Magnetic Measurements at very low field levels at CERN

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Introduction

Motivation and examples

Measurement of weak (10^{-7}~10^{-4} T) background/stray fields is carried out routinely at CERN for a variety of different reasons:

- **EMI in beam lines**:
  - many historical examples e.g. perturbations in SPS, LEP …
  - 8 kHz "hump" hunting in the LHC (2010)
  - ambient fields and field leakage in AD/ELENA pbar rings & experiments (2013-)
  - CNGS tunnel (2010), AWAKE (2017)
  - stray field of steel bolts, reflector supports, ….
- **EMI on test benches**:
  - impact of stray DC fields on fluxmeters
  - impact of 50 Hz fields on vibrating wires
- **Shield effectiveness**:
  - LHC crab cavities
  - squid-based beam current DCCTs
- **Safety reasons**
  - 5 G (legal pacemaker limit) perimeter in the stray field of large magnets

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Beam perturbation investigation

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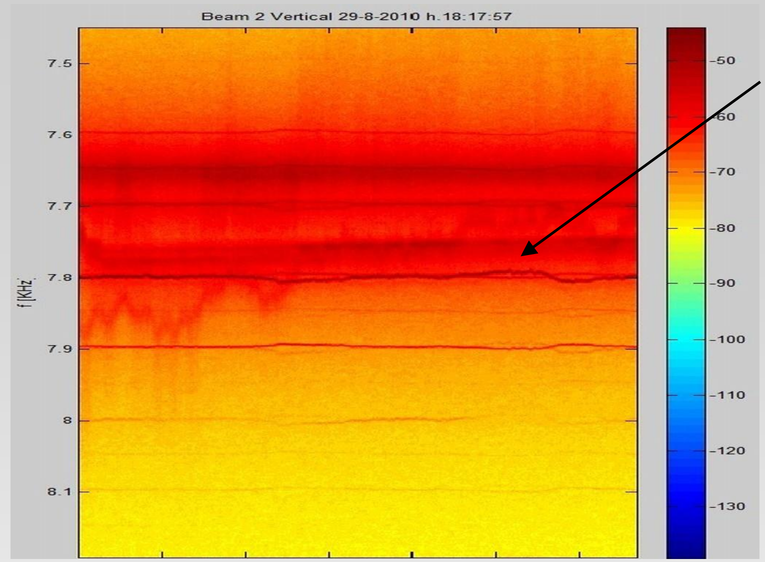
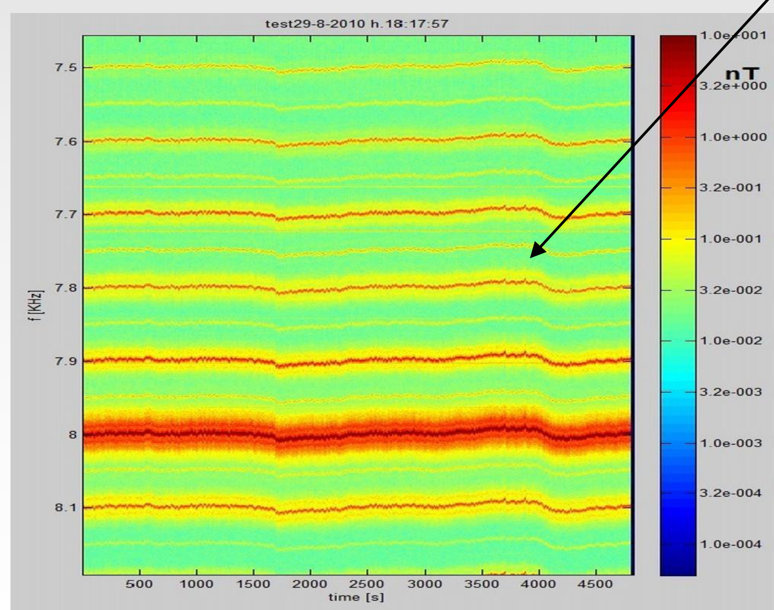
LHC hump hunt (1/2)

- “the hump”: weak excitation bands observed in the LHC transverse spectra at ~8 kHz (& multiples) from 2009 to 2011
- peculiar quasi-periodic frequency drift over a timescale of ~20 min
- localized investigation campaigns carried out with induction coils while equipment categories (pumps, UPS etc …) were switched on and off
- 7 remotely acquired coils left in place in 2011
- some correlations were found but the underlying cause was never clarified
- “spontaneously” disappeared during 2011 YETS

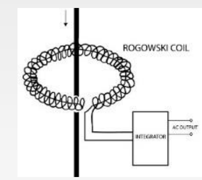
Example: UPS-caused event seen by:



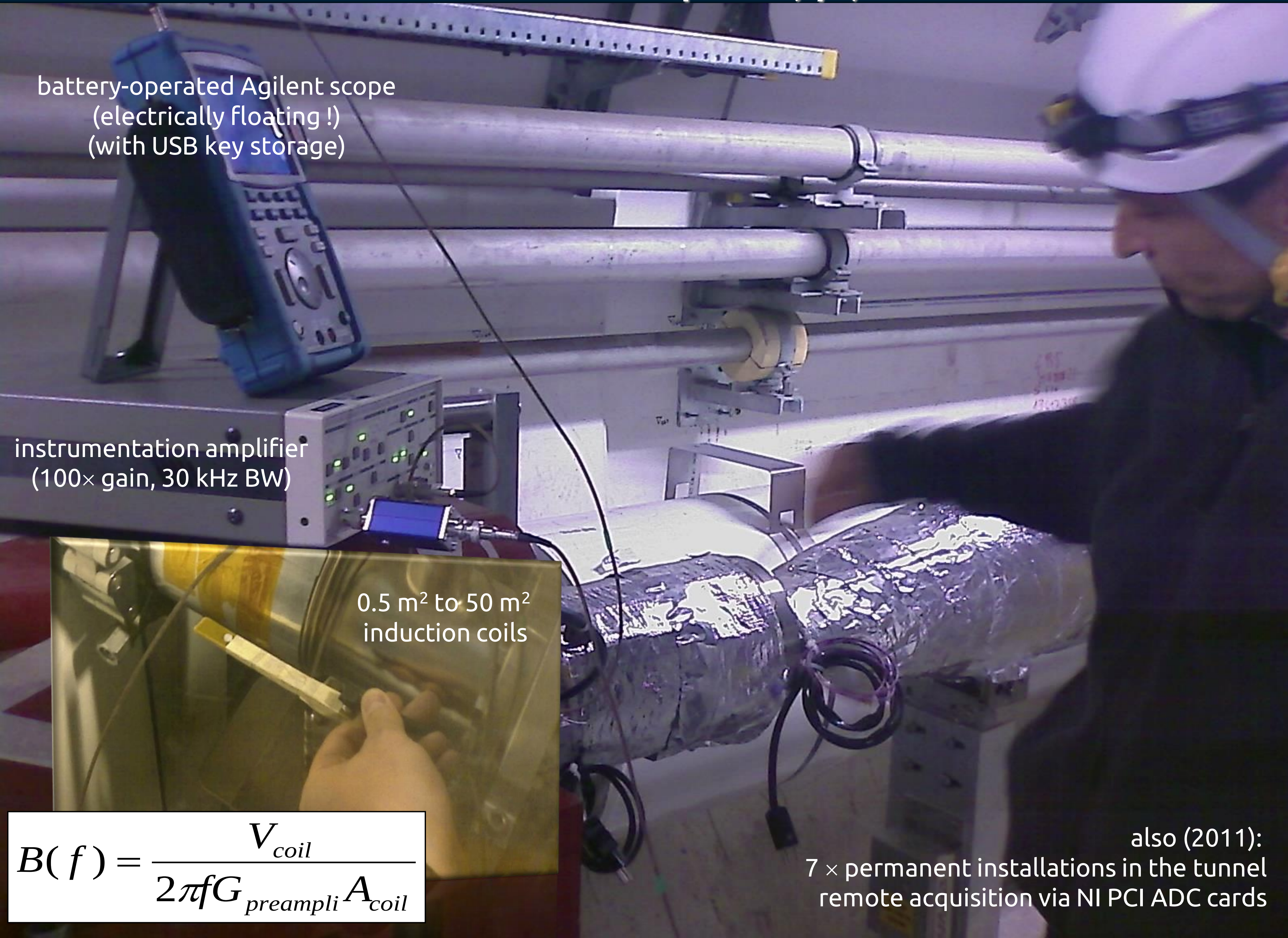
BBQ (tune meas.) on Beam 2



“Rogowski” measurement on a 3-phase UPS



LHC hump hunt (2/2)

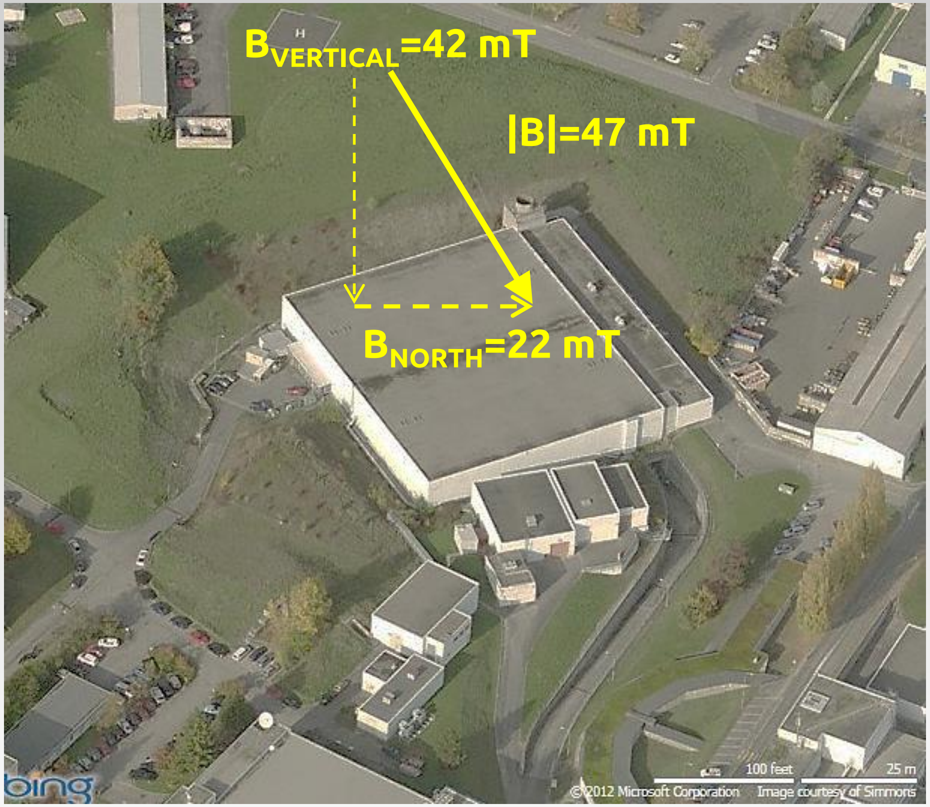


$$B(f) = \frac{V_{coil}}{2\pi f G_{preampli} A_{coil}}$$

Geomagnetic field in Geneva

Daily and yearly change < 1%

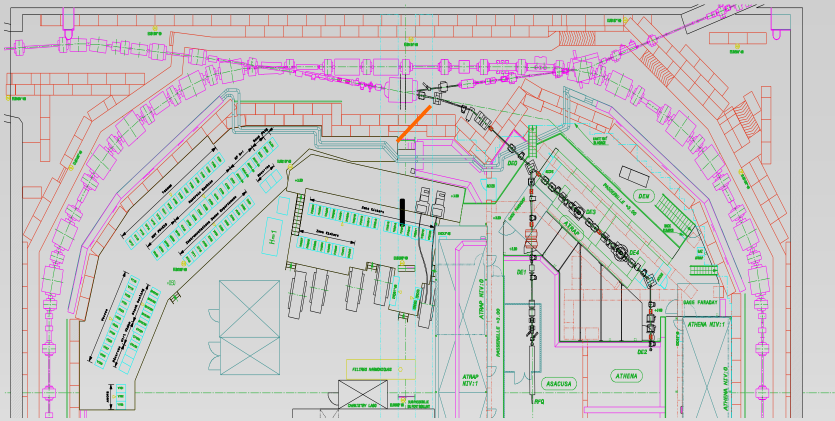
General field level in the hall: $B_{VERTICAL} \sim 35\ \mu T$
$B_{HORIZONTAL} \sim 30\ \mu T$



Scaffolding structure behind kicker spools:
150 μT (70 μT @ 0.2 m)

Field at AD ring concrete shielding blocks:
|B|~ 10 μT (~stable)

AD/ELENA investigations (2/3)



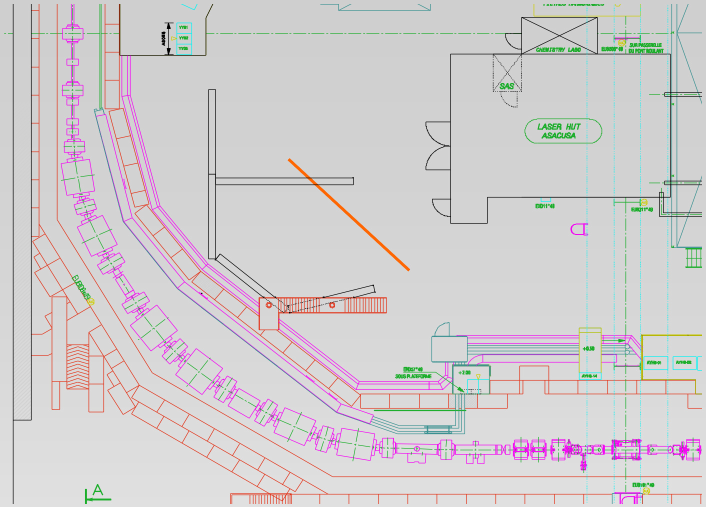
300 μT at the door frame

6500 μT at the Ar bottle

1000 μT at 1 m from the bottle

10 μT baseline in the area

AD/ELENA investigations (3/3)



1500 μT along the corner of the concrete block

50 μT at 1 m

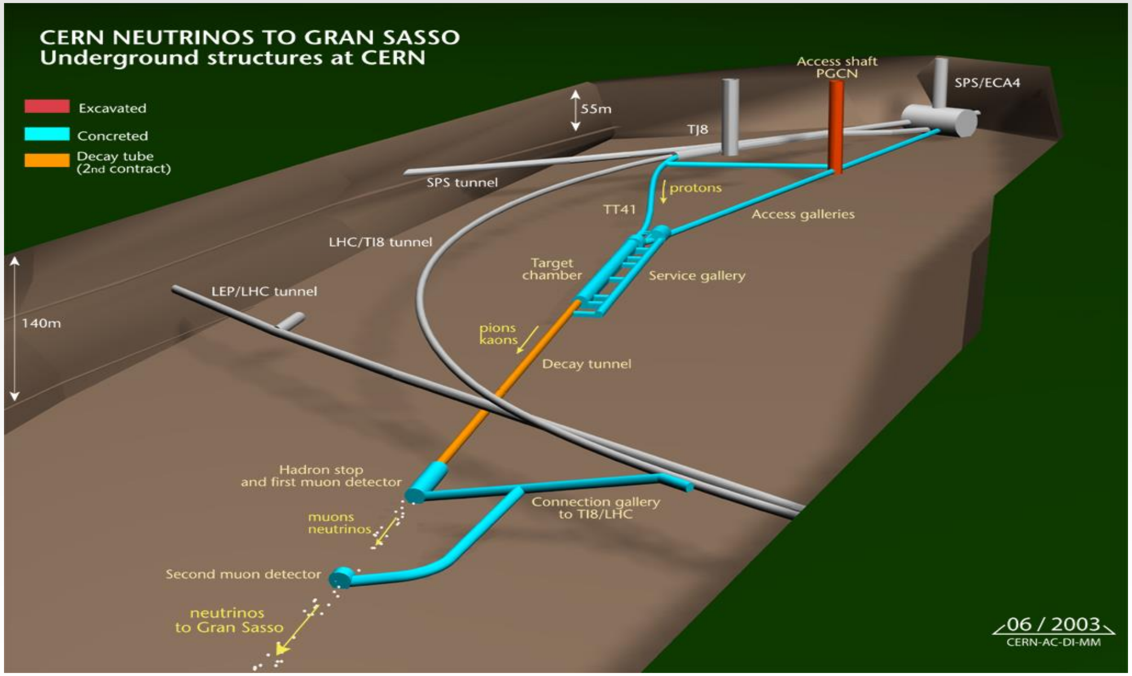
baseline (center of workshop area):

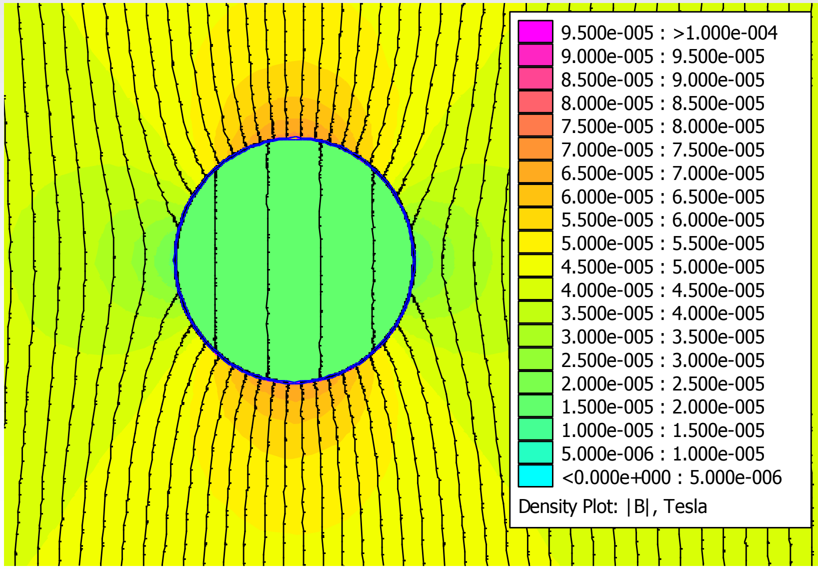
$B_{VERTICAL}$ = **25 μT**

$B_{HORIZONTAL}$ = **25 μT**

CERN Neutrino to Gran Sasso

- pions/kaons were made to decay to neutrinos in the 998 m long CNGS tunnel
- ~200 mm position errors observed at the target over 700 km away, attributed to integrated background field in the tunnel
- measurements within 20-50 μT precision confirmed simulation
- prediction of earth field attenuation difficult due to uncertainty on material properties





Test bench applications

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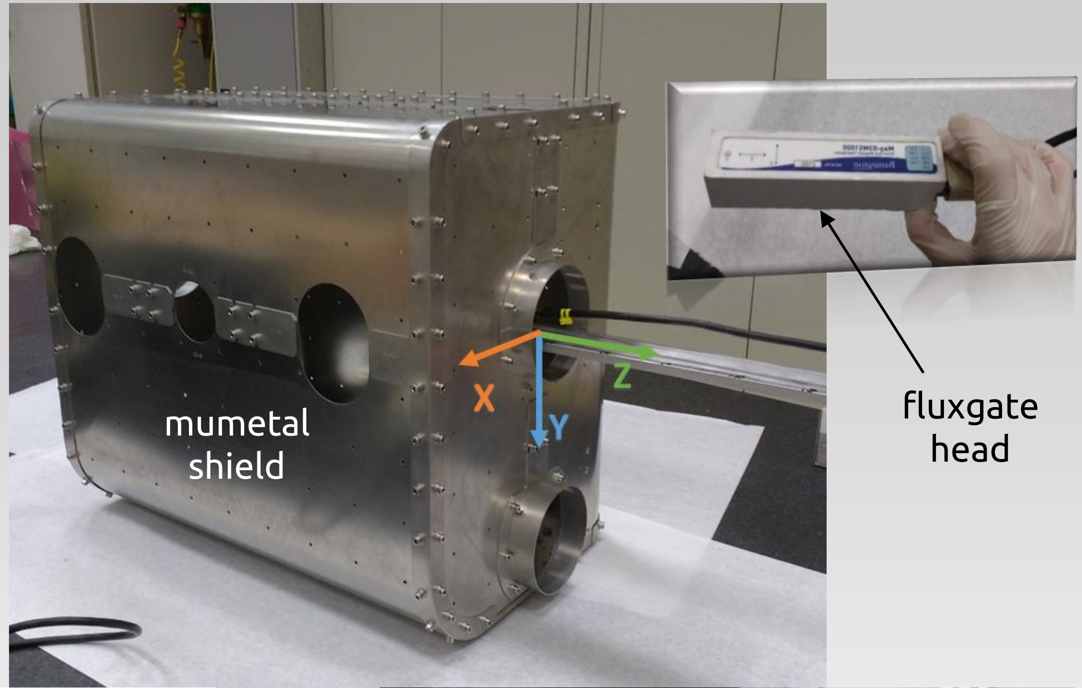
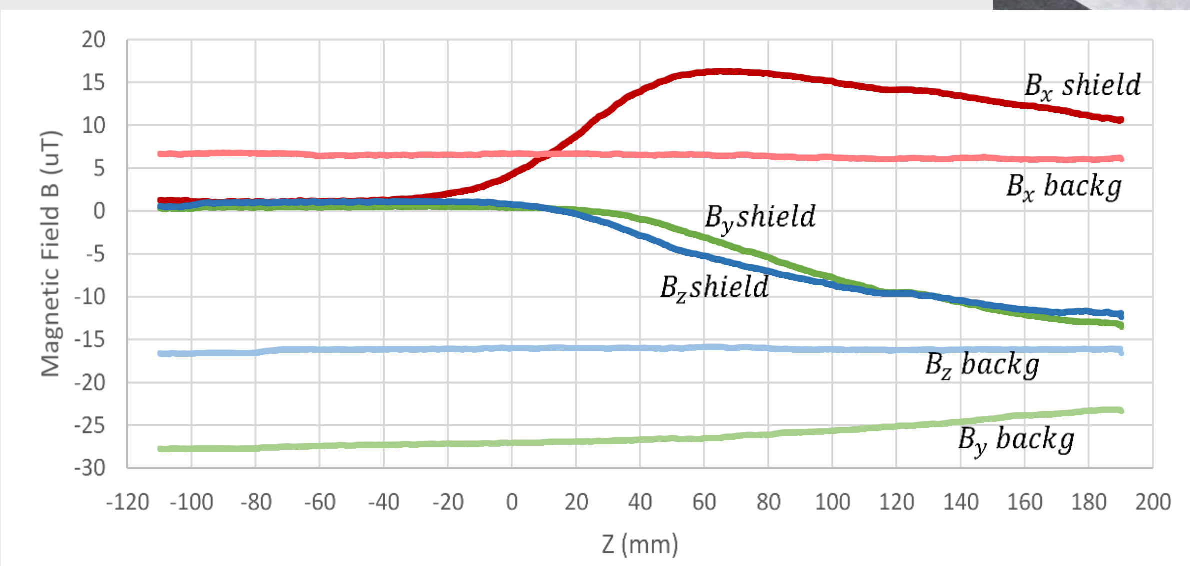
Measurement of LHC Crab Cavity shield effectiveness

- New RF crab cavities have a design field tolerance of ~100 nT → passive shielding necessary
- Magnetic performance of mumetal depends critically upon the thermal and mechanical history of material (20~30% fluctuations between units) → predictive calculation is not possible
- Accurate measurement of shielding factor in the 10^2 range requires sub-μT instrument precision (new head recently acquired)





Bartington fluxgate with battery-operated 3-axis display unit (various models, lowest range is 70 nm to 70 μm, up to few kHz analog out)

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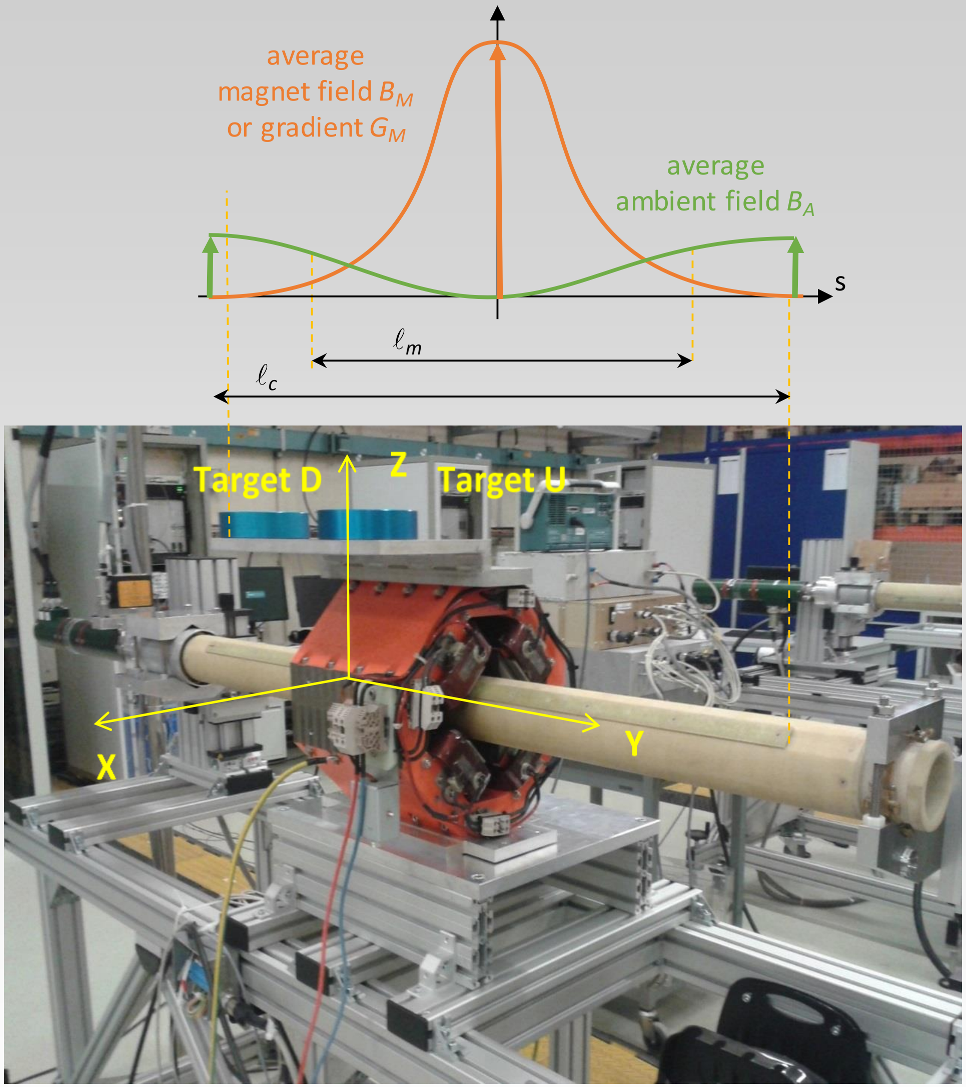
Impact of background DC fields on fluxmetric measurements



- Background fields 0.5~2 G captured by long sensors, penetrate partially inside the magnet
- Compensation can be done by averaging measurements at opposite polarity, not always practically possible
- Typical max. error on dipole magnets:

$$\varepsilon = \frac{B_A(\ell_c - \ell_m)}{B_M \ell_m} \approx 10^{-4}$$

- Typical max. error on quadrupole axis offset:

$$\Delta x = \frac{B_A(\ell_c - \ell_m)}{G_M \ell_m} \approx 10\sim30\ \mu m$$

- These are often negligible, may represent a limit for high-precision applications

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Conclusions

Summary

- DC/VLF background levels fluctuate **between a fraction and several Gauss**, with **strong local peaks** up to few mT levels
- predictive calculations are hardly usable due material uncertainties so measurements are necessary (expect unexpected findings!)
- **commercial fluxgates** and home-made **induction loops** OK so far Hall probes generally too noisy
- next big use case: background mapping of bldg. 193 and magnetic cross-talk measurements for ELENA antiprotons