Detector Construction & Installation

Overview and Status

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NSF Spring Review
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LIGO Livingston Observatory
Livingston, LA

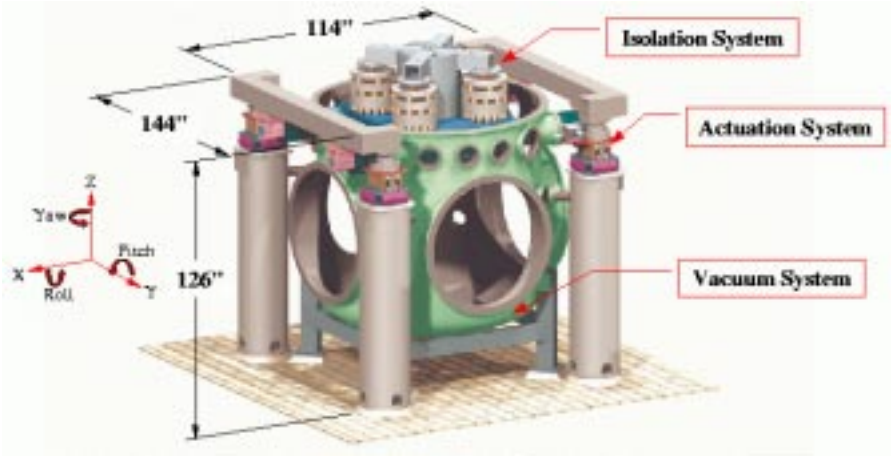
Outline of this talk

- Detector Subsystem Construction & Installation Status
  - Top-Level Status of each Detector Subsystem: design, procurement, fabrication, technical highlights or problems
    - Seismic Isolation System (SEI)
    - Suspensions (SUS)
    - Core Optics Components (COC)
    - Pre-Stabilized Laser (PSL)
    - Input Optics (IO)
    - Core Optics Support (COS)
    - Interferometer Sensing and Control (ISC)
    - Control and Data Systems (CDS)
    - Global Diagnostics System (GDS)
    - Physics & Environment Monitoring (PEM)
- Overall Detector Installation
  - General Comments
  - Performance Against the Plan/Schedule
- Response to 10/98 NSF Review Panel Recommendations

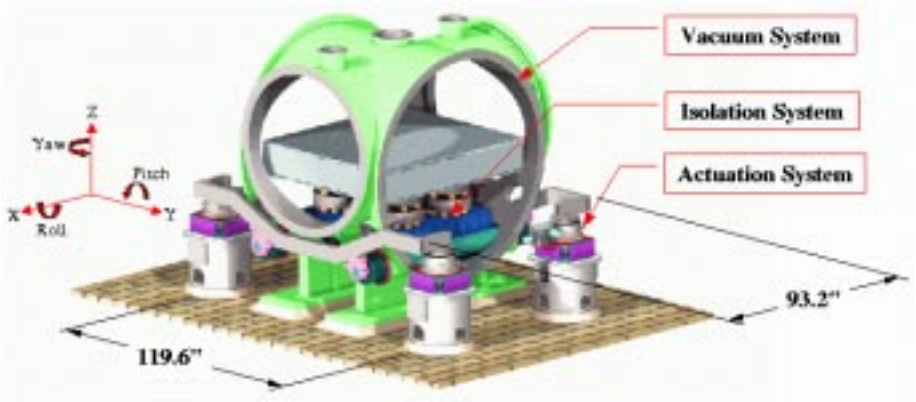
Detector Construction
Seismic Isolation System (SEI)

- Design & first article testing is complete with the exception of servo-control design of the fine actuation system
  - The fine actuator subsystem design meets requirements and components are in production or procurement
  - LIGO will undertake the servo-loop design for tidal motion compensation and mirco-seismic peak attenuation once a 2km long cavity is available for characterization
- Production is well underway for all SEI components
  - all bid risk and virtually all fabrication/installation risk has been passed

BSC (Basic Symmetric Chamber)



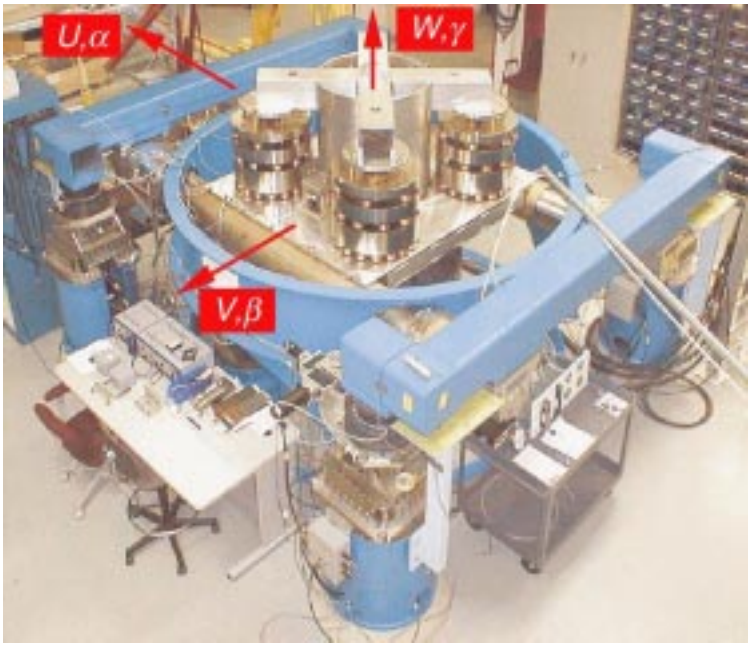
HAM (Horizontal Access Module)



Detector Construction
Seismic Isolation System (SEI)

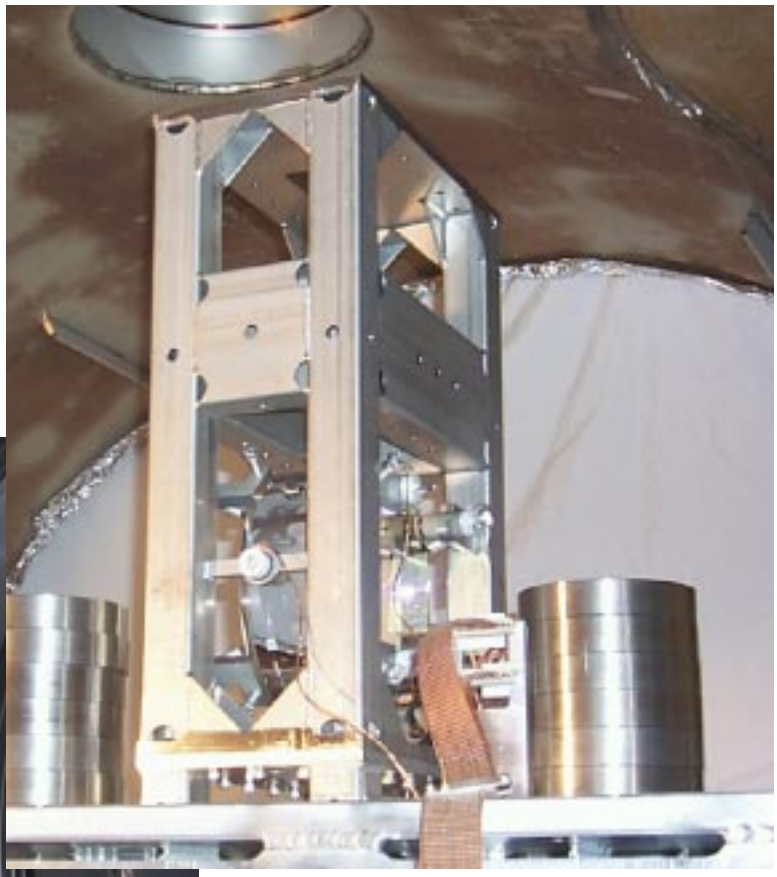
- Production Status:
  deliveries are on schedule

MAJOR COMPONENTS	*VENDOR(S)*	*QTY DELIVERED*	*COMPLETION DATE*
IN-VACUUM STRUCTURAL COMPONENTS	ALLIED ENGINEERING	8 HAM SETS (8 OF 12) 3 BSC SETS (3 0F 15)	9/99
BELLOWS	SENIOR FLEXONICS	14 HAM SETS (ALL) 13 BSC SETS (13 OF 16)	5/99
AIR BEARINGS	SPECIALTY COMPONENTS	8 SETS (8 OF 27)	9/99
SPRINGS	PEGASUS/KTI/?/HYTEC/ASTROPAK	~50%	8/99
COARSE ACTUATORS	HYTEC/HAND PRECISION	2 X,Y,Z SETS (2 OF 9) 0 Z-ONLY SETS (0 OF 6)	8/99
FINE ACTUATORS	HYTEC/HAND PRECISION	0 SETS (0 OF 6)	8/99
SEI ELECTRONIC RACKS	HYTEC	1 RACK/ 4 CHAMBERS (1 OF 4)	8/99
SCISSORS TABLES	HAND PRECISION/SUPERIOR JIG/ HYTEC	8 HAMS (8 OF 12) 3 BSCS (3 0F 15)	9/99



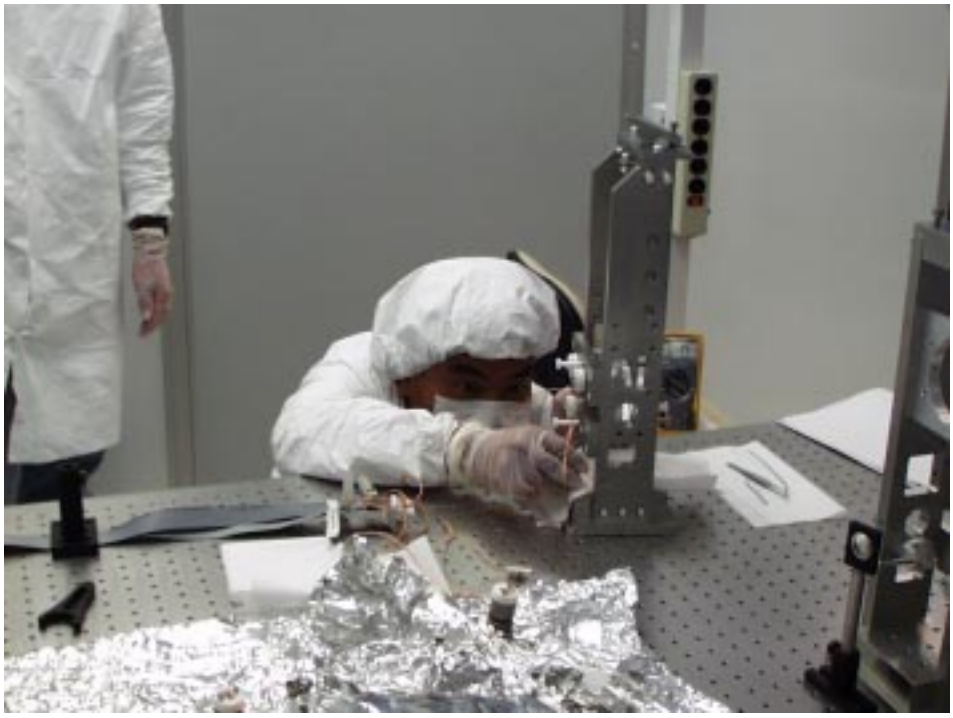
Detector Construction
Suspensions (SUS)

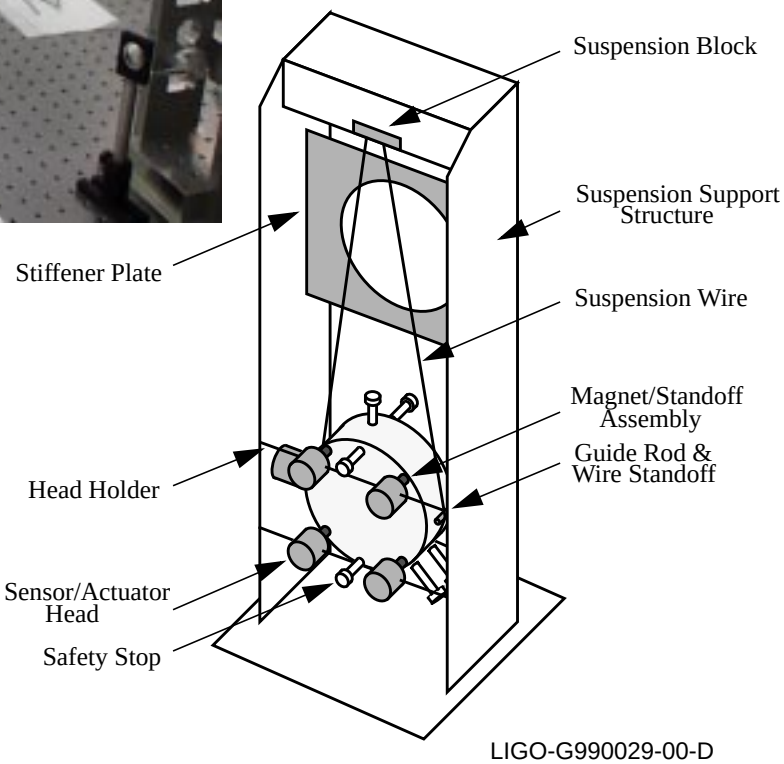
- Large Optic Suspension (LOS) structures:
  - Resolved initial welding, dimensional control, QA and cleanliness problems
  - All height adapters have been delivered (28 units)
  - 26 LOS structures have been delivered; Balance of 2 LOS structures to be delivered by 6/99
  - Most structures are in the queue for vacuum baking



Detector Construction
Suspensions (SUS) continued

- Small Optic Suspension (SOS) structures:
  - All 2km interferometer SOS structures fabricated & assembled (UFL)
  - Most SOS structures fabricated for the 4km interferometer at Livingston (in vacuum bake queue)





Detector Construction
Suspensions (SUS) continued

- Sensor/Actuator Head fabrication:
  - Sufficient quantity fabricated for the 2km interferometer Input Optics and Near-Michelson (plus spares)
  - Production for the balance is keeping pace with schedule

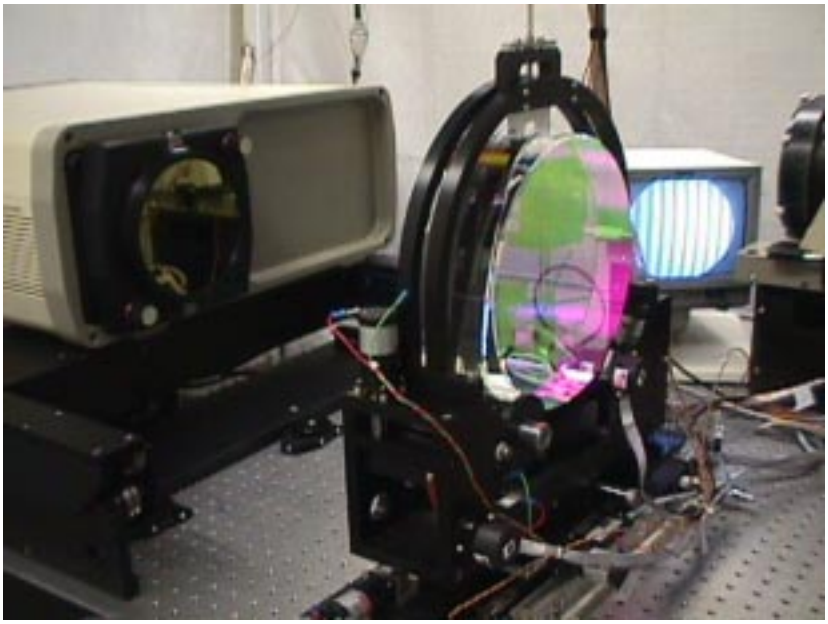
ISSUE	*UNITS AFFECTED*	*RESOLUTION/STATUS*
COIL SHORTING DUE TO COIL WIRE TEFLON INSULATION FAILURE & ELECTRO-STATIC MOLYBDENUM COATING ON BODY	ALL UNITS PRODUCED TO 3/99 (~40 SOS, ~20 LOS)	-ALL UNITS REWORKED (SELECTIVE REMOVAL OF MOLYBDENUM COATING & ADDITION OF TEFLON TAPE TO INSULATE COIL FROM BODY) -FUTURE UNITS CONTINUITY CHECKED AFTER VACUUM BAKING & BEFORE INSTALLATION
DEGRADATION OF PHOTODIODE/LED PAIR (UNBLOCKED VOLTAGE LEVEL)	UNITS SUBJECTED TO MULTIPLE & EXTENDED VACUUM BAKE CYCLES	ALL FUTURE SENSOR/ACTUATOR HEADS WILL BE BAKED IN 2 STEPS TO MINIMIZE TEMP & TIME FOR PD & LED
PHOTODIODES USED IN THE PRODUCTION UNITS HAVE AN OPTICAL FILTER WHICH WAS NOT VACUUM COMPATIBILITY & PROCESS CHECKED	ALL FABRICATED TO DATE	PENDING VACUUM COMPATIBILITY TESTING

Detector Construction
Suspensions (SUS) continued

- Assembly/Suspension:
  - Experienced significant problems in achieving reliable & robust adhesive bonds between the optic/standoff/magnet
  - Initially thought to be a process control, yield problem -- realized the problem is more fundamental and the “patched” solutions introduced additional problems
  - A “tiger team” was formed to address the problem:
    - find solution to immediate adhesive bond problem
    - seek a longer-term, non-epoxy bonding solution
  - “Stop Work” as of 4/13 for all suspension bonding until a revised procedure and fixturing are available
    - expected restart is ~4/28 for SOS and ~ 5/10 for LOS
- Chamfer stop & electrostatic discharge design:
  - Teflon screws were discovered to shed unacceptably
  - Implemented new design (flourel tipped, Ag/SS screws)

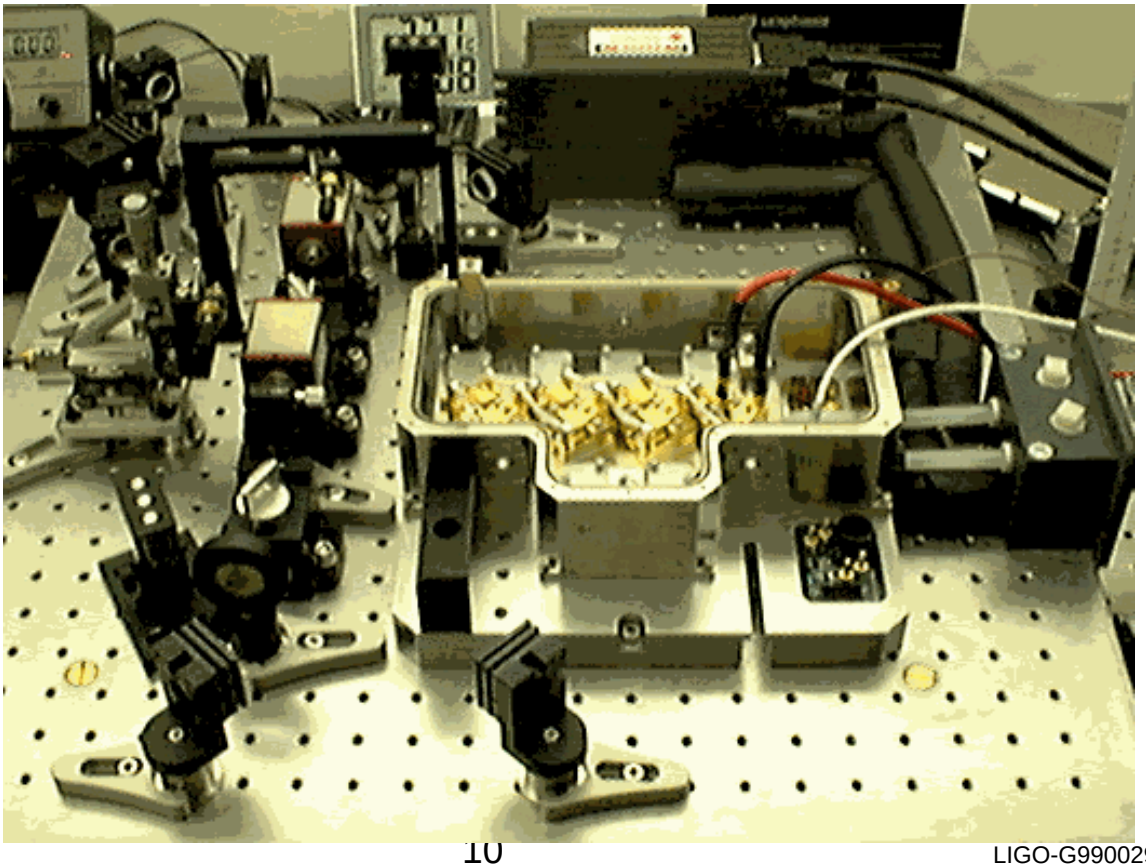
Detector Installation
Core Optics Components (COC)

- All optics polished except 3 ITM, 3 RM
- All optics coated except 6 ITM, 4 ETM, 3 RM
  Final coating run ~June, 99
- IR interferometer operational at Caltech
  - 1 nm rms sensitivity, 2% ROC accuracy
  - IR interferometer performance verified by comparison with measurements done on Pathfinder pieces at NIST, CSIRO
  - measured surface figure of RM, 2 ITM, 2 FM, BS. Data indicates that polish and coating performance as expected: < 1nm rms, ROC in spec
  - - all optics to be measured
- Scatterometer data obtained for arm cavity optics:
  2 ITMs so far
- CO_2 snow developed for in-situ cleaning of particulates



Detector Installation
Pre-Stabilized Laser (PSL)

- Lightwave Production/Enhancement Contract
  - Received five (5) 10W lasers, meeting all specifications (e.g. power, beam quality, frequency and intensity noise)
  - One 10W laser on loan to Byer's group at Stanford to perform design and noise study of 40W MOPA laser
  - Reliability problem with master oscillator laser diode appears solved
  - Reliability problem with power amplifier diodes (affecting 1 laser so far) under vigorous investigation by LW
  - Redesign of master oscillator to give better freq and intensity noise performance for LIGO II laser being pursued under enhancement part of contract
  - LW is selling a commercial version



Detector Installation
Pre-Stabilized Laser (PSL) continued

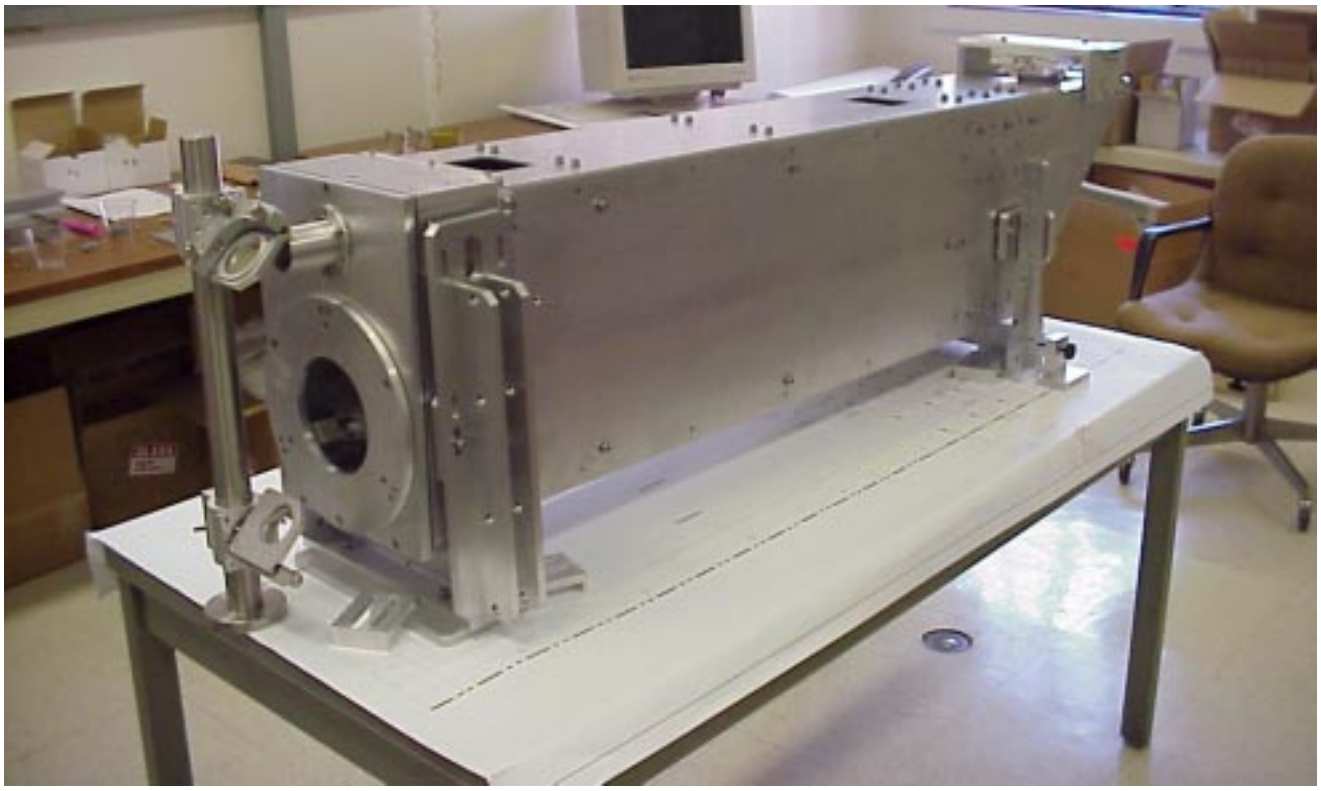
- PSL FDR held Mar 99
- PSL installed and functioning at Hanford 2k
  - performance testing is nearly completed and results are under study
  - further PSL characterization will be done with mode cleaner
  - all servo loops are functioning
  - some tweaking needed (pre-mode cleaner finesse, etc.)
  - diagnostics under implementation
  - beam handed off to the Input Optics (IO) group
- PSL installation at Livingston began April 5

Detector Installation
Input Optics (IO)

- All optics polished and coated
- IO installation at Hanford proceeding
  - in air table optics installed and aligned
  - Most SOS installed in vacuum system (balance pending resolution of the magnet/standoff/optic adhesion problems)
  - The Mode Matching Telescope (MMT) 3rd optic (a LOS) is installed
  - mode cleaner shakedown to start May
- IO installation at Livingston begins May 99
- Mode match WFS experiment proceeding
  - taking and analyzing data now
  - doughnut WFS to be delivered to Hanford ~ June
- Preliminary IO Alignment with Attenuated PSL beam in chamber HAM7 (under LVEA “Laser Hazard” Condition):

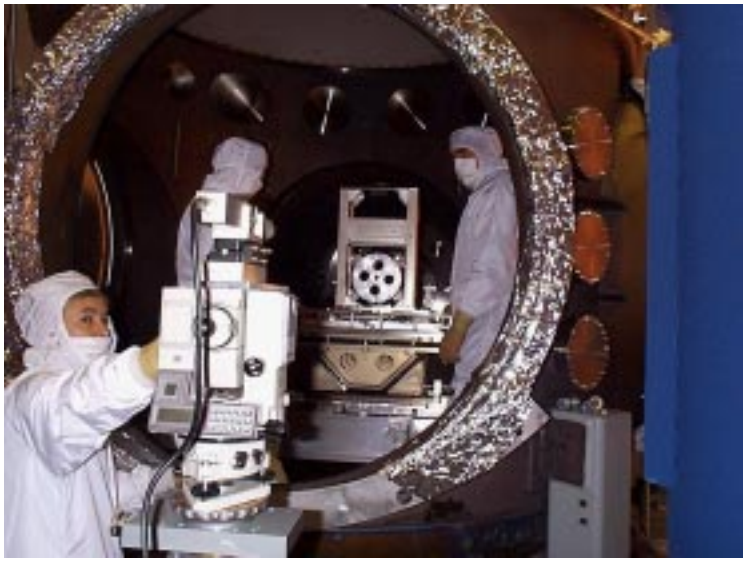
Detector Installation
Core Optics Support (COS)

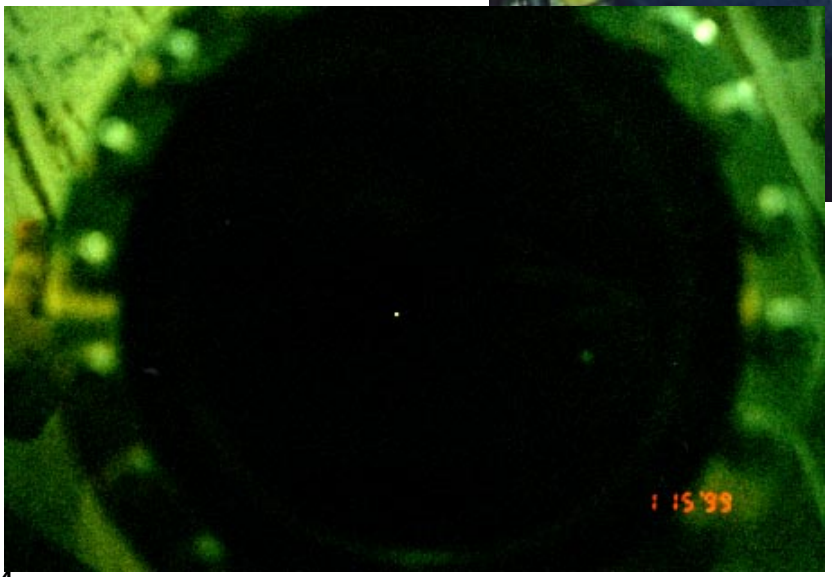
- FDR held Nov. 98
- Fabrication of beam dumps, baffles, telescopes in full swing
- IO baffle installed for the 2km Interferometer
- Beam dump installation starts in April
- Arm cavity baffles and beam reducing telescope installation starts June 99



Detector Installation
Interferometer Sensing & Control (ISC)

- Significant Events:
  - ✓ Hanford viewports are installed; Livingston viewports to be delivery 4/99
  - ✓ 10/98 test alignment of dummy End Test Mass optic at Hanford
  - ✓ 12/99 successful simulation of lock acquisition
  - ✓ 1/99 Hanford y-arm alignment “ground truth” calibration
  - ✓ 1/99 first Wavefront Sensor table shipped to Hanford
  - ✓ 2/99 first large optics aligned in situ (MMT3, RM)
  - ✓ 2/99 integrated test: DSP servo + supervisory controls
  - ✓ 3/99 second Wavefront Sensor table (ISCT7) completed at Hanford
  - ›› 5/99 commissioning of Input Optics mode cleaner controls (expected)





Detector Installation
Interferometer Sensing & Control (ISC)

- Fabrication on schedule
- Technical risks
  - Digital loop control function, performance and diagnostic hooks
  - LIGO cavity lock acquisition
- Schedule risks
  - Software and electronics readiness
  - CDS & ISC manpower conflicts between fabrication and installation/commissioning needs

Detector Installation
Control & Data Systems (CDS)

- Control Area / Networking
  - Completed Timing System designs and installation is proceeding
    - LVEA system infrastructure installed at Hanford
    - LVEA system infrastructure installed at Livingston
  - CDS server, gateway and first operator stations installed at Livingston
  - Network fiber installation completed at Livingston and networks now operational throughout the site.
- Vacuum System Controls
  - Completed test and commissioning of Livingston vacuum control system.

Detector Installation
Control & Data Systems (CDS) continued

- PSL
  - Installed and commissioned control system for Hanford 2k IFO
  - In process of installing Livingston 4k IFO system
- Suspension Controls
  - Installed and tested all Input Optics suspensions controls for Hanford 2k
  - Installed and tested all LVEA core optic suspension controls for Hanford 2k
  - In process of installing suspension test stand in Livingston
  - In process of installing Input Optic suspension controls for Livingston 4k

Detector Installation
Control & Data Systems (CDS) continued

- Length & Alignment Sensing Controls (LSC/ASC)
  - In process of installing and commissioning Input Optics LSC & ASC for Hanford 2km interferometer
  - Completed designs for optical lever and WaveFront Sensor (WFS) photodiode boards; Production has begun for Hanford 2k systems.
  - Development and testing of software for digital control loops is continuing.
  - LSC photodiode final design completed; first article due late April.
  - Prototyping LSC software for digital servo loops.
- Data Acquisition
  - Server and network infrastructure installed at both sites.
  - First data collection units being installed and tested at Hanford.
  - First release of software operational
    - Data collection and framing
    - Dataviewer
    - Network Data Server
    - Data extraction

Detector Installation

- Replanning for initial long Fabry-Perot arm cavity test in advance of power recycled near-Michelson configuration (see Detector Commissioning presentation)
- First time installation tasks have experienced slips
  - procedures and fixtures are improved and staff are trained
  - subsequent repetitions are faster
- Physical installation will generally be paced by staffing and not out-of-house fabrication deliveries, i.e. installation schedule is increasingly under our control
  - exception is SEI continues to be (slightly) paced by fabrication of springs & seats, air bearings and control electronics racks
  - Vacuum bake processing is sometimes a bottleneck, so CIT is adding an additional large vacuum bake oven & increasing Observatory throughput

Detector Installation (continued)

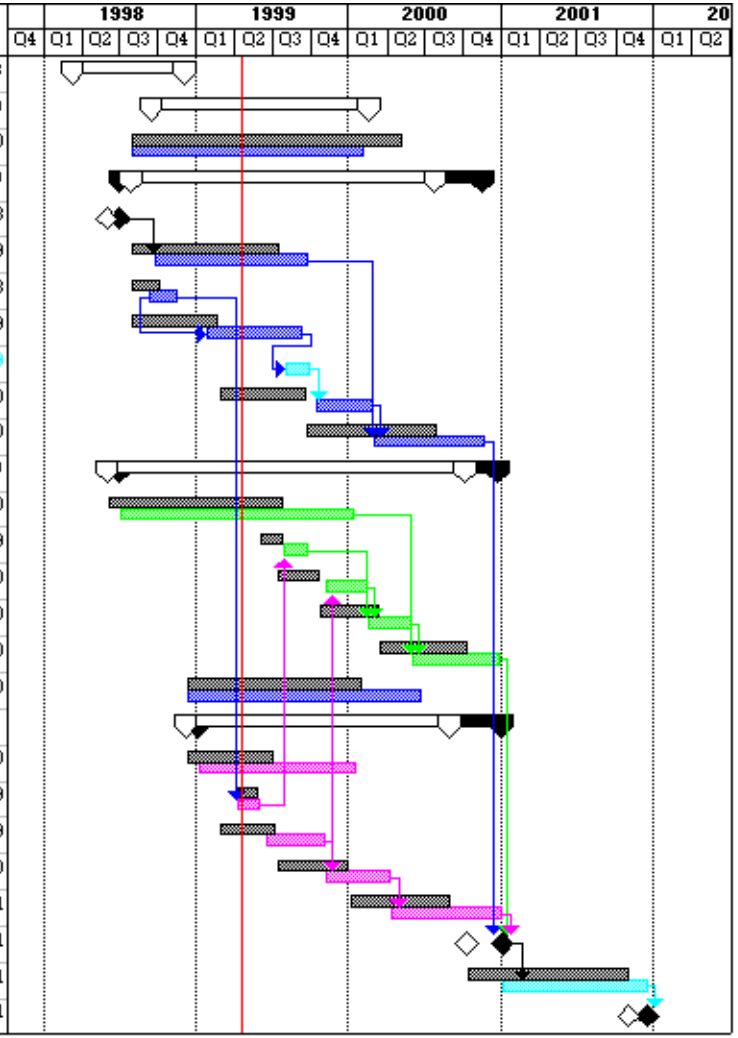
- 2km Interferomter installation has progressed to the point of the first major integrated system test 5/99: Mode Cleaner lock and length/alignment control (involving 9 subsystems)!

Detector Installation (continued)

- Pre-Stabilized Laser and Seismic Isolation installation well underway at Livingston

Detector Installation Summary Schedule

ID	Task Name	Duration	Start	Finish
1	**VE Completion**	**194 days**	**3/11/98**	**12/8/98**
11	**BT Bake Out**	**374 days**	**9/15/98**	**2/21/00**
21	**LHO Detector Infrastructure**	80 wks	7/27/98	2/4/00
22	**LHO 2km IFO**	**624 days**	**7/1/98**	**11/20/00**
23	Start Detector Integration	0 days	7/1/98	7/1/98
24	Install SEI, SUS, COS, ISC	53 wks	9/21/98	9/24/99
25	PSL	10 wks	9/8/98	11/16/98
26	Input Optics	33 wks	1/25/99	9/10/99
27	**long Fabry-Perot cavity test**	9 wks	8/2/99	10/1/99
28	PR Near Michelson	20 wks	10/12/99	2/28/00
29	PR Michelson w/ FP Arms	38 wks	2/29/00	11/20/00
30	**LHO 4km IFO**	**649 days**	**7/1/98**	**12/25/00**
31	Install SEI, SUS, COS, ISC	80 wks	7/1/98	1/11/00
32	PSL	8 wks	7/28/99	9/21/99
33	Input Optics	15 wks	11/2/99	2/14/00
34	PR Near Michelson	15 wks	2/15/00	5/29/00
35	PR Michelson w/ FP Arms	30 wks	5/30/00	12/25/00
36	**LLO Detector Infrastructure**	80 wks	12/8/98	6/19/00
37	**LLO 4km IFO**	**519 days**	**1/6/99**	**1/1/01**
38	Install SEI, SUS, COS, ISC	53.8 wks	1/6/99	1/17/00
39	PSL	8.4 wks	4/5/99	6/1/99
40	Input Optics	20 wks	6/15/99	11/1/99
41	PR Near Michelson	23 wks	11/2/99	4/10/00
42	PR Michelson w/ FP Arms	38 wks	4/11/00	1/1/01
43	Detector Commissioned (h<10^-20)	0 days	1/1/01	1/1/01
44	Observatory Operations & improvements	50 wks	1/2/01	12/17/01
45	Design Sensitivity (h<10^-21)	0 days	12/17/01	12/17/01



Detector
Recommendations *(from 10/98 review)*

- Materials Compatibility Testing:

1. Repeat the experiment that seemed to produce mirror contamination with better instrumentation. Repeat the vacuum cycling without light in the cavity to help eliminate non-photochemical processes as mechanisms.

- ✓ Contamination test apparatus developed with sensitivity of 10 ppm/yr. scatter, 1 ppm/yr. absorption loss
- ✓ Repeated the test multiple times and only caused one additional optical loss event

2. Attempt to clean the contaminated mirrors and test them for reflectivity. The low energy 1064 nm photons used in LIGO should cause less chemical change than the 515 nm photons used in the 40 m system. The contaminating material may thus not be bonded to the surface and might be easily removed.

- ✓ We performed SIMS measurements on the optics to discover the composition of the contaminant
- ✓ Response: All future installed flourel components (spring seats, SUS chamfer stops,...) will be processed per Hard Disk industry practice (multiple 15 psi, water boiling steps)

Detector
Recommendations *(from 10/98 review)*

- Detector Installation and Integration:

1. Because of the heavy dependence on university based LIGO personnel, every effort must be made by LIGO management to make these people effective. This will include continuing the enthusiastic support of these activities that LIGO management has shown so far and using modern electronic communication media to instill a sense of community independent of where people are at any given time.

- ✓ An electronic log system has been developed for both sites, available from the web
- ✓ An installation and an integration web page are maintained