European Organization for Nuclear Research

CLIC/LHC SUB-MICRON GROUND MOTION AND VIBRATION MEASUREMENTS

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http://clic-stability.web.cern.ch/clic-stability/
http://en-dep.web.cern.ch/en-dep/Groups/MME/DEO/MECHANICAL-LAB/

Collaboration Stabilisation WG, participations from:

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Outline

- Measurement devices
- Measured quantities
- Coherence and propagation local vibrations sources
- Some measurements around CMS
- Conclusions

Measurement devices

How to measure nanometers and picometers ?

Catalogue products

<u>Absolute velocity/acceleration measurements</u>

- **Seismometers** (geophones)
- **Accelerometers** (seismic - piezo)

Streckeisen STS2	Guralp CMG 3T	Guralp CMG 40T	Guralp CMG 6T	Eentec SP500	PCB 393B31
x,y,z	x,y,z	x,y,z	x,y,z	z electrochemical	z
2*750Vs/m	2*750Vs/m	2*800Vs/m	2*1000Vs/m	2000Vs/m	1.02Vs²/m
120 s -50 Hz	360s -50 Hz	30 s -50 Hz	30s-80Hz	60 s -70 Hz	10 s -300 Hz
13 kg	13.5 kg	7.5 kg		0.750 kg	0.635 kg

Equipment and settings

- Vibrations sensors

Type	Supplier	Type	Sensitivity	Freq. Range	Axes
Geophones	GURALP	CMG 6T	2000 V/m/s	30s to 100Hz	NS, EW, V
Seismic accelerometers	PCB	393B31	10 V/g	0.1 to 200Hz	V
	ENDEVCO	86	10 V/g	0.1 to 200Hz	V

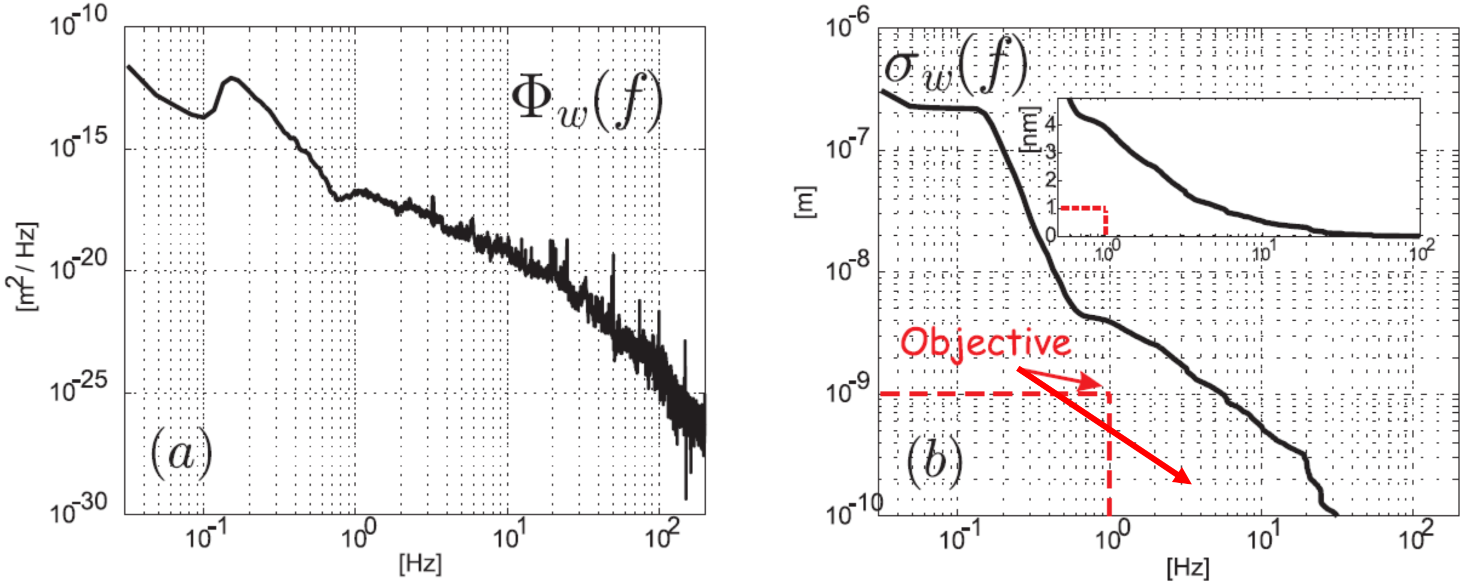
- Data acquisition system
  - Spectrum analyser with 16 channels
  - 24 bits on 10mV for the lowest dynamic range
  - Sampling frequency up to 200kHz
  - Noise level DAC< 1 µV
  - Software for signal treatment (FFT, PSD, Filtering, etc…)

PAK MÜLLER-BBM

Parameters:

Sampling rate	1024Hz
Measurement Length	1440s
Block length	64s
Overlap	66,7%
Window function	Hanning
Averaging	Linear

PSD, RMS objectives

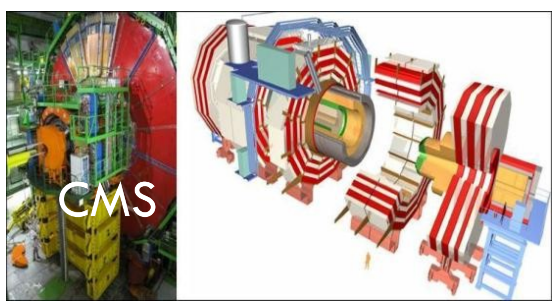


$$\sigma_x(f) = \sqrt{\int_f^\infty \Phi_x(\nu)d\nu}$$

	FF	MBQ
Vert.	**0.2 nm > 4Hz**	**1.5 nm > 1 Hz**
Lat.	**5 nm > 4 Hz**	**5 nm >1 Hz**

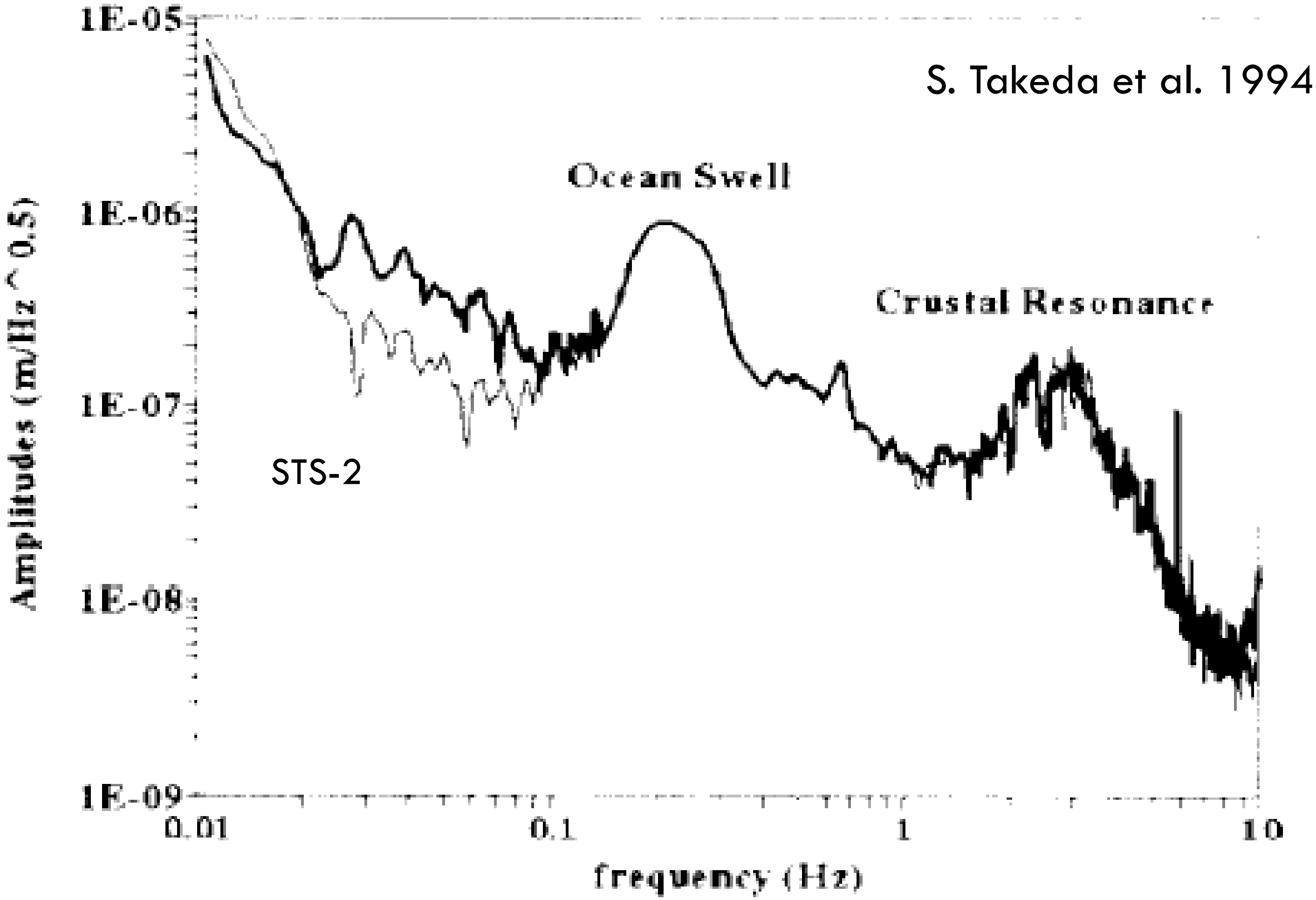
Characterisation vibration sources

Measurements LAPP, DESY, SLAC, …
Broadband seismometers characterisation
> 50 references on http://clic-stability.web.cern.ch/clic-stability/
More measurements by CERN in accelerator environments

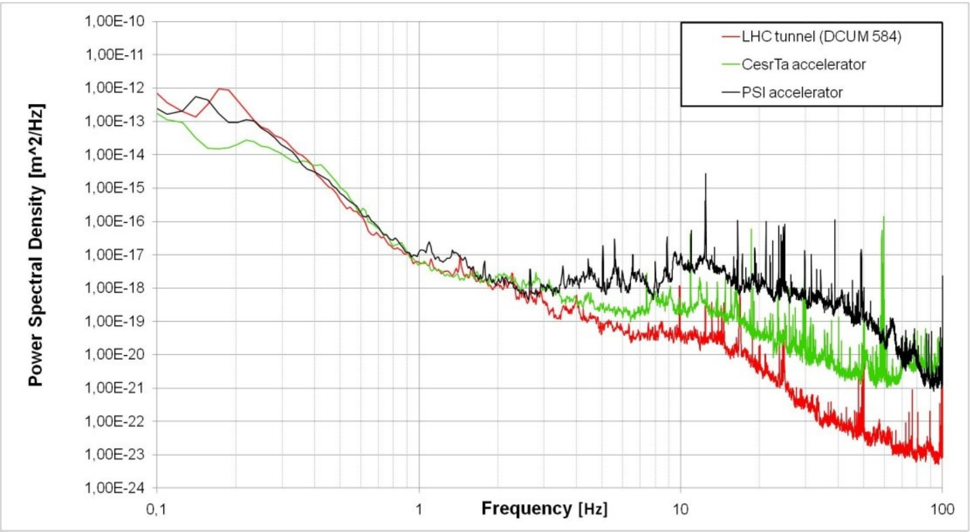


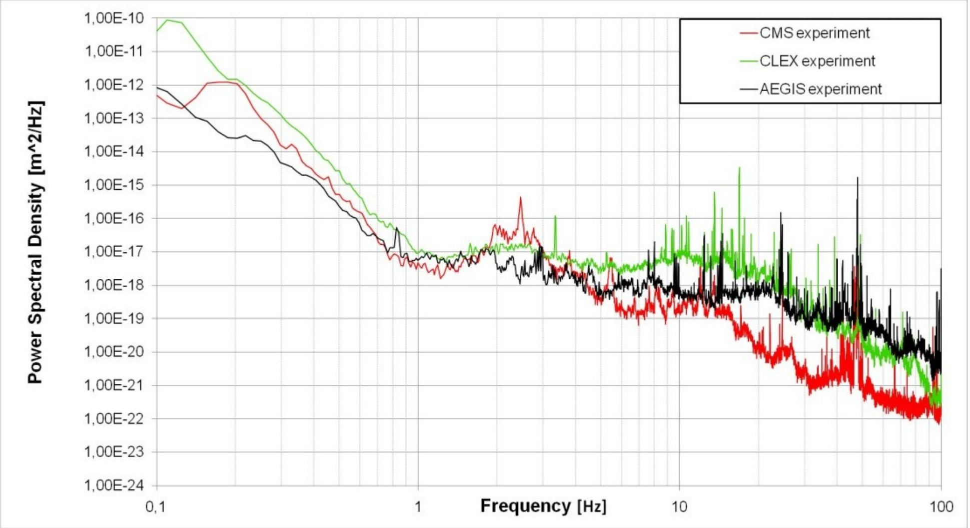
M. Sylte, M. Guinchard, A. Kuzmin, A. Slaathaug

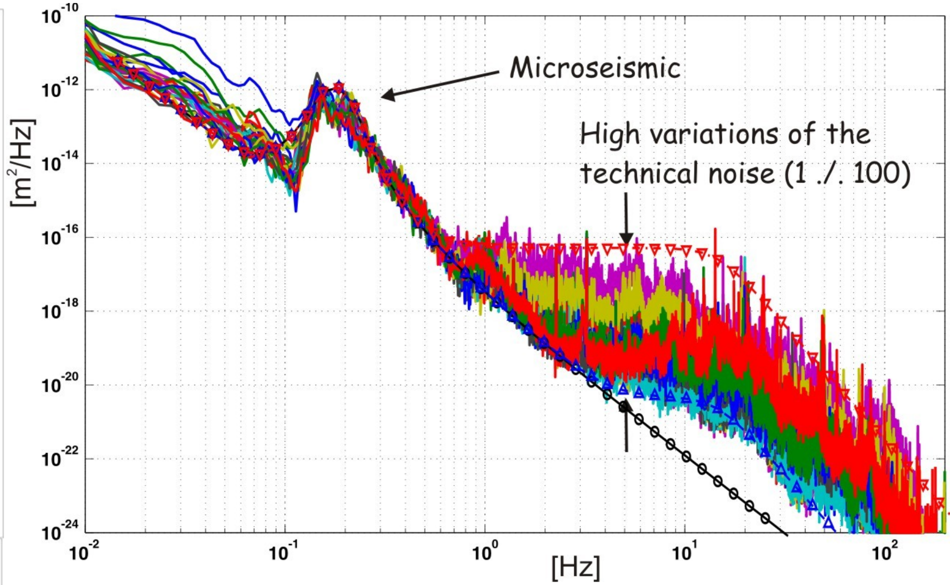
Very low frequency absolute measurements:



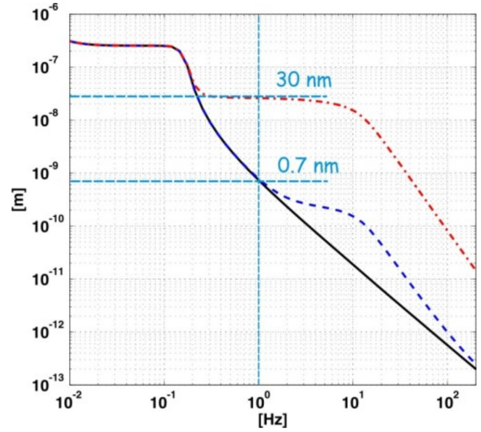
Power Spectral Density



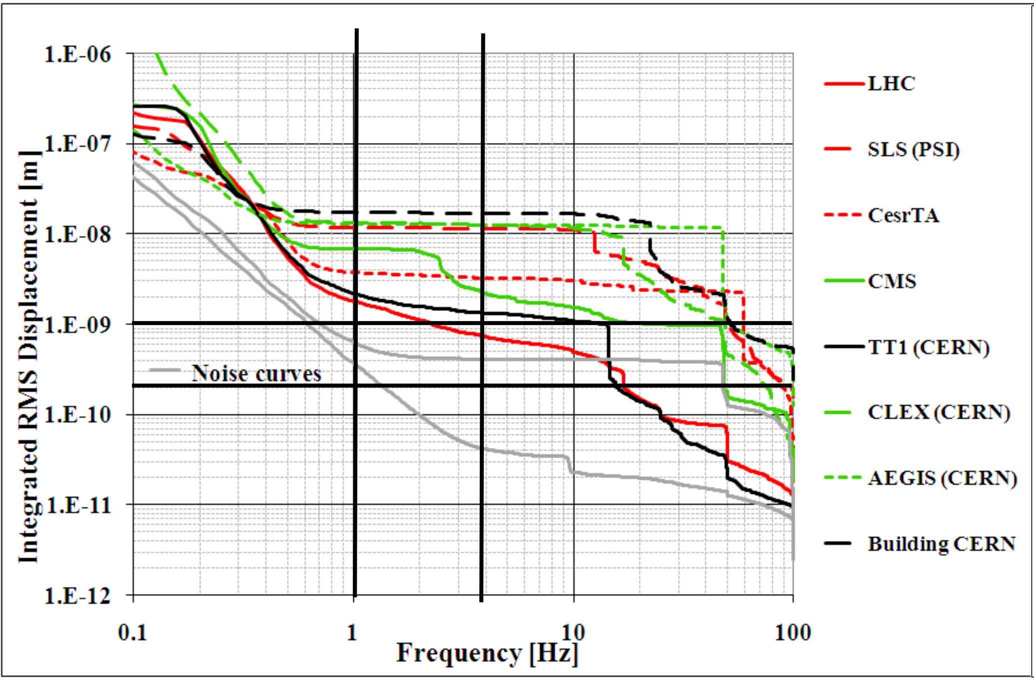




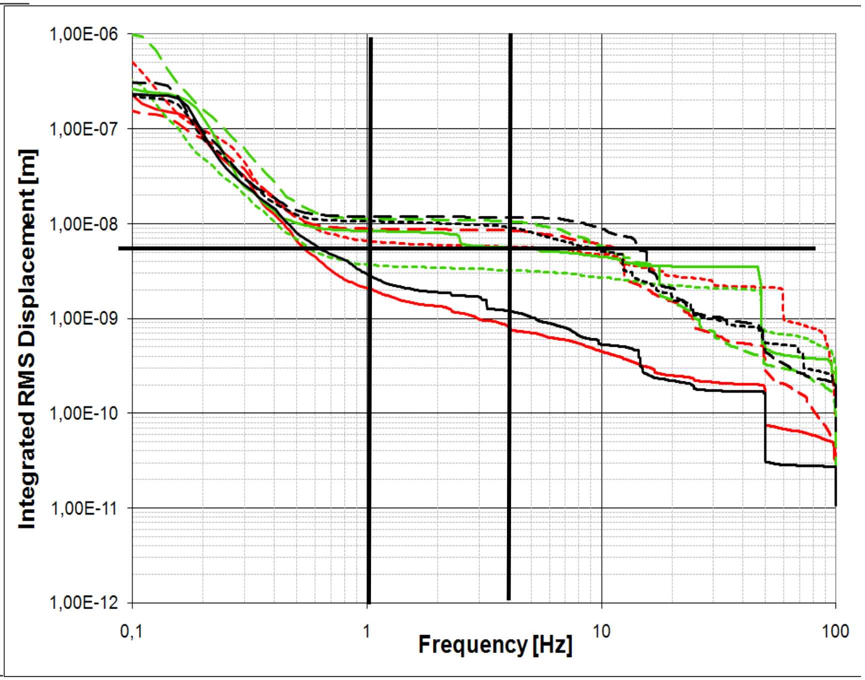
LHC tunnel in operation



Integrated R.M.S. displacements



vertical



lateral

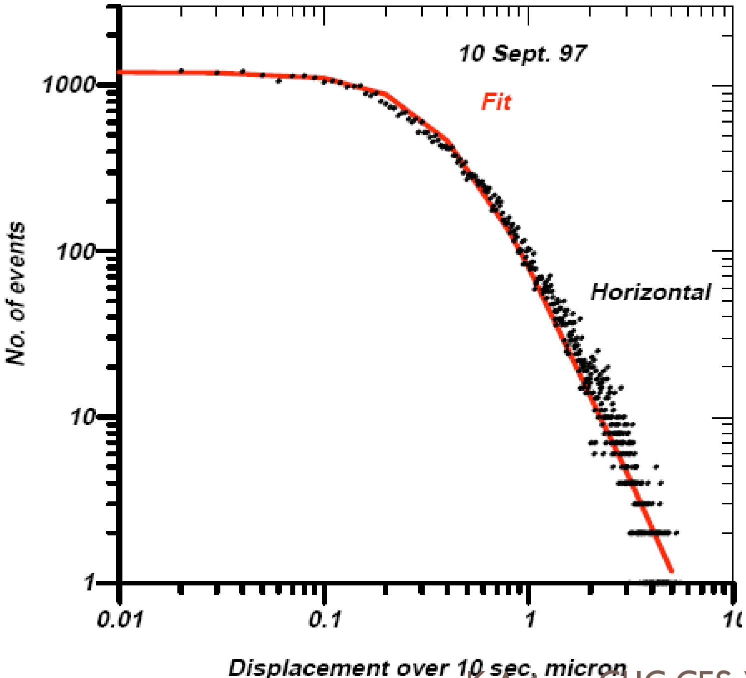
Averaging, window, histogram, color map

50 averages of 64 sec blocks with 66.7% overlap:

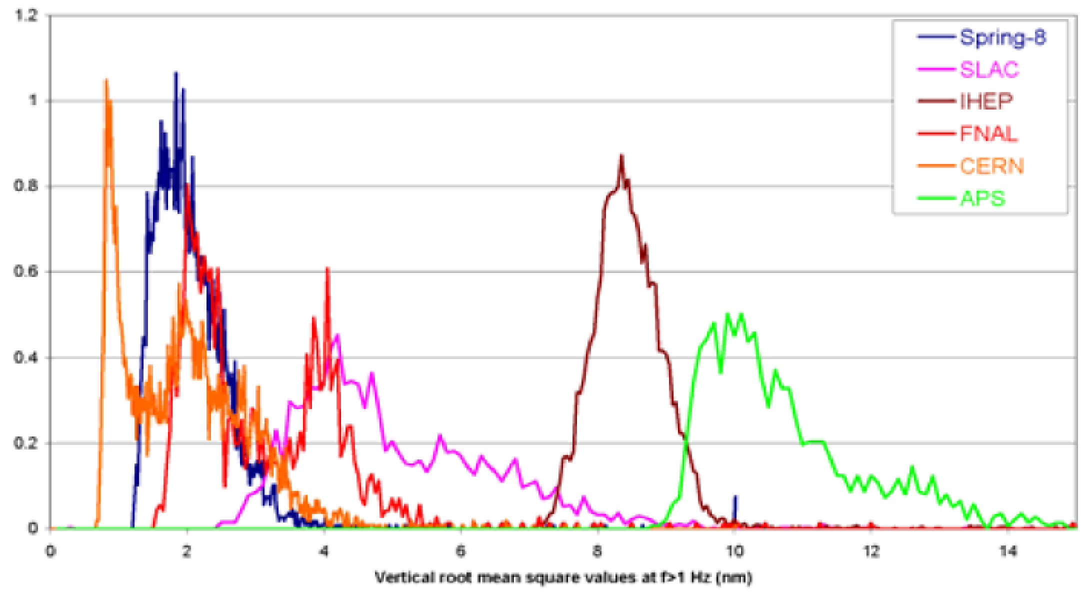
- To have a good frequency resolution + definition of PSD
- To “see” something within the noise

But: it’s an average view → Histogram

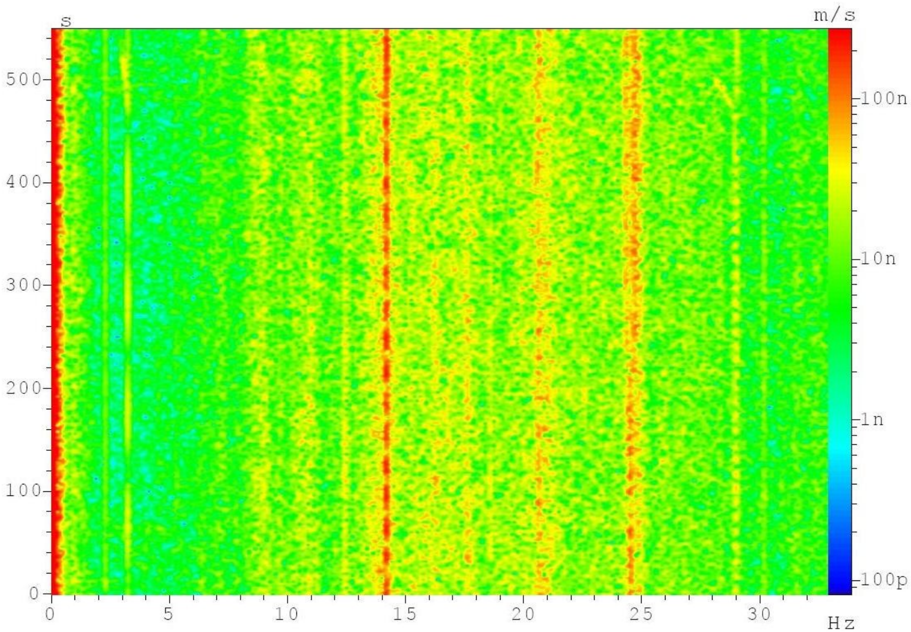
Baklakov, Shiltsev et al. Fermilab 1997

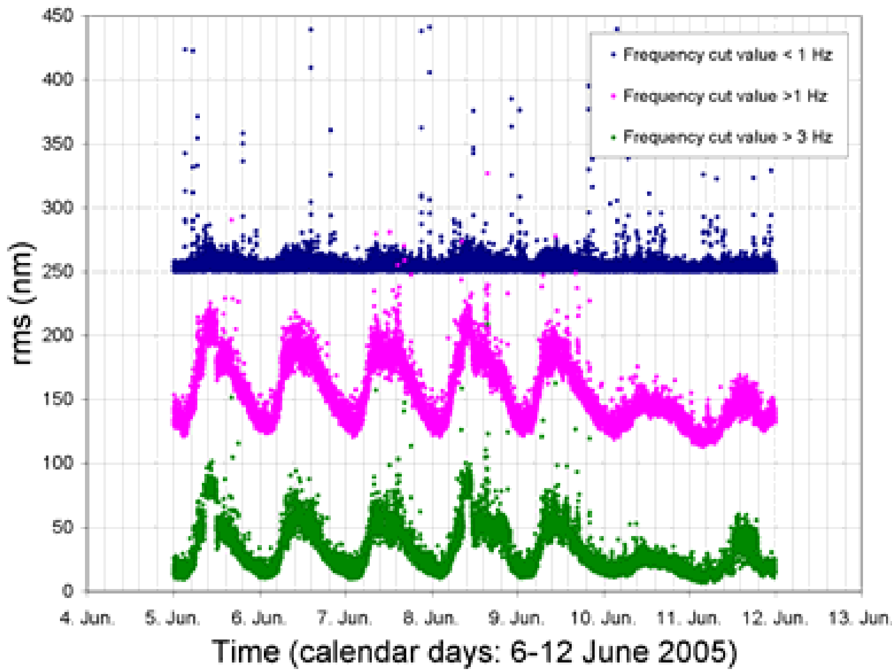


R.Amirikas, A. Bertolini DESY 2005



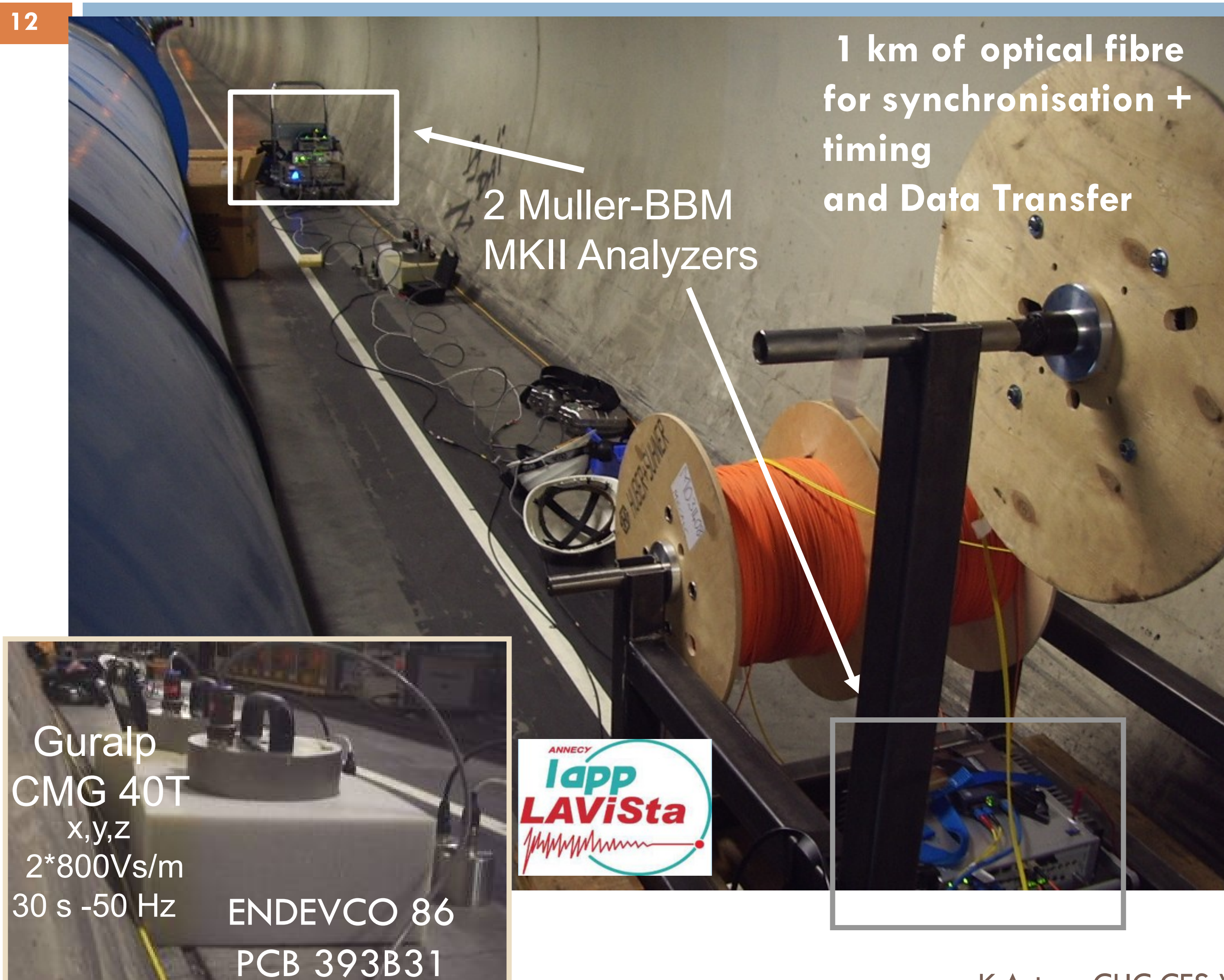
Variation in time of integrated R.M.S.





W. Bialowons et al.

Coherence Measurements



Parameters

Sampling rate
256 Hz
Block duration
64 s
Average
Lin - 50
Overlap
66.7 %

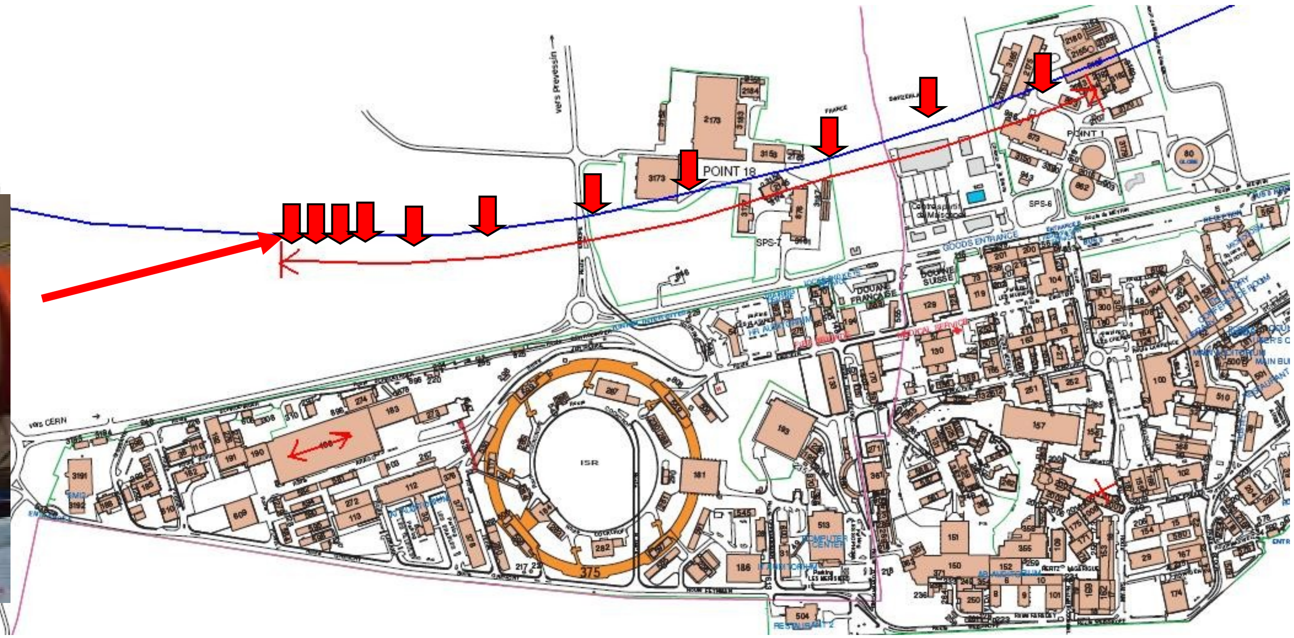
24 bit on 100 mV

Low ADC noise

LHC Measurements

LHC DCUM 1000

~ 80 m under ground



Measurements: 0 1 2 3 4 5 6 7 8 9 10 12 20 30 38 54 108 198 306 412 509 604 706 960 (m)

<u>Specific features :</u>

- Synchronous measurements
- LHC systems in operation, night time
- Multi-directional

Characteristics

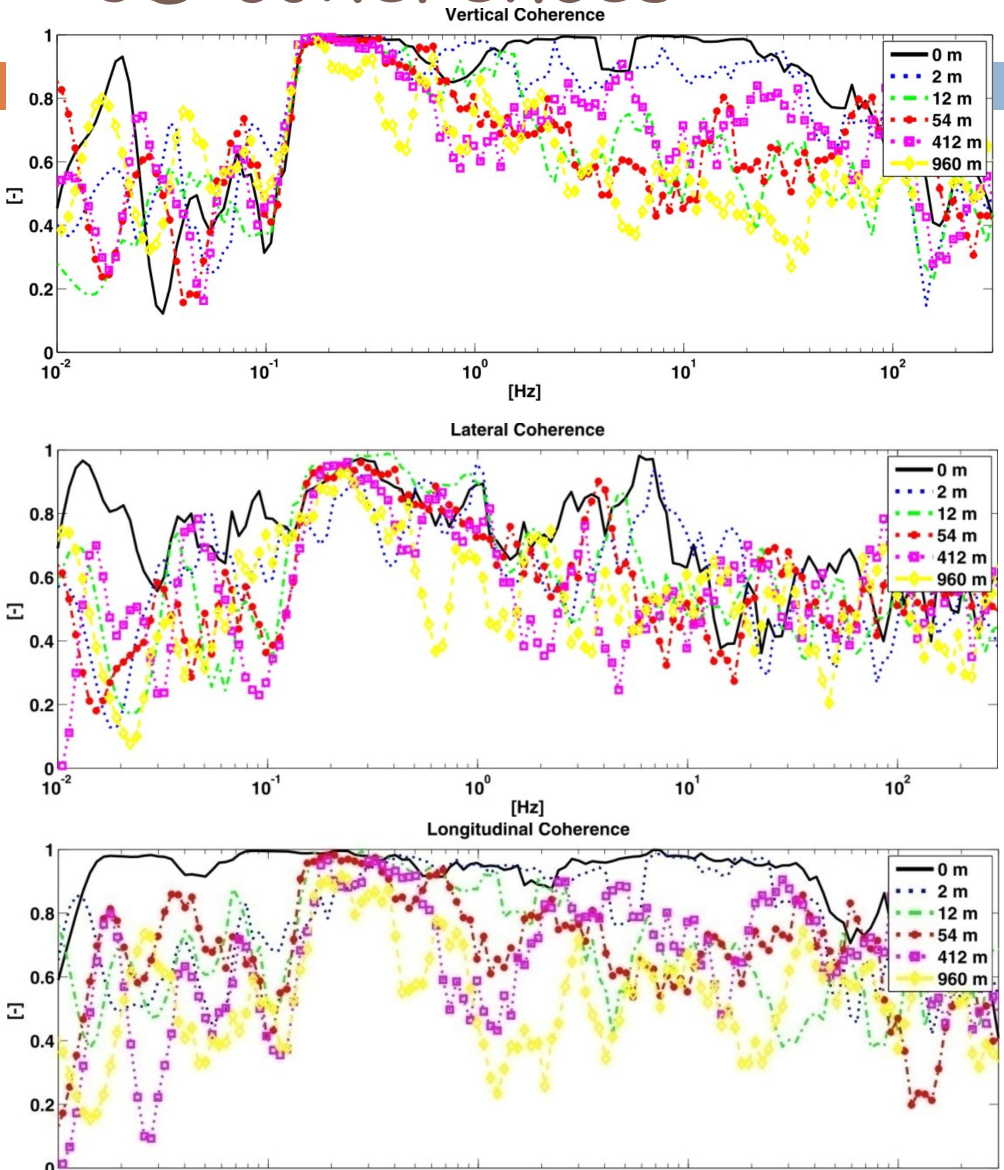
- Correlation function: $$R_{xy}(\tau) = \int_{-\infty}^{\infty} x(t) y(t+\tau) dt$$

- Cross spectral density: $$\Phi_{xy}(\omega) = \int_{-\infty}^{\infty} R_{xy}(\tau) e^{-i\omega\tau} d\tau$$

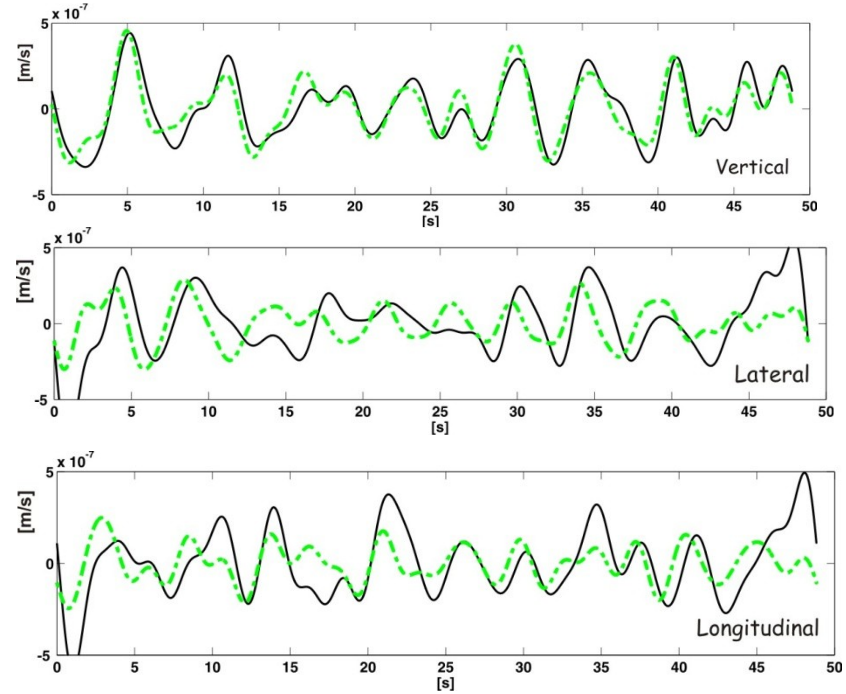
- Normalized spectral density between two measurements x(t) and y(t): $$\gamma_{xy}(\omega) = \frac{\Phi_{xy}(\omega)}{\sqrt{\Phi_{xx}(\omega)\Phi_{yy}(\omega)}}$$

- Power spectral density of the relative motion $d(t)=x_1(t)-x_2(t)$: $$\rho(\omega, L) = \Phi_{xx}(\omega) 2\{1 - Re[\gamma_{x_1 x_2}(\omega)]\}$$

3D coherences



d=960 m; filtered between 0.08 Hz and 0.5 Hz



- Correlation in the low frequency range
- Similar amplitudes in all directions
- Higher frequencies are dominated by local vibration sources

Joints between tunnel segments

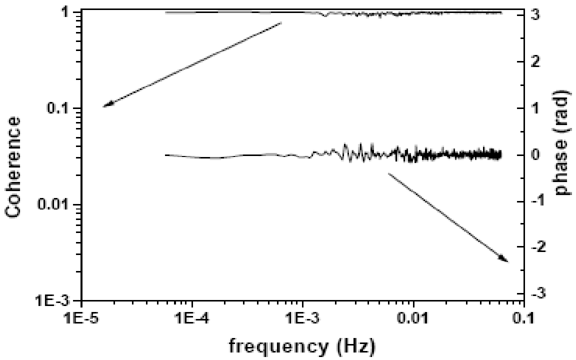


Figure 2: Coherence and phase difference between two sensors separated by 50 cm with no expansion joint.

S. Takeda et al. 1996

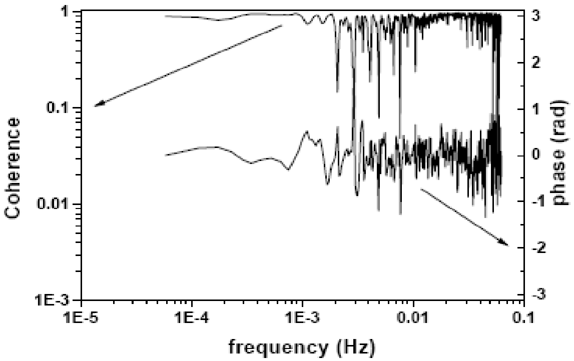
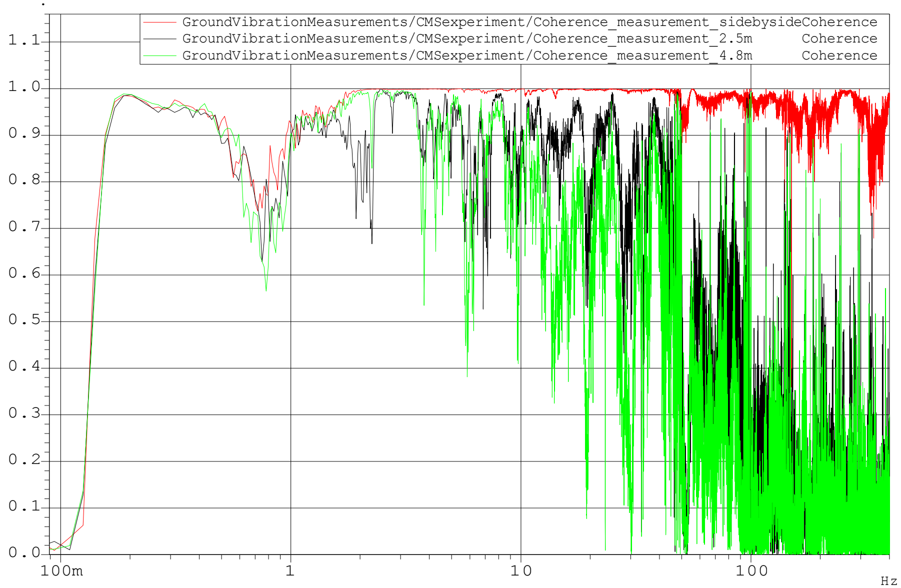
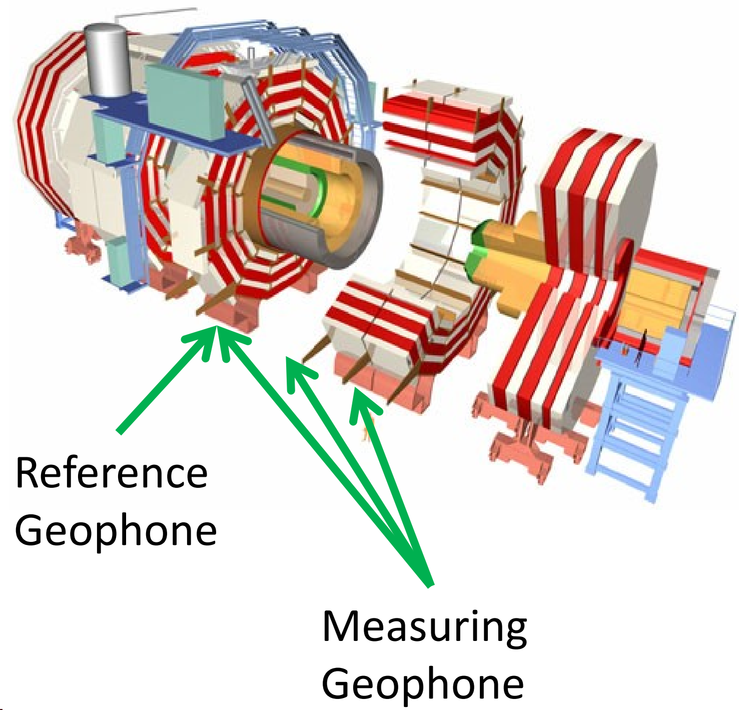


Figure 3: Coherence and phase difference between two sensors separated by 50 cm with an expansion joint.

Coherence Length Measurements

Coherence

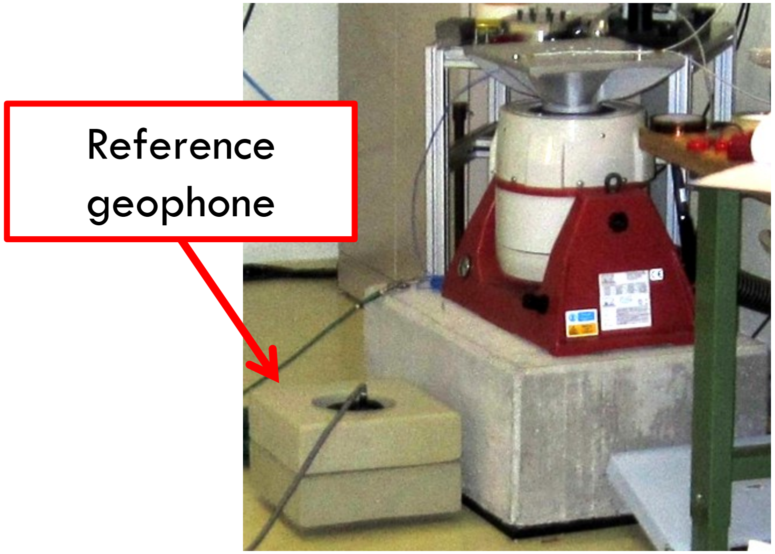




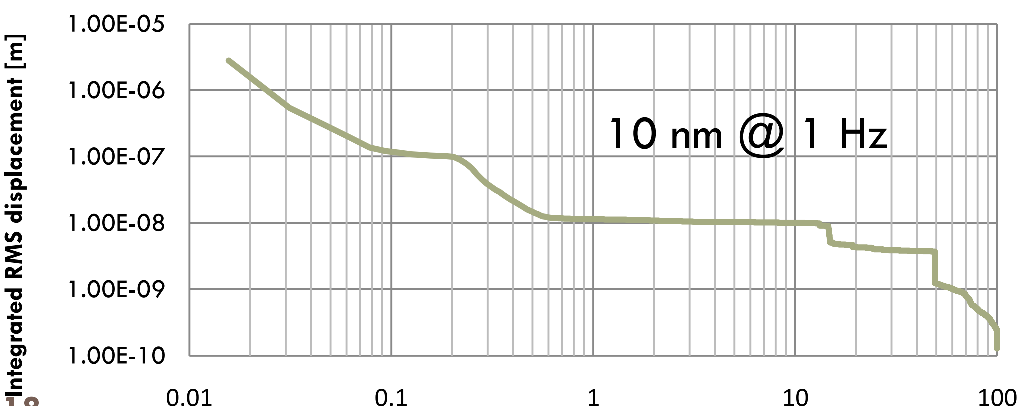
Three measurements were provided:
- Geophones side by side
- Geophones 2.5 m away from each other
- Geophones 4.8 m away from each other

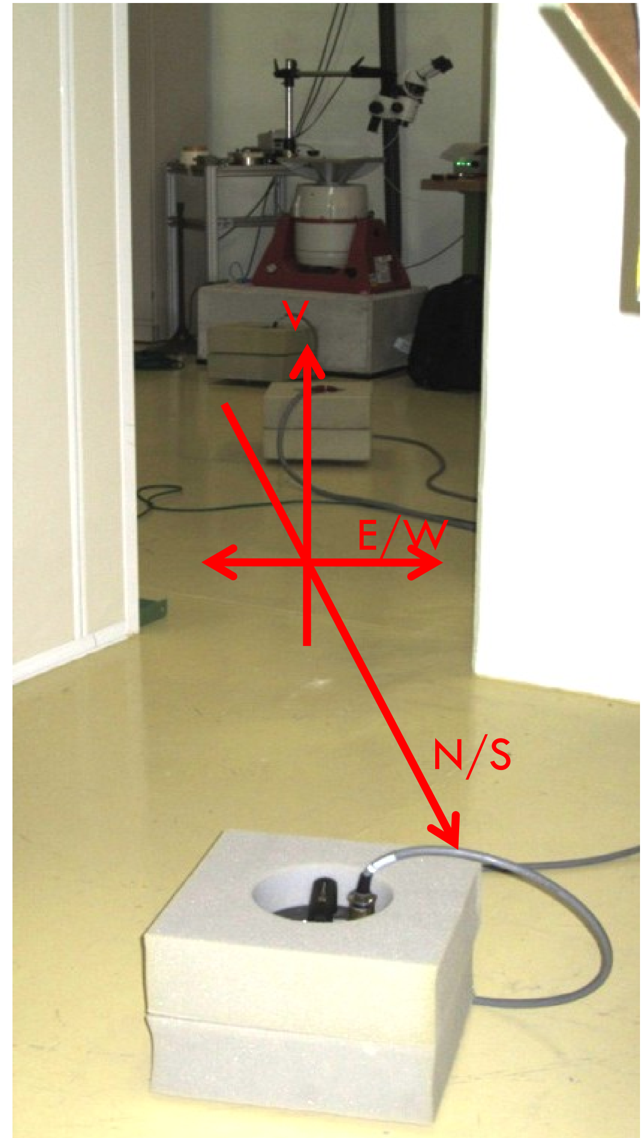
Propagation of local technical noise in concrete floor: some initial tests

Michael Guinchard & Ansten Slaathaug

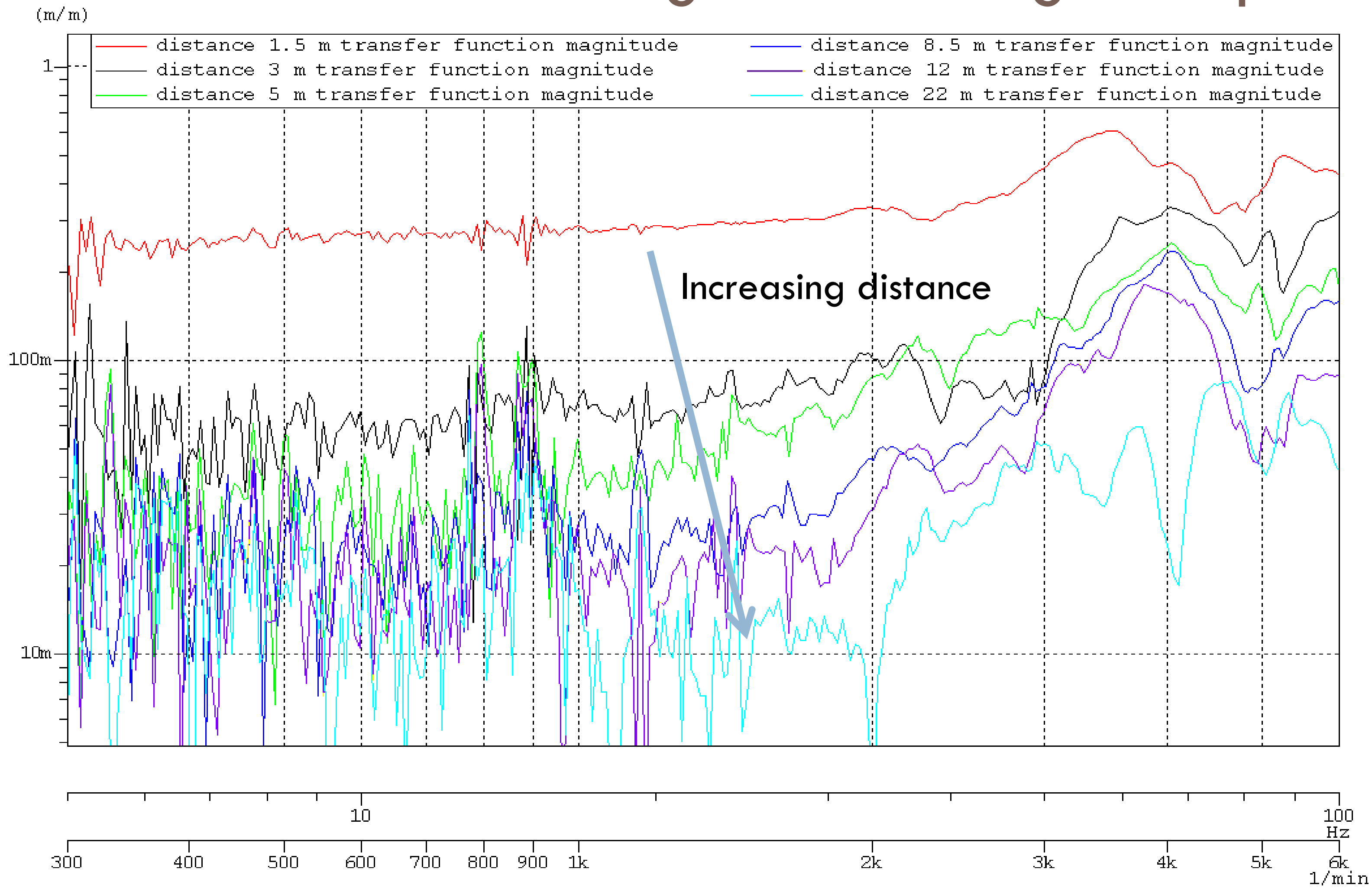


Integrated RMS Bldg 186 without excitation





Transfer function magnitude along sweep sine.



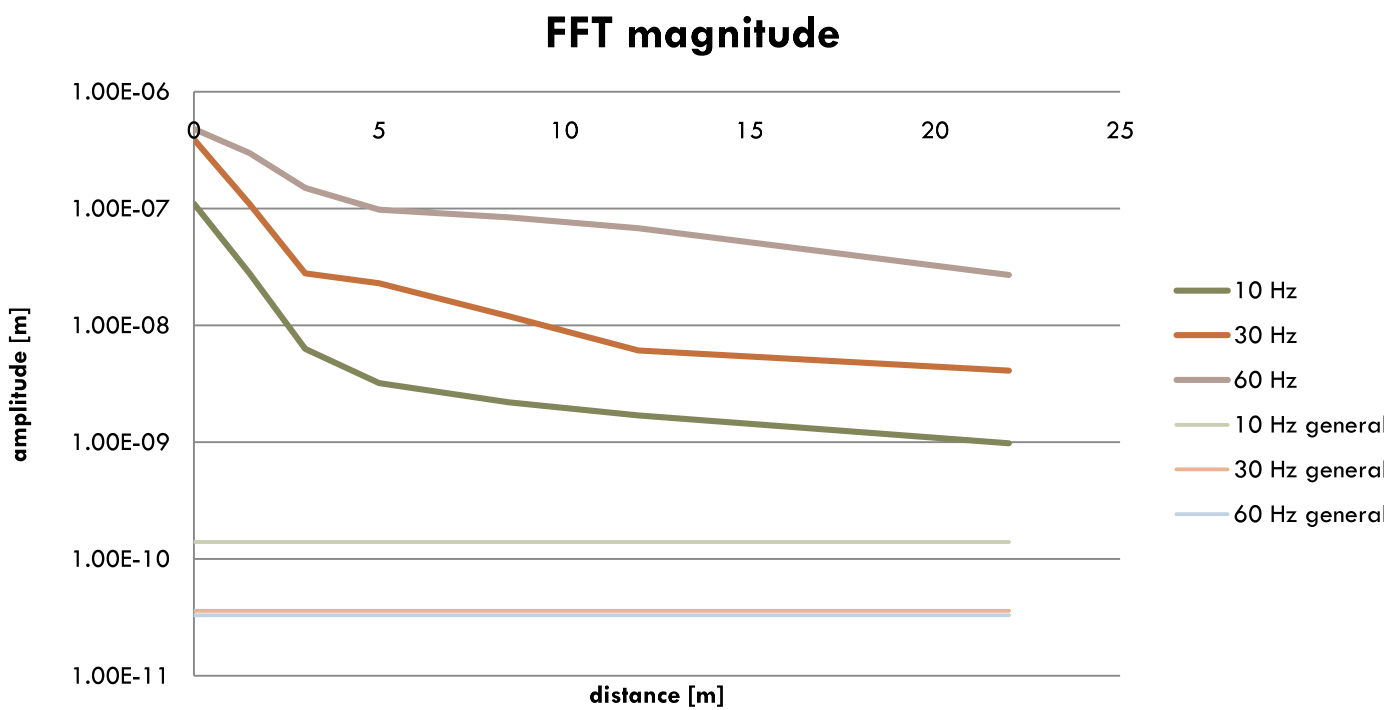
– Transfer function magnitude between reference geophone and geophone at measured points

Results

Experiment2 :

Sine with fixed frequency with the shaker

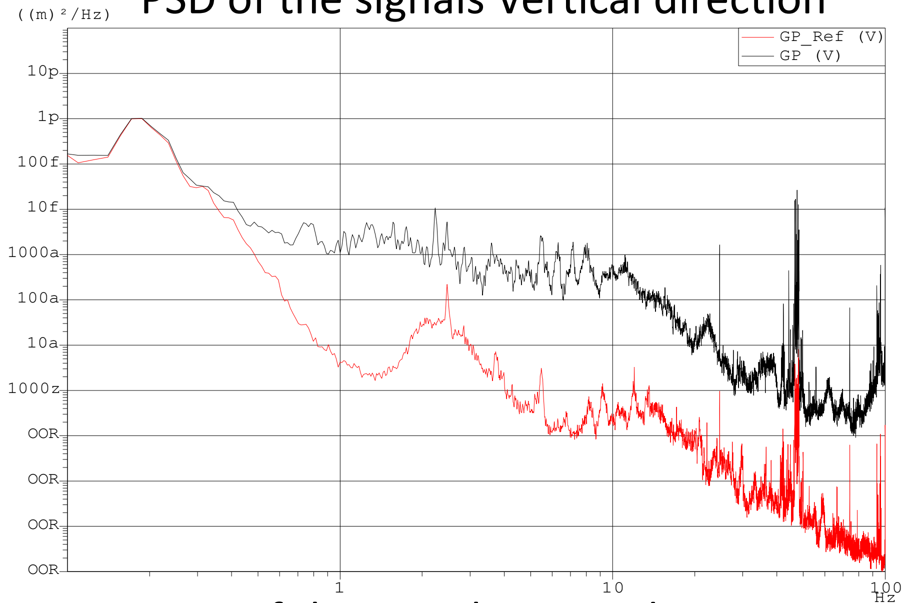
- Vibration level change with distance (general = no excitation)

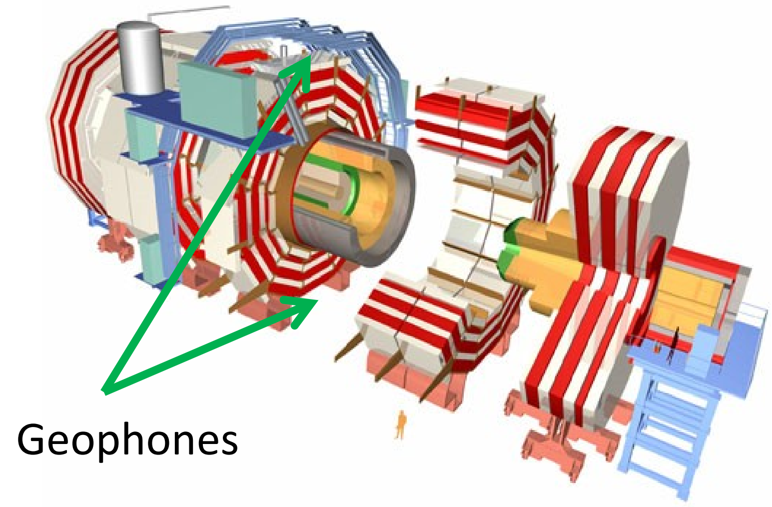


Goal: Test different concrete floors with an exact reproducible vibration source

CMS YB0 motion measurement

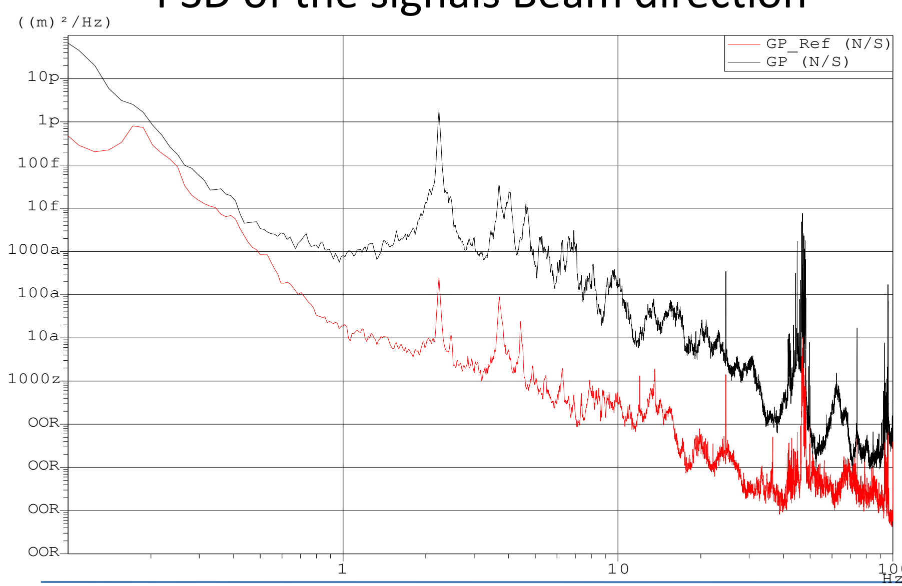
PSD of the signals Vertical direction

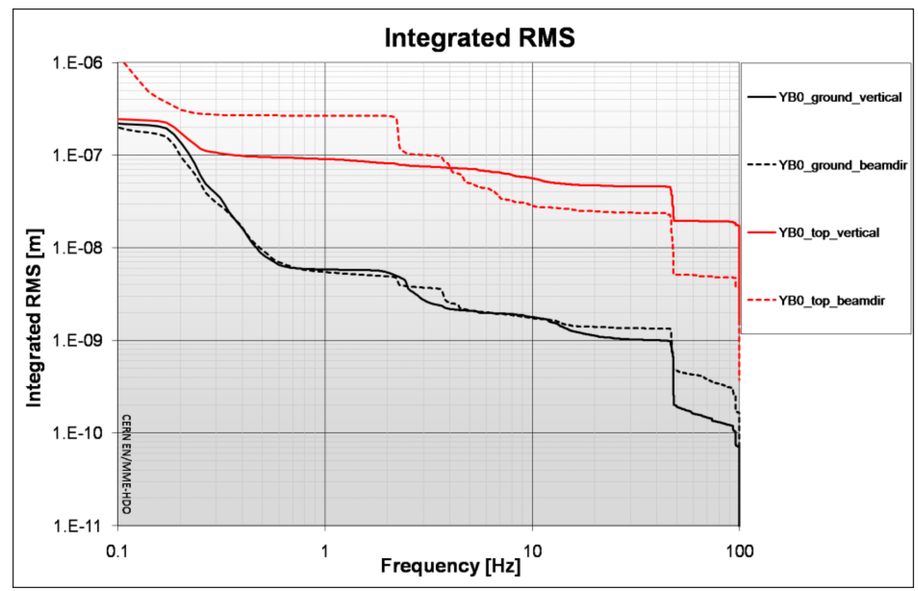




Cooling system OFF

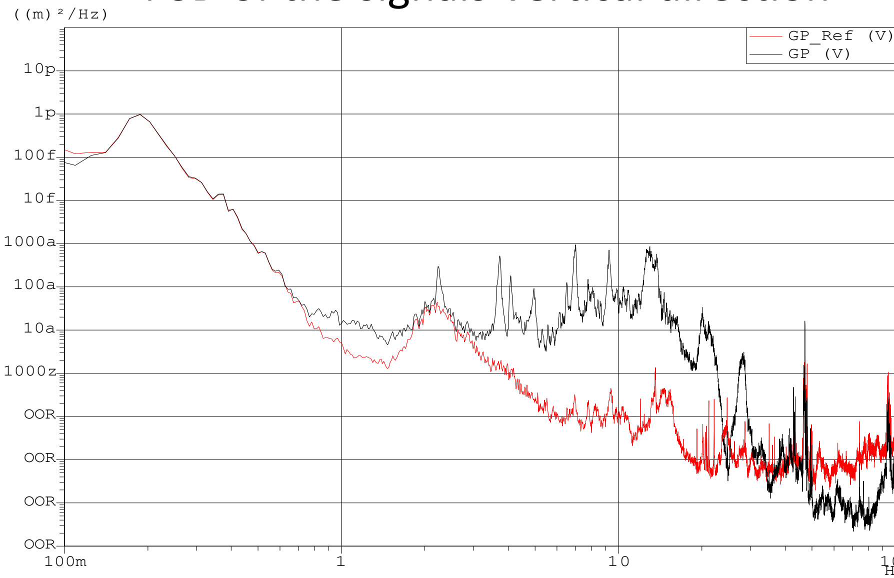
PSD of the signals Beam direction

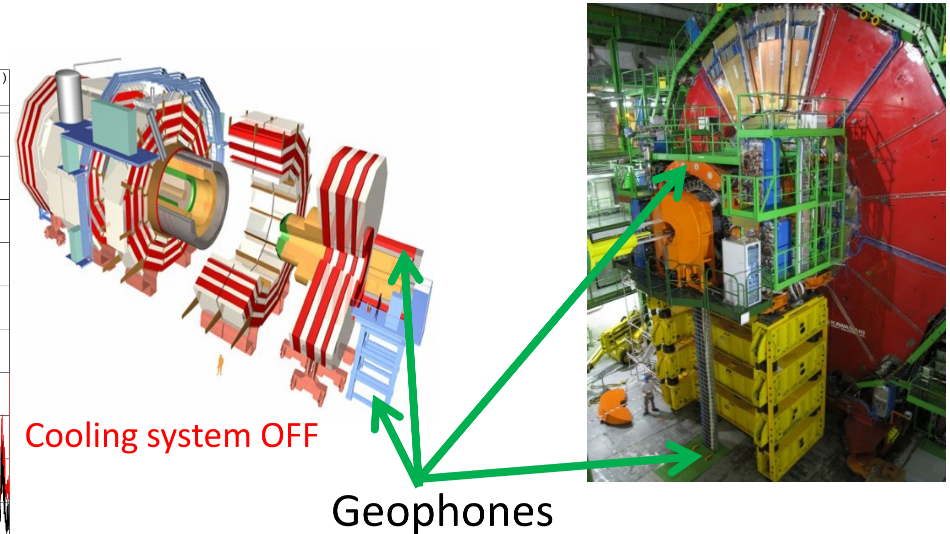




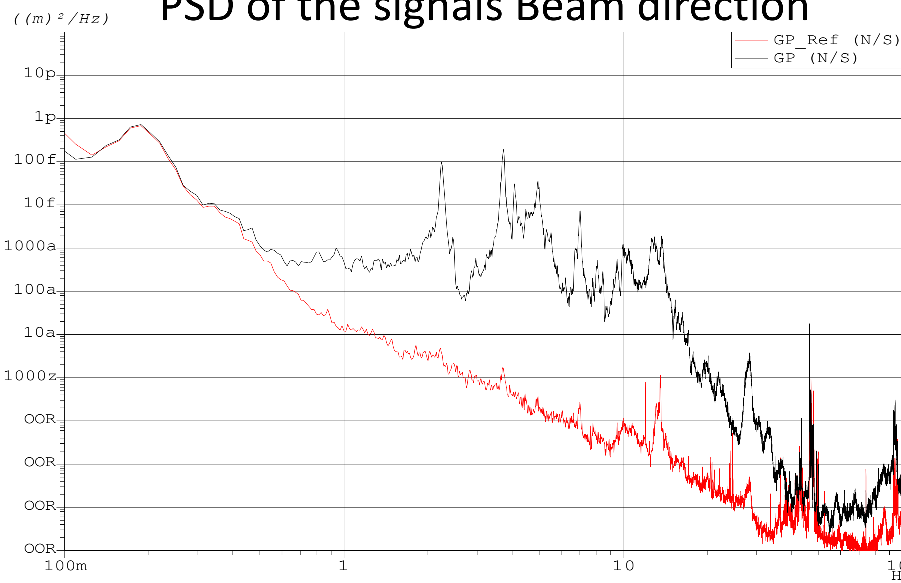
CMS HF structure motion measurement

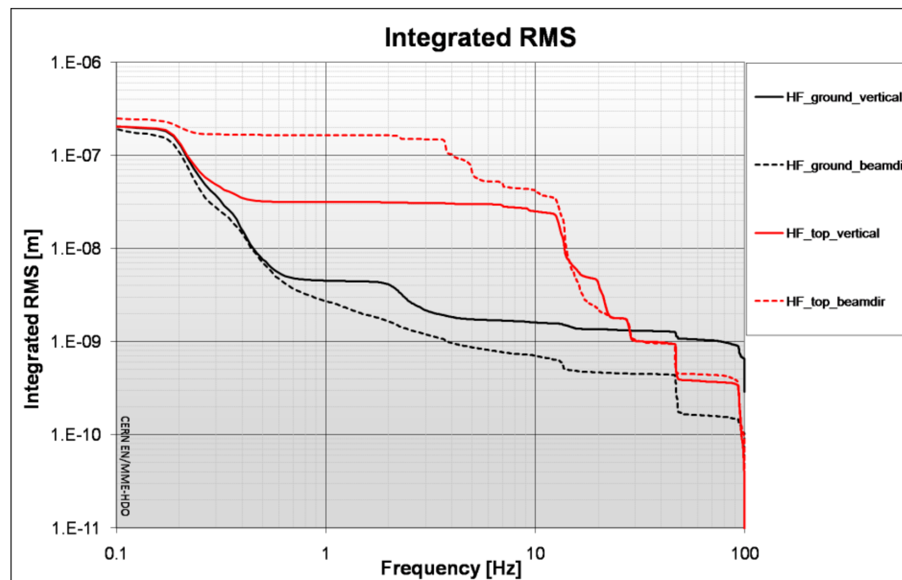
PSD of the signals Vertical direction





PSD of the signals Beam direction



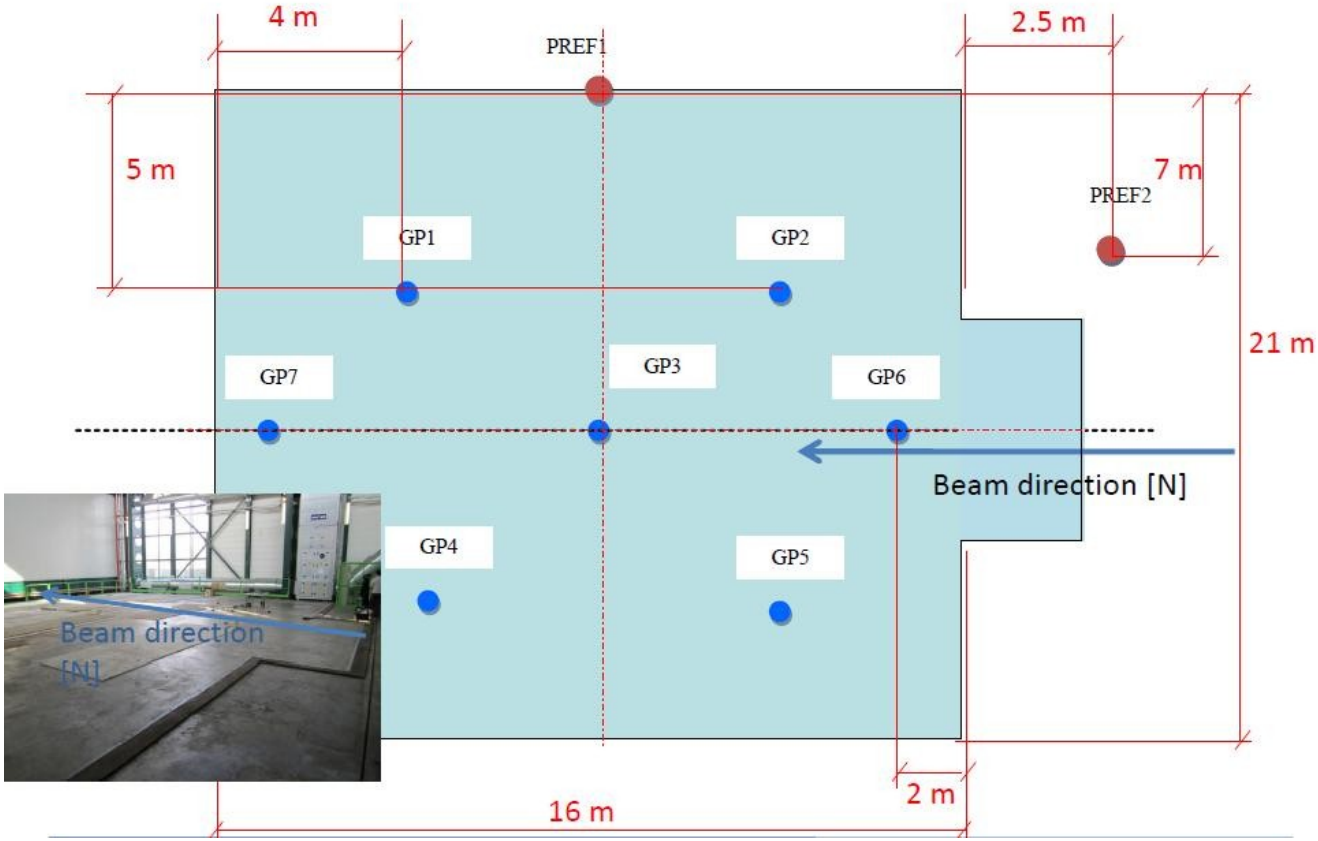


Interpretation

- Technical noise is higher on top of experience at all frequencies.
- Modal analysis is not easy: not enough sensors, not measured at same time, no good phase measurements because low signal to noise ratio, not known excitation,...
- Refer to work of Hiroshi Yamaoka KEK, BELLE

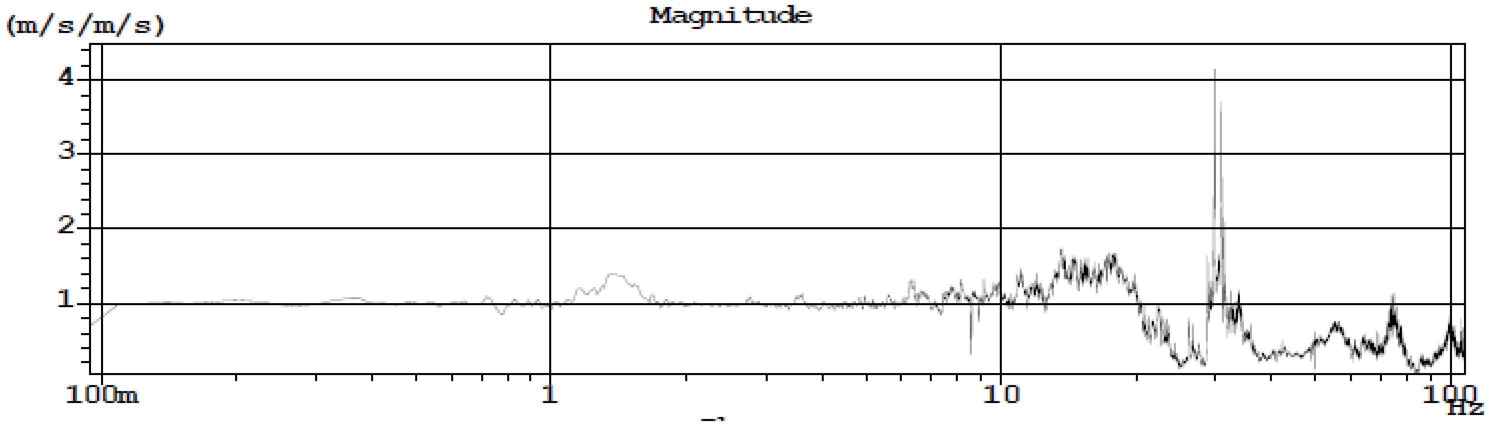
CMS slab measurements

Sensor position

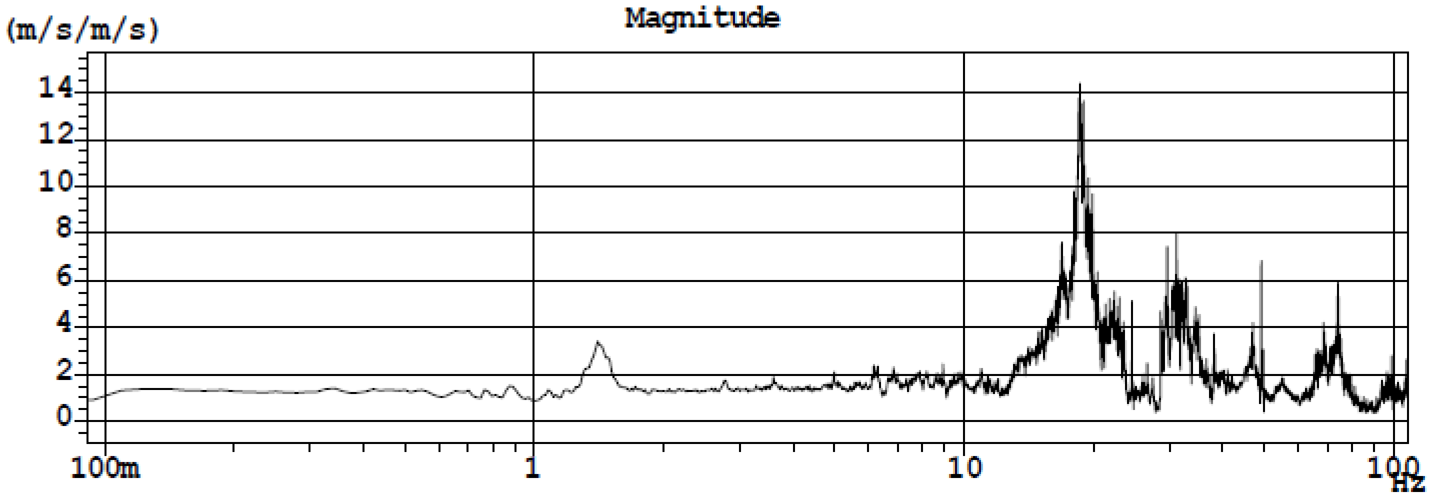


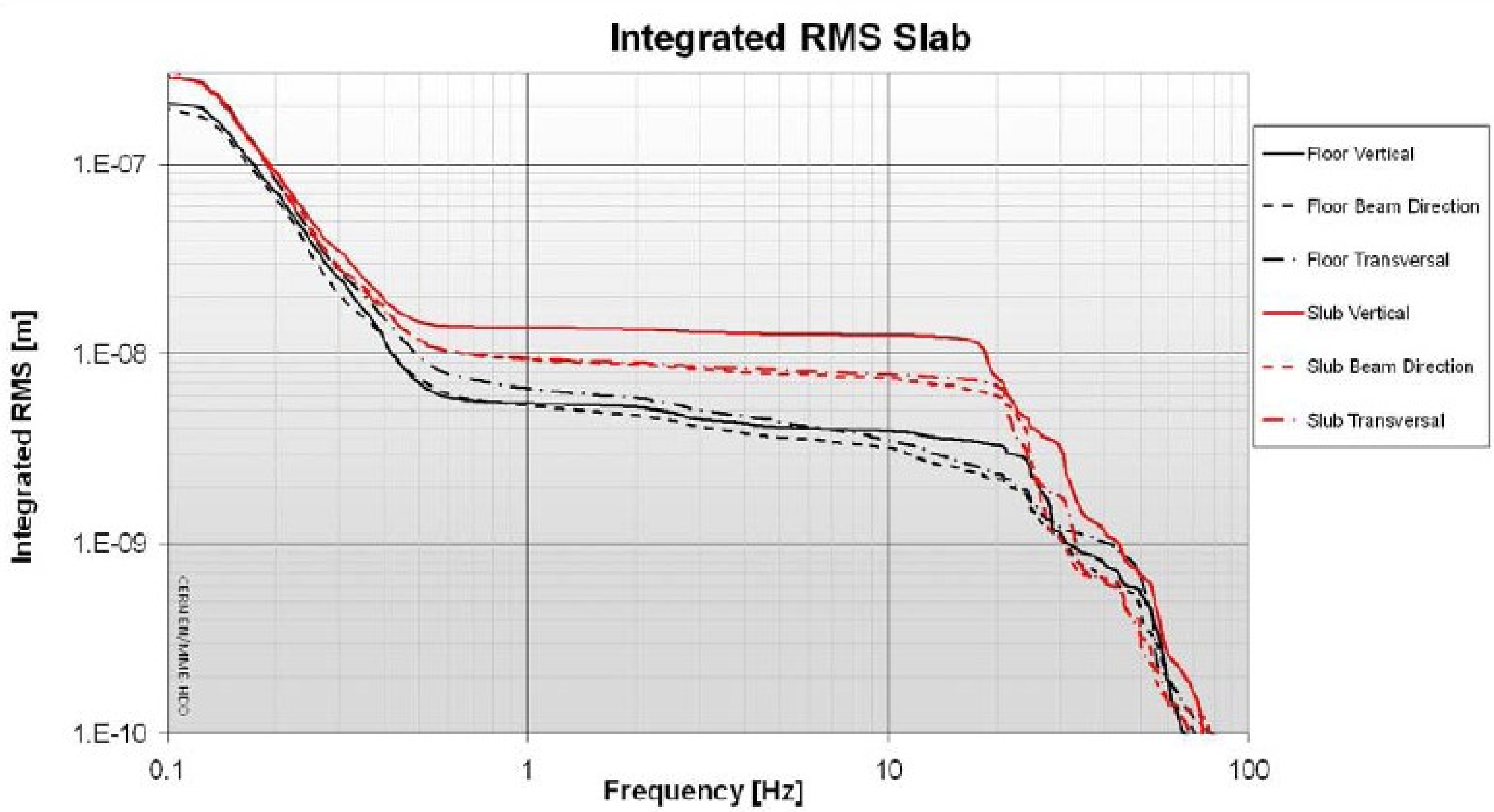
First measurements on CMS slab

Vertical Transfer function (reference seismometer above rail)

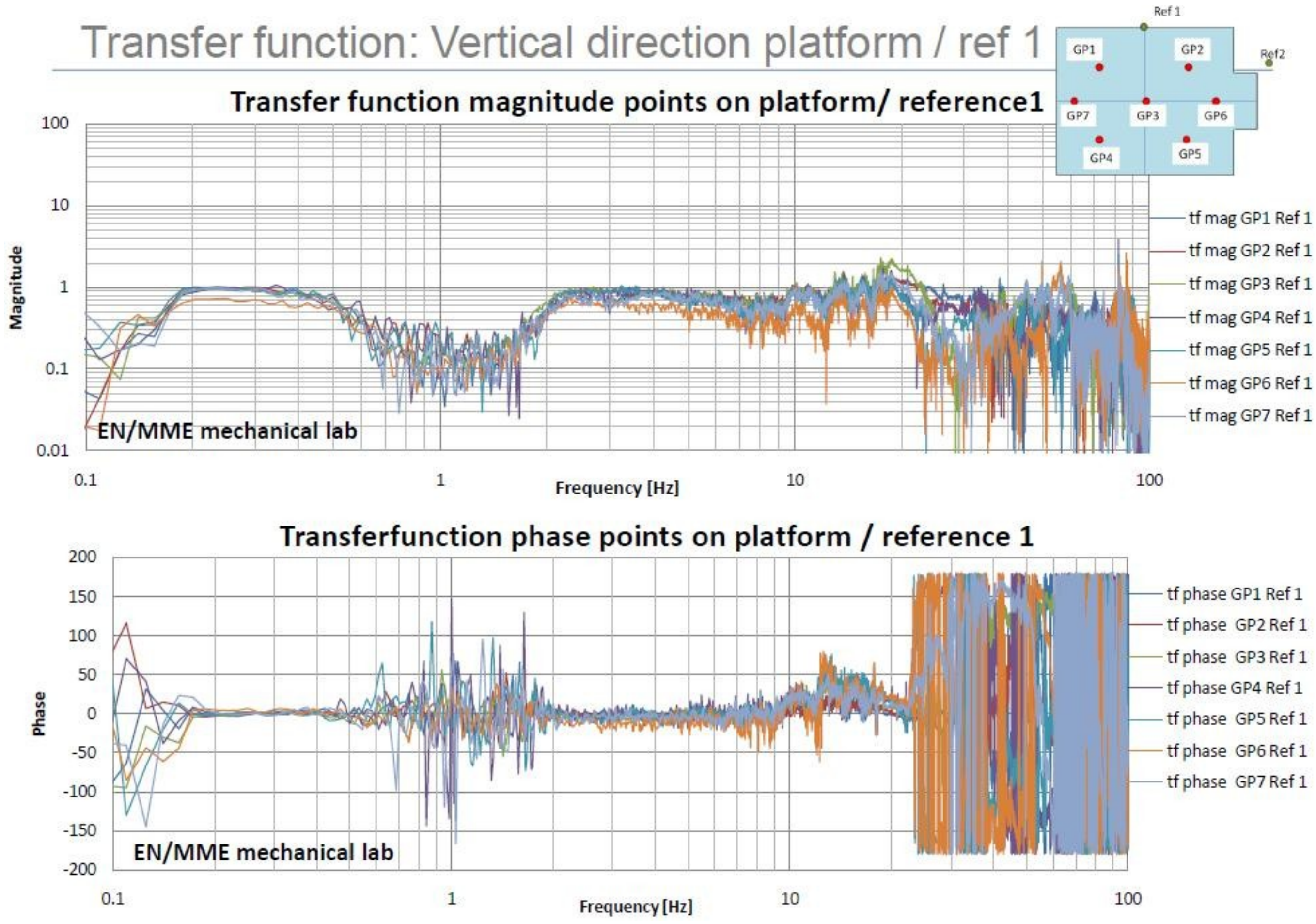


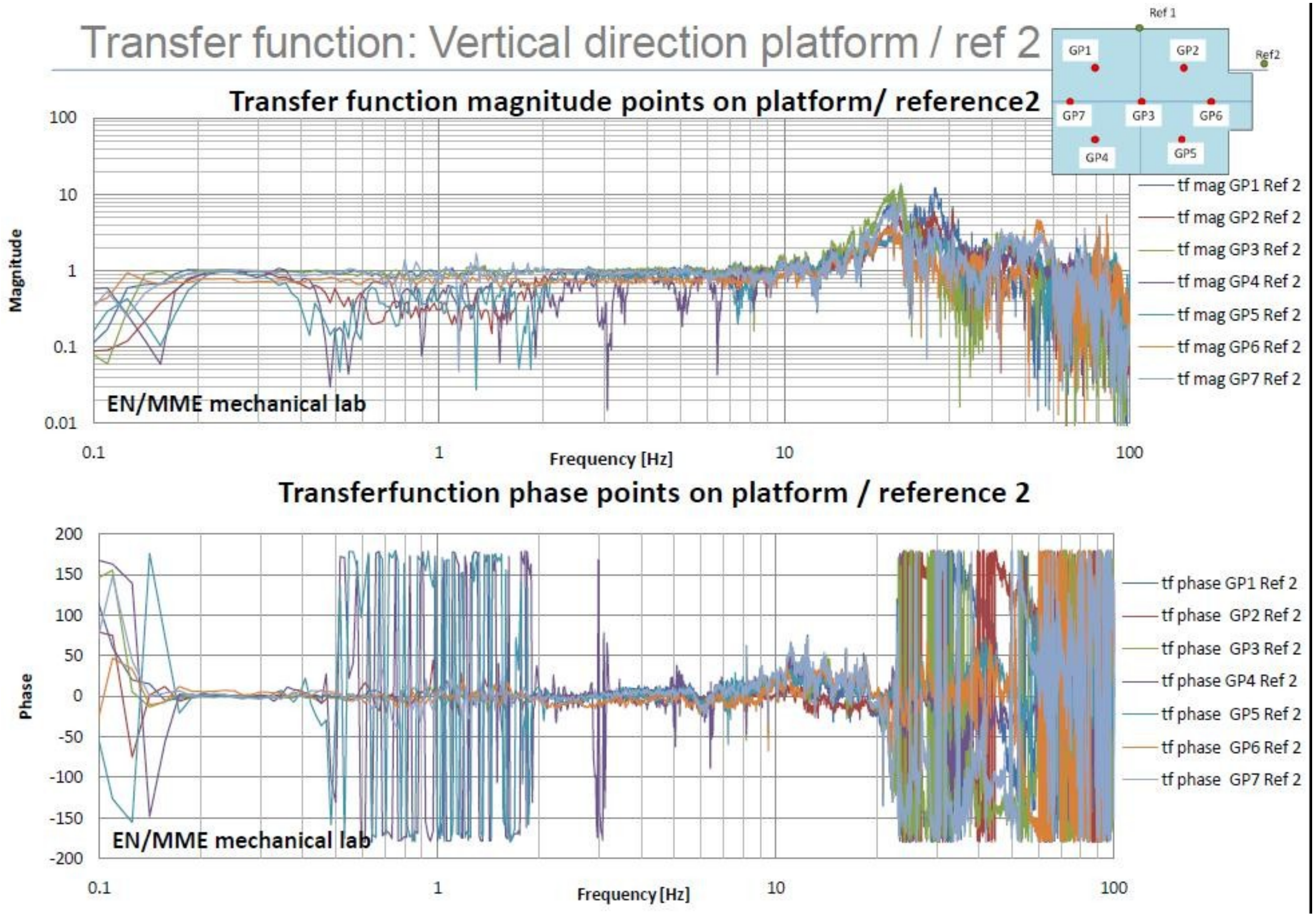
Vertical Transfer function (reference seismometer on floor)




Integrated RMS Slab
Integrated RMS [m]
1.E-07
1.E-08
1.E-09
1.E-10
0.1
1
10
100
Frequency [Hz]
Floor Vertical
Floor Beam Direction
Floor Transversal
Slub Vertical
Slub Beam Direction
Slub Transversal

Second measurements




Transfer function: Vertical direction platform / ref 2
Ref 1
GP1
GP2
Ref2
GP7
GP3
GP6
GP4
GP5
Transfer function magnitude points on platform/ reference2
Magnitude
Frequency [Hz]
EN/MME mechanical lab
tf mag GP1 Ref 2
tf mag GP2 Ref 2
tf mag GP3 Ref 2
tf mag GP4 Ref 2
tf mag GP5 Ref 2
tf mag GP6 Ref 2
tf mag GP7 Ref 2
Transferfunction phase points on platform / reference 2
Phase
Frequency [Hz]
EN/MME mechanical lab
tf phase GP1 Ref 2
tf phase GP2 Ref 2
tf phase GP3 Ref 2
tf phase GP4 Ref 2
tf phase GP5 Ref 2
tf phase GP6 Ref 2
tf phase GP7 Ref 2

Conclusions

- Micro seismic wave (0.1 to 0.25 Hz, 0.1 to 3 micron integrated R.M.S.) Depends on weather conditions + geology (ref. G.E. Fischer)
- Micro seismic wave does not depend on tunnel depth
- Technical noise from surface decreases with depth of tunnel
- Technical noise varies in time. Day night variations of factor 5 on surface and factor 2 for deep tunnels. (ref. measurements DESY)
- Only low frequency ground motion is coherent over long distances. At and above one Hz the ground motion is coherent to maximum 40 m on a continuous concrete floor.
- Local vibration sources are attenuated by the concrete floor over some distance. It would be good to characterize different concretes.
- A particle detector is “noisy”, even during “quiet” conditions.
- The CMS slab amplifies ground motion, mechanism not entirely clear