Detector Status

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27 Oct 98

- Brief schedule/cost update
- Top-level status of each Detector subsystem
  - › design, procurement, fabrication
  - › technical highlights
- R&D activities for initial and advanced LIGO

Detector Milestones

Milestone Description	Management Plan Date	Completion Date
BSC Stack Final Design Review	04/98	08/98
Core Optics Support Final Design Review	02/98	11/98
HAM Seismic Isolation Final Design Review	04/98	06/98
Core Optics Components Final Design Review	12/97	05/98
Detector System Preliminary Design Review	12/97	10/98
I/O Optics Final Design Review	04/98	03/98
Prestabilized Laser Final Design Review	08/98	11/98
CDS Networking Systems Ready for Installation	04/98	03/98
Alignment (Wavefront) Final Design Review	04/98	07/98
CDS DAQ Final Design Review	04/98	05/98
Length Sensing/Control Final Design Review	05/98	07/98
Physics Environment Monitoring Final Design Review	06/98	10/97
Initiate Interferometer Installation	07/98 WA, 01/99 LA	07/98 WA, 01/99 LA
Begin Coincidence Tests	12/00	12/00

Detector Cost Status

Subsystem	Budget	Cost and commitment	Estimate at completion
Control and Data	13497	8787	13409
Physics Environ. Monitor	2196	1067	2052
Pre-Stabilized laser	3210	2728	3148
Input Optics	1860	1886	2149
Core Optics	8102	7517	7979
Core Optics Support	2021	812	1999
Alignment Sensing/Control	4820	2105	4589
Length Sensing/Control	1695	1013	2049
Suspensions	3443	1451	1714
Seismic Isolation	11762	9664	13488
Systems	2244	1886	2231
Support Equipment	1563	640	1566
TOTAL	56414	39556	56372

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Control and Data System (CDS)

Function:

- communication infrastructure, data acquisition, individual subsystem control/monitoring (addressed with subsystem)

Status:

- Final Design Review for Length/Alignment sensing for early 99
- all other Final Design Reviews complete and successful
- detailed layout/engineering/fabrication underway
- installation underway at Hanford

LAN installed at Hanford

- system in use for scientific computing and facilities monitoring

Vacuum controls finished

- complete and in use at Hanford
- being exercised as part of Vacuum Equipment installation at Livingston

Data acquisition

- prototype complete and accepted

Physics Environment Monitor

Function:

- to monitor environment, provide veto and regression information; provide excitation to help characterize interferometer

Status:

- Final Design Review complete; design complete except for cosmic muon detector
- first articles installed for several elements (residual gas analyzer, weather, excitation, stand-alone DAQ)
- installation paced by other activities: vacuum equipment, seismic isolation; all elements ready when needed

Support for seismic isolation first article tests

- used to characterize dynamic performance
- sensors, excitation systems, DAQ employed/exercised

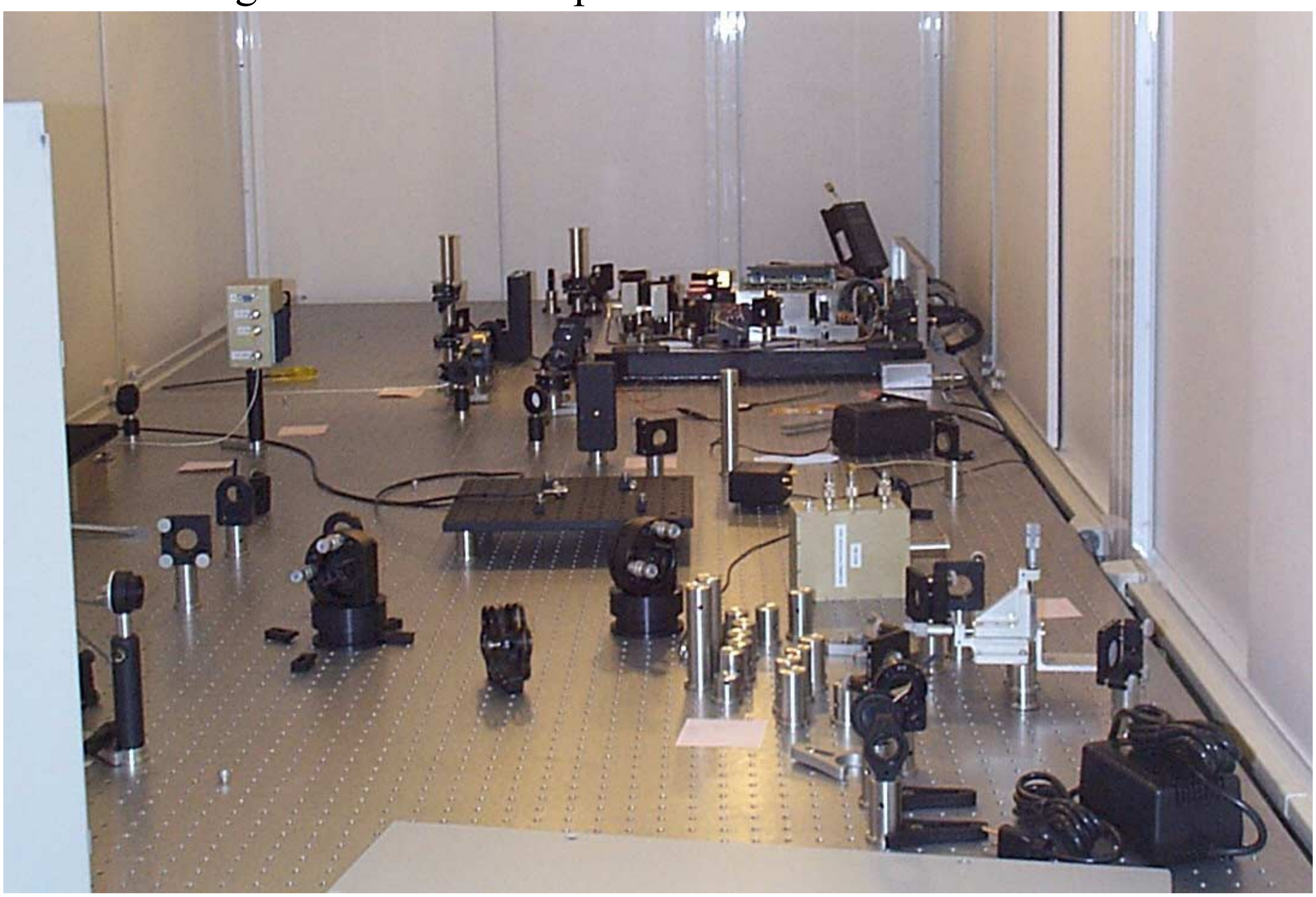
Pre-Stabilized Laser

Function:

- supplies the light to the interferometer, includes the 10W laser source; important element in the overall servocontrols approach

Status

- **first article installed at Hanford (initiated installation of Detector)**
- testing of prototypes completed
- Final Design Review to take place in November '98



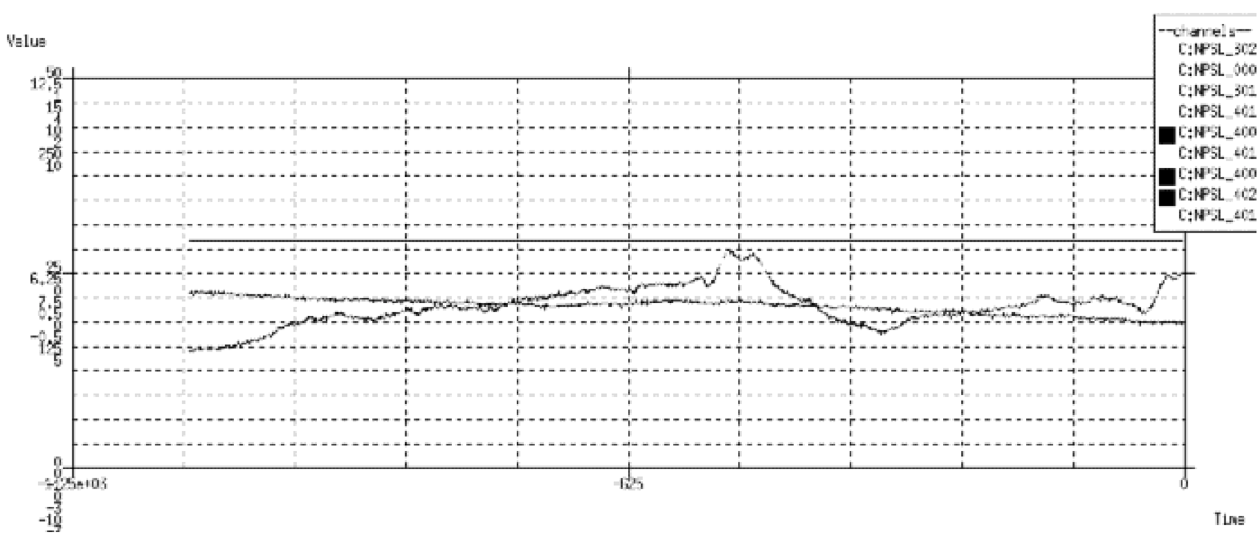
Pre-Stabilized Laser

Laser source

- source lasers showing good reliability
  - › 2000 hours, <3% drop in power
- now commercially available from Lightwave as ‘20 W laser’
- first ‘option’ laser in house - production running on schedule

Prototype tests

- good ‘standalone’ noise performance
- high availability --- days of continuous operation of servosystems
  - › frequency stabilization servo, the PMC servo, the intensity servo and the temperature stabilization servo
  - › robust against environmental changes



Input Optics

- temporal and spatial low-pass filtering of input light, matching of light into the interferometer; important element in servocontrol
- University of Florida has designed and is delivering/installing subsystem
- 2k suspensions completed, most optics in house
- installation for LHO 2k interferometer started, staging at Hanford

Detection system for matching prototyped/tested

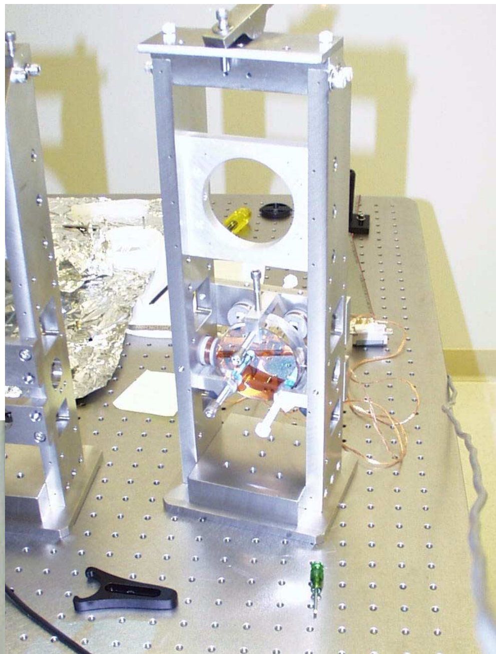
- bulls-eye sensor for circularly-symmetric modes
- dithering system allows independent test, calibration of wavefront sensor

Large optics advancing nicely

- Test-mass sized last mirror presents manufacturing challenges
- long radius of curvature, usual size constraints
- polished, in-house, characterization in process

Input Optics

Setup of suspensions underway at Hanford



- Small Optics Suspension

- UFla and Hanford staff balancing one of the Input Optics

Core Optics Components

- optics for the interferometer, test masses for the strain detection
- all core optics substrates procured, ground; only 6 left to polish, 16 to coat (out of 40)
- testing commencing for figure, loss, point defects
  - › 25-100 defects, >2.5 microns (~20ppm scatter)
- cleaning procedures in qualification

In-house metrology

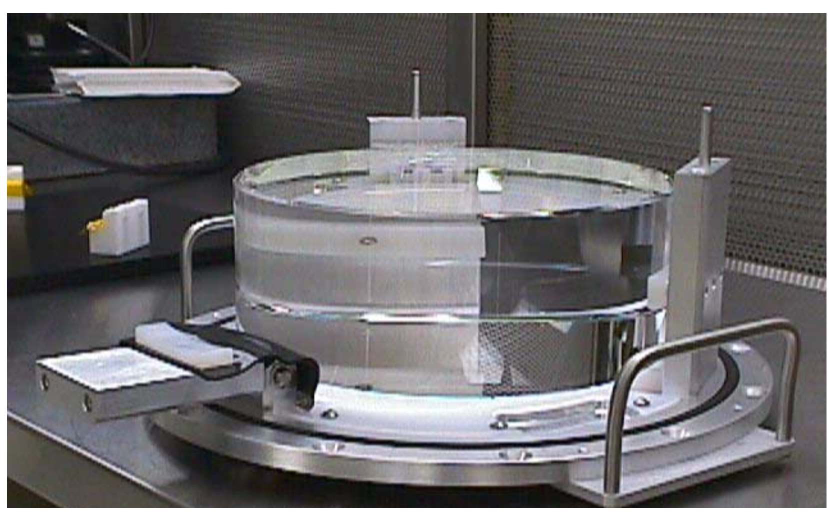
- initial interferometer vendor could not deliver, second vendor has had difficulty
- interferometer now in-house, accepted, and in tests/practice runs
  - › best repeatability of 0.2 nm,

Some difficulties with coating

- improper cleaning at vendor, re-coating needed; improved QA now in place (LIGO personnel present for procedure)
- spares philosophy appears about right

Overall development effort a smashing success

- polishing, metrology, and coating technologies all advanced
- LIGO requirements met or exceeded



Core Optics Support

- Function: bring light out of interferometer for sensing/monitoring; contain scattered light; ‘dump’ unwanted beams
- Preliminary Design well advanced; Final Design Review in November
- detailed design of telescopes well advanced
- prototypes of parts installed in mock-ups

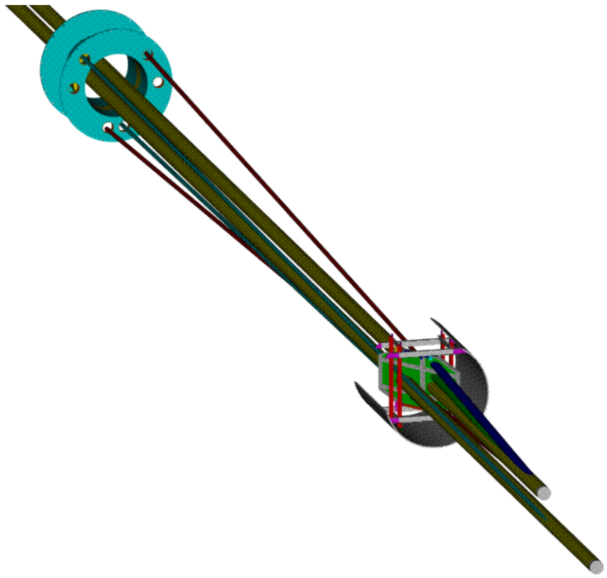
Wavefront flatness a challenge

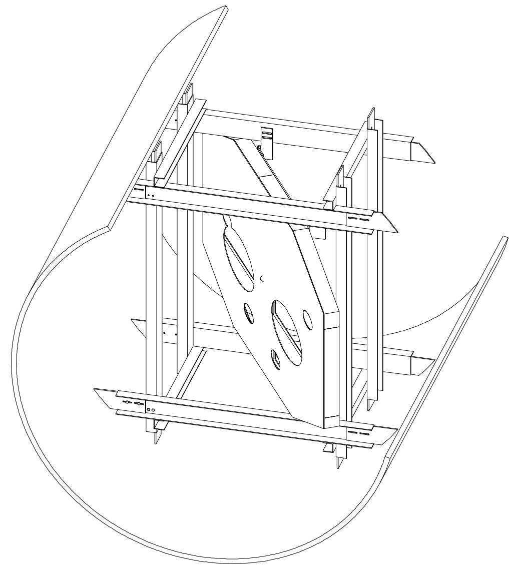
- Alignment sensors require small astigmatism, other distortions
- places strong requirements on beam-reducing telescopes
  - 0.7λ peak-valley phase flatness

Strong interaction with overall optics layout

- baffling must accommodate pointing beams, ghost beams

- has driven (and contributed to) integrated optics layout





Initial Alignment

- establishes the position and angle of optical components at moment of installation; maintain external pointing references to allow quick bootstrap to operational alignment, ease servicing work
- equipment for initial surveying in-house and qualified
- tests of basic procedures exercised at MIT
  - › 80 microrad initial alignment requirement easily fulfilled
- optical lever assemblies in fabrication or shipped

Prototype tests

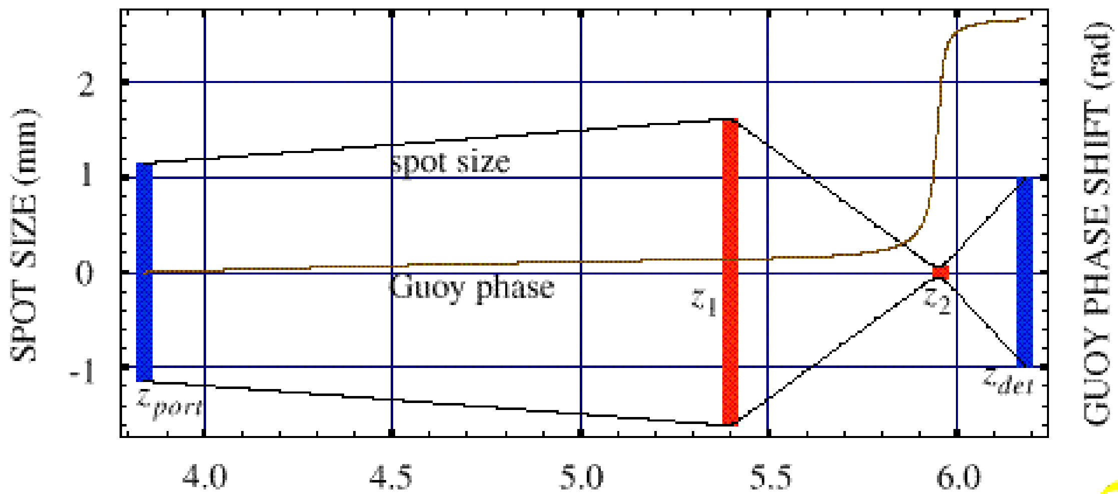
- stability of pointing system exceeds requirements
  - › 50 microrad peak over weeks requirement

Interaction with facilities driven integrated layout

- Vacuum equipment: as-built viewports, deflections on pump-down
- Civil construction: placement of surveying markers, stability

Alignment Sensing/Control

- maintains operational alignment
- prototype tests of sensors completed
- detailed soft/Hardware engineering underway
- details of transformation optics in design



Use on suspended prototypes central to research

- Phase Noise Interferometer
- 40m Interferometer
- models confirmed quantitatively

Digital servo

- 10 degrees-of freedom to sense, control
- requires fully multiple-input multiple-output system
- low bandwidth, but state changes, saturation, sharp filters
- in prototype tests

Length Sensing/Control

- acquire, maintain the operational lengths for the interferometer; read out gravitational-wave strain
- now in detailed software development

Suspended interferometer test of digital control

- MIT Phase Noise Interferometer demonstration (details under R&D)
- proof-of-practice for critical dynamic range and servo questions

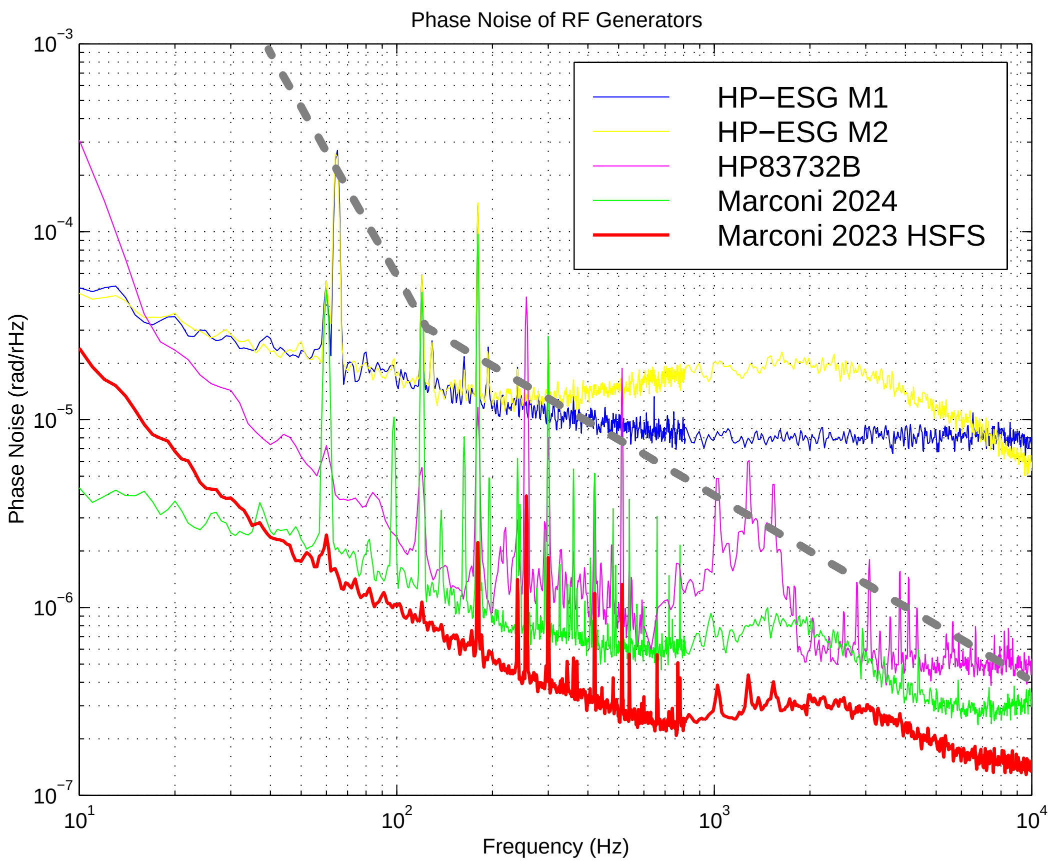
Acquisition modeling well advanced

- modifications but especially exploitation of dynamic model
- increases in calculated critical locking velocity of factor of 10
  - › 3λ/sec; implies locking in several seconds
- also progress on determining initial alignment requirements, with results comparable to earlier expectations

Length Sensing/Control

Modulation source

- comparison of commercial systems for phase noise
  - best is not most expensive
- amplitude stabilization to below $10^{-8} 1/(\sqrt{\mathrm{Hz}})$ requirement



Suspensions

- support test mass and other optics but not compromise thermal noise performance; provide actuators for positioning optics in angle and position
- Final Design Reviews and detailed design completed
- Small Optics Suspensions fabricated
  - › mechanical parts by University of Florida (used in Input Optics)
  - › electronics by Control and Data Systems
  - › in installation at Hanford
- Large Optics Suspension prototype iterated, now in production

Alternative means for attachments investigated

- magnets attached to test masses, used as part of actuator system
- epoxy used to date; cleanliness and assembly time disadvantages
- exploring use of Indium

› measurements indicate better thermal noise performance; roughly 10^{-7} for Indium, factors 3-10 greater loss for epoxy

- Suspension installation fixture in initial setup and test

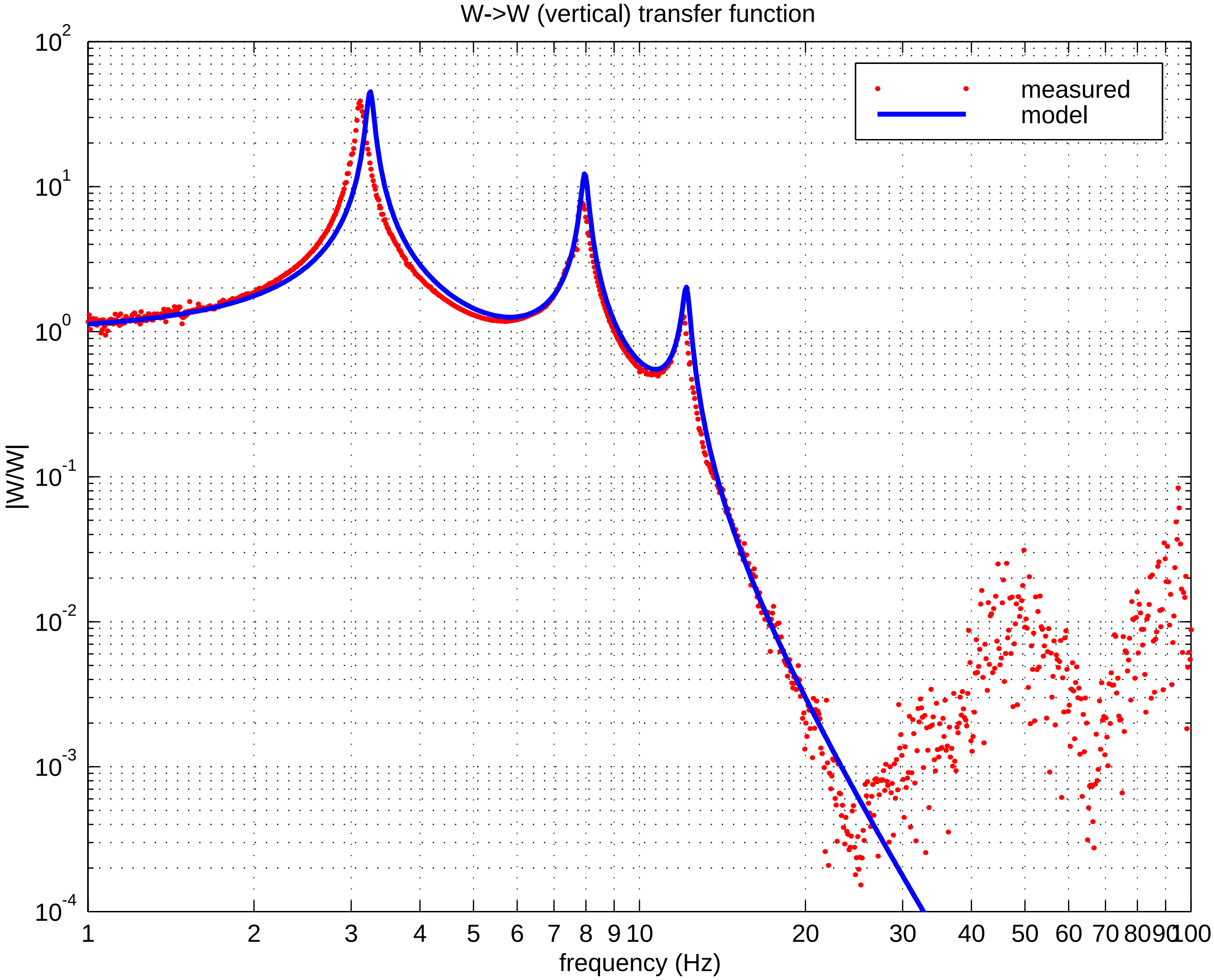
Seismic Isolation

- provide attenuation of seismic noise in-band (>30 Hz); provide actuation at microseismic peak (0.16 Hz); provide coarse positioning, drift compensation
- Final Design Reviews complete
- First article fit-check tests of both basic designs complete
  - HAM (Horizontal Access Module - input optics)
  - BSC (Basic Symmetric Chamber - test masses)
- some remaining issues/tests
  - air-bearing (used as part of positioning)
  - fine actuator and coarse actuator linkage
- fabrication underway for most parts
  - complicated parts, complicated cleaning procedures
  - installation rate will be limited by production rate

Seismic Isolation

First article tests of great value

- in addition to fit checks, fixturing; screw thread clearance; need for left handed springs...
- training for installation and tests of integration approach



- dynamic tests --- comparison with models very good

Research and Development

R&D in support of the initial detector

- largely complete
- efforts to provide 'agile support' for problems discovered in fabrication or field, for example
  - tests of Indium bonding to test masses
  - prototyping of digital controls
- 40m interferometer and Phase Noise interferometer work

Advanced R&D for future improvements to LIGO detectors

- medium- and long-term research programs
- range from engineering obvious solutions to exploring inklings

40m Interferometer

Objectives:

- experience with LIGO configuration on a suspended interferometer
- tests of data acquisition soft/hardware and diagnostics approaches

Difficulties

- continued poor reliability of Argon laser
- recent loss of scientist leading effort
- re-focus on near term goals

Successes in automated alignment, using digital techniques

- alignment control a pre-requisite for operation
- digital loop used to ease matrix transformation

Exercise of the dynamic model for locking

- light storage time comparable to LIGO (high finesse cavities)
- allows comparisons with locking design code

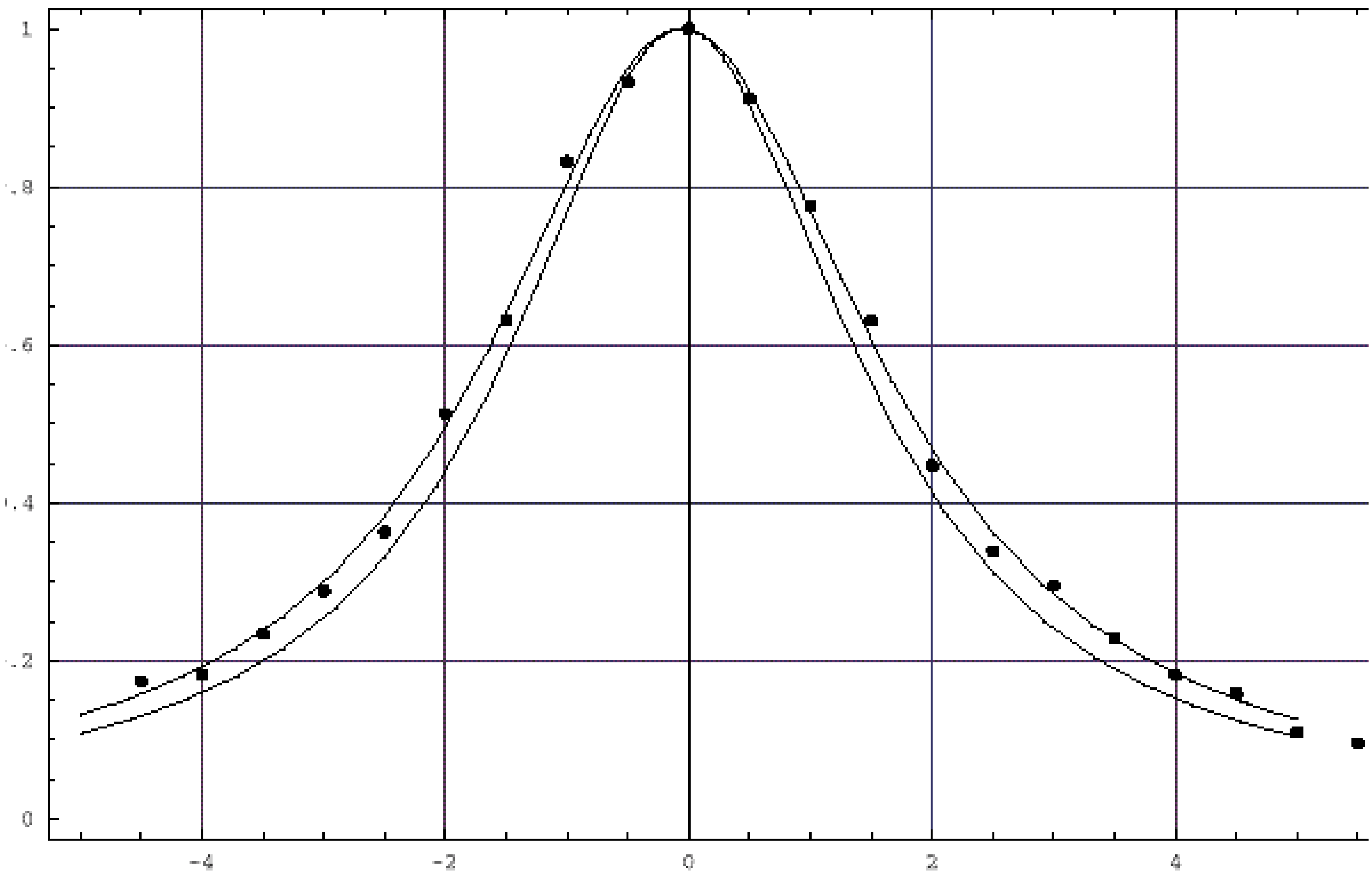
Development of diagnostic techniques on LDAS/DAQ prototype

- full LIGO data acquisition system
- real-time techniques as well as viewing/post-analysis tests created

40m Interferometer

Development of probes of optical performance

- new ways to examine the mode structure of the cavities
- sweeping of modulation frequency, transmission/reflection analyzed



- excellent match of data and model for resonance form
- indication of lack of competing nearby modes to pull error signal

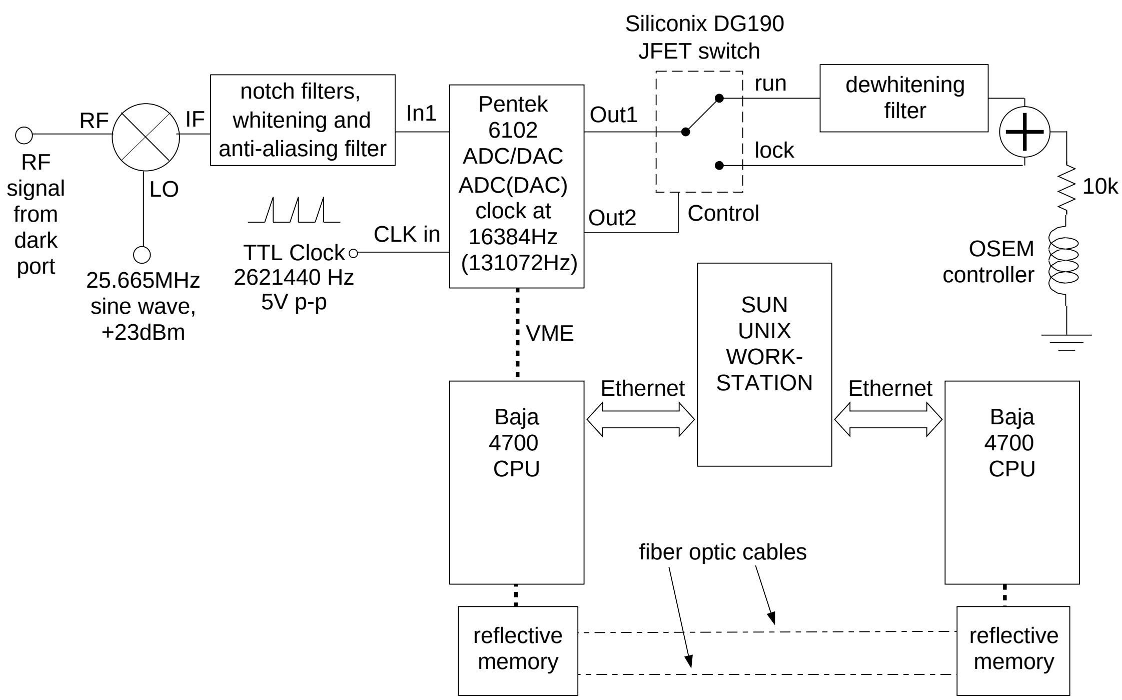
Phase Noise Interferometer

Objectives:

- phase noise demonstration: successfully completed
- tests of digital servoloop technology, real time diagnostics
- tests of photodetection system

Configuration

- power-recycled Michelson
- very similar dynamic range, intensity demands to those in LIGO
- digital filter function/gain replaces analog system
- second crate linked via reflective memory



Phase Noise Interferometer

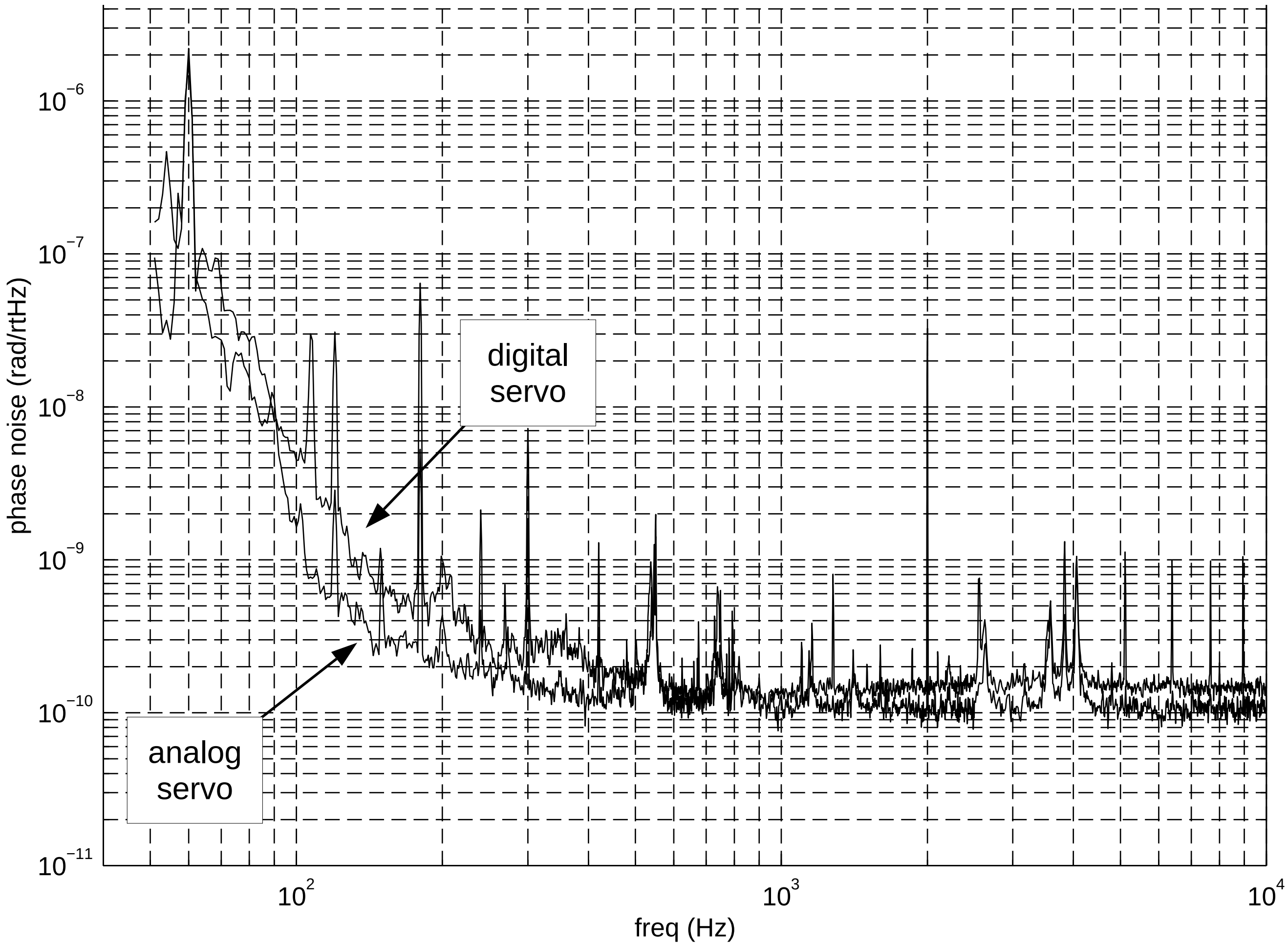
Servoloop tests

- similar loop gains, noise performance to (excellent) analog system
- resonant gains, adiabatic transfer function changes, state switching for acquisition tested successfully

Status

- demonstration complete, lessons learned passed on to design team
- system dismantled with MIT move in July

- chambers now used in other experiments



Advanced R&D

INTERFEROMETER CONFIGURATIONS

- Objective: explore means to tune the frequency response of advanced detectors to match instrument or astrophysical signatures
  - demonstrate Resonant Sideband Extraction on a tabletop Technique: addition of output recycling mirror to make gravitational wave sidebands resonant or anti-resonant
- Experiment: table-top prototype experiment using a control scheme which could be employed in LIGO
- James Mason, CIT graduate student, leading experiment

Status:

- modeling complete; start of construction of system in June
- lab set up, mirror mounts/actuators built, electronics controls designed, built, and tested
- 3-mirror cavities locked, more components being added
- anticipated February '00 completion with planned outcome a recommended design for LIGO

Advanced R&D

SAPPHIRE TEST MASS DEVELOPMENT

- Objective: to push technology of sapphire as optical and mechanical element for advanced LIGO designs
- Technique: international collaboration (VIRGO, ACIGA) to push fabrication techniques, characterize materials

Status:

- Materials procured from Crystal Systems, and China Institute of Optics (SIOM)

- Characterization of optical absorption losses in ACIGA, Stanford, VIRGO; range of values, but generally higher than anticipated (100 ppm/cm), feedback given to producers on some suspects
- General Optics polished a15cm dia surface; difficulties in obtaining a reasonable figure due to bulk fault(s), will try again with new sample
- Mechanical Q testing performed at Caltech
  - › Qs greater than 1×10^{7} seen, but many lower
  - › iterating suspension technique, excitation system

Advanced R&D

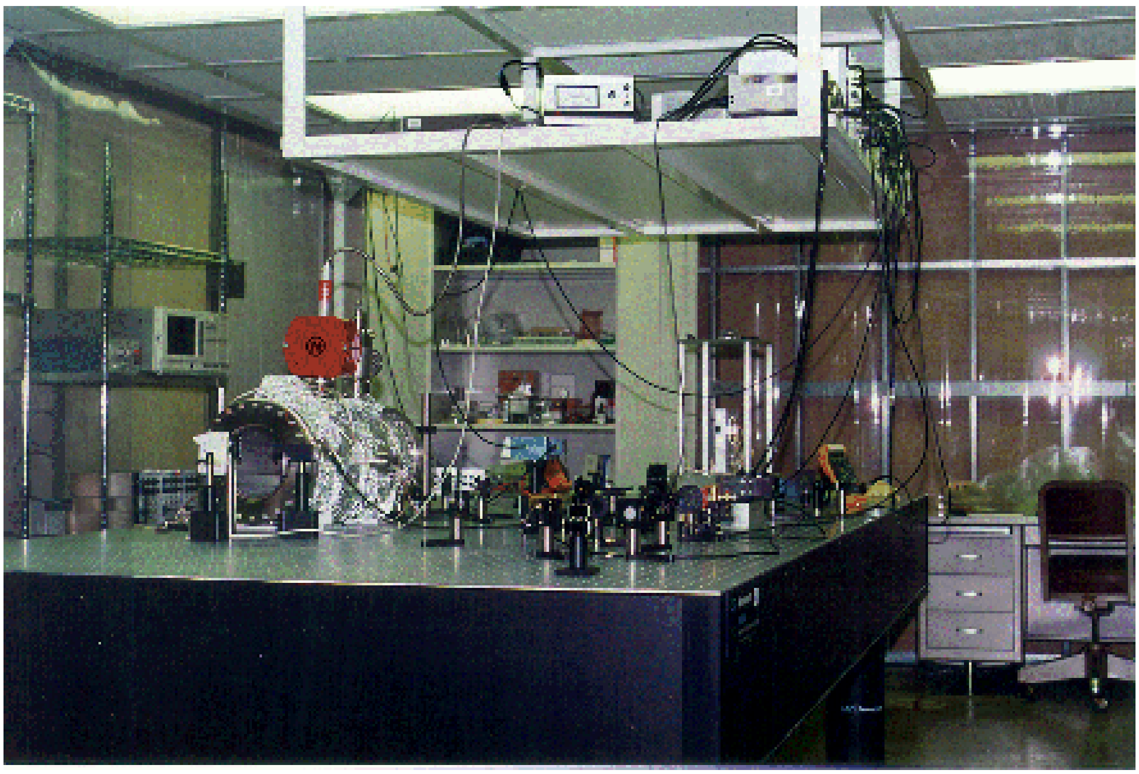
THERMAL NOISE INTERFEROMETER

- Objective: direct measurement of thermal and excesses in realistic suspension systems
- Technique: short-baseline special-purpose interferometer
  - › makes seismic noise ‘common-mode’
  - › relaxes laser frequency-noise requirements
- first measurements on LIGO-I like suspensions
  - › allows learning curve with familiar wire loop
  - › can help debug LIGO-I problems
- later work with advanced LIGO components (fused quartz suspensions)

Advanced R&D

THERMAL NOISE INTERFEROMETER Status

- the pre-stabilized laser has been assembled and tested with a second reference cavity, and functions well



- vacuum chamber and stack (from the Phase Noise Interferometer) are in assembly;
- taken delivery of all the significant optics
- optics suspensions and controls in design/construction
- plan to collect first complete data by December ‘98

Advanced R&D

SUSPENSIONS

- Objective: reduced thermal noise and better isolation for near-term LIGO enhancements
- Technique: incorporation of a fused-quartz suspension, re-allocation of actuator authority
- Experiment: tests of prototypes; ultimately full-scale engineering tests
- Status: infrastructure coming together; design work underway

- Full-scale Advanced System Test Interferometer installation November 2

First tests in smaller vacuum system:

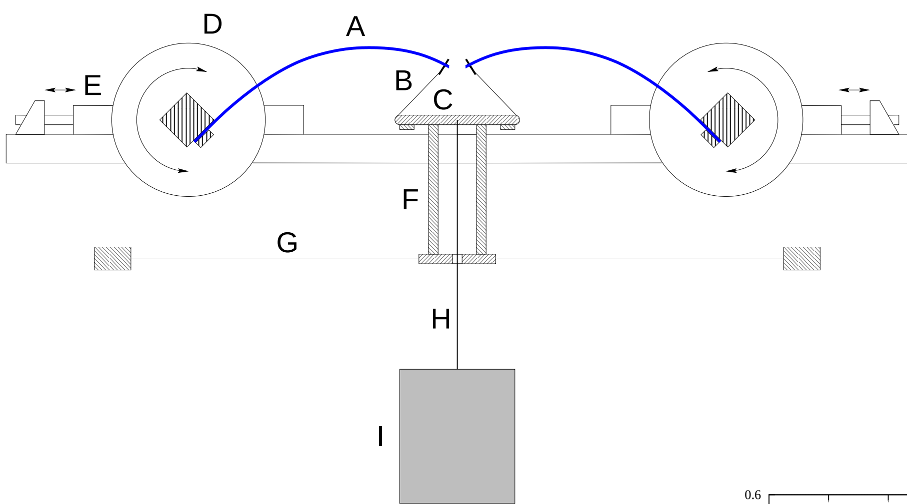
- tests of GEO suspension
- charge control
- tests of sample pre-isolator
- December start of shakedown/tests

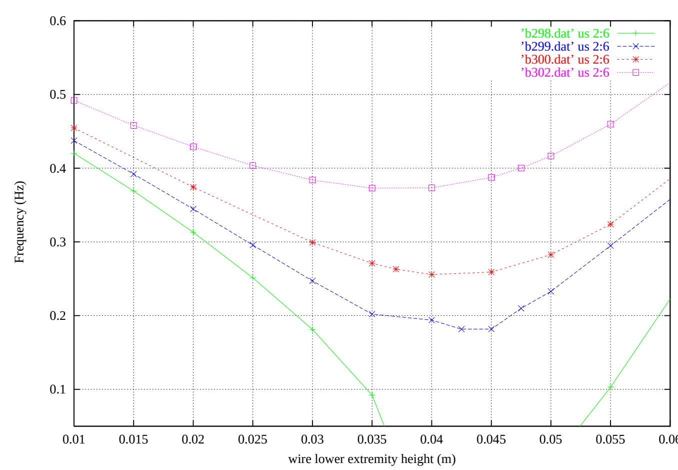
First results by March '99

Advanced R&D

ISOLATION

- Objective: exploration of techniques for advanced seismic isolation
- Technique: redesign and test of VIRGO-like isolation systems
- Experiment: tests of vertical isolation system
- Status: prototype designed, assembled, in first test
  - › low vertical resonant frequencies achieved
  - › sensitive parameters explored





Advanced R&D

FUSED QUARTZ SUSPENSION FIBER DEVELOPMENT

- Plan to develop means to produce reliable reproducible fibers
- ‘lathe’ on order, lab being set up, modeling underway

ADAPTIVE OPTICS

- Plan to develop correction for thermal lensing in test mass substrates, due to absorption of laser beam in substrate and on surface
- experiment in construction (in Phase Noise Interferometer vacuum tank), MIT Grad (Ryan Lawrence) leading effort
- first results in March ‘99

Detector: Summary

Design very nearly complete

Prototyping and first article testing very nearly complete

Fabrication started for most subsystems

Detector effort still (essentially) on schedule and no significant problems

The challenge, and excitement, is becoming the installation

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