COLLEGE OF SCIENCE
DEPARTMENT OF PHYSICS

Report from ICR Magnet Design Team

November 19, 2014

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1. Quadrupole design

The arc quad design is presented in Figure 1 and **Error! Reference source not found.**. It has been designed to produce sweet gradient at the design values for injection (0.1 I_0) and collision (I = 0.8 I_0), with the price that at over an intermediate range between them there is significant octupole. The design has 8 cm diameter bore, and uses the same superconducting cable as the dipoles. I_0 = 15 kA, short sample limit is ~1.1 I_0.

We have designed the pole geometry and windings so that the 4 windings fabricated using a cost-effective sequence:

The 4 windings are wound on hinged tooling from a single length of cable (eliminating splices);

- the 4 windings are compressed in a single set of tooling and the B-stage impregnation is heat-cured to produce stable winding structures of desired dimensions;
- the laminations are stacked/welded in two half-geometry subassemblies.
- the subassemblies are positioned over/under with a ~10 cm gap, and the 4 windings are located in their positions (with the two side windings tilted to clear the side poles of the upper lamination stack);
- the lamination stacks are brought together and the side windings are rotated into their proper locations;
- The support structures are installed and an expansion bladder is filled with fiber-filled epoxy, pressurized to deliver preload to windings, and cured.

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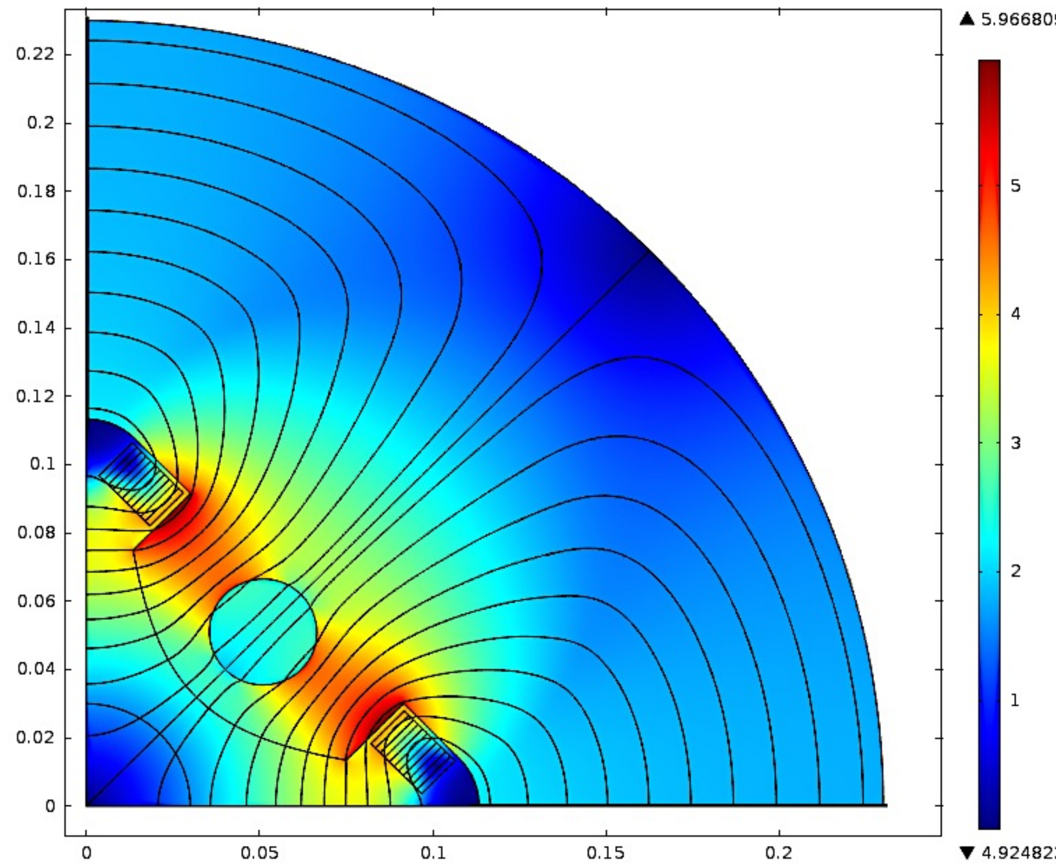


Figure 1. Calculated fields in the ICR arc quadrupole.

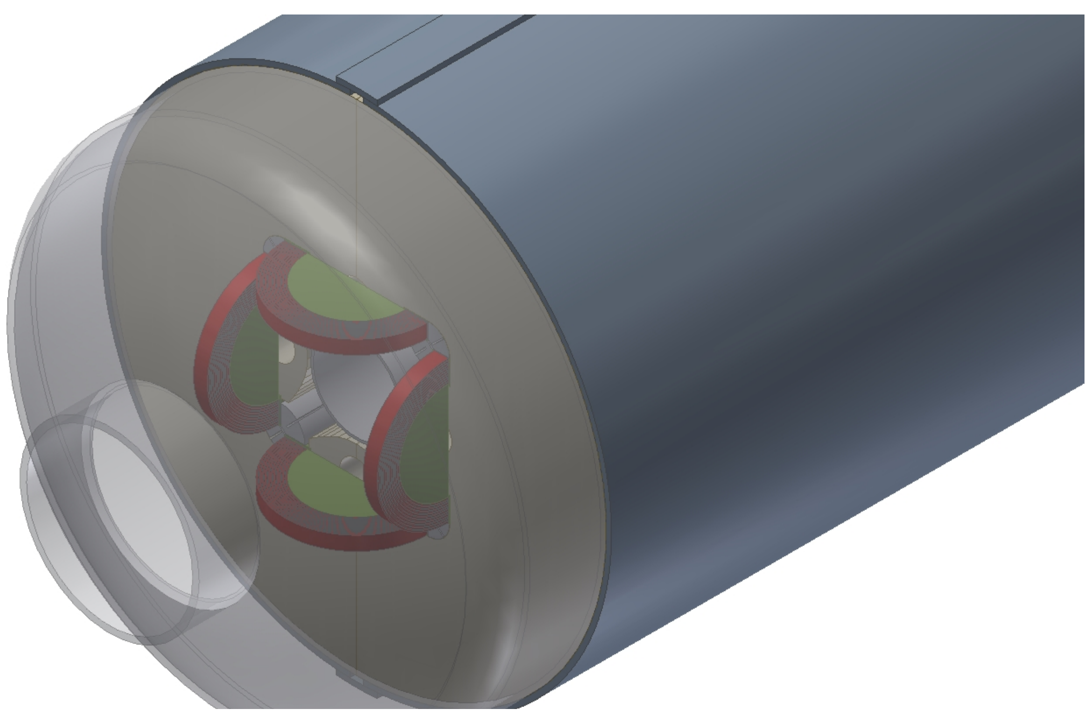
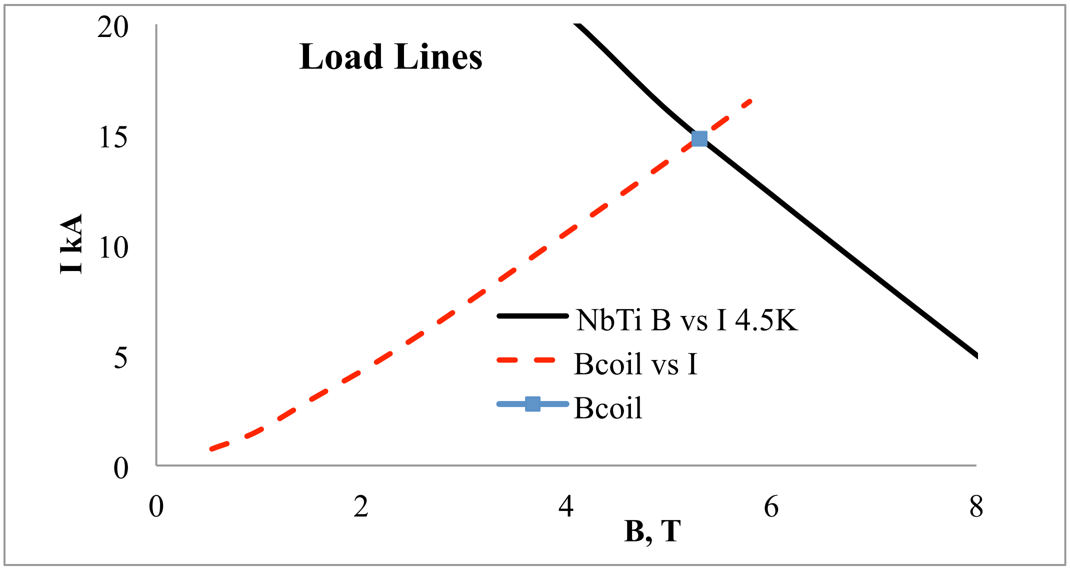
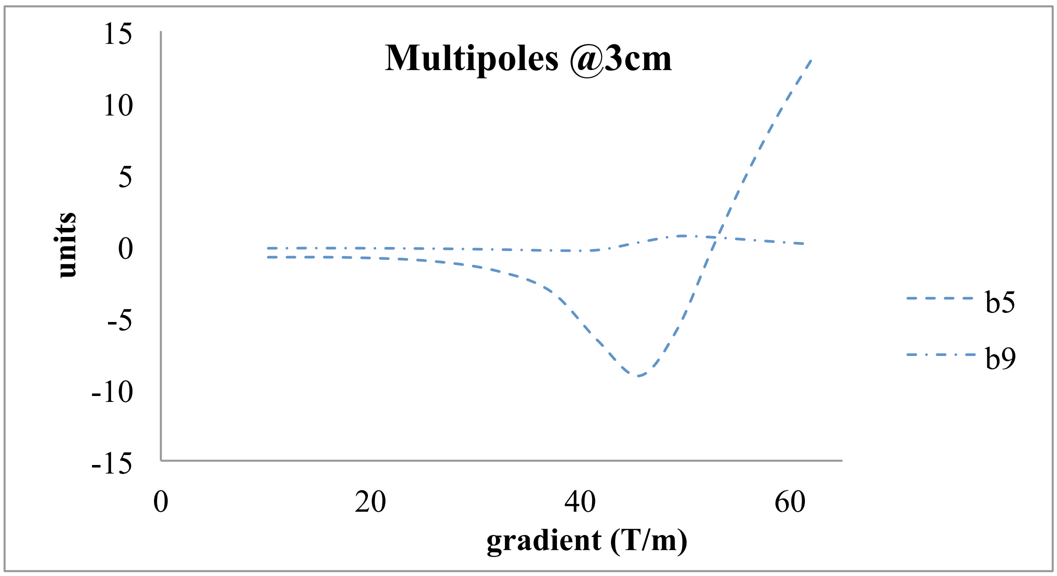


Figure 2. CAD design of quadrupole, showing winding ends, shell, and beam tube (quad not rotated to proper orientation in this view).


Load Lines
I kA
B, T
NbTi B vs I 4.5K
Bcoil vs I
Bcoil
0
5
10
15
20
0
2
4
6
8


Multipoles @3cm
units
gradient (T/m)
b5
b9
15
10
5
0
-5
-10
-15
0
20
40
60

2. Dipole end winding 'wooden soldier'

The practical problems with dipoles almost always come with the winding ends and the splice joints. shows a CAD design for the 4 m arc dipole, with its winding ends, stress shell, end caps, and beam tube. We made a wooden mock-up of the dipole end and wound actual NbTi Rutherford cable in the geometry designed for the ICR arc dipole, in order to spot any problems and determine what is the actual length required for the coil end. The 'wooden soldier' is shown in Figure 3. We determined that the wind-then-flare fabrication strategy is workable and optimal, that the three decks of turns can be easily flared by hand, and that the support of the three decks in the flare can be accomplished using a 4-part mandrel that provides internal, face, and external support.

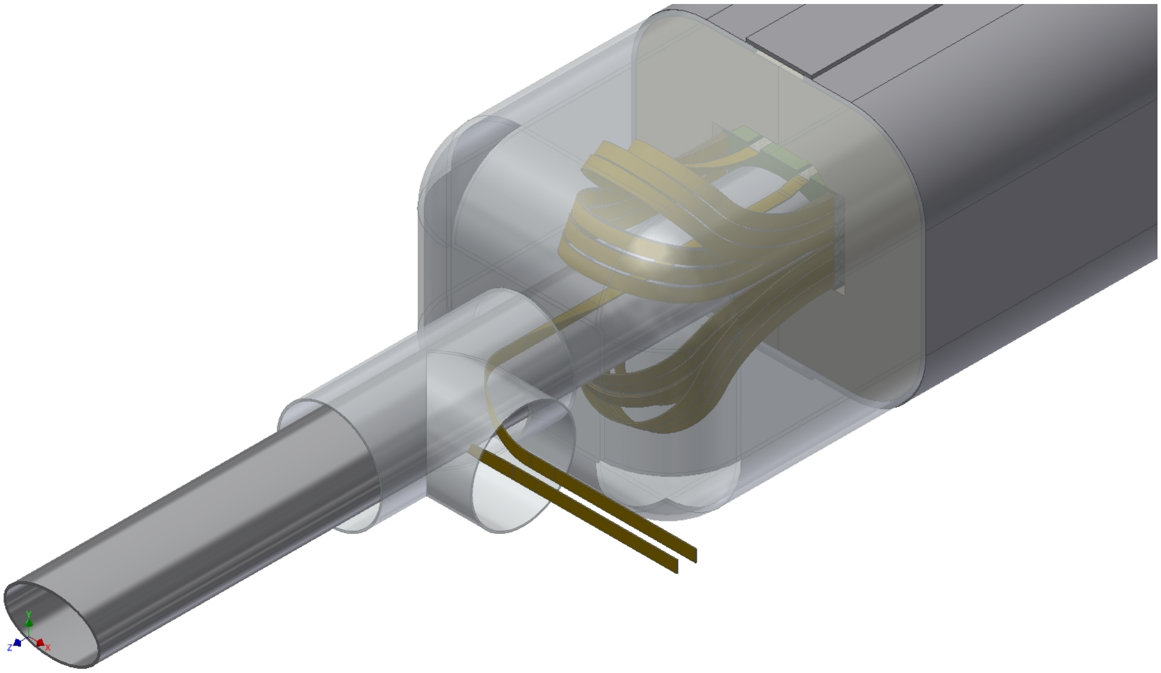


Figure 4. ICR arc dipole structure, showing lead-end cabling, He shell, and beam tube.

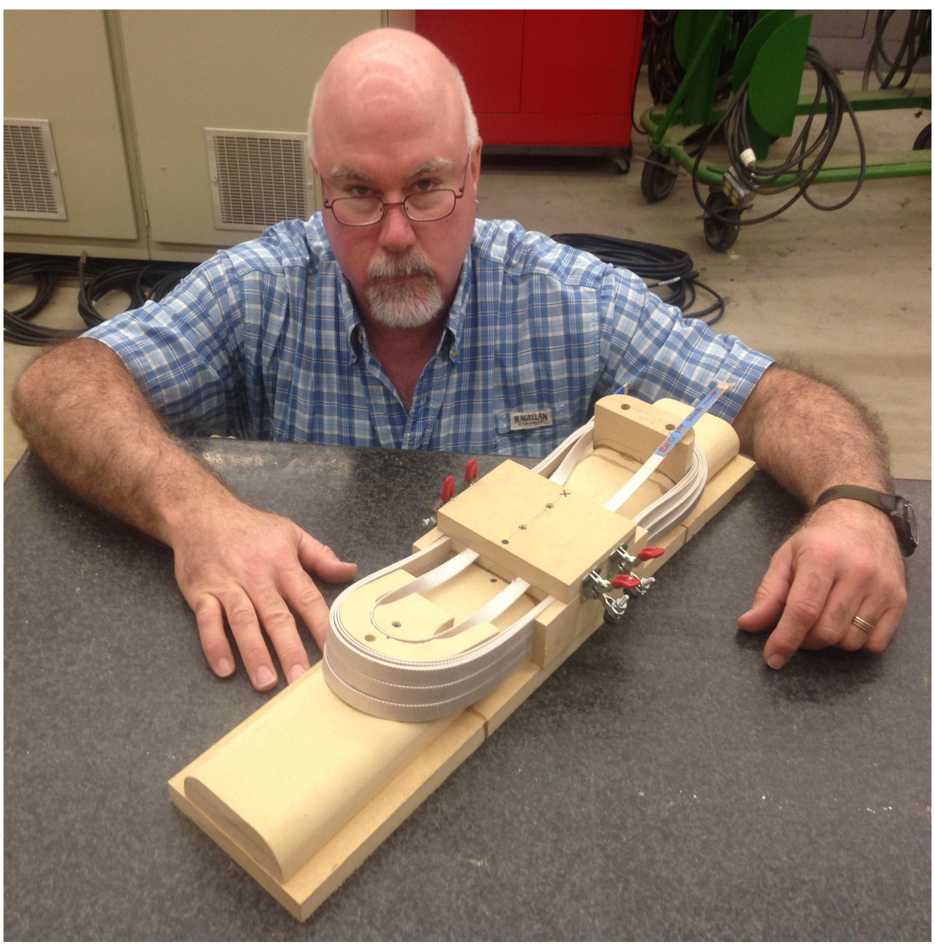


Figure 3. Tim Elliott with 'wooden soldier' model of coil end and leads.

3. Sextupole corrector for dipole body fields

The ICR arc dipole has been designed to produce collider-quality field at injection (0. 3 T) and at collision energy (3 T), but it has significant sextupole component (max ~8 units) in the field range ~2-2.5 T. Figure 5 shows the magnetic design for a sextupole corrector, to be located in the gap between the two 4 m dipoles, to locally correct the dipole body sextupole. It utilizes the same cable as the dipoles, and a 10-cm-long sextupole produces 770 T/m^2 at an excitation of 15 kA.

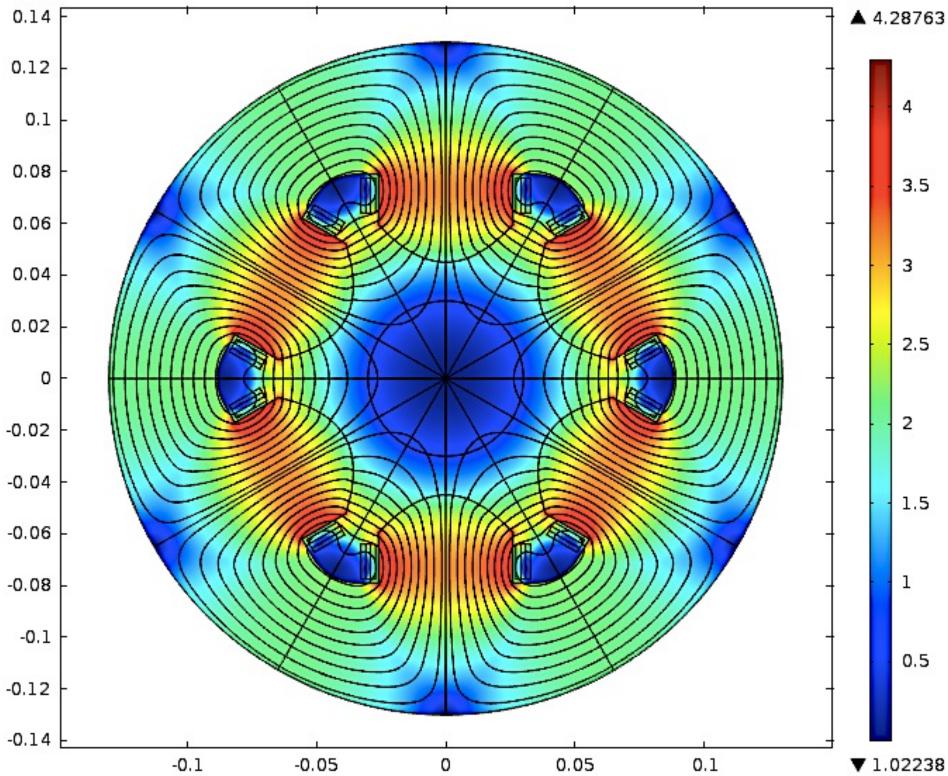


Figure 5. Calculated fields in the body sextupole corrector.

4. Cryostat conceptual design

One half-cell contains the two 4 m dipoles, the sextupole corrector between them, the quadrupole, and short straight sections for correctors, BPMs, and other instrumentation. Several strategic questions must be addressed in arriving at an optimum cryostat design:

1. Does one cryostat house all magnetic elements (2 dipoles and quad) or only the pair of dipoles?
2. How are the magnets supported within the room-temp shell of the cryostat:
    a. A space-frame similar to that of the C-100 SRF cryostats (min cryoload, higher cost, more complex)?
    b. Reentrant column supports from below (max cryoload, stiff support, min cost)?
    c. Tension support from a rail above the magnets (less cryoload, not-stiff support)?
3. Do the cryogen lines run within the cryostat, or are they routed as separate lines that connect to each cryostat through vacuum-jacketed lines?
4. How many half-cells will be connected in series as a cryo-loop?
5. Is the vapor surge from a quench to be taken through a Kautzky valve to a room-temp line running along the back wall of the tunnel?
6. What is the max allowable space between the beam elevation in the ICR and the highest components of the ECR half-cells (in which the cryostat must fit)?

shows a conceptual design for an example cryostat that would utilize a space-frame, house the entire half-cell in a single cryostat, and incorporate all cold piping within the cryostat. It may or may not be optimum among the above design options, but it at least illustrates a particular approach in sufficient detail to begin thinking about issues and answers.

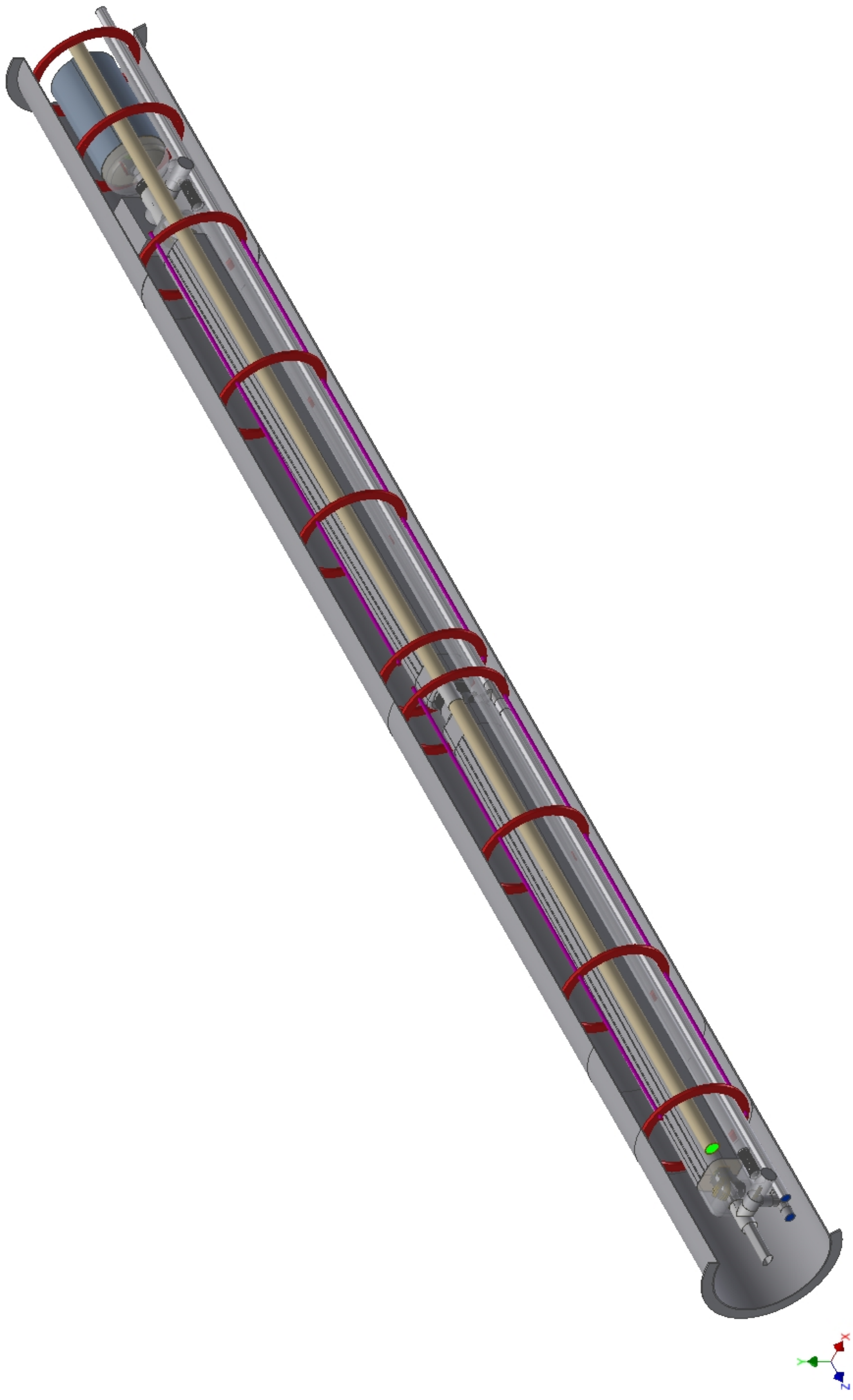
The overall cryostat room-temp housing is 34” diameter (without provision for feet beneath and bracket to support from the wall behind).

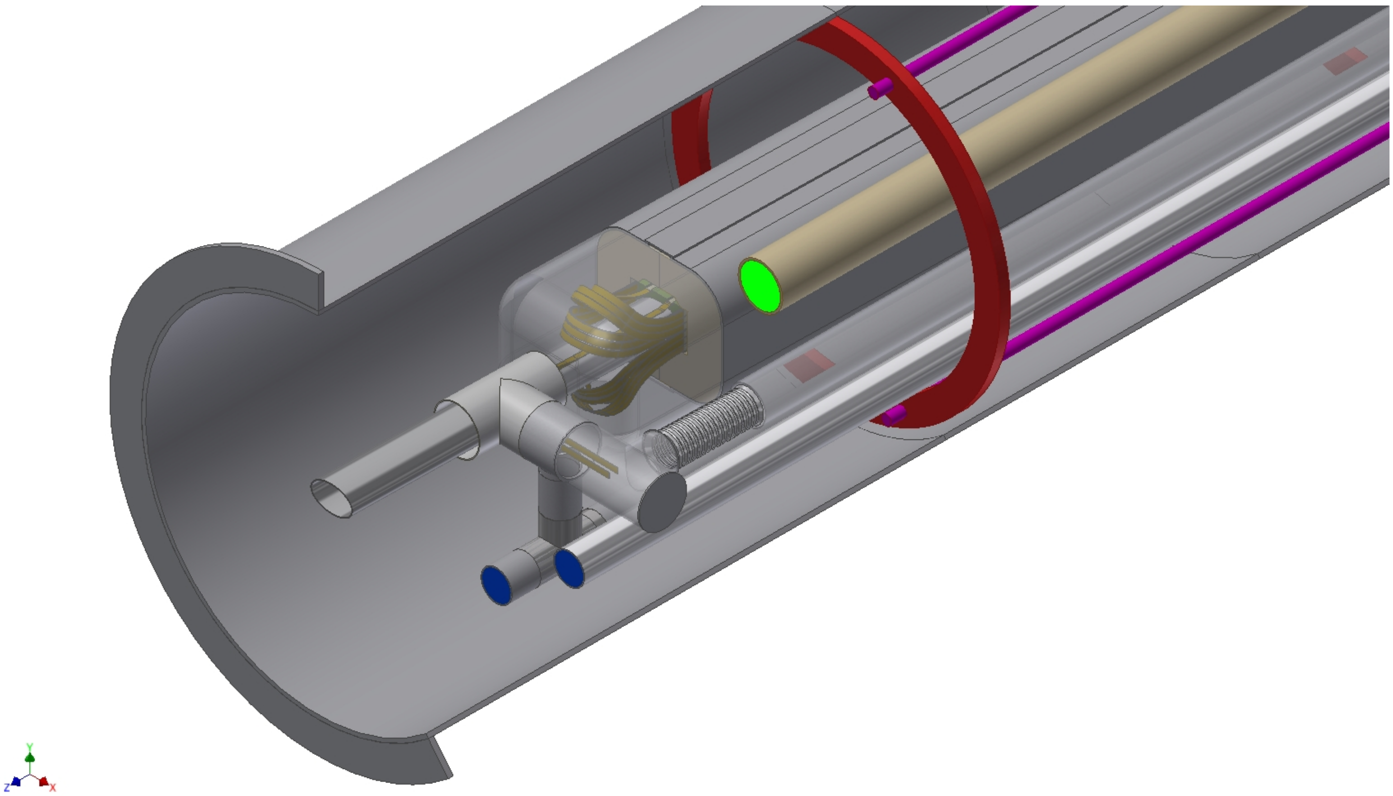
The hoops that are the room-temp support members within the vessel are shown in red. The array of tension rods, and provisions for tensioning them, have not been designed. Ideally the entire cold assembly could be assembled, aligned, and supported on the space frame outside the room-temp shell and then slid inside on rails. The JLab cryo group are the world experts at this, we look forward to their assessment of whether it is feasible given the masses of the magnets (2.5 tons for each dipole, 0.7 tons for the quad).

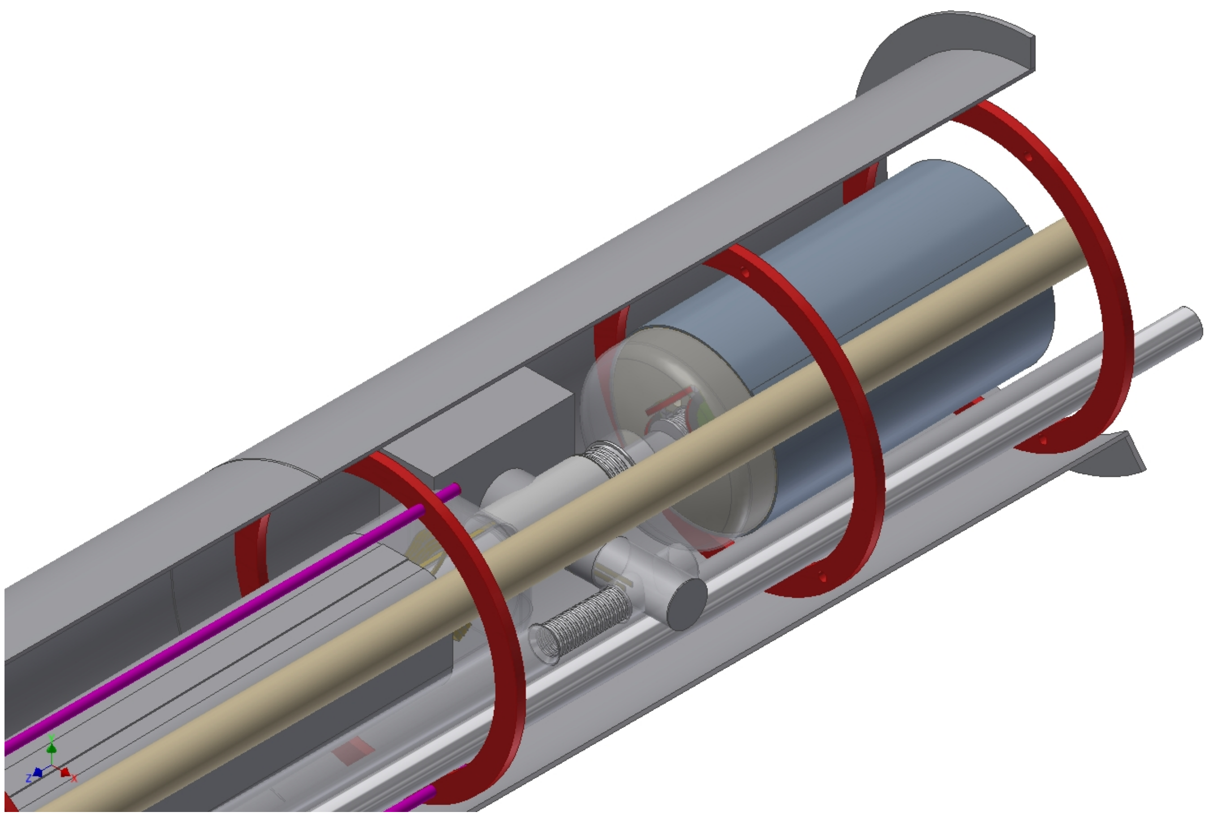
If the space-frame approach is unworkable or expensive, we have experience using reentrant compression supports, integrated within the cryostat.

Ed Daly, please review the concept drawing and let’s discuss the options for the above questions. We hope that you will take the lead on cryostat design.

We have developed the model shown in considerable detail in Inventor 3D. We could provide it as a step file to be compatible with JLab protocols. But we have developed the design in a very rushed way, and so the file structure (constraints, part layering, etc) would be a nightmare for a designer at JLab to pick up and carry forward from. Two options; send a JLab engineer to TAMU after you develop a concept for how you want to configure things, we will dedicate the time of our whiz draftsman to work with him to morph the present design or start the cryostat from scratch; or we can clean up the present CAD file which would require ~a week to do.







5. Technical backup for top-down cost estimation

Tom Mann has developed a substantial technical backup for the top-down cost estimation, and will provide that to Leigh directly.

6. Progress report on bottom-up cost estimation for dipole cold mass

We are nearing completion of the bottom-up cost estimation, with industrial prices for most major components. We anticipate presenting that to Leigh by ~Tuesday of next week.