NEWS KickOff Meeting – July 17, 2017

NEWS Work Package 7

Advanced Superconducting Technologies for Particle Accelerators

Emanuela Barzi, Fermilab

Summary of WP7 Tasks

T6.1: Build and install the superconducting modules of the Mu2e Transport Solenoid (INFN, FNAL). 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: Design and build 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). Applications include performance improvement of superconducting Nb_3Sn wires for High Field Magnets, Radio-frequency cavities, superconducting magnetic shields.

WP7 Deliverables

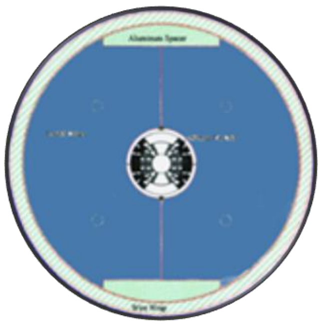
D7.1 : 16 Tesla Dipole Designed [Month No. 24]

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).

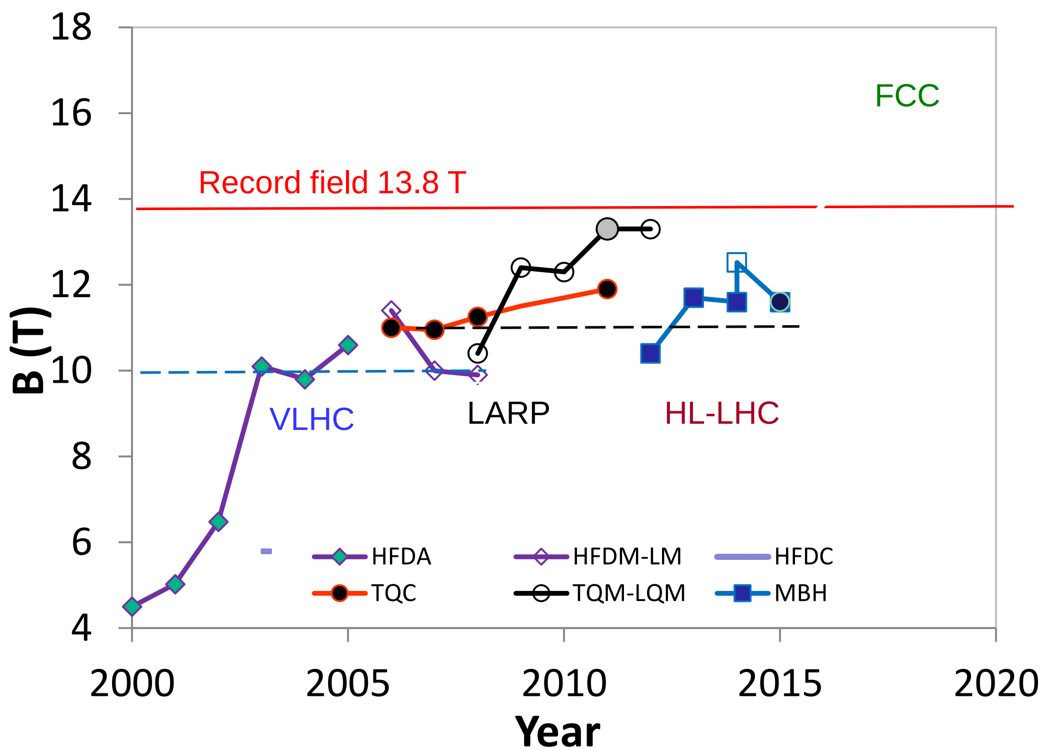
D7.2 : Nb_3Sn Deposition Technique Optimized on Niobium and Copper [Month No. 36]

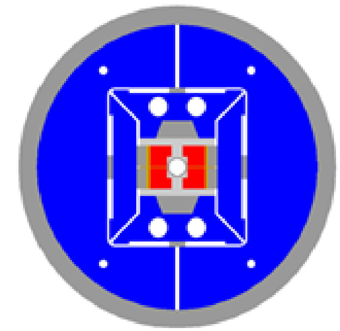
State of the art electrochemical techniques will be optimized to achieve the best uniformity of the deposit across the surface, the best purity and improve the adhesion of the film. Samples will be experimentally characterized.

Progress in Maximum Field in Accelerator Magnets

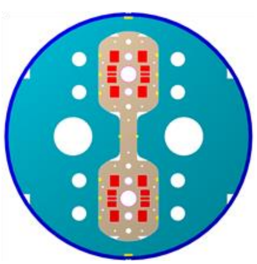


D20 (LBNL)
50 mm dipole
13.5 T (1997)

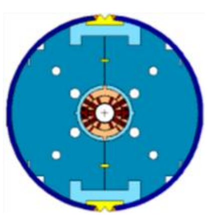




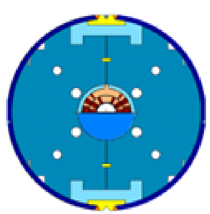
HD2 (LBNL)
35 mm dipole
13.8 T (2008)



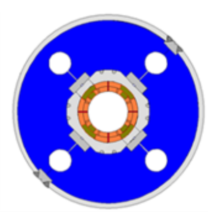
HFDC (R&W)
40 mm 10 T dipole



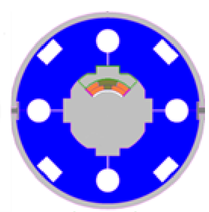
HFDA
43.5 mm
10 T dipole



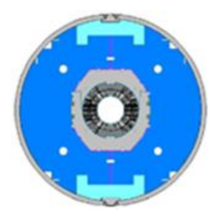
HFDM-LM
Dipole mirror



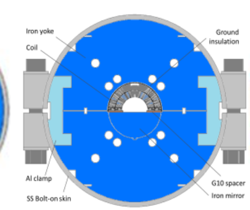
TQC
90 mm 200 T/m
quadrupole



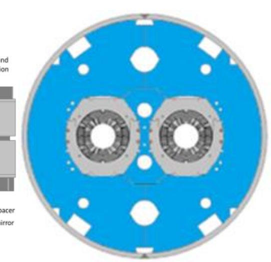
TQM-LQM
Quadrupole
mirror



MBHSP
60 mm 11 T dipole



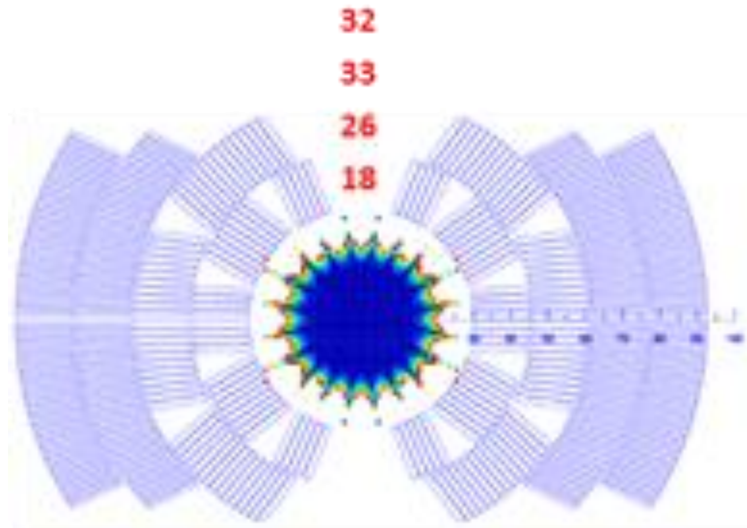
MBHSM
Dipole mirror

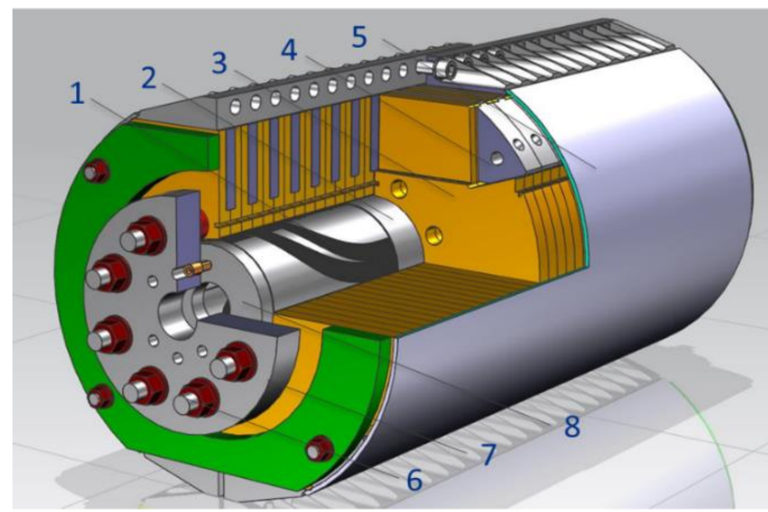


MBHDP
60 mm 11 T dipole

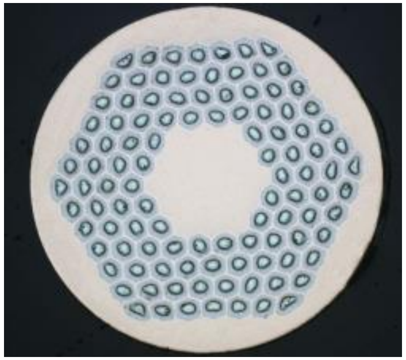
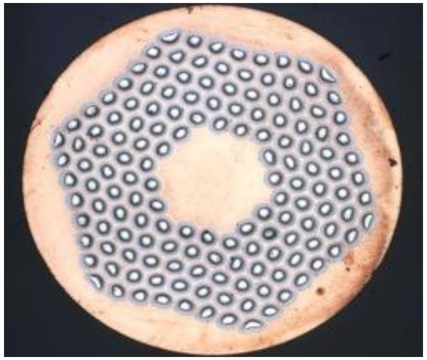
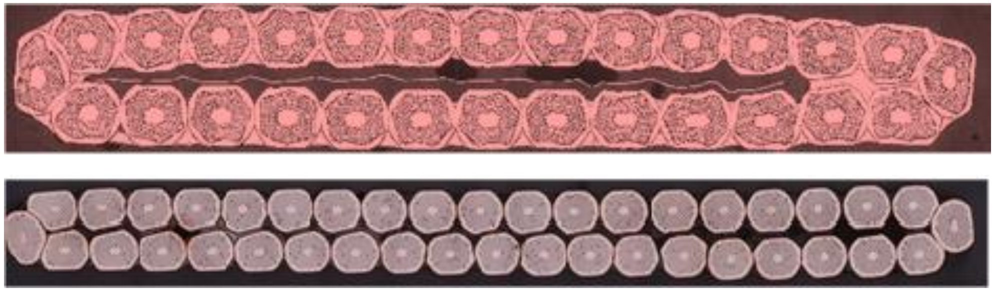
US Magnet Development Program
Cos-theta 15 T Dipole

- **Coil:**
  - 60-mm aperture
  - 4-layer graded coil
  - W_{sc} = 68 kg/m/aperture
- **Mechanical structure:**
  - 2-mm StSt coil-yoke spacer
  - Vertically split iron laminations
  - Aluminum I-clamps
  - 12-mm thick StSt skin
  - thick end plates and StSt rods
  - Cold mass OD<610 mm
- **Fabrication status:** in progress
- **Planned magnet test:** Spring 2018





15 T Dipole: Wire and Cable Parameters (FNAL)

Strand ID	RRP1	RRP2
Stack design	108/127	150/169
Ternary element	Ti	Ti
Production year	2012	2014
Diameter *d*, mm	0.7	1.0
I_c (4.2K, 12 T), A	451-490	1,052-1,111
J_c (4.2K, 12 T), A/mm^2	2,560-2,722	2,597-2,710
I_c (4.2K, 15 T), A	229-245	566-619
J_c (4.2K, 15 T), A/mm^2	1,289-1,365	1,395-1,502
D_S, µm	41	58
Twist pitch, mm	14-16	23-24
Cu fraction λ, %	53.2-54.4	47.5-48.4
RRR	101-226	343-374
Final HT step	640ºC/50h	665ºC/50h

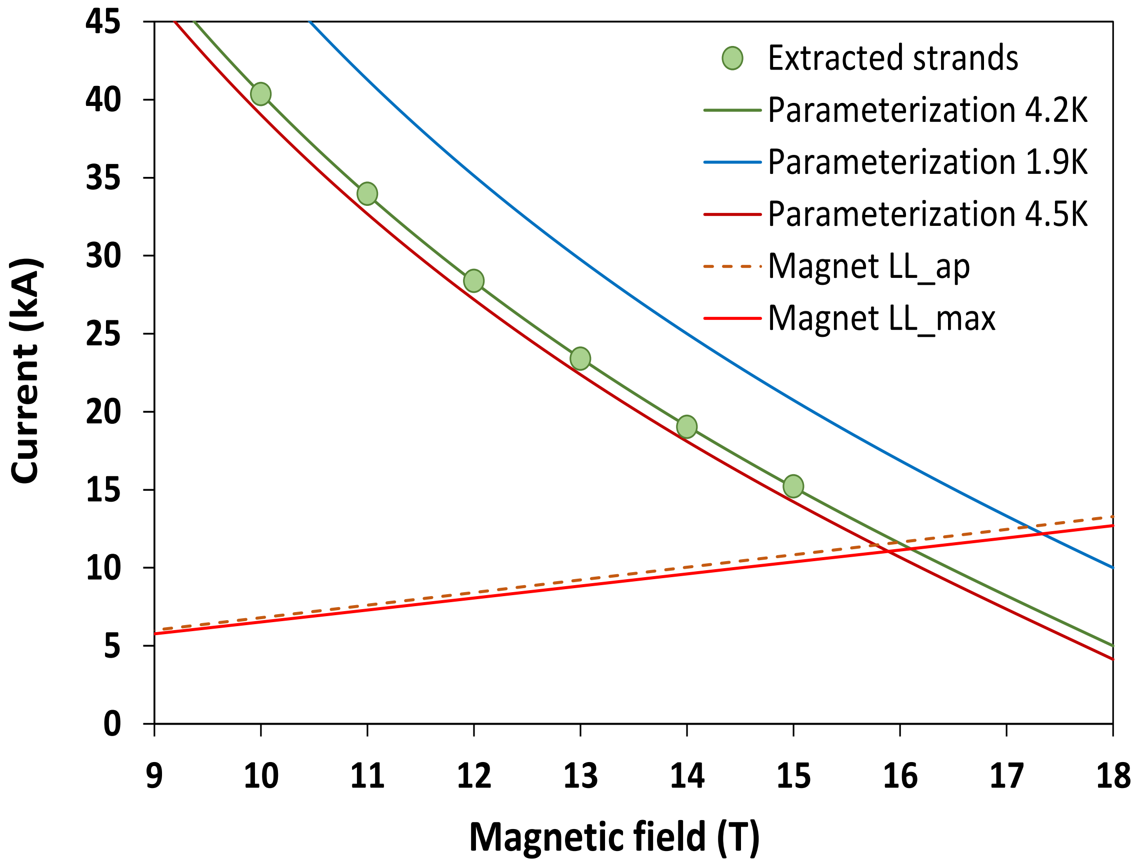
Coil	Cable N x d, mm	RRP® Strand Type	Cable length, m	Cable t_{mid} x w, mm^2	Lay angle, deg.
15 T Dipole Outer Layer	40 x 0.7	RRP1	374	1.251 x 14.71	16.8
15 T Dipole Inner Layer	28 x 1	RRP2	420	1.803 x 14.79	15.5

Both cables have been developed and then manufactured for magnet production.

"Nb_3Sn RRP® Strand and Rutherford Cable Development for a 15 T Dipole Demonstrator", E. Barzi, N. Andreev, P. Li, D. Turrioni, and A.V. Zlobin, IEEE Transactions on Applied Superconductivity, Vol. 26, Issue 4, Art. # 4804305.

15 T Dipole: Short Sample and Design Limits

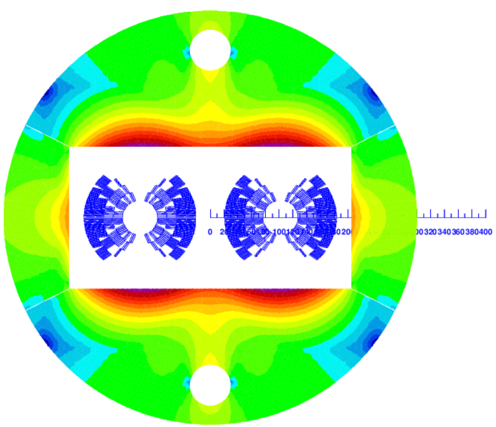
* Magnet **short sample limit** estimated based on extracted strand data
  - Sample HT: 665°C/50 hrs (OST)
  - I_{ssl}=11.05 kA (B_{ap}=15.25 T) at 4.5 K
  - I_{ssl}=12.2 kA (B_{ap}=16.65 T) at 1.9 K

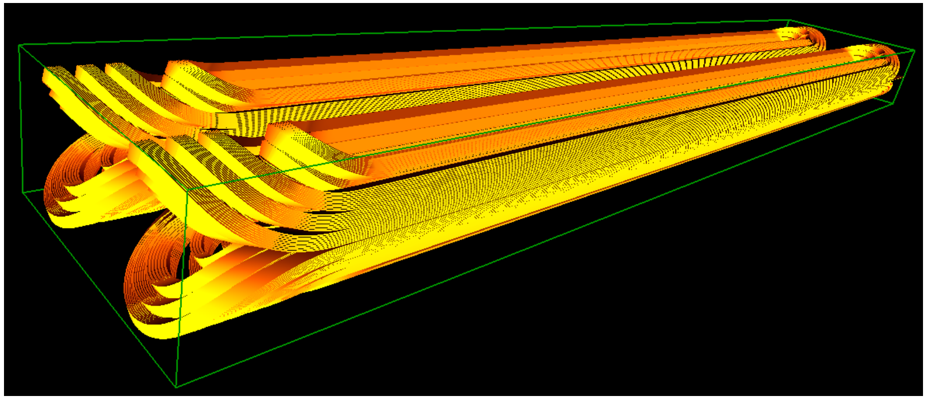


* Magnet **design limit** is determined by mechanical constraints and it is 15 T.

FNAL-INFN 16 T Accelerator Dipole

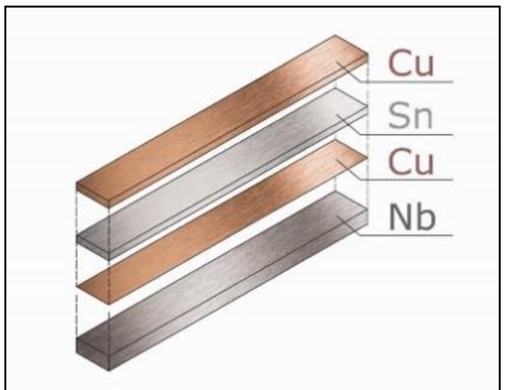
- **The challenge to solve for the INFN-FNAL collaboration is to push the design limit of these magnets to their superconducting potential (or Short Sample limit). To design and build a 16 T Nb_3Sn superconducting dipole, the design limit needs to be at least 17 T.**
- **Within the preferred magnet geometry,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

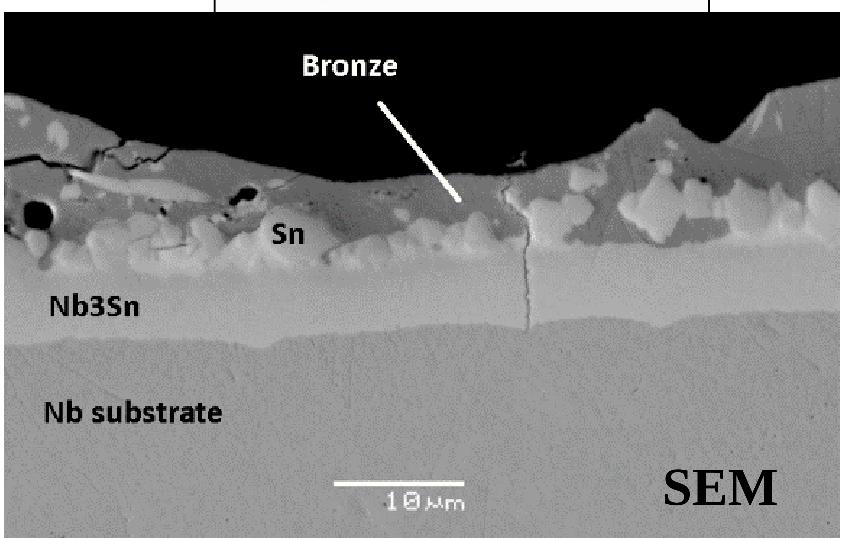


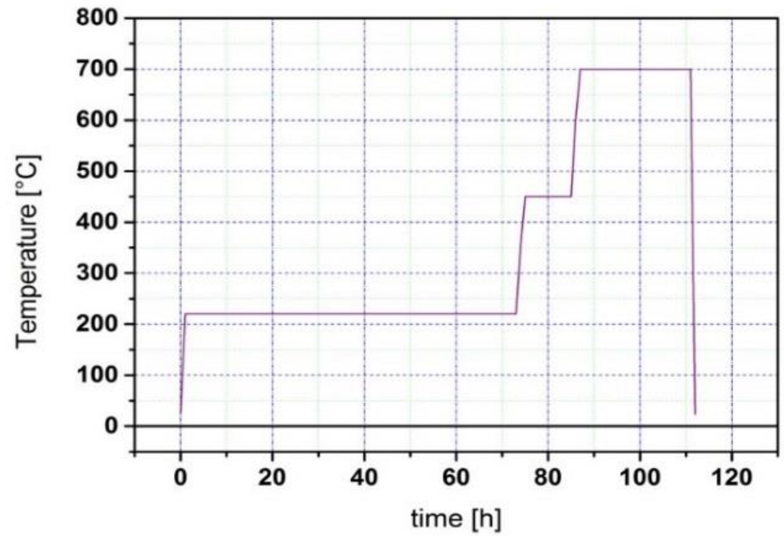


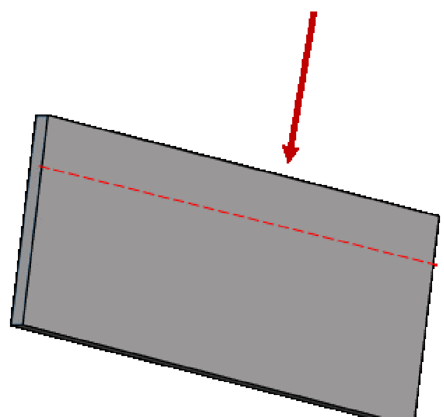
Nb_3Sn Thin Films on Nb

* An electro-chemical deposition technique to produce Nb_3Sn coatings was developed in the last few years by FNAL and the Politecnico di Milano.
* The Nb_3Sn phase is obtained by electrodeposition of Sn layers and Cu intermediate layers onto Nb substrates, followed by high temperature diffusion in inert atmosphere. In 2014, Nb_3Sn superconducting samples between 5.7 and 8.0 μm in thickness were produced with a maximum obtained T_c of 17.68 K and B_{c20} ranging between 22.5 T and 23.8 T.



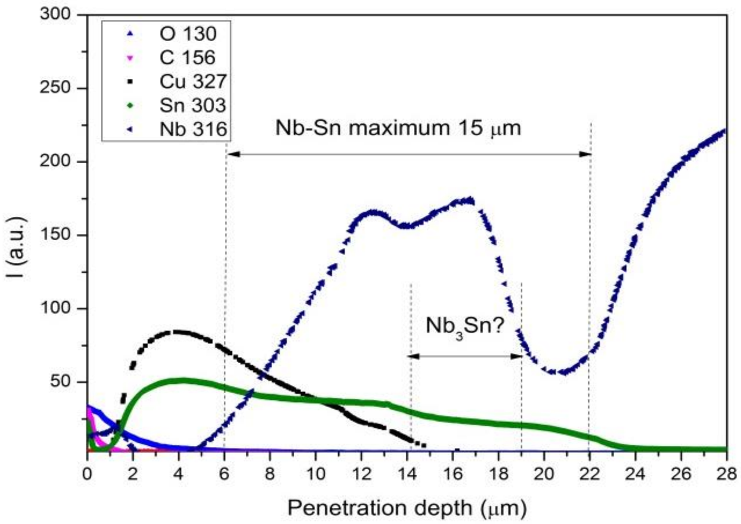




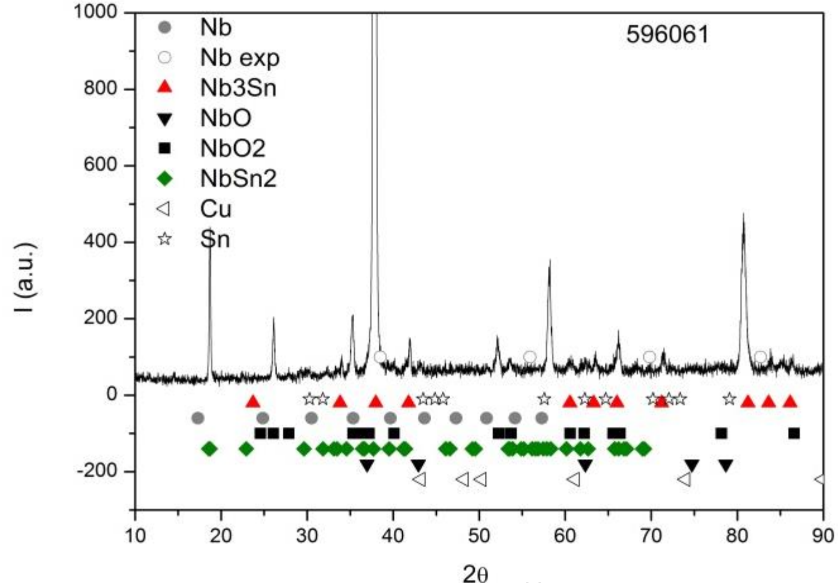


"Synthesis of Superconducting Nb_3Sn Coatings on Nb Substrates", E. Barzi, M. Bestetti, F. Reginato, D. Turrioni and S. Franz, Supercond. Sci. Technol. 29 015009.

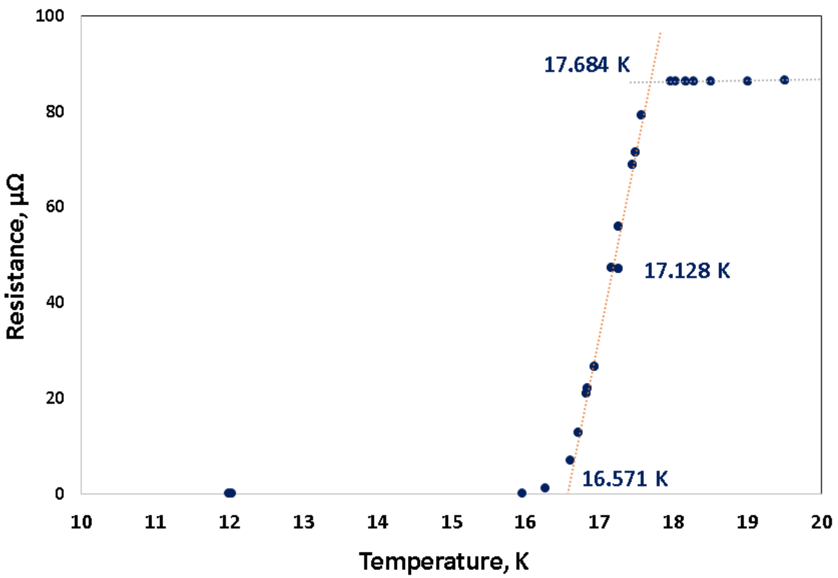
Nb_3Sn Thin Films on Nb –Past Results

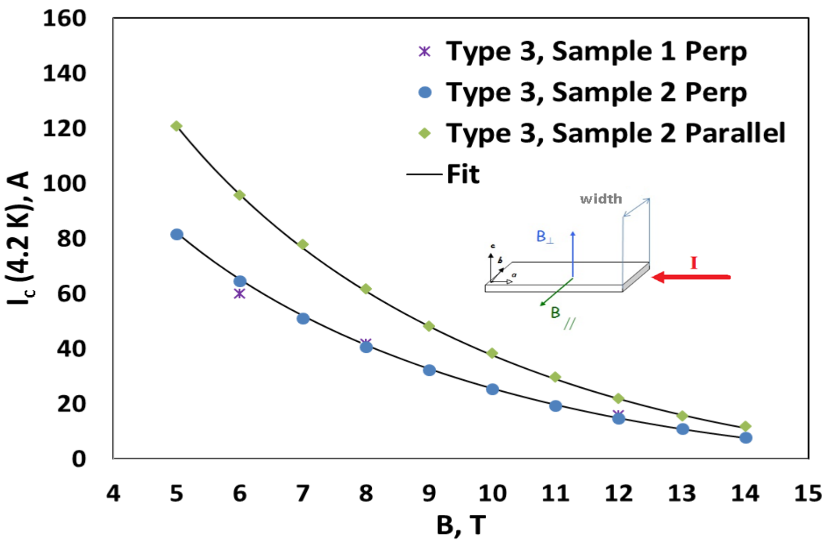


Glow Discharge Optical Emission Spectrometry



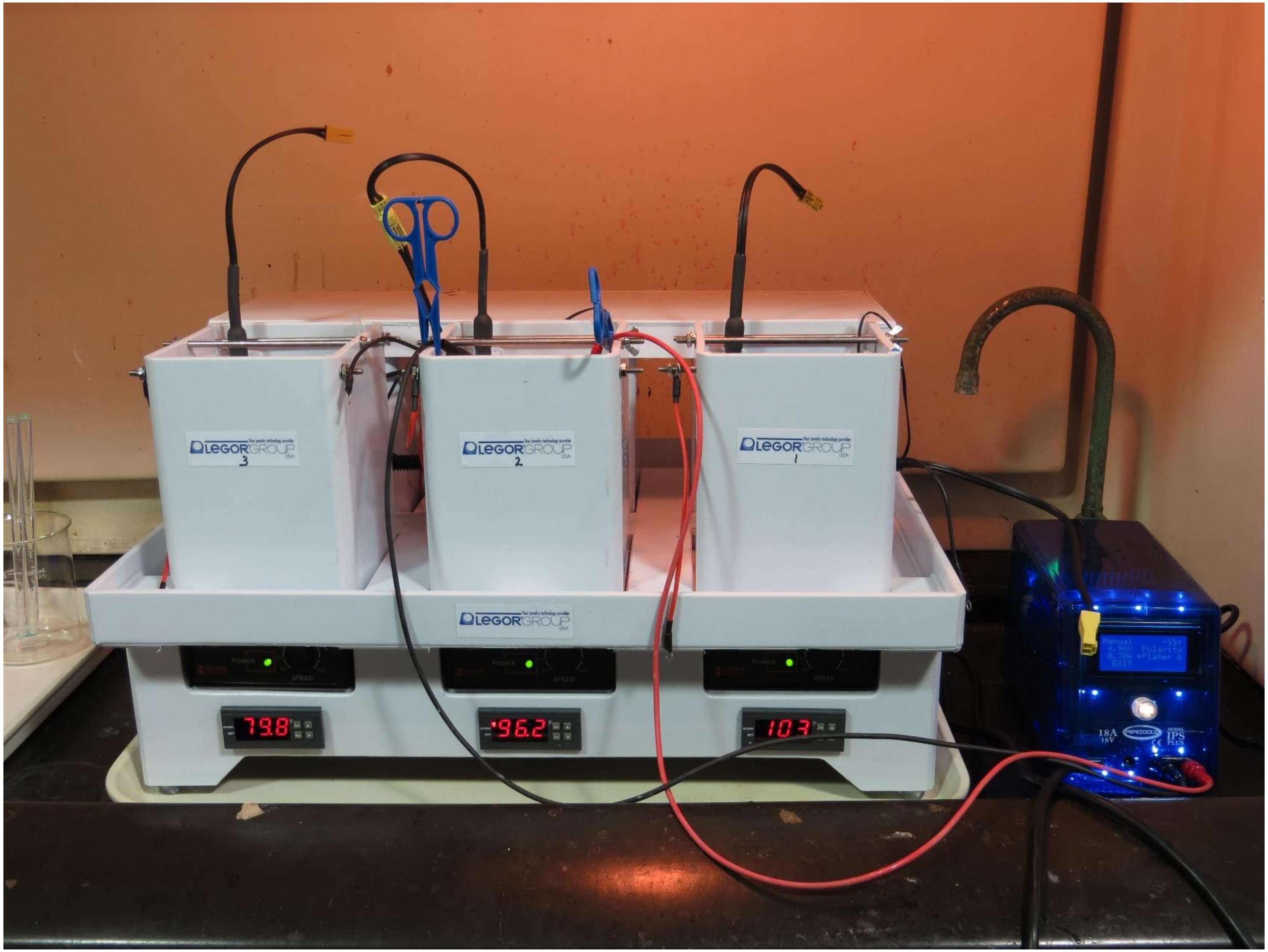
X-ray Diffraction





The maximum obtained T_c was 17.68 K and the B_{c20} ranged between 22.5 T and 23.8 T

New FNAL Setup for Electro-chemical Deposition



Primary Goal for Nb_3Sn Thin Films

Reproduce the original recipe.

Potential for Research and Applications

- **MAGNETS: An inexpensive way to produce Nb_3Sn thin films on Nb can be used as a test bed to try different alloy materials inexpensively and with fast turnaround to test their flux pinning properties to improve performance of wires and cables.**

- **SRF: Nb_3Sn coated cavities would produce High Q, High gradient and Low cost.**