VIRGO SUSPENSIONS

S.Braccini

Naples
E.Calloni
L.DiFiore
M.Varvella

Rome
M.Bonafede
E.Bompiani
E.Majorana
P.Puppo
P.Rapagnani
F.Ricci

Perugia
P.Amico
L.Carbone
F.Marchesoni
L.Gammaitoni
M.Punturo
H.Vocca

Pisa
S.Braccini
C.Bradaschia
R.Cavalieri
G.Cella
V.Dattilo
A.Di Virgilio
F.Fidecaro
F.Frasconi
A.Gennai
G.Gennaro
A.Giazotto
L.Holloway
F.Paoletti
R.Passaquieti
D.Passuello
R.Poggiani

EGO
G.Ballardin
A.Gennai
G.Gennaro
P.Lapenna
R.Taddei

Florence-Urbino
E.Cuoco
G.Calamai
G.Guidi
G.Losurdo
M.Mazzoni
R.Stanga
F.Vetrano
A.Vicere'

LIGO-G030017-00-D

Introduction

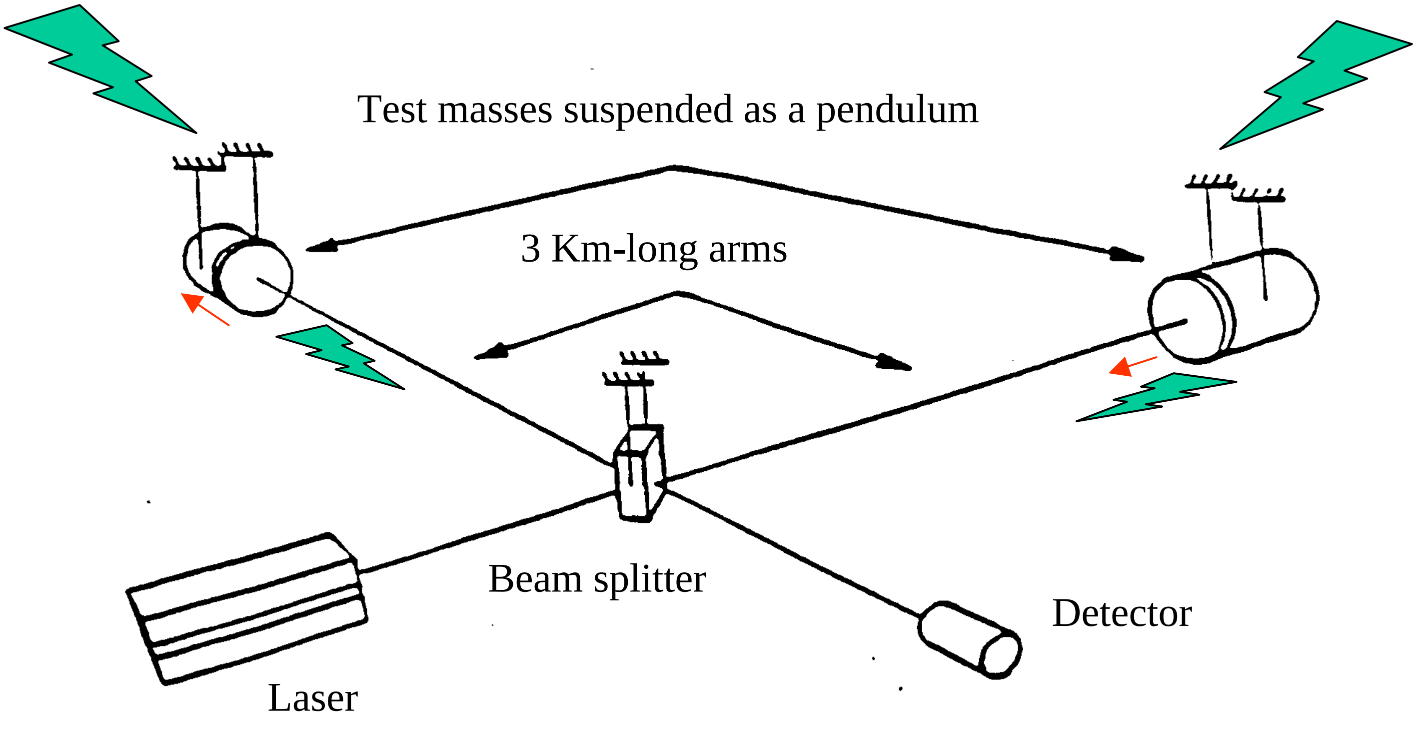
Attenuation Measurements

Mirror Swing Reduction

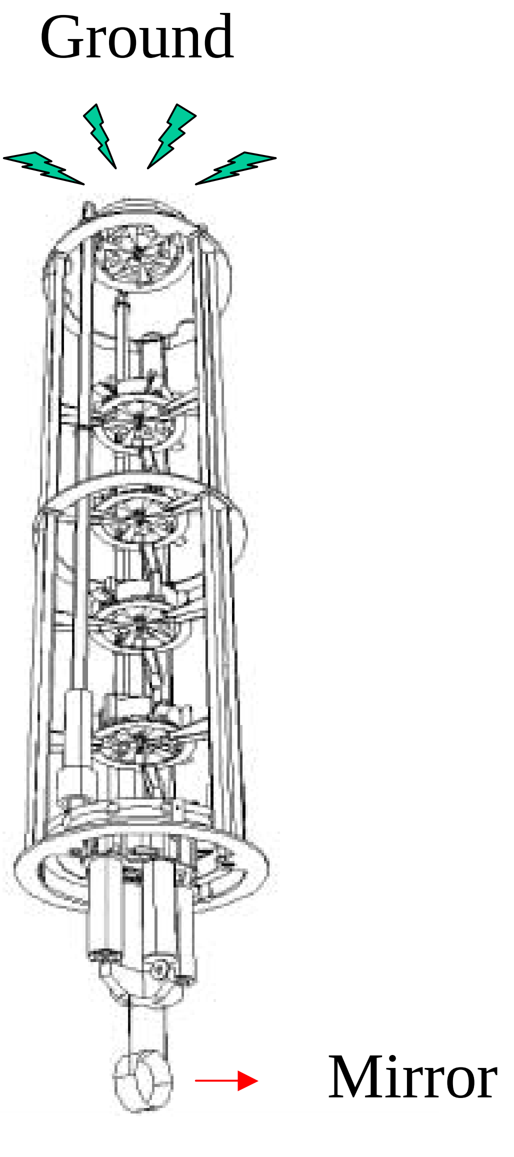
Mirror Local Controls

VIRGO GOAL

Ground Seismic Vibrations are very strong below several tens of Hz



VIRGO Suspensions

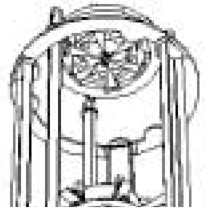


Residual seismic mirror vibrations below the thermal noise floor starting from a few Hz

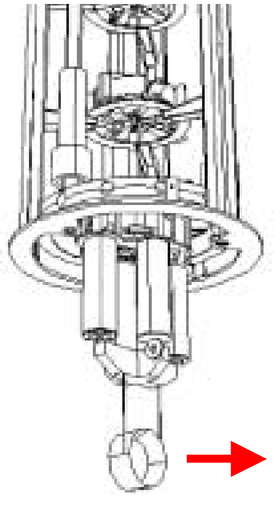
Specification on Horizontal transmission

$\sim 10^{-7} f^{-2}$ m Hz$^{-1/2}$

Seismic Noise



8 orders of magnitude attenuation @ a few Hz

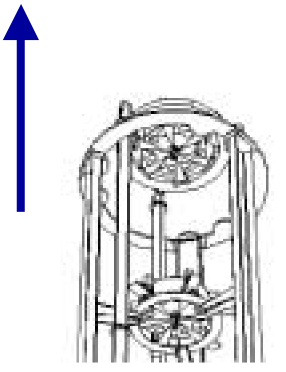


Mirror Thermal Displacement

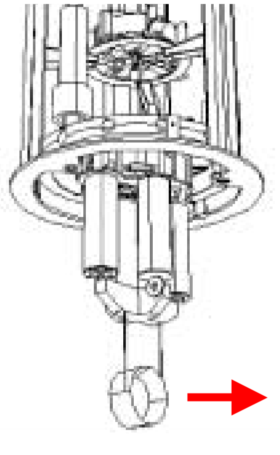
$\sim 3\ 10^{-15} f^{-5/2}$ m Hz$^{-1/2}$

Specification on Vertical transmission

Seismic Noise ***$\sim 10^{-7} f^{-2}$ m Hz$^{-1/2}$***



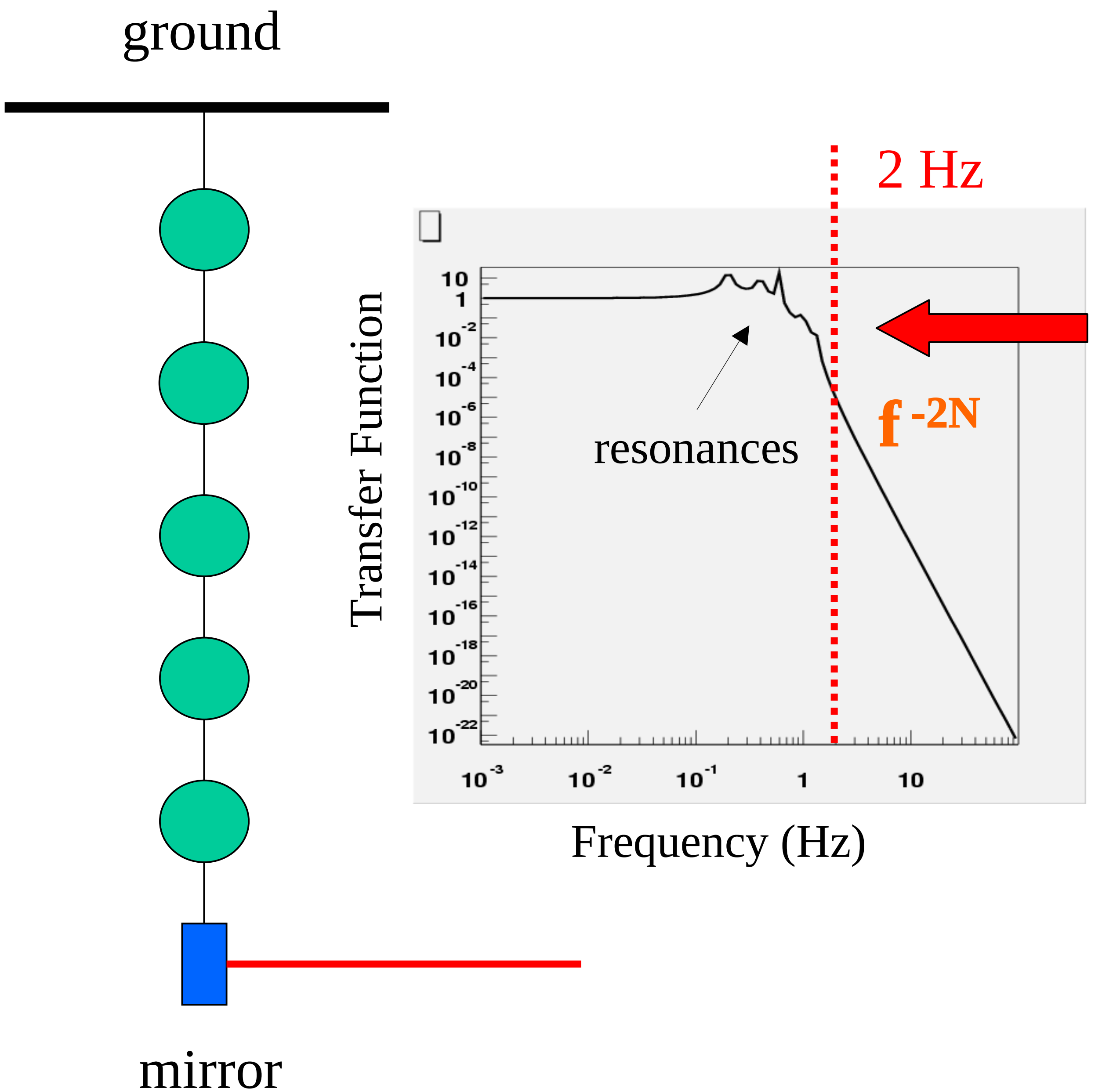
Several orders of magnitude attenuation @ a few Hz



Mirror Thermal Displacement ***$\sim 3\ 10^{-15} f^{-5/2}$ m Hz$^{-1/2}$***

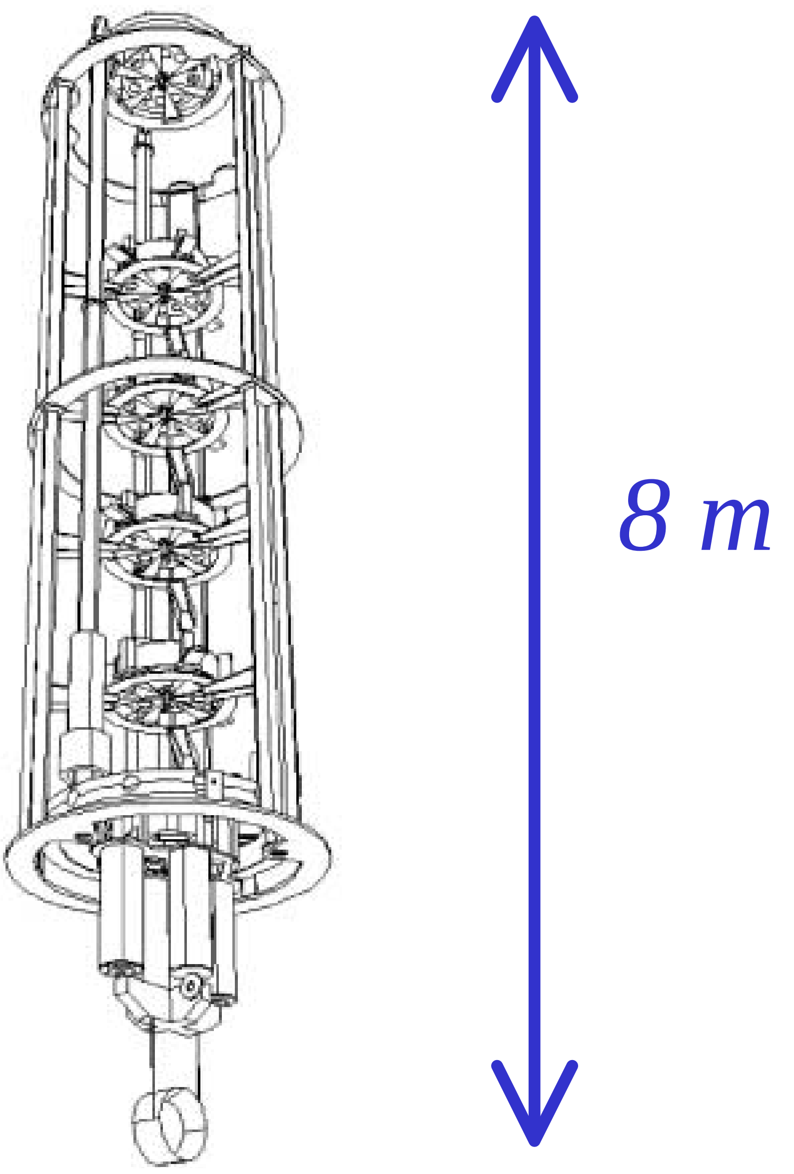
Suspension Working Principle

Horizontal Attenuation



Long Pendula !!!

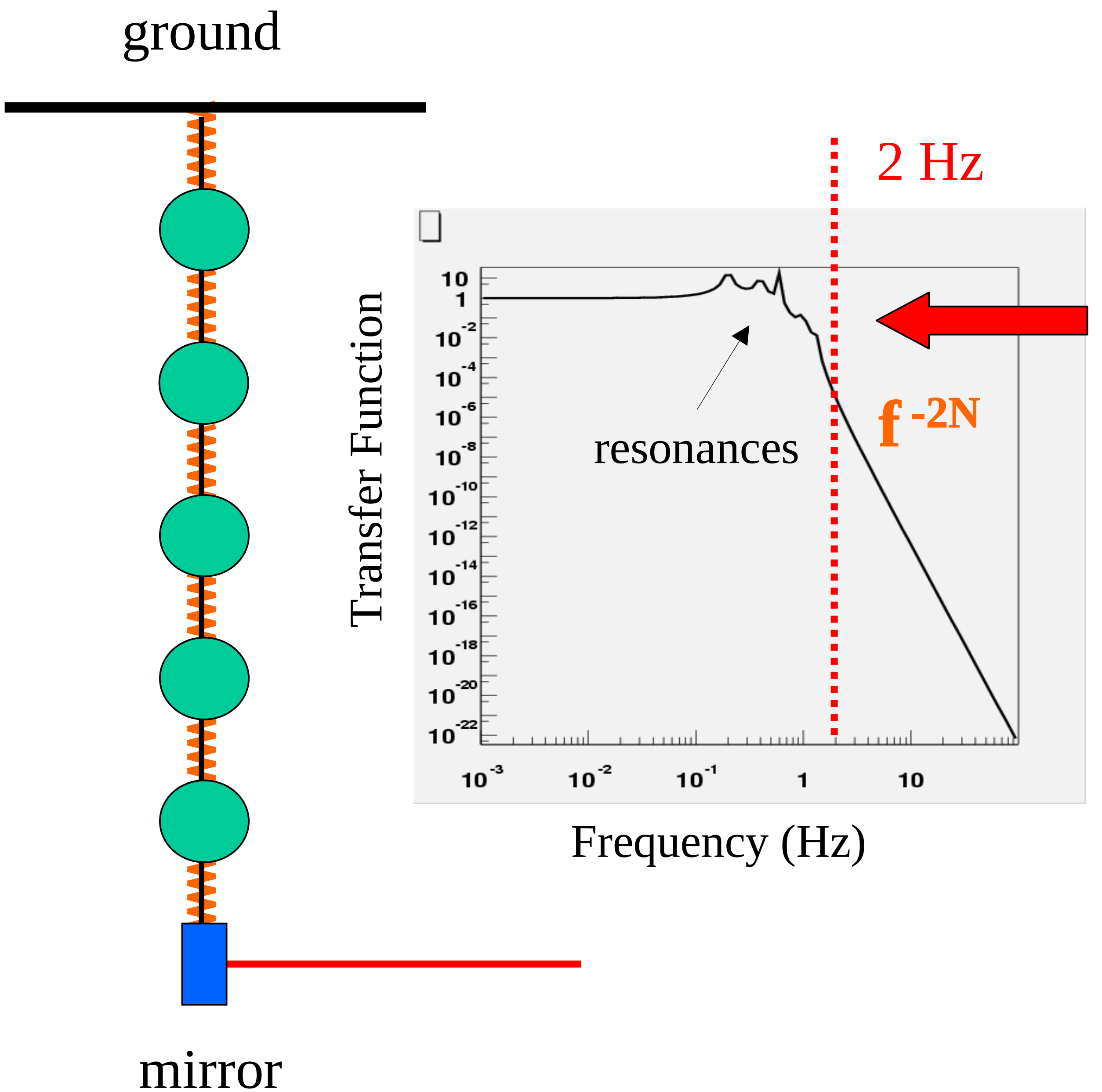
Suspension Working Principle



Chain maximum horizontal frequency around 2 Hz

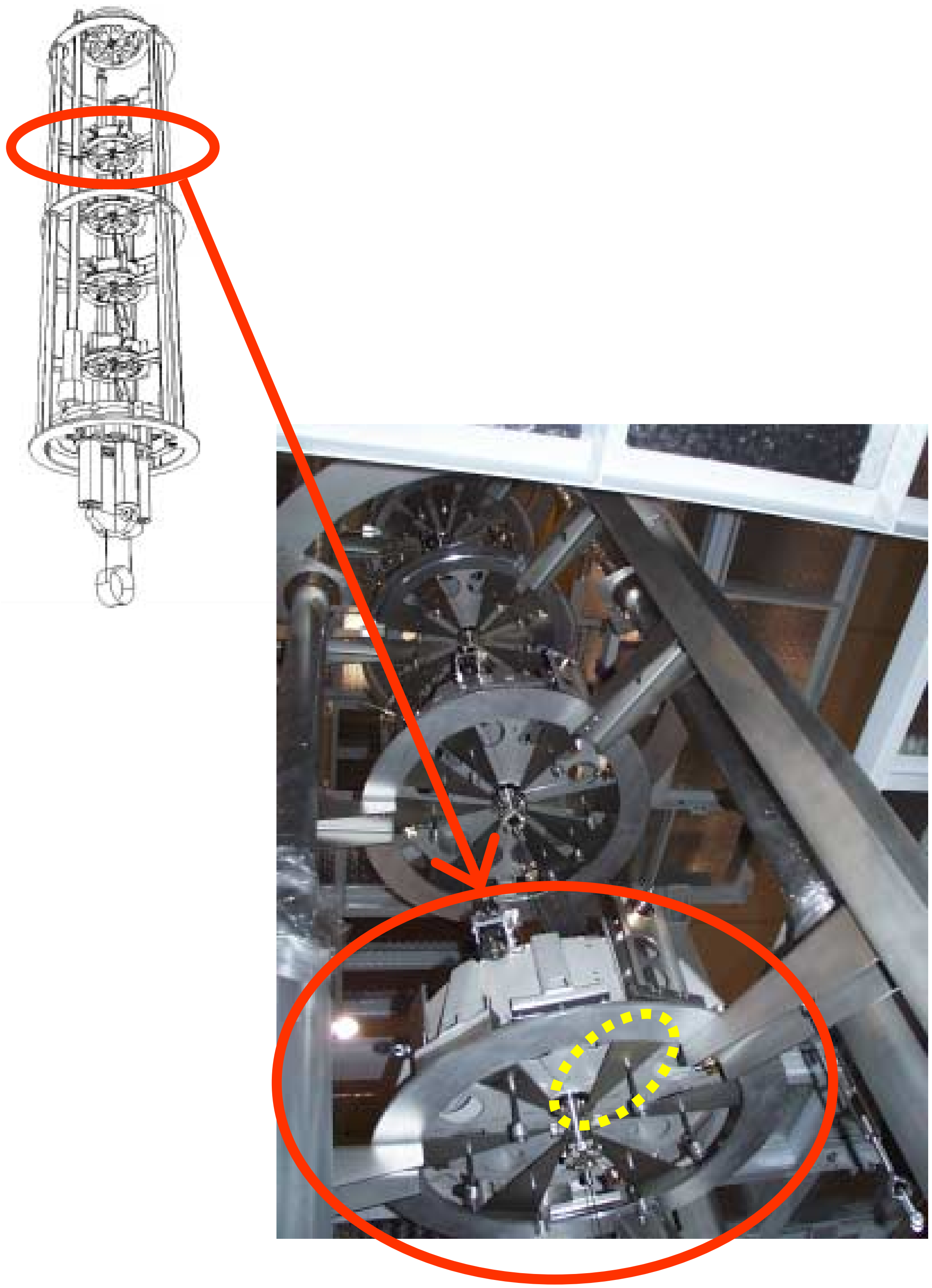
Suspension Working Principle

Vertical Attenuation

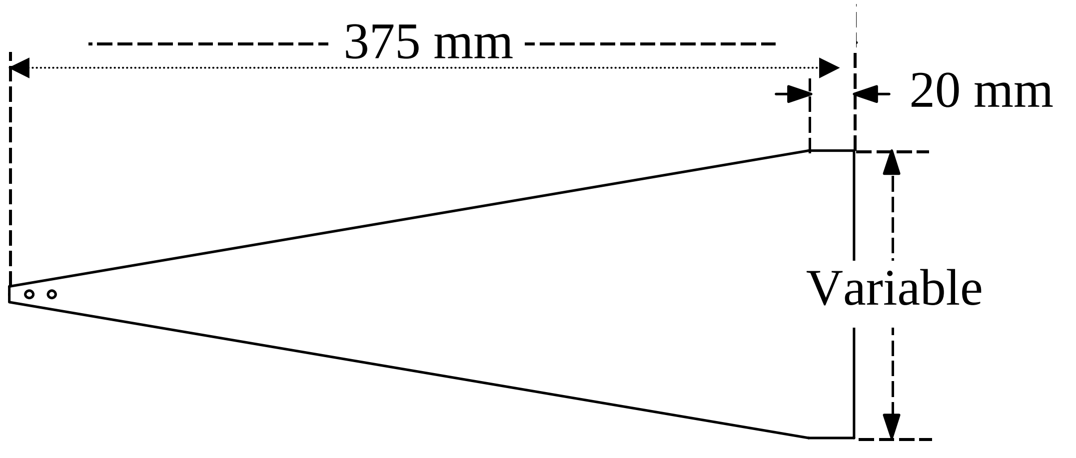


Soft Springs !!!

Suspension Working Principle

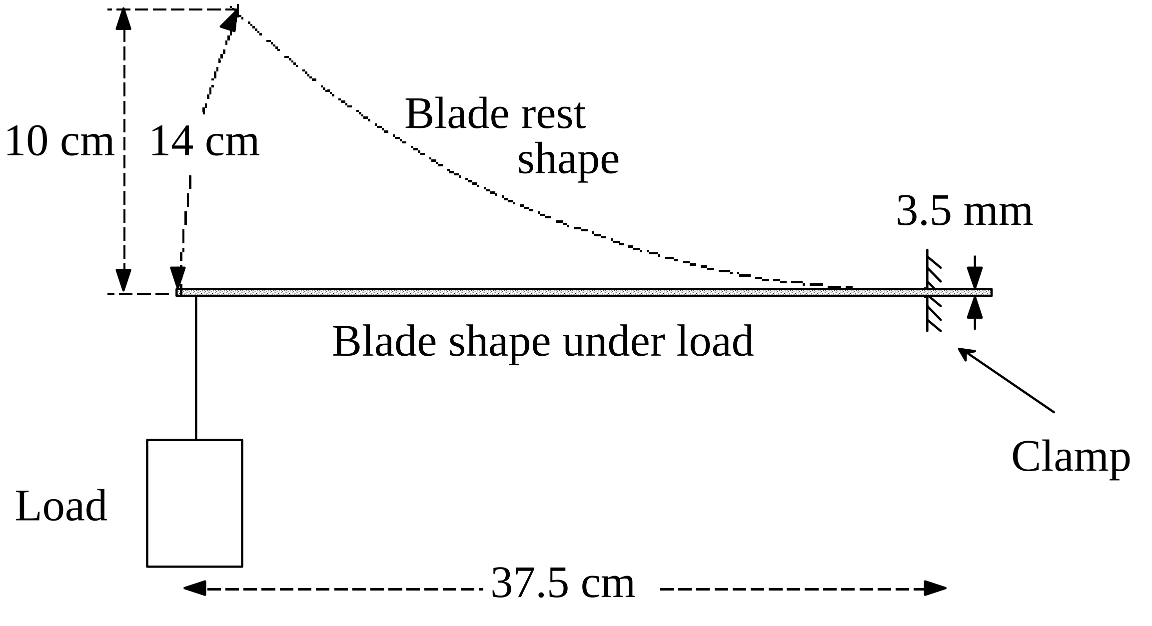


Blade Springs

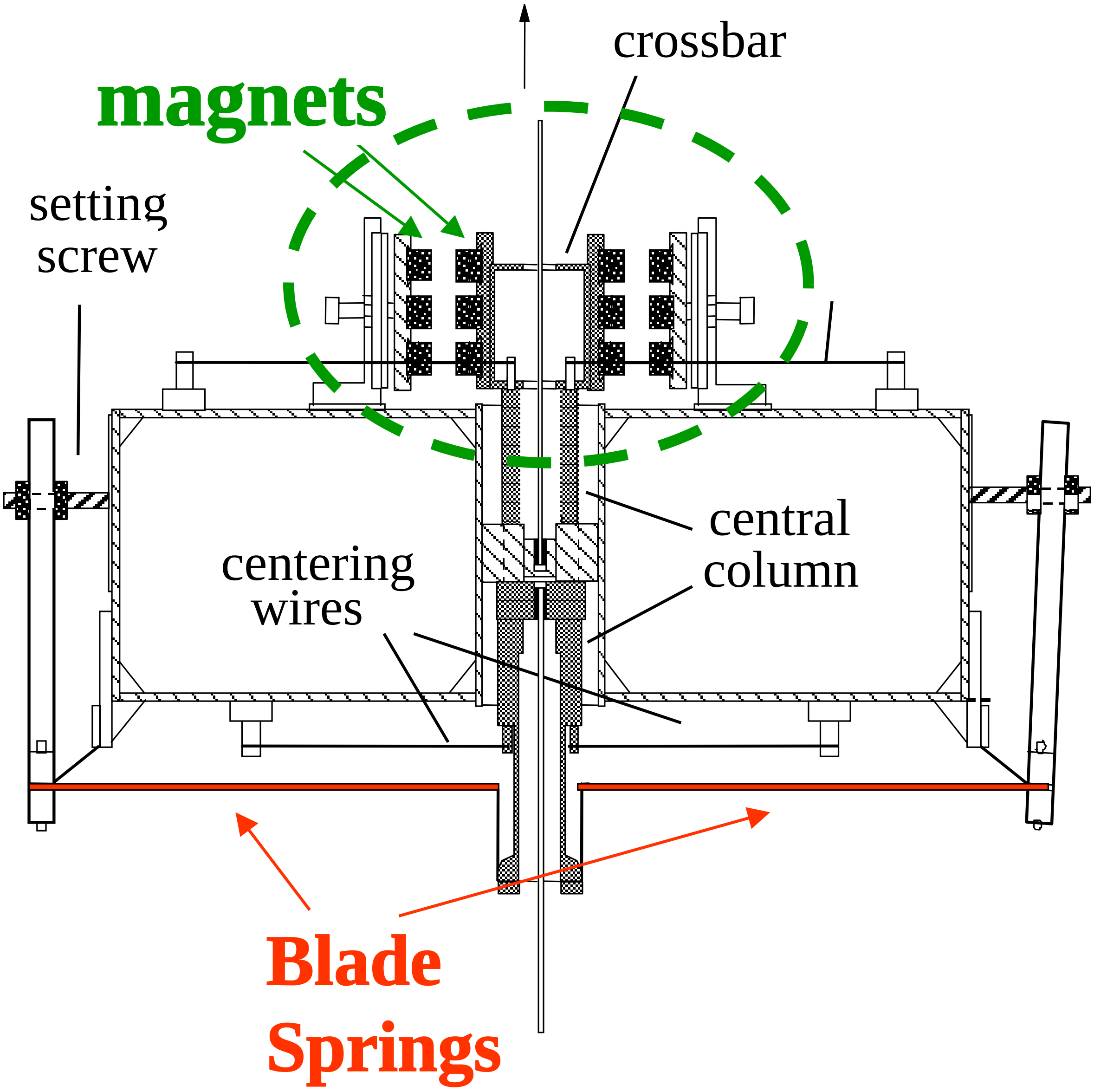


Blade Spring Top View

Blade Spring Side View

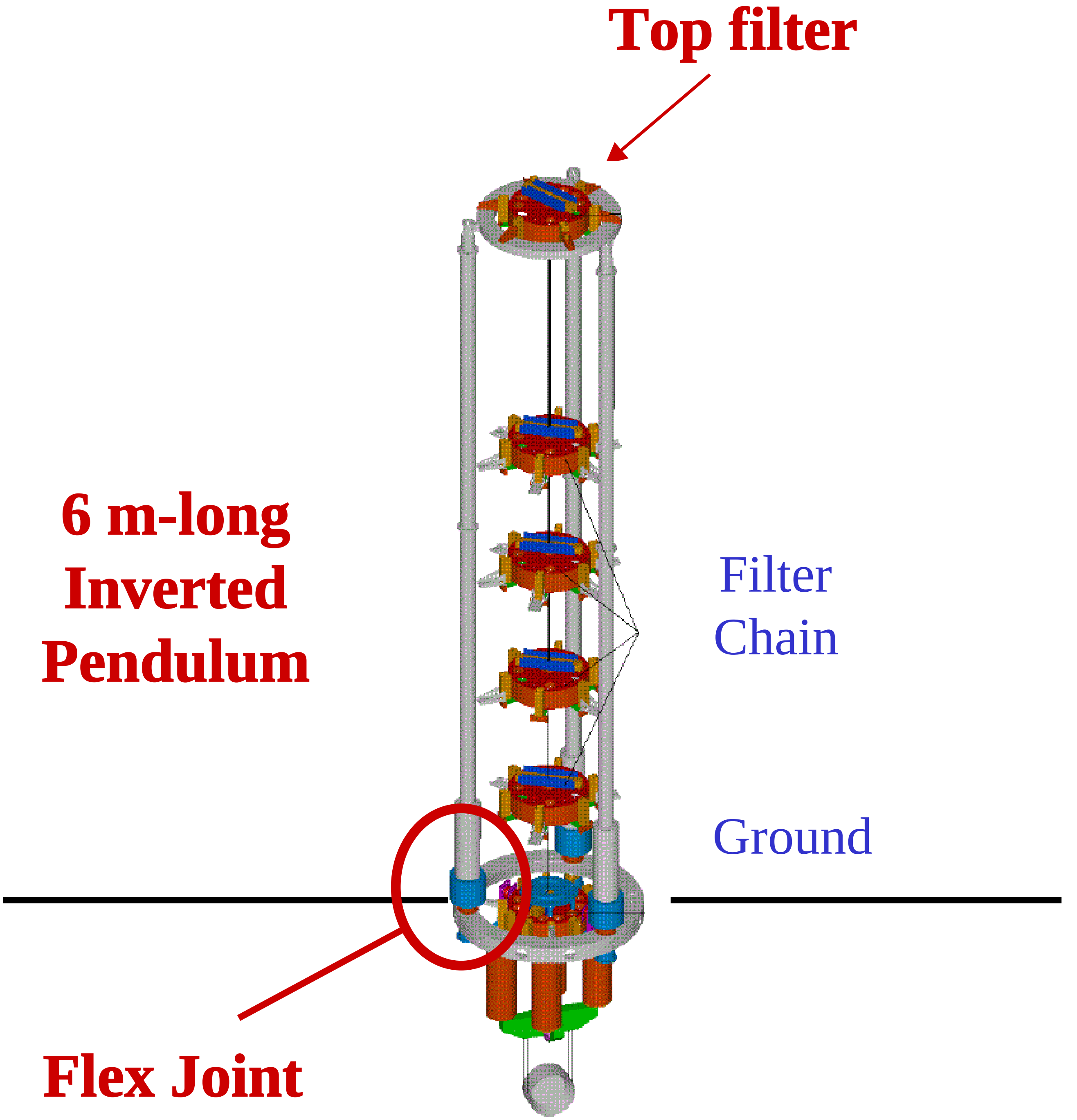


Mechanical Filter



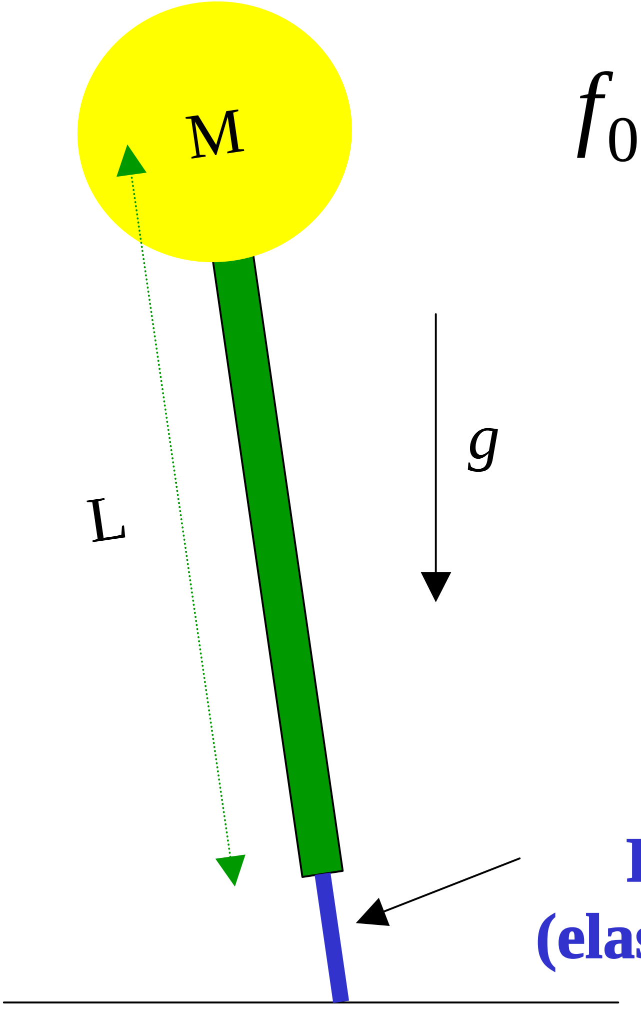
Chain maximum vertical frequency around 2 Hz

Pre-Isolator



Pre-Isolator

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{k}{M} - \frac{g}{L}}$$

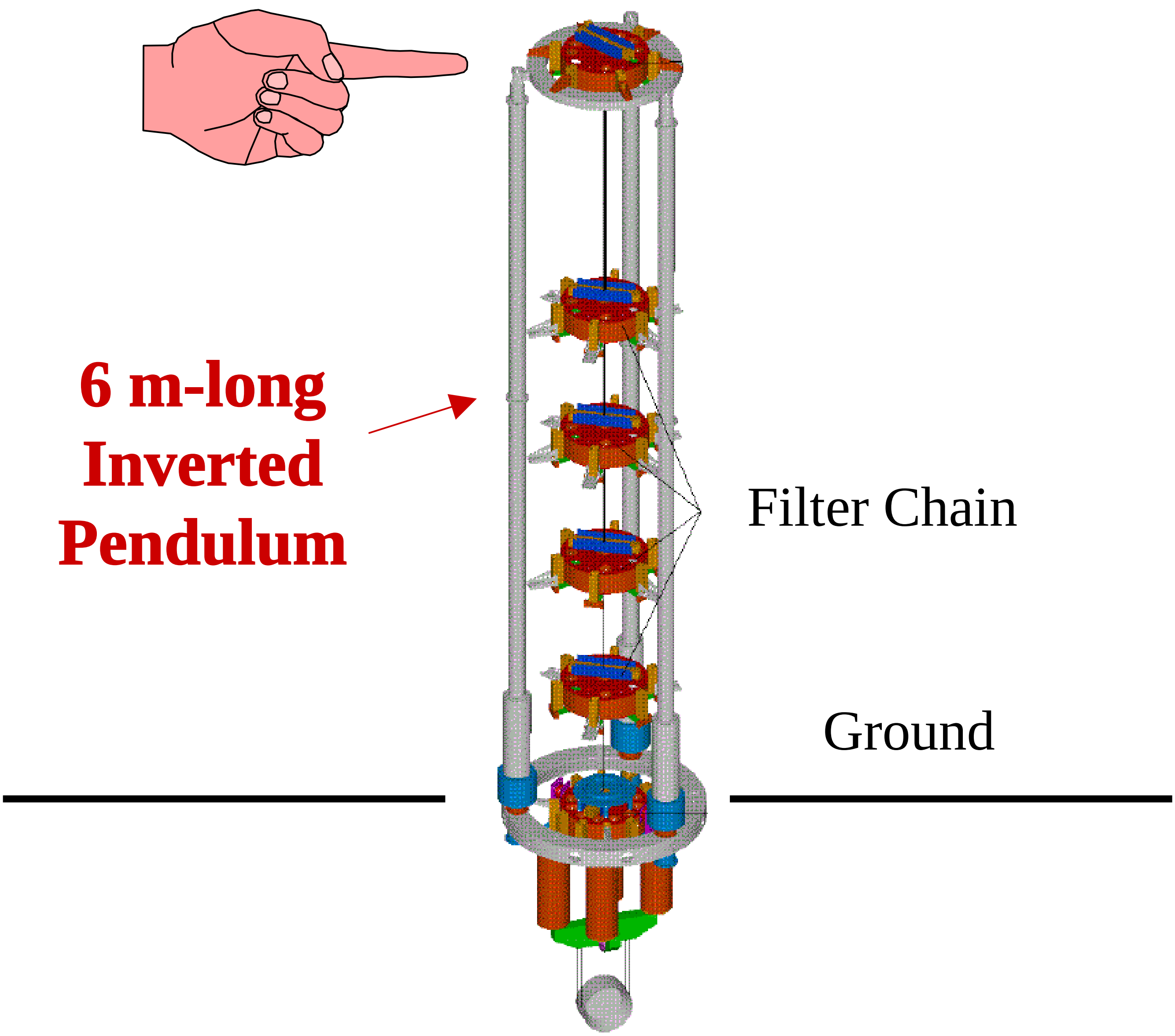


INVERTED
PENDULUM

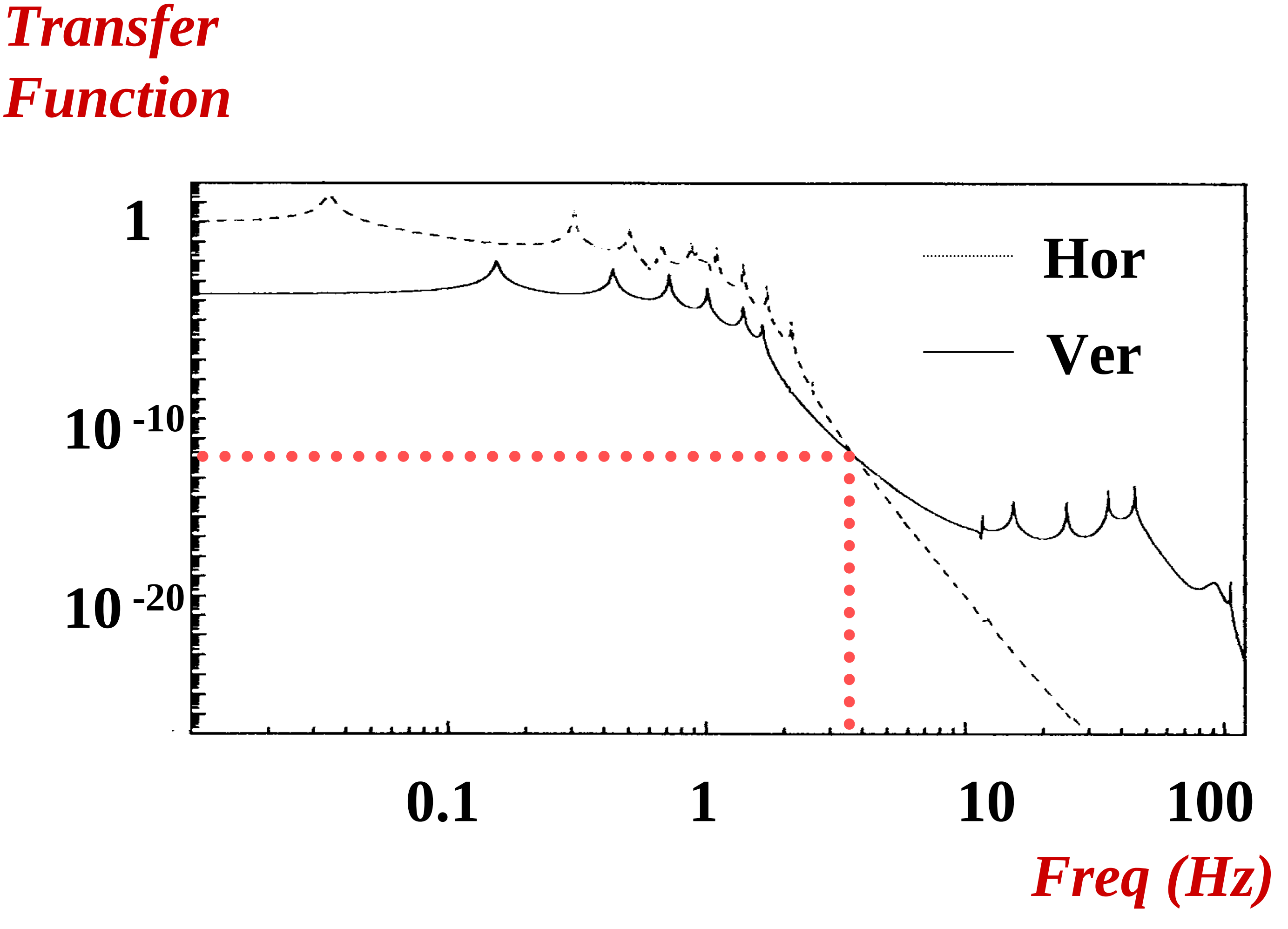
Ultra - low frequency oscillator
(30 mHz)

Pre-Isolator

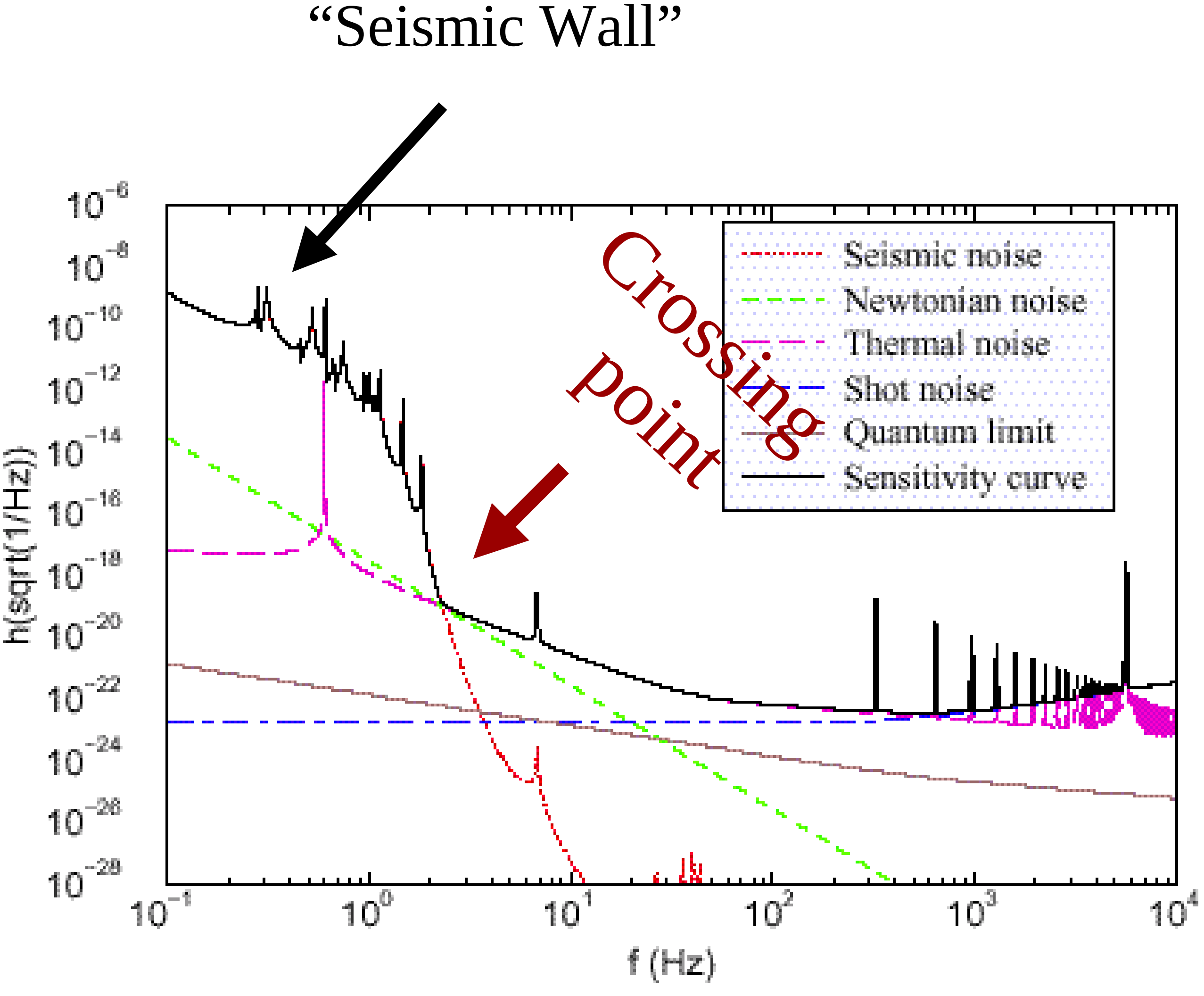
$$F = K\,x = M\,\omega^2 x$$



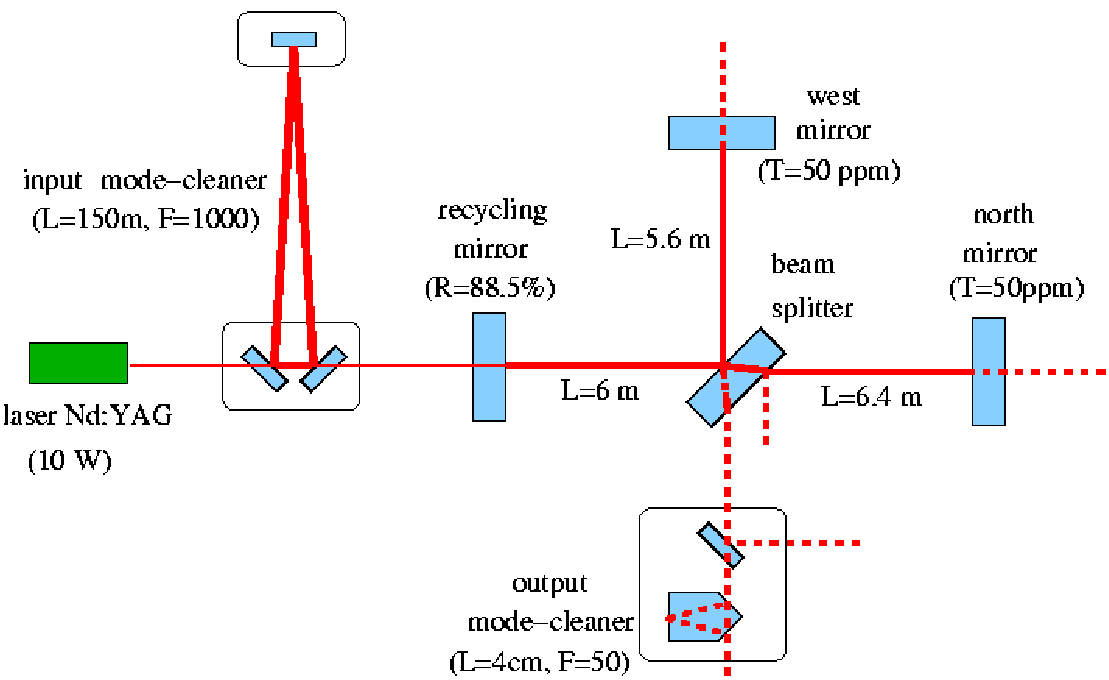
Expected Performances



Expected Residual Seismic Noise

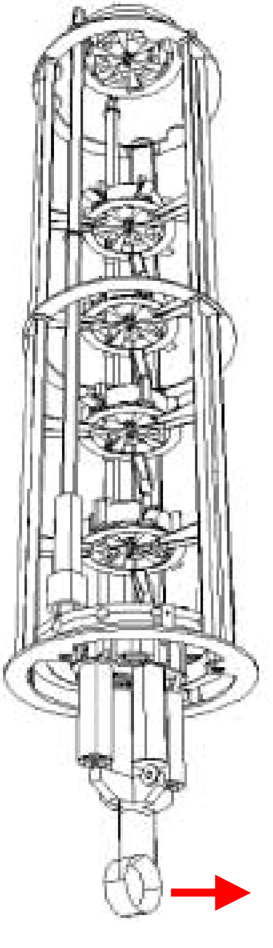


Beam Splitter



Direct Measurement

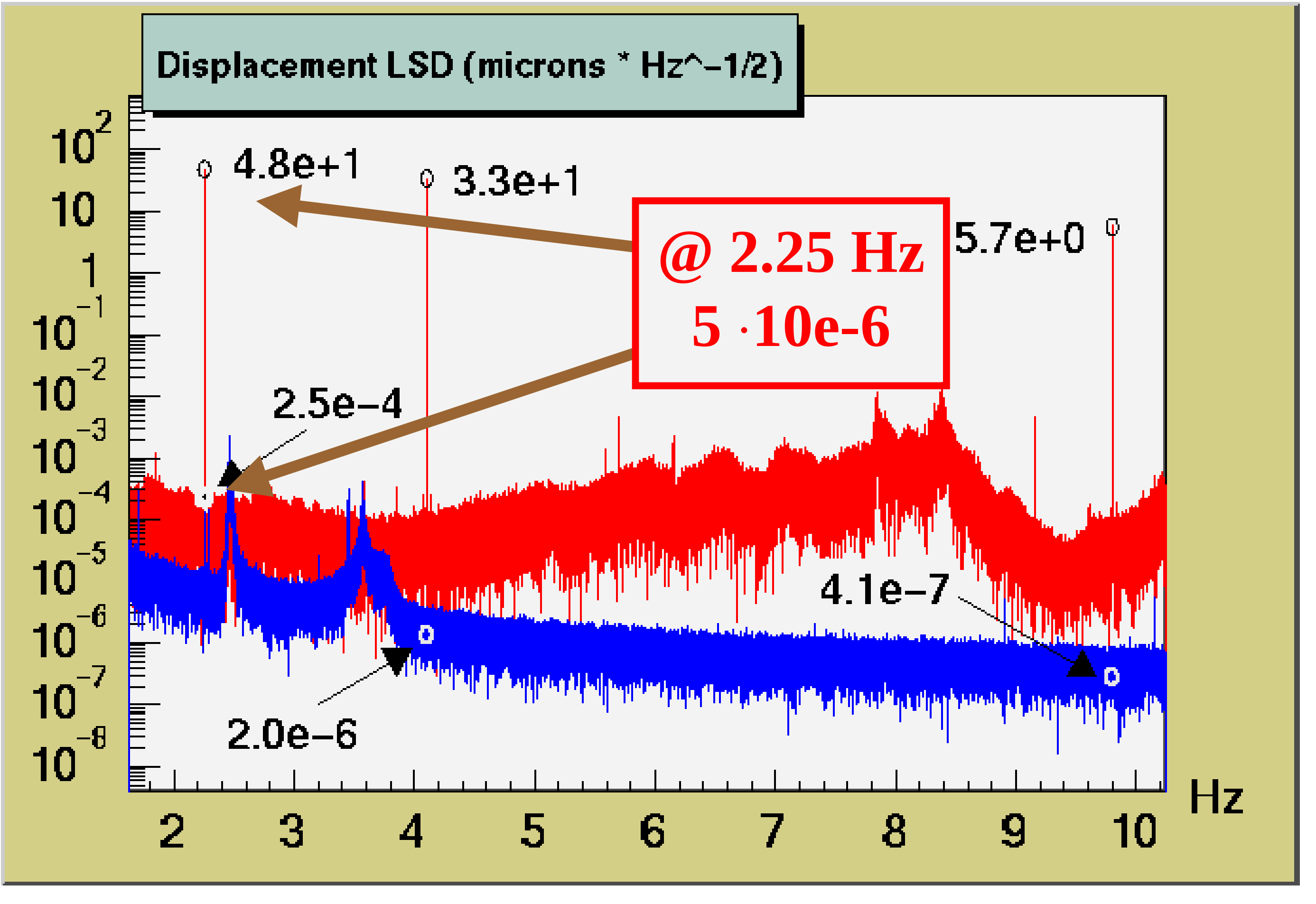
Top Stage Actuators



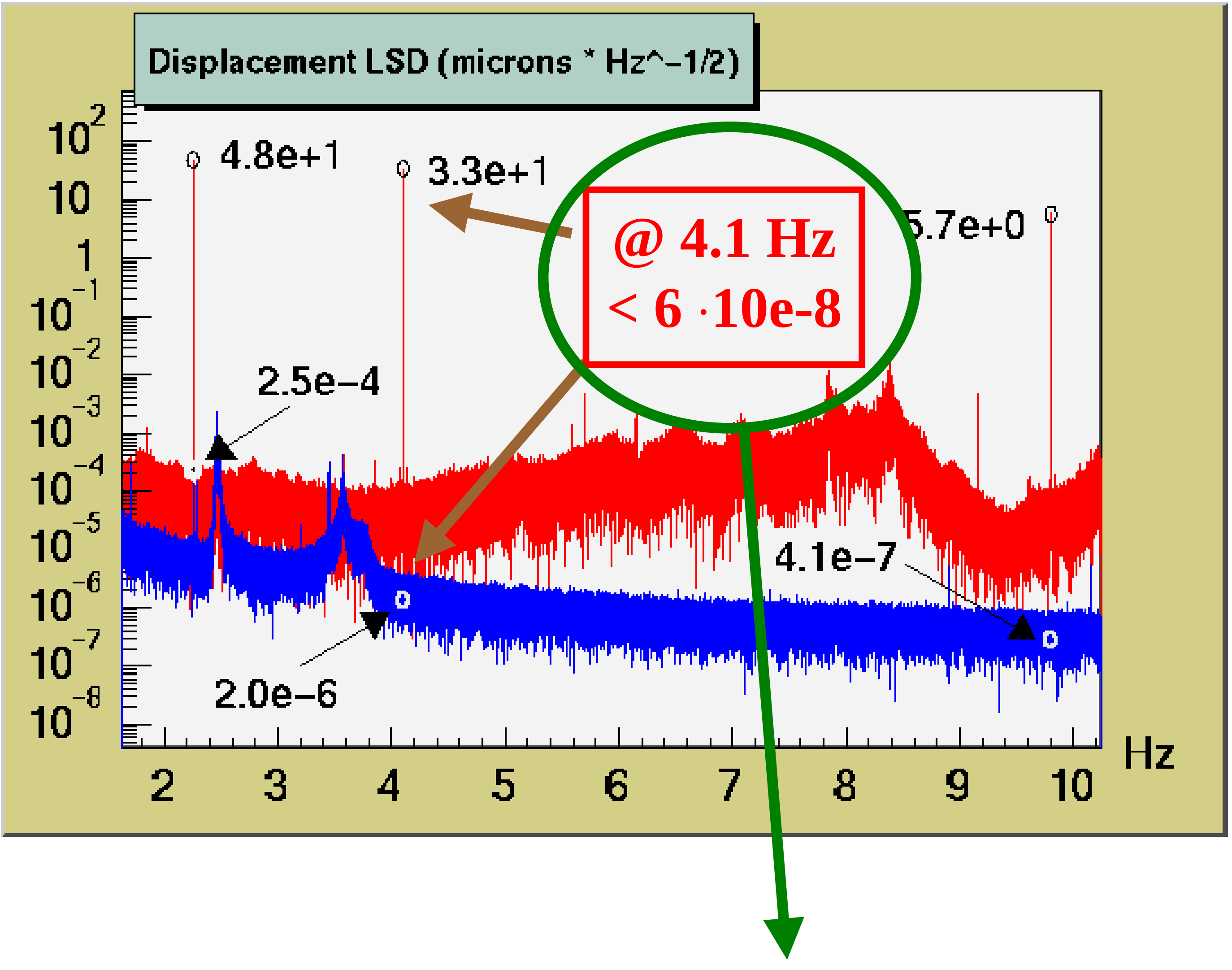
3 Lines
2.25 Hz
4.1 Hz
9.8 Hz

Central Interferometer used as sensor

Results for Horizontal Transmission

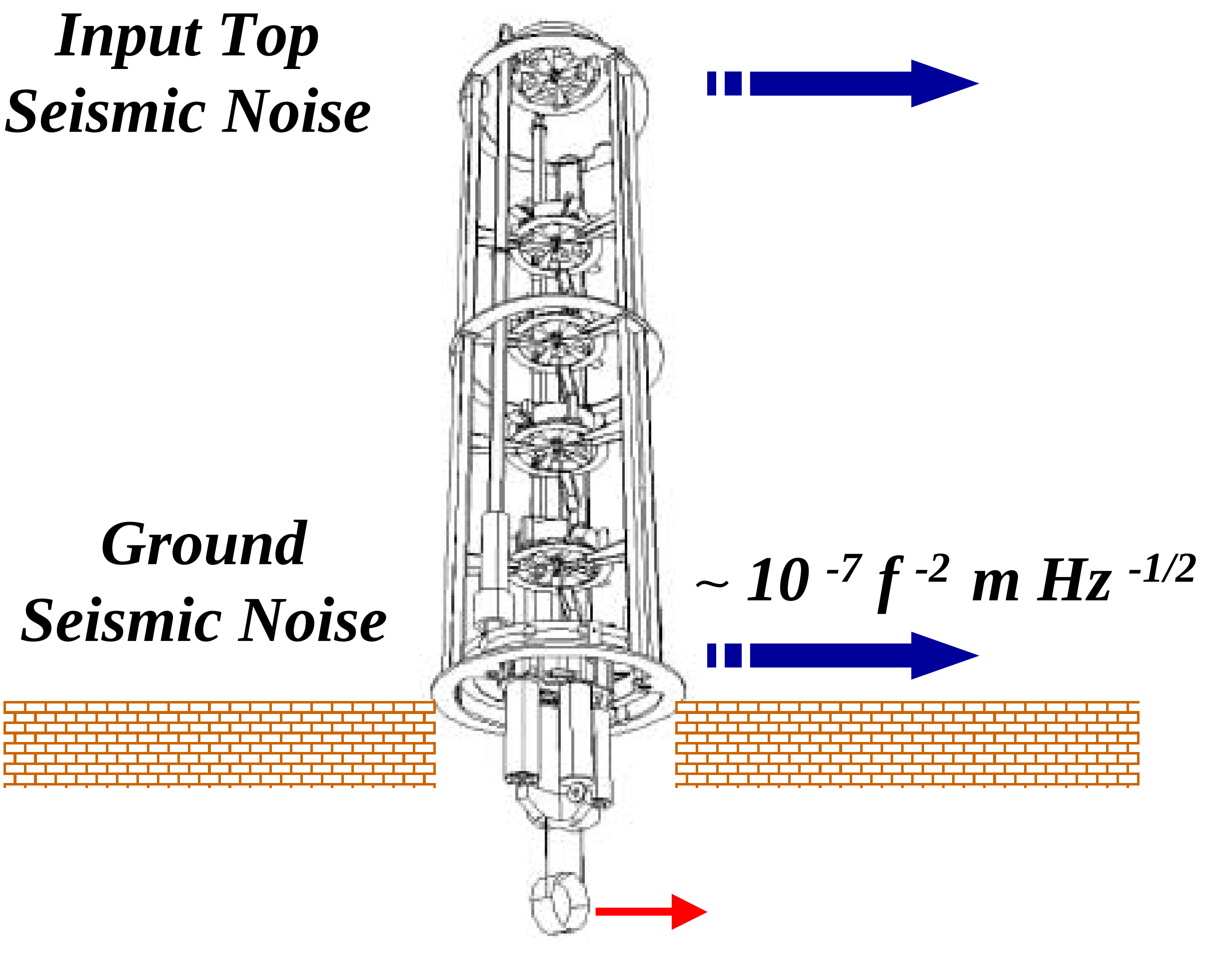


Results for
Horizontal Transmission



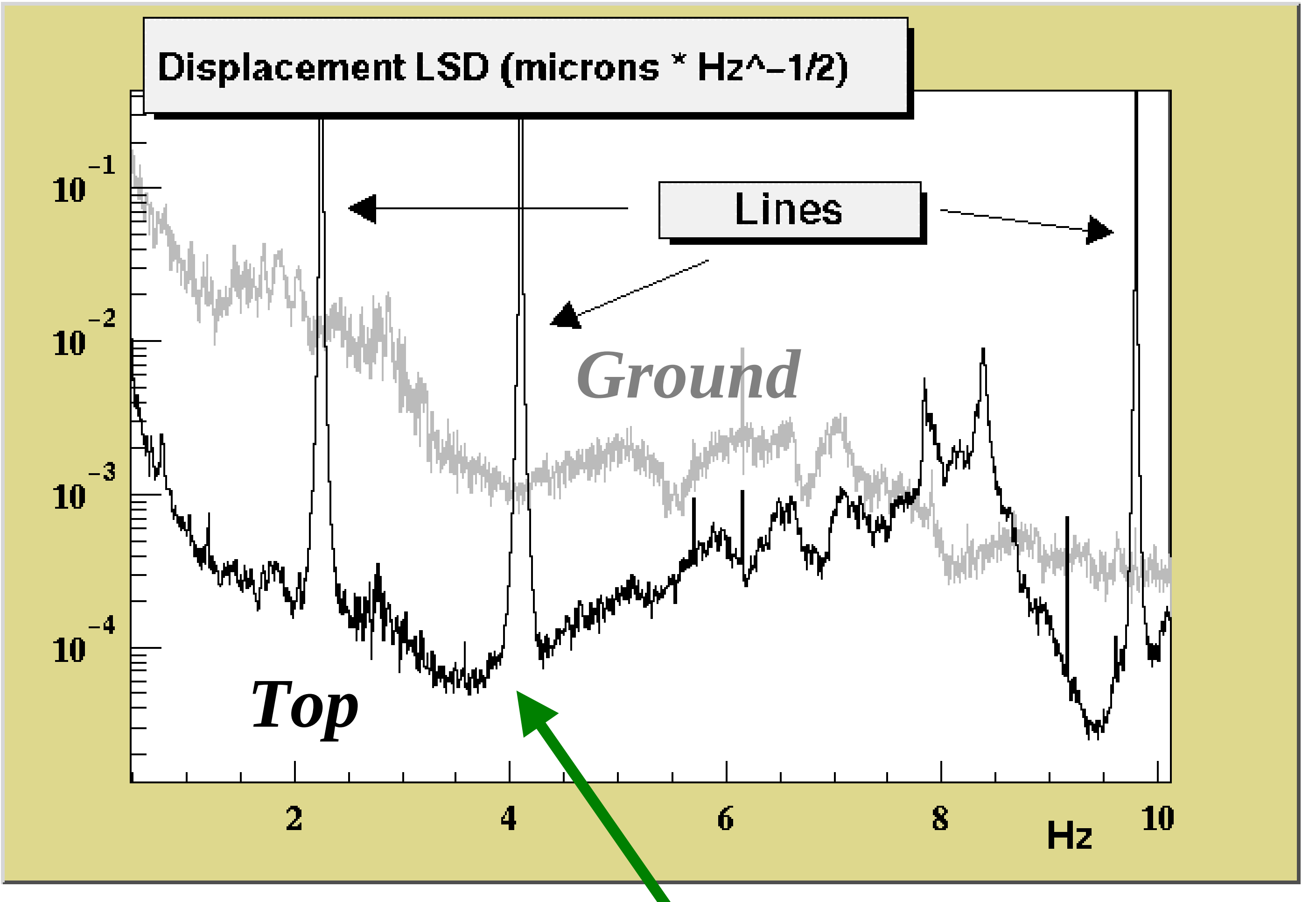
This is only an upper limit !!!

Measured Horizontal Transmission



Attenuation by Inverted Pendulum

Top Stage Seismic Noise on beam direction



$7 \cdot 10^{-11}$ m $\cdot$ Hz$^{-1/2}$

Residual Mirror Seismic Noise

Input Seismic Noise on Top Stage

$7 \cdot 10^{-11}$ m $\cdot$ Hz$^{-1/2}$

X

Chain Transmission Upper Limit

$6 \cdot 10^{-8}$

Upper Limit of Residual Noise

$4 \cdot 10^{-18}$ m $\cdot$ Hz$^{-1/2}$

Mirror displacement induced by horizontal seismic noise

!!!

Residual Seismic Noise Upper Limit @ 4.1 Hz

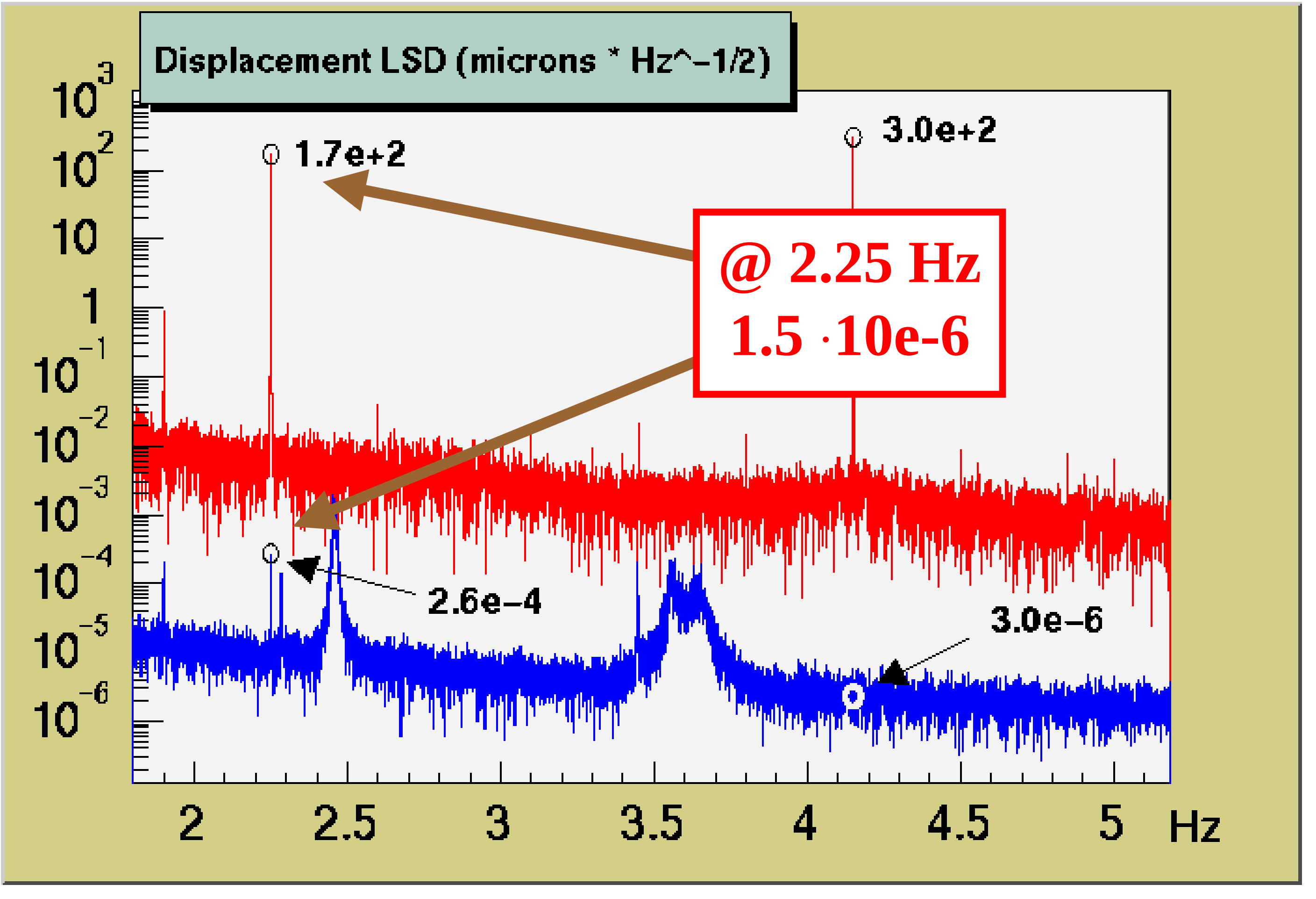
$4 \cdot 10^{-18}\ \mathrm{m} \cdot \mathrm{Hz}^{-1/2}$

$<<$

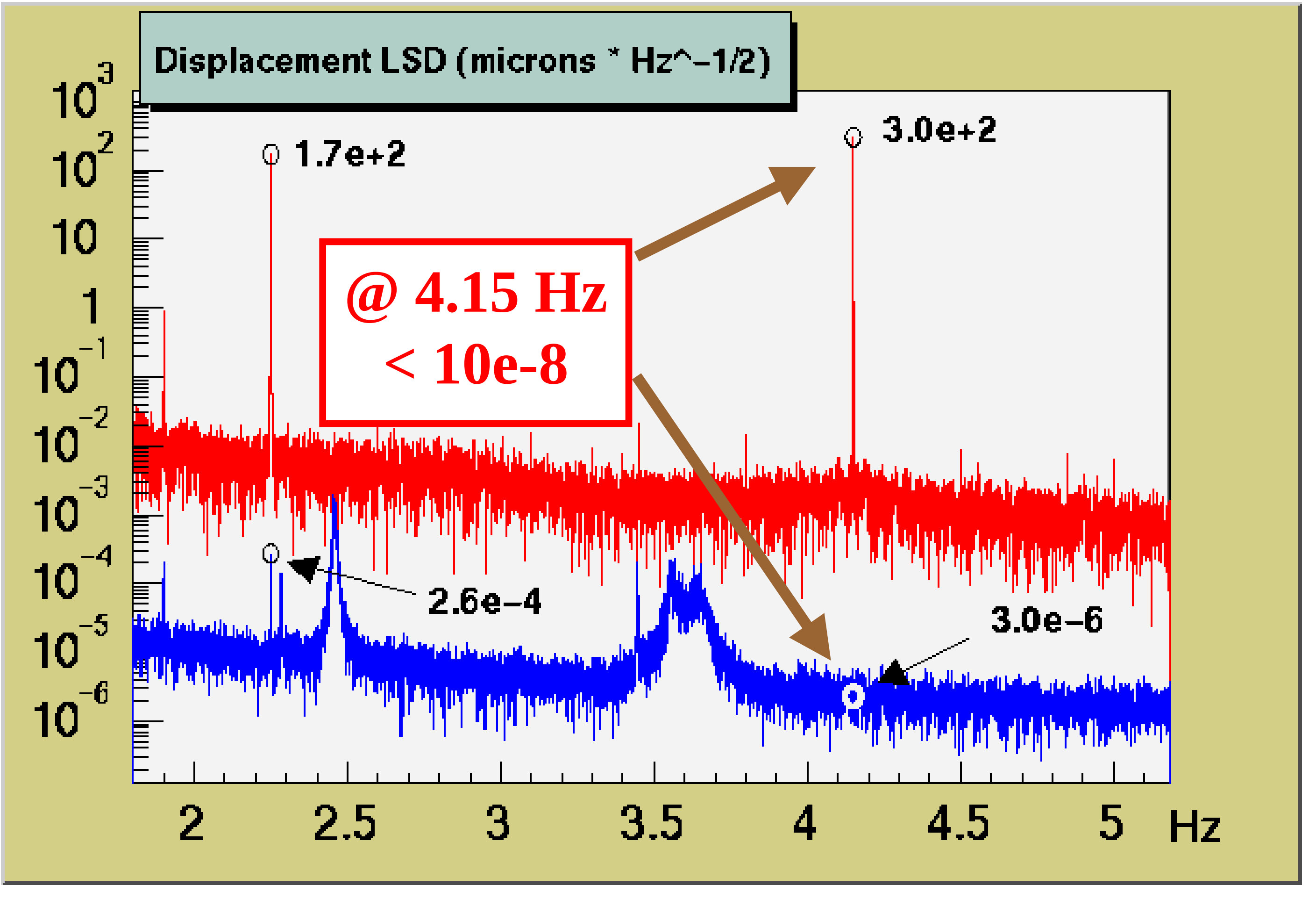
Thermal Noise @ 4.1 Hz

$9 \cdot 10^{-17}\ \mathrm{m} \cdot \mathrm{Hz}^{-1/2}$

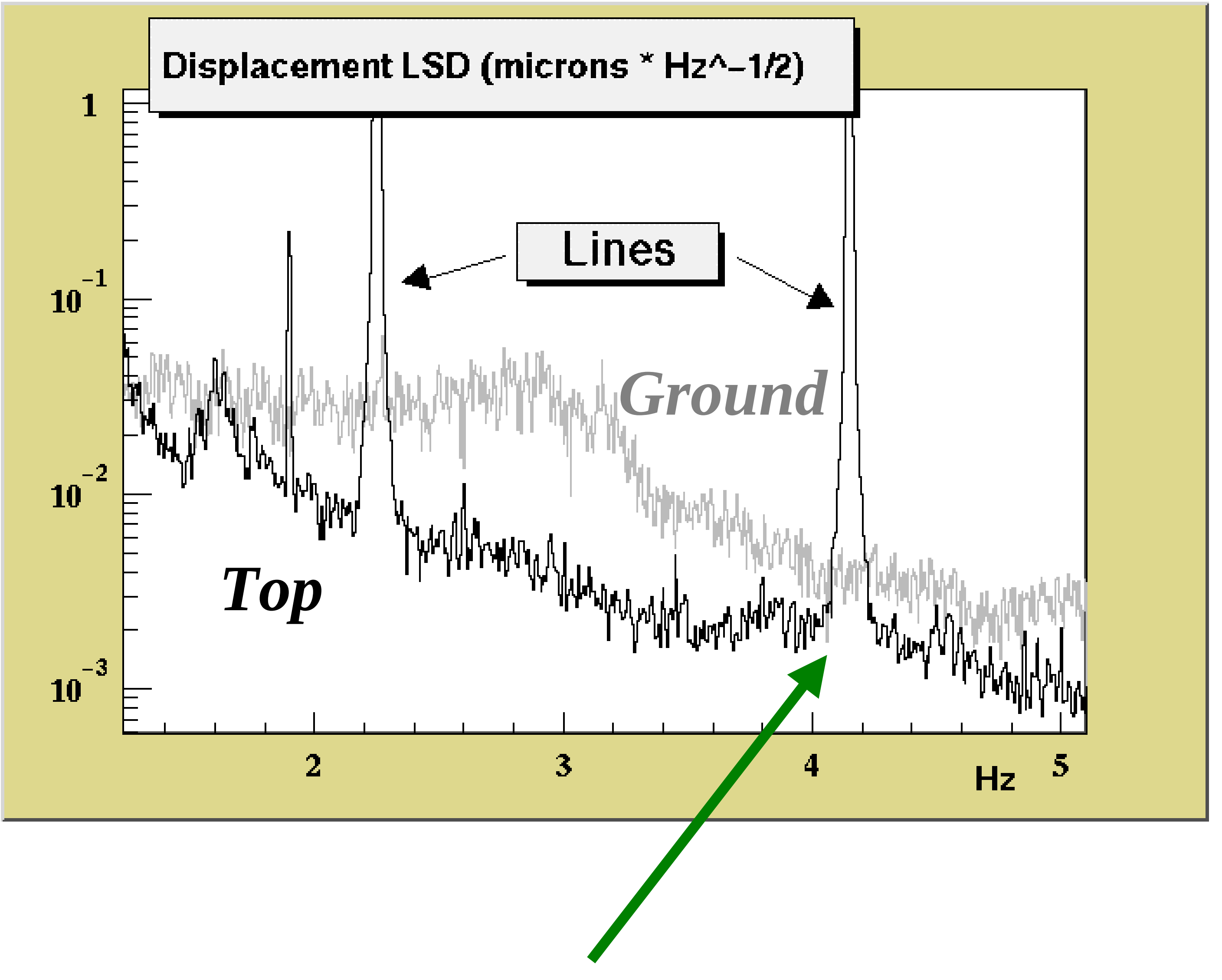
Measured Vertical Transmission



Measured
Vertical Transmission



Top Stage Seismic Noise



$2 \cdot 10^{-9}\ m \cdot Hz^{-1/2}$

Mirror displacement induced by vertical seismic noise

!!!

Residual Seismic Noise Upper Limit @ 4.1 Hz

$2 \cdot 10^{-17}\ \mathrm{m} \cdot \mathrm{Hz}^{-1/2}$

$<<$

Thermal Noise @ 4.1 Hz

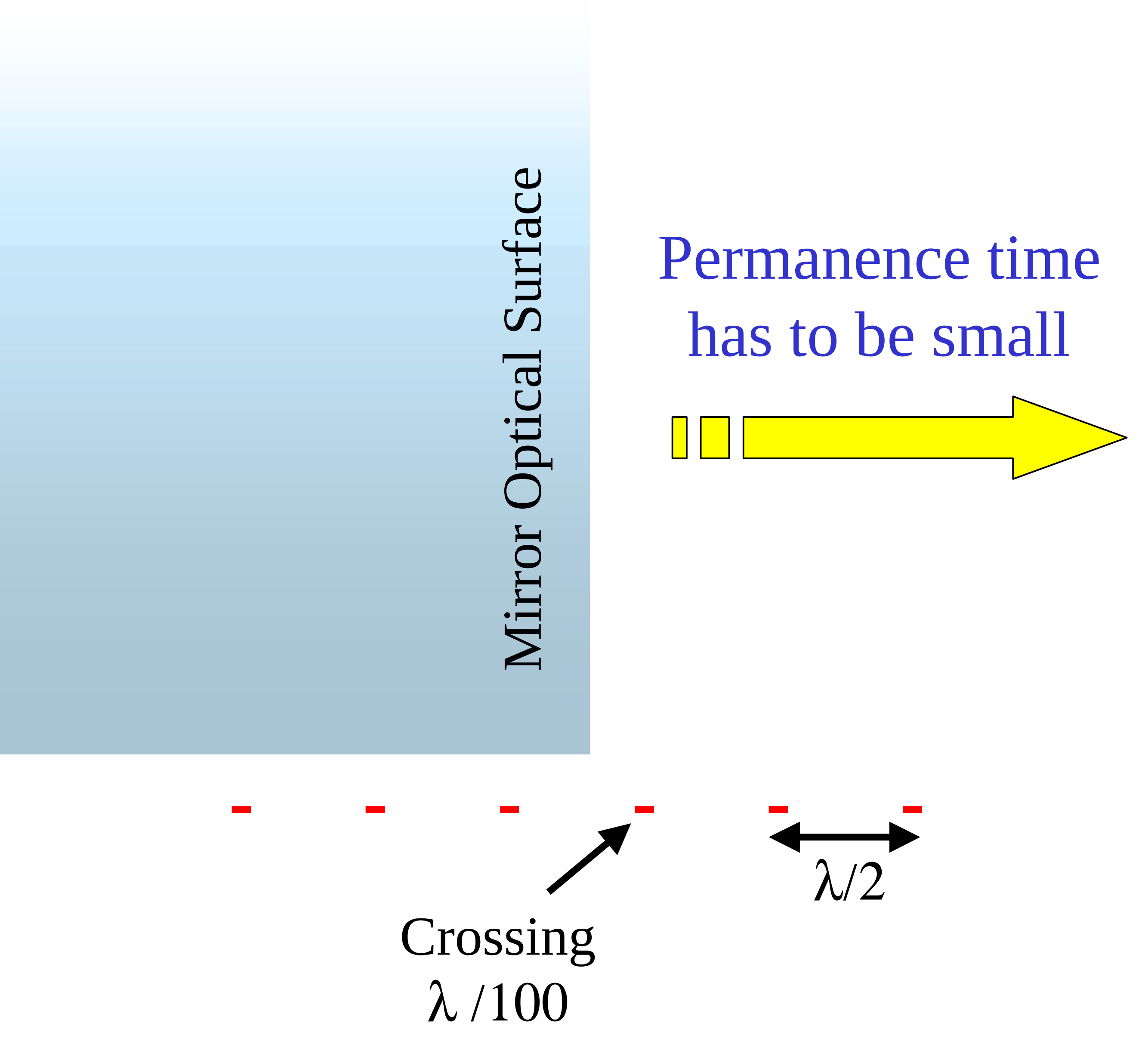
$9 \cdot 10^{-17}\ \mathrm{m} \cdot \mathrm{Hz}^{-1/2}$

Passive attenuation is enough but ……….

Chain resonant frequencies (0.1 Hz < f < 2 Hz) induce tens of microns mirror swings

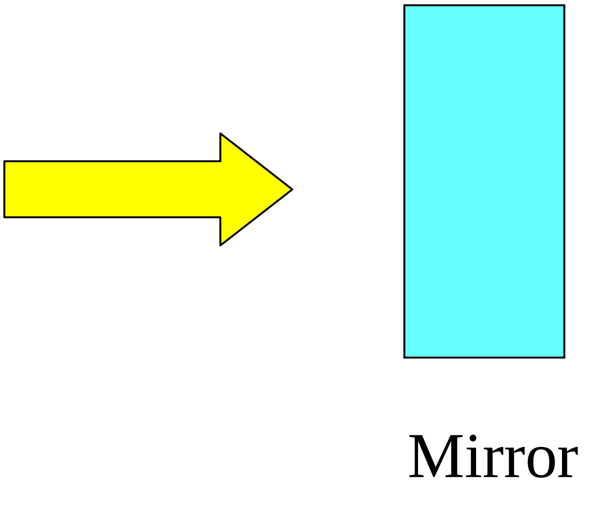
Mirror swing reduction

1 – Help locking acquisition



Mirror swing reduction

2 - Allow noiseless control
of the interferometer



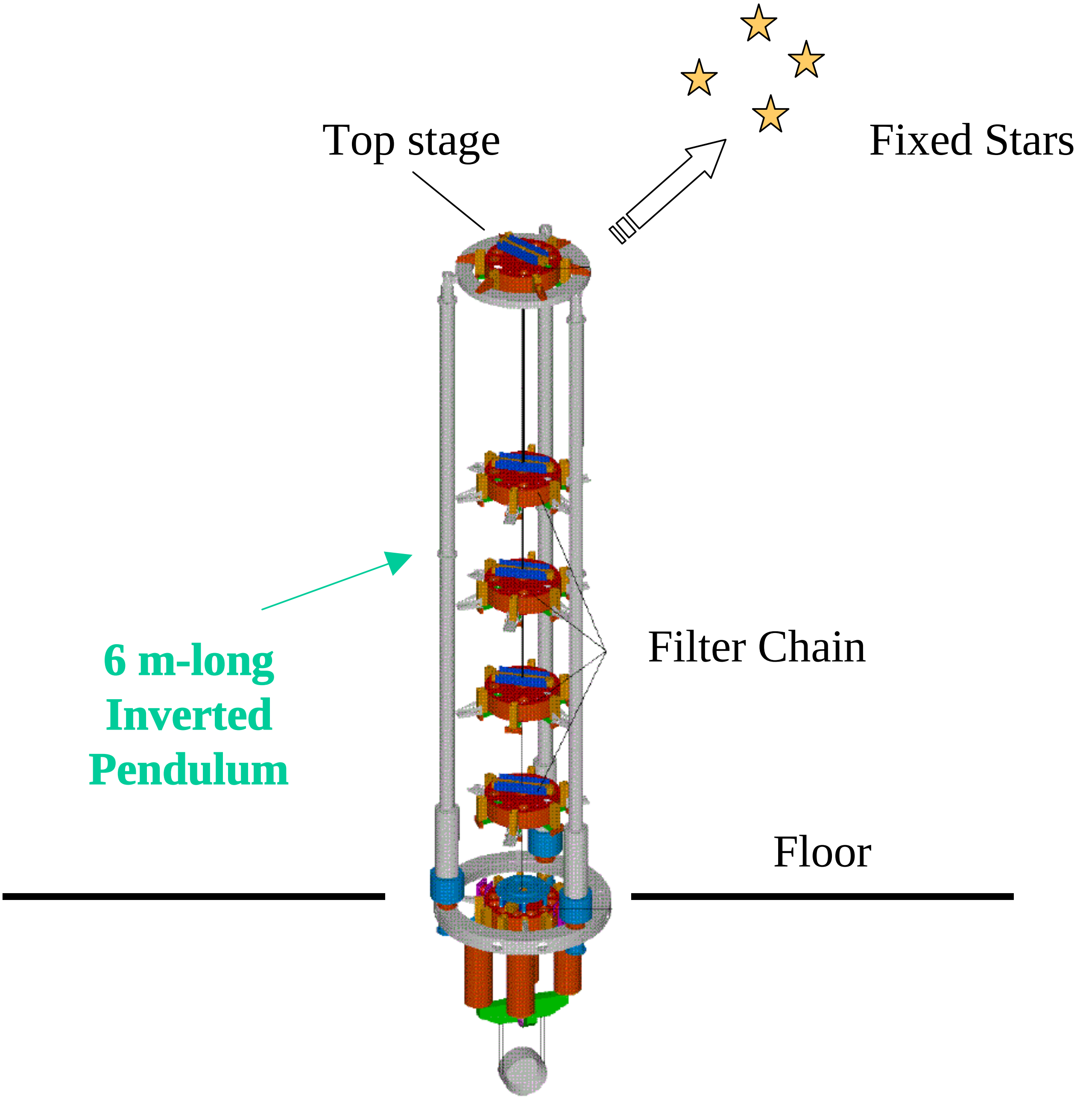
Maximum compensation "close to the mirror" is about one micron

Specifications for mirror swing

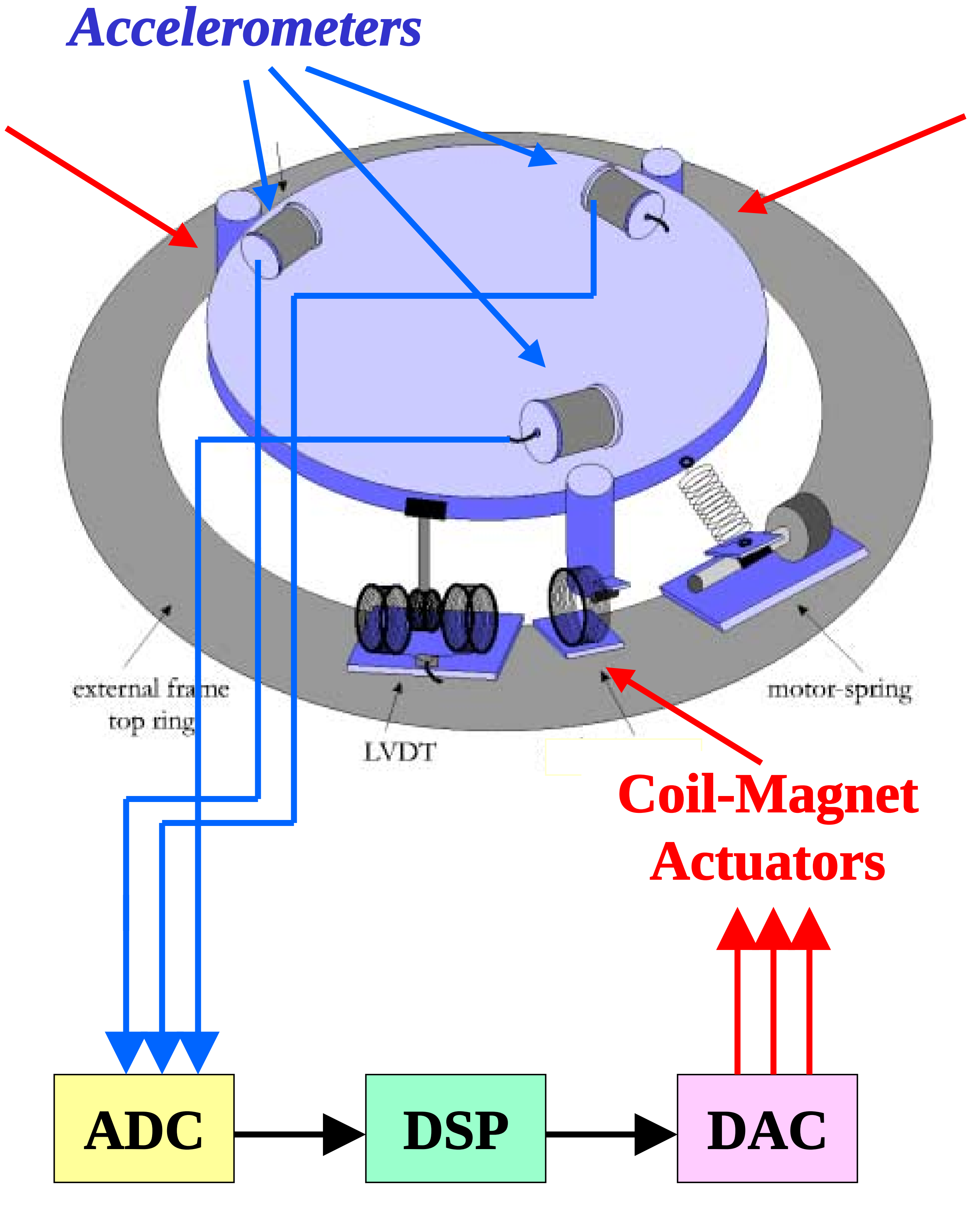
rms mirror velocity
smaller than a few tenths
of micron per second

rms mirror displacement
smaller than one micron
(on a time scale of 10 s)

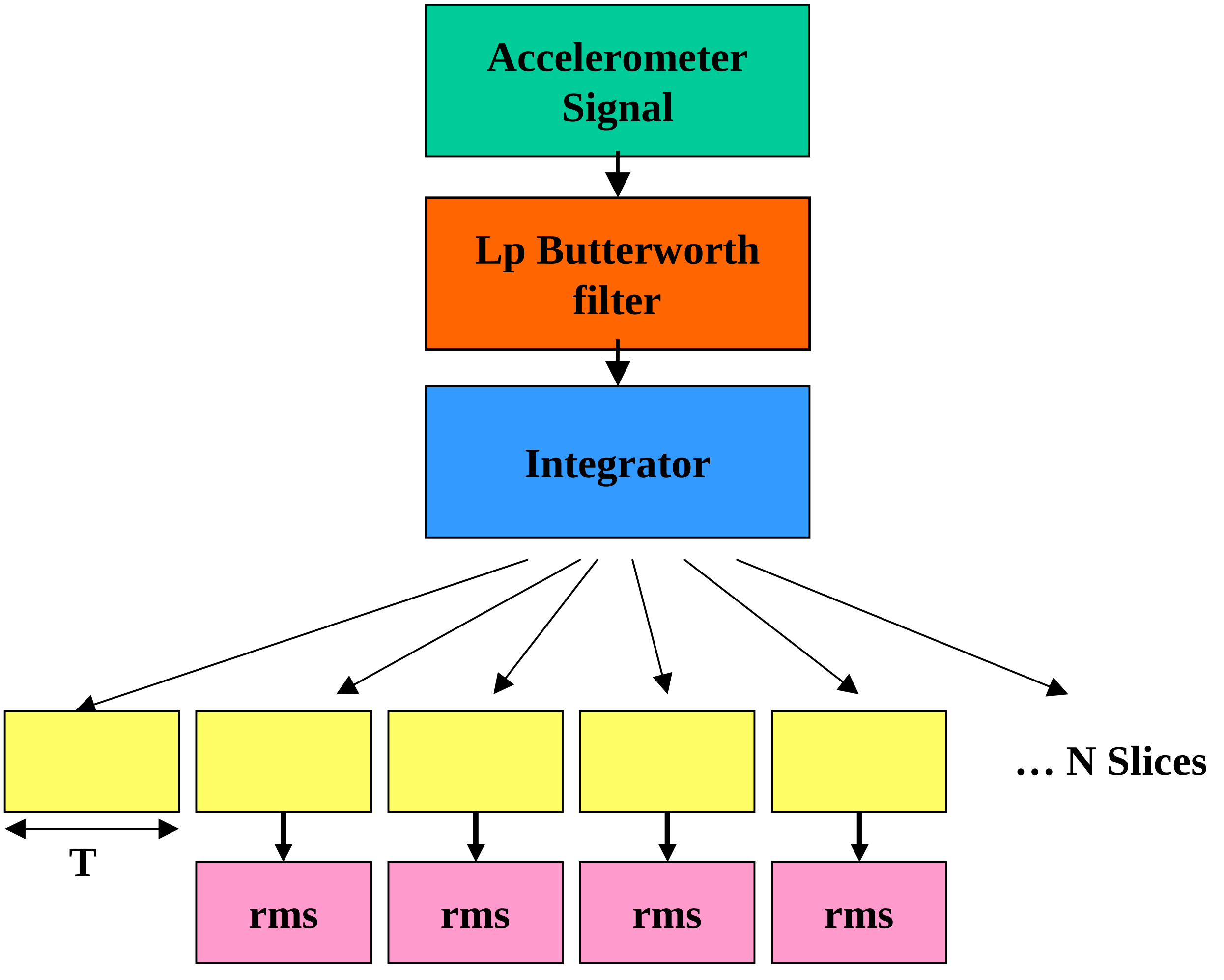
Inertial Damping



Inertial Damping



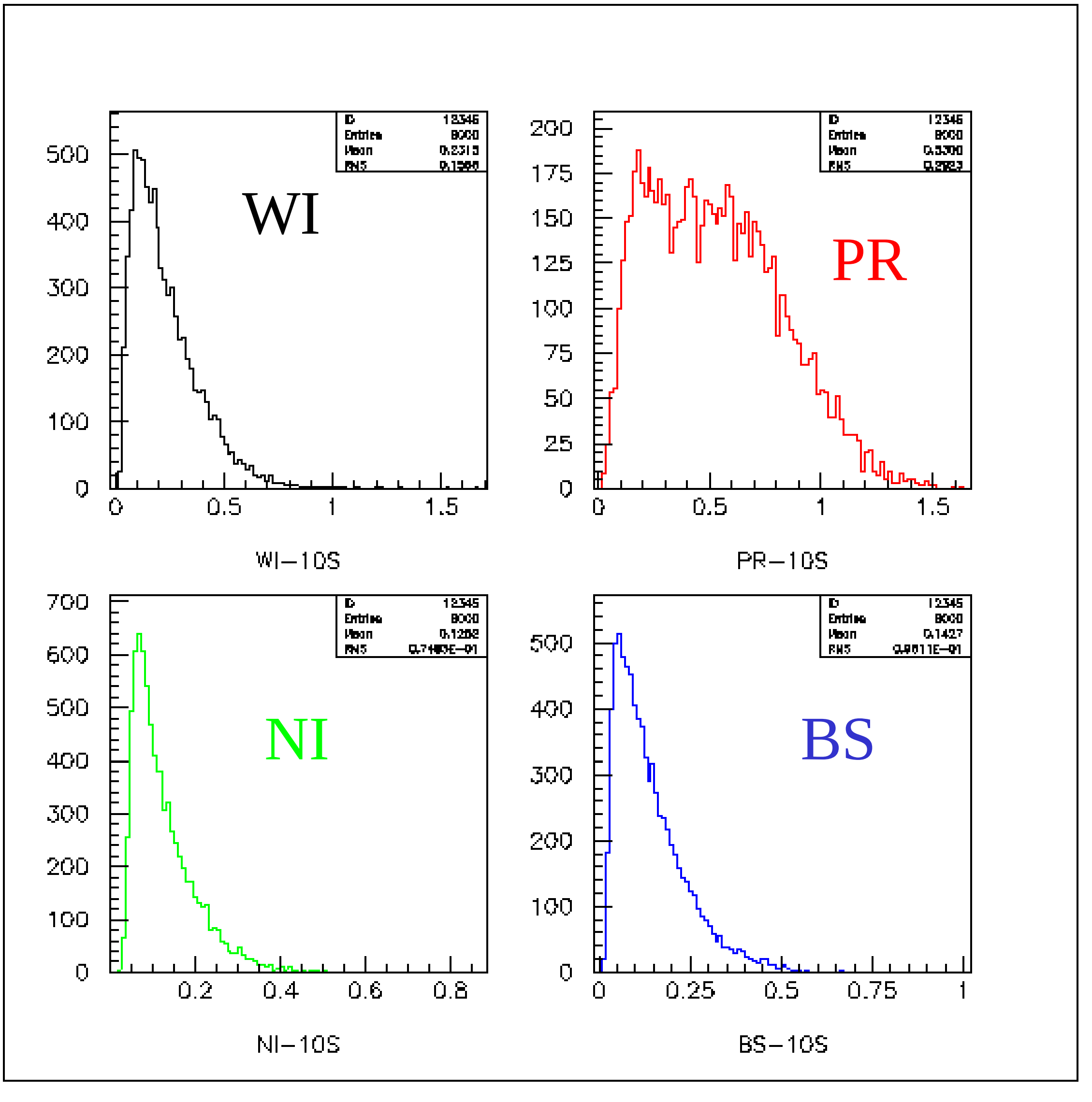
Inertial Damping Stability



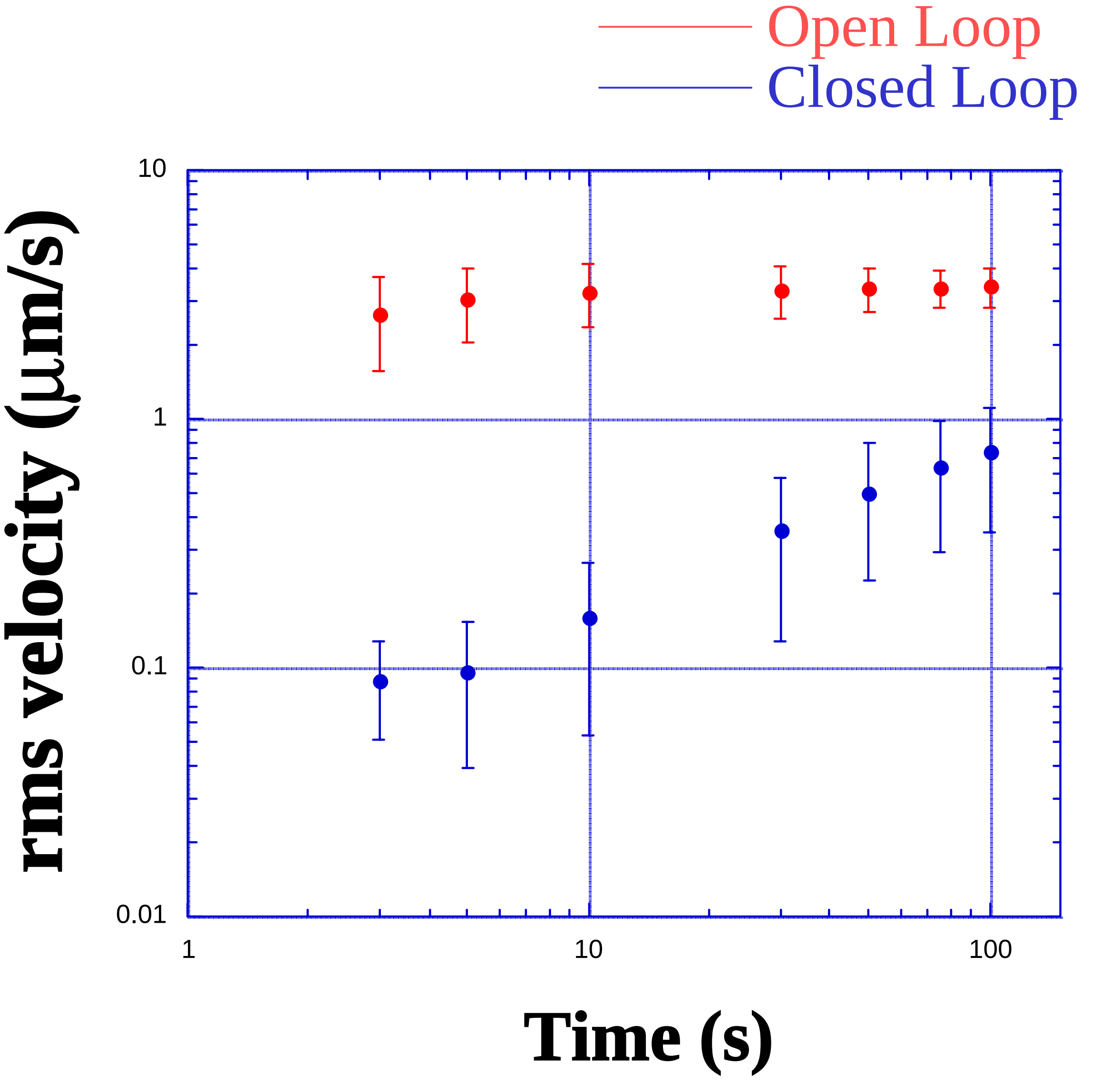
N consecutive measurements of rms velocity

Inertial Damping Stability

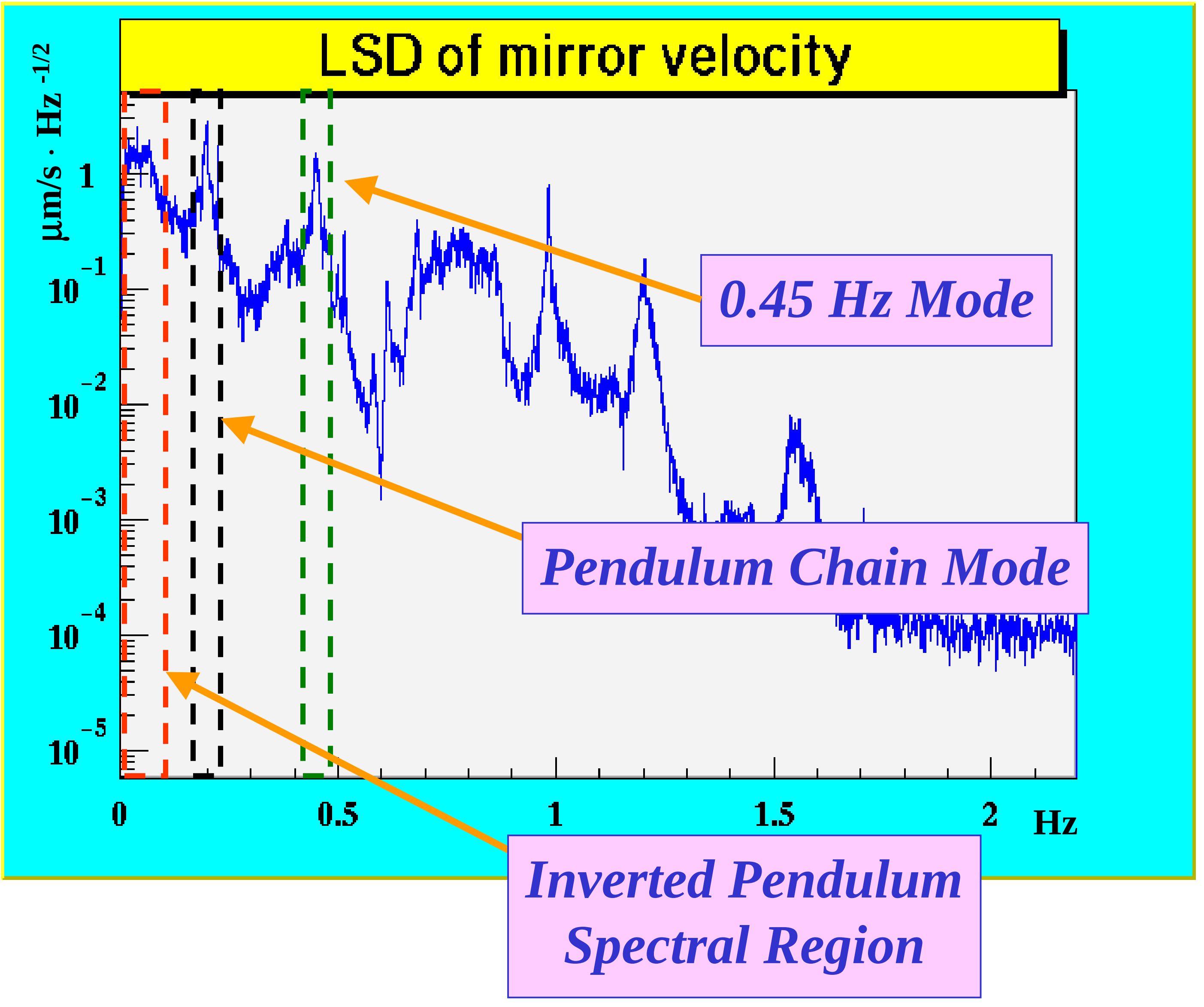
Distribution of 10 s velocity rms



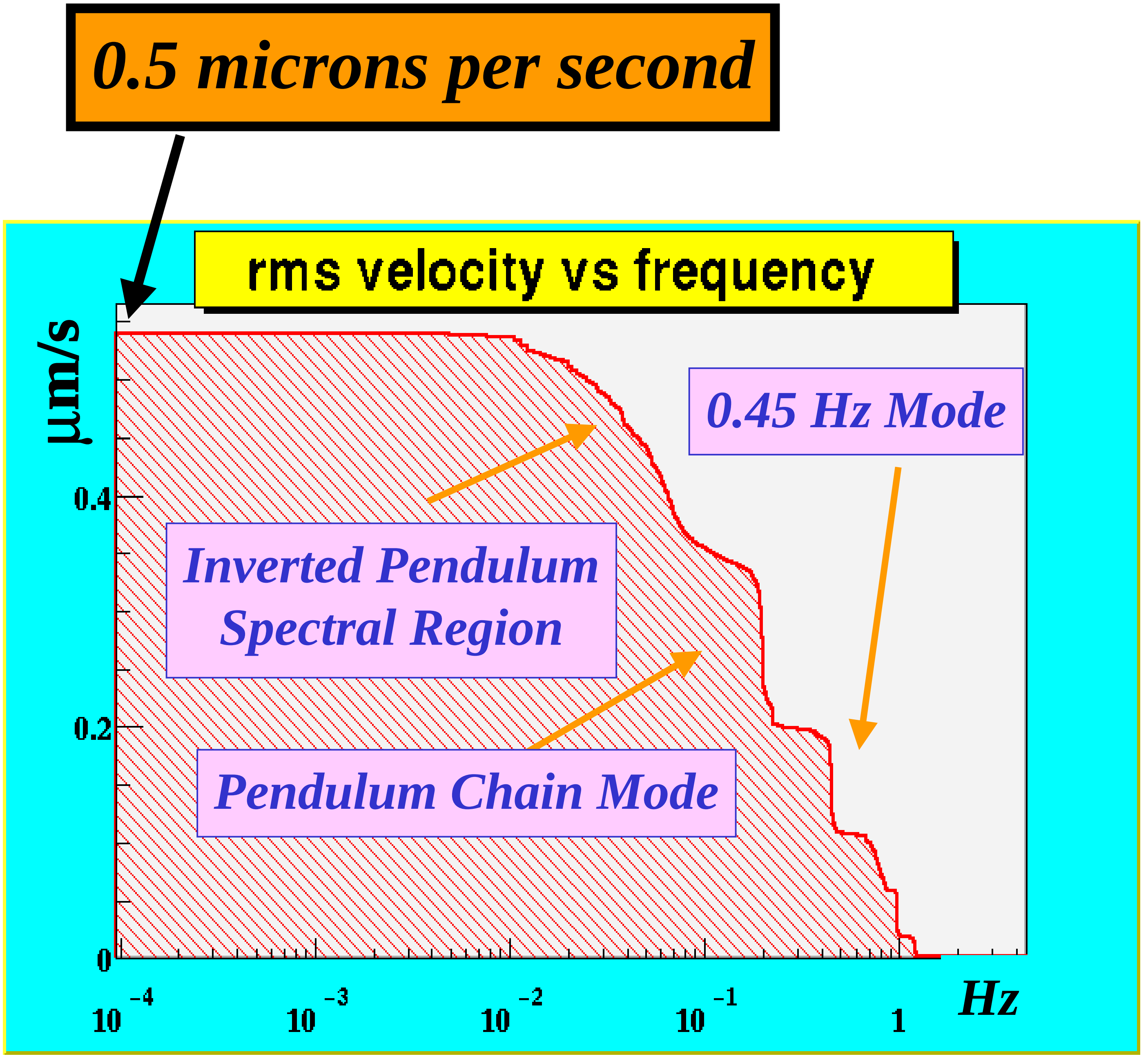
Top-stage RMS



Mirror velocity spectrum

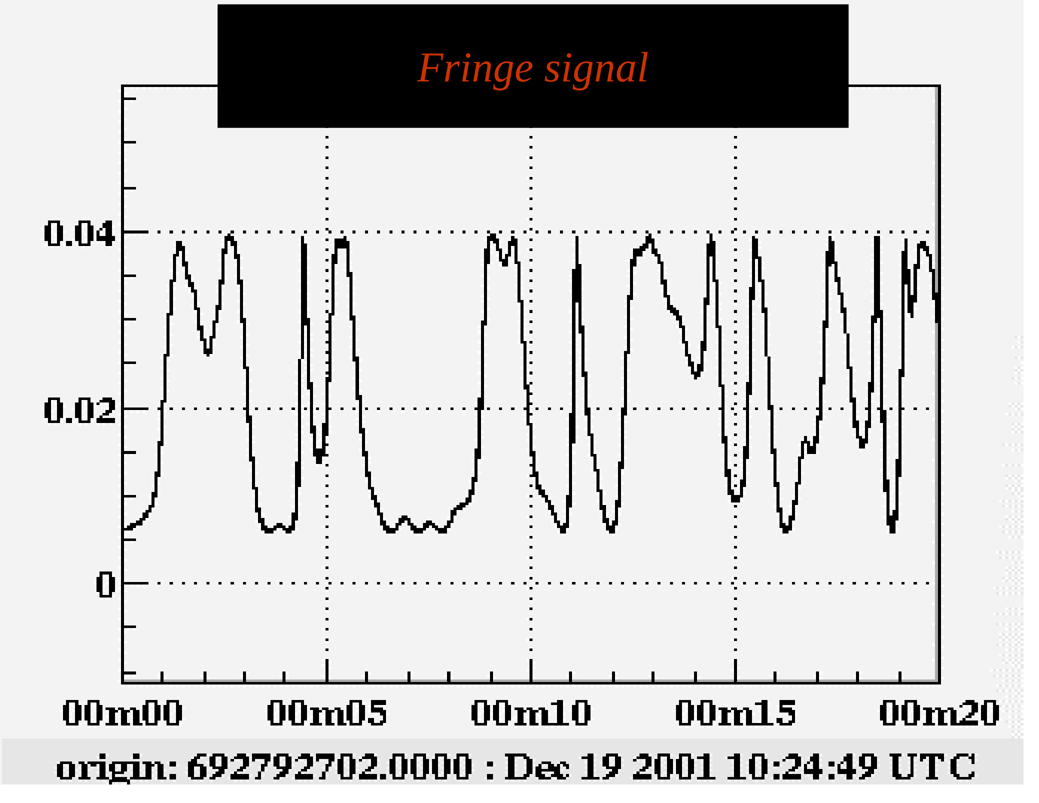


Mirror velocity spectrum

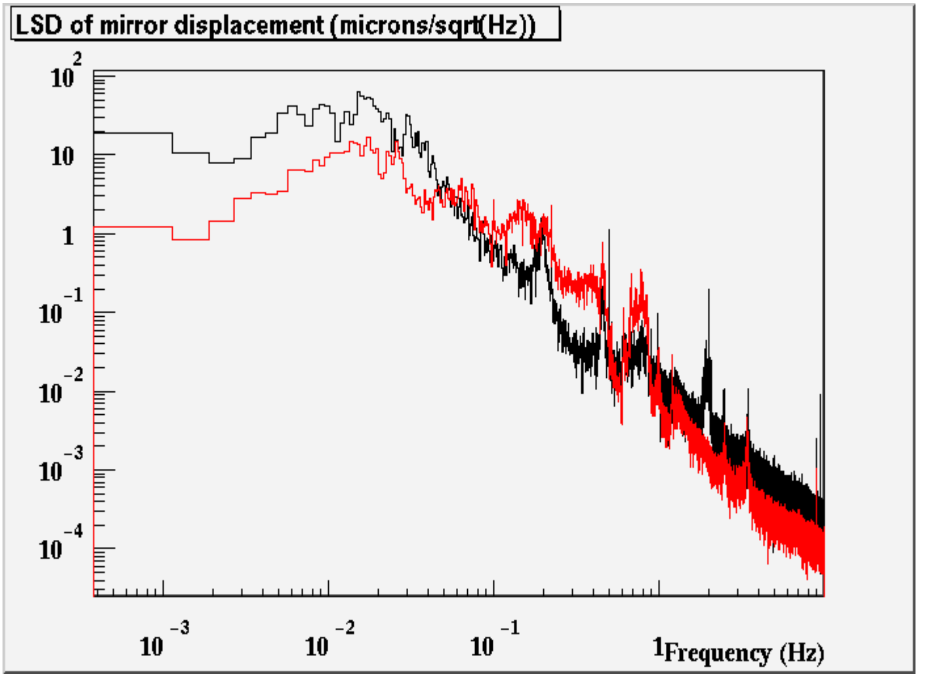


$$x_{rms}(f) = \sqrt{\int_{f}^{\infty} \tilde{x}^{2}(\nu)\,d\nu}$$

Mirror velocity spectrum



IP Contribute



Actual Contribution

to velocity rms is 0.37 μm/s

Cure

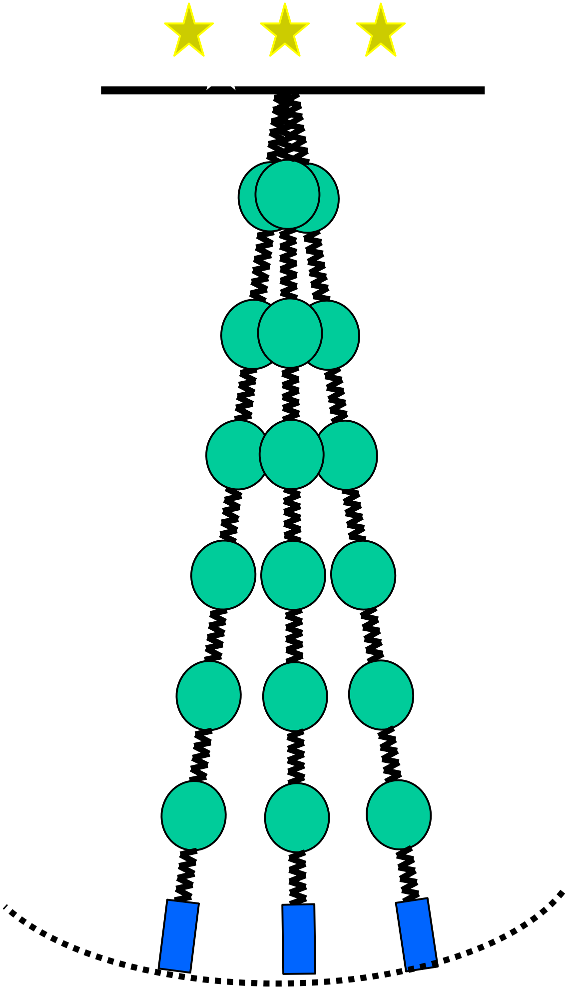
Better crossing

LVDT-Accelerometers in

Inertial Damping Loop

or Top Stage Control

Pendulum Contribute



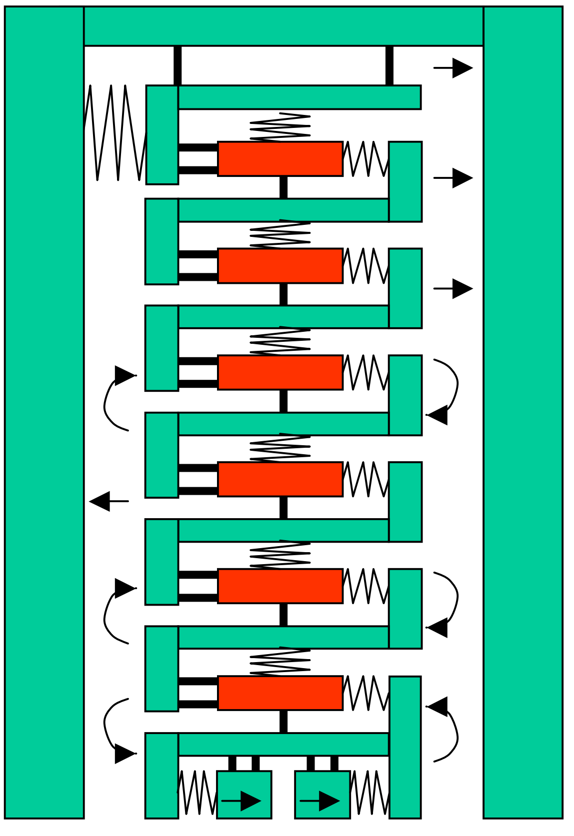
Actual Contribution

to velocity rms is 0.26 μm/s

Cure

Damping from ground based actuators

0.45 Hz Contribute

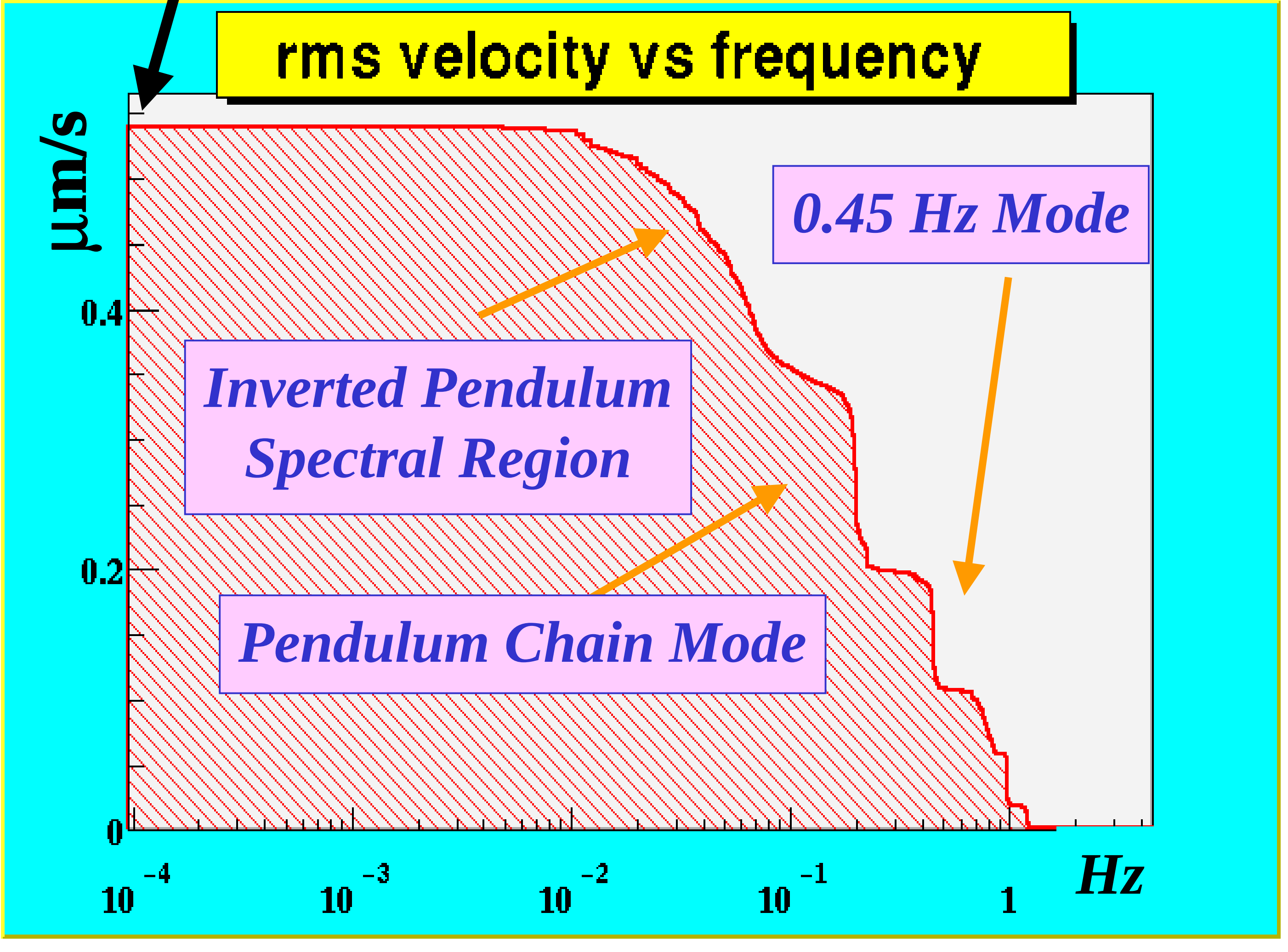


Actual Contribution
to velocity rms is 0.13 μm/s

Cure
Inertial Damping from Top

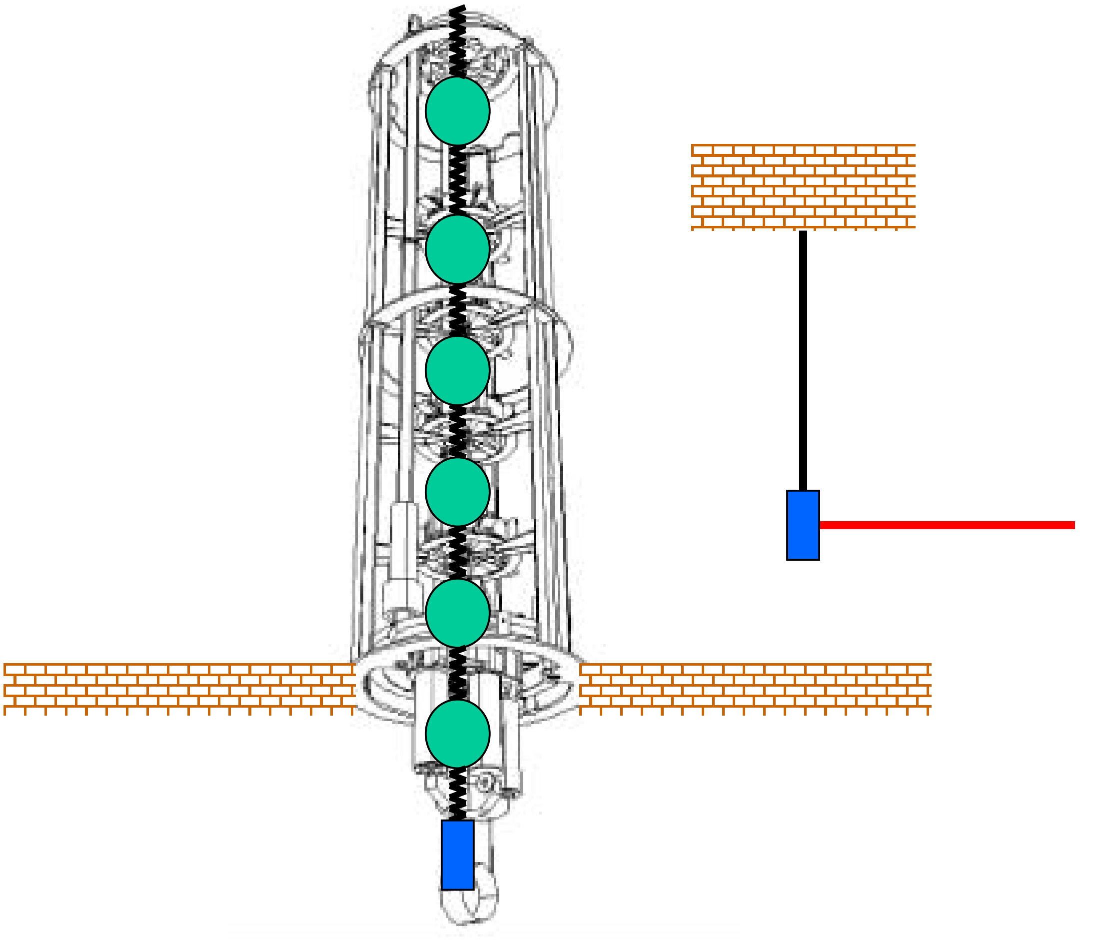
Mirror velocity spectrum

0.5 microns per second

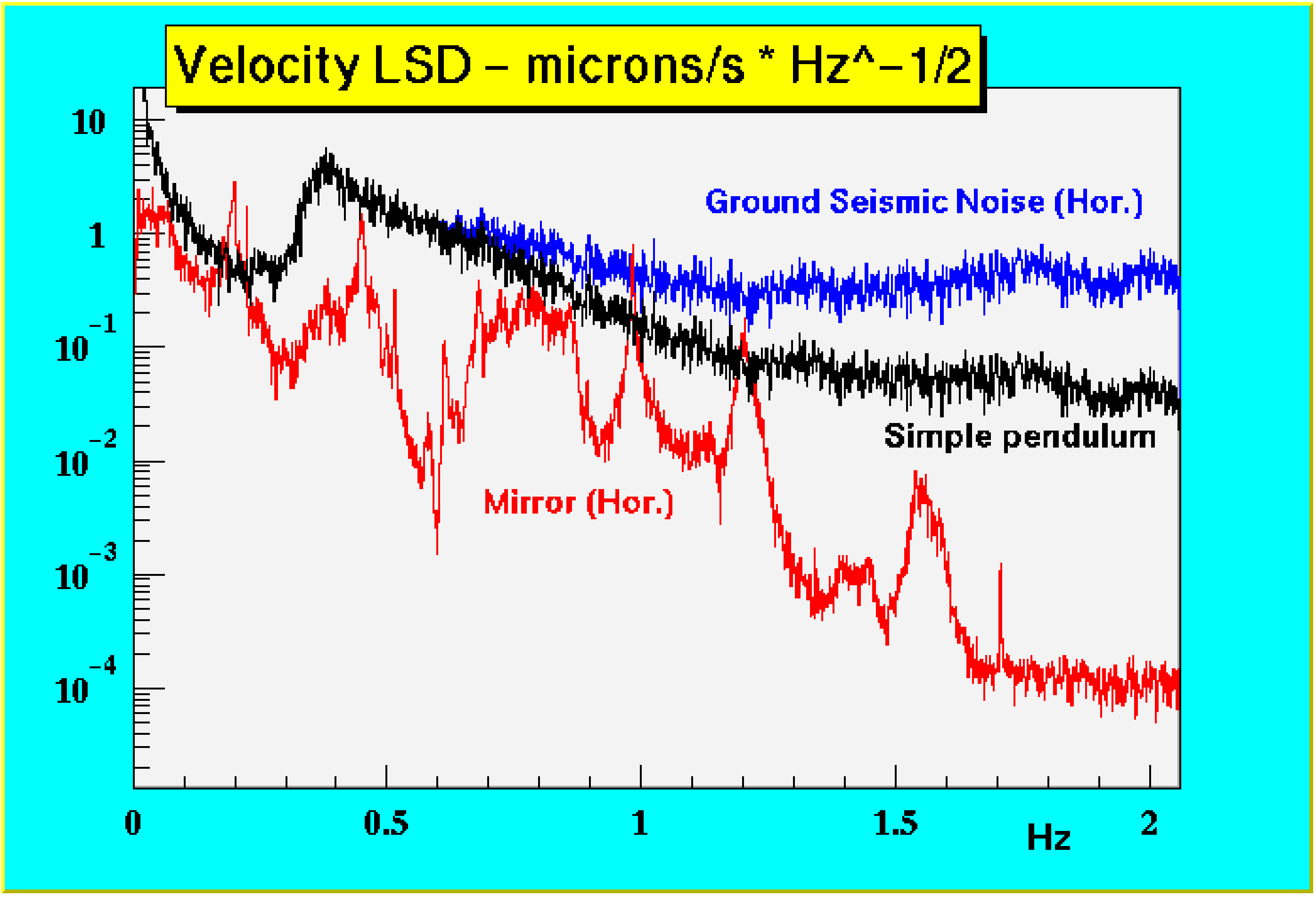


$$x_{rms}(f) = \sqrt{\int_f^\infty \tilde{x}^2(\nu)\,d\nu}$$

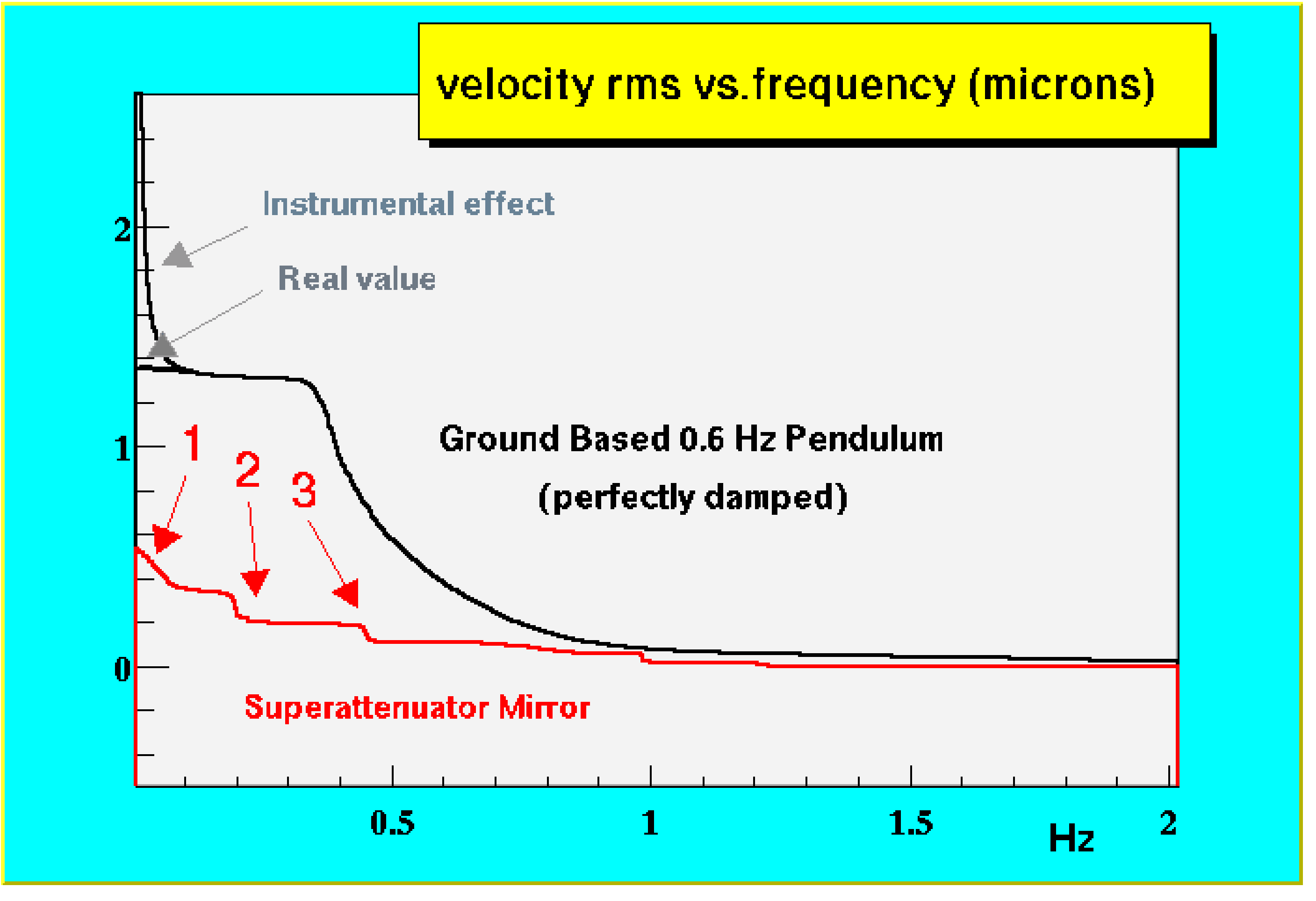
Is the mirror slow ?



Is the mirror slow ?

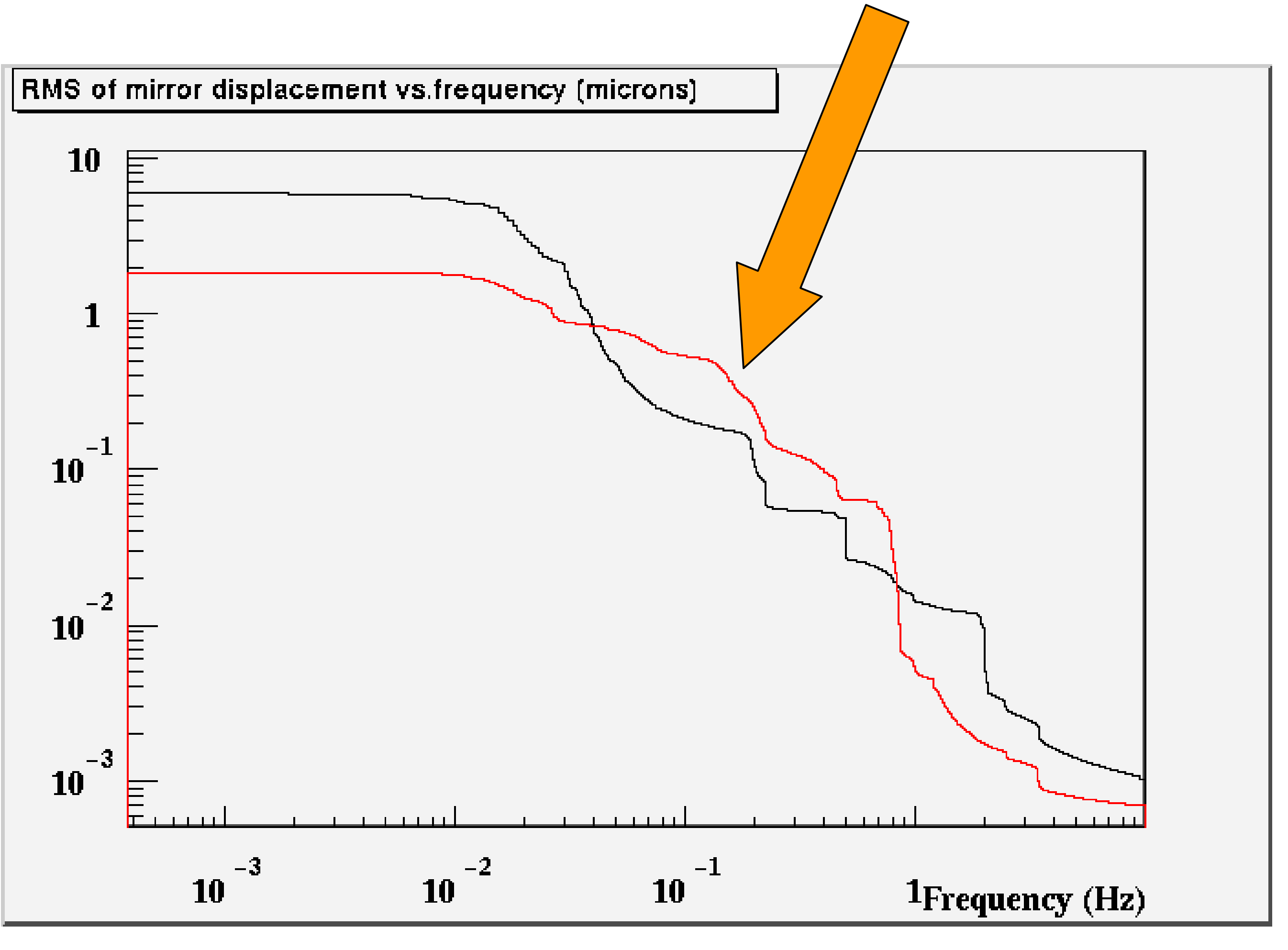


Is the mirror slow ?



Mirror Displacement

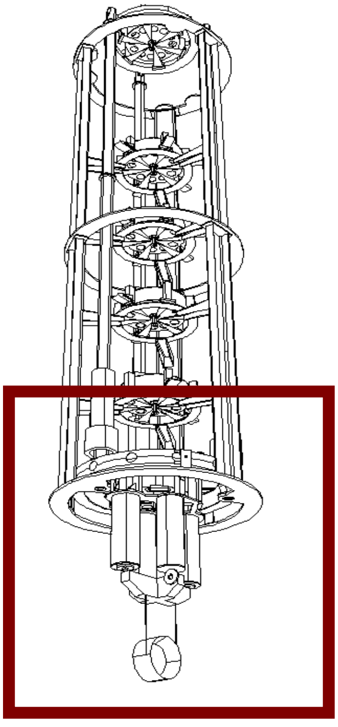
Rms displacement is a few tenths of μm @ 100 mHz



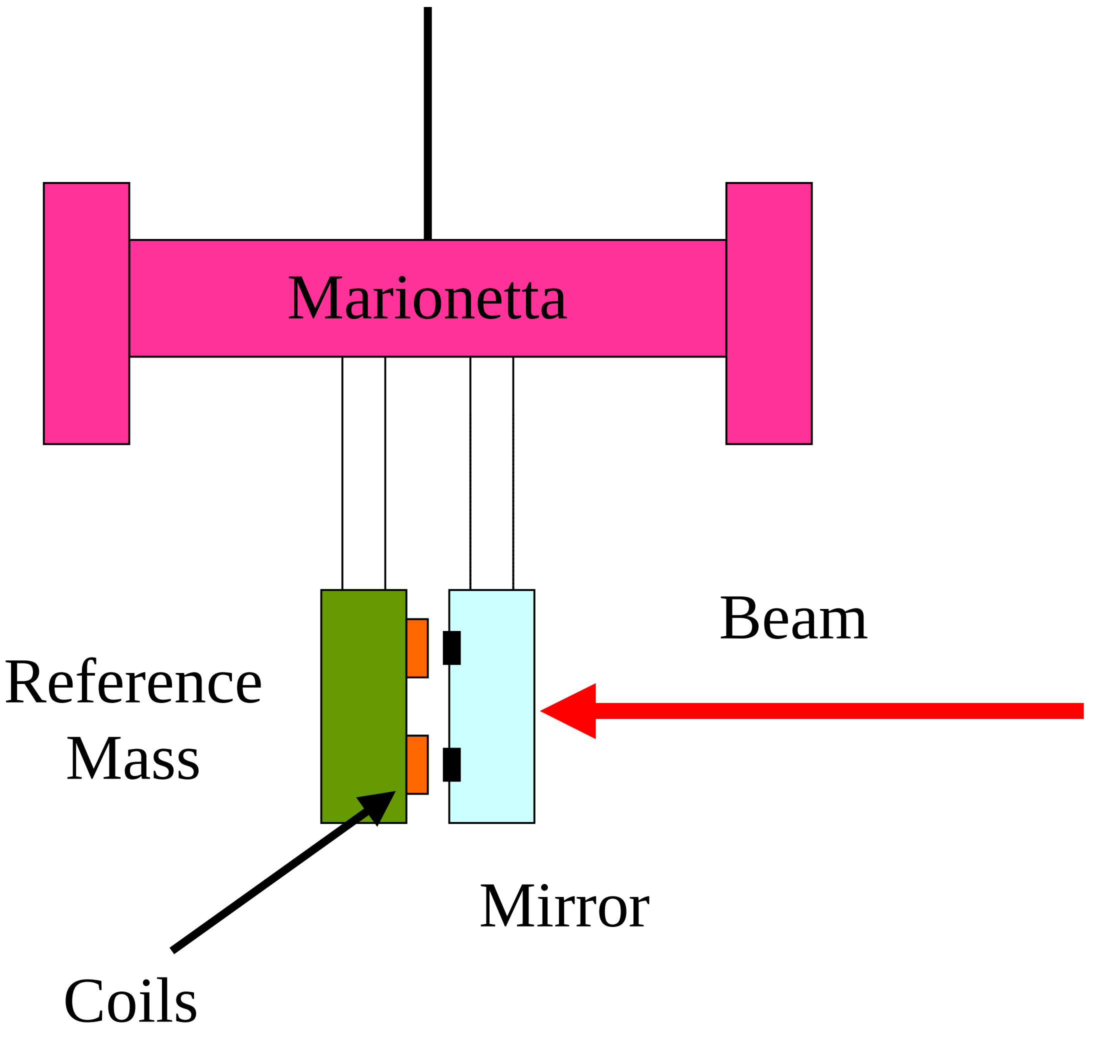
Mirror Swing Specifications

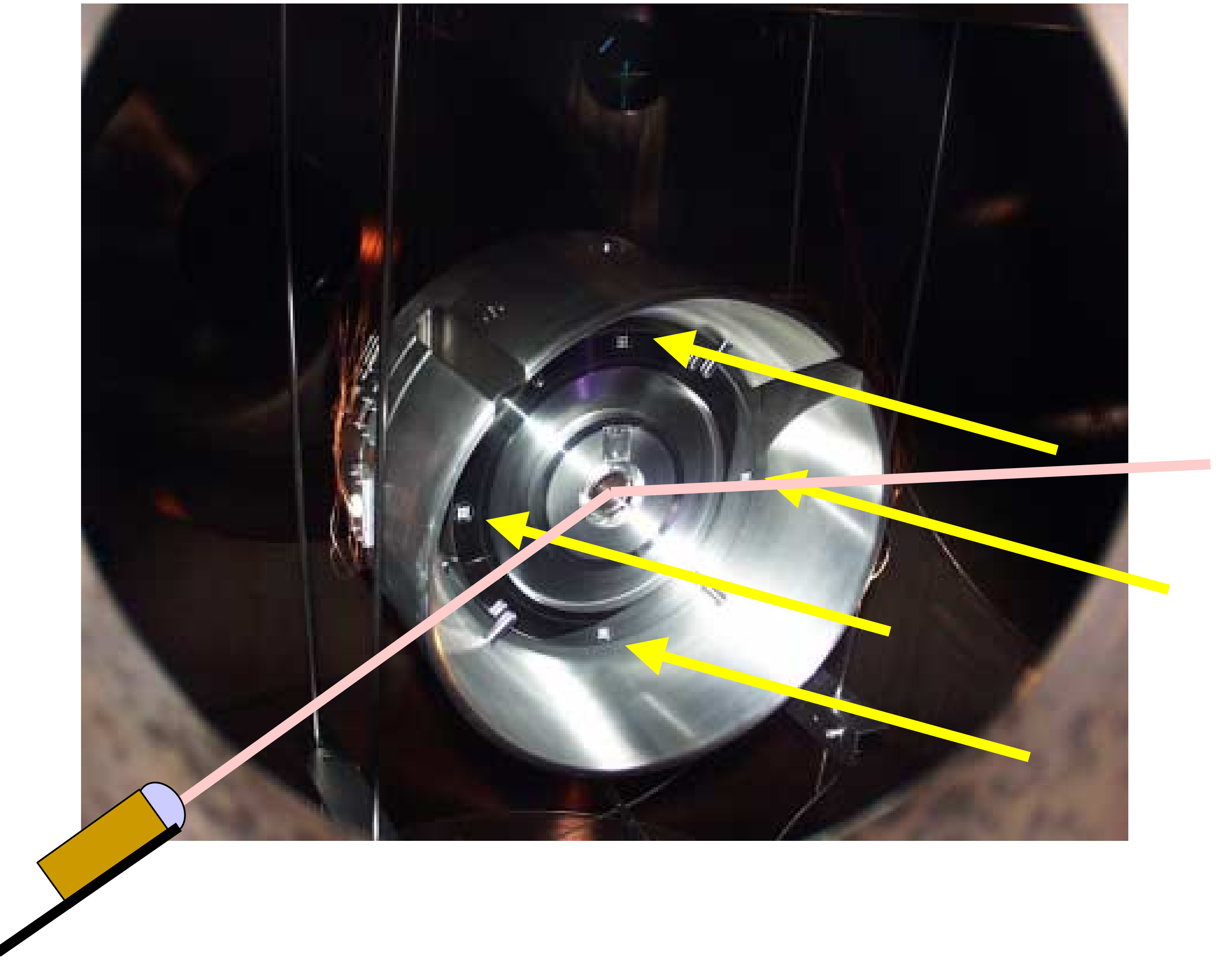
✓ rms mirror velocity smaller than a few tenths of microns per second

✓ rms mirror displacement smaller than one micron on time scales larger than 10 s



Last Stage

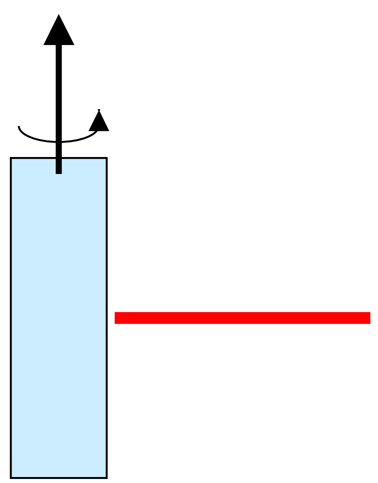




Digital Camera reads the mirror position in all degrees of freedom

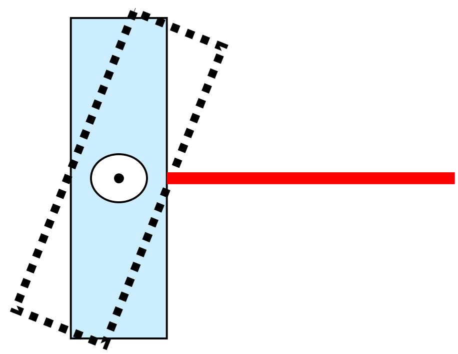
Mirror Angular Control Specifications

To reduce angular swings from a few tens of microradians down to one microradian



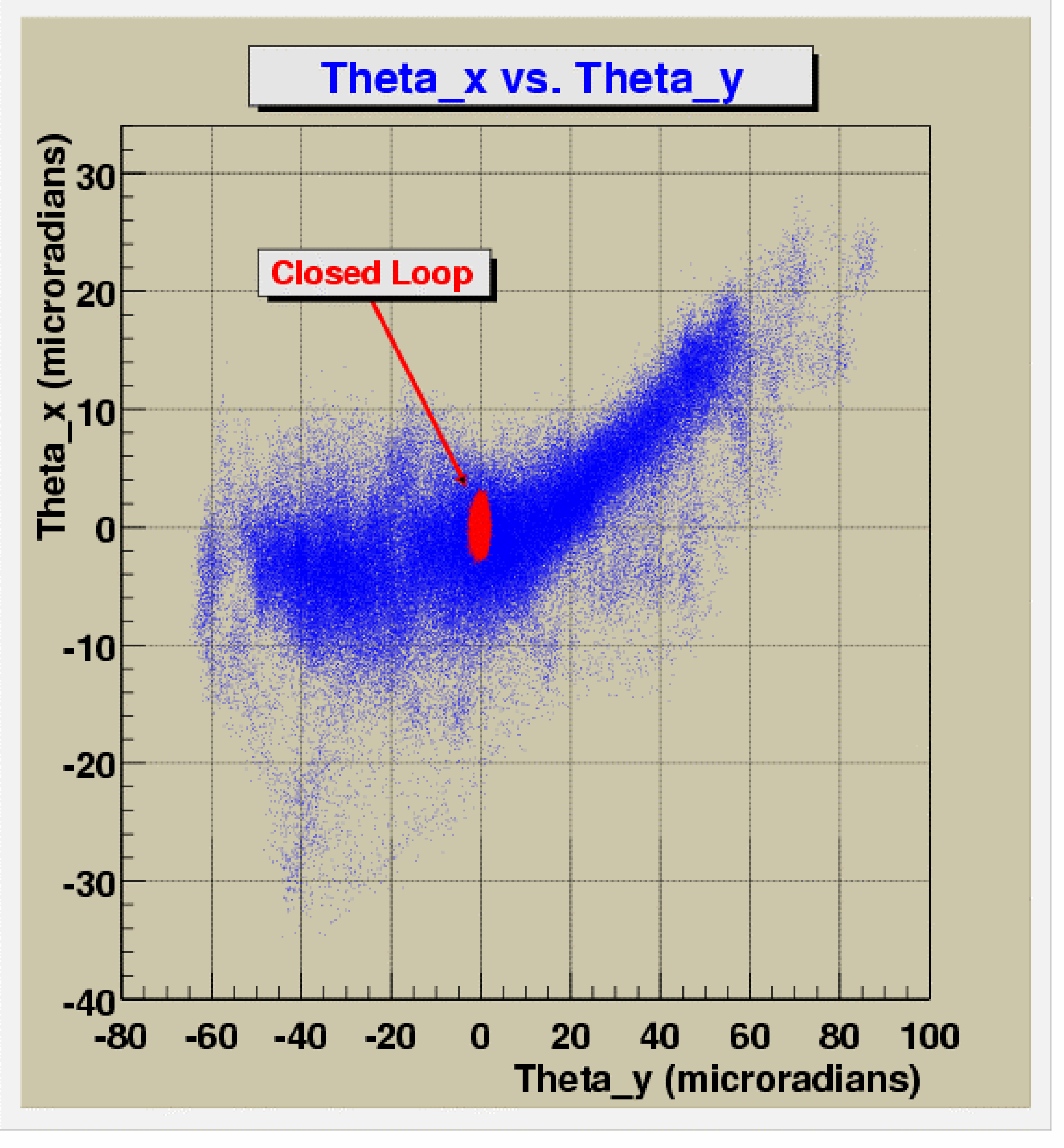
Yaw Swing θ**y**

Pitch Swing θ**x**



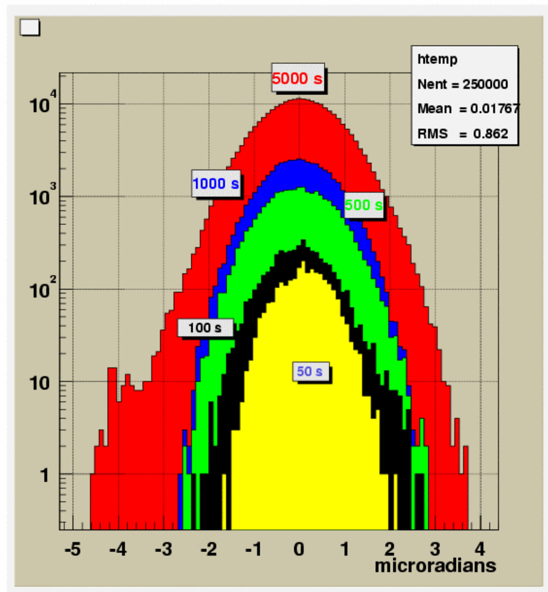
Angular displacements

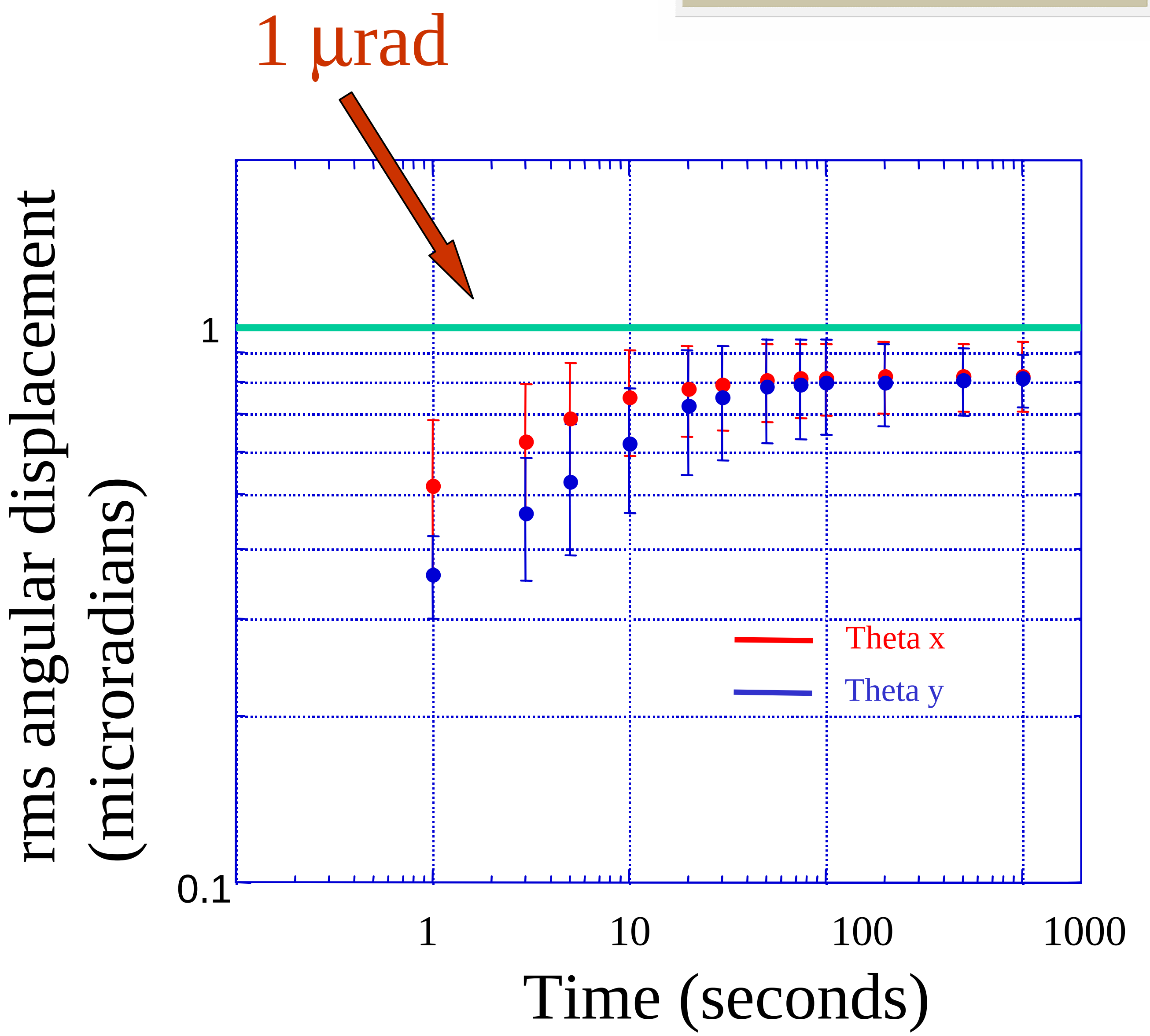
θx



θy

Angular rms


htemp
Nent = 250000
Mean = 0.01767
RMS = 0.862
5000 s
1000 s
500 s
100 s
50 s
10^4
10^3
10^2
10
1
-5 -4 -3 -2 -1 0 1 2 3 4
microradians


1 µrad
1
0.1
1
10
100
1000
Time (seconds)
rms angular displacement (microradians)
Theta x
Theta y

CONCLUSIONS

Vertical and horizontal seismic vibrations induce mirror displacements smaller than thermal noise even around 4 Hz

The mirror swing amplitude has been decreased within the specifications

Camera control reduces the angular swings of the mirror down to less than one microradian