Potential CLIC-Vacuumschmelze Activity Mu-Metal

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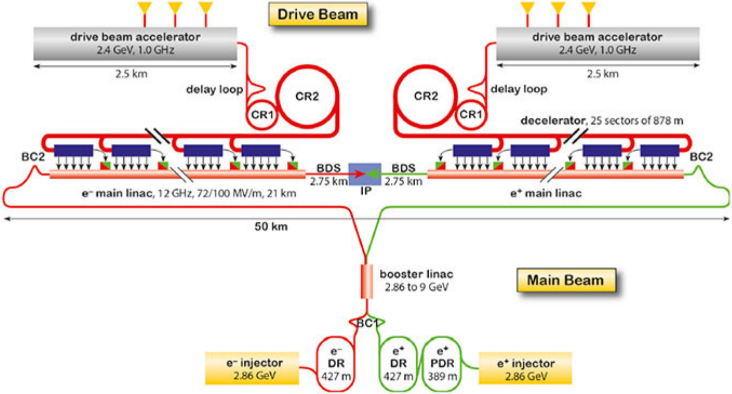
Outline

Motivation



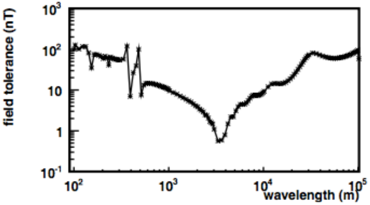
e^-e^+-beams (40 nm x 1 nm) collide at the IP

High quality magnets transport and focus particle beams from source to IP

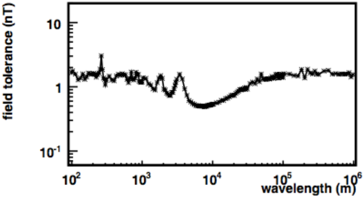
Dynamic field variations may deteriorate machine performance

Sensitivities

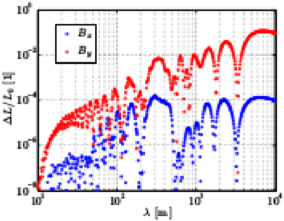
- CLIC sensitivity to magnetic field variations
  - RTML



  - Main Linac



  - BDS

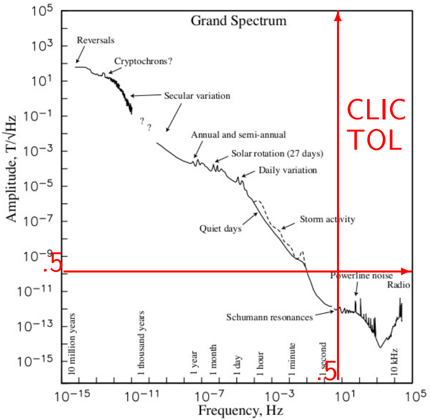


Field Tolerance $\approx$ nT

Frequency $\leq$ 50 Hz

SOURCES

Natural sources expand from ULF (mHz) up to VLF (MHz)



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Earth Field changes due to external and internal sources

- External: Solar Storms unlikely $\geq 2\ nT/s$ @ CERN

$\Downarrow$

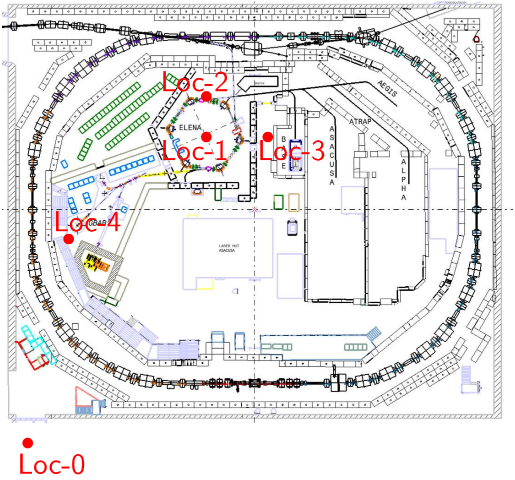
Geomagnetic Induced Currents (GIC)

- Internal: Seismic movements

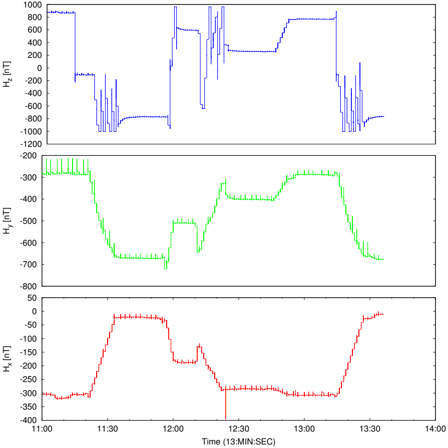
*Figure taken from *Constable, C., Encyclopaedia of Geomagnetism and Geomagnetism*

Nearby Accelerator: Antiproton Decelerator and ELENA

from PS ⇒ Antiproton-deccelerator ⇒ ELENA ⇒ Experiments
26 GeV Target ⇒ 3.5 GeV - 5.3 MeV (Kinetic) ⇒ 100 keV



Zoom In @ Loc-1



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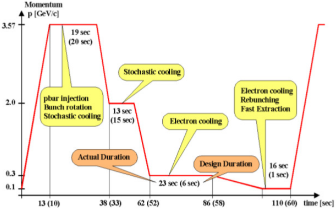
Sketch of AD magnetic cycle†

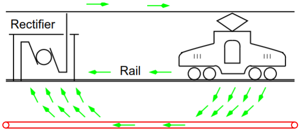
Expected duration ≈60 s

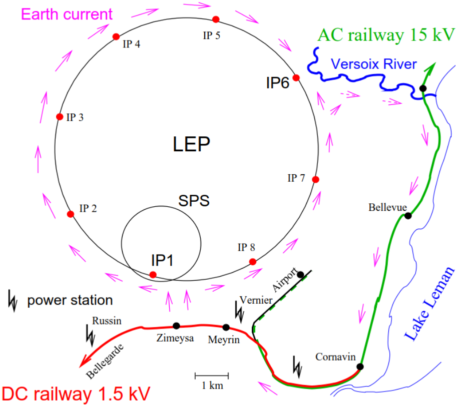


†Figure taken from *Status and Prospects for the AD and ELENA*, Lars V. Jorgensen / CERN / BE-OP

Vagabond Currents

- Explanation by an electrician from Swiss electricity company





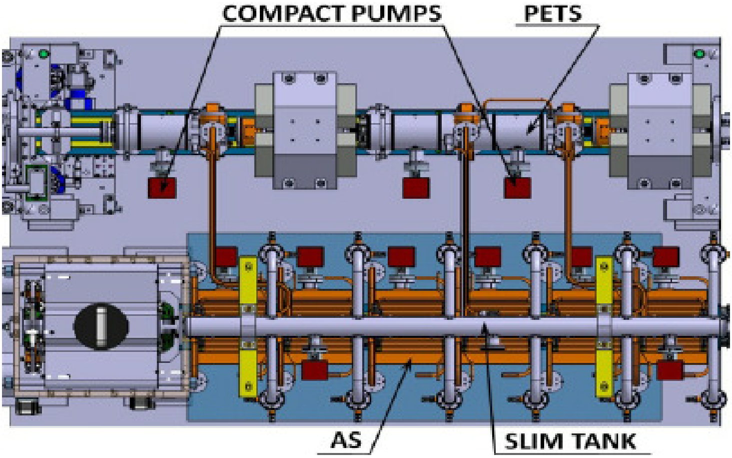
A DC current of **1 A** was flowing on the LEP vacuum chamber

FCCee is ≈4 times larger thus B_{min} ≈4 times smaller*

*Slide taken from *Energy Calibration and Stray Fields at LEP* by J. Wenninger during Mini-Workshop

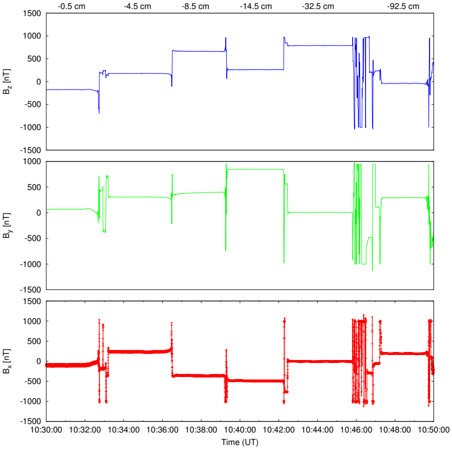
Technical Equipment: Two Beam Module

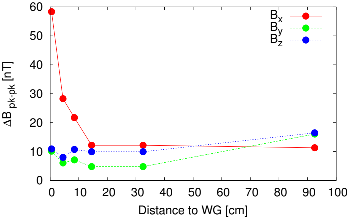
- Drive Beam (high current) perturbs Main Beam
- Waveguides may induce *B*-field variations (XBOX Exp)



Technical Equipment: XBOX Measurement Results

- Few tens of nT variations observed at the vicinity of the waveguide



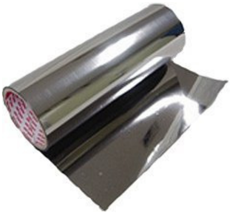


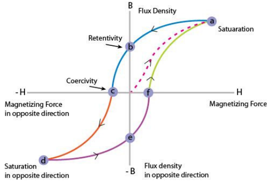
Data is consistent with a current of 13 mA (assuming an infinitely straight current)

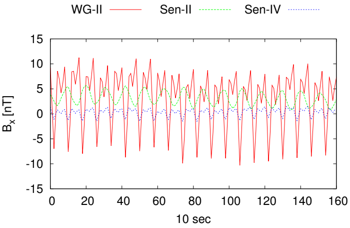
MITIGATIONS

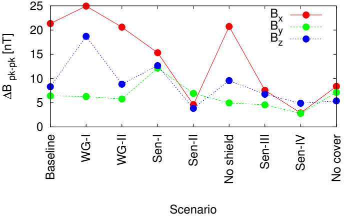
Soft-μ magnetic material Shielding

The measured signal was attenuated by shielding the sensor with a soft-μ magnetic material





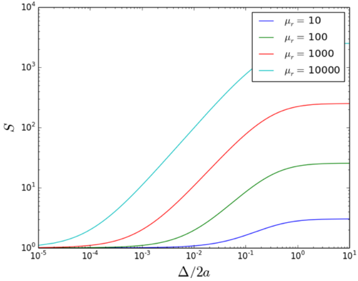




Shielding Factor

$$S = \frac{B_{\text{in}}}{B_{\text{out}}} \quad (1)$$

- Soft-μ material



To achieve $S = 10^3$
Pipe $\oslash = 10\ cm$
Thickness $\Delta = 2\ cm$

- Conductive material

To achieve $S = \frac{1}{e}$ at $f \geq\ kHz$
Pipe $\oslash = 10\ cm$
Thickness $\Delta = 1\ mm$

Ferromagnetic materials

Pros:

- High permeability $\mu_r \approx$10000 - 100000 (special treatment)
- Wider frequency range
- Multi-layer strategy
- Commercially available
- Cost €/Kg ?

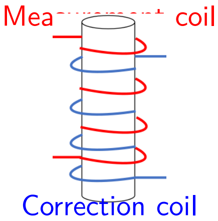
Cons:

- Final properties after treatment (High T baking)
- Handling (soft$\Rightarrow$compromise properties) & Installation
- Cobalt contain (radio-protection)
- Shielding factor at low fields
- Saturation due to high field magnets
- Cost €/Kg ?

2-Coils Compensation

- The current train-to-train feedback system against ground motion will remove the effects of stray fields changes ≤ 1 Hz
- For higher frequencies we need an alternative feedback to correct for the stray field itself

Proposed scheme



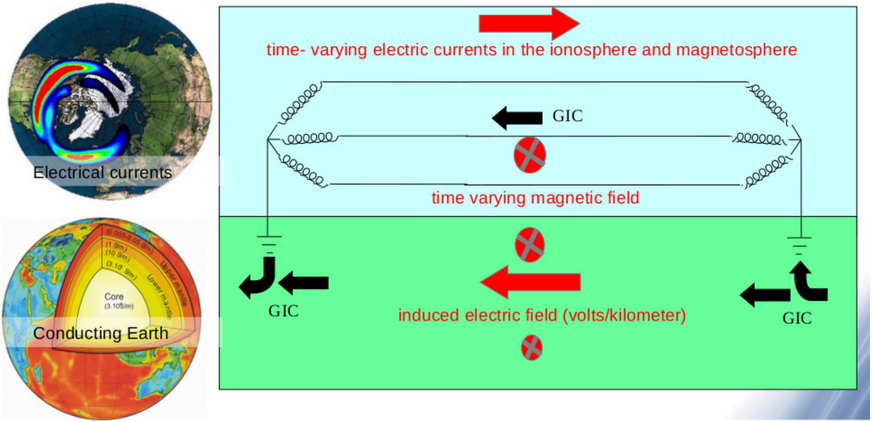
SUMMARY

Summary

- Natural sources seems to be ok
- Environmental and Technical sources are well above tolerances (μT)
- Passive shielding (μm-material) seems to be an effective solution
  - Few tens of km to be shielded 380 GeV Stage ⇒ 60 T assuming (1 mm thickness, $\varnothing\, 10cm$)
  - Performance at low fields and frequencies (Material qualification)
  - Response under strong magnetic environment
  - Response under radiation
  - Treatment & Installation
  - Cost
- Currently setting-up a test-bench for low-B field measurements

BACK UP

Geomagnetic Induced Currents



DC offset in transformer causes: voltage harmonics; loss of reactive power; flux escape from core; overheating; destruction of insulation

[†]Slide taken from *The Earth′s Natural EM environment* by C. Beegan during Mini-Workshop

GIC Impact

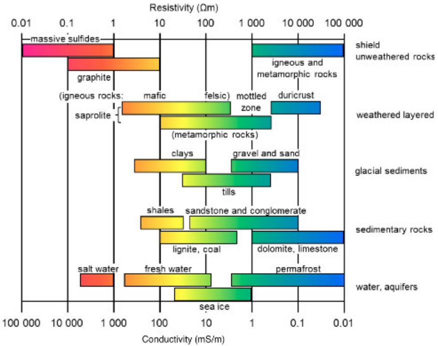
- Failure of Hydro-Quebec system in March 1989
  - Cascaded shutdown of entire grid in 90 seconds
  - 9 hours to restore 80% of operations
  - 5 million people without power (in cold weather)
  - Estimated C$2Bn economic cost (incl. C$12M directly to power company)
  - 2003: UK (2 transformers failed), Sweden (1 hour blackout), Finland, Canada, South Africa (15 transformers failed), Japan, Spain, New Zealand …
- Faults in railway signalling
  - Lights switch to red
  - Points move
  - Communications loss
- Increase in pipeline voltages
  - Long-term corrosion effects
  - Economic loss

‡ Slide taken from *The Earth′s Natural EM environment* by C. Beegan during Mini-Workshop

Possible ELF-VLF (<100 kHz) sources

- Lighting, seismic,..
- VLF transmitters (Rosnay 400 kW)

- **50 Hz and harmonics**
- Instrumental noise through cross modulation



$$\delta = \frac{1}{\sqrt{\pi \mu \sigma f}}$$

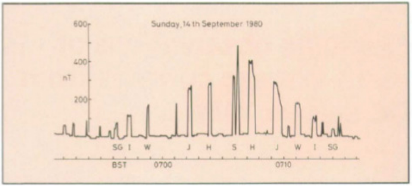
$$\delta \approx 100 \text{ m @ } 24 \text{ kHz}$$

$$\delta \approx 500 \text{ m @ } 1 \text{ kHz}$$

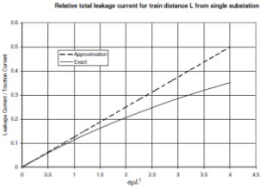
$$\delta \approx 1500 \text{ m @ } 100 \text{ Hz}$$

Long wires act as antennas for VLF $\Rightarrow$ distributes noises along the wire (CLIC can be seen as a 50 km long wire)

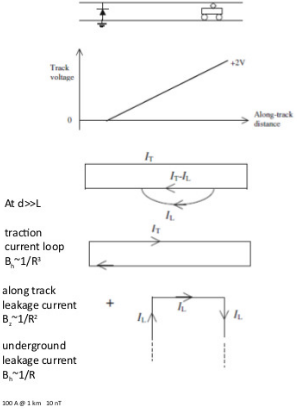
Stray fields from trains (DC case)



DC train noise as it travels from station 4 km along a track (there and back) recorded at 120 m from station H (Lowes, 1987)



Leakage current can be 10s % of traction current (Lowes, 2009)



Simple model for DC trains (Lowes, 2009)

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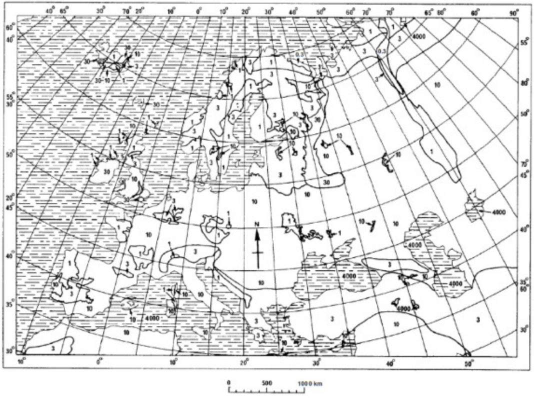
Penetration under the ground

Skin depth

$$\delta = \sqrt{\frac{2}{\mu_0 \sigma 2\pi f}} = 503\sqrt{\frac{1}{\sigma f}} \quad \text{(m)}$$

Ground conductivity σ is typically a few mS/m or a few tens of mS/m.

e.g. σ = 4 mS/m, f = 0.05 Hz → 35,6 km
σ = 40 mS/m, f = 0.05 Hz → 11,2 km



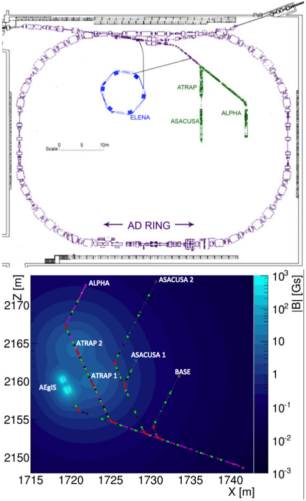
ITU conductivity map for Europe VLF range, in mS/m

†

†Slide taken from talk *Sources: Ultra Low Frequency (ULF) waves* by B. Heilig at Mini-Workshop on Impact of Stray Fields on Accelerators

ELENA Ring: Present Accelerator

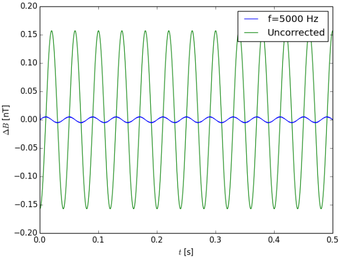
- ELENA receives 5.3 MeV antiprotons from AD ring
- Delivers 100 keV anti-protons to the experiments
- $B\rho$=457 Gm
- B_{Earth} of 0.5 G deflects beam by $\approx$1 mrad
- Transfer lines pass by $\approx G$ solenoids of experiments



2-Coils Compensation

- Signal induced by a sinusoidal magnetic field with frequency 25 Hz
- An error of $\pm 10\%$ was included

Parameter	Value
Number of turns	10
Stray field amplitude	5 nT
Stray field frequency	25 Hz
Radius of coils	10 cm
Length of coils	30 cm
Permeability of coil core	0.126 H/m



- Reduction of about 90%
- Some residual signal

Working principle

- Magneto-static shielding
- **Eddy current shielding**

The choice of material depends on

- $\Delta B \Rightarrow$ *shield saturation*
- Frequency
- Cost

Thickness of the passive shield must be greater than skin depth

$$\delta = \sqrt{\frac{1}{f \mu_0 \mu_r \sigma}} \tag{2}$$

Frequencies $\approx$ kHz $\Rightarrow$ Conductive materials (copper)
Frequencies $\approx$ Hz $\Rightarrow$ Ferromagnetic material (soft-*mu*)

$\Downarrow$

Is a Multi-layer shielding a good idea? different Seebeck coefficient $\Rightarrow$ induces current by longitudinal temperature gradients