Effect of civil engineering activities on the LHC ground motion and magnet stability

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on behalf of the Mechanical Measurement Lab (EN-MME)

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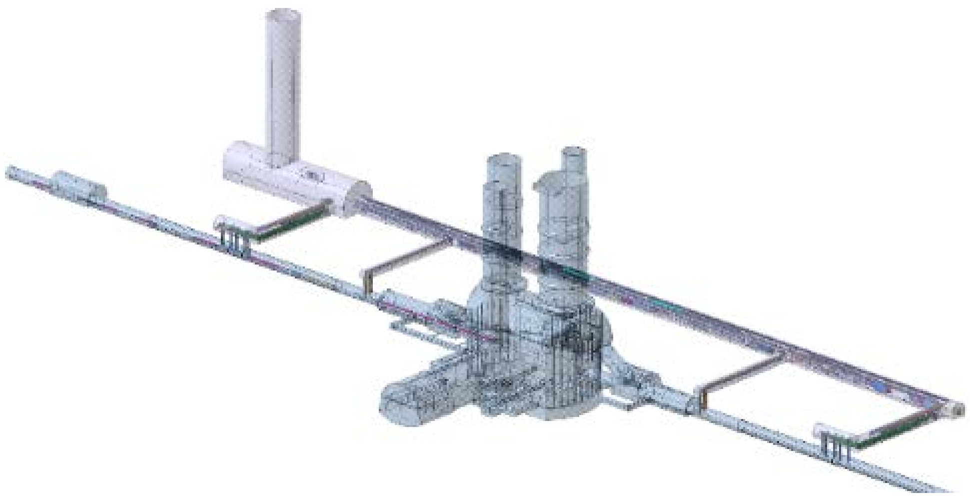
Motivations

- 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 to potential drilling or jetting?

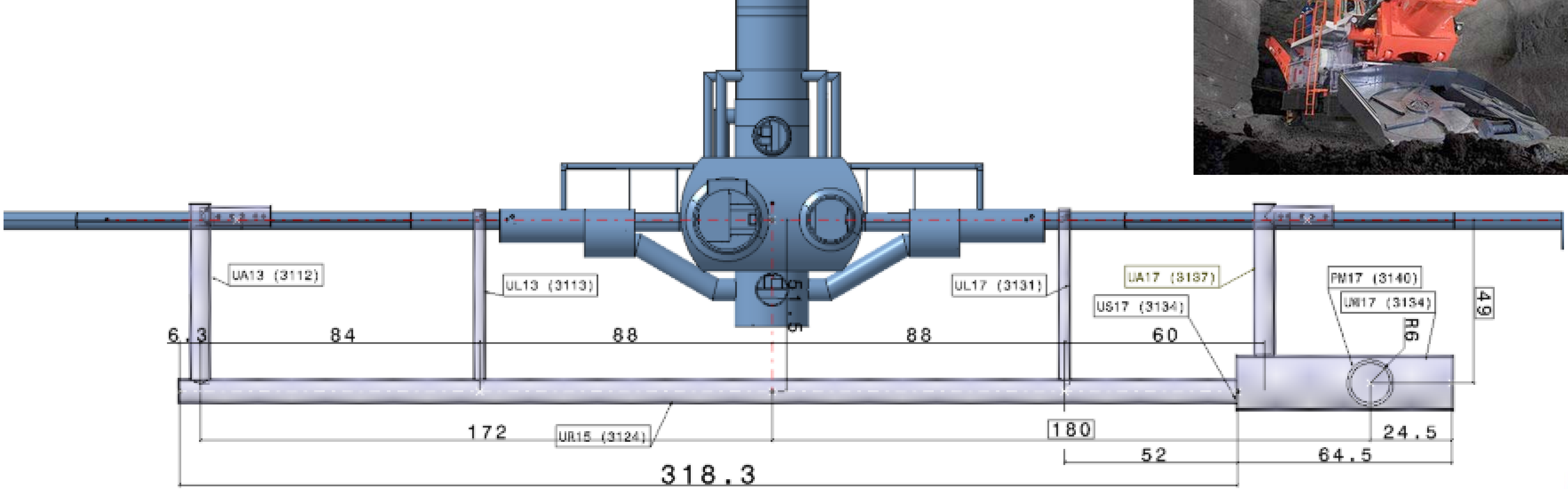
Contents

- Introduction
- Dynamic behaviour of triplet magnets (Q1)
- Vibration propagation through the floor
- Conclusions



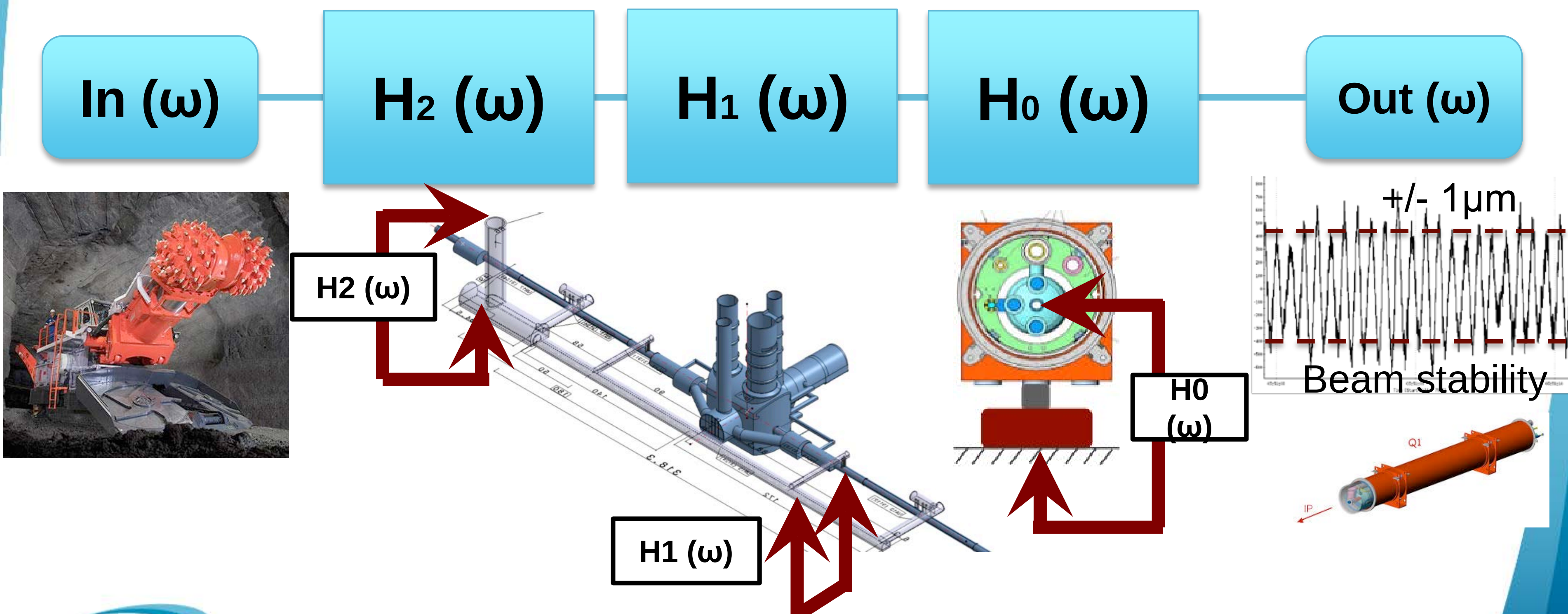
Introduction

- **HL-LHC Civil Engineering**
  (construction of new access shafts,
  underground galleries and caverns in P1 & P5)



Introduction

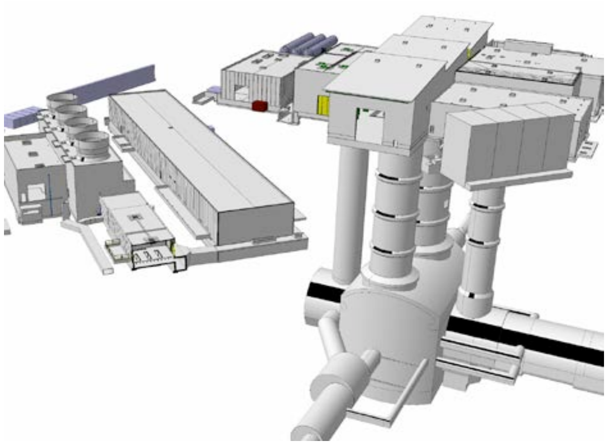
- How measurements can help ?
  - To give a *magnitude order* of vibration effects
  - Sensibility study of the system – transfer functions

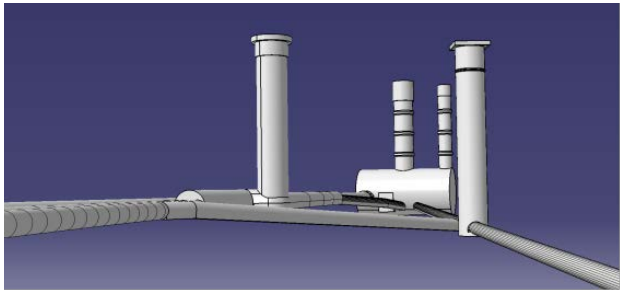


Measurement locations

In (ω) — H_2 (ω) — H_1 (ω) — H_0 (ω) — Out (ω)

Measurements in ATLAS area (UL16/SR1)	Measurements in AWAKE area (TAG41/TT41)	Measurements at SM18 with Q1 triplet spare





Measuring equipment

Sensors

Geophones

Sensitivity:
2000 V/(m/s)
Freq. Range:
30 s – 100 Hz

Seismic Accelerometers

Sensitivity:
1 V/(m/s^2)
Freq. Range:
0.1 – 200 Hz

Excitation devices

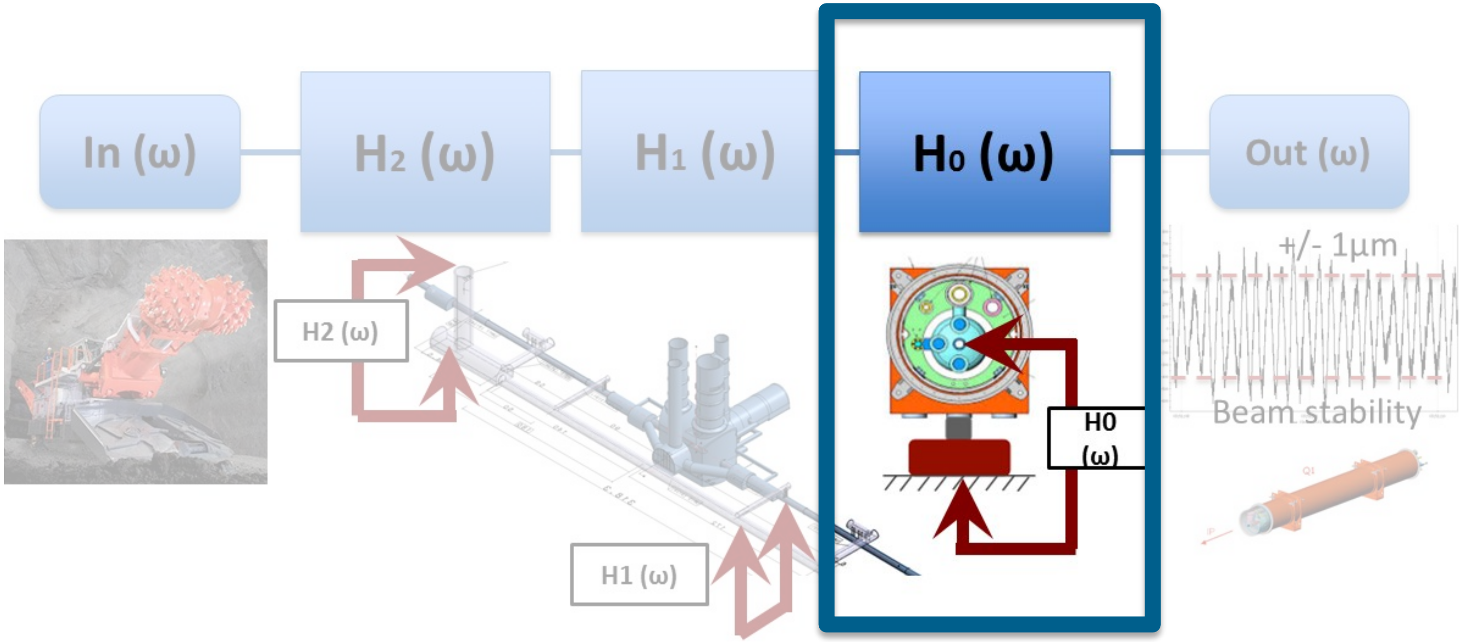
Shaker Truck

Vibrator IVI MARK 4	
Truck weight	20 tons
Excited frequency	4 up to 100 Hz
Excitation type	Fixed and sweep sine
Force injected	17 kN peak

Shaker

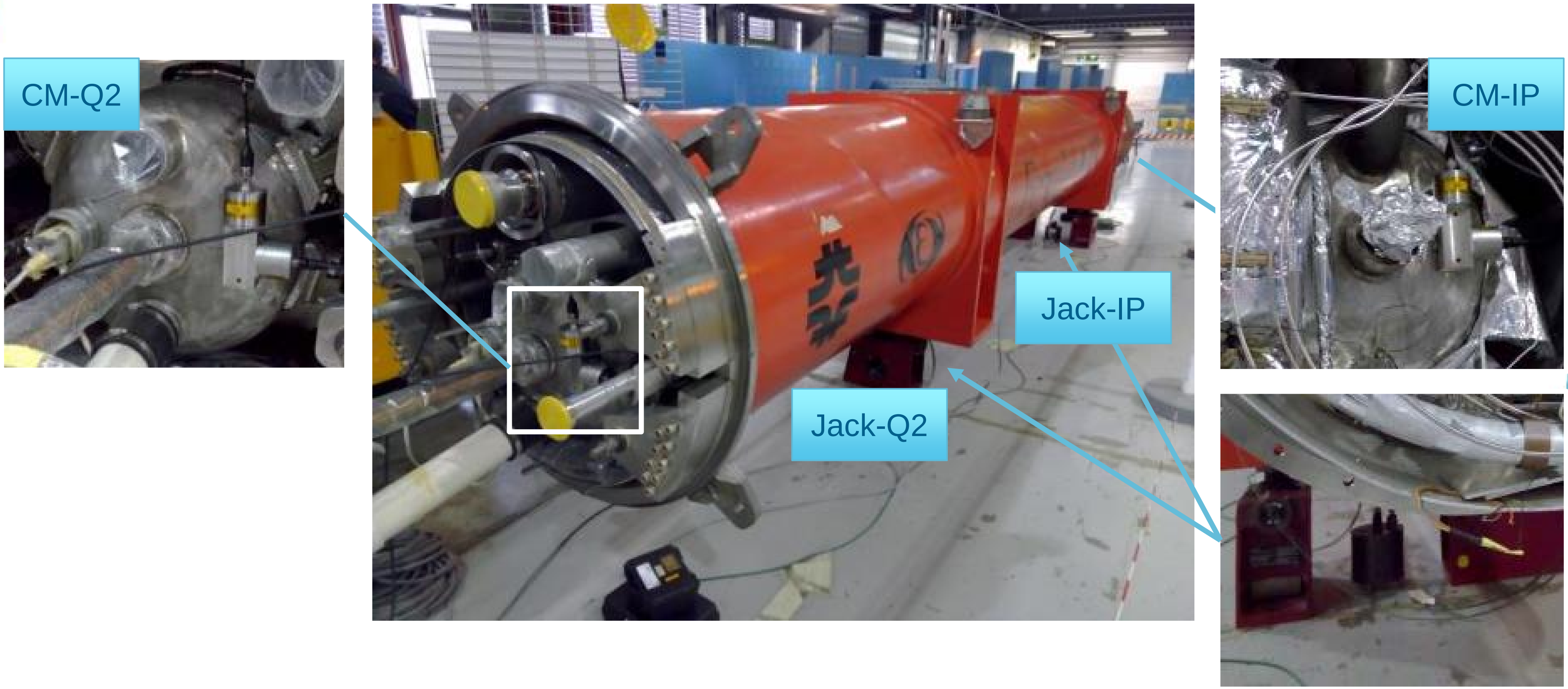
Modal Hammers

$H_0(\omega)$ Results

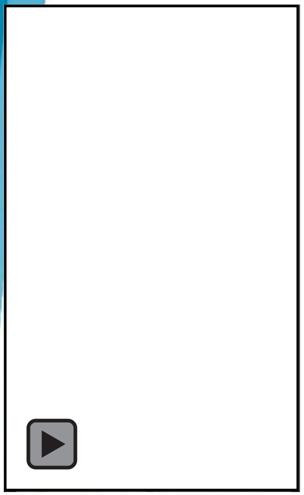


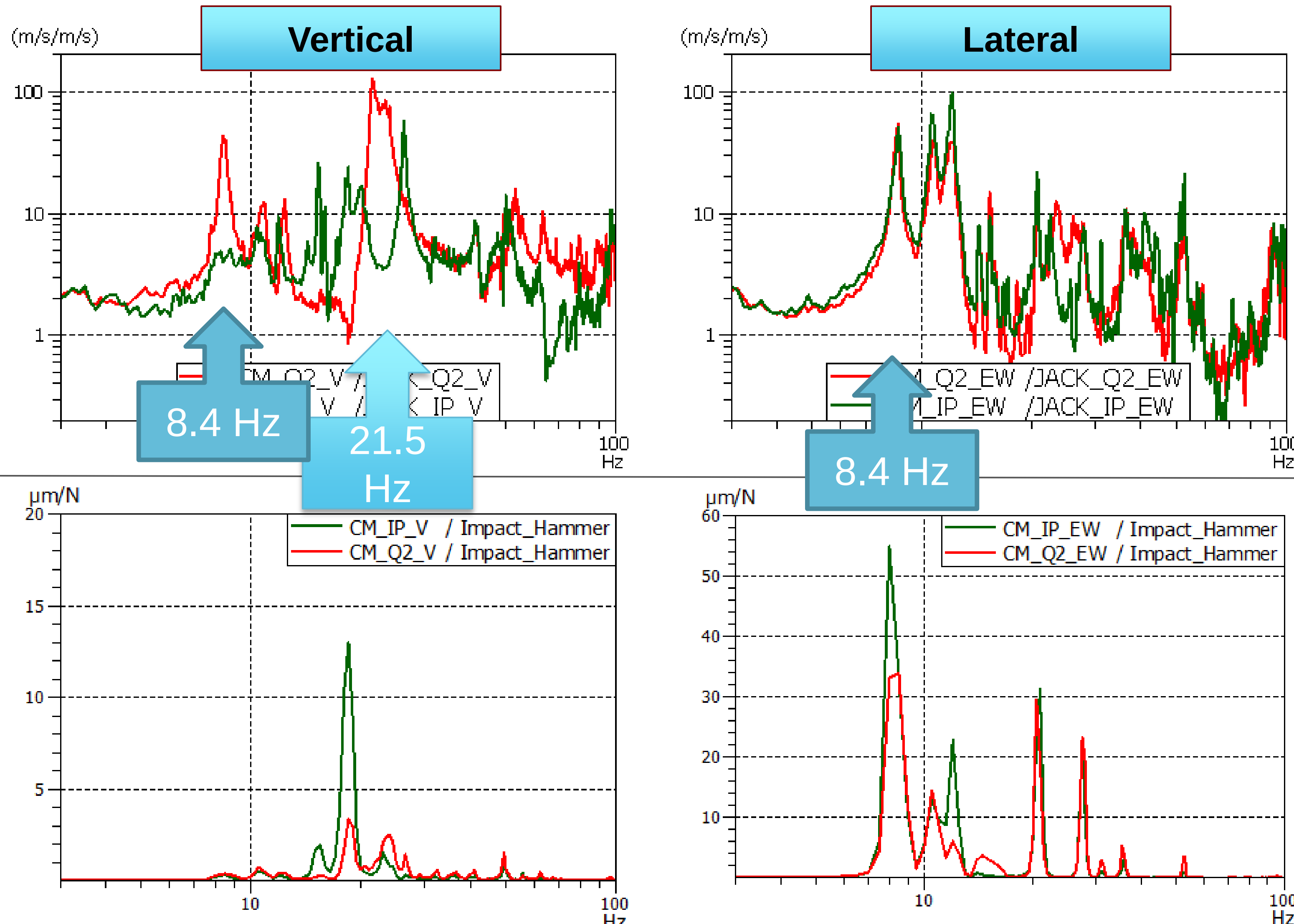
Instrumentation **of Q1**

- Q1 spare magnet installed in stand-alone at SM18

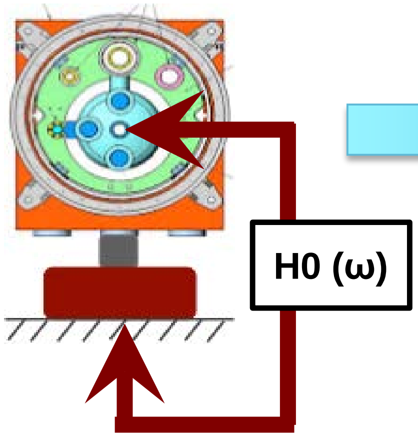


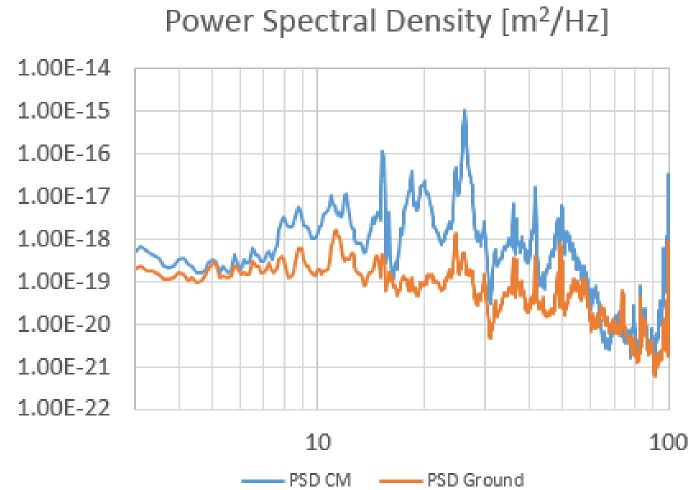
$H_0(\omega)$ Results

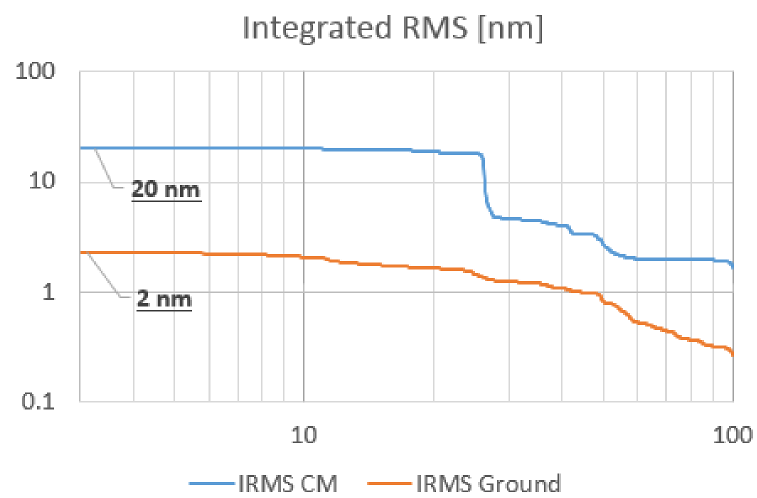




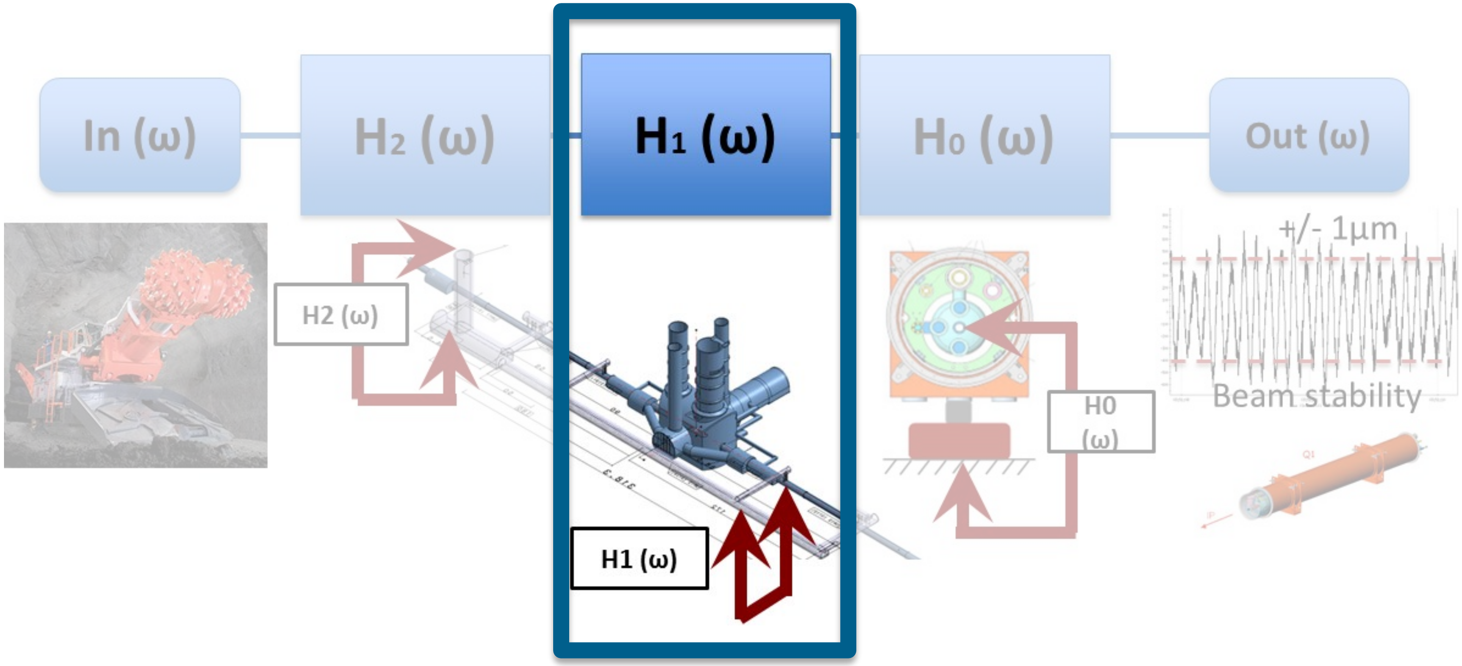
$H_0(\omega)$ Results





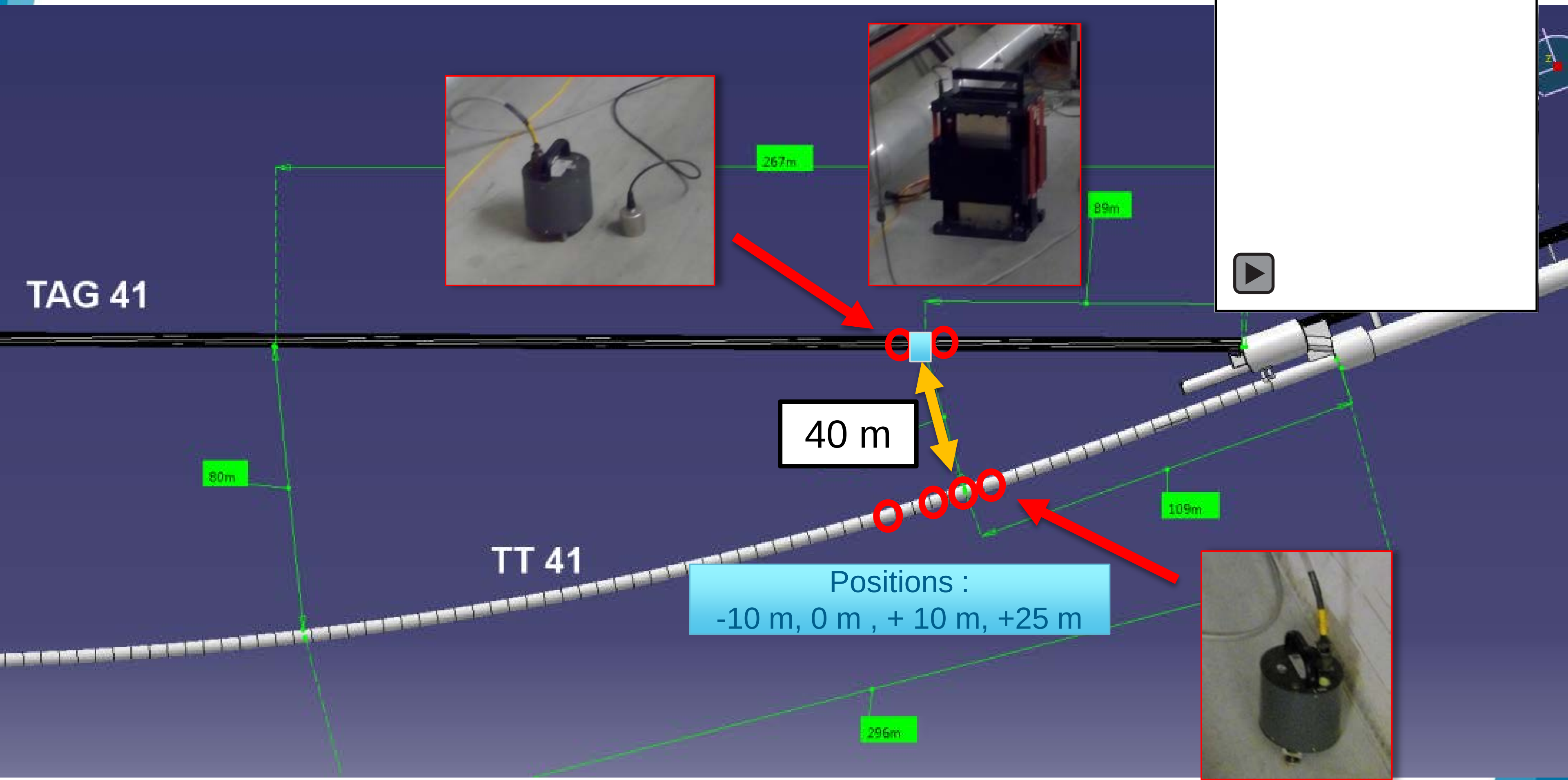


$H_1(\omega)$ Results



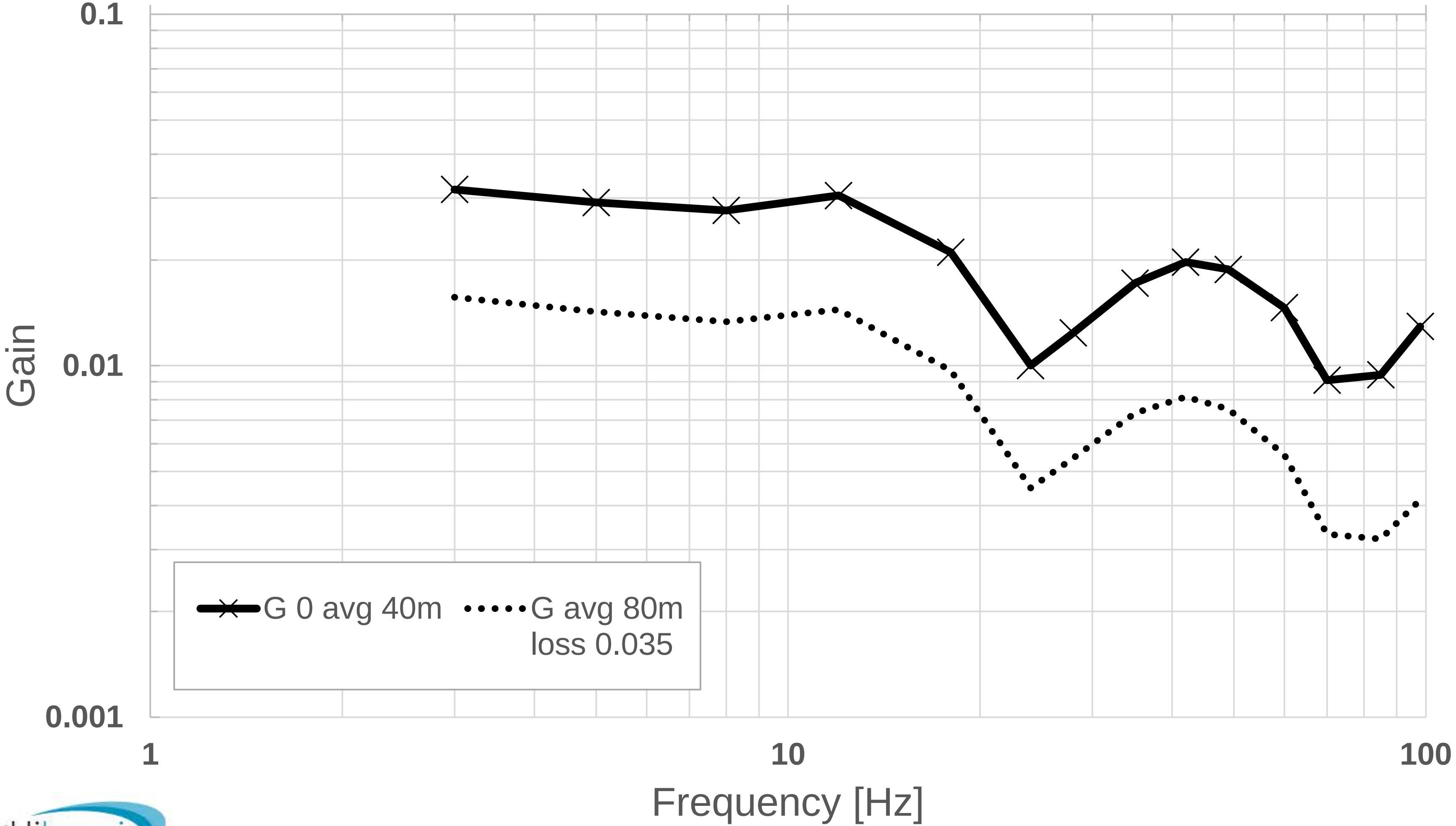
Setup for $H_1(\omega)$

- 40m configuration

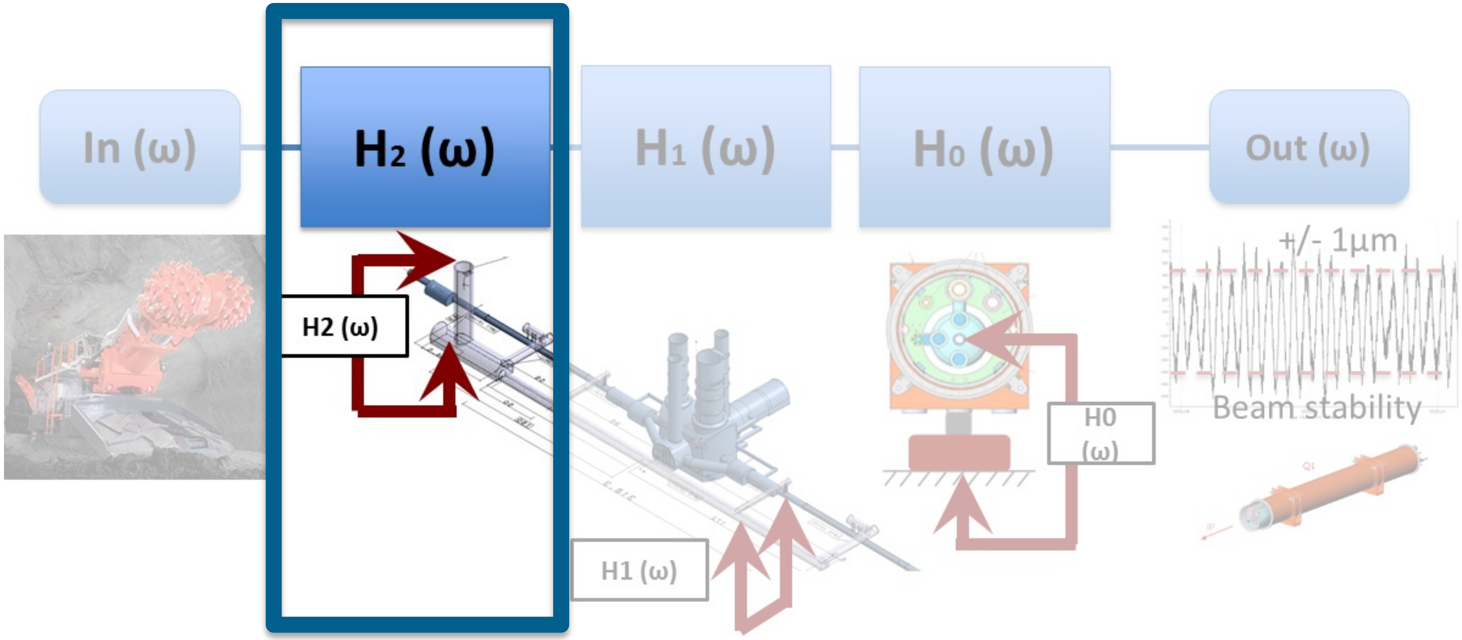


$H_1(\omega)$ Results

- Transfer function TAG41/TT41 – Vertical dir.

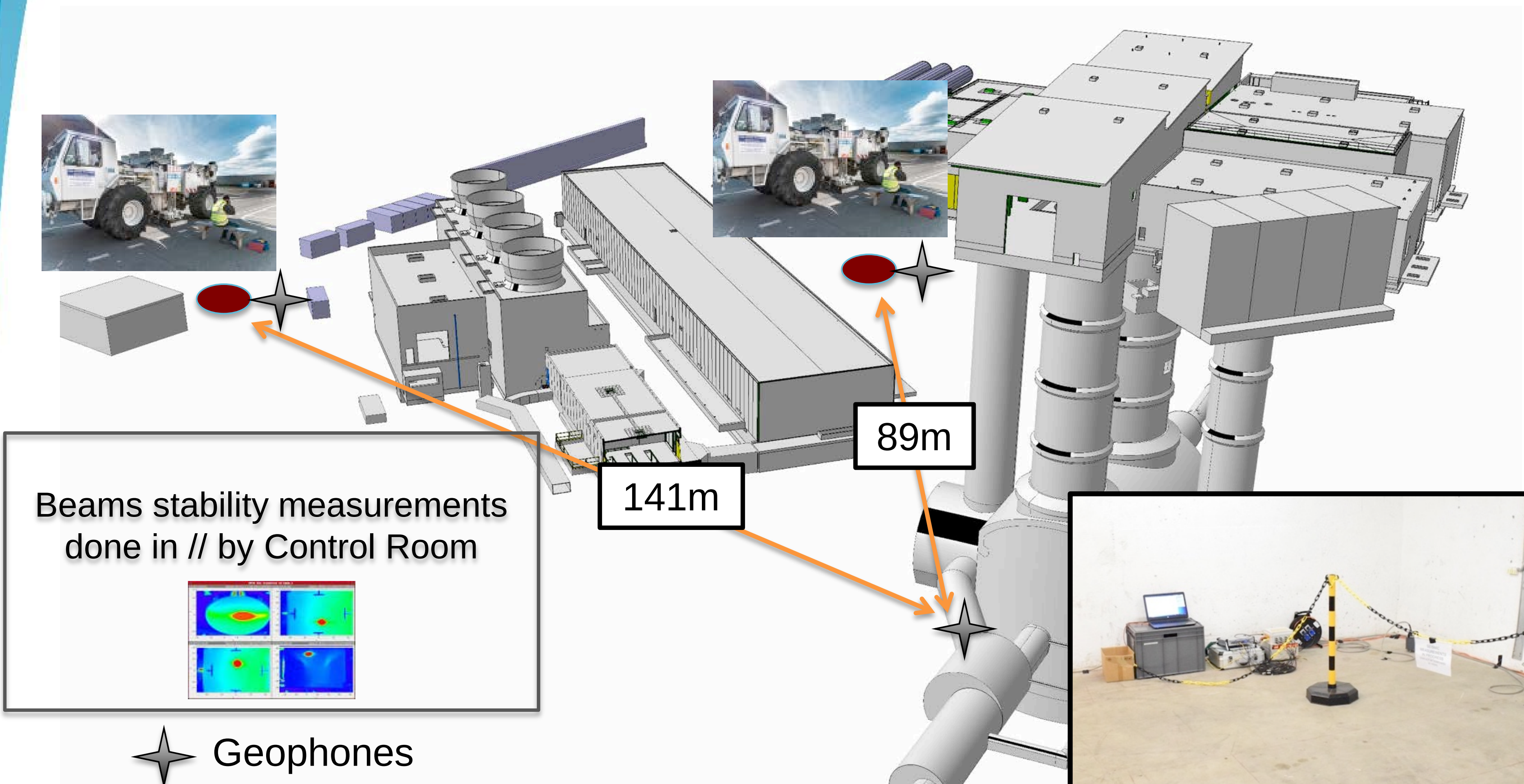


$H_2(\omega)$ Results



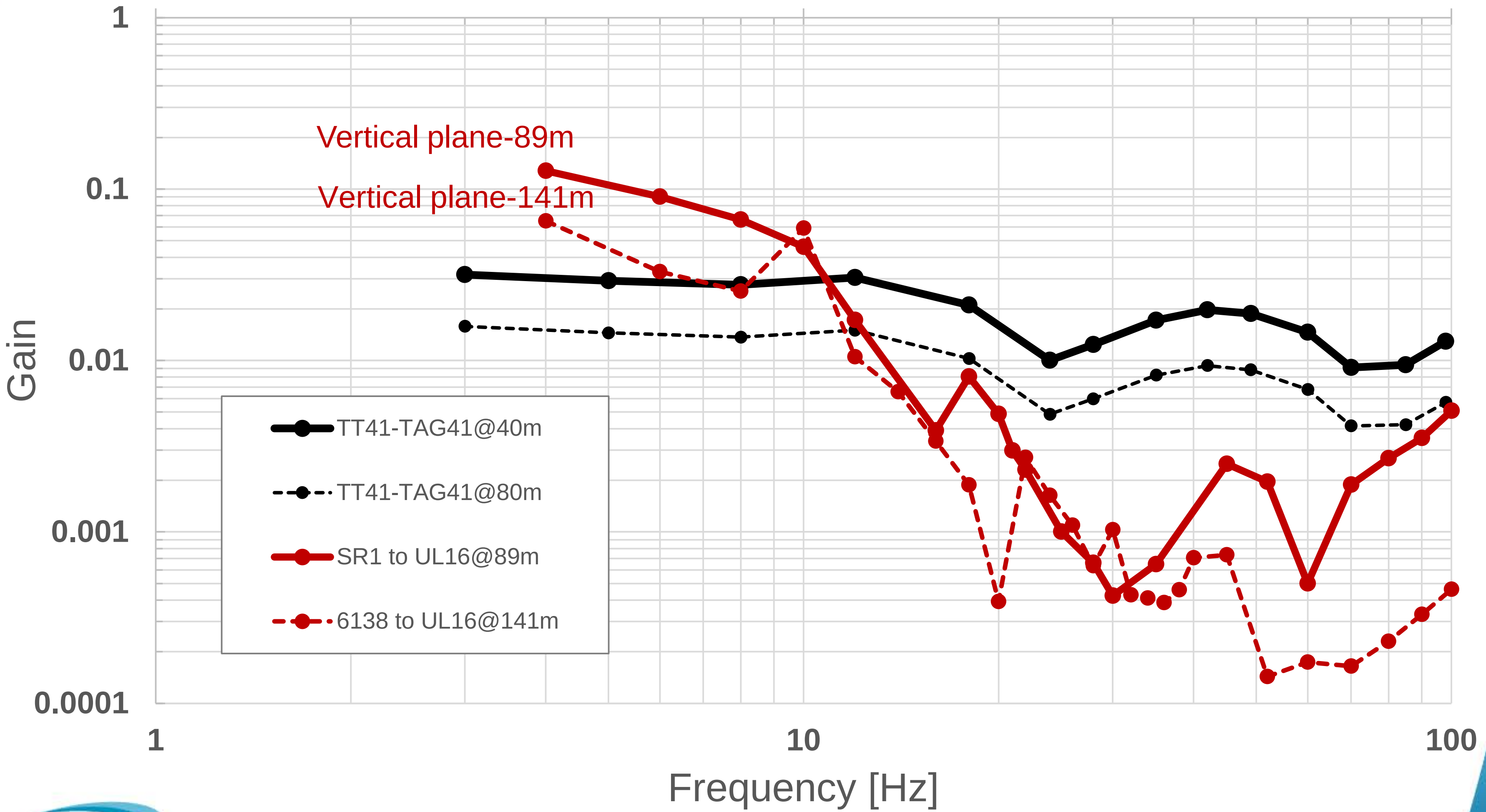
Setup for $H_2(\omega)$

- Vertical TF measurements at P1



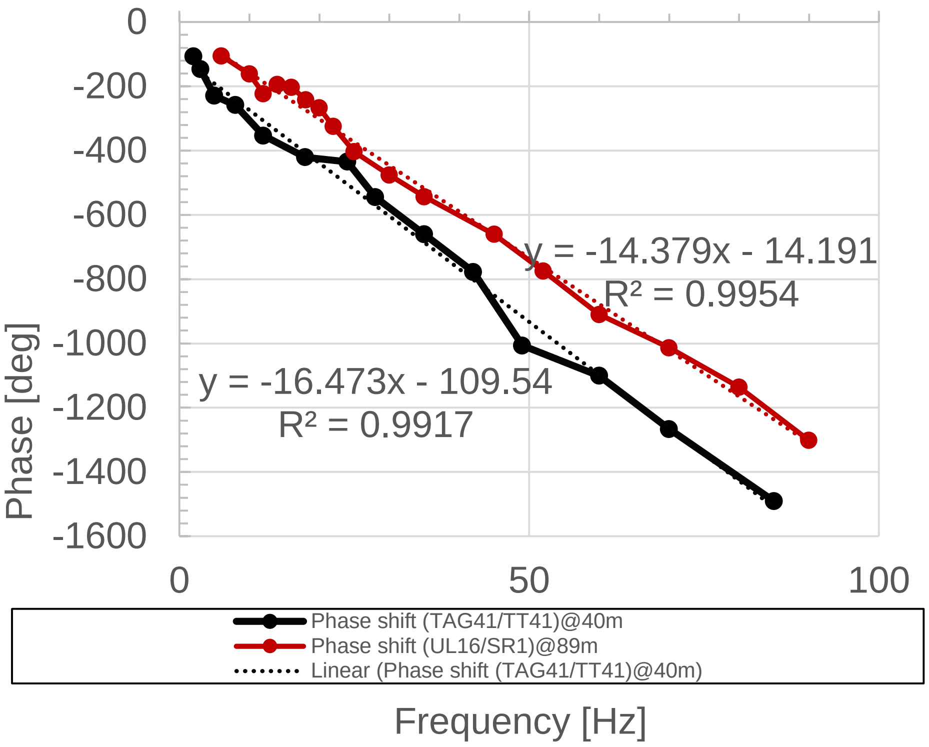
$H_2(\omega)$ Results

- Transfer function SR1/UJ16 – Vertical dir.



$H_2(\omega)$ Results

- Wave velocity between SR1 and UJ16



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

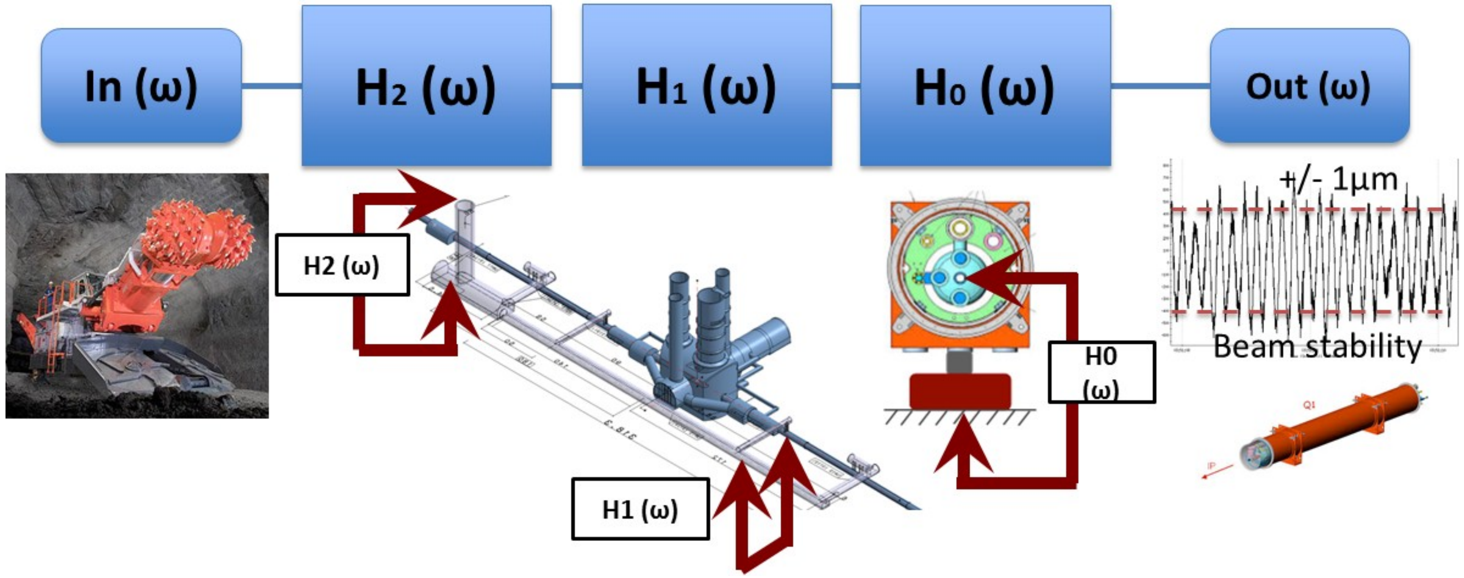
λ – wavelength [m]
z – distance between geophones [m]
θ - phase shift between geophones [rad]

Positions	V [m/s]	Waves (*)
TT41/ TAG41	≅900	Shear
UL16/SR1	≅2200	Pressure

(*) Waves velocity consistent with literature for the molasses

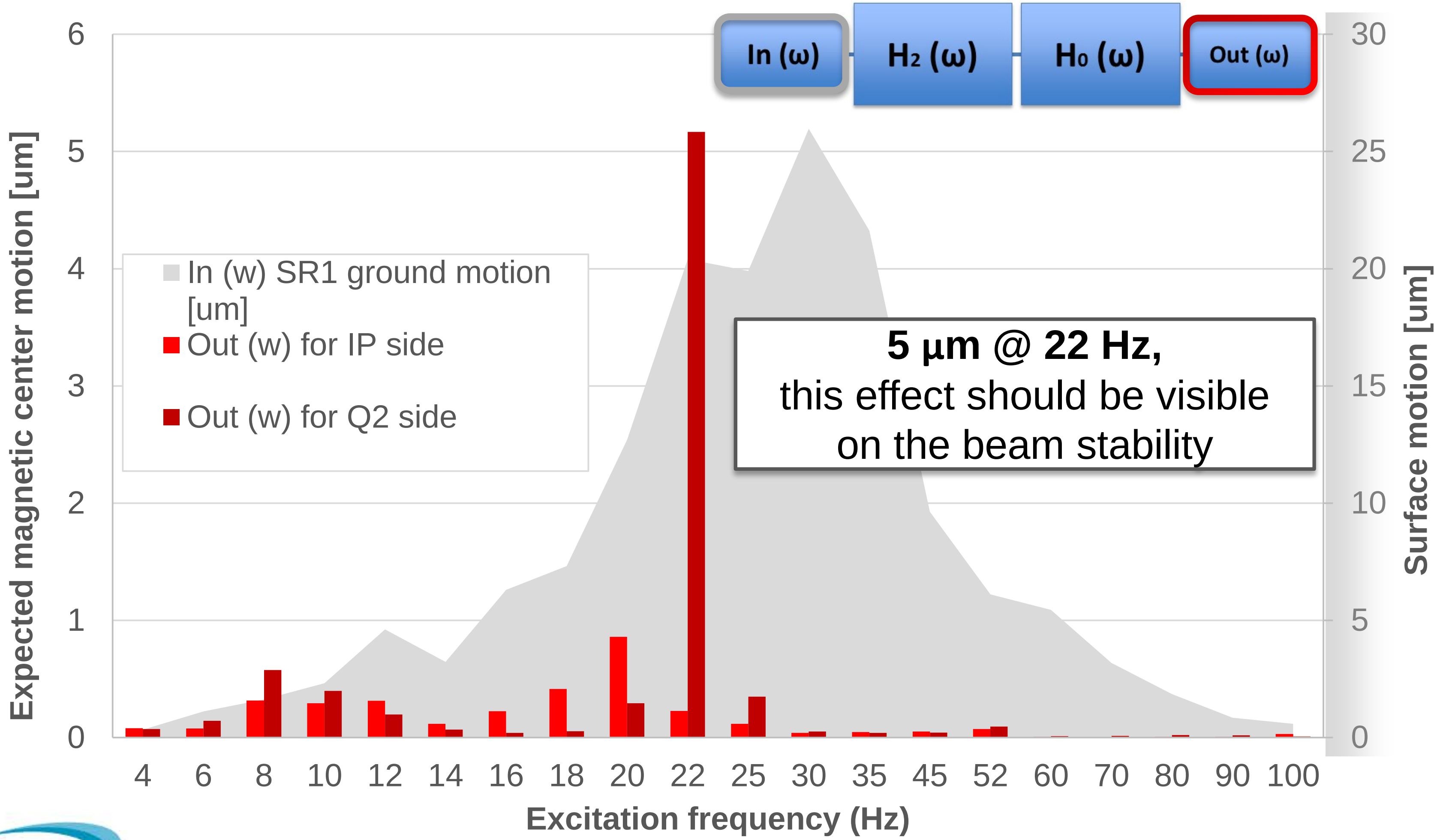
Typical rock velocities, from Bourbié, Coussy, and Zinszner, Acoustics of Porous Media, Gulf Publishing.

Combined Results



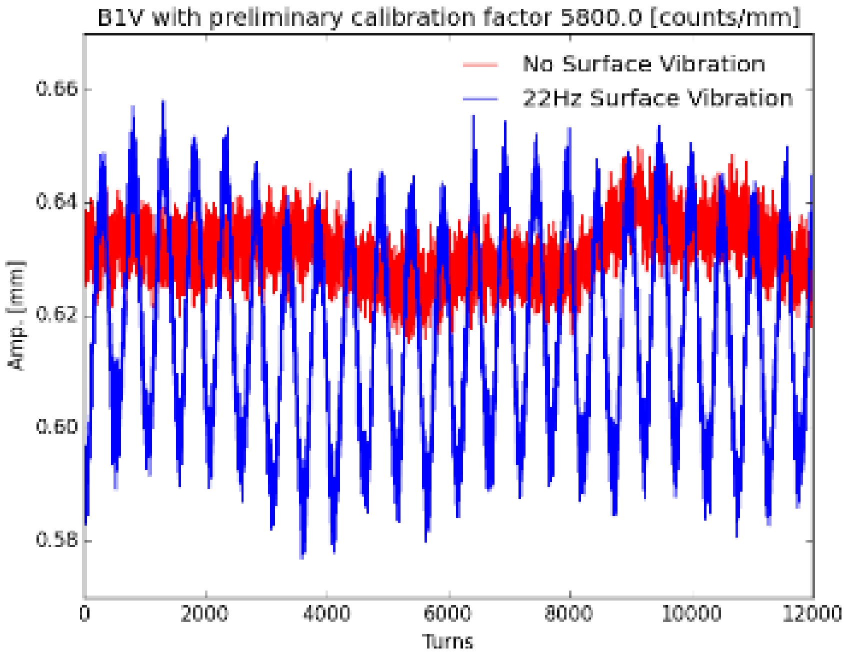
Combined Results

- Expected magnetic center motion

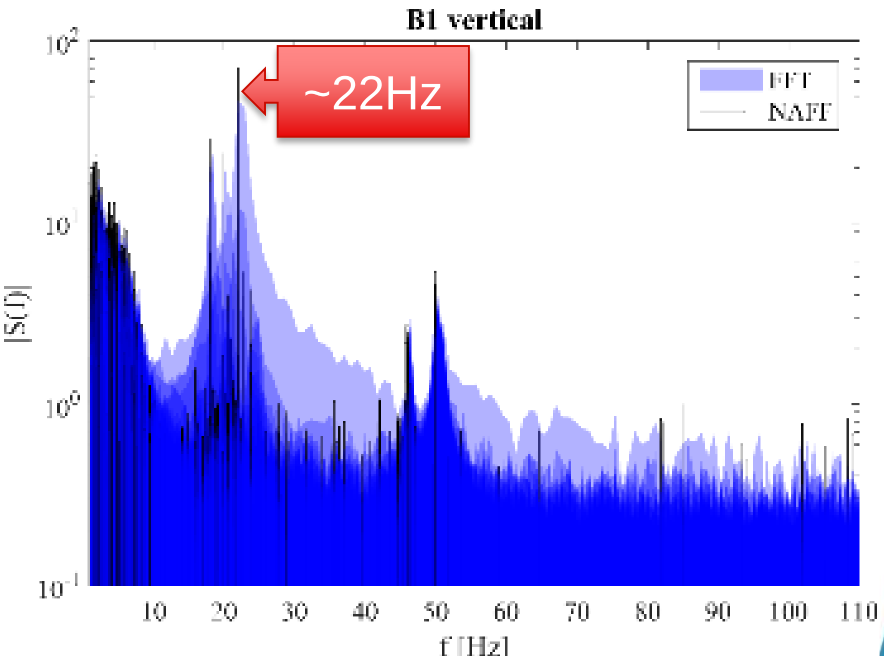


Combined Results

- <u>Vibration truck impact:</u>

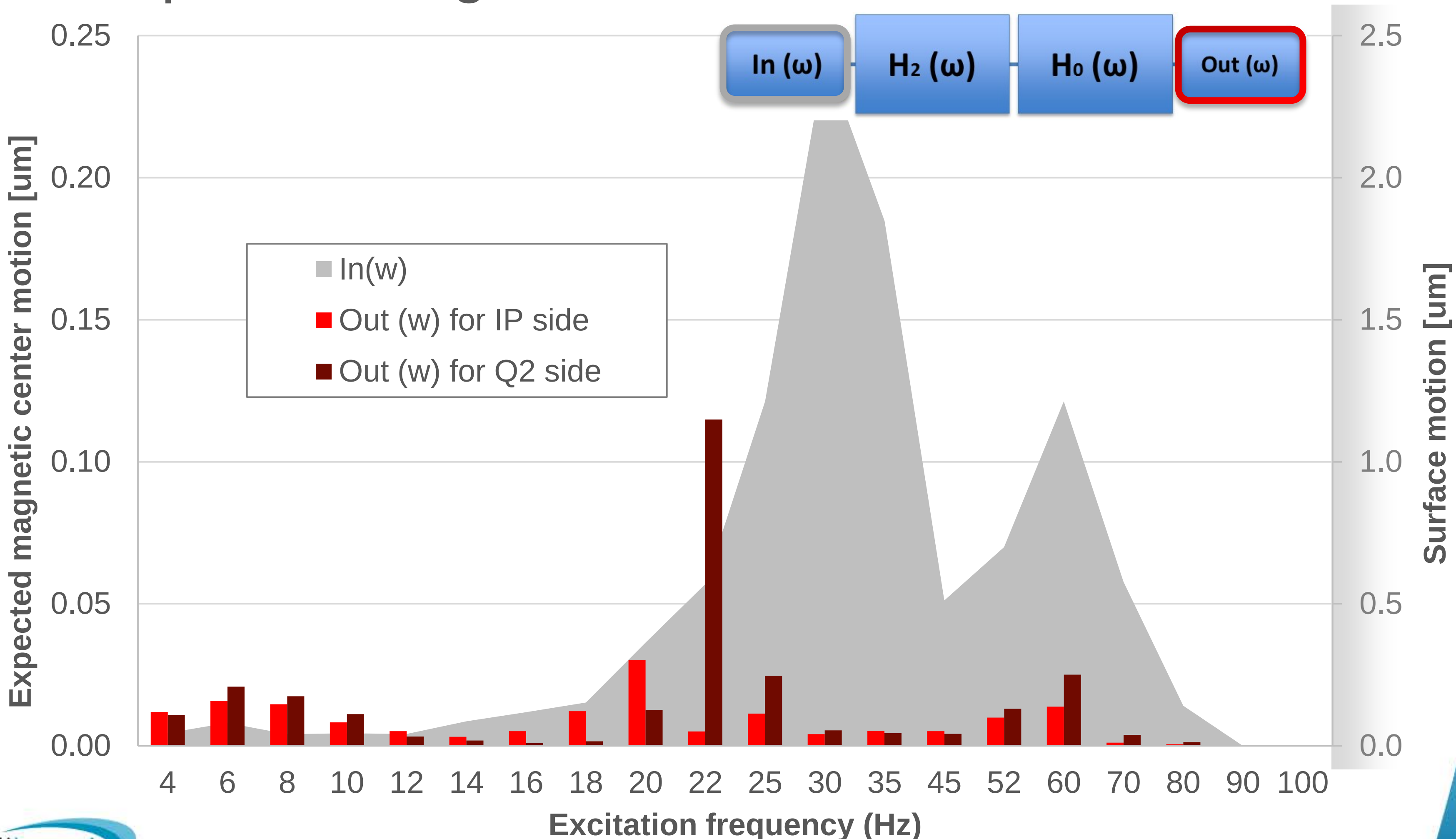


- Beam oscillations observed only for vibration frequencies **(18-22 Hz)**
- Effective amplitudes of triplet quads **few mm** vs **~50 nm** of ground motion
- Observations are consistent with the dynamic properties of the Q1 magnet



Combined Results

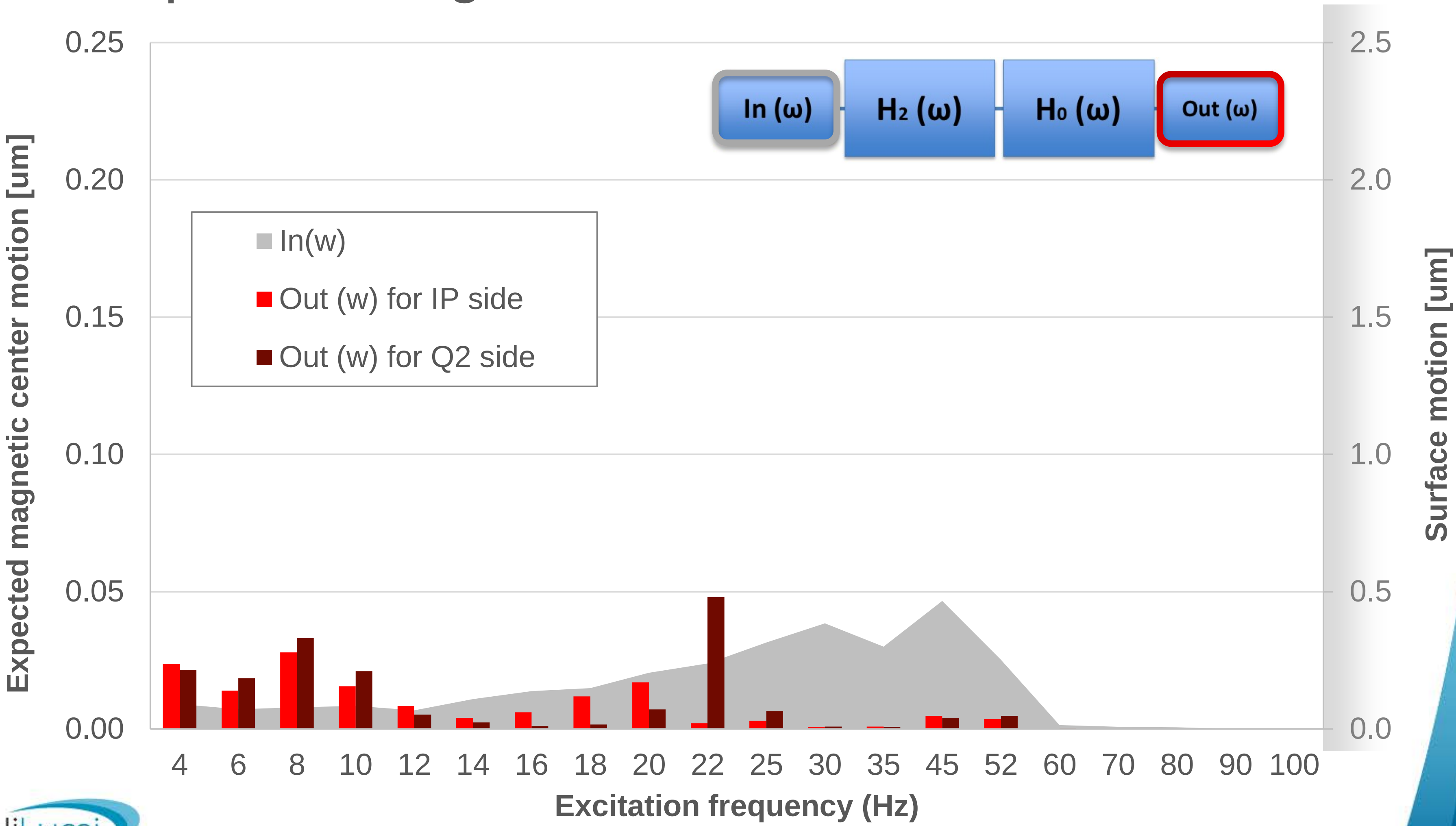
- Expected magnetic center motion



22

Combined Results

- Expected magnetic center motion



Conclusions

- Vibration analysis performed on the Q1 magnet (SM18) have shown several natural frequencies below 100 Hz, with the highest gain around 100 at 22 Hz. This dynamic behaviour was confirmed by beam position stability measurement during tests with the vibrator truck.

- Attenuation factor through the molasse rock was measured around 20 at 5Hz up to 60 at 100 Hz

- With the heavy vibrator truck tests, the expected magnetic center motion has exceeded 1 µm around 22 Hz. This motion was shown on the beam position stability measurement.

- According to the dynamic behavior of Q1 magnet, external vibration source (standard truck for civil engineering) at the surface are able to generate magnetic center motion between 50 nm – few µm

Implications

- The knowledge of the dynamic behaviour of the structure is one of the key elements in order to perform safe civil engineering activities during accelerator operation.

- The ground motion limits (amplitude, frequency) need to specified and considered in advance

- Civil engineering activities during beam operation can be problematic and should be controlled

Thank you!

Questions

$H_0(\omega)$ Results – SSS Comparison

LHC-CRI Technical Note 2002-06
EDMS No: 347269
2002-07-30

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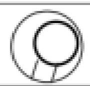
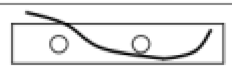
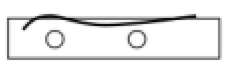
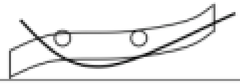
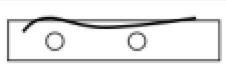
Experimental modal analysis and acceleration measurements during transport of a LHC Short Straight Section

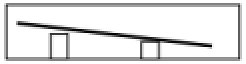
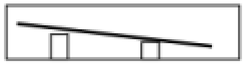
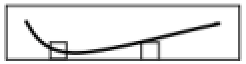
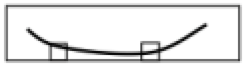
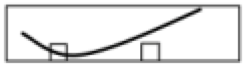
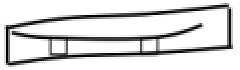
K. Artoos (EST/ME), O. Capatina (LHC/CRI)

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**

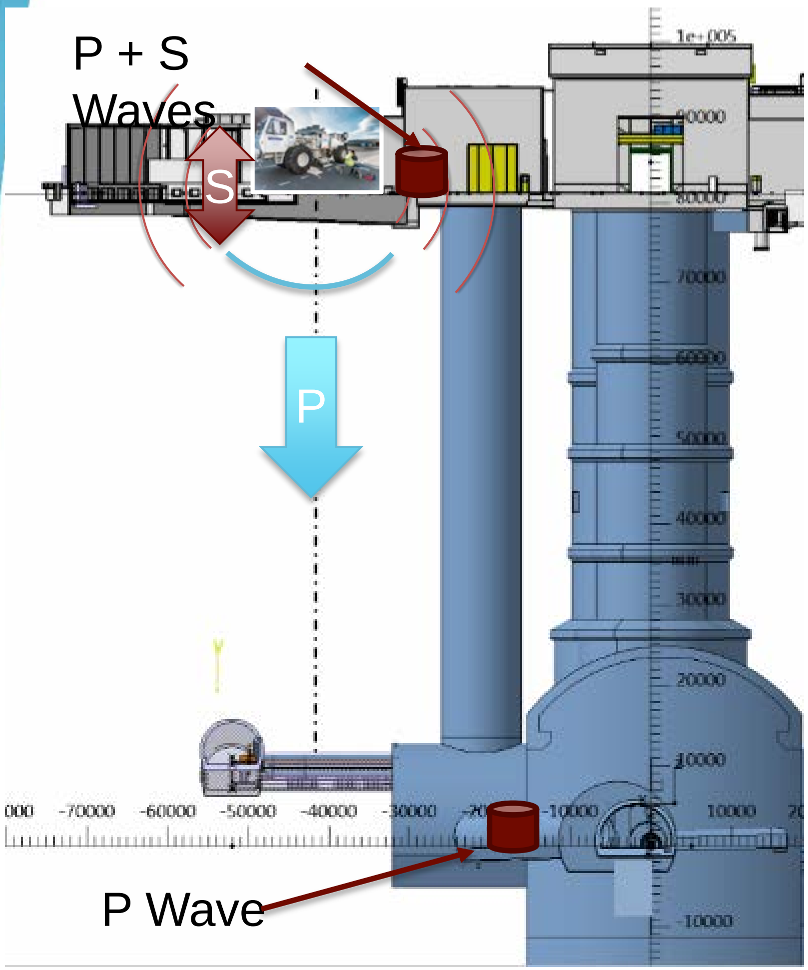
8 Hz for Q1

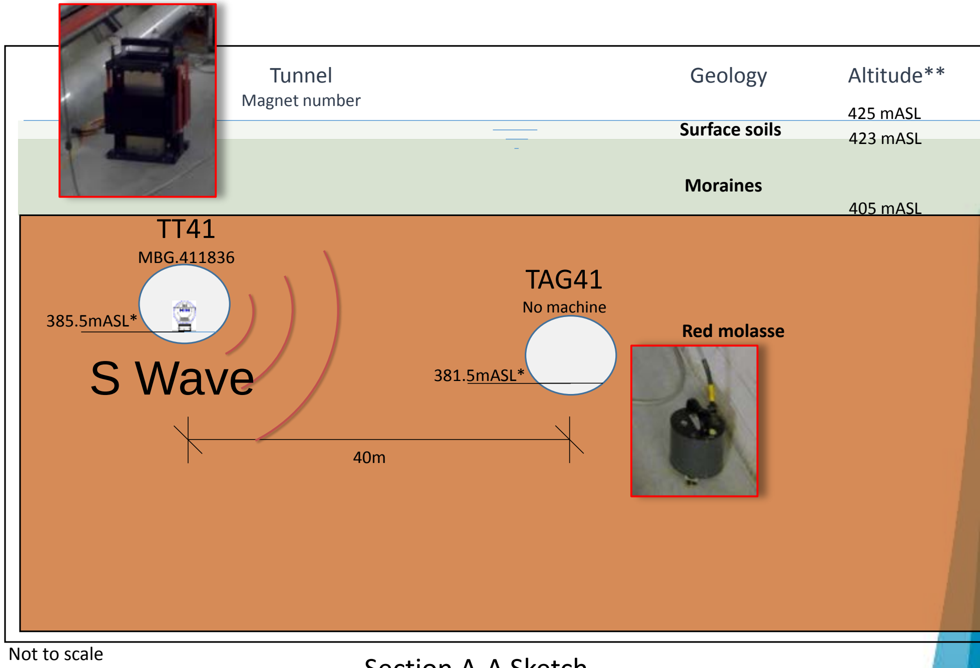
Table 2 - Vertical modes of SSS5, with and without transport restraints

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

Pressure of Shear Waves





Section A-A Sketch