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First Version of the PCMAG Field Map

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Abstract

This memo describes the results of the magnetic field measurement of PCMAG at DESY testbeam and provides a first version of a magnetic field map of PCMAG. This map consists of a model of the coil with parameters set to fit best with the measured data.

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1 Introduction

Within EUDET JRA1 a superconducting large bore magnet (PCMAG, inner radius 86cm, active length 100cm, maximal B-field 1.2T) was installed in the DESY test beam. This magnet will be used as a test facility for TPC prototypes for ILC. To fully exploit the beam and to be able to really test the different detectors at the precision needed the magnetic field needs to be known to better than a few times 10^{-4}. In order to achieve this precision the field was measured in July 2007 by a team from CERN. The data has been corrected for systematic errors and afterwards a model of the coil has been created. The parameters of the coil are set to fit best with the measured data. This model can be used as a field map for PCMAG.
Within this memo the measurement procedure, the systematic errors, the model of the coil as well as the fitting to the data will be described.

2 Field measurement

The magnetic field was measured in July 2007 at its nominal value of 1T. The measurement setup provided and operated by CERN was a bench aligned to the magnetic axis (z-axis) of PCMAG along with two rotating arms (angle ϕ) which could be moved along the z-axis with very high precision. The magnetic field was measured using 24 Hall sensor cards, which hold three Hall probes each to measure the three orthogonal components of the field (B triplet). Prior to the measurements the Hall sensor cards were calibrated in a highly uniform field whose strength was monitored by a NMR probe. The card was continuously rotated to many different orientations and the angles were measured very precisely by pickup coils. The calibrations were repeated at several field strengths (0.37, 0.89, 1.4 Tesla) and temperatures (20°, 24° C) [1].
The cards were equally distributed on the two arms with 12 cards mounted on the front and 12 on the back. They were aligned in such a way that after rotating the arms by 180 degrees and moving the z-position with a fixed amount the probes mounted on the front would fall in the same place as the probes mounted on the back. This was done to allow cross checking of the data with different probes. The precision of individual probe placement is 0.1mm.
During the three days of measurement 48 sets of data where taken at different phi positions (z-scans). In z direction 88 steps with a step size of 14 mm were taken. The step size in ϕ was 5° between 0° and 180° and 15° between 180° and 360°. In total more than 100000 B triplets where measured within the volume of PCMAG. Two more z-scans were taken when the magnet was turned off to provide information on offset values for each individual probe. A NMR probe was placed at the center of the bench to provide reference data and to monitor magnetic field stability. Two additional Hall sensor cards were installed in the front and the back of PCMAG to provide reference measurement during future magnet operation. The measurement setup was aligned with the help of geometers who also measured the relative position of the measurement bench towards the magnet and the test beam area itself.

3 Analysis of data

3.1 Statistical errors

The results of the zero field measurement were used to estimate the statistical error for the individual probes (see Figure 1). The errors are below 2Gauss which is sufficient for the aimed precision since so many data points were taken.
The uncertainty of the measurement position also contributes to a magnetic field error and scales with the gradient of the field. This is the dominant error, especially in the inhomogeneous parts of the field.

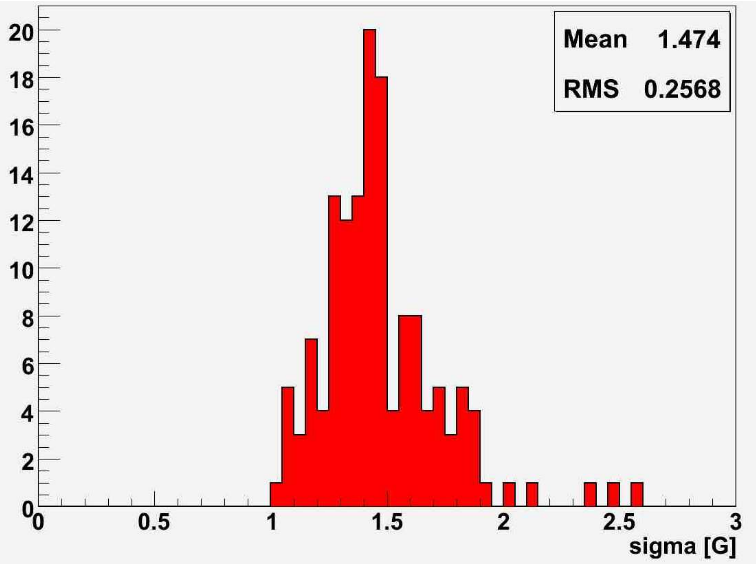

Figure 1: Distribution of individual probe errors taken from the zero field measurement.

3.2 Systematic errors

Several systematic errors have been corrected for. The spacial separation of the three Hall probes (~2 millimeters) on the sensor cards was taken into account. The sensor cards are calibrated in a perfectly homogeneous field, where this separation has no effect. However, due to the field gradients in PCMAG a correction needs to be applied for the exact distance between the three probes measuring the three components of the field. This also leads to an apparent non-zero phi component of the magnetic field, emphasizing the need for the appropriate geometrical correction of the individual sensor positions. Since the measurement bench was aligned to the axis of the magnets bore, which is not necessarily the axis of the coil, an offset and a tilting of the bench had to be applied.

3.3 Model of PCMAG

In order to provide a field map a model of the magnetic field has been created and the parameters have been set to fit best with the measurement data. As there is no iron within the magnet, the model used is a superposition of single closed current loops with the magnetic field being calculated by Biot-Savart law. The parameters fitted are the length and radius of the coil, the current and the distance between the different layers of windings.

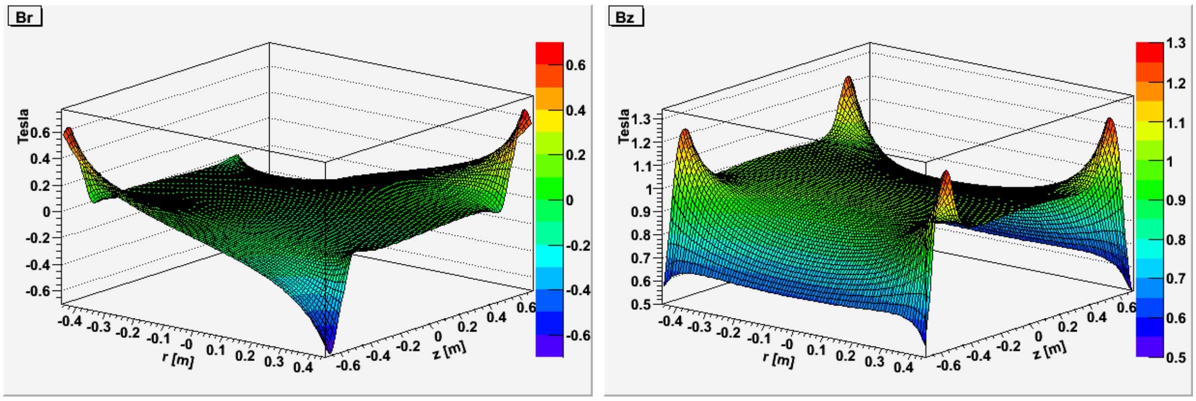

Figure 2: Field map from magnetic field model after fitting.

3.4 Fitting procedure

First the data have been corrected for the known systematic effects including probe position and card orientation (the cards on the front were mounted in the opposite direction of the probes on the back of the arms).

In order to compare the data with the model the raw data are assumed to be in the direction of r,ϕ and z within the measurement system, with small misalignment relative to the sensor card being corrected for by the probe calibration. Subsequently all possible rotations and offsets have been applied to the probe position to get the position in the coil system. Finally $\vec{B}$ of the model was projected into the direction of the data and those values have been compared. These residuals were minimized in order to get the best parameters for the model.

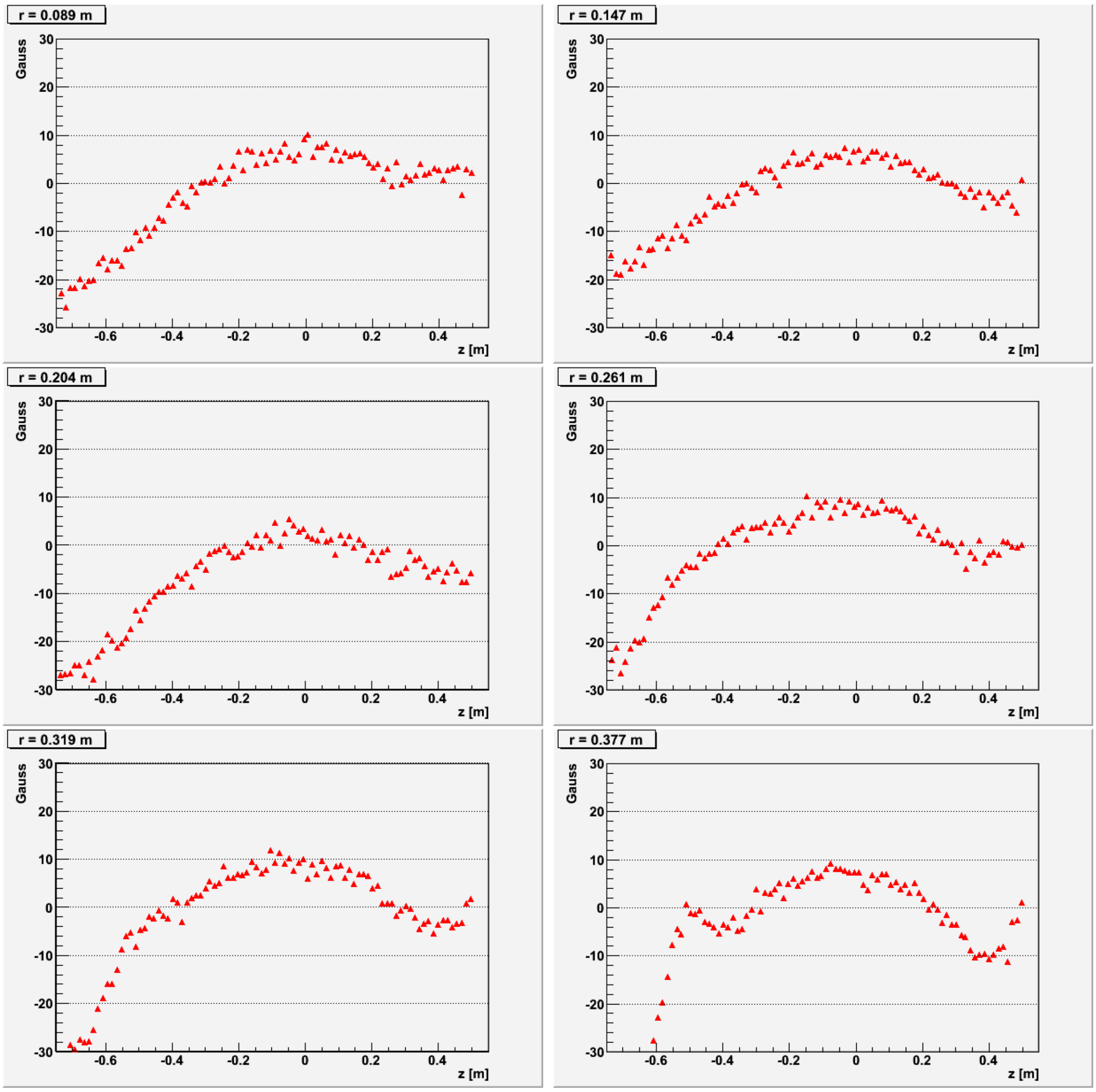

Figure 3: Residual fields for Bz at different distances from the axis.

4 Conclusion and outlook

The magnetic field of PCMAG has been measured successfully and a model of the magnetic field has been created to fit the data. This model can be used as a field map of PCMAG and so the EUDET Milestone has been reached. The field map can be provided as a real time computation or as a fixed map of points which then has to be interpolated. The choice between the two methods made available to the user is a trade-off between fast data availability and ultimate precision.
The precision of the field map is estimated to be 10Gauss within the volume which will be used during TPC operation. This precision can and will be improved in an ongoing analysis to understand more systematic effects within the data.

Acknowledgement

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References

[1] F. Bergsma, "Calibration of Hall sensors in three dimensions", 13^{th} International Magnetic Measurement Workshop, Stanford, 2003.