MICE Cooling Channel Magnets:

- Spectrometer Solenoid Procurement
- RF Module Coupling Coil Proposal

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Lawrence Berkeley National Lab
Spectrometer Solenoid Overview

• Order for two spectrometer solenoid magnets was placed with Wang NMR by LBNL in June ‘06
• Design review was held by Wang on Sept 6, 2006
  - Complete design package book provided to LBNL
• Detailed magnet design is now complete
• Superconducting wire was provided by LBNL (IIT)
• First machined coil former completed last week
• Coil winding will begin within two weeks
• First magnet scheduled to be shipped end Aug 07
Purpose of the Spectrometer Solenoids

- The spectrometer solenoids provide a uniform field for the scintillating fiber tracker & match the uniform field section into the rest of MICE.

- The long center coil with its two short end coils are designed to generate a 4 T field:
  - Field uniformity is better than 0.3% over a 1000 mm long, 300 mm diameter region.
  - Uniformity is better than 0.1% over most of the region.
MICE Field on Axis in the Flip Mode
Spectrometer Solenoid Cold Mass

Coil Cover

End Coil 1

Match Coil 1

Match Coil 2

Coil Spacer

End Coil 2

Center Coil

Liquid Helium Space

490 mm

2544 mm

690 mm
First Completed Coil Winding Form
Spectrometer Solenoid Conductor

1.00 mm

1.65 mm

RRR > 70 @ 4.2 K

41 μm Nb-Ti
222 Filaments

Cu/SC = 3.9 ± 0.4
Twist pitch: 19±3 mm
121.5 km purchased
Design Overview (coil construction)

• Single piece 6061-T6 aluminum coil former
• Each layer wet wound using Stycast 2850 FT
• 2.5 mil thick fiberglass between winding layers
• Aluminum coil banding will provide hoop force support and ensure coils are tight after cooldown
• Conductor joints are to be lapped by at least 24” to minimize the $I^2R$ losses
• Passive quench protection will be provided by a system of diodes & resistors
Cold Mass Support System (50 T axial force)

- Cold Mass Assembly
- 300 K Support End
- 60 K Support Intercept
- Support Band
- 4 K Support End
Design Overview (coil cooling)

- Indirect cooling using liquid helium condensers
- Baseline design will use two cryocoolers but will allow mounting of a third cooler, if necessary
- High $T_C$ leads will be accessible by means of a removable cover plate
- 60K (or less) thermal shield is conductively cooled using the first stage of the cryocoolers
- Thermal shield copper mass will protect the high $T_C$ leads and provide extra cooling margin
Design Overview (PV’s & supports)

- Helium vessel (Al) and vacuum vessel (304SS) to be designed & tested according to PV code
- He vessel will contain two relief paths for safety
- Unidirectional S-2 fiberglass cold mass supports using race-track shaped links (safety factor of 4)
- 304 SS support design derived from LBNL/Oxford
- Cold mass support design allows cold shipping
The Blue rings are the tracker scintillating fiber planes. Plane spacing: 150mm, 180mm, 200mm and 470mm. All fiber planes are in the magnet good field region.

$\Delta B/B = \pm 0.105\%$ at $R=0$, $L=1050$ mm

$\Delta B/B = \pm 0.262\%$ at $R=150$ mm, $L=1050$ mm
## Estimated Heat Loads

<table>
<thead>
<tr>
<th>Component</th>
<th>Heat Leak (W)</th>
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<tbody>
<tr>
<td></td>
<td>@ 60 K</td>
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<tr>
<td>Cold Mass Supports</td>
<td>~7</td>
</tr>
<tr>
<td>Radiation through MLI</td>
<td>~11</td>
</tr>
<tr>
<td>Necks and Instrumentation</td>
<td>~11</td>
</tr>
<tr>
<td>Current Leads</td>
<td>~80</td>
</tr>
<tr>
<td>Total Estimated Heat Leak</td>
<td>~109</td>
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</tbody>
</table>

- The magnets can be cooled with a pair of 1.5 W pulse tube coolers
- The temperature of the cooler first stage is about 52 K instead of 60 K
- Given the temperature margin, the magnets can operate at 4.5 K
- The peak field at the cooler rotary slide valve is about 0.05 T
Magnet Coil Load Lines

Magnet Peak B and Conductor B (T)

Margin @ 4.2 K:
- M1 = ~1.7 K
- M2 = ~1.9 K
- E1 = ~1.6 K
- C = ~2.0 K
- E2 = ~1.5 K

M1 = 3.4 K
M2 = 4.2 K
M = 5.0 K
Tracker M1
Tracker M2
Tracker E1
Tracker C
Tracker E2
Quench Protection & Power Supply Hookup

- Power Supply: ±10 V, 300 A
- Power Supply: ±5 V, ±50 A
- Quench Diodes
- 300 Amp Leads
- 50 Amp Leads
- Match 1
- Match 2
- End 1
- Center
- End 2
- Steve Virostek - Lawrence Berkeley National Laboratory
Pulse Tube Cryocoolers

• Magnets to be cooled to as low as 45 K (1\textsuperscript{st} stage) and 3.8 K (2\textsuperscript{nd} stage) using two 1.5 W pulse tube coolers

• Magnetic field at the cooler rotary valve motors is \sim 0.05 T (no iron shielding needed on the valve motors)

• Cryocoolers (up to three) can be installed and removed without breaking cryostat vacuum

• Coolers connected to He liquid bath w/a thermal siphon heat pipe to reduce \(\Delta T\) between coil & cooler 2\textsuperscript{nd} stage

• Four Cryomech 1.5 W pulse tube coolers ordered by IIT - first unit shipping to Wang on February 19th
Magnet Power Supplies

• Three power supplies of +300 A at ±10 V for the center and two match coils (shared for 2 magnets)
  - two quadrant power supply
  - current regulation of < ±0.01% from 50 A to 275 A

• Four power supplies of ±50 A at ±5 V for the two end coils (2 per magnet)
  - four quadrant power supply
  - current regulation of < ±0.03% from 5 A to 45 A

• Power supply specification is complete
• Lead time is 3 months - order to be placed soon
## Schedule Summary

<table>
<thead>
<tr>
<th>Task Description</th>
<th>2006</th>
<th>2007</th>
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<tbody>
<tr>
<td>Place Magnet Order with Wang NMR (LBNL)</td>
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<tr>
<td>Complete Magnet System Design</td>
<td></td>
<td></td>
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<tr>
<td>Write QC/QA Administration &amp; Test Report</td>
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<tr>
<td>Procure &amp; Deliver Superconductor to Wang (LBNL)</td>
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<tr>
<td>Conduct Magnet Design Review</td>
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<tr>
<td>Procure Coil Formers from Subcontractor</td>
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<tr>
<td>Write Spec and Procure High $T_c$ Leads</td>
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<tr>
<td>Write Spec and Procure Cryocoolers (LBNL)</td>
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<tr>
<td>Write Spec and Procure Power Supplies (LBNL)</td>
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<tr>
<td>Wind Coils on Coil Formers</td>
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<tr>
<td>Assemble and Leak Check He Shell</td>
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<tr>
<td>Install Superinsulation and Cold Mass Supports</td>
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<tr>
<td>Install Hi-Tc Leads, Recondensers &amp; Cryocoolers</td>
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<tr>
<td>Leak Checks, Cool down &amp; Acceptance Tests</td>
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<tr>
<td>Ship Magnets</td>
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Summary

- Detailed magnet design is now complete
- 1st coil former arriving at Wang this week
- High $T_c$ leads will arrive early February
- Cryomech cryocoolers (4 each) on order
- Power supply spec is complete - order soon
- First magnet to be shipped by end Aug 07
- Second magnet to follow 1 month later
Progress towards LBNL/ICST Collaboration

- **Scope**: design, fabricate and test one MuCool coil and two MICE coupling coils
- **Preliminary discussions** began last year
  - Mike Green visit to ICST 4/06 and at MICE CM15 & CM16
- **LBNL visit to ICST** at Harbin in December ‘06
  - Attendees: M. Zisman, D. Li, S. Virostek, M. Green
  - ICST presented preliminary coupling coil designs
- **Design work** is continuing by ICST engineers
- **Unresolved issues**: level and sources of funding
MICE RF Cavity & Coupling Coil Module

Coupling Coil
RFCC Module Cross Section

- Pulse Tube Cryocooler
- Coupling Coil
- RF Cavities
- Vacuum Manifold
- 8” Cryopump
- RF Cavity Vacuum Vessel
Goals of the ICST/LBNL Collaboration

• Develop a coupling coil design for MICE, MuCool
  - Preferably one design that meets both project’s needs

• Fabricate and test three coupling coils at ICST
  - Coil for MuCool is needed as soon as possible
  - Two MICE coils can follow later (if appropriate)

• Integrate the coil design with the requirements of the MICE RF/Coupling Coil Module
  - Issues: RF vacuum vessel, RF couplers, tuners, forces
LBNL Role in the Coil Development

• Develop engineering concept & initial analysis
• Specification of coil parameters & requirements
• Provide project oversight and design approval
• Procurement of superconductor, cryocoolers, leads, power supplies, etc. for all three coils
• Funding to ICST for added cost of MuCool coil
  - Additional material: coil winding form, cryostat, coil vacuum vessel, MuCool coil support structure
ICST Role in the Coil Development

• Perform engineering analyses and detailed design of the MICE/MuCool coupling coil
• Fabricate & test one MuCool coil with funding, material and components provided by LBNL
• Provide effort and material to complete the fabrication and testing of the two MICE coils
• Contribute to the collaboration by reporting progress at MICE meetings and in publications
Coupling Coil Specification (LBNL)

- General system description
- Applicable codes and standards
- Coil parameters and requirements
- Inspection and testing plans
- Packing, shipping and handling
- List of LBNL furnished materials
- Quality assurance requirements
- Conceptual design drawings
Coupling Coil Design Review

• Coupling coil design review to be held by ICST
  - Attendees: LBNL, MICE collaborators, other experts
  - Complete design package documentation to be provided
  - Follow up on issues & actions items identified in review

• Present engineering analyses and calculations

• All fabrication drawings ready for review

• Fabrication and assembly plans and procedures

• Coil test plans: electrical, thermal, mechanical

• Quality assurance and process control plans
Coupling Coil Components (ICST)

- Thermal Shield
- Cryo-cooler
- Leads
- Support band
- Coil windings
- He vessel cover
- Winding form
- Insulation
- Cold mass supports
- Vacuum vessel
- Cryo-cooler
Cooling Circuit Details (ICST)

- Cryo-cooler
- Leads
- VHe piping
- Cool-down return piping
- Bayonets
- Cool-down supply piping
- Recondenser
- LHe piping
Cryocooler and Condenser Details (ICST)
The coil is cooled by conduction with liquid helium.

6061-T6 Al

4.2K

6061-T6 Al
Helium Vessel Stress Analysis (ICST)

Radial, longitudinal and gravity forces and 4 bar internal pressure.

Supports

25mm thk aluminum

541885 787E+07 152E+08 225E+08 299E+08 372E+08 445E+08 518E+08 592E+08 665E+08
MICE: Spectrometer Solenoid & Coupling Coil

Coupling Coil Magnetic Field Analysis (ICST)

\[ B_{\text{max}} = 6.58 \text{T (ICST analysis)}, \quad B_{\text{max}} = 6.51 \text{T (MICE conceptional design)} \]
Project Deliverables from ICST

- Design package containing fabrication drawings
- One MuCool coil with dedicated support (ASAP)
- Two coupling coils for the MICE Project
- Fabrication process documentation
- Magnet testing documentation
- Coupling coil project final report
## Timeline - Early MuCool Coil Delivery

<table>
<thead>
<tr>
<th>Task Description</th>
<th>2007</th>
<th>2008</th>
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<tbody>
<tr>
<td></td>
<td>Jan</td>
<td>Feb</td>
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<tr>
<td>Complete Magnet System Design</td>
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<tr>
<td>Conduct Magnet Design Review</td>
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<tr>
<td>Procure &amp; Deliver Superconductor to ICST (LBNL)</td>
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<tr>
<td>Procure Material and Fabricate Coil Former (Coil 1)</td>
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<tr>
<td>Procure &amp; Deliver High Tc Leads to ICST (LBNL)</td>
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<tr>
<td>Wind Coils on Coil Former (Coil 1)</td>
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<tr>
<td>Procure &amp; Deliver Cryocoolers to ICST (LBNL)</td>
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<tr>
<td>Assemble and Leak Check He Shell (Coil 1)</td>
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<tr>
<td>Install Superinsulation and Cold Mass Supports (Coil 1)</td>
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<tr>
<td>Procure &amp; Deliver Power Supplies to ICST (LBNL)</td>
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<tr>
<td>Design and fabricate MuCool Support Structure</td>
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<tr>
<td>Install Hi-Tc Leads, Recondenser &amp; Cryocooler (Coil 1)</td>
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<tr>
<td>Leak Checks,Cooldown &amp; Acceptance Tests (Coil 1)</td>
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<tr>
<td>Ship MuCool Coupling Coil (Coil 1) to FNAL</td>
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<tr>
<td>Fabricate Coil Formers (Coil 2 and 3)</td>
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<tr>
<td>Wind Coils on Coil Formers (Coil 2 and 3)</td>
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<tr>
<td>Assemble and Leak Check He Shells (Coil 2 and 3)</td>
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<tr>
<td>Install Superinsulation &amp; Cold Mass Supports (Coil 2 and 3)</td>
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<tr>
<td>Install Hi-Tc Leads, Recondensors &amp; Cryocoolers (Coil 2 &amp; 3)</td>
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<tr>
<td>Leak Checks,Cooldown &amp; Acceptance Tests (Coil 2 and 3)</td>
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<tr>
<td>Ship 2nd and 3rd Coupling Coils to FNAL</td>
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Proposed Fabrication Plan Summary

- LBNL to provide design concept & specification
- ICST to develop detailed coupling coil design
  - Engineering analyses and design drawings
  - Design review to be held prior to fabrication
- LBNL will supply some components and material
  - Superconductor, cryocoolers, power supplies, etc.
- ICST will fabricate and test the coupling coils
- LBNL will oversee the design and fabrication