SoLID magnet modelling with CLEO steel (again)

Jay Benesch

24 March 2020

Discussion

A TOSCA model prepared in Fall 2017 with 3*17 cm octagonal steel was revised to once again use the first two layers of the CLEO steel. These were delivered to JLab in summer 2019. Appendix A of TN-17-044 is attached and updated. This details how I built the model including storage levels and maximum element size. A typo in coil 1 was found by Steve Lassiter when he examined my conductor file. This 3 mm error caused all the torques in TN-17-044. The error did provide a means to optimize mesh. The mesh on the octant has 225M non-zeroes, 10.5% of the maximum allowed by TOSCA. This was chosen to allow the model to be run without octagonal symmetry to examine the effect of the cryo stack cut-out. Since the effect was minimal in the volume to be occupied by detectors it will not be repeated. See 17-044. The mesh in detector air can therefore be reduced in maximum size to 1 cm from 2 cm, increasing non-zeroes to 858M. The 2 cm mesh allows solution in sixteen hours. The 1 cm mesh model took xxx hours.

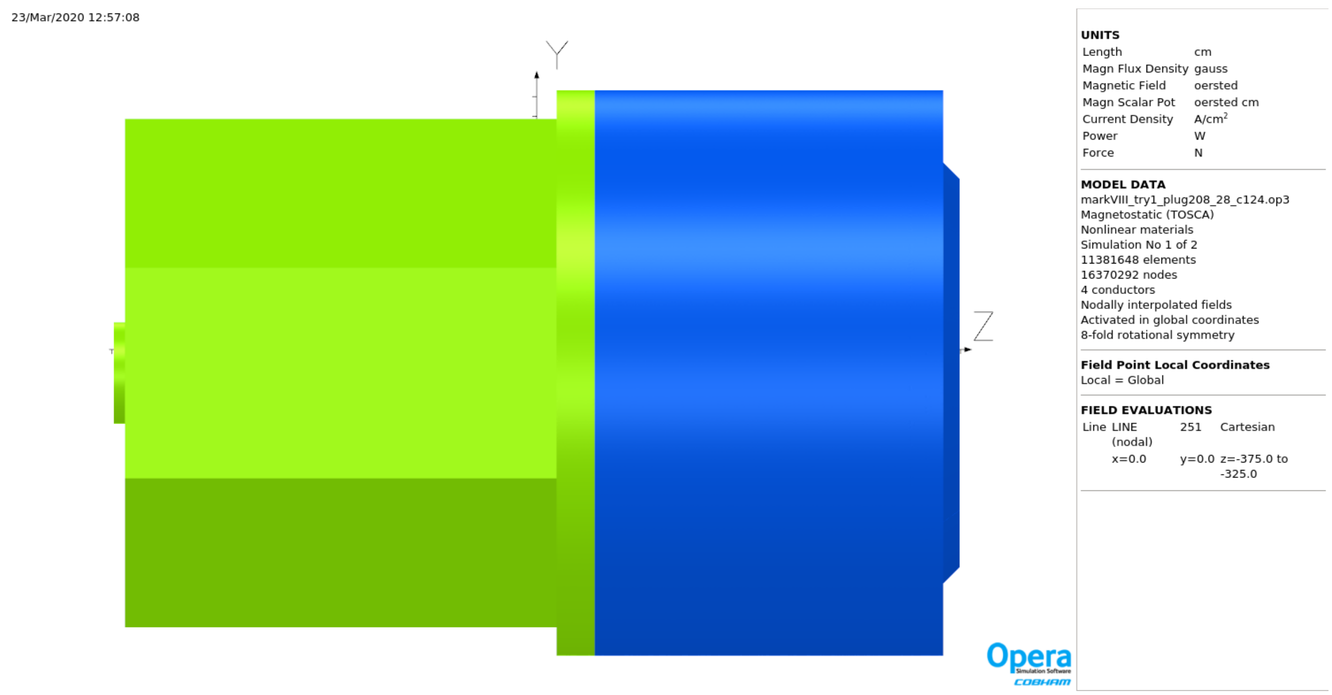

Figure 1. The outside of the model. The blue steel has the B in the BH curve of the green multiplied by 0.98 to simulate the slots needed to get cables out. Implied: area of the slots is 2% of the surface. Longitudinal slots rather than holes as the field in the cylinder is longitudinal, returning the flux from the solenoid. The small green item at left is a thin steel ring around the correction coil (page 3), mostly to protect it from damage. It does reduce current needed a bit by returning flux.

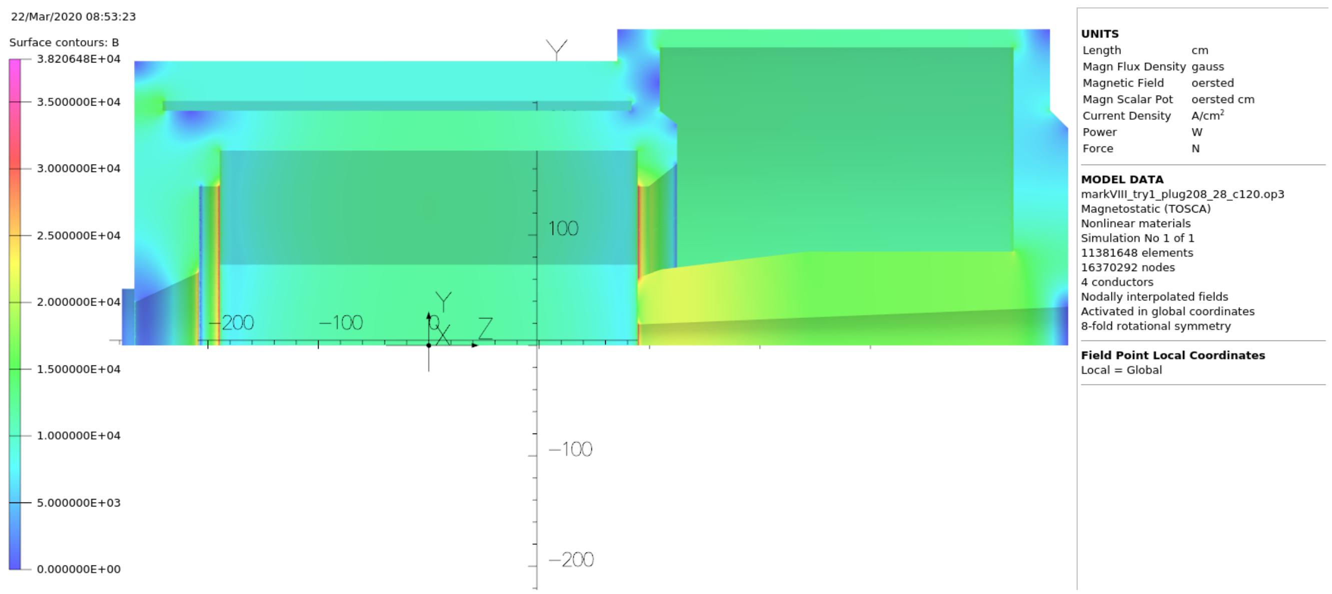

Figure 2. Field on the surface of the steel. Highest values (38 kG) are non-physical.

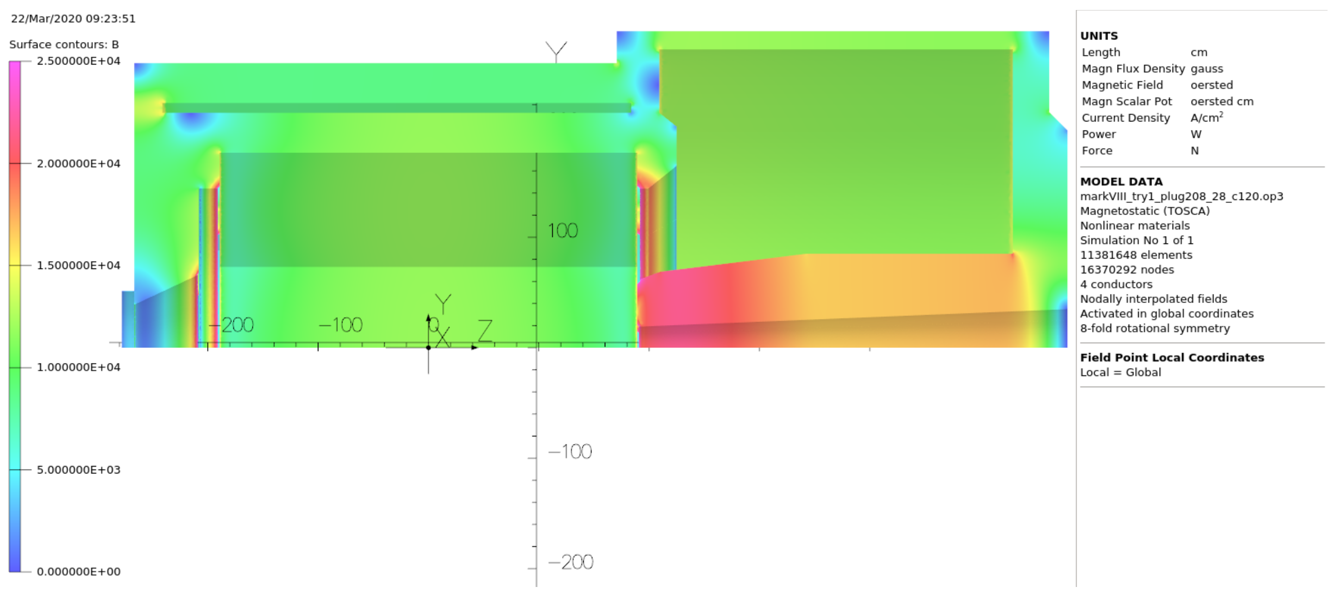

Figure 3. Same as Figure 2 except field maximum is limited to 25 kG. Steel above that value is missing from the figure.

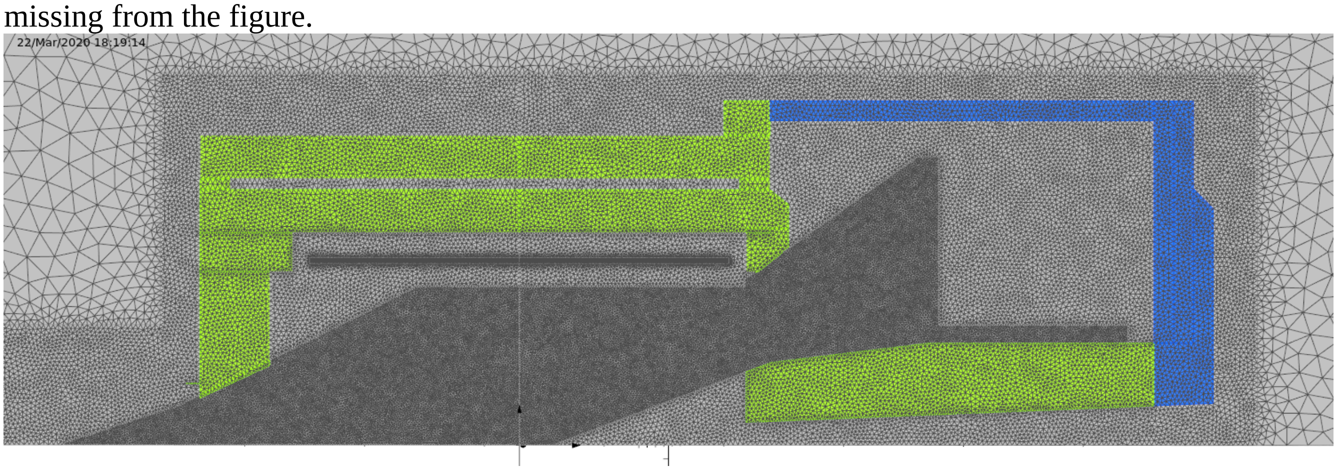

Figure 4. Mesh with 2 cm maximum tetrahedra in dark region, 4cm otherwise except coil. Side view of octant so Y axis must be mentally multiplied by √2.

Three years ago Thia Keppel suggested adding a single resistive coil around the conical entrance to the device to null the flux which leaks from it. The He3 polarized target to be used for one set of experiments requires low, controlled fields. See TN-17-051. This coil is described in detail in 17-044. It is 9 cm square cross-section with 100 A/cm^2 J. The plots below use the multiplier for this J as part of their labels.

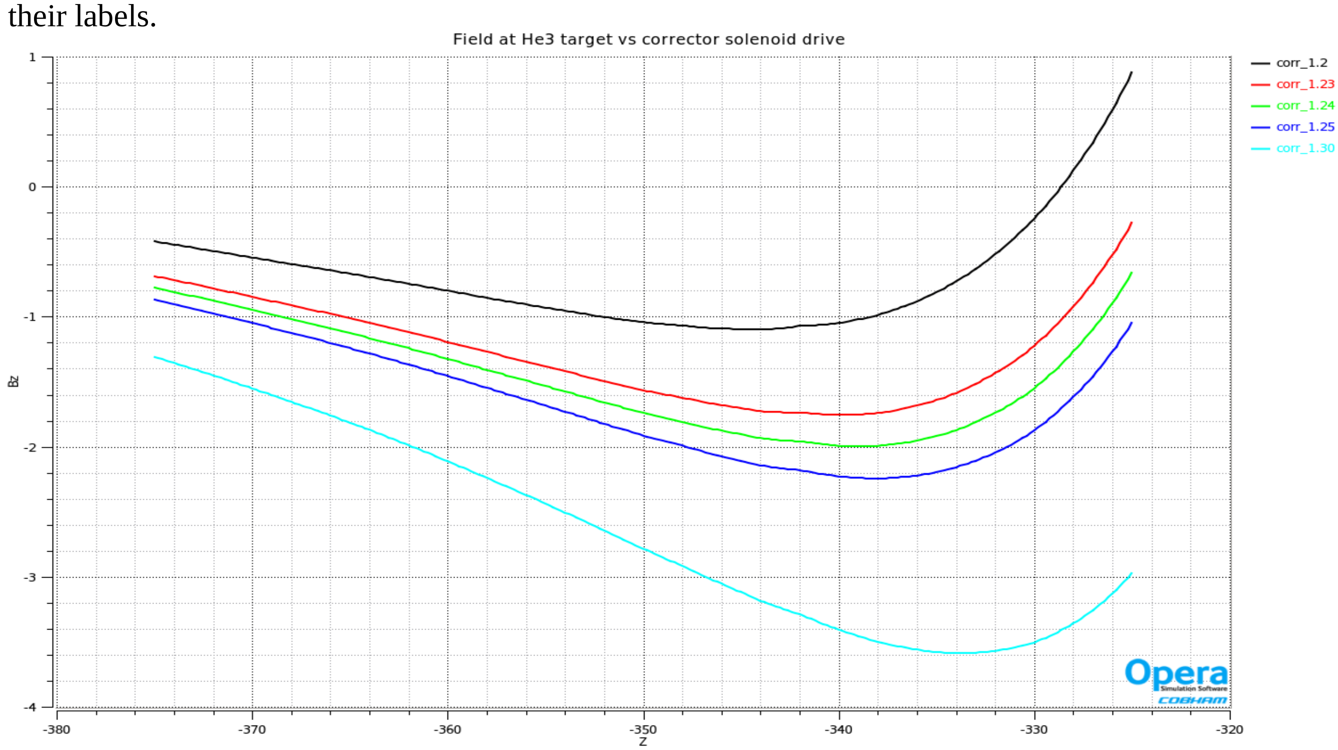

Figure 5. He3 target will be centered at Z=-350. The target may be as long as 60 cm but I graph only 50 cm here. The multiplier for the drive coil (8100 AT) varies from 1.2 to 1.3. 0.05 steps were used initially 1.2-1.35 and then refined.

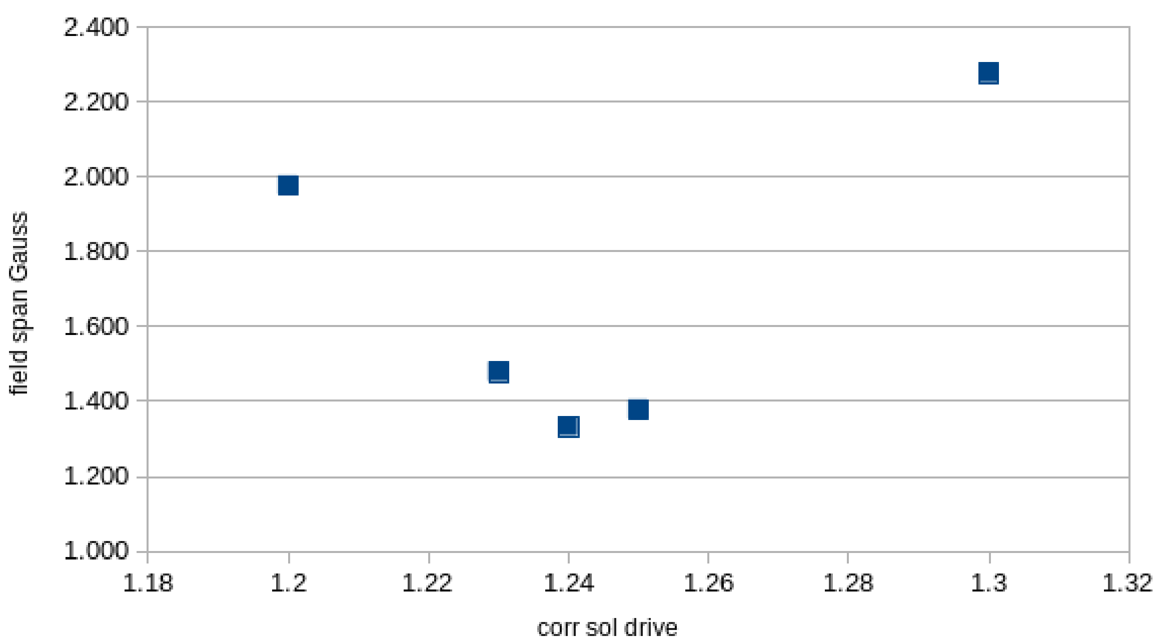

Figure 6. The field span, maximum-minimum, of the five coils in figure 5 are plotted against the drive multiplier. 1.24 is close enough to an absolute minimum to use it as nominal.

Forces

The forces on the coils were computed as a function of the Z terminus of the plug with conical hole.

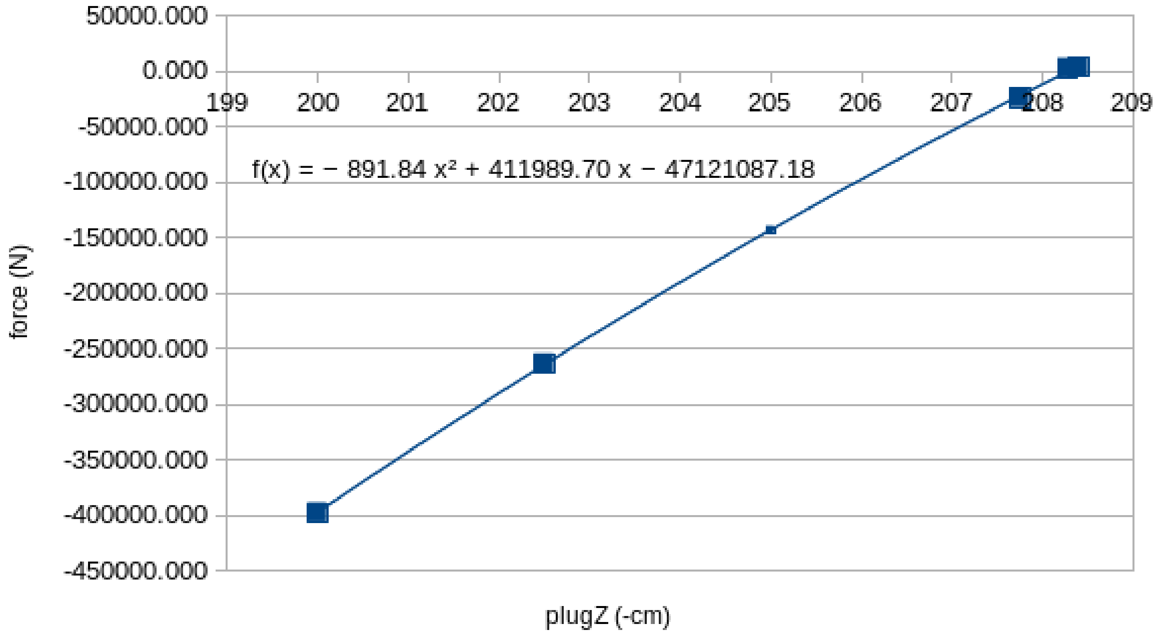

Figure 7. |Z| plug terminus vs force on coils. The quadratic was solved. The zero is supposed to be at Z 208.29. The modeled value at 208.28 is 2681 N. Close enough. Slope 42 kN/cm.

Calculating forces on steel parts is tedious in Opera Post-processor. One must have labeled each during the model build. Then one must set "Full" symmetry. Finally, one must hide all parts except the one wants to evaluate force on. I provide only Z forces and torquest below unless the X, Y values don't cancel. Torque point is the center of the solenoid unless otherwise specified.

<u>Correction coil steel ring</u>
Z-direction: 390 N
Z around (0,0,0): 6 N-cm

<u>Upstream plug</u>
Z-direction: 1.634E+06 N
Z around (0,0,0): -14205 N-cm

<u>Upstream coil collar</u>
Z-direction: 0.810E+06 N
Z around (0,0,0): -40817 N-cm

<u>Inner octagon</u>
Z-direction: 0.238E+06 N
Z around (0,0,0): 442800 N-cm

<u>Upstream spacer bars (all eight)</u>
Z-direction: 1340N
Z around (0,0,0): -127000 N-cm

Downstream spacer bars (all eight)
Z-direction: -5N
Z around (0,0,0): -106150 N-cm

Outer octagon
Z-direction: 78660 N
Z around (0,0,0): -85180 N-cm

Downstream collar
Z-direction: -1.11E+06 N
Z around (0,0,0): -110700 N-cm

Interface: octagons to end cap cylinder
Z-direction: 1.44E+06 N
Z around (0,0,0): -36900 N-cm

Cone and attached end plate, figure 8
Z-direction: -1.654E+06 N
Z around (0,0,0): -14700 N-cm
Z around (0,0,562.61) -14700 N-cm. This is NOT torque due to gravity.

Endcap cylinder
Z-direction: -0.263E+06 N
Z around (0,0,0): -93 N-cm

17cm end plate 1
Z-direction: -1.214E+06 N
Z around (0,0,0): -420 N-cm

17cm end plate 2
Z-direction: -0.111E+06 N
Z around (0,0,0): 3 N-cm

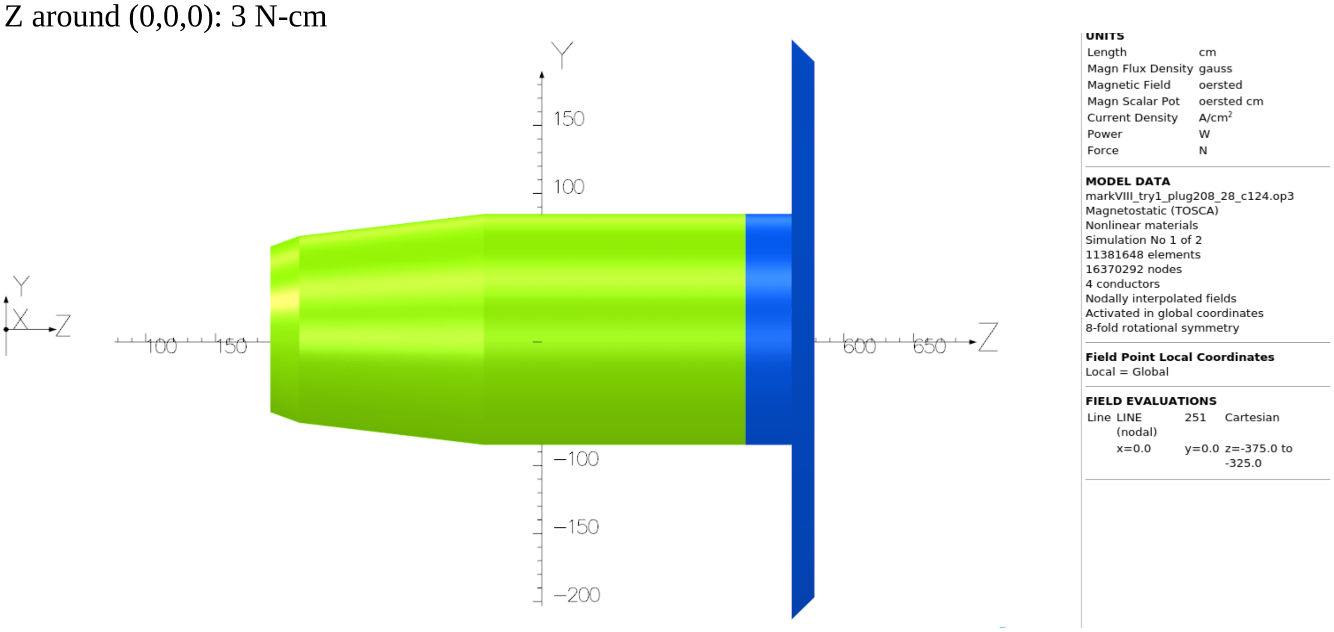

Figure 8 Cone and attached end plate

Fields in detector regions

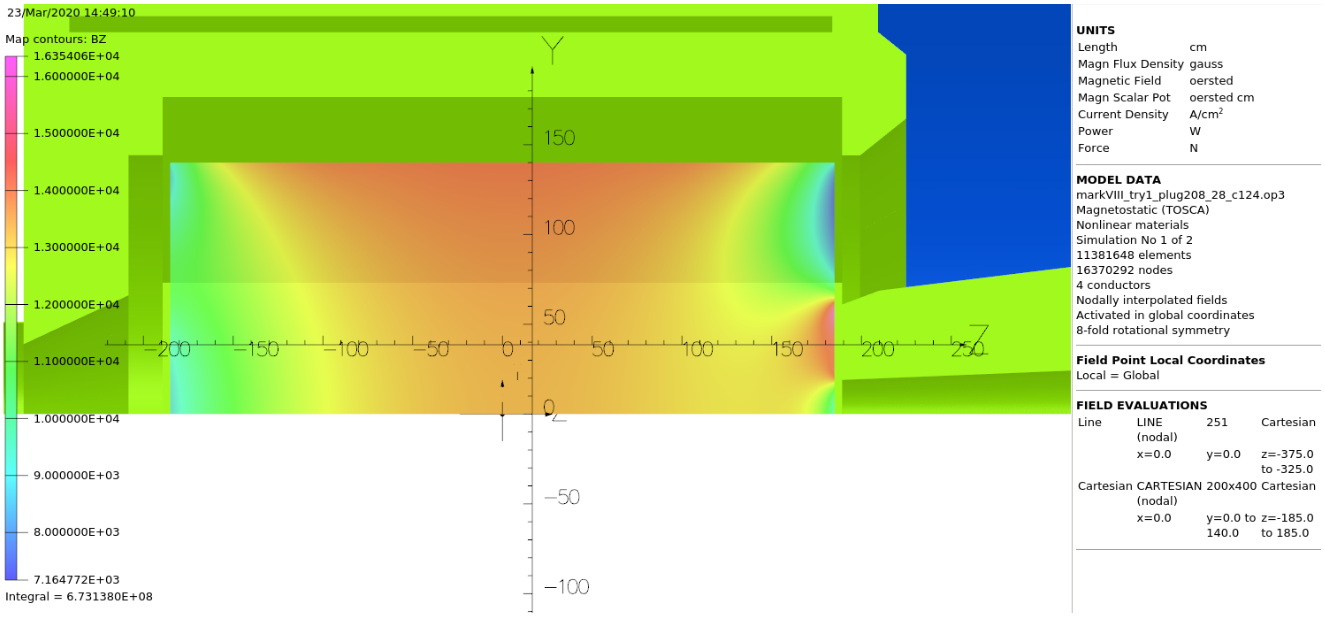

Figure 9. Bz in bore, ending 4.23 cm from cone nose.

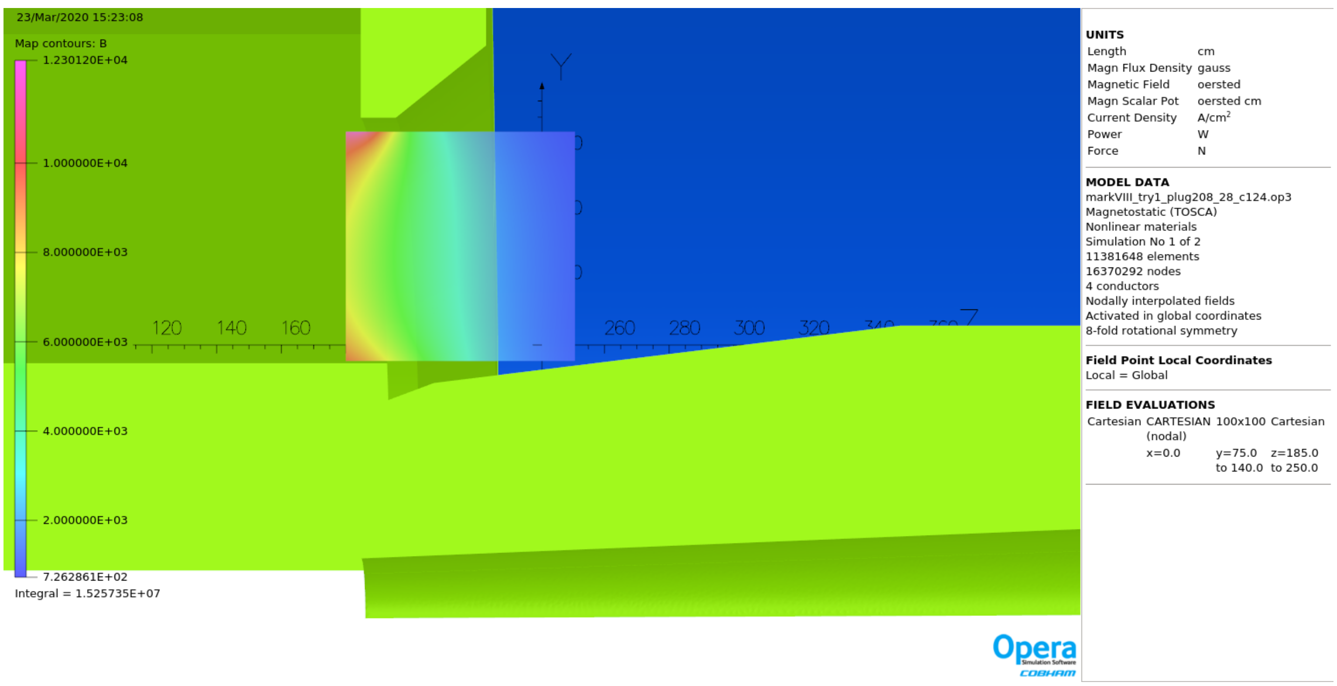

Figure 10. |B| in the transition from solenoid to endcap

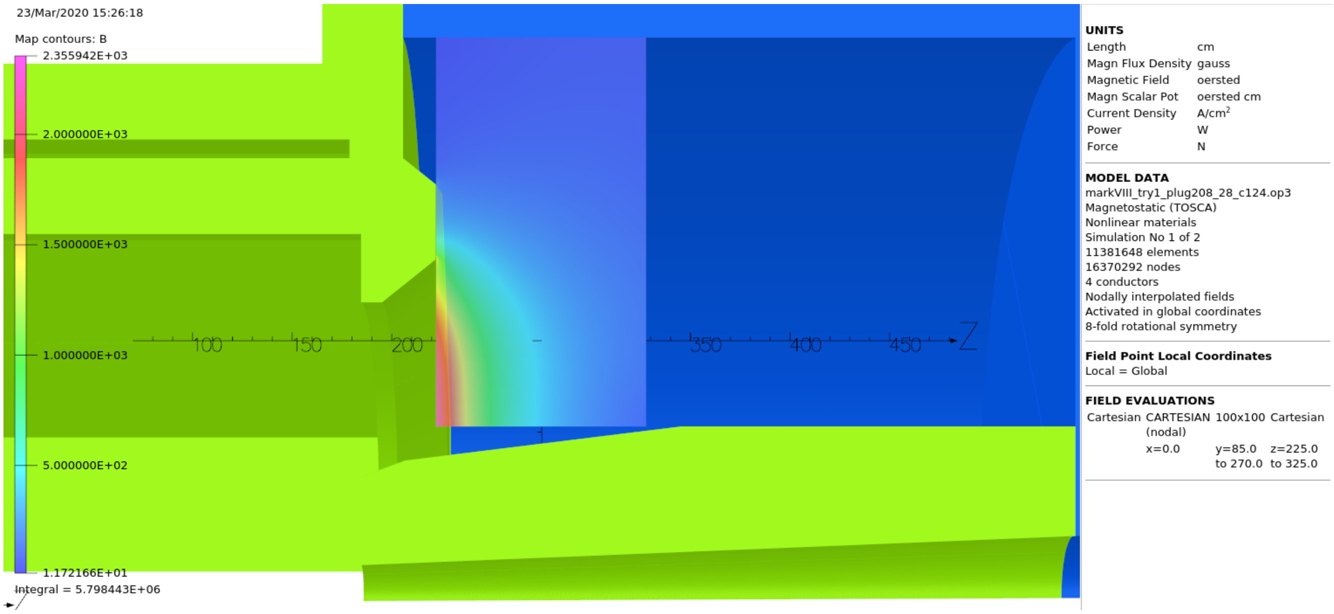

Figure 11. |B| over cone in first part of end cylinder.

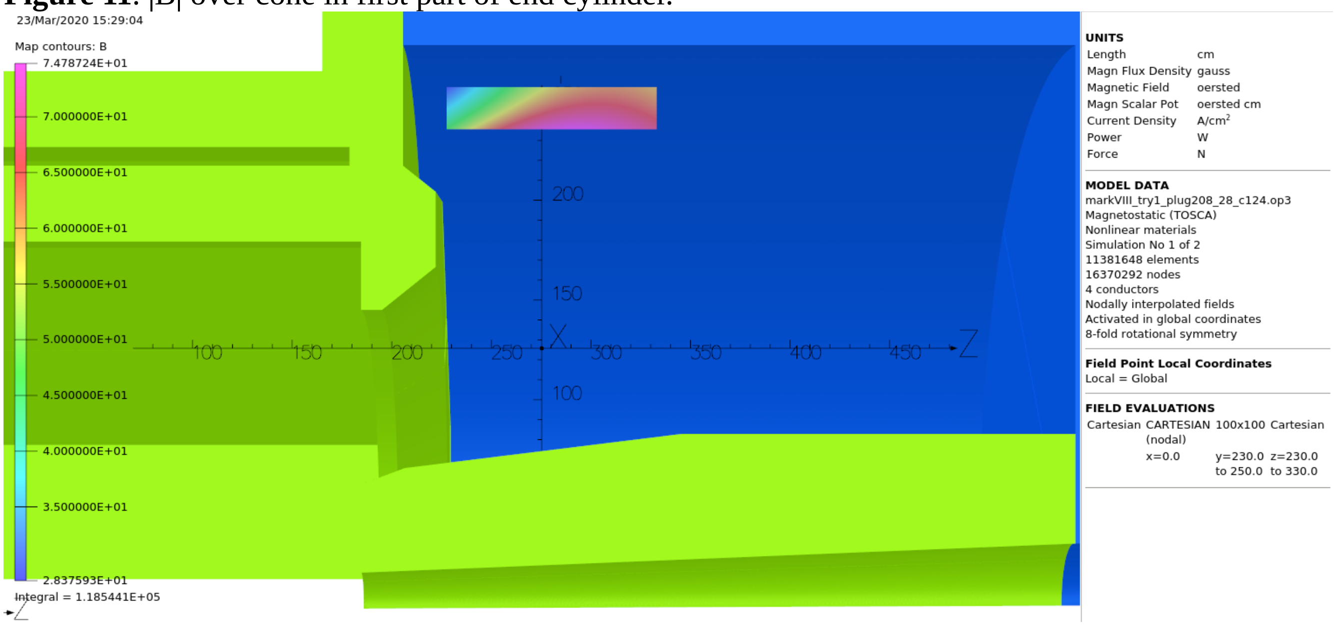

Figure 12. |B| in vicinity of HGC and LGC PMTs. 28-75 G.

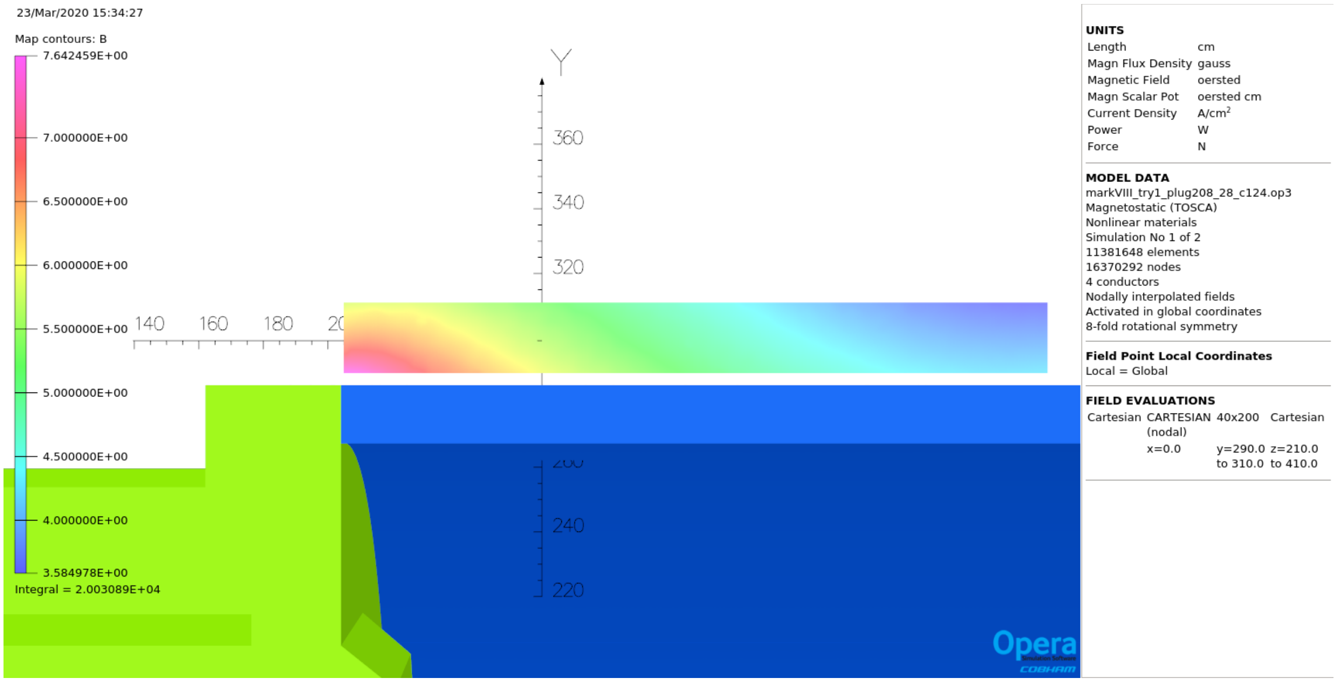

Figure 13. |B| in vicinity of GEM electronics 3.6 - 7.6 G

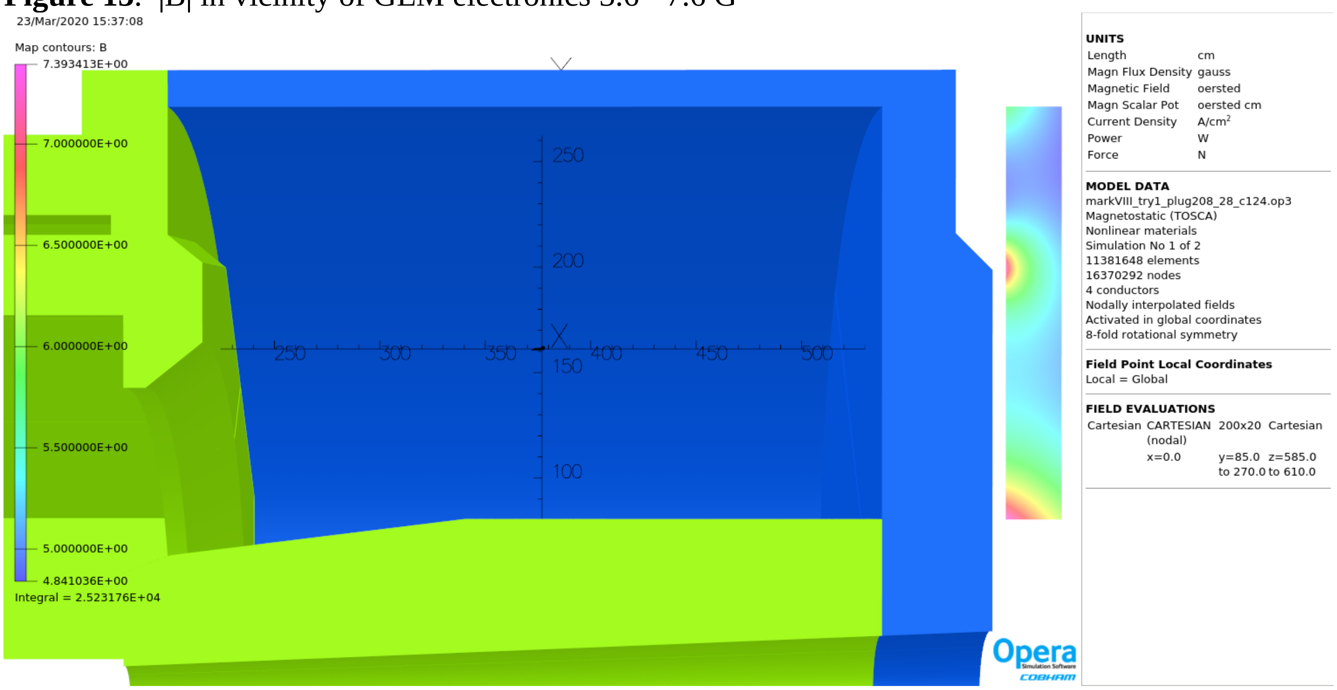

Figure 14. |B| in vicinity of calorimeter PMTs. 4.8 to 7.4 G. If the hot spot at the chamfer is a problem, changing from 45° to 60° might help.

Figures 9-11 show that the field encountered by the electrons is complicated so detailed field maps are needed for simulation. Unfortunately, even in octant form field maps with 1 cm intervals ate GB because the volume of interest is so large. Figures 12-14 show that PMTs can easily be shielded from fields once one is well into the endcap.

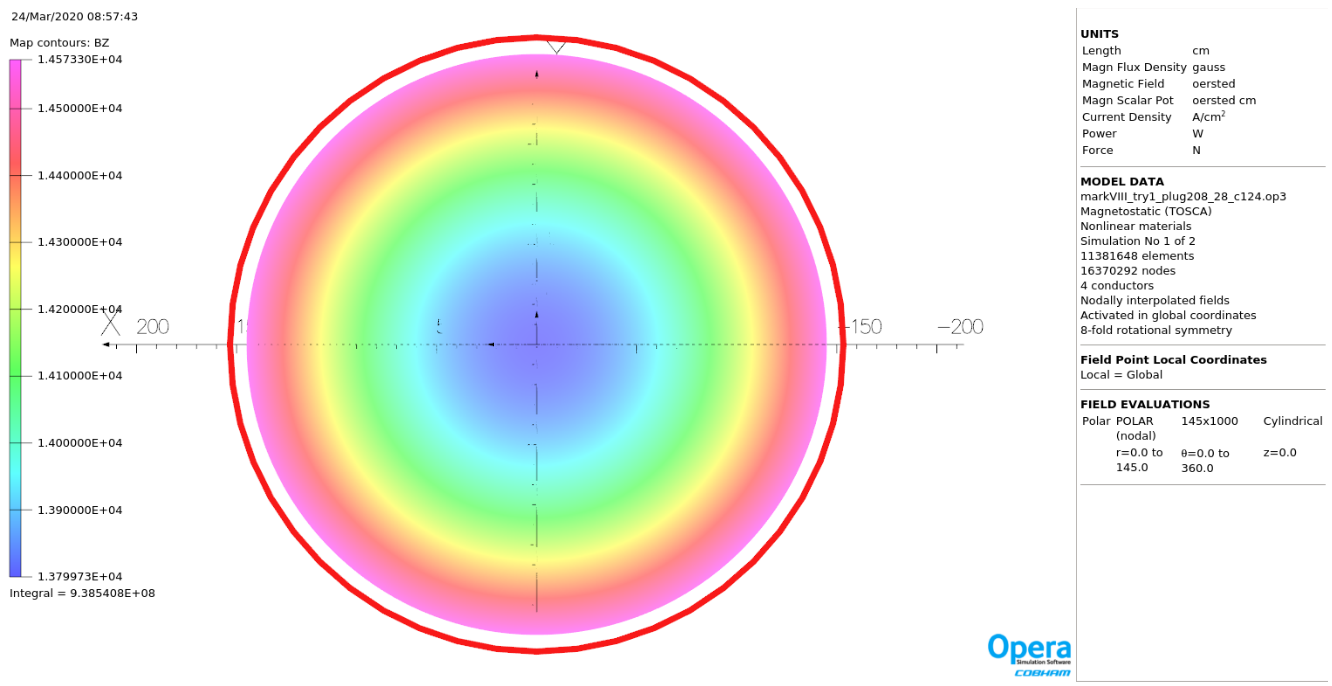

Figure 15. Bz at center of solenoid. At this Z field is uniform to 0.1% in theta. At Z=-100, field uniformity 0.3%. Near the entrance to the endcap, 1.7%.

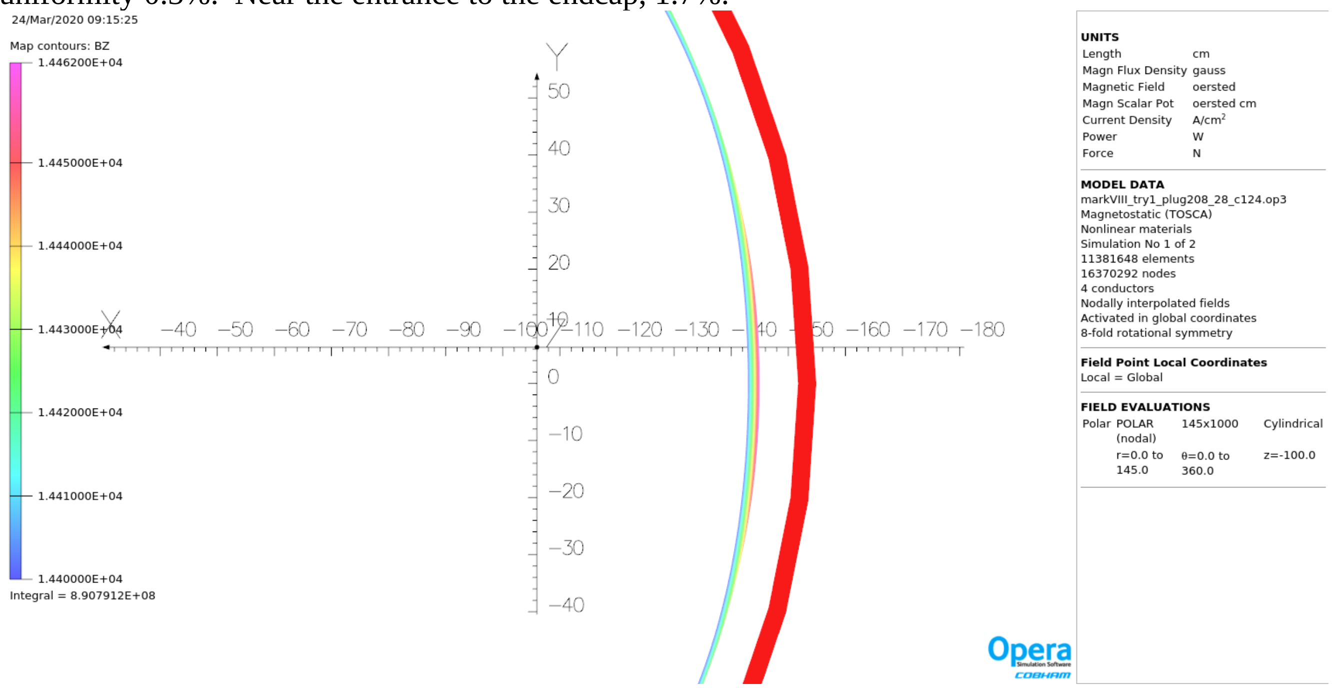

Figure 16. Bz at Z=-100. Field range restricted to only 62 Gauss so one can see higher field where the steel is closer to the coil.

I am unable to generate a field map like the one in figure 16 near the coil at Z=185 which illustrates the 1.7% non-uniformity in theta. The full disk follows.

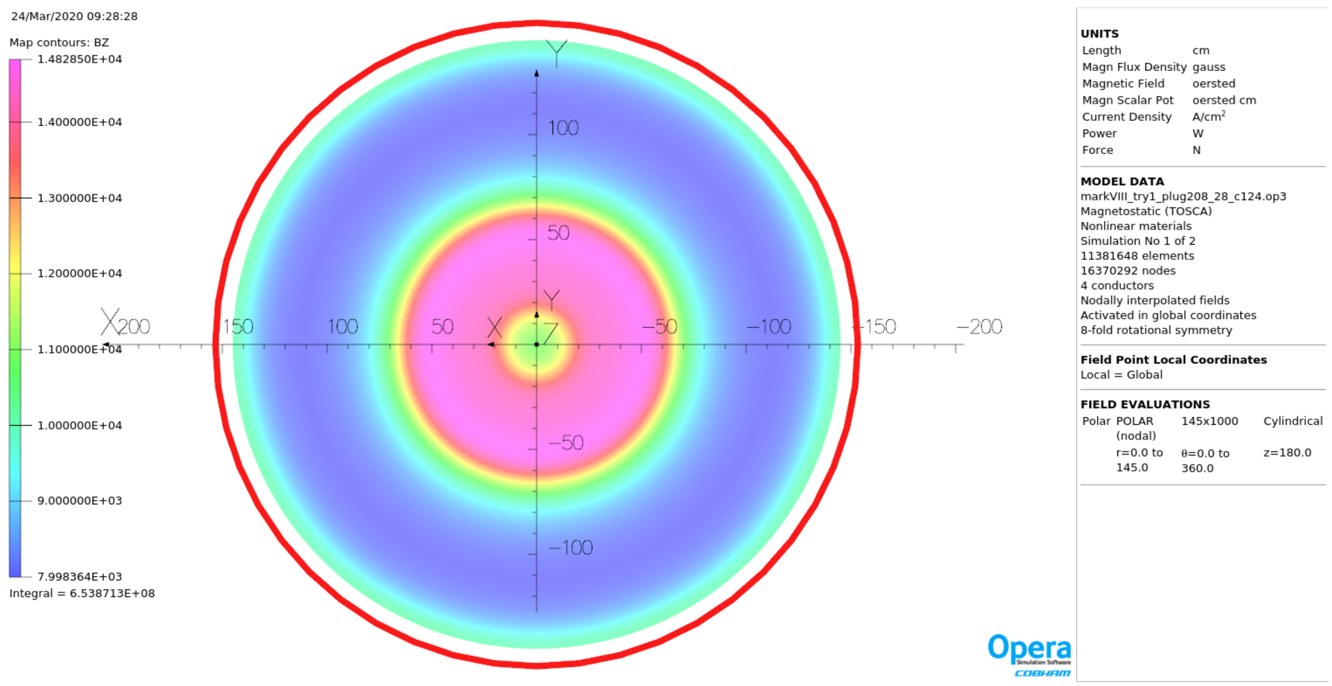

Figure 17. Bz(x,y) at Z=180. Cone starts at Z 189.23. There are two bands of 11 kG field, near center and near coil.

The 1.7% discrepancy seen when OPERA produces numerical values for Bz at (145,0,185) and (133.96,55.49,185), aka points closest and farthest from octagonal steel, suggest to me that a full octagonal field map is needed, not just (Br, Bz). (Acknowledgment Jixie Zhang) If Whit's support structure reduces the accessible radius well below 145 cm shown here, the conclusion may change.

Appendix A: Modeller primitives used to build Opera models revised 3/23/2020

Inner octagon steel1 level 92 4cm

inside Y 69.5” = 176.53 cm * (1/cos 22.5)= 191.075 IR
outside Y 83.71” =212.62 cm * (1/cos 22.5) = 230.142 OR
radial thickness 39.069 cm.
Z -266.7 to 224.79

Opera has a operation: make n-sided polygon. Using 230.142 OR and thickness 39.069 one arrives at an octagon with the inside and outside heights on the Cornell drawing 6052-303 sheet 3.

Chamfer at Z 224.79 OR 15.56 in Z by 12.45 in R

Notch construction air at end of inner octagon

Whit has a 1.5” notch running Z=189.23 to 224.79 which is 1.5” deep to match hexagonal OD of new coil collar. But coil collar has round ID. So I have to make a hexagonal notch in inner octagon and then trim overlap. As above, the OR 71” = 180.34*(1/cos 22.5) = 195.2,
IR 69.5” =176.53*(1/cos 22.5) = 191.075 but use deltaR 4.25 and Z 225 max to grab it.

Outer octagon steel2 level 91 4cm (so I can make it air BH later)

outside Y 101.42” = 257.61*(1/cos 22.5) = 278.832 OR
radial thickness 39.069 cm
Z -266.7 to 209.23
Again, make n=8 polygon of this Opera “tube”

Spacer bars steel2 level 91 4cm (so I can make them air BH later)
Between octagons: I figured out the volume of the bars and determined that cutting the Z extent to 25.5 cm would maintain the steel volume. Z extent: -266.7 to -241.2, 183.73 to 209.23. This simplifies the model a lot. These end annuli are merged with the outer octagons in the model and trimmed by inner - no air gaps.

Coils used cold dimensions from OMT manual, including Z shrinkage, and warm Z lengths of outer segment from winding drawing.

IR 151.7 OR 154.9
Z1 -173.75 to -85.45 3814.273 A/cm^2
Z2 -85.45 to 85.45 3708.32 A/cm^2
Z3 85.35 to 173.75 3814.273 A/cm^2

Current densities were derived by looking at total turns, 1281, and conductor sizes from IEEE paper and estimating winding pattern. Only later did I see the winding drawing. I can't find turns count on it. I did learn that the 4.9 mm conductor is used only on the outer winding outer layer, not both layers. More recently I've multiplied the current densities above by -1.0072 (ends) and -0.9961 (center) to get the ratio closer to 1.04 quoted in the paper. Correction solenoid 9 cm square, -1.2

Upstream coil collar steel1 93 4cm
OR 194.145 cm, 113.50” ID => 144.145 cm IR, deltaR 50, Z -266.7 to -189.23 cm (30.5” extent).
Trim overlap with inner octagon.

Coil air: level 100 2cm
OR 156 cm, thickness 5 cm, Z -175 to 175 cm

Upstream plug steel1 93 4cm
Z -266.7 to **-208.28** cm (23")with Zhiwen taper on steel cone. Plug OR 144.145 cm. Solid to start. Create a cone with 1 mm R tip at Z=-350 and base 74.61 cm R at Z=-190, aka 25 degree angle. Trim overlap of steel with air, then delete air leaving conical hole. *Bold value varied to null force on coils.*

Downstream collar steel1 94 4cm

Z 189.23 to 224.79
tube OR 195.20 deltaR 51.2
at IR 144, Z 224.79 chamfer R 20.447 Z 25.56
trim overlap to inner octagon notch made on previous page

Cone steel1 95 4cm

R66.25 at Z 189.23 from 7 degree constraint
R85 at Z 342.27 from 7 degree constraint and 85 cm OR maximum

Zhiwen_taper s 96 4cm

R61 Z189.23
R68.759 Z210
trim overlap with cone above. Check for errors before and after.

CylinderA steel1 95 4cm
OR 85 Z 342.27 to 579.12

Endcap_cyl steel1 90 4cm
OR 286.51delta R 16.51 (6.5") Z 209.23 to 529.59

End_plate1 steel1 90 4cm
OR 286.51 delta R 201.51 (leaving 85 cm for CylinderA), Z 529.59 to 546.1

End_plate2 steel1 90 4cm
OR 286.51 delta R 201.51 (leaving 85 cm for CylinderA), Z 546.1 to 562.61

Cone_plate steel1 95 4cm
OR 213.36 delta R 128.36 (leaving 85 cm for CylinderA), Z 562.61 to579.12.
chamfer at OR 16.51 by 16.51

Hole in cone: IR 19 cm at Z 189.23, IR 35 at Z 581.85 from 2 and 3.5 degree constraints

Interface_endcap steel1 90 4cm
OR 286.51 delta R 32 Z 183.83 to 209.23 aka 10": interface octagons to end cap cylinder. Trim overap with outer octagon.

Inner_air level 80 4cm
R310 Z -300 to 600. R100 Z -450 to -300
And in gap between octagons: Z -240 to 184 overlaps bars a bit OR 240 deltaR 10 should cover gap.
Use cut plane at Z=0 to see gap and trim overlap sequentially.

Detector air, level 82 2cm

part 1: R132 Z [-188,188] *part 2*: OR 258, dR 173 Z [224.79,508.79] shorter OK per Xiaochao

Outer air 70 32cm
R500 Z -500 to 800. level 70.

Background cylinder has multipliers applied to stuff I defined. Z 9 R 8 320 cm max mesh. Meshes out to 5000 cm both directions.

corrector_ring steel1 97 2cm
OR 51.435 deltaR 0.635 so IR 50.8 (20")
Z -266.7 to -278

correction_coil IR 40 cm vs end plug hole 38.84 IR. Cross section 9 cm square. J 100 A/cm^2 Offset -277 cm so downstream end is at -268, 1.3 cm from plug face. #8 square conductor is 0.1298+0.005 = 0.1348 maximum dimension. 0.3424 cm. Assume conductor is butted within layers and there is 0.010" glass between layers to wick epoxy. 25 turns/layer +1 for transition, 24 layers, 600 turns total.

Service turret steel removal. I built a rectangular parallelopiped of air inclined at 22.5 degrees with 13.2" X width and 14" Z width. I made it substantially longer than the chord of the paired octagons. I moved it to 30.75" from -Z end at the edge of the top plate. I trimmed the overlap of the steel and air, then deleted the air. "Inner air" above fills the gap created.