Exit beam shielding for the HKS experiment

Jay Benesch

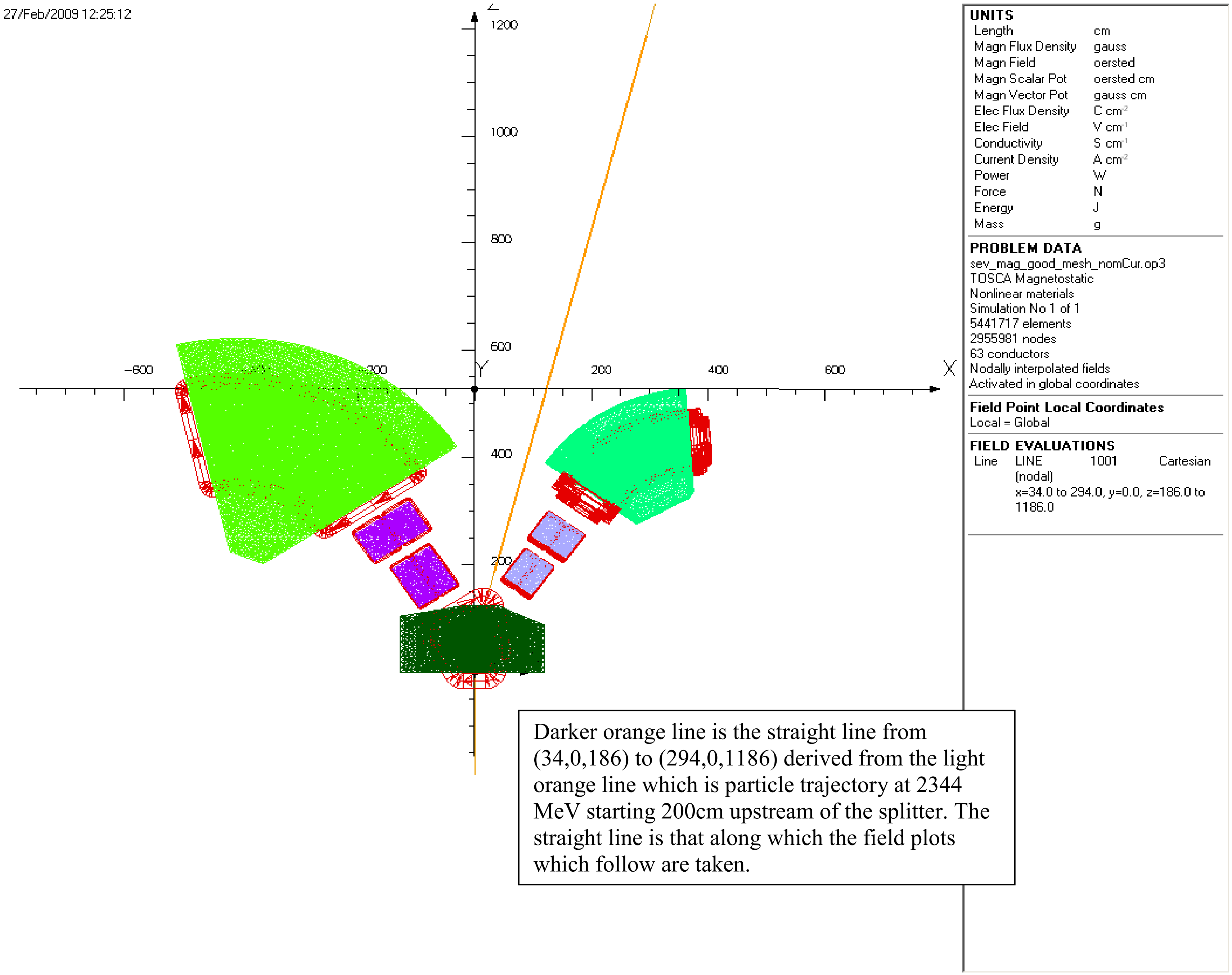
Abstract

A TOSCA model of the seven magnets used for the hypernuclear experiment in hall C was obtained from Daisuke Kawama. The model was made more detailed using the unlimited element Opera/TOSCA license owned by JLab. The fields along the beam line after the target were found to be too large for compensation by planned correctors. Shielding compatible with the existing beam line was added to the model. This cut the required vertical field correction capacity in half. Results of the unshielded and shielded models will be shown. Advice from the vendor was required for sucessful meshing of the shielding. This will summarized for posterity.

Background

The HES spectrometer dipole was built with fields in the steel of approximately 2T so substantial field leaks out of the dipole. The field in the HKS kaon dipole is lower but the stray field is still significant, perhaps one seventh of the electron dipole. The splitter magnet has substantial stray field at its exit. All of these will affect the orbit of the "spent" electron beam exiting the splitter/target, most of it at full energy. The stray fields must be compensated or shielded so the beam gets to the beam dump.

This work has two parts. First, in a "large enough" model, calculate the field integral the beam will see. Second, determine if a mechanically feasible shielding concept will suffice to allow the existing correctors to satisfy the need.



Darker orange line is the straight line from (34,0,186) to (294,0,1186) derived from the light orange line which is particle trajectory at 2344 MeV starting 200cm upstream of the splitter. The straight line is that along which the field plots which follow are taken.

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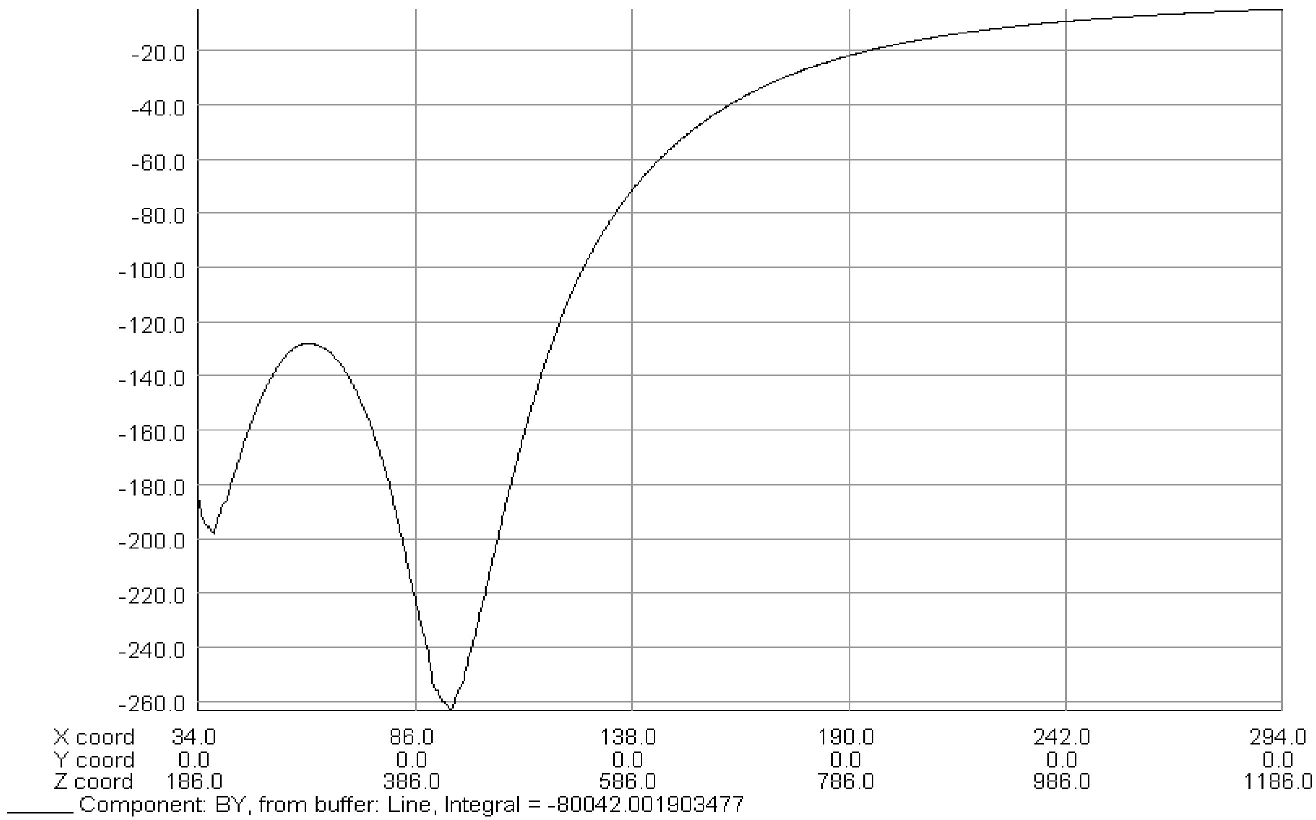

UNITS

Length	cm
Magn Flux Density	gauss
Magn Field	oersted
Magn Scalar Pot	oersted cm
Magn Vector Pot	gauss cm
Elec Flux Density	C cm^{-2}
Elec Field	V cm^{-1}
Conductivity	S cm^{-1}
Current Density	A cm^{-2}
Power	W
Force	N
Energy	J
Mass	g

PROBLEM DATA

sev_mag_good_mesh_nomCur.op3
TOSCA Magnetostatic
Nonlinear materials
Simulation No 1 of 1
5441717 elements
2955981 nodes
63 conductors
Nodally interpolated fields
Activated in global coordinates

Field Point Local Coordinates

Local = Global

FIELD EVALUATIONS

Line LINE 1001 Cartesian
(nodal)
x=34.0 to 294.0, y=0.0, z=186.0 to 1186.0

Vector Fields
software for electromagnetic design

Vertical field along the orange line shown on page 2

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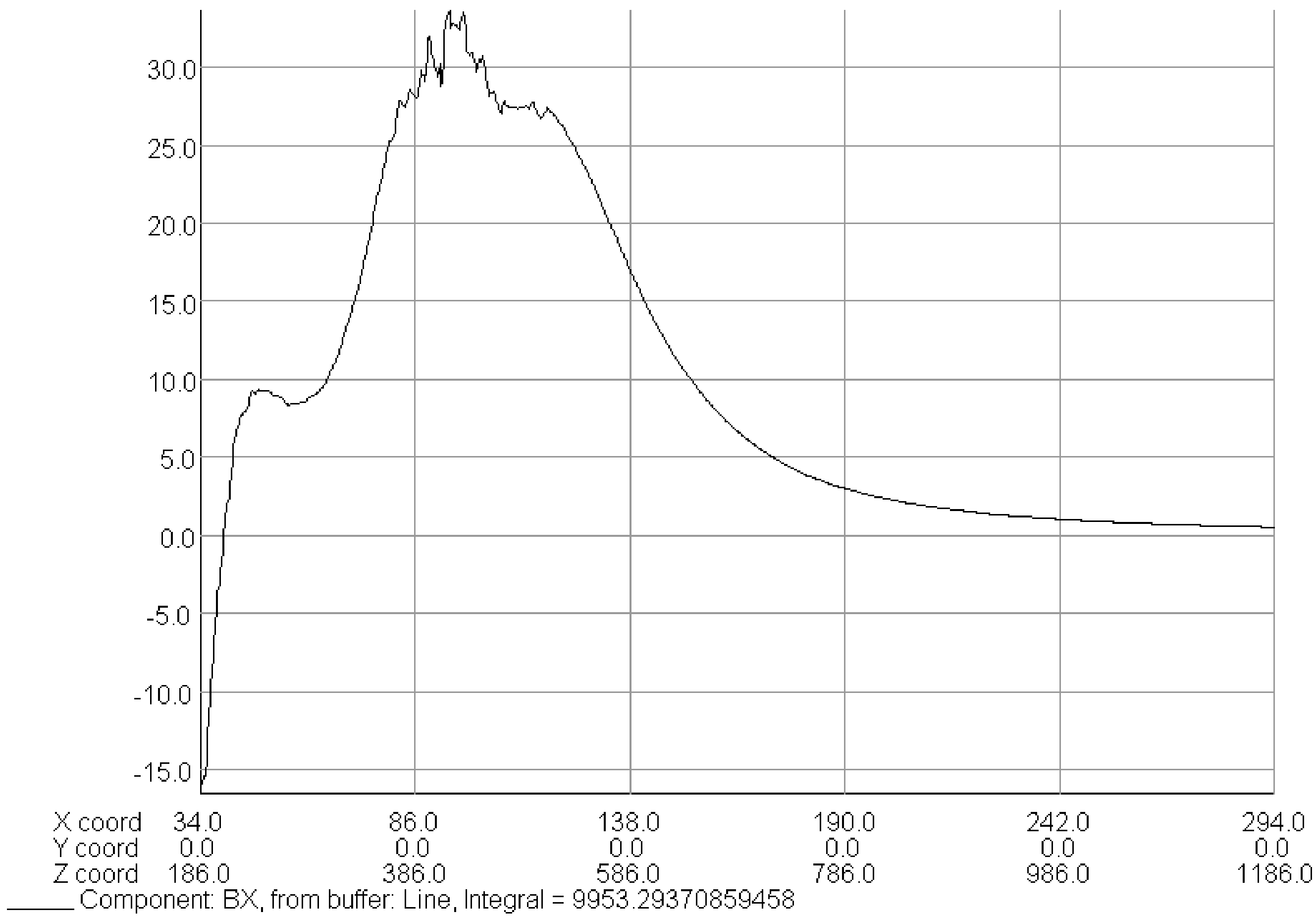

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sev_mag_good_mesh_nomCur.op3
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5441717 elements
2955981 nodes
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FIELD EVALUATIONS

Line LINE (nodal) 1001 Cartesian
x=34.0 to 294.0, y=0.0, z=186.0 to 1186.0

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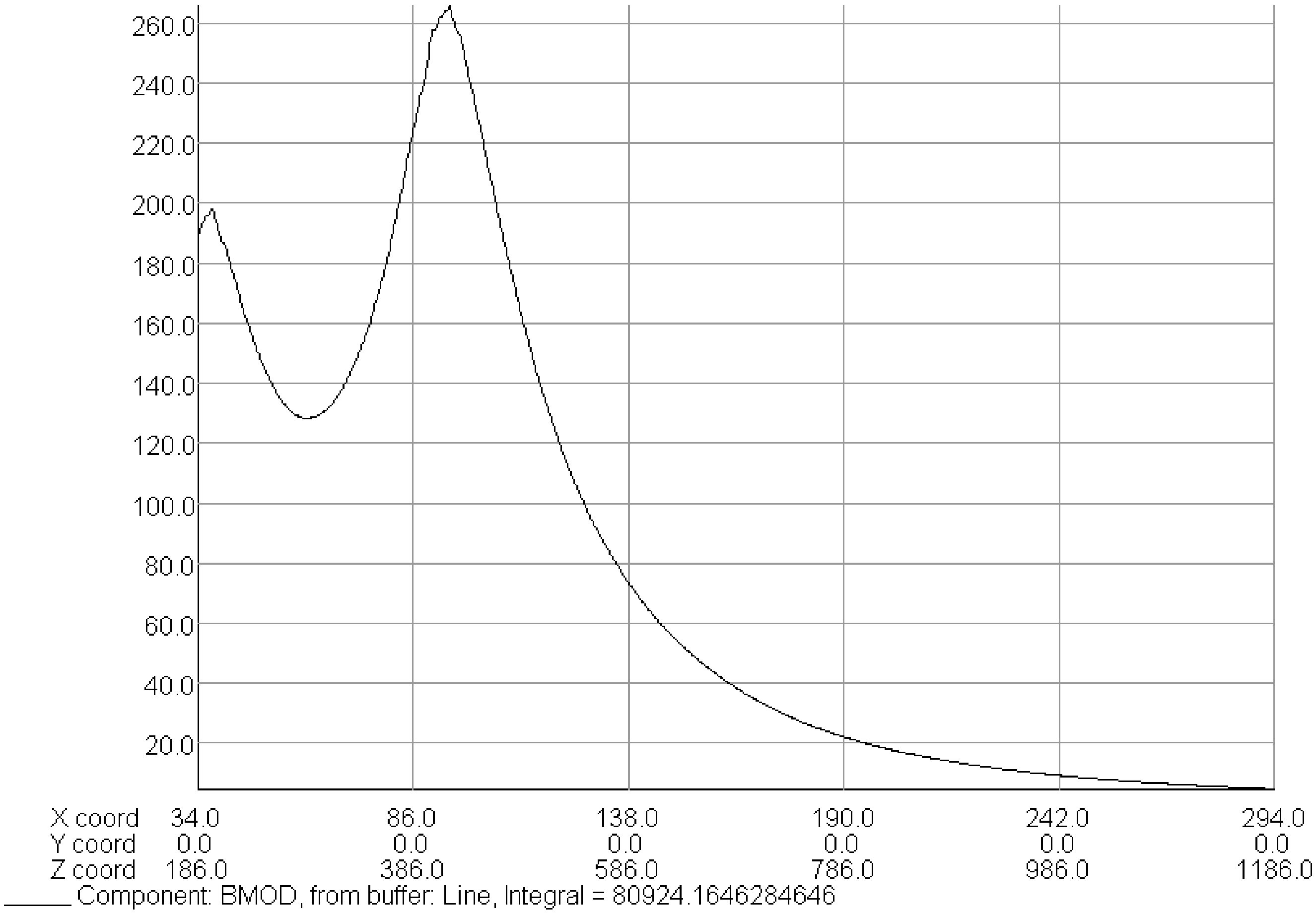

Total field along the orange line on page 2

Vector Fields
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UNITS

Length	cm
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Magn Scalar Pot	oersted cm
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Elec Flux Density	C cm^{-2}
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(nodal)
x=34.0 to 294.0, y=0.0, z=186.0 to 1186.0

The By and Bmod plots show that shielding is needed. The mechanical design of the exit beam pipe requires large shields which in turn increase the thickness needed to exclude flux from the volume inside the shield.

The straight line and the actual particle track differ by less than 2cm over the 10m or so. How does a line from (34,0,186) to (294,0,1186) compare with the actual dump line path, corrected for the actual coordinate system? Arctangent ((294-34)/(1186/186)=14.57 degrees. A shorter straight line from (30.1,0,172.3) to (130.1,0,551.3) gave me 14.78 degrees. Closer to 15.17 degrees, tehe design value, than the longer line but still 0.35 off. I get 15.12 degrees by looking at a short line from (30.1,0,172.3) to (40.1, 0, 209.3). This shows the effect of the stray fields. Over a short distance exiting the splitter I near the design angle, 15.12 (trajectory) vs 15.17 degrees. As I increase the path length over which I compute the angle, it drops to 14.78 degrees and then 14.57 degrees as the integrated effect of the stray field influences the trajectory.

Full model including air is shown on the next page. I'm not sure why the steel didn't show up in this view - it's supposed to be there. The coils are red so you can see that the model is a large enough to have the field be close to zero at the boundaries. If the boundary condition (tangential field = 0) is not to affect the calculated value in the region with the beam the model must be large enough that the calculated value near the boundary is below one Gauss. In Kawama's model the value near the boundary was 90G. Forcing the field to zero at the boundary affected every point in the model. With no element limit I was able to halve the mesh size in the steel and increase the background volume by a factor of sixty. There are 5.4M elements in this model.

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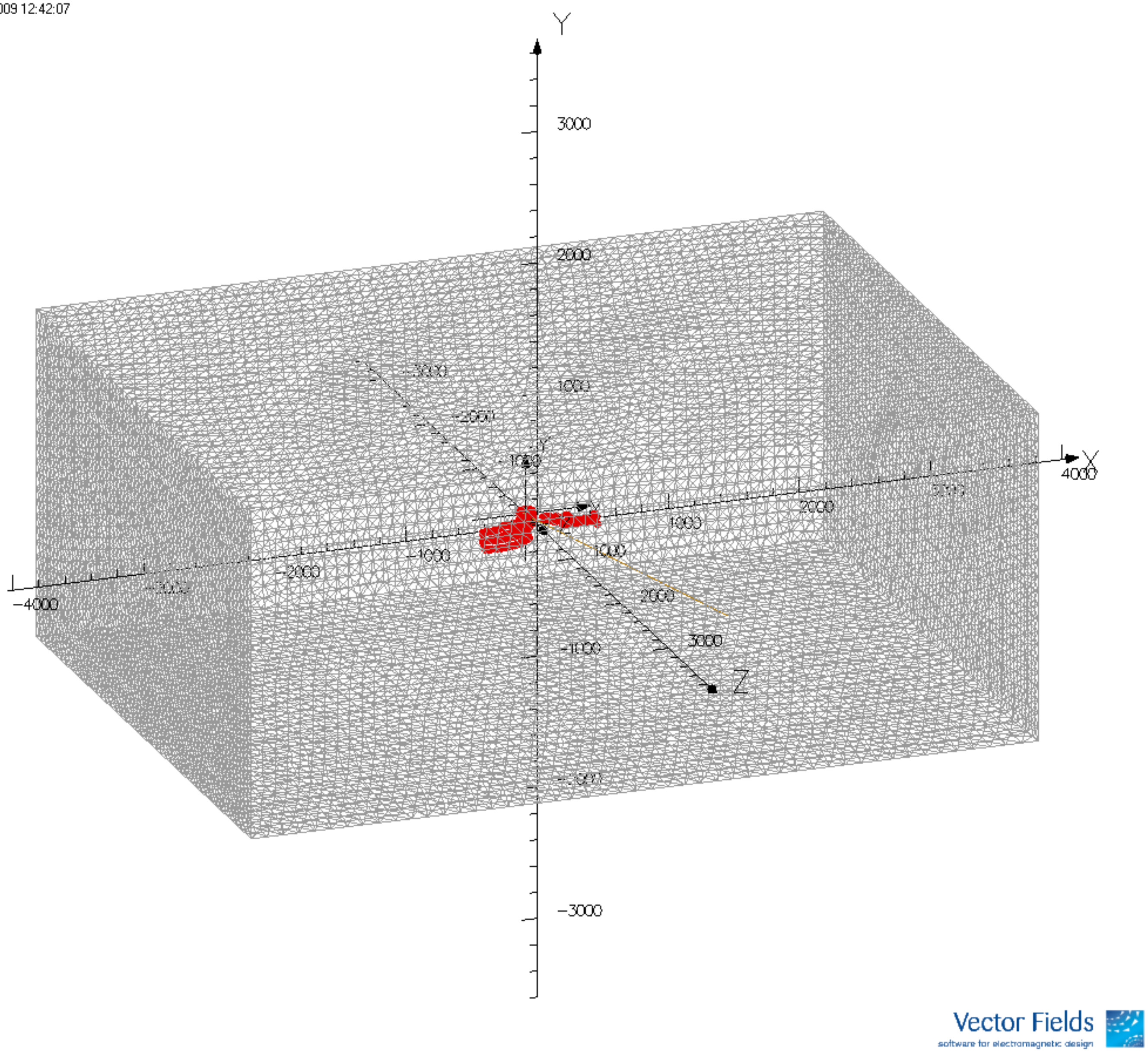

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PROBLEM DATA

sev_mag_good_mesh_nomCur.op3
TOSCA Magnetostatic
Nonlinear materials
Simulation No 1 of 1
5441717 elements
2955981 nodes
63 conductors
Nodally interpolated fields
Activated in global coordinates

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FIELD EVALUATIONS

Line LINE 1001 Cartesian (nodal)
x=34.0 to 294.0, y=0.0, z=186.0 to 1186.0

Shielding

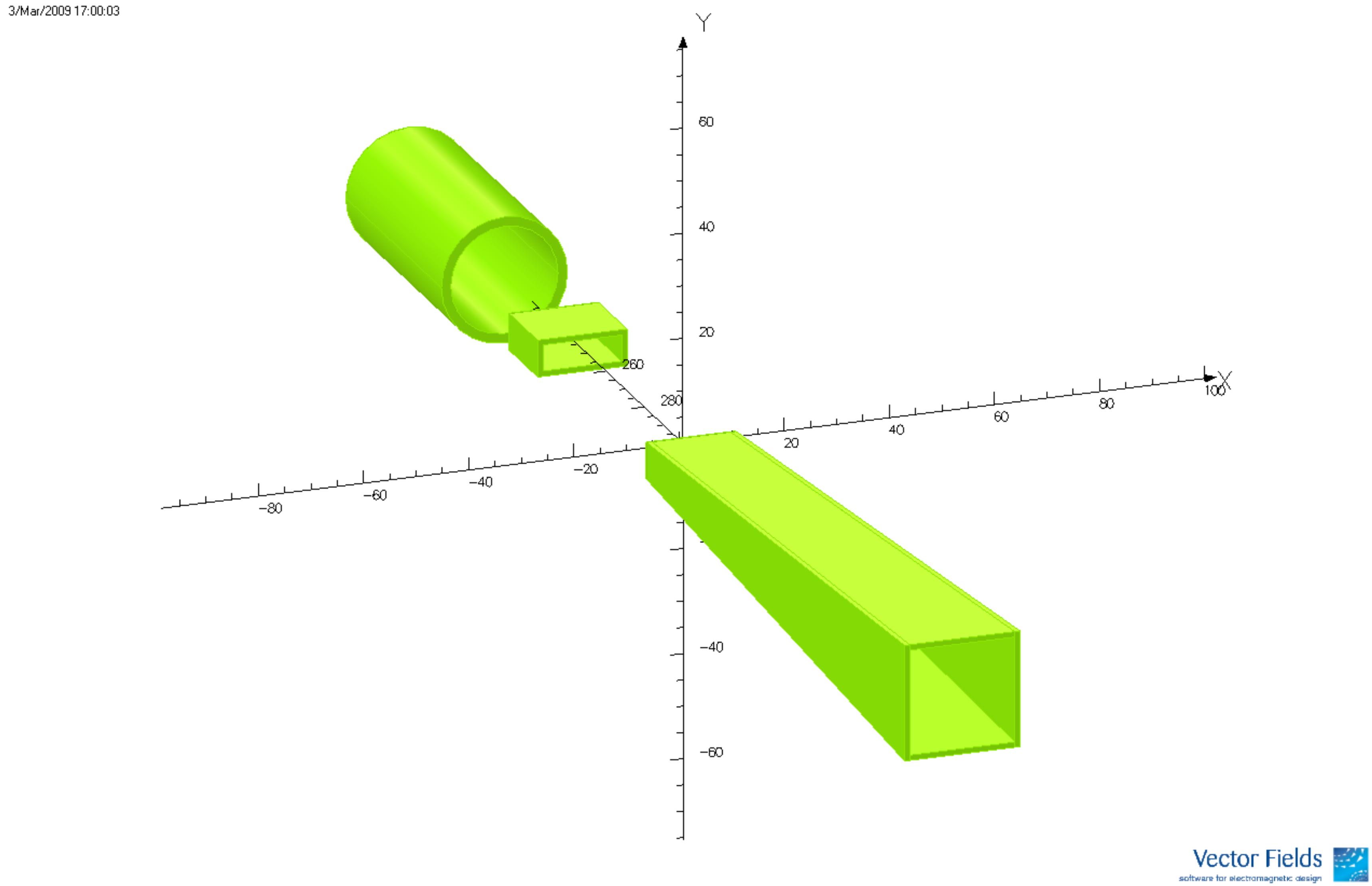
I built the shielding along the Z axis for convenience. Distances are such that everything ends up in the right place when rotated 15.17 degrees and placed in the seven magnet model. Units: centimeters.

<u>Cylinder</u>
bottom center (0,0,159); top center (0,0,209); outer radius 12, thickness 1.8

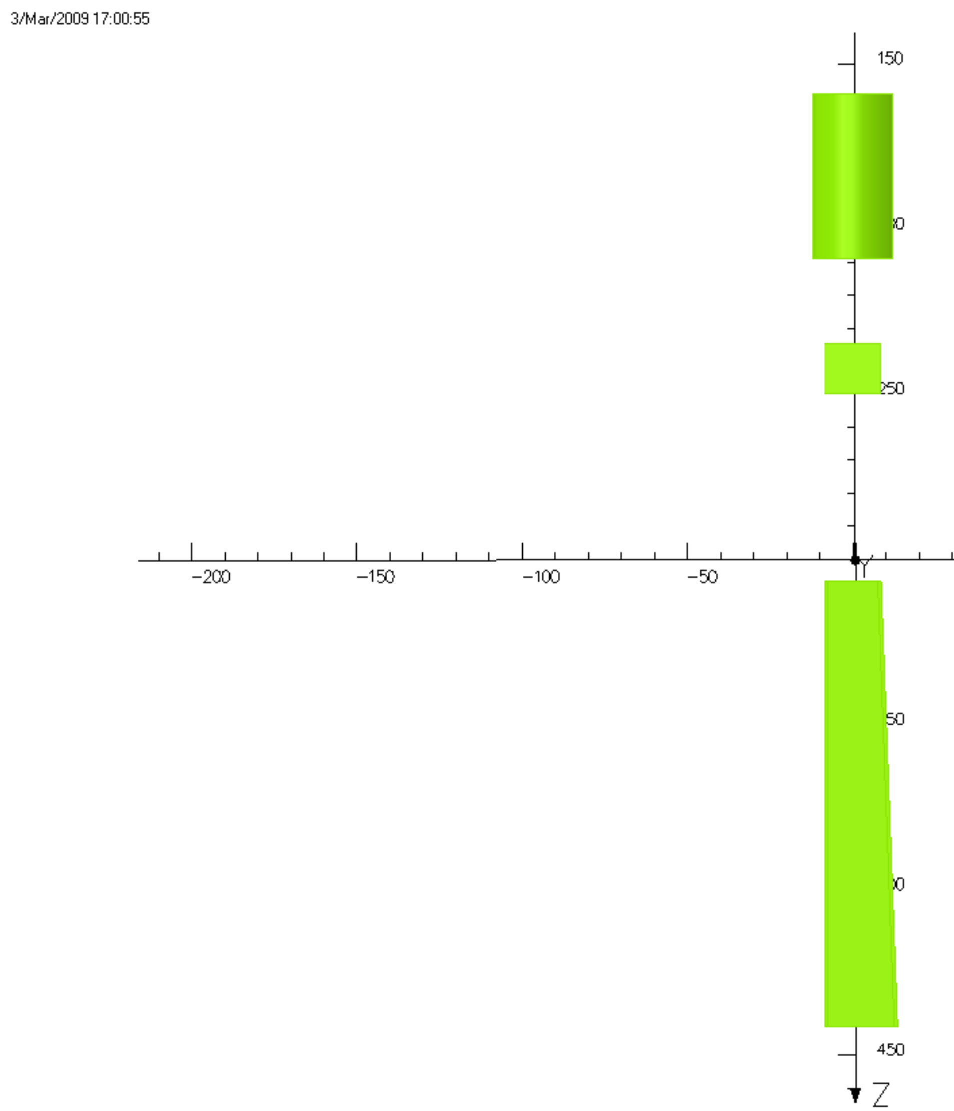
<u>Hollow block</u>
outer corners (8.5, 3.5, 234.75), (-8.5, -3.5, 249.75)
smaller block (7.5, 2.5, 234.75), (-7.5, -2.5, 250)
subtract smaller block from larger block to get something 1cm thick and 15cm long

<u>Tapered rectangular pipe approximation</u>
1cm thick
inside corners at Z=306.5
(-7.5,-2.5) (-7.5,2.5) (7.5,2.5) (7.5,-2.5)
inside corners at Z=441.5
(-7.5,-10) (-7.5,10) (12.5,10) (12.5,-10)

The last caused problems meshing even though the program reported the body had no errors. After two days without success I sent the model to Vector Fields support for advice. They cut the tapered piece into four pieces lengthwise and with a plane at Y=0. The shielding was imbedded in an air volume. I changed what VF did with that, imbedding the shielding assembly in a 15 cm square air volume rather than increasing the thickness of one Kawama had established. I set the mesh size in the steel to 1cm and in the air to 2cm. The shielding/air ensemble was then positioned in the seven magnet model shown on page two and Boolean operations used to ensure no volume was defined twice. This was then solved with three different meshes, 8.5M, 13.5M and 23.7M elements. The last two agree reasonably well. Since the last took 4.25 days to solve, I am not going to further refine the mesh. Results of the last follow.



Perspective view of three part shielding. I created this assuming the beam is along the Z axis. It was dropped into the seven magnet model at the correct angle after cutting planes were added in the tapered region.



Gap between cylinder and box is "filled" with CO corrector. Gap between box and tapered shield is filled with DW corrector. Gaps are 4-5 cm longer than the correctors and centered about the correctors. The shield steel symmetry and the 2-2.5cm gap between shield and corrector should prevent any effect on corrector performance.

OTOH, the corrector bodies will provide shielding which is not included in thes models.

Vector Fields
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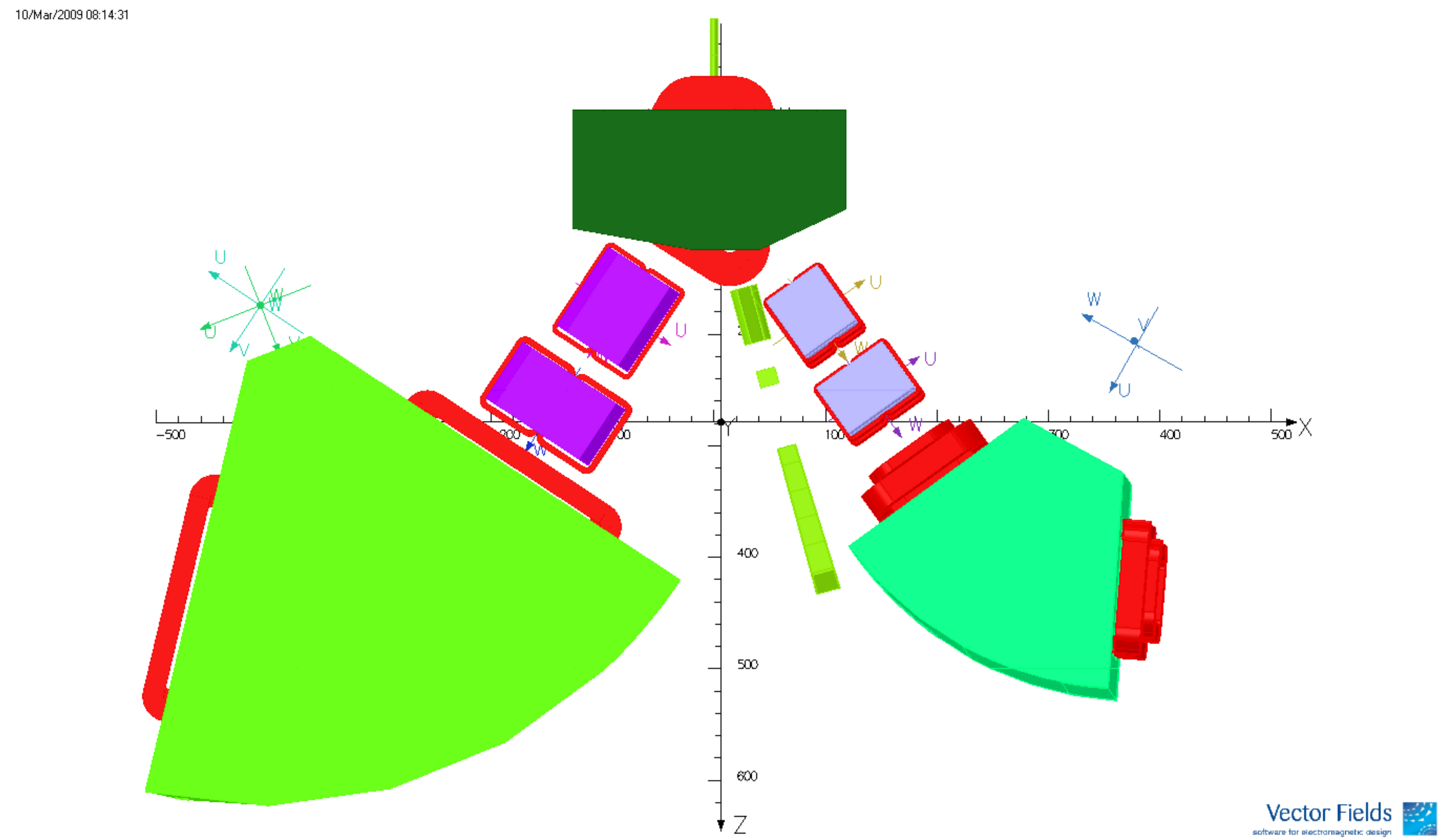
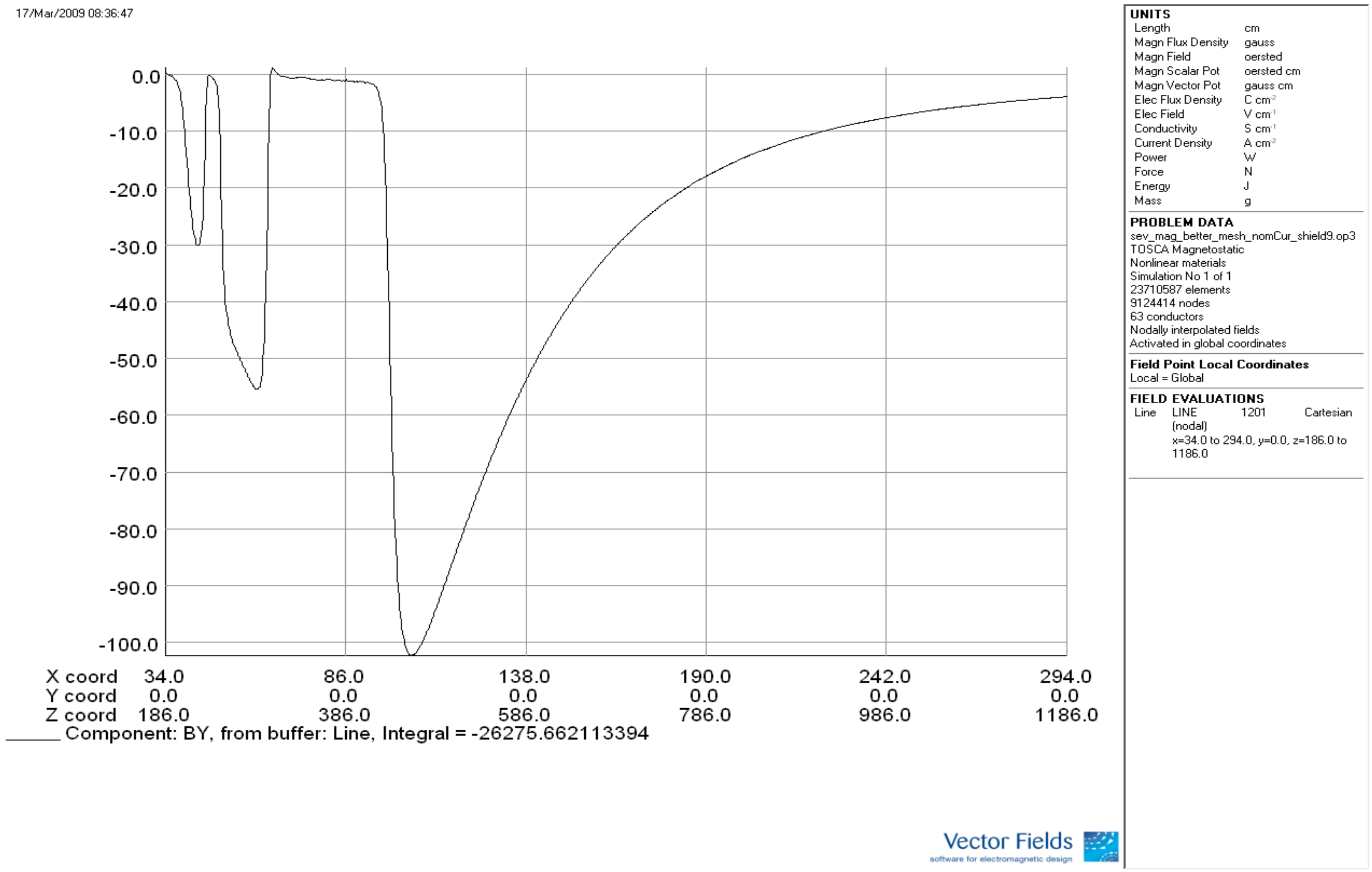
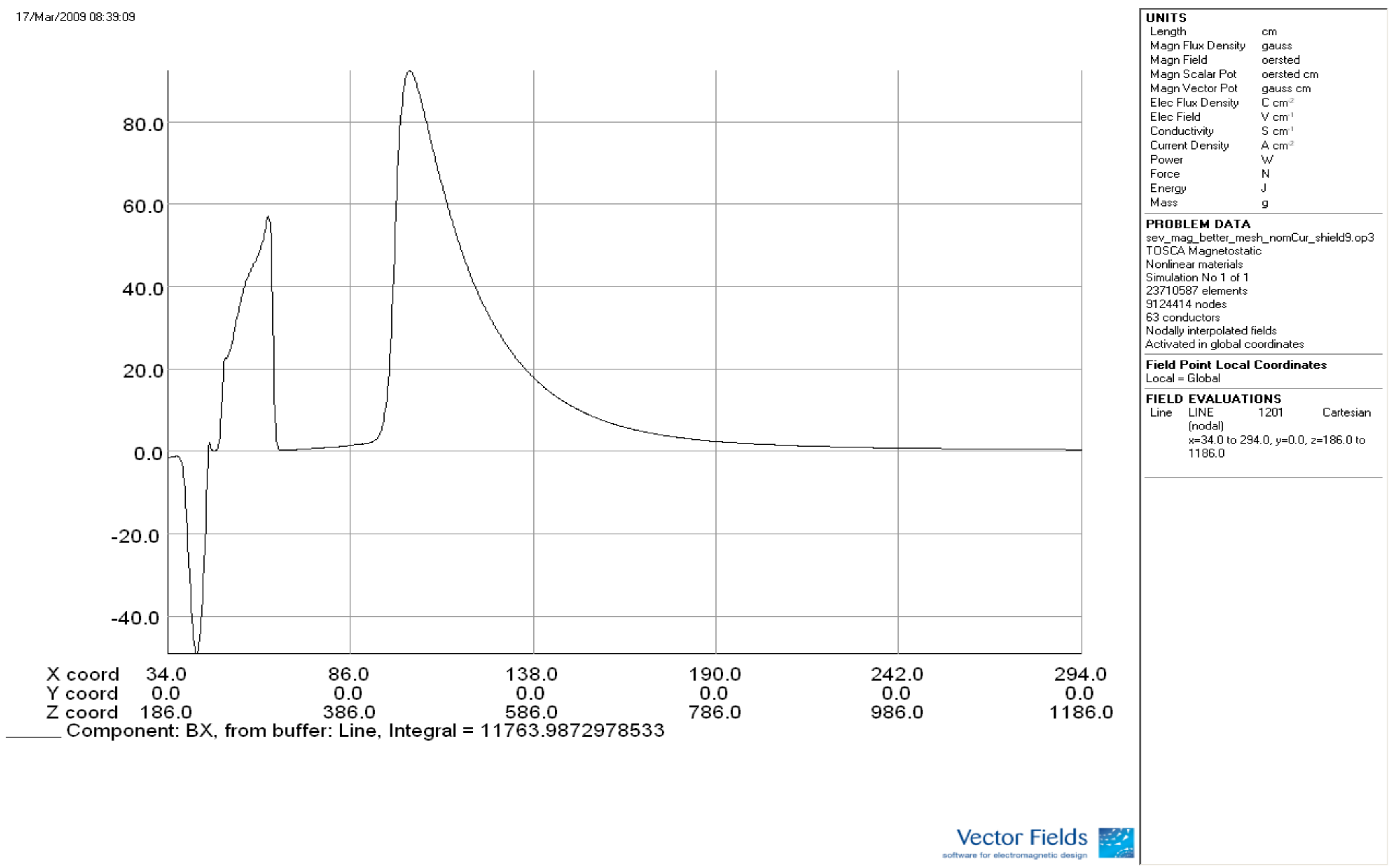
View from above. Taper in X from 15cm to 20cm all takes place on the low energy side of the beam, close to electron dipole. Taper in Y is symmetric about ZX plane.



Model with shielding solved in three versions, 8.5M, 13.5M and 23.7M elements. Shield cylinder is maximum allowable thickness given EQ1, 1.8cm. Rectangular shields are 1cm here. Results which follow confirm the choice of 1 cm in the rectagular shields. Cylindrical shield may be reduced to 1.3cm if necessary mechanically. 23.7M model results shown.



By with shield. Abrupt increase in field around Z=425cm is the end of the shield. Same line as in plots without shield. Reduction in field integral by two thirds. Were it not that the exit beam pipe abruptly expands to 60cm diameter around Z=425cm I'd recommend shield extention by 3m.



Bx with shield. I am not sure why the value has increased over the unshielded model. The solver reports inadequate meshing around the coils in all these models, with errors in 10^{-4} range.

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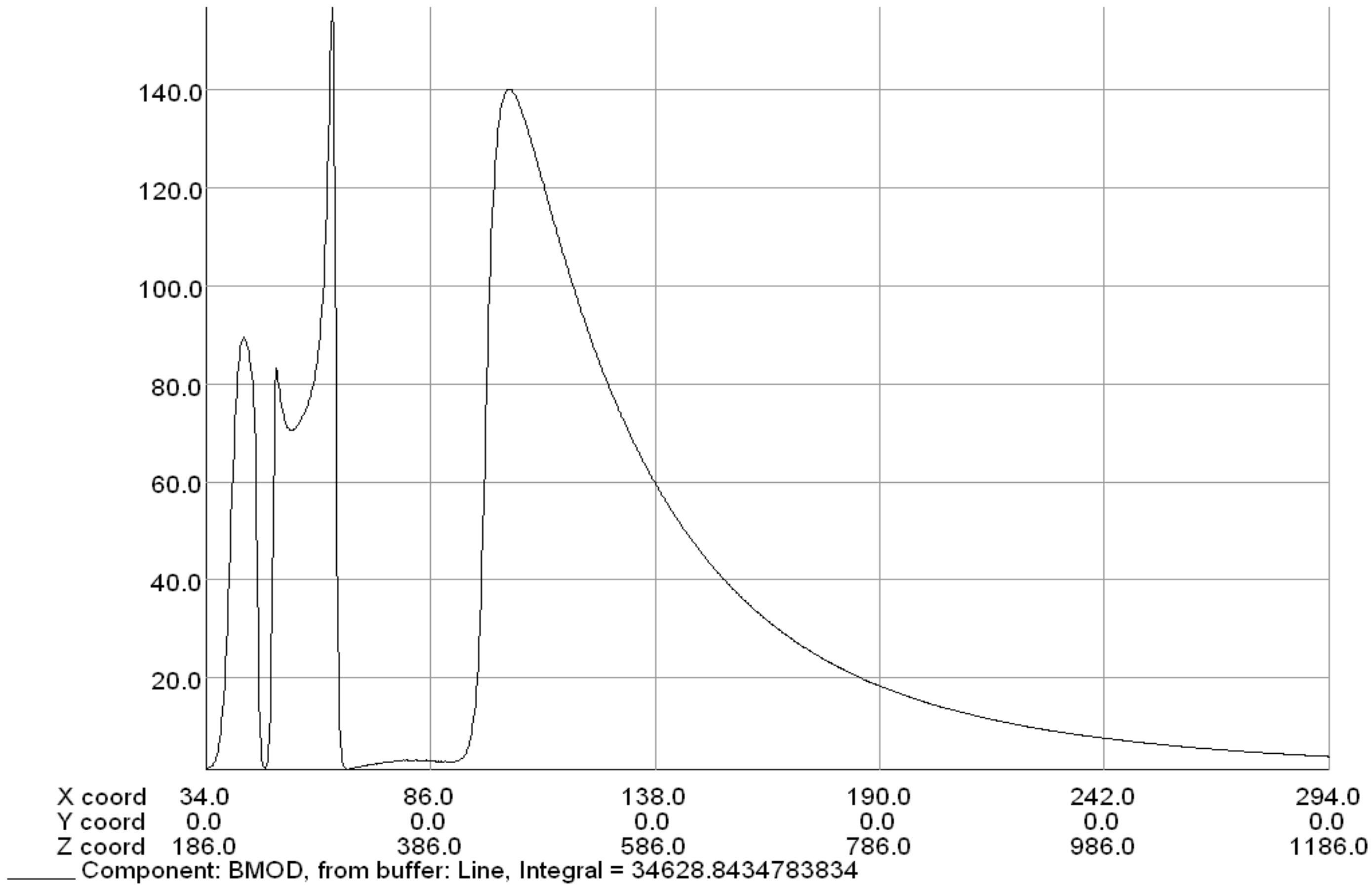

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Elec Field	$V\ cm^{-1}$
Conductivity	$S\ cm^{-1}$
Current Density	$A\ cm^{-2}$
Power	W
Force	N
Energy	J
Mass	g

PROBLEM DATA
sev_mag_better_mesh_nomCur_shield9.op3
TOSCA Magnetostatic
Nonlinear materials
Simulation No 1 of 1
23710587 elements
9124414 nodes
63 conductors
Nodally interpolated fields
Activated in global coordinates

Field Point Local Coordinates
Local = Global

FIELD EVALUATIONS
Line LINE 1201 Cartesian
(nodal)
x=34.0 to 294.0, y=0.0, z=186.0 to 1186.0

Vector Fields
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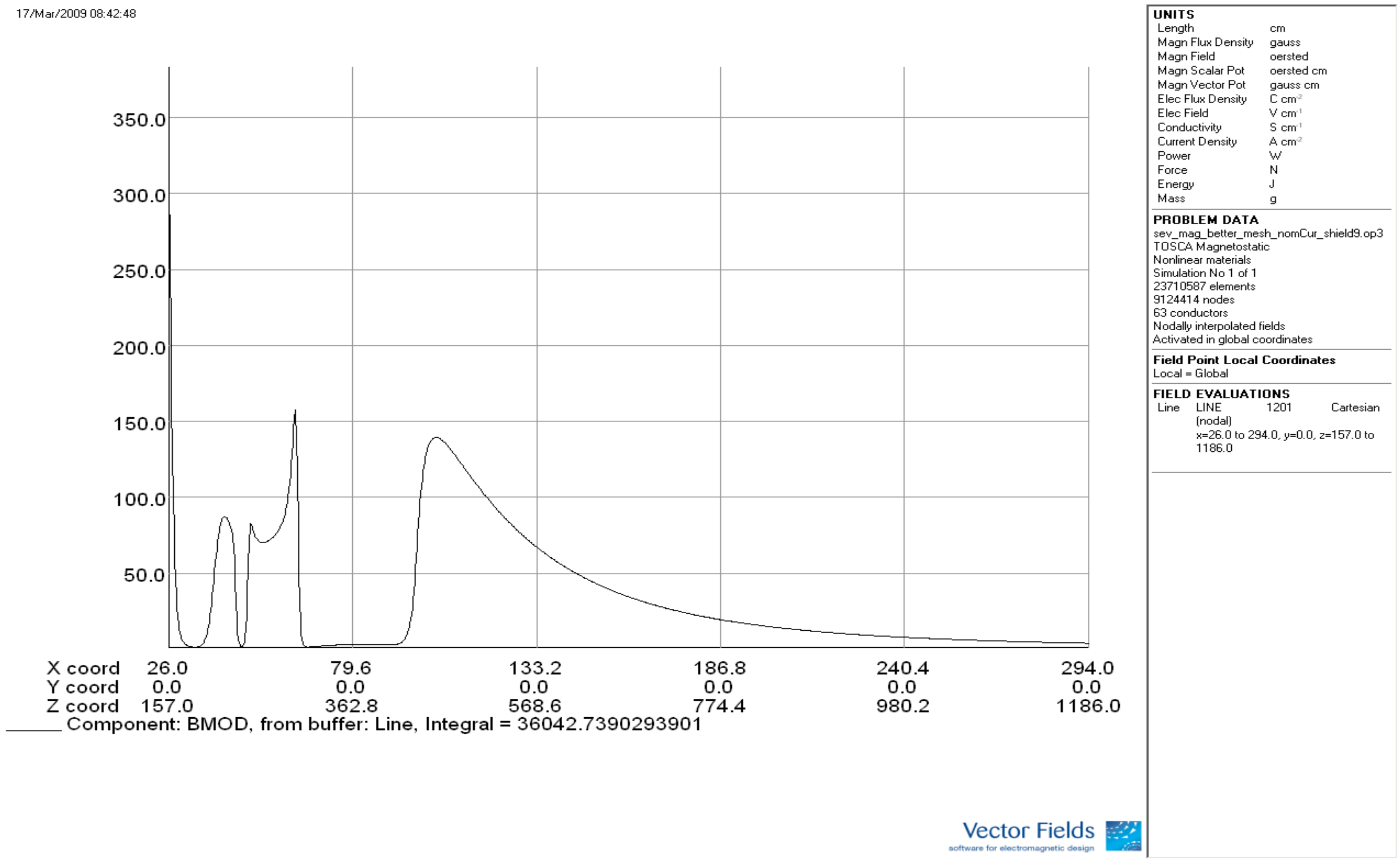
Bmod with shield



Bmod with shield starting from splitter coil. One can see the effect of the full 50 cm long cylindrical shield here. BdL increases only 4% from the previous graph due to the shield. The same is true for Bx and By. This graph starts at (26,0,157) while previous graphs start at (34,0,186).

Conclusions

It is possible to model shielding steel even in a complicated environment with many magnets if one has a TOSCA/Opera license with unlimited elements, patience, and a PC with enough RAM. A back of the envelope calculation of shield thickness before making the model is sufficient to get the engineering-required thickness right in one iteration of the model, as here.

DW2 corrector should have ample range with 100A power supply. CO corrector may require a 12A trim card like those used in the re-injection chicane.