Stray Field Measurements

E. Marin[1], B. Heilig[2], J.Pfingster[3], D. Schulte[1]

[1]CERN, (Switzerland)
[2]Geological and Geophysical Institute of Hungary, (Hungary)
[3]University of Oslo, (Norway)

Monday, March 6th 2017
Session: Beam Dynamics 1 : Main Linac and RTML
CLIC Week Workshop, CERN

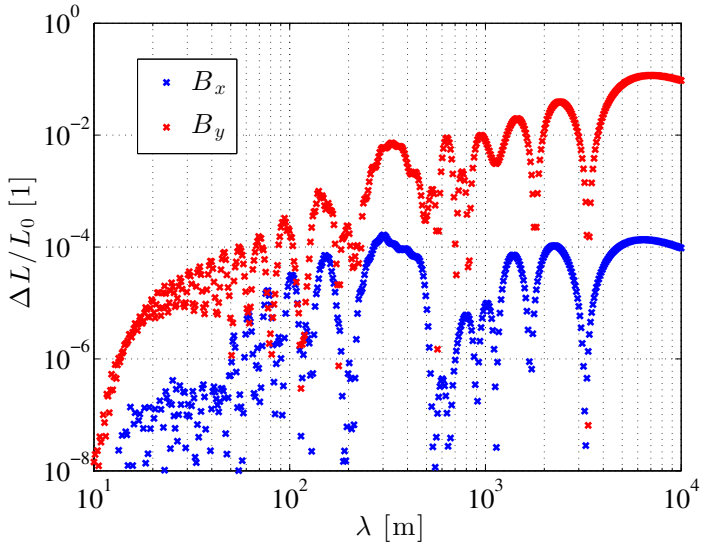
Outline

MOTIVATION

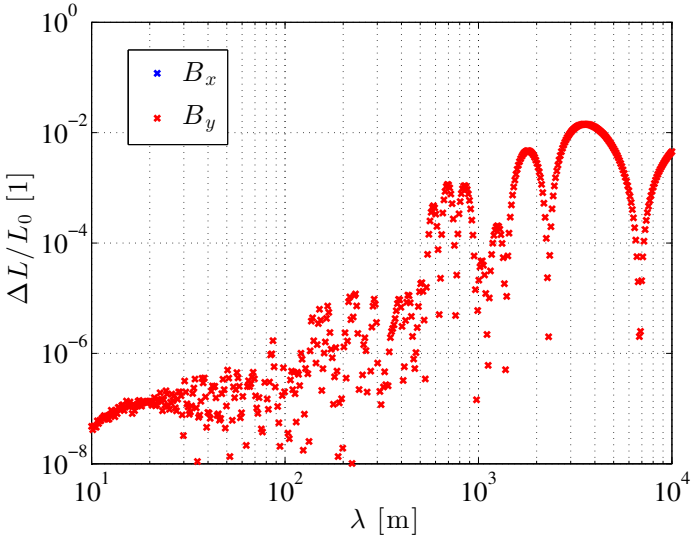
CLIC-BDS Sensitivity to Stray Fields

- In 2010 simulation study of stray field impact on CLIC †
  - Tolerance of ≈nT for the BDS (collimation section)
  - Mitigation techniques (shielding, feed-forward system)
  - Lack of measurements on equipment
- Presently J. Pfingster calculations confirm tolerances and critical sections to Stray Field variations

Due to position offset



Due to angle offset

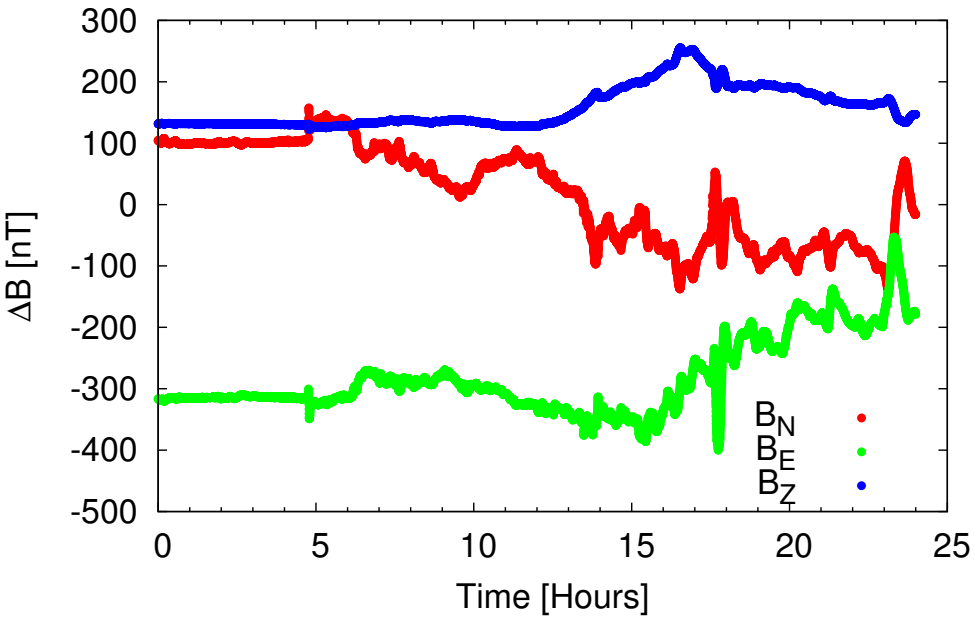


† J. Snuverink et al, WEPE023, IPAC'10

Magnetic Field Variation

- Natural Magnetic Fields (Earth's field, geomagnetic storm)
- $\vec{B}$-fields due to technical equipment

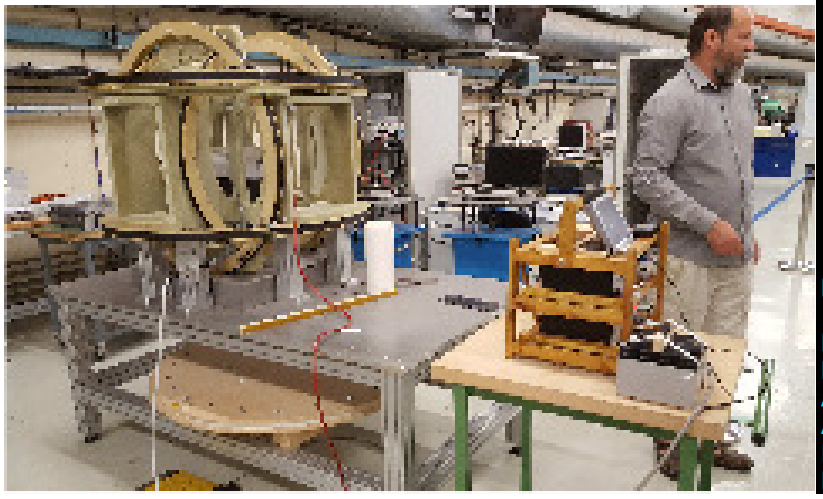
- Geomagnetic storm at Tihany Geophysical Observatory [a]
- Magnetic field expressed in XYZ components (X-North, Y-Eastern, Z-Vertical)
- Max. $\Delta\vec{B}$ observed during severe storm $\approx \mu$T (infrequent and predictable)



[a] similar latitude as Geneva
Data courtesy of B. Heilig

STRAY FIELD MEASUREMENTS @ CERN

Measurement Set-up



LEMI-035 magnetometer

MAIN TECHNICAL PARAMETERS

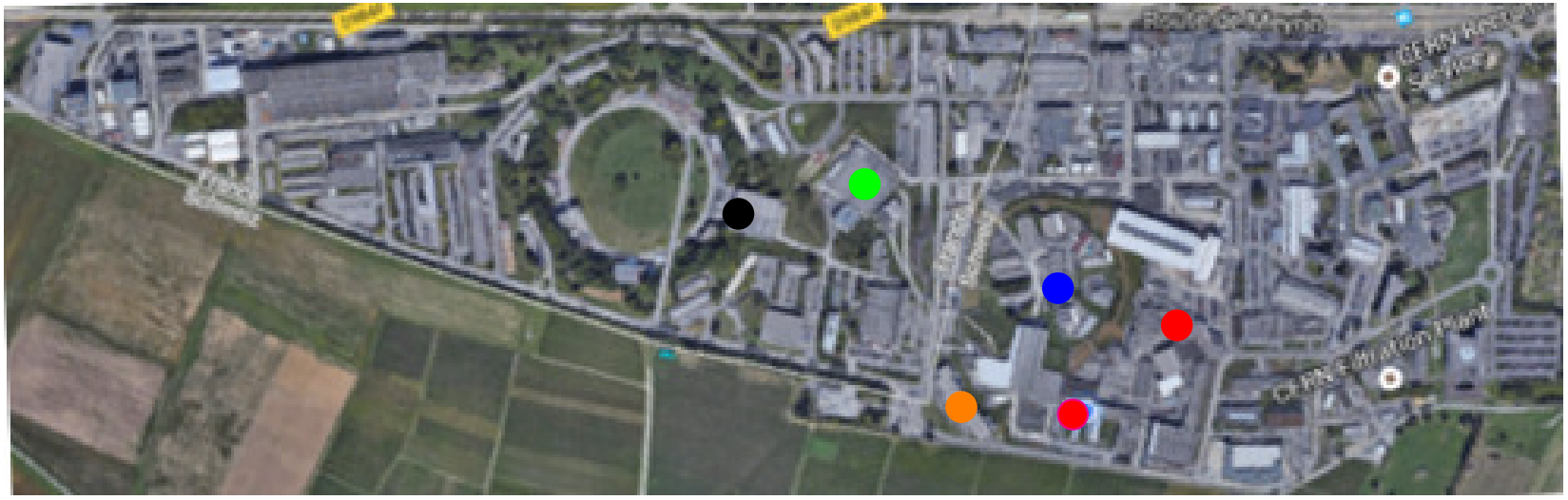
Measurement range	± 70000 nT
Magnetic field variation range (w/o additional compensation)	± 1000 nT
Analog output sensitivity	5 mV/nT
Analog output range	± 4.8 V
Frequency band, 4th order Butterworth low-pass filter	0…20 Hz
Noise level at 1 Hz	< 10 pT

- Compact, portable and easy to set-up
- Specifications are not perfectly fitted to our requirements
  - Data acquisition at 128 Hz
  - Filter cut-off of the magnetometer is at 20 Hz
  - **Not operational under radiation**

Scenes

- 1^{st} measurement campaign: 20/06/2016-29/06/2016
- 2^{nd} measurement campaign: 16/01/2017-20/01/2017

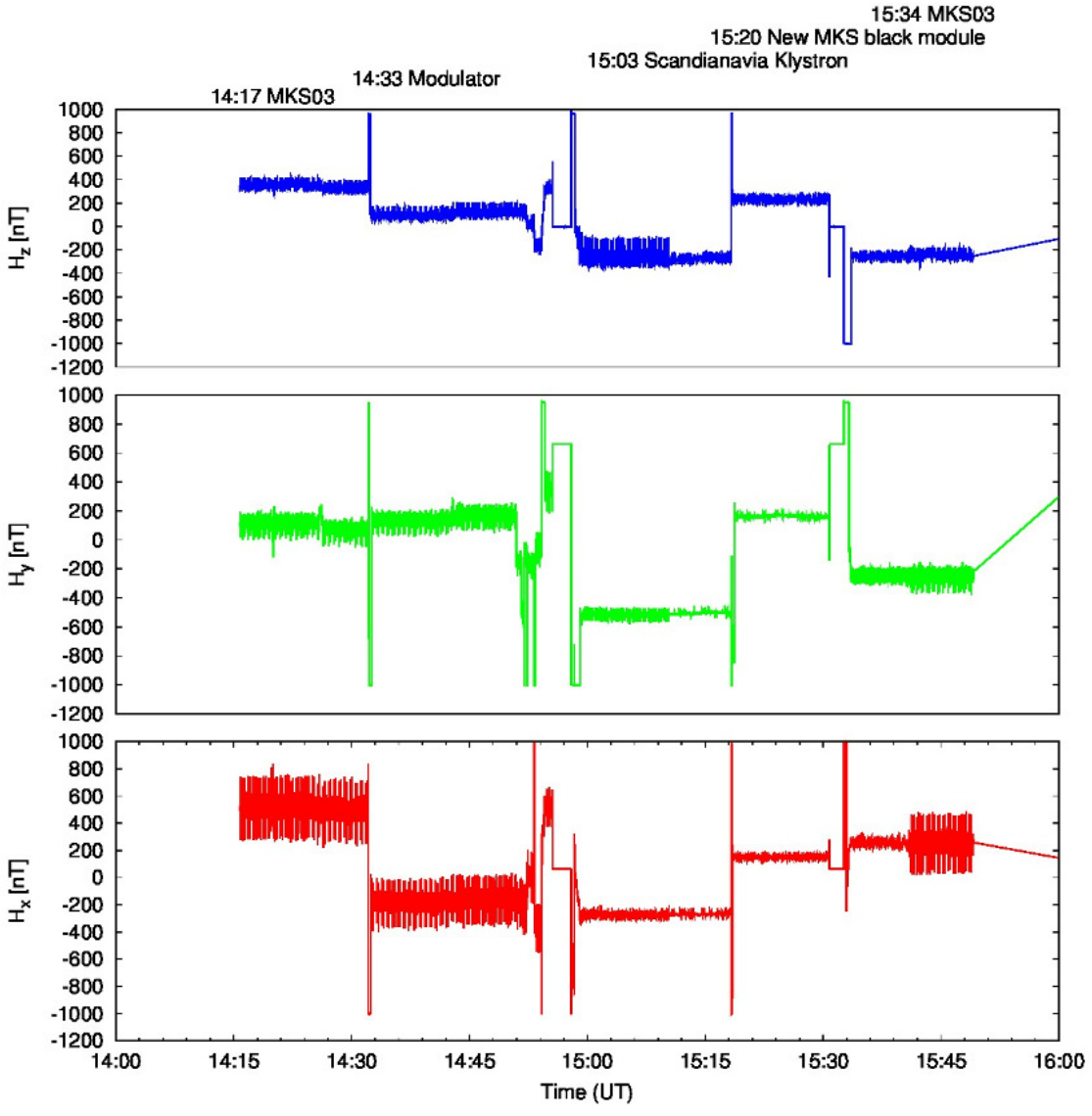
- CTF3
- AD Hall
- PS Ring
- PACMAN
- XBOX
- LINAC-4



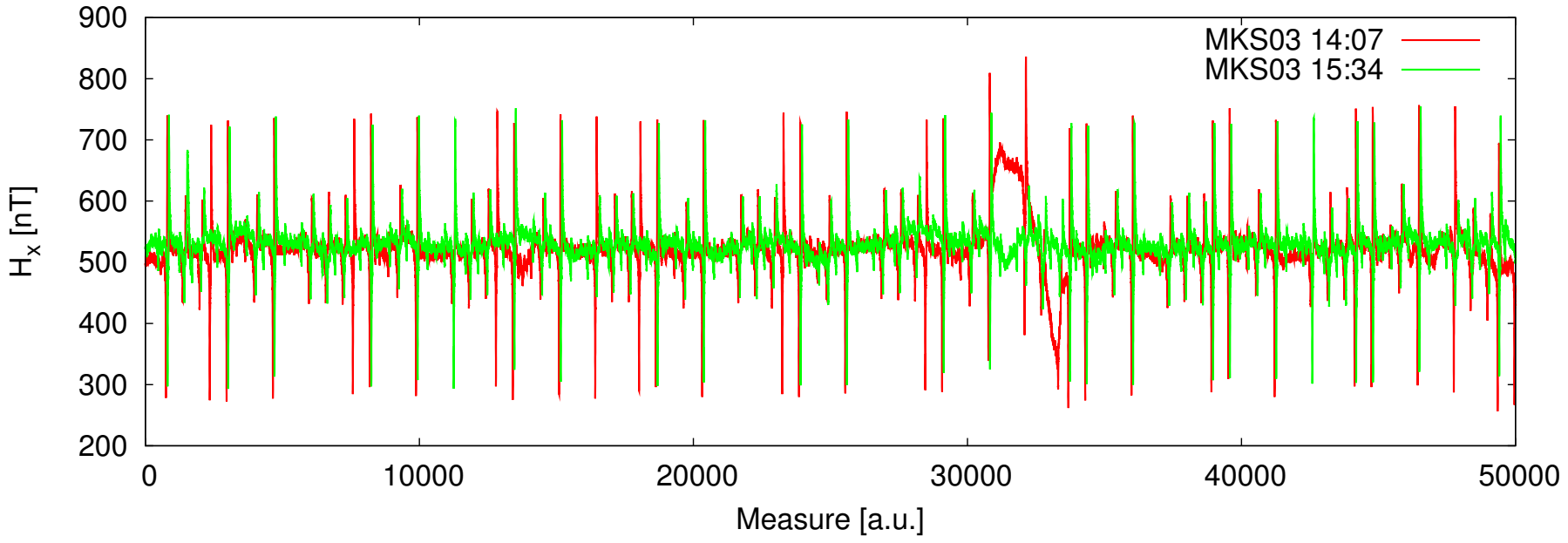
CTF3

Measurement at the Klystron Gallery

- MKS03
- Modulator
- Scandinavia
- New MKS
- MKS03



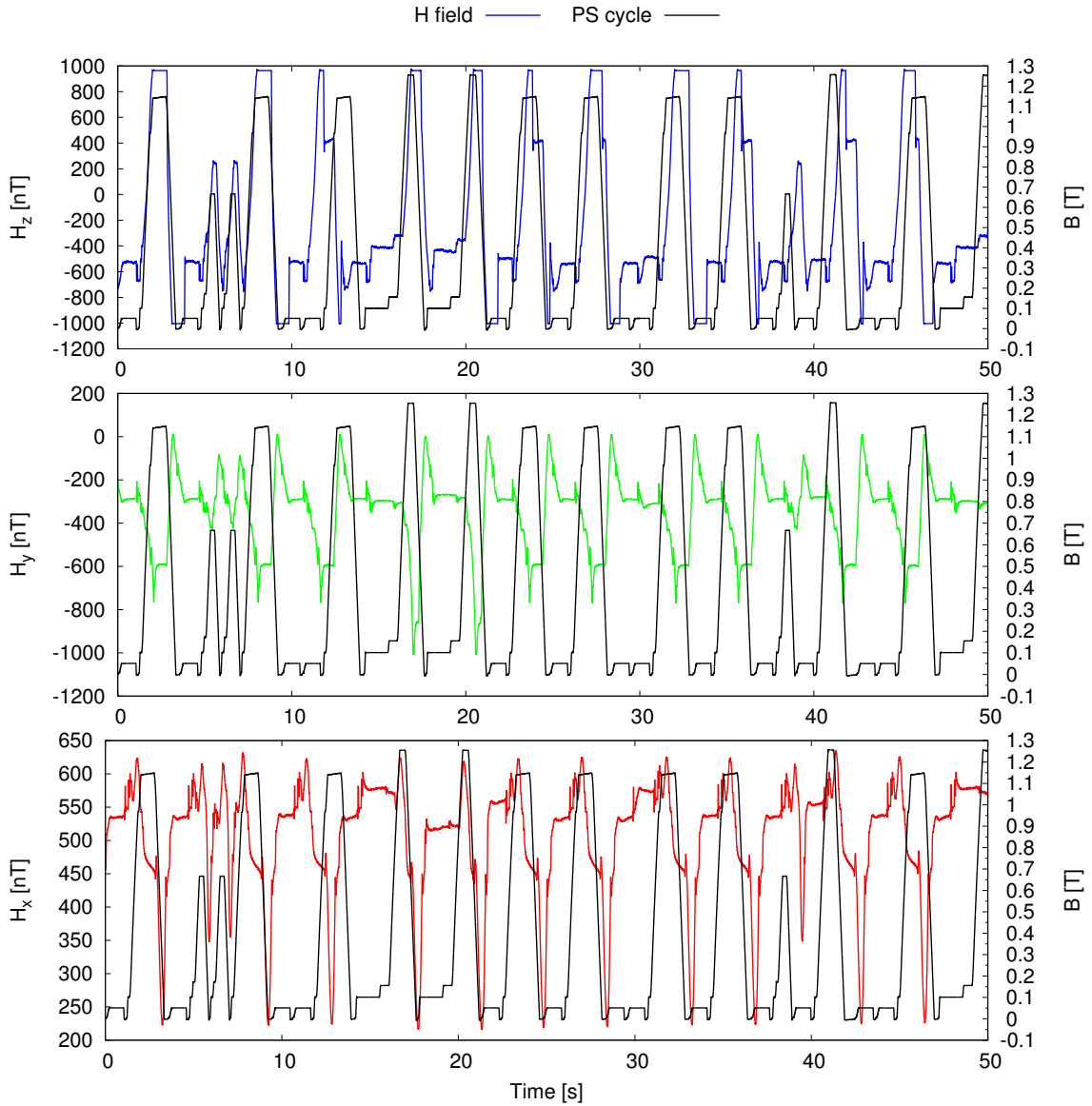
A common pattern was observed at all locations



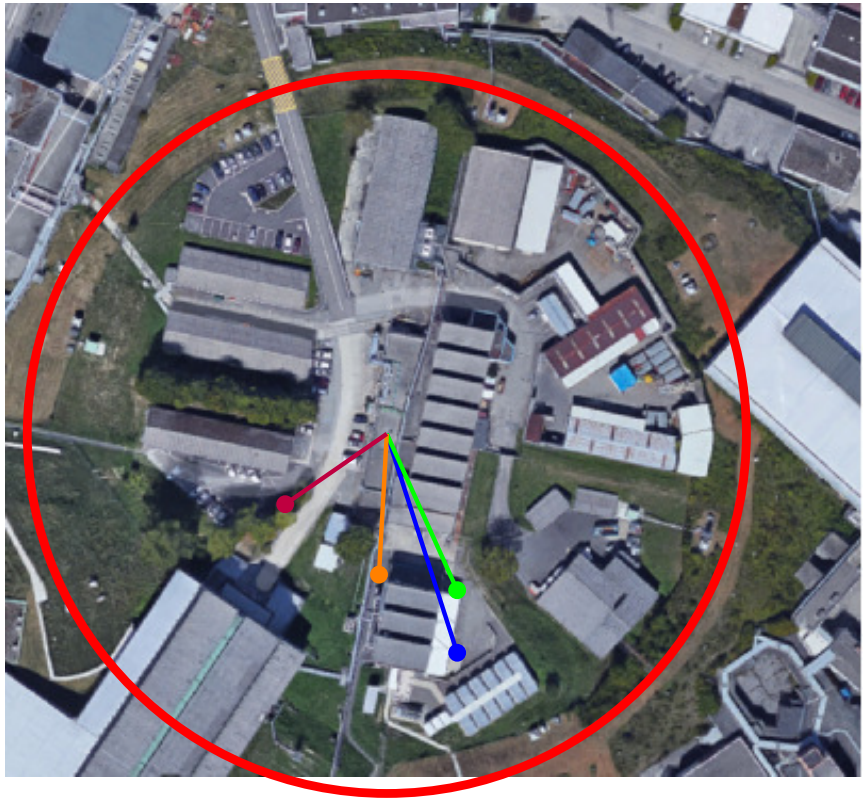
Is this coming from the PS?

Protron Synchrotron Pulsing

Clear correlation between measured signal and PS cycle

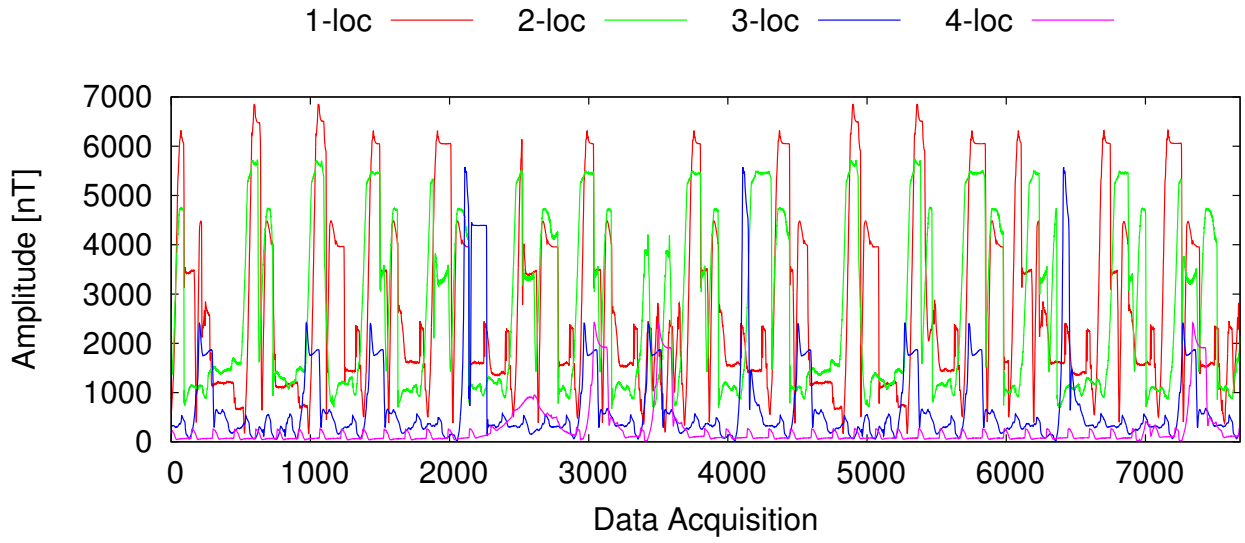


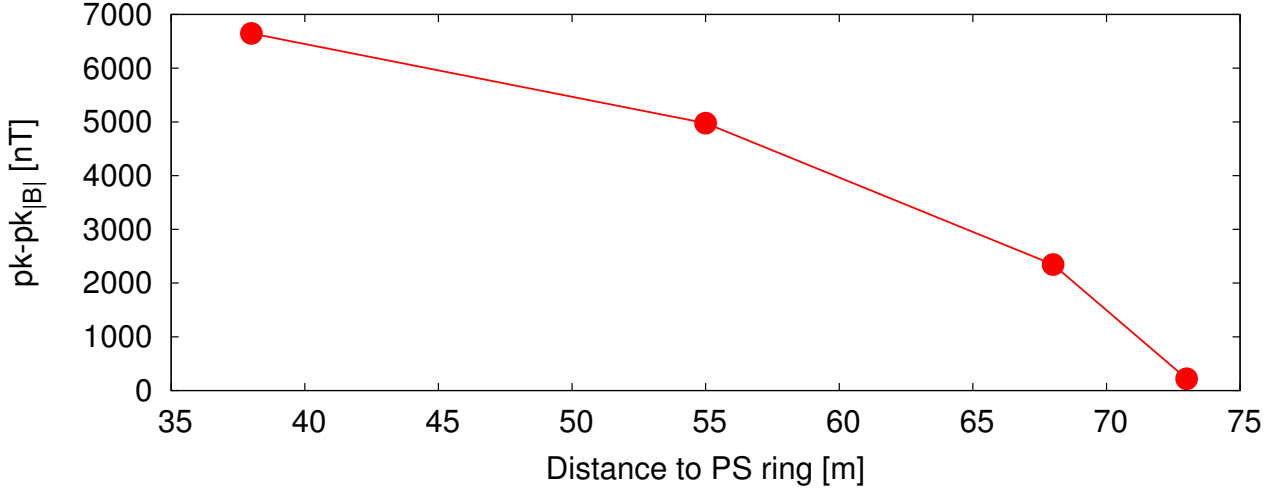
Proton Synchrotron



		Measurement Spots			
		L1	L2	L3	L4
Distance to center	[m]	62	45	31	27
Duration	[min]	12	9	2	5

Clear correlation between measured signal and PS cycle

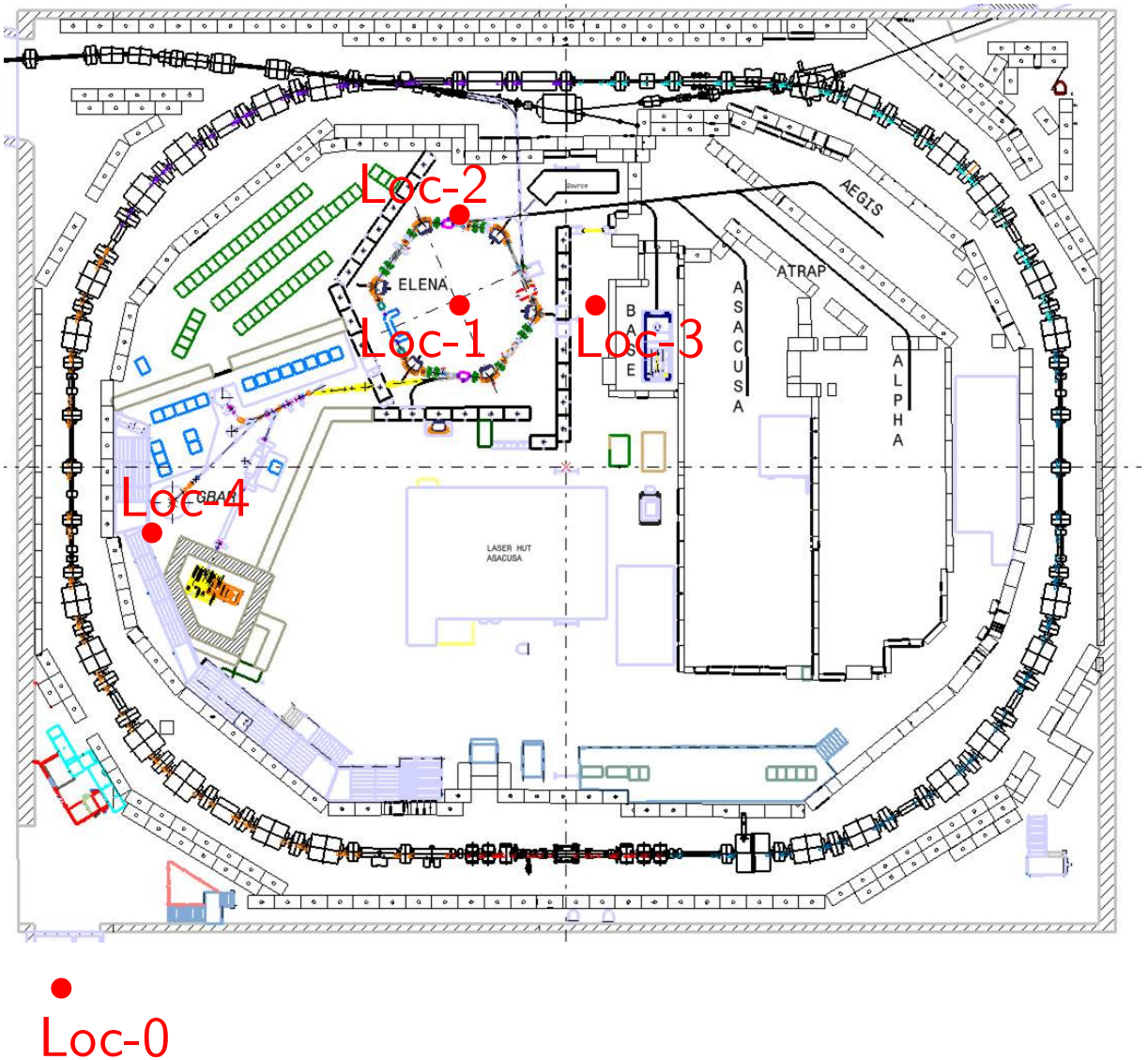




Signal is attenuated as we move towards PS center

Antiproton Decelerator

AD Locations



Antiproton Decelerator

Baseline measurement was taken outside bldg. 193 (Loc-0). Time[†] lapse: 12:27- 12:40

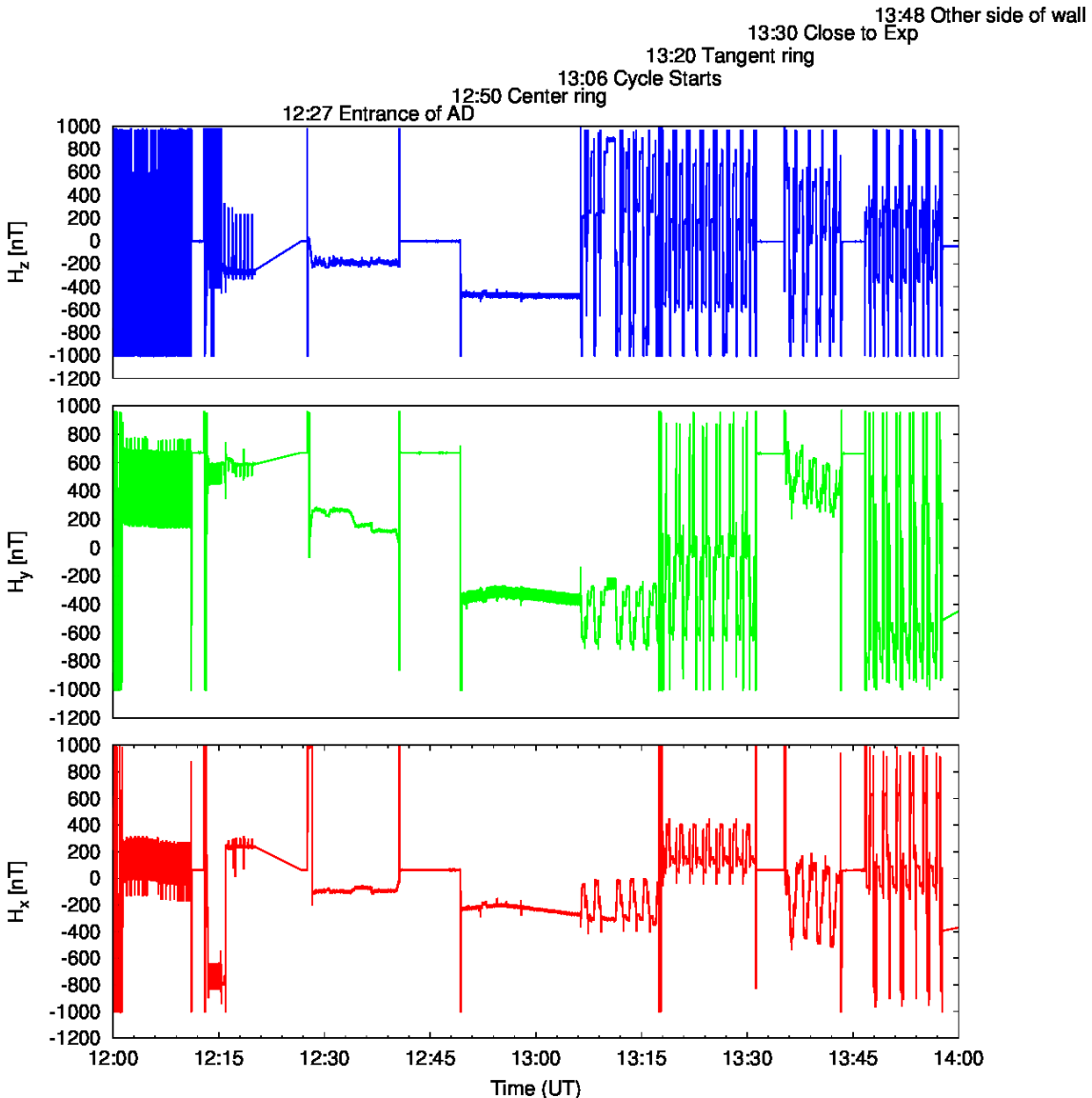
4 addtitional locations were considered for measurements inside the AD hall;

- Center of ELENA ring (Loc-1)
  - Cycling OFF (Time lapse: 12:50-13:06)
  - Cycling ON (Time lapse: 13:06-13:18)
- Tangent of the Ring (Loc-2)
  (Time lapse: 13:20-13:30)
- Close to Experiment (Loc-3)
  (Time lapse: 13:36-13:43)
- Close to AD ring (Loc-4)
  (Time lapse: 13:48-13:58)

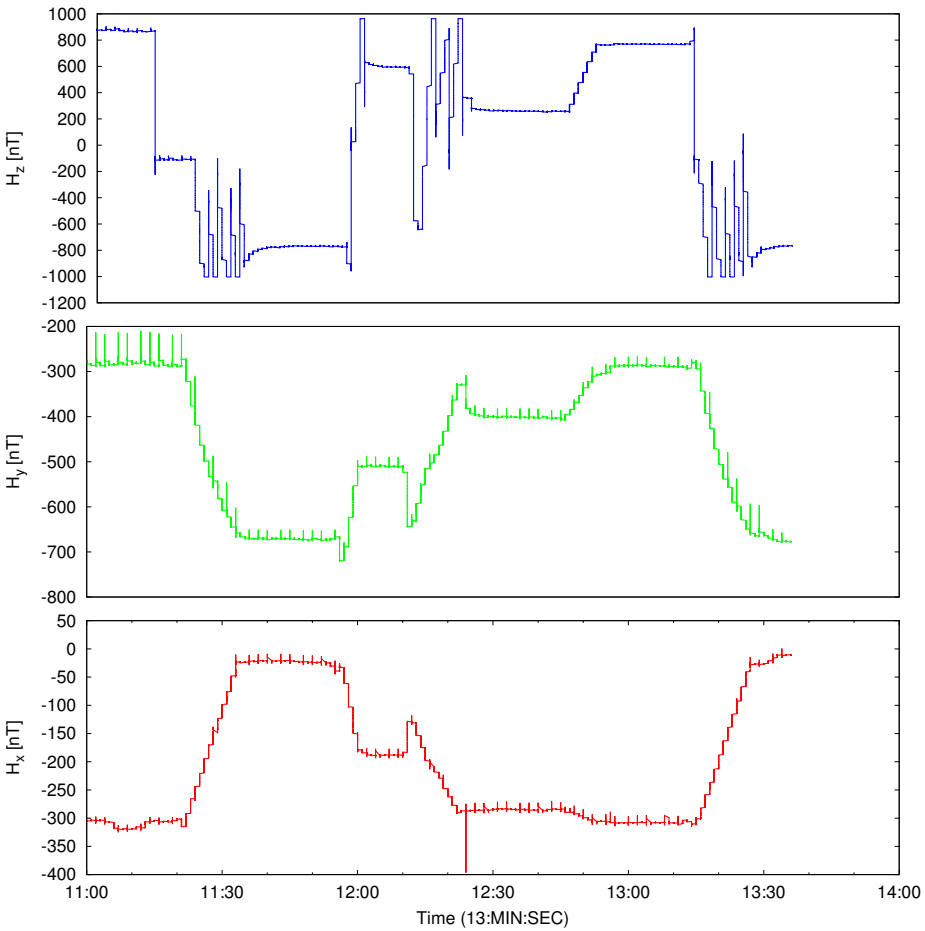
[†]UTC time

Measurement

Observed variations of few μT when AD is pulsing

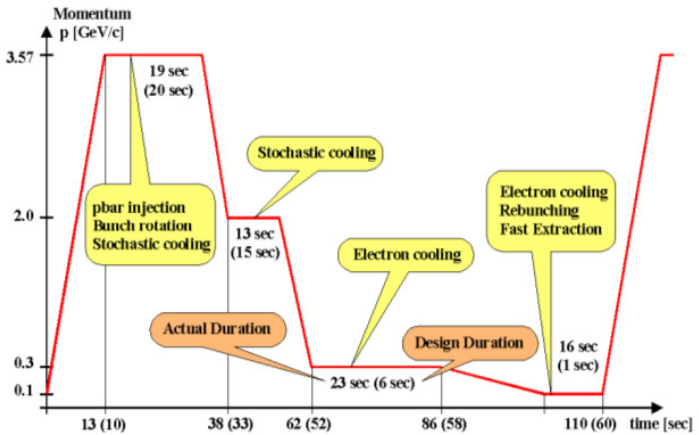


Zoom In @ Loc-1



†

Sketch of AD magnetic cycle†
Expected duration ≈60 s

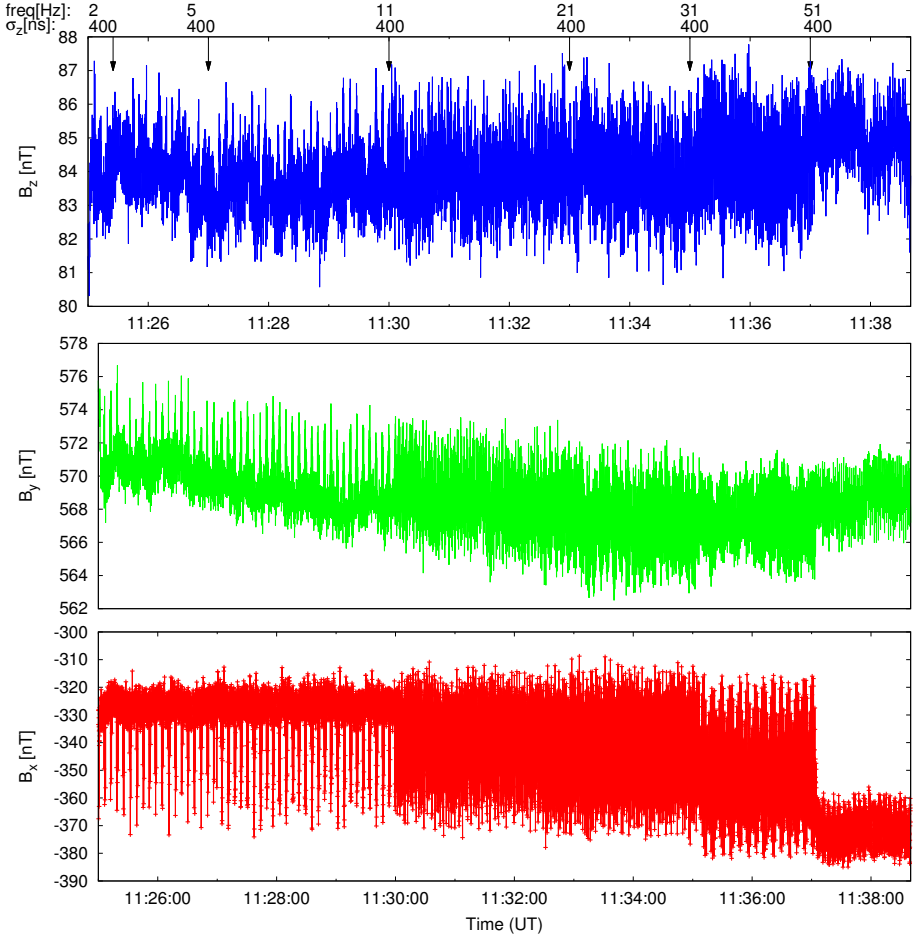


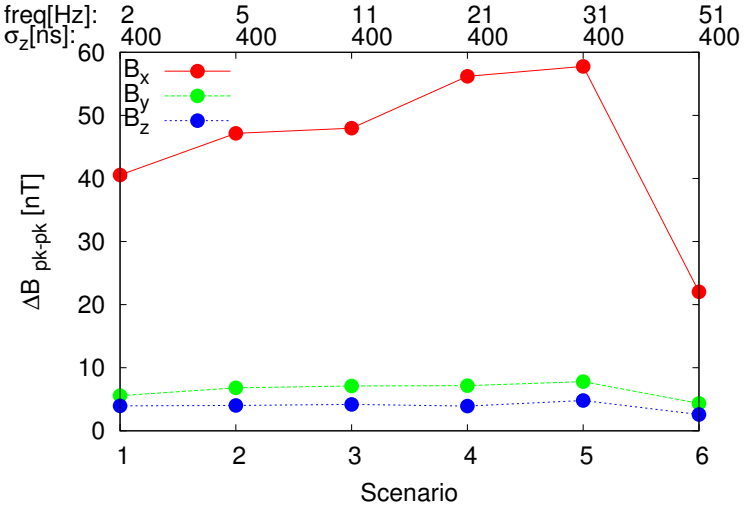
†Figure taken from *Status and Prospects for the AD and ELENA*, Lars V. Jorgensen / CERN / BE-OP

XBOX

Klystron-A

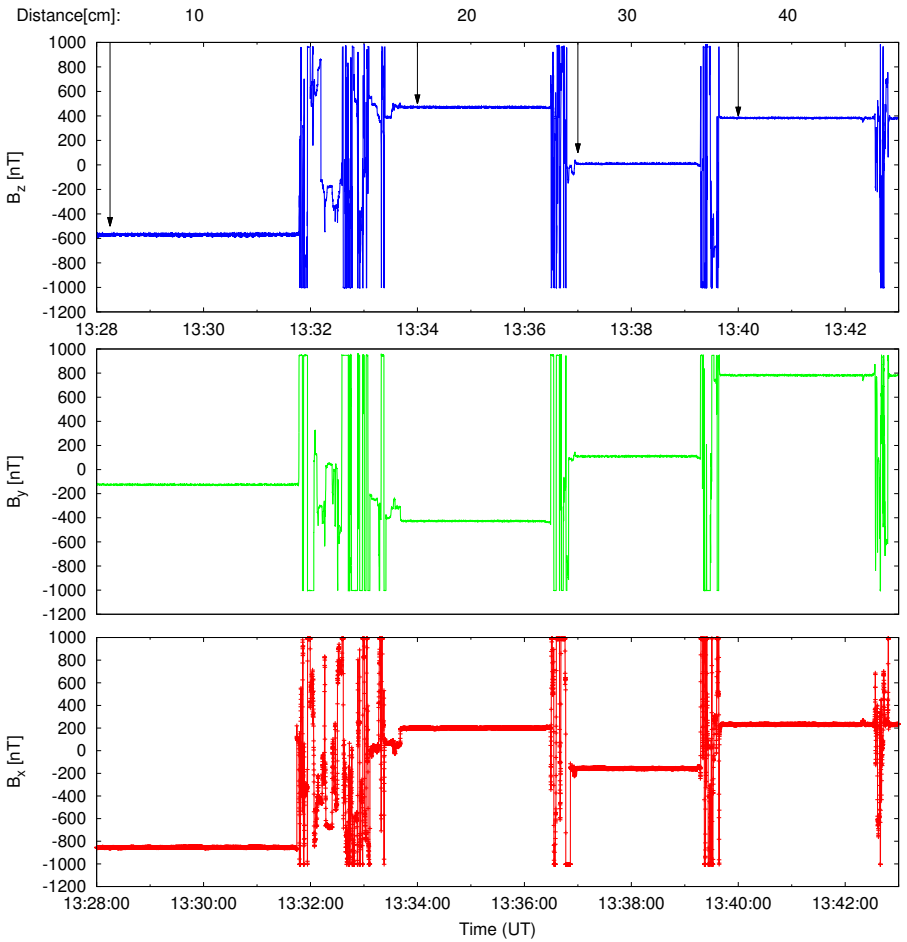
- Measurement on 17/01/2017: Sensor was located 1 cm below the waveguide. X-axis perpendicular to waveguide. Frequency scan

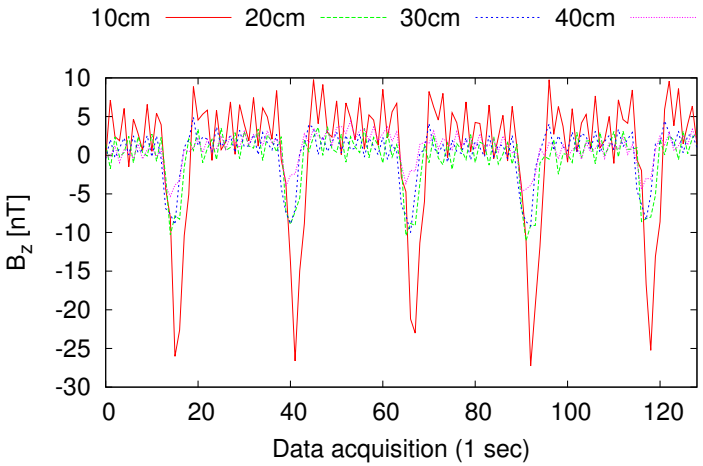


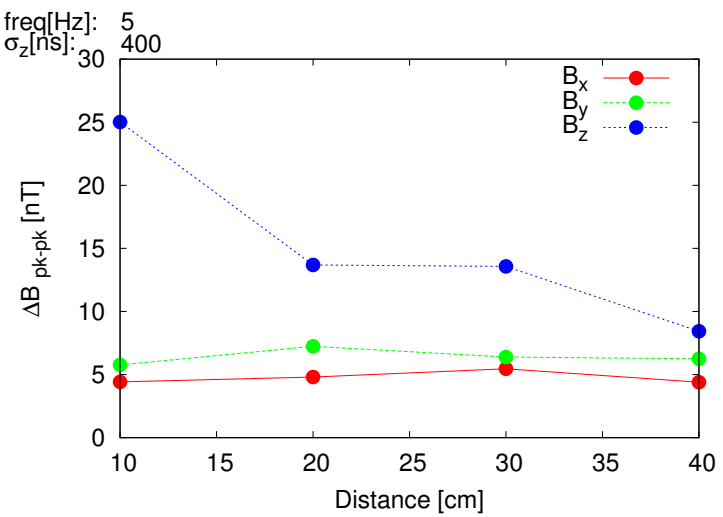


Klystron-A

- Measurement on 17/01/2017: Distance scan (horizontally). Sensor was next to waveguide. Z-axis perpendicular to waveguide

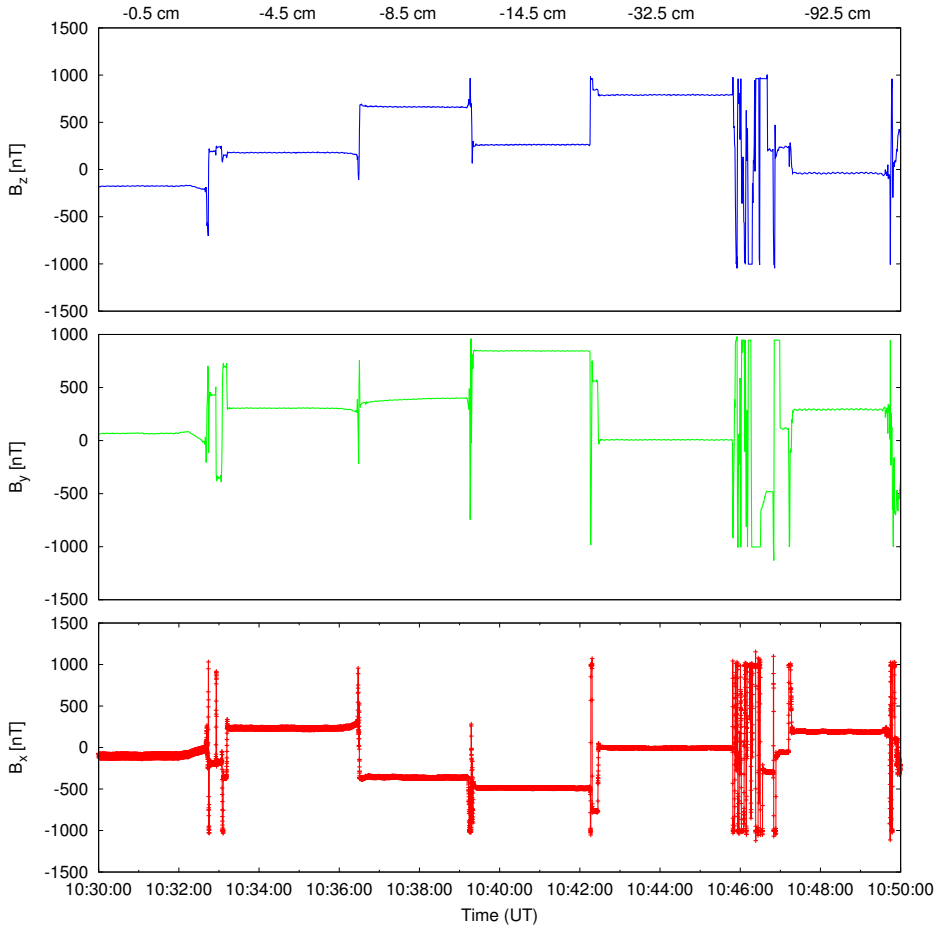


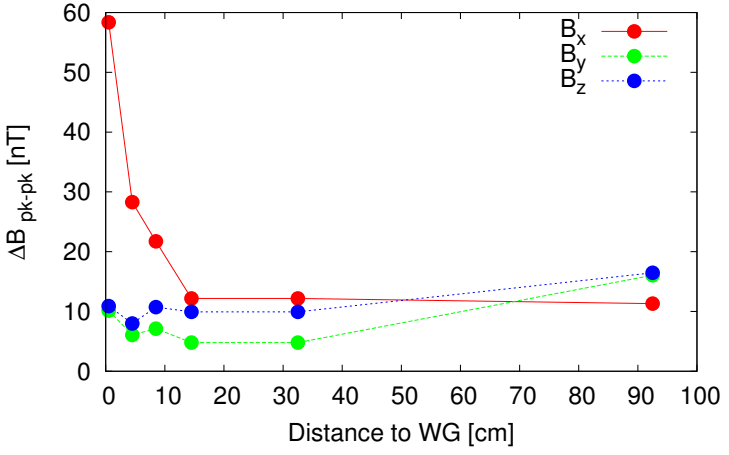




Klystron-C&D

- Measurements on 19/01/2017: Distance scan (vertically). Sensor was below the waveguide. X-axis perpendicular to waveguide





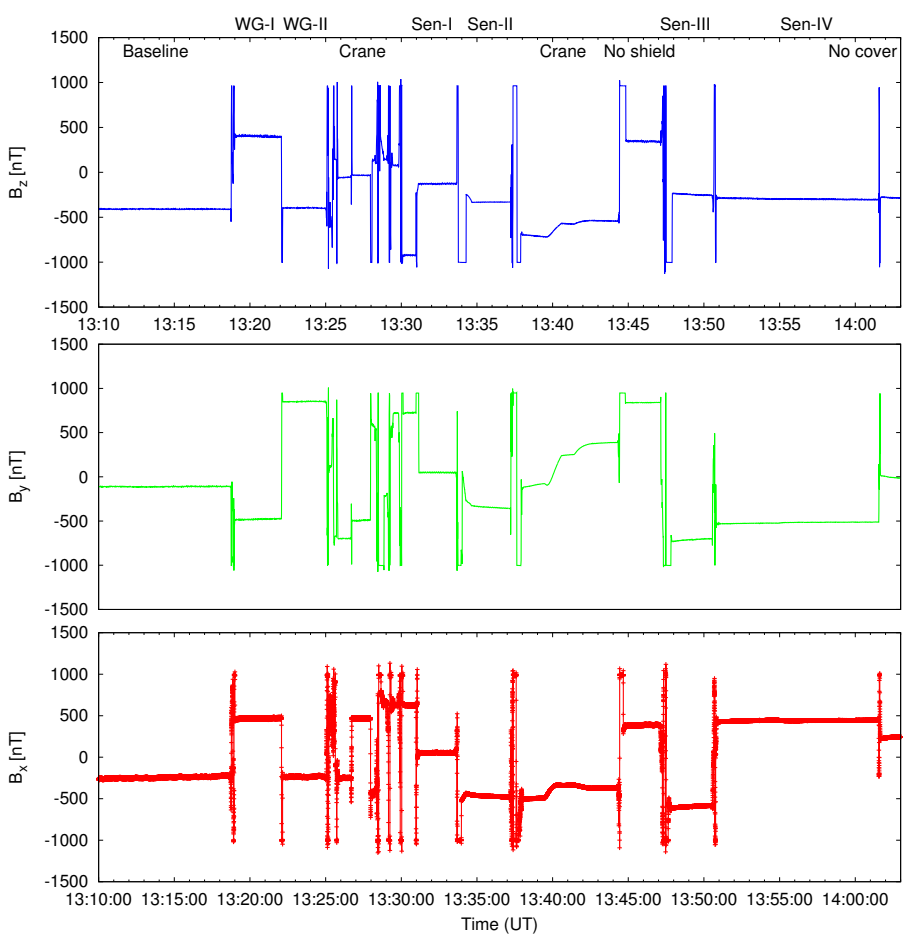
Data is consistent with a current of 13 mA (assuming an infinitely straight current)

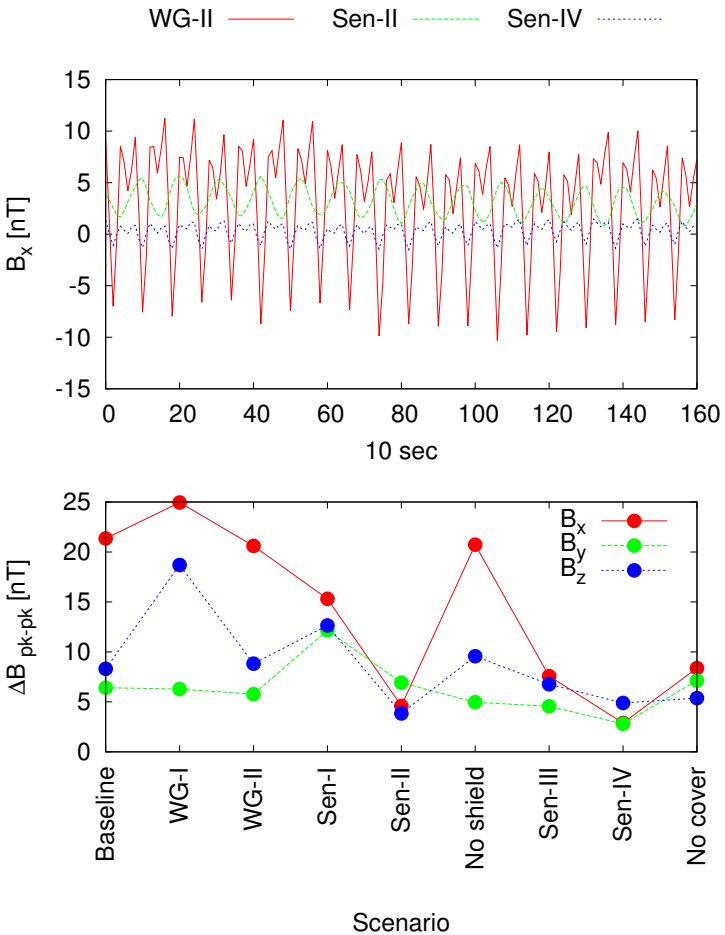
Shielding

- Shield waveguide (soft-μ-material)
- Shield sensor (Aluminium pipe, soft-μ-material)

Scenario	Starting Time	Finishing Time	Observations
	[H:M:S]	[H:M:S]	
Baseline	13:10:00	13:18:00	Sensor 7cm below WG
WG-I	13:20:00	13:22:00	Shielding WG
WG-II	13:23:00	13:25:00	Shielding WG without contact
Sen-I	13:32:00	13:34:00	Shielding MS 25cm from WG
Sen-II	13:35:00	13:37:00	Shielding MS 7cm from WG
No shield	13:45:00	13:47:00	No shielding
Sen-III	13:49:00	13:51:00	Shielding MS 7cm from WG
Sen-III	13:52:00	14:00:00	Shielding MS 7cm from WG and covered
No cover	14:01:00	14:03:00	Shielding MS 7cm from WG without cover

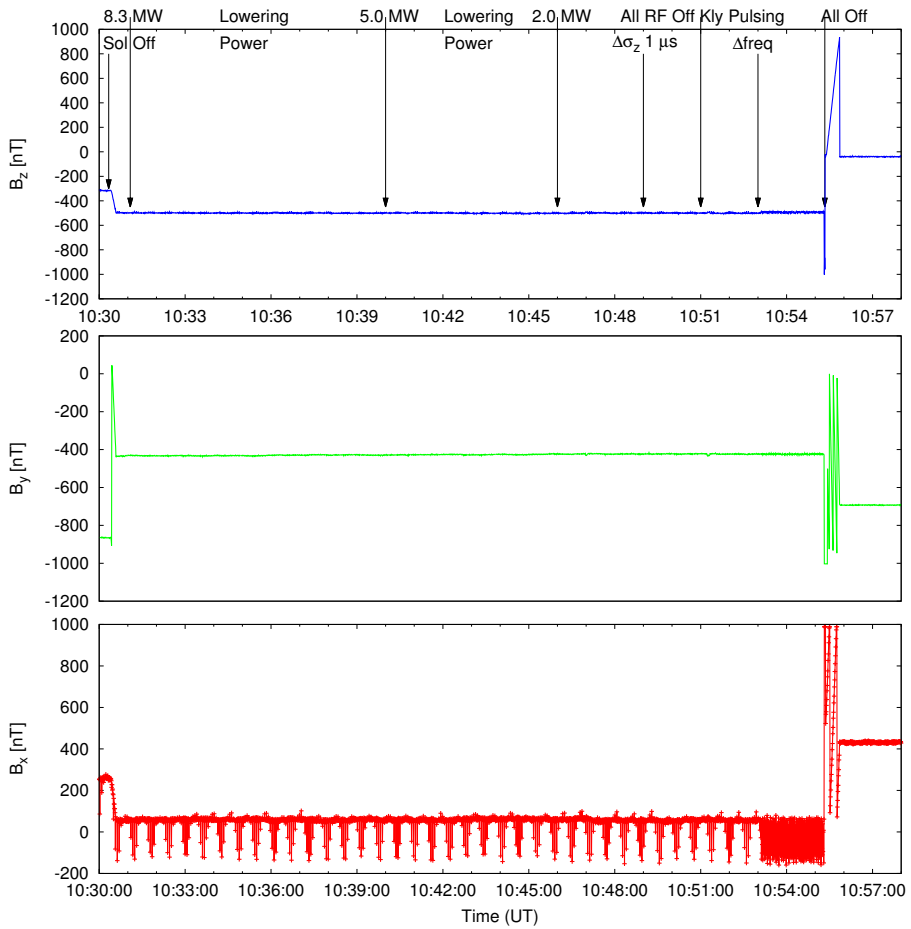
Shielding


WG-I WG-II
Sen-I Sen-II
Sen-III
Sen-IV
Baseline
Crane
Crane
No shield
No cover
B_z [nT]
B_y [nT]
B_x [nT]
1500
1000
500
0
-500
-1000
-1500
13:10 13:15 13:20 13:25 13:30 13:35 13:40 13:45 13:50 13:55 14:00
13:10:00 13:15:00 13:20:00 13:25:00 13:30:00 13:35:00 13:40:00 13:45:00 13:50:00 13:55:00 14:00:00
Time (UT)


WG-II
Sen-II
Sen-IV
B_x [nT]
15
10
5
0
-5
-10
-15
0 20 40 60 80 100 120 140 160
10 sec
ΔB_{pk-pk} [nT]
25
20
15
10
5
0
B_x
B_y
B_z
Baseline
WG-I
WG-II
Sen-I
Sen-II
No shield
Sen-III
Sen-IV
No cover
Scenario

Source

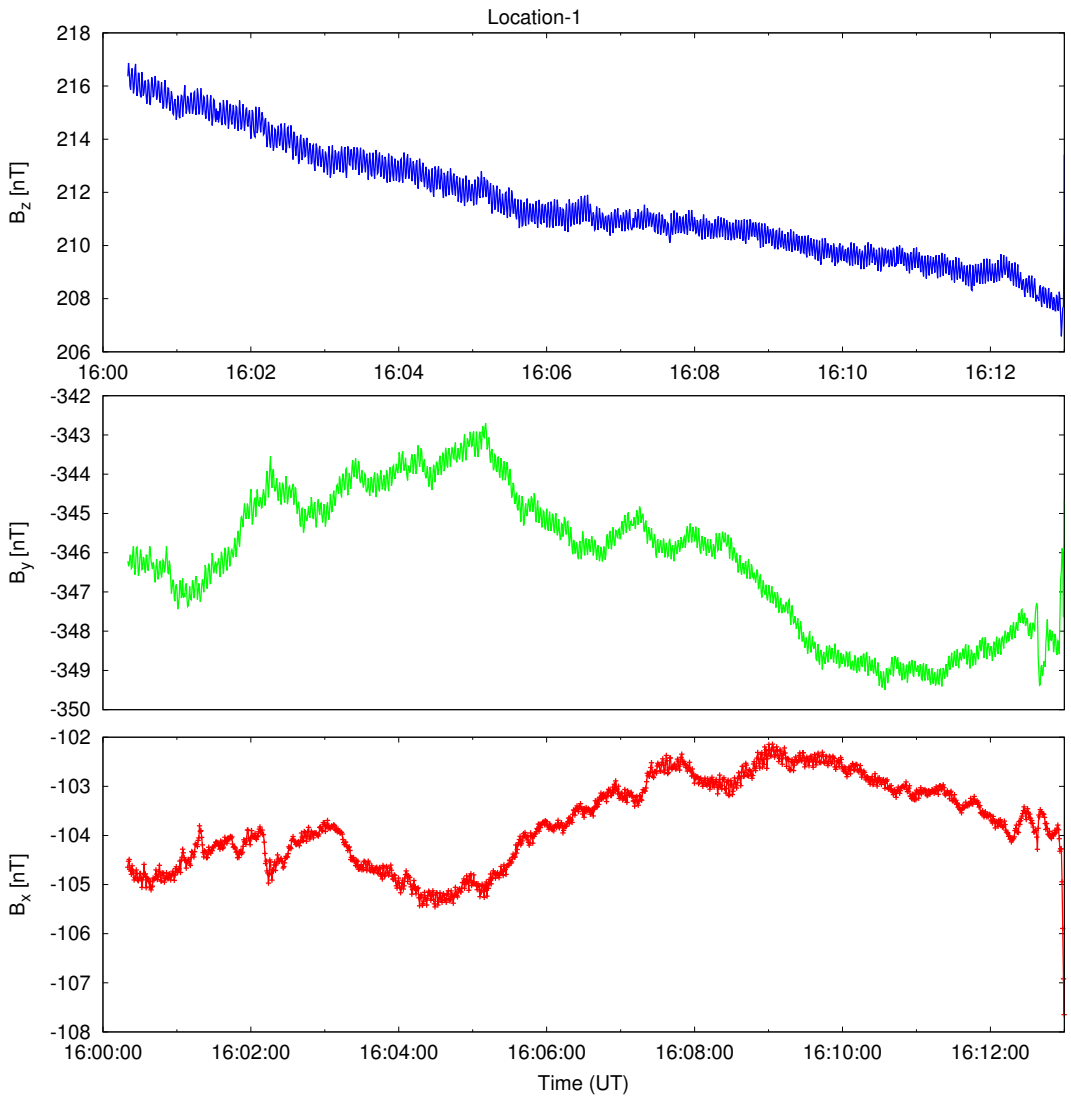
- Power scan
- Pulse width scan
- On/Off low-level RF
- On/Off Solenoid



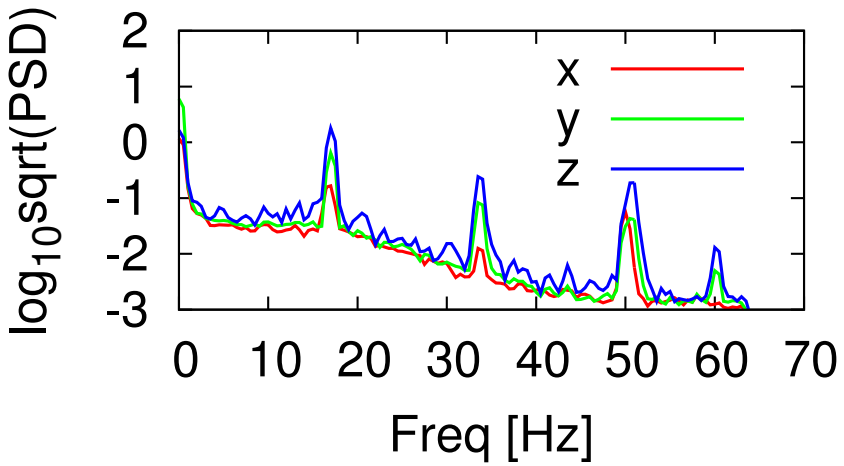
Thoiry

Measurement Outside CERN

Thoiry



Frequency Spectra (*by B. Heilig*)



Multi-harmonics:

- X: 16.7, 33.6 and 50 Hz
- Y,Z: 16.7, 33.6 and 50 Hz
  30, 44 and 60 Hz

Signals at 1/3*50 Hz (16.7 Hz), 2/3*50 Hz (33.4 Hz) and 50 Hz multi-harmonics are likely produced by 15 kV 16.7 Hz AC trains

This technical solution for railway electrification is widely used in Germany, Austria, Switzerland, Norway and Sweden (but as far as I know not in France). If this is true, these multi-harmonic signals should be produced by stray currents coming from Switzerland [†]

[†] https://en.wikipedia.org/wiki/15_kV_AC_railway_electrification

CONCLUSIONS & PROSPECTS

Conclusions & Prospects

- BDS is most sensitive to wavelength (≈7 km), 12% $\mathcal{L}_{\text{loss}}$ for 1 nT amplitude stray field without any countermeasure
- Natural and man-made magnetic field sources are well-above that tolerance at Earth's surface

- Variations of $\geq \mu T$ are observed at CTF3 due to the PS cycle
- Variations of tens of nT are observed closed to the waveguides
  - Signal can be shielded by a soft-μ material

- $\vec{B}$ measurements underground
- 2D stray field spectrum would be very helpful
- Potential implications of PS/AD and XBOX results on CLIC (Klystron-based)
- Developing strategies for mitigating intolerable variations of magnetic field

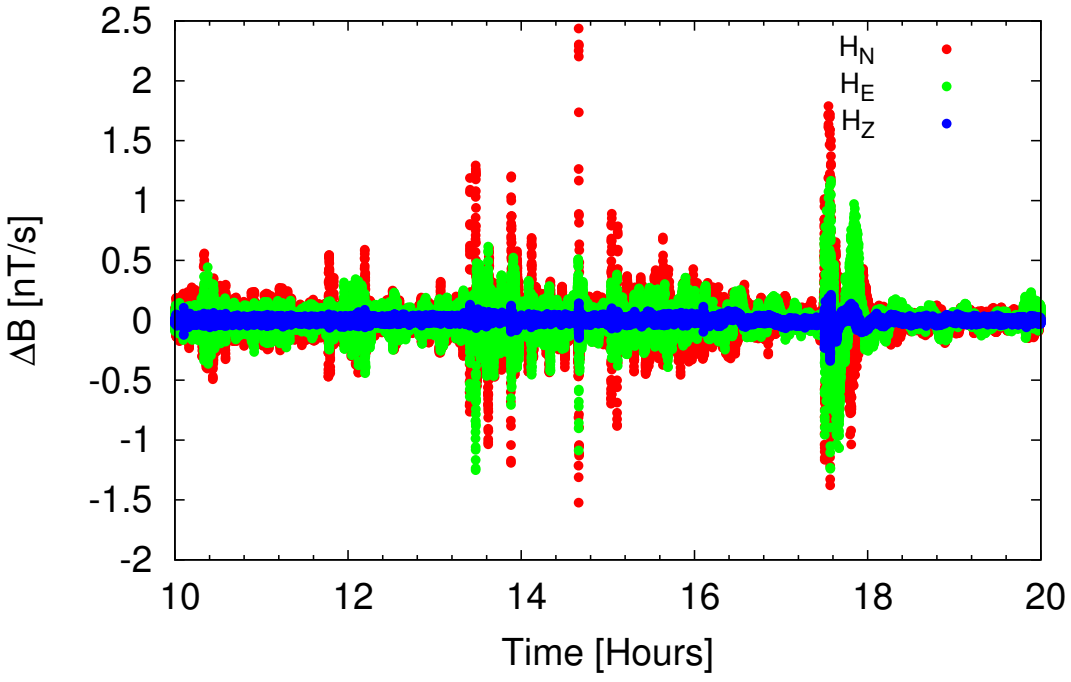
Acknowledgements

- All the people working at the XBOX, specially M. Volpi
- The CTF3 team, specially W. Farabolini
- C. Carli for allowing us to measure at the AD hall
- A. Lombardi for arranging our visit at LINAC-4
- D. Tshilumba for his help during the PACMAN measurement

Thank you for your attention!

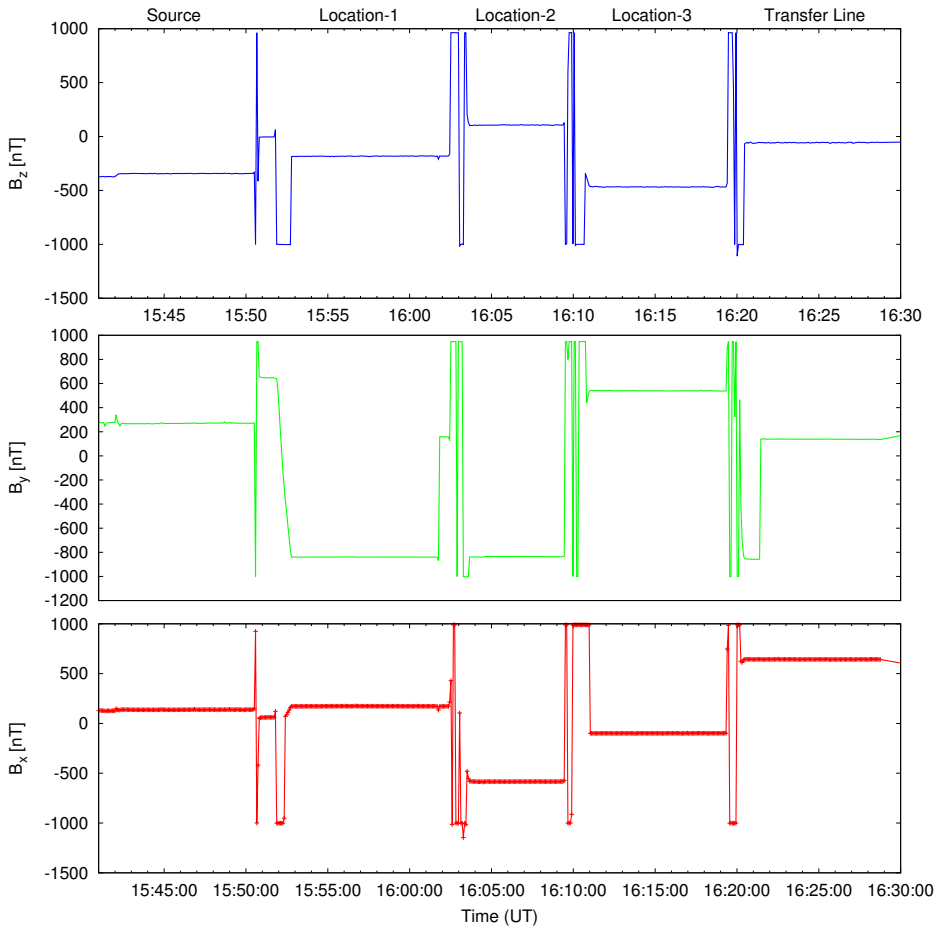
BACK-UP

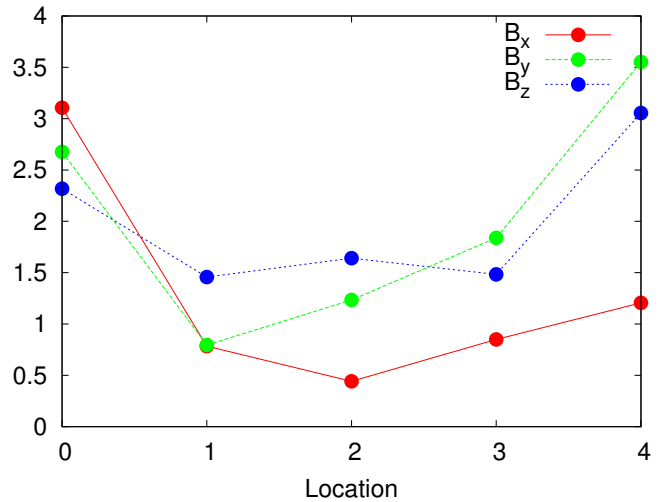
Magnetic Field Variation



- Maximum variation observed at 1 Hz is ≈nT
- Measurements at higher frequencies would be needed to cope with the fields generated by equipment
- Might be compensated by means of feed-back system

LINAC-4


Source
Location-1
Location-2
Location-3
Transfer Line
B_z [nT]
B_y [nT]
B_x [nT]
15:45
15:50
15:55
16:00
16:05
16:10
16:15
16:20
16:25
16:30
15:45:00
15:50:00
15:55:00
16:00:00
16:05:00
16:10:00
16:15:00
16:20:00
16:25:00
16:30:00
Time (UT)


B_x
B_y
B_z
Location