ILC Main Linac Superconducting Cryogen Free Splittable Quadrupole (Technical Design)

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for Superconducting Magnet Team

Splittable Quad Review, March 2, 2010, FNAL

Splittable Quadrupole Milestones

Task from ILC Project Management: Design and manufacture Splittable Quadrupole to provide the quadrupole package installation and replacement outside of a very clean room.

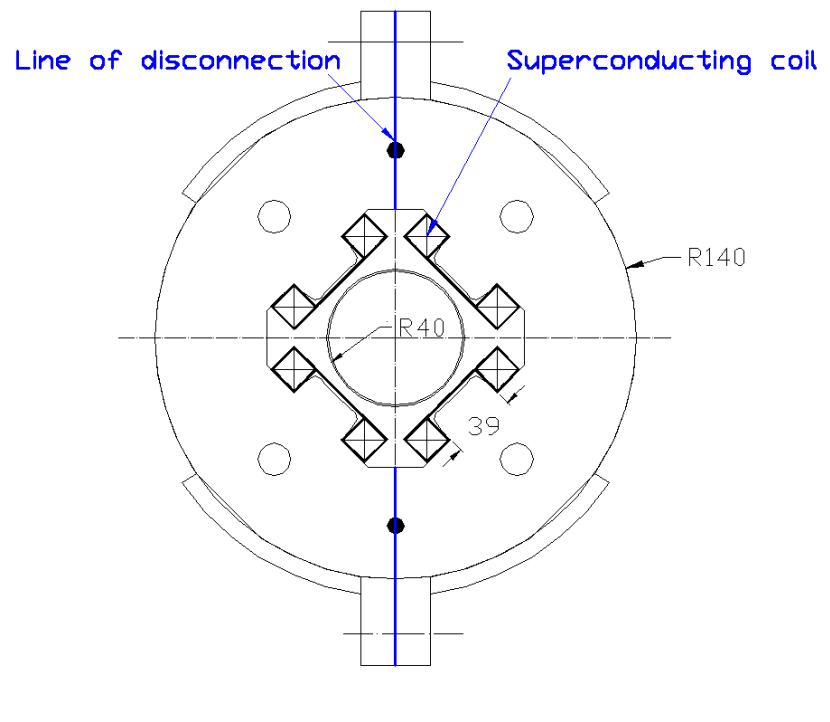
Milestones:

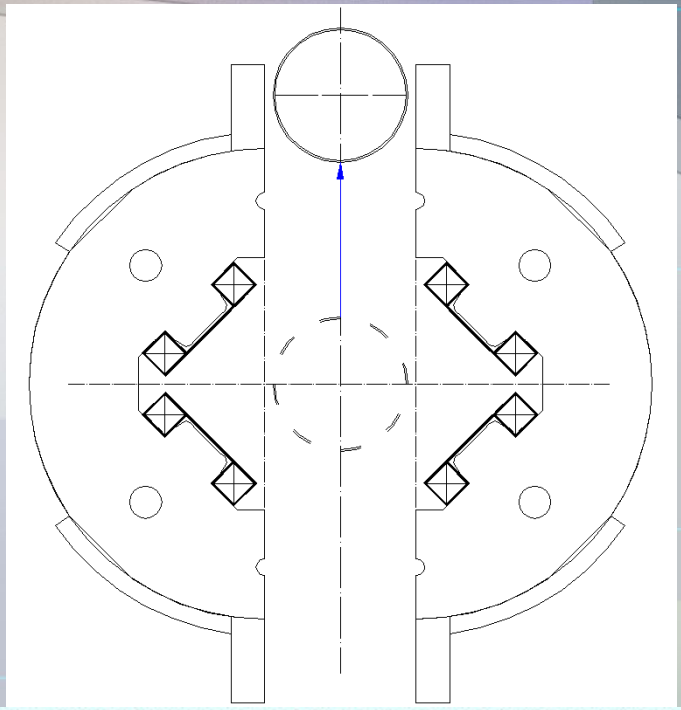
- Magnetic, mechanical, thermal design.
- Quadrupole drawings.
- Parts order.
- Quadrupole manufacturing
- Instrumentation and preparation for test.
- Quadrupole test.

Main issues:

- Stable magnetic and mechanical design.
- Effective conductive cooling.
- Easy assembly /disassembly around beam pipe.
- Quadrupole+BPM rigid connection.
- Magnetic axis stability.
- Quench protection.
- Mechanical properties of SC wire insulation.
- Fringe fields.

Quadrupole Mechanical Concept





It was chosen the quadrupole design with racetrack coils which easy to split in vertical or horizontal direction.

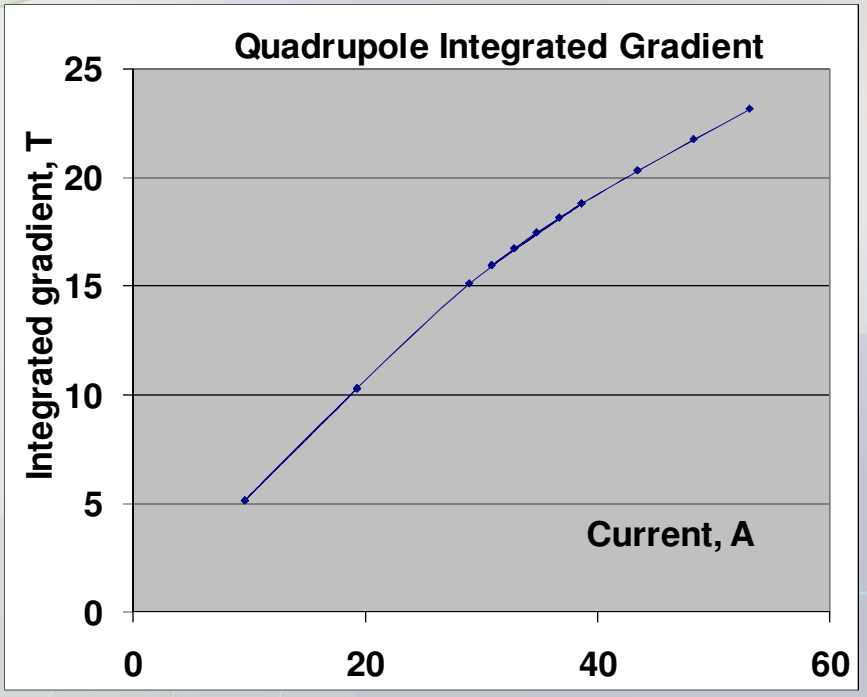
QUADRUPOLE MODEL PARAMETERS

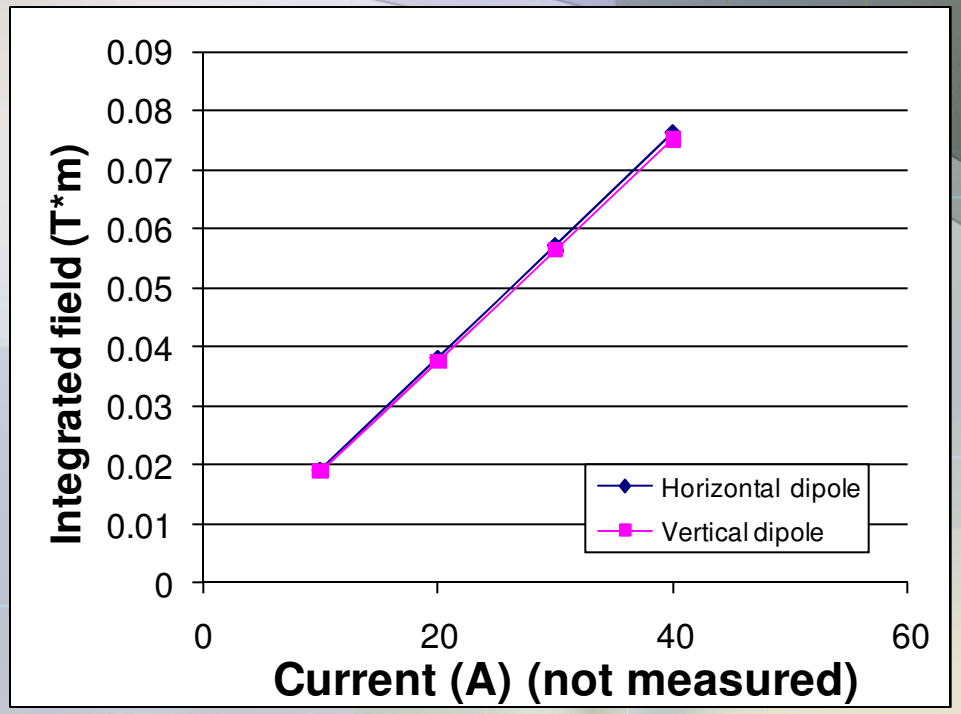
Parameter	Unit	Value
Peak current at 36 T gradient	A	100
Magnet length	mm	680
NbTi superconductor diameter	mm	0.5
Superconductor filament size	μm	3.7
Superconductor critical current at 5 T and 4.2 K	A	200
Coil maximum field	T	3.3
Quadrupole coil number of turns/pole		700
Yoke outer diameter	mm	280

ILC Quadrupole Specification

Parameter	Unit	Value
Integrated gradient	T	36
Aperture	mm	78
Effective length	mm	660
Peak gradient	T/m	54
Field non-linearity at 5 mm radius	%	0.05
Dipole trim coils integrated strength	T-m	0.075
Quadrupole strength adjustment for BBA	%	-20
Magnetic center stability at BBA	micron	5
Magnetic center offset in cryomodule	mm	0.5
Quadrupole azimuthal offset in cryomodule	mrad	0.3
Liquid helium temperature	K	2

ILC HGQ01 Quadrupole Test Results (1)





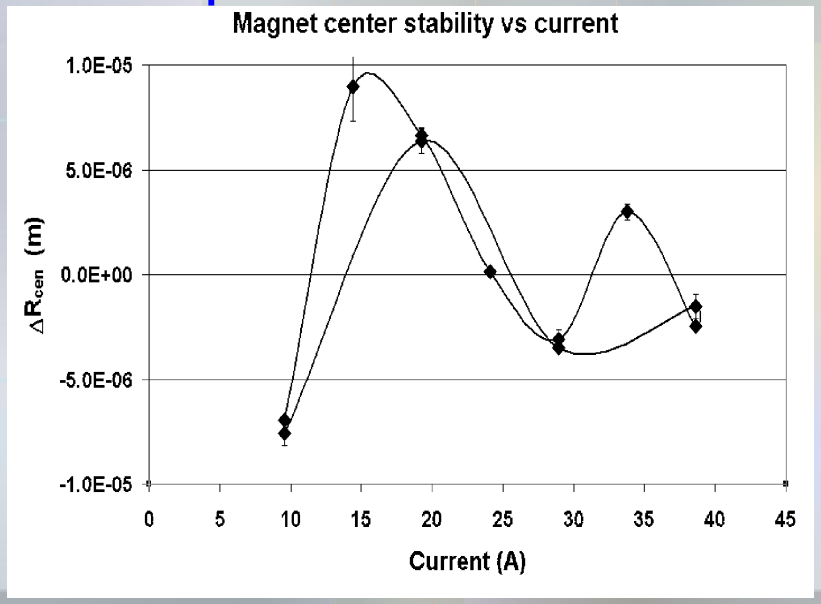
The magnet integrated gradient was measured at 700 turns/pole.

200 turns were used for dipoles. The final points at 60-80 A on the left figure are not shown.

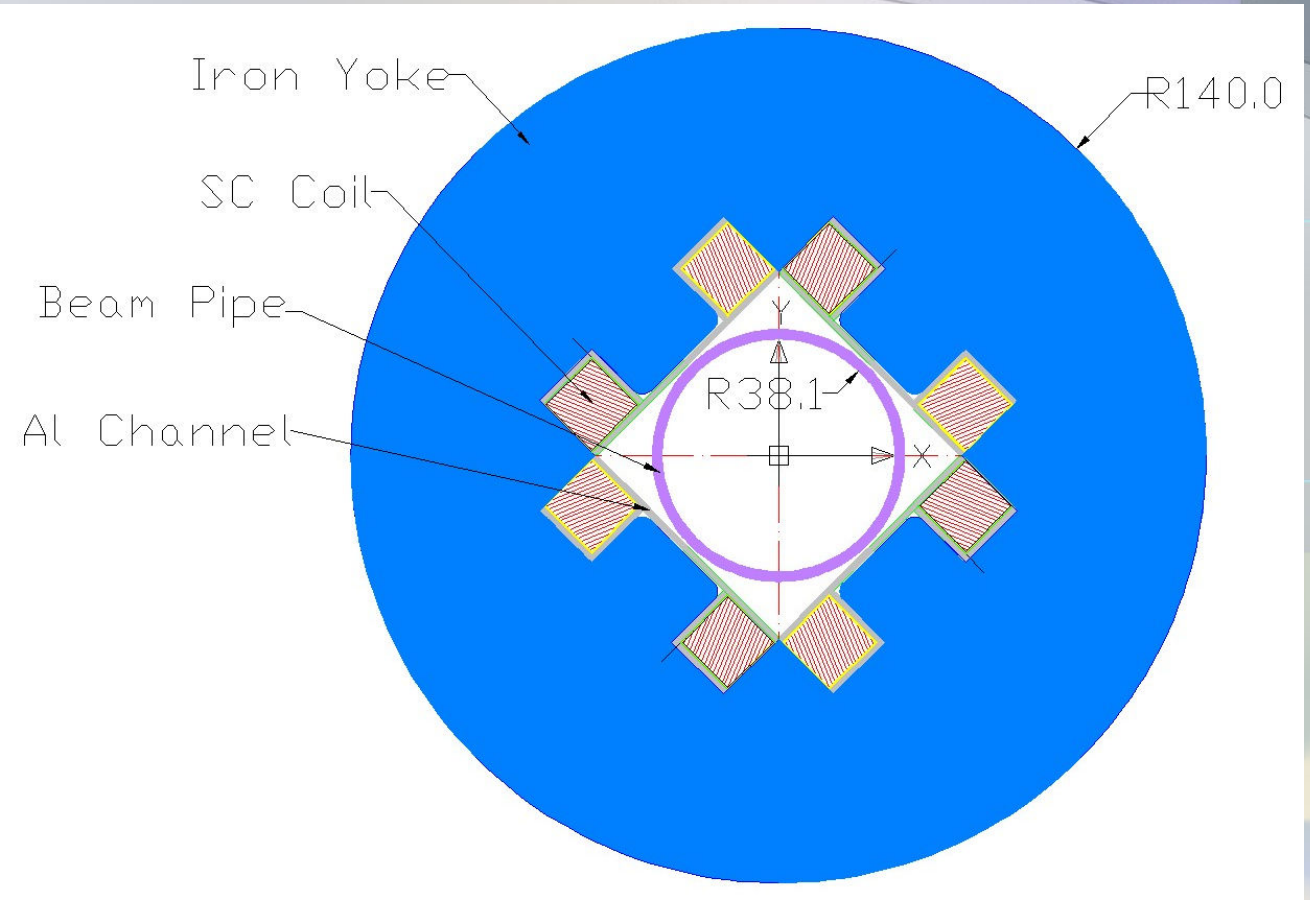
The dipole correctors generate specified integrated field 0.075 T-m at current 40 A

ILC HGQ01 Magnetic Center Stability

- Magnet center moves in the limits of ±2.5 μm when the current is between 3 A and 10 A.
- From 10 to 40 A the quadrupole center moved linearly with a derivative 4 μm/A of quadrupole current. This effect will be investigated during next tests and may be caused by the probe or quadrupole coils offsets, or unequal number of turns in the coils.
  - Correctors can be used to compensate linear dependence.
  - After subtracting this correction, the variation of quadrupole center is in the limits of < 8 μm

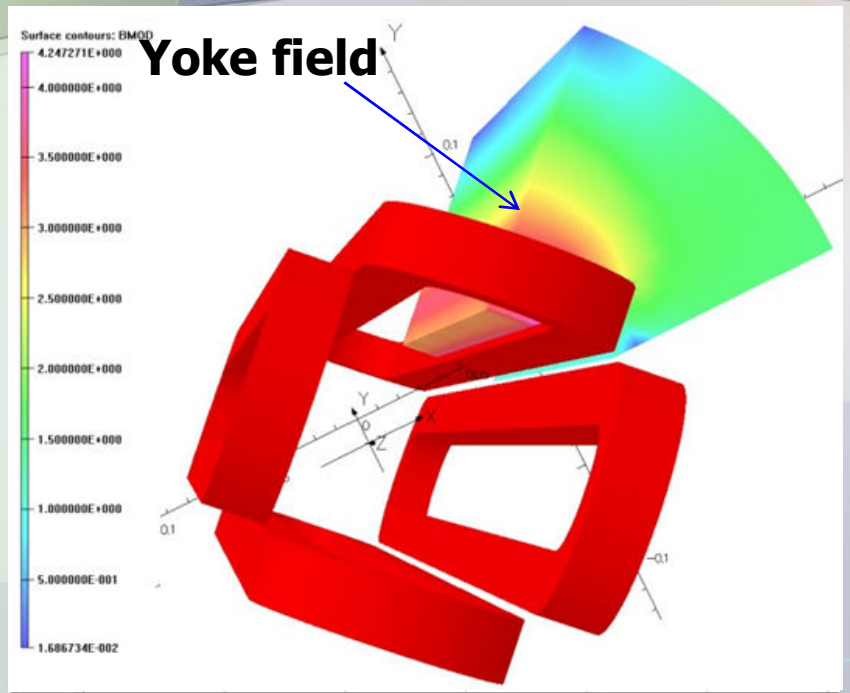


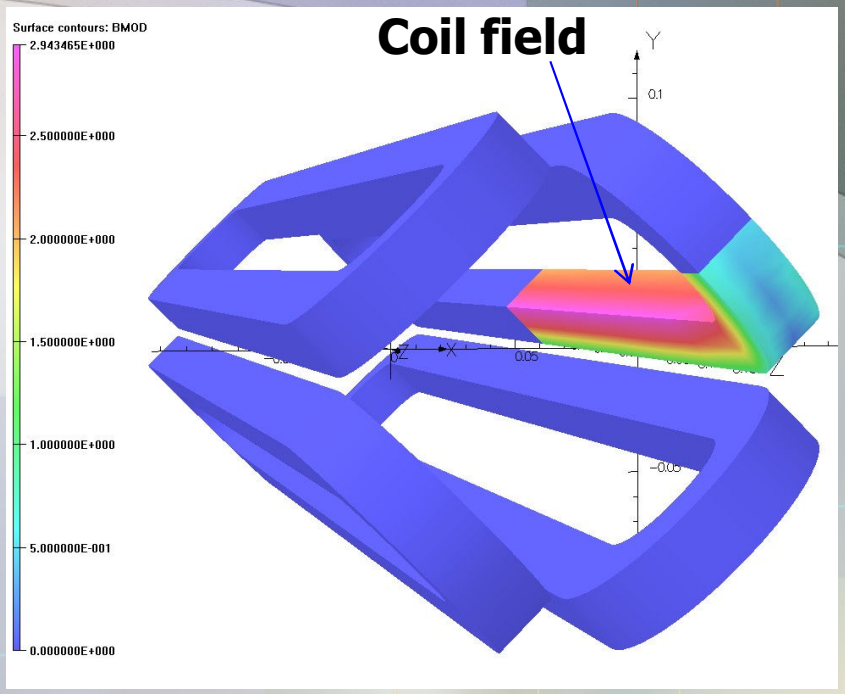
Updated Quadrupole Package Cross-Section

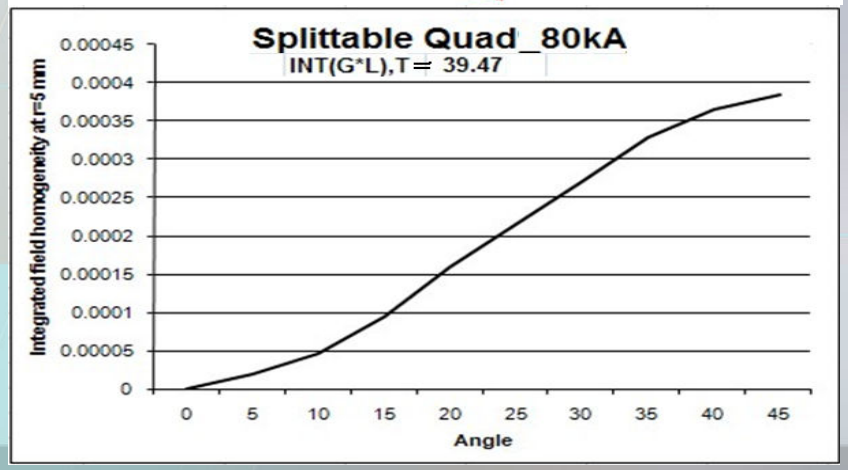


Updated design. Coil mounted and glued inside yoke slots.
Coils wound into Al channel. SC wire has additional insulation.
Al coil channels at ends connected to the outer Al shell.

Quadrupole Magnetic Field (1)

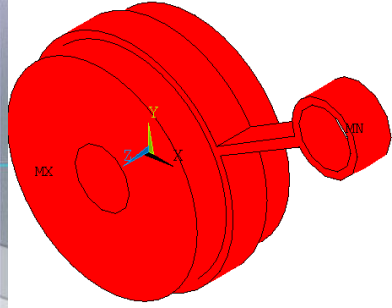






- Peak field 4.3T is at the pole ends.
- Coil peak field is 2.9 T.
- Integrated gradient at 80 kA total coil current is 39 T.
- Integrated gradient homogeneity at R=5 mm is 4 units.

Quadrupole Cooling-Down

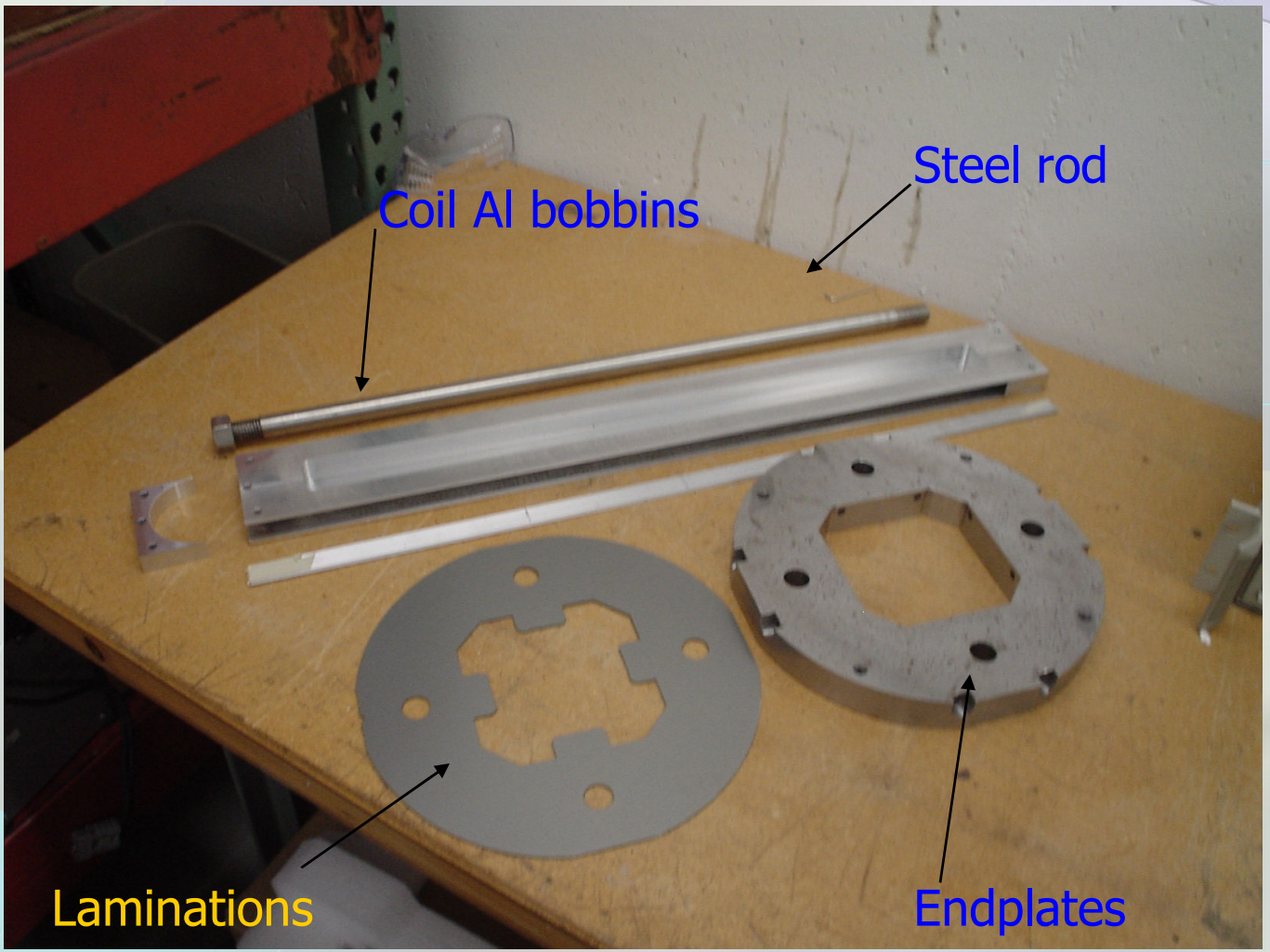


- The quadrupole will be cooled using conductive cooling.
- Five heat transfer leads with cross-section 50 mm x 10 mm will thermally connect quadrupole Al shell and LHe supply line.
- The quadrupole Al shell will be also in a good thermal contact with Ø300 mm He return line.
- Cooling down time for the whole cryomodule is 30 hours.
- During cooling initially the cold He gas goes through supply and return lines and temperature changes from 300 K to 2 K. In such regime the enthalpy of the cold gas between 4.2 K and 300 K is utilized as well.
- To cool down 1 kg steel from 300 K to 2 K is needed to evaporate 0.8 liters of LHe. The quadrupole mass is ~ 280 kg.
- Quadrupole cooled down from 300K to 3.5K in 38 hours.

Quadrupole Package Modifications

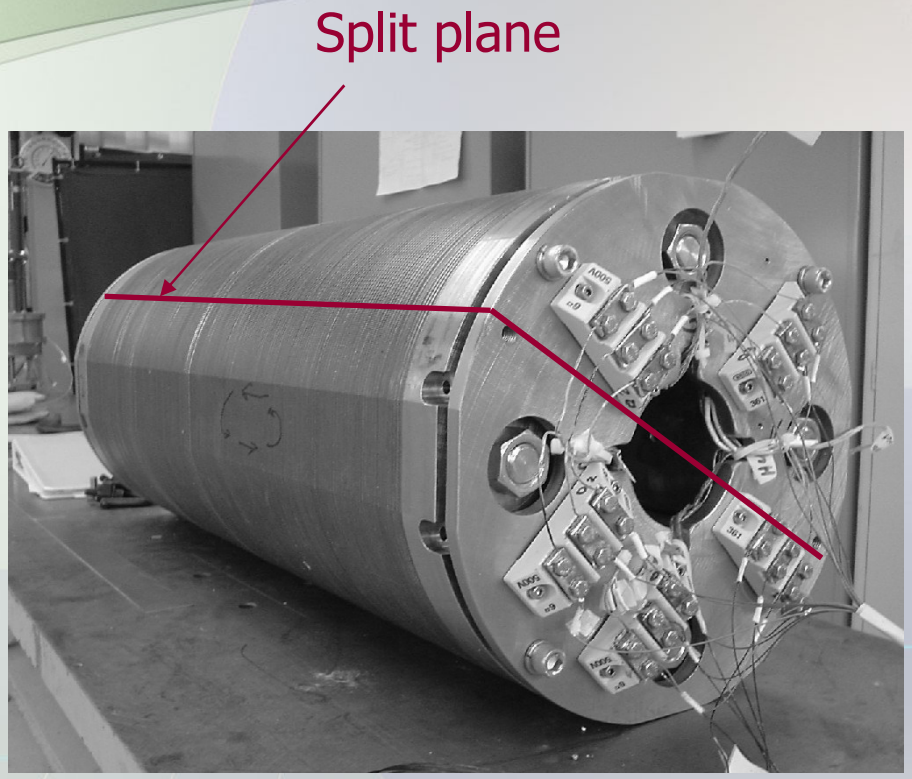
- The quadrupole structure must be mechanically stable to avoid magnetic center shift during excitation.
- Current leads between cold mass and leads LHe tank should be modified to provide operation in a conduction cooling mode.
- Easy magnet assembly and disassembly.
- Modify the coil bobbins for better conduction cooling.
- Improve superconducting wire electrical insulation mechanical properties.
- Provide good thermal passes from coils and core to the LHe supply line.
- Provide coil temperature monitoring.

HGQ01 Quadrupole Parts



There is enough 0.5 mm dia. superconductor to wind new magnet coils.

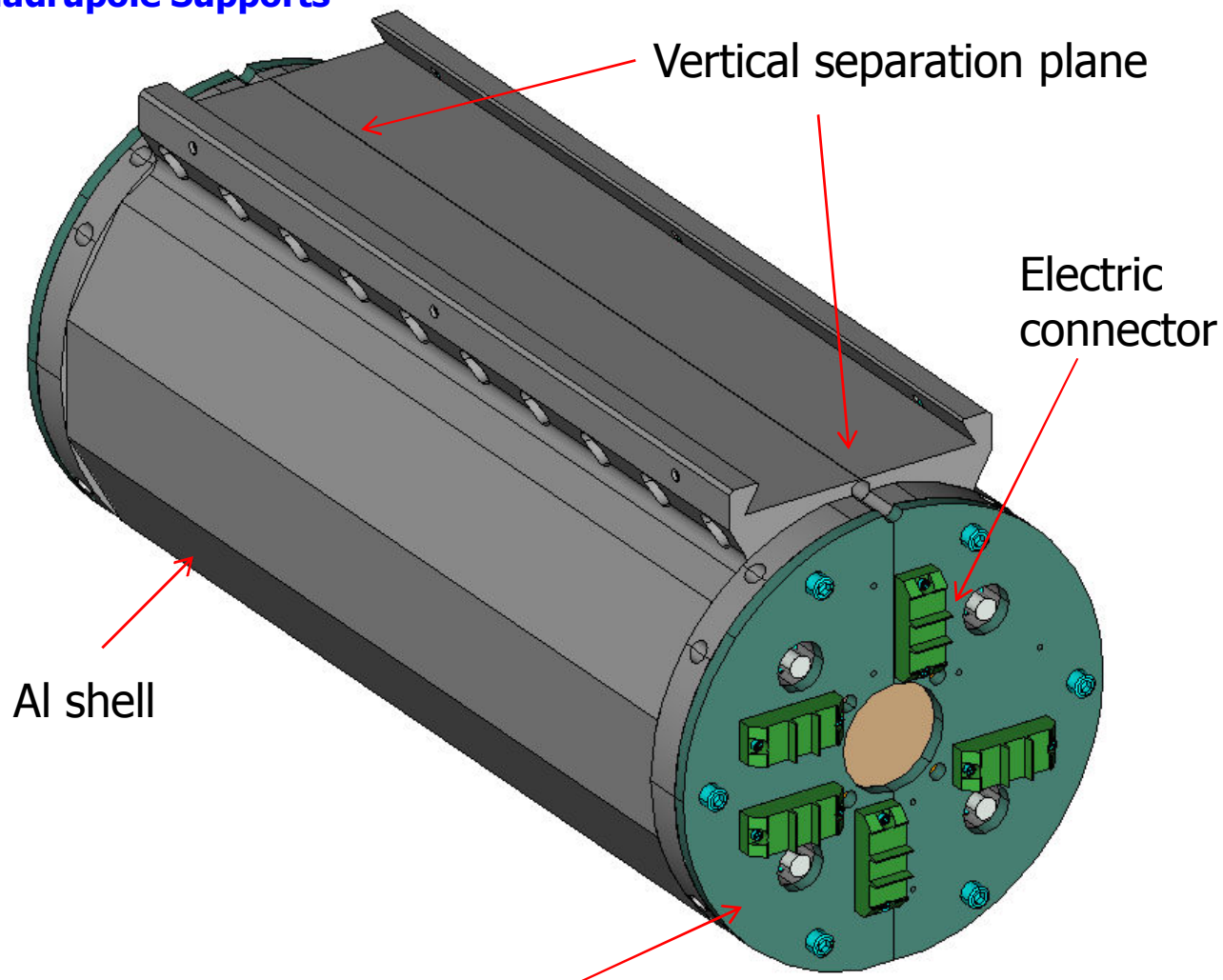
HGQ01 Quadrupole Modifications



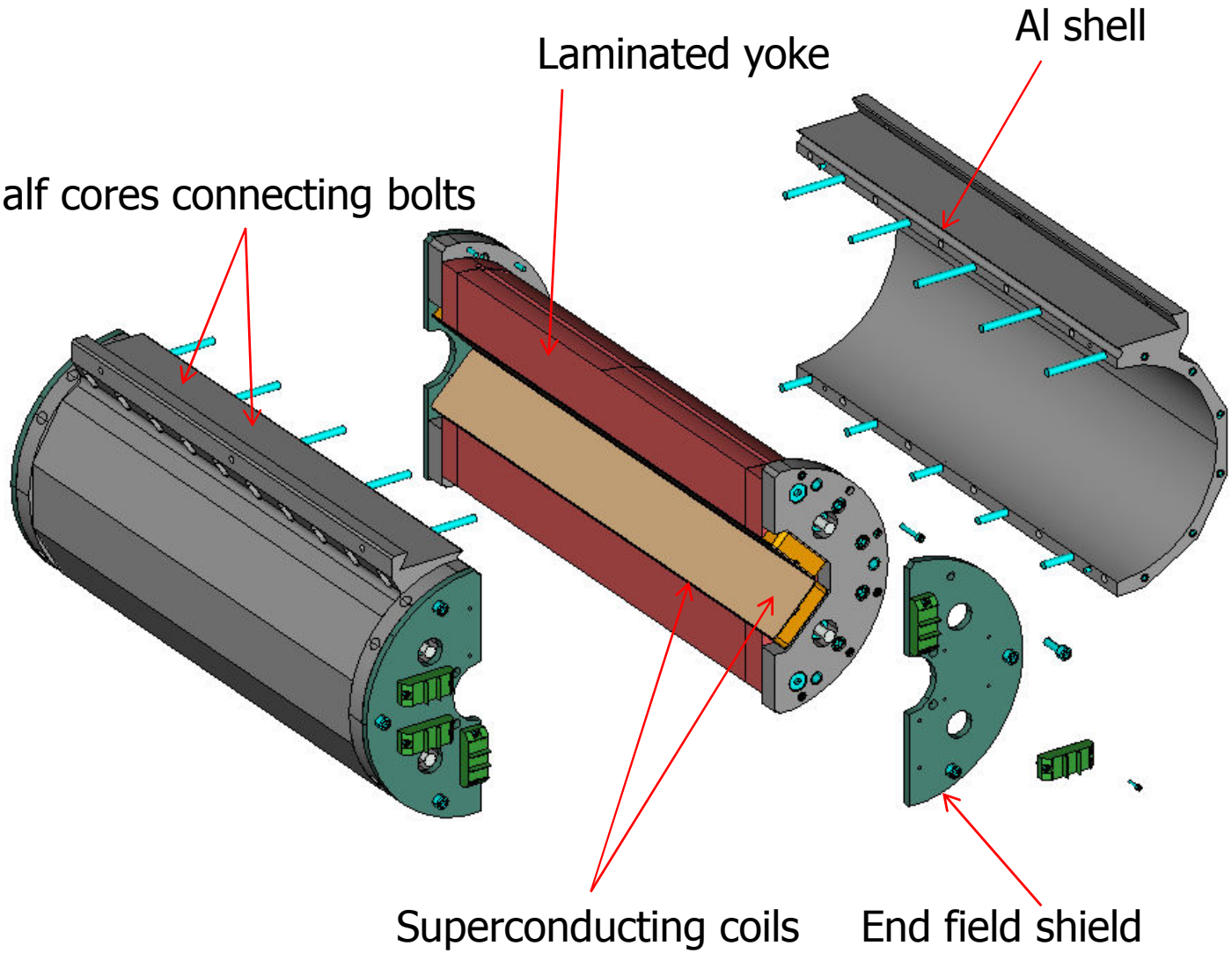
- Qudrupole laminated yoke consists of two halves;
- Laminations laser cutted with accuracy 20 microns;
- Long calibrated rods connect two thick side plates and laminations in the solid unit;
- Two coils mounted in each half core.
- There is an easy assess to provide accurate coil mounting relatively pole and provide the coil frame prestress;
- The half units identical and exchangeable;
- All current leads should be heavily stabilized with extra copper material.

New Quadrupole Cold Mass

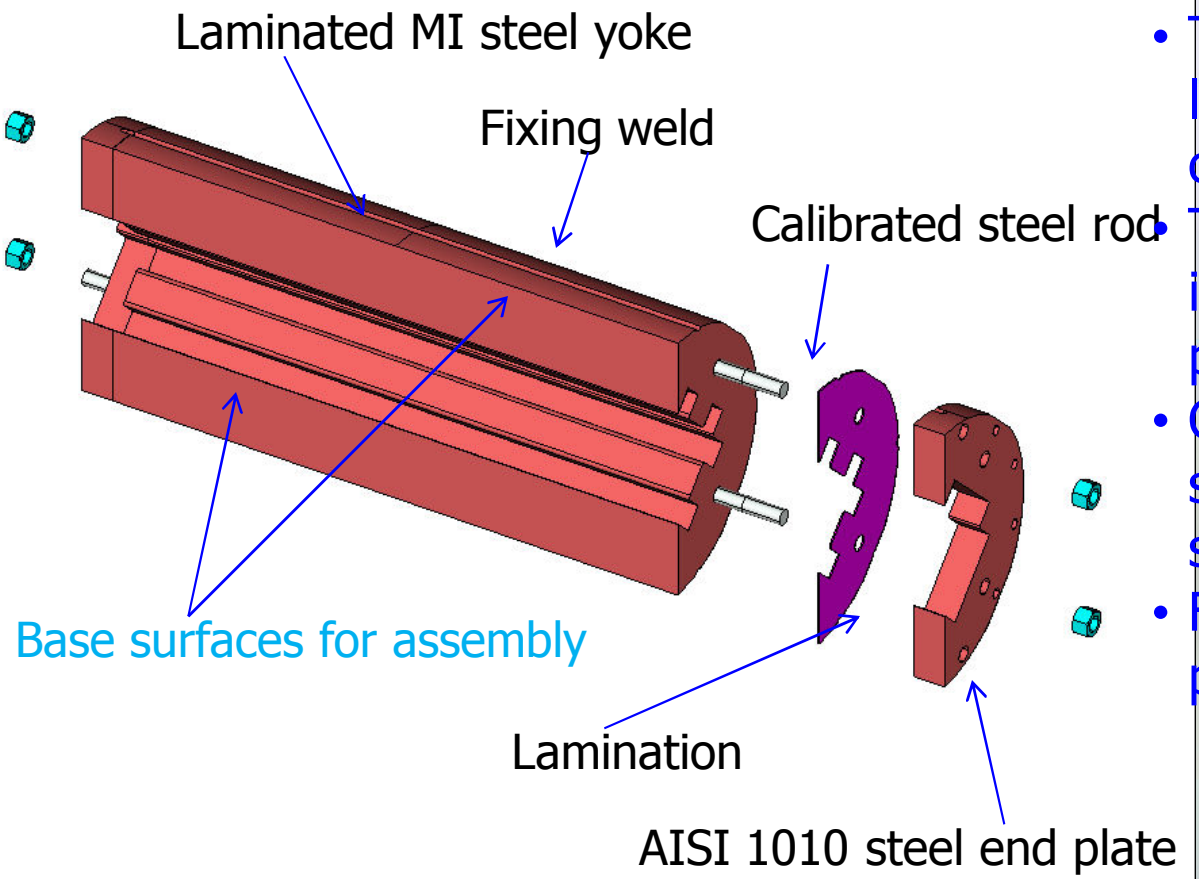
Quadrupole Supports



Quadrupole Exploded View

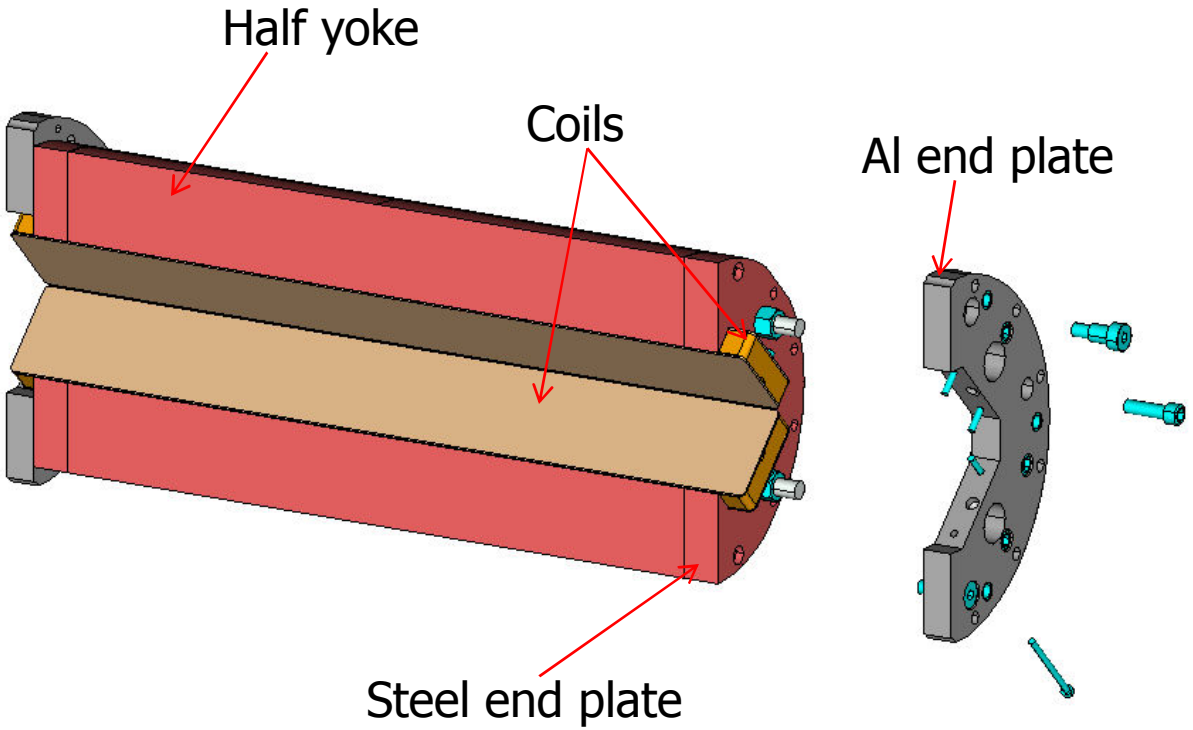


Half of Iron Yoke Assembly



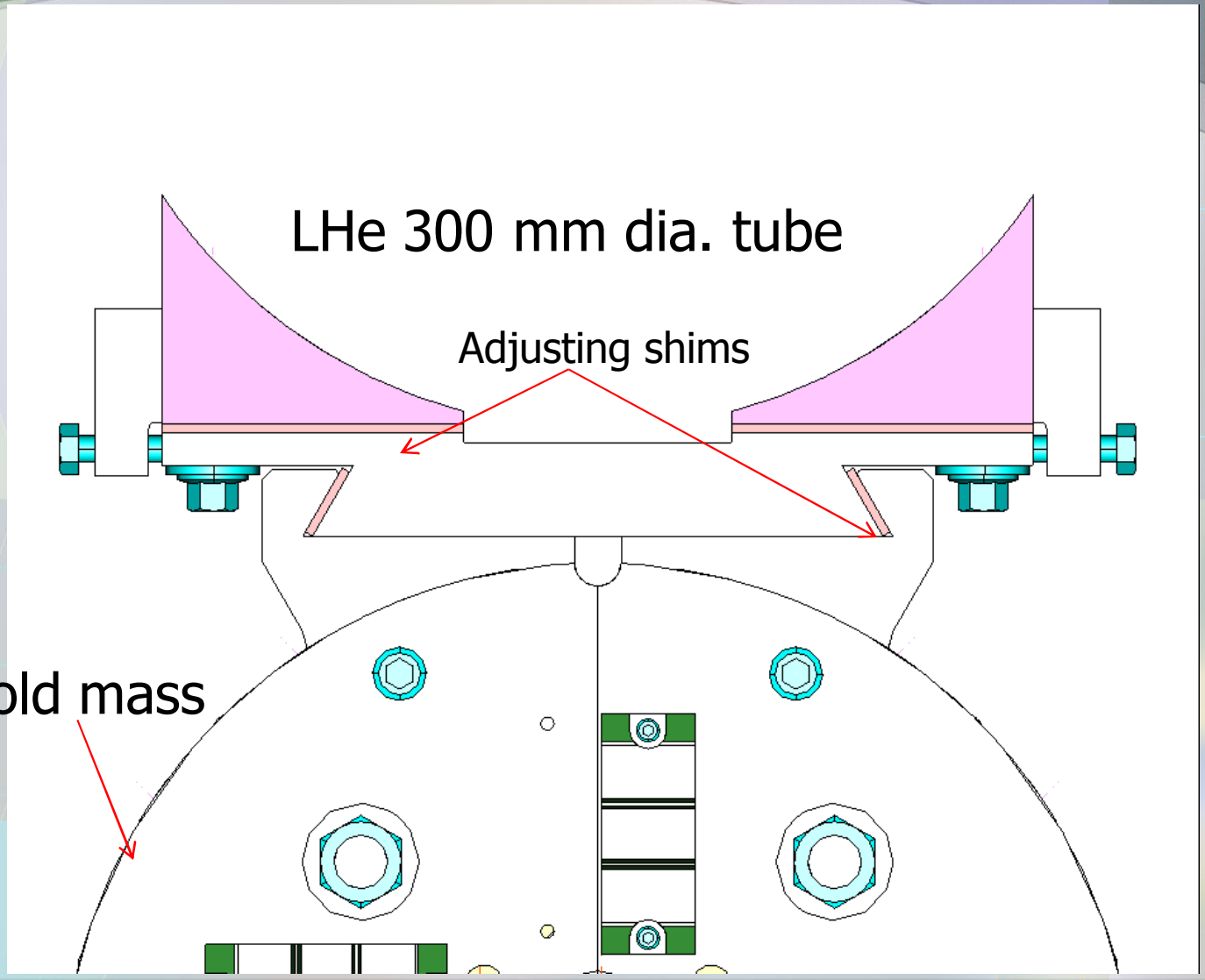
- The yoke laminations are laser cutted from MI low carbon 1.5 mm thick steel.
- The half core is assembled in the FNAL IB2 horizontal press.
- Calibrated rods and base surfaces provide package straightness.
- Final mechanical rigidity provided by fixing welds.

Half Yoke with Al End Plate

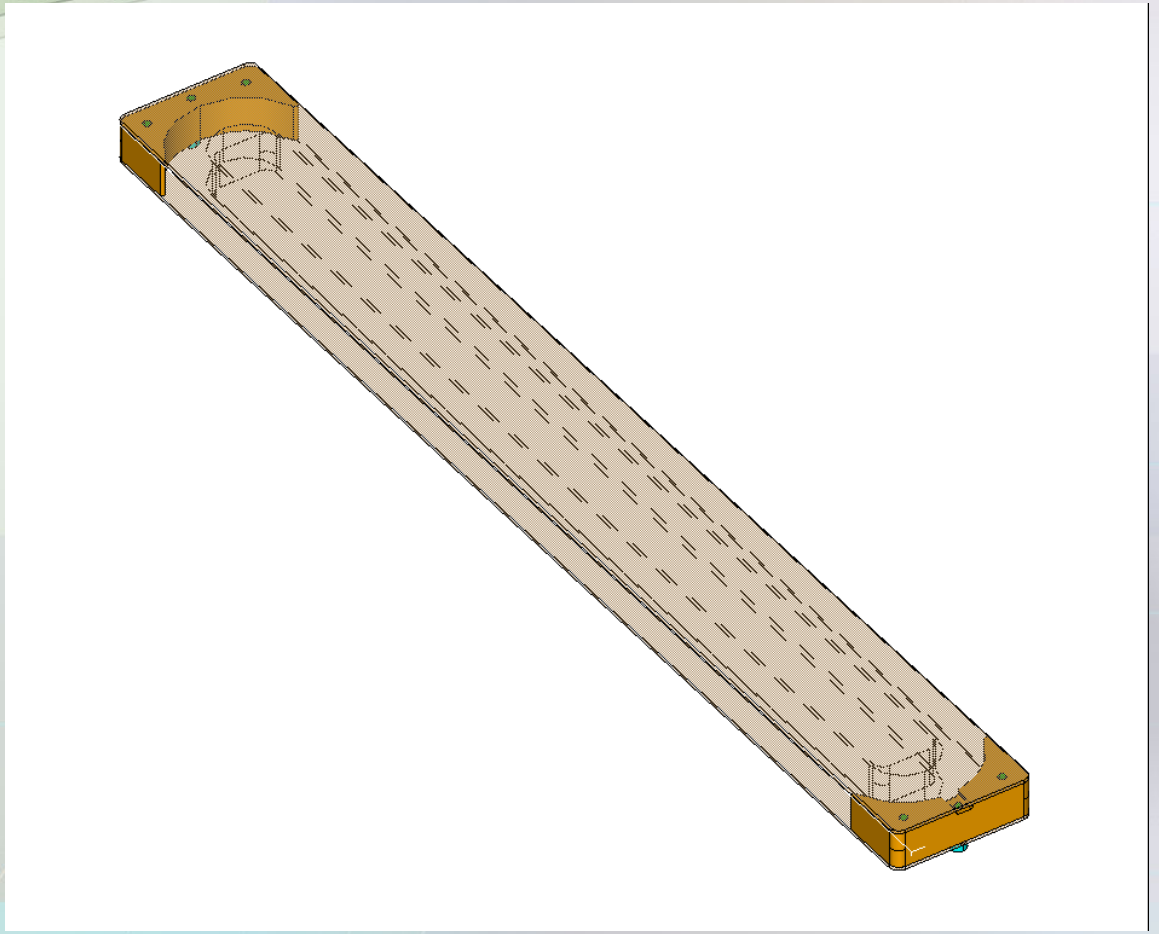


Al end plate mechanically and thermally connected to the coil and outer shell Al collars providing better thermal conductivity between coils and cooling tube.

Quadrupole Lifting and Positioning



Superconducting Coil



The coil is wound inside Al channel. The 0.5 mm dia. NbTi wire has enamel insulation and additional layer of glass fiber. The coil assembly is vacuum impregnated with epoxy. The coil leads are soldered to more strong conductively cooling leads.

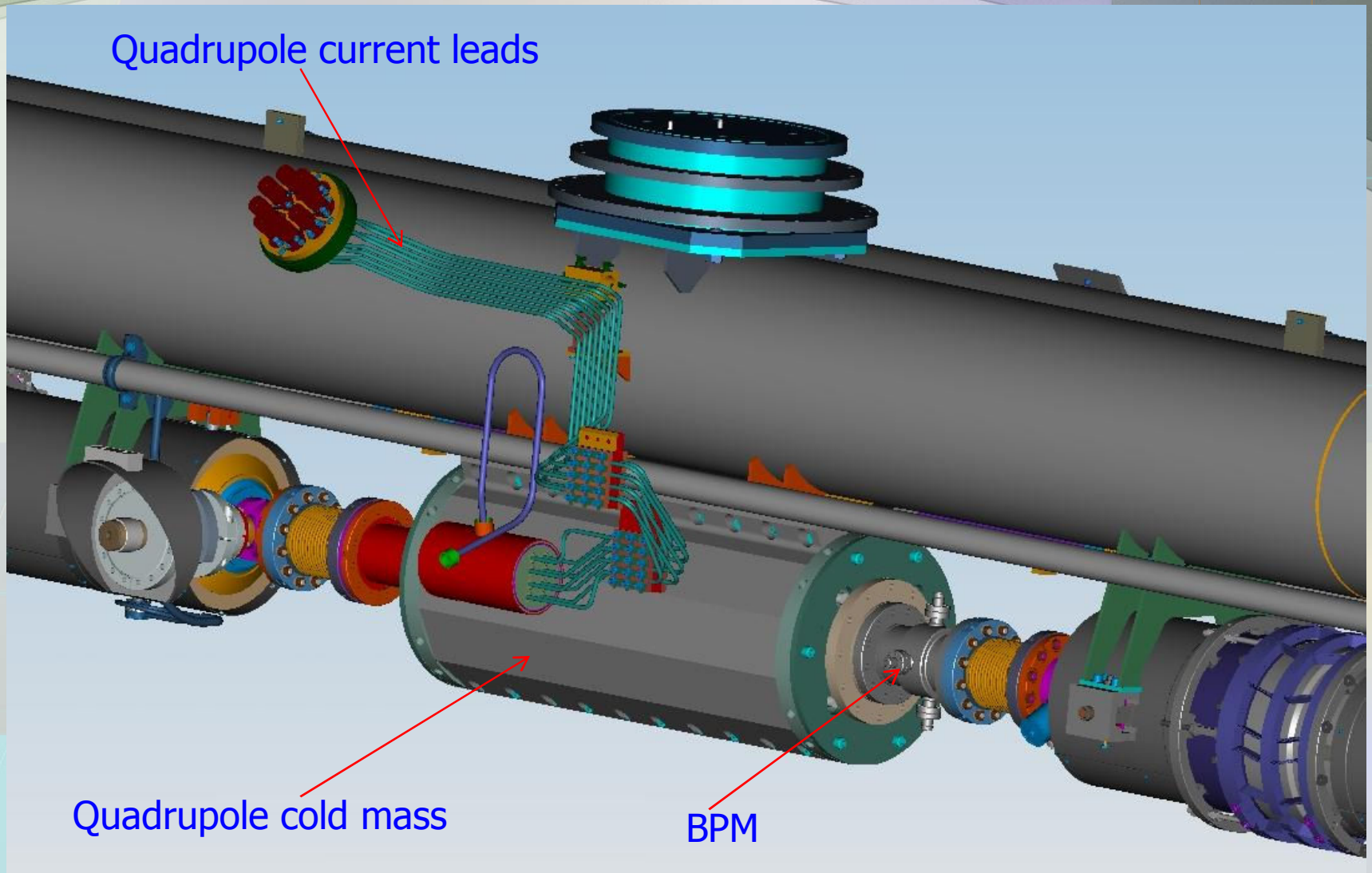
Coil has 800 turns with peak current 100 A.

Superconductor Choice

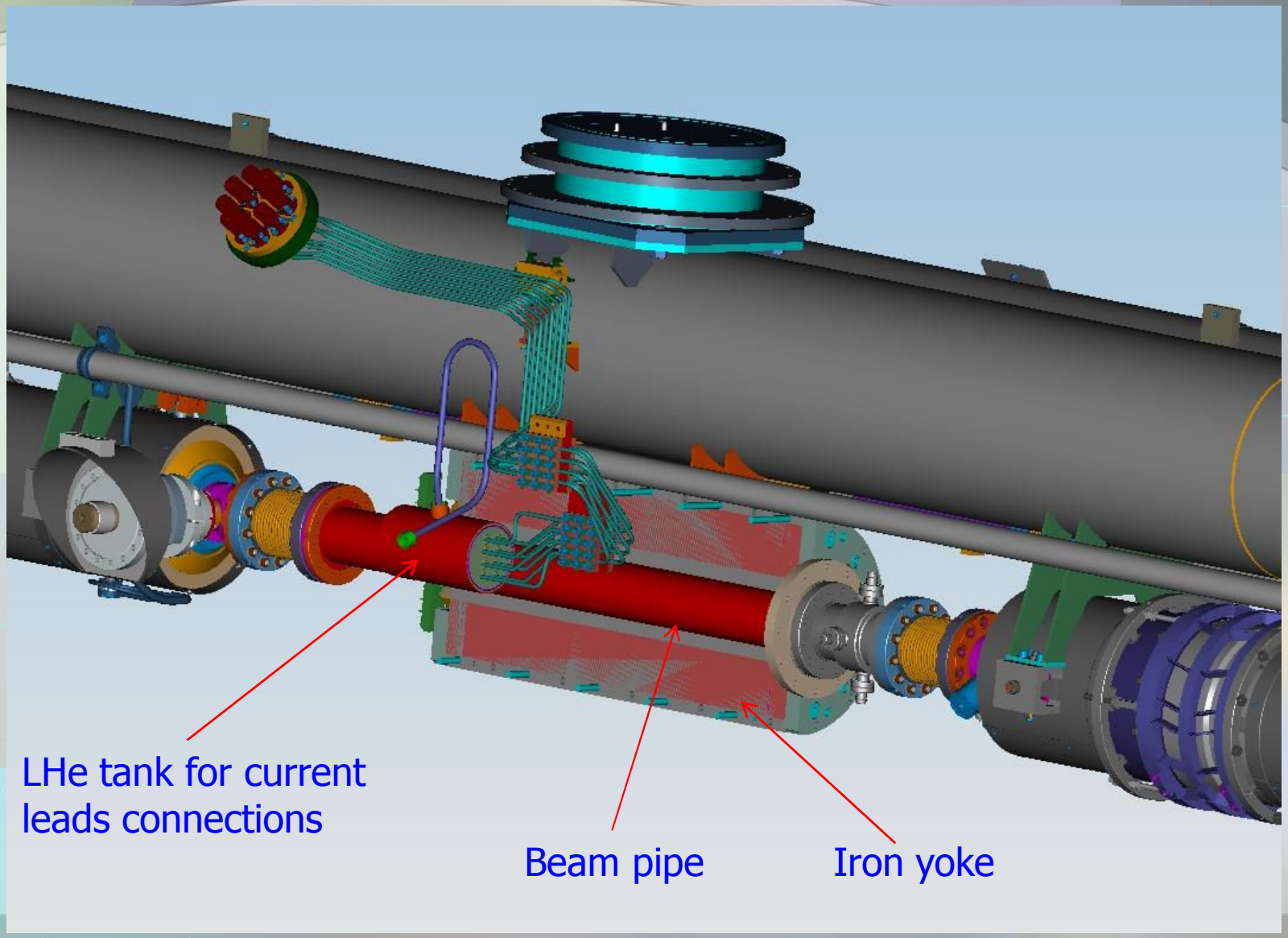
NbTi wire diameter	0.5 mm
Number of filaments	7242
Filament diameter,	3.7um
Copper : Superconductor	1.5
Insulated wire diameter, mm	0.54
Enamel insulation	Formvar
Wire diameter with an additional glass fiber insulation	0.58-0.64 mm
Twist pitch, mm	25
RRR of copper matrix	100
Critical current Ic @4.2K, 5T	204 A

- Superconductor type: NbTi – well known technology and cost efficient at specified fields
- Small filament size < 5 um achievable to reduce superconductor magnetization effects
- Ø 0.3-0.5 mm for currents <=100 A to reduce heat load from current leads and cables from power supply
- Cu:Sc ratio ~ 1.5-2 to provide safe quench protection
- RRR 50-100 to improve SC stability and quench parameters
- Efficient electrical insulation: polyimide, formvar, etc

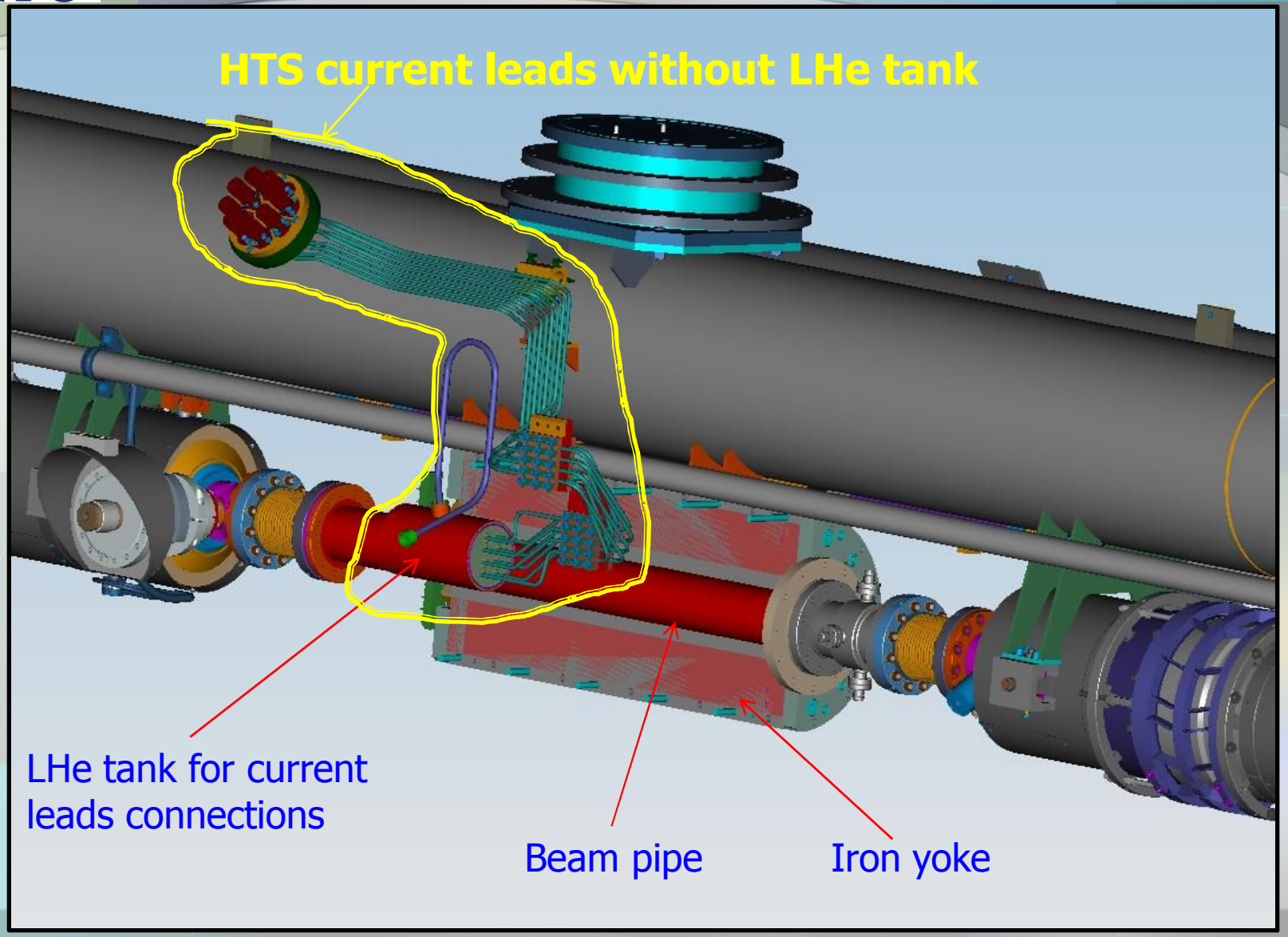
Quadrupole Inside Cryomodule



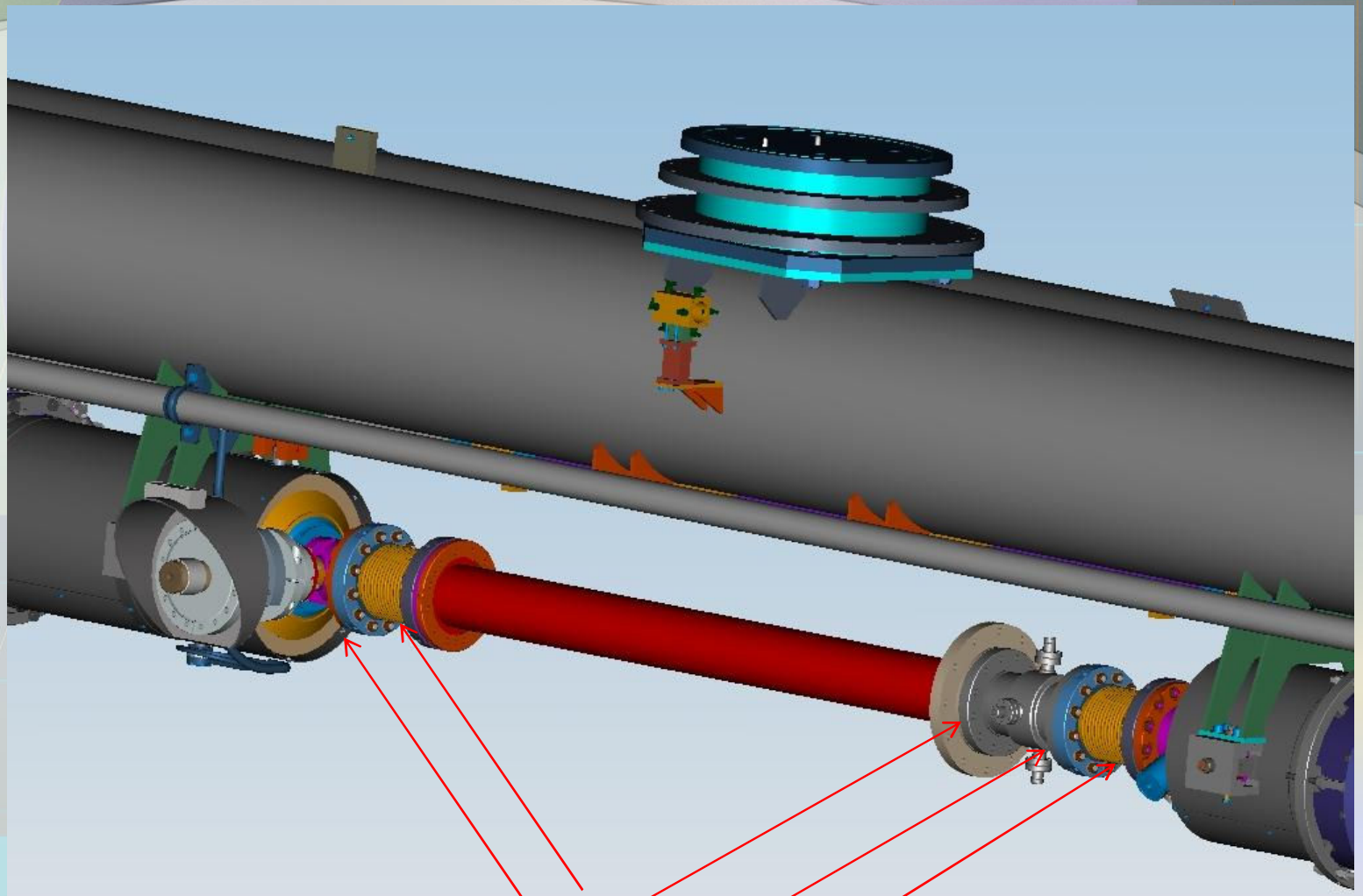
Quadrupole Cross-Section



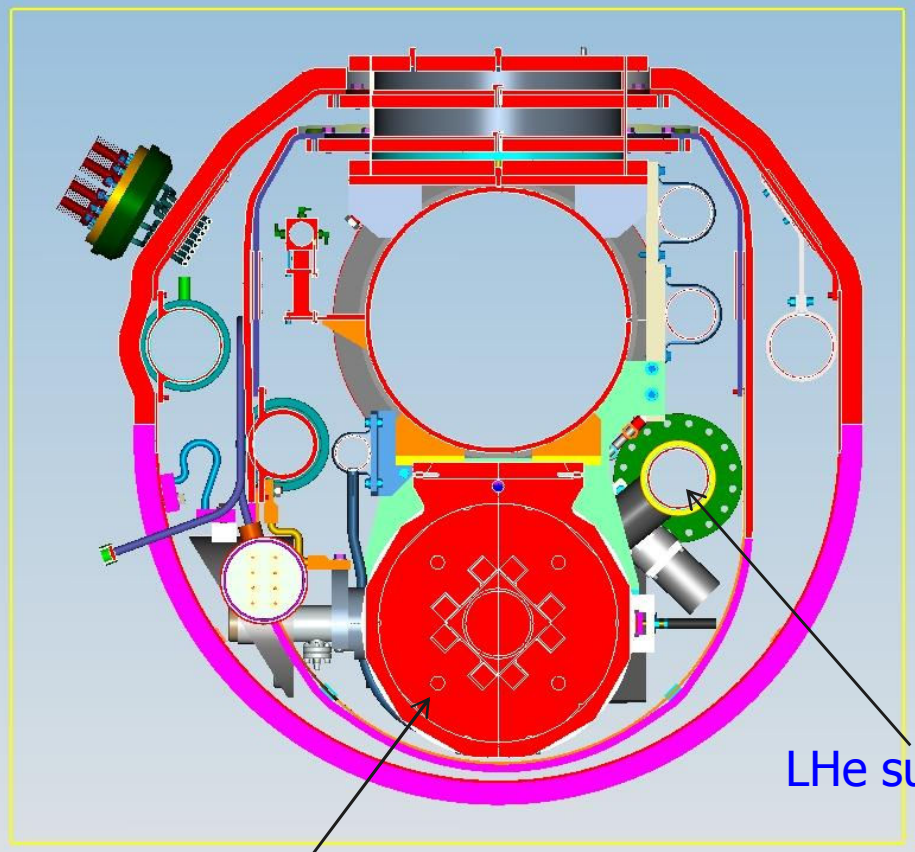
Possible modification

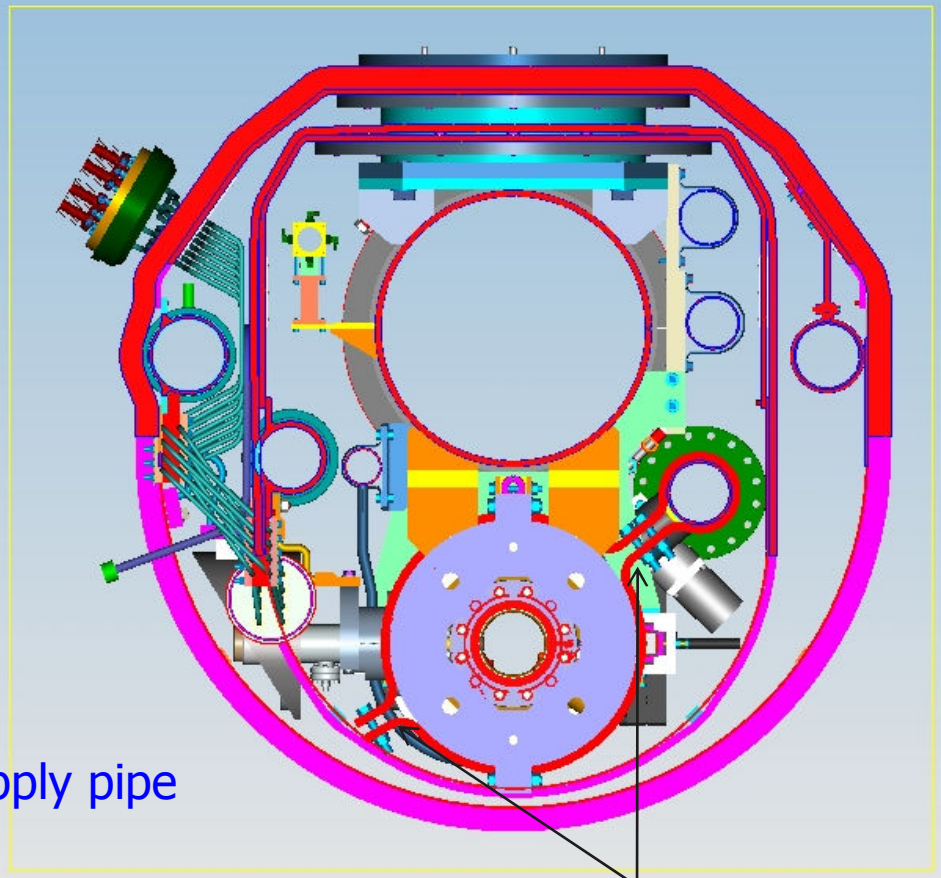


Cryomodule Before Quadrupole Installation



Cryomodule Cross-Section





LHe supply pipe

Quadrupole cold mass

Thermal leads to LHe supply pipe

Splittable Quadrupole FY10 Schedule

	Cryogen Free Splittable Quadrupole, March 2, 2010											
2	**Month**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
3	**Quadrupole**												
4	Magnetic design												
5	Mechanical design												
6	Thermal design												
7	Quadrupole drawings												
8	Cryomodule integration drawings												
9	Tooling drawings												
10	Superconductor glass fiber insulation												
11	Laser cut laminations												
12	Parts procurement												
13	Coil fabrication												
14	Quadrupole assembly												
15	Quadrupole test in VMTF (bath cooling)												

Summary

- The splittable cryogen free quadrupole could be fabricated in FY10.
- Proposed the quadrupole with a vertical split and racetrack coils.
- The quadrupole set of drawings is released.
- Quadrupole has a conduction cooling from the LHe supply pipe.
- Quadrupole mounted around the beam pipe outside of a clean room.
- BPM has tight connection with quadrupole.
- Quadrupole bolted to the strong 300 mm diameter He return pipe.
- Special attention paid on the magnet assembly and mounting tolerances.
- Magnet cooling down time ~ 38 Hours.
- The magnet in 2010 only could be tested in TD/VMTF in a bath cooling mode.

VMTF Measurement System

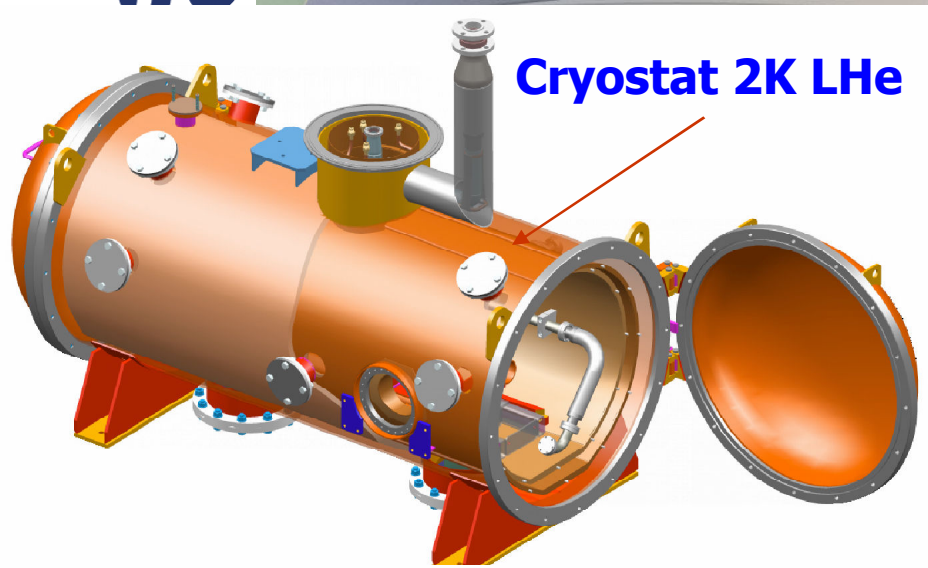
The quadrupole first test could be made in VMTF. Only a bath cooled mode is possible. The rotational coil system with large number of sampling allows to reach accuracy ~ 3 um (proved by HGQ01 model test).

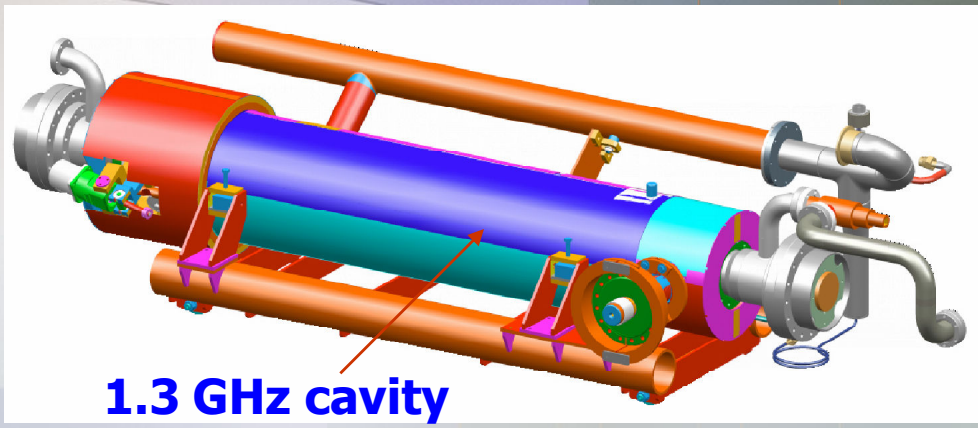
VMTF allows to test and measure:

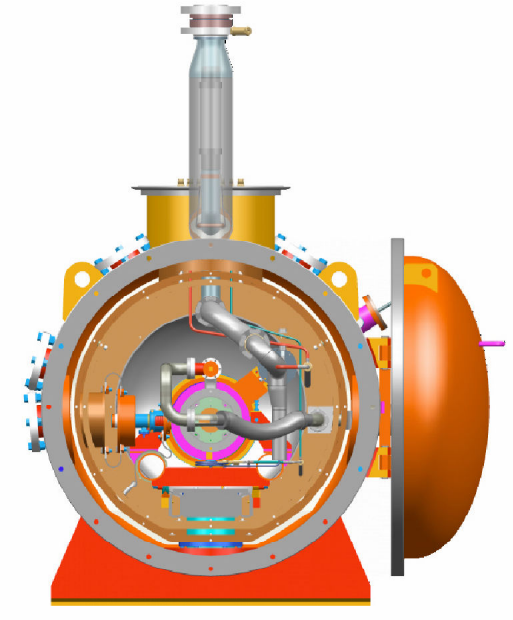
- *Magnet training and quench current.*
- *Quench detection and protection system.*
- *Magnetic field harmonics in the bore.*
- *Quadrupole effective length and integrated gradient.*
- *Magnetic center shift at different currents with accuracy up to several microns.*
- *Measurements at 4.2K and 2 K.*

- The Magnet Systems Department has started a functional specification for a joint mu2e / split quad test cryostat. ILC would share costs w/ mu2e
- In the new year the new test stand will be in place
- More detailed cost information would exist in the next couple of months

Modifications in FNAL SCRF 2K Test Stand







- FNAL SCRF Horizontal Test Stand (HTS) could be used for Quadrupole test in a conduction cooling mode@2 K.
- Should be added 200 A current leads, instrumentation, and power supplies.
- For magnetic measurements should be added a room temperature bore.
- Modernization of HTS or building new ?

SLAC 4.2K Stand Relocation to FNAL

Cryostat 4.2 K LHe

Power supplies and control system

- ILC Quadrupole Test Stand shipped from SLAC to FNAL, stored in Bld. 38.
- SLAC safety documentation is enclosed and will be reviewed.
- Commissioning ?