Type B seismic isolation tower specifications and some proposed solutions.

General dimensioning

The type B vacuum chambers shall be 1.5 m in diameter, shall have a beamline of 1.2 m above ground, have 1 m diameter inline vacuum flanges, suspend 250 mm diameter mirrors 100 mm thick (ex-LIGO) for the three recycler units and a 380 mm diameter 120 mm thick beam splitter.

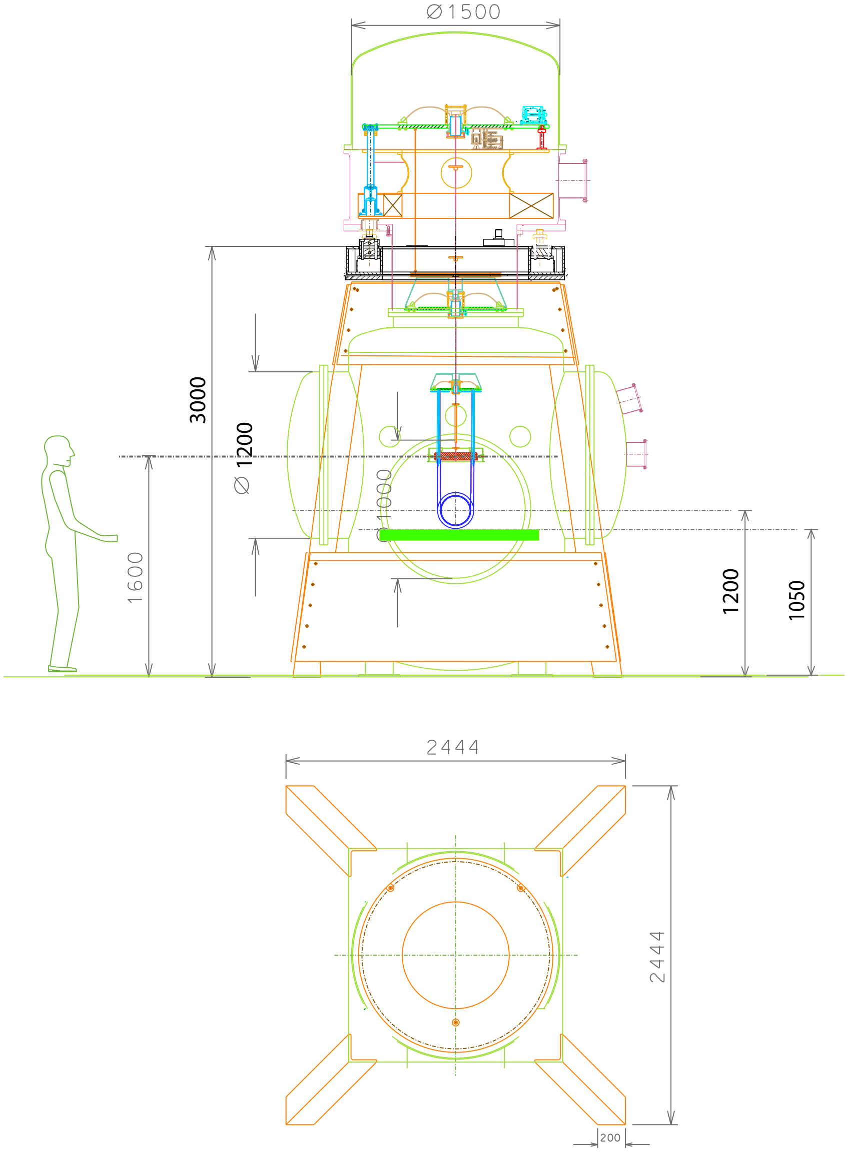


Figure: sketch of the type B seismic attenuator.

The mechanical structure will be built to use the same standardized components of the type-A chains (standard filter, top filter, Inverted pendulum, leveling structure, vacuum dome) and to offer the same facilities (remote control alignments, remote fine positioning, mode damping) designed for speedy interferometer commissioning.

Seismic attenuation requirements

The payload shall be formed by a double pendulum stage.
The payload shall be isolated by two seismic attenuation stages.

The recycler mirror Payload requirements.

In the recycler version of the type-B seismic attenuation tower, due to the vicinity of folded and ghost beams, the mirror recoil mass must be hidden behind the mirror profile.

Additionally, because at the transmitted beam of PR2 and SR2 need to be collected for monitoring reasons, the recoil mass needs to have a minimum central clearance of 6 sigmas = 4*6 = 24 radius. We chose a central clearance of 100 mm diameter. The conceptual mirror-recoil mass design will be an "inline" geometry like the one sketched below.

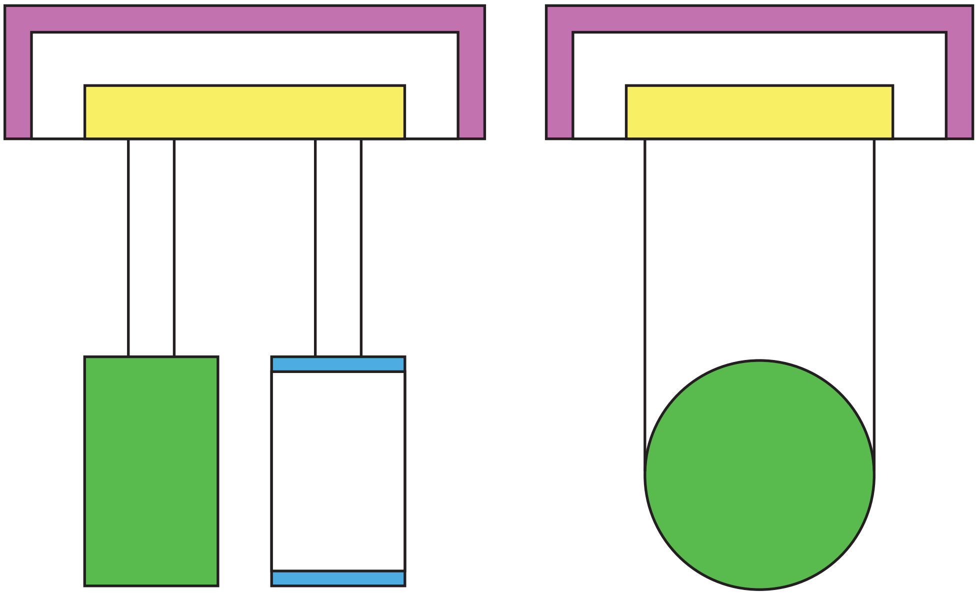


Figure: In-line geometry of the recycler mirrors. Side and front view.
At least 5 cm clearance is required to make space for the OSEMs that control the mirror (green) and the intermediate mass (yellow). In the test masses no electrically conducing plane or body should be closer than 5-6 diameters from any control coil (Virgo had to re-do their marionettas for this reason). It is not clear how much this constraint can be released for the recycler mirrors.

To minimize translation-tilt coupling, it is likely advantageous to mount the mirror in axis with the suspension wire, with the recoil mass sitting behind, balanced by a forward ballast mass on the intermediate mass. Not too much extra mass will be needed because the recoil mass will be lighter than the mirror.

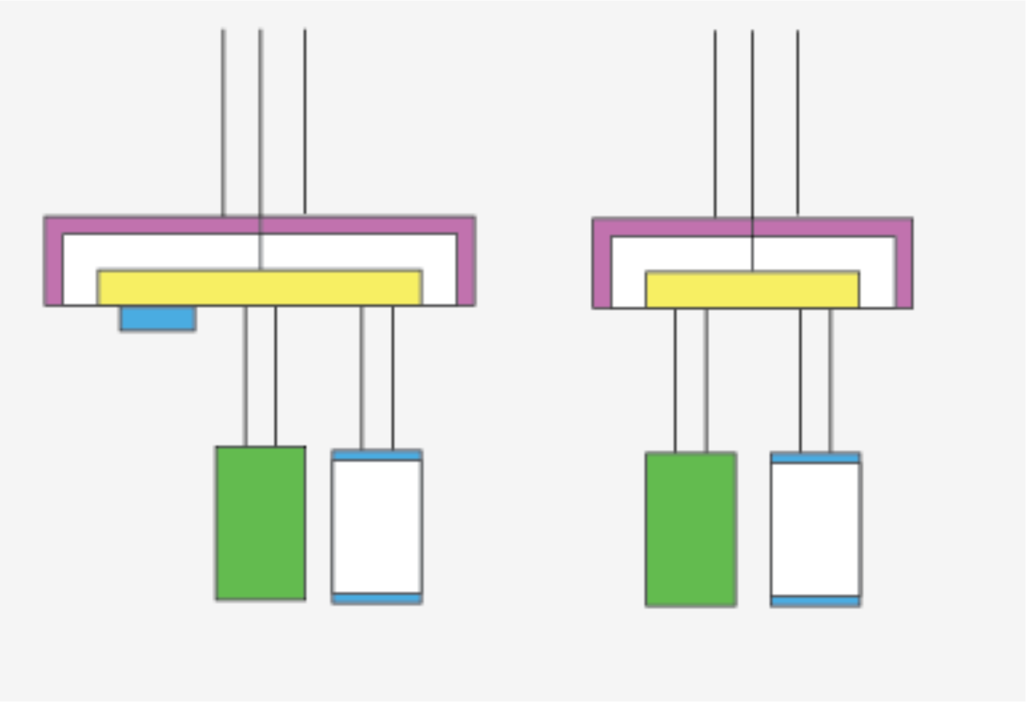
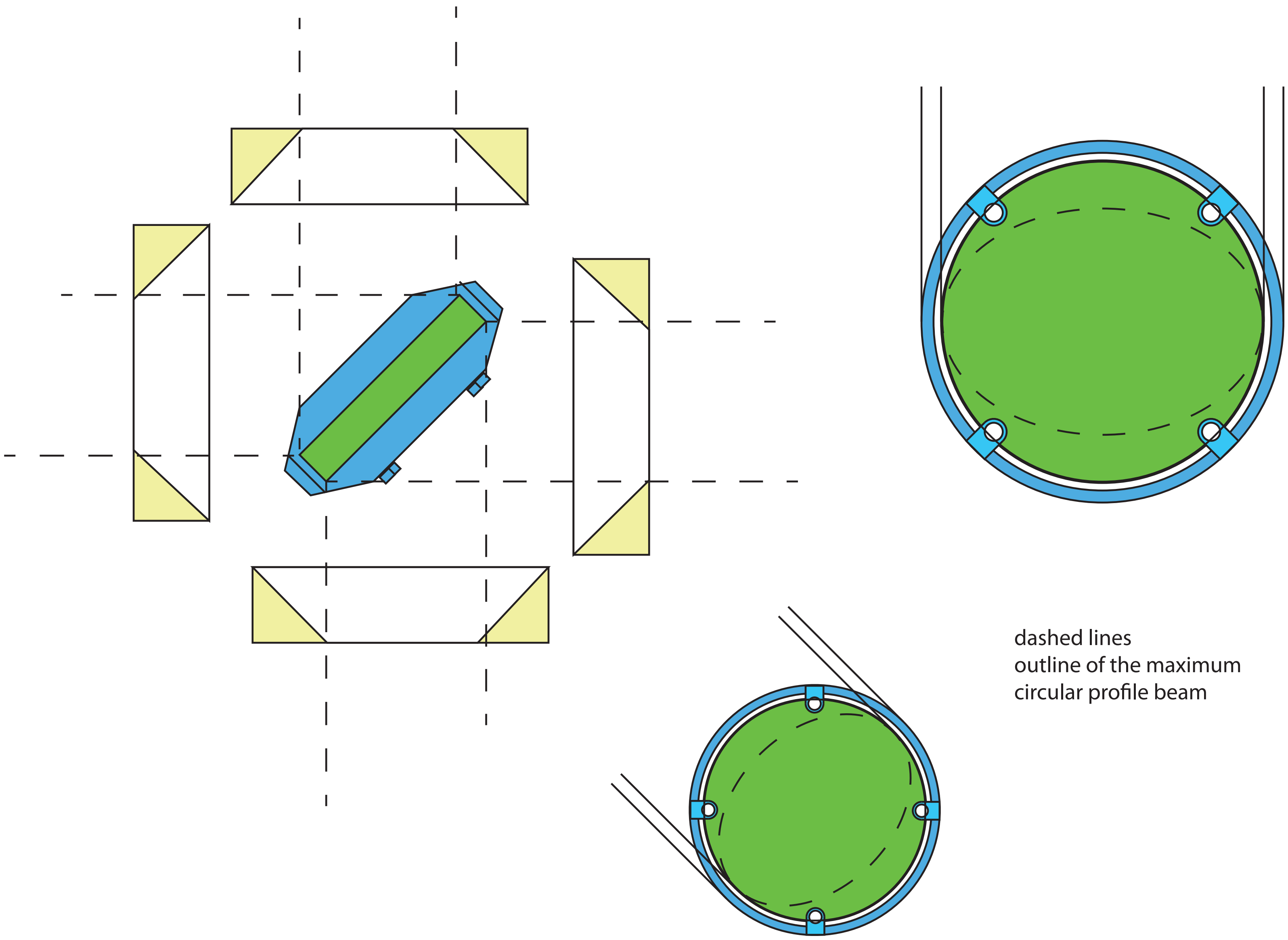


Figure: Two options to choose from for the recycler mirror controls.
On the left the mirror sits at the center, with its recoil mass behind, and a ballast mass in front of the intermediate mass. In this configuration the suspension vertical degree of freedom does not mix with the mirror tilt mode
On the right a similar geometry with the mirror on one side and its recoil mass on the other of the suspension point .

Beam splitter payload requirements

The recoil mass of the beam splitter has to be concentric to the mirror and clear the view on al four sides. A possible beam splitter/recoil mass configuration is sketched below.

Figure: Beam splitter reaction mass configuration.
The four beam limiting suspended baffles are shown as well.



dashed lines
outline of the maximum
circular profile beam

Access and pickoff beam requirements

The vacuum chamber will have 1.2 m diameter side flanges for access.
Three 150 mm viewports shall be located above the beampipe, to route monitor beams and for observations. Additional viewports can be added at a later time on the side doors, if need arises. Unlike the forward and backward looking viewport, which need to be above the beamline, these viewport may be at the beamline level.

Longitudinal and lateral separation requirements.

The largest offset between type B towers (i.e. between PRM and PR3 and SRM and SR3) will be 260 mm while their minimal longitudinal separation will be 2360 mm. This will produce a non negligible jog between PRM and PR3 and between SRM and SR3

A study on three ways how to do the job is shown below:

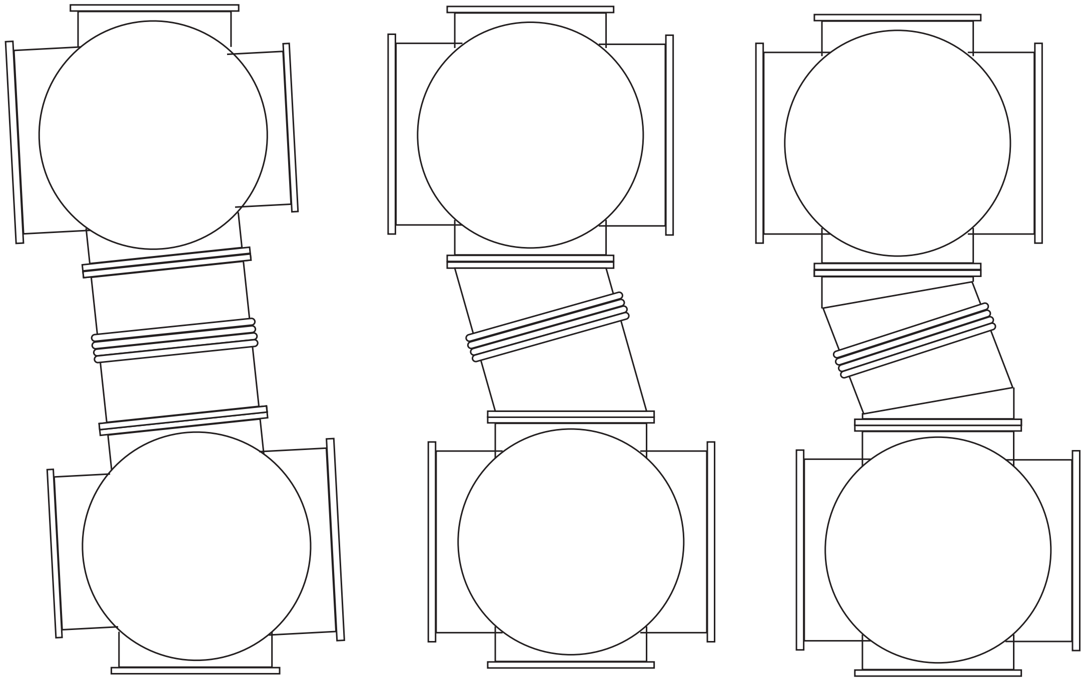


Figure: Three options to achive te dogleg between PRM and PR2.
In the case on the left, the beamline flanges have been rotated, one by plus and one by minus three degrees.
In the two cases on the right the flanges of the towers are kept straight and the dogleg lateral shift is obtained with shaped spools of different type.
In the first case the tressle structure holding the IP pre-isolator will have to be wider to account for the shifted space between the flanges. Additionally the access port on the “inside” side has been reduced from 1200 to 1000 mm diameter.
A choice between these options have to be made before designing the tressle structure.

Longitudinal tuning requirements

To match the requirement of the radiofrequency sidebands, all towers must be moveable along the beamline by 500 mm.

Seismically isolated optical bench specifications.

The vacuum chamber must house a seismically isolated optical bench, 150 mm below the beamline carrying relay mirrors for the pickoff beams and auxiliary optics.

At least two stages of seismic isolation are required.

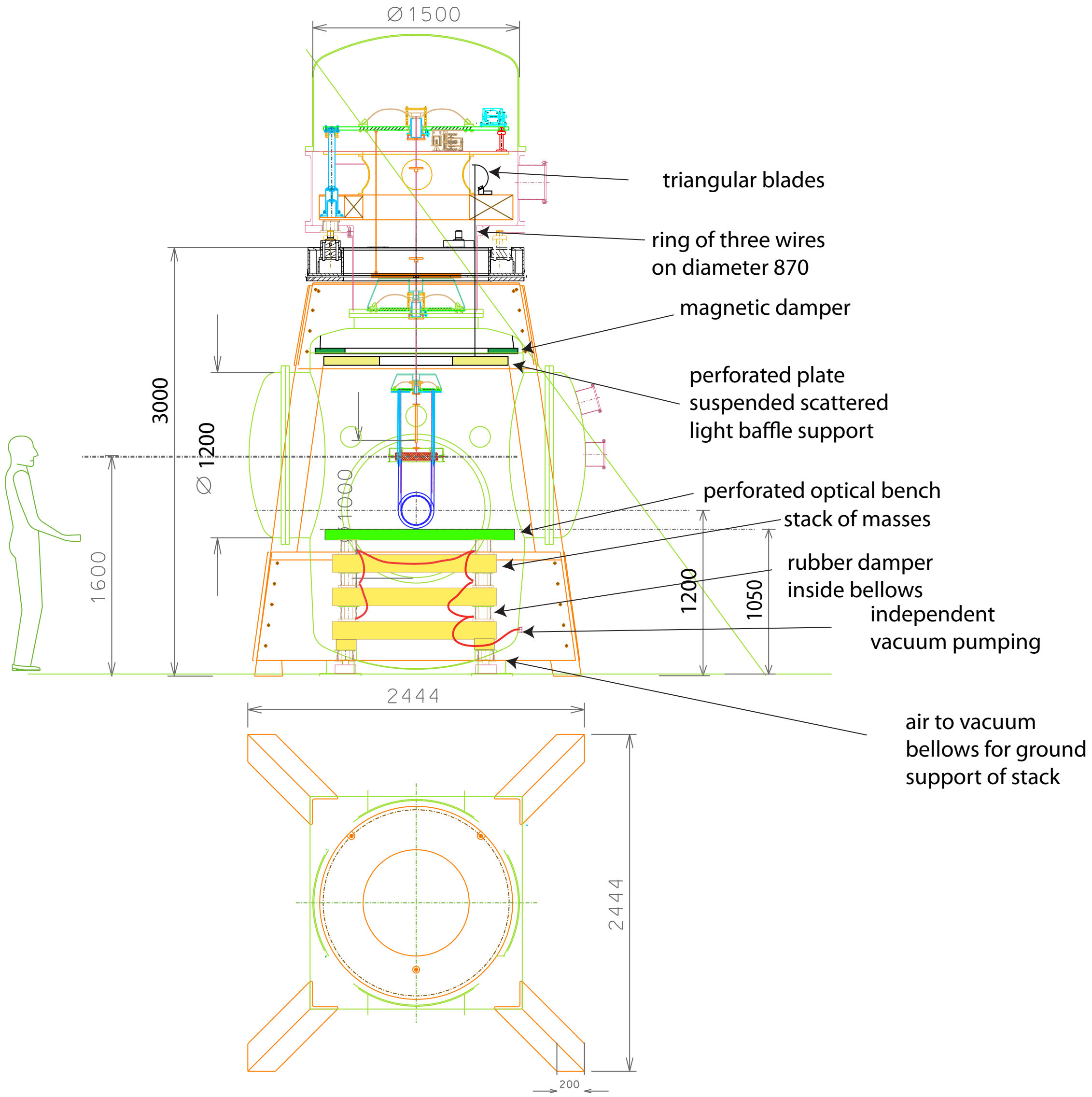
Provisions must be made for suspending seismically isolated baffles for safe scattered light dumping. These baffles may be suspended from the chamber's ceiling.

Two options are illustrated and compared.

The first option is a bench on stacks of rubbery supports, and a suspended bench. The stack option requires three bellows at the bottom of the vacuum chamber, to allow anchoring the stack to ground (it is obvious that the stack cannot reside on the bottom). For outgassing reason the rubber blocks would have to be enclosed in independently vacuumed metal bellows. A minimum of 6 bellows (for a two stage stack) or 9 bellows (for a three stage stack) would be required.
Two or three stainless steel plates would be used as intermediate masses.

The second option is an optical bench suspended from cantilever springs and wires. Three springs mounted on the IP base structure support an intermediate ring, which is also the support for scattered light baffles. The intermediate ring modes, similarly to filter 1, are damped by a magnet plate. Four more cantilever springs, mounted below the intermediate ring, would support the optical bench through four wires. A four wire configuration is chosen to place the wires out of the way, in the corners between the beam pipes and the access doors. The modes of this structure would be efficiently damped by strengthening the magnetic damper of the baffle support.

Note that the intermediate ring, or an equivalent structure, would be needed in both the stack or suspended solution, to suspend the scattered light baffles.



First solution: optical bench on stacks.

Comparison:

Complexity:

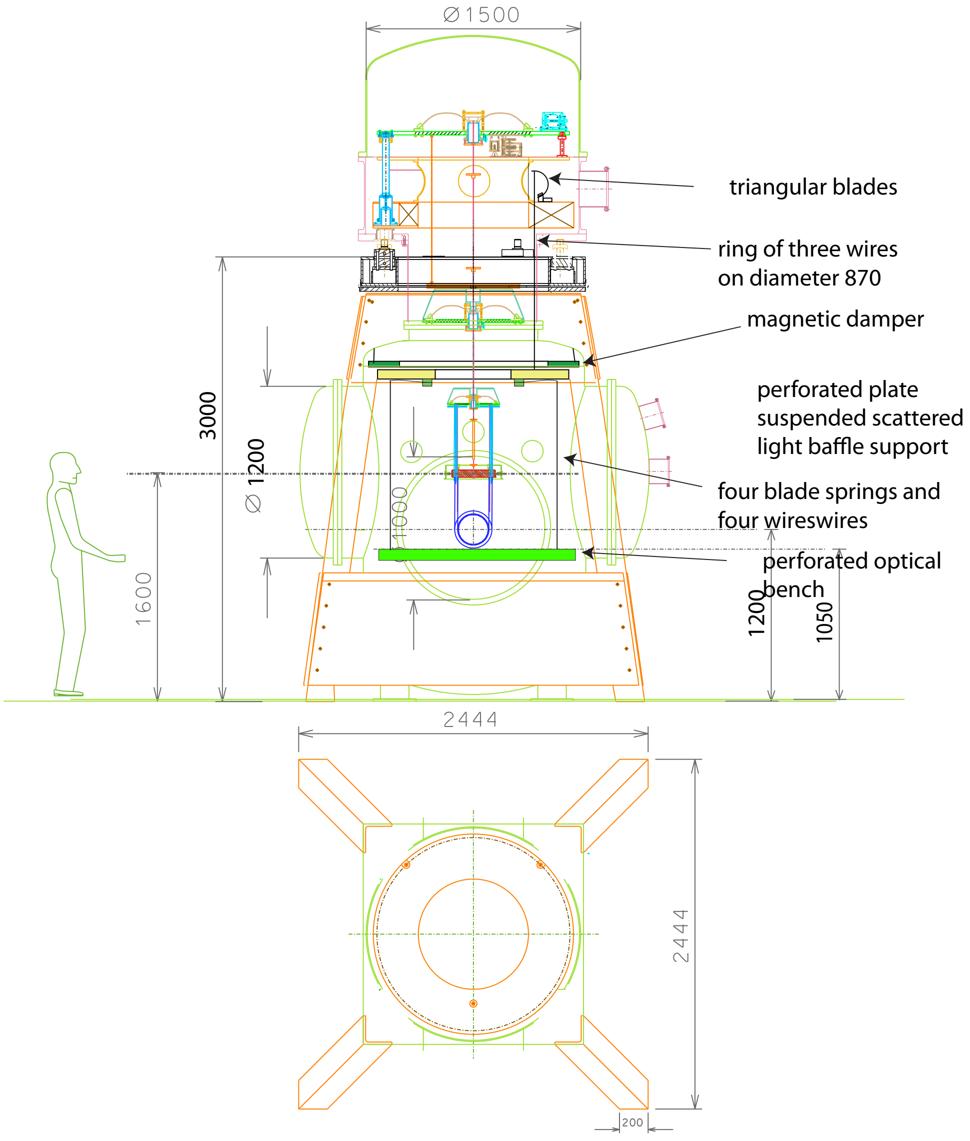
1. The suspended solution requires
   - Four cantilever blades and
   - Four wires, with leveling achieved with turnbuckles acting on the wires.

2. The stack solution requires:
   - three air to vacuum baffles, with tuneable height to level the stack,
   - six to 9 vacuum to vacuum bellows, with soft independent vacuum piping
   - two to three intermediate masses

- additional vacuum penetration for independent bellow vacuuming

Stability:

- The suspended solution is subject to blade's creep, which using maraging springs is negligible and well under control.
- The rubber support of the stacks are subjected to long term flow, as an example the initial LIGO stacks, which had only a small fraction of elastomer, and are mainly metal springs, suffered creep of the order of the millimeter and tilting for about one year.



Second solution: suspended optical bench.

Cost:

- Ready to use blades and suspension wires cost 20 to 30 k¥ each. If the cost of the baffle support ring and of the optical bench (which are in common to both solutions) are not taken into account, the total cost is ~ 200 k¥ per bench.
- Bellows cost of the order of 40 k¥ each, counting 12 bellows it makes 480 k¥. For in-vacuum tubing we assume 30 k¥, and 45 k¥ for three additional conflate flanges at the base of the vacuum tank. Assuming 1.2 m diameter, 5 cm thick intermediate stainless steel plates, it makes 400 kg each (not counting waste), counting 350 ¥/kg it makes 140 k¥ which for 3 plates is 420 k¥ for material only. For the independent vacuum pumping system we assumed 500 k¥. The total (also not accounting common parts) is ~ 1.5 M¥ per optical bench.

The price differential is at least ~ 1.3 M¥ per type-B system, ~9 M¥ for the 7 units.

Performance:
The suspended solution would undoubtedly have better performance than the two level stack solution. The three level stack solution would have a steeper attenuation curve ($1/f^6$ instead of $1/f^4$) but its attenuation curve would start at higher frequency. For most practical purposes the performance would be roughly equally satisfactory.

Weight:
The stack option weights about 1 ton more for each type 2 system.

Risk:

- The suspended solution has practically no additional risks
- The stack solution has several additional vacuum bellows and seals, each of them can cause leaks, that in the case of the rubber support bellows may be difficult to locate and fix.

Convenience:
One of the requirements is that the type-B seismic attenuators can be moved along the beam line.
There are two kinds of footing, the vacuum chamber footing, for which only structural integrity under shear stress is required, and the optical load footing, for which high flatness and high rigidity are required, but not high mechanical integrity under shear stress. The vacuum tank footing have to sustain the multi-ton asymmetric stress that happens if a gate valve is closed and vacuum is vented on one side. The seismic footings, instead, are subject to only vertical load.

- The suspended option is entirely supported on the four feet of the external structure while the vacuum chamber feet are all at a smaller distance from the center. Therefore the location change can be achieved by sliding the four external structure feet on two smooth rails solidly buried in the concrete floor, while the vacuum chamber feet would ride and hook on 2 separate rails.

- The stack option necessitates three additional high rigidity feet for the stacks. The positioning of the stack feet is within the vacuum chamber diameter and interferes with that of the vacuum chamber feet. One could solve the problem of changing position by mounting the feet in an hexagon and adding a third central rail at additional expense and at the cost of mounting both noisy vacuum tank and quiet seismic footing on the same rails, which would be subject to variable tilt when pumping vacuum.

While the suspended chain and optical bench can be secured against their earthquake stops during re-location, because of the stack feet alignment, it is not obvious that re-location can be done without stack disassembly.

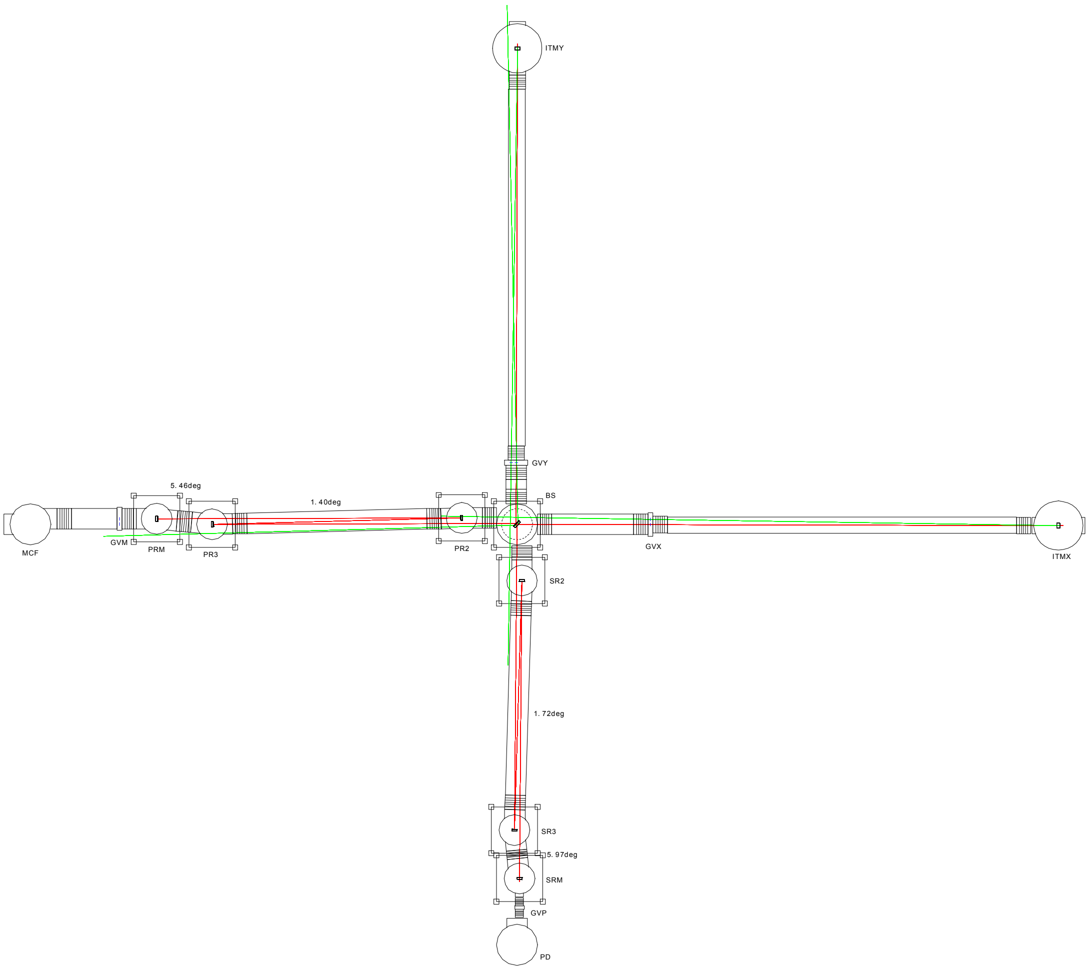
The vacuum tanks are presently not thought with full diameter flanges. This arrangement means that the stack would have to be implemented through the 1.2 m access flanges, with cantilever supports. This is already somewhat awkward for the optical bench. It would be four times as much and somewhat more complex for the stack elements that have to be lowered deeper into the vacuum chamber after feeding them through the side access port.
In alternative one could add 1.5 m diameter vacuum flanges at the top of the chambers for vertical installation, at a relatively large additional cost, and some extra vacuum leak risk.

The suspended option would use the same mechanical techniques (blades and wires) as the rest of the interferometer, while the stack option would use heterogeneous techniques (the addition of rubber dampers and vacuum flanges).

Comparison summary:
There appear to be no advantage in the use of the stack option.

Table 1 Position of the mirrors in the central station: The type-B attenuation towers are shown in blue

	X	Y
ITMX	126.414	49.895
ITMY	100.060	73.152
BS	100.042	49.958
PRM	82.490	50.220
PR2	97.349	50.260
PR3	85.187	49.962
SRM	100.165	32.696
SR2	100.282	47.215
SR3	99.918	35.057
MCF	76.342	49.958
PD	100.042	29.458
GVX	106.542	49.946
GVY	100.007	52.958
GVM	80.678	50.220
GVP	100.165	31.278



Fugure: beam layout