LIGO Overview

Barry Barish

March 31, 1998

LIGO
schedule

- Construction (1995-1999)
  - » Facilities and Initial Detector
  - » **presently 78% complete !**

- Commission (1999-2001)
  - » Implement Initial Detectors
    - – $h \sim 10^{-20}$ - Coincidence (Hanford/Livingston)
      - Engineering run (end of 2000)
    - – $h \sim 10^{-21}$ - Initial Design Sensitivity (end 2001)

- Operations (2002 + ...)
  - » Data Taking/Analysis
  - » Enhance Initial Detector
  - » Advanced Detectors

LIGO Schedule

main activities

1996	Construction Underway
	-mostly civil
1997	Facility Construction
	-beam pipe & enclosure
1998	Construct Detectors
	-complete vacuum systems
1999	Install Detectors
	-interferometers in vacuum
2000	Commission Detectors
	-first light; testing
2001	Engineering Tests
	-sensitivity; engineering run
2002	Initial LIGO Detector Run
	- $h \sim 10^{-21}$

Technical Status
facilities

- Hanford Construction
  - » building occupied, nearly complete
  - » we own the beam tube !! (prebake ~2 10^{-7} torr)
  - » near term activities - beam tube bakeout, vacuum system implementation

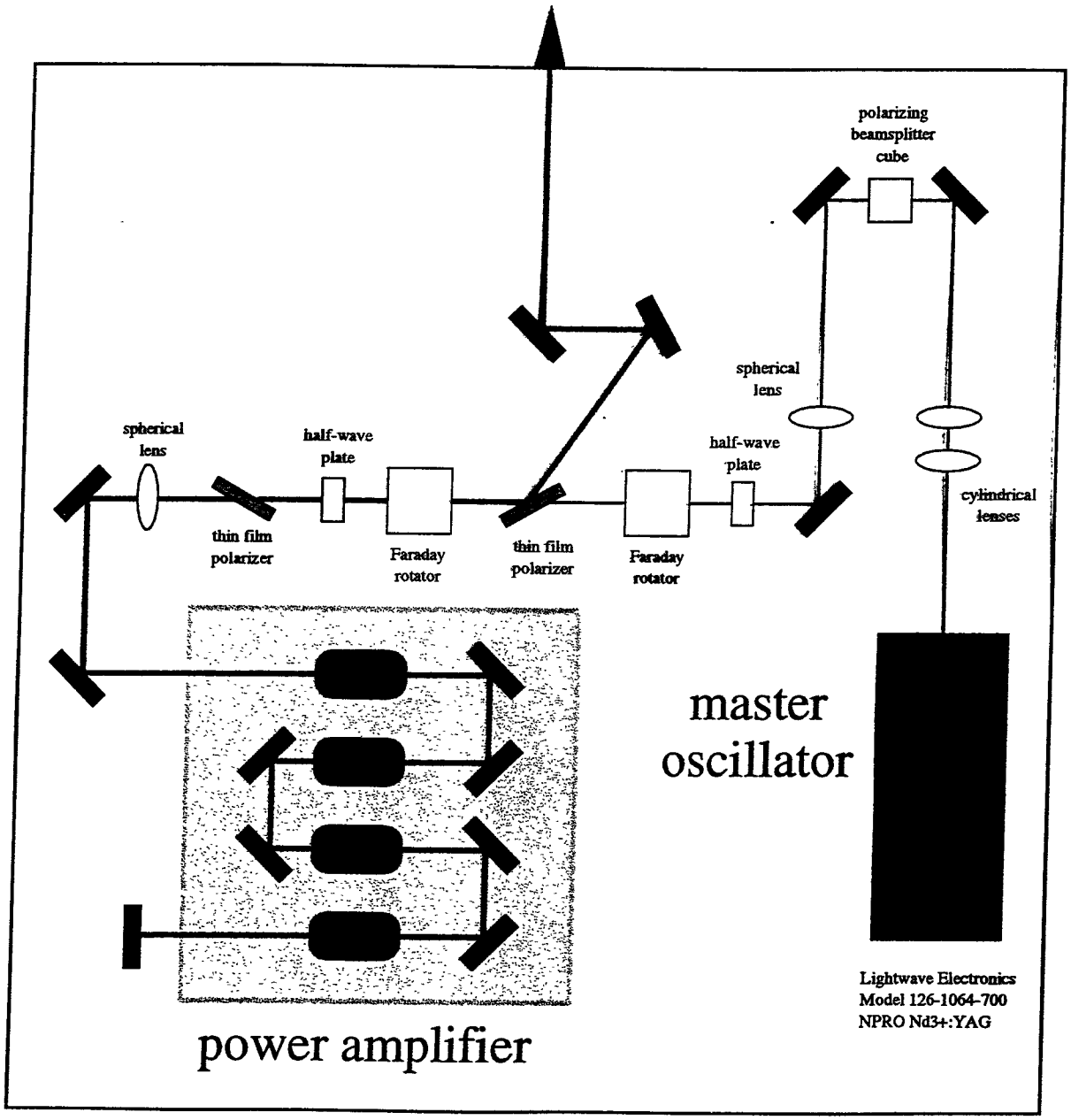
- Louisiana Construction
  - » buildings recently occupied
  - » 4 km beamtube complete
  - » near term activities - second 4 km beam tube

Outgassing Result From First 2 km Module

Table 1: Prebake Outgassing Rates (torr liters/sec cm^2)

gas	measured at 1100 hrs	assumed 1/t	comments
H_2	$< 7.4 \times 10^{-14}$		larger than QT by 2 max correction for ordinary 304 SS 2.7×10^5 cm^2 at $J(H_2) = 1 \times 10^{-11}$ $J_{equiv}(H_2) < 3.5 \times 10^{-14}$
CO	6.9×10^{-15}	7.6×10^{-12} / t(hr)	smaller than QT by 10
CO_2	1.9×10^{-14}	2.1×10^{-11} / t(hr)	smaller than QT by 2
CH_4	5.2×10^{-16}	5.6×10^{-13} / t(hr)	larger than QT by 4
H_2O		8.0×10^{-9} / t(hr)	*see table 7 and 8* smaller than QT by 2
Hydrocarbons $\sum_{41, 43, 55, 57}$		$8 \times 10^{-3} * J(H_2O)$	larger than QT by 2

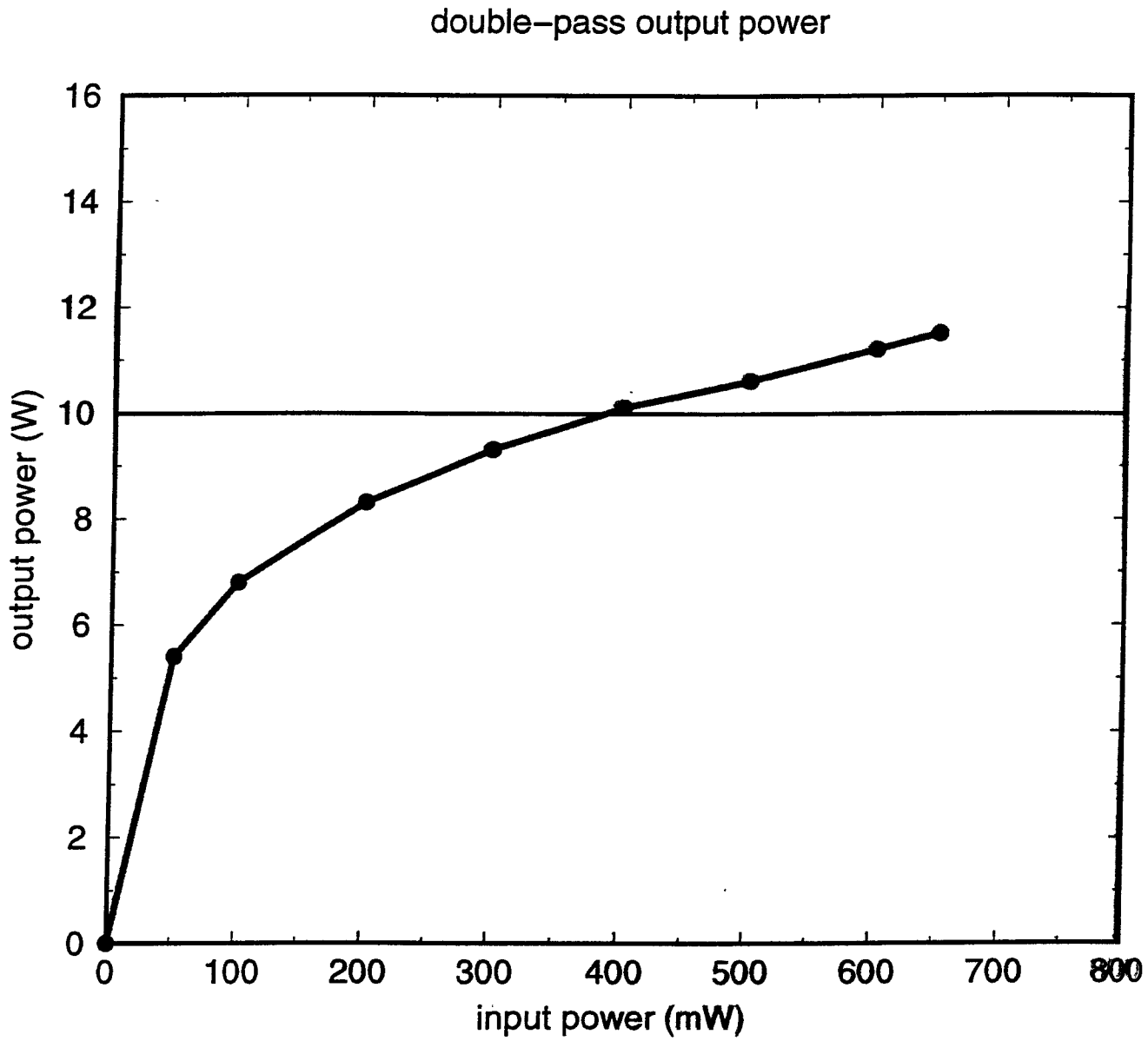
LIGO 10-W Laser Schematic Diagram



Pre-stabilized Laser Performance Requirements

- Output power
  - >> > 8.5 W in a circular TEM_{00} mode
- Beam quality
  - >> < 100 mW total in all non-TEM_{00} modes
- Relative power fluctuations in the gravitational-wave band
  - >> $< 10^{-7}\ 1/\sqrt{\text{Hz}}$ from 100 Hz to 10 kHz
- Relative power fluctuations above 24.5 MHz
  - >> < 1.005 × the shot noise limit for 600 mW of laser power
- Frequency fluctuations
  - >> $< 0.1 \times (100/f)\ \text{Hz}/\sqrt{\text{Hz}}$ from 100 Hz to 1 kHz
- Beam relative pointing angle fluctuations
  - >> $< 2 \times 10^{-6}\ 1/\sqrt{\text{Hz}}$

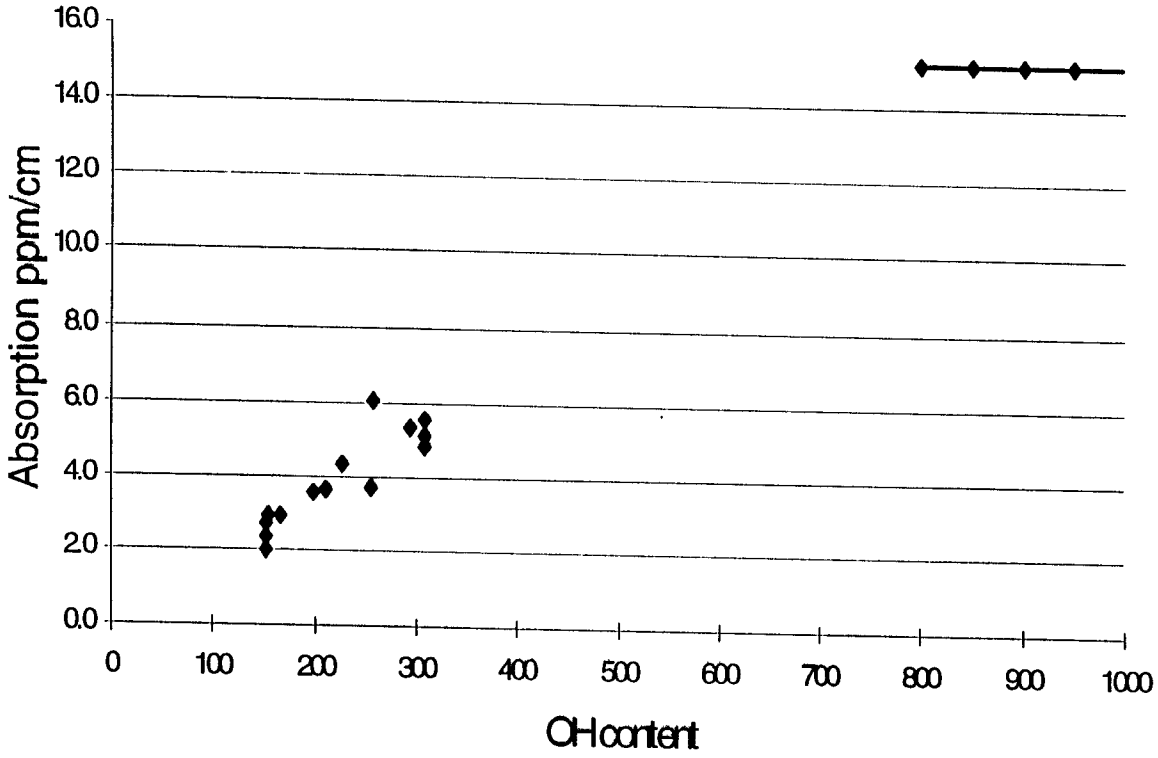
LIGO 10-W Laser Brassboard Unit Data



Core Optics Requirements

- High purity fused silica
  - 25 cm diameter x 10 cm thick (except beamsplitter: 4cm thick)
  - Beams fill some optics (to ~1ppm level)
  - 1064 nm HR mirrors and AR second surface coatings.
- Principal performance requirements:
  - < 50 ppm loss per surface (limits resonant stored energy: shot noise)
  - Surface figure errors to scatter negligible power from TEM_{oo} (best dark fringe)
    - Similar requirement for bulk inhomogeneity
  - High mechanical Q to "suppress" thermal noise ($Q \geq$ few x 10^6)
  - Low bulk (<~5ppm/cm) and coating (<2ppm) absorption (thermal lensing limit to beam power and dark fringe contrast).

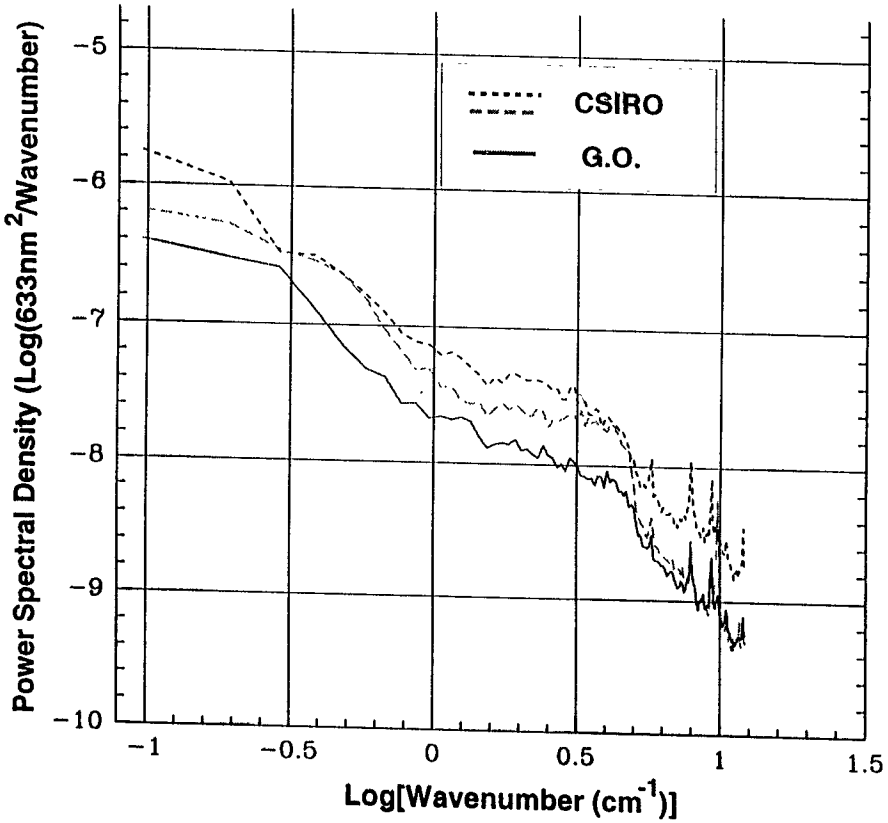
Absorption in Input Test Masses



›› Measured in collaboration with VIRGO

Pathfinder Polishing Surface Figure Results

›› NIST measurements of CSIRO and GO parts



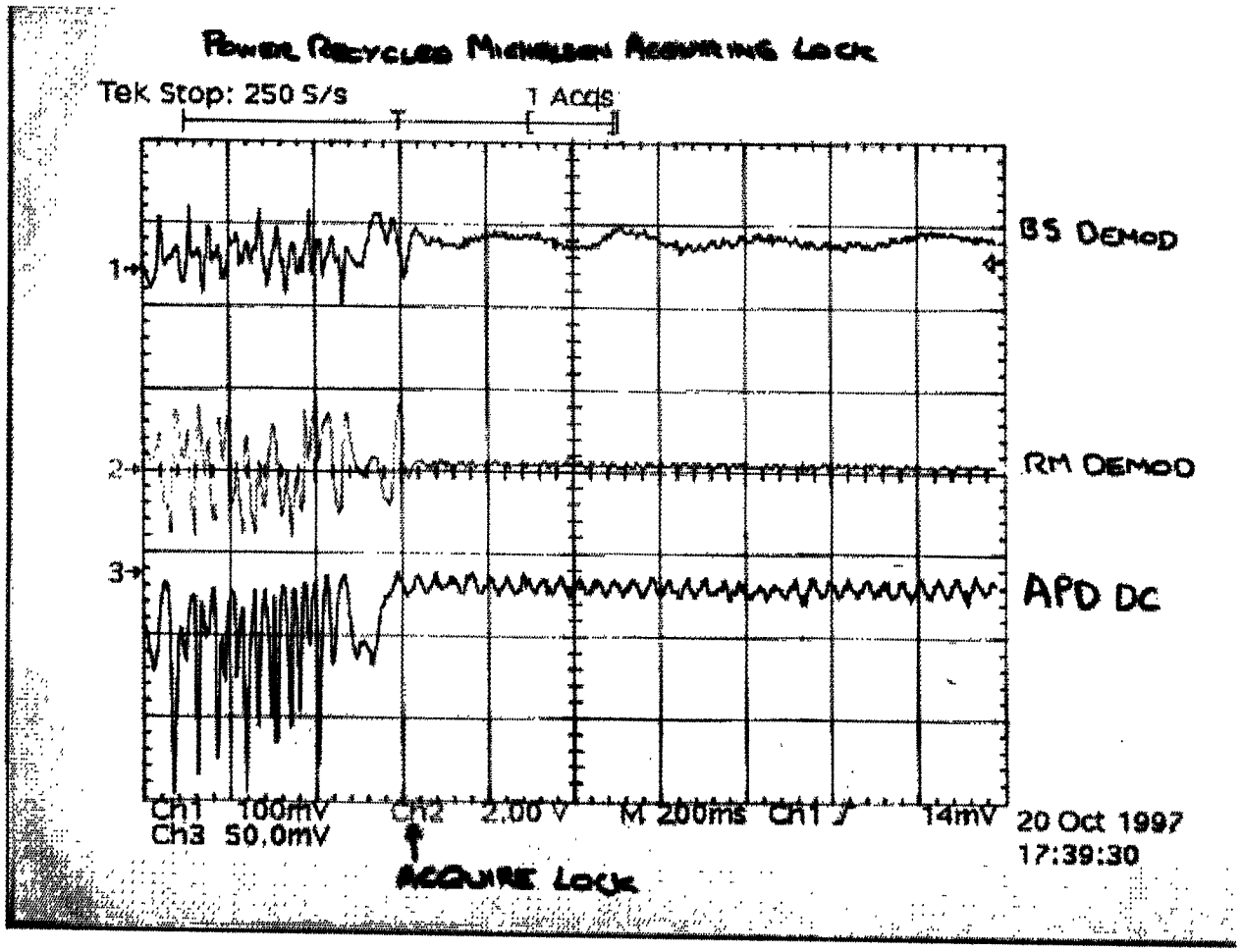
One dimensional power spectra from NIST metrology of curved surfaces. Z(0,0),Z(1,1) Z(2,0),Z(2,2),Z(3,1),Z(3,3),Z(4,0) removed

Detector Status

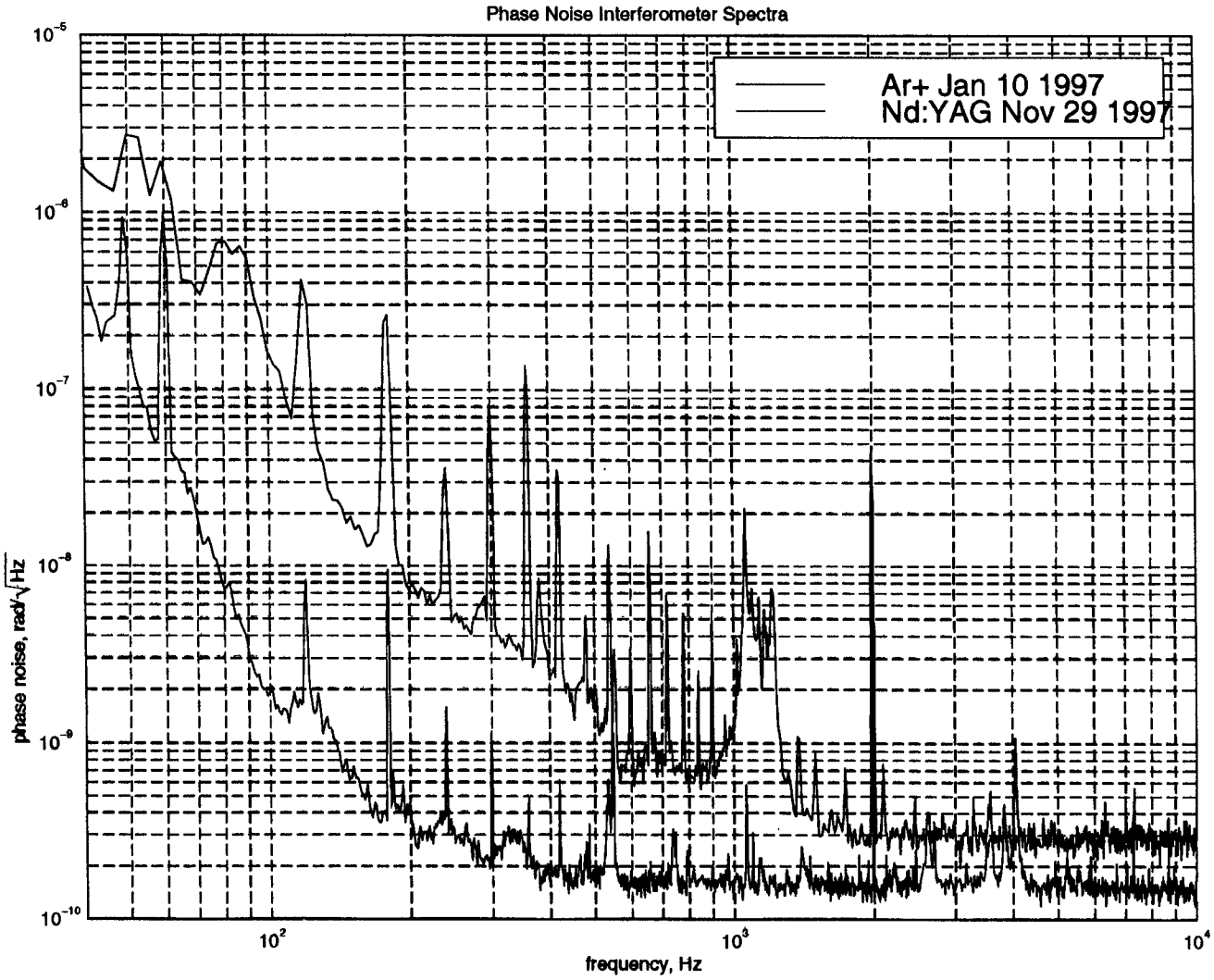
detector/r&d

- Initial Detector
  - » most subsytems are in final design or under construction
- Detector focus
  - » Laser developed and constructed at Lightwave; prestablization at Caltech (Hanford summer 98)
  - » Input Optics - Florida (Hanford summer 98)
  - » Core Optics - optics, polishing (under construction)
  - » Seismic Isolation - procurements;(first article 98)
  - » Data Acquisition/Data Analysis - (construction)
  - » Length and Alignment Sensing - (design)
- R&D
  - » Phase Noise Interferometer - (near goal)
  - » 40 meter Interferometer - (recycling established)
  - » LIGO Lab advanced R&D program - (initiated)

Power Recycled Michelson Acquiring Lock



PNI Spectrum



LIGO Funding

by task and by year

- Construction Project
  - » R & D in support of initial detector
  - » deliver operational facilities
  - » deliver constructed detector
- Operations
  - » physical detector integration
  - » commission detector
    - – coincidences end of 2000 $h = 10^{-20}$
    - – design sensitivity end of 2001 $h = 10^{-21}$
- Advanced R&D funding
  - » develop enhanced detector subsystems
  - » new interferometer configurations

fiscal yr	construction	R & D	operations	advanced R&D
thru 1994	35.9	11.2		
1995	85	4		
1996	70	2.4		
1997	55	1.6	0.3	0,8
1998	26.2	0.9	7.3	2,7
1999			20.9	2.8
2000			21.1	2.9
2001			19.1	2.9
total	**272.1**	**20**	**68.7**	**12.1**

LIGO

construction costs

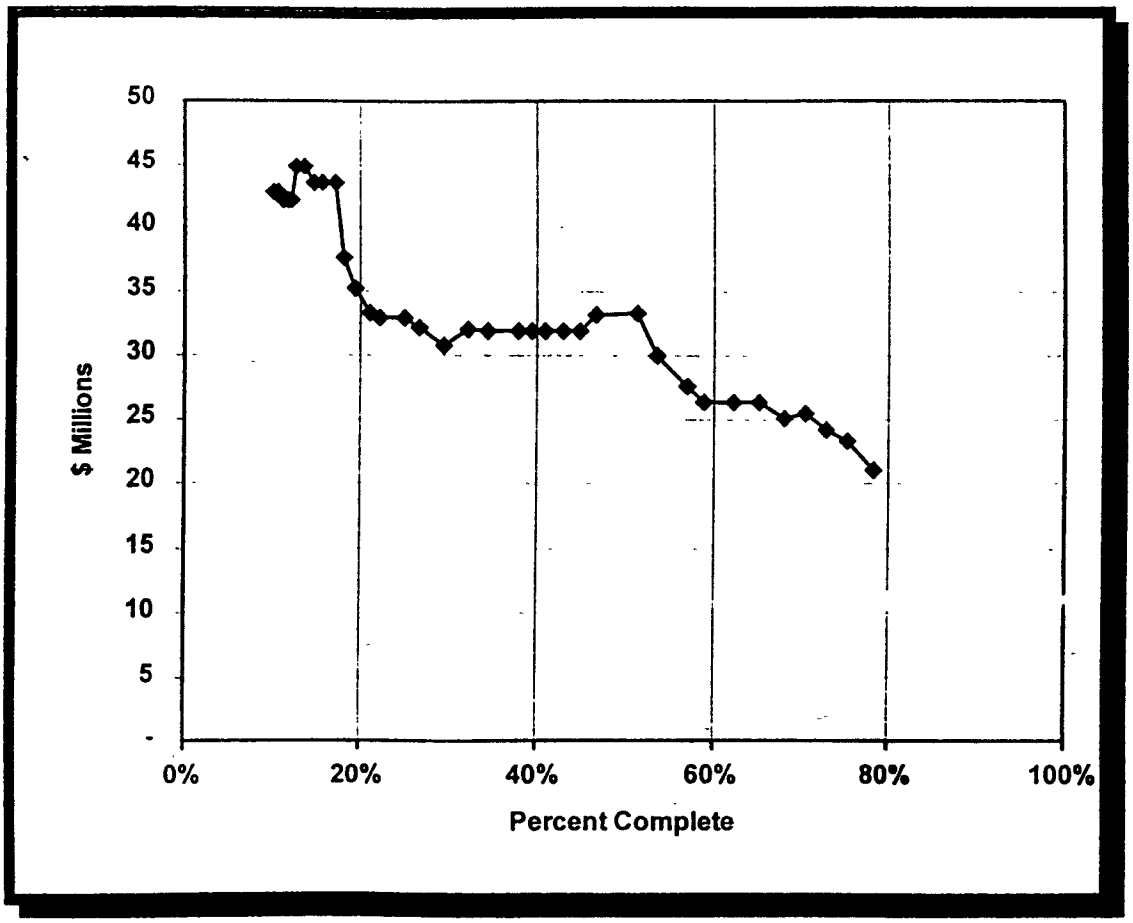
- tracking integrated cost-schedule reporting
  - » construction funds $292.1M
  - » costed as of end Feb $200.7M
  - » committed $249.0M ?
  - » remaining contingency $ 21.0M
- emphasize now on cost to complete analysis
- running contingency analysis

task	percent complete	actual costs	estimate to complete	estimated percent contingency
facilities	88%	137.5	28	9%
detector	35%	18.7	34.8	35%
R & D	87%	20.3	3.1	0%
project mgt	84%	24.1	28.5	22%
data system			5.5	
total	**78%**	**200.7**	**70.4**	**30%**

LIGO

contingency analysis

- rate of spending contingency remains reasonable (eg. $2.9M since Oct 97)
- we have committed about 50% or original contingency while completing 78% of LIGO construction project



Change Control Log

Change Requests approved since October 1997 Review

Change Request Number	WBS	Description	Submittal Date	Amount
CR-970033	1.1.4	Civil Construction, Hanford, A&E Support	Sep-97	50,000
CR-970034	1.1.4	Civil Construction, Hanford, Landscaping	Sep-97	228,000
CR-970035	1.4.4	General Computing - Hanford	Sep-97	250,000
CR-970036	1.4.4	General Computing - Livingston	Sep-97	250,000
CR-970038	1.1.5	Beam Tube Vacuum Bake Phase 2	Oct-97	(441,000)
CR-970039	1.1.4	Operations Support Building Modifications - Hanford	Nov-97	110,000
CR-970040	1.1.4	Operations Support Building Modifications - Livingston	Nov-97	110,000
CR-970041	1.1.2	Beam Tube Labor Rate Adjustment - Louisiana	Nov-97	873,140
CR-970042	1.1.4	Civil Construction - Levernier Field Work Directives	Dec-97	324,328
CR-970043	1.1.2	Beam Tube In-House Miscellaneous	Dec-97	1,088,000
CR-980001	1.1.4	Hensel Phelps Field Work Directives (info)	Jan-98	38,331
CR-980002	1.1.4	Civil Construction Added Scope - Hanford	Jan-98	104,115
CR-980003	1.1.4	5000 Square Foot Building at Hanford	Feb-98	510,000
CR-980004	1.2.3	Physics Environment Monitoring Effort Replan	Feb-98	(757,000)
CR-980005	1.1.4	Extending Parsons Support at Hanford	Feb-98	68,000
CR-980006	1.2.1	Seismic Isolation - Spring Cleaning and Bellows Fabric	Mar-98	147,052
		Total		

LIGO

potential calls on contingency

- To manage contingency and assess change control requests, we keep a running list of all identified potential calls on contingency
  - » total of potential calls consistent with remaining contingency
  - » Most recent contingency calls come from the list
  - » reasonable fraction of items are discretionary

- We have the ability to manage the remaining contingency and complete LIGO on cost!

Analysis of Potential Contingency Needs for Facilities

Description	CR	WBS	Direct	Benefits	Overhead	Total
Additional Quality/Safety	CR-980009	1.1.1	164,241			164,241
Chamber Floor Elevation Change	CR-980008	1.1.1	200,000			200,000
Labor Rate Escalation	CR-980009	1.1.1	200,000			200,000
Light Duty Cranes/Hoists	CR-980009	1.1.1	45,000			45,000
RGA Calibration/Outgassing Measurement System	CR-980009	1.1.1	50,000			50,000
Shop Tools	CR-980009	1.1.1	50,000			50,000
Site Forklift (Livingston)	CR-980009	1.1.1	50,000			50,000
Stiles/Scaffolding (Access over VE Doors/Covers)	CR-980009	1.1.1	50,000			50,000
LA Additional Tube Cleaning FTIRs		1.1.2	5,000			5,000
LA Baffle Installation Cleaning		1.1.2	20,000			20,000
LA Module End Conditions	CR-980010	1.1.2	22,700			22,700
Mount GNB Valves Early on Y Arm		1.1.2	25,000			25,000
Purchase Leftover GPS Equipment		1.1.2	50,000			50,000
Receive Reimbursement for LN2 Dewars		1.1.2	(180,000)			(180,000)
Reimburse CB&I for Y1, Y2 Leak Location Tests		1.1.2	150,000			150,000
Taxes (WA B&O and Additional Sales)	CR-980010	1.1.2	36,868			36,868
Potential Loss of Woodrow Wilson Tax Reduction	CR-970020	1.1.3	332,500			332,500
Potential Gain of ACME Tax Reduction (under litigation)		1.1.3	-			-
Bid Package Costs		1.1.4	50,000			50,000
Building Customization - both sites	CR-980002	1.1.4	896,000			896,000
Cleaning Procedure for HVAC System at Livingston		1.1.4	250,000			250,000
Corner Station Telephones (both sites)		1.1.4	300,000		14,363	314,363
Erosion Control/Landscaping Hanford	CR-970034	1.1.4	68,000		-	68,000
Extend Parsons Representative at Hanford	CR-980005	1.1.4	50,000		14,363	64,363
Extend Parsons Representative at Livingston		1.1.4	40,000		14,363	54,363
Site Cleanup (both sites)		1.1.4	200,000		28,725	228,725
In-House Labor Rate Variances		1.1.4	100,000	25,000	71,813	196,813
Modifying Water Systems at Hanford		1.1.4	300,000		14,363	314,363
New Well Installation		1.1.4	35,637		14,363	50,000
Hanford Power 1998		1.1.4	130,000			130,000
Beam Tube Bake		1.1.5	150,000		28,725	178,725
Beam Tube Bake Electrical Power	CR-980011	1.1.5	202,000			202,000
Facilities Total			4,042,946	25,000	201,075	4,269,021

LIGO
schedule

- facilities construction nearing completion on schedule
- detector is about 3 months behind schedule

Facilities

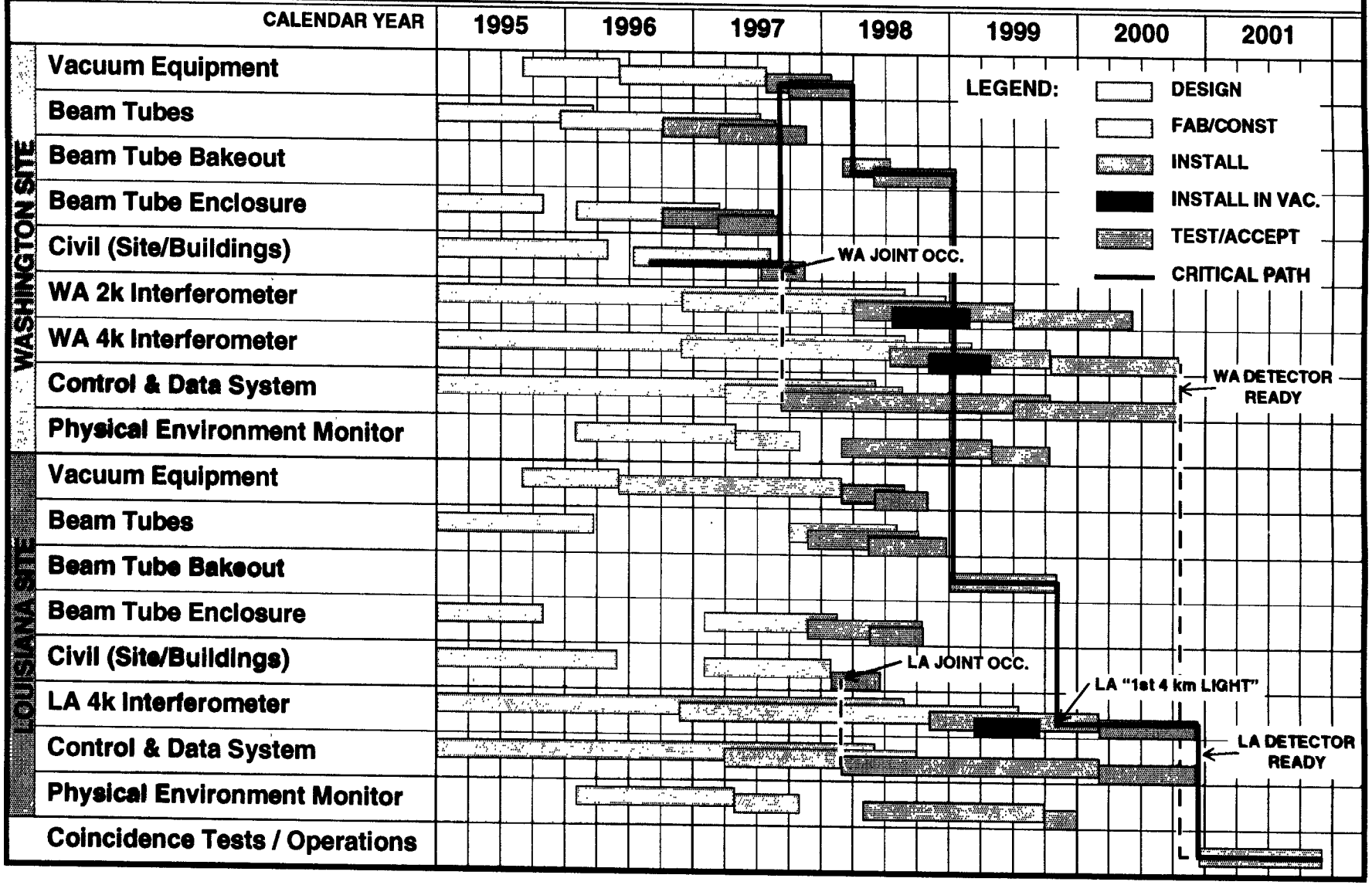
Milestone Description	PMP *	Current Projection	PMP *	Current Projection
Facilities				
Initiate Site Developemnt	Mar-94	Complete	Aug-95	Complete
Beam Tube Final Design Review	Apr-94	Complete	Apr-94	Complete
Select A&E Contractor	Nov-94	Complete	Nov-94	Complete
Complete Beam Tube Qual Test	Feb-95	Complete	Feb-95	Complete
Select VE Contractor	Mar-95	Complete	Nov-94	Complete
Complete Performance Baseline	Apr-94	Complete	Apr-94	Complete
Initiate Beam Tube Fabrication	Oct-95	Complete	Oct-95	Complete
Initiate Slab Construction	Oct-95	Complete	Jan-97	Complete
Initiate Building Construction	Jun-96	Complete	Jan-97	Complete
Joint Occupancy	Sep-97	Complete	Mar-98	Complete
Accept Tubes and Covers	Mar-98	Complete	Mar-99	Oct-98
Beneficial Occupancy	Mar-98	Complete	Sep-98	Sep-98
Accept Vacuum Equipment	Mar-98	Jul-98	Sep-98	Dec-98
Initiate Facility Shakedown	Mar-98	Jul-98	Mar-99	Dec-98

Project Management Plan Milestones Status
Detector

Milestone Description	PMP Proposed	Current Projection
Detector		
Beam Splitter Chamber Stack FDR	Apr-98	Jun-98
Core Optics Support FDR	Feb-98	Aug-98
Horizontal Access Module FDR	Apr-98	Jun-98
Core Optics Components FDR	Dec-97	Mar-98
Input/Output Optics FDR	Apr-98	Mar-98
Pre-Stabilized Laser FDR	Aug-98	Oct-98
Wavefront Sensing FDR	Apr-98	Jul-98
Length Sensing Control FDR	May-98	Jul-98
WA Controls Area Net Ready to Install	Apr-98	Apr-98
CDS Data Acquisition FDR	Apr-98	Apr-98
Physics Environ Monitoring FDR	Jun-98	Complete
Detector System PDR	Dec-97	Jul-98
Begin WA Interferometer Installation	Jul-98	Jul-98
Begin LA Interferometer Installation	Jan-99	Jan-99
Begin Coincidence Tests	Dec-00	Dec-00

OCTOBER 1997

SUMMARY INTEGRATED SCHEDULE



Construction

summary

Construction Project

- Total costs, milestones, variances
  - » construction project 78% complete; variances small
    - – facilities near complete
    - – detector under construction
  - » Estimate to complete and contingency analysis consistent with budget
- Construction Schedule
  - » facilities are on schedule; mostly operational
  - » detector within ~3 months of schedule

Early Operations

- Develop site based support
- Detector physical integration
  - » detailed plan developed; resource loaded; management determined
- Testing and commissioning