MICE Cooling Channel Magnets:

- **Spectrometer Solenoid Procurement**
- **RF Module Coupling Coil Proposal**

NFMCC 07 @ UCLA

January 31, 2007

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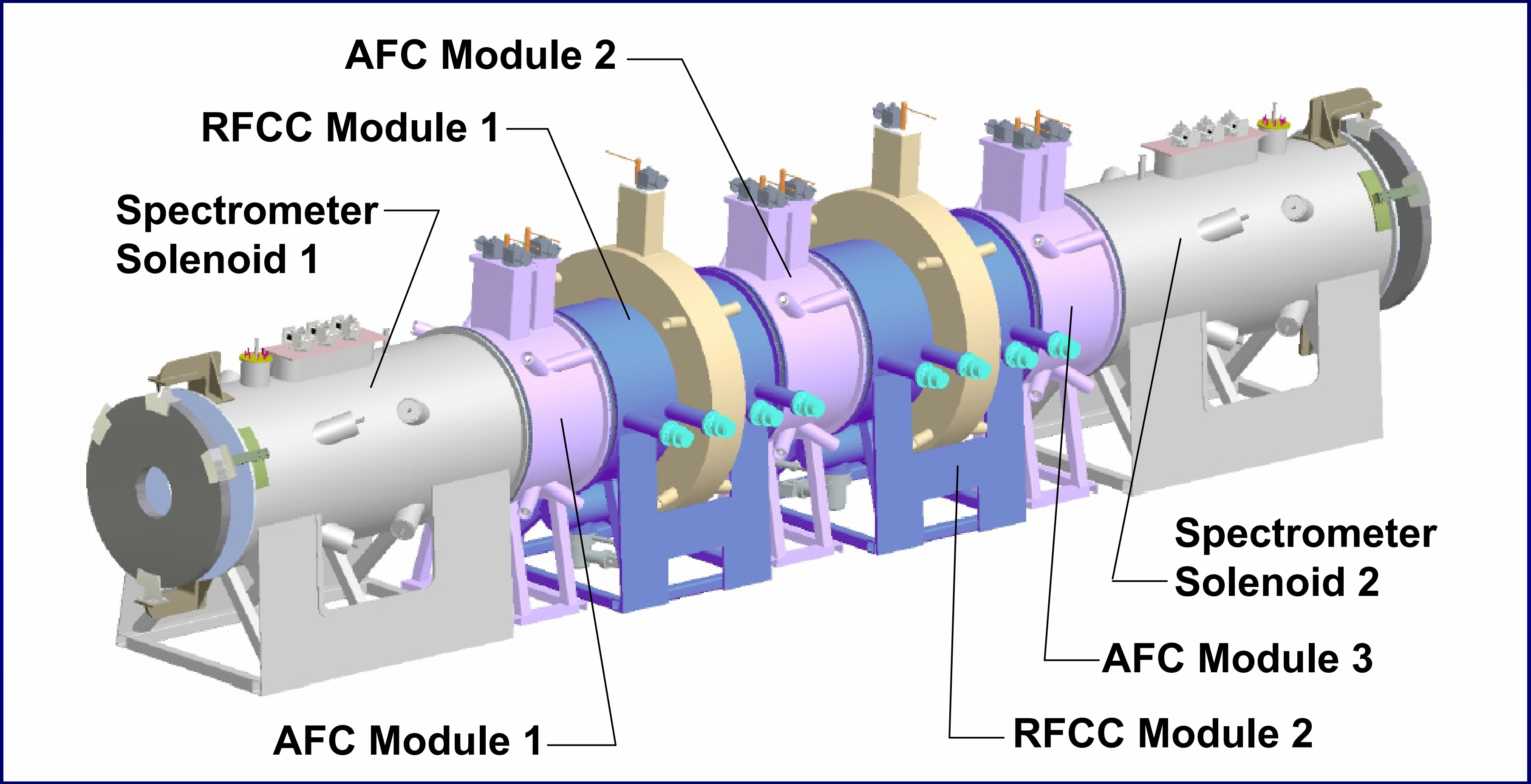
Lawrence Berkeley National Lab

MICE Cooling Channel Layout



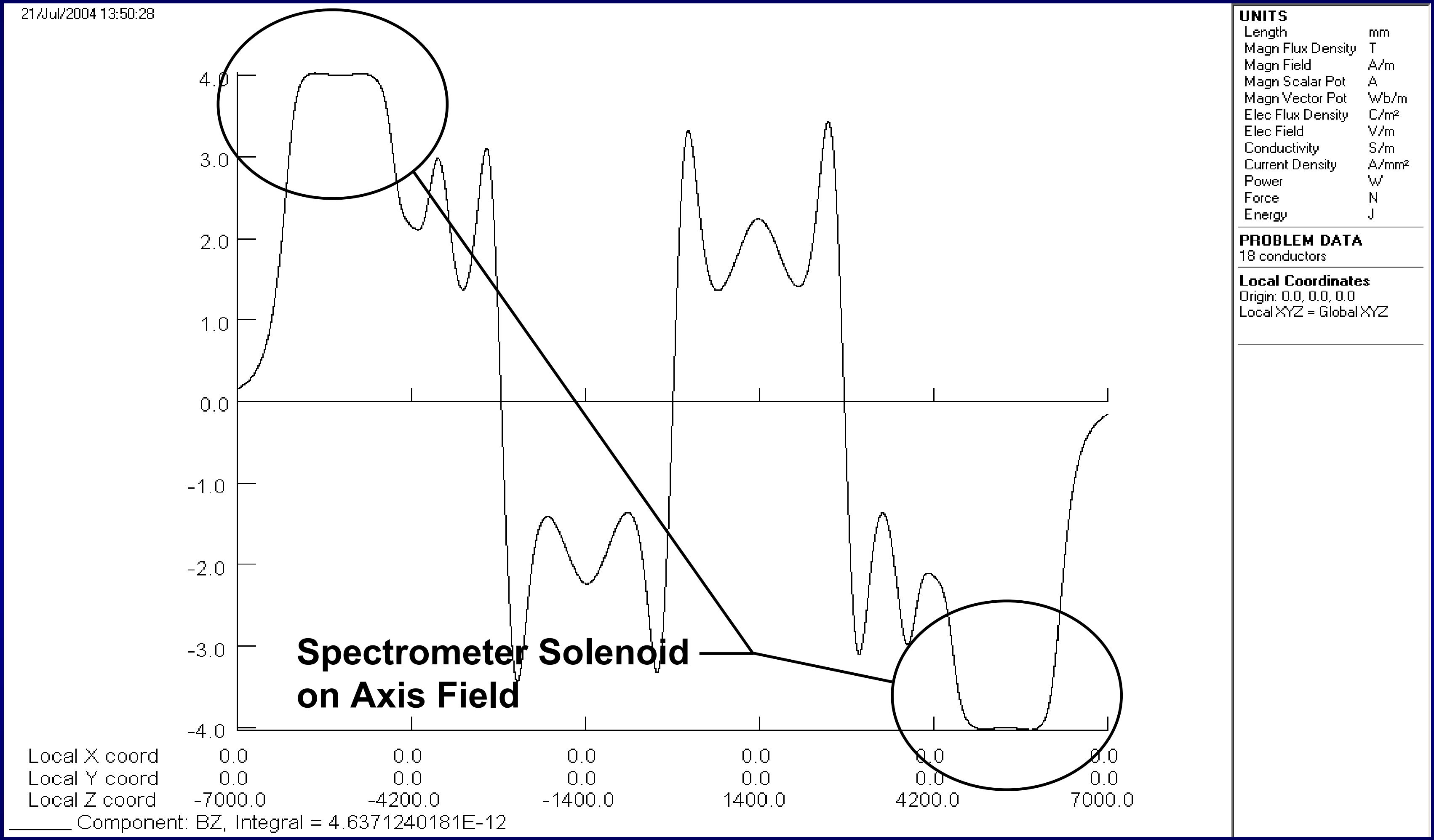
Spectrometer Solenoid Overview

- 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

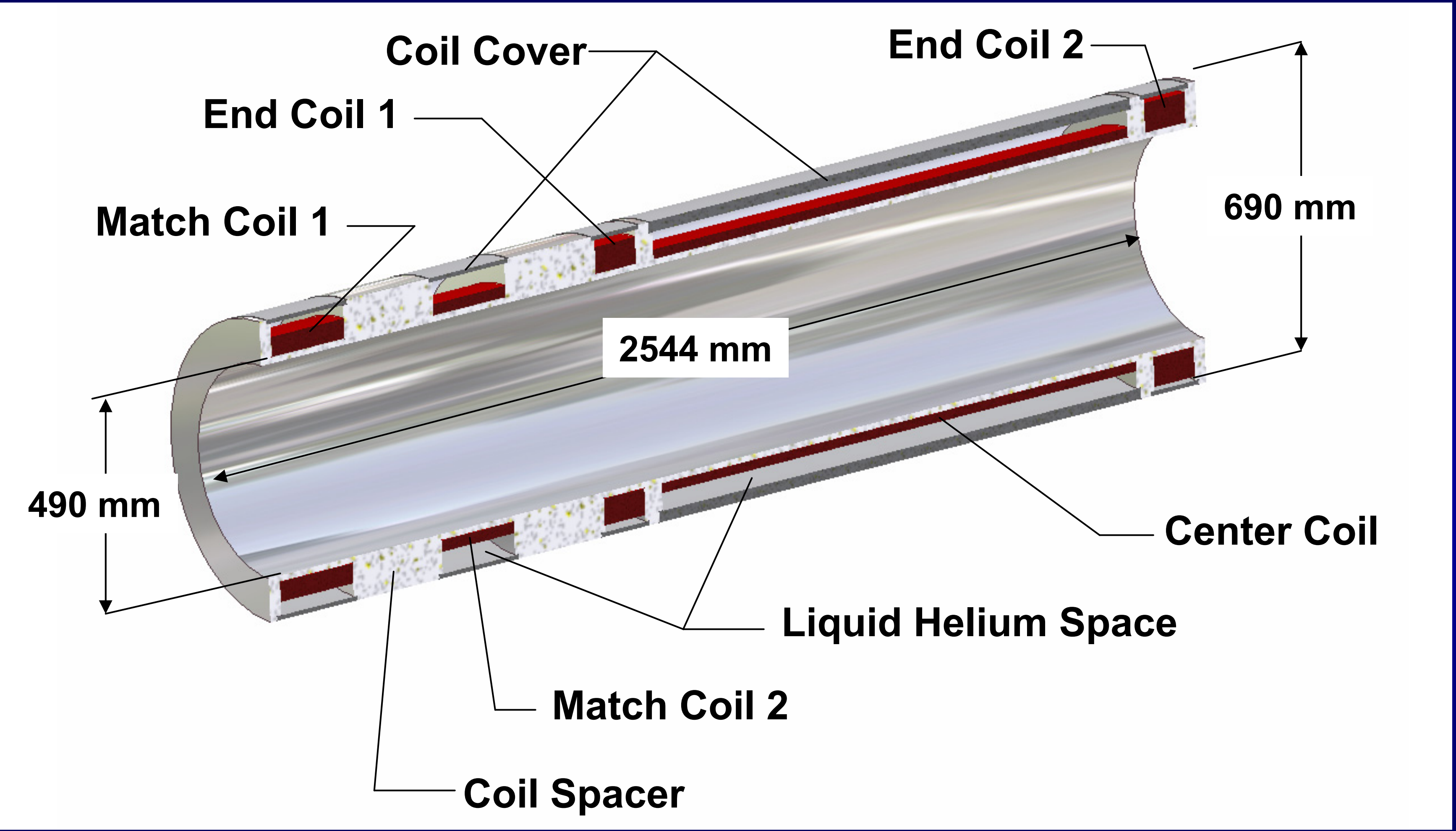
Purpose of the Spectrometer Solenoids

- 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

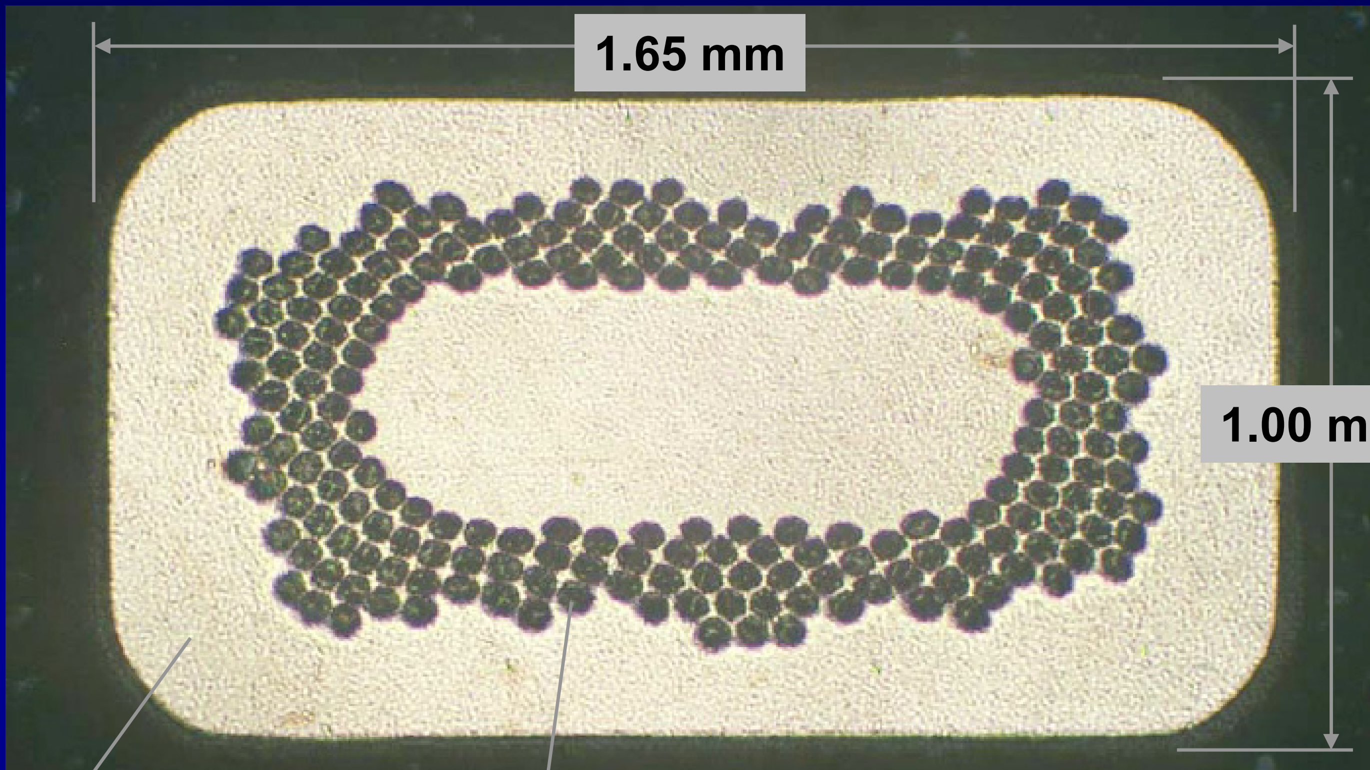


Spectrometer Solenoid Cold Mass



First Completed Coil Winding Form

Spectrometer Solenoid Conductor



RRR > 70 @ 4.2 K

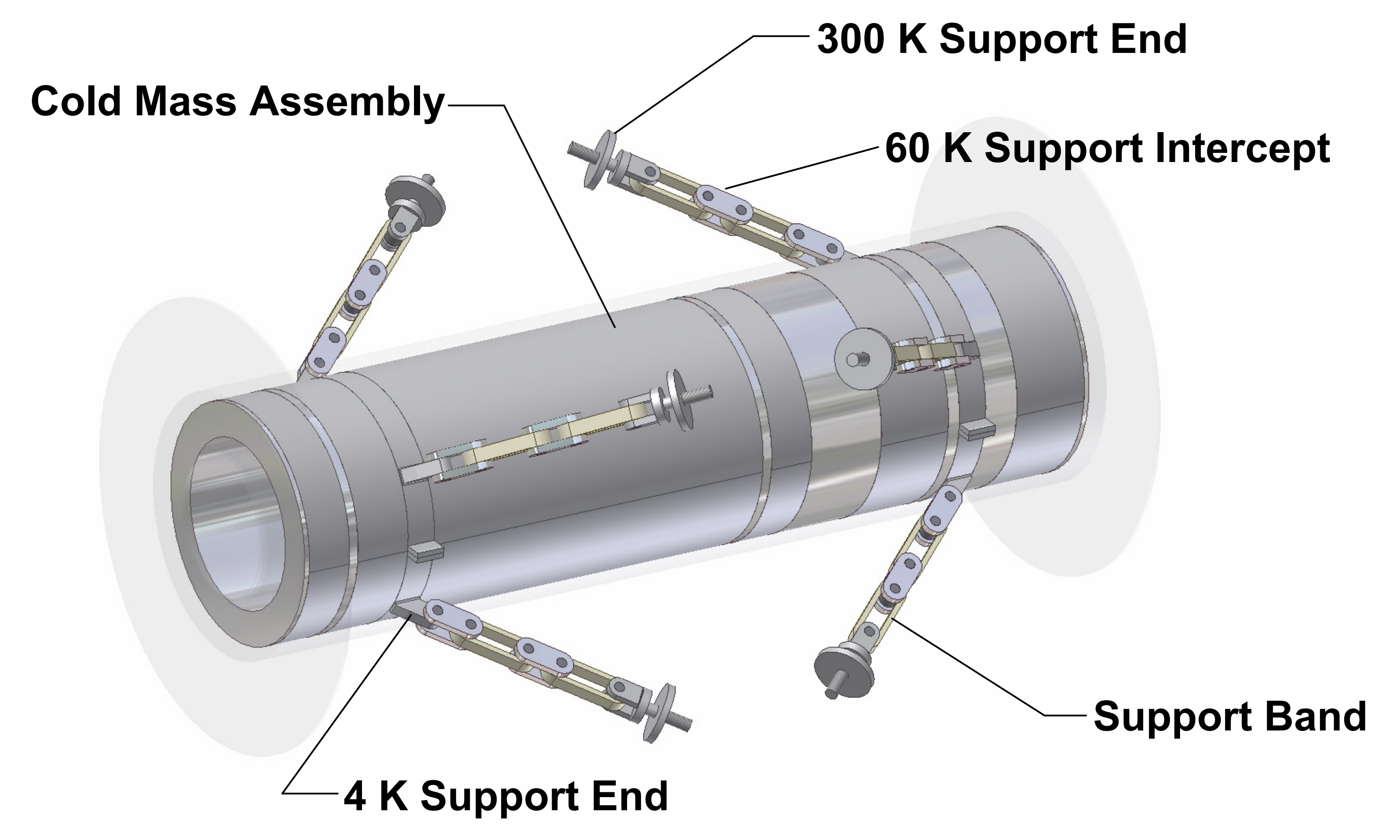
41 μm Nb-Ti
222 Filaments

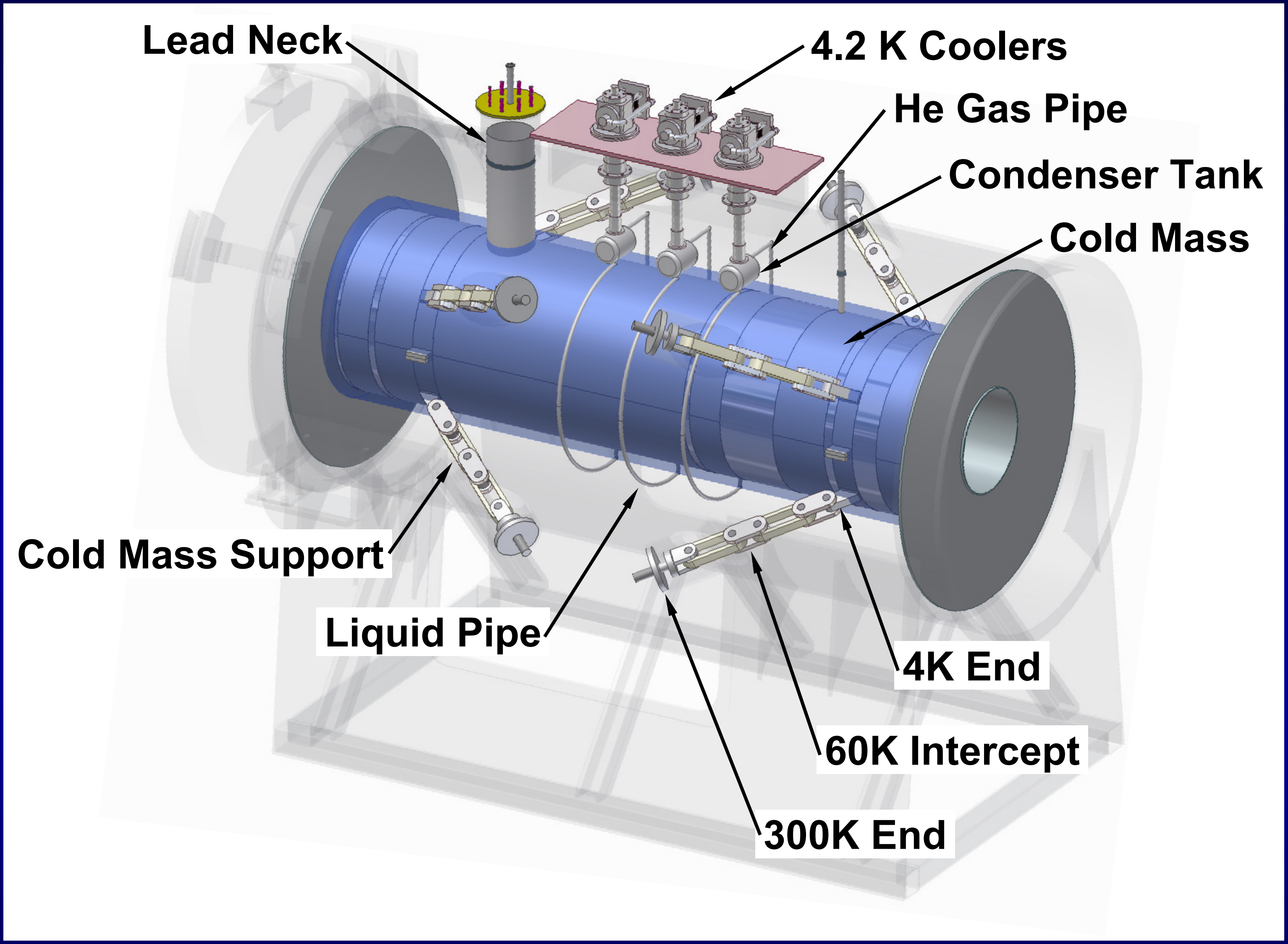
Cu/SC = 3.9 ± 0.4
Twist pitch: 19±3 mm
121.5 km purchased

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)

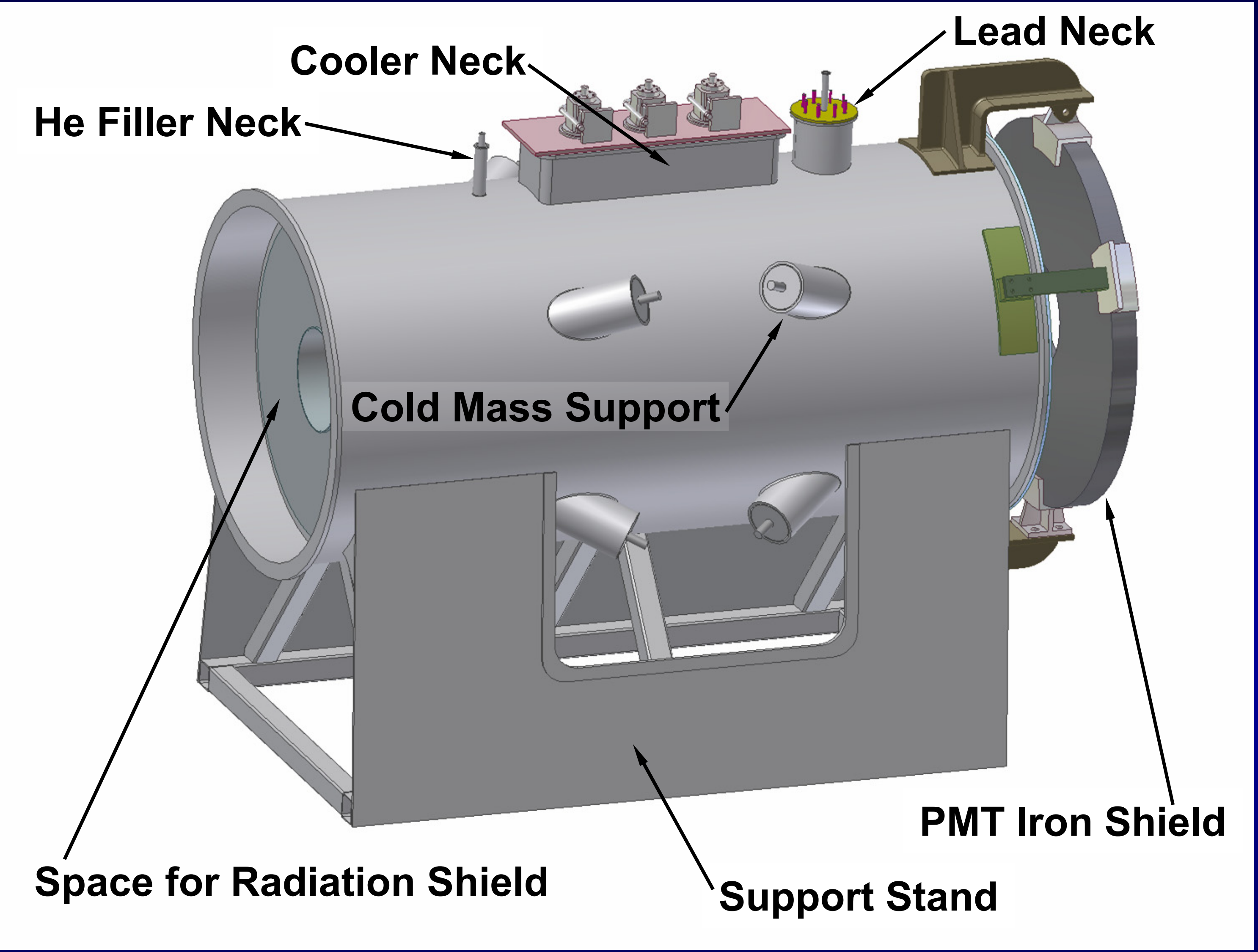




Lead Neck
4.2 K Coolers
He Gas Pipe
Condenser Tank
Cold Mass
Cold Mass Support
Liquid Pipe
4K End
60K Intercept
300K End

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

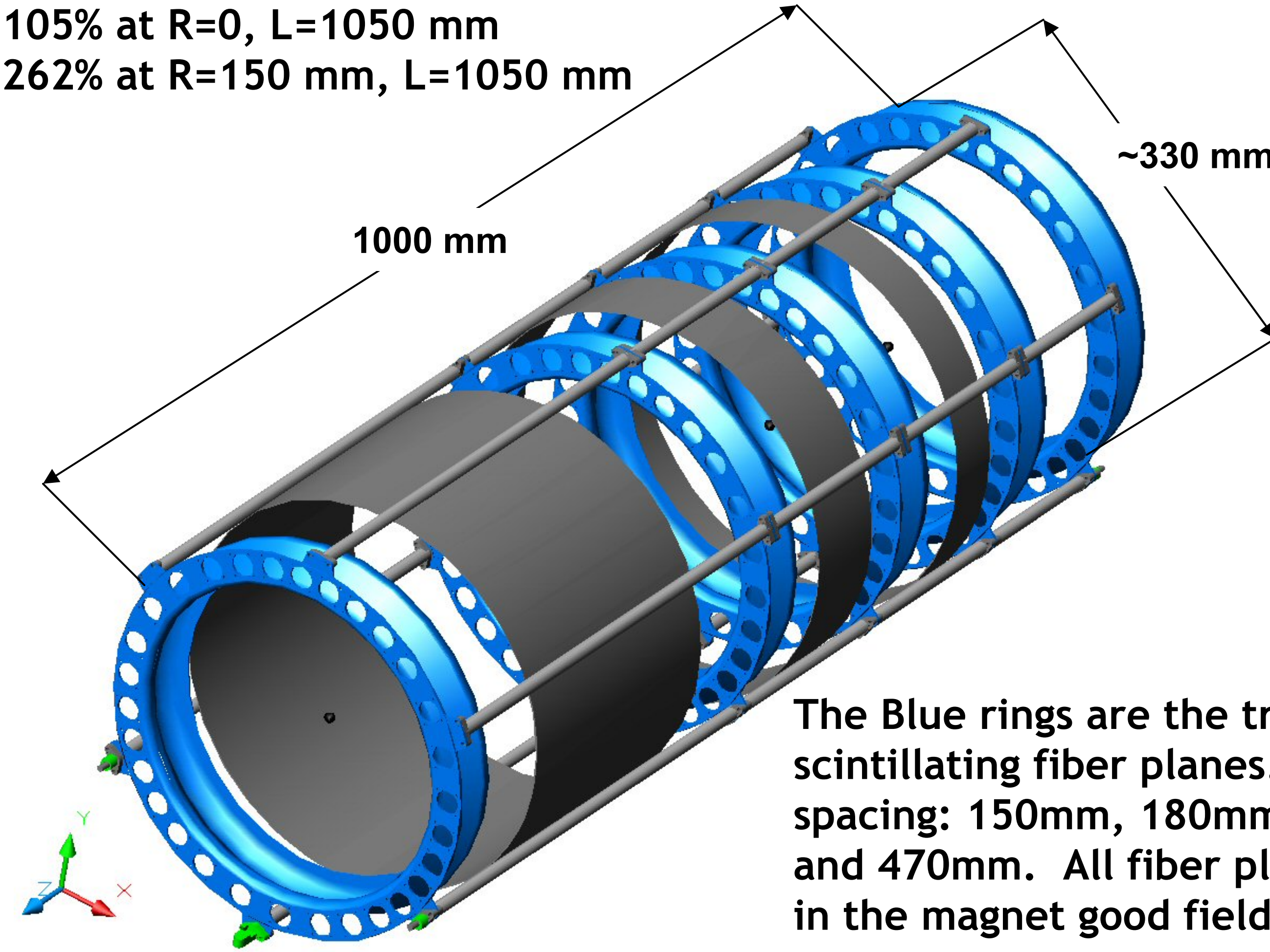

Lead Neck
Cooler Neck
He Filler Neck
Cold Mass Support
PMT Iron Shield
Space for Radiation Shield
Support Stand

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

MICE Scintillating Fiber Tracker Module

$\Delta B/B = \pm 0.105\%$ at R=0, L=1050 mm
$\Delta B/B = \pm 0.262\%$ at R=150 mm, L=1050 mm



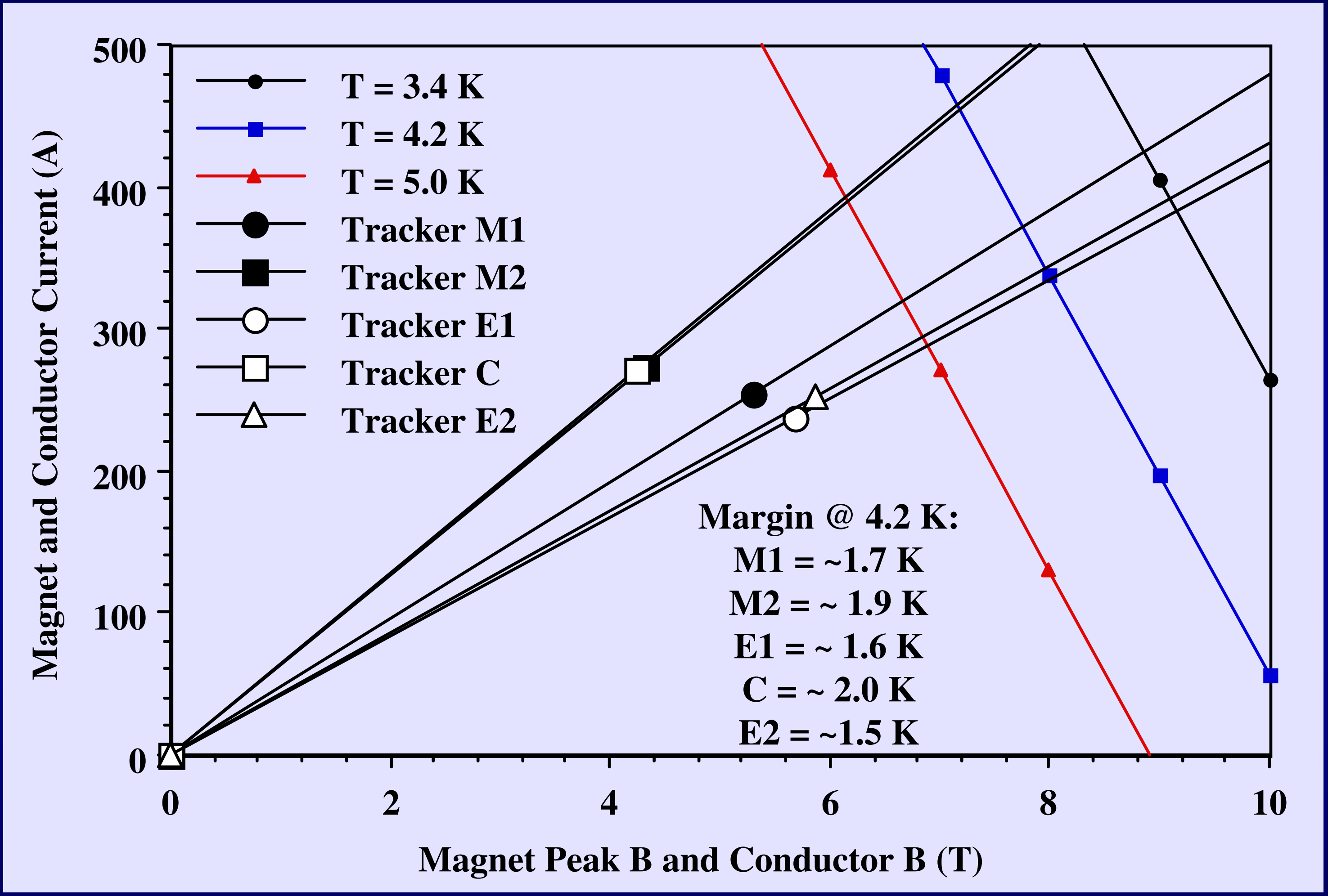
The Blue rings are the tracker scintillating fiber planes. Plane spacing: 150mm, 180mm, 200mm and 470mm. All fiber planes are in the magnet good field region.

Estimated Heat Loads

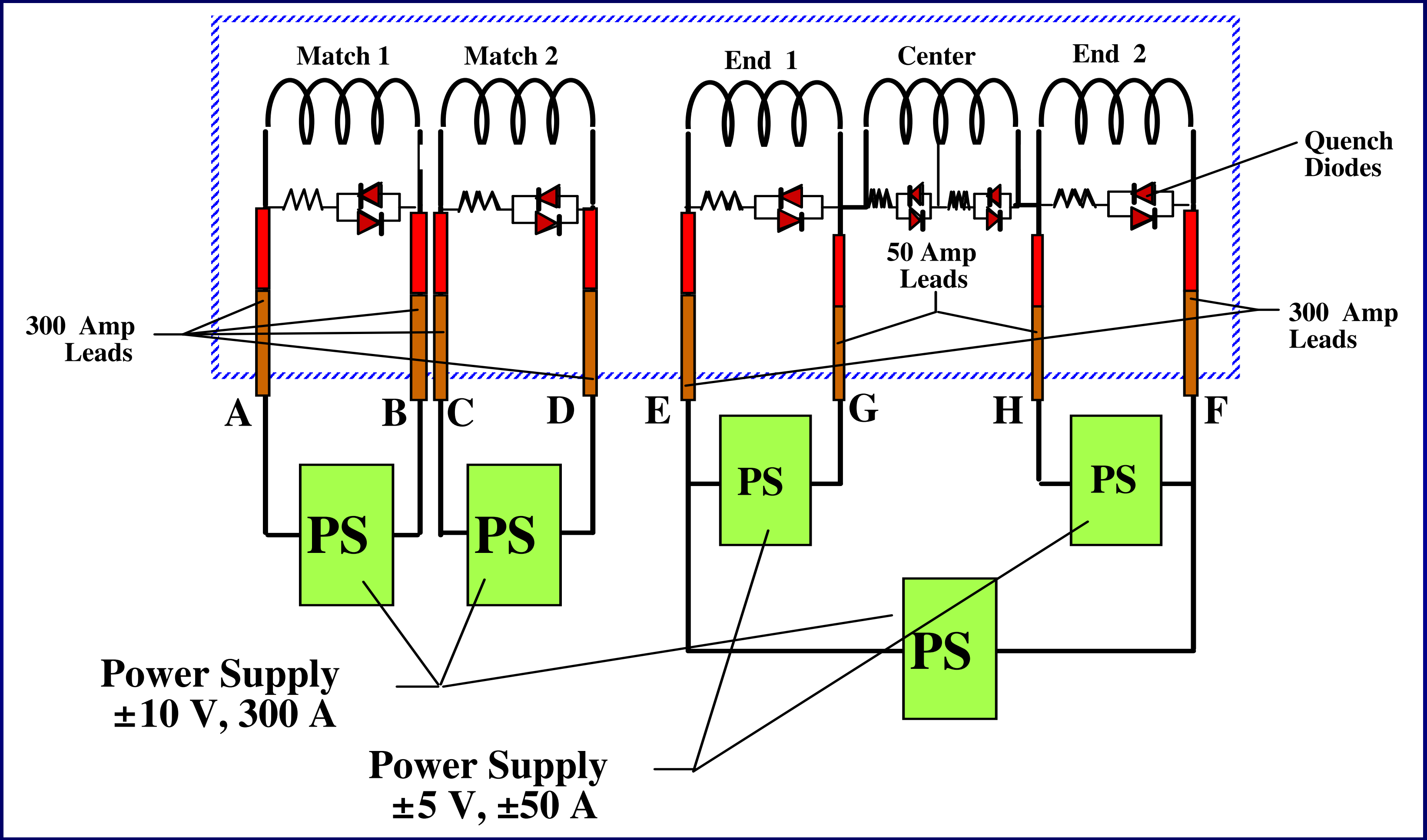
Component	Heat Leak (W) @ 60 K	Heat Leak (W) @ 4 K
Cold Mass Supports	~7	0.31
Radiation through MLI	~11	~0.4
Necks and Instrumentation	~11	~0.55
Current Leads	~80	1.05
Total Estimated Heat Leak	~109	~2.31

- 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



Quench Protection & Power Supply Hookup



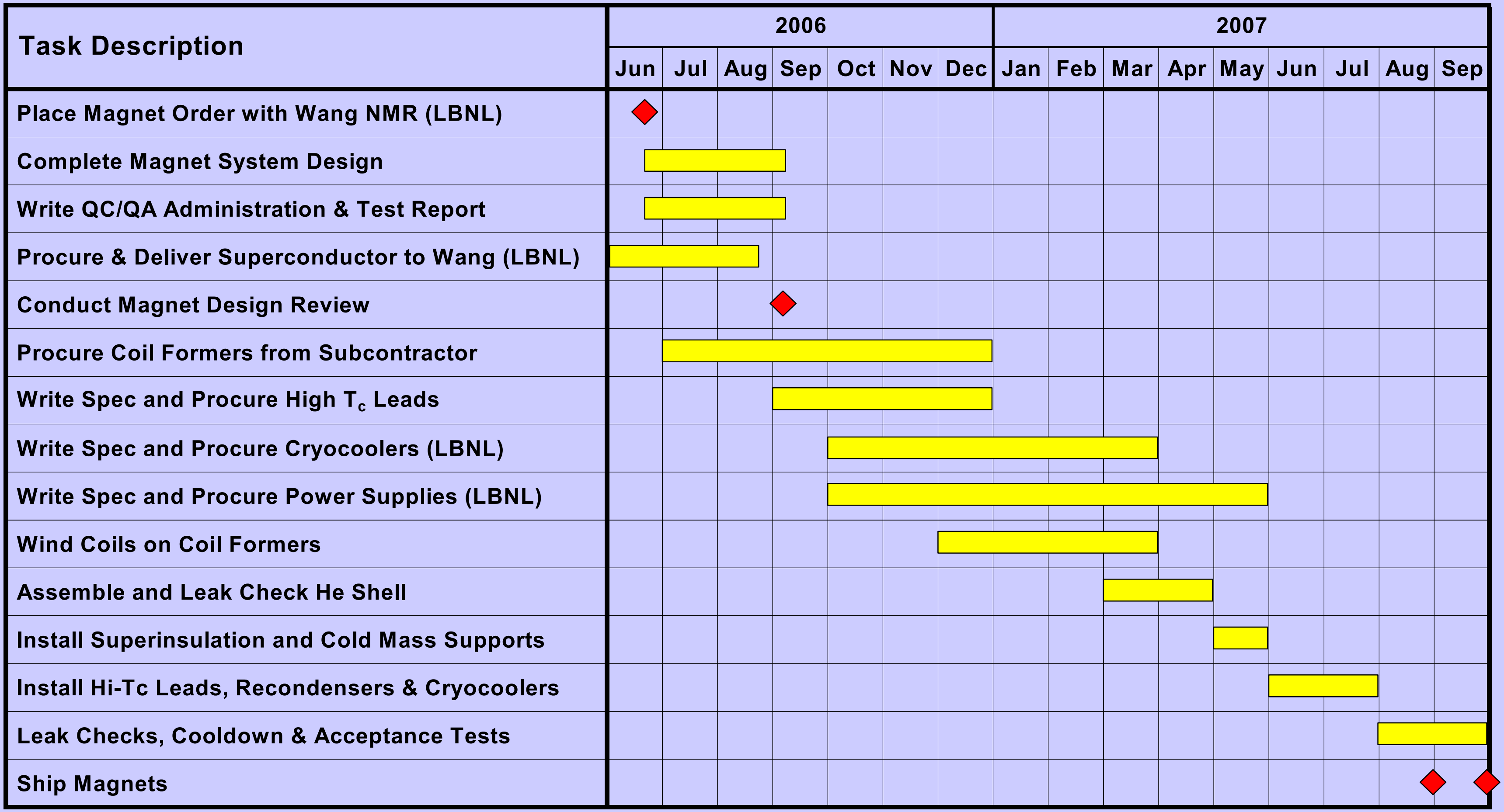
Pulse Tube Cryocoolers

- Magnets to be cooled to as low as 45 K (1st stage) and 3.8 K (2nd stage) using two 1.5 W pulse tube coolers
- Magnetic field at the cooler rotary valve motors is ~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 ΔT between coil & cooler 2nd 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



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

MICE Coupling Coil Fabrication Plan Proposal

Lawrence Berkeley National Laboratory (LBNL)

Institute of Cryogenic & Superconductivity Technology (ICST)
at the Harbin Institute of Technology

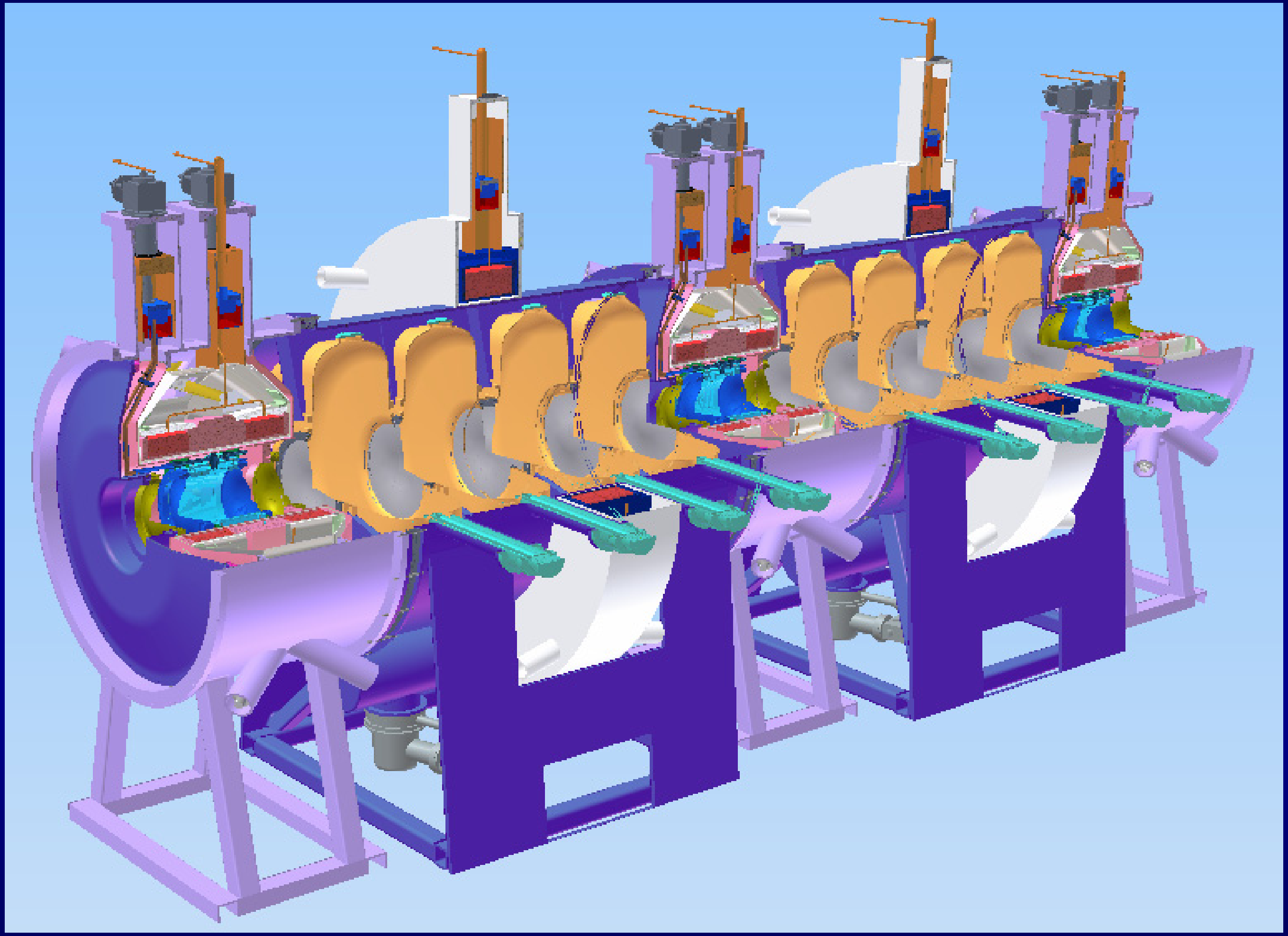
Berkeley Lab
75 Years of World-Class Science 1931-2006

Neutrino Factory
Muon Collider
MICE

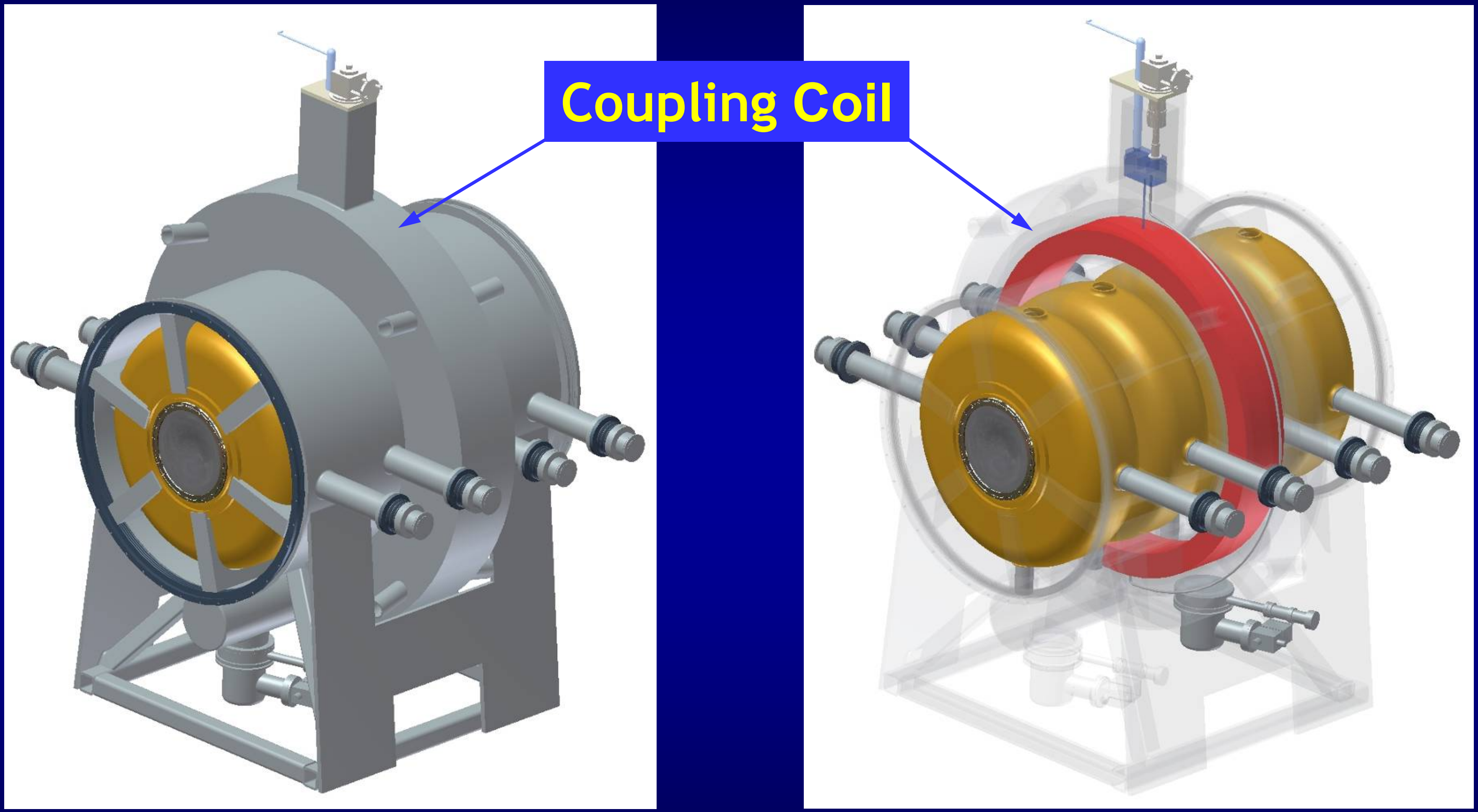
Progress towards LBNL/ICST Collaboration

- **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**

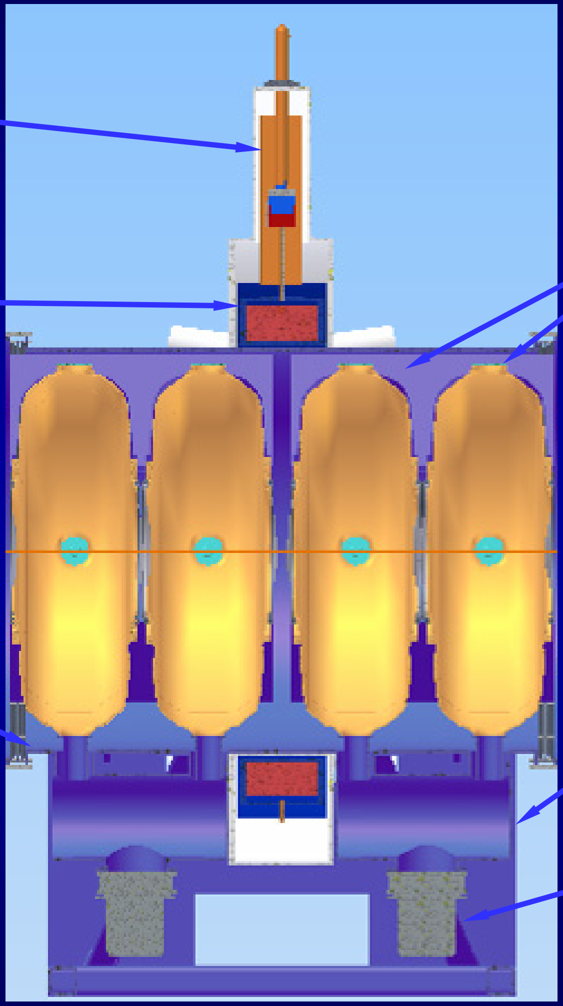
MICE Cooling Channel



MICE RF Cavity & Coupling Coil Module



RFCC Module Cross Section



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

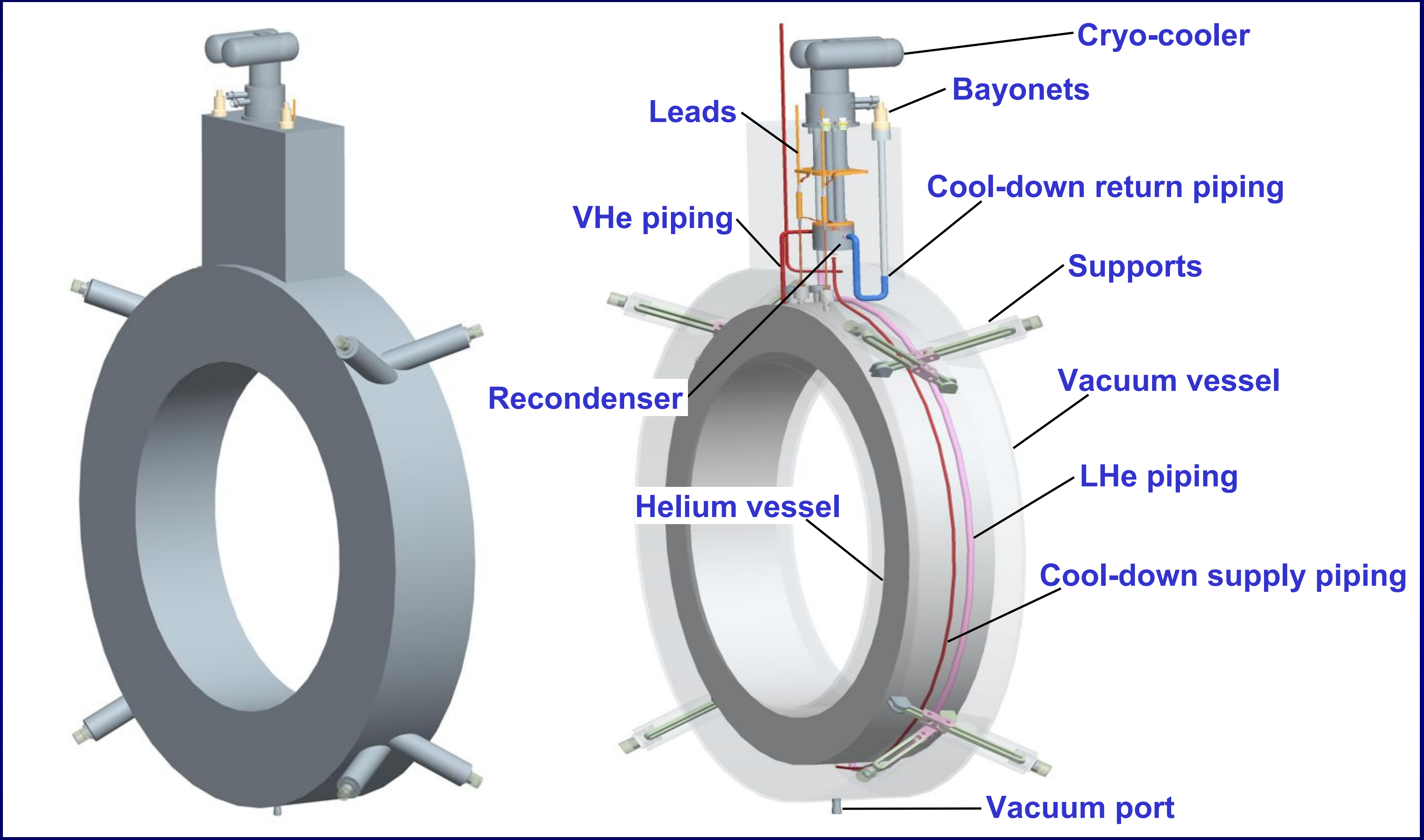
Coupling Coil Specification (LBNL)

- 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

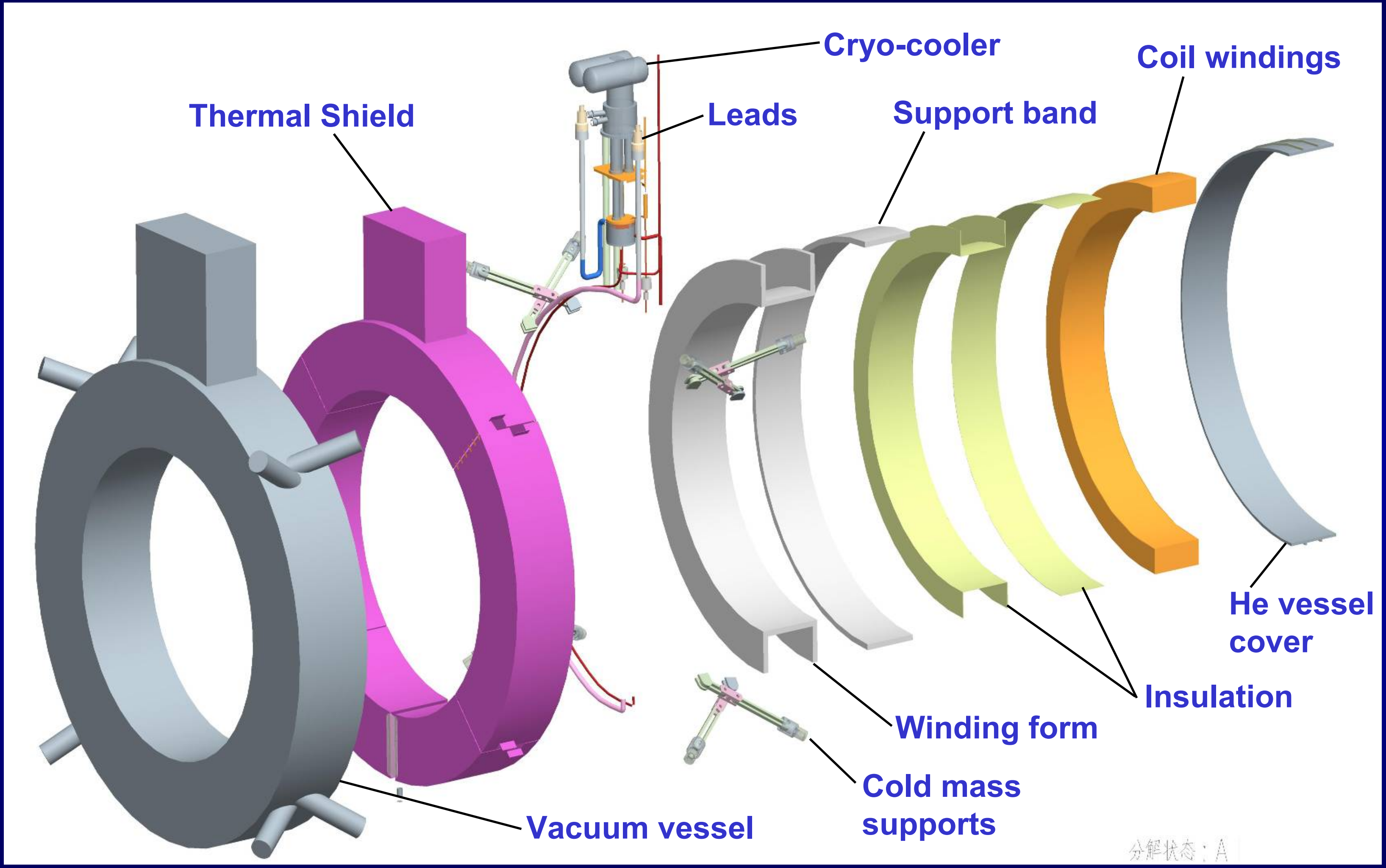
Coupling Coil Design Review

- **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**

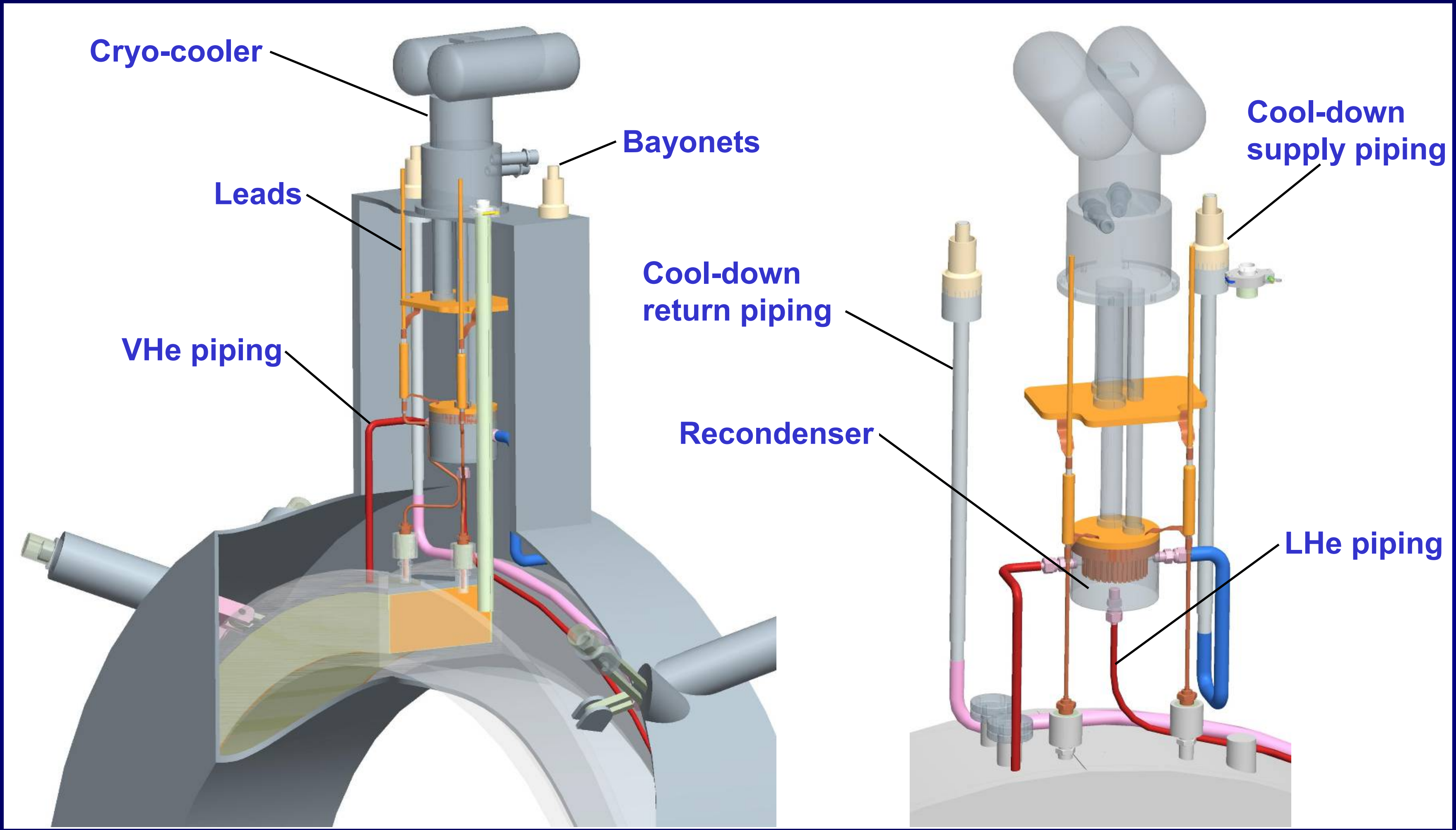
ICST Coupling Coil CAD Model



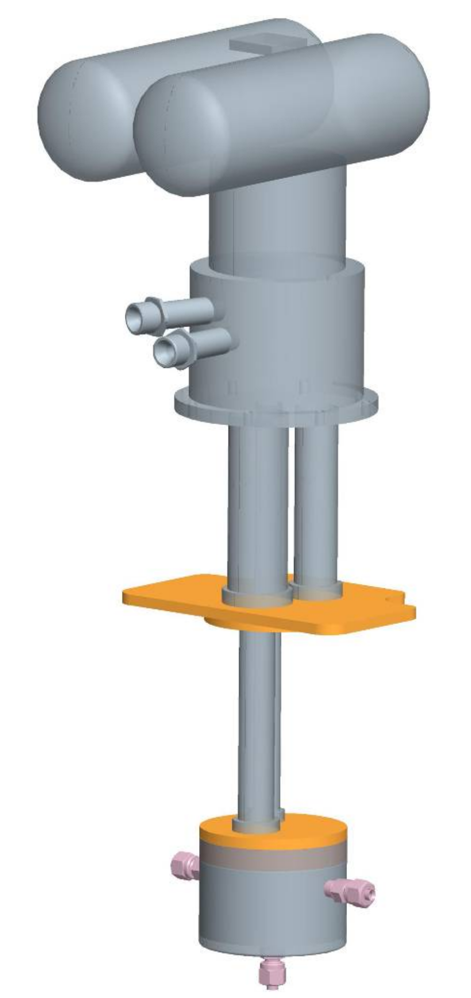
Coupling Coil Components (ICST)

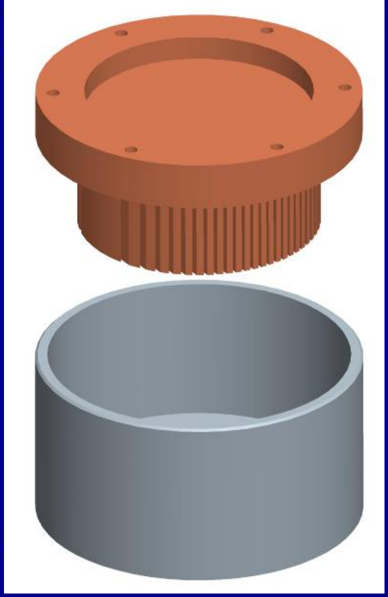


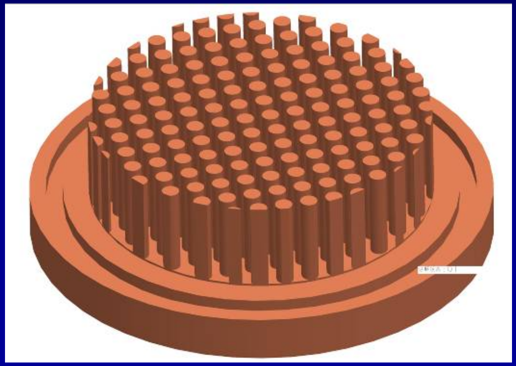
Cooling Circuit Details (ICST)

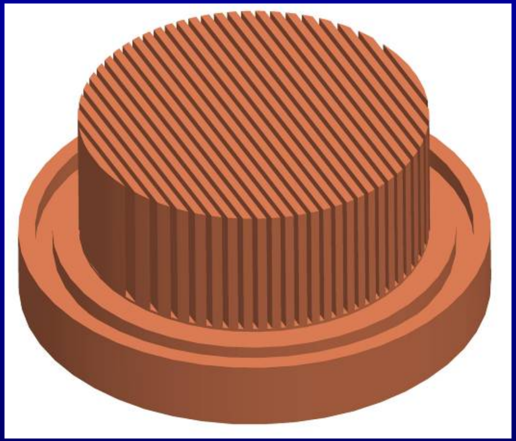


Cryocooler and Condenser Details (ICST)

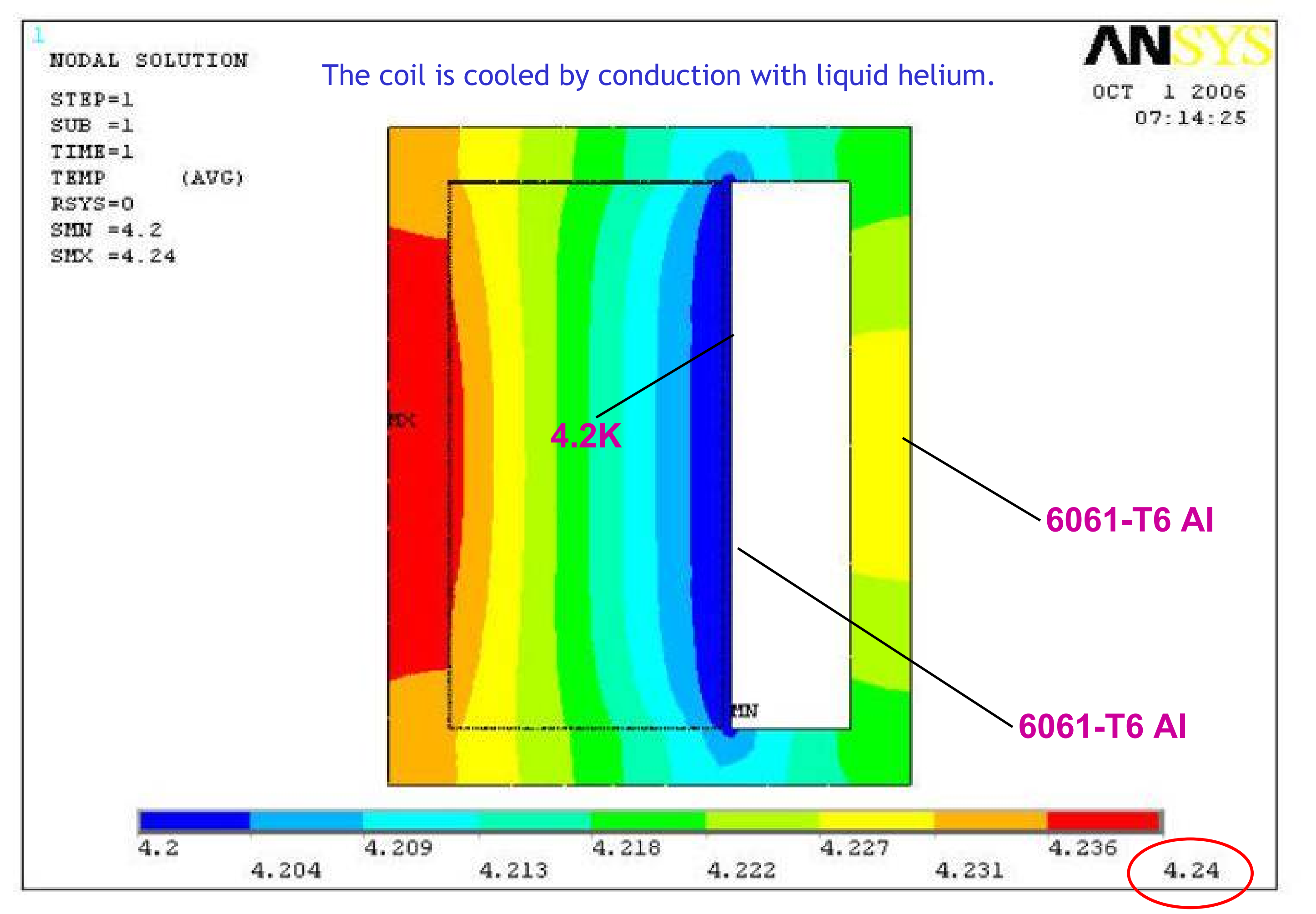




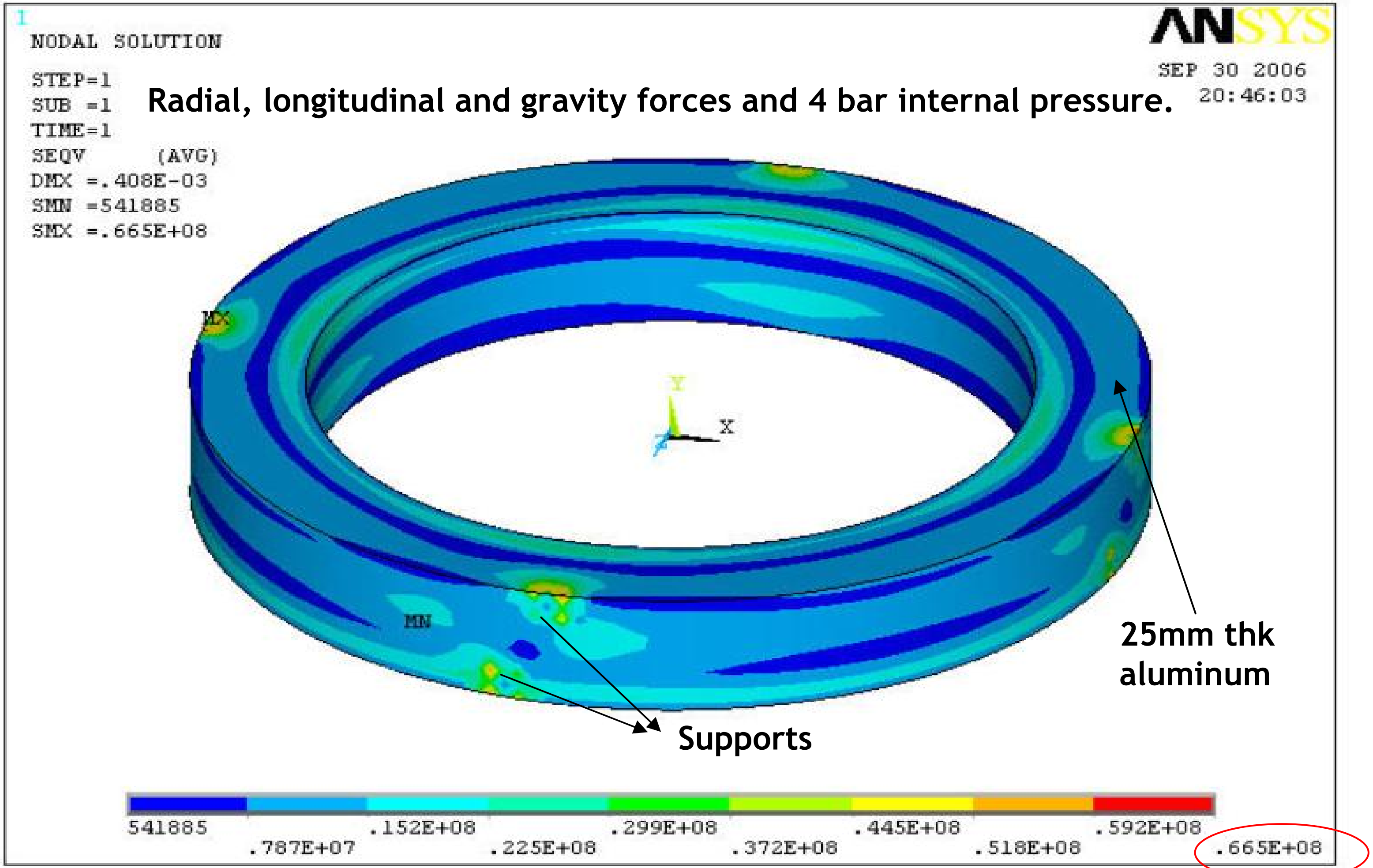




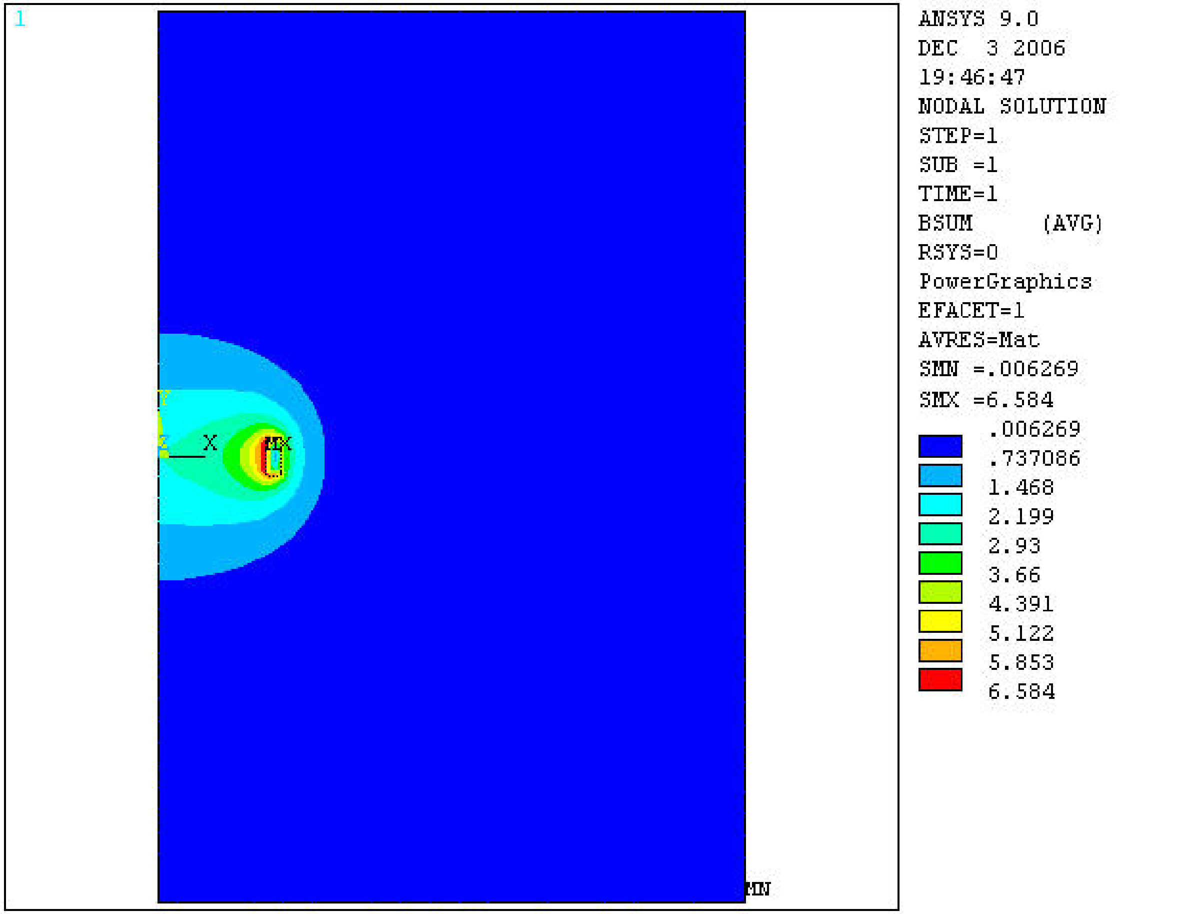
Helium Vessel Thermal Analysis (ICST)



Helium Vessel Stress Analysis (ICST)



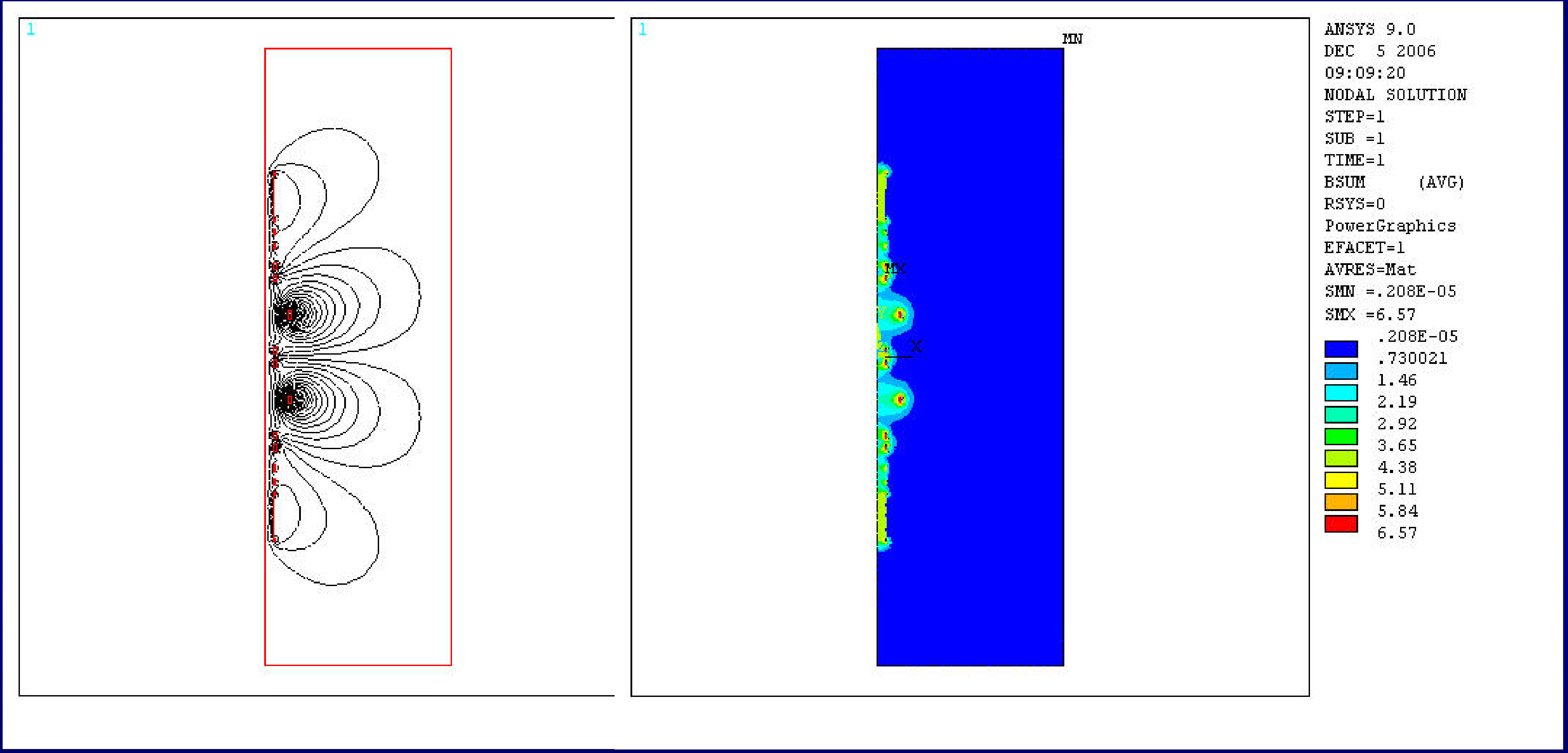
Coupling Coil Magnetic Field Analysis (ICST)



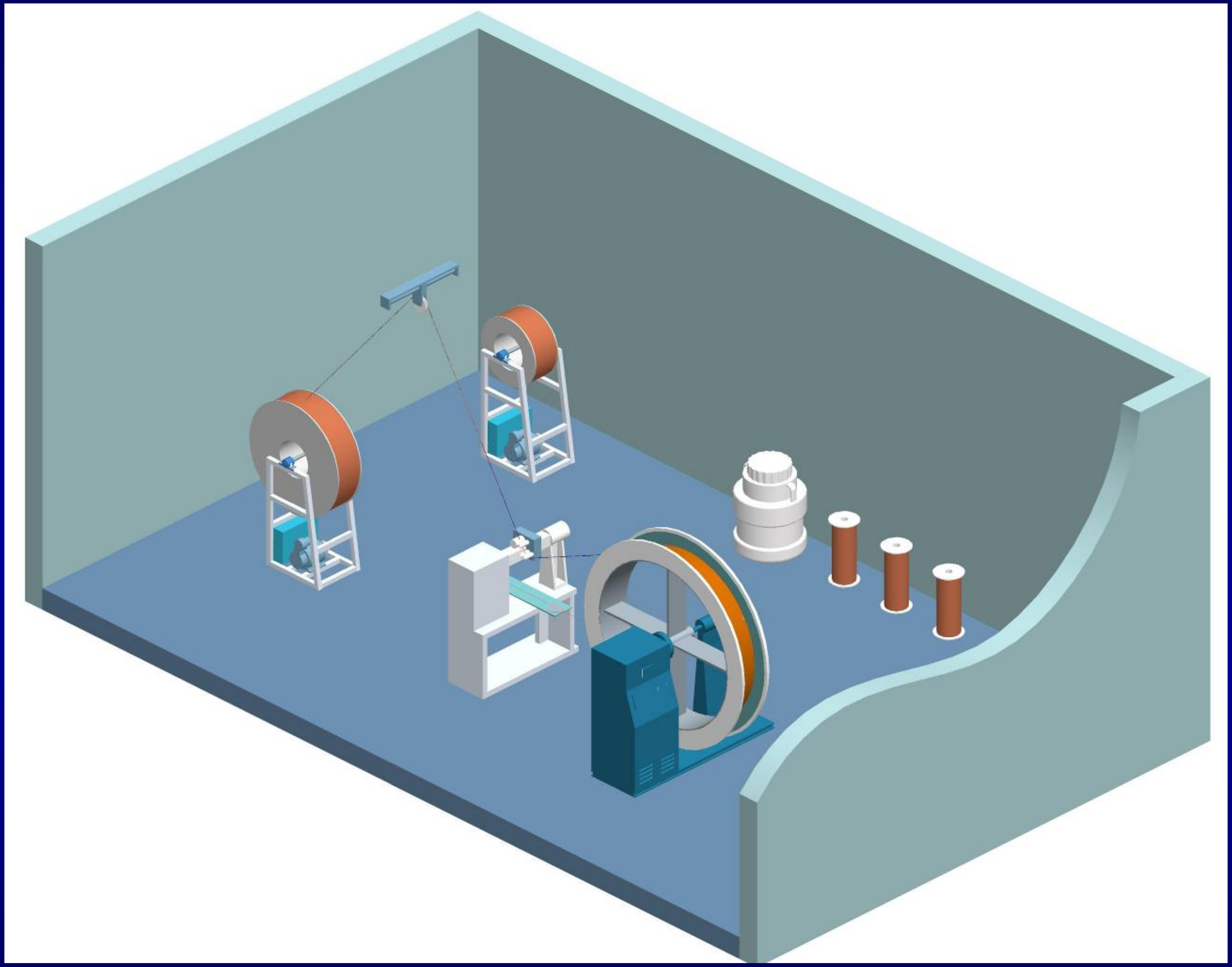
B_{max} = 6.58T (ICST analysis), B_{max} = 6.51T (MICE conceptional design)

MICE Channel Magnetic Field (ICST)

Flip Mode (Case1)



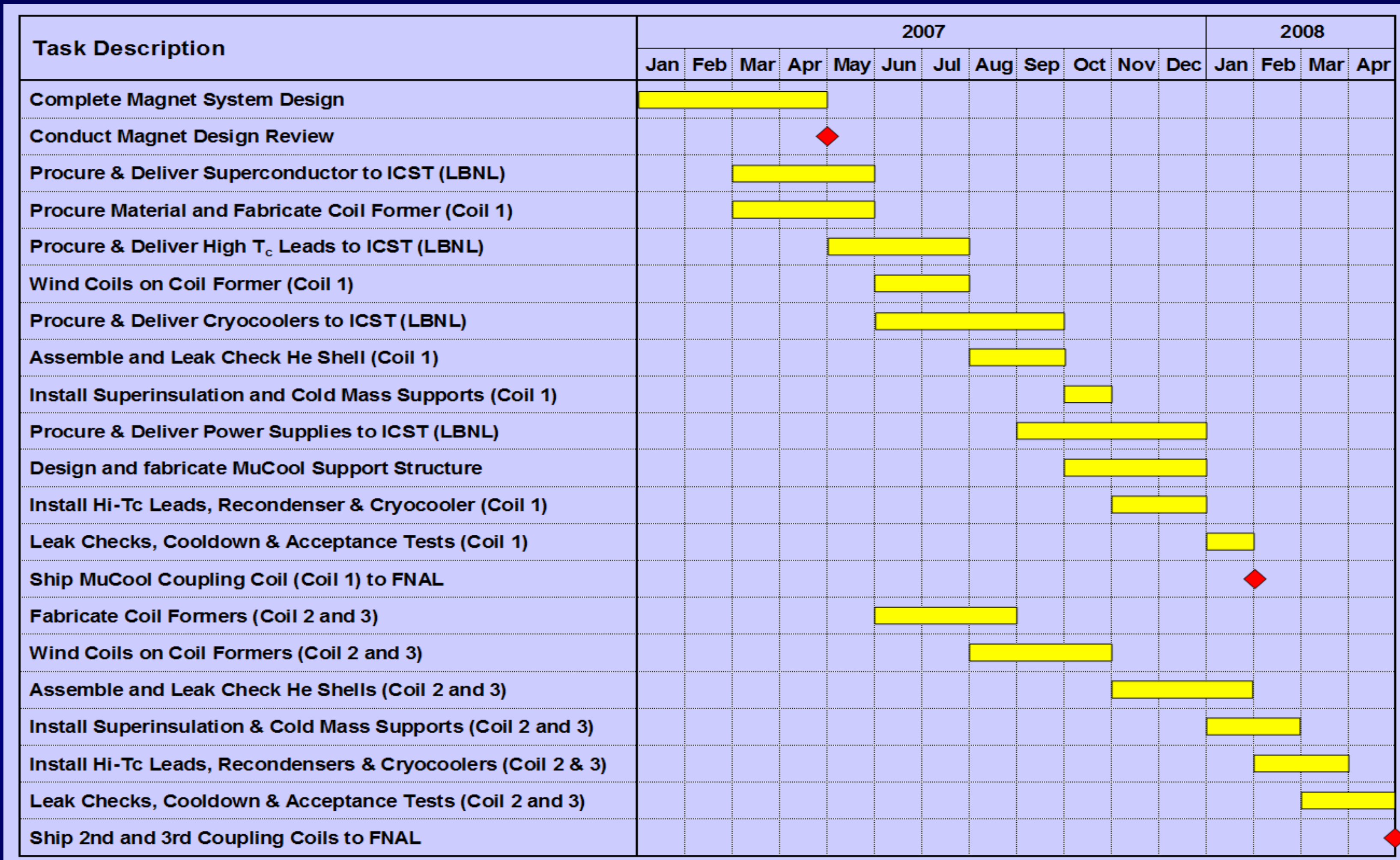
ICST Proposed Coil Winding Facility



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



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