

Calibration of the Virgo interferometer

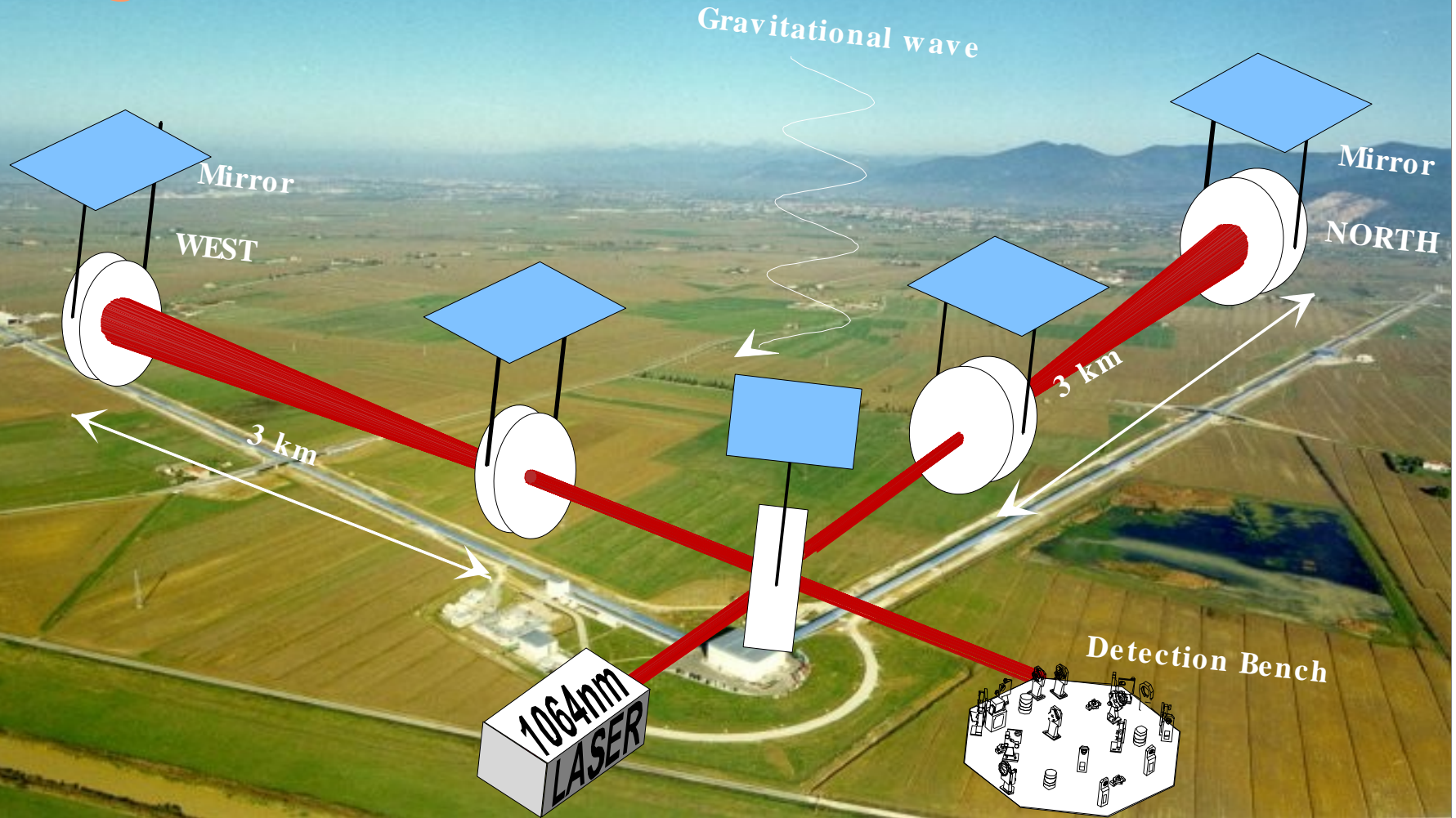
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Virgo

Michelson Interferometer (giant) for gravitational wave detection



What does calibration mean for an interferometer (ITF)?

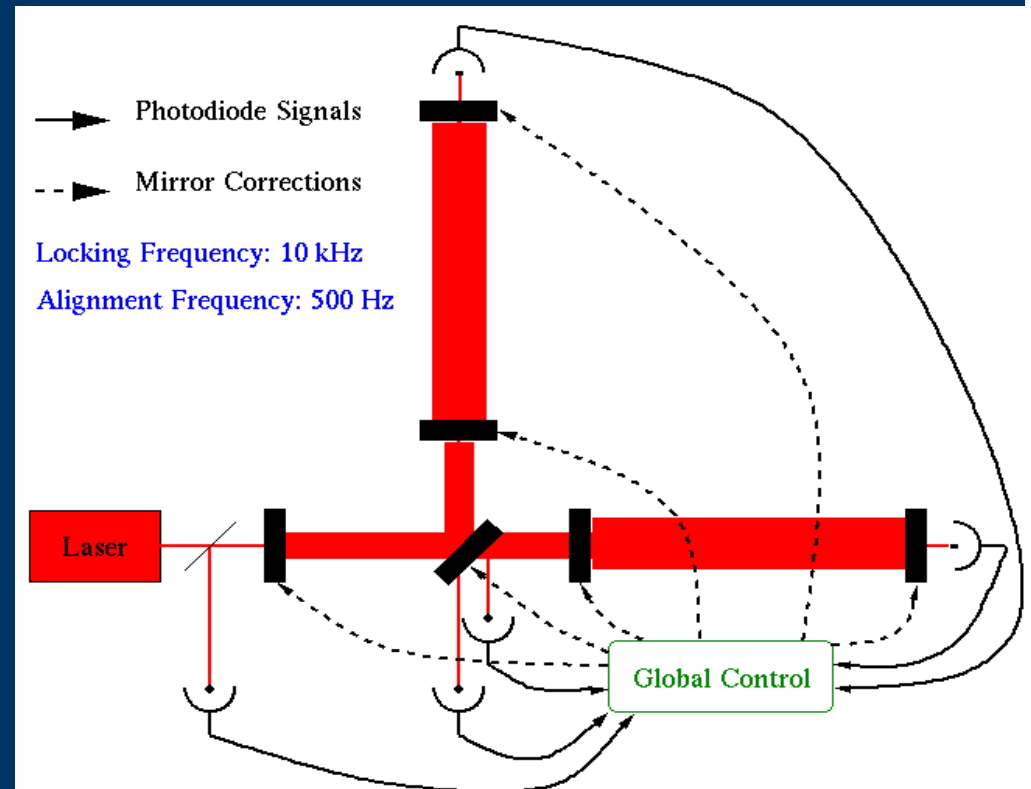
- Effect of a GW into the output signal
 - Output signal is in Watt on a photodiode
 - No GW (+ no noise)
 - the ITF is "locked" on the dark fringe
 - A GW passes by
 - the ITF try to move away from the dark fringe
- Calibration: to quantify this effect
 - The ITF response is not flat in frequency
 - ◆ The mirror positions are disciplined by control loops
 - ◆ The Fabry-Perot cavities also act like filters
 - ➔ Want to characterize the ITF on the full bandwidth

How to realize a calibration?

- Characterize the ITF on the full bandwidth
 - In frequency domain, *the calibration*:
 - ◆ Inject broadband movement on the mirror
 - ◆ Measure the transfer function of the ITF
 - In time domain, *the reconstruction*:
 - ◆ Inject permanent "lines" to monitor on-line the ITF response level in several frequencies
 - ◆ Input to a model of the ITF response
- Inject a calibration signal (white noise or frequency line):
 - *Principle* : move a mirror
 - ◆ Use the position control of the mirror
 - ◆ Use an auxiliary laser

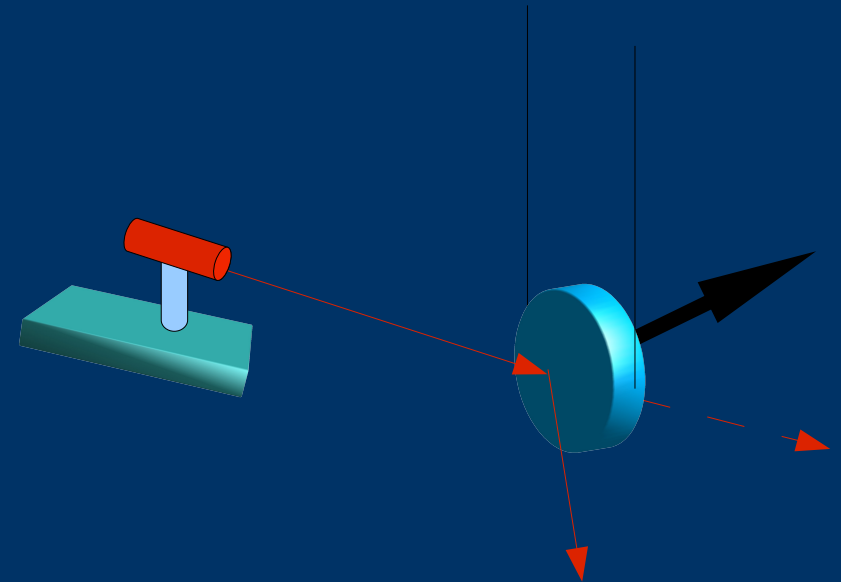
The "classical" calibration

- Mirrors position controlled
 - Control loop with feed back
 - Injection of calibration signal in the correction
- Utilization of actuators of the control system
- Need to calibrate these actuators



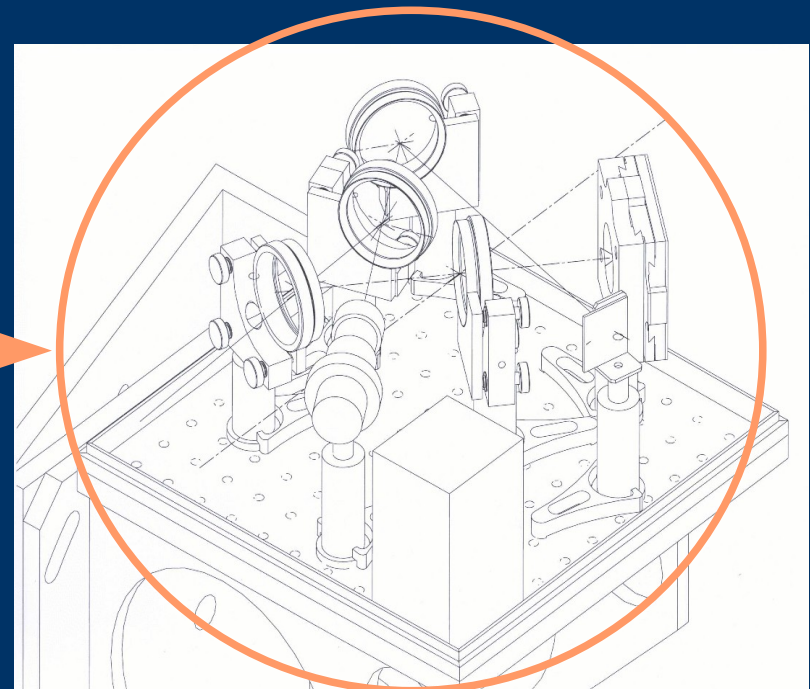
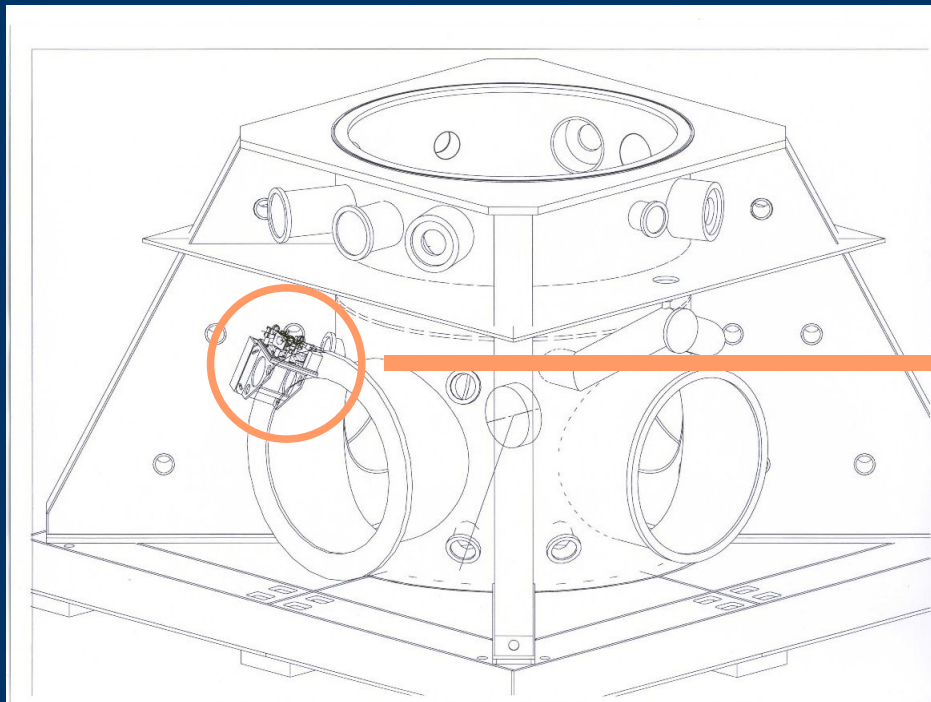
The optical calibrator

- *Aim* : Better accuracy on the sensitivity measurement
 - ♦ Independent of the interferometer control
 - ♦ Redundancy
- *Principle* : Auxiliary laser
 - ♦ Action on the mirror by radiation pressure
 - ♦ Modulation of the laser power by the calibration signal



Optical calibrator : realization

- Hardware installed on two mirrors :
 - ◆ optical bench, setup and aligned
 - ◆ electronics for monitoring and control of the stabilized laser installed
- To be tested soon



Calibration and sensitivity curves

- Using calibration

- Computation of the transfer function (TF)
 - ◆ White noise injection

$$TF = \frac{\text{Injected noise (meters)}}{\text{Interferometer response (Watt)}}$$

- Computation of the sensitivity curve
 - ◆ Select 5 minutes of “science mode” data
 - ◆ Compute interferometer output signal spectrum (FFT)
 - ◆ Multiply by the TF

- Using reconstructed data

- Compute directly the spectrum (FFT) of h-reconstructed data

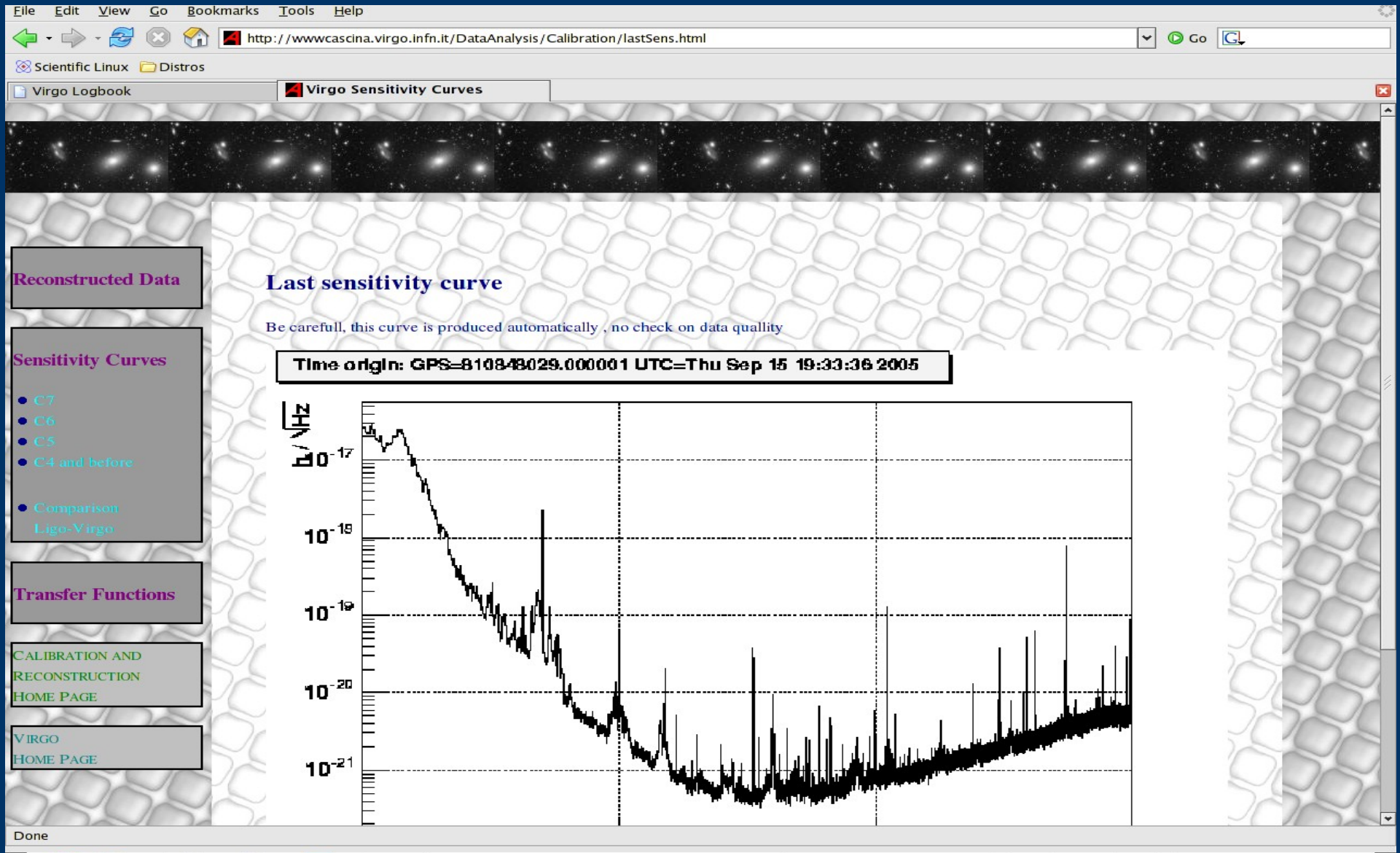
Automation

- Detector is getting closer to data taking
 - Automation of all usual tasks has started
- Calibration automation :
 - ♦ Data taking with "noise" injection
 - ♦ Data taking in science mode
 - ♦ Computation of the sensitivity curve
 - ♦ Last curve is automatically available on the web

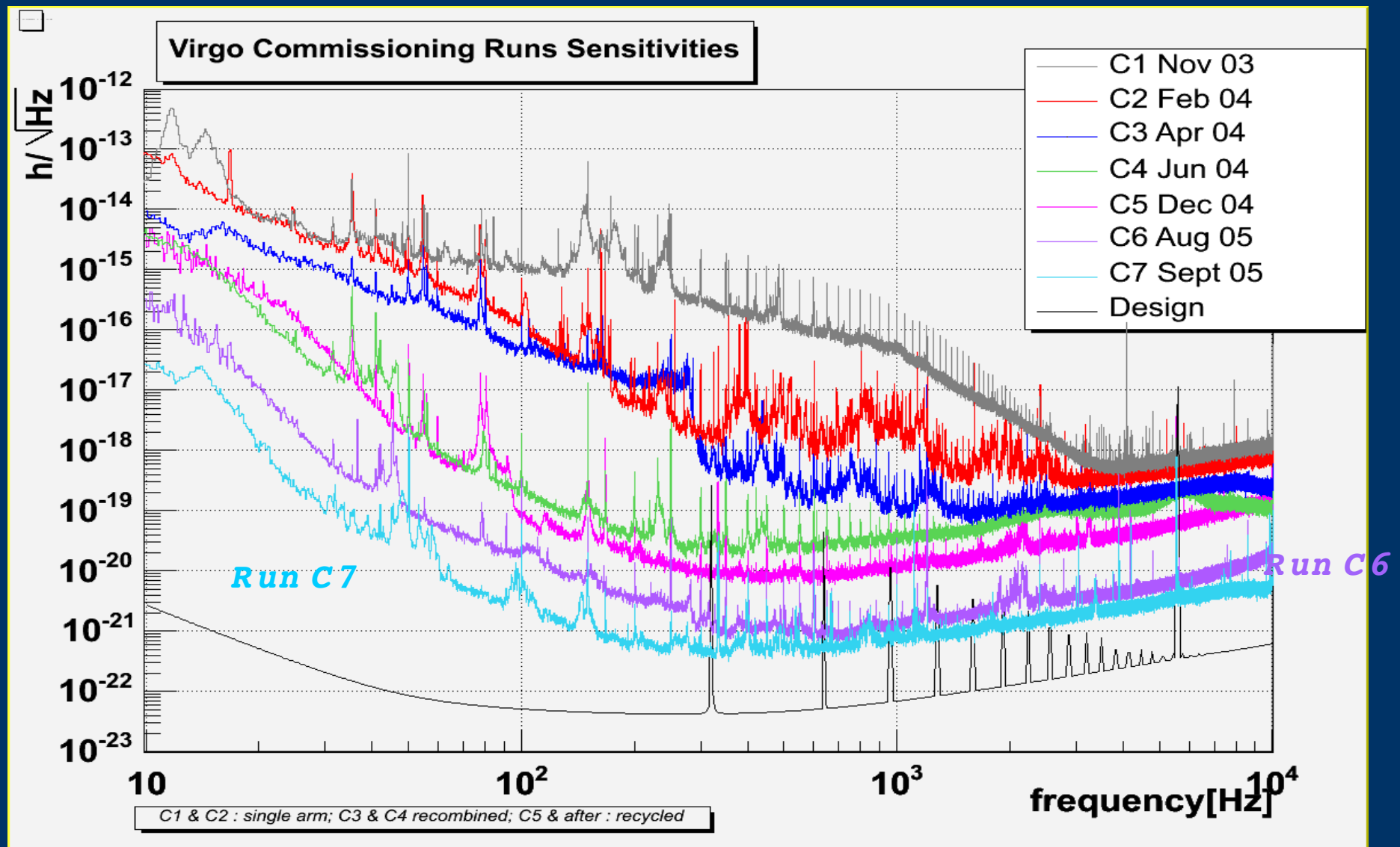
The screenshot shows the 'Automation' software interface. At the top, there's a title bar with the name 'Automation' and system icons. Below that is a terminal window displaying log output for various components like AlpAII, AlpCa, AlpDet, and AlpSa. The log shows timestamps and status messages such as 'checklock completed'. Below the terminal is a table with columns for component names (AlpAII, AlpCa, AlpDet, AlpSa, AlpGuard, AlpRecycled), their status (e.g., Recombined, Golden, unknown, DBA...), and detailed configuration information including GPS IDs and latency/etime values. A menu is open in the bottom-left corner, listing options like 'Start', 'Edit Config', 'Exit', 'Alp Init', 'DBA', 'Align Alignment', 'Measure Sensitivity Curve with/without Noise Injection', 'StartUp', 'DBA Restore', 'Load Macro', and 'Stop Macro'. The 'Measure Sensitivity Curve with/without Noise Injection' option is circled in red.

Component	Status	Configuration
AlpAII	Recombined	GPS825256738-FR10070 Recombined >Ali_Main >WAIT 7 - latency 1.96 - etime 0.001636
AlpCa	Golden	GPS825256738-FR10070 Golden >No macro - latency 2 - etime 0.001662
AlpDet	Golden	GPS825256738-FR10070 Golden >Det_Main completed - latency 1.94 - etime 0.00145
AlpSa	Golden	GPS825256738-FR10070 Golden >No macro - latency 1.98 - etime 0.000175
AlpGuard	unknown	Alp Guard server
AlpRecycled	DBA...	GPS825256677-FR10009 DBA... >No macro - latency 2.06 - etime 0.001369

The calibration web page



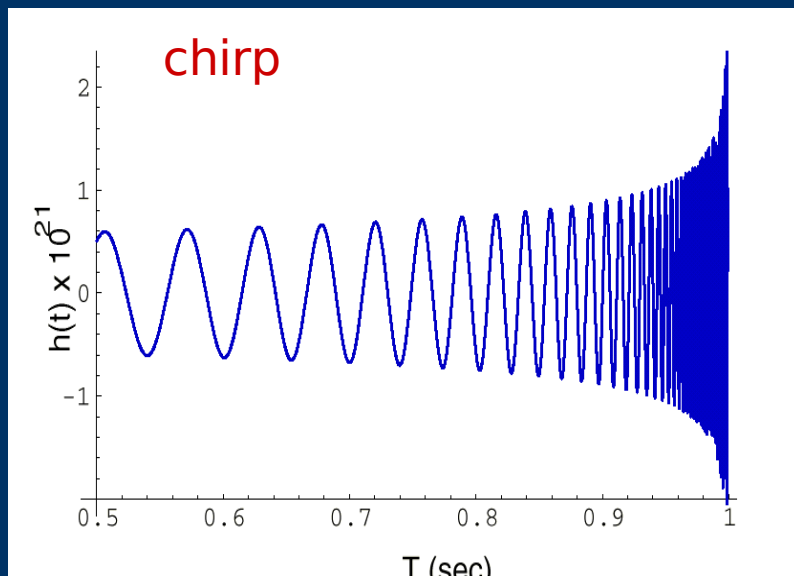
Sensitivity curves



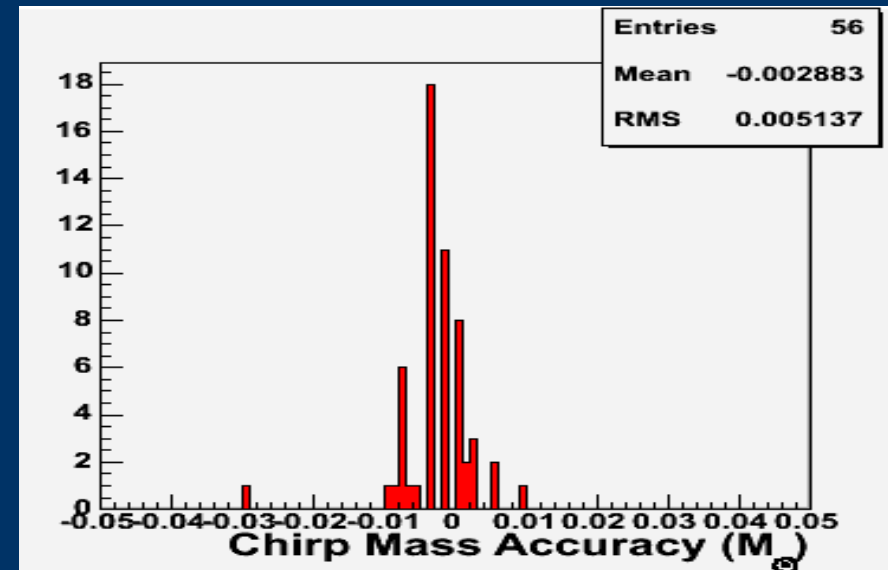
Hardware events injection

Use of the calibration signal injection procedure

- Inject realistic GW event signals
- The analysis software find out the events
- Global test of the h-reconstruction



Example of waveform injected:
chirp from a binary inspiral



Example of the accuracy on a reconstructed parameter : the chirp mass of the binary

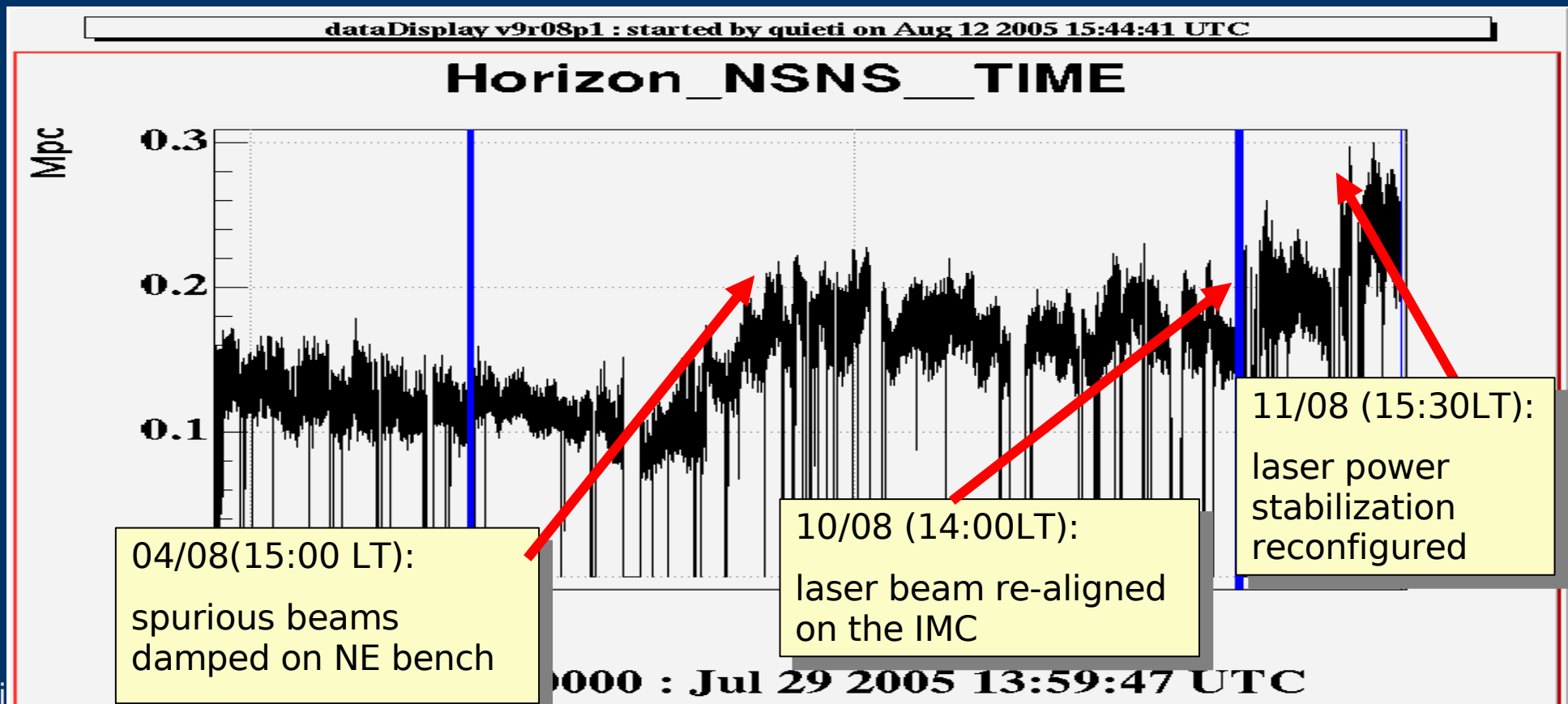
$$M = \left(\frac{m_1 m_2}{m_1 + m_2} \right)^{3/5} \times (m_1 + m_2)^{2/5}$$

By-product of the h-reconstruction

Tool for commissioning:

Binary inspiral range, "horizon" :

distance until which we can detect a "standard event"
(*NS-NS inspiral optimally oriented*)
above a conventional level



Conclusion

- ◆ Calibration of Virgo interferometer is now "routine", fully automated
- ◆ Cross-checks are possible and planned with the optical calibrator
- ◆ h-reconstruction runs on-line during data taking
- ◆ Both are providing useful tools for the commissioning

Spares slides

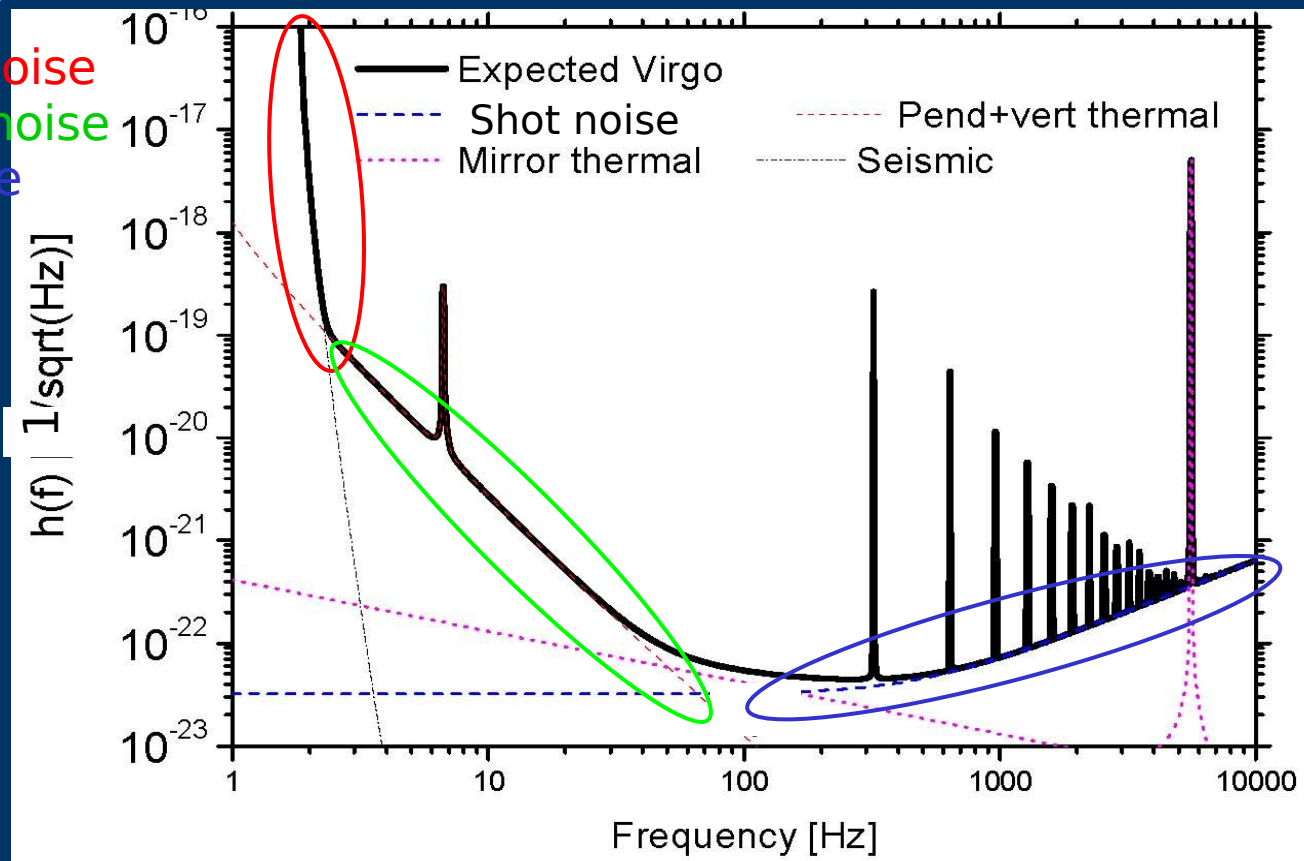
VIRGO design sensitivity

Main sources of noise limiting the VIRGO design sensitivity

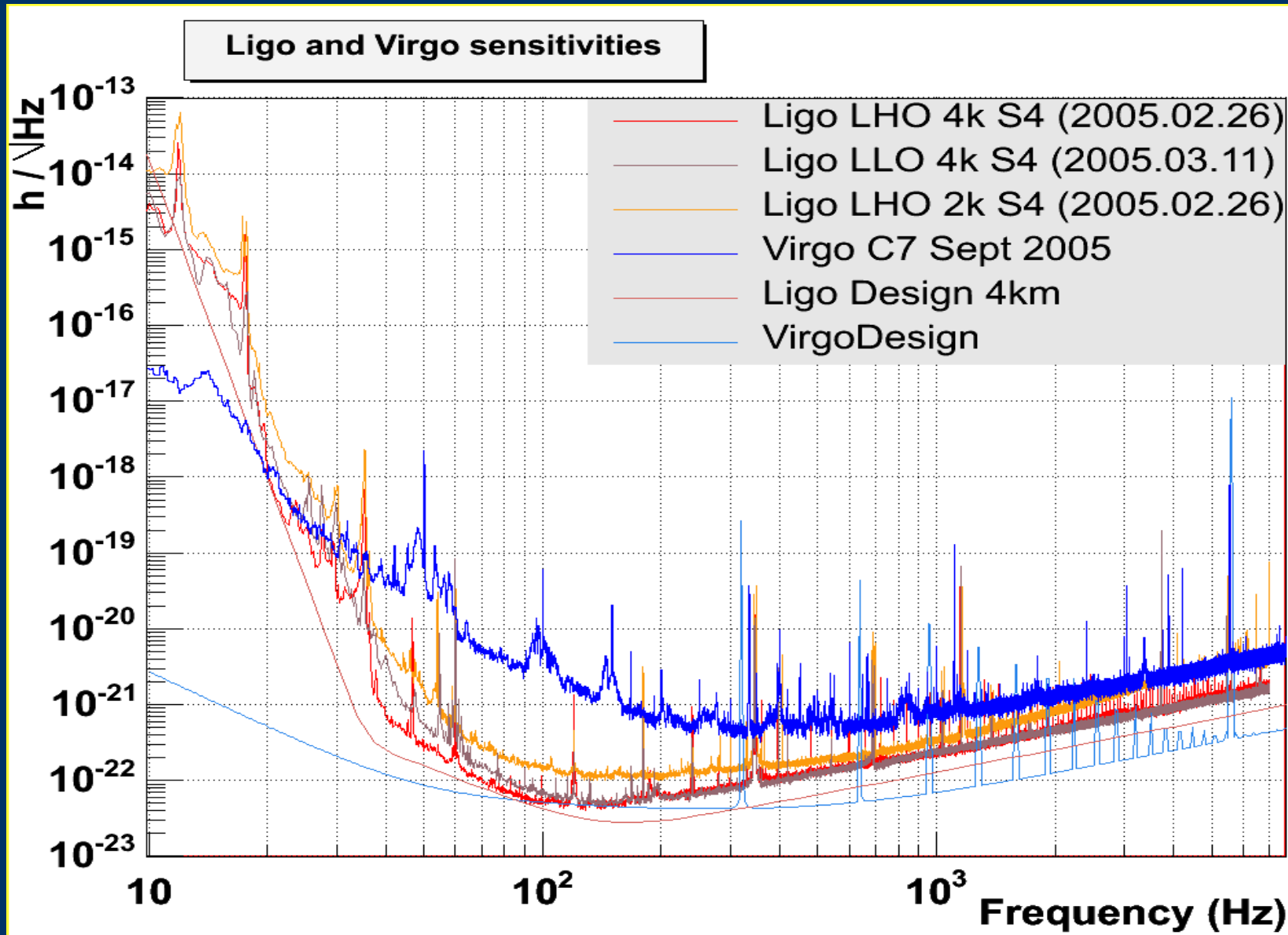
Seismic noise

Thermal noise

Shot noise



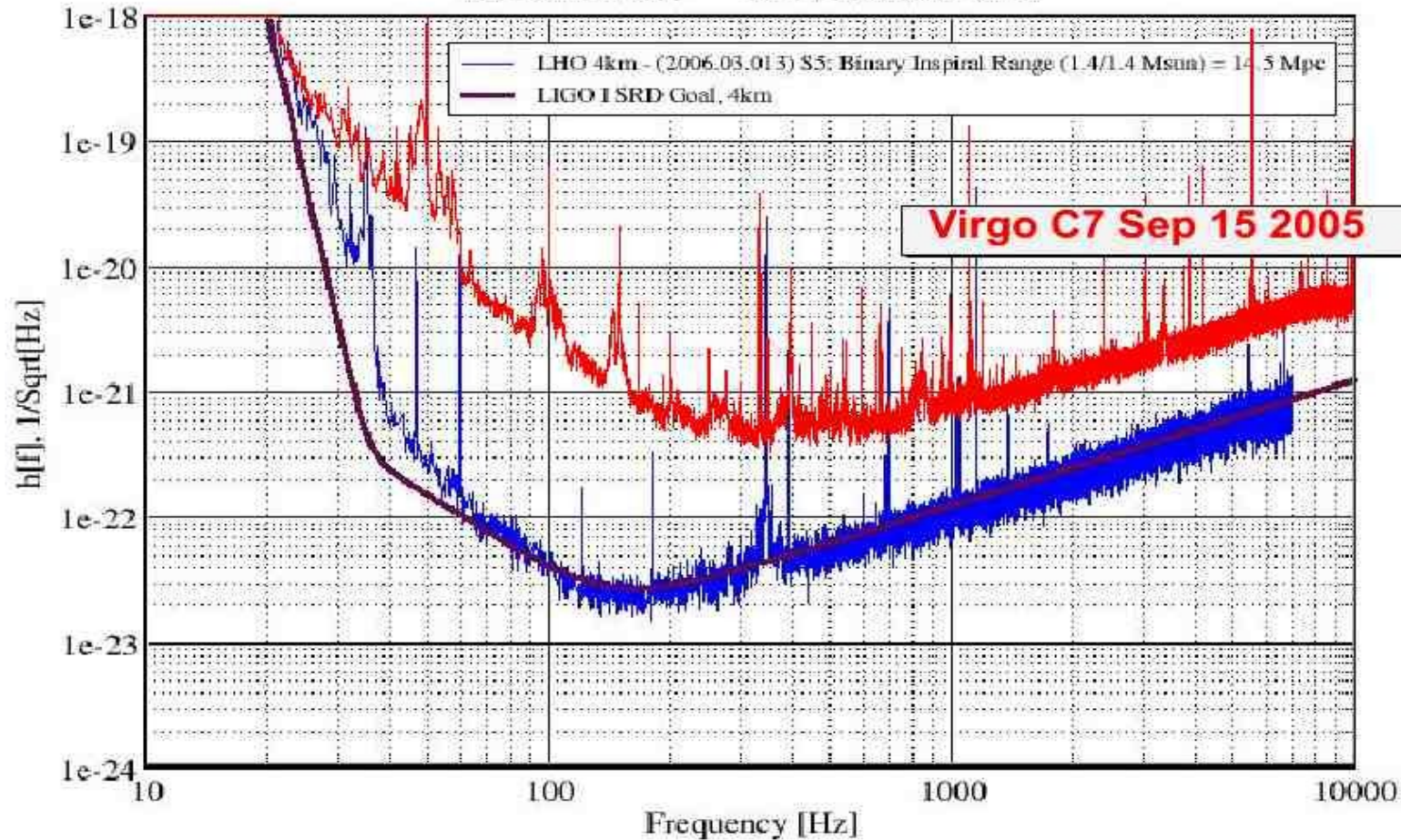
LIGO/Virgo sensitivity



Last LIGO/Virgo comparison

Strain Sensitivity for the LIGO Hanford 4km Interferometer

S5 Performance LIGO-G060051-00-Z



Ligo-Virgo common data taking

- ◆ LIGO is already at its nominal sensitivity
 - ◆ Taking data for one year
- ◆ Virgo getting close to its nominal sensitivity
 - ◆ Data taking together with LIGO at the end of the year
- ◆ Analysis will be done in common
- ◆ Upgrades already planned for both detectors