U.S. MAGNET DEVELOPMENT PROGRAM

SMCT mirror magnet update

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U.S. MDP Meeting

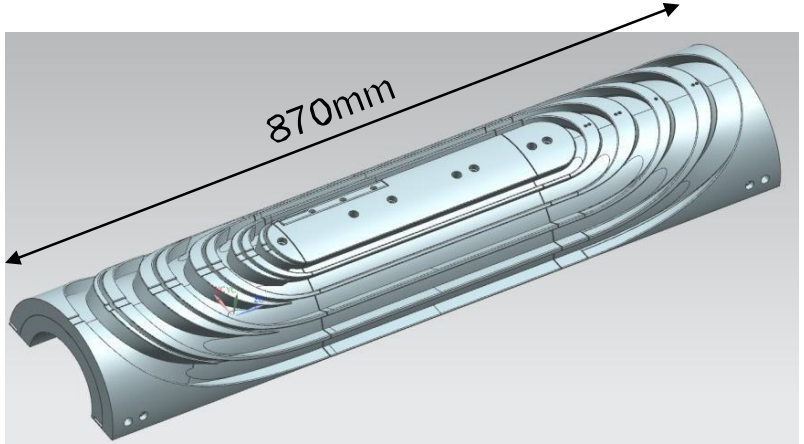
5/10/2023

4-layer mirror magnet with SMCT coil

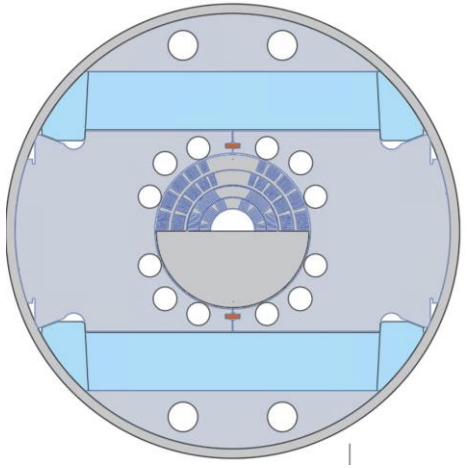
Nb_3Sn Rutherford cable - 145m

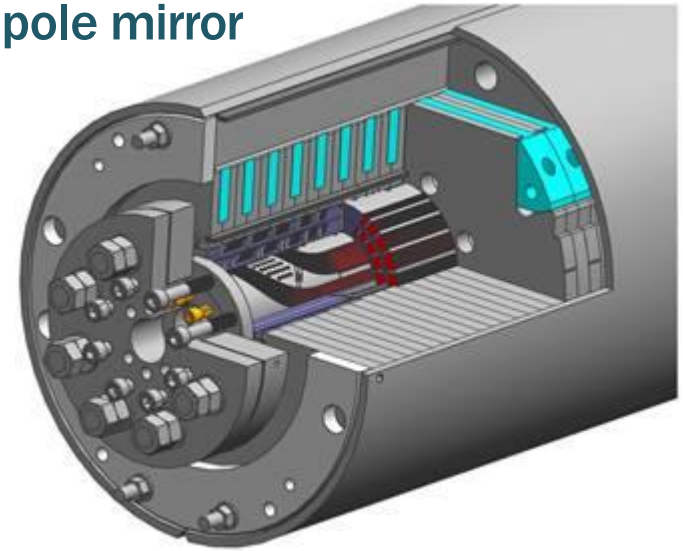
reacted dimensions: 15.1x1.319 mm
Jc(12T, 4.2K)=2650A/mm^2

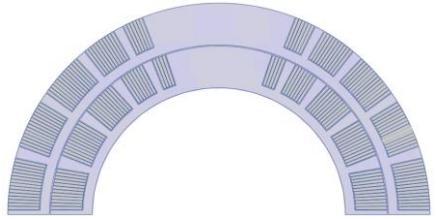
Stress management for whole coil using stainless steel 3D printed mandrels



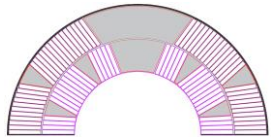
Cos-theta dipole mirror







New SMCT coil ID=120 mm



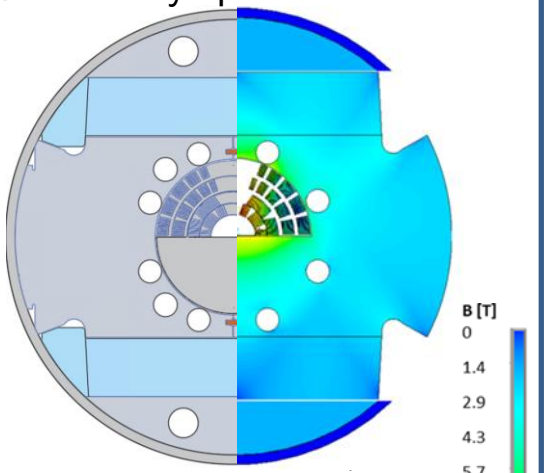
Inner coil for 15T dipole ID=60 mm

Modified MDPCT1 structure

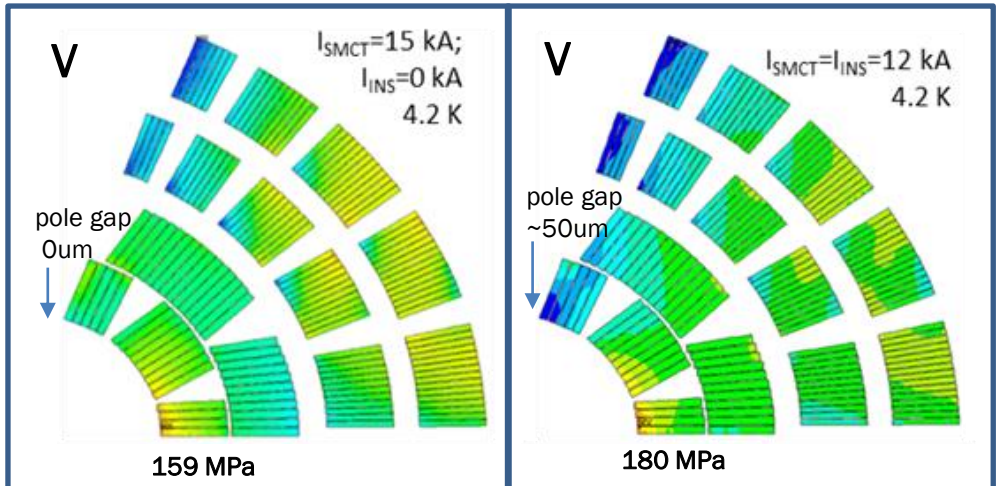
- Cold mass OD=610 mm
- 12.5 mm thick SS shell
- Aluminum I-clamps

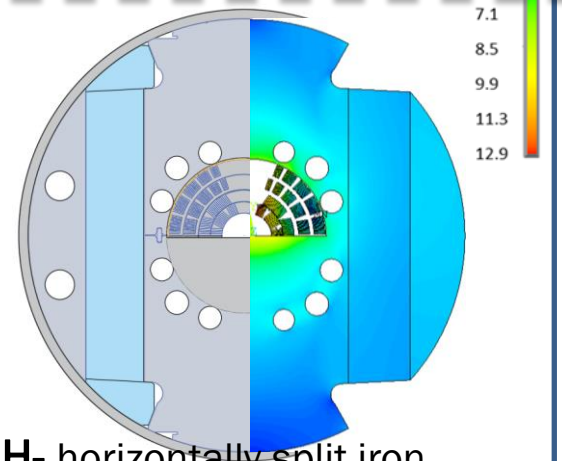
Mirror magnet magnetic and mechanical analysis

V-vertically split iron

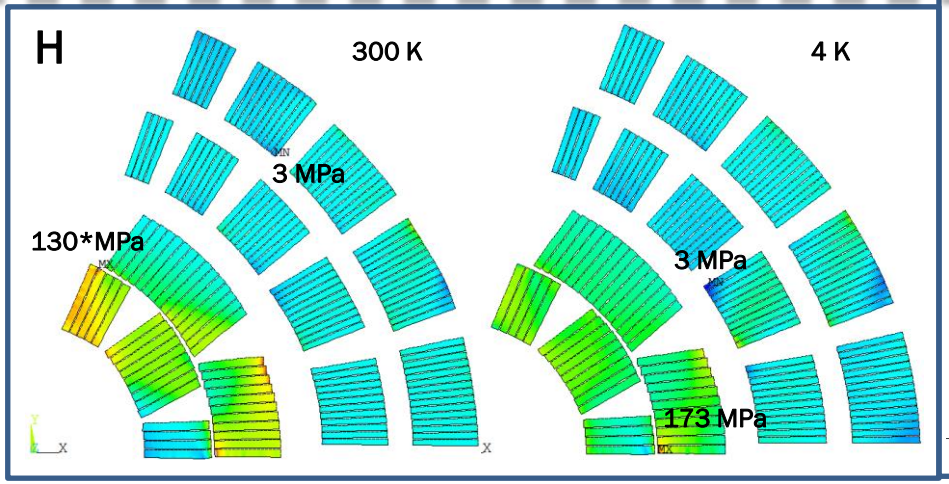


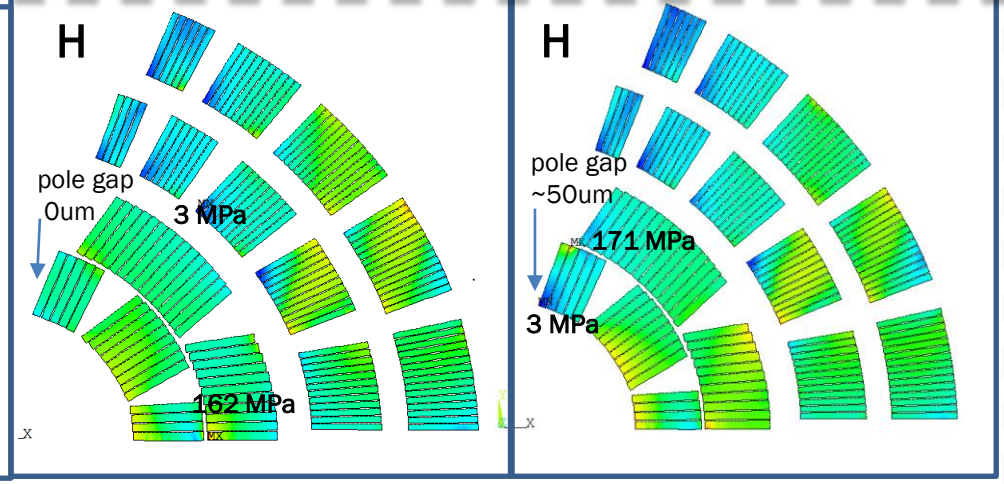
- Two versions of iron configuration
- Two electromagnetic loads: for 2-layer/4-layer
- 4-layer case has 35% higher EM load
- H and V cases are almost identical for the coil stress distribution for two loads
- Coil loading with 130MPa (max) at 300K leads to 170-180MPa at max current of 12kA for 4-layer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



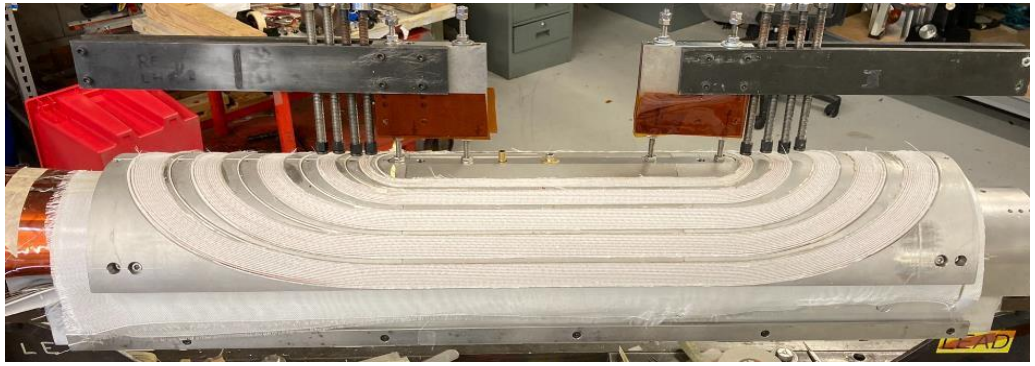


H- horizontally split iron

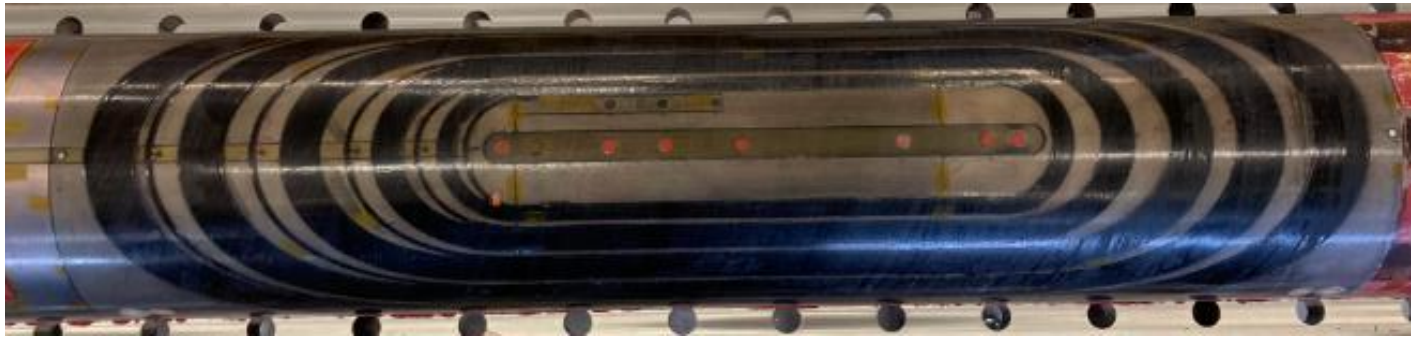




SMCT coil

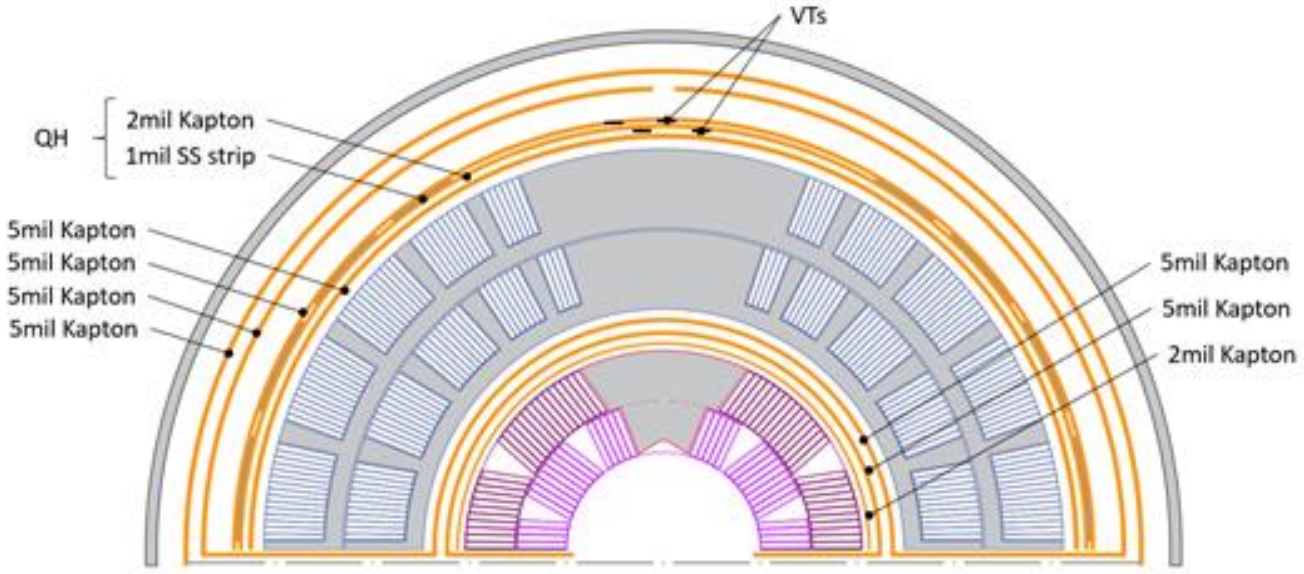


Completed outer layer (L2) winding



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

SMCT coil after reaction.



Coil ground insulation and instrumentation schematic

Coil block assembly and clamping

MP shimming

Electrical test before clamping

Yoke assembly

Mirror at press table

Clamping press

- Iron lams with aluminum clamps formed a coil pre-compressed cylindrical cavity
- Iron clamping was done under vertical and side pressure.
- Inner coil gauges monitor the process
- SG's data compared with FEA prediction
- The electrical insulation is constantly checked at all stages of the assembly process.

Two side views of the clamped iron

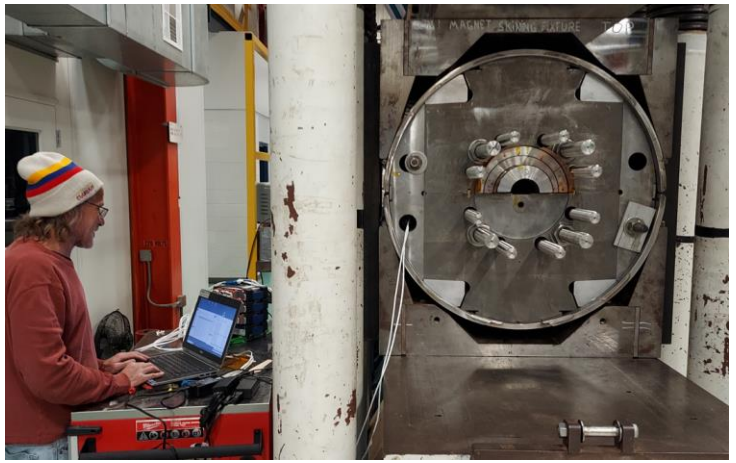
Mirror cold mass assembly

The clamped mirror in the bottom shell

Iron filler insertion

- Clamped iron positioned in the bottom half-shell.
- The fillers inserted from both sides to form round-shape iron.
- Top half-shell and the contact tooling cover entire iron assembly.
- The tooling placed into the vertical press for welding
- Inner coil and skin strain gauges monitor the process

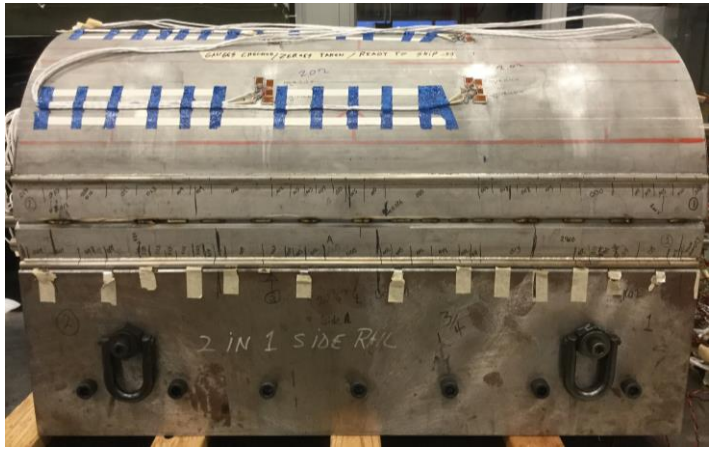
The mirror in the contact tooling for welding



The welding contact tooling in the press

Mirror skin welding

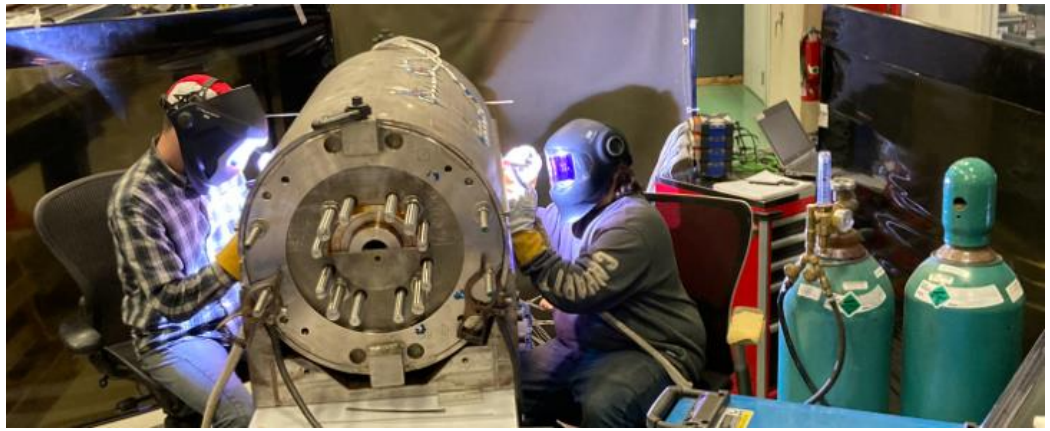
The stich welding under press load



The skin after stich welding in the press

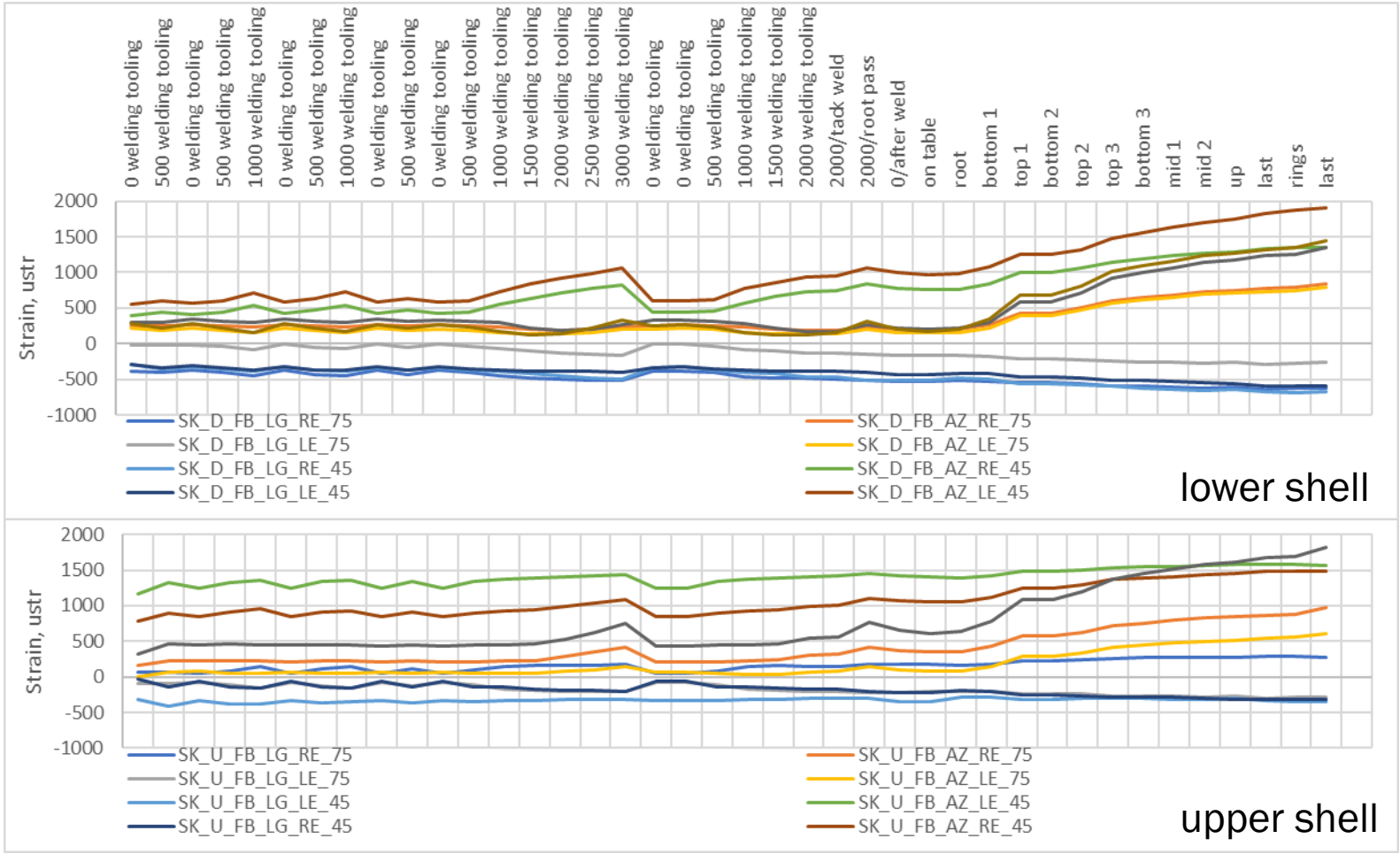
We are using the same stainless-steel skin for the 3d time!

- The welded stainless-steel shell finalized the coil assembly prestress
- The half-shells stich welded in the contact tooling under vertical pressure
- Final filling welds perform from both side simultaneously.
- Two end rings welded to the shell to form a stainless-steel casing for the iron
- Inner coil gauges and skin gauges monitor the process



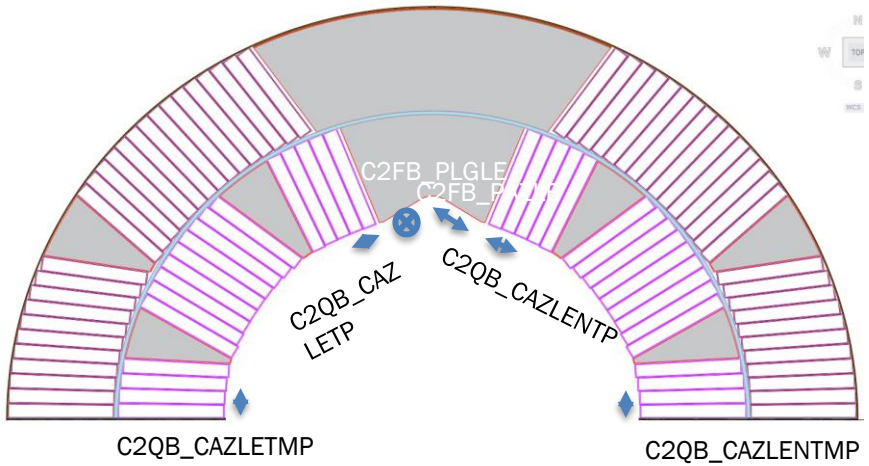
Two new welders perform the skin filling-welds on both sides simultaneously

SG data for the welding process



Avr. Inner coil stress after skin welding in MPa

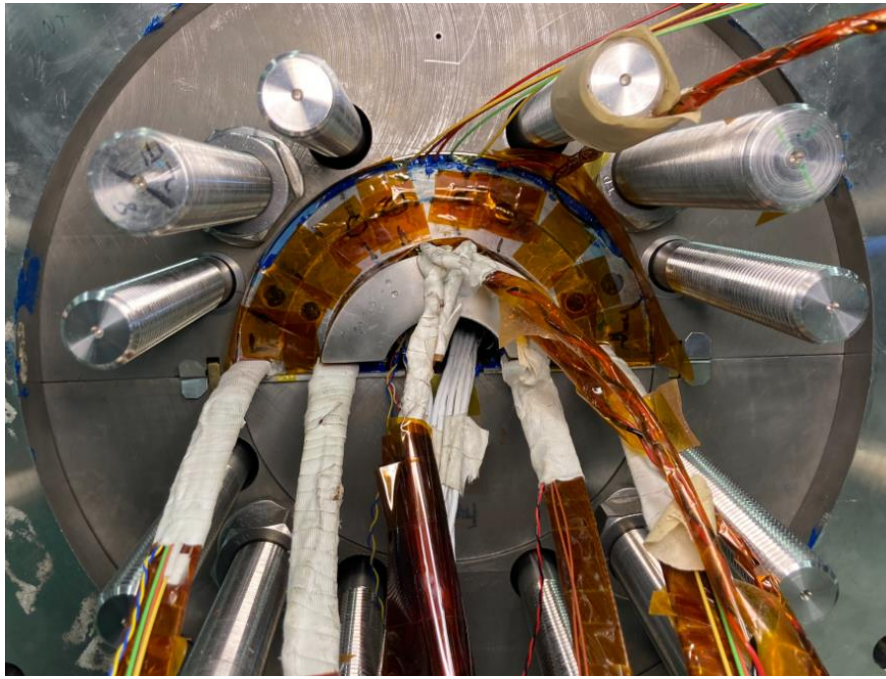
	FEA	LE	RE
Coil Pole	-100	-47	-93
Coil MP	-50	-60	-50
Pole AZ	-170	-165	-40



LE wiring and insulation work

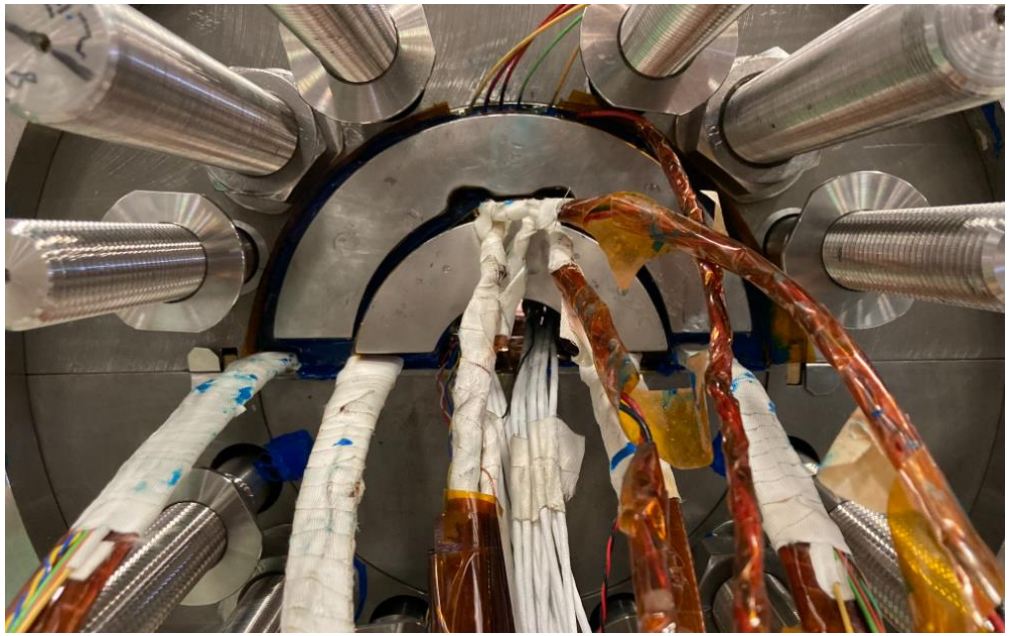
Magnet leads with VTs

- Surface preparation before gluing the SMCT coil pusher plate on the LE
- All VTs on the inner layer of the SMCT coil were lost during coil production
- As a preventive measure, the SMCT coil was insulated from ground and checked with a 1kV Hi Pot test before and after end loading

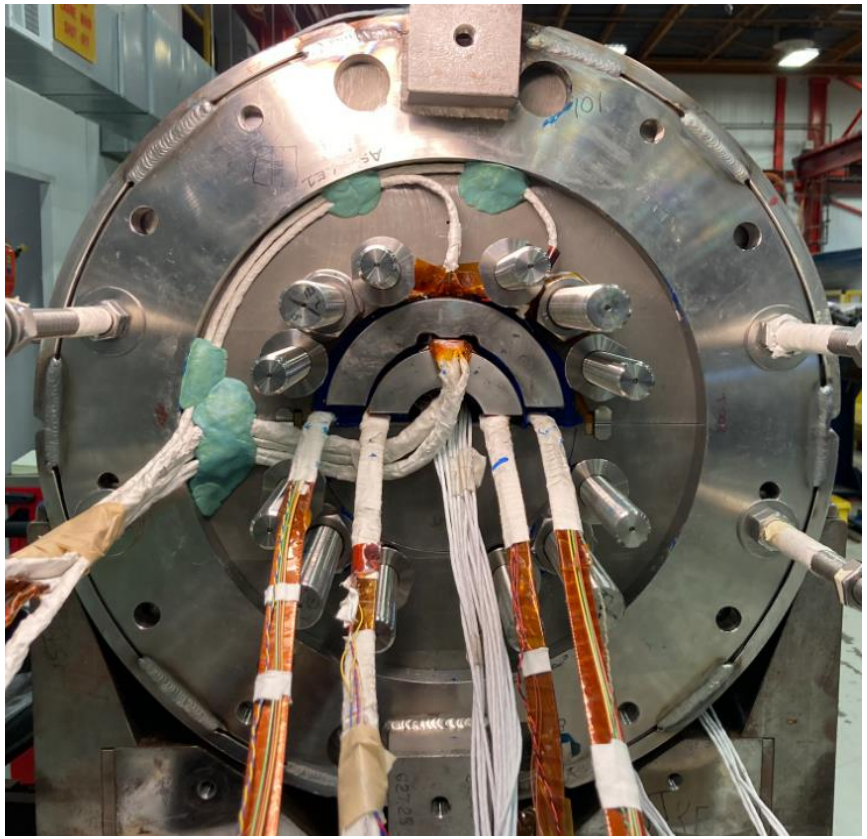


SMCT coil inter-layer insulation on LE

LE pusher plates and wire bundling

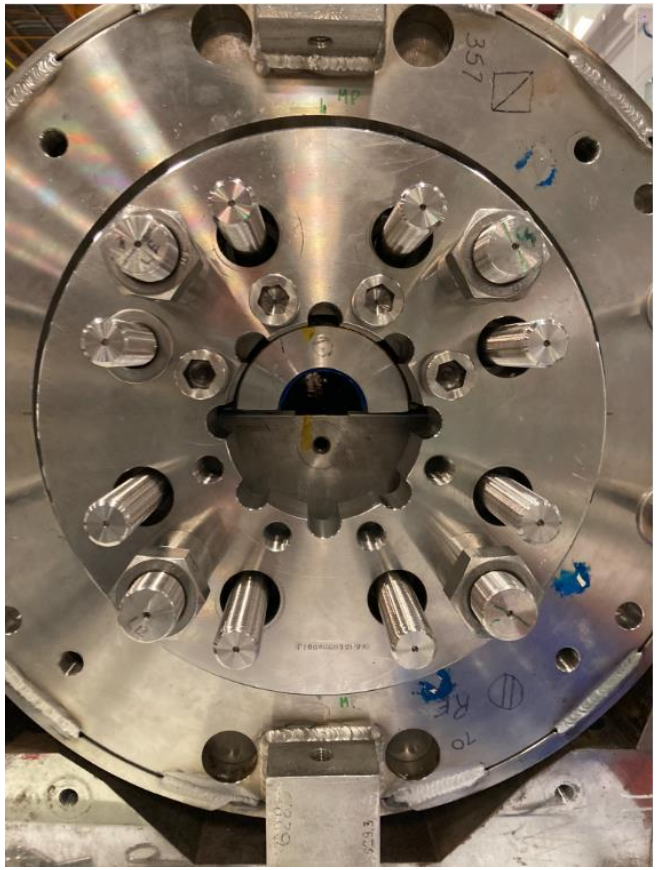


Installed pusher plates on the magnet LE

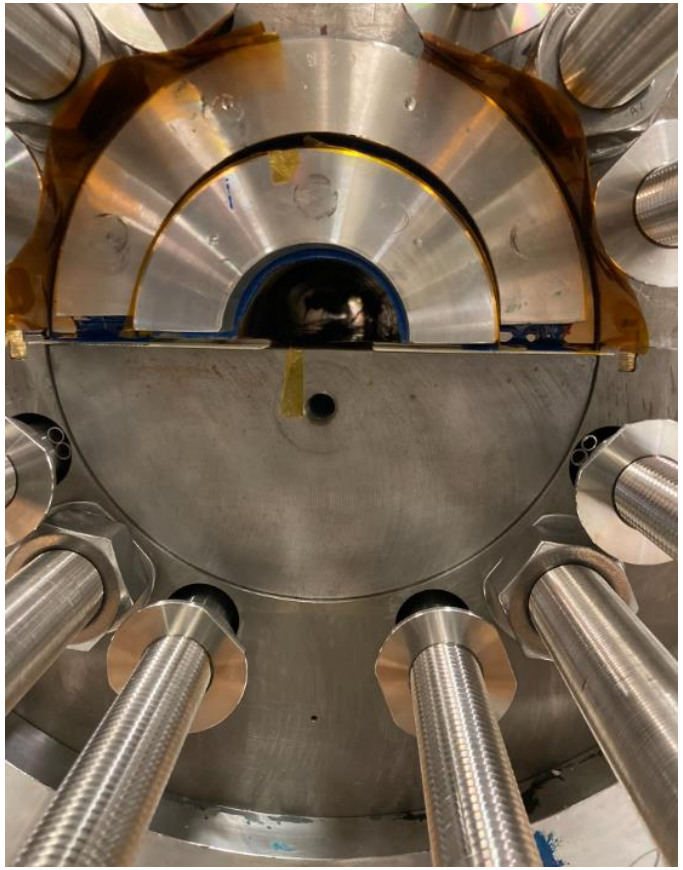


Wire bundles layout on the magnet LE

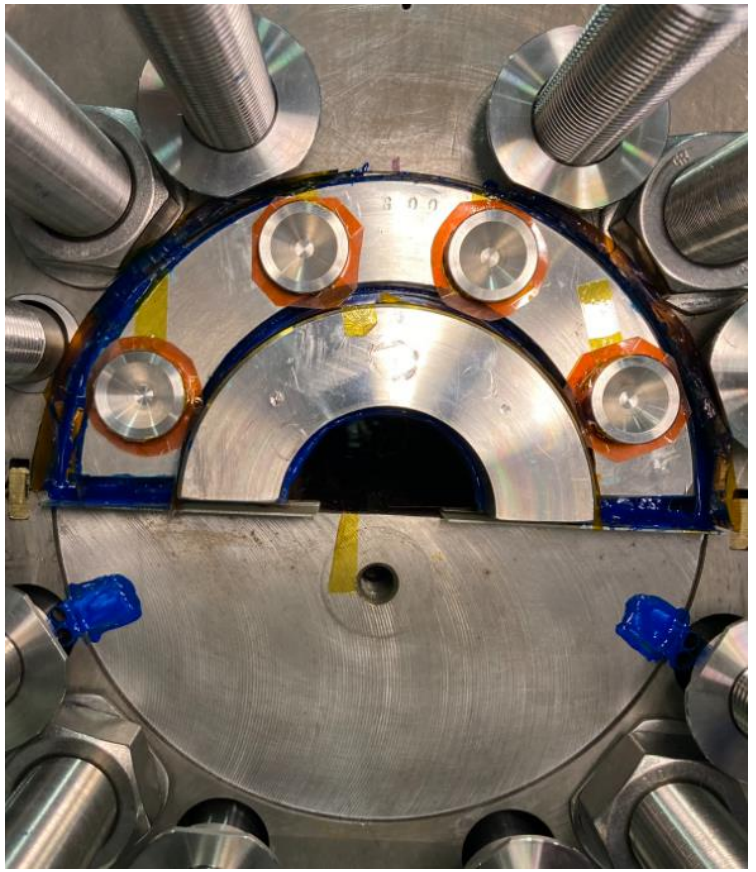
RE pusher plates



Gluing SMCT coil pusher plate at the RE



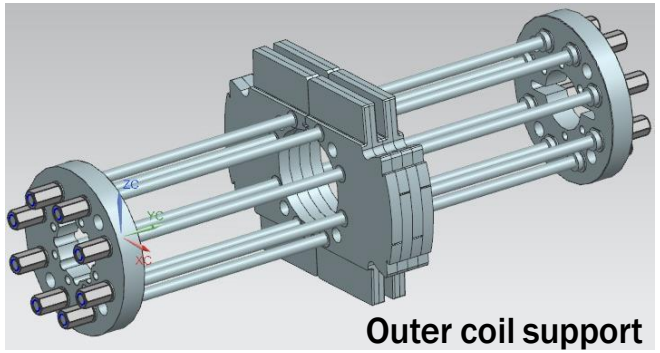
Installed pusher plates at the RE



Bullet's saddles at the RE

End plates for SMCT coil

The RE end plate for the SMCT coil

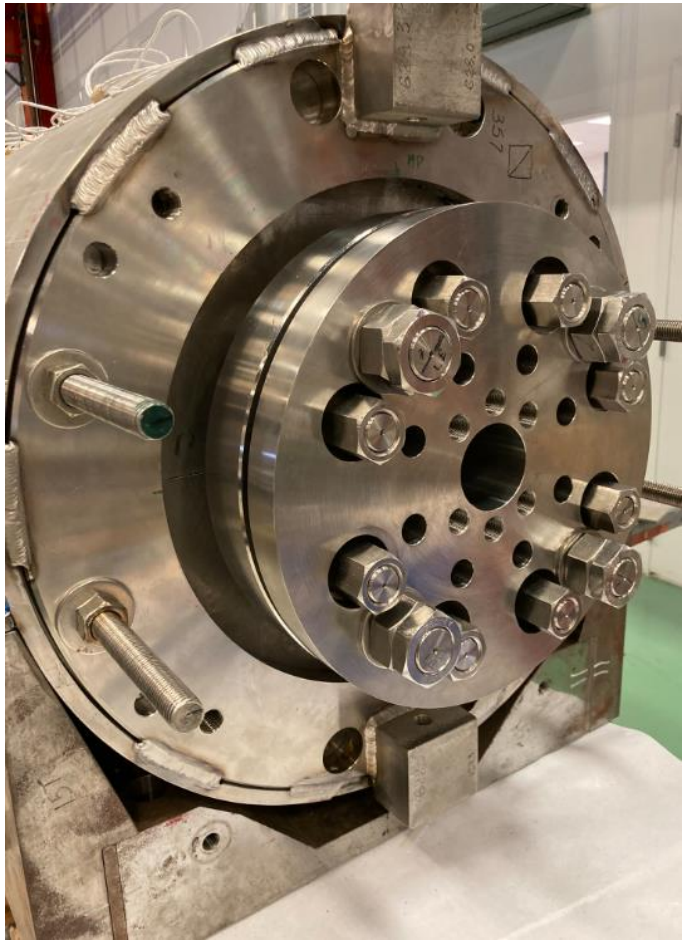


Outer coil support

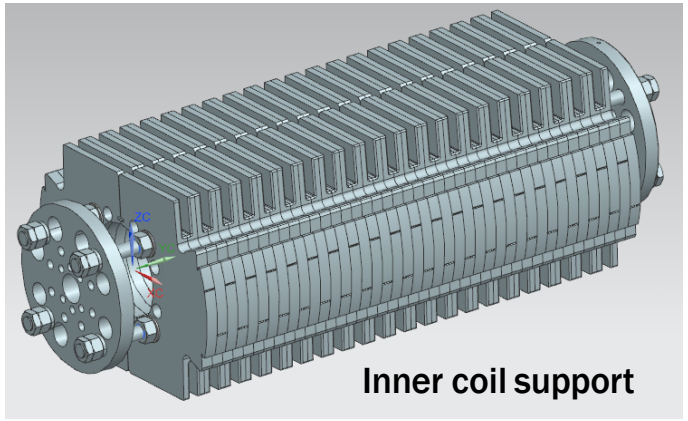
- Modified SMCT (outer) coil end support
- 8xØ24mm rods with the middle anchors
- 50mm-thick end plates with instrumented bullets

The LE end plate for the SMCT coil

End plates for inner coil



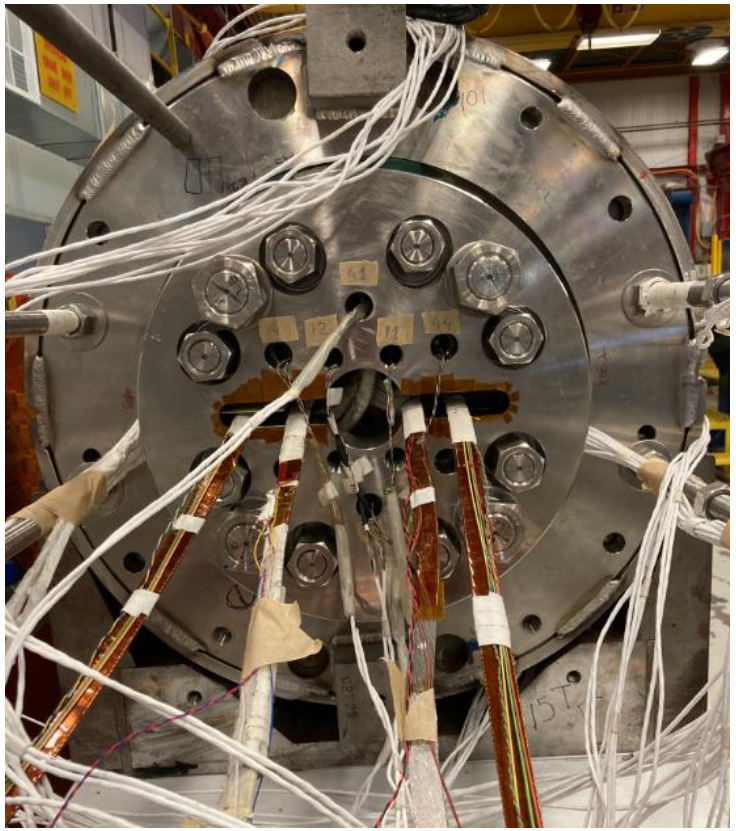
The RE end plate for the inner coil



- Unmodified inner coil end support
- 4xØ30mm rods with the iron-end anchors
- 35-50mm-thick end plates with instrumented bullets

The LE end plate for the inner coil

Bullets loading

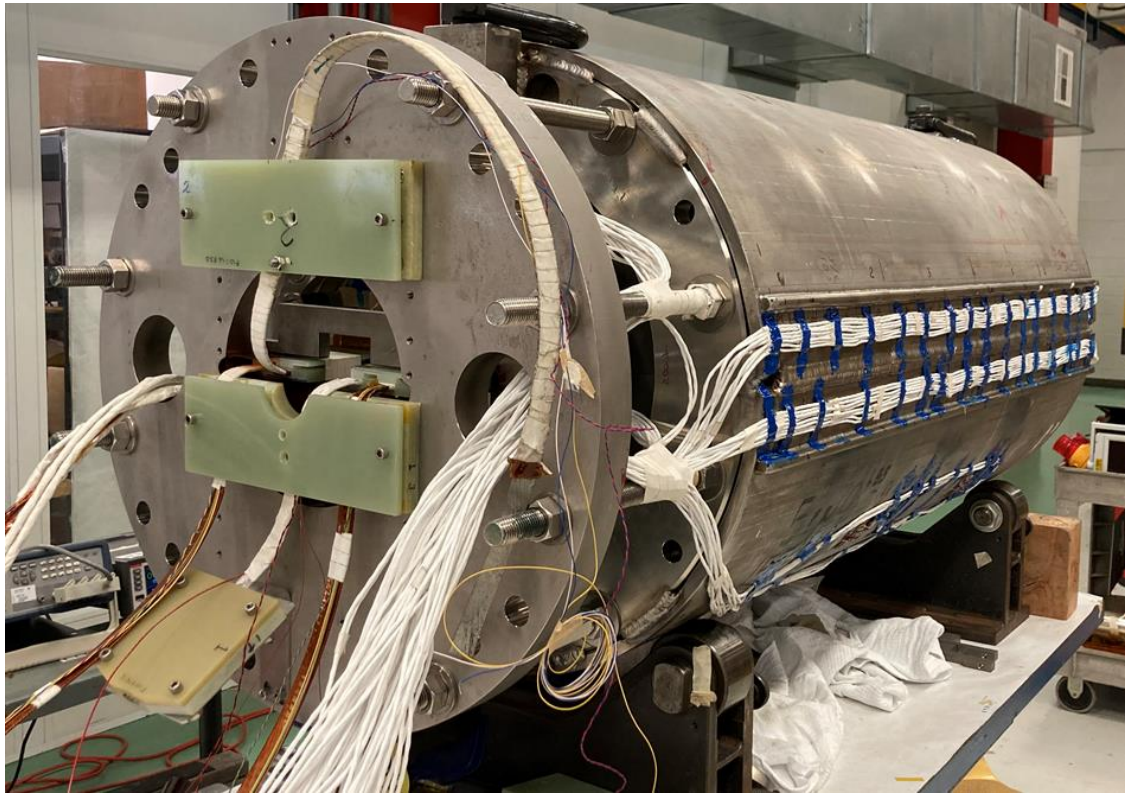


Bullet's location at the LE

- The inner coil bullets provide a coil support at 4K and torque to the same load as in 15T magnet
- The SMCT coil bullets have the same purpose – “cold contact” and torque to smaller load

Bullet’s location at the RE

Supporting plate, coil leads, VT and SG wires are ready for hypertonic connectors



Magnet LE view

Magnet RE view

U.S. MAGNET DEVELOPMENT PROGRAM

Final electrical check for the mirror magnet

MAGNET NAME:

IB3/IB1 CVT CHECKOUT FORM

IB3 Apply 1A Current between LEAD+ AND LEAD-

1B1 Apply 10A Current between LEAD+ AND LEAD-

Measurements of Voltage between LEAD- and VTAP

IB3 James Karambis 5/9/2023

IB1 Inspector(s): Date:

IB1-Data IB3-Data

VOLTAGE DROP (mV) or RESISTANCE	Label of Instr.Tree Connector	Pin	DAQ Wire Label	MAGNET WIRE LABEL	LAMBDA PLATE CONNECTOR(S)	Module	Pin	Breakbox LABEL [CVT]	VOLTAGE DROP IN (mV)	Distance from Positive Leads to Vtap	Expected Voltage, mV	Measured V /Expected V, %
	CVT 001/008	A	CVT001	VTSM1C01	VT-1	F2	1	001/036	.001356			#REF!
		B	CVT002	VTSM1C02		F2	2	002/037	.001627			#REF!
		C	CVT003	VTSM1C03		F2	3	003/038	n/a			#REF!
		D	CVT004	VTSM1C04		F2	4	004/039	n/a			#REF!
		E	CVT005	VTSM1C05		F2	5	005/040	n/a			#REF!
		F	CVT006	VTSM1C06		F3	5	006/041	n/a			#REF!
		G	CVT007	VTSM1D07		F3	4	007/042	.133060			#REF!
		H	CVT008	VTSM1D06		F3	3	008/043	.13950			#REF!
	CVT 009/016	A	CVT009	VTSM1D05		F3	2	009/044	.162725			#REF!
		B	CVT010	VTSM1D04		F3	1	010/045	.199390			#REF!
		C	CVT011	VTSM1D03		F4	1	011/046	.246501			#REF!
		D	CVT012	VTSM1D02		F4	2	012/047	.305222			#REF!
		E	CVT013	VTSM1D01		F4	3	013/048	.306023			#REF!
		F	CVT014	VT03A01		F4	4	014/049	.000486			#REF!
		G	CVT015	VT03A02		F4	5	015/050	.000501			#REF!
		H	CVT016	VT03A03		F5	5	016/051	.009506			#REF!
	CVT 017/024	A	CVT017	VT03A04		F5	4	017/052	0.033364			#REF!
		B	CVT018	VT03A05		F5	3	018/053	0.045028			#REF!
		C	CVT019	VT03A06		F5	2	019/054	0.04141			#REF!
		D	CVT020	VT03A07		F5	1	020/055	0.045028			#REF!
		E	CVT021	VT03A08		F6	1	021/056	0.046702			#REF!
		F	CVT022	VT03A09		F6	2	022/057	0.046801			#REF!
		G	CVT023	VT03B08		F6	3	023/058	0.046702			#REF!
		H	CVT024	VT03B07		F6	4	024/059	0.04688			#REF!
	CVT 025/032	A	CVT025	VT03B06		F6	5	025/060				#REF!
		B	CVT026	VT03B05		F7	5	026/061	0.048037			#REF!
		C	CVT027	VT03B04		F7	4	027/062	0.0797			#REF!
		D	CVT028	VT03B03		F7	3	028/063	0.082932			#REF!
		E	CVT029	VT03B02		F7	2	029/064				#REF!
		F	CVT030	VT03B01		F7	1	30	0.12544			#REF!
		G	CVT031			F8	1	31				#REF!
		H	CVT032			F8	2	32				#REF!
		A	CVT033			F8	3	33				#REF!
		B	CVT034			F8	4	34				#REF!

FVT(30kA) | CVT(1-64) | CVT(65-128) | RTDs | STRIP HEATERS(30kA) | STRAIN GAUGES(30kA)

IB3/IB1 STRIP HEATERS CHECKOUT FORM FOR 30kA TOP PLATE

IB3 Inspector(s): James Karambis Date:5/9/2023

IB1 Inspector(s):

HEATER	IB3 WARM HEATER RESISTANCE Ω (2-WIRE)	IB3 WARM HEATER RESISTANCE TO GROUND Ω (2 WIRE)	30kA INSTRUMENTATION TREE CONNECTOR(S)	PIN	DAQ WIRE LABEL		MAGNET WIRE LABEL	MOI
SH1	G2-5-MID	4.446	(ON TOP-HAT) PWR-STRIPH-1/2	1	PWR-STRIPH 1 (+)	I+	B01	F
				2	PWR-STRIPH 1 (-)	I-	B04	F
			(ON TOP-HAT) FVT STRIPH 1-4	A	FVT STRIPH 1 (+)	V+		F
				B	FVT STRIPH 1 (-)	V-		F
SH2	G3-4-MID	3.872	(ON TOP-HAT) PWR-STRIPH-1/2	3	PWR-STRIPH 1 (+)	I+	B02	F
				4	PWR-STRIPH 1 (-)	I-	B03	F
			(ON TOP-HAT) FVT STRIPH 1-4	C	FVT STRIPH 1 (+)	V+		F
				D	FVT STRIPH 1 (-)	V-		F
SH3	G2-5,G3-4 - MID	2.2681	(ON TOP-HAT) PWR-STRIPH-3/4	1	PWR-STRIPH 1 (+)	I+		F
				2	PWR-STRIPH 1 (-)	I-		F
			(ON TOP-HAT) FVT STRIPH 1-4	E	FVT STRIPH 1 (+)	V+		F
				F	FVT STRIPH 1 (-)	V-		F
SH4			(ON TOP-HAT) PWR-STRIPH-3/4	3	PWR-STRIPH 1 (+)	I+		F
				4	PWR-STRIPH 1 (-)	I-		F
			(ON TOP-HAT) FVT STRIPH 1-4	G	FVT STRIPH 1 (+)	V+		F
				H	FVT STRIPH 1 (-)	V-		F
SH5			(ON TOP-HAT) PWR-STRIPH-5/6	1	PWR-STRIPH 1 (+)	I+		F
				2	PWR-STRIPH 1 (-)	I-		F
			(ON TOP-HAT) FVT STRIPH 5-8	A	FVT STRIPH 1 (+)	V+		F
				B	FVT STRIPH 1 (-)	V-		F
SH6			(ON TOP-HAT) PWR-STRIPH-5/6	3	PWR-STRIPH 1 (+)	I+		F
				4	PWR-STRIPH 1 (-)	I-		F
			(ON TOP-HAT)	C	FVT STRIPH 1 (+)	V+		F

FVT(30kA) | CVT(1-64) | CVT(65-128) | RTDs | STRIP HEATERS(30kA) | STRAIN GAUGES(30kA)

IB3/IB1 SG CHECKOUT FORM

PERFORM 4-WIRE RESISTANCE MEASUEMENTS OF STRAIN GAUGES

IB3 Inspector(s): James Karambis Date: 5/9/2023

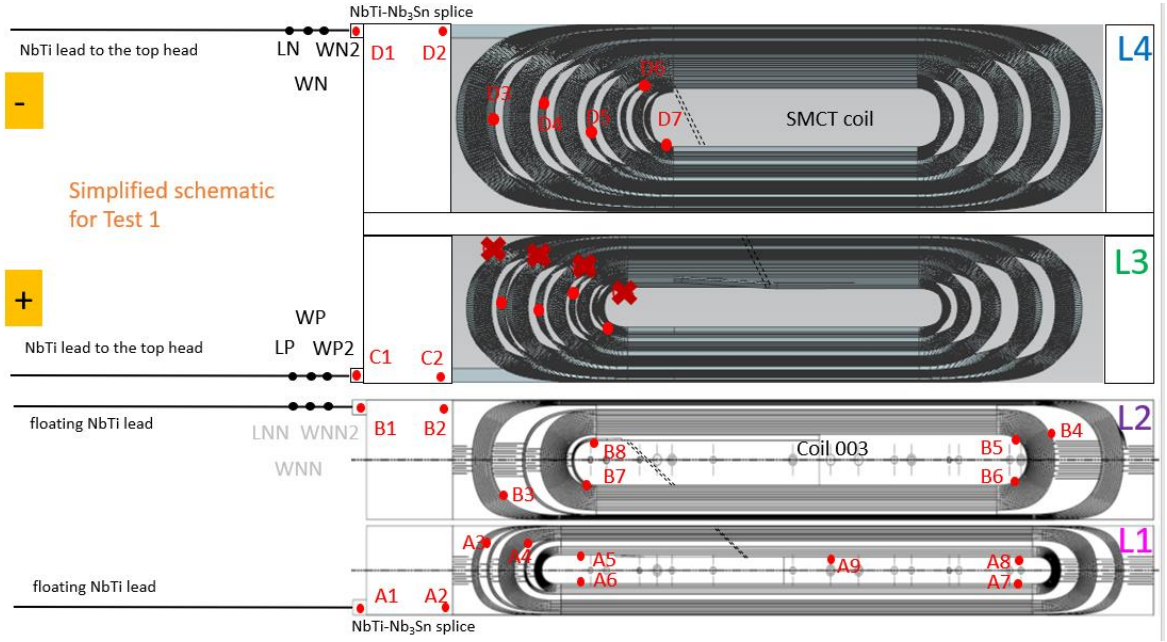
IB1 Inspector(s): Date:

IB3- READINGS R to Gad	R (OHM)	Inst. Tree connector	Pins (Form)	DAQ Wire Label	MAGNET WIRE LABEL	LAMBDA PLATE CONNECTOR	Module	PINS	Breakbox LABEL [SG]	IB1- READINGS R (OHM)	WIRE COLOR	R(IB3)/R (IB1), 100%	R to Gad
		SG 01/04	A-D	SG001	03_FB_P_LG_LE	SG-1	F9	12/13/14/15	#1f17733f49		R/B/G/Y	#DIV/0!	
			E-H	SG002	03_FB_P_AZ_LE		F9	16/17/11/10	#2f18234f56		R/B/G/Y	#DIV/0!	
			J-M	SG003	03_FB_P_LG_RE		F9	9/8/7/1	#3f19935f51		R/B/G/Y	#DIV/0!	
			N-S	SG004	03_FB_P_AZ_RE		F9	2/3/4/5	#4f20934f52		R/B/G/Y	#DIV/0!	
		SG 05/08	A-D	SG005	03_OB_C_AZ_LE_T_P		F8	12/13/14/15	#5f21f37f53		R/B/G/Y	#DIV/0!	
			E-H	SG006	03_OB_C_AZ_LE_T_MP		F8	16/17/11/10	#6f22233f54		R/B/G/Y	#DIV/0!	
			J-M	SG007	03_OB_C_AZ_LE_NT_P		F8	9/8/7/1	#7f23439f55		R/B/G/Y	#DIV/0!	
			N-S	SG008	03_OB_C_AZ_LE_NT_MP		F8	2/3/4/5	#8f24440f56		R/B/G/Y	#DIV/0!	
		SG 09/12	A-D	SG009	03_OB_C_AZ_RE_T_MP		F7	12/13/14/15	#9f15241f57		R/B/G/Y	#DIV/0!	
			E-H	SG010	03_OB_C_AZ_RE_T_P		F7	16/17/11/10	#1f17733f49		R/B/G/Y	#DIV/0!	
			J-M	SG011	03_OB_C_AZ_RE_NT_MP		F7	9/8/7/1	#2f18234f50		R/B/G/Y	#DIV/0!	
			N-S	SG012	03_OB_C_AZ_RE_NT_P		F7	2/3/4/5	#3f19935f51		R/B/G/Y	#DIV/0!	
		SG 13/16	A-D	SG013	SK_D_FB_LG_LE_75		F6	12/13/14/15	#4f20934f52		R/B/G/Y	#DIV/0!	
			E-H	SG014	SK_D_FB_AZ_LE_75		F6	16/17/11/10	#5f21f37f53		R/B/G/Y	#DIV/0!	
			J-M	SG015	SK_D_FB_LG_RE_75		F6	9/8/7/1	#6f22233f54		R/B/G/Y	#DIV/0!	
			N-S	SG016	SK_D_FB_AZ_RE_75		F6	2/3/4/5	#7f23439f55		R/B/G/Y	#DIV/0!	
		SG 17/20	A-D	SG017	SK_D_FB_AZ_LE_45		F5	12/13/14/15	#8f24440f56		R/B/G/Y	#DIV/0!	
			E-H	SG018	SK_D_FB_LG_LE_45		F5	16/17/11/10	#9f25241f57		R/B/G/Y	#DIV/0!	
			J-M	SG019	SK_D_FB_AZ_RE_45		F5	9/8/7/1	#1f17733f49		R/B/G/Y	#DIV/0!	
			N-S	SG020	SK_D_FB_LG_RE_45		F5	2/3/4/5	#2f18234f50		R/B/G/Y	#DIV/0!	
		SG 21/24	A-D	SG021	SK_U_FB_AZ_LE_75		F4	12/13/14/15	#3f19935f51		R/B/G/Y	#DIV/0!	
			E-H	SG022	SK_U_FB_LG_LE_75		F4	16/17/11/10	#4f20934f52		R/B/G/Y	#DIV/0!	
			J-M	SG023	SK_U_FB_LG_RE_75		F4	9/8/7/1	#5f21f37f53		R/B/G/Y	#DIV/0!	
			N-S	SG024	SK_U_FB_AZ_RE_75		F4	2/3/4/5	#6f22233f54		R/B/G/Y	#DIV/0!	
		SG 25/28	A-D	SG025	SK_U_FB_LG_LE_45		F3	12/13/14/15	#7f23439f55		R/B/G/Y	#DIV/0!	
			E-H	SG026	SK_U_FB_AZ_LE_45		F3	16/17/11/10	#8f24440f56		R/B/G/Y	#DIV/0!	
			J-M	SG027	SK_U_FB_LG_RE_45		F3	9/8/7/1	#9f15241f57		R/B/G/Y	#DIV/0!	
			N-S	SG028	SK_U_FB_AZ_RE_45		F3	2/3/4/5	#1f17733f49		R/B/G/Y	#DIV/0!	
		SG 29/32	A-D	SG029	SK_D_OB_AZ_LE_75		F2	12/13/14/15	#2f18234f50		R/B/G/Y	#DIV/0!	
			E-H	SG030	SK_D_OB_AZ_RE_75		F2	16/17/11/10	#3f19935f51		R/B/G/Y	#DIV/0!	
			J-M	SG031	SK_U_OB_AZ_LE_75		F2	9/8/7/1	#4f20934f52		R/B/G/Y	#DIV/0!	
			N-S	SG032	SK_U_OB_AZ_RE_75		F2	2/3/4/5	#5f21f37f53		R/B/G/Y	#DIV/0!	
		SG 33/36	A-D	SG033			F1	12/13/14/15	#6f22233f54		R/B/G/Y	#DIV/0!	
			E-H	SG034			F1	16/17/11/10	#7f23439f55		R/B/G/Y	#DIV/0!	
			J-M	SG035			F1	9/8/7/1	#8f24440f56		R/B/G/Y	#DIV/0!	
			N-S	SG036			F1	2/3/4/5	#9f15241f57		R/B/G/Y	#DIV/0!	
		SG 37/40	A-D	SG037	BUL_57_A_TO_LE	SG-2	F9	12/13/14/15	#1f17733f49		R/B/G/Y	#DIV/0!	
			E-H	SG038	BUL_57_B_TO_LE		F9	16/17/11/10	#2f18234f50		R/B/G/Y	#DIV/0!	
			J-M	SG039	BUL_11_A_LE		F9	9/8/7/1	#3f19935f51		R/B/G/Y	#DIV/0!	
			N-S	SG040	BUL_11_B_LE		F9	2/3/4/5	#4f20934f52		R/B/G/Y	#DIV/0!	
		SG 41/44	A-D	SG041	BUL_12_A_LE		F8	12/13/14/15	#5f21f37f53		R/B/G/Y	#DIV/0!	
			E-H	SG042	BUL_12_B_LE		F8	16/17/11/10	#6f22233f54		R/B/G/Y	#DIV/0!	
			J-M	SG043	BUL_4_A_LE		F8	9/8/7/1	#7f23439f55		R/B/G/Y	#DIV/0!	
			N-S	SG044	BUL_4_B_LE		F8	2/3/4/5	#8f24440f56		R/B/G/Y	#DIV/0!	
		SG 45/48	A-D	SG045	BUL_41_A_LE		F7	12/13/14/15	#9f15241f57		R/B/G/Y	#DIV/0!	
			E-H	SG046	BUL_41_B_LE		F7	16/17/11/10	#1f17733f49		R/B/G/Y	#DIV/0!	
			J-M	SG047	BUL_44_A_LE		F7	9/8/7/1	#2f18234f50		R/B/G/Y	#DIV/0!	
			N-S	SG048	BUL_44_B_LE		F7	2/3/4/5	#3f19935f51		R/B/G/Y	#DIV/0!	
		SG 46/52	A-D	SG049	BUL_47_A_TO_RE		F6	12/13/14/15	#4f20934f52		R/B/G/Y	#DIV/0!	
			E-H	SG050	BUL_47_B_TO_RE		F6	16/17/11/10	#5f21f37f53		R/B/G/Y	#DIV/0!	
			J-M	SG051	BUL_54_A_RE		F6	9/8/7/1	#6f22233f54		R/B/G/Y	#DIV/0!	
			N-S	SG052	BUL_54_B_RE		F6	2/3/4/5	#7f23439f55		R/B/G/Y	#DIV/0!	
		SG 53/56	A-D	SG053	BUL_55_A_RE		F5	12/13/14/15	#8f24440f56		R/B/G/Y	#DIV/0!	
			E-H	SG054	BUL_55_B_RE		F5	16/17/11/10	#9f15241f57		R/B/G/Y	#DIV/0!	
			J-M	SG055	BUL_56_A_RE		F5	9/8/7/1	#1f17733f49		R/B/G/Y	#DIV/0!	
			N-S	SG056	BUL_56_B_RE		F5	2/3/4/5	#2f18234f50		R/B/G/Y	#DIV/0!	
		SG 57/60	A-D	SG057	BUL_42_A_RE		F4	12/13/14/15	#3f19935f51		R/B/G/Y	#DIV/0!	
			E-H	SG058	BUL_42_B_RE		F4	16/17/11/10	#4f20934f52		R/B/G/Y	#DIV/0!	
			J-M	SG059	BUL_43_A_RE		F4	9/8/7/1	#5f21f37f53		R/B/G/Y	#DIV/0!	
			N-S	SG060	BUL_43_B_RE		F4	2/3/4/5	#6f22233f54		R/B/G/Y	#DIV/0!	
		SG 61/64	A-D	SG061	BUL_45_A_RE		F3	12/13/14/15	#7f23439f55		R/B/G/Y	#DIV/0!	
			E-H	SG062	BUL_45_B_RE		F3	16/17/11/10	#8f24440f56		R/B/G/Y	#DIV/0!	
			J-M	SG063	BUL_46_A_RE		F3	9/8/7/1	#9f15241f57		R/B/G/Y	#DIV/0!	
			N-S	SG064	BUL_46_B_RE		F3	2/3/4/5	#1f17733f49		R/B/G/Y	#DIV/0!	

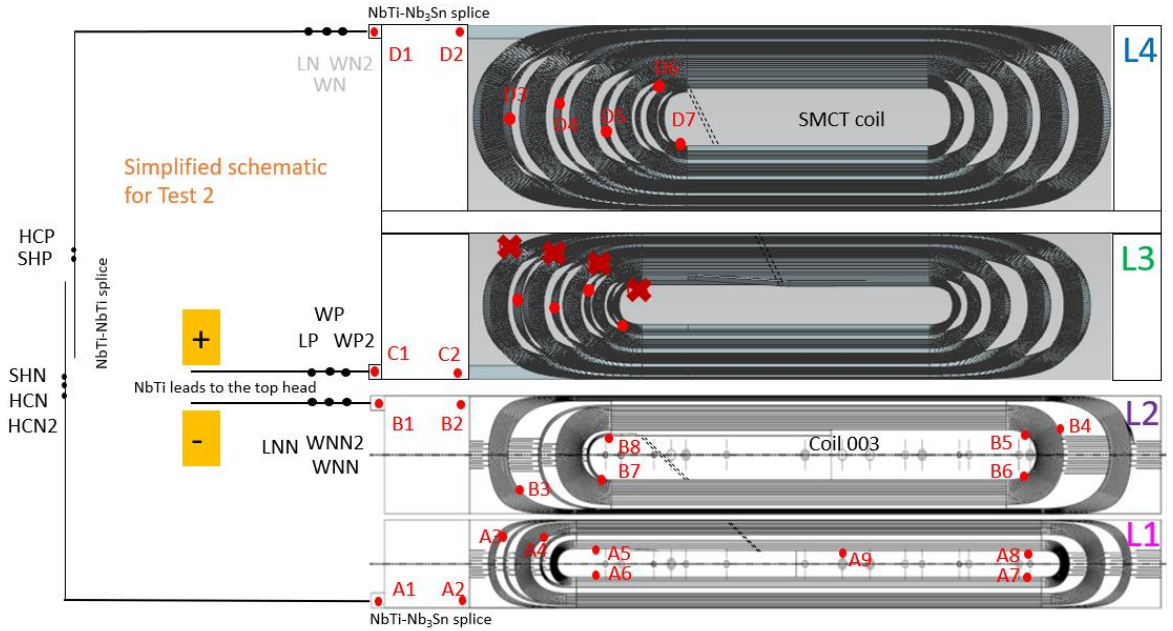
FVT(30kA) | CVT(1-64) | CVT(65-128) | RTDs | STRIP HEATERS(30kA) | STRAIN GAUGES(30kA)

Checkout documents for the mirror magnet

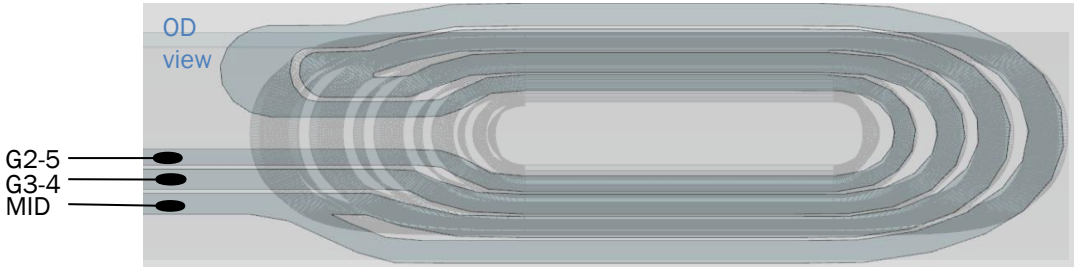
Coil's VT schematics and PH diagram for the 4-layer mirror magnet



For test #1

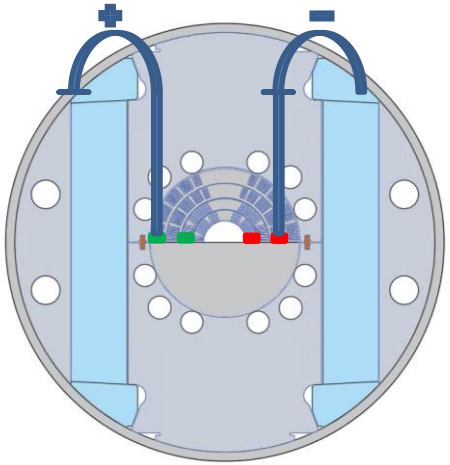


For test #2

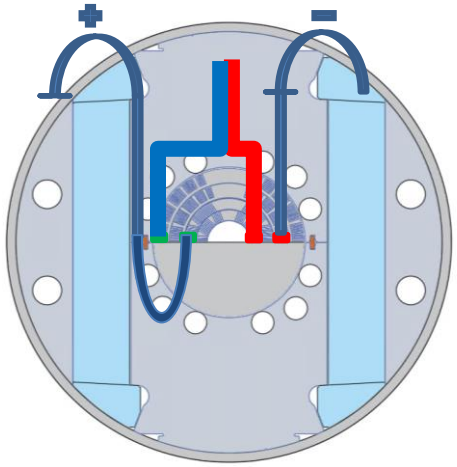


Protection heater for the SMCT outer coil

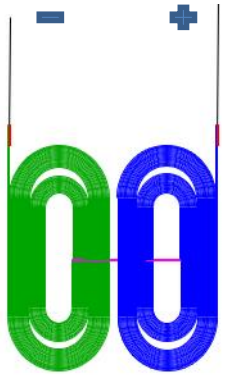
Leads connections for two tests

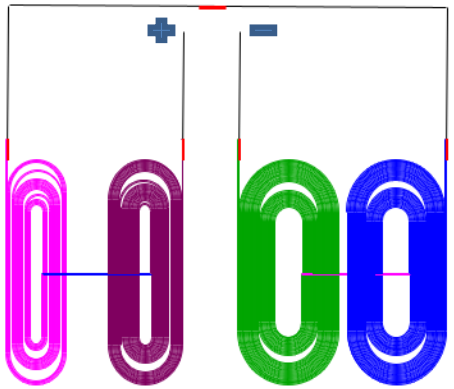


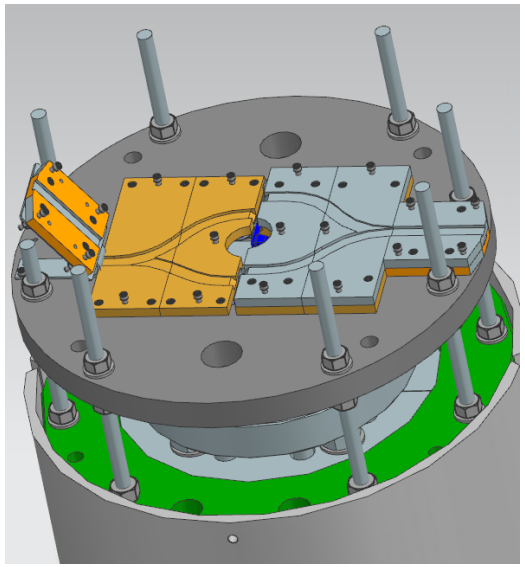
Test 1:
Only SMCT (outer) coil powered



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







Modified “pizza box” and parts for the leads

Working space for the lead's 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 completed
  - Mirror magnet assembly completed
  - Magnet is at the hypertonic connectors stage
- Next steps
  - Mirror magnet test in two configurations
  - SMCT mirror magnetic and mechanical analysis update