LIGO

LIGO
Status and Plans

Barry Barish

LSC Meeting

19-Aug-02

LIGO

Schedule and Plan

1996	**Construction Underway (mostly civil)**
1997	**Facility Construction (vacuum system)**
1998	**Interferometer Construction (complete facilities)**
1999	**Construction Complete (interferometers in vacuum)**
2000	**Detector Installation (commissioning subsystems)**
2001	**Commission Interferometers (first coincidences)**
2002	**Sensitivity studies (initiate LIGO I Science Run)**
2003+	**LIGO I data run (one year integrated data at $h \sim 10^{-21}$)**
2006+	**Begin 'Advanced LIGO' installation**

LIGO

LIGO Goals and Priorities

- **Interferometer performance**
  - » Integrate commissioning and data taking consistent with obtaining one year of integrated data at $h = 10^{-21}$ by end of 2006
- **Physics results from LIGO I**
  - » Initial upper limit results by early 2003
  - » First search results in 2004
  - » Reach LIGO I goals by 2007
- **Advanced LIGO**
  - » Prepare advanced LIGO proposal this fall
  - » International collaboration and broad LSC participation
  - » Advanced LIGO installation beginning by 2007

LIGO Lab Planning Memo

August 2001

- **"…The LIGO Laboratory will carry out the E7 run before the end of the year. We anticipate that the run will take place during December and will be scheduled for two full weeks. The run is an engineering run and will be the responsibility of the LIGO Laboratory…"**

- **"…The S1 run will be held in May 2002. The prime purpose for this run is to carry out the first scientific searches. This run will be the joint responsibility of the Laboratory and the LSC. The sensitivity goal is a two site coincidence with 3 interferometers running and the achieved scientific reach (volume searched x observation time in coincidence) should be an order of magnitude better than achieved in the E7 run. At least one interferometer at each site should be operated in the full recycled configuration…"**

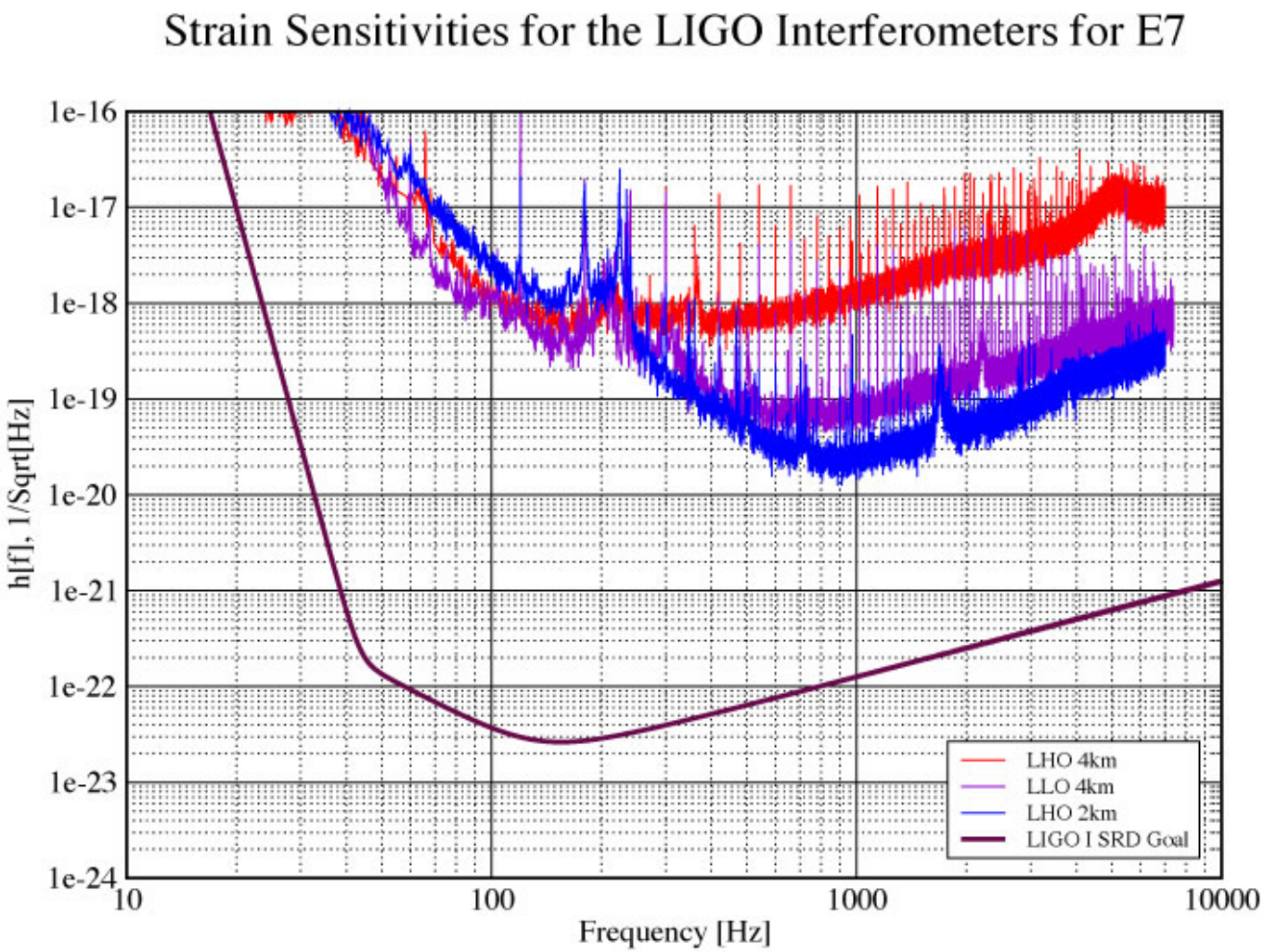
LIGO Engineering Run (E7)

Sensitivities

Final LIGO Milestone

"Coincidences Between the Sites in 2001"

Engineering Run 28 Dec 01 to 14 Jan 02



LIGO + GEO Interferometers

E7 Engineering Run

28 Dec 2001 - 14 Jan 2002 (402 hr)

Singles data

	All segments	Segments >15min
L1 locked	284hrs (71%)	249hrs (62%)
L1 clean	265hrs (61%)	231hrs (53%)
L1 longest clean segment: 3:58		
H1 locked	294hrs (72%)	231hrs (57%)
H1 clean	267hrs (62%)	206hrs (48%)
H1 longest clean segment: 4:04		
H2 locked	214hrs (53%)	157hrs (39%)
H2 clean	162hrs (38%)	125hrs (28%)
H2 longest clean segment: 7:24		

Coincidence Data

	All segments	Segments >15min
2X: H2, L1		
locked	160hrs (39%)	99hrs (24%)
clean	113hrs (26%)	70hrs (16%)
H2,L1 longest clean segment: 1:50		
3X : L1+H1+ H2		
locked	140hrs (35%)	72hrs (18%)
clean	93hrs (21%)	46hrs (11%)
L1+H1+ H2 : longest clean segment: 1:18		
4X: L1+H1+ H2 +GEO:	77 hrs (23 %)	26.1 hrs (7.81 %)
5X: ALLEGRO + …		

Conclusion: Large Duty Cycle Looks Attainable

Upper Limits

E7 Data Analysis Working Groups

- **Compact binary inspiral:** ***"chirps"***
- **Supernovae / GRBs:** ***"bursts"***
- **Pulsars in our galaxy:** ***"periodic"***
- **Cosmological Signal** ***"stochastic background"***

Reports scheduled at the LIGO I Meeting this Thursday

LIGO Lab Planning Memo

August 2001

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Upper Limits Runs - S1 and S2

March 2002

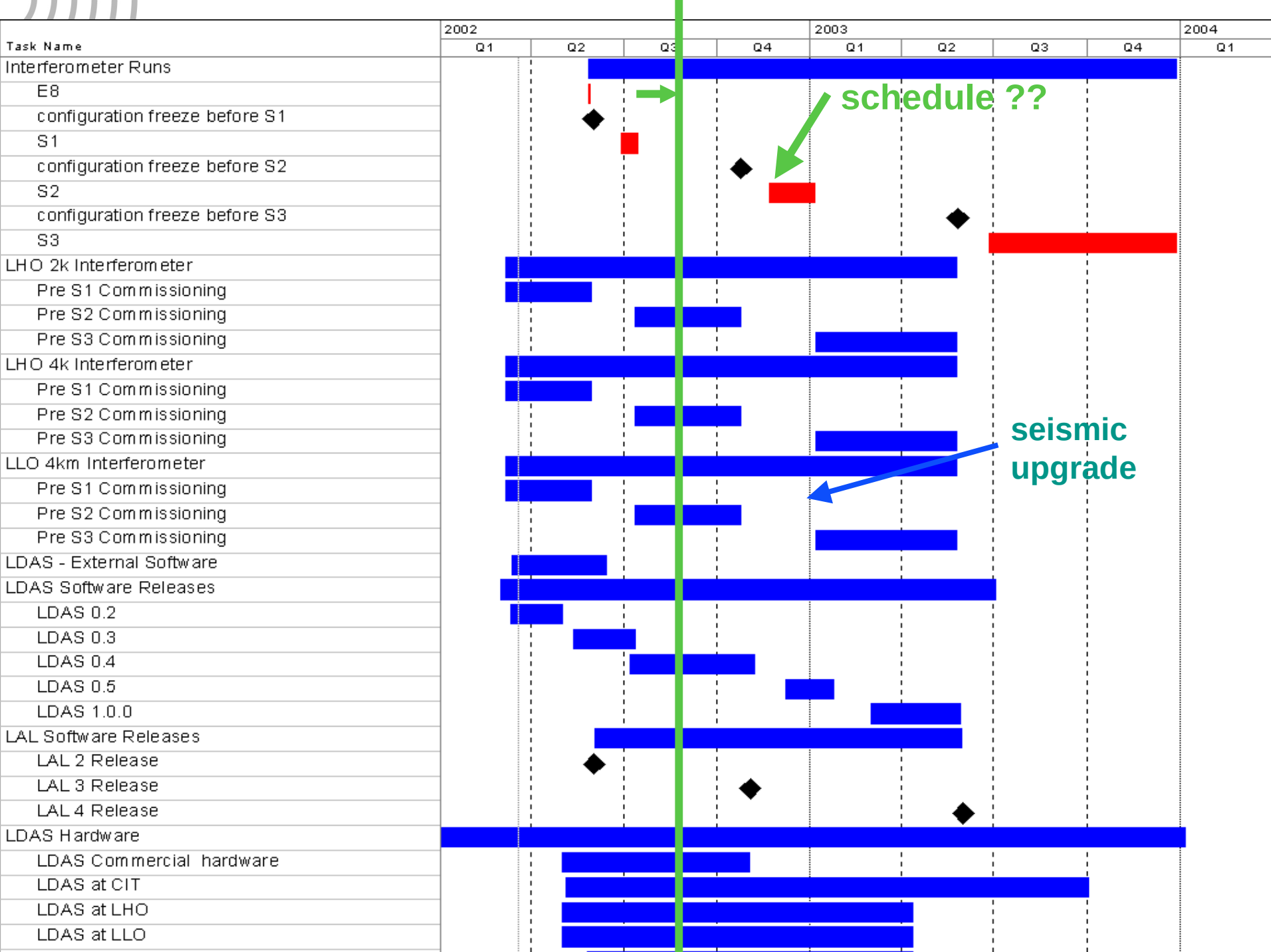
- **"… schedule the S1 run to begin at 8:00 am Pacific time on Saturday, June 29 and to be completed at 8:00 Pacific on Monday, July 15...The sensitivity goal is a two site coincidence with 3 interferometers running and the achieved scientific reach (volume searched x observation time in coincidence) should be an order of magnitude better than achieved in the E7 run. At least one interferometer at each site should be operated in the full recycled configuration."**
- **"The S2 run will have a goal of at least an order of magnitude improvement in scientific reach … beyond S1 and should follow successful completion of analysis of the S1 data…we will schedule the next science run to begin at 8:00 am Pacific Friday November 22, 2002 with completion at 8:00 on Monday, January 6, 2003."**
- **"These two runs will complete the upper limit running and the orientation for the LIGO running experience. We believe that this should lead to a broad set of new publishable limits, well beyond what has been previously published."**

Search for Gravitational Waves

March 2002

- **"The S3 run will mark the beginning of true search running, representing a step beyond setting upper limits on selected gravitational wave searches. S3 will be intended to accomplish a real search for gravitational waves with … astrophysical *significance*. We expect to schedule S3 to commence about June 27, 2003 and this run will be planned for several months duration."**

- **"During 2003 and 2004, we will plan to run in this search mode for at least 50% of the calendar time, followed by the planned one year integrated LIGO science run at design sensitivity. This science run will be completed prior to proposed major interferometer replacements."**


Task Name
2002
2003
2004
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Interferometer Runs
E8
configuration freeze before S1
S1
configuration freeze before S2
S2
configuration freeze before S3
S3
LHO 2k Interferometer
Pre S1 Commissioning
Pre S2 Commissioning
Pre S3 Commissioning
LHO 4k Interferometer
Pre S1 Commissioning
Pre S2 Commissioning
Pre S3 Commissioning
LLO 4km Interferometer
Pre S1 Commissioning
Pre S2 Commissioning
Pre S3 Commissioning
LDAS - External Software
LDAS Software Releases
LDAS 0.2
LDAS 0.3
LDAS 0.4
LDAS 0.5
LDAS 1.0.0
LAL Software Releases
LAL 2 Release
LAL 3 Release
LAL 4 Release
LDAS Hardware
LDAS Commercial hardware
LDAS at CIT
LDAS at LHO
LDAS at LLO
schedule ??
seismic upgrade

Proposal Budget

LIGO Operations (2002 – 2006)

	FY 2001 ($M)	FY 2002 ($M)	FY 2003 ($M)	FY 2004 ($M)	FY 2005 ($M)	FY 2006 ($M)	Total 2002-6 ($M)
Currently funded Operations	22.92	23.63	24.32	25.05	25.87	26.65	125.52
Increase for Full Operations		5.21	5.20	4.79	4.86	4.95	25.01
Advanced R&D	2.70	2.77	2.86	2.95	3.04	3.13	14.76
R&D Equipment for LSC Research		3.30	3.84	3.14			10.28
Total Budgets	25.62	34.91	36.21	35.93	33.77	34.74	175.57

FY 2001 currently funded Operations ($19.1M for ten months) is normalized to 12 months and provided for comparison only and is not included in totals.

"Revised" Proposal Budget

LIGO Operations (2002-2006)

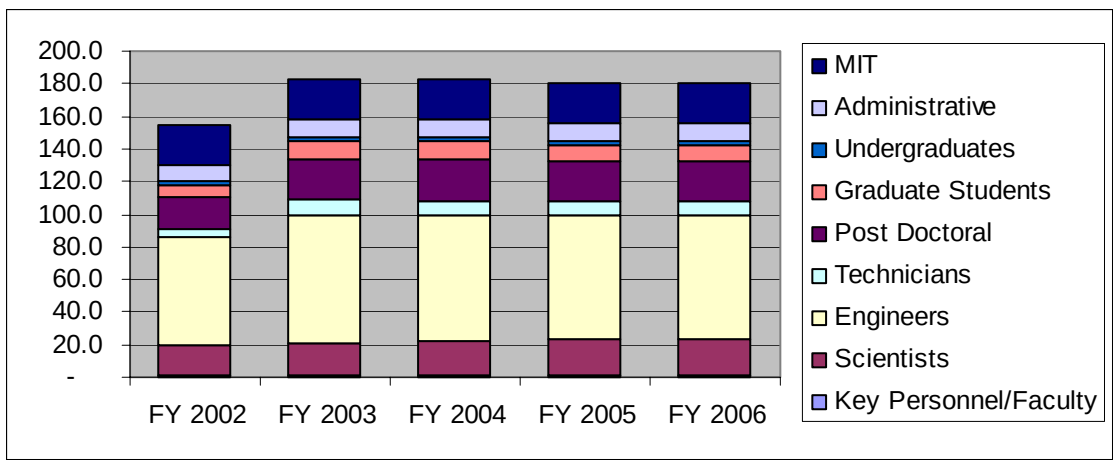
- **$28 million provided for FY 2002 Operations in February and May 2002**
  - » **Reduced or deferred hiring, Adv R&D, equipment, outreach, etc**
- **Our working assumption is that $33M will be awarded in 2003**
  - » **Priority for commissioning and toward LIGO I 24x7 Operations,**

	FY 2002 ($M)	FY 2003 ($M)	FY 2004 ($M)	FY 2005 ($M)	FY 2006 ($M)
Operations	$24	$29	$30	$30	$30
Advanced R&D	$4	$4	$3	$3	$3

Staff

budgeted

	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006
Key Personnel/Faculty	1.3	1.3	1.3	1.3	1.3
Scientists	17.8	19.8	20.8	21.8	21.8
Engineers	66.3	78.8	77.3	75.8	75.8
Technicians	6.0	9.0	8.5	9.0	9.0
Post Doctoral	18.8	25.3	25.8	24.3	24.3
Graduate Students	7.0	11.0	11.0	10.0	10.0
Undergraduates	2.5	2.5	2.5	2.5	2.5
Administrative	10.4	10.7	10.7	10.7	10.7
MIT	25.0	25.0	25.0	25.0	25.0
Total	155.1	183.3	182.8	180.3	180.3



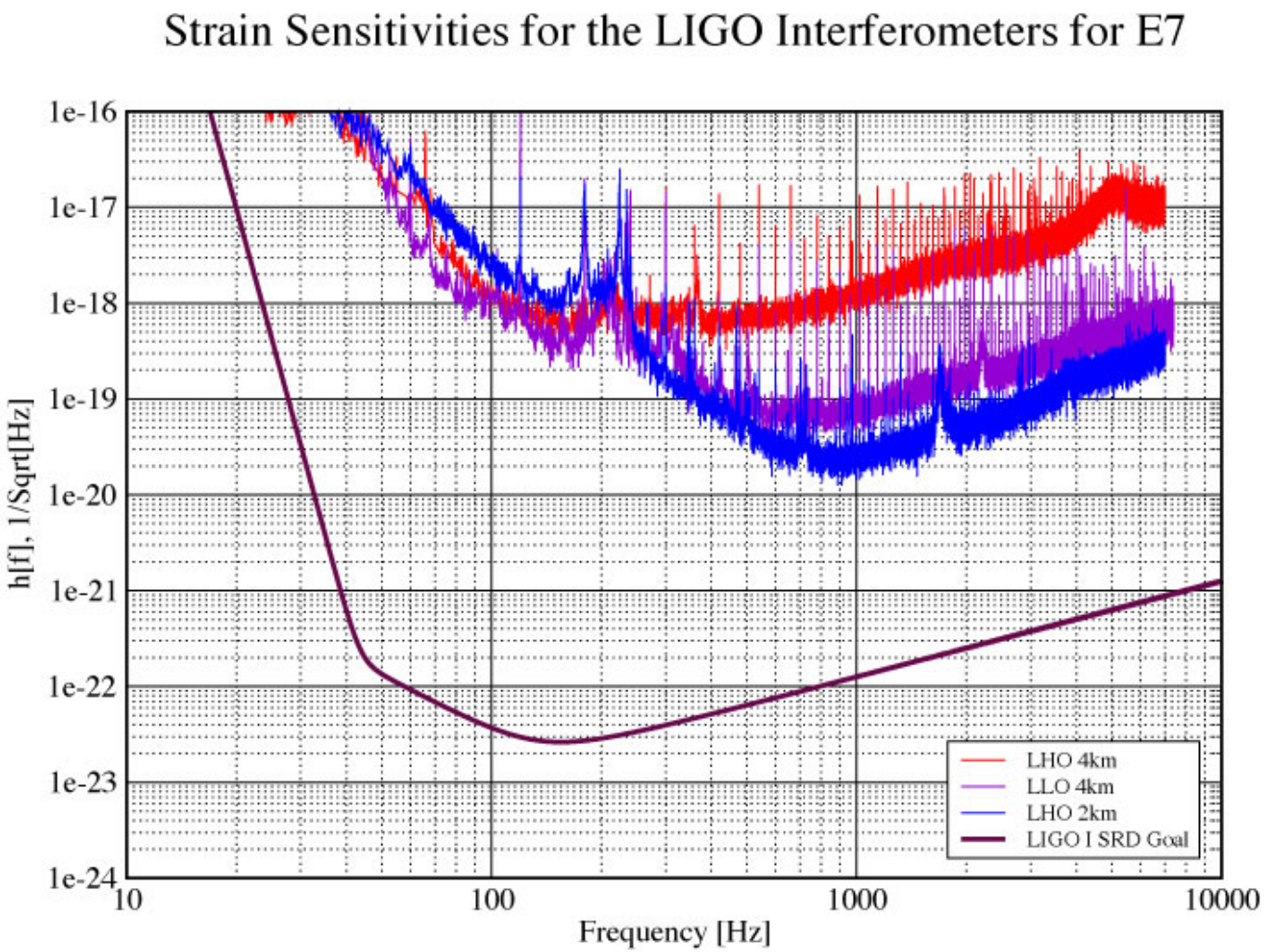
LIGO Engineering Run (E7)

Sensitivities

Final LIGO Milestone

"Coincidences Between the Sites in 2001"

Engineering Run 28 Dec 01 to 14 Jan 02

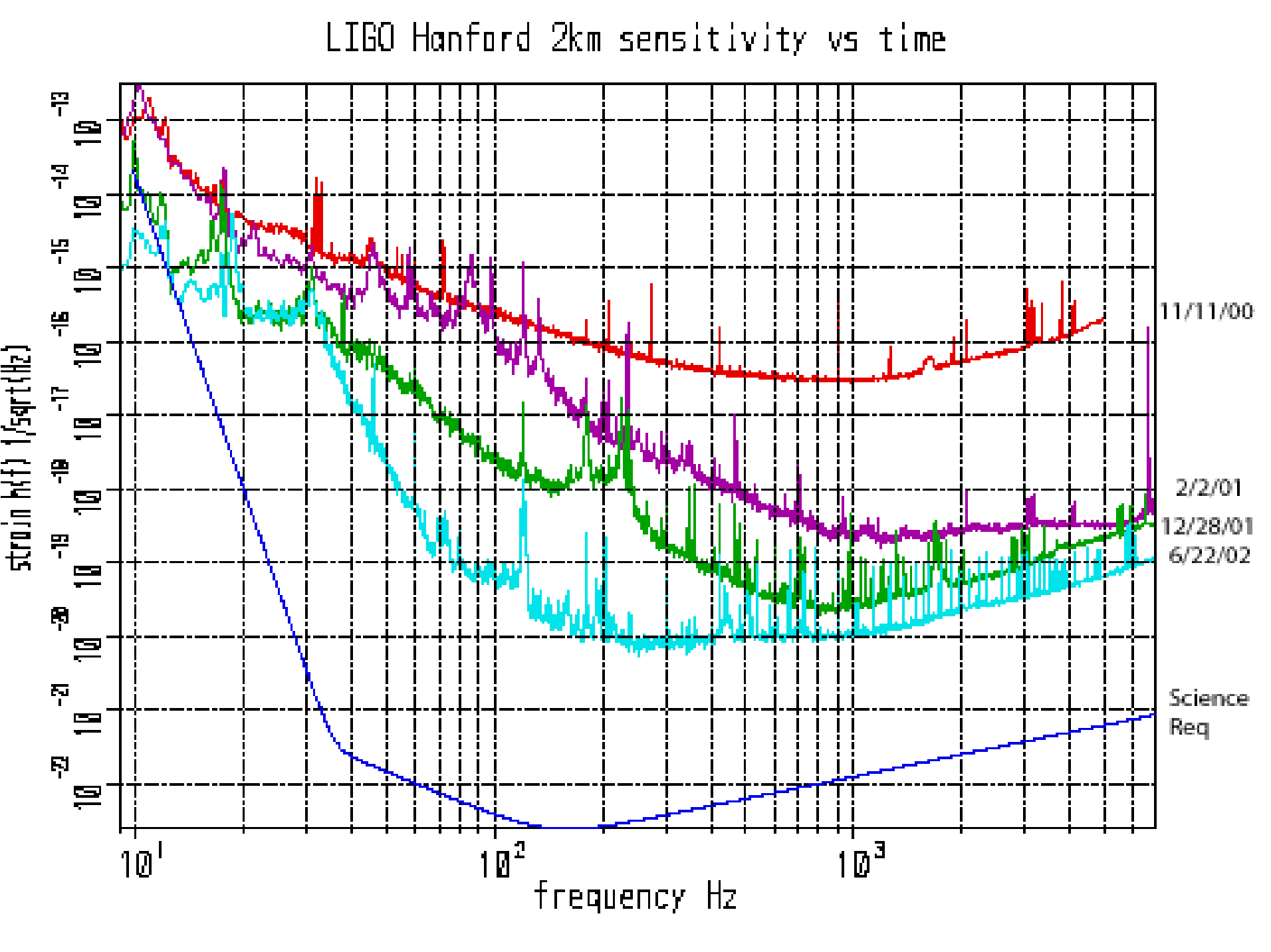


LHO 2 km Interferometer

status – June 02

- **Locked in power recycled configuration**
  - » recycling factor up to 25, but typically ~15
- **Common mode servo implemented**
  - » Frequency stabilization from average arm length
  - » Establishes control system “gain hierarchy”
- **5 W power into mode cleaner**
  - » Attenuators at photodiodes give effective input power 20 - 40 mW
- **Tidal feedback operational**
  - » Lock duration up to 15 hours
- **DISPLACEMENT Sensitivity**

Summer 2001	~ 3×10^{-16} m/Hz$^{1/2}$
December 2001 (E7)	~ 5×10^{-17} m /Hz$^{1/2}$ (~600 Hz)
Spring 2002	~ 2×10^{-17} m /Hz$^{1/2}$ (~350 Hz)

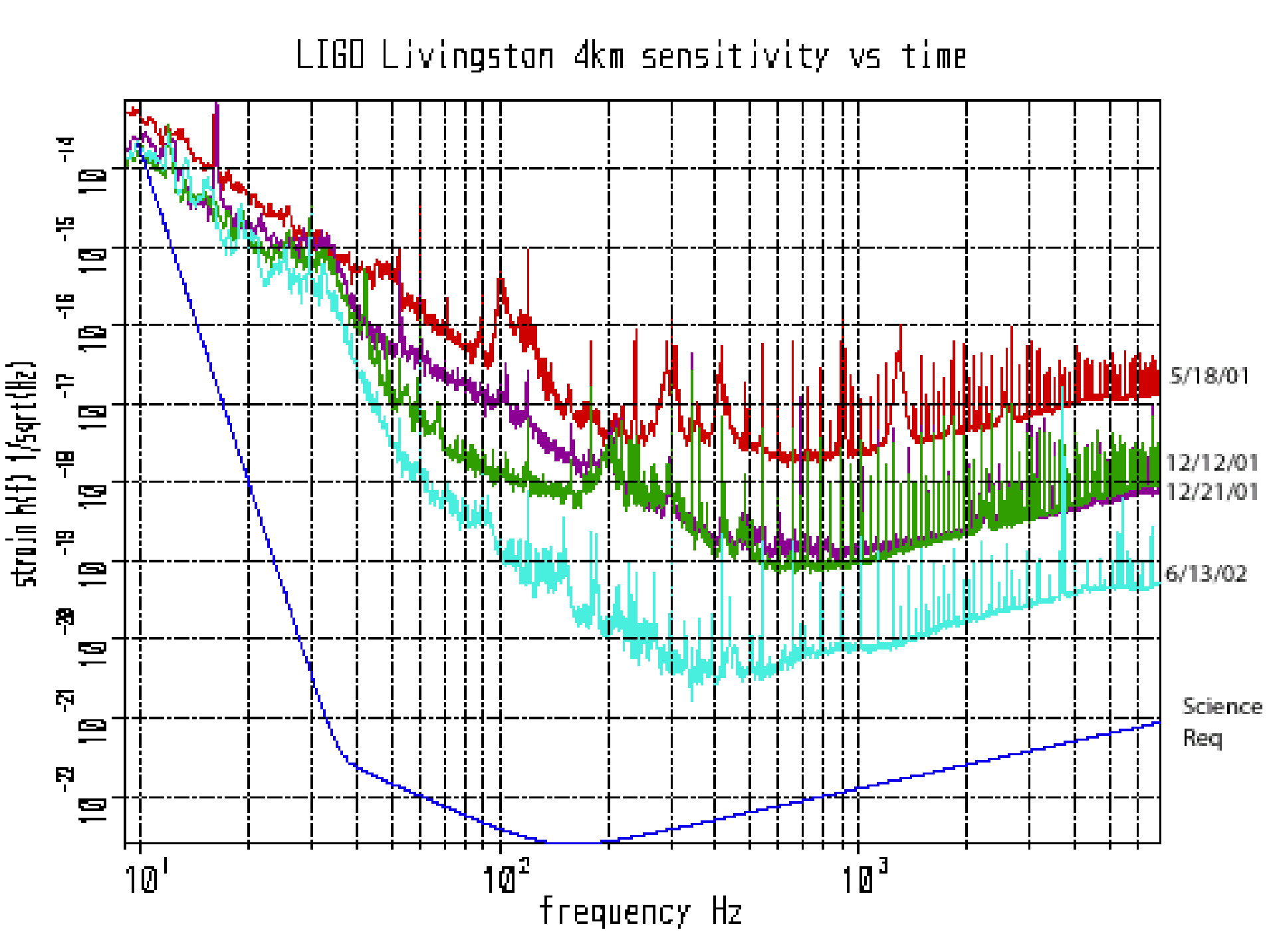

LIGO Hanford 2km sensitivity vs time
strain h(f) 1/sqrt(Hz)
10^-13
10^-14
10^-15
10^-16
10^-17
10^-18
10^-19
10^-20
10^-21
10^-22
10^1
10^2
10^3
frequency Hz
11/11/00
2/2/01
12/28/01
6/22/02
Science
Req

LLO 4 km Interferometer

status and sensitivity history

- **Power recycled configuration**
- **1.9 W power input laser power into mode cleaner**
  - » **Power recycling gain ~ 50**
  - » **25-30 dB attenuation at dark port**
- **Reasonably robust lock during night**
  - » **Up to 4 hours**
  - » **15 s – 3 min lock acquisition time**
  - » **Tidal feedback operational**
  - » **Wavefront alignment control operating on end mirrors**
  - » **Microseismic feedforward reduces the dynamic range required from the controller (unique to LLO at present time)**
  - » **PEPI reduces the seismic noise injected between 0.3 to 5 Hz at the end masses**

DISPLACEMENT Sensitivity ~1.5 x 10^{-17} m/$Hz^{1/2}$ @ 400 - 600 Hz


LIGO Livingston 4km sensitivity vs time
strain h(f) 1/sqrt(Hz)
frequency Hz
5/18/01
12/12/01
12/21/01
6/13/02
Science Req

LHO 4 km Interferometer

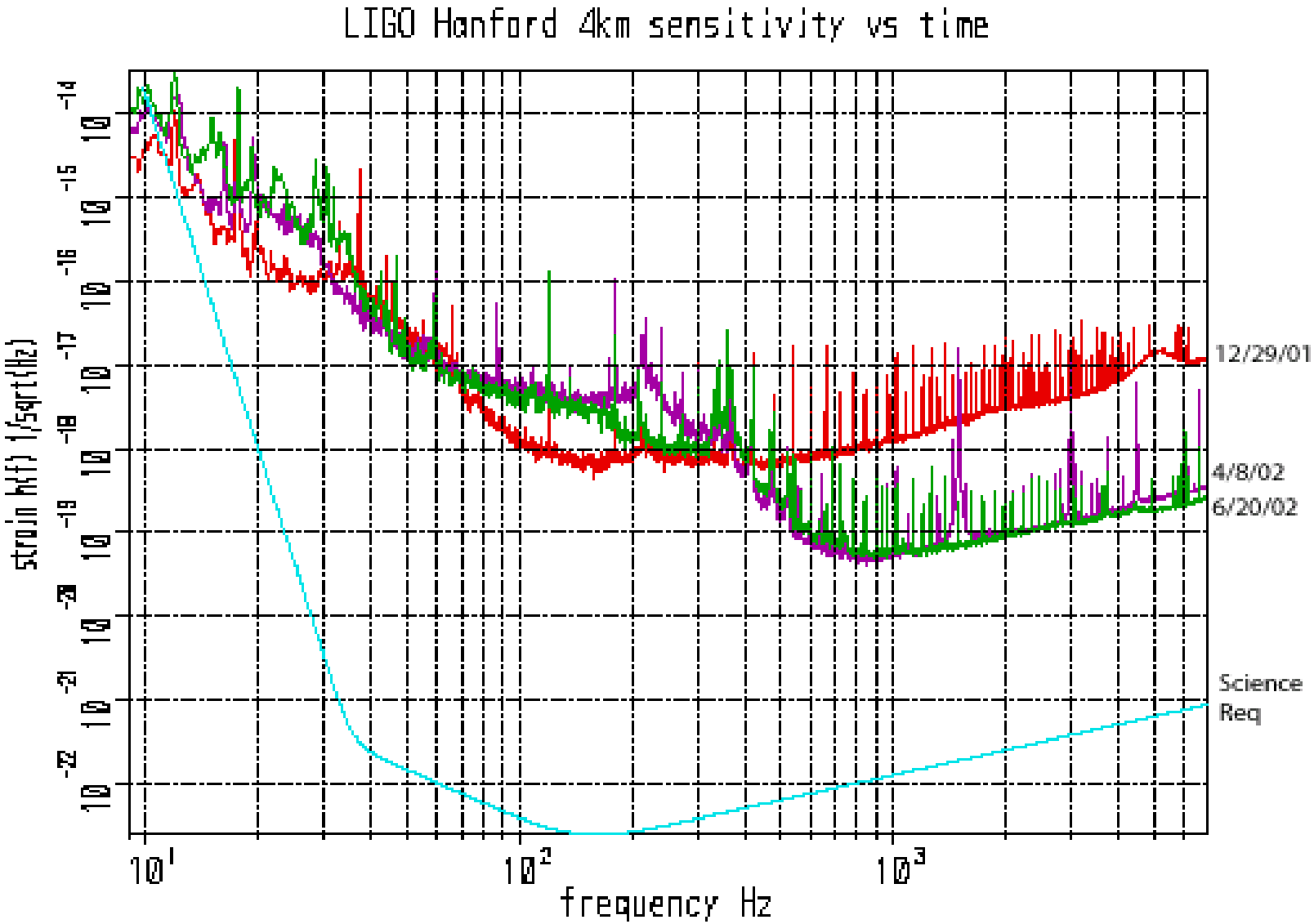
status & sensitivity history

- **In-vacuum installation completed last summer**
- **Digital suspension controllers**
  - » **Greater flexibility for tuning servos to improve reliability/noise**
  - » **Permits frequency dependent orthogonalization of the displacement and angular control of the suspensions**
  - » **Will be implemented on other interferometers after tests done**
- **1 W power into mode cleaner**
  - » **Attenuators at photodiodes give effective input power 20 mW**
- **Locked in power recycled configuration**
  - » **Recycling factor typically 40-50**
- **Tidal feedback operational**
  - » **Locks up to 4 hours**
- **DISPLACEMENT Sensitivity ~2 x 10^{-16} m/$Hz^{1/2}$**

LIGO

Interferometer

sensitivity history



LIGO

Status for S1

improvements since June 02

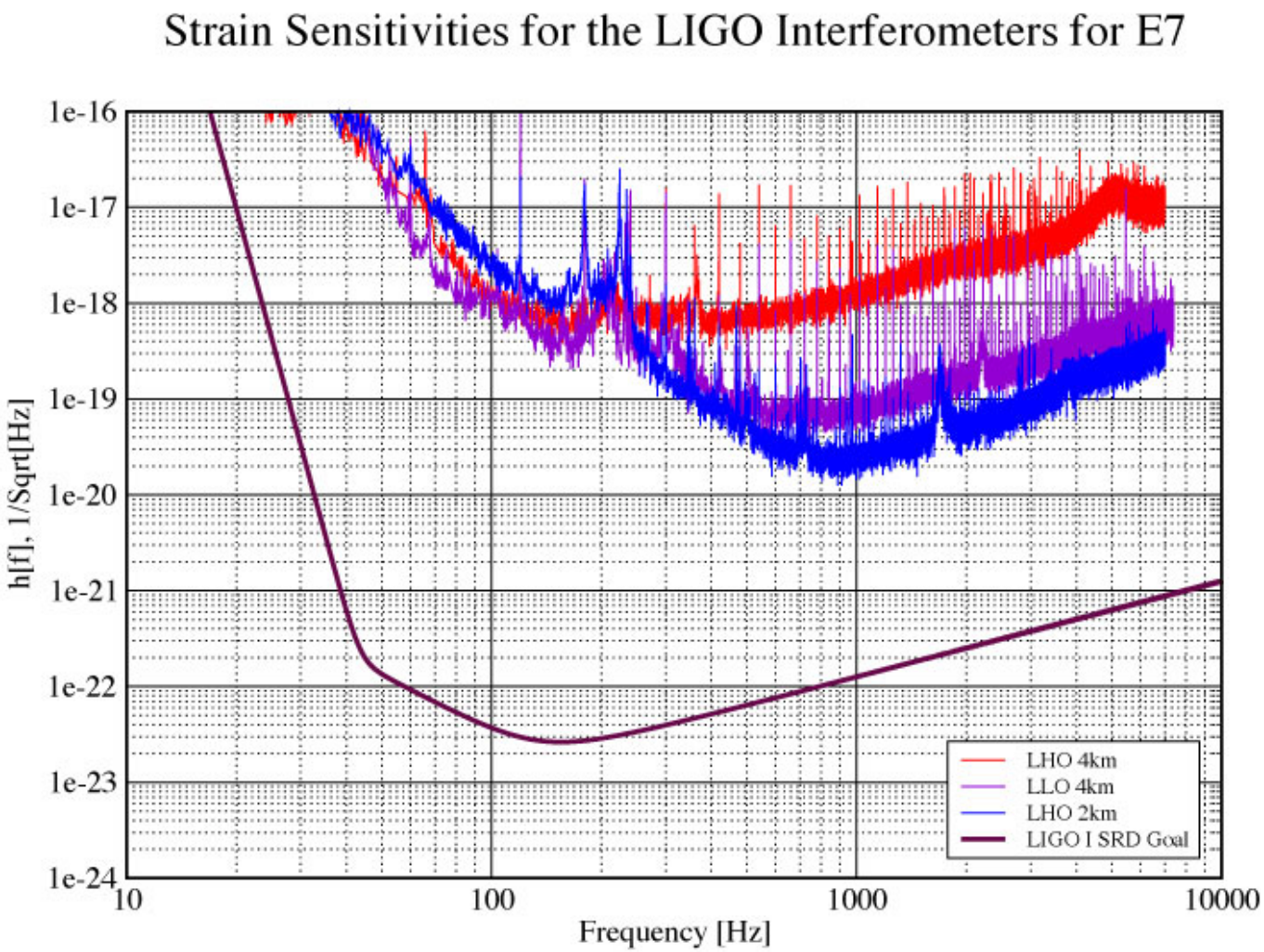
LIGO Engineering Run (E7)

Sensitivities

Final LIGO Milestone

"Coincidences Between the Sites in 2001"

Engineering Run 28 Dec 01 to 14 Jan 02



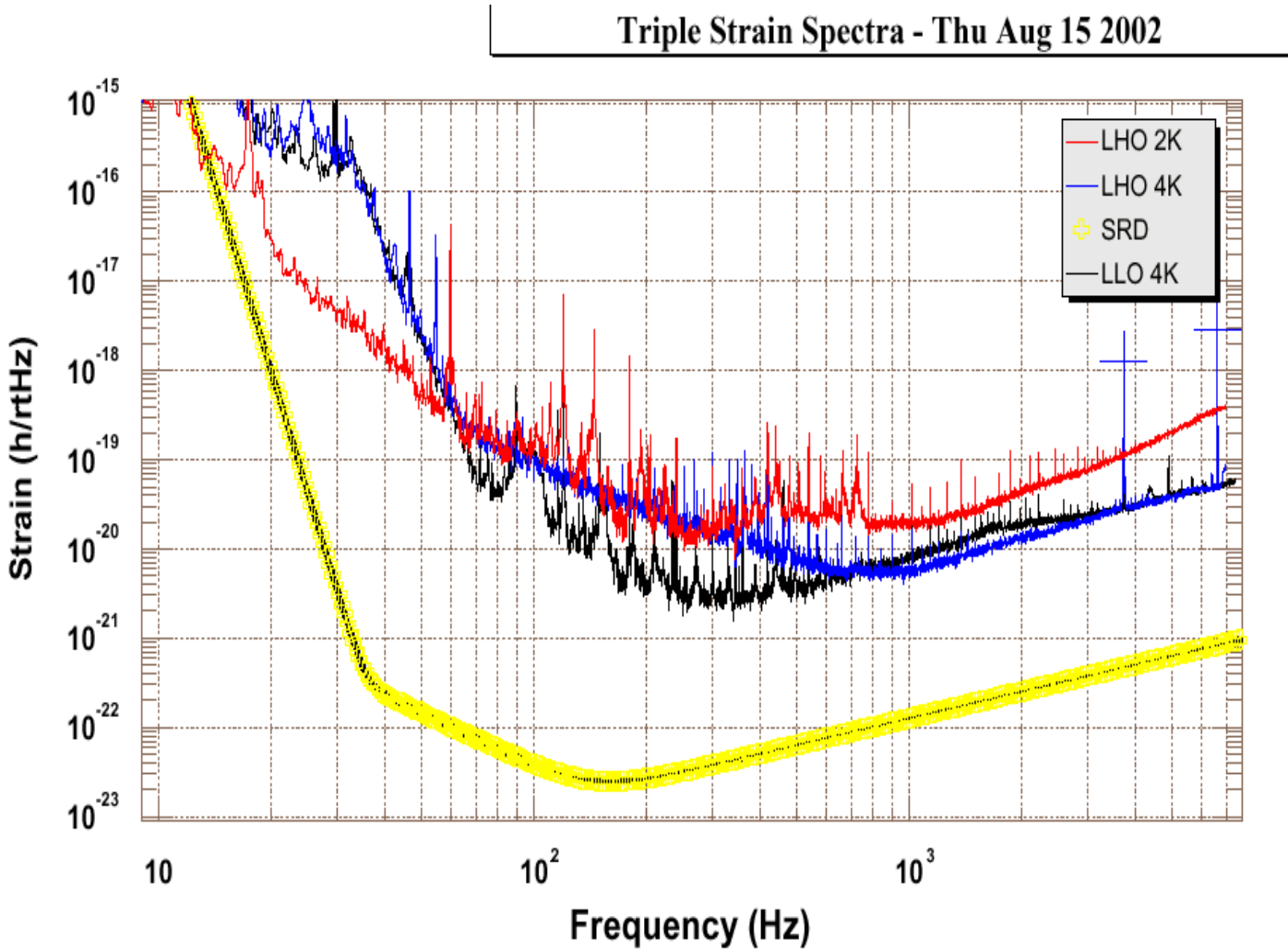
LIGO Science Run (S1)

triple strain sensitivities

LIGO
S1 Run

"First Upper Limit Run"

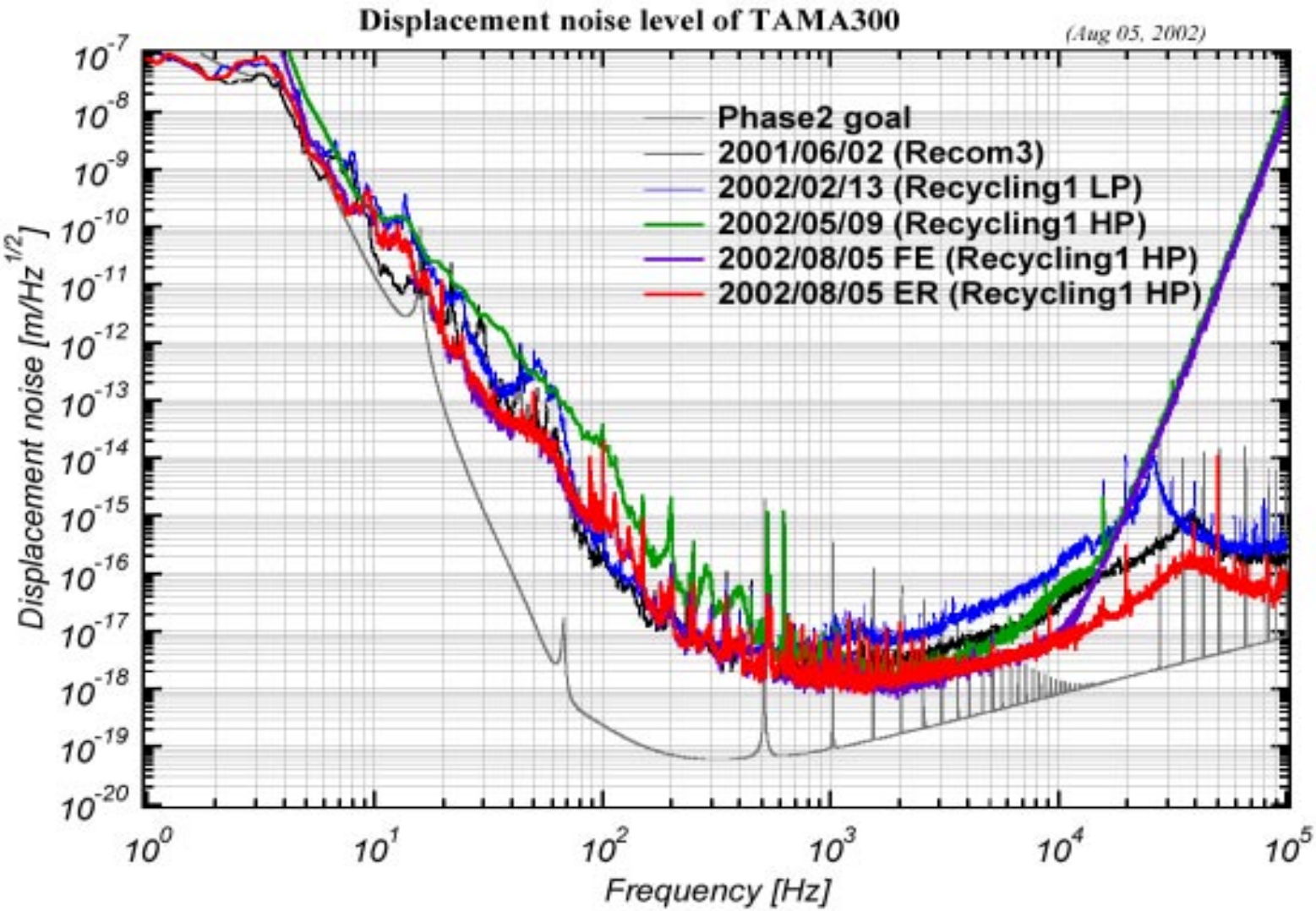
Aug – Sept 02



LIGO

S1 Run

LIGO + GEO + TAMA



Physics Goals for S1 Results

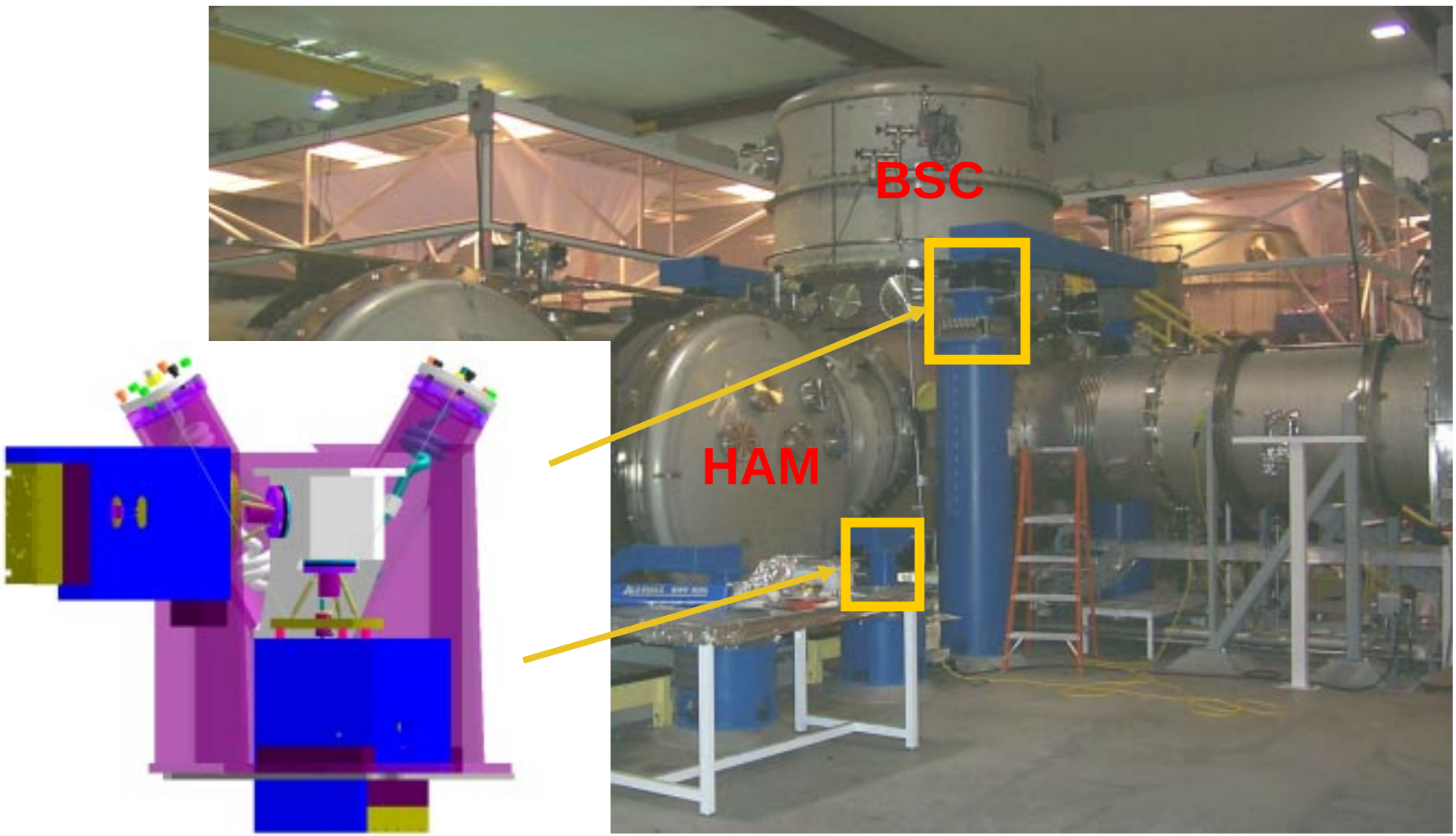
- Each working group define physics goals from S1 immediately following the data run
- Vetted data analysis with significant upper limits from all four working groups by year end
- Preliminary drafts of scientific papers containing approved results for presentation outside of LIGO

LIGO

Advanced Detector R&D and Advanced LIGO

Planned Detector Modifications

active external seismic



LIGO

Advanced LIGO R&D Status

- Working toward construction proposal in Fall 2002
- “bottoms-up” costing has nearly been completed
- Plan assumes construction funding available 1Q2005
  - some long lead funds in 1Q2004
- Supports an installation start of 4Q2006
- Soon ready to confront scope decisions (number of interferometers, trimming features to control costs, etc.)
- Advanced R&D program is proceeding well
- GEO and ACIGA teams forming strong international partnership

Advanced LIGO R&D Status

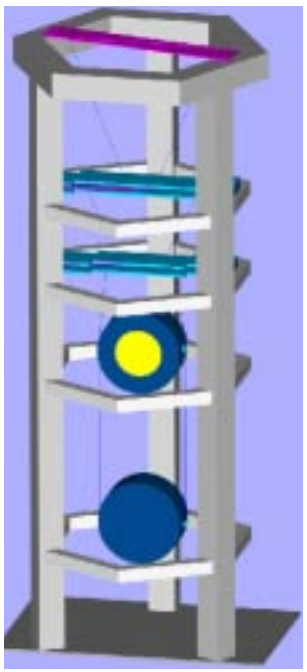
- **Interferometer Sensing & Control (ISC):**
  - **GEO 10m "proof of concept" experiment:**
    - **Preparation proceeding well**
    - **Results available for 40m Program in early 2003 (lock acquisition experience, sensing matrix selection, etc.)**
  - **40m Lab for Precision Controls Testing:**
    - **Infrastructure has been completed (i.e. PSL, vacuum controls & envelope, Data Acquisition system, etc.)**
    - **Working on the installation of the 12m input MC optics and suspensions, and suspension controllers by 3Q02**
  - **Gingin facility for High Power Testing:**
    - **Within the next year the LIGO Lab will deliver two characterized sapphire test masses and a prototype thermal compensation system (beam scan and/or ring heater)**
    - **The facility development is advancing nicely**
    - **Activities closely linked with subsystem, LASTI R&D plan**

Advanced LIGO R&D Status

- **Seismic Isolation system (SEI):**
  - » **Development of pre-isolation system accelerated for use in retrofit on initial LIGO**
    - – **hydraulic & electro-magnet actuation variants**
    - – **To be tested at the LASTI facility**
  - » **“Technology Demonstrator” system has been fabricated**
    - – **a two stage, 12 degree of freedom active, stiff, isolation system**
    - – **being installed into the Stanford Engineering Test Facility (ETF)**
- **LASTI infrastructure has been completed (including BSC stack to support pre-isolation full scale testing for initial LIGO)**

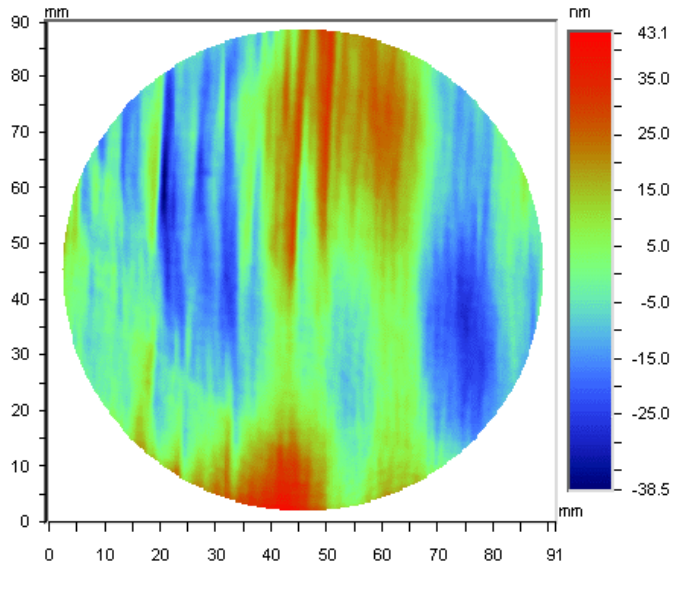
Advanced LIGO R&D Status

- **Suspension System (SUS):**
  - » Complete fused-quartz fiber suspensions functioning in the GEO-600 interferometer
  - » Progress, in theory and in experiment, on both circular fibers (tapered) and ribbons
  - » Dynamics testing is underway on a quadruple pendulum prototype
  - » Silica-sapphire hydroxy-catalysis bonding looks feasible; silica-leadglass to be explored
  - » Significant design work underway for ‘triple’ suspensions
  - » TNI nearing final results for fused silica; sapphire mirrors ready in Fall 2002 for next phase



Advanced LIGO R&D Status

- **Core Optics Components (COC):**
  - » New optical homogeneity measurements along the ‘a’ crystal axis are close to acceptable (13nm RMS over 80mm path length)
  - » Tests to compensate for optical inhomogeneity if required, look promising (computer controlled ‘spot’ polishing and ion beam etching)
  - » Recent sapphire annealing efforts are encouraging (reductions to 20 ppm/cm vs a requirement of 10 ppm/cm)
  - » Coatings on large optics show sub-ppm losses (SMA/Mackowski)
  - » Coating mechanical loss program in full swing; materials rather than interfaces seem to be the culprit

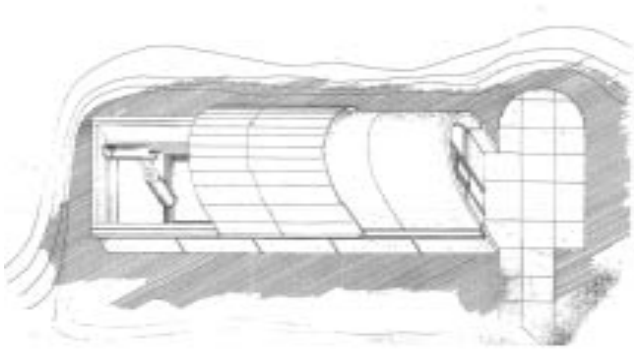


LIGO

LIGO Outreach

Deferred new initiatives due to budget shortfall

LLO Telescope



Draft building concept utilizes surplus beam tube enclosures on raised footings with roll-off roof

Proposed telescope location on fire access road gives clear view to south

Telescope facts:

16 inch Richey Chretien telescope built by Optical Guidance Systems

Telescope provided by state funds via LSU. LIGO provides site and internet connection and incorporates telescope use into outreach program.

Internet accessible to facilitate classroom use

LIGO

Conclusions

- Reduced budgets and limited manpower are resulting in deferring some work and making difficult priority choices
- Progress is steady on three fronts: commissioning; data runs and analysis; preparations for advanced LIGO
- The coming year should be very exciting !