Status of the South Magnet Mapping Analysis

Introduction

In this document the current status of the South Magnet Mapping analysis is described. After a brief description of the mapping methodology, we present a comparison between the measured magnetic field values and the ones calculated by the finite element program TOSCA. Finally, we comment on the results and we point out possible reasons for discrepancy between the measured and calculated values.

Detailed information about that system can be found at reference \cite{Muon_Arms}

Mapping method

PHENIX experimentalists followed a novel method for the determination of the magnetic field inside the muon magnets.

A triangular aluminum fixture capable of rotating itself around the z (beam line) axis was positioned inside in the Muon magnet. On the surface of the fixture Hall probes were positioned, capable of measuring the r (perpendicular to the z-axis) or z (parallel to the z-axis) components of the magnetic field, depending on their orientation.

The triangular fixture was assembled by using 3 panels with mounting holes in order to accommodate the Hall probes. Each of the panels was precisely engineered and therefore the position of each probe relative to an arbitrary origin on the panel was precisely fixed. The fixture was populated with a total of 196 probes, used for the magnet mapping, from a possible maximum of 467 possible.

The three panels along with the South magnet were individually surveyed by the BNL survey and alignment group with respect to PHENIX frame of reference. This way the position of each probe with respect to the South magnet and PHENIX frame of reference were measured. Each set of 18 probes (of the total 196) was bussed together at the same cable. At Figure 1 we show the fixture with the position of the Hall probes used for the South Magnet mapping. Each number corresponds to a different cable.

Along the perimeter of the fixture, Hall probes were positioned in such a way, so that they measure the component of the magnetic field perpendicular to the frame perimeter, and therefore perpendicular to the surface of revolution being formed from the fixture rotation. At the interior of the fixture, the probes were arranged either in a line perpendicular to the Z axis measuring the Z component of the field as a function of R, or in almost horizontal lines measuring the R perpendicular to the Z axis field component.

The rotation of the fixture was controlled by means of a stepping motor, and every 3 degrees step, a magnetic field map was taken. Therefore a map consists of the parallel or perpendicular to the PHENIX z-axis magnetic field (depending on the probe orientation) at 196 points inside the muon magnet, at a particular angle of the fixture.

After having completed a full 360 degrees rotation, we had a measurement of the perpendicular component of the magnetic field on the surface of revolution formed by the fixture's perimeter.

Gauss theorem ensures us that if we know the perpendicular component of the magnetic field on a closed surface, we can calculate the magnetic field in every point in the interior of the surface in absence of electric currents. Thus, by exploring that property and by using our measurements we are able to calculate the magnetic field in the magnet's interior.

Currently there are two proposals regarding the calculation of the magnetic field inside the Muon Magnets. One is based in the TOSCA finite element software package. TOSCA is a commercial software package from Vector Field

Ltd., Kidlington, England. \cite{tosca1,tosca2} Its purpose is the general solution of three-dimensional magneto-static equations. Gauss theorem ensures the uniqueness of the Maxwell equation solution for a particular boundary value problem. Therefore if TOCSA reproduces the magnetic field component normal on the boundary surface in the muon magnet, it will also reproduce the magnetic field inside the magnet's volume. The second approach for the problem is based on a software packet named MAPPER, operated by Roy Thern. The magnetic field component normal to the boundary surface of the muon magnet is input to that software package. The Maxwell's equations are solved and the magnetic field inside the Muon Magnet volume is calculated.

Magnetic field measurements inside the South Muon Magnet have been taken and currently the analysis of these data is under way. The quality of the measured data is checked against the magnetic field calculated by the TOSCA software finite element package.

TOSCA and Magnet Mapping data comparison

We have been provided with a TOSCA reconstructed Bx,By,Bz magnetic field mapping inside the Muon South magnet on a 4cmx4cmx4cm three-dimensional grid. (Wu Zheng). The exact positions of the Hall probes do not necessarily coincide with points of the 4cmx4cmx4cm grid where the magnetic field has been calculated by the TOSCA finite element program. In order to estimate the TOSCA magnetic field at the exact position of measurement, we used the four-point interpolation method applied for each phi angle separately, at the four closest grid points on the plane of the mapping fixture, surrounding the measurement position.

In this section we compare the measured magnetic field with the values interpolated from TOSCA map. We present a number of plots where the measured and TOSCA fields are presented along the perimeter and inside the area spanned by the mapping fixture. Comparisons were done separately for each mapping angle. More specifically:

Figures 2 and 3 compare the measured and calculated by TOSCA magnetic field along the inner piston of the South Muon Magnet, for various phi angles. Figure 2 covers angles from 0 to 30 degrees and Figure 3 from 40 to 70 degrees. At the plot of the fixture, this line is depicted with probes of cables 1,2,4 and 3 (with the number 1,2,4 and 3).

Figures 4 and 5 compare the measured and calculated by TOSCA magnetic field along the side of the fixture closest to the magnet's lampshade, along the outer edge of the magnet cone. Similarly, Figure 4 covers angles from 0 to 30 degrees and Figure 5 from 40 to 70 degrees.

At the plot of the fixture, this line is depicted with probes of cable 6 (with the number 6).

Figures 6 and 7 compare the measured and calculated by TOSCA z components (Bz) of the magnetic field along the hall probe line perpendicular to z-axis at the magnet's entrance (near the location of

Station-1 Chambers). Figure 6 covers angles from 0 to 30 degrees and Figure 7 from 40 to 70 degrees. At the plot of the fixture, this line is depicted with probes of cable 7 (with the number 7).

Figures 8 and 9 compare the measured and calculated by TOSCA z components (Bz) of the magnetic field along the hall probe line perpendicular to z axis at the back of the magnet (near the location of Station-3 Chambers). Figure 8 covers angles from 0 to 30 degrees and Figure 9 from 40 to 70 degrees. At the plot of the fixture, this line is depicted with probes of cable 5 (with the number 5). The mapping fixture apart from Hall probes measuring the magnetic field component perpendicular to magnet volume boundary, contains probes measuring the z and r component of the magnetic field in the interior of the magnet. Figures 10 to 19 present the data from those probes.

Figures 10 and 11 compare the measured and calculated by TOSCA z components (Bz) of the magnetic field along the hall probe line perpendicular to z axis near the middle of the inner piston (near the location of Station-2 Chambers). Figure 10 covers angles from 0 to 30 degrees and Figure 11 from 40 to 70 degrees. At the plot of the fixture, this line is depicted with the probes of cable 3 (with the number 3), forming a line perpendicular to z-axis at about |z|=3.5 meters. At this area we are getting the greatest discrepancy between measured and calculated data.

Figures 12 and 13 compare the measured and calculated by TOSCA r components (Br) of the magnetic field along the Hall probe line denoted by letter B at the mapping frame diagram at Figure 1.

Figure 12 covers angles from 0 to 30 degrees and Figure 13 from 40 to 70 degrees. Figures 14 and 15 show the same component Br measured along the line denoted by the letter A, figures 16 and 17 the Br measured along the line noted as 9 and figures 18 and 19 the Br along the line formed by the probes of cable 8.

Lastly Figure 20 shows the line integral of the magnetic field along the 3 (almost) horizontal lines denoted by B, A and 9 at the fixture diagram. We give compare the result by using measured field values (square) and values from the TOSCA map (circles). We present the results for various mapping phi angles.

The magnet mapping software

In order to analyze measured, calculated from TOSCA and future reconstructed data, we modified the Magnet Mapping Analysis Software \cite{federica}, (already used for the analysis of the Central

Magnet Mapping data) in accordance to the needs of the Muon Magnet analysis.

All measured data files are located in the /phenix/workarea/phemap/data directory. The subdirectories /southmagnet/ and /northmagnet/ contain various maps of the south and north muon magnets.

Each of the subdirectories therein, contains files corresponding to different phi angles of the mapping fixture around the z-axis. The subdirectory /currentscan/ contains mapping data for a variety of magnet currents, while the phi angle is constant. Each of the subdirectories containing mapping data, contains also ASCII files (with the extension .dat) with calibration parameters, voltage offsets and other constants for each Hall-probe. It is necessary that these files exist at every directory along with data files.

The analysis software is contained in the /phenix/workarea/phemap/southmagnet or

/phenix/workarea/phemap/northmagnet directories. The subdirectory structure remains the same as described in reference \cite{federica}.

Conclusion and necessary further studies

First of all we observed a small number of Hall probes malfunctioning. The measured field from these probes was a source of discontinuity when compared with the field from the other probes. Identified bad measurements or probes will be excluded from further consideration.

We observed regions where there is good agreement (2\% or less) between the measured and the calculated by TOSCA data, as well as regions with significant disagreement (can reach 10-12\%).

A general observation is that disagreement if higher in a high field region than in a low one. Thus, the disagreement at the entrance of the magnet is higher than the one observed at the back. Also as we move closer to the z-axis (from lampshade to the inner piston) the disagreement is more profound.

Another issue, is the quality of the Magnetic field data produced by the TOSCA package.

The calculated line integral of the magnetic field along horizontal lines populated with probes within the South Muon magnet, seems to differ with the corresponding integral calculated by using

TOSCA results, by 2 or 3 percent. The disagreement is higher at regions closer to the inner piston.

Another noticeable issue regards the quality of the field calculations by TOSCA. The inner piston geometry has been assumed (in the TOSCA configuration) totally symmetric with respect to phi angle. However investigation of the

TOSCA magnetic field, for close to the inner piston points of constant Z and radius, has revealed variations with respect to phi angle of the order 1-3\% depending on the Z coordinate. Figures 21 and 22 show the phi dependence of the Bz and Br calculated by TOSCA quantities for two points of constant r and z coordinates. The location of the points is near the inner piston (assumed cylindrically symmetric). Currently, the effect of mesh definition, on the quality of the calculated magnetic field is under investigation.

From the above mentioned observations, we think that the following studies are necessary.

- Check the quality of the TOSCA magnetic field calculations (choose the right mesh).
- Tune the properties of the material (magnetic permeability) in TOSCA.
- Implement the correct South Muon Magnet geometry.

Bibliography

\Muon_Arms {The PHENIX Muon Arms: Current Design and Status. The Phenix Muon Arms Collaboration. January 19, 1996}

\pdaq{PDAQ A data acquisition system for lab tests of the PHENIX detectors. ONCS, September 3, 1997}

\pstuff{PSTUFF An interim online monitoring package for the PHENIX experiment. Technical note 298, M.L. Purschke, June 3, 1997.}

\tosca1{The TOSCA Reference Manual, Vector Fields Limited, 24 Bankside, Kidlington, Oxford, OX5 1JE, England.}

\tosca2{The TOSCA User Guide, Vector Fields Limited, 24 Bankside, Kidlington, Oxford, OX5 1JE, England.}

\federica{Magnet Mapping Analysis Software, Federica Ceretto, December 22, 1998}

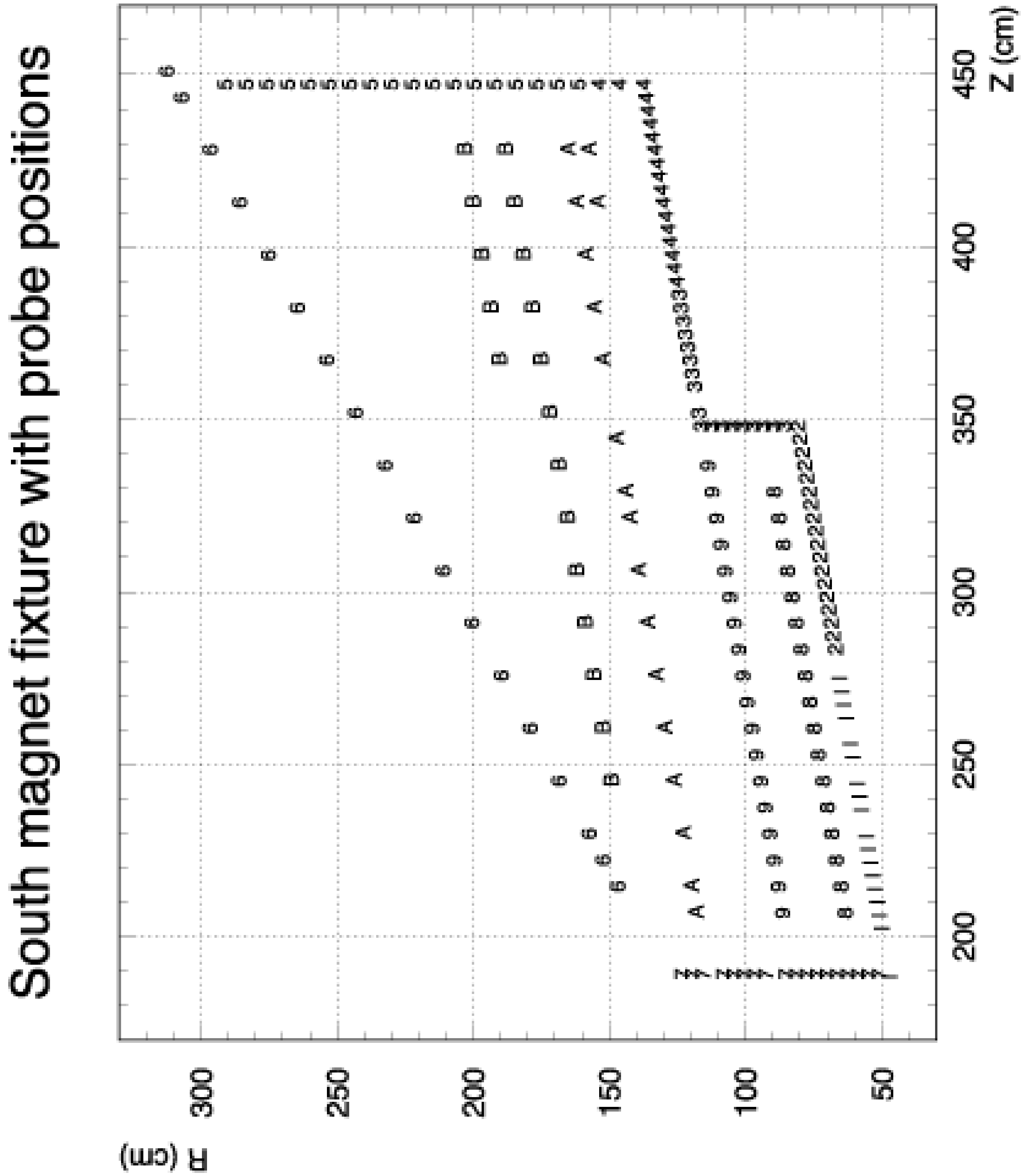

Figure 1. The fixture with the position of the Hall probes used for the South Magnet mapping. Each number corresponds to a different cable.

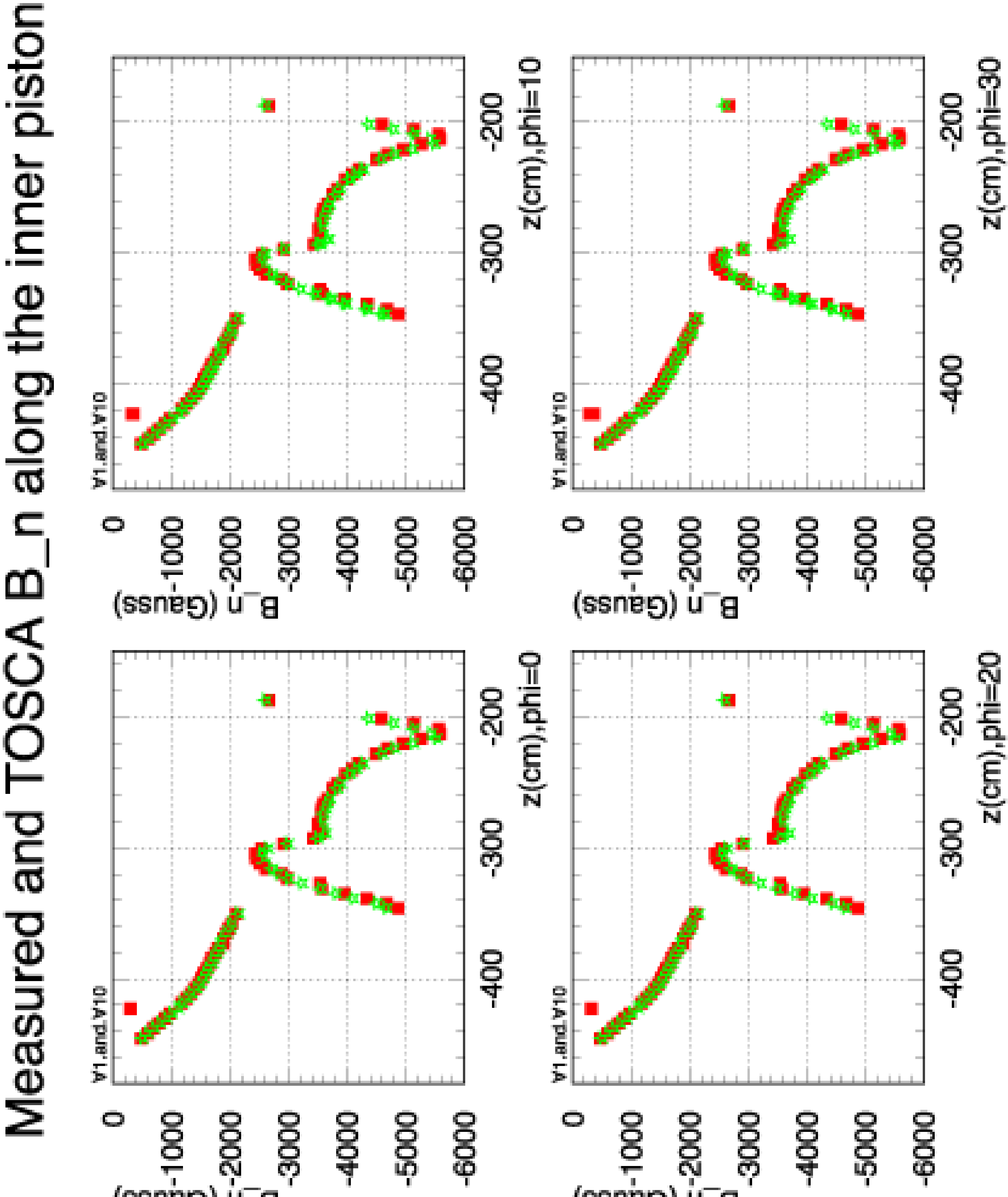

Figure 2. measured and TOSCA magnetic field values near the inner piston of the South Muon Magnet as a function of z, for phi=0,10,20,30 degrees. The components of the magnetic field measured is the one perpendicular to the fixture side near the piston. The squares are the measured values and the stars the values calculated by TOSCA.

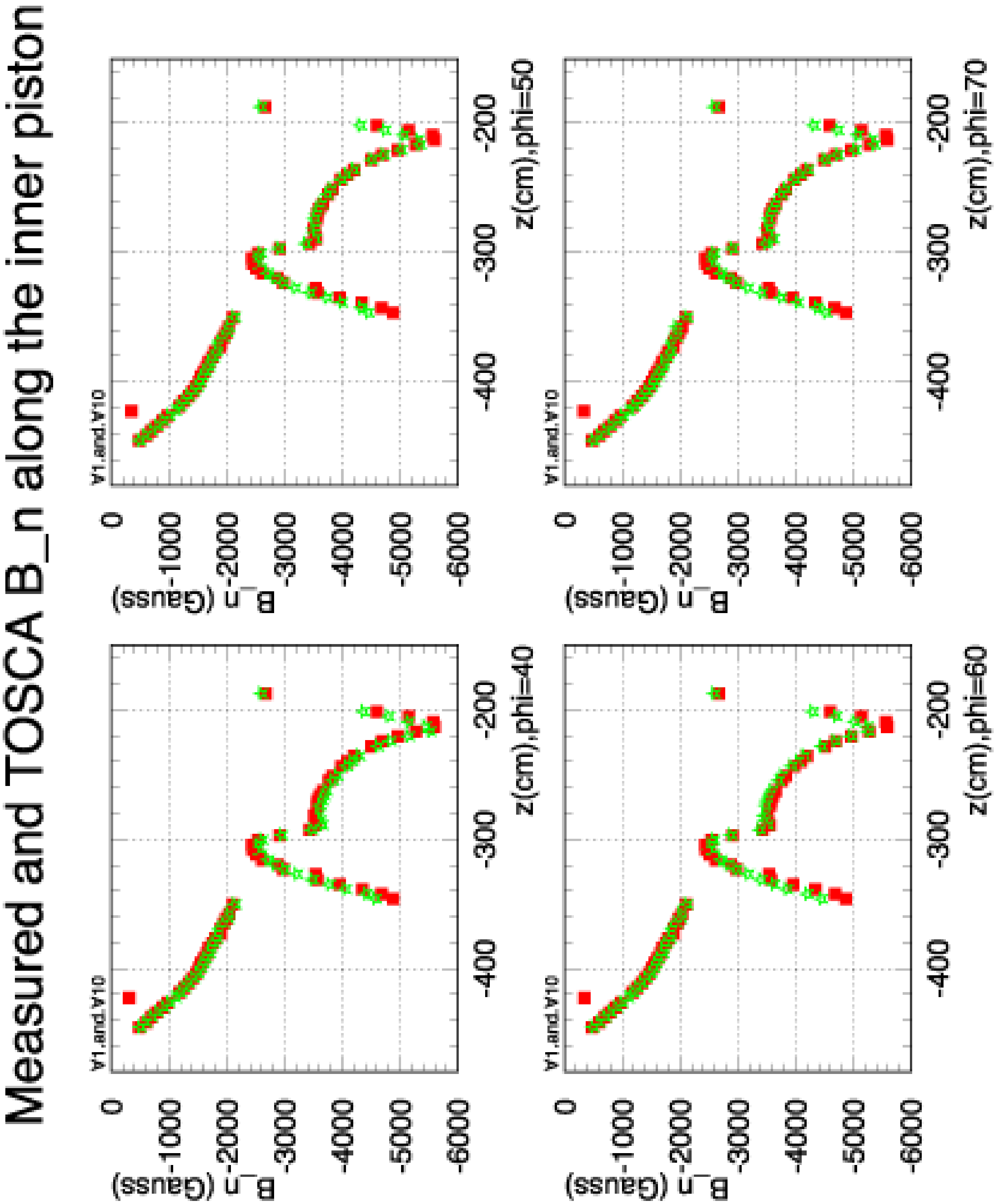

Figure 3. measured and TOSCA magnetic field values near the inner piston of the South Muon Magnet as a function of z, for phi=40,50,60,70 degrees. The components of the magnetic field measured is the one perpendicular to the fixture side near the piston. The squares are the measured values and the stars the values calculated by TOSCA.

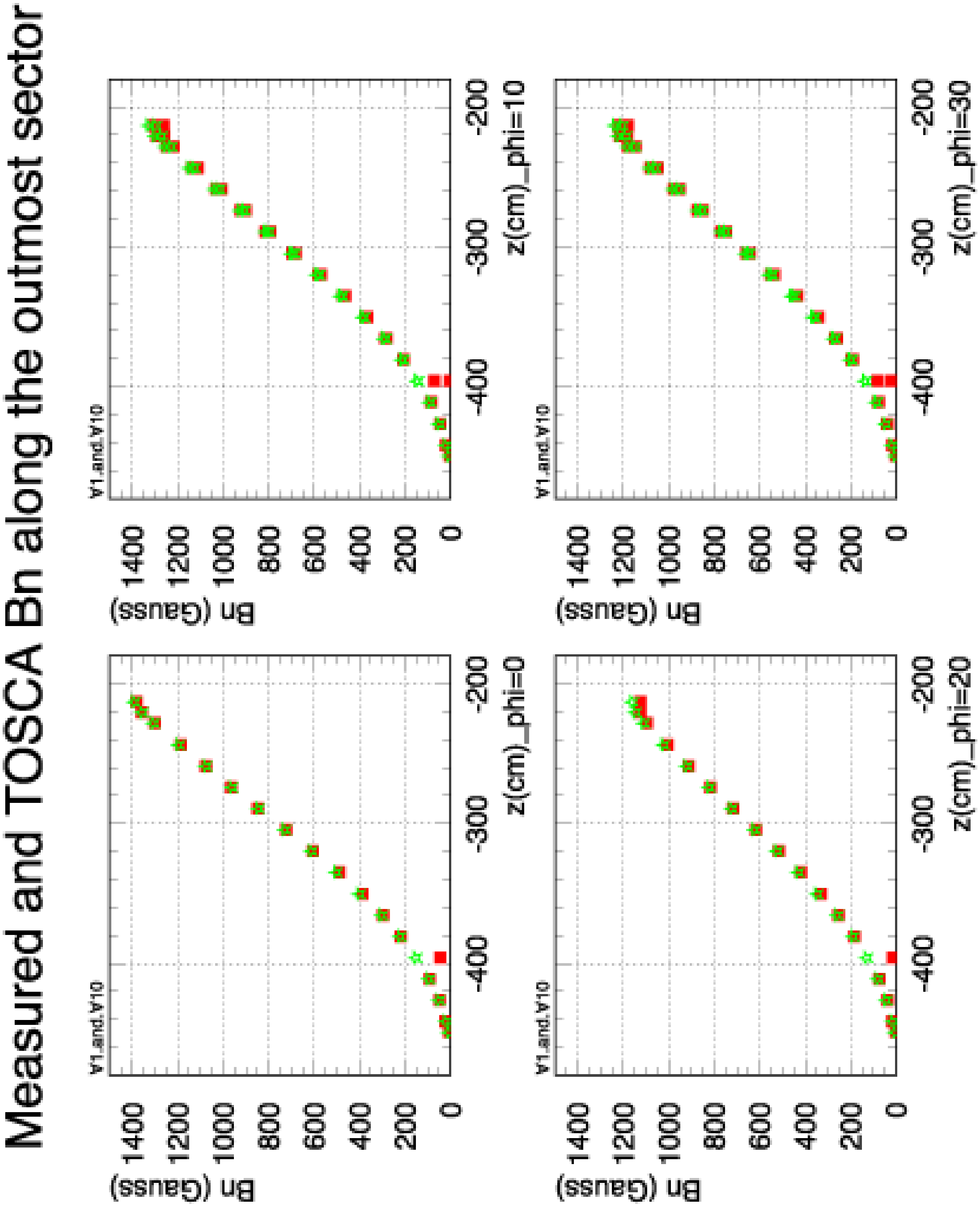

Figure 4. Measured and TOSCA magnetic field values near the outer edge of the South Muon Magnet cone as a function of z, for phi=0,10,20,30 degrees. The component of the magnetic field measured is the one perpendicular to the fixture side near the lampshade. The squares are the measured values and the stars the values calculated by TOSCA.

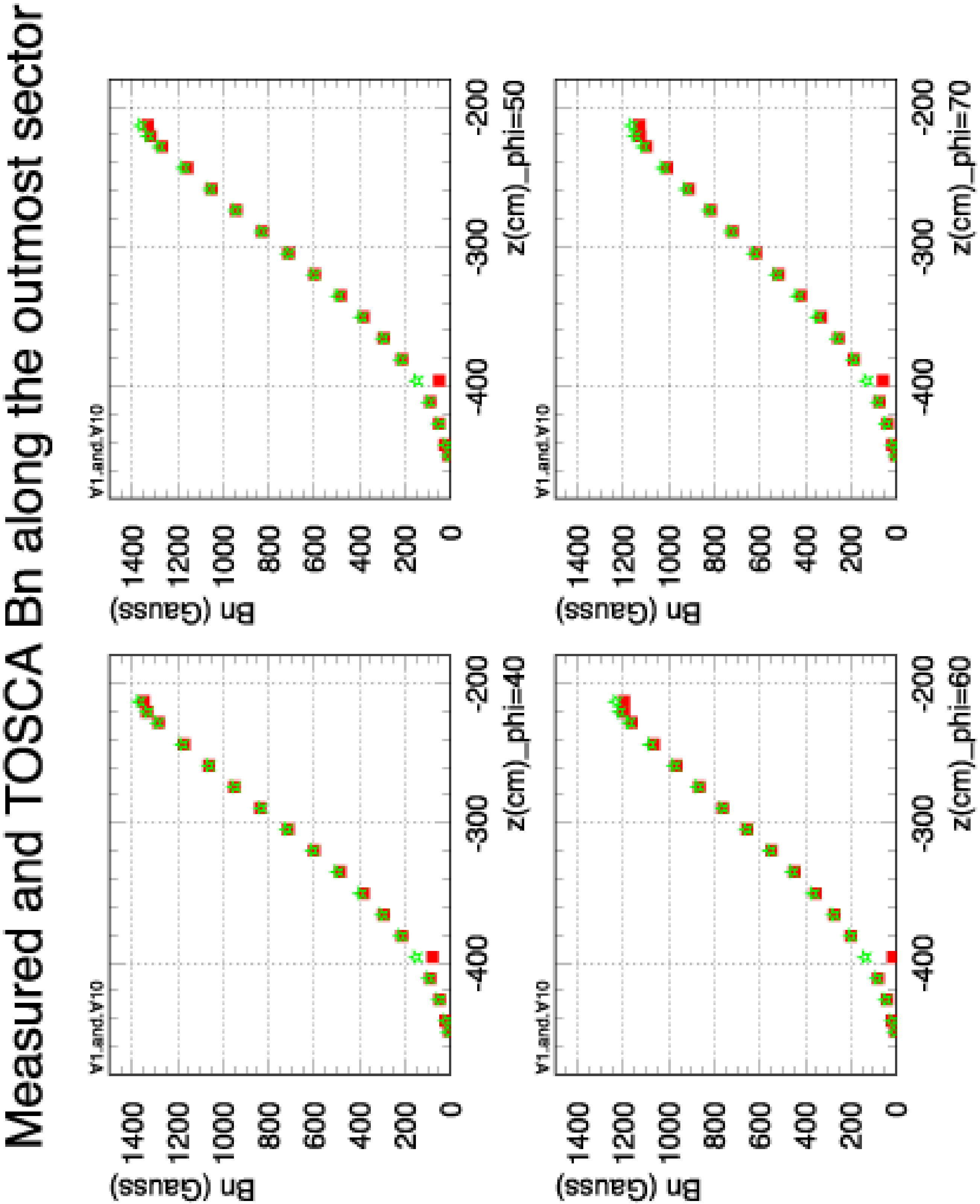

Figure 5. Measured and TOSCA magnetic field values near the outer edge of the South Muon Magnet cone as a function of z, for phi=40,50,60,70 degrees. The component of the magnetic field measured is the one perpendicular to the fixture side near the lampshade. The squares are the measured values and the stars the values calculated by TOSCA.

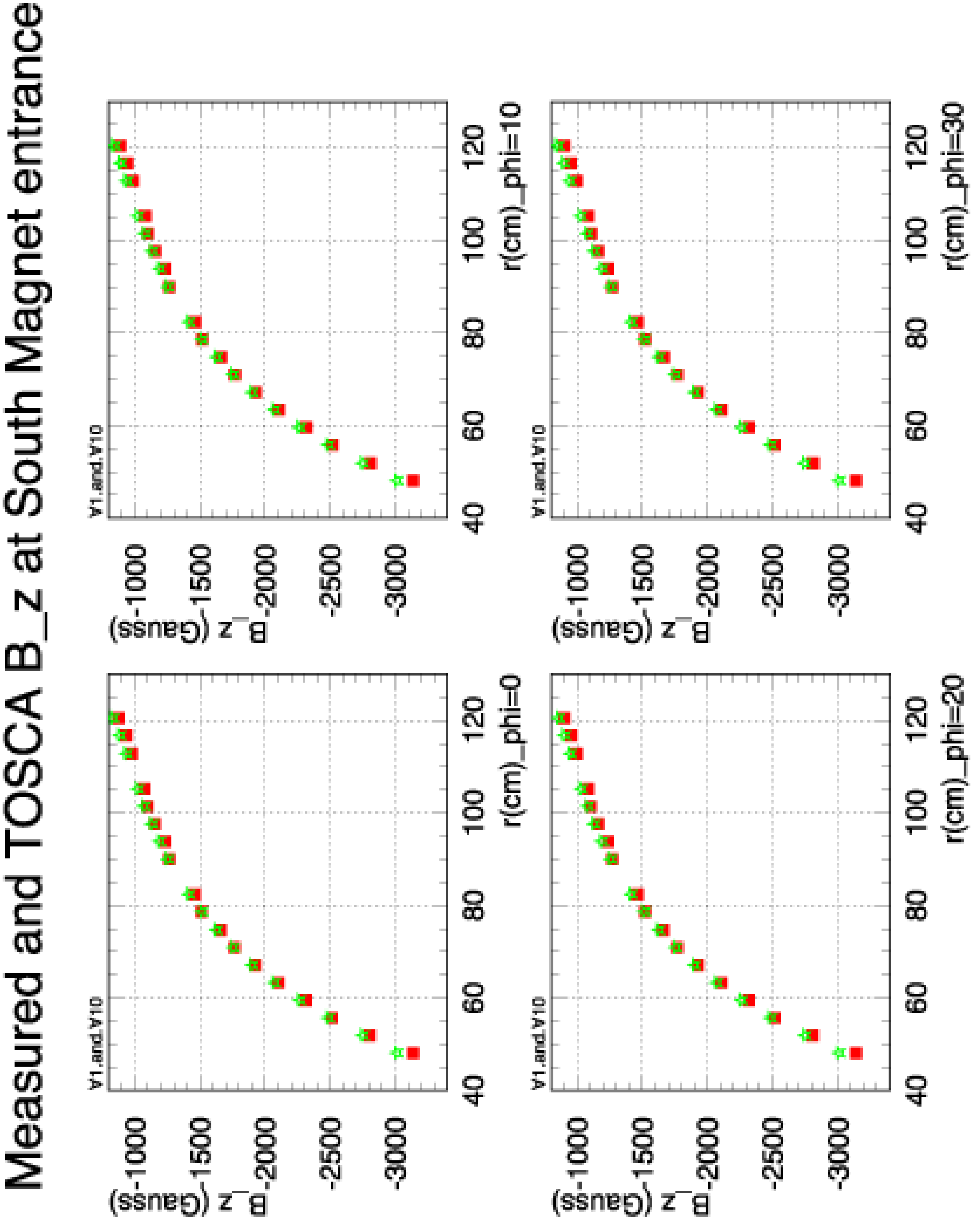

Figure 6. Measured and TOSCA Bz magnetic field values as a function of radius r (distance from the Z-axis) near the entrance of the South Muon Magnet, for phi=0,10,20,30 degrees. The squares are the measured values and the stars the values calculated by TOSCA.

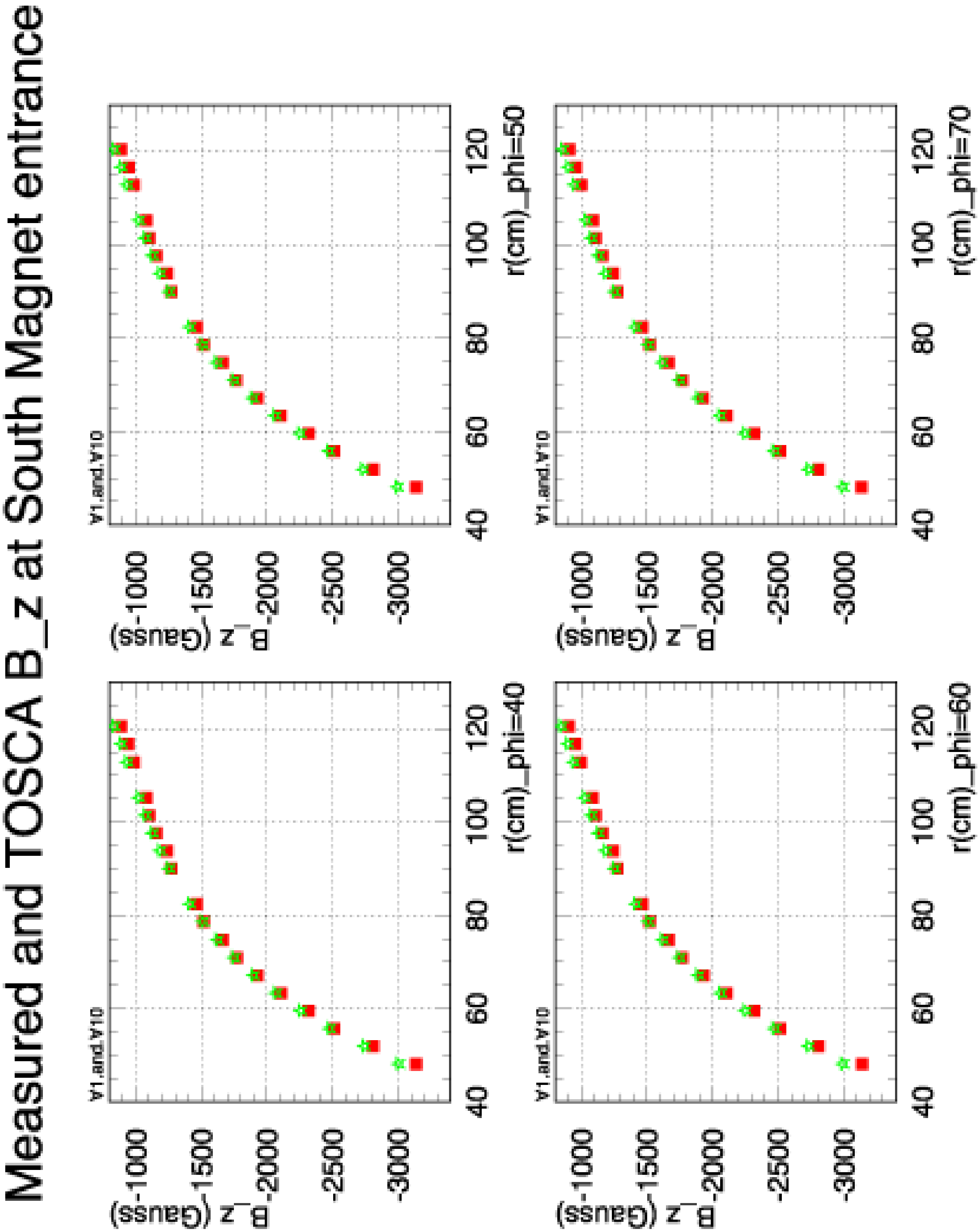

Figure 7. Measured and TOSCA Bz magnetic field values as a function of radius r (distance from the Z-axis) near the entrance of the South Muon Magnet, for phi=40,50,60,70 degrees. The squares are the measured values and the stars the values calculated by TOSCA.

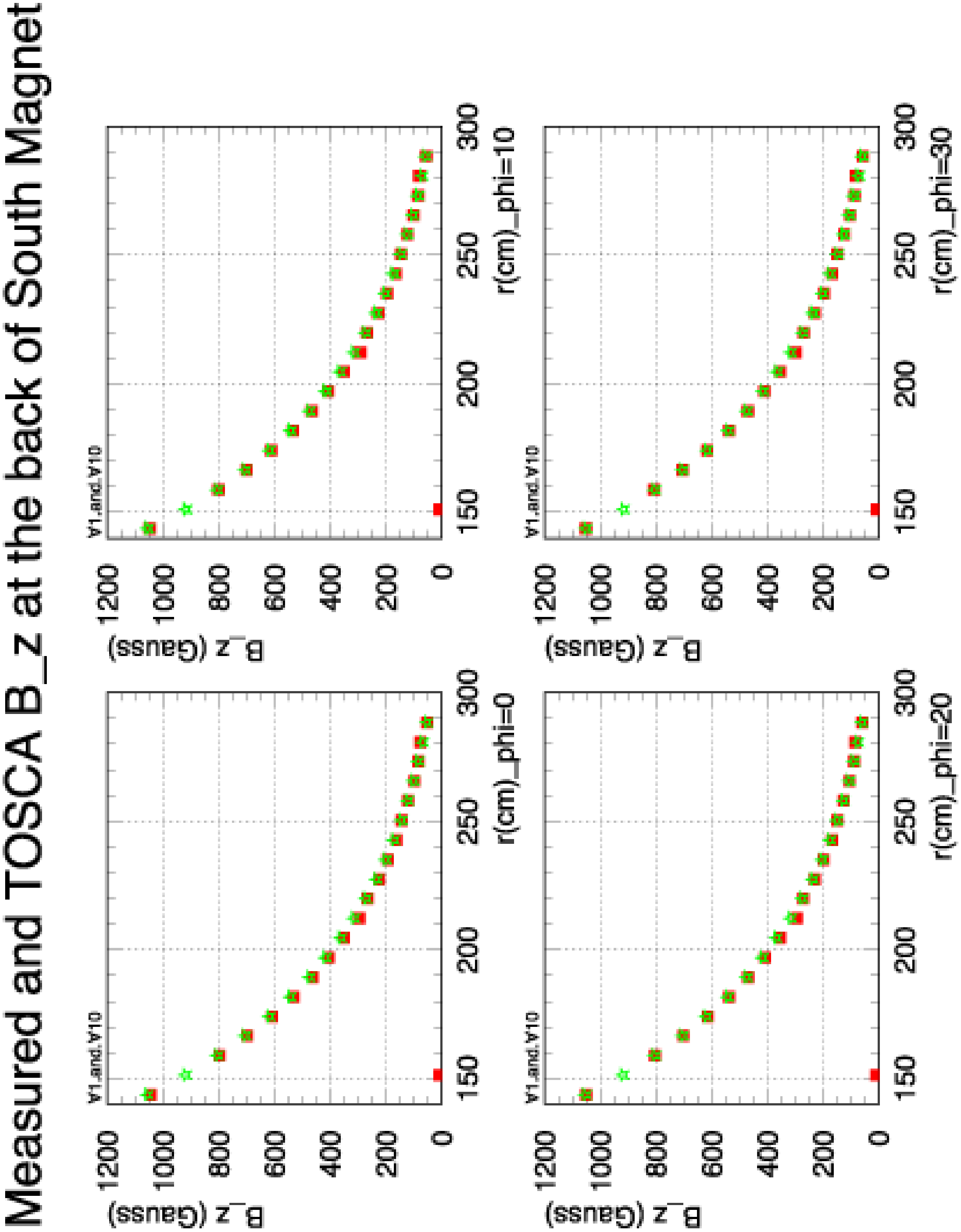

Figure 8. Measured and TOSCA Bz magnetic field values as a function of radius r (distance from the Z-axis) at the back of the South Muon Magnet, for phi=0,10,20,30 degrees. The squares are the measured values and the stars the values calculated by TOSCA.

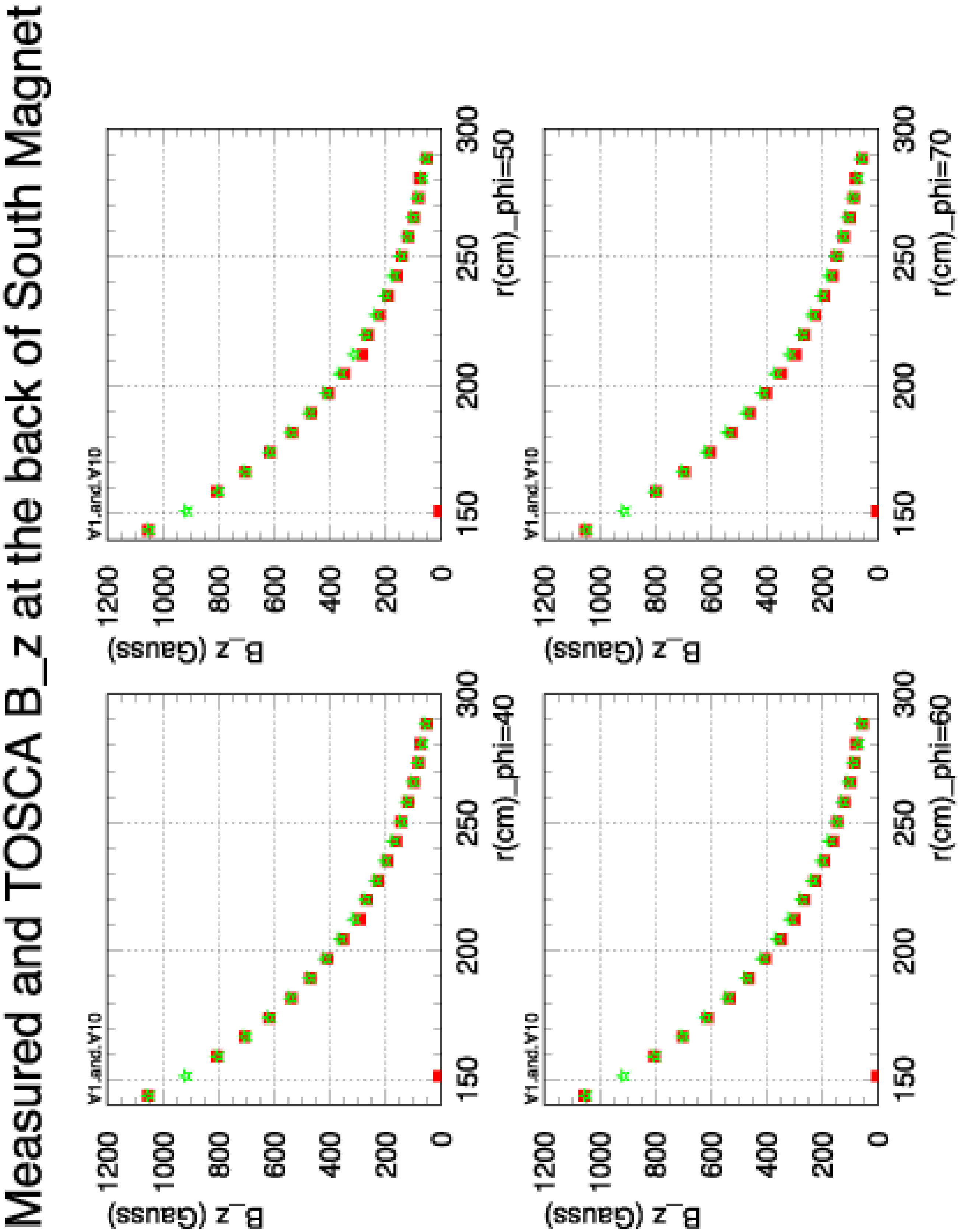

Figure 9. Measured and TOSCA Bz magnetic field values as a function of radius r (distance from the Z-axis) at the back of the South Muon Magnet, for phi=40,50,60,70 degrees. The squares are the measured values and the stars the values calculated by TOSCA.

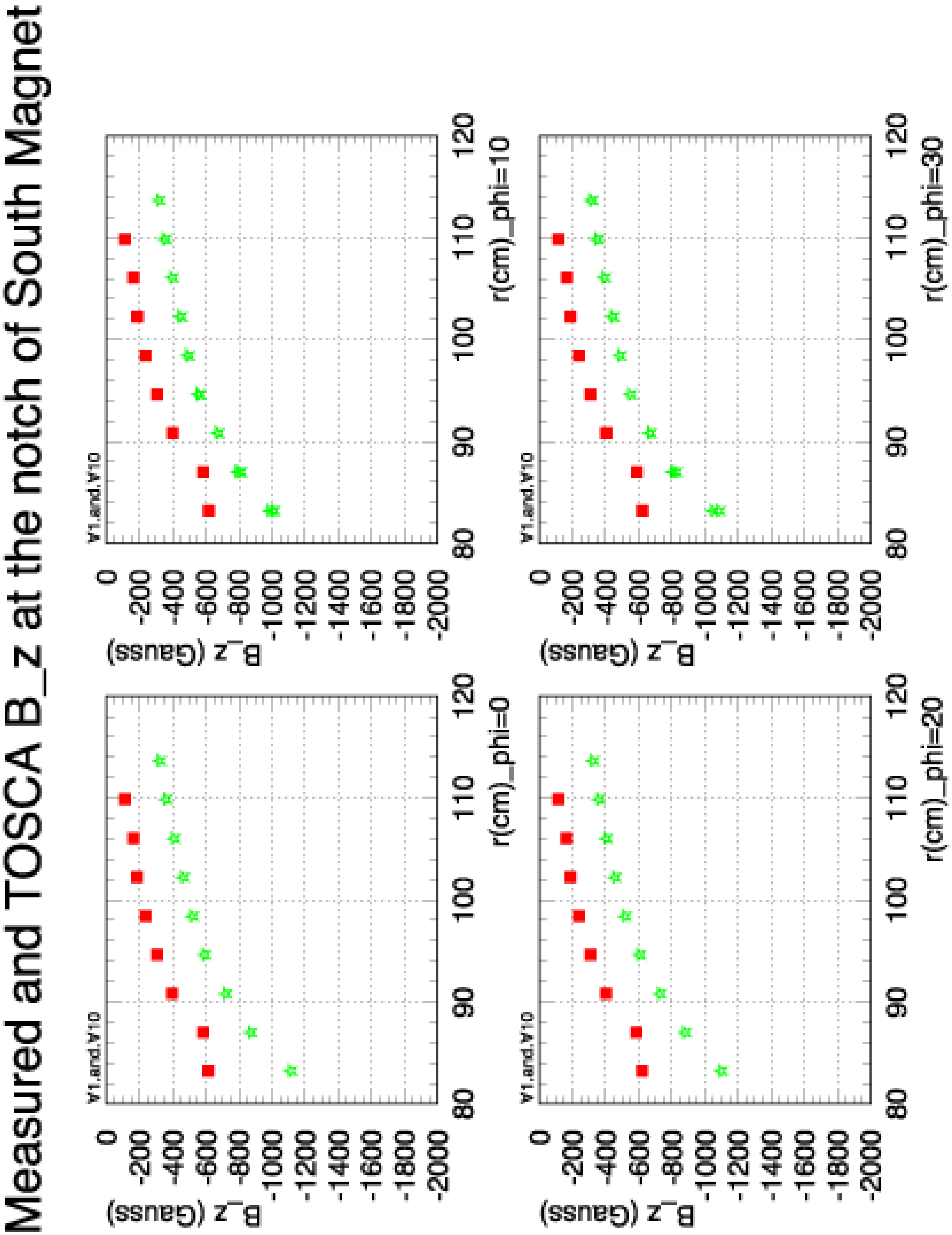

Figure 10. Measured and TOSCA Bz magnetic field values as a function of radius r (distance from the Z-axis) near the middle of the inner piston of the South Muon Magnet (|z|=3.5 m), for phi=0,10,20,30 degrees. The squares are the measured values and the stars the values calculated by TOSCA.

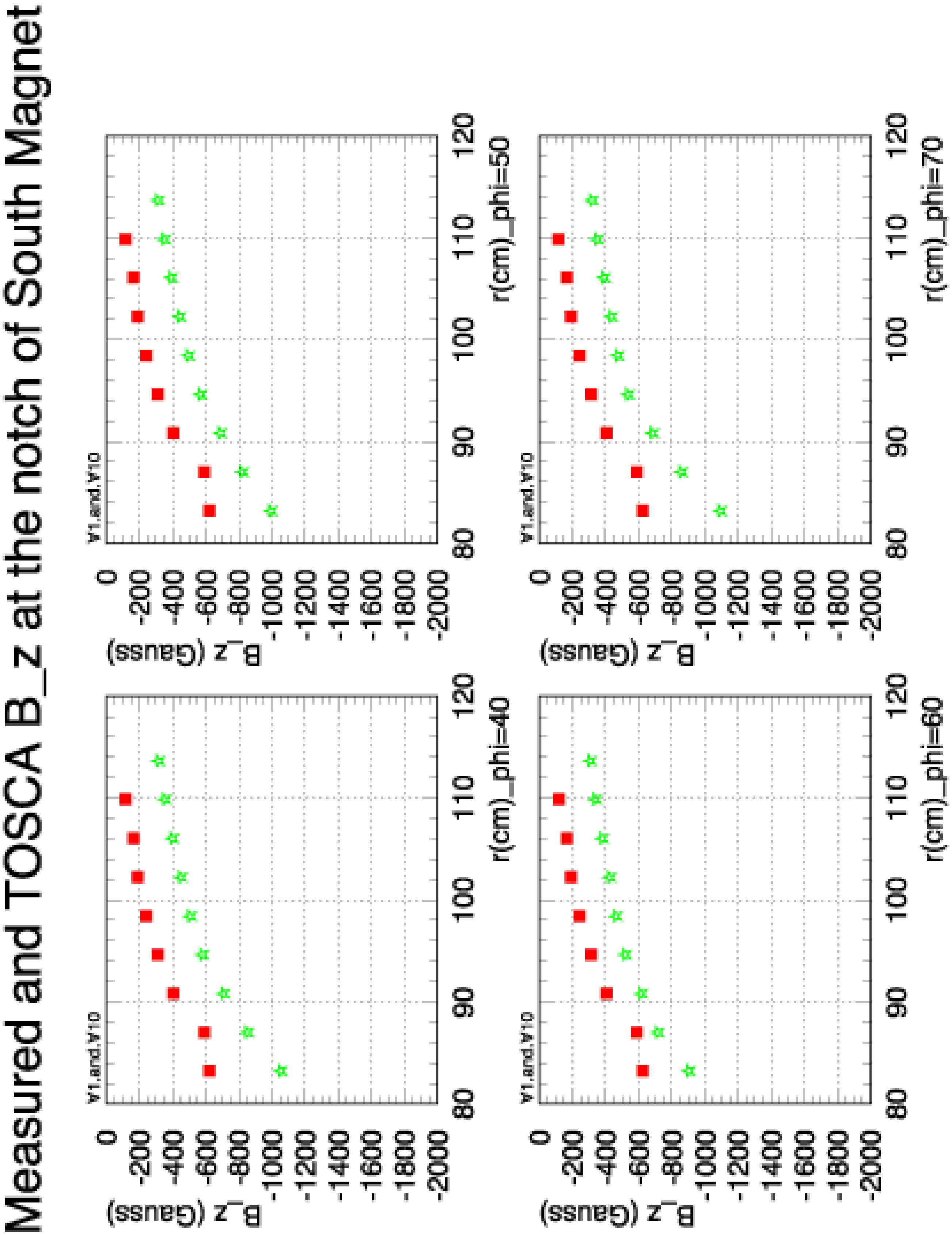

Figure 11. Measured and TOSCA Bz magnetic field values as a function of radius r (distance from the Z-axis) near the middle of the inner piston of the South Muon Magnet (|z|=3.5 m), for phi=40,50,60,70 degrees. The squares are the measured values and the stars the values calculated by TOSCA.

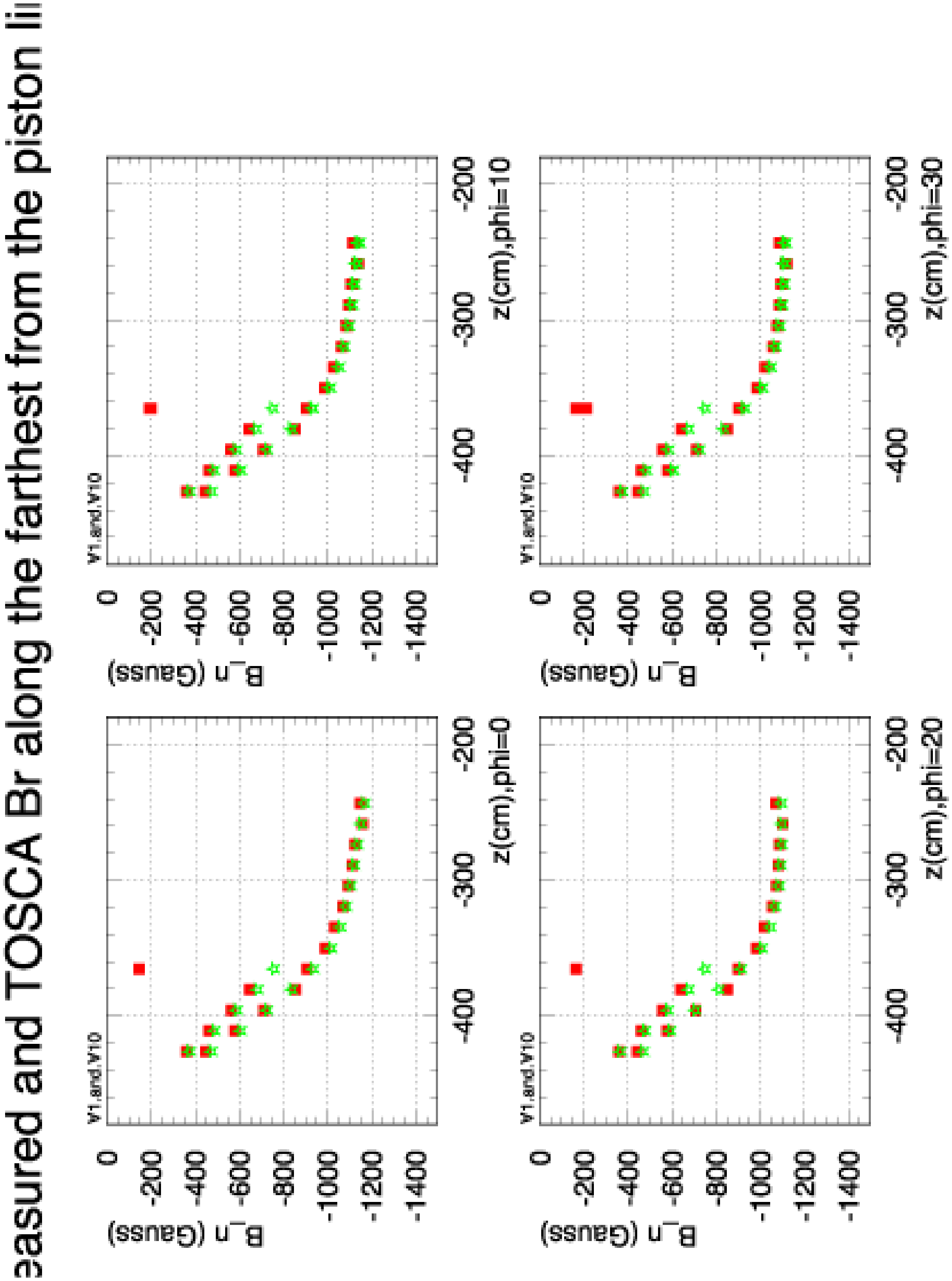

Figure 12. Measured and TOSCA Br magnetic field values as a function of Z coordinate along the line formed by the Hall probes noted as B at the fixture diagram. (phi =0,10,20,30 degrees.) The squares are the measured values and the stars the values calculated by TOSCA.

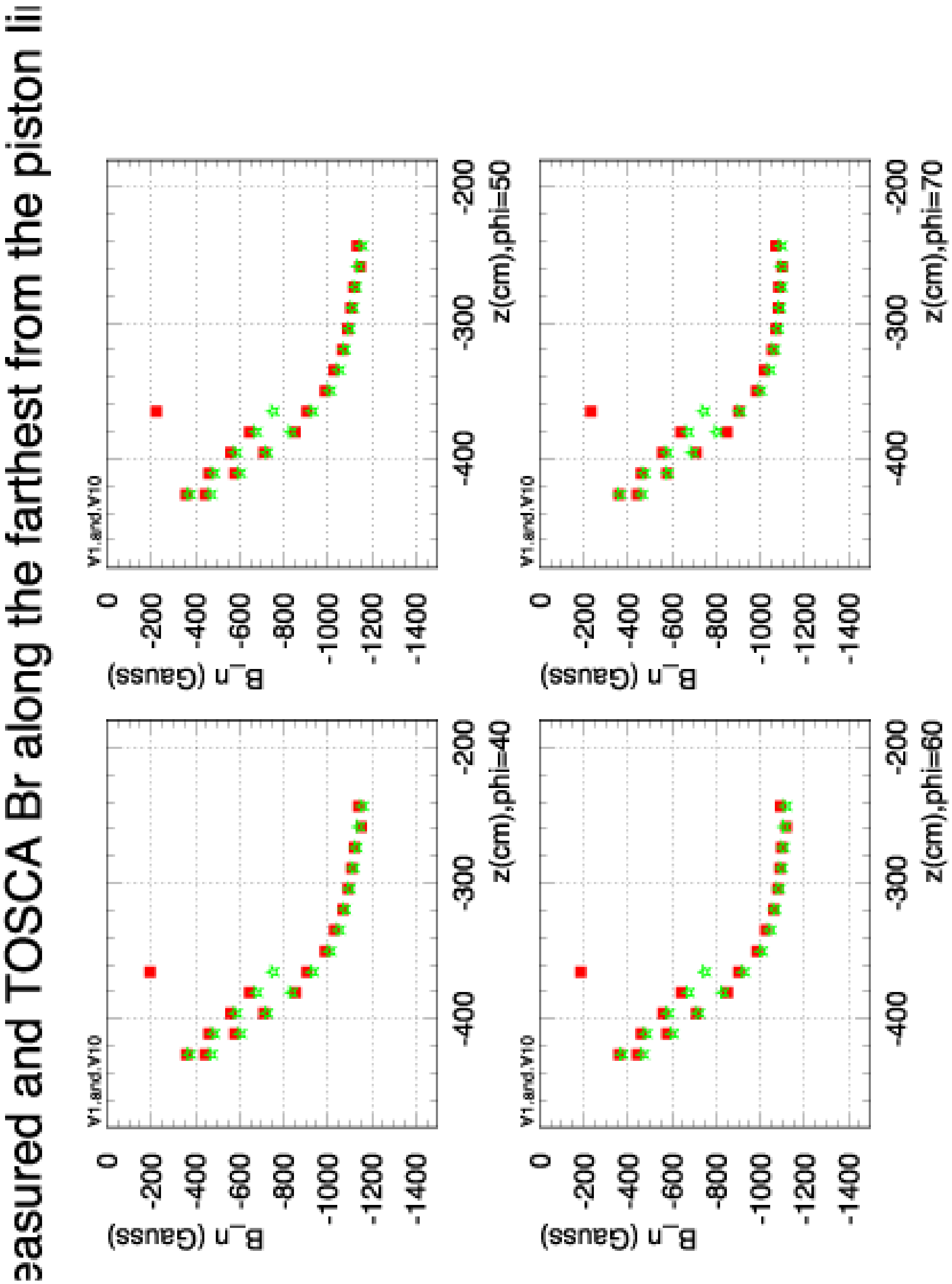

Figure 13. Measured and TOSCA Br magnetic field values as a function of Z coordinate along the line formed by the Hall probe noted as B at the fixture diagram. (phi =40,50,60,70 degrees.) The squares are the measured values and the stars the values calculated by TOSCA.

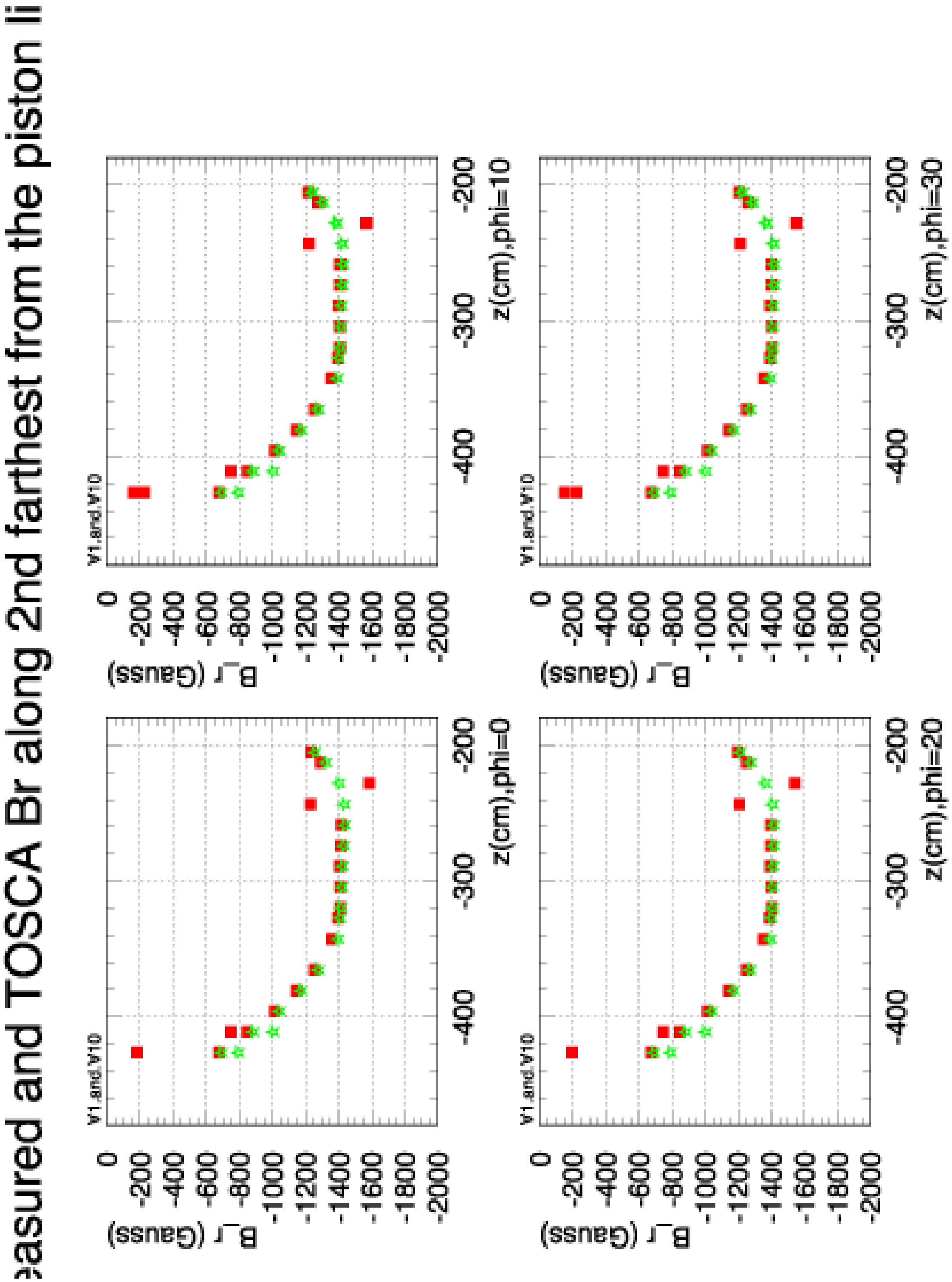

Figure 14. Measured and TOSCA Br magnetic field values as a function of Z coordinate along the line formed by the Hall probes noted as A at the fixture diagram. (phi =0,10,20,30 degrees.) The squares are the measured values and the stars the values calculated by TOSCA.

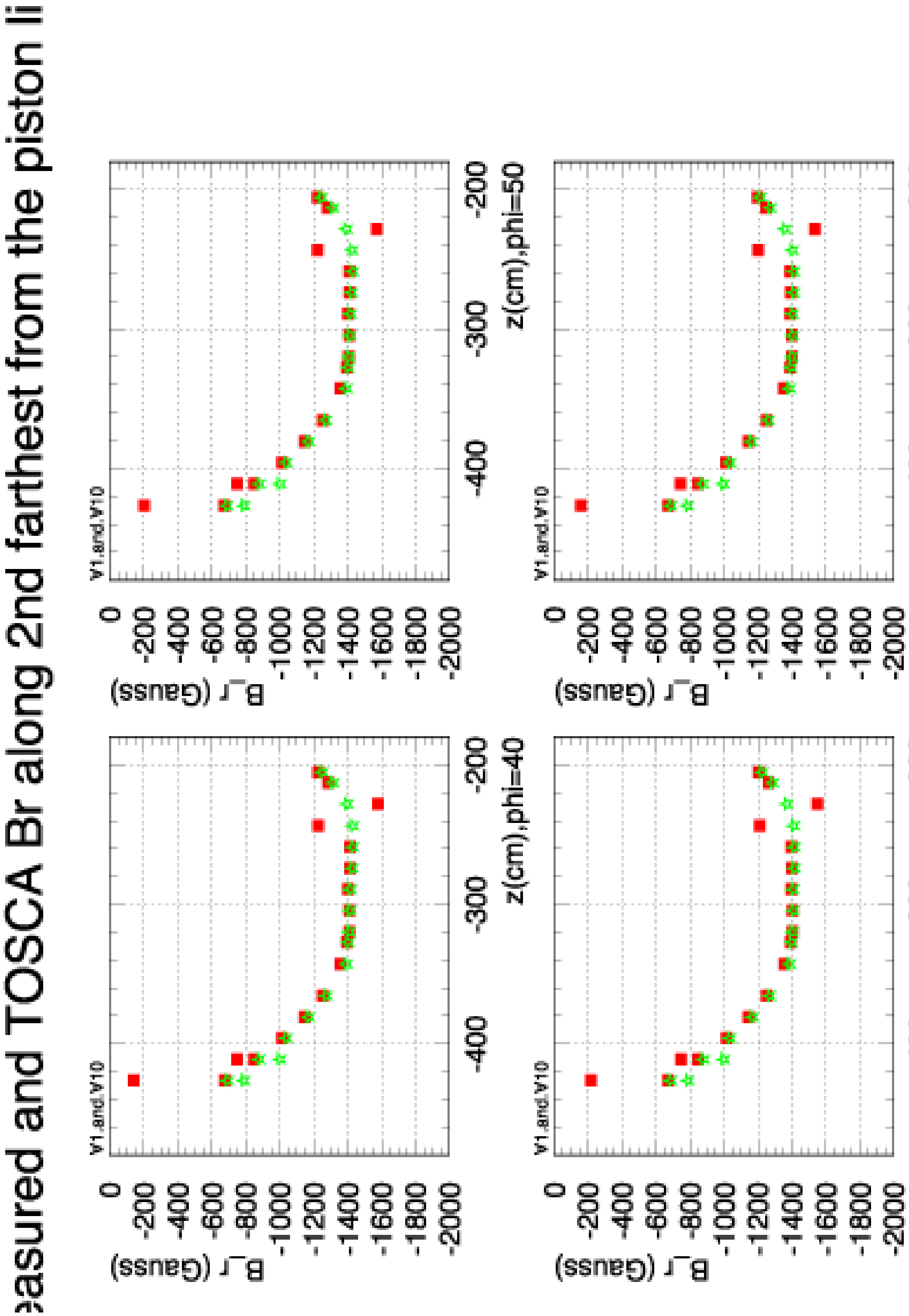

Figure 15. Measured and TOSCA Br magnetic field values as a function of Z coordinate along the line formed by the Hall probes noted as A at the fixture diagram. (phi=40,50,60,70 degrees.) The squares are the measured values and the stars the values calculated by TOSCA.

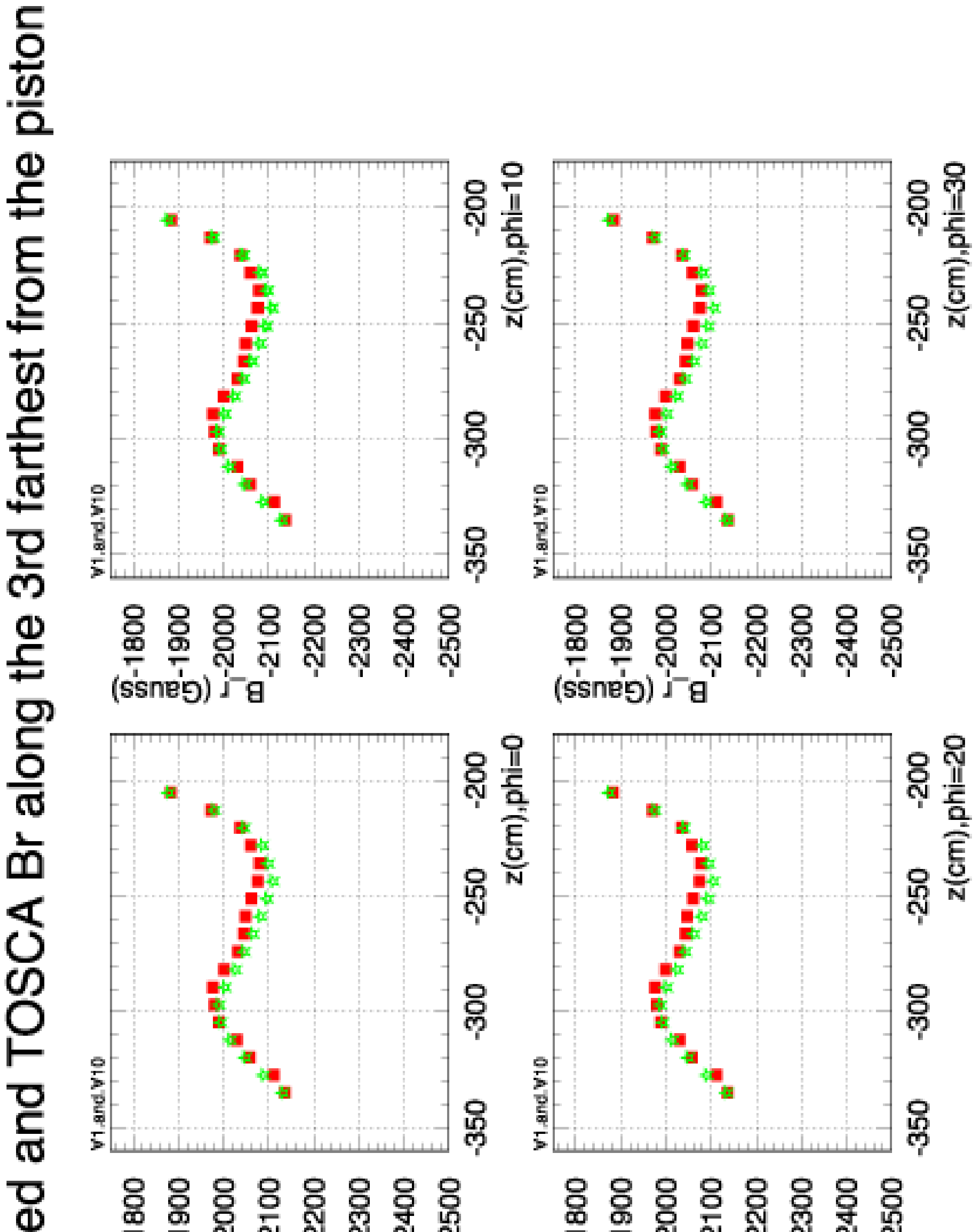

Figure 16. Measured and TOSCA Br magnetic field values as a function of Z coordinate along the line formed by the Hall probes noted with the figure 9 at the fixture diagram. (phi =0,10,20,30 degrees.) The squares are the measured values and the stars the values calculated by TOSCA.

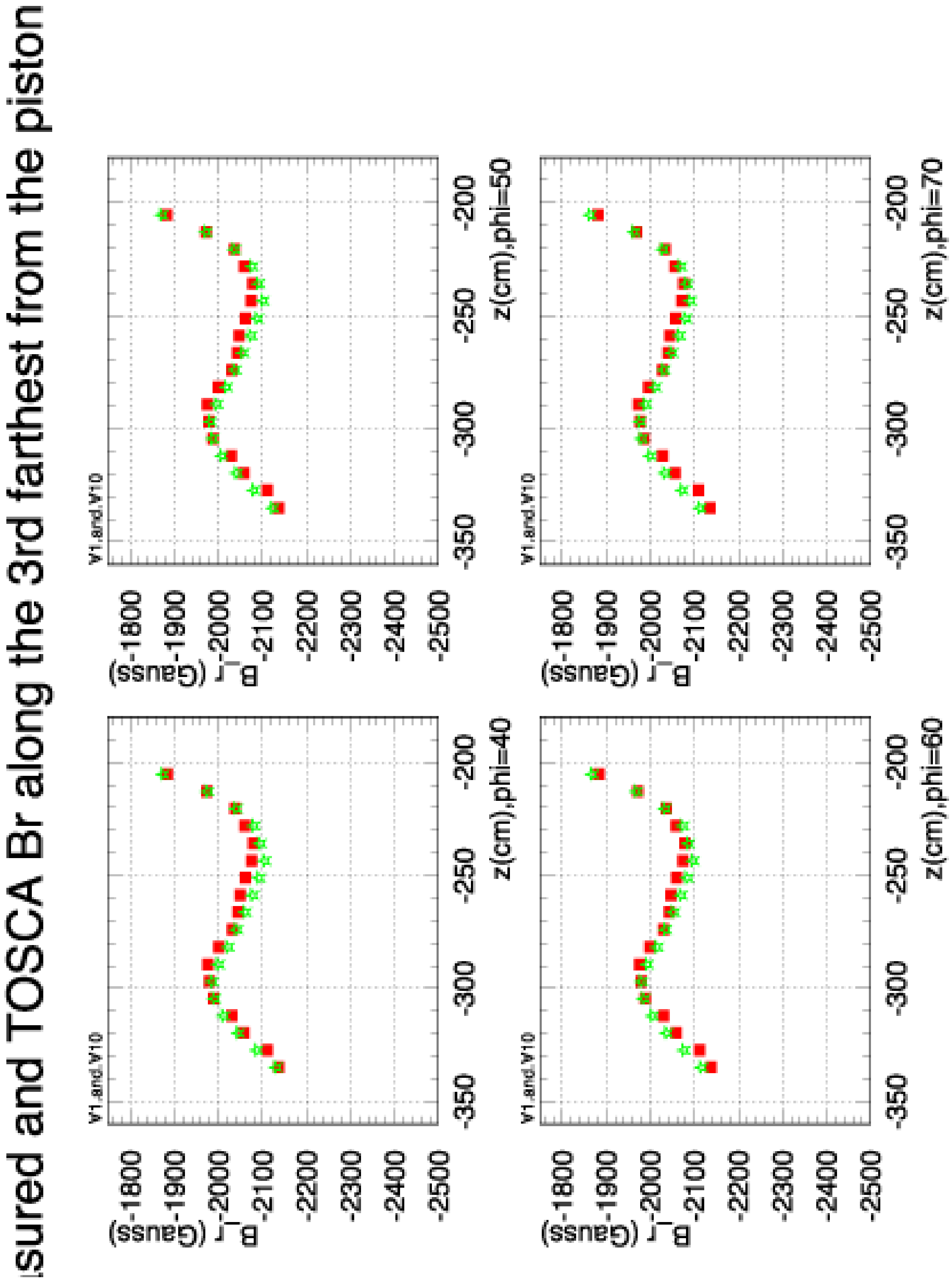

Figure 17. Measured and TOSCA Br magnetic field values as a function of Z coordinate along the line formed by the Hall probes noted with the figure 9 at the fixture diagram. (phi =40,50,60,70 degrees.) The squares are the measured values and the stars the values calculated by TOSCA.

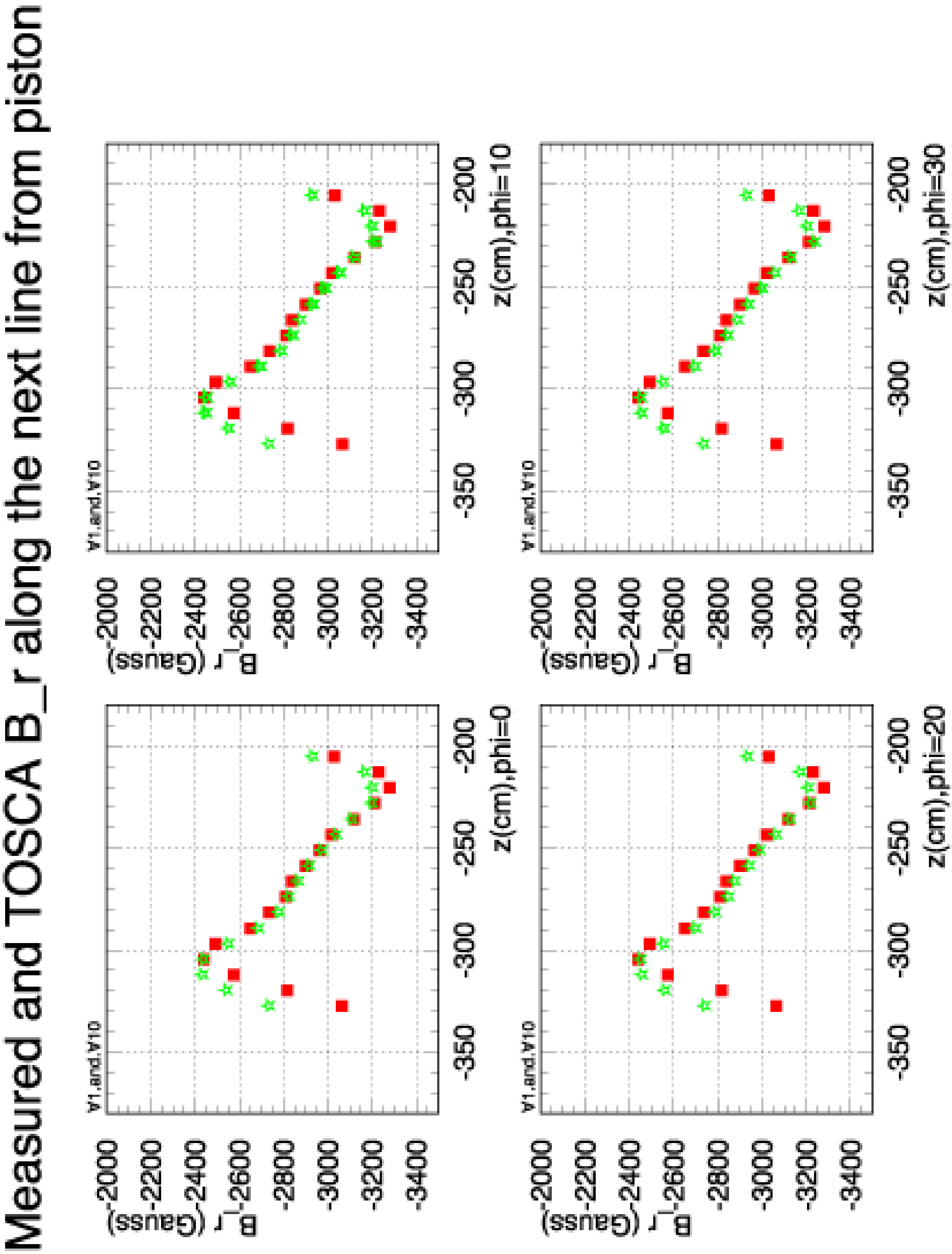

Figure 18. Measured and TOSCA Br magnetic field values as a function of Z coordinate along the line formed by the Hall probes noted with the figure 8 at the fixture diagram. (phi =0,10,20,30 degrees.) The squares are the measured values and the stars the values calculated by TOSCA.

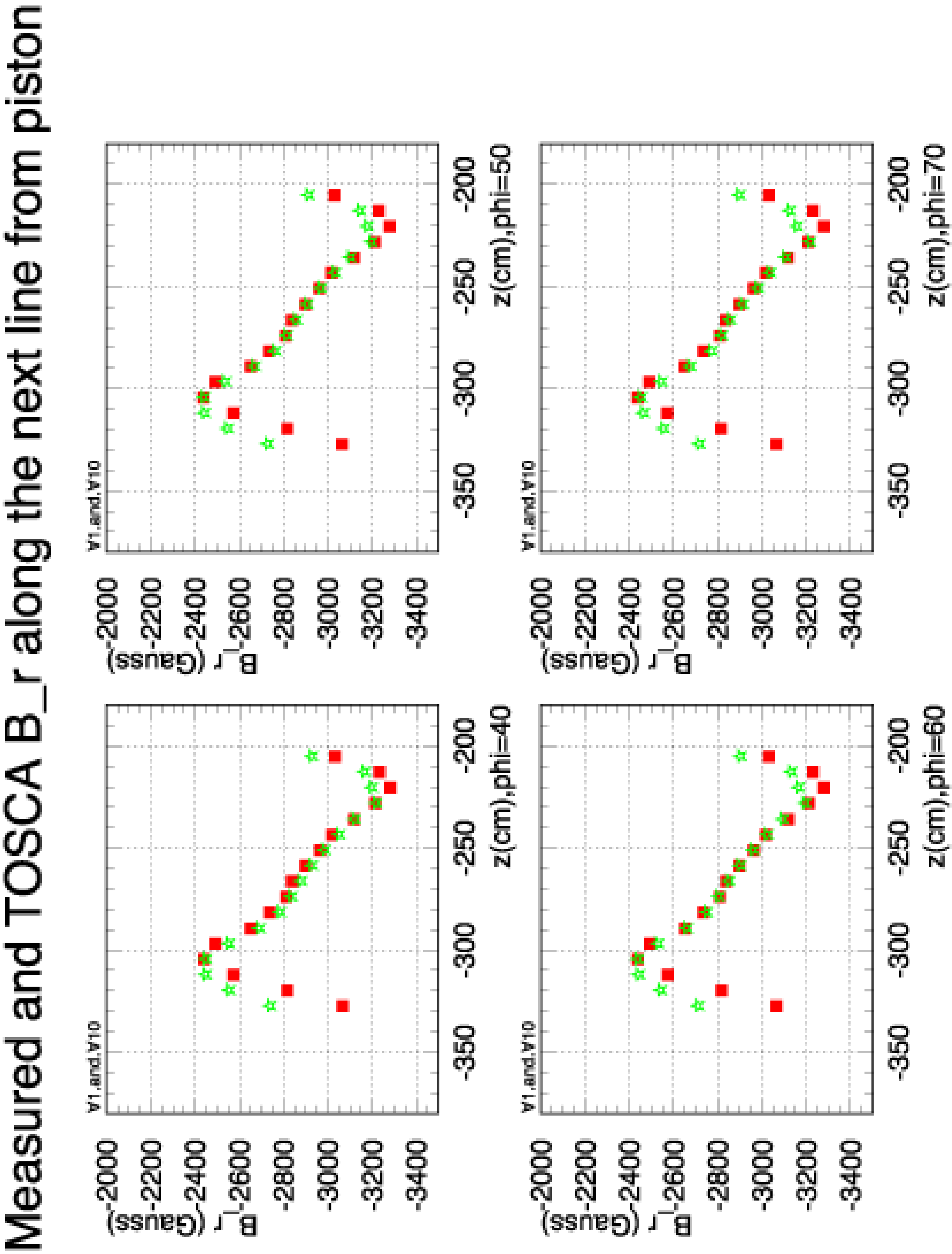

Figure 19. Measured and TOSCA Br magnetic field values as a function of Z coordinate along the line formed by the Hall probes noted with the figure 8 at the fixture diagram. (phi=40,50,60,70 degrees.) The squares are the measured values and the stars the values calculated by TOSCA.

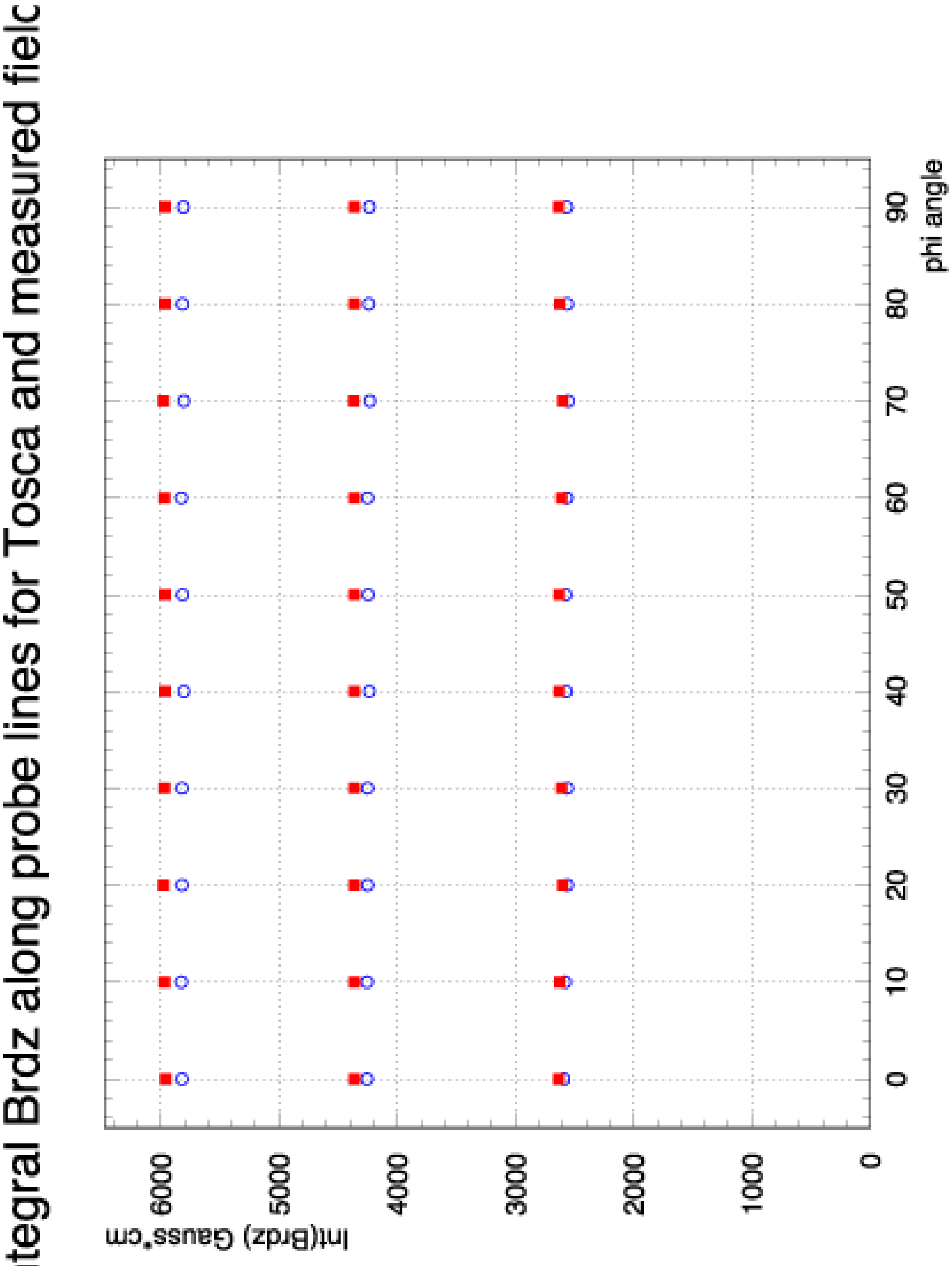

Figure 20. Measured and calculated by TOSCA integral of the magnetic field Bz with regards to Z along the 3 horizontal lines, populated with hall probes at the interior of the magnet mapping fixture. The difference between the values calculated by using the TOSCA field and the values calculated by using the measured field is ~3% for the two top lines and ~2.4% for the bottom line.

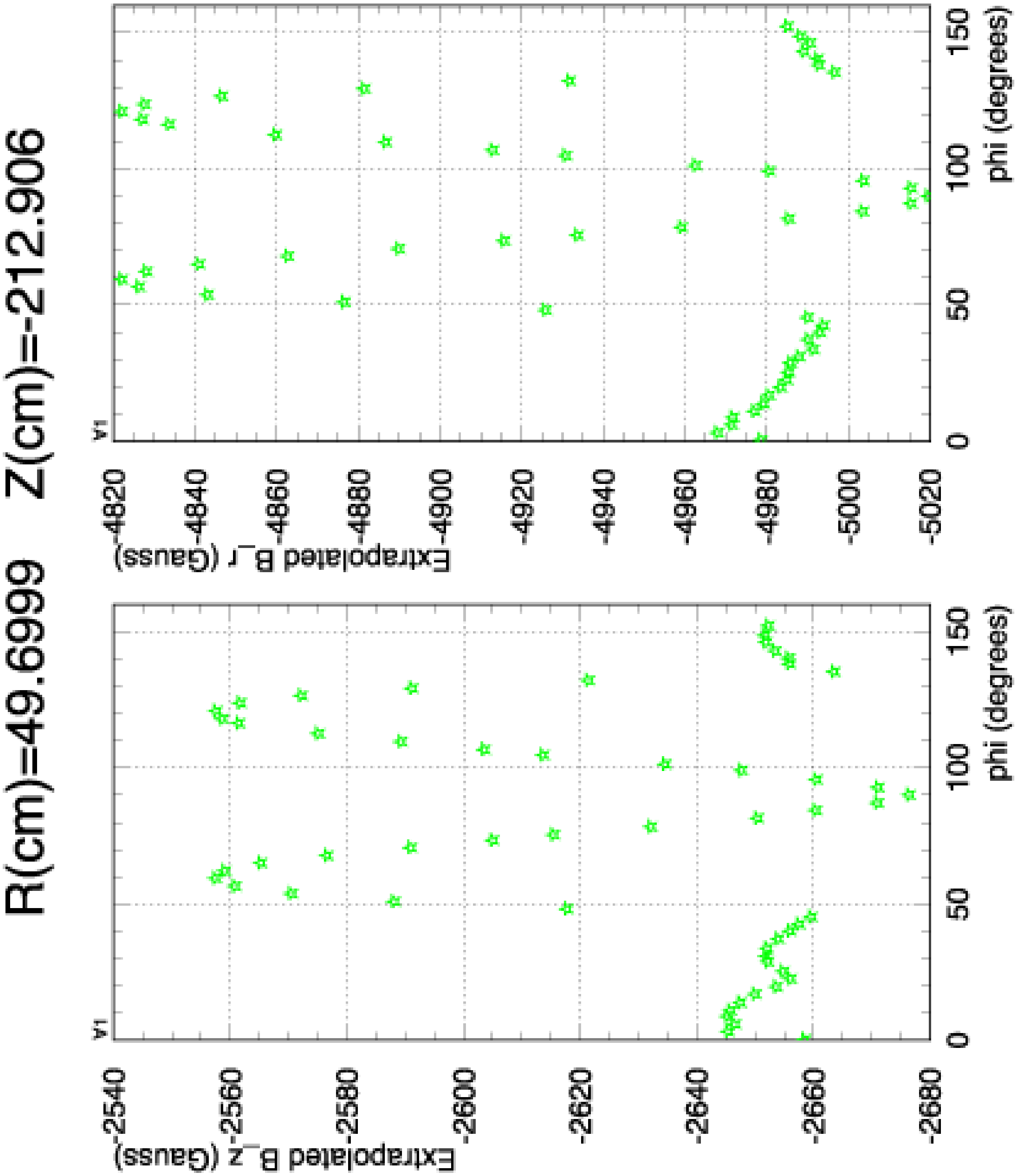

Figure 21.
Variations with respect to phi angle of the z and r components TOSCA calculated magnetic field components at the Z and R position indicated. The position is close to inner piston in the front side (entrance) of the South magnet. The assumed geometry is cylindrical and ideally there should be no phi dependence.

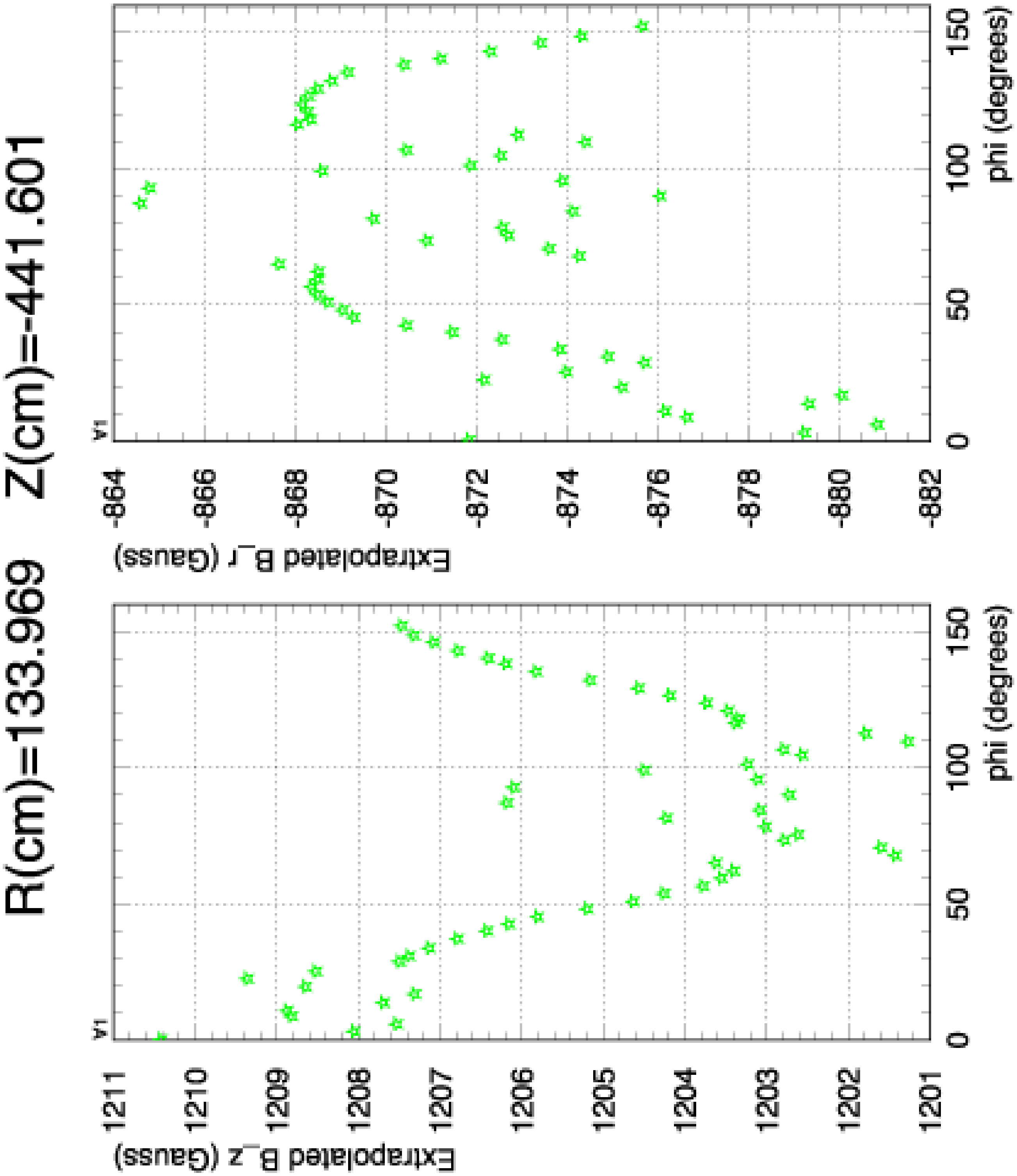

Figure 22. Variations with respect to phi angle of the z and r components TOSCA calculated magnetic field components at the Z and R position indicated. The position is close to inner piston in the backside part of the South magnet. The assumed geometry is cylindrical and ideally there should

be again no phi dependence.}