Beam Pointing Control system for Advanced Virgo

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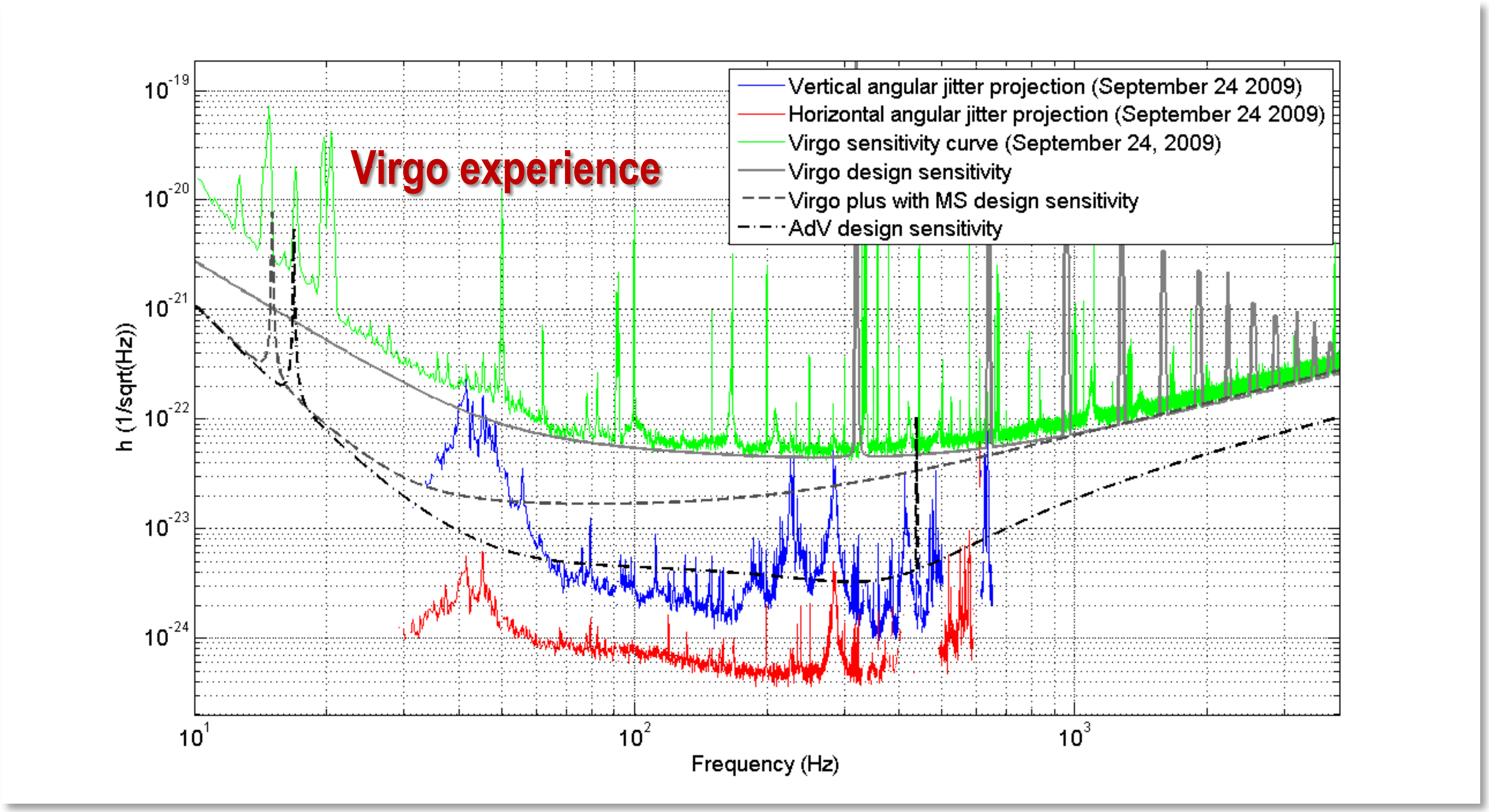
EGO

LIGO-G1400266

VIR-0088A-14

Introduction

The Input Beam Jitter is a potential limiting noise source in the large scale interferometer detectors.

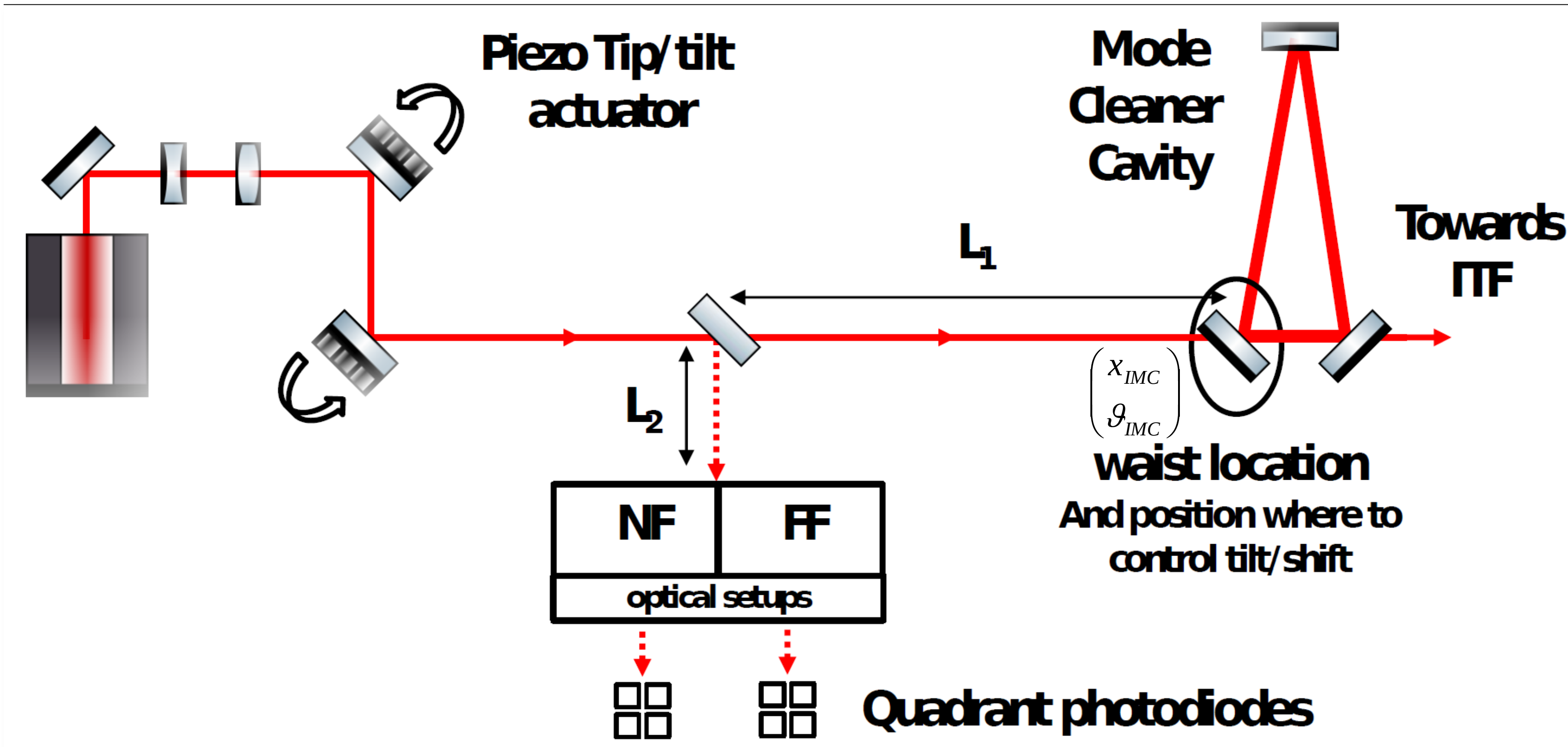


Introduction

In this presentation the **simple but effective** control system to monitor and mitigate the beam jitter at the input of the Input Mode Cleaner cavity will be shown.

The Beam Pointing Control (**BPC**) system, developed and tested for the **Advanced Virgo** configuration, will be presented showing the design principles and the experimental performance.

Control System scheme

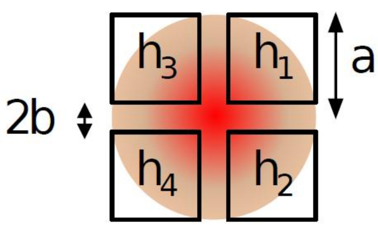


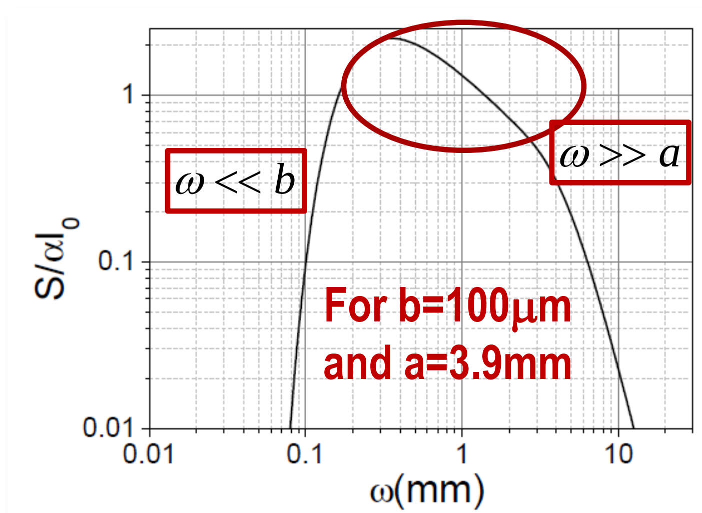
The Near Field (NF) and Far Field (FF) optical setups will be designed to optimize and decouple the sensing. Near Field and Far Field QPDs will sense the shift and the tilt at the IMC input (x_{IMC} , ϑ_{IMC}) respectively.

Optical system design: sensing

The sensing is formed by two quadrants: the NF sensitive only to shift and FF sensitive only to tilt

Step 1: determine the best beam size for the given QPD properties (gap between QPD elements and active area)





$$S_N = \frac{S}{\alpha I_0} \approx \frac{2\sqrt{\frac{2}{\pi}}}{\omega} x_{QPD}$$

$$\omega >> b \wedge \omega << a$$

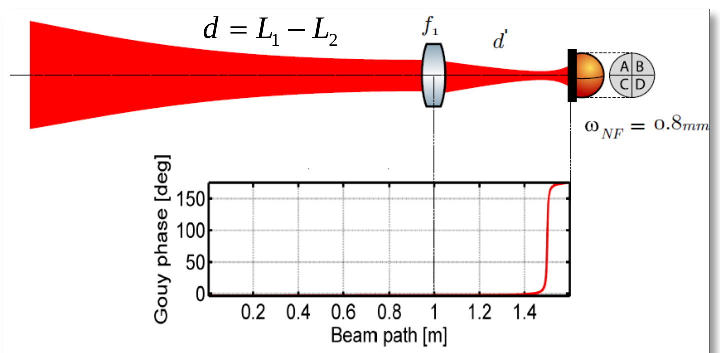
⬇

$$400\,\mu m < \omega < 1mm$$

Optical system design: sensing

Step 2: design the sensing optical scheme to have two well decoupled sensors.

The **shift** of the beam is detected by the **NF QPD** (image plane)

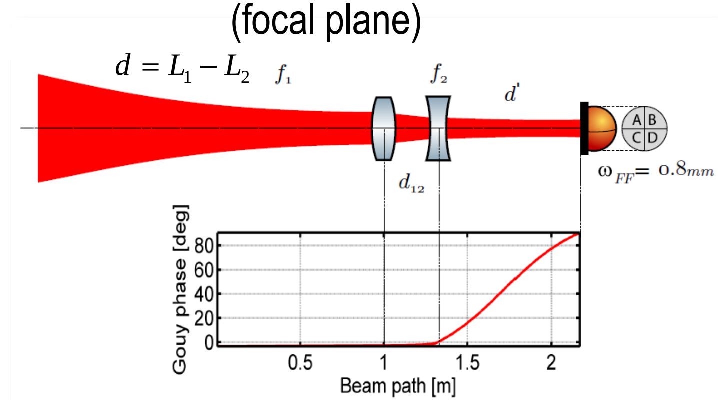


$$x_{QPD} = x_{IMC}\left[1-\frac{d'}{f}\right] + \vartheta_{IMC}\left[d'-d\left(1-\frac{d'}{f}\right)\right]$$

if $d' = \dfrac{df}{d+f}$ → $x_{QPD} = x_{IMC}\left(\dfrac{f}{d+f}\right)$

$$S_{NF} = 2\sqrt{\frac{2}{\pi}}\frac{x_{IMC}}{\omega_{NF}}\left(\frac{f}{d+f}\right) = 2\sqrt{\frac{2}{\pi}}\frac{x_{IMC}}{\omega_0}$$

The **tilt** of the beam is detected by the **FF QPD** (focal plane)

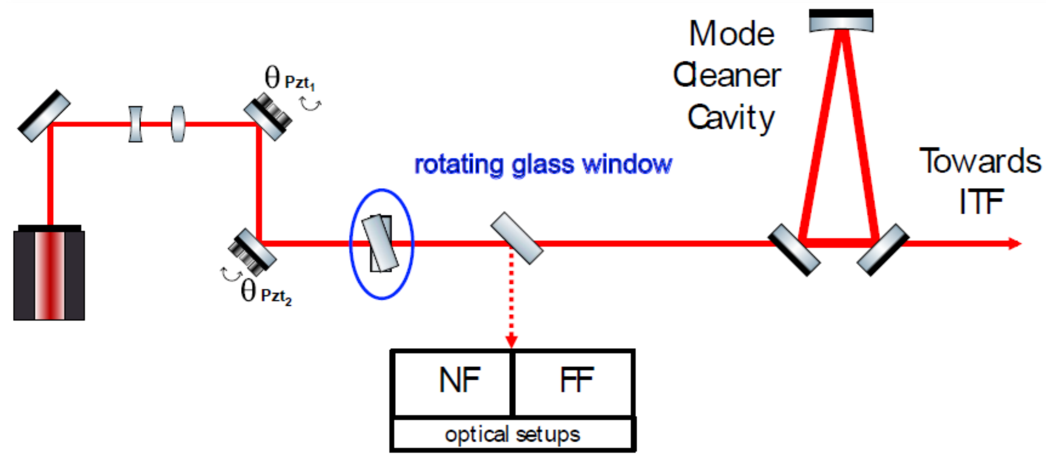


$$x_{QPD} = x_{IMC}\left[-\frac{d'}{f_2} - \frac{d'+d_{12}\left(1-\frac{d'}{f_2}\right)}{f_1} + 1\right] + \vartheta_{IMC}\left[d'+d_{12}\left(1-\frac{d'}{f_2}\right) + d\left(-\frac{d'}{f_2} - \frac{d'+d_{12}\left(1-\frac{d'}{f_2}\right)}{f_1} + 1\right)\right]$$

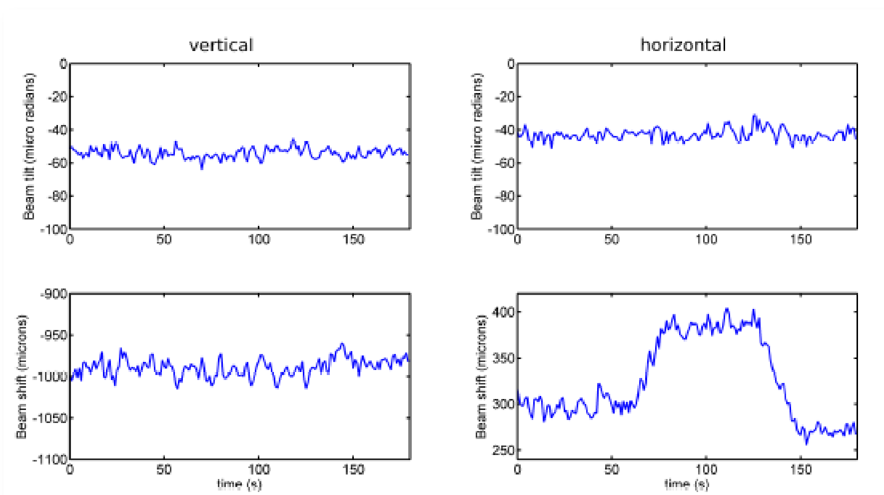
if $d' = \dfrac{f_2(d_{12}-f_1)}{d_{12}-f_1-f_2}$ → $x_{QPD} = x_{IMC}\left(\dfrac{f_1 f_2}{f_1+f_2-d_{12}}\right)$

$$S_{FF} = 2\sqrt{\frac{2}{\pi}}\frac{\theta_{IMC}}{\omega_{FF}}\left(\frac{f_1 f_2}{f_1+f_2-d_{12}}\right) = 2\sqrt{\frac{2}{\pi}}\frac{\vartheta_{IMC}}{\lambda/(\pi\omega_0)}$$

Signal decoupling

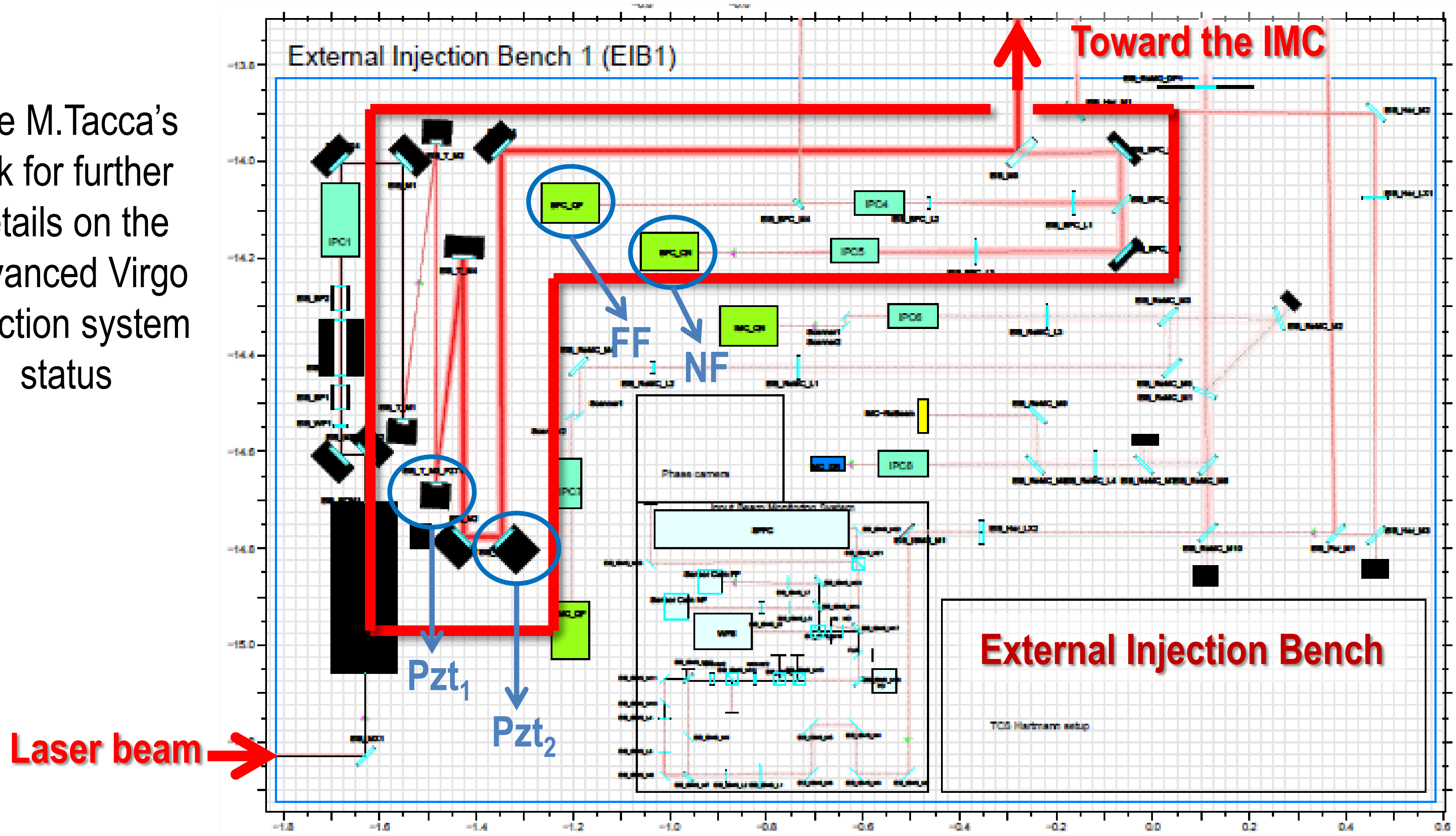


The two quadrant signals decoupling can be easily evaluated by inserting and rotating a glass window to purely shift the beam at the Input Mode Cleaner input.



Implementation of the system for Advanced Virgo

See M.Tacca's talk for further details on the Advanced Virgo Injection system status

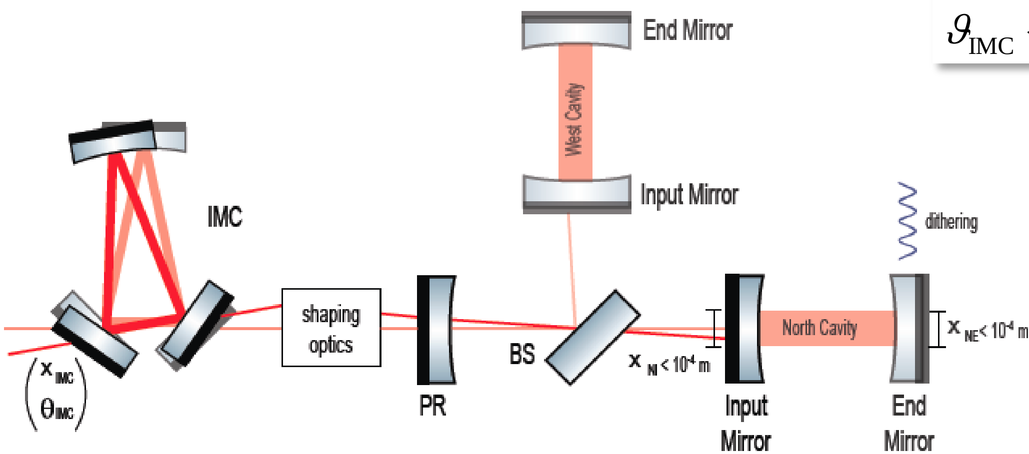


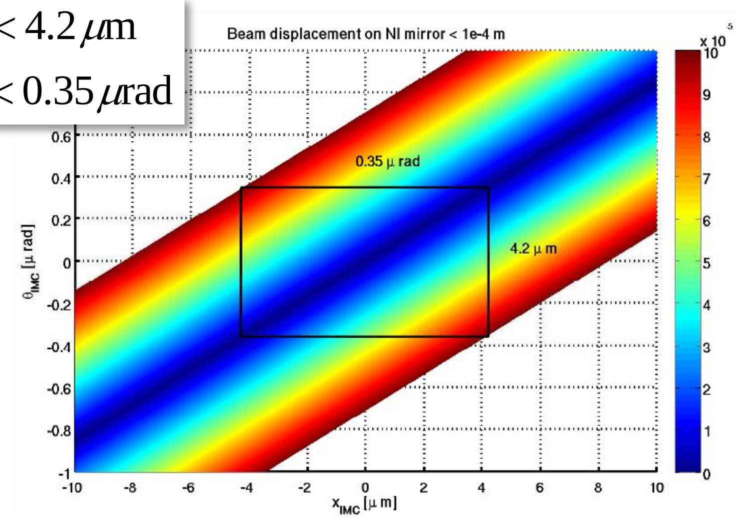
Requirements

In order to properly face with the Advanced Virgo sensitivity the accuracy (low frequency requirement) and noise (high frequency requirement 10Hz-10kHz) requirements for the Input Beam Jitter have to be evaluated.

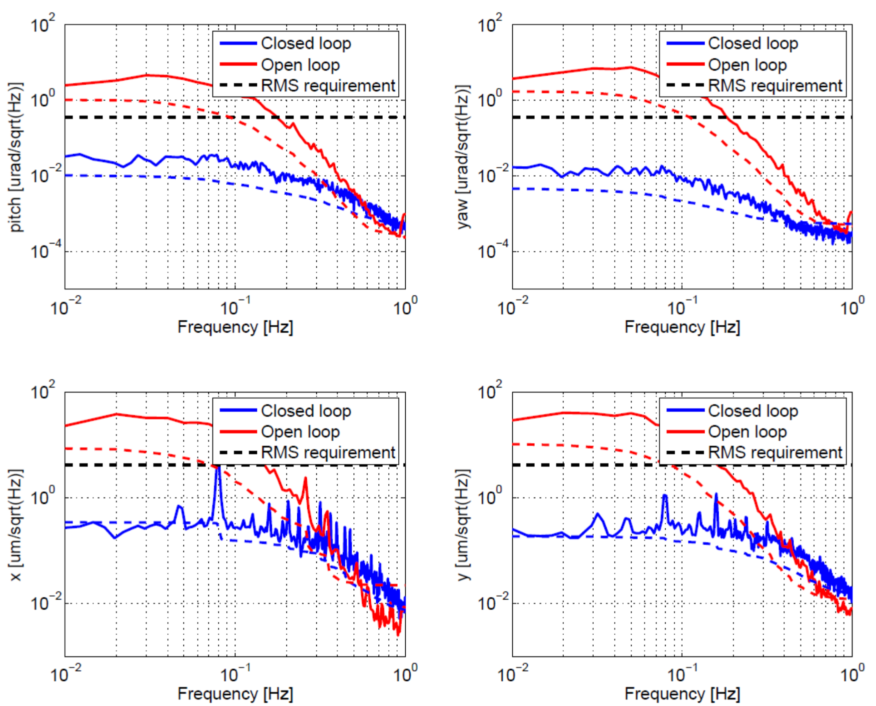
DC: the requirement on the beam jitter is set in order to do not displace the beam on the test masses more than the beam displacement due to the ITF mirrors misalignment (taking into account the shaping optics between the IMC output and the ITF and the IMC servo).

$$x_{IMC} < 4.2\,\mu m$$
$$\vartheta_{IMC} < 0.35\,\mu rad$$

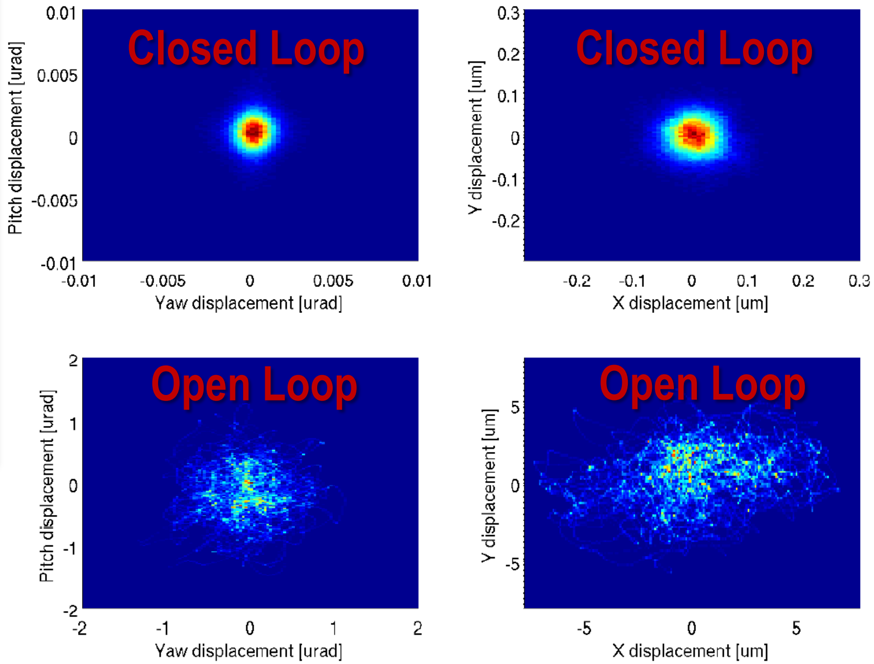




Low frequency performance



The control bandwidth is ~1Hz for the shift direction and ~10Hz for the tilt direction.



The control system fulfills the accuracy requirements

Requirements

10Hz-10kHz: The jitter for the ITF input beam couples into the dark fringe signal through optical asymmetries between the two arms, mainly due to the residual misalignment of the core optics.

The requirement has been set in order to the have the Power Noise, due to the linear coupling of the 01 mode of the Carrier at the input of the ITF with the 00 mode at the output of the ITF, below the Advanced Virgo sensitivity of a factor 10.

$$S_{jitter}\Big|_{PR} = \frac{h_{AdV}}{10} \cdot \frac{TF_{W/h}}{TF_{TEM_{01}}}$$

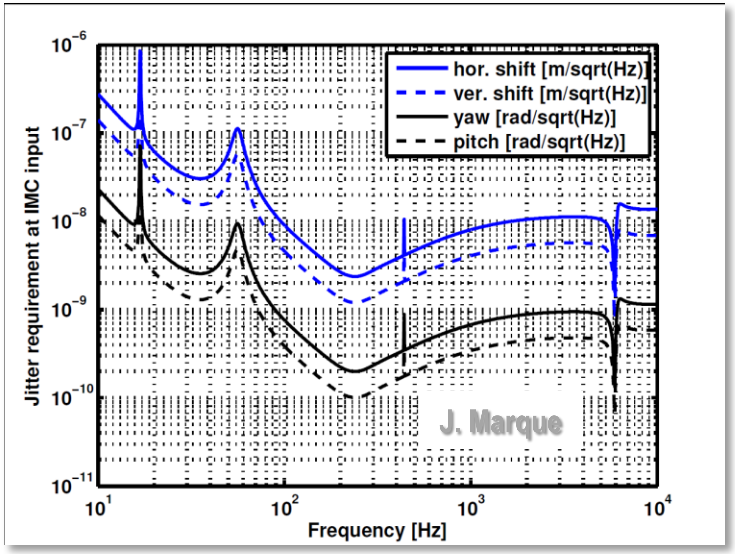
Modeled with Optickle

Modeled with Finesse

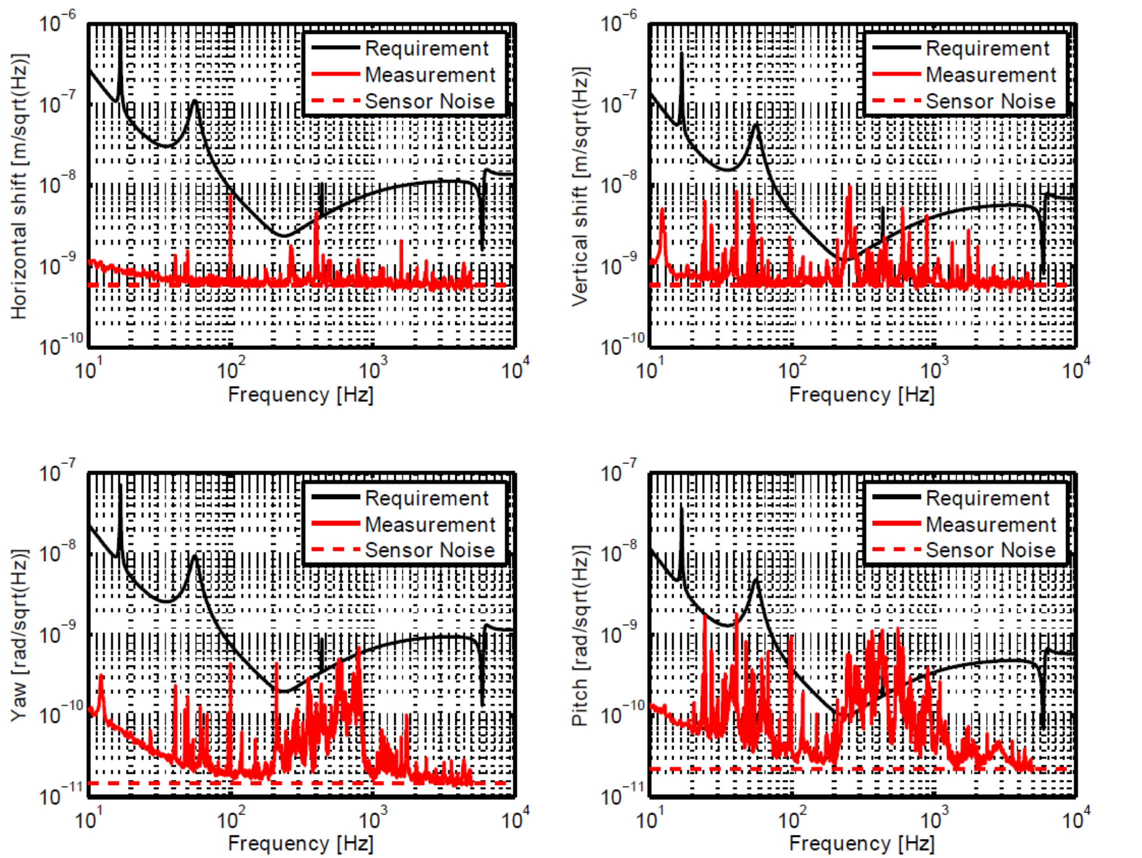
@ PR

Applying the combination of the misalignment of the main optics which generates the largest effect.

Then it is computed at the level of the IMC taking into account the shaping optics and the filtering effect of the IMC cavity



High frequency performance



The QPD noise level is compliant with the Advanced Virgo requirement.

The lab measurement are dominated by acoustic and seismic noise. The first will be reduced for Advanced Virgo by the acoustic enclosure (which surrounds the optical bench), the last by the seismic attenuation system of the bench (EIB SAS).

Moreover the optical mounts have been carefully designed in order to be very rigid to bring the resonance frequencies well above 200 Hz.

Conclusion

A very simple and effective control system to mitigate and monitor the input beam jitter for Advanced Virgo has been developed and tested with unprecedented performance of control accuracy

The system fulfills the requirements and shows a high reliability.

The system will be very useful during the Advanced Virgo commissioning because it will allow also to perform Input Jitter noise projection.


The end….