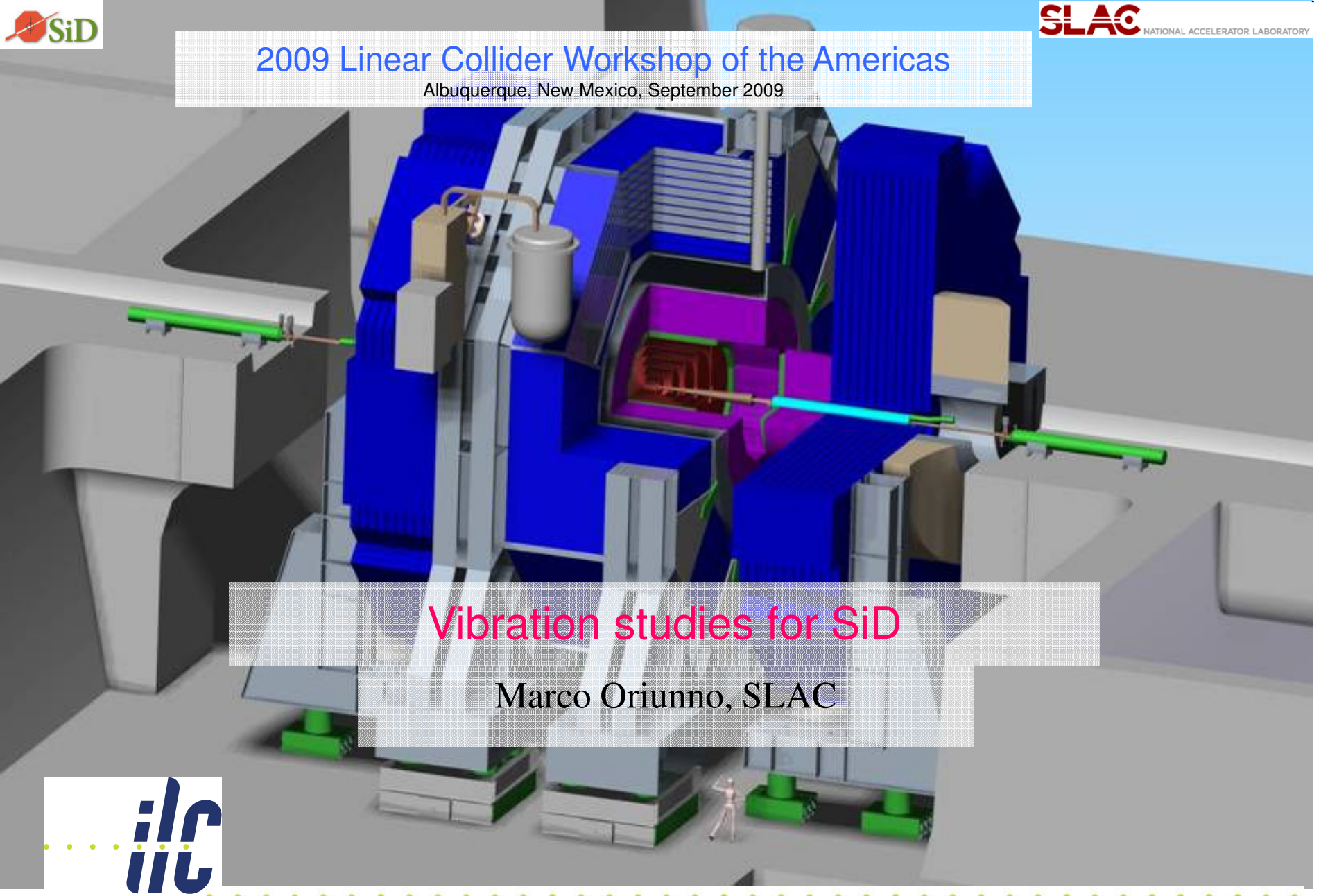
2009 Linear Collider Workshop of the Americas

Albuquerque, New Mexico, September 2009



Vibration studies for SiD

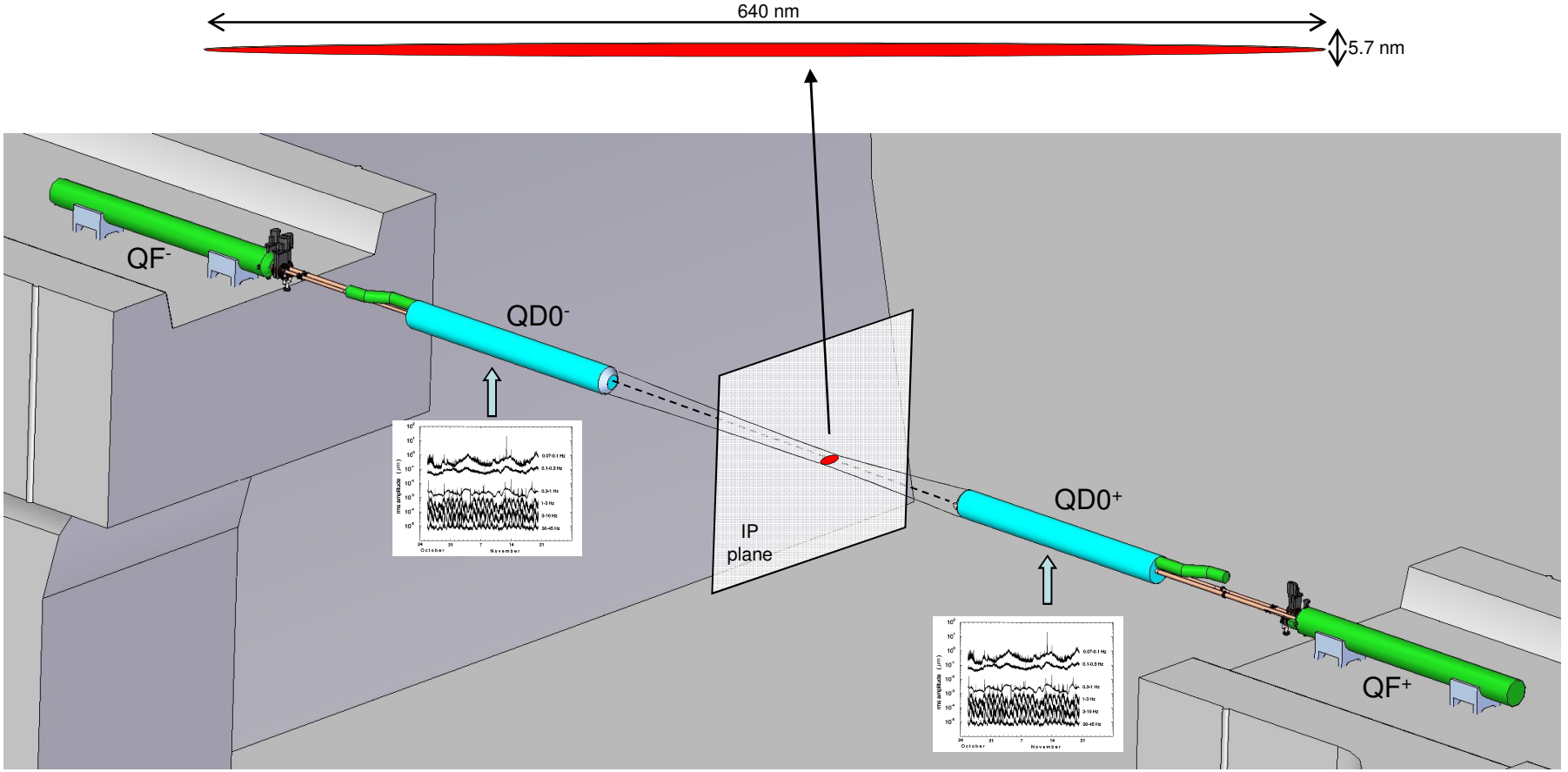
Marco Oriunno, SLAC

Introduction

Sub-nanometric stability of the focusing system is required to maintain the luminosity to within a few percent of the design value.

Ground motion is a source of vibrations which would continuously misaligning the focusing elements.

The design of the support of the QD0 is a fundamental issue



Luminosity feedback systems and stability

Two Luminosity Feedback systems are implemented in ILC :

A 5 Hz to control the orbit in the BDS (low frequency)

A Intra-train system to address ground motion and mechanical disturbances (high frequency~1000 Hz)

The mechanical stability requirements of the QD0 are set by the capture range of the IP fast feedback, as written in the "Functional Requirements" document, ILC-Note-2009-050

" The QD0 mechanical alignment accuracy and stability after beam-based alignment and the QD0 vibration stability requirement are set by the capture range and response characteristics [8] of the inter-bunch feedback system.

• QD0 alignment accuracy: ± 200 nm and 0.1 μrad from a line determined by QF1s, stable over the 200ms time interval between bunch trains

• QD0 vibration stability: Δ(QD0(e+)-QD0(e-)) < 50 nm within 1ms long bunch train "

Ground motions (A.Seryi et al.)

Ground vibrations measurements are available for all the major accelerators sites in form of Power Spectrum Densities. Datasets available at http://vibration.desy.de

Main features :

Separation at ~few Hz between geology and human induced noise (pretty much the separation between the slow and fast luminosity feedback)

Some site are quiet and some are noisy

Motion falls as $1/\omega^4$

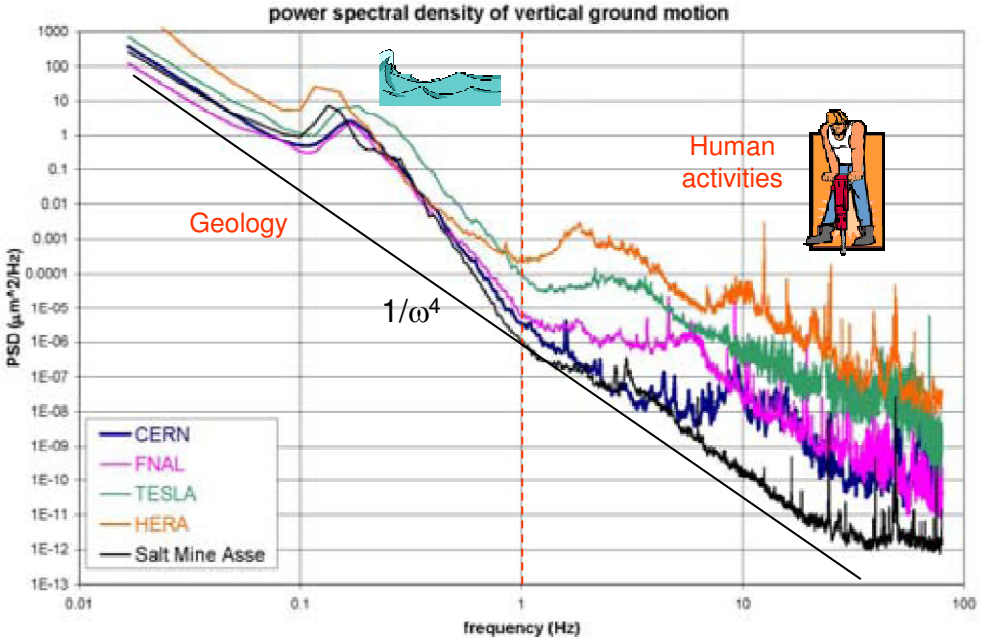
For a given a ground motion time history x(t), the PSD is defined as

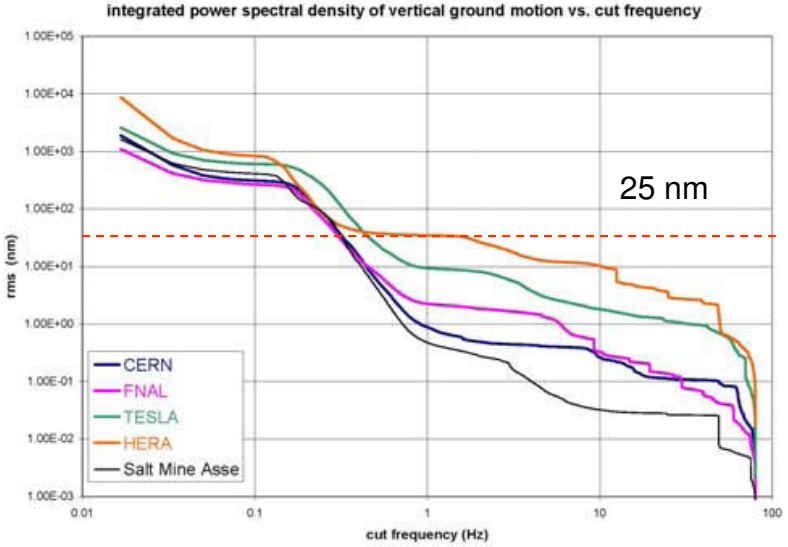
$$P(f) = \lim_{T\to\infty} \frac{1}{T} \left| \int_{-T/2}^{T/2} x(t) e^{-i\omega t} dt \right|^2$$

i.e. *PSD* is the Fourier transform of the *autocorrelation* function R(0) of te signal x(t).

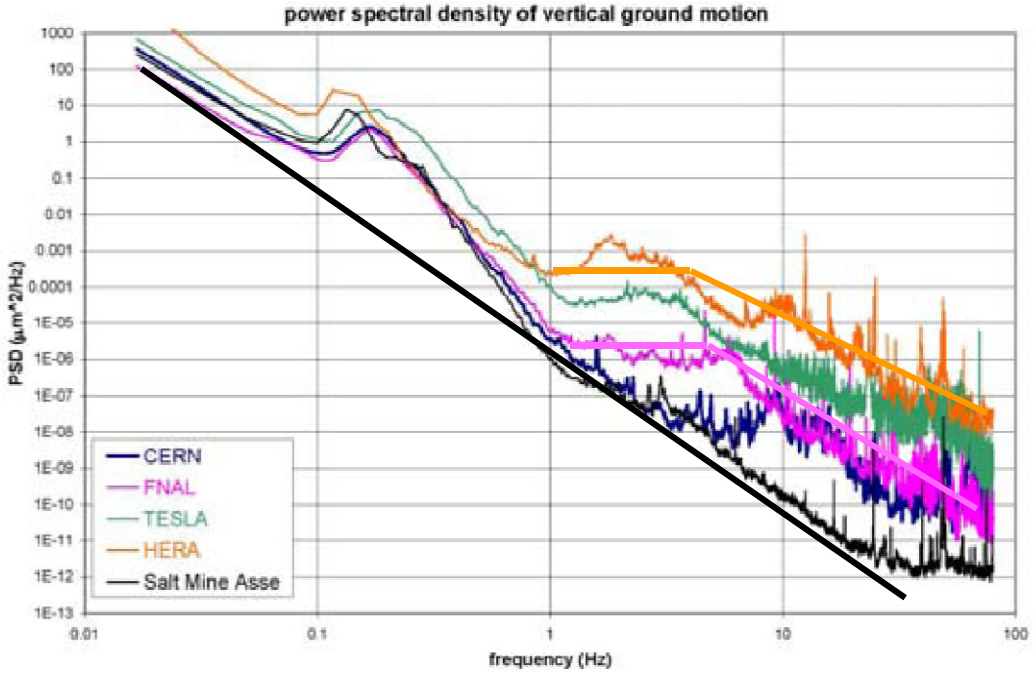
The main property of the PSD is that the variance of x(t) is given by:

$$\sigma^2 = \langle x^2 \rangle = \int_{f_1}^{f_2} P(f) df$$

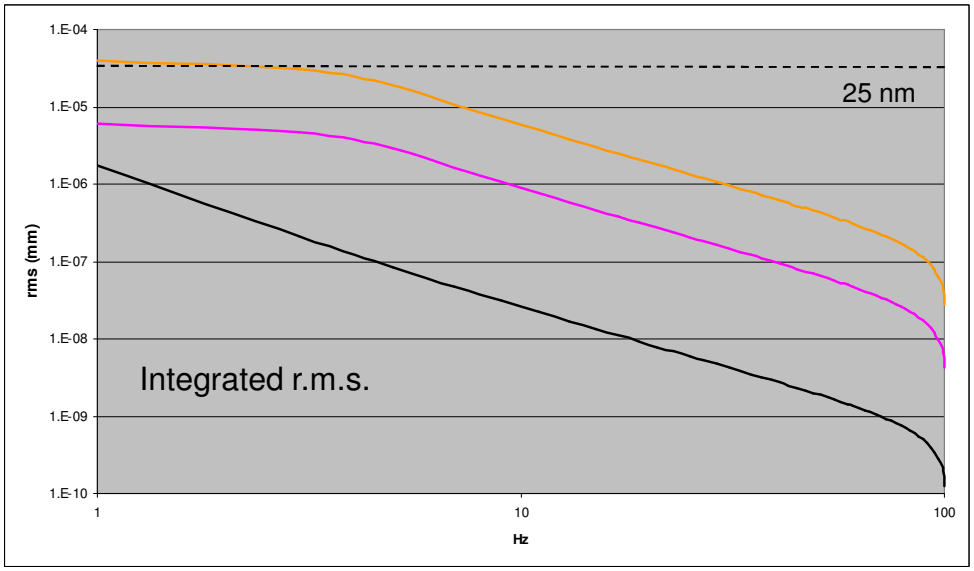




Simplified PSD Models

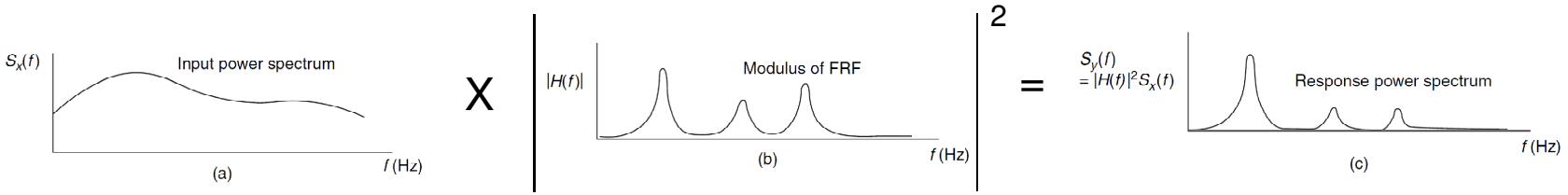


$$P(f) \approx \frac{A}{f^4}$$



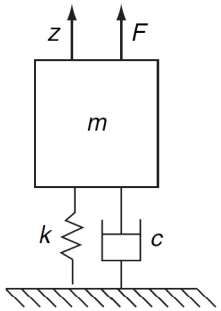
$$\sigma^2 = \left\langle x^2 \right\rangle = \int_{f_1}^{f_2} P(f)\,df$$

Random vibrations model



Ground Motion PSD

Frequency Response Function

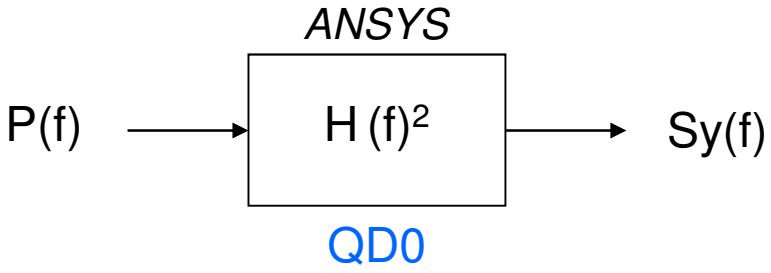


One degree-of-freedom

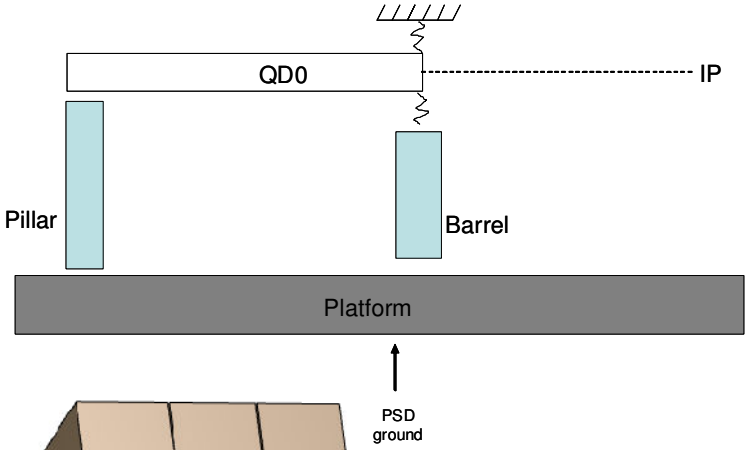
FRF for one d.o.f. $\Rightarrow$ $$|H(f)| = \frac{1}{m(2\pi f_n)^2 \sqrt{(1-\Omega^2)^2 + (2\gamma\Omega)^2}}$$

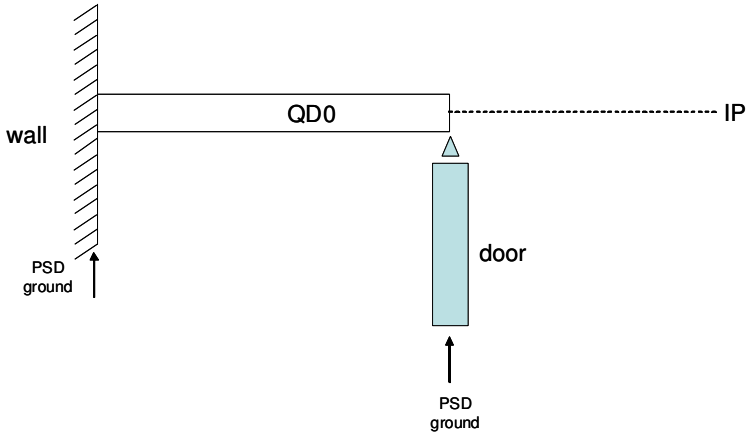
$$Sy(f) = |H(f)|^2 P(f)$$

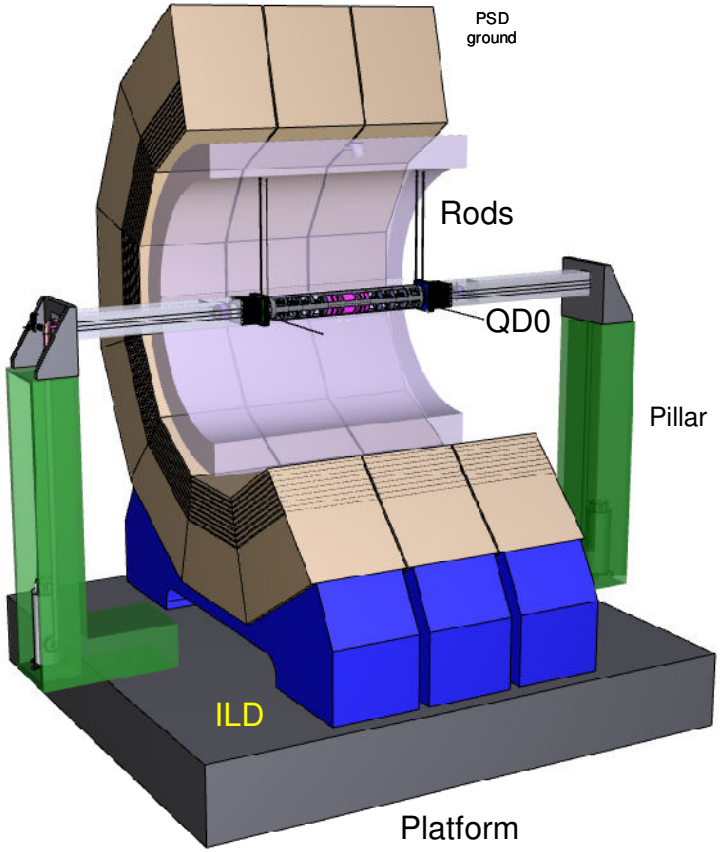
The FRF of multi degree-of-freedom system, like QD0 and SiD, is obtained a FEM (e.g. ANSYS)

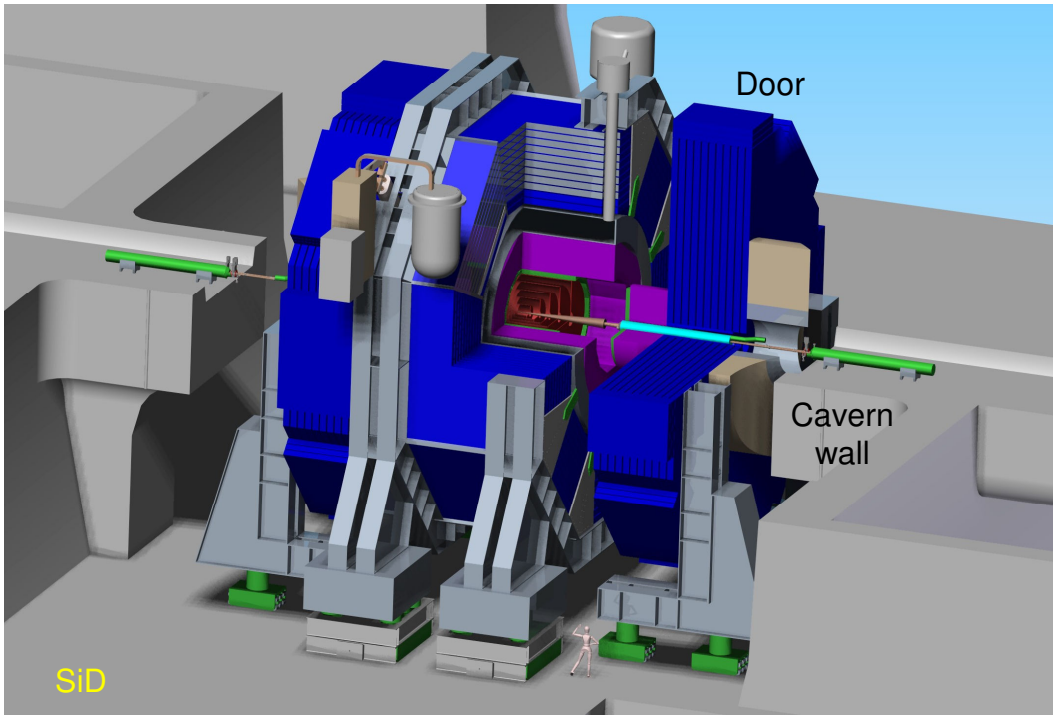


QD0 supports for ILD and SiD

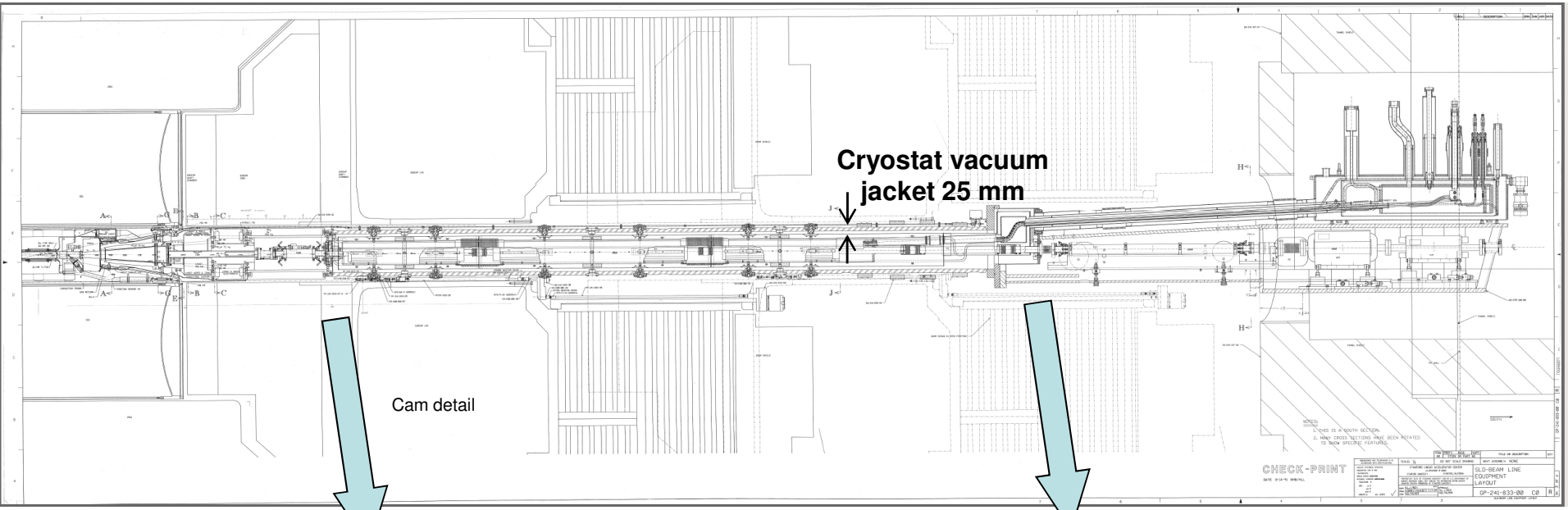








QD0 integration and movement as in SLD

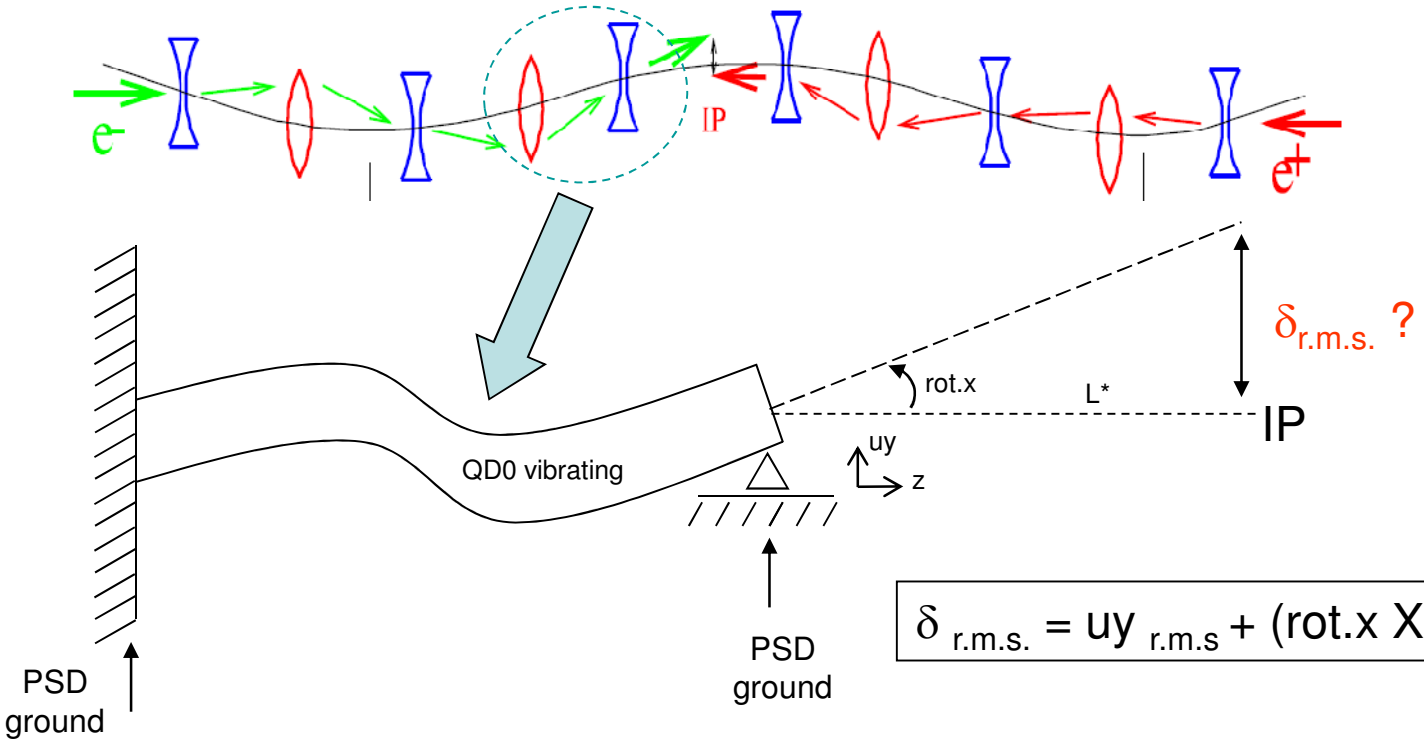


Random Vibration effects Metric

Ground motion effects are usually accounted as perturbation of the lattice elements through the girders, the magnetic cells assumed point-like (rigid body)

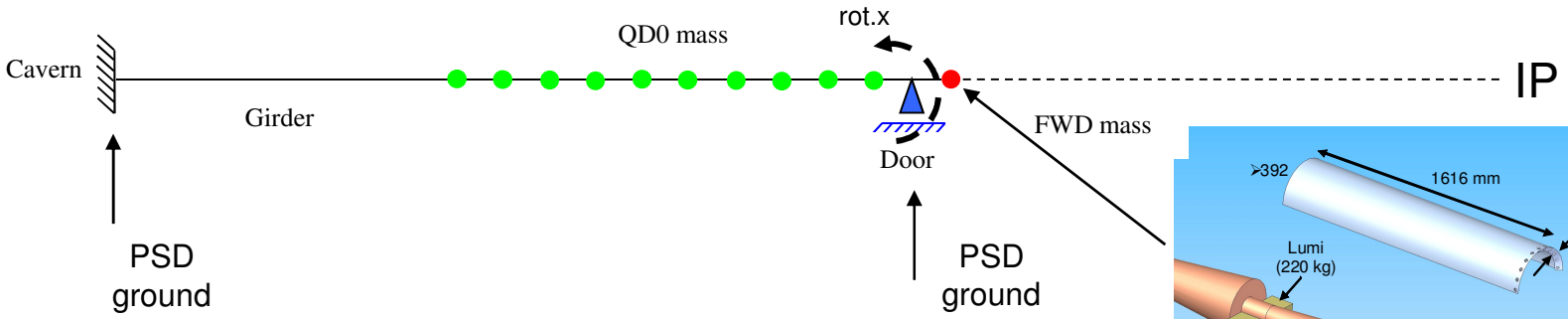
Final Focusing element deforms along the full length under random vibration effects

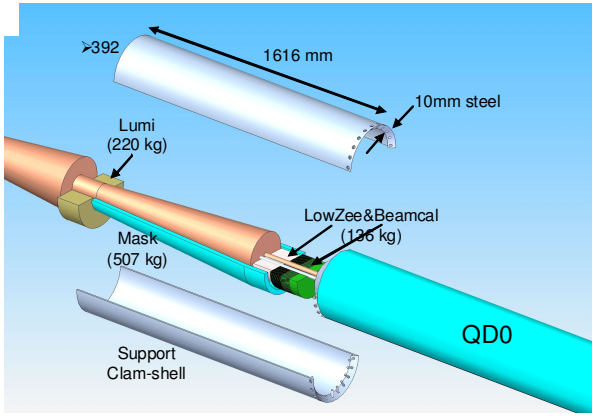
How define the metric of the net effect of the displacement at the IP ?



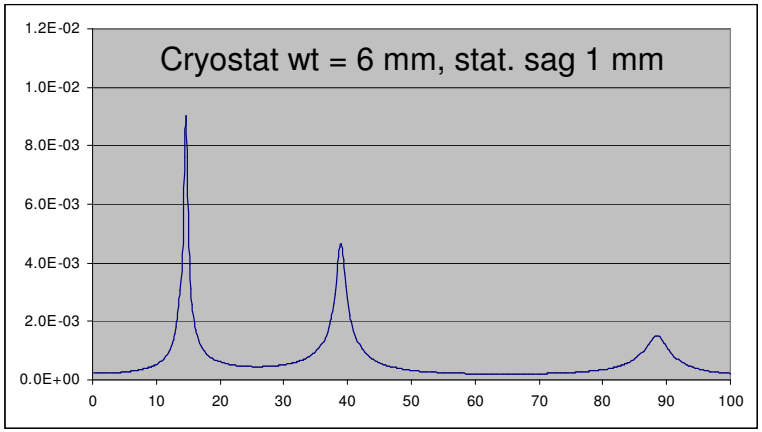
$$\delta_{r.m.s.} = uy_{r.m.s} + (rot.x \times L^*)_{r.m.s}$$

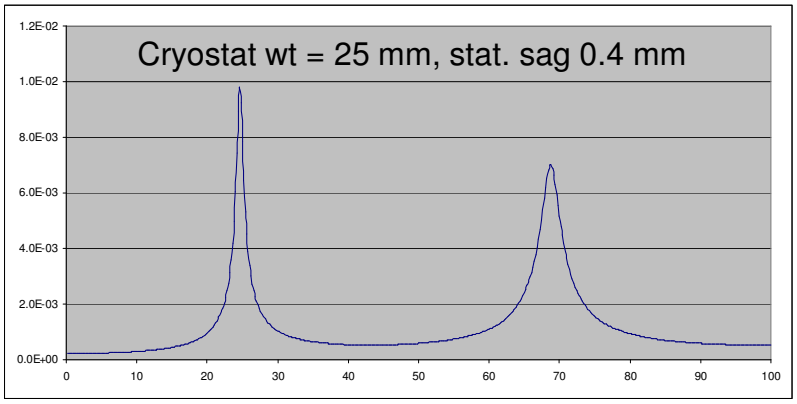
QD0 supported on the door

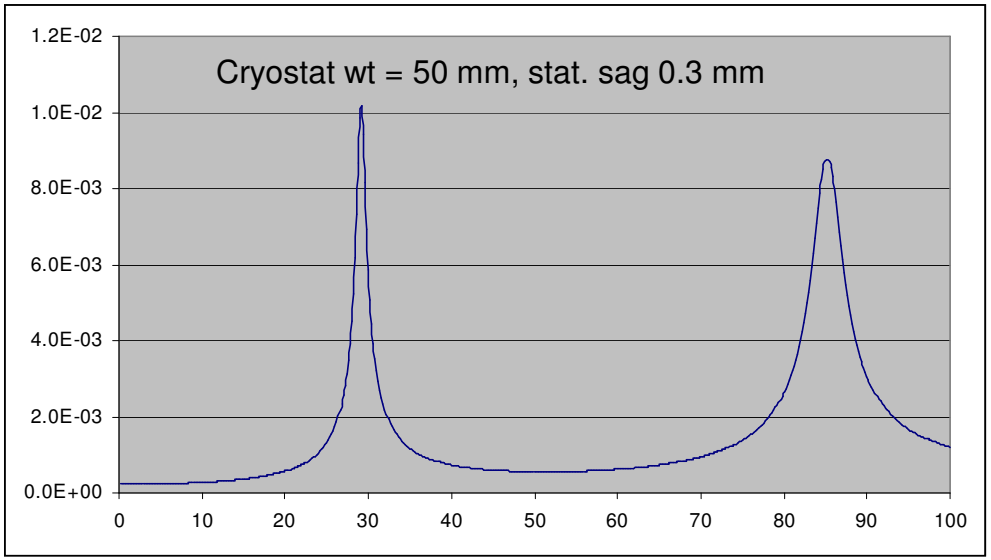




Rot.x Harmonic analysis response for two different cryostat wall thickness: t=6 mm (ILC Nominal), t=25 (SLD), t=50 mm

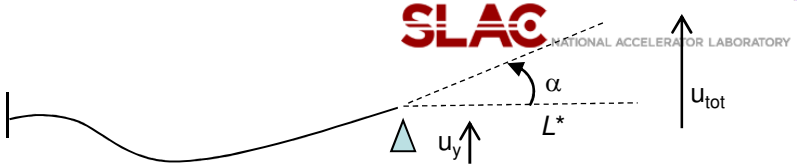


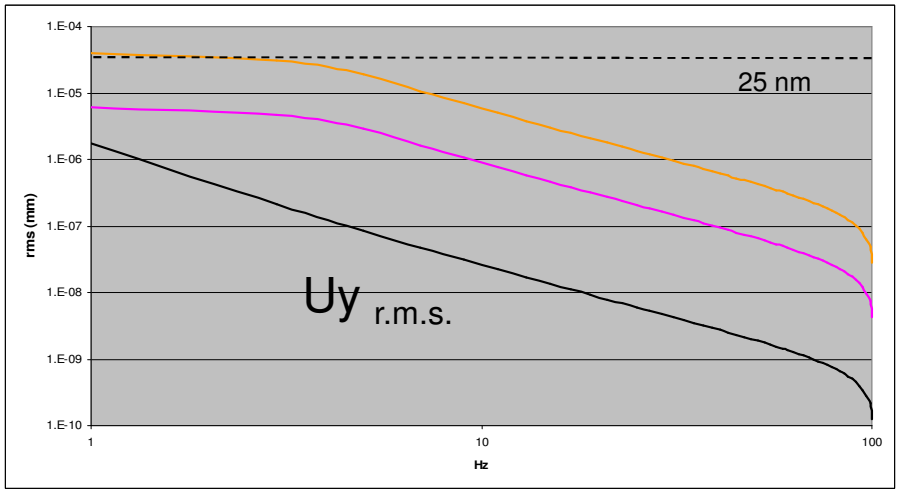




Salt Mine Asse
FNAL
HERA

PSD response

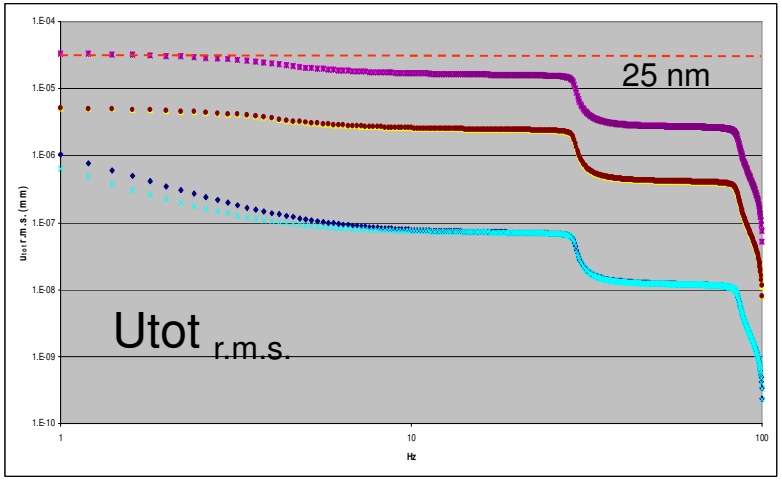


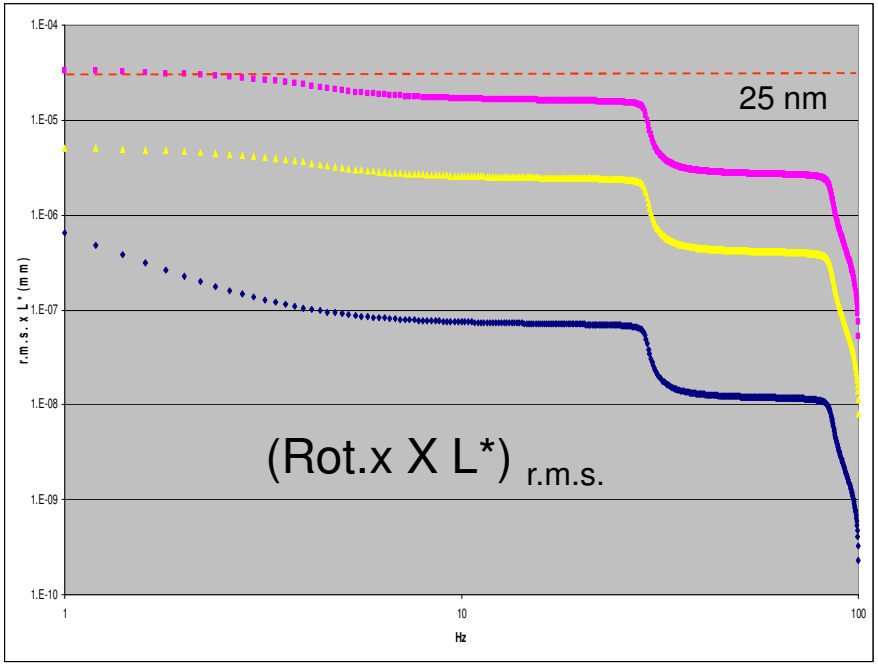


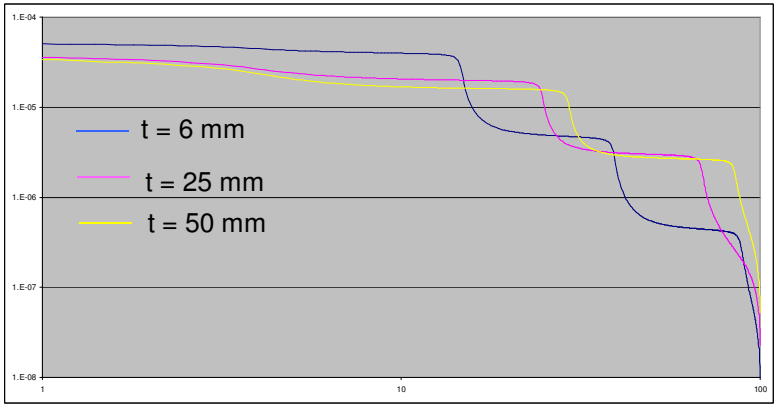
$$\left\langle u_{tot}^{\,2}\right\rangle = \left\langle \left(u_y + \alpha\cdot L^*\right)^2\right\rangle = \left\langle u_y^{\,2}\right\rangle + \left\langle \left(\alpha\cdot L^*\right)^2\right\rangle + 2\left\langle u_y \times \alpha\cdot L^*\right\rangle$$

$$\left\langle u_y^{\,2}\right\rangle = \int_{f1}^{f2} S_{u_y}\,df, \quad \left\langle \alpha^2\right\rangle = \int_{f1}^{f2} S_{\alpha}\,df, \quad \left\langle \alpha^2\right\rangle = FRF(f)\cdot\left\langle u_y^{\,2}\right\rangle,$$

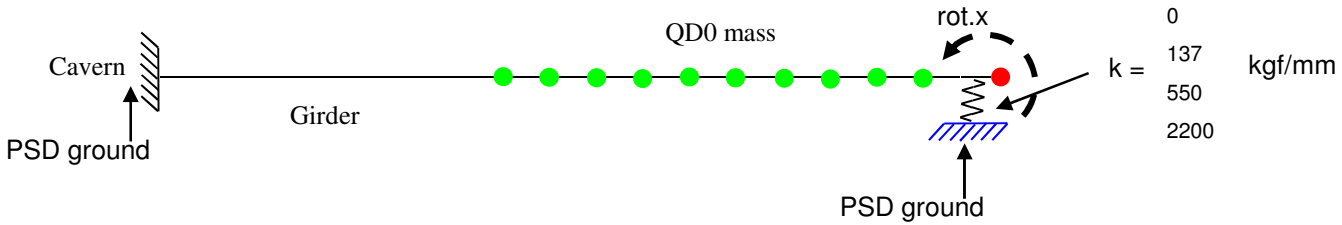
$$\left\langle u_y \times \alpha\cdot L^*\right\rangle = 2\cdot L^*\cdot\int_{f1}^{f2}\left(S_{u_y}\cdot \mathrm{Re}\left[FRF(f)\right]\right)df$$

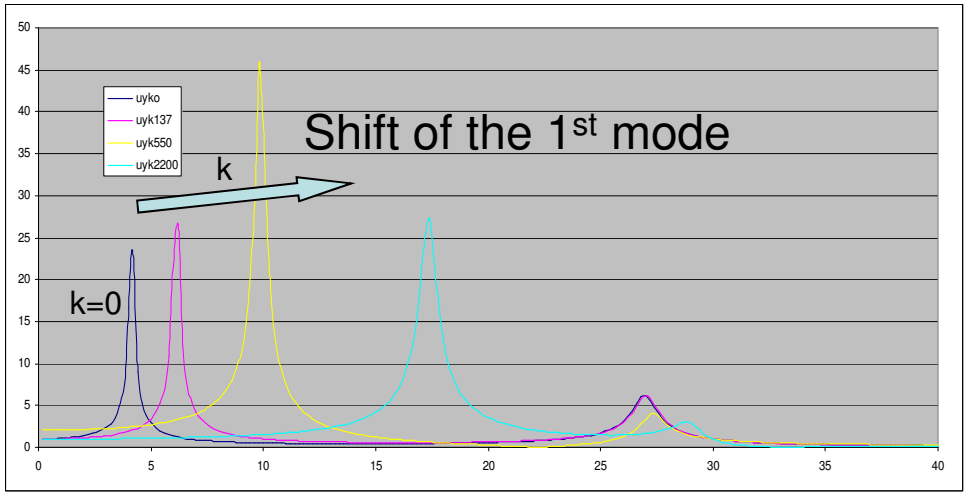


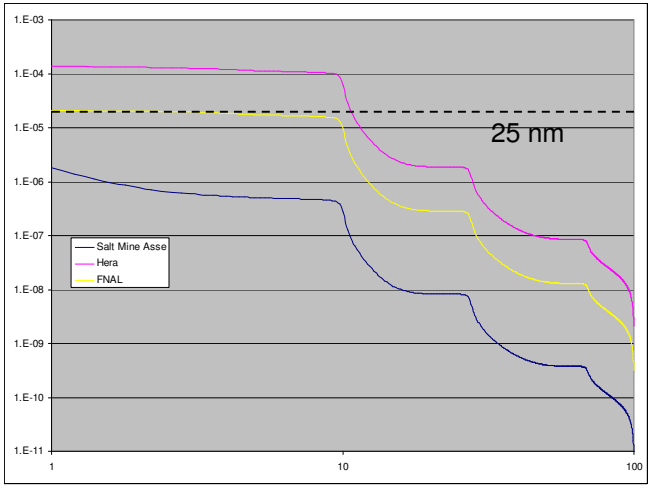


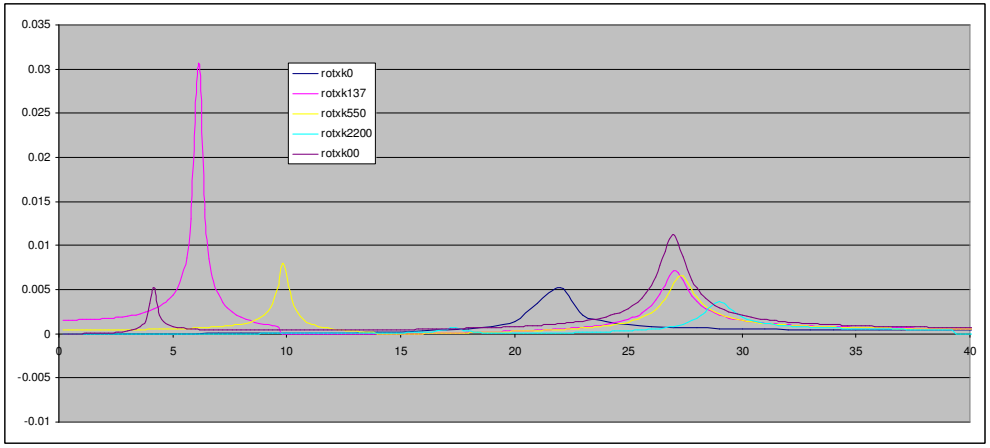


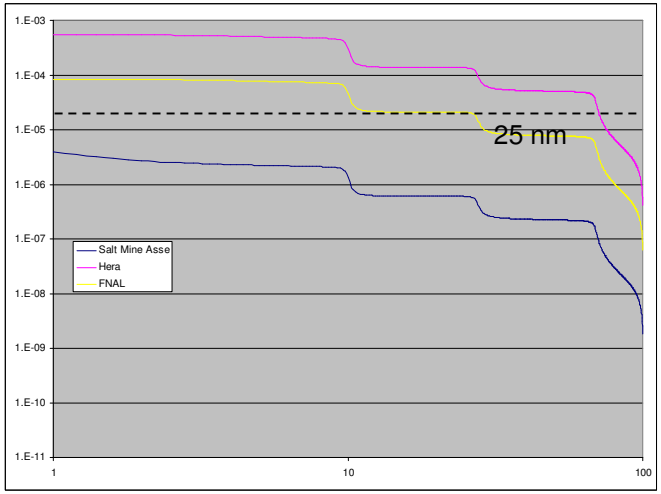
QDO cantilevered + spring suspension from the barrel











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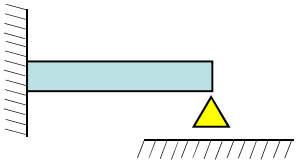

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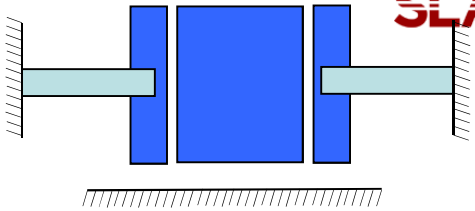
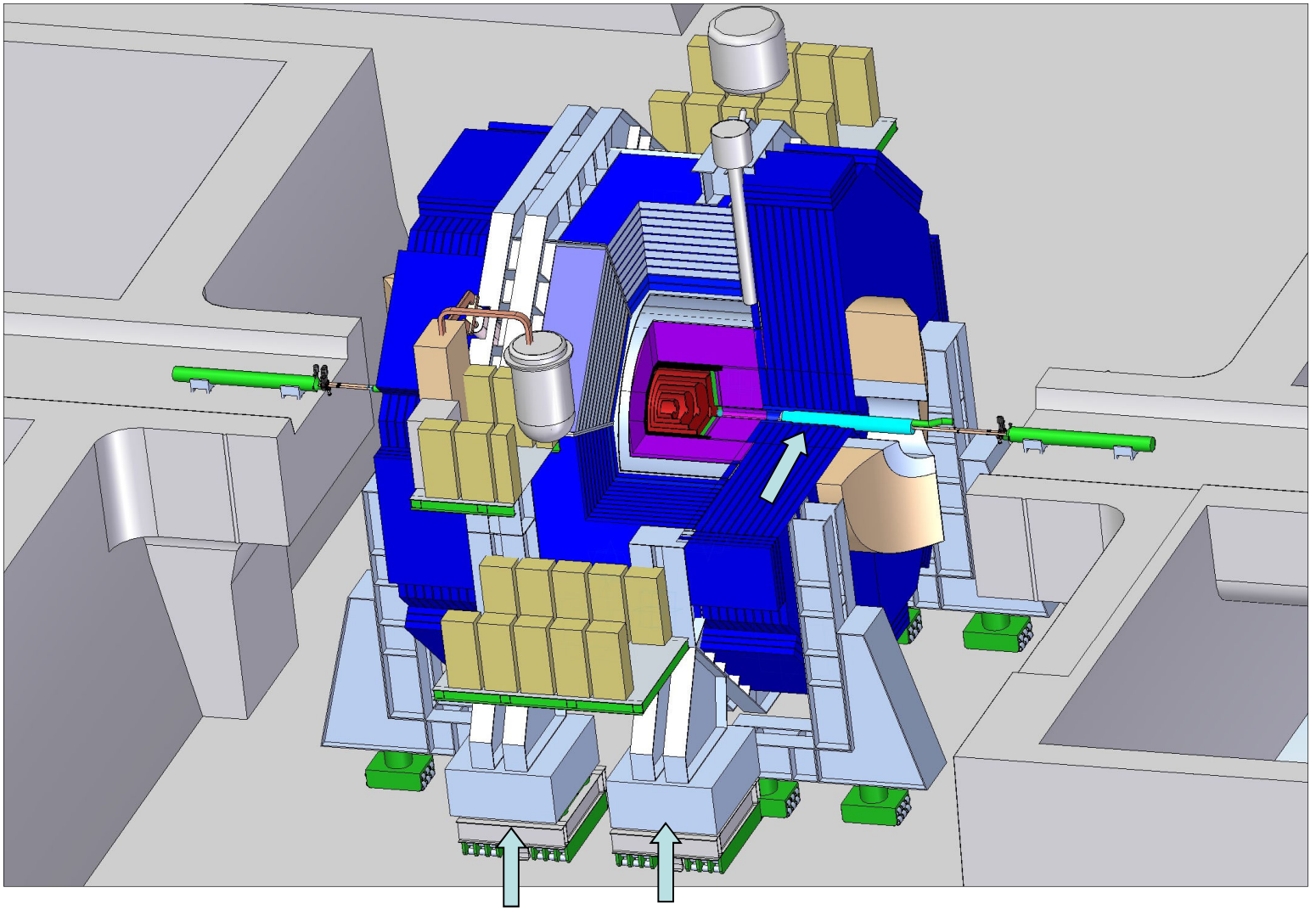
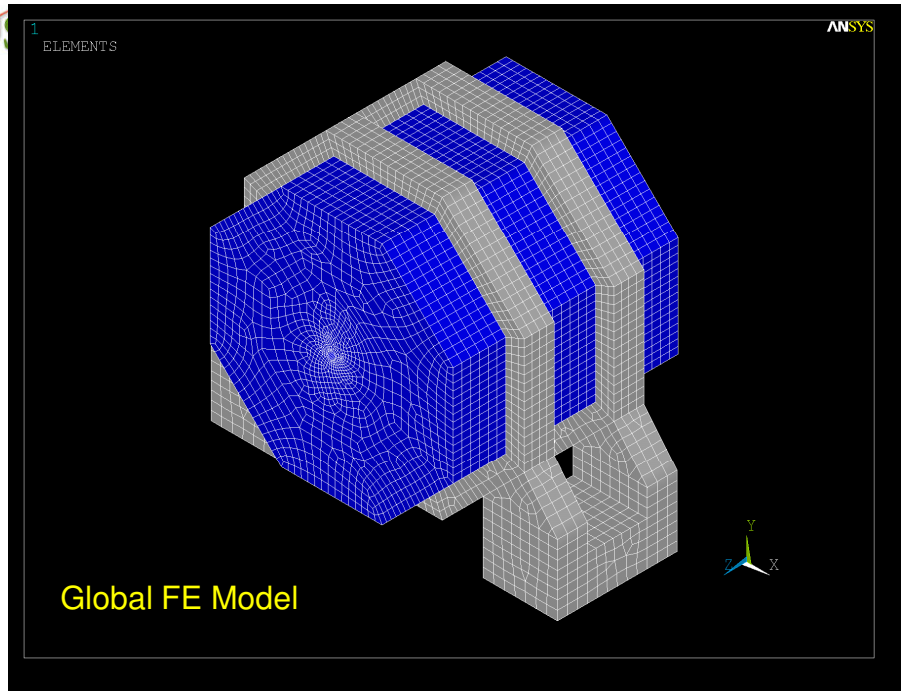
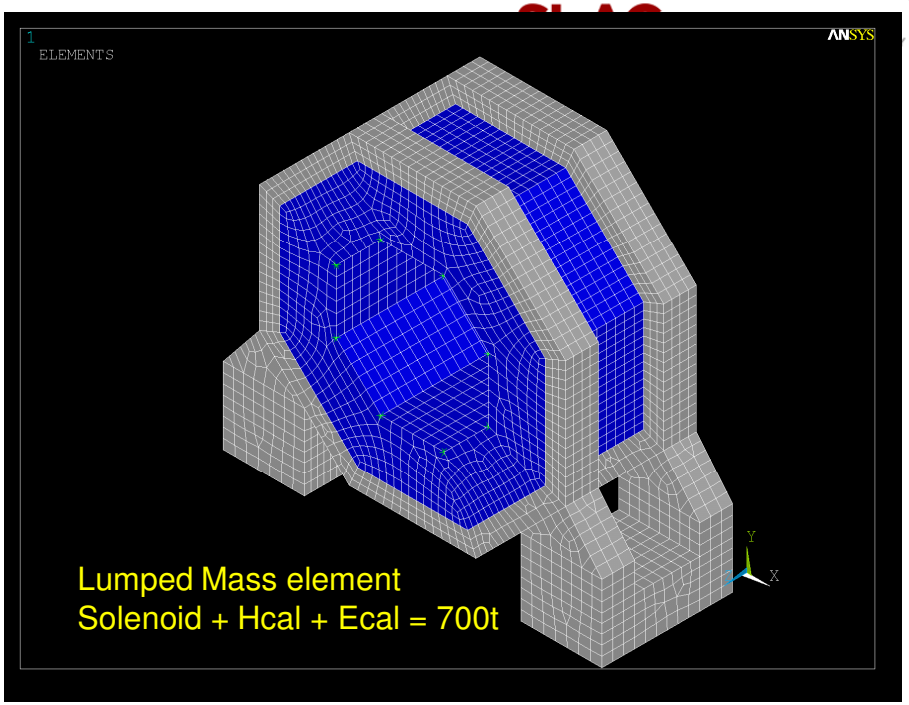
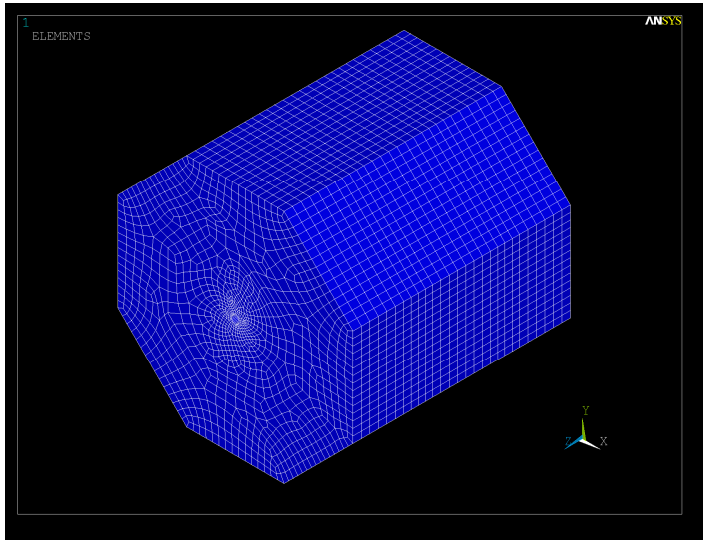




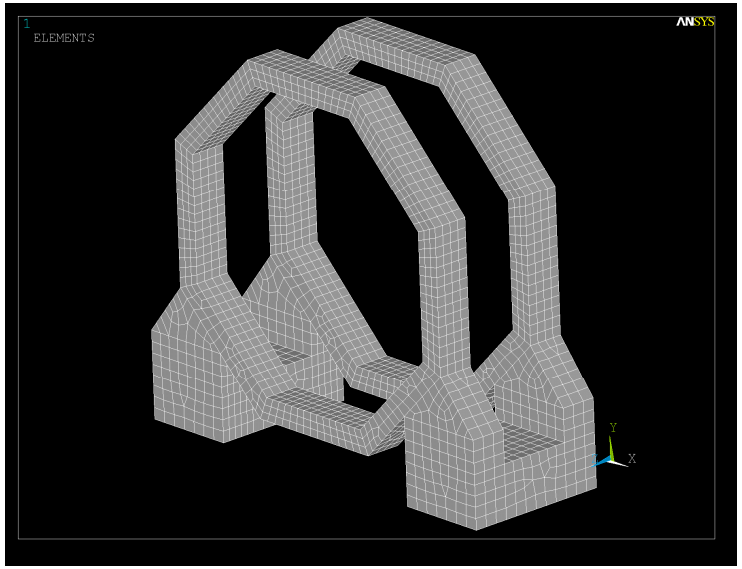
Ground motion through the feet





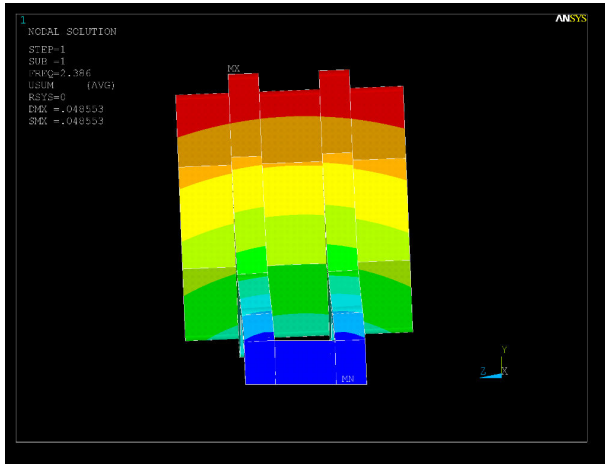


3D Solid Elements for the Iron Yoke, 9000 t

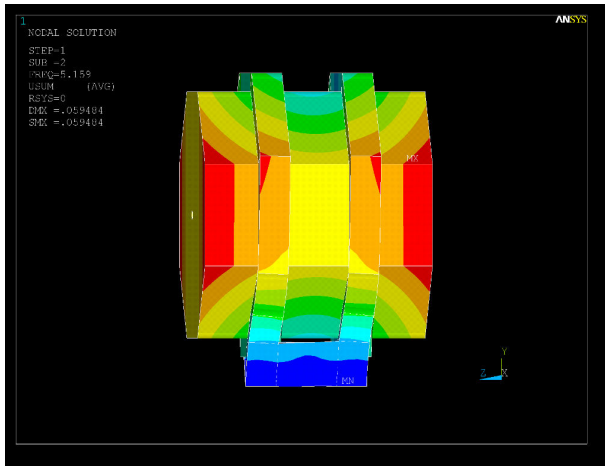


3D Shell Elements for the Arch, thickness 50mm

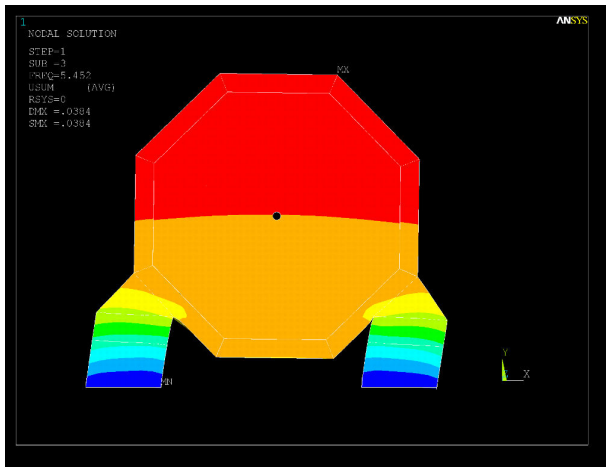
Free Vibration Mode



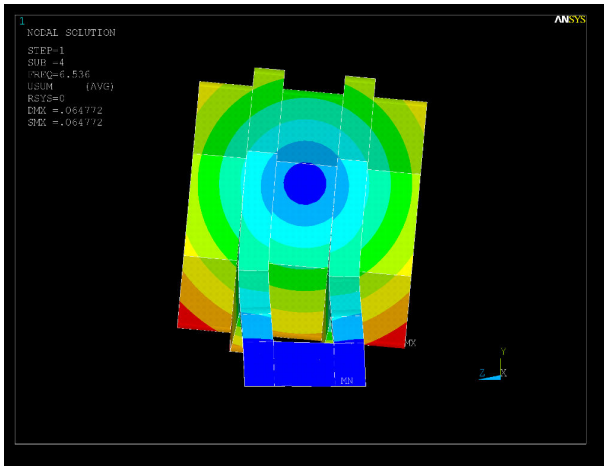
1st Mode, 2.38 Hz



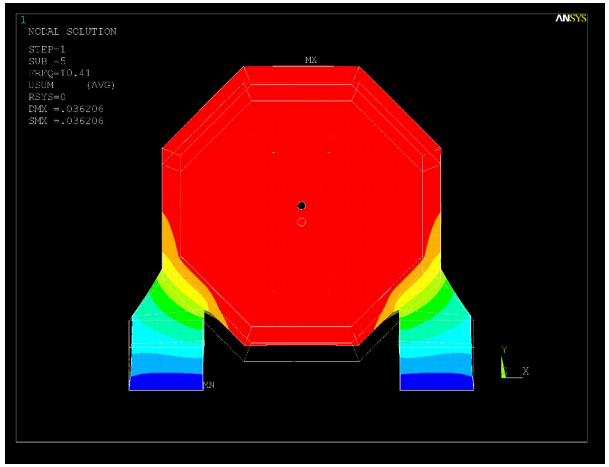
2nd Mode, 5.15 Hz



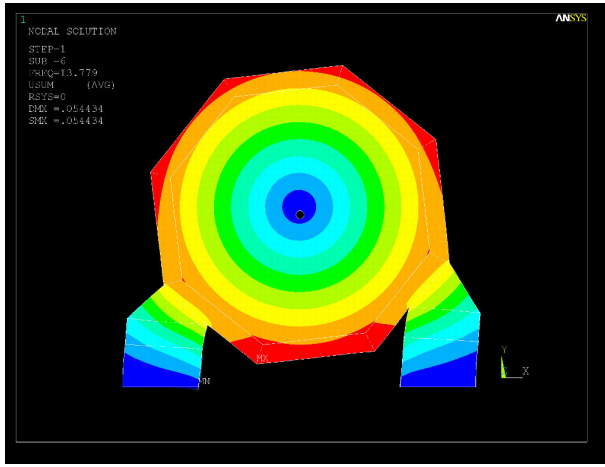
3rd Mode, 5.45 Hz



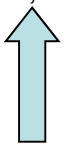
4th Mode, 6.53 Hz



5th Mode, 10.42 Hz



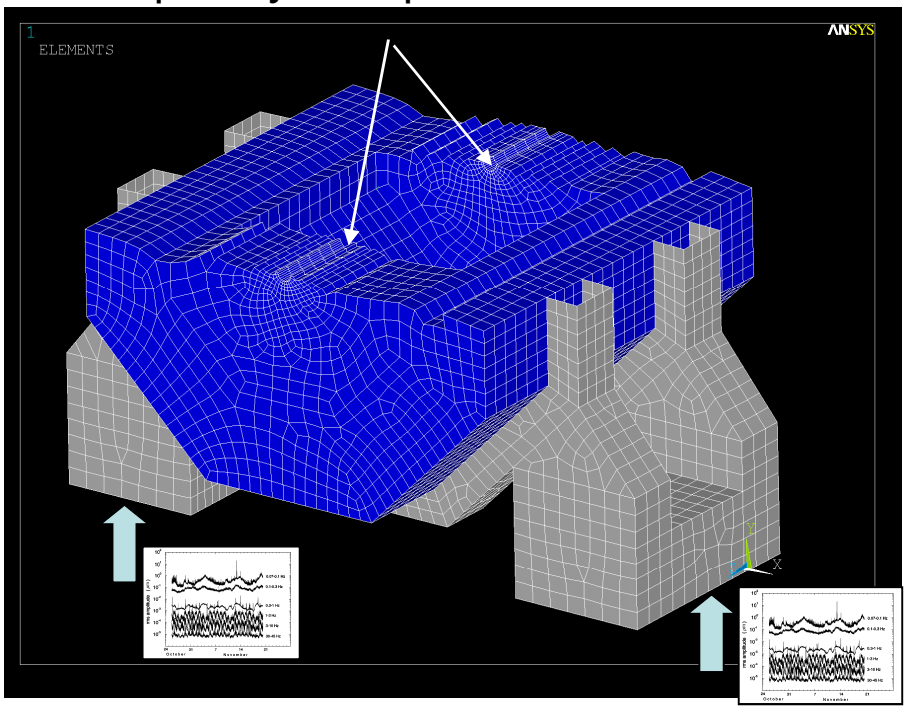
6th Mode, 13.7 Hz

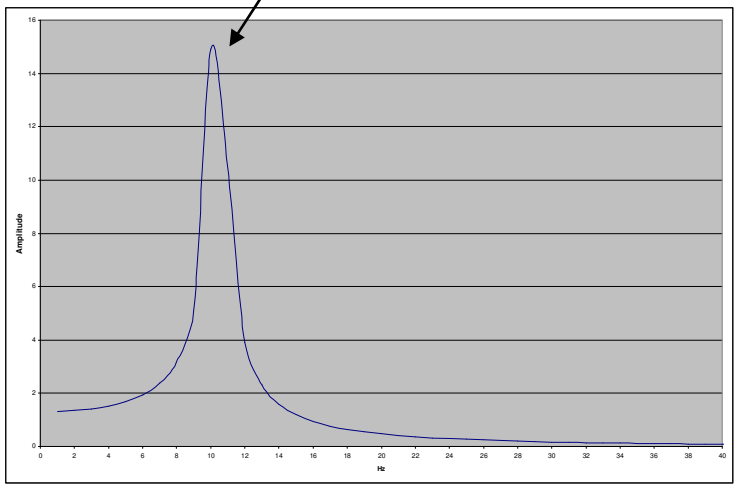


Vertical motion

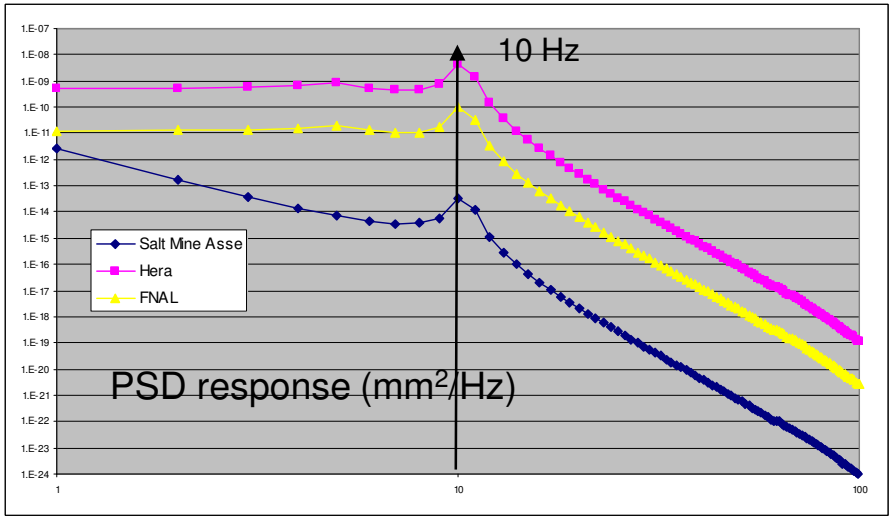
Harmonic Analysis

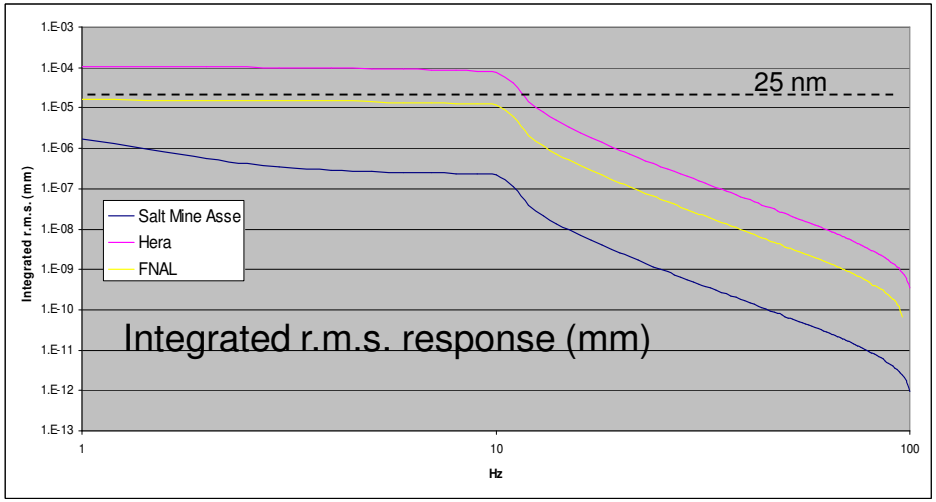
Frequency Response Function





To mitigate the r.m.s. response, the resonance mode must be as high as possible





Resonance mitigation

The vertical mode of resonance depends on the elasticity of the feet

To increase the resonance frequency one can :

Reduce the detector mass ->less iron->more stray field

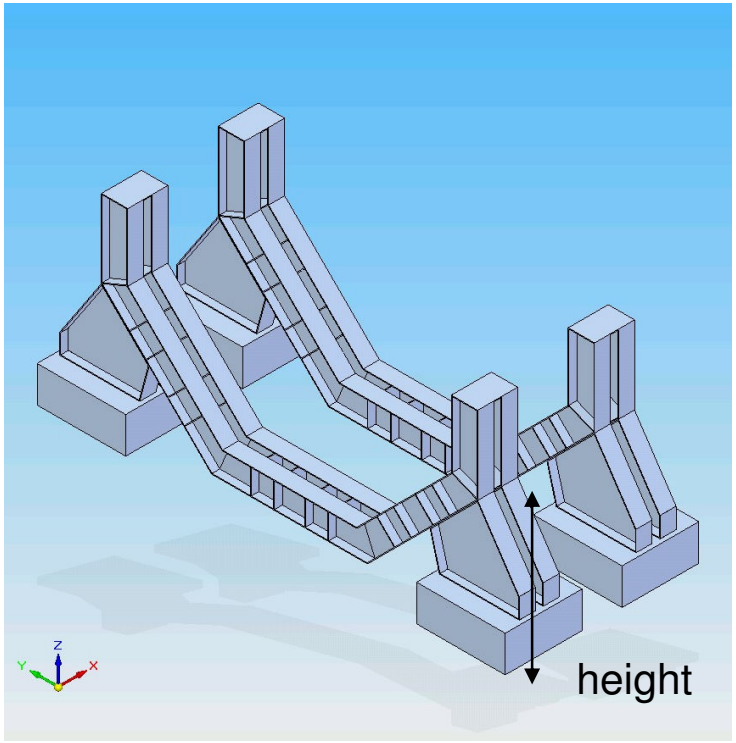
Select a more rigid material -> SSteel ~210GPa

⇒ Lower the height the foot -> lower the center of gravity ~ factor 2

⇒ Increase the cross section area f the foot -> thicker plate ~ factor 2

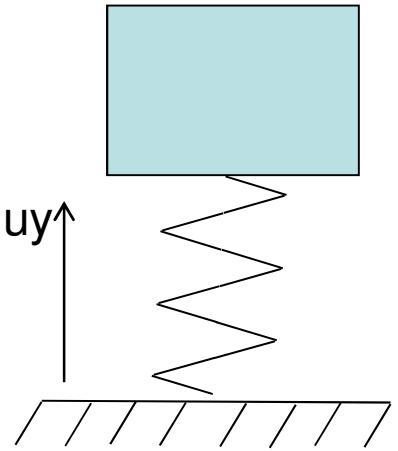
⇒ Additional supports to reduce the specific mass per foot ~ factor 2

~ factor 6- 8, i.e. fo*sqrt(8) ~ 28 Hz



M = ¼ of SiD mass

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{M}}$$



$$k = \frac{YoungMod \cdot Area}{height}$$

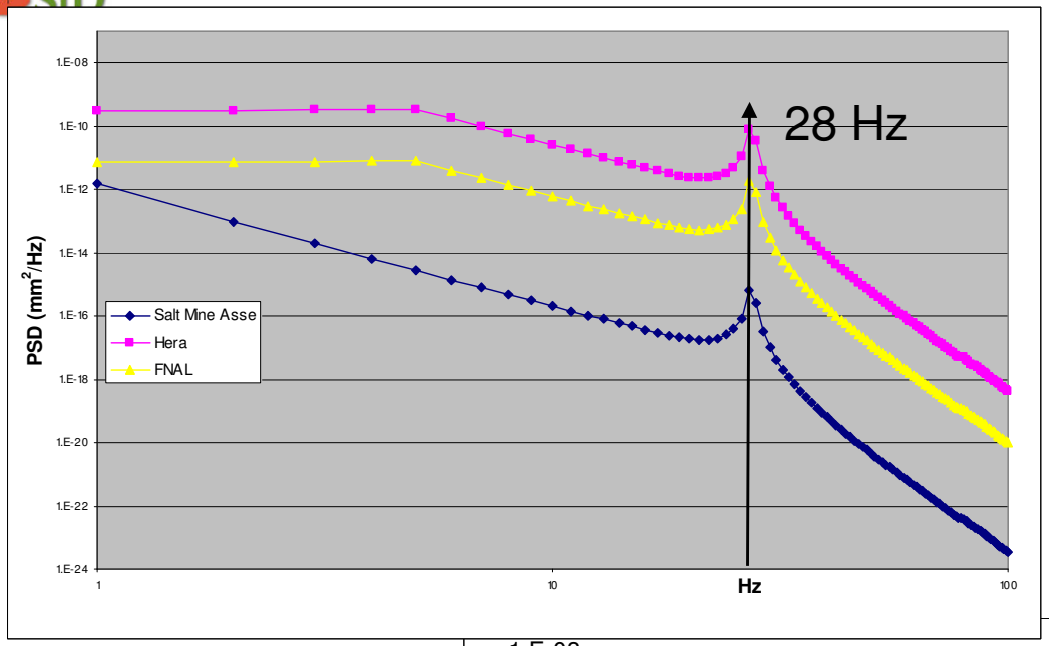
M=2500 tons

E=210 GPa

Height =3 m

Plate thickness =30 mm

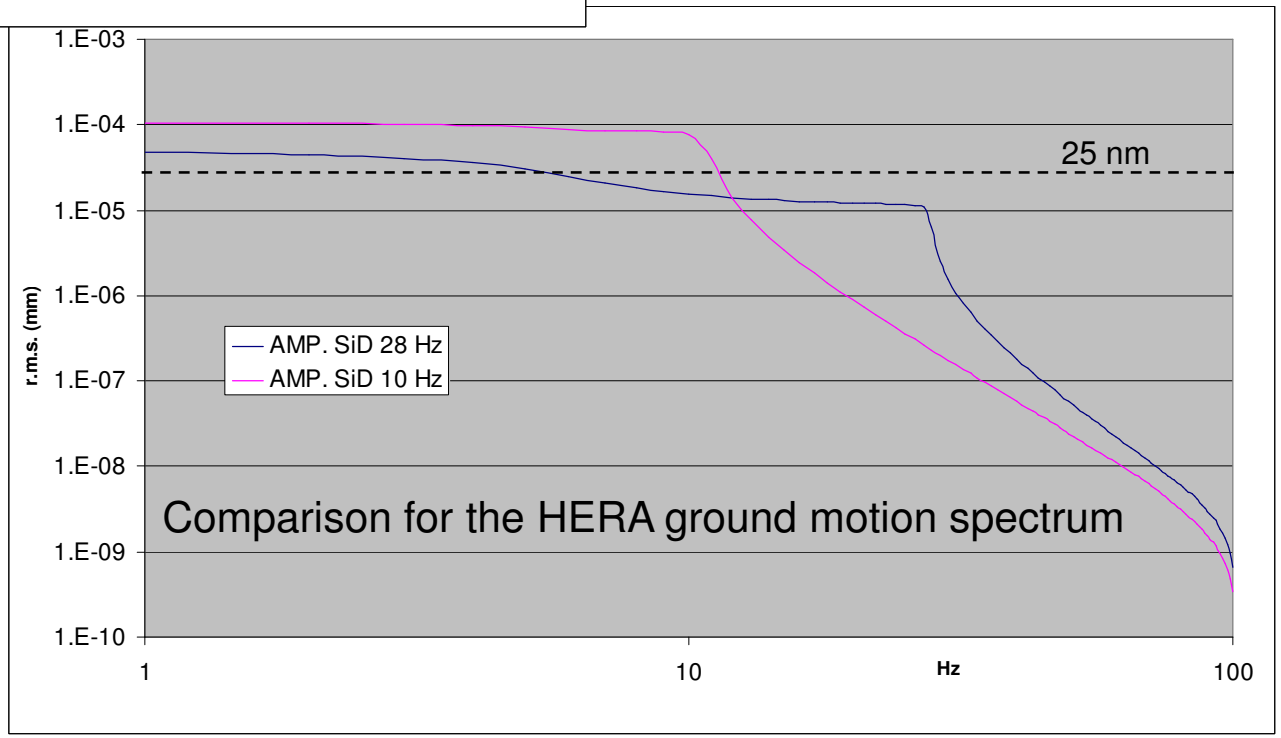
f = 10 Hz



Shift of the resonance mode from 10 to 28 Hz

~ factor 2 on the r.m.s. amplitude at low freq.

~ wider range at higher freq.

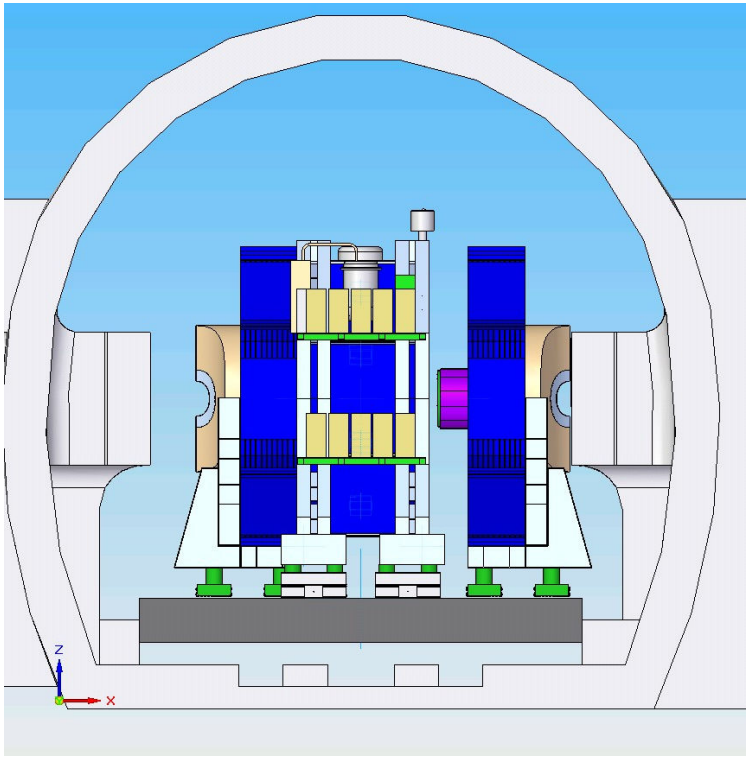


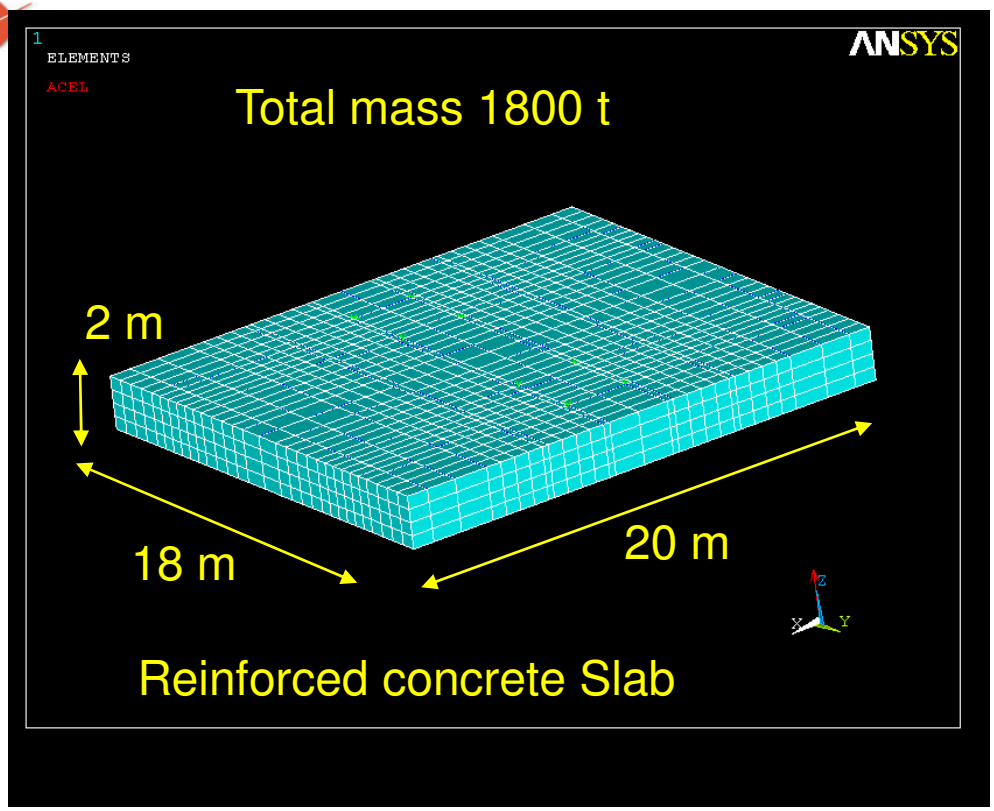
The platform

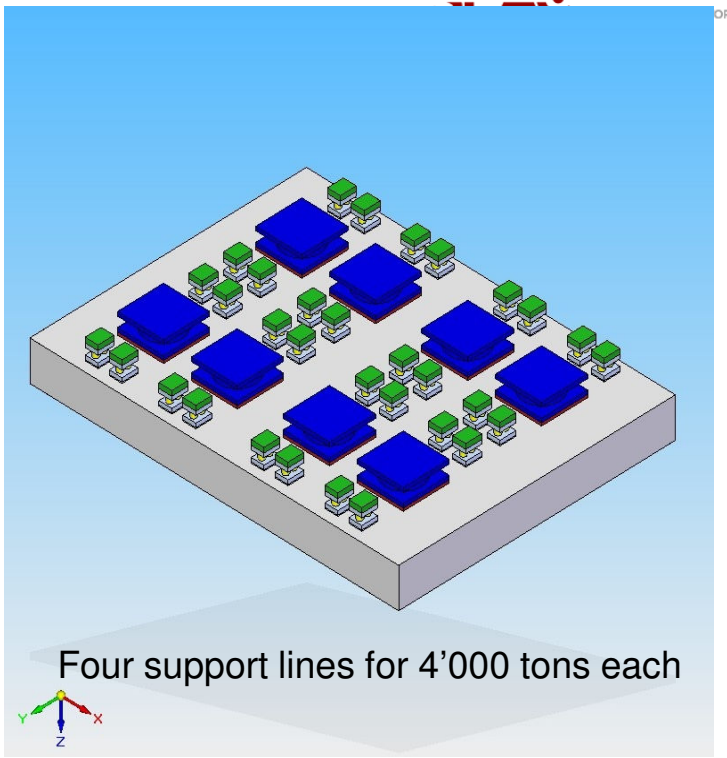
One of main concerns that triggered the stabilization studies of the final focus system is the effectiveness of a platform concept versus the shielding of the ground motions :

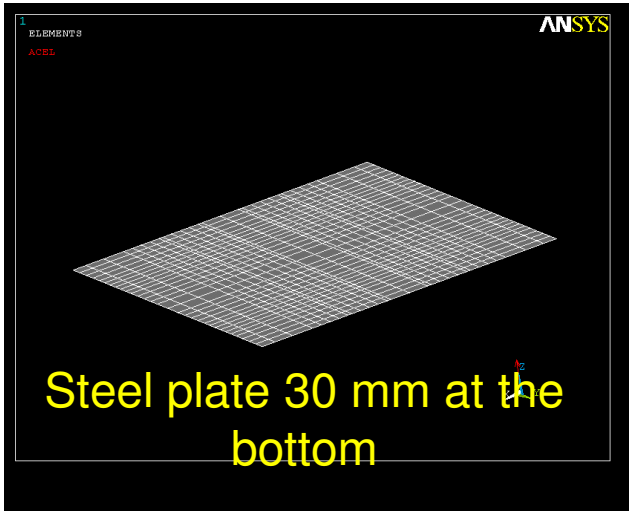
- Is a detector on a platform experiencing amplified, reduced or same levels of ground motion ?

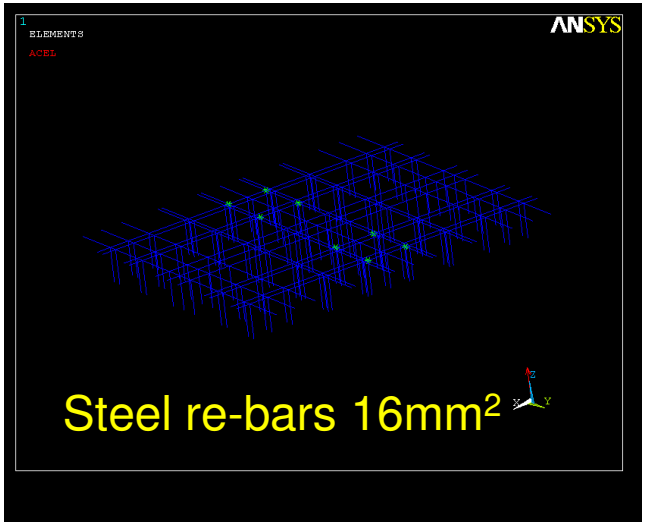
The question is subordinate to the availability of an the engineering design of the platform and how the detector and the QD0s are secured on board.





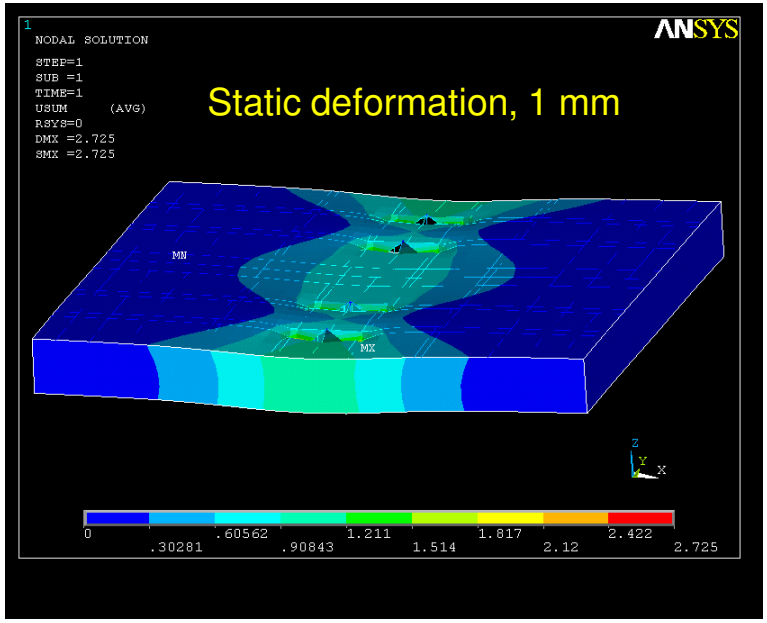


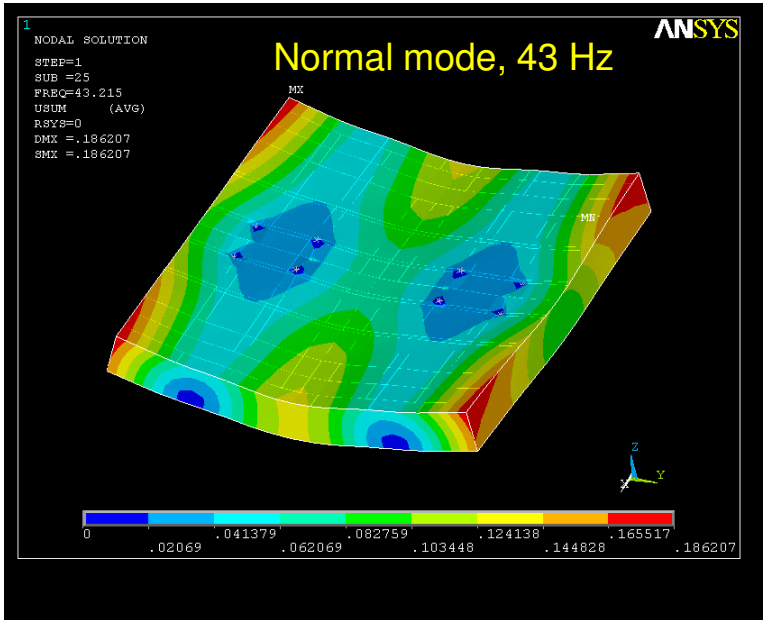


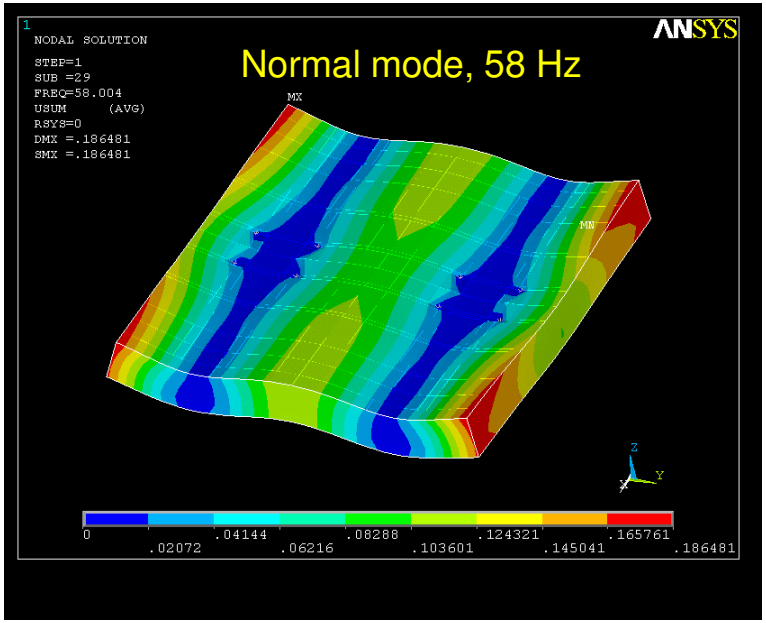


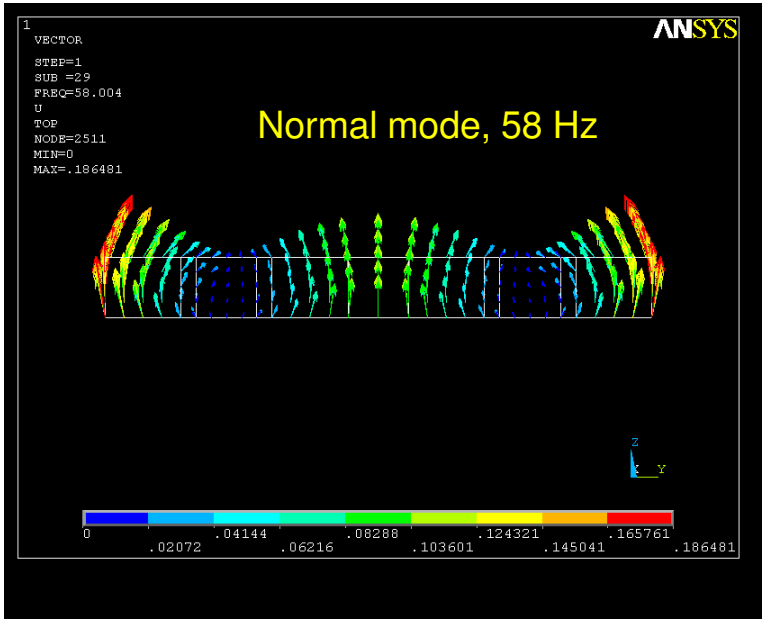
10kt Anti-seismic supports

Modal analysis

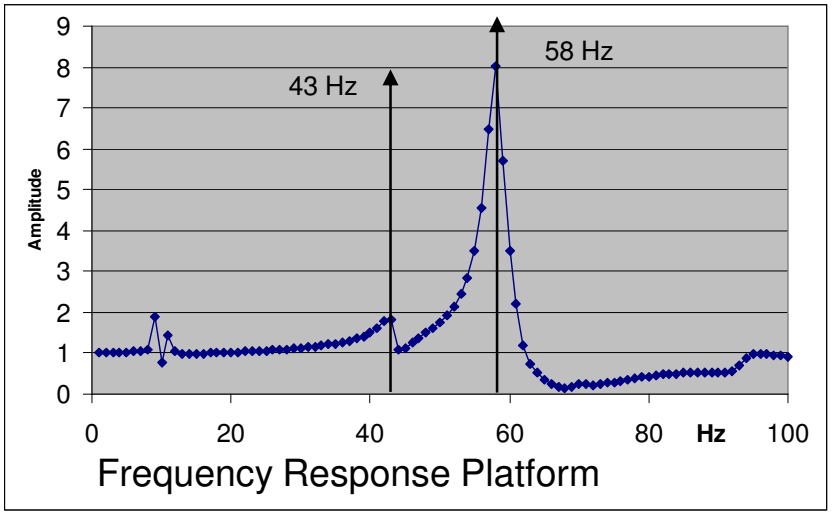


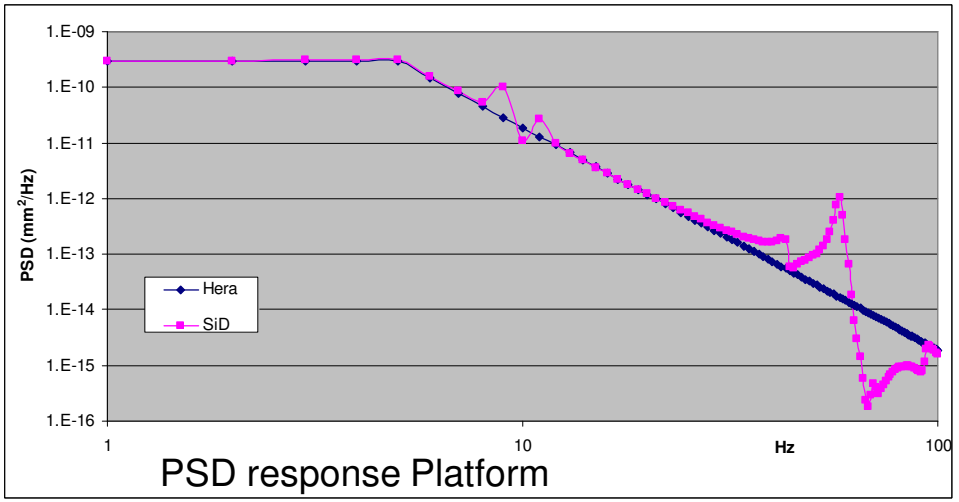


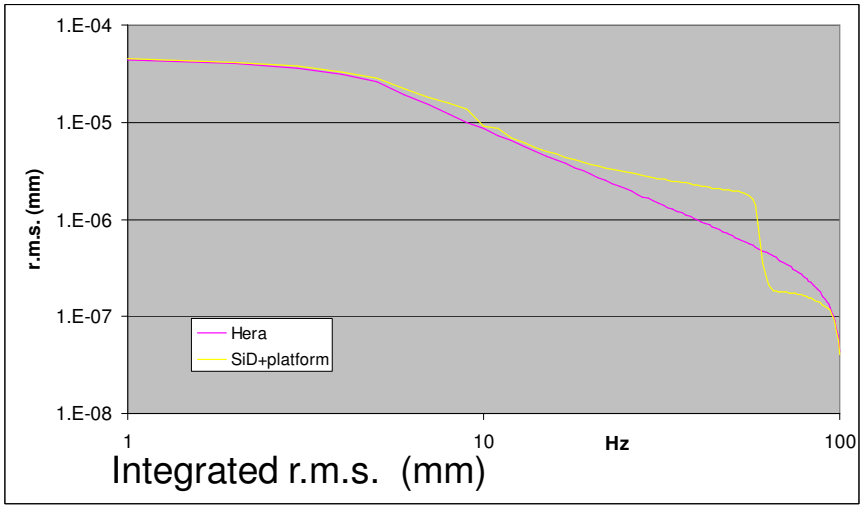


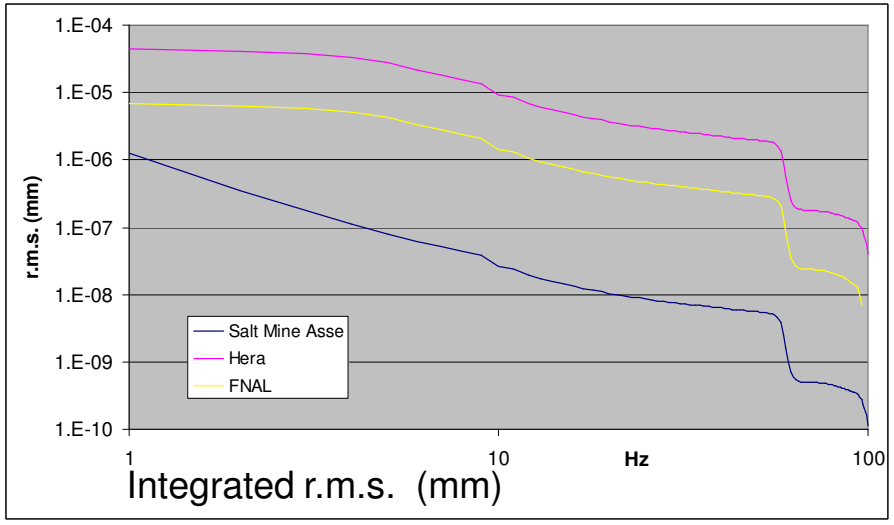


Random vibrations

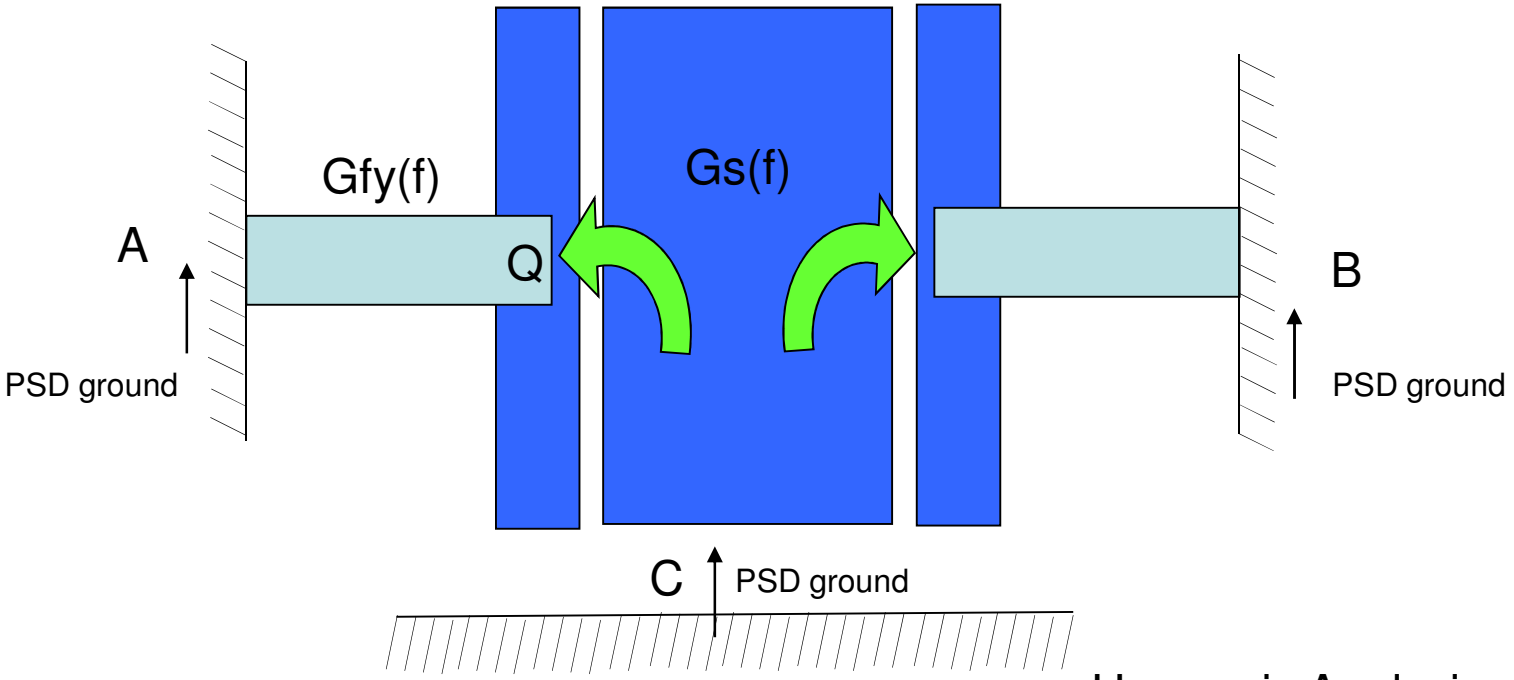








The global effect



Harmonic Analysis

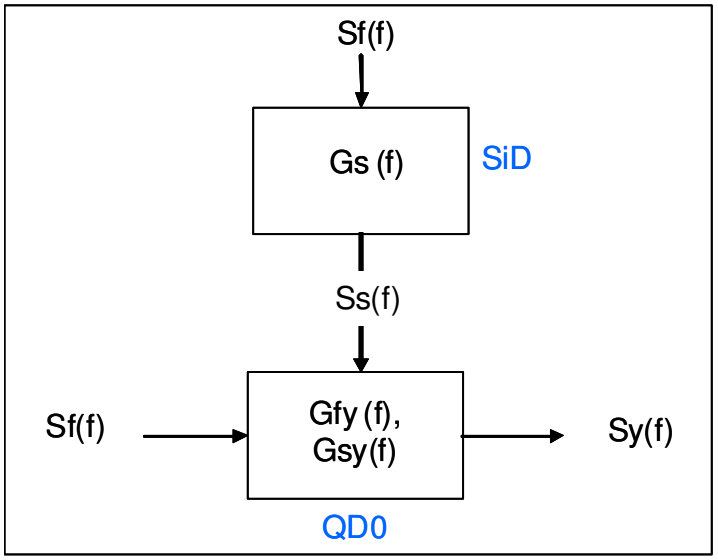
Gfy(f) transfer function through the cavern wall

Gs(f) transfer function through SiD

$$Sy(f) = |Gfy|^2 \cdot Sf + \mathrm{Gfy}^* \cdot \mathrm{Gsy} \cdot \mathrm{Ssf} + \mathrm{Gfy} \cdot \mathrm{Gsy}^* \cdot \mathrm{Sfs} + |Gsy|^2 \cdot Ss$$

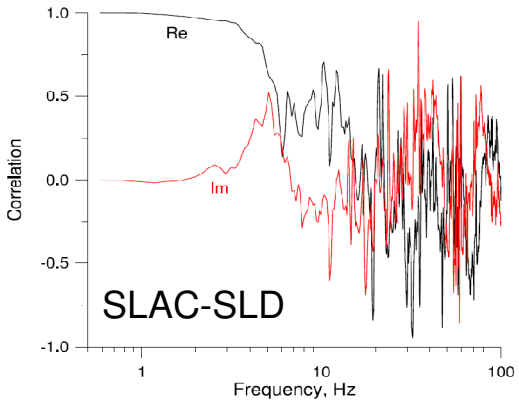
and finally :

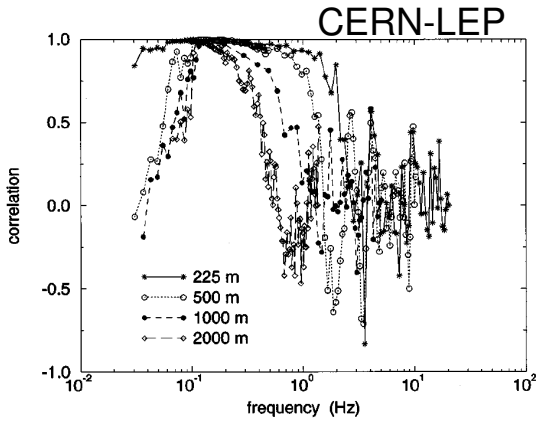
$$Sy(f) = \left[|Gfy|^2 + \mathrm{Gfy}^* \cdot \mathrm{Gsy} \cdot Gs + \mathrm{Gfy} \cdot \mathrm{Gsy}^* \cdot Gs + |Gsy|^2 \cdot |Gs|^2 \right] \cdot Sf$$

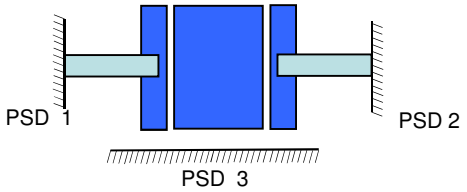


Ground Motion Coherence

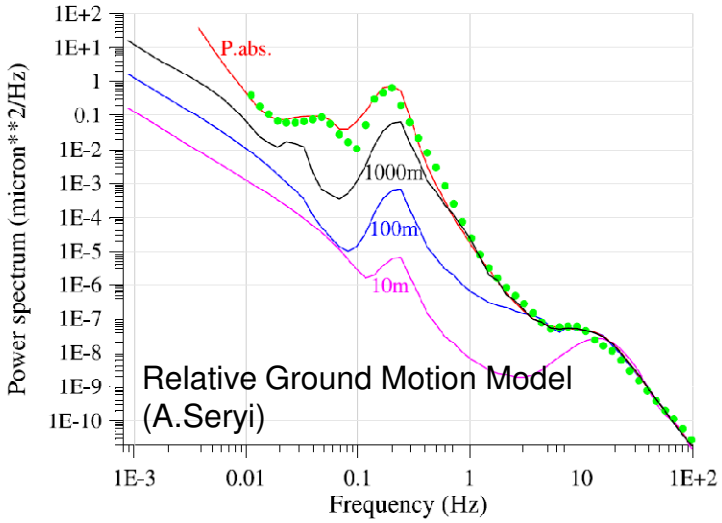
Final Focus system vibrations would not be a problem, if there were a coherent ground motion.

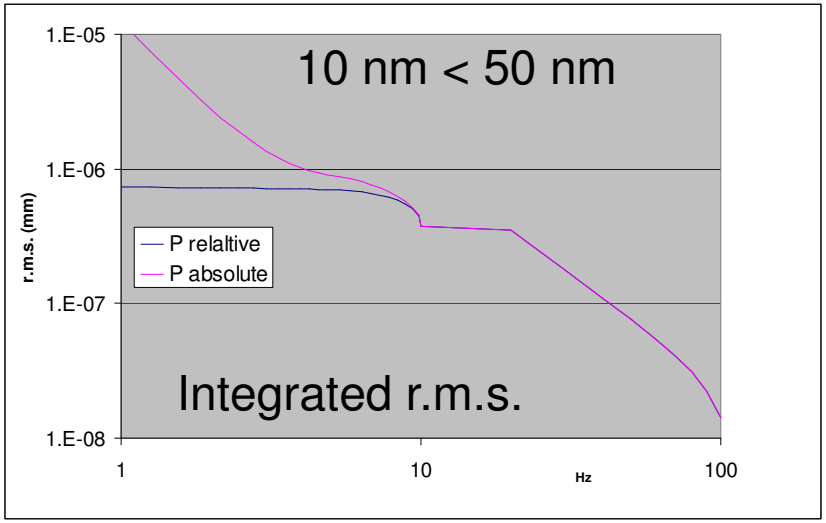






Measurement at different sites show large uncorrelated ground motions for f > 1 Hz, between sensors placed in the cavern and at the final focus systems





Summary

We started the process to produce a model to quantify the vibration effects on SiD.

Preliminary results shows that supporting the QD0s from the doors in combination with the cavern wall is viable solution (proven in SLD)

For a random vibrating QD0, it is need to quantify the net effect of the random vibrating magnetic field on the final path of the beam.

The progress of mechanical design of the QD0 would allow to model the internal vibration of the cold mass inside the cryostat.

We have the estimation of the resonance modes of SiD alone which helps in optimizing the detector supports.

Preliminary calculations of a platform show that more engineering design would be required to confirm the resonance modes range.

We aim to agree on the use of a common set of PSD spectra to benchmark the results.

More work required on the implementation in the dynamic simulation of the not coherent ground motions.