# Optics in VIRGO

VIRGO Status

Injection Sytem in Virgo

Selected topics in Frequency stabilization

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# VIRGO status

Setup overview

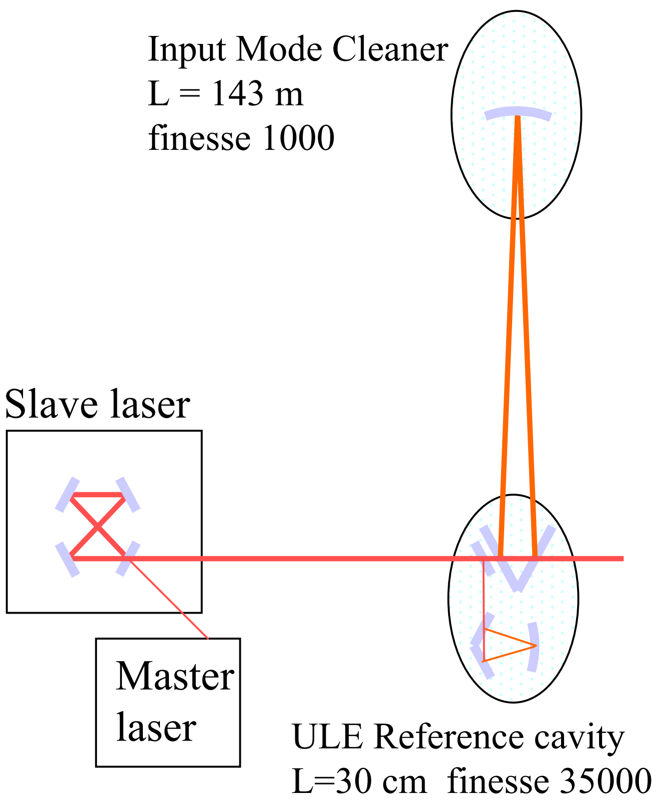
Sensitivity (m/$\sqrt{}$Hz)

Reliability

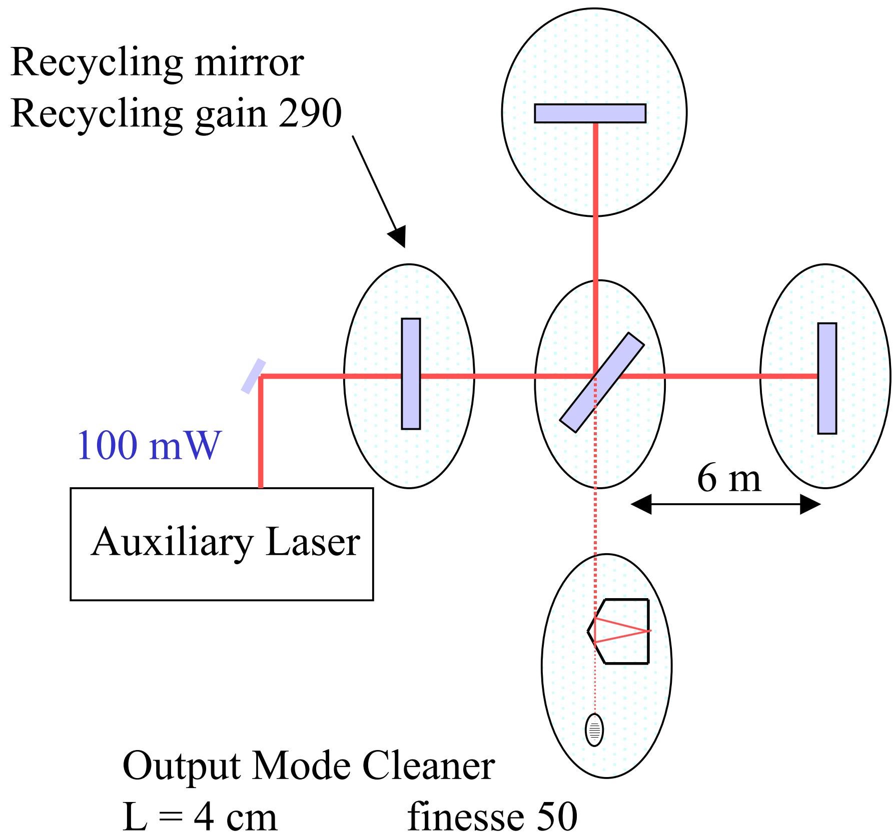
Details (servo loops, suspensions, etc.)

# Setup up to April 2002

## Injection system



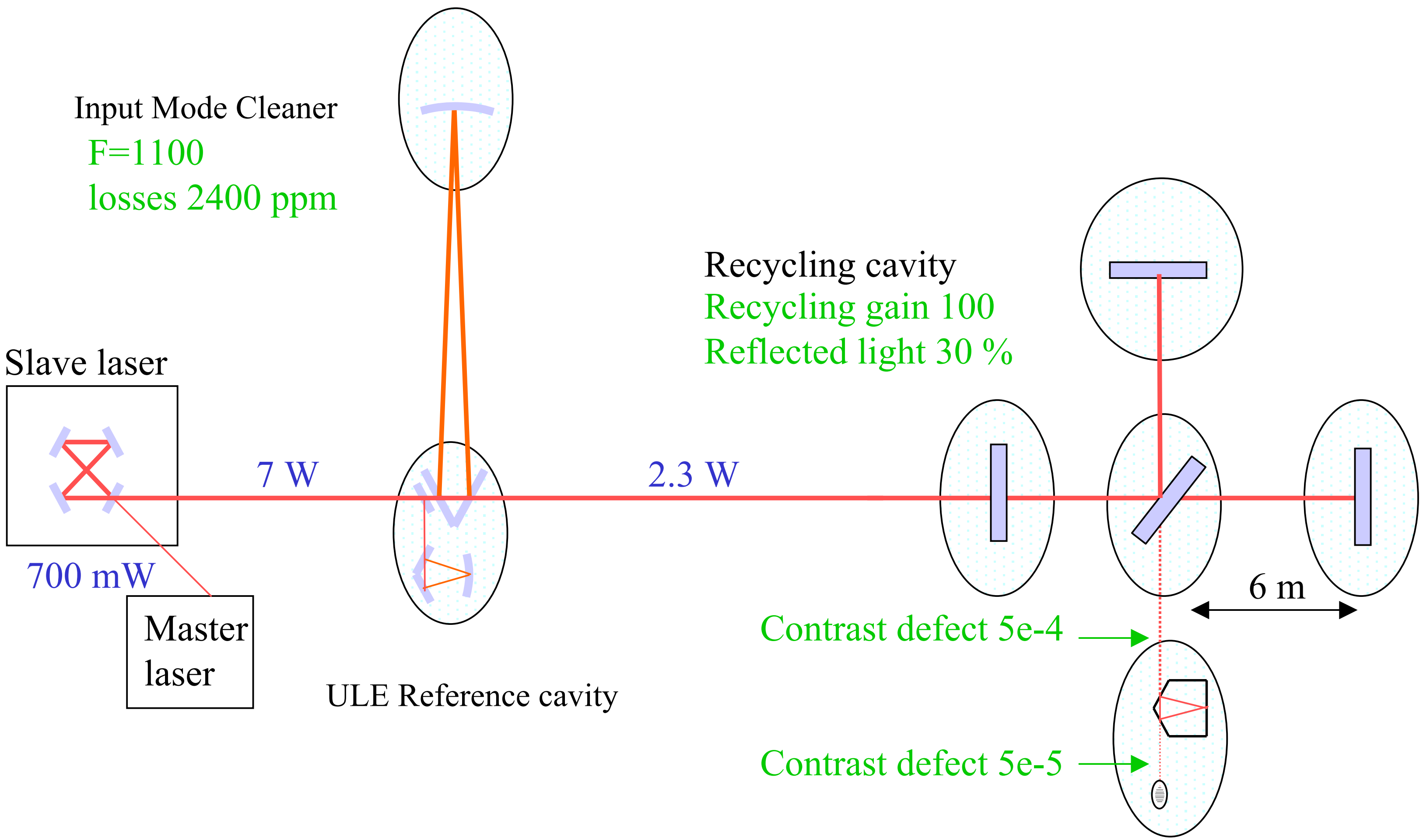

## « central interferometer »



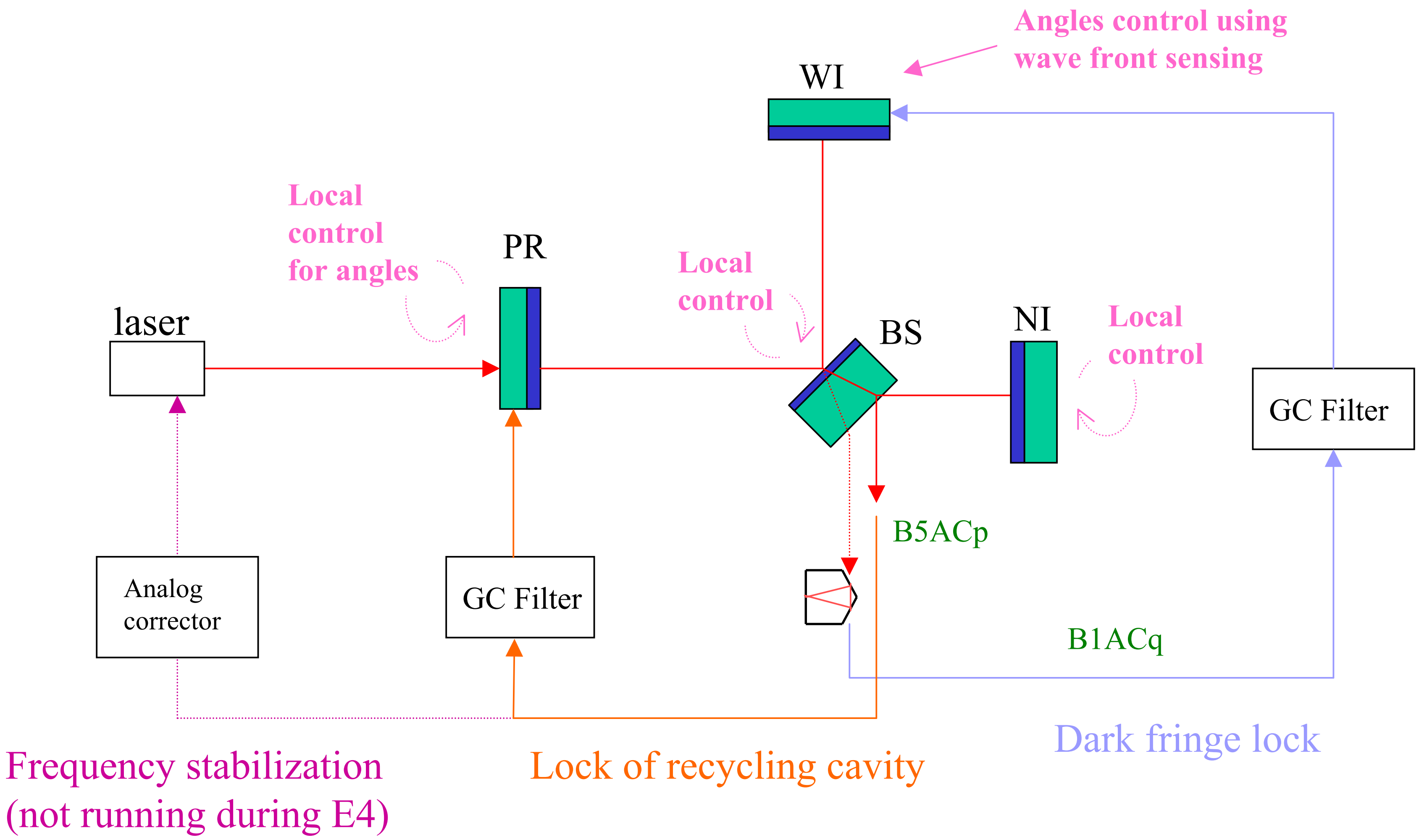
# Setup in June and July 2002

Injection system

« central interferometer »



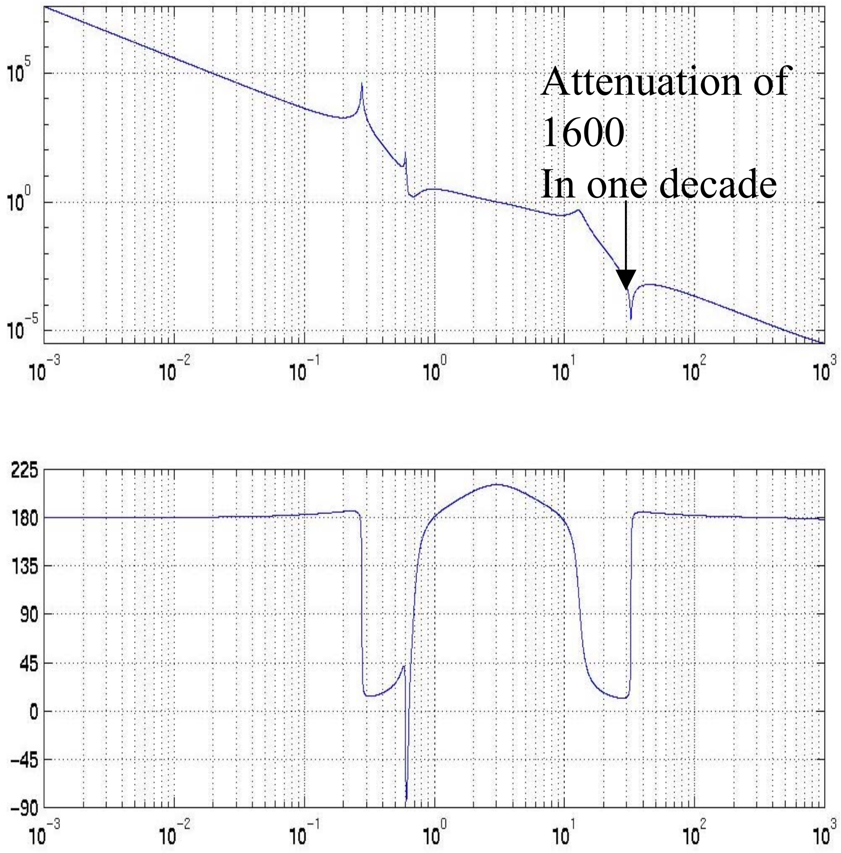
# Servo loops to lock the central interferometer



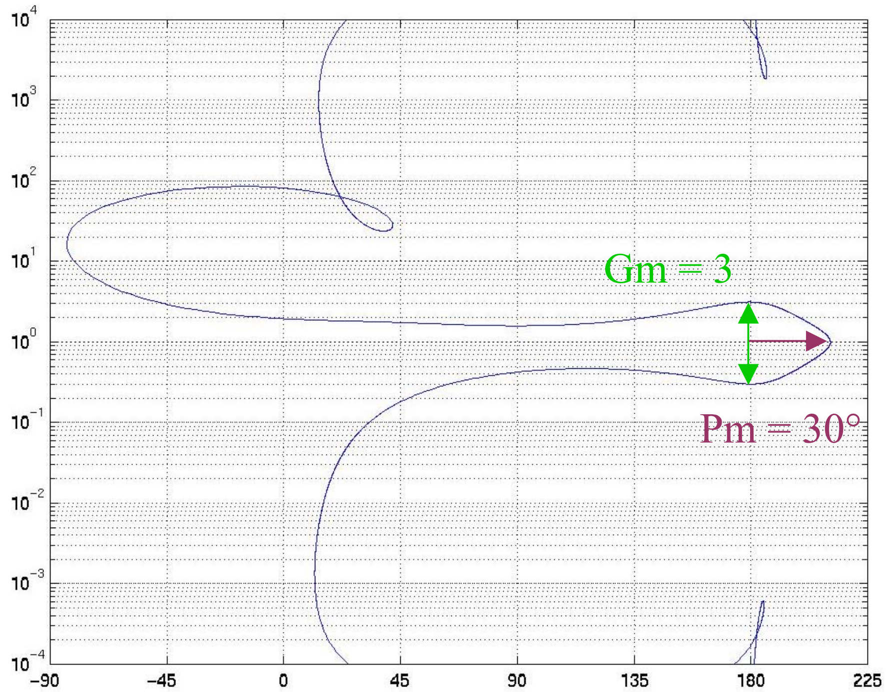
# Digital filter used to lock PR

(design Jean-Pierre Coulon)

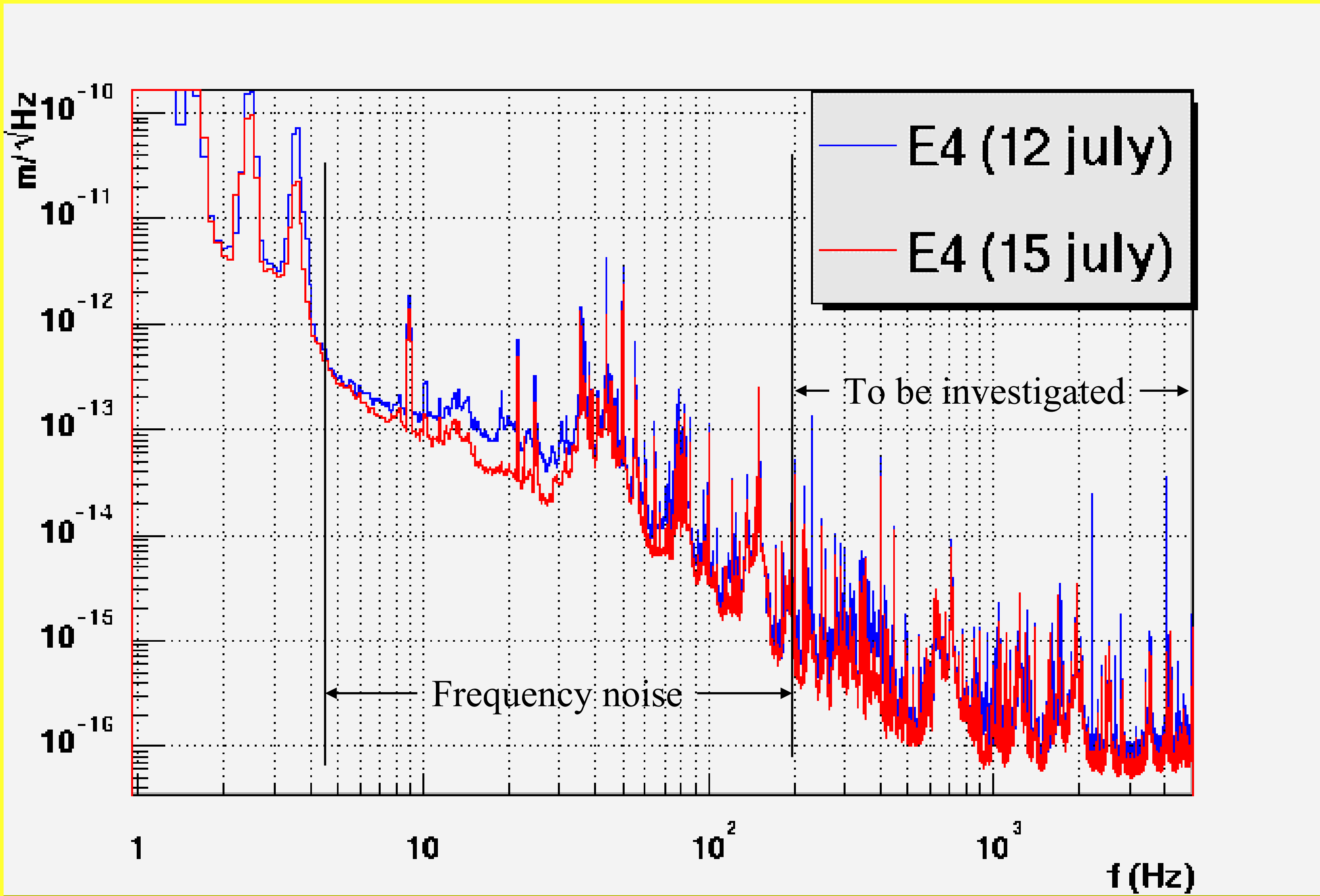
Bode diagram




Nichols diagram

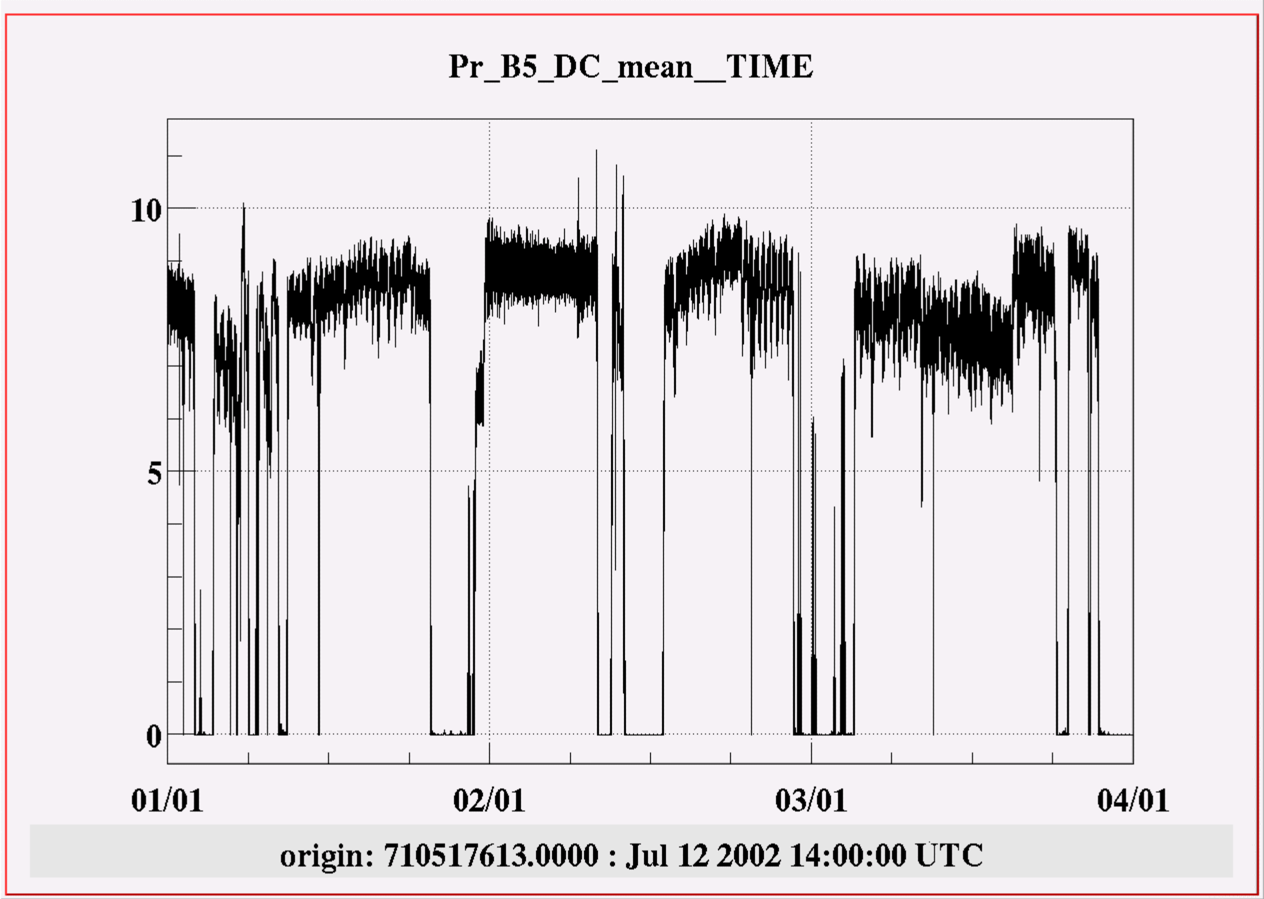


# Engineering Run #4, July 12-15 2002



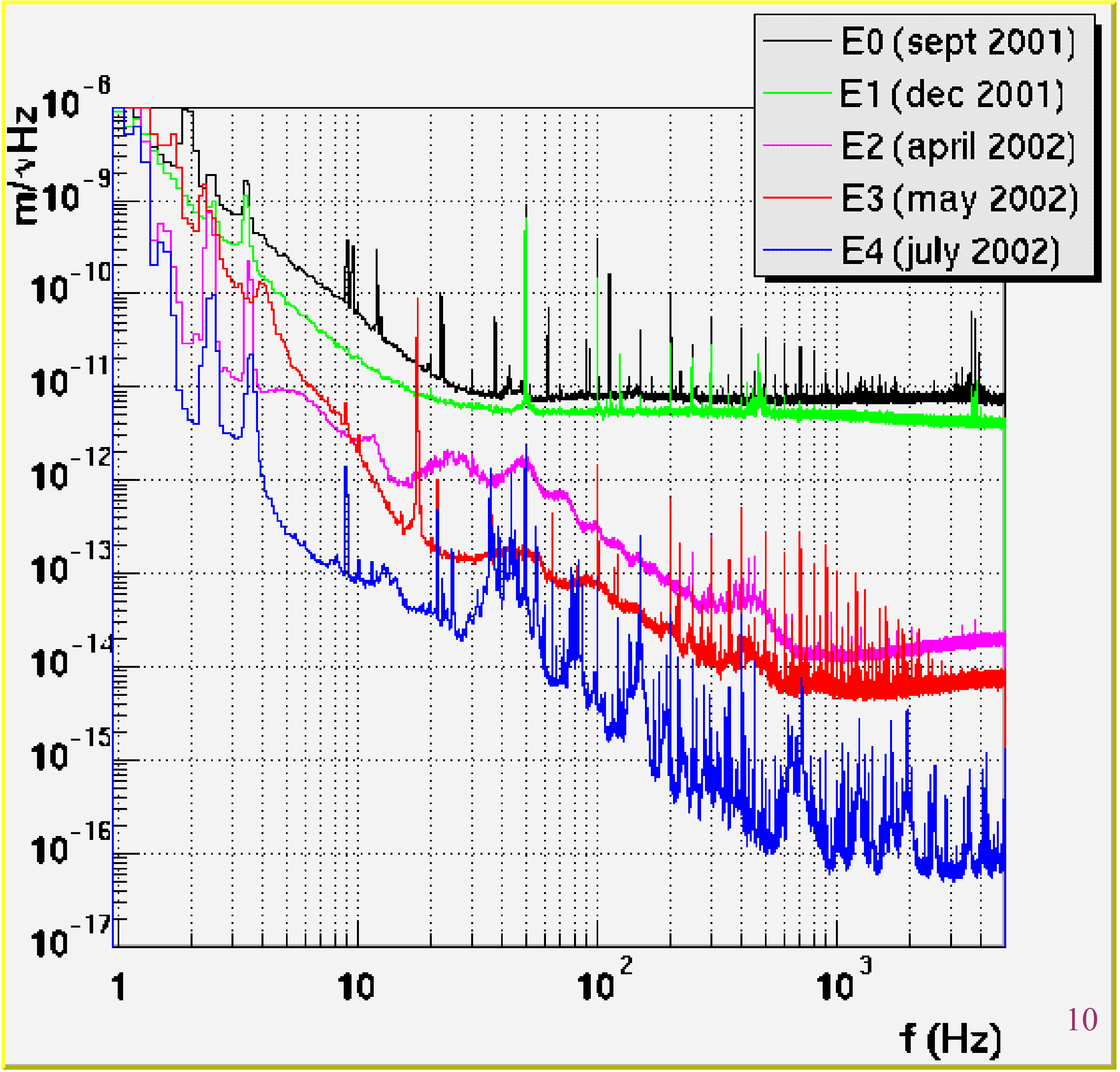
# Engineering Run #4, July 12-15 2002

Power in recycling cavity
Vs time (3 days)




- 5 unwanted losses of lock (similar to previous runs)
- lock acquisition longer than before ⇒ duty cycle ~ 80%

VIRGO
Central
Interferometer
Sensitivity
Progress



# VIRGO status / Summary

Commissioning of central interferometer is finished
(injection system 10 W, full suspensions, data acquisition system, interferometer control…)

20 W laser to be installed on site end of sept. 2002

First long arm cavity to be commissioned this fall

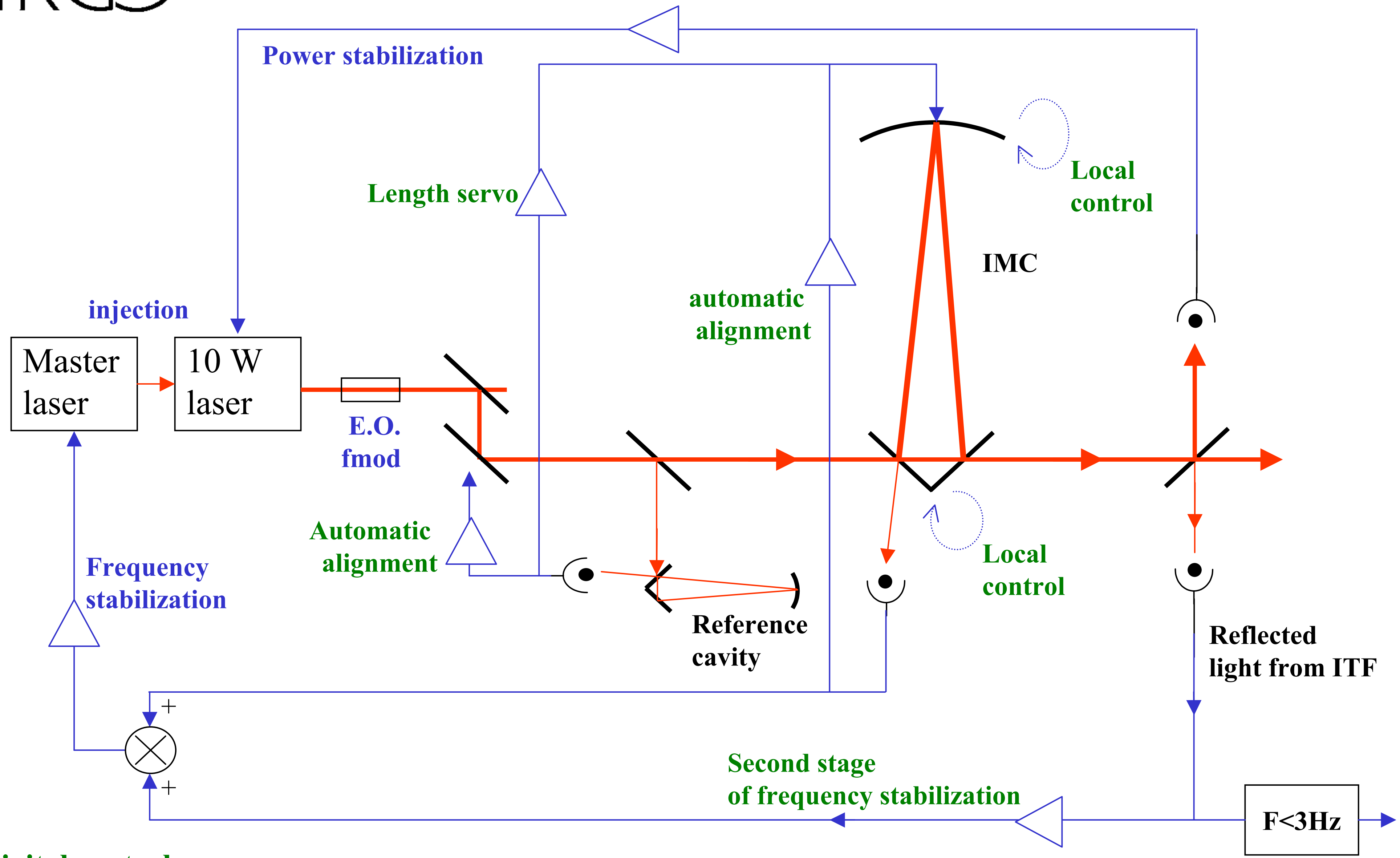
End of commissioning foreseen for end 2003.

# Injection system

All functions demonstrated to work,
almost within Virgo specifications

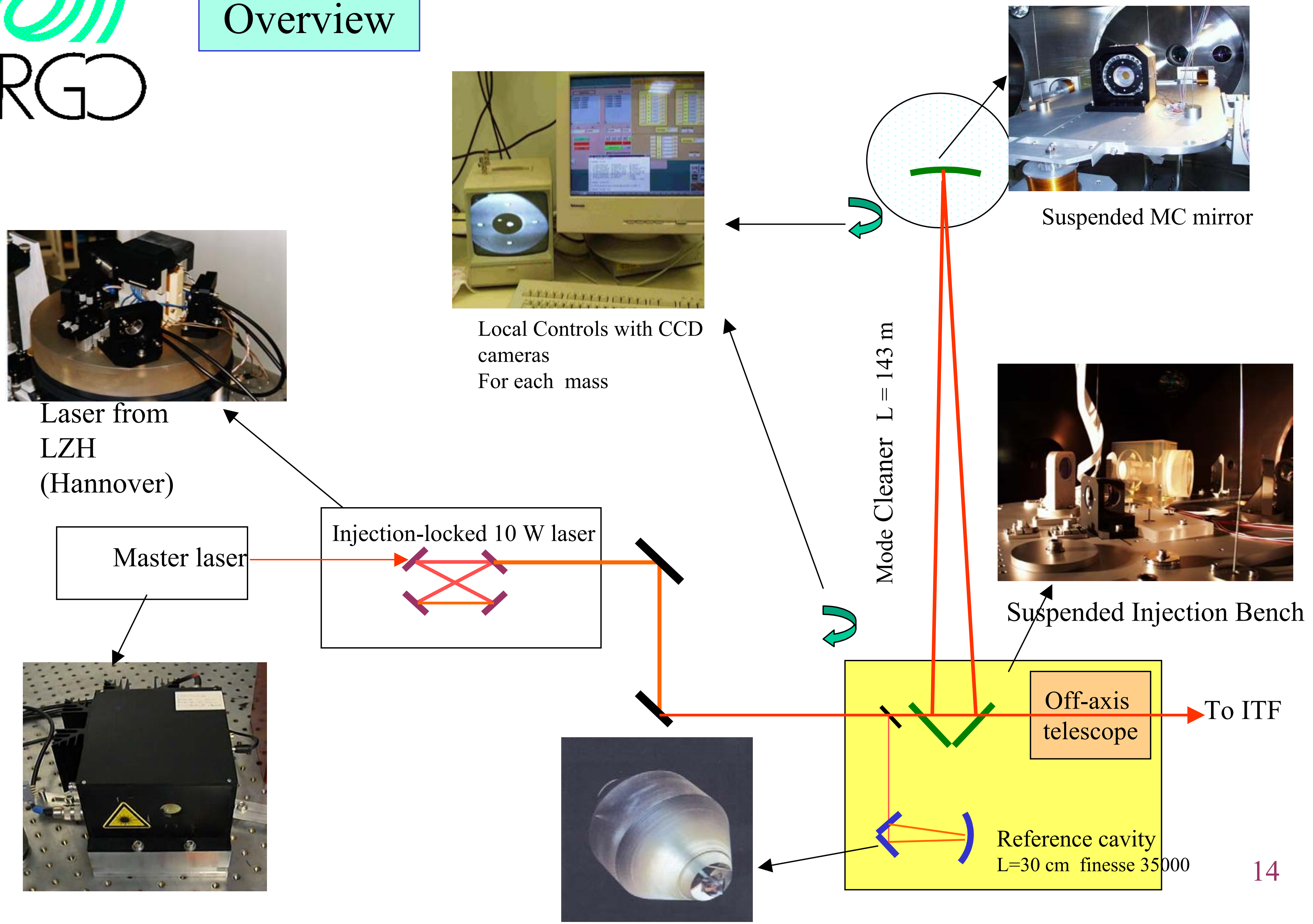
- laser beam
- suspensions inertial damping and local controls
- alignments
- filtering with a long Mode Cleaner cavity
- stabilizations (power, frequency, position)

# VIRGO Injection System: Setup



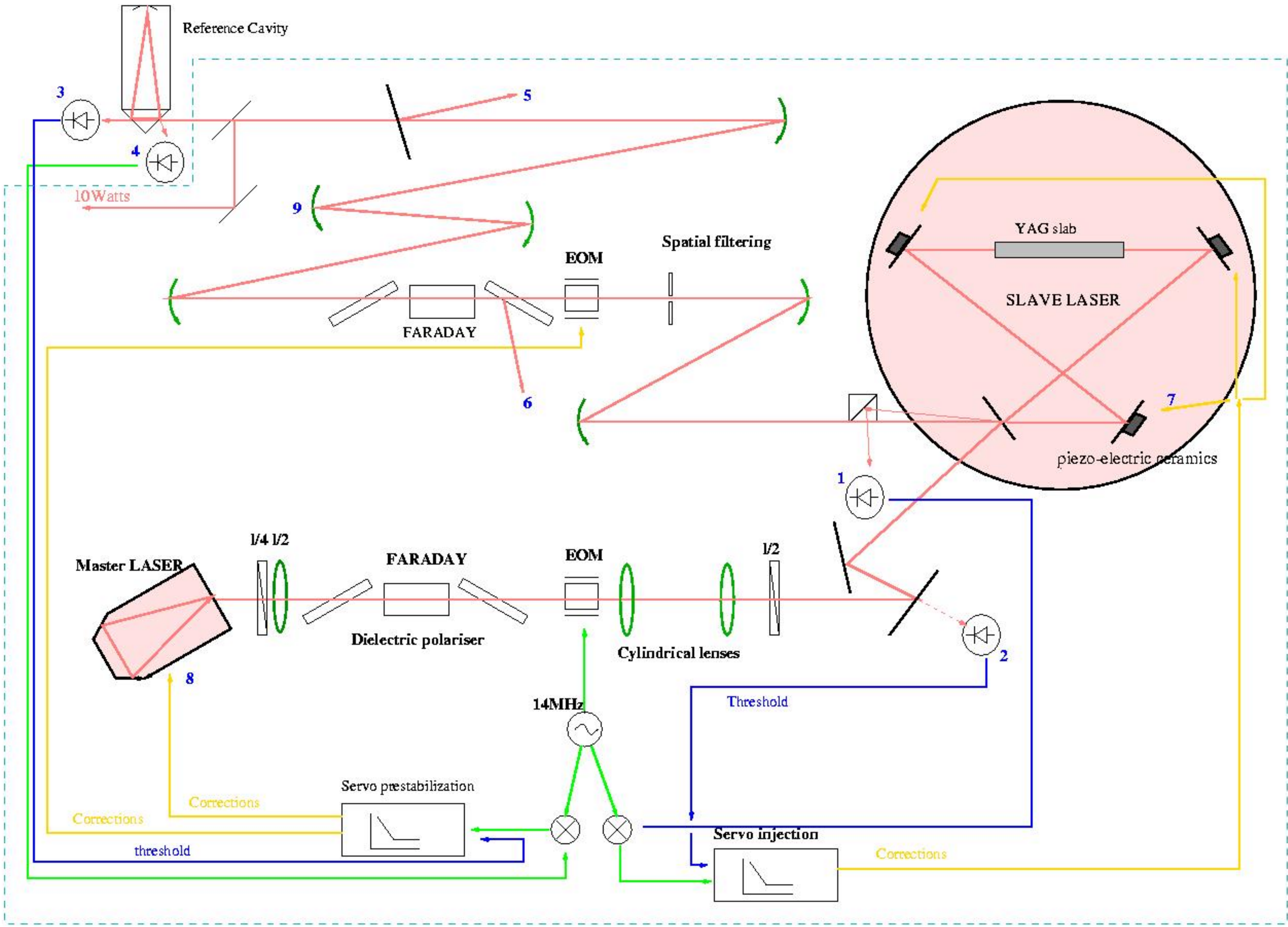

-- : digital control

# Overview

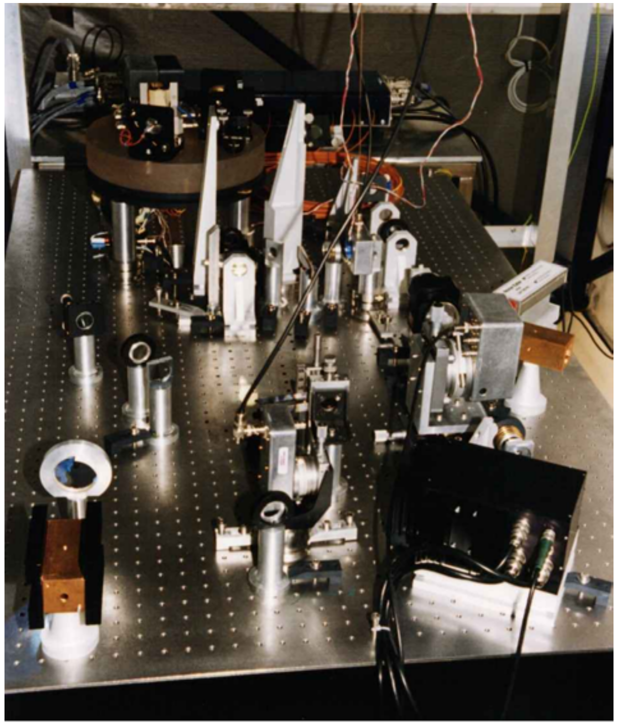


Suspended MC mirror
Local Controls with CCD cameras
For each mass
Laser from LZH (Hannover)
Mode Cleaner L = 143 m
Injection-locked 10 W laser
Master laser
Suspended Injection Bench
Off-axis telescope
To ITF
Reference cavity
L=30 cm finesse 35000

# 10 W Laser bench setup (Frédéric Cleva)

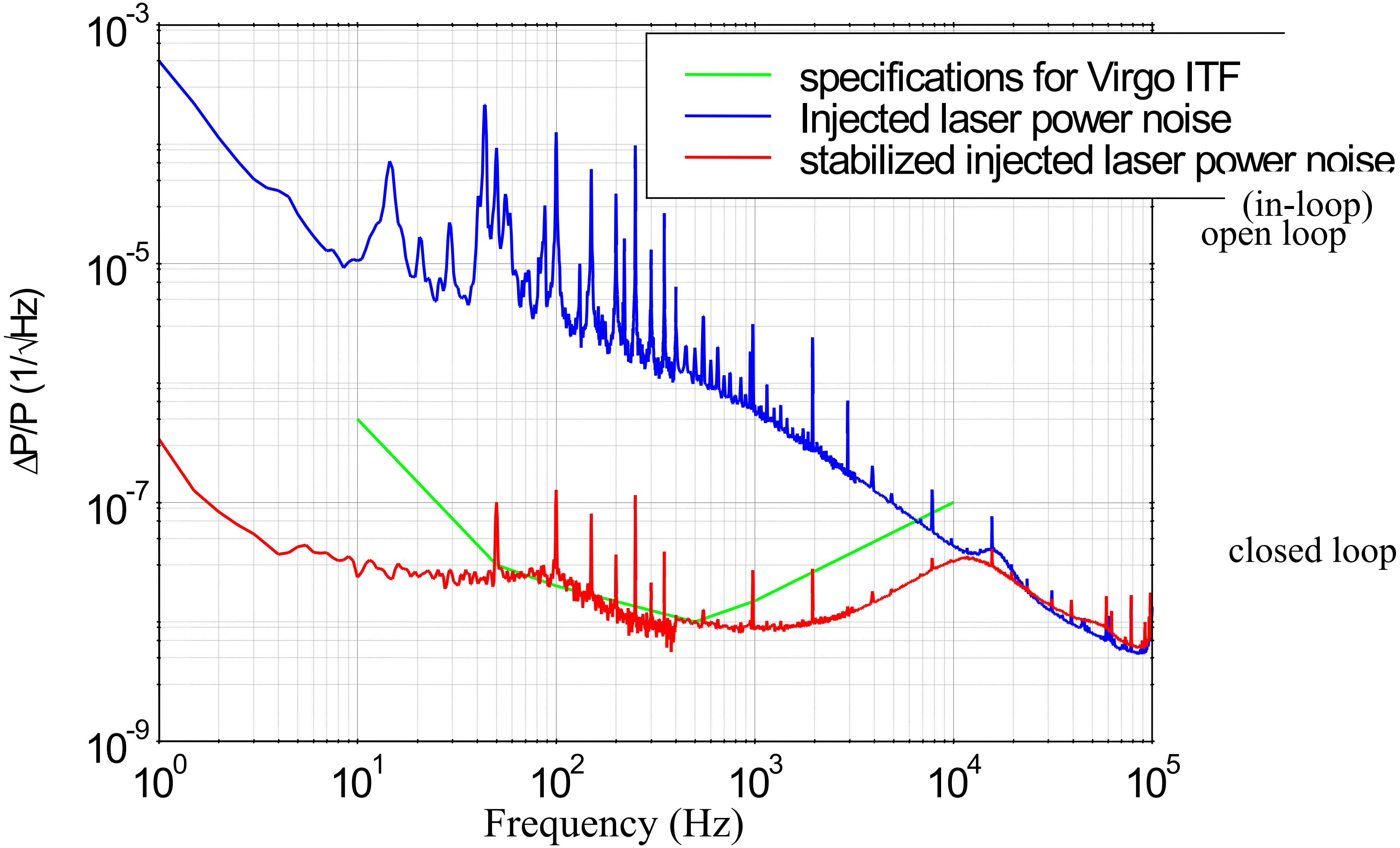


# Injected Laser Performances



- Master Laser 700 mW, Slave Laser 11 W
- Injection bandwidth 100 kHz
- 11 W, mono-mode, single-frequency
- In operation since July 1999
- > 7000 hours of operation
- remote monitoring

# Power Stabilization

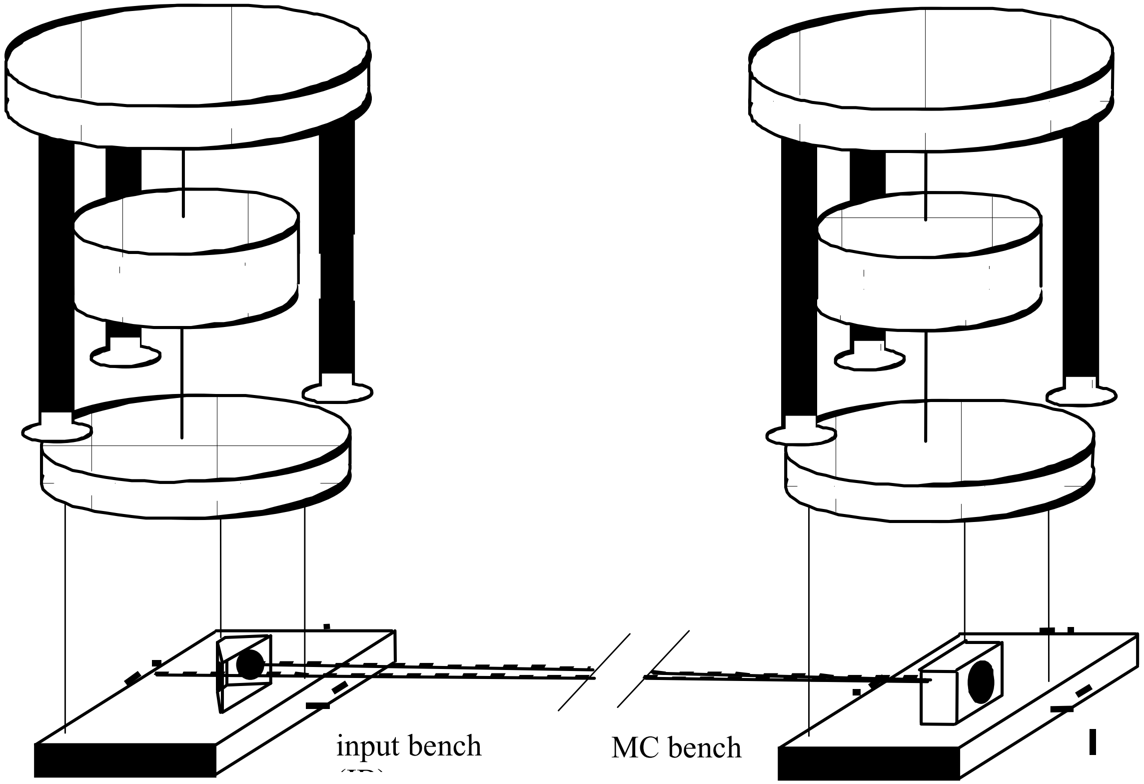


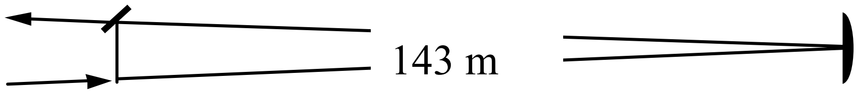
# Input Mode Cleaner

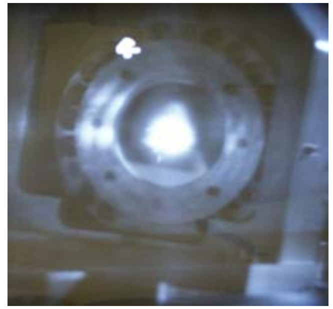
**Short Suspensions:**

- **Inverted pendulum**
- **2 filters**
- **Marionetta**
- **Last stage**

**Input dihedron:**
**Optically contacted mirrors,**
**Ø 80 mm**



**Curved mirror**
**R = 180 m**
**Ø 80 mm**

**Digital local control:**

- **CCD camera, DSP,**
- **Coils+magnets**

**Beam waist: 5 mm**

**Digital global length and alignment control**

# MC parameters Measurement

| | | | |
|---|---|---|---|
| Finesse | 1120 +/- 10 | Cavity decay time | Expected: 1000; excess of 2380 ppm losses |
| Contrast in reflection | 79 % | | |
| Transmission | 33 % | Ptransmitted/Pincident | |
| Coupling<br>on 02 + 20 modes | 7 % | Measurement of transmitted power | |
| Round trip length | 285,46 +/- 0,3 m | Notch in TF at f=FSR | |
| Curvature | 186,5 +/- 0,4 m | Notch in TF at 356 kHz | |

# Injection system

All functions demonstrated to work,
almost within Virgo specifications,
High reliability of the laser system

- More on laser frequency specs: see 3rd part

- To be fixed:
- Back scatter of light in mode cleaner
- transmission of the mode cleaner
- automatic lock acquisition
- mode cleaner length noise

# Frequency stabilization

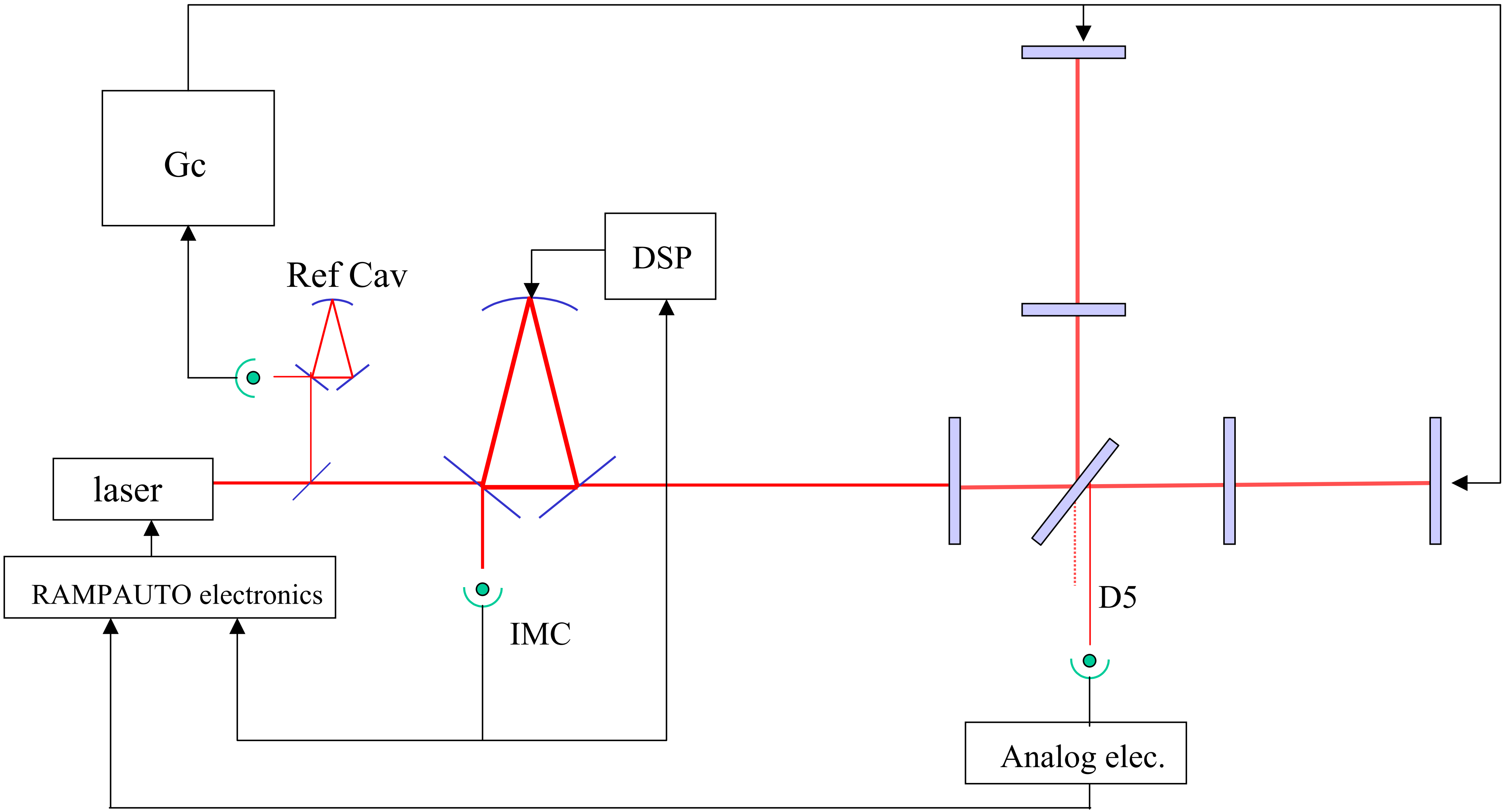
Design of feedback for the virgo interferometer

Design of efficient and stable servo loops

« optical transfer function »

CARM sensing for LHO-4K

# New reference solution: Locking Scheme



# Design of efficient digital filters

Programm CROSSXP, by Jean-Pierre COULON:

X = filter order

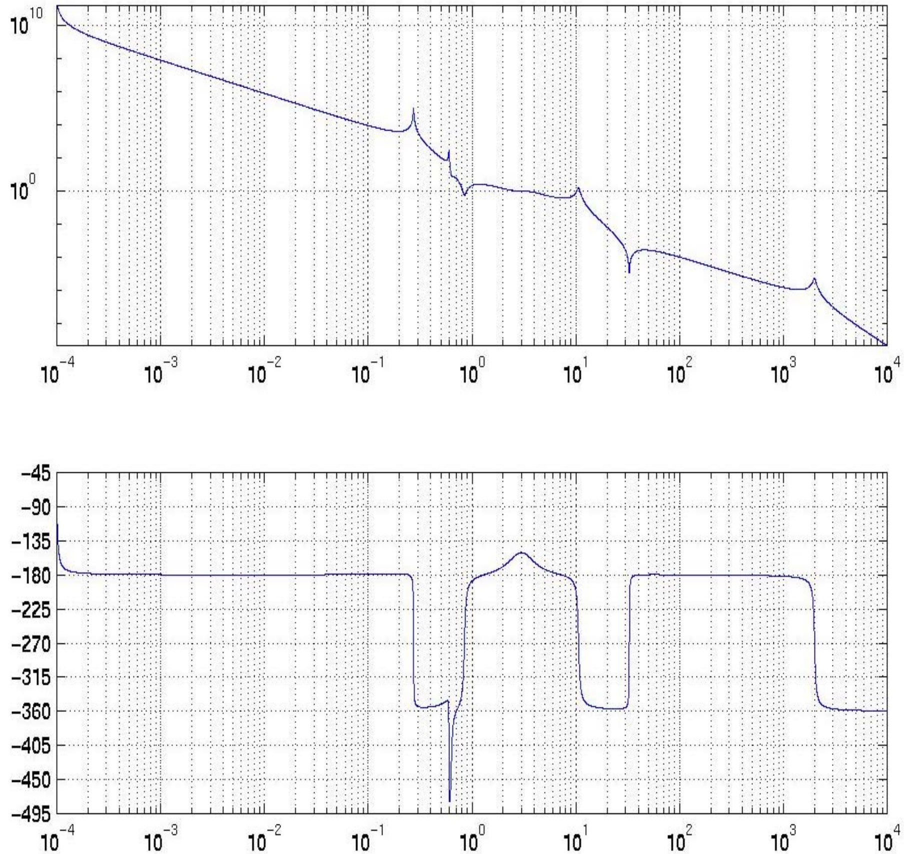
Enter required phase and gain margin,

Enter band (wrt unity gain) over which high attenuation is required

=> Finds a « good filter » (depends on the starting seed)

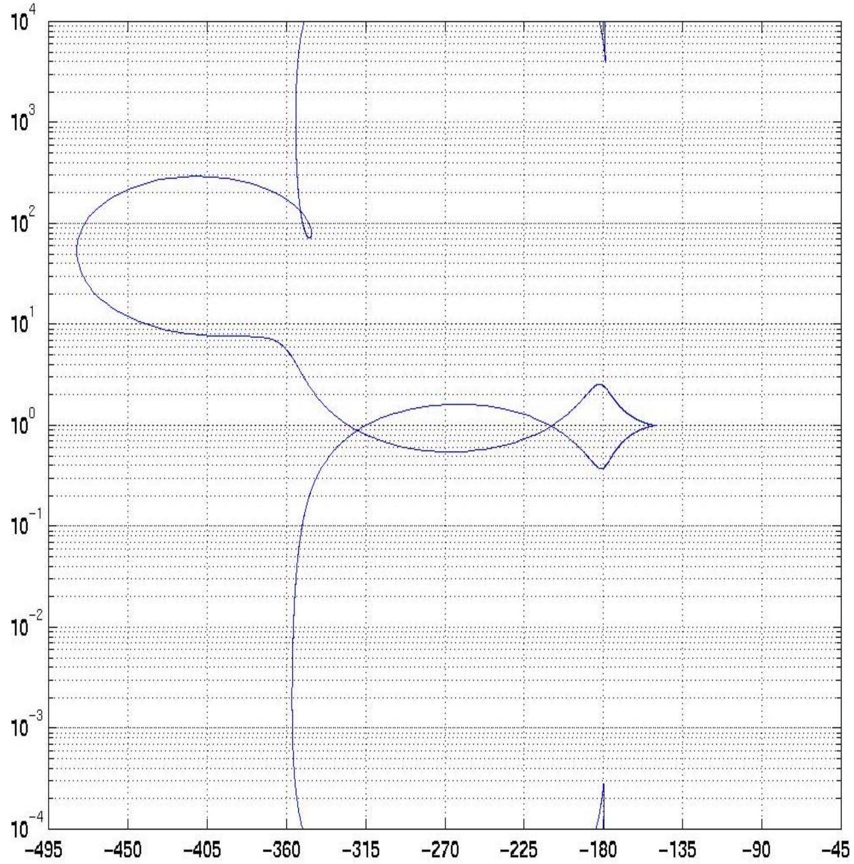
# Example of filter (worked successfully)

Bode plot




Nichols plot

Gain margin=2
Phase margin 30°




Attenation at 10*UG = 4000
Gain at UG/10 = 8000

# Frequency stabilization spec

- Unity gain of « Common Mode » servo has to be less than Free Spectral Range of long Fabry Perot cavity
- (something « bad » happens at f = FSR ??)

- Specs for prestabilization stage
  = specs for light entering ITF / common mode loop gain

# Optical transfer function

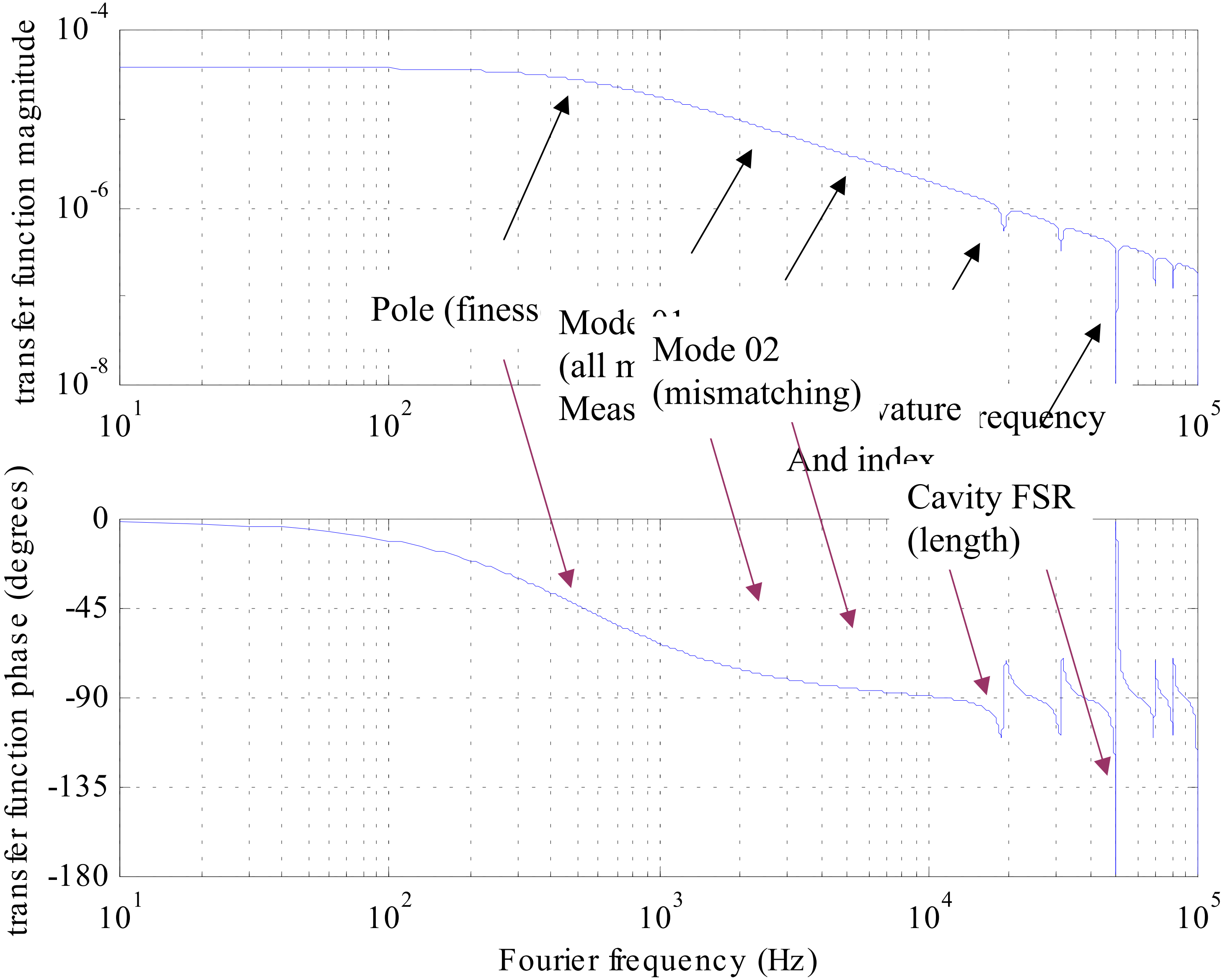
- Definition:

$$\text{Optical transfer function} = \frac{\text{Photodiode demodulated current}}{\text{Frequency noise}}$$

STF: MATLAB model of interferometer to study sensing function

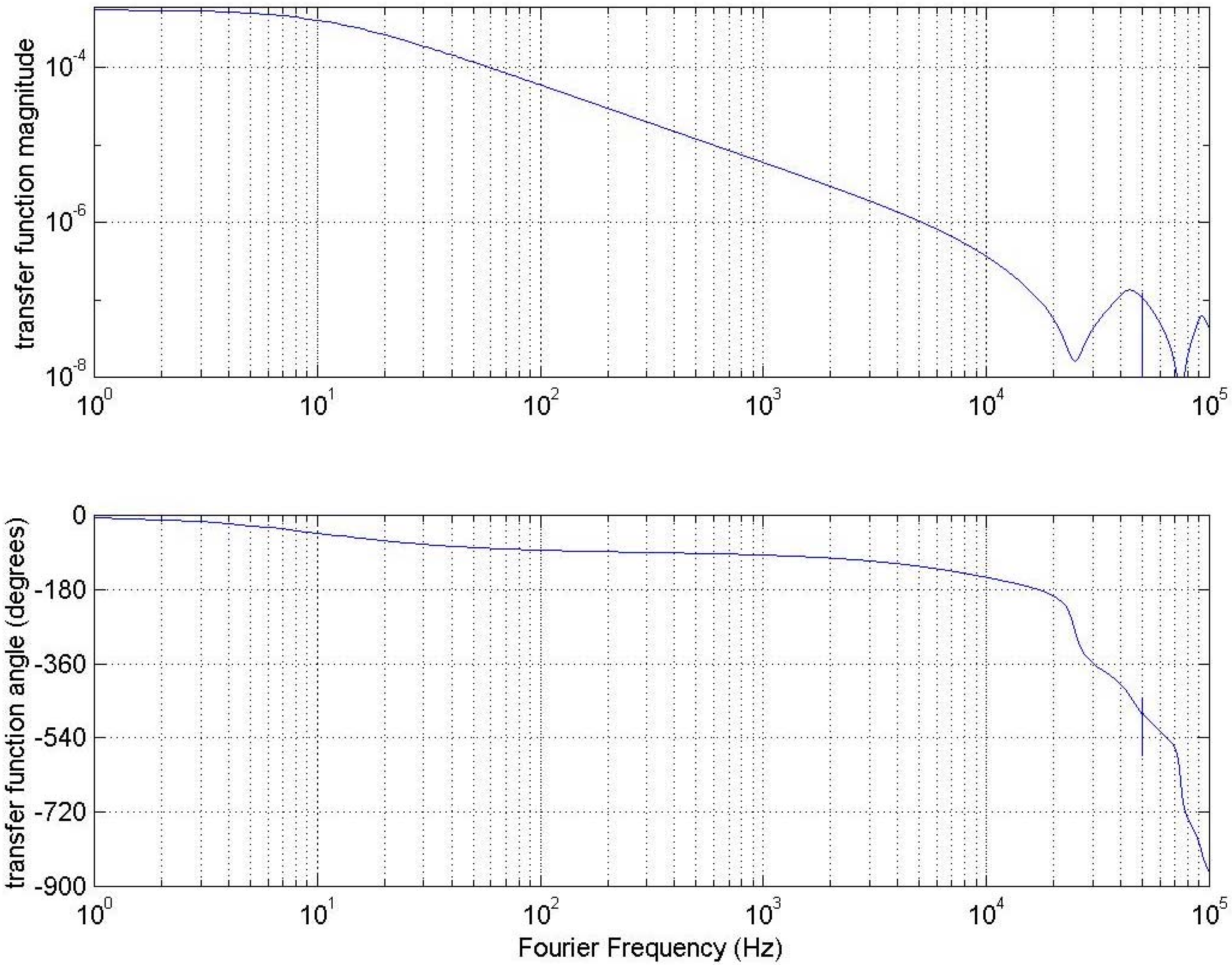
« object oriented », computes compound optical objects reflectivities and/or transmissions, and then optical transfer function.

# Ex. Of a simple FP cavity



# TF for frequency stabilization

VIRGO Transfer function between frequency noise and demodulated signal in phase on D2



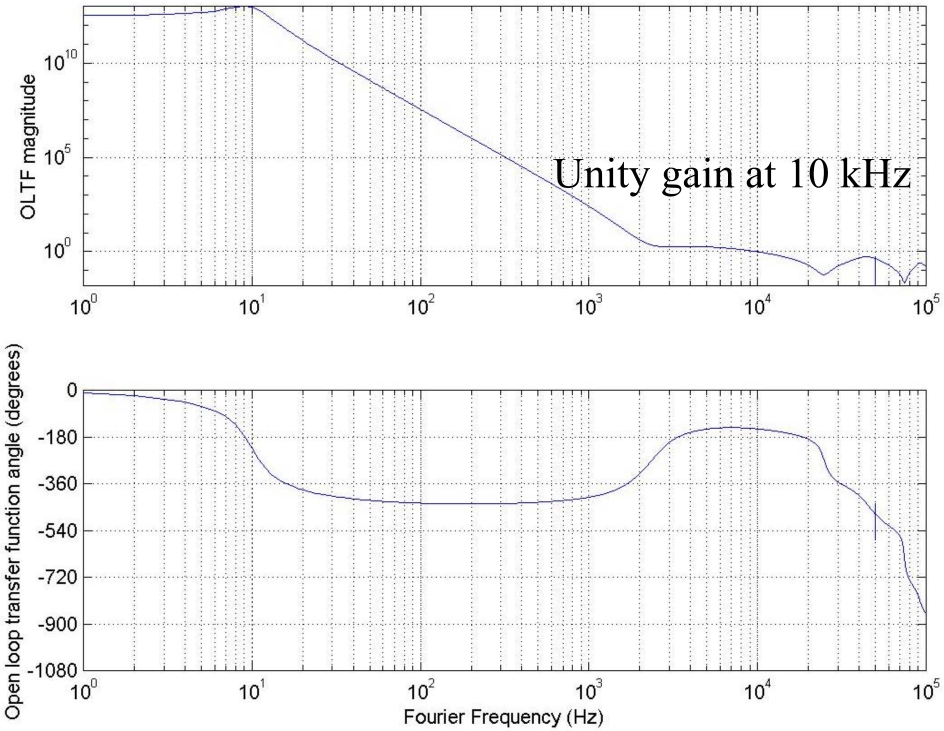
# Design of correction filter

Design of correction filter:

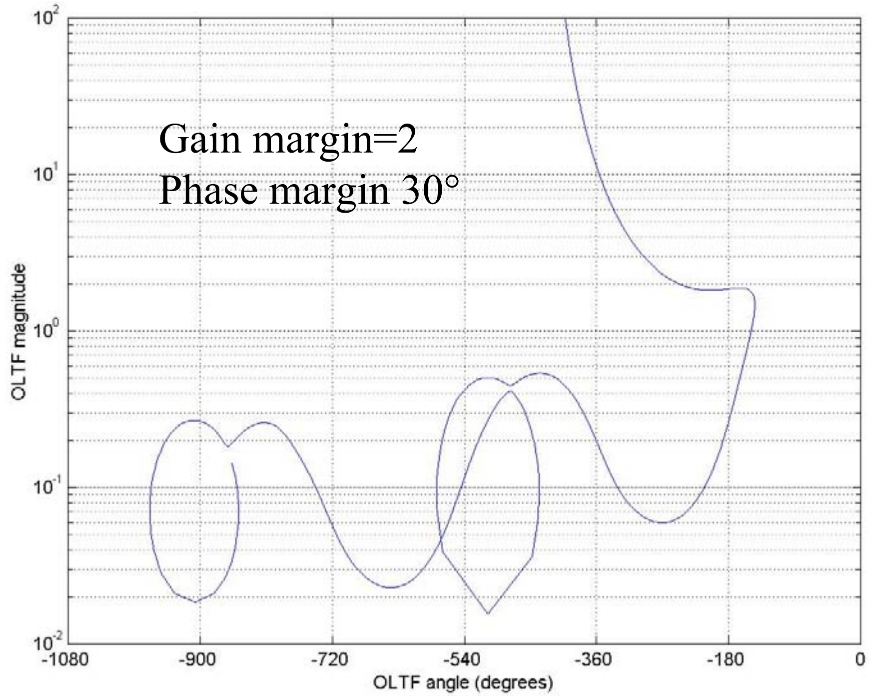
Zeros:
f=2.3 kHz, Q=2
f=2.3 kHz, Q=2

Poles:
f=10 Hz, Q=2
f=10 Hz, Q=2

OPEN LOOP TRANSFER FUNCTION

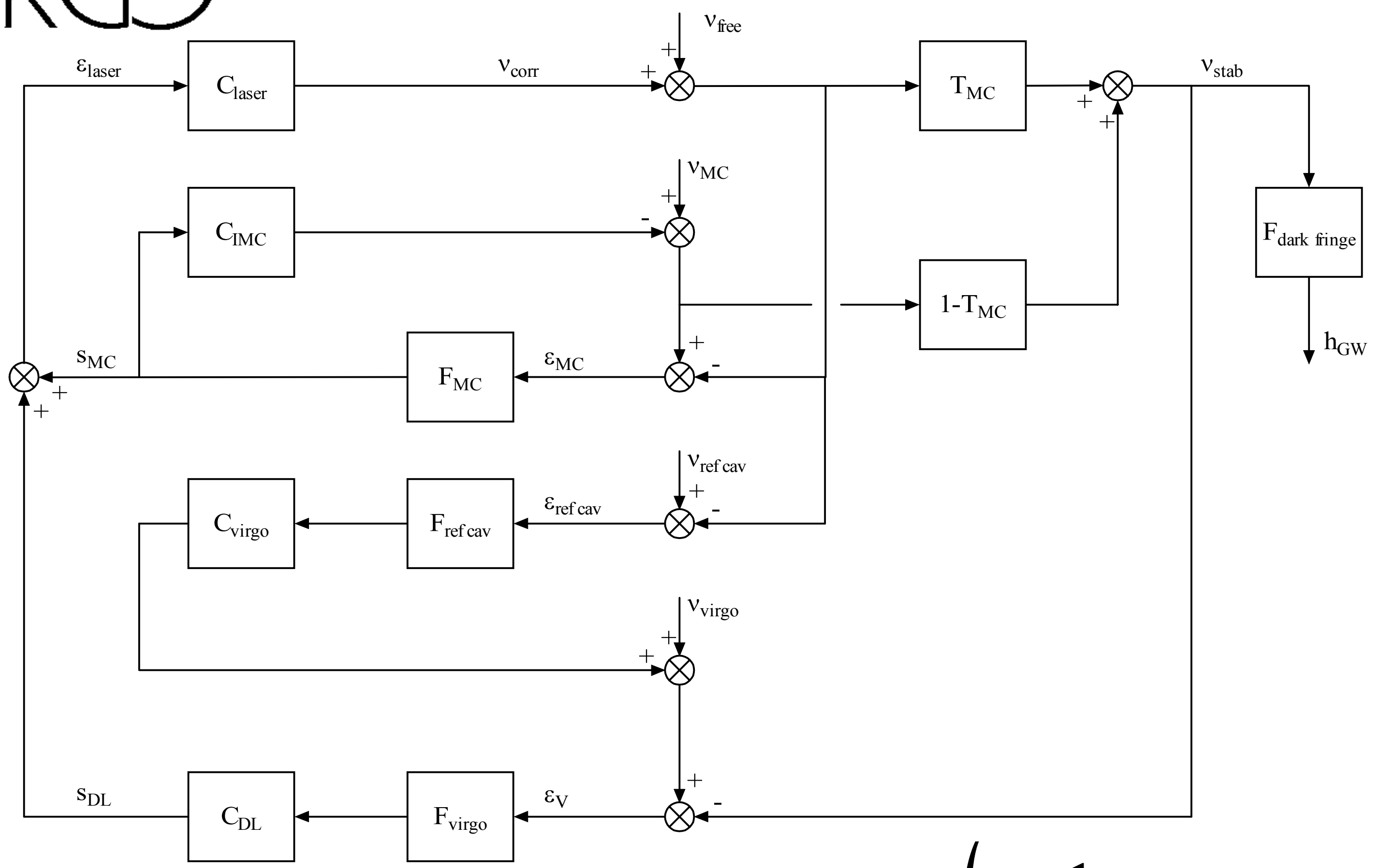



Bode plot




Nichols plot

# New Reference Solution Scheme



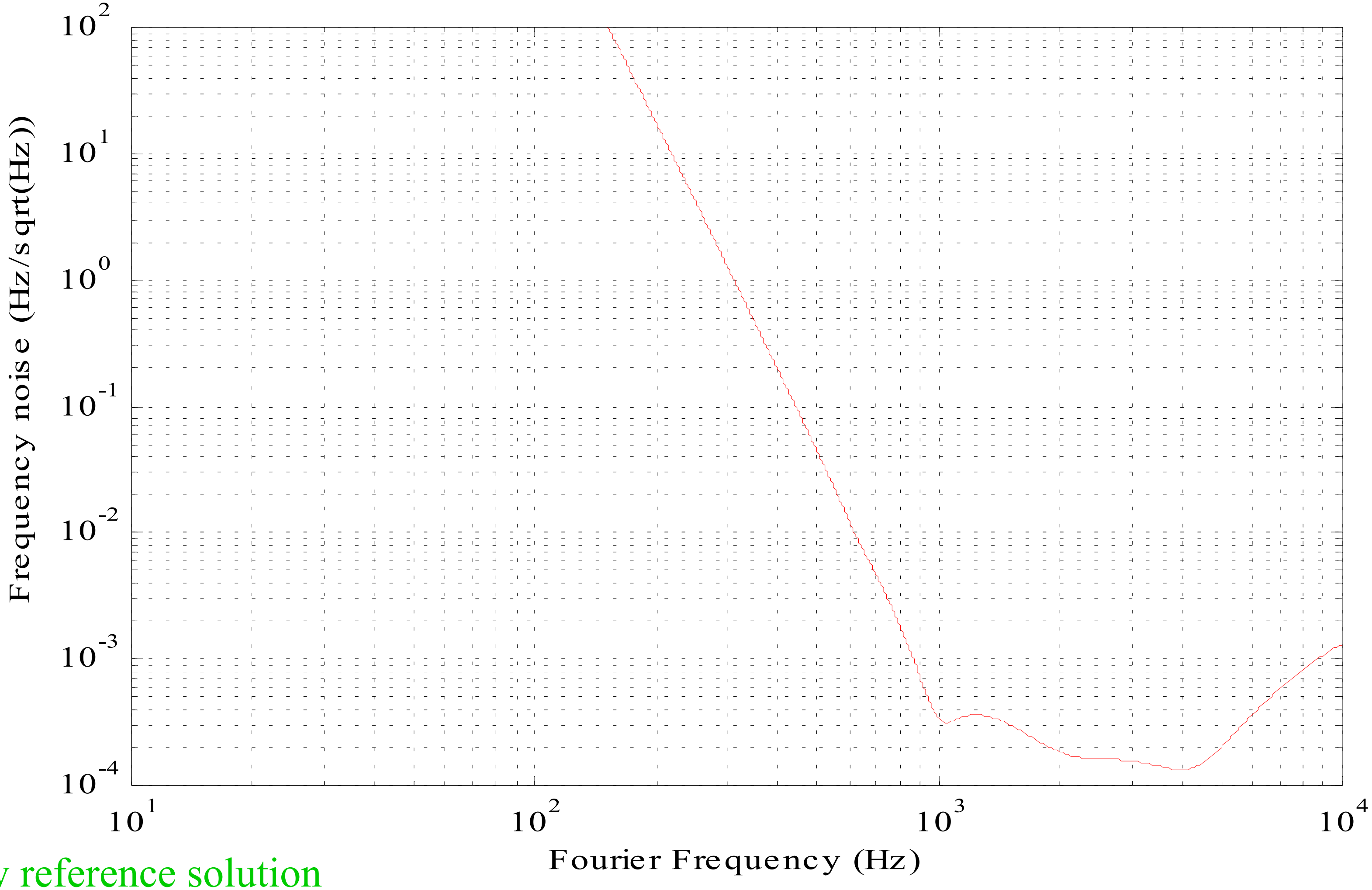

$$G_T = G_{las1}\left(\frac{1}{1+G_{MC}} + G_{las2}\left(1+G_{em}\right)\right)$$

Overall loop: stable, gain margin 2.7, phase margin 70 degrees

New reference solution

# New Reference Solution: specifications

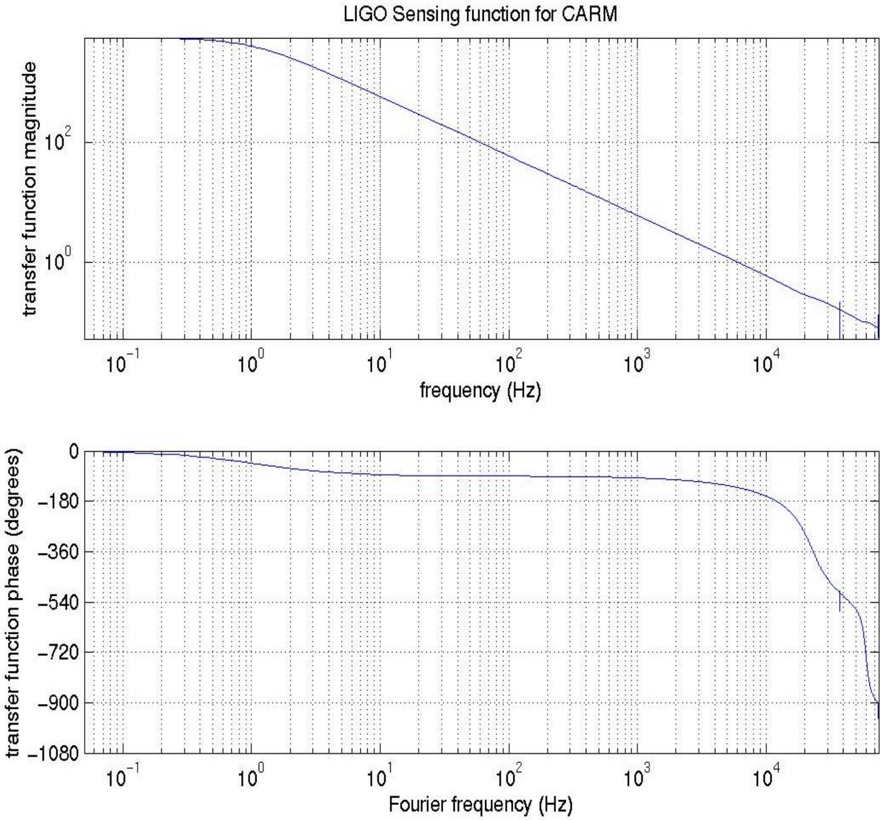
SPECIFICATIONS FOR INPUT MODE CLEANER LENGTH + SHOT NOISE



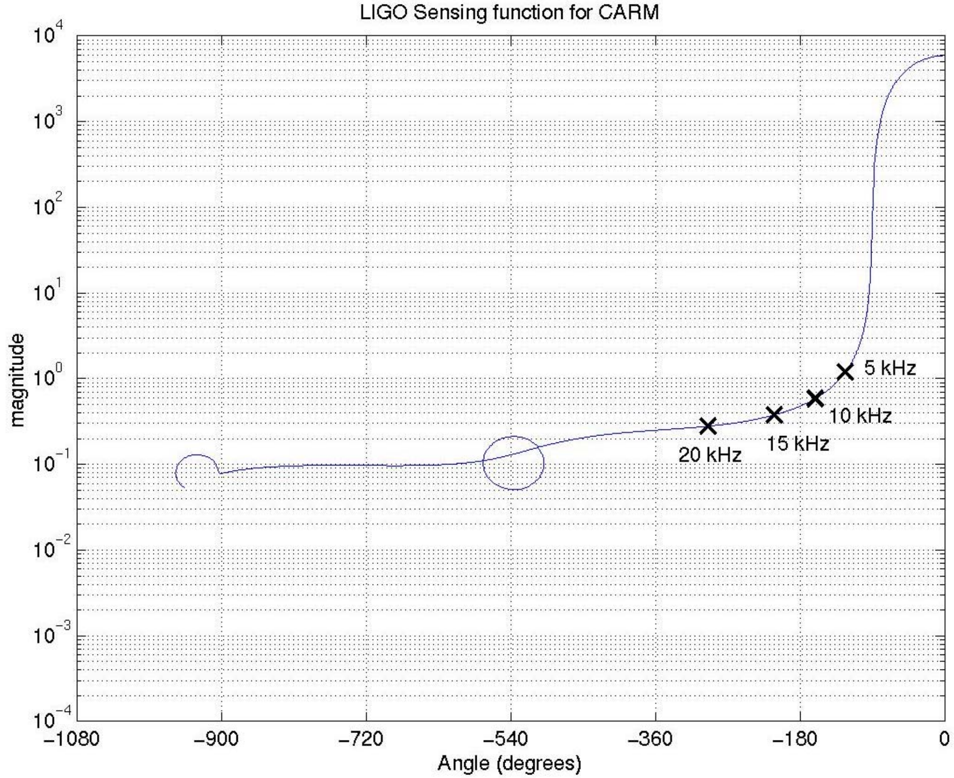

New reference solution

# LIGO4K common mode sensing

TRANSFER FUNCTION, used « as is », UG = 6 kHz




Bode plot




Nichols plot

# Design of common mode feedback

Difficult to achieve high unity gain for common mode servo

=> specs for prestabilization stage (MC for Virgo) higher

… If modulation frequency (Virgo) is switched from 6 to 18 MHz, then bandwidths of few 100's kHz possible !! (LIGO4K : window at 40 MHz).

# Conclusions

- Phase of “central interferometer” is finished.
- VIRGO Injection system: some issues to be fixed. Change of topology w/ respect to frequency stabilization.
- Frequency stabilization: tough to make a high bandwdith « CARM »; specs for frequency prestabilization higher.
- Would be nice to check the sensing function of the interferometer…

# Co-workers

Nice group:

Nary Man
Alain Brillet
François Bondu
Eric Chassande-Mottin
Hervé Trinquet (Ph.D.)
Frédéric Cleva
Magali Loupias
Henrich Heitmann
Jean Cachenaut
Jean-Pierre Coulon
Jean-Yves Vinet

And :

Pisa group (suspension, vacuum)
Orsay group (Control-command)
Annecy group (vacuum tanks, DAQ)
Napoli group (environment monitoring)
Roma group (marionettas)
Lyon and Paris groups (mirrors)