Muon Collider Magnets

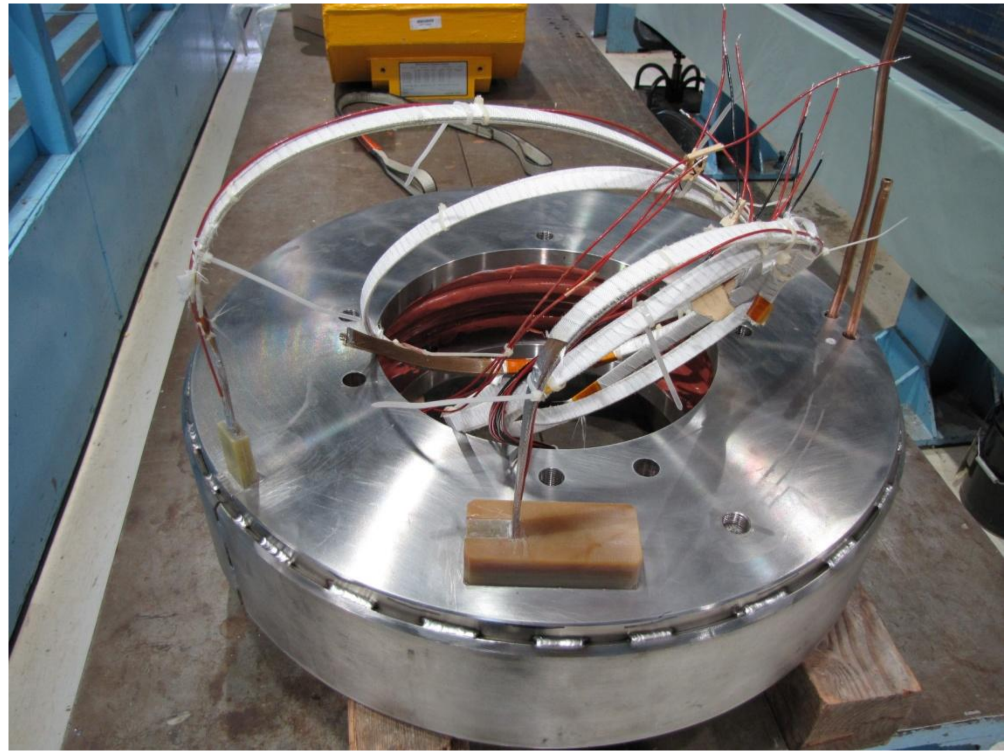
Magnet System Department, July 25, 2010
Fermilab/TD

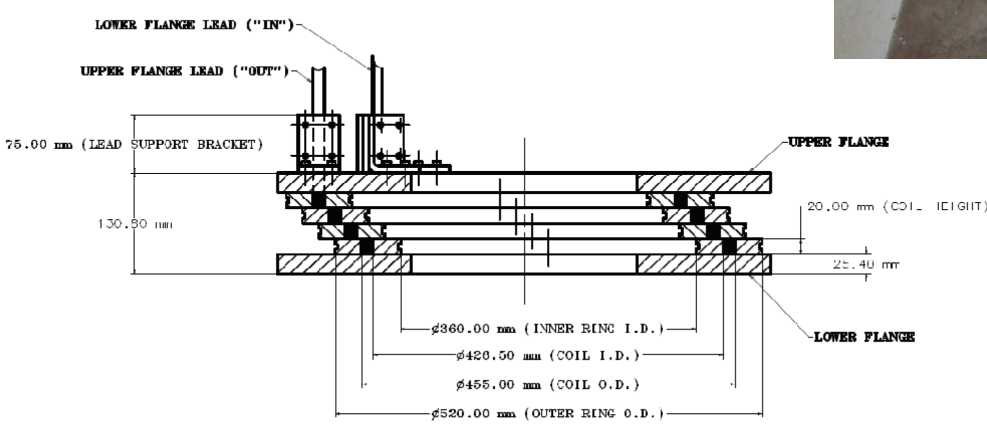
1. Helical Solenoid (HS) Model 2 & 3
2. Helical Solenoid Cooling Section
3. Muon Collider Dipoles & Quadrupoles
4. HTS Helical Solenoid Model
5. R&D towards 50 T solenoids

HS 4-Coil Model 2

Table 1: Solenoid Parameters

Parameter	Units	Value
Coil inner diameter	mm	426
Coil outer diameter	mm	455
NbTi superconducting cable	mm	12.34 x 1.46
Cable critical current at 7 T, 4.2 K	A	9660
Jc (non-Cu)	A/mm^2	1730
Copper to superconductor ratio		1.5:1
Strand diameter	mm	0.8
Helical orbit radius	mm	255
Number of turns per coil		10
Coil width	mm	20

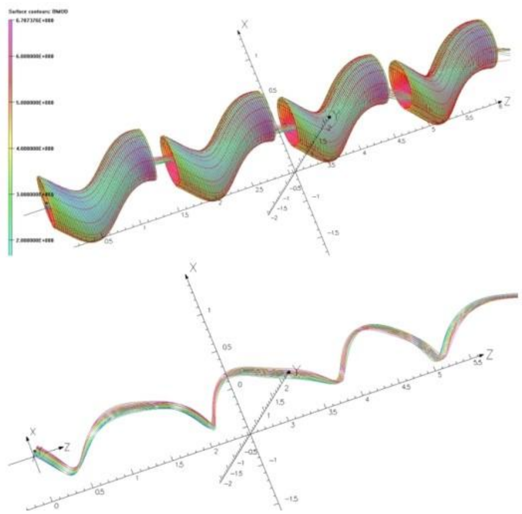


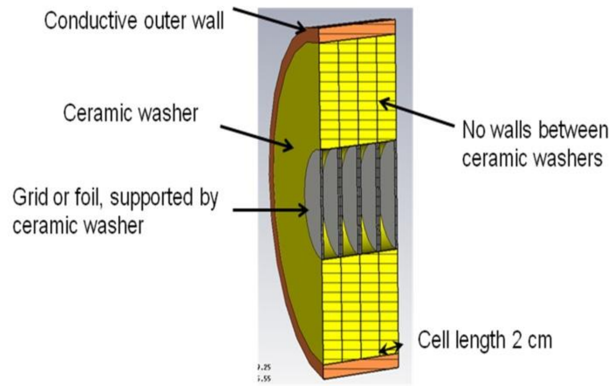


Improved:
- Leads design
- Two stage epoxy impregnation
- Cable closer to rectangular
- Electrical insulation

Model 2 built and waiting a time slot for test

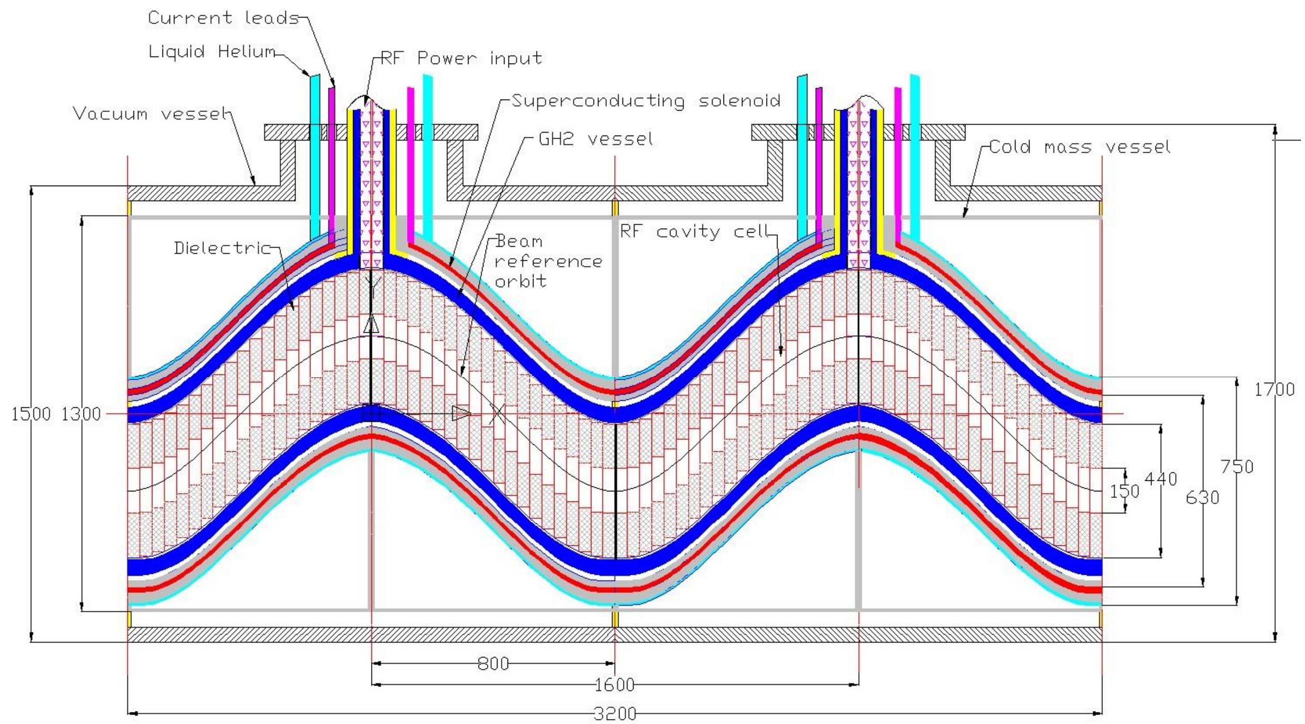
Helical Solenoid Cooling Section





Parameter (per cavity)	Unit	200MHz	325MHz
Cavity outer diameter	mm	440	316
Accelerating gradient	MV/m	10	10
Energy gain for β=0.9	MeV	8	5
Q-factor		4425	4360
Eff. Shunt impedance	MΩ	0.38	0.293
Pulsed losses in copper	MW	25	17.5
Pulsed losses in ceramic	MW	143	67.5
Total pulsed power losses	MW	168	85
Duty factor	%	0.006	0.007
Losses in ceramic	kW	8	5

Parameter	Unit	V. 1	V. 2
Helix orbit radius	m	0.255	0.16
Helix period	m	1.6	1.0
HS coil radius	m	0.315	0.3
DS coil radius	m	-	0.5
RF cavity OD	m	0.44	0.36
Coil width in Z direction	m	0.02	0.02
Number of coils/section		80	50
Distance between sections	m	0.24	0.2
Total HS coil current	kA	100	100
Total DS current/meter	kA	-	25
Coil peak field	T	6.8	7.1
B_z – field at orbit centre	T	-4.8	-4.9
B_T - tangential field	T	1.33	0.88
$d B_T/dr$ – field gradient	T/m	-0.96	-0.06



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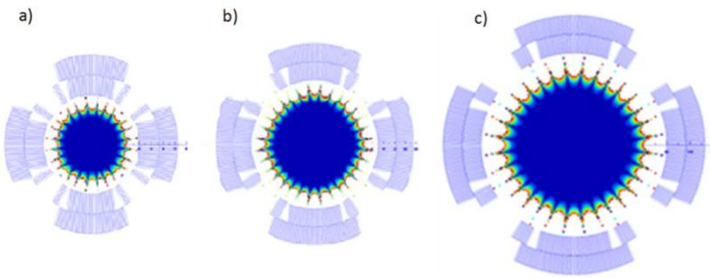
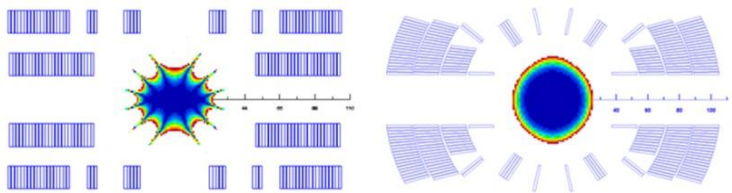
MC Dipoles & Quadrupoles



Q1 (a), Q2 (b), Q3-Q5 (c) cross-sections.

Table 6: IR Quadrupole Parameters.

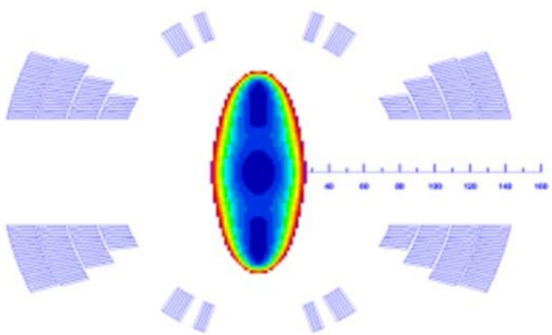
Parameter	Q1	Q2	Q3-Q5
Aperture (mm)	80	110	160
B_{max} coil at 4.5 K (T)	12.76	13.19	13.49
G_{max} apert at 4.5 K (T/m)	281.5	209.0	146.0
G_{op} (T/m)	250	187	130
Inductance at G_{op} (mH/m)	3.57	6.58	12.88
Stored energy at G_{op} (kJ/m)	493.0	771.3	1391.8
F_x at G_{op} (kN/m)	1790	2225	2790
F_y at G_{op} (kN/m)	-2180	-2713	-3380



MC Storage Ring dipole based on 4-layer block-type coil (left) or 4-layer shell-type coil (right).

Table 4: Storage Ring Dipole Parameters.

Parameter	Block design	Shell design
B_{max} coil at 4.5K (T)	13.37	13.13
B_{max} at 4.5 K (T)	11.24	11.24
B_{op} (T)	10.0	10.0
Inductance at B_{op} (mH/m)	6.72	9.52
Stored energy at B_{op} (kJ/m)	1280	1100
F_x at B_{op} (kN/m)	4084	3990
F_y at B_{op} (kN/m)	-2216	-1870



IR dipole cross-section.

Table 8: IR Dipole Parameters.

Parameter	Value
Aperture (mm)	160
B_{max} in coil at 4.5 K (T)	13.03
B_{max} in aperture at 4.5 K (T)	9.82
B_{op} (T)	8.0
Inductance at B_{op} (mH/m)	15.89
Stored energy at B_{op} (kJ/m)	1558
F_x at B_{op} (kN/m)	3960
F_y at B_{op} (kN/m)	-1650

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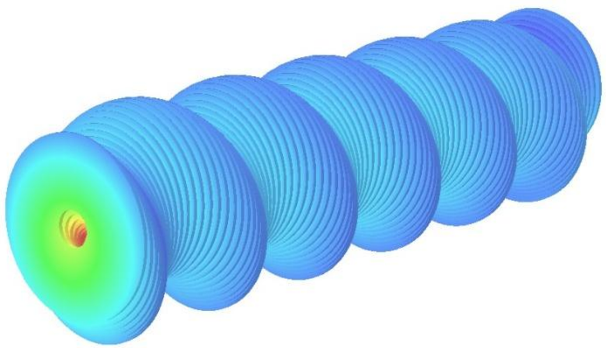
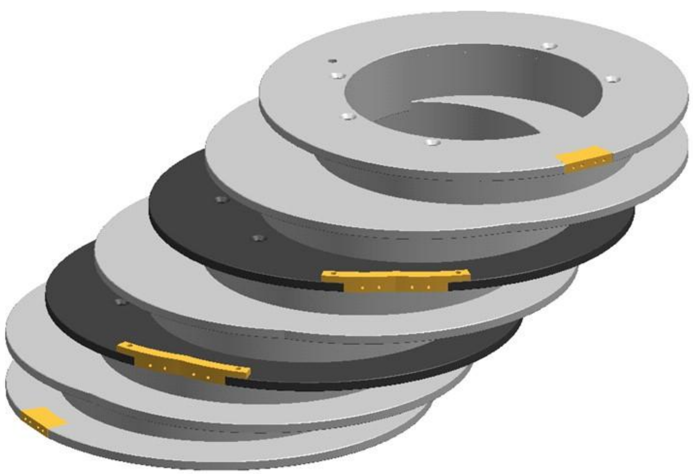
HTS Helical Solenoid Model





· Due to the high cost of the HTS conductor as well as the complicated magnet geometry, the model will be scaled down.
· Model is limited in the axial size to 2-6 rings and coil thickness to 7.6 mm.
· Model will address the building issues such as splices (inner and outer), winding, insulation, and mechanical supports.
Model winding in progress now

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R&D Areas towards 50 T Solenoids

1. HTS Conductor R&D

- Wires – Studies of J_{eng} as a function of B, T, angle, and bending, longitudinal and transverse strains.
- BSCCO-2212 Rutherford-type Cables – Major challenges are J_c, stringent reaction in O_2, powder leaks, strain sensitivity.
- YBCO Roebel Cables – Very high parallel J_c, very strong. Present challenges are anisotropy and J_c homogeneity.

2. Magnet design studies

- Analytical Study of Stress State in HTS Solenoids – Stress distribution in a solenoid was studied for various constraint configurations, max. stresses were produced as a function of coil self-field, and results compared with FEM.

  Main results: A 40 T solenoid produces 900 MPa + in the coil itself, a pre-load decreases somewhat the max. hoop stress of the solenoid, but increases much more that on the outer skin.
- Co-wound and impregnated YBCO coil represented by a mesomechanic FEM model

  Main results: Anisotropy does not sensibly change the stress in the coil package, but dramatically increase that in the outer skin.

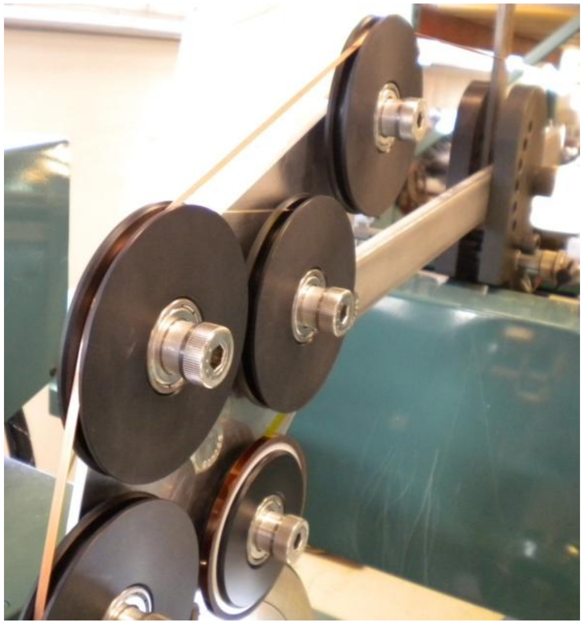
3. Coil Technology

- Winding method and tooling.
- Impregnation techniques.
- Splicing procedures.
- R&D on thermally conductive insulation.

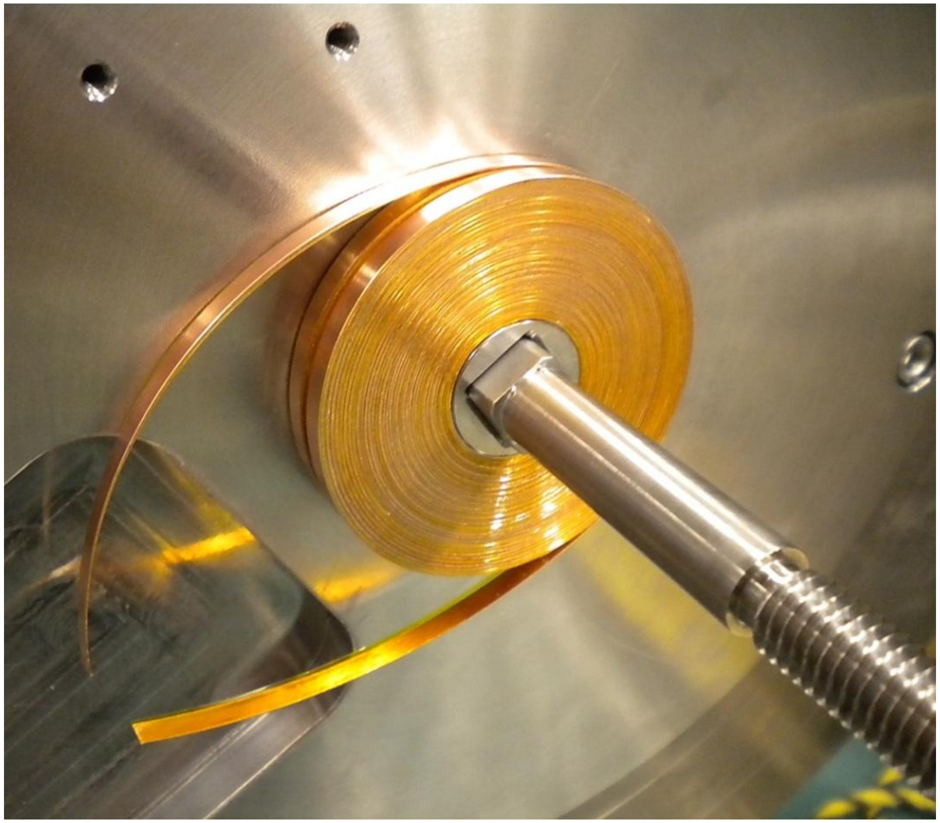
4. Coil Test

- Provide feedback to Coil Technology. Test pancake assemblies in 14 T/ 77 mm bore existing magnet and in 10 T/ 147 mm bore upcoming (August 2010) magnet.

Winding Method and Tooling



⟸ Co-Winding Tooling for YBCO and Insulating Tape



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19 mm / 62 mm Copper&Kapton practice Double Pancake Coil

Summary of Double pancake 2G YBCO coils tested in 14 T, 77 mm bore magnet

Coil ID	Conductor	ID/OD	Coil Length (m)	Impregnation	Test Setup	SSL	Notes
DPY01	SP M3-569 (spool4)	60mm/62mm	2	dry	Individual		Top coil resistive, bottom ok
DPY02	SP M3-569 (spool4)	60mm/62mm	2	dry	Individual		Resistive after first quench in helium
DPY03	SP M3-569 (spool4)	60mm/62mm	2	dry	Individual	SSL(77K,0T)=100% SSL(4.2K,0T)=100%	1000A in Self Field.
DPY04	SP M3-569 (spool4)	60mm/62mm	2	dry	Individual	SSL(77K,0T)=100% SSL(4.2K,12T)=76%	Unsupported joints Ic(4.2K,12T) = 570 A Joint degradation.
DPY05	SP M3-569 (spool4)	60mm/62mm	2	CTD101 (whole coil)	Individual		Top pancake showed early quench
DPY06	SP M3-569 (spool4)	60mm/62mm	2	CTD101 (last layer)	Individual		very thick epoxy (3mm) – ok in nitrogen, coil damaged before first test in helium
DPY07	SP M3-565 (spool5)	60mm/62mm	2	CTD101 (last layer)	Individual		Impregnation thickness adjustments (1.5 to 0.5mm). Ic(4.2K,12T) = 400 A
DPY08	SP M3-565 (spool5)	60mm/62mm	2	CTD101 (last layer)	Individual		Replica of DPY07. Damaged during winding.
DPY09	SP M3-565 (spool5)	60mm/62mm	2	CTD101 (last layer)	ITF		High resistive Joint.
DPY10	SP M3-565 (spool5)	60mm/62mm	2	Stycast (last layer)	ITF	SSL(77K,0T)=100% SSL(4.2K,12T)=75%	Ic(14T)=523 A Ic(12T)=558 A Ic(10T)=604 A

Future Plans

The nearest goals are:

- Test HS Model 2
- Design HS Nb3Sn Model 3
- Order Nb3Sn superconductor for Model 3
- Finish fabrication HTS HS and test it
- Continue design studies of MC magnets and HCC
- Continue HTS Solenoids R&D