Thoughts on the seismic isolation for ET

Paolo Ruggi - EGO

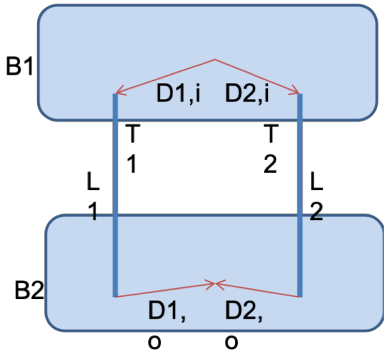
Giovanni Losurdo – INFN Pisa

THIS TALK

- Discuss the ET baseline for seismic isolation (8 years after the conceptual design)
- Outline possible R&D paths
- Is there room for coordinated R&D?

TOOL

- OCTOPUS (developed by P Ruggi): dynamical models, in frequency domain and linear approximation, of rigid bodies and elastic links, arbitrarily interconnected
  - Used successfully to reproduce the behavior of the Superattenuator (**SA**), including its active controls



RIGID BODY
m: mass
I: inertia
ELASTIC LINK (beam)
e: Joung modulus
r: density
l: length
s: surface of the section
J: inertia of the section
D: displacement from/to CM
T: tension

For each element, a 12X12 impedance matrix is defined:

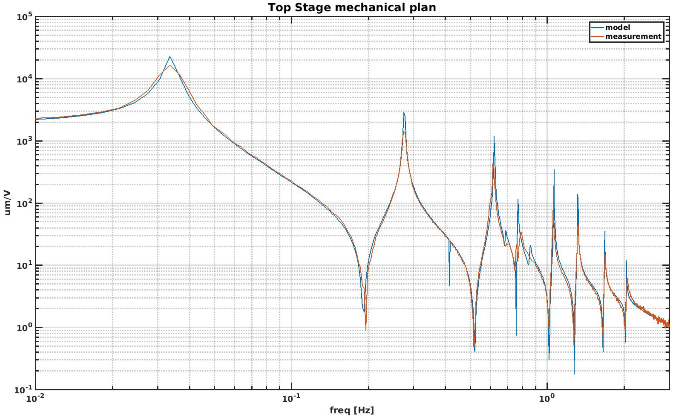
$$\begin{pmatrix} X_o \\ F_o \end{pmatrix} = \mathbf{Z} \begin{pmatrix} X_i \\ F_i \end{pmatrix} \Rightarrow \mathbf{B}(\mathrm{m,I,\omega})\ ;\ \mathbf{L}(\mathrm{e,\rho,l,s,J,D,T,\omega})$$

For a given layout and a given pair IN/OUT, an algebraic functional of impedances defines a 6X6 TF (modulus/phase)

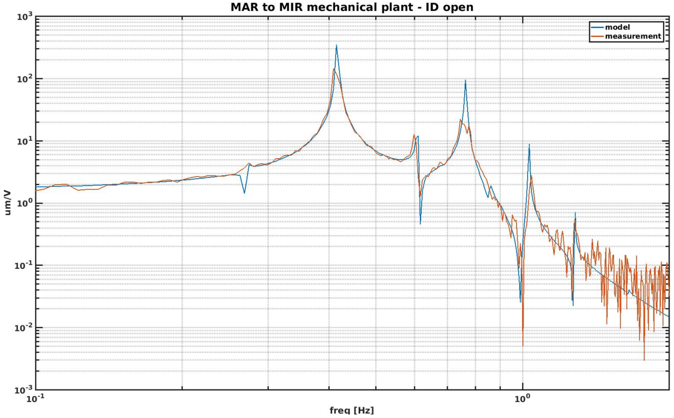
$$X_i \to X_o = \Omega(\mathbf{B_1},\mathbf{B_2},\mathbf{L_1},\mathbf{L_2})\,|_\omega$$

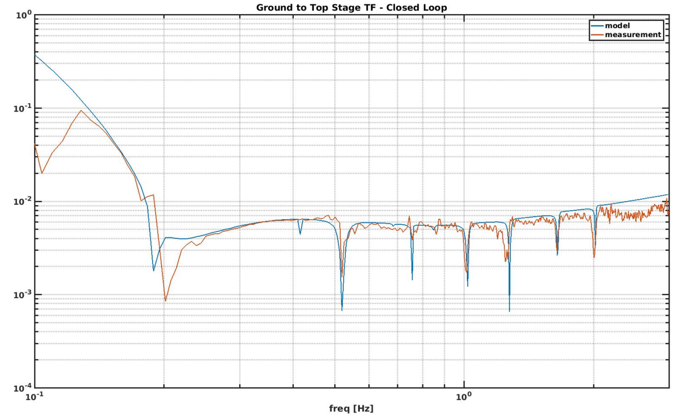
$$F_i \to X_o = \Gamma(\mathbf{B_1},\mathbf{B_2},\mathbf{L_1},\mathbf{L_2})\,|_\omega$$

OCTOPUS

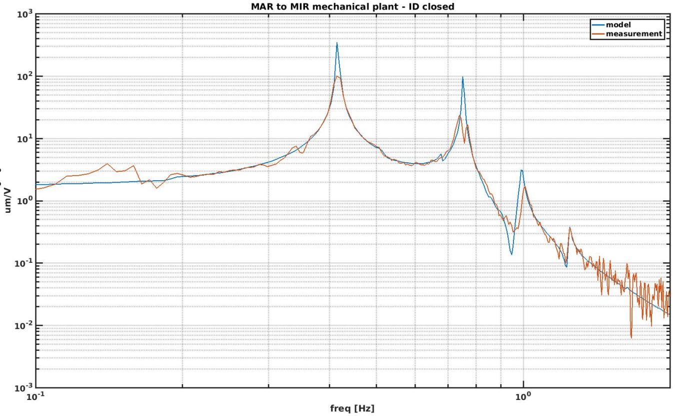


TRANSFER FUNCTIONS:
CONTROLS OFF



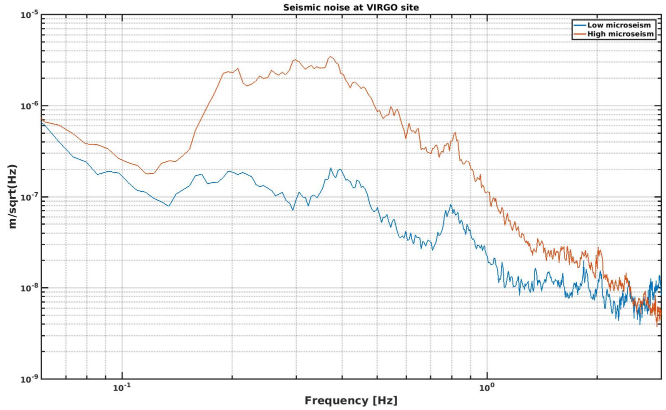


TRANSFER FUNCTIONS:
CONTROLS ON

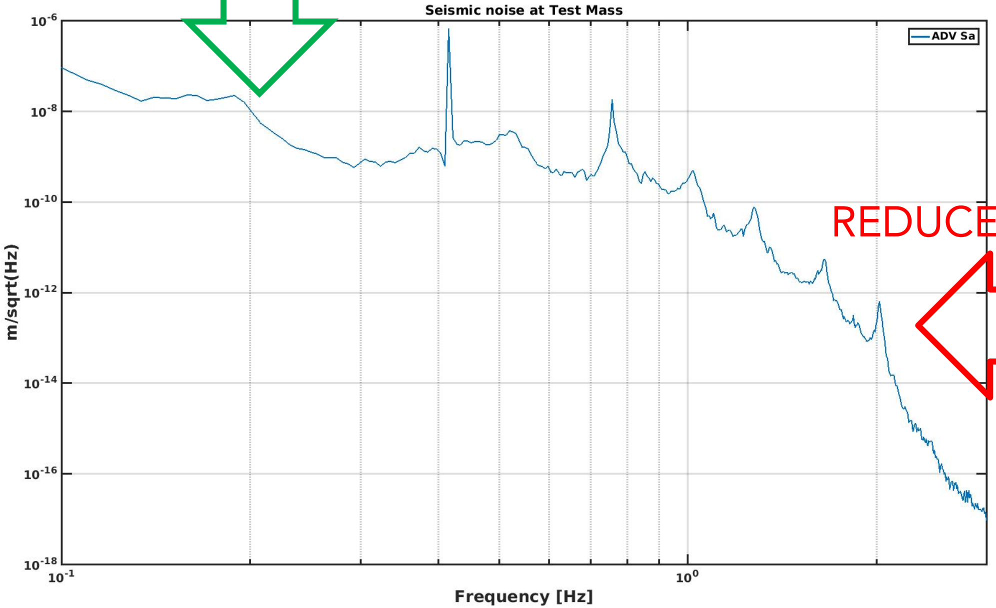


P Ruggi - G Losur

TEST MASS MOTION (ADV)



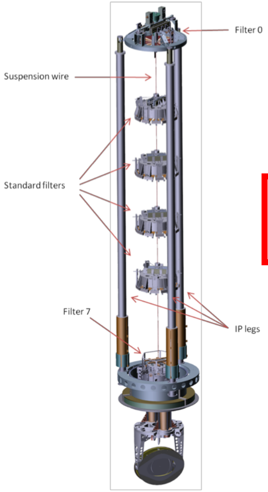
REDUCE MIRROR RMS MOTION



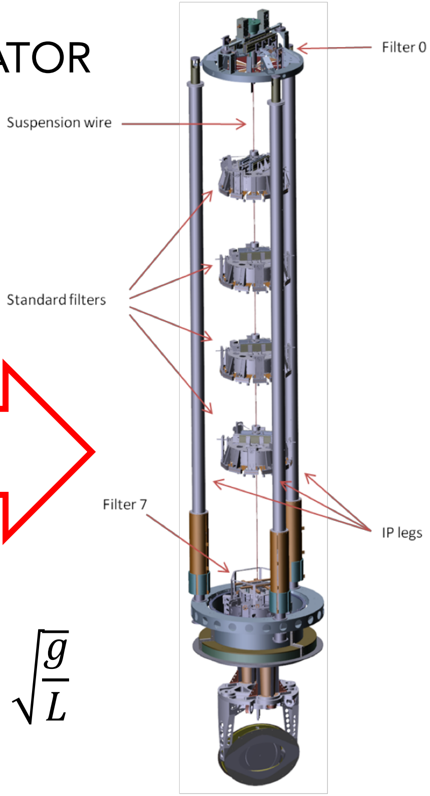
REDUCE f_{low}

REDUCING f_{min}

MAKE THE ISOLATOR LONGER



$$f_0 \propto \sqrt{\frac{g}{L}}$$



OR

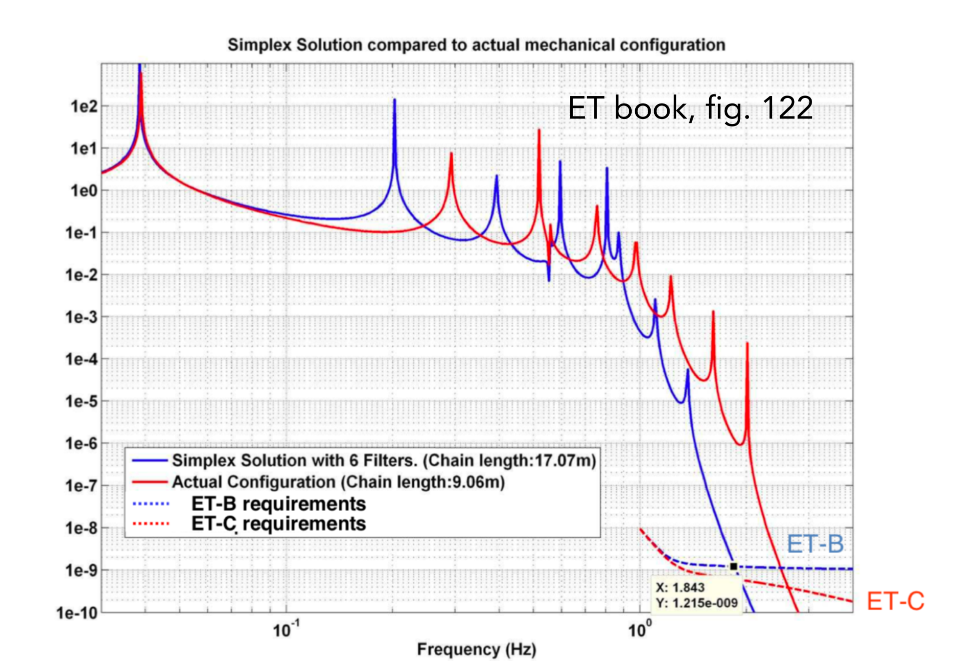
- CASCADE INVERTED PENDULUMS?
- ?

ET CONCEPT – VIBRATION ISOLATION

REFERENCE SOLUTION

- Technology: superattenuator (**SA**)
- Height: 17 m (9 in Virgo)
- Seismic wall: ~2 Hz (~3 in Virgo)

$$2 \sim \sqrt{\frac{9}{17}} \cdot 3$$



S Braccini et al., 2010

IS IT OK?

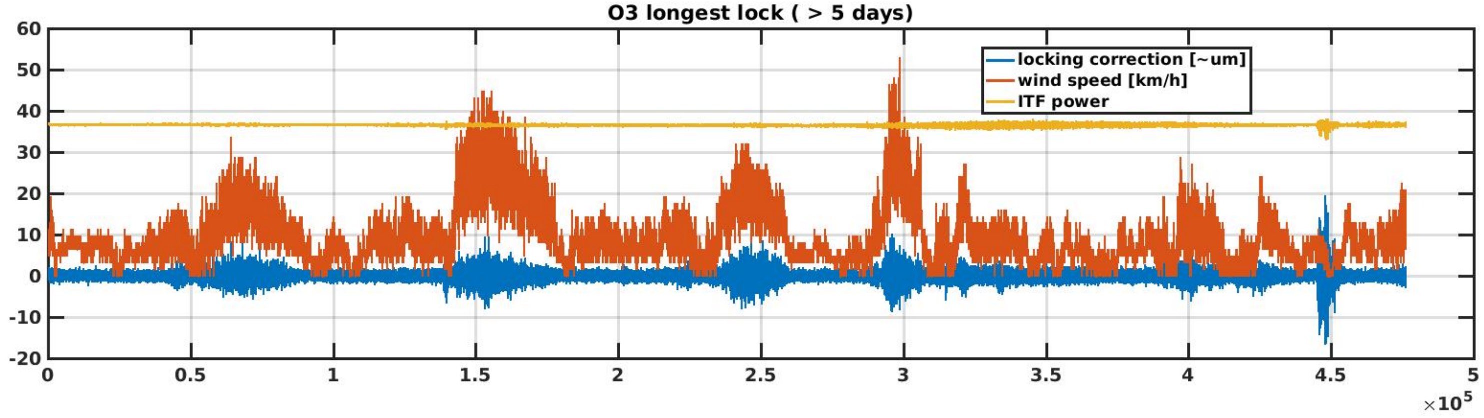
THE TECHNOLOGY IS RIGHT

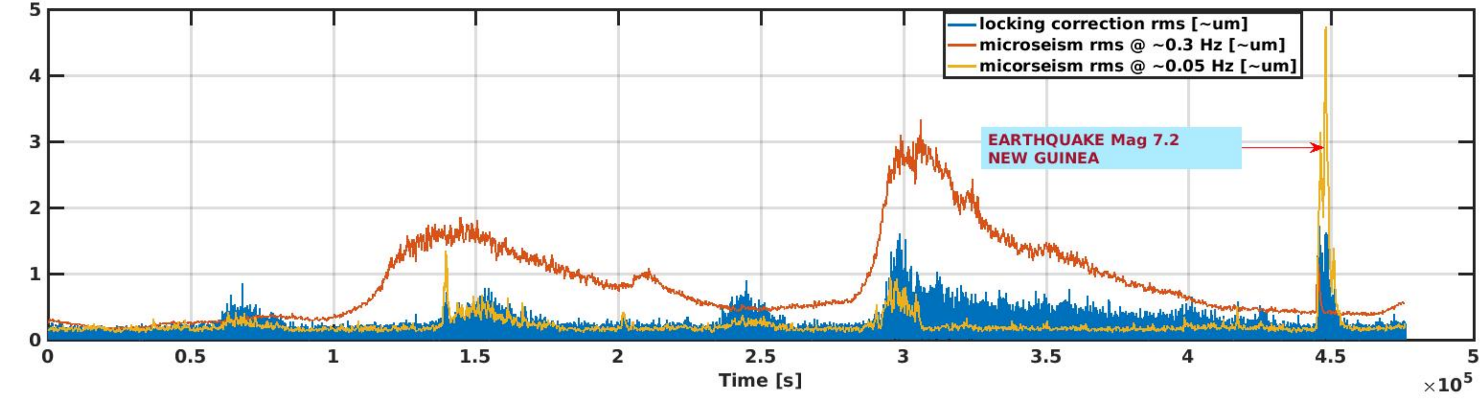
- **SA** works beautifully since ~20 years
- The stability of Advanced Virgo is impressive

BUT…

- Making it longer is not sufficient to reach the 1 Hz goal ($f_{min} \propto \sqrt{L}$, 81m needed)
- Cavern cost/engineering issues
- We have the chance to improve the performance further

"**SA** works beautifully"

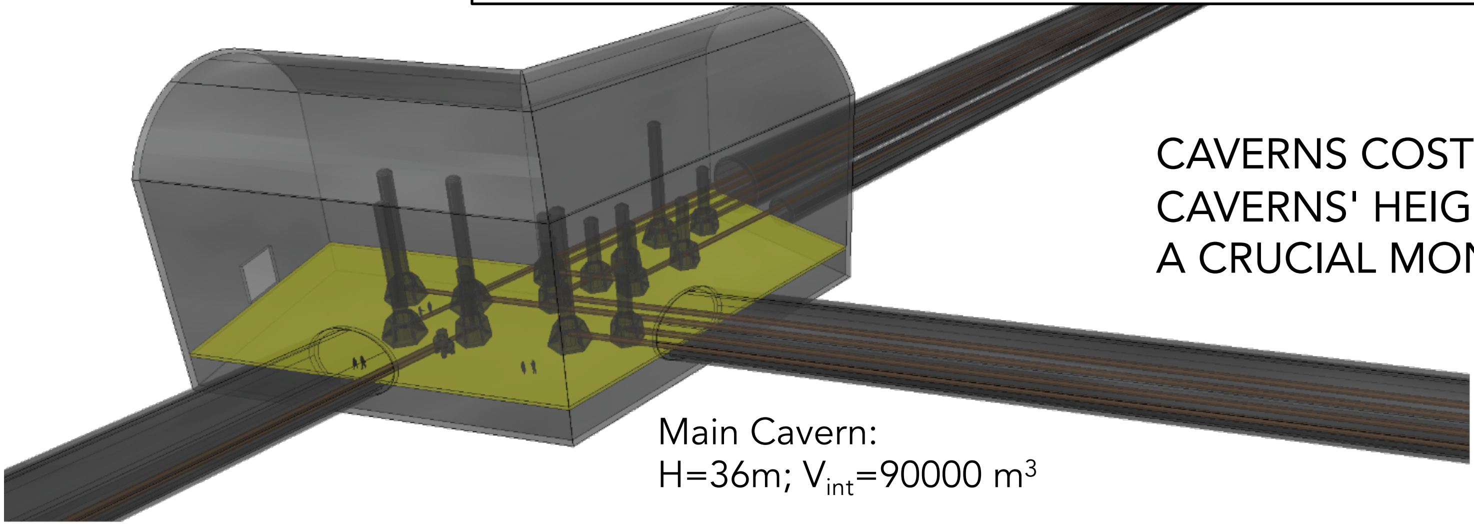




COST - SUMMARY TABLE

	ET book p.313	Triangle "realistic"	L
TUNNELS	280	727	367
CAVERNS	110	97	60
ACCESSES	61	164	117
TOTAL	**451**	**988**	**544**

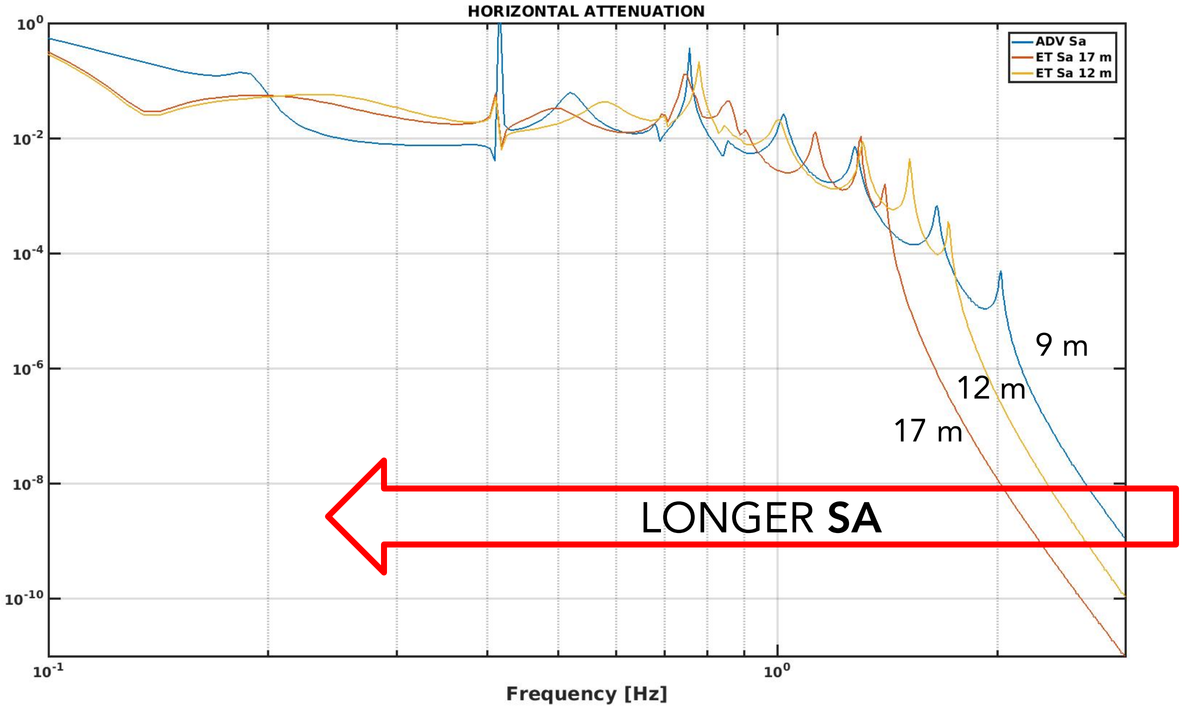
cost in Meuros, no contingency



Main Cavern:
H=36m; V_{int}=90000 m^3

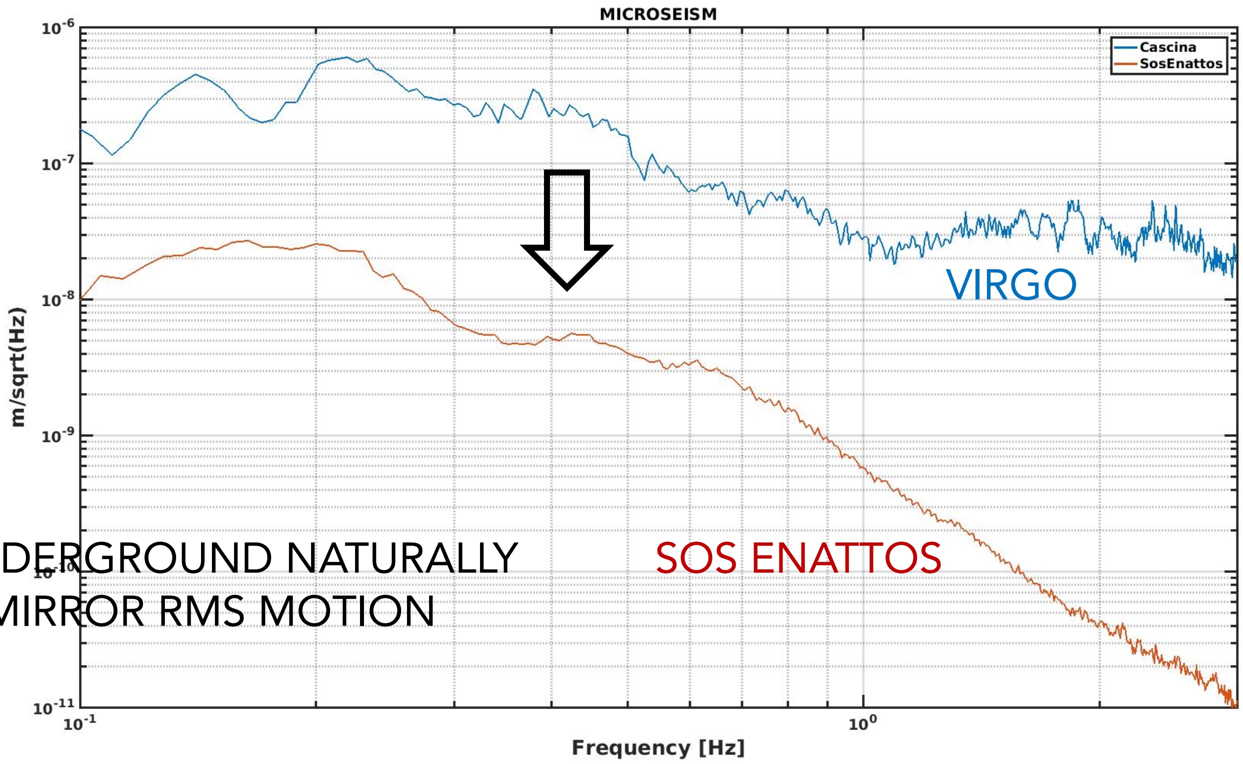
CAVERNS COST ~10%
CAVERNS' HEIGHT IS NOT A CRUCIAL MONEY SAVER

SA MODELS



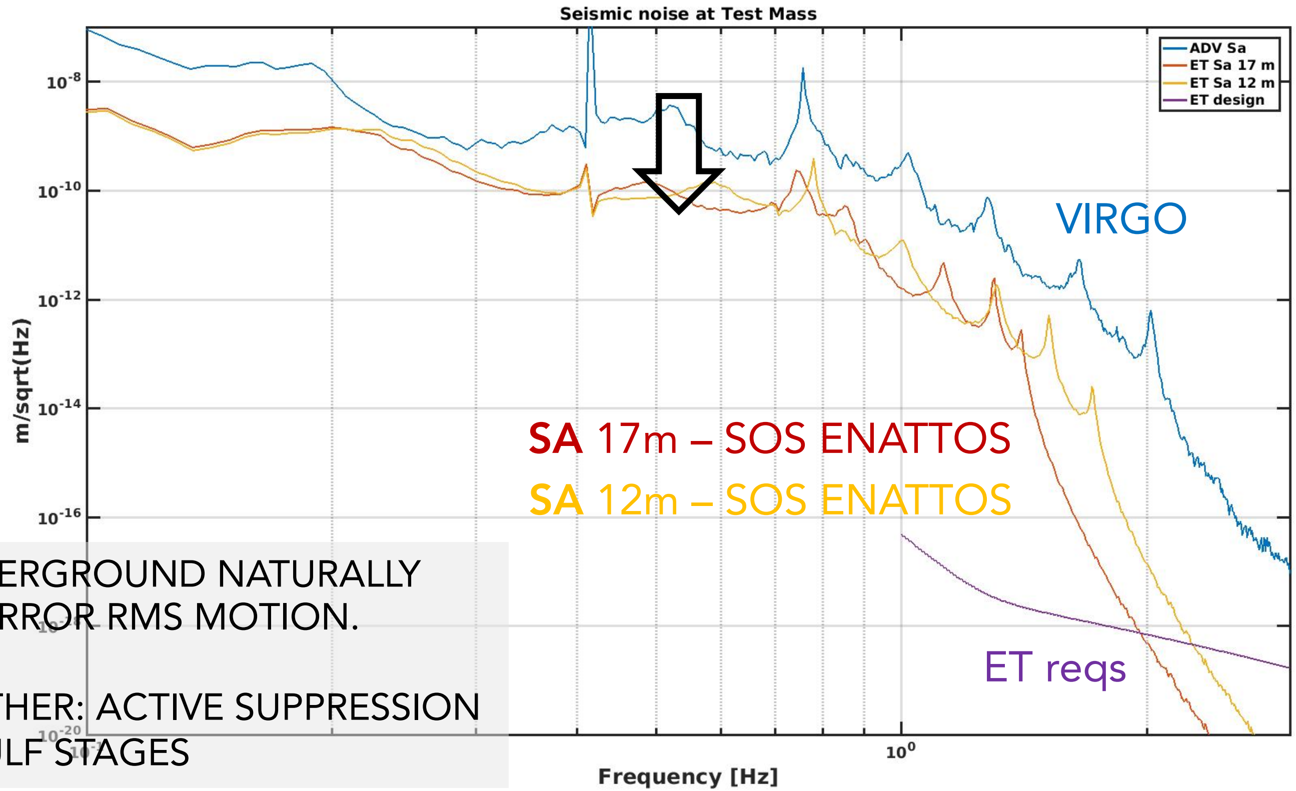
HORIZONTAL ATTENUATION
ADV Sa
ET Sa 17 m
ET Sa 12 m
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-1}
10^{0}
Frequency [Hz]
9 m
12 m
17 m
LONGER **SA**

INPUT SEISMIC NOISE



GOING UNDERGROUND NATURALLY REDUCES MIRROR RMS MOTION

TEST MASS RESIDUAL MOTION

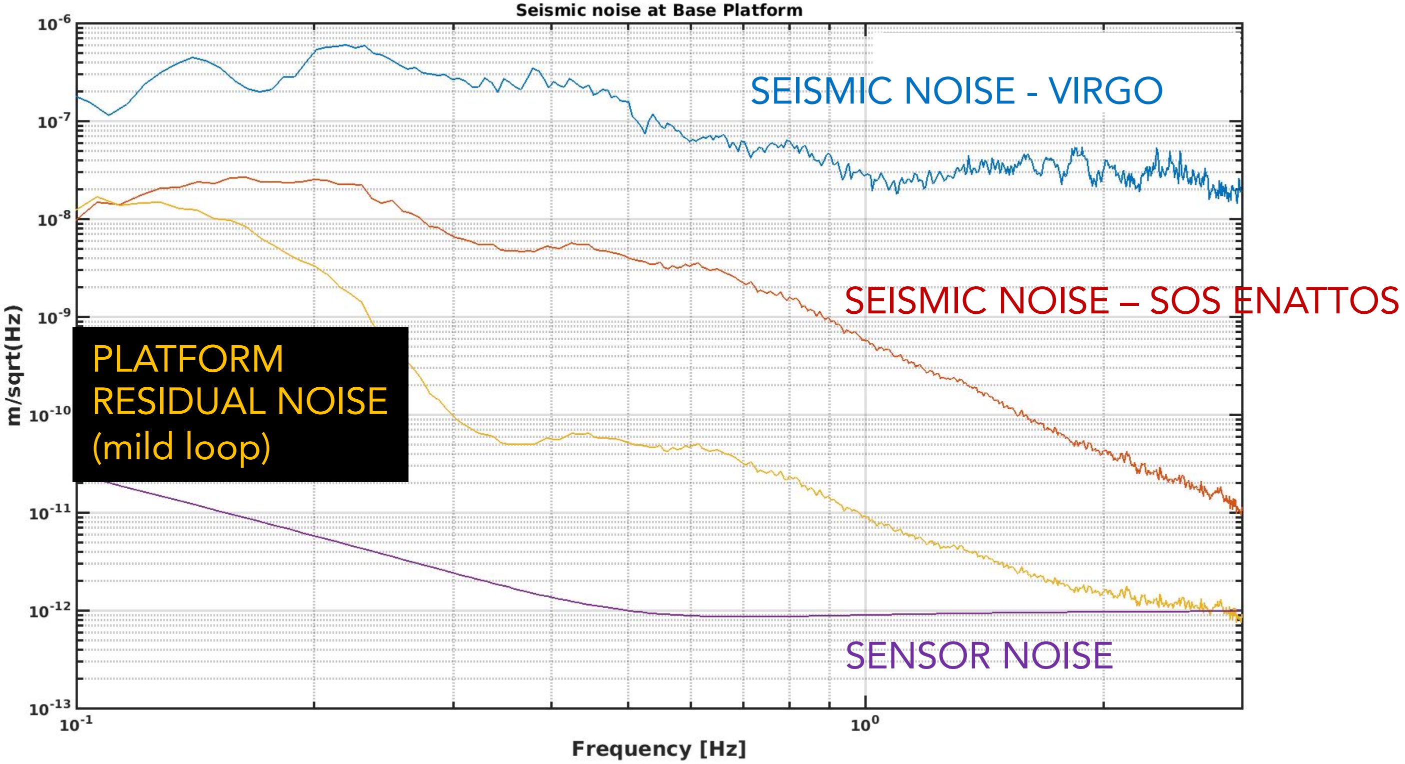


GOING UNDERGROUND NATURALLY REDUCES MIRROR RMS MOTION.

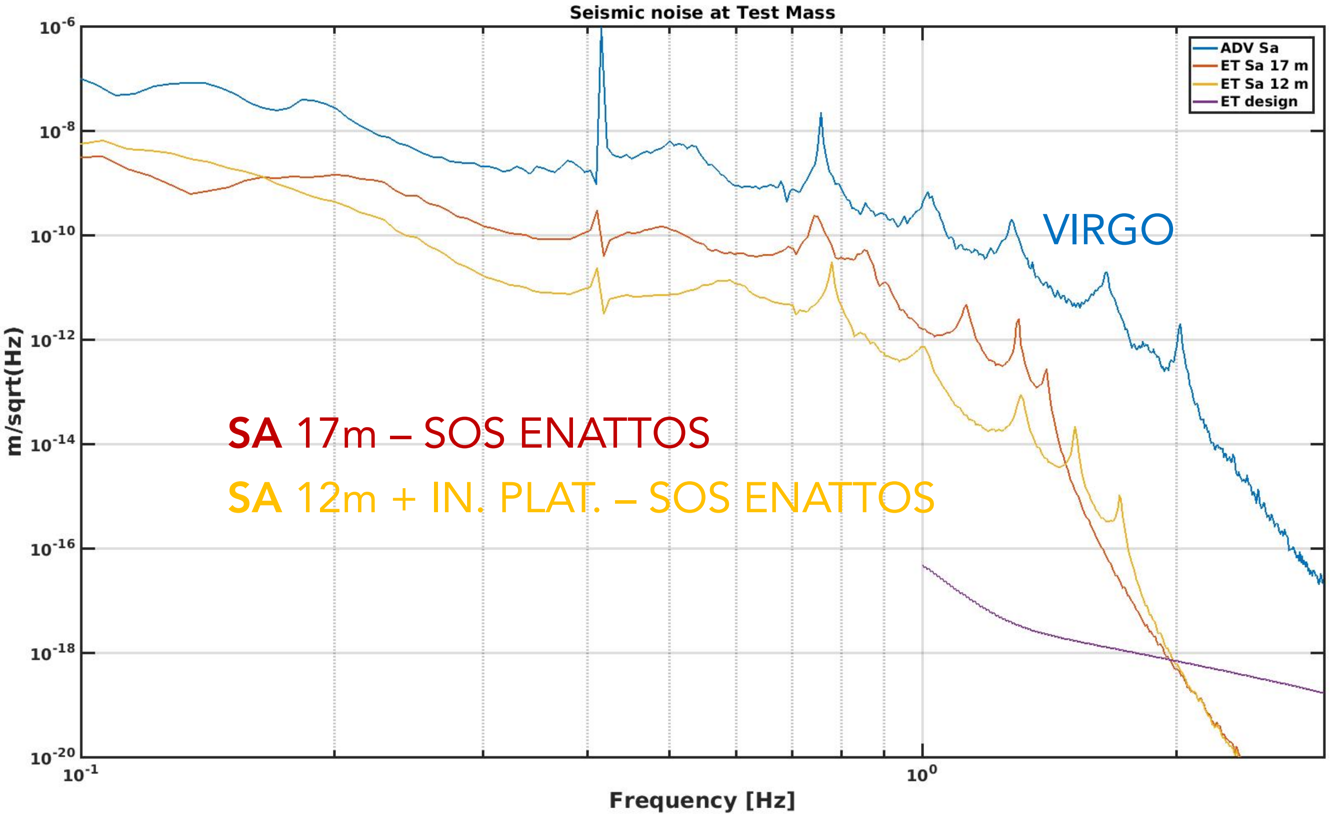
GOING FURTHER: ACTIVE SUPPRESSION (aLIGO) OR ULF STAGES

BENCHMARK OPTIONS

- *Baseline*: 17m **SA**, same Virgo design/control strategy
- *Shorter*: 12 m **SA**, same Virgo design/control strategy
- *R&D*: 12 m **SA** on a inertial platform
    - Platform "mildy" controlled (gain comparable to aLIGO SEI)
    - Conservative sensor noise: ~10^{-12} m/√Hz
    - One dof simulated, no actuation noise considered


Seismic noise at Base Platform
m/sqrt(Hz)
Frequency [Hz]
SEISMIC NOISE - VIRGO
SEISMIC NOISE – SOS ENATTOS
PLATFORM
RESIDUAL NOISE
(mild loop)
SENSOR NOISE

RESIDUAL MIRROR MOTION



MESSAGE 1:

IN PRINCIPLE COUPLING A 12 m SUPERATTENUATOR TO A "MILD" INERTIAL PLATFORM MAY LEAD TO BETTER PERFORMANCE THAN A 17m **SA**

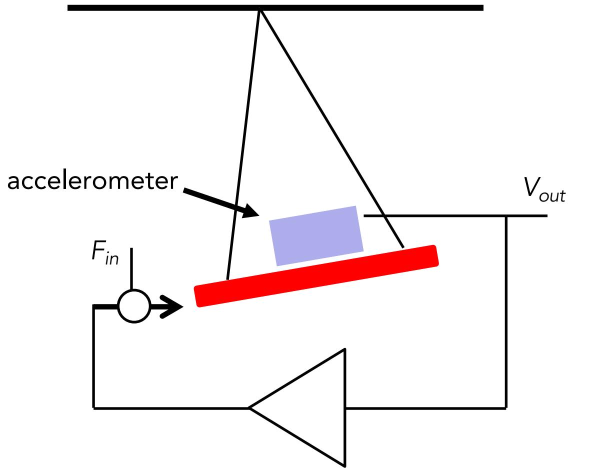
CAVEAT: experiments are more difficult than simulations

SUPERATTENUATOR

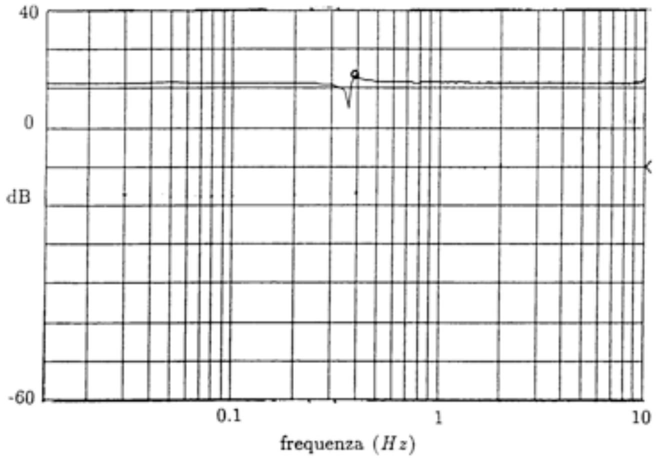
- THE **SA** IS NOT JUST A PASSIVE ISOLATOR
- The IP pre-isolator is a soft platform used for inertial damping and tide control
- The entire **SA** sits on a tilt controllable base

THE EARLY TIMES

ACCELEROMETERS AND TILT
(1st observation at Virgo)

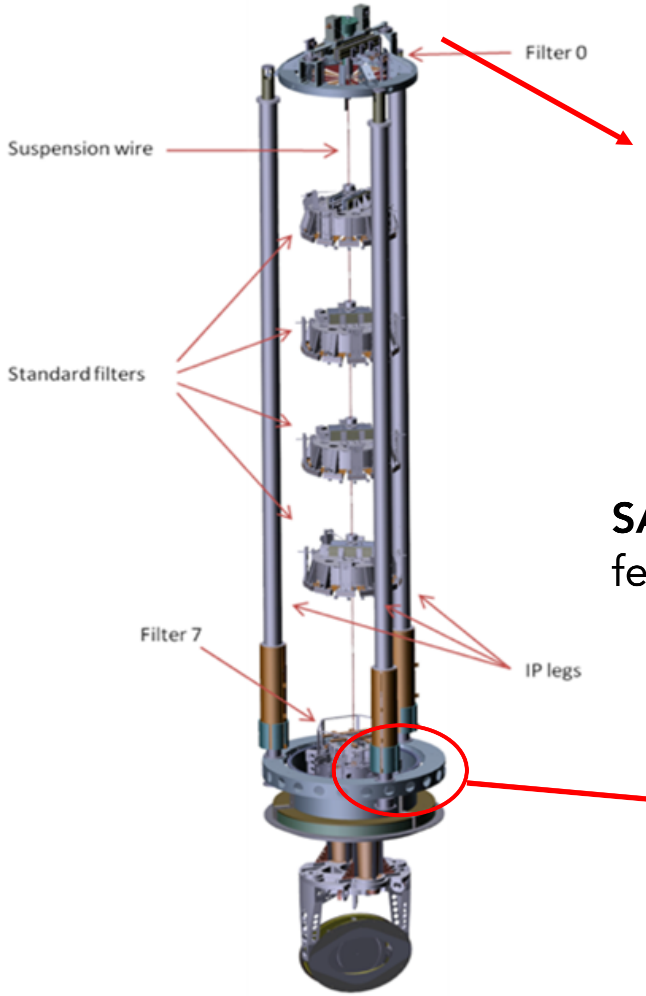


Test of inertial control of a suspended table: surprising result!



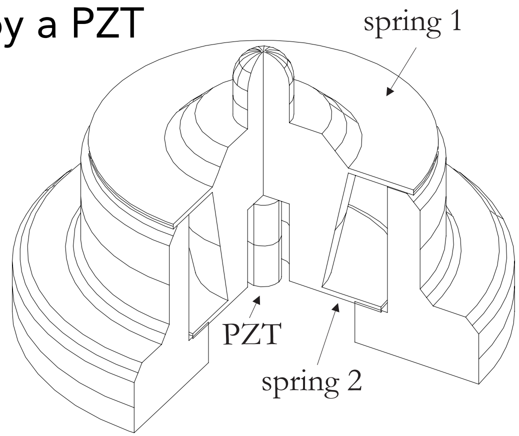
This could be explained by considering the tilt in the Accelerometer response.
This finding triggered the design of tilt control in the SA.

(Gennai, Giazotto, Losurdo, Paoletti, Passuello, 1992)



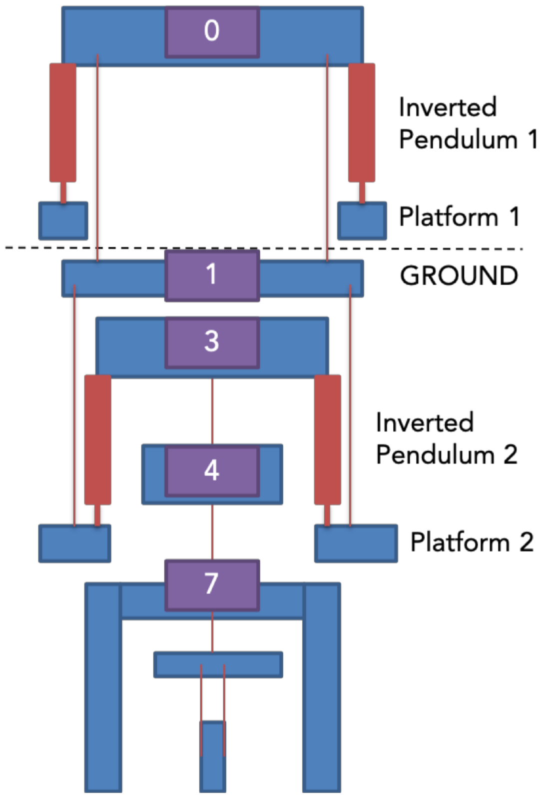
INVERTED PENDULUM: passive pre-isolator
And soft platform for active controls

SA sits on a rigid ring, resting on 3 elastic feet, actuated by a PZT

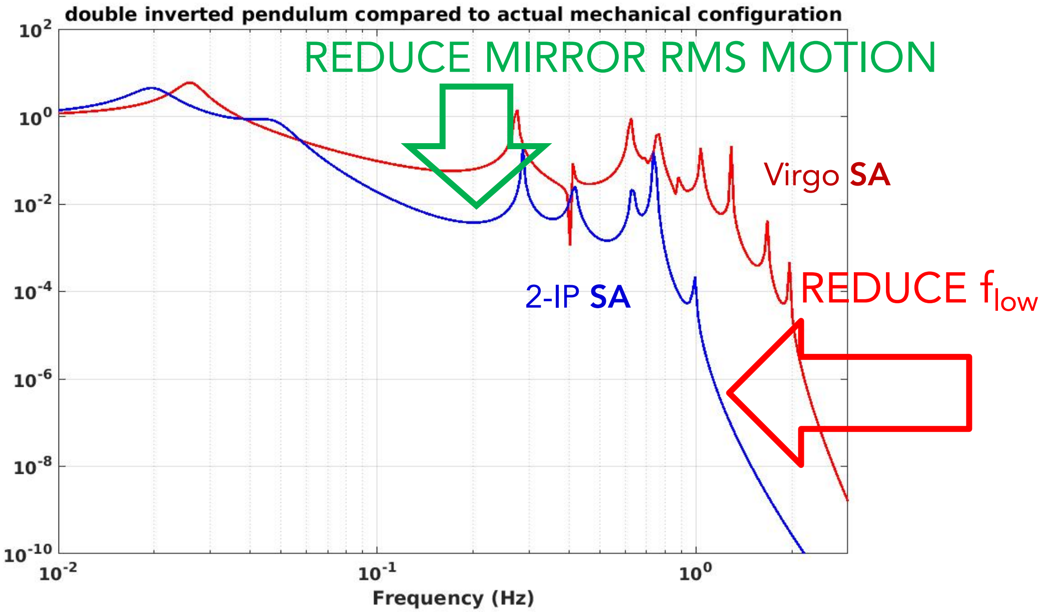


- The combination of the tilt control on the base and the HOR/VER controls on the IP can realize a full 6 dof inertial platform
    - IP so far is used just for damping the resonances
    - With some modifications (e.g. remove blade resonances) the control bandwidth could be extended to make it a high gain inertial platform
- However, moving the HOR control (at least the sensors) on the base would allow to exploit better the IP passive isolation and have better final performance
- Eventually, the final performance will be determined by the sensor/actuator noise
    - This is the crucial line of research

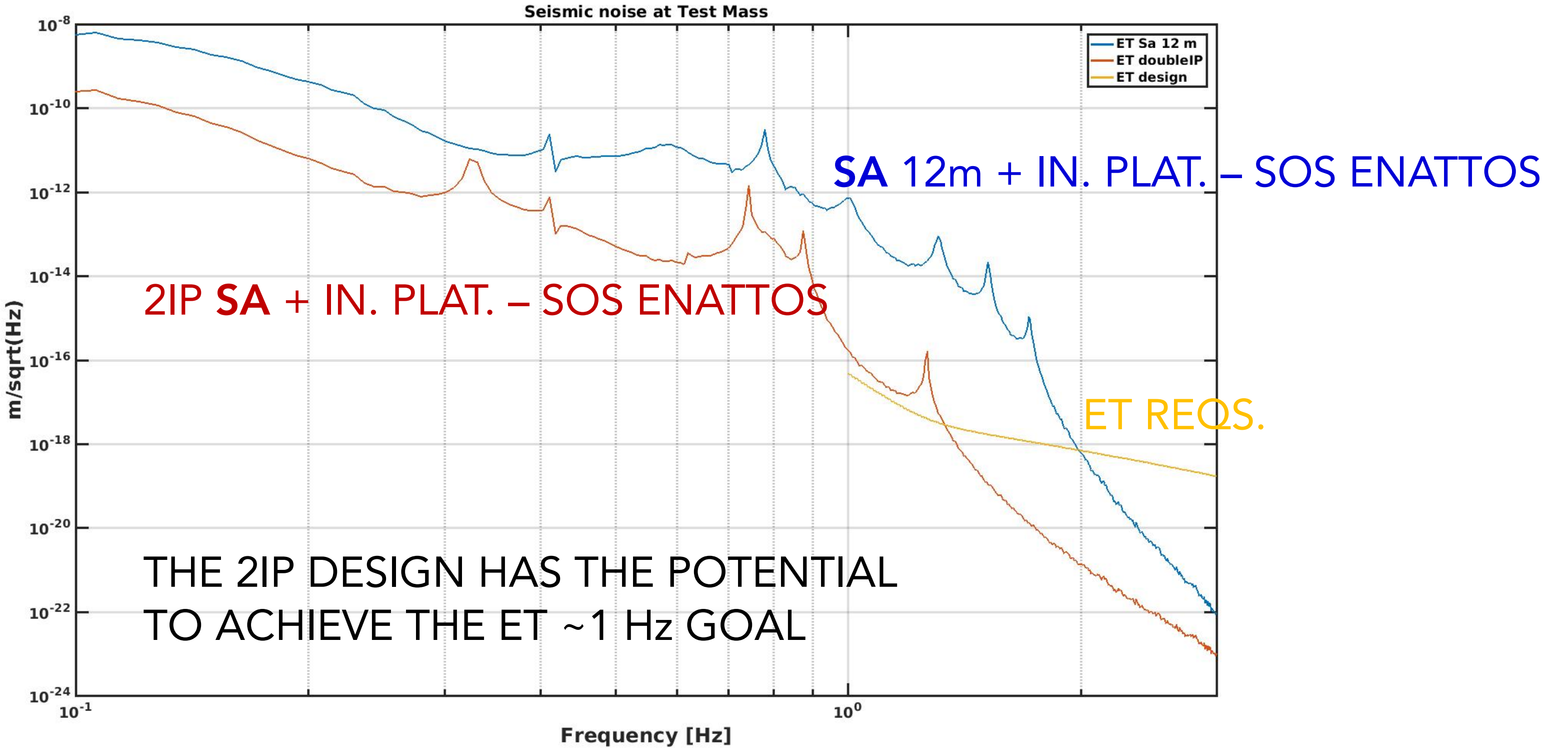
DOUBLE IP (CONCEPT)



INTERESTING CONCEPT, LONG-TERM R&D: EXTREME PASSIVE ISOLATION + ADVANCED ACTIVE CONTROLS



PERFORMANCE – RESIDUAL MOTION



MESSAGE 2:

NOT ONLY THE **ET** BASELINE: THERE ARE (AT LEAST) TWO ALTERNATIVES BASED ON **SA** TECHNOLOGY:

- A SHORTER **SA** COUPLED TO AN INERTIAL PLATFORM (MID-TERM R&D)
- A NEW **SA** BASED ON A DOUBLE INVERTED PENDULUM (LONGER TERM R&D)

MESSAGE 3:

THE R&D ON THIS TOPIC COULD BE AN IDEAL FIELD FOR A COORDINATED/COLLABORATIVE EFFORT: *SENSOR DEVELOPMENTS, CONTROL STRATEGY, MECHANICAL DESIGN*

CONCLUDING REMARKS

- A reliable simulation tool (OCTOPUS) to help in mechanical design/control strategy is available
- **SA** technology works fine but can be further improved and even meet ET requirements by enhancing the active controls
  - We have proposed some investigation lines for the ET vibration isolation system
- Next steps:
  - Move from sketchy ideas to more refined designs
  - Design suitable control strategies
  - Make comprehensive 6 dof models
  - Study the noise budget
  - Propose a prototype