Mapping the Magnetic Field of the ATLAS Solenoid

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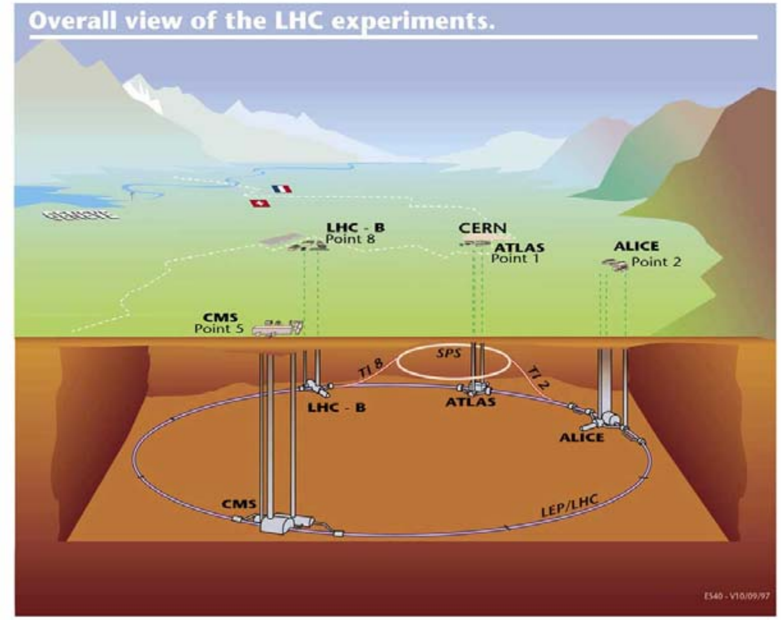
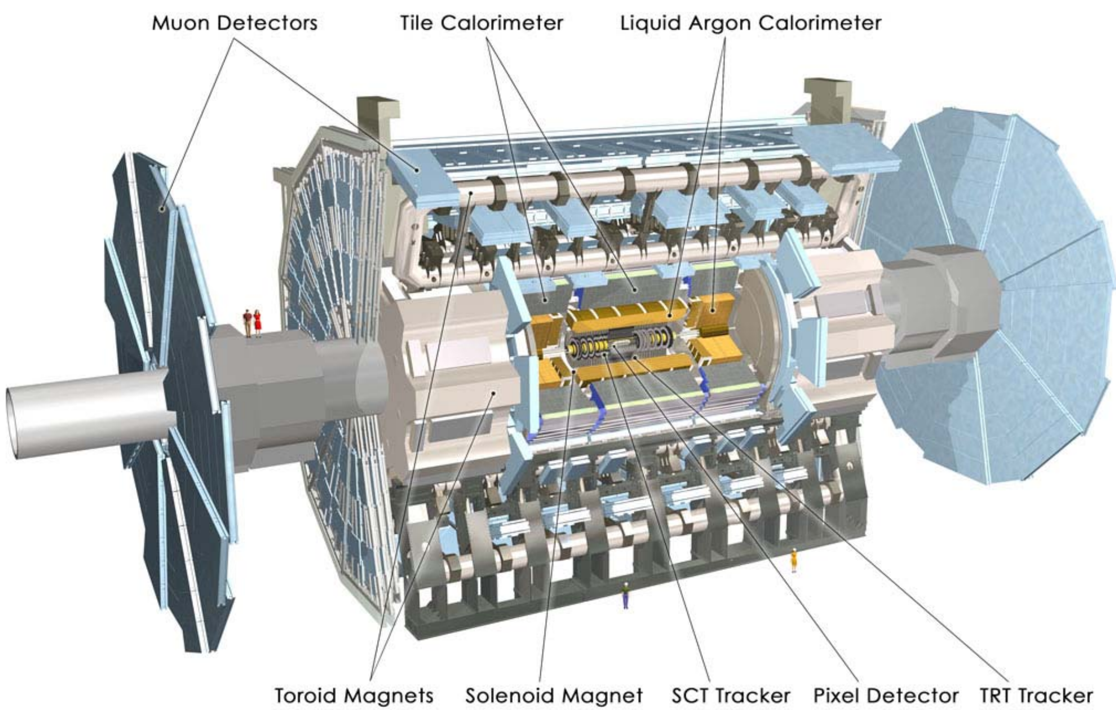
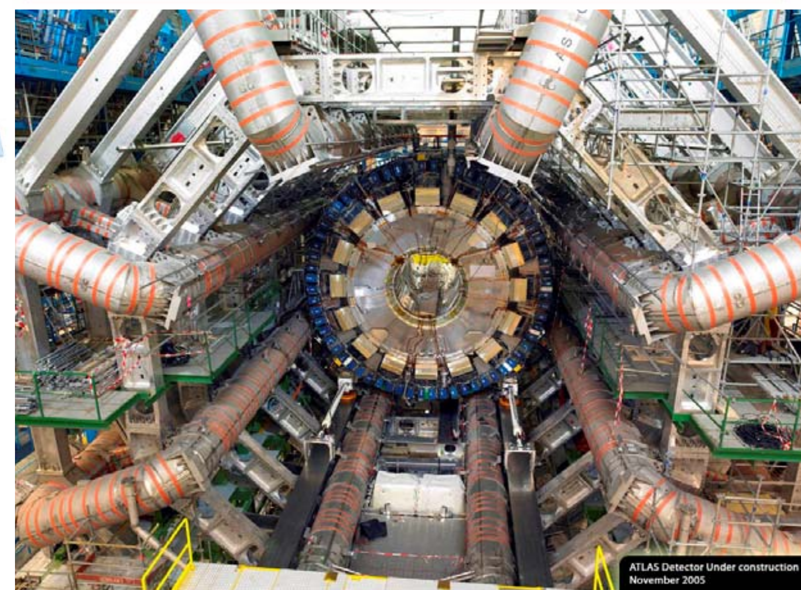
- ATLAS experiment + solenoid
- Objectives
- Field mapping machine
- Simple field model
- Machine performance
- Realistic field model
- Conclusions + future plans

ATLAS Experiment

- LHC will produce proton-proton collisions:
  - cms energy 14 TeV
  - 25 ns bunch spacing
  - 1.1×10^{11} protons/bunch
  - design luminosity 10^{34} $cm^{-2}s^{-1}$
- ATLAS is a general-purpose detector:
  - diameter 25 m
  - length 46 m
  - overall mass 7000 tonnes







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ATLAS Solenoid

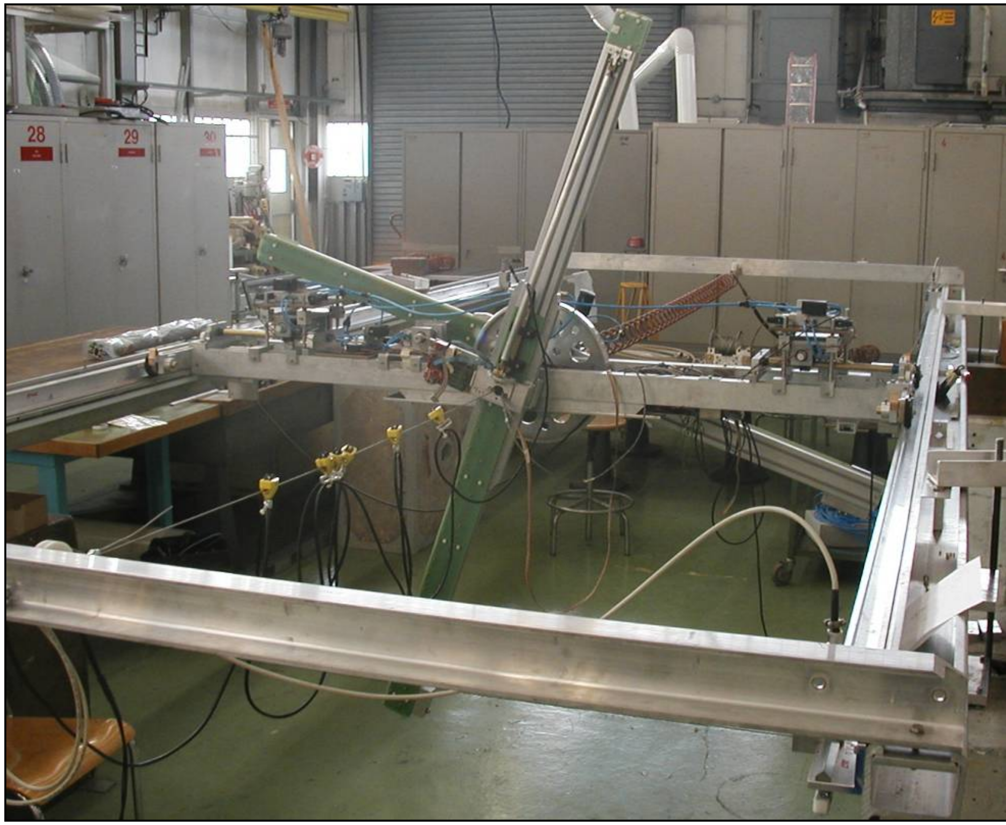
- Solenoid built from 4 coils welded together to give a single coil:
  - 1159 turns
  - length 5.3 m
  - radius 1.25 m.
- Operated at 7600 A to produce an axial field of 2 Tesla at centre of solenoid.
- Return current cable runs along surface of solenoid containment vessel.
- Cables are routed through a magnetically shielded chimney to the power supply.

Objectives

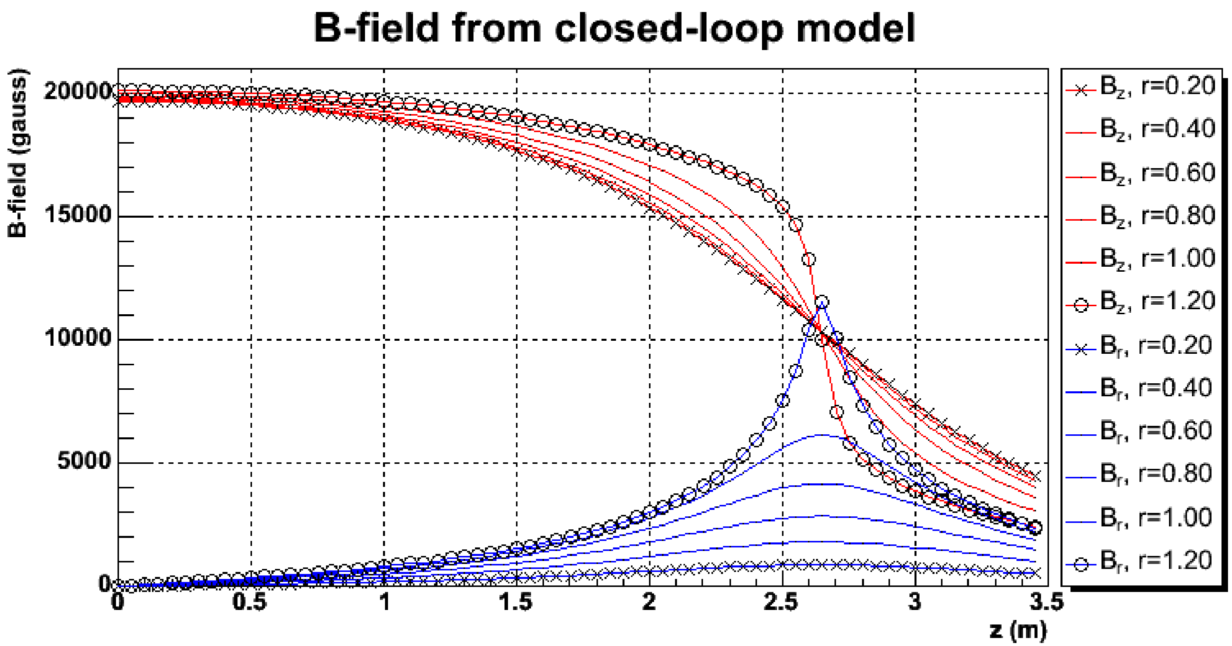
- A useful test of the Standard Model would be measurement of *W* mass with uncertainty of 25 MeV per lepton type per experiment.
- *W* mass derived from the position of the falling edge of the transverse mass distribution.
- Momentum scale will be dominant uncertainty in *W* mass measurement:
  - Need to keep uncertainty in momentum down to ~15 MeV.
- Measure isolated muon tracks with $p_T \sim 40$ GeV over large range of η:
  - Uncertainty in energy loss negligible.
  - Concentrate on alignment and B-field.
- Momentum accuracy depends on $\int r(r_{max} - r)B_z dr$:
  - Field at intermediate radii, as measured by the sagitta, is most important.
- Typical sagitta will be ~1 mm:
  - Limit on silicon alignment, even with infinite statistics and ideal algorithms, will be ~1 µm.
  - Field mapping team targets an accuracy of 0.05% on sagitta to ensure that B-field measurement is not the limiting factor on momentum accuracy.

Field Mapping Machine

- Mapping machine designed and built by team at CERN.
- Two propeller arms which rotate in ϕ.
- Carriage slides in z along rails.
- 48 Hall probes on both sides of both arms.
- Cross-checks between probes on opposite sides of same arm.
- Also have cross-checks between arms.
- Machine measures field inside solenoid before Inner Detector installed.
- Also have 4 NMR probes permanently fixed to solenoid to set overall scale.
- An additional NMR probe fixed to machine carriage.



Simple Field Model



- Basis of model is field due to a single coil of nominal dimensions:
  - Modelled as a series of closed circular loops evenly spaced in *z*.
  - Each loop approximated as a series of straight-line segments, and Biot-Savart law applied to each segment.
- Added in field due to magnetised iron outside the solenoid (4% of total field).
- Model is symmetric in ϕ and even in *z*.

Mapping Machine Simulation

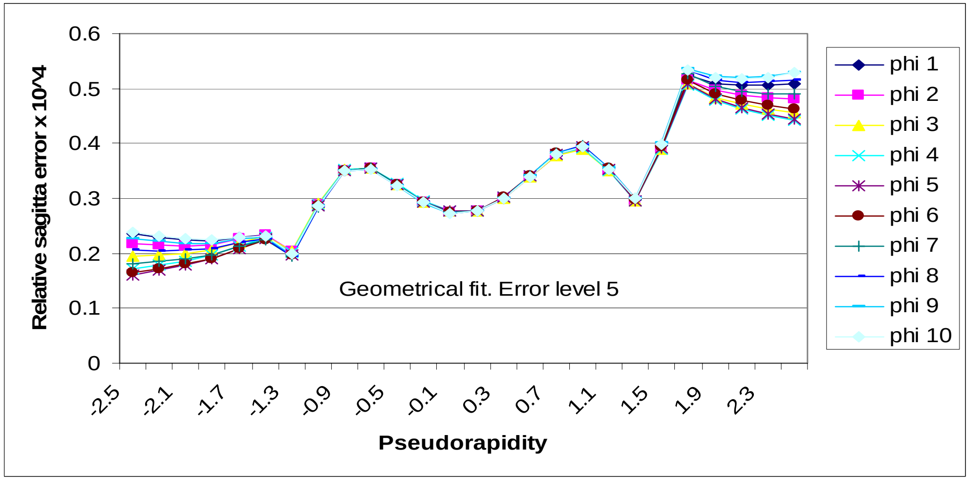
- Simulated performance of mapping machine during a typical scan:
  – Included periodic measurements at calibration points near centre and end of solenoid.
- Added various errors to simulated data:
  – Random measurement errors of solenoid current and B-field.
  – Random walk drifts of solenoid current and Hall probe measurements.
  – Random calibration scale and alignment errors of Hall probes.
  – Displacement and rotation of solenoid field relative to mapping machine axis.
  – Systematic rotation of Hall probes.

Field Fitting

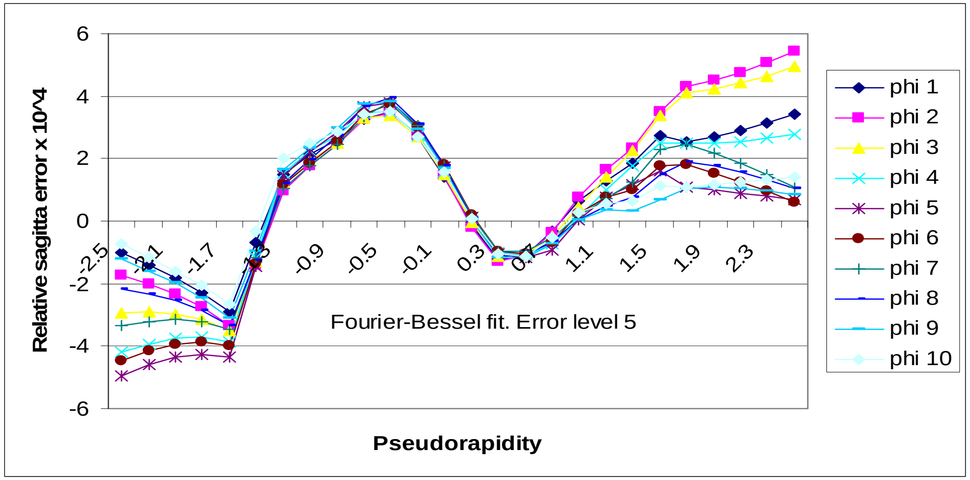
- First, correct for drifts in solenoid current and Hall probe measurements.
- Calibrated data fitted with two methods:
  1. Geometrical fit
     - Sum of simple fields known to obey Maxwell's equations
       - Long-thin coil (5 mm longer, 5 mm thinner than nominal)
       - Short-fat coil (5 mm shorter, 5 mm fatter)
       - Four terms of Fourier-Bessel series (for magnetisation)
     - Use Minuit for χ^2 fit to data
     - Fit gives information about position, shape, etc of coil
  2. Fourier-Bessel fit
     - General fit able to describe any field obeying Maxwell's equations
     - Uses large number of parameters obtained by direct calculation
       - Calculate Fourier terms from B_z on outer cylinder
       - Fit hyperbolic terms to ends of cylinder
       - Fit B_r to find z-independent component of field
     - Poor fit indicates measurement errors rather than incorrect model
- Results from fit used to calculate corrections for Hall probe normalisation and alignment.

Fit Quality

- Quality of fit measured by comparing track sagitta in field model with track sagitta in fitted field.
- Both fits accurate within target level of 5×10^{-4}.
- Probe normalisation and alignment (PNA) correction improves fits.

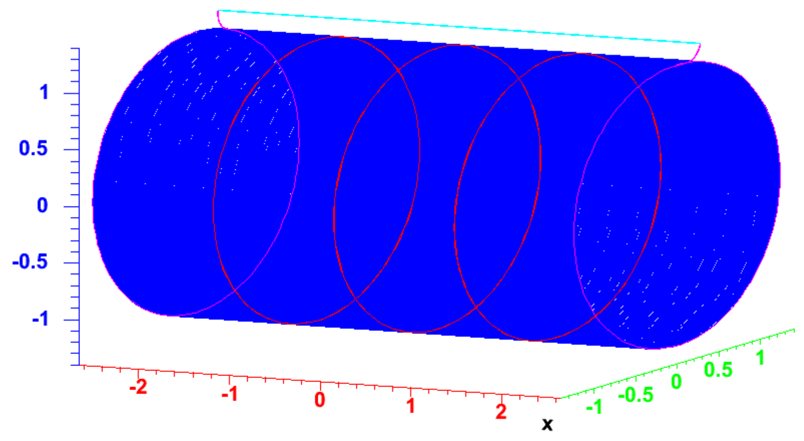


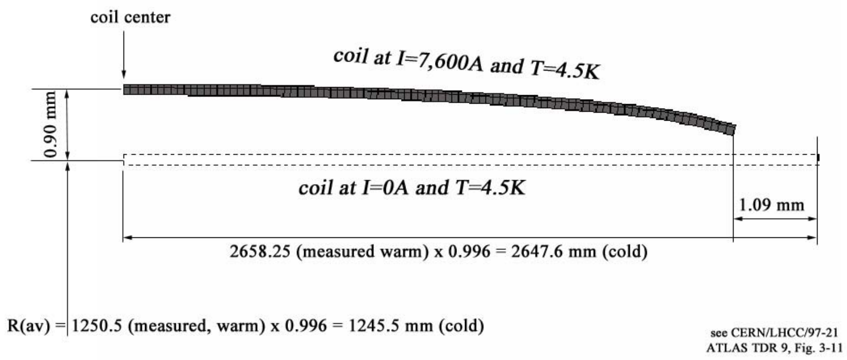
Fit	PNA corr	Relative sagitta error / 10^{-4}			
		Mean	Rms	Max	Min
Geom	No	-0.99	2.42	2.44	-4.62
Geom	Yes	-0.97	1.04	-0.43	-1.70
F-B	No	-3.32	4.43	5.59	-11.52
F-B	Yes	-2.79	3.61	4.20	-10.70



Realistic Field Model

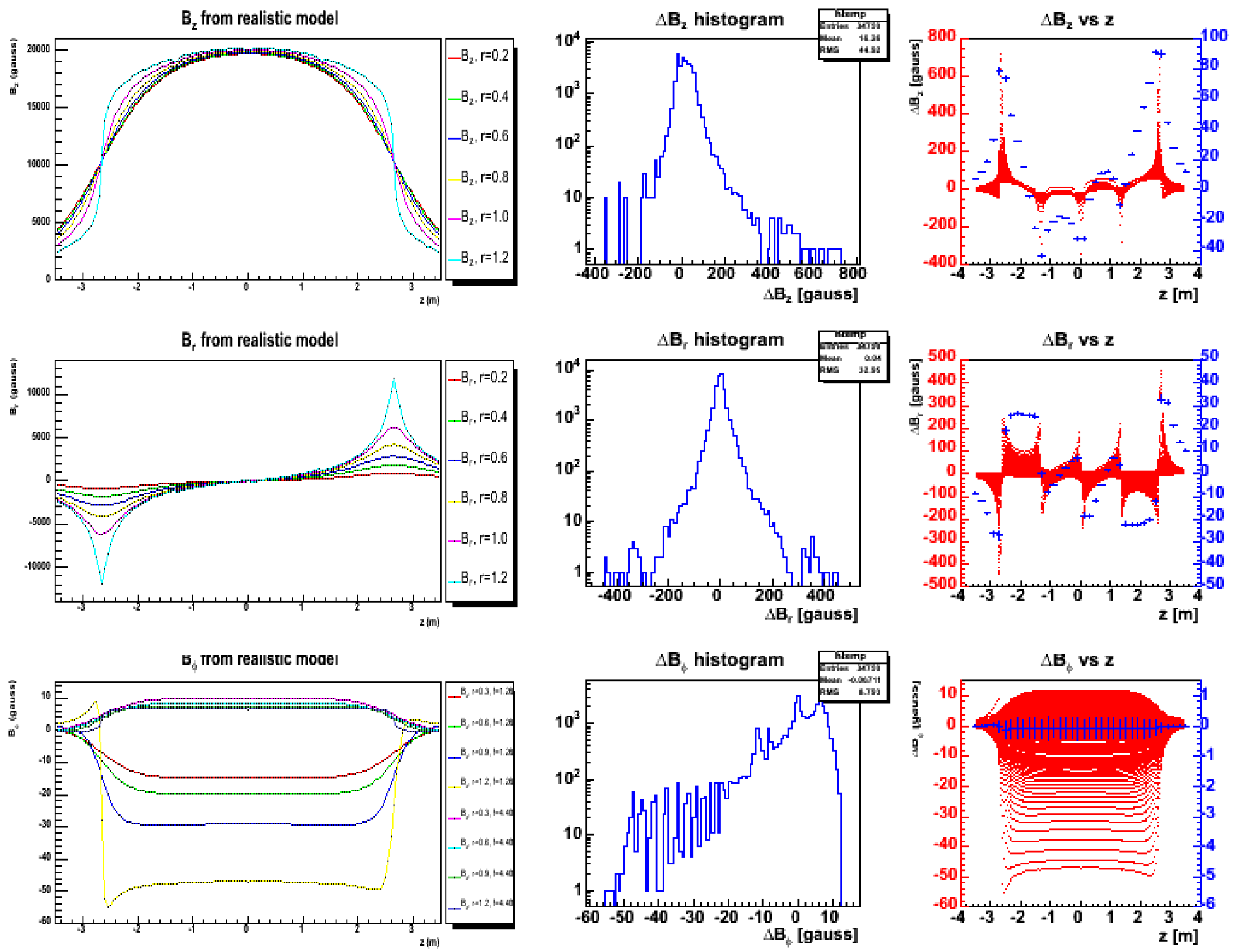
- Developed realistic field model which makes several improvements over the simple field model.
  - Modelled the actual current path:
    - four main coil sections, each as a helical coil
    - welds between main sections
    - welds at end of solenoid
    - return current conductor
  - Modelled real shape of solenoid:
    - shrinkage due to cool down
    - bending due to field excitation





Field from Realistic Model

- Comparisons with previous model:
  - Most adjustments to B_z and B_r components are O(10 gauss).
  - Greatest adjustments are at boundaries (coil ends, weld regions).
  - See effects of different pitches of each coil section.
  - Return cable has greatest effect on B_ϕ component.



Conclusions

- Solenoid field mapping team will measure the solenoid magnetic field with a target accuracy of 0.05% on the sagitta.
- A propeller-type mapping machine has been designed and built, and its performance simulated.
- Two fitting methods (geometrical + Fourier-Bessel) have been developed:
  - Tests with a simple field model show that both fits meet the target accuracy.
  - These fits can form the basis for more detailed fits suitable for the actual field.
- A realistic field model has been developed and makes several improvements over the simple closed-loop model:
  - Models the actual current path.
  - Models real shape of solenoid.
- Comparisons made with previous model:
  - Most adjustments are *O*(10 gauss).
  - Greatest adjustments are caused by features of realistic model (coil ends, weld regions, different pitches, return cable).

Future Plans

- Study performance of field mapping machine and fitting routines using realistic field model.
- Field mapping machine commissioned underground during April + May 2006.
- Data taking scheduled for June 2006.
- Final field map prepared for September 2006.

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