# Vibration analysis of the ILD QD0-support system

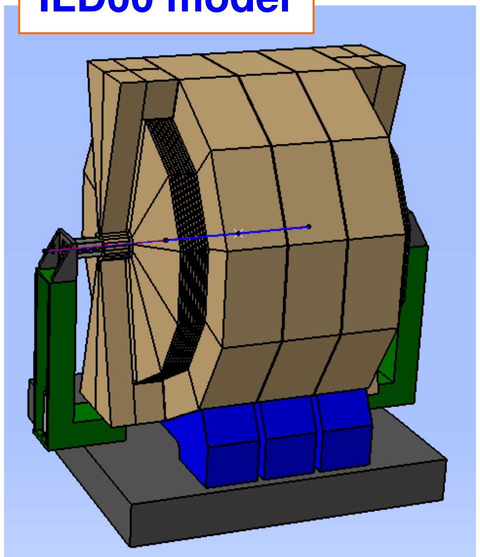
**KEK Hiroshi Yamaoka**

- **Results of Vibration analysis**
- **Coherency measurement at KEKB**

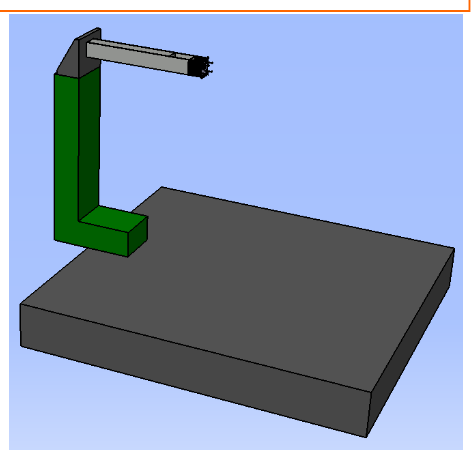
# Introduction

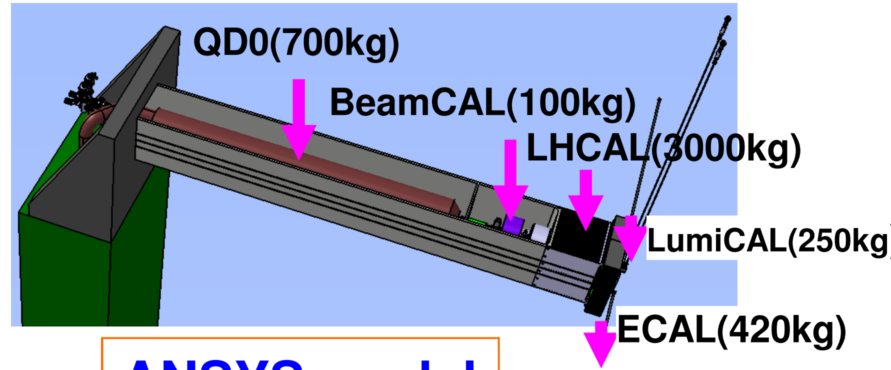
**Vibration properties of the ILD QD0 support system has been studied.**

ILD00 model

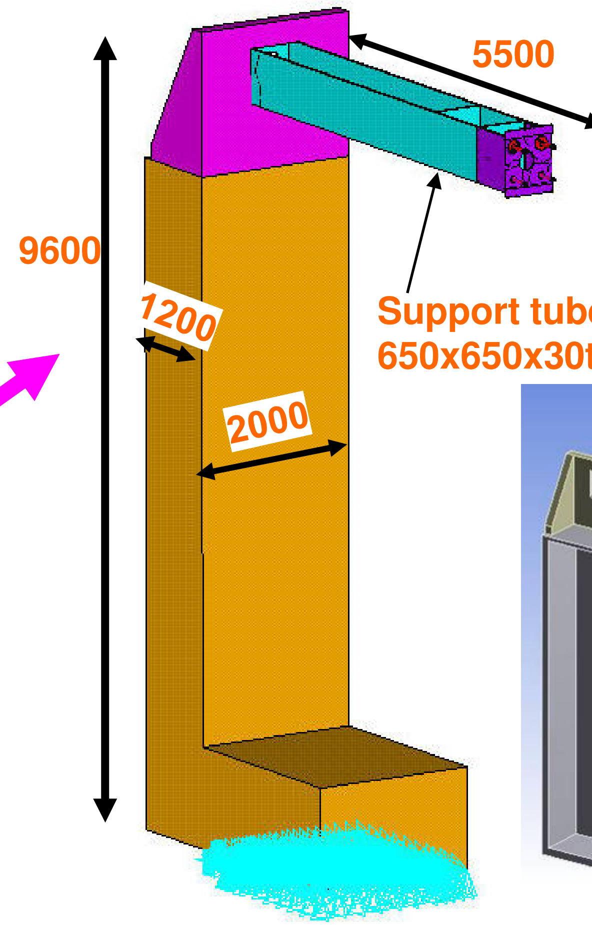


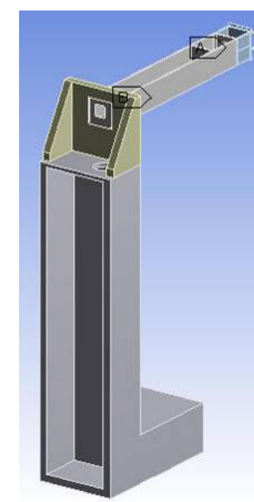
ILD QD0 support system



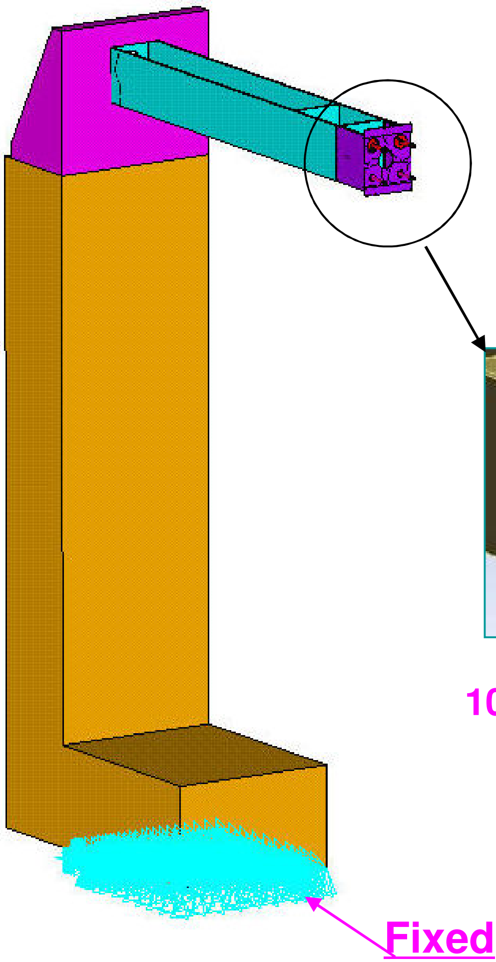


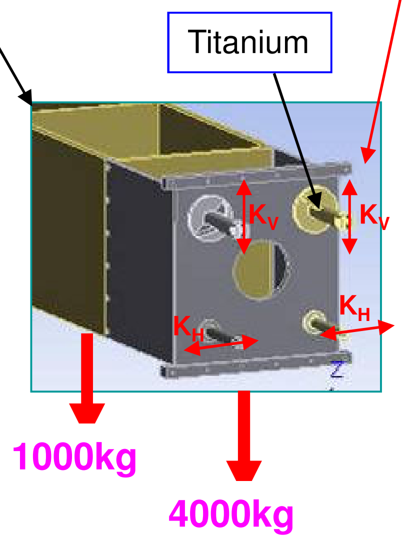

ANSYS model

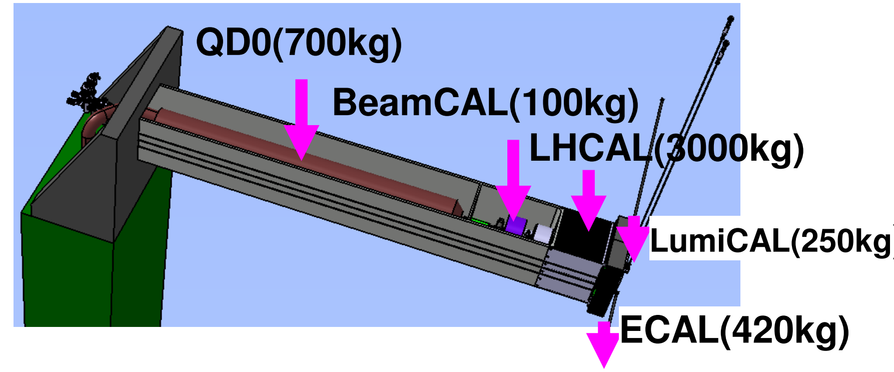


# Assumptions




**- Spring constant**
**- Static loads**
**are defined.**

**Calculation of spring constant of the tension rods.**

**For the modeling of tension rods, spring constants are defined on the top of support rods.**

**Tension rods; CFRP**
**E=130GPa**
**Density: 1.5e-6kg/mm^3**

$$\sigma = \varepsilon \cdot E$$

$$P/A = \frac{\Delta l}{l} \cdot E$$

$$P = \frac{\Delta l}{l} \cdot E \cdot A$$

When $\Delta l$ is $1mm$, P shows the spring constant.

$$P_{vertical} = \frac{1}{3180} \cdot 1.3 \times 10^4 \cdot (50 \times 2)$$
$$= 410kg$$

$K_V = 410\,kg/mm$ : Spring constant of the vertical tension rods.

$$P_{horizontal} = \frac{1}{3000} \cdot 1.3 \times 10^4 \cdot \pi\left(20^2 - 18^2\right)$$
$$= 1035kg$$

$K_H = 1035\,kg/mm$ : Spring constant of the horizontal tension rods.

# Approaches to know vibration behavior

Ref.: ANSYS help file

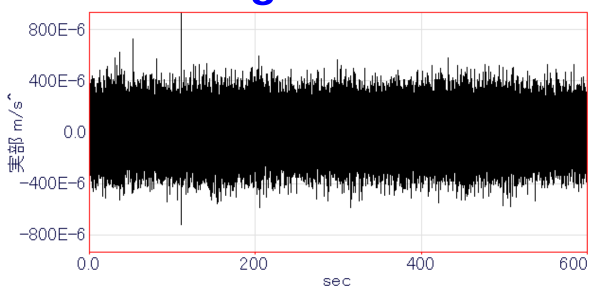
## 1. P.S.D. (Power Spectrum Density) analysis

A *PSD* is a statistical measure of the response of a structure to random dynamic loading conditions. It is a graph of *the PSD value versus frequency*, where the PSD may be a displacement PSD, velocity PSD, acceleration PSD, or force PSD. Mathematically, the area under a PSD-versus-frequency curve is equal to the variance (square of the standard deviation of the response).

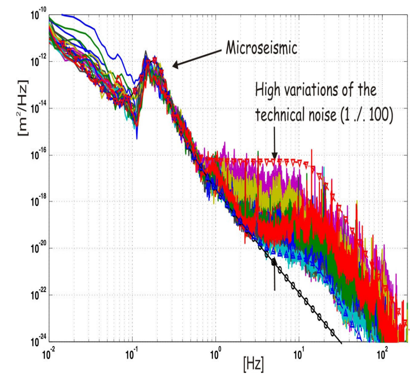
## 2. Spectrum (SPRS) analysis

A *response spectrum* represents the *response* of single-DOF systems to a time-history loading function. It is a graph of response versus frequency, where the response might be displacement, velocity, acceleration, or force. Two types of response spectrum analysis are possible: single-point response spectrum and multi-point response spectrum.

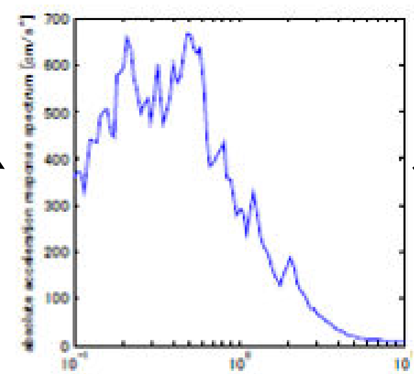
**Measure ground motion**



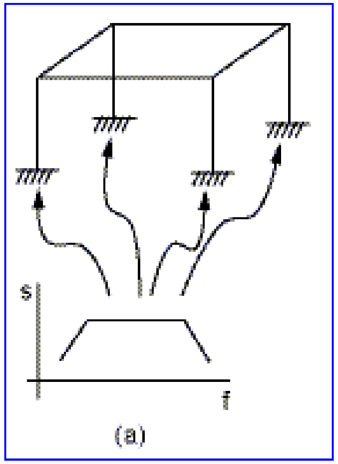

**1. P.S.D.**




**2. Make R. spectrum**



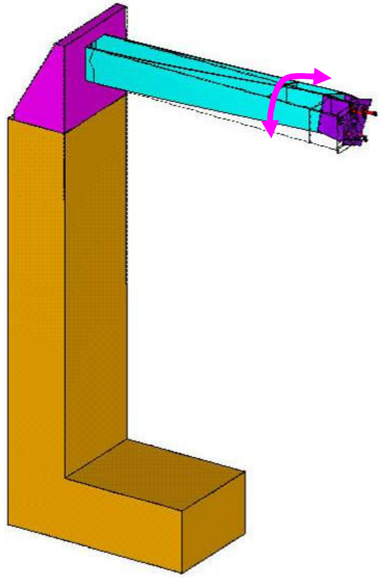

Input each data to constraints positions.



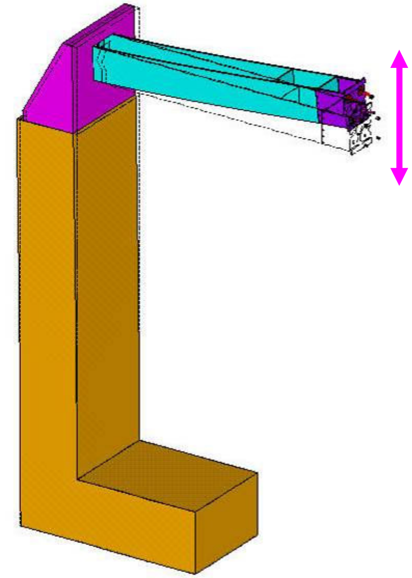

Get respond amplitude/stress at each position.

# Natural frequency

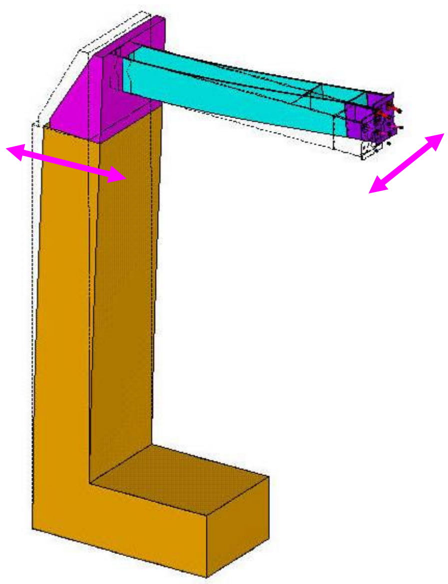
4.5Hz



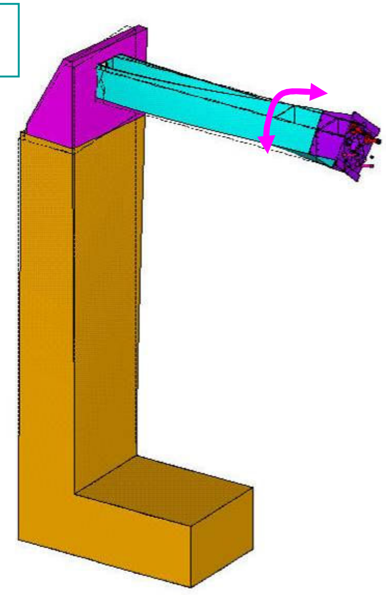
7.9Hz



10.4Hz

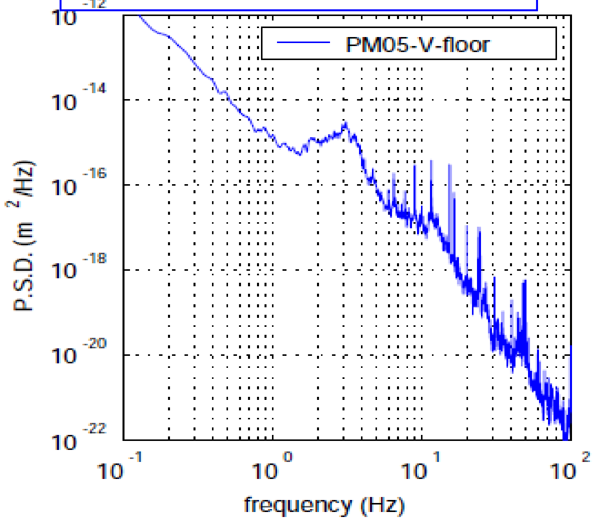


13.6Hz



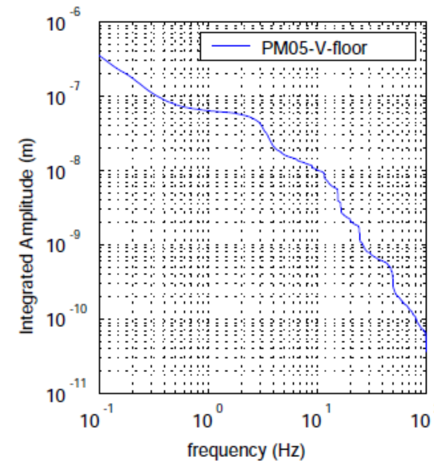
# P.S.D. (Power Spectrum Density) analysis

ATF-2004Feb10-17:00UD

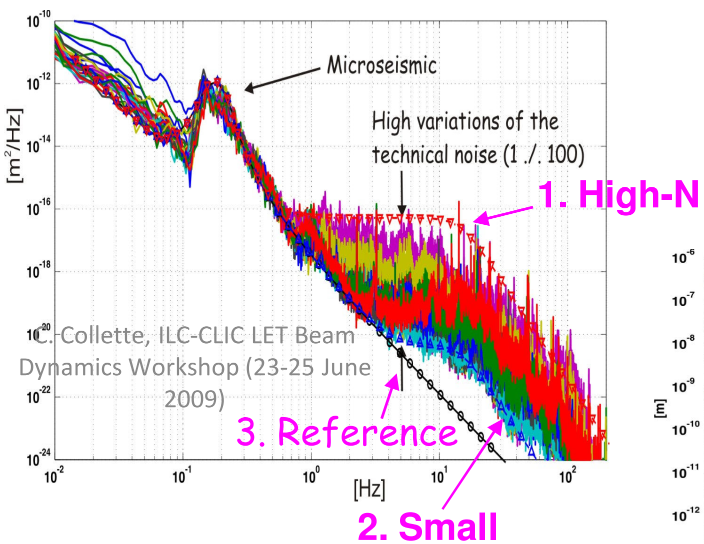



## Each P.S.D. data is used.

| Freq. (Hz) | P.S.D. (m²/Hz) |
|---|---|
| 0.1 | 1e-11 |
| 0.3 | 1e-14 |
| 0.4 | 1e-13 |
| 1 | 1e-15 |
| 3 | 1e-14 |
| 200 | 1e-29 |




Vertical ground motion




***1. High-N***

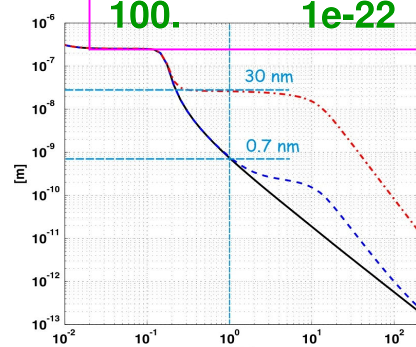
| Freq. (Hz) | P.S.D. (m²/Hz) |
|---|---|
| 0.1 | 1e-14 |
| 0.15 | 1e-12 |
| 0.7 | 8e-17 |
| 10. | 8e-17 |
| 100. | 1e-22 |

***2. Small-N***

| Freq. (Hz) | P.S.D. (m²/Hz) |
|---|---|
| 0.1 | 1e-14 |
| 0.15 | 1e-12 |
| 0.7 | 8e-17 |
| 4.0 | 1e-20 |
| 13. | 5e-21 |
| 100. | 3e-26 |

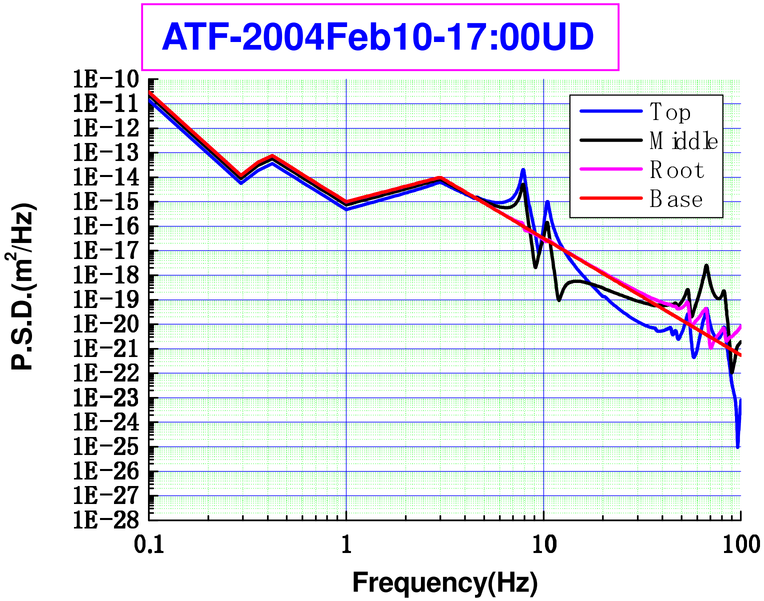
***3. Reference***

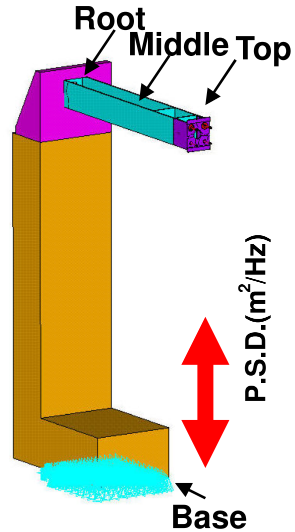
| Freq. (Hz) | P.S.D. (m²/Hz) |
|---|---|
| 0.1 | 1e-14 |
| 0.15 | 1e-12 |
| 0.7 | 8e-17 |
| 100. | 8e-28 |

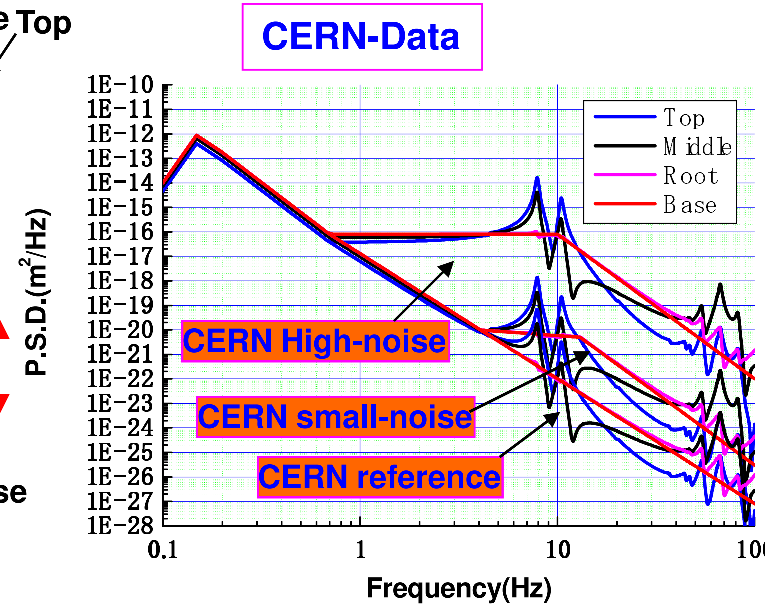


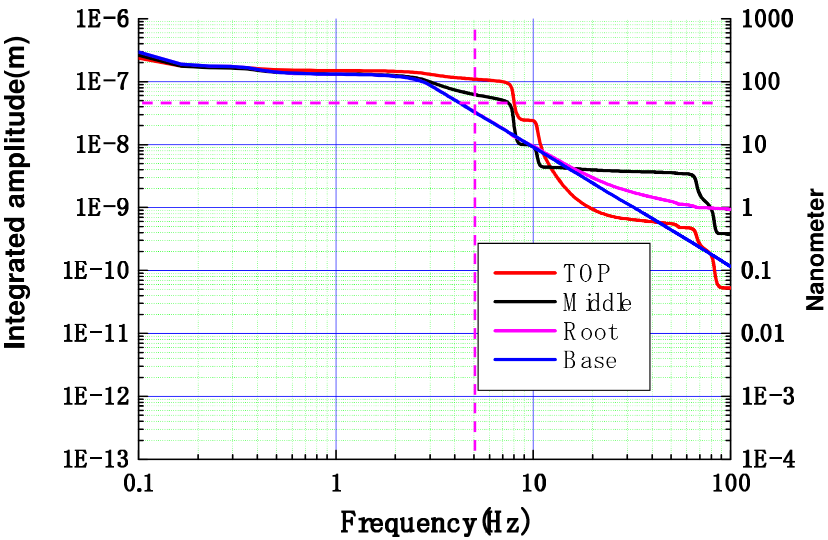

**Allowable Amplitude**
**→ 50nm at 5Hz**

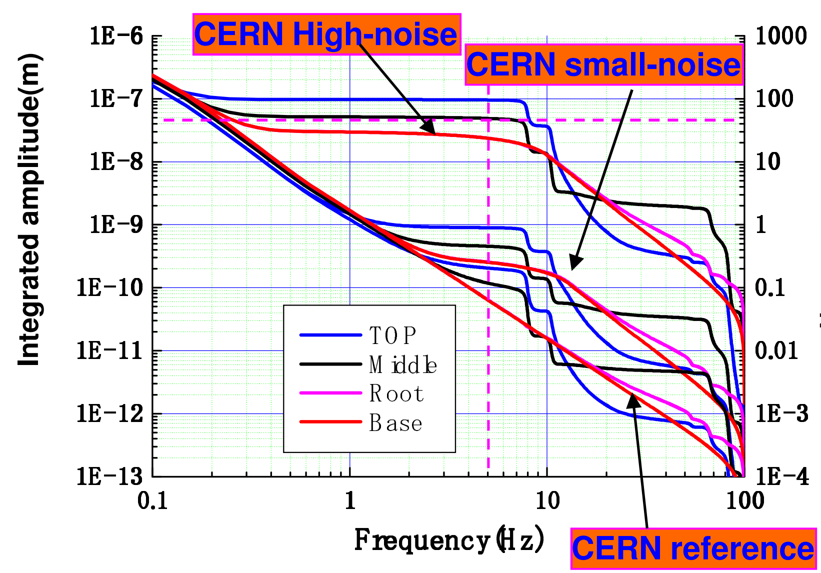
# Calculation results: *Vertical direction*



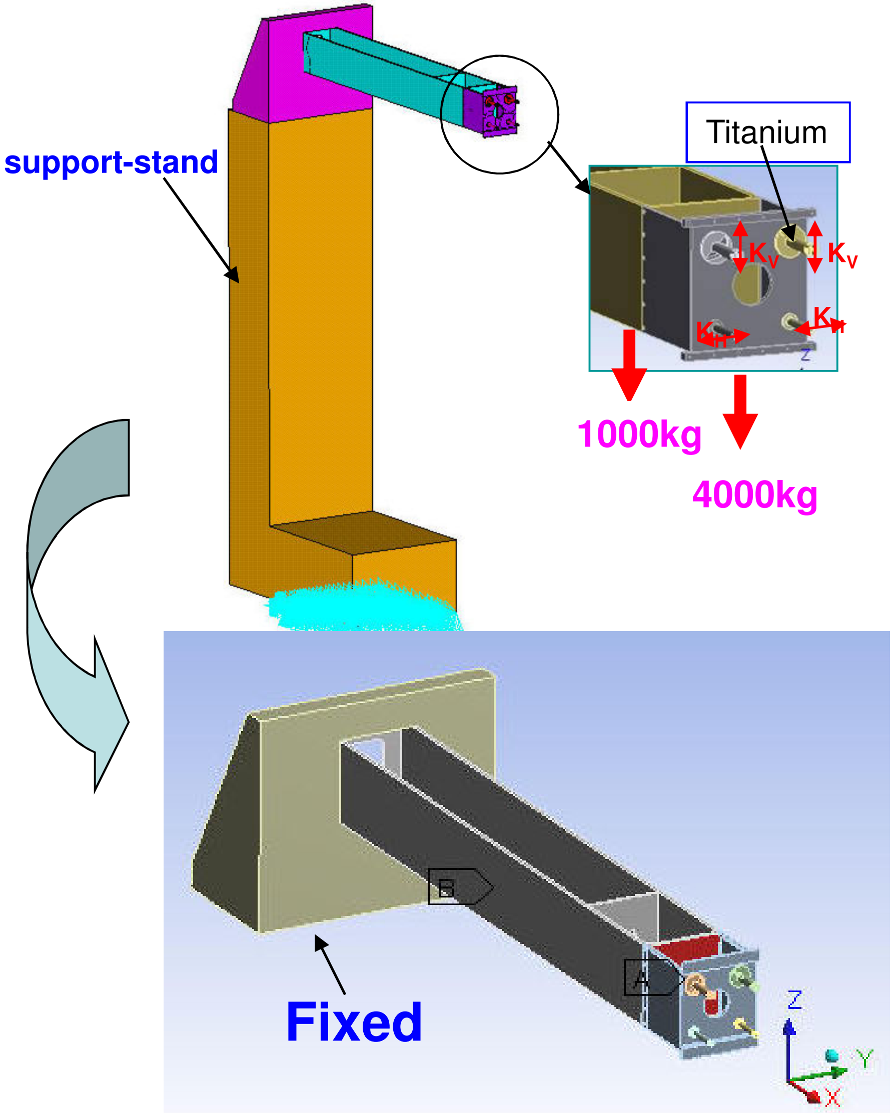



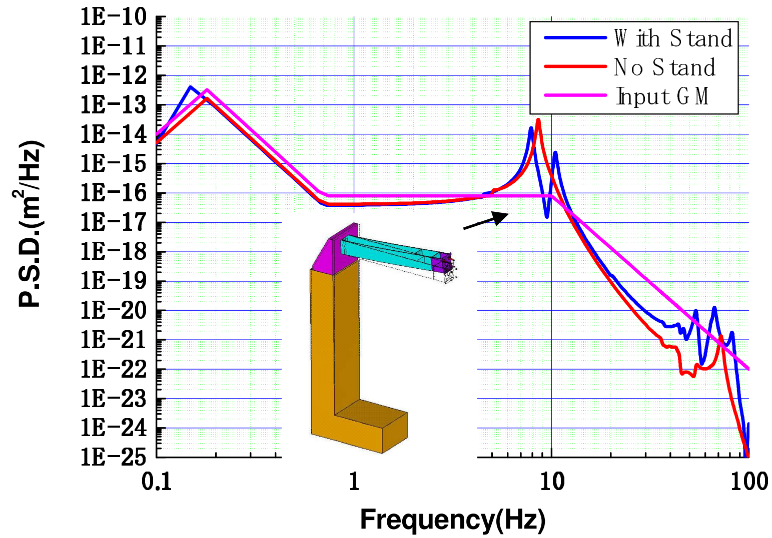



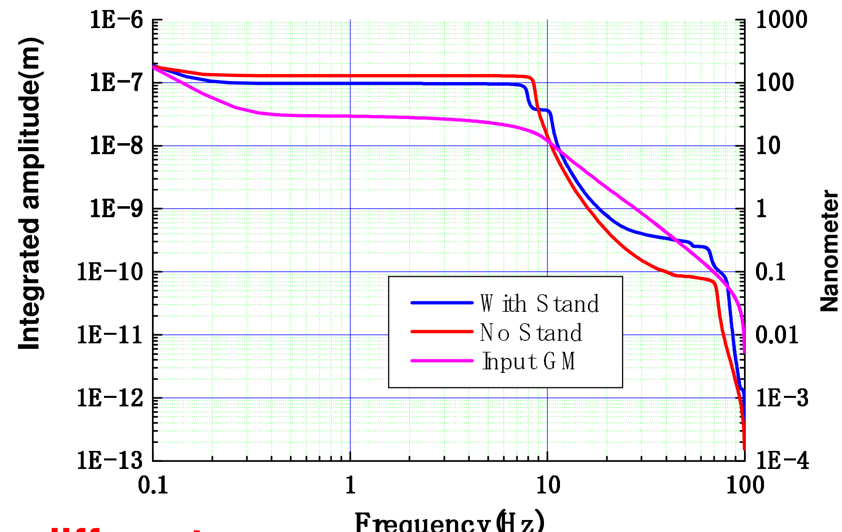




➔ **Integrated amplitude at 5Hz: Larger than 50nm.(ATF, CERN High)**
**Much smaller than 50nm(CERN small, Reference)**

# If the support-stand were removed,



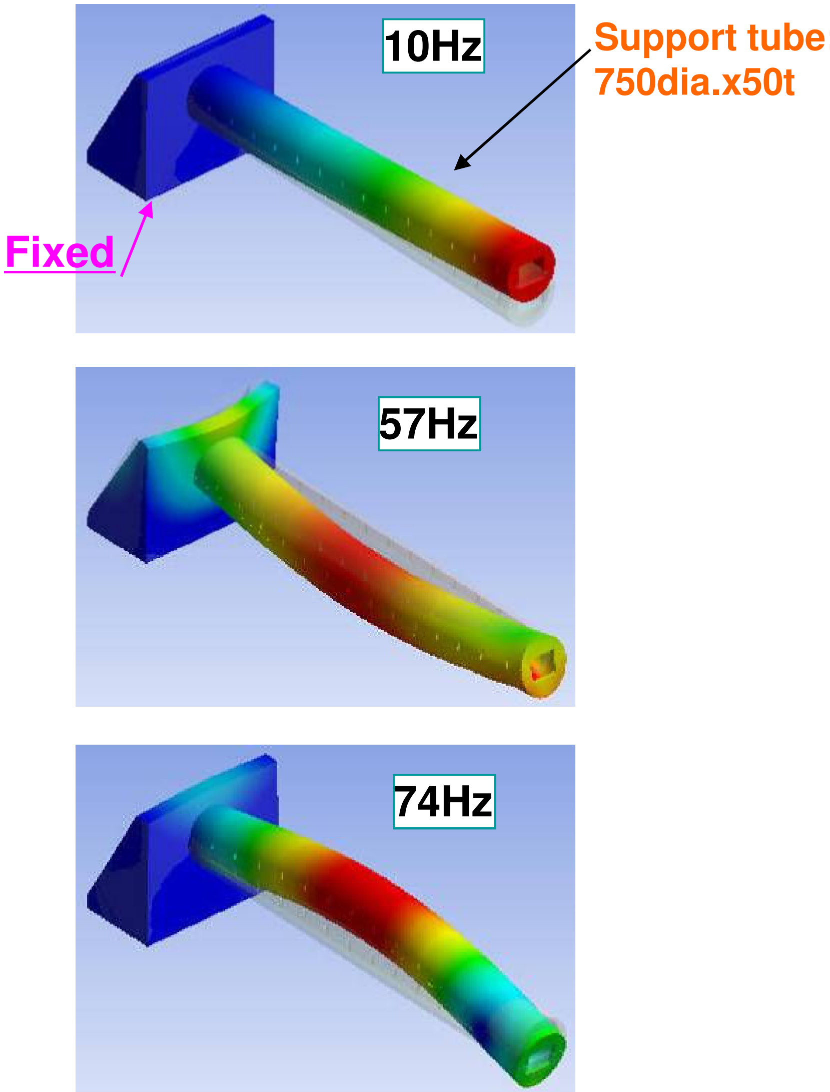



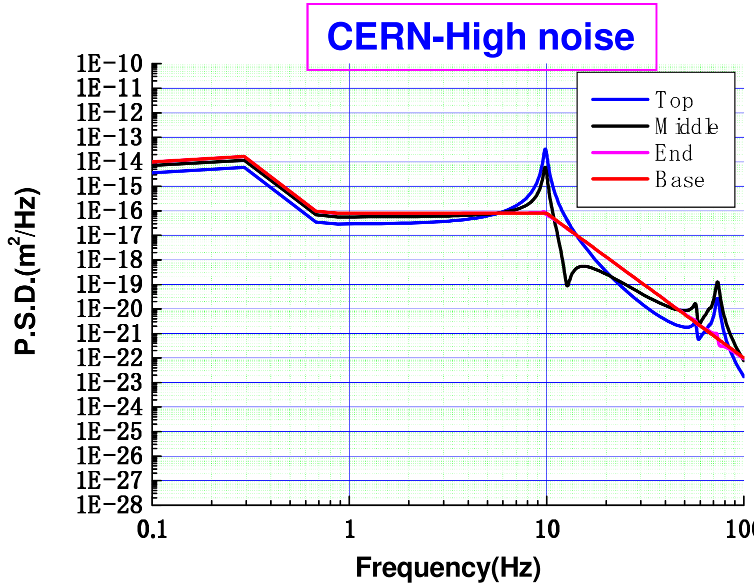



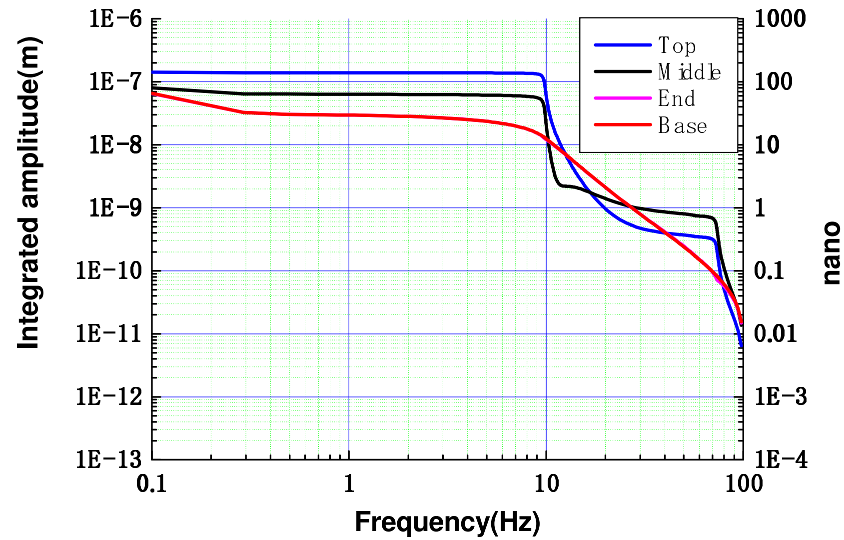

➔ Integrated amplitude at 5Hz: It is not so different.
Integrated amplitude at above 10Hz: 'No-support-stand model' is smaller.

Amplitude is mainly determined by the amplitude of the support tube.

# In case of cylindrical support-tube;



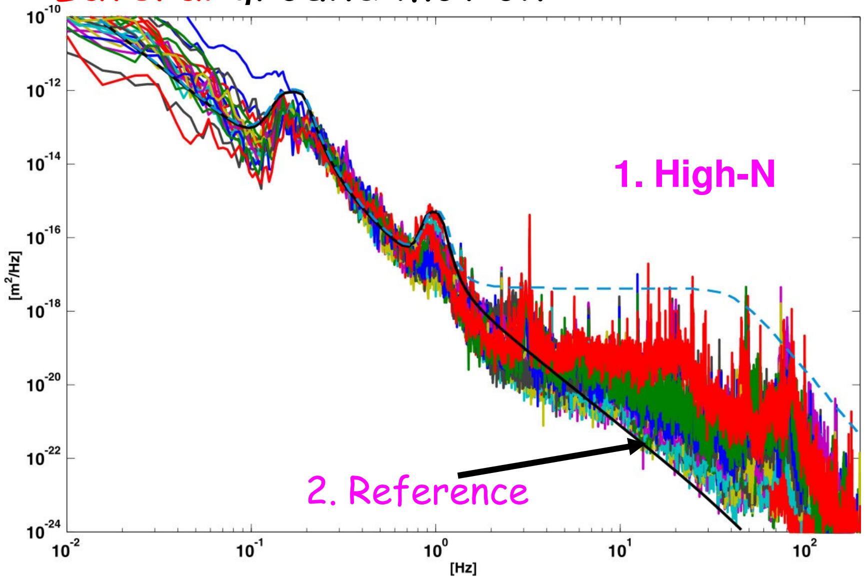




→ Integrated amplitude at 5Hz: It is not so different from Square-tube.

→ 1st mode of natural frequency is almost same.

# Calculation: *Horizontal direction*

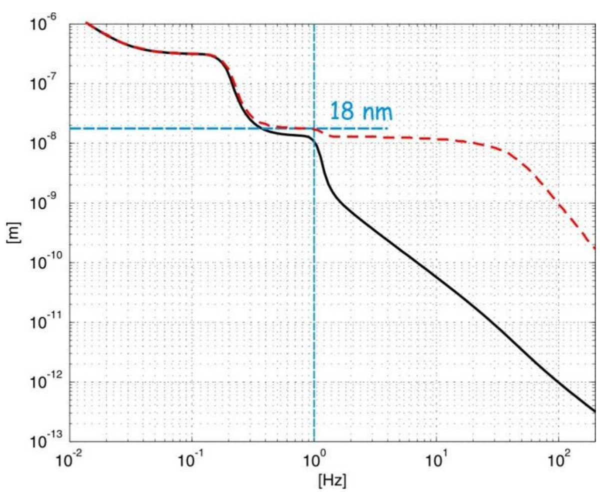
Lateral ground motion

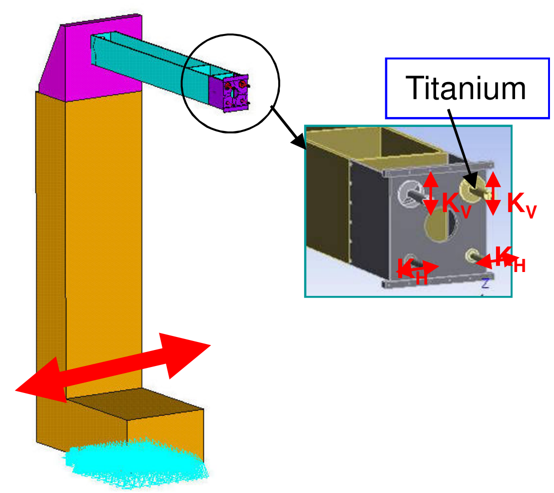



C. Collette, ILC-CLIC LET Beam Dynamics Workshop (23-25 June 2009)

| *1. High-N* | |
|---|---|
| Freq. (Hz) | P.S.D. ($m^2$/Hz) |
| 0.1 | 1e-13 |
| 0.16 | 1e-12 |
| 0.7 | 8e-17 |
| 0.95 | 8e-16 |
| 1.3 | 1e-17 |
| 33. | 7e-18 |
| 200. | 3e-22 |

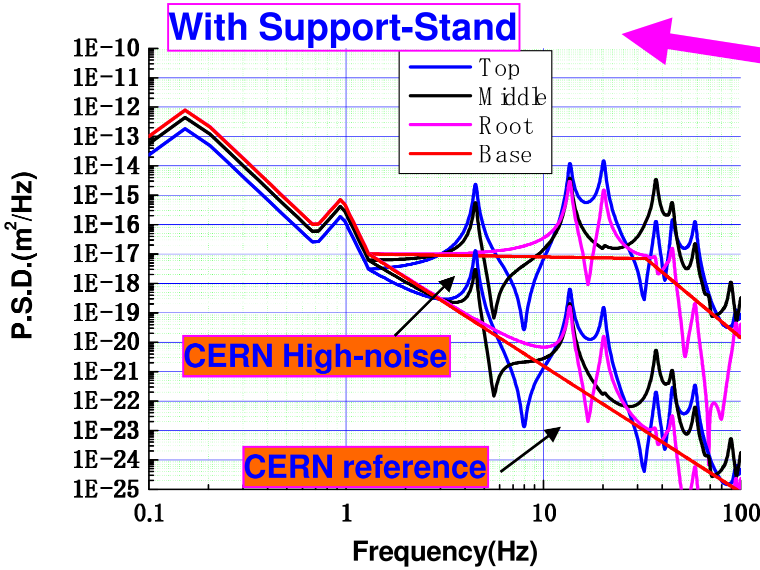
| *2. Reference* | |
|---|---|
| Freq. (Hz) | P.S.D. ($m^2$/Hz) |
| 0.1 | 1e-13 |
| 0.16 | 1e-12 |
| 0.7 | 8e-17 |
| 0.95 | 8e16 |
| 1.3 | 1e-17 |
| 200. | 4e-27 |

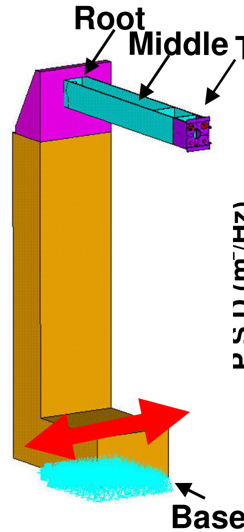


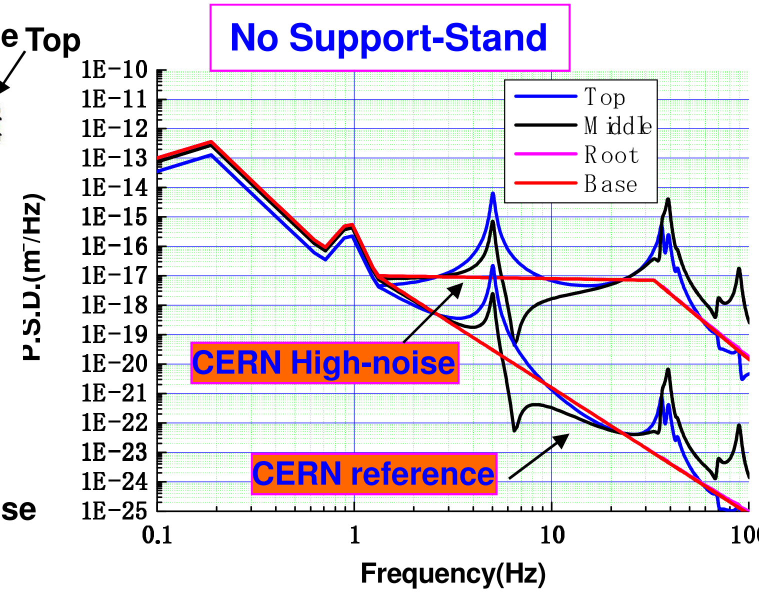



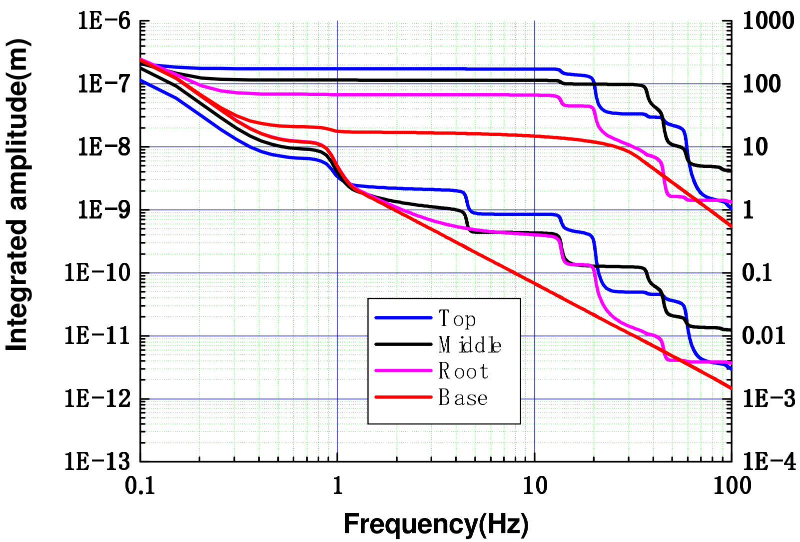

**Allowable Amplitude**
**→ 300nm at 5Hz**

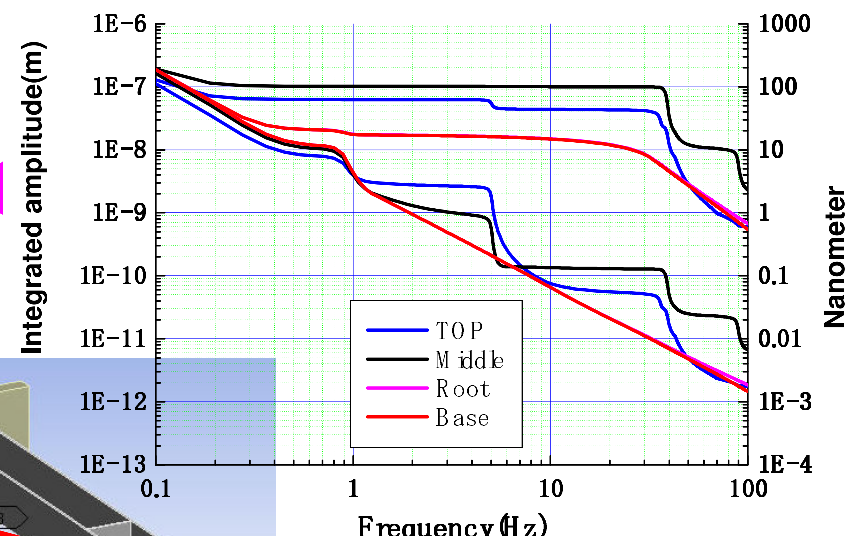
# Calculation results: Horizontal direction (Y-direction.)

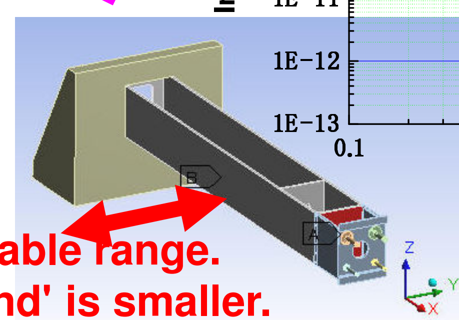


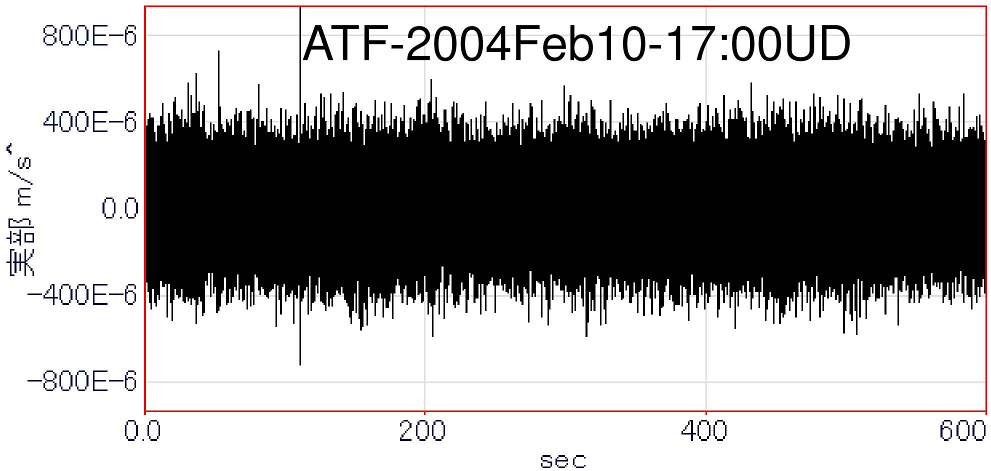



- Integrated amplitude is within the allowable range.
- Integrated amplitude at 'no-support-stand' is smaller.
  But it not so drastic improvement.

# Spectrum (SPRS) analysis




$$m\ddot{x}_i + c\dot{x}_i + kx_i = -m\ddot{z}_i$$

$$m\ddot{x}_{i+1} + c\dot{x}_{i+1} + kx_{i+1} = -m\ddot{z}_{i+1}$$

$$x_i, \dot{x}_i, \ddot{x}_i, \ddot{z}_{i+1}, dt = t_{i+1} - t_i$$

$$\ddot{x}_{i+1} = -\frac{\ddot{z}_{i+1} + 2h\omega\left(\dot{x}_i + \frac{1}{2}\ddot{x}_i dt\right) + \omega^2\left(x_i + \dot{x}_i dt + \left(\frac{1}{2} - \beta\right)\ddot{x}_i dt^2\right)}{1 + h\omega dt + \beta\omega^2 dt^2}$$

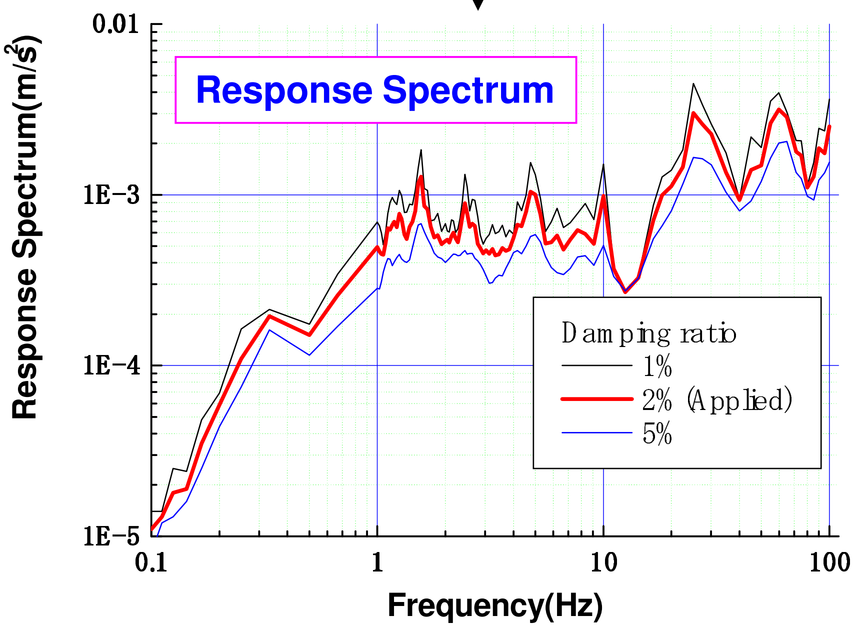
$$\dot{x}_{i+1} = \dot{x}_i + \frac{1}{2}(\ddot{x}_i + \ddot{x}_{i+1})dt$$

$$x_{i+1} = x_i + \dot{x}_i dt + \left(\frac{1}{2} - \beta\right)\ddot{x}_i dt^2 + \beta\ddot{x}_{i+1} dt^2$$

$$i = i + 1$$

図4.22 Newmarkの β 法

**Make response spectrum**



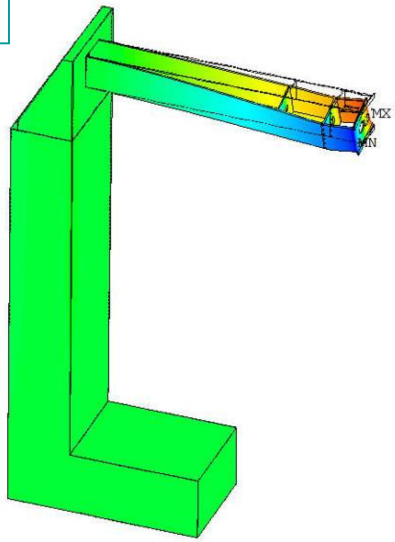

**These spectrum are applied.**

| | |
|---|---|
| 0.1Hz | 1e-5m/s$^2$ |
| 1Hz | 6e-4m/s$^2$ |
| 10Hz | 6e-4m/s$^2$ |
| 100Hz | 2e-3m/s$^2$ |

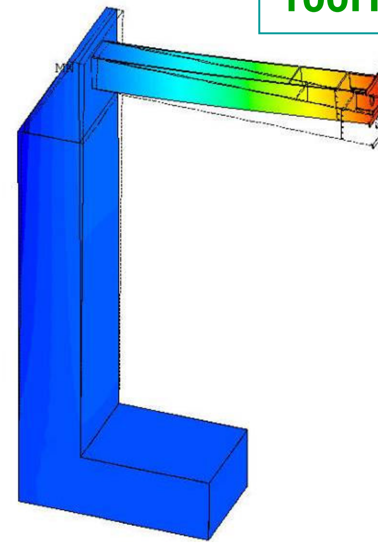
# Results: Responded amplitude at each resonance. (Vertical direction)

| @ KEK-ATF | |
|---|---|
| 0.1Hz | 1e-5m/s$^2$ |
| 1Hz | 6e-4m/s$^2$ |
| 10Hz | 6e-4m/s$^2$ |
| 100Hz | 2e-3m/s$^2$ |

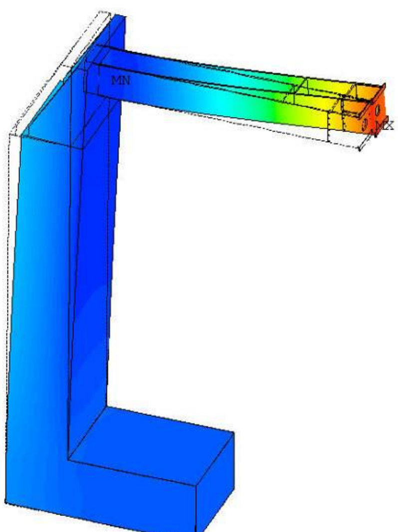
4.5Hz
1.5nm



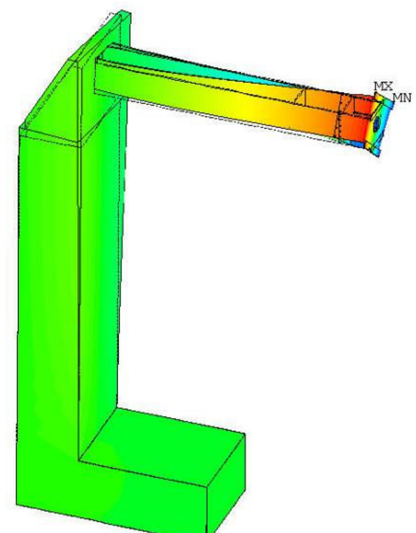
7.9Hz
240nm



10.4Hz
50nm



13.6Hz
0.3nm



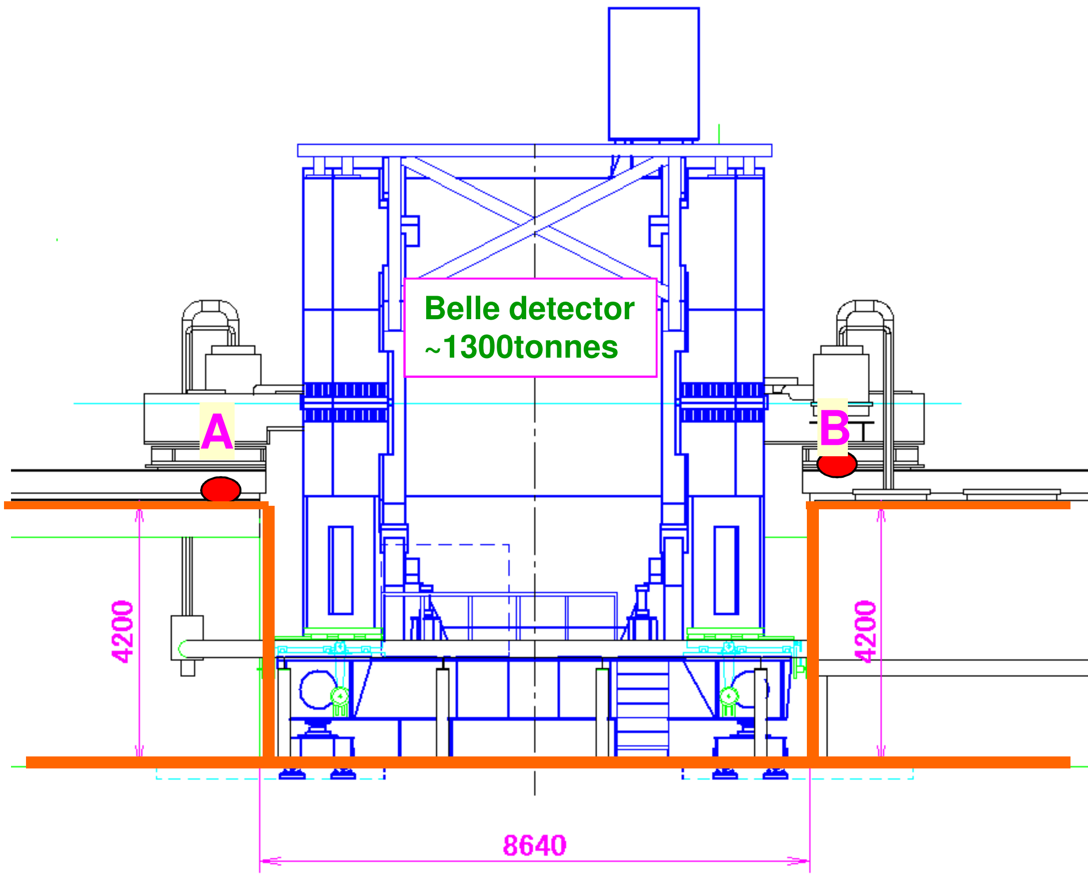
# Coherency measurement at KEKB-tunnel

**Measurement: A**

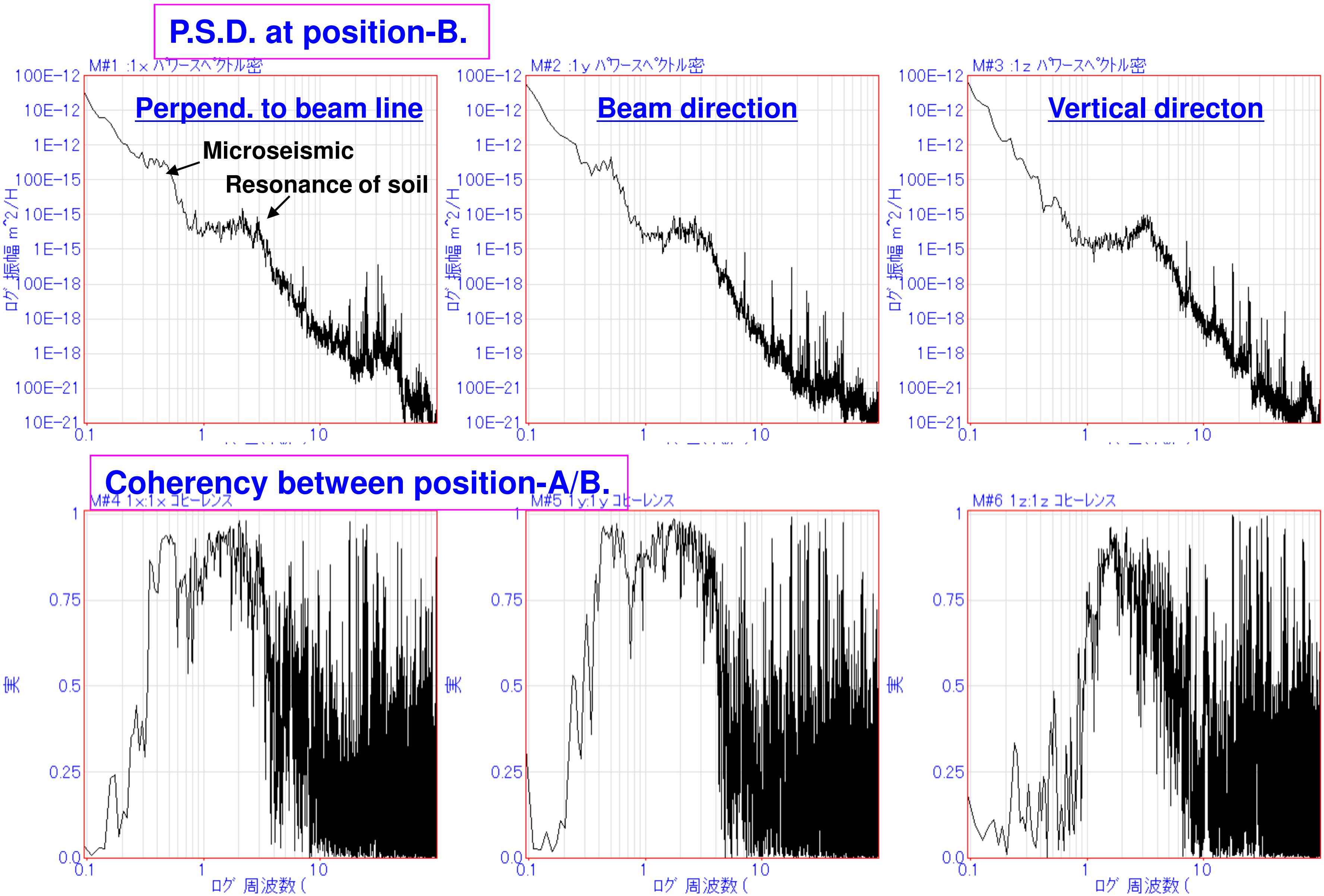
**How is the coherency between the position-A and B?**
**These two points keep coherency??**

| Servo Accelerometer MG-102 | Tokkyokiki Corp. |
|---|---|
| Size | 40×40×50mm |
| Max. input | ±2G |
| Resolution | 1 / $10^6$G |

Acc. 0.1 ~ 400Hz
Acc. 60dB = 1gal/V




# Results



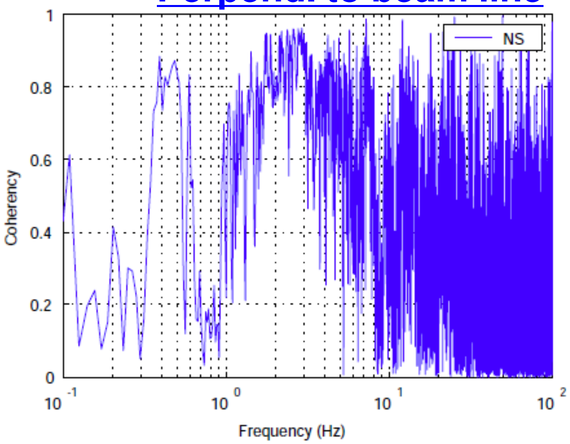

➔ It seems that there is no coherency between two positions.

Except for the frequency of microseismic(0.XHz) and resonance of soil(~3Hz).

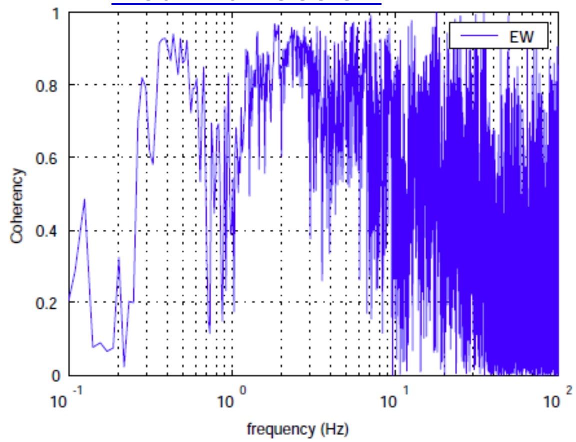
# Measurement: B

## How is the coherency between the tunnel and floor?

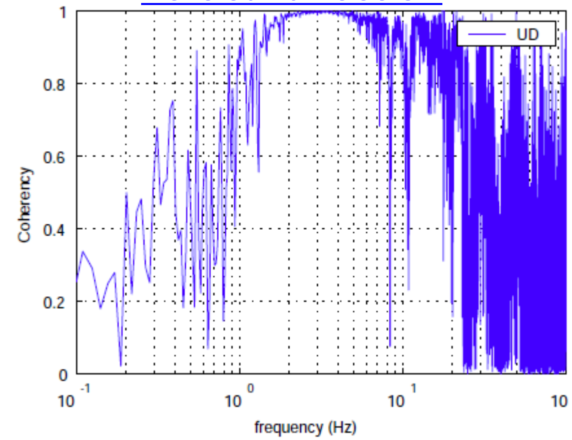
### Perpend. to beam line

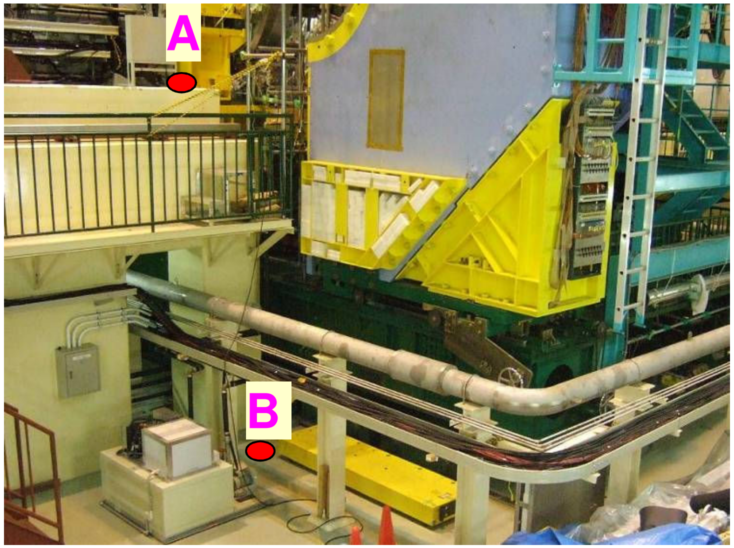


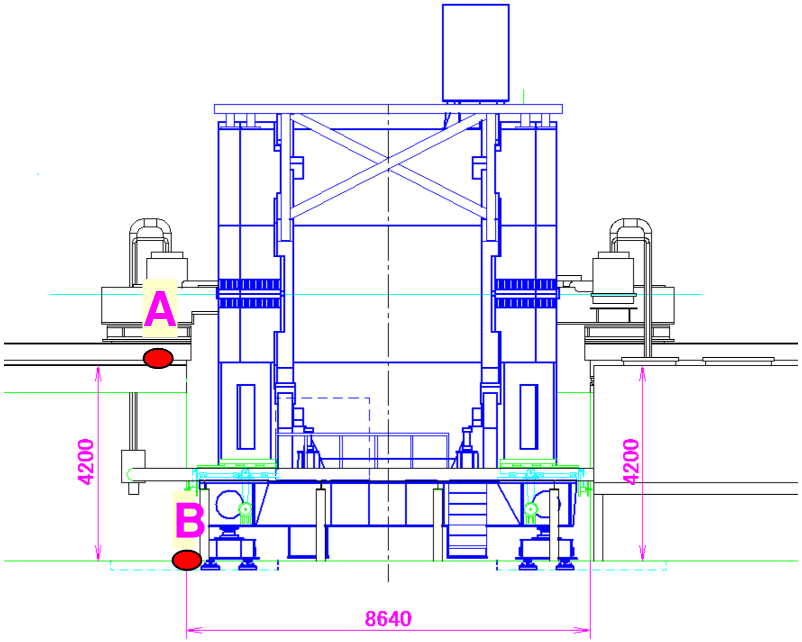

### Beam direction




### Vertical direction



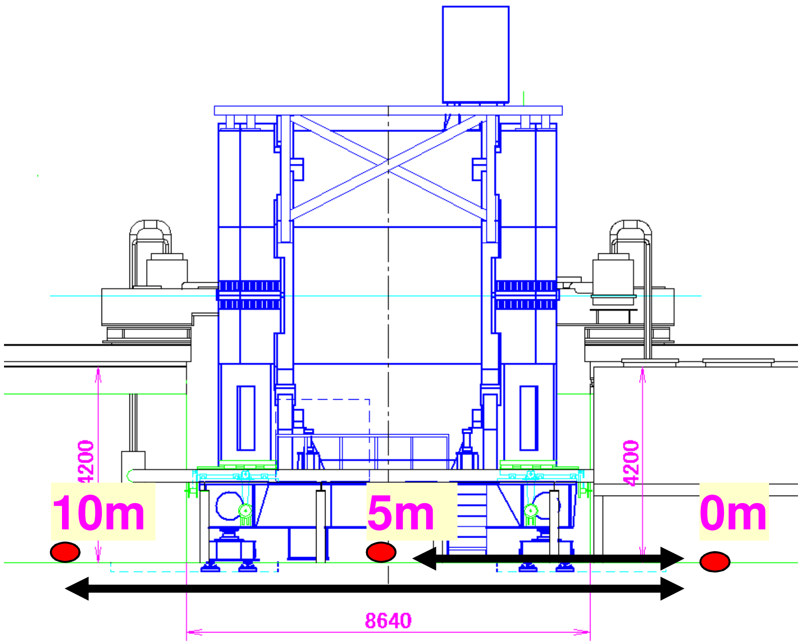



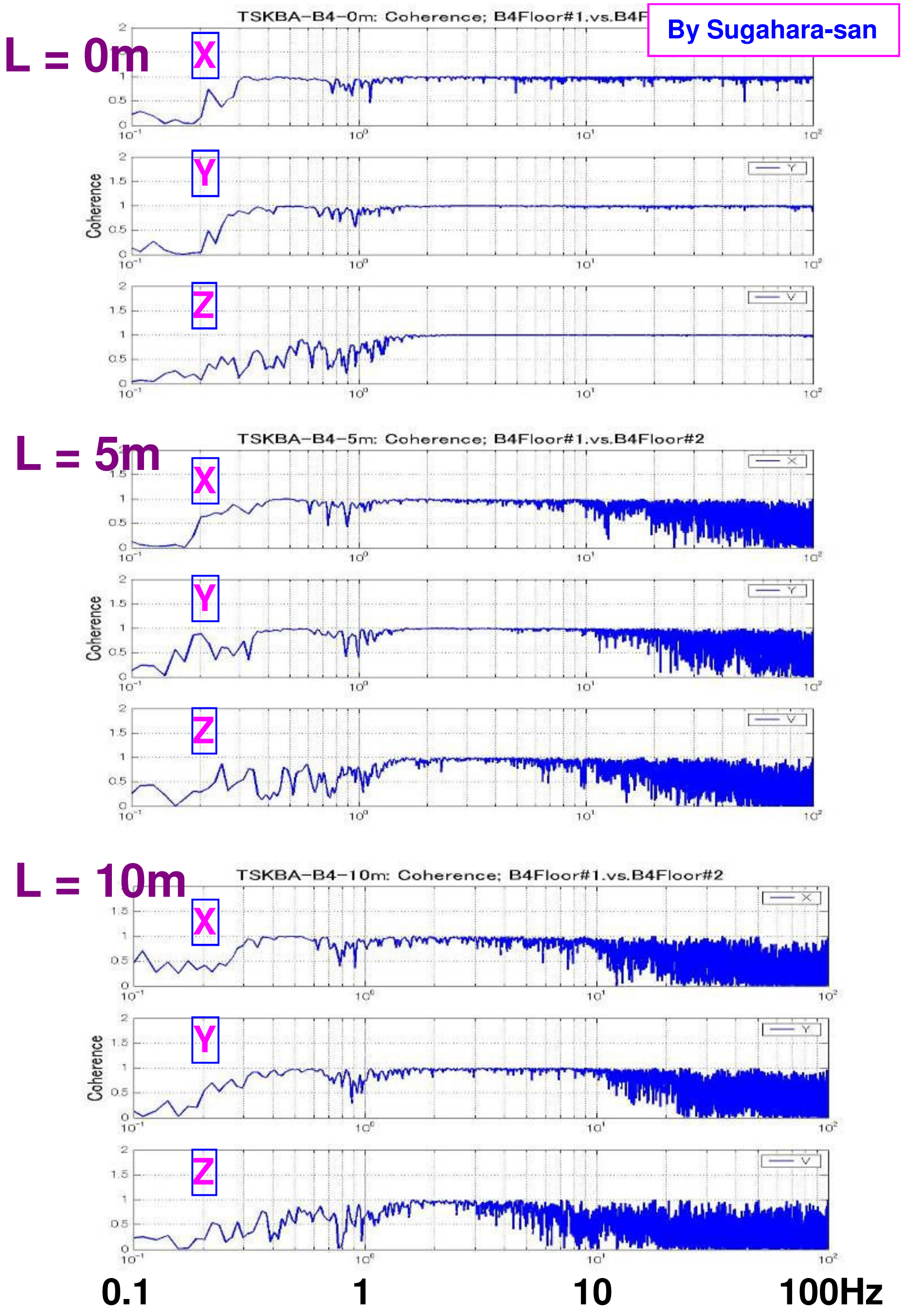

- Horizontal dir.: 0.~Hz, ~3Hz
- Vertical dir.: 1 ~ 20Hz

# Measurement: C

**How is the coherency between two positions?**

**Measure: Distance dependency.**



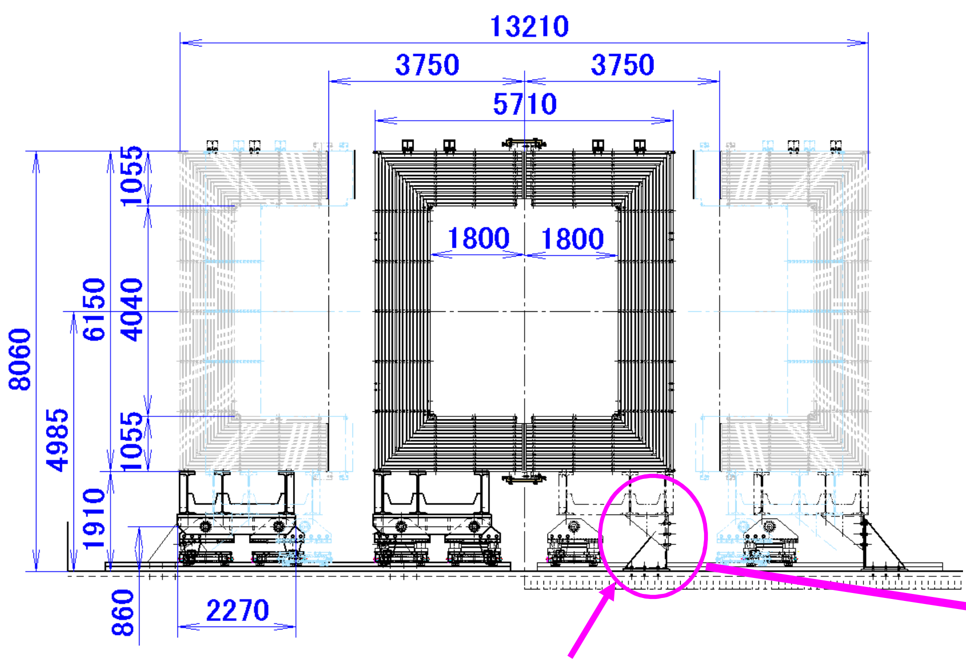

- Coherency: >10Hz is getting worse.
- Vertical dir.: <1Hz is bad.

# Investigations of efficiency of detector support structure

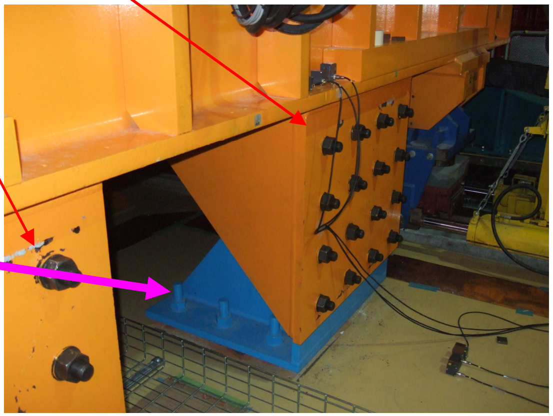
- Detector should be fixed to the floor?? or, Is it enough to just placed it on the floor??

➔ Difference of vibration properties between fixed and un-fixed the yoke to the support bracket were measured.

**ND280 detector (Total: 1100tonnes)**

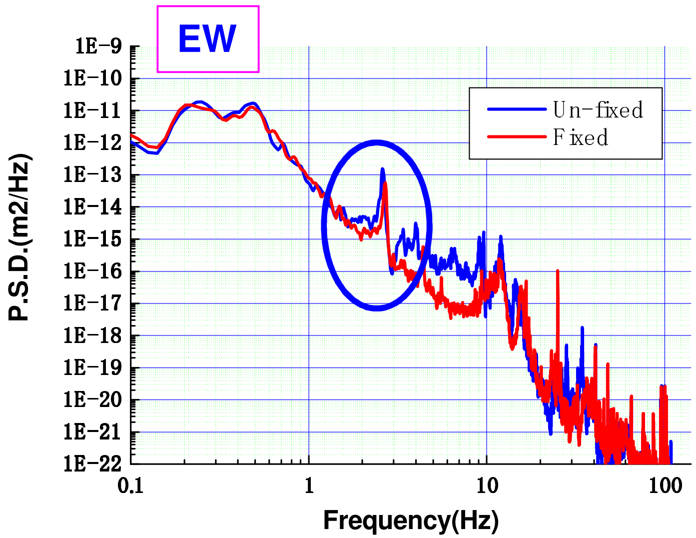


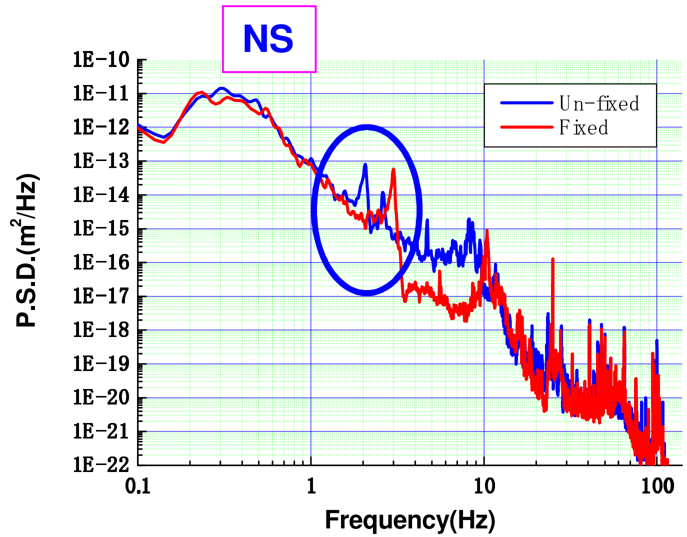

2-16xM36

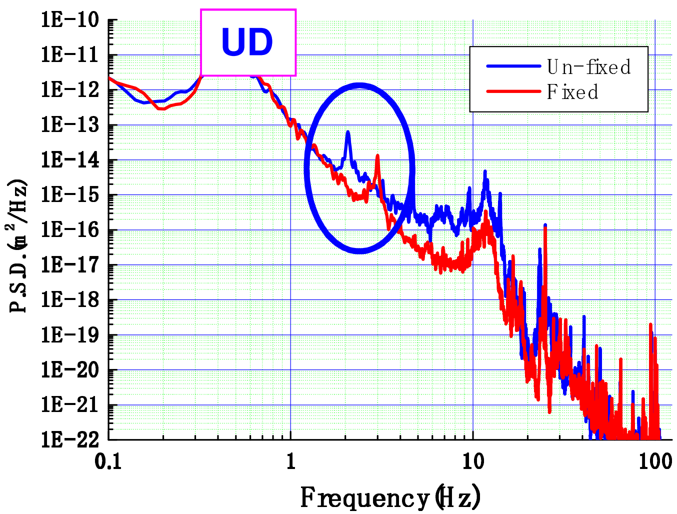


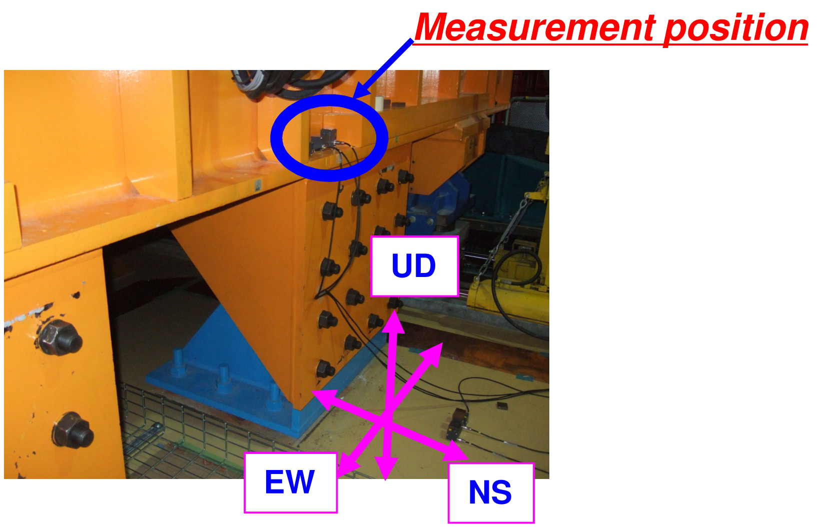
- The ND280 detector is fixed to the support-brackets with ***2-16xM36 thread bolts***.
- The support bracket is designed to withstand against ***0.5G seismic force***.

# Results




→ - Natural frequency after fixed to the bracket is increased to ~1Hz(NS, UD).
- P.S.D. is reduced because natural frequency is increased.

→It is not so big different but it's efficient to use the support-brackets.



→ Support stiffness is increased.

# Conclusions

- Vibration behavior for the ILD QD0 support system was studied.
  Measurement data of ATF/CERN were input.
  Integrated amplitude of the support system was calculated.

→ Integ. amplitude in case of ATF and CERN high-noise are larger than 50nm at 5Hz.

➔ Stiffness of (support tube + support position) should be increased.

- Coherency between long distance(~5m, ~10m) was measured.

➔ Good coherency was measured only the frequency around microseismic(~0.XHz) and resonance of soil(~3Hz).

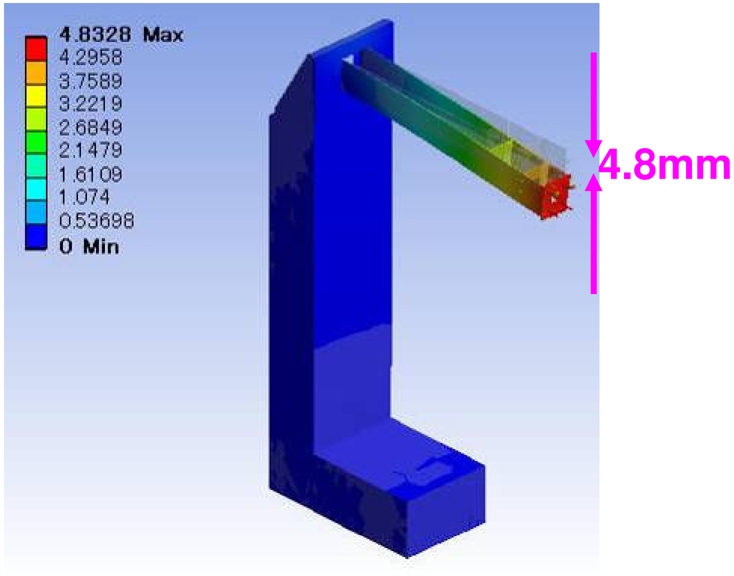
- Efficiency of support structure was investigated with the ND280 detector.
  ~ Natural frequency is ~1Hz increased after fixed the detector.
  P.S.D. is decreased because of increasing of natural frequency

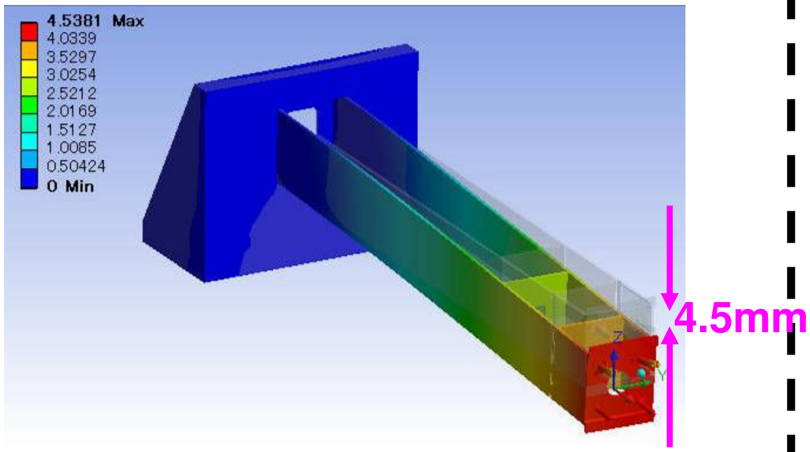
➔ Support stiffness of the detector is increased. So the support structure is effective.

END

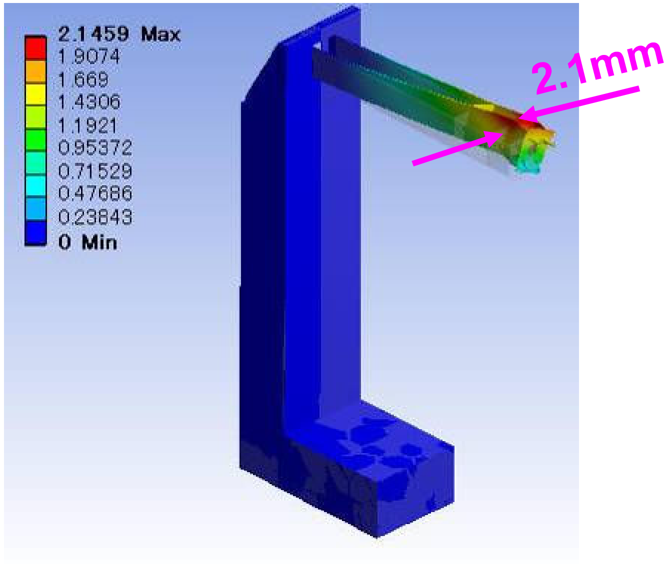
# Static analysis

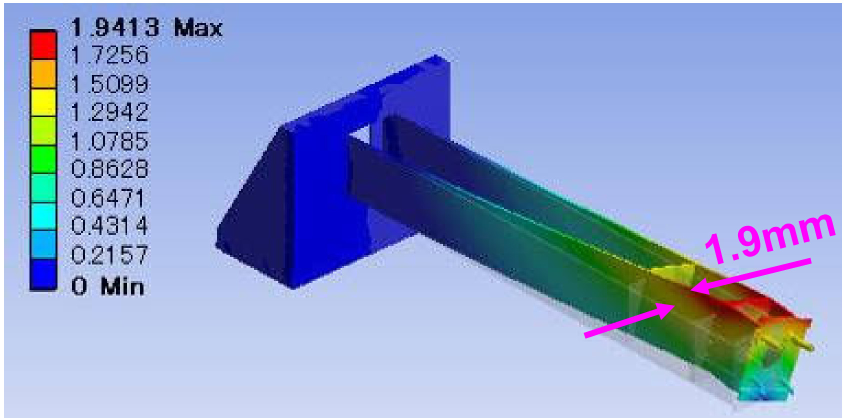
## Vertical direction



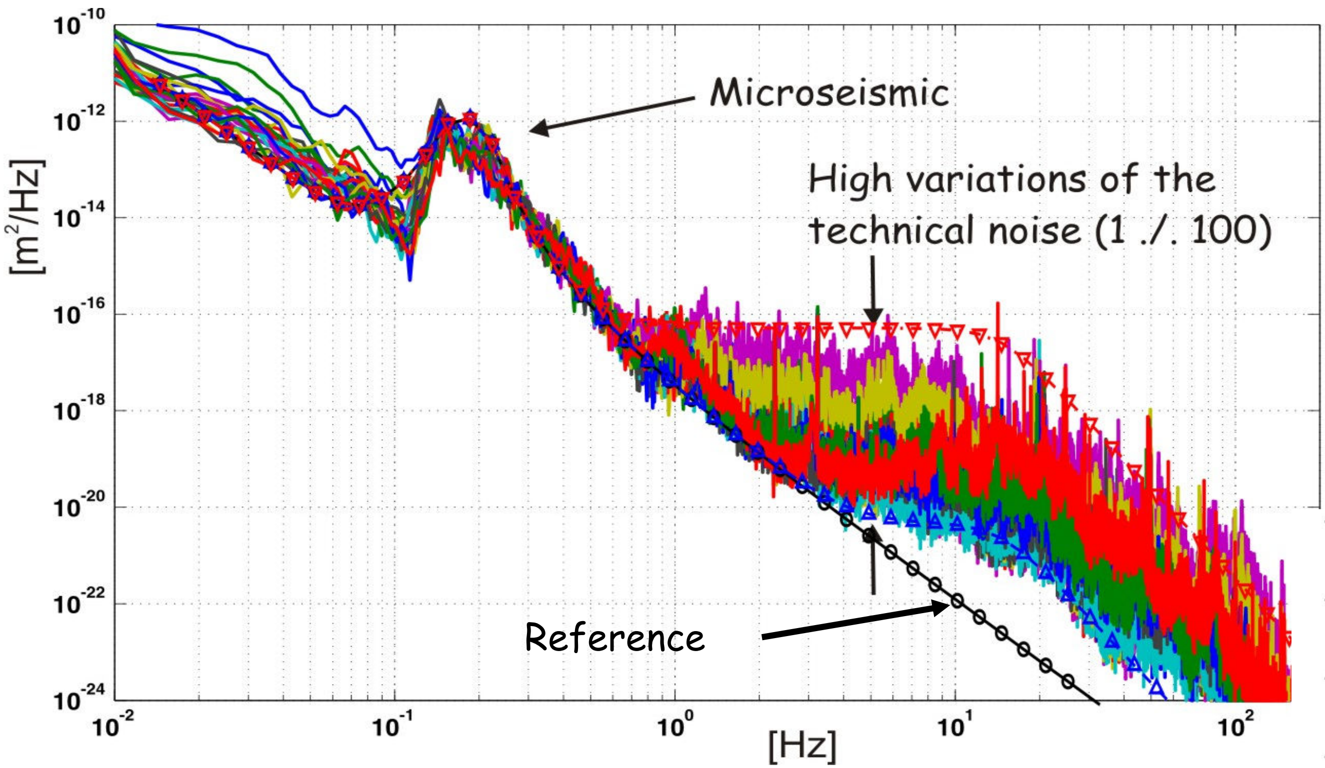

## Horizontal direction(0.15G)



# Local excitations

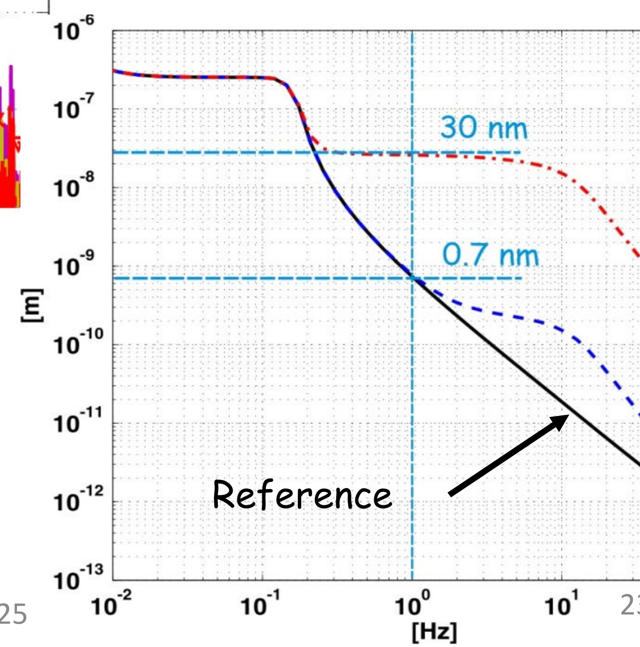
Vertical ground motion




Additional technical noise:

$$N(\omega) = \frac{N_0}{1 + (\frac{\omega}{\omega_0})^6}$$

$$f_0 = 2\pi(Hz)$$




Low technical noise: $N_0 = 5 * 10^{-3} (nm^2/Hz)$

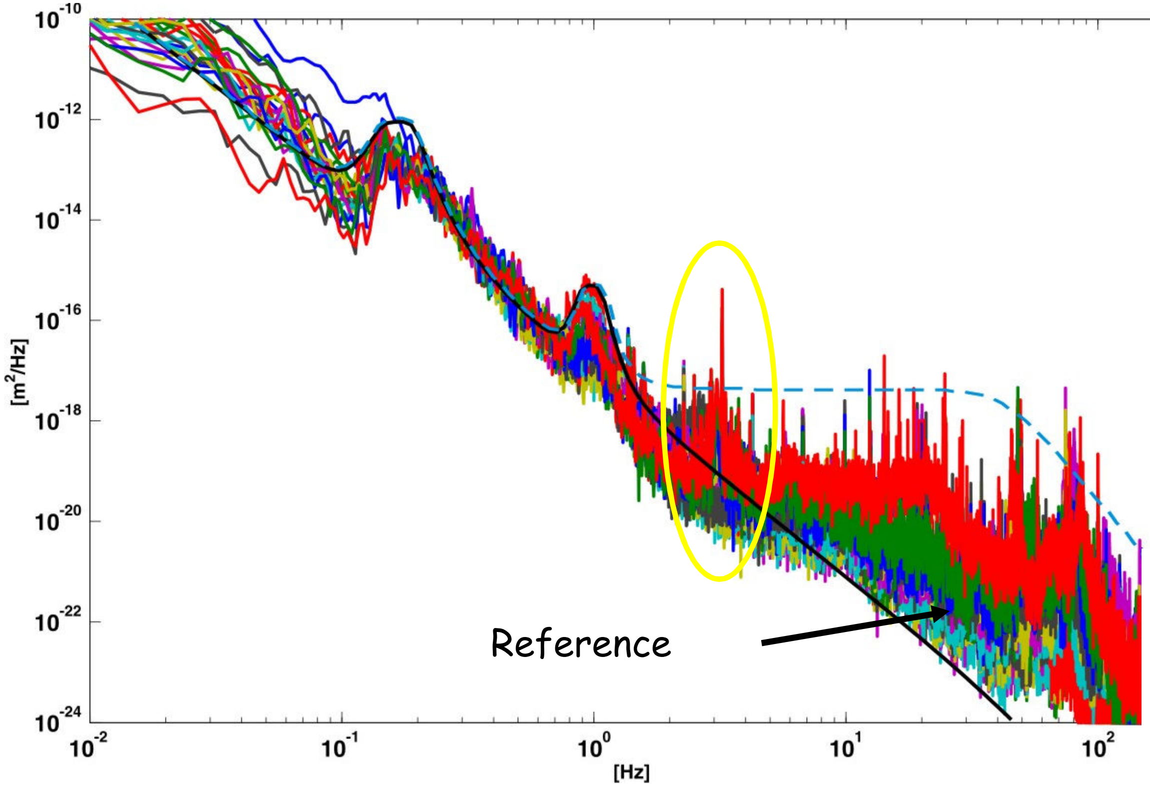
High technical noise: $N_0 = 50 (nm^2/Hz)$

**Ref. :** $A = 10^{-4}\ (\mu m^2 s^{-1} m^{-1}); B = 10^{-4}\ (\mu m^2 s^{-3});$

$\omega_1 = 2\pi * 0.14\ (rad/s); d_1 = 5; a_1 = 0.1\ (\mu m^2/Hz); v_1 = 1000\ (m/s)$

# Local excitations

Lateral ground motion

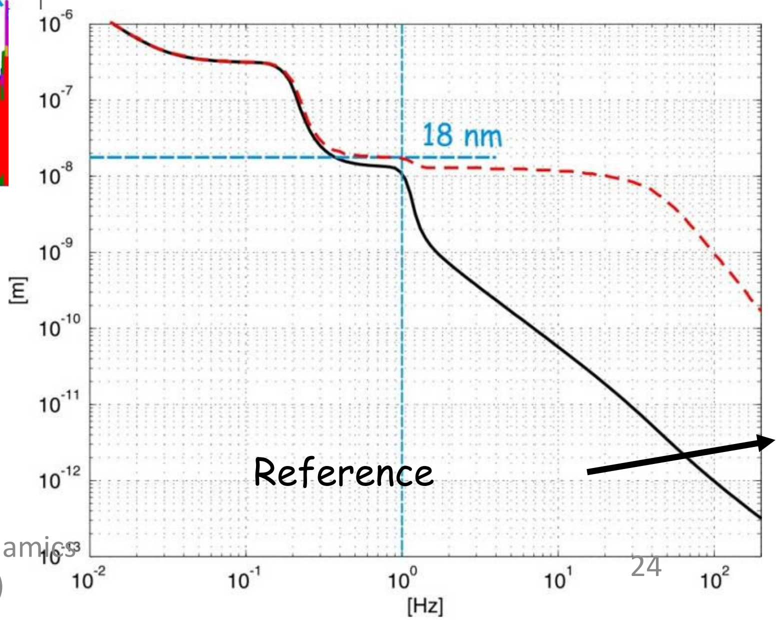



Additional technical noise:

$$N(\omega) = \frac{N_0}{1 + (\frac{\omega}{\omega_0})^6}$$

$$N_0 = 0.5 (nm^2/Hz)$$

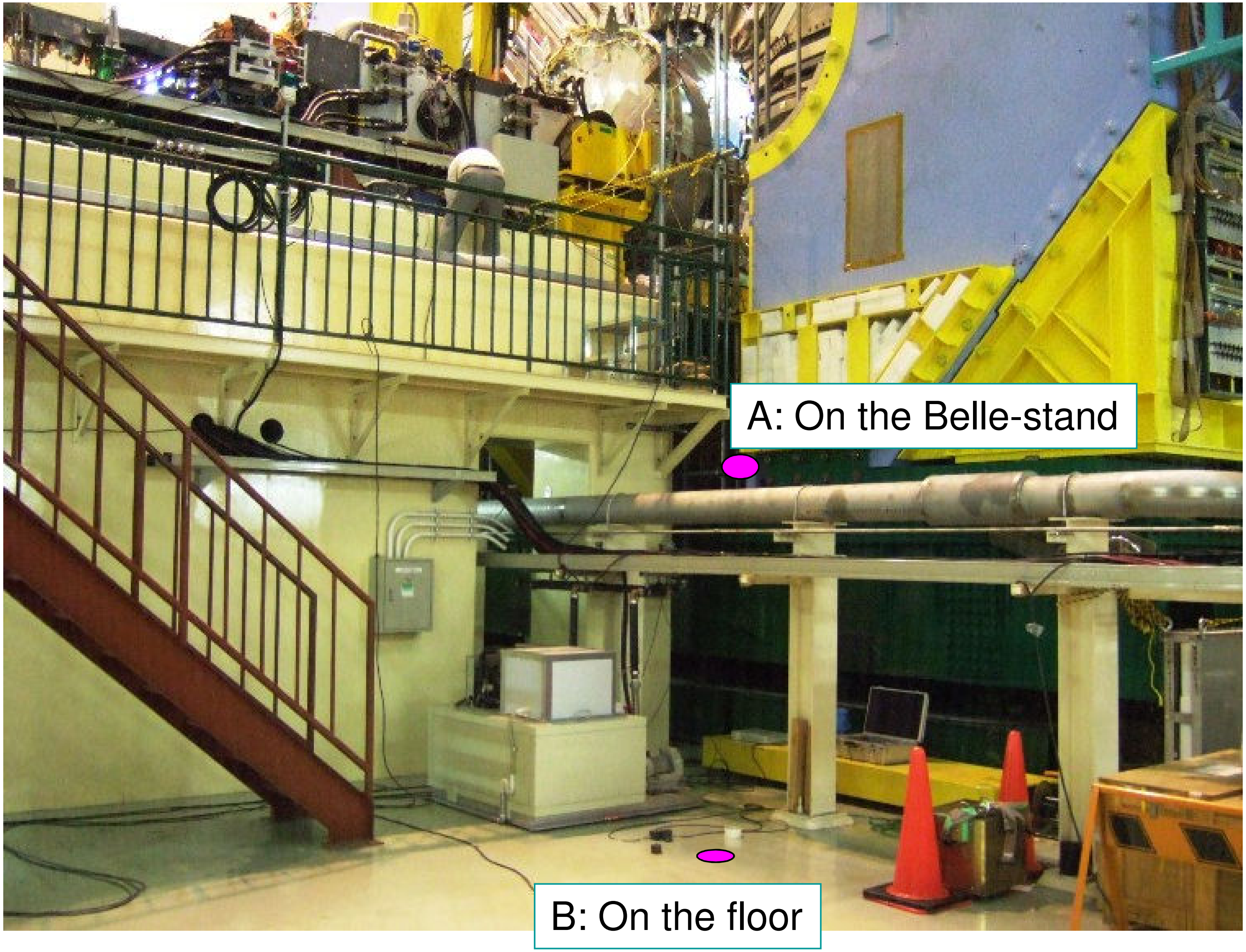
$$f_0 = 40 (Hz)$$




Ref. : $A = 10^{-3}\ (\mu m^2 s^{-1} m^{-1}); B = 10^{-2}\ (\mu m^2 s^{-3});$

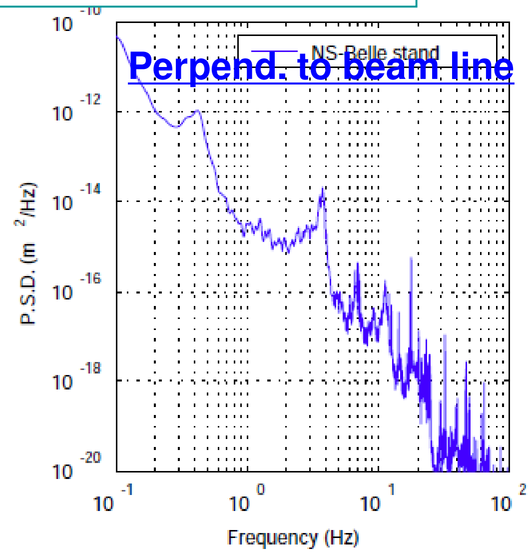
$\omega_1 = 2\pi * 0.17\ (rad/s); d_1 = 5; a_1 = 0.5\ (\mu m^2/Hz); v_1 = 1000\ (m/s)$

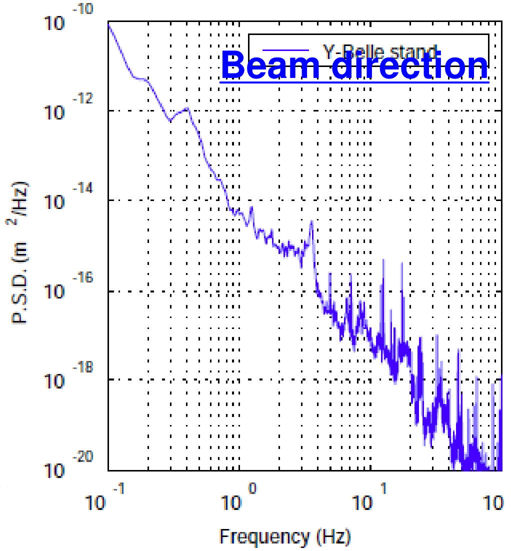
$\omega_2 = 2\pi * 1\ (rad/s); d_2 = 8; a_2 = 5 * 10^{-4}\ (\mu m^2/Hz); v_2 = 400\ (m/s)$

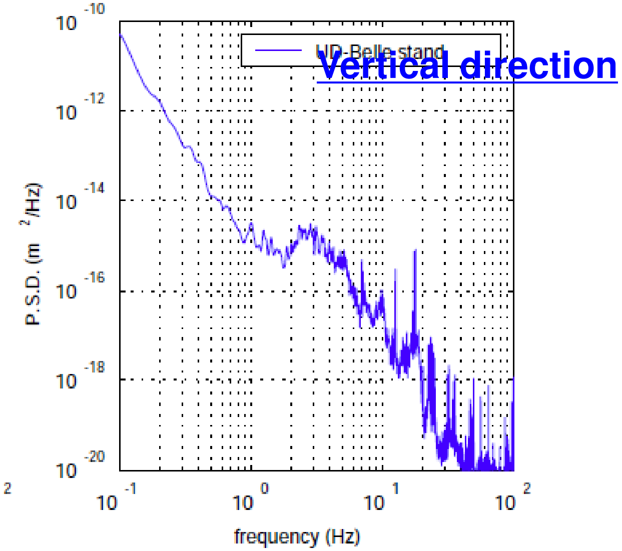

A: On the Belle-stand
B: On the floor

# Power Spectrum Density

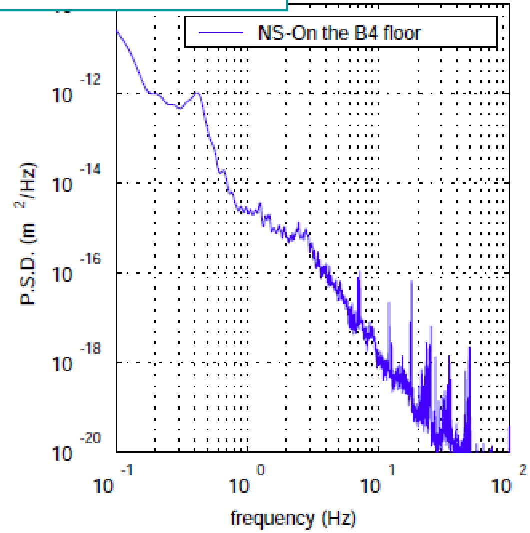
## A: ( On the Belle-stand)

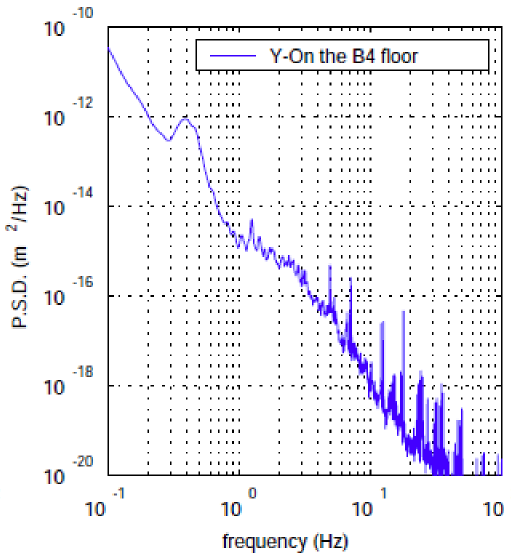


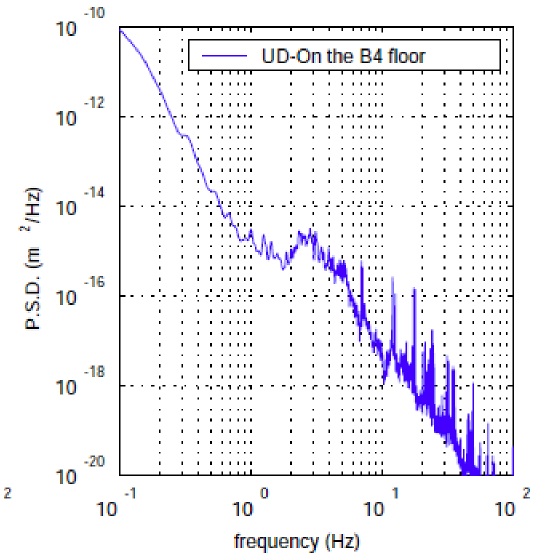



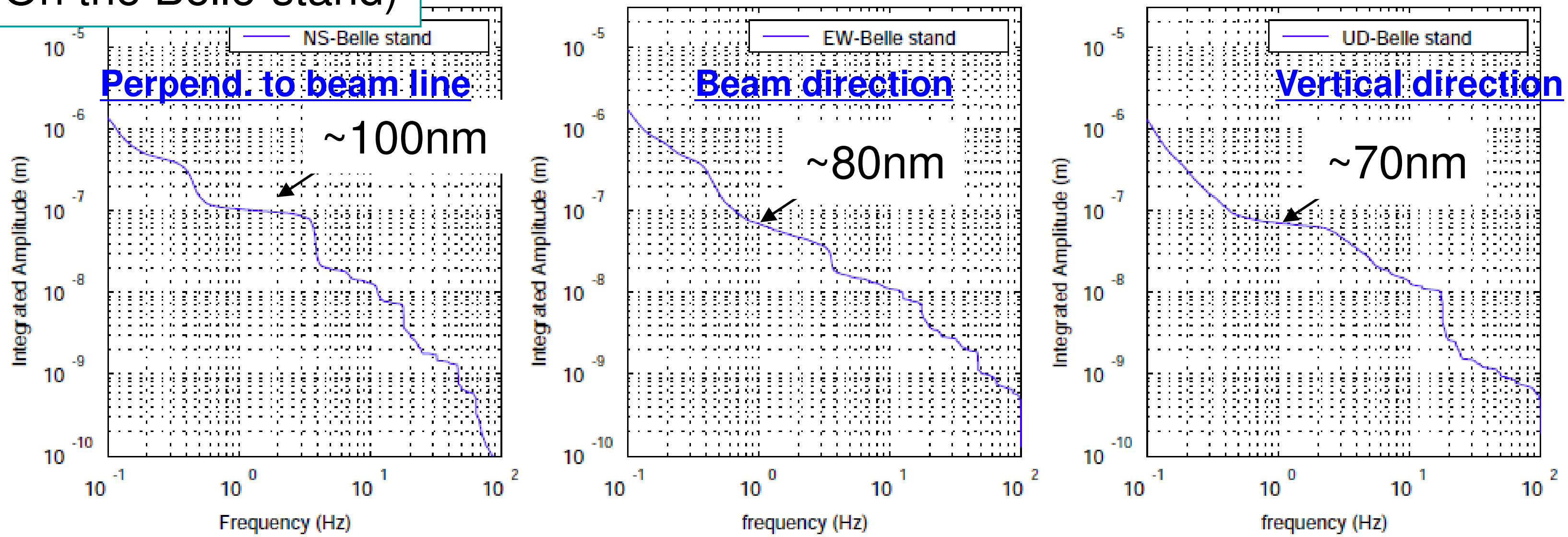

## B: (On the floor)



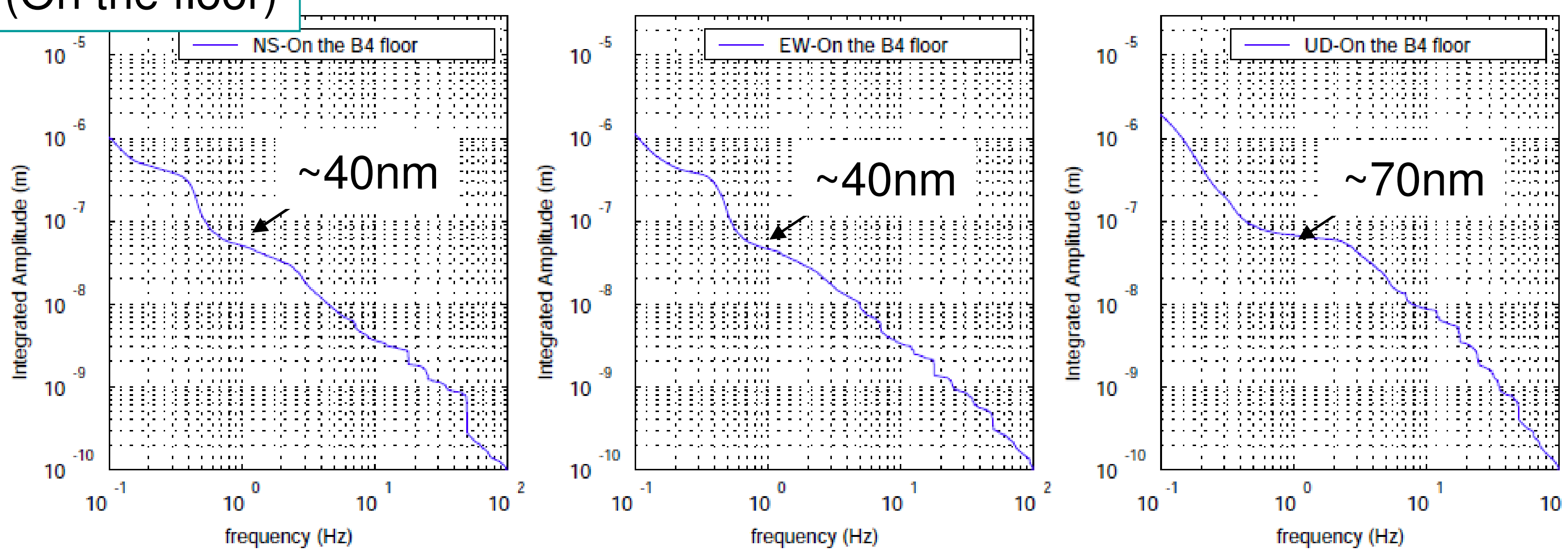



A: ( On the Belle-stand)

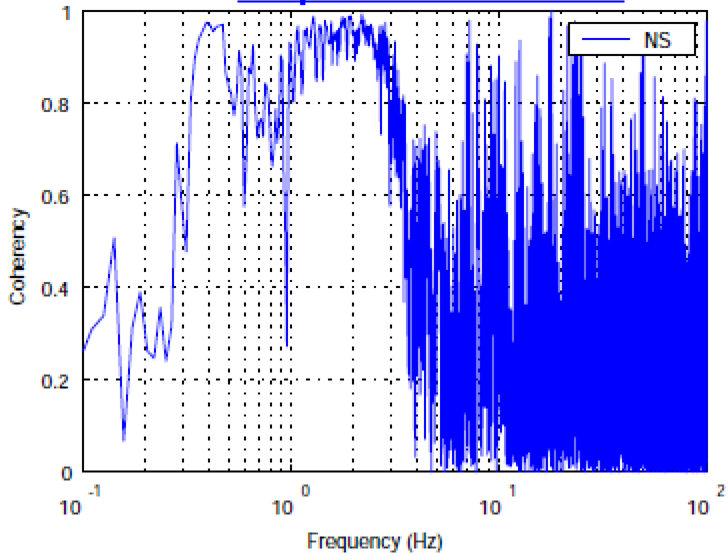



B: (On the floor)

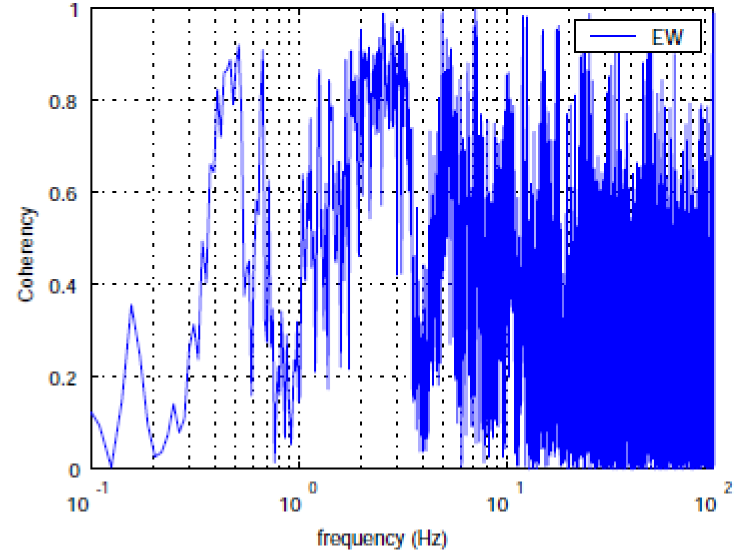


## Coherency

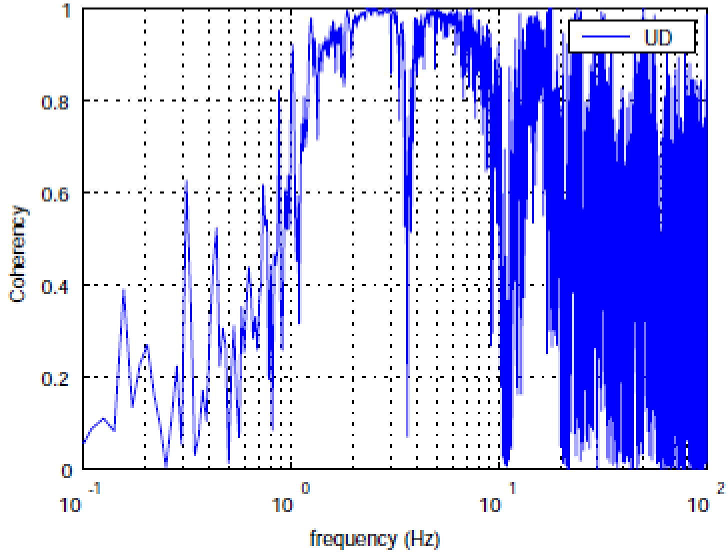
**Perpend. to beam line**




**Beam direction**

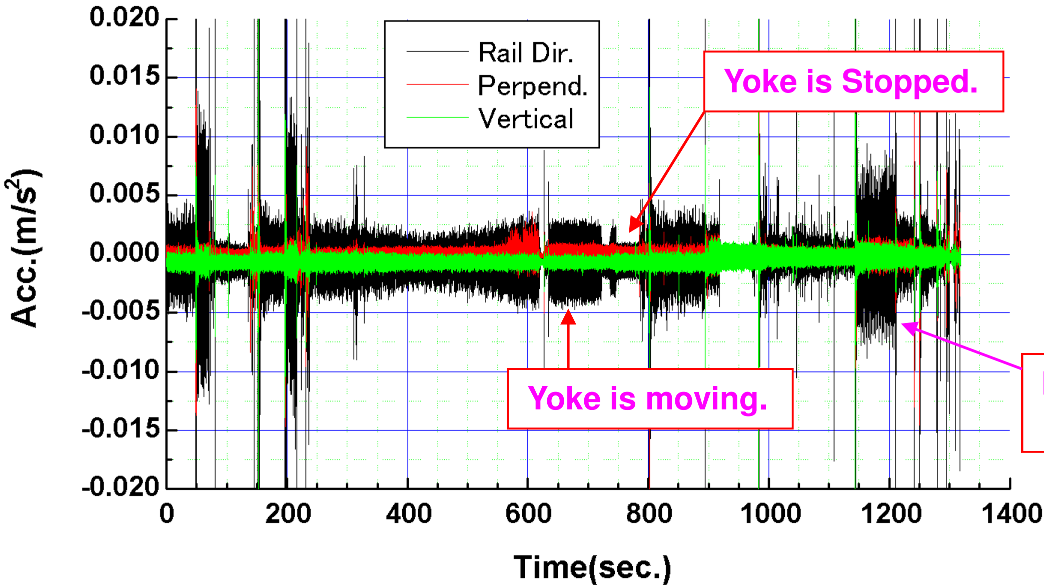


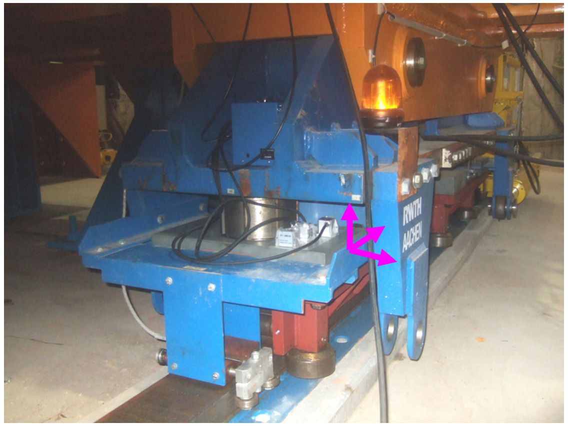

**Vertical direction**



# Measurement results

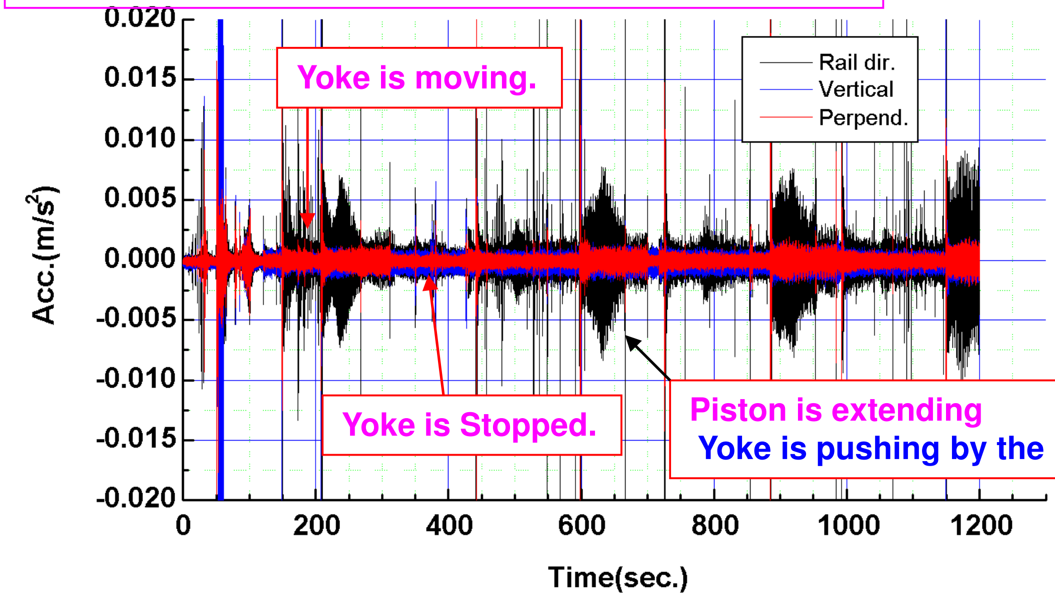
## Time data- On the roller (@South yoke)



Piston is extending
Yoke is pushing by the mover.

## Time data- On the support stand (@North yoke)

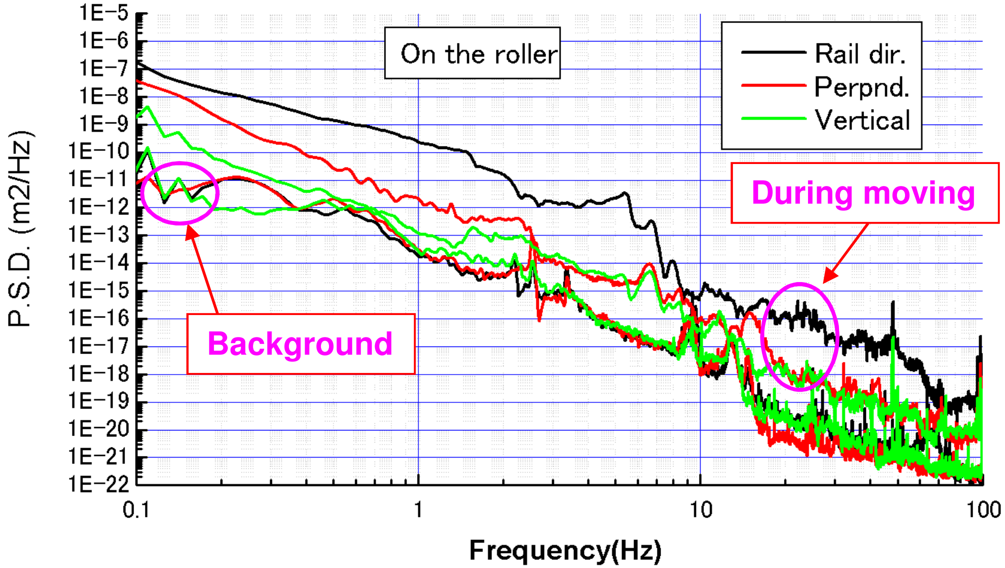


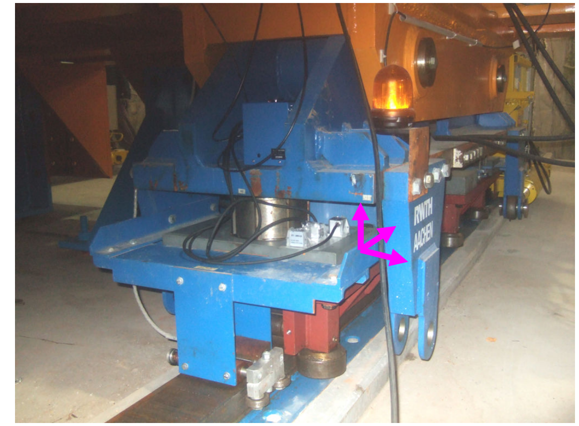

Piston is extending
Yoke is pushing by the mover.



- Piezo-sensor couldn't detect these vibrations.

## Time data- On the roller (@South yoke)



## Time data- On the support stand (@North yoke)