He3 target coils and SoLID or other nearby steel
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Abstract

After modeling the gun test stand (TN17-048) I realized the presence of the large steel mass would affect the “Helmholtz” set for the He3 target. While SoLID is the situation examined here, the HB bender in Hall C is close enough to the He3 target to affect all field directions. One possibility to avoid the interaction, not examined here, is to enclose the He3 target system in a steel box so the boundary is fixed independent of hall and adjacent equipment.

Present coil set

After a year of misunderstanding, I learned in a meeting October 9, 2017 that the He3 target has been used with only two coil pairs, generating Bx and Bz, except for the transversity experiment. Alan Gavalya provided coil dimensions. I approximated the amp-turns specified on the wiki by using 50 A/cm^2 current density. This coil set is offset 15 cm vertically. The model contains only the first 30” of SoLID steel and the thin steel ring about the compensation coil which brings the field exiting SoLID down to about 4 G in the target region.

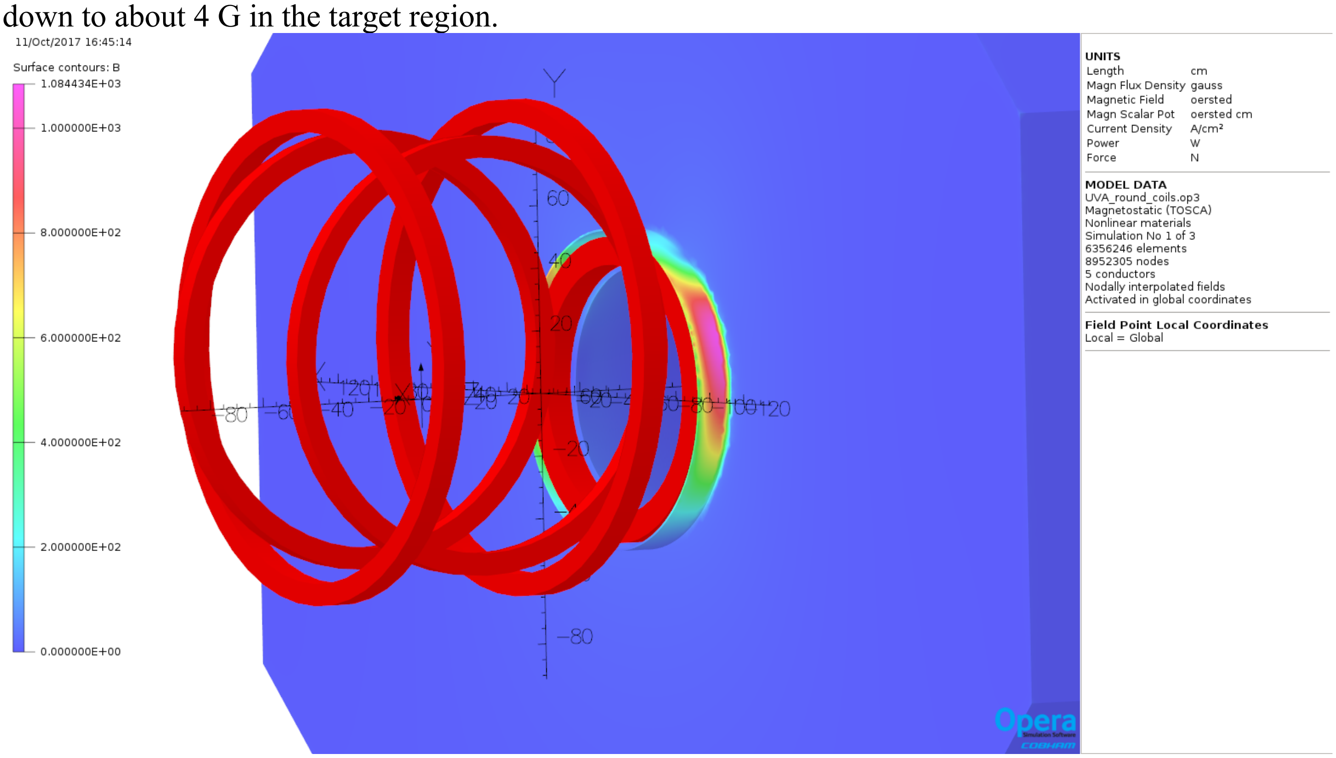

Figure 1. Bx/Bz coil set from Temple University that is planned for use with He3 target. 2316.8 AT Bx, 0 Bz. ~1 kG induced in the 1.27 cm thick steel ring about the compensation coil. Vertical asymmetry due to 15 cm offset.

The Bx coil set is 7.15 cm thick radially and 6.48 cm wide. Mean radius 66.76 cm. The Bz coil set is 7.14 cm thick radially and 8.1 cm wide. Mean radius 75.81 cm.

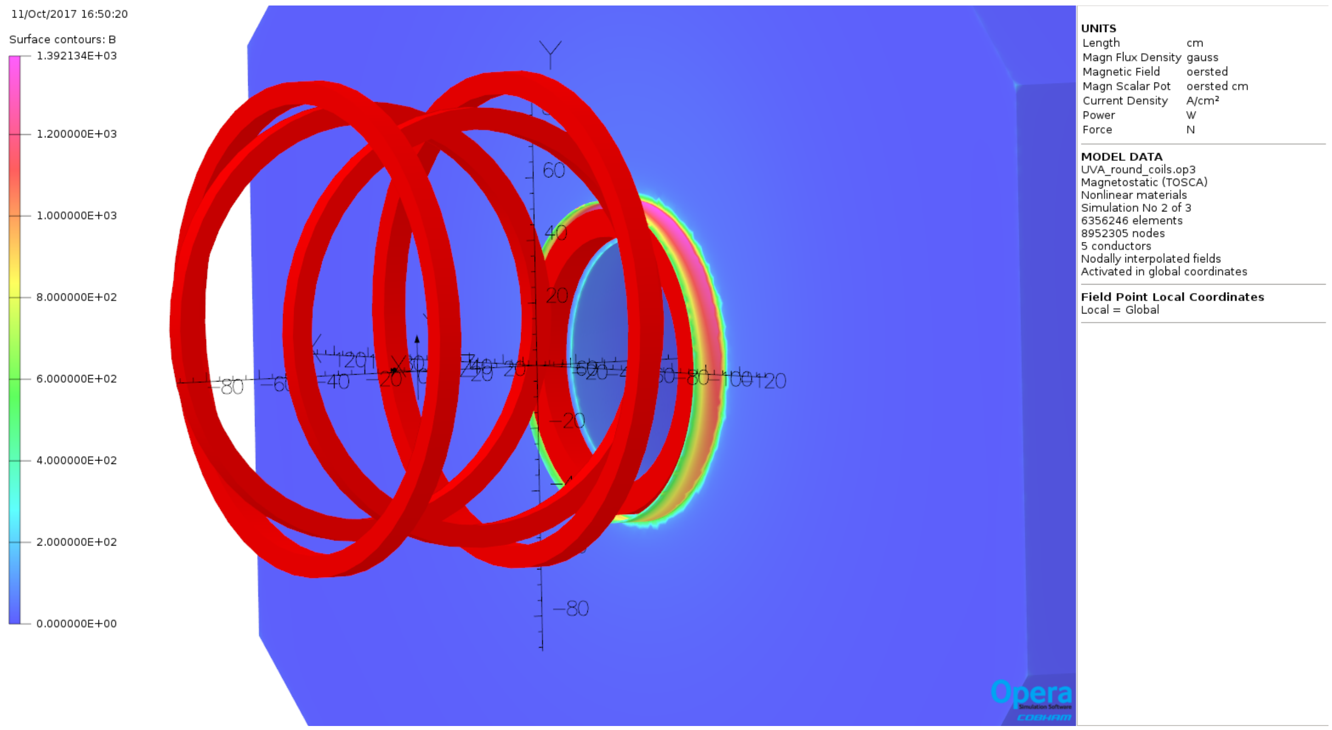

Figure 2. Bz 2889.7 AT, 0 Bx.

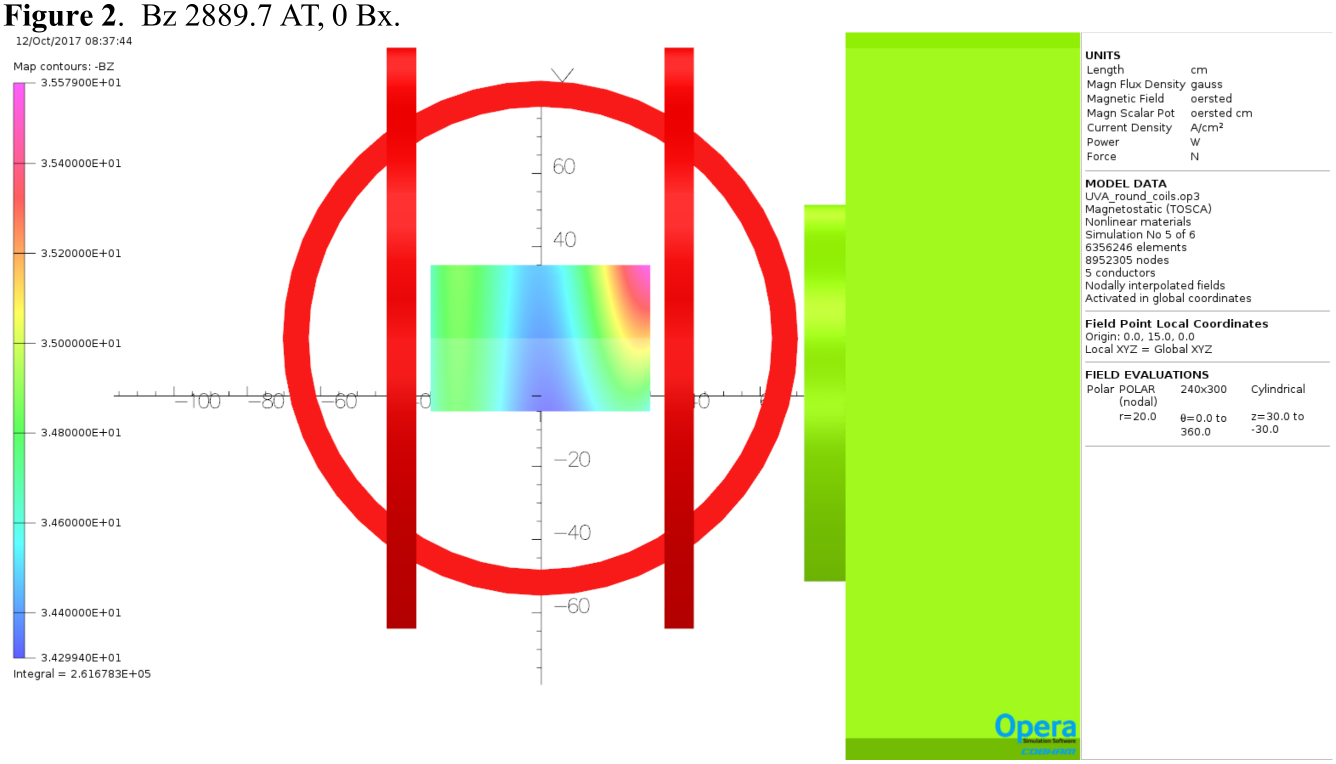

Figure 3. Side view of existing Bx/Bz coil set with Bz on 40 cm radius cylinder offset 15 cm vertically. Upstream Bz coil 2890 At, downstream 82.5% of that.

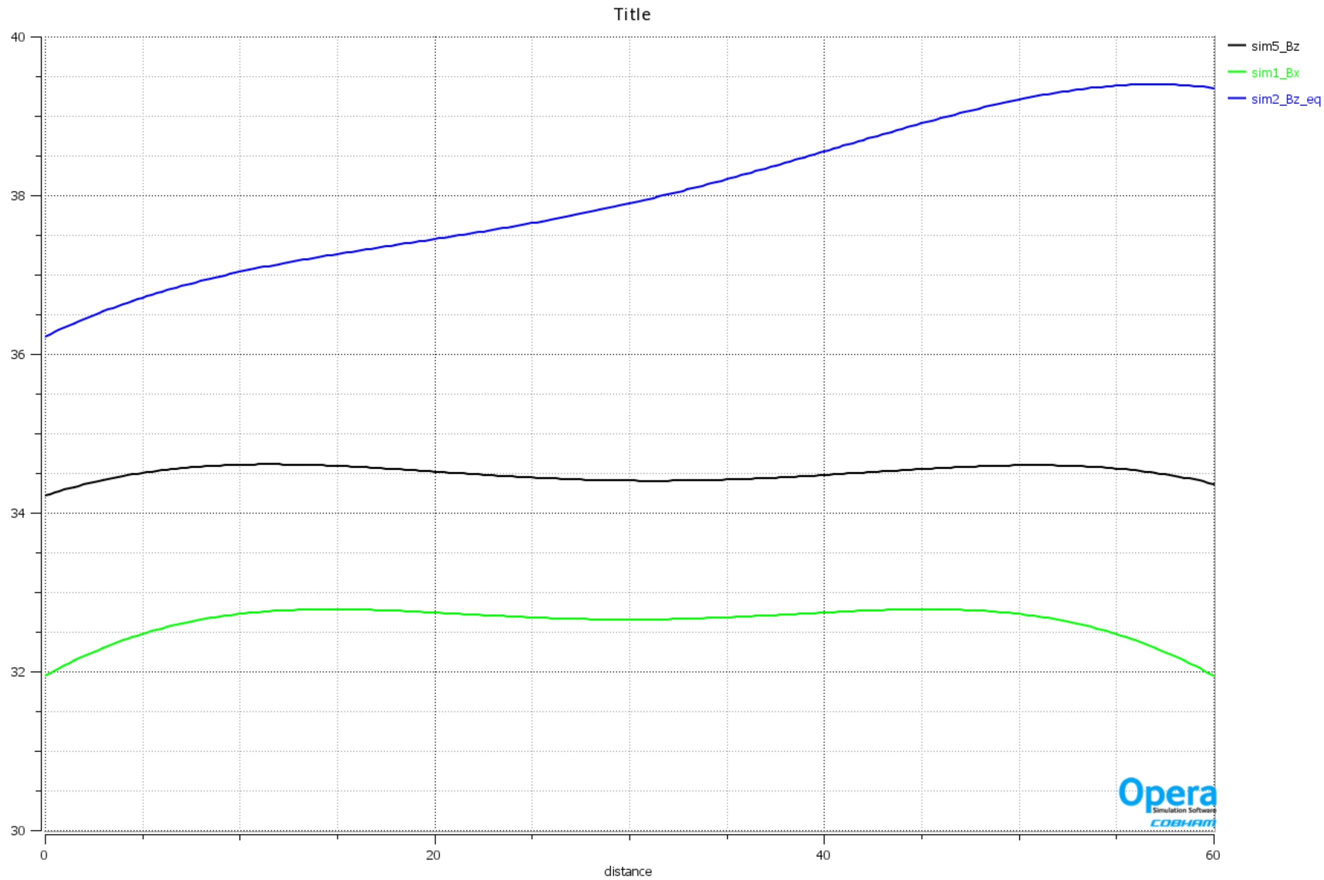

Figure 4. Field along X or Z axis for the two coil sets. The blue line is the two Bz coils with 2890 AT each. The black line is the Bx set with 2317 AT. The green line has the upstream Bz at 2890 AT and the downstream at 82.5%.

While this set will work for a spectrometer which is approximately cylindrically symmetric about the Z axis, it's not clear to me that it is sufficient for a system with large amounts of iron at an angle. At least one experiment with SBS plans to use a two-layer steel box to shield the He3 target from stray field (V. Nelyubin/R. Wines design). The interaction of the SHMS HB steel with this coil set will be checked by others.

Field exiting SoLID

C. Keppel suggested early in 2017 that I add what I'm calling the compensation coil to the outside of the entry hole in SoLID upstream plug to flatten the exiting field. I tried a number of coil cross-sections with only marginal effect. The coil shown above is 25 turns by 26 layers of #8 square aluminum or copper, 40 cm inner radius, Z=[-277,-268]. The current used in Figure 5 is a compromise between the depth of the dip around 40 cm and the rise thereafter. If I push down the peak at 60 cm the variation in the middle 40 cm increases dramatically and I believe central flatness is more important, espcically since the target is only 40 cm long at the moment. An increase to 60 cm is planned, hence all the plots herein show 60 cm spans.

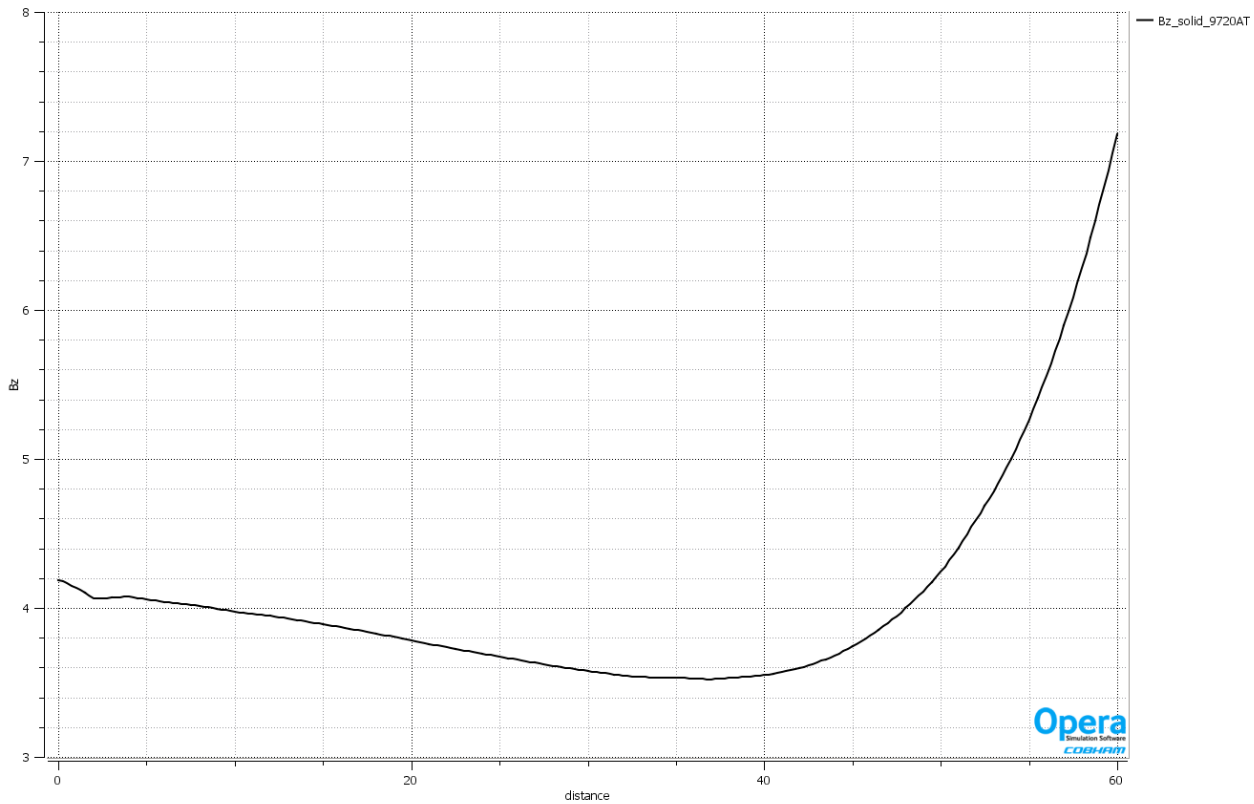

Figure 5. Field from SoLID spanning Z=[-380,-320] with 9720 AT in compensation coil.

Classic Helmholtz set

A classic Helmholtz set which does not interfere with SoLID was defined and modeled.

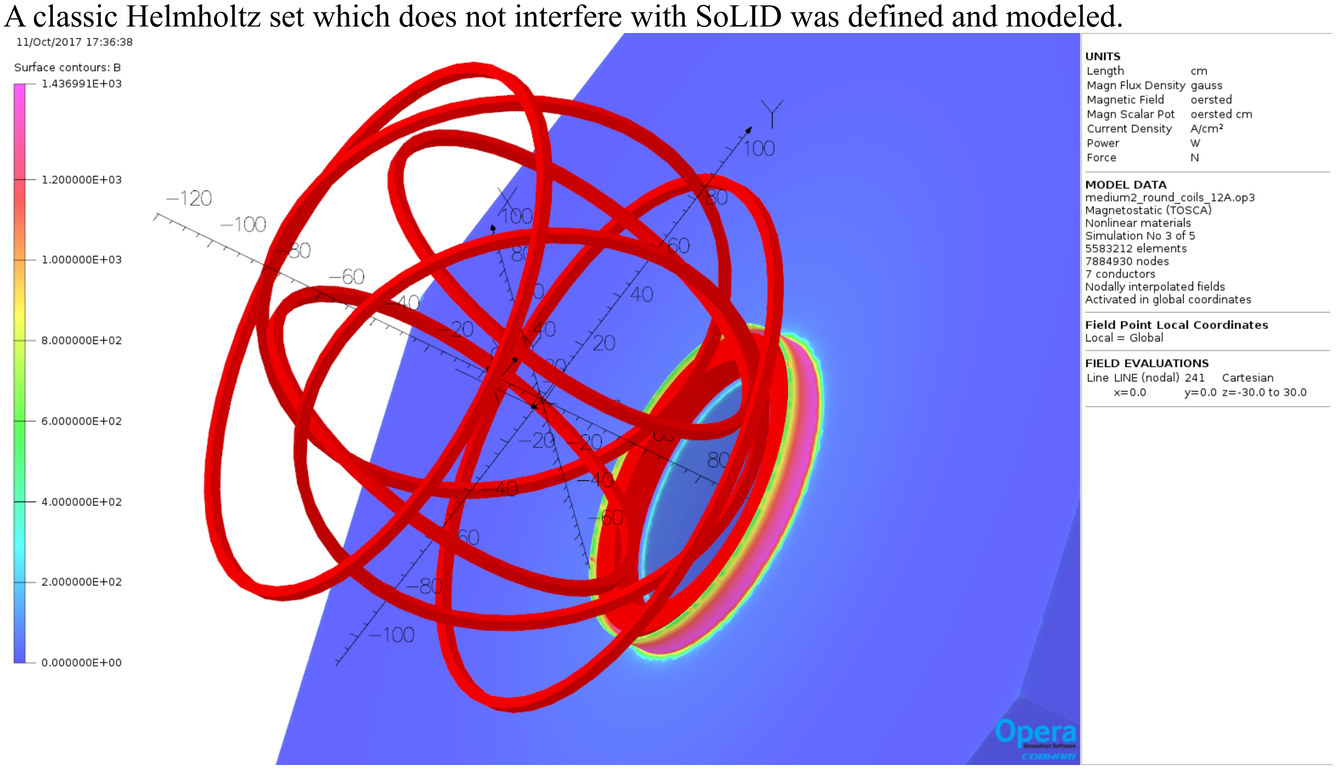

Figure 6. By set innermost, mean R 62.46 cm. Bx next, mean R 70.26 cm. Both offset 10 cm vertically. Centered outer pair Bz with 2880 AT. Mean R 85.26 cm to allow offset of Bx/By pairs.

Simulations were run with 2880 AT in each of the X, Y and Z pairs and then with different currents in the two Z coils so as to flatten the field in the presence of the steel.

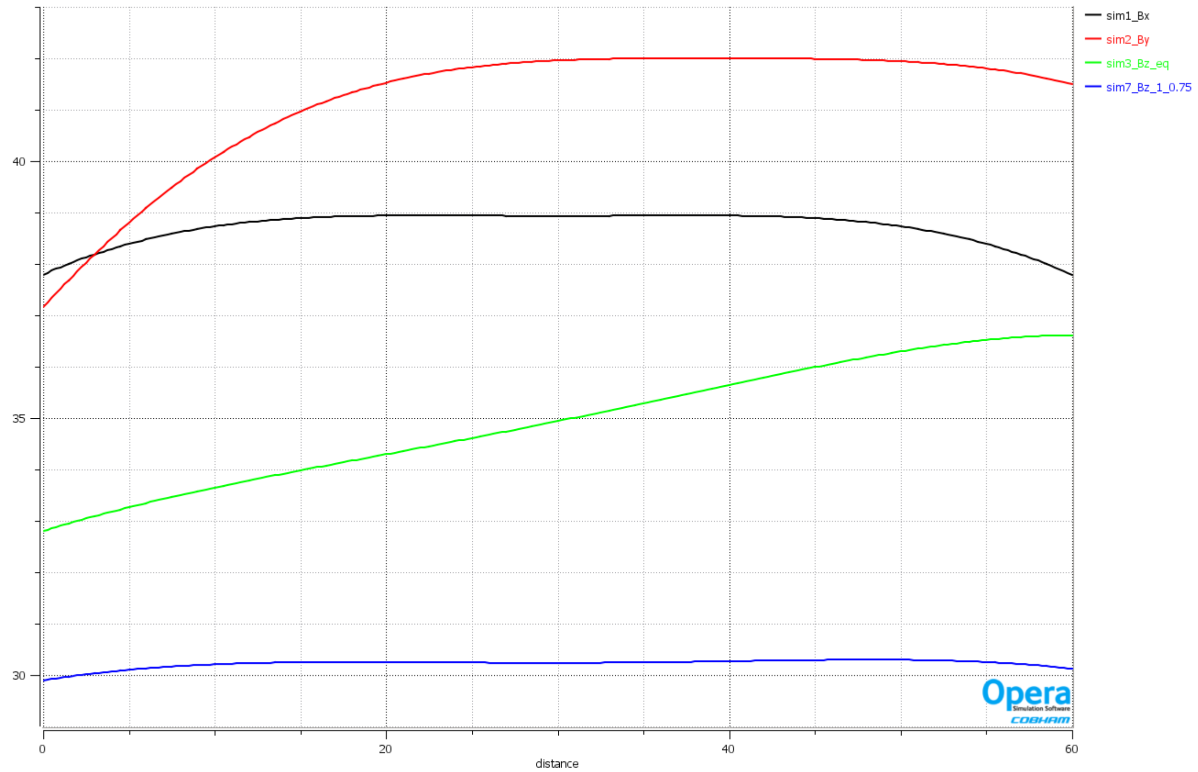

Figure 7. B along axes with equal currents (2880 AT) in the paired coils. By (red) is asymmetric because the pair is offset 10 cm vertically. Effect of SoLID steel on Bz field (green) is profound. The blue line shows the Bz field along the axis with downstream coil at 75% of upstream.

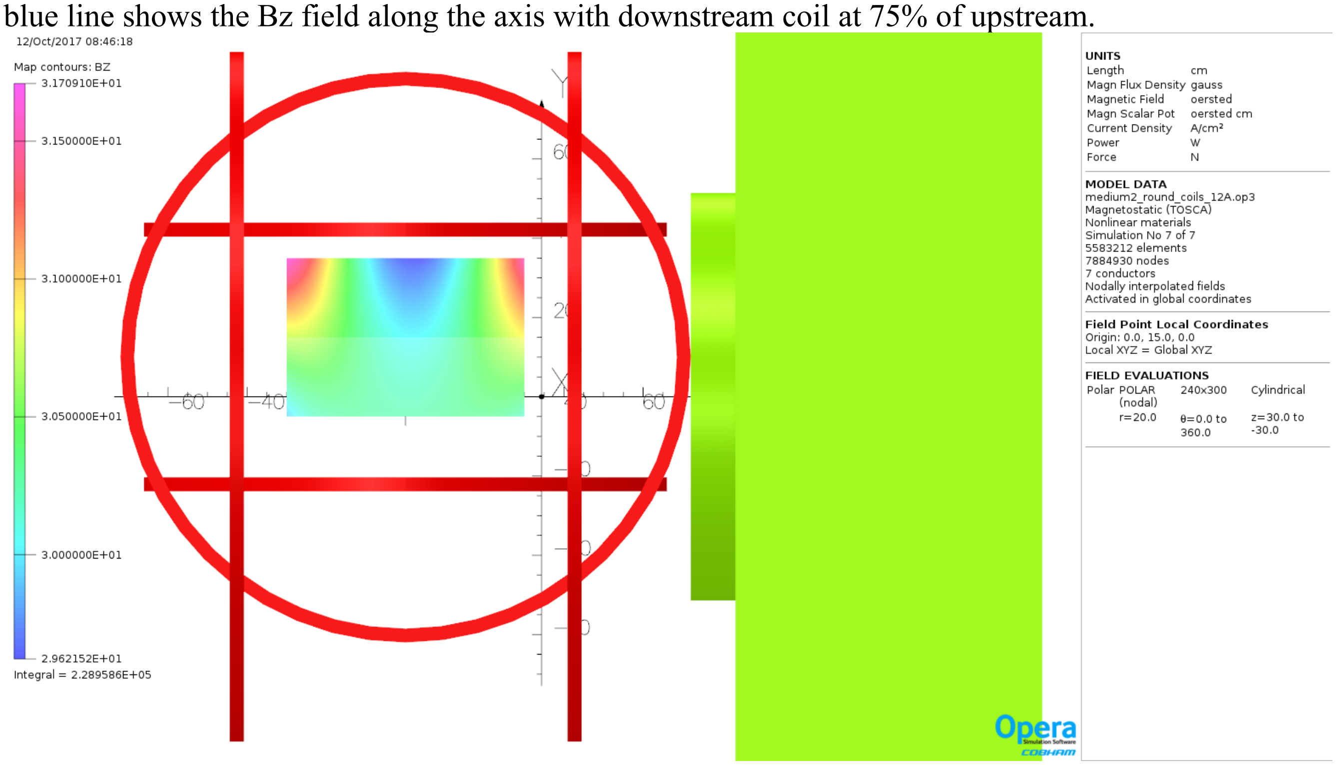

Figure 8. Bz on surface of 40 cm diameter cylinder 60 cm long, offset 15 cm vertically as in Figure 3. Bz with 2880 AT upstream and (75%) 2160 AT downstream. Minimal clearance between Bx coils and steel at right but OK in 3D. Bx and By coils offset +10 cm.

Comparing the round coil sets:

- Mean radii: Temple Bx 66.8 cm, Bz 75.8 cm
- Mean radii proposed: Bx 70.3 cm Bz 85.3 cm By 62.6 cm
- Temple offset vertically 15 cm, proposed new 10 cm given larger radii in x, z.

Coils on a cube

From experience in a Yale atomic physics lab 4.4 decades ago I know that at large sizes the fields of six coils arranged in a cube do an adequate job of providing a flat field in a volume which, while smaller than that of the classic Helmholtz set, may still be adequate. I also modeled such a coil set.

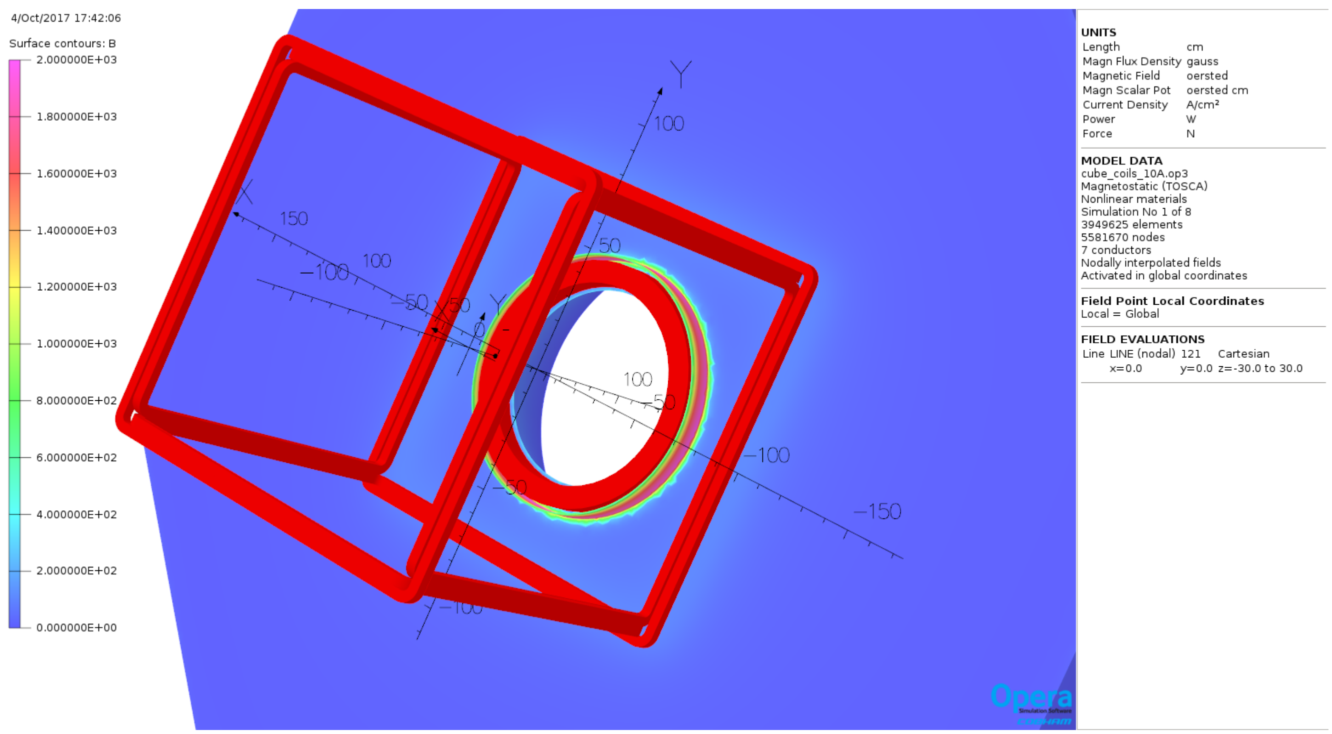

Figure 9. Cubic coil set. 2400AT in Z coils, |B| on surface of steel

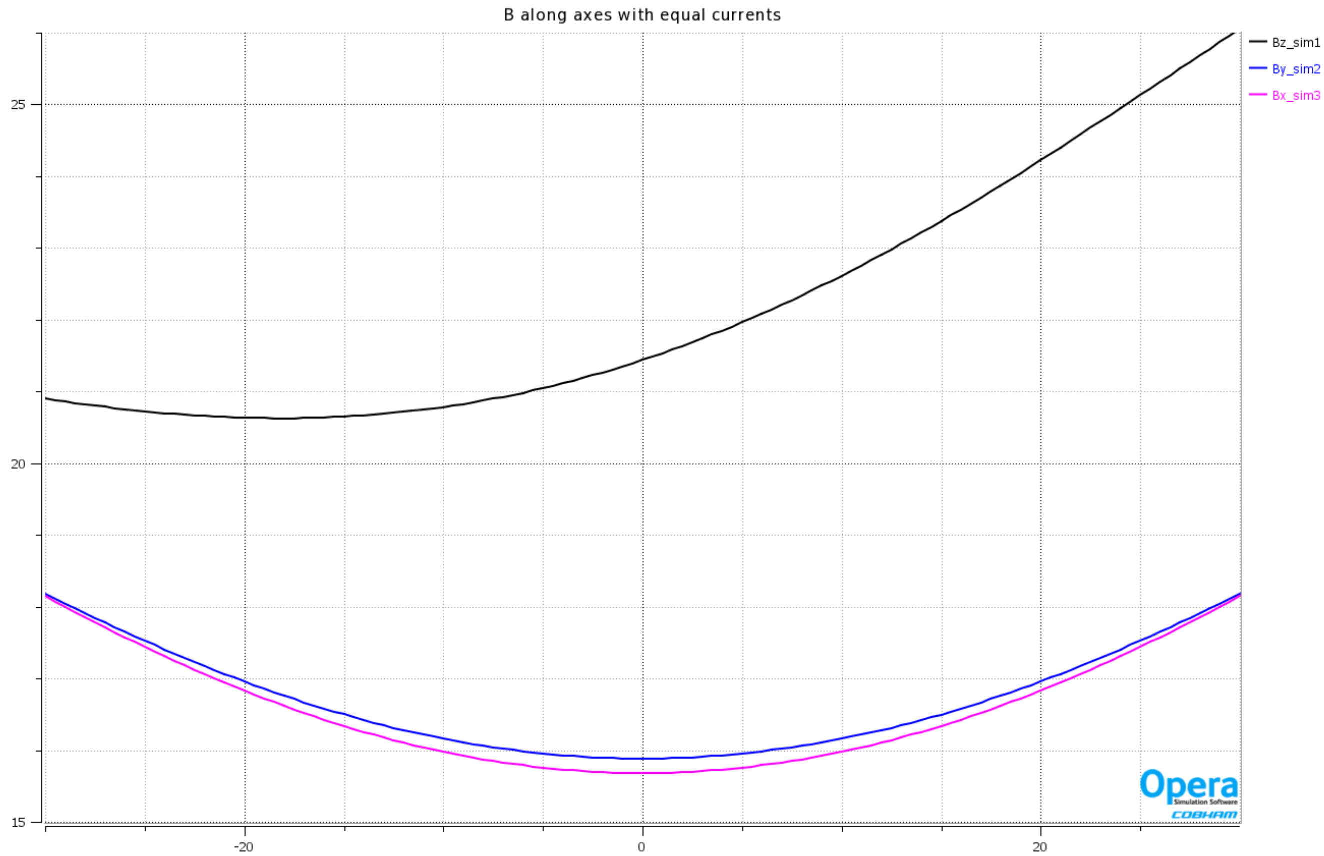

Figure 10. B along x/y/z axes as appropriate. 2400 AT in each coil. Since volume is larger, field is lower than with round coils. Black curve, Bz, shows effect of SoLID steel.

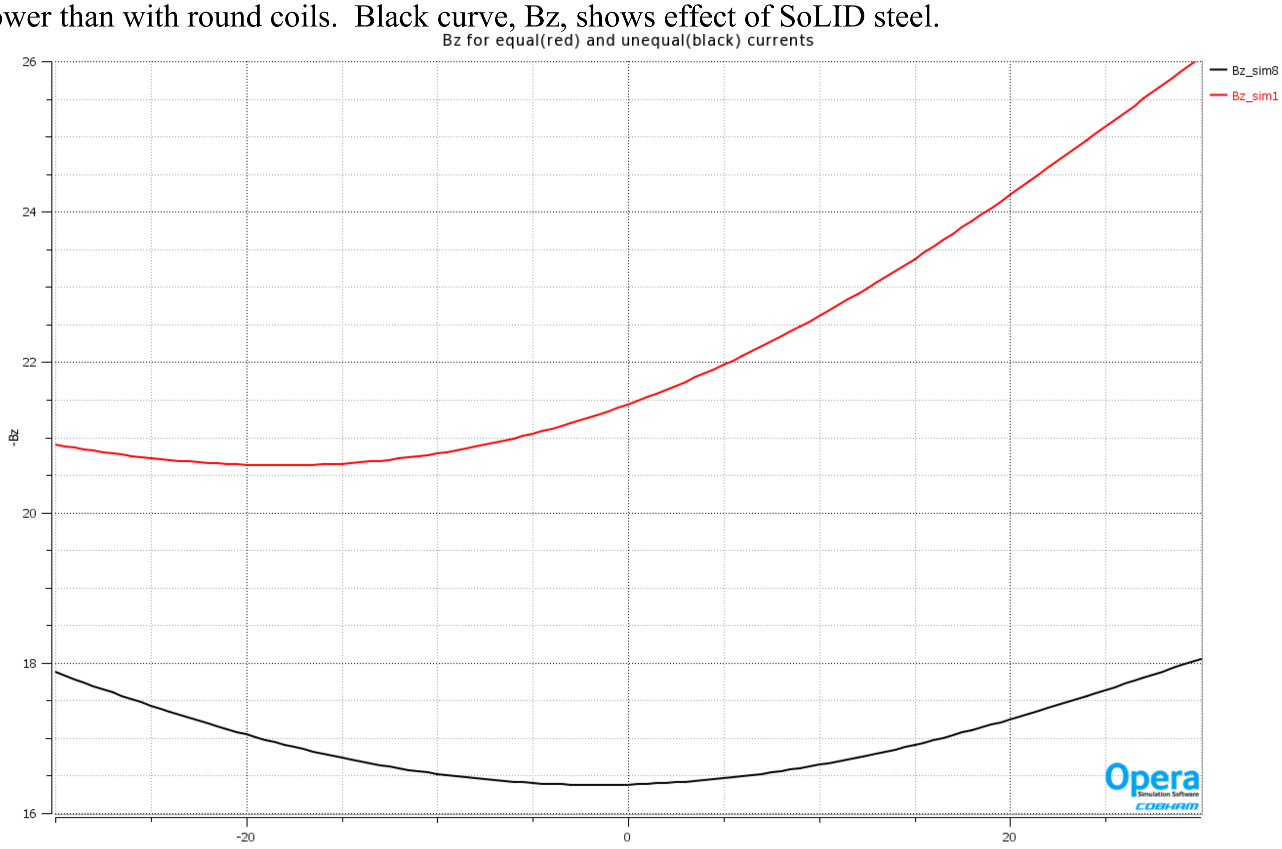

Figure 11. Red: 2400AT in both. Black 2400AT upstream, 1472 AT downstream.

Comparisons

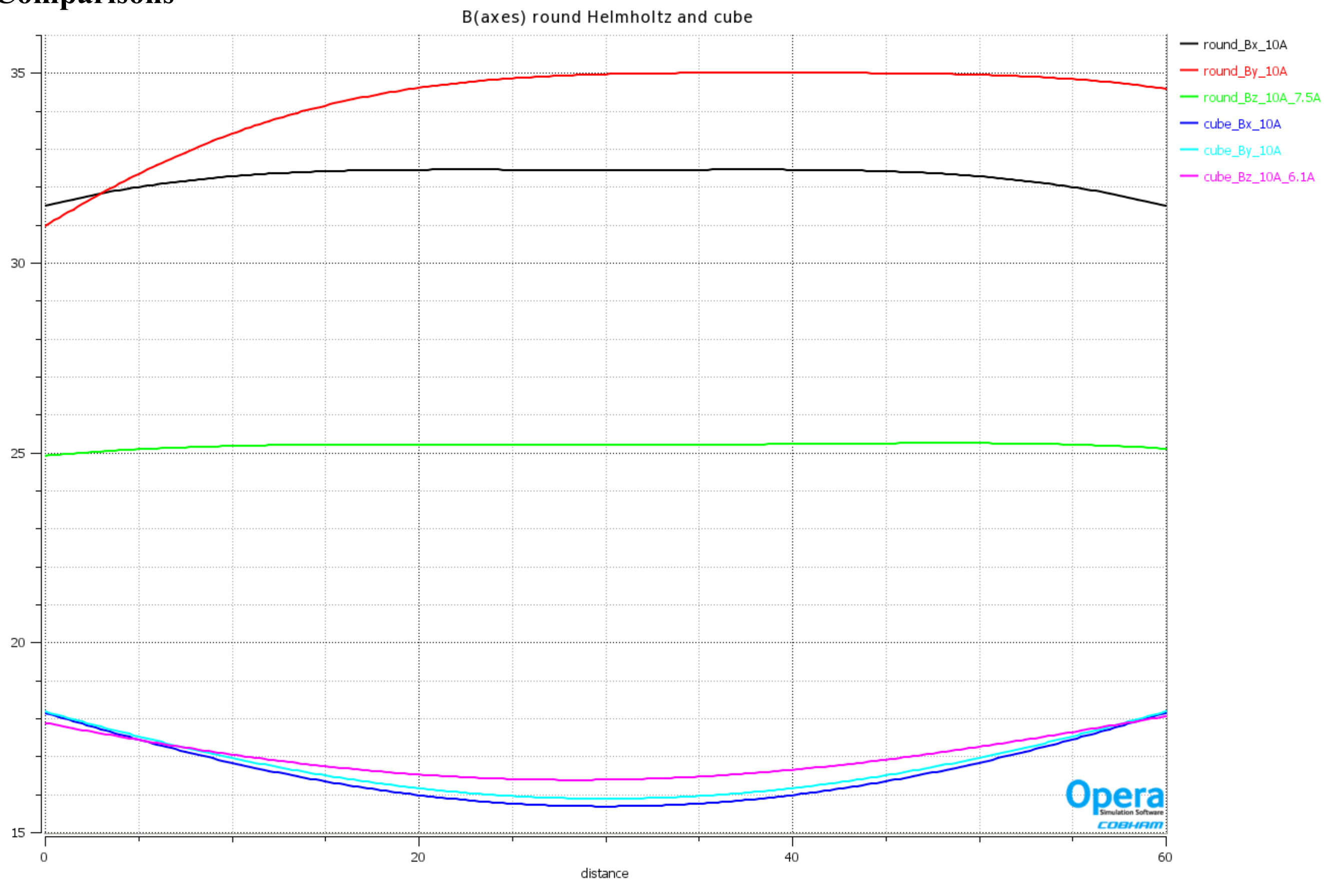

Figure 12. Fields due to my round coils are at top, square coils are at the bottom. X and Y pairs have 2400AT in each coil. Z upstream 2400AT. Z downstream 1800 AT round, 1472AT square

Looking at figure12 one sees that the classic Helmholtz set is flat within 1 G over 50 cm along respective axes. Since the Z set has the largest diameter, its excursion is ~0.5G over that distance. For the cube, the Z excursion is ~1.1 G over 50 cm. The X and Y excursions are ~1.8G over 50 cm but the target does not extend that far vertically or horizontally. One could bring the X and Y square coils somewhat closer together to reduce this excursion while maintaining better access to the target system than with the classic Helmholtz set. Radiusing the corners of the square coils 5-10 cm would also help.

Conductor

For the round Bx and By sets, #12 square copper was assumed, 240 turns in a 15 turn by 16 layer array, 3.52 cm by 3.6 cm. For the larger round Bz pair, #10 square. For the larger cube set I modeled a 4 cm square cross section. Using #10 square copper here yields a 4.4 cm square section; the size difference doesn't affect the results shown. All were sized with the 20A/75V trim supply in mind. Conductor size was chosen to make the coils current limited (20A) at room temperature. In figure 12 10A currents are shown so twice these fields are available. If 30 G is not quite enough (cube), radius the corners ~10 cm to lower volume enclosed or shrink the cube slightly or both.

Power supplies

As mentioned above, conductor was chosen with the 20A/75V trim supplies in mind. This is also true of the 9 cm square section, 40 cm IR coil which rings the opening in SoLID to flatten (to 4G) the Bz field coming out of the hole. That coil could be made of aluminum conductor if activation is a concern. I recommend buying eight of the trim supplies, seven needed plus one spare.

Setting the currents

I recommend the approach taken for four decades in the MRI business: measure the field on the surface of a cylinder with an accurate probe and use simplex to minimize it. Eight maps are needed with spectrometers off: environmental field baseline and each of the seven coils individually at, say 10A, measuring the coil and the linear interaction with the steel. Subtract the environmental map to get a useful map for each of the seven coils. The final map is the field on the cylinder with the environmental fields, 9 cm square single coil at 9720 AT (to improve S/N), and SoLID at field. Minimize |B| at perhaps 200 points on the surface of the cylinder with seven currents as inputs.

One possibility to avoid the interaction, not examined here, is to enclose the He3 target system in a steel box so the boundary is fixed independent of hall and adjacent equipment. The mapping and initial setup could then be done elsewhere without schedule pressure.

Conclusions

Three coil sets have been modeled so those familiar with the He3 target can examine them for viability. Field maps through volumes at few-mm intervals can be produced upon request. The coil sets used may be exported from Opera and sent to Hall A and C engineers so they may examine the effects of other systems, e.g. SHMS Horizontal Bender, BigBite or Super Big Bite, on the target. Or I can simply provide dimensions.