Virgo status and commissioning results

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for the Virgo Collaboration

5th LISA Symposium – 13 july 2004

VIRGO is an French-Italian collaboration for Gravitational Wave research with a 3 km long ground-based interferometer.

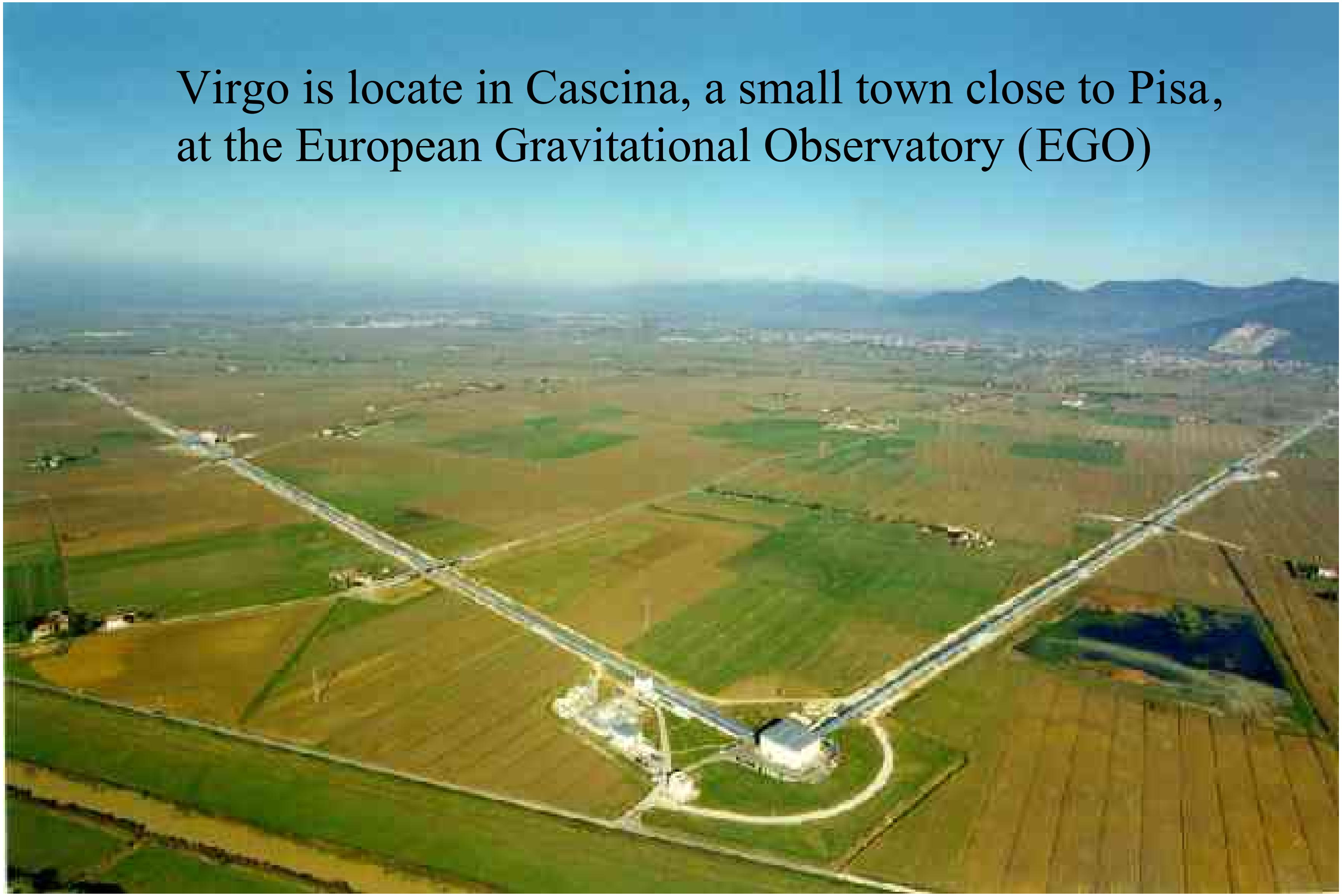
ITALY - INFN

- Firenze-Urbino
- Frascati
- Napoli
- Perugia
- Pisa
- Roma

FRANCE - CNRS

- ESPCI – Paris
- IPN – Lyon
- LAL – Orsay
- LAPP – Annecy
- OCA - Nice

Virgo is locate in Cascina, a small town close to Pisa, at the European Gravitational Observatory (EGO)

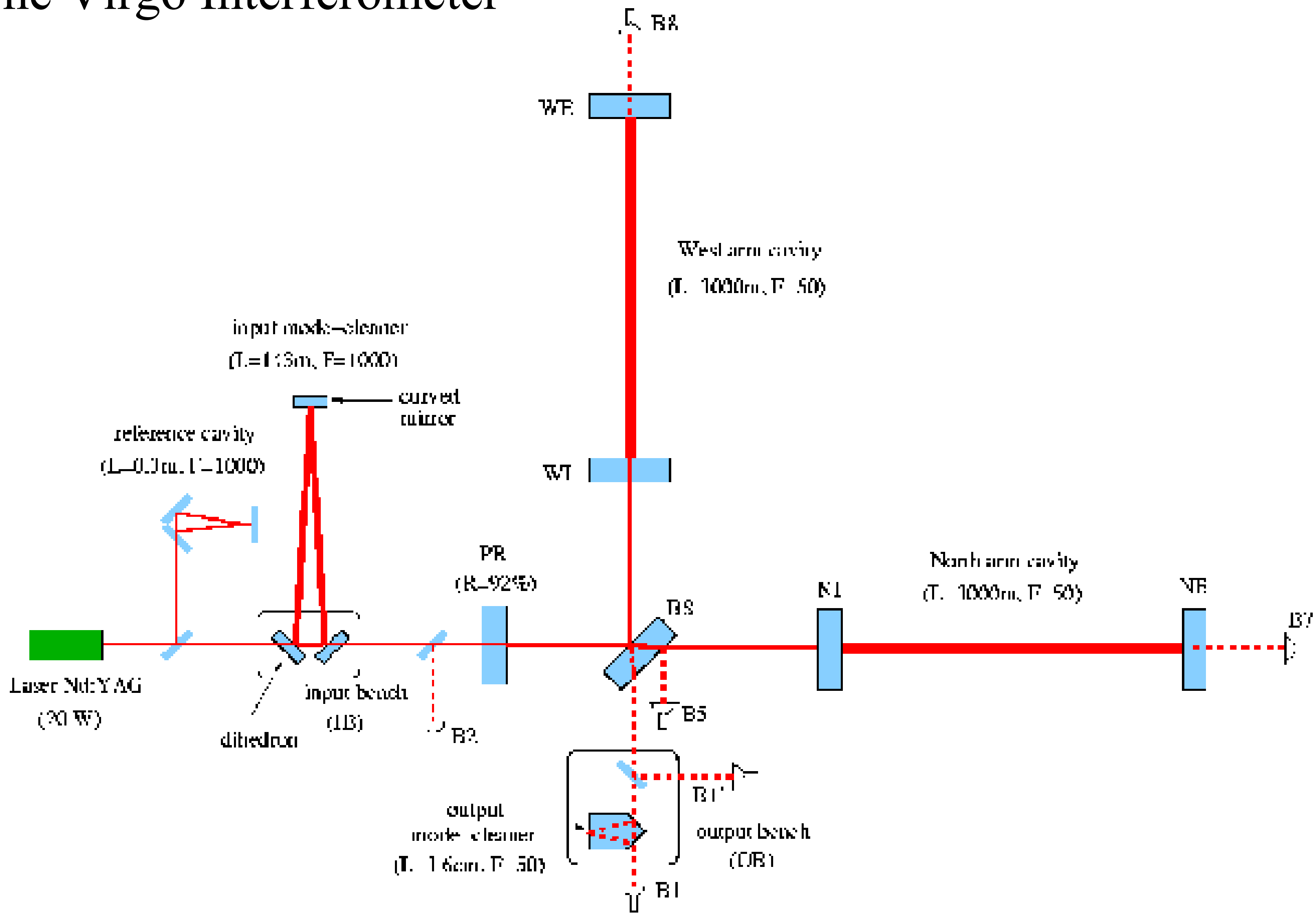


EGO is a Consortium settled up by the CNRS and the INFN

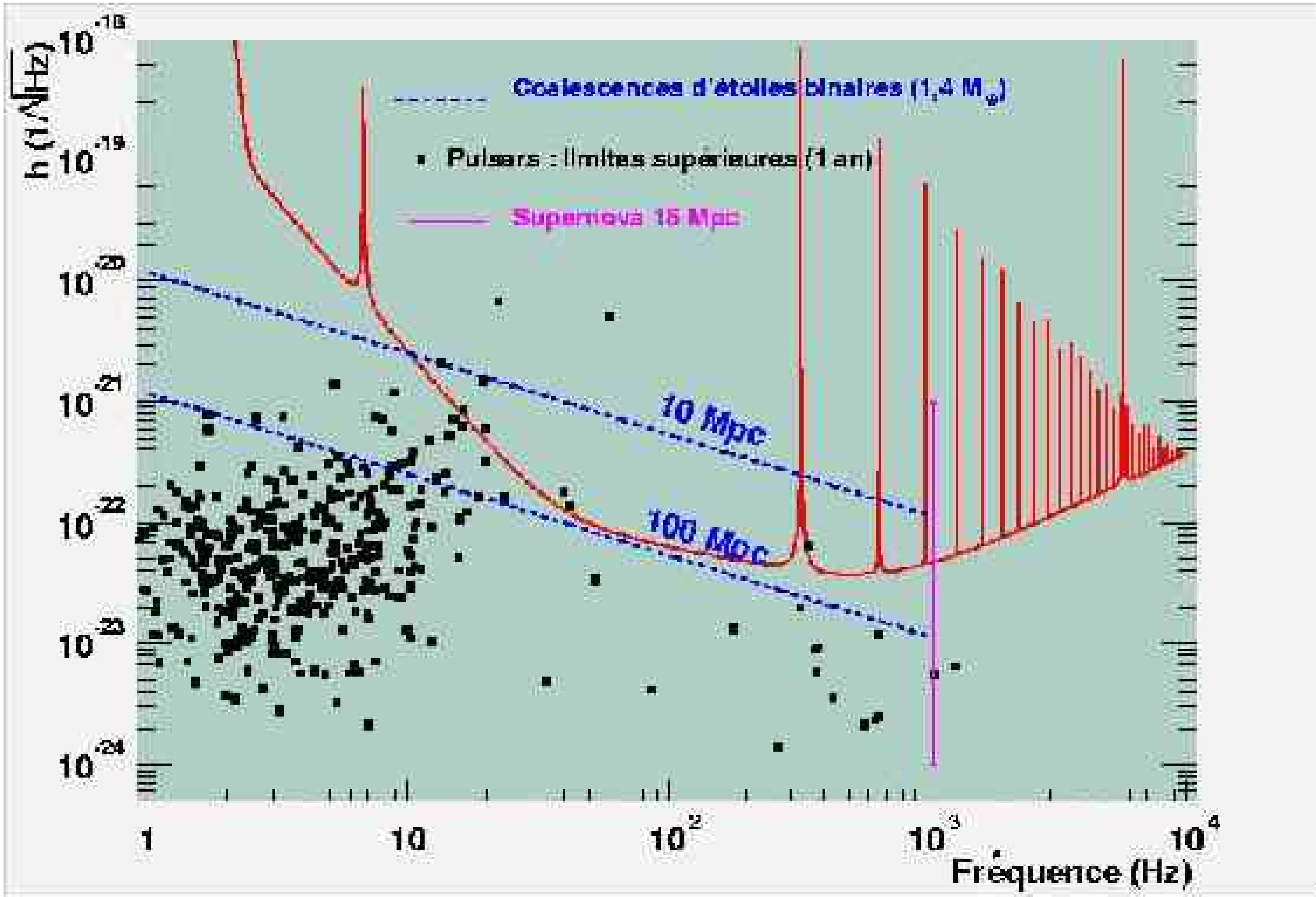
- **Main objectives of EGO**

1) to support the commissioning of Virgo, its operation, maintenance and upgrades
2) to create and run a computing center for the analysis of data,
3) to ensure the maintenance of the site and the related infrastructures
4) to promote R&D useful for the detection of gravitational waves

The Virgo Interferometer



Planned Sensitivity

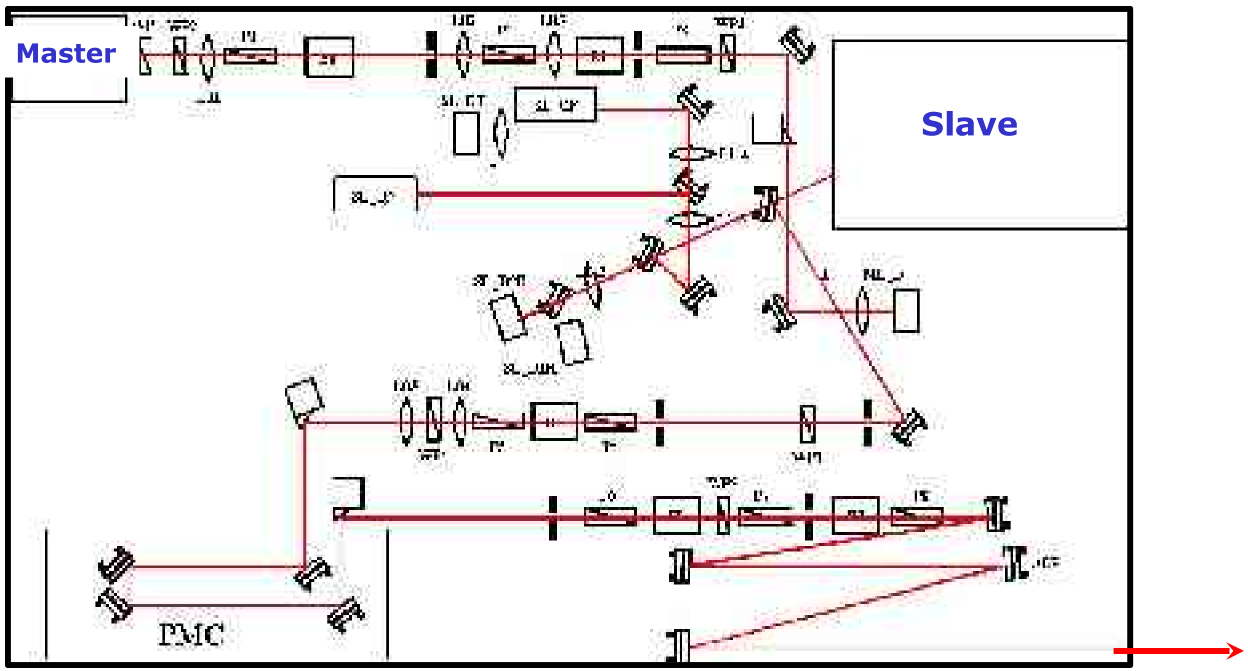


Vacuum System

- Two tubes: 3 km long, 1.2 m in diameter, installed and tested, in vacuum since June 2003, 10^{-6} mbar
- All tower (6 long, 2 short) pumping systems: installed, tested and put in operation, 10^{-9} mbar

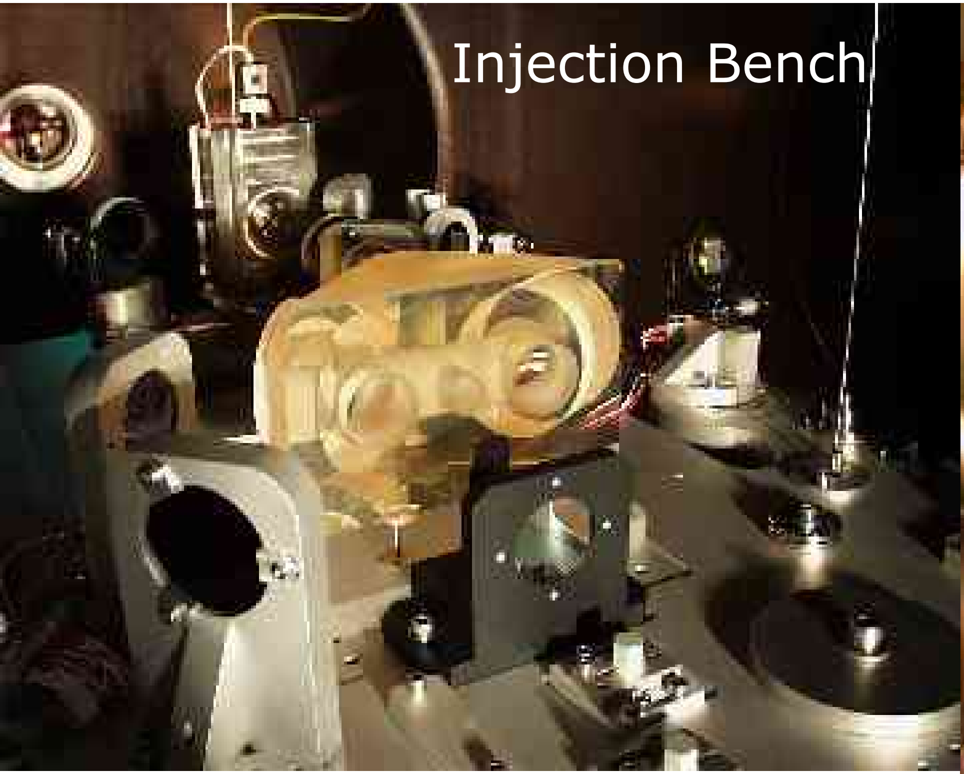
Laser system

- 20W, Nd:YVO4 laser, two pumping diodes
- Injection locked to a 1W Nd:YAG master laser
- Required power stability: 10^{-8}
- Required frequency stability: μHz



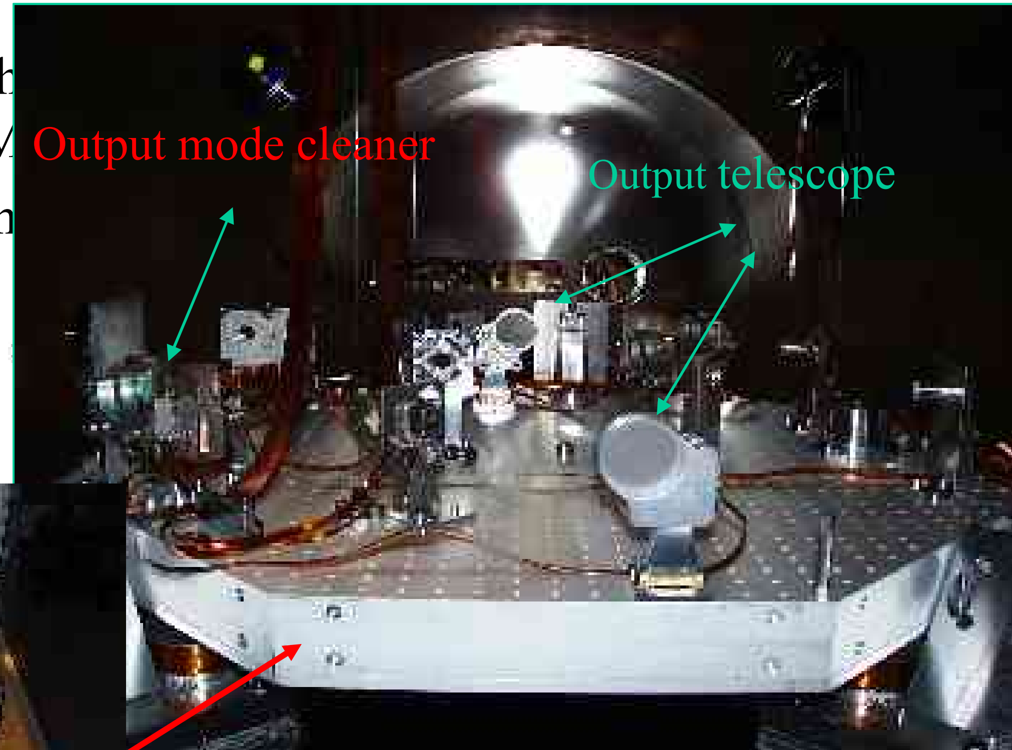
Input Mode Cleaner

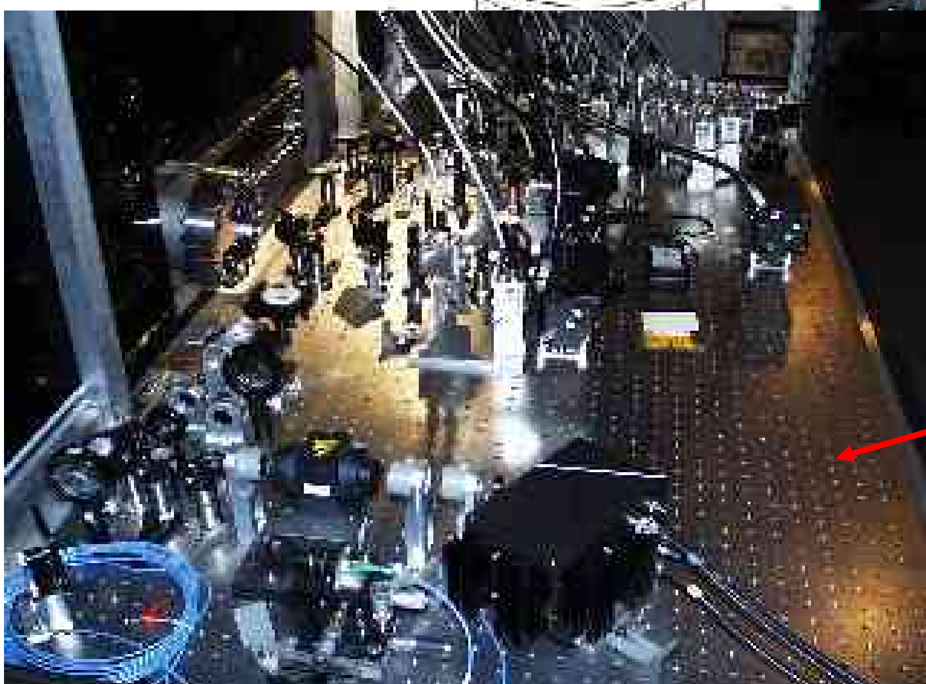
- Triangular cavity, 144 m long, Finesse=1000
- Input optics and two flat mirrors are located on a suspended optical bench
- End mirror suspended with a reference mass for actuation
- Transmission 50%

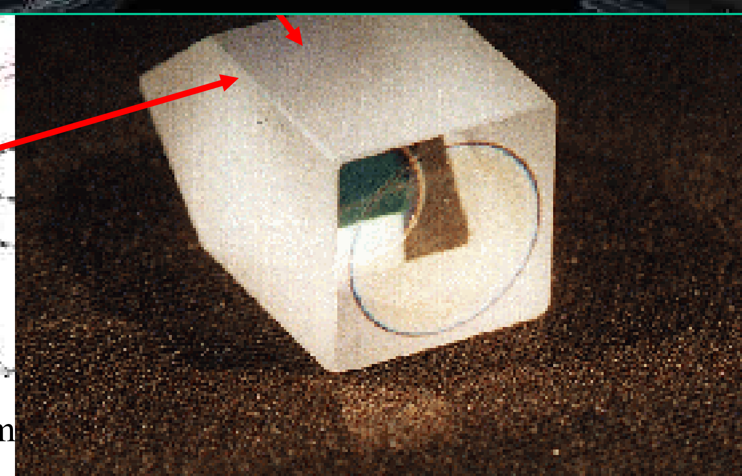


Detection System

- Suspended bench in vacuum with and the output mode cleaner (OM
- Detection, amplification and dem on external bench

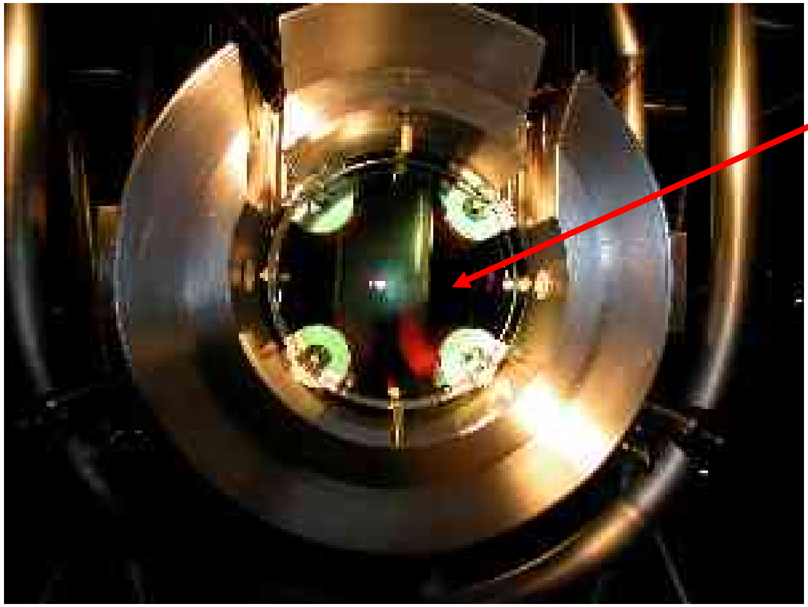






Virgo Mirrors

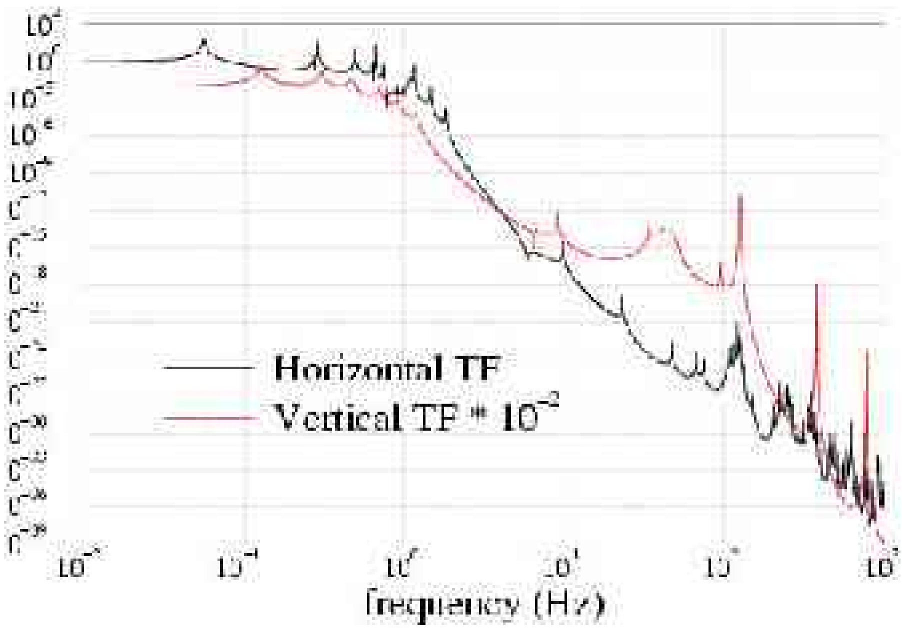
- Material: fused silica
- Dimension: 35 cm diameter, 10 cm thick
- Mass: ~ 21 Kg
- Substrate losses: 1 ppm
- Coating losses: <5 ppm
- Surface deformation: $\lambda/100$ (rms on 150mm)

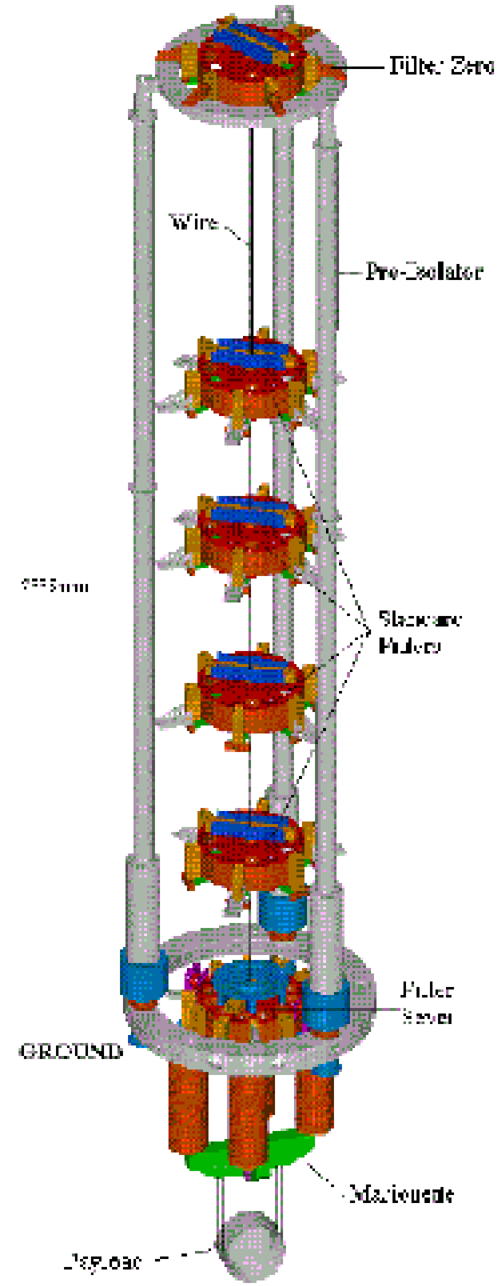


Suspension System

The Super-attenuator (SA) is a multi-stage seismic attenuator with an inverted pendulum as pre-isolator

Expected attenuation @10 Hz > 10^{14}

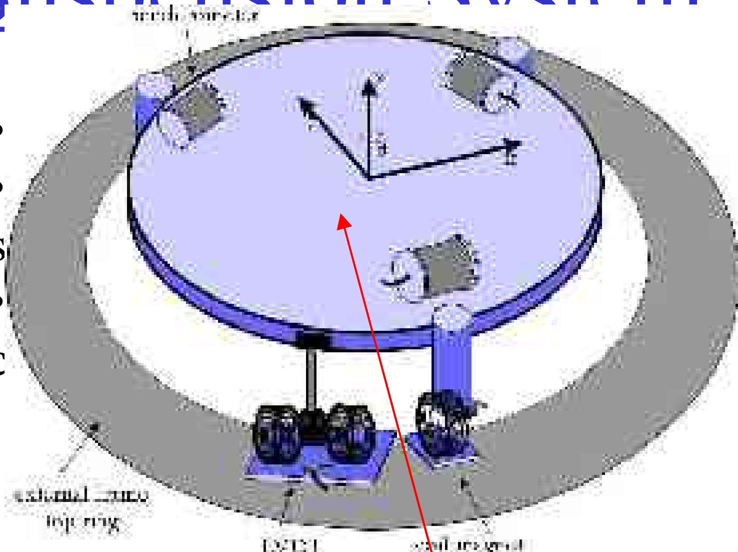


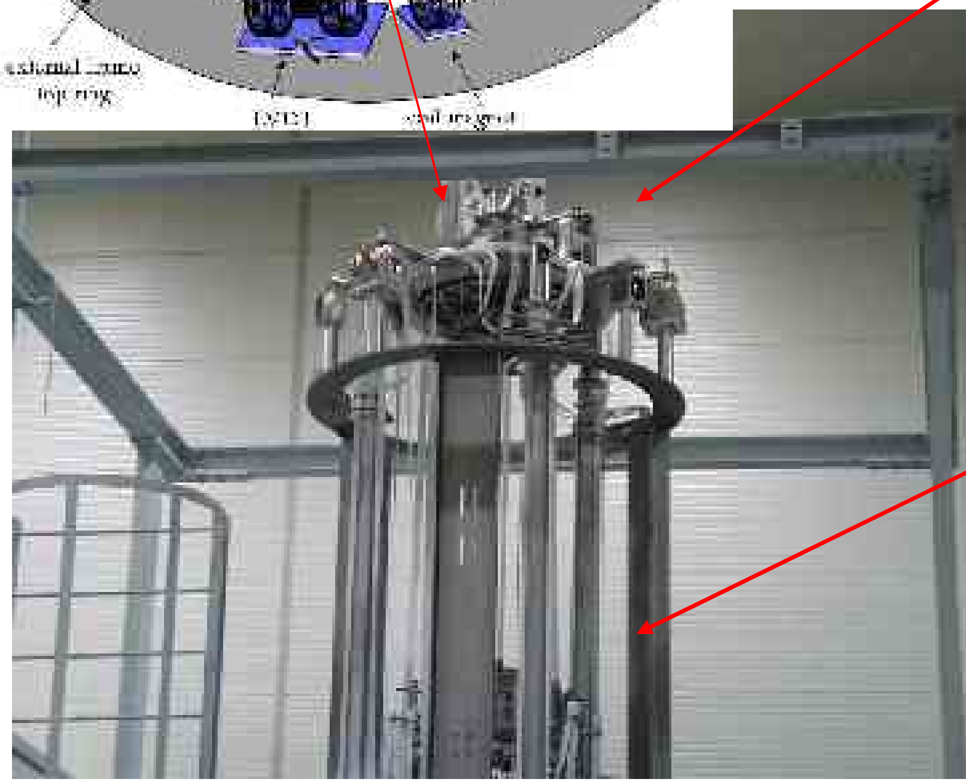


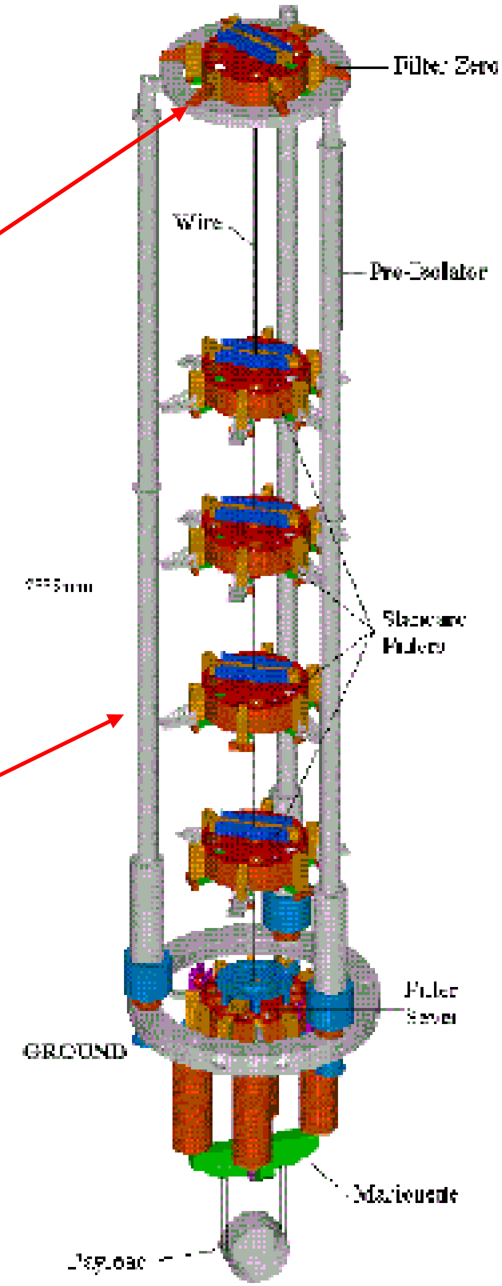
Suspension System

Pre-isolator

- …ulum
- …elerometers and LVDT s… …or Inertial damping
- …sion point (used for tide c…





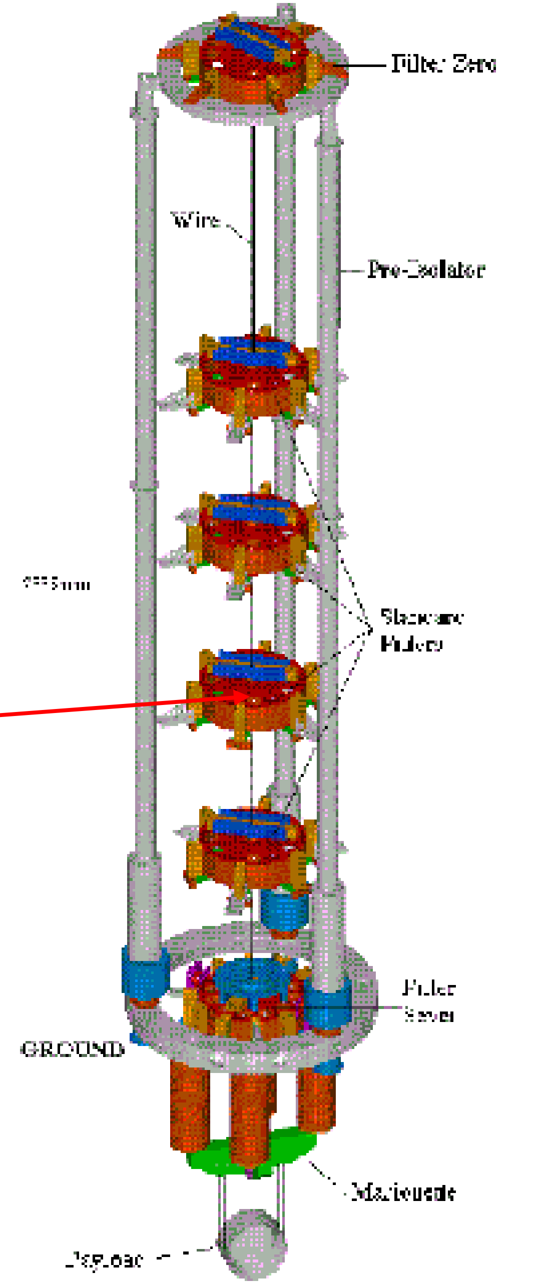


Suspension System

passive filters

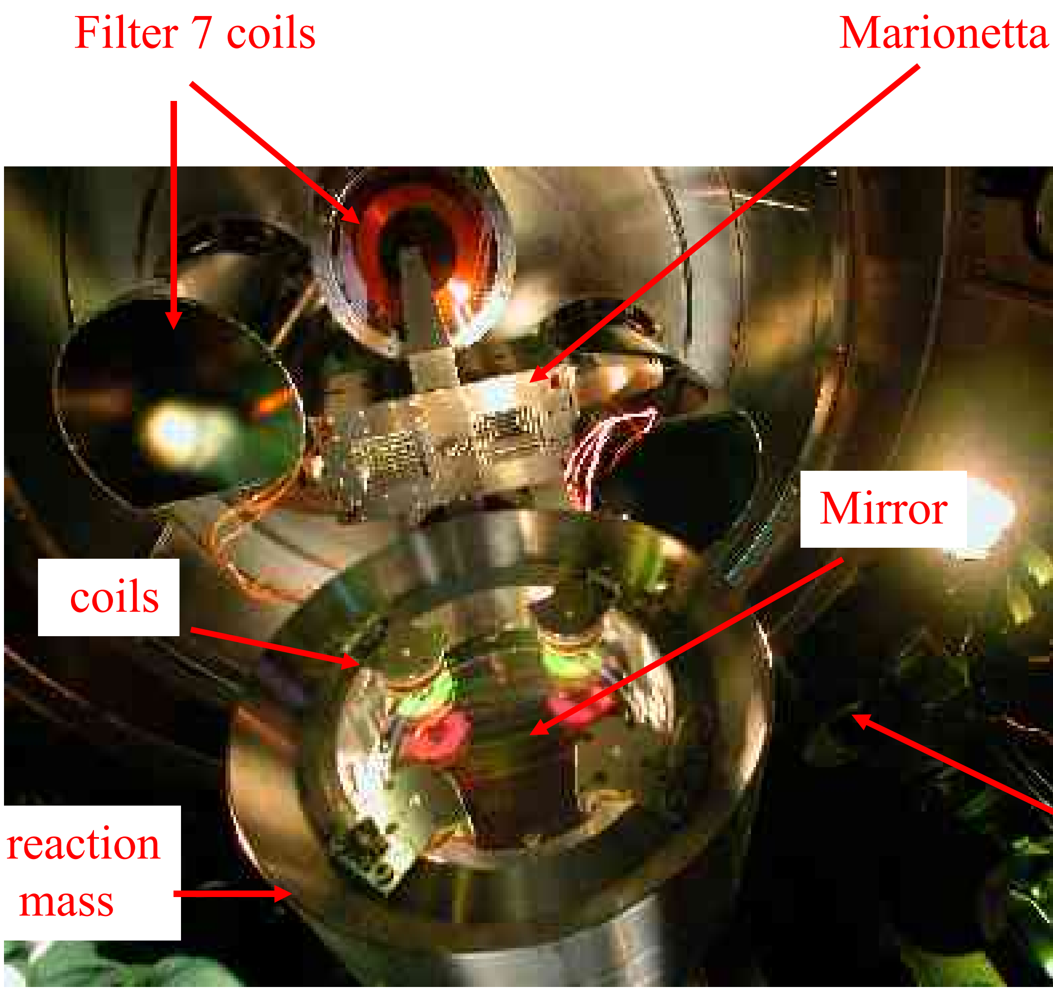
after the pre isolator there are 5 passive filter supported by steel wires

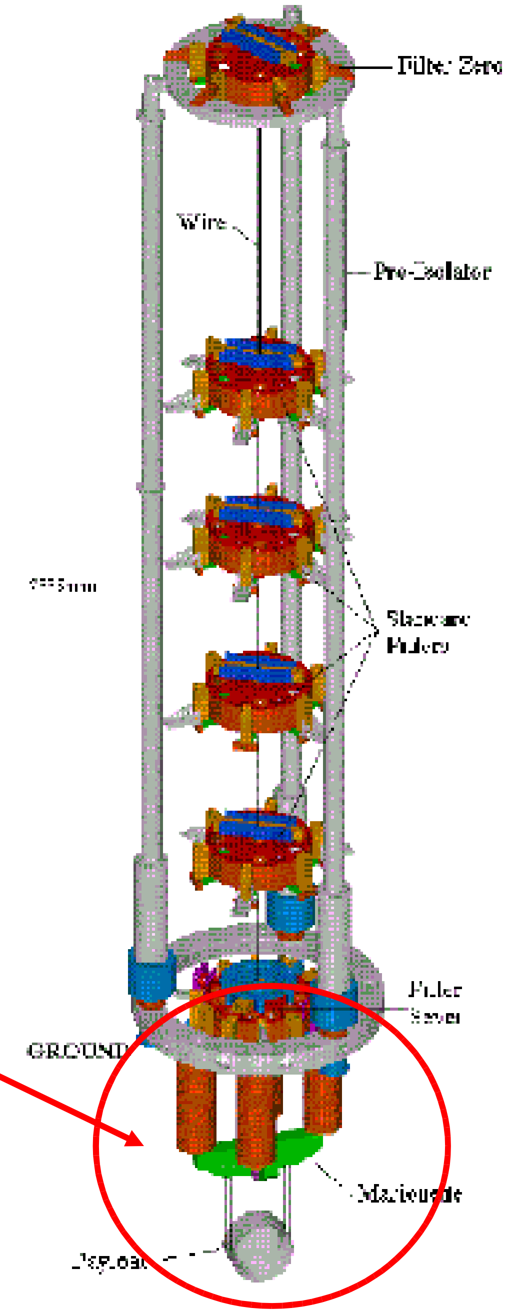
Vertical isolation is provided blade-springs with magnetic anti-springs



Suspension System

Payload

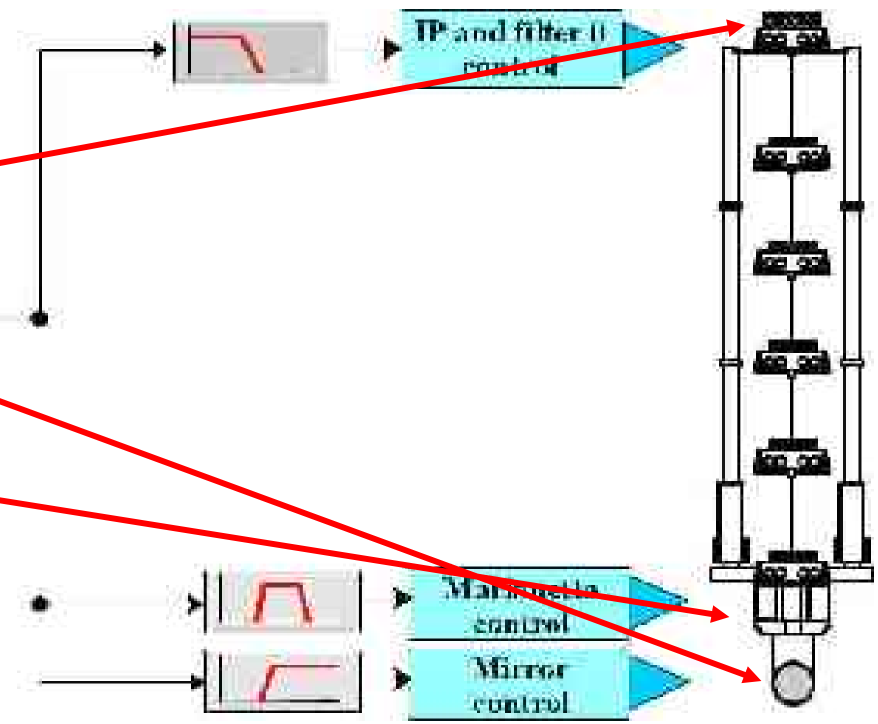




Suspension and mirror control

A very important issue is the distribution of control forces along the attenuator chain

The error signals come from both local references (local controls) o global control (interferometer signals)



Mirror with RM coils:

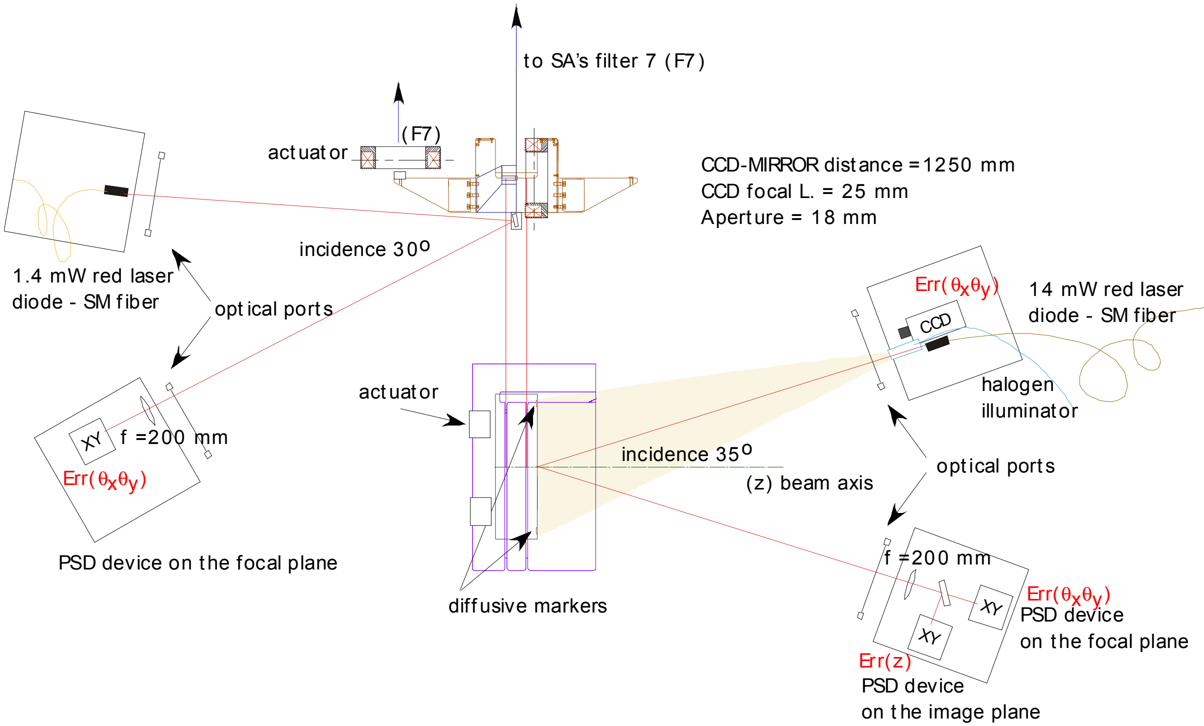
- payload NM damping (optical levers with PSD)
- ITF Locking (fast)
- IT[...]
- ITF alignment

Local Controls

sensors: CCD Camera and PSDs
The control is automatically switched from CCD to PSD according to oscillation amplitude

Control of mirror angular position
(residual motion < 1 μrad rms)

Damping of mirror longitudinal oscillations
(useful for lock acquisition)



Present status

milestones of Virgo construction

1996 - 1998 - Construction of central area

1999 - 2002 - Construction of the arms and the terminal buildings
Installation and commissioning of the central interferometer

2001 - 2003 - Vacuum tubes installation

2002 - 2003 - Installation of final mirrors and of terminal suspensions

June 2003 - last mirror installed

July 2003 - Virgo inauguration

2003 - Start detector commissioning

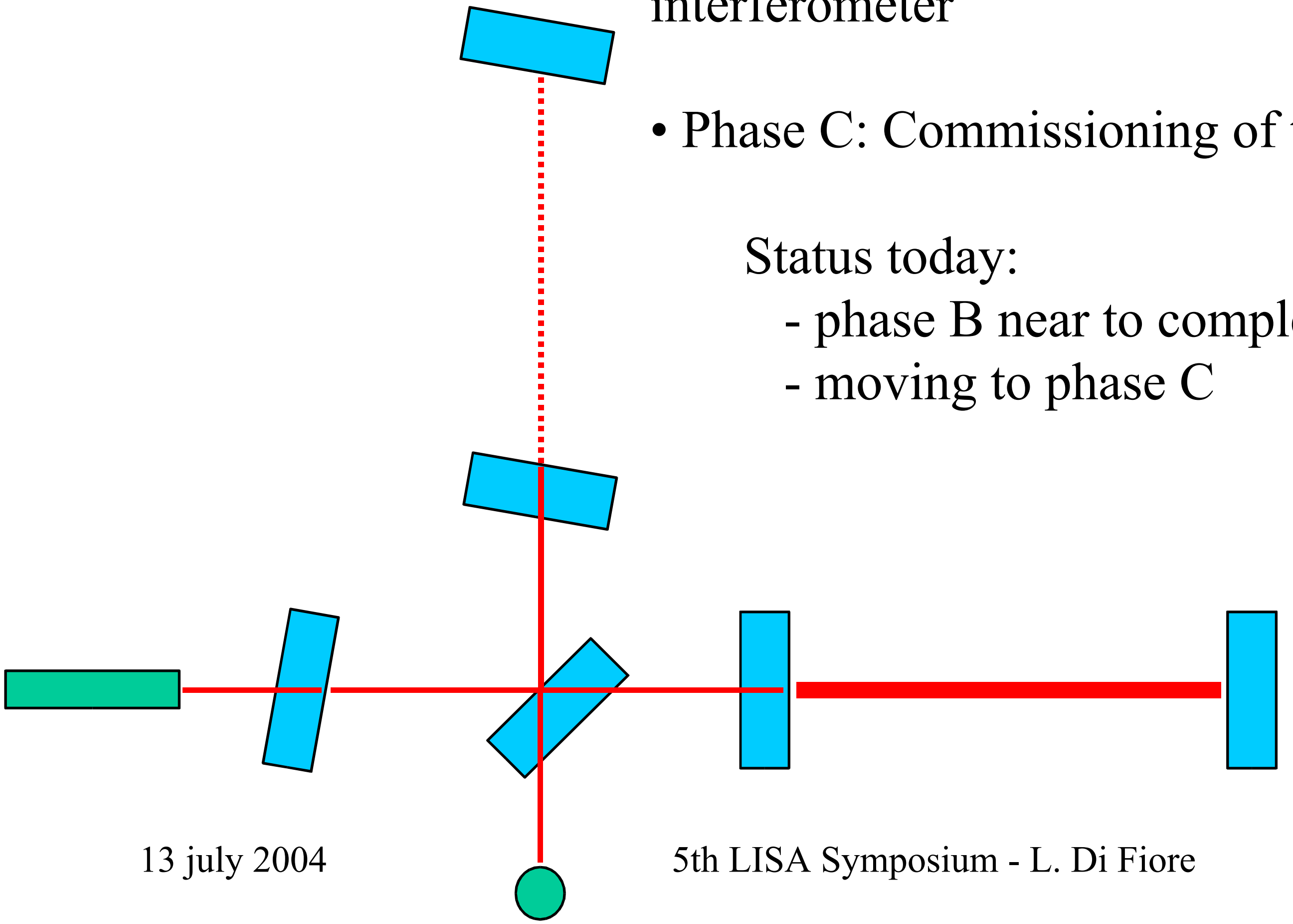
Commissioning plan overview

• Phase A: Commissioning of interferometer arms

• Phase B: Commissioning of the recombined interferometer

• Phase C: Commissioning of the recycled interferometer

Status today:
- phase B near to completion
- moving to phase C



Phase A: Fabry-Perot cavities

Commissioning of interferometer arms

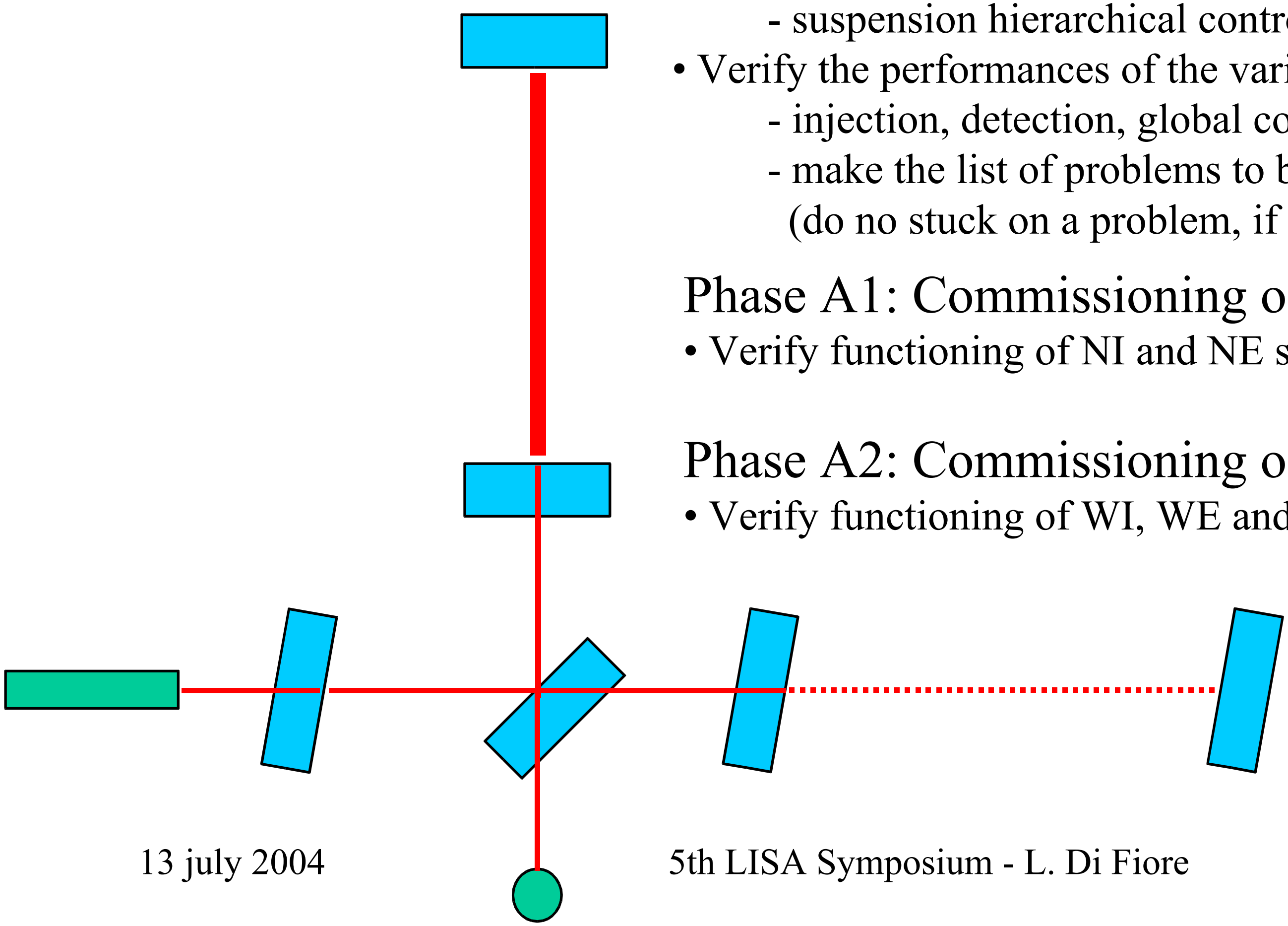
- Test all aspects of control systems in a simple optical configuration
  - locking
  - automatic alignment
  - second stage of laser frequency stabilization
  - suspension hierarchical control
- Verify the performances of the various sub-systems:
  - injection, detection, global control, DAQ, data storage, …
  - make the list of problems to be solved in a following phase (do no stuck on a problem, if possible !)

Phase A1: Commissioning of north arm

- Verify functioning of NI and NE suspension controls

Phase A2: Commissioning of west arm

- Verify functioning of WI, WE and part of BS suspension controls



Phase B: Recombined Interferometer

Commissioning of interferometer in ‘recombined mode’

- Useful intermediate step towards full interferometer lock
- Start noise investigations

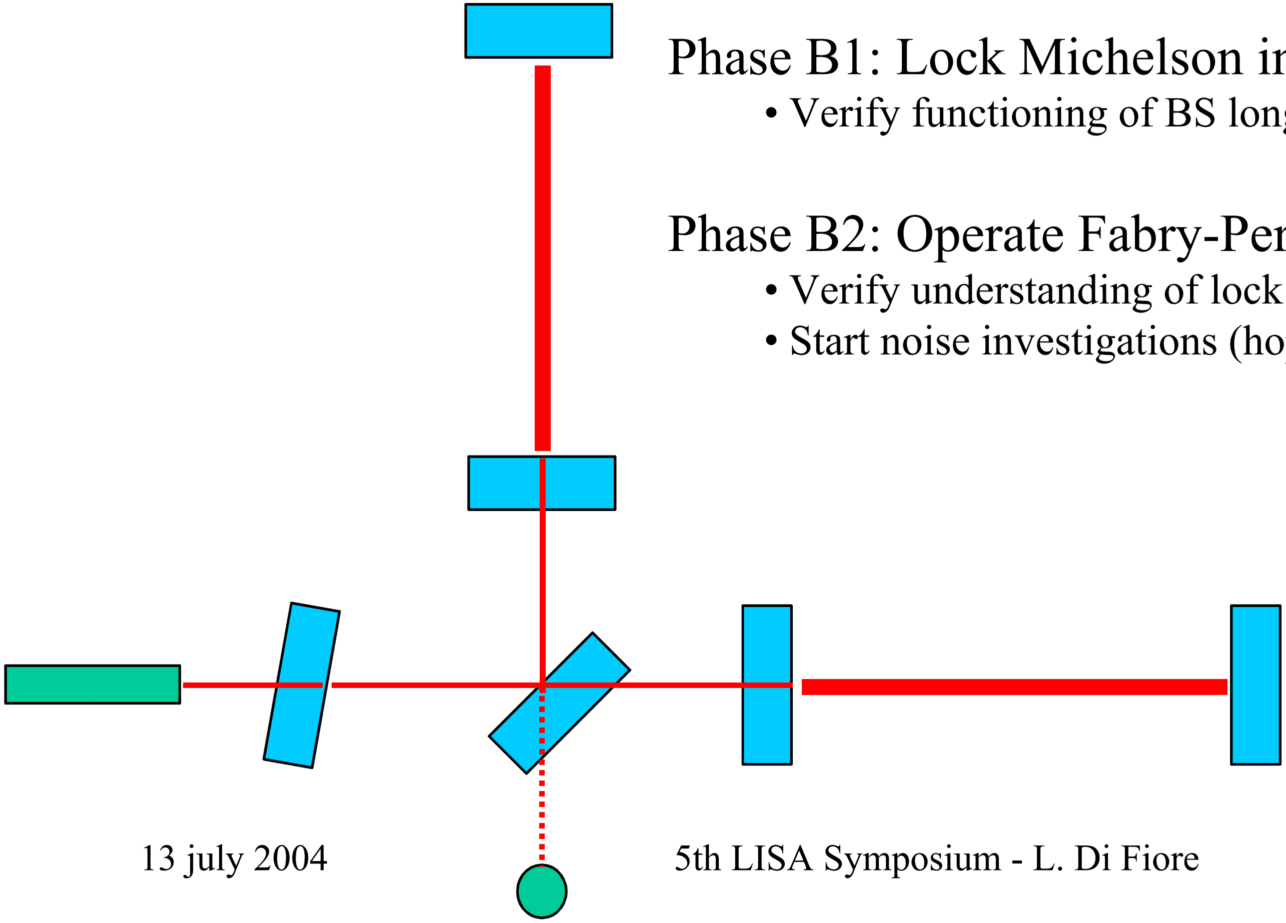
⇒ make the list of problems to be solved in a following phase

Phase B1: Lock Michelson interferometer

- Verify functioning of BS longitudinal control

Phase B2: Operate Fabry-Perot Michelson interferometer

- Verify understanding of lock acquisition and linear alignment
- Start noise investigations (hopefully others than laser noises)



Phase C: Recycled Interferometer

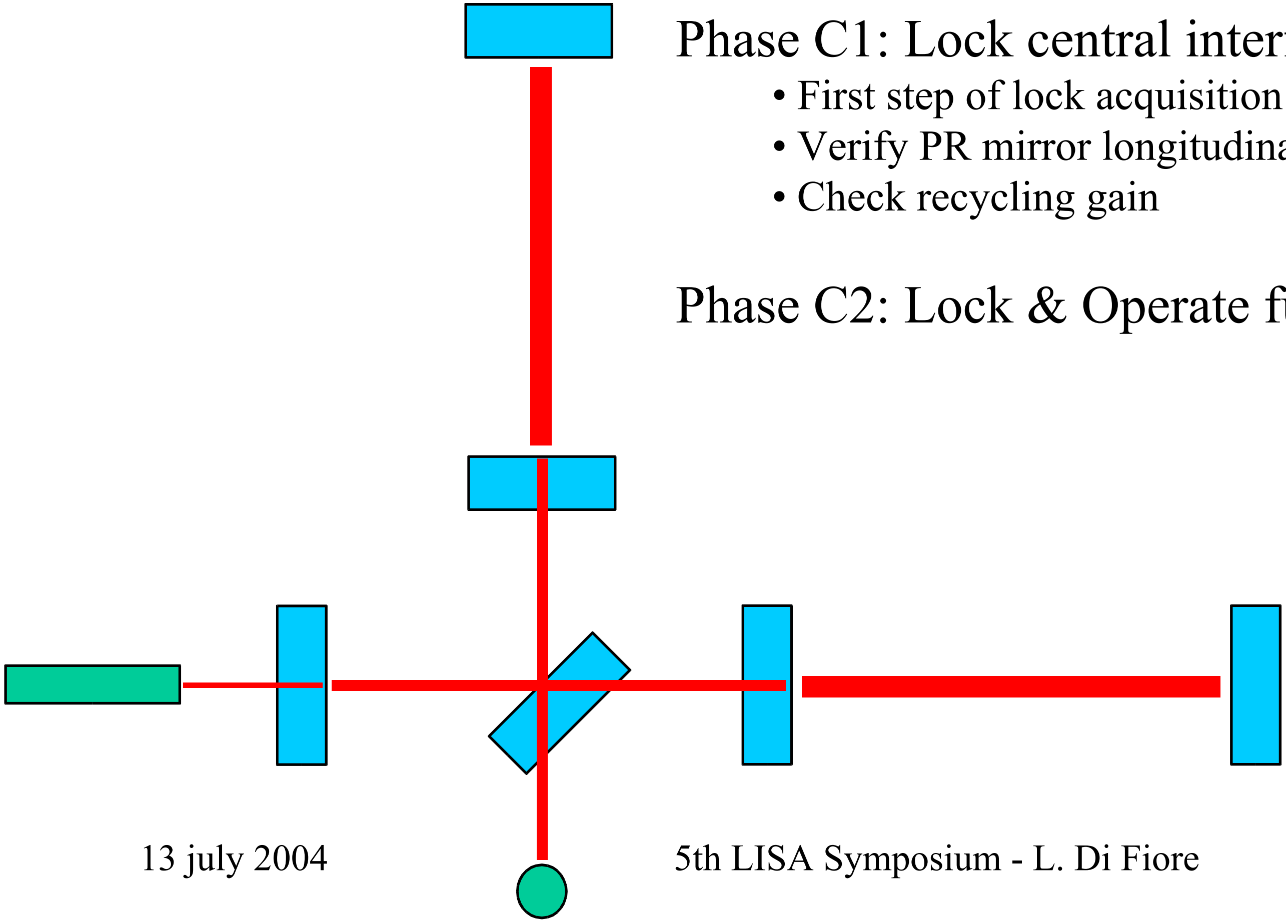
Commissioning of Recycled Fabry-Perot interferometer

- Test full locking acquisition process
- Implement complete wave-front sensing control
- Noise hunting

Phase C1: Lock central interferometer

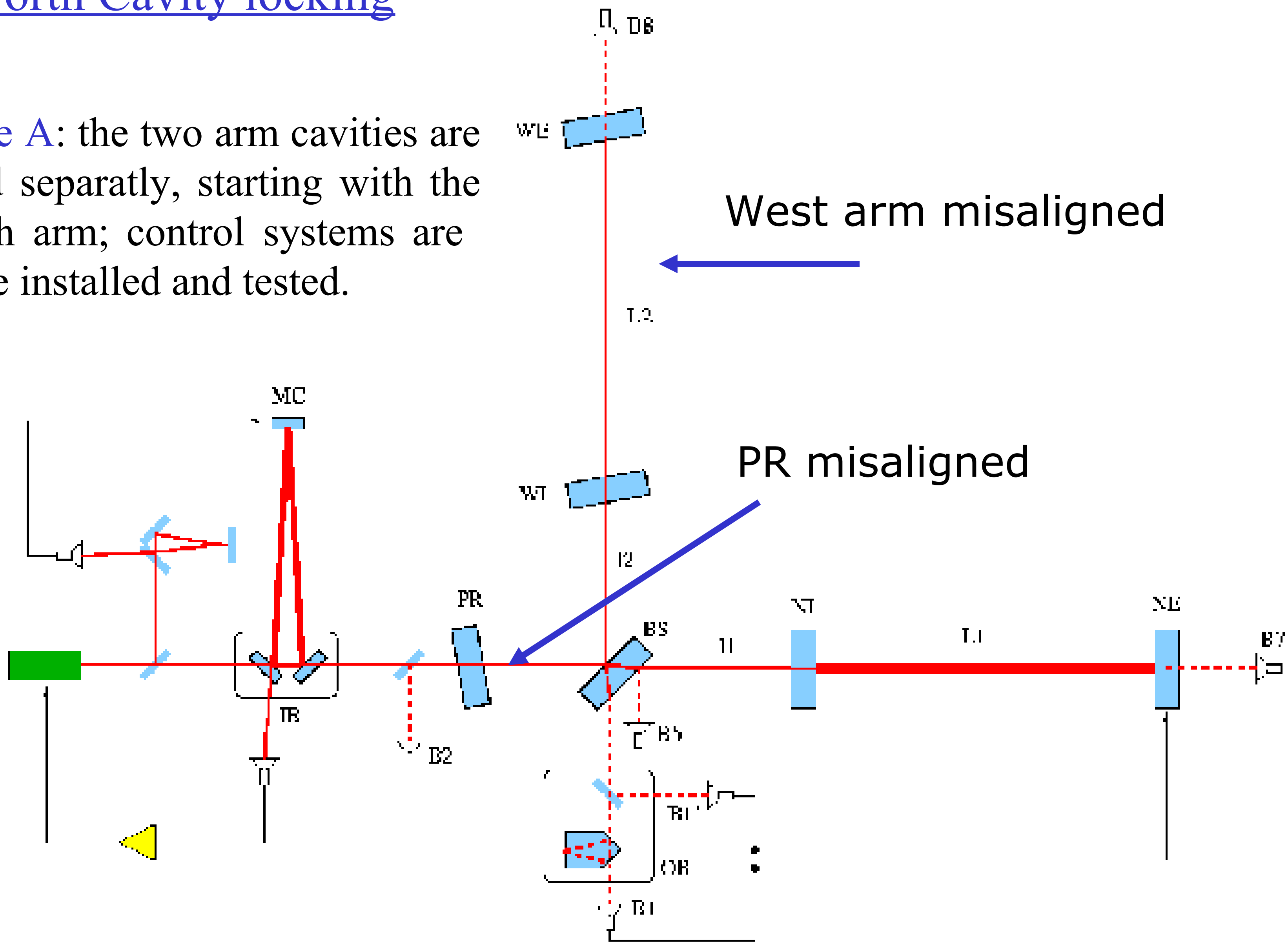
- First step of lock acquisition
- Verify PR mirror longitudinal control
- Check recycling gain

Phase C2: Lock & Operate full interferometer



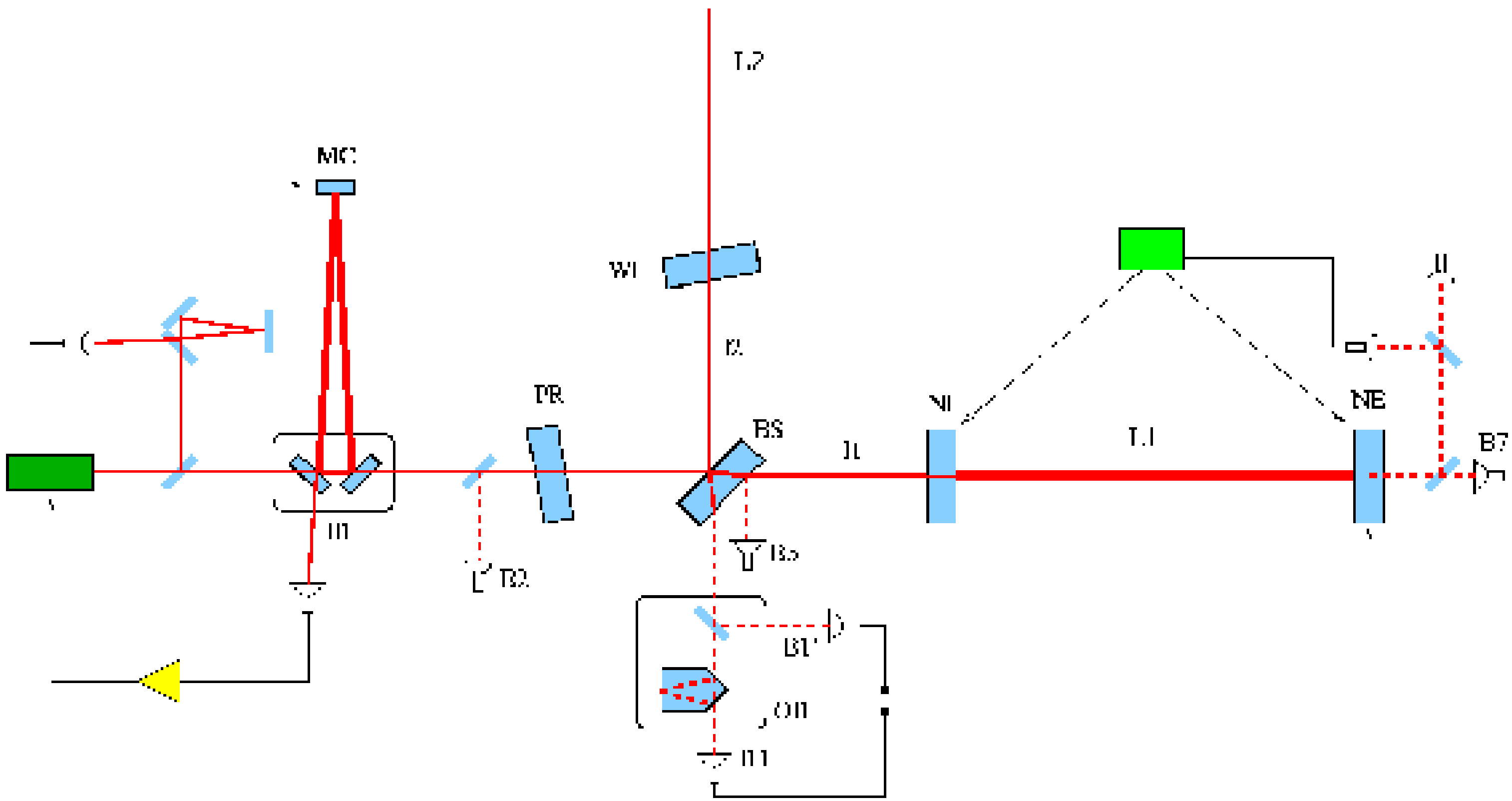
North Cavity locking

Phase A: the two arm cavities are used separatly, starting with the north arm; control systems are to be installed and tested.



Automatic alignment: principle

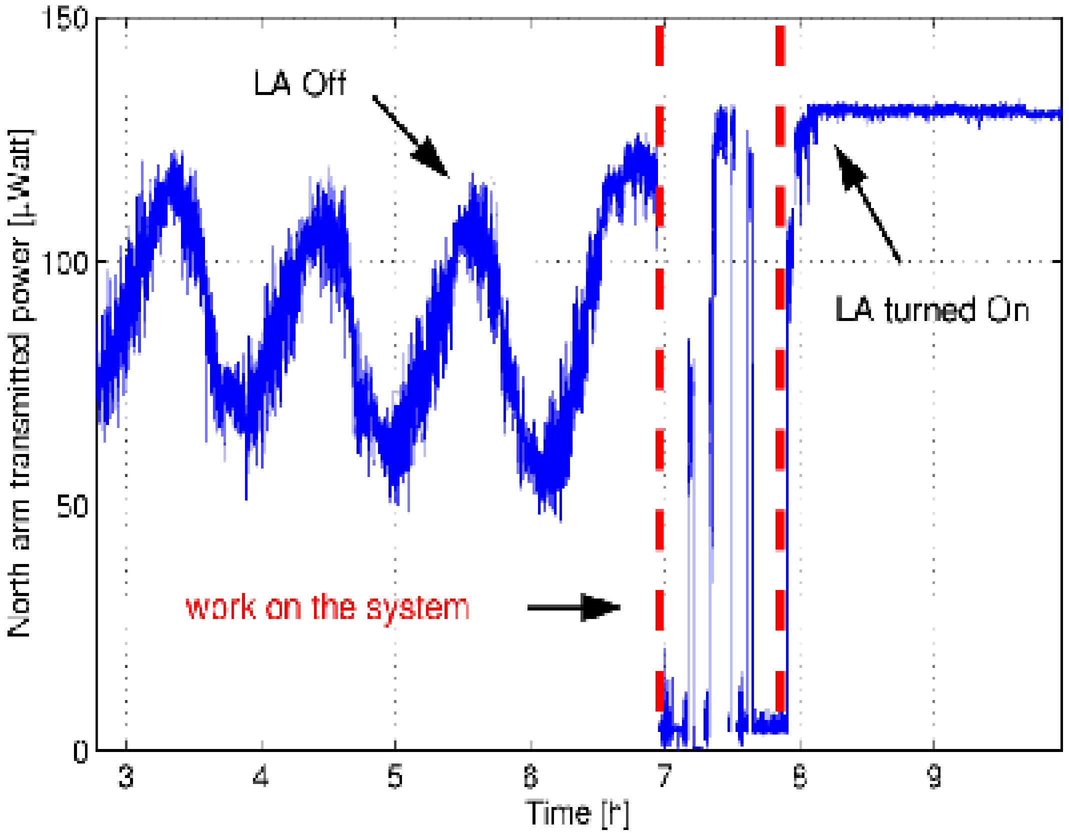
- Anderson technique:
  - Modulation frequency coincident with cavity TEM01 mode
  - Two quadrants looking at the cavity transmission (at two different Guoy phases)
  - Four signals to control the 2x2 mirror angular positions (NI & NE)



Automatic alignment: results

• Automatic alignment operated on both arms
- bandwidth ~ 3-4 Hz
- control precision ~ 0.5 μrad

• It allows to:
- switch completely OFF local controls on all four cavity mirrors
- stabilize power stored in the cavity
- increase locking duration

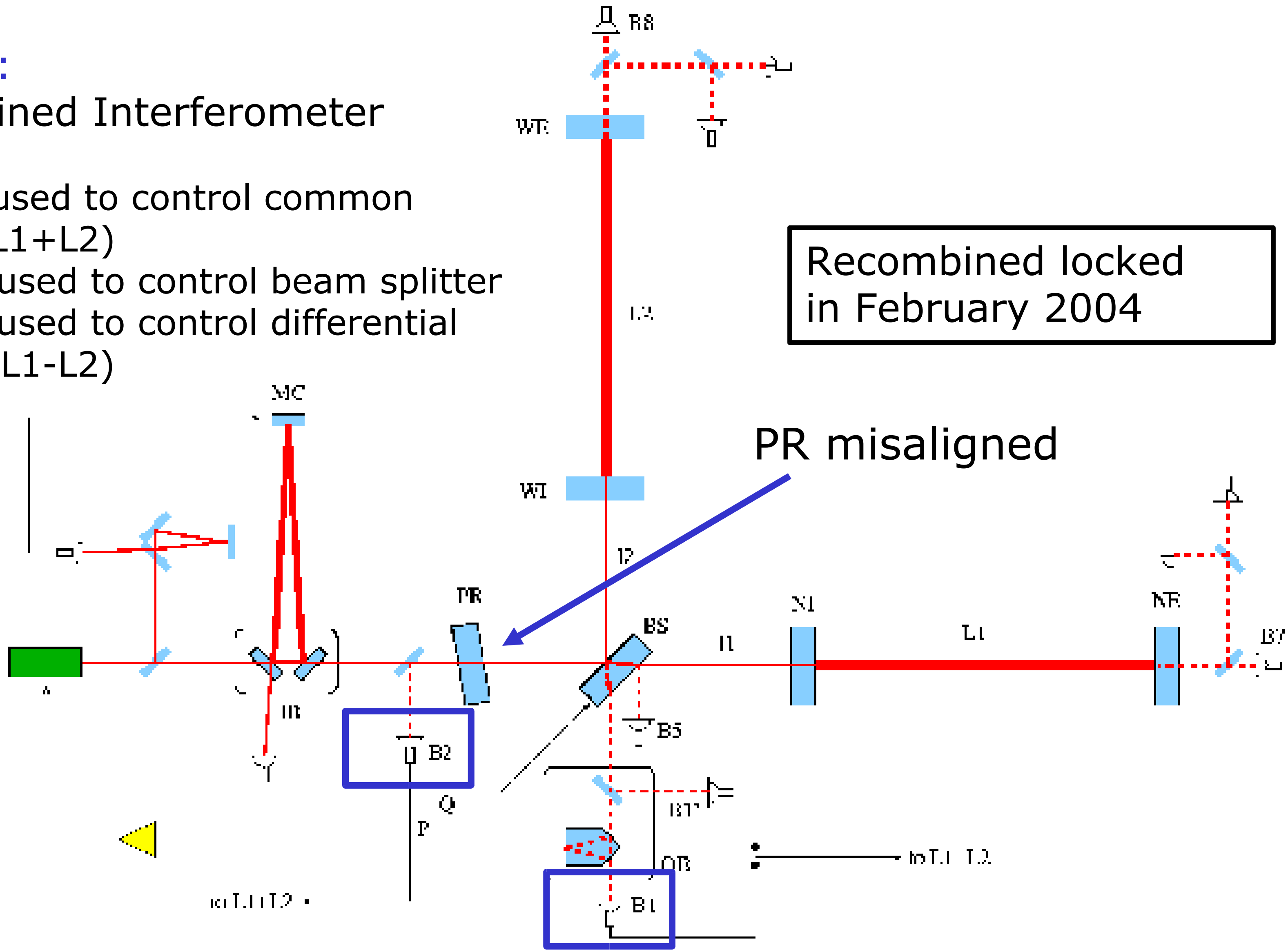


Recombined Interferometer

Phase B:
Recombined Interferometer

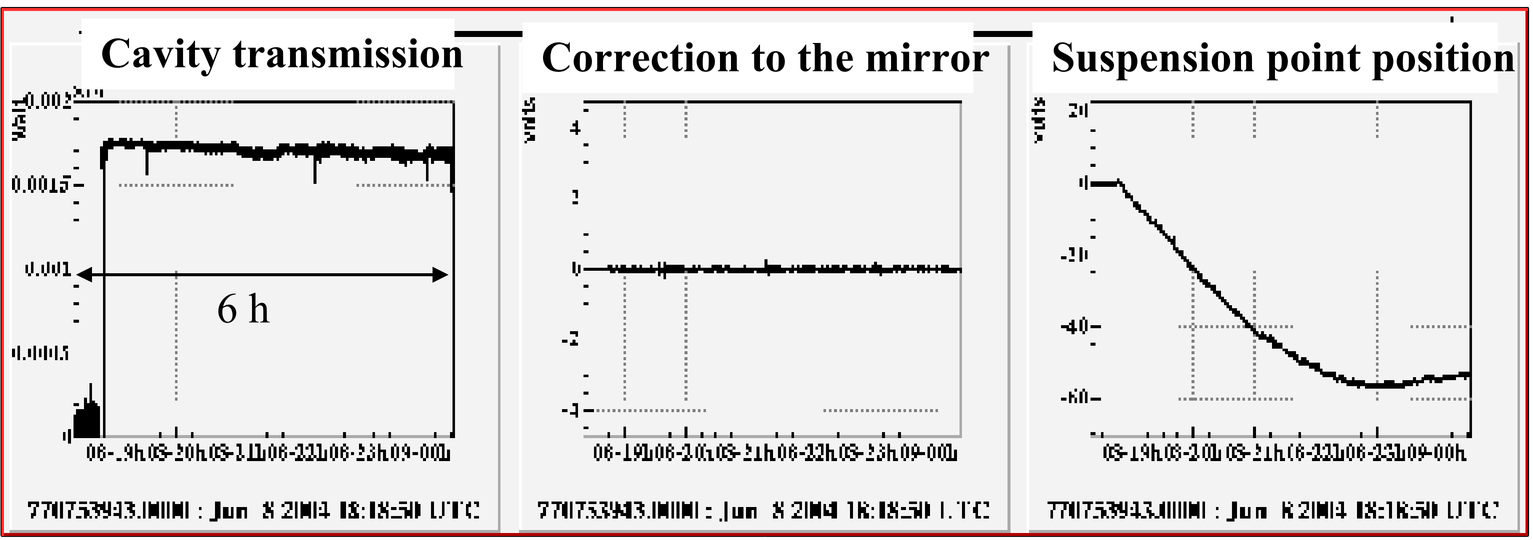
- B2 (P) used to control common mode (L1+L2)
- B2 (Q) used to control beam splitter
- B1/B1′ used to control differential mode (L1-L2)

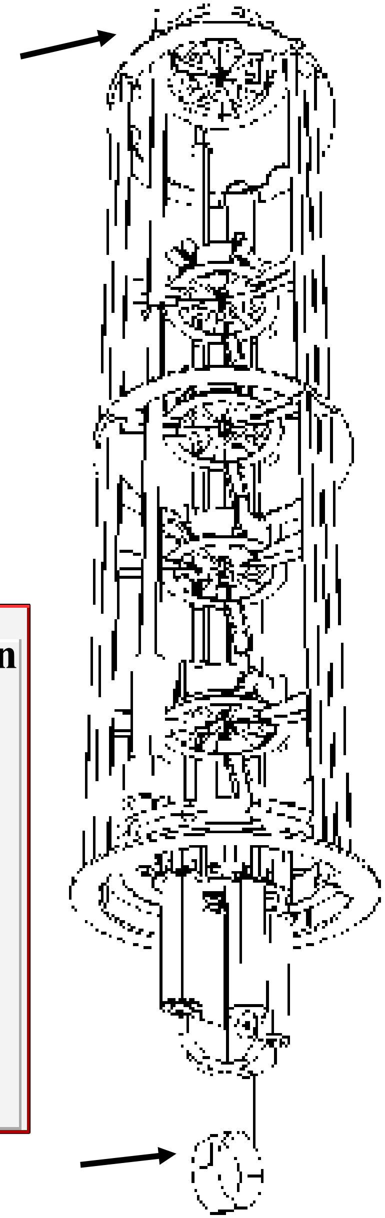
Recombined locked in February 2004



Tide Control

- Earth tide > Mirror actuators range (~ 100 μm)
- Move low frequency component of the correction to the top of the inverted pendulum

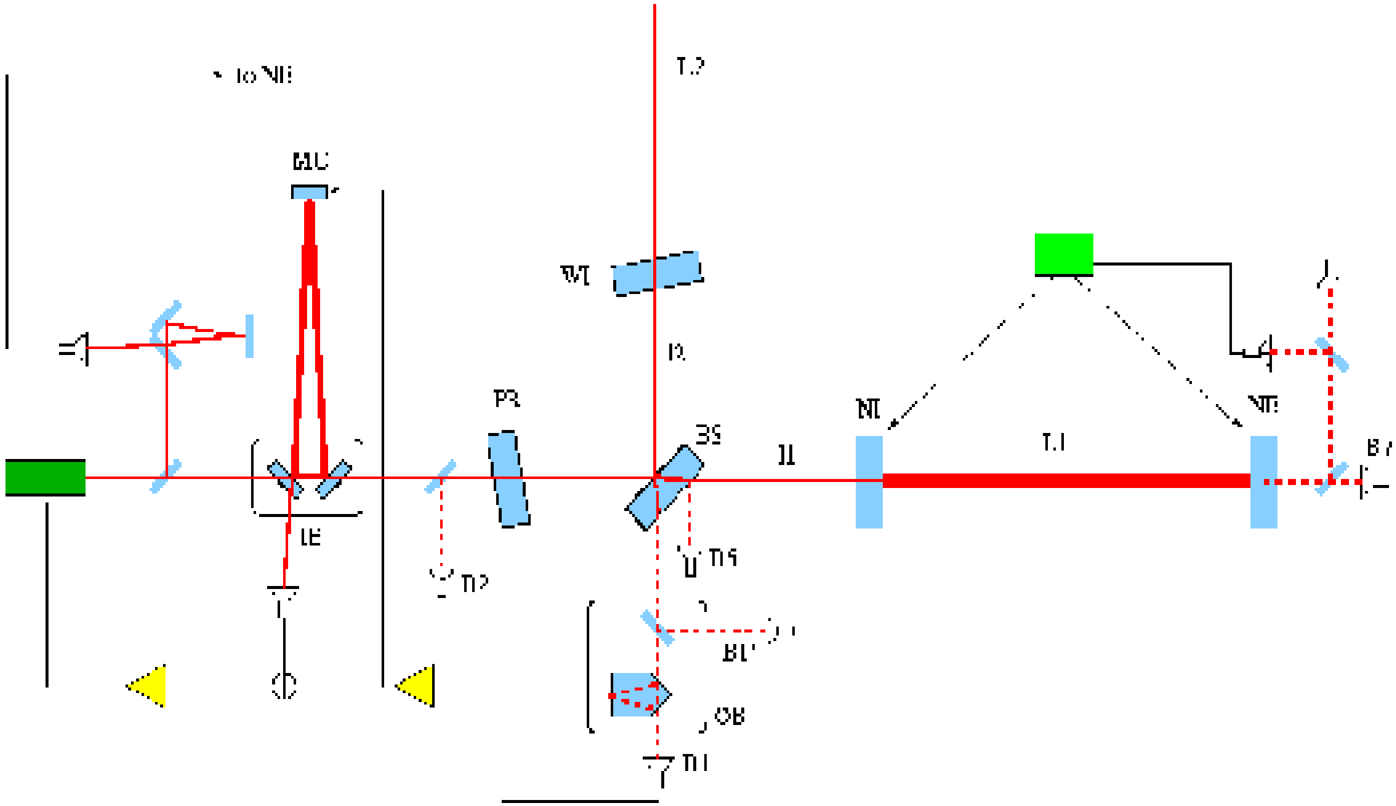




Laser frequency stabilization

• First test with North arm cavity

- North cavity error signal sent to the input mode-cleaner (below 200 Hz) and to the laser (above 200 Hz)
- Reference cavity error signal used to control cavity length at DC



Commissioning Runs

Continuous data taking periods are scheduled every second month:

- C1: 14.-17. November 2003
  - North arm cavity longitudinally controlled
- C2: 20.-23. February 2004
  - North arm cavity with longitudinal and angular control
- C3: 23.-27. April 2004
  - Recombined interferometer
  - North arm with second stage of frequency stabilisation
- C4: 24.-29. June 2004
  - Recombined interferometer with angular control and second stage of frequency stabilisation

Phase A (single cavity): C1, C2 & C3

• Each run last 3-4 days

• Goals:

- Verify ITF cavities performances on longer time scales
- Provide real data to the collaboration

• C1 (14-17/11/2003)

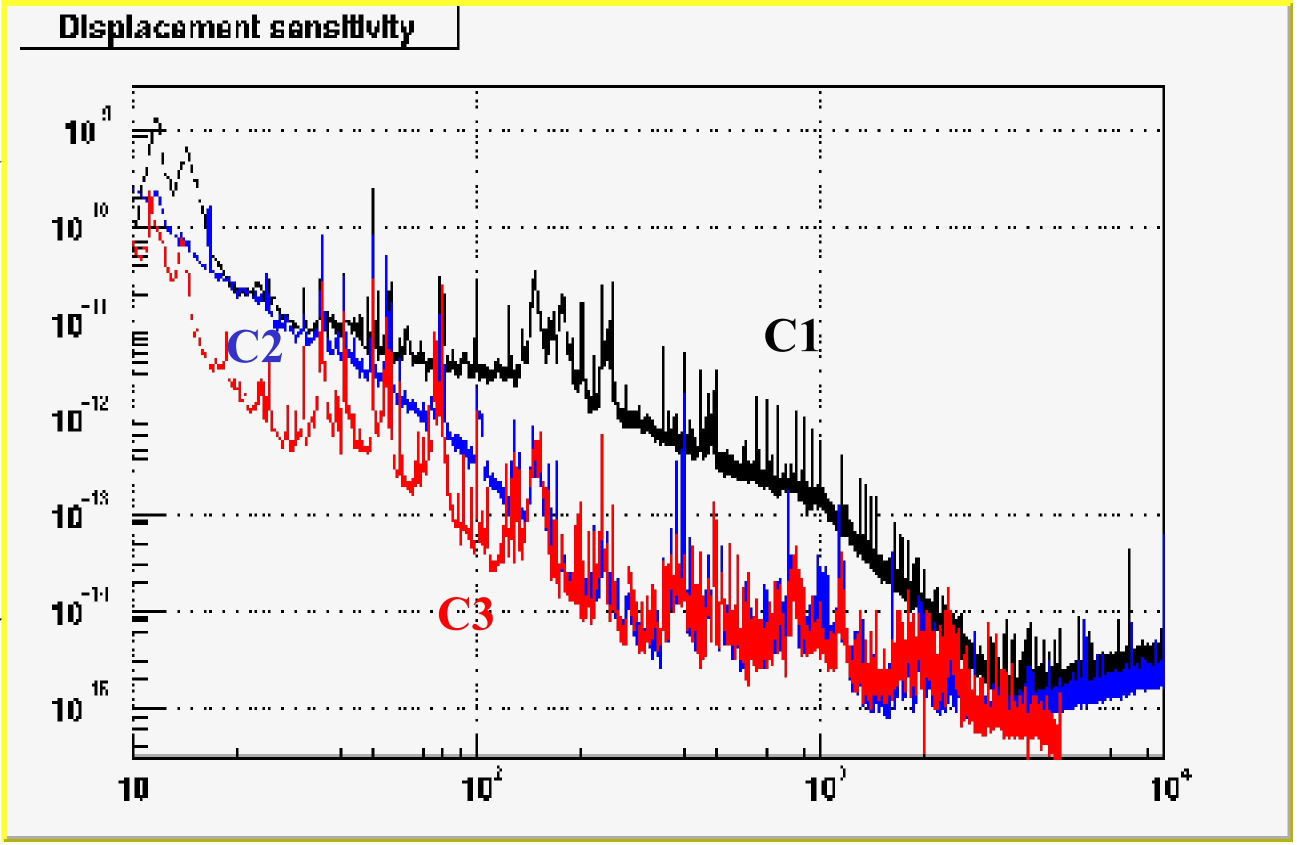
- North cavity and OMC locked

• C2 (20-23/02/2004)

- C1 + Automatic alignment
- West arm locked

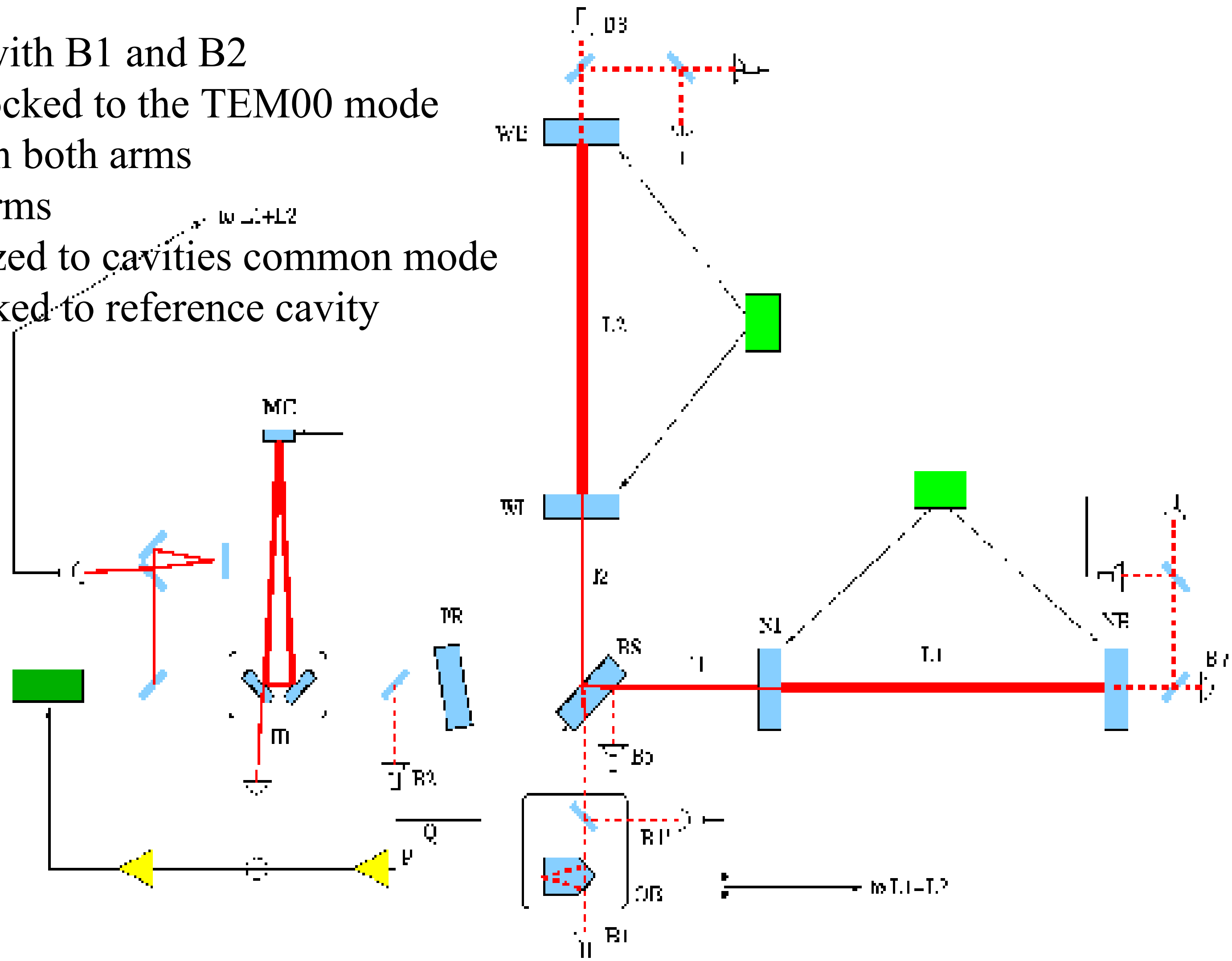
• C3 (23-27/04/2004)

- C2 + Laser frequency stabiliza



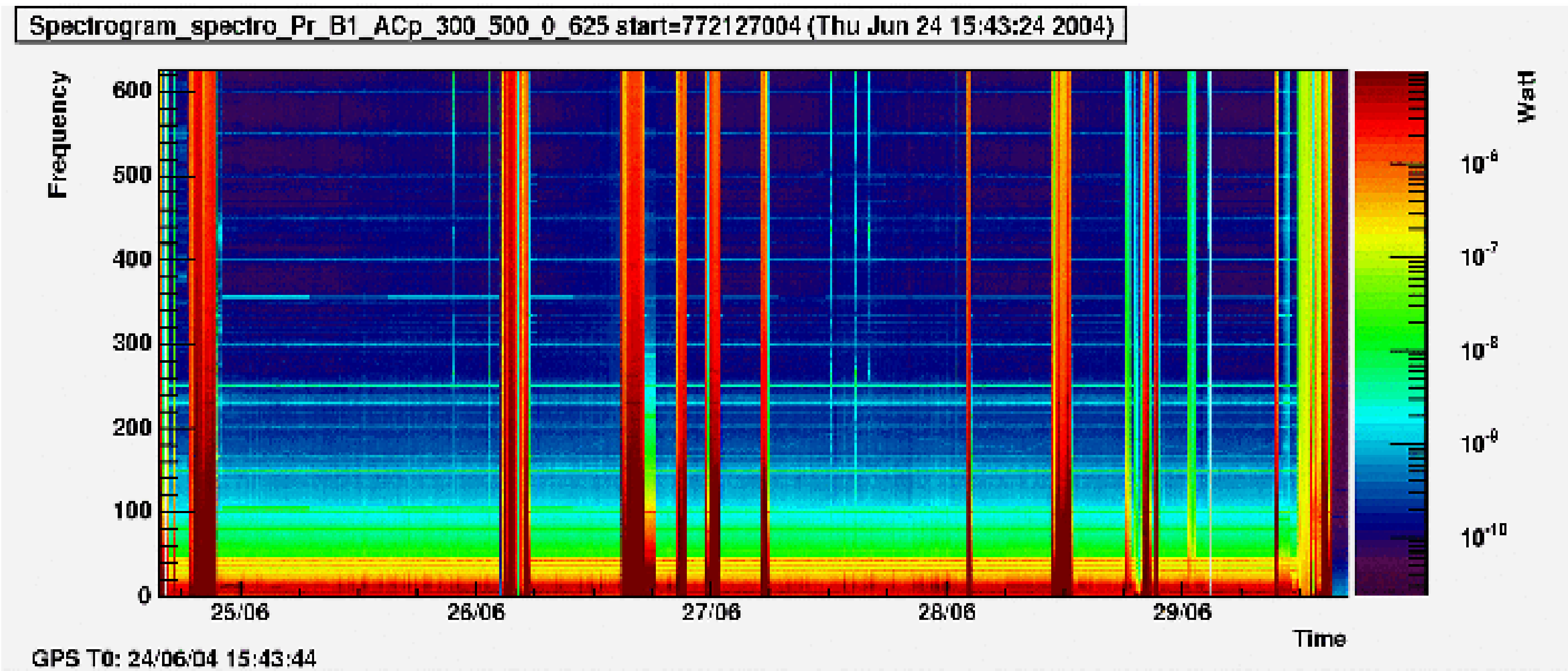
Phase B (recombined ITF): C3 & C4

- Interferometer locked with B1 and B2
- Output mode-cleaner locked to the TEM00 mode
- Automatic alignment on both arms
- Tidal control on both arms
- Laser frequency stabilized to cavities common mode
- ITF common mode locked to reference cavity

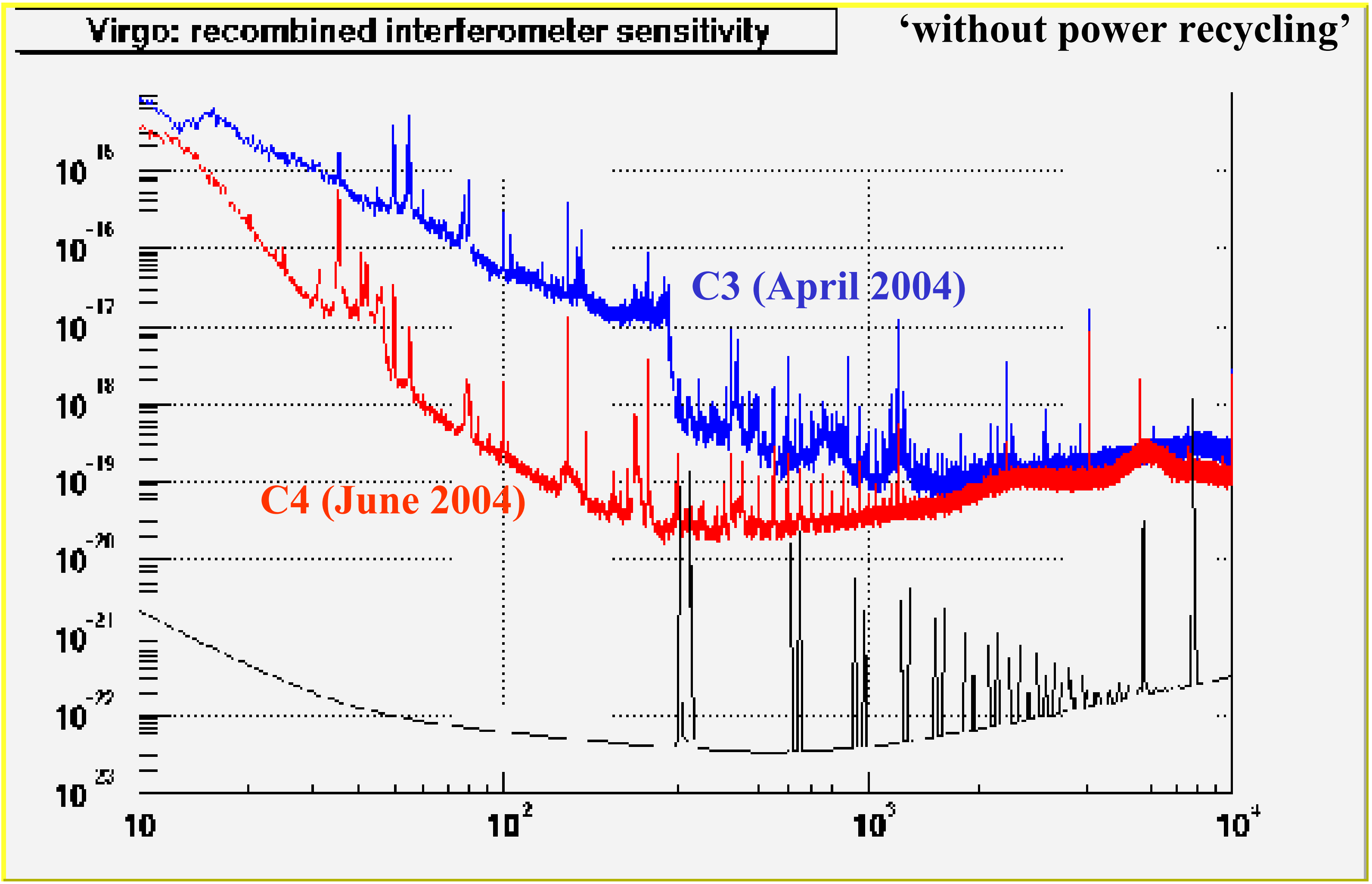


C4 run

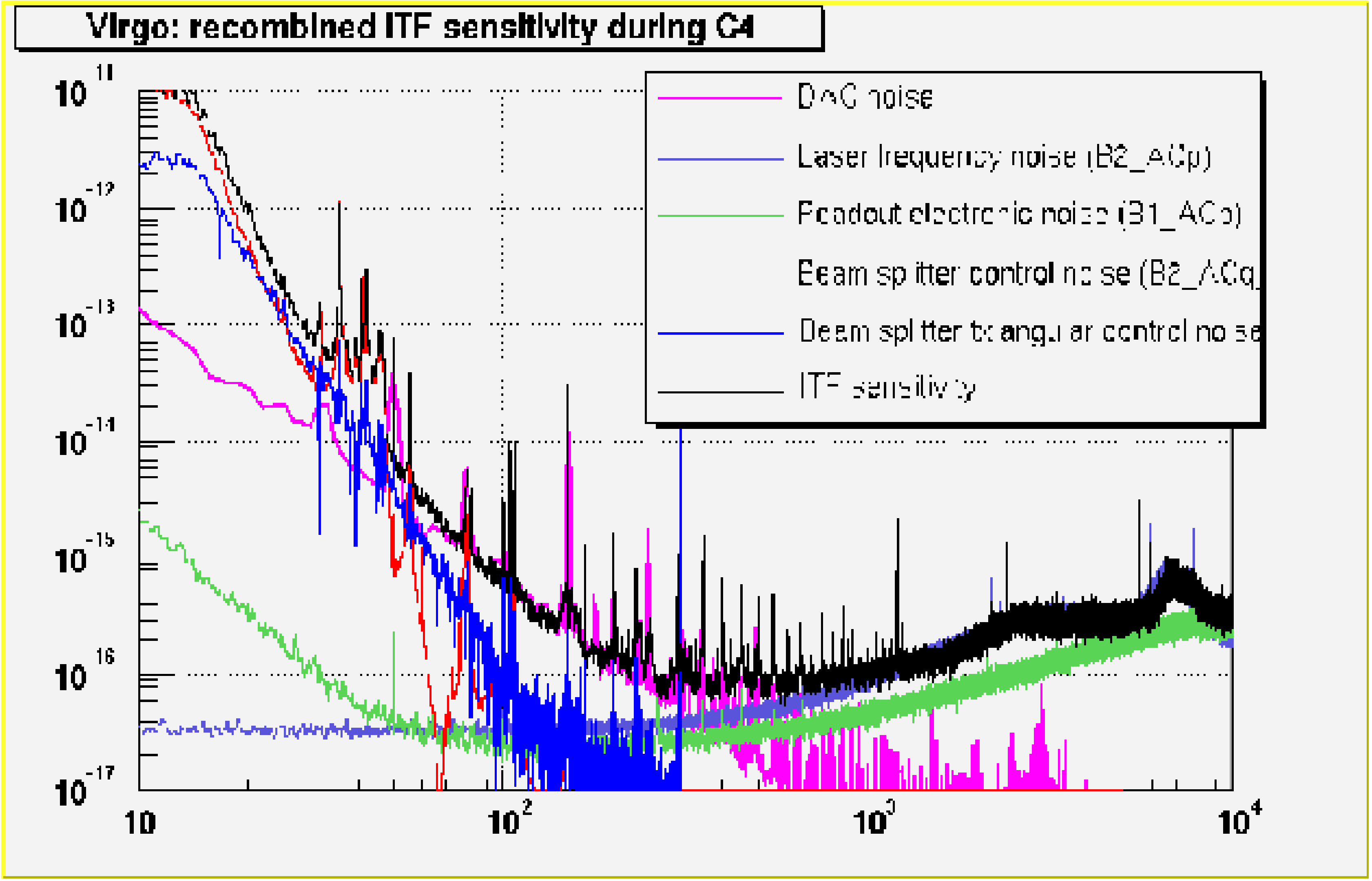
- Configuration: recombined ITF with 'nearly' complete control system
- Duration: 5 days, 24-29 June 2004
- Test periods at the beginning and at the end of the run
- 9 losses of lock during quiet periods (all understood, one due to an earthquake in Alaska)
- Longest locked period: ~ 28 h, relatively stable noise level



C4 run: ITF sensitivity

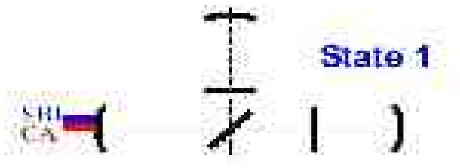


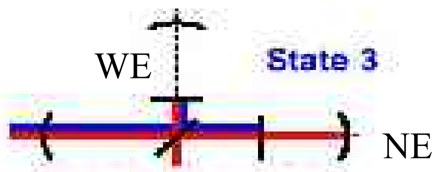
C4 run: Noise Sources

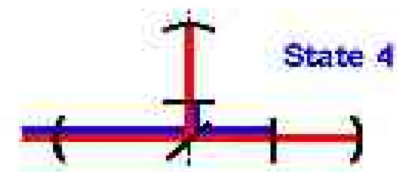


Next steps

• **Lock recycled interferometer**







• Present status:
- State 2: locked
-State 3: locked for 10 min with WE mirror misaligned

Potential problem due to light backscattered inside the input mode-cleaner
Short term solution: reduce light entering the interferometer
Mid-term solution: add optical isolation between the interferometer and the IMC

• **Force re-allocation to marionetta (for reducing DAC noise effect)**

This topic is under study and test will start in the immediate future

Conclusion

- Construction of Virgo Completed
- Commissioning started October 2003
- Commissioning of recombined interferometer almost completed
- Commissioning of recycled interferometer starting
- Some upgrade of input bench are necessary (end of 2004 ?)
- Goal: first Scientific Run during 2005