Virgo Upgrades
Toward Virgo+

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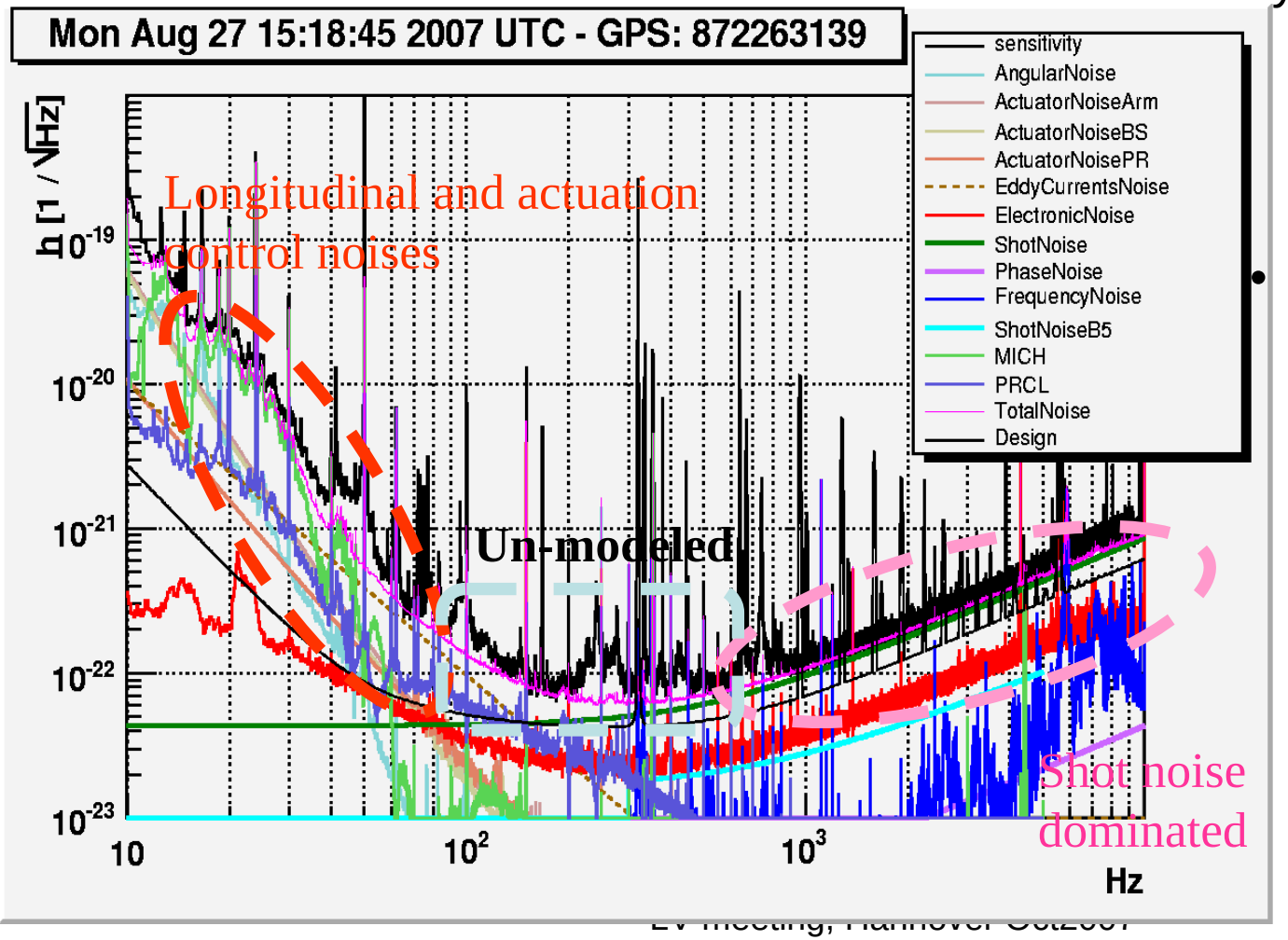
Upgrades Motivations

- The motivations of these upgrades (including the Virgo+ packages) are (obviously) science-driven
  - To understand it let start from the current sensitivity and budget noise

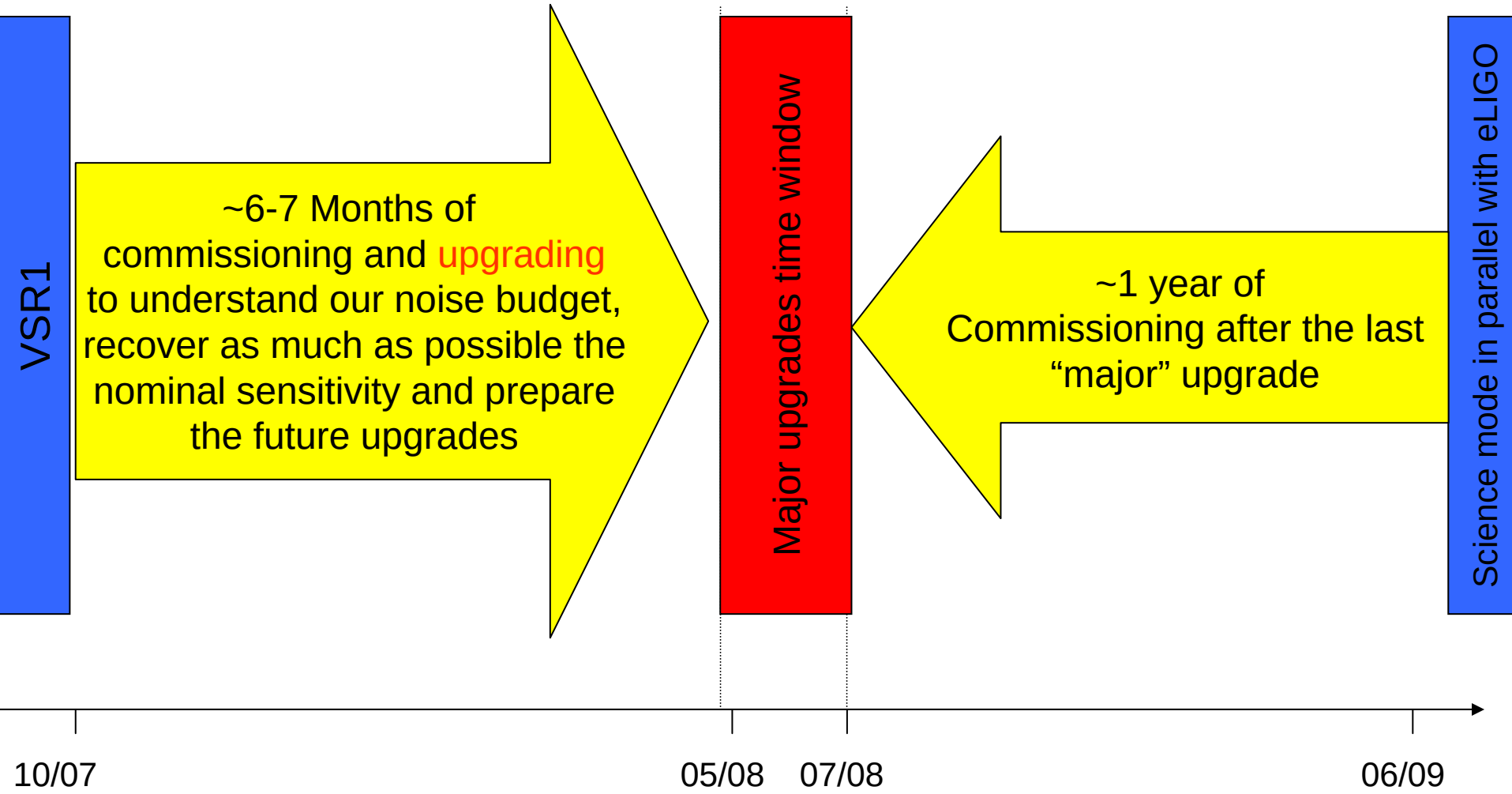


- To reduce these noise sources we need:
  - Commissioning
  - Upgrades

Proposed strategy

- Virgo+ needs a series of preliminary upgrades interlaced with the commissioning activity
  - Coil drivers, thermal compensation, fast centering quadrant PHD, …
    - Part of them are described in the Virgo commissioning talk
- The Virgo+ upgrade strategy should respect the following
  - Aim:
    - To maximize the detection probability
      - To maximize the coincidences with eLIGO
  - Constrains:
    - Need of an intense and “enough long” commissioning after VSR1 to understand the low-medium frequency noise of Virgo
    - Have an enough long (~1 year) post-upgrade commissioning period
    - Be back in science mode in (middle) 2009
    - Have a Virgo+ sensitivity comparable with eLIGO in a wide frequency range

Plan Construction

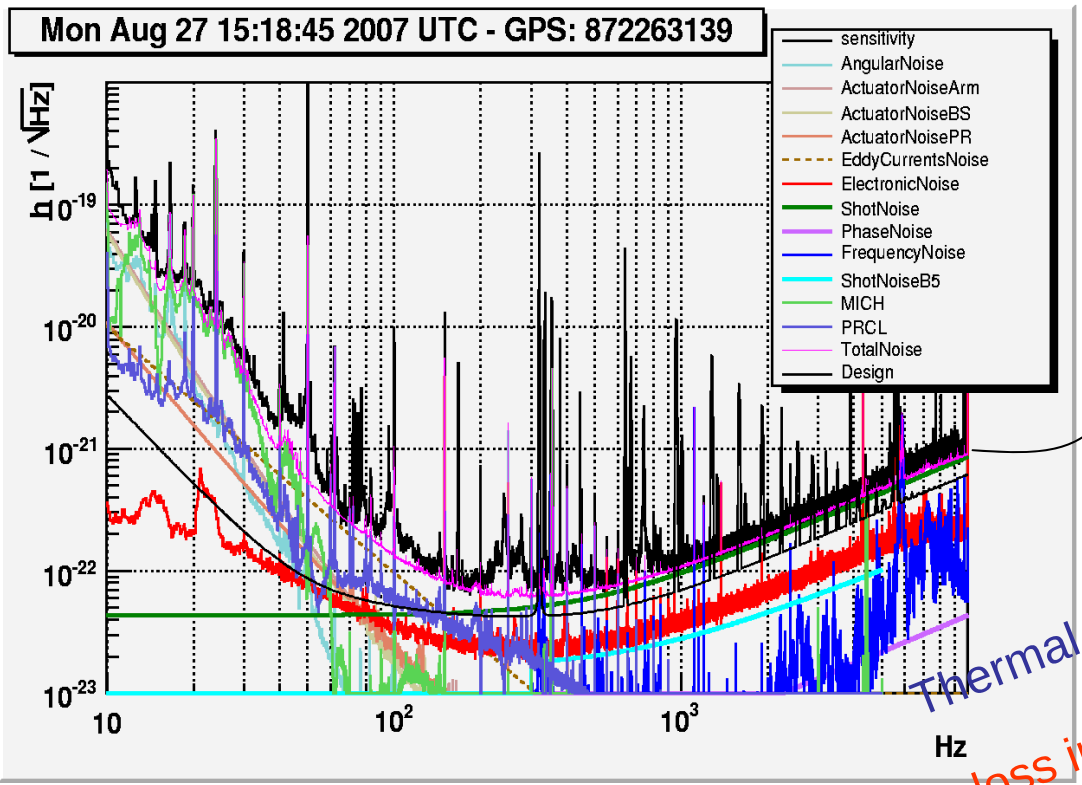


Post VSR1-Commissioning (2007-early 2008)

- Aim
  - Understanding the machine and reduce the noises that could affect the designed Virgo+ upgrades
- Foreseen activities:
  - See Edwige's talk

Virgo+ upgrades

- Let start again from the noise budget:



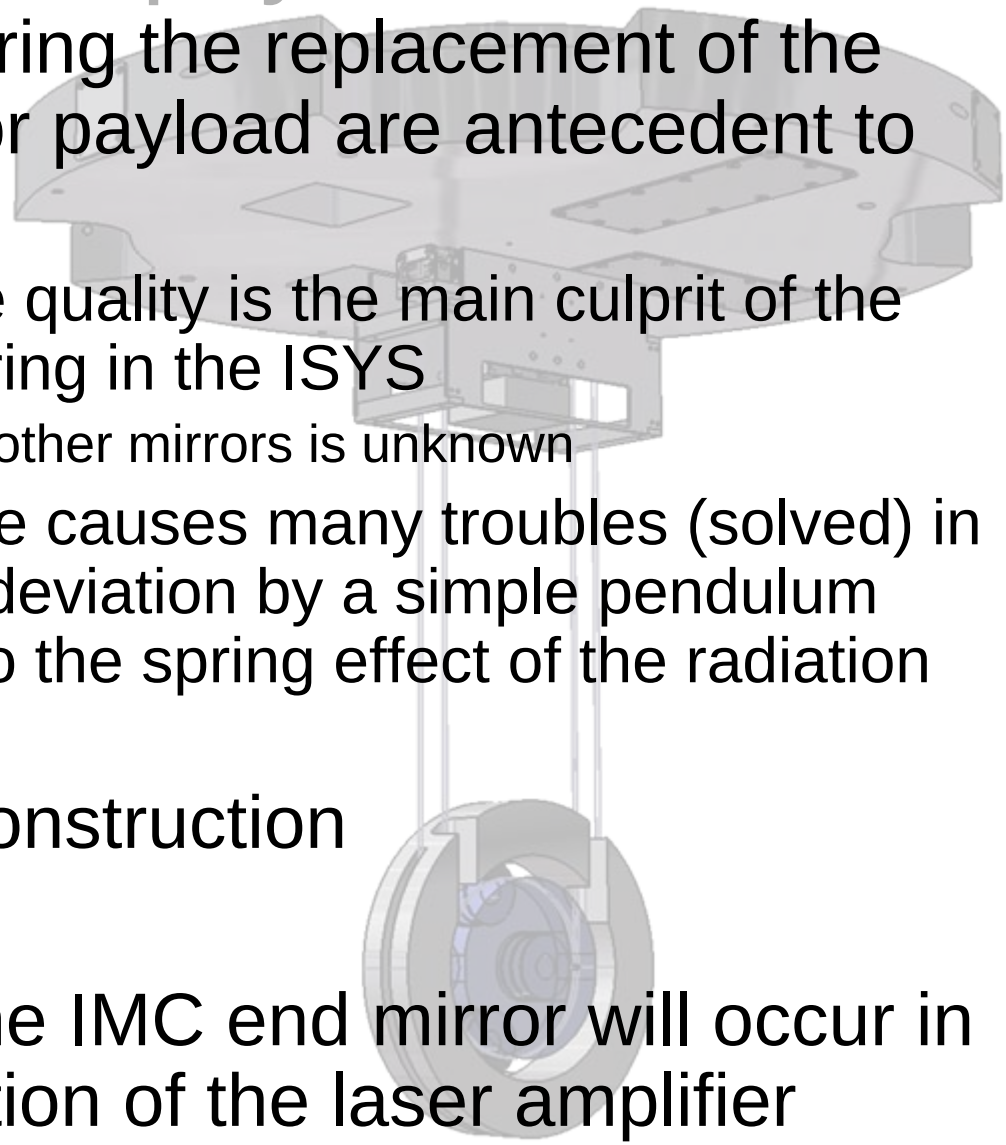
- Causes of the discrepancy:
  - Lower power recycling factor
  - OMC matching
  - Lower injected power
    - Laser max power 21W
    - Laser power at the LB exit: 17W
    - Currently injected power 12.5W
    - Power after the IMC: 8W

Thermal effects

Power loss in the IMC

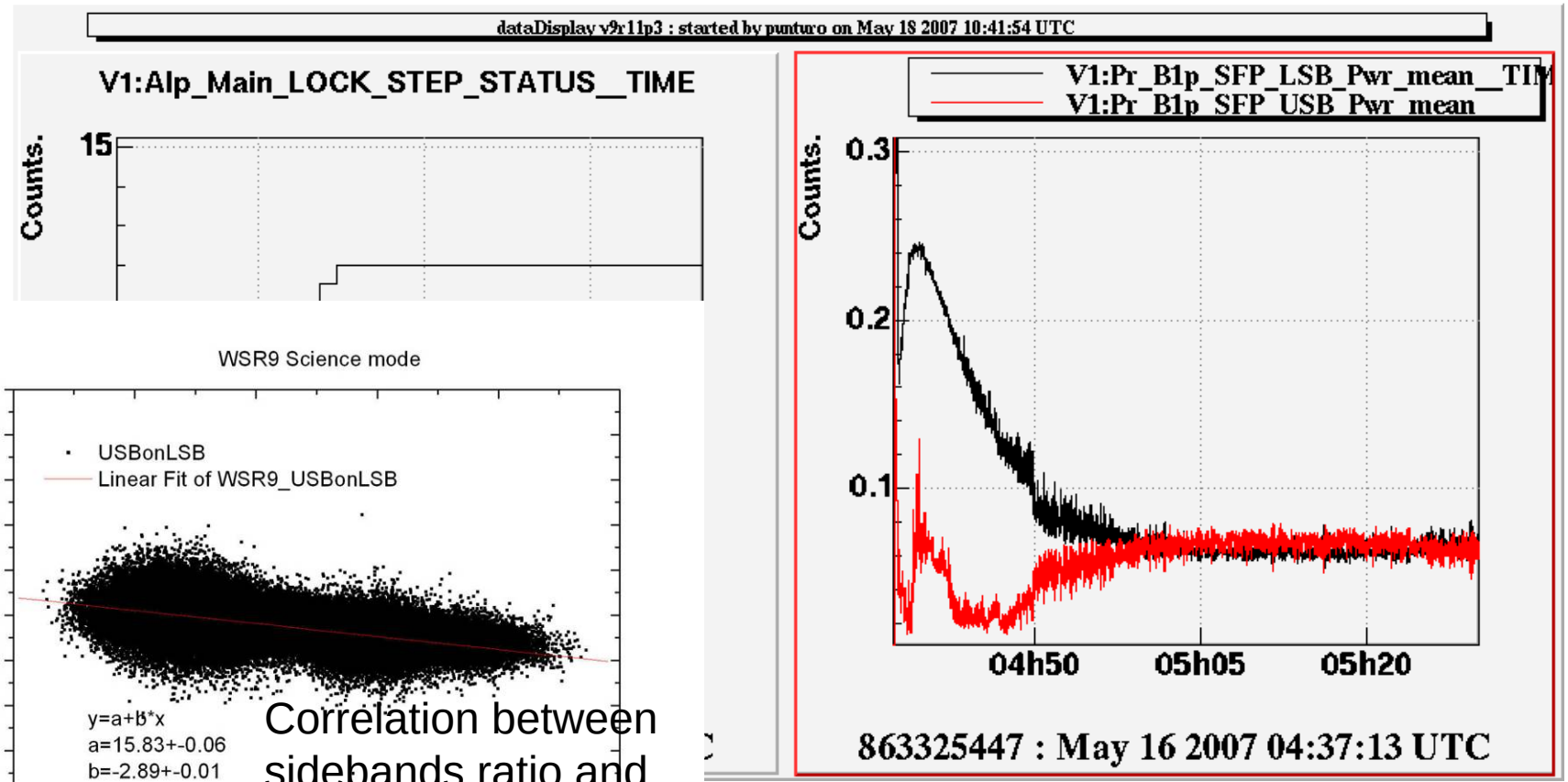
New IMC payload

- The motivations requiring the replacement of the current IMC end mirror payload are antecedent to the VIRGO+ project:
  - Certified bad substrate quality is the main culprit of the power loss and scattering in the ISYS
    - The contribution of the other mirrors is unknown
  - The very light substrate causes many troubles (solved) in the control due to the deviation by a simple pendulum transfer function and to the spring effect of the radiation pressure
- New payload under construction
- New mirror polished
- The replacement of the IMC end mirror will occur in parallel to the installation of the laser amplifier



Thermal lensing and sidebands

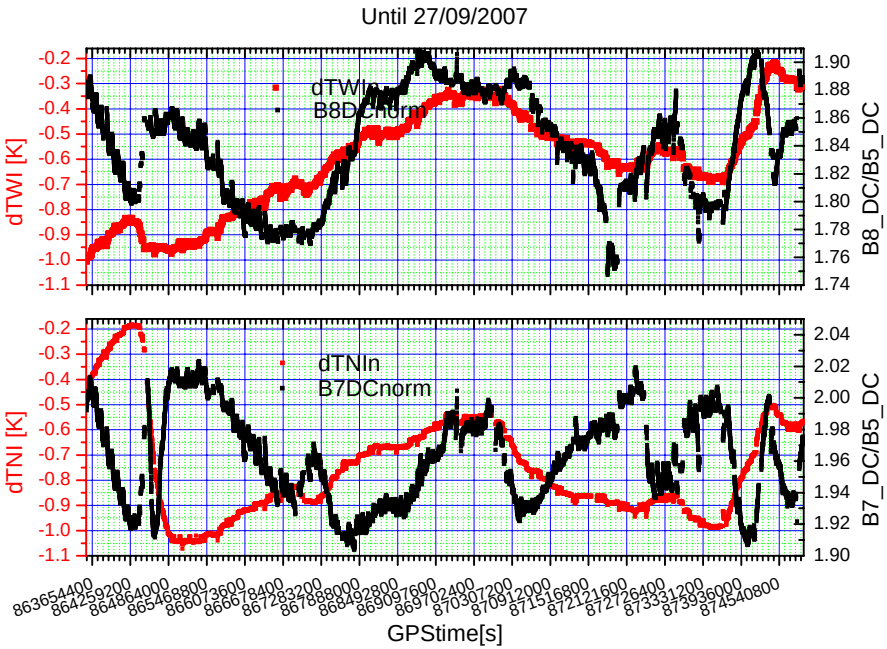
- The main limitation to the injected power increase is the thermal lensing in the input mirrors

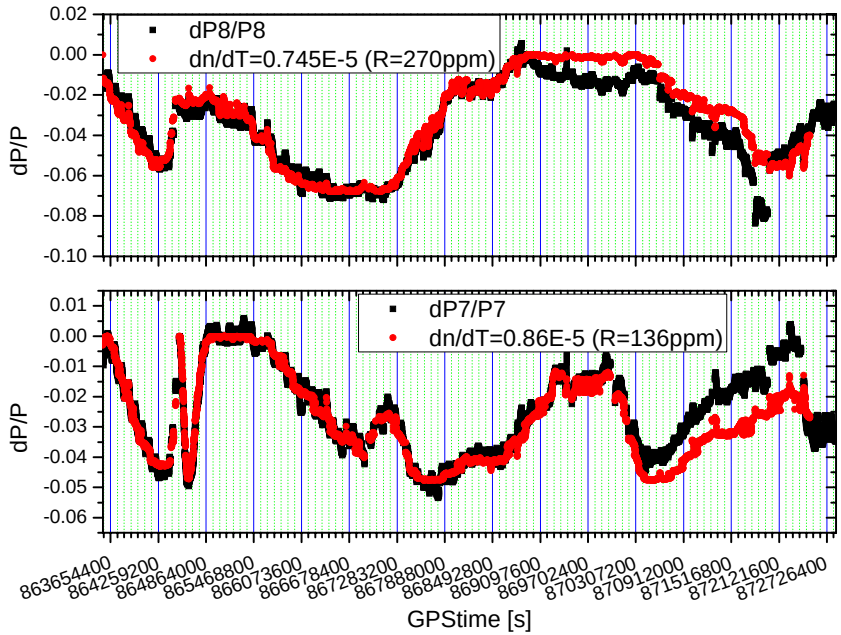


Correlation between sidebands ratio and injected power

Mirror temperature measurement

- The mirror resonant mode permitted to track the input mirrors temperature during all the VSR1 run
- Through the etalon effect in the input mirror we has been able to better characterize the optical properties of these mirror

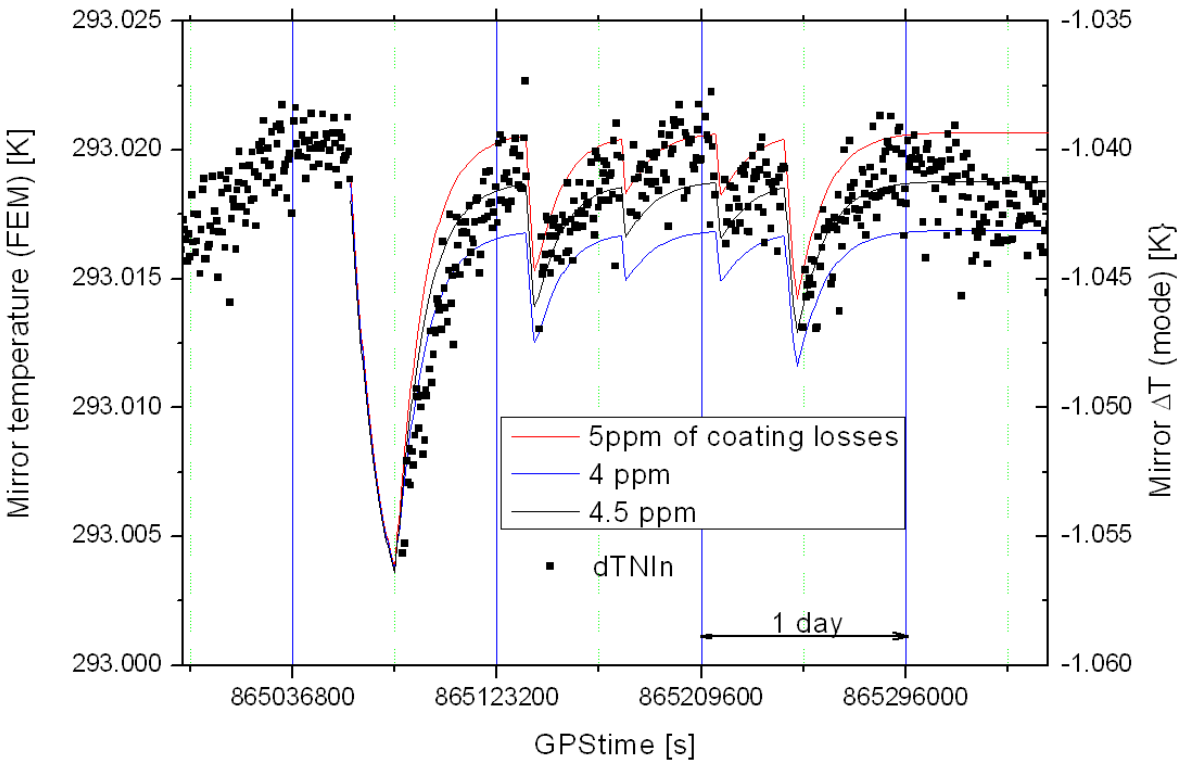




- We measured the dn/dT and the AR coating residual reflectivity, but what is more important the absorption of the input mirrors

Absorption excess

- Suprasil-SV is expected to have 0.7ppm/cm absorption and the mirror coating should have 1.3ppm/cm
- Using the thermal mode technique, measuring the mirror temperature increase during the lock and comparing with the expectation given by an “ad hoc” FEM, we obtain:



NI: (ppm) 4.5 ±0.50 (stat)
± 0.23 (laser power)
+- 0.15 (finesse fluctuation)
+- 0.38 (calibration)

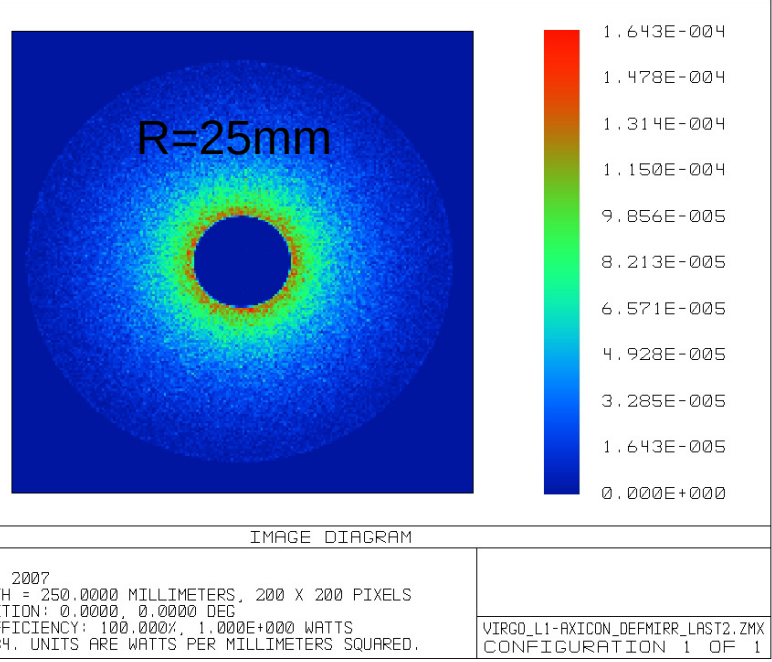
WI: (ppm) 6.7-7ppm but larger error because of some measurement problem

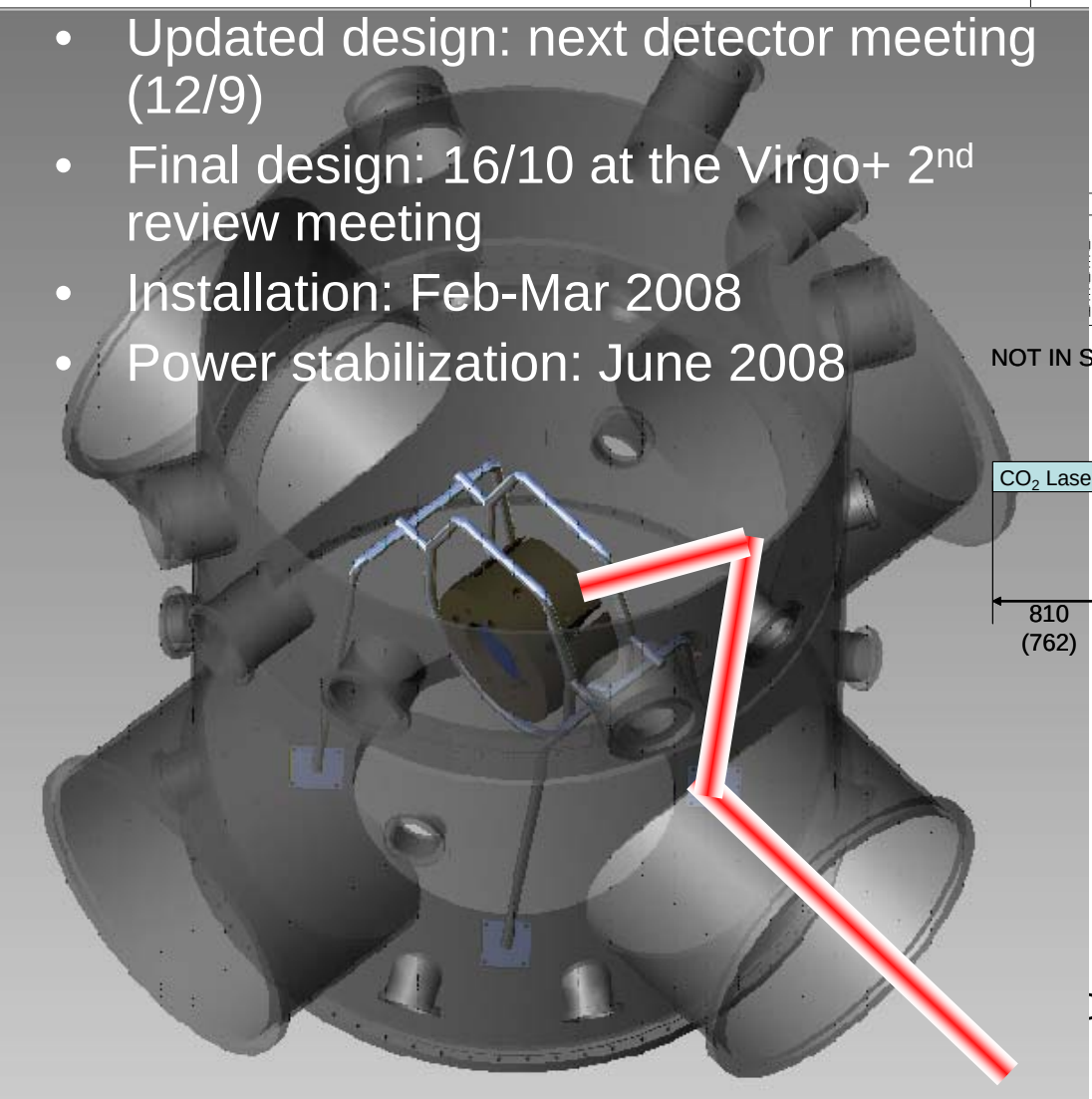
Thermal lensing mitigation

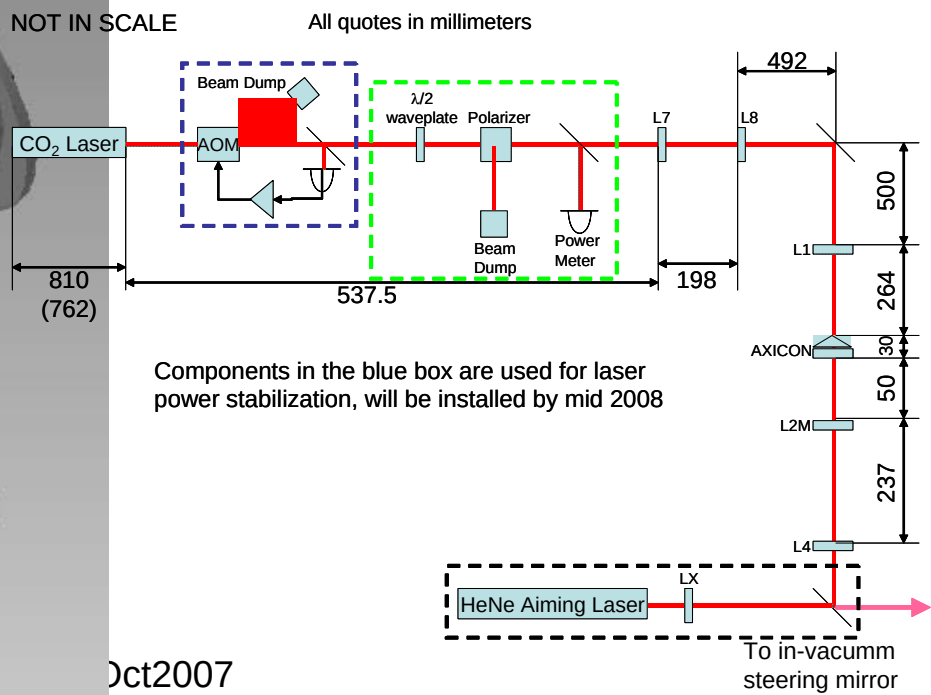
- The first action to reduce the thermal lensing is the reduction of the absorbed power:
  - Input mirror cleaning
    - Under preparation with the experts
      - Cleaning attempt using commercial cleaning polymer (end of Nov)
  - “Final solution”: TCS (Thermal compensation system)
    - Solution already adopted in LIGO
      - Similar principle, but original implementation because of different geometry
      - Implementation expected in Feb-Mar2008
    - Error signal generation
      - Use a pin-hole mirror and a couple of PHD
      - Implementation expected before the end of 2007

Status TCS

- Preliminary Design presented at the June detector meeting
- Updated design: next detector meeting (12/9)
- Final design: 16/10 at the Virgo+ 2nd review meeting
- Installation: Feb-Mar 2008
- Power stabilization: June 2008



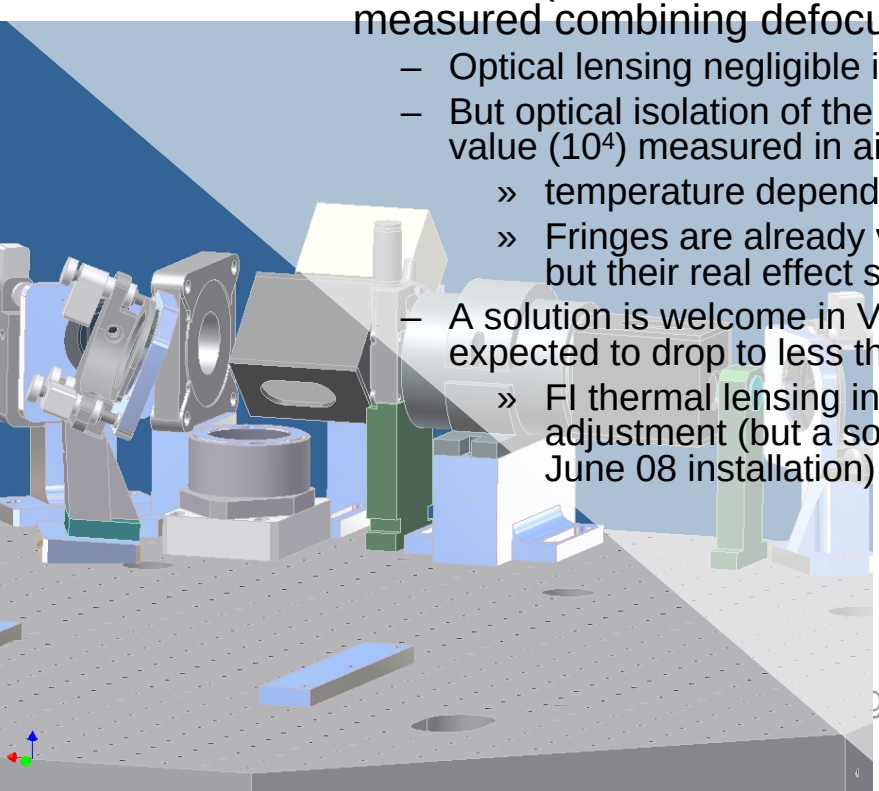


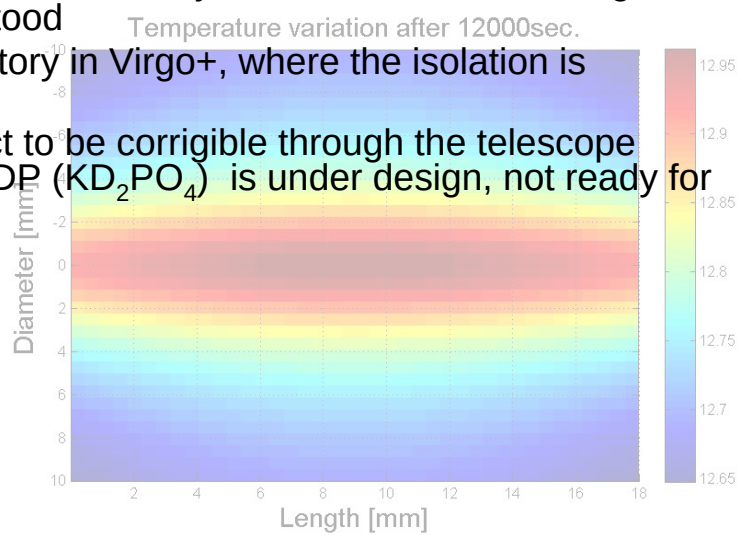


Oct2007

Thermal related upgrades

- A set of upgrades are foreseen to mitigate the other thermal effects we are suffering in Virgo
- The installation of these upgrades, before the increase of the laser power, will simplify our transition to the Virgo+ design
  - Remote tuning of the injected laser power
    - A remotely controlled $\lambda/2$ waveplate will be installed in the laser bench to adjust the injected power according to the detector needs
  - Remote adjustment of the suspended Faraday Isolator
    - Our TGG (d=20mm, h=18mm) crystal shows small losses (159±10 ppm/cm) measured combining defocusing measurement and *ad hoc* FEM modeling
      - Optical lensing negligible in Virgo
      - But optical isolation of the suspended FI is reduced (10^3) in vacuum respect to the value (10^4) measured in air (in tower)
        - » temperature dependence of the Verdet's constant demonstrated by FEM
        - » Fringes are already visible in the ISYS caused by the ITF back reflected light, but their real effect still to be understood
      - A solution is welcome in Virgo, but mandatory in Virgo+, where the isolation is expected to drop to less than 10^2.
        - » FI thermal lensing in Virgo+ is expect to be corrigible through the telescope adjustment (but a solution using DKDP (KD_2PO_4) is under design, not ready for June 08 installation)

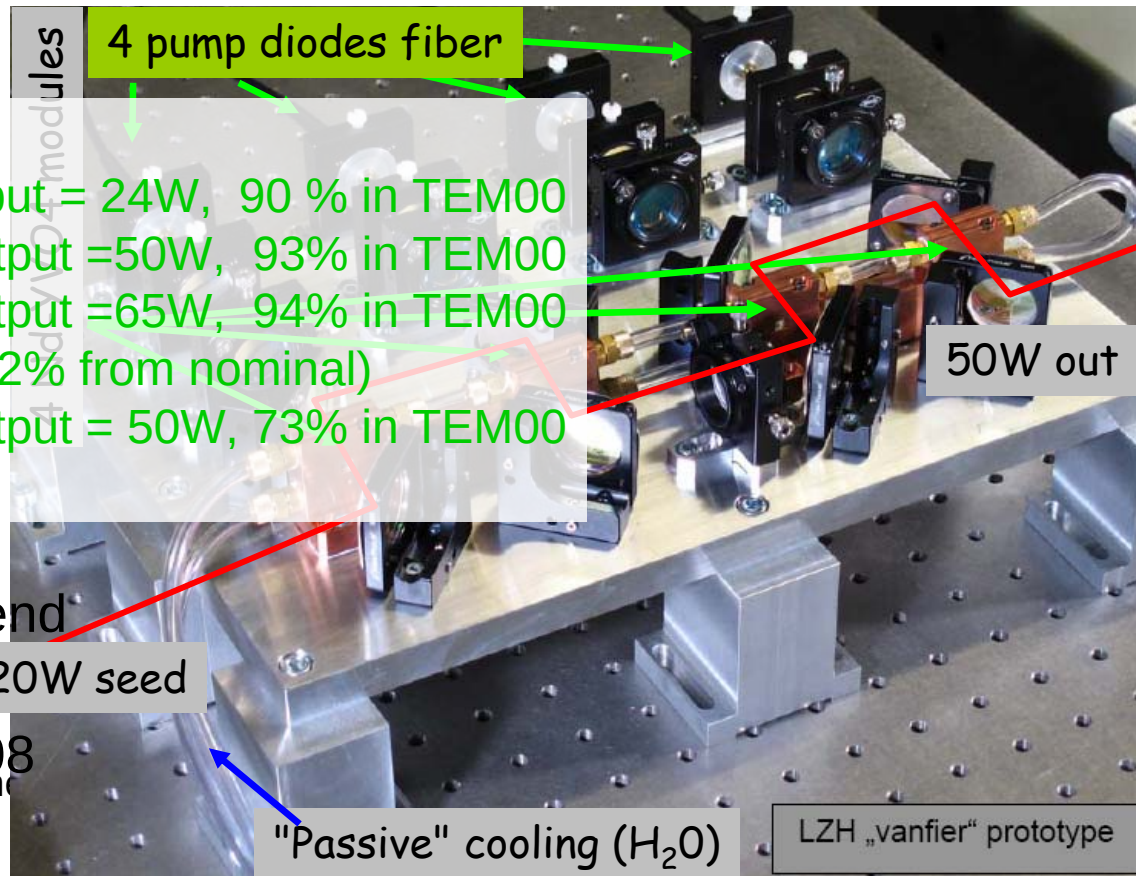




Virgo+ upgrade: Laser Amplifier

- The new laser amplifier is the core upgrade that will permit the reduction of the shot noise at high frequency below the nominal sensitivity
- It is a “standard” device (produced by LZH/GEO and adopted also in eLIGO)

For nominal amplifier pumping
Seed = 1W, amplifier output = 24W, 90 % in TEM00
Seed = 10W, amplifier output =50W, 93% in TEM00
Seed = 20W, amplifier output =65W, 94% in TEM00
Reduced amplifier pumping (72% from nominal)
Seed = 20W, amplifier output = 50W, 73% in TEM00



- Already available, commissioning phase 2 will end in Jan08
  - Installation in May-June 08

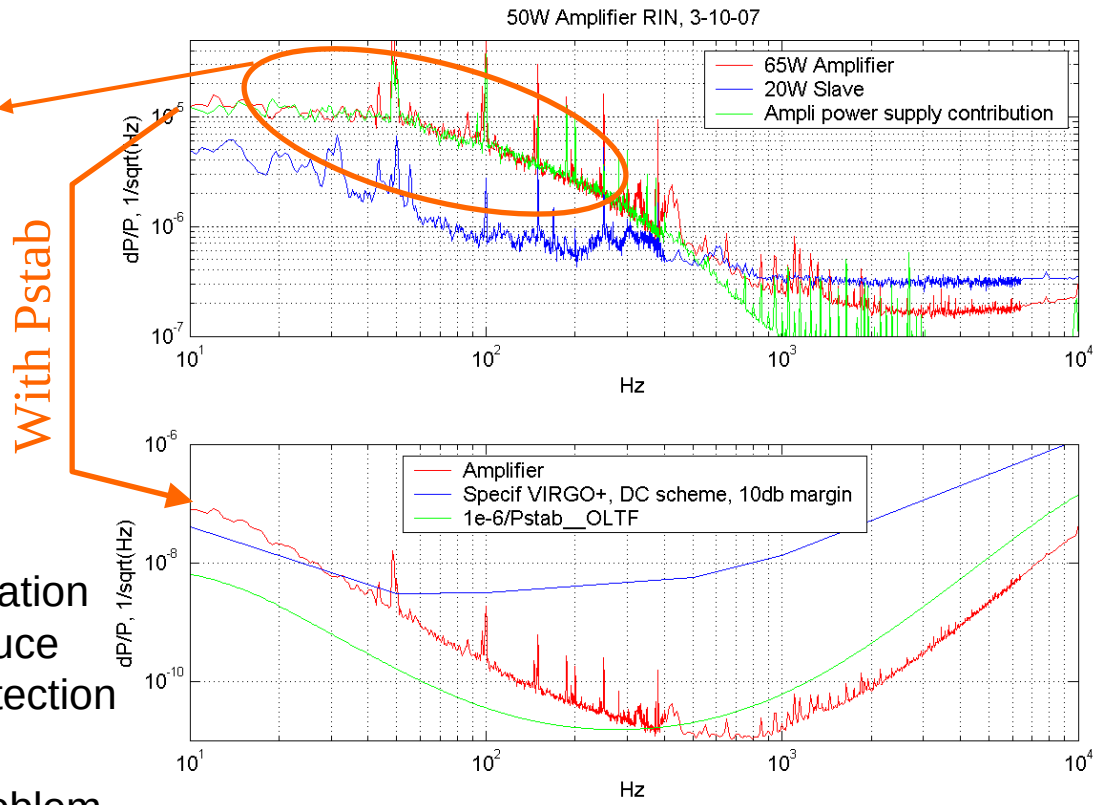
LV m

Laser Amplifier characterization

- The laser amplifier in under characterization at the Nice-OCA lab

Extra RIN below 300Hz, dominated by present pump current noise
New power supplies (10times quieter) will lower this RIN contribution

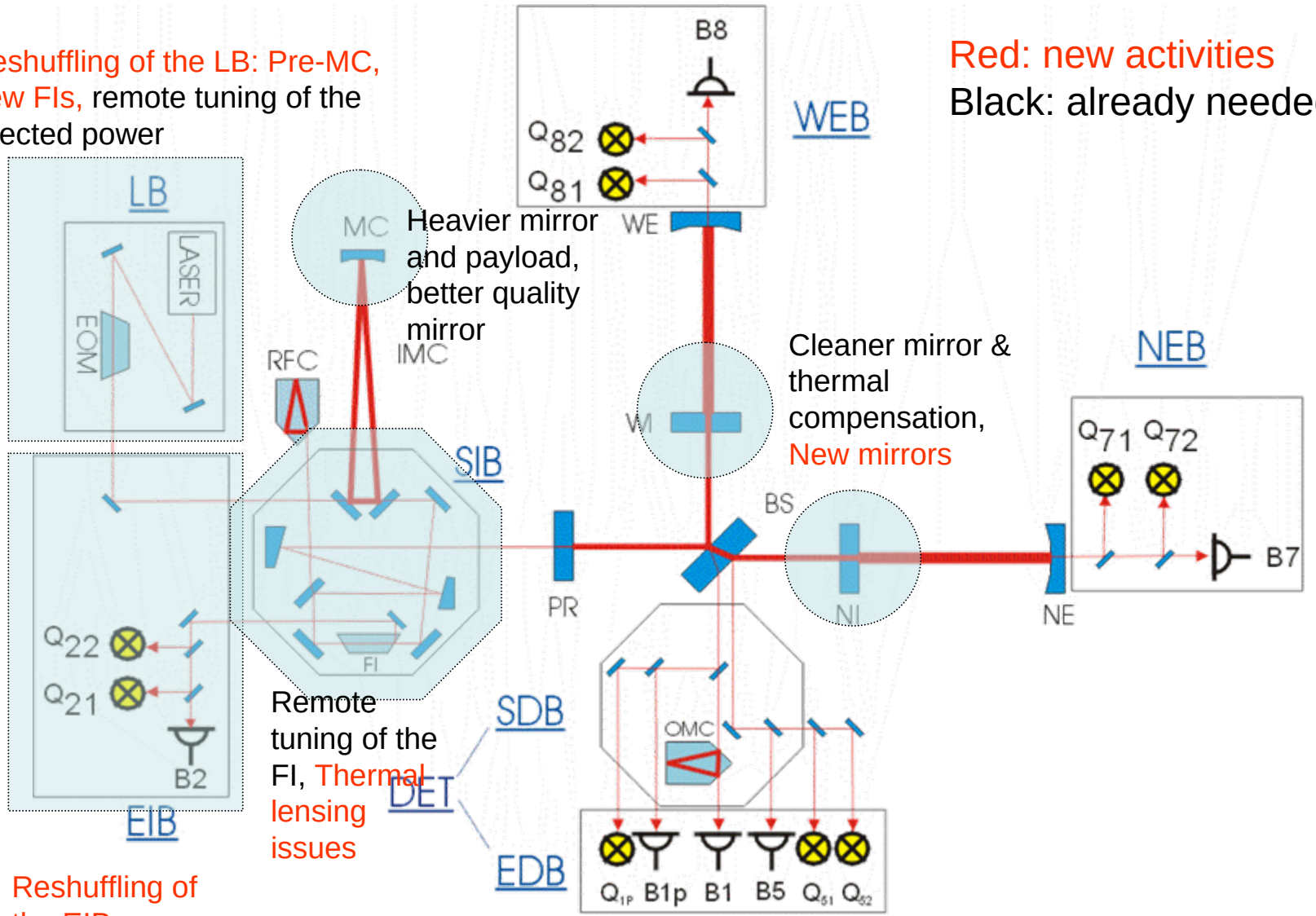
Pstab gain can be adjusted if mandatory *(higher gain below 100Hz)*



- RIN @ 6.26MHz
  - Technical noise at the modulation frequency is expected to reduce the Virgo+ sensitivity (AC detection scheme) by 23%
    - PMC could solve this problem
- Beam jitter:
  - Excess beam jitter measured, but not caused by the Amplifier
    - Beam path between the slave laser and the amplifier should be the culprit
    - More investigations

Cascade effect on the ITF

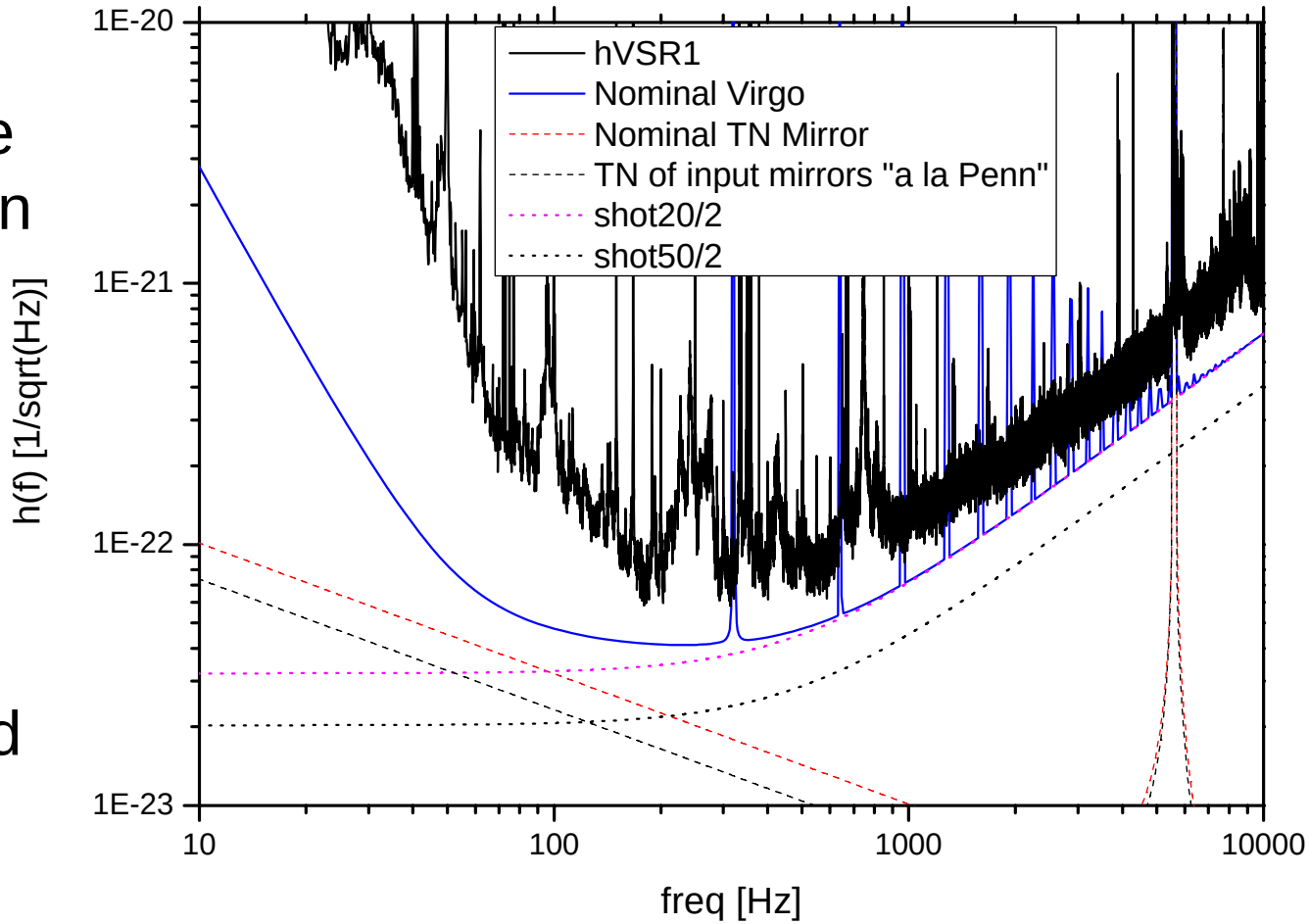
- Obviously the laser power increase will affects all the ITF



50W amplifier sensitivity gain

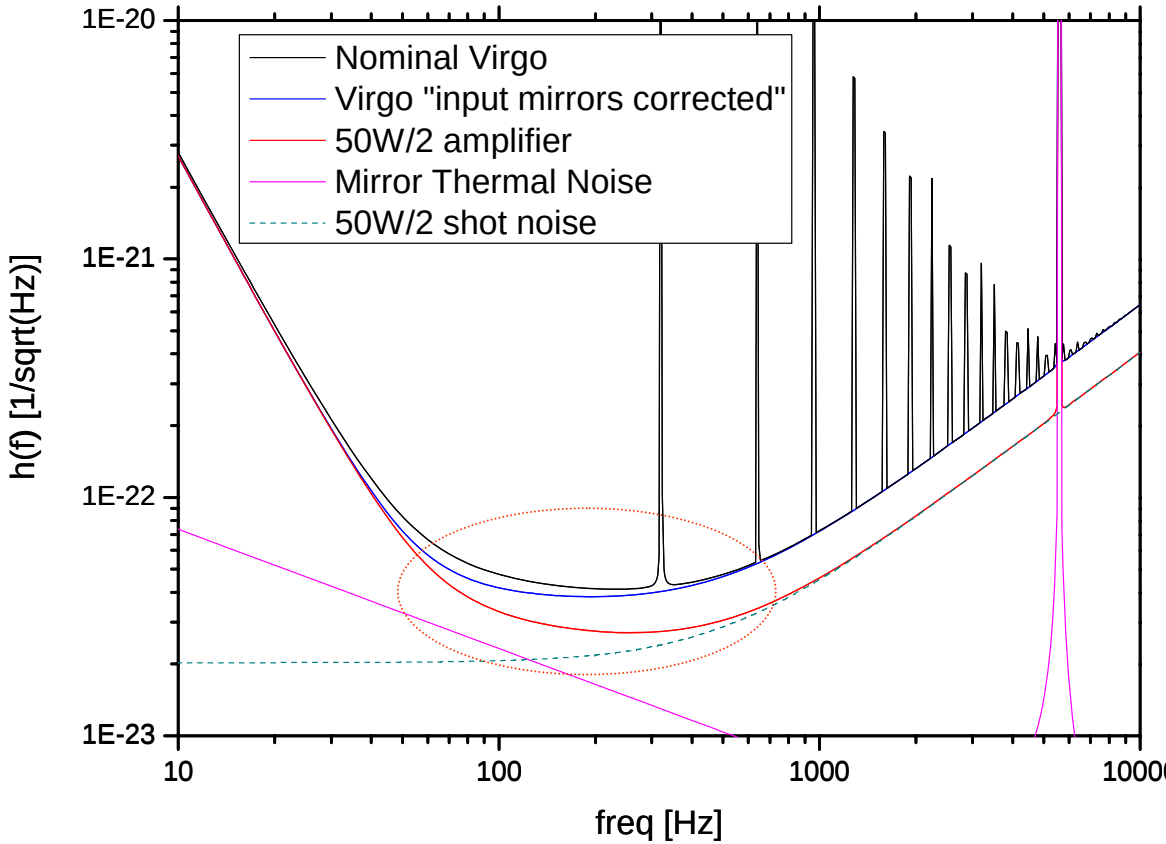
- For a “conservative” evaluation of the sensitivity, we always consider ½ of the laser power injected in the ITF

- According to the loss angle model of Penn & coll. (ϕ(f)), since the Virgo input mirrors are in Suprasil, our mirror TN is overestimated



“Minimal” Virgo+ sensitivity

- Considering to implement “only” the high power laser package, the expected sensitivity becomes



NS-NS (average) distance:
15Mpc

BH-BH (average) distance:
68Mpc

In this configuration, we don’t use all the potentialities of the ITF in the central region

Playing with the Finesse it is possible to improve the sensitivity in that region crucial for the NS-NS

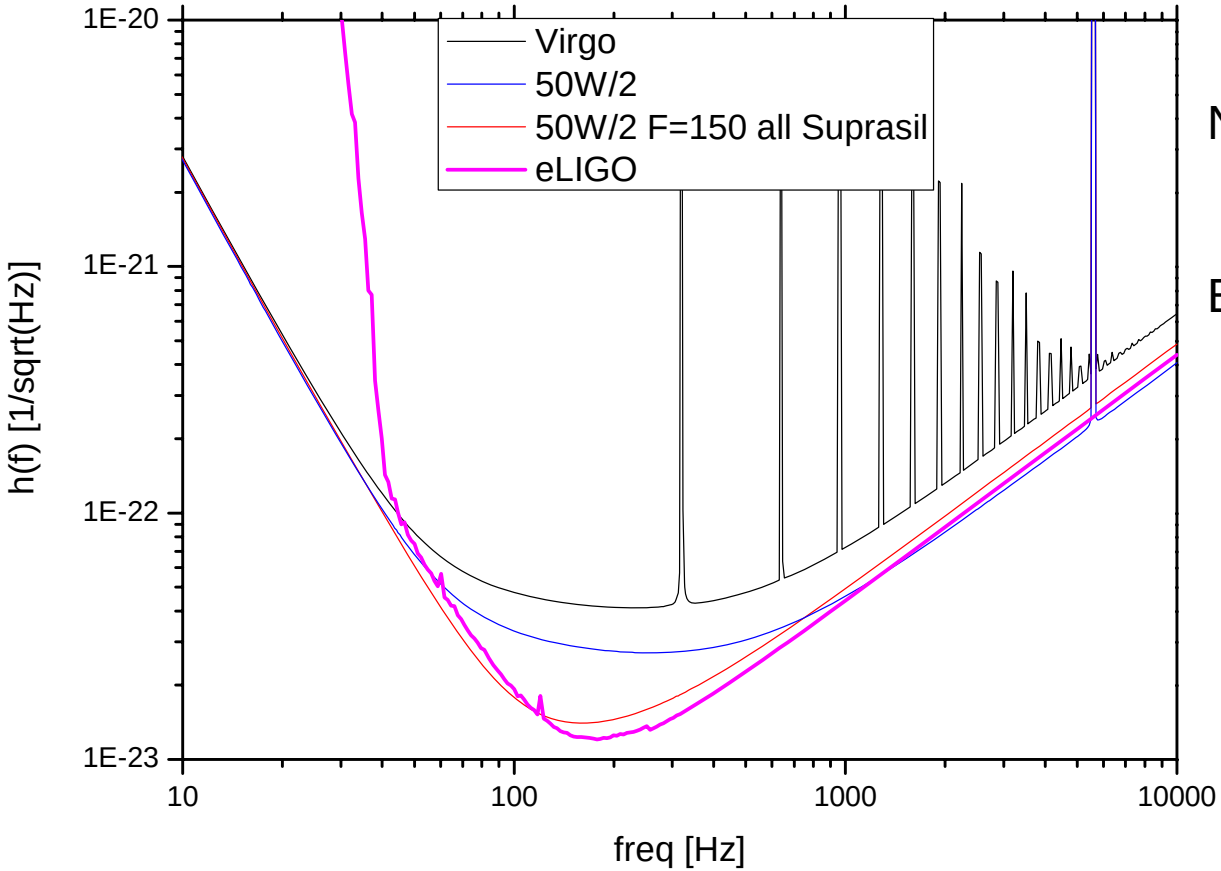
New mirrors… a list of motivations

- Current mirrors are probably polluted by the installation procedure and a cleaning operation, effected in tower, probably will not recover the full performances
  - The new mirrors could be delivered with the protection film, to be removed at the end of the installation
- The magnets in the input mirror are mounted with parallel polarity, meanwhile the minimization of the magnetic dipole requires pairs with anti-parallel orientation. Furthermore the magnets are a factor 5 more intense of the original design and this increase the coupling with the environmental magnetic noise

New mirrors… a list of motivations

- The end mirrors have no anti-reflecting coating in the back face. This causes (measured) multiple beam scattering in the end benches.
- Replacing the input mirrors we can increase the reflectivity up to R=95.9% to obtain a Finesse of 150 and largely improving the sensitivity
- Replacing the end mirrors we can use Suprasil-SV to further reduce the thermal noise (and cure the AR coating absence)
- Replacing all the mirrors we can
  - have mirrors with a better flatness (source of scattering and losses, according to the simulation)
  - Use the new Ti doped coating for a further TN reduction

New mirrors: effect on the sensitivity

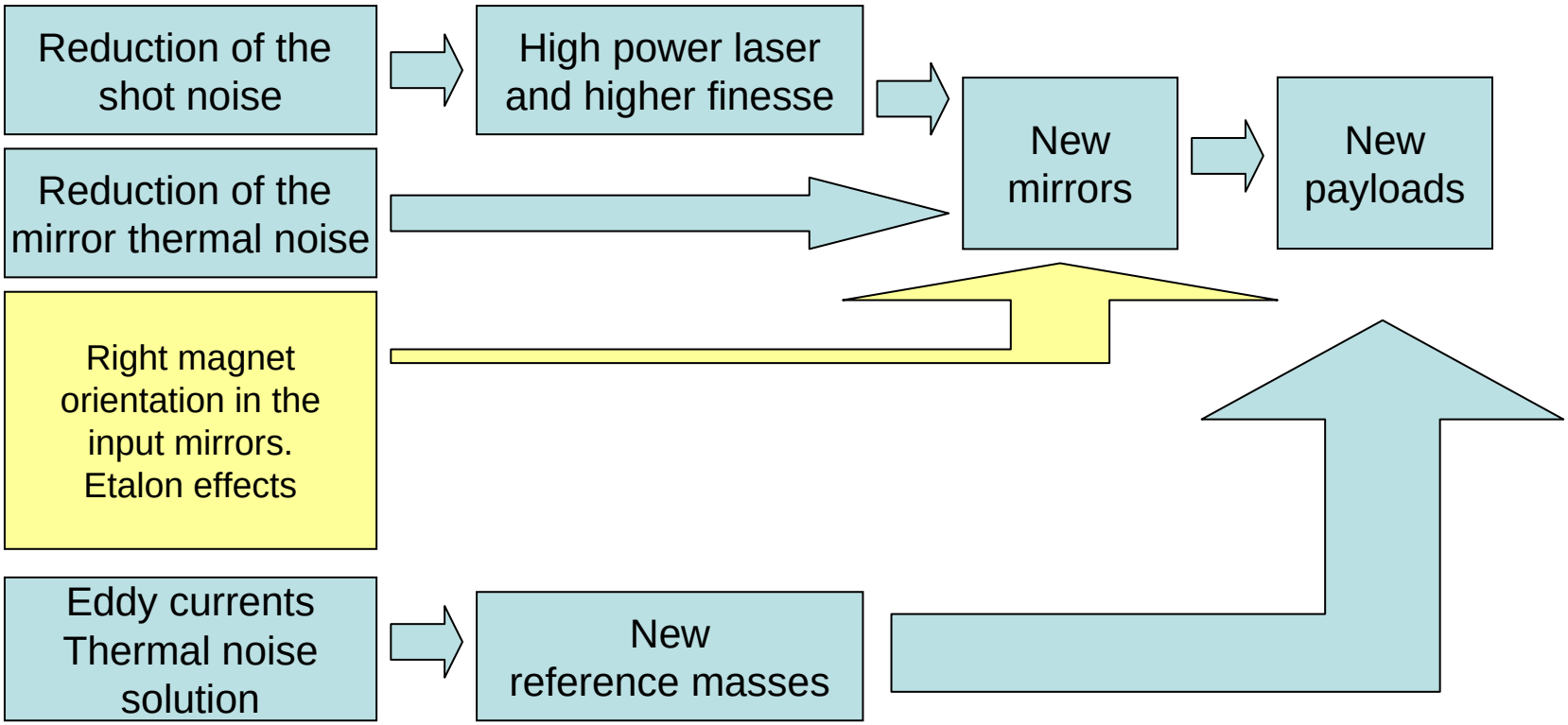


NS-NS (average) distance:
28Mpc

BH-BH (average) distance:
142Mpc

- The drawback of an higher finesse is an increase of the losses and then a minor power recycling factor
  - Sensitivity decrease at high frequency

New payloads



- The need to have new payloads is driven by many motivations
  - This triggered our attempt to mount monolithic suspensions in Virgo+

Virgo+ upgrade: monolithic suspensions

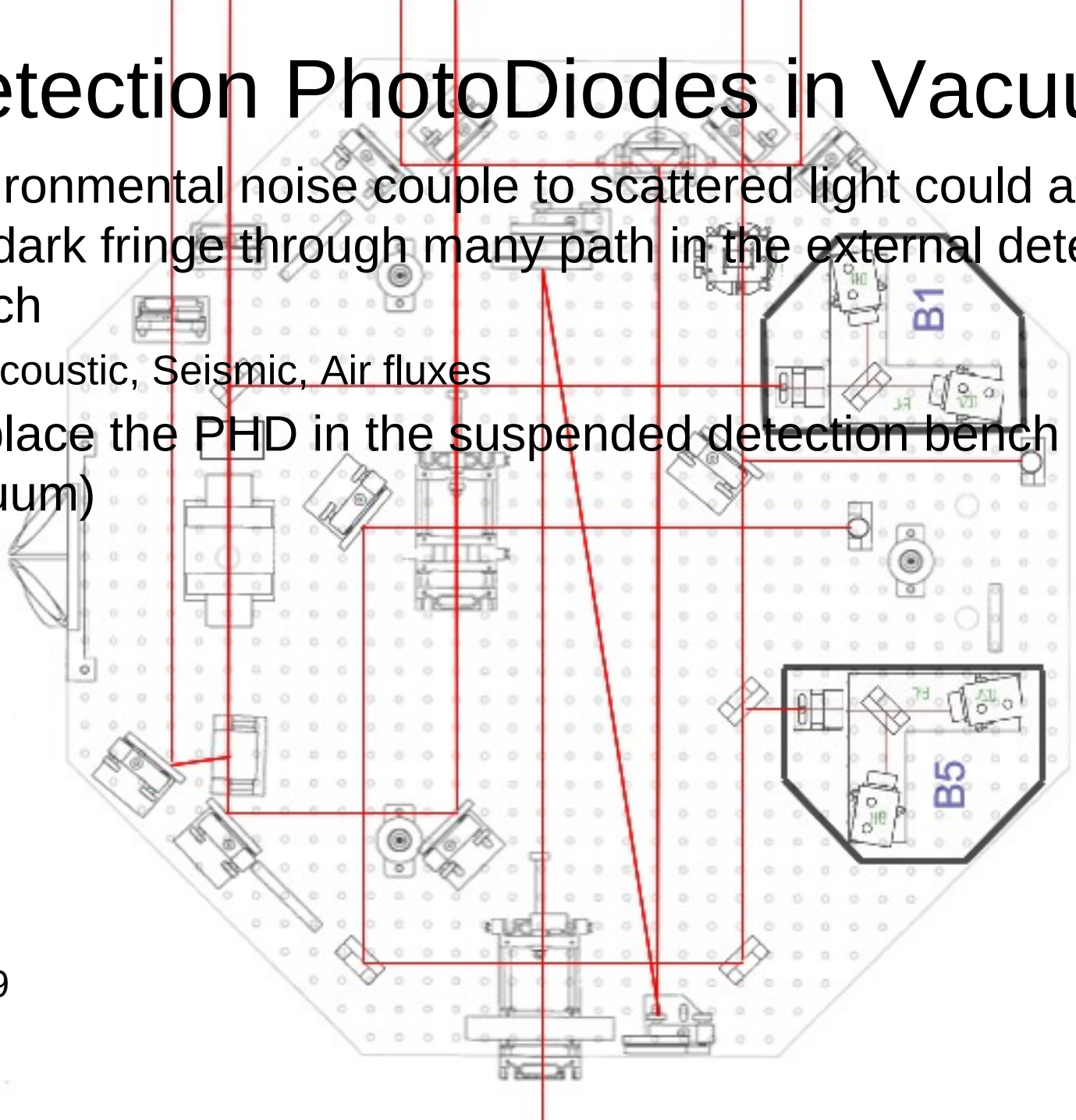
- Monolithic fused silica suspension development is still an heavy activity in Virgo but the engineering of the solution is still far
  - Incompatible with the May 2008 shutdown and mainly with the June 2009 data taking
- The replacement of the current payloads with ameliorated standard steel solution is still an open possibility
  - Decision (I hope) soon

Control & DAQ electronics

- New DSP development in Pisa (important for the low frequency part), and a series of upgrades of the DAQ electronics has been foreseen and supported by EGO
- Design activity progressing in Annecy:
  - Development of new **timing system** (obsolescence of the hardware)
    - GPS receiver/signal generator (tested, patched and ready; more boxes to be purchased)
    - TDBox (Timing distribution box): design ready for production
    - MUX/DeMUX: router for the optical links between TOLM and ADC boards. Prototype available. Production and tests on September-October 2007
    - TOLM: A prototype available and used for ADC tests, TOLM /DSP interface tested. Two versions expected to be produced: PMC and PCI64 formats. Production expected for the March 2008.
  - **ADC**: ADC selection done (AD7674 18bit @ 800kHz); 16 differentials channels with analog anti-alias filter at 400KHz. Digital anti-alias filters in embedded DSPs(4 channels per DSP ADPS-21262 @150MHz) Several production steps foreseen, but final production expected to end in March-April 2008.
  - Use of **regular PCs**: Tests have shown that the main Virgo control loop (photodiode readout and global control) could run up to 40 KHz on a commercial PC running a real time version of Linux. This will provide more computing resource for various control loops (global and local).
- Installation:
  - Expected in May 2008-July 2008

Detection PhotoDiodes in Vacuum

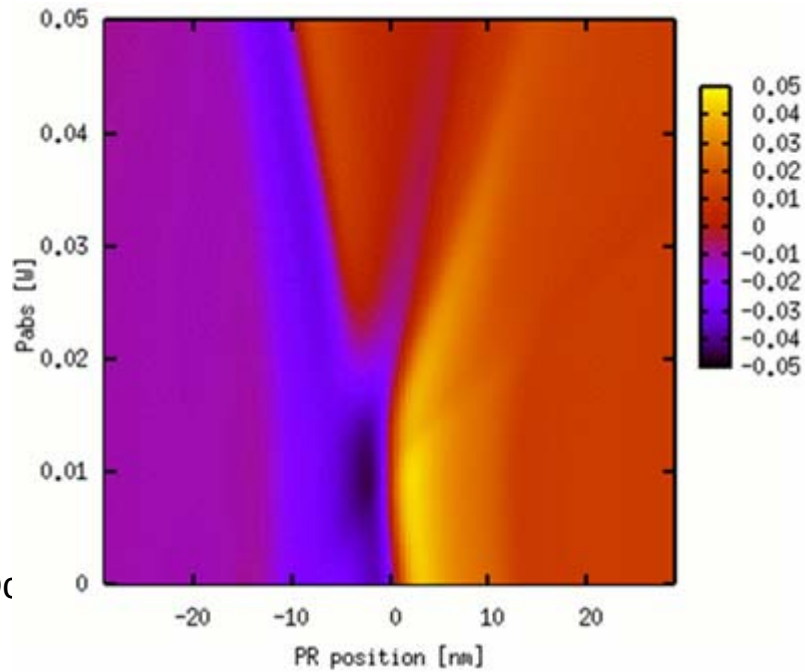
- Environmental noise couple to scattered light could affect the dark fringe through many path in the external detection bench
  - Acoustic, Seismic, Air fluxes
- Displace the PHD in the suspended detection bench (in vacuum)



Modulation frequency change?

- Virgo selected as modulation frequency the Anderson frequency
  - the 1st higher order mode (TEM1) of the Upper Sideband is resonant in the FP cavities when the fundamental mode of the carrier is also resonant in the FP cavities (Fmod=6.2643MHz)
  - Some alignment signal available in transmission of the long FP cavities
- This choice demonstrated to be unlucky
  - Bi and tri-instabilities in case of larger absorption in the input mirrors

PR longitudinal error signal for a double cavity with respect to the power absorbed by the Input mirror (Fmod =Anderson). As the thermal effect increases, a second zero appears in the error signal



…modulation frequency change?

- TCS should recover this effect, but other problems are related to the Anderson frequency (coupling between PRCL amd MICH DOF, optimal recycling length depending on doesn't correspond to the max decoupling of PRCL and MICH, optimal recycling length depends on the Finesse of the FP cavities,….)
- We are almost convinced that we must escape from the Anderson frequency, but the discussion is where to go?
  - Small displacement
    - Minor impact on the infrastructures, but real advantages?
  - Nominal frequency (Fmod=6.2709MHz)
    - both sidebands are anti-resonant in the FP cavities (sidebands have then the same properties of resonance in the FP cavities)
    - Many advantages, but major impact on the ITF infrastructures
      - We must displace one or more towers
      - 1 month of "installation" and longer recovery
      - Alternative alignment scheme still undefined
    - Further analysis needed, decisional point probably displaced to the end of November

Planning

Possible planning evolution