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# The commissioning of the Virgo interferometer

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for the VIRGO collaboration

- ~~Edification~~
- ~~Updat~~
- ~~Realtimeing~~
- ~~Outk~~

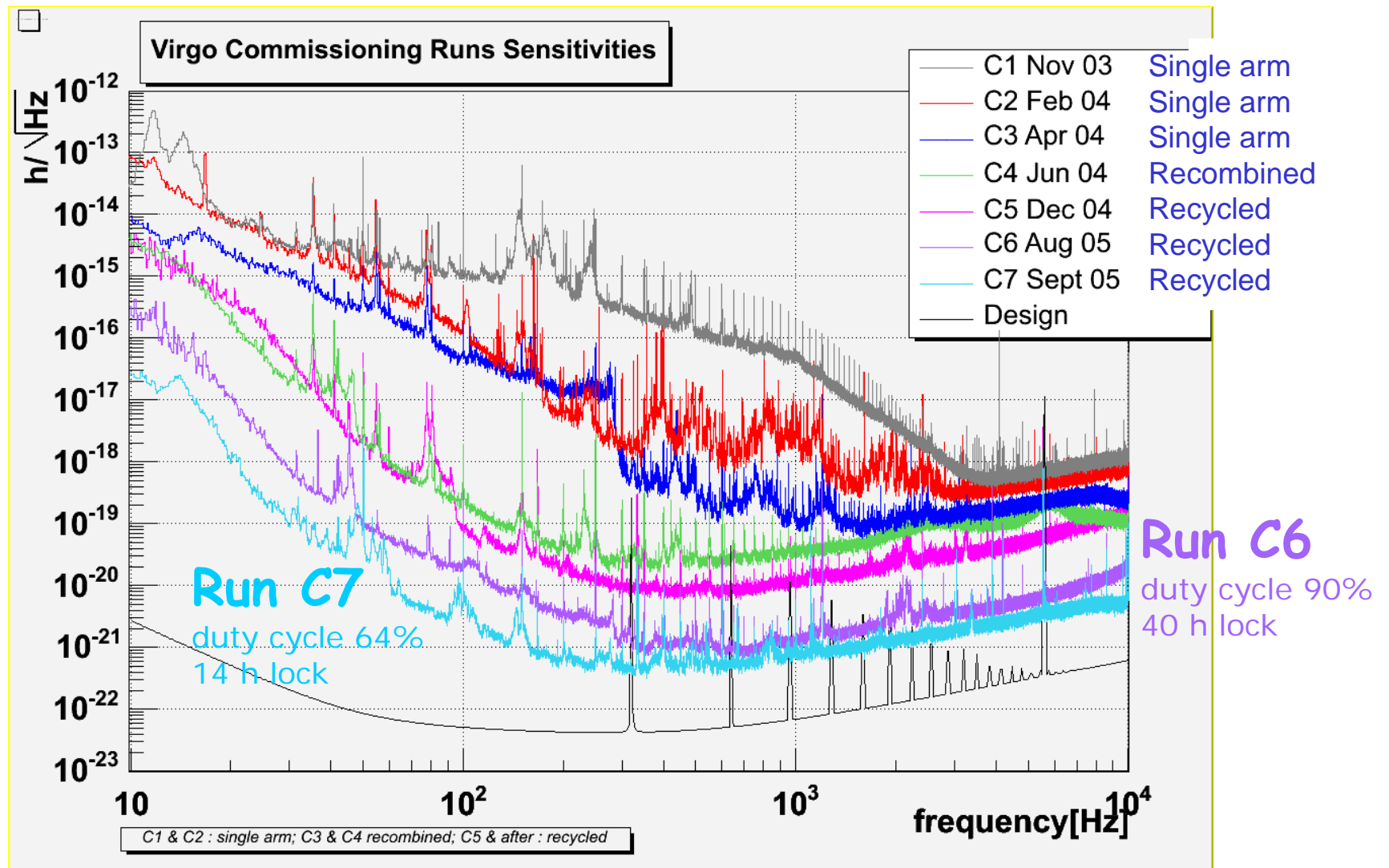


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# Satzformeln in der Physik



# Commissioning sensitivity evolution





## Problems with configuration up to C7

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### High detection rate

=> Operate with reduced power (10%)

### Nonlinear and overexcitation

Resonances => Control problems

Shift sensitivity => alignment drifts



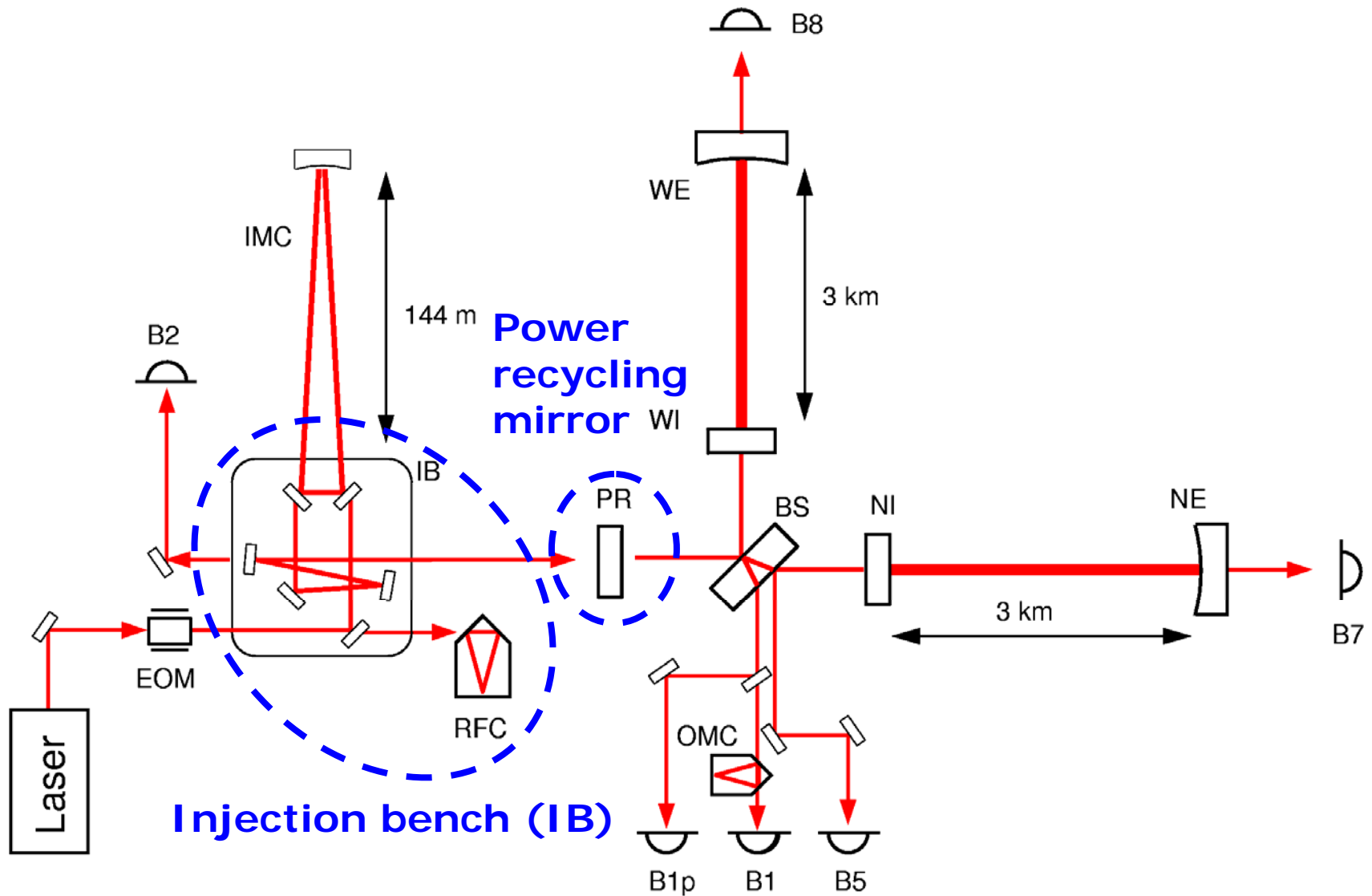
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## Reinigungs

- New power recycling mirror
- New injection bench



# VIRGO layout



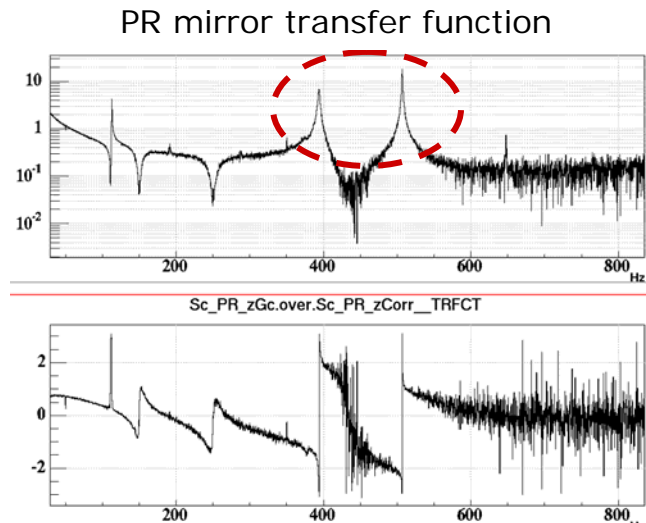
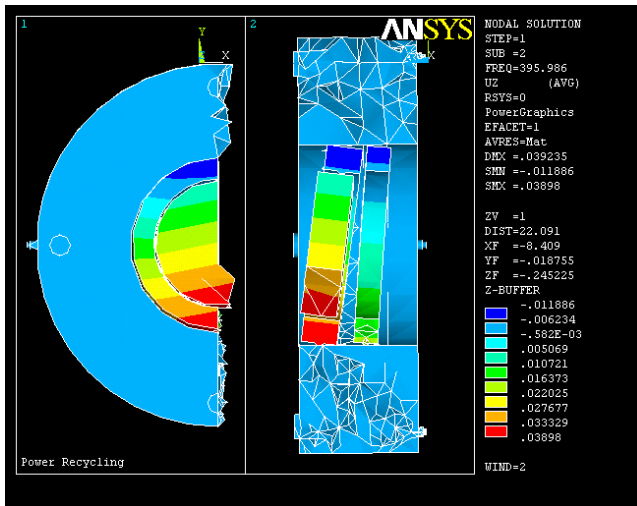
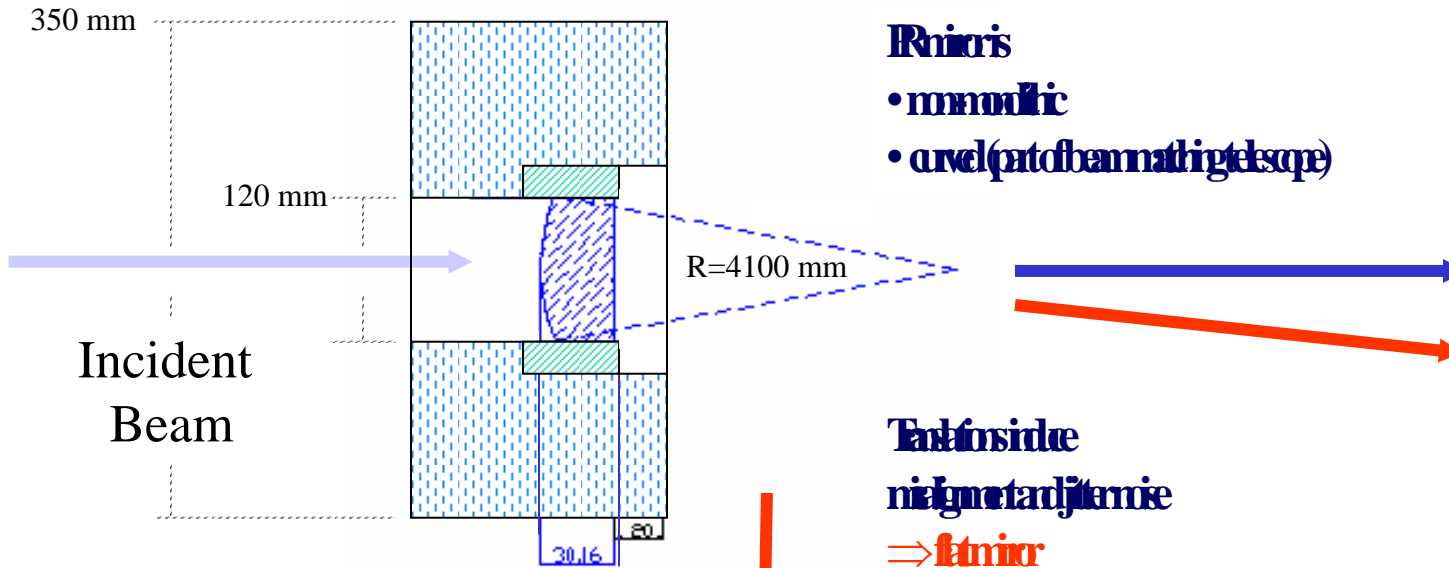


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# **Rezeptions**



# Old power recycling mirror







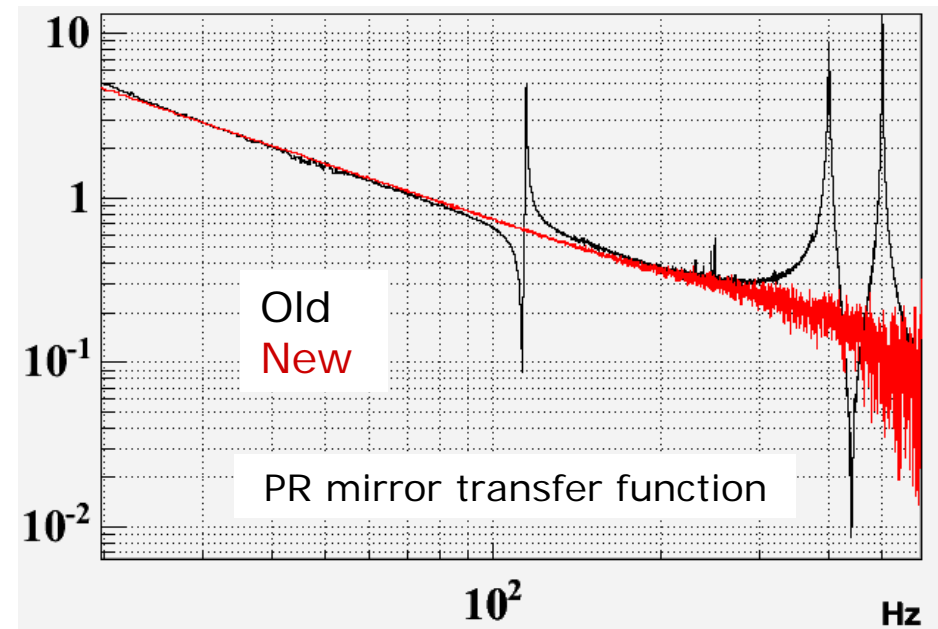
# New power recycling mirror

## Multimir

No more internal resonances in the control band !!

## Itsufacs

- => no more lens effect (no more part of input telescope)
- => larger beam coming out of injection bench
- => **parabolic telescope needed on IB**



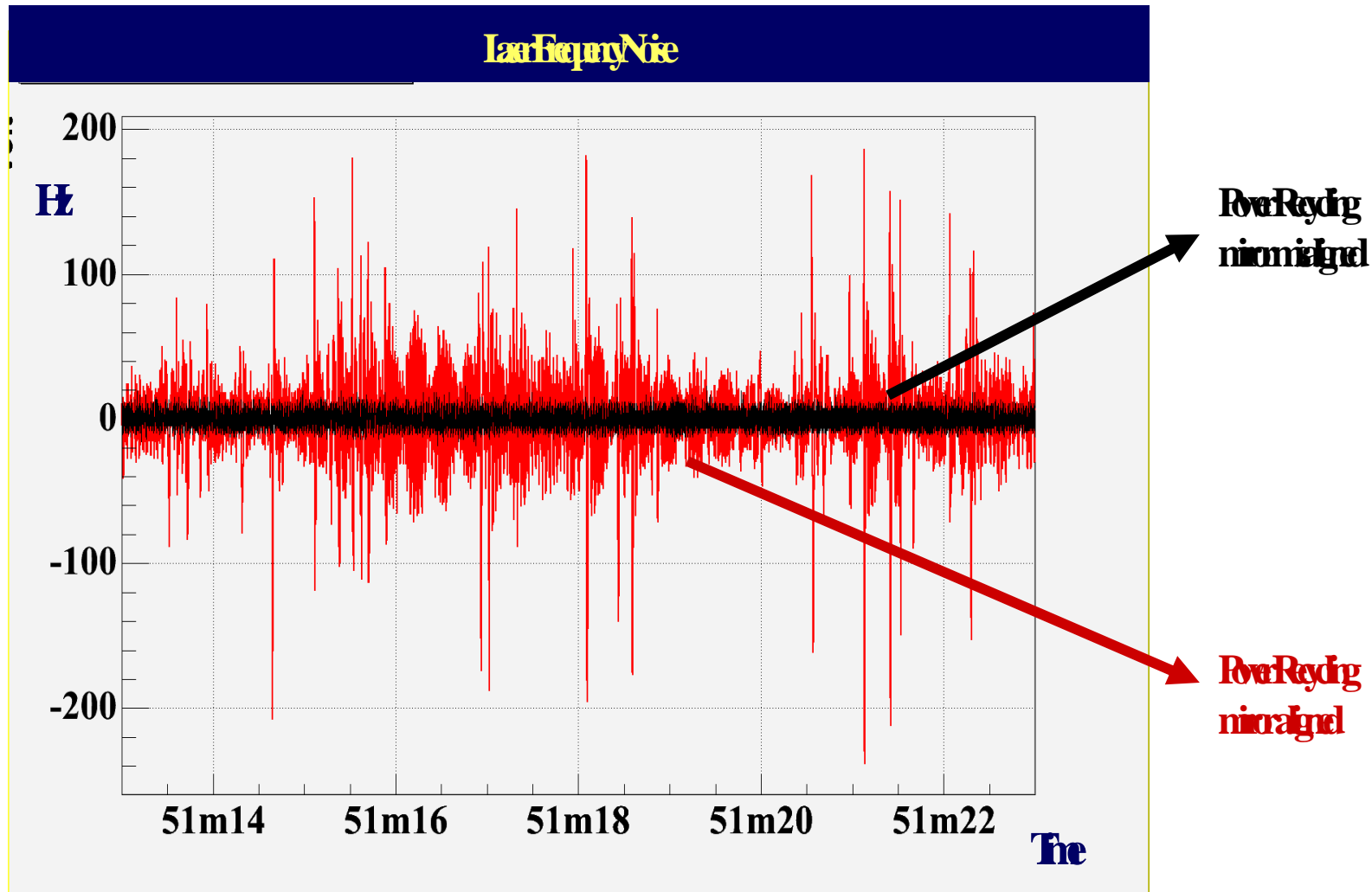


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# Hjónbænd

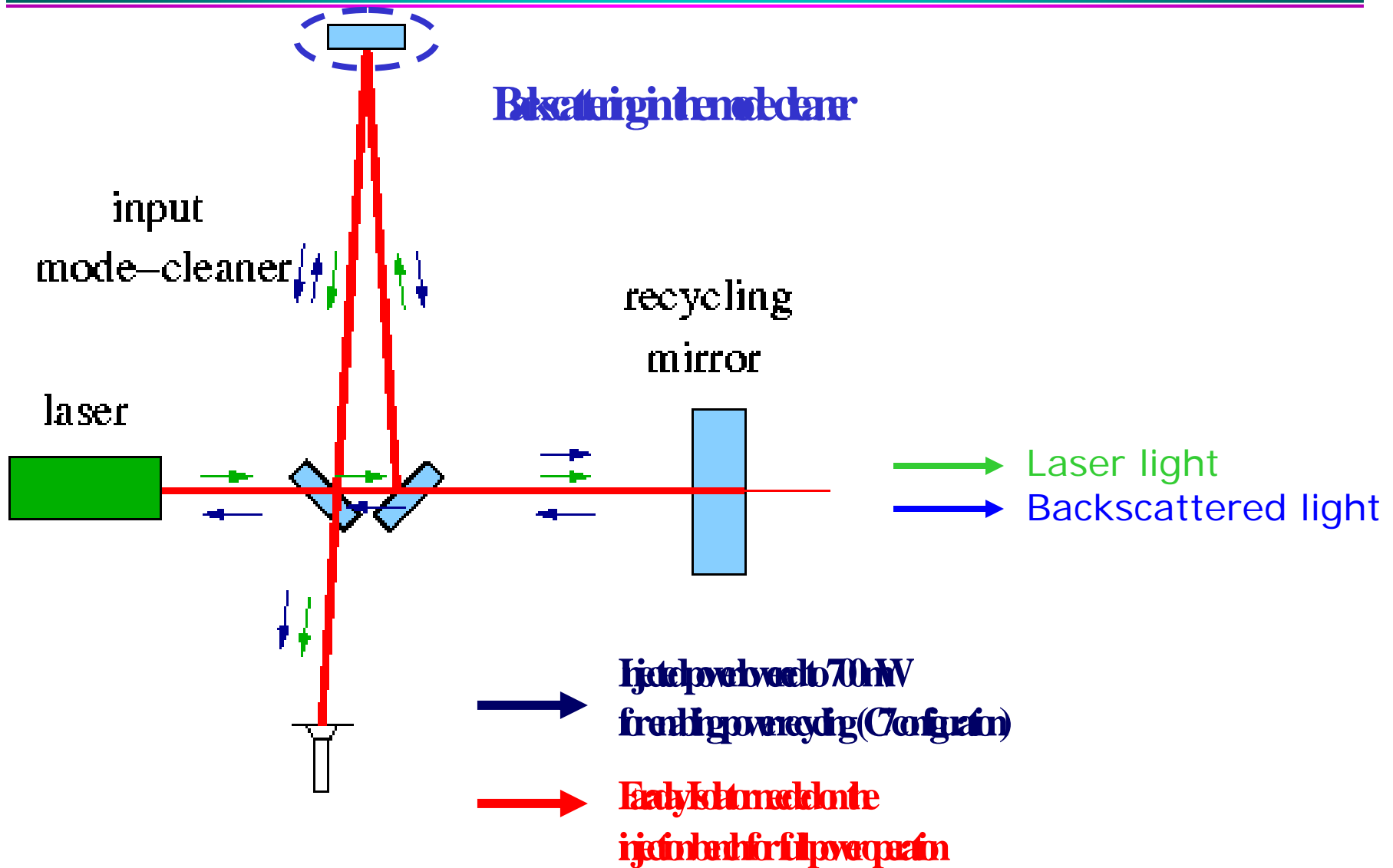


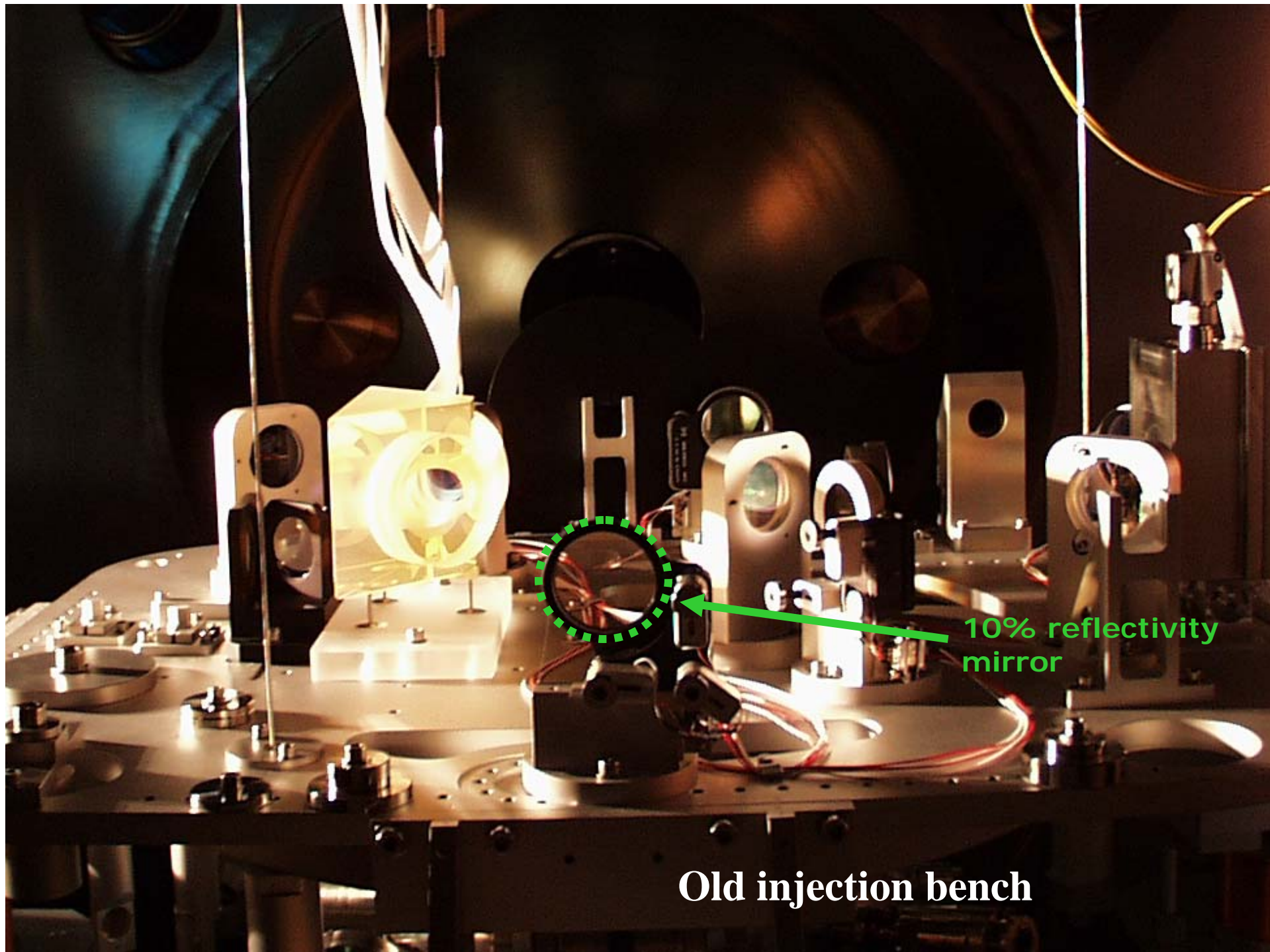
# Fringes in the interferometer





# Origin of the fringes





**Old injection bench**



# New injection bench

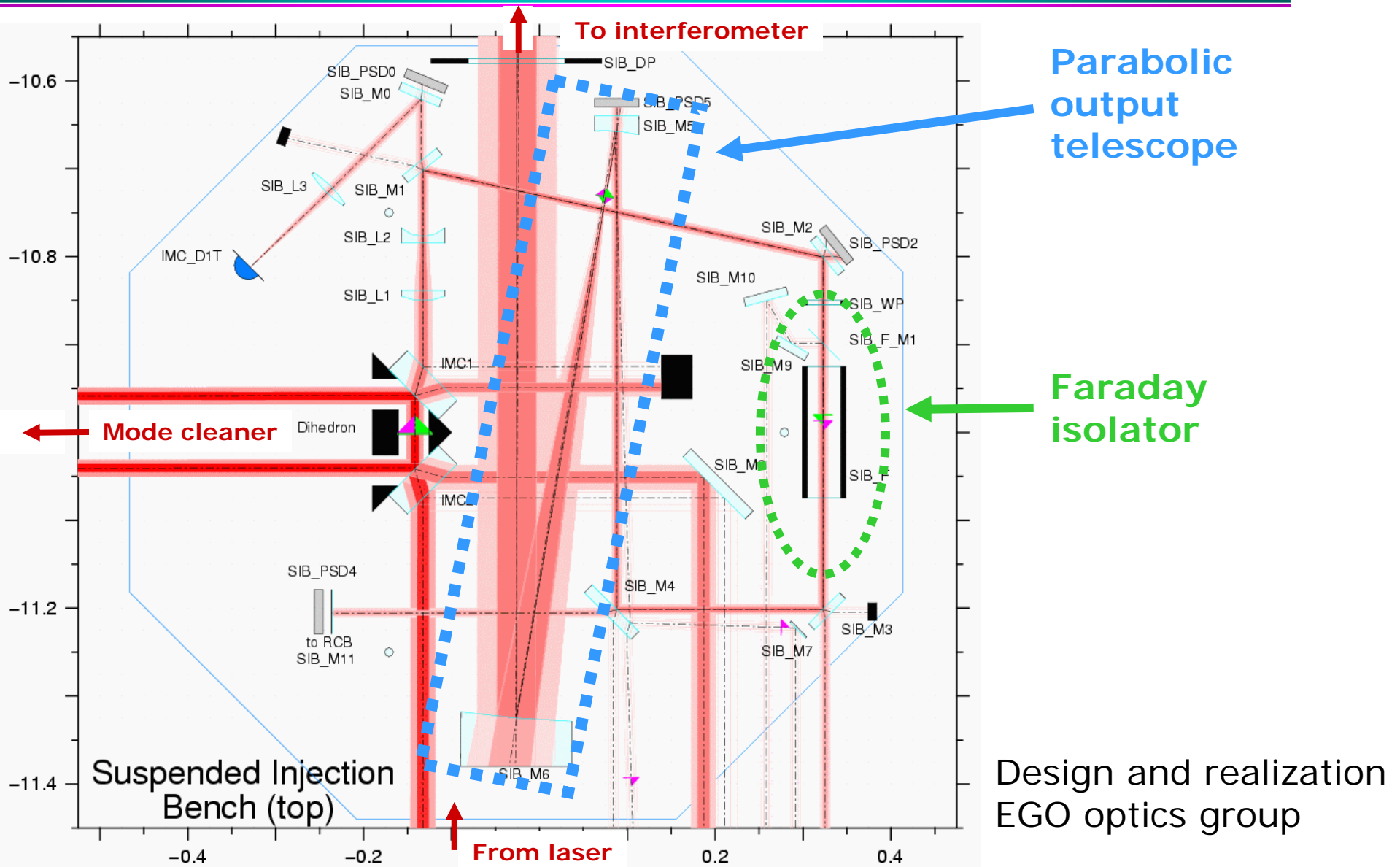
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## Meqients

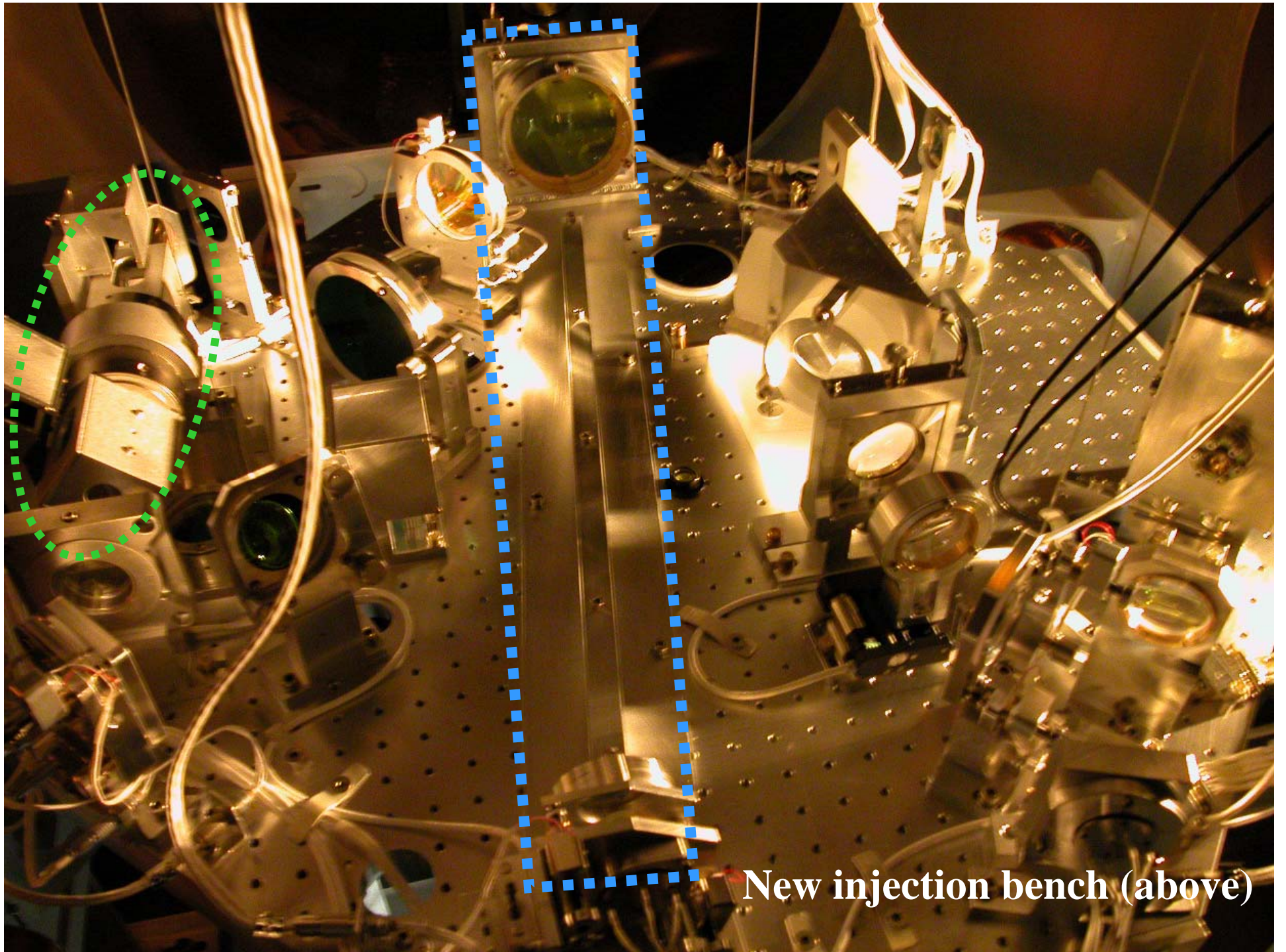
- Faraday isolator
- Parabolic output telescope
- Thinner suspension wires  
more suitable resoance frequencies



# New injection bench (OptoCad design)



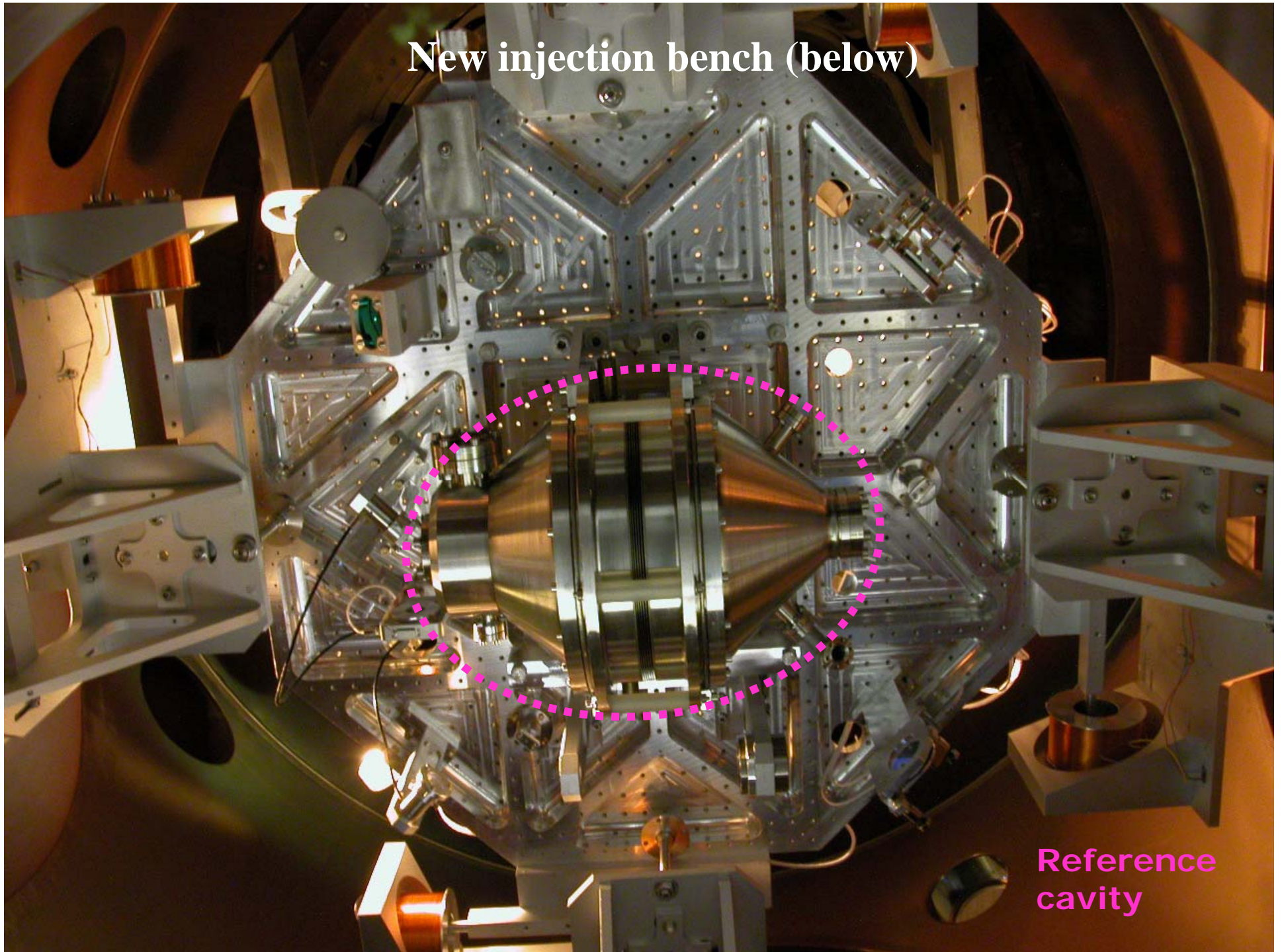
Design and realization  
EGO optics group



**New injection bench (above)**



New injection bench (below)



Reference  
cavity



## New injection bench status

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### **Basis**

installed  
aligned  
controlled

### **Beam**

output power 7 W (10x C7)  
matching: coupling into arm cavities 95-97%



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## Source: ~~www~~ ~~com~~ ~~is~~ ~~ing~~ ~~ad~~ ~~ies~~

- The variable finesse locking technique
- Mode cleaner mirror radiation pressure
- Suspension improvements
- New injection system autoalignment



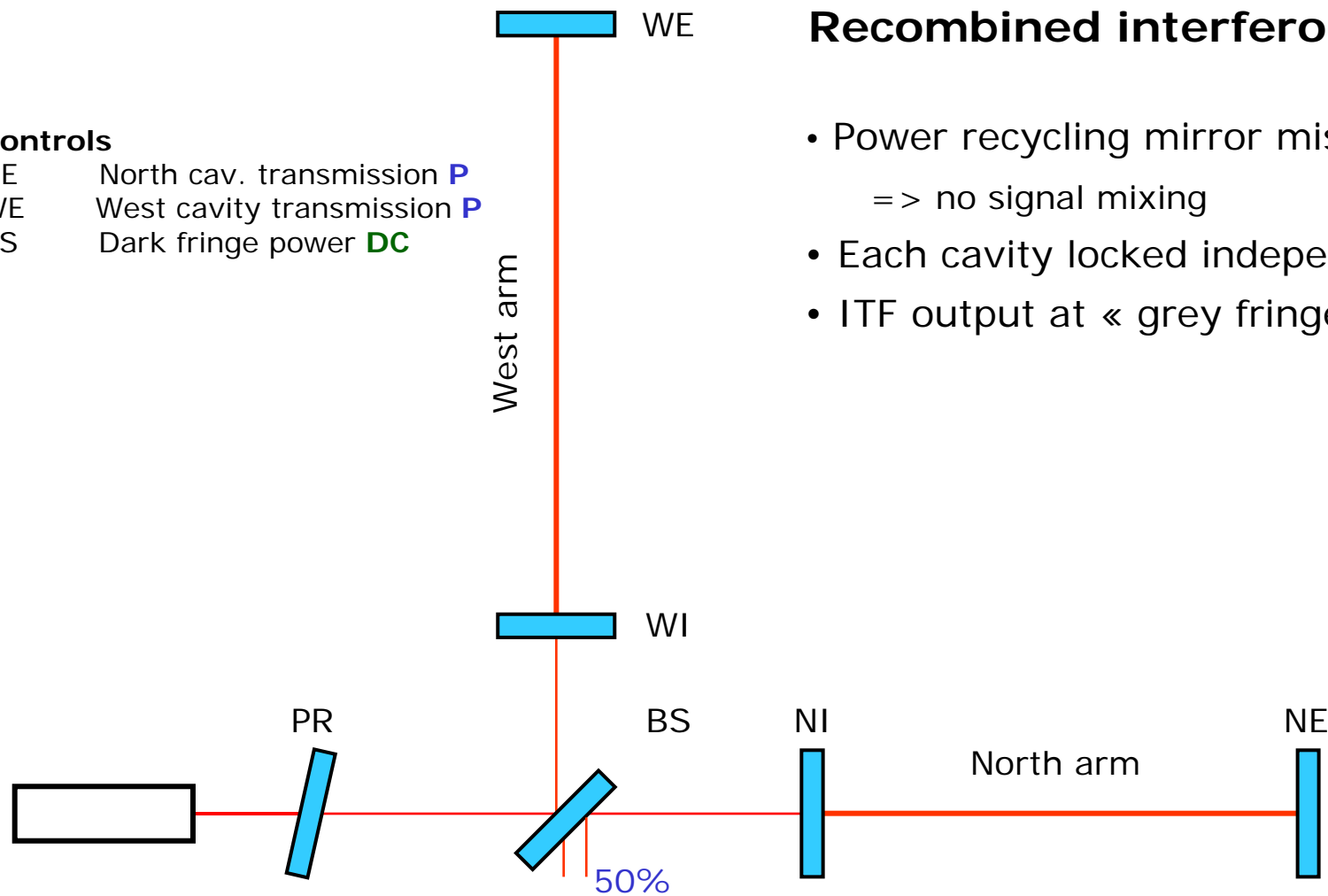
# Teambesprechungsprotokoll



# Locking: Step 1

## Controls

NE North cav. transmission **P**  
WE West cavity transmission **P**  
BS Dark fringe power **DC**



## Recombined interferometer

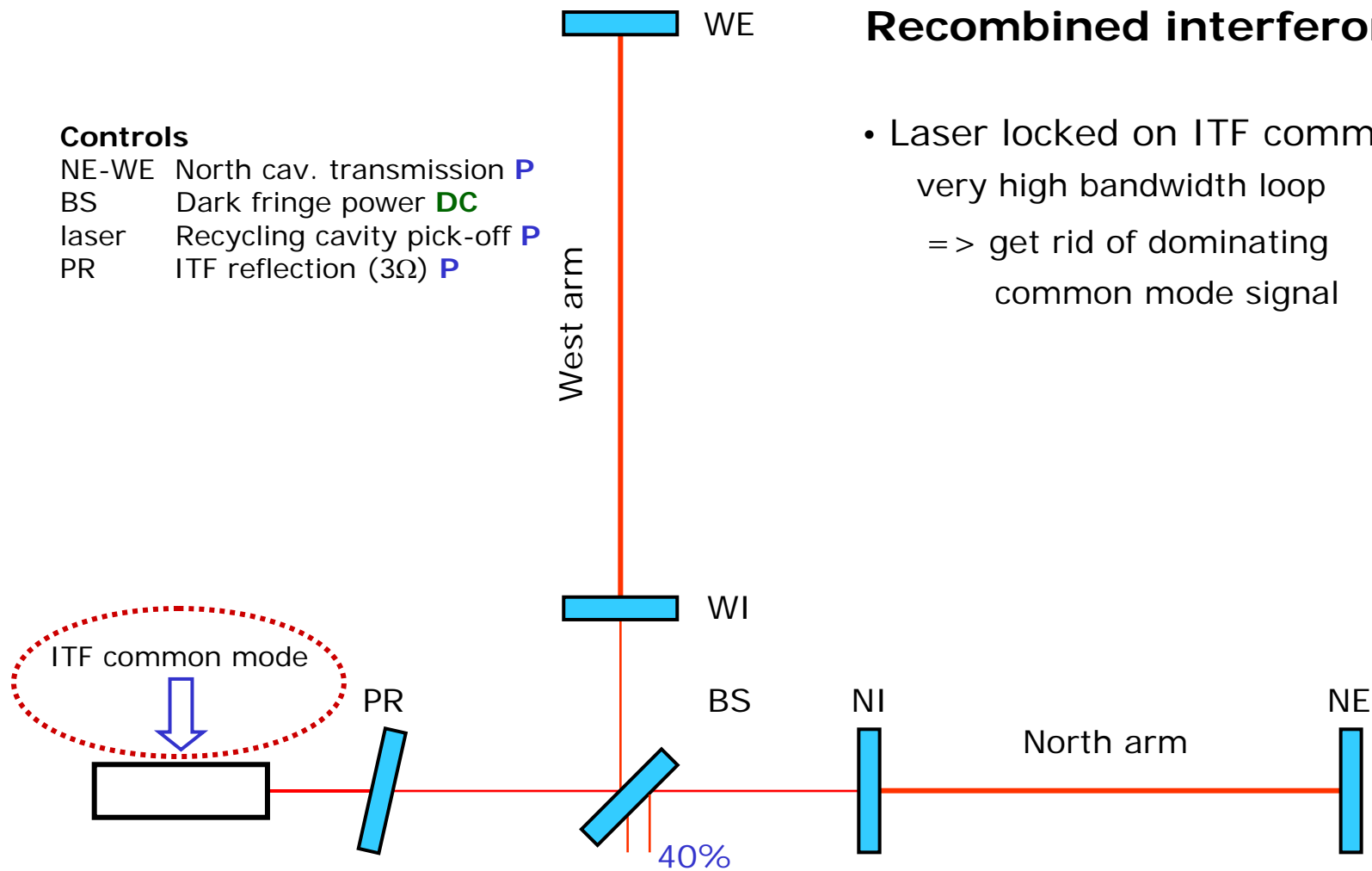
- Power recycling mirror misaligned  
=> no signal mixing
- Each cavity locked independently
- ITF output at « grey fringe » (50%)



# Locking: Step 2

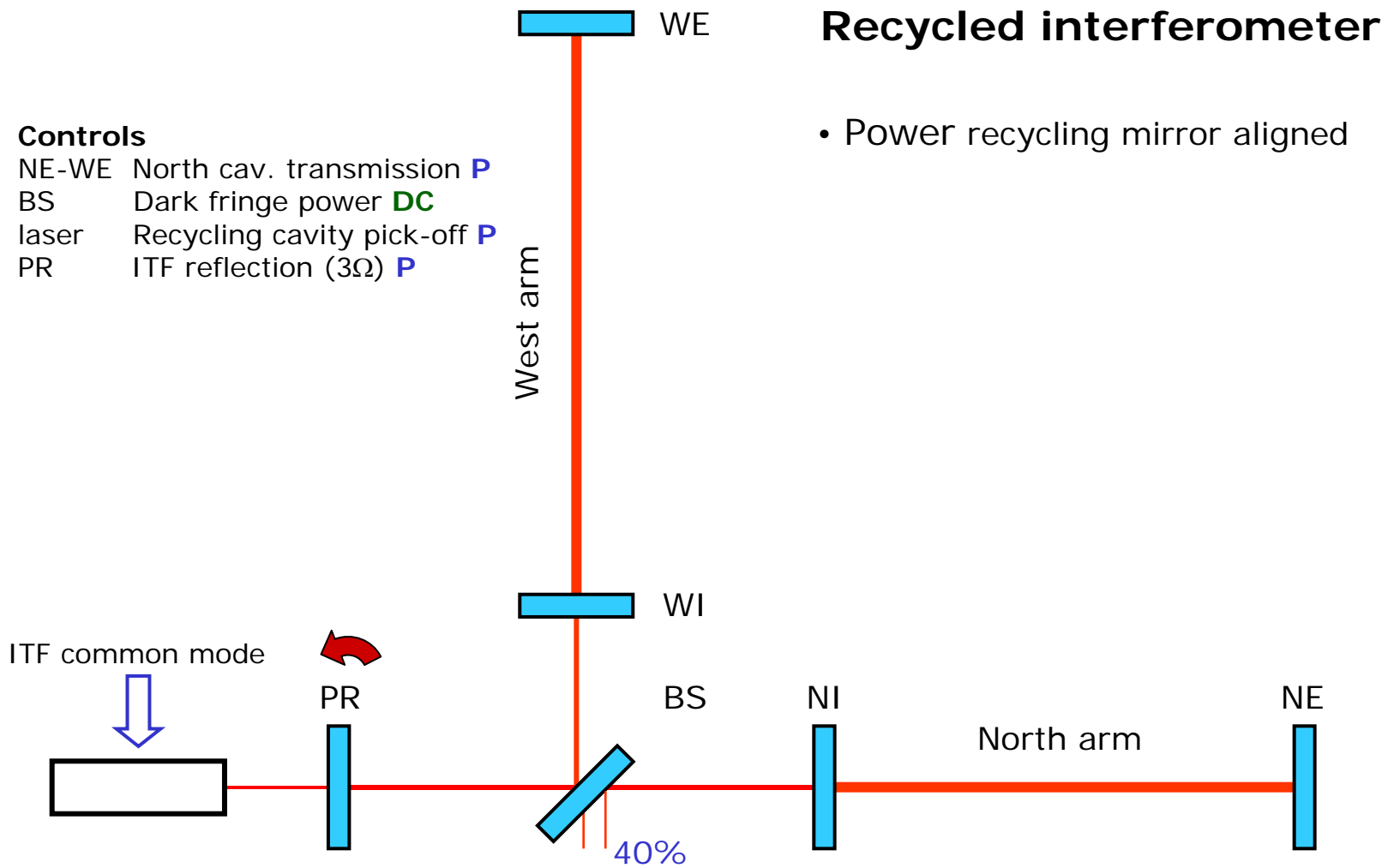
## Controls

NE-WE North cav. transmission **P**  
BS Dark fringe power **DC**  
laser Recycling cavity pick-off **P**  
PR ITF reflection ( $3\Omega$ ) **P**



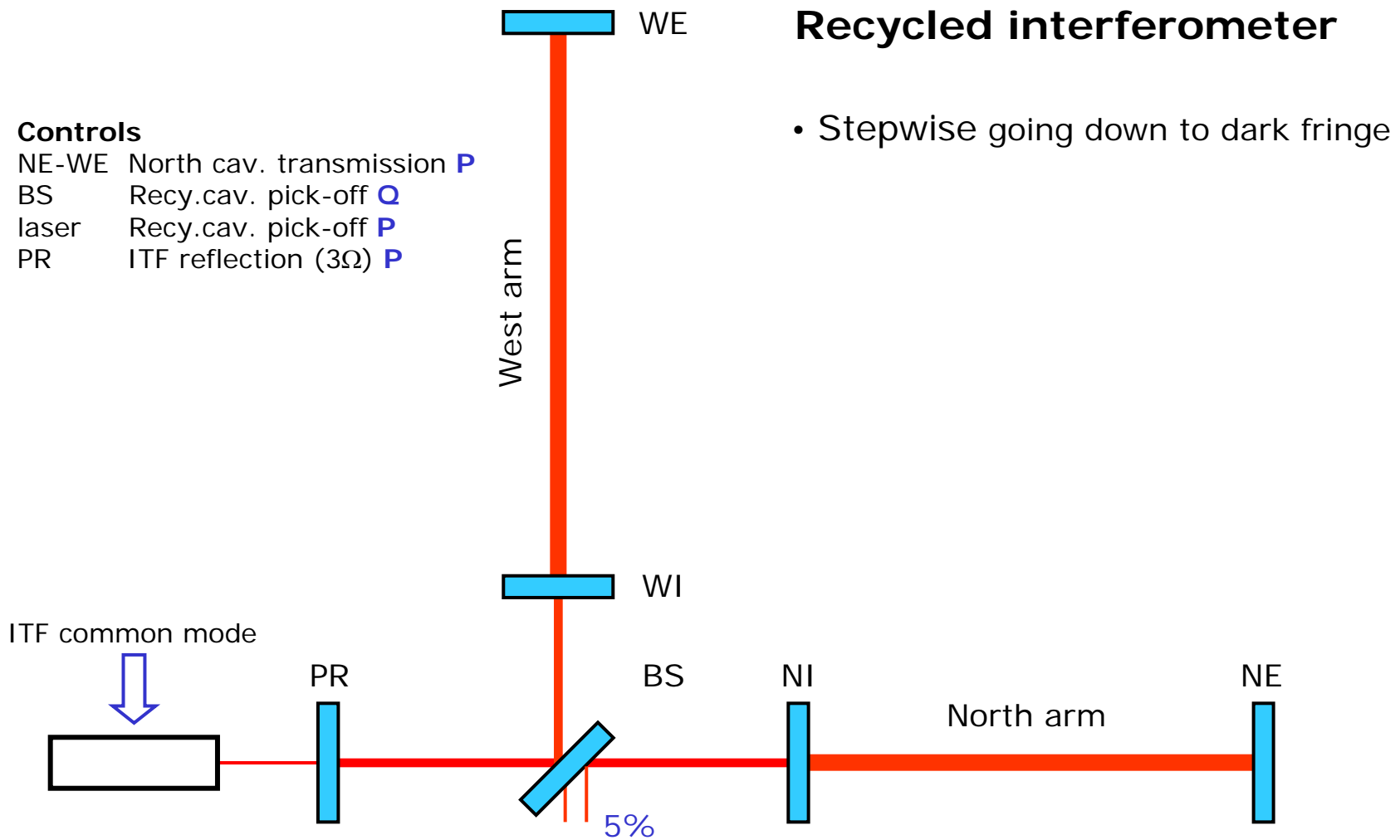


# Locking: Step 3





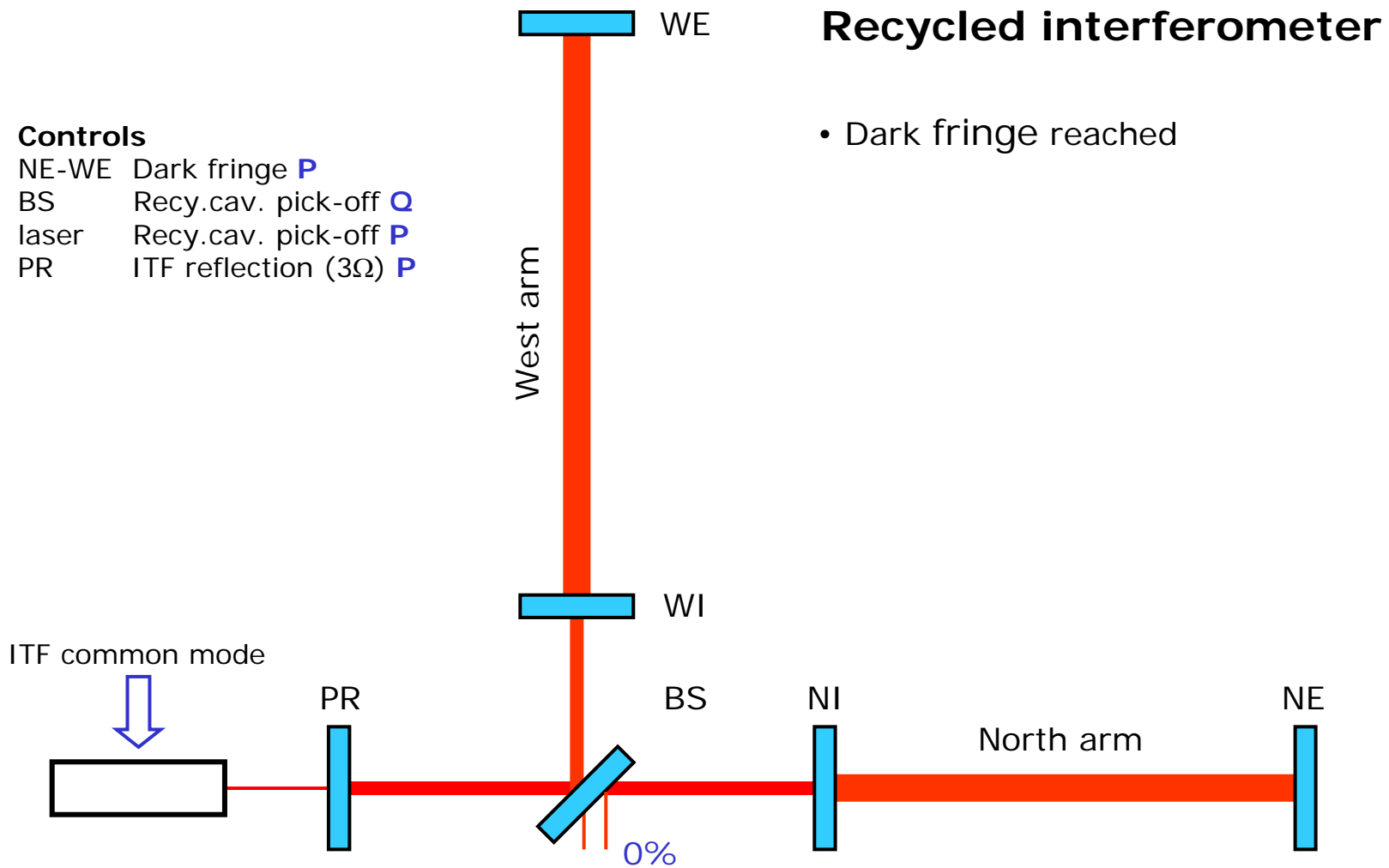
# Locking: Step 4







# Locking: Step 5



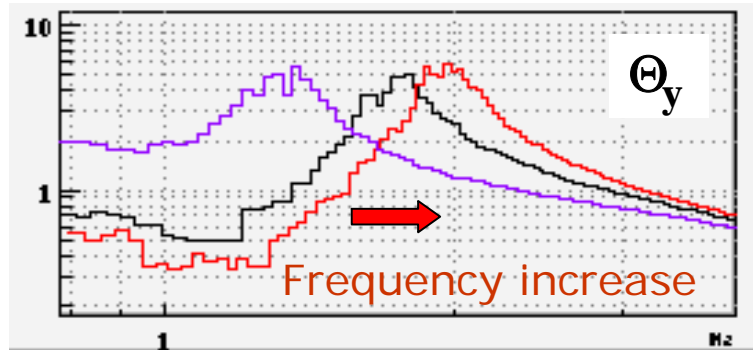


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# **Meldung: Kampagne**



# Mode cleaner mirror: radiation pressure effect

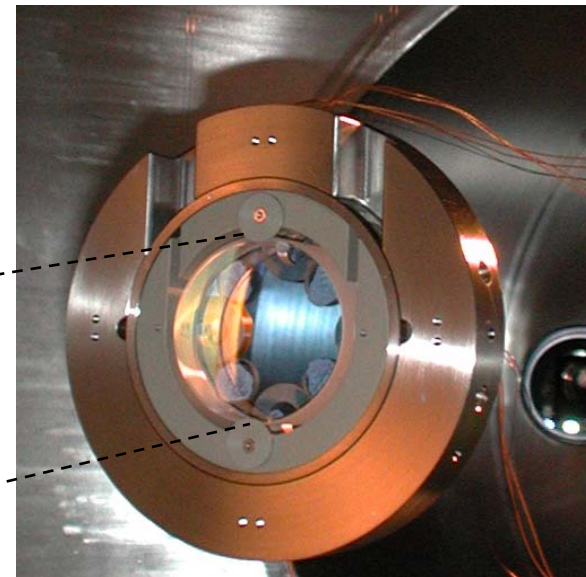
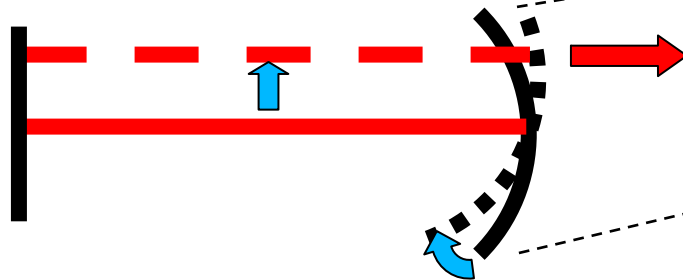


MC locked full power  
MC locked 60% power  
MC unlocked  
 $\Theta_x$ : 2.13 -> 1.97 Hz  
 $\Theta_y$ : 1.27 -> 2.0 Hz

Mode position changes with mirror alignment  
⇒ extra torque  
⇒ resonance frequency change

Problem:

- Autoalignment loops became unstable
- Corrector adaptation was needed



mirror dimensions: 30x80 mm  
360 grams



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# Reinigungsmaßnahmen

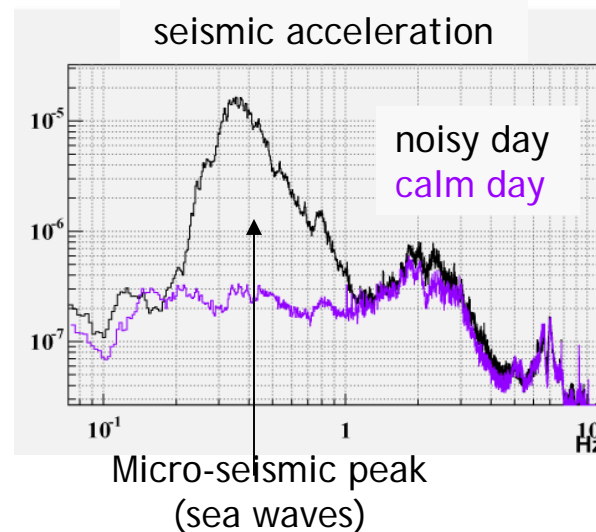
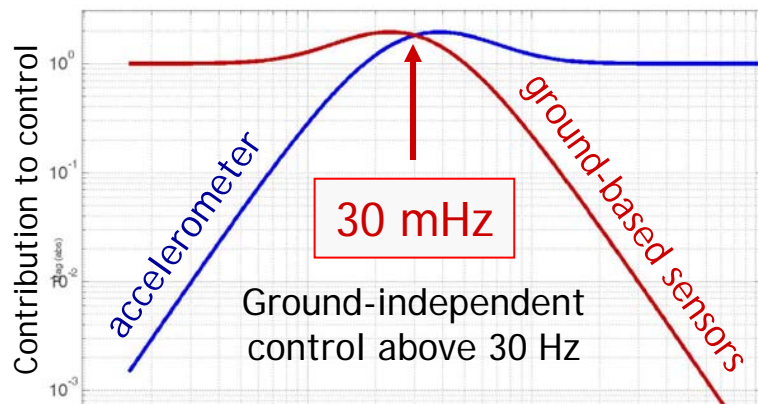


# Suspension: recent problems and solutions

## Mirror excitation with bad weather

⇒ less stable lock

## Changed suspension top stage control

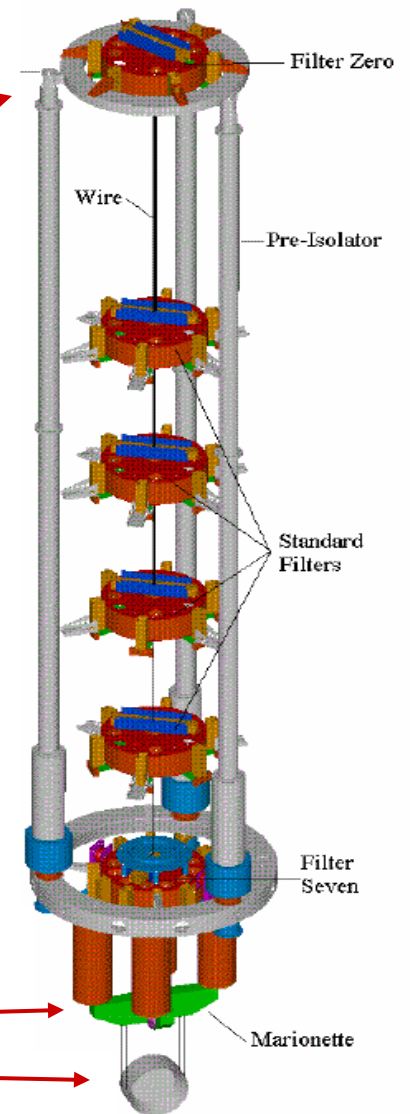


## DAC noise on mirror actuation coils

## Hierarchical control

Rearrange forces going to the suspension  
Switch to low-noise coil drivers

(See talk by G. Losurdo)





# **Navigationssysteme**

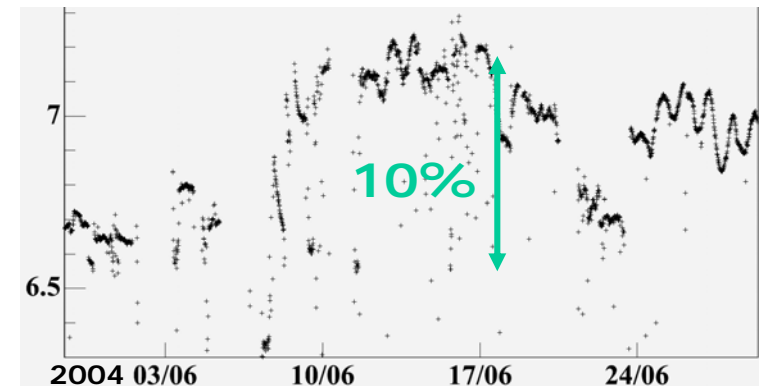


# Injection system autoalignment

## Old system

*Idea:* if IB is rigid, no misalignments  
(turned out not to be true)  
IB under local control

Mode cleaner transmitted power fluctuations



## New system

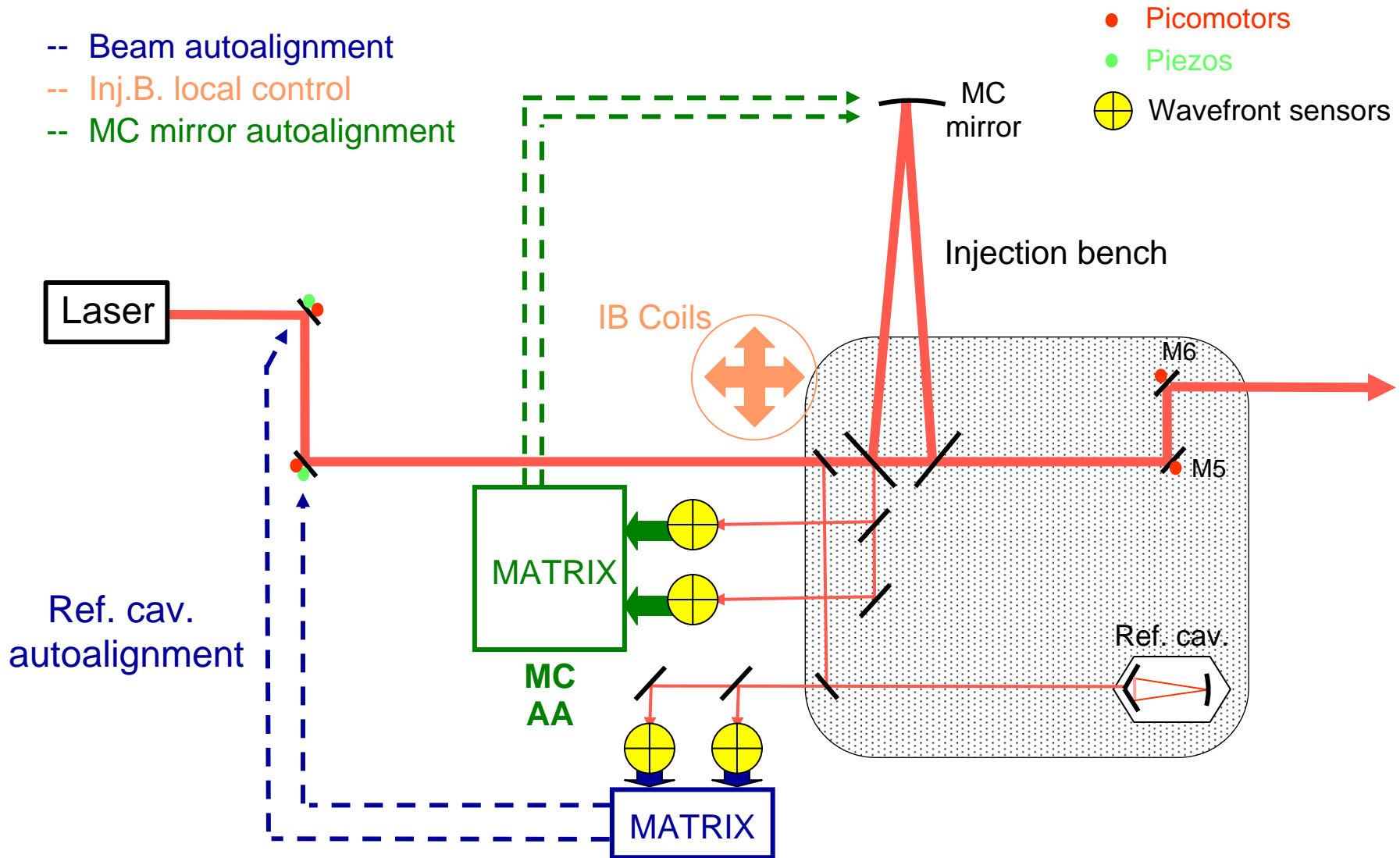
Beam aligned on fixed mechanical reference (external bench)  
Mode cleaner fully aligned on beam  
Autocentering of beam onto MC end mirror

## Attachment

Beam aligned on 3 km target



# Old injection system autoalignment layout



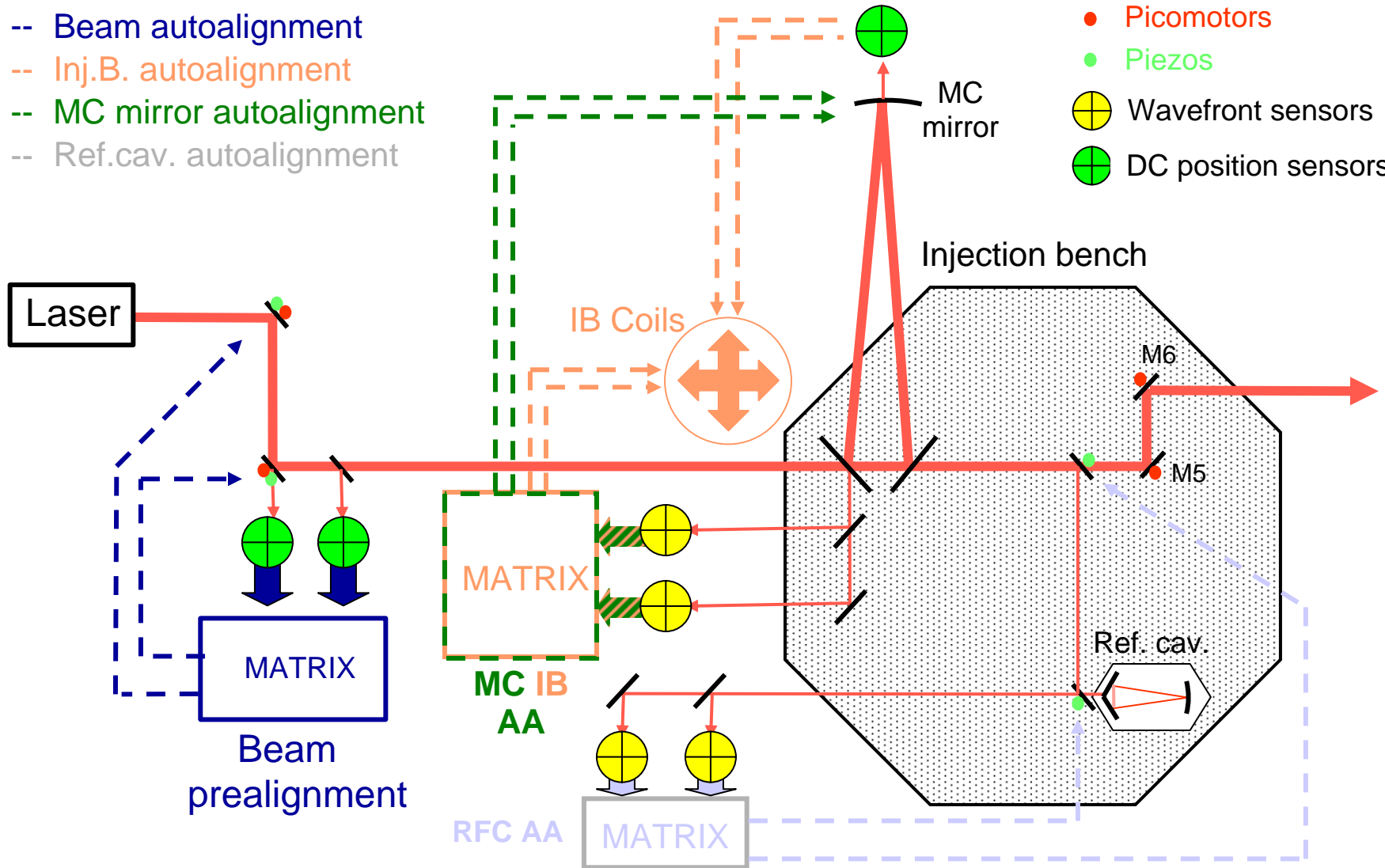




# New injection system autoalignment layout

- Beam autoalignment
- Inj.B. autoalignment
- MC mirror autoalignment
- Ref.cav. autoalignment

- Picomotors
- Piezos
- ⊕ Wavefront sensors
- ⊕ DC position sensors





**Globk**



## Present status

### Locking interface

1-2 hours locking periods  
or 5 minutes ...

### Thermal effects

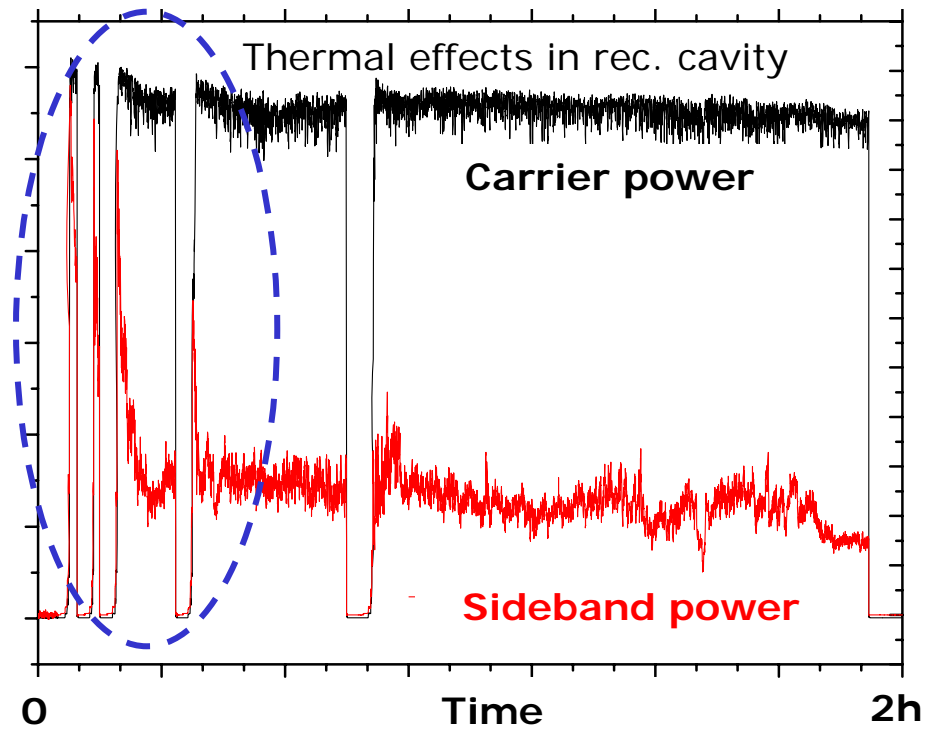
Affect recycling cavity stability  
(modulation sidebands drop)

### 30-50 Hz excess (skeephs)

Locking stability problems

### Alignment sensitivity?

Hasten full autoalignment (5/10 d.o.f. OK)





## Next steps

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### Imprecision

- Low frequency
  - control noise (alignment)
  - modulation frequency tuning (servo)
- Medium frequency
  - scattered light
  - acoustic shielding in laser lab
- High frequency
  - increased power
  - new low-noise HF modulation generator

### New Mirror

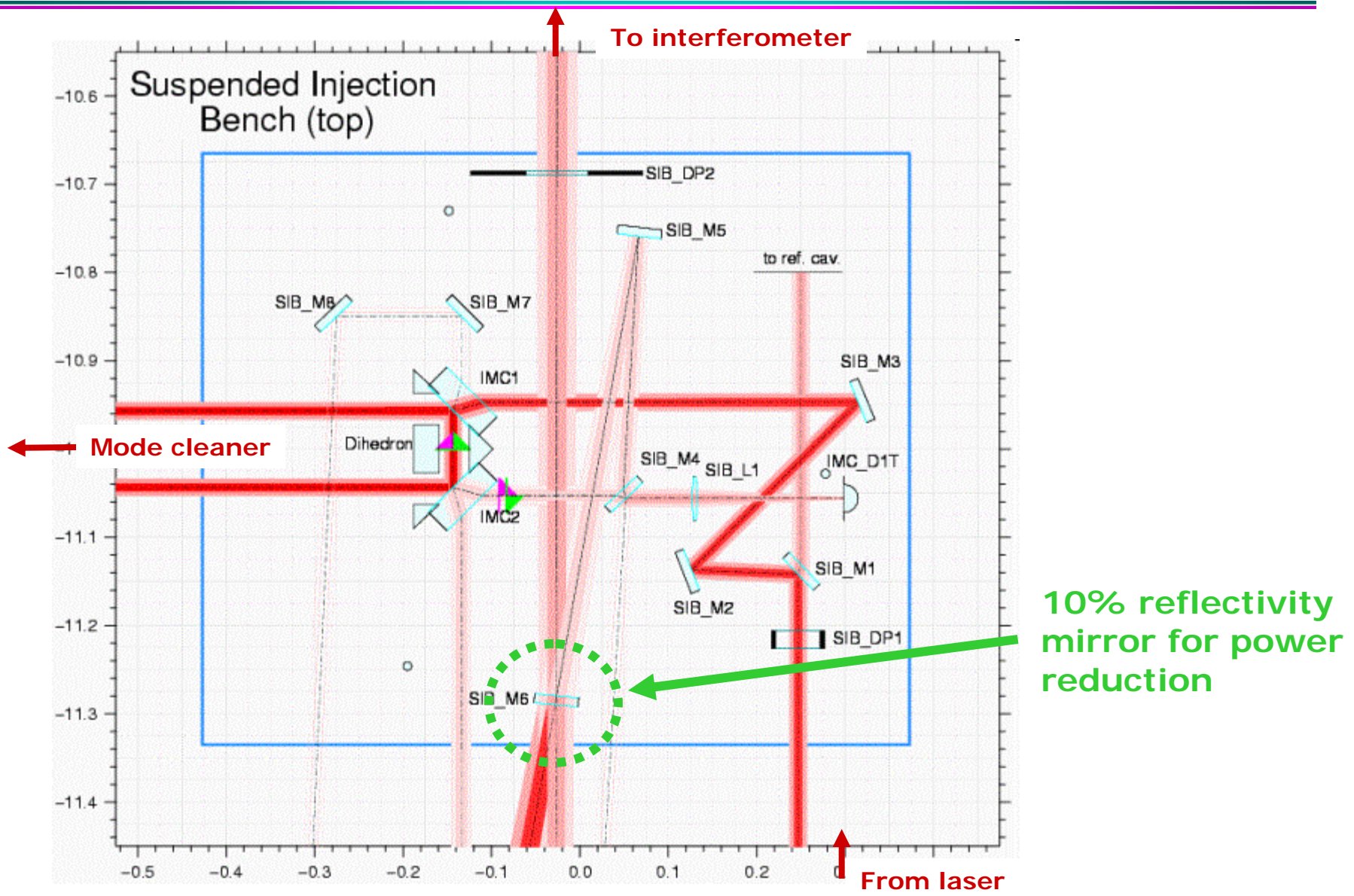
- better surface quality
- lower losses
- larger, heavier?
  - avoid radiation pressure problems
  - facilitate control

...

*End*



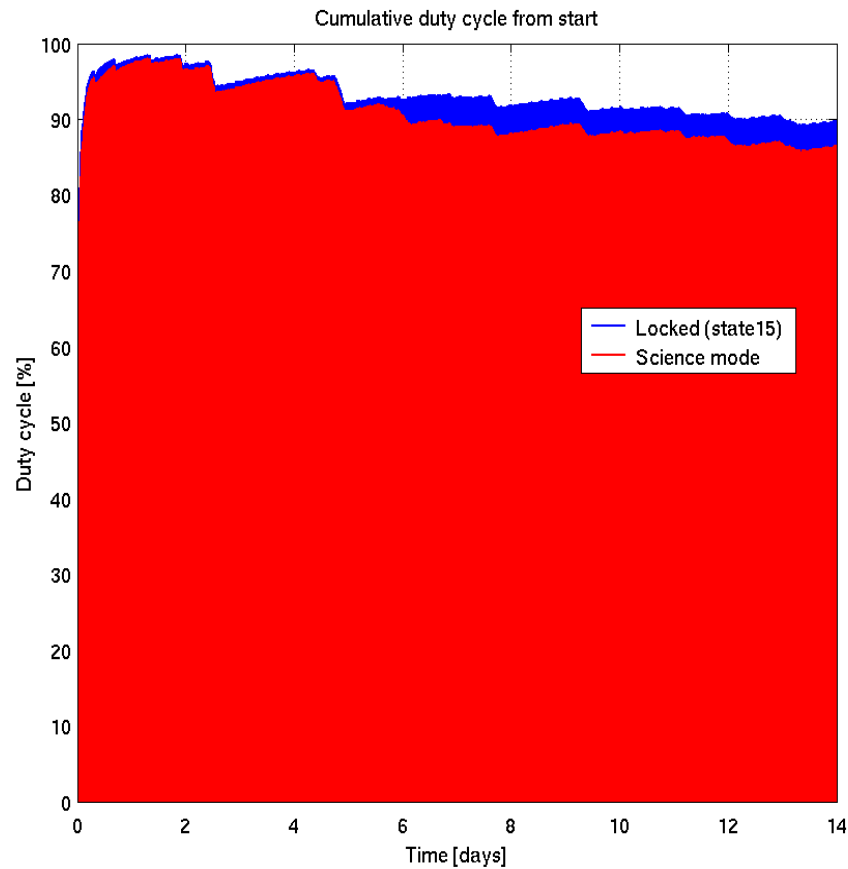
# Old injection bench (OptoCad design)





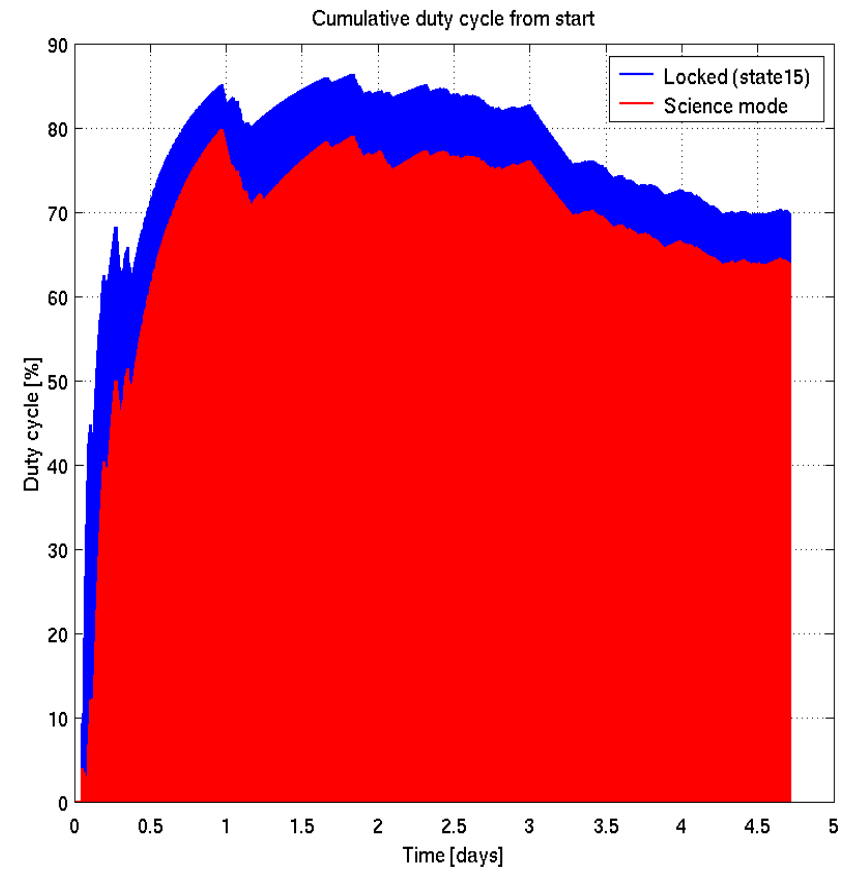
# Duty Cycle of last two commissioning runs

C6 (14 days Aug. 2005)



40 hours locked

C7 (5 days Sept. 2005)



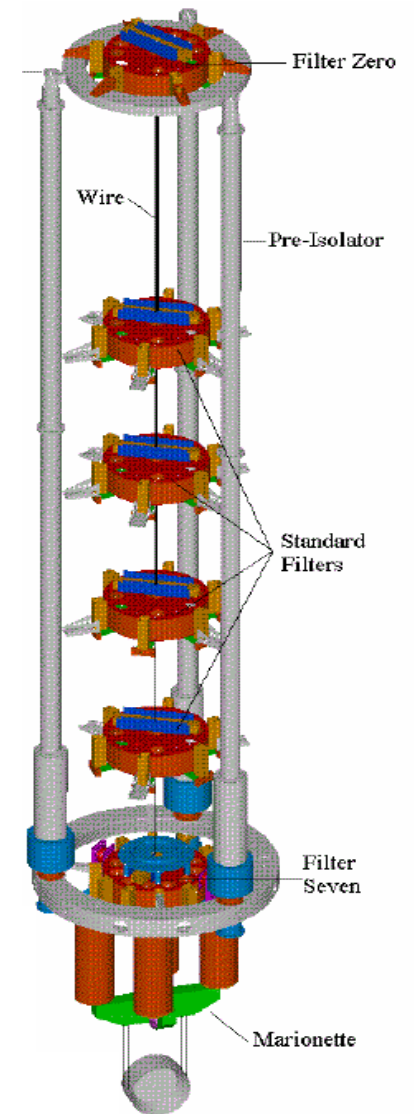
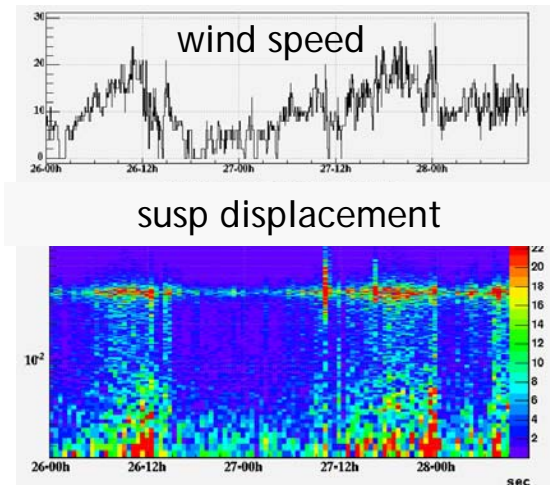
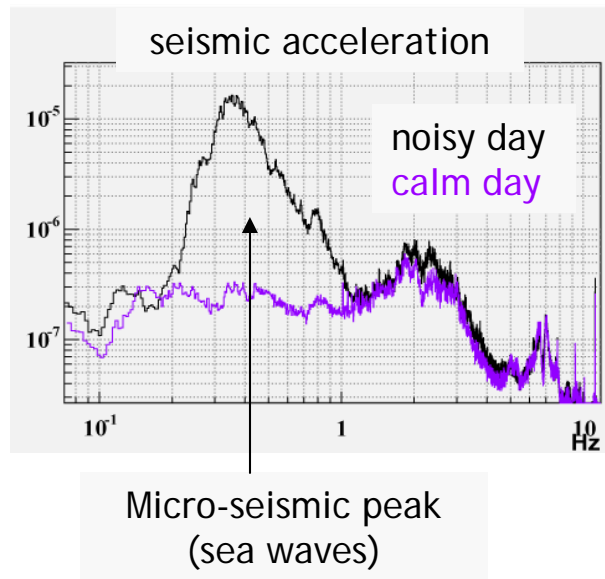
14 hours locked



# Suspension: recent problems

## 1. Micro-seismic conditions

=> more frequent unlocks when weather is bad



## 2. DAC micro-dynamics

High force needed for lock acquisition

=> bad DAC dynamics in steady conditions (low force)





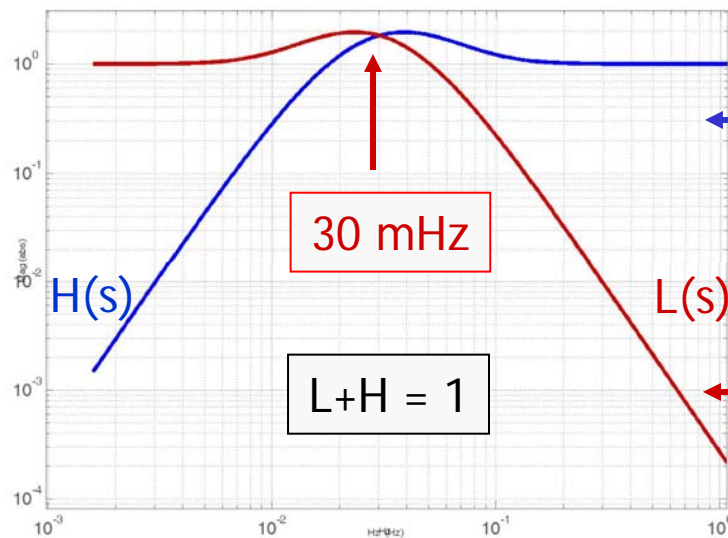
# Suspension: inertial damping modification

## Intention

- Inverted pendulum top platform is immobilized by
- H** accelerometers (inertial sensors)
- L** LVDT's (ground based) => introduce seismic noise

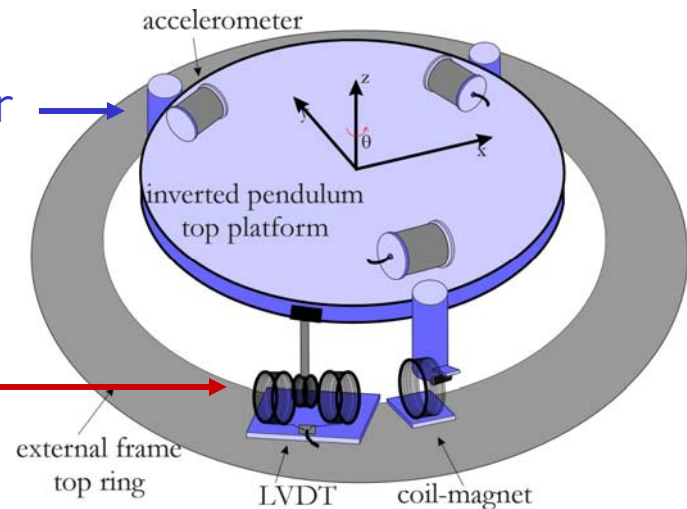
## Stim

- Reduced HF/LF cross-over frequency to 30 mHz
- Not so simple ... (see G. Losurdo's talk)



accelerometer

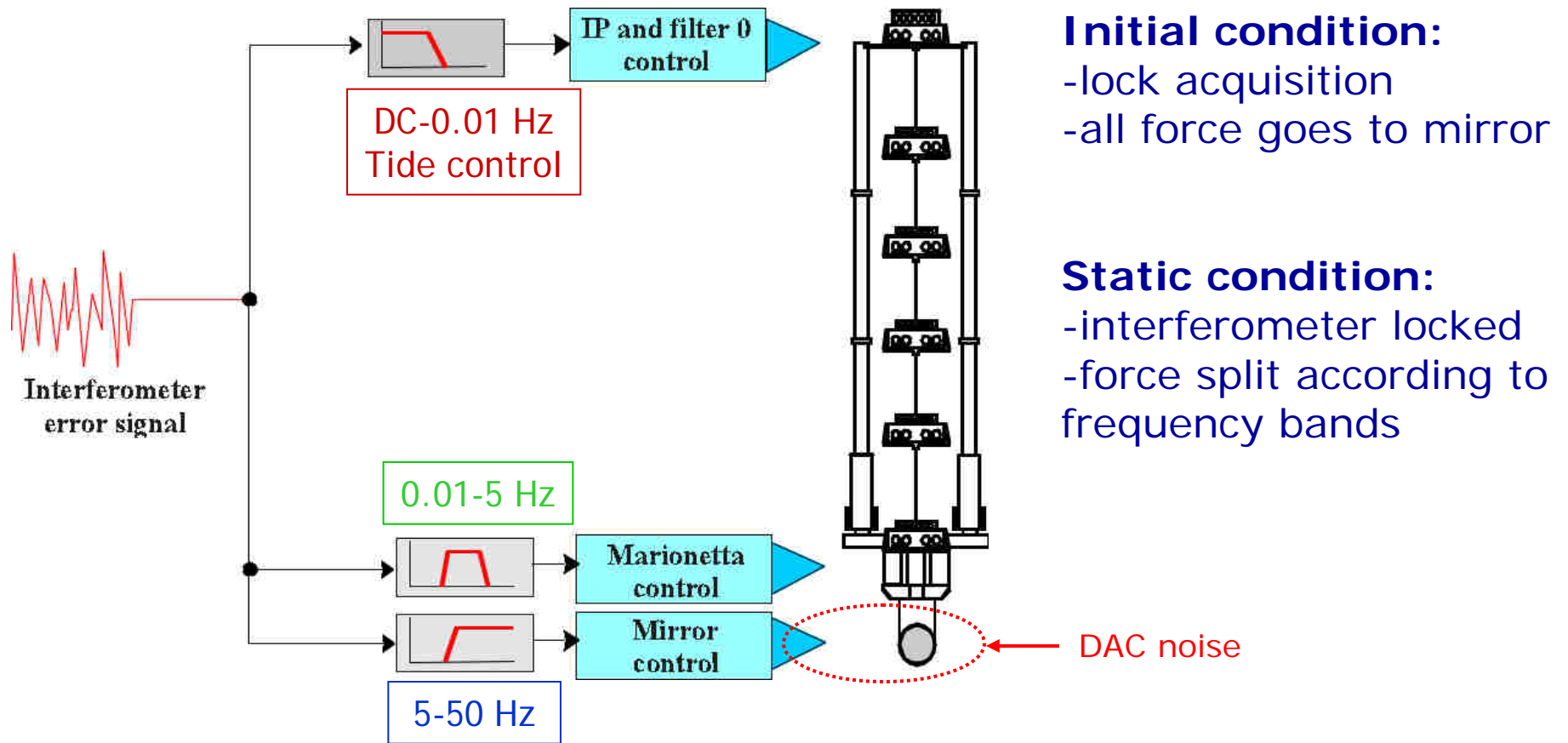
LVDT



LVDT = linear variable differential transformer



# Suspension: hierarchical control

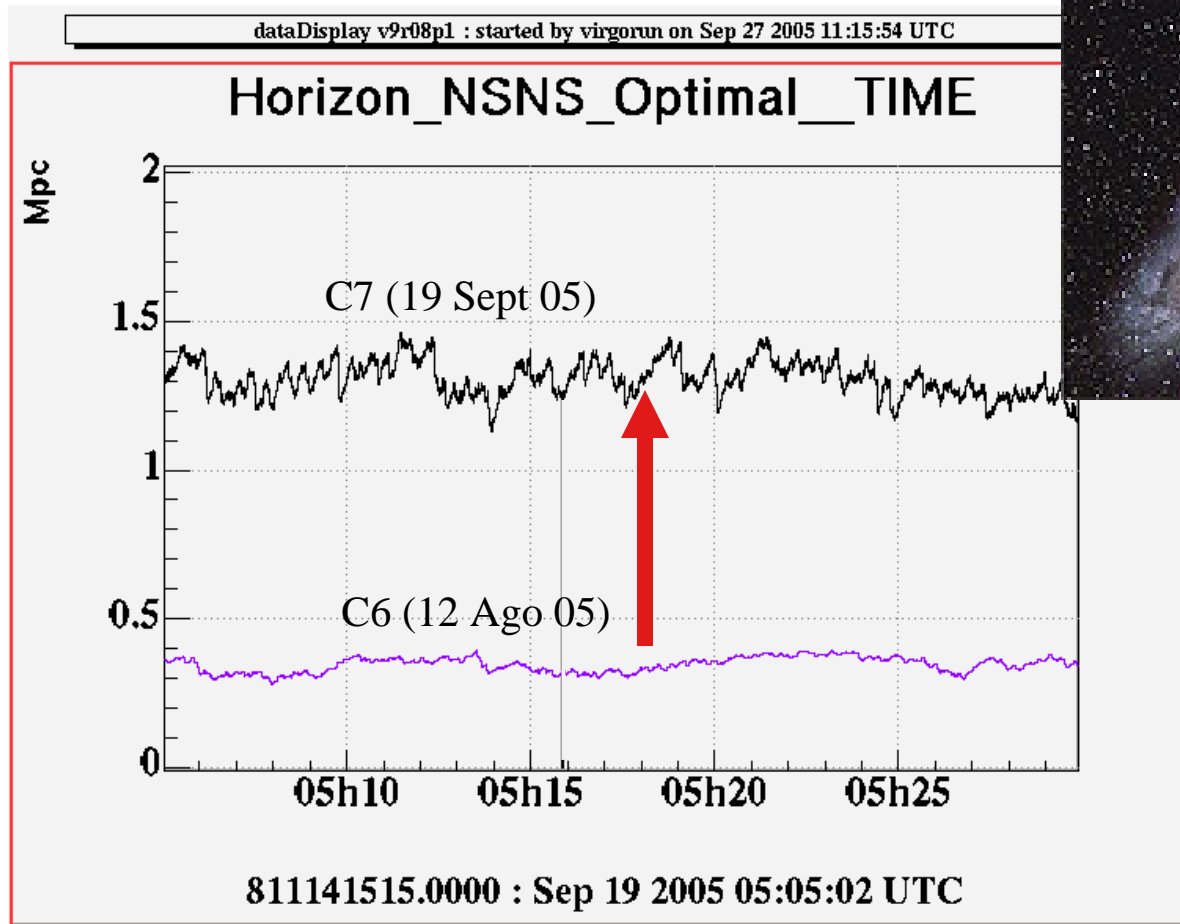
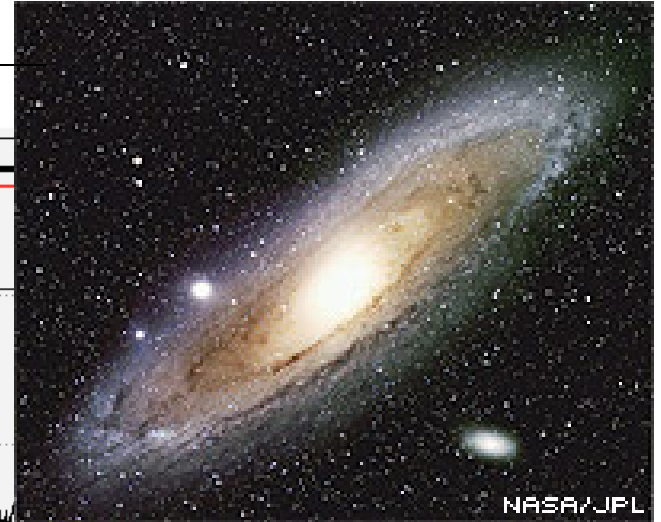


After lock acquisition: reduction of mirror actuator gain  
=> **reduction of DAC noise**



# 1.4 $M_{\odot}$ coalescence detection range

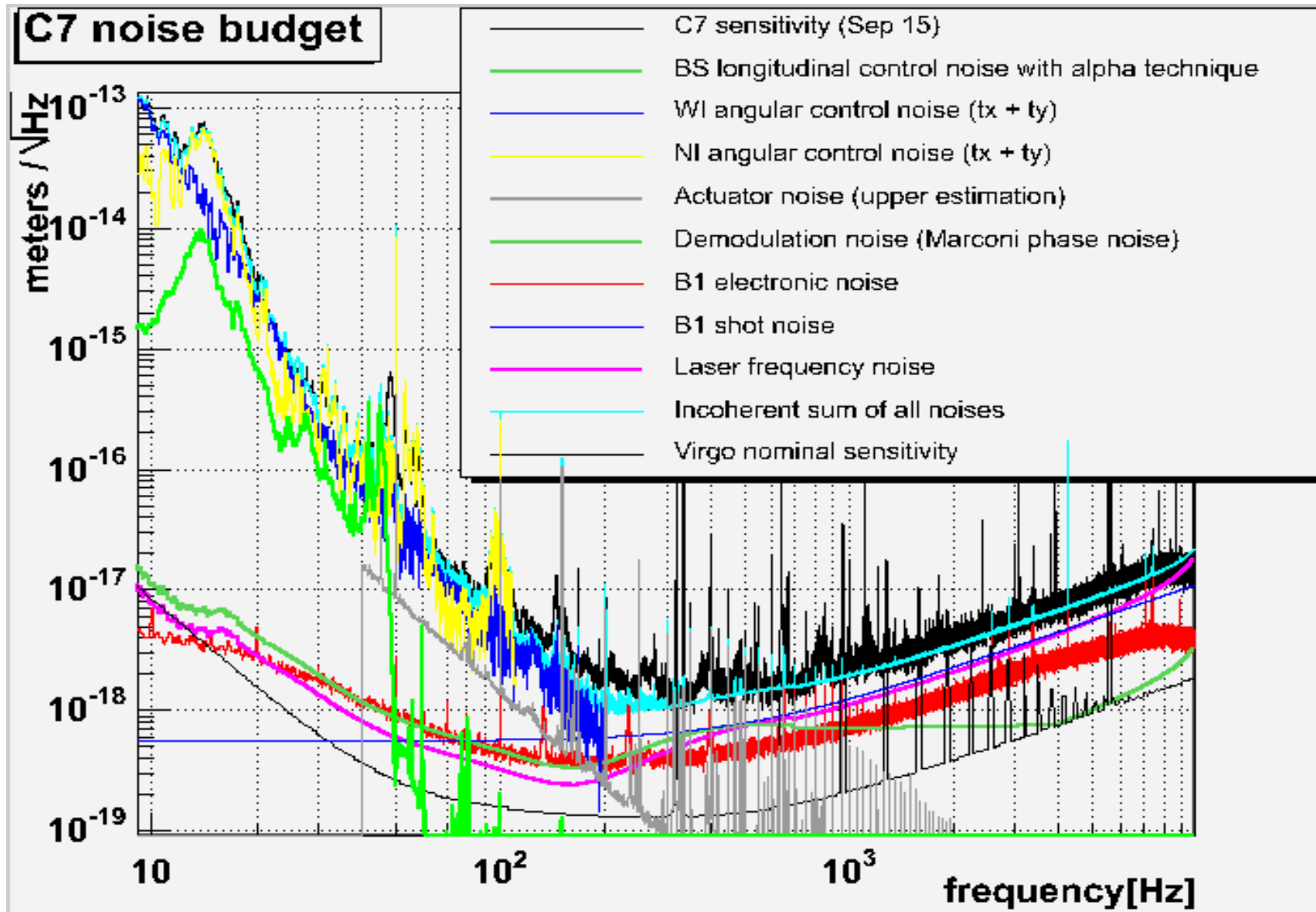
M31 (Andromeda) 700 kpc



Environmental disturbance re-injection through the control system



# C7 noise budget





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# Nitratig



# Mirror centering

## Nachbearbeitungsmaschinen

## Alignmentstechnik für Spiegel

Necessary for reducing alignment noise which limits us at low frequencies

## Techniken

Visual centering

Where possible...

Mirror shaking at natural resonance

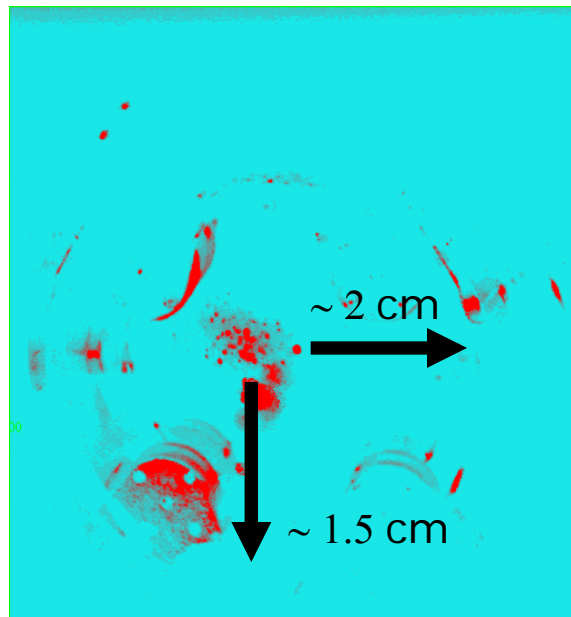
Find frequency in longitudinal motion (locking error signal)



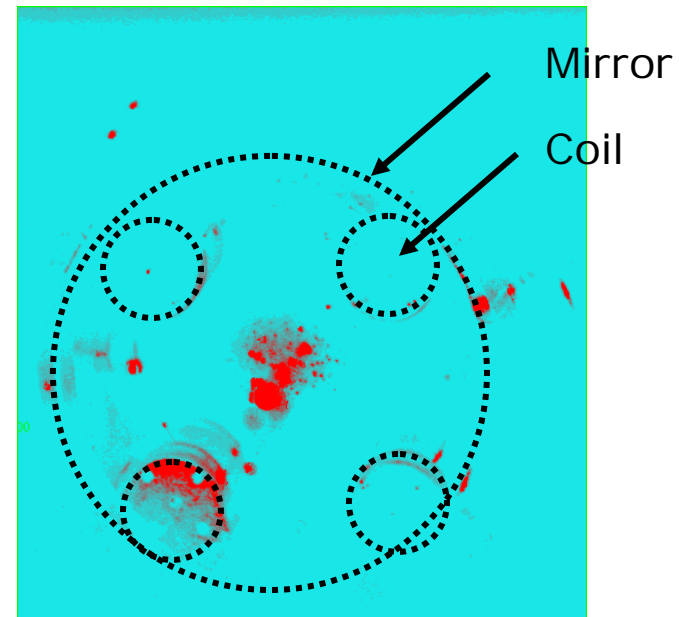


## Beam visualization

observation of diffused beam spot while moving mirror



❑ Before centering



❑ After centering