Vibration measurements for civil engineering activities

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on behalf of the Mechanical Measurement Lab (EN-MME)
with contributions from many people from integration, civil engineering team,…

CERN – 16 July 2015

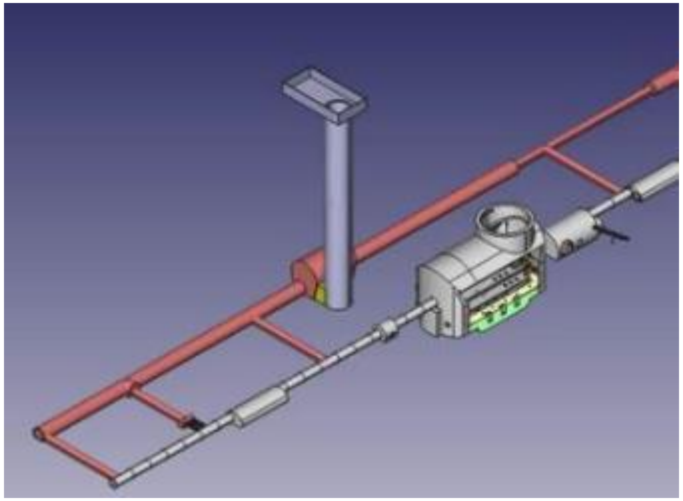
The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Motivations

- This study was requested for two main reasons :
  - HL-LHC : Estimate the vibration effects during civil engineering activities?
  - Geneva Program "Géothermie 2020", to be able to evaluate the sensitivity of CERN's installation from potential drilling or jetting?

Contents

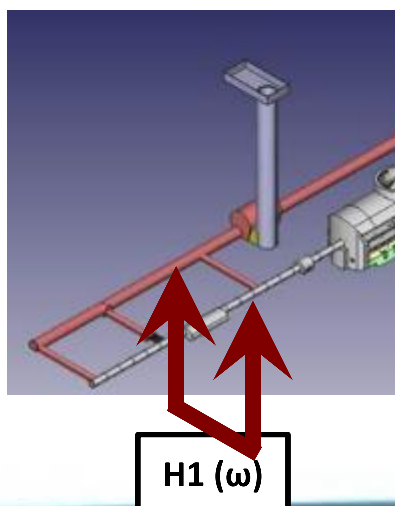
- Introduction
- Dynamic behaviour of triplet magnets (Q1)
- Vibration propagation between tunnels
- Conclusion

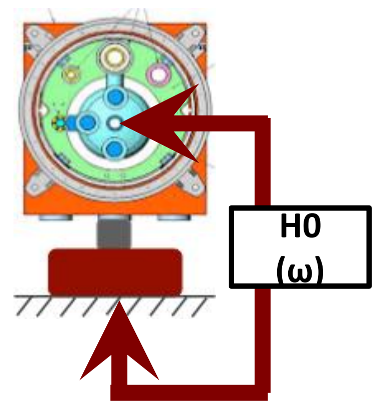


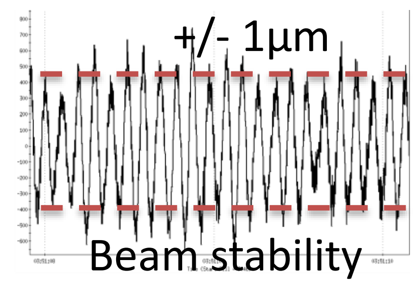
Introduction

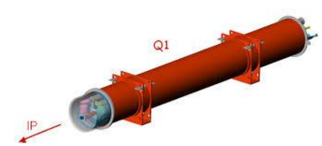
- How measurements can help ?
  - To give a magnitude order of vibration effects;
  - Sensibility study of the system – transfer functions:

In (ω) — H_1 (ω) — H_0 (ω) — Out (ω)









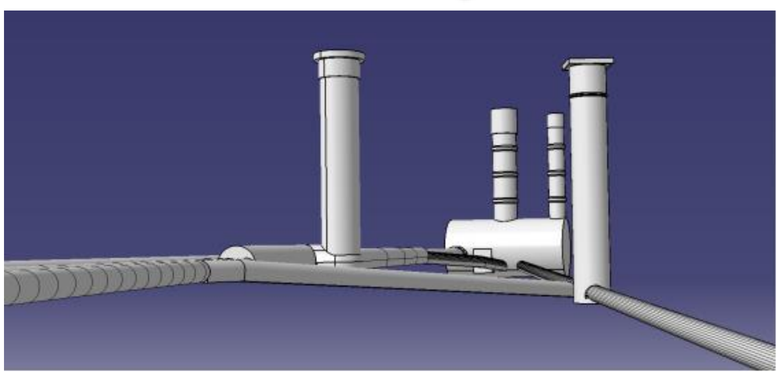
Introduction

- How measurements can help ?

In (ω) — $H_1(\omega)$ — $H_0(\omega)$ — Out (ω)

Measurements done in AWAKE area (TAG41/TT41)

Measurements done at SM18 with Q1 triplet spare



Introduction

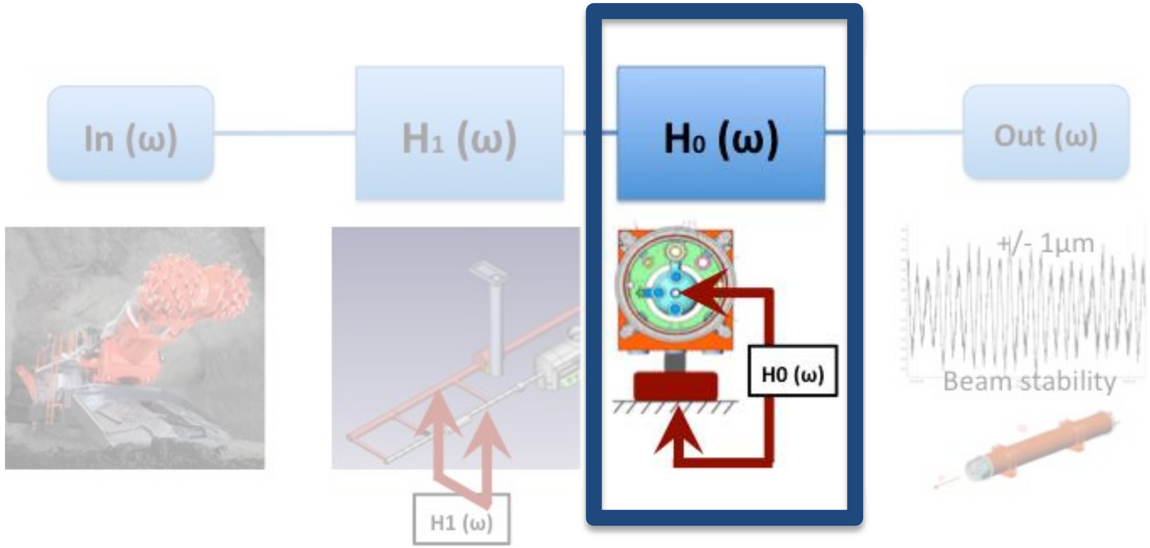
- Equipment for vibration measurements
  - Seismic geophones (Velocity) :
    - CMG-T60-0004 from Guralp Systems
    - Three directions measurements
    - Sensitivity of 2000 [V/(m/s)], Bandwidth 30 [s] to 100 [Hz]

  - Seismic accelerometers (Acceleration) :
    - Mono axial measurements
    - Sensitivity of 1 [V/(m/s^2)], Bandwidth 0.1 to 200 [Hz]

Introduction

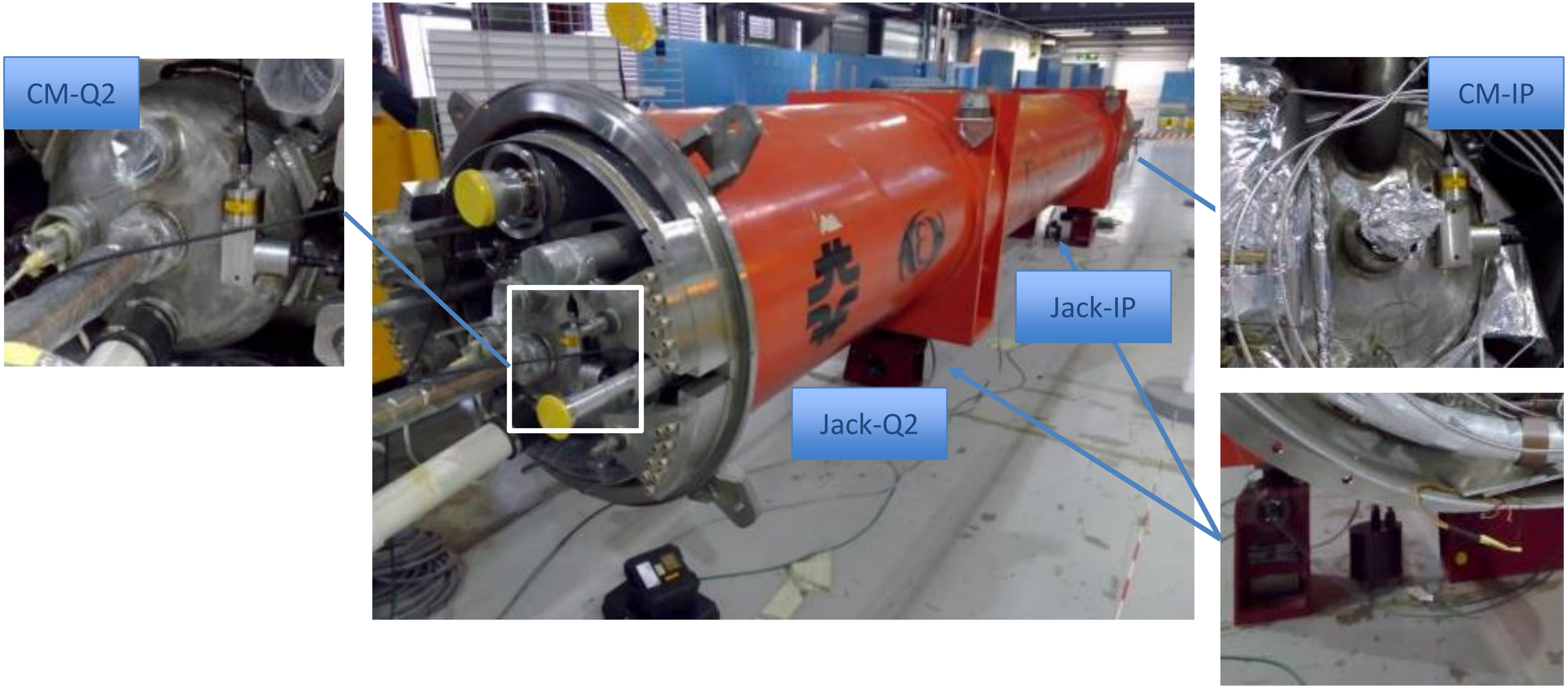
- Equipment for vibration measurements
  - Spectrum analyzer (DAQ) :
    - Two MKII® analysers of 16 channels, 24-bit resolution, 204.8 kSa/s sampling rate
    - Synchronous vibration measurements up to several kms done by **optical fibre connection**
    - Phase shift below 0.1° on the bandwidth between two spectrum analyser

H_0 (ω) Results

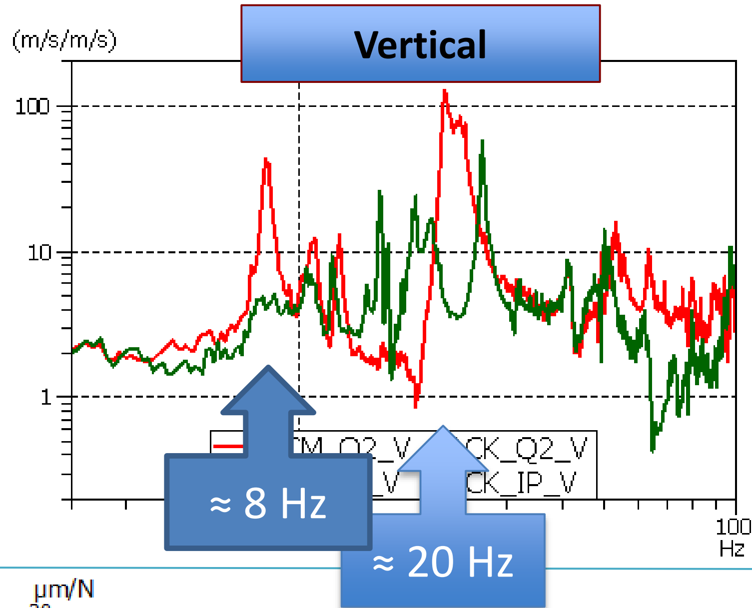


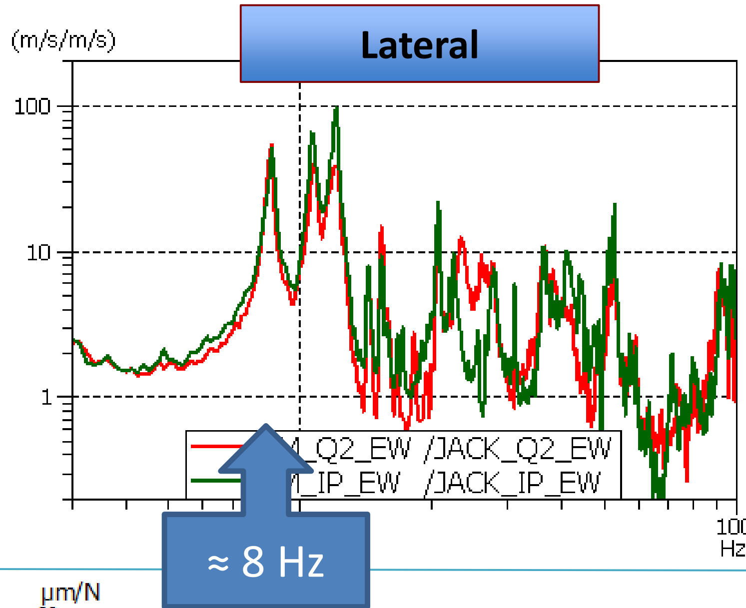
Instrumentation of Q1

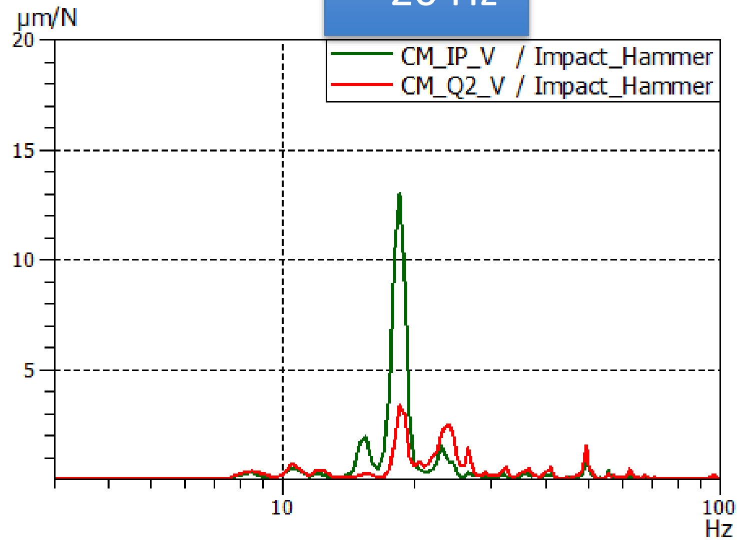
- Q1 spare magnet installed in stand alone at SM18

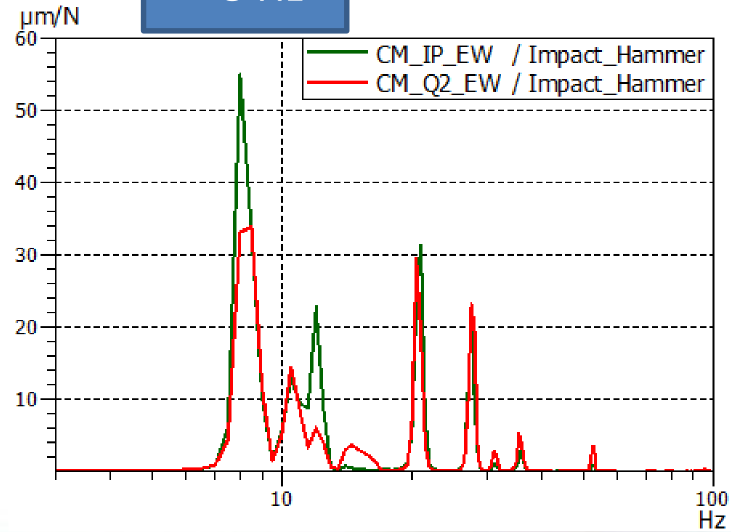


Results H0 (ω)


(m/s/m/s)
Vertical
100
10
1
100
Hz
≈ 8 Hz
≈ 20 Hz


(m/s/m/s)
Lateral
100
10
1
100
Hz
≈ 8 Hz


μm/N
20
15
10
5
CM_IP_V / Impact_Hammer
CM_Q2_V / Impact_Hammer
10
100
Hz


μm/N
60
50
40
30
20
10
CM_IP_EW / Impact_Hammer
CM_Q2_EW / Impact_Hammer
10
100
Hz

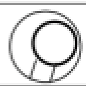
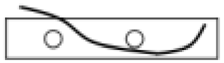
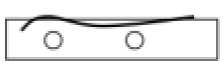
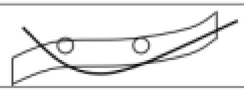
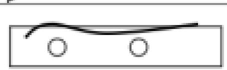
Comparison SSS vs Q1

LHC-CRI Technical Note 2002-06
EDMS No: 347269
2002-07-30
Kurt.Artoos@cern.ch

Experimental modal analysis and acceleration measurements during transport of a LHC Short Straight Section

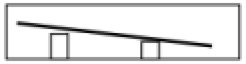
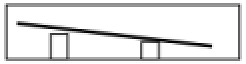
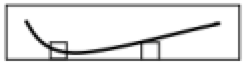
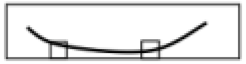
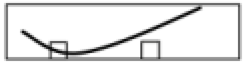
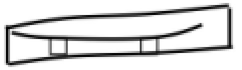
K. Artoos (EST/ME), O. Capatina (LHC/CRI)

Table 1 – Lateral modes of SSS5, with and without transport restraints

Mode	Modal shape	Frequency (Hz)	
		Without restraints	**With** restraints
Lateral 1		7	[illegible]
Lateral 2		12	14
Lateral 3		14	15
Lateral 4		29	29
Lateral 5		40	40
Lateral 6		46	/
Lateral 7		54	55

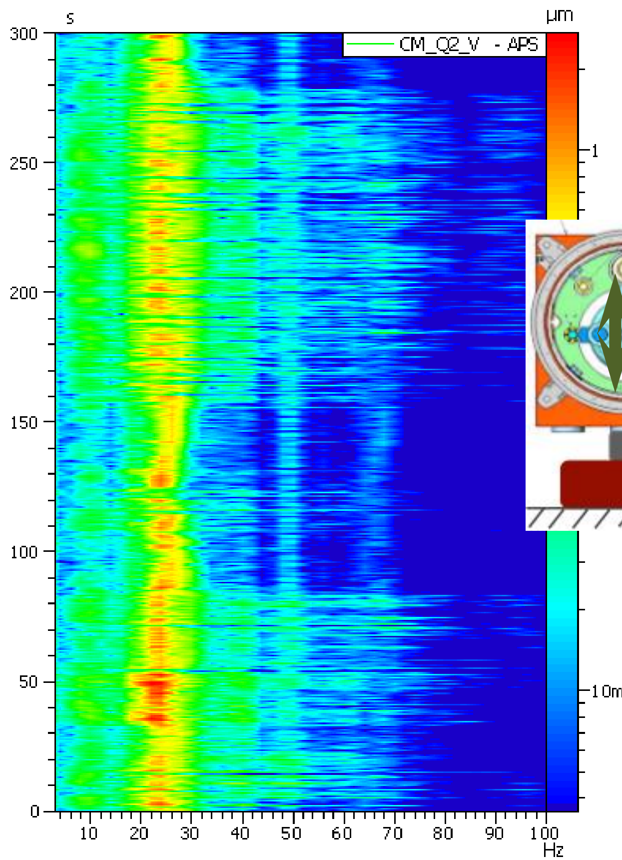
8 Hz for Q1

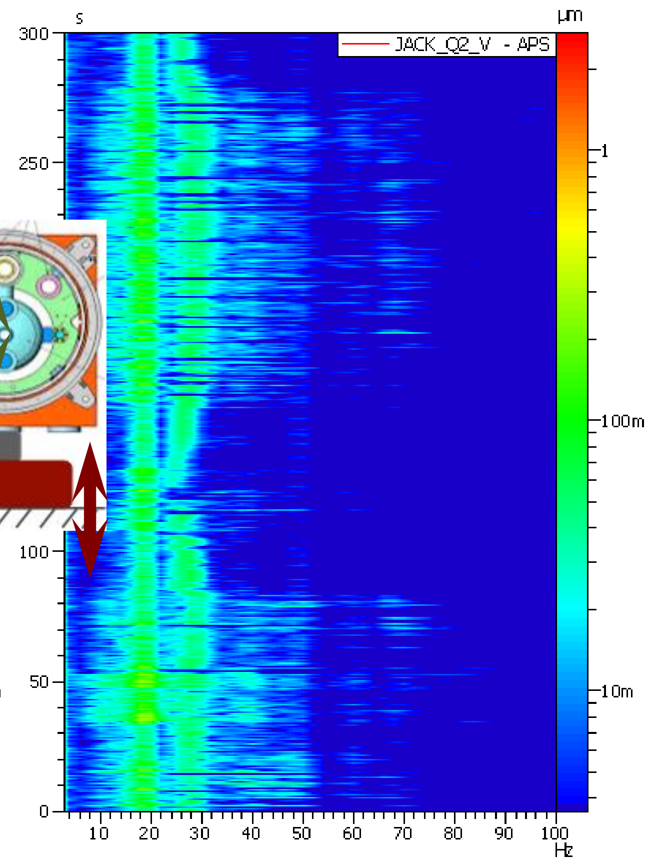
Table 2 - Vertical modes of SSS5, with and without transport restraints

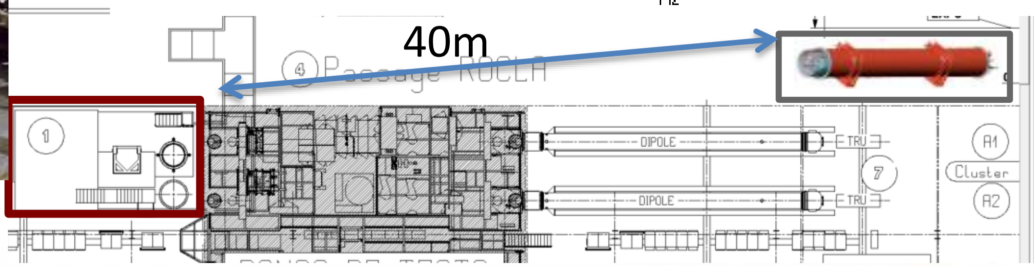
Mode	Modal shape	Frequency (Hz)	
		Without restraints	**With** rest
Vertical 1		22	[illegible]
Vertical 2		27	28
Vertical 3		42	42
Vertical 4		/	44
Vertical 5		53	53
Vertical 6		/	57

18 Hz for Q1

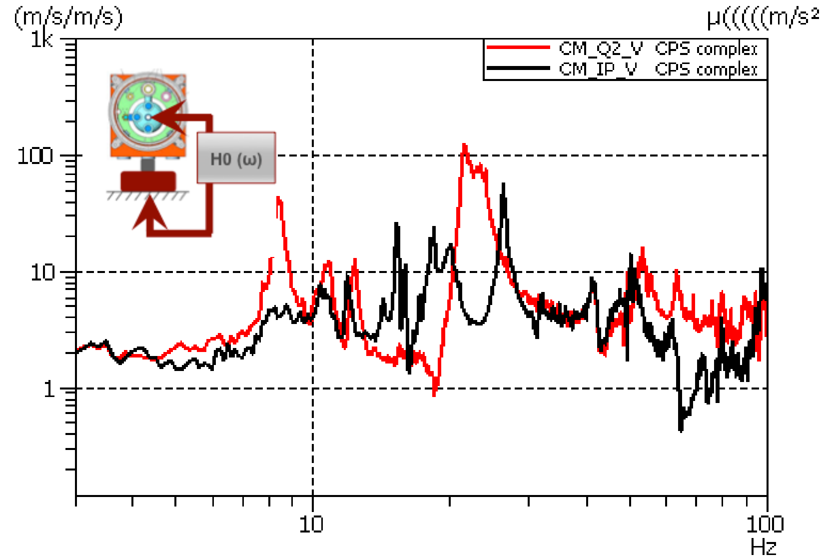
Extra Information from $H_0(\omega)$

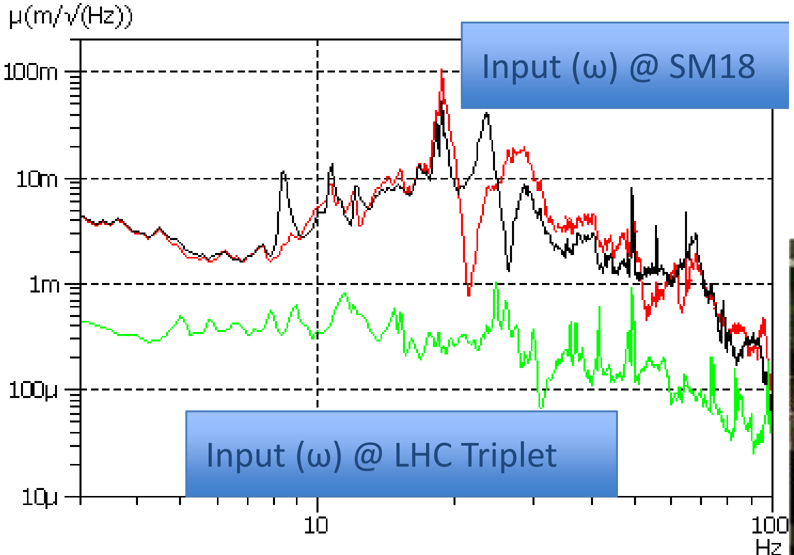


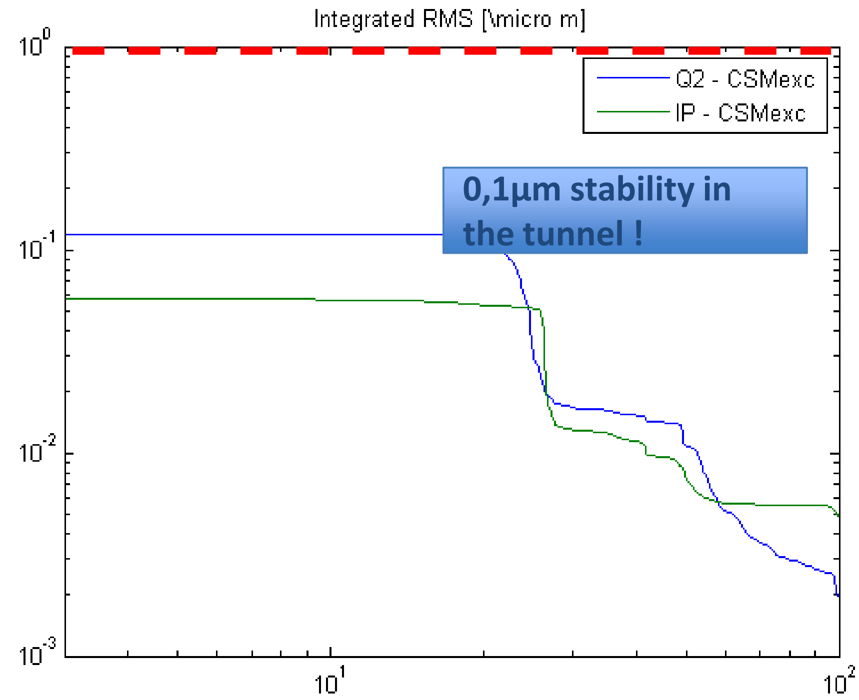




Extra Information from H0 (ω)





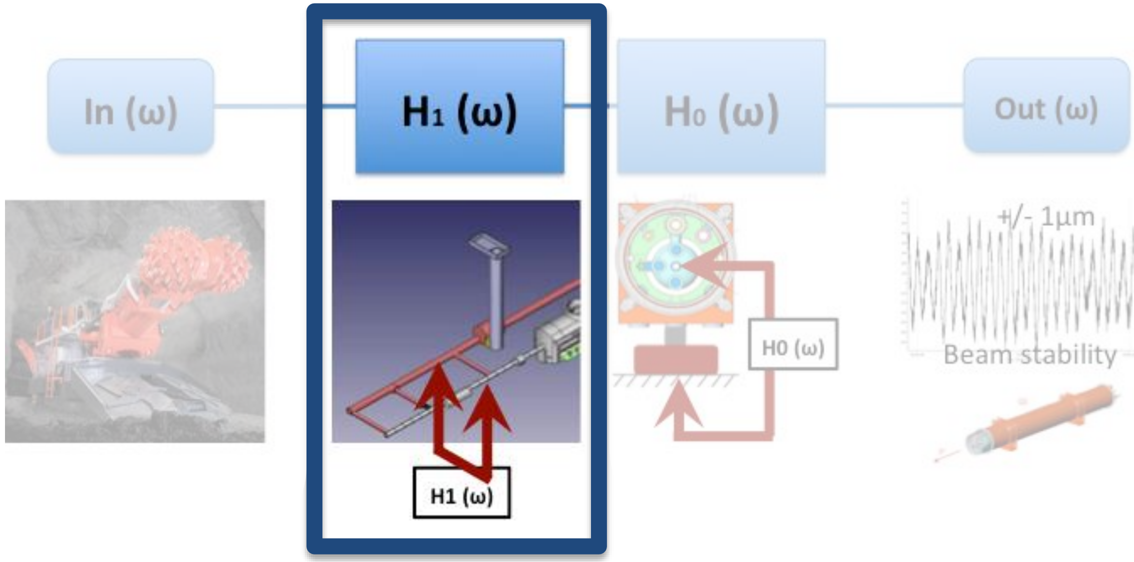


H_0 (ω) Conclusion

- High vibration amplification between the floor and cold mass was measured mainly due to the dynamic behavior of the Q1 structure (max gain of 100 on the 0-100 Hz bandwidth) ;
- Several natural frequencies were identified below 50 Hz, and comparable to LHC quadrupoles ; Triplet inteconnections should have a limited impact on the dymanic behaviour (Vertical and Lateral directions)
- At SM18 **without** civil engineering activities, the cold mass motion is **close to the limit of 1 µm** (0-peak). With activities, a level of several microns is achieved ;
- According to the transfert function measured at SM18 on Q1, the expected motion of the coldmass during **LHC operation** is around **0,1 µm** integrated from 100 Hz

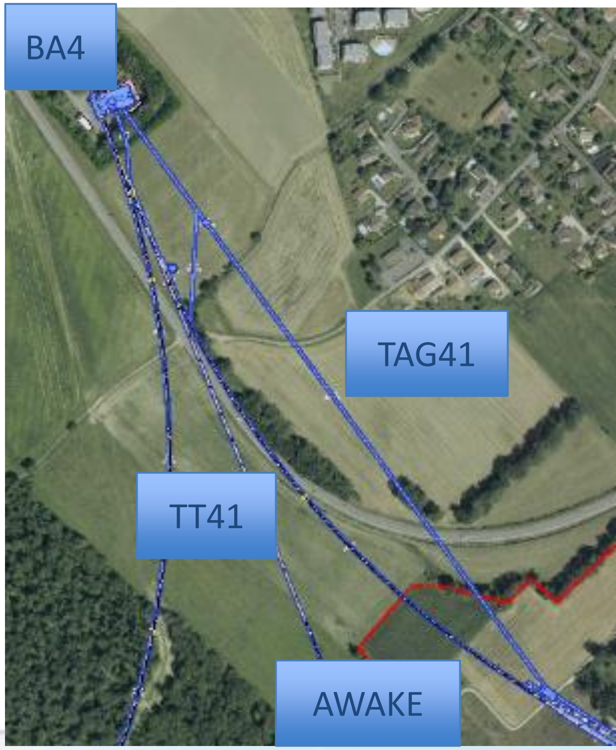
High Luminosity LHC

H_1 (ω) Results



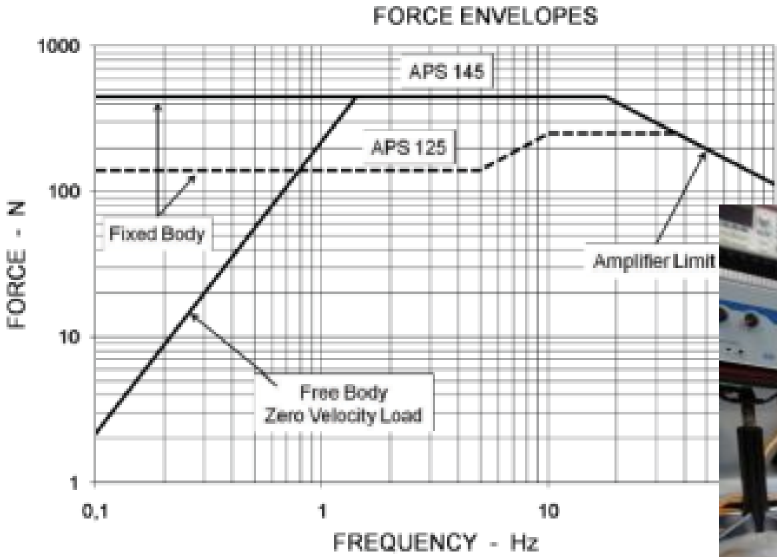
Introduction

- No chance to reach the same conditions today than HiLumi Project !
- Use actual tunnels to do some preliminary tests
- Why TAG41/TT41 ?
    - Molasse rock as Pt1 and Pt5
    - Tunnel distance (up to 85 m)
    - Around 50 m depth
    - TAG41 : Access tunnel
    - TT41 : under assembly



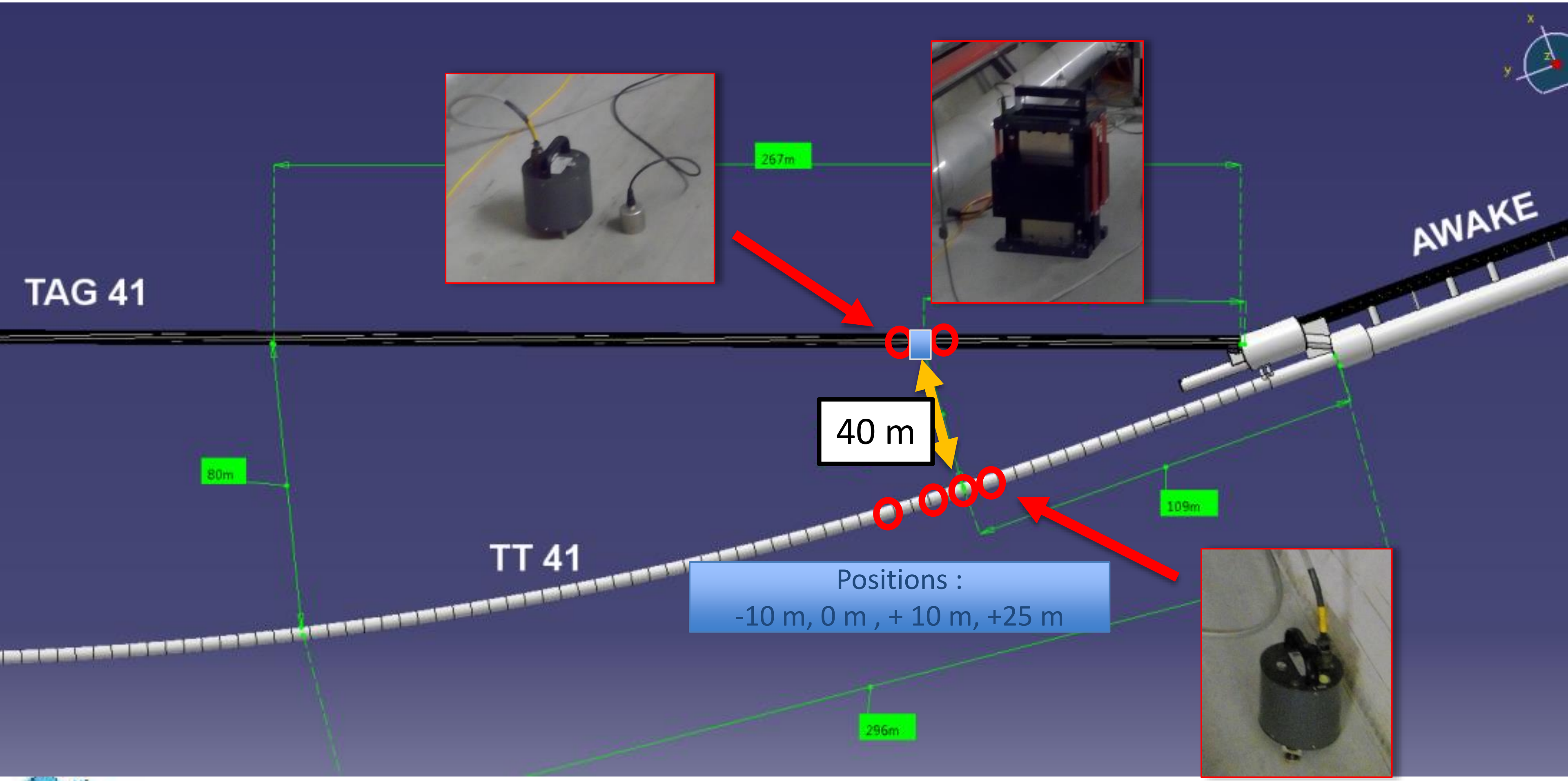
Equipment

- Electro shaker used like known excitation source



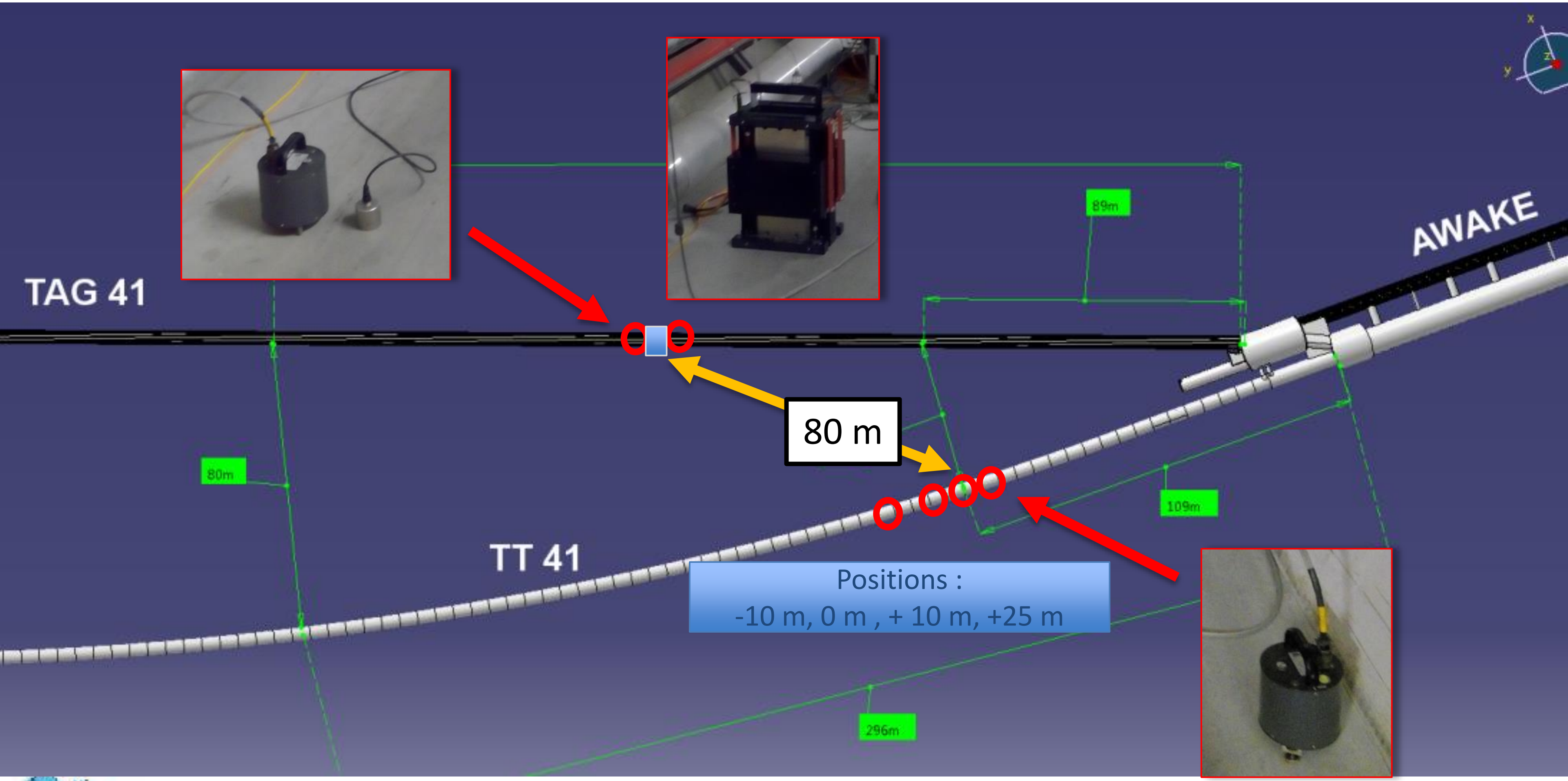
Setup for H1 (ω)

- 40m configuration



Setup for H1 (ω)

- 80m configuration

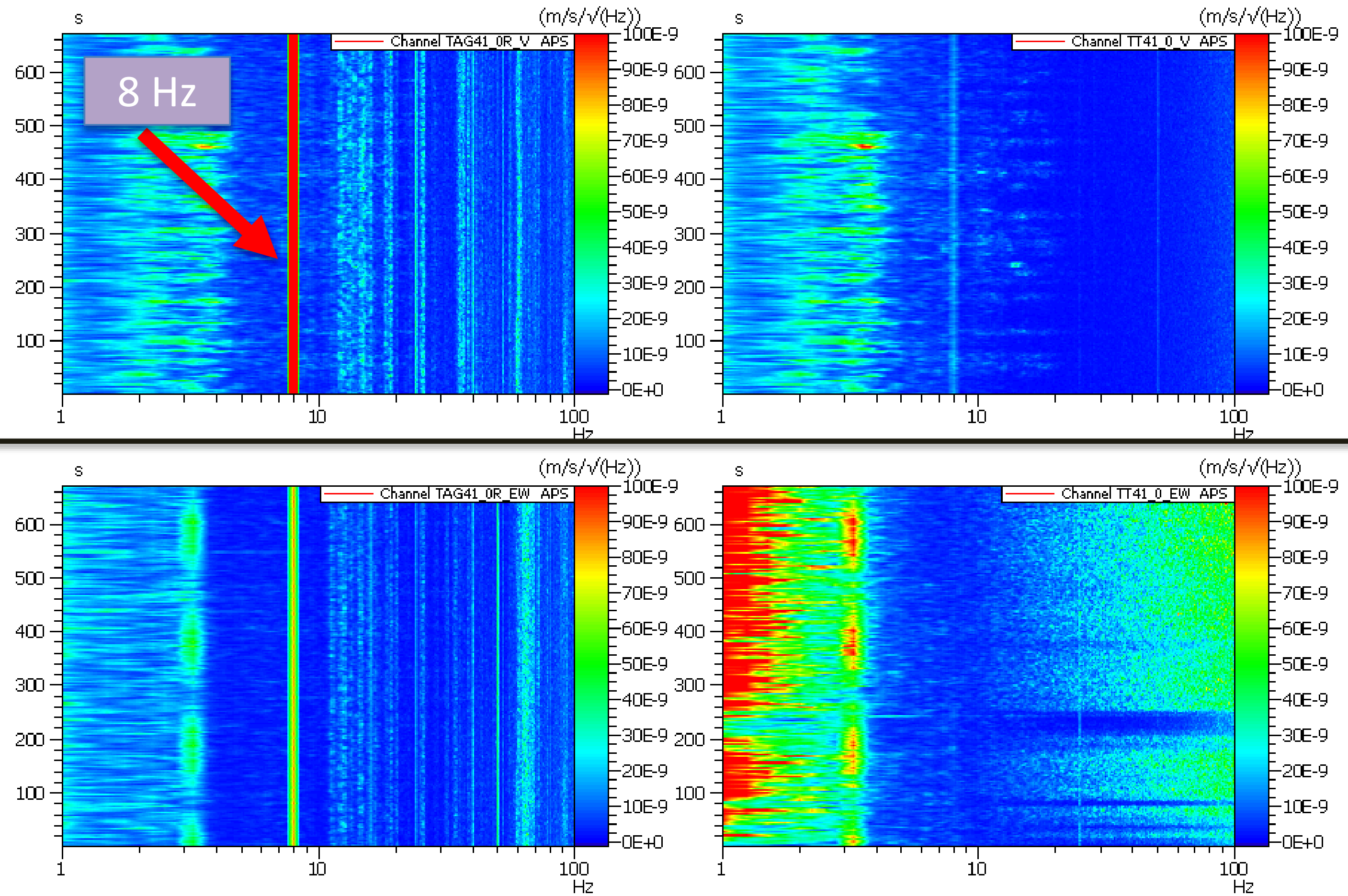


H1 (ω) Results

Tunel with shaker → TT41 (response)

Vertical

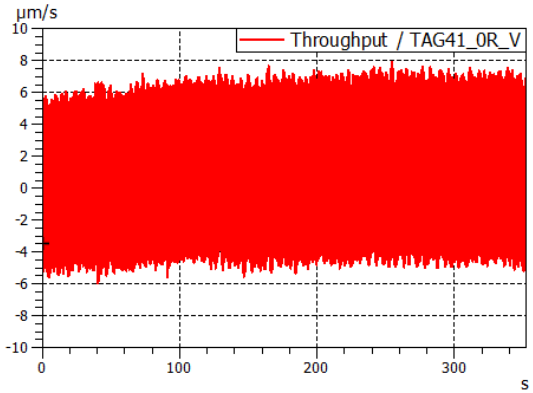
Lateral



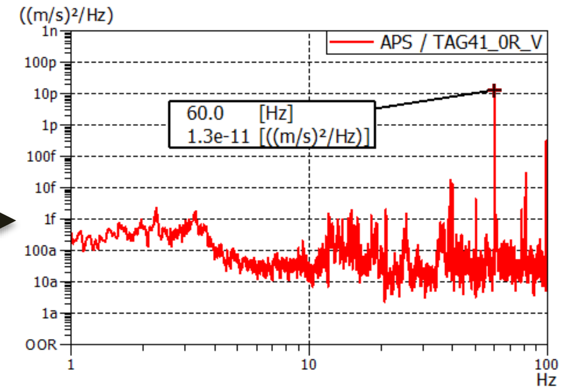
H1 (ω) Results

- Gain determination- example for 60Hz excitation

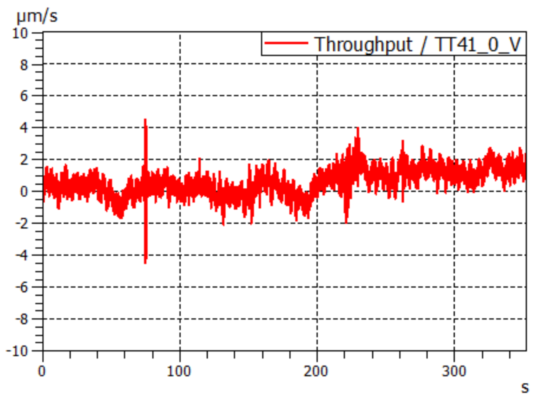
Time data



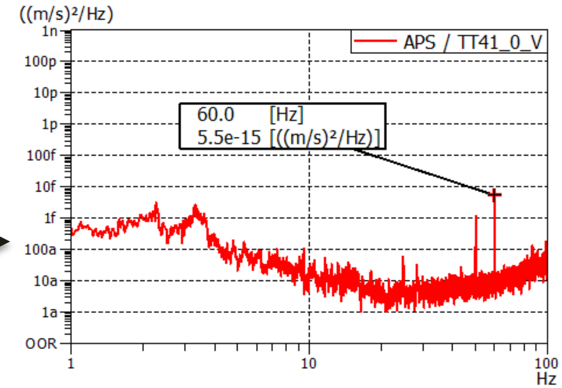
Power Spectral Density



FFT



FFT

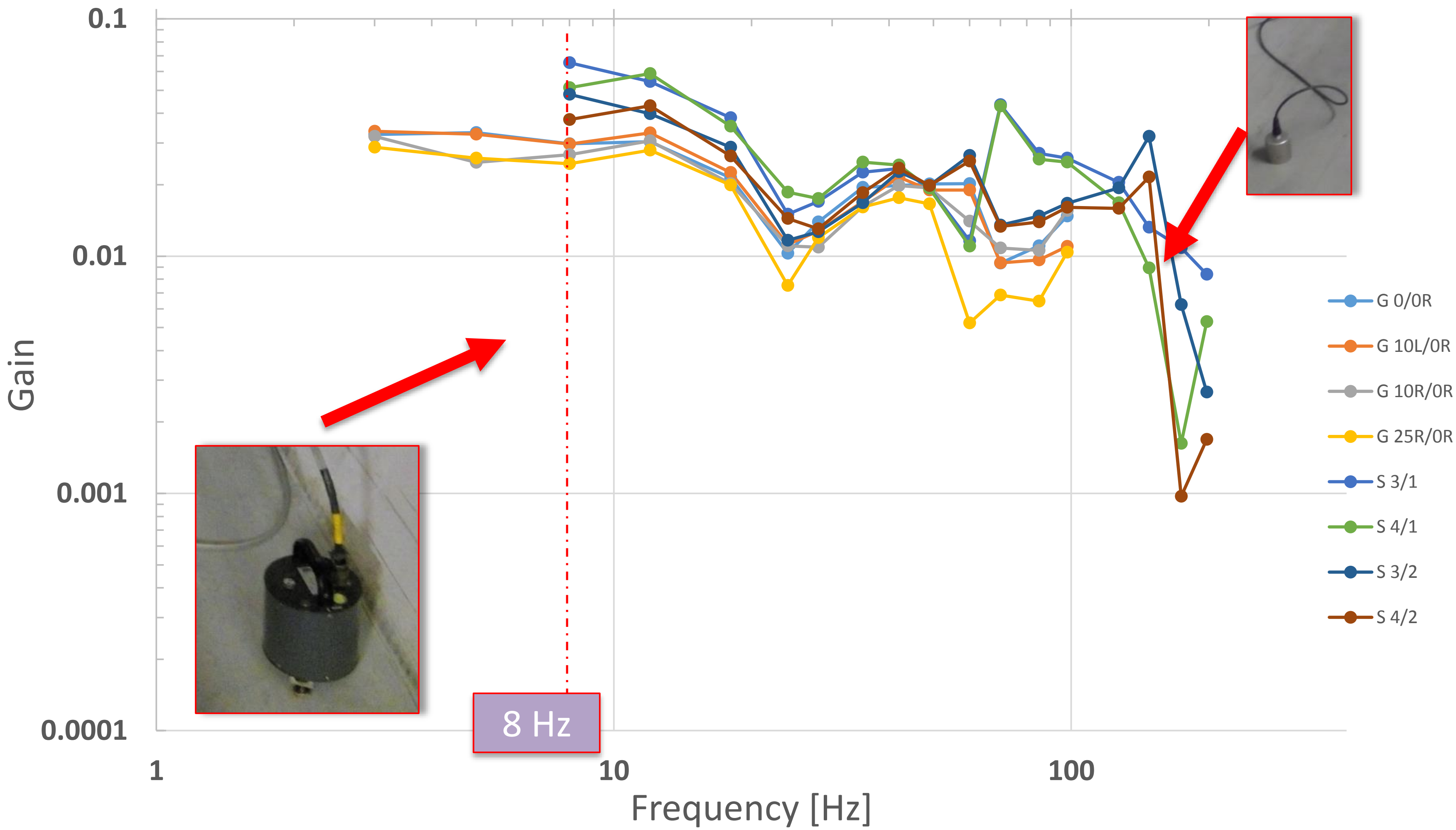


Fs	1024 Hz
Freq. Lines	25601
Resolution	0.015 Hz
Window	Hanning
Overlap	50%
Nb Average	20

High Luminosity LHC

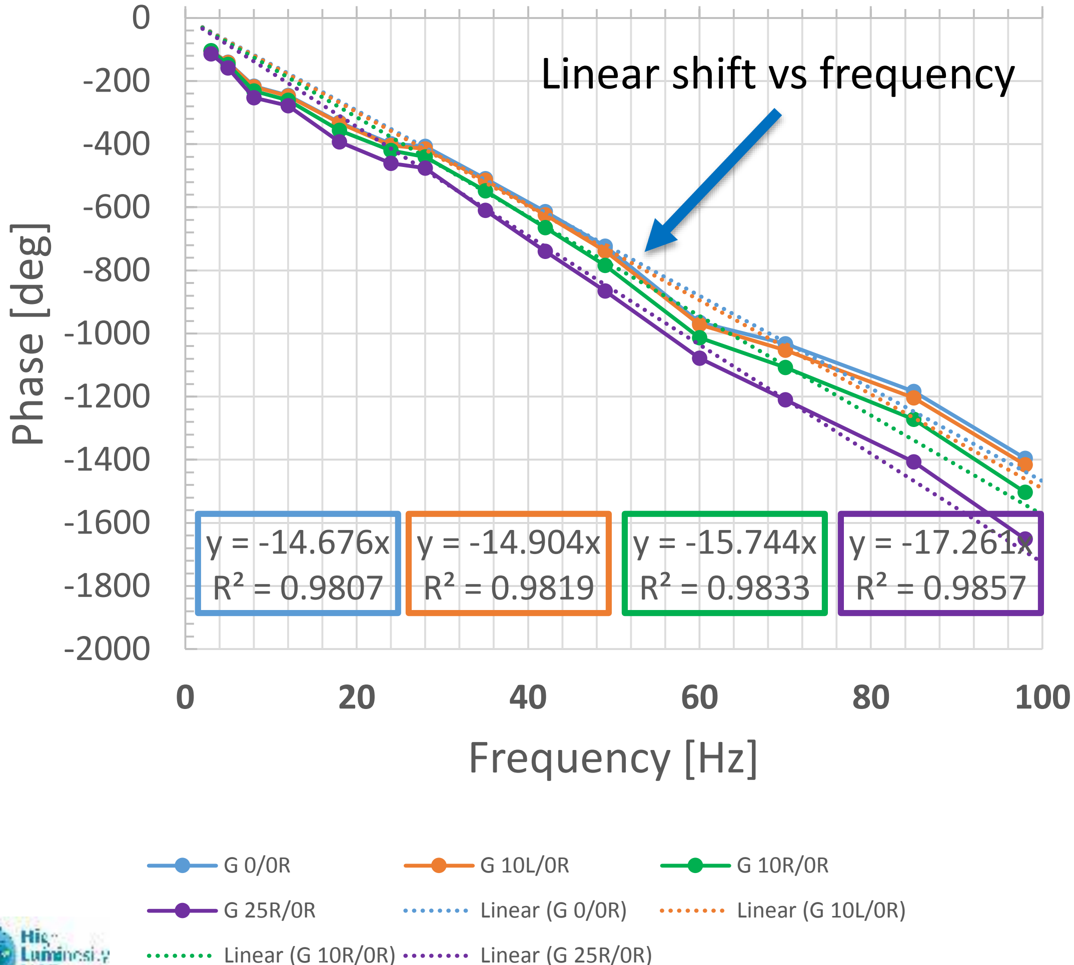
H1 (ω) Results

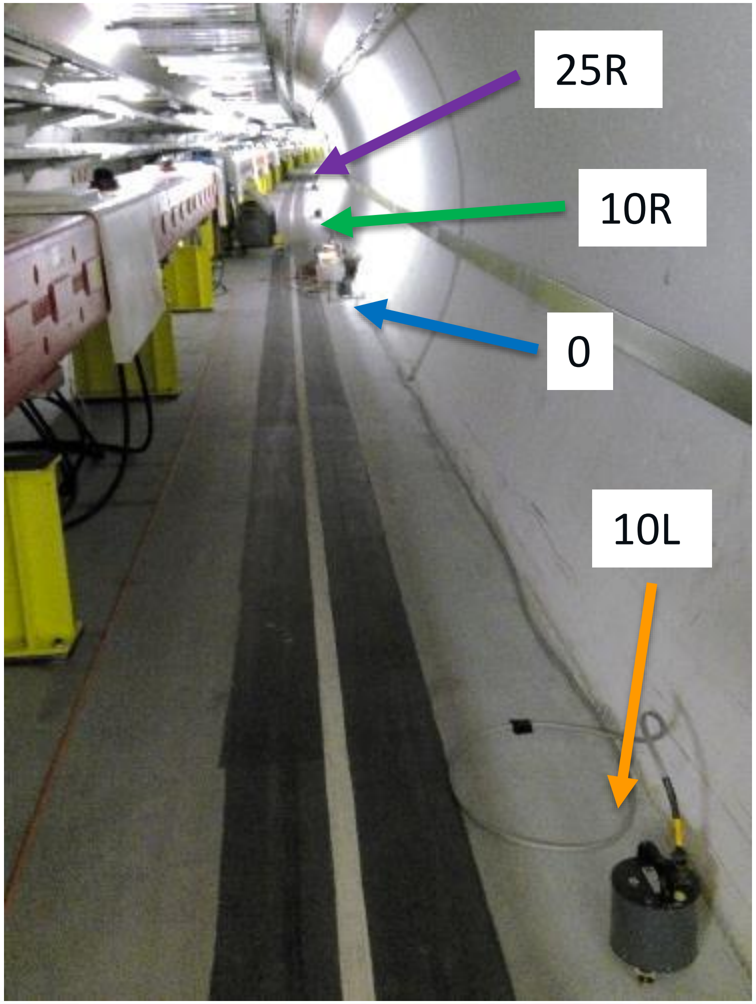
- Vertical transfer function – TAG41/TT41 - Gain



H1 (ω) Results

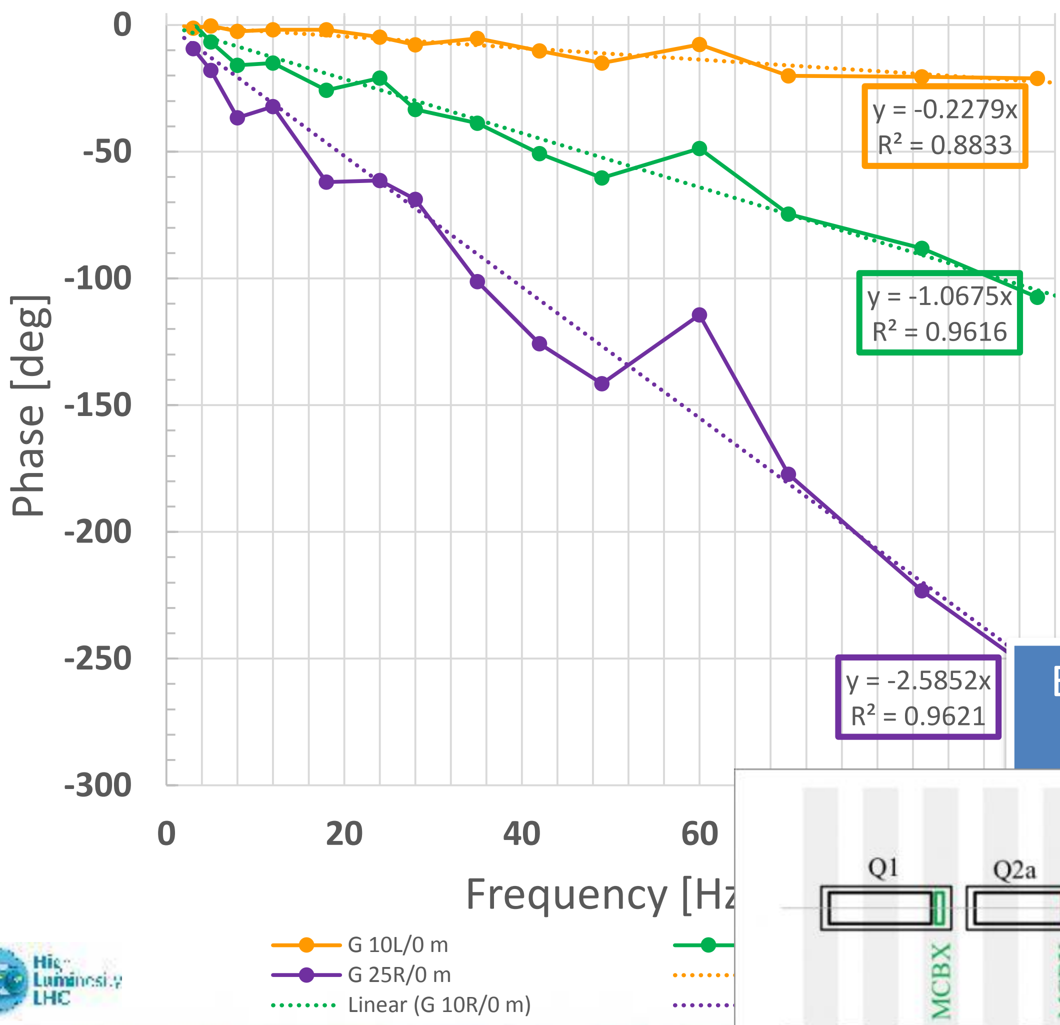
- Vertical transfer function – TAG41/TT41 - Phase

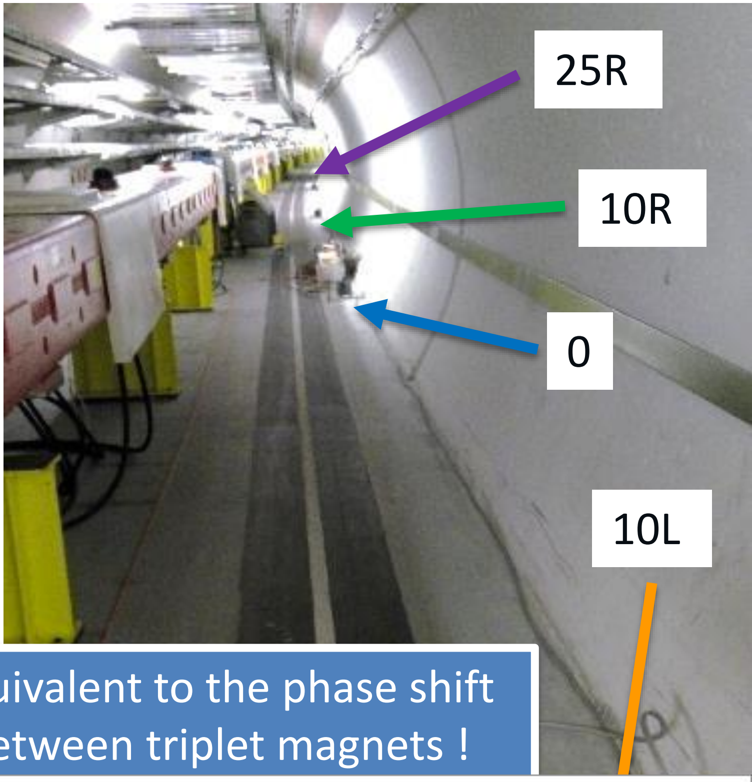




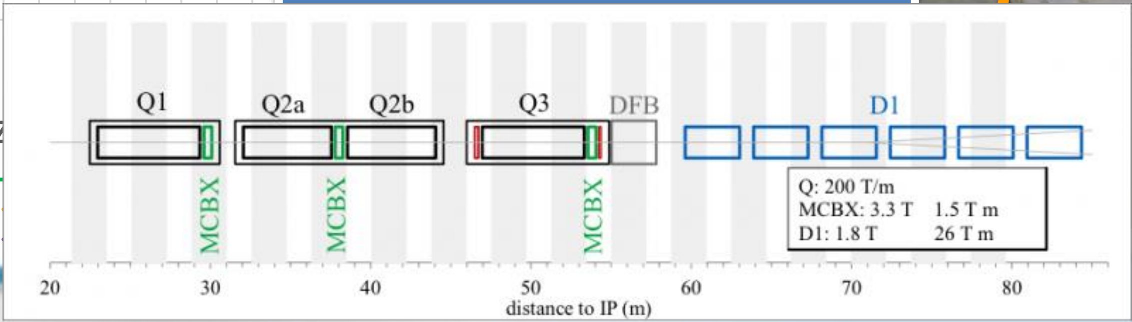
H1 (ω) Results

- Phase shift vs distance in TT41





Equivalent to the phase shift between triplet magnets !



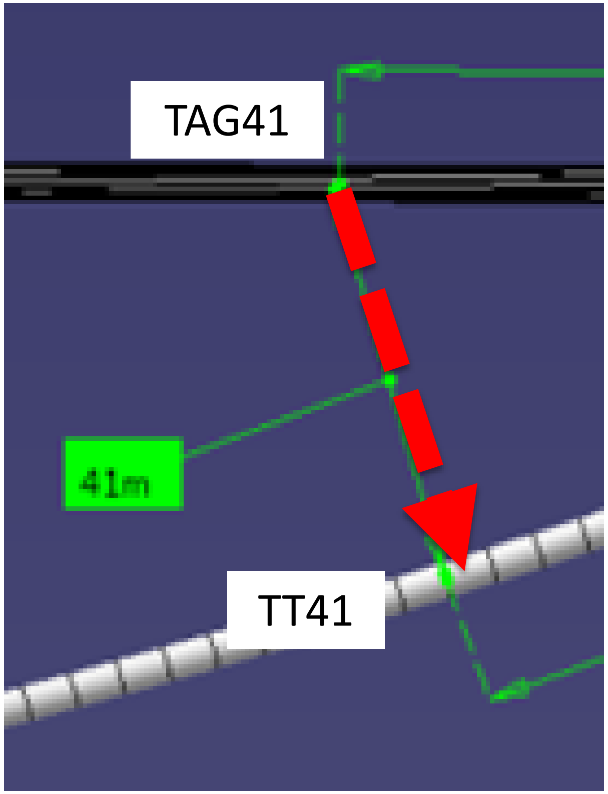
Extra Information from $H_1(\omega)$

- Wave velocity between tunnels

$$V = \lambda \cdot f = 2\pi z \cdot f / \theta$$

λ – wavelength [m]
z – distance between geophones [m]
θ - phase shift between geophones [rad]

Geophone TT41	Geophone TAG41	V [m/s]
0	0R	981
10L	0R	995
10R	0R	942
25R	0R	983

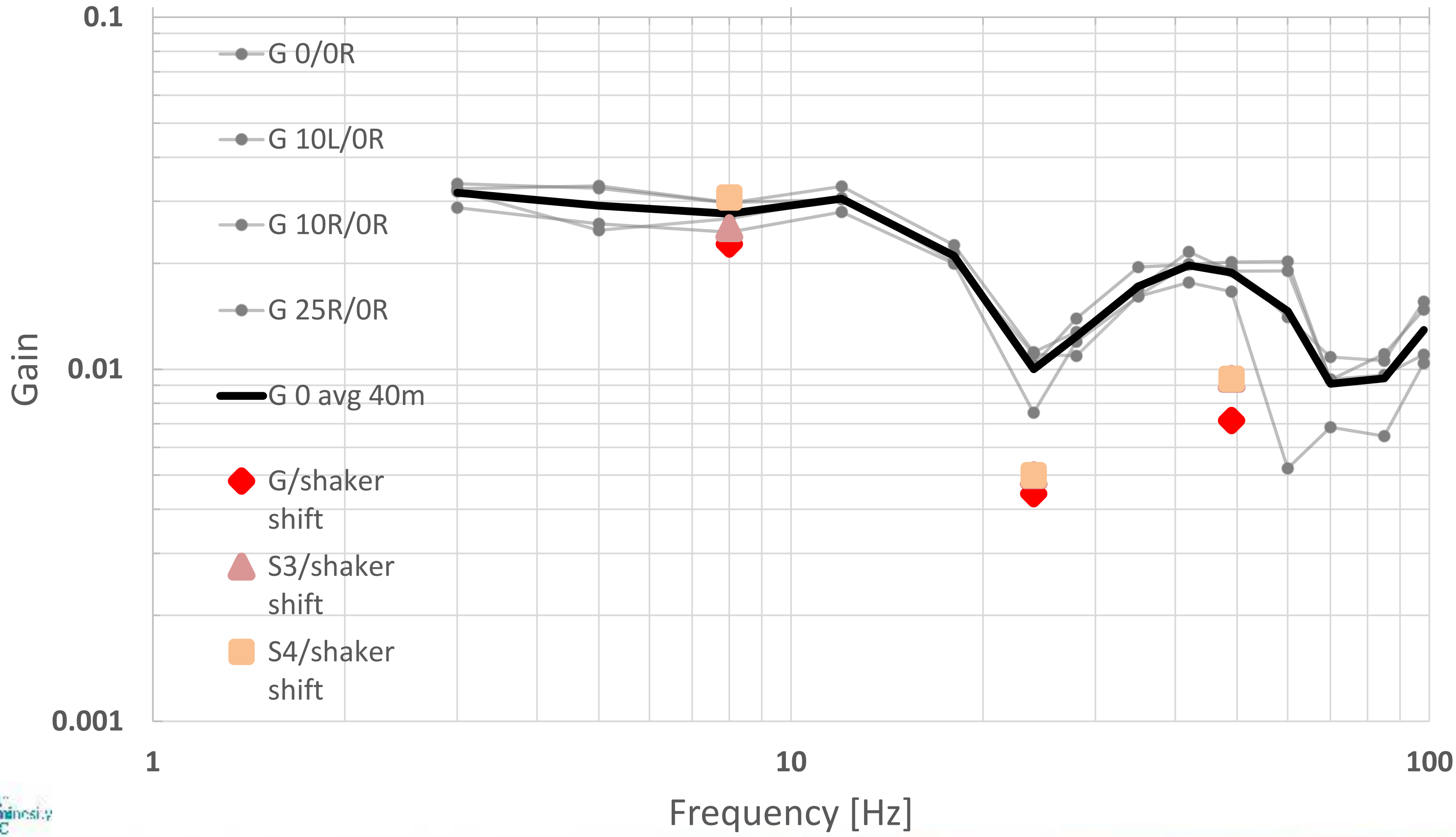


➔Consistency with literature (800 up to 1500 m/s in the molasses)
➔Shear waves

Typical rock velocities, from Bourbie, Coussy, and Zinszner, Acoustics of Porous Media, Gulf Publishing.

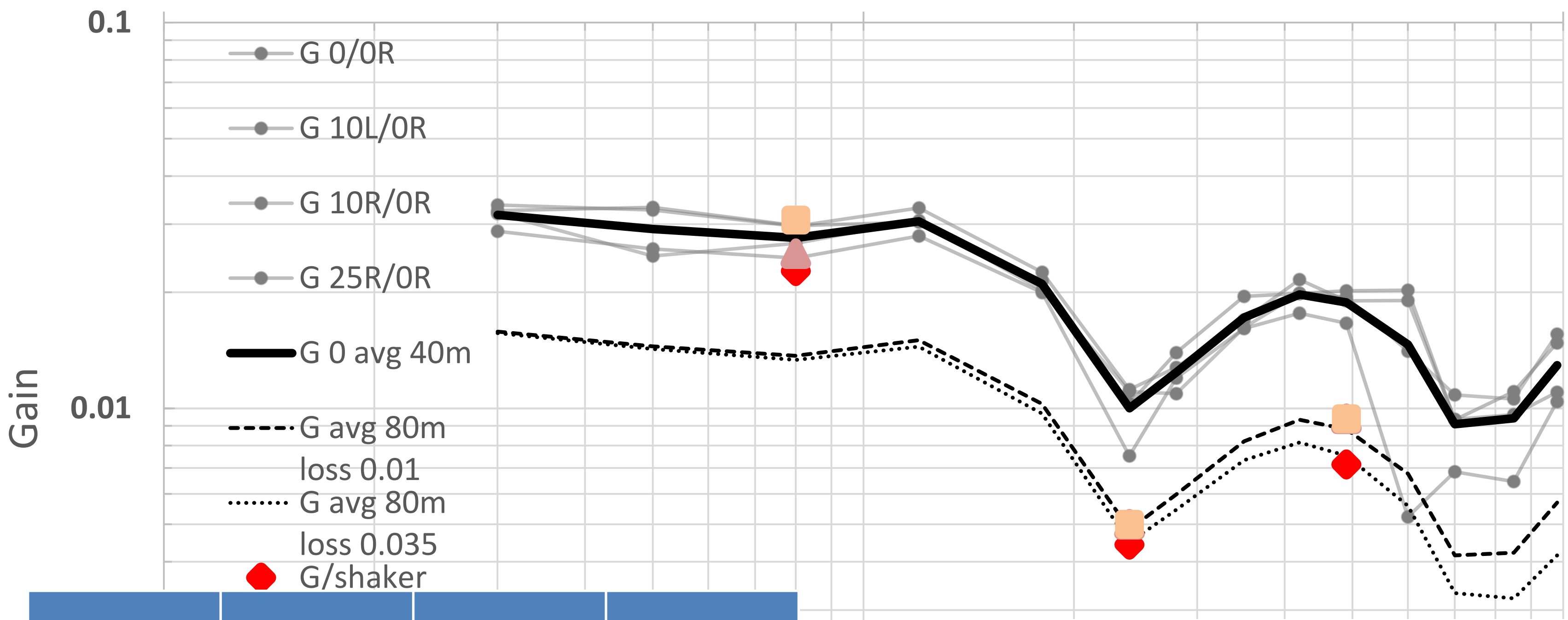
Extra Information from $H_1(\omega)$

- Attenuation with distance

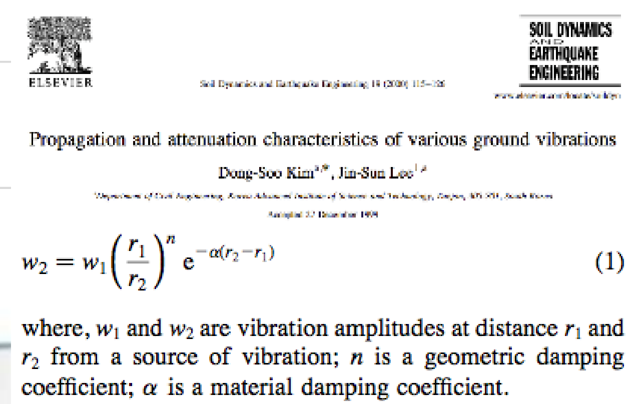


Extra Information from $H_1(\omega)$

- Attenuation with distance



Frequency [Hz]	S3/Shaker 40m/80m	S4/Shaker 40m/80m	Theoretical Ratio
8	1.1	0.9	2.0
24	2.0	2.2	2.1
60	2.2	2.2	2.2


ELSEVIER

SOIL DYNAMICS AND EARTHQUAKE ENGINEERING

Propagation and attenuation characteristics of various ground vibrations

Dong-Soo Kim, Jin-Sun Lee

$$w_2 = w_1\left(\frac{r_1}{r_2}\right)^n e^{-\alpha(r_2-r_1)} \quad (1)$$

where, w_1 and w_2 are vibration amplitudes at distance r_1 and r_2 from a source of vibration; n is a geometric damping coefficient; α is a material damping coefficient.

H_1 (ω) Conclusion

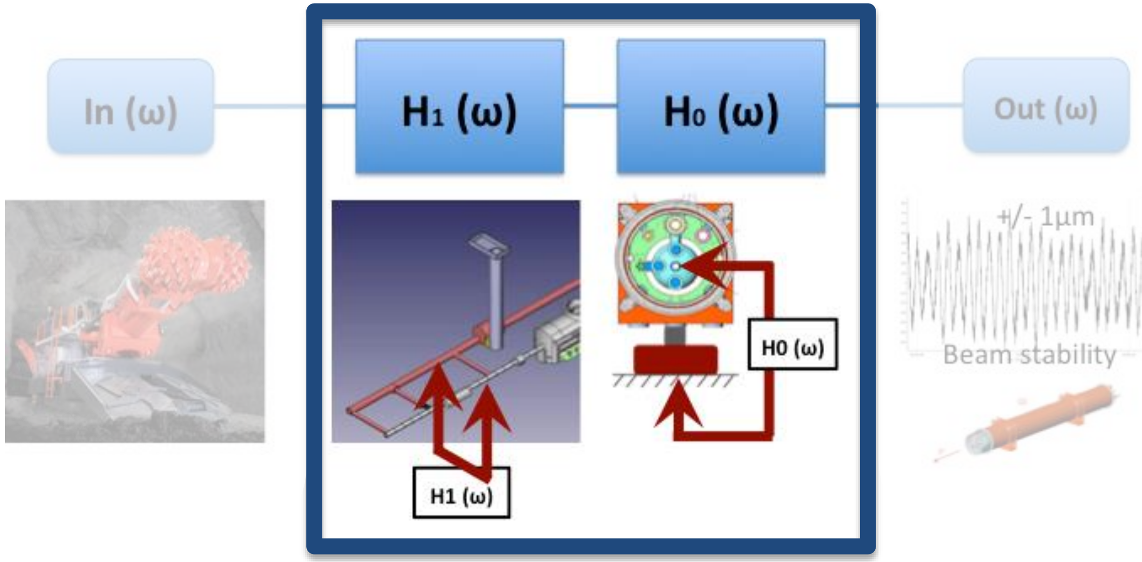
- An attenuation factor between 20 (@6 Hz) up to 50 (@100Hz) was measured between TAG41 and TT41 tunnels seperated by 40m of molasse rock ;

- An addition attenuation factor of 2 was measured when the distance from the exitator is multiply by 2 ;

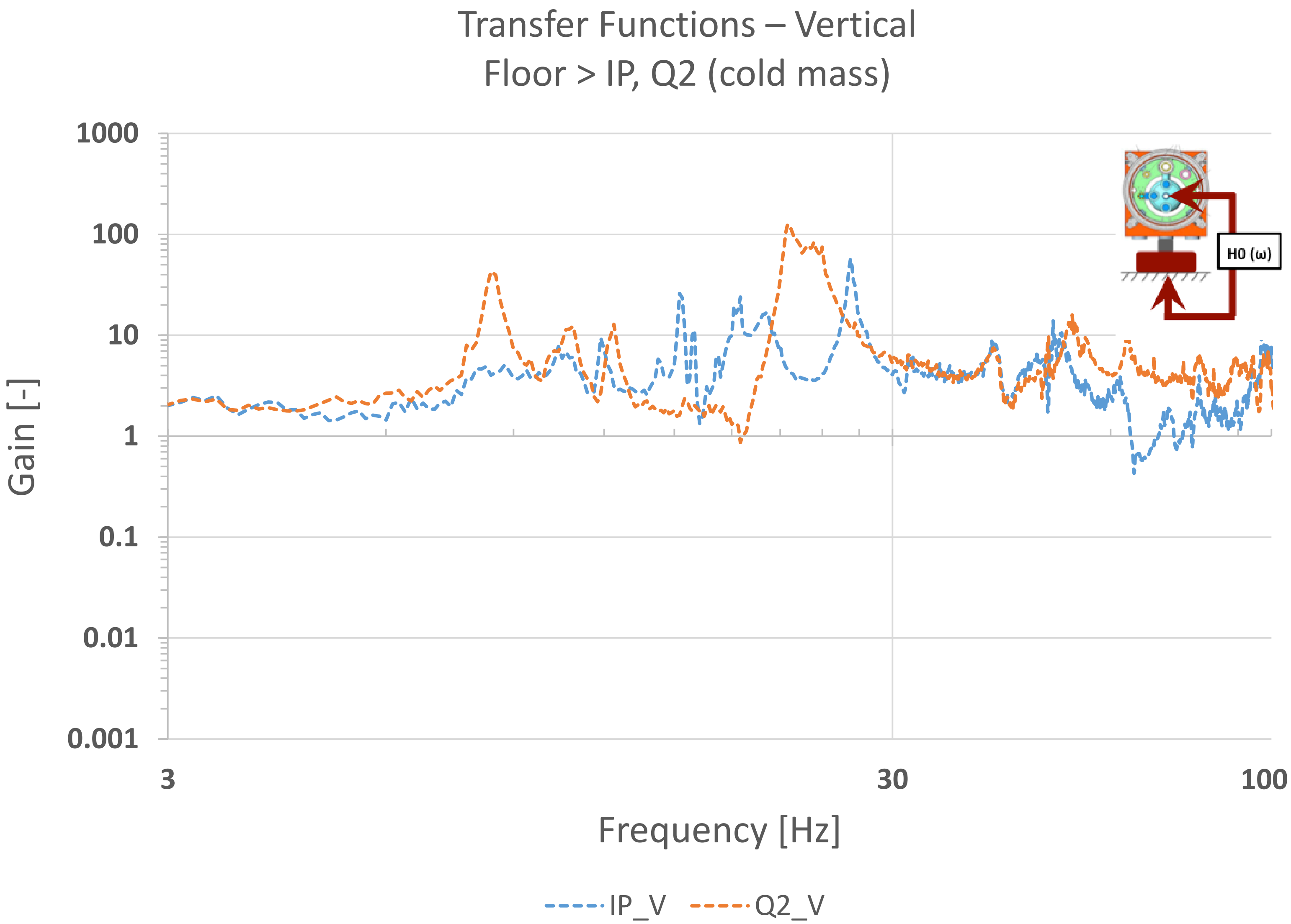
- The velocity of waves generated during the measurements was around 950 m/s, consistent with a shear wave ;

- Vibration results are consistent with the literature ;

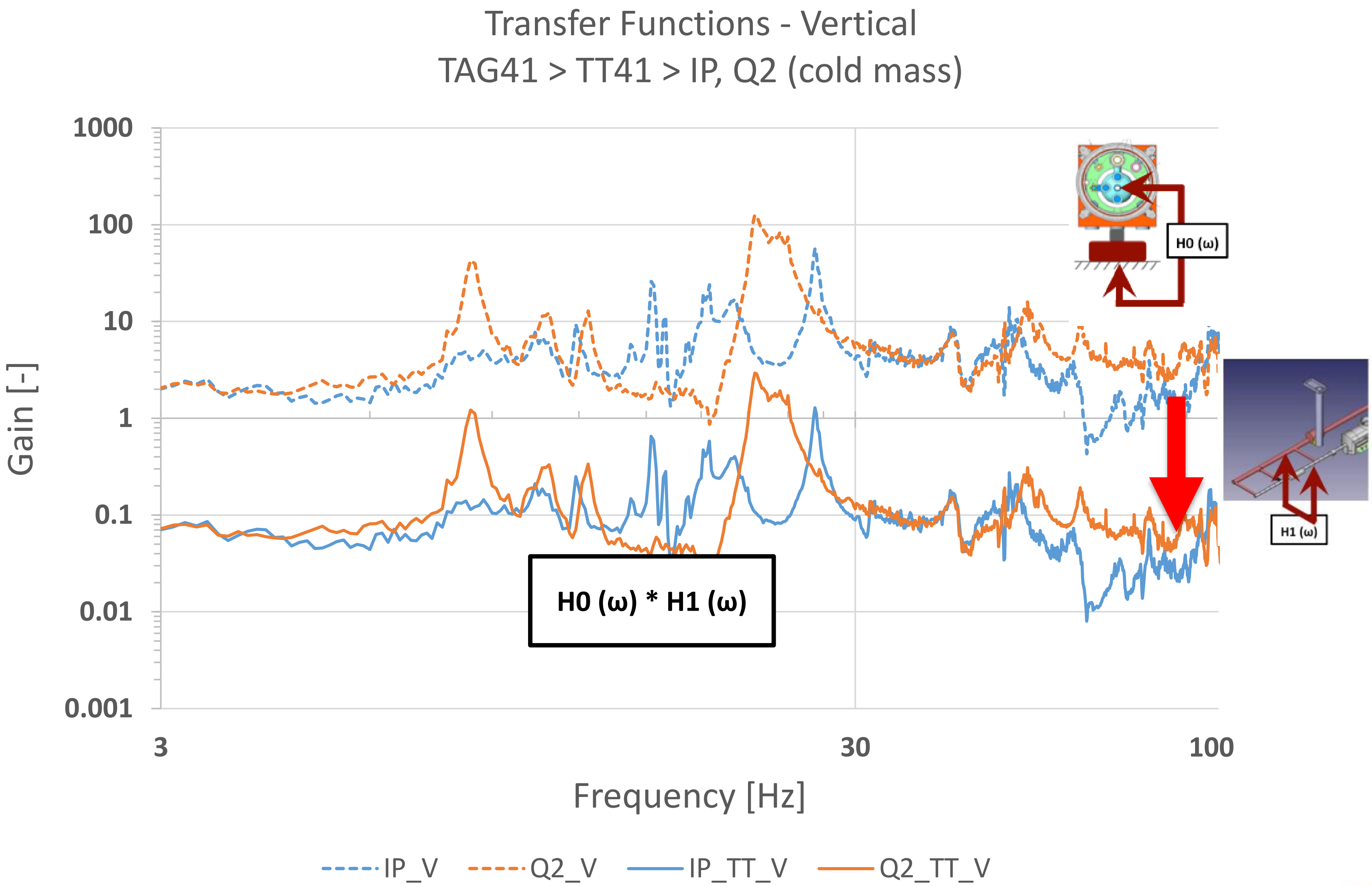
H_1 (ω).H_0 (ω) Results



H0(ω).H1(ω) Results



H0(ω).H1(ω) Results



Conclusion

- The study was done in order to give a magnitude order of vibration effects and to evaluate the sensibility of the system (Triplet and distance) ;
- A high vibration amplification between the floor and cold mass was measured on Q1, due to the dynamic behavior of the structure (max gain of 100 on the 0-100 Hz bandwidth) ;
- Q1 in standalone position at SM18 do not achieved the target of 1um with general vibration excitation ;
- An attenuation factor between 20 (@6 Hz) up to 50 (@100Hz) was measured between TAG41 and TT41 tunnels seperated by 40m of molasse rock ;

Next steps

- Disussion in progress to collect data from several types of rock-header.

Flums, Switzerland

The tunnel network currently consists of numerous galleries, caverns, testing areas, laboratories, training facilities as well as essential infrastructure such as electricity, ventilation, workshops, canteen and much more over a total length of more than 5 km. Tunnel cross-sections reach 130m2 in varying geologic formations.

AMBERG ENGINEERING

High Luminosity LHC

Thank you !

Questions