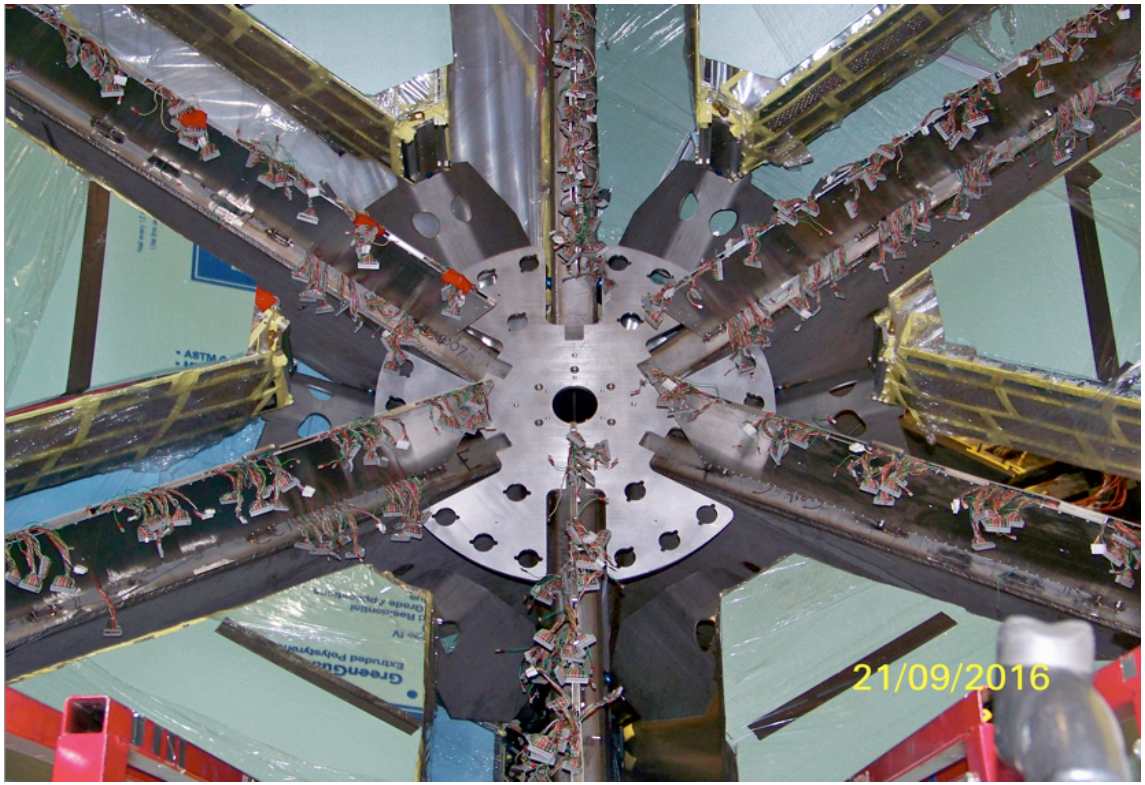


TORUS Field Mapping Update

Joseph Newton

CLAS Collaboration Meeting

March 6, 2018

Objectives and Physics Specifications

- **TORUS consists of six superconducting coils which produces a symmetric, mainly azimuthal field**
- **Joint-effort by Jefferson Lab and Fermilab**
- **Design allows for large acceptance of forward going particles (50% acceptance at 5 degrees from the beam axis)**
- **Maximum current is at 3770 A with the full field at 3.58 T**

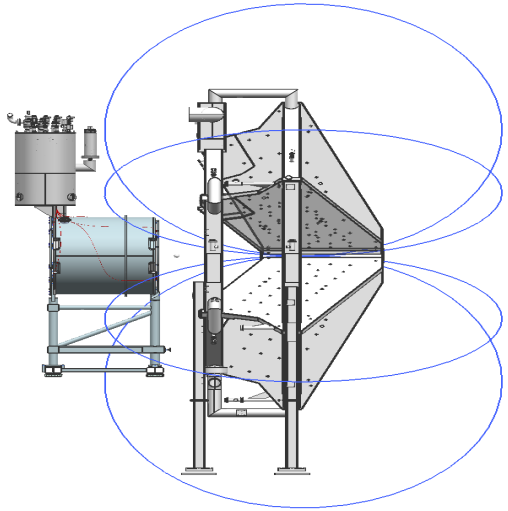


Fig. 1. Schematic of TORUS magnet and direction of the field lines

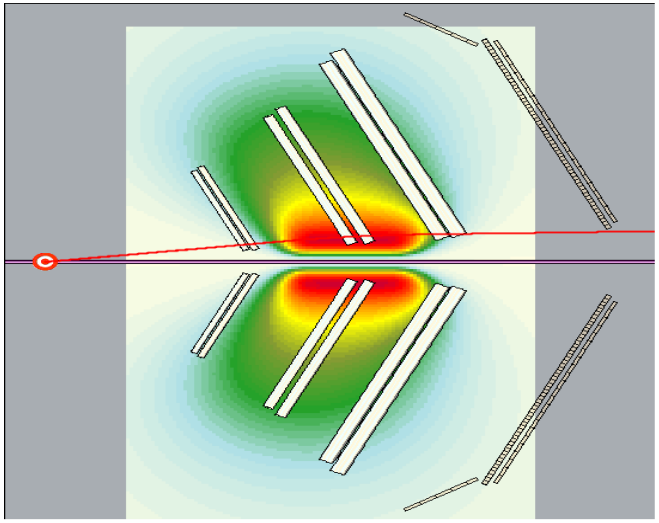


Fig. 2. In-bending track in the presence of the TORUS nominal field configuration

- Must understand the deviations of the coil positions and angular orientations due to manufacturing and installation process

Measurement Procedure

- Measure all components of the TORUS field at 24 positions in the XY plane along 40 positions along the z-axis and calculate the "distortion field"
- Minimize a chi-squared function that compares the measured and modeled "distortion fields" caused by the anticipated movements of the six coils

$$\chi^2 = \sum_{pts=1}^{24} \sum_{dim=1}^{3} \left(\frac{\Delta B_{meas}(dim, pts) - \Delta B_{calc}(dim, pts)}{\delta B(dim)} \right)^2$$

- **Hall Probes measured the field (Bx, By, Bz) and were pushed by a LabView-controlled apparatus into non-magnetic Carbon tubes**
- **Current was at 3000 Amps (roughly 80% of the maximum field)**
- **Data was taken from November 3 through November 6**

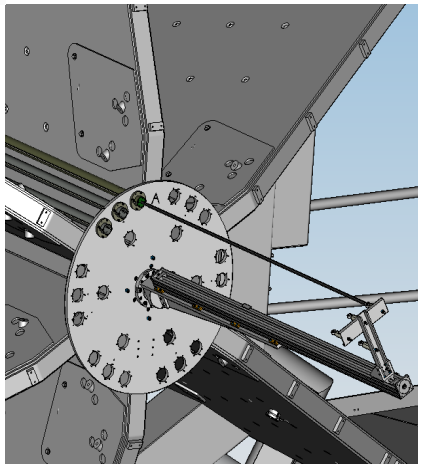
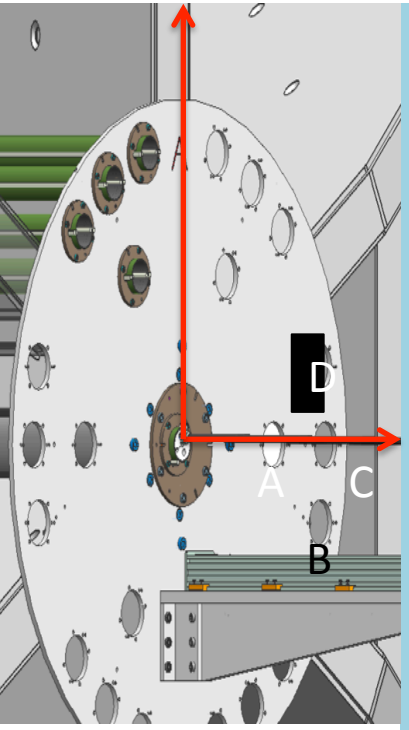


Fig. 3. Visual model of the Hall probe being pushed by a motor along the beam axis inside a non-magnetic Carbon tube



The y-component, which points in azimuth, was measured with great precision

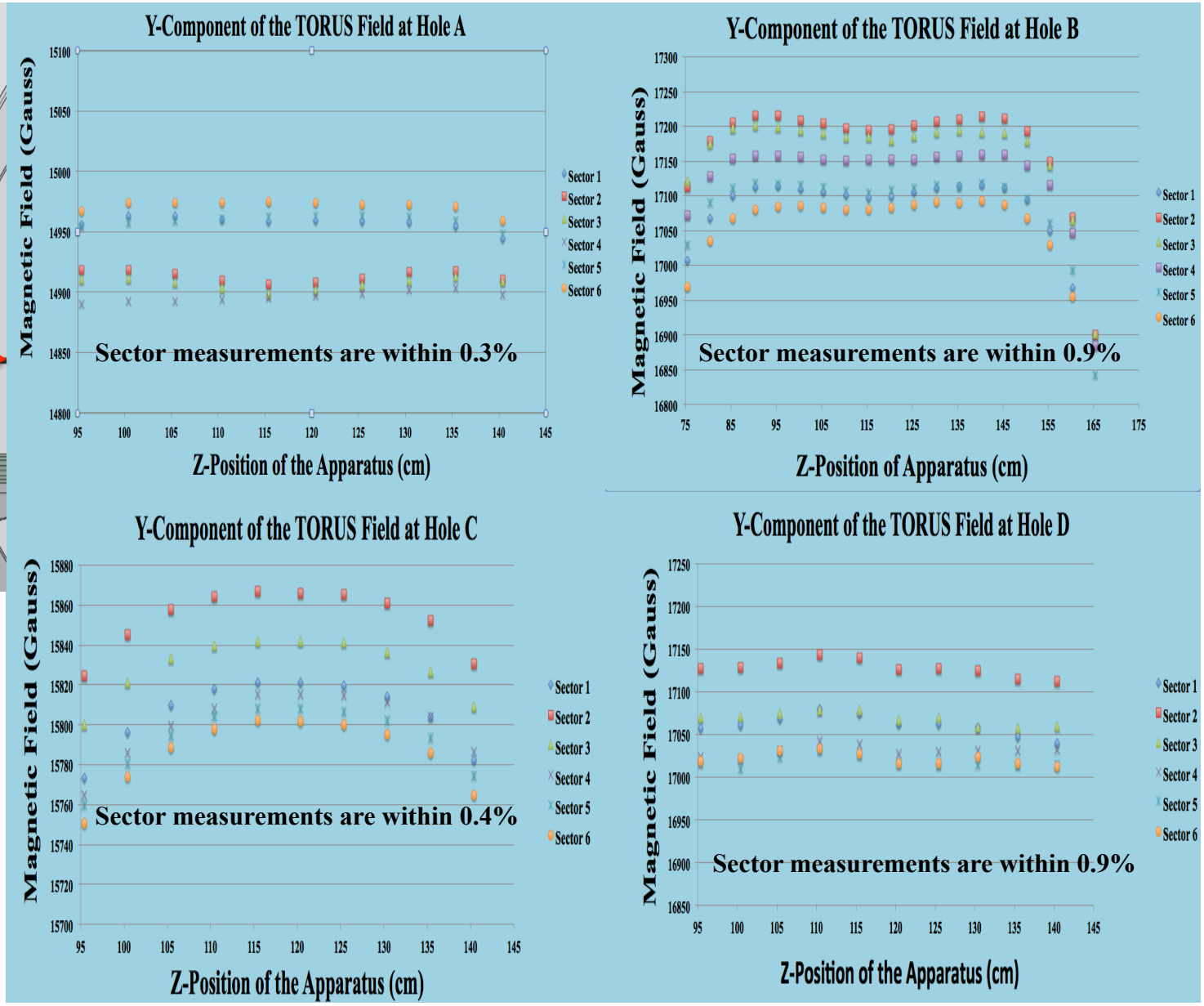
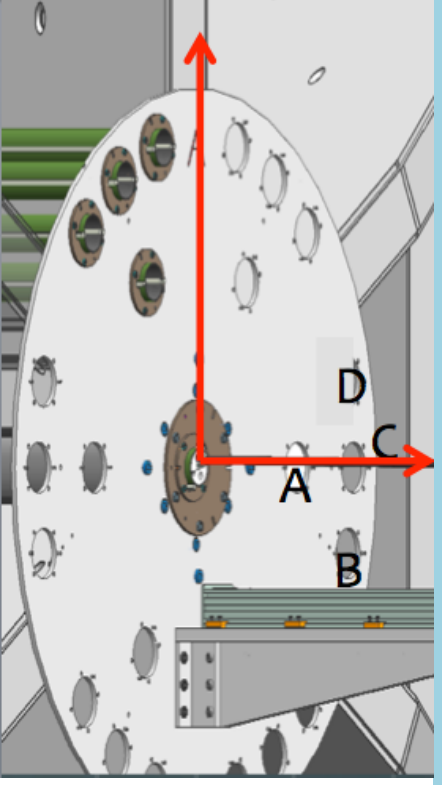


Fig. 4. Large component of the TORUS field at Holes A-D as measured in all six sectors.



The x-component, especially at Holes A and C, are viable ways of checking for systematic errors

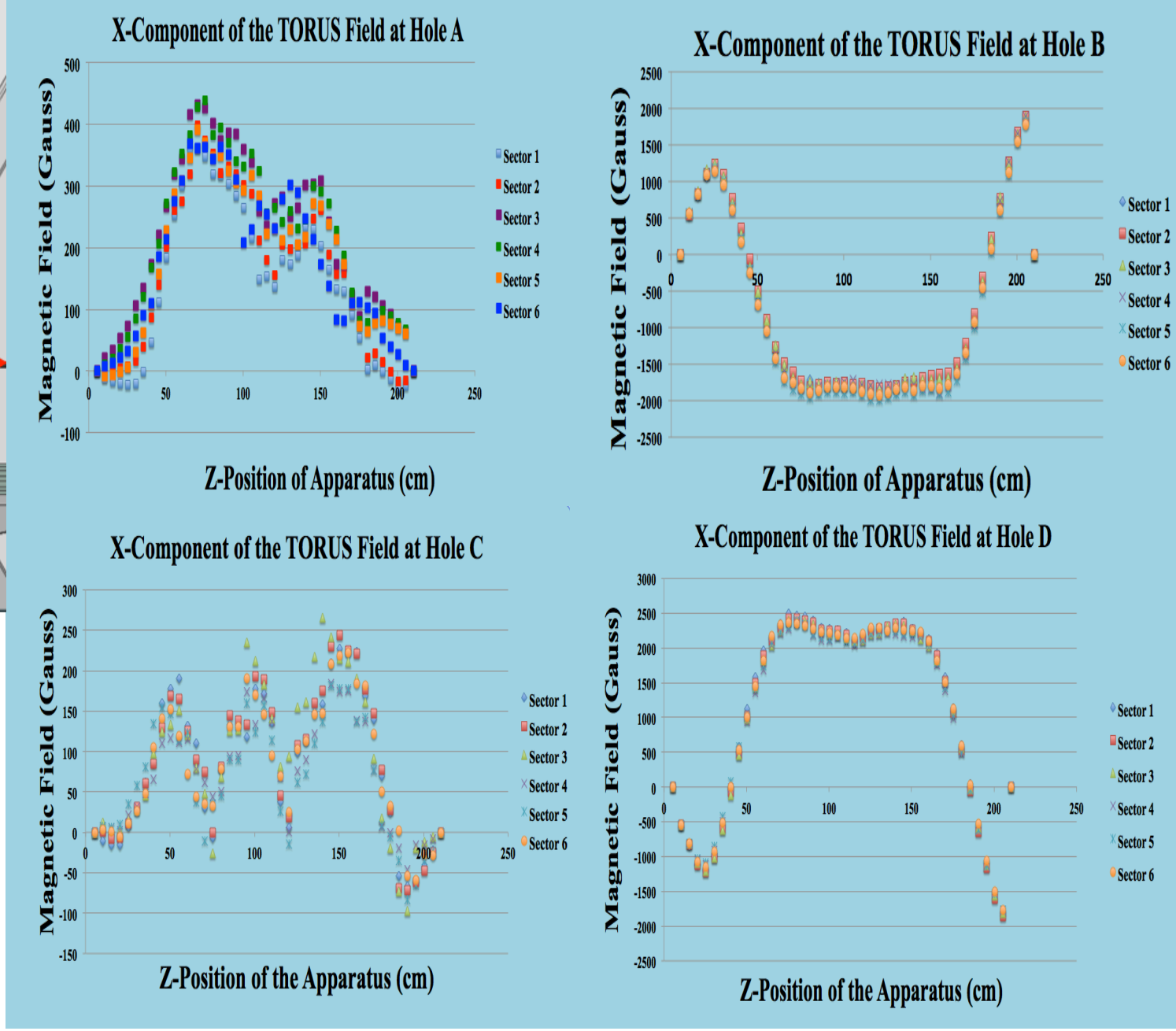
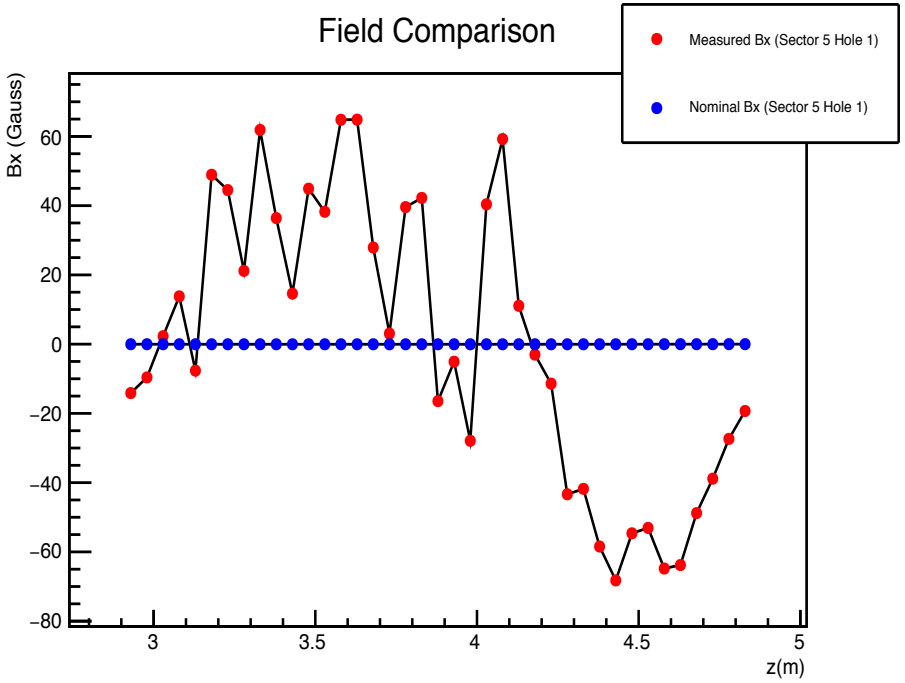
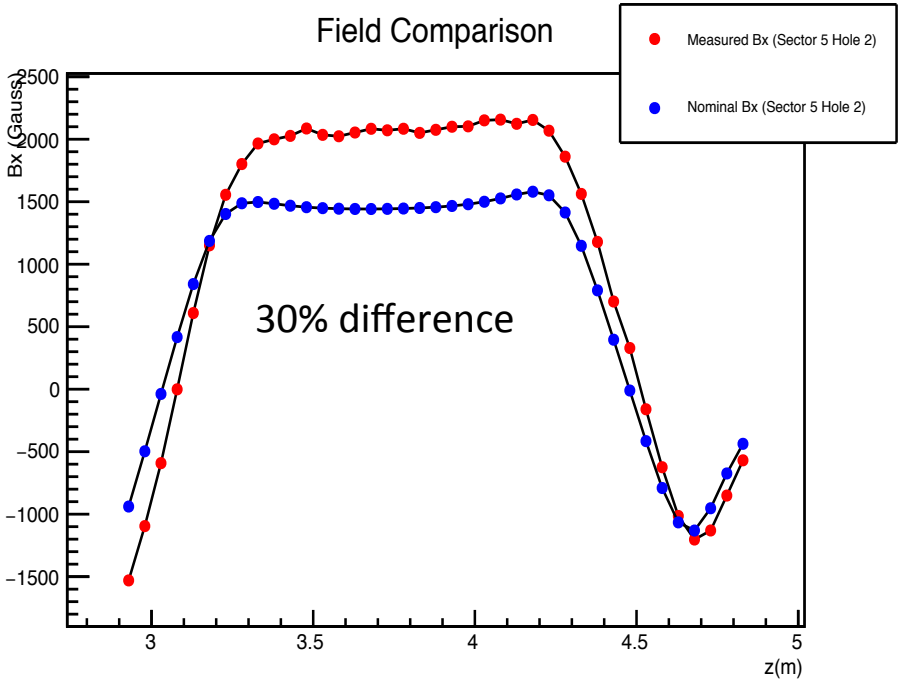
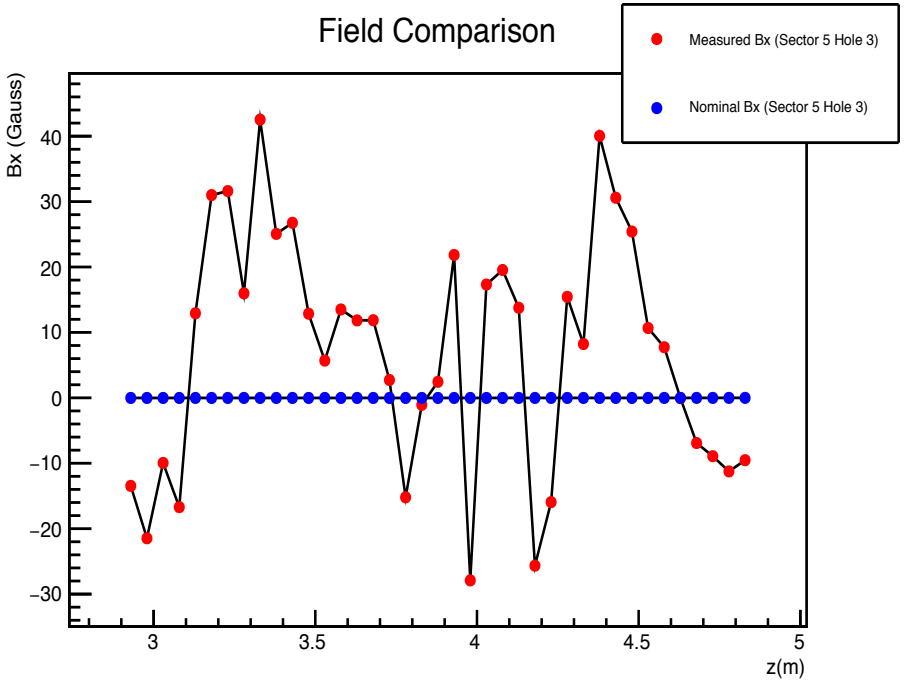
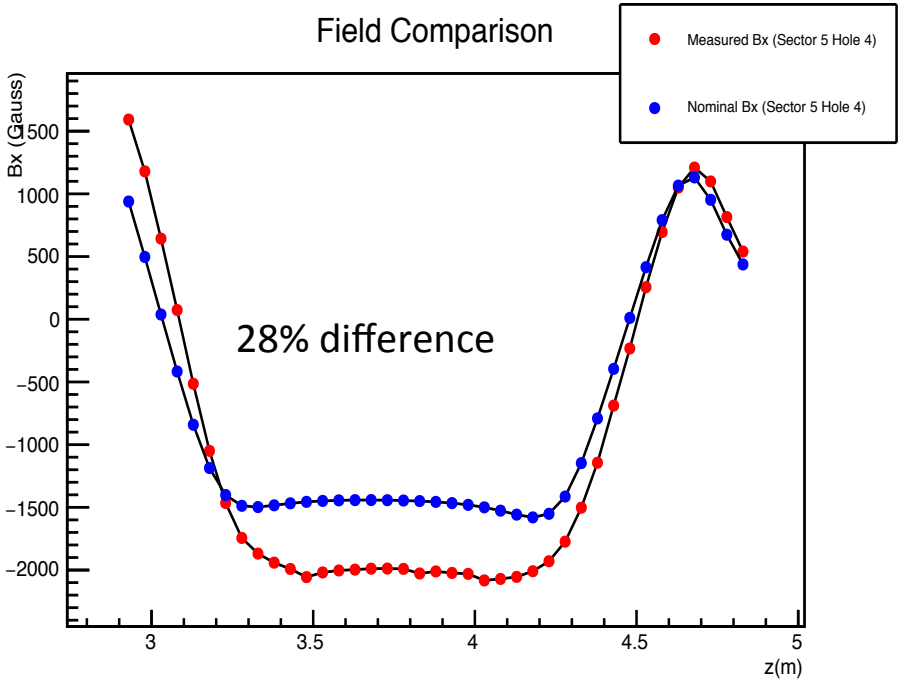


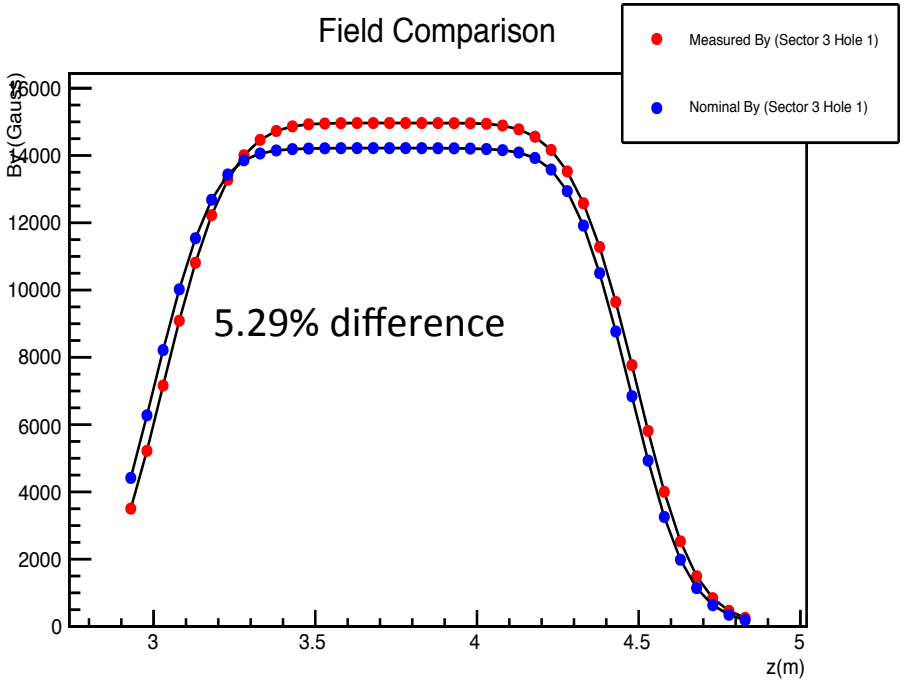
Fig. 5. X-component of the TORUS field at Holes A-D in Sectors 1-6.

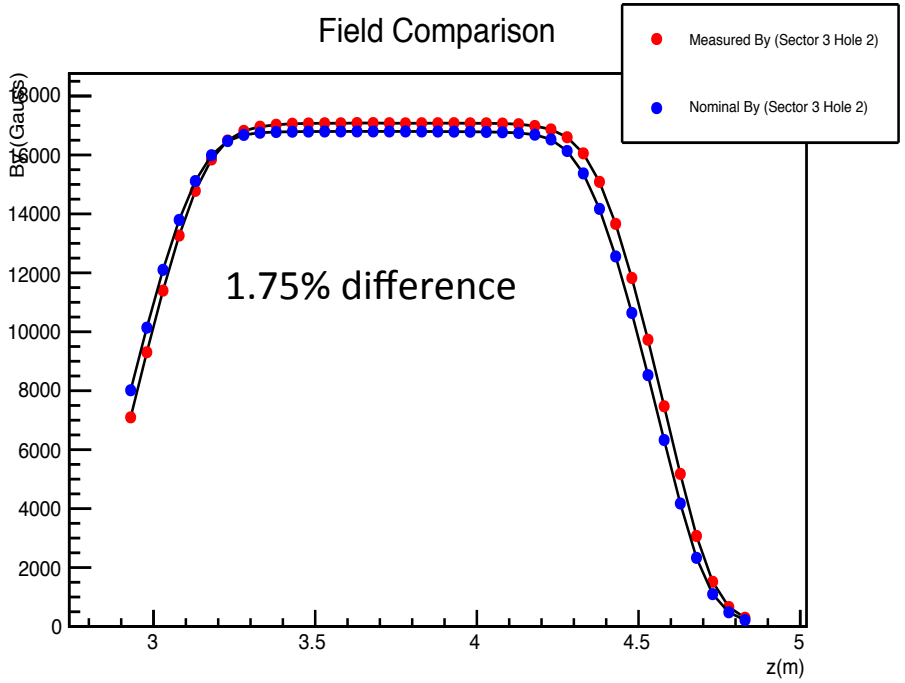

Field Comparison
Measured Bx (Sector 5 Hole 1)
Nominal Bx (Sector 5 Hole 1)
Bx (Gauss)
z(m)

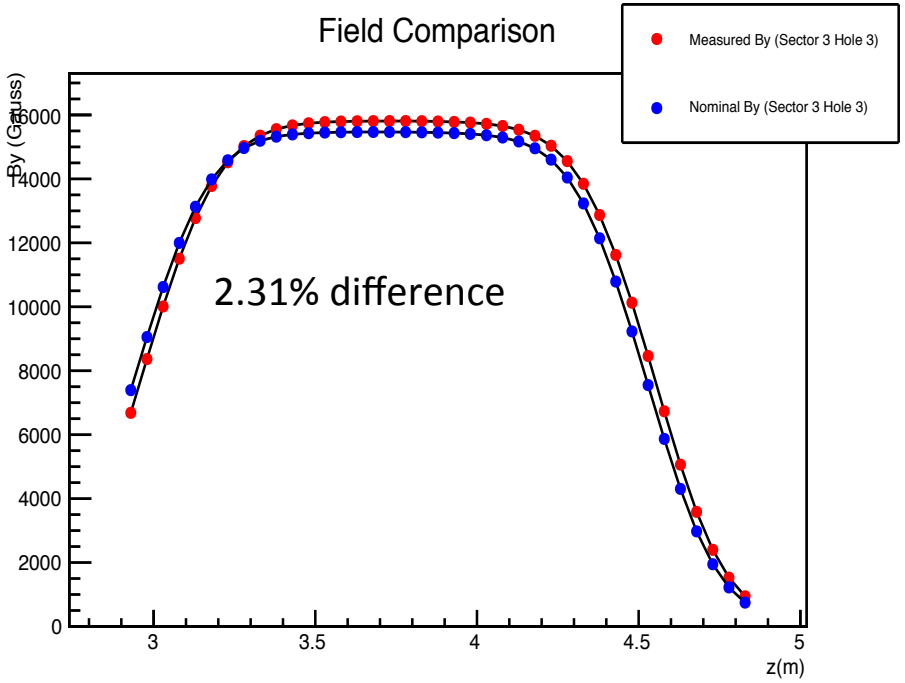

Field Comparison
Measured Bx (Sector 5 Hole 2)
Nominal Bx (Sector 5 Hole 2)
30% difference
Bx (Gauss)
z(m)

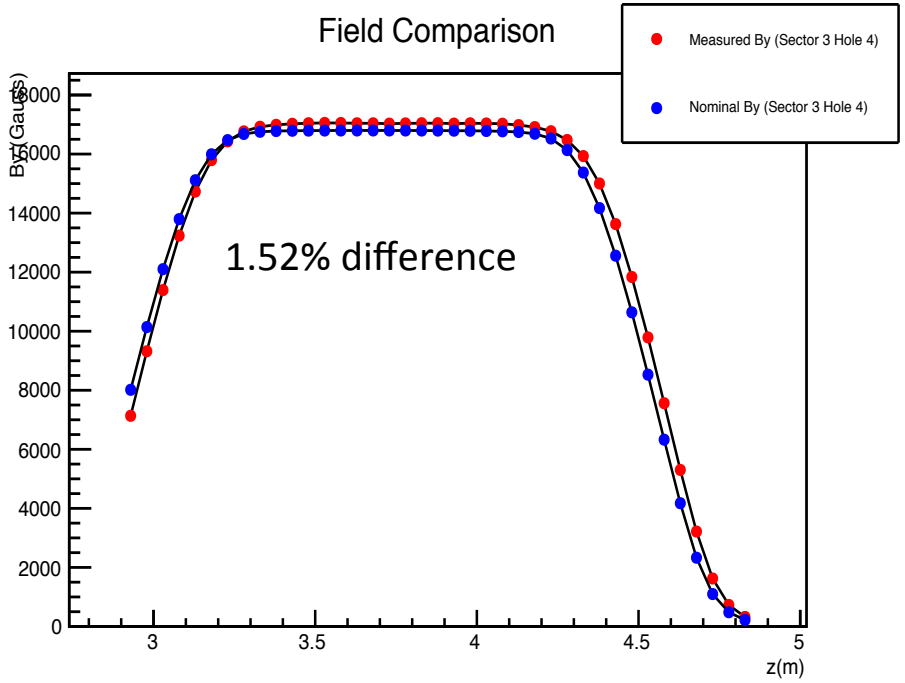

Field Comparison
Measured Bx (Sector 5 Hole 3)
Nominal Bx (Sector 5 Hole 3)
Bx (Gauss)
z(m)

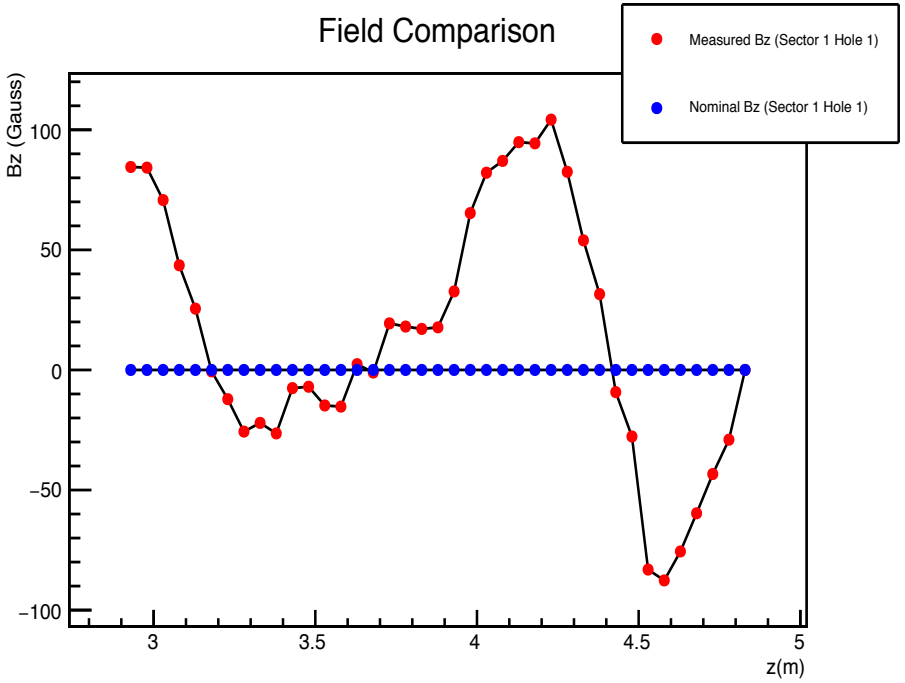

Field Comparison
Measured Bx (Sector 5 Hole 4)
Nominal Bx (Sector 5 Hole 4)
28% difference
Bx (Gauss)
z(m)

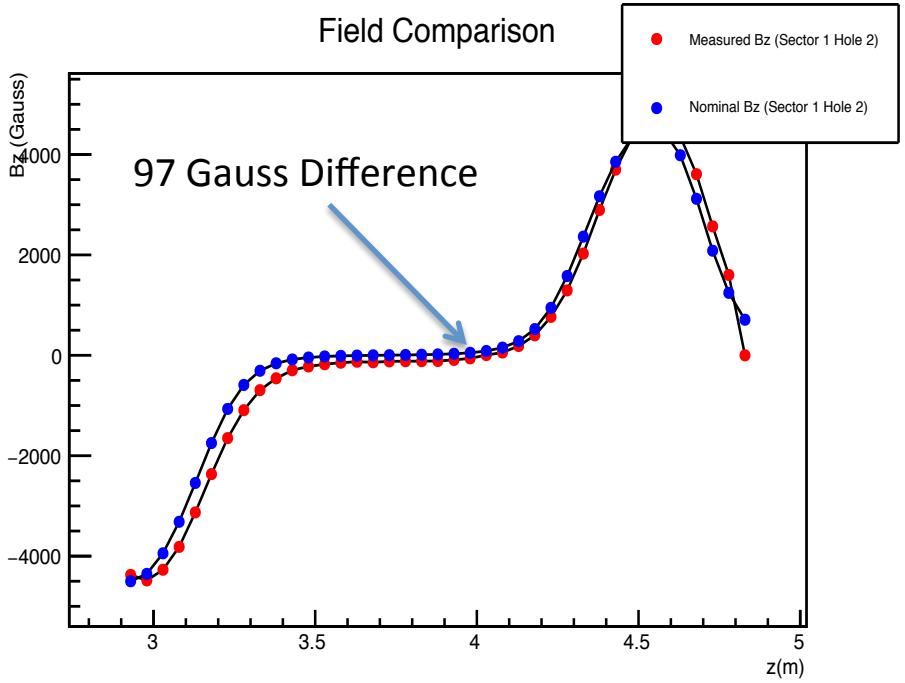

Field Comparison
Measured By (Sector 3 Hole 1)
Nominal By (Sector 3 Hole 1)
Bx (Gauss)
z(m)
5.29% difference

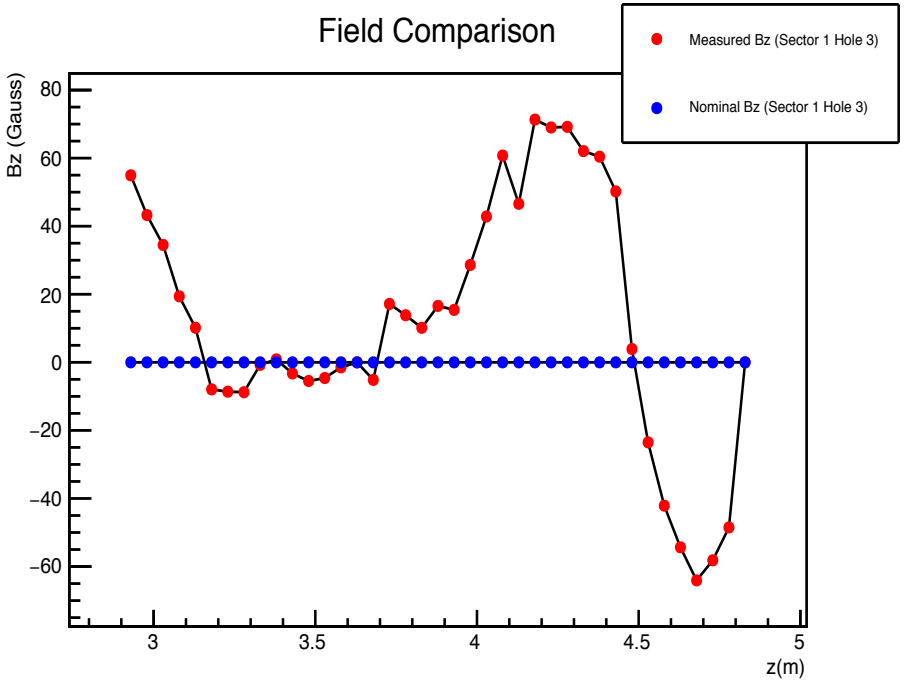

Field Comparison
Measured By (Sector 3 Hole 2)
Nominal By (Sector 3 Hole 2)
Bx (Gauss)
z(m)
1.75% difference

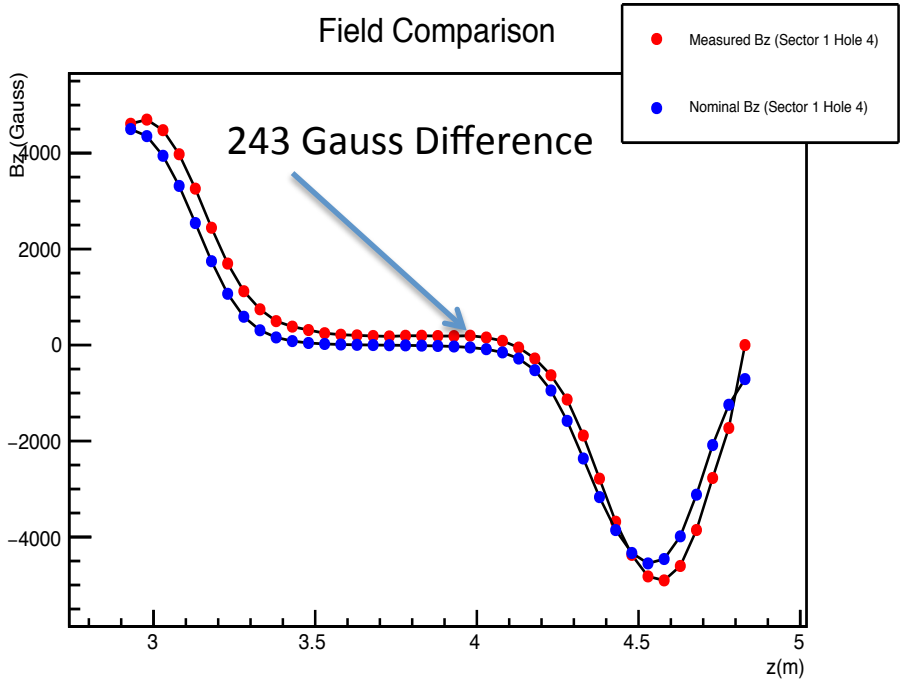

Field Comparison
Measured By (Sector 3 Hole 3)
Nominal By (Sector 3 Hole 3)
By (Gauss)
z(m)
2.31% difference


Field Comparison
Measured By (Sector 3 Hole 4)
Nominal By (Sector 3 Hole 4)
Bx (Gauss)
z(m)
1.52% difference


Field Comparison
Measured Bz (Sector 1 Hole 1)
Nominal Bz (Sector 1 Hole 1)
Bz (Gauss)
z(m)


Field Comparison
Measured Bz (Sector 1 Hole 2)
Nominal Bz (Sector 1 Hole 2)
97 Gauss Difference
Bz (Gauss)
z(m)


Field Comparison
Measured Bz (Sector 1 Hole 3)
Nominal Bz (Sector 1 Hole 3)
Bz (Gauss)
z(m)


Field Comparison
Measured Bz (Sector 1 Hole 4)
Nominal Bz (Sector 1 Hole 4)
243 Gauss Difference
Bz (Gauss)
z(m)

Production of TORUS Models

- Software -> Opera
- Produced By -> Dr. Probir Ghoshal
- Measured Data
- Nominal Data
- Field Map For Unit Distortion #1
- Field Map For Unit Distortion #2
- Field Map For Unit Distortion #3

$$\chi^2 = \sum_{pts=1}^{24} \sum_{dim=1}^{3} \left(\frac{\Delta \mathrm{B}_{\mathrm{meas}}(\mathrm{dim}, \mathrm{pts}) - \Delta \mathrm{B}_{\mathrm{calc}}(\mathrm{dim}, \mathrm{pts})}{\delta B(dim)} \right)^2$$

$$\Delta \mathrm{B}_{meas}(dim, pts) = [\mathrm{B}_{meas}(dim, pts) - \mathrm{B}_{ideal}(dim, pts)]$$

$$\Delta \mathrm{B}_{\mathrm{calc}}(\mathrm{dim}, \mathrm{pts}) = \sum_{icoil=1}^{6} \sum_{mode=1}^{3} \alpha_{mode,icoil} (\mathrm{B}_{\mathrm{ideal}}(\mathrm{dim}, \mathrm{pts}) - \mathrm{B}_{\mathrm{distortion}}(\mathrm{dim}, \mathrm{pts}, \mathrm{icoil}, \mathrm{mode}))$$

*ROOT/C++ script attempts to minimize chi-squared function which depends on the comparison of measured data's deviation from nominal with pre-produced data from nominal

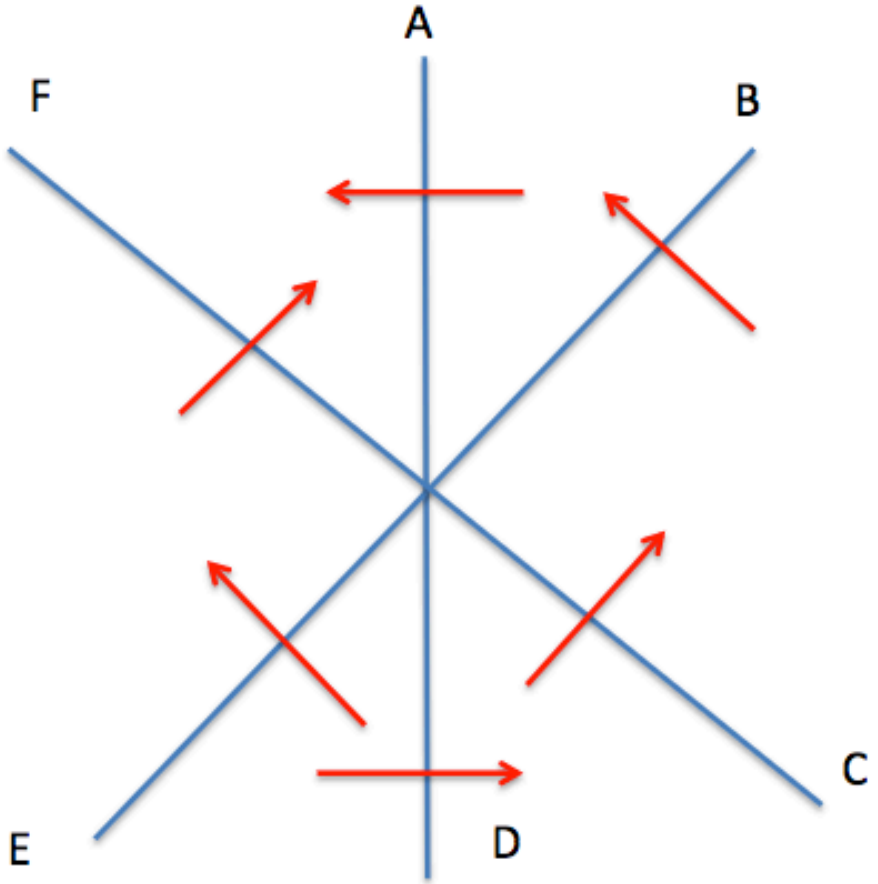
Preliminary Results For Selected Z-Positions

Coil A moved radially in by 12.5295 mm (towards the bore/hub)
Coil B moved radially in by 10.5152 mm (towards the bore/hub)
Coil C moved radially in by 9.38943 mm (towards the bore/hub)
Coil D moved radially in by 8.81748 mm (towards the bore/hub)
Coil E moved radially in by 10.5103 mm (towards the bore/hub)
Coil F moved radially in by 12.4902 mm (towards the bore/hub)

Coil A moved along the bore/beam towards DS along Z by 9.9118 mm
Coil B moved along the bore/beam towards DS along Z by 15.6313 mm
Coil C moved along the bore/beam towards DS along Z by 13.9002 mm
Coil D moved along the bore/beam towards DS along Z by 13.1716 mm
Coil E moved along the bore/beam towards DS along Z by 10.673 mm
Coil F moved along the bore/beam towards DS along Z by 16.0749 mm

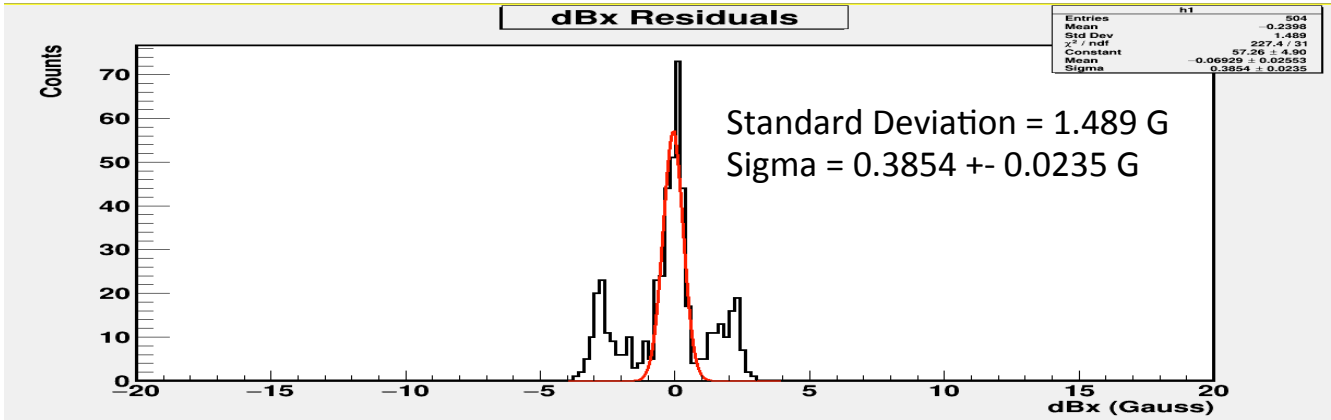
Coil A moved in azimuth by 0.0748273 mm (Refer to Diagram)
Coil B moved in azimuth by 0.624114 mm (Refer to Diagram)
Coil C moved in azimuth by 1.03096 mm (Refer to Diagram)
Coil D moved in azimuth by 0.079318 mm (Refer to Diagram)
Coil E moved in azimuth by 2.43371 mm (Refer to Diagram)
Coil F moved in azimuth by 1.76178 mm (Refer to Diagram)

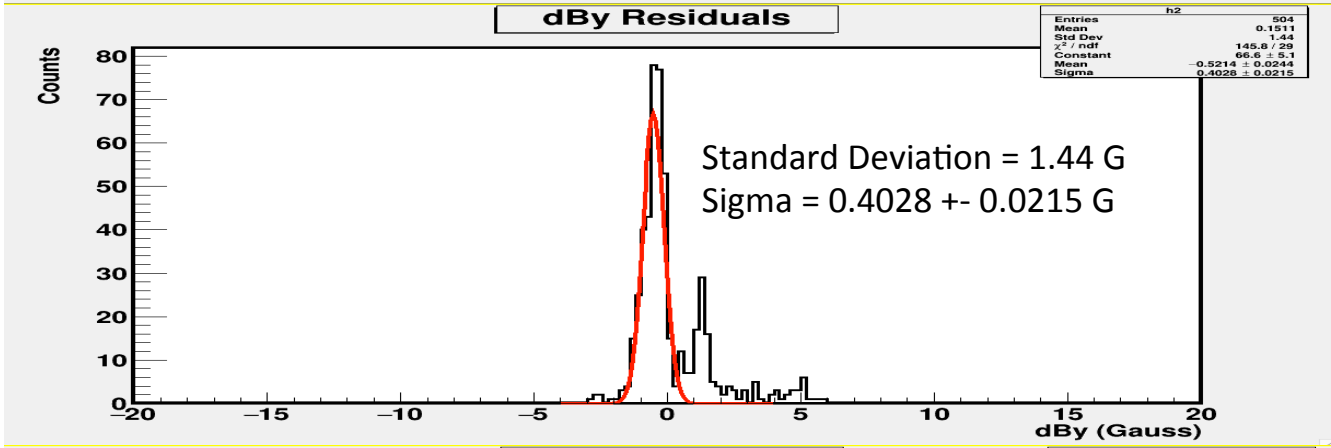
With shifts in azimuth, the entire coil moves translationally. There is no rotation.

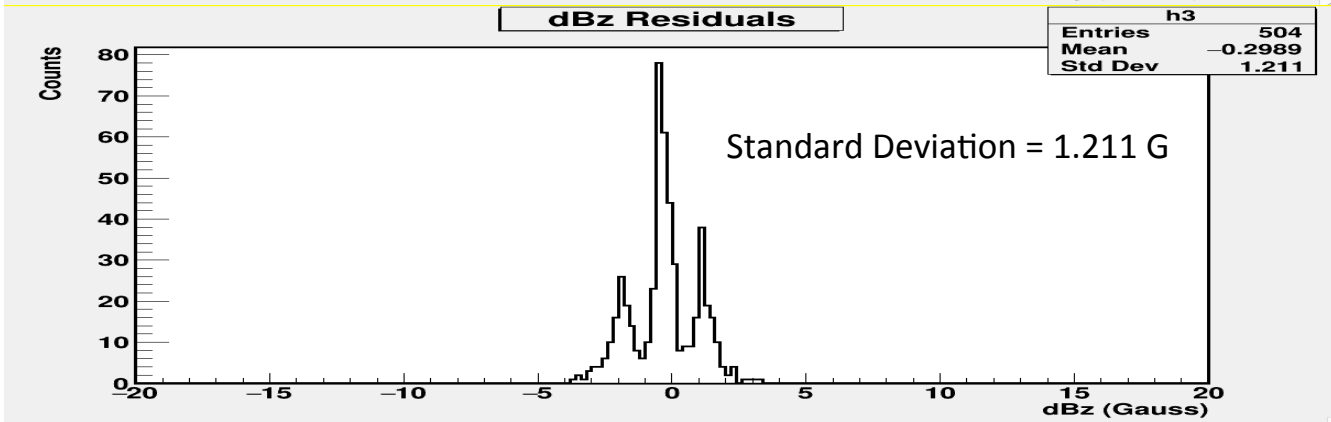


Validation of Fitting Procedure

*After MINUIT optimized the chi-squared function, the 18 coefficients were put into the function and the residuals were distributed among zero, showing the quality of the fit.

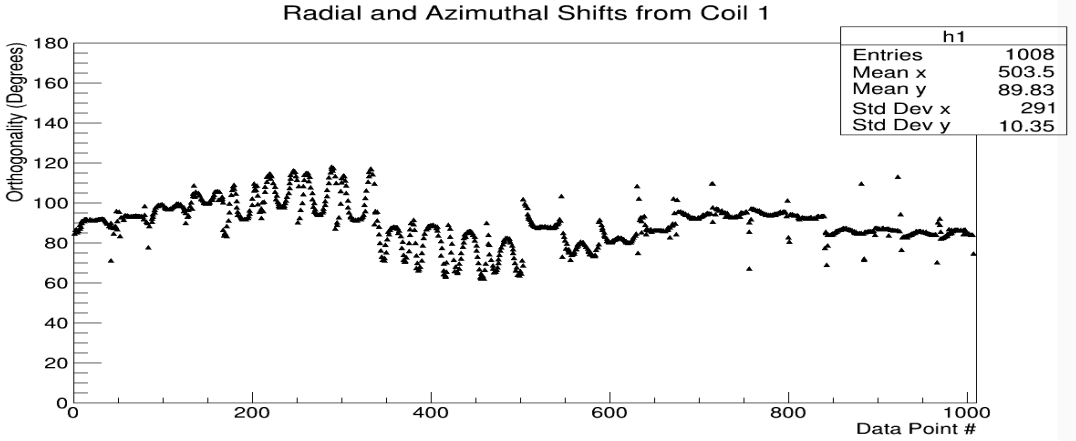


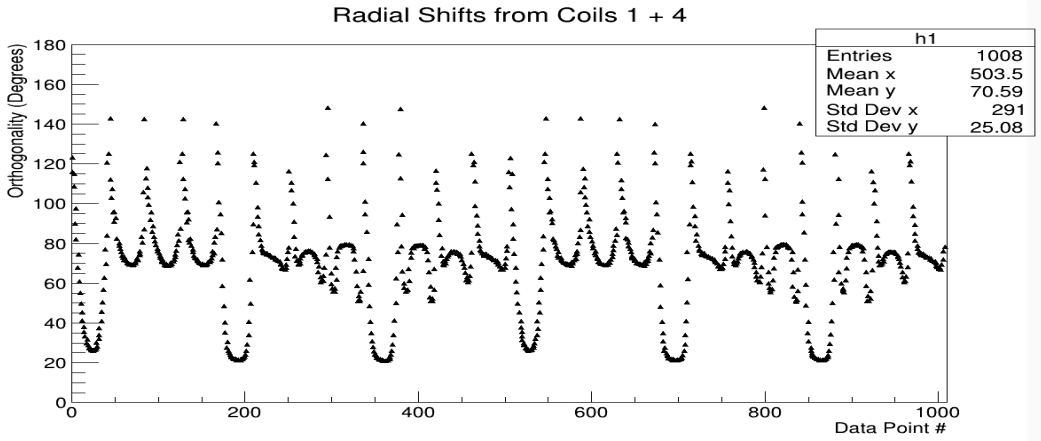


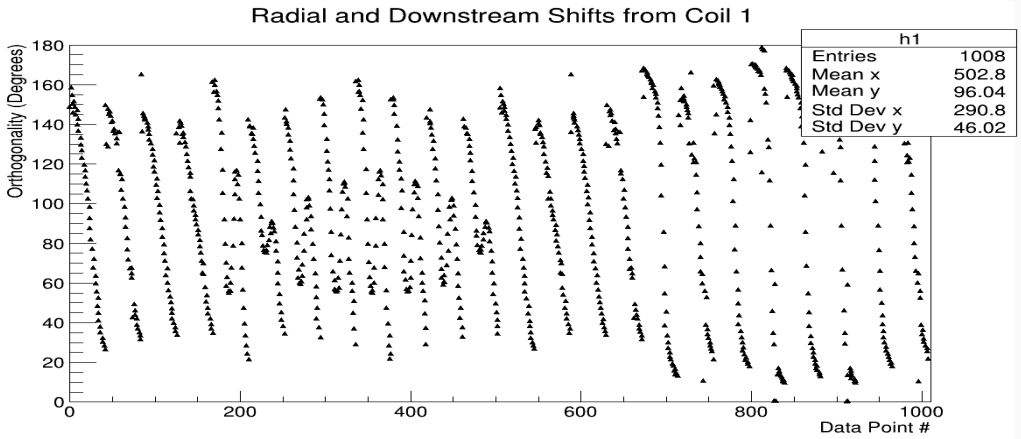


Orthogonality Between Field Displacement Effects

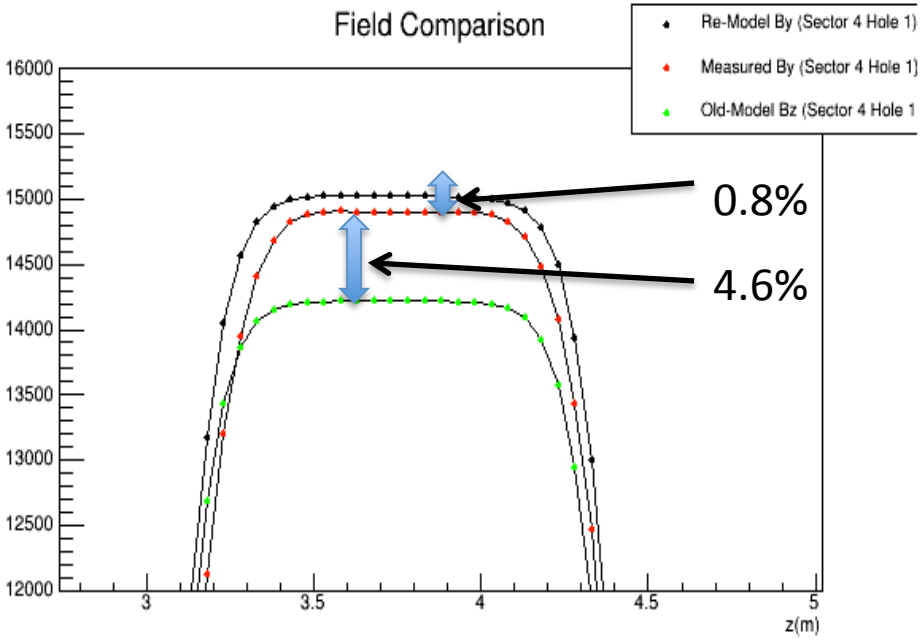
*Orthogonality was defined as the angle associated with the dot product of the two “distortion” fields at any given measurement position. 0 degrees would be complete correlation. 180 degrees would be complete anti-correlation. 90 degrees would be no correlation.

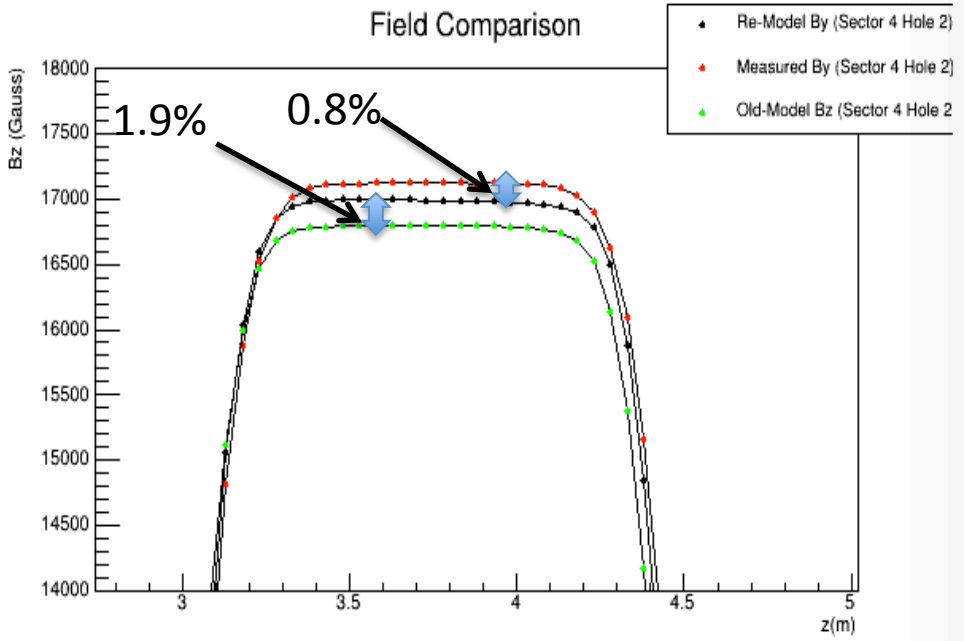


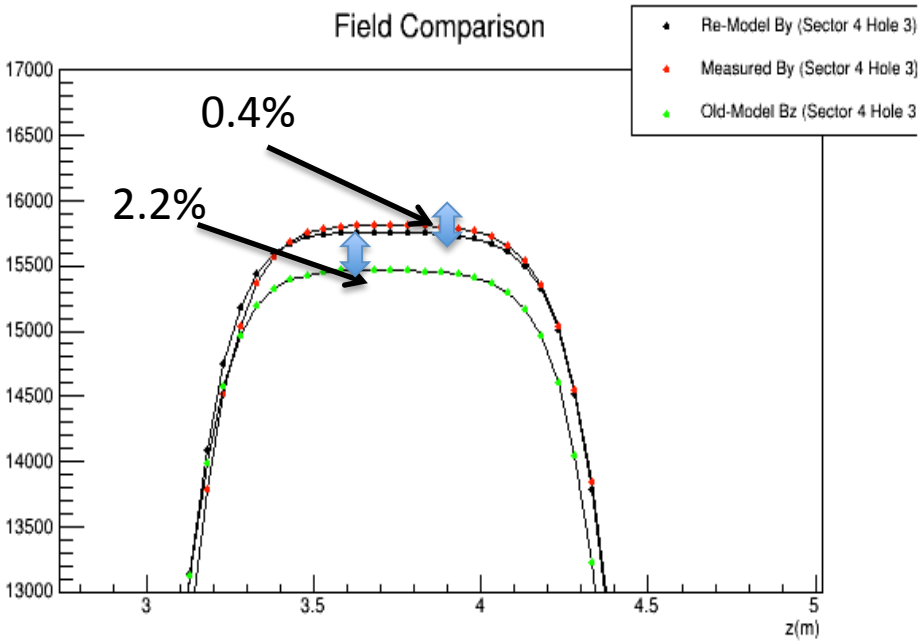


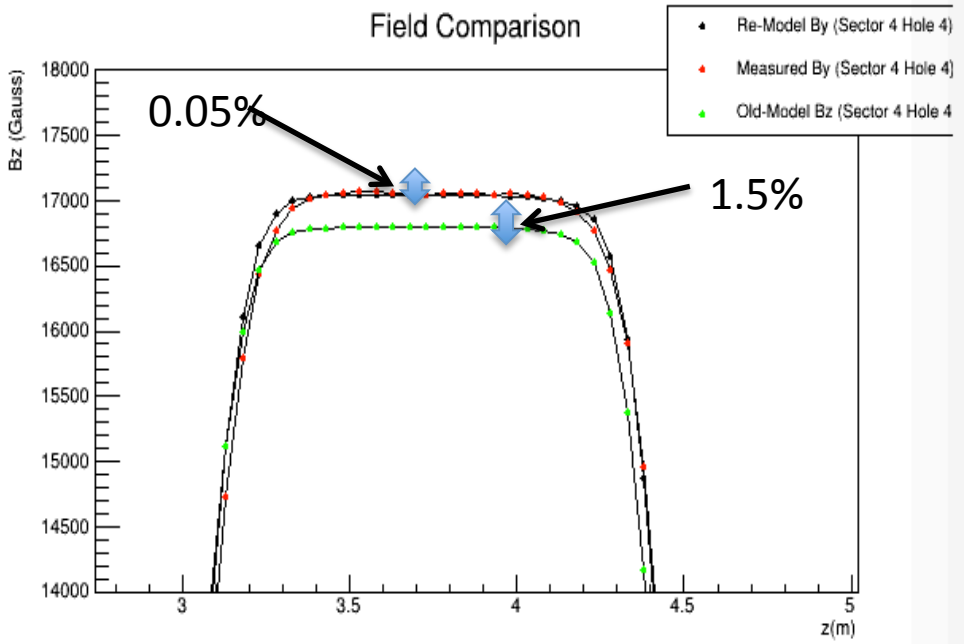


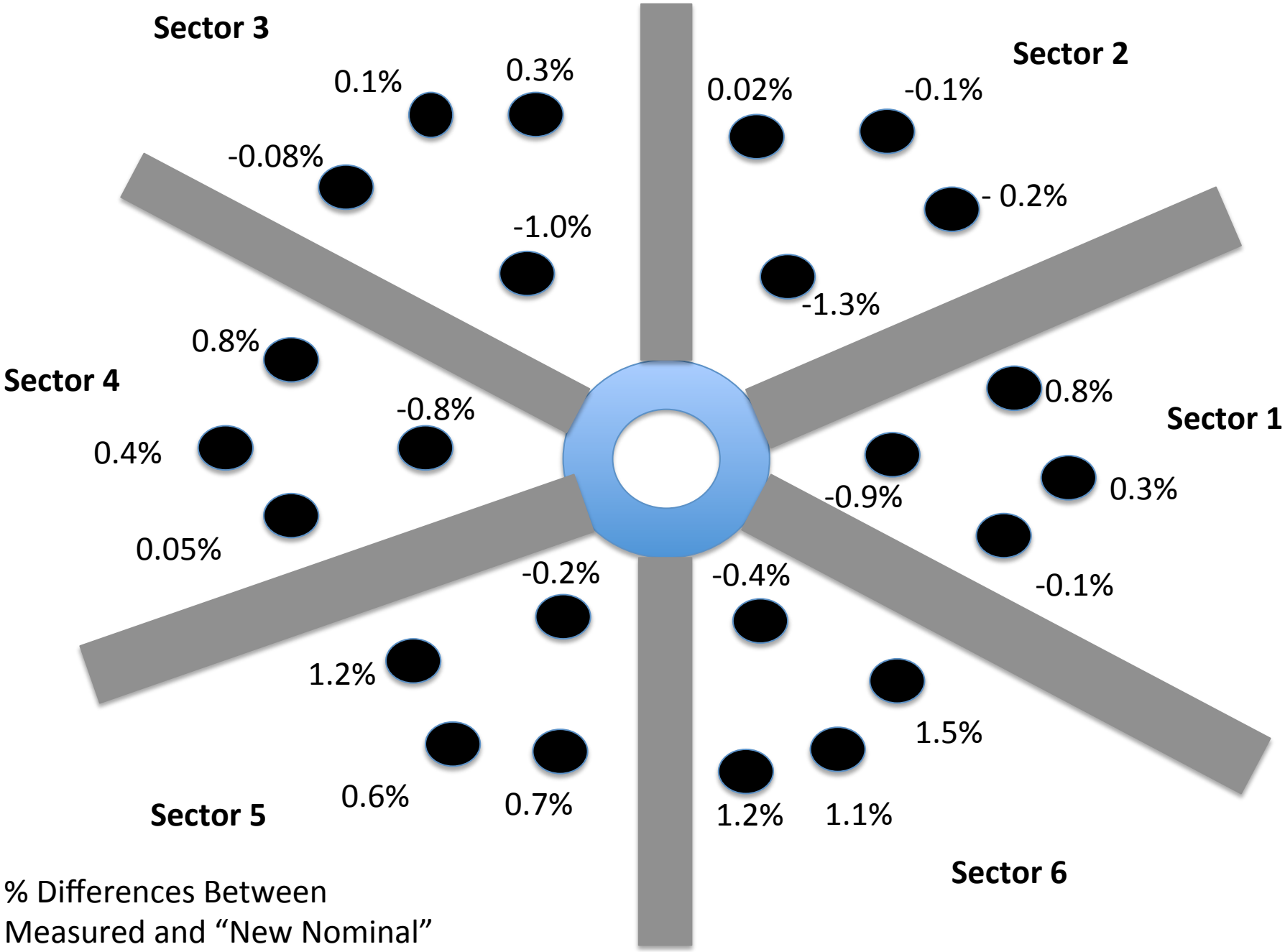
Three Fields: What We Measured, Old Model, and the Better Model







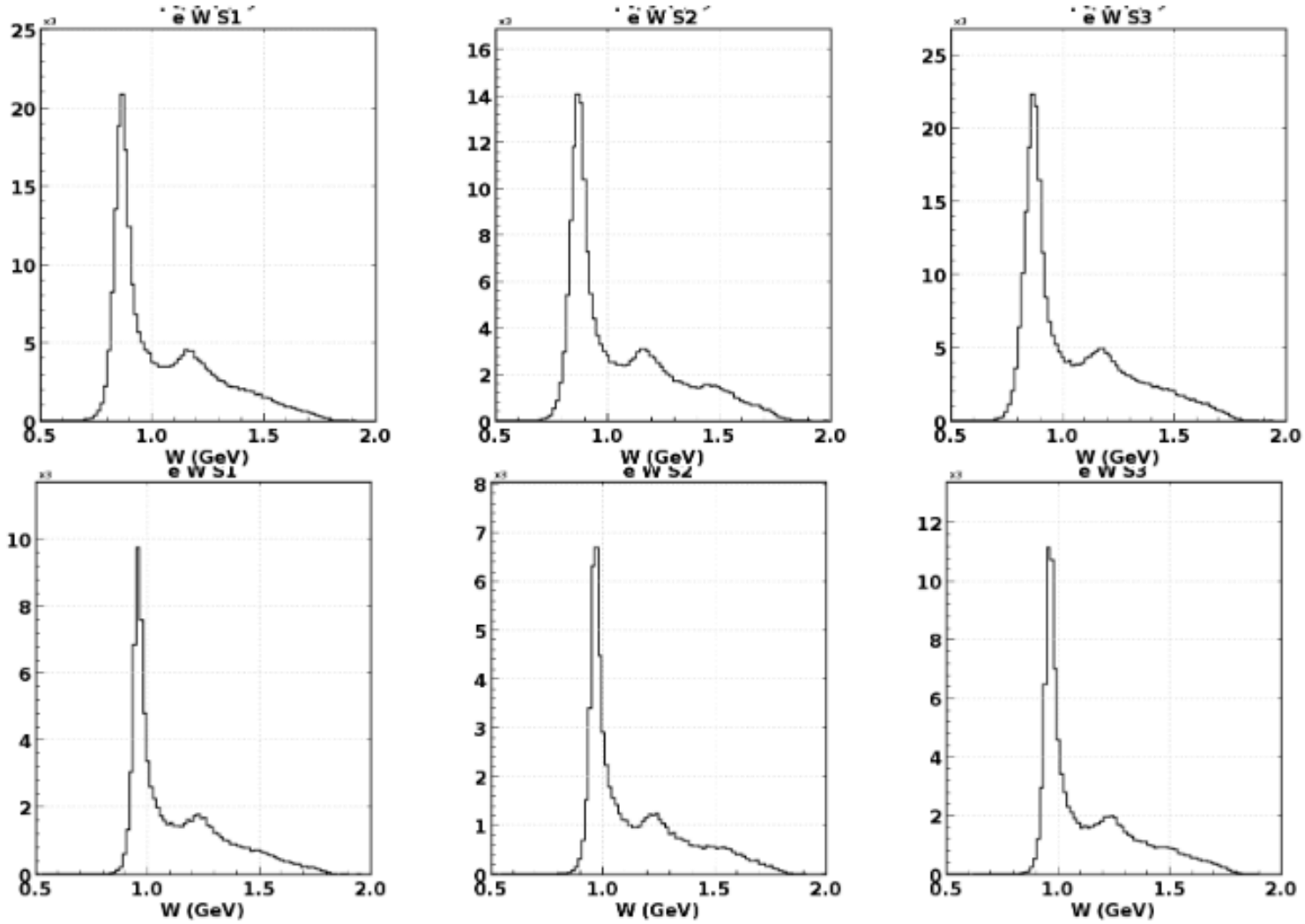




% Differences Between Measured and "New Nominal" Map

New map effect on W spectrum

F.X. Girod



Better momentum resolution

Future Steps For Improved Tracking

- Improve the Torus nominal field map by modifying the Torus coil shape to a design closer to what's in the Hall
- Re-fit the chi-squared function and re-calculate the parameters
- Work needs to be done regarding alignment of the drift chambers to improve tracking precision

Acknowledgements

- Thanks to our project managers: Mac Mestayer and Renuka Rajput-Ghoshal
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- Thanks to our field model producer: Probir Ghoshal
- Thanks for the work on improving Torus coil representation in model: Dave Kashy
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