



Overview of Fermilab Work on Superconducting Magnets

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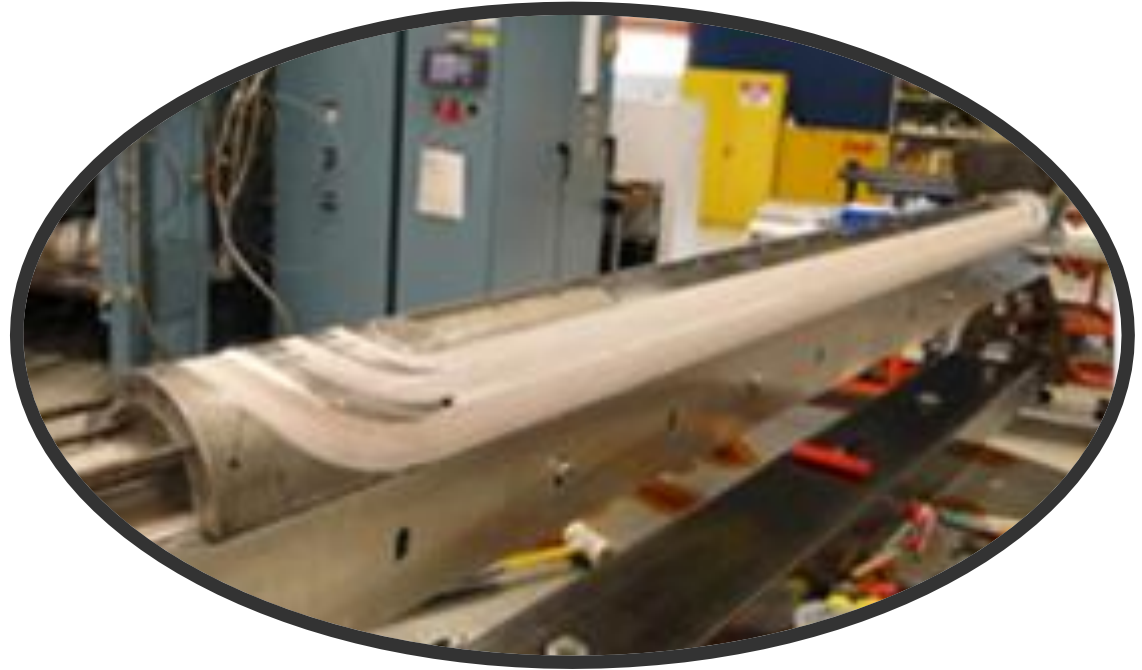
OUTLINE

- **WEBINAR Research and Development of Nb₃Sn Wires and Cables for High-Field Accelerator Magnets.**
- **High Field Magnets for Particle Accelerators, including Fermilab's world record of 14.6 T for accelerator dipole.**
- **High Temperature Superconducting (HTS) Magnets, including:**
 - **20 Tesla accelerator magnets**
 - **Fast cycling magnets for muon colliders (*not shown*)**
 - **Persistent current magnets at liquid Nitrogen temperature (*not shown*)**
- **Mu2e magnets (production, transport and detector solenoids).**
- **Fermilab and Argonne National Laboratory produced the first successful Nb₃Sn undulator for the Advanced Photon Source storage ring (*not shown*).**

Accelerator Magnet Technology at Fermilab using Superconducting Nb₃Sn



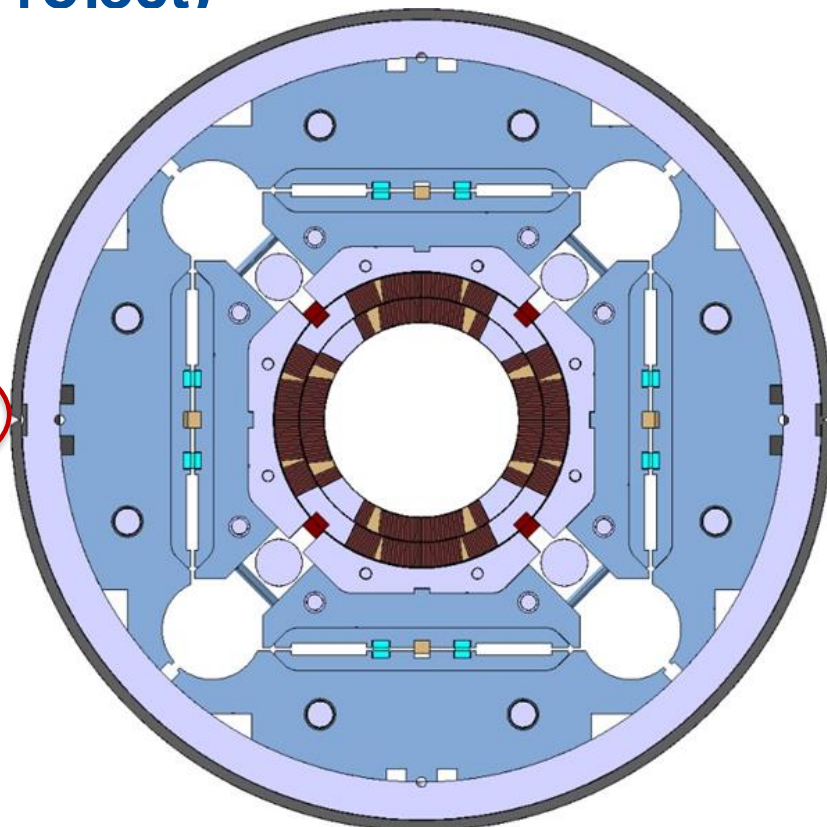
**Cross section of quadrupole
(4 coils total)**



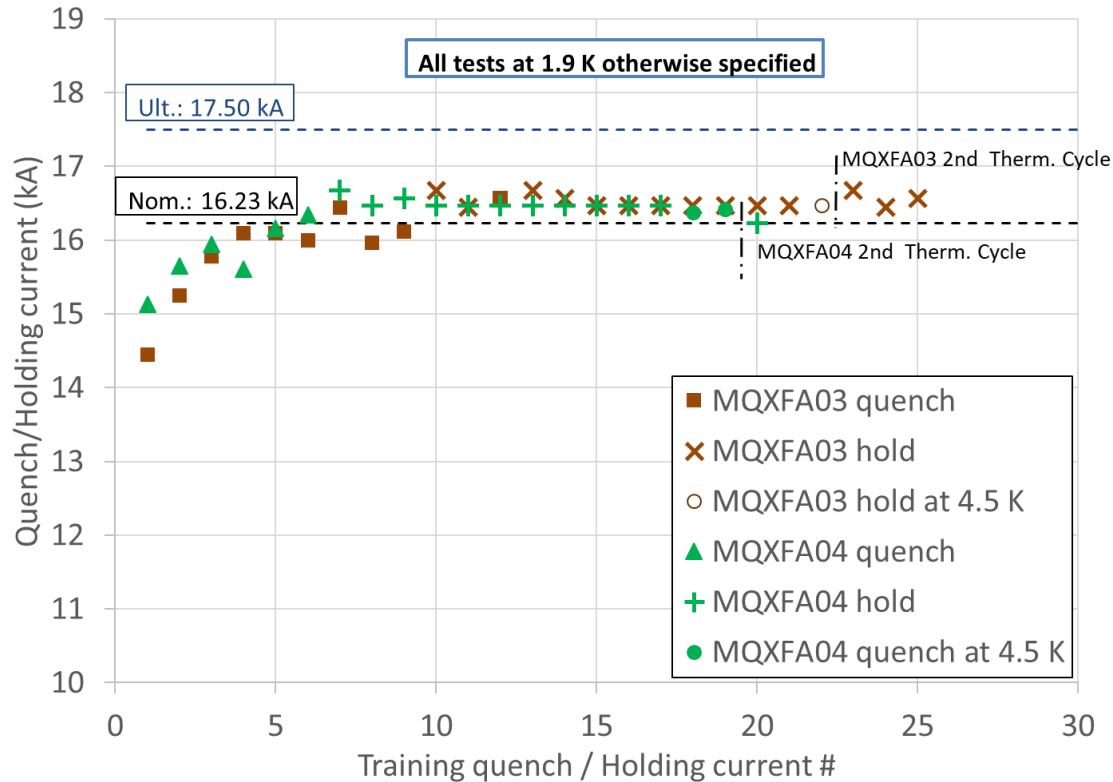
One of two dipole coils

Nb₃Sn Quadrupoles for the U.S. High-Luminosity Large Hadron Collider at CERN (AUP Project)

PARAMETER	Unit	MQXFA/B
Coil aperture	mm	150
Magnetic length	m	4.2/7.15
N. of layers		2
N. of turns Inner-Outer layer		22-28
Operation temperature	K	1.9
Nominal gradient	T/m	132.2
Nominal current	kA	16.23
Peak field at nom. current	T	11.3
Stored energy at nom. curr.	MJ/m	1.15
Diff. inductance	mH/m	8.26
Strand diameter	mm	0.85
Strand number		40
Cable width	mm	18.15
Cable mid thickness	mm	1.525
Keystone angle		0.4



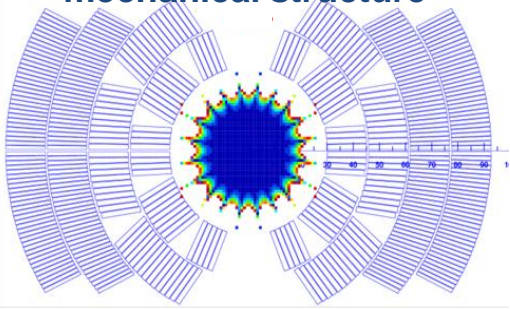
AUP Quadrupoles Quench Current Behavior (for MQXFA03 and MQXFA04 coils)



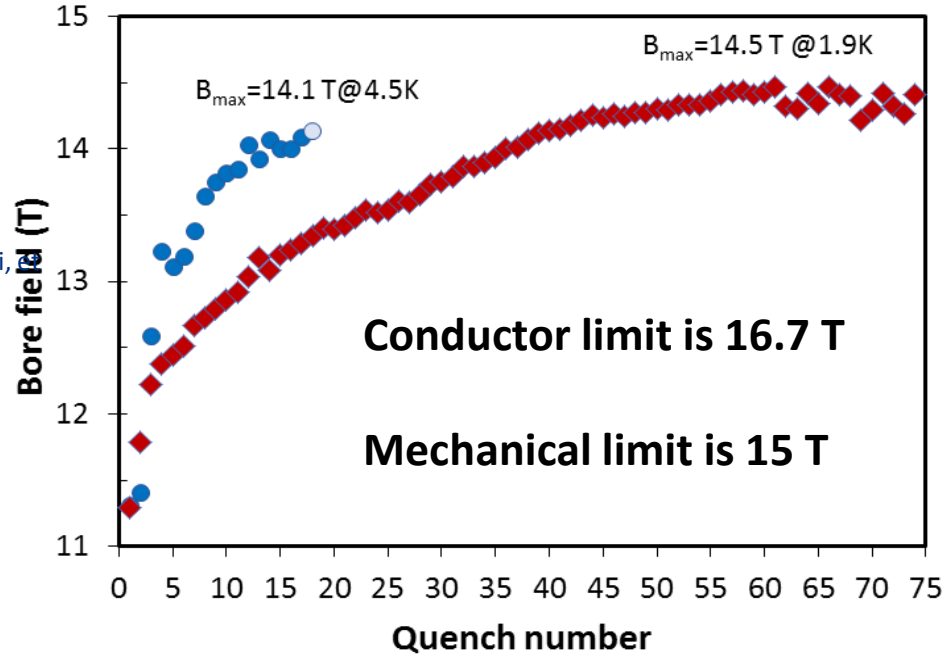
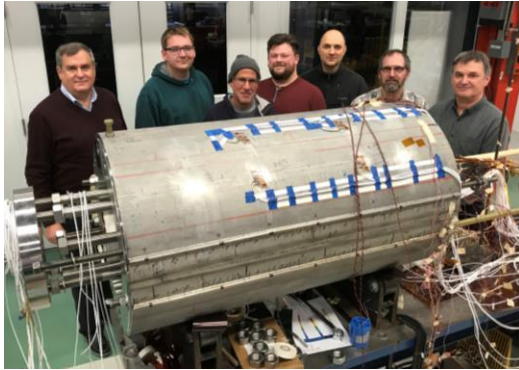
J. Muratore et al., "Test Results of the First Pre-Series Quadrupole Magnets for the LHC Hi-Lumi Upgrade", IEEE Trans. Appl. Superc. 2021, #4001804

Record 14.6 Tesla Accelerator Magnet at Fermilab (within US-Magnet Development Program)

60-mm aperture, innovative
mechanical structure

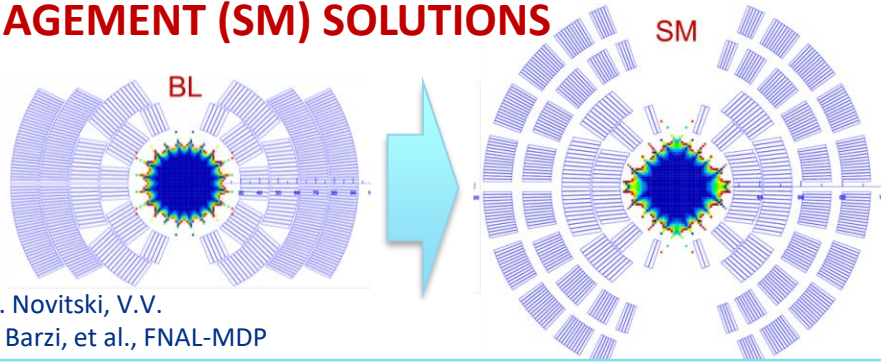


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al., FNAL-MDP

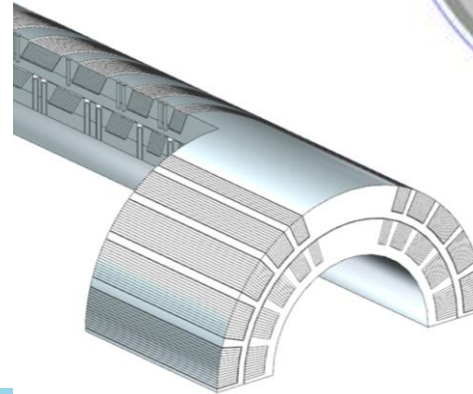
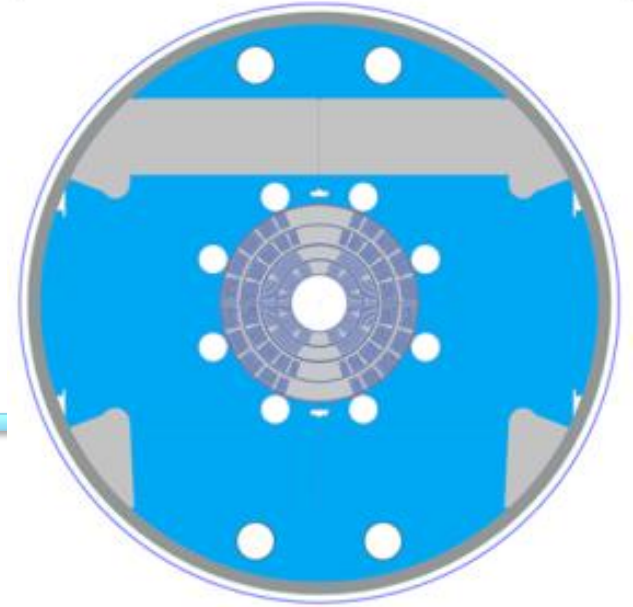


Beyond 15 T → 17 T Nb₃Sn dipole with stress management

From **BASELINE (BL)** to **STRESS MANAGEMENT (SM) SOLUTIONS**



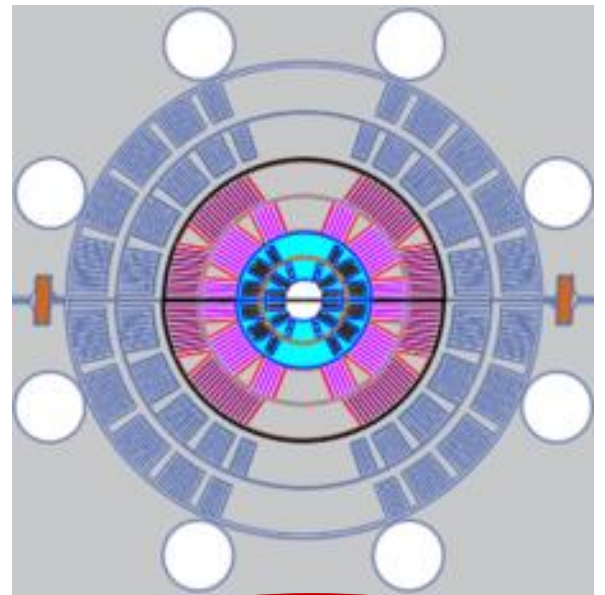
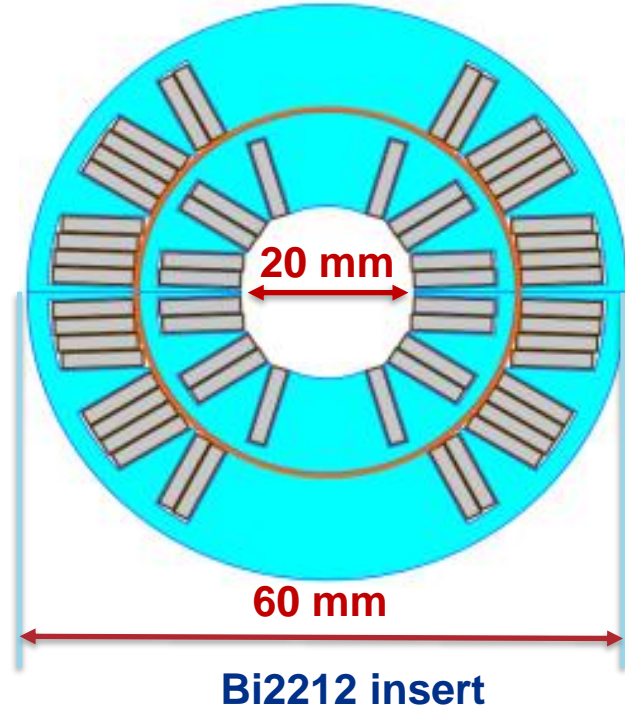
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Towards 20 T → Hybrid Dipole Models with HTS Coil Inserts



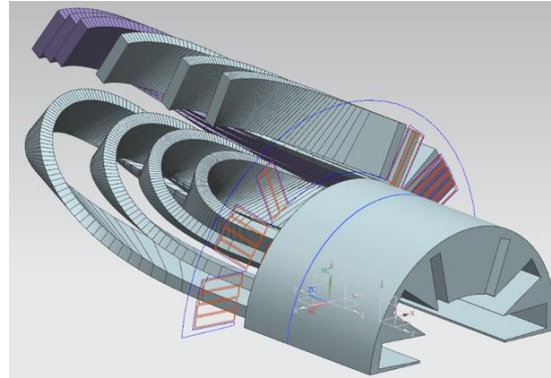
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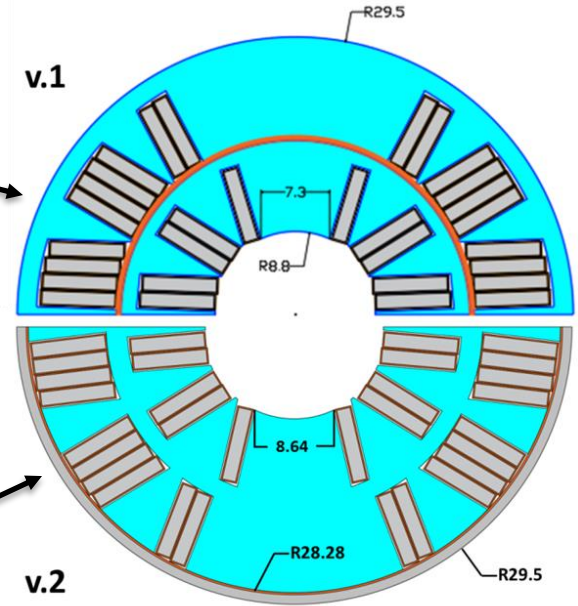
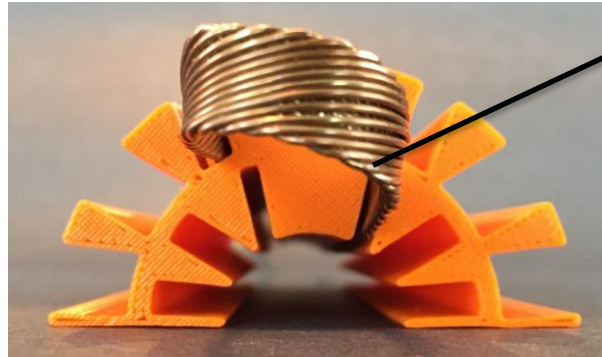
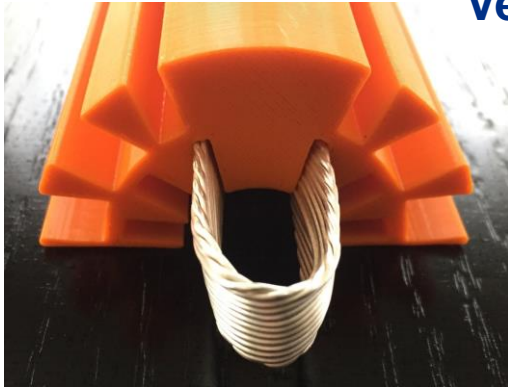
Total of 19 Tesla are expected from Bi2212 insert inside 17 T Nb₃Sn dipole coil

Structural Design of HTS Inserts

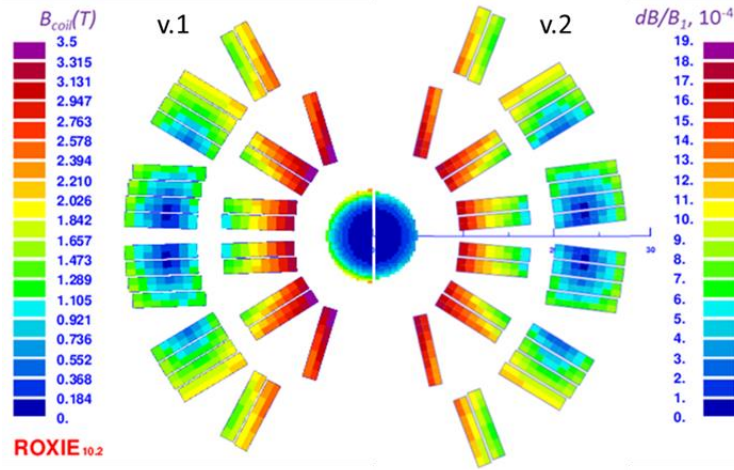
Versione 1
Due pezzi



Versione 2, pezzo unico



Magnetic Design of HTS Inserts

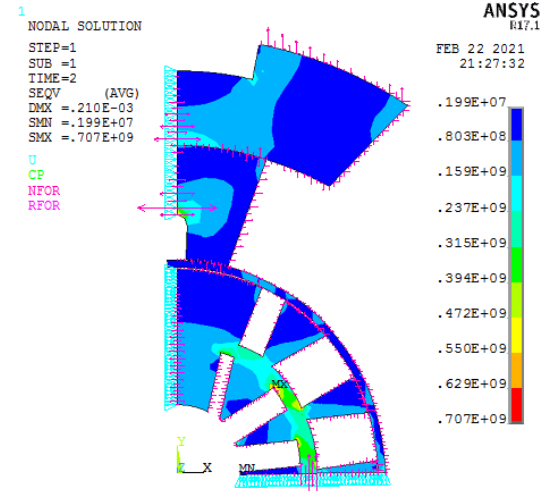
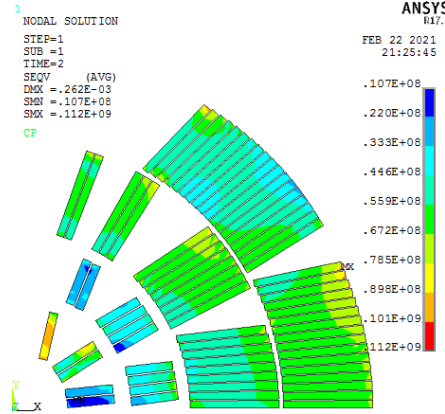


n	Design	3	5	7	9	11
$b_n, 10^{-4}$	v.1	-0.76	-9.6	3.43	-0.23	0.03
	v.2	0.015	-5.12	1.46	0.003	0.05

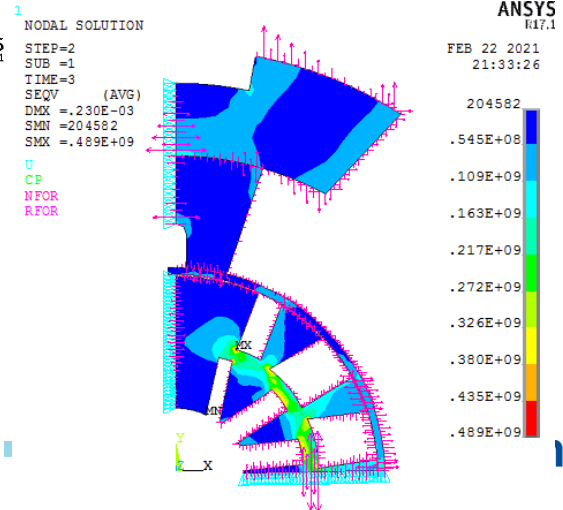
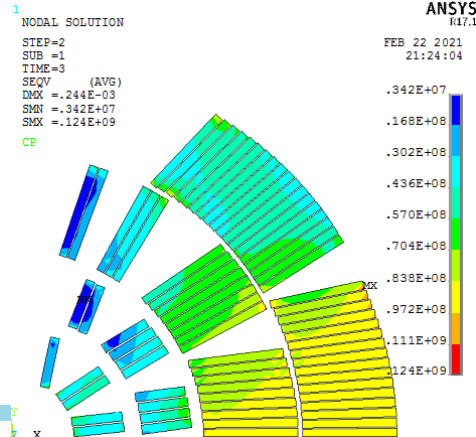
Mechanical Analysis in 11 T Dipole

Von Mises Stress in coil < 100 MPa
Von Mises Stress in structure < 600 MPa

4.2 K, no current



4.2 K, $I = 8$ kA, $B_{max} = 12$ T



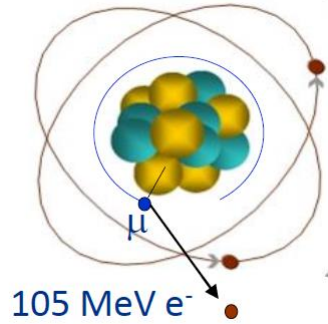
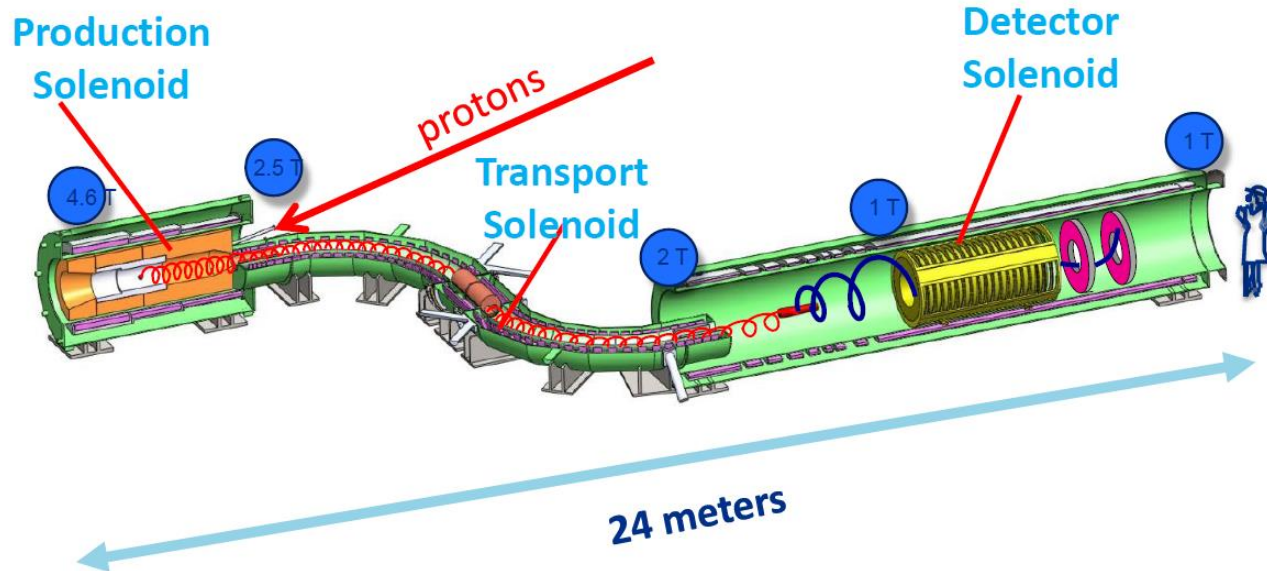
Mu2e Magnets

The Mu2e Experiment

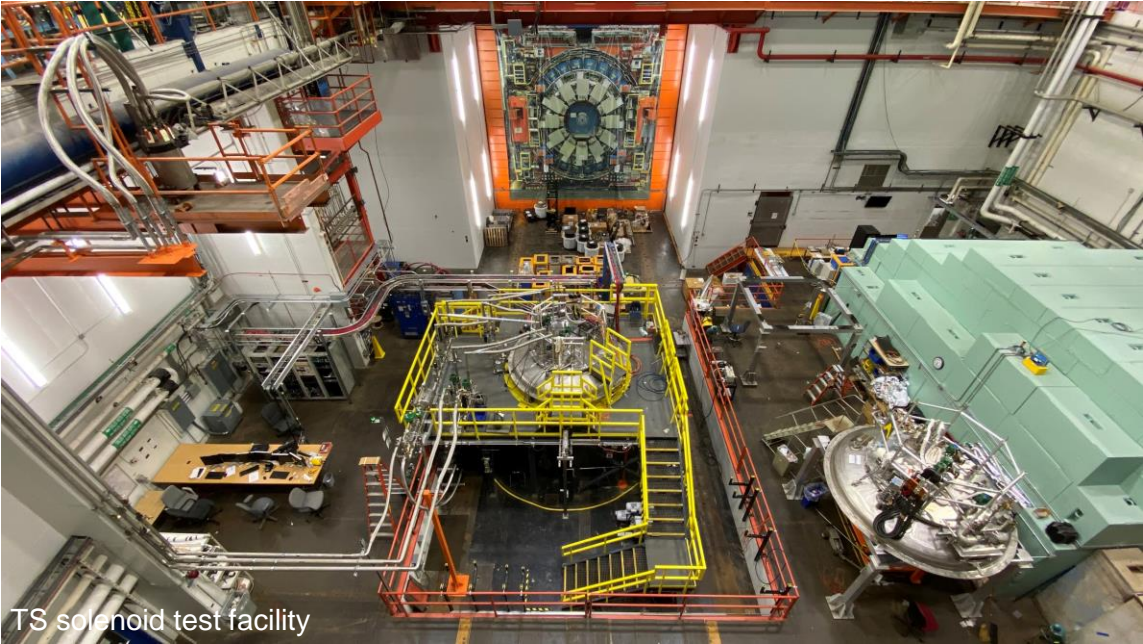
- Search for Charged Lepton Flavor Violation (CLFV) via the coherent conversion of

$$\mu^- N \rightarrow e^- N$$

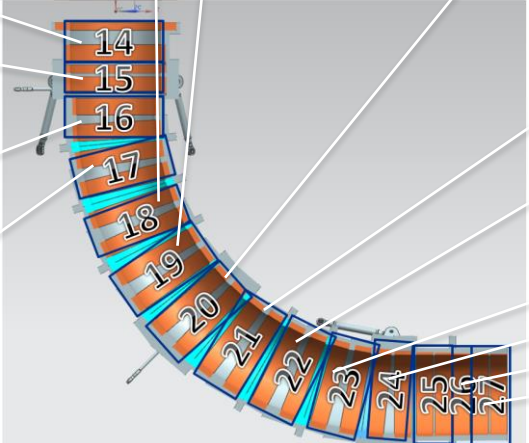
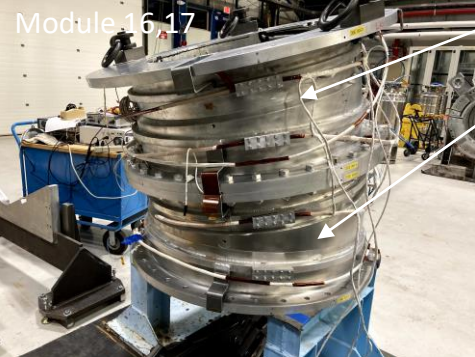
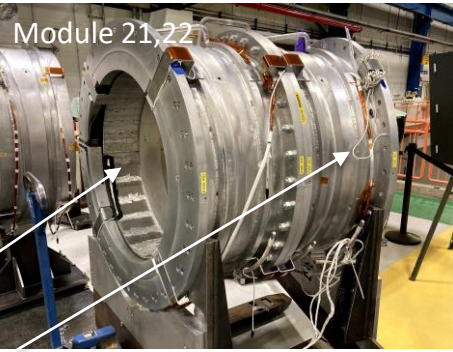
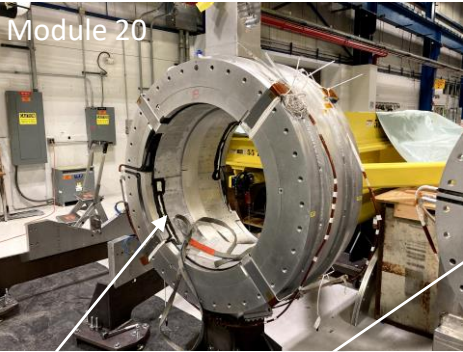
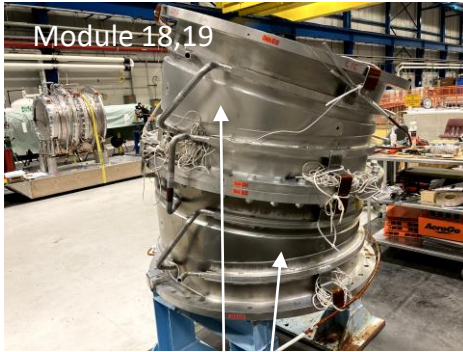
- Three solenoids, provide magnetic field for experiment



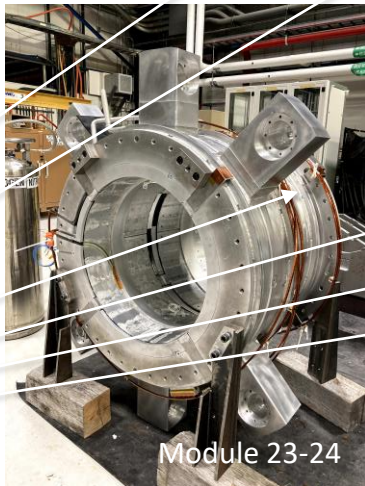
TS test facility at Fermilab



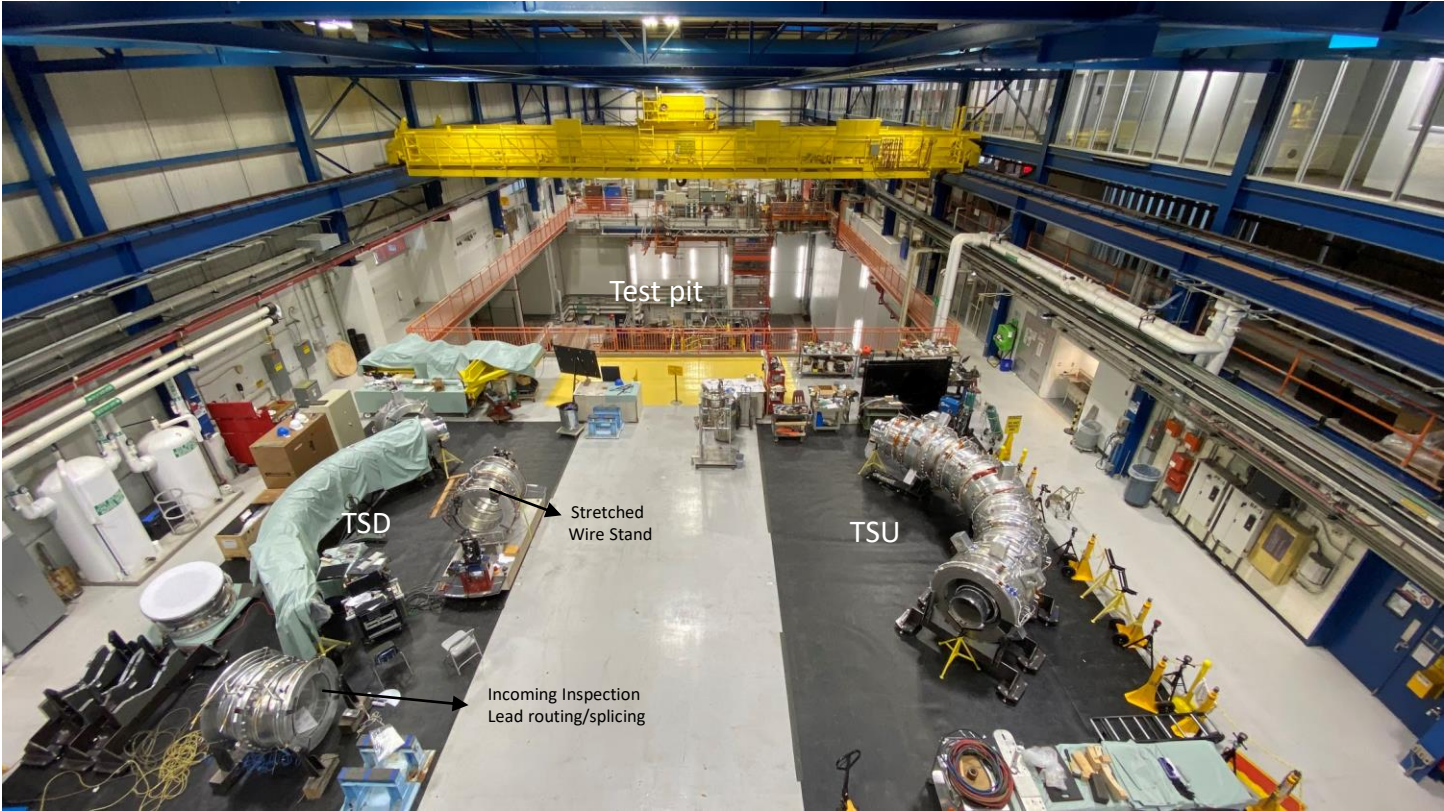
Coils Tested



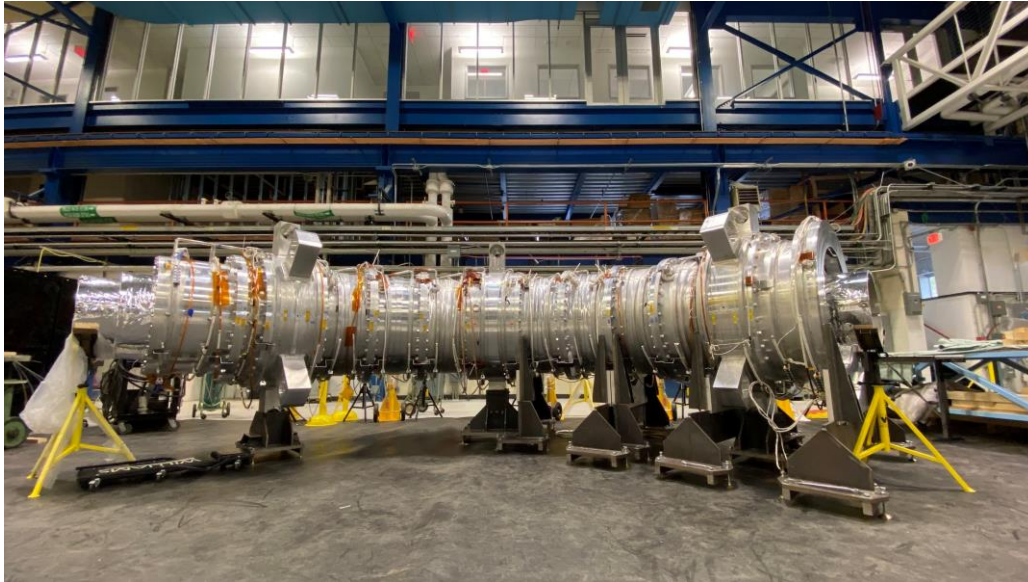
Transport Solenoid Downstream
27 coils / 14 modules / 7 test units



TS activities at Fermilab



Status of TS cold mass units



Tests on ALL TSU units have been successfully completed. All units have been approved for payment to the vendor. All TSU units fully assembled. Metrology completed.

Tests on TSD units is ongoing. 4 out of 7 have been tested and approved. Testing on the last 3 units is currently ongoing.

