LIGO-I Detector

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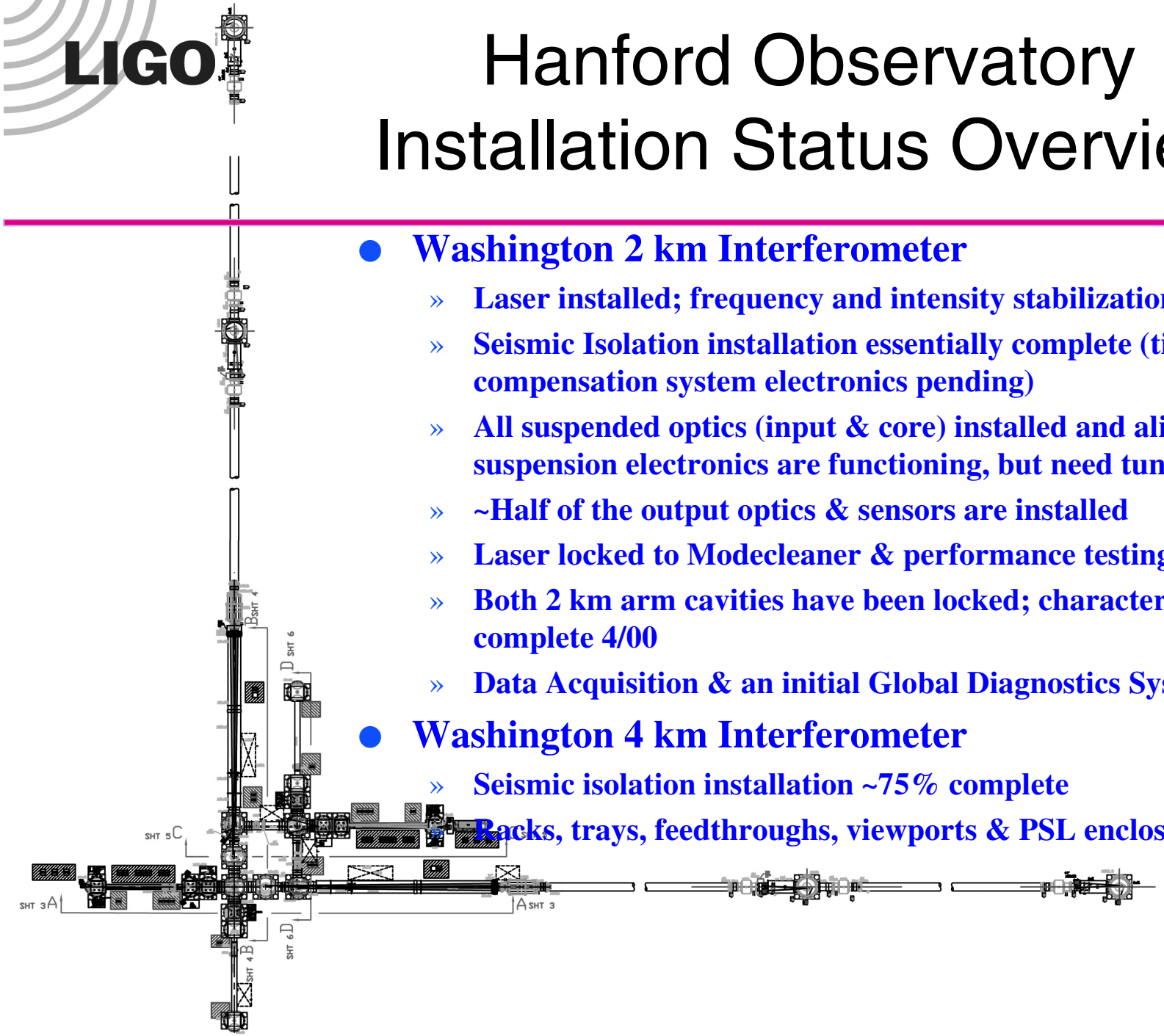
LIGO Lab
February 14, 2000

Detector

- Installation
- Commissioning
- Schedule Status

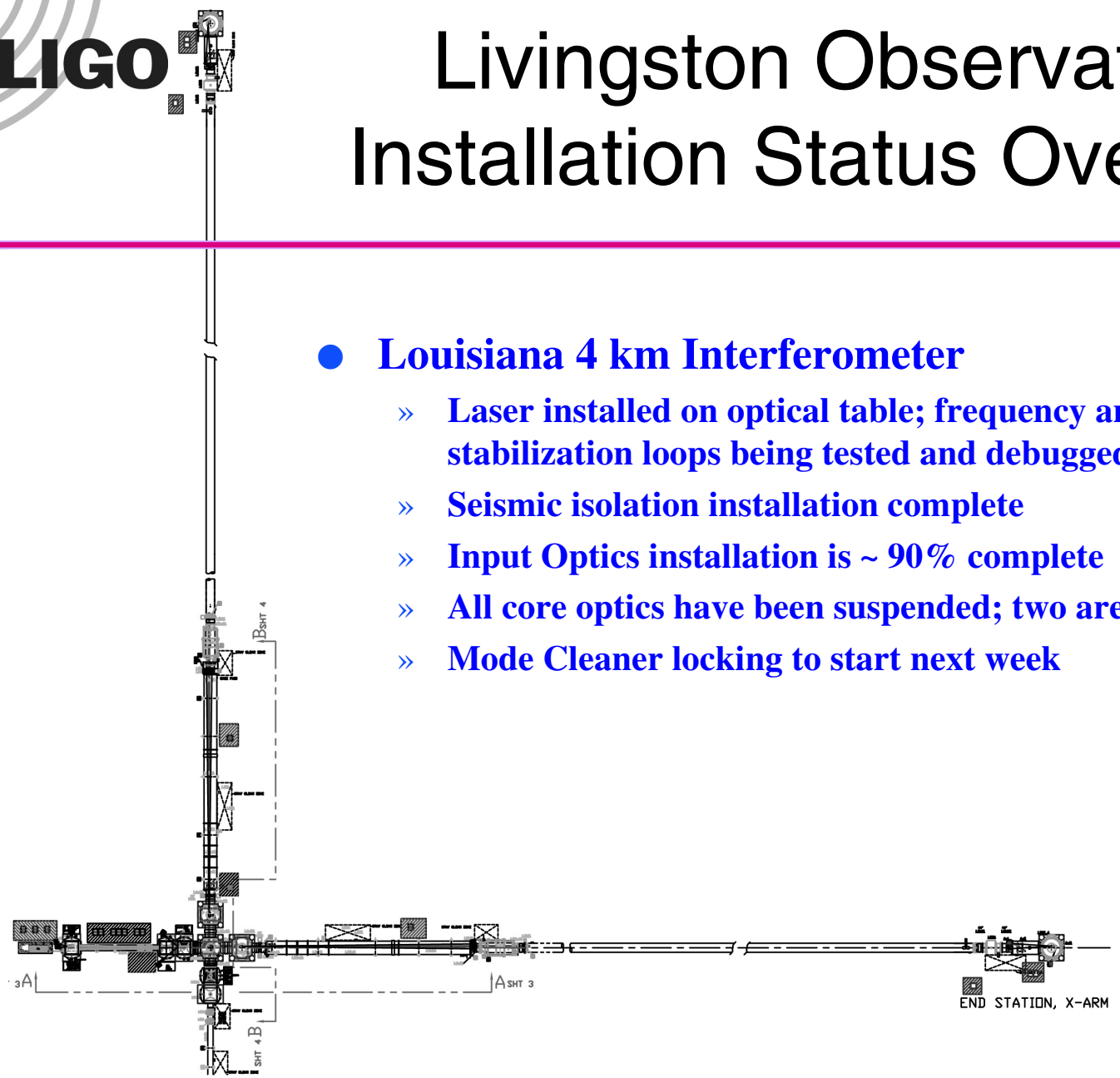
Hanford Observatory Installation Status Overview



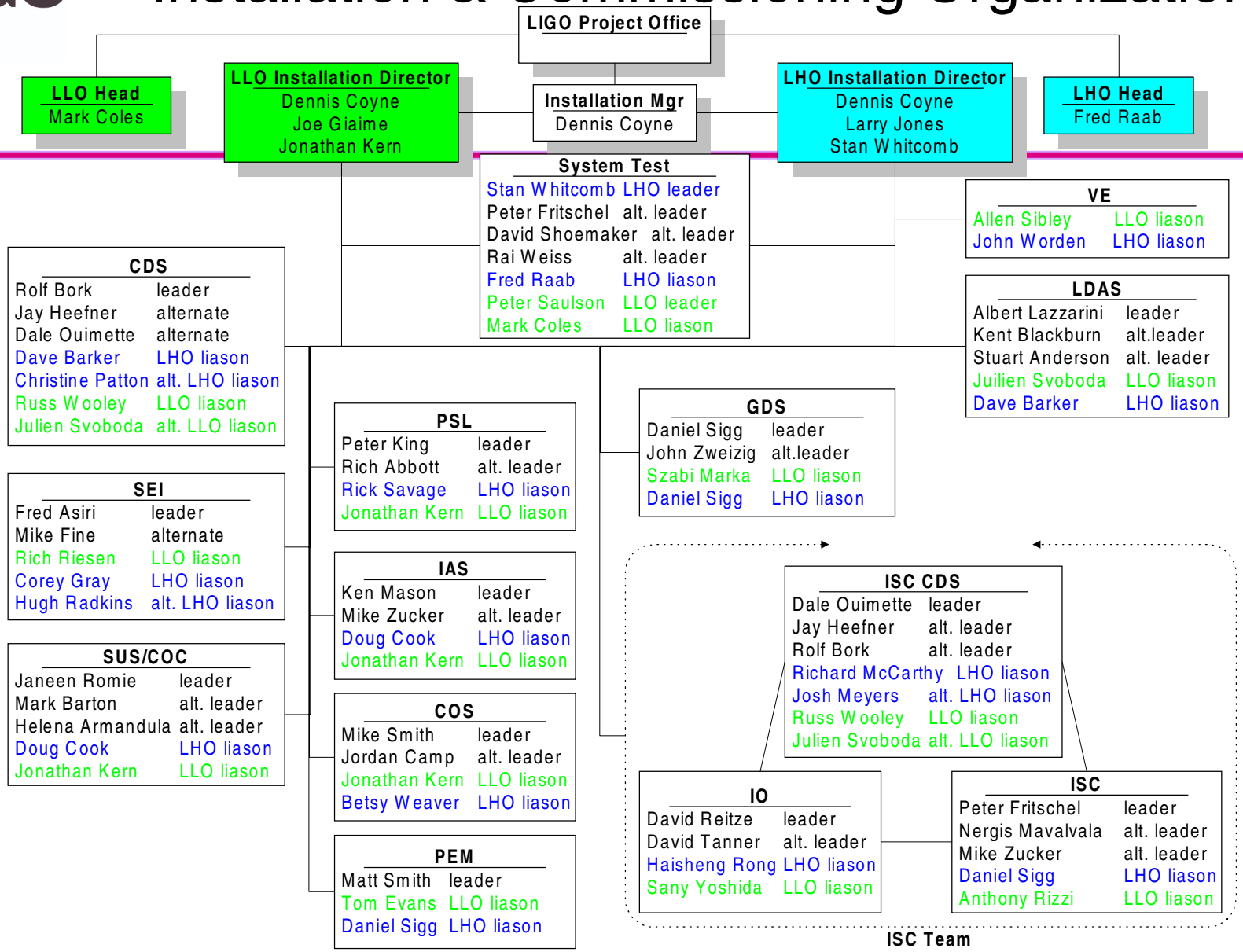
- **Washington 2 km Interferometer**
  - » **Laser installed; frequency and intensity stabilization operational**
  - » **Seismic Isolation installation essentially complete (tidal motion compensation system electronics pending)**
  - » **All suspended optics (input & core) installed and aligned; suspension electronics are functioning, but need tuning**
  - » **~Half of the output optics & sensors are installed**
  - » **Laser locked to Modecleaner & performance testing in progress**
  - » **Both 2 km arm cavities have been locked; characterization to be complete 4/00**
  - » **Data Acquisition & an initial Global Diagnostics System installed**
- **Washington 4 km Interferometer**
  - » **Seismic isolation installation ~75% complete**
  - » **Racks, trays, feedthroughs, viewports & PSL enclosure in place**

Livingston Observatory Installation Status Overview

- **Louisiana 4 km Interferometer**
  - » **Laser installed on optical table; frequency and intensity stabilization loops being tested and debugged**
  - » **Seismic isolation installation complete**
  - » **Input Optics installation is ~ 90% complete**
  - » **All core optics have been suspended; two are installed**
  - » **Mode Cleaner locking to start next week**



Installation & Commissioning Organization



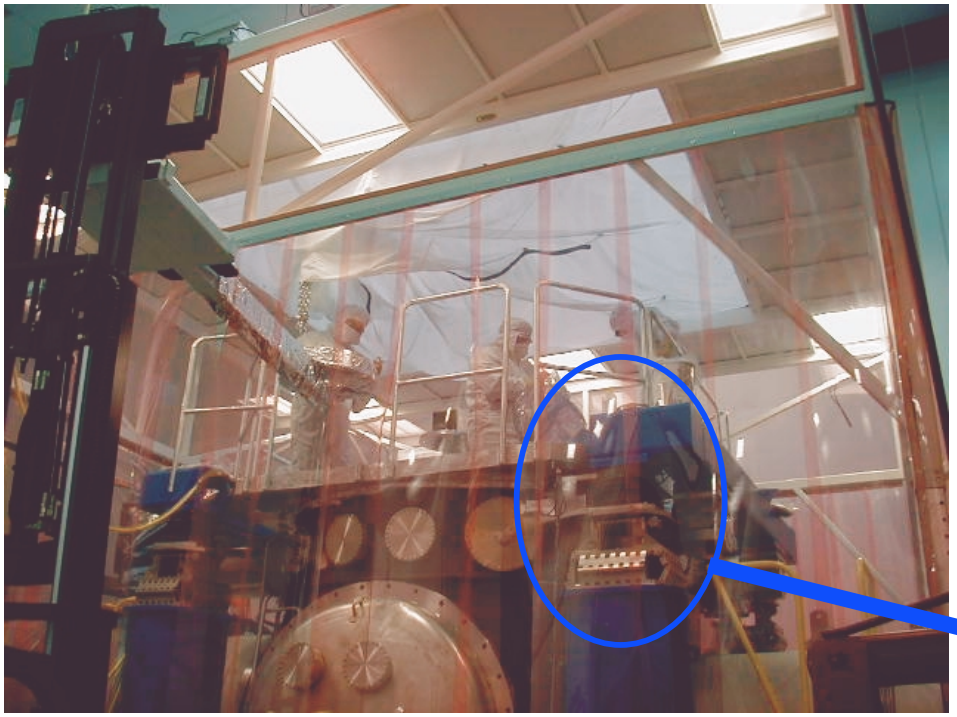
Seismic Isolation Systems

- Outstanding progress:
  - » production and delivery of components meeting or exceeding installation schedule needs (and almost entirely complete)
  - » Early quality problems have mostly disappeared; There have been a few problems with the quality of metal seal knife edges but we have been able to perform the required rework
  - » The coarse actuation system for the BSC seismic isolation systems has been installed and tested successfully in the LVEA at both Observatories
  - » BSC seismic systems at Livingston went as quickly as any installation at Hanford indicating that the transfer of experience was successful.
- Hanford 2km & Livingston seismic isolation system installation has been completed, with the exception of the tidal compensation (fine actuation) system
- Hanford 4km seismic isolation installation is ~75% complete

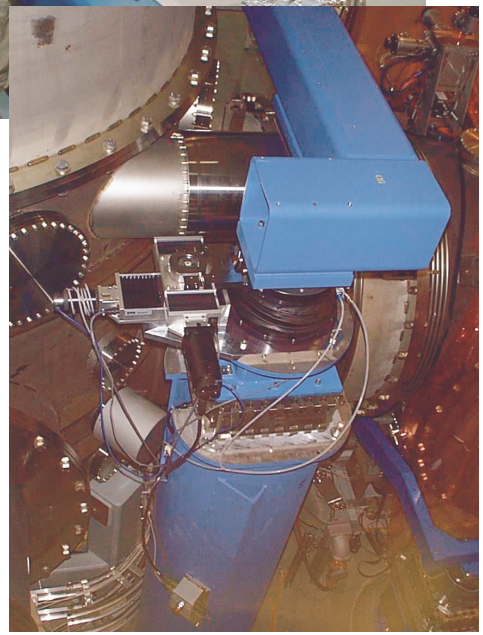
HAM Door Removal
(Hanford 4km)

Seismic Isolation Systems

Support Tube Installation
(Hanford WBSC7)



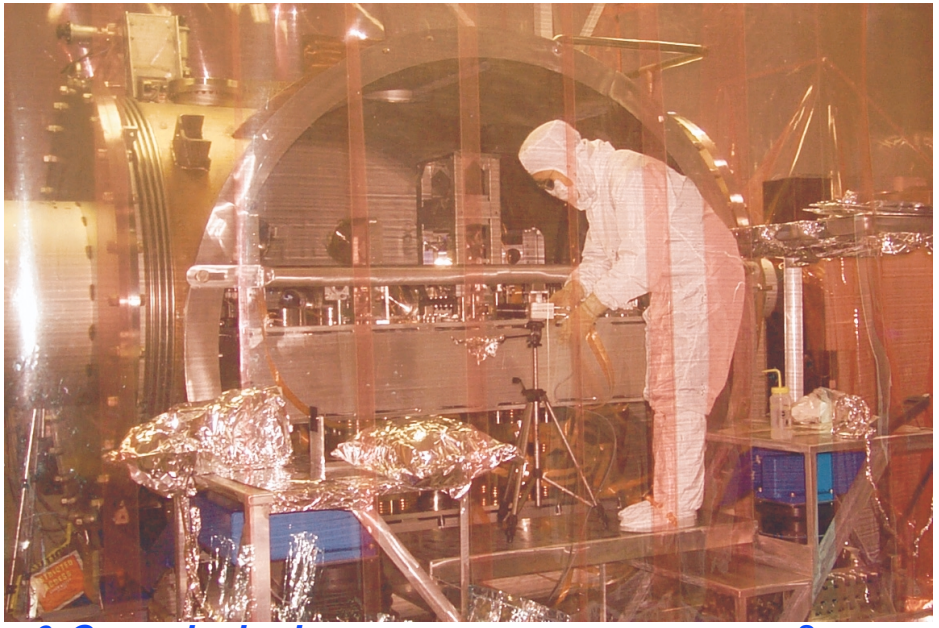
Stack Installation
(Hanford X-Mid)



Coarse Actuation
System

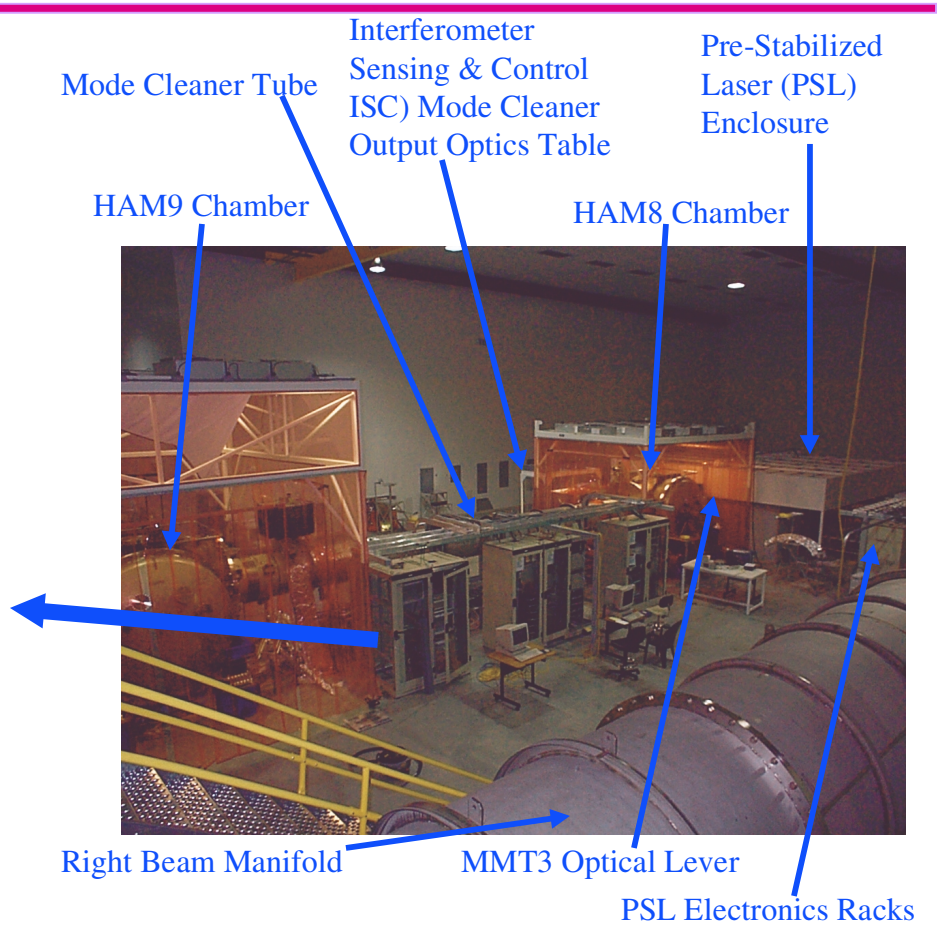
Input Optics (IO)

- The 2km Input Optics (IO) subsystem installation has been completed
  - The Mode Cleaner routinely holds length servo-control lock for days
  - Mode cleaner parameters are close to design specs, including the length, cavity linewidth and visibility
  - Further characterization is underway (optics suspension diagonalization & PSL freq. noise measurement)
- Livingston IO subsystem:
  - Alignment will be completed this week (with the exception of a Faraday isolator assembly)
  - Final installation and first lock is scheduled for next week



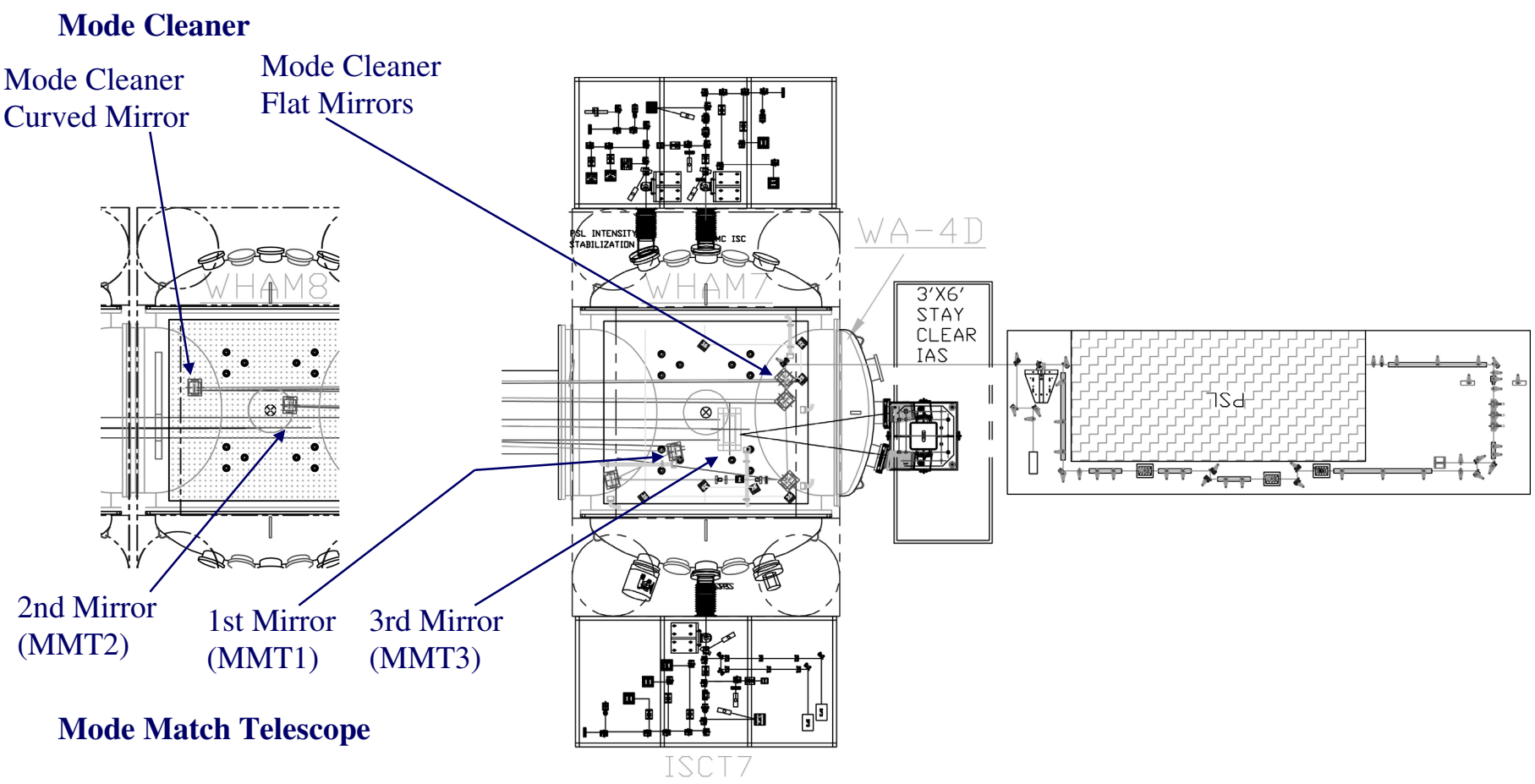
Input Optics (IO)

Control System Racks
(2km Interferometer)

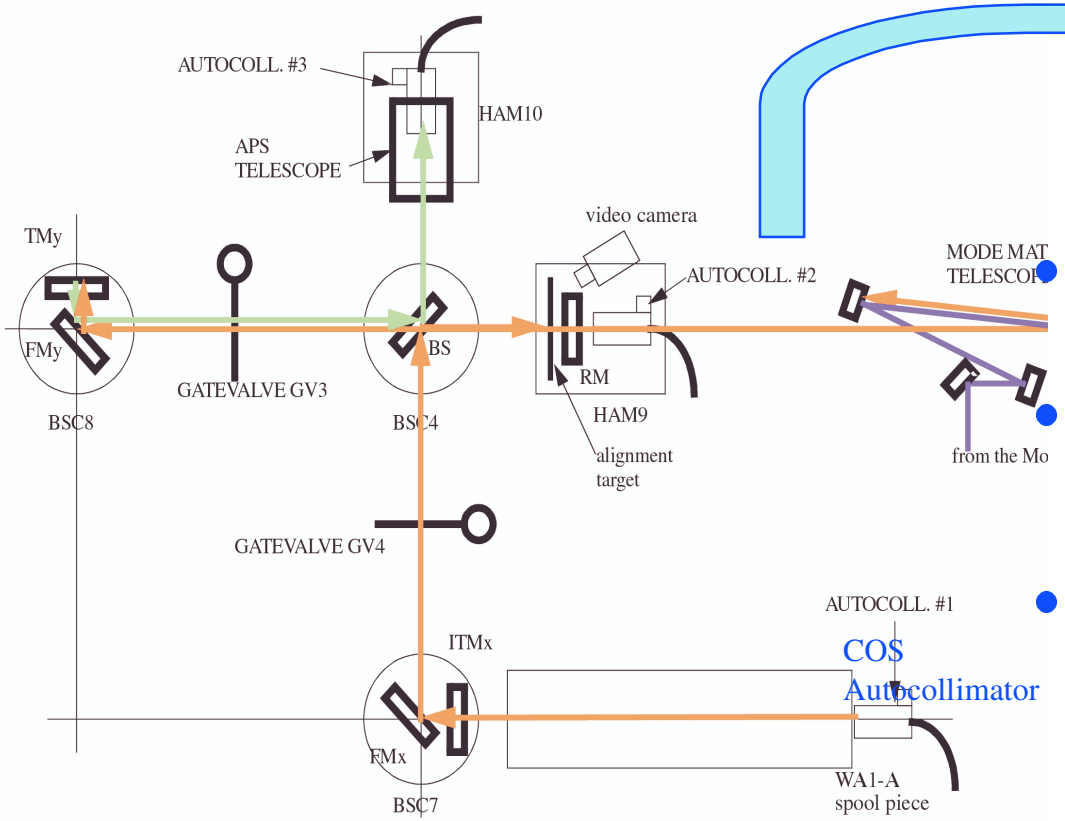


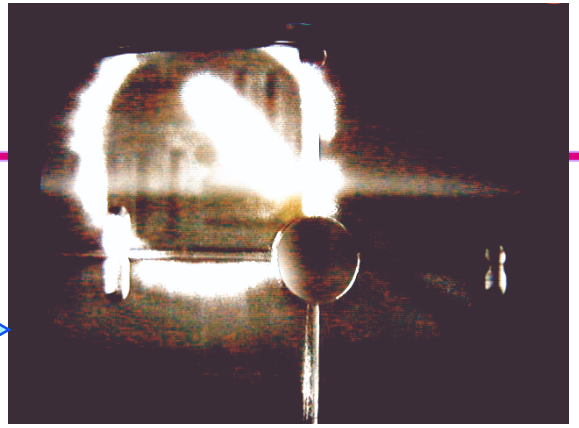
Input Optics Section
(2km Interferometer)

Input Optics (IO) Layout



Recycling Cavity Alignment

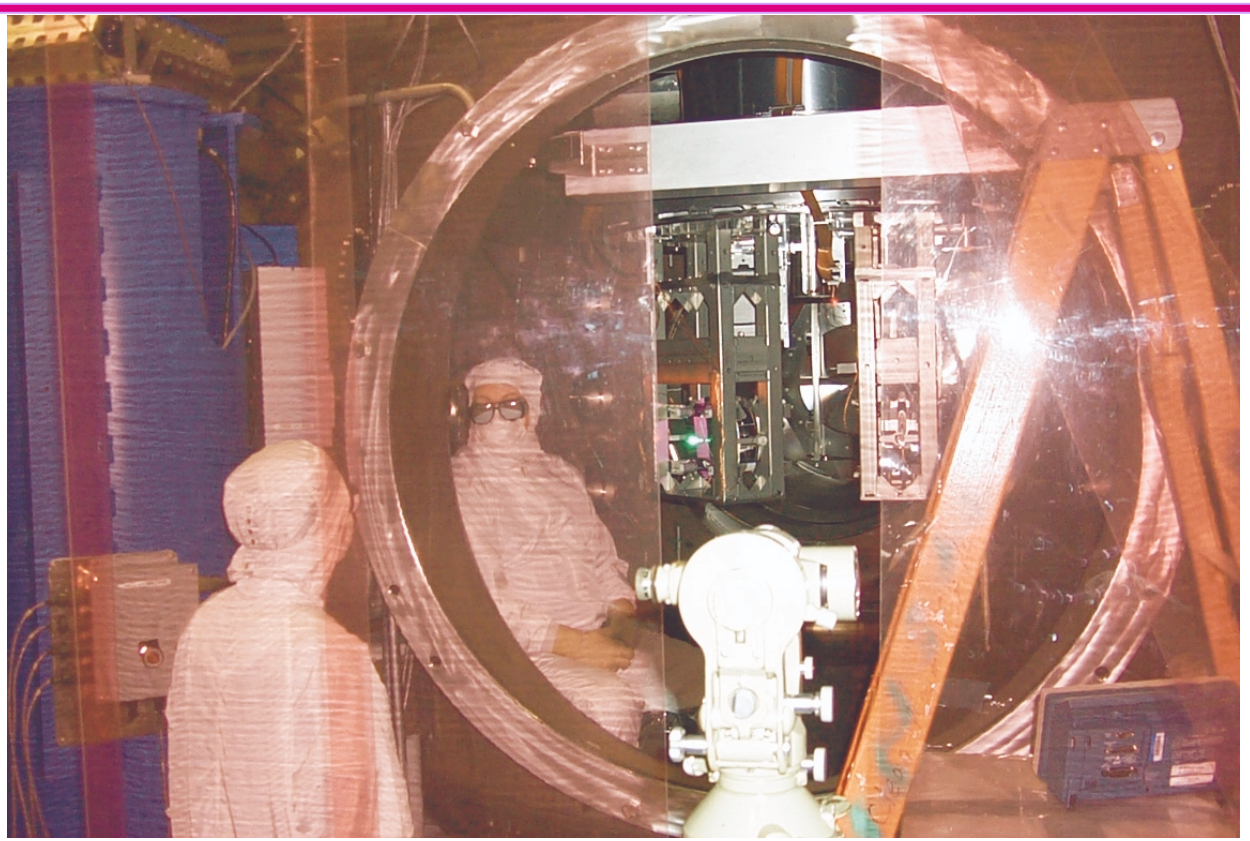




Projected reticule pattern & PSL beam on target in front of MMT2

- Absolute positioning & alignment reference from laser autocollimator co-boresighted to a theodolite
- co-alignment of the recycling cavity optics accomplished with an alignment telescope used alternately as an autocollimator & projector (940nm)
- alignment of the mode match telescope to the recycling cavity was accomplished by aligning the PSL beam to the projected reticule pattern & then by retroreflection from the RM

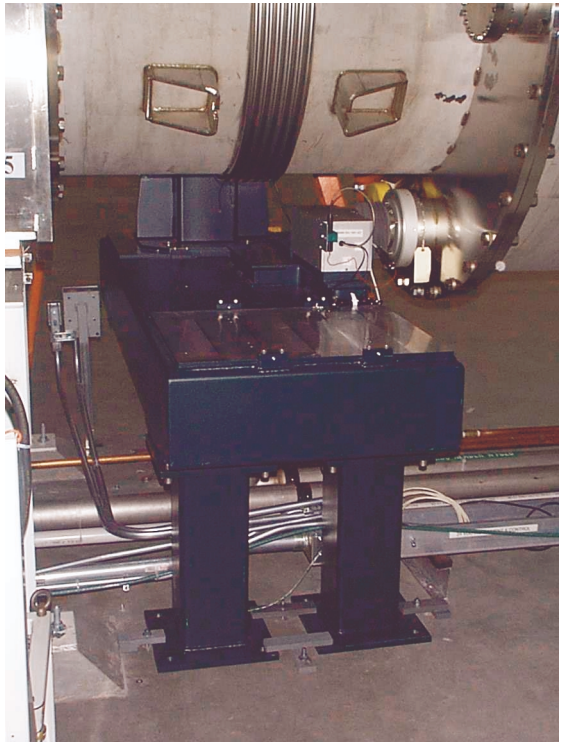
Recycling Cavity Alignment



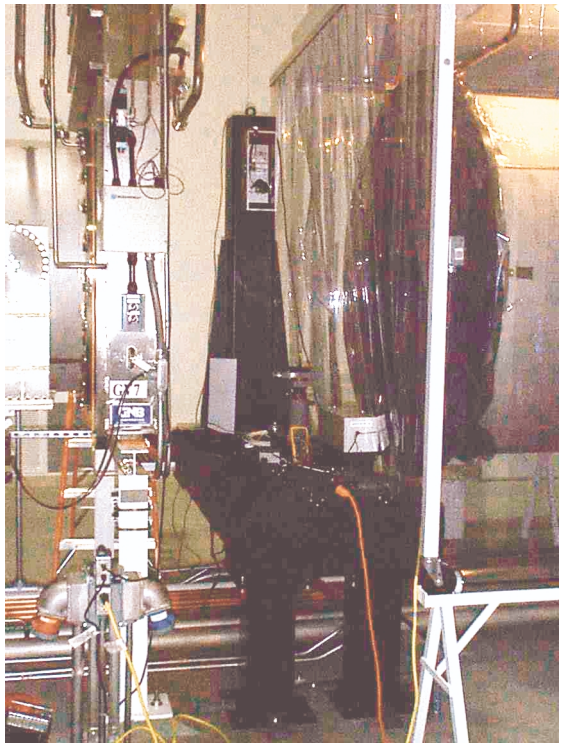
Adjusting the Fold Mirror (FMx) Alignment

Initial Alignment System: Optical Levers

- Optical levers have been installed, aligned & are operational for all core optics in the 2km interferometer

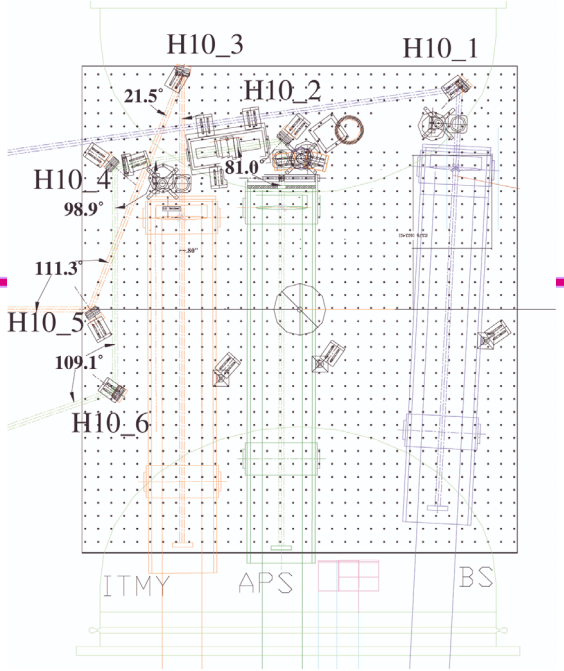


Input Test Mass (ITMx) Optical Lever

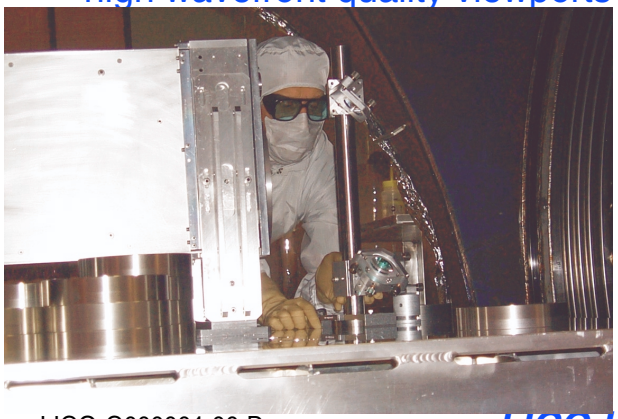


Transmit & Receive modules visible with spool piece removed for ITMx alignment

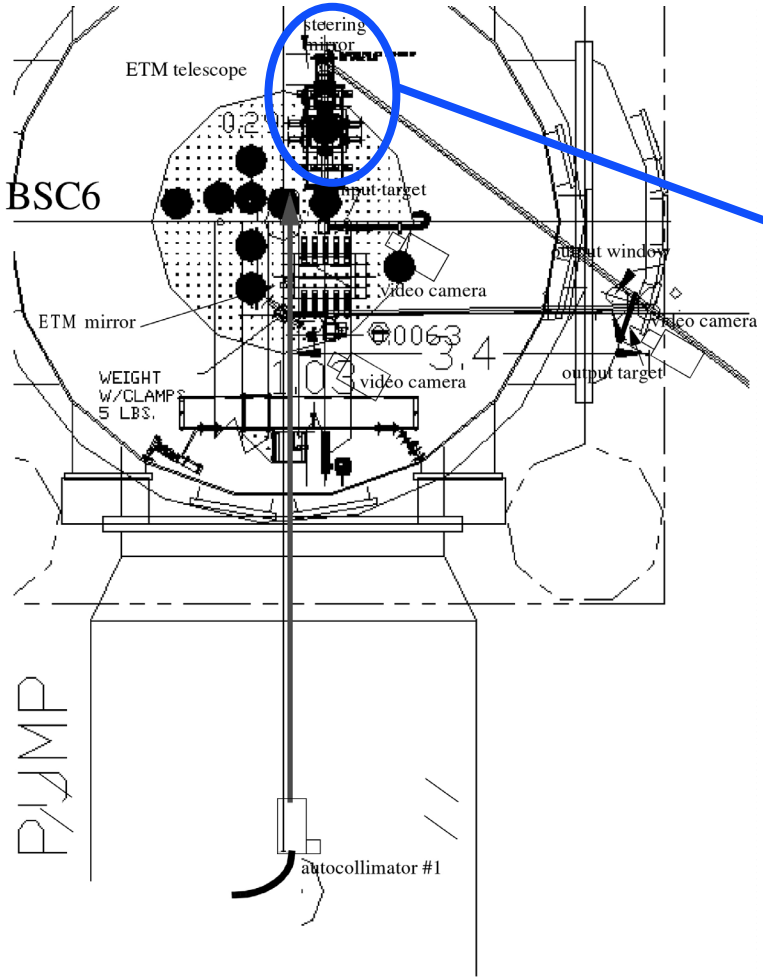
Core Optics Support



- Fabrication has bee completed
- Installed for the 2km:
  - » Beam Dumps (most)
  - » Recycling cavity baffles, IO baffle & cryopump baffle
  - » Pick-Off Mirrors
  - » Antisymmetric Port Pick-Off Telescope
  - » Both End Test Mass Transmission Telescopes
- Pending installation for the 2km:
  - » arm cavity baffles
  - » 3 pick-off telescopes
  - » high wavefront quality viewports



Core Optics Support:
End Test Mass Transmission Telescope

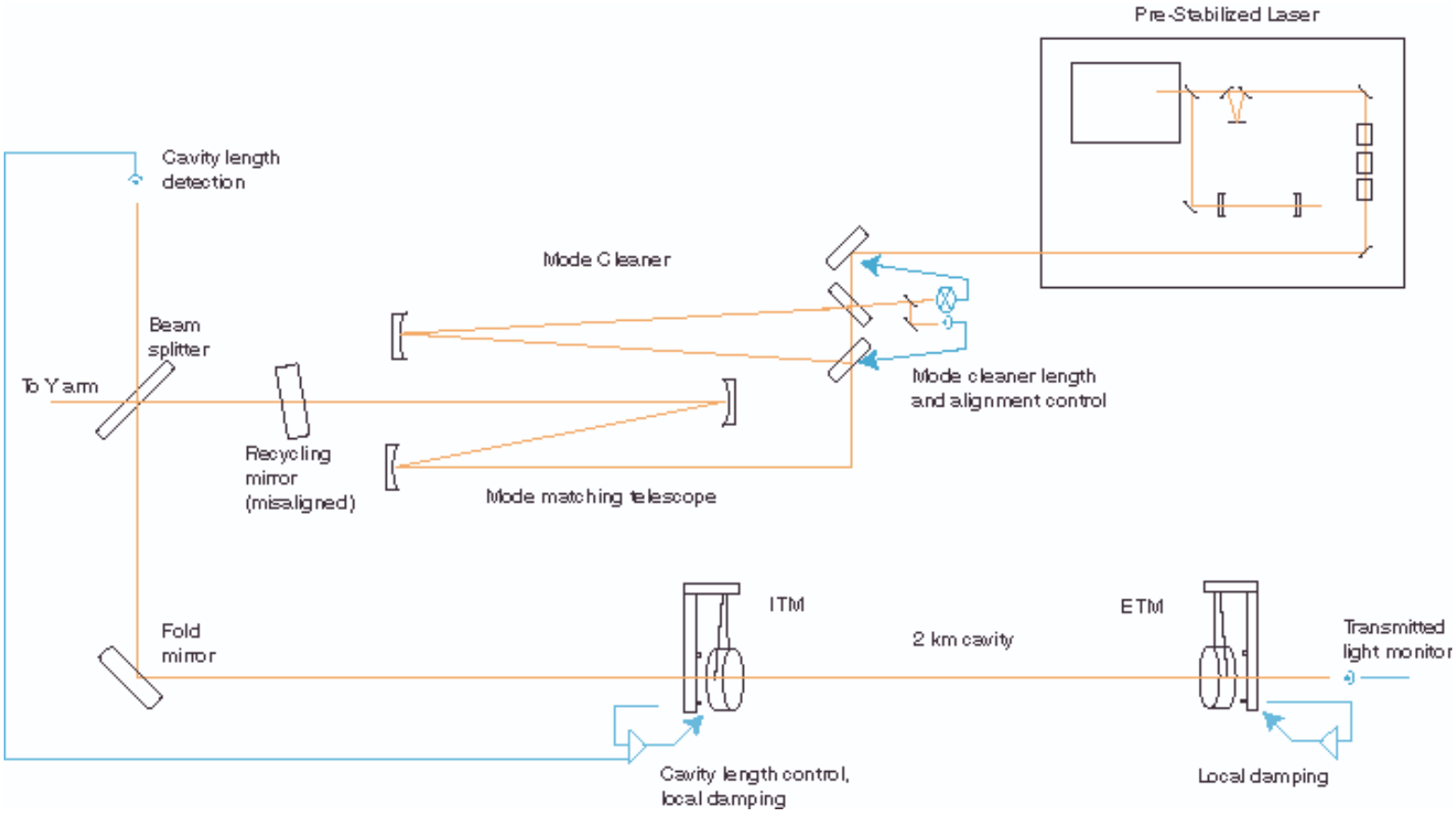


Commissioning Configurations

- Mode cleaner and Pre-Stabilized Laser
- Michelson interferometer
- 2km one-arm cavity

- At present, activity focussed on Hanford Observatory
- Mode cleaner locking imminent at Livingston

Schematic of system

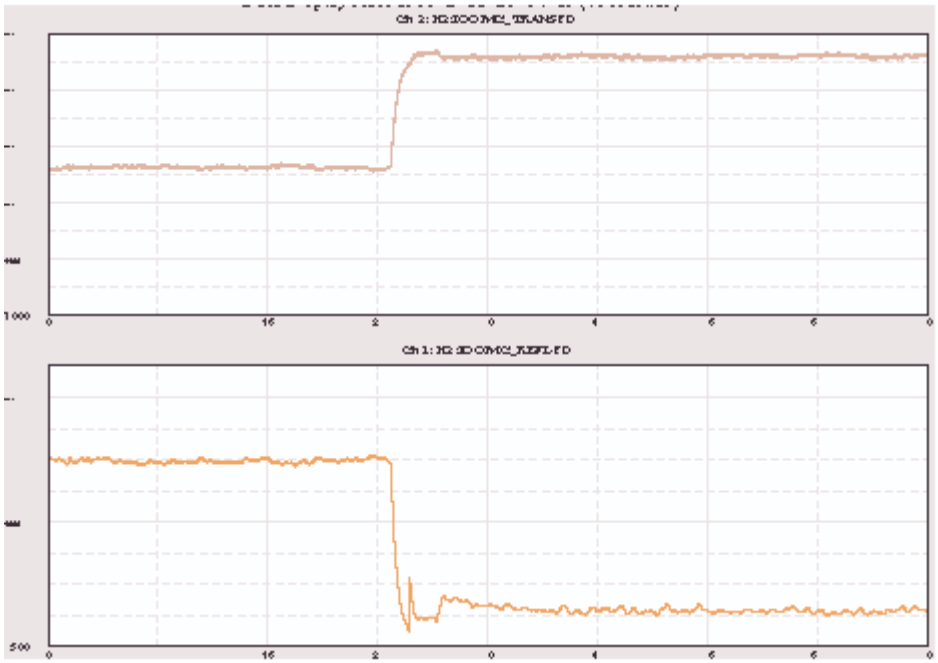


Pre-Stabilized Laser-Mode Cleaner

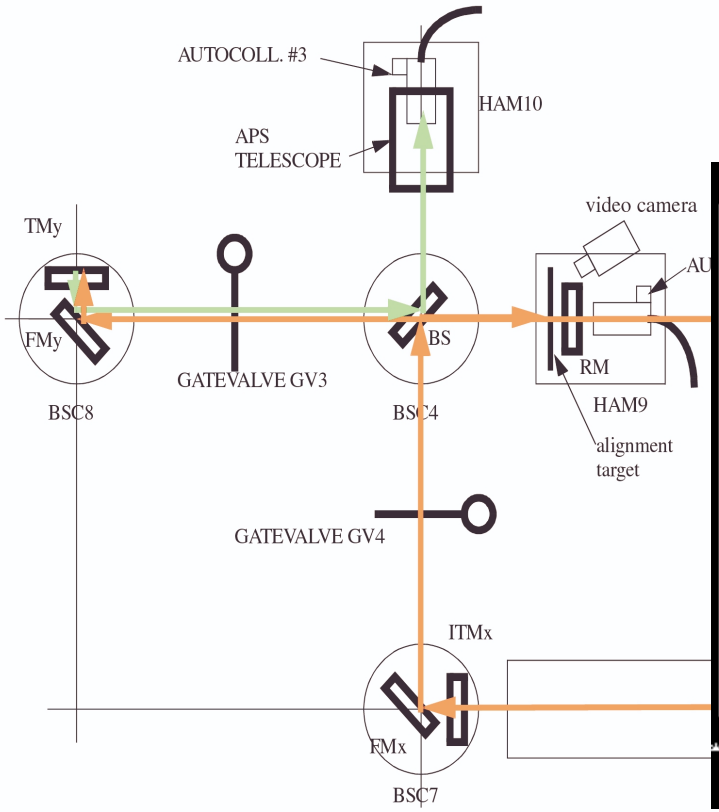
- suspension characterization
  - » actuation/diagonalization
  - » sensitivity of local controls to stray Nd:YAG light
  - » Qs of elements measured, 3e5-1e6
- Laser - Mode Cleaner control system shakedown
- laser frequency noise measurement

Wavefront sensing on Mode Cleaner cavity

- Alignment system function verified



Michelson Interferometer



- Interference quality of recombined beams
  - » >0.99
- Measurements of Qs of Test Masses

Table 1. Internal Resonance Measurement Data

Optic Name	*Resonant Frequency fo (kHZ)*	*Mode Name*	*Q Measured*	*Q Theoretical*
ITMx	6.7475	Butterßy	1.40×10^6	1.3×10^6
ITMx	9.395	Drum Head	*6.16×10^5	
ITMx	14.3737	Breathing	1.20×10^7	
BS	3.7337	Butterßy	1.85×10^6	
BS	5.4775	Drum Head	2.50×10^4	
BS	7.812	3-Fold Radial	2.65×10^5	2.6×10^6
BS	11.1387		3.60×10^5	
ITMy	9.3975	Drum Head	9.98×10^5	1.3×10^6

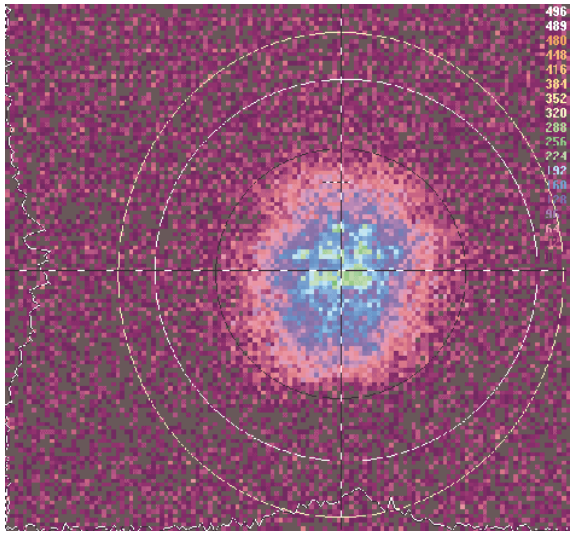
*A rough estimate compared to other values in table (data analysis method for this value was different). Betsy Weaver 1/19/00

2km Fabry-Perot cavity

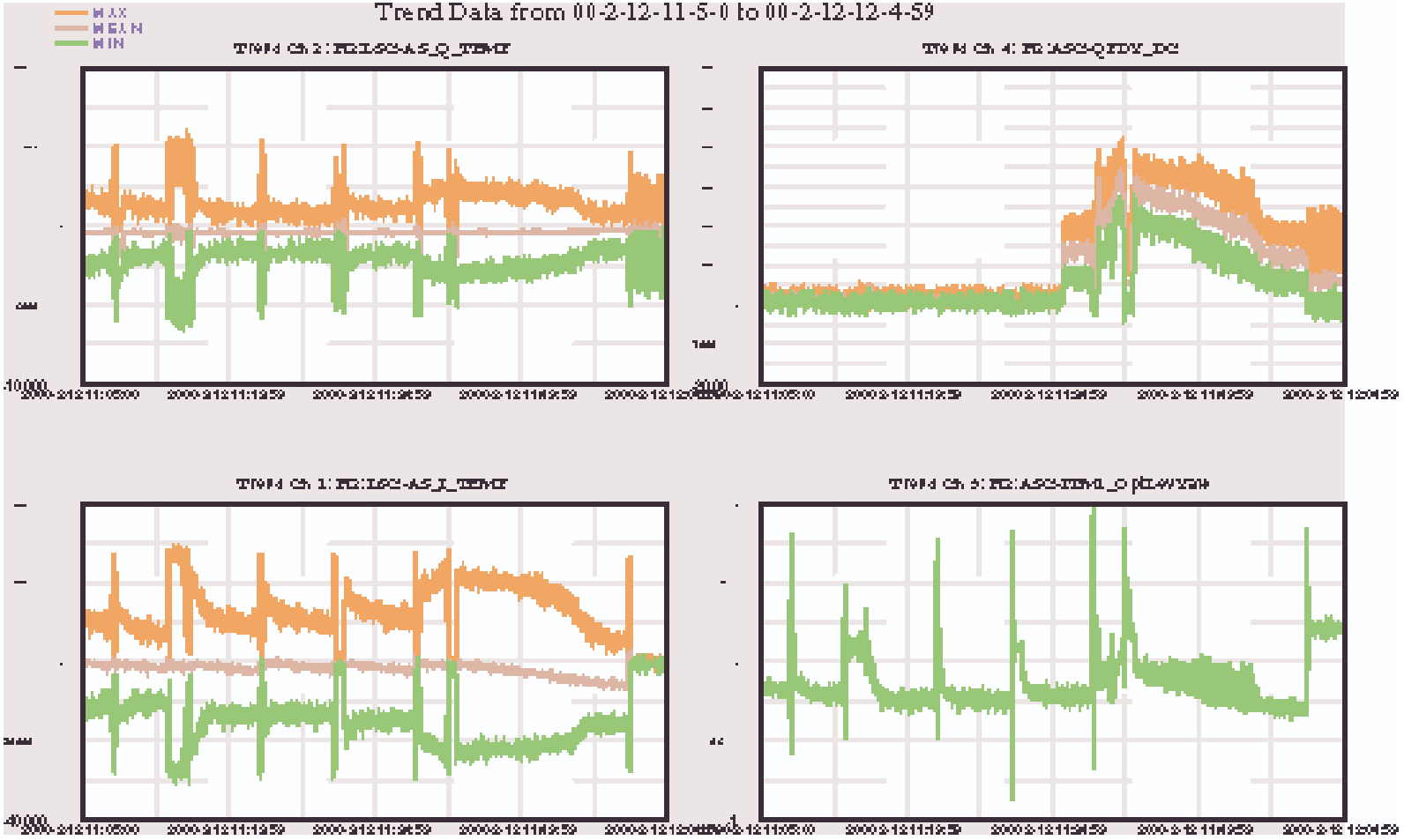
- Includes all interferometer subsystems
  - » many in definitive form; analog servo on cavity length for test configuration
- confirmation of initial alignment
  - » ~100 microrad errors; beams easily found in both arms
- ability to lock cavity improves with understanding 0 sec 12/1 flashes of light
  - » 0.2 sec 12/9
  - » 2 mins 1/14
  - » 60 sec 1/19
  - » 5 mins 1/21 (and on a different arm)
  - » 18 mins 2/12

2km Fabry-Perot cavity

- models of environment
  - » temperature changes on laser frequency
  - » tidal forces changing baselines
  - » seismometer/tilt correlations with microseismic peak
- mirror characterization
  - » losses: ~6% dip, excess probably due to poor centering
  - » scatter: appears to be better than requirements
  - » figure 12/03 beam profile



2km Fabry-Perot cavity: 15 minute locked stretch



Software tools for Diagnostics

- Data acquisition system
  - » site-wide, synchronized, flexible
  - » reduced data sets for later study
- time series viewing tools
  - » multiple time series, trends
- diagnostic analysis tools
  - » fourier transforms, coherence, etc.
- Change of paradigm: research performed in the control room

Commissioning

- Relatively ‘young’ undertaking
  - » unlike (much better than) previous prototype environments
- tools, researchers quickly maturing
- learning rules for structuring the work
  - » temporary hardware setups
  - » useful software tools
  - » coordination with installation
  - » multiple shifts
- second derivative is non-zero and positive

Progress Against Schedule?

- Installation and commissioning of the interferometers have been progressing and preliminary results are encouraging
- However there have been delays and problems:
  - » production start problems in seismic isolation and a slow early production pace
  - » process control problems for the magnet/standoff assembly adhesion to the optics
  - » handling and fixture problems associated with the transport and alignment of completed suspension assemblies
  - » re-manufacture of much of our flourel component stock as a result of losses from a tornado which destroyed the manufacturing facility
  - » re-baking of the flourel spring seats (and associated seismic stack rebuild) to mitigate water load on the vacuum system
  - » There have also been a number of secondary delays (not pushing the critical path, but “just in time”) indicating that the project has been stressed to meet the demanding installation schedule

Reformulated Installation and Commissioning Plan

- The original installation and commissioning plan suffers from two main weaknesses and one unnecessary constraint:
  - » The first weakness is that by installing all three interferometers before beginning commissioning, any design deficiencies are replicated three times
  - » The second weakness is that having a period of installation followed by a period of commissioning does not use the range of skills of the LIGO staff as effectively as possible
  - » The constraint that coincidence testing begin only after all three interferometers are operational, unduly drives the installation of the third interferometer

Reformulated Installation and Commissioning Plan (continued)

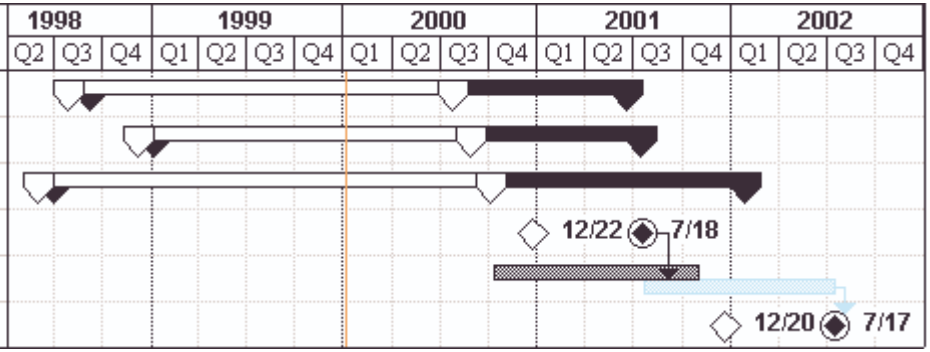
- Delay completion of the third interferometer (the Hanford 4km interferometer) :
  - » Enable lessons learned from the first two interferometers to be realized in redesign before installation (minimizes re-work/re-installation)
  - » Reduce simultaneous installation and commissioning workload on the LIGO lab staff
- Use the Hanford 2 km interferometer as a "pathfinder" to identify problems early
- Use the Livingston 4 km interferometer for problem resolution & detailed characterization
- Initiate Coincidence testing when the first two interferometers are at an operational strain sensitivity

Reformulated Installation and Commissioning Plan (continued)

- Define clear decision points in the schedule for the third interferometer installation elements:
  - » Perform all in-vacuum work and infrastructure as early as possible
  - » Delay installation of the servo-control electronics until we've gained enough experience to incorporate anticipated re-design.
- LIGO I Science Run
  - » Begins with reliable and calibrated coincidence data on three interferometers and stable configuration
  - » Improvements to reach final design goals in sensitivity and reliability will be alternated with data running
  - » Goal is to obtain at least one year of integrated sensitivity at $h \sim 10^{-21}$ before initiating LIGO II

Top Level Schedule

ID	Task Name
1	LHO 2km IFO
14	LLO 4km IFO
30	LHO 4km IFO
44	Coincidence Engineering Run starts
45	Observatory Operations & improvements
46	Science Run starts



Projected Significant Events

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Hanford 2km interferometer	Single arm test complete installation complete interferometer locked	6/00 8/00 12/00
Livingston 4km interferometer	Input Optics completed interferometer installed interferometer locked	7/00 10/00 2/01
Coincidence Engineering Run (Hanford 2km & Livingston 4km)	Initiate Complete	7/01 7/02
Hanford 4km interferometer	All in-vacuum components installed interferometer installed interferometer locked	10/00 6/01 8/01
LIGO I Science Run (3 interferometers)	Initiate Complete (obtain 1 yr @ h ~ 10^{-21})	7/02 1/05

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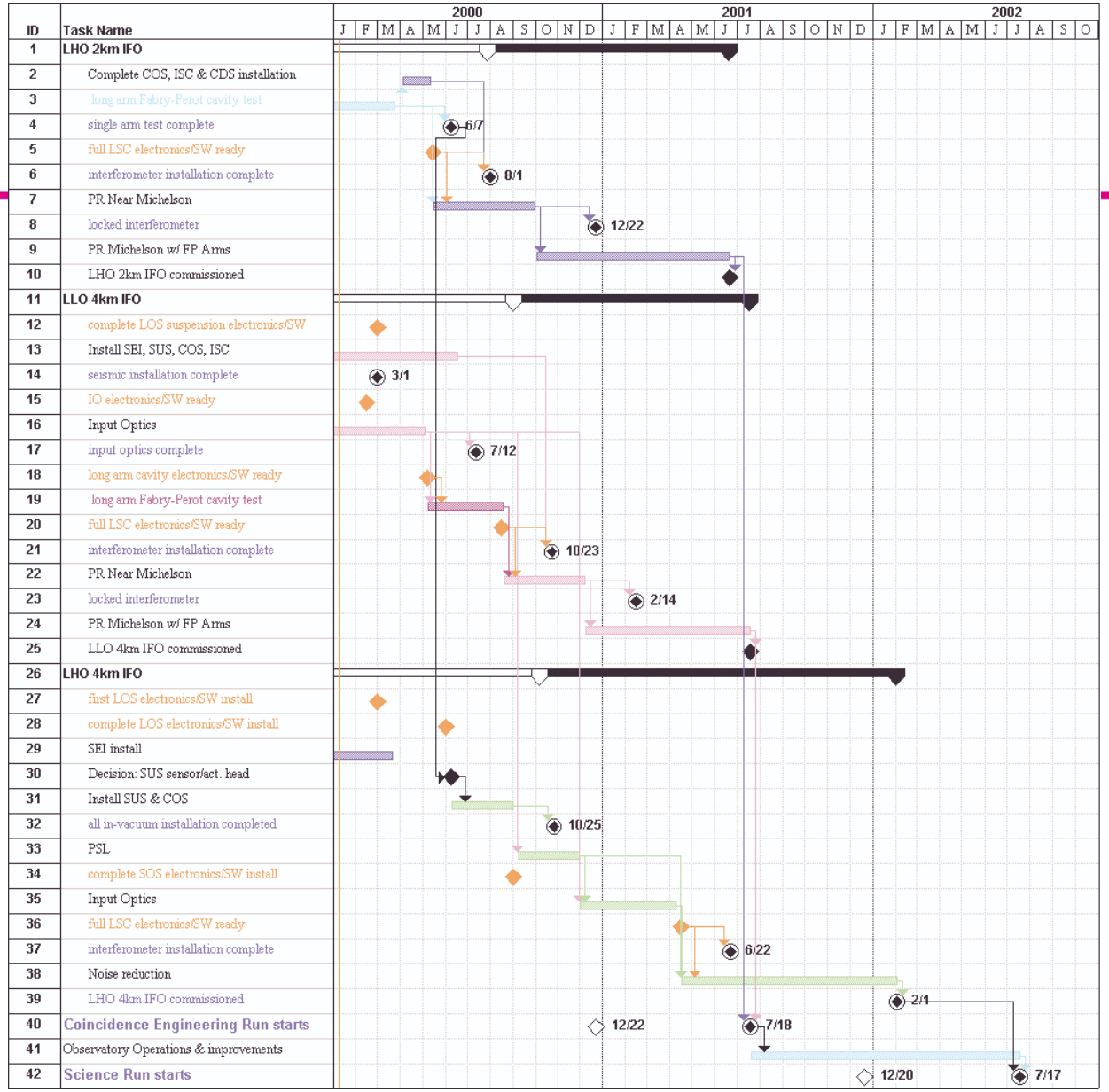
Schedule


2000
2001
2002
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
ID
Task Name
1 LHO 2km IFO
2 Complete COS, ISC & CDS installation
3 long arm Fabry-Perot cavity test
4 single arm test complete
5 full LSC electronics/SW ready
6 interferometer installation complete
7 PR Near Michelson
8 locked interferometer
9 PR Michelson w/ FP Arms
10 LHO 2km IFO commissioned
11 LLO 4km IFO
12 complete LOS suspension electronics/SW
13 Install SEI, SUS, COS, ISC
14 seismic installation complete
15 IO electronics/SW ready
16 Input Optics
17 input optics complete
18 long arm cavity electronics/SW ready
19 long arm Fabry-Perot cavity test
20 full LSC electronics/SW ready
21 interferometer installation complete
22 PR Near Michelson
23 locked interferometer
24 PR Michelson w/ FP Arms
25 LLO 4km IFO commissioned
26 LHO 4km IFO
27 first LOS electronics/SW install
28 complete LOS electronics/SW install
29 SEI install
30 Decision: SUS sensor/act. head
31 Install SUS & COS
32 all in-vacuum installation completed
33 PSL
34 complete SOS electronics/SW install
35 Input Optics
36 full LSC electronics/SW ready
37 interferometer installation complete
38 Noise reduction
39 LHO 4km IFO commissioned
40 Coincidence Engineering Run starts
41 Observatory Operations & improvements
42 Science Run starts
6/7
8/1
12/22
3/1
7/12
10/23
2/14
10/25
6/22
2/1
12/22
7/18
12/20
7/17

Installation & Commissioning Summary

- Installation & Commissioning successes!
  - » The 2 km interferometer Mode Cleaner (MC) is aligned and locked
  - » The 2 km Interferometer recycling cavity and both arms are aligned
  - » The 2km long arm cavity test started Nov and will complete in Mar (Lock durations of ~20 minutes!)
  - » The Livingston 4km interferometer Mode Cleaner (MC) is aligned; final installation and first lock will be next week
- Delays have caused us to re-evaluate our Installation & Commissioning plan & schedule :
  - » Delays due principally to installation problems on the critical path
  - » Anticipated problems/delays in the servo-control electronics
  - » We project a 7 month slip in the start of coincidence testing, redefined as a single interferometer at each site operating reliably and at a low strain sensitivity