The Virgo noise budget

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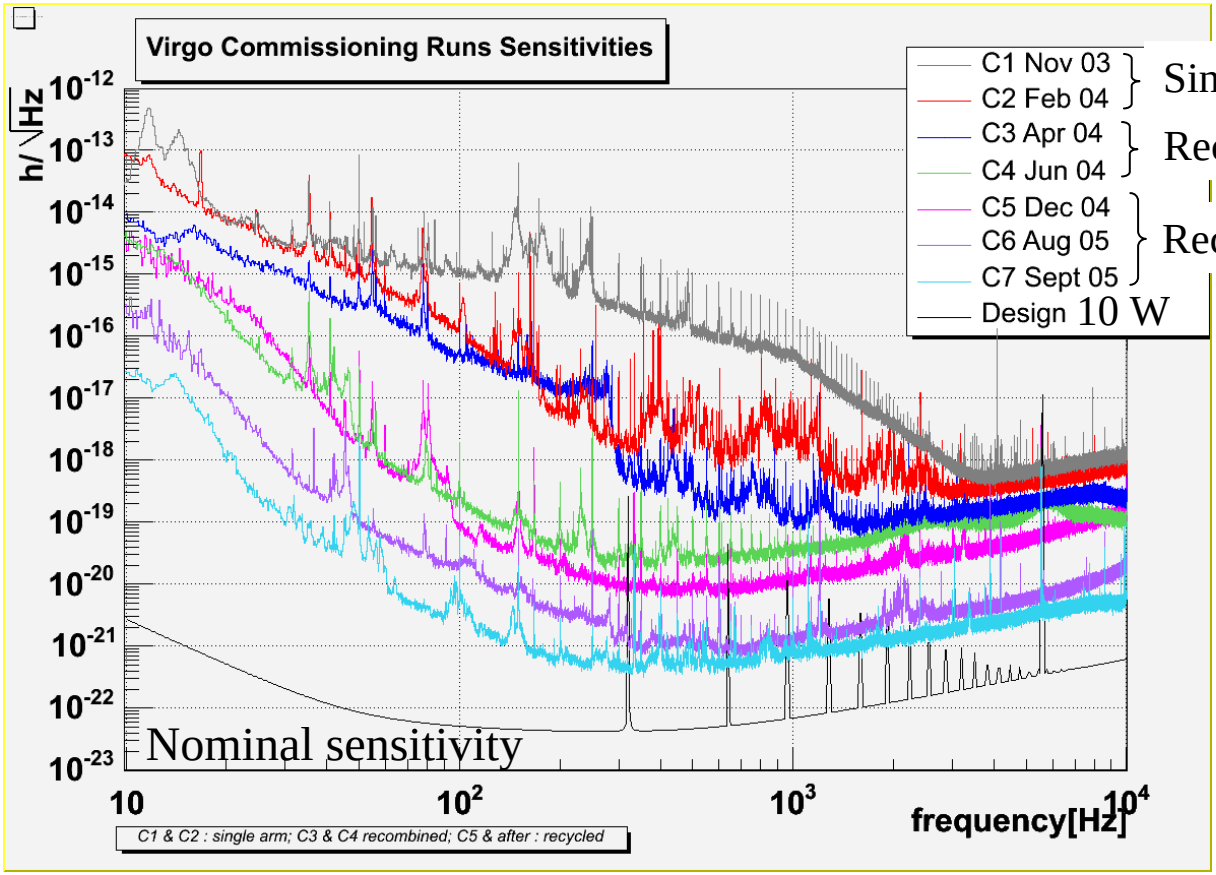
GWADW 2006, Isola d’Elba

LIGO-G060340-00-Z

Summary

- Introduction : the sensitivity curves of Virgo Commissioning
- Analysis of the technical noises :
  - *Length control noise*
  - *Angular control noise*
  - *Mirror actuator noise*
  - *Oscillator phase noise*
  - *Laser frequency noise*
- Noise budget of the C7 run (September 2005)
- Conclusion

The sensitivity curves of Virgo Commissioning



Single Fabry-Perot cavity

Recombined (7 W)

Recycled (0.7 W)

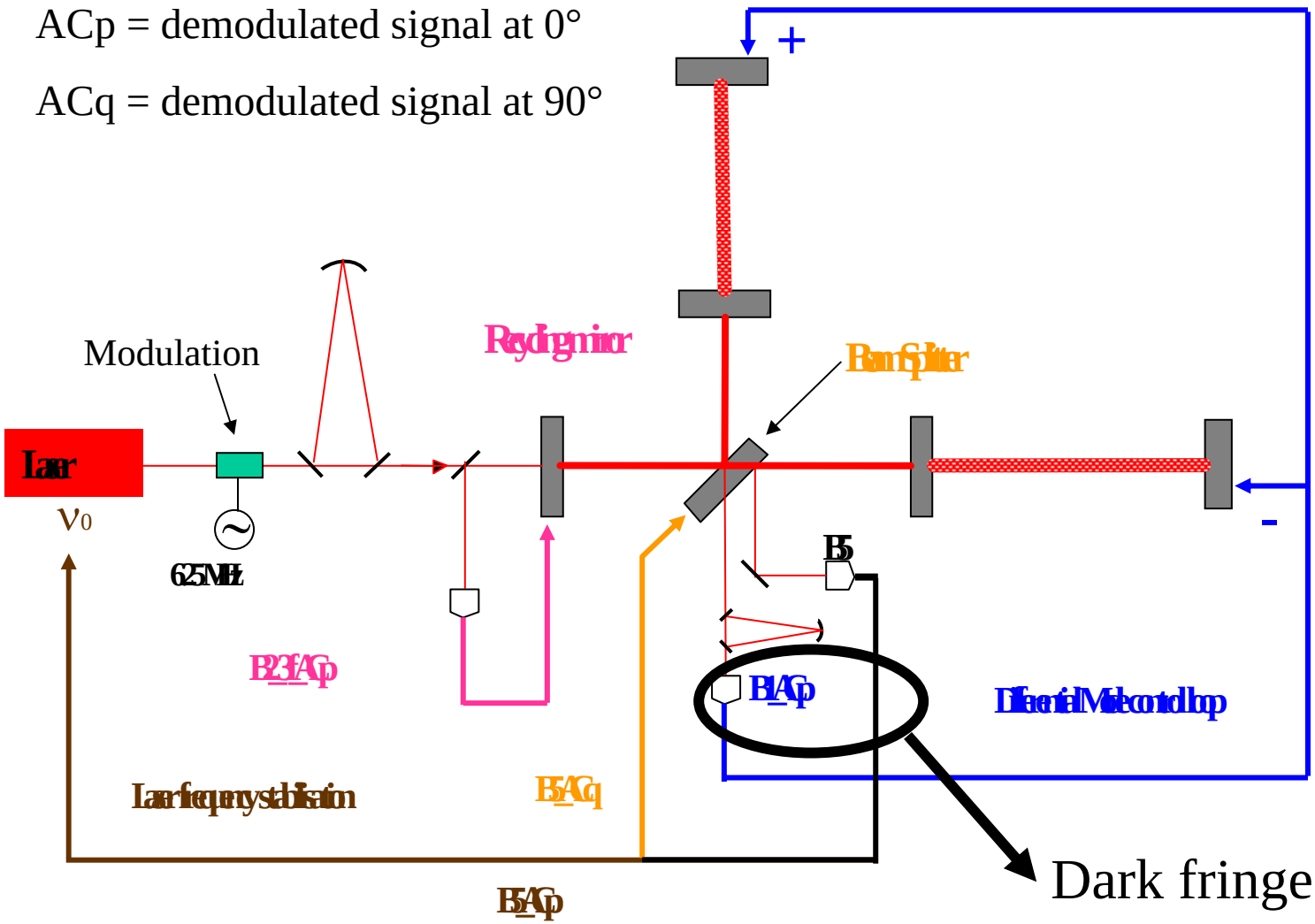
To reach the Virgo nominal sensitivity:

⇒ Technical noises have to be identified in order to be cured

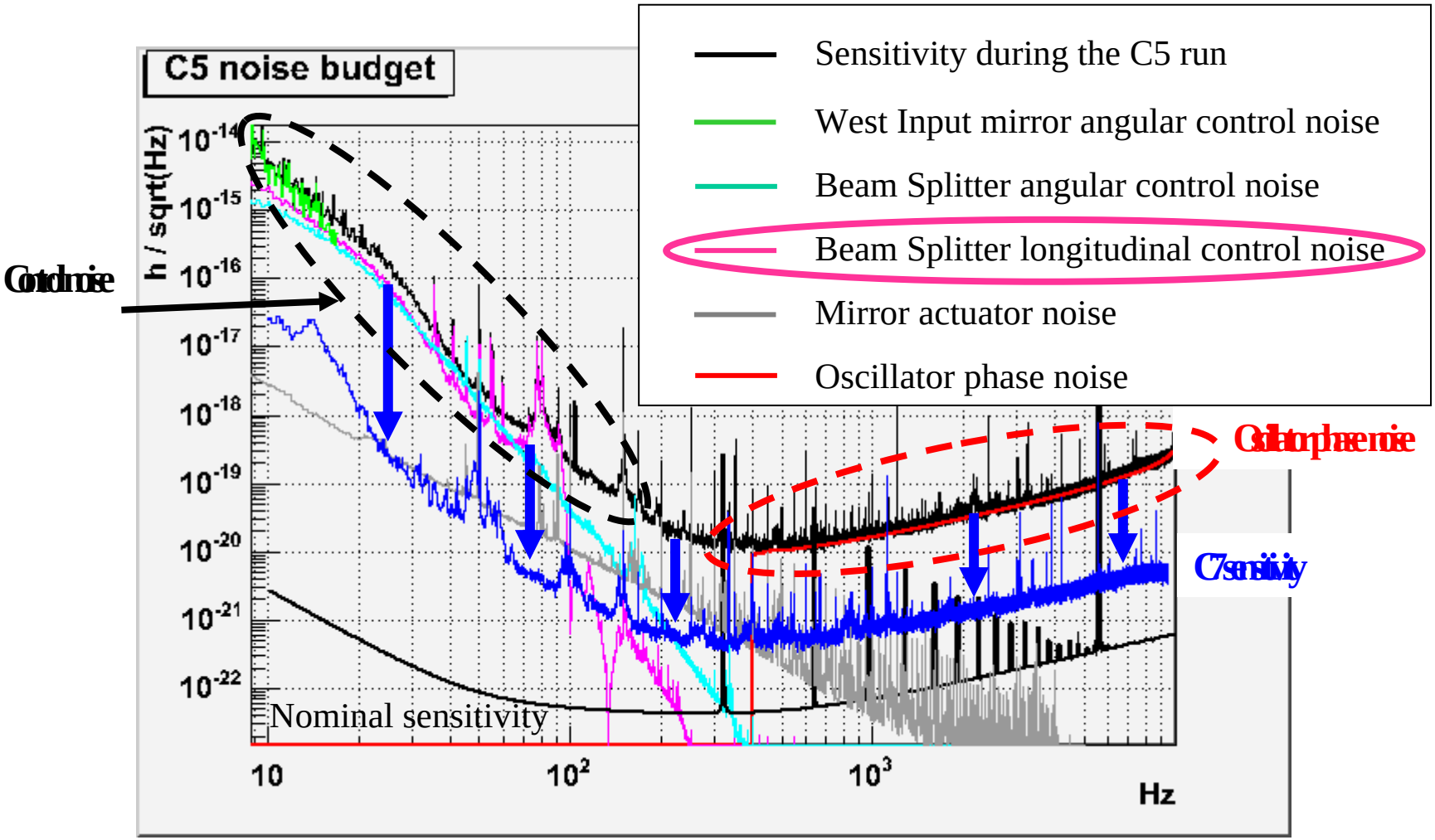
The recycled interferometer : locking scheme

ACp = demodulated signal at 0°

ACq = demodulated signal at 90°



Noise budget of the C5 run (december 2004)



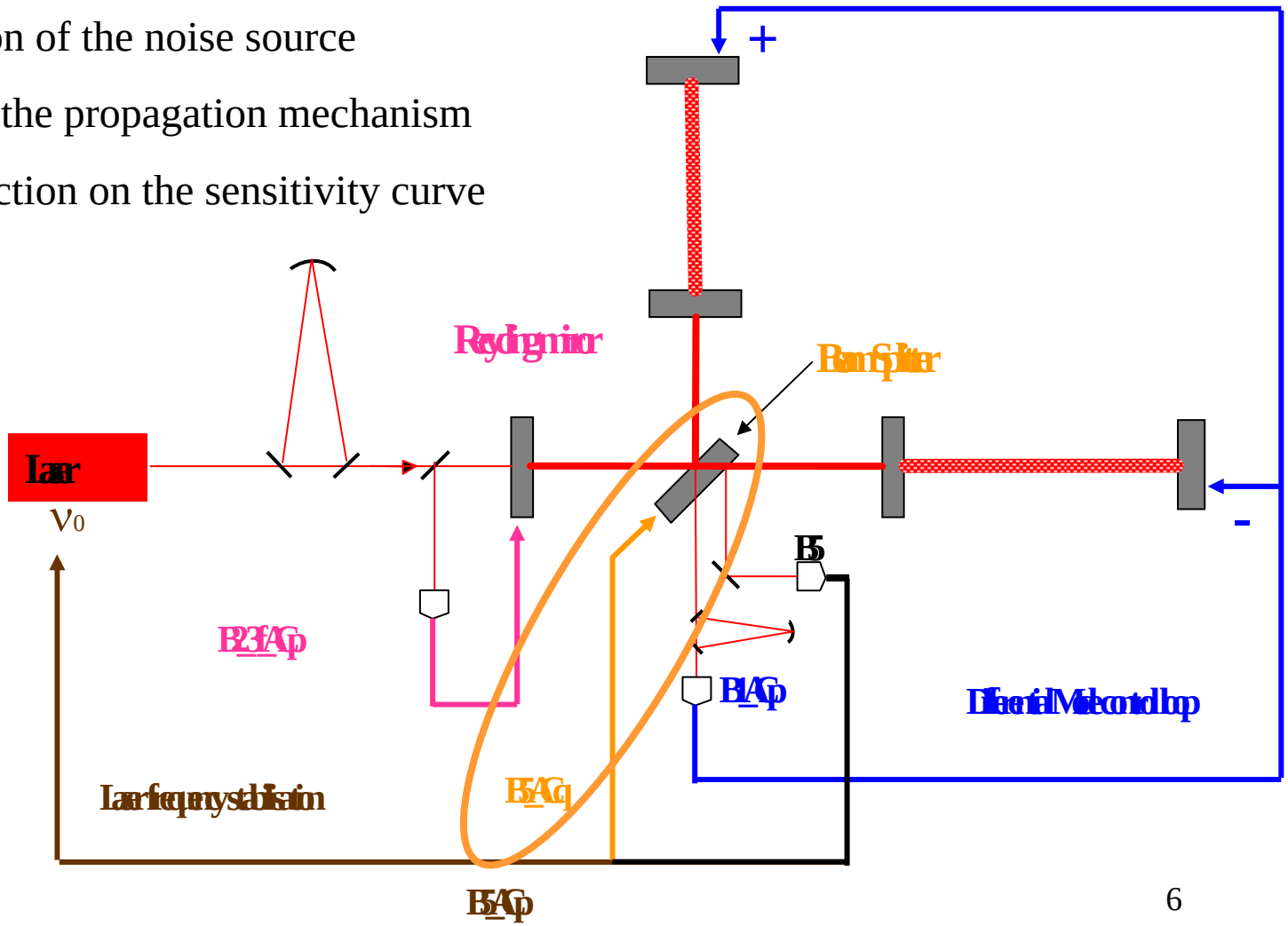
How these noises have been identified ?

Which technical upgrades between C5 and C7 runs ?

Beam Splitter longitudinal control noise

Noise analysis in 3 steps:

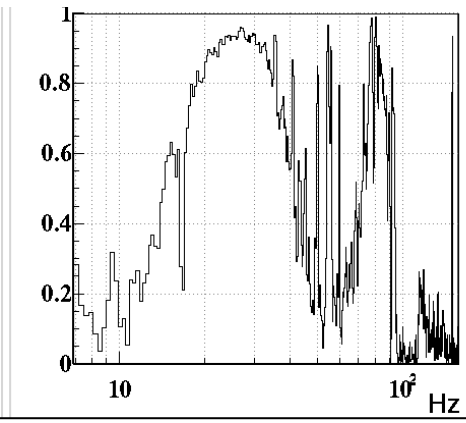
1. Identification of the noise source
2. Analysis of the propagation mechanism
3. Noise projection on the sensitivity curve



Beam Splitter longitudinal control noise

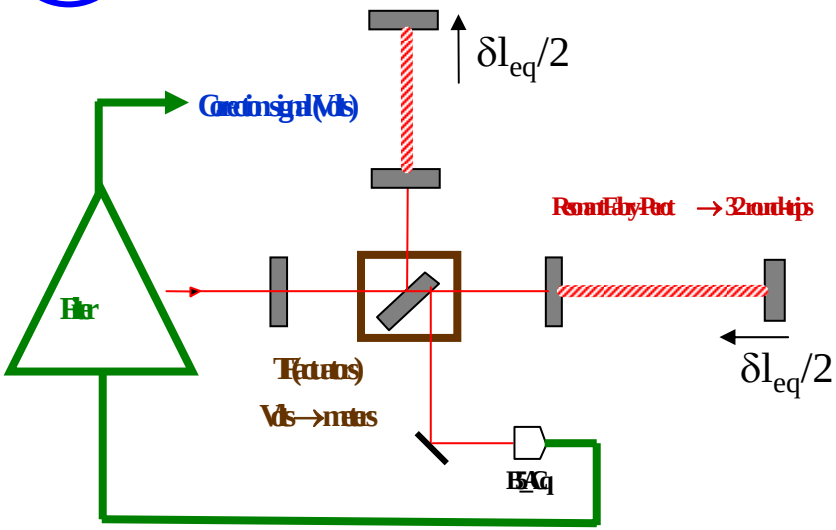
1 Looking for coherent channels to identify the source

Coherence: Darkfringe signal vs Correction signal



2 Analytical model

δl_{eq} = Correction signal x TF(actuators) x √2 x 1/32



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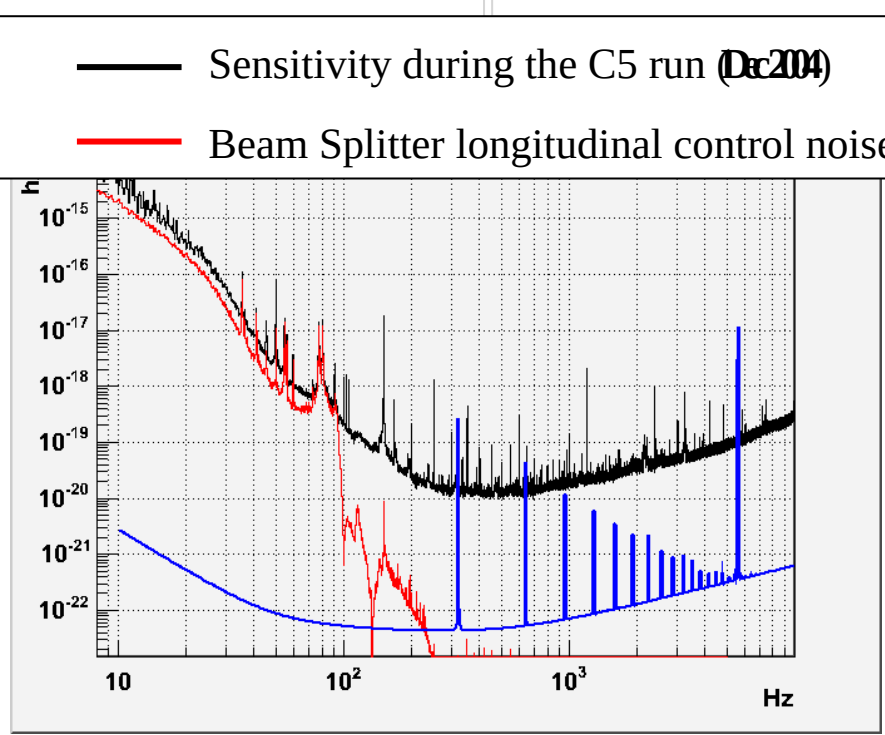
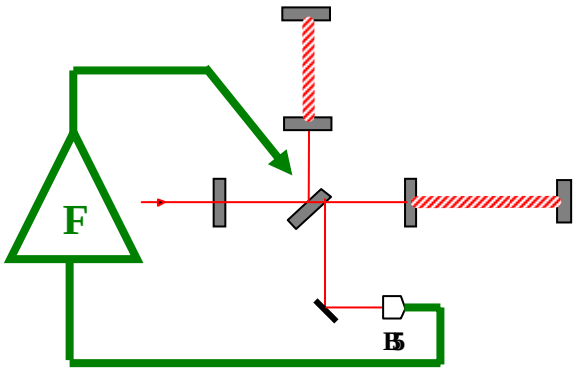


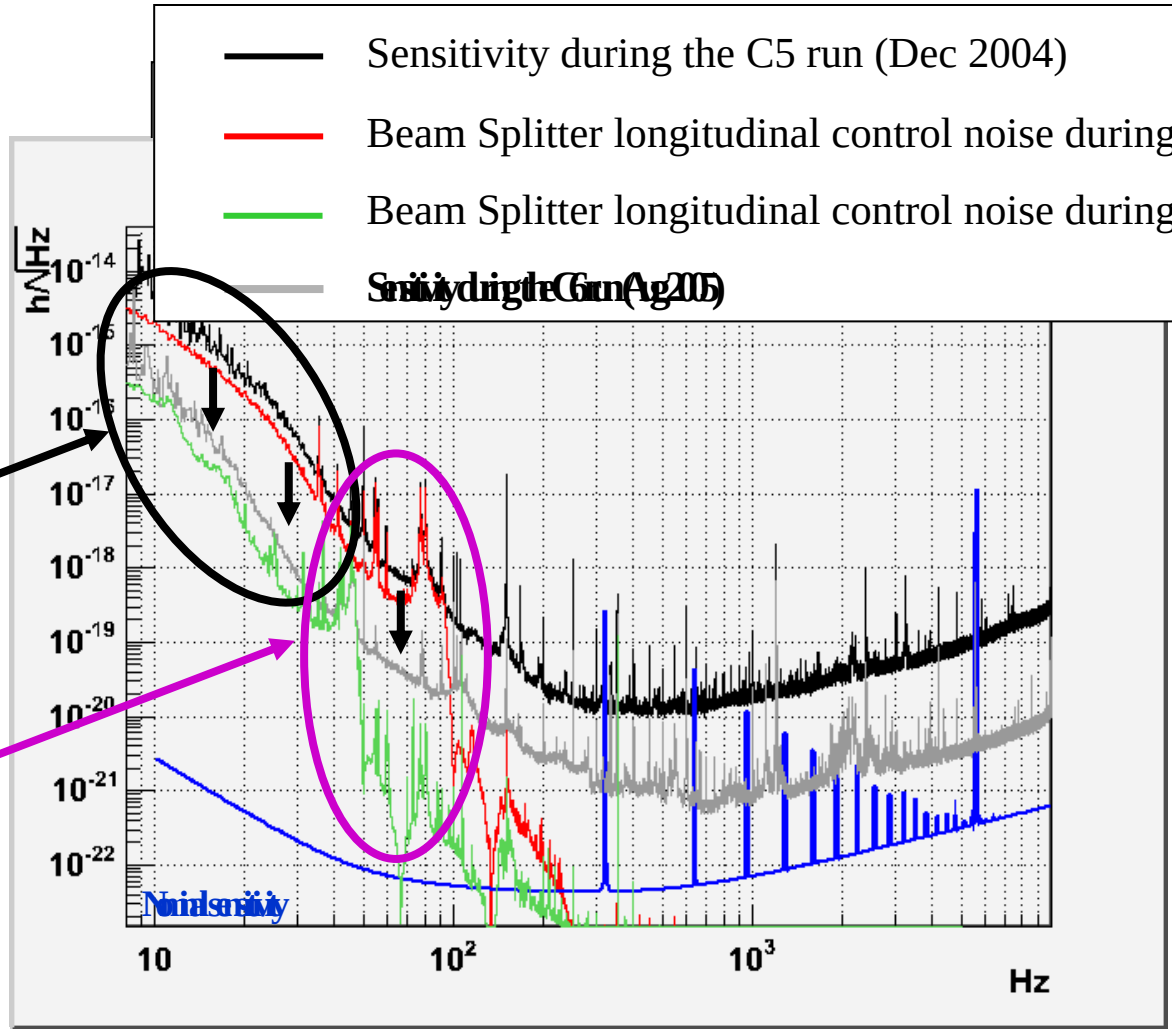
Reduction of the Beam Splitter control noise : from C5 to C6

Technical upgrades : → Electronics optimization



Improvements of the Beam Splitter angular control (coupling $z \leftrightarrow \theta_x$)

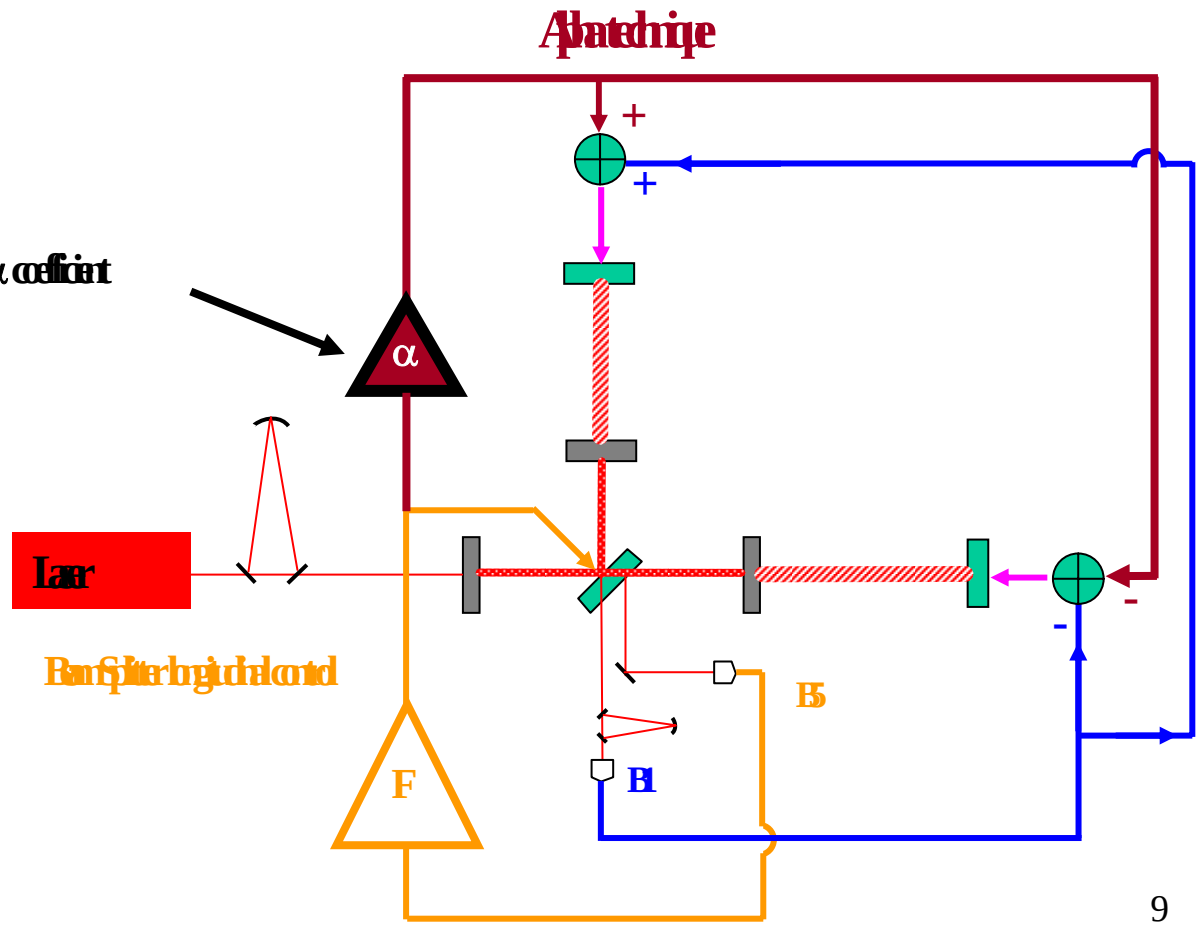
Reduction of the Beam Splitter longitudinal control noise



Reduction of the Beam Splitter control noise : from C6 to C7

Technical upgrades : → Substraction of the Beam Splitter control noise by sending appropriate corrections to the end arm mirrors (=Advanced technique)

⇒ Efficient substraction requires a tuning of the α coefficient



Reduction of the Beam Splitter control noise : from C6 to C7

Technical upgrades : → Substraction of the Beam Splitter control noise by sending appropriate corrections to the end arm mirrors (=Adaptive technique)

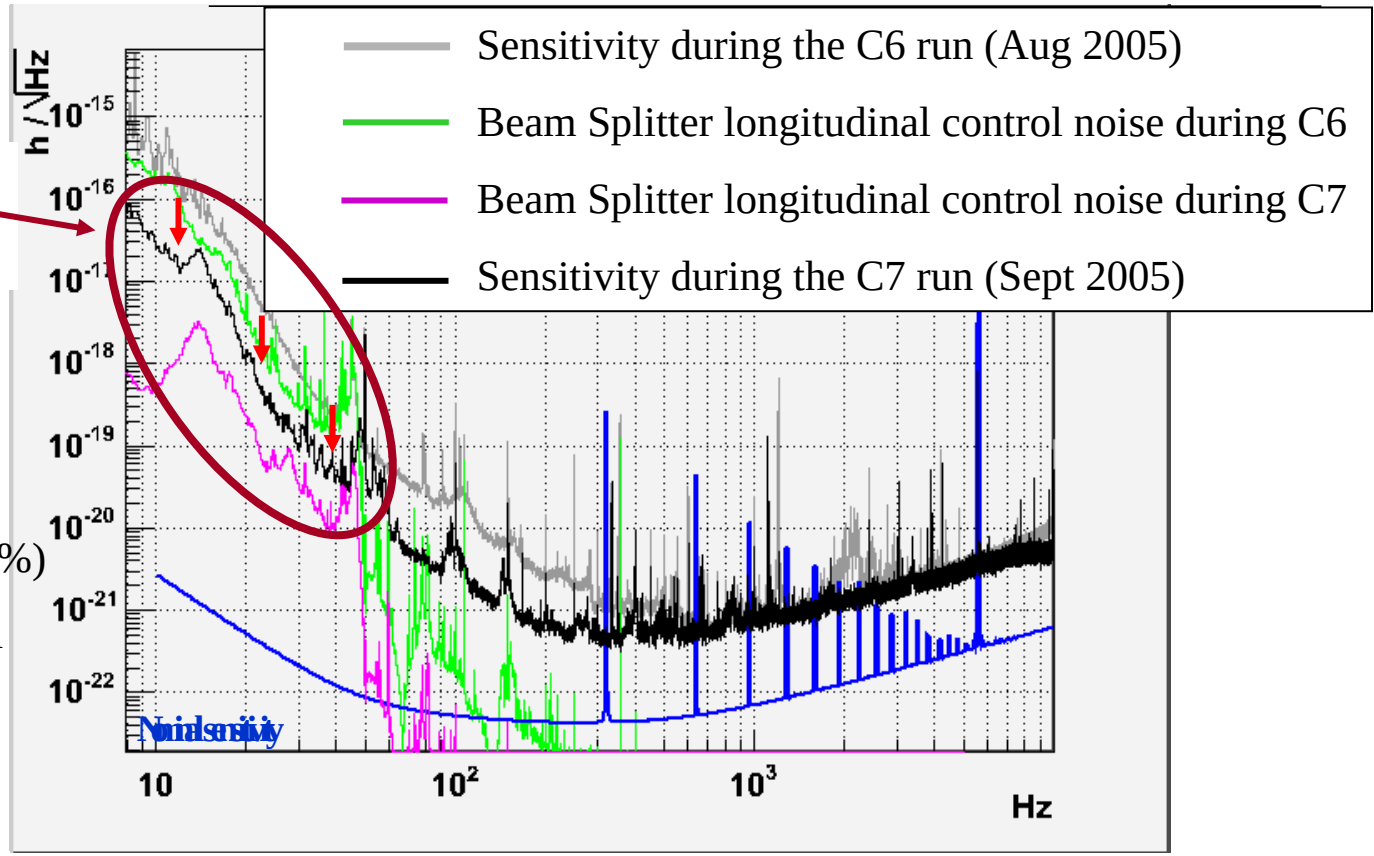
Adaptive technique

⇒ α coefficient tuned with an accuracy of 7%

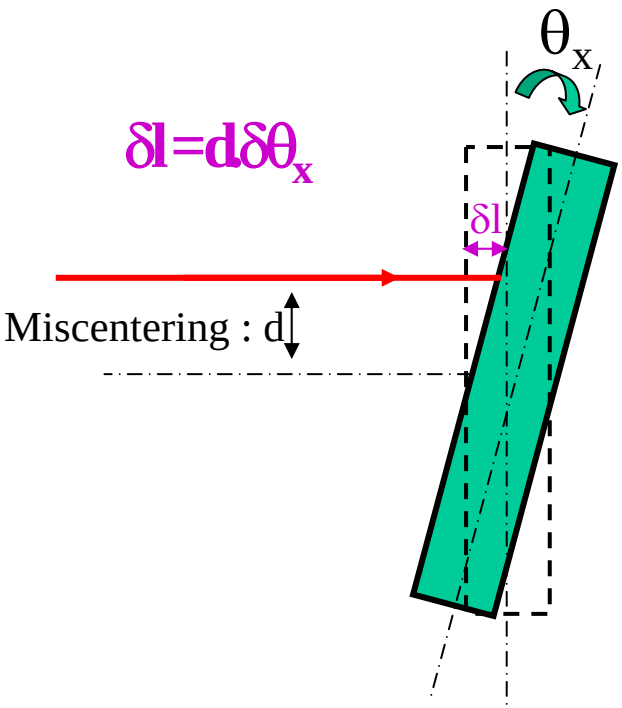
How to obtain further improvements?

- With a better tuning of α (1%)

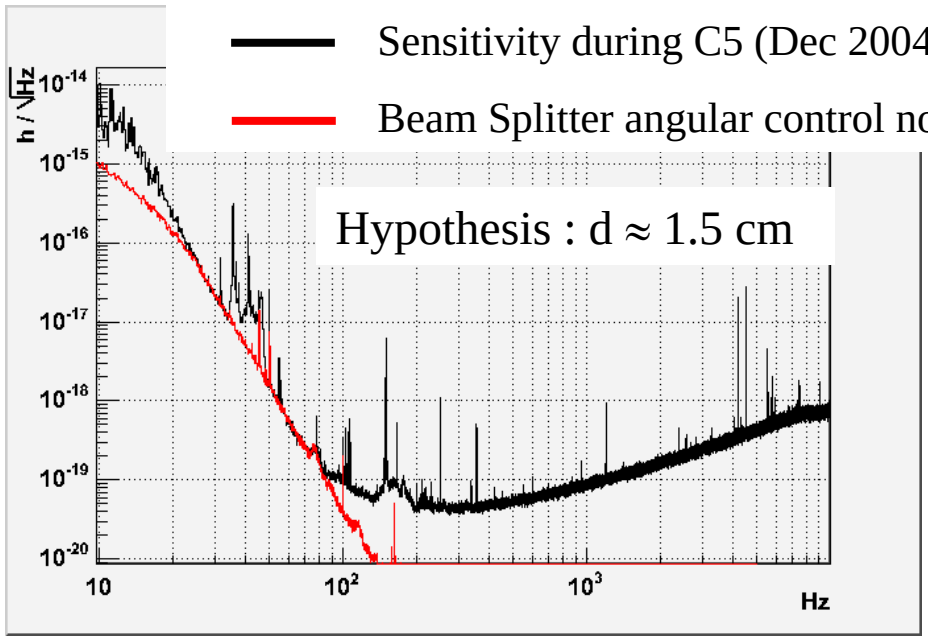
- By reducing angular control noise (coupling $z \leftrightarrow \theta_x$) ?



Angular control noise



⇒ Impact of angular control noise proportional to the beam miscentering



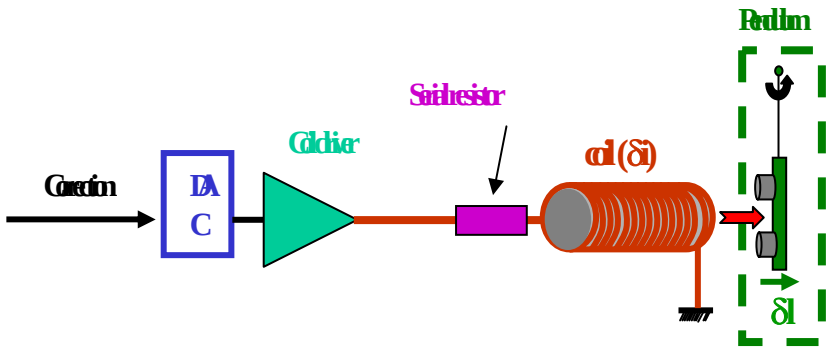
From C5 to C7 : reduction of Beam Splitter angular control noise

During C7 : sensitivity limited by Input Mirrors (NI, WI) angular control noise

April-May 2006 : A vertical miscentering of about 1 cm has been corrected

⇒ sensitivity improvements are expected

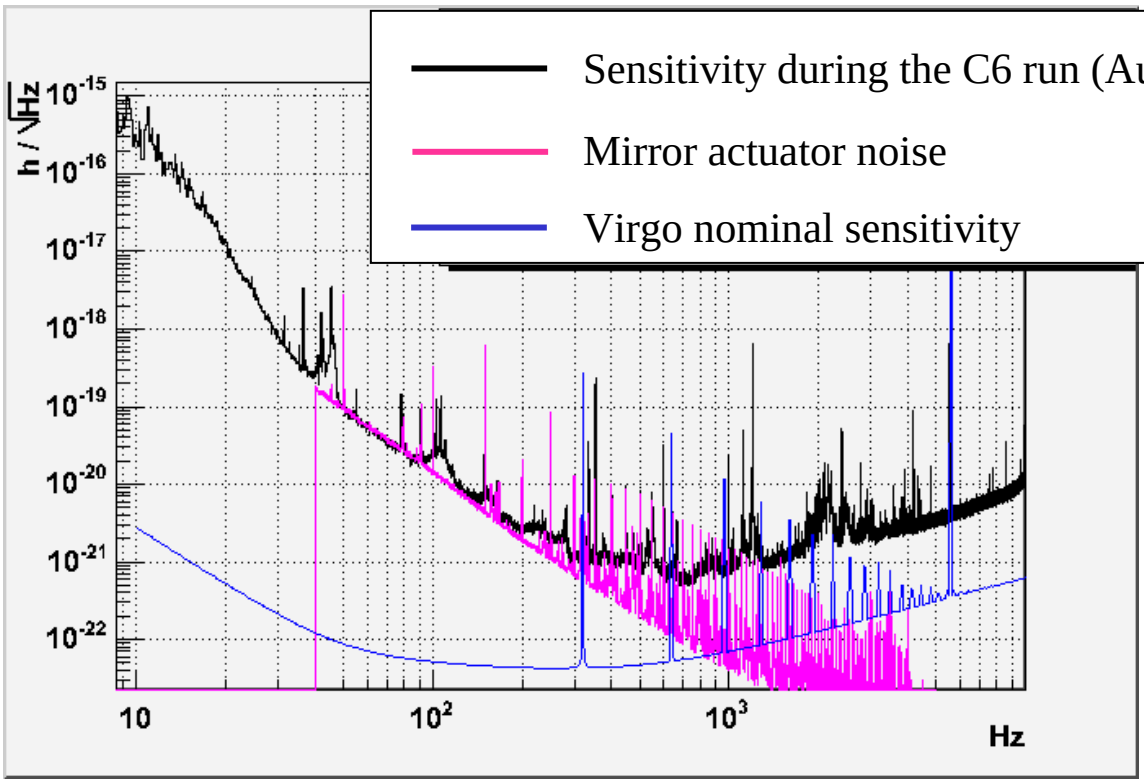
Mirror actuator noise



Origin: DAC and coil driver noise

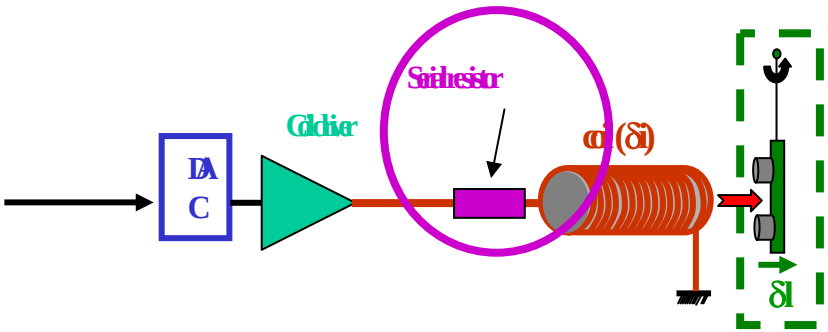
Measurement of the coil current noise estimation

⇒ Actuator



⇒ C6 sensitivity limited by actuator noise between 50 and 300 Hz

Reduction of the actuator noise : from C6 to C7

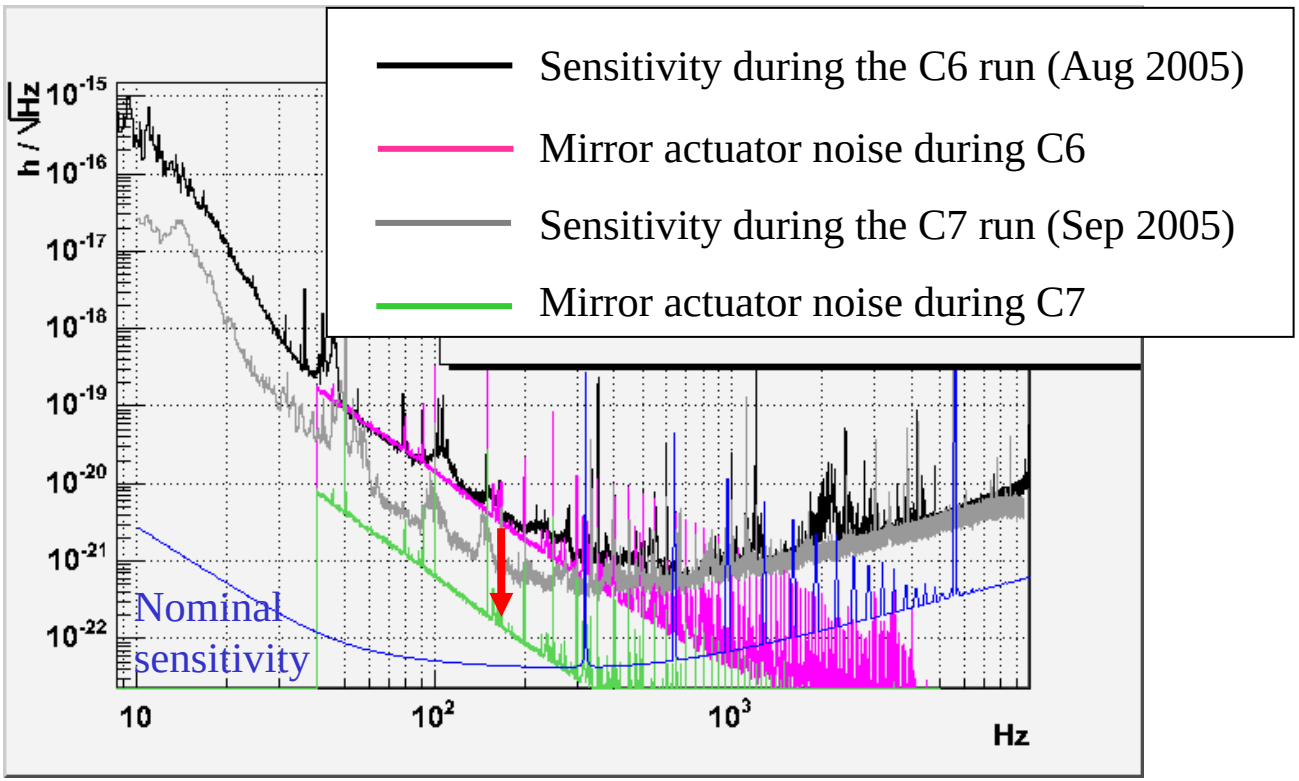


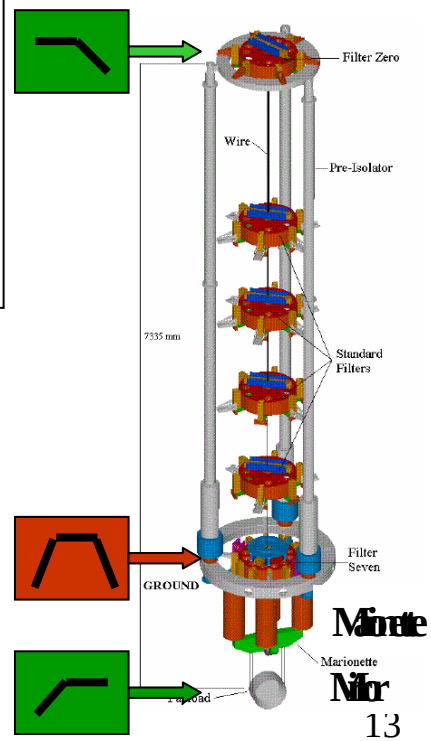
Serial resistor increased from 250 Ω to 6 kΩ (arm mirrors)

⇒ Actuator noise reduced by a factor 23

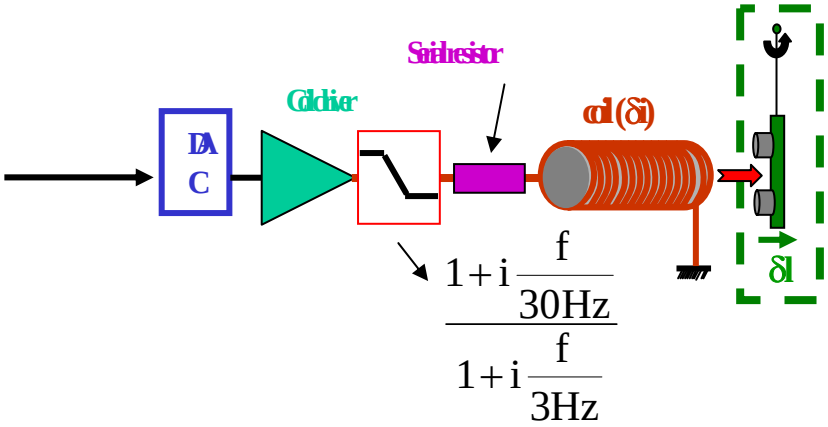
Problem : the maximum strength applied to the mirror has to be reduced (because of the DAC saturation voltage)

⇒ Hierarchical control is needed (see G. Losurdo's talk)



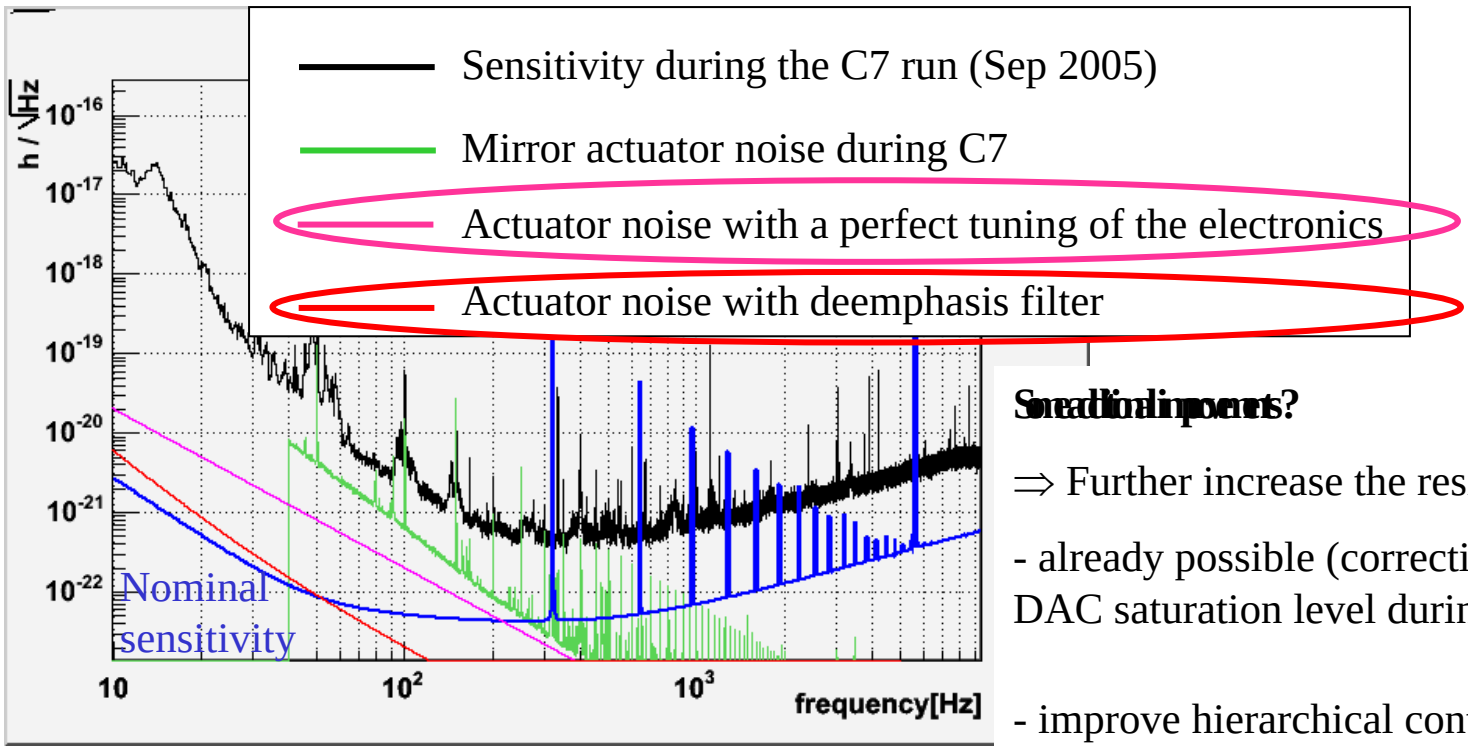


Reduction of the actuator noise : towards the design



Next upgrades:

- Fine tuning of the DAC electronics
- Implementation of an analog "deemphasis" filter



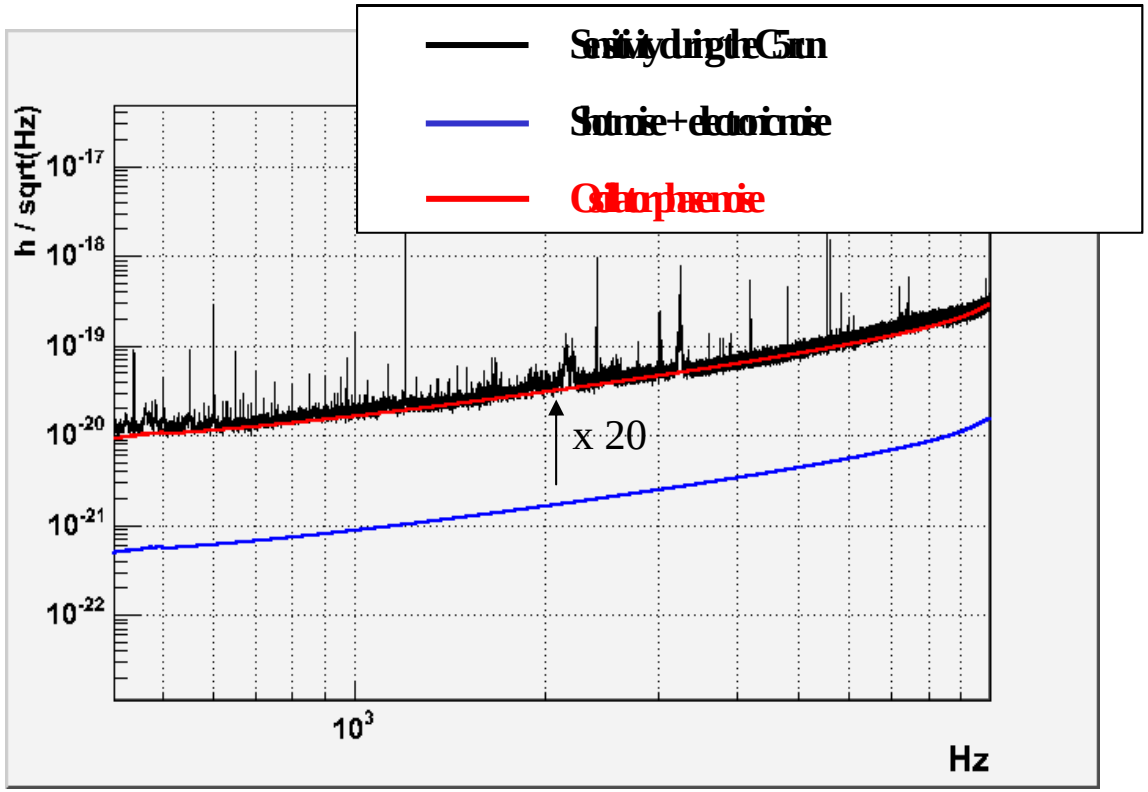
Spreading improvements?

⇒ Further increase the resistor :

- already possible (correction at 20% of the DAC saturation level during C7)

- improve hierarchical control

Noise at high frequency during the C5 run



@ high frequency : Noise higher than electronic noise and shot noise by a factor 20

⇒ C5 sensitivity limited by oscillator phase noise

Oscillator phase noise

• Coupling during the demodulation process:

Photodiode signal: $S = S_p + S_q = s_p \cos(\Omega t) + s_q \sin(\Omega t)$

Oscillator signal: $LO = \cos(\Omega t + \delta\varphi)$

Demodulation process → S x LO

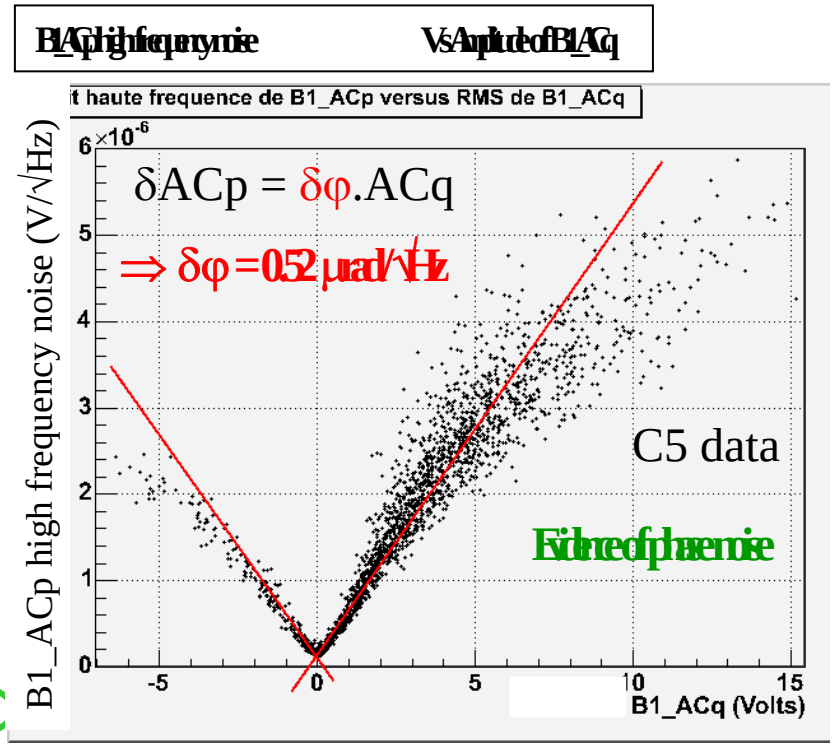
Baking signal: $B1\_ACp = S \times LO = (s_p + s_q\, \delta\varphi)/2$

Oscillator phase noise

Demodulated at 0°

⇒ Noise in the ACp channel proportional to the amount of signal in the ACq channel

Demodulated at 90°

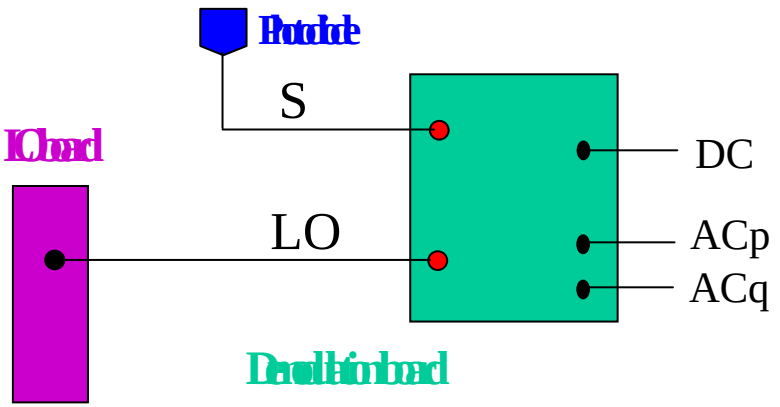


• Origin of phase noise ?

LO board contribution of the oscillator signal to the demodulation board

Measurement of the noise induced by LO board:

δφ = 0.47 µrad/√Hz (agrees with C5 estimation)



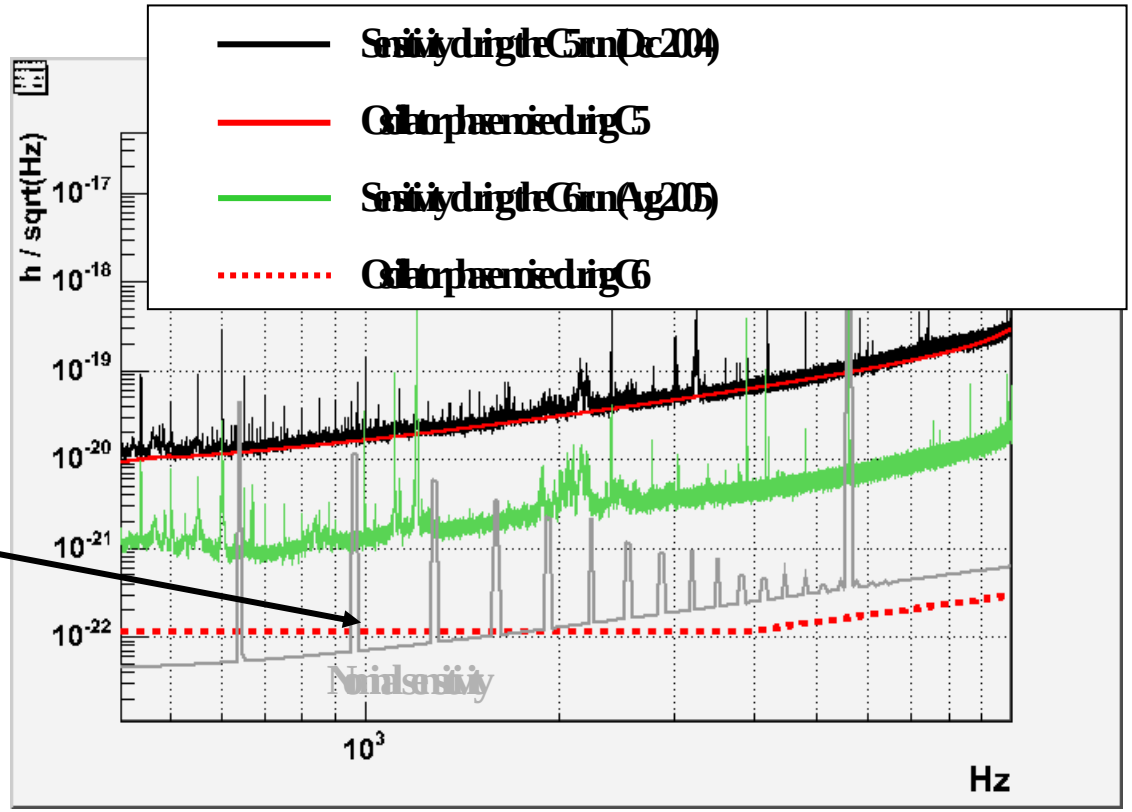
Reduction of the oscillator phase noise

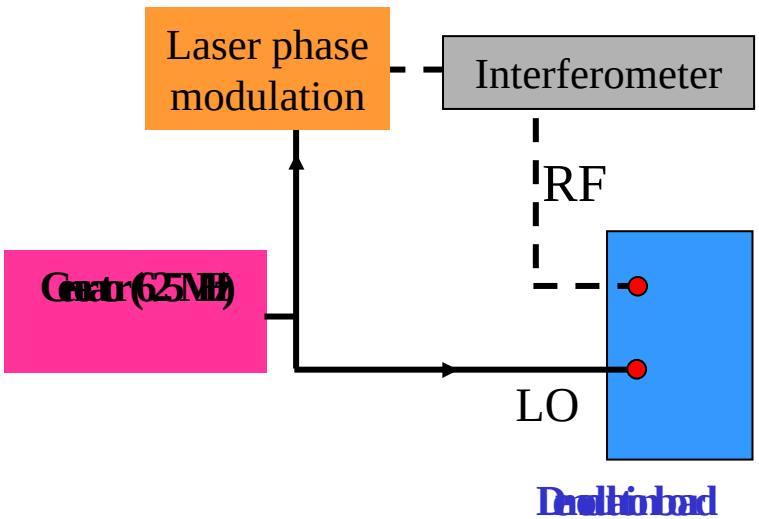
Technical upgrades after C5:

$\delta ACp = \delta\varphi . ACq$

- Improvement of the LO boards
⇒ Reduction of $\delta\varphi$
- Alignment conditions improved with the mirror automatic alignment
⇒ Reduction of the ACq signal

⇒ Phase noise reduced by ~ 10 at 1 kHz





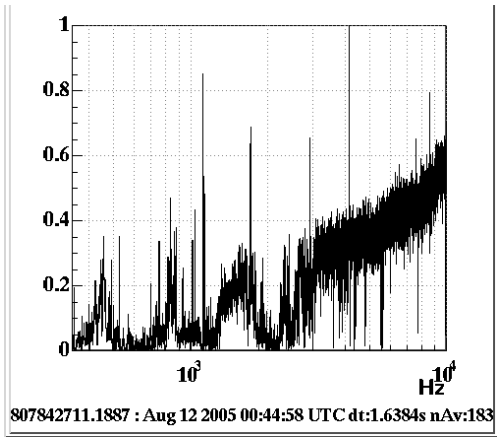
Impact on the Virgo noise sensitivity:

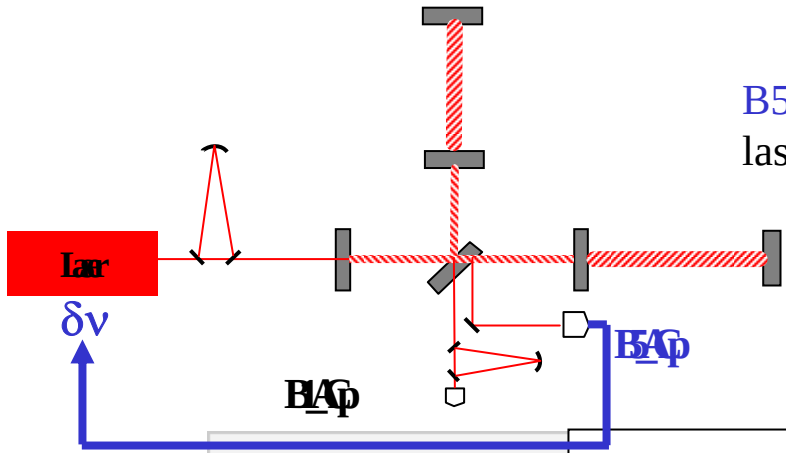
Reduction of the phase noise

→ Marconi 2040 replaced by LNFS-100 (less noisy)

Laser frequency noise

Coherence between B1_ACp and B5_ACp ⇒ sensitivity limited by laser frequency noise





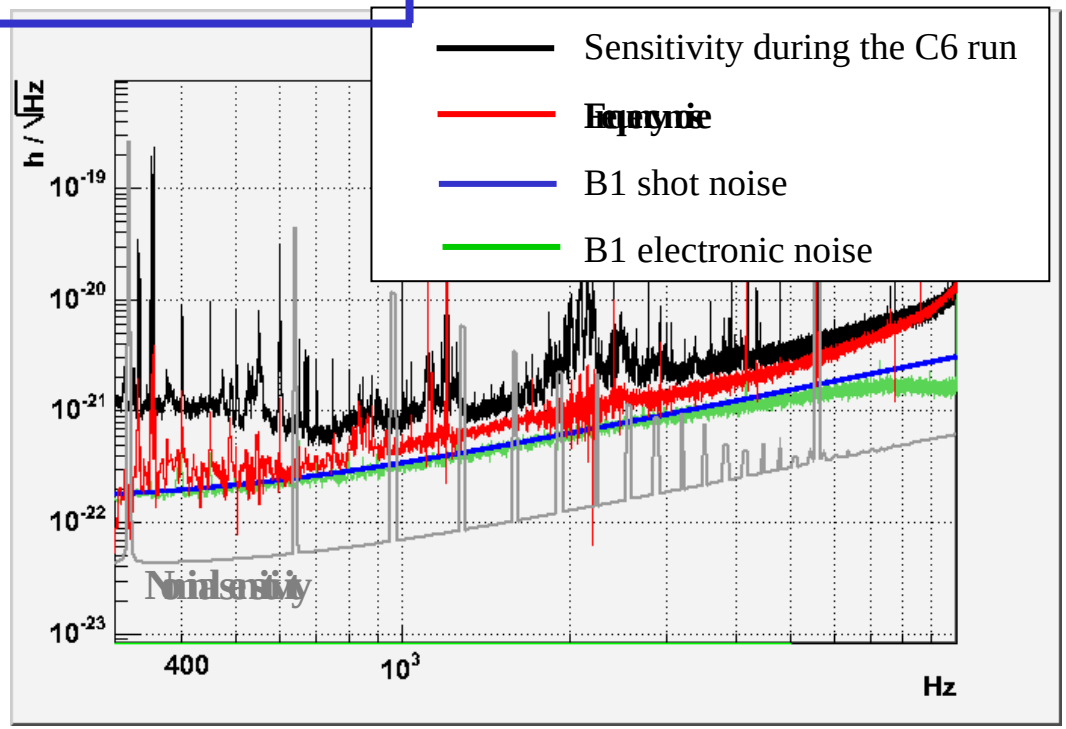
B5_ACp : measures the laser frequency noise

• Propagation of frequency noise compatible with a CMRF (arm asymmetry) of about 10^{-3}

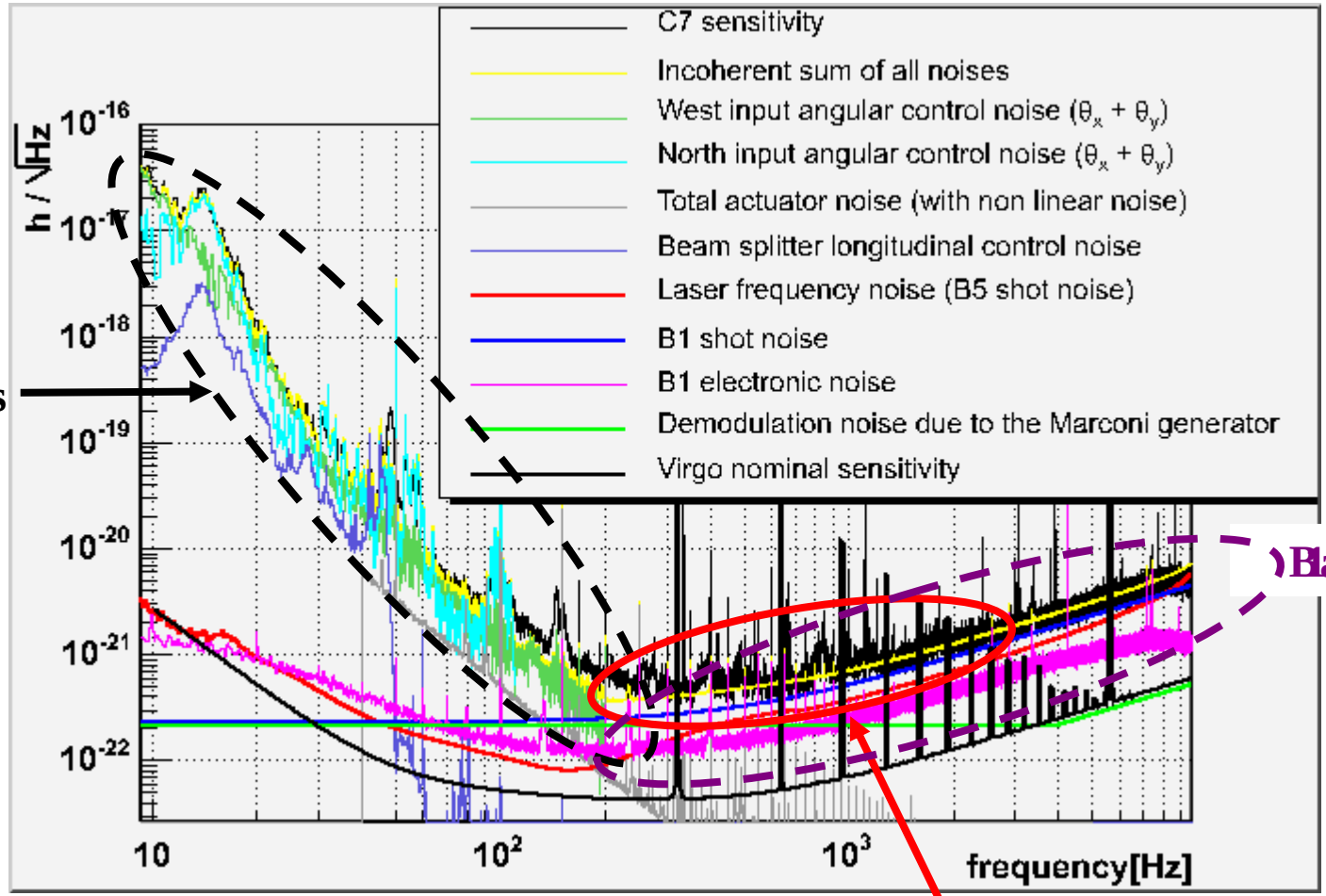
⇒ Reduction of the CMRF by improving the arm symmetry

• Main origin suspected : shot noise in the B5_ACp signal

⇒ Reduction of the shot noise by increasing the power of the incoming beam



Noise budget of the C7 run (Sep 2005)



Control noises

B1 and B5 shot noise

Environmental noise (see F. Paletti's talk)

Conclusion

- The sensitivity of the C7 run is well understood

- The main sources of noise are :
  - Control noises (above all angular) @ low frequency
  - Environmental noise (sometimes correlated with diffused light)
  - Shot noise @ high frequency

- How the sensitivity will be improved ?
  - Centering of the beam with respect to the mirrors *(started)*
  - Implementation of the full automatic alignment system *(started)*
  - Fine tuning of the alpha technique *(planned)*
  - Reduction of actuator noise *(started)*
  - Isolation of the optical benches *(planned)*
  - Power increased x 10 *(already performed)*

Specifications for generator phase noise