Seismic Attenuation System (SAS) Prototype Test

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LIGO-G030018-00-D

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SAS

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Introduction: TAMA SAS

Aims, Background

Features

R&D Program

Prototype Tests of Subsystems

3m Fabry-Perot Experiment

Summary

SAS TAMA SAS (1)

TAMA SAS (Seismic Attenuation System)

Aims

- *Lower Frequency Limit of GW Detection*
- *Improve Stability of GW Detectors*

Background

Upgrade of TAMA300 (2002 – 2006)

Advanced GW Detectors (LCGT etc.)

- Improve TAMA300 Performance
- Establish Low Frequency Isolation Technique for Future Detectors

SAS TAMA SAS (2)

Main Functionalities

Passive Low Frequency Isolation

- Low Resonant Frequency Mechanics (in all d.o.f.)
  - **Highly Robust Isolation Performance**
  - **Reduce Bandwidth Interferometer Controls**
- Specs Overkilling Design
  - Against Spurious Cross-Coupling, Internal Resonances

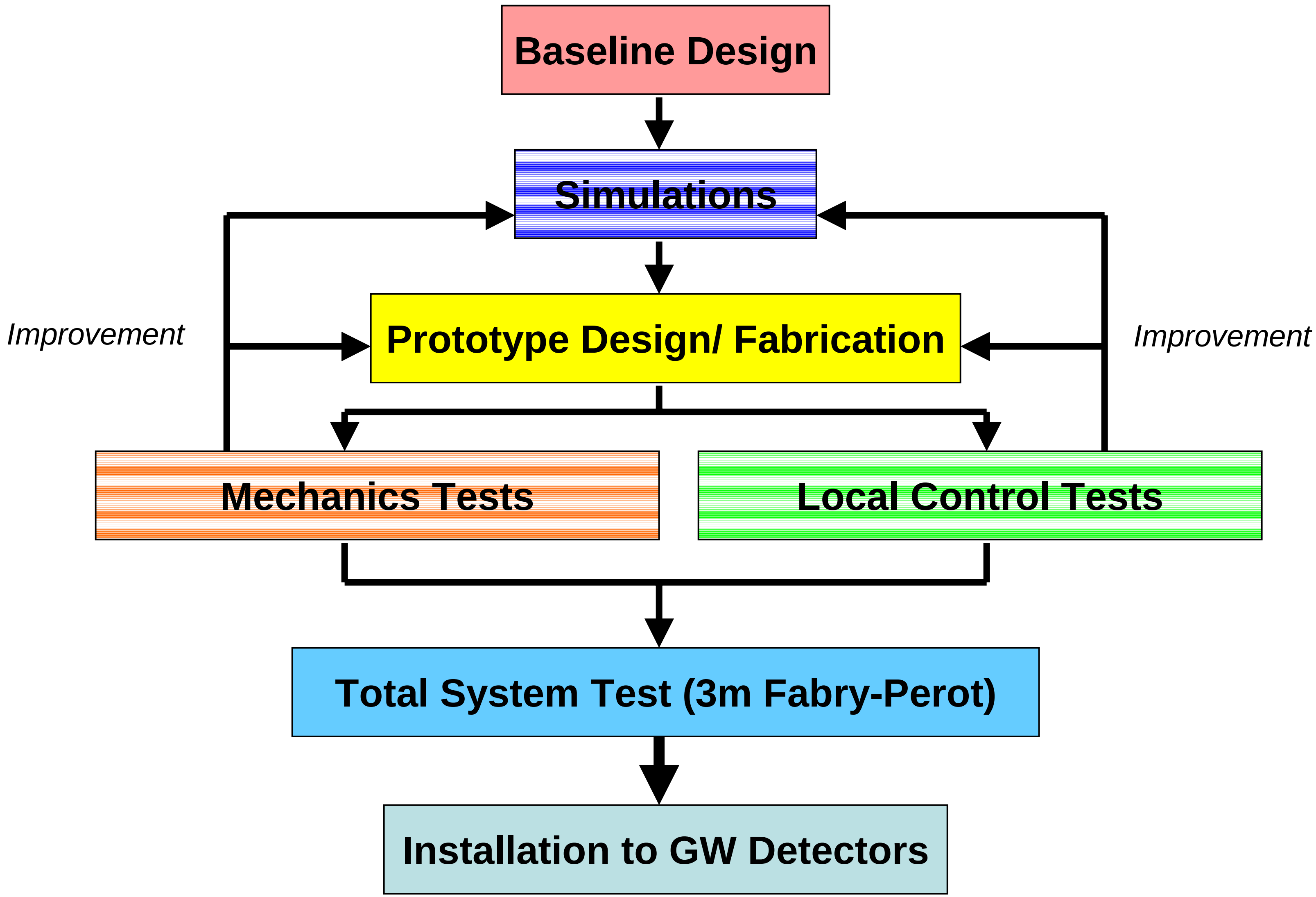
Suppression of Residual Mirror Motion

- Attenuation at Micro Seismic Activity
- Active/ Passive Damping for Mech. Resonances

Provides Mirror Controllability

- Actuators for Hierarchical Controls

SAS R&D Program



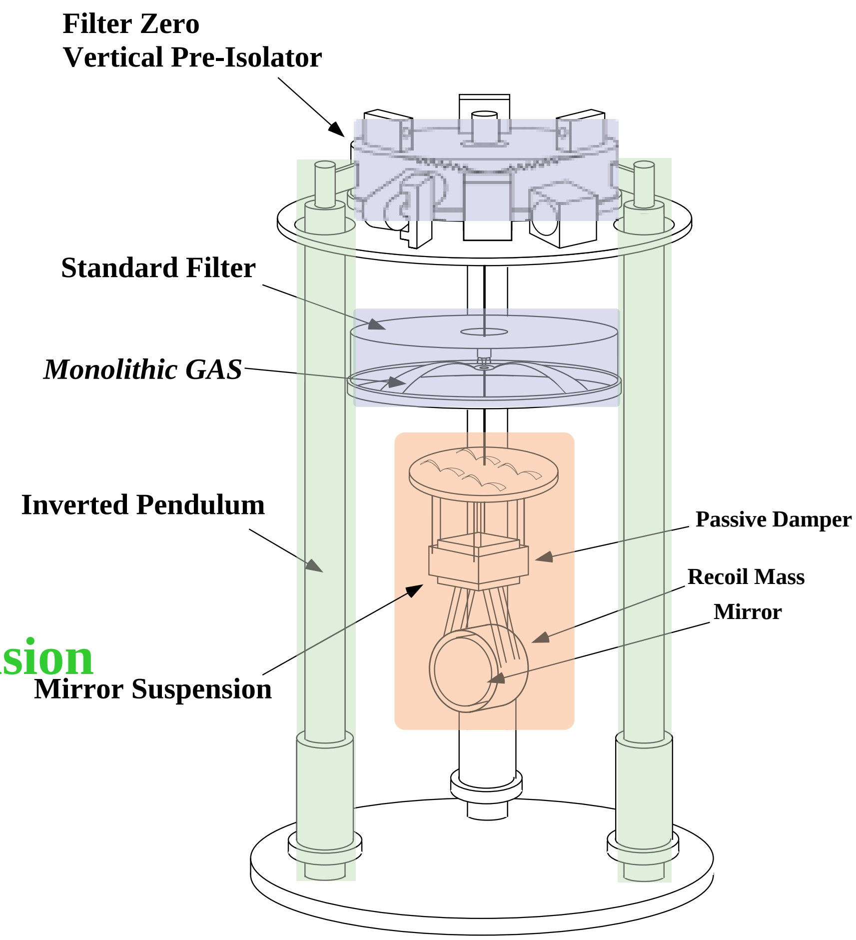
SAS Baseline Design

Mechanics

- 5–Stage Passive Isolator
- Passive Low Frequency Isolators
  - Inverted Pendulum (IP)
  - MGASFs
- Mirror Suspension

Damping System

- Active Damping on IP
- Passive Damping on Mirror Suspension

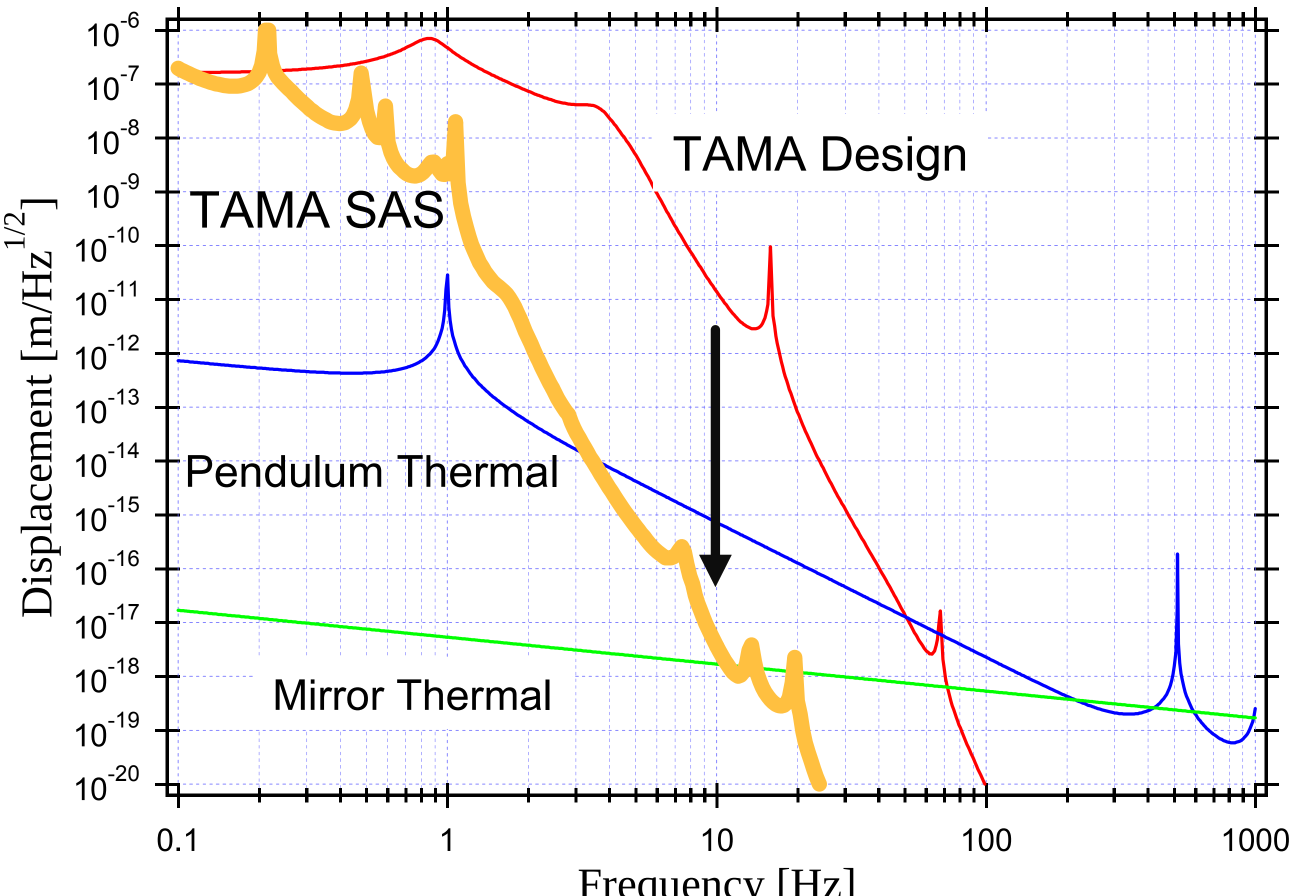


TAMA SAS

SAS Simulation

Design Performance

- Achieve Pendulum Thermal Noise Level below 10 Hz



SAS Contents

Introduction: TAMA SAS

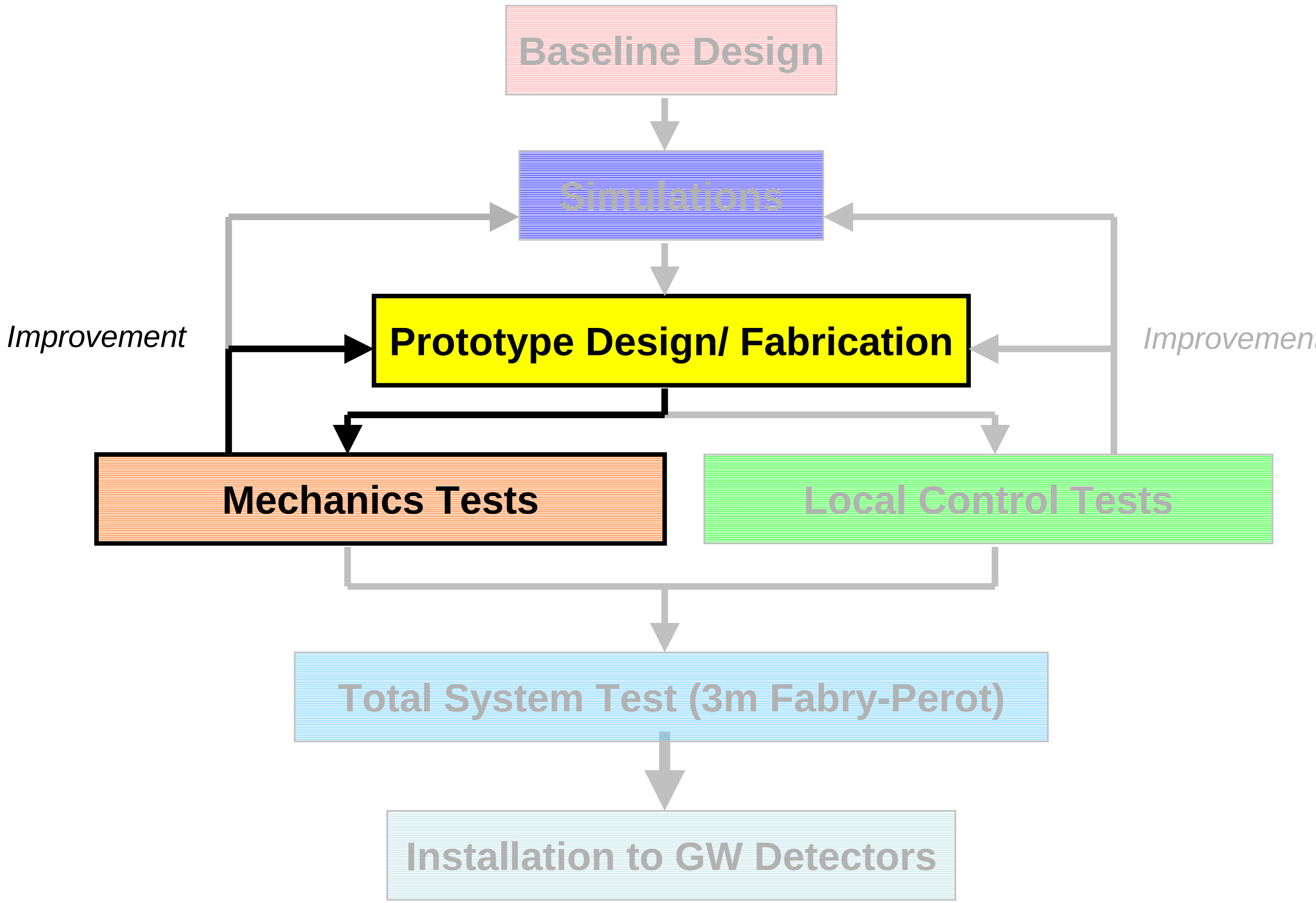
Prototype Tests of Subsystems

- Mechanics
- Local Control

3m Fabry-Perot Experiment

Summary

SAS Testing Mechanics



SAS Inverted Pendulum (1)

Horizontal Pre-Isolator

Ultra Low Frequency Passive Isolation

- **Translational Mode**
  - Tuned to a Few Tens of mHz
- **Attenuation at Micro Seismic Activity Frequencies**
- **Compensation of c.o.p. Effect**

Stage for Active Damping

Compact Design

- **2m Height**
- **High Internal Mode Frequency: ~ 60 Hz**

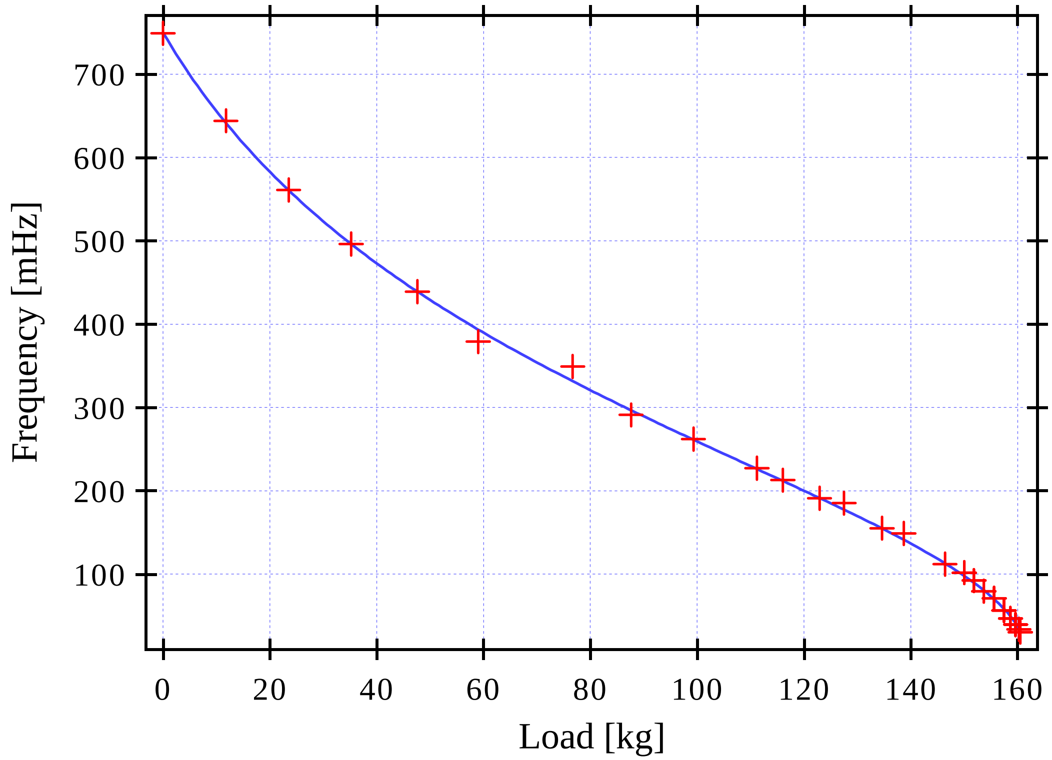
IP for TAMA SAS

SAS Inverted Pendulum (2)

IP Prototype Tests

Tuning Resonant Frequency

- **Tuned to 30 mHz ~ 70 mHz**
  - Limitation due to Non-Linear Effect



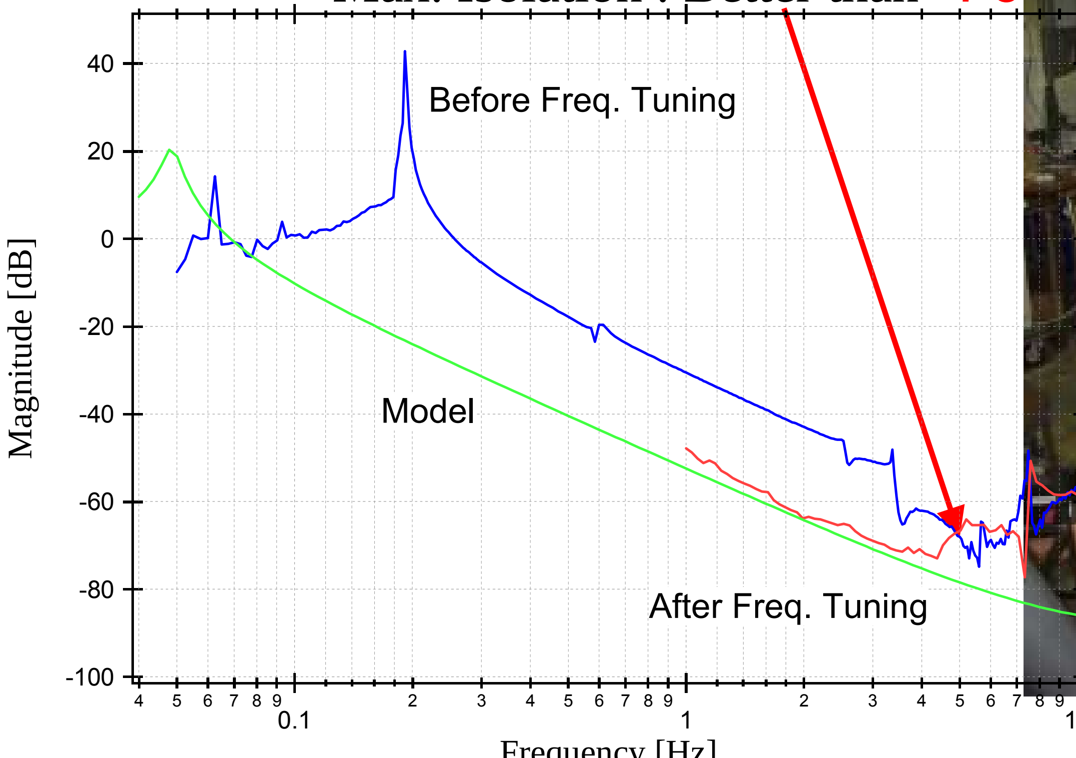
Freq. Tuning

SAS Inverted Pendulum (3)

Horizontal Isolation Performance

Vibration Tests

- Compensation of c.o.p. Effect
  - Max. Isolation : Better than -70



Horizontal Isolation Setup for Vib. Test

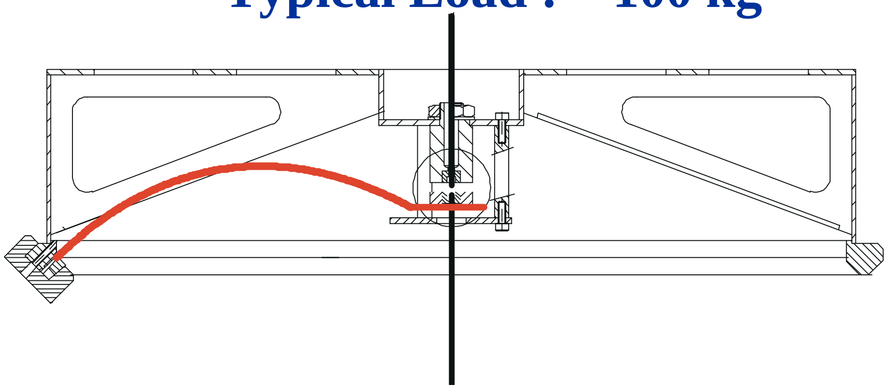
SAS MGASF (1)

Monolithic Geometric Anti-Spring Filter

Low Frequency Vertical Isolator

Completely Passive System

- **Vertical Res. Freq.**
  - Tuned to a few hundreds mHz
  - Hight : ~ 10 cm
- **Typical Load : ~ 100 kg**



SAS MGASF (2)

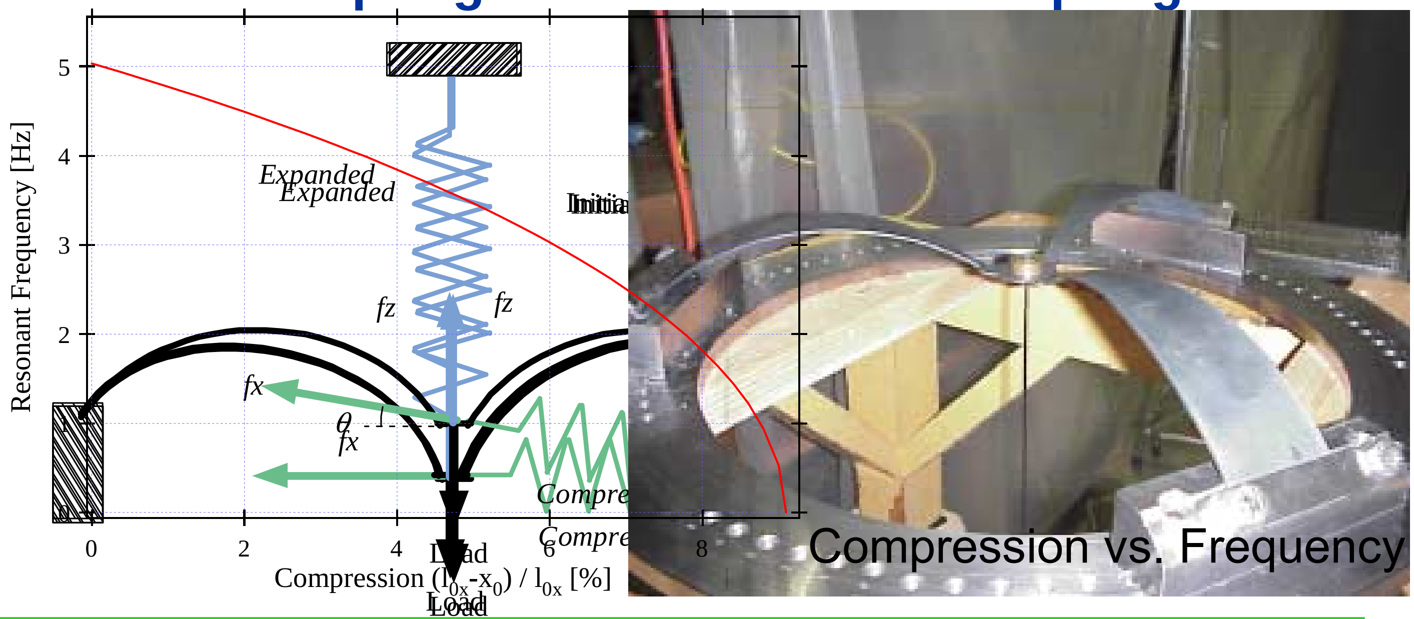
Working Principle

Vertical Isolation by Cantilever Springs

- Horizontal Compression

Passive Geometric Anti-Spring Effect

- ‘Linear’ Model
- Vertical Normal Spring vs. ‘Horizontal’ Anti-Spring

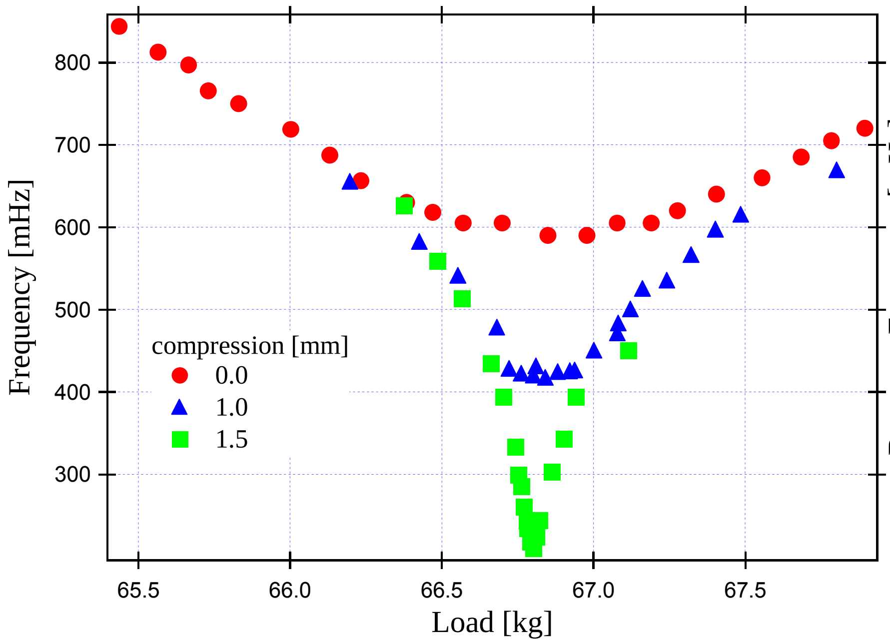


SAS MGASF (3)

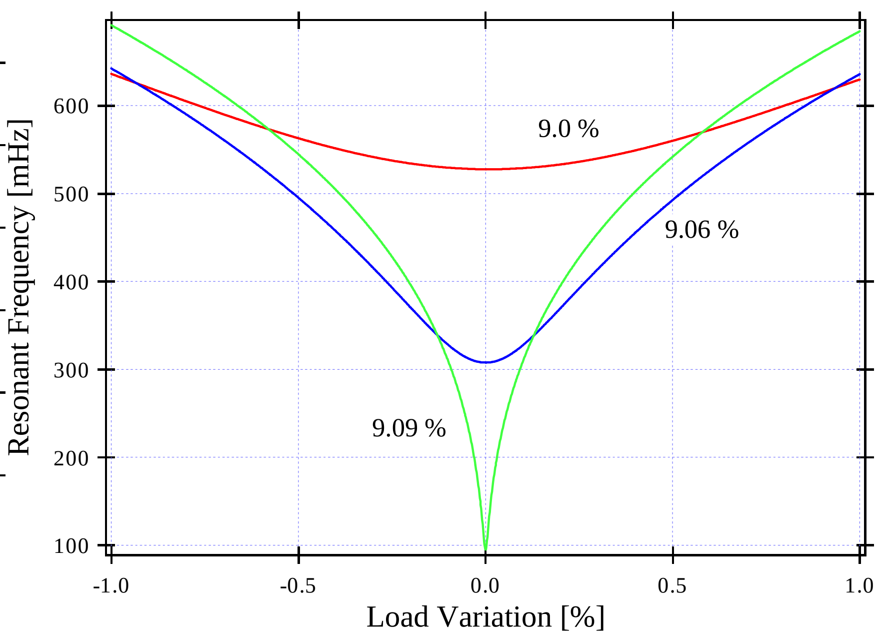
MGASF Prototype Tests

Frequency Tuning

- Compression / Optimal Load (Working Position)
- Typ. Freq. :200 mHz ~ 500 mHz
  - Hysteresis



Load vs. Frequency



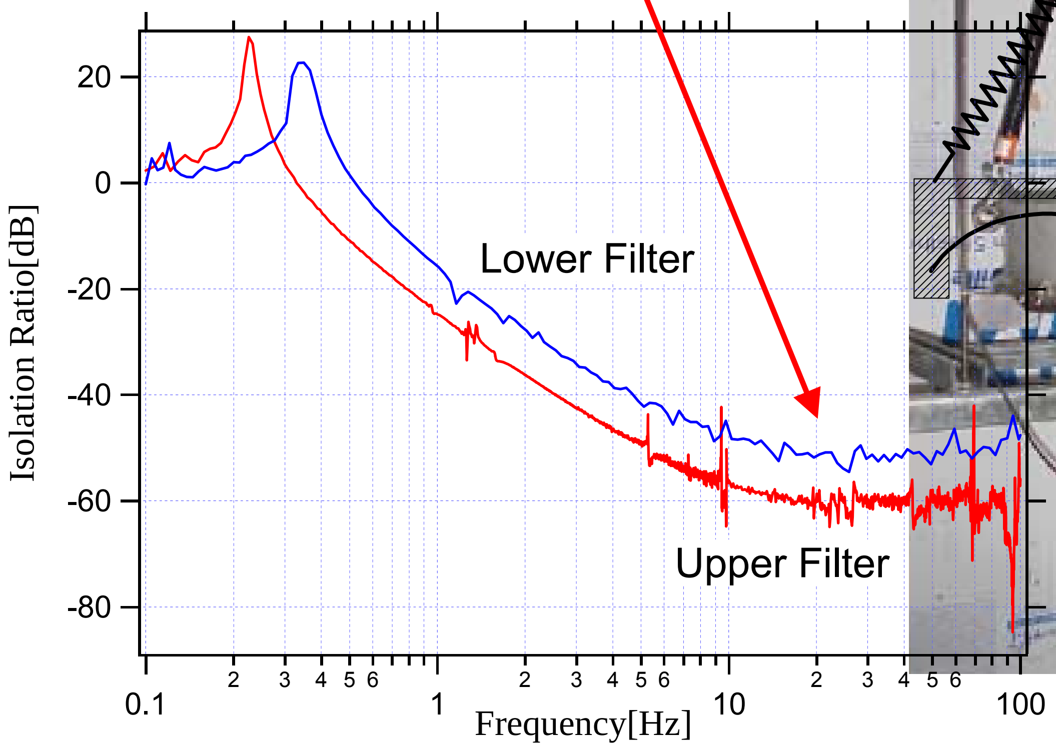
'Linear' Model

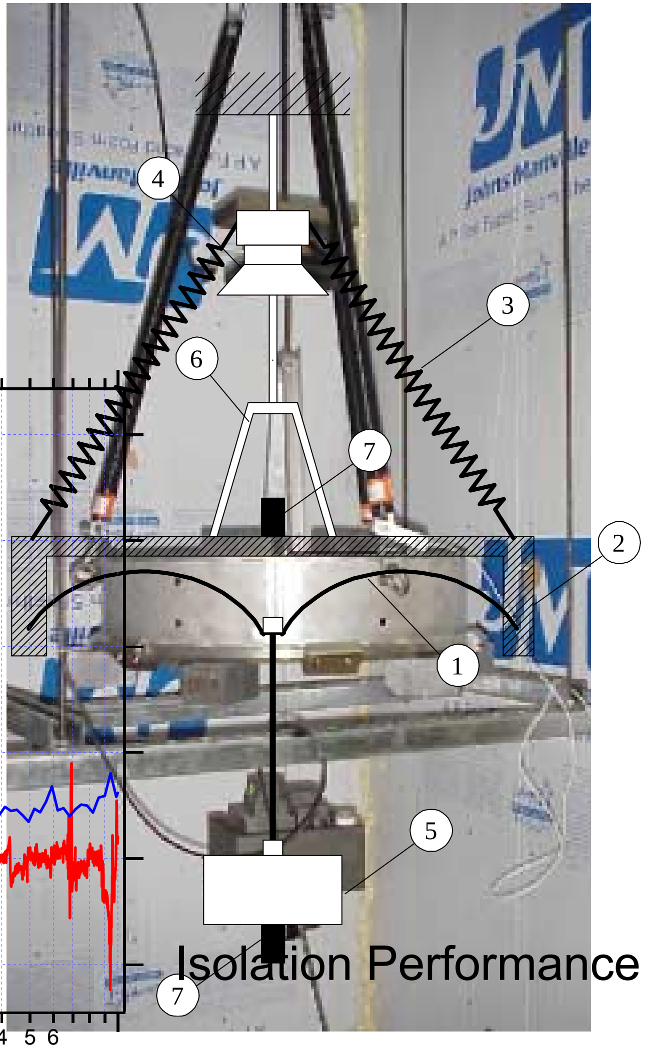
SAS MGASF (4)

Vertical Isolation Performance

Vibration Test

- Single Filter
  - Max. Attn. Level: -50 ~ -60 dB





Setup

SAS Mirror Suspension (1)

Features

Double Pendulum

Passive Damping on Int. Stage

- Validated by TAMA300
- Complement to Active Damp

Low Freq. Vertical Isolation

- Mini MGAS

Control using Recoil-Mass

- Simple Mirror Control

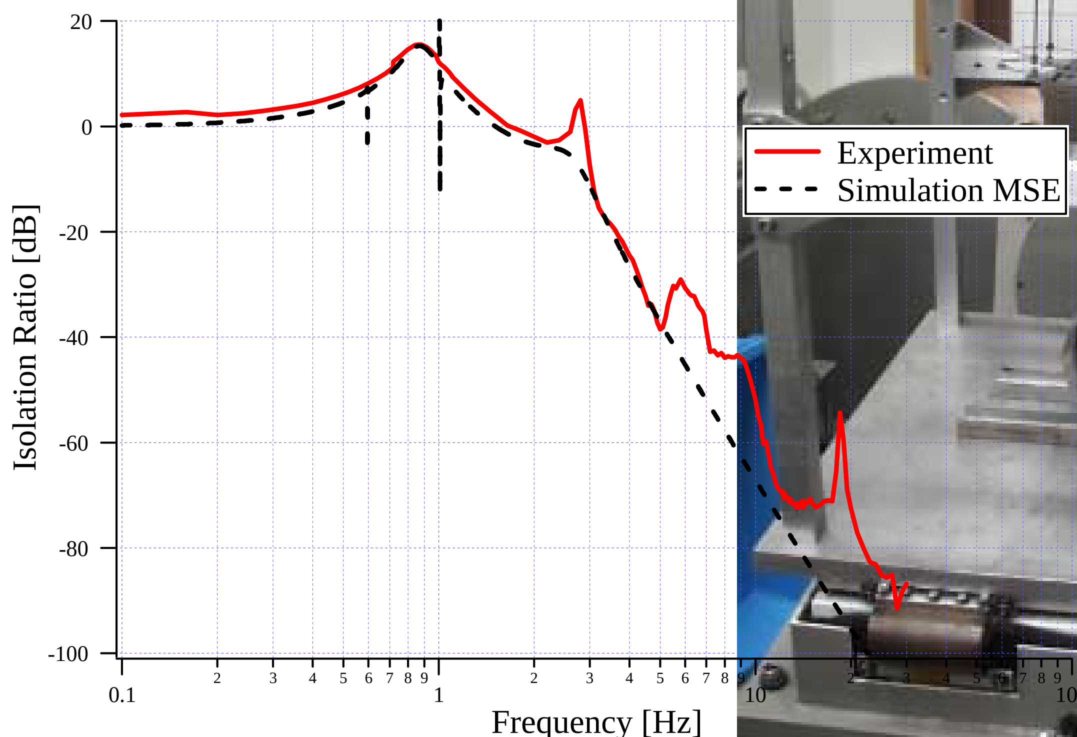
Prototype Mirror Suspension

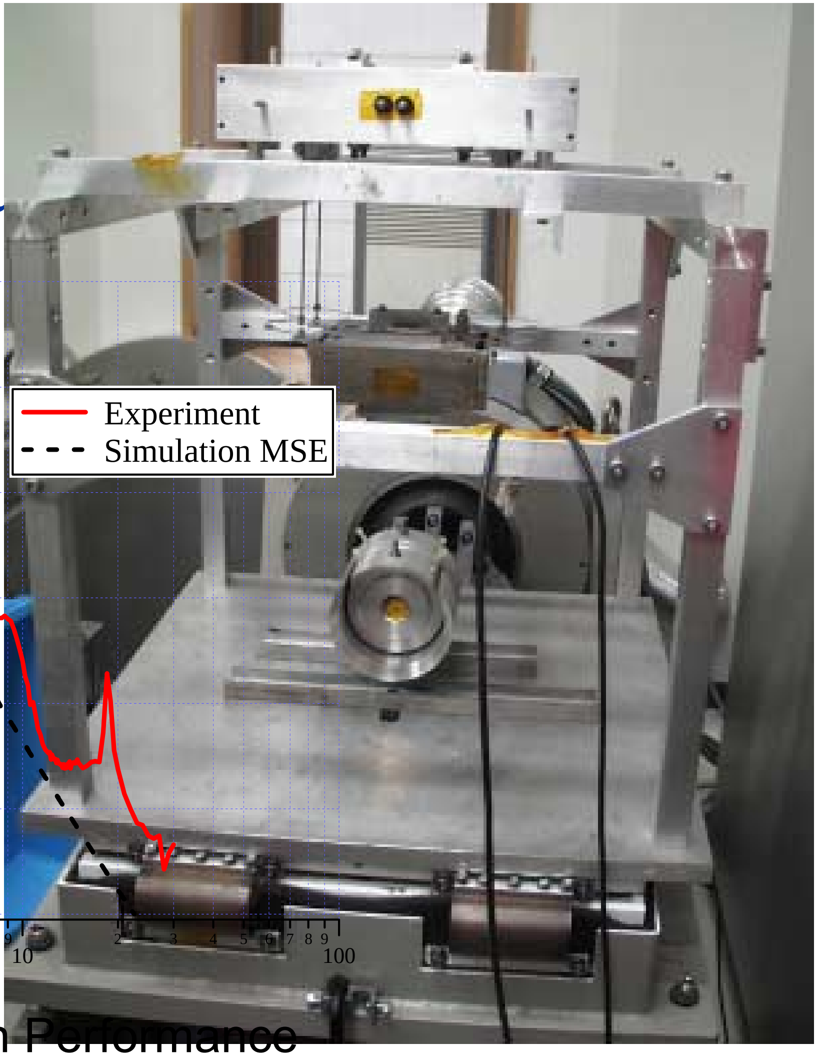
SAS Mirror Suspension (2)

Isolation Performance

Vibration Tests

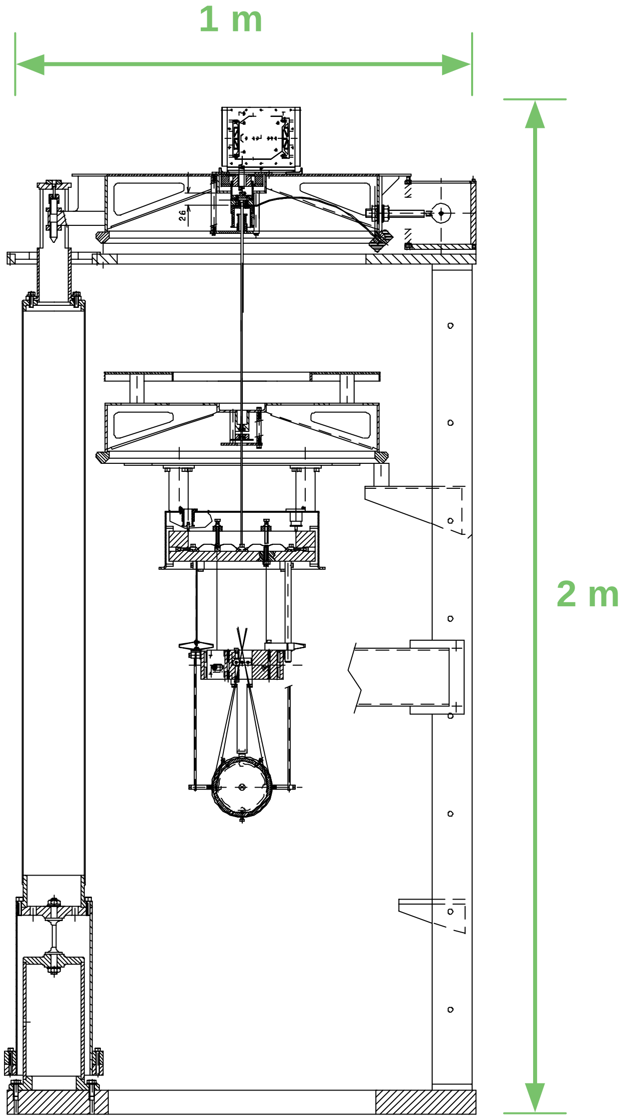
– **Good Agreement with Simu**



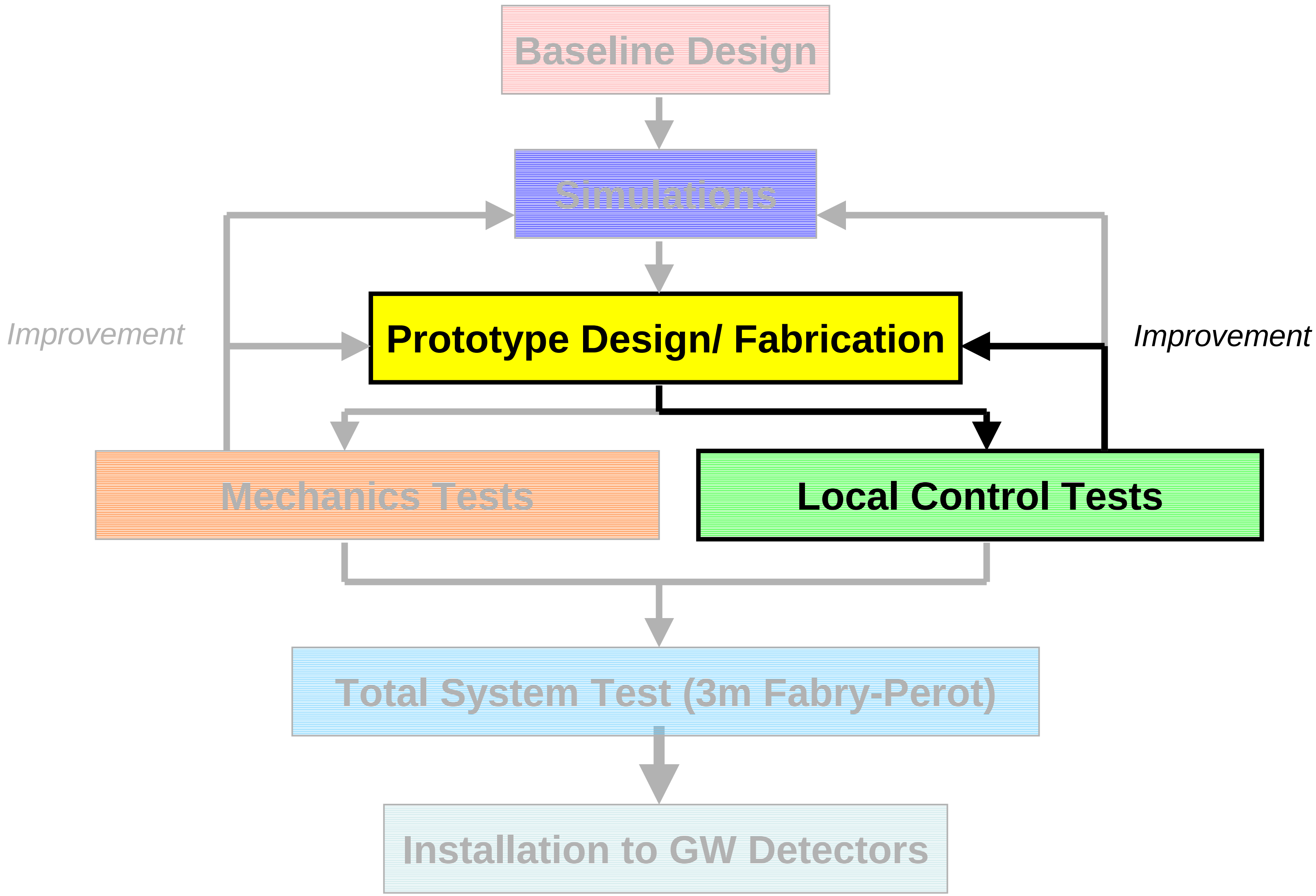


Longitudinal Isolation Performance

SAS Prototype TAMA SAS



SAS Testing Local Controls



SAS Local Controls

Principle & Features (1)

Active Velocity Damping

- Suppress Horizontal Rigid-Body Modes of SAS

Utilize Inertial Sensor (Accelerometer)

- Ideal Velocity Damping with Respect to Inertial Frame
- LVDT Position Sensor for DC Stabilization

Sensing / Acting on IP

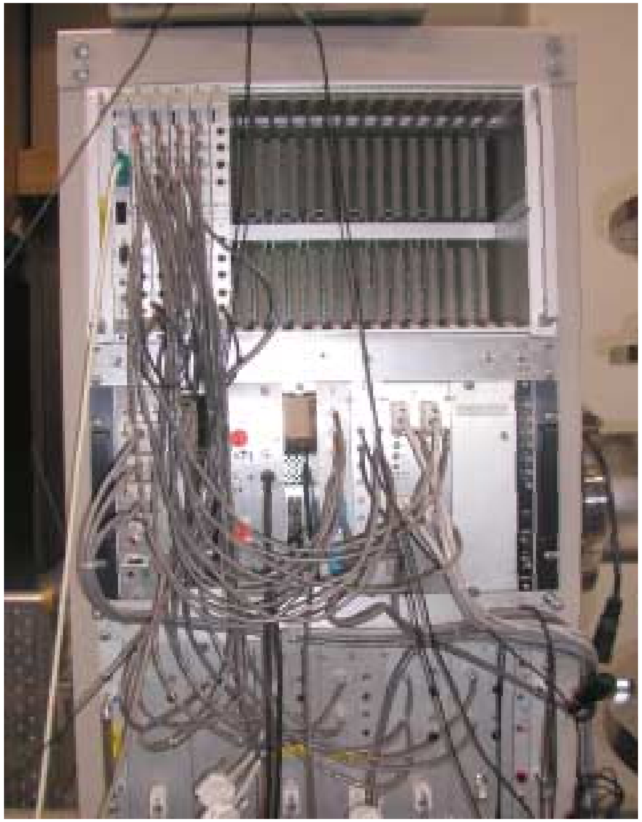
- Recoil Effect of Rigid-Body Modes
- Minimize Control Noises
  - Passive Isolation by MGASFs, Mirror Suspension
  - Limited Frequency Band: below 10 Hz

SAS Local Controls

Principle & Features (2)

Digital Signal Processing

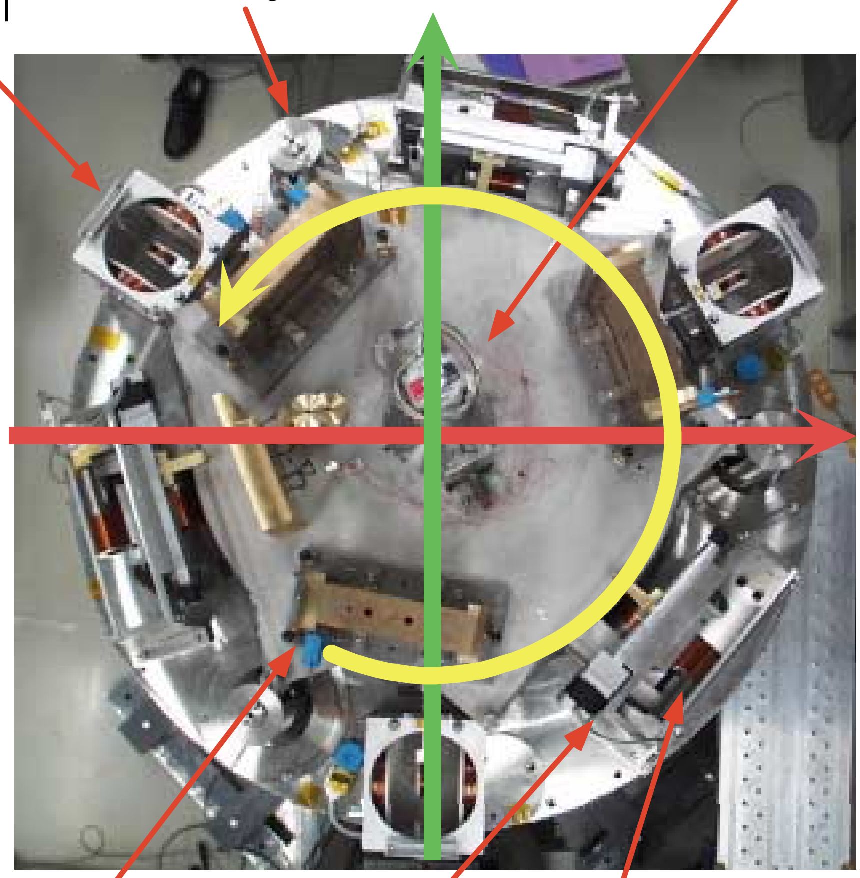
- Ultra Low Frequency (1 mHz) Filtering
- Flexibility for Servo Design



Local Controller Rack

SAS Local Controls

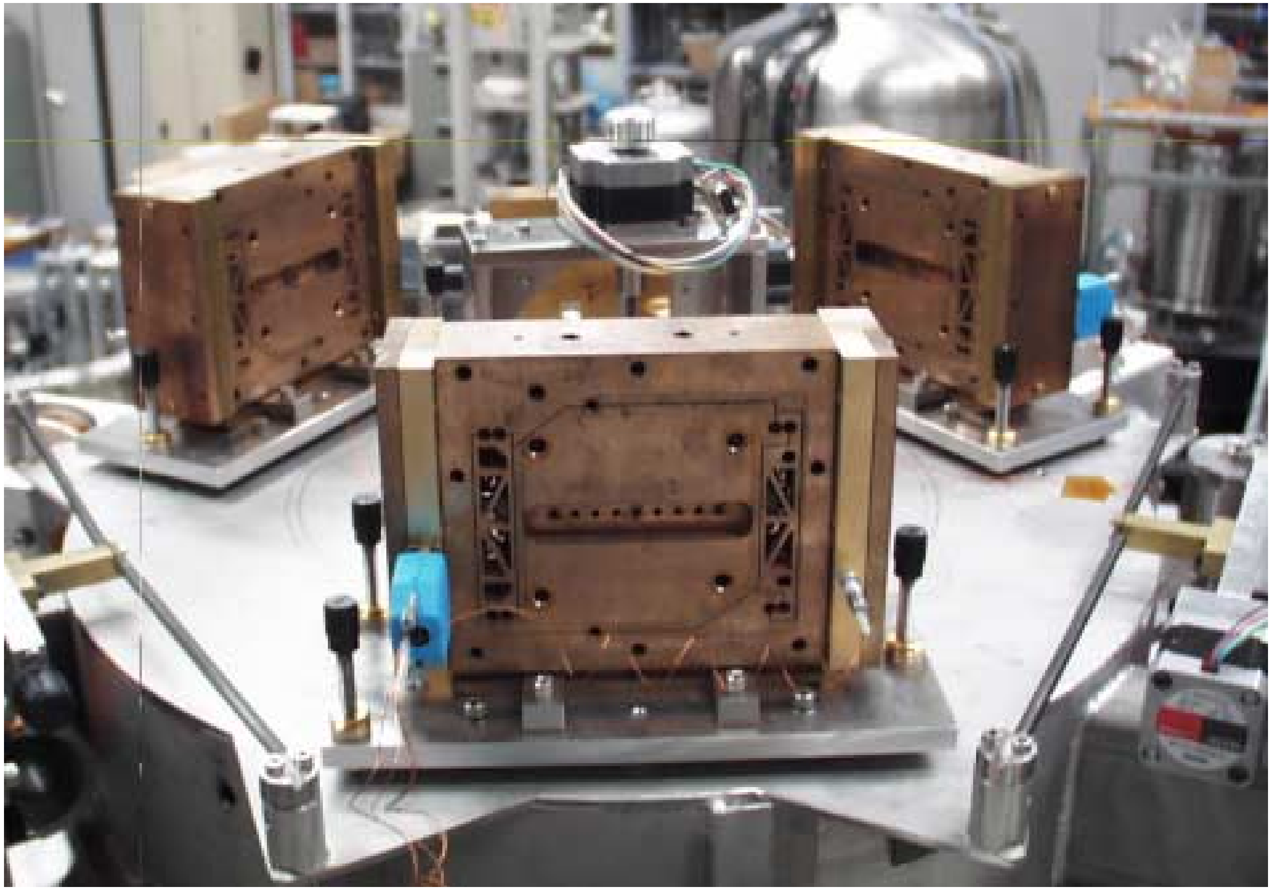
Apparatus



IP Top View

SAS Local Controls

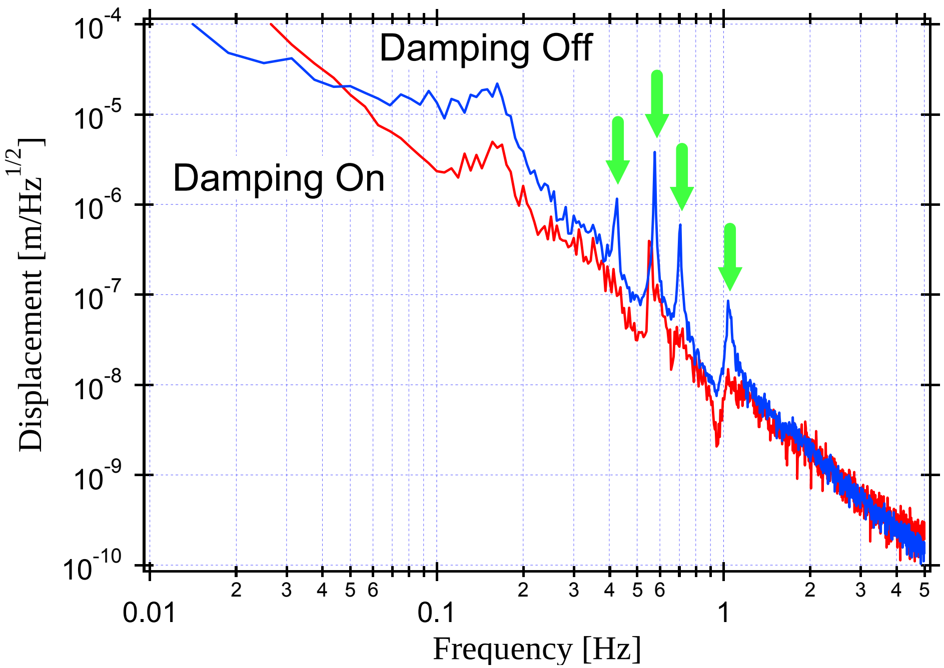
Accelerometer



SAS Local Controls

Experimental Results

- **Horizontal Rigid-Body Modes: Sufficiently Damped**
  - Residual Peak due to Cross-Talk from Vertical Mode
  - IP Motion at 1 Hz: 1×10^{-8} m/rtHz
- **Residual IP Motion**
  - 1×10^{-6} m: Suppression Factor =5



IP Motion Detected by Accelerometer out of the Loop

SAS

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Prototype Tests of Subsystems

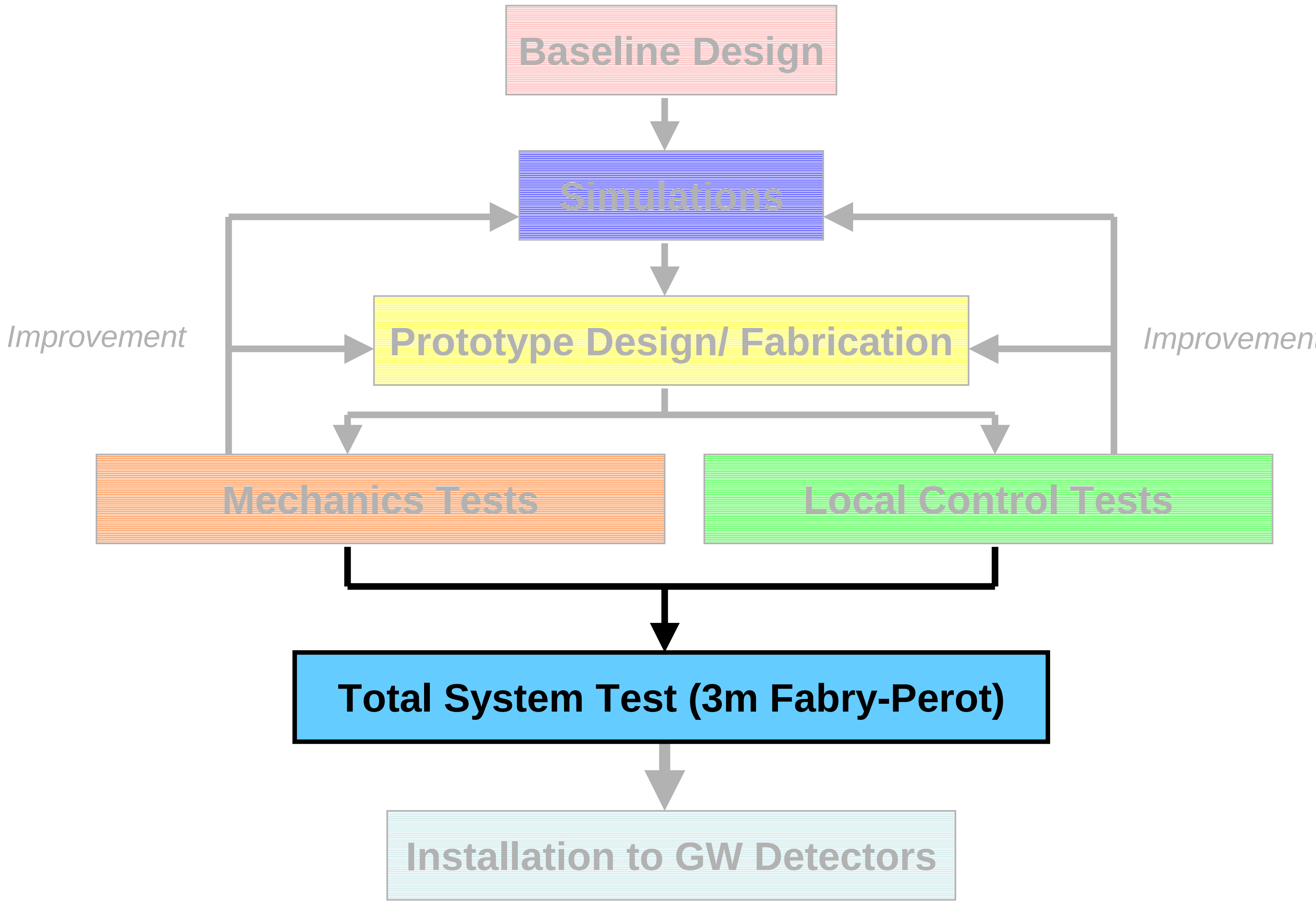
3m Fabry-Perot Experiment

- Setup
- Results

Summary

SAS

3m Fabry-Perot Experiment



SAS Scope

Evaluation of Total System of TAMA SAS

Components' Validation Completed

Demonstrate TAMA SAS Compatibility to F-P Operation

Quantitative Evaluation of Isolation Performance

- **Cavity Length Stability**
- **Effect of Local Control**
  - **With Respect to Frequency Stabilized Laser**

Collect Information for Justification for TAMA300

- **Handling, Stability, etc.**

SAS Setup

2 TAMA SAS Prototye Towers

- House 3m Fabry-Perot Cavity
- IP Resonant Frequencies: 40 ~ 70 mHz
- MGASF Vertical Frequency: ~ 500 mHz

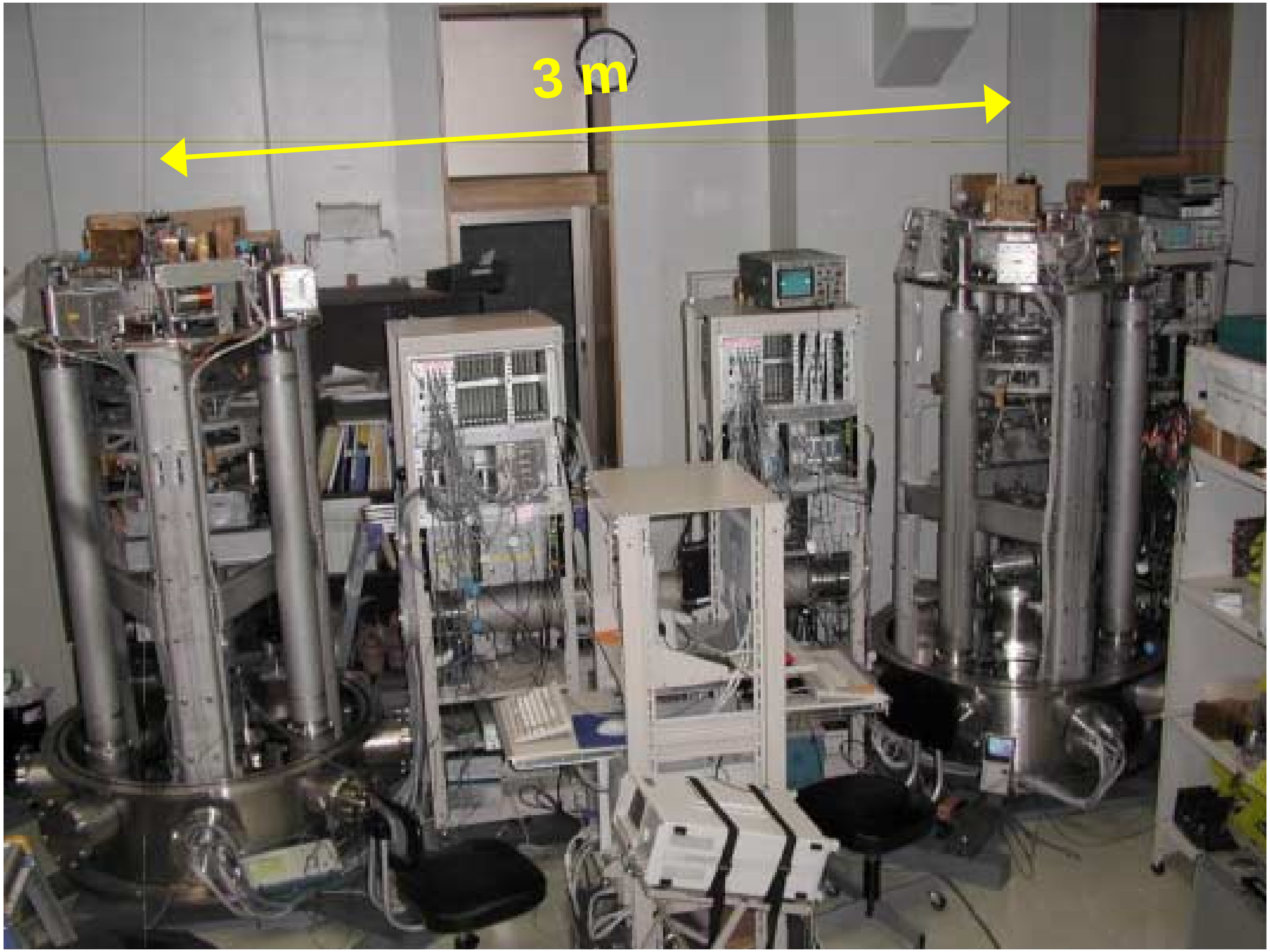
Optical System

- Nd:YAG Laser
- Frequency Locked to Rigid F-P Cavity

Vacuum System

- Scroll Pump
  - Operation ~ 0.1 Torr

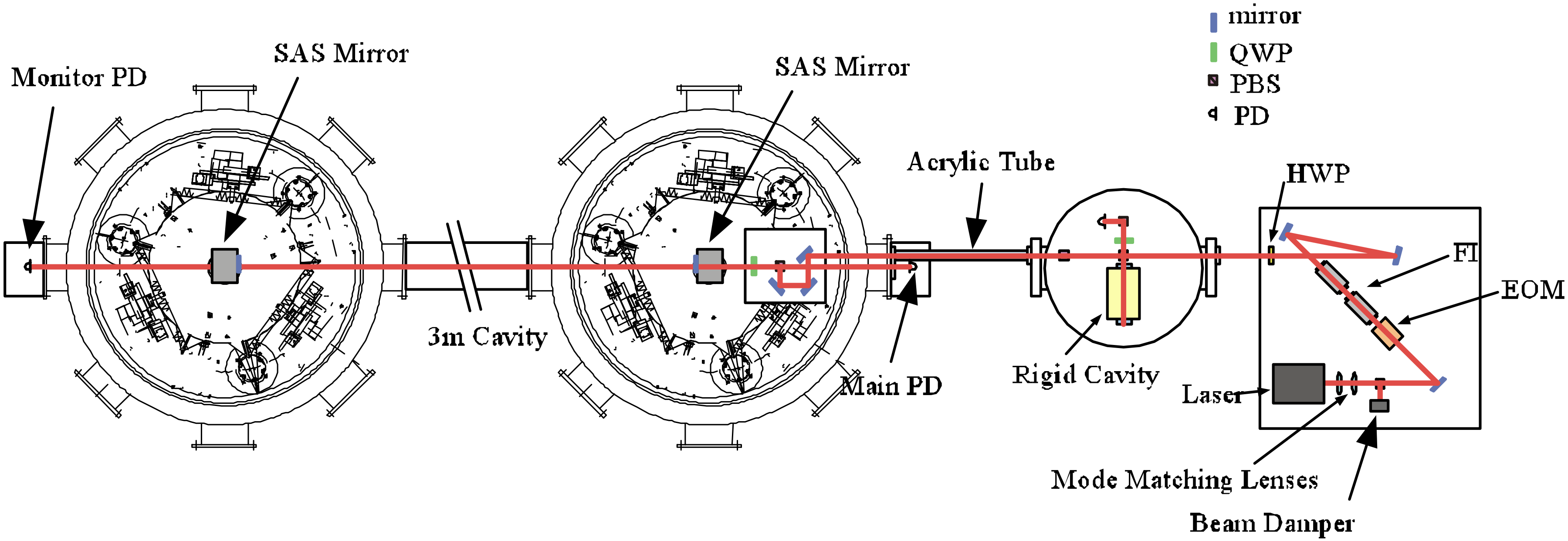
SAS Setup: Laboratory



SAS Setup

- 2 TAMA SAS Prototye Towers
  - House 3m Fabry-Perot Cavity
  - IP Resonant Frequencies: 40 ~ 70 mHz
  - MGASF Vertical Frequency: ~ 500 mHz
- Optical System
  - Nd:YAG Laser
  - Frequency Locked to Rigid F-P Cavity
- Vacuum System
  - Scroll Pump
    - Operation ~ 0.1 Torr

SAS Setup: Optics Layout



SAS Setup

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Optical System

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Vacuum System

- Scroll Pump
  - Operation ~ 0.1 Torr

SAS Setup: Vacuum Envelope

SAS 3m Fabry-Perot Cavity

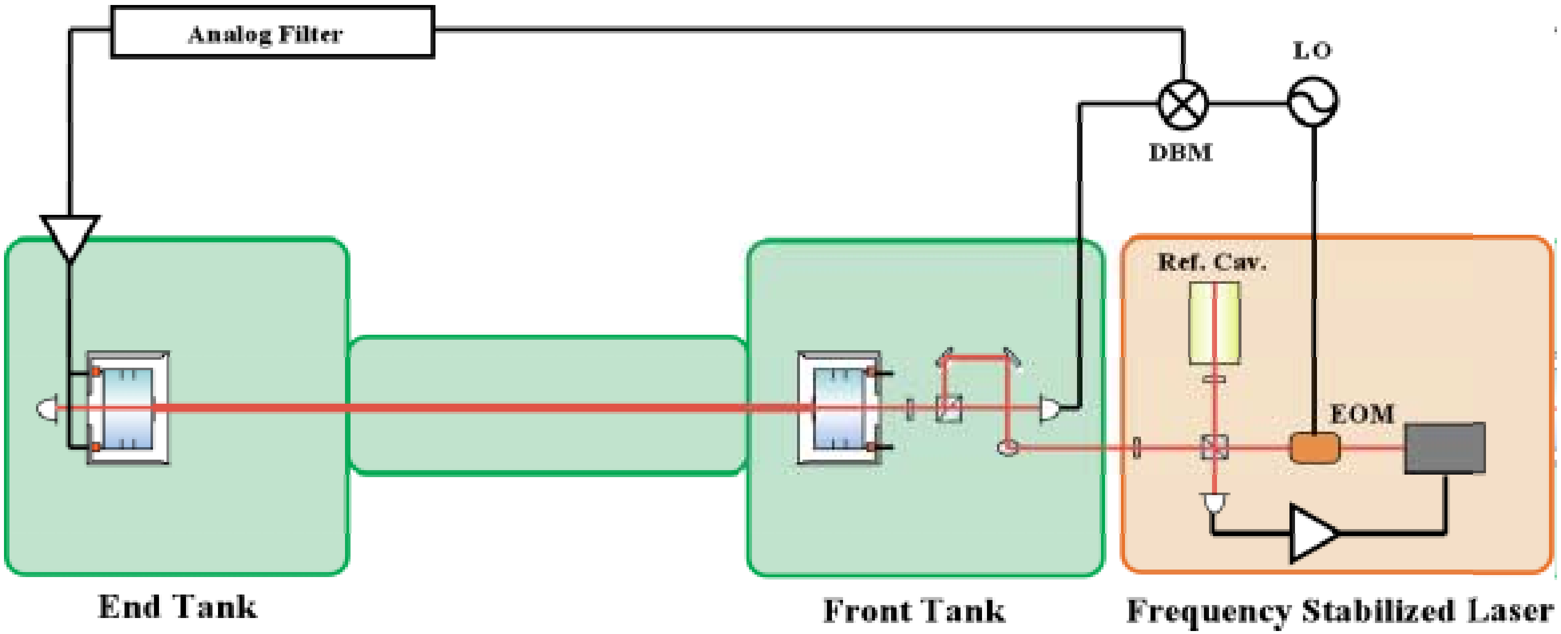
Length Control

Error Signal Obtained by Pound-Drever-Hall Technique

Feedback only to End Test Mass

Analog Filters (Bandwidth DC ~1 kHz)

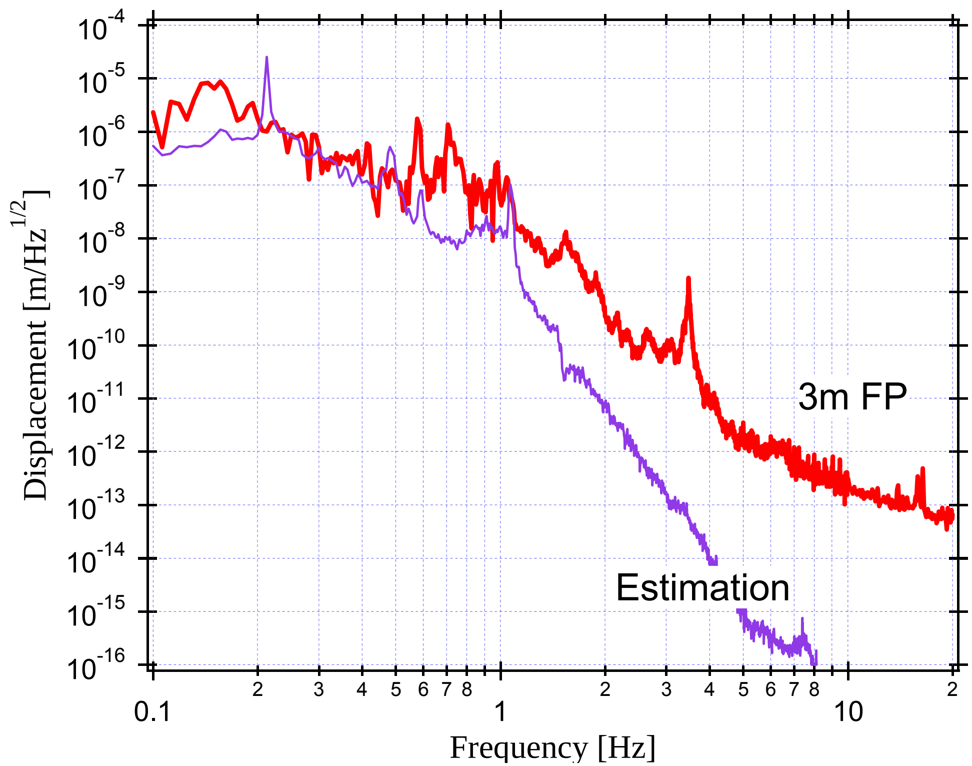
No Automatic Alignment Control



SAS Results (1)

Cavity Length Fluctuation

- 10^{-8} m/rtHz @ 1Hz (Floor)
  - No Common Mode Rejection Observed
- Stable Operation: ~4 hours (Intentionally Unlocked)

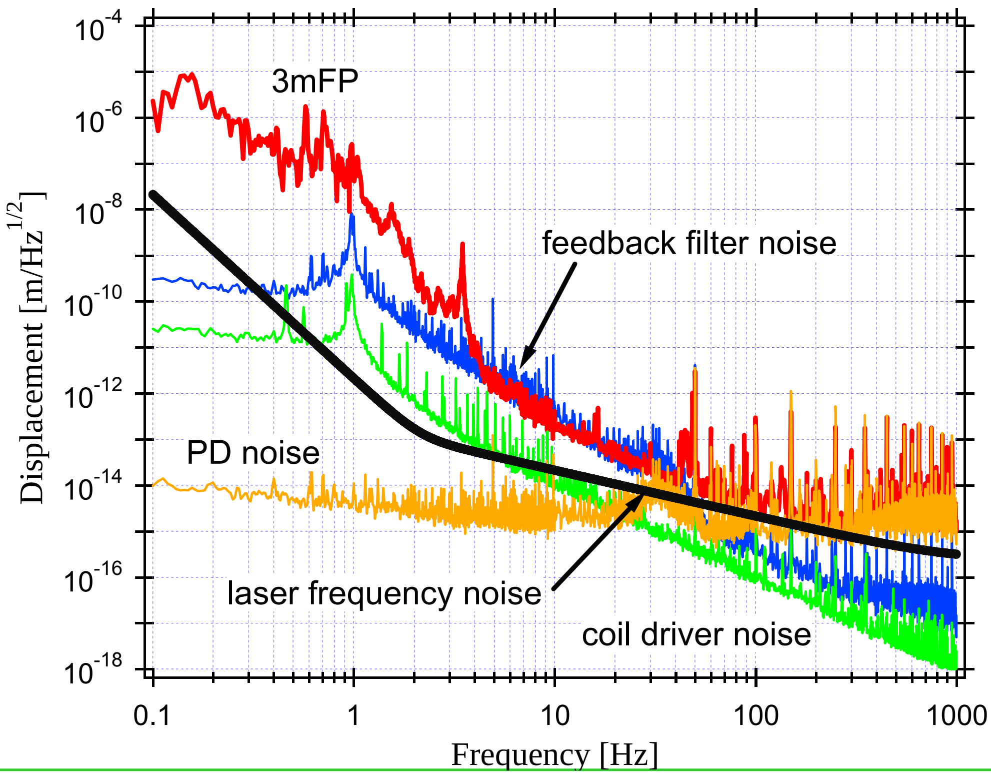


Length Fluctuation

SAS Results (2)

Noise Evaluation

- **1~3 Hz: Disagreement with Evaluation**
  - Possible Reason: Mirror Angular Fluctuation
- **Above 3 Hz: Electronic Noise Dominant**

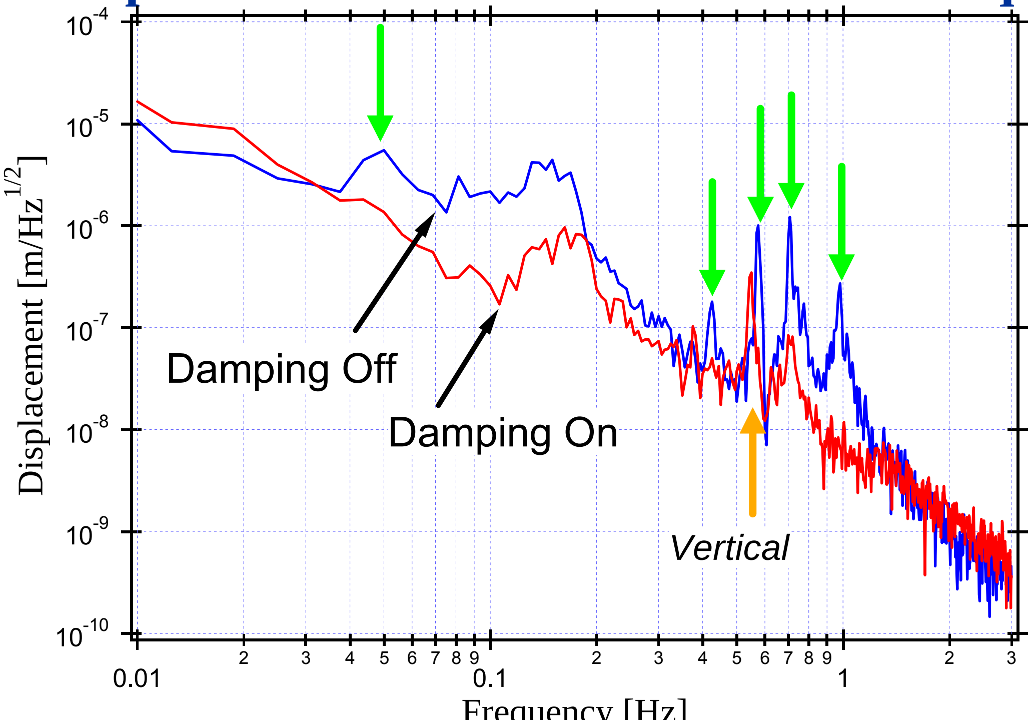


Evaluated Noises

SAS Results (3)

Effect of Local Control

- **Agreement with Measurements on IP**
- **Horizontal Rigid-Body Modes: Well Damped**
  - Residual Peak at 500 mHz: MGASF Vertical Mode
- **Improvement at Micro Seismic Peak Frequencies**



Damping Effect

SAS Results (4)

Effect of Local Control (cont'd)

– **Residual Motion (0.1 Hz ~ 10 Hz)**

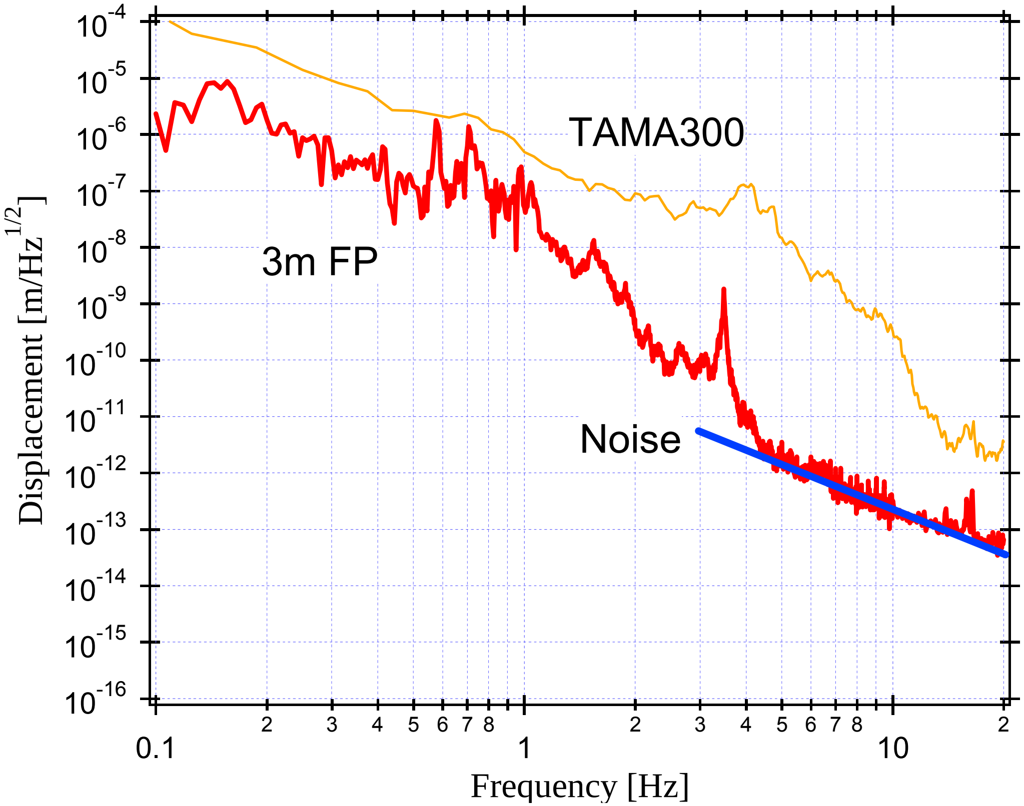
	Displacement	Velocity
Ground	1.2 μm	2.6 μm/s
F-P Cavity		
Damping Off	0.9 μm	1.2 μm/s
Damping On	**0.2 μm**	**0.3 μm/s**

Improvement Factor: 5 – 10

SAS Results (5)

Expected Improvement in TAMA300 Seismic Noise

- Below 10 Hz: Factor 100 – 10000 (Measured)
- Above 3 Hz: Over 10000 times (Estimated)



Displacement Noise

TAMA SAS

Contents

SAS Summary

SAS Components

- Individual Validation of TAMA SAS Prototype Components

  Mechanics

  Local Control System

Evaluated Total System Performance

- 3m Fabry-Perot Experiment

  Demonstrated TAMA SAS Compatibility to F-P Operation

  Residual Motion: Suppressed by Local Control

  Estimated Performance in TAMA300

  - Improvement Factor: 100 ~ 10000 (Experimentally Guaranteed)

Installation to TAMA300 in 2004, Baseline for LCGT

SAS Future Works

Installation to TAMA300, Future Detectors

- Further Evaluation in TAMA300
- Study on Hierarchical Controls
- Minor Modification
  - Frequency Matching for Better Damping Performance
  - Adding Initial Adjustment Devices
- Further Understanding on 3m FP Noise (1 – 3 Hz)
- Study on Compatibility to Cryogenic Mirror Suspension (LCGT)

Other Applications

- Reference for Laser Frequency Stabilization
- Sensor Noise Measurement Facility (Accelerometer)
- Low Frequency Accelerometer (Seismometer)