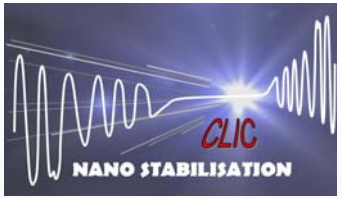
“Recent ground vibration measurements at CERN ”
(Surface and underground)

Comparison with other measurements and overview methods

K.Artoos, M. Guinchard

16th October 2008, CLIC workshop



Contents :

- Overview references Ground Vibration measurements
- CERN measurements in LHC tunnel + surface
  - Power Spectrum Density
  - Integrated RMS + *RMS histogram*
  - Coherence
- Conclusions

More information:

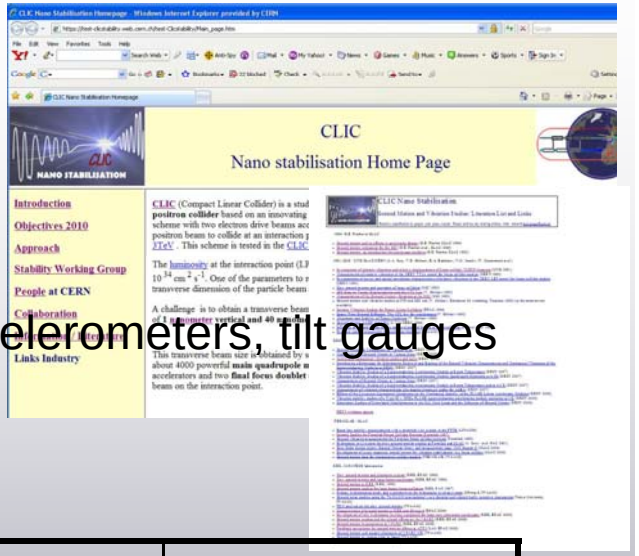
http://clic-stability.web.cern.ch/clic-stability/

http://www.cern.ch/info-mechanical-measurement-lab

References ground vibration measurements

- list of references (> # 60) Available on new website

http://clic-stability.web.cern.ch/clic-stability/Ground%20Vibration%20Studies.htm



Methods:

- Absolute measurements : Seismometers, accelerometers, tilt gauges — This talk
- Relative measurements : WPS, HLS, LASER
- Closed Orbit Distortion measurements

V. Shiltsev, A. Sery et al., 1991- now INP	Modified SM-3KV 8E4 Vs/m 0.05-150 Hz	12 bit ADC	64 averages, blocks 1 minute at 1 kHz	Synchronisation: Electrical start trigger (~ ms)
S. Takeda et al. KEK 1994-now + other Japanese institutes	STS-2 2*750 Vs/m120s- 50 Hz tilt meter, HLS	16 bit ADC		Synchronisation LON Network
R. Amirikas, A. Bertolini et al. DESY	CMG-3TD, CMG-6TD, Digital 24 bit, 360,60s - 80 Hz 2*750Vs/m 200 Hz down sampling	24 bit	1 minute blocks, minimum 15 minutes averaging	GPS UTC time

Why more measurements?

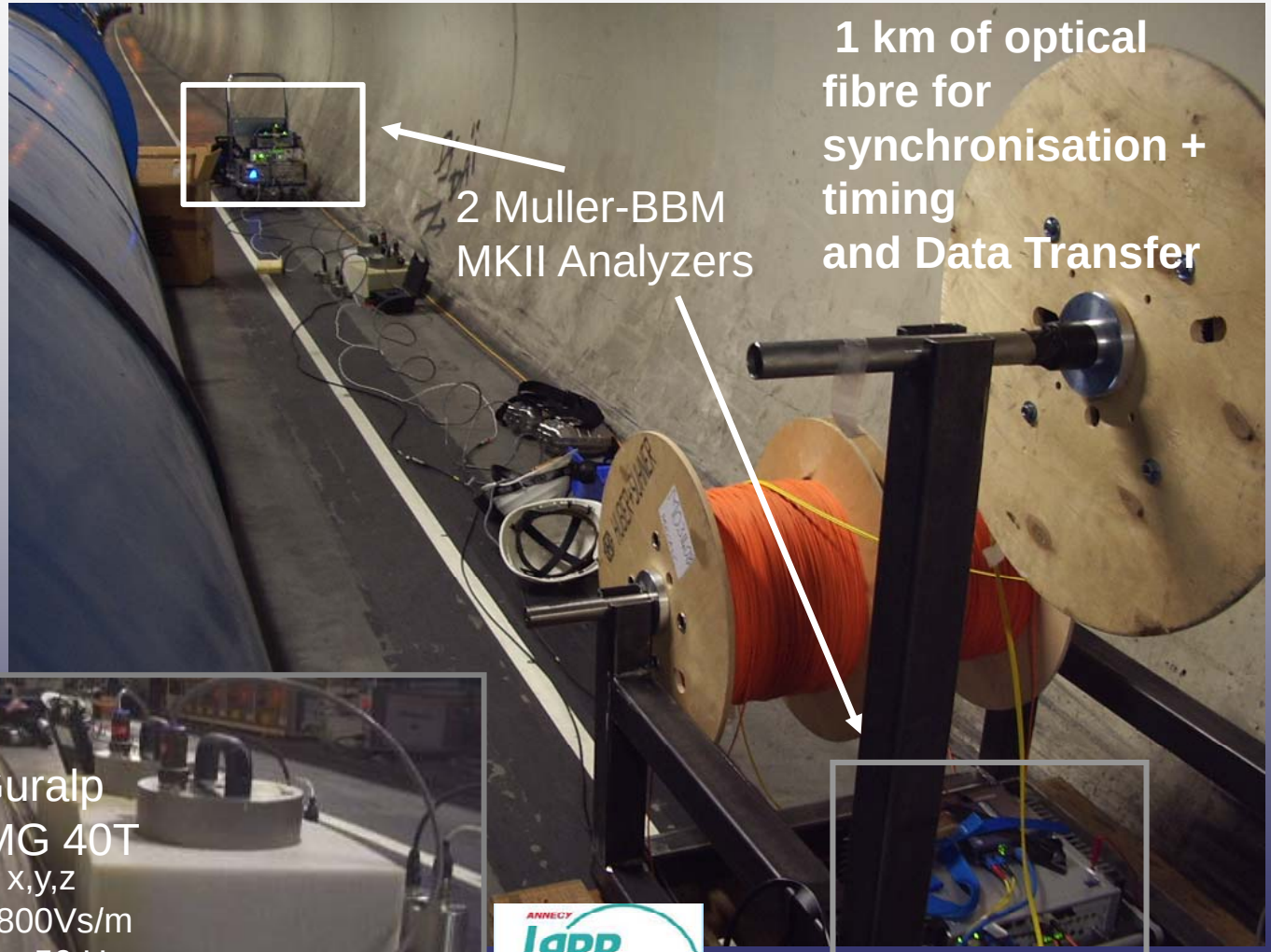
USGS, CEA,... Specialised Geological survey

CLIC, NSLS II, DIAMOND, XFEL,...

Demonstrator !

Design phase

Set-up measurements at CERN :



Parameters

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

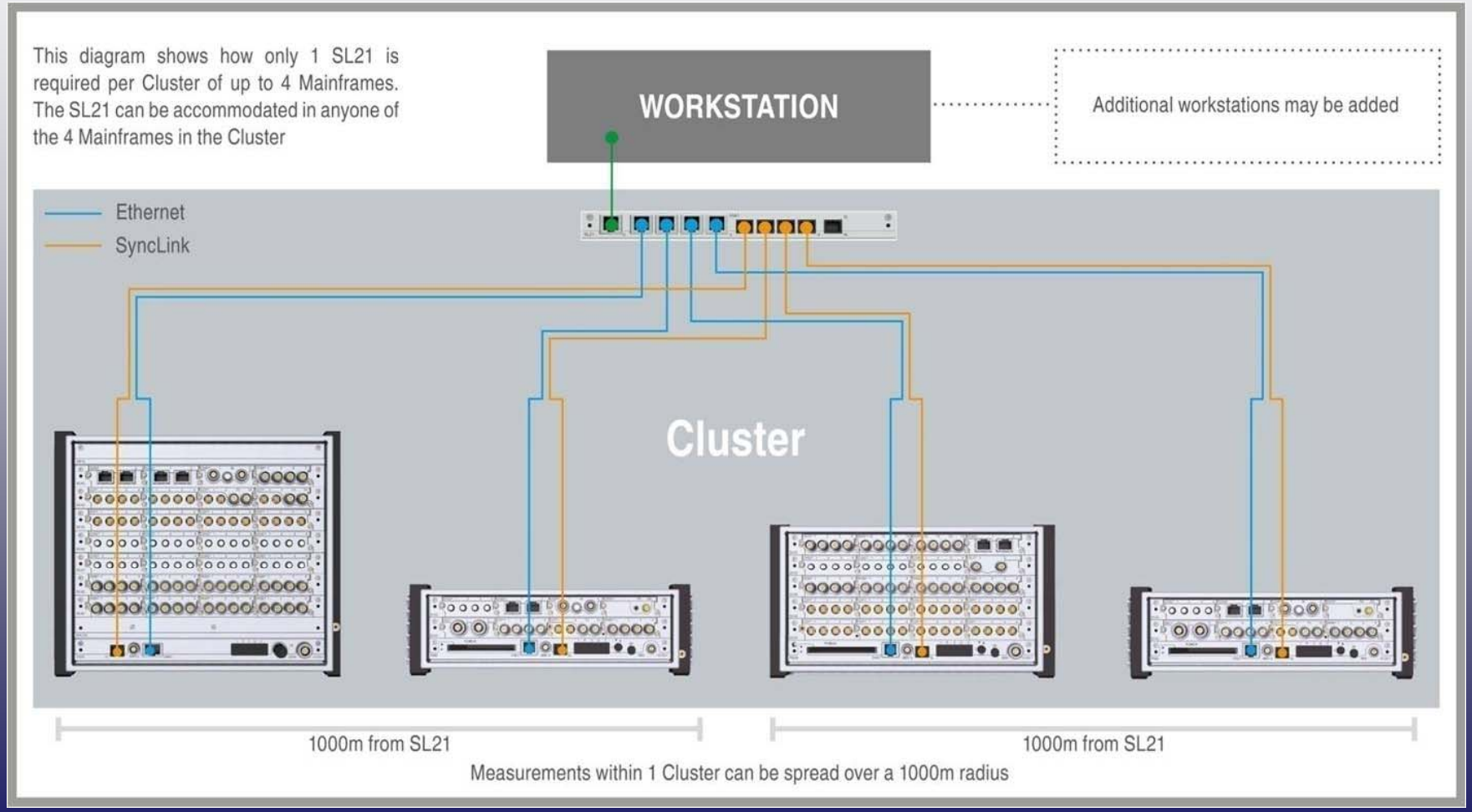
24 bit on 100 mV

Low ADC noise

Special credits to B. Bolzon, A. Jeremy !

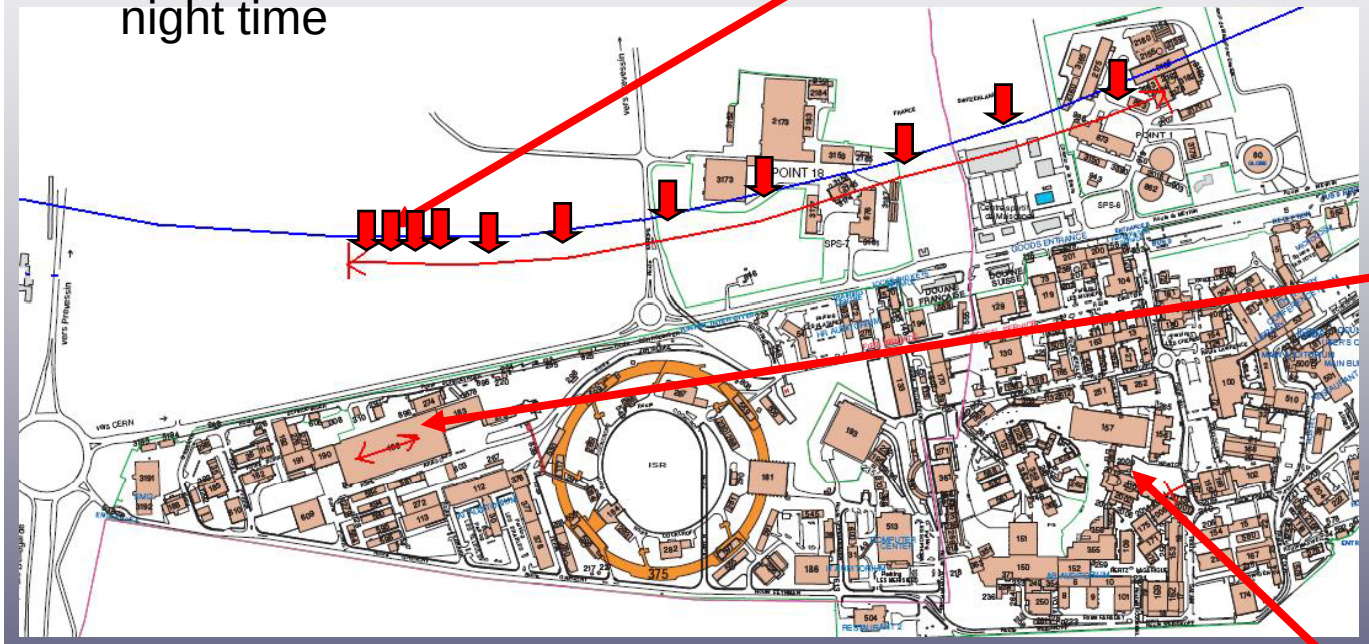
Synchronisation

Phase error < 0.01 deg



Measurements

LHC DCUM 1000
~ 80 m under ground
LHC systems in operation, night time

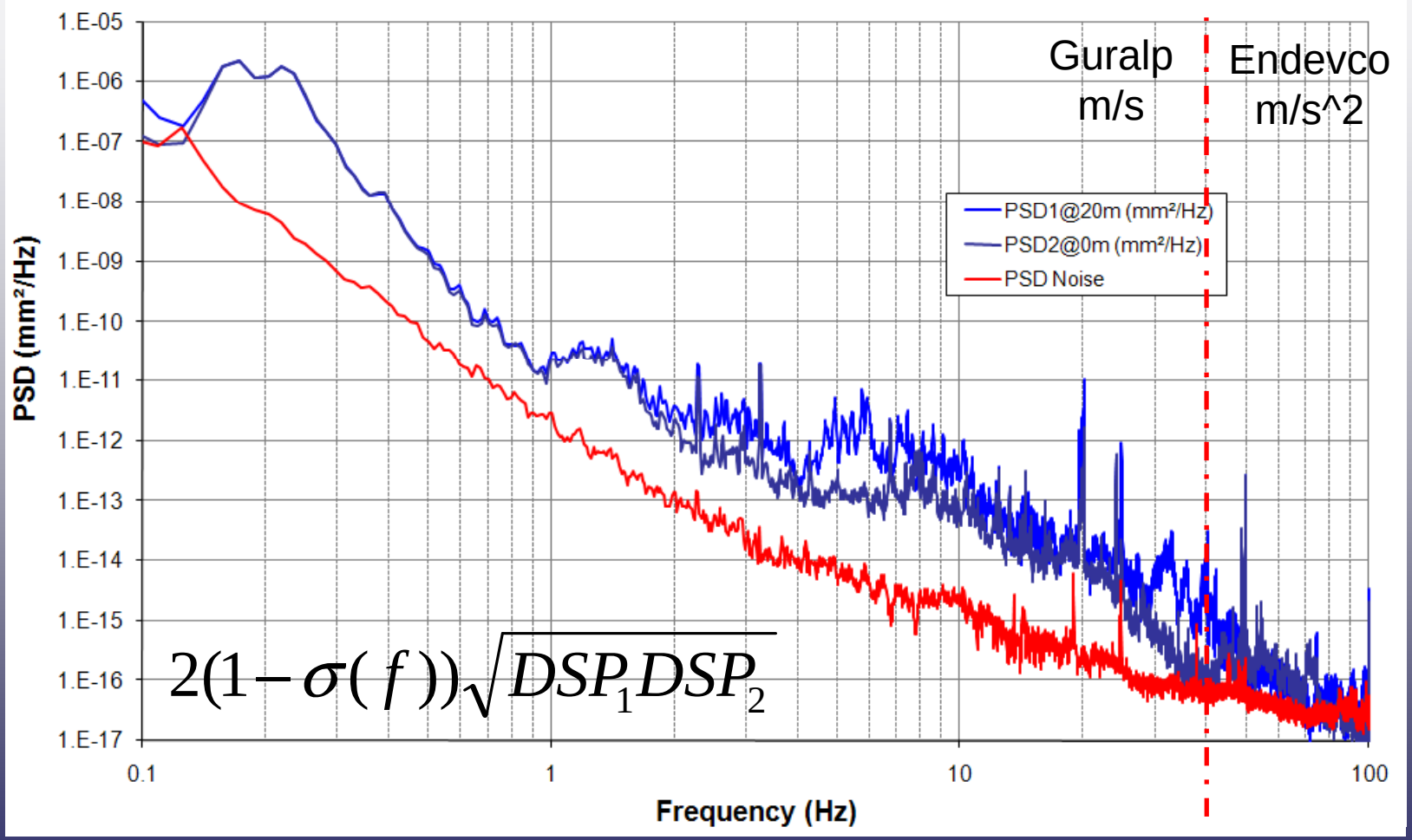


Floor building 180

Building 180
Surface
No technical systems in operation, night time

Measurements Combiner ring CTF 3
Some technical systems in operation, day time

Power Spectrum Density

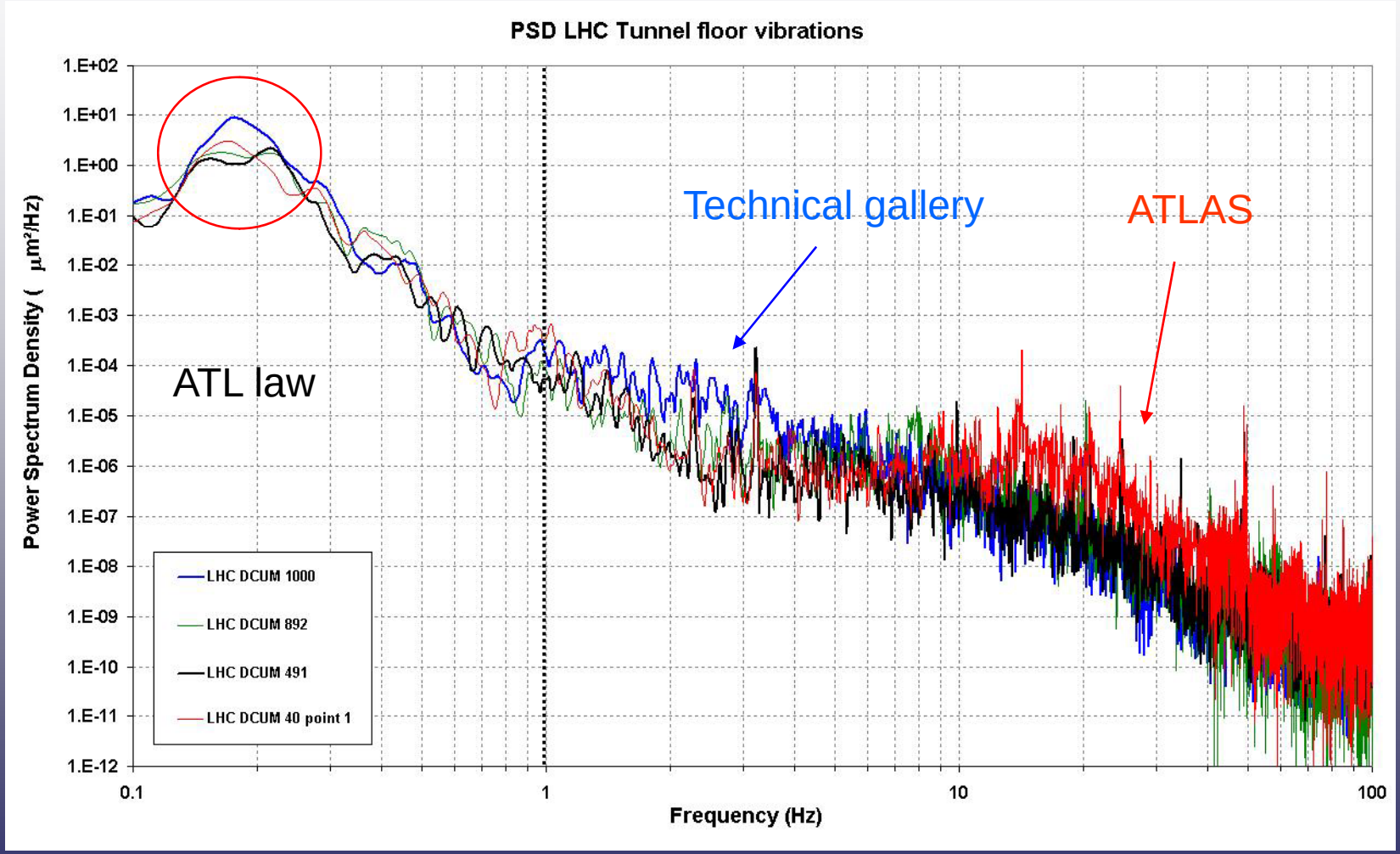


Noise (error) estimation by corrected difference

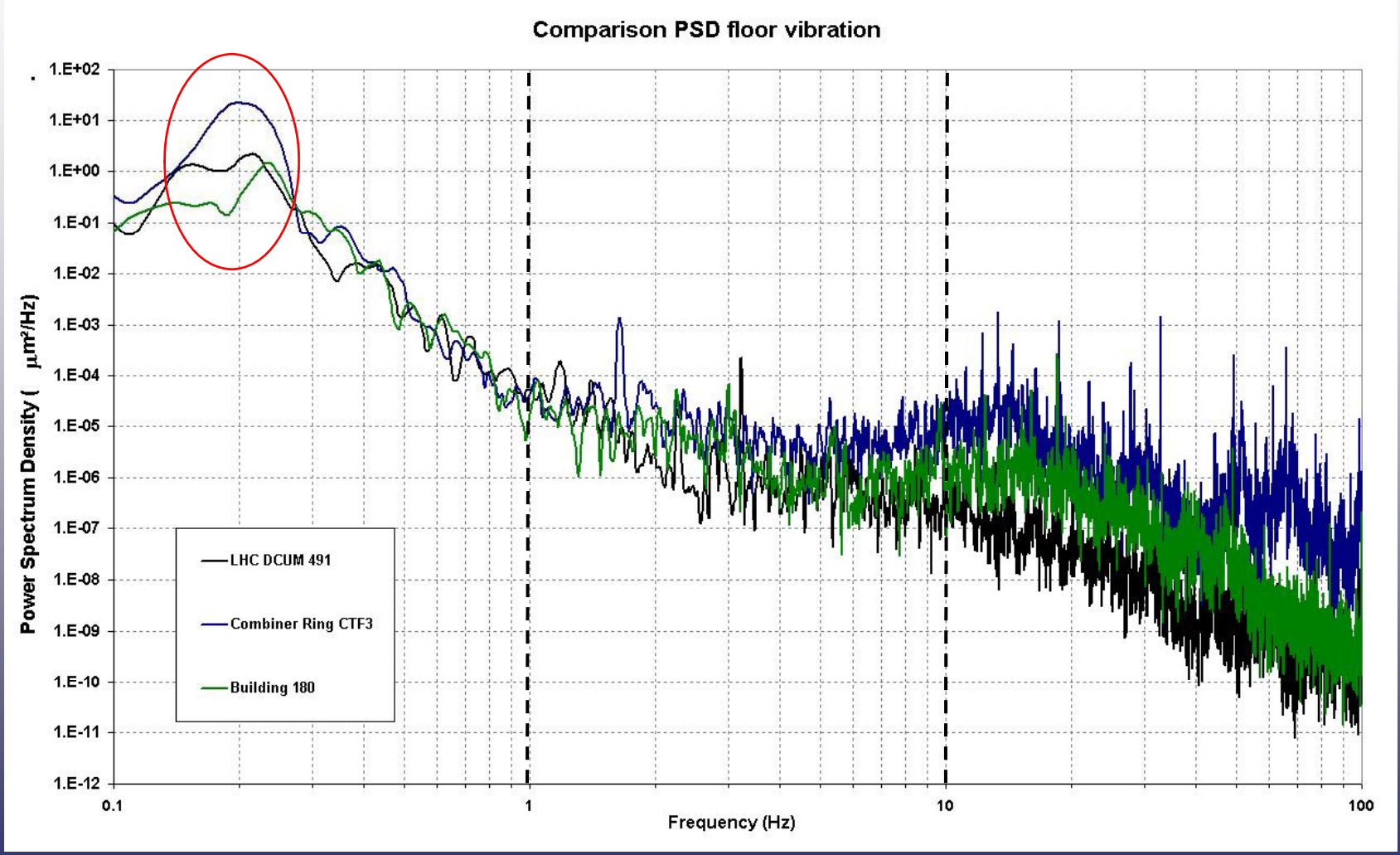
40 Hz

Power Spectrum Density: LHC Tunnel

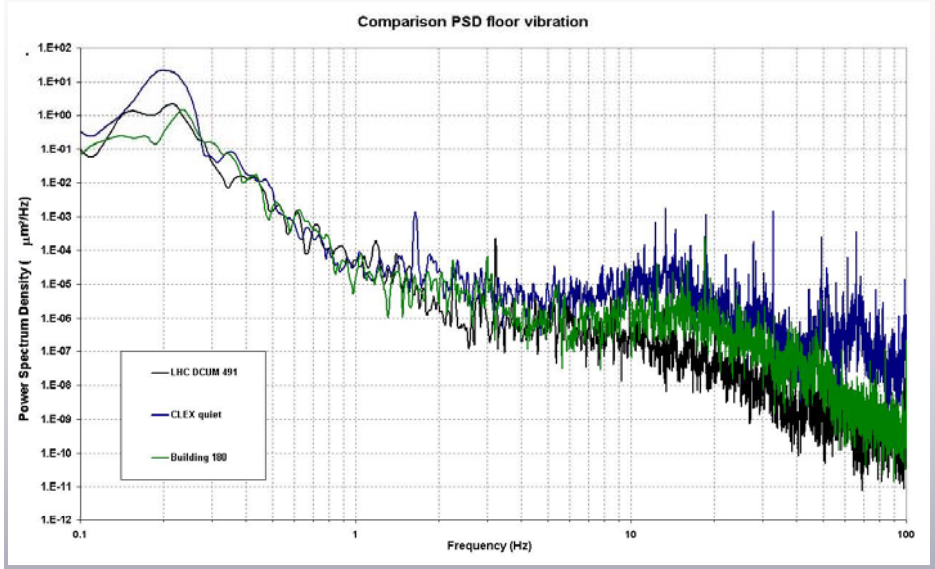
Vertical

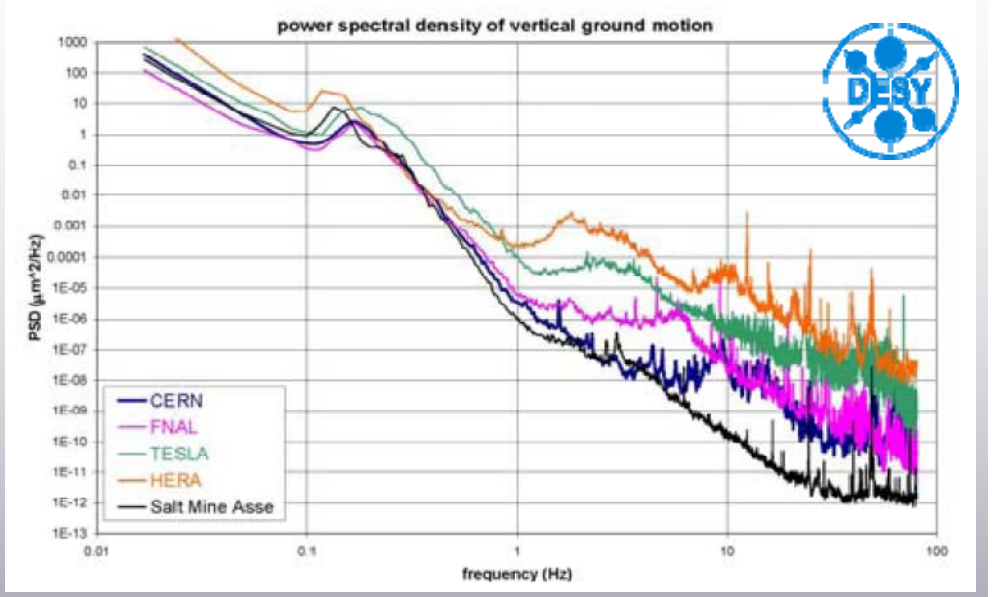


Power Spectral Density

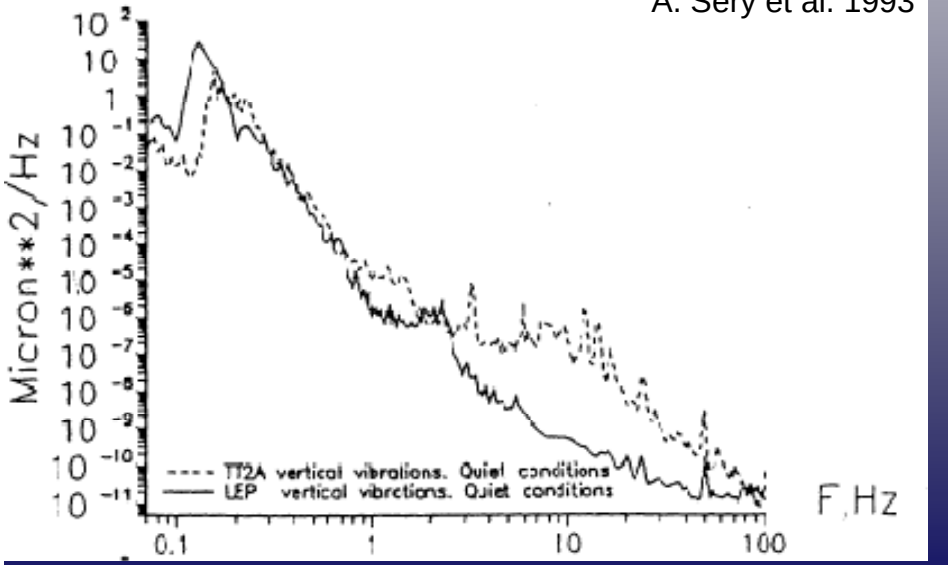


Power Spectral Density

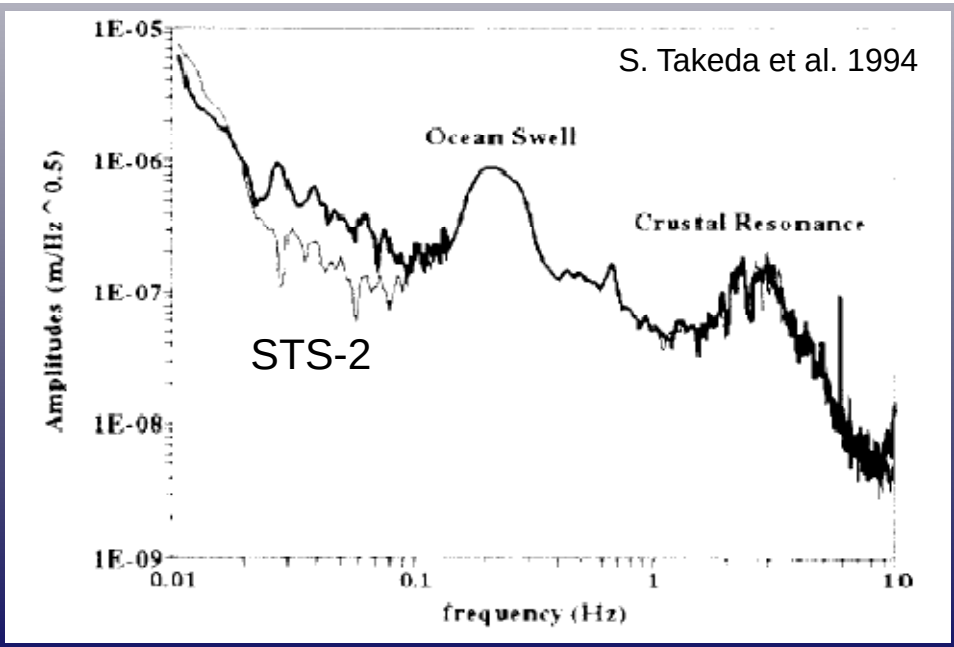




A. Sery et al. 1993

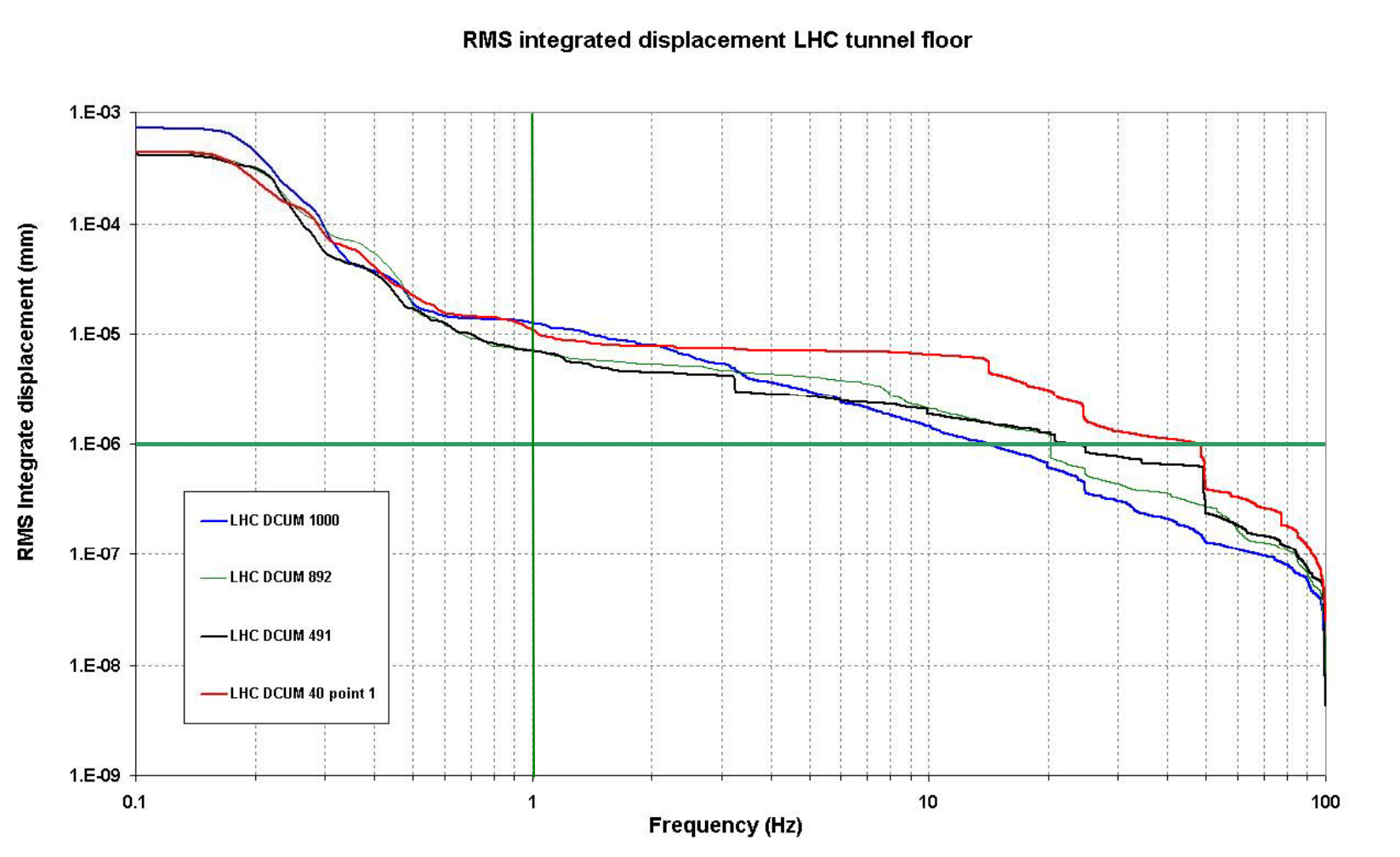


S. Takeda et al. 1994

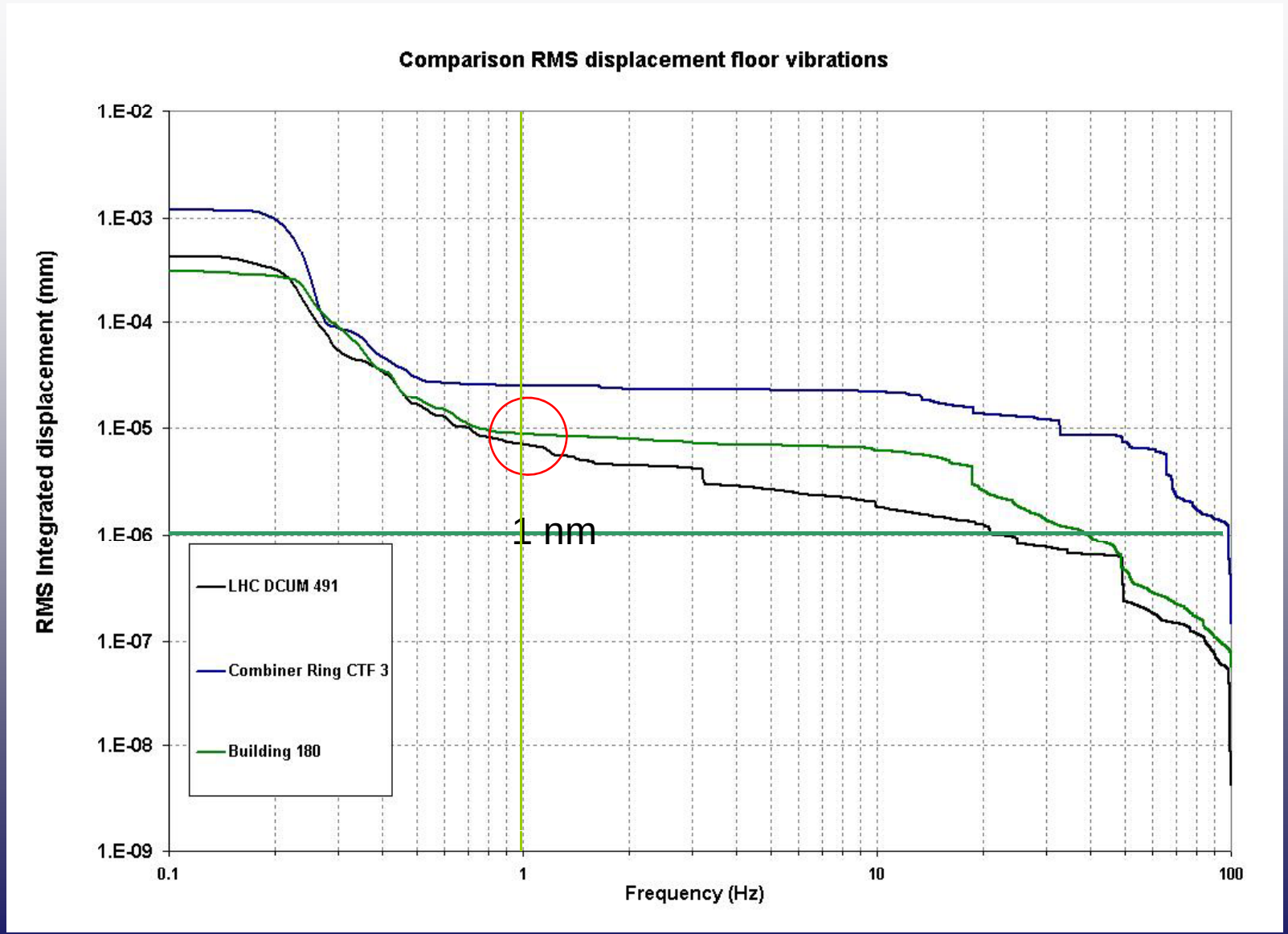


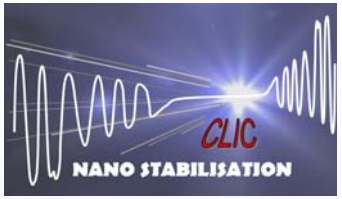
Integrated R.M.S. LHC Tunnel

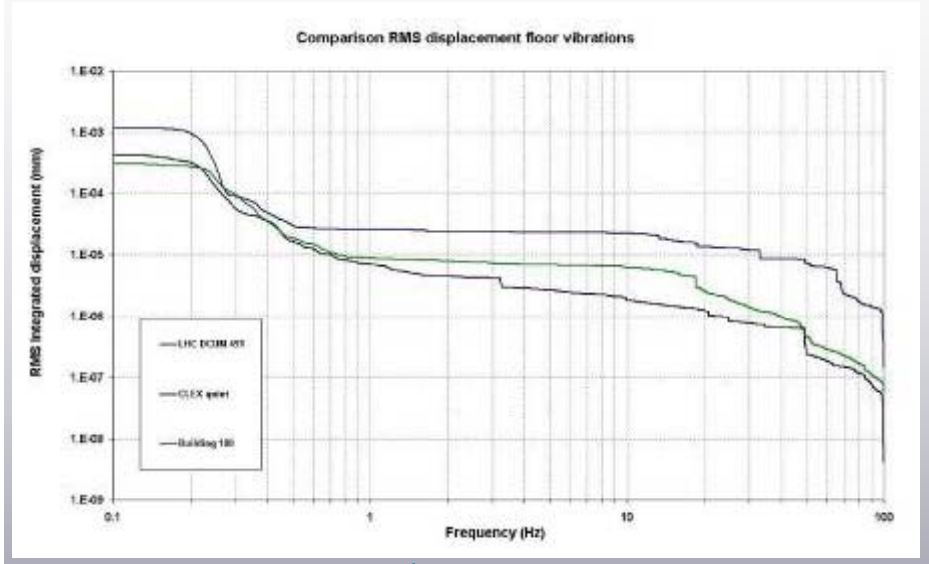
$$RMS_{\text{int}}(k) = \sqrt{\sum_{k1}^{k2} DSP(k).\Delta f}$$

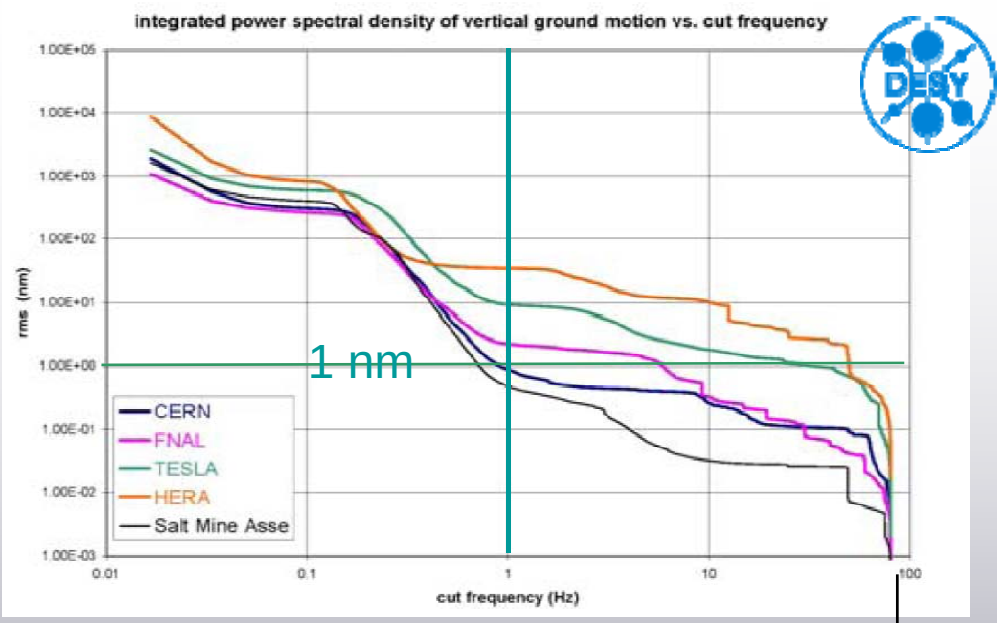


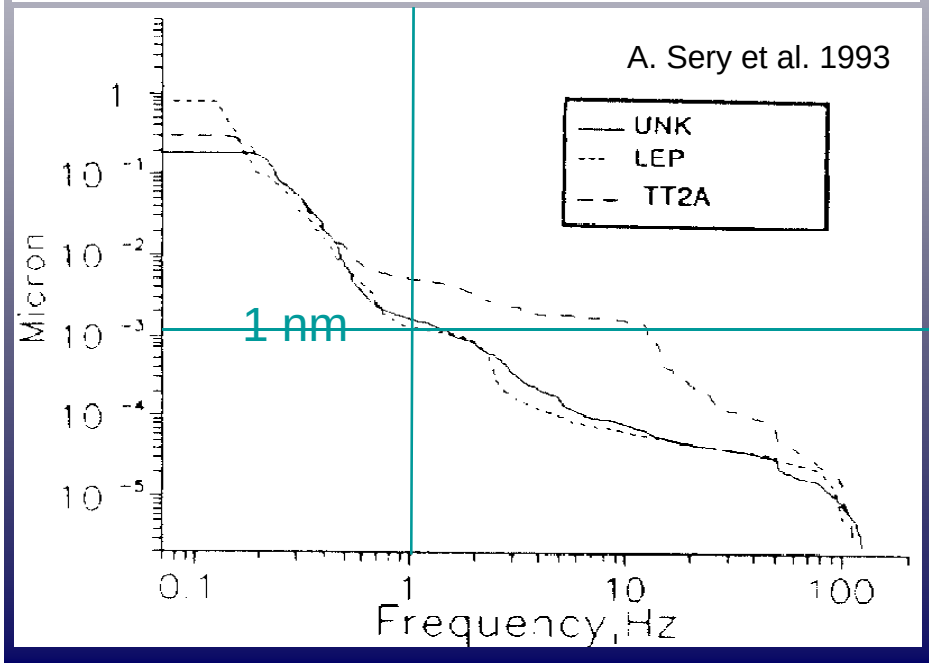
Integrated R.M.S.

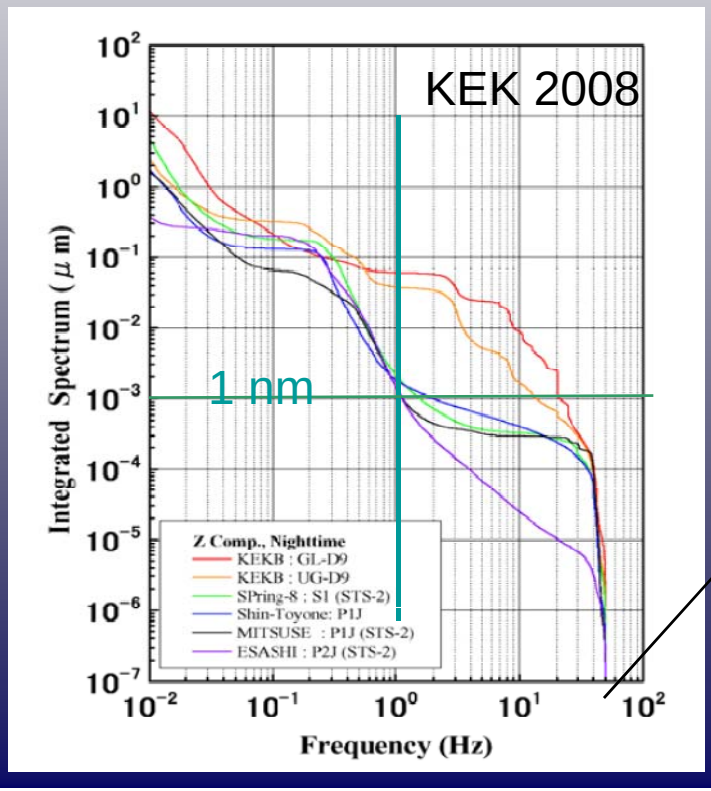



CLIC
NANO STABILISATION


Comparison RMS displacement floor vibrations
RMS integrated displacement (nm)
Frequency (Hz)


integrated power spectral density of vertical ground motion vs. cut frequency
rms (nm)
cut frequency (Hz)
1 nm
CERN
FNAL
TESLA
HERA
Salt Mine Asse

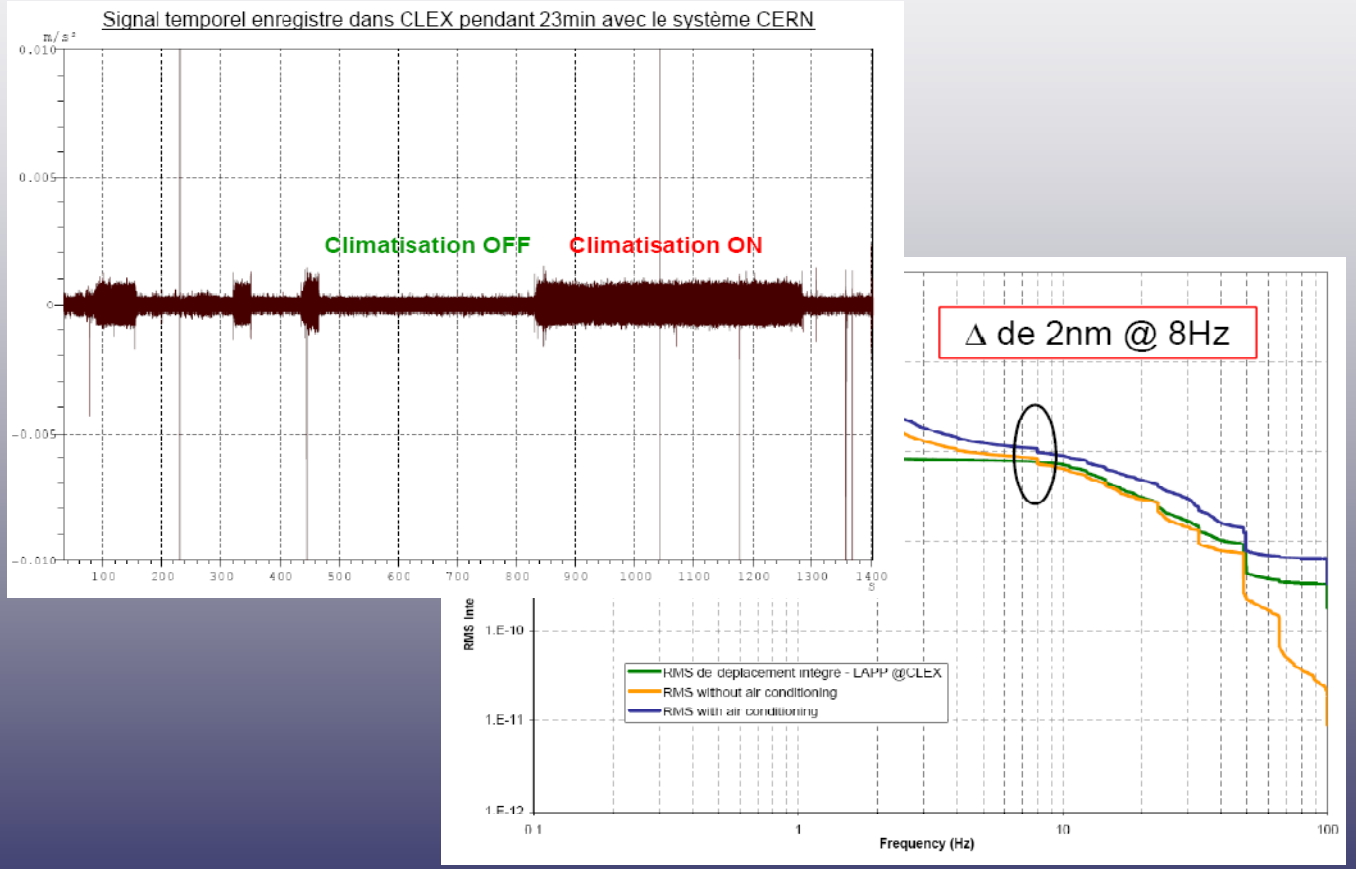

A. Sery et al. 1993
UNK
LEP
TT2A
1 nm
Micron
Frequency,Hz


KEK 2008
1 nm
Integrated Spectrum (μm)
Frequency (Hz)
Z Comp., Nighttime
KEKB : GL-D9
KEKB : UG-D9
SPring-8 : S1 (STS-2)
Shin-Toyone: P1J
MITSUSE : P1J (STS-2)
ESASHI : P2J (STS-2)

80 Hz

50 Hz

Example influence ventilation CLEX



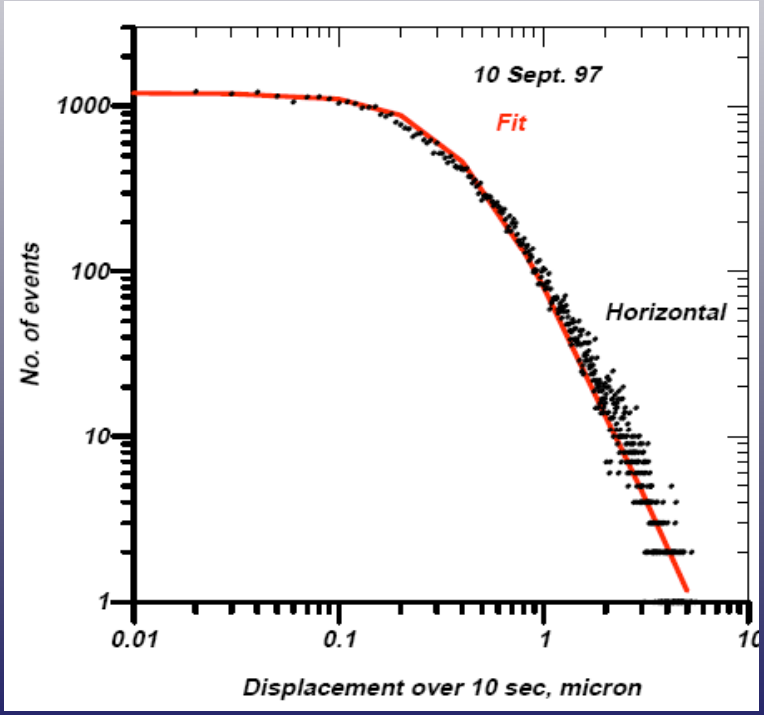
Averaging, window, histogram, color map

50 averages of 64 sec blocks with 66.7% overlap:

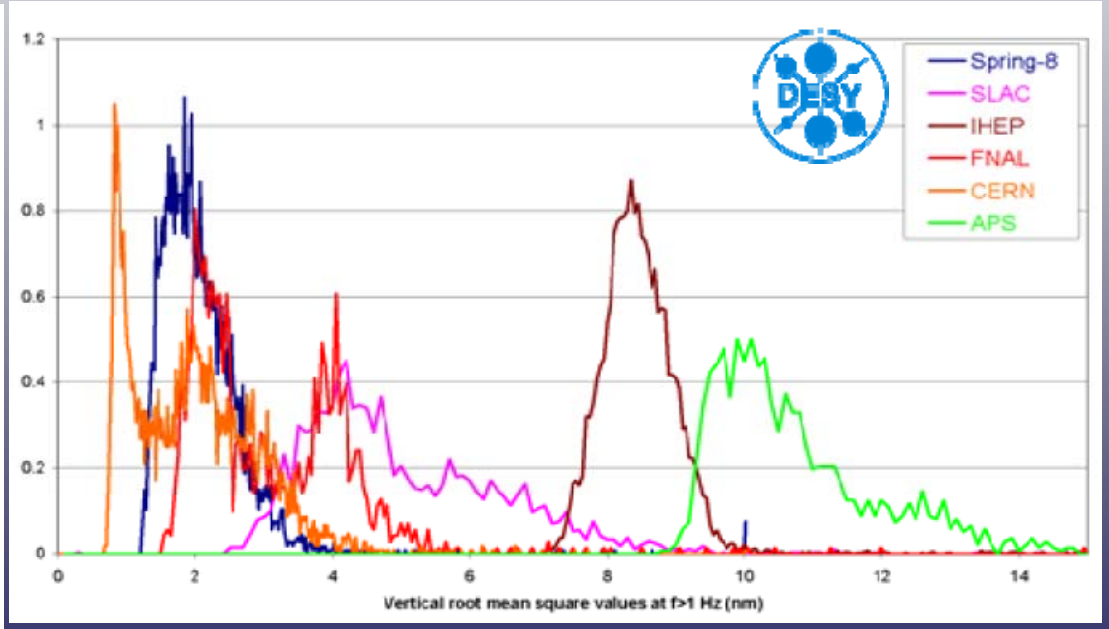
- To have a good frequency resolution + definition of PSD
- To “see” something within the noise

But: it’s an average view ⟶ Histogram

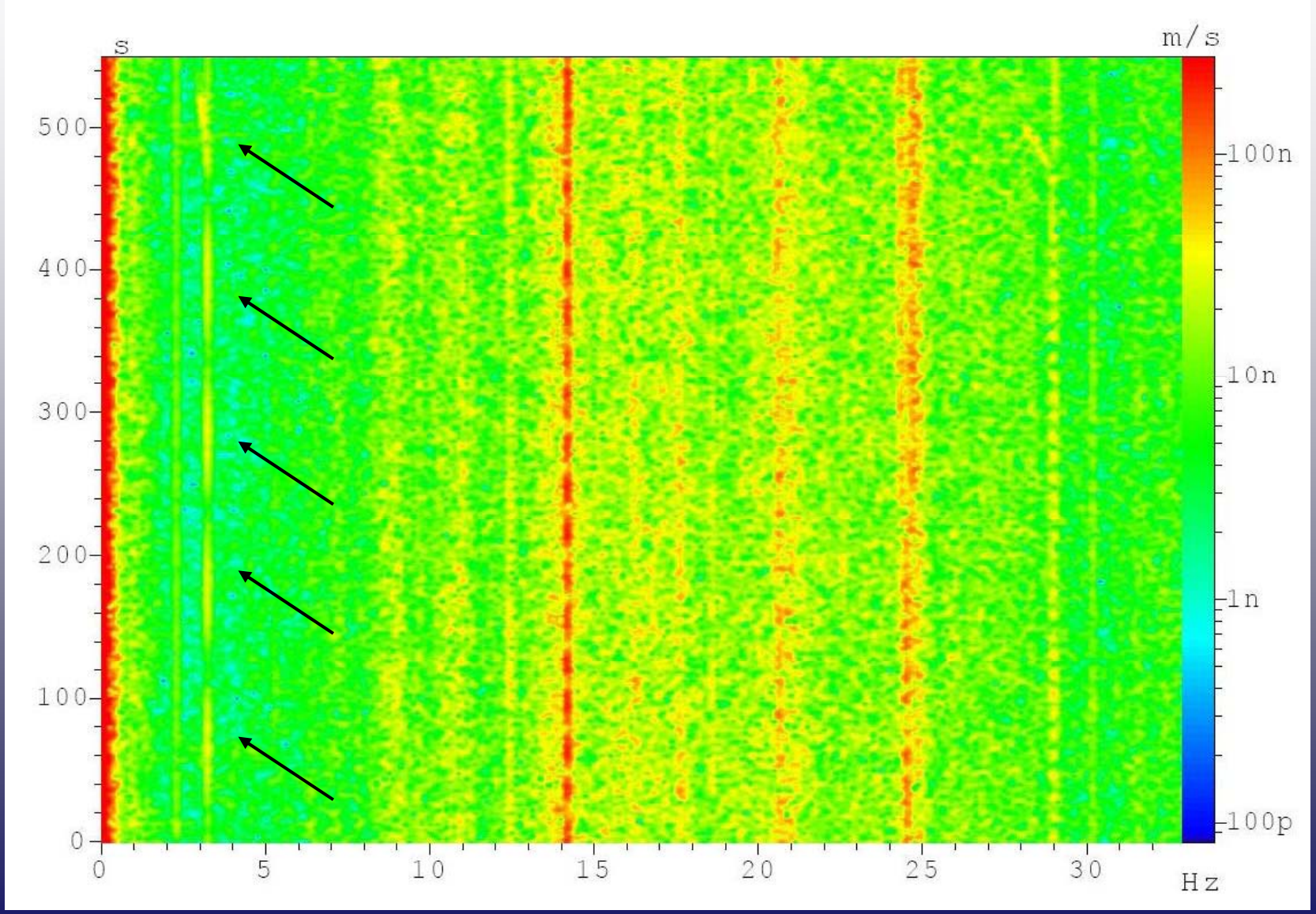
Baklakov, Shiltsev et al. Fermilab 1997



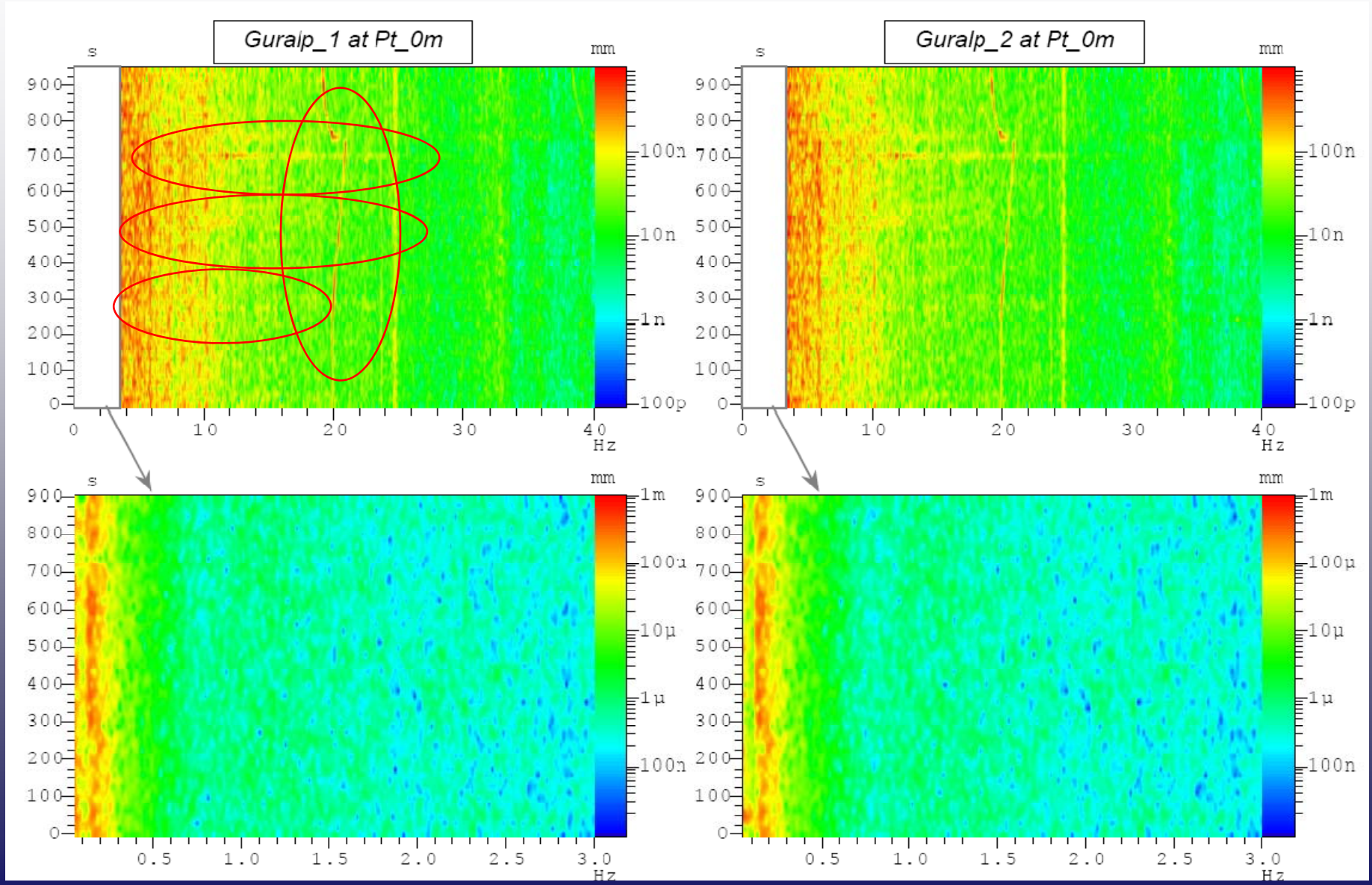
R.Amirikas, A. Bertolini DESY 2005



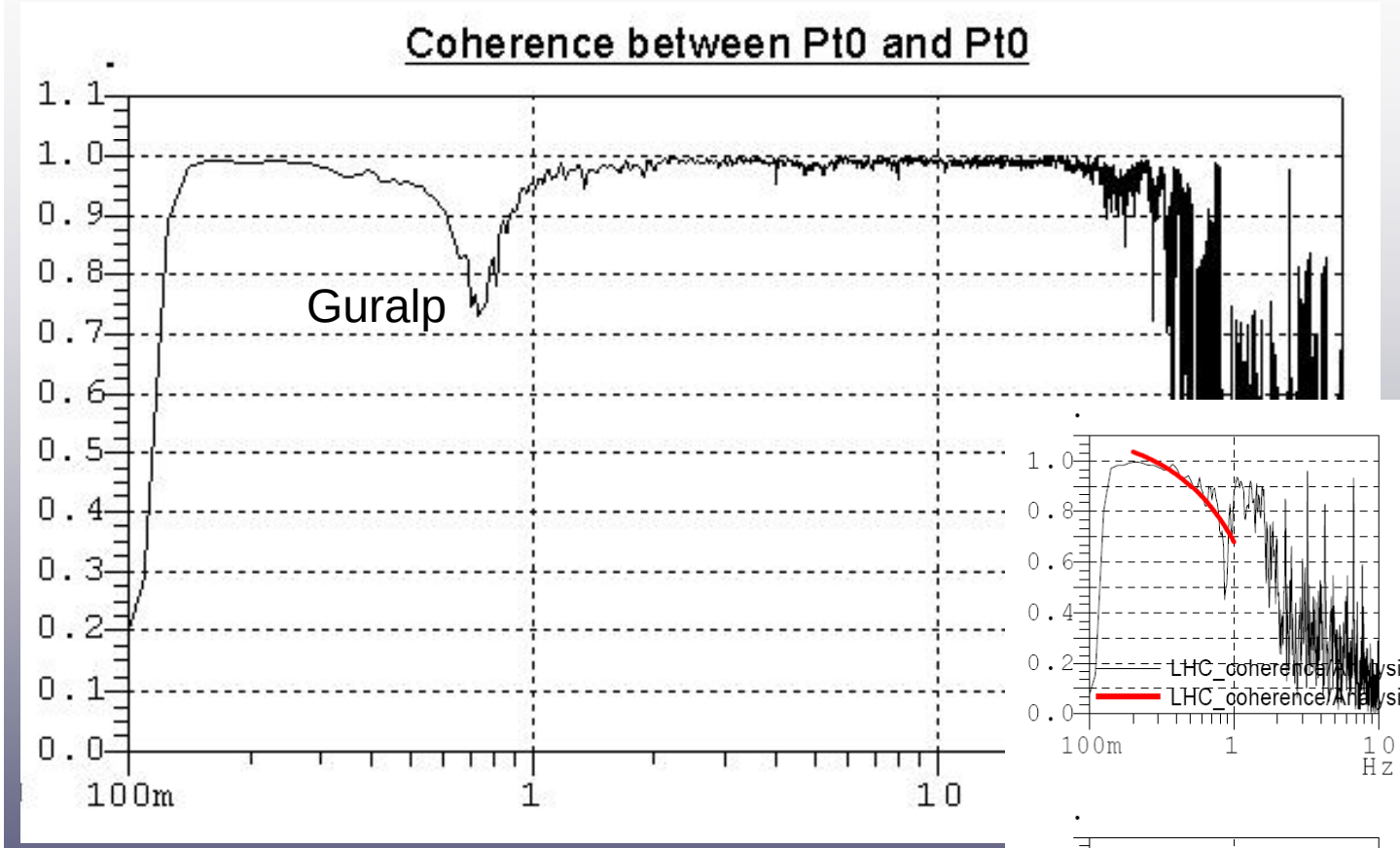
Color map

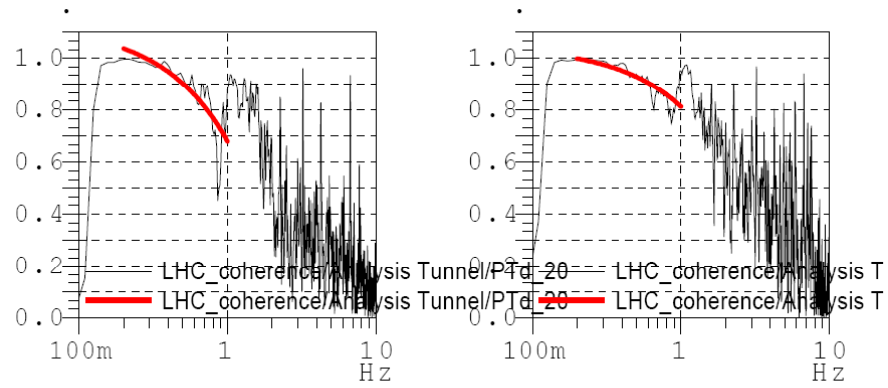


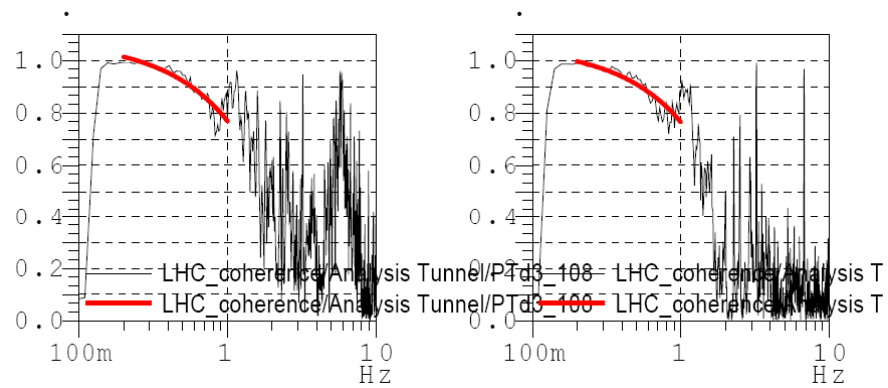
Color map


Guralp_1 at Pt_0m
Guralp_2 at Pt_0m
s
mm
Hz
100n
10n
1n
100p
1m
100µ
10µ
1µ
100n

Coherence measurements

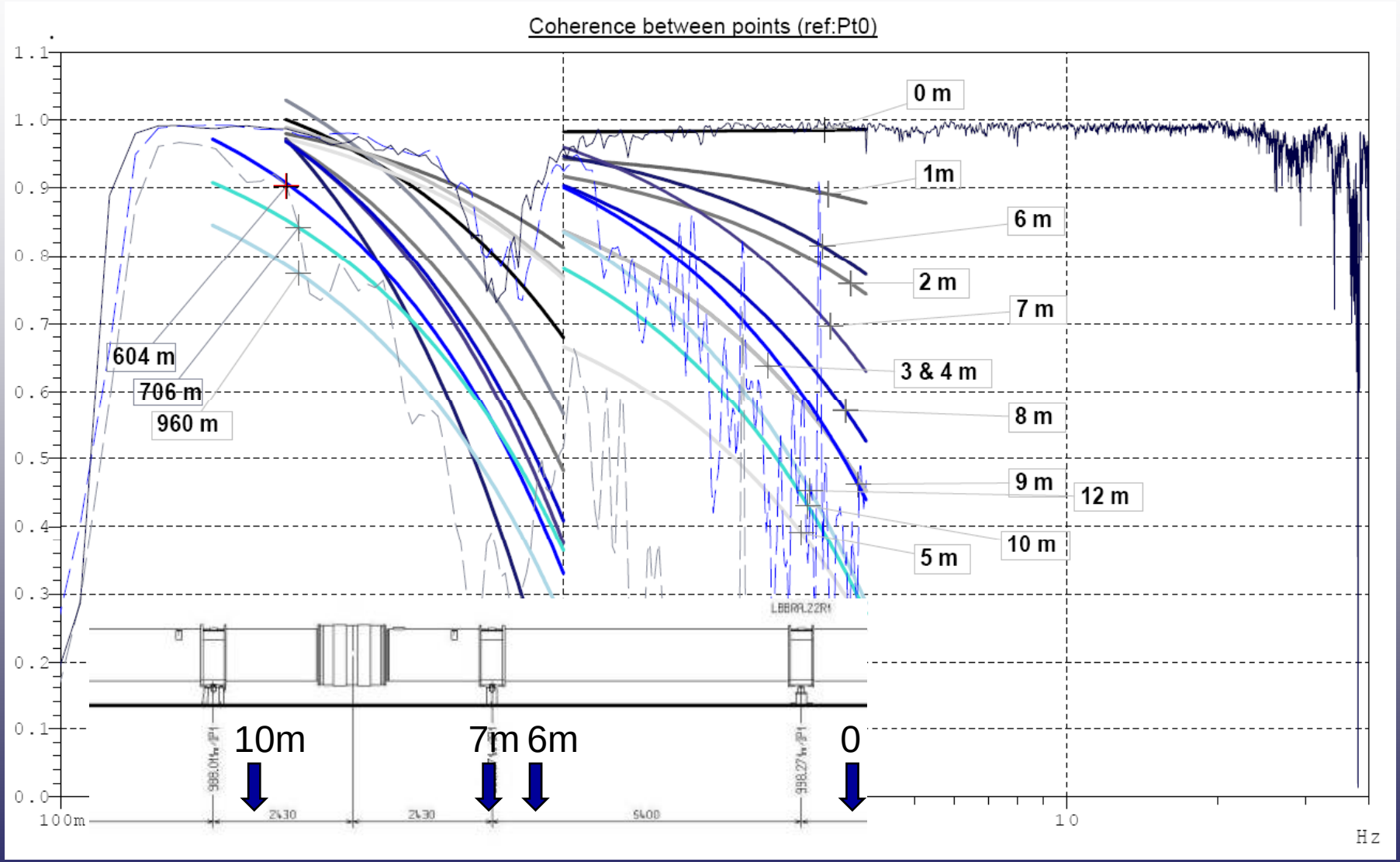






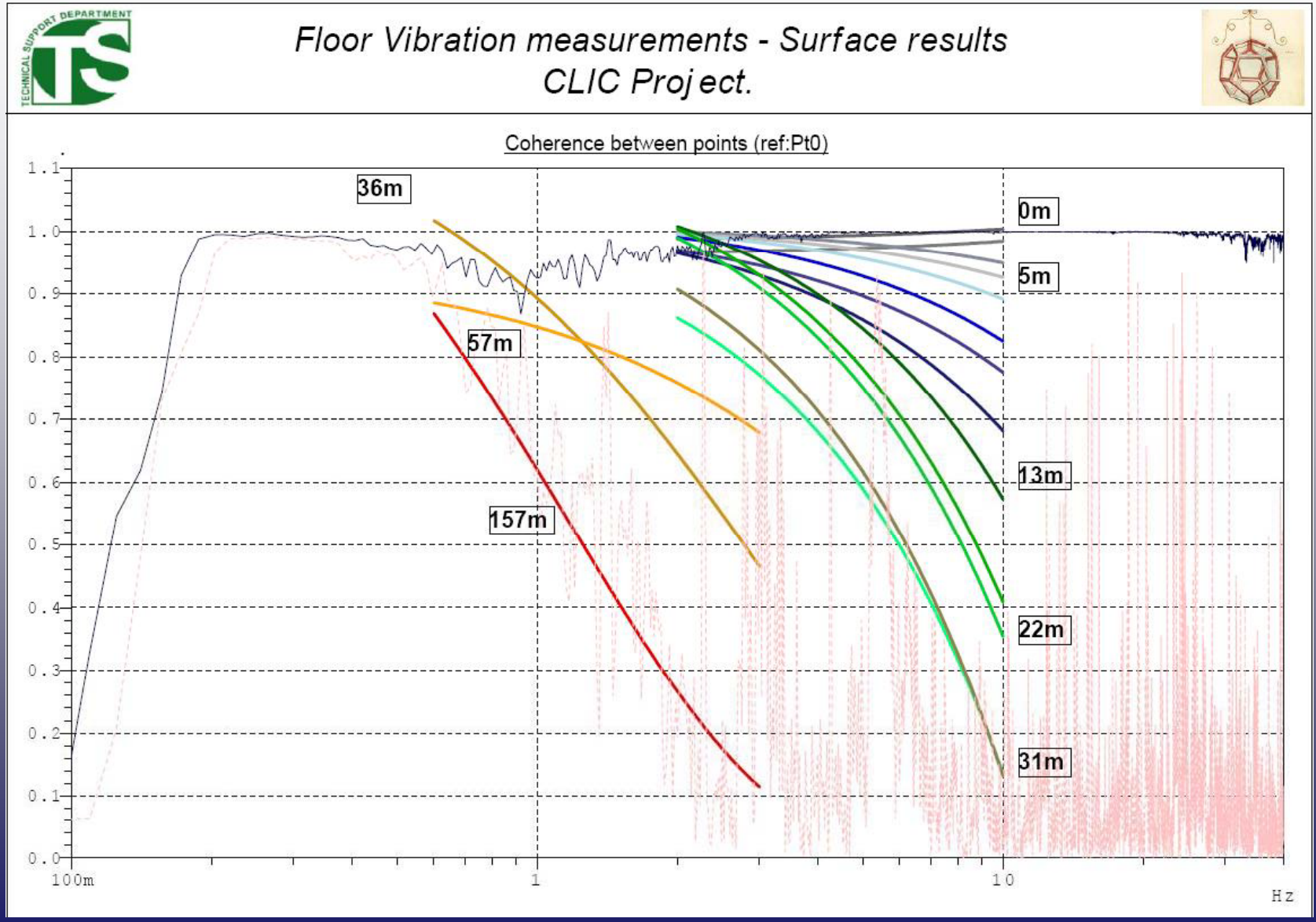
Regression and interpolation analyser software PAK

Coherence measurements LHC tunnel



Coherence measurements Surface Building 180

Floor Vibration measurements - Surface results
CLIC Project.

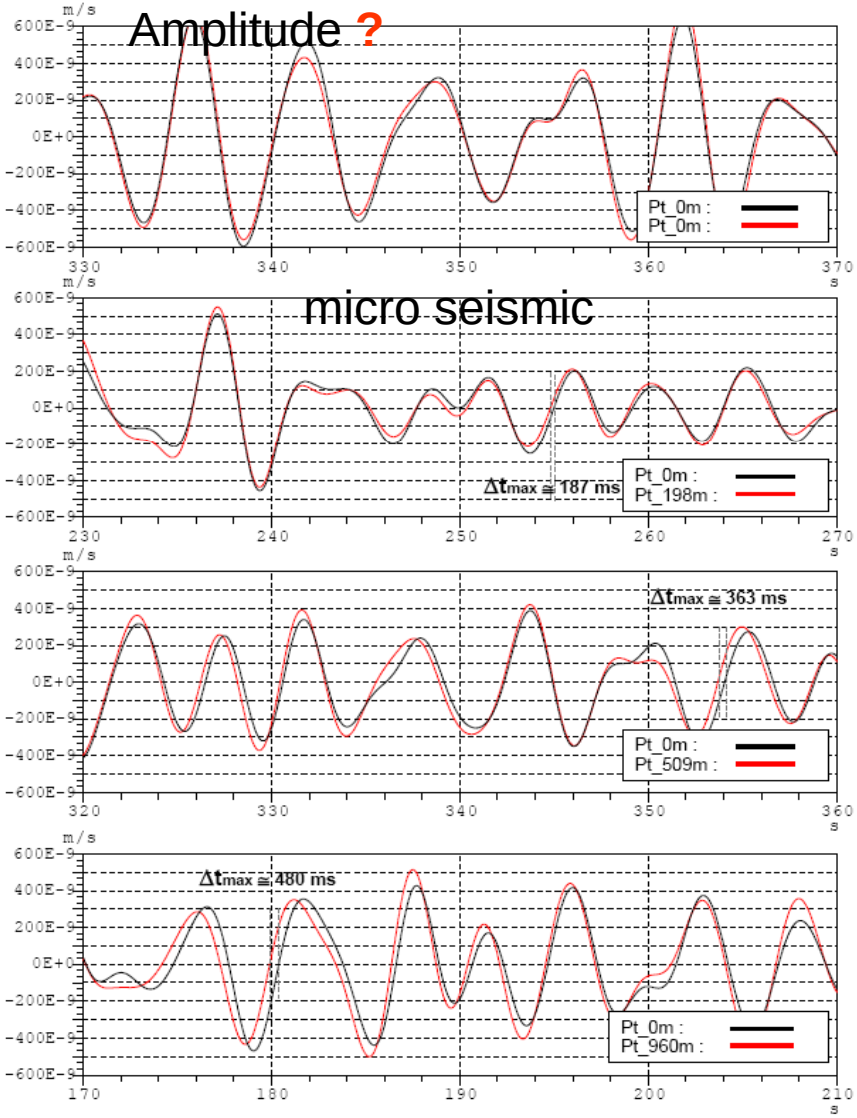


What can influence coherence measurements?

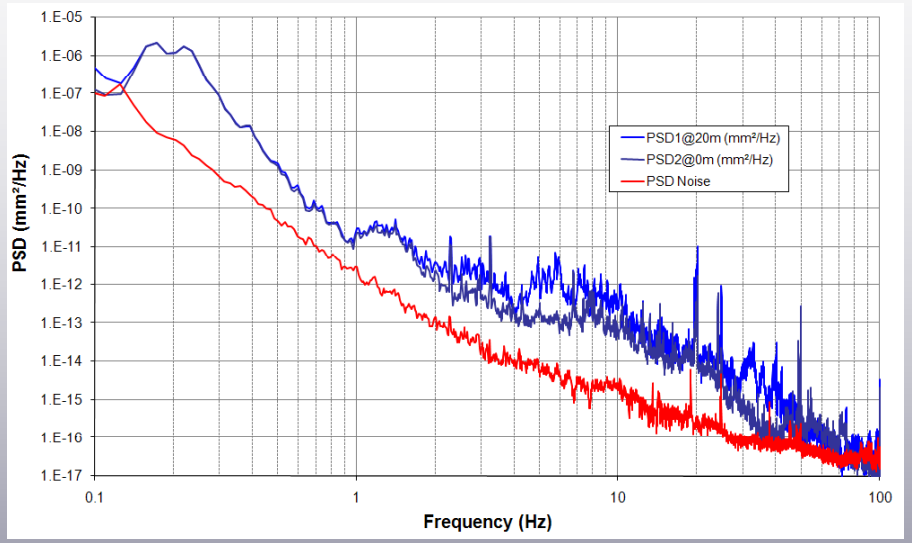
Phase shift

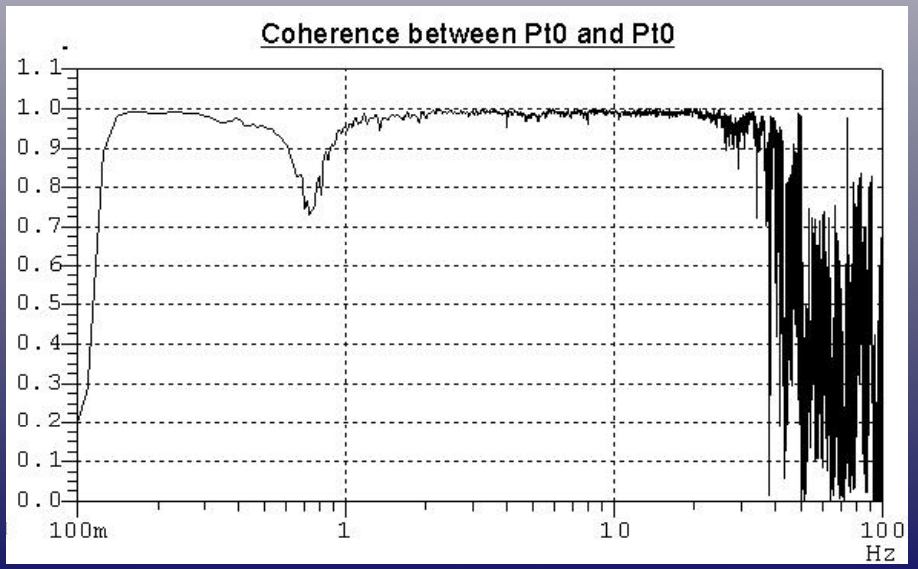
Amplitude ?

micro seismic



Low signal to noise ratio





Joints between concrete modules

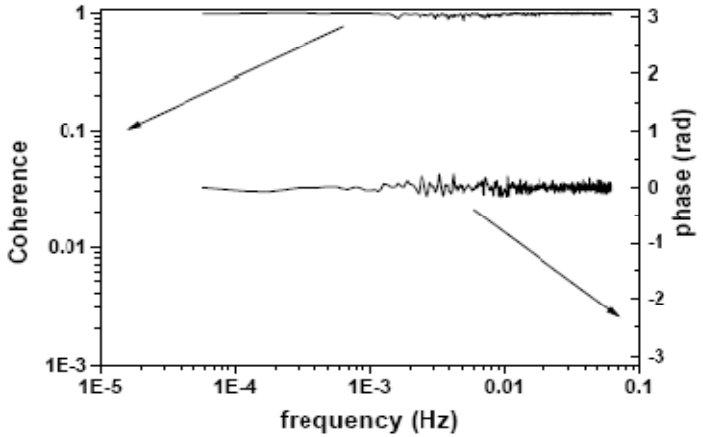


Figure 2: Coherence and phase difference between two sensors separated by 50 cm with no expansion joint.

S. Takeda et al. 1996

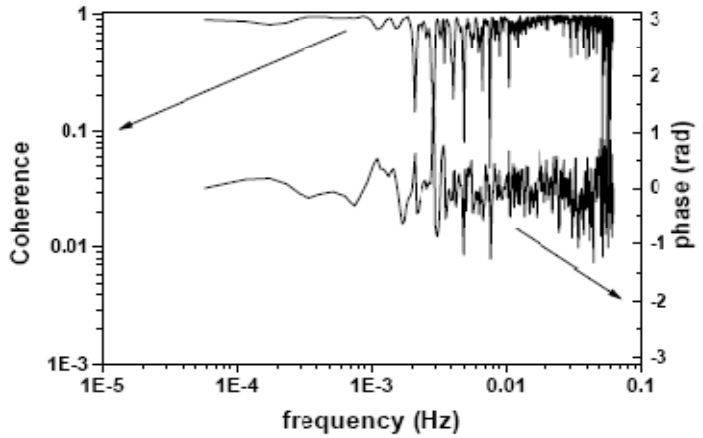
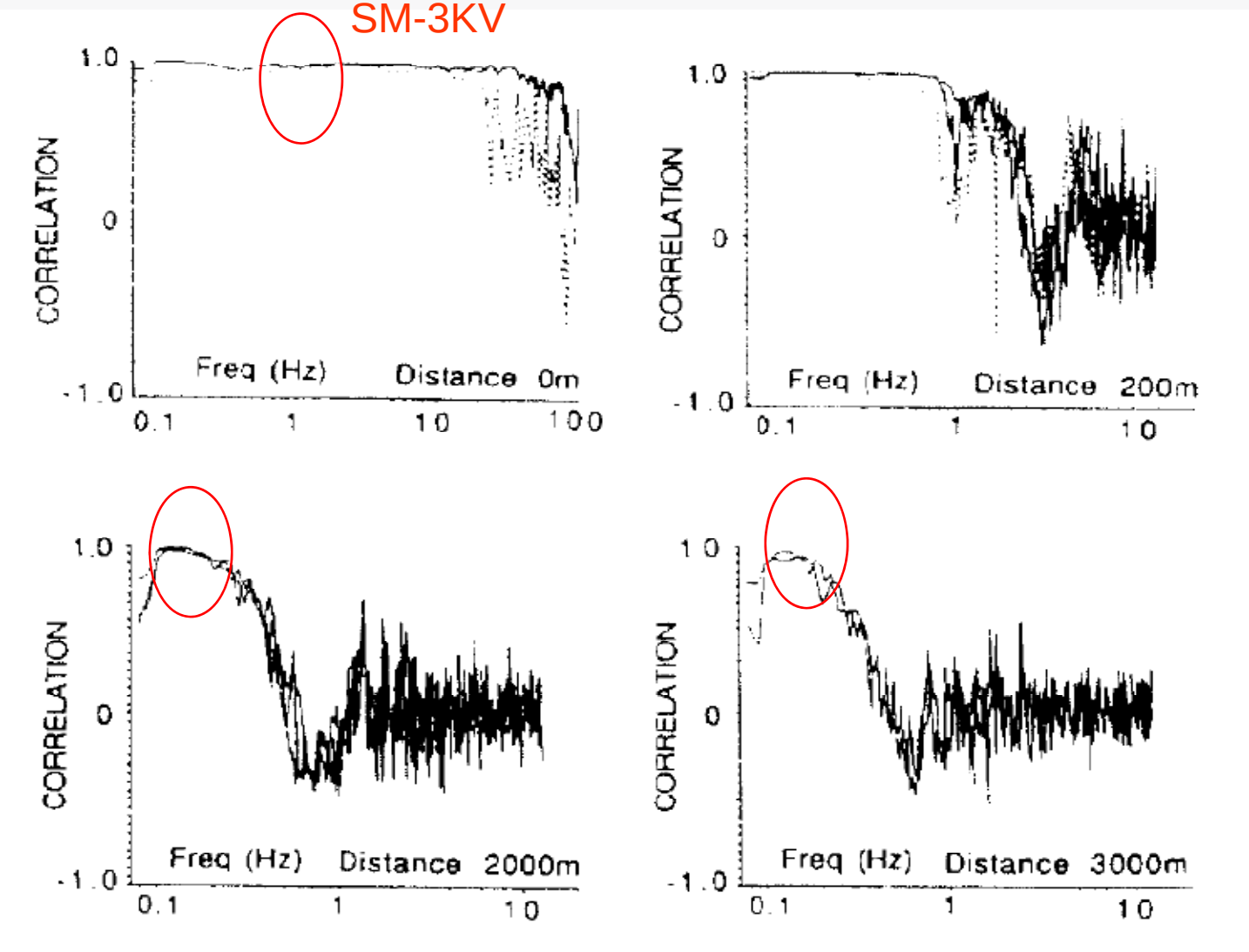


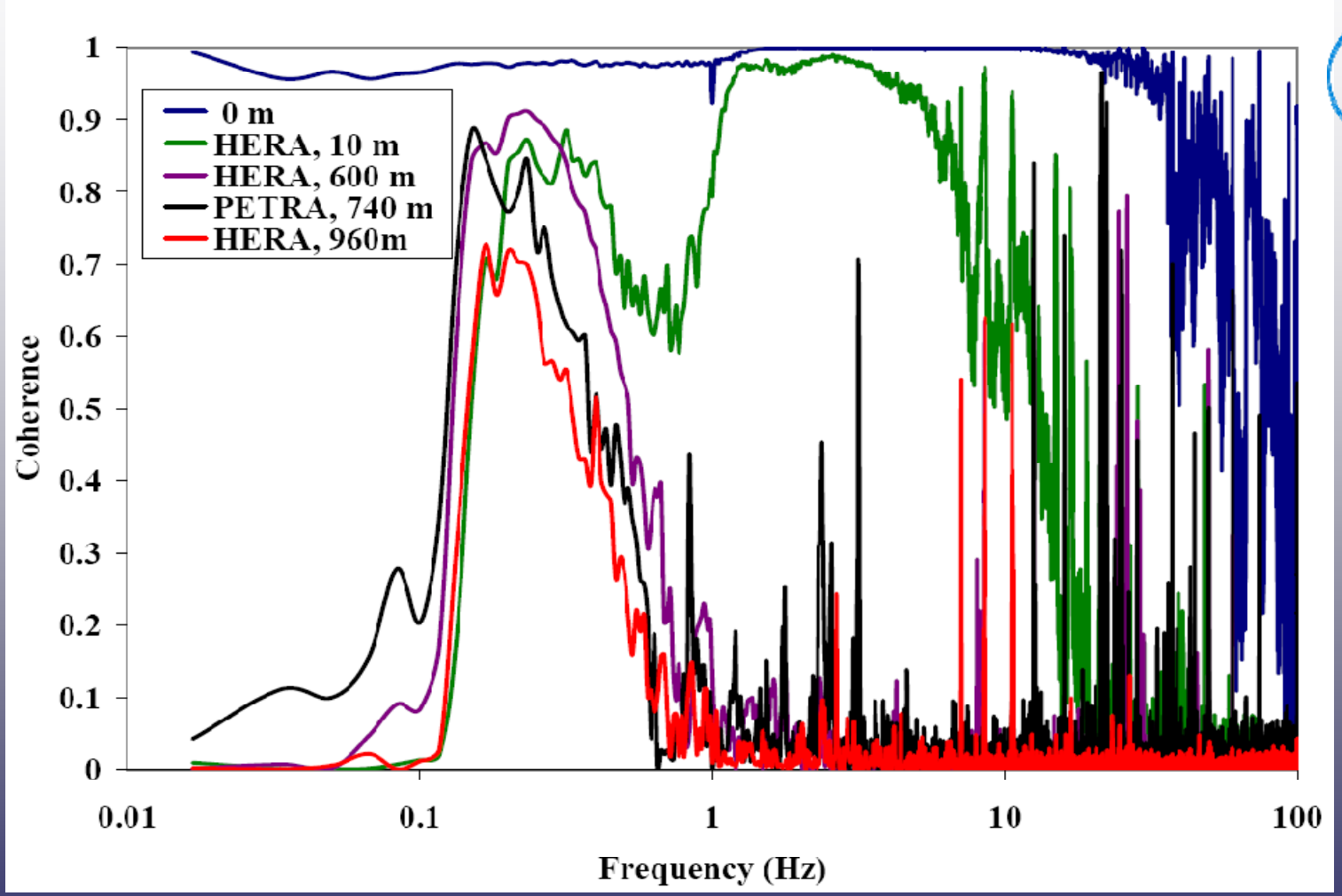
Figure 3: Coherence and phase difference between two sensors separated by 50 cm with an expansion joint.

Coherence: Comparison other measurements



A. Sery, Coosemans 1994 LEP

Coherence: Comparison other measurements

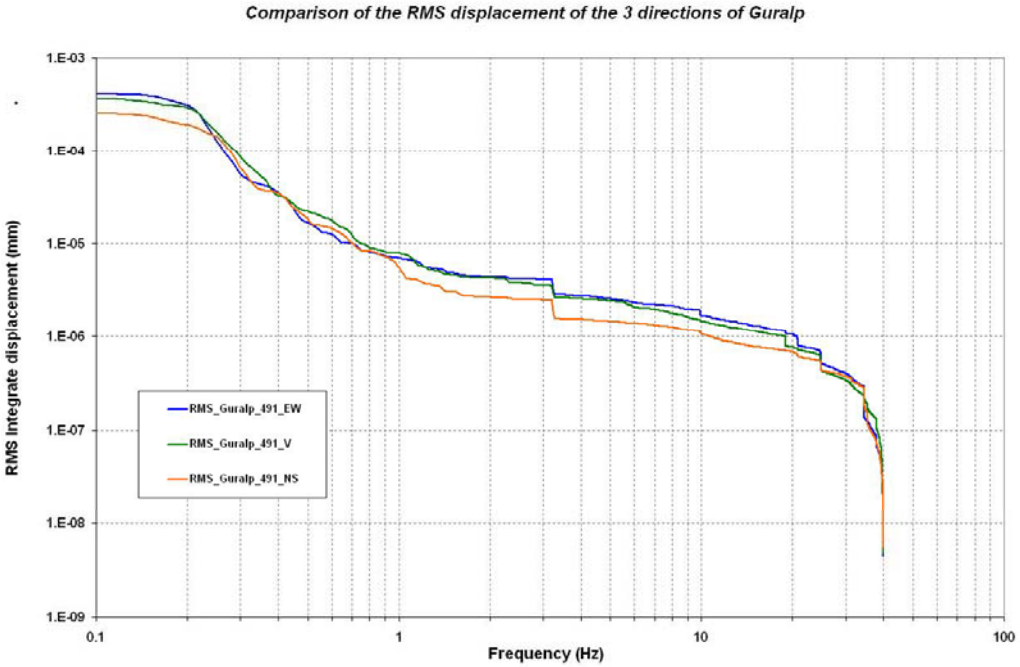


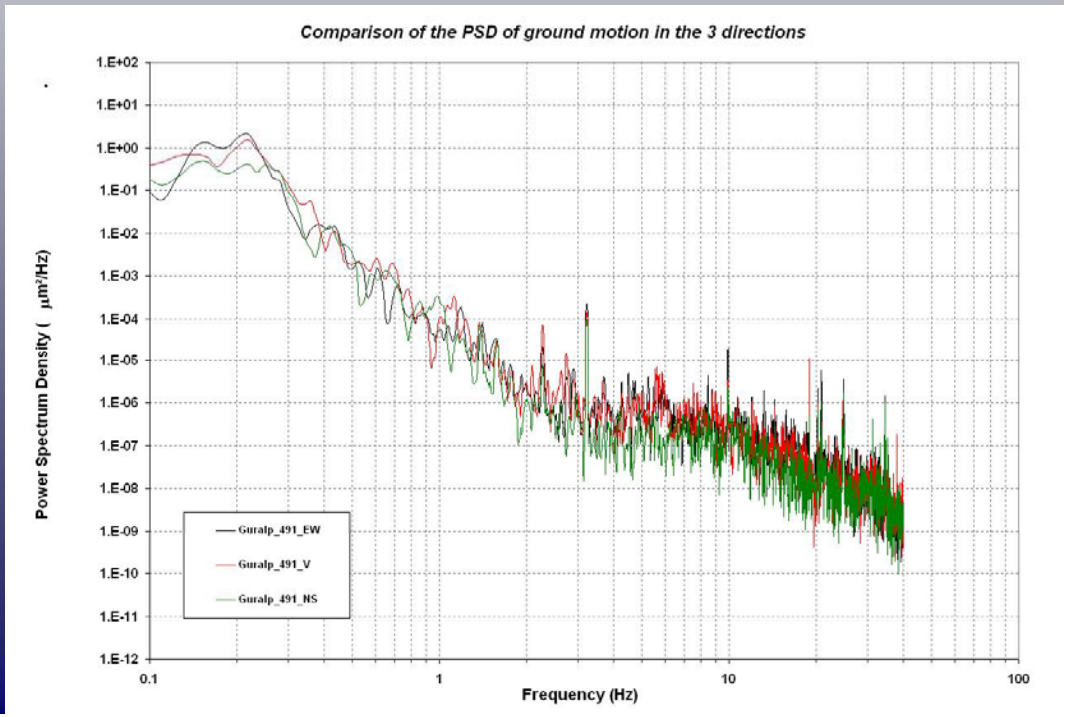
Conclusions

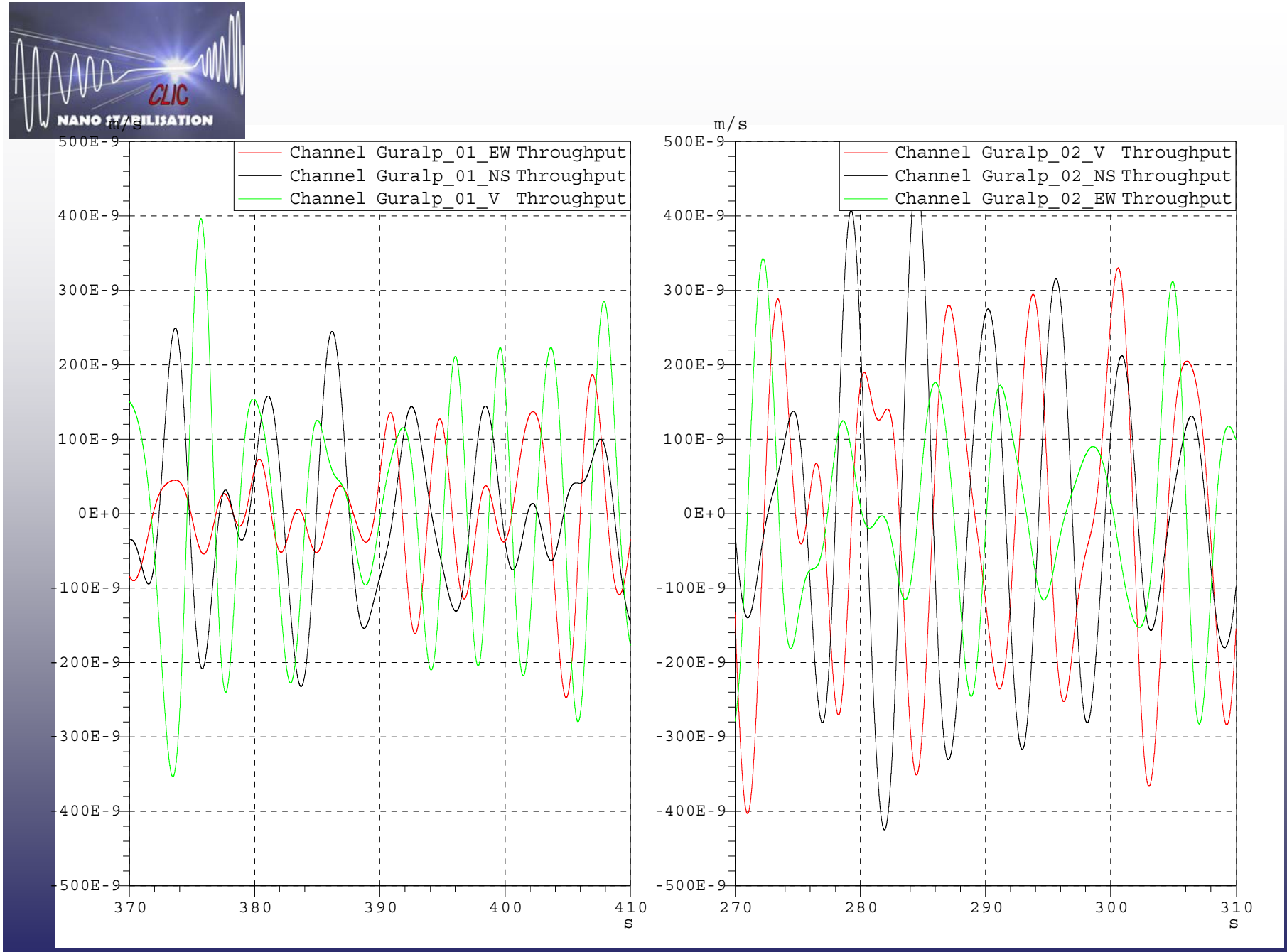
- Ground vibration level between 1 and 10 nm “average integrated RMS” at 1 Hz seems possible.
- Possible vibration sources like water cooling and ventilation should be carefully designed.
- Support or objects can amplify the ground vibration levels
- The ground vibration level can be increased by the resonance of a support or object
- For frequencies > 1Hz, coherence drops over a short distance

- It is possible to measure (averaged) nanometre displacements with seismometers but some characterisation of devices and analysis methods is still needed.
- Seismometers with better signal to noise ratio are needed for active control purposes.

Spares


Comparison of the RMS displacement of the 3 directions of Guralp
RMS Integrate displacement (mm)
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
1.E-08
1.E-09
0.1
1
10
100
Frequency (Hz)
RMS_Guralp_491_EW
RMS_Guralp_491_V
RMS_Guralp_491_NS


Comparison of the PSD of ground motion in the 3 directions
Power Spectrum Density (µm²/Hz)
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
1.E-08
1.E-09
1.E-10
1.E-11
1.E-12
0.1
1
10
100
Frequency (Hz)
Guralp_491_EW
Guralp_491_V
Guralp_491_NS


m/s
500E-9
400E-9
300E-9
200E-9
100E-9
0E+0
-100E-9
-200E-9
-300E-9
-400E-9
-500E-9
370
380
390
400
410
s
Channel Guralp_01_EW Throughput
Channel Guralp_01_NS Throughput
Channel Guralp_01_V Throughput
m/s
500E-9
400E-9
300E-9
200E-9
100E-9
0E+0
-100E-9
-200E-9
-300E-9
-400E-9
-500E-9
270
280
290
300
310
s
Channel Guralp_02_V Throughput
Channel Guralp_02_NS Throughput
Channel Guralp_02_EW Throughput