L'augmentation de la puissance du laser et les enjeux associés

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Advanced Virgo – The Goal

IOP Publishing

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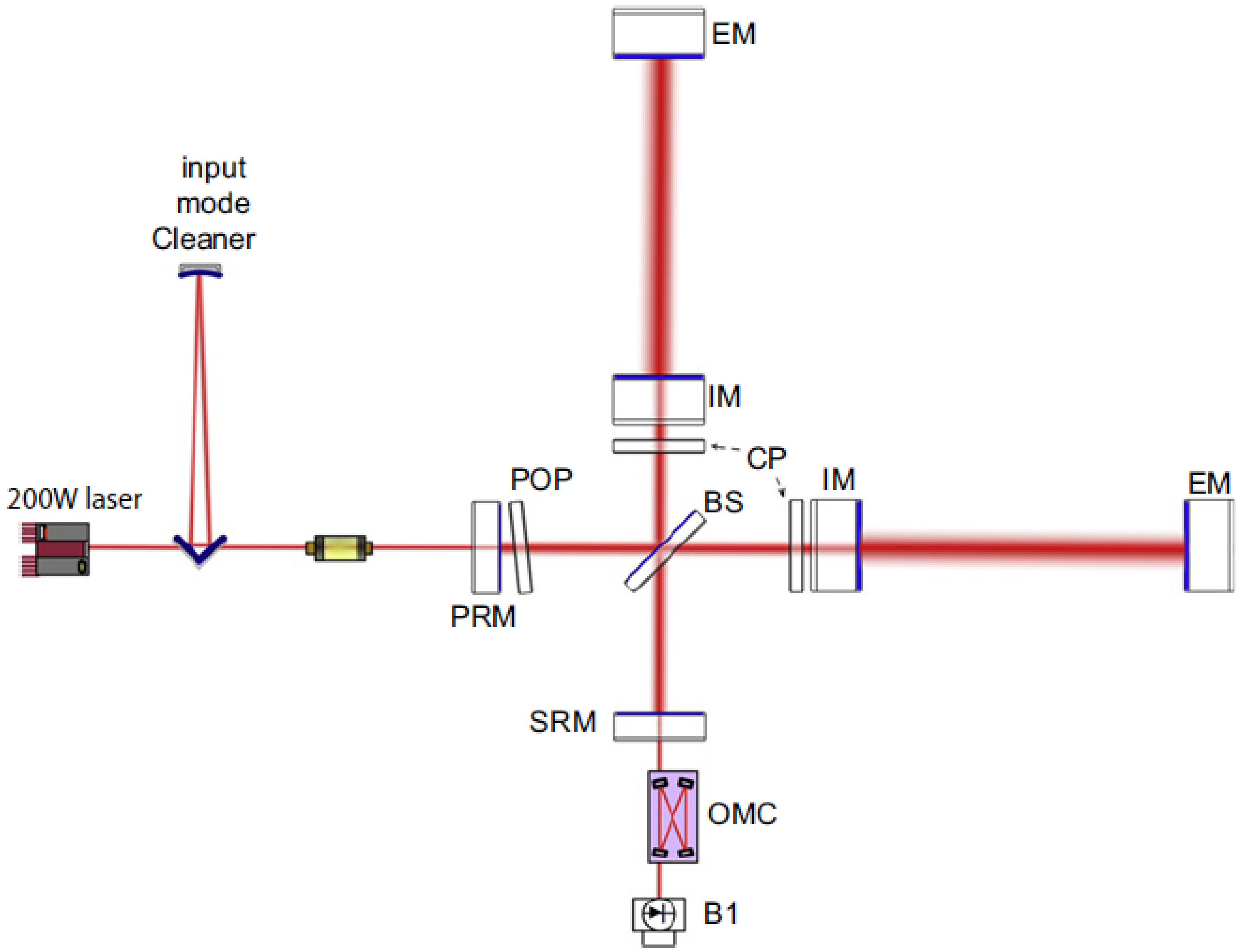
Advanced Virgo: a second-generation interferometric gravitational wave detector

Advanced Virgo – The Goal

The
path to
200 W



Advanced Virgo – The Path To 200 W

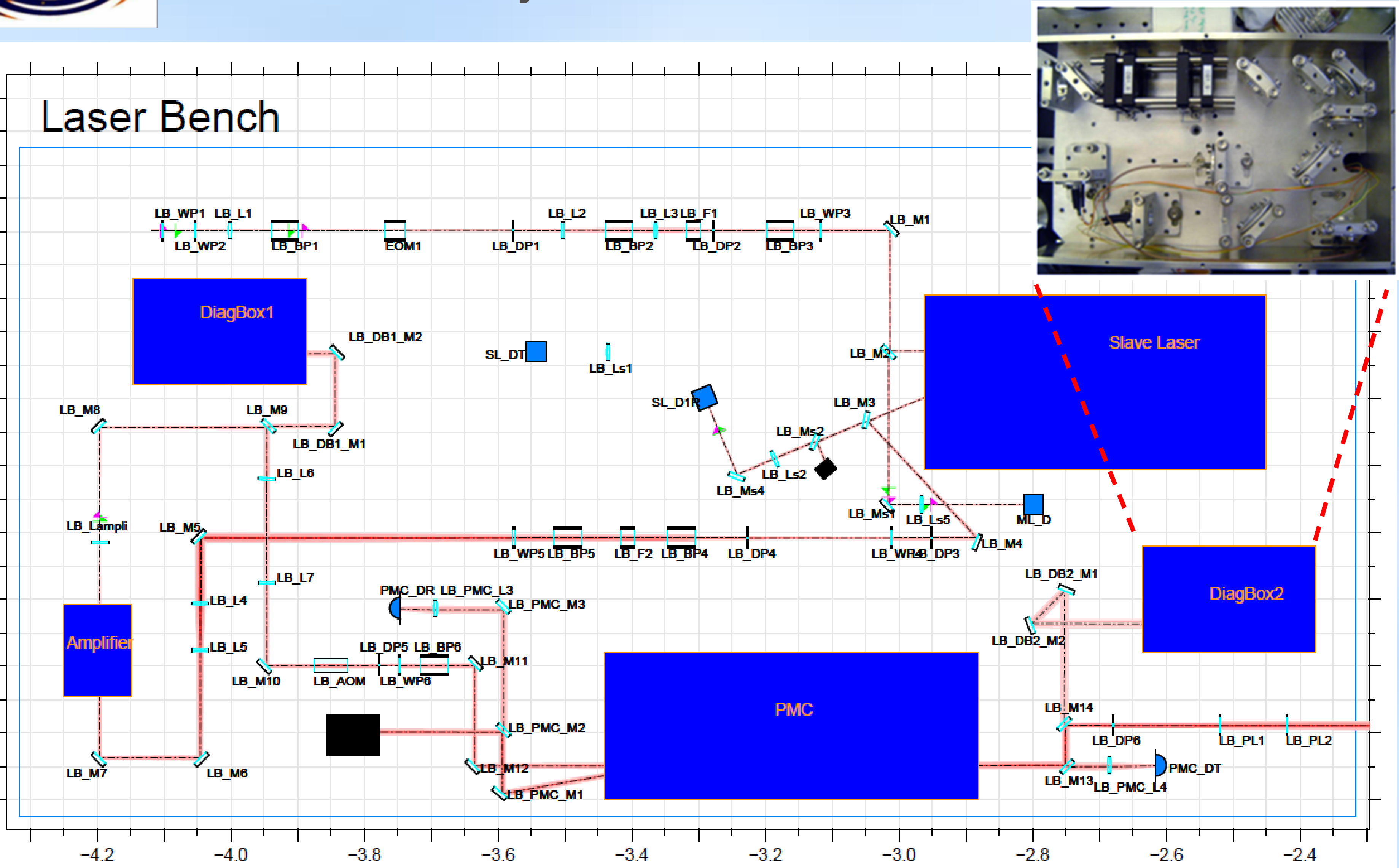
- For O3 there is a 100 W solid state laser amplifier from neoLase that has been installed.
- 100 W fiber laser amplifier has also been demonstrated to meet the Advanced Virgo requirements.
- Coherent addition of two 50 W has been demonstrated => 200 W with the coherent addition of two 100 W lasers.
- Possibility that a single 200 W fiber laser could be developed.

O3 Advanced Virgo Laser

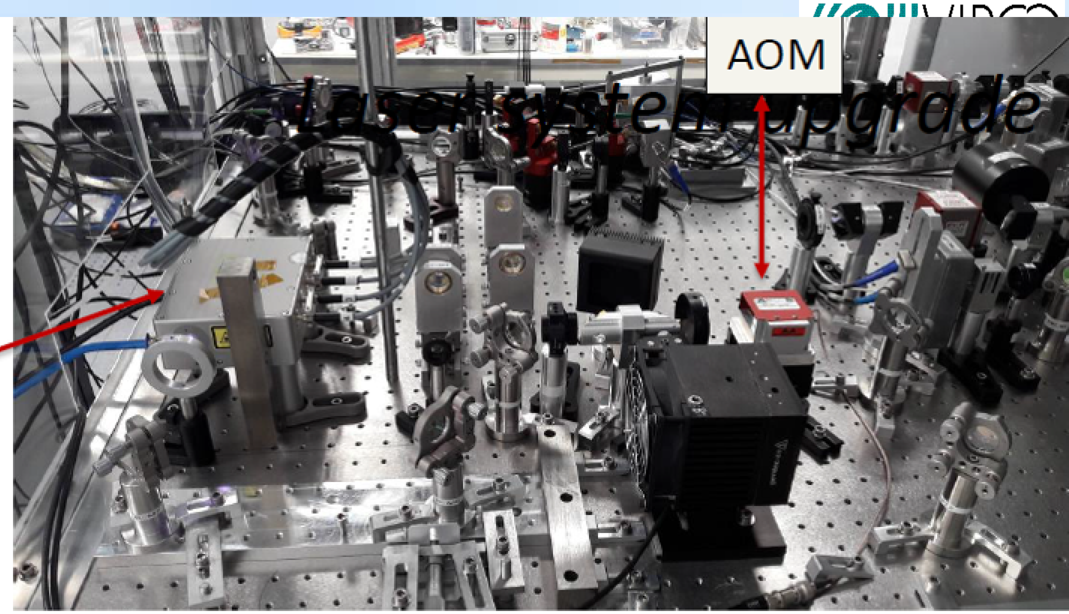
- A 100 W laser was installed for O3
- Solid-state laser (NeoLASE)
- Up to ~50 W interferometer input power
- New Pre-Mode Cleaner
- Lower losses
- Better high-power compatibility
- New power stabilization scheme - using an AOM instead of acting on amplifier pumping diodes
- Installed on the existing laser bench

F. Cleva, F. Kéfélian, J-P Coulon, + EGO Team

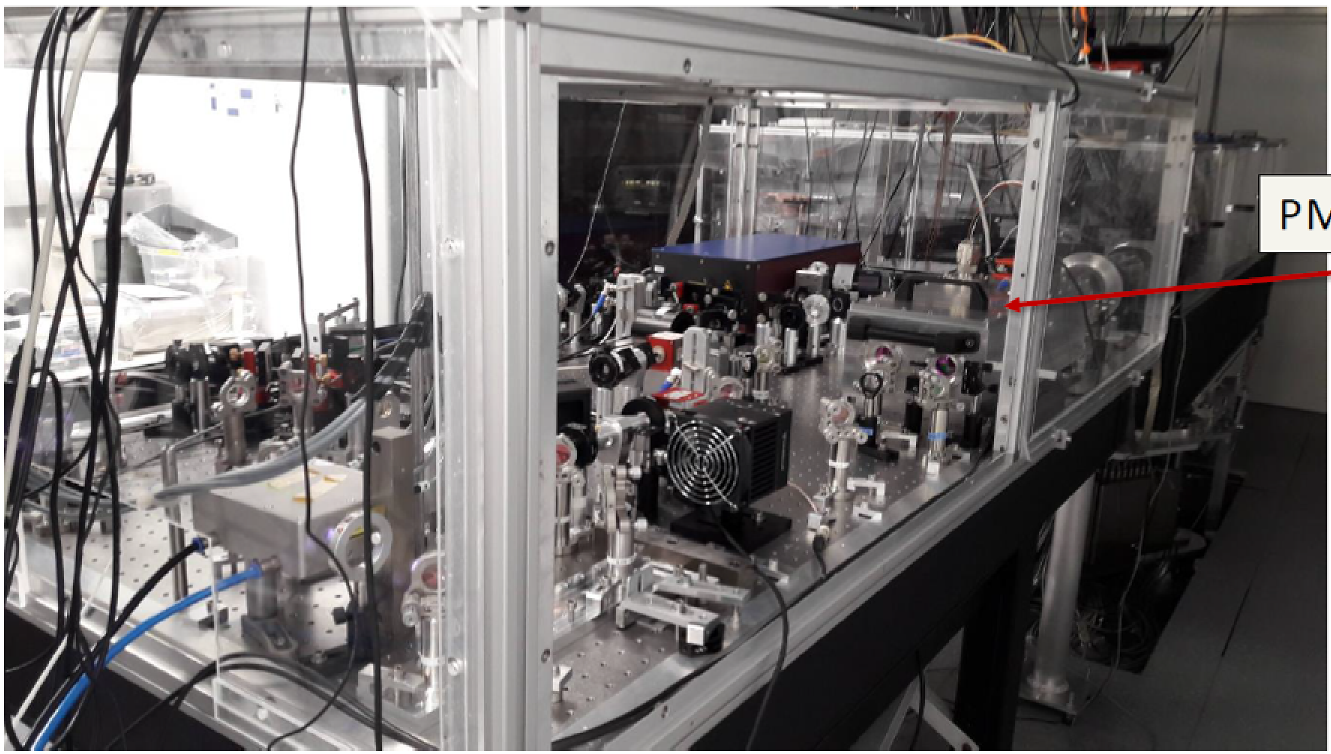
New layout of laser bench



PSL bench after upgrade completion

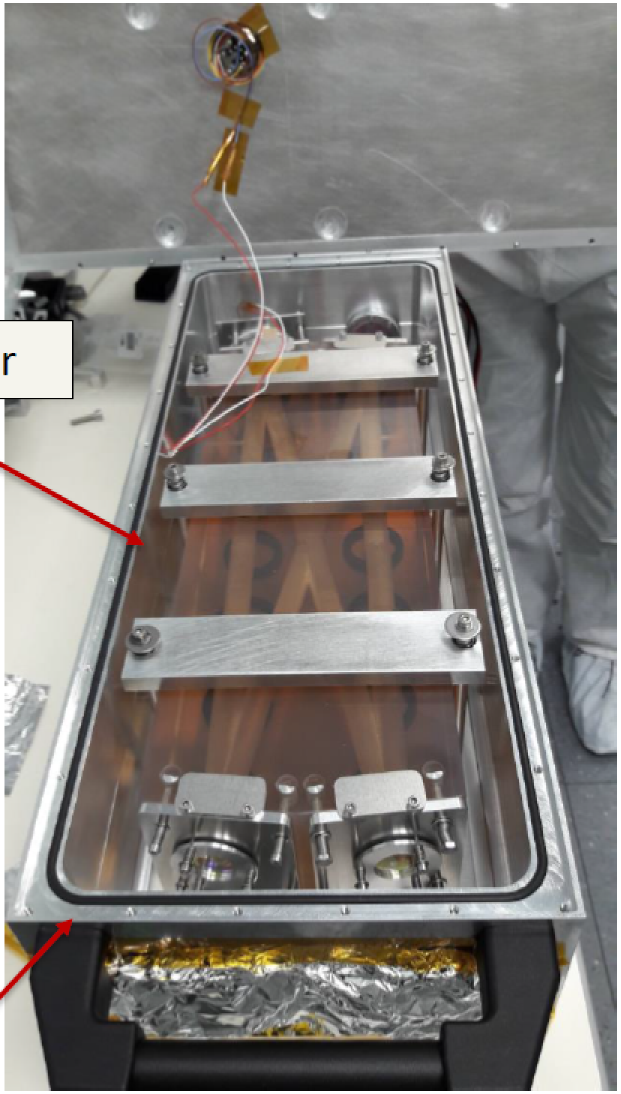


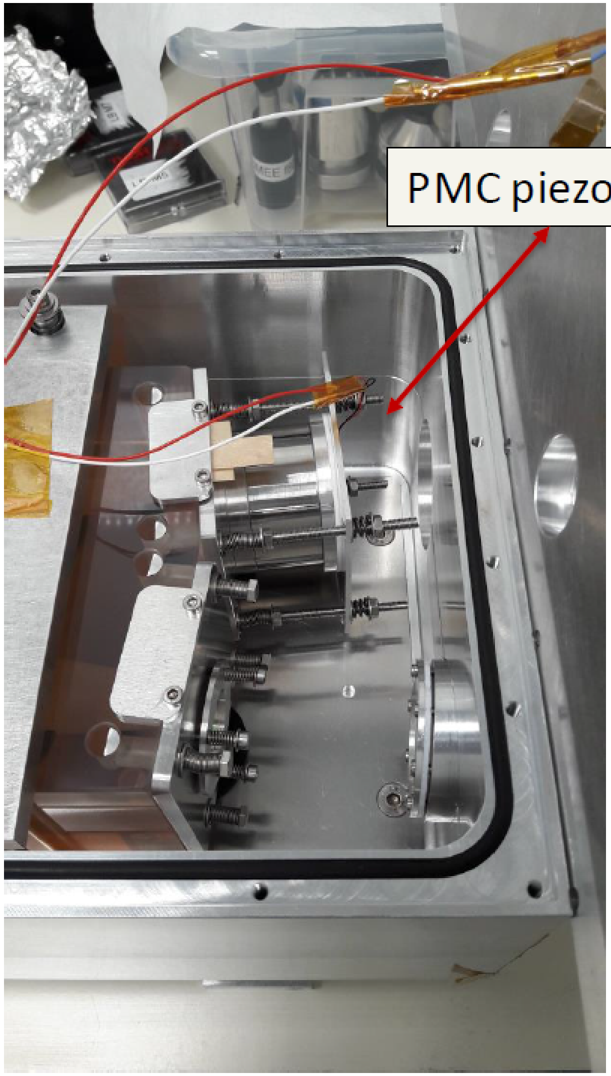
neoVAN-HP



PMC enclosure

New Pre-Mode Cleaner



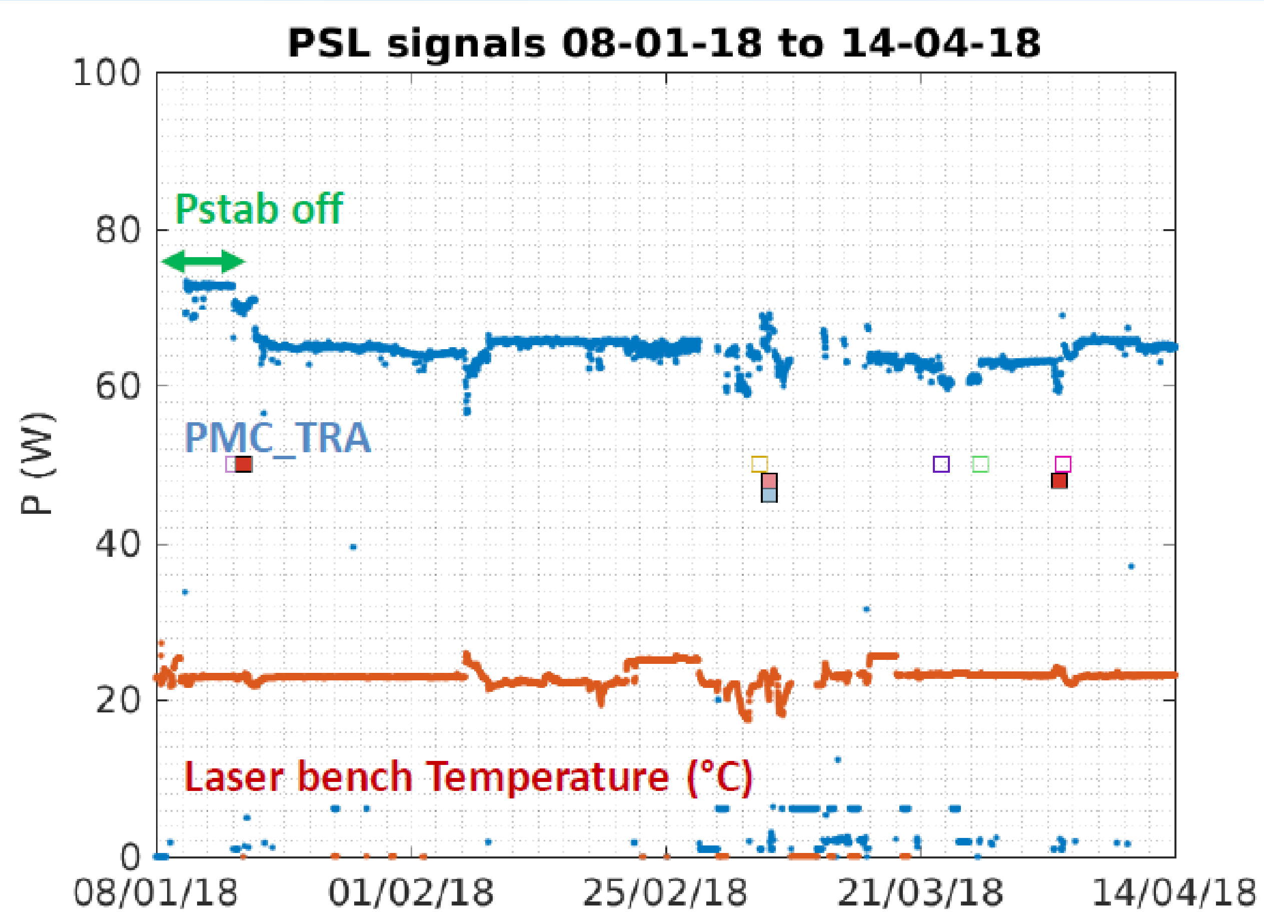


Power at laser bench output (after PMC)

Power at output

65 W after Pre-Mode Cleaner (14/04/18)

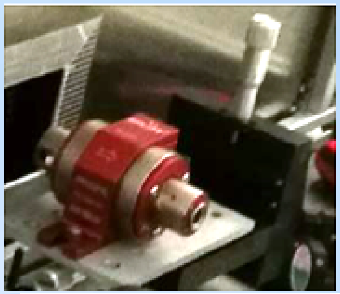
48 W at Interferometer input (74% transmission from PMC to ITF)

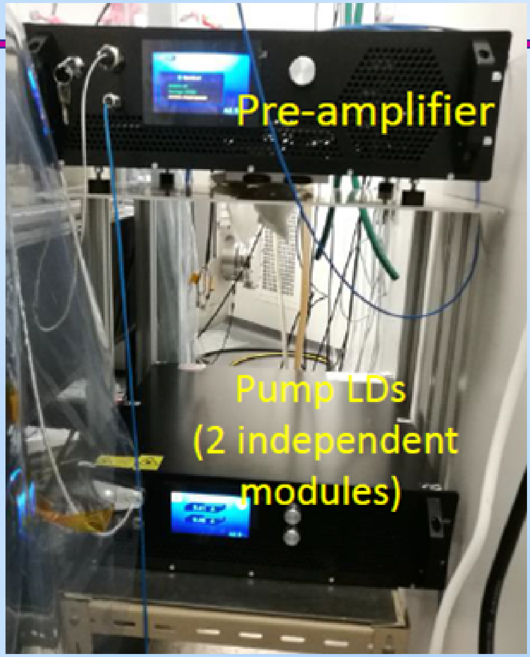


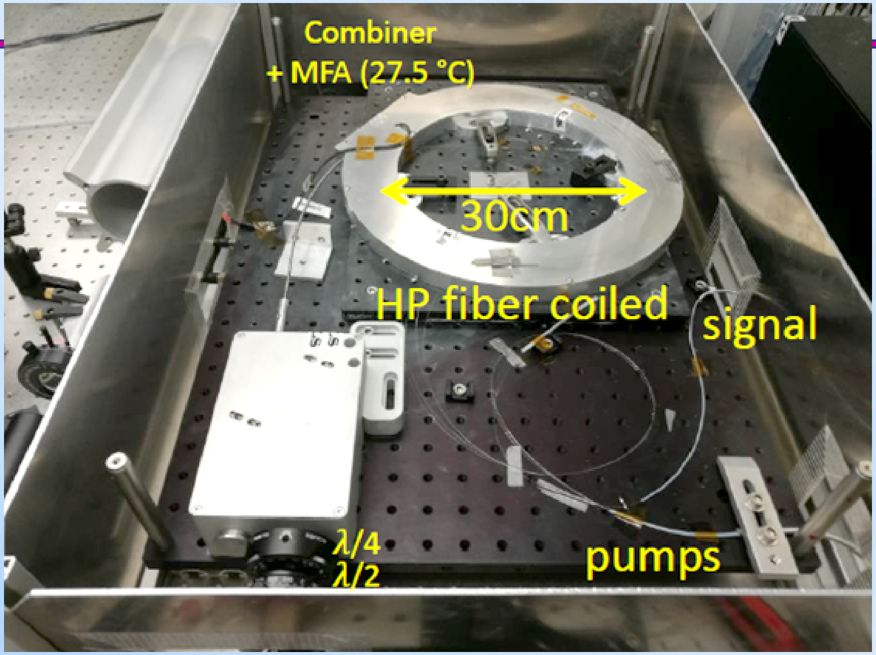
3-months survey

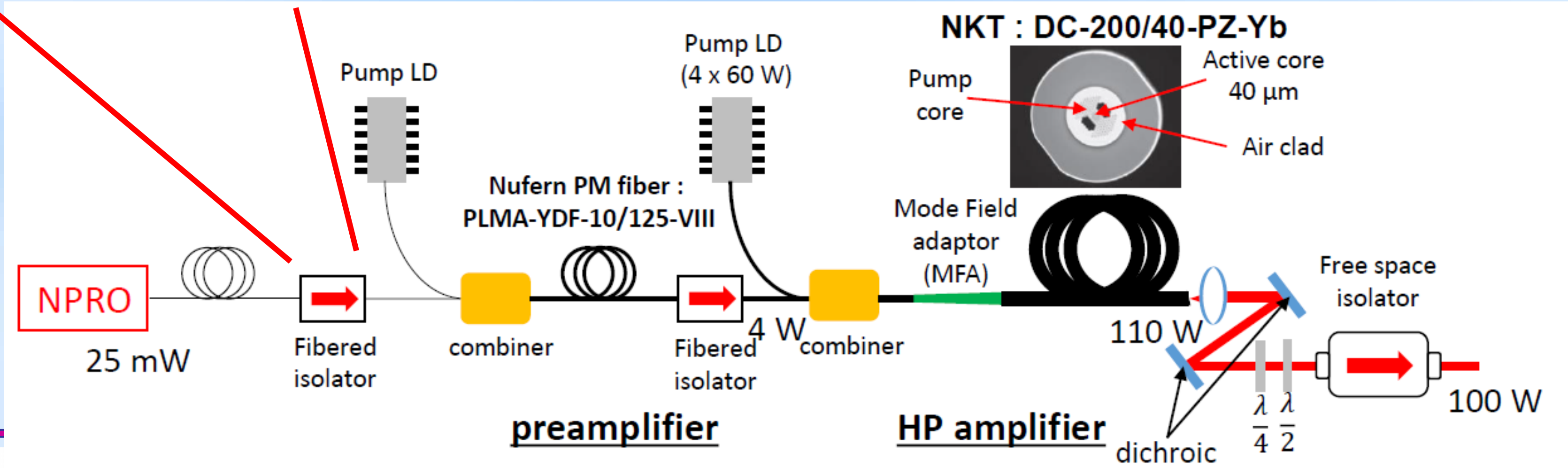
Power fluctuations related to problems with laser lab air conditioning, now improved

Fiber amplifier layout

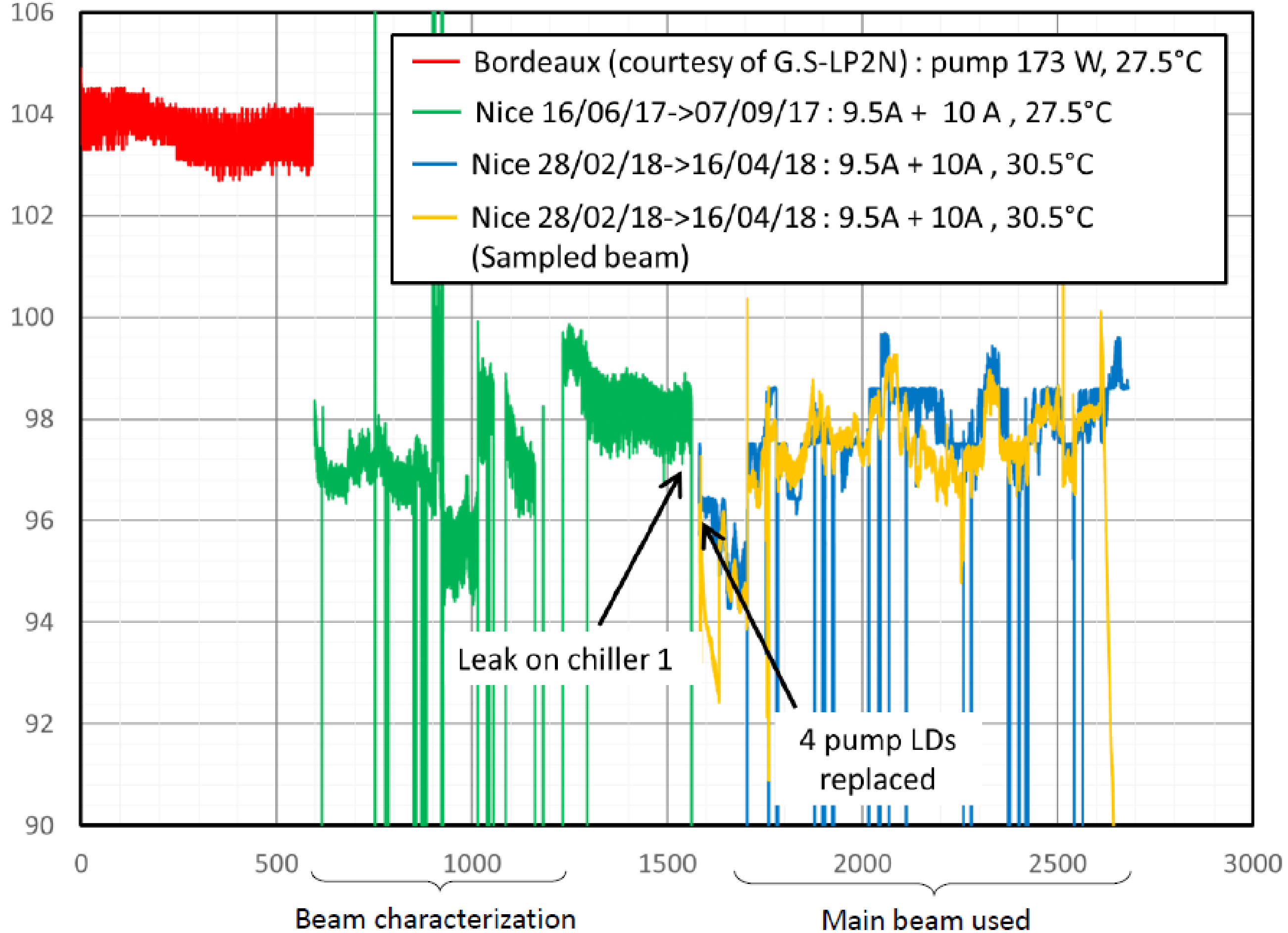






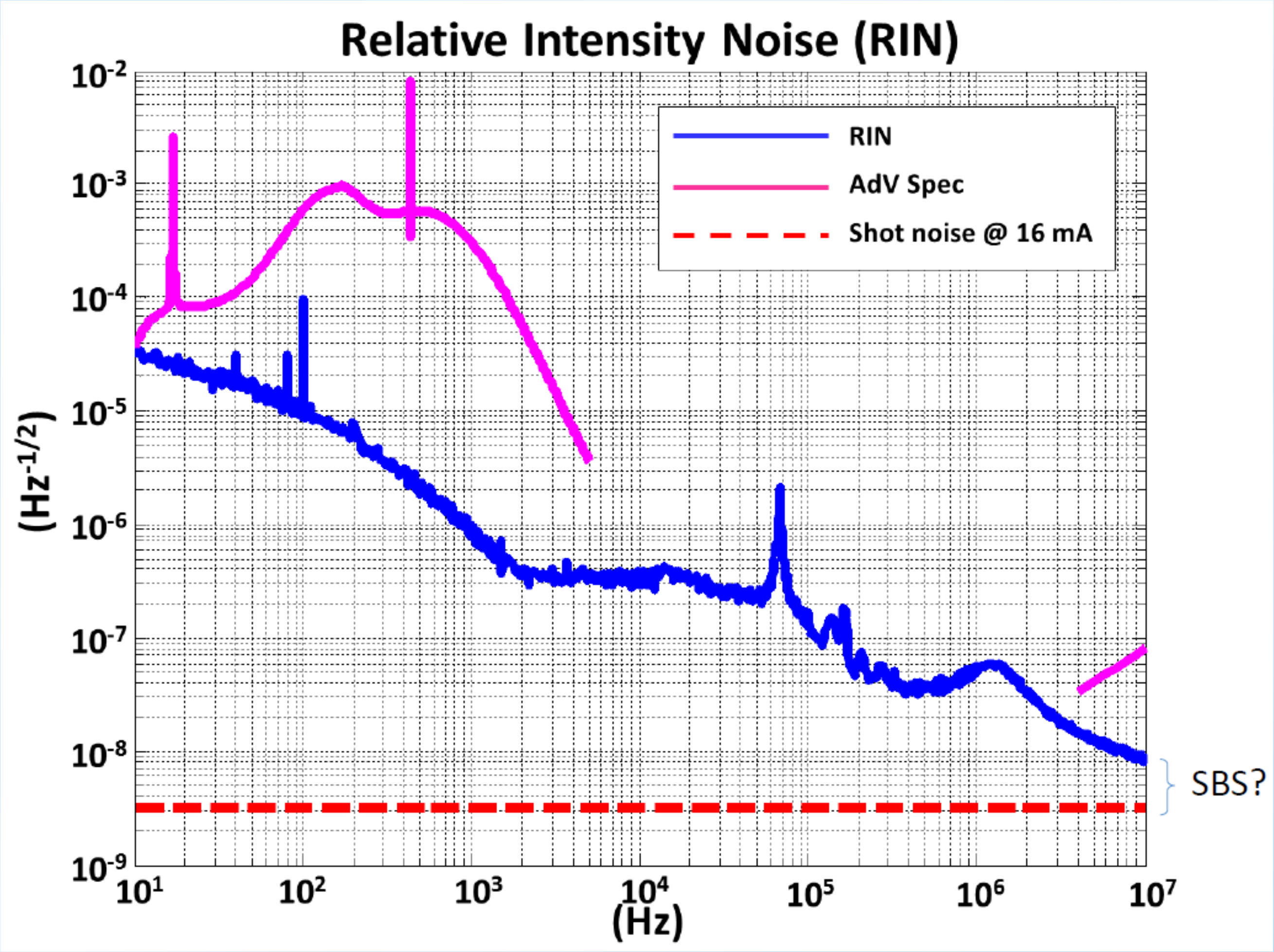


Fiber laser long term stability

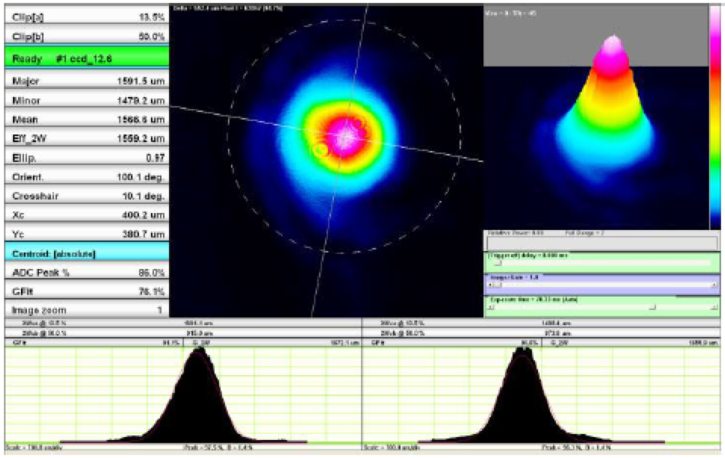


- Overall functioning time > 2500 h, longest continuous period 1100 h
- Output power fluctuation ~ 3W peak to peak (mainly due to the monitoring)

Fiber laser intensity noise

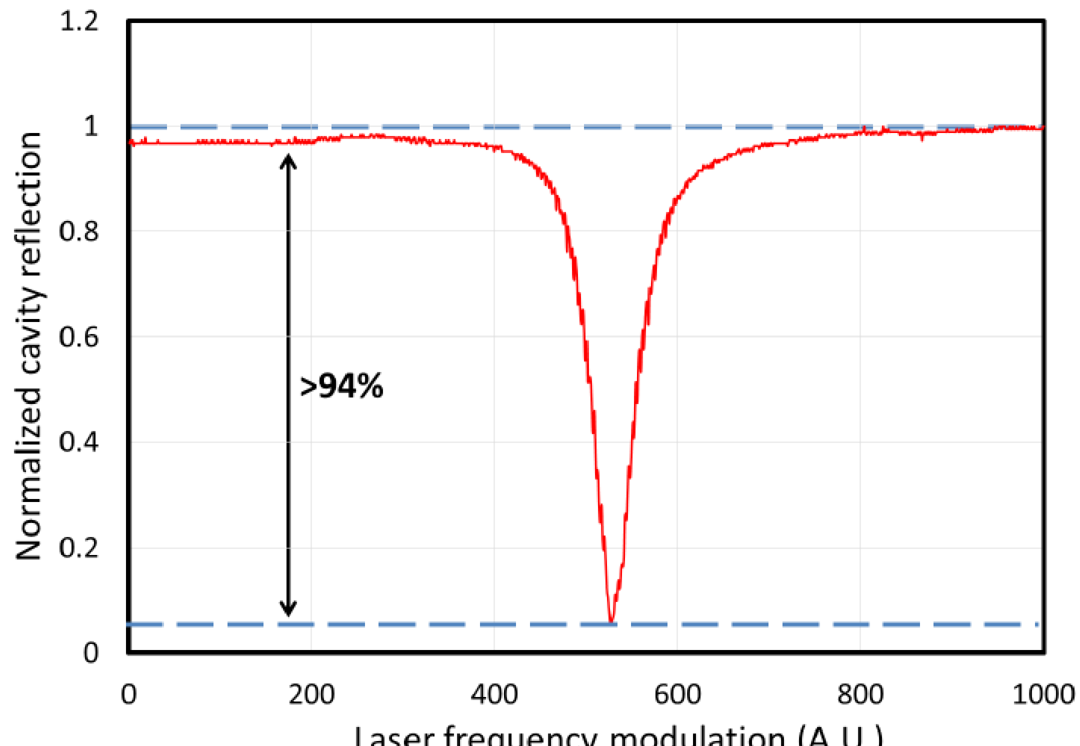


Fiber laser Gaussian mode content



Beam shape, radius @ waist ~ 600 µm

Coupling into a reference cavity.
Finesse = 900



For more information on fiber laser ...

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https://doi.org/10.1007/s00340-018-6989-7

Applied Physics B
Lasers and Optics

CrossMark

High-power all-fiber ultra-low noise laser

Jian Zhao[1,6] · Germain Guiraud[1,2] · Christophe Pierre[3] · Florian Floissat[1] · Alexis Casanova[1,5] · Ali Hreibi[4] · Walid Chaibi[4] · Nicholas Traynor[2] · Johan Boullet[3] · Giorgio Santarelli[1]

Received: 1 February 2018 / Accepted: 19 May 2018

Abstract
High-power ultra-low noise single-mode single-frequency lasers are in great demand for interferometric metrology. Robust, compact all-fiber lasers represent one of the most promising technologies to replace the current laser sources in use based on injection-locked ring resonators or multi-stage solid-state amplifiers. Here, a linearly polarized high-power ultra-low noise all-fiber laser is demonstrated at a power level of 100 W. Special care has been taken in the study of relative intensity noise (RIN) and its reduction. Using an optimized servo actuator to directly control the driving current of the pump laser diode, we obtain a large feedback bandwidth of up to 1.3 MHz. The RIN reaches – 160 dBc/Hz between 3 and 20 kHz.

Fiber laser research at MIT + Lincoln Laboratories, and at AEI Hannover.

Coherent Addition

Li Wei PhD thesis demonstration and

- Optics Letters Vol. 41, Issue 24, pp. 5817-5820 (2016)

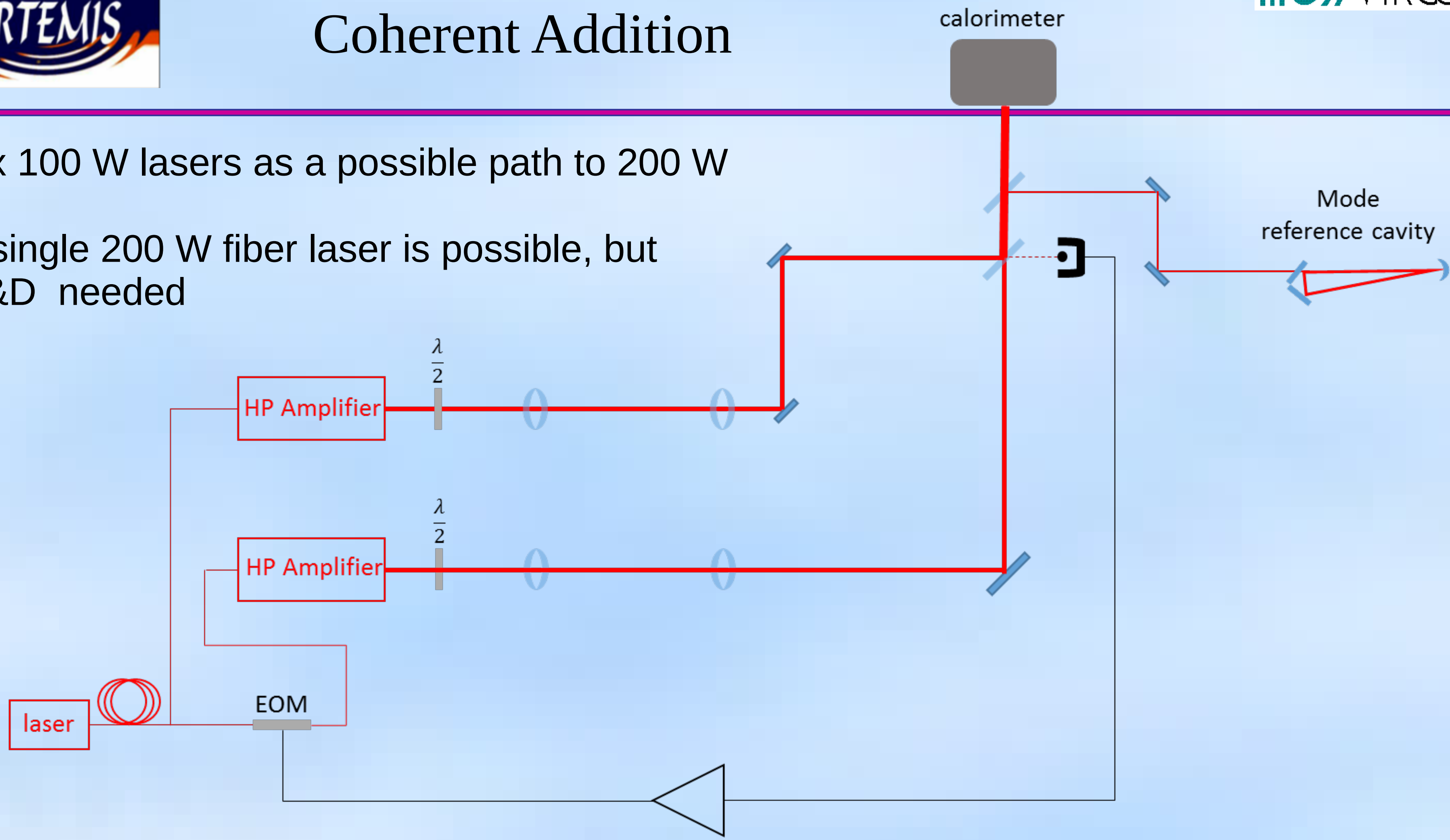
Current work on new design (two 50 W lasers)

Same method could be used for adding 2 x 100 W lasers → 200 W (pre O4)

Coherent Addition

2 x 100 W lasers as a possible path to 200 W

A single 200 W fiber laser is possible, but R&D needed



- Triangular cavity as a mode reference cavity on which the two beams are adapted
- Beam matching : 95% and 98.5% → Combination contrast > 95%

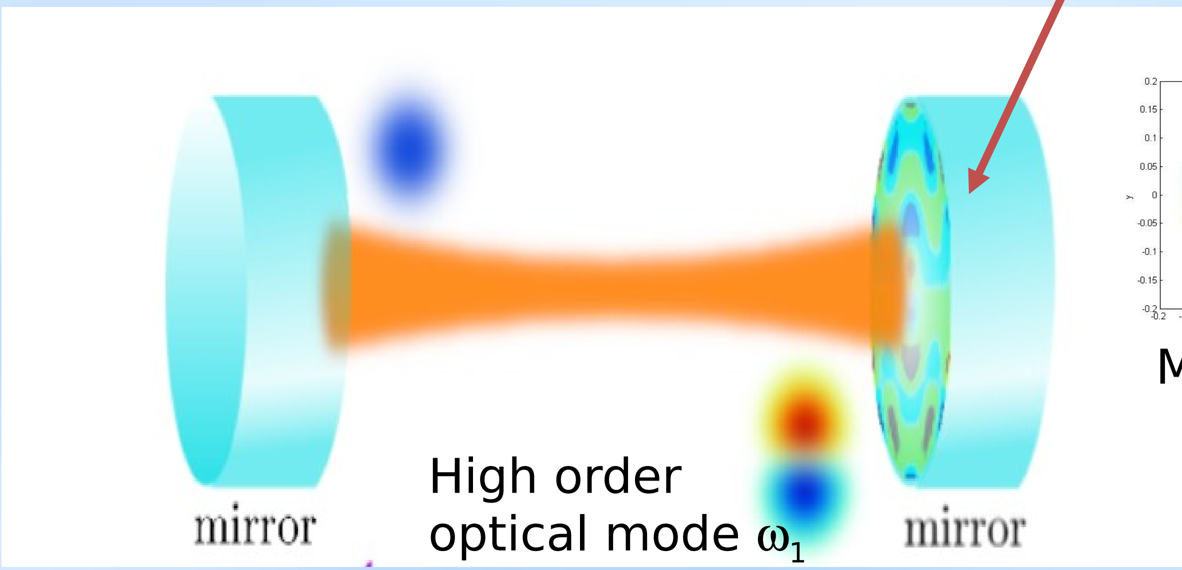
Issues With High Power

- High power brings issues and problems
- Up to 700 kW in cavities at design sensitivity
- Parametric instabilities
- Thermal lensing: optics that are crossed by the probe beam require the use of a thermal compensation system
- Stray light
- etc

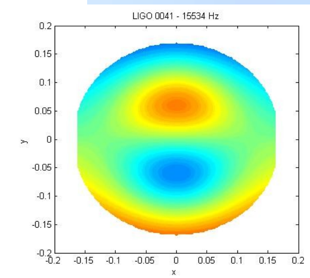
Parametric Instability: 3 modes interaction

Cavity fundamental mode ω_0

Radiation pressure



High order
optical mode ω_1



Mechanical mode ω_m

Thermally excited acoustic mode scatters TEM_{00} mode sidebands $\omega_o \pm \omega_m$

Resonance with high order TEM_1 if $\omega_o \pm \omega_m = \omega_1$ due to radiation pressure

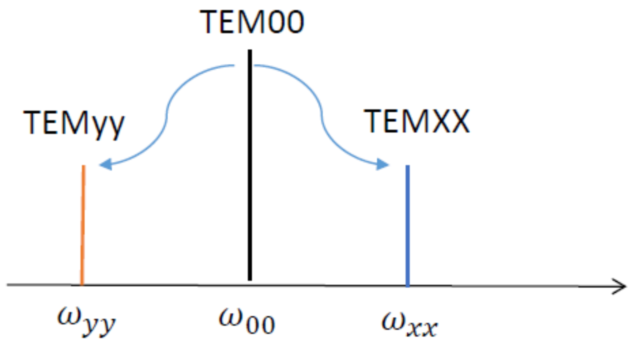
Resonance condition:

$\omega_o - \omega_1 = \omega_m$, high spatial overlap

Parametric Instabilities

Two conditions for PI to happen

Resonance condition:



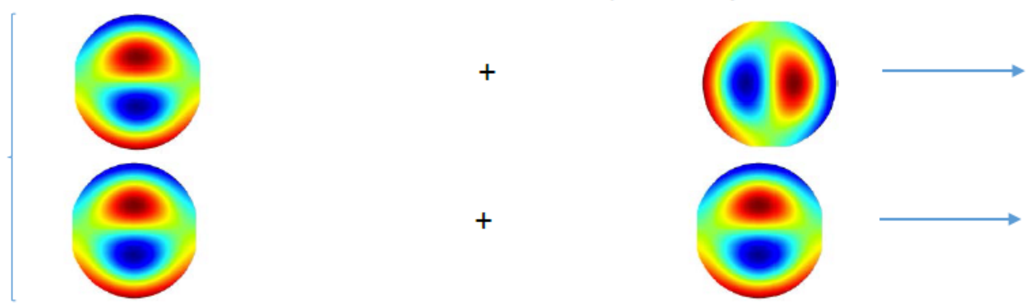
Instability: $\omega_{00} - \omega_{yy} = \omega_m$

Damping: $\omega_{xx} - \omega_{00} = \omega_m$

Overlap between mechanical and optical modes:

Mechanical mode shape (mirror surface motion)

Optical mode shape (intensity distribution at mirror position)



Orthogonal modes
No PI

PI if resonance condition fulfilled

Parametric Instabilities

Related to the optical gain of the scattered field

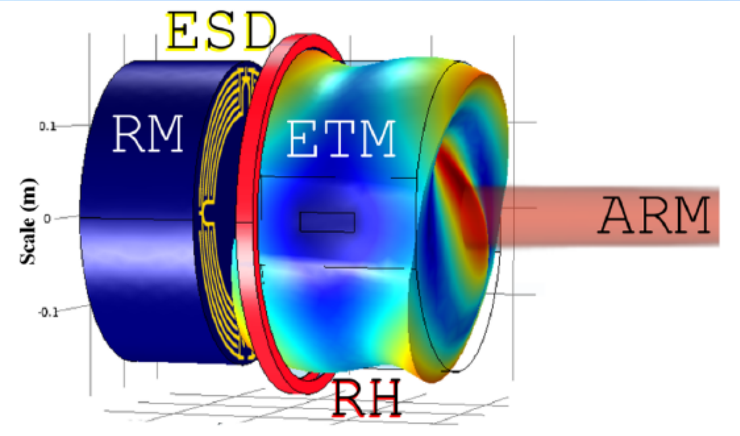
Figure of merit: Parametric Gain

$$R_m = \frac{8\pi Q_m P_{\text{arm}}}{M\omega_m^2\, c\,\lambda} \sum_{n=0}^{\infty} \boxed{\Re[G_n]}\,\boxed{B_{m,n}^2}$$

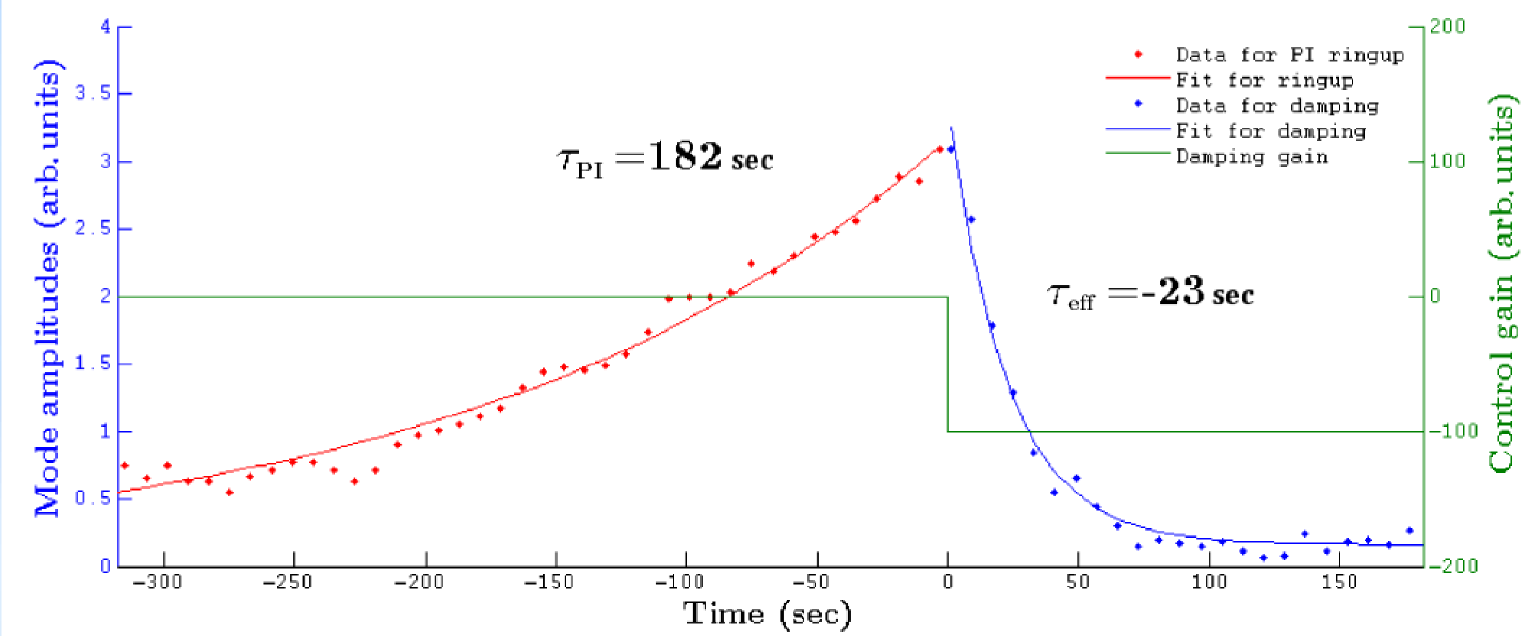
Overlap between mechanical and optical modes

If R is negative, the parametric oscillation is suppressed, otherwise, if it is greater than 1, it gets enhanced

Parametric Instabilities – Observed in aLIGO



Damping with electrostatic actuation.
Will not work for Virgo – magnetic actuators.



PI Mitigation Work

- PI mitigation
  - Actuation
    - Proposal from Artemis for PI damping with wobbled laser
    - Use of thermal compensation (Roma TOV)
    - Use of coils (Rome)
  - Sensing:
    - Parametric instabilities: precursor sensing

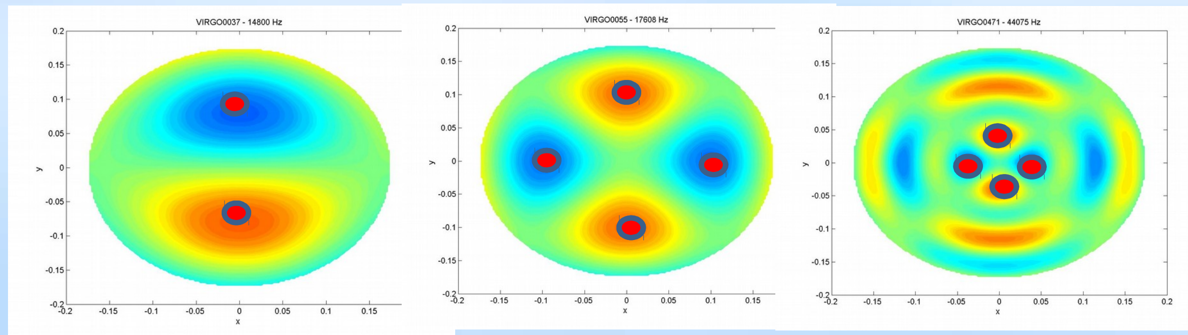
(F. Bondu, M. Romanelli – Univ. Rennes; L. Rolland - LAPP)

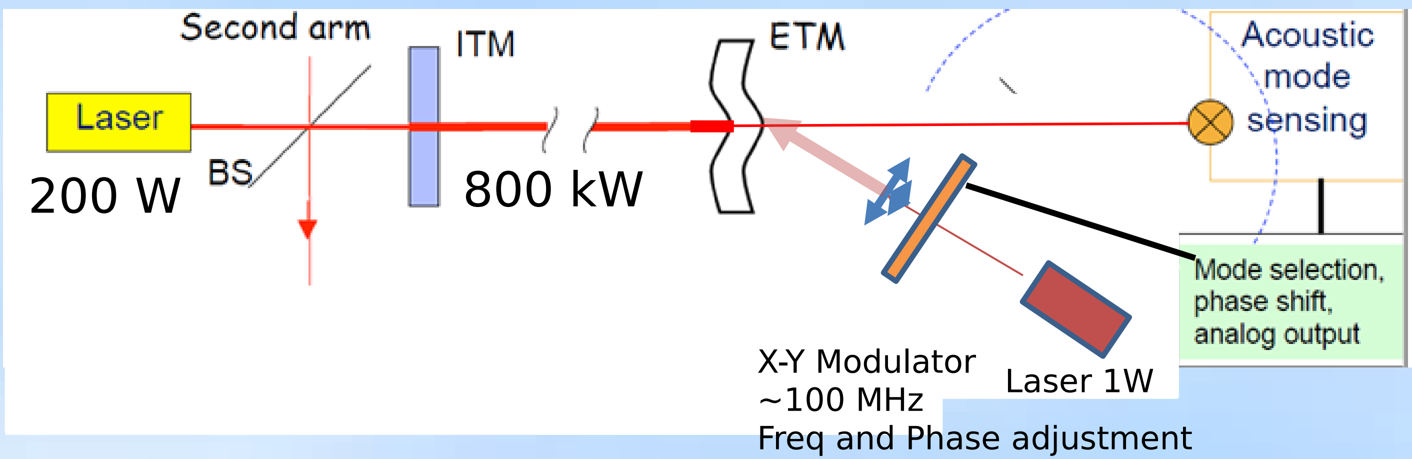
Laser pump

Proposal by Oualid Chaibi, Artemis

Concept:

- Use two acousto optic modulators: vertical and horizontal displacement
- Modulate beam, on and off, to damp mirror modes at correct times.





Ring Heater for tuning
CO_2 preheating for transient PI

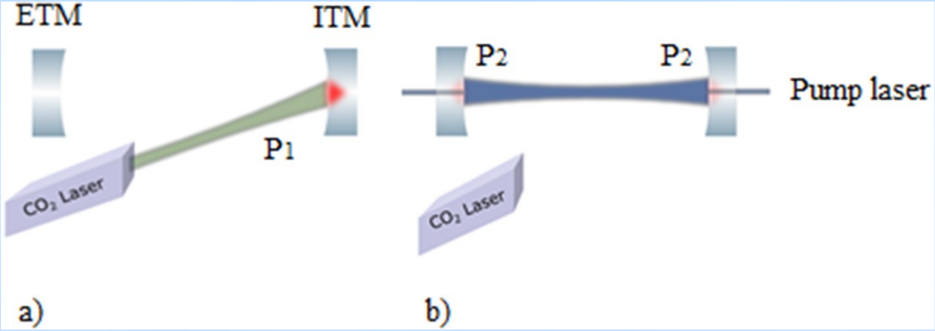
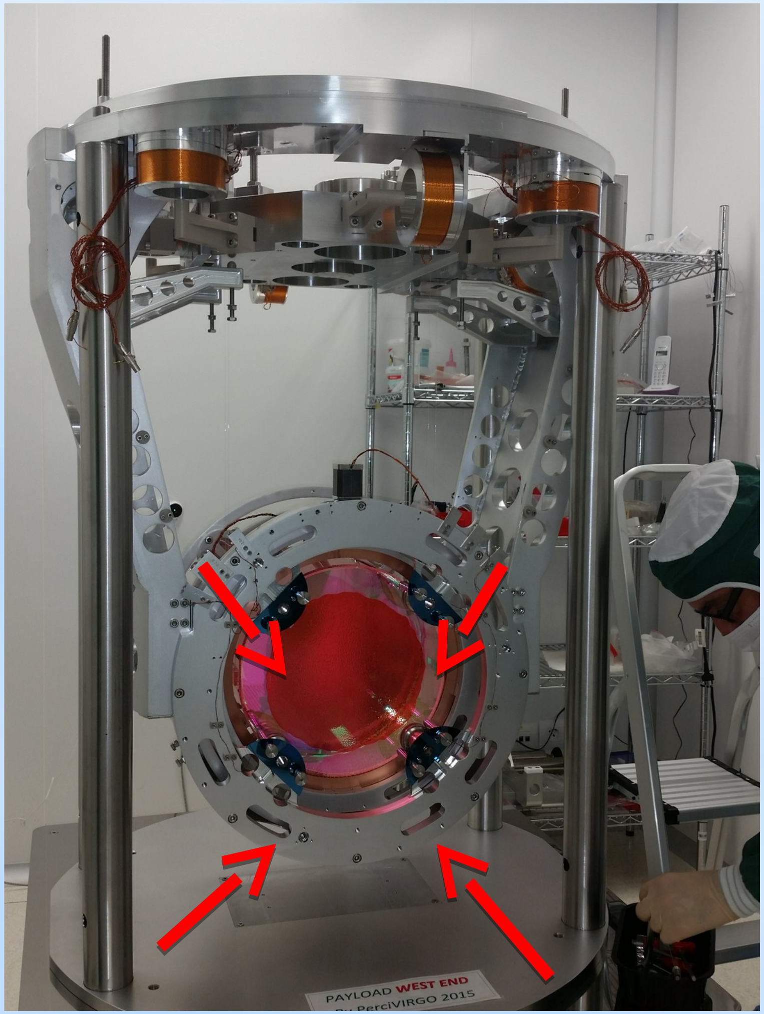


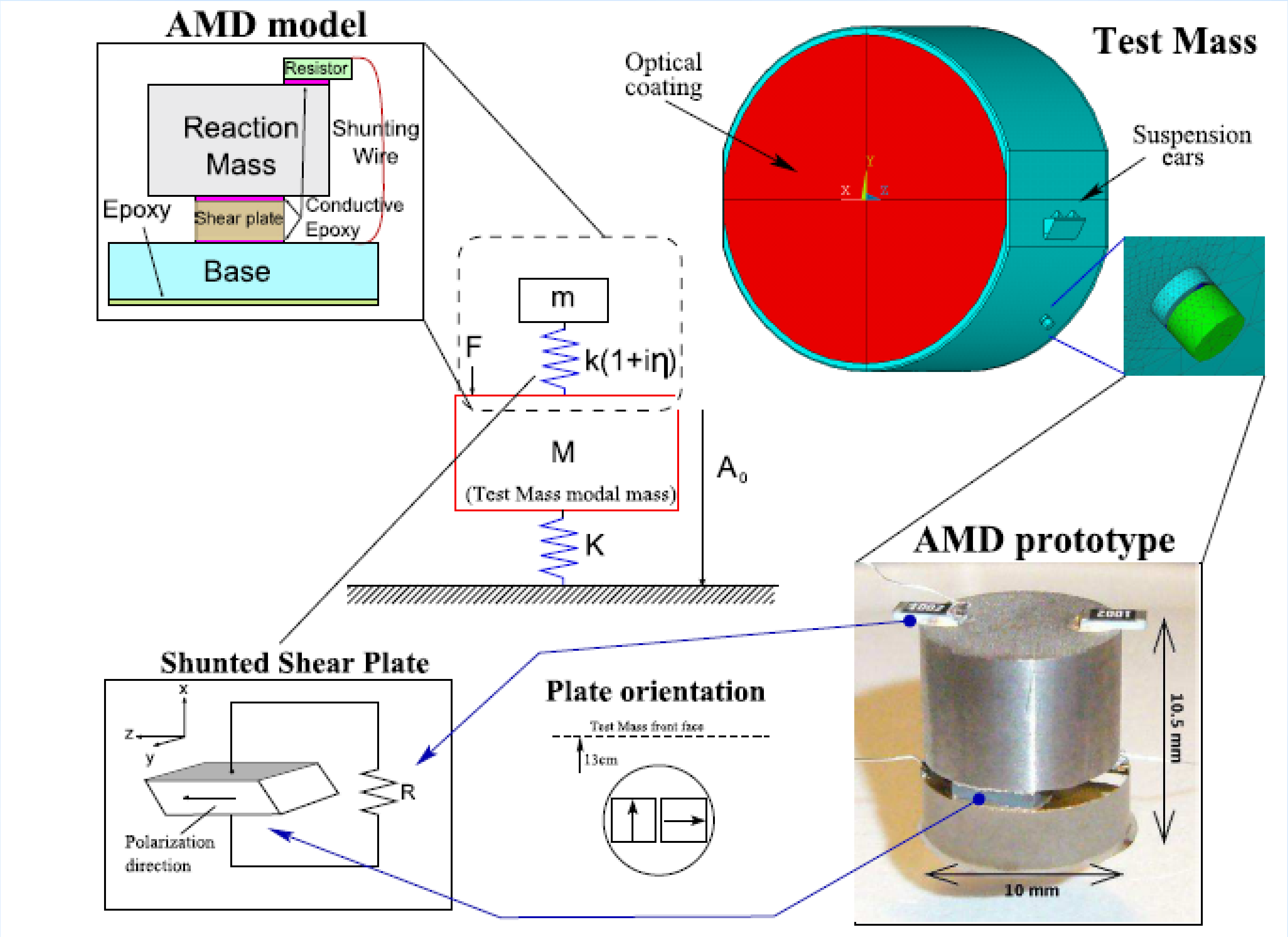
Figure 2. Thermal transient compensation system scheme; (a) CO_2 laser preheating ITM with power P_1 when the cavity is not locked; (b) When the cavity is locked, the self-heating dissipates power P_2 in both mirrors. The CO_2 laser is simultaneously turned off.

Coils damping (Roma 1)

- Are the coil drivers BW enough (>15 kHz)?
- Estimation of the force required for damping (LIGO ~ nN)
- Low Noise regime seems useful (to be checked)



Beyond O3 – Passive damping



"Acoustic Mode Dampers" that use the piezoelectric effect to reduce the coupling of optical to mechanical energy.

Installed in aLIGO for O3

Needs to be studied for AdV and AdV+

Work in progress on simulations

- LKB (T. Jacqmin), Artemis (G. Bogaert)
  - Refine simulations and produce clean results for full inteferometer configuration (mid december)
  - Understand the role or PR and SR (mid december)
- Roma 1 (P. Puppo, L. Naticchioni)
  - Include the anchors in FEM (by end of 2017)
  - Measurements of frequencies to refine (FEM) simulation (by end of 2017 on O2)
  - Measurements of Q's with monolithic suspensions (during O3 commissioning)

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Mitigation activities

- Artemis: (Laser)
  - N. Christensen
  - W. Chaibi
  - G. Bogaert
  - PhD student
- LAL: (on Cascina site for mitigation)
  - N. Arnaud
  - D. Cohen (PhD student on Cascina site)
- LAPP: (sensing)
  - L. Rolland
- Roma 1: Coils and passive dampers
  - P. Puppo
  - E. Majorana
- Univ. Rennes 1 (sensing)
  - F. Bondu
  - M. Romanelli
- Rome Tor Vergata (TC)
  - A. Rocchi
  - V. Fafone
  - Master Students

Thermal Compensation

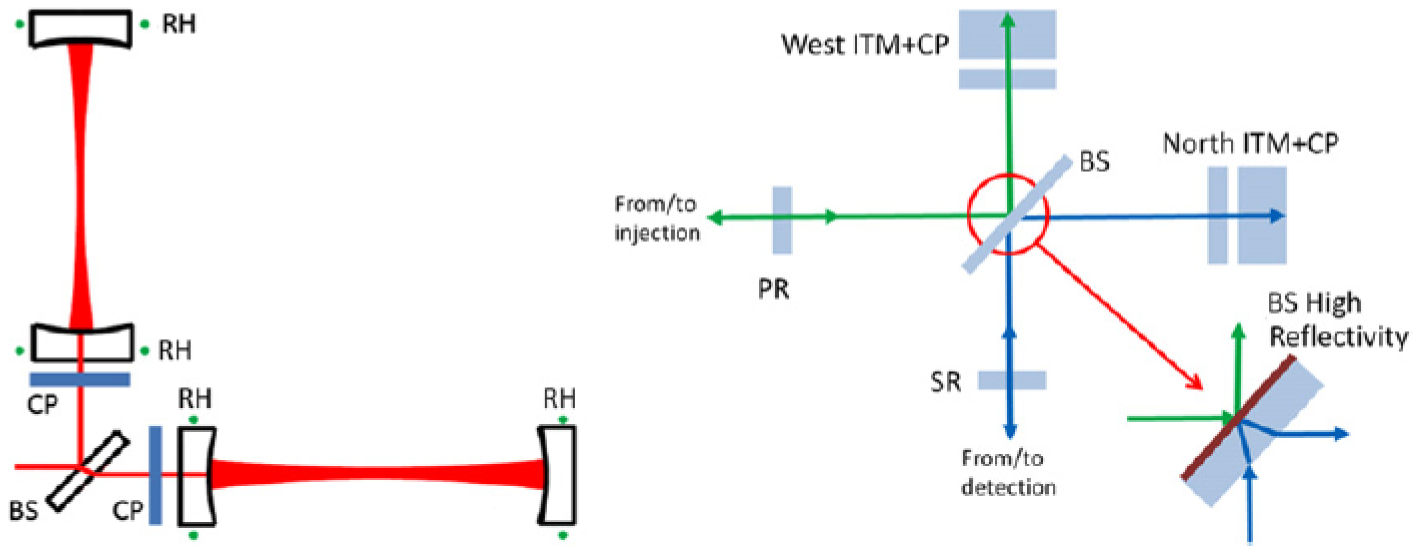

Figure 6. Left: actuation scheme of the AdV TCS: blue rectangles represent the CP (heated by the CO_2 lasers), while the green dots around the test masses are the RH. Right: conceptual layout of the HWS probe beams in the recycling cavity. For the sake of clarity the beams have different colors, but the wavelength is the same.

(Roma TV)

Thermal Compensation

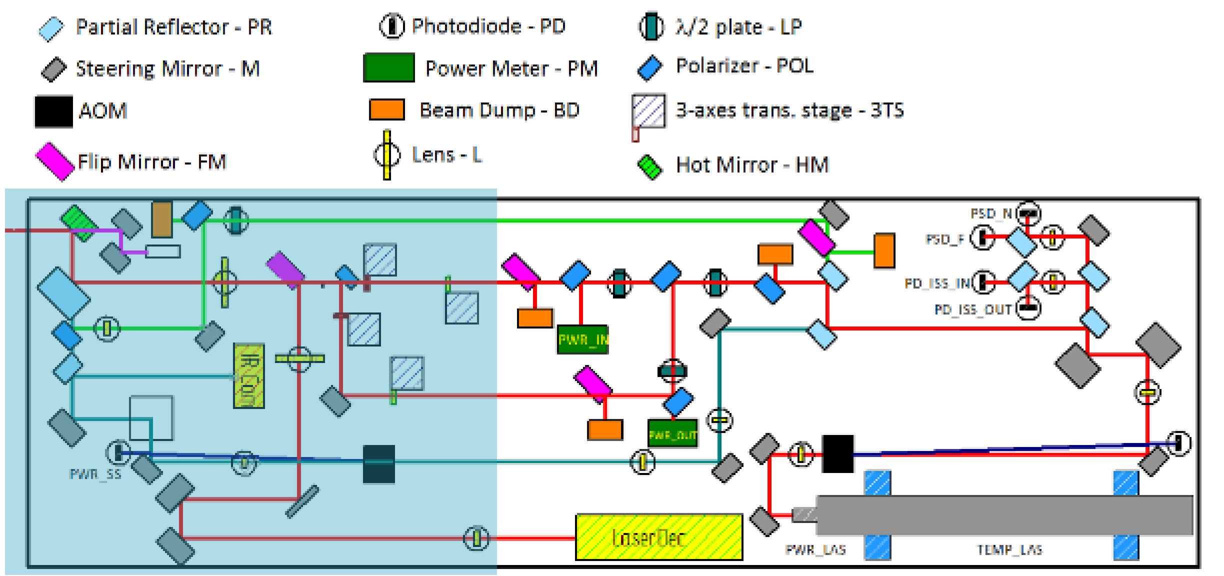

Figure 7.8: *Current layout of the CO_2 laser projector optical table. The shaded area shows the portion of the bench that needs to be modified to cope with enlarged beams.*

Scattered Light

Stray light is laser light in the interferometric antenna that does not follow the designed path.

Can recombine with the main beam after probing the position of different structures outside of the intended path, thus causing spurious information to enter the detection port.

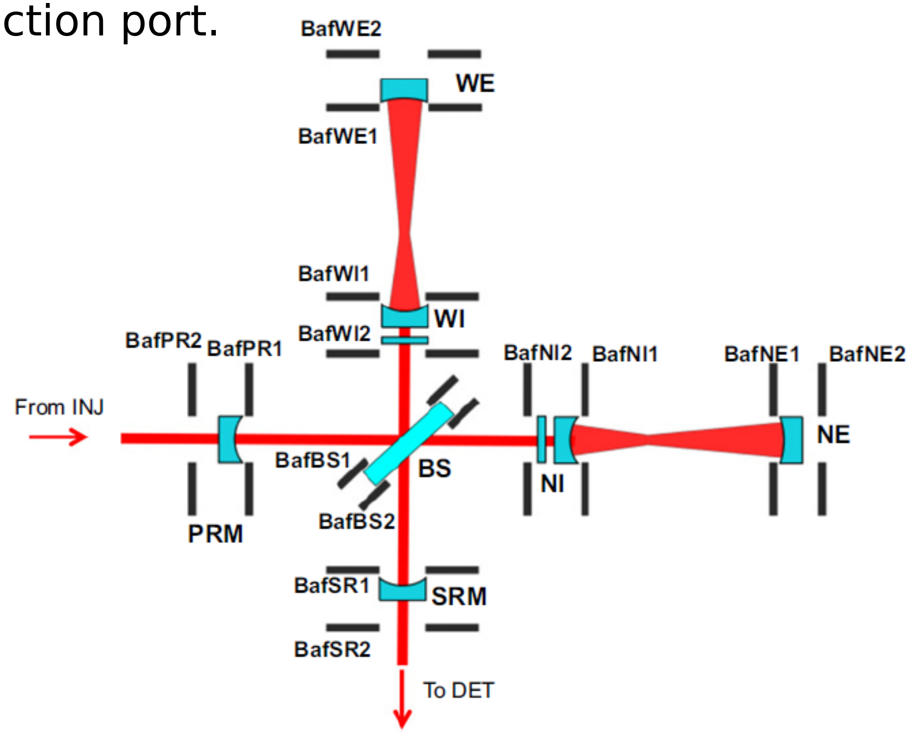

Figure 21. Schematics of the baffles suspended to the core optics-related SA. 320 baffles are welded to the pipes in the long arms, not shown here.

Summary

- High power creates complications for Advanced Virgo, and will do the same for Advanced Virgo +
- Lots of possible research topics to help address these issues.