Installation and Commissioning Status

Stan Whitcomb

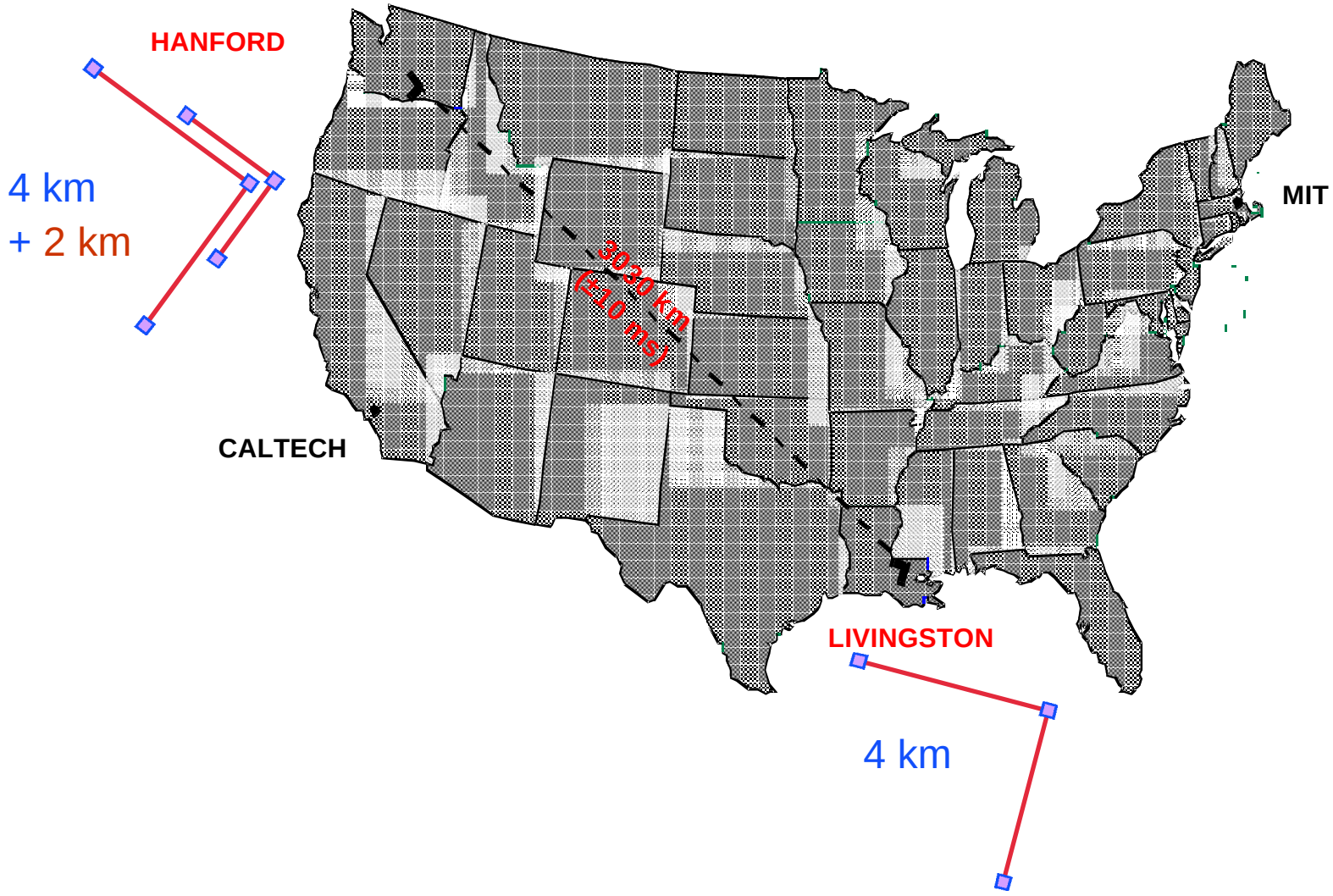
Program Advisory Committee

14 June 2001

Caltech

LIGO-G010234-00-D

LIGO Observatories



Installation/Commissioning Philosophy

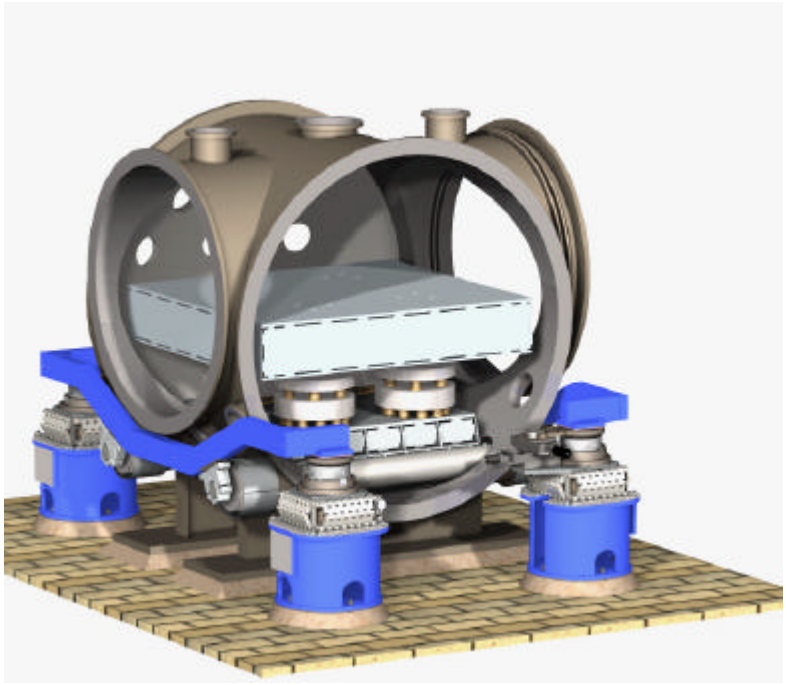
- Each interferometer has a specific role in commissioning
  - » 2 km Interferometer: “Pathfinder”, move quickly, identify problems, move on
  - » LLO 4 km Interferometer: Systematic characterization, problem resolution
  - » LHO 4 km Interferometer: Scheduled so that all fixes can be implemented prior to installation
- Stagger the installation and commissioning activities to make optimal use of available staff

Installation Status

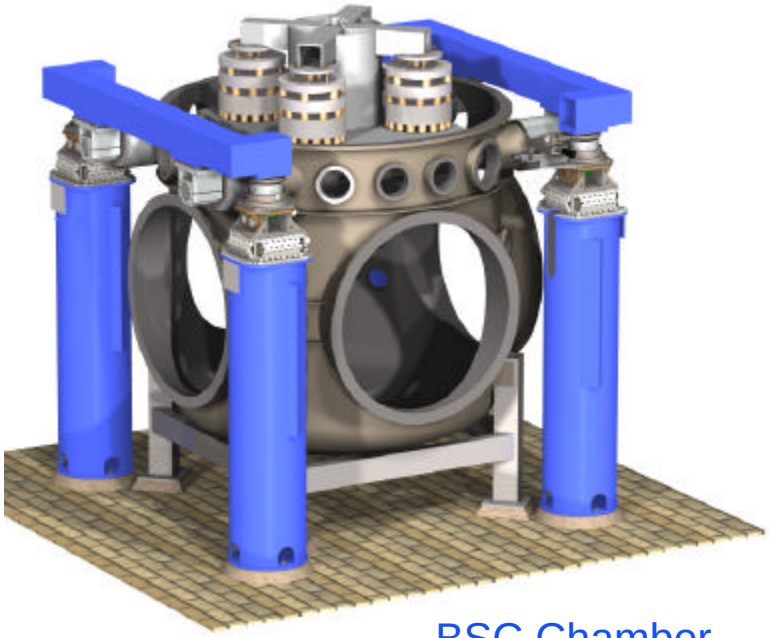
- LHO 2km and LLO 4km interferometers
  - » All installation complete
  - » Commissioning underway
- LHO 4km interferometer
  - » All installation complete, except for one end mirror
  - » Commissioning underway
- Data Acquisition/Control Network infrastructure complete at both sites
  - » Basic functionality in place; still working on reliability, enhancements
- Olympia earthquake forced repairs and realignment of 2 km LHO interferometer
  - » Magnets broken off some suspended optics

Vibration Isolation Systems

- » Reduce in-band seismic motion by 4 - 6 orders of magnitude
- » Little or no attenuation below 10Hz
- » Large range actuation for initial alignment and drift compensation
- » Quiet actuation to correct for Earth tides and microseism at 0.15 Hz during observation

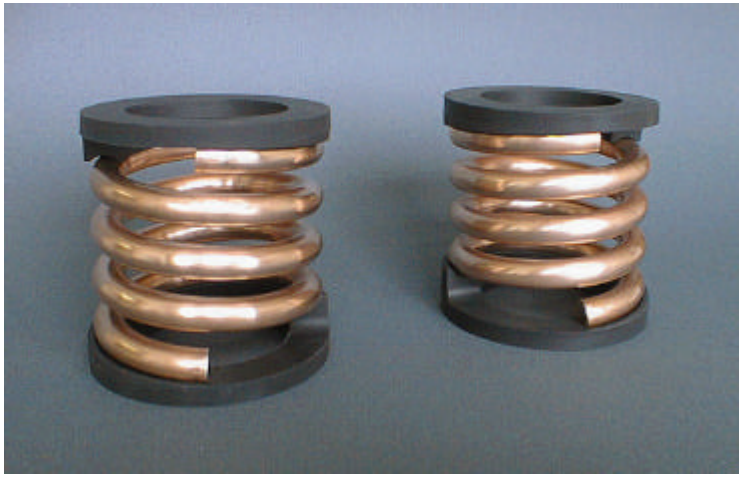


HAM Chamber

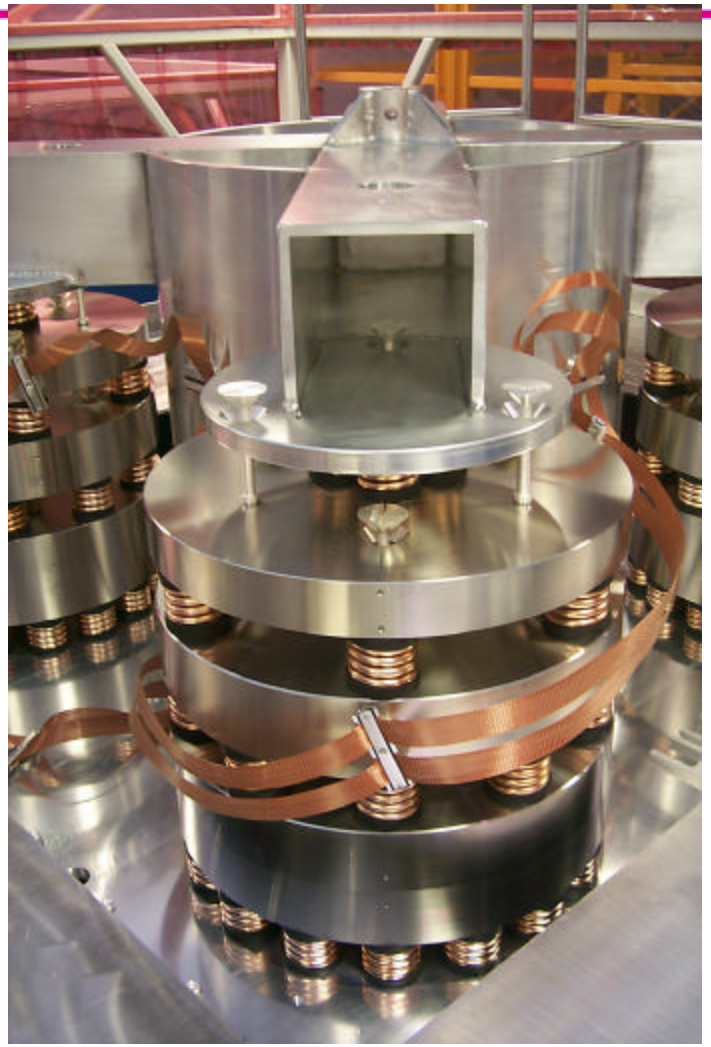


BSC Chamber

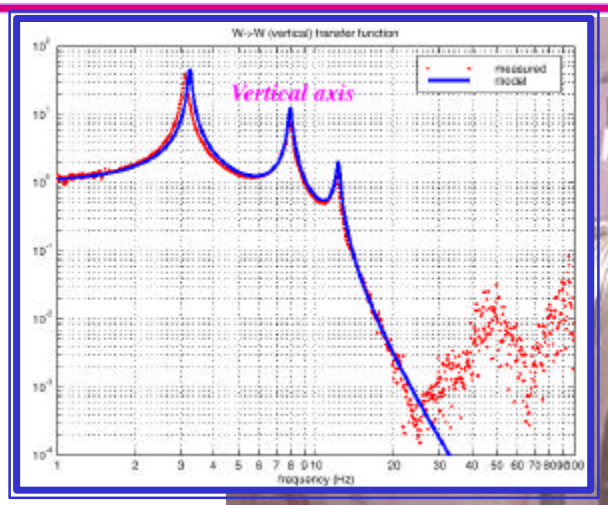
Seismic Isolation – Springs and Masses



damped spring
cross section

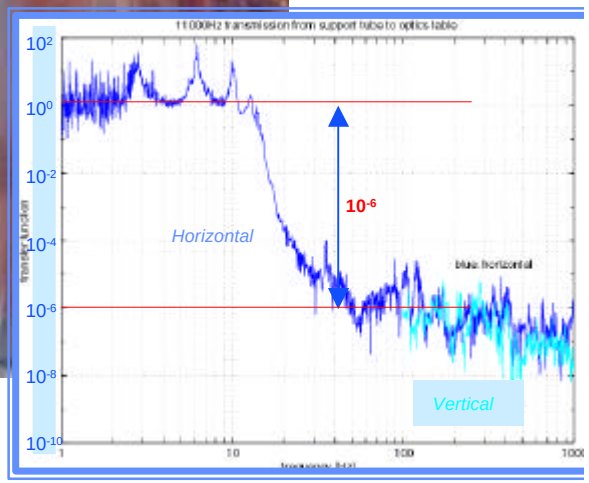


Seismic System Performance



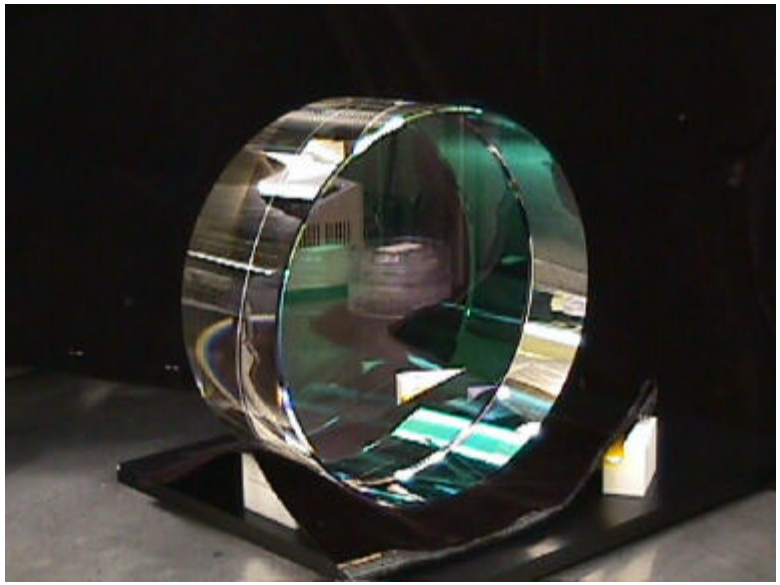
HAM stack
in air

BSC stack
in vacuum



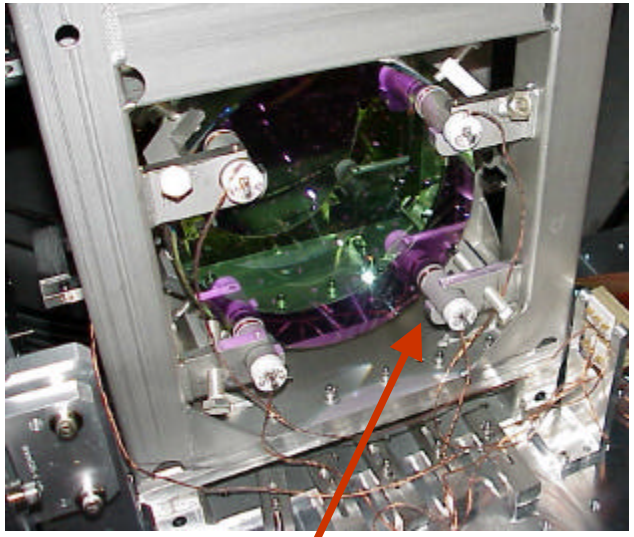
Core Optics

- Substrates: SiO_2
  - » 25 cm Diameter, 10 cm thick
  - » Homogeneity < 5 x 10^{-7}
  - » Internal mode Q's > 2 x 10^{6}
- Polishing
  - » Surface uniformity < 1 nm rms
  - » Radii of curvature matched < 3%
- Coating
  - » Scatter < 50 ppm
  - » Absorption < 2 ppm
  - » Uniformity <10^{-3}



- Production involved 6 companies, NIST, and LIGO
- Optics for all three interferometers delivered to sites
  - » Plus spares on hand for emergencies

Core Optics Suspension and Control

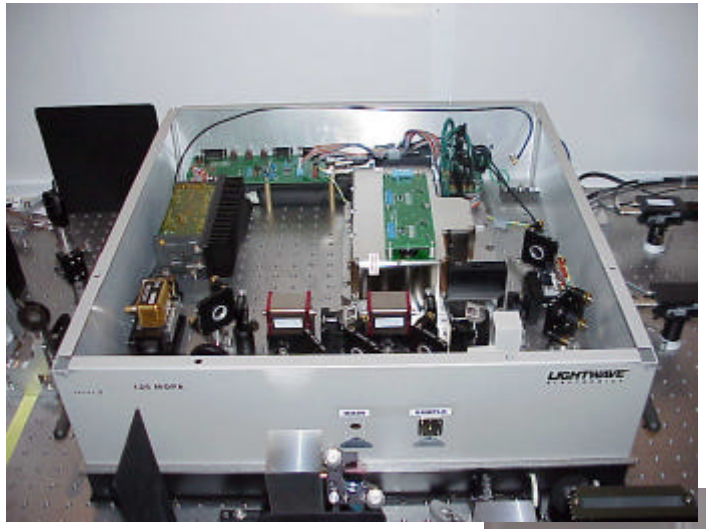


- Optics suspended as simple pendulums
- Local sensors/actuators for damping and control
- Problem with local sensor sensitivity to laser light

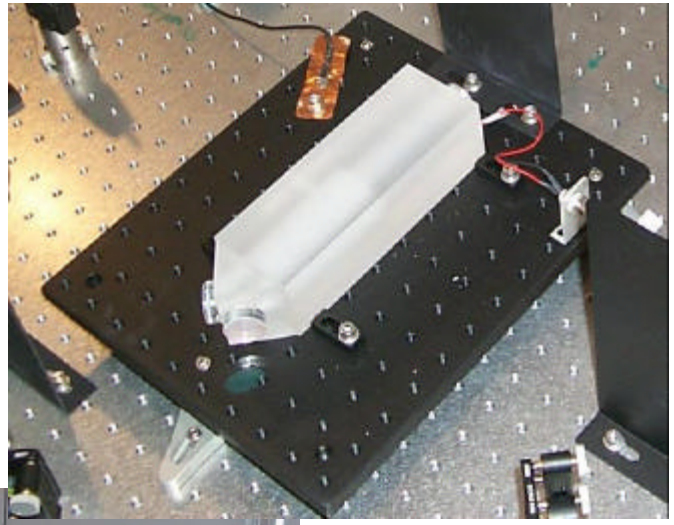
New Suspension sensors

- Developed in parallel with low power commissioning activities
  - » Develop a robust solution without pressure of critical path
- Use different LED/photodiode combination with interference filter to discriminate against scattered laser light
- Implementation scheduled to minimize impact on commissioning
  - » LHO 4 km installation scheduled to make use of new sensors from beginning
  - » LHO 2 km retrofit made in combination with earthquake repairs
  - » LLO 4km retrofit in progress
- LHO 2 km modecleaner successfully tested to full power this past weekend!

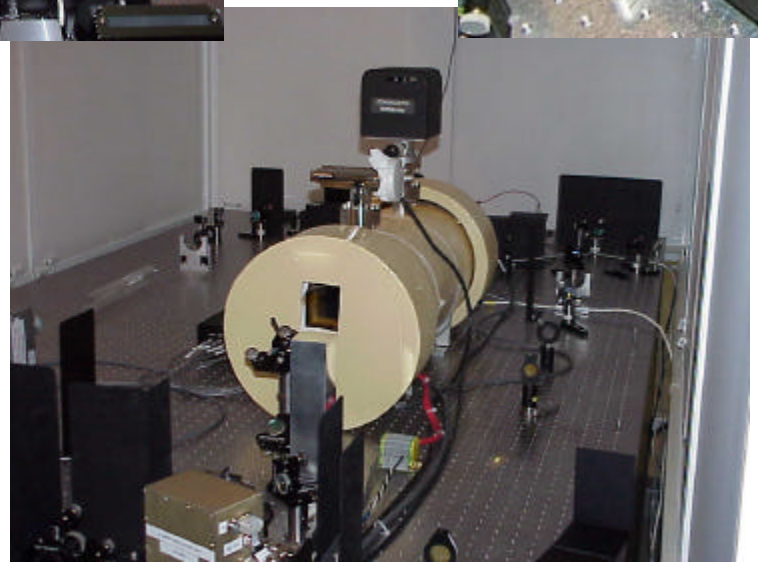
Pre-stabilized Laser (PSL)



Custom-built
10 W Nd:YAG Laser,
joint development with
Lightwave Electronics
(now commercial product)



Cavity for
defining beam geometry,
joint development with
Stanford

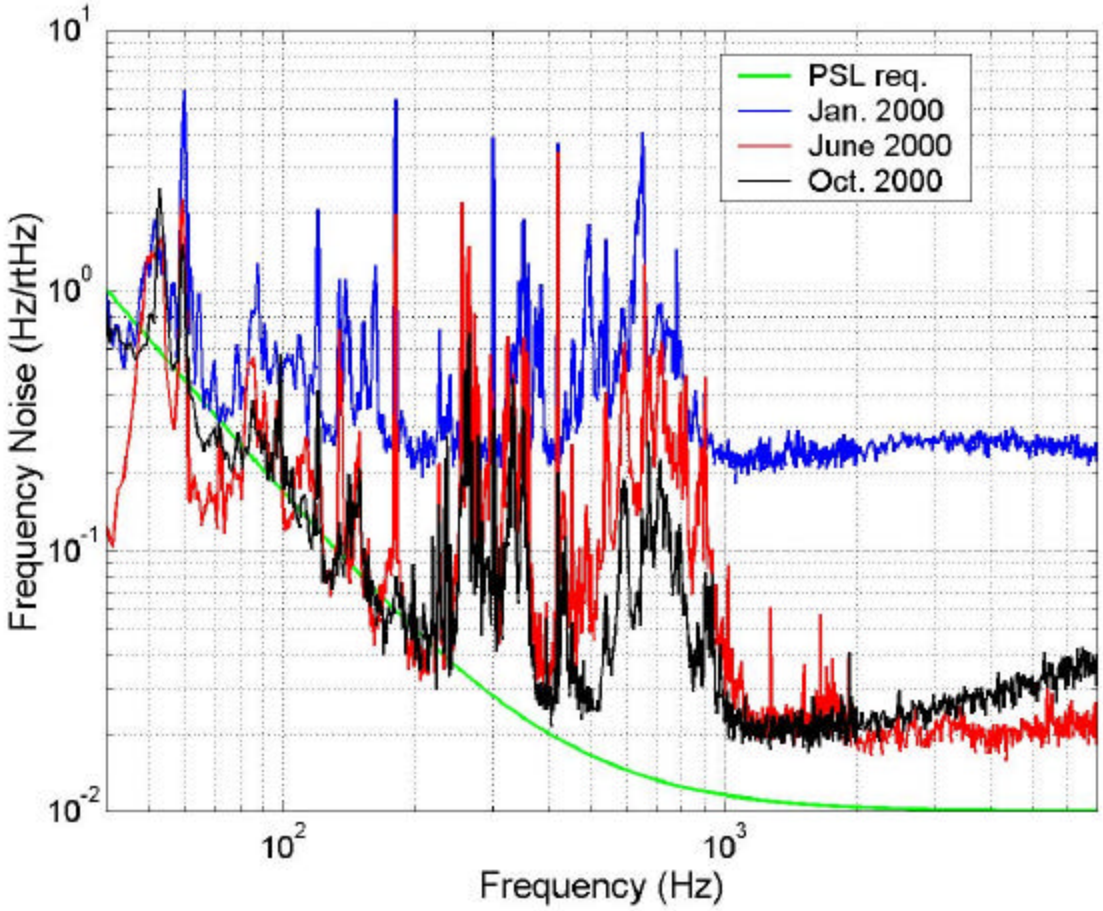


Frequency stabilization
cavity

(Shown Last PAC meeting)

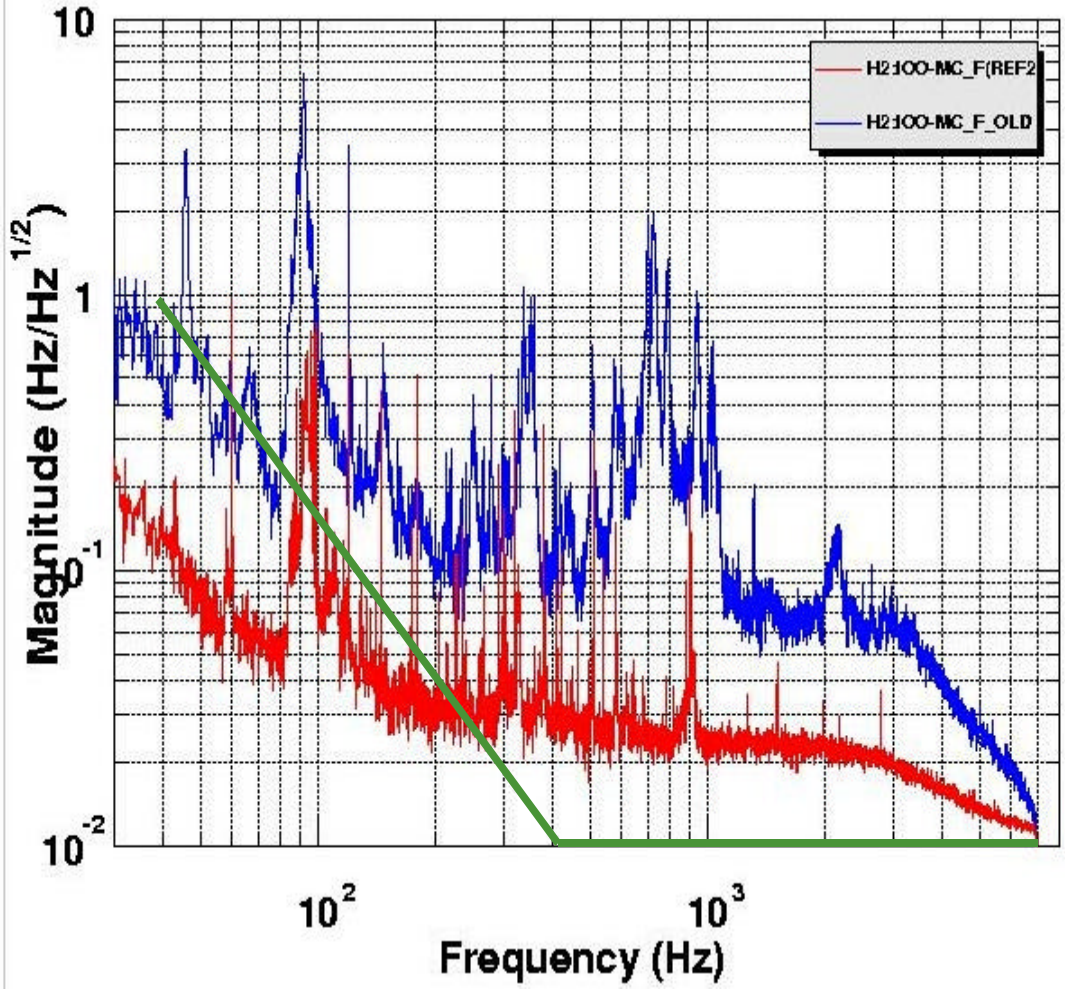
WA 2k Pre-stabilized Laser Performance

- > 20,000 hours continuous operation
- Frequency lock typically holds for months
- Improvement in noise performance
  - » electronics
  - » acoustics
  - » vibrations



Continued improvement in PSL Frequency Noise

- Simplification of beam path external to vacuum system eliminates peaks due to vibrations
- Broadband noise better than spec in 40-200 Hz region



Control and Data System

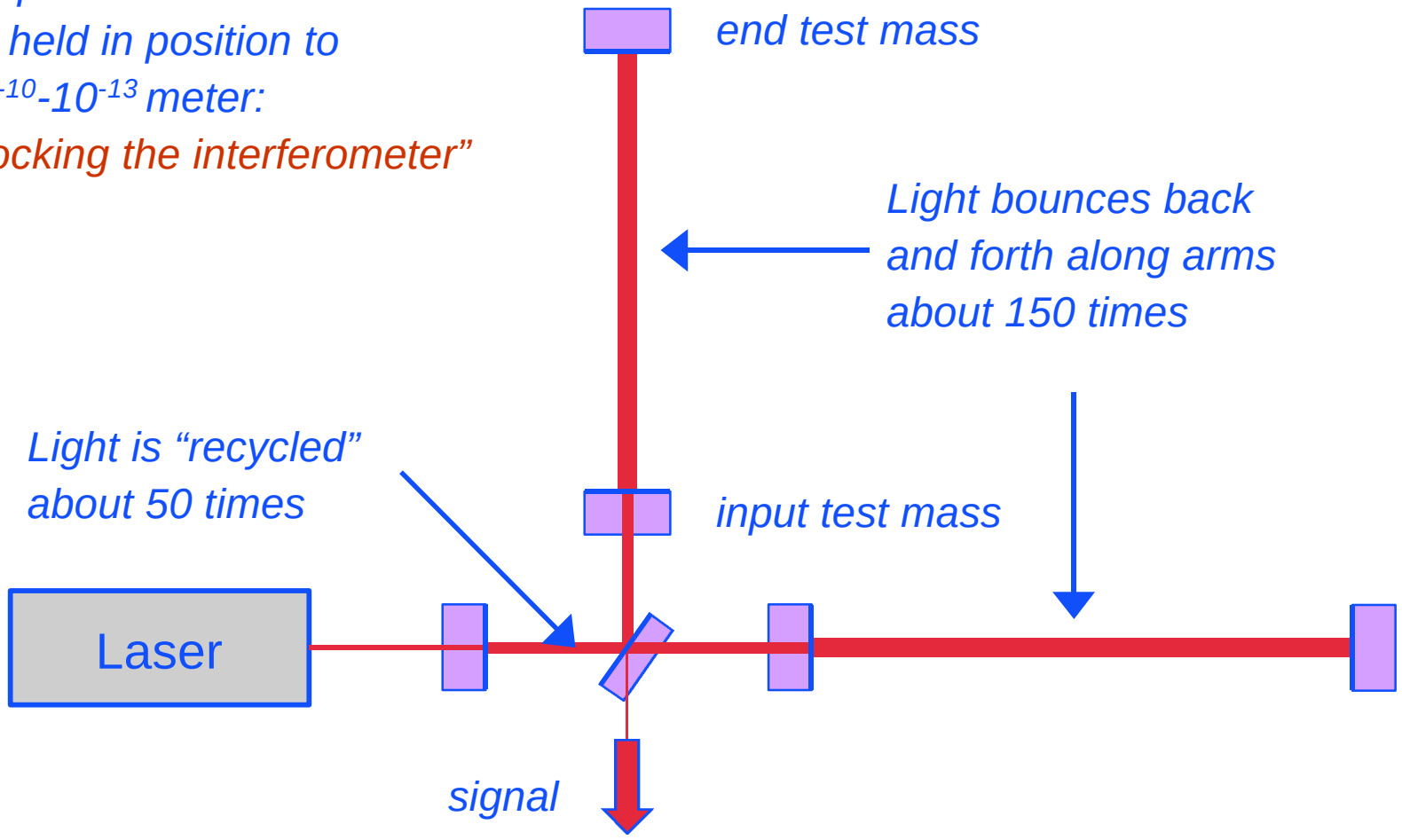
- EPICS-based distributed real-time control system
  - » ~50 real-time processors, ~20 workstations per site
  - » ~5000 process variables (switches, sliders, readings, etc) per interferometer
  - » Fiber optic links between buildings
- Data acquisition rate of 3 MB/s per interferometer
  - » Reflective memory for fast channels, EPICS for slow ones
  - » Synchronized using GPS
  - » Data served to any computer on site in real-time or playback mode using same tools
- Multiplexed video available in control room and next to the interferometer

Commissioning Status

- LHO 2 km interferometer
  - » Modecleaner testing uncovered problem with laser light scattering into suspension sensors – moved to lower power while redesign underway
  - » Full interferometer locked at low input power (100 mW)
    - All longitudinal degrees of freedom controlled
    - Partial implementation of wavefront-sensing alignment control
  - » Commissioning interrupted by earthquake repairs/susp. sensor replacement
- LLO 4 km interferometer
  - » Careful characterization of laser-modecleaner subsystems
  - » Single arm testing complete (both arms locked individually)
  - » Recombined Michelson with Fabry-Perot arms locked successfully
  - » Repetition of 2 km integrations taking much less time than expected
- LHO 4 km Interferometer
  - » PSL and modecleaner locked, with new suspension sensors, digital suspension controllers

Locking an Interferometer

Requires test masses to be held in position to 10^{-10}-10^{-13} meter:
"Locking the interferometer"



(Shown Last PAC meeting)

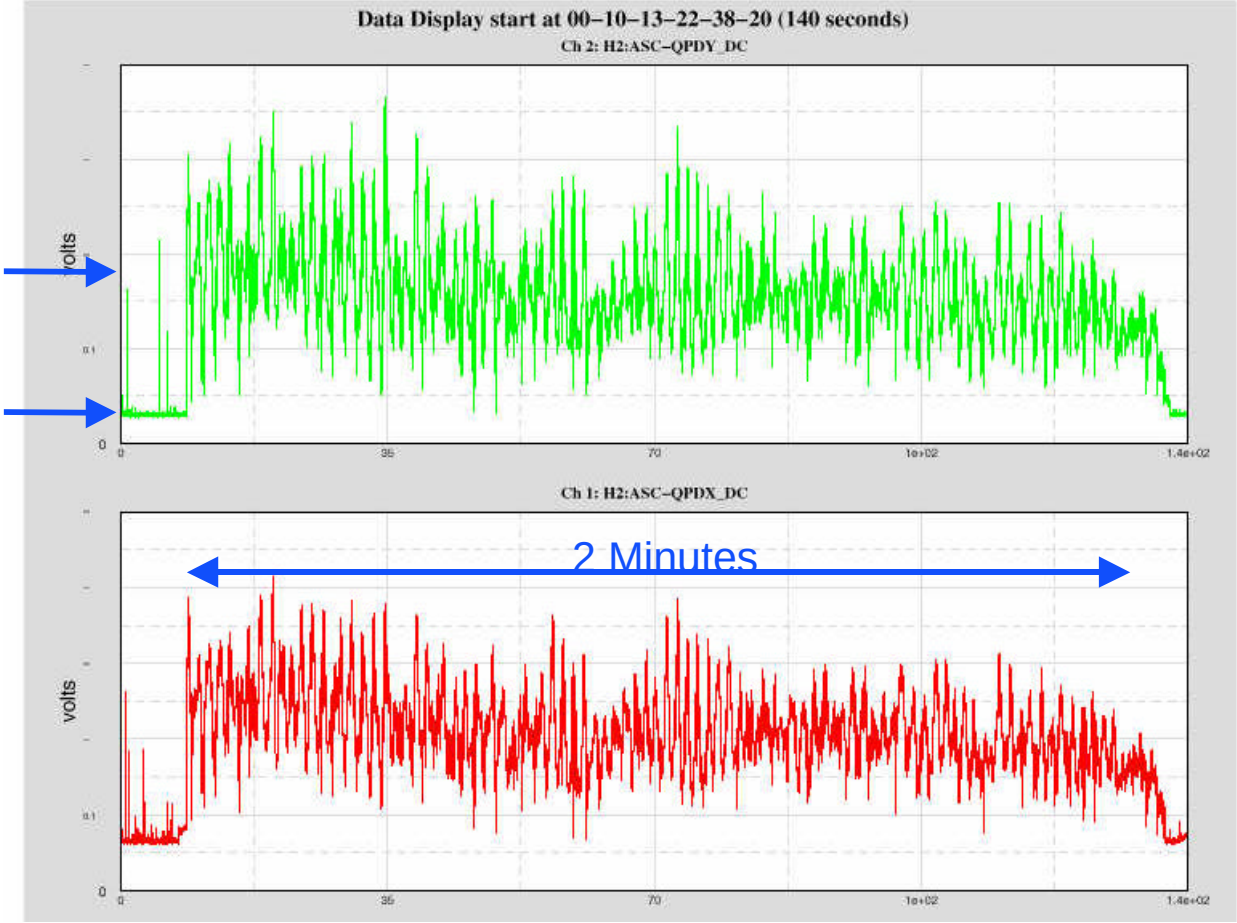
Full Interferometer Locking

- Still a bit tenuous…….

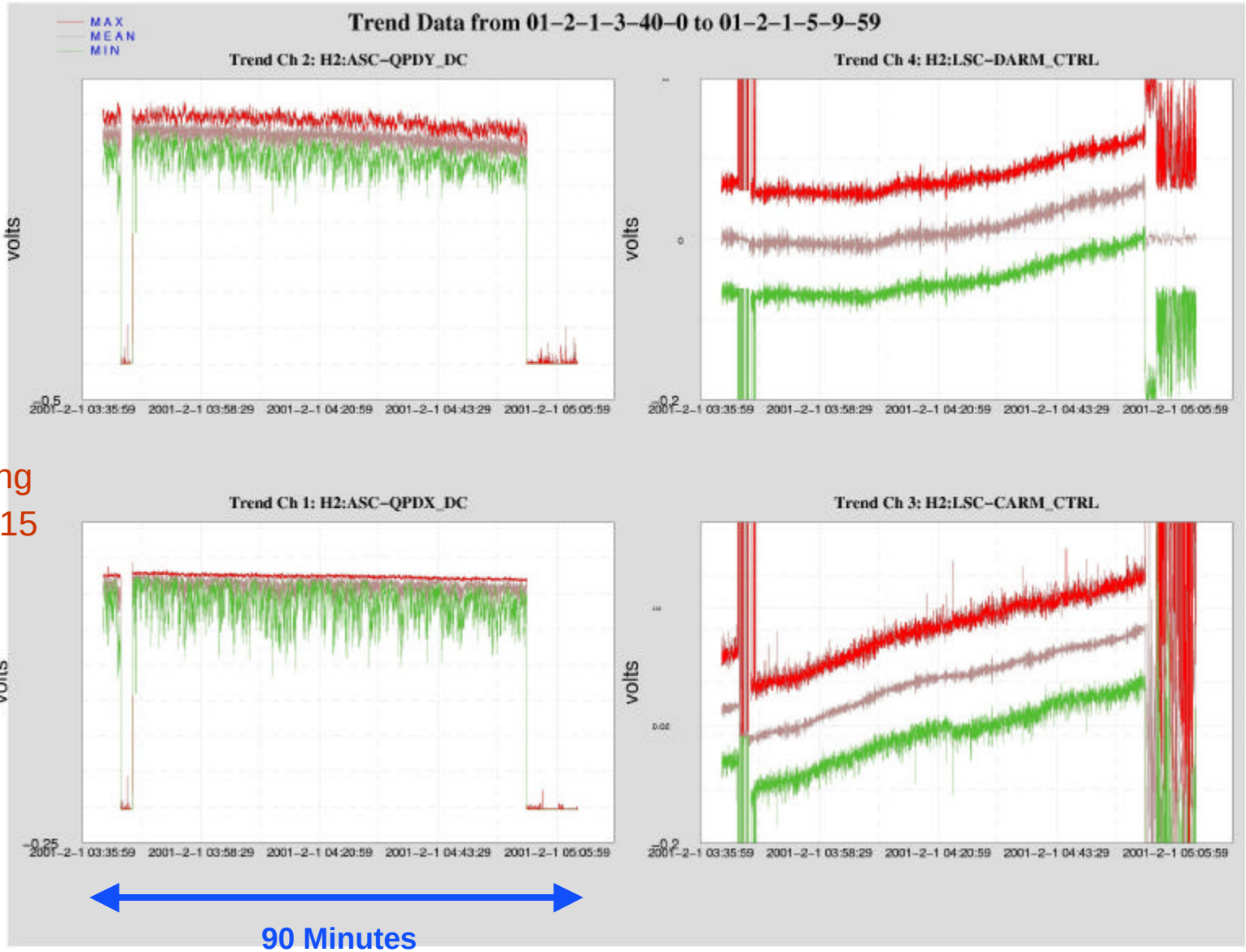
Locked

Unlocked

Recycling factor ~0.5



Full Interferometer Locking



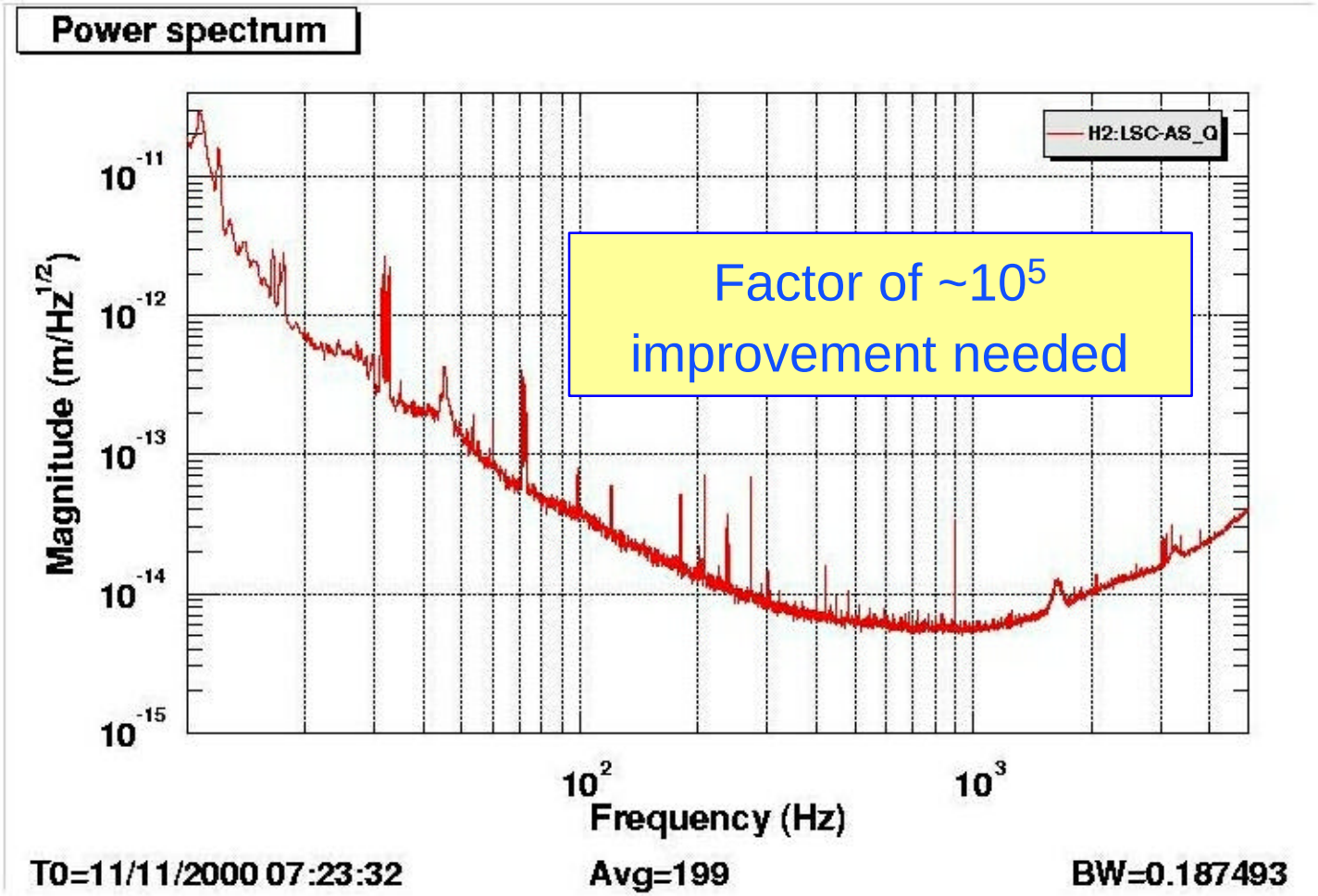
Recycling factor ~15

Engineering Runs

- Means to involve the broader LSC in commissioning
- Engineering Runs are a key part of our commissioning plan
  - » Test interferometer stability, reliability
  - » Well-defined dataset for off-site analysis
  - » Develop procedures for later operations
- First Engineering Run (E1) in April 2000
  - » Single arm of 2 km interferometer
  - » 24 hour duration
- Second Engineering Run (E2) November 2000
  - » 2 km interferometer as recombined (but not recycled) Michelson with Fabry-Perot arms
  - » One week duration

(Shown at last PAC meeting)

E2: Recombined Interferometer Spectrum



Factor of ~10^5 improvement needed

First differential arm spectrum, Nov. 2000

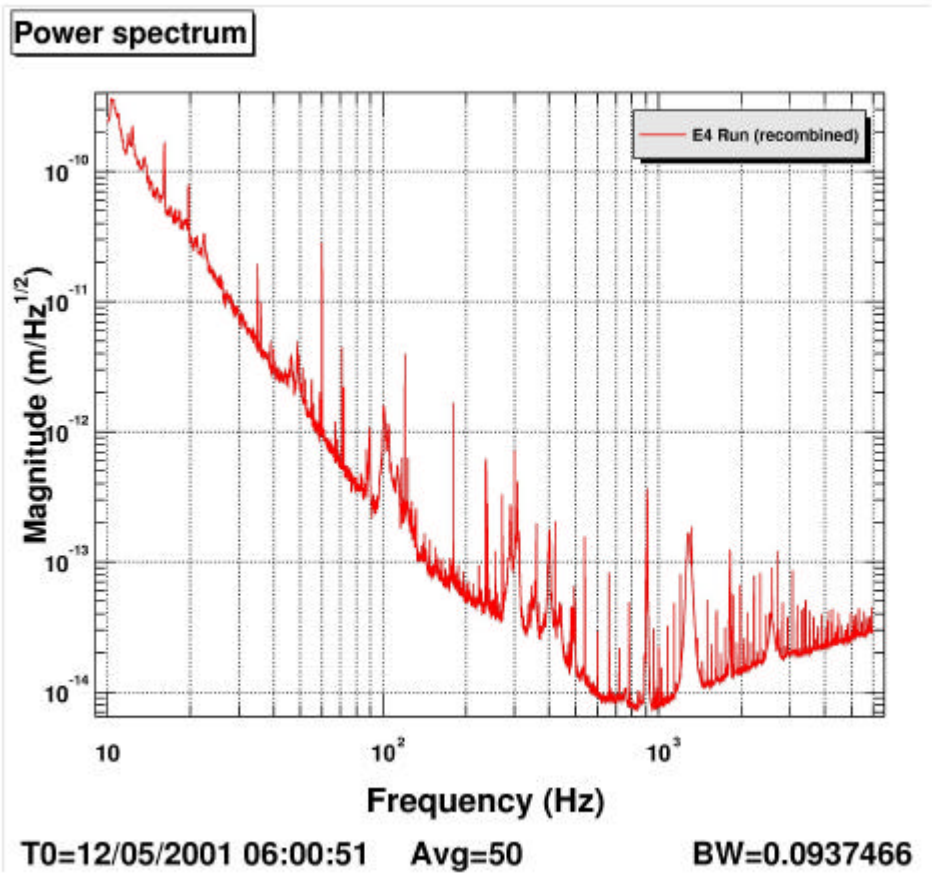
E3 Engineering Run

- Held March 9-12
- Planned as first coincidence run between LHO 2 km interferometer (full recycled configuration) and LLO 4 km interferometer (single arm)
- Specific goals
  - » Correlations between environmental signals
  - » Integration of data streams from two sites (including timing)
  - » (First operation of full recycled F-P Michelson interferometer)
- Earthquake (10 days before start) reduced LHO to environmental data only

E4 Engineering Run

- Held May 11-14
- LLO 4 km interferometer (recombined Michelson with F-P arms) plus LHO environmental data
- …
- Clarified correlation between anthropogenic ground noise and poor locking behavior
  - » 1-3 Hz noise well correlated with poor locking
  - » May indicate a need for external ground noise compensation (or may not…)

E4: Recombined Interferometer Spectrum

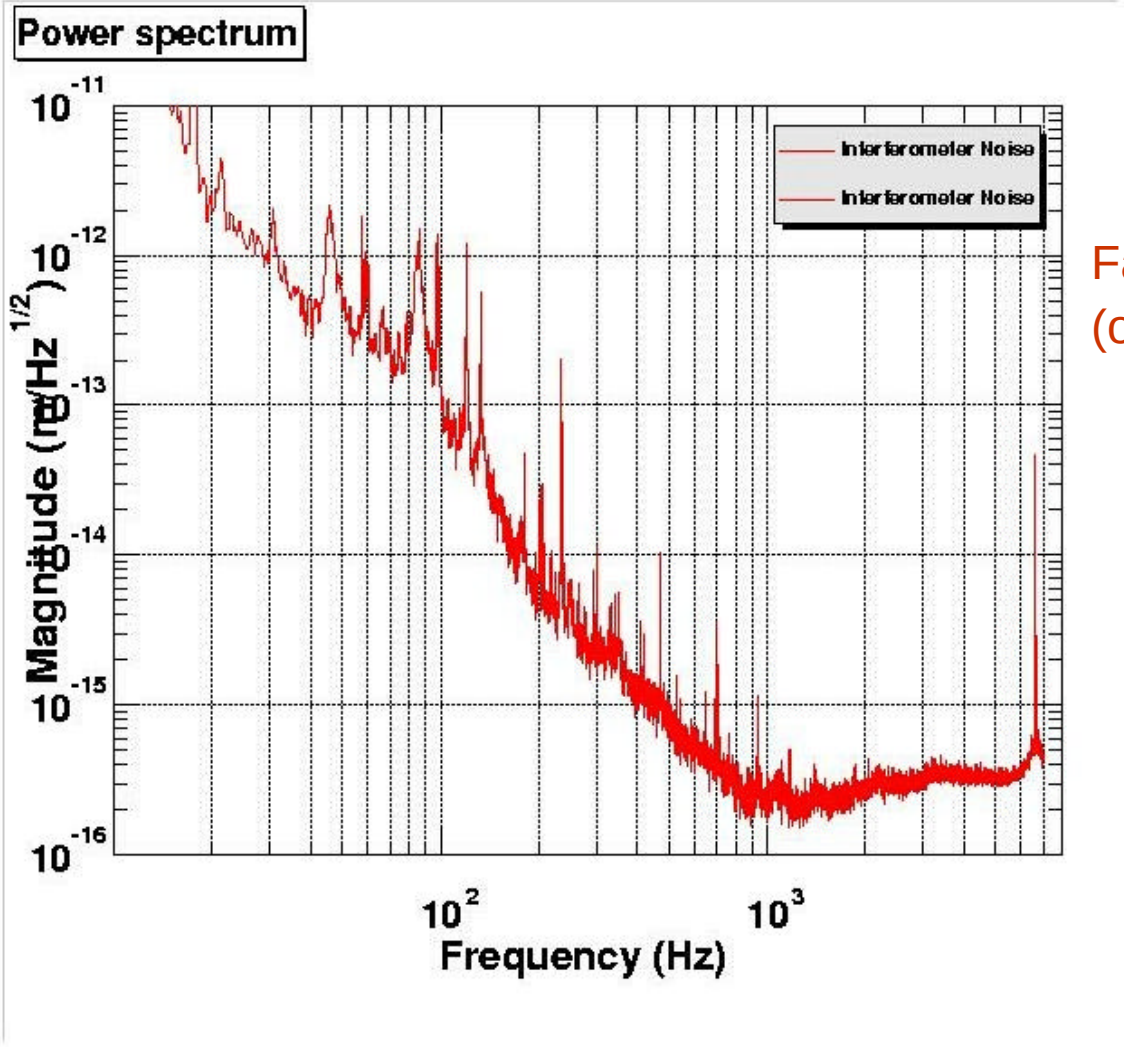


Comparable to first LHO differential arm spectrum

New Emphasis: Work on Interferometer Noise

- Emphasis to date primarily:
  - » Get the hardware in place and working
  - » Make the operation robust
- First noise spectrum (E2) pretty much what we expected
  - » No showstoppers!
  - » But a long way to go …

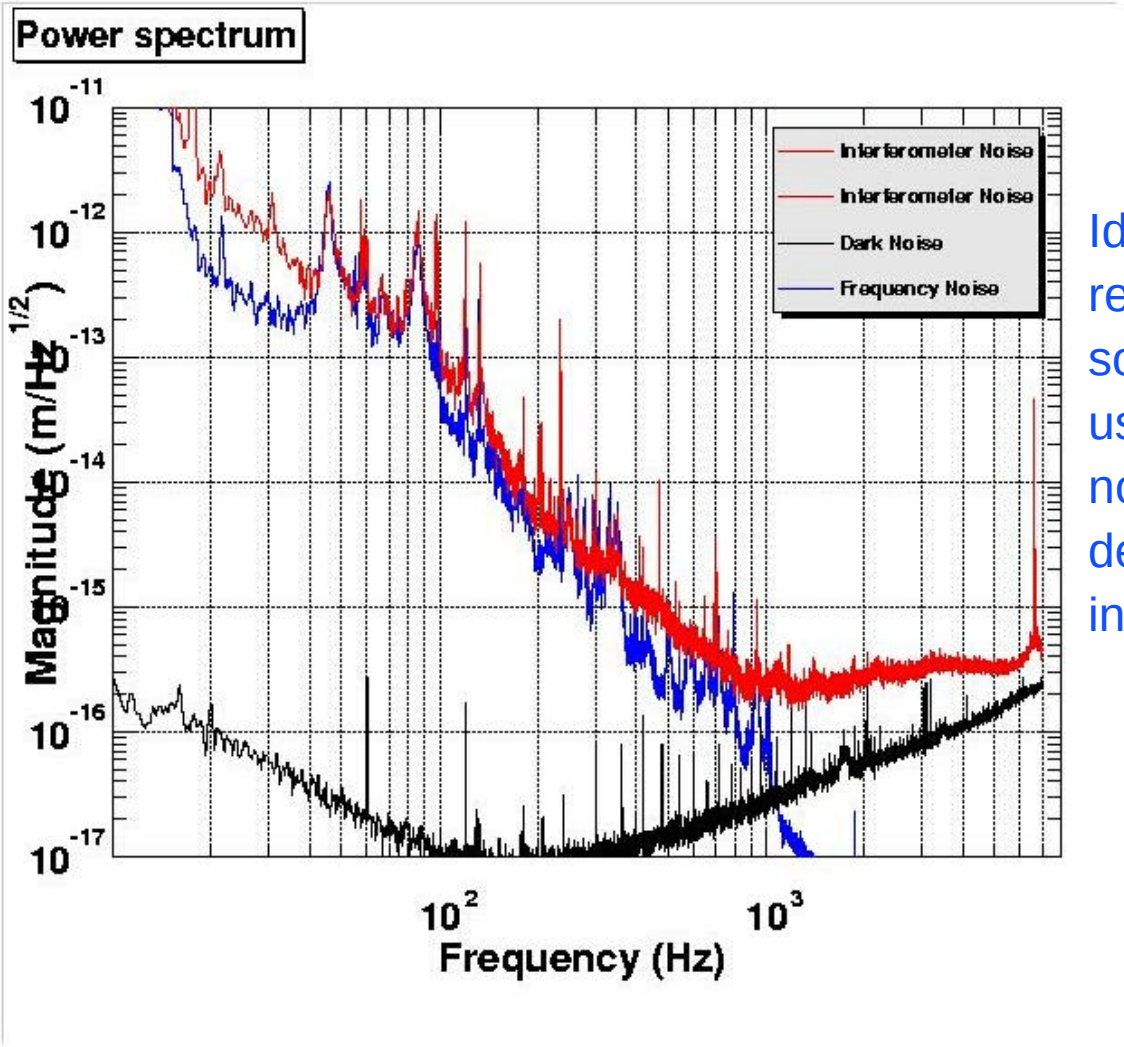
2 km Noise Spectrum (pre-earthquake)



Factor of 20 improvement (over E2 spectrum):

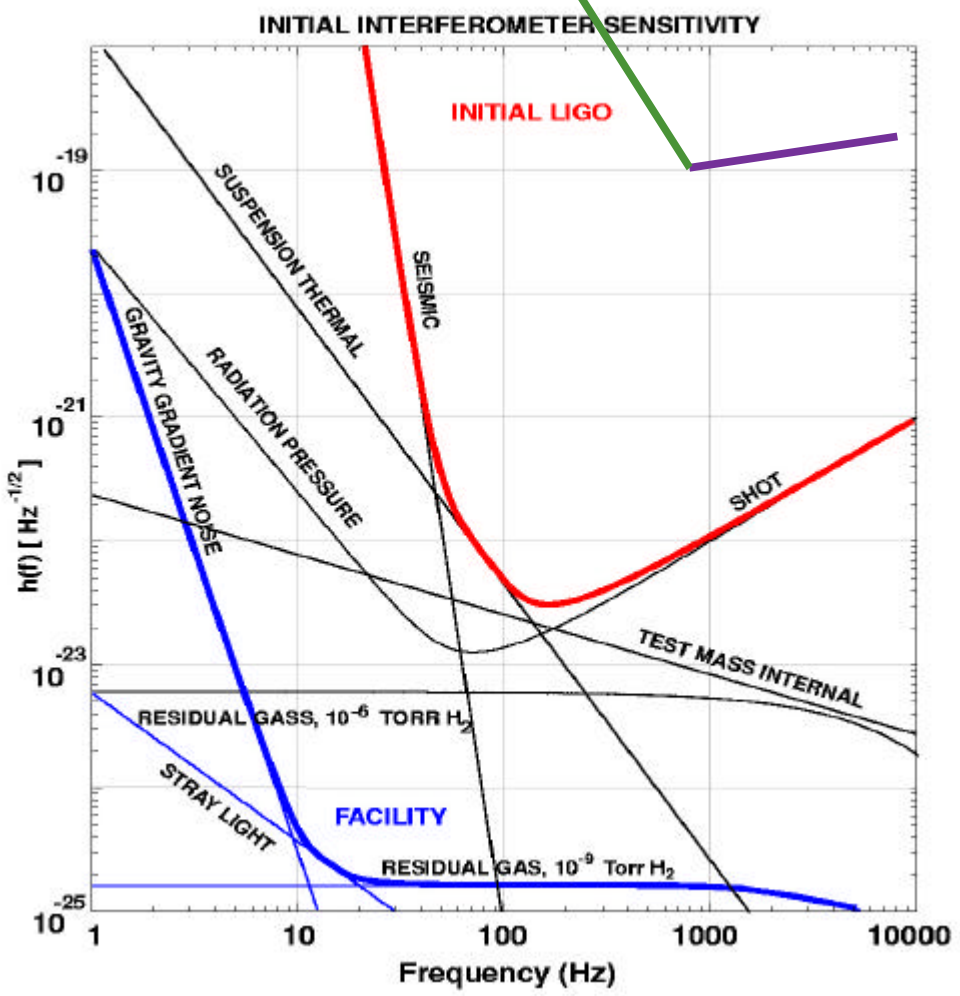
- Recycling
- Reduction of electronics noise
- Partial implementation of alignment control

Known Contributors to Noise



Identification and reduction of noise sources underway using well-established noise-hunting techniques developed on prototype interferometers

Initial LIGO Sensitivity Goal



- Frequency noise
  - » Improve PSL Table layout (done)
  - » Tailor MC loop (done)
  - » Implement common-mode feedback from arms
- Electronics noise
  - » Scales as P^{-1}
  - » Increase power from 12 mW to 6 W
  - » Increase recycling factor from 15 to 30-50 (Wavefront-sensing alignment servos)

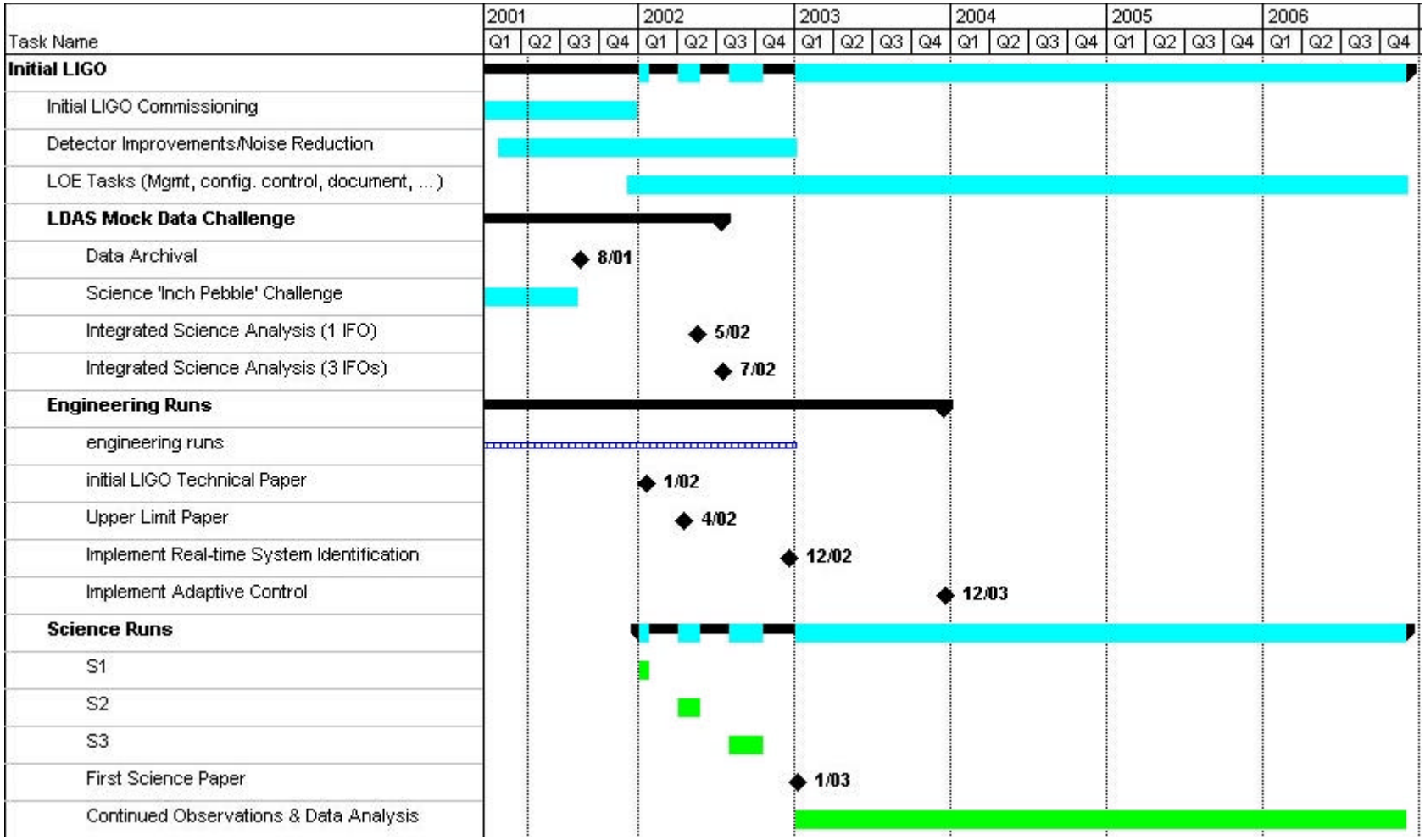
Plan to Reach Science Run

- May
  - » E4 run: LLO 4 km, operating in recombined mode + LHO environmental data
- May - July
  - » LHO 2k, bring full interferometer back on-line, sensitivity studies
  - » LLO 4k suspension sensor replacement, bring back on-line
  - » LHO 4k, PRM locking (no arms yet)
- August
  - » E5: LHO 2k in full recycled configuration, LLO 4k in recombined configuration(?), LHO 4k in recombined configuration
- Aug - Sept
  - » LLO 4k, attain full interferometer lock, sensitivity studies
  - » LHO 2km sensitivity studies, 4k lock full interferometer

Plan to Reach Science Run, Part 2

- Early Oct
  - » E6: triple coincidence run with all 3 interferometers in final optical configuration (“upper limit run”)
- Oct – early 2002
  - » Improve sensitivity and reliability
  - » Alternate diagnostic testing with engineering runs
- Jan 2002
  - » Papers documenting LIGO detector design and performance
- Apr 2002
  - » Submit upper limit papers

Initial Detector Milestones



Summary

Engineering Run 3 in the Livingston Observatory control room

- Detector installation nearly complete
- Commissioning proceeding well
- 2001
  - » Improve sensitivity/reliability
  - » First coincidence operation
  - » Initial data run (“upper limit run”)
- 2002
  - » Begin Science Run
  - » Interspersed data taking and machine improvements
- 2003-2006
  - » Minimum of one year of integrated data at 10^{-21} sensitivity