U.S. MAGNET DEVELOPMENT PROGRAM

SMCT mirror design, fabrication and instrumentation

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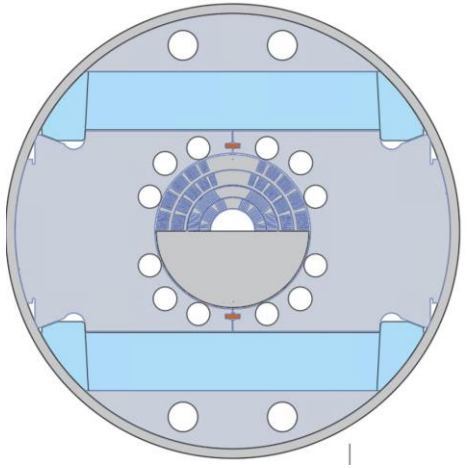
U.S. MDP Collaboration Meeting

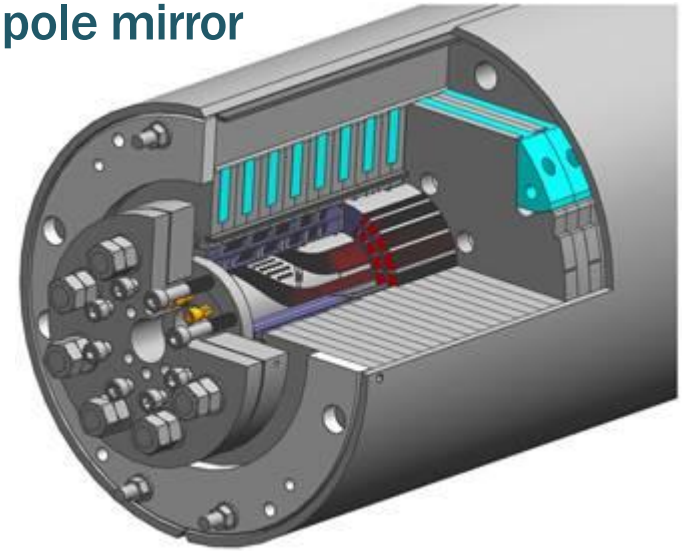
3/21/2023

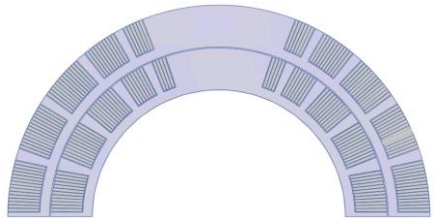
Introduction - Dipole mirror with SMCT coil

- Mirror design
- Coil design and fabrication
- Mirror shim plan
- Iron modification
- Clamping
- Skin welding
- End support
- Next steps
- Summary

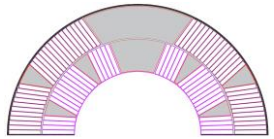
Cos-theta dipole mirror







New SMCT coil ID=120 mm



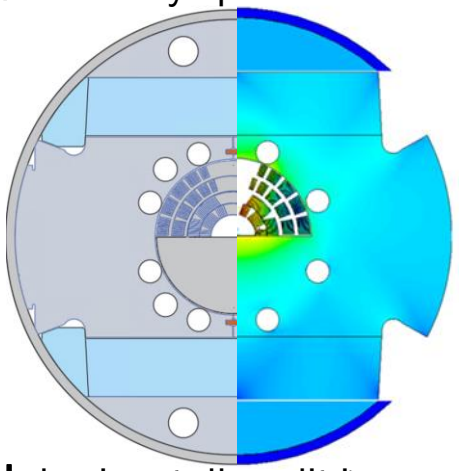
Inner coil for 15T dipole ID=60 mm

Modified MDPCT1 structure

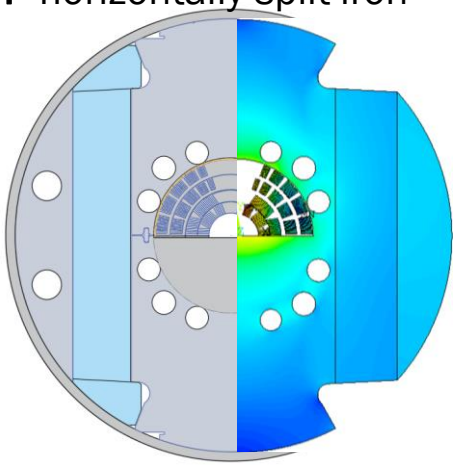
- Cold mass OD=610 mm
- 12.5 mm thick SS shell
- Aluminum I-clamps

Mirror magnet magnetic and mechanical analysis

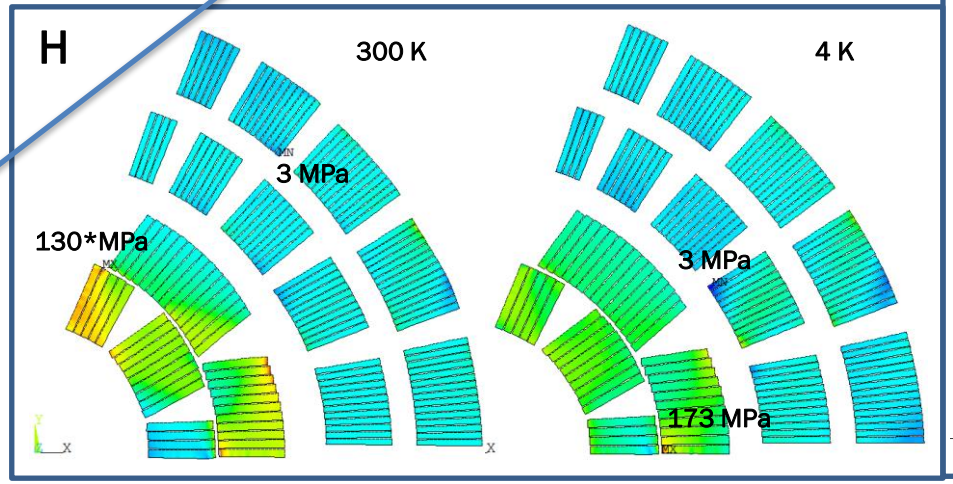
V-vertically split iron

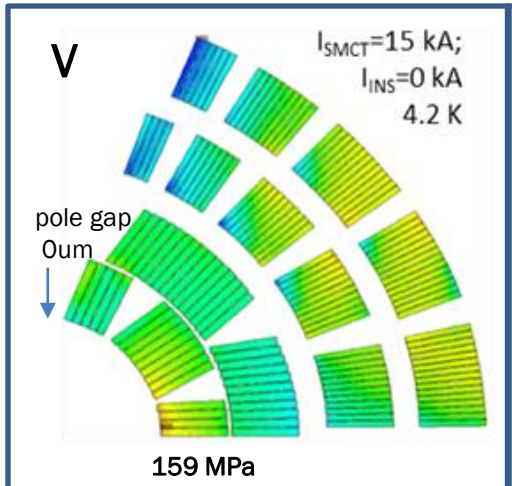


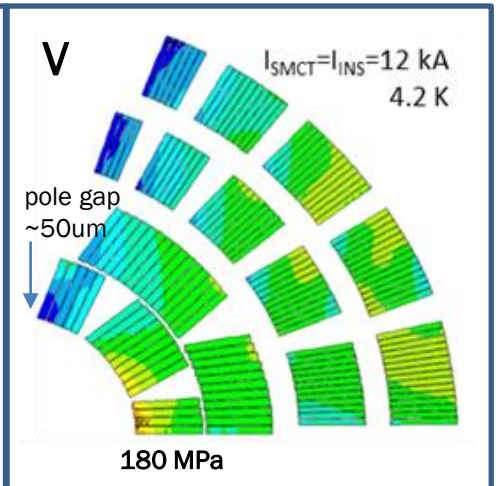
H- horizontally split iron

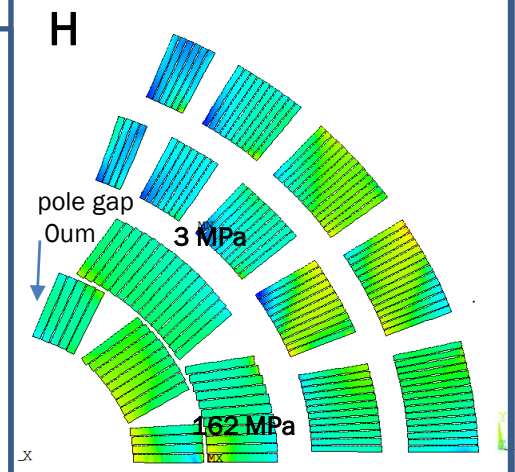


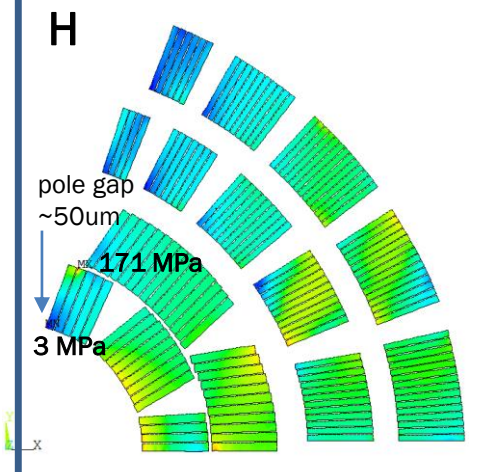
- Two versions of iron configuration
- Two electromagnetic loads: for 2-layer/4-layer
- 4-layer case has 35% higher EM load
- H and V cases are almost identical for the coil stress distribution for two loads
- Coil loading with 130MPa (max) at 300K leads to 170-180MPa at max current of 12kA for 4-layer case in both designs
- The horizontally split iron is easy to assemble





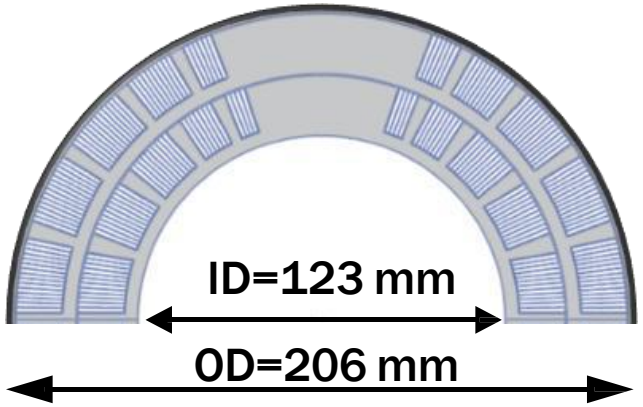






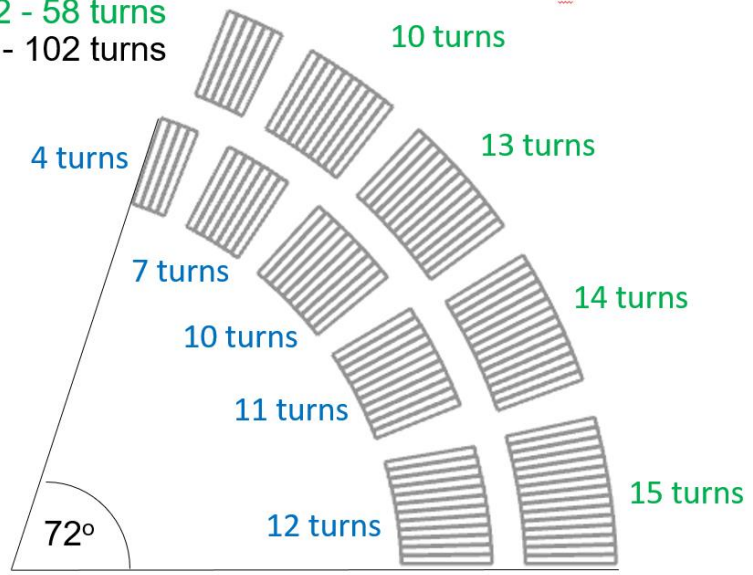
SMCT coil design and parameters

Large aperture dipole coil

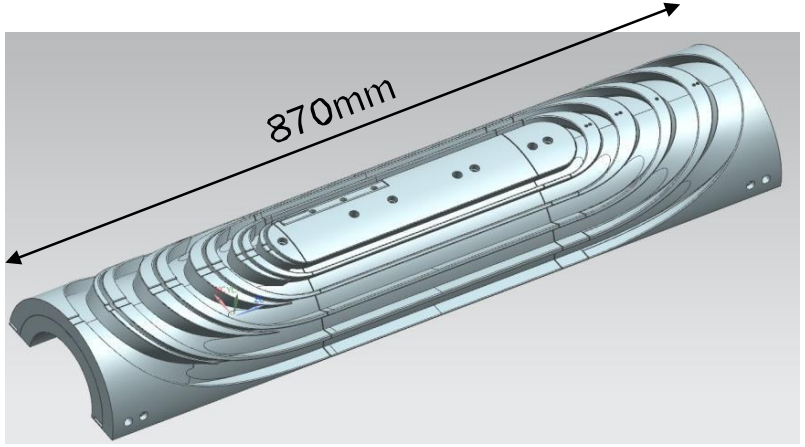


5 block per layer
L1 - 44 turns
L2 - 58 turns
Σ - 102 turns

t_r – 3.2 mm
t_s - 4.5 mm



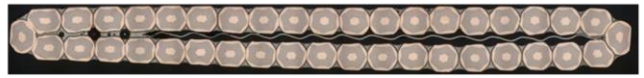
Stress management for whole coil using stainless steel 3D printed mandrels



Nb_3Sn Rutherford cable - 145m

0.7 mm RRP108/127
40-strand cable

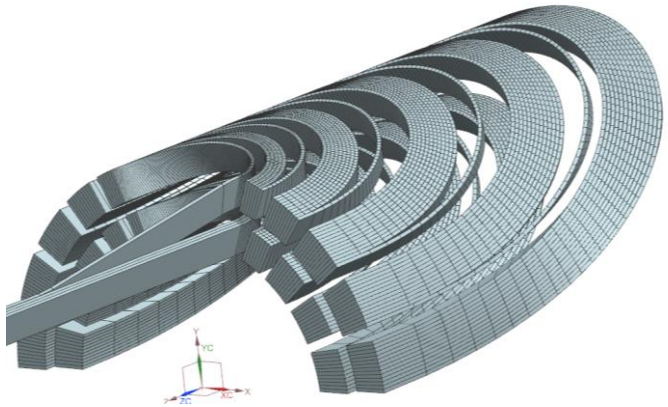
from 11T coils



reacted dimensions: 15.1x1.319 mm
Jc(12T, 4.2K)=2650A/mm^2

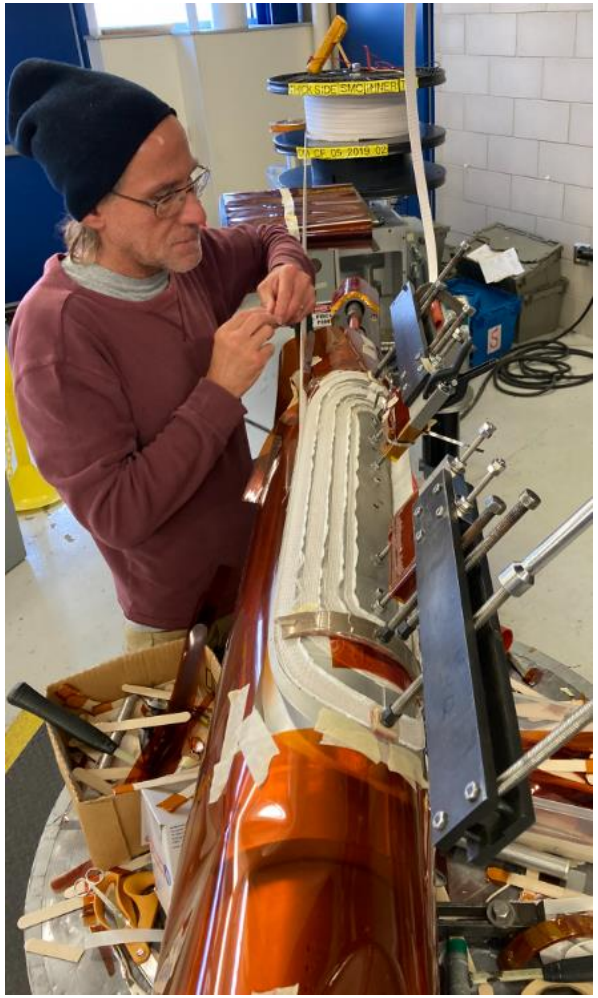
Insulation thickness per side:
cable E-glass - 0.15 mm
groove S2+mica - 0.36 mm

interlayer S2 - 0.5 mm
on coil OD S2 - 0.125 mm

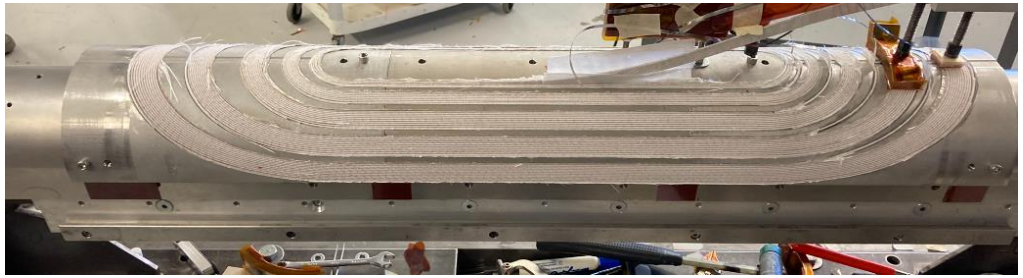


Cable layout at Lead End with ramp

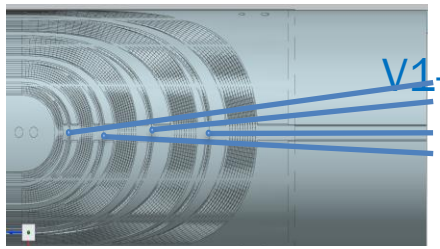
SMCT coil winding



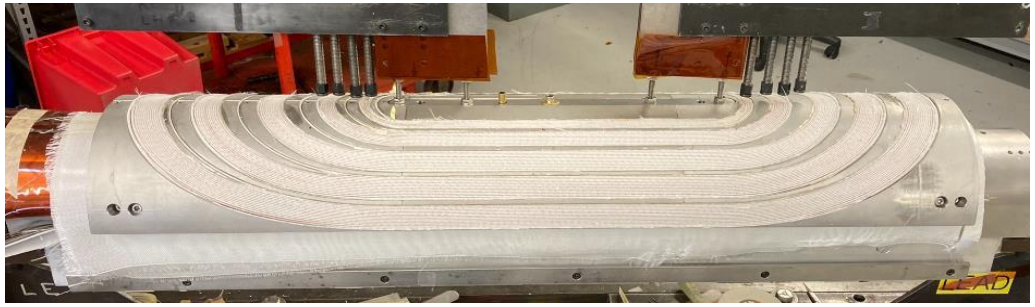
Coil winding process



Completed inner layer (L1) winding



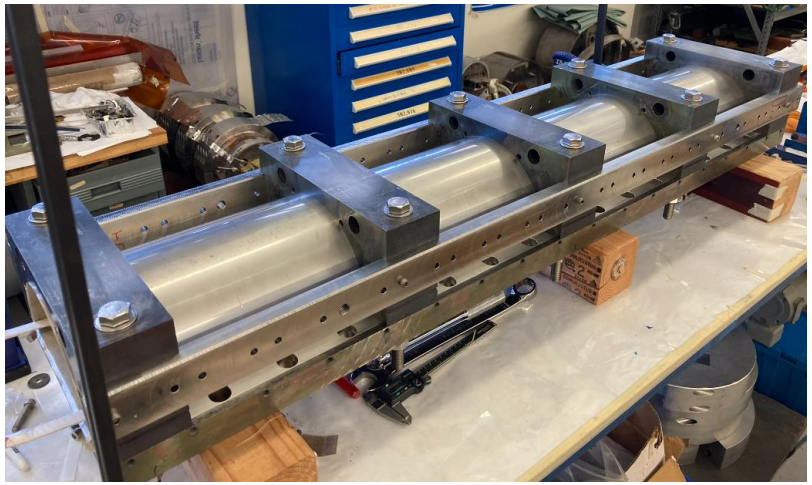
L1 VT strips located between two inter-layer blankets and will be not accessible after HT



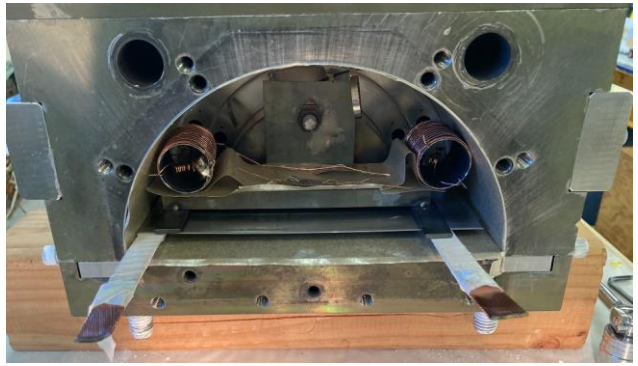
Completed outer layer (L2) winding

Coil 3D printed mandrel for L2

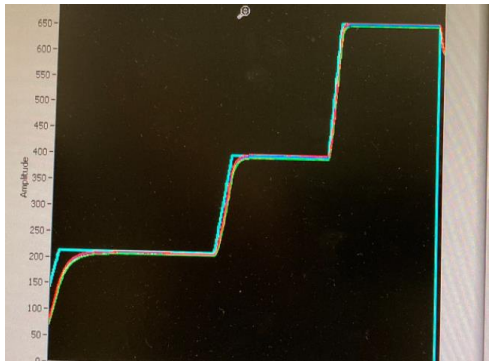
SMCT coil reaction



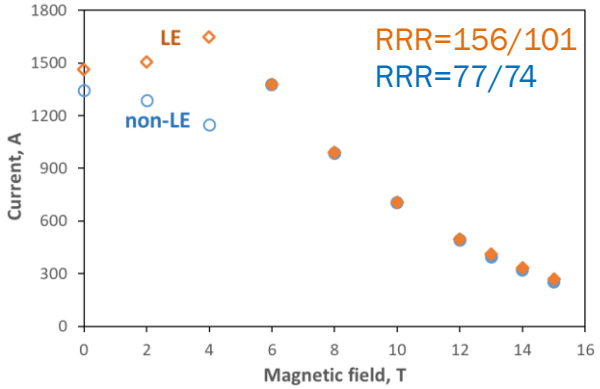
Coil reaction tooling assembly



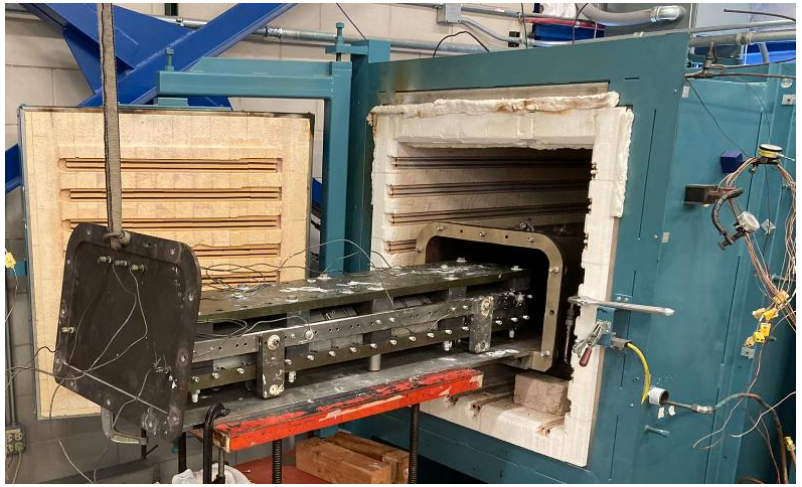
Position of the witness samples at the LE



200h 3-step reaction cycle with Tmax=658°C/48h in Argon gas



SMCT coil witness sample (extracted) I_c vs. B at 1.9 K.



Coil tooling loading into reaction retort

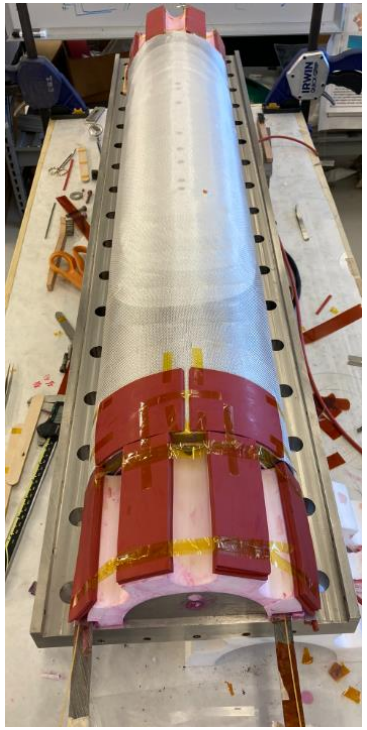
SMCT coil after reaction.

At 6 T and higher fields the measurement data overlap for both samples.
Quench currents at low fields induced by the flux-jump instabilities are shown with open symbols.

SMCT coil vacuum impregnation

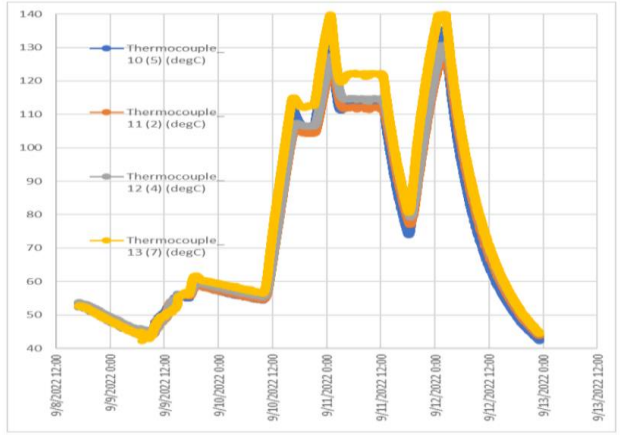
Nb-Ti flexible cables were spliced to Nb_3Sn coil leads

All voids were filled with S2-glass or G10 fillers



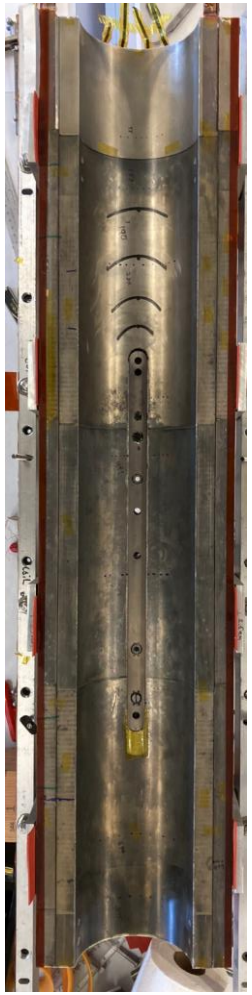
The coil was wrapped with 0.125 mm thick S2-glass blanket

Coil potted with CTD101K epoxy resin, and cured at 125°C for 16 hours



a)

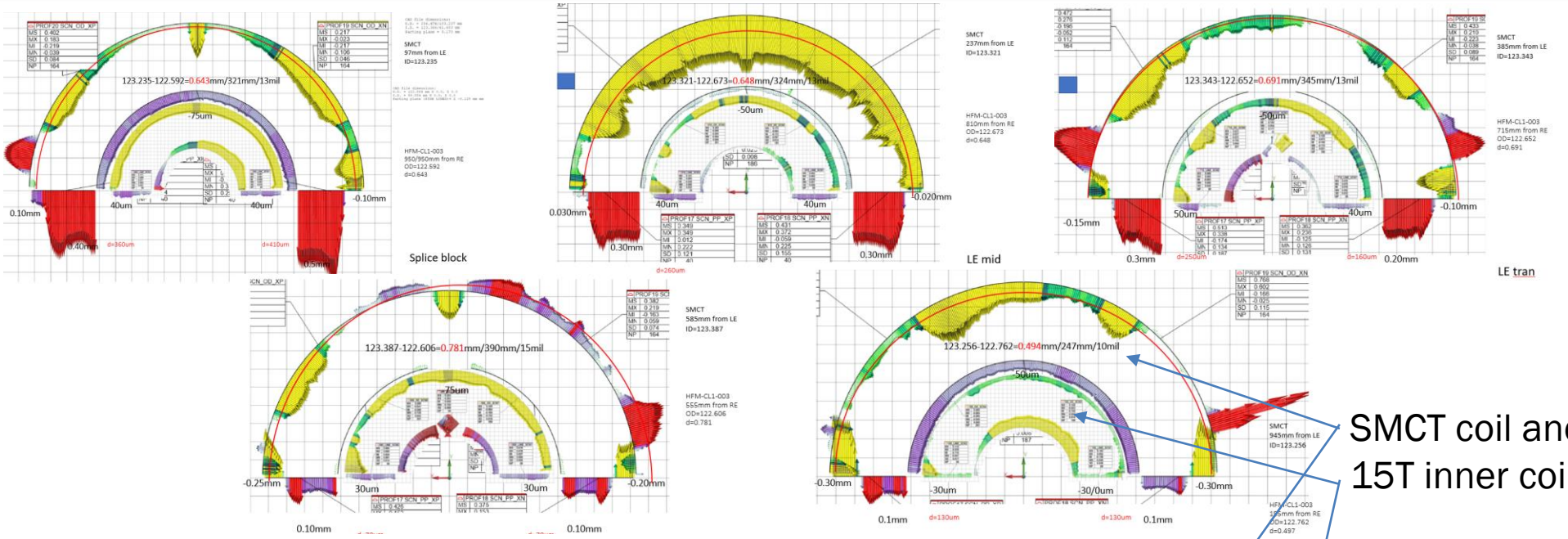
b)



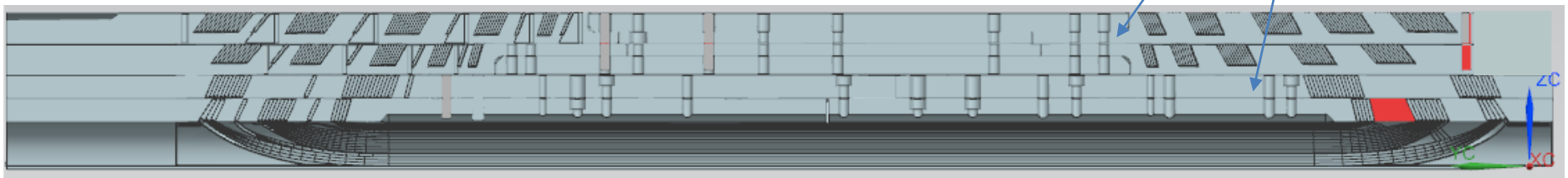
Coil view after impregnation: a) from OD, b) from ID

SMCT coil and mirror coil block sizes

CMM of SMCT impregnated coils

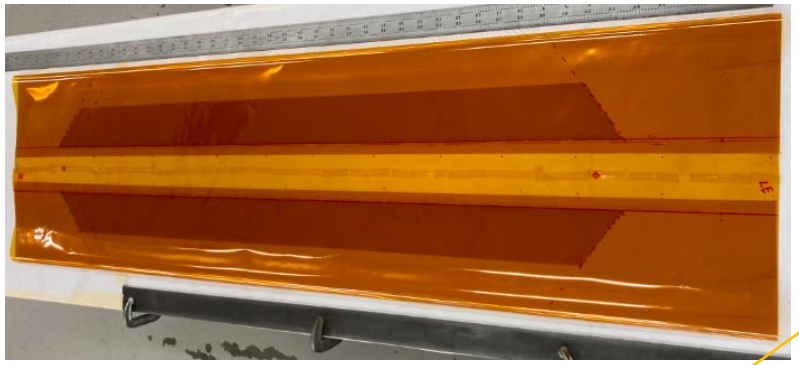


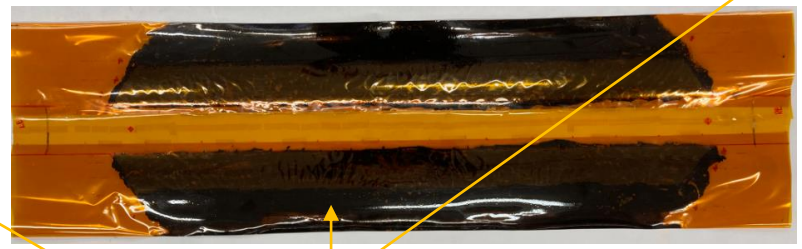
Variations of ±0.08 mm were found on the coil outer diameter in the straight section. The coil OD will be equalized by special azimuthal and midplane shims.



Cross-section view of the mirror coil block

Shims for SMCT coil





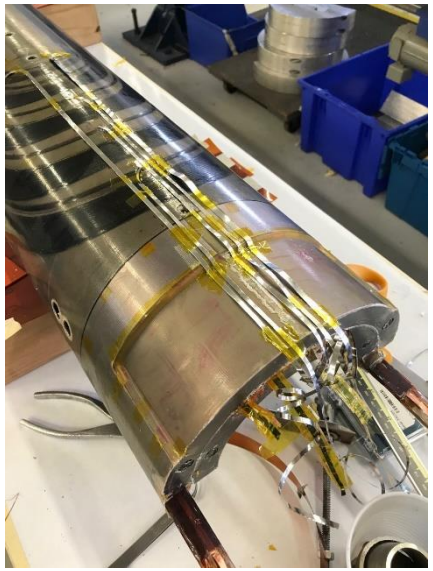
MP and OD casted shims

OD casted shim properly located on the coil

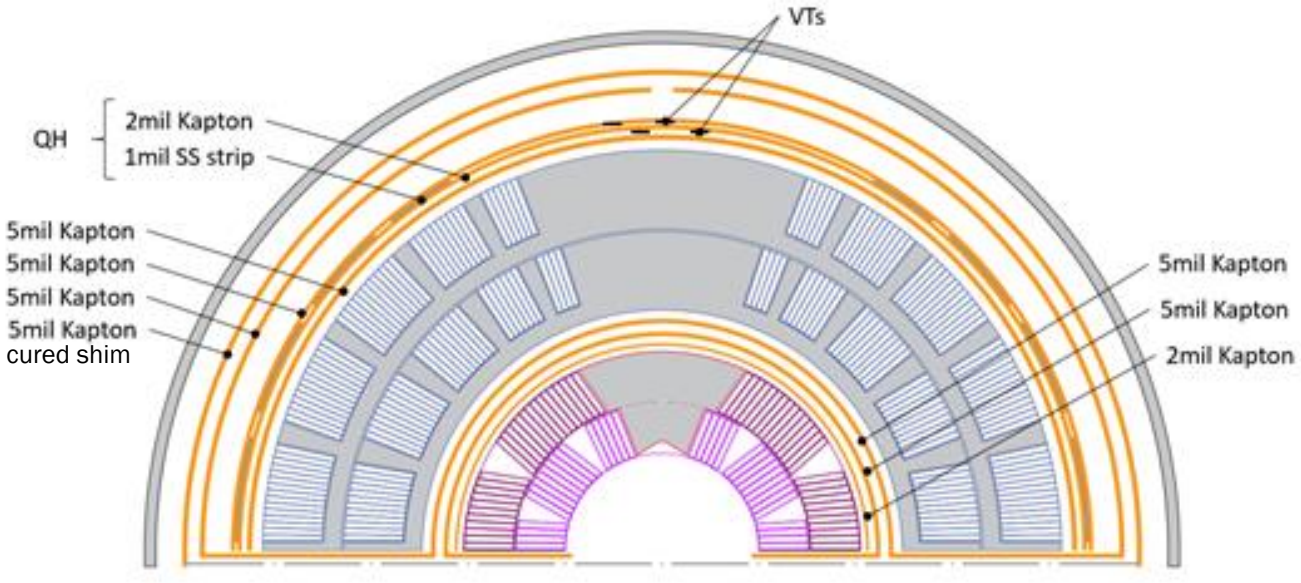
FJ test result

- MP and OD shims were casted using real iron laminations under small press pressure
- Shim plan for the mirror had been finalized after FJ paper test.

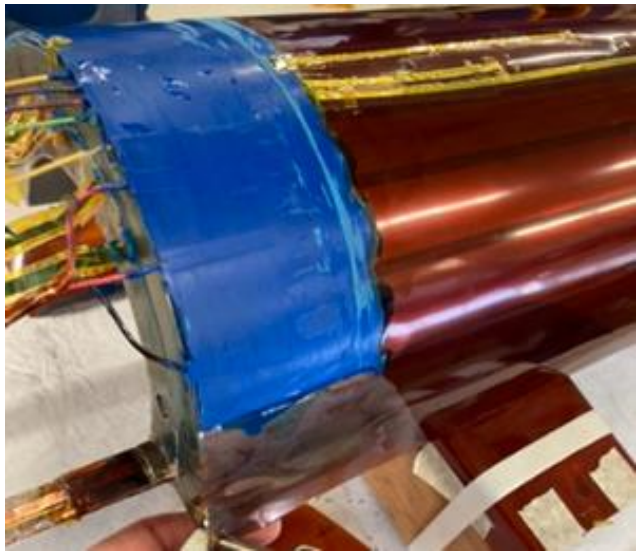
Coil instrumentation and insulation



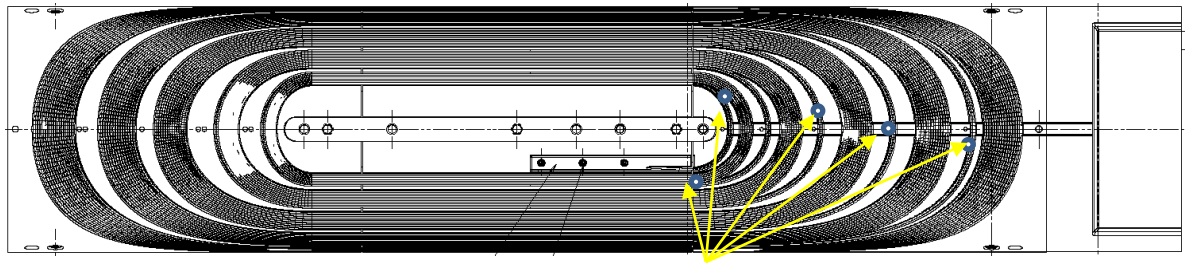
VT's foil strips on coil OD



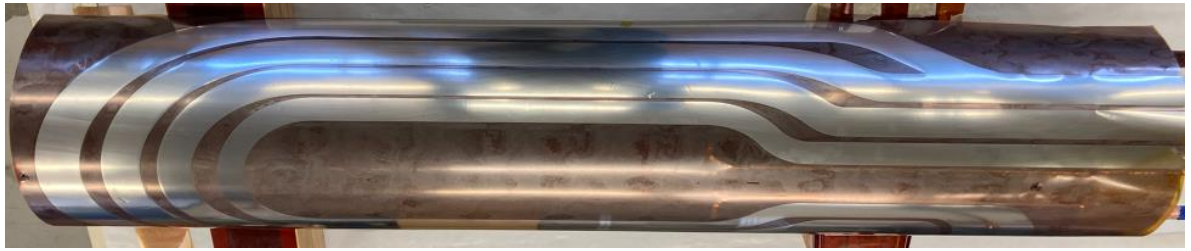
Coil ground insulation and instrumentation schematic



Coil terminals with stycast filler

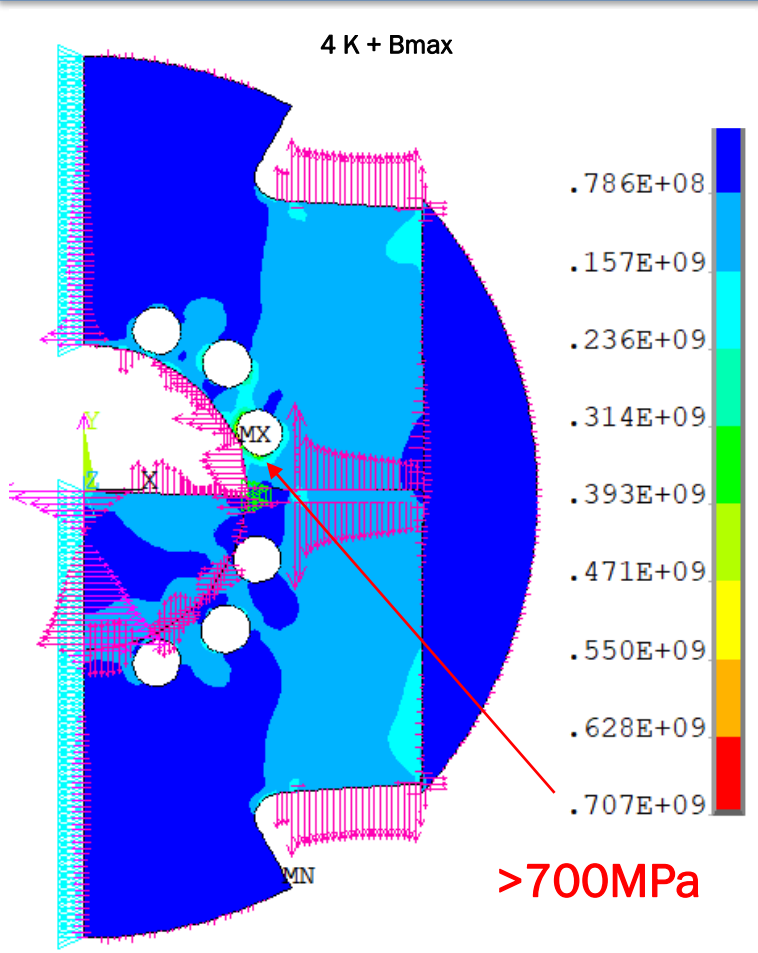


Schematic of VT's positioning



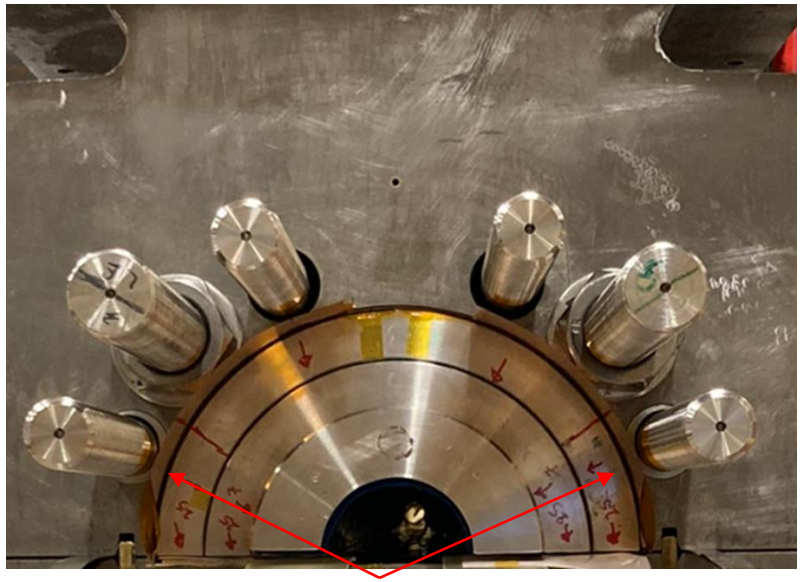
Protection heater for SMCT coil covers 4 largest cable blocks

Mechanical analysis – yoke lamination

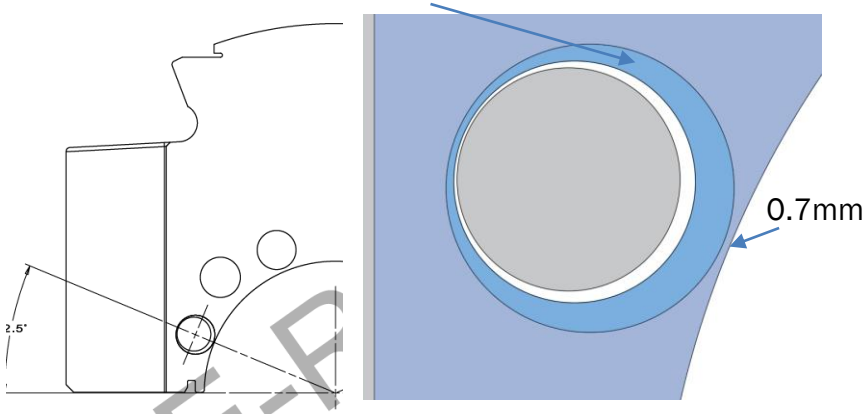


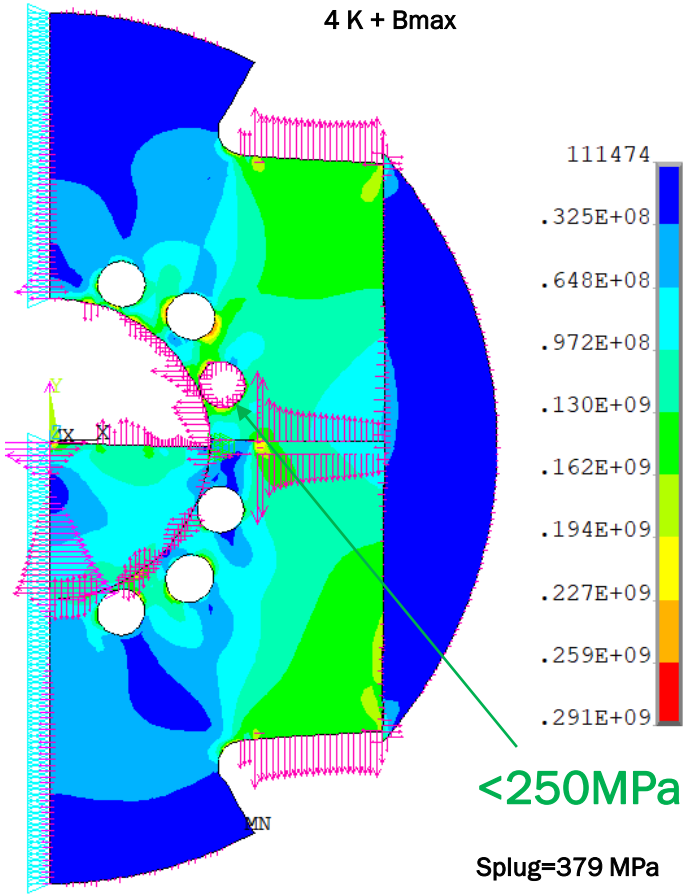
>700MPa

Stresses in iron lamination



Steel plugs for two holes



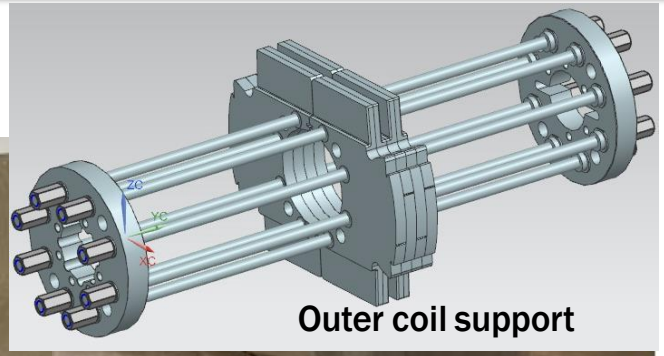


<250MPa

Splug=379 MPa

Stresses in iron lamination with steel plug will decrease by ~2.5 times

Block of iron yoke laminations



Steel plugs for two holes in laminations

Steel bushings for rods anchoring to support SMCT coil

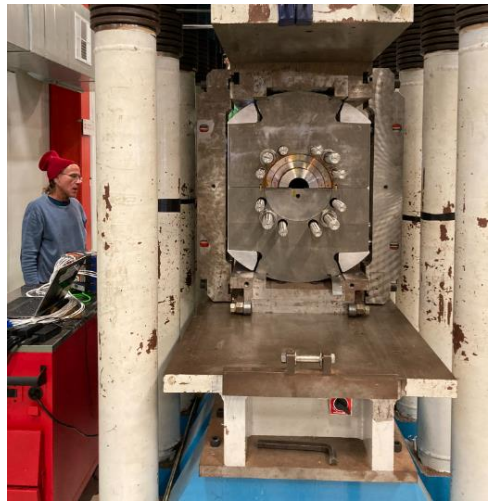
Coil block assembly and clamping

MP shimming

Electrical test before clamping

Yoke assembly

Mirror at press table

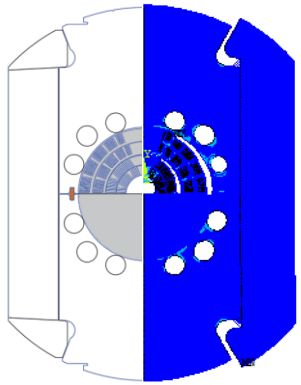


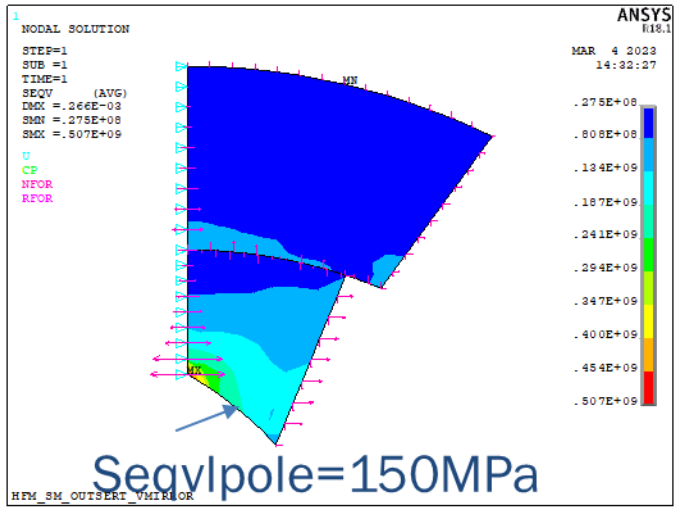
Clamping press

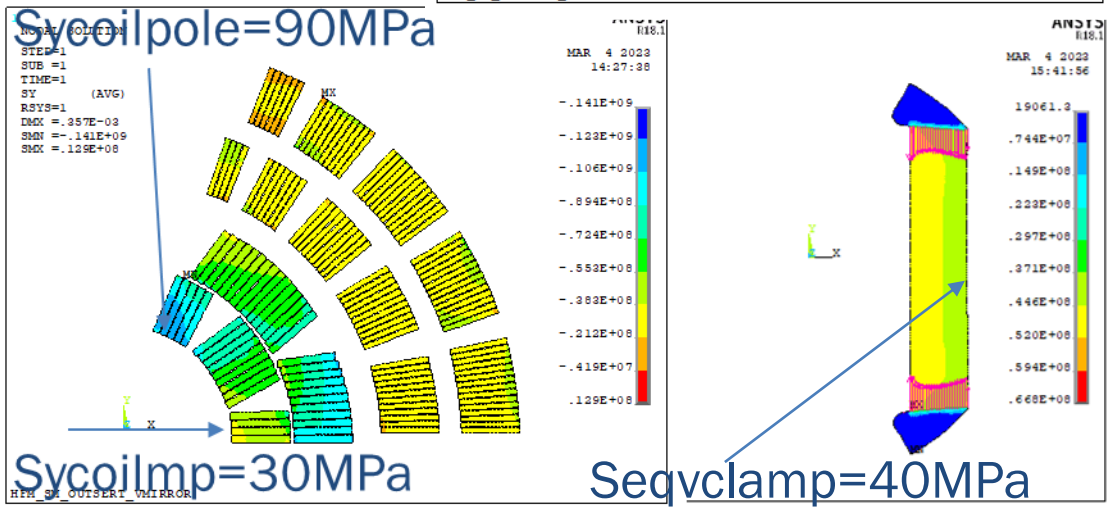
- Clamping was done under vertical and side pressure.
- The inner coil gauges are monitoring the process
- SG's data were compared with FEA prediction
- Final mirror magnet prestress will be reevaluated after skin welding

Two side views of the clamped iron

Mirror clamping – inner coil SG data

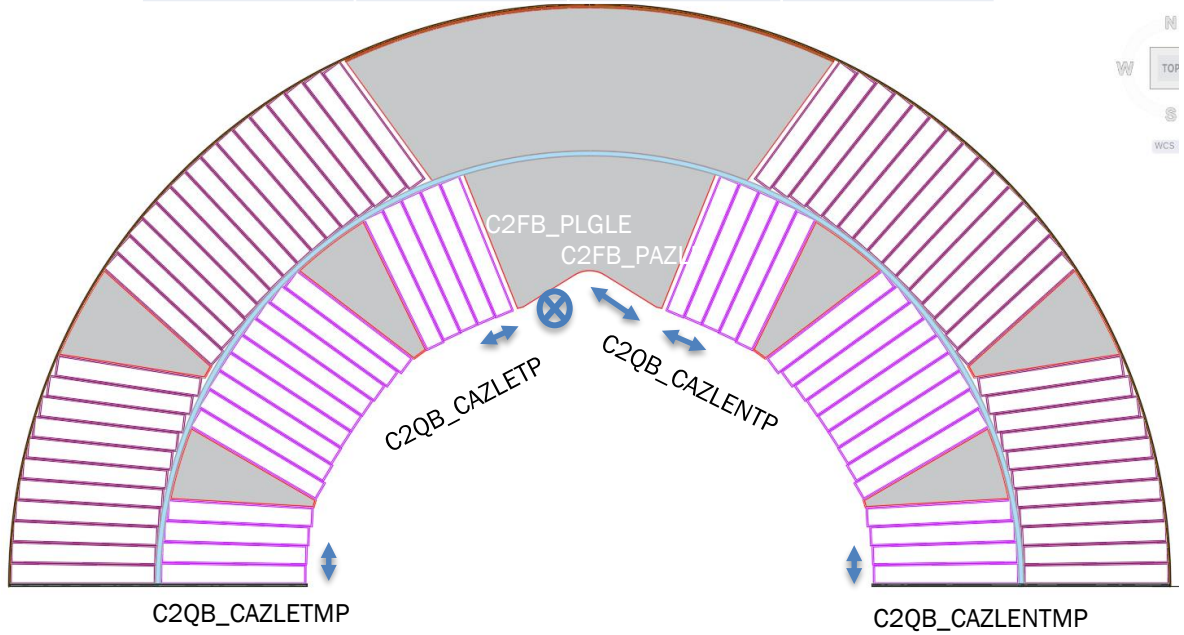






Avr. Stress after clamping in MPa

	FEA	LE	RE
Coil Pole	-90	-40	-85
Coil MP	-30	-45	-35
Pole AZ	-150	-147	-45
Clamps	-40		-42



Mirror skin welding

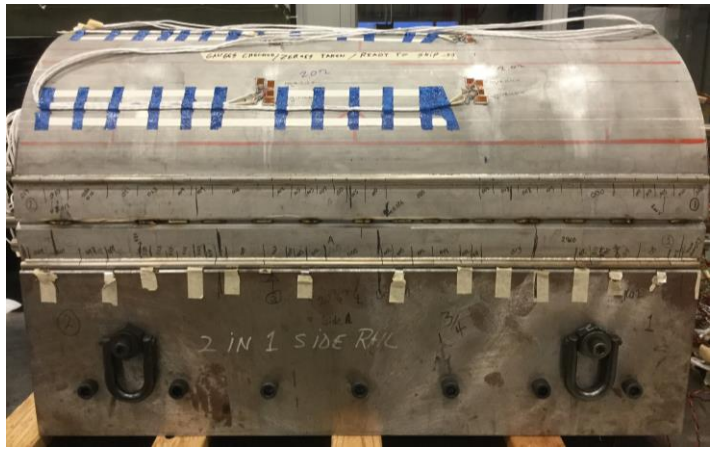
The clamped mirror in the bottom shell

The mirror in the contact tooling for welding

The stich welding under press load

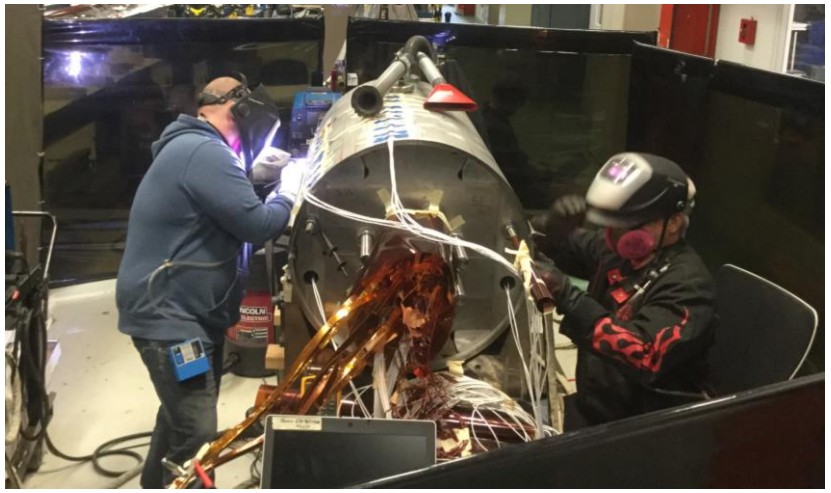
Iron filler insertion

The welding contact tooling in the press



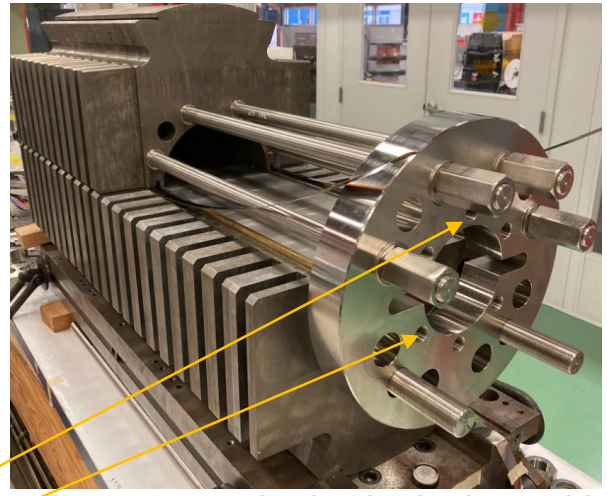
The skin after stich welding in the press

Next steps

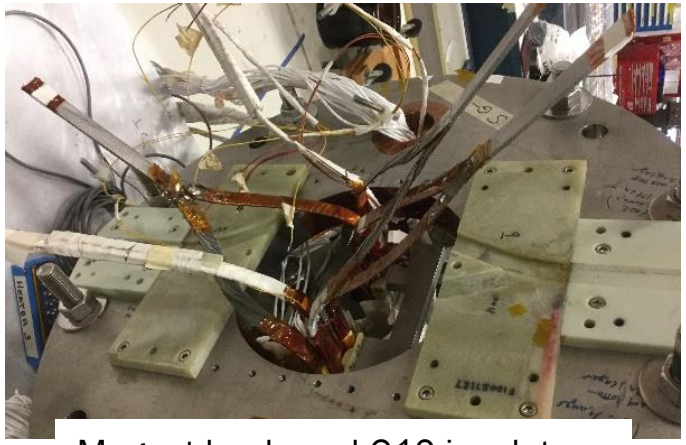


Skin filling-welds

Inner coil support anchored to the iron ends



Outer coil support anchoring in the iron middle

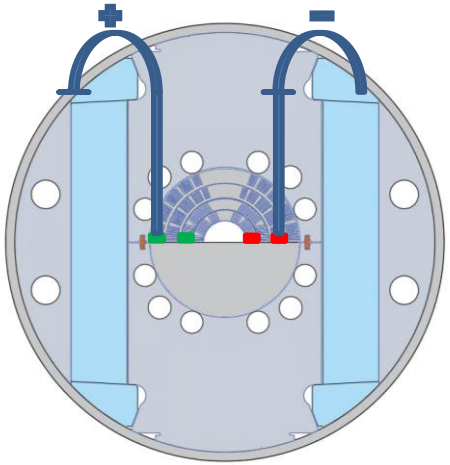


Magnet leads and G10 insulators

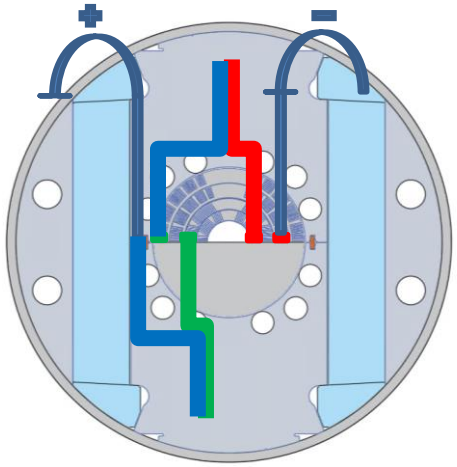
- Skin filling-welds
- End plates installation and (10-in/14-out) bullets loading
- VTs and SGs connectors
- Leads splicing
- Final electrical

View of the completed magnet with skin SGs

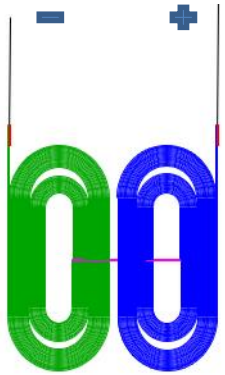
Leads connections for two tests

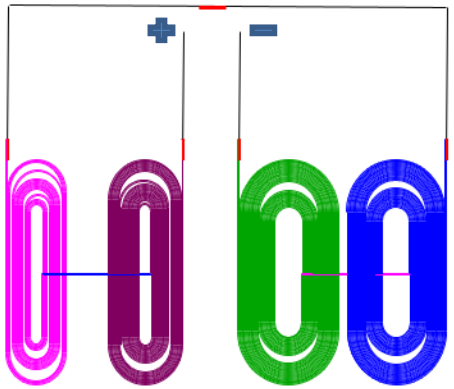


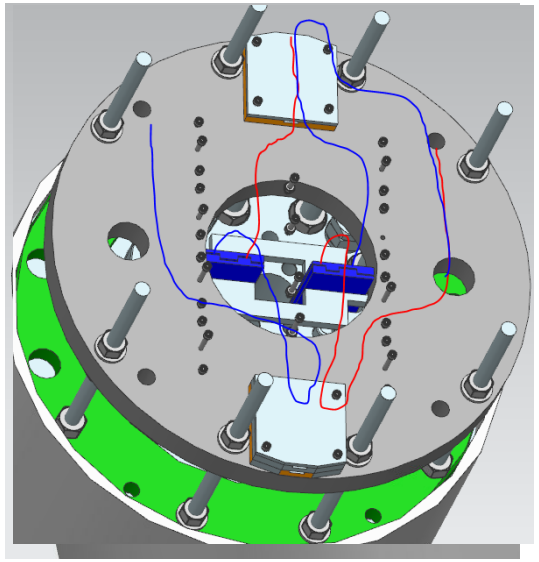
Test 1:
Only SMCT (outer) coil powered



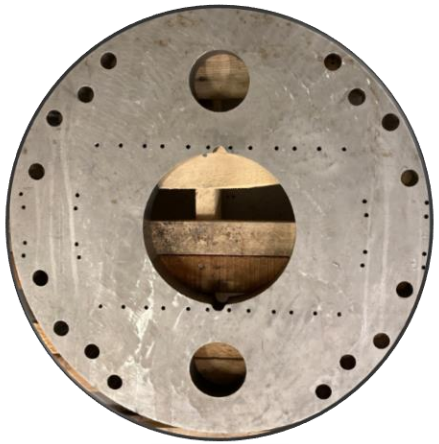
Test 2:
15T inner and SMCT (outer) coils powered

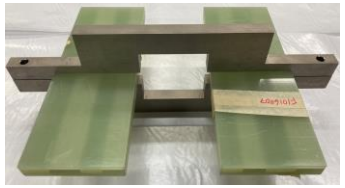


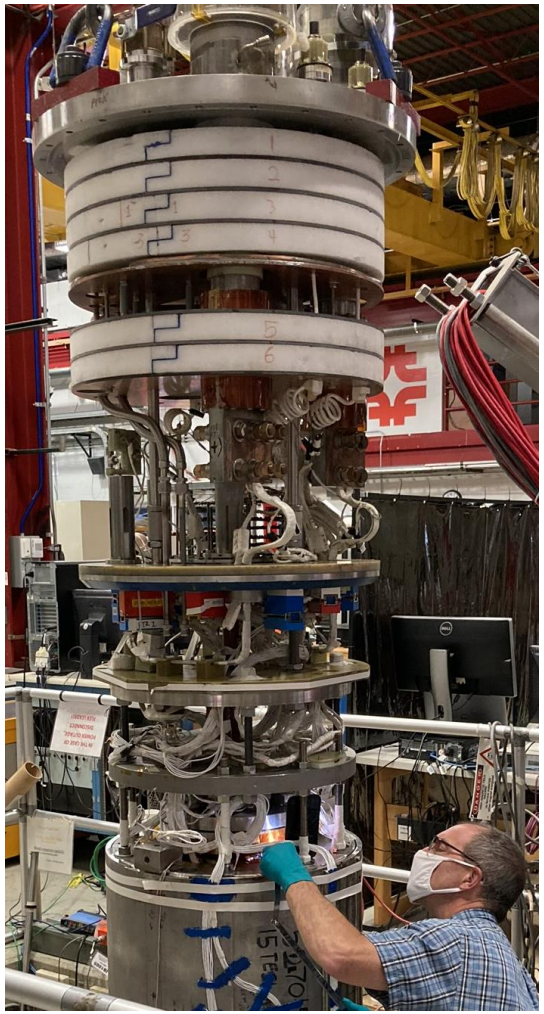




Modified “pizza box” and parts for the leads







Working space for the leads reconnection

Summary

- SMCT concept R&D is a key part of the updated MDP plan
- Even with limited resources (techs) the task is progressing towards the goal
  - 2D magnetic and mechanical analysis for 2L and 4L Mirror with SMCT coil is complete
  - MDPCT1 structure for the SMCT 4L Mirror and 4L Dipole has been modified and procured
  - SMCT coil fabrication and instrumentation is complete
  - Mirror magnet assembly is at the skin welding stage
- Next steps
  - Finishing the mirror magnet assembly and magnet test
  - SMCT mirror magnetic and mechanical analysis update for the real case

Acknowledgment

Thank to Vadim Kashikhin for the magnetic optimization of the coil cross-section, Jodi Coghill for the design work, Carry Lawless for the parts procurement, Emanuela Barzi and Daniele Turrioni for the cable characterization and coil reaction, Allen Rusy and James Karambis for the technical support of this work.

This work was supported by Fermi Research Alliance, LLC, under contract No. DE-AC02-07CH11359 with the U.S. Department of Energy and the US-MDP.