



Simulation, the Magnetic Spectrometer of the MINERvA Experiment

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MINERvA Test Beam Line

The Cuprum target

The collimator select the charge particles produced to 16°

Four wire chambers and two dipole magnets provide momentum reconstruction

Beamline components ToF, WC, and Halo Vetos combined into DAQ hardware trigger to select relevant events

MINERvA Test Beam detector consists of 40 mini-planes (63 strips instead of 127) 1.1 x 1.1m

Dipole Magnets Features

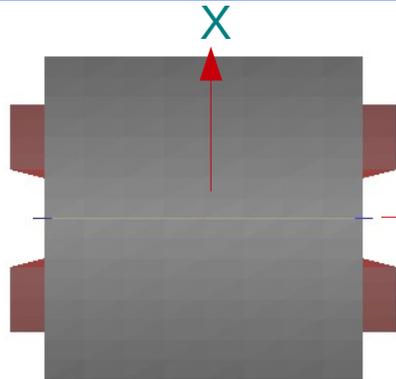


- 2 Identical Magnets.
- 200 turns by coil.
- 100 Amperes.
- 133.8 °C.

- Laminated core of “Fe”.
- Weight 1700 pounds.
- The Magnetic field measured in the center; 3379.80 Gauss.



Dipole Magnets Measured

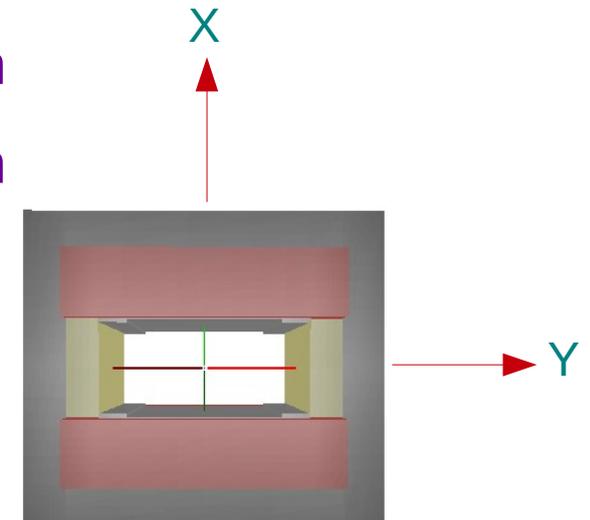


Lateral View (Z Axis)

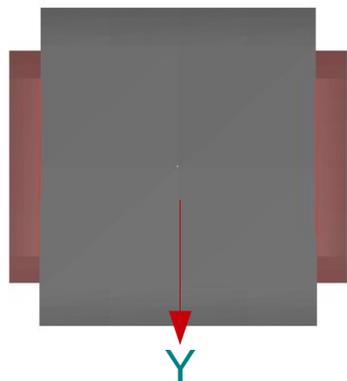
- Core; 46.274 cm
- Inner Coil; 48.814 cm
- Outer Coil; 58.974 cm

Frontal View (X Axis)

- Separation coils; 15.006 cm
- Core; 47.467 cm



Upper View (Y Axis)



- Core; 56.610 cm
- Outer Coil; 41.910 cm
- Inner Coil; 31.750 cm

Goals

- Simulate from first principles the 3D magnetic field of the two dipole magnets of the Minerva Experiment.
- Analyze the 2D simulations made by the Test Beam Group.
- Analyze the magnetic field measurements of the dipole magnets.
- Compare my simulation results with previous simulations and measurements.

The Induction Magnetic Field

The Induction Magnetic field to Electromagnet is give by;

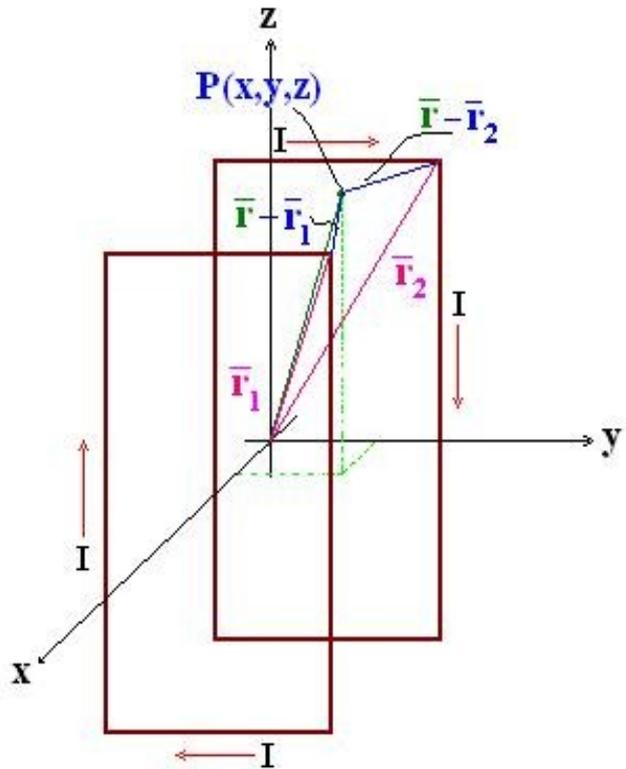
$$\vec{B}(\vec{r}) = \frac{\mu_{air}}{4\pi} N I \oint \vec{dl} \times \frac{(\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|^3} + \frac{\mu_{air}}{4\pi} \iint [\vec{M}(\vec{r}') \cdot \hat{n}] \frac{(\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|^3} da' - \frac{\mu_{air}}{4\pi} \iiint [\nabla' \cdot \vec{M}(\vec{r}')] \frac{(\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|^3} dv' + \mu_{air} \vec{M}(\vec{r}')$$

Where

- 1st Term; Coils contribution.
- 2nd Term; Surface of core contribution.
- 3rd Term; Volumetrical core contribution.
- 4th Term; Magnetization contribution.

Dipole Magnets Simulation

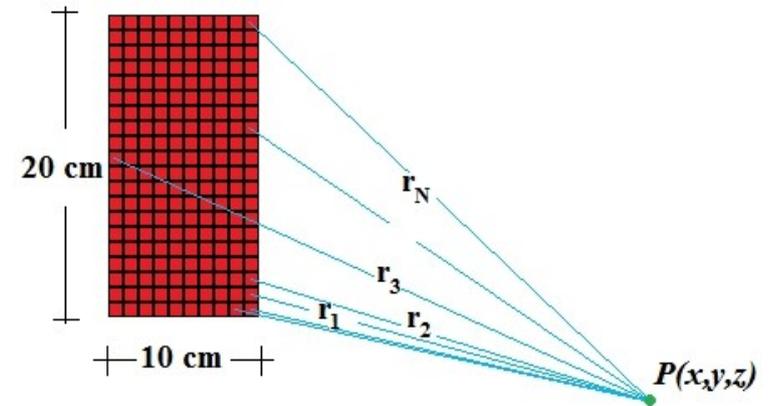
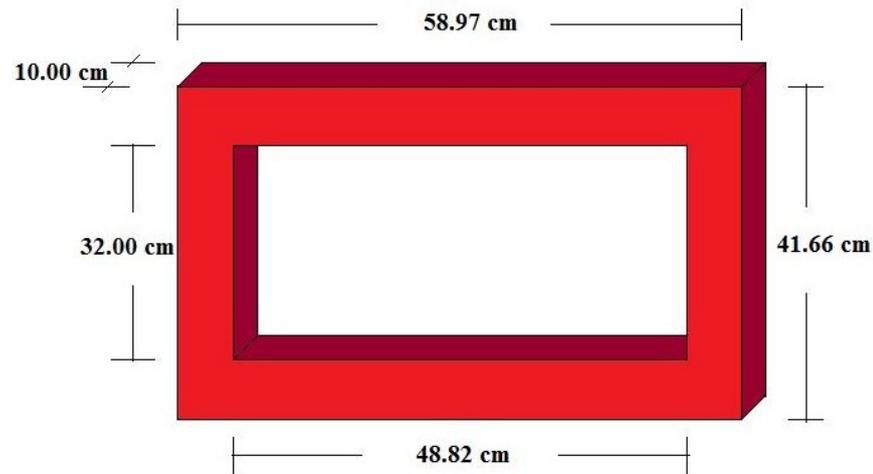
Coils Building



- ◆ The corners of the coils are right angle.
- ◆ Superpose of the straight wire.
- ◆ Apply the Biot-Savart Law each straight wire.
 - ◆
$$\vec{B}(\vec{r}) = \frac{\mu}{4\pi} I \oint_{I_1} \frac{d\vec{l} \times (\vec{r} - \vec{r}_1)}{|\vec{r} - \vec{r}_1|^3}$$
 - ◆
$$\vec{B}(\vec{r}) = \frac{\mu}{4\pi} I \oint_{I_2} \frac{d\vec{l} \times (\vec{r} - \vec{r}_2)}{|\vec{r} - \vec{r}_2|^3}$$
- ◆ Add the Induction Magnetic field for each straight wire.
- ◆ The magnetic Permeability for Copper: -9.7E-6 Tm/A.

Dipole Magnets Simulation

Coils Considerations

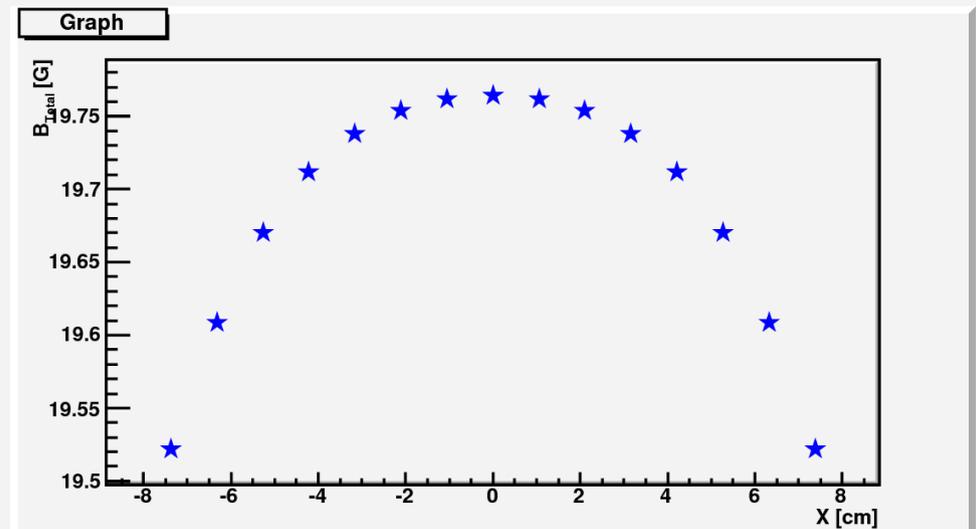
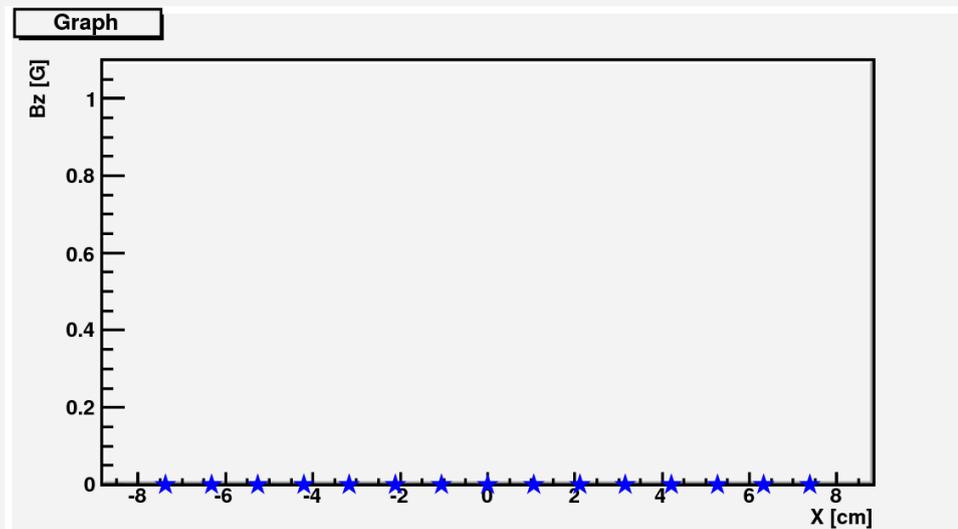
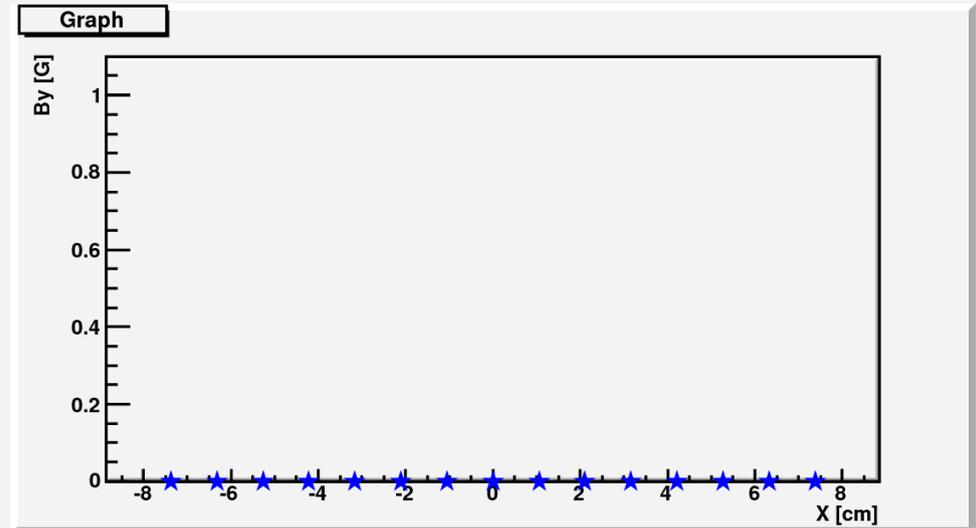
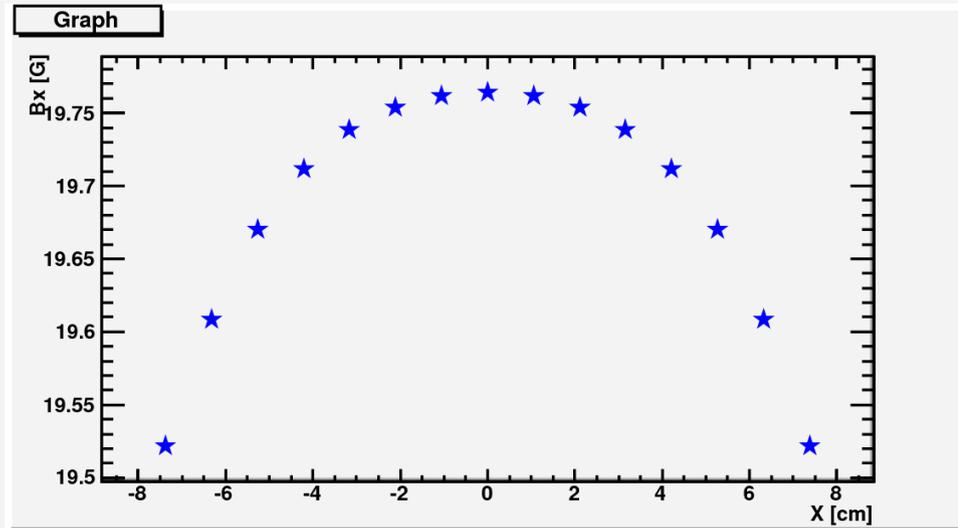


$$\vec{B}(\vec{r}) = \frac{\mu}{4\pi} I \oint_{l_1} \frac{d\vec{l} \times (\vec{r} - \vec{r}_1)}{|\vec{r} - \vec{r}_1|^3}$$

$$\vec{B}(\vec{r}) = \frac{\mu}{4\pi} I \oint_{l_2} \frac{d\vec{l} \times (\vec{r} - \vec{r}_2)}{|\vec{r} - \vec{r}_2|^3}$$

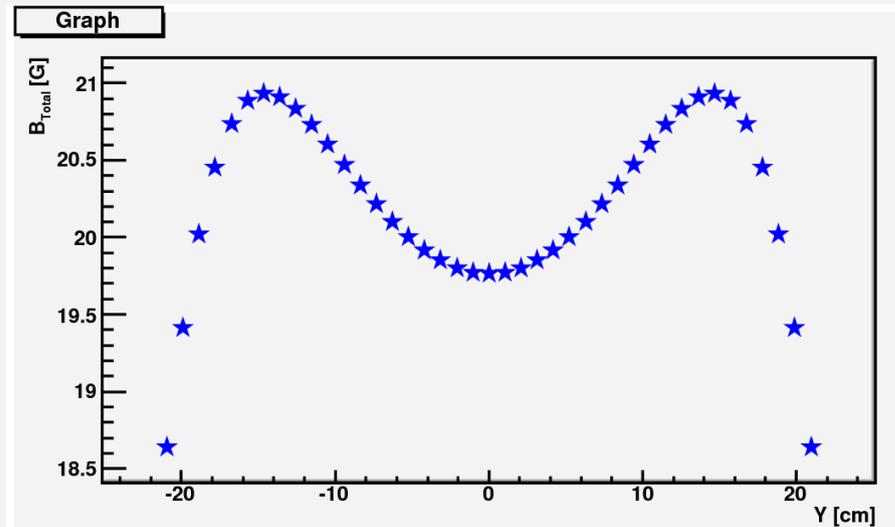
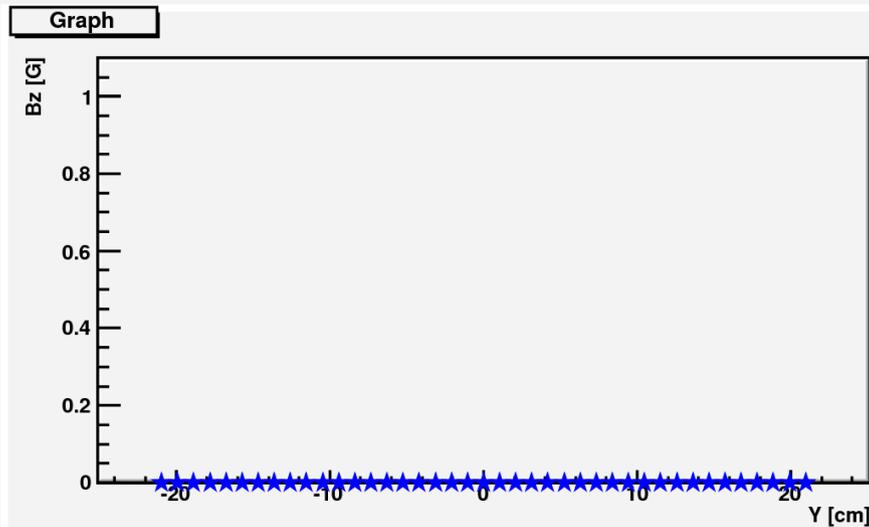
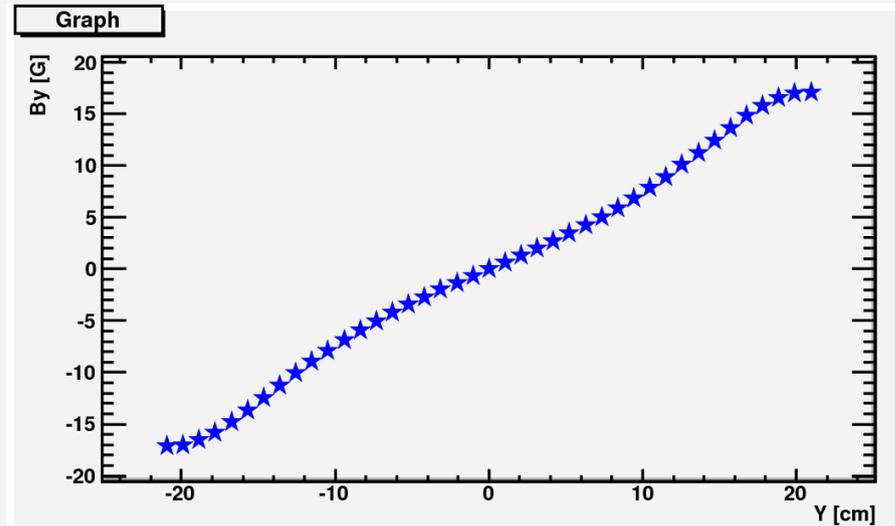
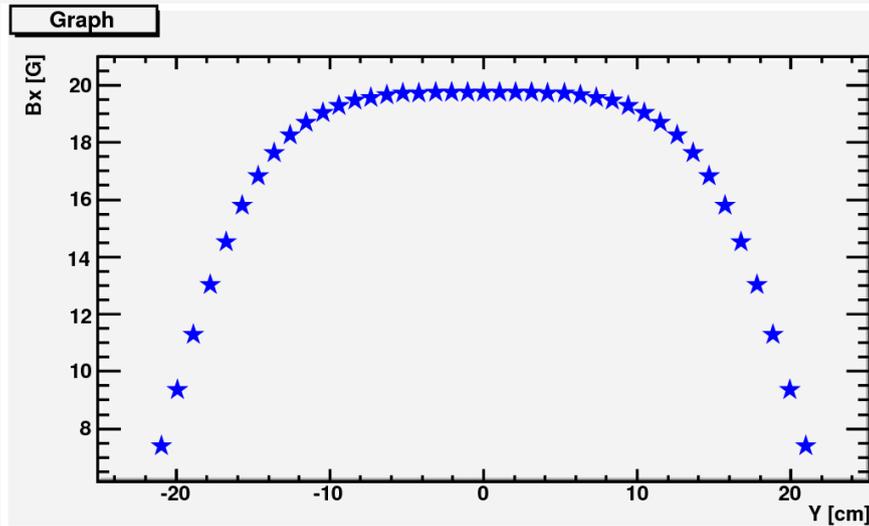
Coils Contribution

Magnetic Field Along to X Axis



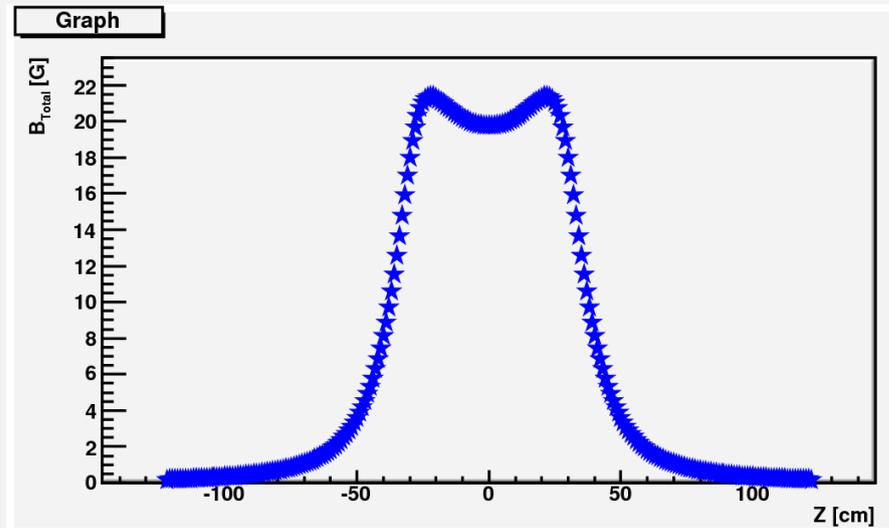
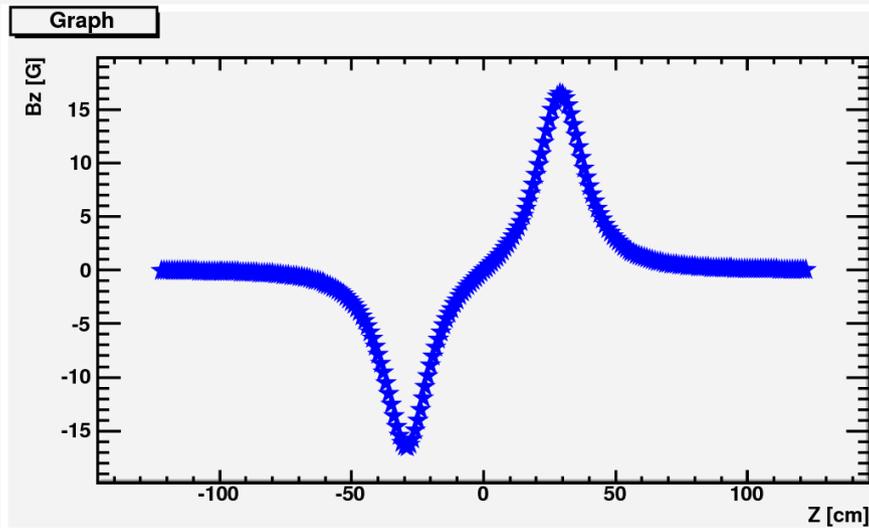
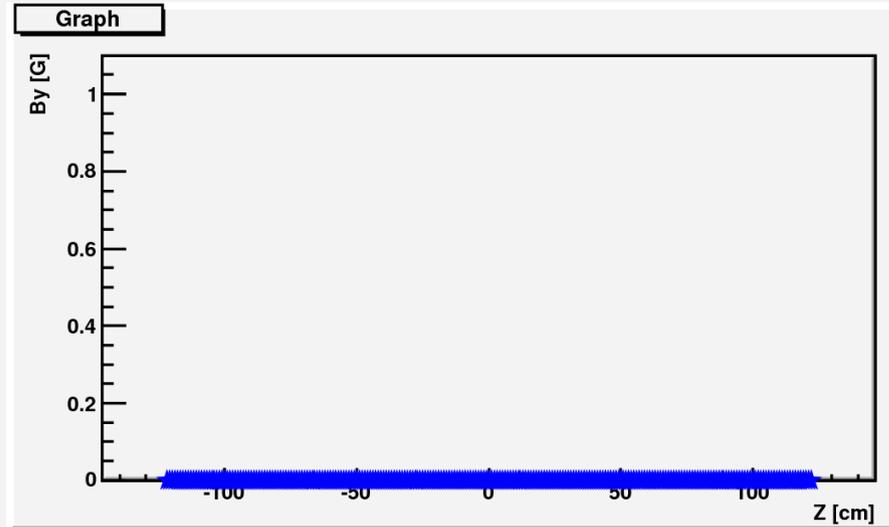
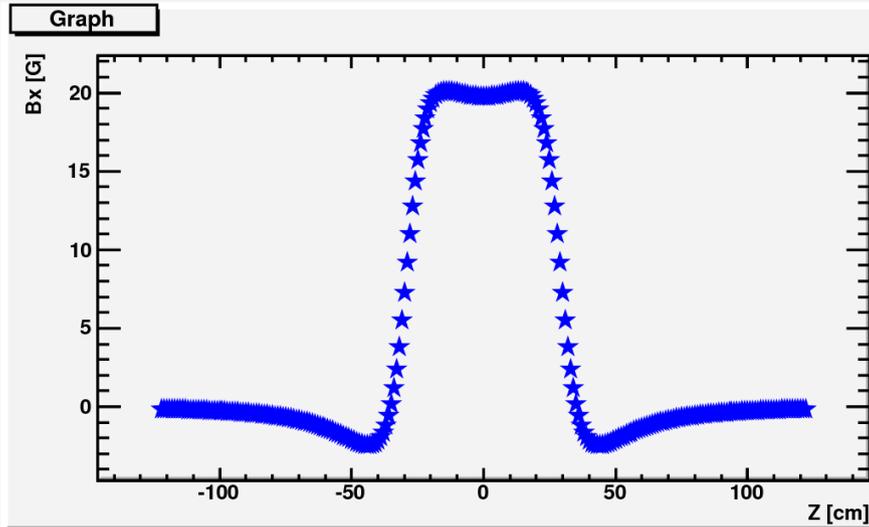
Coils Contribution

Magnetic Field Along to Y Axis



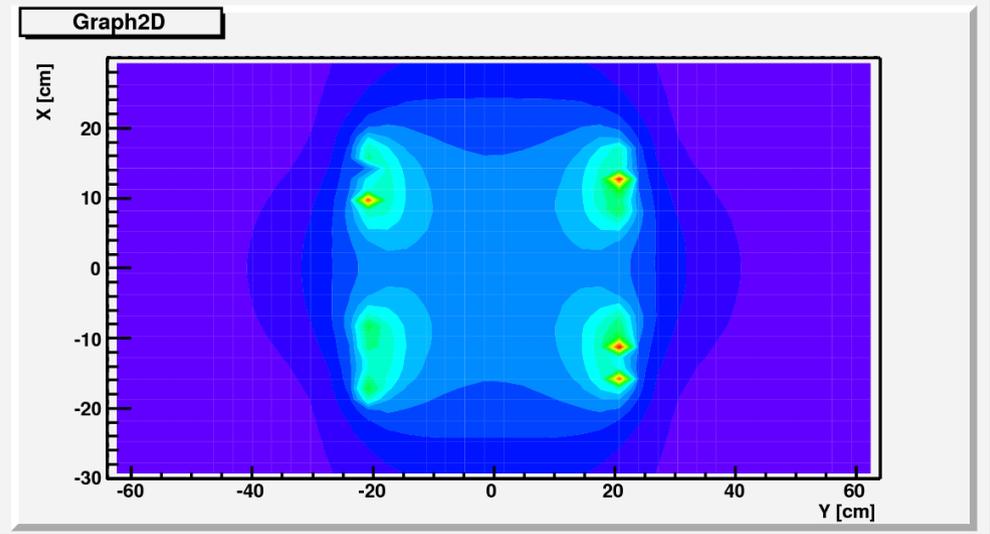
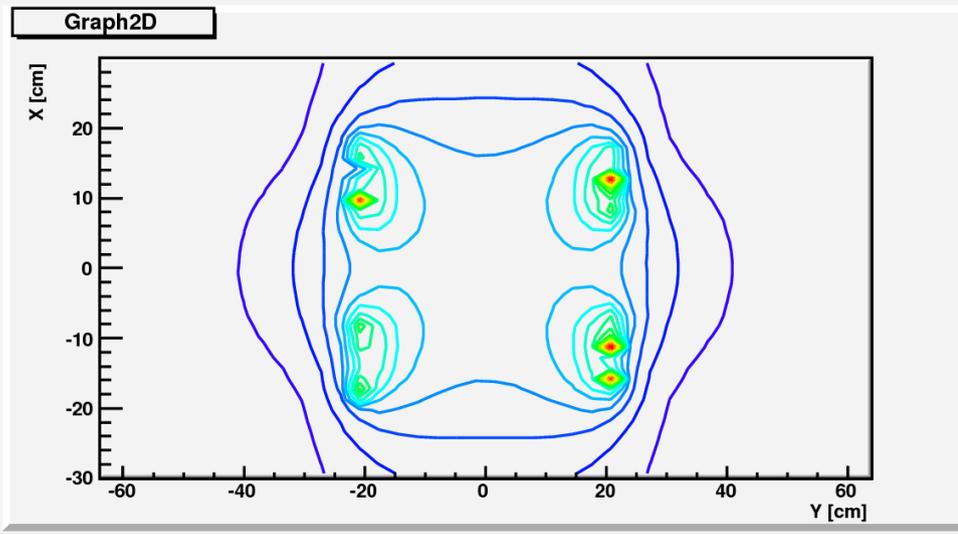
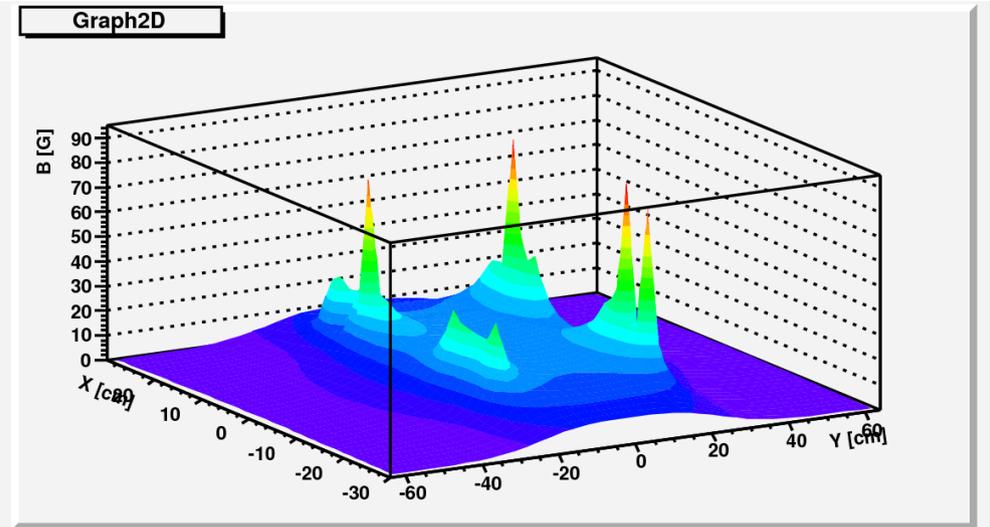
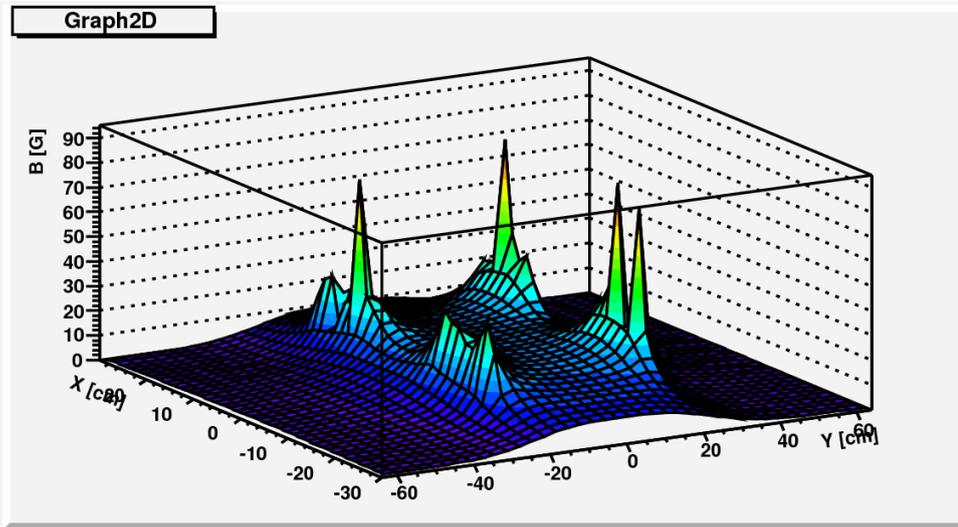
Coils Contribution

Magnetic Field Along to Z Axis



Coils Contribution

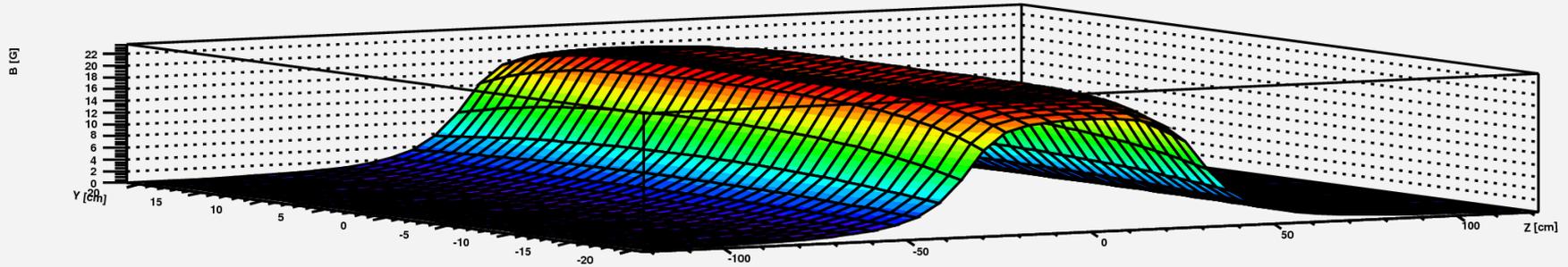
Magnitude of Magnetic Field on XY Plane



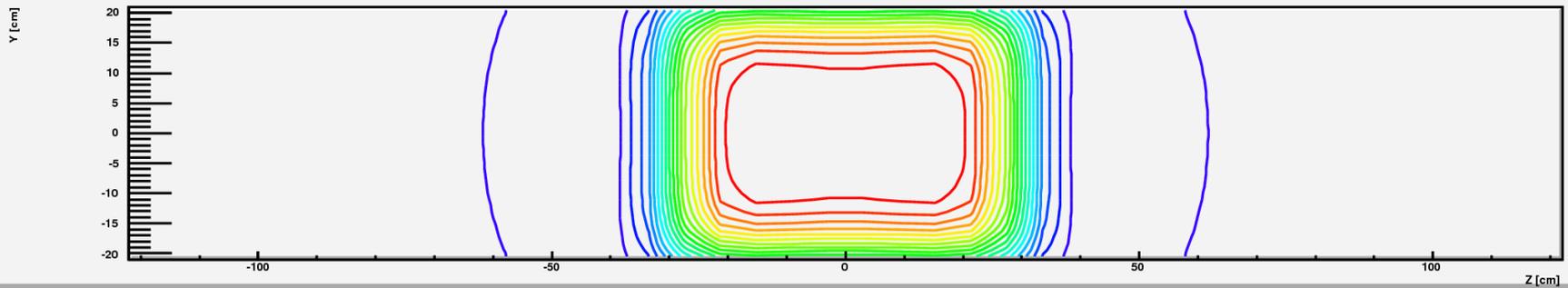
Coils Contribution

Bx Component on YZ Plane

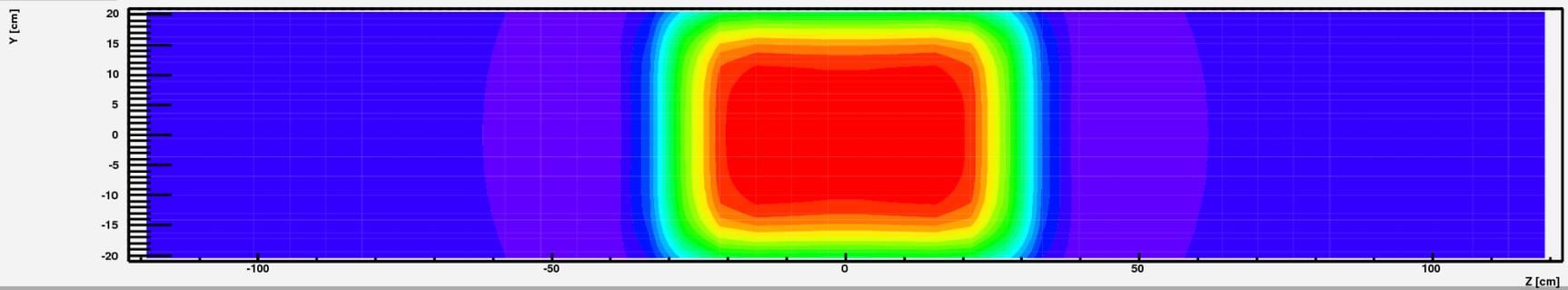
Graph2D



Graph2D

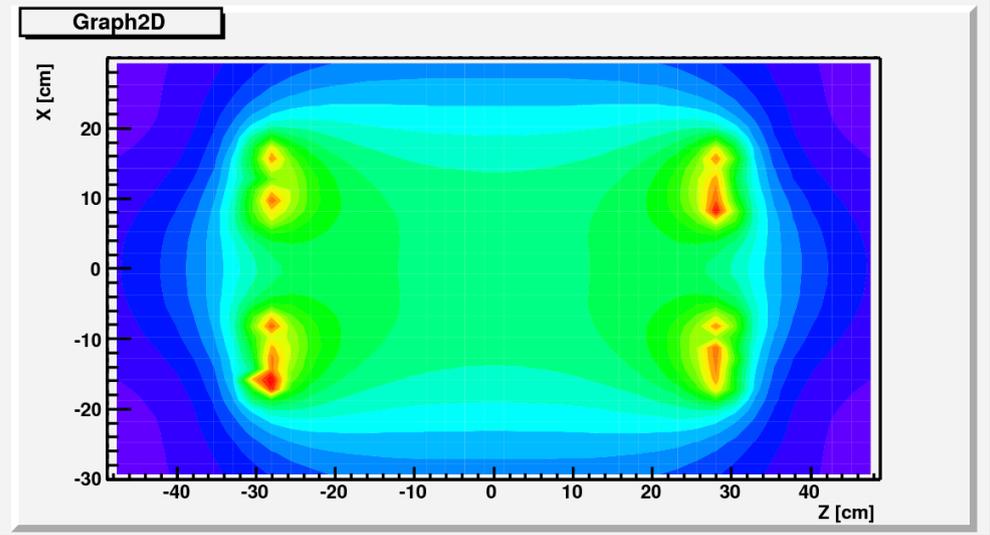
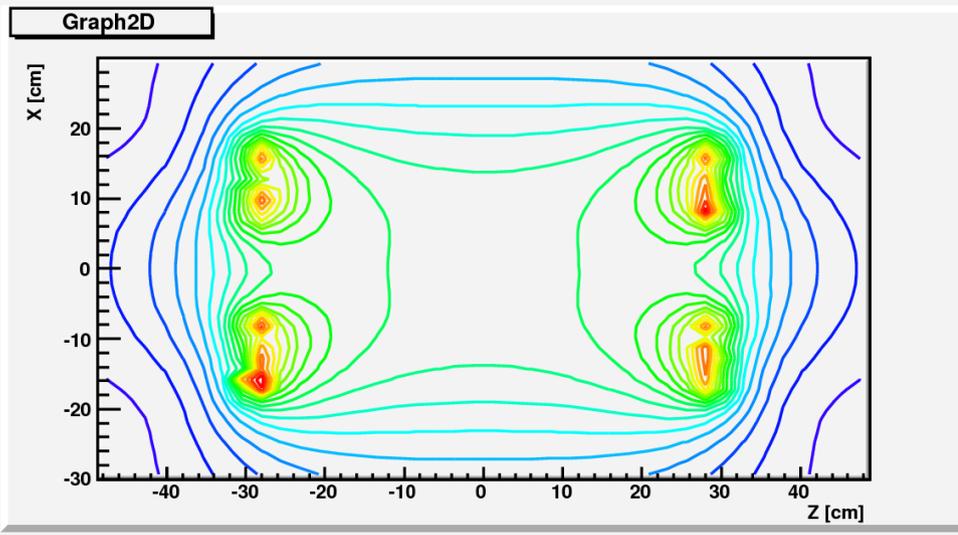
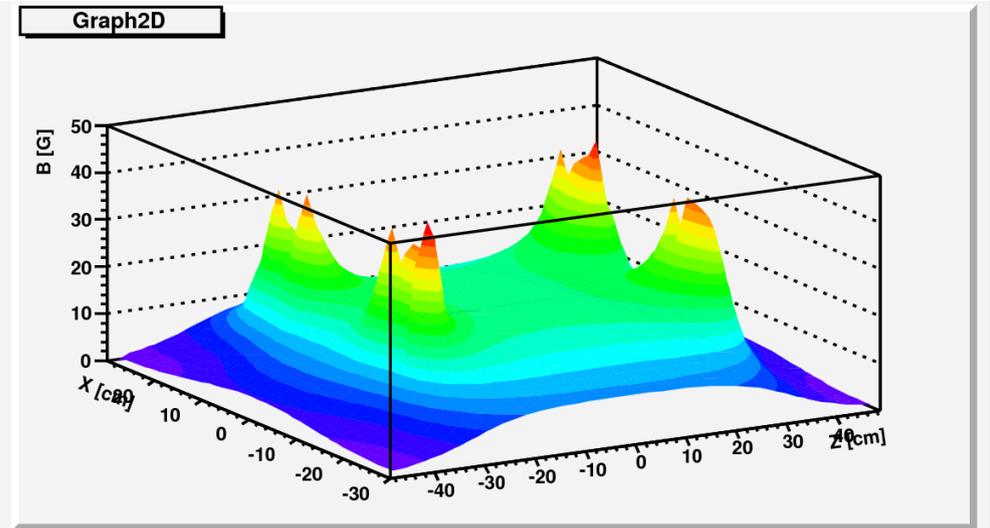
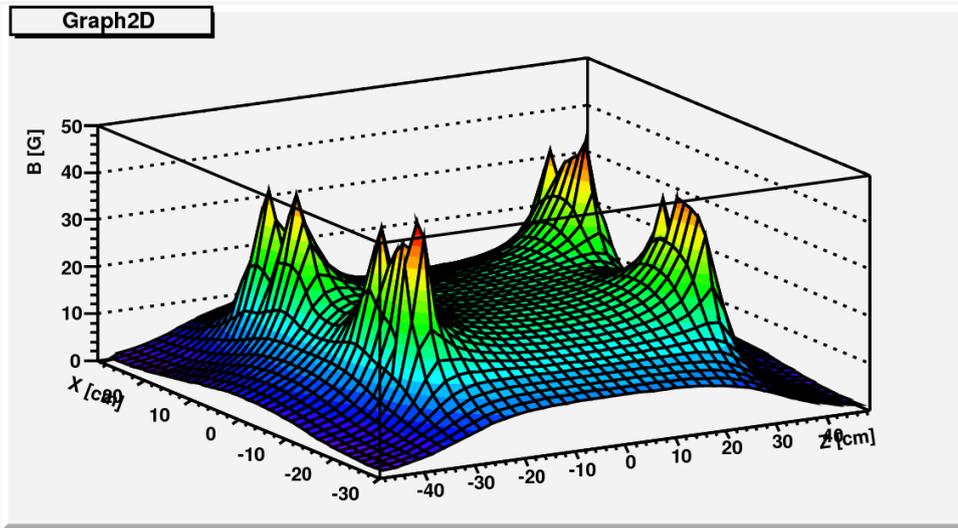


Graph2D



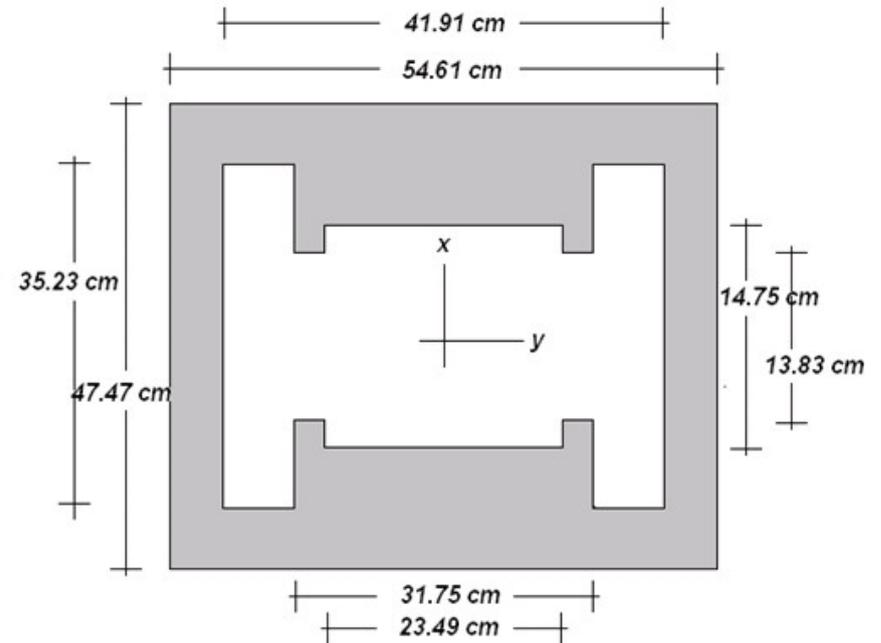
Coils Contribution

Magnitude of Magnetic Field on XZ Plane



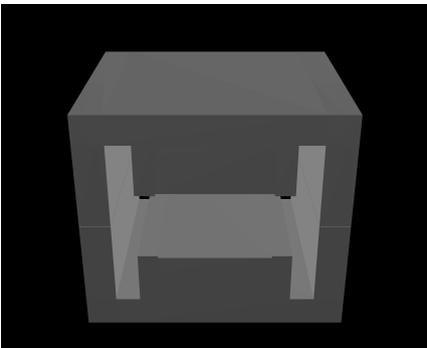
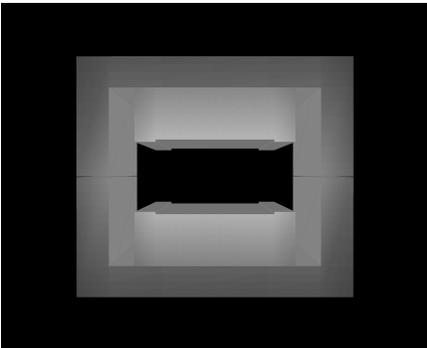
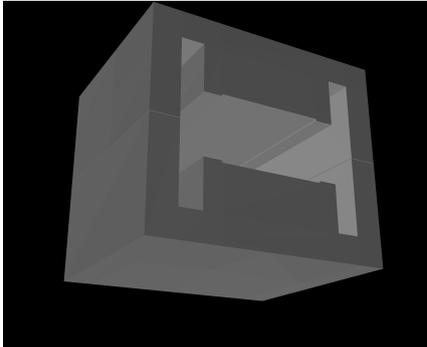
Dipole Magnets Simulation

Geometrical Dimensions



Dipole Magnets Simulation

Iron Core



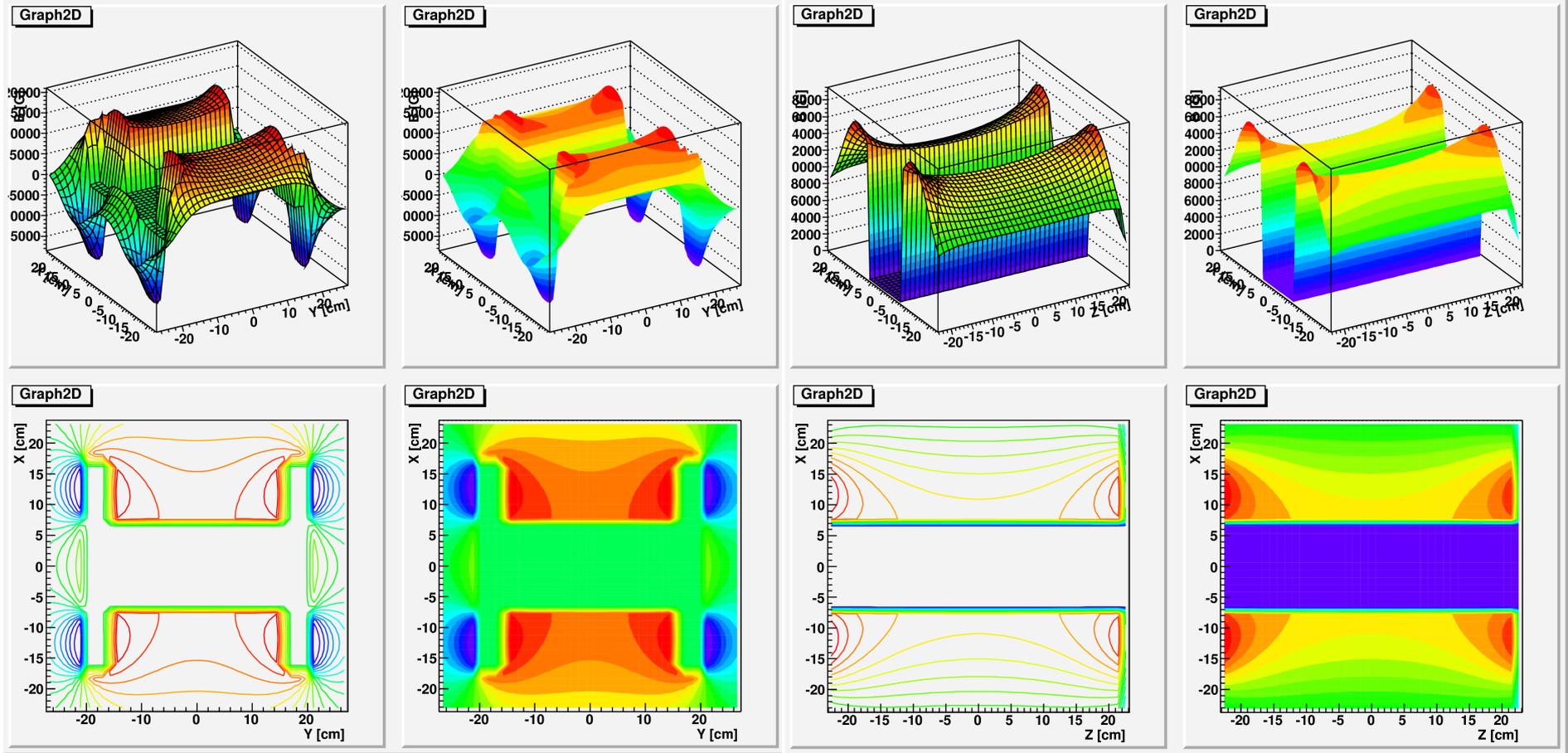
- ◆ The corners are in right angle.
- ◆ Homogeneous and Isotropic.
- ◆ Linear relation between Induction Magnetic Field and Magnetization.

$$\vec{M} = \left(\frac{\mu_{Core} - \mu_{air}}{\mu_{Core} \mu_{air}} \right) \vec{B}$$

- ◆ The magnetic Permeability for core material is unknown.
- ◆ I am Supposing the magnetic permeability its some times of the air.

Magnetization of the Iron Core

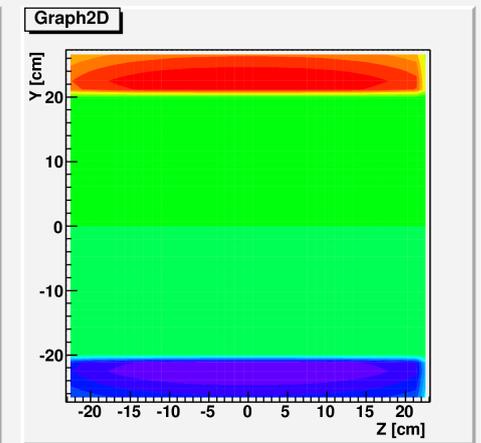
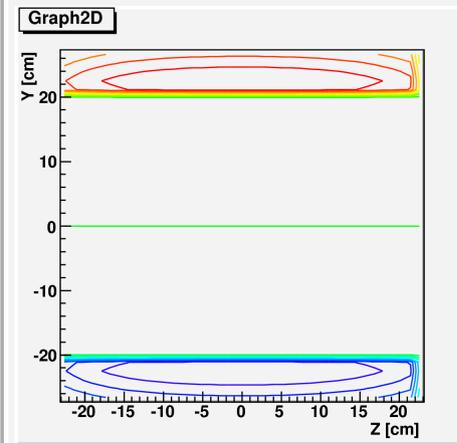
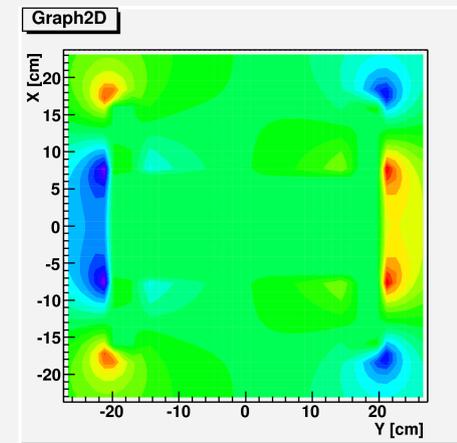
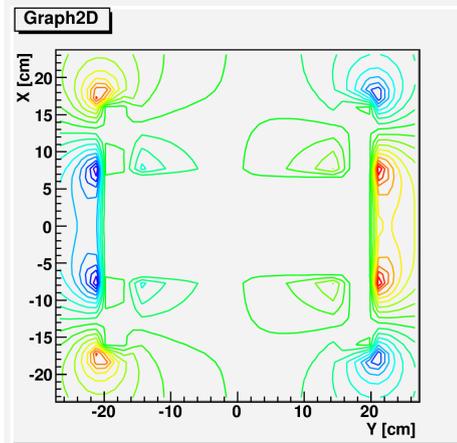
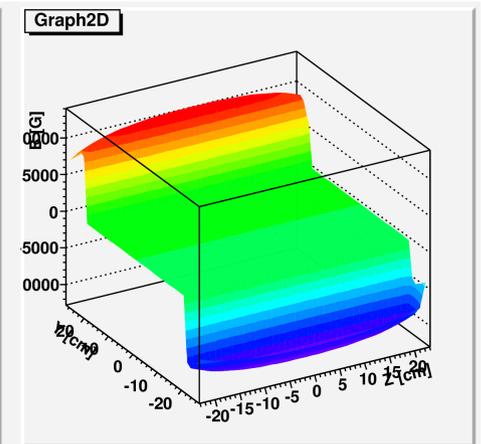
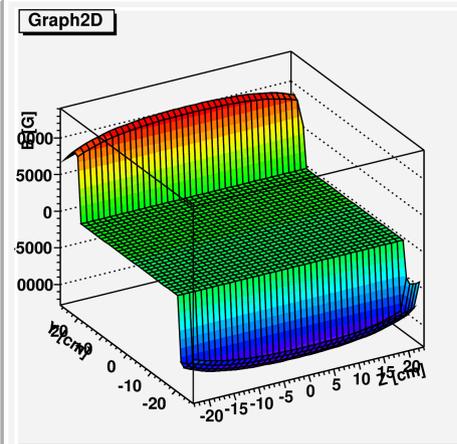
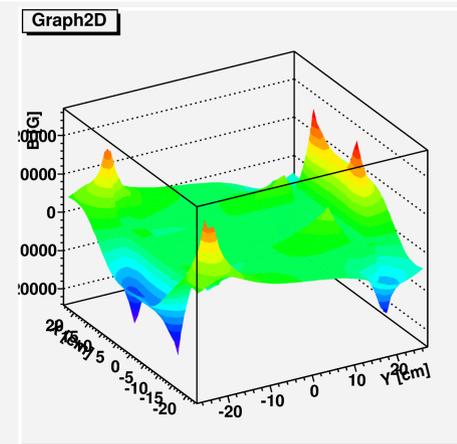
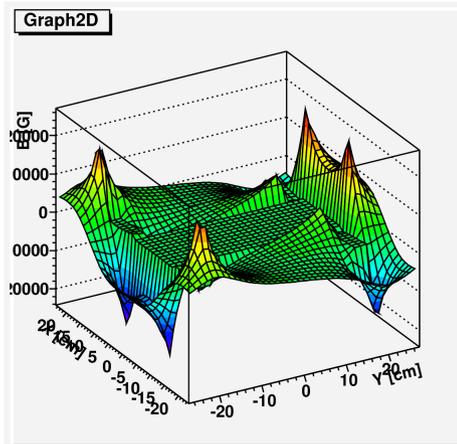
Bx Component



Plane XY

Plane XZ

Magnetization of the Iron Core By Component

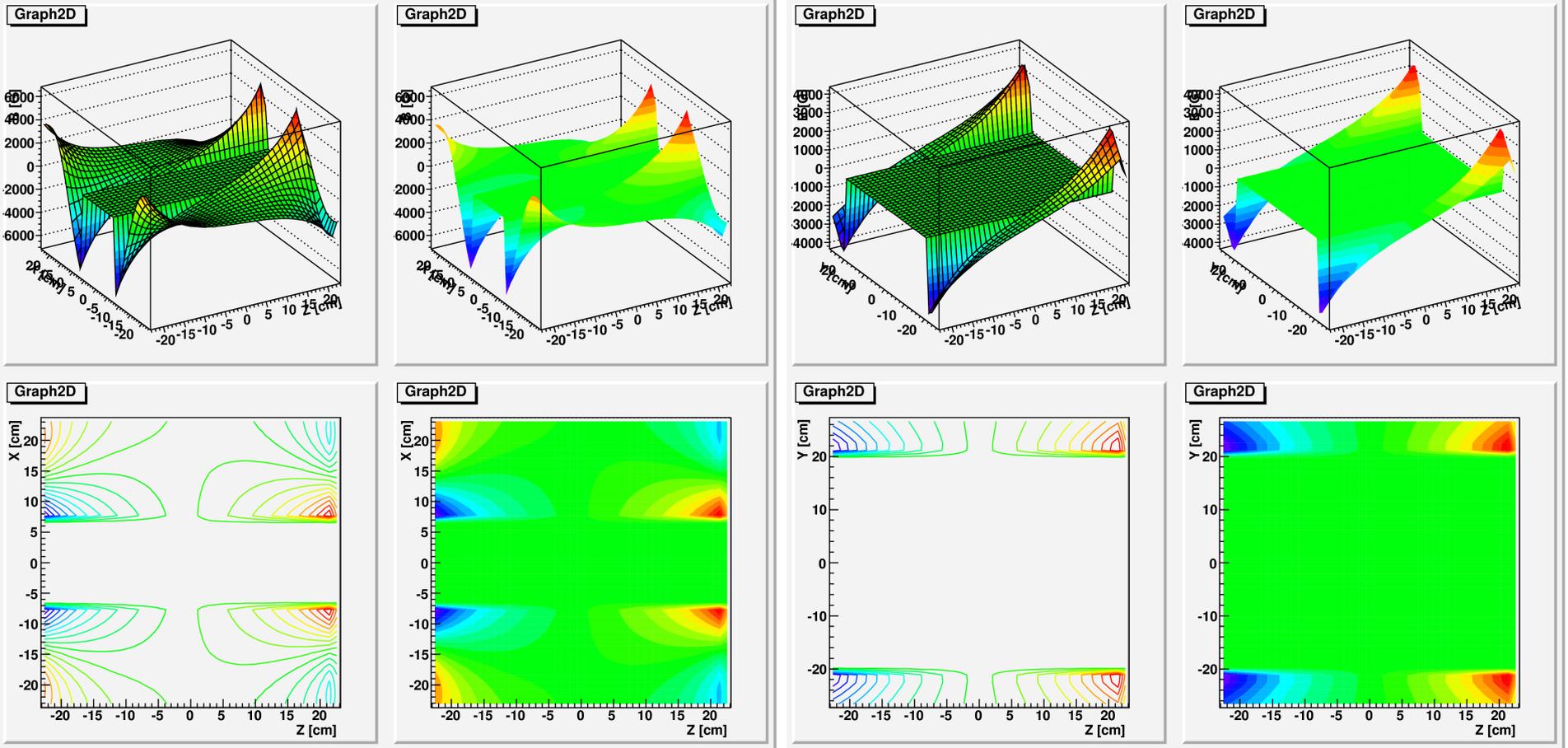


Plane XY

Plane YZ

Magnetization of the Iron Core

Bz Component

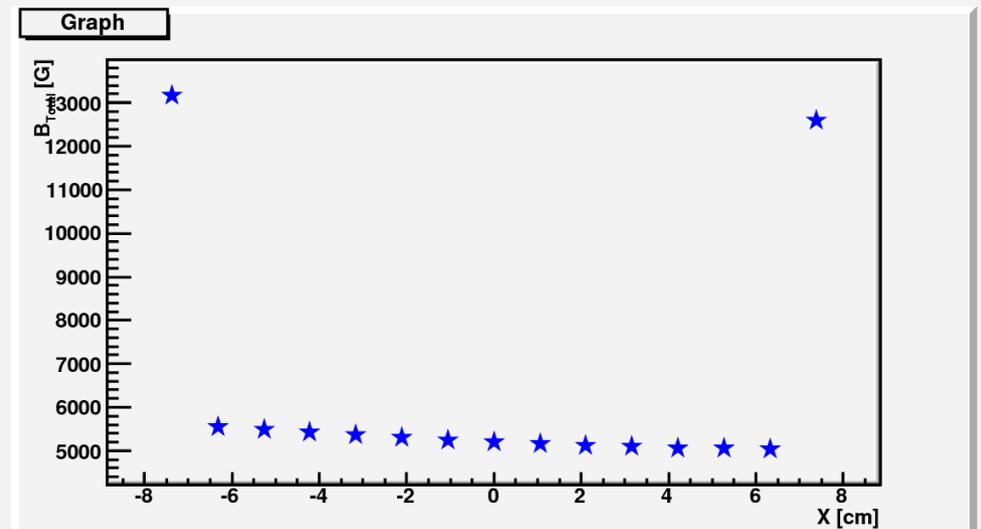
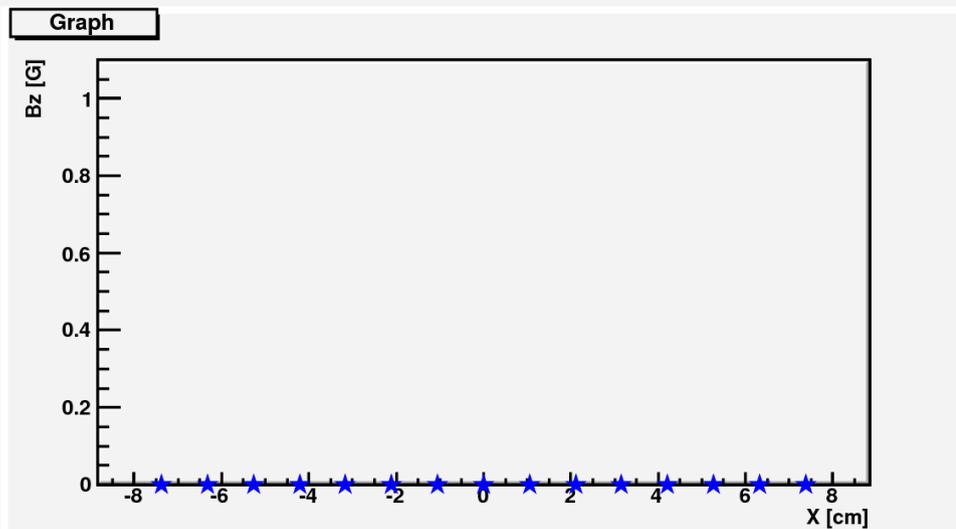
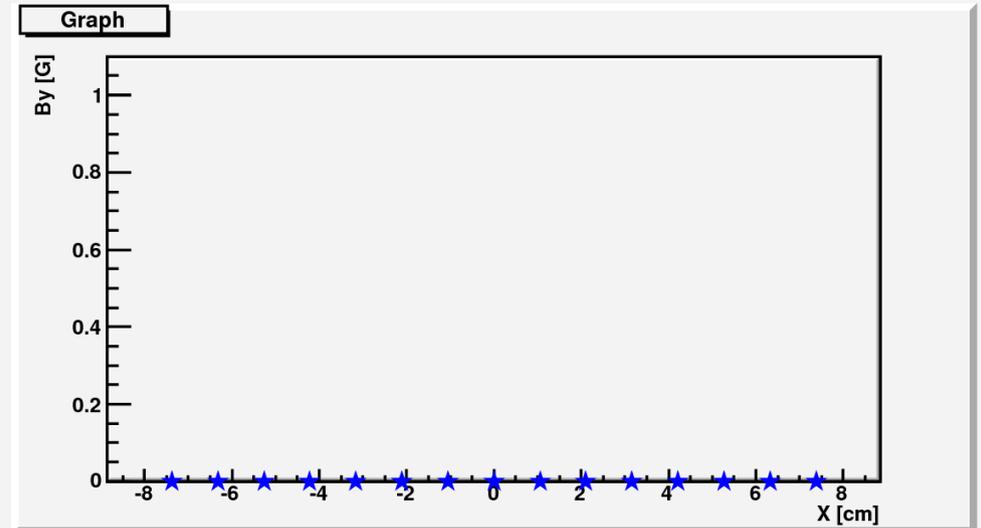
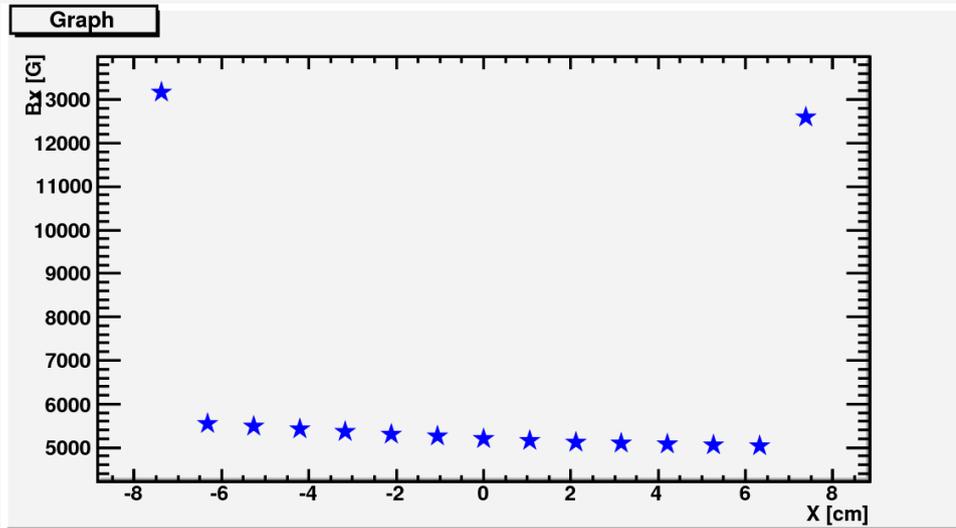


Plane XZ

Plane YZ

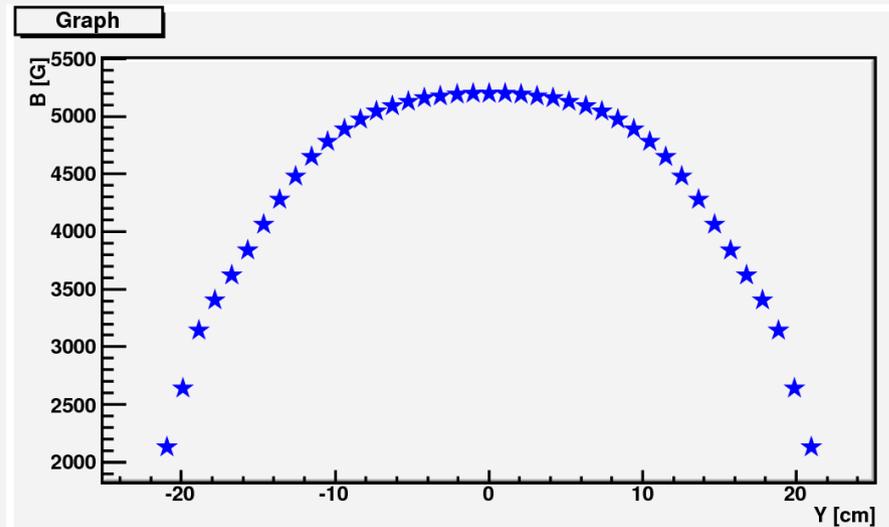
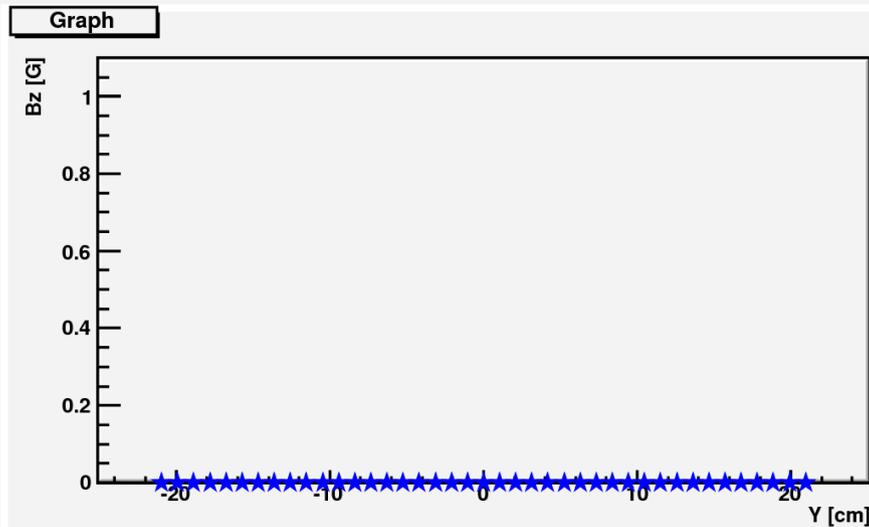
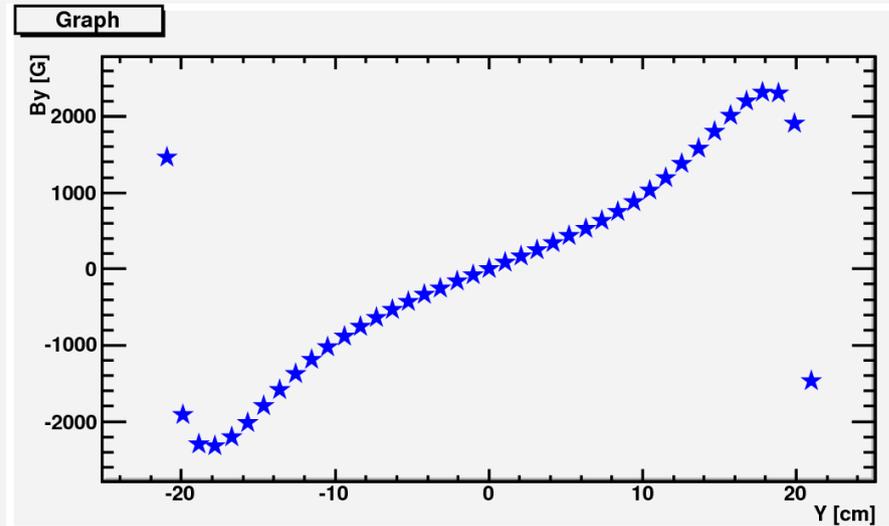
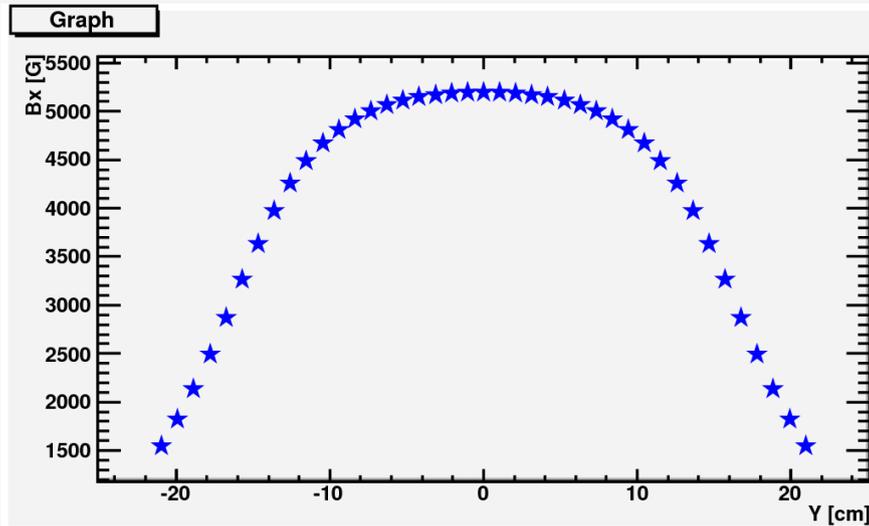
Surface Contribution

Magnetic Field Along to X Axis



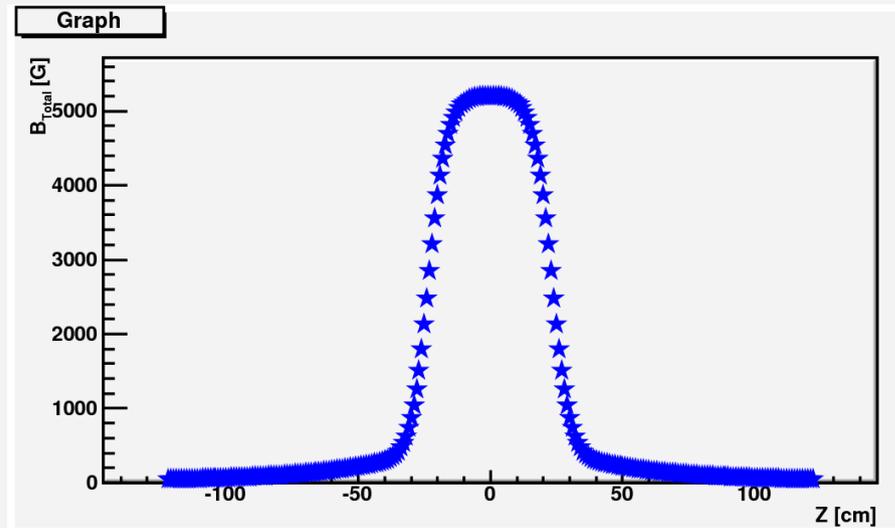
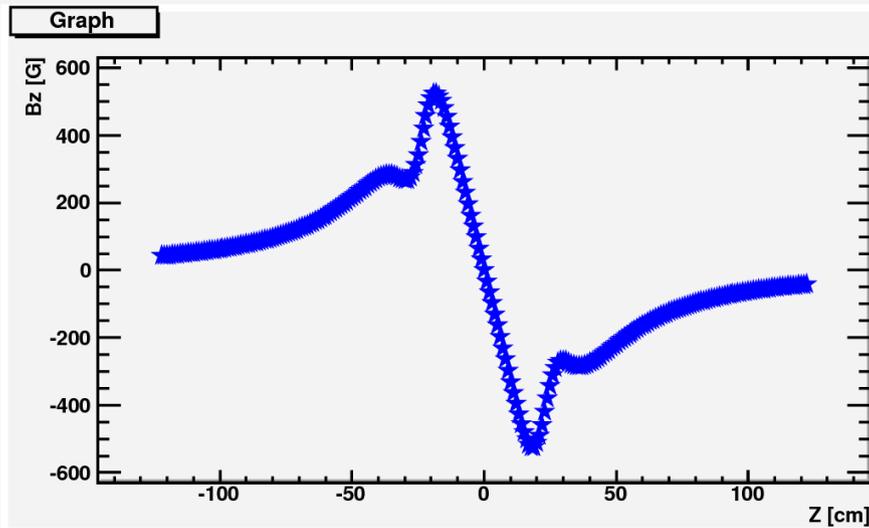
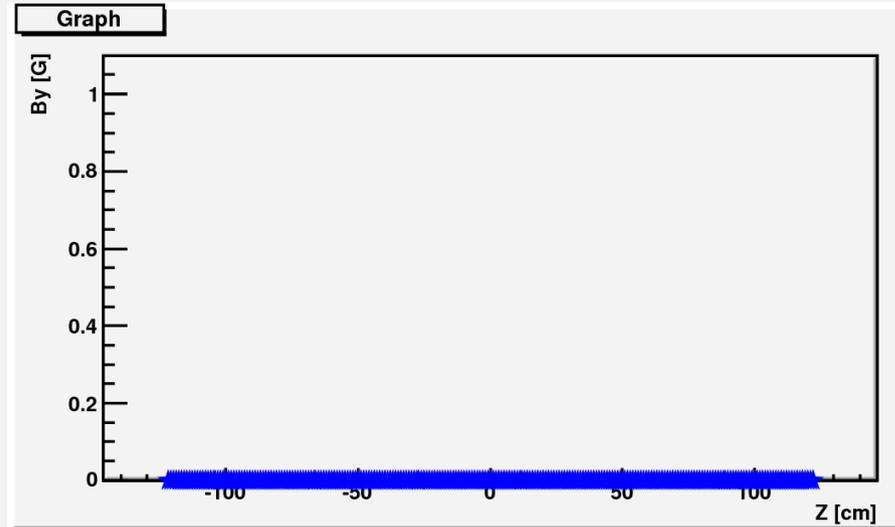
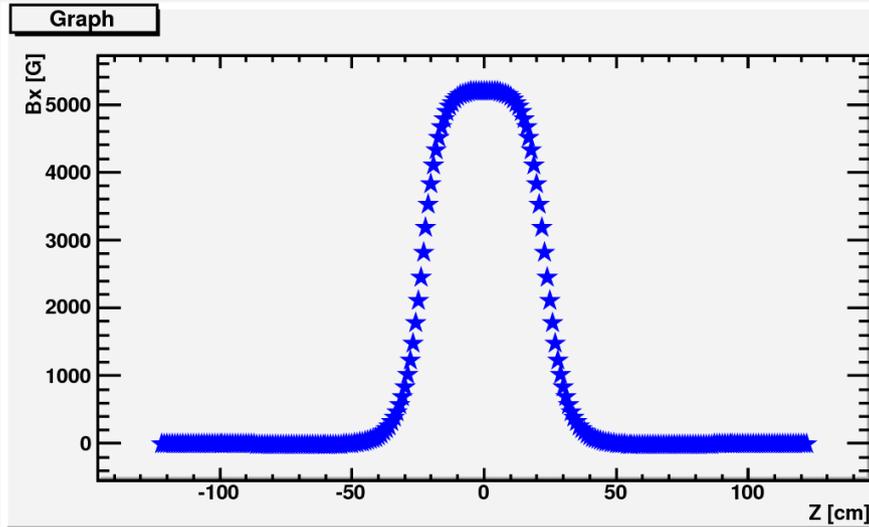
Surface Contribution

Magnetic Field Along to Y Axis



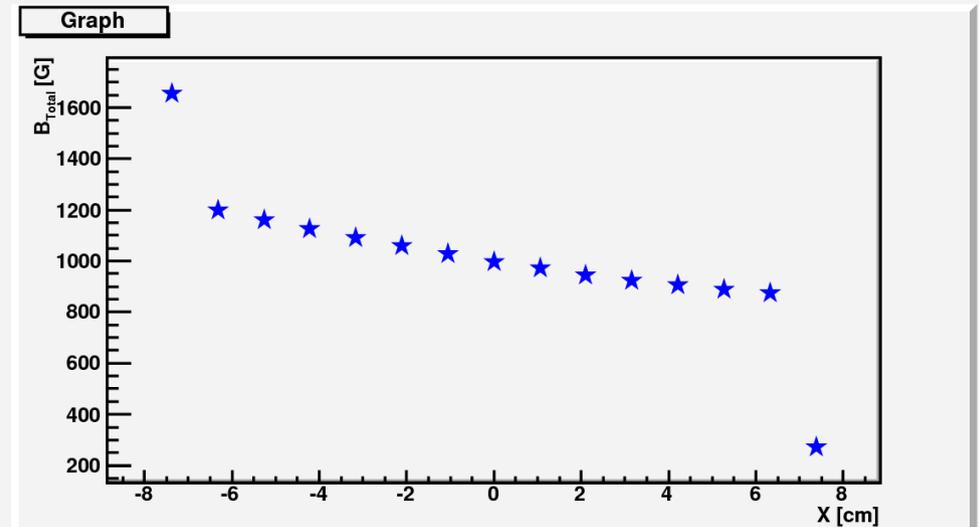
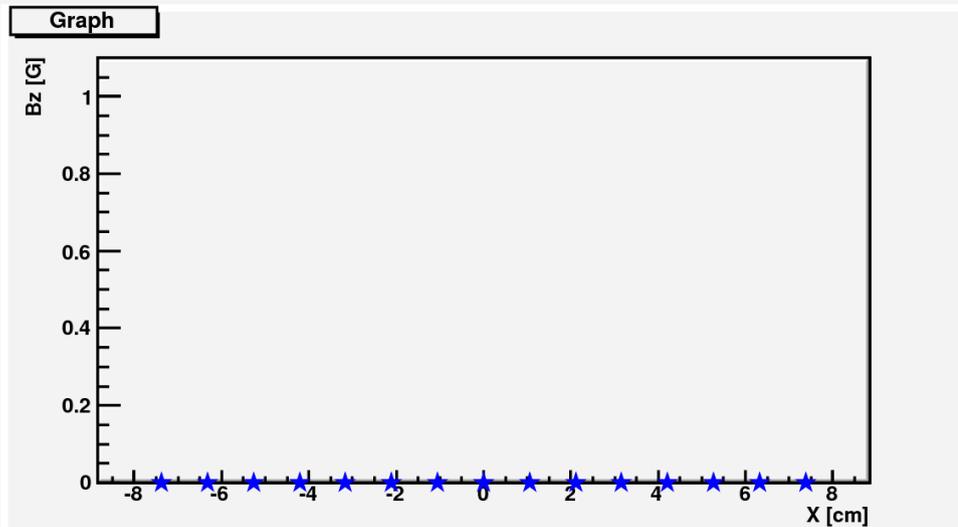
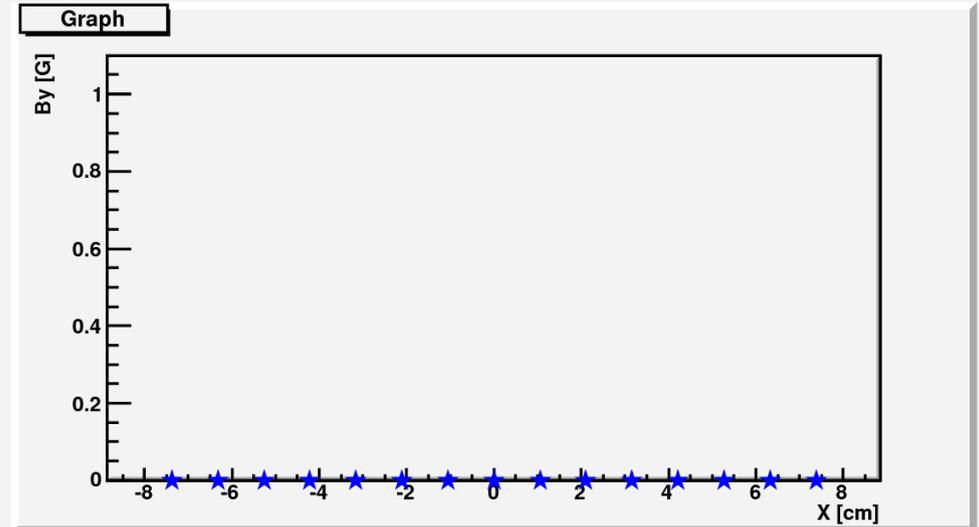
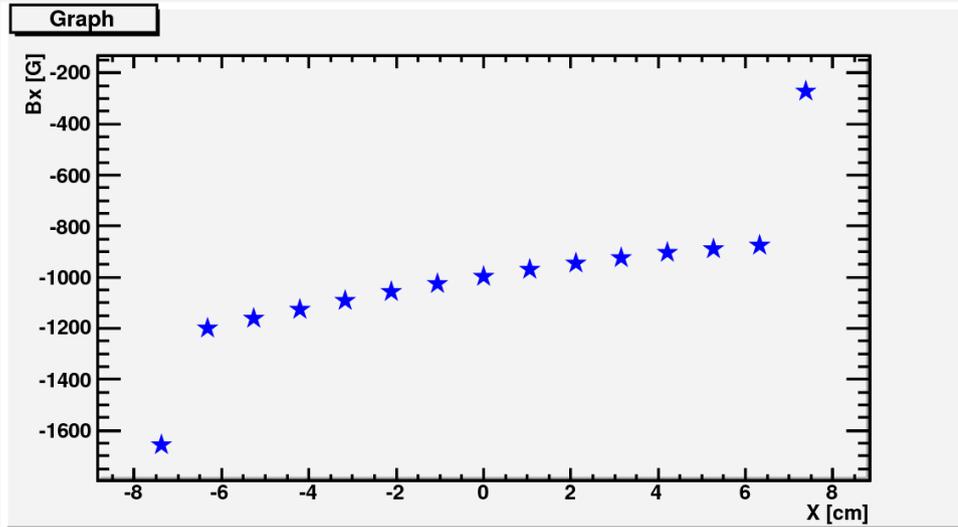
Surface Contribution

Magnetic Field Along to Z Axis



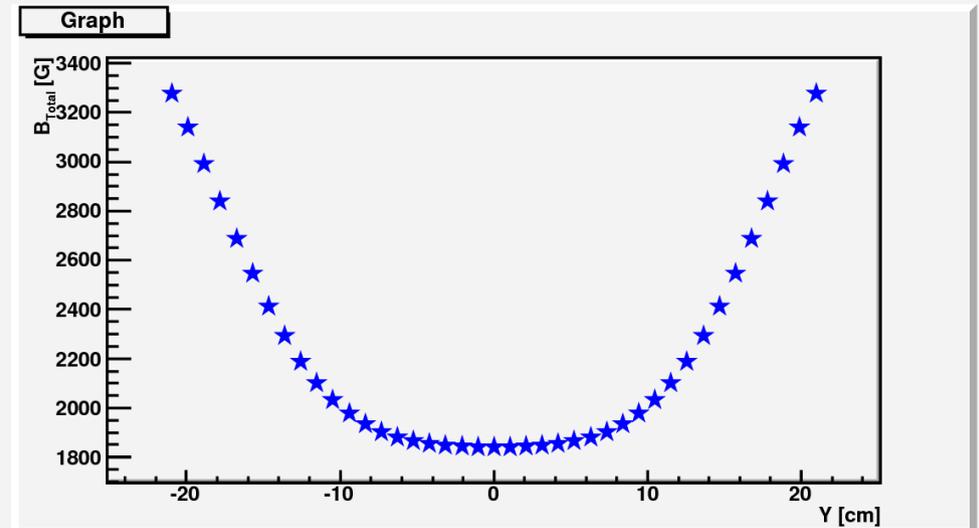
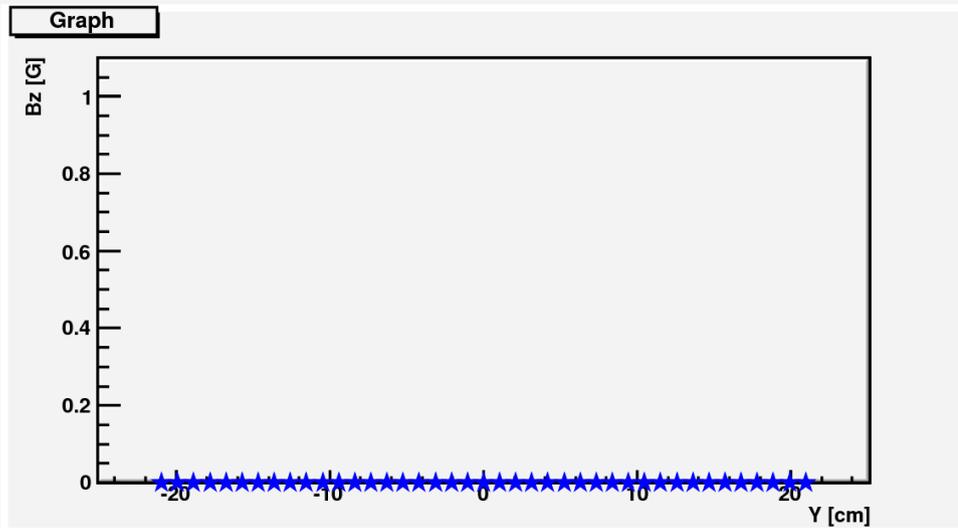
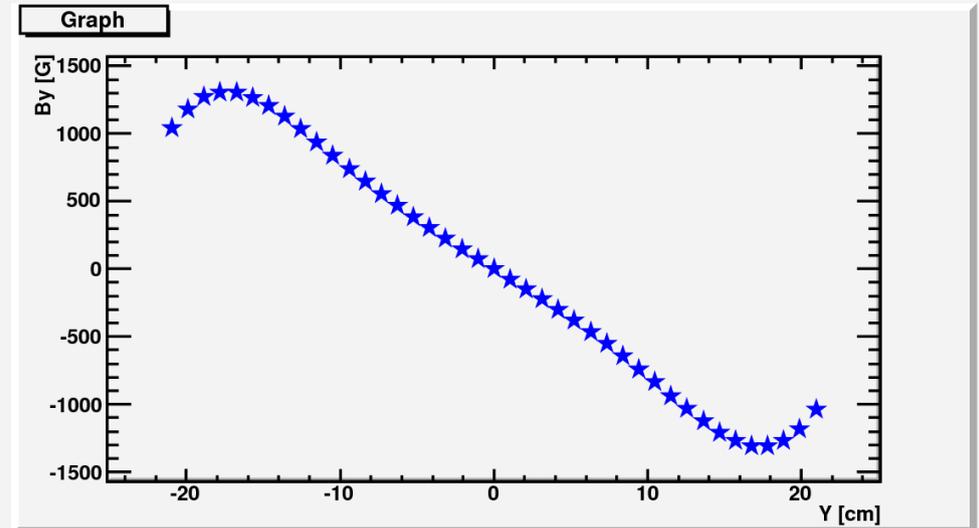
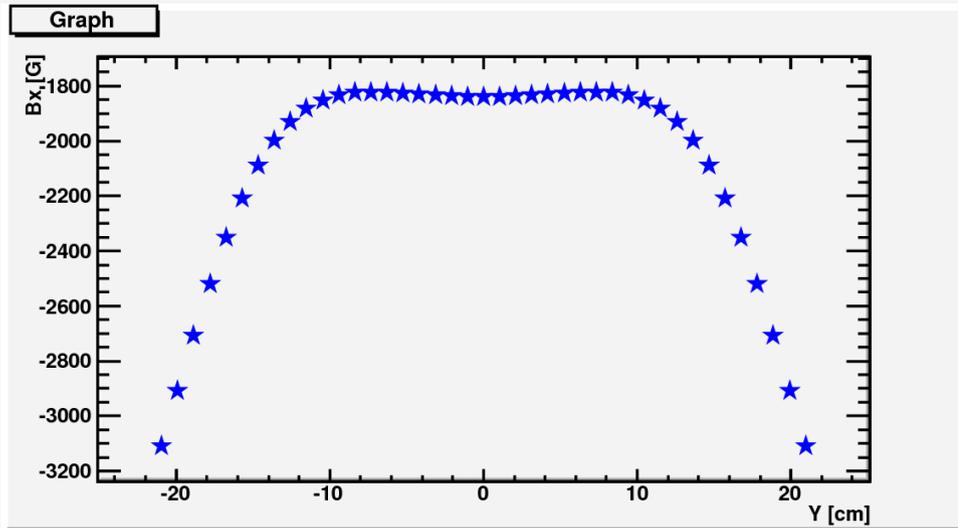
Volumetric Contribution

Magnetic Field Along to X Axis



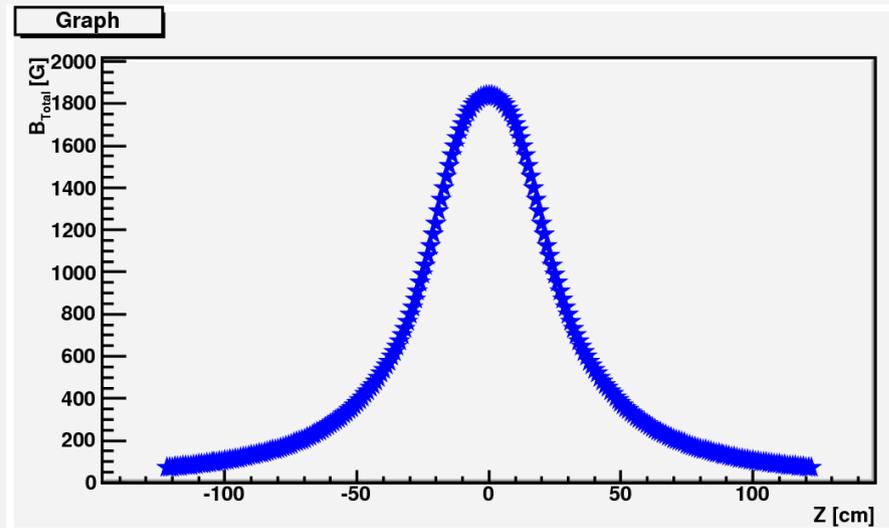
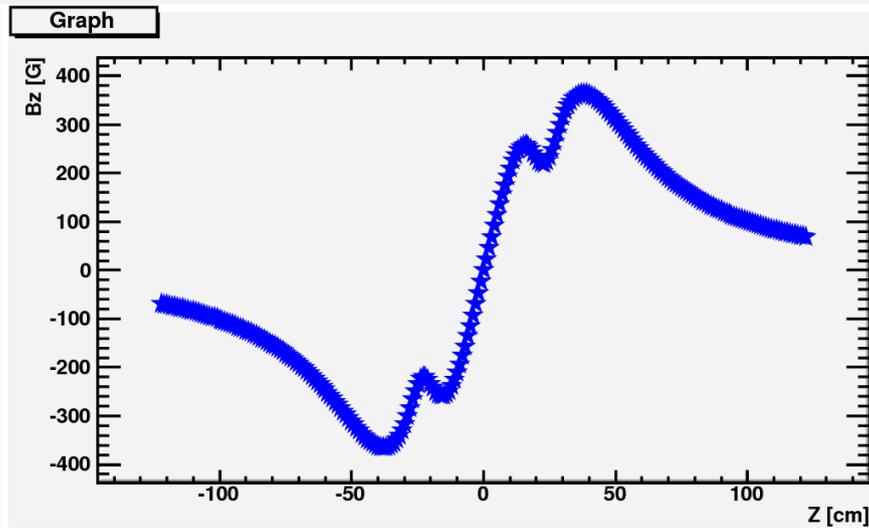
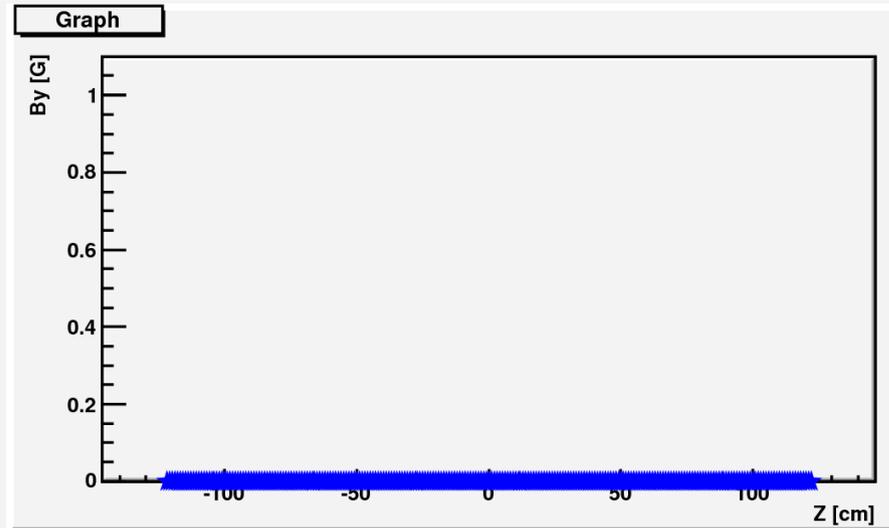
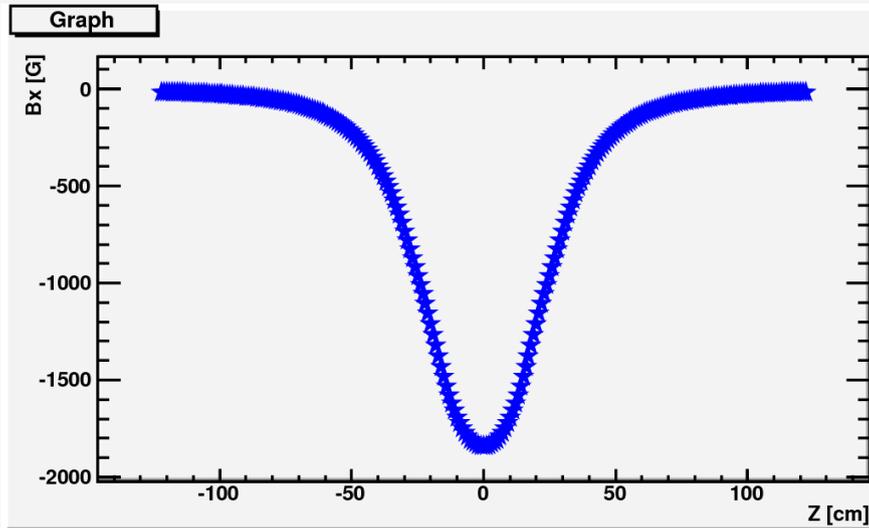
Volumetric Contribution

Magnetic Field Along to Y Axis



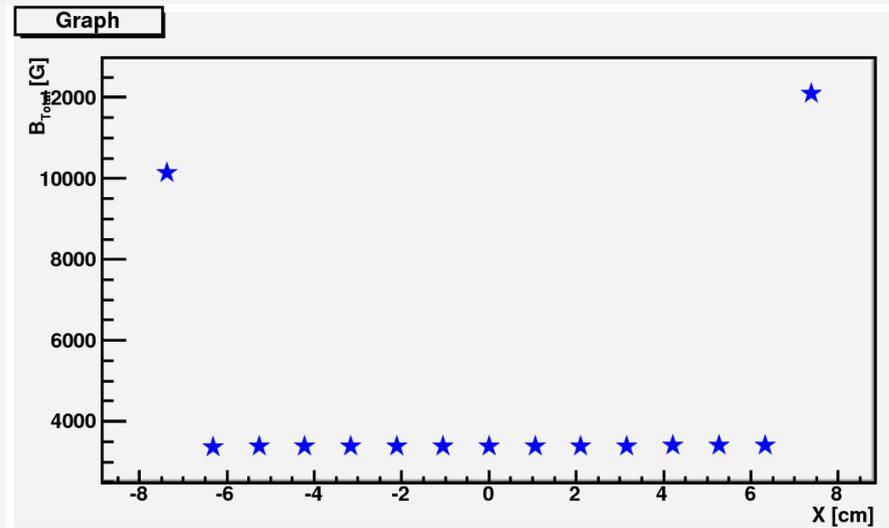
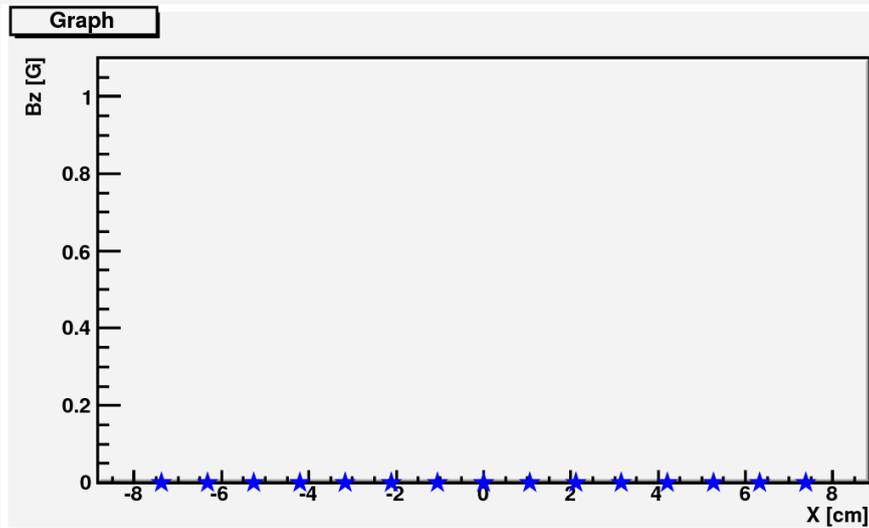
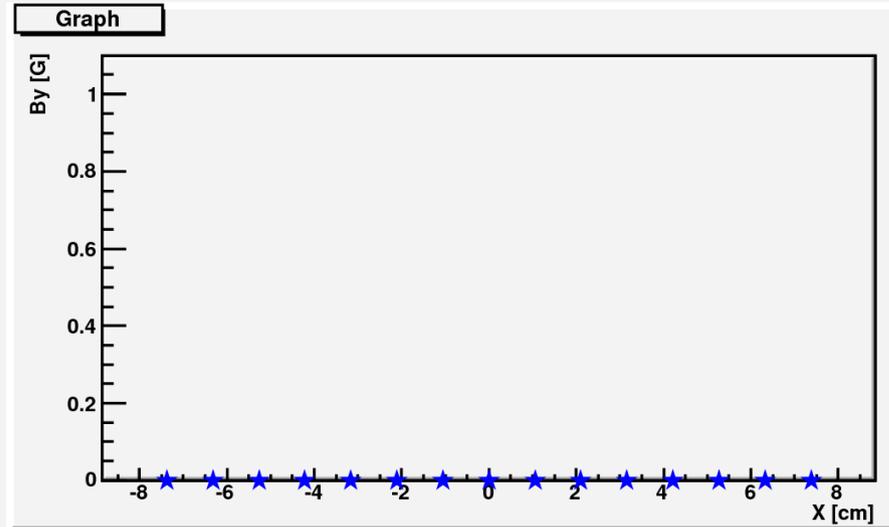
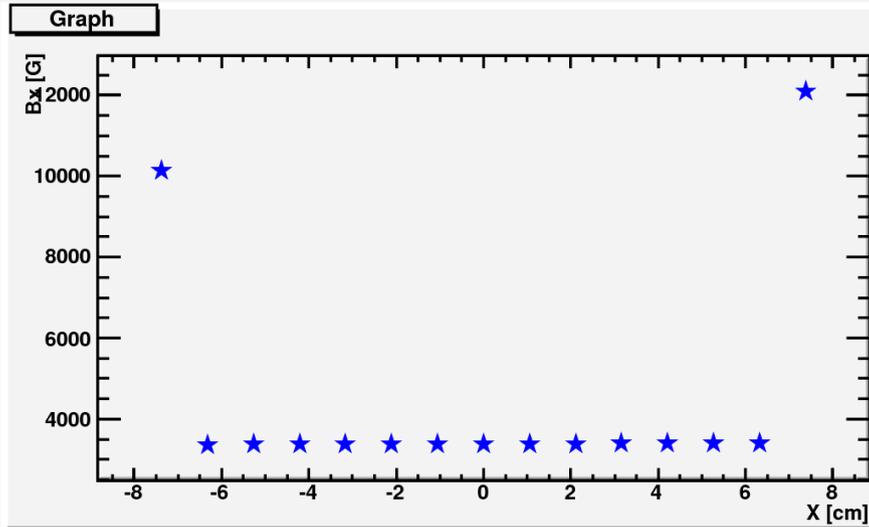
Volumetric Contribution

Magnetic Field Along to Z Axis



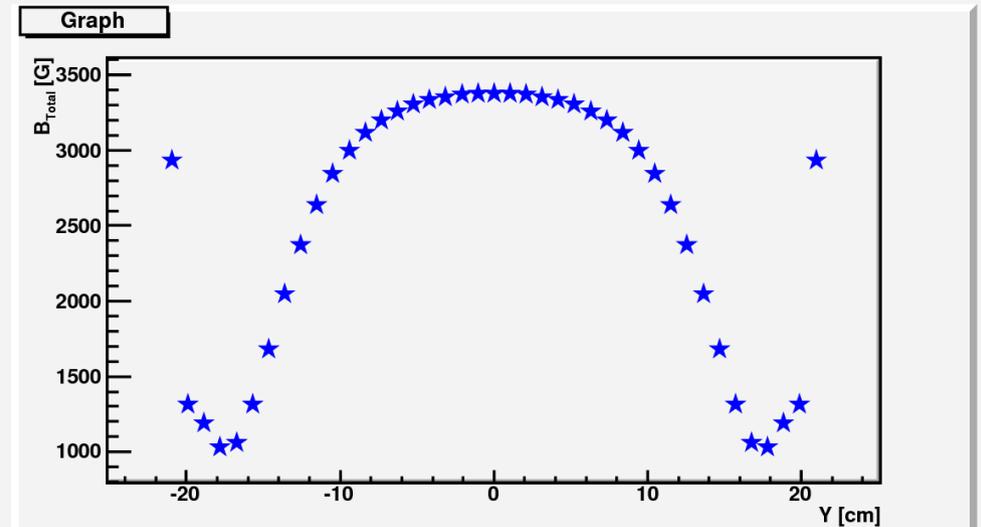
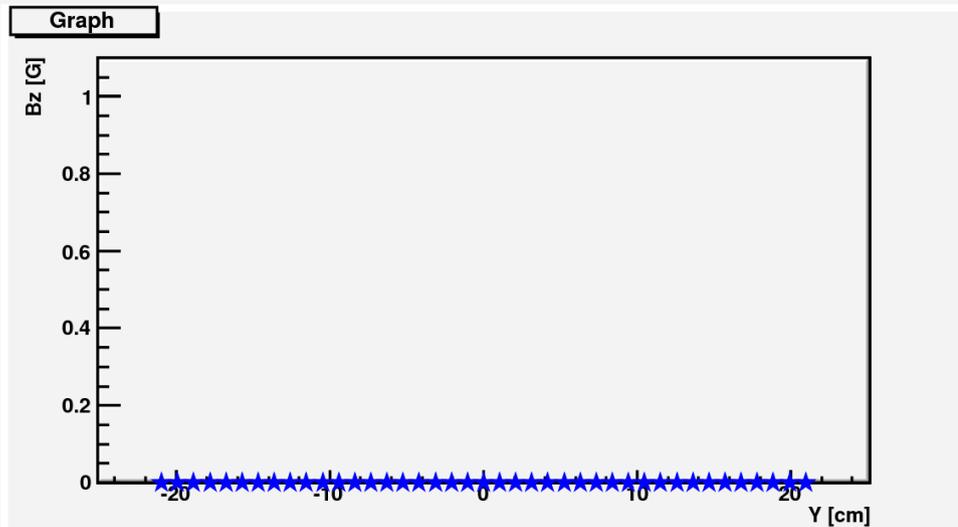
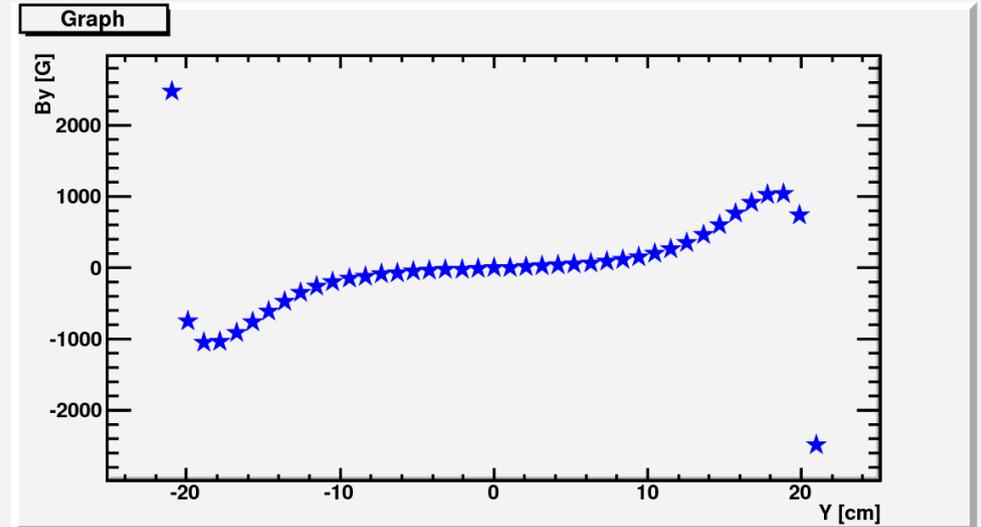
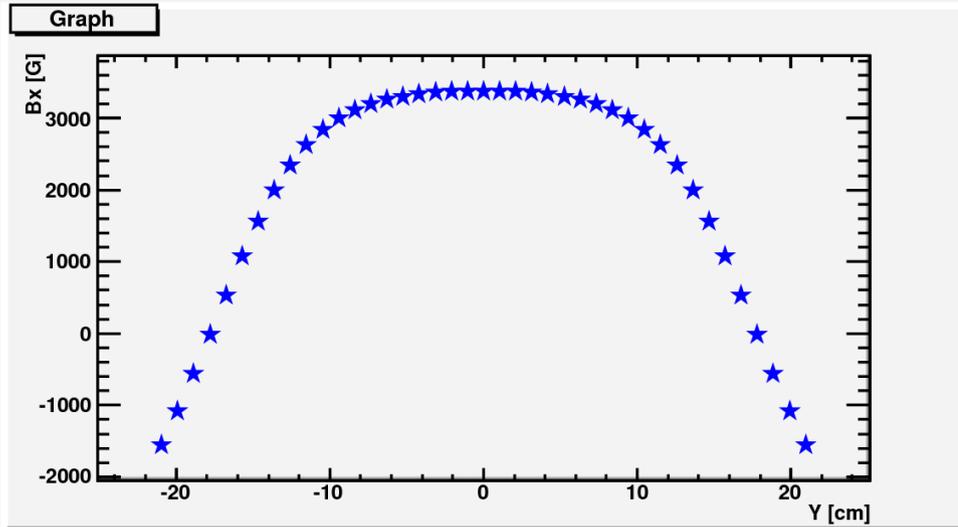
Final Magnetic Field

Magnetic Field Along to X Axis



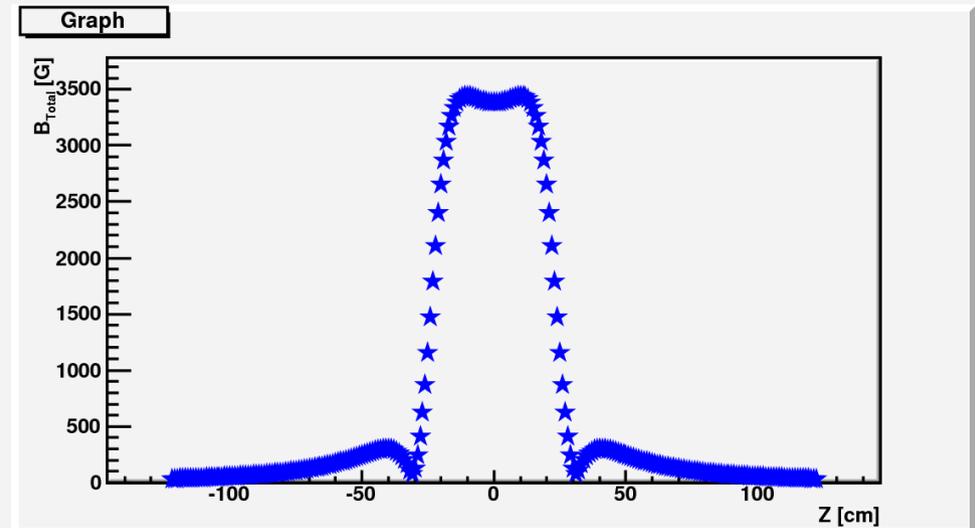
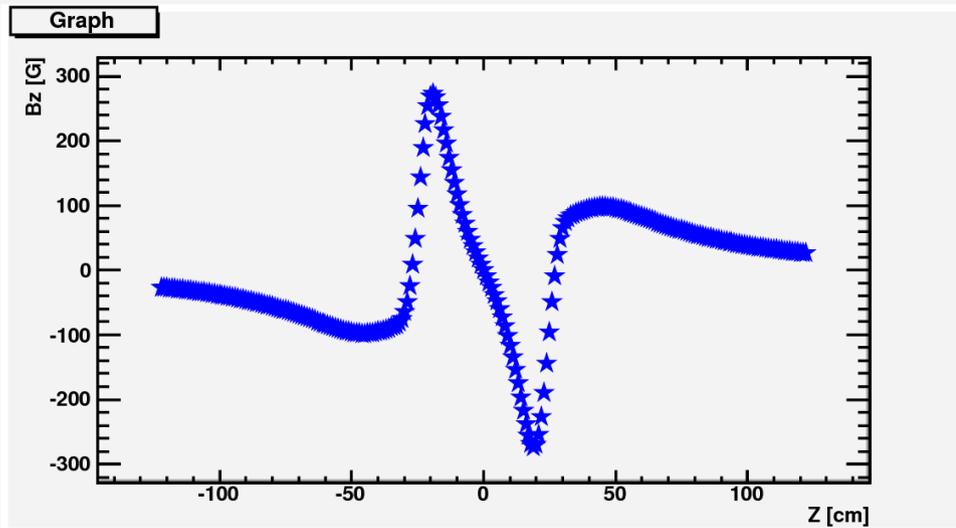
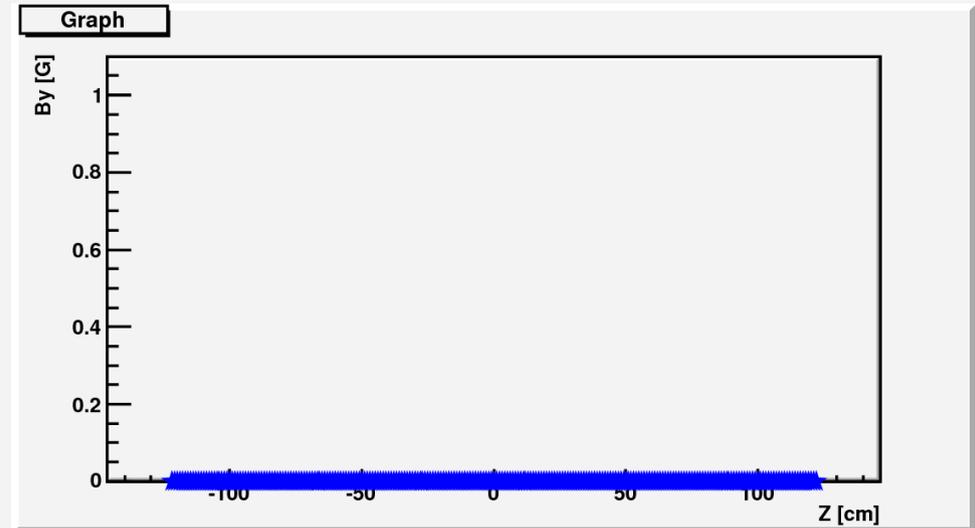
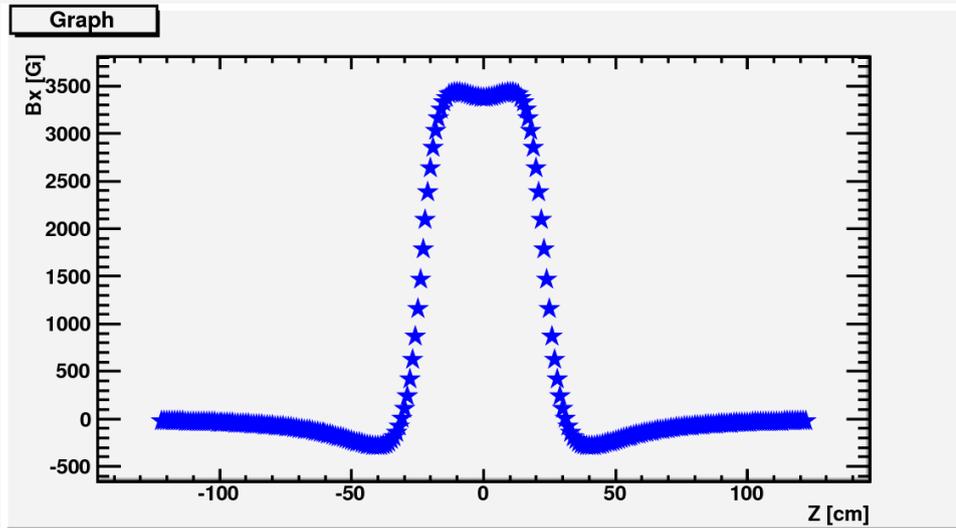
Final Magnetic Field

Magnetic Field Along to Y Axis



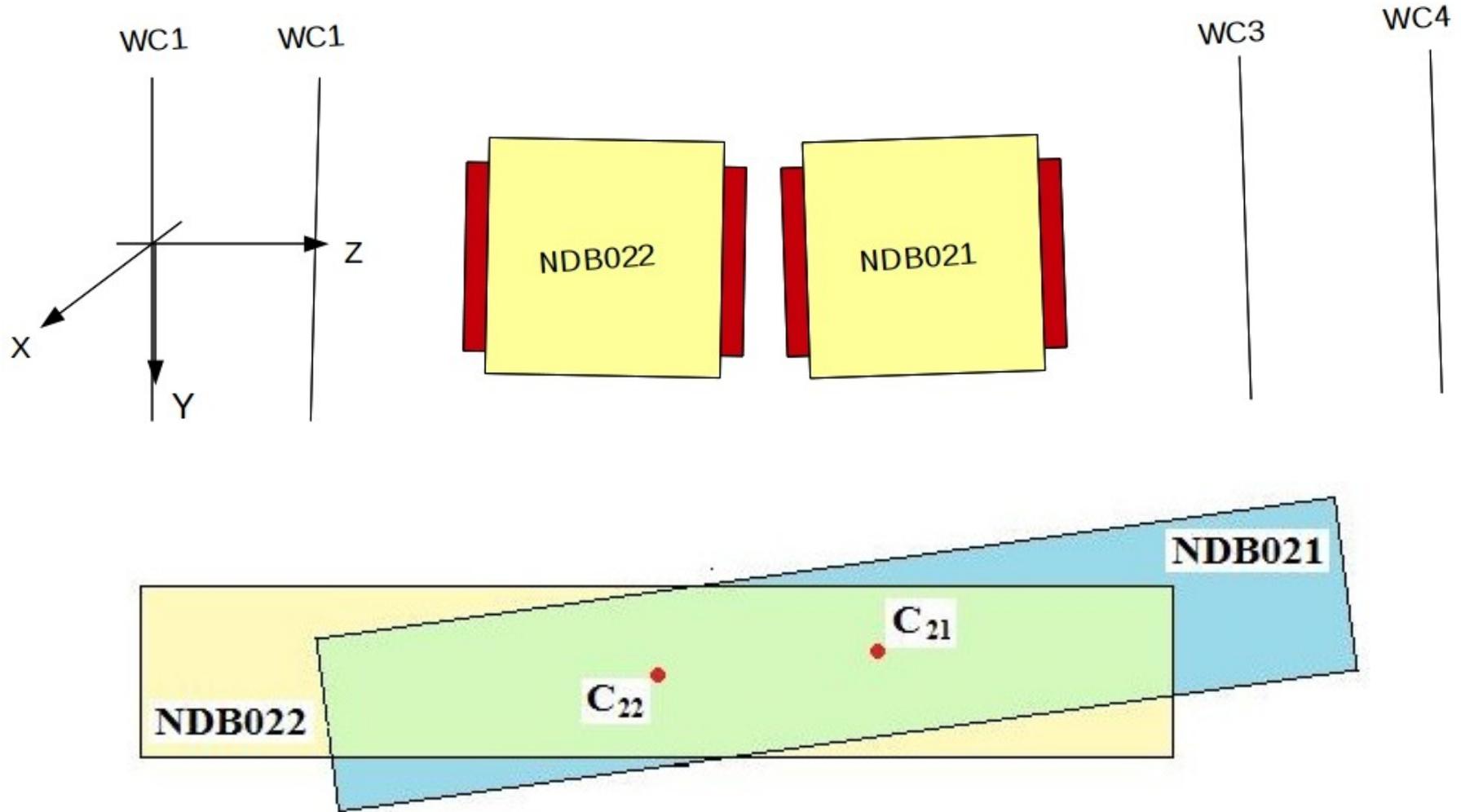
Final Magnetic Field

Magnetic Field Along to Z Axis



My Coordinated System

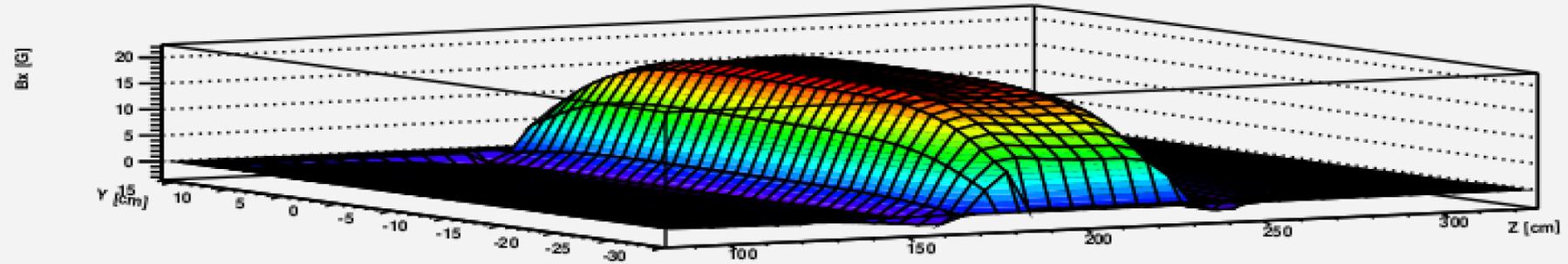
Main Idea



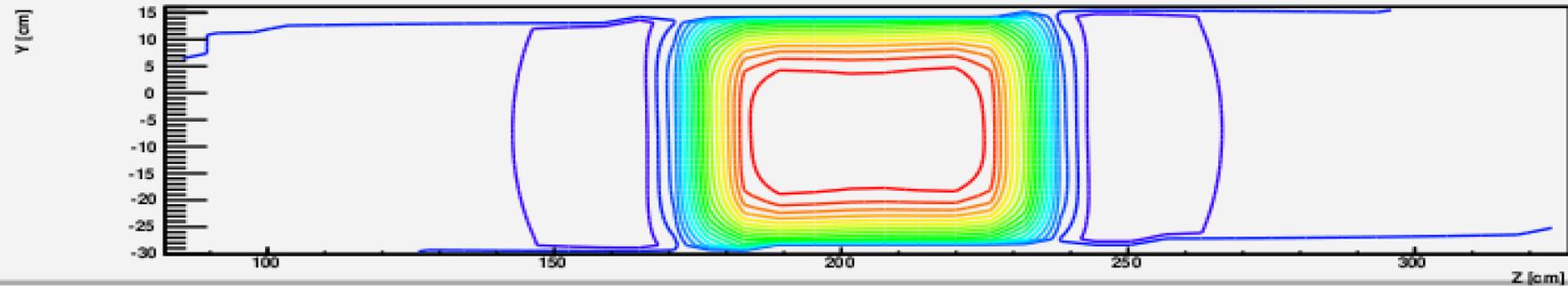
Final Magnetic Field of NDB022

Bx Component on YZ Plane

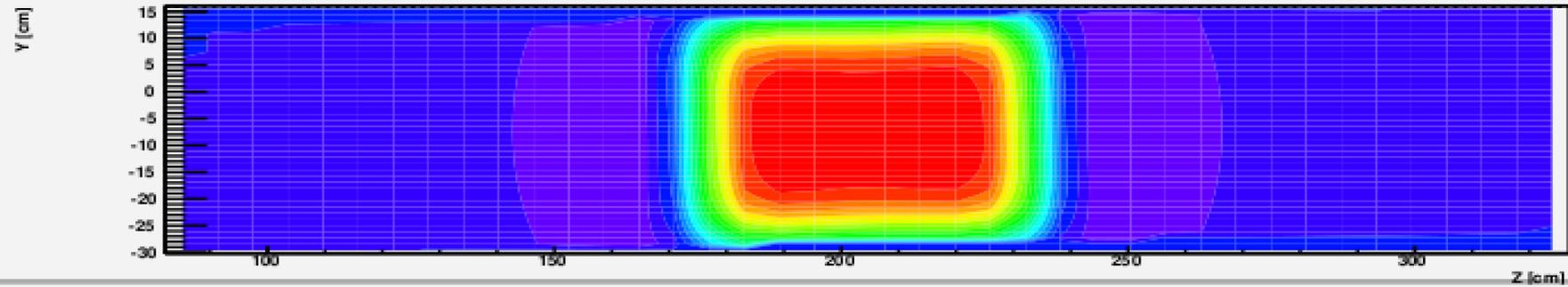
Graph2D



Graph2D

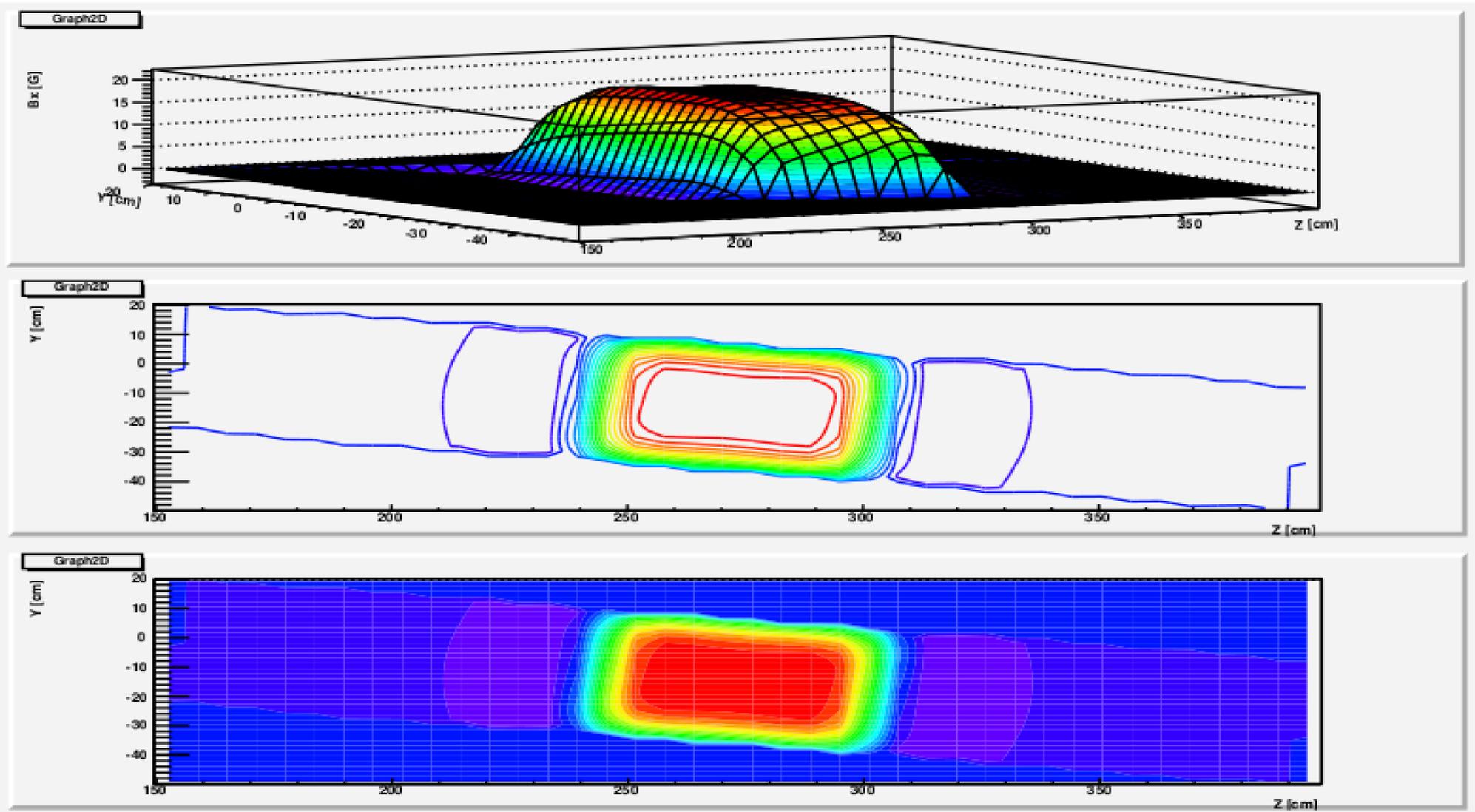


Graph2D



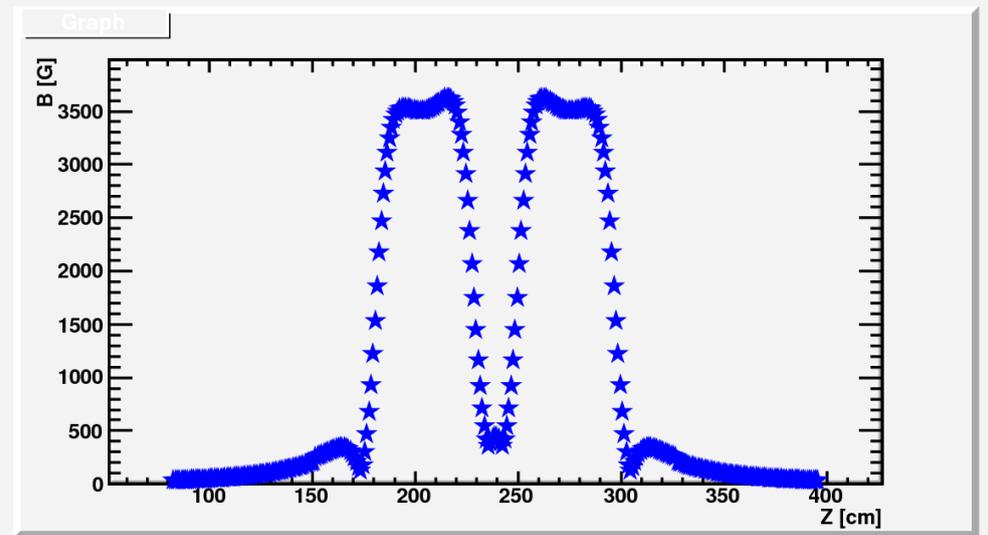
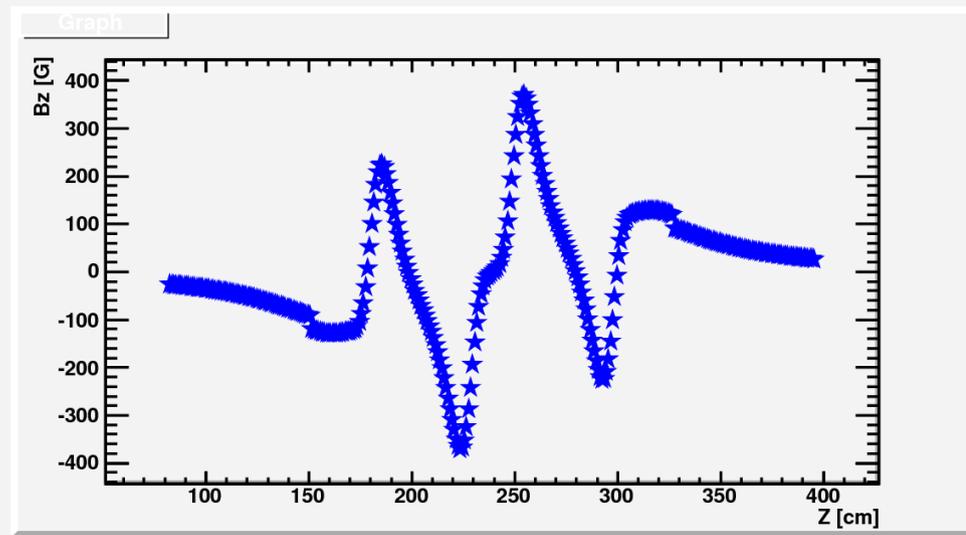
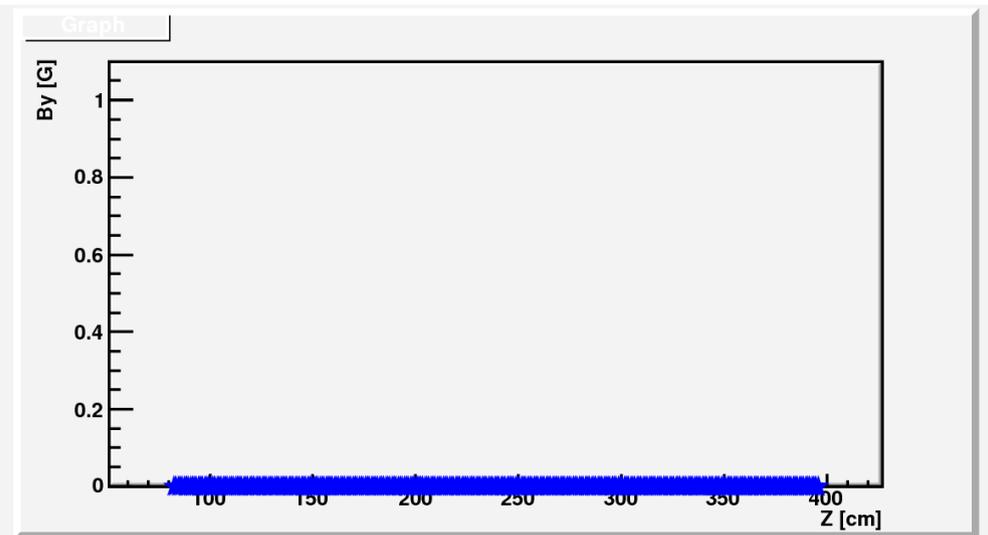
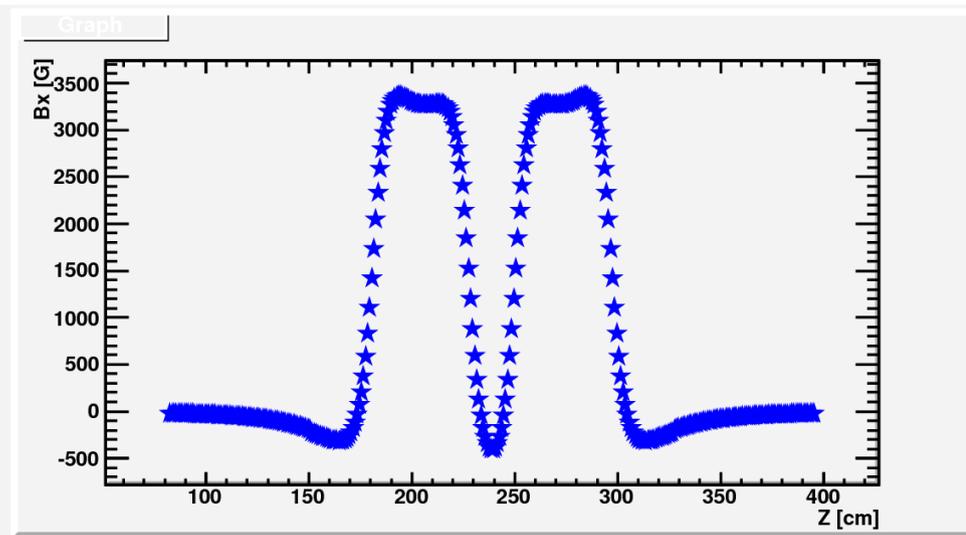
Final Magnetic Field of NDB021

Bx Component on YZ Plane



Final Magnetic Field in the Test Beam

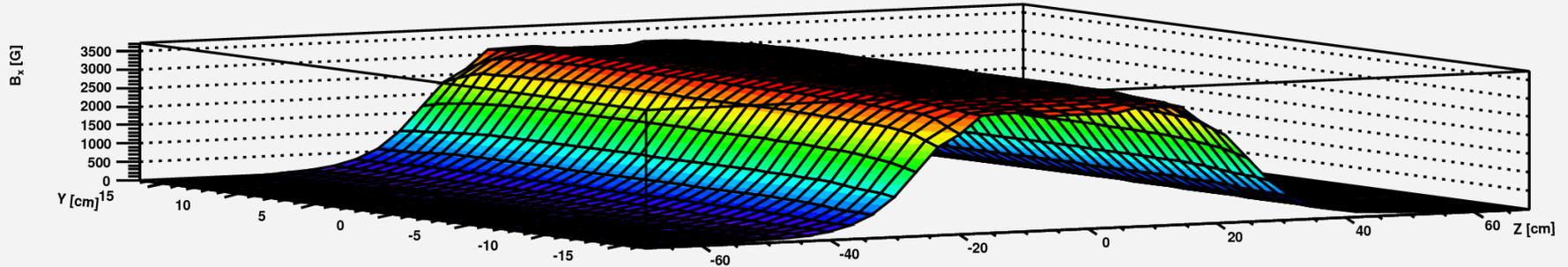
Along to Z Axis



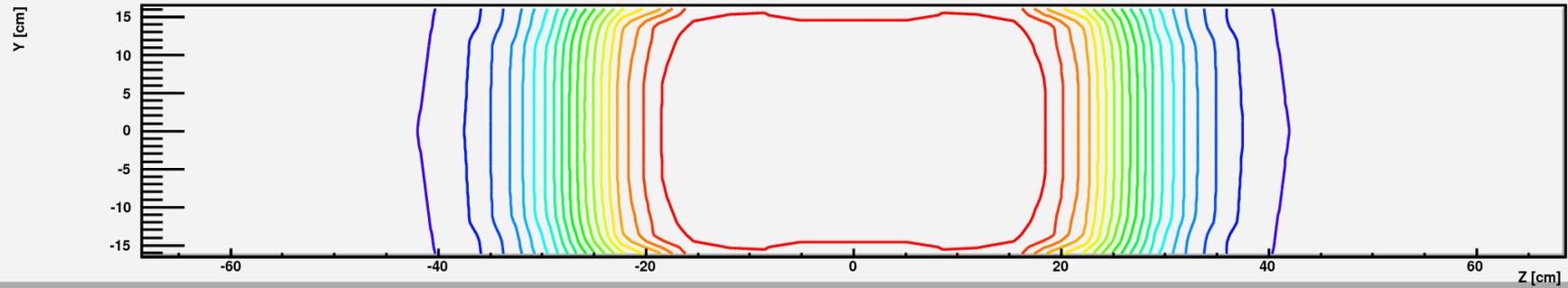
The Measurement

Bx Component on YZ Plane

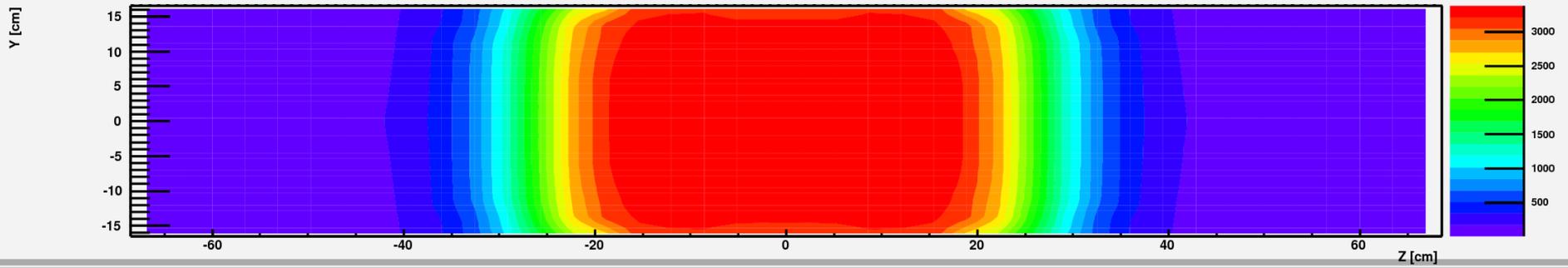
Graph2D



Graph2D

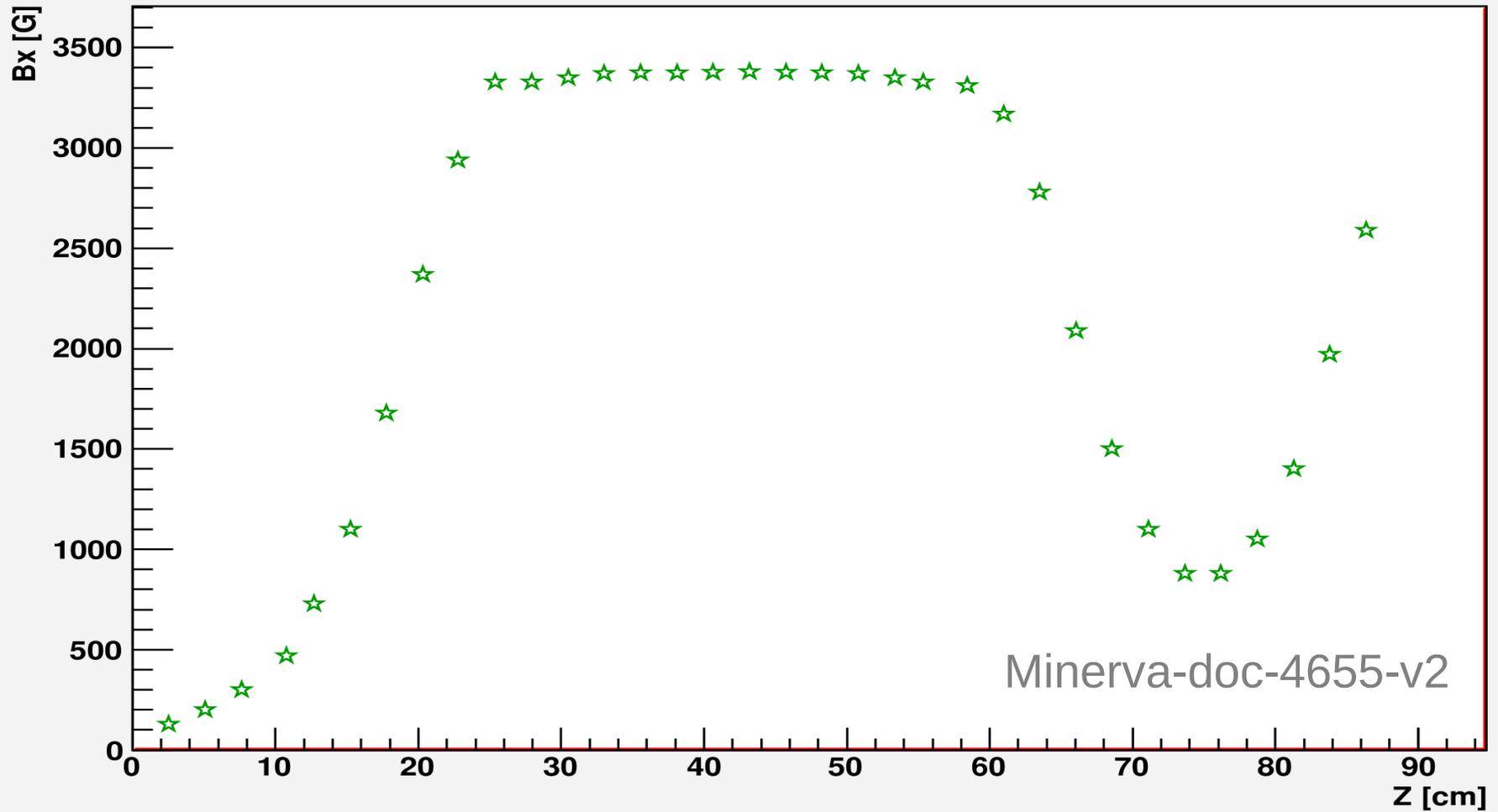


Graph2D



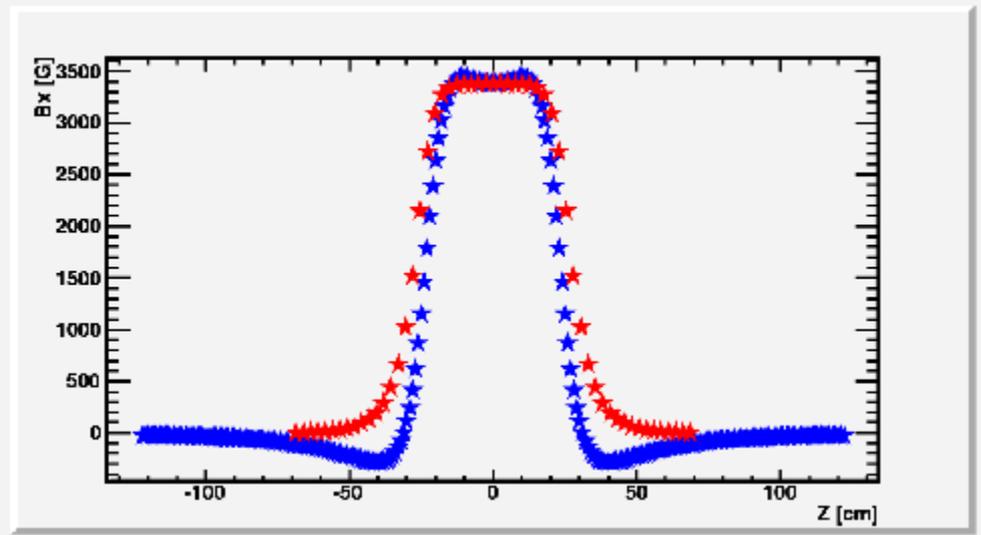
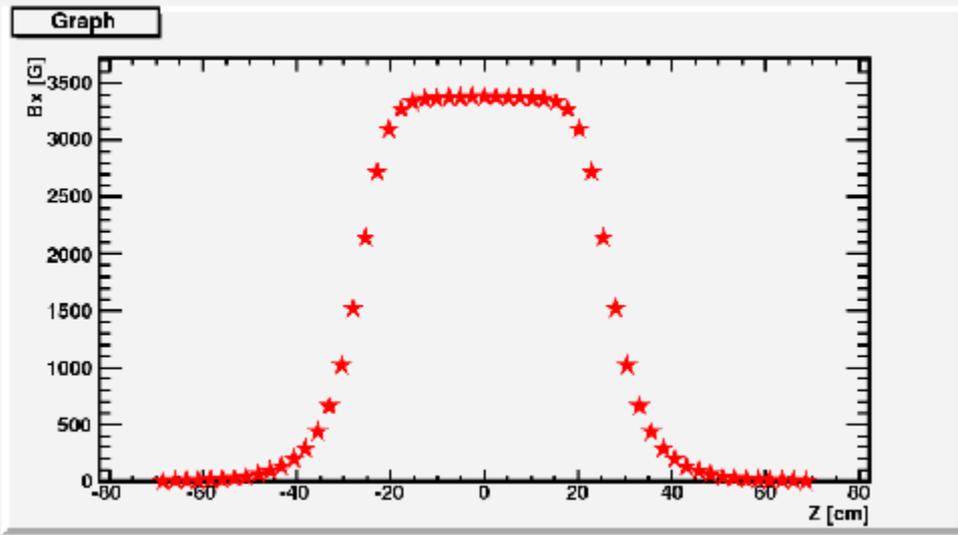
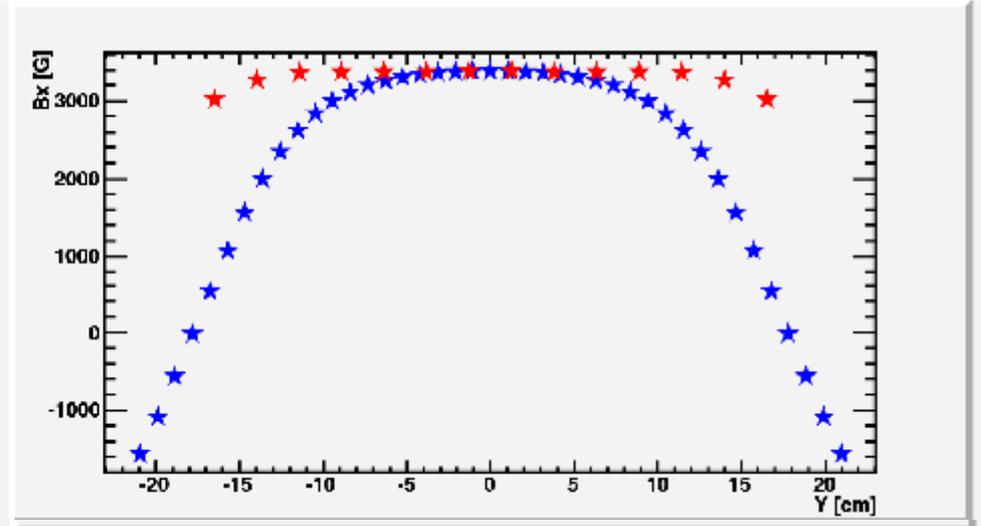
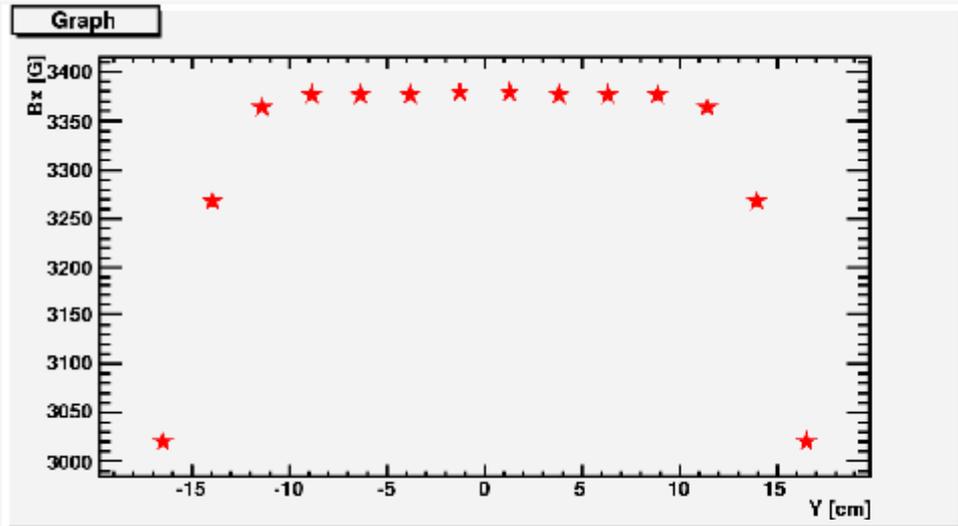
The Measurement

Bx Component Along to Z Axis



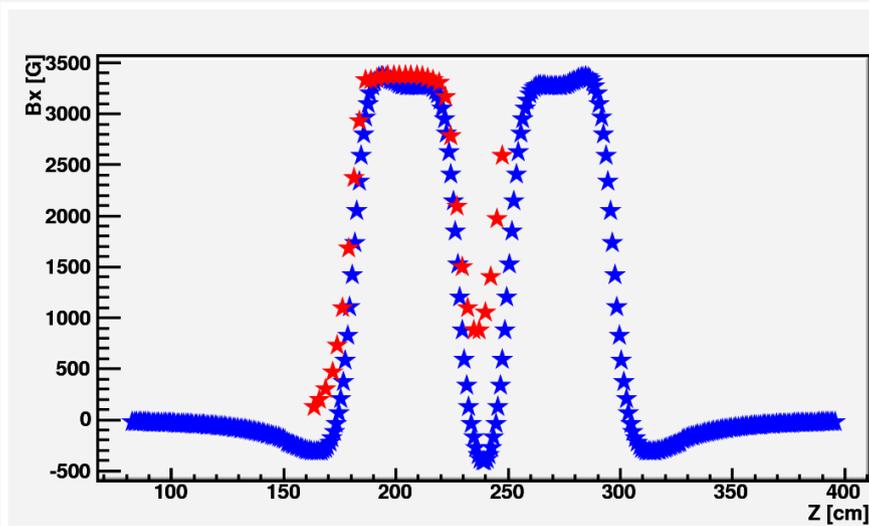
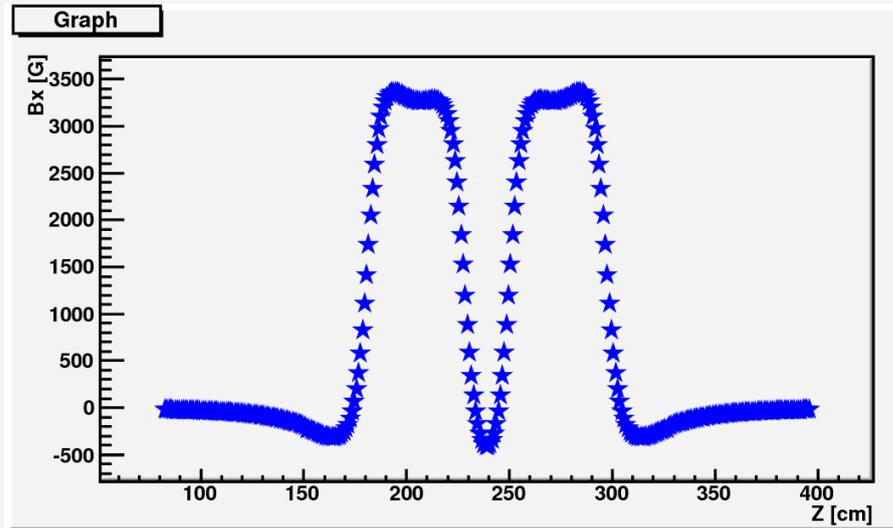
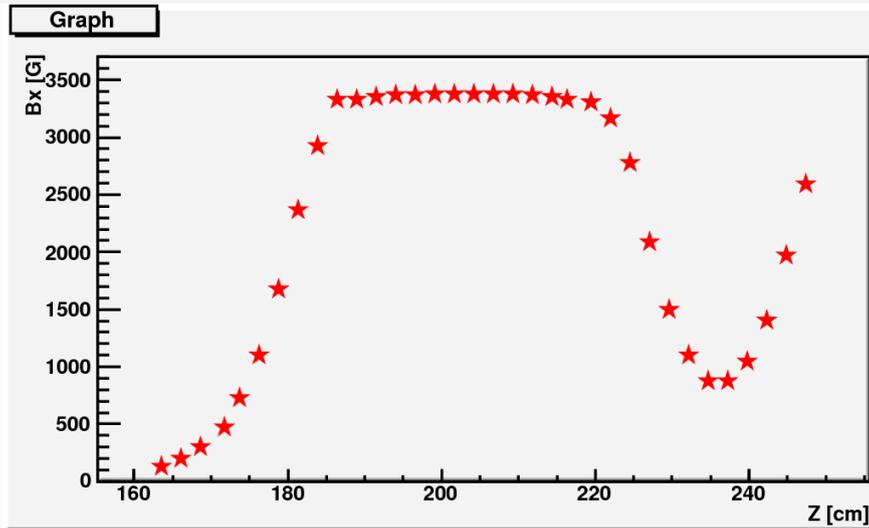
Results Comparison

Bx Component



Results Comparison

Bx Component Along to Z Axis



Conclusions

★ I obtain the Magnetic Field in the center of the magnet:

★ $B_x(0,0,0) = 3379.62 \text{ G}$

★ Measurement in Minerva-doc-4293-v1 :

★ $B_x(0,0,0) = 3379.80 \text{ G}$

★ Then, the Magnetic Permeability of the Iron Core is near:

★ $\mu_{Core} = 483.85 \mu_{Air}$