5 Year Plan: Magnets

Outline

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MC and NF Magnets Challenging Parameters

- Neutrino Factory and Muon Collider accelerator complexes require magnets with quite challenging parameters and magnet technology:
- Peak field up to 30 T;
- HTS superconductors and technology;
- Helical Solenoid configurations with high fields;
- High radiation loads and open plane magnets;
- Fast ramping at 550 Hz warm dipoles;
- 20 T pions capture wide aperture solenoid.

Main Directions of 5 Year Plan Magnet R&D

- HTS solenoid R&D to define the parameters that could be achieved with a further specified R&D program, and hence the role of HTS magnets in the cooling channel baseline design;
- HCC magnet R&D to assess the feasibility of this type of cooling channel and eventually build a demonstration magnet for an HCC test section;
- Open mid-plane dipole magnet R&D to assess the viability of this magnet type for the collider ring;
- Other magnet studies to inform choices, parameters and cost estimates for the target-station solenoid and accelerator magnets;
- After 2 years of R&D define the base line design for Muon Cooling Channel.

High Field Cooling Channel Solenoids (1)

- Very high field solenoids with fields in excess of 30 T and apertures on the order of 50 mm, are part of the baseline design for the MC final cooling channel.

- The technology for building these magnets using HTS has been demonstrated in the 20 T regime, but it needs to be extended to higher fields with good field quality, and with reliable construction at a reasonable cost.

High Field Cooling Channel Solenoids (2)

The plan:

1. Develop with accelerator designers a set of functional specifications for a high field solenoid.
2. Summarize the ongoing status of conductor properties (HTS, A15, NbTi, strands, and cables), including maximum current density *vs*. field (or field direction for tapes) and temperature; longitudinal, bending, and transverse stress/strain tolerances; quench protection and cooling requirements; cabling capabilities and performance. Also, as needed and not otherwise supported by existing data or the proposed national HTS program, evaluate new conductors and insulation materials.

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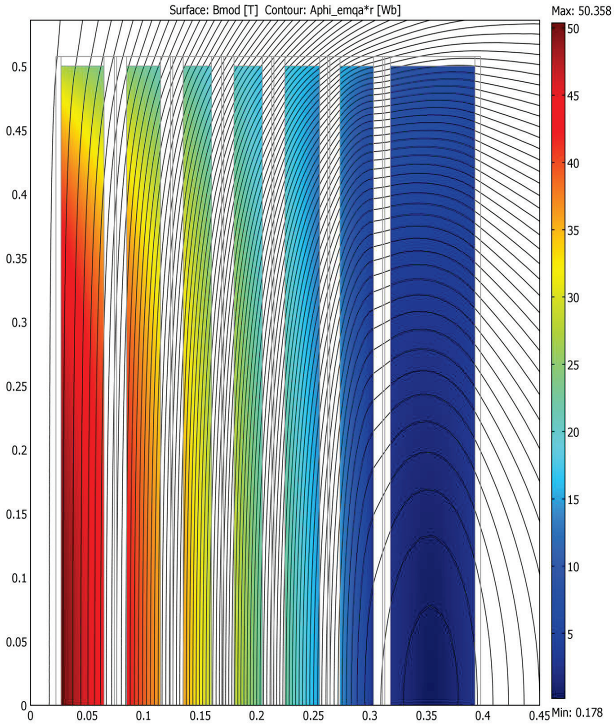
High Field Cooling Channel Solenoids (3)

3. Develop conceptual designs for magnets that meet specifications from Task 1 and conductor properties from Task 2. Investigate magnetic, mechanical, magnet cooling, power and quench protection issues of HTS and hybrid designs.
4. Build and test representative HTS and hybrid-insert models to develop and demonstrate HTS coil technology and performance, and to study model magnetic, mechanical, thermal and quench properties.
5. Based on the results of tasks 1–4 present a plan (conceptual design, time, effort, cost) to build a 1 m long >30 T solenoid in 2013–2015.



Very High Field Solenoid Concept

Helical Cooling Channel Magnets (1)

In order to produce a practical Helical Cooling Channel, several technical issues need to be addressed, including:

- Magnetic matching sections for downstream and upstream of the HCC;
- A complete set of functional and interface specifications covering field quality and tunability;
- The interface with RF structures;
- Heat load limits (requiring knowledge of the power lead requirements);
- Gas absorber and pressure vessel specifications.

Helical Cooling Channel Magnets (2)

To prepare the way for an HCC test section we would:

1. Develop, with accelerator designers, specifications for the magnet systems of a HCC, including magnet apertures to accommodate the required RF systems, section lengths, helical periods, field components, field quality, alignment tolerances, and cryogenic and power requirements. The specification will also consider the needs of any required matching sections.
2. Perform conceptual design studies of helical solenoids that meet Task 1 specifications, including a joint RF and magnet study to decide how to incorporate RF into the helical solenoid bore, corrector coils, matching sections, etc.

Helical Cooling Channel Magnets (3)

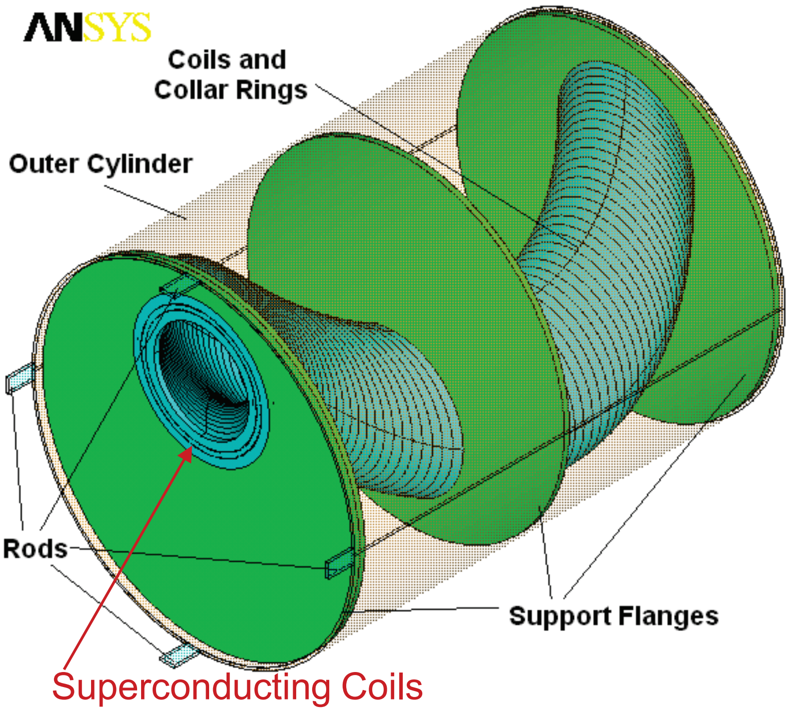
3. Fabricate and test a series of four-coil helical solenoid models to develop and demonstrate the coil winding technology, pre-load and stress management, cooling, and quench protection for low-field sections based on NbTi and/or Nb3Sn cable. The proposed timeline for these studies is:

- NbTi model based on SSC cable and hard-bend winding in 2008;

- NbTi models based on easy-bend winding and indirect coil cooling in 2009.

In addition, a set of coils based on hybrid Nb3Sn-HTS superconductor may be developed for the high-field sections. This work would be supported by SBIR funding;

Helical Cooling Channel Magnets (4)



4. Develop and test a “short” (one-quarter to one period) demonstration helical solenoid section capable of housing RF cavities in a cryostat (i.e., a helical cooling cryomodule).

The associated timeline for this would be:
- Conceptual design in 2010
- Engineering design and construction and test in 2011–2012
- Magnet test results to be in time for MC-DR report in late 2012.

Collider Ring Magnet Requirements

- The collider ring will consist of arc dipoles, quadrupoles, correctors, and interaction region dipoles and quadrupoles.
- The arc dipoles should operate at high field in order to keep the ring circumference small, providing a larger number of crossings for a given number of stored muons and lifetime.
- These magnets must also operate in a high radiation and high heat load environment resulting from the muon decay electrons, which are preferentially swept into the magnet mid-plane.
- In order to avoid quenches, limit the cooling-power requirements, and maintain an acceptable lifetime, the superconducting coils must be protected from excessive energy deposition due to these decay electrons.
- Similar considerations apply to the arc and IR quadrupoles.

Collider Ring Magnets R&D (1)

The effort for the collider magnets will include design analysis, technology development, and prototype fabrication. Its main sub-tasks will be to:

1. Compare design options for the arc dipoles, and identify a baseline magnetic, mechanical, and thermal design. This activity will benefit from previous studies of conventional and open mid-plane designs carried out for the muon collider as well as the LHC "dipole-first" IR upgrade scheme.
2. Compare design options for arc and interaction region quadrupoles, and select a baseline design. Options considered include large bore designs with thick liners and designs with the open mid plane. In addition, conventional quadrupoles were considered, where most of loss could be absorbed by a cooled absorber outside the quadrupole.

Collider Ring Magnets R&D (2)

3. Provide sets of magnet parameters (aperture, length, integrated strength, tolerances) taking into account the radiation deposition issues, to be used for the machine optimization.
4. Define and implement technology tests in support of the magnet design and prototyping. These include models, sub-scale coil tests, experiments to determine thermal margin and radiation lifetime, materials characterization, etc. This effort will also take advantage of collaborations with other ongoing R&D efforts (such as LHC upgrades) to carry out larger scale tests.
5. Design of the main magnetic elements (arc dipoles and quadrupoles, and IR quadrupoles), to a level sufficient to support preliminary cost estimates.
6. Provide cost estimates for further R&D and prototyping, and preliminary cost envelopes for magnet production.

Fast Ramping Synchrotron Magnets

- One novel muon acceleration concept utilizes a very rapid cycling synchrotron. In a proposed scenario using the existing Tevatron tunnel to accelerate muons from 30 to 750 GeV in 72 turns (See D.J. Summers talk this Meeting).
- Each of the Tevatron half-cell's four main dipoles are replaced by three fast ramping dipoles that ramp at 550 Hz from –1.8 T to +1.8 T, interleaved with 8 T fixed superconducting dipoles.
- These magnets would utilize 3 mm copper tubing and 0.28 mm grain-oriented silicon steel laminations, plus a 2% duty cycle, to mitigate eddy-current losses.
- This would be a two-year program, with the 30 cm long prototype dipole built in the first year and the 6.3 m long prototype dipole built in the second year.

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Preliminary Cost and Effort

	M&S (K$)	FY08	FY09	FY10	FY11	FY12	
2.3	Magnets						
	High Field Solenoid	50	200	350	350	200	1150
	Helical Cooling Channel Magnets	60	150	350	500	600	1660
	Collider and IR Magnets	0	60	500	700	810	2070
	Other Magnets	0	175	375	375	525	1450
	Cost model for magnetic components	0	0	0	0	0	0
	Sum	110	585	1575	1925	2135	6330

	FTE	FY08	FY09	FY10	FY11	FY12	
2.3	Magnets						
	High Field Solenoid	0.3	5.0	5.0	5.0	5.5	20.8
	Helical Cooling Channel Magnets	0.5	6.0	8.0	12.0	8.0	34.5
	Collider and IR Magnets	0.0	2.7	2.0	3.5	5.4	13.5
	Other Magnets	0.1	4.1	4.3	3.8	3.3	15.6
	Cost model for magnetic components	0.0	0.1	0.1	0.1	0.1	0.4
	Sum	0.8	17.9	19.35	24.35	22.3	84.7

Progress in 2008 R&D

- The first 4- Coil NbTi model of Helical Solenoid built and successfully tested (V. Kashikhin talk);
- Conceptually designed Helical Solenoids with: different apertures, helix periods, correction coils, non-circular configurations, anti-solenoid. Designs based on NbTi, Nb3Sn, and HTS superconductors (V. Kashikhin talk);
- Conceptually designed 50 T hybrid solenoid based on HTS insert, Nb3Sn and NbTi outer solenoids. The mechanical concept uses a stress management (V. Kashikhin talk);
- Tested large number of HTS, Nb3Sn, Nb3Al superconductor samples. This data used for the realistic magnet designs (A. Tollestrup talk);
- Proposed concepts of Collider Ring Magnets with open and closed mid-plane capable to withstand a high radiation load and losses;
- Proposed a novel muon acceleration synchrotron based on fast cycling magnets installed in the Tevatron tunnel (D.J. Summers talk);
- Proposed magnet concepts for Guggenheim (P. Snopok talk) and snake configurations.

Summary

- Magnets will be one of the base technologies for the muon collider
- We presented an R&D plan and needed resources to study key magnetic elements required for a Muon Collider.
- Models cost and R&D results will be used to develop a cost estimate for a future Muon Collider.
- Whenever possible, we will incorporate existing technology and benefit from ongoing accelerator magnet programs, however…
- It will require a significant effort from the DOE National Labs as well as substantial SBIR and University participation.