Study of point-like absorbing defects in large mirrors for gravitational wave detectors

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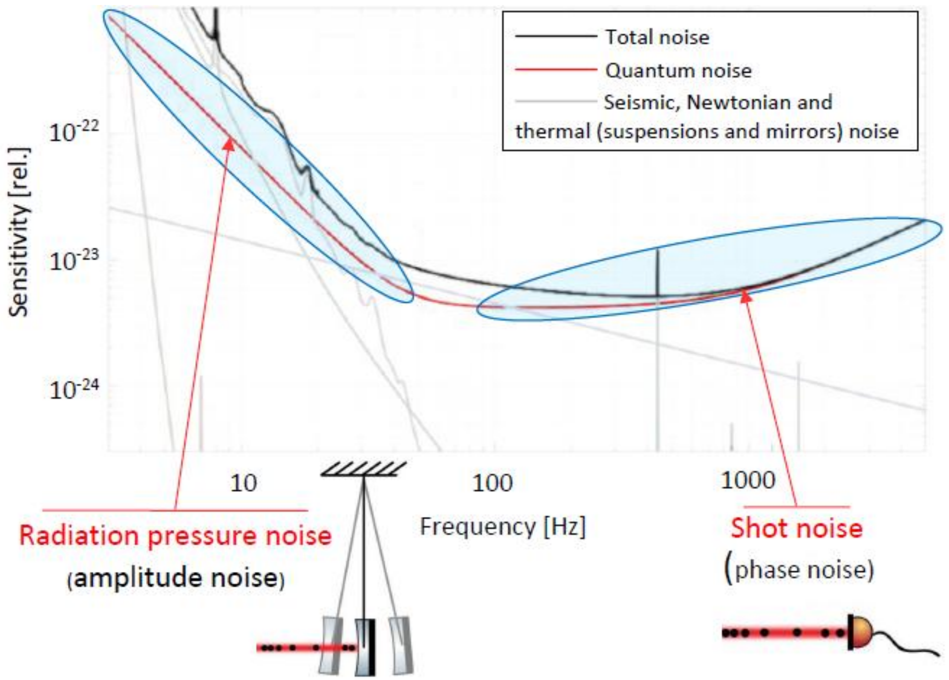
Increasing the circulating power



- Direct way to decrease shot noise
- Comes with drawback :
  - Wavefront distortion
  - Radiation pressure
- We have possibilities to counterbalance the drawback
  - Quantum Squeezing
  - Thermal compensation systems

- Virgo Attempts

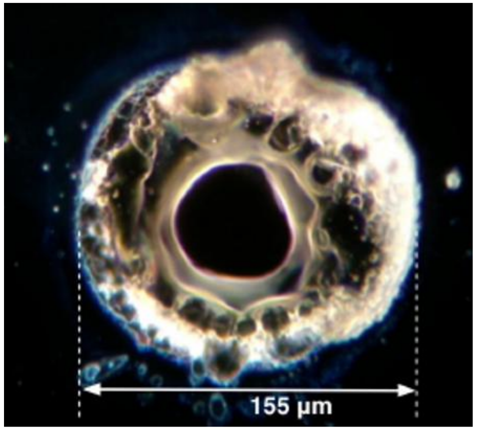
Period	Input Power
Aug 2017 (O2)	14W
Nov 2017	26W
Apr 2018 (After monolithic installation)	12W
Jul 2018 (Increased power)	25W
Nov 2018	18W

→ **Still problematic until now**

Increase of power attempts at O4

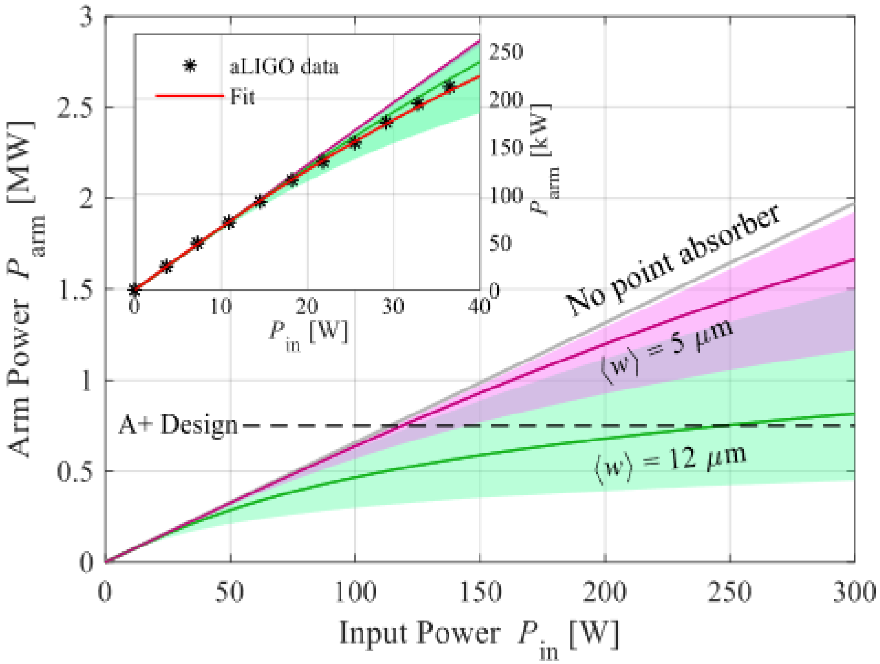
not completely succesfull

Point absorbers (PA)

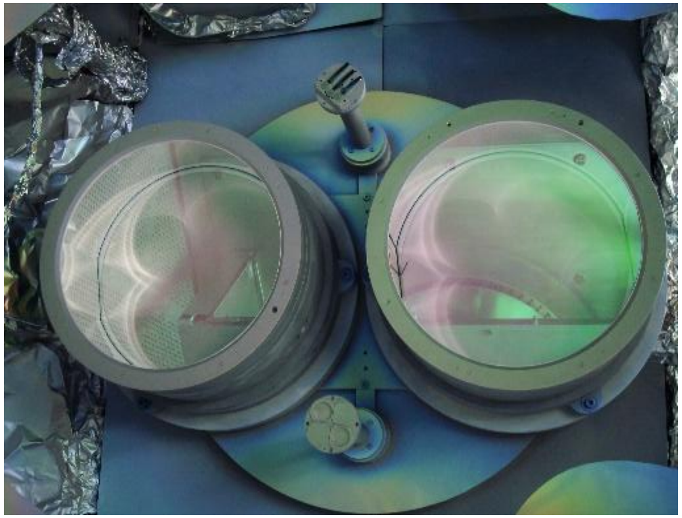


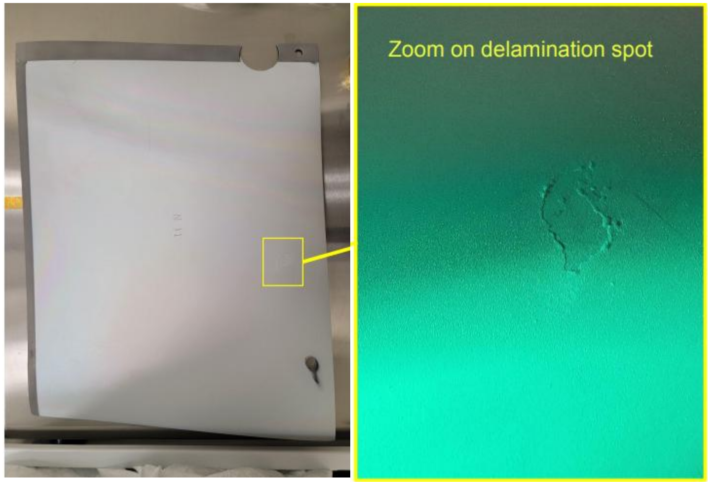
- A punctual site of excess absorption
- Wide range of diameters [10 – 500] µm
- Wide range of local absorption expected
- There can be several PA's per mirrors
  (2018 : LHO ITMY → « Constellation of PAs »)

- Generally of metallic nature (Al)
- The more power is in the ITF, the more problematic the PAs become -> limits improvements of the detectors
- Critical for arm cavity mirrors



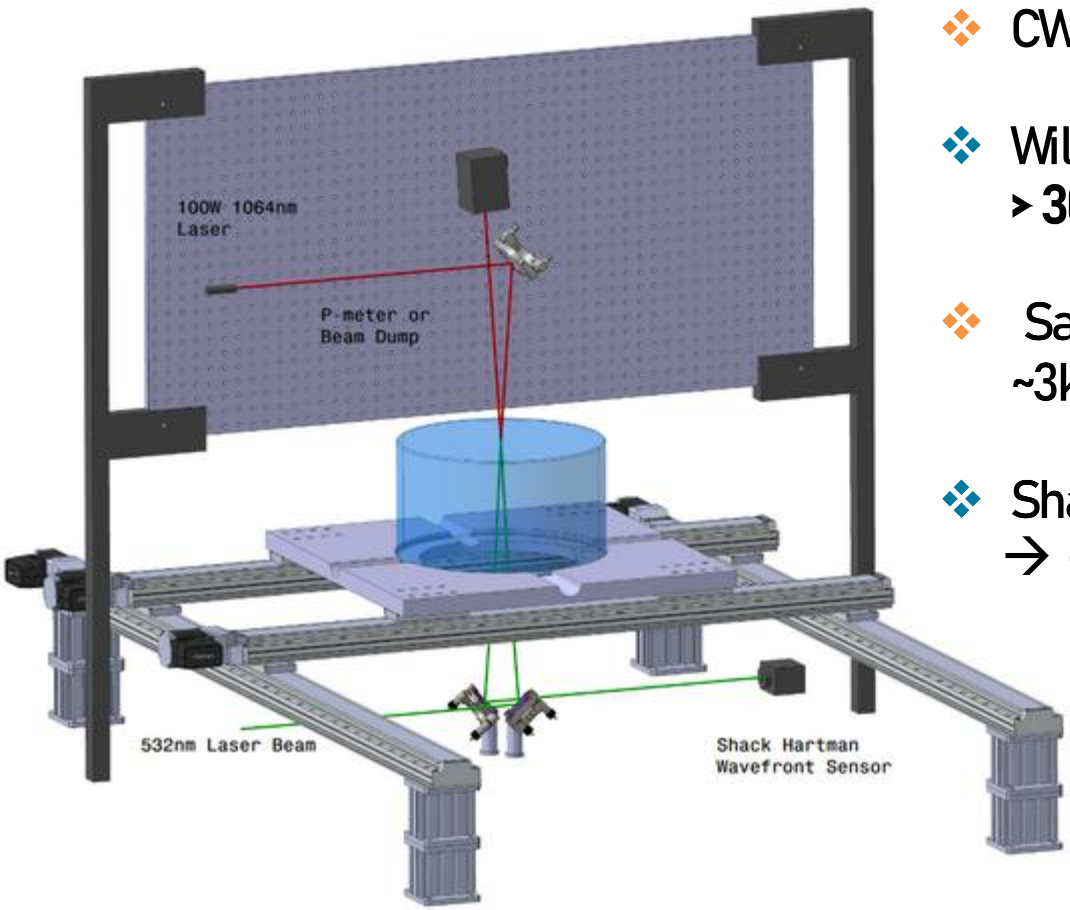
Detecting them at LMA





- Originate from deposition process
  - Embedded in the coating
  - Small particules from mounts, walls, protective sheets
- Detecting them before their installation in the ITF. (Corrective treatments, preparing compensations …)
- Virgo cannot detect PAs before mirror installation
- A joint study LIGO/LMA has already allowed to reduce the population of PA's
- Benefitial for other projects high optical power experiments

Expanding the Caltech bench (TM-HPAD) Test mass Hartman PA Diagnostic

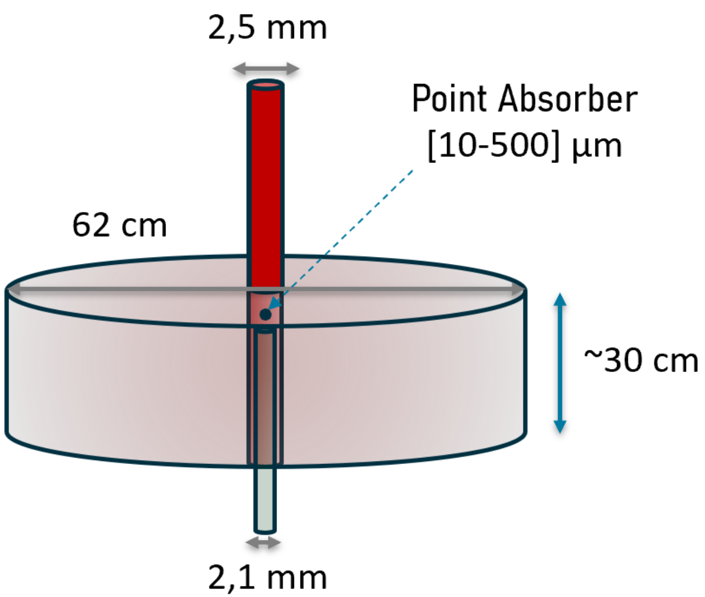


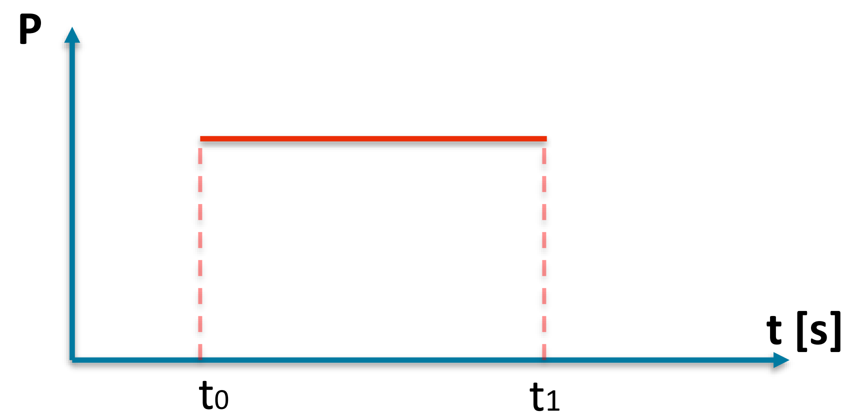
- CW laser at **1064 nm (200 W)**
- Will be able to holds **62 cm diameter and > 300kg test masses**
- Same **power density than in** AdV ~3kW/cm²
- Shack-Hartman wavefront sensitivity → (λ/100)

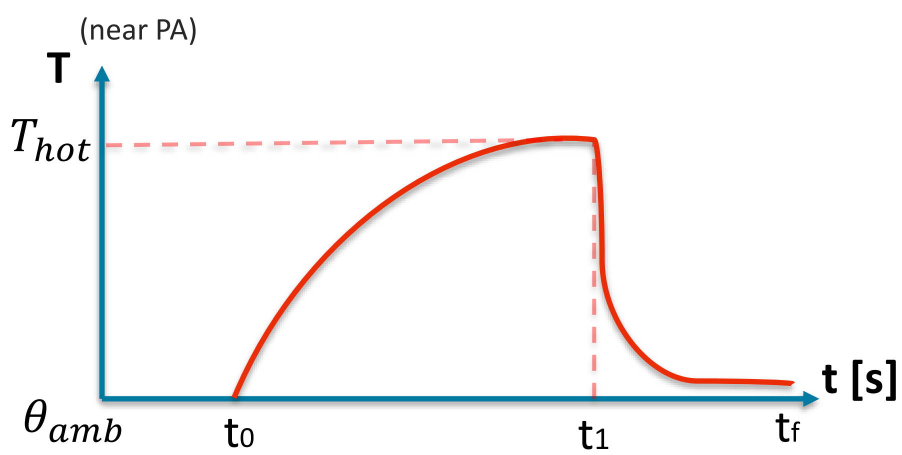
Bonus :

Scattering **measurement** with CCD camera

Principle scheme of measurement



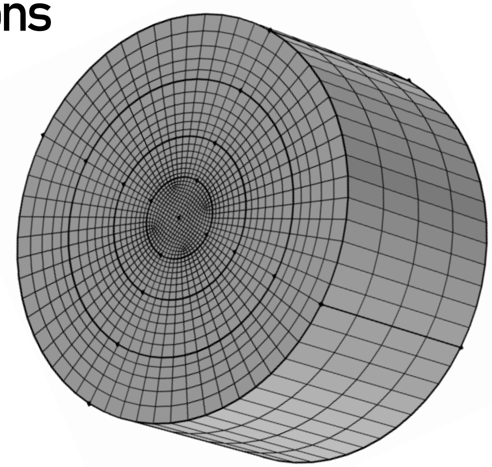




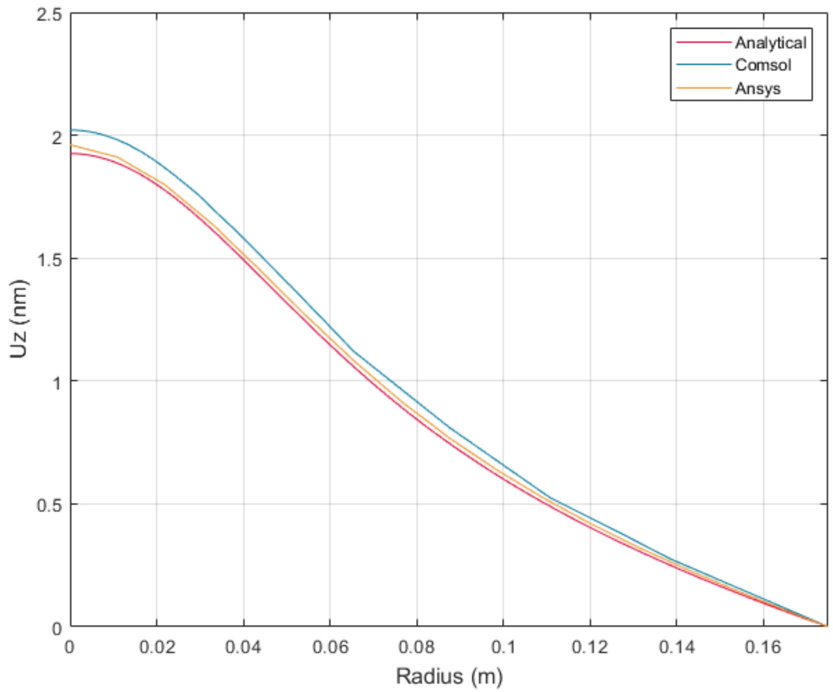
Numerical simulations

Finite element simulation (FEM)

- Discretization of the geometry and linearization of equations
- Finds approximate solutions for fields (T, u, θ_{ij}, …)
- Compute for stationary solution or transient evolution
- Point absorbers are simulated by declaring nodes as heat sources



→ Simulation of an AdV test mass in the ITF configuration



- Silica cylinder **ϕ = 35cm**
- Parameters from Suprasil material
- Incident Power **100kW** (AdV+)
- Uniform Absorption $\alpha =$ **0.2ppm**
- Below Shack-Hartman sensitivity
- **Stationnary solution**

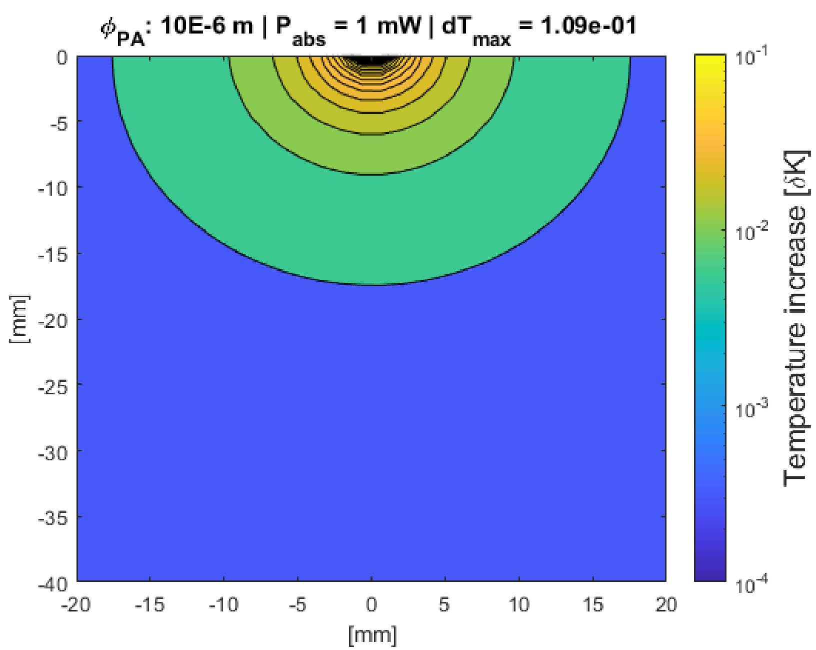
Results on uniform absorption are convincing enough to use COMSOL model to simulate point absorbers

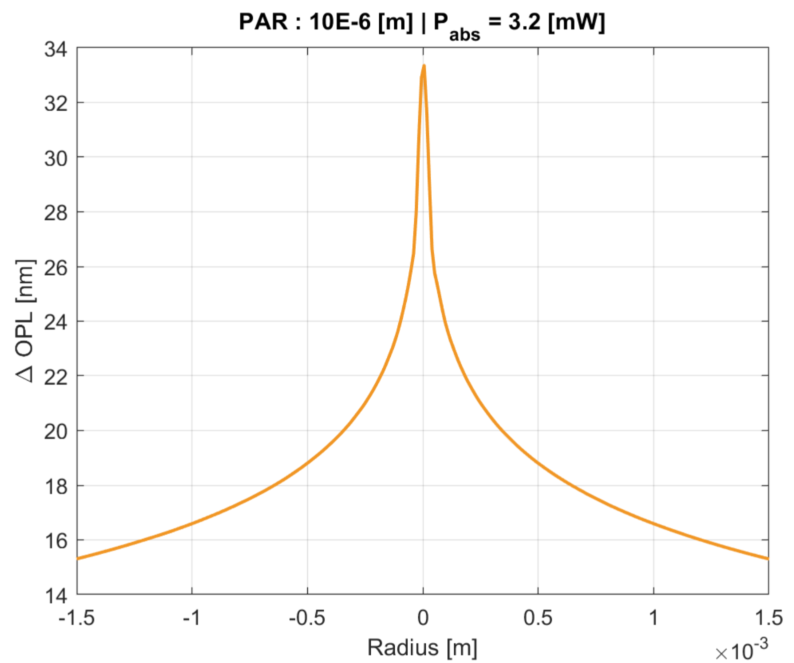
Point absorbers

- Conditions of our setup
  P = 200W , ω_0 = 2,5mm

- PA properties :
  Radius : 10 μm, Abs = 1 mW

$$\Delta OPL(r) = \beta \int_0^L \Delta T(r,z)dz + 2\,(n-1)\Delta \mathrm{L}(\mathrm{r})$$

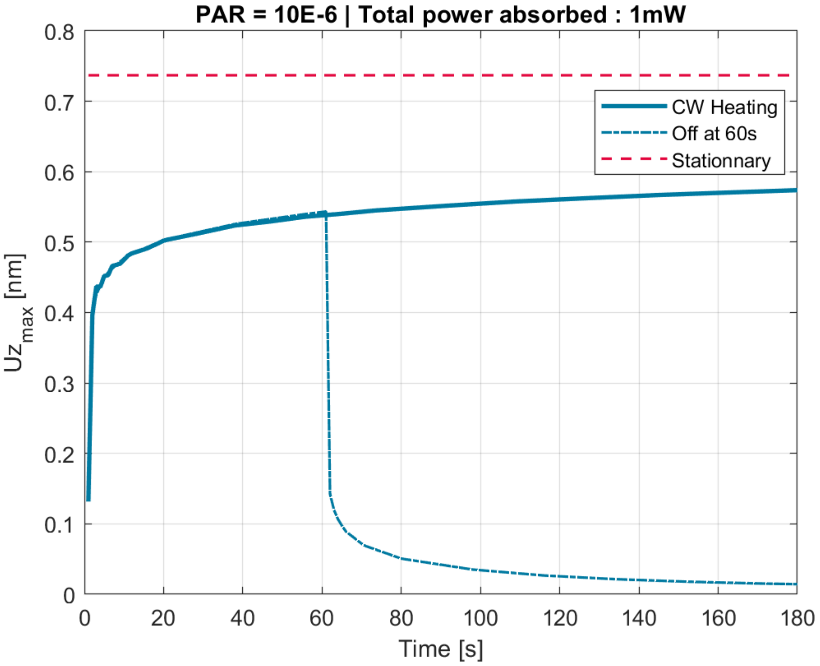




- Few comparable ressources for point absorption

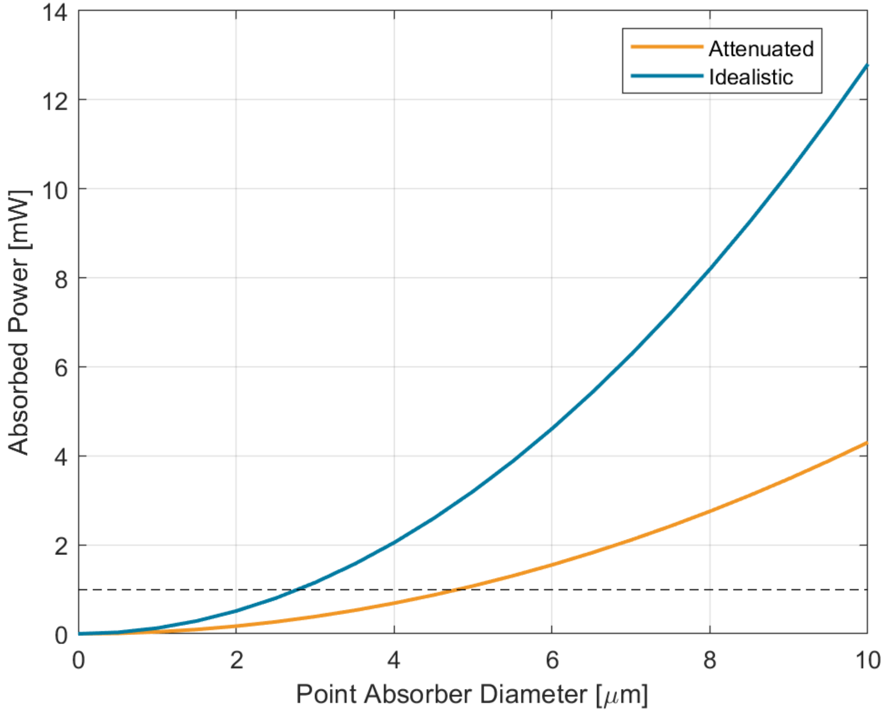
Transient evolution

- We observe a convergence of the transient evolution to the stationary value
- For point absorbers we expect to have more than 70% of the effects after 20s of pump time duration
- The cooling dynamics could also be used to improve the detection accuracy

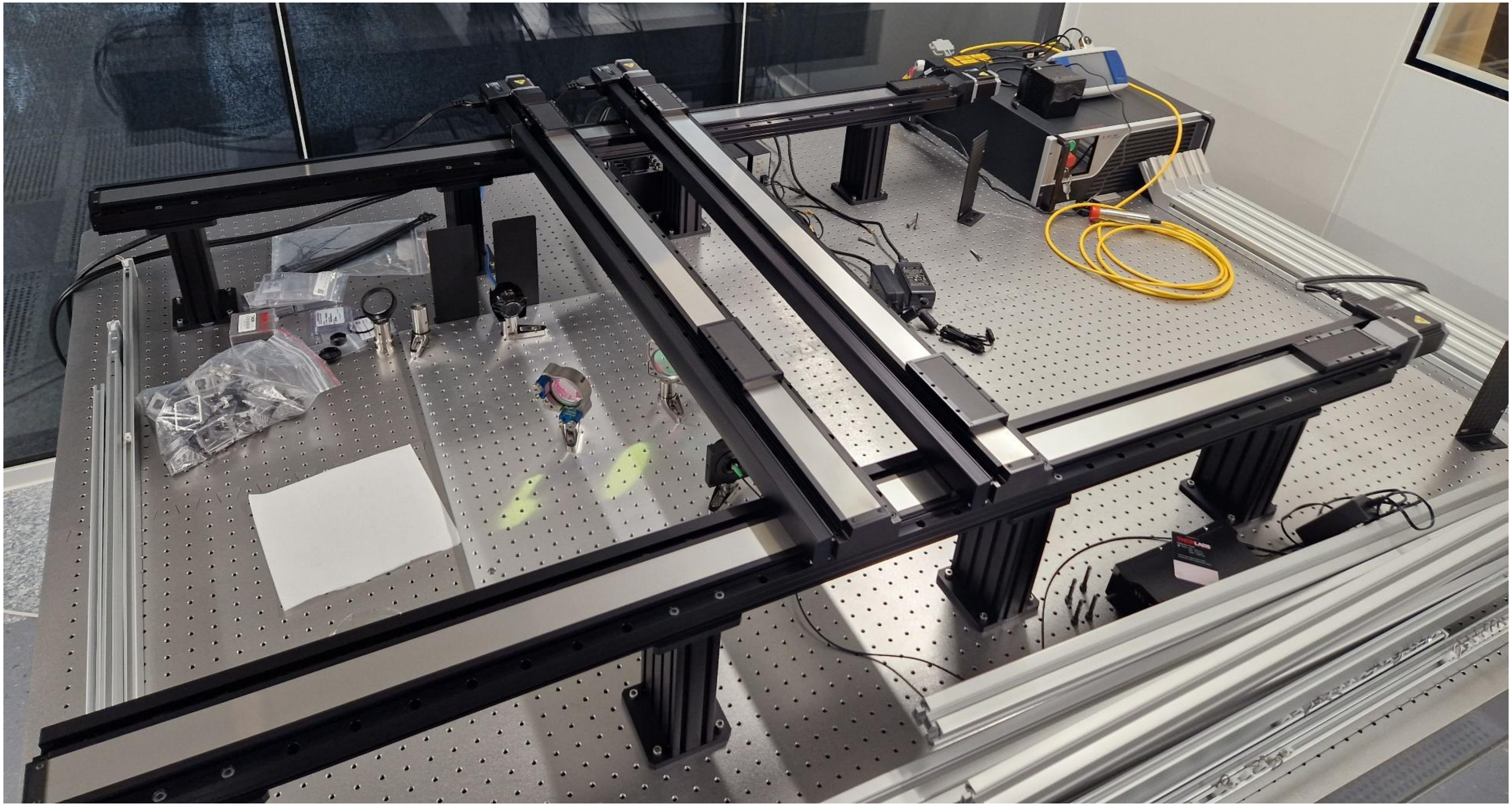


Theoretical capabilities of our setup

- A size limit we could choose is one dictated by the dark field microscope
- Even in defavorable cases we'll be able to detects Pas of larger size
- May be improved by a deeper analysis of the wavefront or the dynamical evolutions
- Similar to Caltech's bench sensitivity



Status of the setup

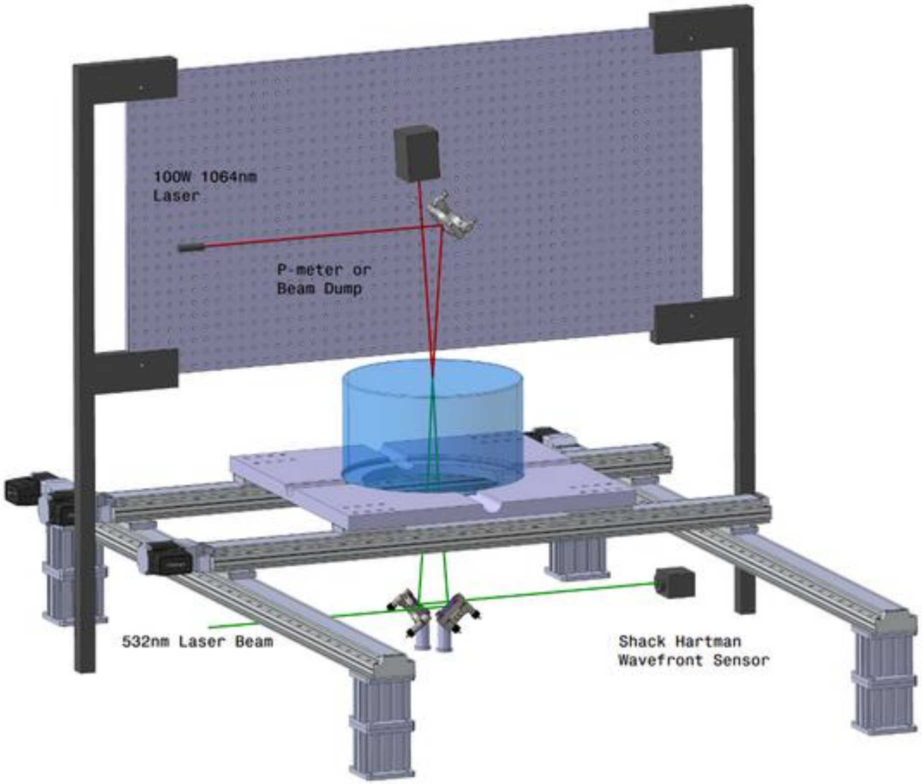


(Installed in the cleanroom)

Upcoming work

- Automatise callibrations / data acquisition / logs and error handling/...
- Enhancing the sensivity by reducing vibrations, optimizing optical alignment
- Design of the large mount and adaptations
- Collecting datas over test samples (relatively long scan time, provide feedback for coating R&D processes)
- Develop an analysis pipeline for theses datas
- Testing Virgo test masses ?

- Remote-Controlled Elements :
  - Laser 200W
  - 2x Piezo-mounts
  - 4x Linear Stages
  - Power-meter
  - Wavefront sensor



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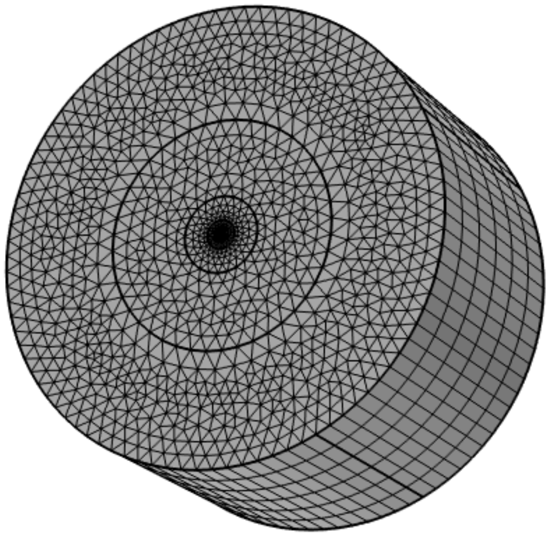
Computation details

- Thermo-elastic effects
  - $\theta_{ij} = \delta_{ij}(\lambda E - \nu \Delta T) + 2\mu E_{ij}$
- Thermo-optical effects
  - $\Delta \mathrm{W}(\mathrm{r}, \theta) = \frac{dn}{dT}\int_0^h \Delta T(r, \theta, z)dz$
- Elasto-optic effects
  - $\Delta W(r, \theta) = -\alpha p_{11} \int_0^h \Delta T(r, \theta, z)dz$

COMSOL

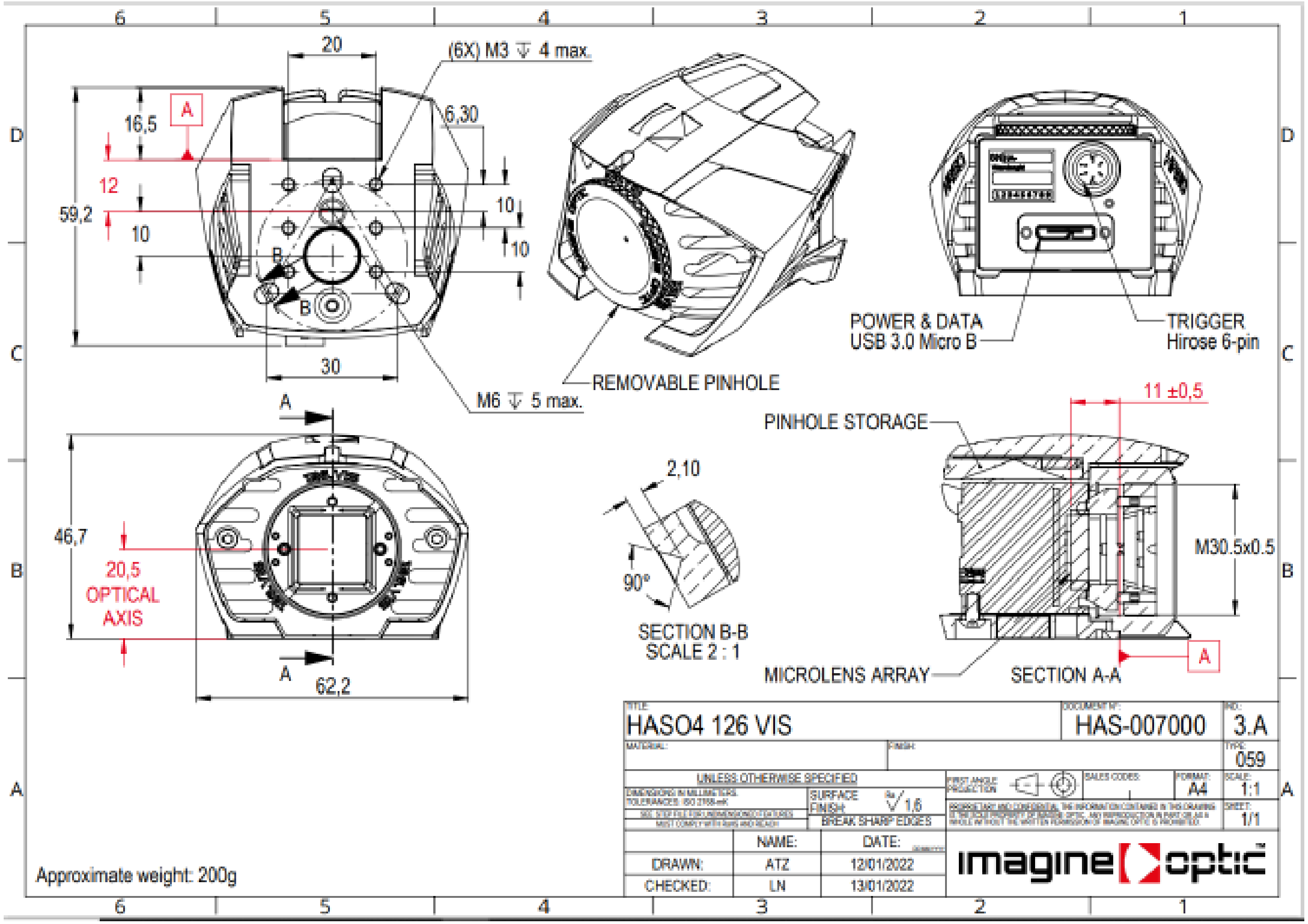


Small mounts

- The large mount takes time to design and manufacture so I ordered a solution to scan smaller mirrors

- 100 diameter samples :
  30 min scan time duration

SHWFS HASO 4



20
(6X) M3 ↧ 4 max.
16,5
A
6,30
12
59,2
10
10
10
B
B
30
M6 ↧ 5 max.
REMOVABLE PINHOLE
POWER & DATA
USB 3.0 Micro B
TRIGGER
Hirose 6-pin
11 ±0,5
PINHOLE STORAGE
A
2,10
M30.5x0.5
46,7
20,5
OPTICAL
AXIS
90°
SECTION B-B
SCALE 2 : 1
A
62,2
MICROLENS ARRAY
SECTION A-A
A
HASO4 126 VIS
HAS-007000
3.A
059
UNLESS OTHERWISE SPECIFIED
A4
1:1
1/1
BREAK SHARP EDGES
NAME:
DATE:
DRAWN:
ATZ
12/01/2022
CHECKED:
LN
13/01/2022
imagine optic
Approximate weight: 200g

Resume of PA in LIGO test masses

OPTIC PT	P_{abs}	ΔP_{arm} or P_{HPAD}	ABS* Dependent on measurement system	Relative or absolute intensity	Circular diameter	REF
H1-ETMX [A]	5.5mW	~90kW	~60ppb	Unknown [80%]	24µm	G2102068
L1-ETMX [α]	19.5mW	~210kW	~93ppb	~30%	49µm	aLOG 46090
L1-ETMX [β]	13.7mW	~210kW	~65ppb	~28%	42µm	aLOG 46090
L1-ETMY [main]	~5mW	~113kW	~45ppb	~60%	24µm	aLOG 54361
H1-ITMX [O1/O2]	25.5mW	~137kW	~190ppb	17 ± 7 W/mm²	44 + [13,-7] µm	aLOG 34900, LDAS
H1-ITMY [1] (O1/O2)	2.3mW	~137kW	~17ppb	2.6 ± 1.6 W/mm²	39 ± 15 µm	G2200069
H1-ITMY [2] (O1/O2)	8.2mW	~137kW	~60ppb	10.8 ± 1.3 W/mm²	31 ± 2 µm	G2200069
H1-ITMY [3] (O1/O2)	2.0mW	~137kW	~15ppb	4.3 ± 2.1 W/mm²	27 ± 8 µm	G2200069
H1-ITMY [4] (O1/O2)	4.1mW	~137kW	~30ppb	8.7 ± 2.2 W/mm²	25 ± 4 µm	G2200069
H1-ITMY [5] (O1/O2)	1.5mW	~137kW	~11ppb	1.8 ± 1.3 W/mm²	40 ± 18 µm	G2200069
H1-ITMY [6] (O1/O2)	1.1mW	~137kW	~8ppb	4.5 ± 2.1 W/mm²	20 ± 6 µm	G2200069
ITM11 - i [HPAD]	0.47mW	95W	4.9ppm	1.2 - 2.4W/mm²	16 - 22µm	G2200069
ITM11 - b [HPAD]	51µW	95W	0.54ppm	1.2 - 2.4W/mm²	5 - 7µm	G2200069
ITM11 - g [HPAD]	48µW	95W	0.51ppm	1.2 - 2.4W/mm²	5 - 7µm	G2200069