



CEBAF TN-95-063  
Oct. 19, 1995

## Analysis of solenoid field measurements for the FEL injector test stand

Hongxiu Liu

**Abstract** Two solenoid lenses have been manufactured for the FEL injector test stand under development. Their field profiles at different testing current values and radial positions have been measured recently. The analysis shows that the measurements agree with the theoretical model within  $\sim 1\%$ , so we can rely on the theoretical model to study some more complicated issues such as aberration and fringing field effects without doing more lengthy and difficult measurements. All the raw data from the measurements for these two lenses (SOL00110.DAT - SOL00130.DAT for lens #1, and SOL00201.DAT to SOL00209.DAT for lens #2) are placed in the directory of "usr/user4/liu/sol.dir" on CEBAFH which is free for anyone at CEBAF to access.

### Introduction

Two solenoid lenses were designed using POISSON some time ago for the CEBAF FEL injector test stand under development [1]. They have been manufactured, and their field profiles have been measured recently by K. Sullivan. These lenses are the critical elements for the FEL injector test stand in the sense that they control the transverse beam optics matching and emittance growth in the 500 kV region. Therefore, their field profiles have been measured in detail. In this note, we document the measurements with some analysis based on the POISSON calculations. We show that the measurements agree extraordinarily well with the POISSON calculations.

### Lens #1

First we compare the measured on-axis magnetic field profiles with those from the POISSON calculations conducted during the design stage of this lens. The results are shown in Figs. 1 - 3 for three different testing current values of 4.775, 7.162 and 8.595 A, respectively. It is seen that the agreement between the measurement and calculation is excellent. The differences in the peak magnetic field strength in these cases are 1.4%, 1.2% and 1.0%, respectively, showing that the measurements agree with the calculations at a  $\sim 1\%$  level. This excellent agreement means that we can rely on the theoretical model confidently for some more complicated studies such as aberration and fringing field effects from this lens.

Fig. 4 shows the on-axis peak magnetic field vs testing current for this lens. In the POISSON calculations, we assumed infinite permeability, so the saturation was not taken into account for high operating current. The nominal operating current of this lens by design is 4.9 A [2]. Even though we planned a safety margin of a factor-of-2 stronger focussing as we may need, which corresponds to an operating current of 7.0 A, Fig. 4 shows that the peak magnetic field is perfectly linear with respect to the operating current in the whole range of measurement.

Fig. 5 shows the peak magnetic field (at the mid-plane of the lens) vs the horizontal coordinate  $x$  for the testing current values of 4.775, 7.162 and 8.595A, respectively. The excellent flatness of each curve indicates that the spherical aberration effect from this lens would be negligible, since the beam radius would be about 1 cm at the mid-plane of the lens, and the field is linear up to  $r = 2$  cm.

### Lens #2

Lens #2 is identical with Lens #1 except that it has no water cooling. The field measurements for this lens are shown in Figs. 6 and 7 with the corresponding POISSON calculations, where Fig. 6 shows that the field is linear with respect to the operating current up to 9 A, and Fig. 7 shows that the lens has good cylindrical symmetry as is the case in the theoretical model.

Given the excellent agreement between measurement and calculation, we conclude that from this point on we can rely on the theoretical model to derive some more complicated properties of these lenses such as aberration and fringing field effects.

### Acknowledgment

I would like to thank G. Biallas and C. Sinclair for reading this note.

### References

- [1] H. Liu et al., presented at PAC-95., Dallas, Texas, May 1-5, 1995.
- [2] H. Liu et al., *Nucl. Instr. Meth. A* **358**, 475 (1995).

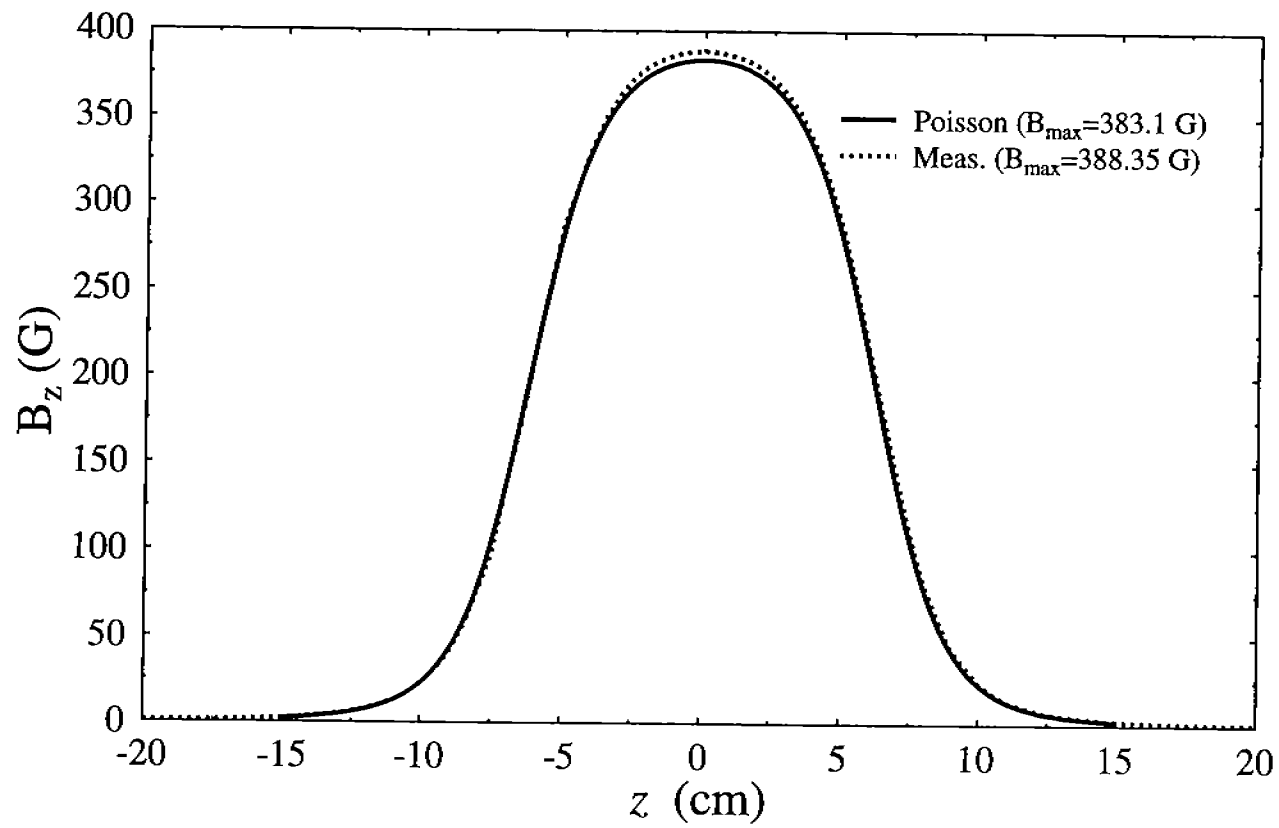


Fig. 1 On-axis magnetic field profile for FEL lens #1 operating at 4.775 A.

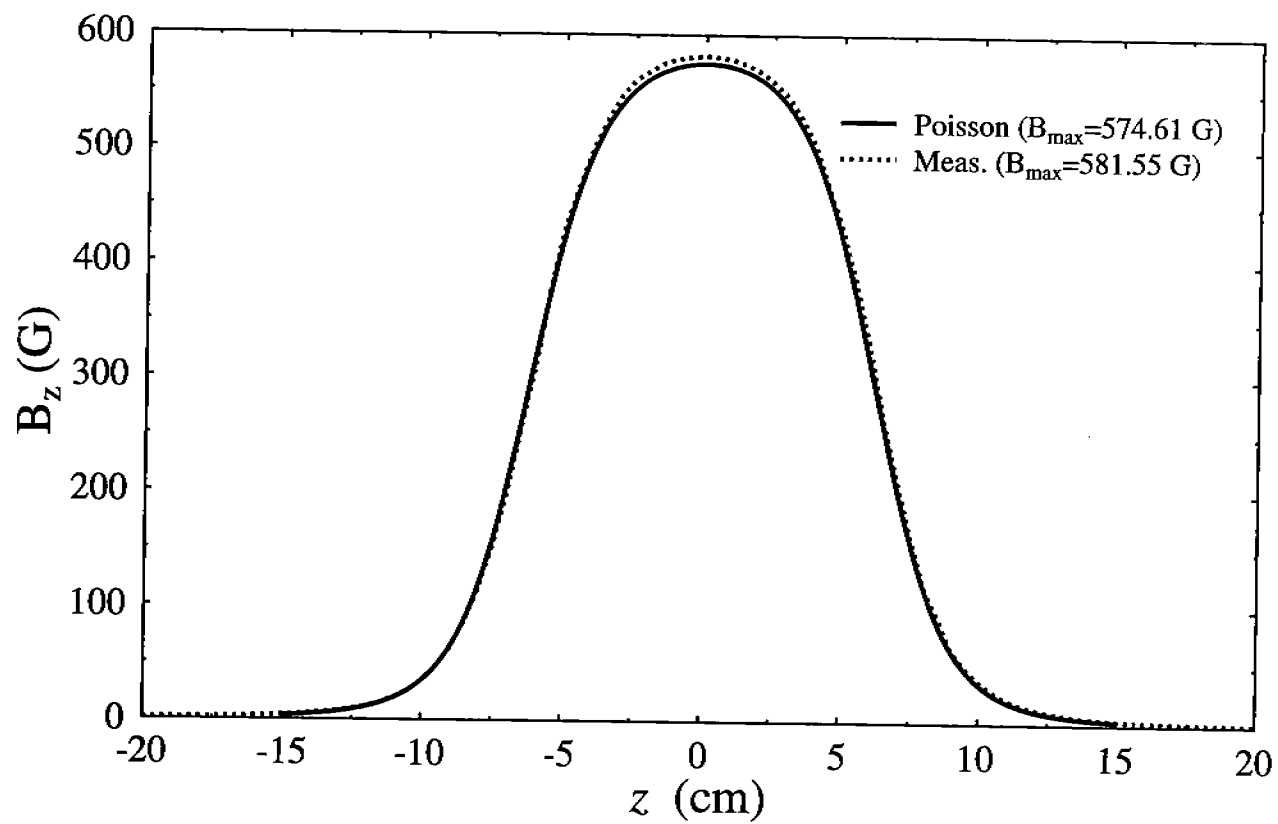


Fig. 2 On-axis magnetic field profile for FEL lens #1 operating at 7.162 A.

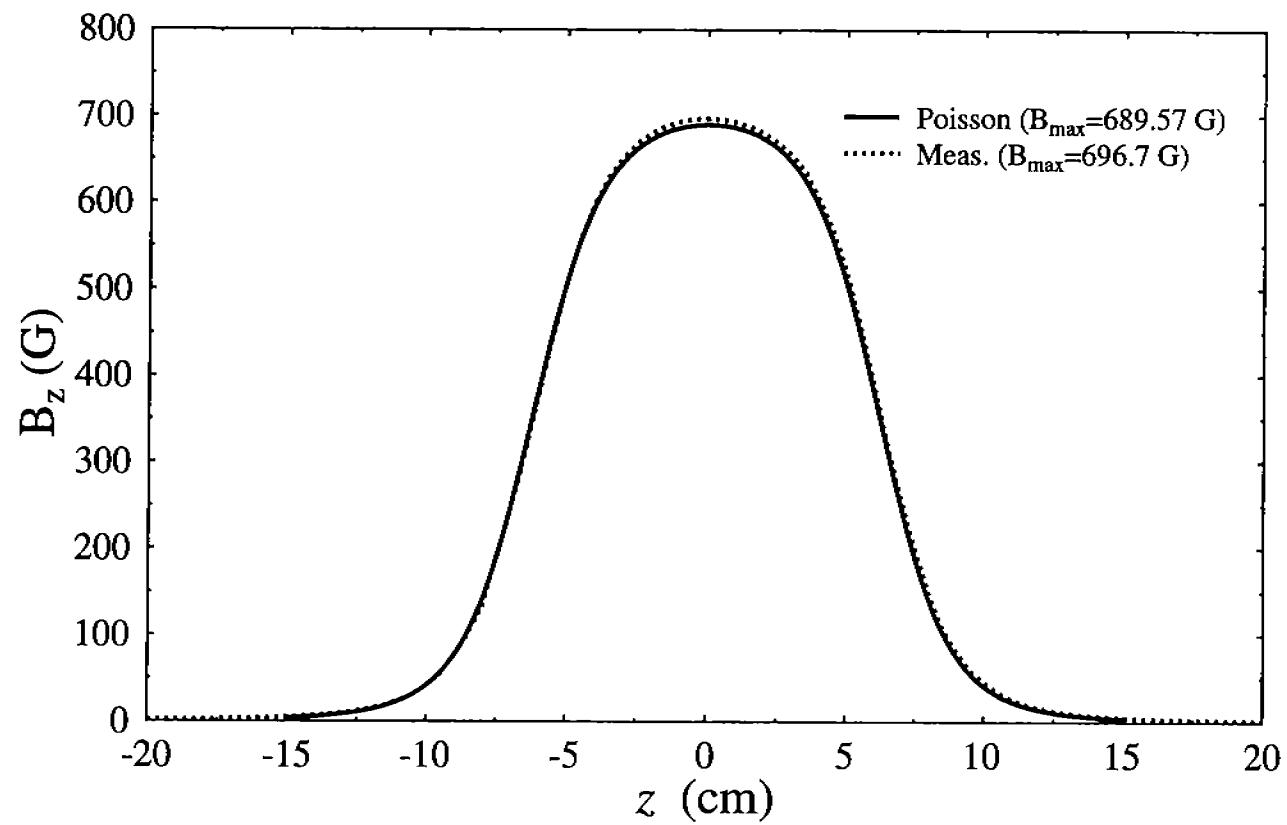


Fig. 3 On-axis magnetic field profile for FEL lens #1 operating at 8.595 A.

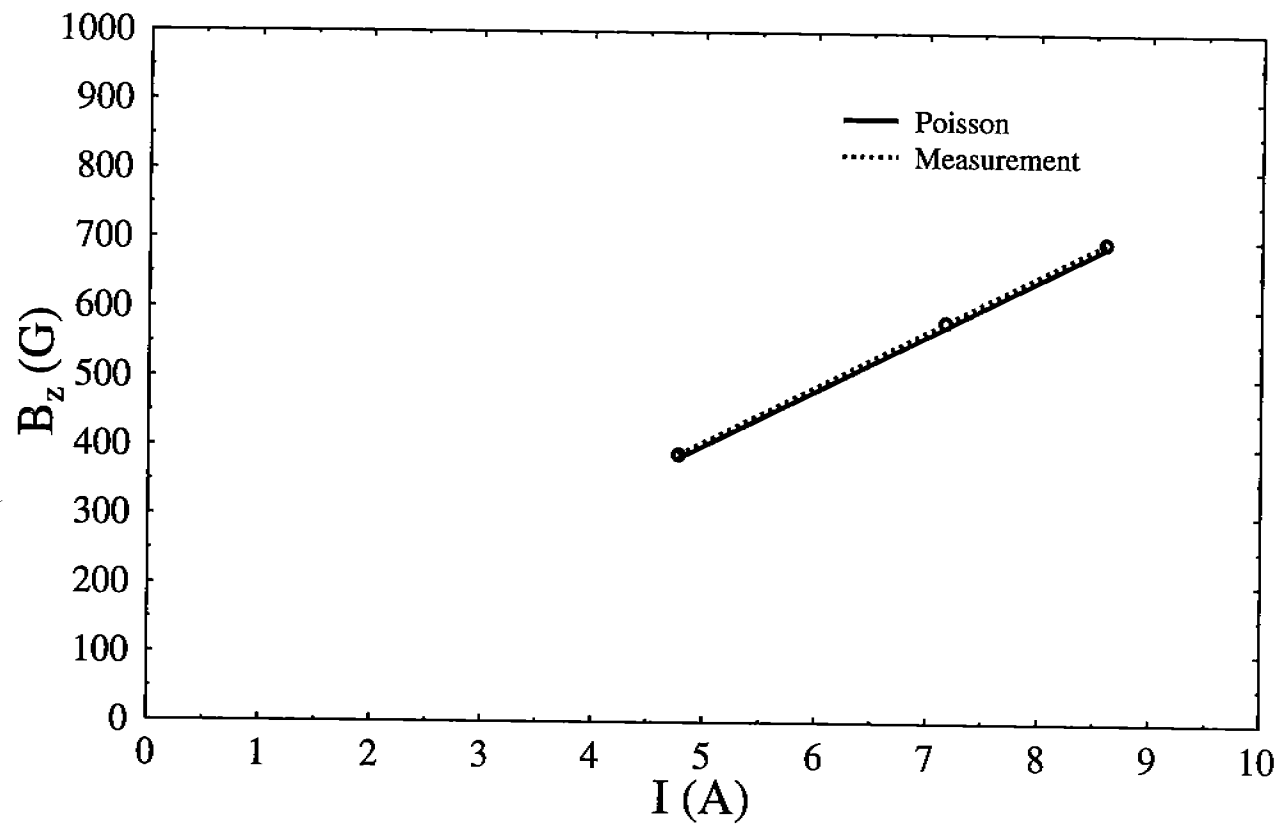


Fig. 4 On-axis peak magnetic field strength vs operating current for FEL lens #1.

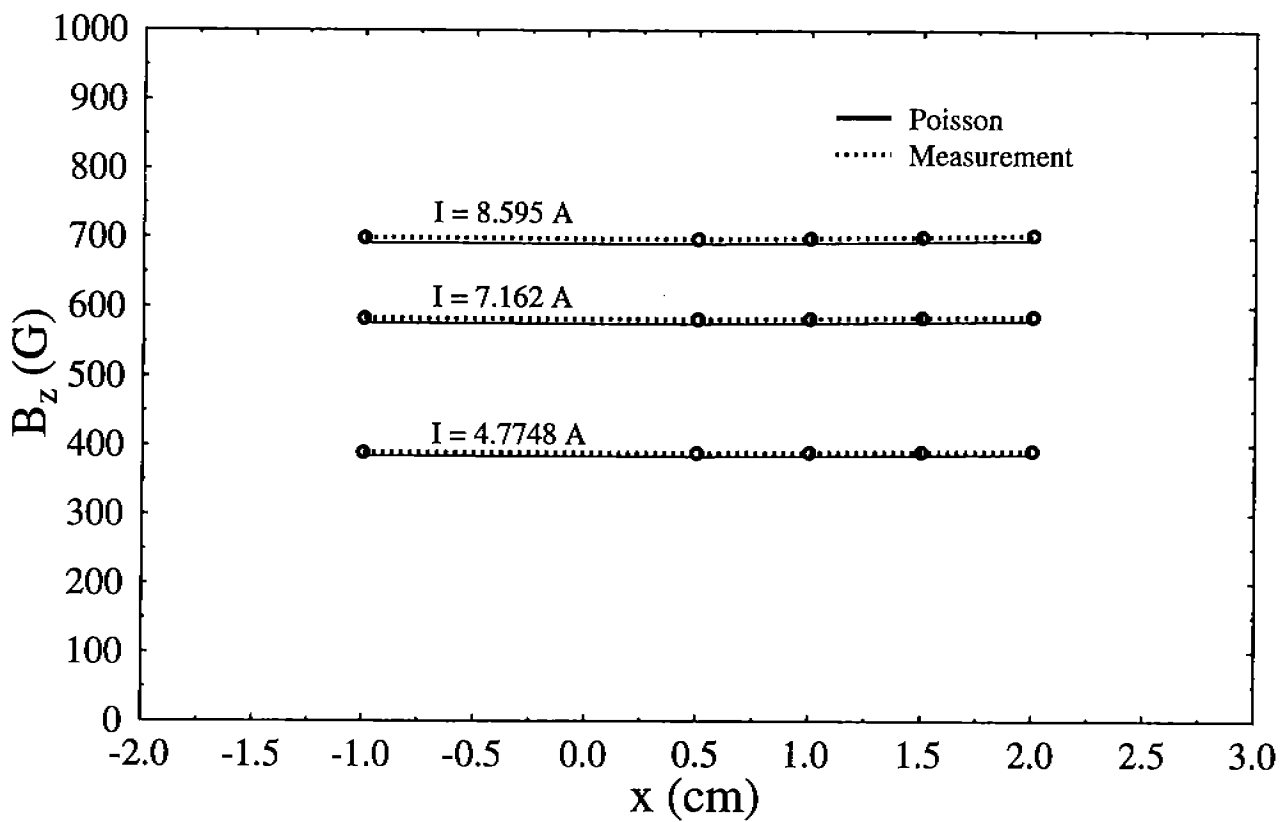


Fig. 5 Mid-plane magnetic field strength vs horizontal coordinate  $x$  for FEL lens #1.

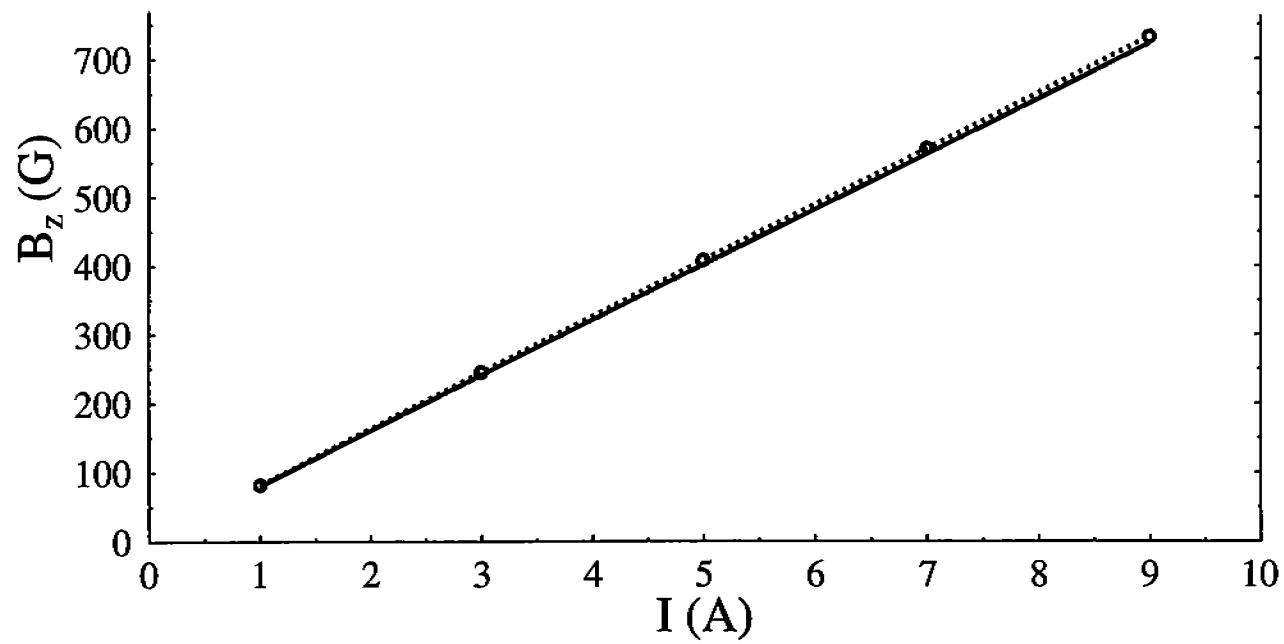


Fig. 6 On-axis peak magnetic field strength vs operating current for FEL lens #2.

fel-L2-fig1.gle HL/sol.dir 18:14:34 Wed Oct 18 1995

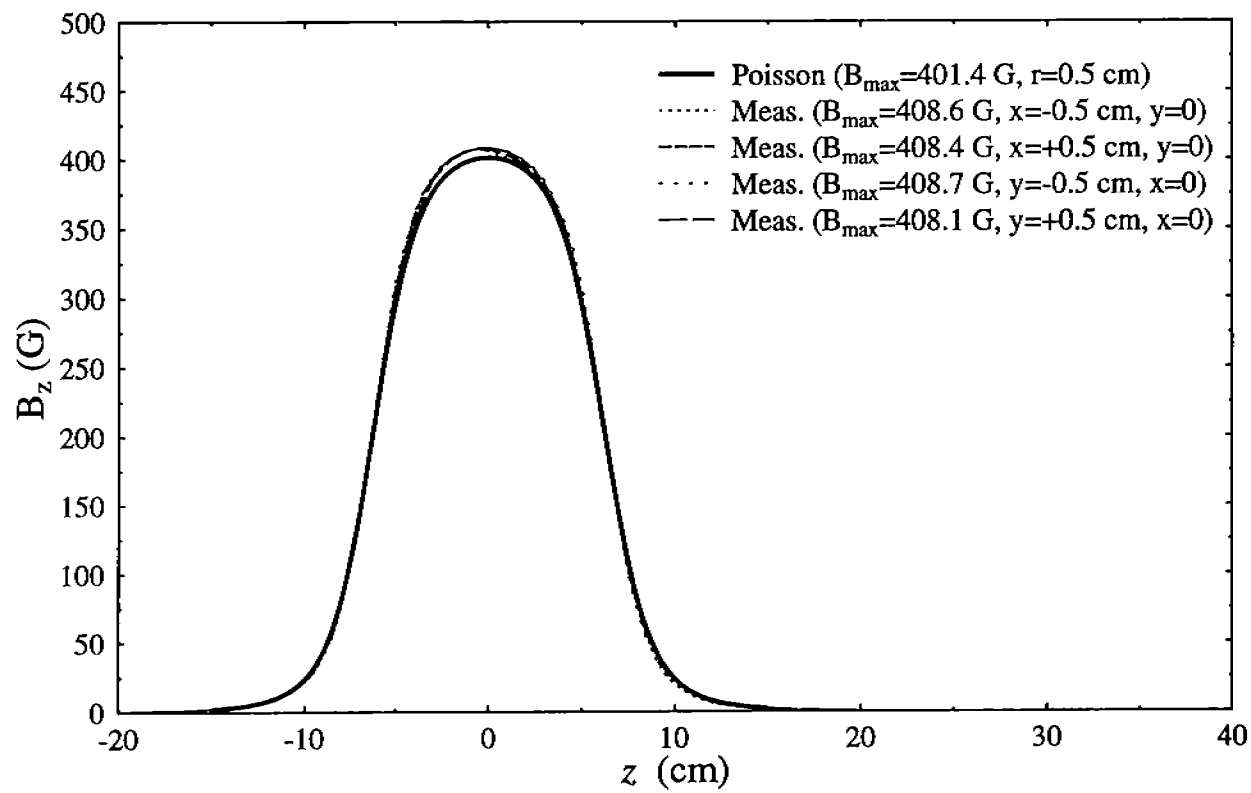


Fig. 7 Off-axis magnetic field profile for FEL lens #2 operating at 5 A.

## Summary of the measurements done by K. Sullivan

## (1) Lens #1:

SOL00110.DAT:Comment = : :water cooled i=8.9546 center of bore  
SOL00111.DAT:Comment = : :water cooled i=7.162 center of bore  
SOL00112.DAT:Comment = : :water cooled i=4.775 center of bore  
SOL00113.DAT:Comment = : :water cooled i=8.595 -x 1cm  
SOL00114.DAT:Comment = : :water cooled i=7.162 -x 1cm  
SOL00115.DAT:Comment = : :water cooled i=4.7748 -x 1cm  
SOL00116.DAT:Comment = : :water cooled i=8.595 +x .5 cm  
SOL00117.DAT:Comment = : :water cooled i=7.162 +x .5 cm  
SOL00118.DAT:Comment = : :water cooled i=4.7748 +x .5 cm  
SOL00119.DAT:Comment = : :water cooled i=8.595 +x 1cm  
SOL00120.DAT:Comment = : :water cooled i=7.162 +x 1cm  
SOL00121.DAT:Comment = : :water cooled i=4.7748 +x 1cm  
SOL00122.DAT:Comment = : :water cooled i=8.595 +x 1.5cm  
SOL00123.DAT:Comment = : :water cooled i=7.162 +x 1.5cm  
SOL00124.DAT:Comment = : :water cooled i=4.775 +x 1.5cm  
SOL00125.DAT:Comment = : :water cooled i=8.595 +x 2cm  
SOL00126.DAT:Comment = : :water cooled i=7.162 +x 2cm  
SOL00127.DAT:Comment = : :water cooled i=4.875 +x 2cm  
SOL00128.DAT:Comment = : :water cooled i=8.595 y up 1cm  
SOL00129.DAT:Comment = : :water cooled i=7.162 y up 1cm  
SOL00130.DAT:Comment = : :water cooled i=4.775 y up 1cm

## (2) Lens #2:

SOL00201.DAT:Comment = : :Air cooled I=9 center of core, 161f  
SOL00202.DAT:Comment = : :Air cooled I=7 center of core, 161f  
SOL00203.DAT:Comment = : :Air cooled I=5 center of core, 161f  
SOL00204.DAT:Comment = : :Air cooled I=3 center of core, 161f  
SOL00205.DAT:Comment = : :Air cooled I=1 center of core, 161f  
SOL00206.DAT:Comment = : :Air cooled, I=5, -x .5cm  
SOL00207.DAT:Comment = : :Air cooled, I=5, +x .5cm  
SOL00208.DAT:Comment = : :Air cooled, I=5, -y .5cm  
SOL00209.DAT:Comment = : :Air cooled, I=5, +y .5cm

Note: in SOL00110.DAT, the testing current should be 8.5946 A instead of 8.9546 A. The measurements for the second lens show no saturation up to 9 A.