PCMAG Final Field Map

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Christian Grefe

CERN

Outline

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- **Magnetic Field Measurements**
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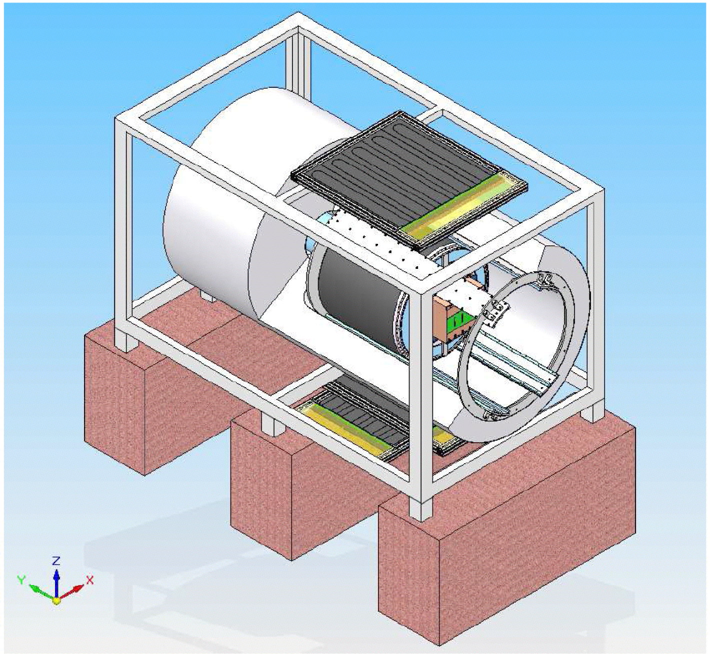
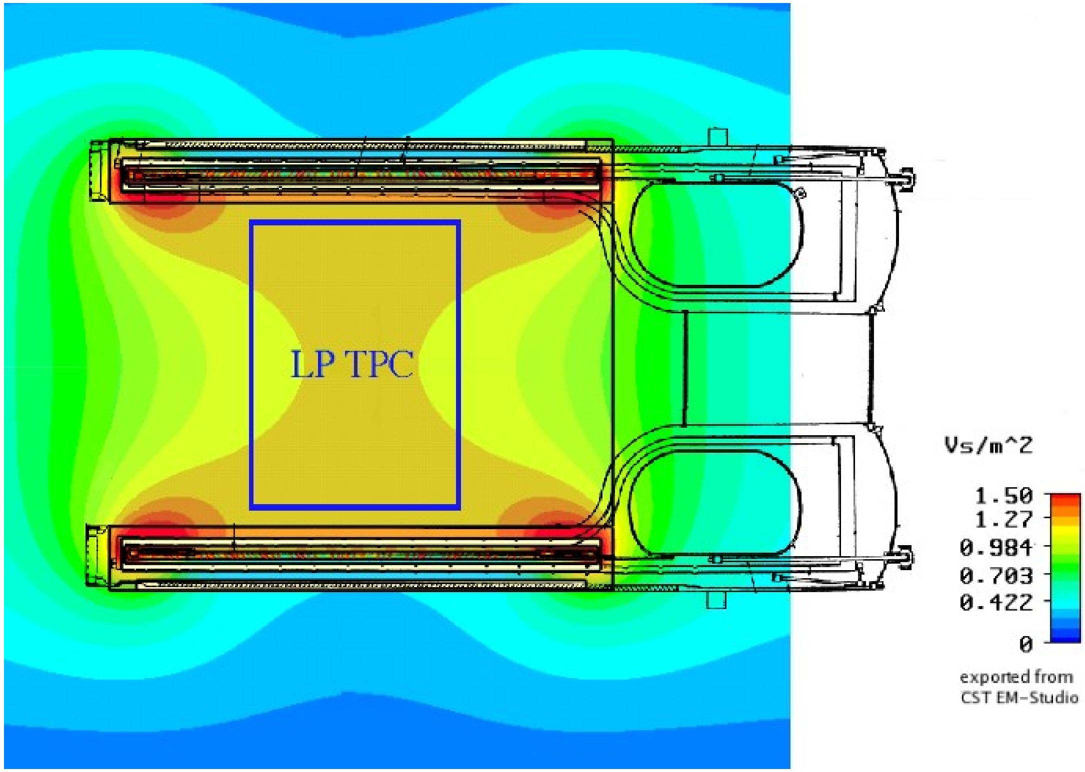
More details in my thesis:

http://www.cern.ch/cgrefe/documents/diplomathesis.pdf

Aims of the Project

- provide a field map for the PCMAG at DESY which will provide the magnetic field (1T) for the Large Prototype (LP) of the LCTPC
- the field of PCMAG is not very homogeneous and the LP will be operated at different positions in the PCMAG to simulate the effects of an (Anti-)DID
- a detailed fieldmap is needed to take into account the inhomogeniety
- test which accuracy is reasonably achievable

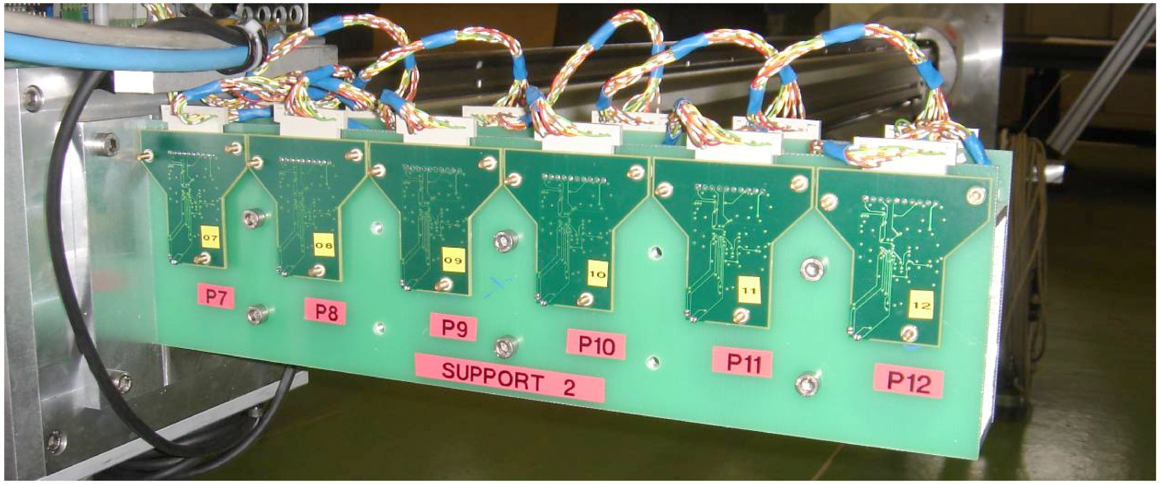


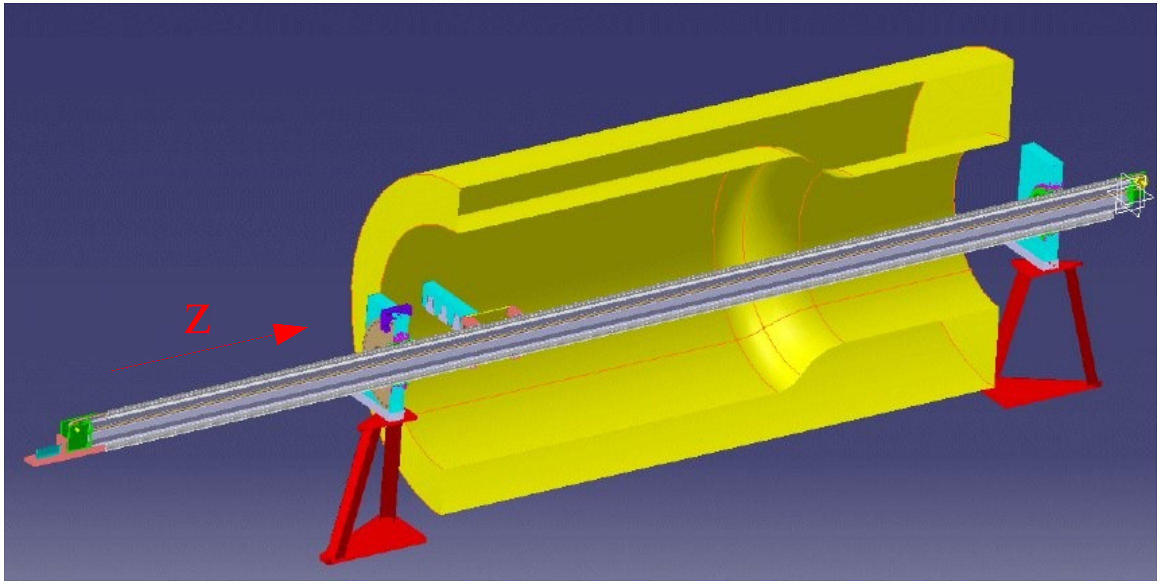


earlier field calculations by Peter Schade

Magnetic Field Measurements

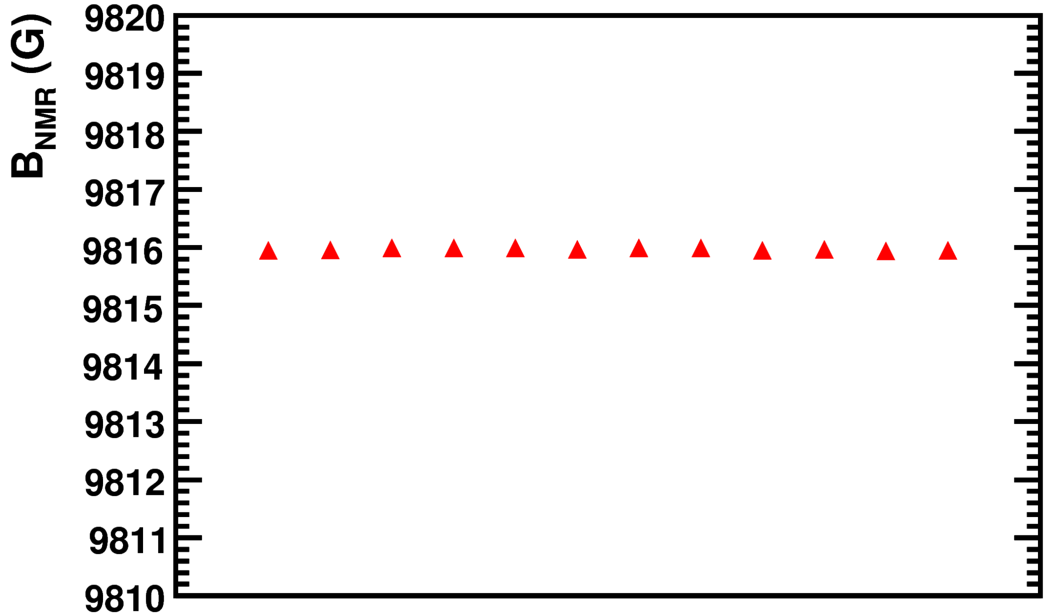
- a set of 24 sensor cards, with 3 Hall sensors each, distributed on 2 arms were used to map the field
- the arms were movable along the rail as well as turnable around the rail
- the field was mapped at 88 z positions for each of the 48 angular positions
- in total of more than 100000 B-triplets have been measured





Magnetic Field Stability

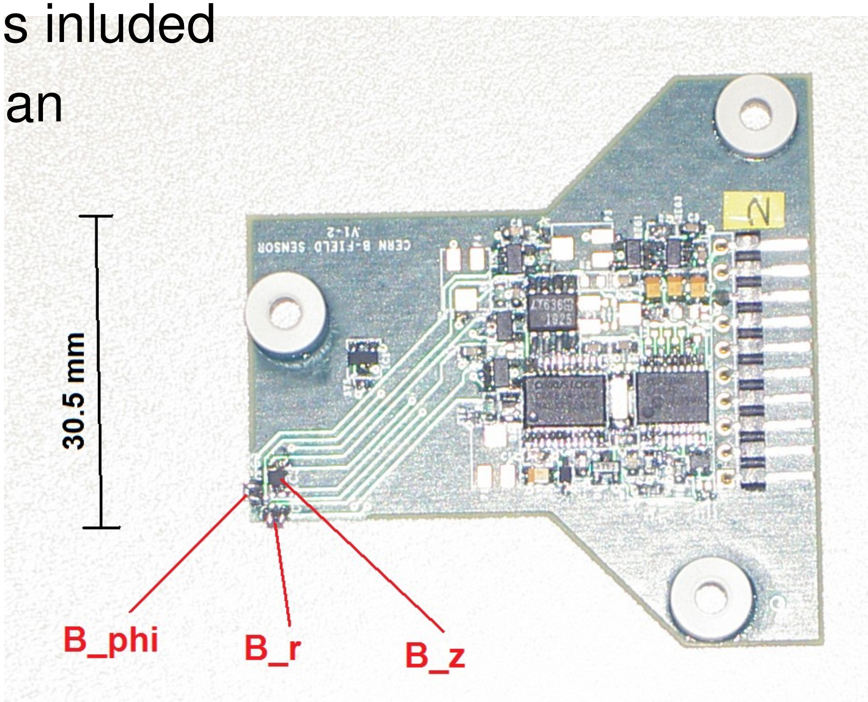
- addidtional reference measurement from an NMR probe at the center of the coil
  - it turned out that the magnet is extremely stable over time, fluctuating only by a fraction of a Gauss
- how good can you reproduce the field?
  - only one test excitation as data, which was less than 2 G off
- the field was only mapped at one current, so we can not say anything about linearity and change of the field shape for different currents



Data of 3 days of measurements

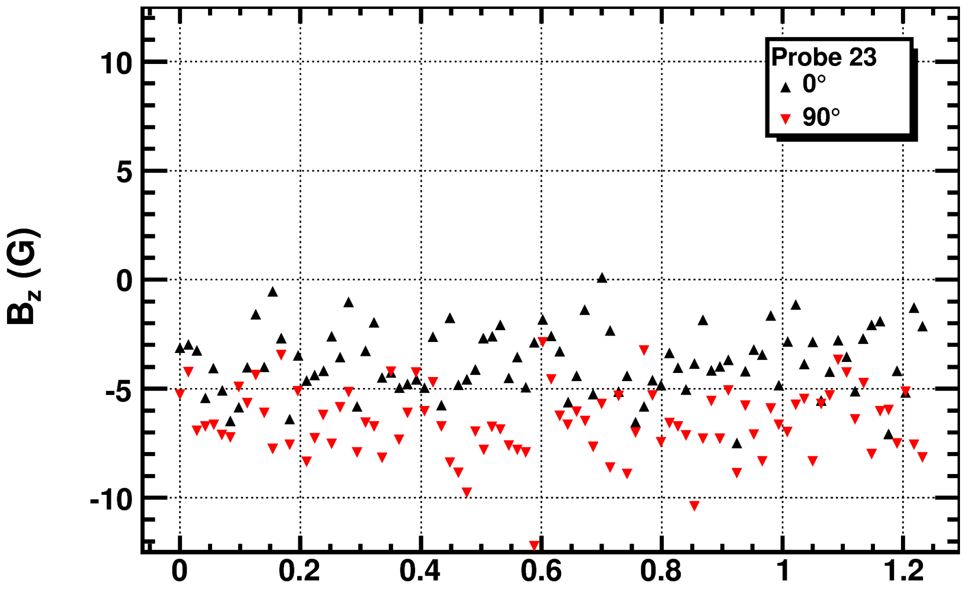
Calibration Issues

- the sensor cards were calibrated before in a homogeneous 2T field
- for details on the 3d calibration see old talk by Felix Bergsma:
  http://cern-eudet.web.cern.ch/cern-eudet/JRA1/FelixIMWW14.ppt
- the 3 components are calibrated together while being rotated in a homogeneous field and decomposed afterwards using spherical harmonics
  - takes into account higher order effects (planar Hall effect, etc.)
  - relative orientation of the hall probes is inluded
  - but you lose some of this accuracy in an inhomogeneous field because of the different positions of the 3 probes
    - solution:
      split the triplet into three measurements at three positions

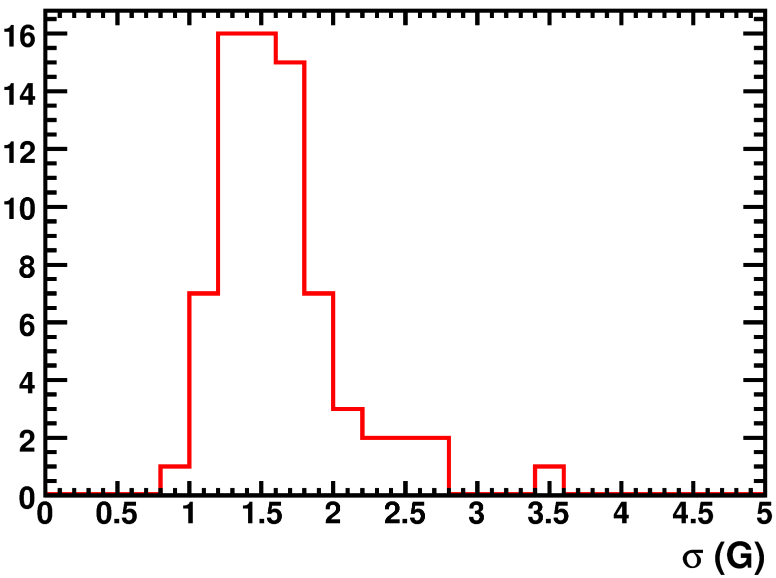


Calibration Issues

- manually put in card positions, card orientation (cards on front and back are mounted inverse), arm position, arm angles ...
  - assume a perfectly rigid measurement bench (no sack)
  - assume arms to be perfectly rectangular
- use zero field measurements to check probe quality
- apply (small) corrections for drifting of calibration for all probes



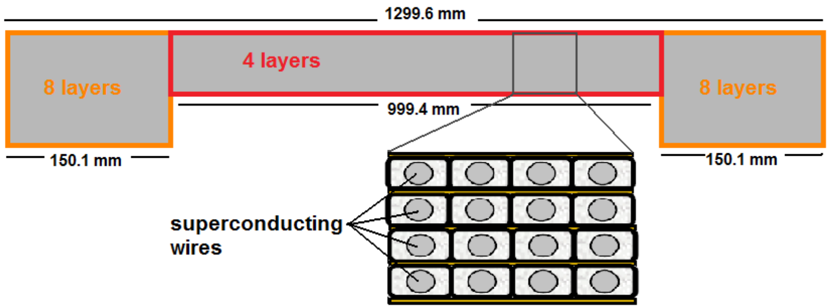
Zero field measurement



Distribution of probe erros

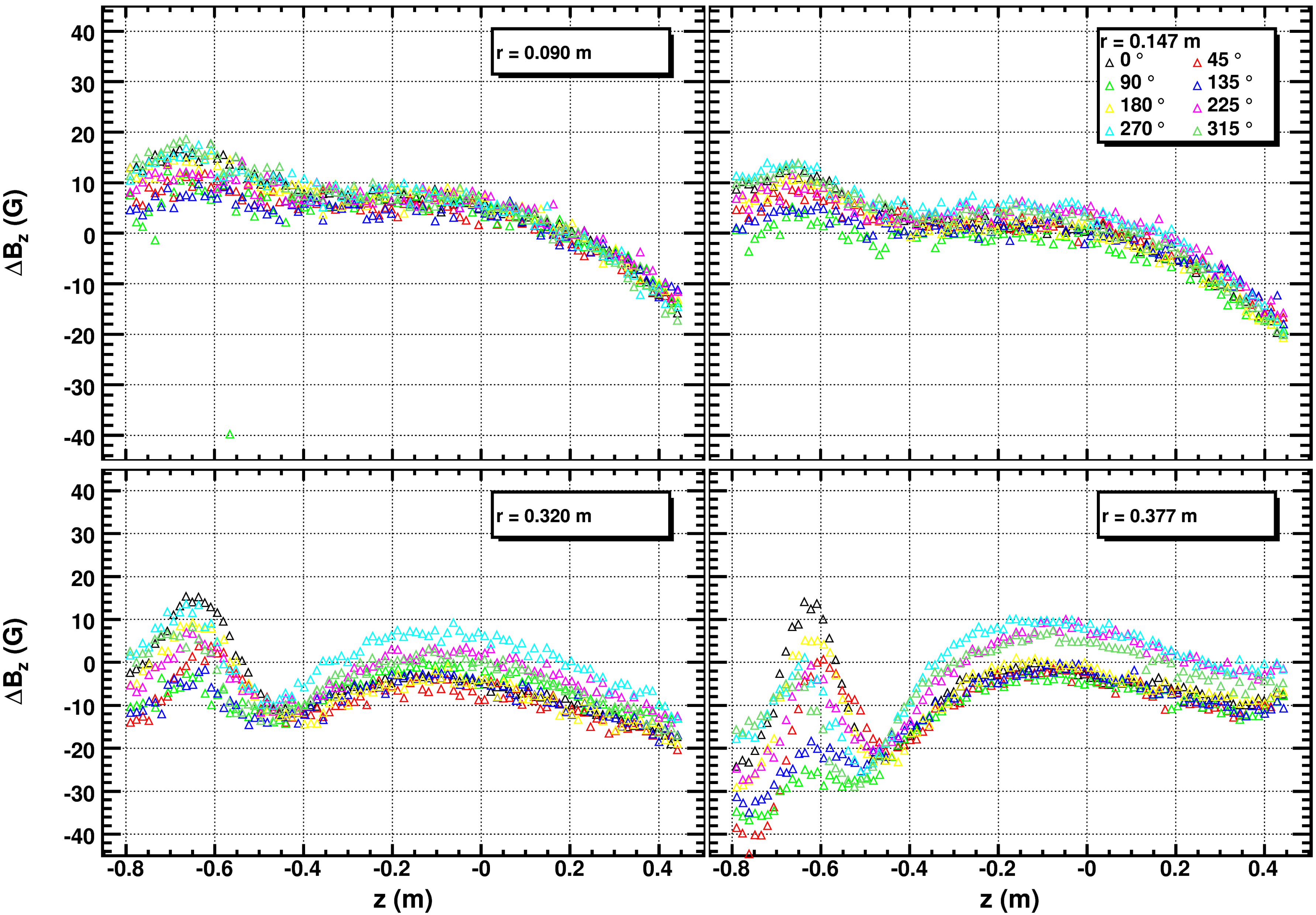
Simple Coil Model

- 3344 closed current loops → calculate with Biot-Savart
  - gives a pretty accurate description of the field with a minimum set of parameters (when you assume equal wire pitches)
    - length (= pitch in z)
    - inner radius
    - radial pitch
    - current



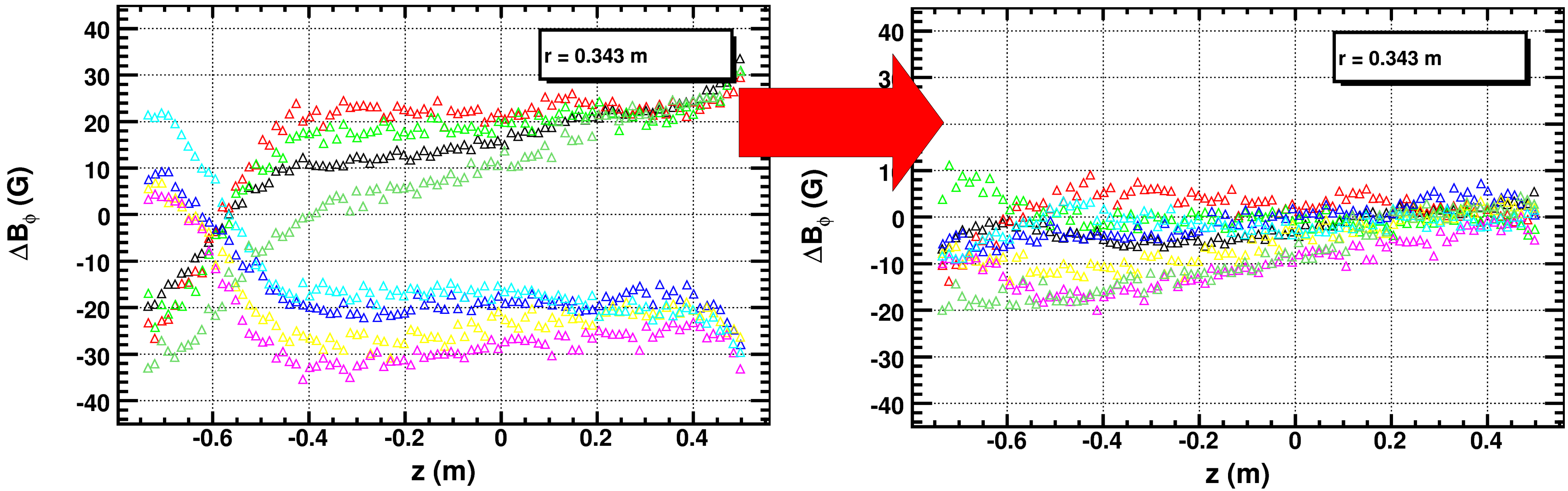
  - while the number and the pattern of the wires is fixed
  - the same fit has been done using an even simpler geometry by combinig 4x2 windings into one
    - the fit quality is equal while the calculation speed increases a lot
- also fit the global alignment:
  - measurement coordinatesystem → coil coordinate system (position and angles)
  - only very small misalignment: < 0.1 °

Simple Coil Model



Sensor Card Rotations

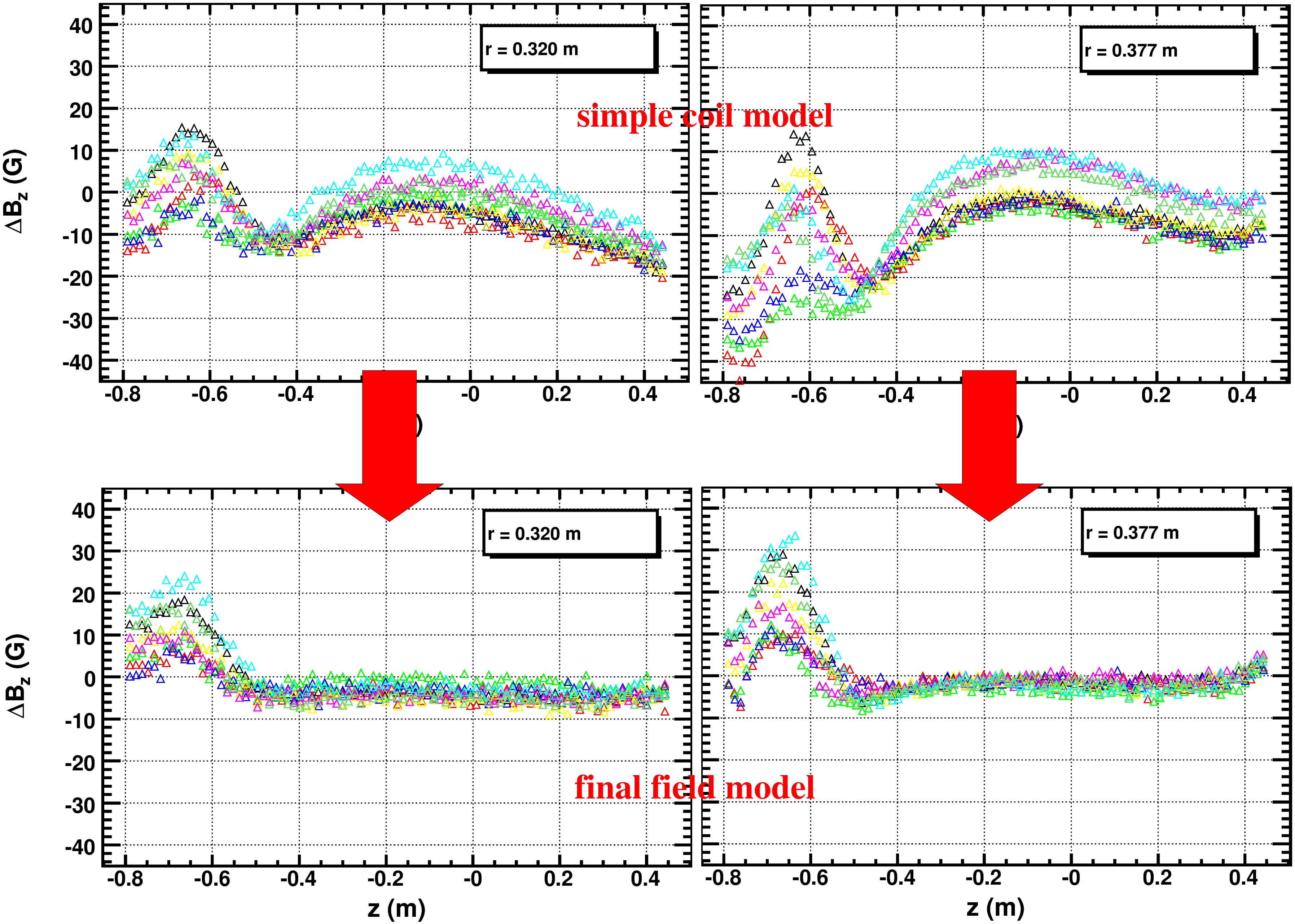
- B_φ and B_r are very sensitive to misalignments because they get mixed with B_z
- including 3 angles per card as free parameters leads to a huge improvement for the B_φ and B_r components



Using Maxwell's Equations

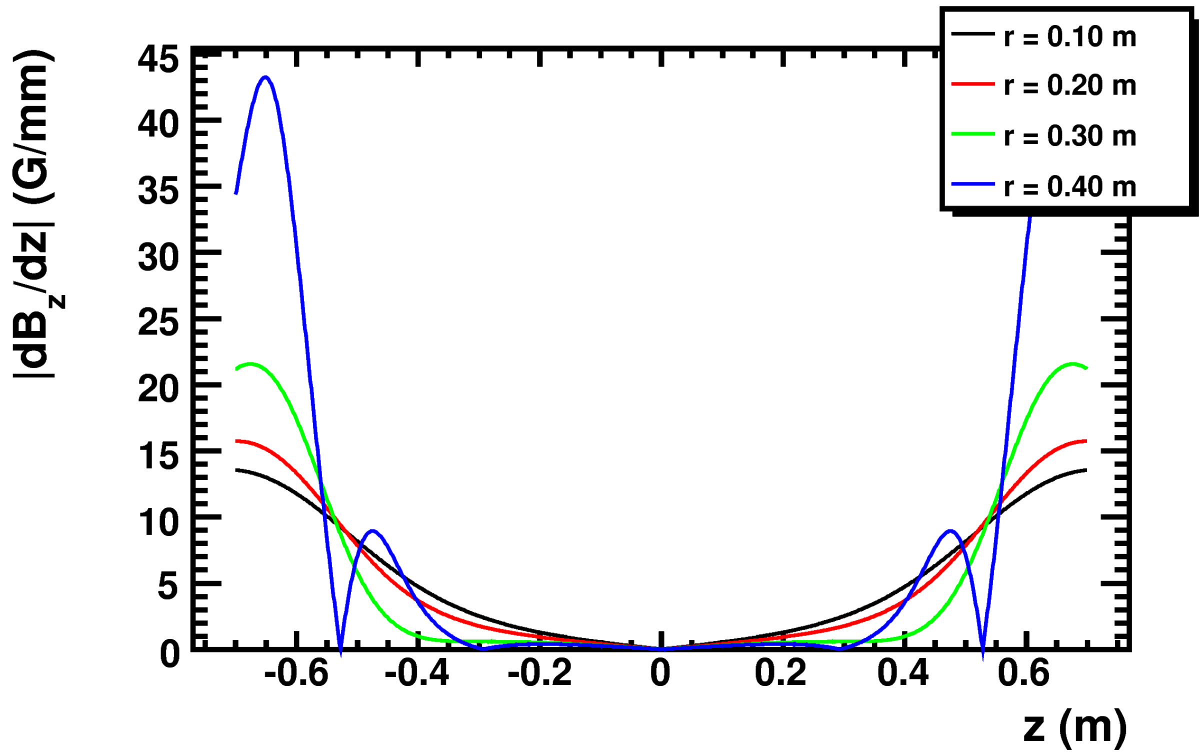
- expansion into Fourier-Bessel-series
  - general approach using Maxwell's equations in cylindrical coordinates
    - field on a cylindrical surface determines the field in the complete volume
    - only a subset of the measured data is used to get the parameters, and the full set is used for error estimation
  - this leads to a double fourier expansion in z and φ ($2z_{max}$-periodic) and a double fourier expansion in r and φ
  - In order to disentangle these two expansion the r-φ part is set to 0 on the curved survace of the cylindrical volume
  - there are also z independant multipole terms included (only B_φ and B_r)
- where to truncate these series?
  - more parameters means better description of the measurement, but also leads to oscilations at the boundaries of the volume of interest
    - move the boundaries out of the measurement volume (increase z_{max})
    - increase number of points by interpolation (this I have not done)

Final Field Model



Magnetic Field Model

- the residuals are actually dominated by the accuracy of the measurement position



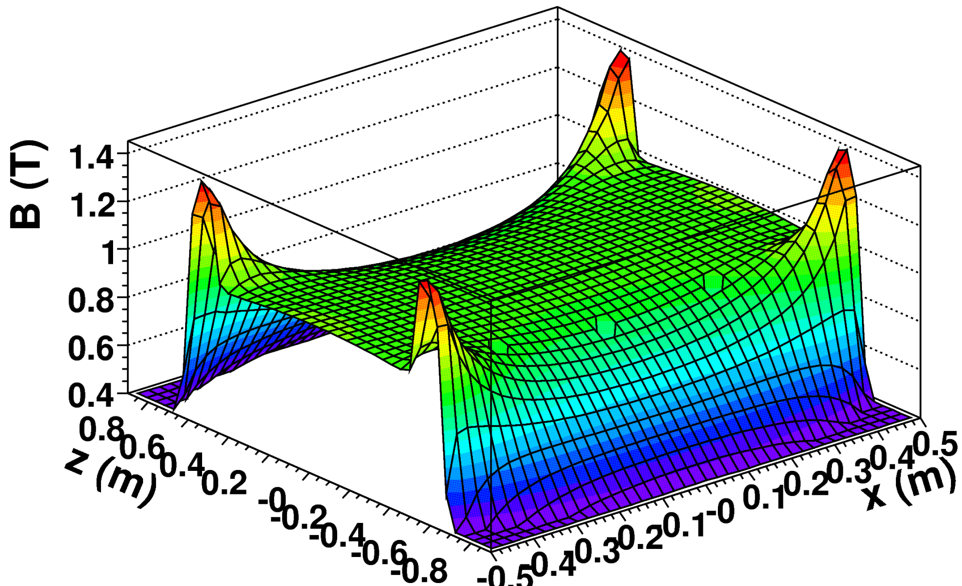
- keep this in mind when using the field map for the TPC, especially when moving the TPC
  - how rigid is the mounting structure?

Final Field Model

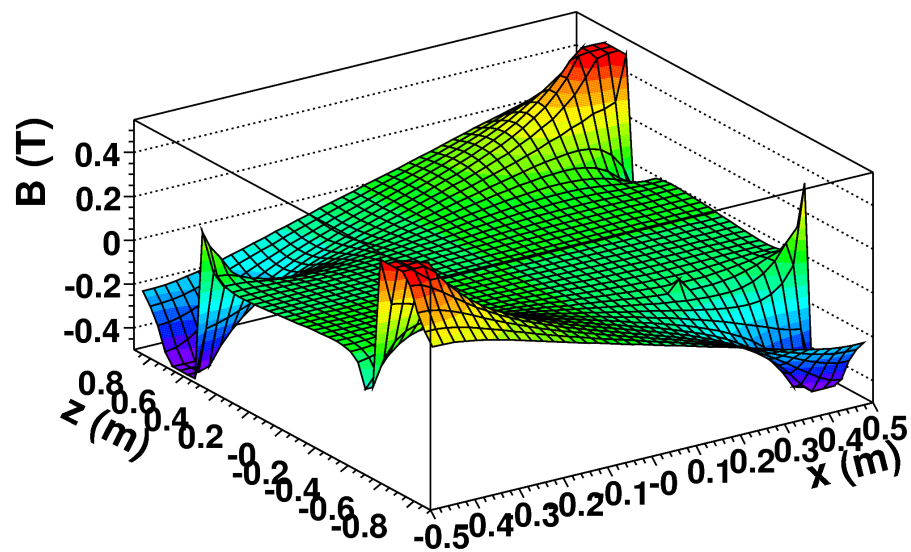
- most of the imperfections from the simple coil model are taken care of by the Fourier-Bessel-series
  - this also implies that there are imperfections from a perfect cylindrical shape
  - the series expansion can take care of these but does not show where they origin
- It is not clear how changing the magnet setup will affect the field
  - turning the magnet etc.
- there will also be magnetizable material introduced to the magnet surrounding (mounting struncture to move the magnet)
  - this has be be added by pure simulations

Final Field Model

- is a composition of two field models
  - coil model with a minimum set of parameters using the coil geometry
    - available as the „full coil model“ or the simplified model combining 4x2 wires into one
  - Fourier-Bessel-series with a total of 234 parameters



B_z



B_r

Error Estimations

- the errors were estimated as RMS over the difference between the measurement and the model for all measured points
- the volume was split into two parts
  - inner volume: -0.4m < z < 0.4m
  - outer volume: 0.4m < |z|

	RMS_{inner} (G)			RMS_{outer} (G)			RMS_{total} (G)		
	B_r	B_{phi}	B_z	B_r	B_{phi}	B_z	B_r	B_{phi}	B_z
full CM	27.8	47.2	7.3	29.1	34.3	17.8	28.3	43.0	12.2
full CM + rot	9.8	6.6	7.3	14.2	11.5	16.9	11.6	8.7	11.7
simp. CM	27.8	47.2	7.6	29.2	34.3	17.1	28.3	43.0	12.0
simp. CM + rot	11.1	6.2	7.6	13.6	9.4	15.6	12.1	7.5	11.1
CM + FB	10.5	6.1	5.7	11.6	8.8	14.7	10.9	7.2	9.9

Software Implementation

- the field map will be available within the MarlinTPC framework
- MarlinTPC can use inhomogeneous E or B fields for the track reconstruction (see also talk by Ralf Diener yesterday in NA2)
- within this framework the field map can be provided as
  - analytical description using the models and parameters obtained from the analysis
  - as a 3d grid using interpolation
- this has to be decided by the needed speed for track reconstruction
- one can also choose which part of the model to use (coil model or simplified coil model with or without the Fourier-Bessel corrections)

Summary

- a magnetic field map for PCMAG has been created from the measurements
- it is available in different forms, depending on the needed accuracy and speed for track reconstruction
- fhe field map is accurate to a few Gauss, depending on region of the PCMAG
- a MarlinTPC implementation of the field map is availabe
- there is still some room for improving the accuracy if this is needed, but the strongest constraint comes from the positioning accuracy
- changing the sensor cards from 3 to 6 Hall probes with internal interpolation to have a „real“ field triplet at the center would be much better suited to measure inhomogeneous fields