

Magnetic field calculations for the solenoid and dipole magnets

Guangliang Yang
Glasgow University

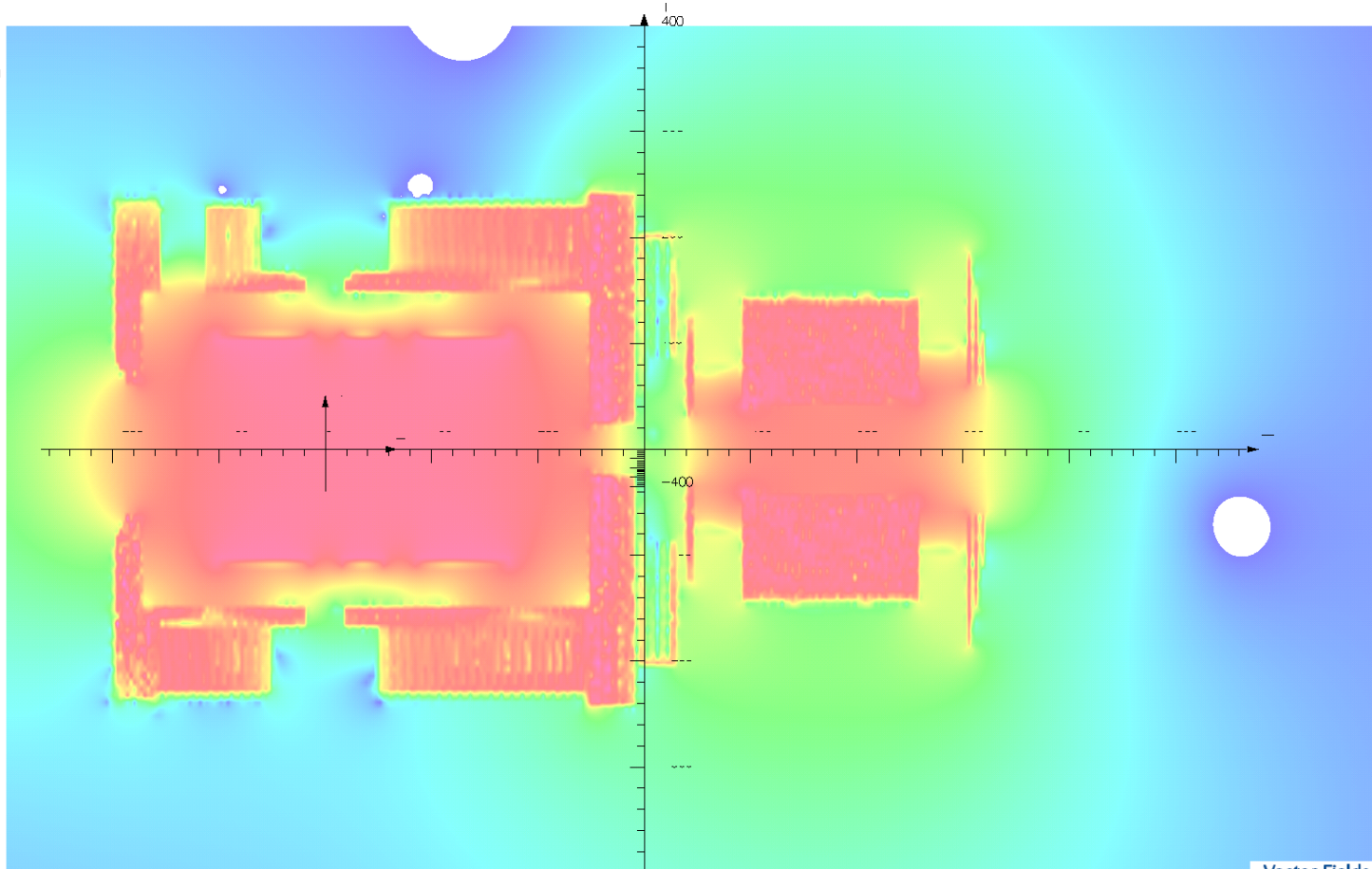
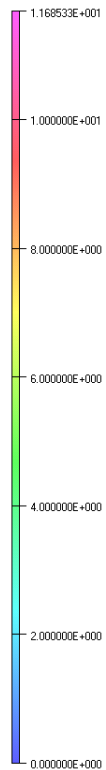
New calculations for the solenoid and the dipole magnets

- New calculations with a large background region: x -35 to 35 m, y -35 to 35 m, z -40 to 40 m.
- Previous calculations with a small background region: x -7 to 7 m, y -7 to 7 m, z -10 to 14 m.
- With a large background, field accuracy at area of interest has been improved.

Outer surface with normal magnetic boundary condition

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Map contours: LOG(BMOD)



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

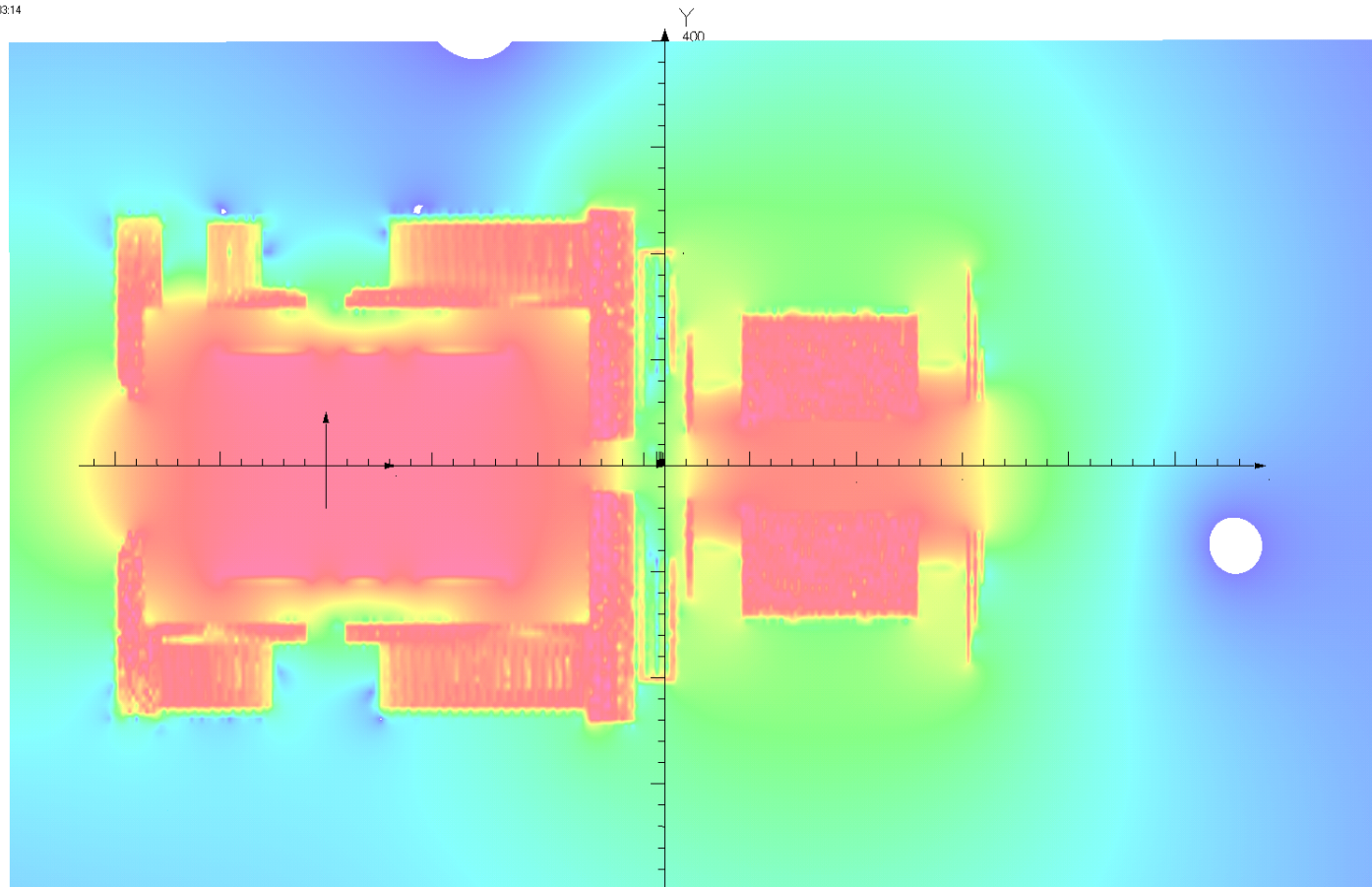
PROBLEM DATA
18022010jostnm.op3
TOSCA Magnetostatic
Nonlinear materials
Simulation No 1 of 1
18810579 elements
6089839 nodes
4 conductors
Fields by integration
Activated in global coordinates
Reflection in YZ plane (X field=0)

Field Point Local Coordinates
Local = Global

FIELD EVALUATIONS
Cartesian CARTESIAN 130x400
(Integral)
x=0.0, y=400.0 to 400.0
1000.0

Outer surface with tangential magnetic boundary condition

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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	
18022010post.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
18810679 elements	
6089839 nodes	
4 conductors	
Fields by integration	
Activated in global coordinates	
Reflection in YZ plane (K field=0)	

Field Point Local Coordinates	
Local = Global	

FIELD EVALUATIONS	
Cartesian	CARTESIAN 130x400 Cartesian
(Integrel)	
x=0.0, y=-400.0 to 400.0, z=-300.0 to 1000.0	

3D MULTIPOLE EXPANSION

- Motivation: help to reduce the amount of work related to field mapping.
- Theory: refer to PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 9, 012401 (2006).
- How? Using the field data on a cylindrical surface to recover 3D field inside the volume.

The field components in cylindrical coordinates

$$B_r = \sum_{m=0}^{\infty} \sum_{\ell=0}^{\infty} (-1)^\ell \frac{m!(2\ell + m)}{2^{2\ell} \ell! (\ell + m)!} \times C_{m,\alpha}^{[2\ell]}(z) r^{2\ell+m-1} \begin{Bmatrix} \sin(m\theta) \\ \cos(m\theta) \end{Bmatrix},$$

$$B_\theta = \sum_{m=0}^{\infty} \sum_{\ell=0}^{\infty} (-1)^\ell \frac{m!m}{2^{2\ell} \ell! (\ell + m)!} \times C_{m,\alpha}^{[2\ell]}(z) r^{2\ell+m-1} \begin{Bmatrix} \cos(m\theta) \\ -\sin(m\theta) \end{Bmatrix},$$

$$B_z = \sum_{m=0}^{\infty} \sum_{\ell=0}^{\infty} (-1)^\ell \frac{m!}{2^{2\ell} \ell! (\ell + m)!} \times C_{m,\alpha}^{[2\ell+1]}(z) r^{2\ell+m} \begin{Bmatrix} \sin(m\theta) \\ \cos(m\theta) \end{Bmatrix}.$$

Where the generalized gradient $C_{m,\alpha}(z)$ can be calculated by

$$C_{m,s}(z) = \frac{1}{2^m m!} \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} dk \exp(ikz) \frac{k^{m-1}}{I_m'(kR)} \tilde{\mathcal{B}}_m(R, k),$$

$$C_{m,c}(z) = \frac{1}{2^m m!} \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} dk \exp(ikz) \frac{k^{m-1}}{I_m'(kR)} \tilde{\mathcal{A}}_m(R, k),$$

Here $\tilde{\mathcal{B}}_m(R, k)$ and $\tilde{\mathcal{A}}_m(R, k)$ are the Fourier transforms of $\mathcal{B}_m(R, z)$ and $\mathcal{A}_m(R, z)$

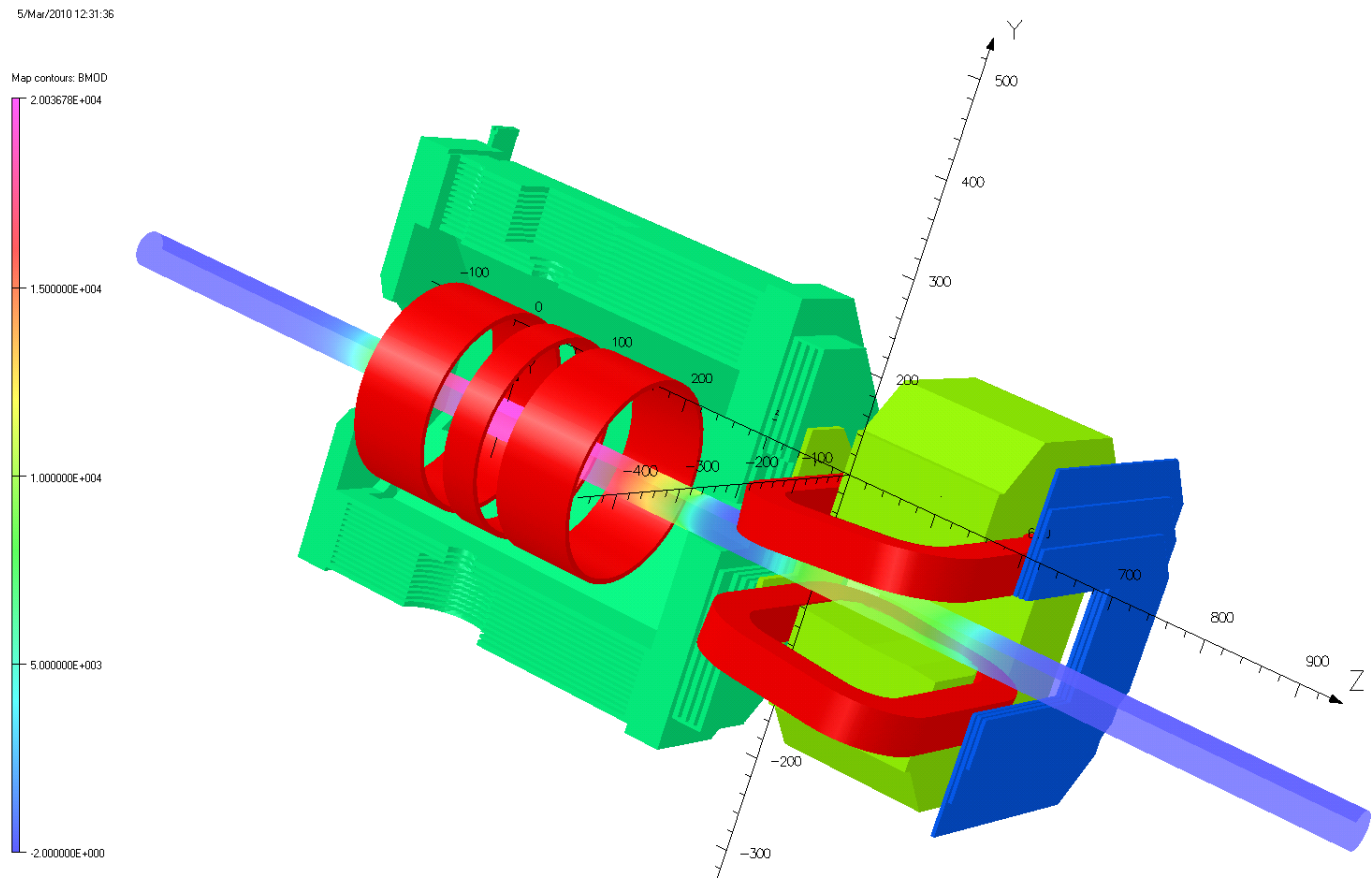
$$\tilde{\mathcal{B}}_m(R, k) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} dz \exp(-ikz) \mathcal{B}_m(R, z),$$

$$\tilde{\mathcal{A}}_m(R, k) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} dz \exp(-ikz) \mathcal{A}_m(R, z).$$

where $\mathcal{B}_m(R, z)$ and $\mathcal{A}_m(R, z)$ are the amplitudes of the normal and skew components of $B_r(R, \theta, z)$ harmonics of order m .

$$B_r(R, \theta, z) = \sum_{m=0}^{\infty} \mathcal{B}_m(R, z) \sin(m\theta) + \mathcal{A}_m(R, z) \cos(m\theta),$$

Magnetic field on a cylindrical surface



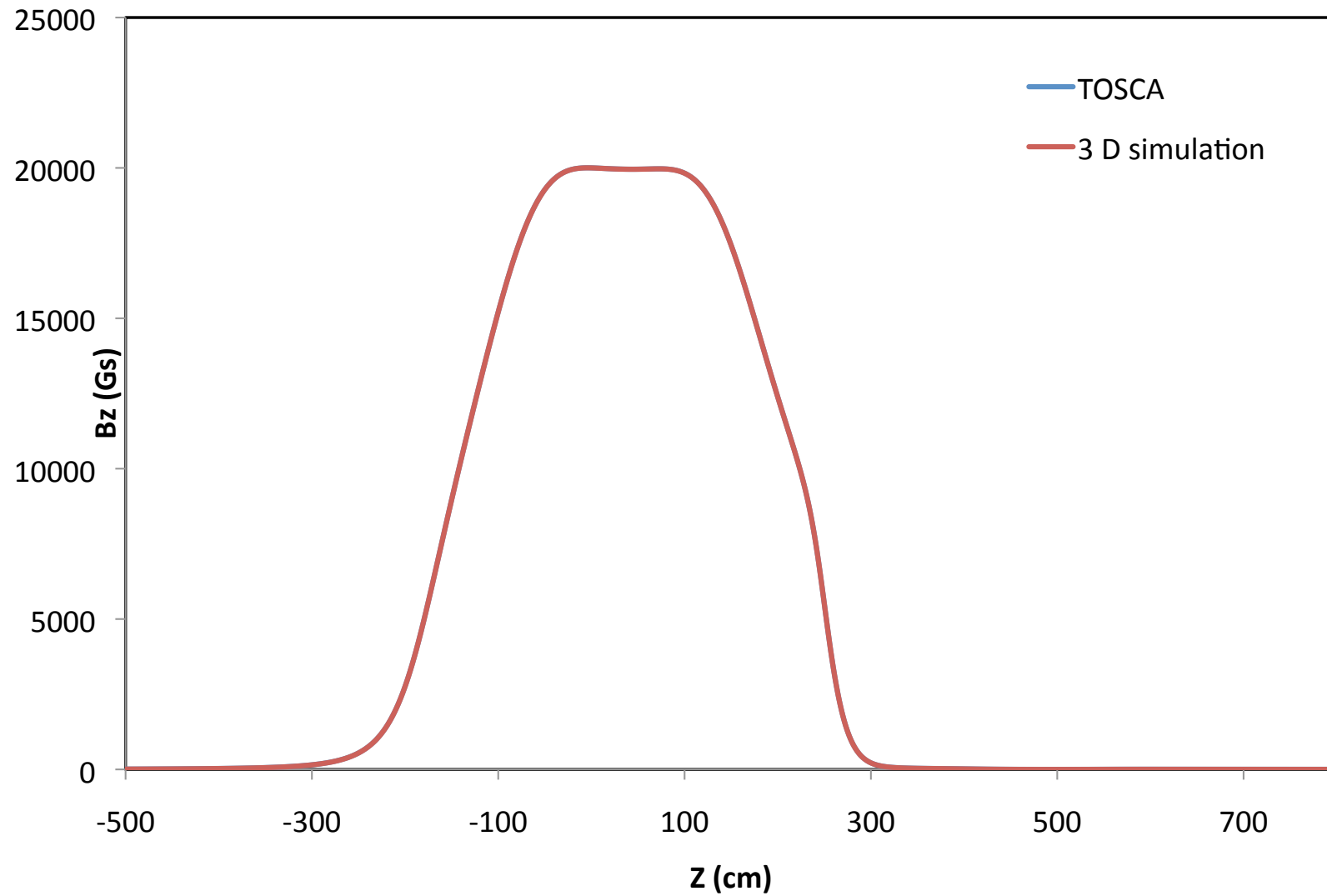
UNITS	
Length	cm
Magn Flux	gaus
Density	
Magn Field	oerst
Magn Scalar	oerst
Pot	cm
Magn Vector	gaus
Pot	cm
Elec Flux	C/cm
Density	
Elec Field	V/cm
Conductivity	S/cm
Current	A/cm
Density	
Power	W
Force	N
Energy	J
Mass	g

PROBLEM	
DATA	
18022010post.op3	
TDS/CA	
Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
18810679 elements	
6089839 nodes	
4 conductors	
Nodally interpolated fields	
Activated in global coordinates	
Reflection in YZ plane (X field=0)	

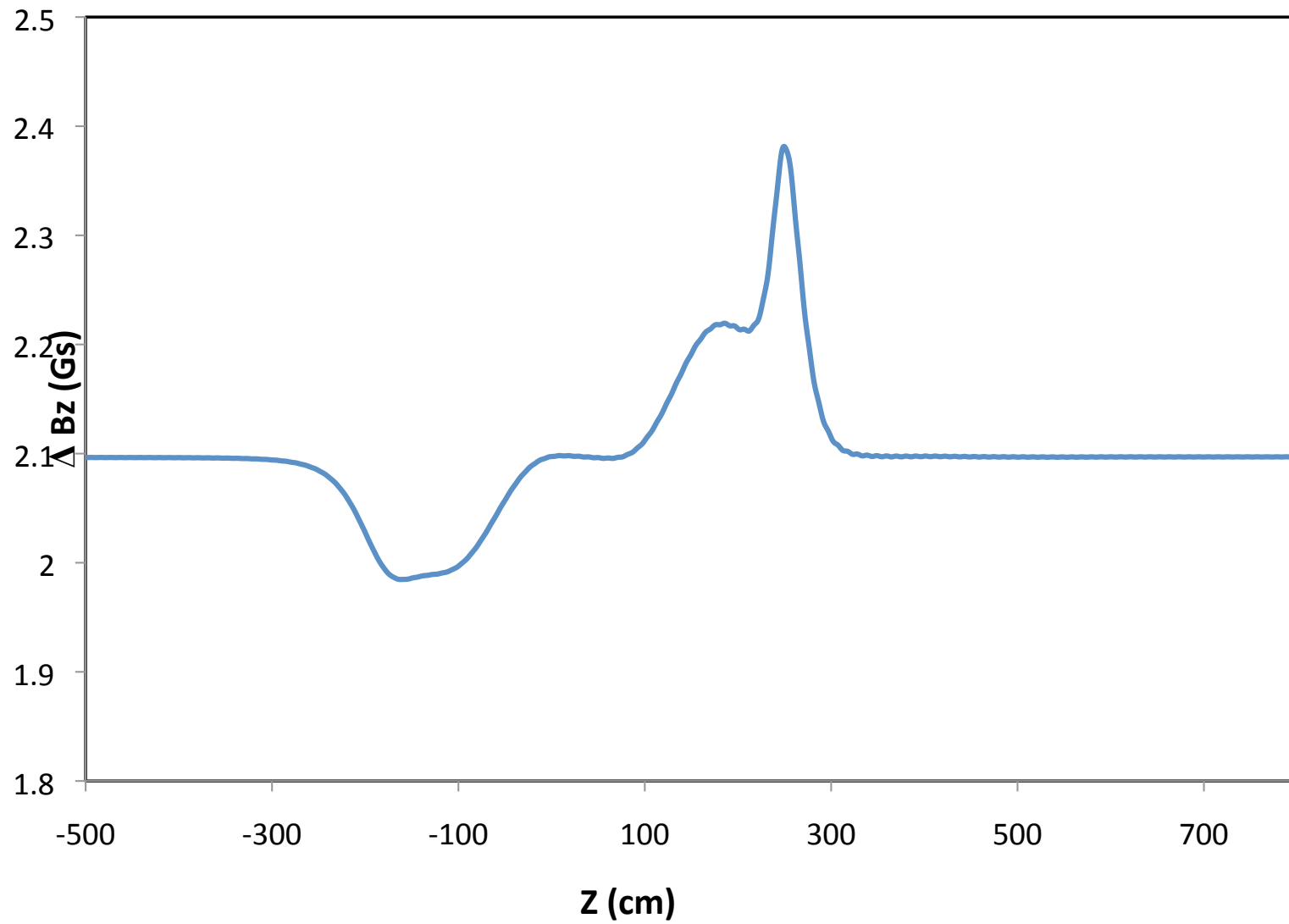
Field Point Local Coordinates	
Local = Global	

FIELD EVALUATIONS	
Polar	POLAR 2
(nodal)	
r=20.0, e=0	
to 500.0	

Bz on the z axis



Difference in B_z between multipole expansion and TOSCA simulation data



Conclusion and outlook

- It is possible to calculate the 3D field multiple extension from the field data on a cylindrical surface.
- If this method is not sensitive to the error raw field data on the cylindrical surface, then it can be used to help the field mapping.
- Further work need to be done, to verify how the error of raw field data will affect the calculated 3 D field.