Modeling the TWIST Magnet

Sanaz Fotoohi

TRIUMF

September 12, 2005

Abstract

In TWIST Experiment the magnetic field inside the Spectrometer needs to be known precisely. To achieve this goal, the magnet mapper will take the values of the magnetic field at discrete points and a simulation in Opera will generate a three component field map. Previous works has been done to model the TWIST Magnet in Opera since 2002 by Mike Barnes, Roberto Armenta, and Camille Boucher. As Roberto's full model was lost, and Camille couldn't get a full model to mesh, my mission was to get a full model without the Quads and Dipoles mesh. I finally got a full model to mesh by using methods of layering and cutting planes. Solving the model and post_processing it, I generated the field maps of the magnetic field in the tracking region. It took less that 24 hours to create the table of the values by using nodal averaging rather than integration. The maps of the new model matches none of the existing measured and opera maps, but the new maps confirm that the doors have been modeled properly.

Contents

Chapter 1

Introduction

Previous work has been done for modeling the TWIST Magnet in Opera. The purpose of this study was to get the field values in the tracking region as close to the measured values as possible. To this end, first step was to mesh a complete model. This report summarizes the details for generating a volume mesh for a complete model, the maps generated from the new model, and the results of the comparisons of the new maps with the existing maps.

Chapter 2

Description of TWIST

The TWIST (TRIUMF Weak Interaction Symmetry Test) experiment is designed to measure the spectrum of positrons from muon decay in a wide range of energy and angle. The experiment uses a highly polarized surface muon beam from the M13 secondary beam line at TRIUMF. A muon is stopped in the center of a symmetric stack of planar wire chambers and decays at rest to a positron and two neutrinos($\mu^+ \rightarrow e^+\nu_e\bar{\nu_\mu}$). A 2 T uniform magnetic field created by a large bore superconducting solenoid magnet preserves the direction of the spin of the stopped muons. The decay positron spirals outward in the magnetic field, leaving hits on the wires. The hits are recorded by TDC's and analyzed to reconstruct the trajectory of the particle and determine its energy and angle with respect to the magnetic Field.

2.1 TWIST Detector

The TWIST apparatus uses wire chambers as the primary source of information. There are two types of chambers in the detector: drift chambers (DC), and proportional chambers (PC). The tracking chambers record where the particles go so that their momentum and trajectory can be calculated. The wire chambers are placed inside a 2 T superconducting solenoid. The solenoid together with the outside steel yoke produce a highly uniform magnetic field in the tracking region. Although highly uniform, the field is not perfect, so we need to map it to get the needed field values. Modeling the magnet, we are able to get the magnetic field values at different points. The main goal of my study was to get a full model without the Quads and dipoles mesh. The values of the magnetic field is needed for calculating the momentum and trajectory of the particle.

2.2 Magnet Mapper

The field mapper was designed to measure the longitudinal component of the field (Bz) through out the tracking region and close to the yoke entrance at increments of 5 cm in the longitudinal (Z) direction, 4.13 cm in the radial (r) direction, and 15 degrees in the azimuthal direction. It uses the NMR probes and the Hall probes to measure the values. The NMR probes measure the total magnetic field (Bmod); the Hall probes measure only one component of the field. In TWIST experiment these probes are aligned to measure the Z component of the field.

There are either 5 or 7 probes on the arm. TWIST uses 5 probes to get the fringe field values, and 7 probes to measure the field in the tracking region. The probes read the values every 15 degrees as the arm rotates. The probe at the center reads the values of the field at the same position for 360/15 = 24 times. Averaging these values, we get the average value of Bz at that specific Z. For $-65 < Z < 65$, the values of the averaged Bz at r = 0 is stored at **/home/olchansk/twist/magnet/sum/sum.Center.Hall.20kG.txt**. These measurements are at discrete points; therefore a magnetic field simulation is run in Opera to generate a three component field map.

Chapter 3

The Model

3.1 The original Model

I started with Camille's model stored at : Trshare/public/e614/camille/operamap/BH100_BHus100_BHds100_2quads_1dipole20cmDialHoleNoAngle_quartermodel_in_Z_1400cm_gradient_asymmetry_rescaled.opcb on windows network. This is a quarter model (-X,-Y quadrant) generated in Opera 10.0 (the background defining the universe for Opera covers only a quarter of the model). It has the quads and dipole in it. There are six pairs of coils, each with an inner and outer coil with a common center. The coils are located at the same position in Roberto's model (which was lost) that is the coils are located at the nominal position with coil pairs 1 and 6 being shifted toward the center by 0.18 cm. The relative current density (scaling factor) is the same as in Roberto's report, but the absolute current densities are different from Roberto's model, and they have to be re-adjusted again to get the field right in the new model. See tables 3.1 and 3.2 for coil positions and currents.

Outside coils	LCS(local coordinate system in Z(cm))Origin	Current Density(A cm^2)	Total Current(A)
6	-76.515	-6683.58105	-617813.523309375
5	76.515	-6683.58105	-617813.523309375
4	-33.23	-6683.58105	-308500.7341059
3	33.23	-6683.58105	-308500.7341059
2	-10.315	-6683.58105	-221366.219598945
1	10.315	-6683.58105	-221366.219598945

Table 3.1: The position and currents of Outside Coils in Camille's Model _ all coils are centered in X and Y

Inside coils	LCS(local coordinate system) Origin	Current Density	Total Current
6	-76.515	-4720.26334	-585194.6475765
5	76.515	-4731.12075	-586540.69498125
4	-33.23	-4640.01966	-161723.24522964
3	33.23	-4640.01966	-161723.24522964
2	-10.315	-4720.26334	-113810.26939074
1	10.315	-4720.26334	-113810.26939074

Table 3.2: The position and currents of Inside Coils in Camille's Model _ all coils are centered in X and Y

Camille managed to mesh and solve a quarter model with the quads and dipoles (she couldn't get the total model to mesh). My mission was to get the total model mesh.

3.2 Changes that I did to the model

In order to get the model mesh I had to simplify it as much as possible; therefore I made some changes to the model. I also started working in Opera 10.506.

1. I deleted the Quads and Dipole.
2. I layered the upstream and downstream doors, the yoke, and the holes in the yoke. (Refer to Section 3.2.1)
3. I used six cutting planes to simplify the yoke and the background. (Refer to Section 3.2.2)
4. I defined a smaller background which was flush to the yoke.
    - Opera did not have a problem with meshing the model with a bigger background which is not flush to the yoke, but it did have memory problems with solving the op3 file generated from the model with bigger background as the number of nodes exceeded its limit. In order to get the model with a background not flush to the yoke mesh I added twelve planes to simplify the model.

3.2.1 Layering

There are several things that one has to define for Opera before layering the cells such as:

- Material type: The MATERIAL parameter controls the material label attached to a cell. The properties associated with such a label are set using the MATERIALS command.

- Volume property label: The VOLUME parameter holds the volume property label that may be attached to a cell. The properties associated with such a label are set using the VOLUME command.

- Data storage level: The LEVEL parameter controls the storage of data when there is a conflict during the merging of multiple cells, faces, or edges. The data set with the greater level will be maintained. The result of merging 2 cells, faces, or edges with the same level is indeterminate.

- Maximum element size: It is one of the mesh control parameters and is also called Mesh Control Size which controls the mesh size of elements in the cell and near the faces of the cell when generating the surface and volume mesh.

- Number of layers: There are two kinds of layering, Backward layering in which the layers go into the cell and Forward layering in which the layers come out of the cell. In both cases we have to define the numbers of layers.

- Layer offset: This is just the thickness of each layer. According to Mike Barnes' suggestion the layer offset should always be smaller than the maximum element size, at the same time the maximum element size divided by layer offset must be smaller than 10; in our case he suggests that it be smaller than 3. The thickness of the cells that are supposed to be layered are crucial because if the layer offset times the number of layers is bigger than the thickness of the cell layered, then the layers will penetrate into the adjacent cells with different data storage level and maximum element size; this will cause a problem for generating the volume mesh!

The first thing is to figure out the thickness and the properties of the cells to be layered. (Table 3.3)

Material Type	Volume Property Label	The Thickness	Maximum Element Size	Data Level
iron door_ds	irondoor_downstream	8 cm	3.4	5
irondoor_us	irondoor_upstream	8 cm	3.4	5
iron	ironsides	the sides of the yoke with holes=20.96cm and sides without holes=20.95cm	6.5	4
Air	AirCutOuts	20.96 cm	5.4	4

Table 3.3: Properties of the cells to be layered in the model I started with.

The thickness of the downstream and upstream doors are 8 cm. To layer them I chose 3 backward layers with the offset of 3cm, and then put a zero thickness plane (refer to section 3.2.2 for the description of cutting planes) at the places that the doors are adjacent to the yoke.

Then I layered the yoke. As the sides of the yoke have two different thickness (20.96 and 20.95 cm), I chose three backward layers with the offset of 6. $3 * 6 = 18 < 20.95$. Because the yoke is a single cell and the layers will not cover the whole thickness of the iron sides, a thin layered box (with the thickness 2.95-2.96 cm) will still remain around the air layers inside the yoke called AirTotRoundRed. This is a complicated shape for Opera to be able to generate the volume mesh. To solve this problem I used zero thickness planes.

The next thing that I layered was the air holes (volume property label = AirCutOuts) in the yoke sides perpendicular to the Y axis. These air holes have the thickness 20.96 cm. The holes were also layered the same way as the yoke sides with air holes were layered. Even though the Mesh Control size of the air is 5.4, to match the mesh control size of the yoke around the AirCutOuts (same layering properties), I changed it to 6.5.

3.2.2 Cutting Planes

As mentioned in Opera manual one can create the zero thickness planes perpendicular to the Z axis by simply creating a zero thickness block, but to create other kinds of planes that are not perpendicular to the Z axis one should copy the faces of the block and rotate, displace, reflect, or...it. These planes help to simplify the model.
I put zero thickness planes at the places that the doors are adjacent to the yoke. I also simplified the thin layered box that was created after layering the yoke by putting zero thickness planes in the places that the internal yoke sides are adjacent to the AirTotRoundRed. I created the planes by copying the faces of the yoke and displacing them along the X and Y axis, the displacement vector is as big as the thickness of the yoke sides.
One can see clearly the status of the planes on the opc file by deleting the model body!
In section 3.2 I pointed out to get the model with a background not flush to the yoke mesh twelve planes were added overall to simplify the model. In addition to the 6 planes explained in the last paragraph, I had to add six additional zero thickness planes on the faces of the yoke and doors_ two planes perpendicular to X, two planes perpendicular to Y, two planes perpendicular to Z. So I copied and displaced the planes of the background and made them flush to the yoke; therefore there are 4 planes added. There are also 2 planes flush to the outer side of the doors (note that the planes didn't stick out of the yoke). I saved the file at:
Trshare/public/e614/sanaz/the_ones_done_in_10.5/BH100_withoutQuads_-wholmod_yokeandairholesanddoorslayered_12XYZplanes_-changesdonein10.5.opc.
This simplified the background around the yoke so Opera was able to generate a volume mesh!

3.2.3 Defining Background

Background defines the region of the model that Opera is supposed to solve.
So far the changes that I've done have simplified the yoke. As mentioned in section 3.2 I tried two things:

- A bigger background with the points (200,200,550), and (-200,-200,-550) being the first and the opposite corners of the block.

- A background flush to the yoke with the points (-130.49,-130.5,200), and (130.49,130.5,-200) being the first and opposite corners of the block.

In both cases the Mesh Control Size is 25 and the Data Storage Level is 1. To mesh the first one I had to add six zero thickness planes and to mesh the second one I had to add 12 zero thickness planes.

But the problem with the bigger background is that Opera 10.506 is not able to solve the datafile because when I created the op3 file at:

Trshare/public/e614/sanaz/the_ones_done_in_10.5
BH100_withoutQuads_wholmod_yokeandairholesanddoorslayered_-12XYZplanes_changesdonein10.5.op3,

the number of nodes exceeded Opera 10.506 limit, and it couldn't solve the op3 file through the Interactive solver. The error message was:

```
ERROR Level :1
 MM_ReadDropFile: error recovering from file stream
FATAL ERROR: ANALYSIS HALTING
Opera Job Failed!
```

We contacted the support group of vector fields (The company that produces Opera) and they came up with a newer version 10.516 that can deal with bigger files. I also tried smaller background flush to the yoke! This model is stored at:

Trshare/public/e614/sanaz/the_ones_done_in_10.5/BH100_-smallerbackgroundflushtoyoke_nothingoutsideyoke_wholmod_-yokeandairholesanddoorslayered_sixXYZplanes_changesdonein10.5.opc.

This model does not need the extra six zero thickness planes that are adjacent to the yoke since the background is flush in X and Y direction! The data file was solved through the interactive solver, and is stored in:

Trshare/public/e614/sanaz/the_ones_done_in_10.5/BH100_-smallerbackgroundflushtoyoke_nothingoutsideyoke_wholmod_-yokeandairholesanddoorslayered_sixXYZplanes_changesdonein10.5.op3

3.3 Post_Processor

To get the field values, I ran the op3 file through the post_processor. I have two data files of the B values.

- The values of Bz along the Z axis from -300 to 200 cm. Simply define a line by clicking on the button: **Field on a straight line_Zdirected**; then plot the values through the button **Plot graph of field values**, and choose the Field component you want to plot. The output file is stored at: **/home/sanaz/magnetmaps/opera_logs/Opera3d_Post_13_nonlinearBH_-stepsize1.lp**.

- The values of Bx, By, Bz, BT(total) starting at (-30,-30,-300) to (30,30,150) with stepsize one in X,Y,Z direction. In order to do this define a grid by clicking on **Table/table of field values on a grid**. The output file is stored at: **/home/sanaz/magnetmaps/opera_logs/fieldmap2_sanaz_completemodel.table**.

The important thing to mention about getting the field values is Field Calculation Methods. The two methods are: nodal interpolation, and Integration. Integration takes much longer than nodal averaging, but it generates more accurate results. Because of the shortage of time, we chose nodal interpolation, and it took less than 24 hours to generate the grid. You can define this option by clicking on **Options/Field Calculation Methods**.

I did several comparisons with the existing field values to see the progress of the model, and plotted them in root.

Chapter 4

Comparison of Output Maps to Previous Maps

The very first model (The Nominal Model) was designed by Mike Barnes back in January 2002. The output field map from the nominal model in use to create the bfld files for feeding GEANT and MOFIA was field-map.0003 stored at :
/home/e614/e614soft/caldb_ascii/field_map.0003.
The CFM (Calibration File Manager) field map(bfld map) that is for use in GEANT and MOFIA now is **/home/e614/e614soft/caldb_ascii/bfld_map.00012**. This field map is the Shifted asymmetric opera field map from Mike Barnes field_map.0007 (generated from Roberto's tuned model), with as-measured asymmetry in Z. I use field map **/home/e614/e614soft/caldb_ascii/field_map.0007** for my comparisons. There is also the Measured field maps that were taken in April 2002. The major Measured map that I use for my comparisons is stored at:
/home/olchansk/twist/magnet/sum/sum.Center.Hall.20kG.txt (Refer to Section 2.2).
The first thing I compared was Opera field map 0003 and the Measured field map.

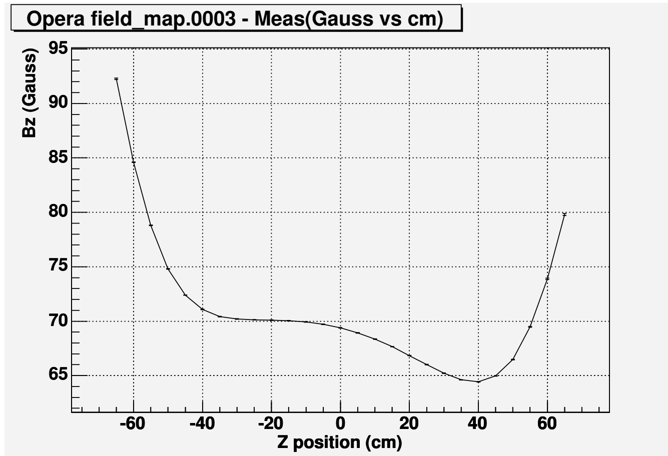

Figure 4.1: Bz vs. Z for Opera-map.0003 (Nominal Magnet) minus measured 20.0 kGauss at X=Y=0.

This is exactly the same map as in Roberto's report, Chapter3, Figure3. This figure confirms that my tools for comparison are working properly; moreover it is a useful baseline in that it's what we get without any tuning.

The next Comparison that I made was field_map.0007_barnes vs. fieldmap2_sanaz_completemodel at X=Y=30 cm; the line along X=Y=30 cm passes through the yoke (Figures 4.2, 4.3, 4.4).

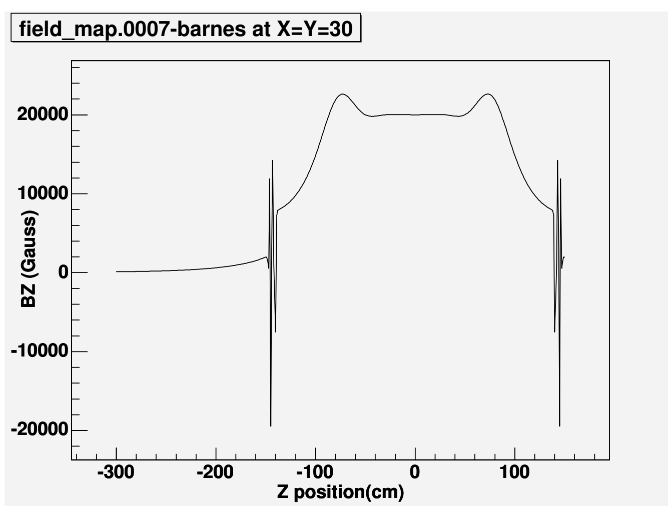

Figure 4.2: Bz vs. Z field_map.0007-barnes (Roberto's Tuned Model) at X=Y=30 cm.

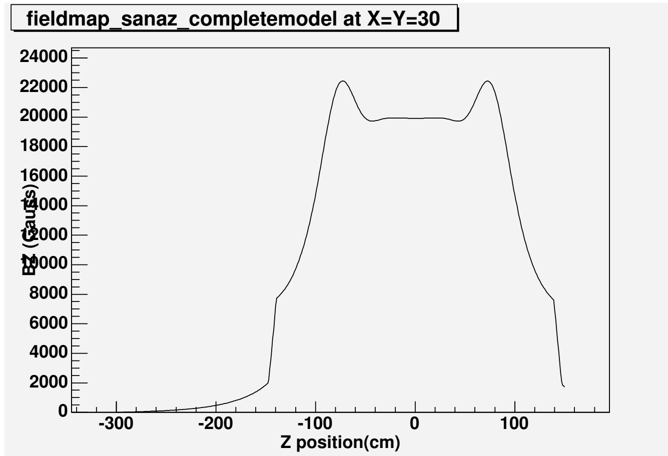

Figure 4.3: Bz vs. Z fieldmap_sanaz_completemodel at X=Y=30 cm.

and their difference is:

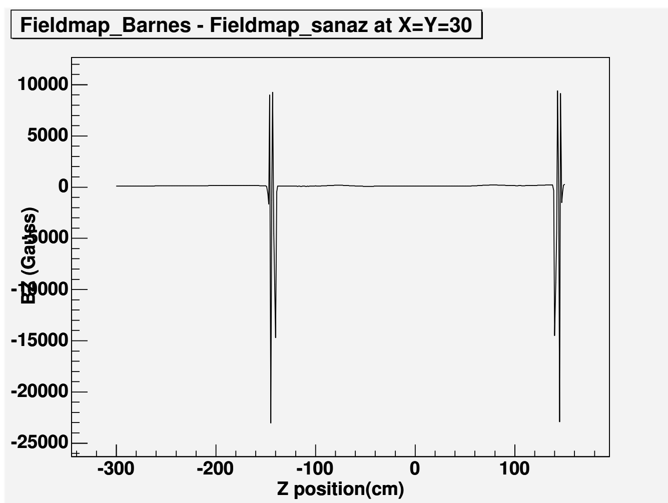

Figure 4.4: Bz vs. Z field_map.0007-barnes minus fieldmap_sanaz at X=Y=30 cm.

Figure 4.4 compares the field map currently in use to the field map from the new model with background flush to the yoke. Look at Figure 4.2 at $Z = +/-140$ where the upstream and downstream doors are located. After layering the doors and putting the zero thickness planes, we see in Figure 4.3 the values of Bz change continuously at the doors. That means the yoke and the doors are modeled correctly.

Then I compared the Measured 2T map to fieldmap2_sanaz_completemodel.

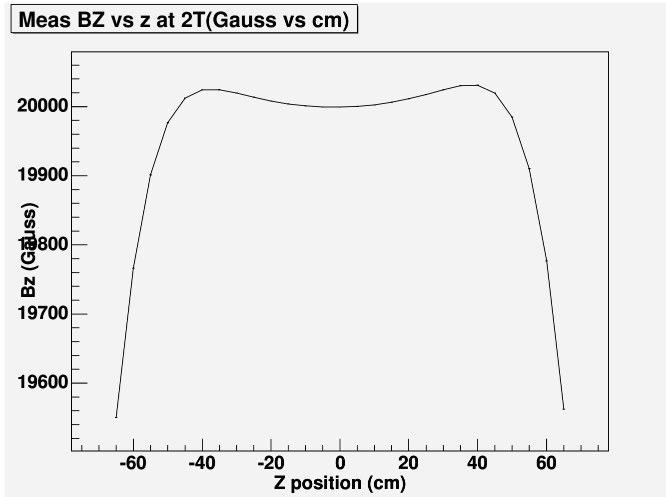

Figure 4.5: Bz vs. Z Measured 2 T field map at X=Y=0

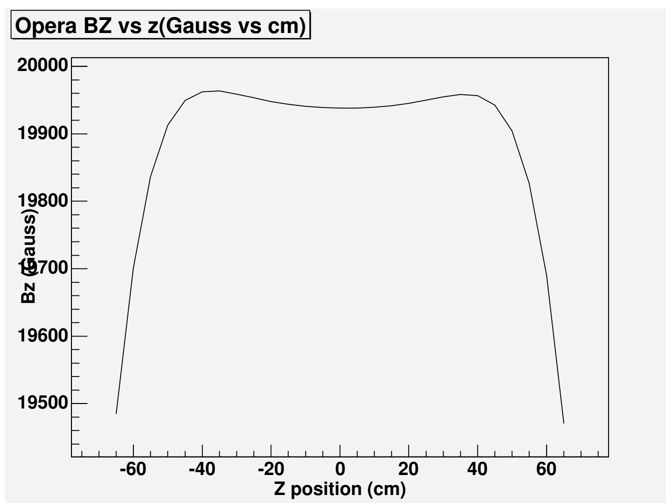

Figure 4.6: Bz vs. Z fieldmap_sanaz_completemodel from Z=-65 to Z=65 cm at X=Y=0. This part of fieldmap2_sanaz_completemodeltable is the same as Opera3d_Post_13_-nonlinearBH_stepsize1.lp

and their difference is:

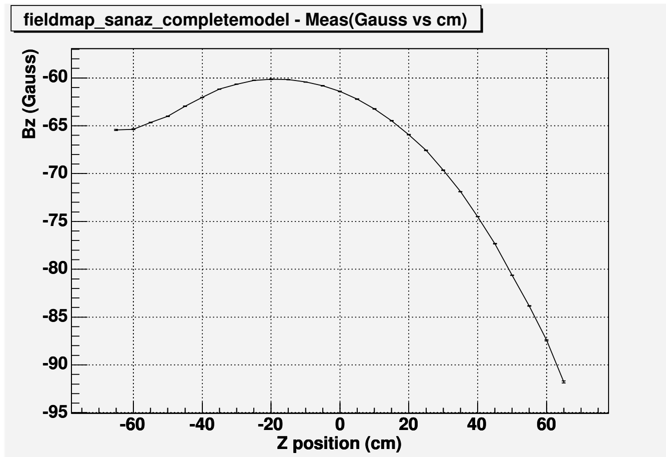

Figure 4.7: Bz vs. Z fieldmap_sanaz_completemodel - Meas.

Please note that figure 4.5 contains the average measured field values from Z=-65 cm to Z=65 cm at r=0.

I also compared fieldmap2_sanaz_completemodel to field_map.0007-barnes and field_map.0003 at X=Y=0. See the results in the next two figures (Figures 4.8 and 4.9).

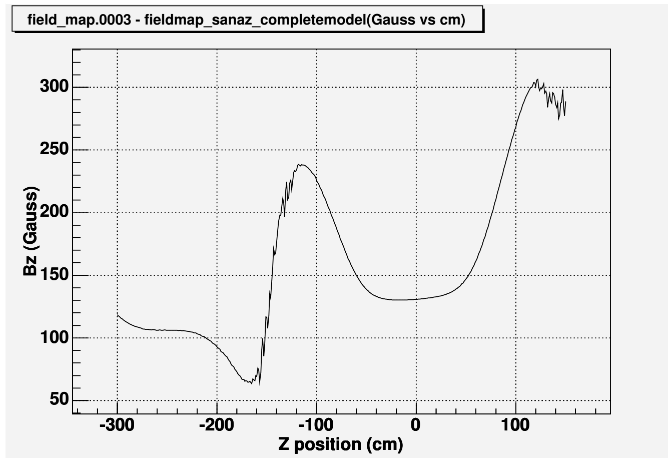

Figure 4.8: Bz vs. Z field_map.0003 (Nominal Model) - fieldmap_sanaz_completemodel

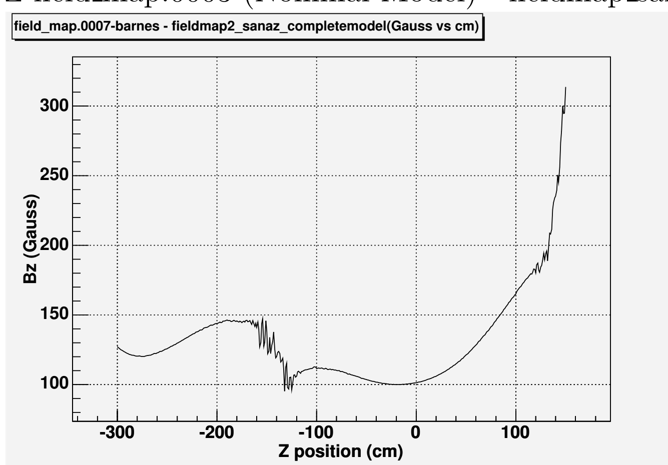

Figure 4.9: Bz vs. Z field_map.0007 (Tuned Model) - fieldmap_sanaz_completemodel

As you see in Figures 4.8 and 4.9, fieldmap_sanaz_completemodel does not give us he same values for Bz along the Z axis in the yoke as in the nominal or tuned model!

In Figure 4.9 the difference at Z=0 is 100 Gauss; in order to get close to zero difference at Z=0 I reduced the current densities in tables 3.1 and 3.2 by $100Gauss/20.0KGauss = 0.5\%$ in the model and saved the model with mesh at :

Trshare/public/e614/sanaz/the_ones_done_in_10.5/twistmagnet_August26_-2005_half_percent.opcb. I solved and Post_processed it, and got the field values on a Grid from point (-30,-30,-300) to (30,30,150), and saved the file as

Trshare/public/e614/sanaz/the_ones_done_in_10.5/twistmagnet_August26_-

2005_half_percent.table. Then I plotted the difference of field_map.0007_barnes and the twistmagnet_August26_2005_half_percent. See the results in Figures 4.10, 4.11, 4.12.

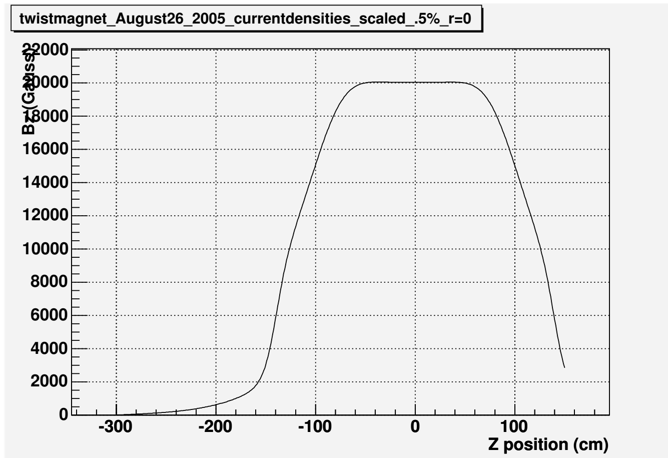

Figure 4.10: Bz vs. Z twistmagnet_fieldmap_currentdensities_scaled_.5percent

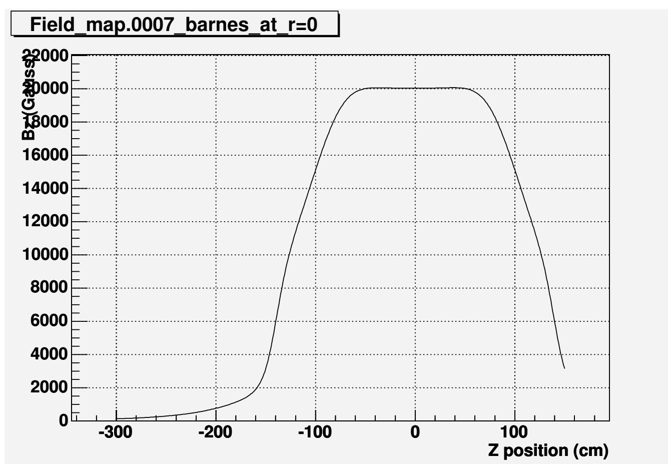

Figure 4.11: Bz vs. Z field_map.0007 (Tuned Model)

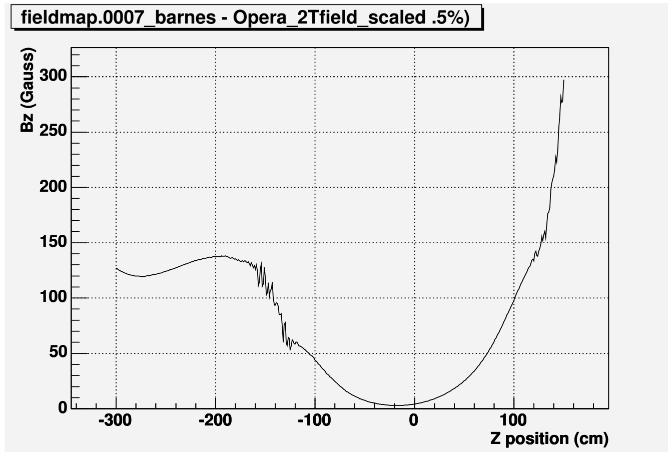

Figure 4.12: Bz vs. Z field_map.0007 (Tuned Model) - twistmagnet_fieldmap_currentdensities_scaled

As we notice in Figure 4.12, the difference of Roberto's Tuned model and the scaled model in the tracking region which is at $Z = +/-50$ is between 25 and 8 Gauss.

To get 1.96 T field map, I multiplied the current densities of the model: **twistmagnet_August26_2005_half_percent.opcb** by 0.98 (1.96/2.0 = 0.98), and created a new model at: **Trshare/public/e614/sanaz/the_ones_done_in_10.5/-twistmagnet_August26_2005_half_percent_196.opcb**. I solved and Post_processed the data file(.op3 file), and got the field values on a Grid from point (-30,-30,-300) to (30,30,150), and saved the file as **Trshare/public/e614/sanaz/the_ones_done_in_-10.5/twistmagnet_August26_2005_half_percent_196.table**. I compared the values of Bz at X=Y=0 with field_map.0007_barnes. Look at Figures 4.13 and 4.14.

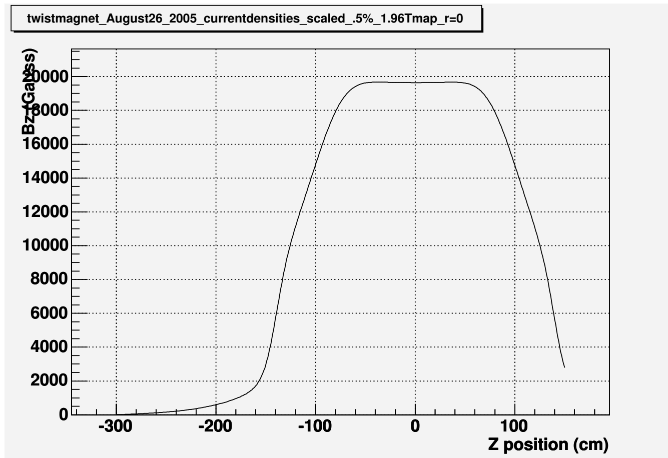

Figure 4.13: Bz vs. Z twistmagnet_fieldmap_currentdensities_scaled_.5percent_196Tmap

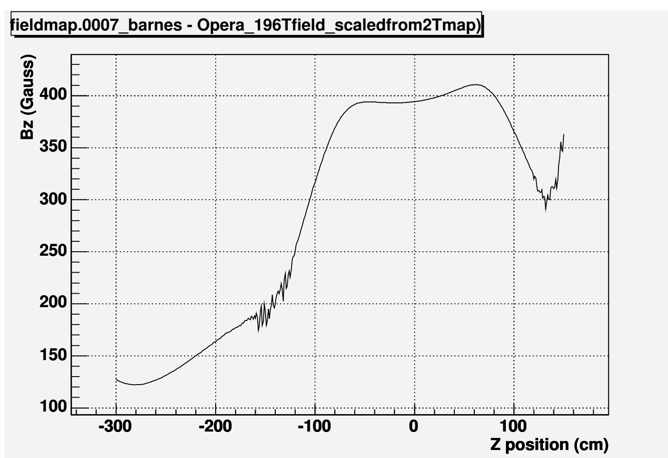

Figure 4.14: Bz vs. Z field_map.0007 (Tuned Model) - twistmagnet_fieldmap_currentdensities_scaled_.5percent_196Tmap

In Figure 4.14, there is discontinuity at the doors. If I compare twistmagnet_fieldmap_currentdensities_scaled_.5percent to twistmagnet_fieldmap_currentdensities_scaled_.5percent_196Tmap, the discontinuity will disappear. See the comparison of Figures 4.10 and 4.13 in Figure: 4.15.

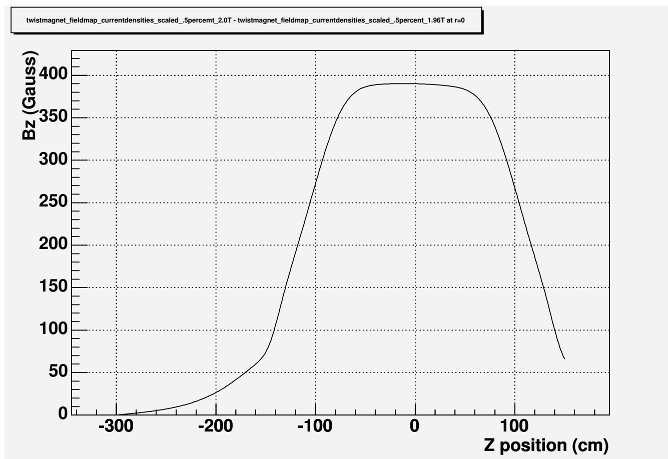

Figure 4.15: Bz vs. Z twistmagnet_fieldmap_currentdensities_scaled - twistmagnet_fieldmap_currentdensities_scaled_.5percent_196Tmap

I also generated the 2.04 T field map. I multiplied all the current densities in the model of the model: **twistmagnet_August26_2005_half_percent.opcb** by 1.02 (2.04/2.0 = 1.02), and created a new model at: **Trshare/public/e614/sanaz/the_ones_done_in_10.5/-twistmagnet_August26_2005_half_percent_204.opcb**. I solved and Post_processed the data file (.op3 file), and got the field values on a Grid from point (-30,-30,-300) to (30,30,150), and saved the file as **Trshare/public/e614/sanaz/the_ones_done_in_-10.5/twistmagnet_August26_2005_half_percent_204.table**; then I compared the values of Bz at X=Y=0 with field_map.0007_barnes and twistmagnet_fieldmap_currentdensities_scaled_.5percent. See the results in Figures 4.16, 4.17, and 4.18.

Looking at Figures 4.17 and 4.18, one can see that the discontinuity at the doors is gone after comparing the 2.04 T map to the 2 T map with current densities scaled.

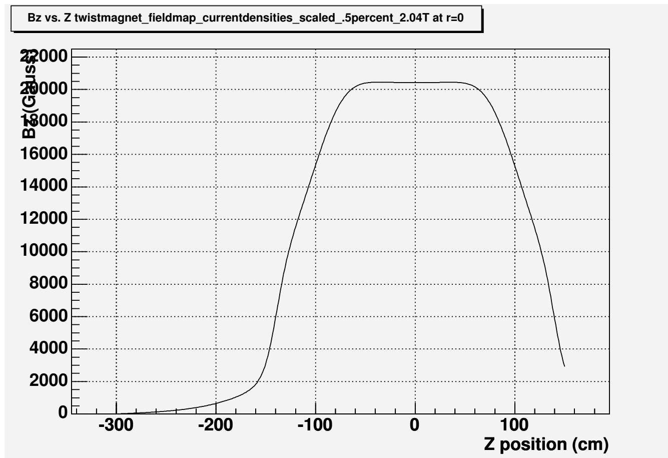

Figure 4.16: Bz vs. Z twistmagnet_fieldmap_currentdensities_scaled_.5percent_2.04Tmap

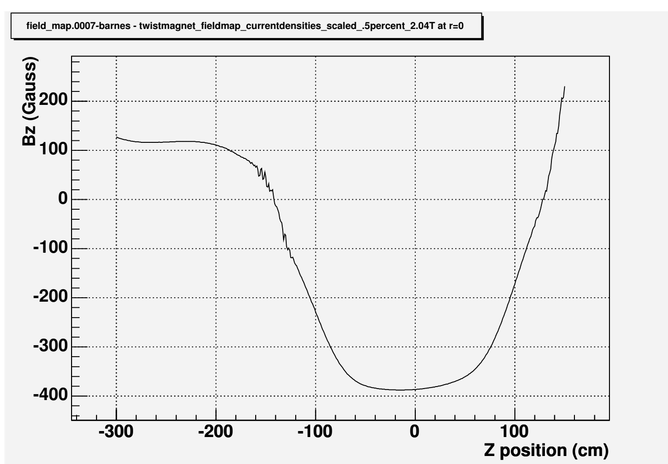

Figure 4.17: Bz vs. Z field_map.0007 (Tuned Model) - twistmagnet_fieldmap_currentdensities_scaled_.5percent_2.04Tmap

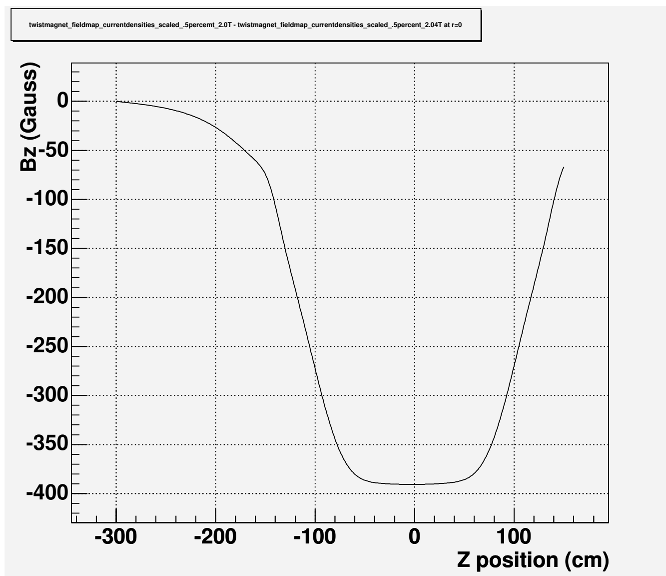

Figure 4.18: Bz vs. Z twistmagnet_fieldmap_currentdensities_scaled_.5percent - twistmagnet_fieldmap_currentdensities_scaled_.5percent_2.04Tmap

Chapter 5

Conclusion

By looking at Figures 4.2, 4.3 it is obvious that the steel is modeled correctly.
At the moment we have a working model that we are able to mesh and solve and get the field values at the desirable points.
The working model does not generate the same results as the existing fieldmaps 0007, 0003, or the measured field.
After scaling the current densities by 0.5%, the difference of Roberto's Tuned model and the scaled model in the tracking region is between 25 and 8 Gauss.

Chapter 6

Future Works

Now that we have a complete model to mesh and solve, the main focus is generating maps in which the Bz values are as close as to the measured Bz values. Therefore the first thing is to create the original model designed by Mike Barnes (The Nominal Model), and to adjust all the currents and the coil positions to those in Mike's; basically, we want to use this as a starting point from which we can re-tune the new model, using Roberto's work as a guide.

References

[1] TWIST Official Website: http://tw04.triumf.ca.

[2] J. Musser, "Measurement of the michel parameter ρ in muon decay," Ph.D. dissertation, Texas A&M University, 2005.

[3] Roberto Armenta, "TWIST Magnet: Field Map Study Final Report,TRIUMF", August 2002.

[4] Camille Boucher-Veronneau, "The TWIST Solenoid Magnetic Field", 2004.

[5] Opera-3d Reference Manual, Version 10.506, 2004.