Virgo Control Noise Reduction

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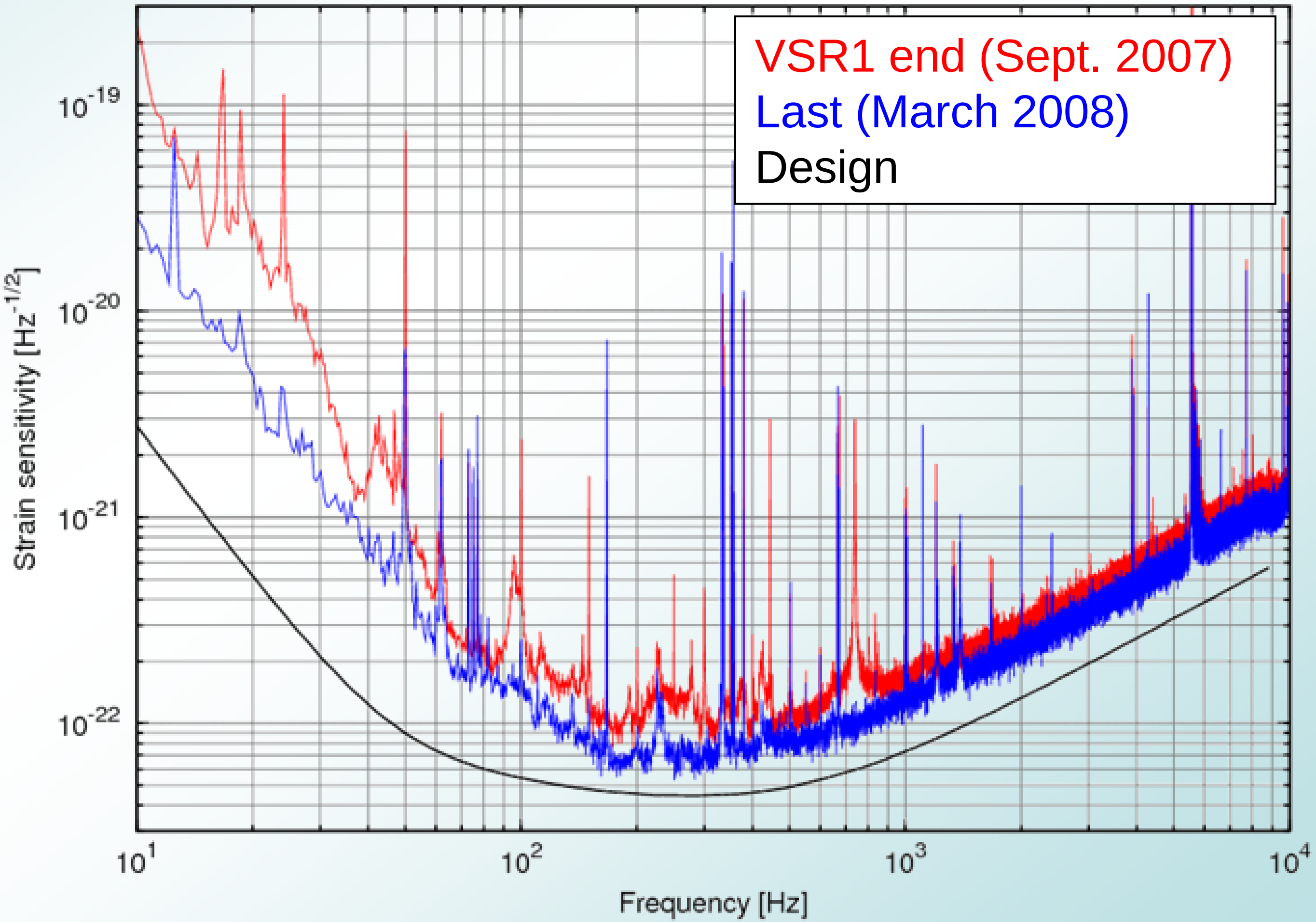
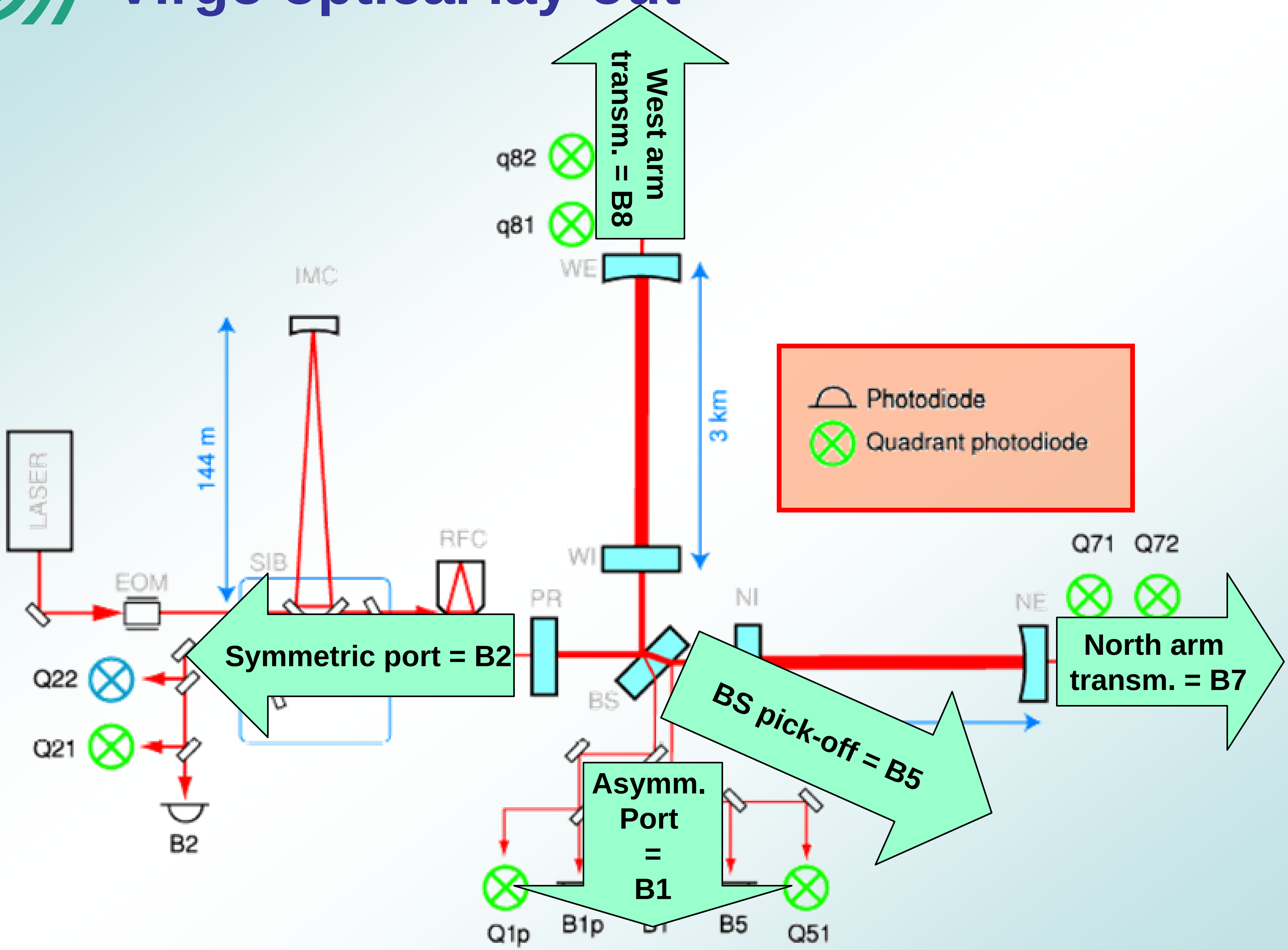
Summary

- Many sensitivity improvements after the end of VSR1
- Made possible by large reduction of control noises

- **Angular control noise** (alignment system)
- **Longitudinal control noise** (locking system)

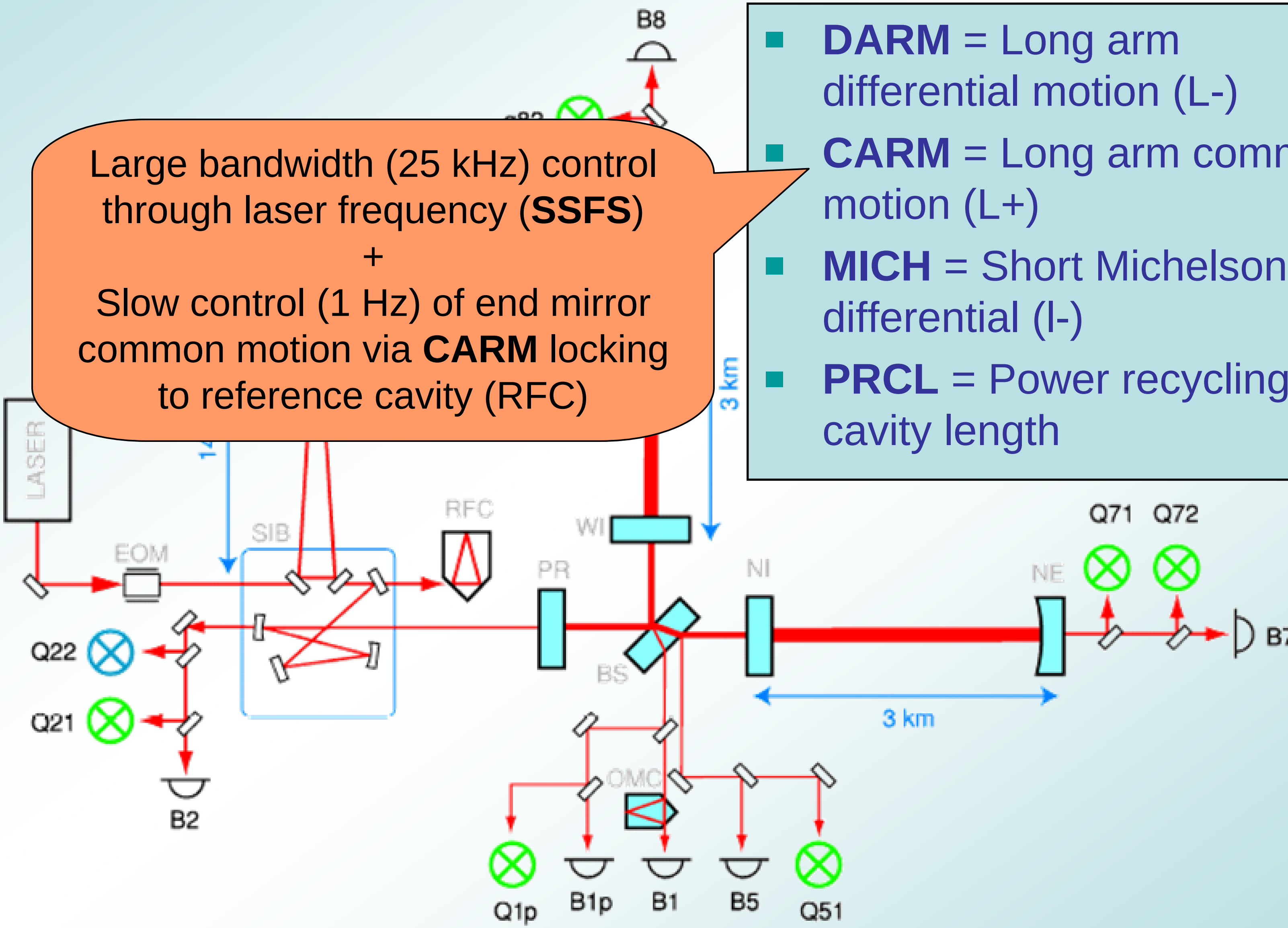


Virgo optical lay-out



Longitudinal control noise

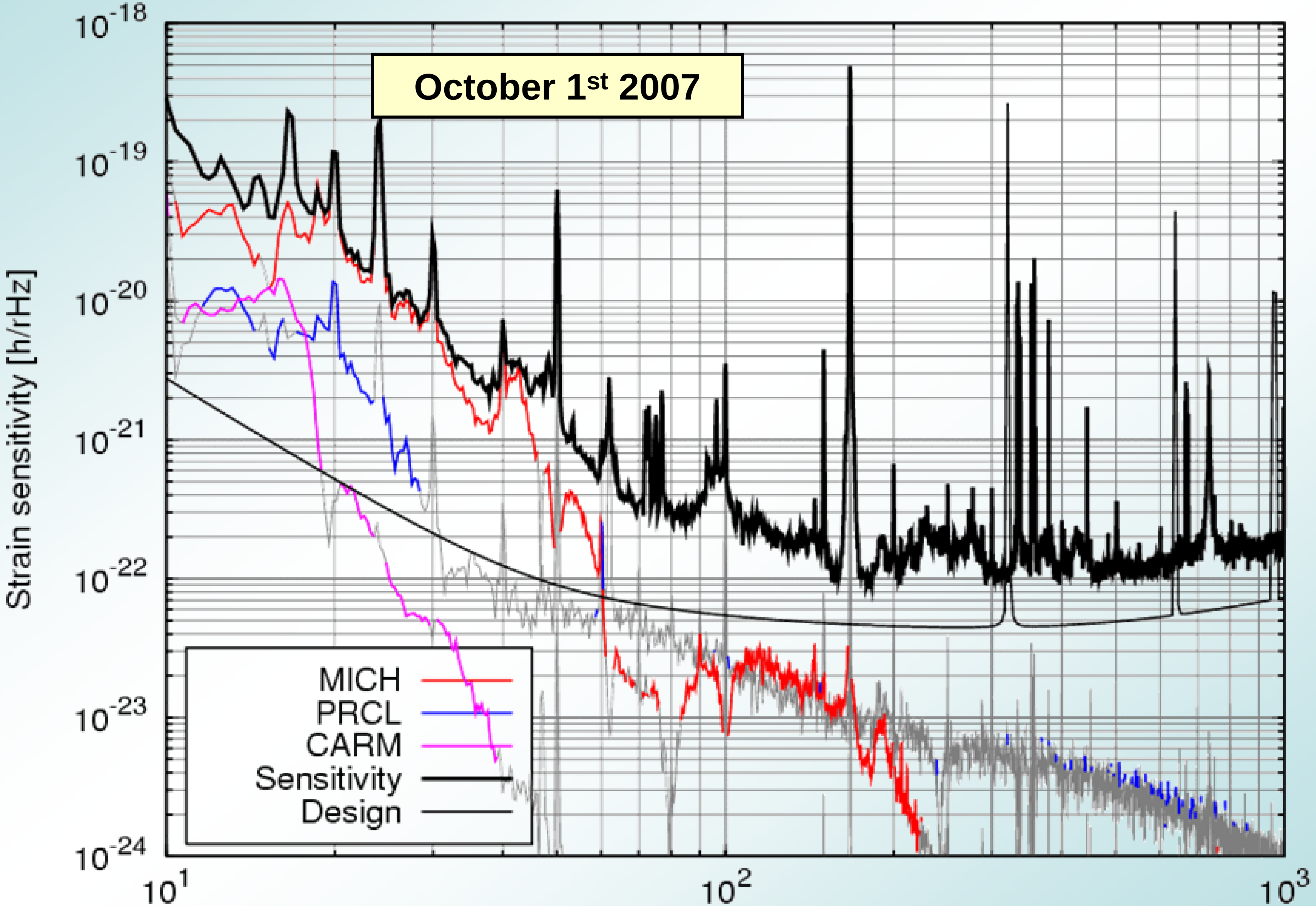
Longitudinal control



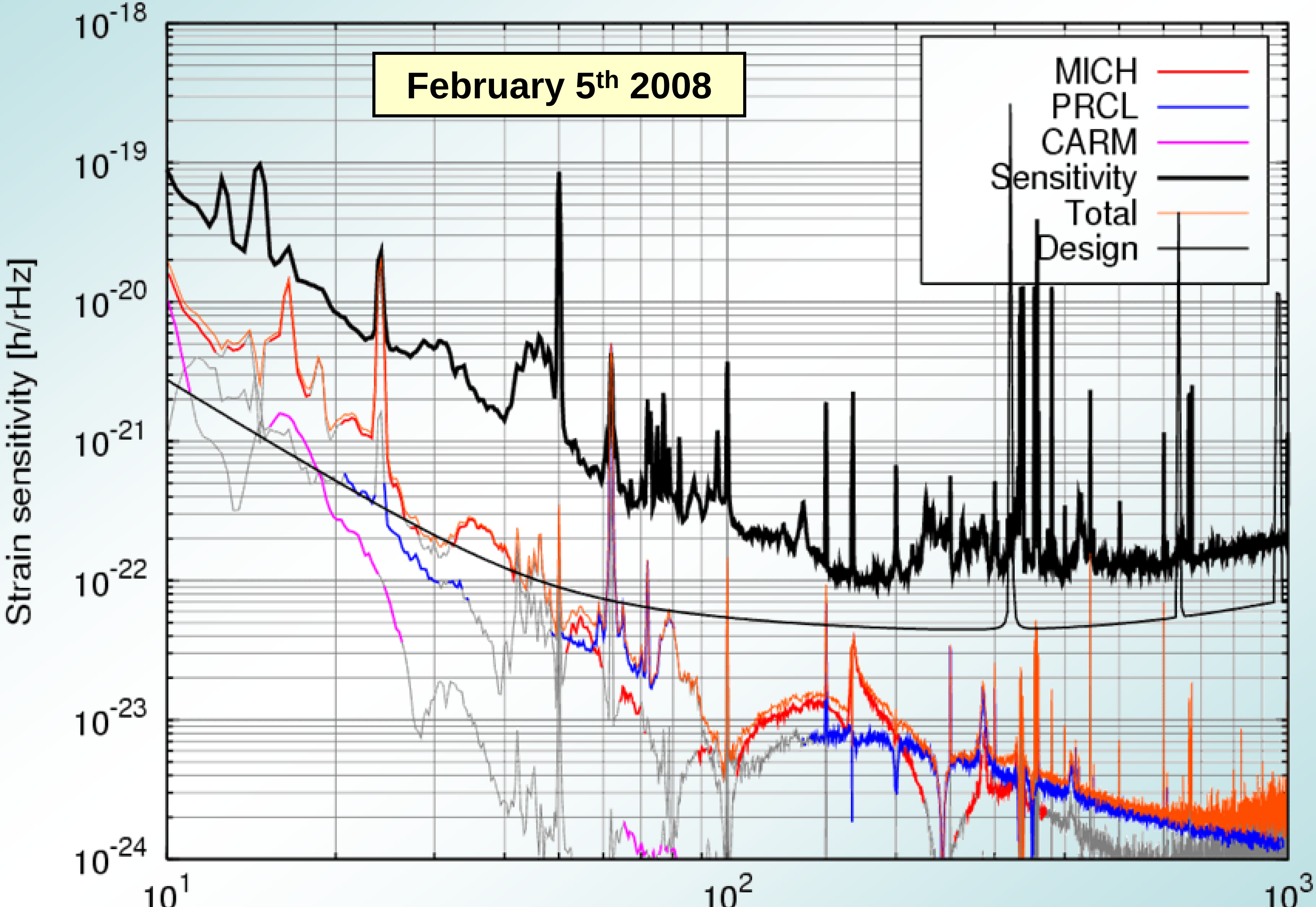
Large bandwidth (25 kHz) control through laser frequency (**SSFS**)
+
Slow control (1 Hz) of end mirror common motion via **CARM** locking to reference cavity (RFC)

- **DARM** = Long arm differential motion (L-)
- **CARM** = Long arm common motion (L+)
- **MICH** = Short Michelson differential (l-)
- **PRCL** = Power recycling cavity length

Longitudinal control noise / 1



Longitudinal control noise / 2



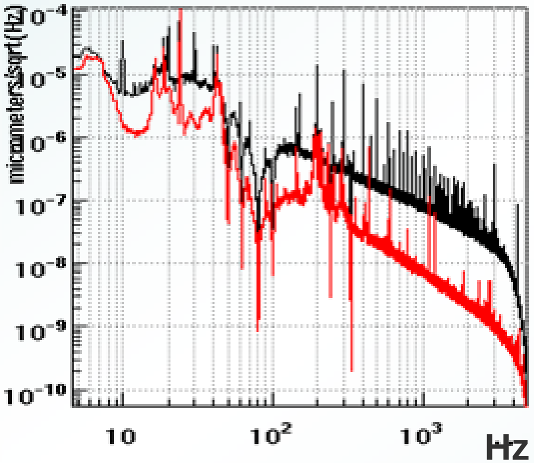
Longitudinal control improvements / 1

- Main modulation frequency 6.24 MHz used for longitudinal and angular control
  - Resonant in PRC
  - Anti-resonant in Fabry-Perot cavities
  - TEM 01 resonant in Fabry-Perot Cavity (Anderson-Giordano technique)
- After the run, new modulation at 8.32 MHz phase-locked to main one
  - Not resonant in PRC or FP
  - ITF reflection demodulated at 8.32 MHz

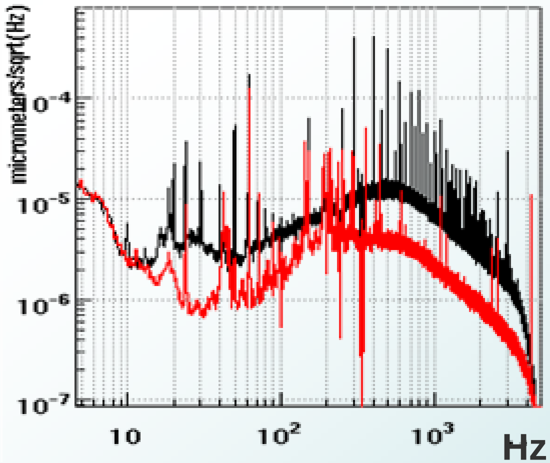
Change in longitudinal error signals

Old (VSR1) configuration	New sensing scheme
MICH Controlled with B5_Q + B2_6MHz_P + B2_18MHz_P (< 5 Hz) UGF @ 15 Hz **PRCL** Controlled with B2_6MHz_P + B2_18MHz_P (< 5 Hz) UGF @ 40 Hz	**MICH** Controlled with B2_8MHz_P UGF @ 10 Hz **PRCL** Controlled with B5_Q UGF @ 80 Hz

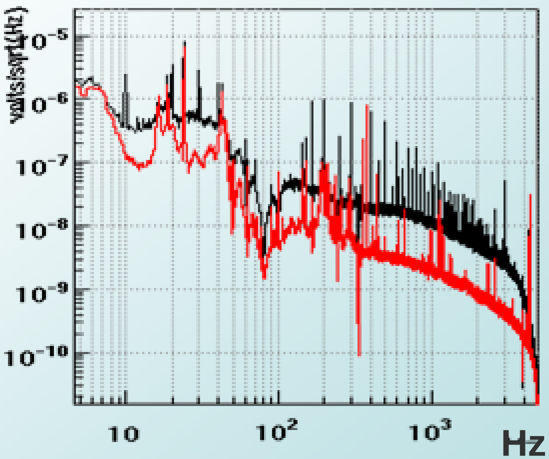
MICH correction



PRCL correction



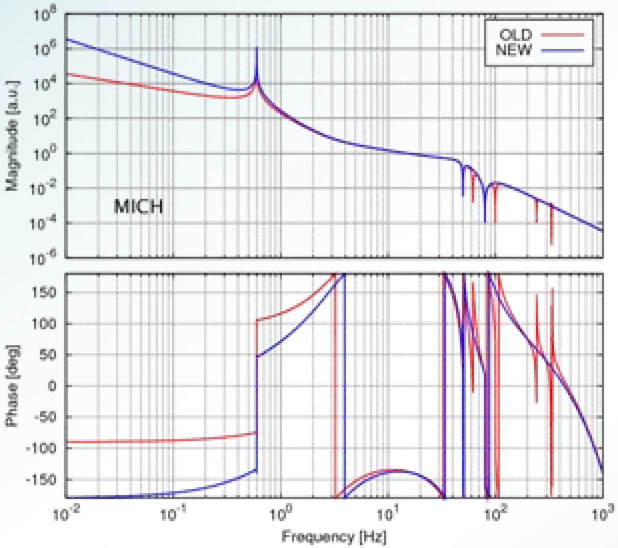
End correction



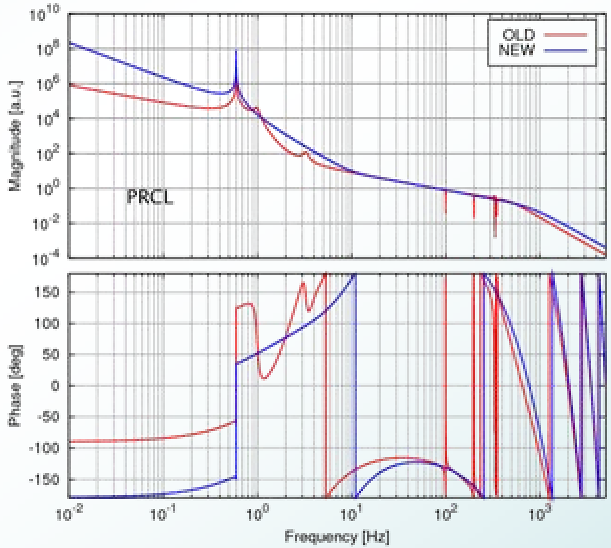
Change in control filters / 1

- Better accuracy (improved gain below 100 mHz)

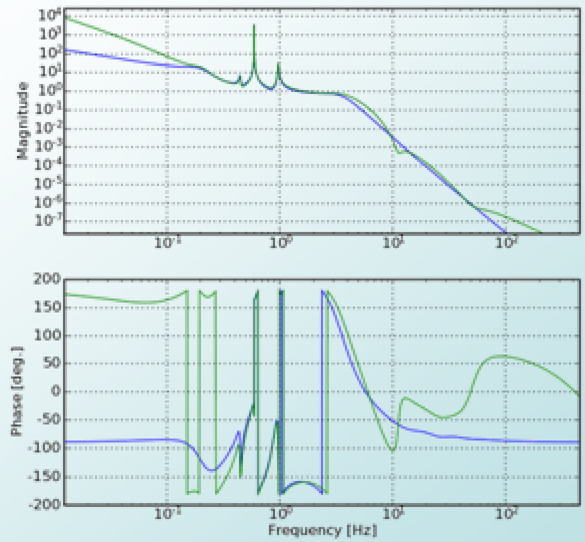
MICH



PRCL

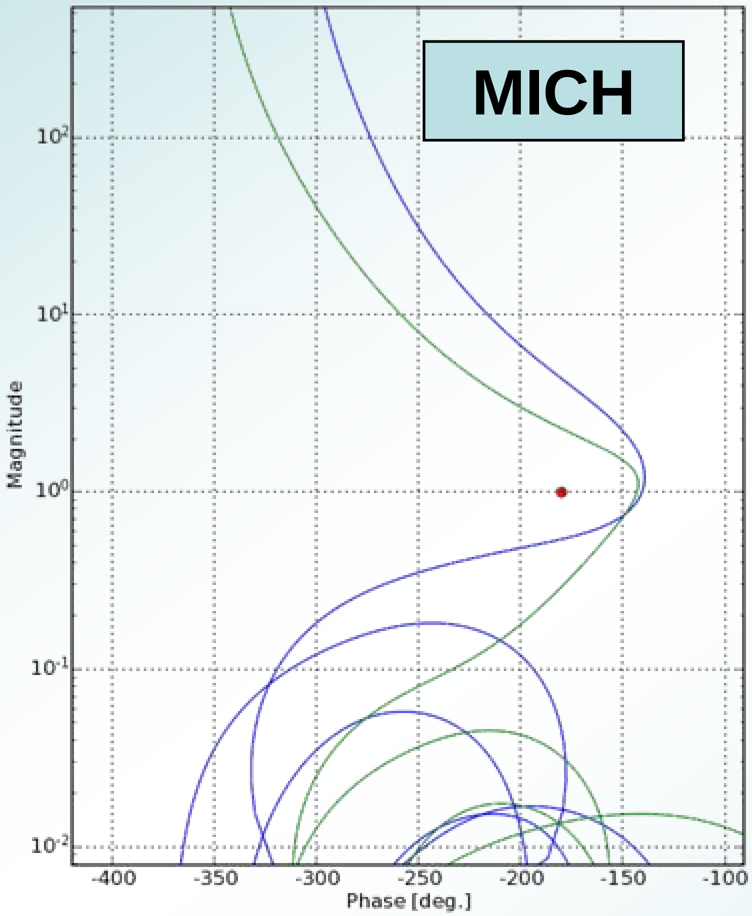


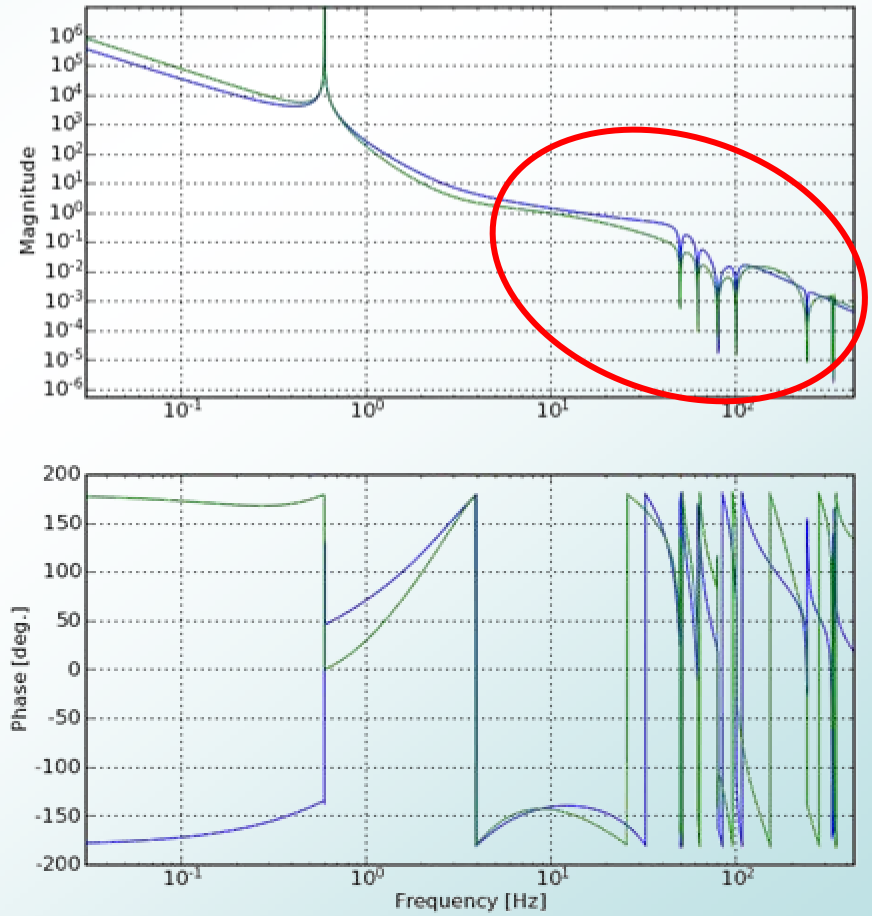
CARM



Change in control filters / 2

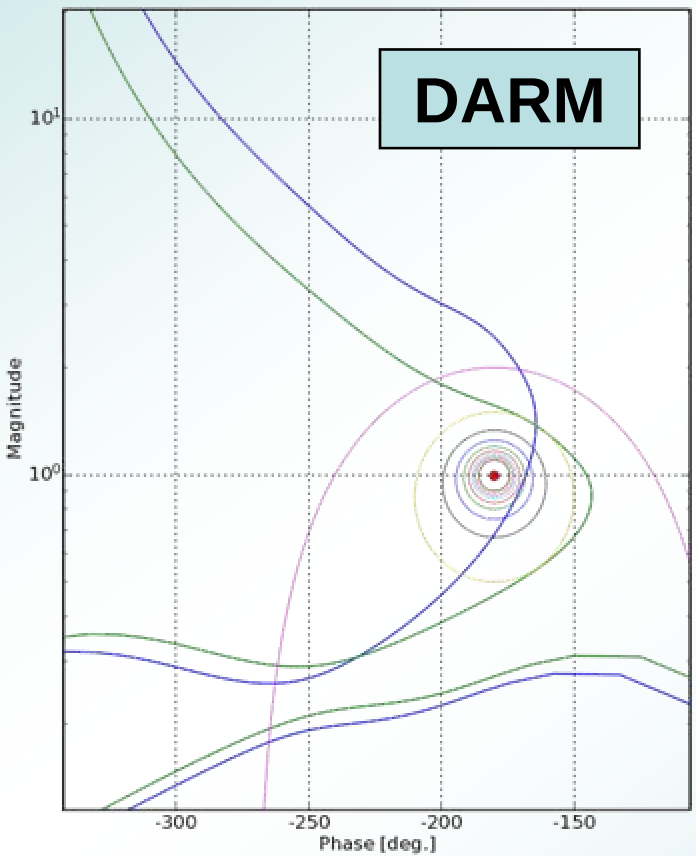
- Better optimization of high frequency cut-off (above 10 Hz)

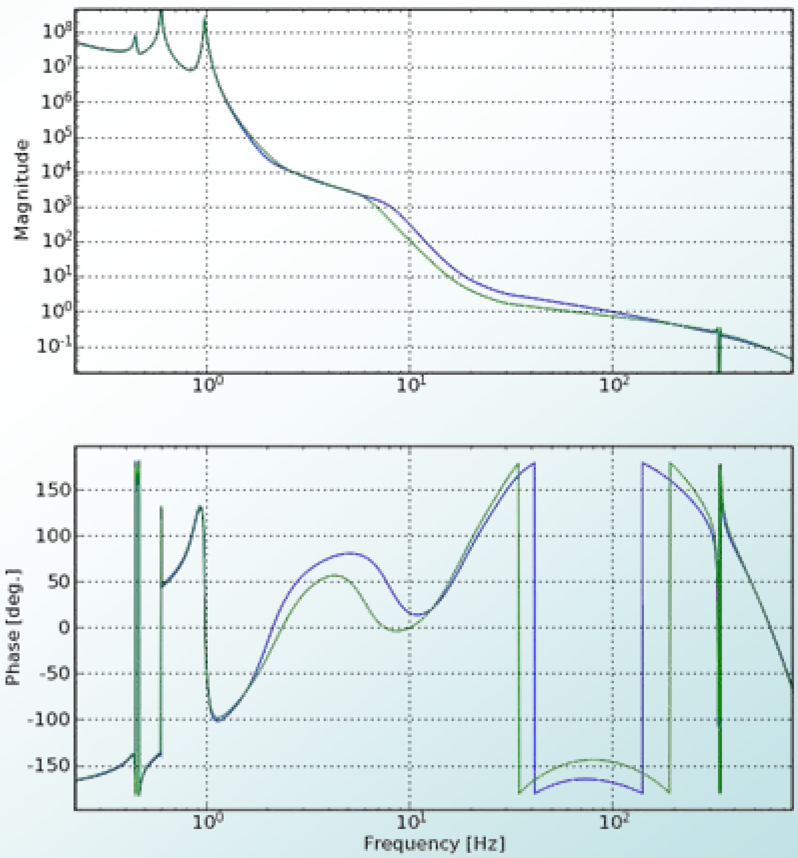




Change in control filters / 3

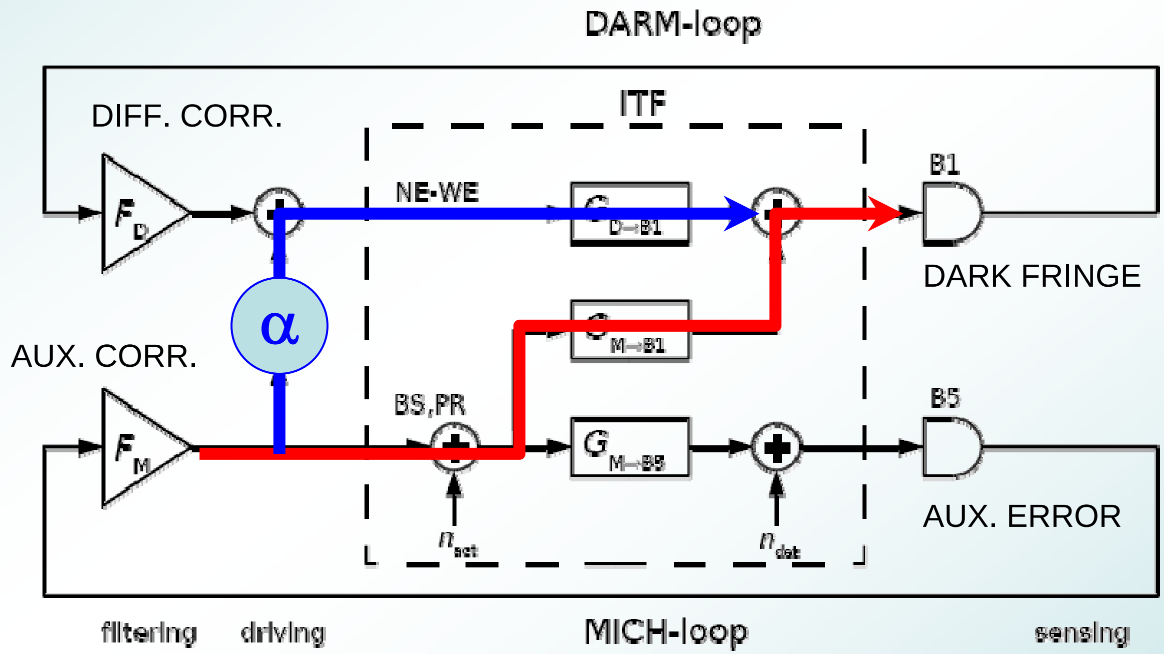
- Optimized phase and gain margins
  - To avoid calibration transfer function variations with cavity pole frequency (driven by Etalon effect in input mirrors)





Noise cancellation techniques

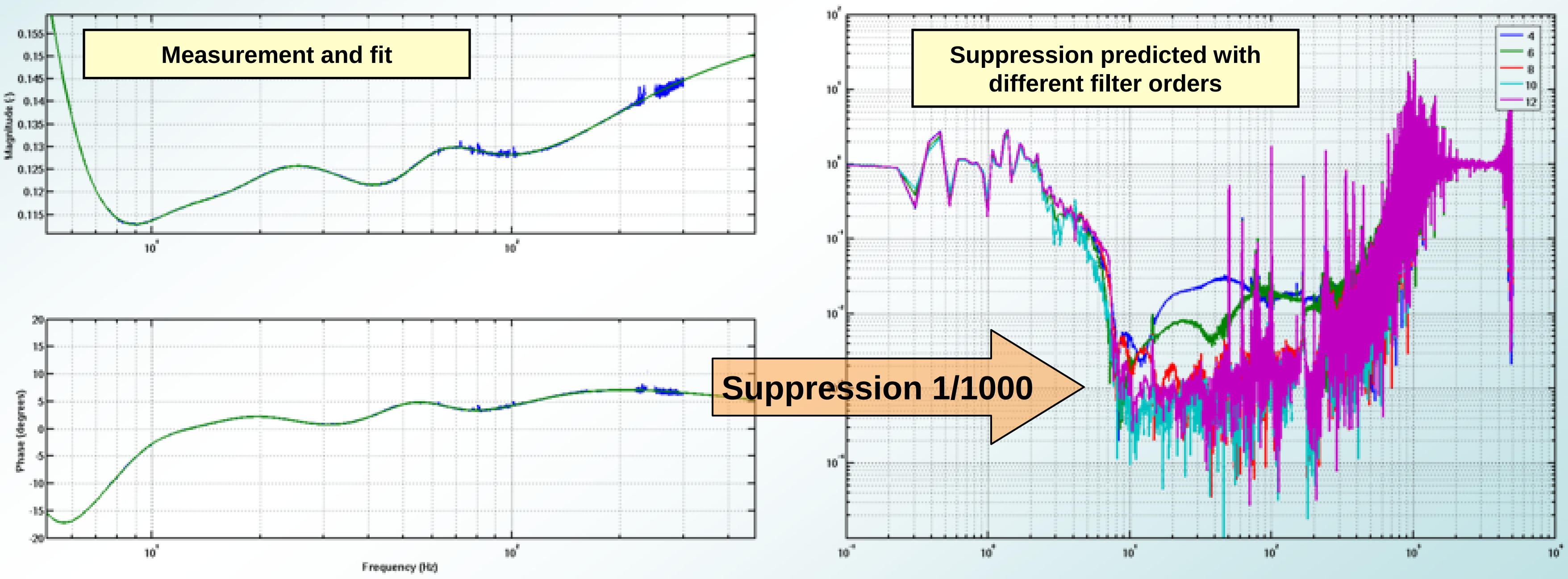
- Auxiliary loop control noises have a large coupling to dark fringe
- "Cancellation" technique:
  - MICH, PRCL, CARM corrections are sent to the end mirror differential mode
  - Corrections need to be filtered to compensate different actuator responses



- With suitable noise injection the correct filter can be computed
- High accurate fitting to obtain digital filter for the online noise cancellation

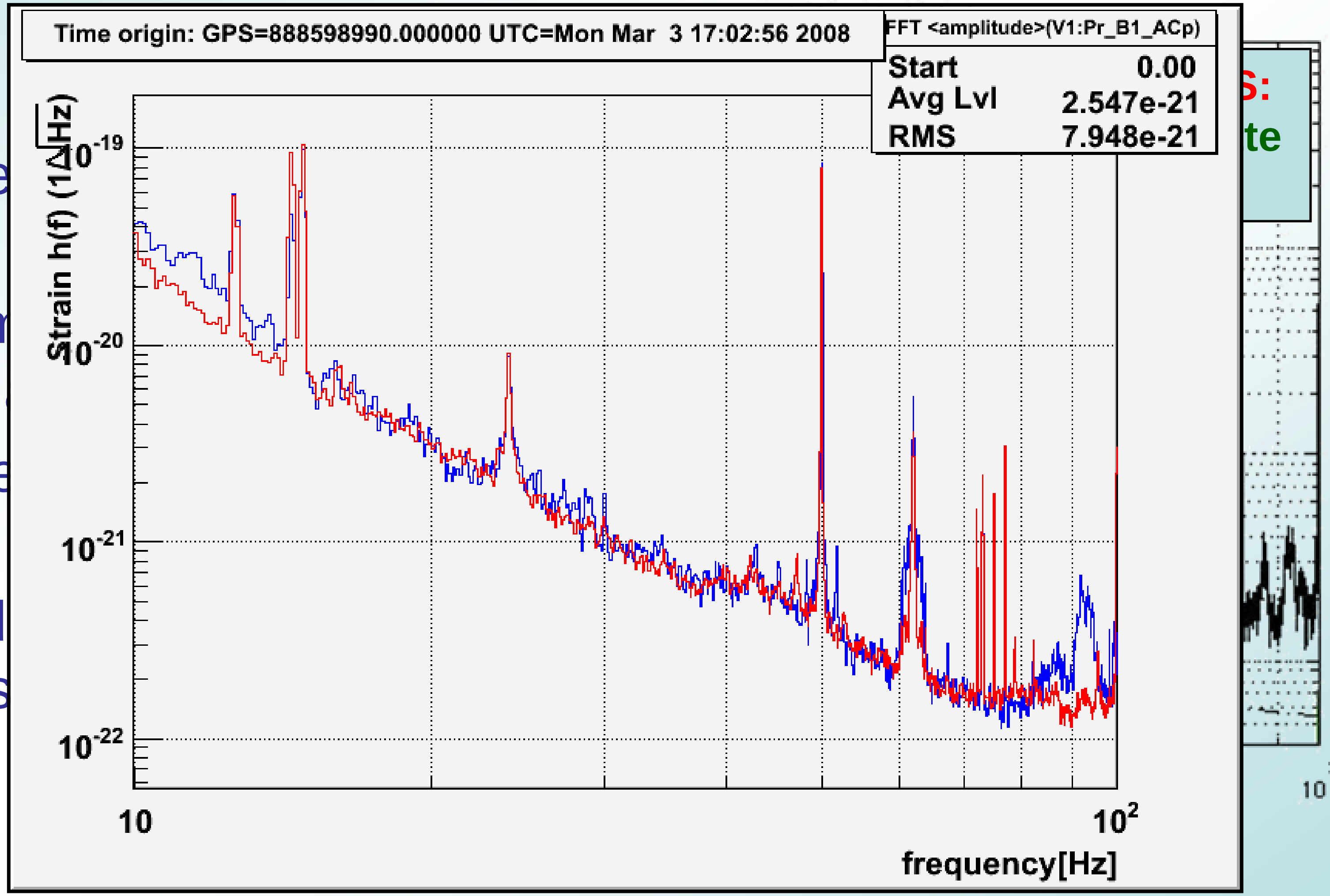
Noise cancellation techniques /2

- Very good performances
  - MICH control noise suppressed by ~1000 between 10 and 300 Hz
  - PRCL control noise suppressed by ~10 between 10 and 1000 Hz
  - CARM control noise suppressed by ~50 between 1 and 30 Hz
- Shape is very stable (depends only on actuator responses)
- Gain is changing a lot: servoed using a calibration line (bandwidth ~20 mHz)



Actuation noise reduction

- Actuator dominate noise
- Better em de-empha
- Larger se resistor
- Reduced present s

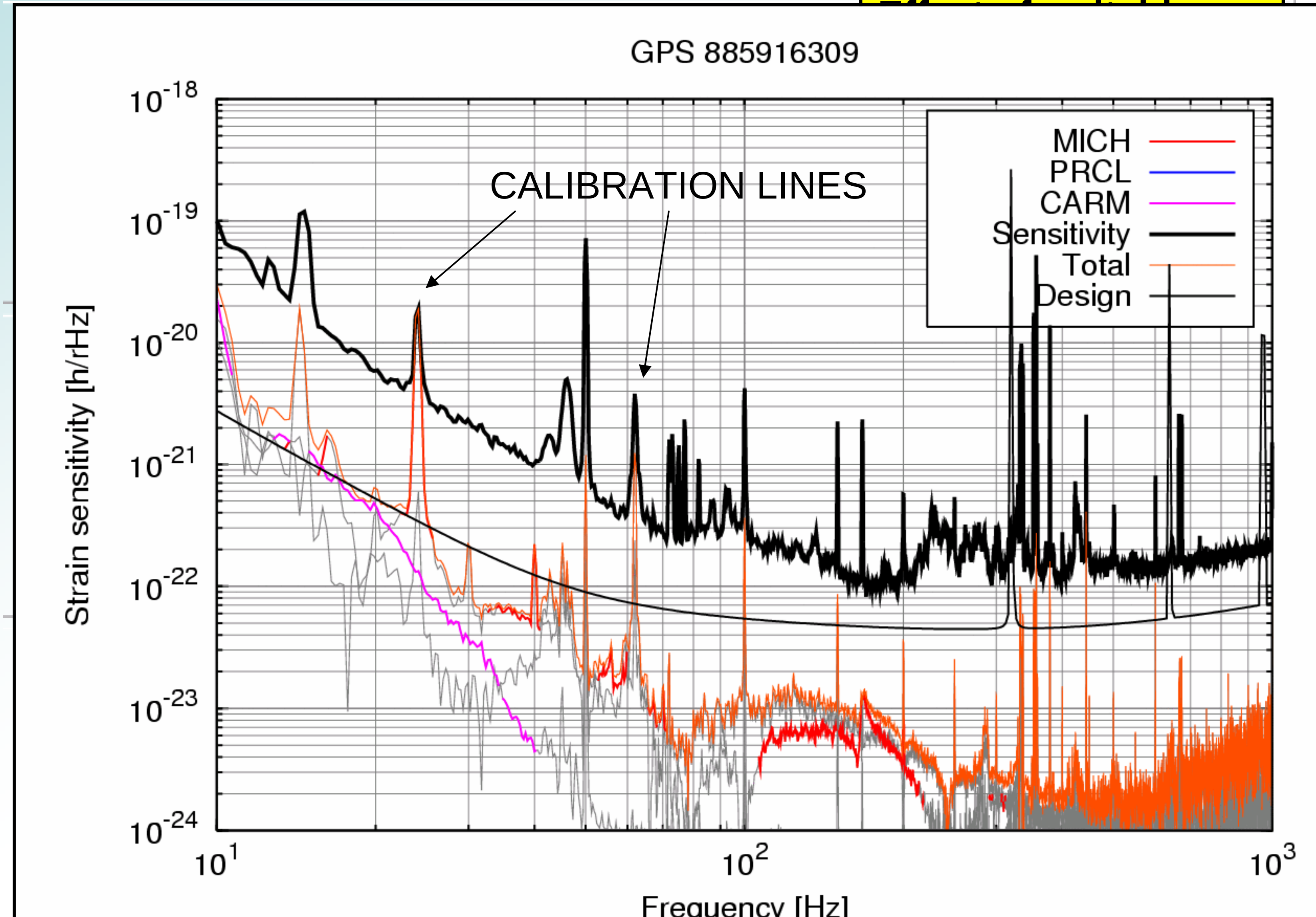


Environmental noise

MICH err

PRCL err

CARM err



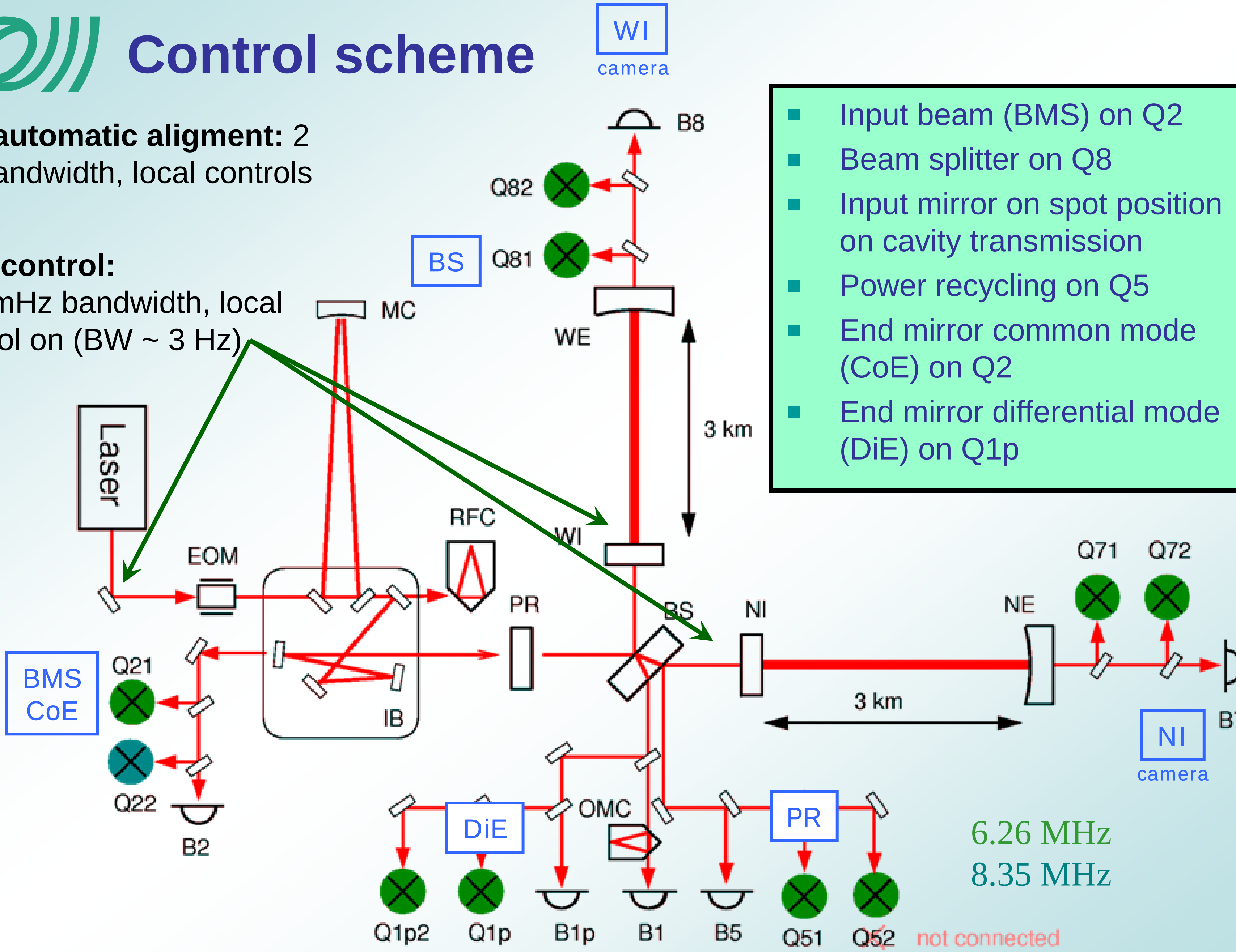
Angular control noise

Control scheme

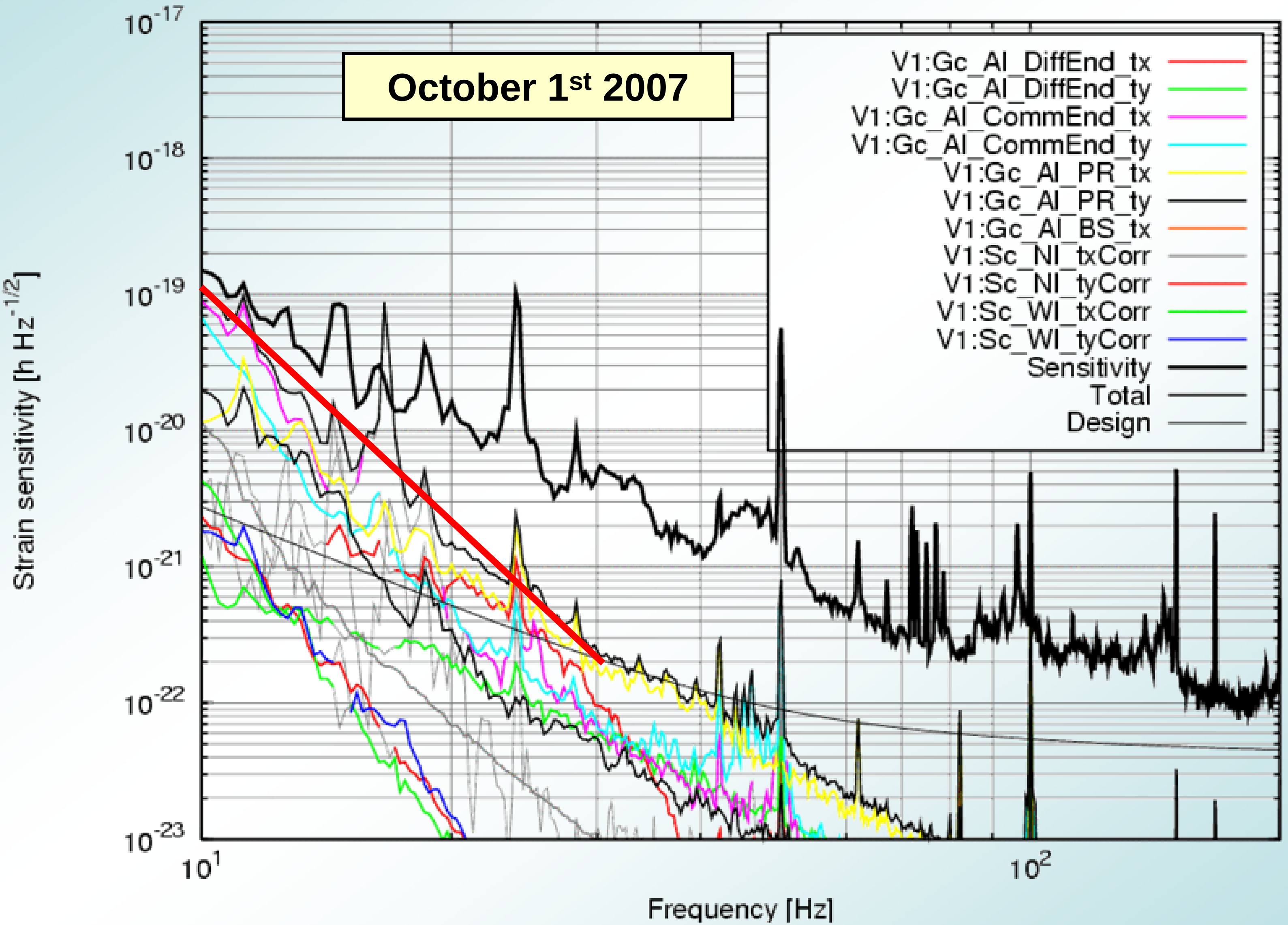
Full automatic aligment: 2 Hz bandwidth, local controls off

Drift control:
~10 mHz bandwidth, local control on (BW ~ 3 Hz)

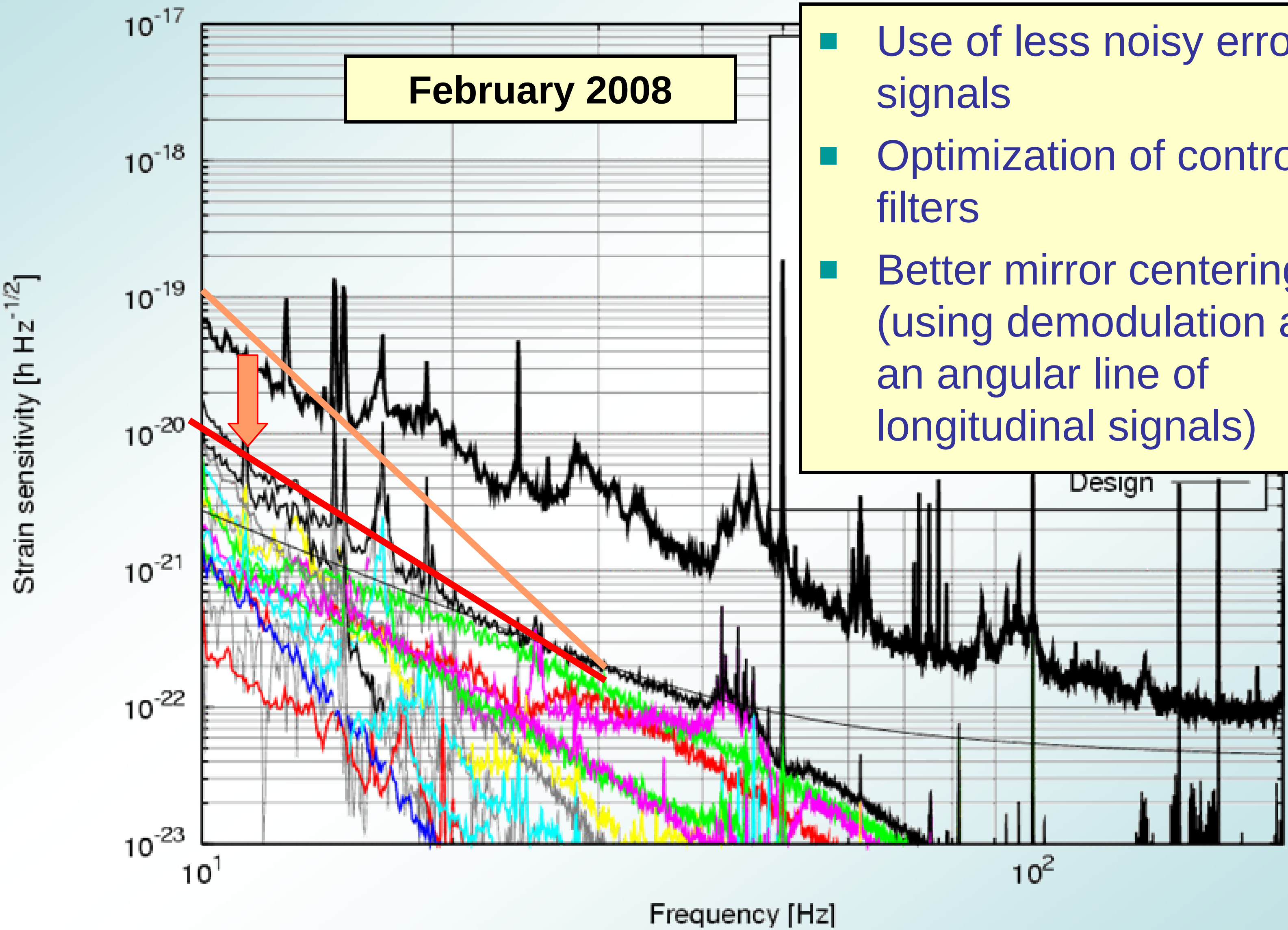
- Input beam (BMS) on Q2
- Beam splitter on Q8
- Input mirror on spot position on cavity transmission
- Power recycling on Q5
- End mirror common mode (CoE) on Q2
- End mirror differential mode (DiE) on Q1p



Angular control noise /1



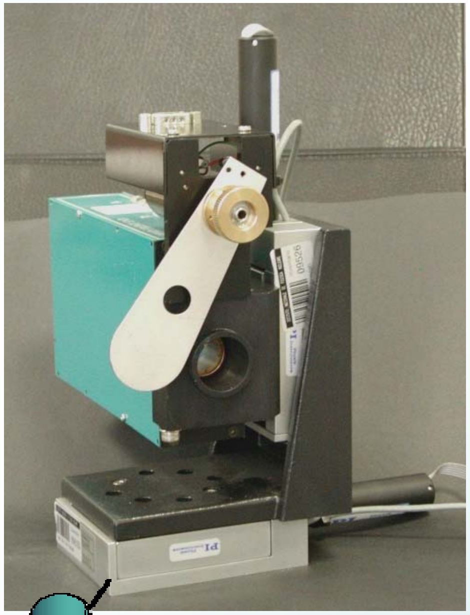
Angular control noise /2

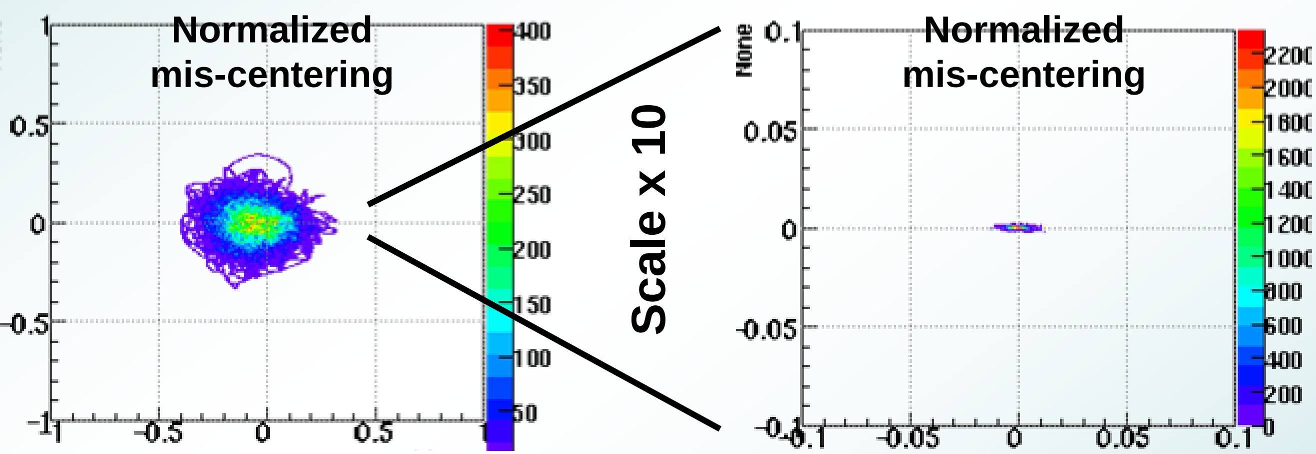


- Use of less noisy error signals
- Optimization of control filters
- Better mirror centering (using demodulation at an angular line of longitudinal signals)

Galvo centering systems

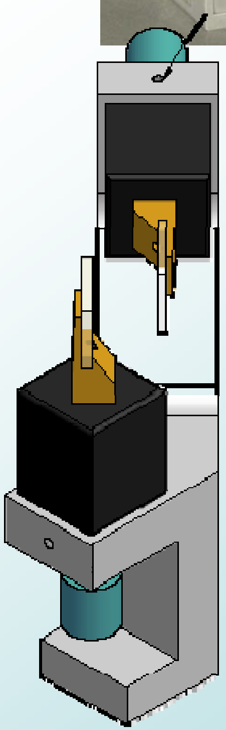
- Quadrant-diodes mounted on translation stages
  - Noisy and slow
- Better centering with galvo systems
- Installed on both end benches
- Avoid mis-alignments induced by quadrant mis-centering

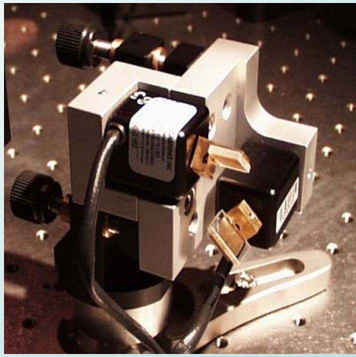




Galvo OFF

Galvo ON

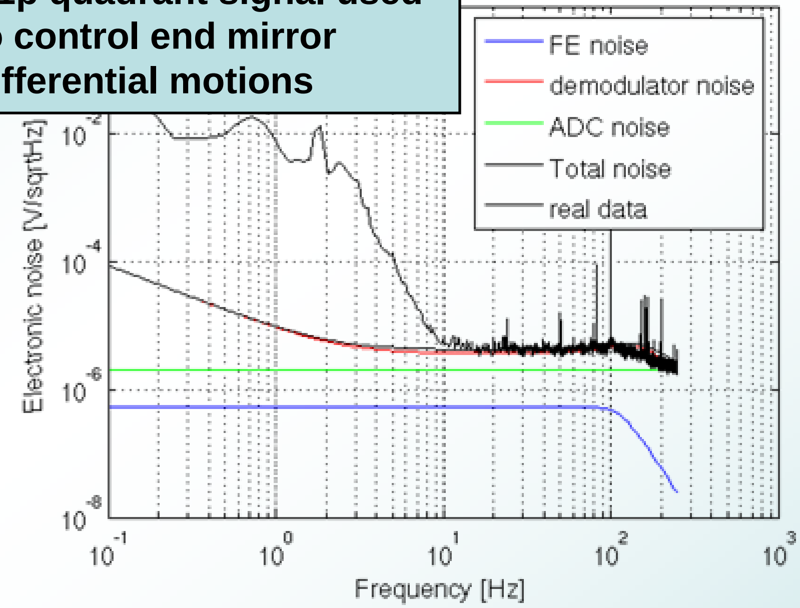


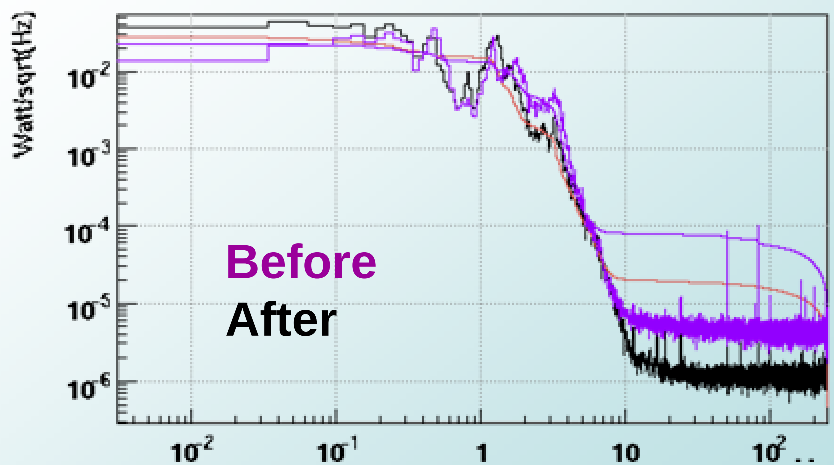


Sensor noise reduction

- Some signals were limited by electronic noise (demodulator board noise)
- Improved electronic installed
- Allow switchable electronic gains to cope with different beam powers

B1p quadrant signal used to control end mirror differential motions

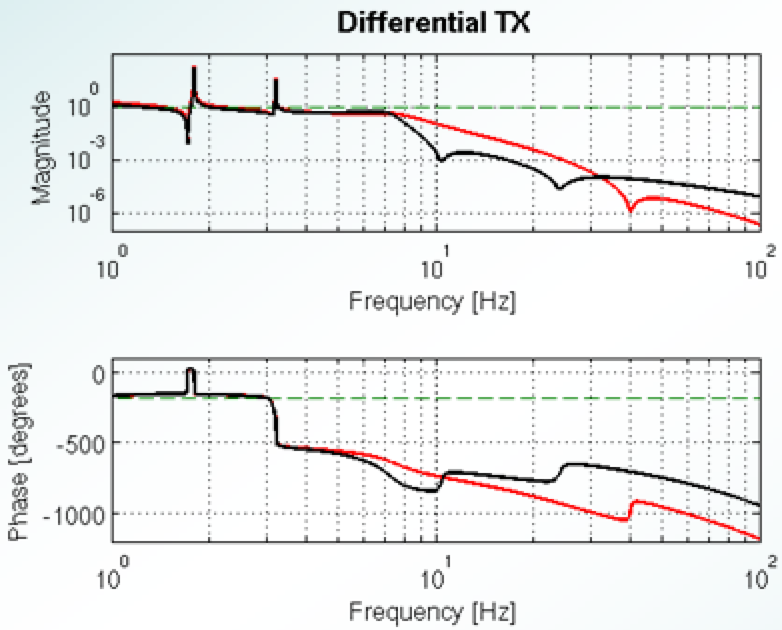


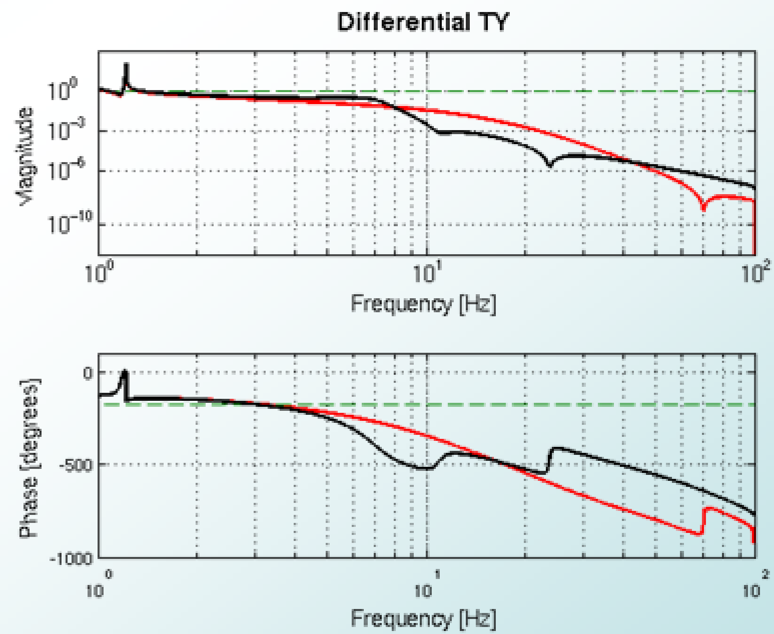


Improved control filte

Crucial to reduce noise in the
100-400 Hz region
Scattered light up-conversion

- To increase accuracy by i ea
(below 1 Hz)
- To reduce high frequency noise re-introduction (above 5 Hz)





Conclusions

- Longitudinal and angular control noise **no more limiting the sensitivity**
- Below design from 20-30 Hz up
- In 4 month after the run reduced
  - Angular noise by a factor ~10 at 10 Hz
  - Longitudinal noise by a factor ~30 at 30 Hz
- Allowed a better understanding and mitigation of other noise sources
  - Environmental, actuation, magnetic, etc…