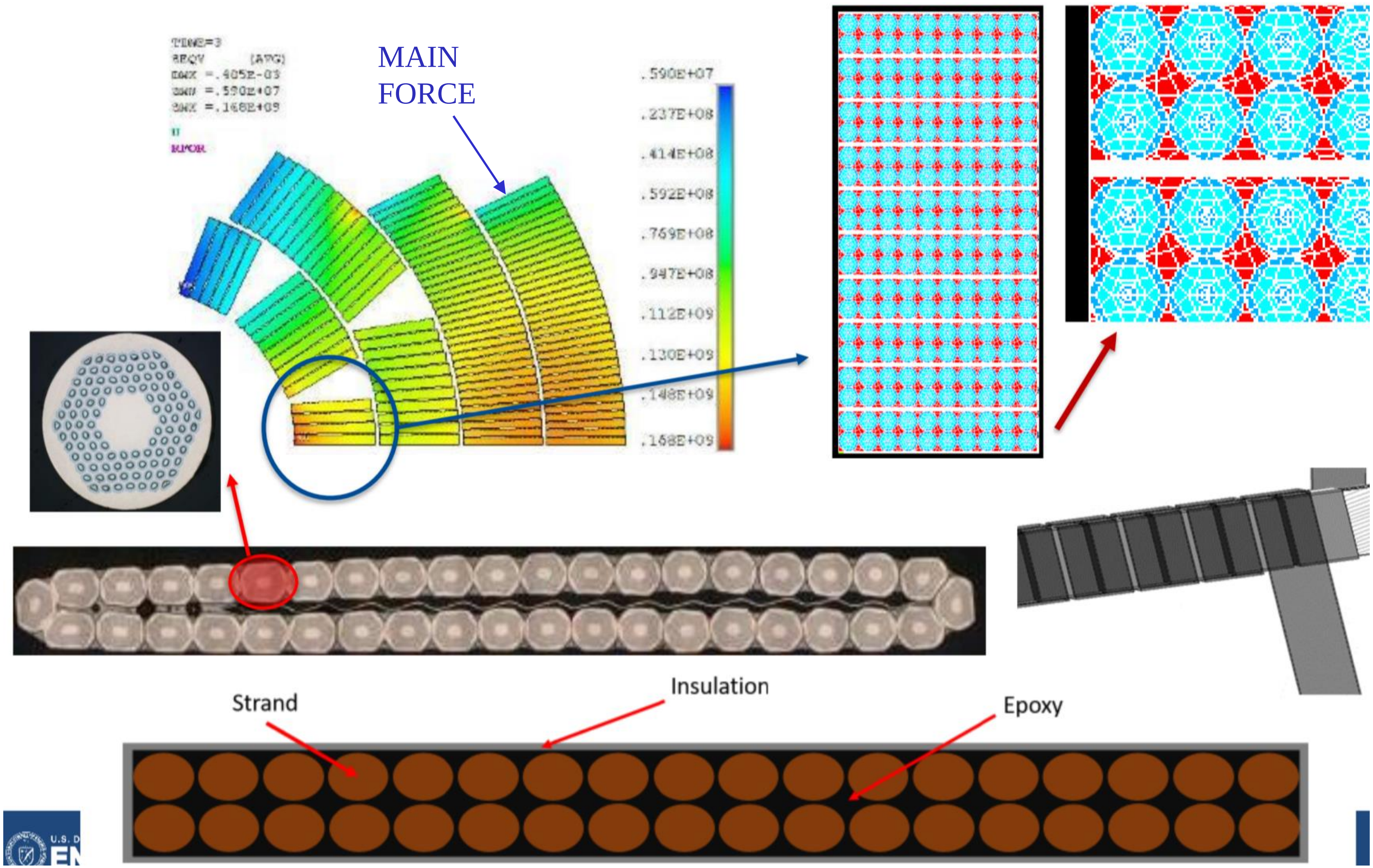
2. Mechanical structure developed and analyzed.

- 630 mm outer diameter for test in vertical magnet test facility at Fermilab
- Al shell, Al clamps

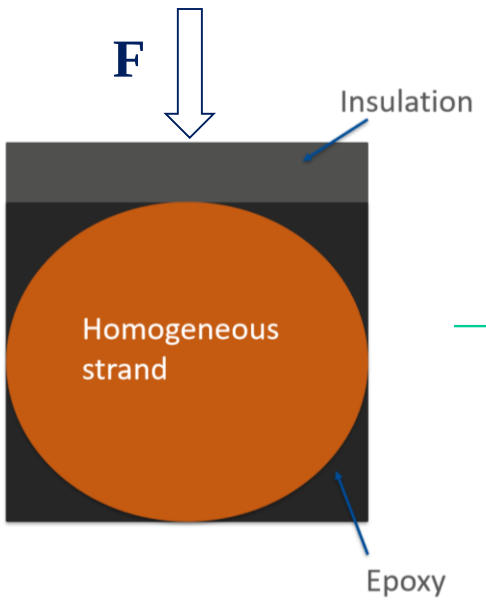


Stress Management Developed for 2-layer Coils

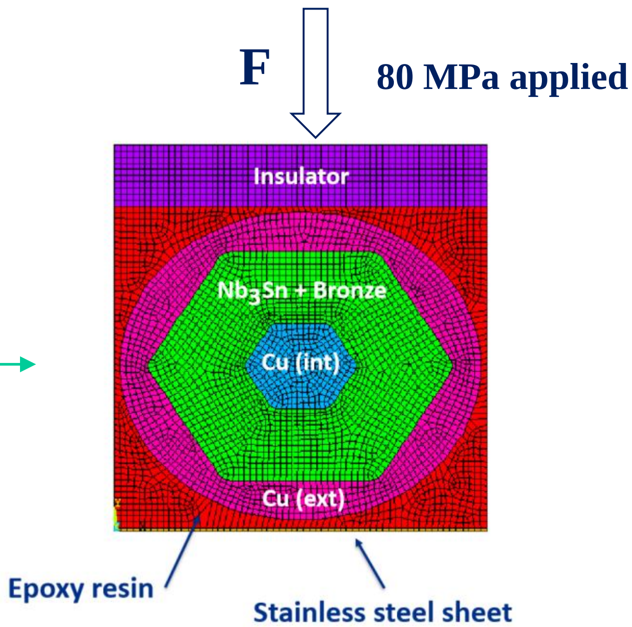
Study Stress Concentration in Coils through Sub-Modelling

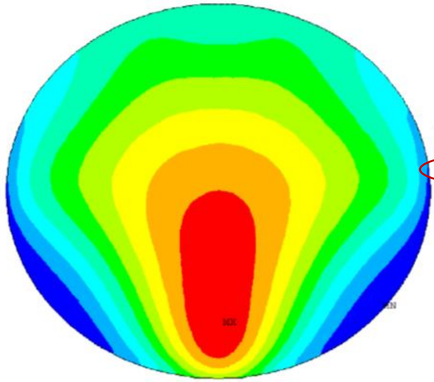


Sub-Modelling at Various Detailing Levels

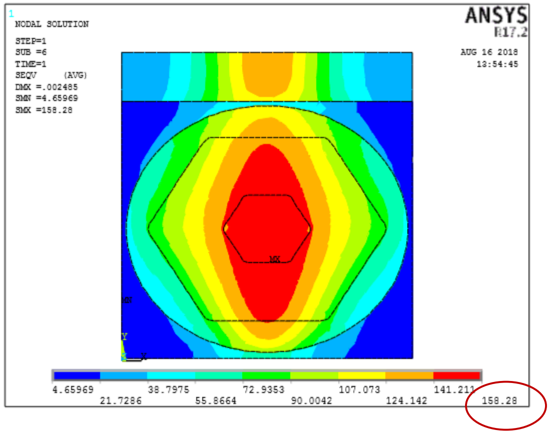


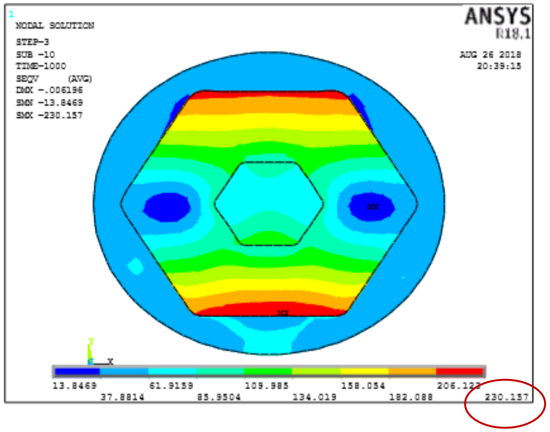
INCREASING DETAIL





Max at 40 MPa→ 81.6 MPa
Max at 80 Mpa→163 MPa
Max at 120 Mpa→245 MPa





ROOM TEMPERATURE

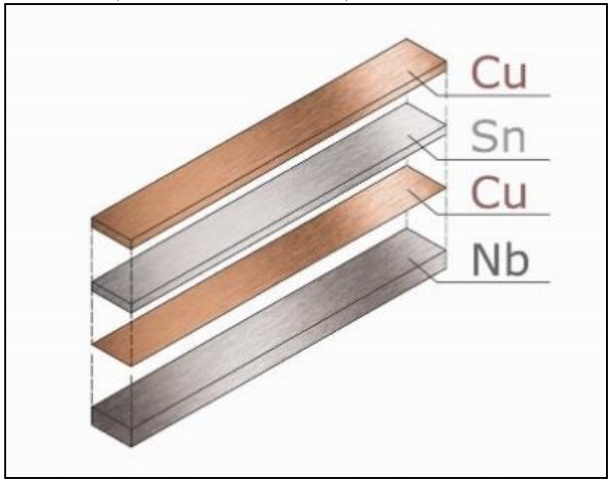
ROOM TEMPERATURE

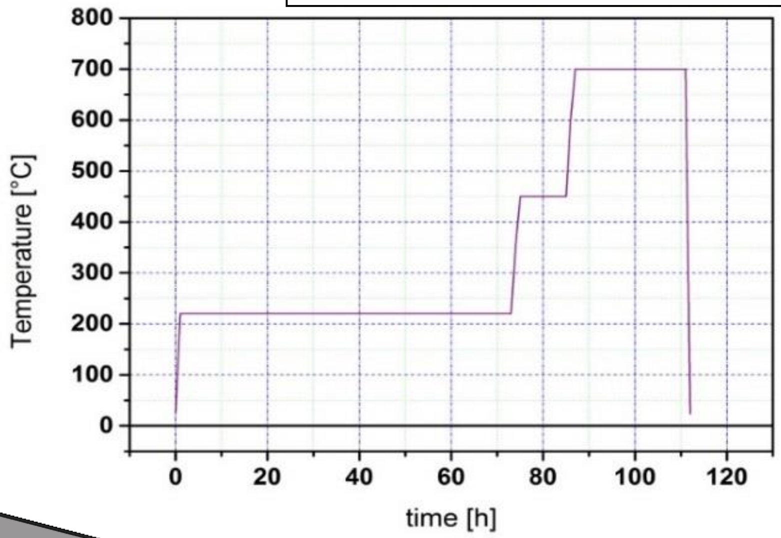
CRYOGENIC TEMPERATURE

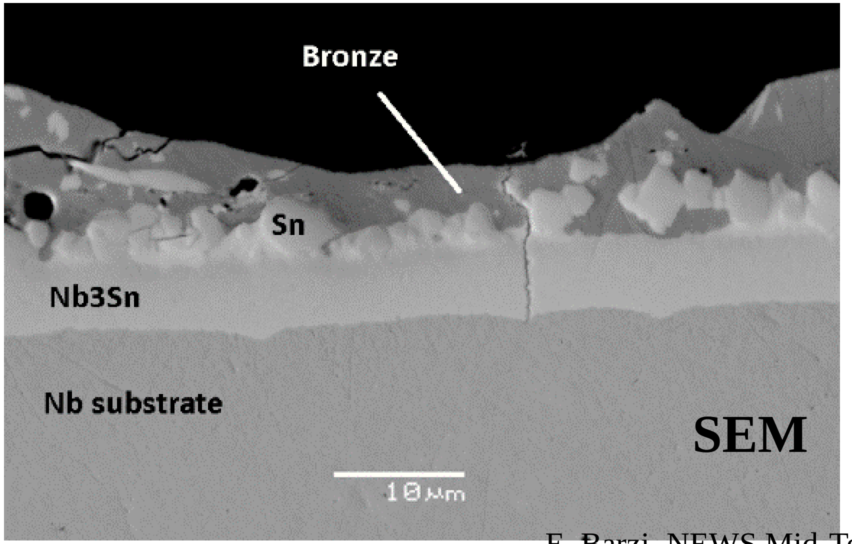
Nb_3Sn Thin Films on Nb (T6.3)

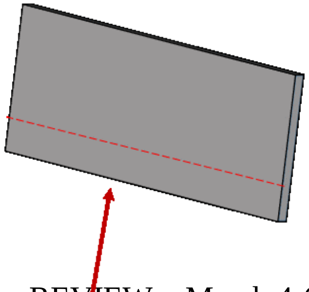
- A Nb-Sn composite is obtained by electrodeposition of Sn layers and Cu intermediate layers onto Nb substrates. <u>This is done at near room temperature (40 and 50°C) and atmospheric pressure</u>.

- Nb_3Sn is formed through solid diffusion by heat treating the multi-layered samples in inert atmosphere (argon) using a temperature profile with a <u>maximum temperature of 700°C</u>.

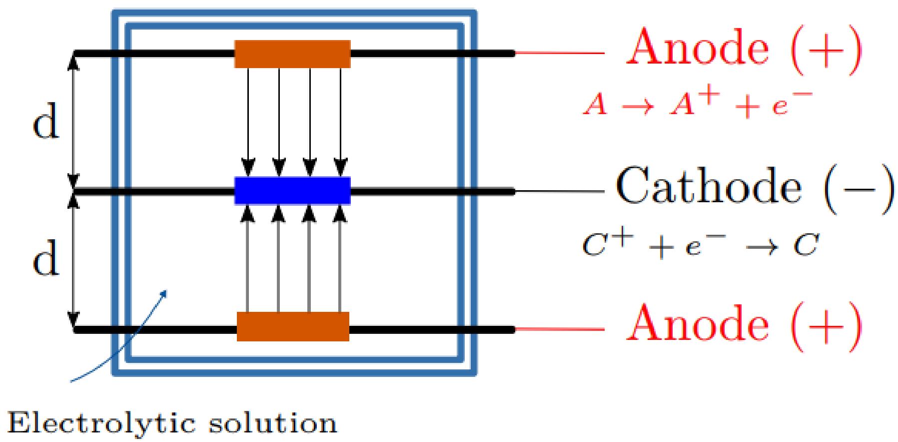


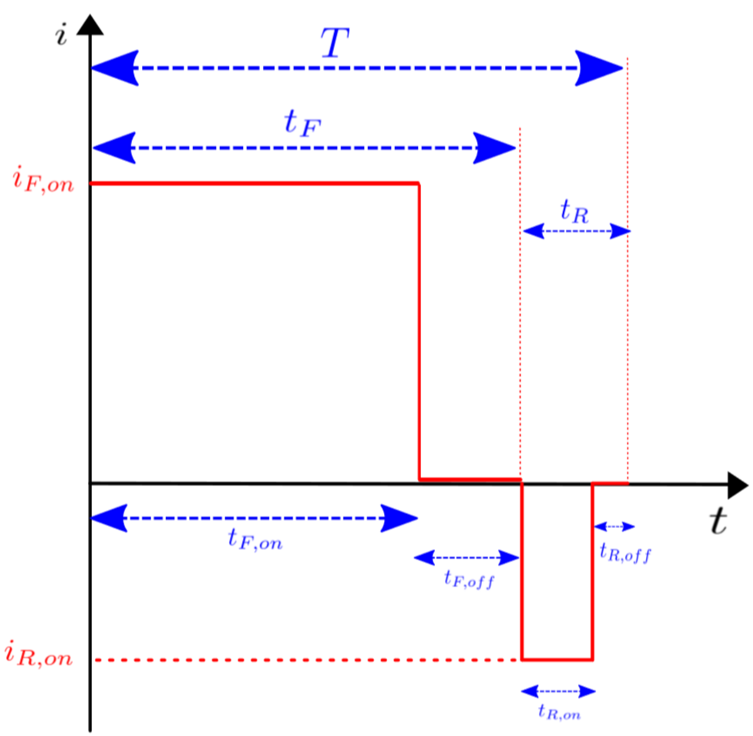






Chemical Electrodeposition



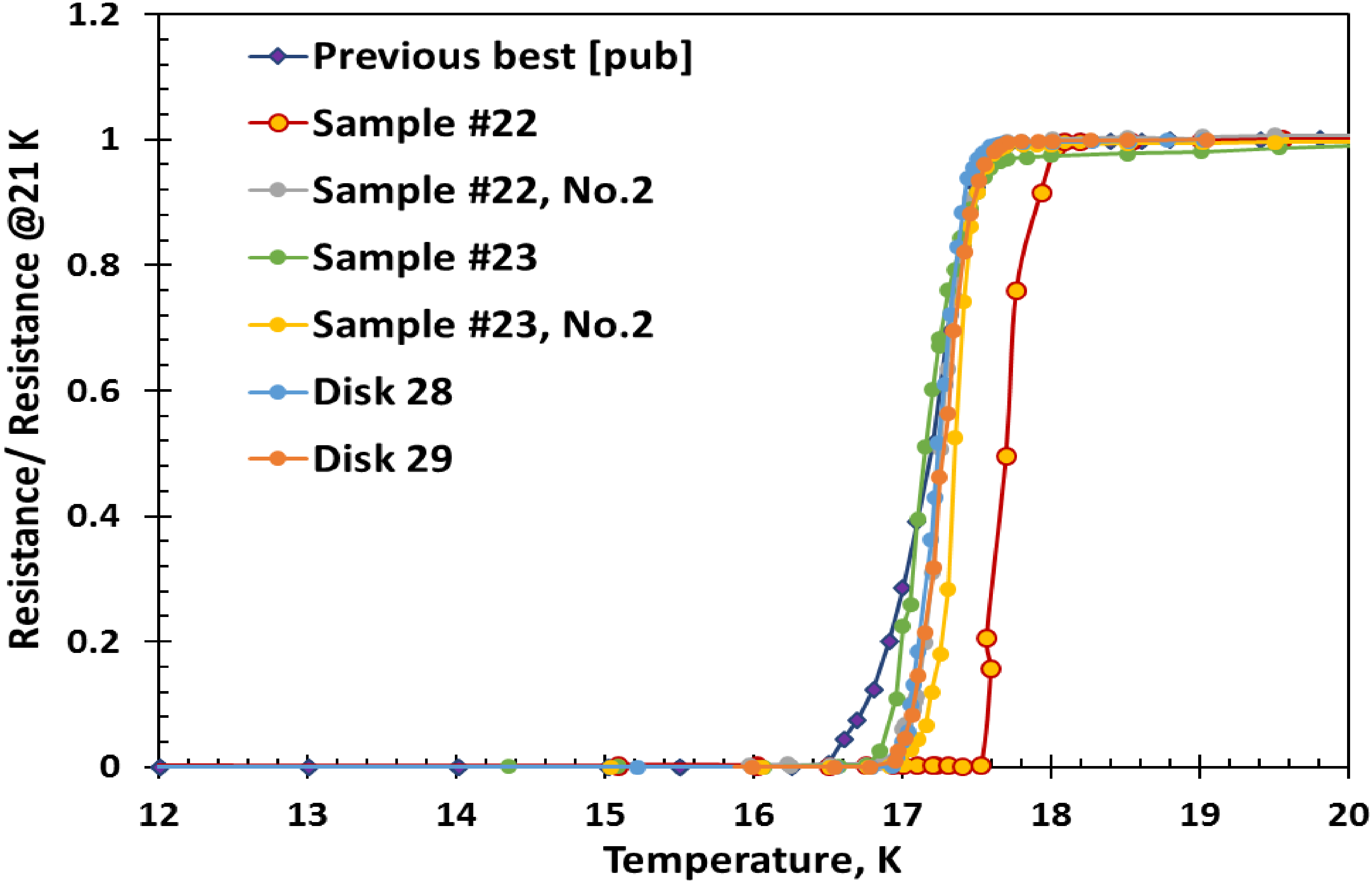


For ADHESION, THICKNESS CONTROL and UNIFORMITY, optimize:

- **Bath composition and anode materials for each of the three deposition steps;**
- **Current densities, deposition times, stirring rates, and cathode and anode relative orientation in DC mode;**
- **Current densities, deposition times, stirring rates, cathode and anode relative orientation, pulse frequen-cies, and duty cycles in pulsed mode.**

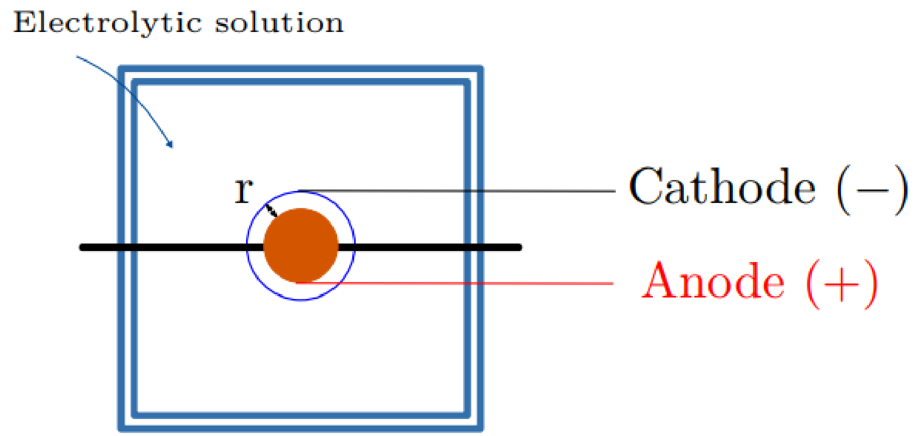
The pulsed mode was eventually chosen for all three deposition steps.

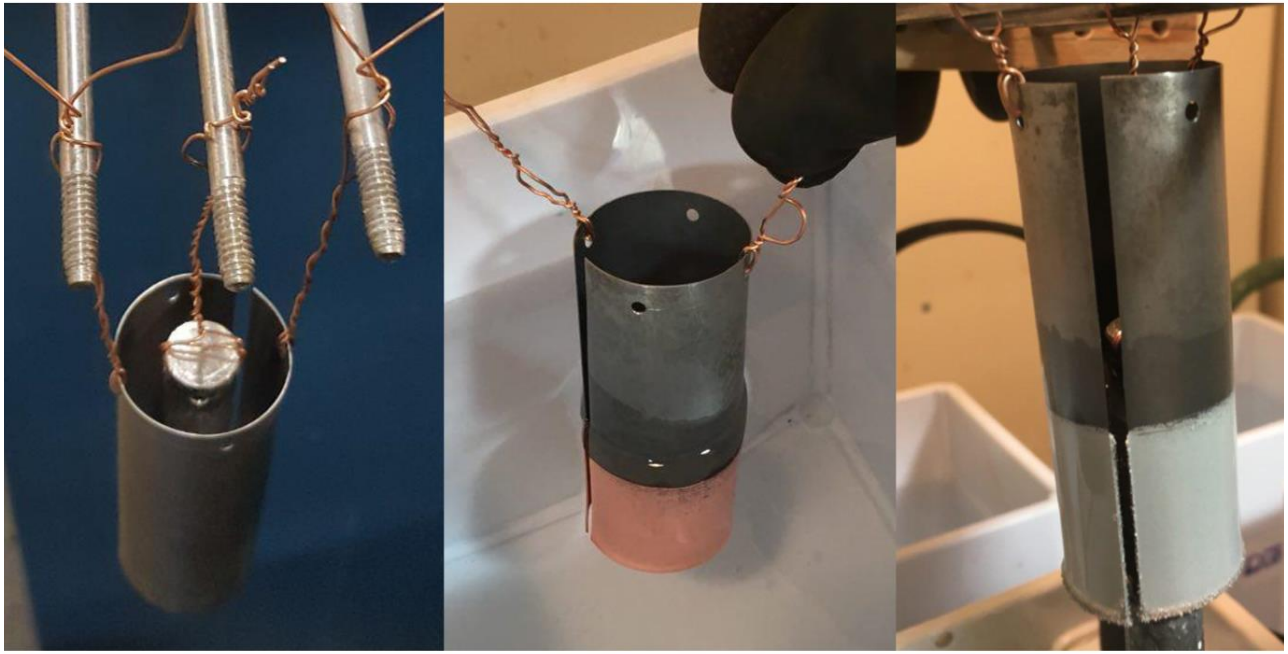
Comparison of DC Test Results of Critical Temperature



IMPROVEMENT AND REPRODUCIBILITY

Cylinders Coating – In progress





Summary

MS9 : Mu2e Transport Solenoid Constructed [By February 2019]:

- **3/27 modules tested or under test, 24 more to be tested by end of 2019.**

D7.1 : 16 Tesla Dipole Designed [By June 2019]:

- ***Conceptual design complete, including magnetic and mechanical analyses. Mechanical structure to support coils designed.***
- ***Sub-modelling studies with increased level of details also perormed to understand stress concentrations in coils.***

D7.2 : Nb_3Sn Deposition Technique Optimized on Niobium and Copper [by June 2020]:

- The goal of optimizing the technique was already achieved at FNAL for the deposition of Nb_3Sn on Nb substrate.
- Polimi will be leading the technique for Nb_3Sn deposition on Cu substrate.