EINSTEIN TELESCOPE

IP and PIP Shortening the seismic attenuation chain

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ET-LF requirements

LF noise is given by

- Microseism motion
- Newtonian noise
- Upconversion of residual motion into the detection band
- Control noise

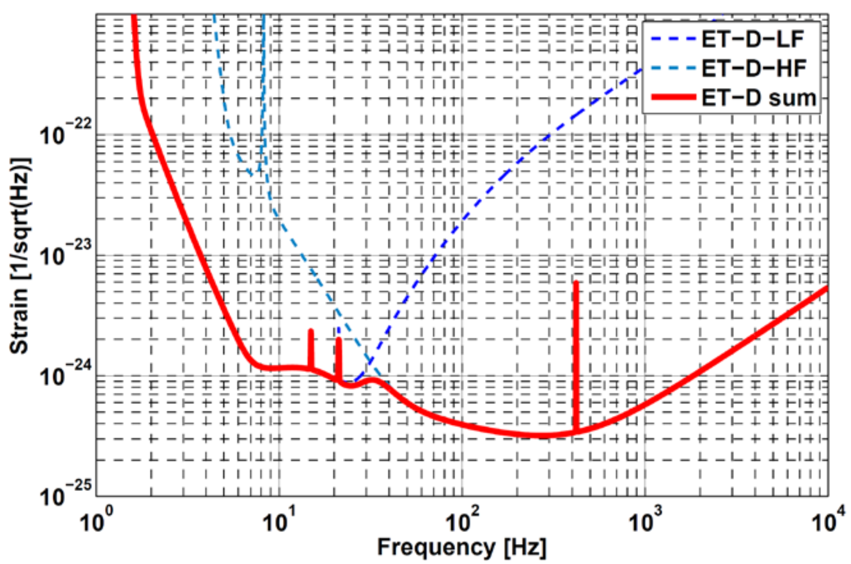
Design curve based on 17 m tall suspensions

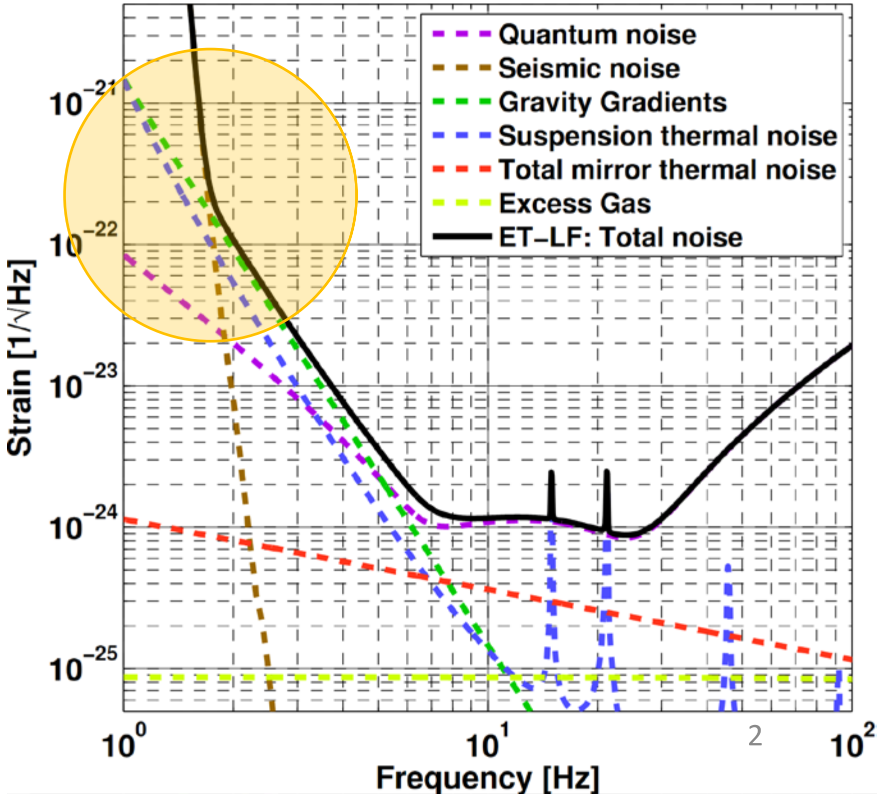
Reduction to less than 10 m:

- Significantly lower cavern excavation cost
- Suspension management similar to Virgo

Newtonian noise crossing:

2 10^{-22} $Hz^{-1/2}$ at 1.8 Hz (AdV: 3.2 Hz)





ET Seismic levels

Sardinia vertical

$3\ 10^{-8}\ ms^{-2}\ Hz^{-1/2}$ at 2 Hz

$7.5\ 10^{-10}\ m\ Hz^{-1/2}$ at 2 Hz

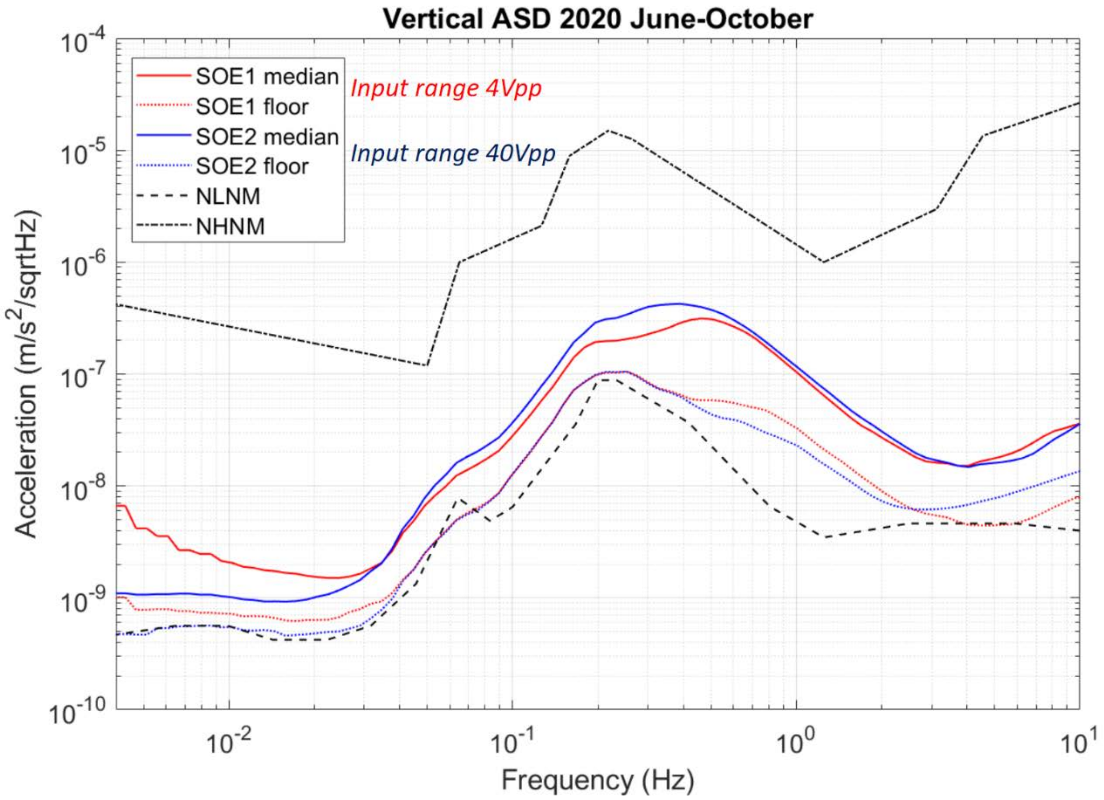
Suspension point 30 mHz IP

$10^{-13}\ m\ Hz^{-1/2}$ at 2 Hz

Mirror

$2\ 10^{-22}\ Hz^{-1/2}$ at 2 Hz

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



Required attenuation: $A=10^{-5}$ including marionetta and mirror

Virgo Seismic levels

Cascina

$3\ 10^{-9}$ m $Hz^{-1/2}$ at 6 Hz

Suspension point

$7.5\ 10^{-14}$ m $Hz^{-1/2}$ at 6 Hz

Mirror

10^{-22} $Hz^{-1/2}$ at 6 Hz (ET Scenario 1)
$1.5\ 10^{-19}$ m $Hz^{-1/2}$ at 6 Hz
$9\ 10^{-19}$ m $Hz^{-1/2}$ at 6 Hz for PR or SR (70/450 finesse ratio)

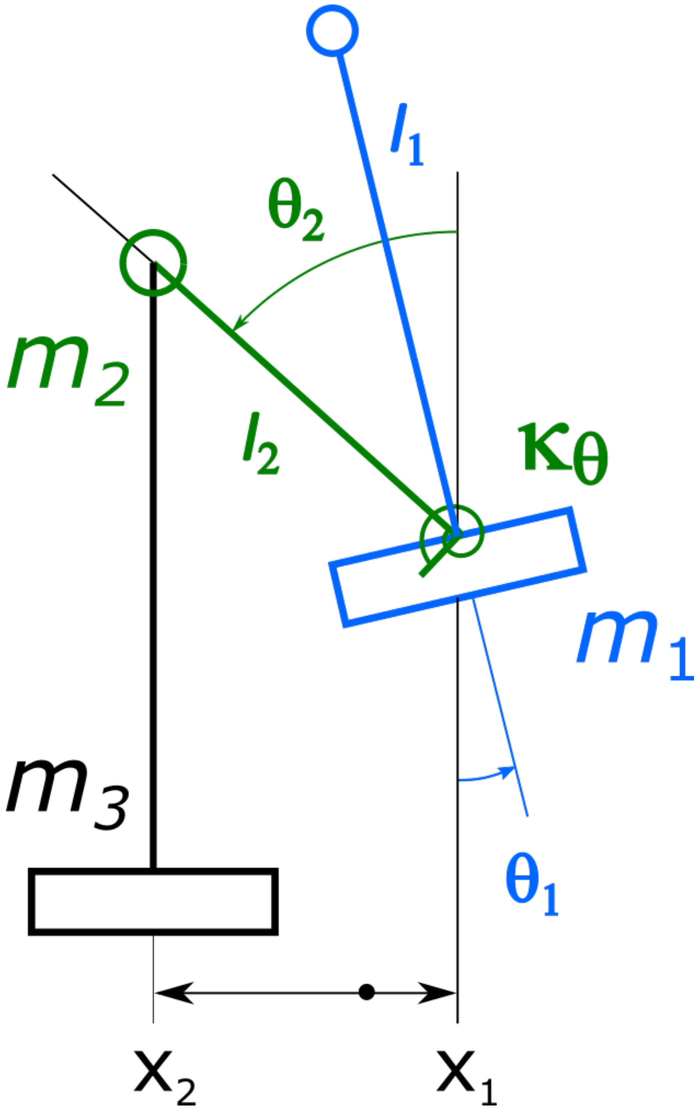
Attenuation: $A=10^{-5}$ including marionetta and mirror

Pendulum – Inverted pendulum

How to soften a suspension stage

- Spare length
- For κ_θ sufficiently stiff, the system is stable

```
• l1:  1.544, # Pendulum length\
• l2:  0.520, # IP length\
• T1: 2551.0, # Pendulum tension\
• T2: 1766.0, # IP compression\
• m1:   80.0, # Pendulum mass\
• m2:   80.0, # Filter mass\
• m3:  100.0, # Load\
• I1s:  20.0, # Pendulum moment of inertia \
• I2s:   0.8, # IP moment of inertia\
• k:  1700.0, # flex joint elastic constant\
```



Normal mode frequencies
0.68 Hz 0.74 Hz

Attenuation of Pendulum-Inverted Pendulum

Horizontal attenuation of a single PIP

$$A = \left(\frac{f_0^2}{f^2 - f_0^2}\right)^2$$

For f_0 = 0.75 Hz

A_2 : attenuation at 2 / 6 Hz — $2.7\ 10^{-2}$ / $2.5\ 10^{-4}$

Two PIP

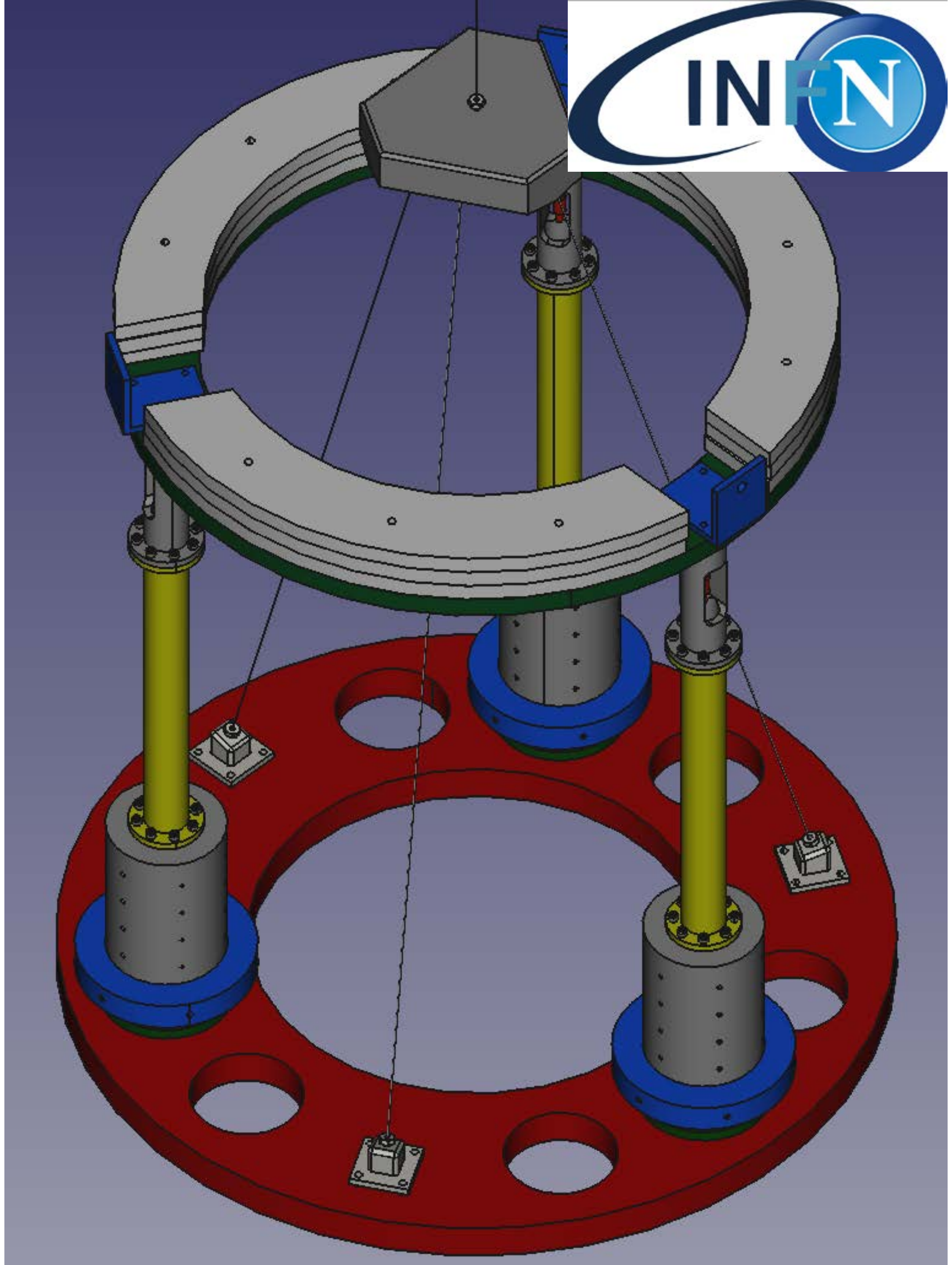
A_2 : attenuation at 2 / 6 Hz — $7.2\ 10^{-4}$ / $6.3\ 10^{-8}$

Three PIP

A_2 : attenuation at 2 / 6 Hz — $1.9\ 10^{-5}$ / $1.6\ 10^{-11}$

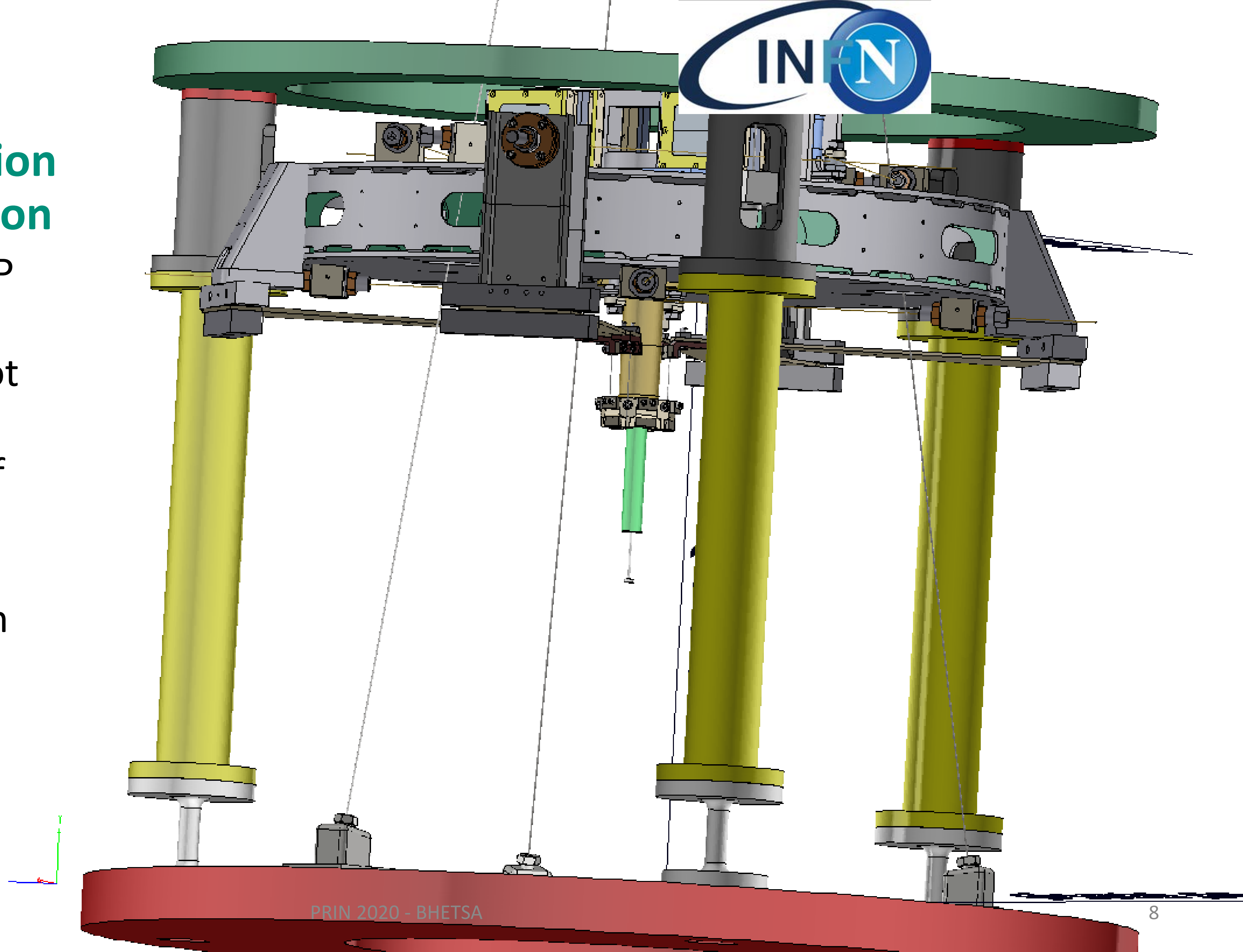
Basic structure

Explicit coupling of pendulum and roll DOF



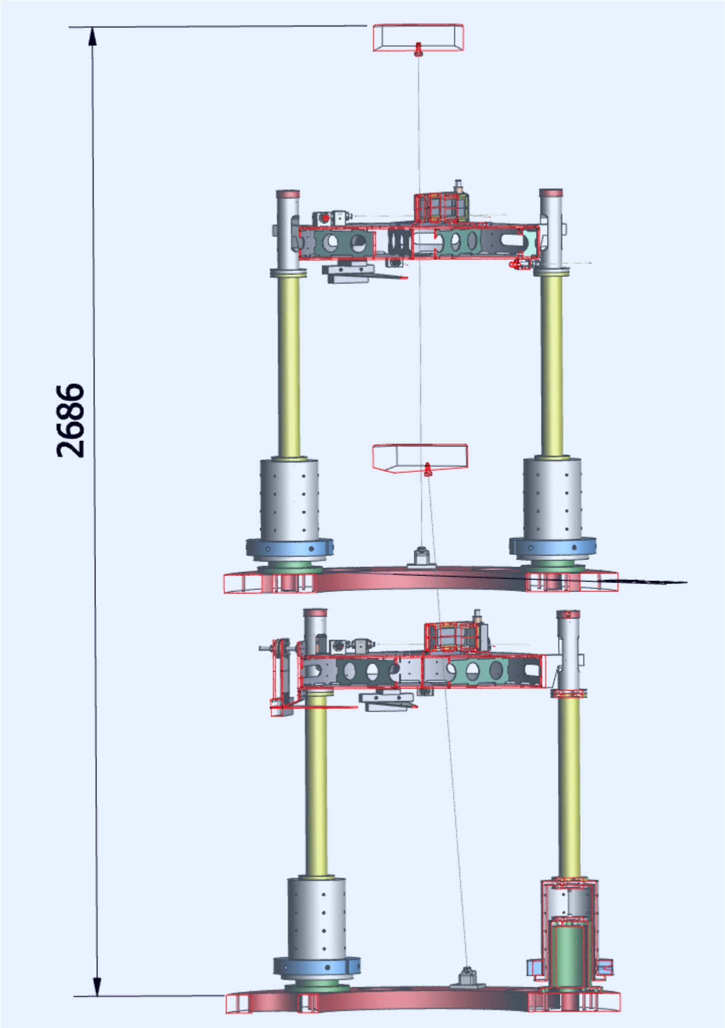
Standard filter addition for vertical attenuation

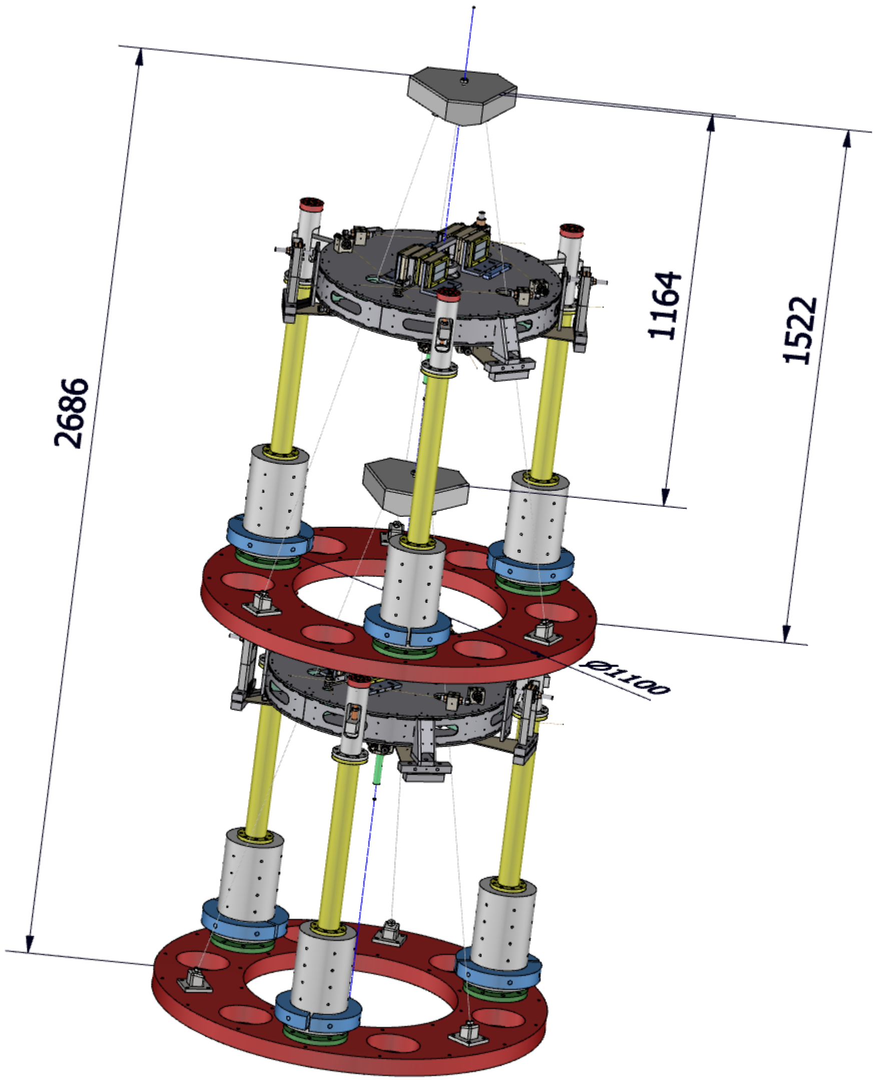
- Filter suspended to IP legs
- IP counterweights not represented
- Includes one stage of vertical attenuation
- Hook to next stage above first pendulum mass



e-PIP

- **Entangled PIP**
- **Four filters in 2.70 m**



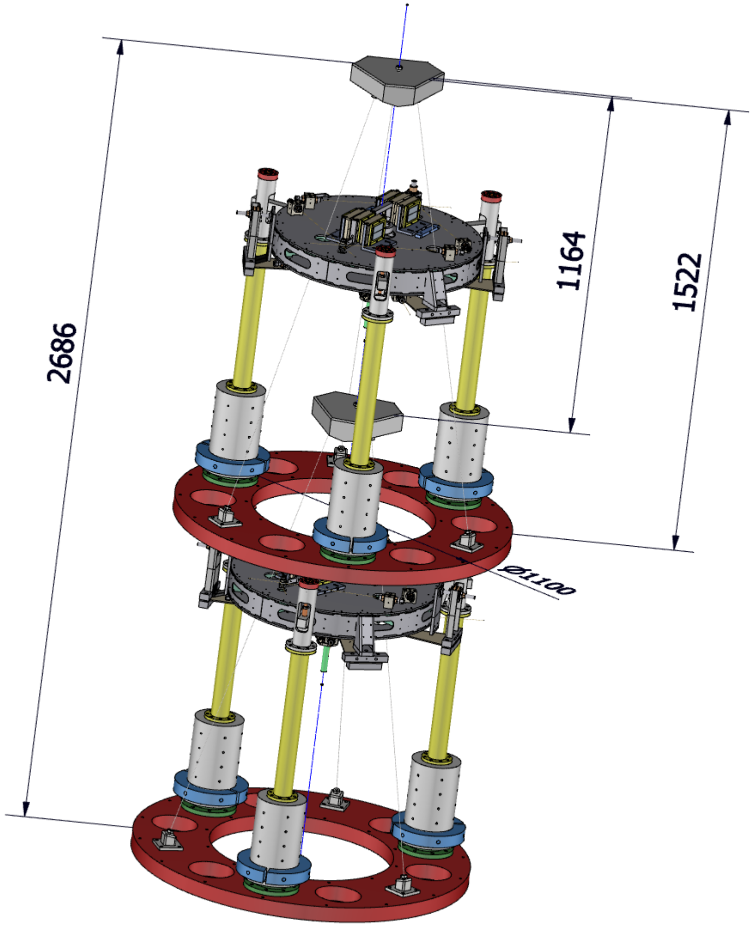


Overall length

- **A PIP chain can be built**
  - Hook of the second PIP above the first filter
  - Current PIP length 1.55 m
  - Two PIP can live in 2.70 + 0.30 = 3.0 m accounting for a dedicated vertical attenuation stage
  - Three PIP can live in 4 m
  - Proximity of different stages allows feedback control of normal modes, where sensor noise is not dominant (em or optical sensors like HoQI)

Suspensions for SRC mirrors

- **Requirement on seismic isolation met with 1 IP and 2 PIP.**
- **Height of suspension point wrt mirror**
  - Mirror: 0.7 m, marionetta: 1.0 m, 2 PIP hooks: 2.2
- **Seismic isolation for stable recycling cavity mirrors could fit in 4 m from mirror center to suspension point**



Simulation needs: OctoPYus Python package

- **Package overview**
  - MATLAB version developed by Paolo Ruggi
  - To be hosted on Gitlab
  - Now private repo, at some point public
  - Available for developers (via git)
  - Available for end users (via PIP, only on gitlab Package Registry, then move to Python Package Index
- **Structure**
  - Creation of configuration via GUI
  - Configuration saved to JSON format
  - Network solving to include feedback loops
  - Calculation of transmission matrices
  - Calculation of Transfer Function
- **Python scripts to iterate on parameters for optimization (see poster # 72)**

Suspensions for Virgo mirrors

- **PIP designed to fit into the Virgo towers**
- **VIRGO_nEXT calls for a low thermal noise payload -> additional low dissipation filter above marionetta**
- **Seismic isolation should be shortened**

- **2 – 3 PIP easily fit in the Virgo towers. R&D for VIRGO_nEXT proposed**

- **Progress in vertical attenuation to be included**

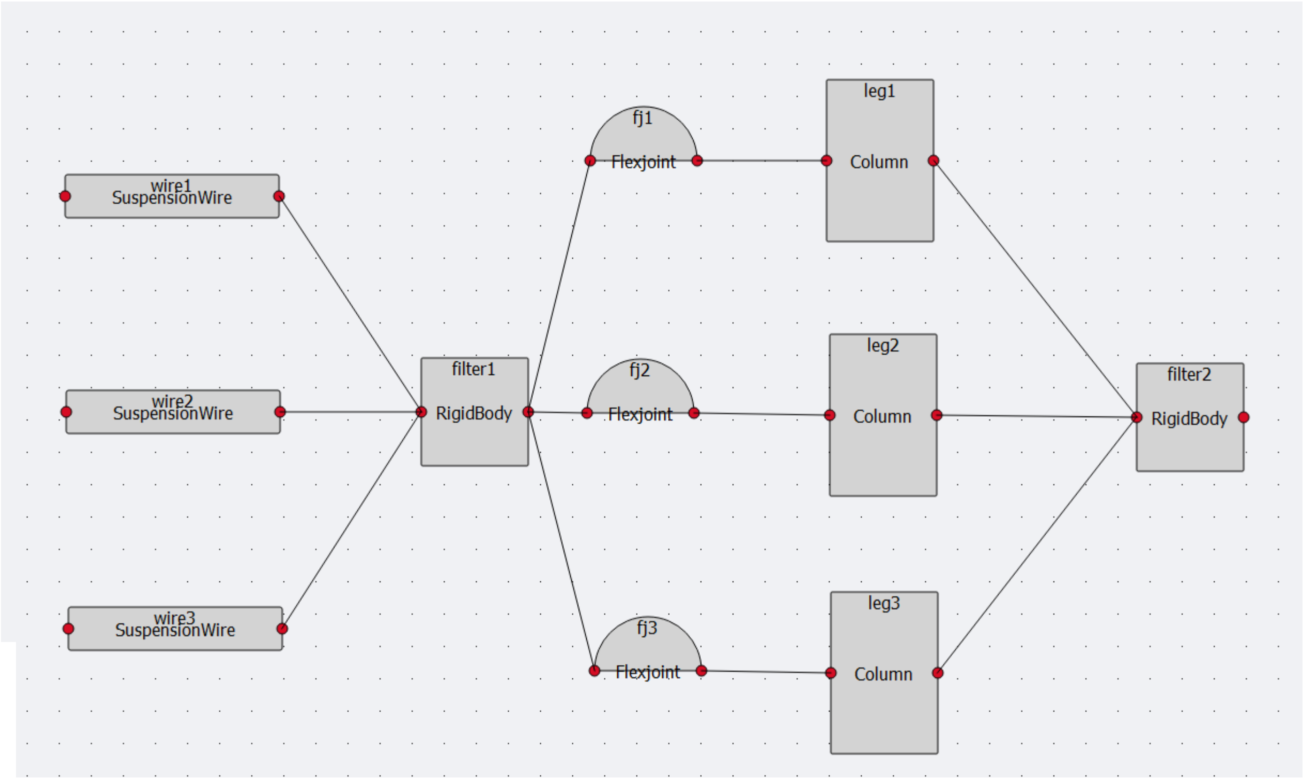
OctoPYus development

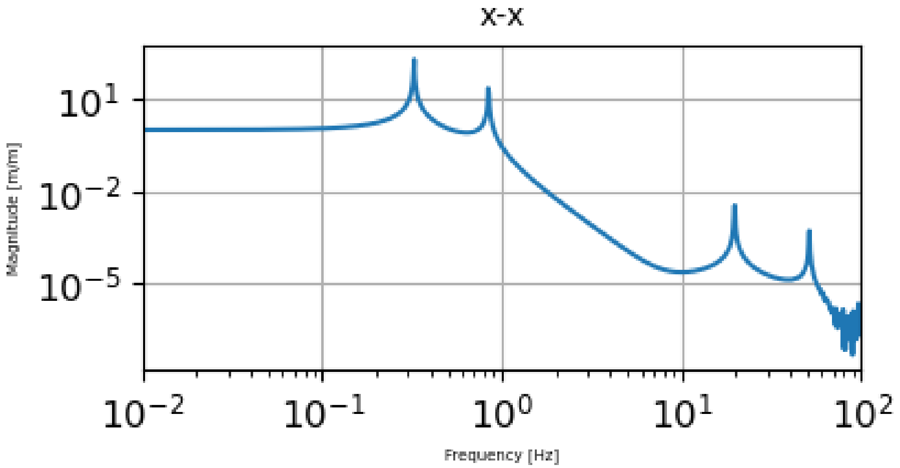
- **Main Features**
  - Python (should be easy and multi-platform)
  - Make it available for public usage (later on in the BHETSA life)

- **Development point of view**
  - Implemented automatic documentation via Sphinx
  - Implemented Pipelines for Continuous Integrationx
  - Unittest for testing pieces of code
  - Move to public platforms (Readthedocs and Python Package Index)
  - Test against different versions of Python3
  - Implement for usage with multi platform (Windows, MacOS2)
  - Integrating new features (e.g. NetSolver class)

Test case: schematic PIP

- **PIP**
  - Resonances @0.2 Hz (pend) and 0.8 (IP)
  - attenuation $1/f^4$





L. Massaro Master thesis

Coding progress

- **General structure**
  - Pipelines done
  - Switch to public repo/documentation/package index when ready

- **Package development**
  - Test with multi platform
  - Finalize GUI
  - Implement basic configurations as test cases
  - Integrate network solver (already in Gitlab, merge done, test integration)

Perspective

- **PIP Prototype construction**
  - Principle verification vs simulations
  - Engineering verifications
  - Assembly
- **Design optimization**
- **Proposal for a short seismic attenuation chain for ET**
- **Proposal for a shorter seismic attenuation chain for Virgo mirrors**
- **Proposal for a compact suspension for SRC mirrors**

Collaboration welcome!

Posters

- **#72 OctoPyus: a package to simulate seismic isolation systems for the third-generation Gravitational Wave detectors M. Razzano**
- **#100 The statics of the maraging blades in SuperAttenuators: simulation and tests P. Chessa**
- **#79 The Gravitational Wave Sky Simulator: a new package for fast simulations of gravitational wave sources L. Papalini**
- **#81 Machine learning for glitches classification in Advanced Virgo O3 M. Vacatello**
- **#82 Gravitational Wave Data Manager – A Python package for managing multichannel gravitational wave data M.A. Palaia**

Virgo seismic levels

- **Seism parametrization**
- $x(f) = 10^{-7} m\, Hz^{-1/2} \left(\frac{1\, Hz}{f}\right)^2$, **at 6 Hz** $3 \cdot 10^{-9} m\, Hz^{-1/2}$
- **One 30 mHz IP attenuates**
  - $2.5 \cdot 10^{-5}\, \tilde{x} = 7.5 \cdot 10^{-14} m\, Hz^{-1/2}$
- **ET scenario 1 at 6 Hz as ultimate Virgo_nEXT**
  - $h = 10^{-22} Hz^{-1/2}$
  - $\tilde{x} = 1.5 \cdot 10^{-19} m\, Hz^{-1/2}$ for a single test mass
  - $\tilde{x} = 9 \cdot 10^{-19} m\, Hz^{-1/2}$ for PR or SR (70/450 finesse ratio)
- **Total attenuation 10^{-5} including pendulum (10^{-2}) -> 10^{-4} required**