# Research activities at the Caltech 40m prototype

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LIGO-G1101178

# Outline

- Targets of the 40m prototype
- Length Sensing & Control
- Simulated Plant
- Active noise cancellation

# The 40m prototype

- Facility located on the campus of Caltech

- A fully instrumented engineering and control prototype of the aLIGO IFOs
  i.e. vac chambers, suspensions, MC and full IFO

- Current mission:

  To promote and accelerate commissioning of aLIGO

- Two main thrust areas:

  Optical configuration

  Control issues of the IFO

# Staus

- **Previous configruation (~2009):**
  - **Detuned RSE**
  - -> Lock Acquisition, Length Control, Noise coupling
  - **Detailed in Rob Ward's thesis (LIGO Doc P1000018)**

- **Upgrade of the 40m**
  - **Increase the resemblance to aLIGO**
  - **Upgrade installation**
  - -> started on Feb 2010, completed on Dec 2010

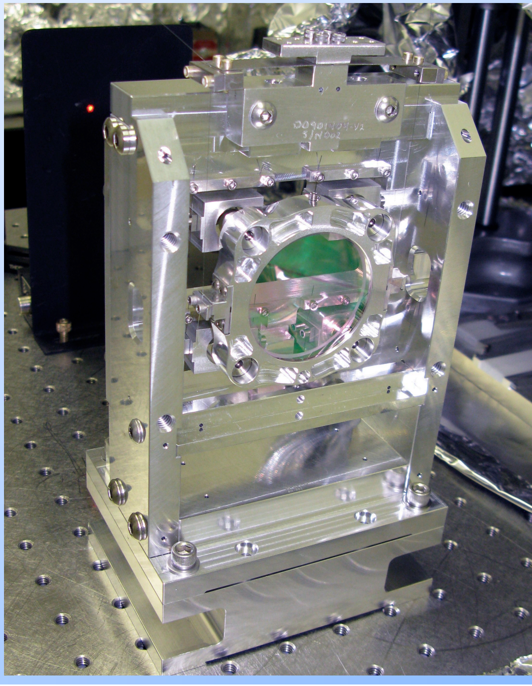
- **Achieved milestones**
  - **ALS (a.k.a. Green locking) demonstrated for an arm**
  - **Lock of the DRMI**

# New optical configuration

## Dual Recycled Michelson with Fabry-Perot arms

### - Length Sensing & Control: greater resemblance to aLIGO

- Dichroic TMs & 532nm beam injection for Arm Length Stabilization
  - Mimicking aLIGO : $F$(1064nm) = ~450, $F$(532nm) = ~100
- Small Schnupp asymmetry: $\Delta l$ = ~3cm
  - Similar to the aLIGO's 5cm
  - Adjusted such that the 55MHz sidebands reach the dark port
- Longer power and signal recycling cavities (PRC, SRC)
  - PRC =6.8m, SRC=5.4m
  - Folded by ANU Tip-Tilt suspensions
- **Primarily "no detuning"**



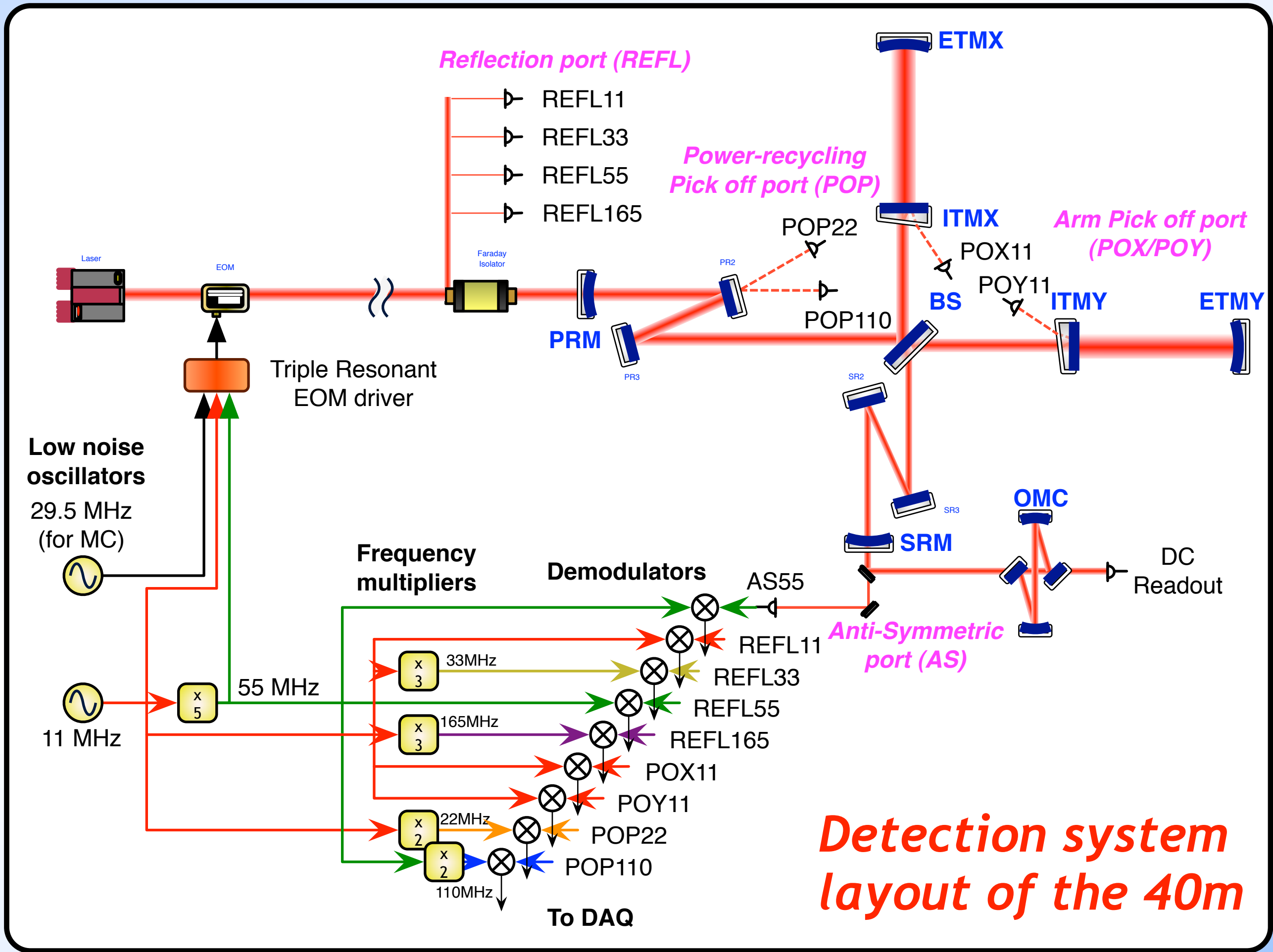
- Smaller test masses with SOS suspensions
  - 3 inch dia. x 1 inch thick.
  - Same DC radiation pressure effect as in aLIGO
    - mass 0.25kg/40kg vs power 3kW/850kW

# Length Sensing and Control

## 2 phase mod. (no MZ) and demods at harmonic freqs

### - 11MHz and 55MHz modulation sidebands

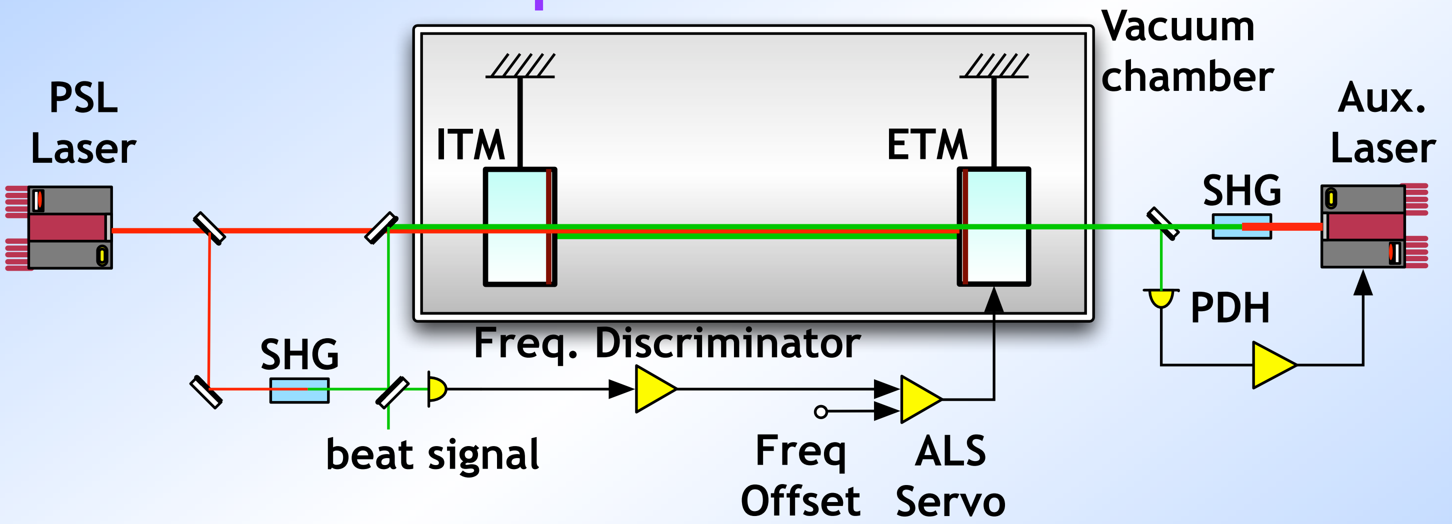
3rd harmonic demod. for robust extraction of the signals
2nd harmonic demod. for sideband power monitor

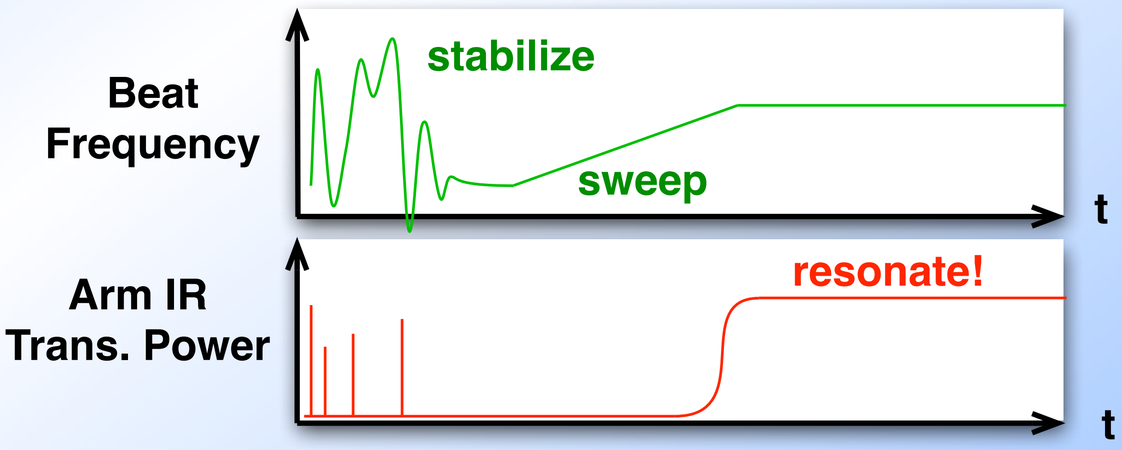


# Arm Length Stabilization (ALS)

## Stabilizes the arm lengths before the lock

- Utizing beat notes between 532nm beams
- Stabilizes arm fluctuation: from ~1um (~10MHz) to ~100pm (~1kHz)
- For deterministic lock acquisition

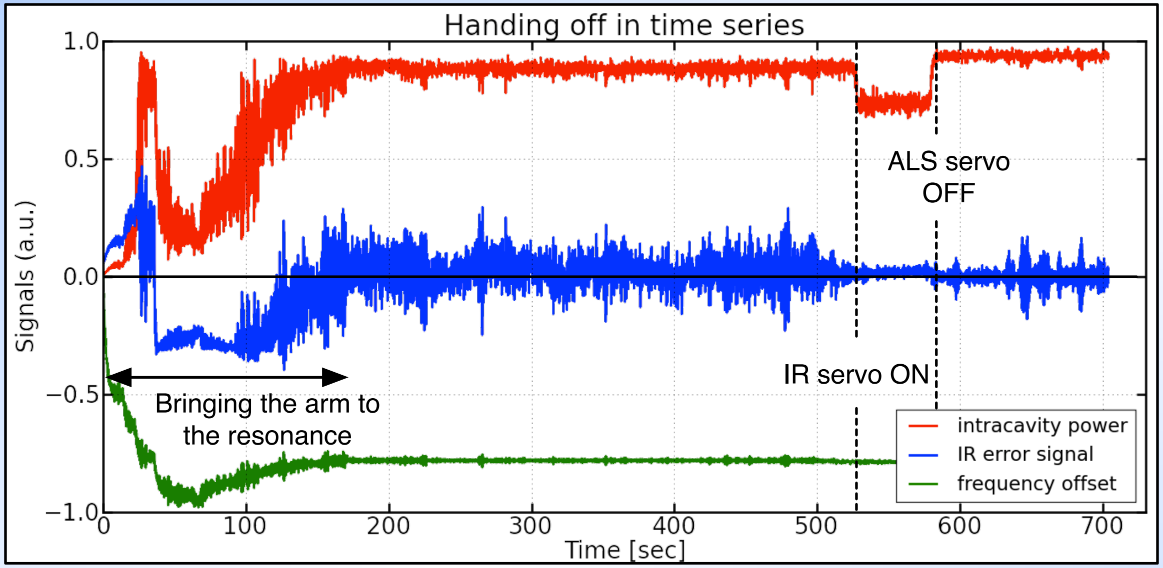


# ALS: Demonstration

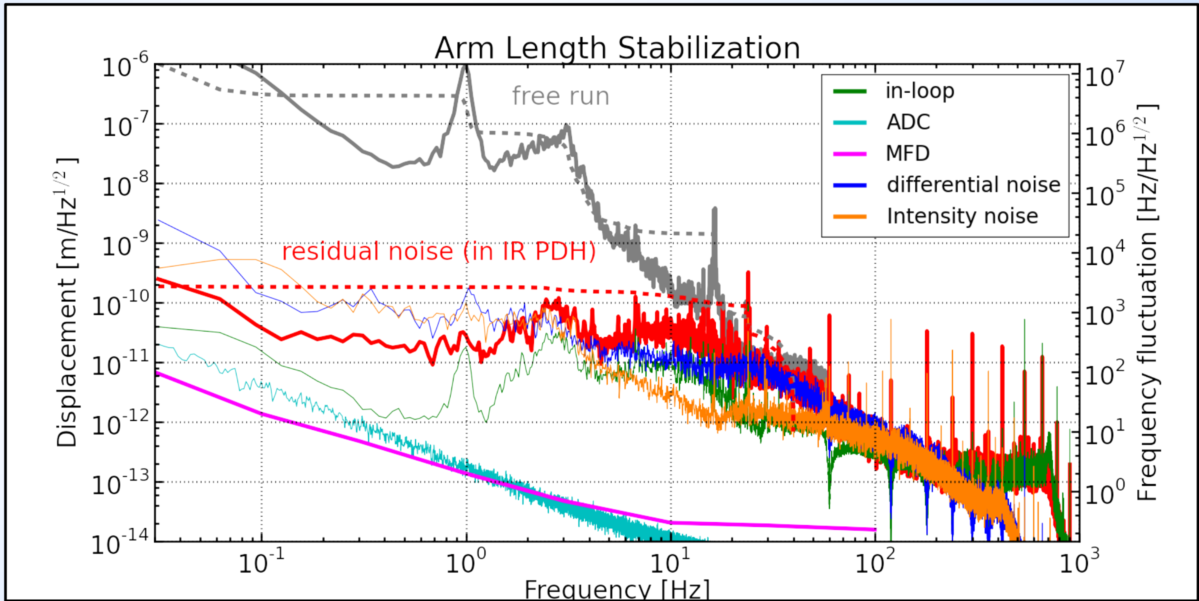
**Beat freq sweep**

The transmission (red) is kept at the top of the resonance without locking with the IR beam (100s-520s)




**ALS noise budget**

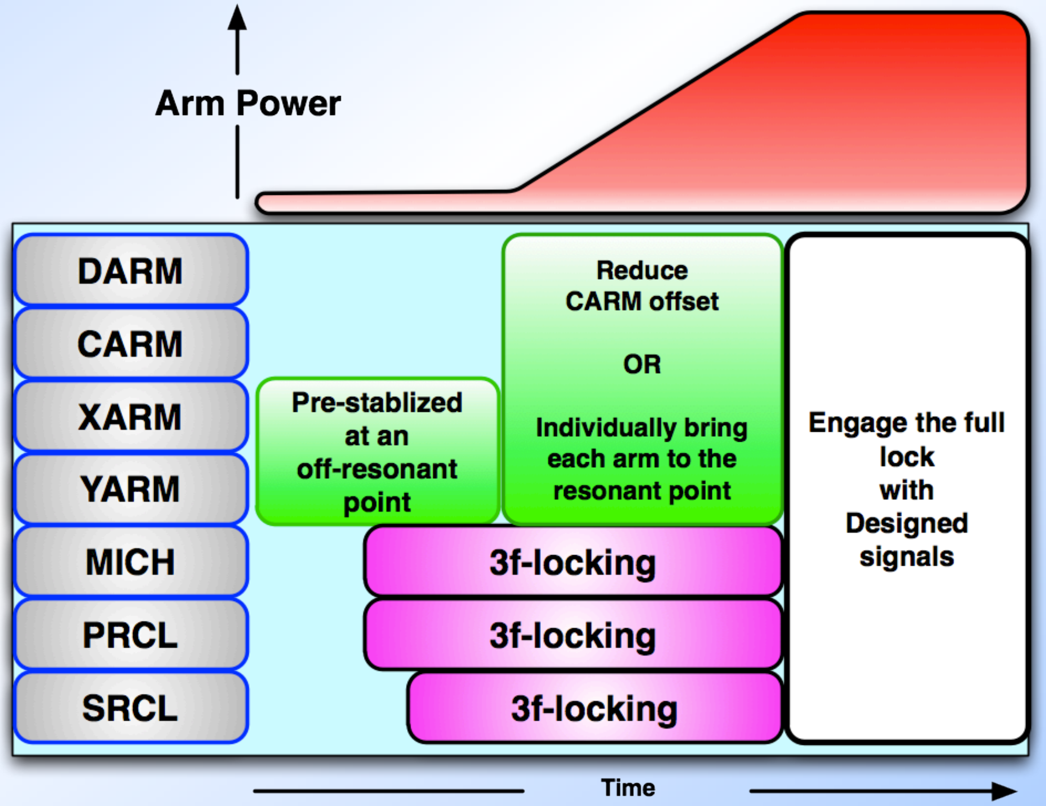
200pm in RMS was achieved



# Lock Acquisition

## - Full lock acquisition sequence

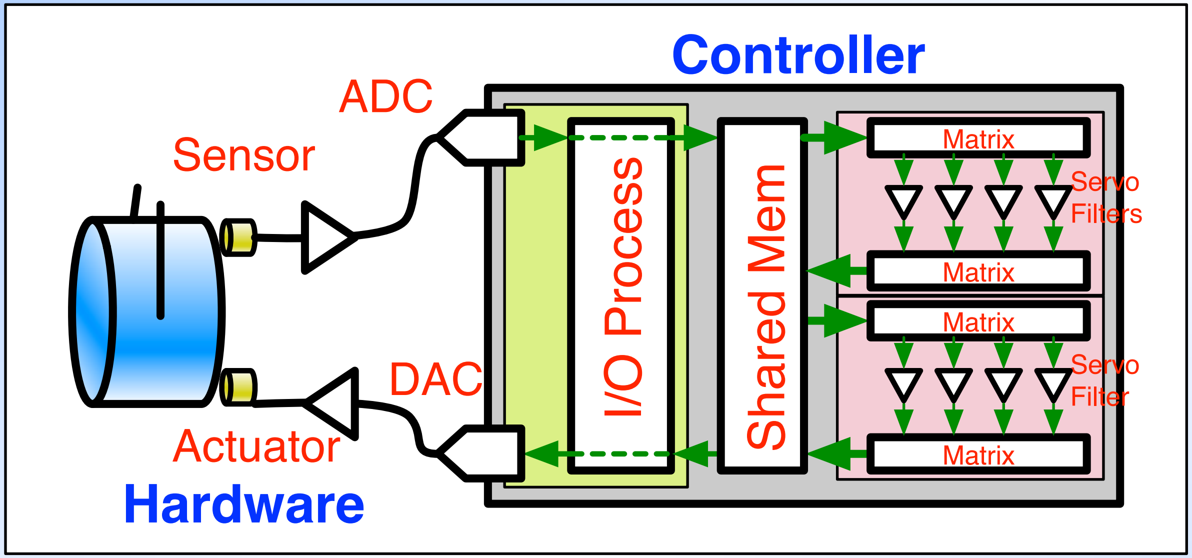
1. Pre-stabilize the arms at an off-resonant point
2. Lock the vertex part with the 3f-locking technique
3. Bring the arms to their resonances
4. Hand off the ALS servo to IR locking



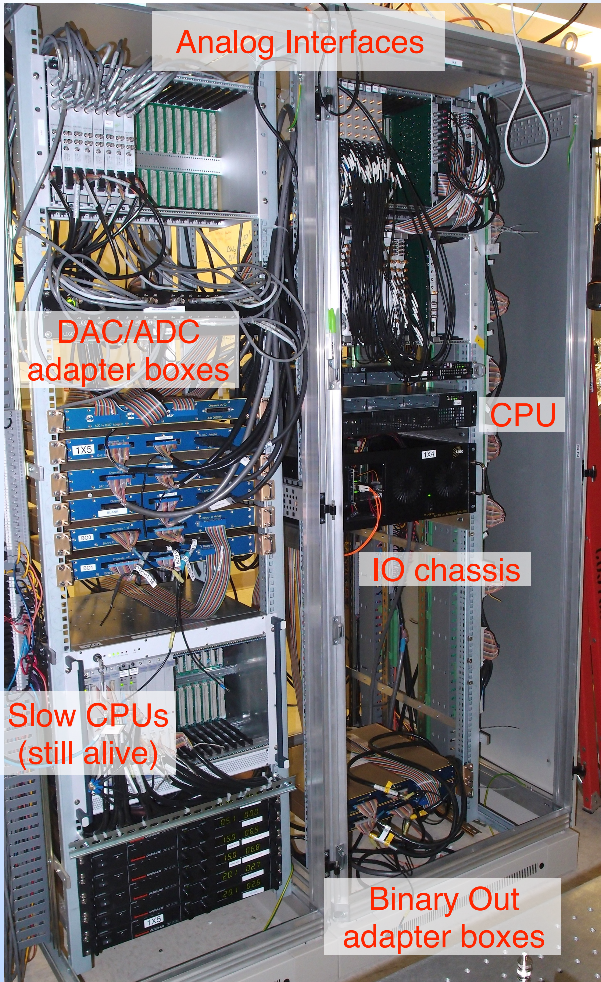
# Digital control system

## New aLIGO-style distributed digital control system

Replaces the old iLIGO-type hosts while keeping the analog modules




**General structure of the realtime controller**




**Suspension controller & I/F electronics**

Employs 5 multicore controller hosts connected with reflective memory networks.

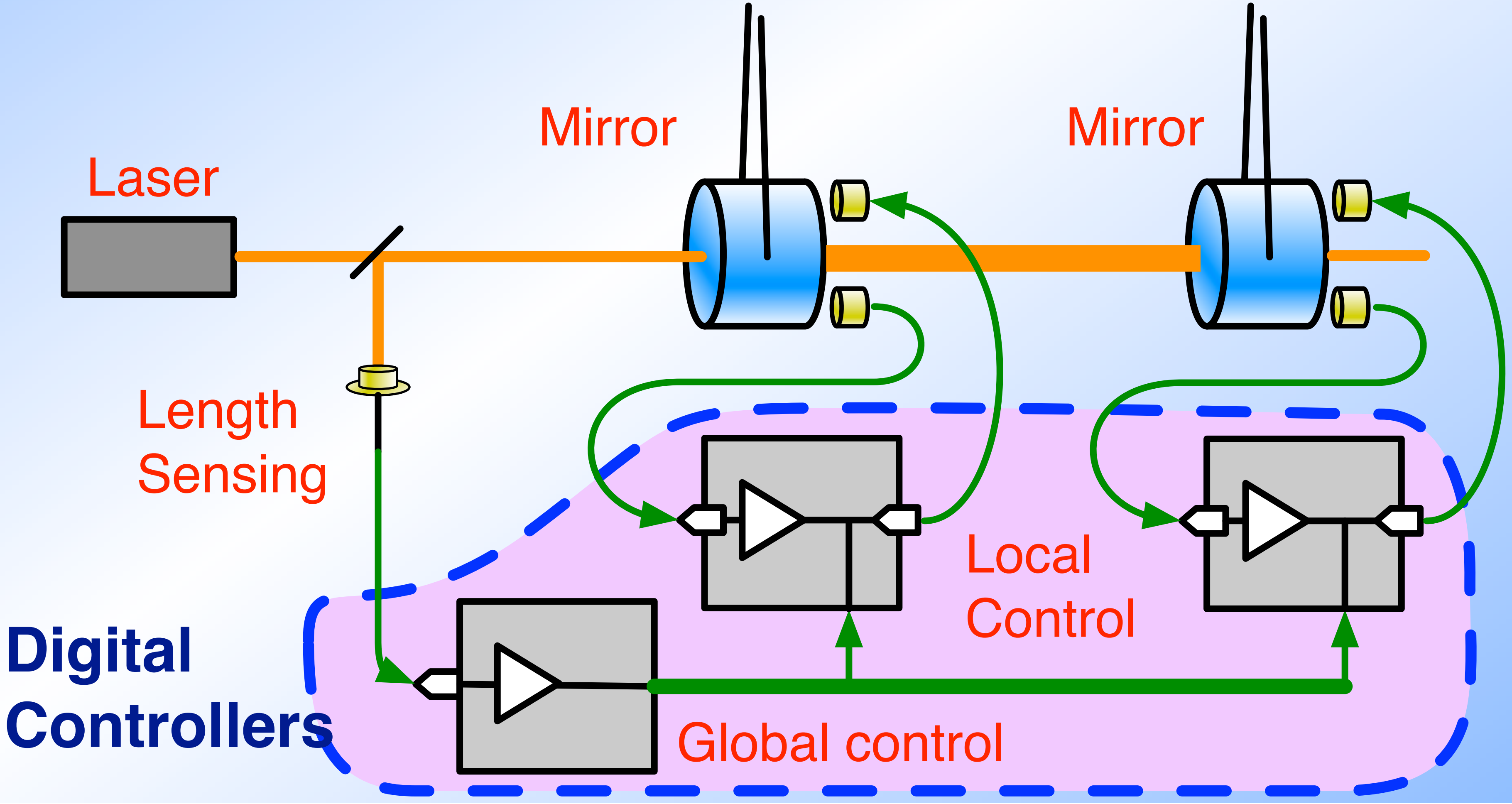
# Simulated Plant ~ Basic Idea

For more details
DCC G1000546-v1

**Interferometer control:**

  **Local control (suspension)**

**+ Global control (interferometric)**



# Simulated Plant ~ Basic Idea

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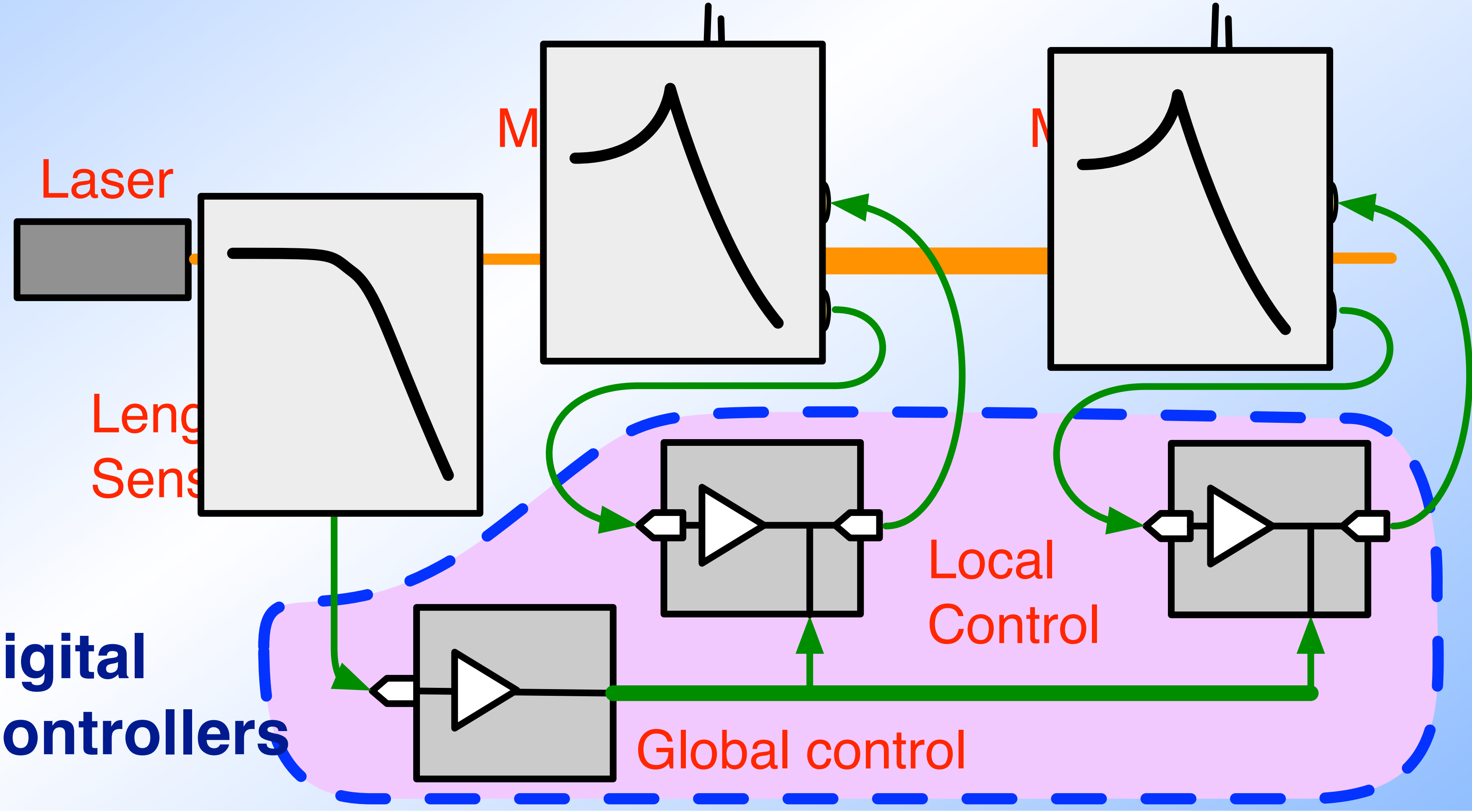



**Digital Controllers**

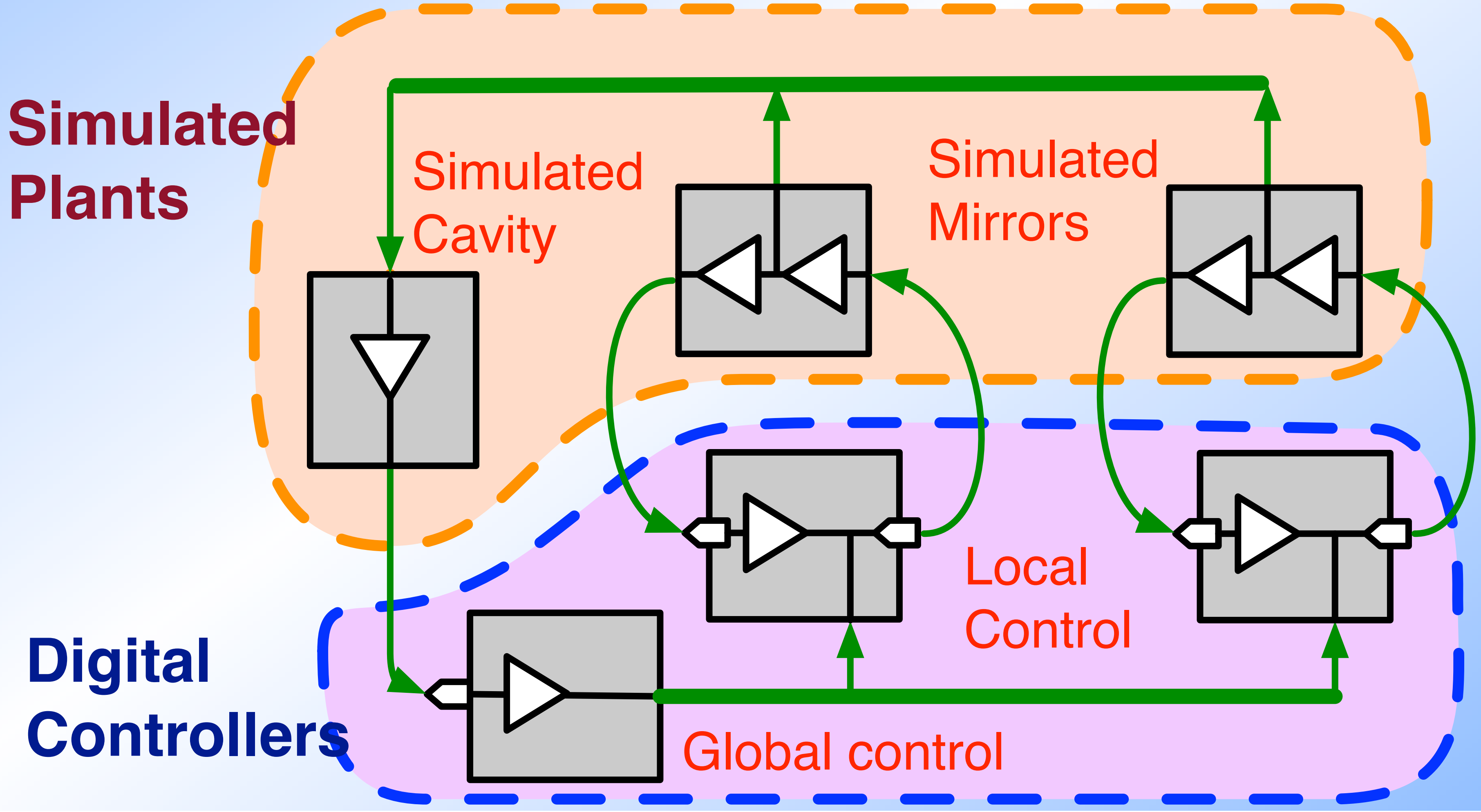
# Simulated Plant ~ Basic Idea

For more details
DCC G1000546-v1

Replaced hardware responses with digital filters

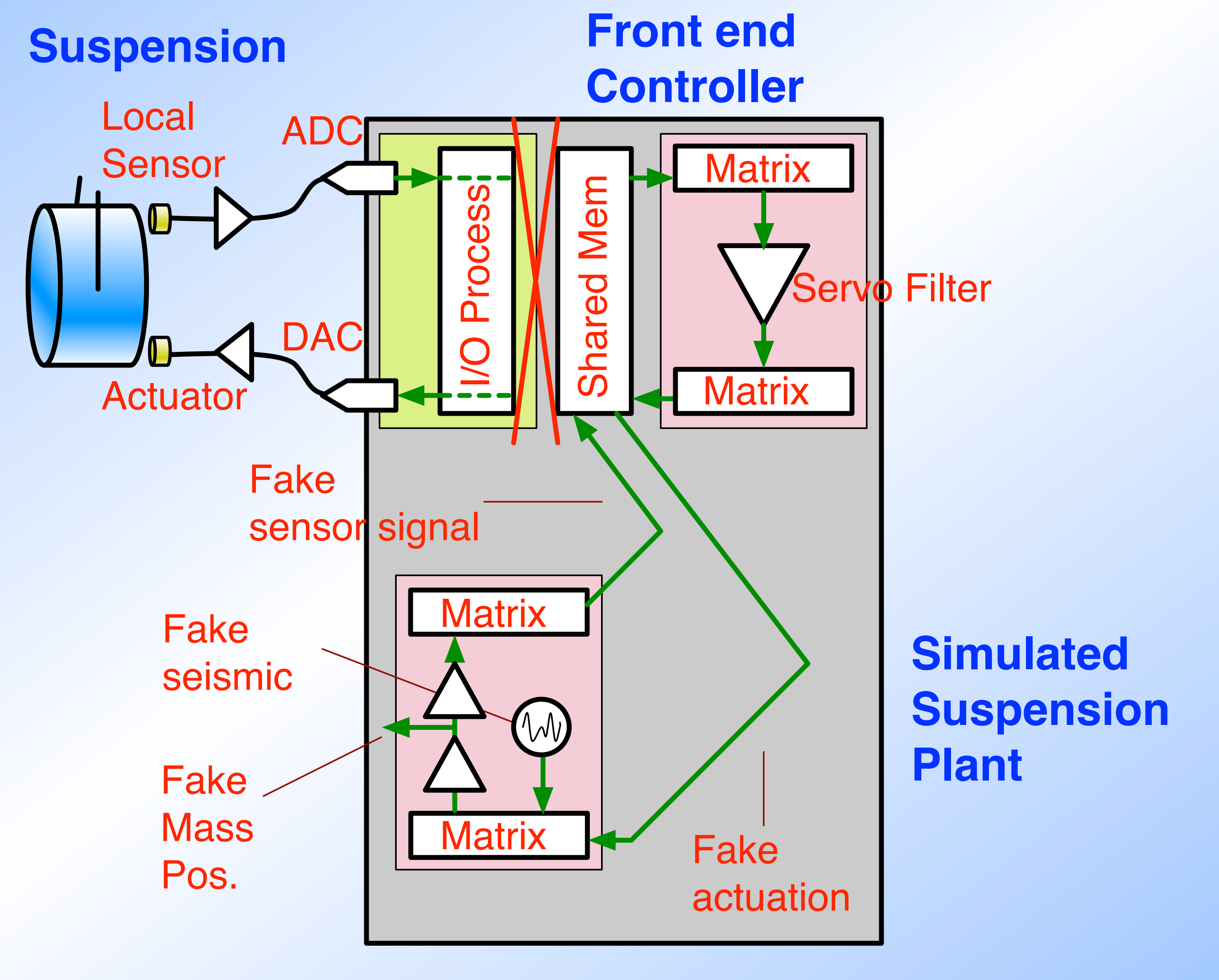
==> simulated plants

The servo loops remains stable



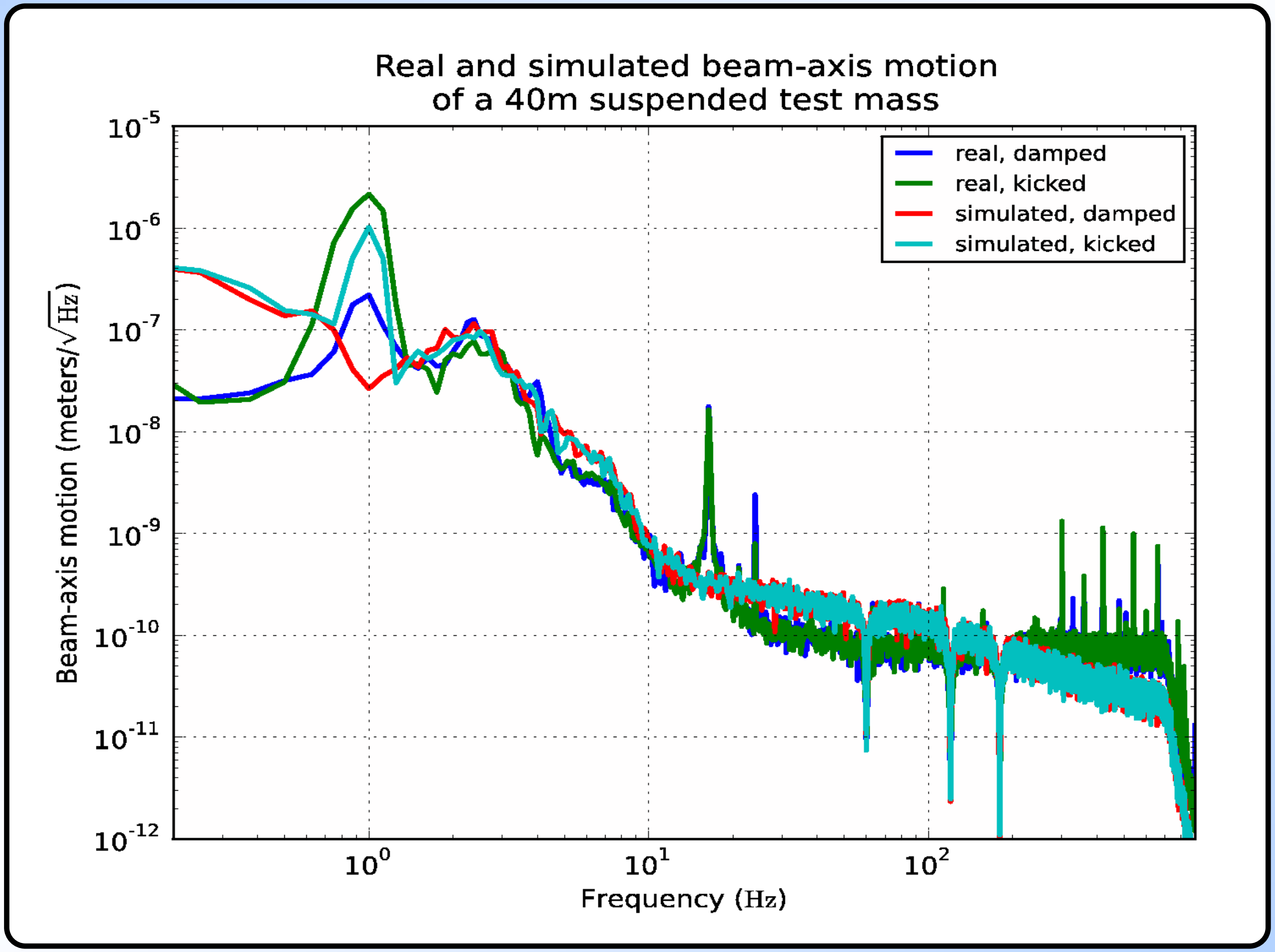
# Simulated Plant ~ Realization

- Simulated Plant: Introduce fake sensor signals and obtain actuation signal via the shared mem.



# Simulated Plant ~ Realization

## - Emulation example of the suspension plant




**Comparison of noise levels**
**between the simulated and real suspensions**

# Adaptive noise cancellation

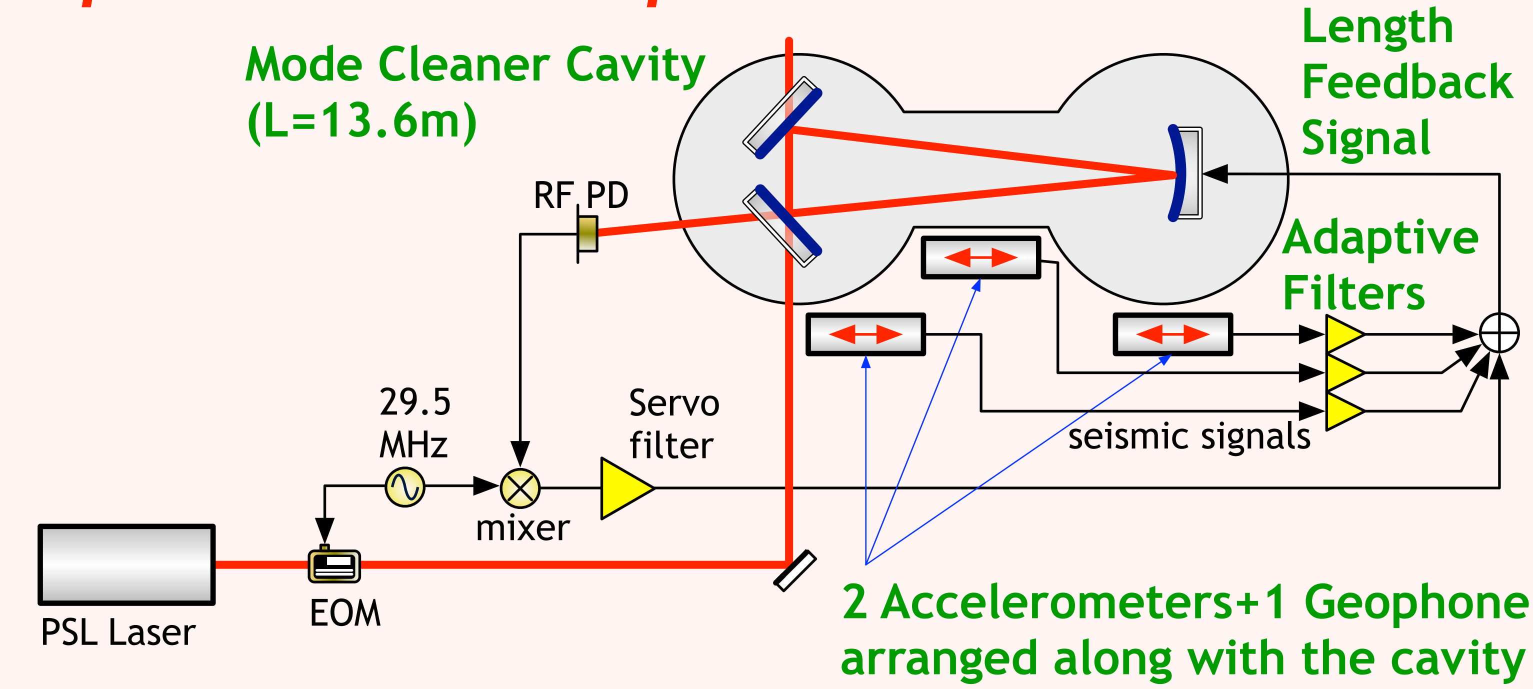
## Feedforward to cancel coherent noise couplings

**- The seismic feedforward works as an active vibration isolation**

even in the low freq band where the passive isolation is not effective

**- Applicable to any noise as long as the witness and the signal are coherent. (e.g. Newtonian gravity noise, magnetic, acoustic)**

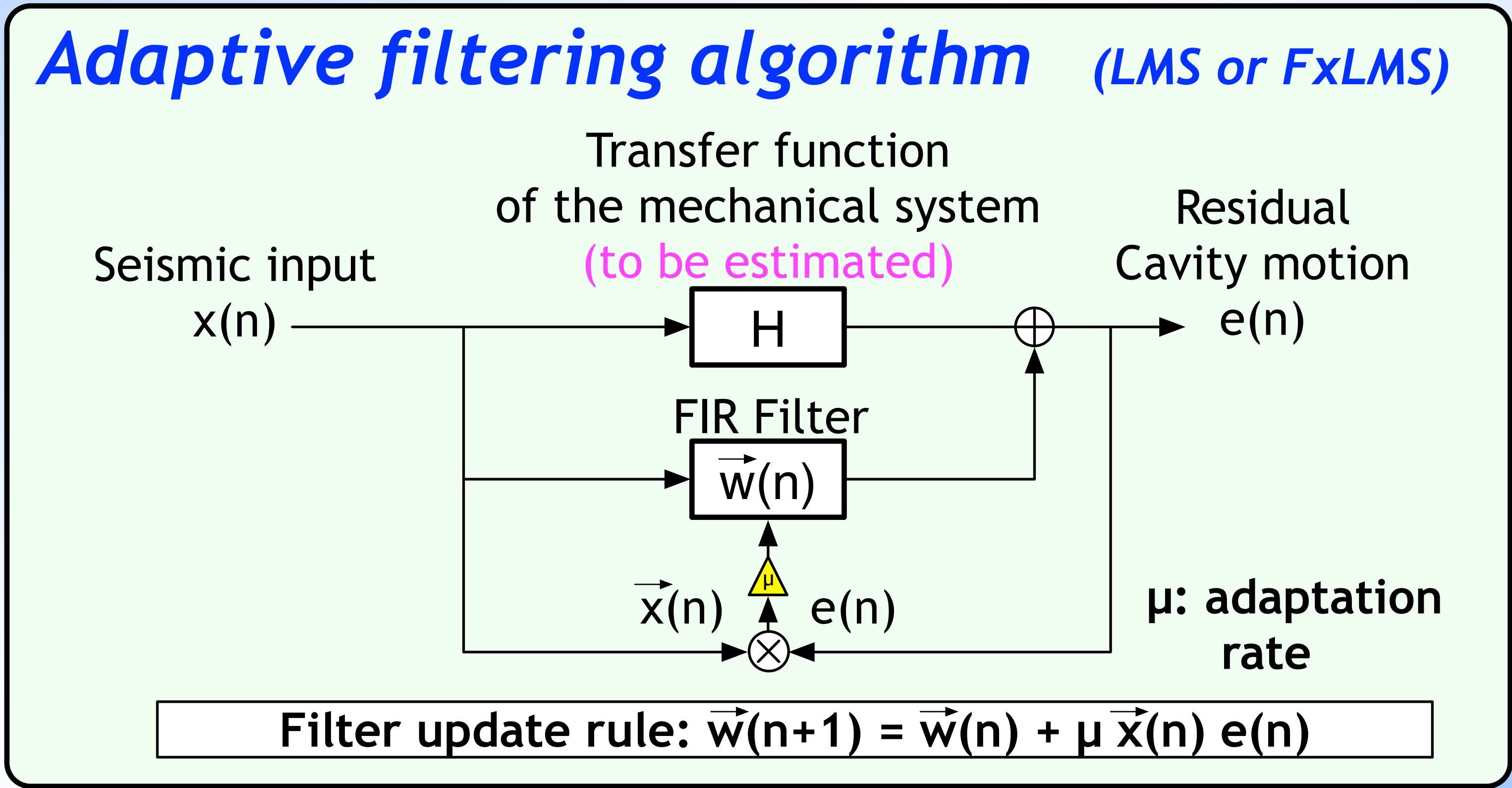
### Experimental Setup



# Adaptive noise cancellation

## Algorithm: train the FIR filter with the product of the witness signal and the residual error

**The FIR filter asymptotically get close to the wiener filter**

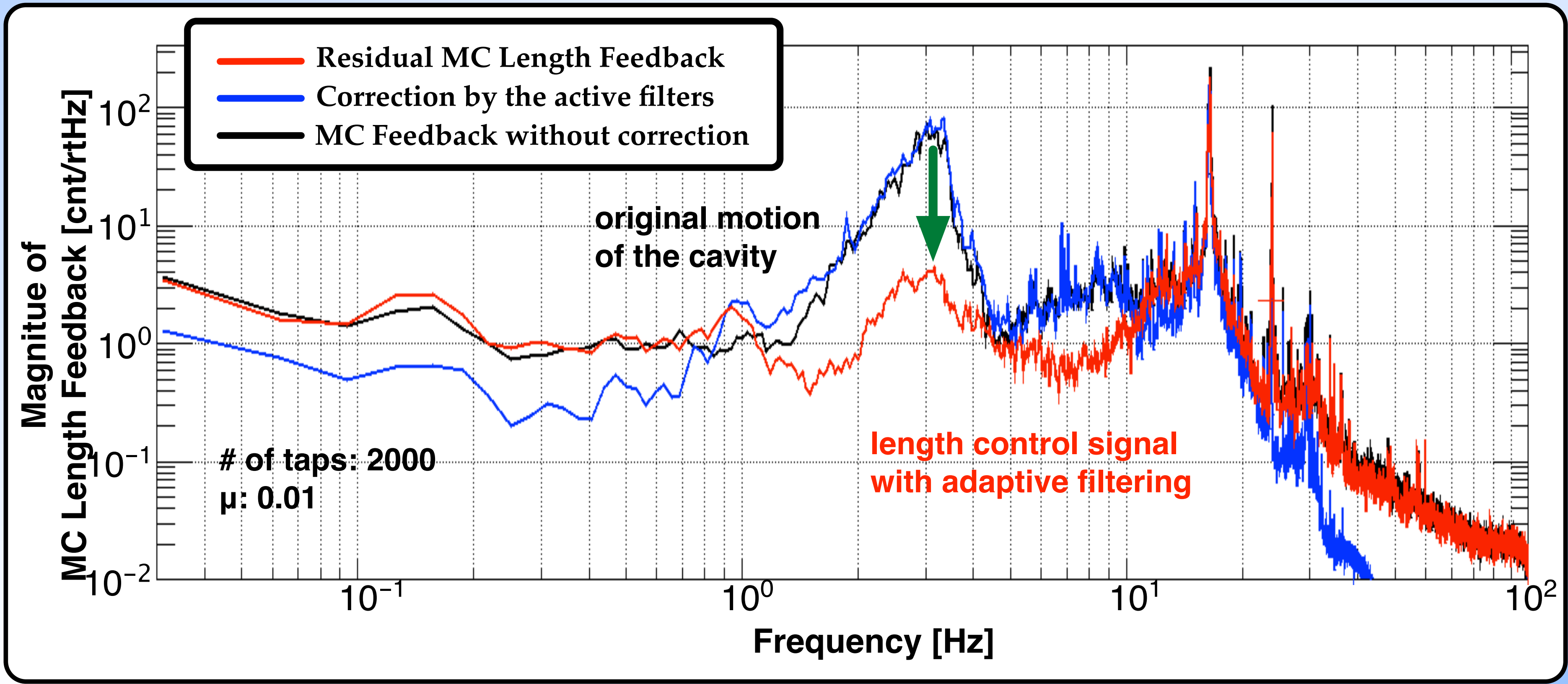


# Adaptive noise cancellation

- **Demonstrated reduction of the MC motion**

  three sensor signals are used as the witness channels

  Reduction by a factor of 17 at 3Hz



# Summary and Plans for 2011

- **Interferometer sensing and control:**

- Two arms are locked with 532nm and 1064nm beams
- Arm length stabilization of 200pm$_{RMS}$ has been realized
  with auxiliary 532nm laser injection from one of the arm end
- Dual-recycled Michelson is regularly locked and is operating

**=> Plan: Characterization of DRMI**
**Demonstration of full lock with Arm Length Stabilization**

- **Digital control system**

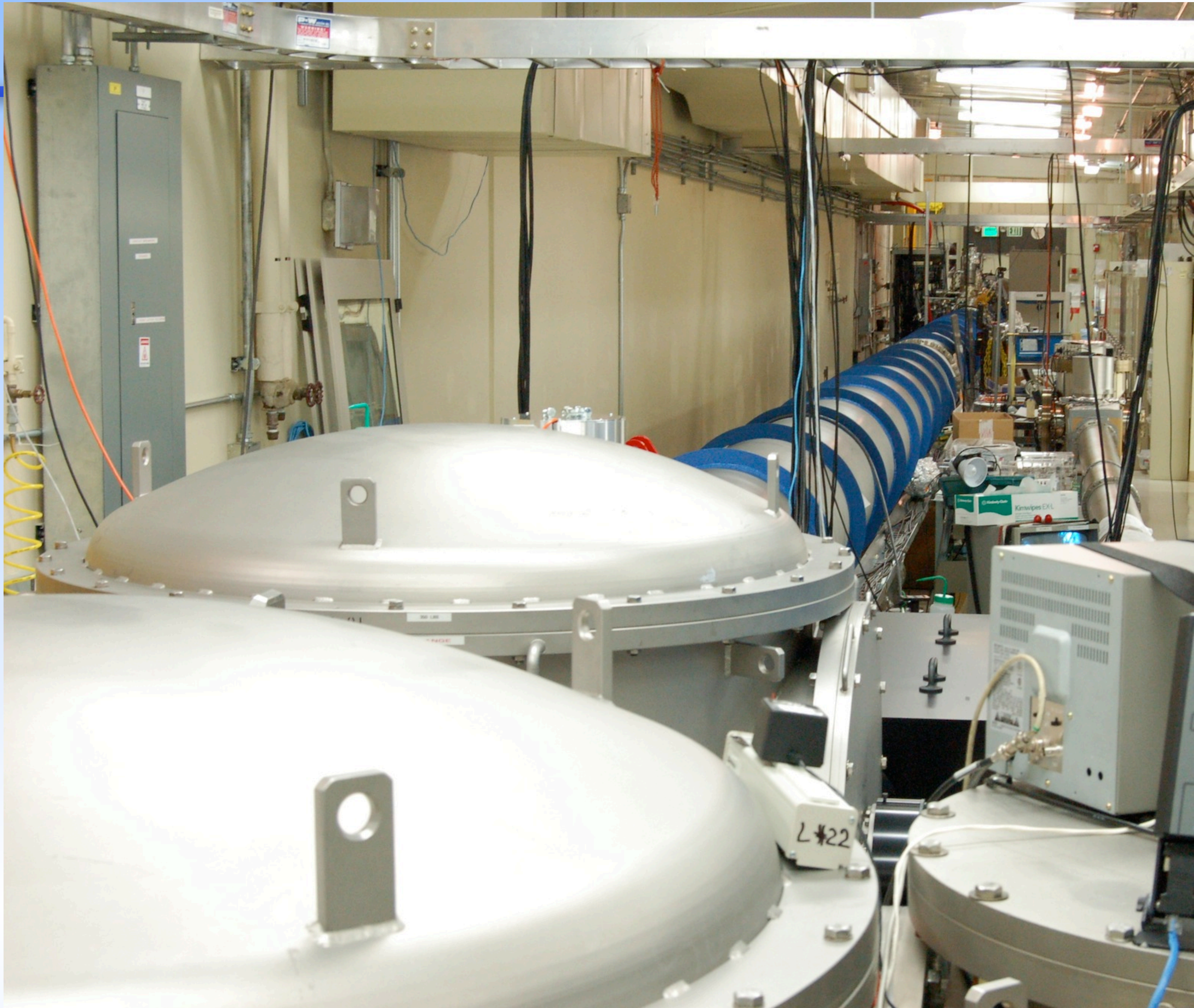
- Controllers for the suspensions and length control were implemented
- Simulated plant: suspensions and a simple cavity have been modeled

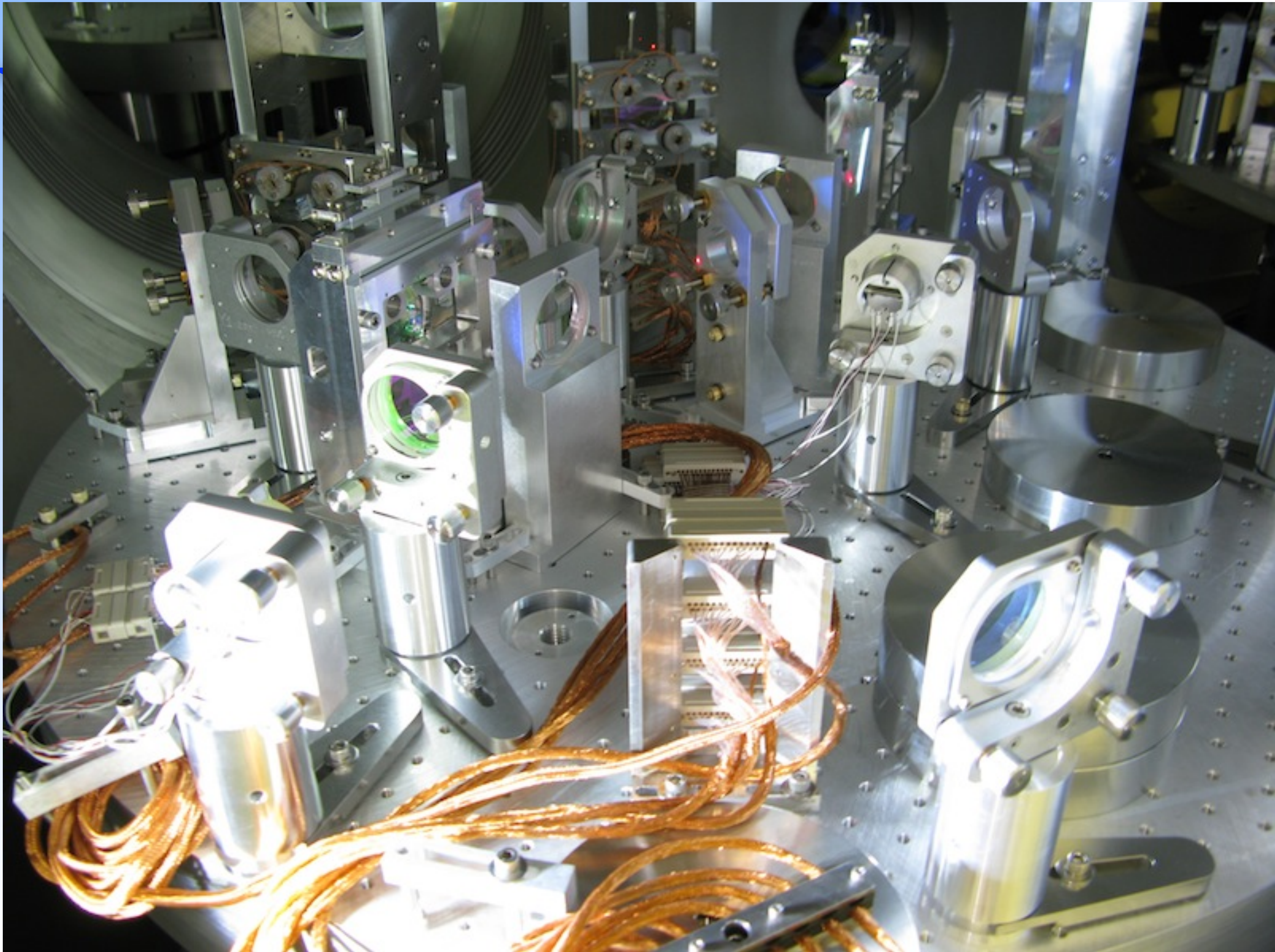
**=> Plan: Expansion of the simulated models for full IFO**

- **Adaptive seismic noise cancellation**

- Achieved reduction of the MC length change

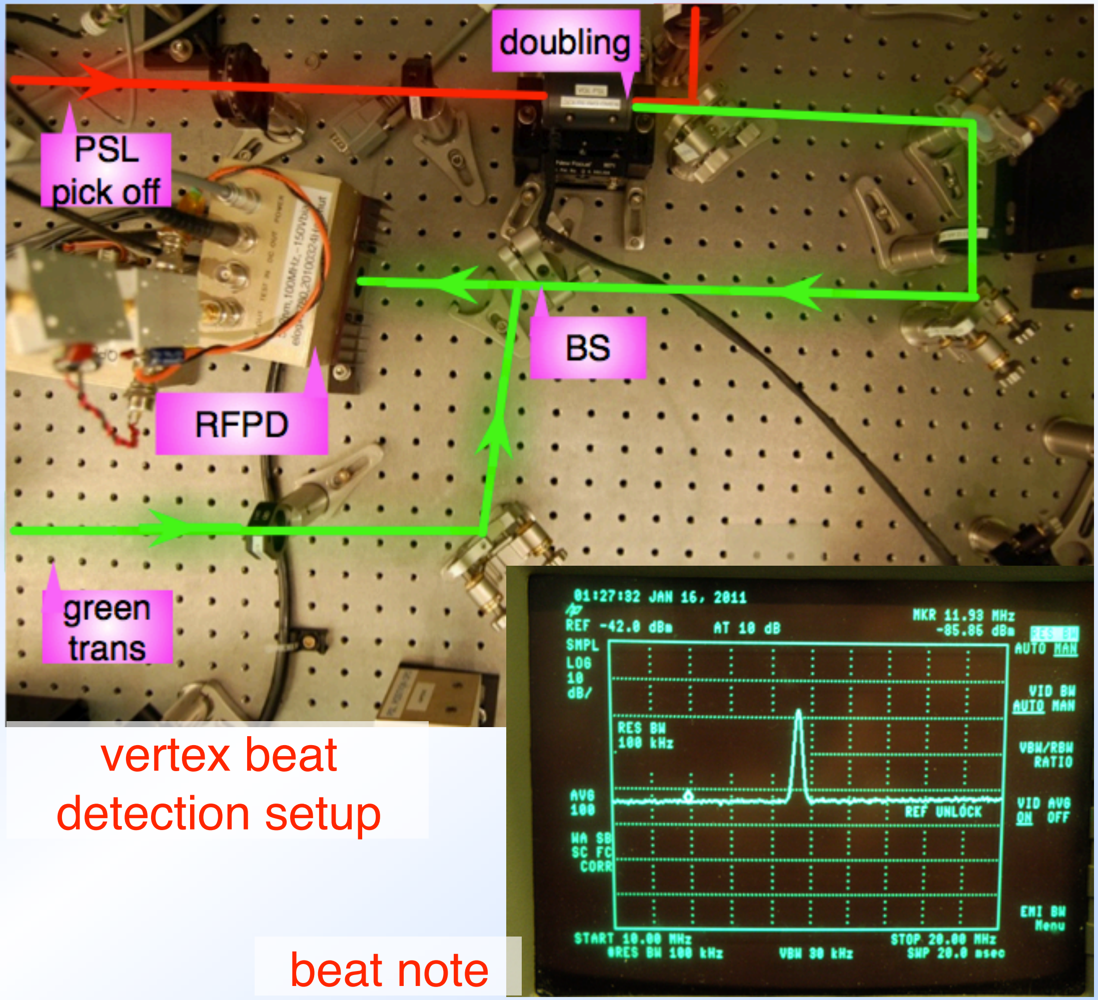
**=> Plan: Implementation of the technique**
**to the main arm cavities**

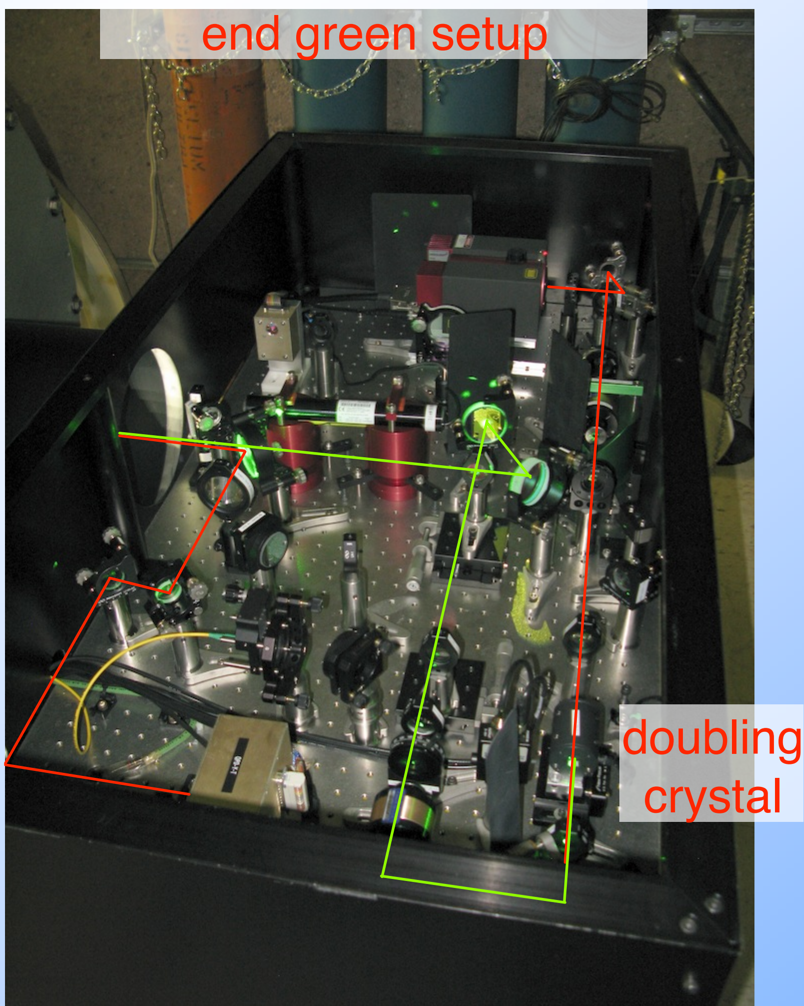

Kimwipes EX-L
L*22



# ALS: Setup

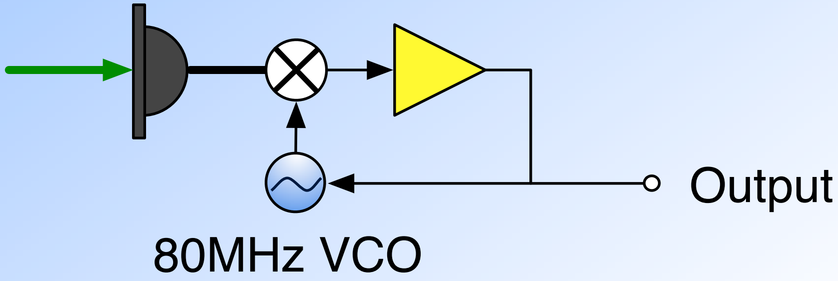
- both arms locked with green
- beat note at the vertex obained and stabilized
- beat freq sweep / differential freq noise



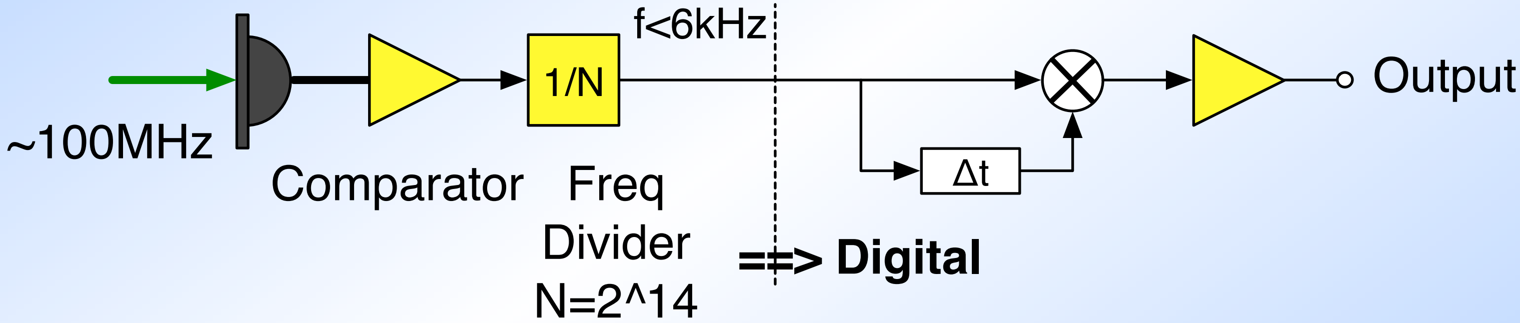



# ALS: 3 options for freq discrimination

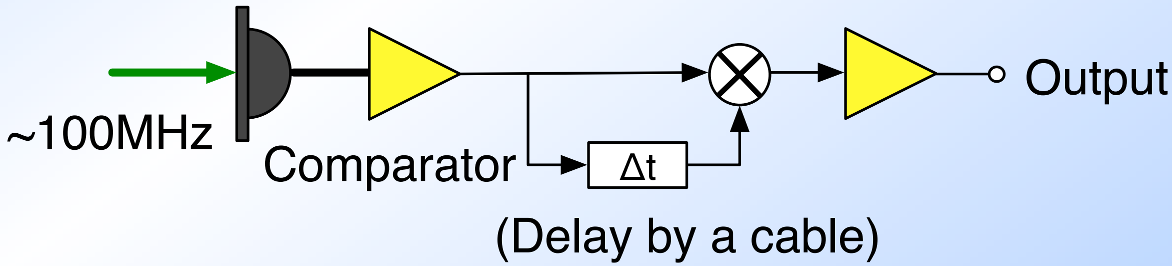
## - PLL with VCO




## - Digital Freq Discriminator with freq divider




## - Mixer Freq Discriminator




Another option is the phase frequency discriminator which is being considered for aLIGO

https://awiki.ligo-wa.caltech.edu/aLIGO/PhaseFrequencyDiscriminator

# ALS: Mixer Frequency Discriminator (MFD)

## Basic idea:

**Delay: Δt ⇒ $\phi(f)$**

**Mixer: $\phi(f)$ ⇒ Voltage**