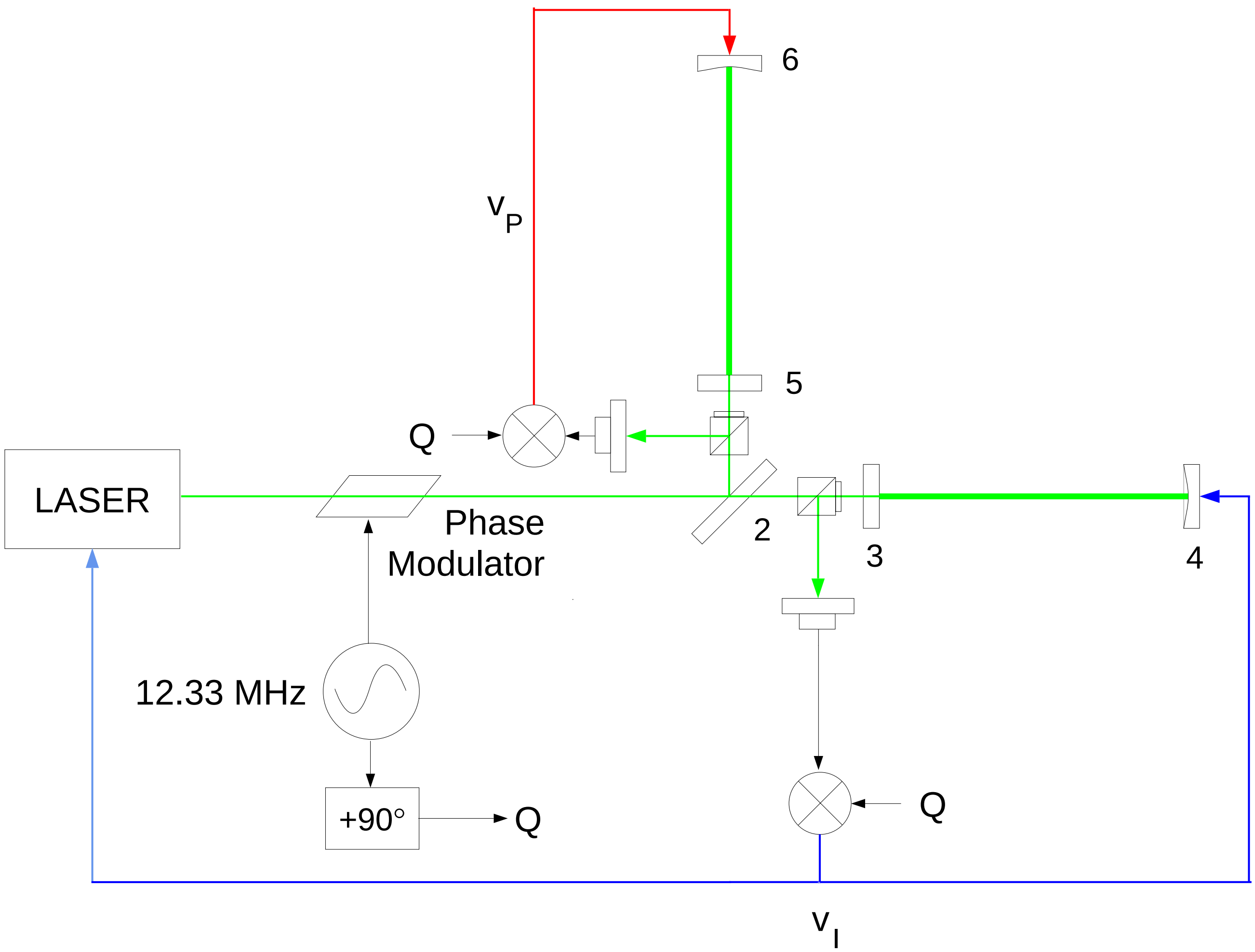
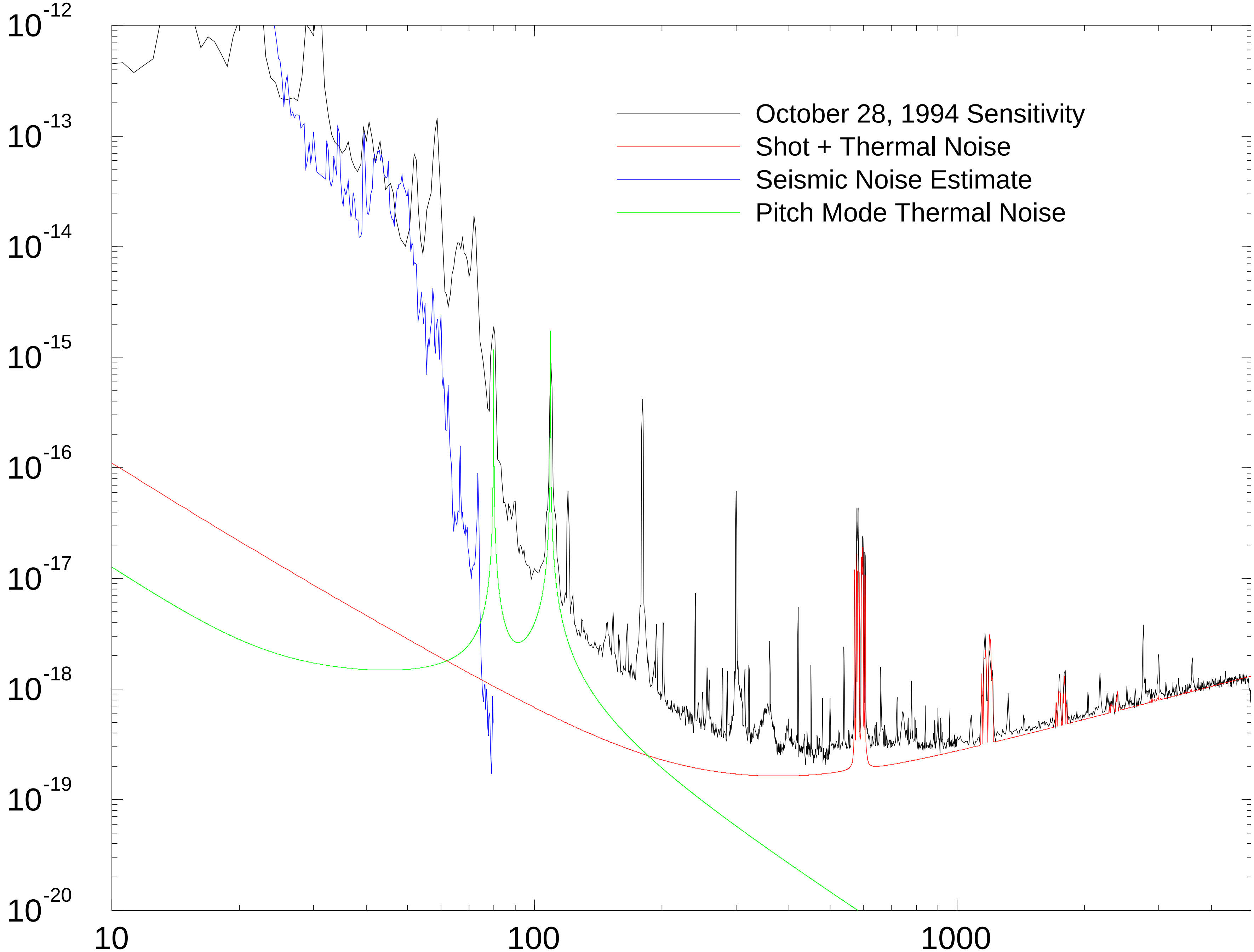
Plans for the 40m Upgrade

- The 40m Program
- Purpose of the upgrade
- Timescale — why now?
- Restrictions on the scope of the upgrade
- Obvious anticipated upgrades
- Paths towards advanced configurations
- Details: PSL, COS, MC, SOS, oplevs, vacuum, seismic stacks, CDS, building, safety
- Schedule
- Budget
- Personnel

LIGO-G990132-00-R, /home/ajw/Docs/G990132-00.pdf

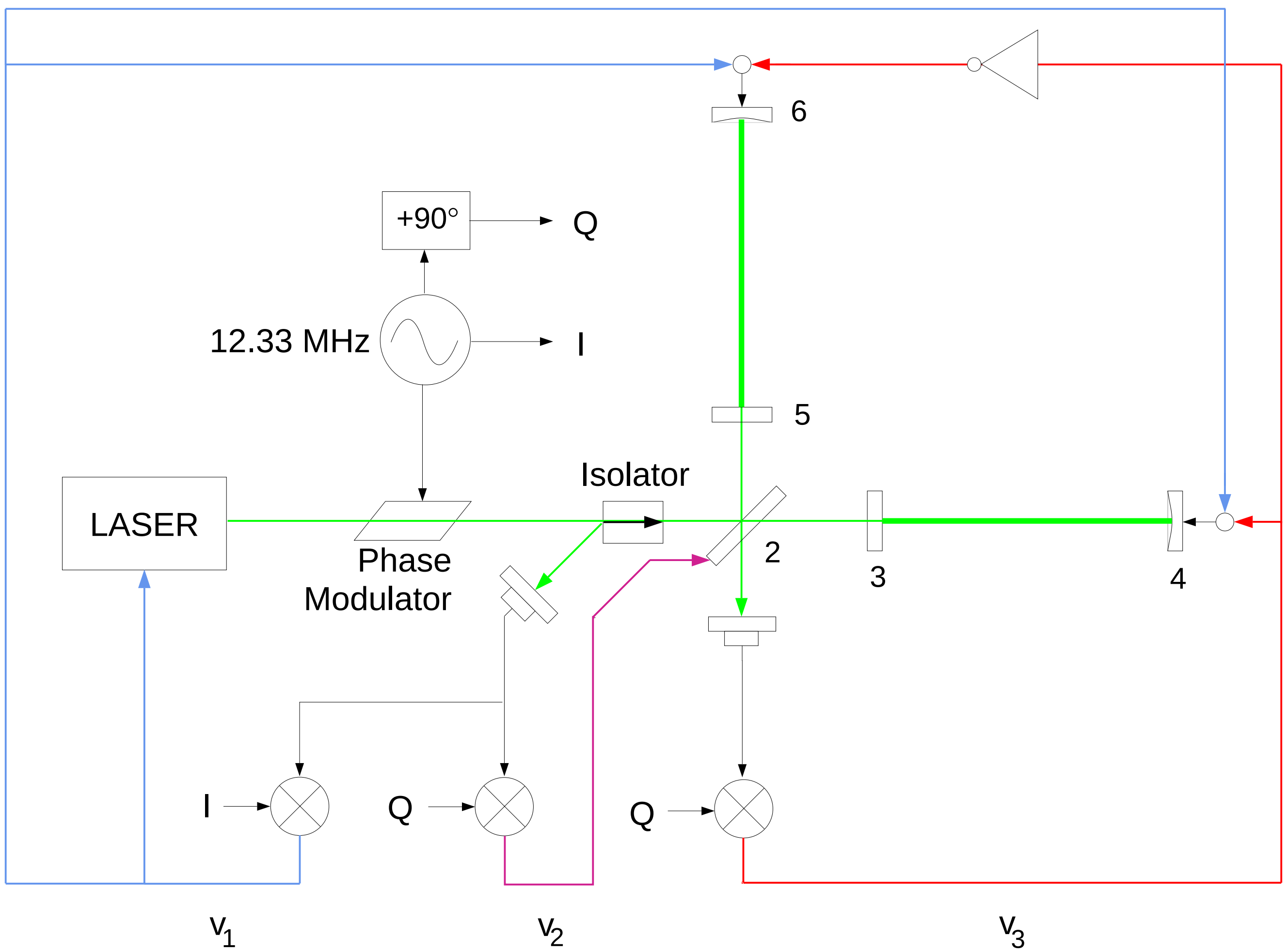
- 40m IFO under development since 1982
- 1992—1994: F-P (unrecombined) configuration; reduce displacement noise $x(f)$; expose fundamental noise sources

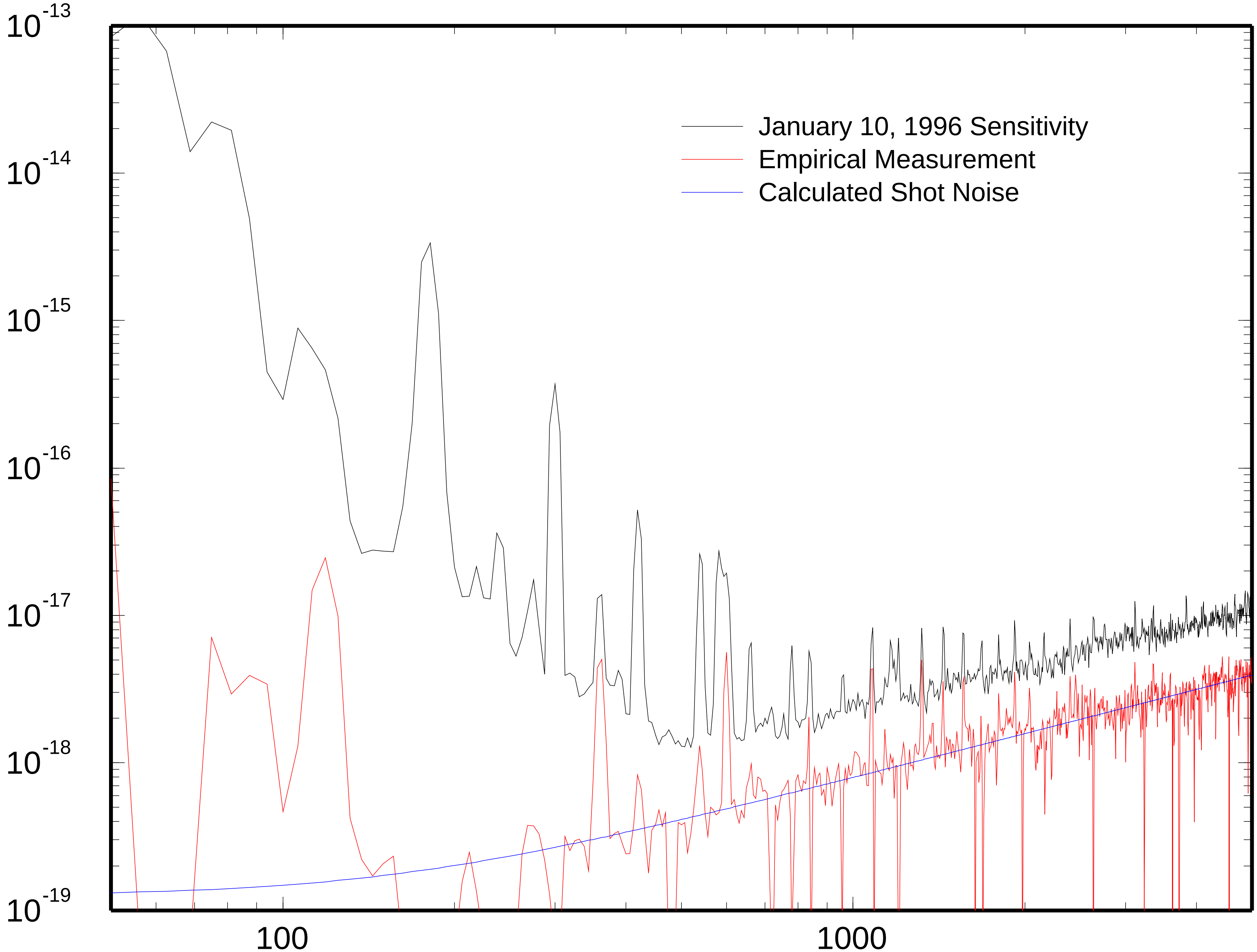



October 28, 1994 Sensitivity
Shot + Thermal Noise
Seismic Noise Estimate
Pitch Mode Thermal Noise
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10
100
1000

Recombined Config

- 1994—1996: recombined configuration
- Design/commission length controllers for dark port operation; lock acquisition
- studied major noise sources

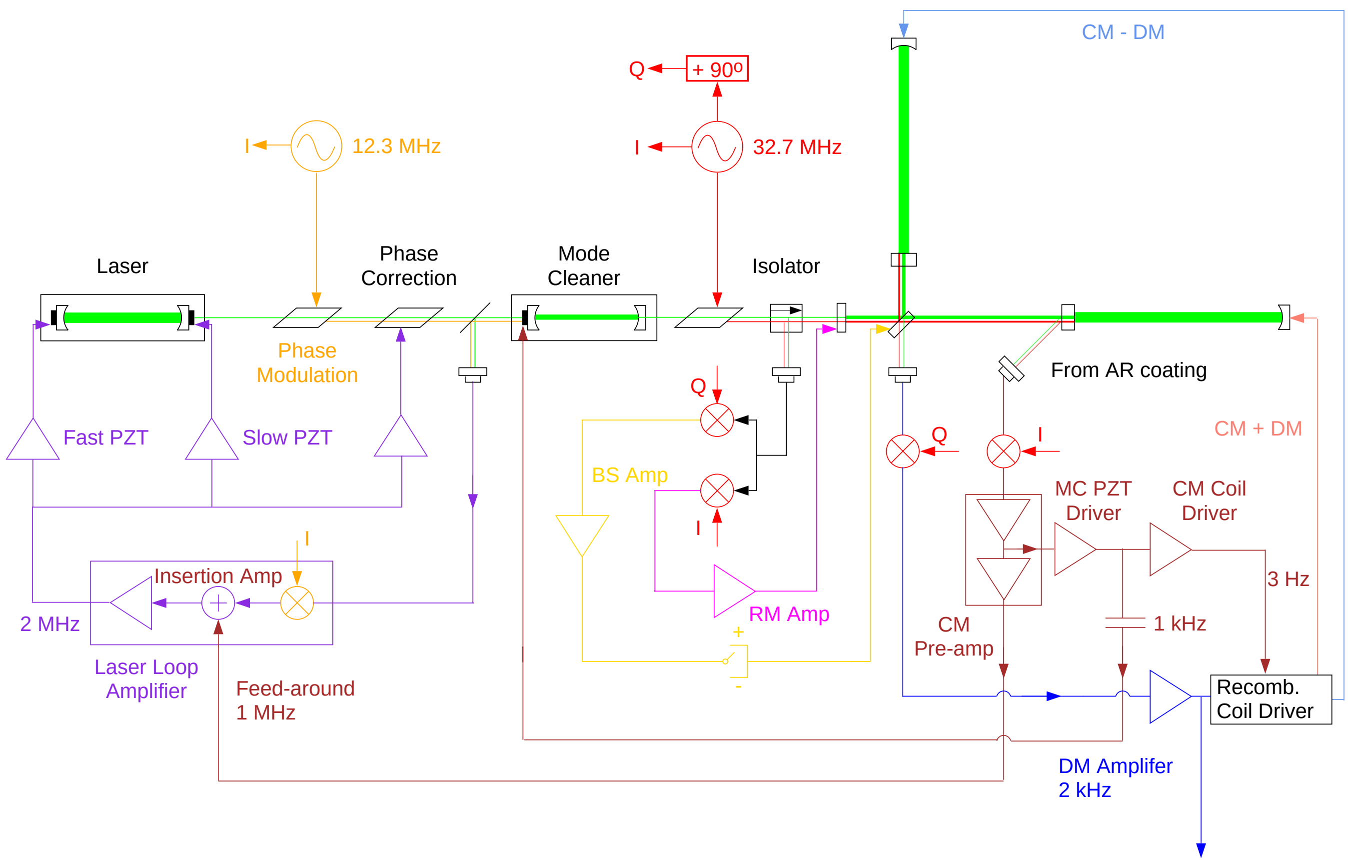



January 10, 1996 Sensitivity
Empirical Measurement
Calculated Shot Noise
10-13
10-14
10-15
10-16
10-17
10-18
10-19
100
1000

40m Power Recycling experiment

- Since 1996: the 40m Power Recycling experiment. Logan, Kells, Spero, Mavalvala, Riles, Gustafson, Vass, Ware, Bork, Heefner, Ouimette, and a cast of thousands ...
- New recycling mirror, and pickoff control servo
- LIGO-prototype suspensions and controllers (RM, BS, EV), optical levers
- LIGO DAQS.
- Focus on length sensing control system, lock acq.
- 1998: Wavefront sensing implemented
- Last winter: use 3rd harmonic demod to lock fully aligned IFO
- recycling experiment now completed

POWER RECYCLING TOPOLOGY



JEL
~jlogan/40m/Diagrams/rec_config.ild

Noise in 40m Power Recycling Config

- Focus of PR expt was LSC and ASC
- Throughout, little attention paid to noise
- Many technical problems:
  increased mirror losses, carrier under-coupling, mode mismatch, pockels cell heating, RF noise, *etc.*
- For the 40m to be a useful platform for advanced configurations, an upgrade program would be necessary to study, understand, and eliminate all technical noise sources, to expose fundamental noise sources (seismic, thermal, shot).
- Every time a new DOF was added,
  it took $\sim$ 2 years to understand the IFO!

Purpose of the upgrade

- **Advanced optical configurations (LIGO II):**
  Resonant Sideband Extraction (RSE), dual recyc (DR);
  focus on shot-noise limited (high frequency) response
- **Other advanced configurations:**
  Readout techniques, suspensions, seismic isolation,
  thermal noise control, QND
- **Testing of small improvements:**
  Staging/testing new control system hardware/software
- **Physicist education/training.**
  (My main motivation!).
- **Public education.**
  Tours, seminars, *etc.*, as always
- Complements other facilities, such as the
  prototyping efforts at MIT and Stanford,
  which focus on low-frequency response

Timescale — why now?

Presently, activity at the 40m lab is at a low level.
Any effort at 40m detracts from LIGO;
Where will we get the expertise, time and personnel?
Why pursue this now?

- It will take 1–2 years to produce upgrade ready for R&D on advanced optical configurations.
- People may become free within 2 years, eager to develop LIGO II. The time to plan and begin the 40m upgrade is now.
- Make use of LIGO engineering resources and expertise before they disappear in 1-2 years.
- NSF has allocated ∼ $1M, starting this year.
- The 40m remains a powerful learning tool, but hampered by technical problems, insufficient instrumentation, *etc.*. Rebuilding the 40m would be a tremendous learning tool in and of itself.

Restrictions on the scope of the upgrade

- Real-estate (the building/enclosure).
  - Rack space
  - More distributed optics tables
- Vacuum envelope (beam tubes and optics chambers).
  - dark port optics chamber exists; no seismic stack or optical table. Leaves little access room to east arm
  - Vacuum pumps, valves/controllers are adequate. Control software will certainly be upgraded.
- The LIGO IR PSL table (12'x5') = 40m (6'x10')
- Seismic isolation stack.
  Refurbish? Upgrade to LIGO springs?
- long suspended-mass mode cleaner?
  Leaves little access room to south arm

Obvious Anticipated Upgrades - "LIGO-like"

Why make it as "LIGO-like" as possible?

- Extrapolating the results of advanced R&D from the 40m to LIGO is more reliable
- LIGO-engineered and tested components (especially the electronics and controls) minimizes the need for extensive re-engineering.
- Testing and staging of small modifications to LIGO (such as improved control systems) at the 40m will be most relevant.
- Many instrumental difficulties, noise sources in current configuration must be remedied
- LIGO-engineered controls are the simplest, fastest, cheapest (?) way to do this
- Physicist education and training on the 40m will be most relevant.
- The 40m charter: an "engineering prototype" for LIGO

"LIGO-like" upgrades

- A LIGO-like 1064 nm pre-stabilized laser (PSL)
- LIGO-like core optical elements
  (5 mirrors and one beam splitter).
- Suspension for 6th (RSE) mirror.
- A suspended mass mode cleaner??
- LIGO-like suspensions and sensor/controllers.
- LIGO-like length sensing and control (LSC) system
- LIGO-like alignment sensing/control (ASC) system.
  (oplev: existing; WFS: some existing)
- LIGO-like data DAQS, disk farm, software, displays.
- LIGO-like EPICS-based detector control system.
- LIGO-like EPICS-based vacuum control system.
- LIGO-like environmental monitoring (PEM), scaled
- Rebuild seismic stacks, bake-out tubes, pumps, stacks

Parameters: LIGO vs 40m (1998)

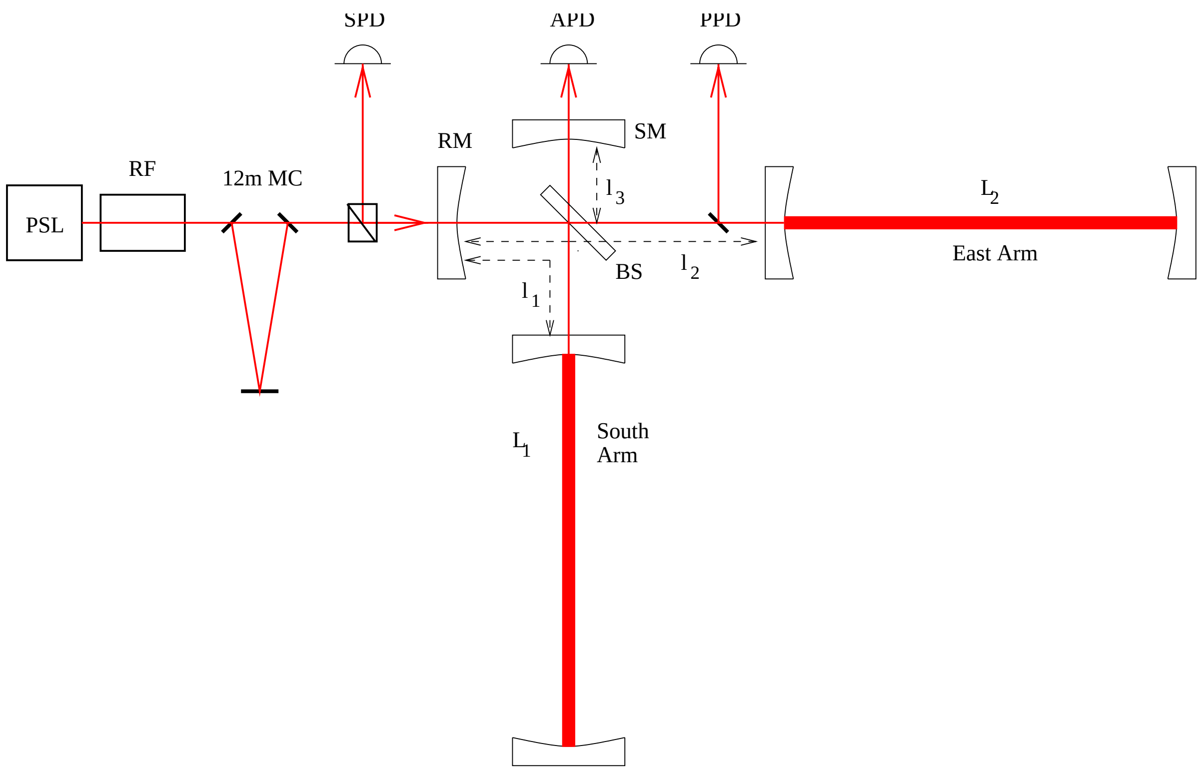
Parameter	LIGO	40m	units
Carrier λ	1064.	514.5	nm
RF frequency f_{mod}	23.97	32.7	MHz
RF Modulation index Γ	0.63	0.45	
PR Cavity length	9.4875	2.565	m
Arm Cavity lengths	3999.01	38.25	m
Asymmetry length	0.215	0.542	m
Transmissivity T(RM)	0.0244	0.1375	
Transmissivity T(IM)	0.02995	0.00565	
Transmissivity T(EM)	1.5E-5	1.2E-5	
Power Loss L(RM)	5.0E-5	0.006	
Power Loss L(IM)	5.0E-5	7.E-5	
Power Loss L(EM)	5.0E-5	7.E-5	
FP Cavity Finesse	205	1080	
Rec Cavity Finesse	101	39	
mirror diameter	25.0	10.16	cm
mirror length	10.0	8.89	cm
mirror mass	10.8	1.58	kg
mirror density	2.20	2.20	g/cm^3
Index @ 1064 n	1.46	1.46	
radius recycling mirror	14900	∞	m
radius vertex mirror	14558	∞	m
radius end mirror	7402	62	m

Paths towards advanced configurations

- Chamber at dark port to accomodate optical elements such as signal recycling mirror.
- Additional vacuum envelope between PSL and RM to accomodate more complex IO;
  long suspended-mass mode cleaner?
- Higher frequency RF (100 MHz or higher) generators and optical modulators (IR Pockels cells?) to accomodate modified optical configurations under the constraint of the existing cavity lengths
  (Schnupp asymmetry).
  This will also require re-engineered RF shielding, photodiodes, *etc.*.

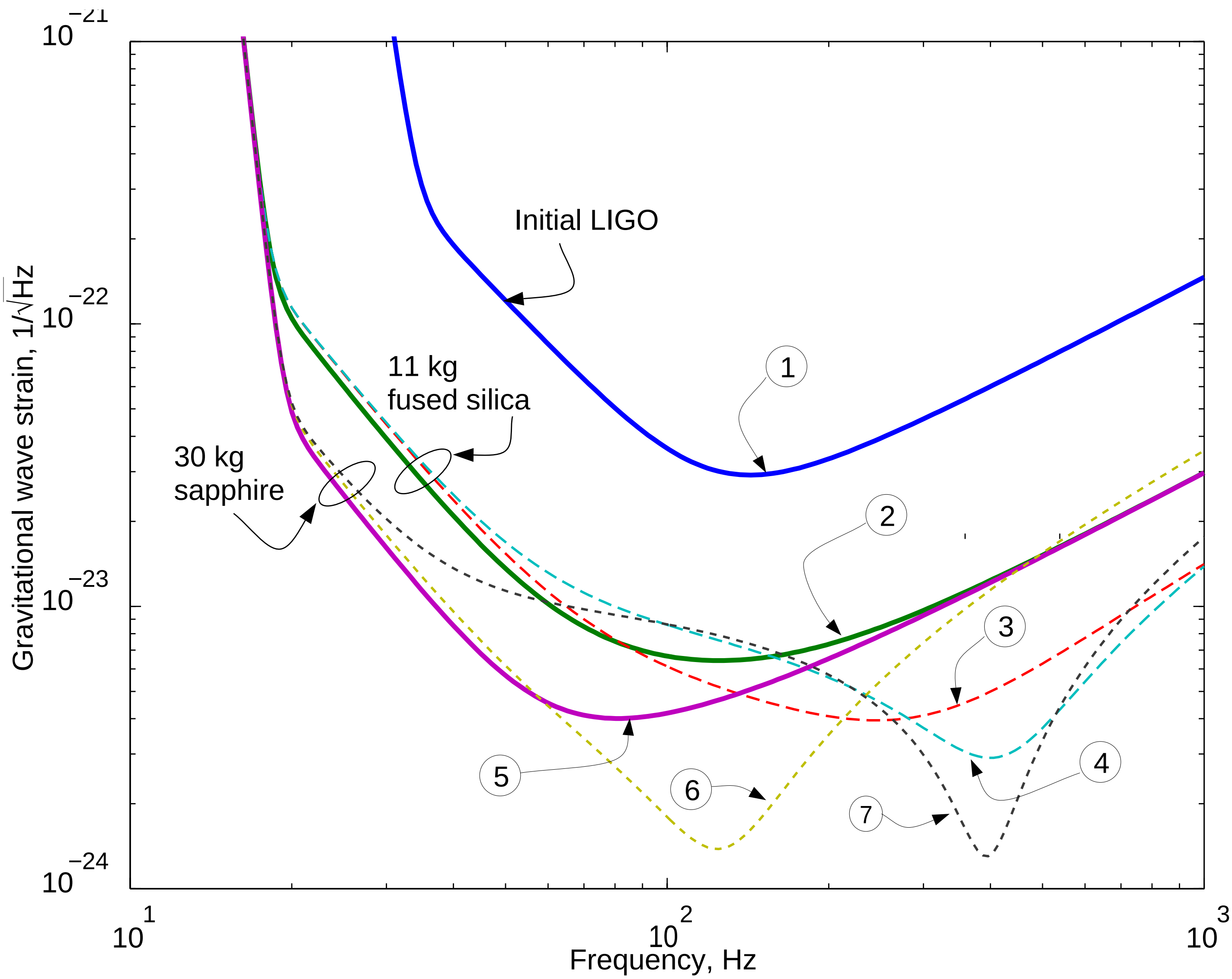
RSE/DR Configurations

- To accomodate RSE configuration:
- Need output port vacuum chamber,
  SR mirror suspension
- Highly desireable: a "straw-man" configuration
  for broadband operation,
  specifying lengths of PR, SR cavities



ADVANCED OPTICAL CONFIGURATIONS

From LSC White Paper, September 1998:



Details: PSL

- A LIGO-like PSL, with 6 W at RM,
  is desired for at least some advanced R&D,
  will minimize re-engineering from LIGO → 40m
- Of course, requires rebuild of all 40m optics
- IR light is invisible → inconvenience and safety
- Abbott & King deliver their last laser to LHO4K, 10/99. We could be next in their queue.
- We are already in Lightwave queue for laser
- LIGO specs (intensity stabilization, frequency stabilization, and mode matching) are fine for 40m(?)
  Minimal re-engineering required
- Lower power operation, during vents and coarse alignment. Shunts/dumps required.
  We should be able to turn down the laser somewhat, at the cost of beam quality.
- Wall-plug power at 6W output is $<$ 1KW
- infrastructure: water cooling, ground loops, *etc.*
- Safety enclosures and procedures.

Details: Core optics

- Optics: Corning and Heraeus SV fused silica blanks
- 4" core optics, (quantum limit),
  with LIGO SOS or scaled LOS, and SOS controllers
- polishing: "superpolishing" to reduce scattering
- coatings: Multi-layer, resonant coating.
  Keep Fresnel number same as LIGO.
- AR coatings (also multilayer) on back side.
- Optical constraints on substrate, curvature, polishing, coating, R/T, for 40m
- magnet attachment
- Suspended mass mode cleaner optics (?)
- Other Secondary (fixed) optics
  (telescopes, steering mirrors).
- Pockels cell for IR. Faraday isolators.

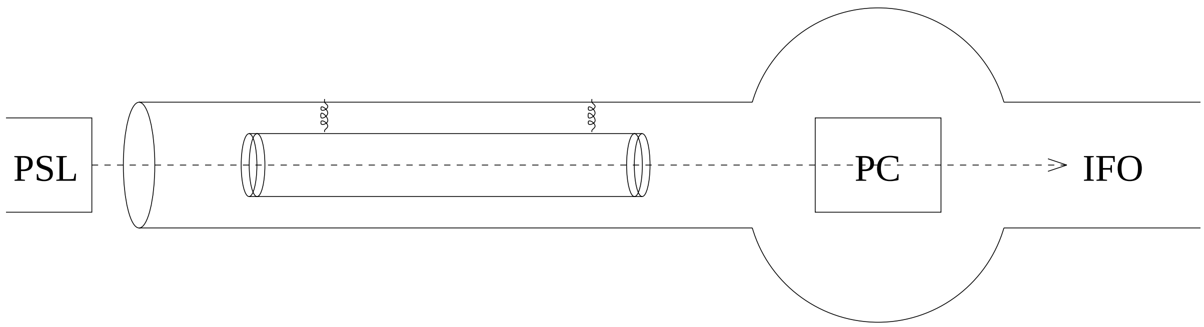
Details: Mode Cleaner

Do the physics goals of the upgrade (advanced optical configuration development requiring beam stability) require a long suspended-mass mode cleaner?

- It would probably be the single most complex piece of engineering for 40m upgrade.
- 40m noise floor has not been limited by f-noise, HOM, pointing jitter.
- current 40m: fixed mirror MC in 1m quartz tube, suspended from beampipe on springs. Used for f FB. May be adequate design.
- A 12m suspended-mass mode cleaner was designed for the 40m, was partially built but never installed, and was subsequently disassembled.
  Parts may exist; and engineering drawings.

Details: Mode Cleaner and Pockels Cell

- current 40m: mode cleaner → pockels cell → IFO.
  MC not required to pass the sidebands.
  This simplifies the requirements on the MC;
  But noise in pockels cell → IFO.



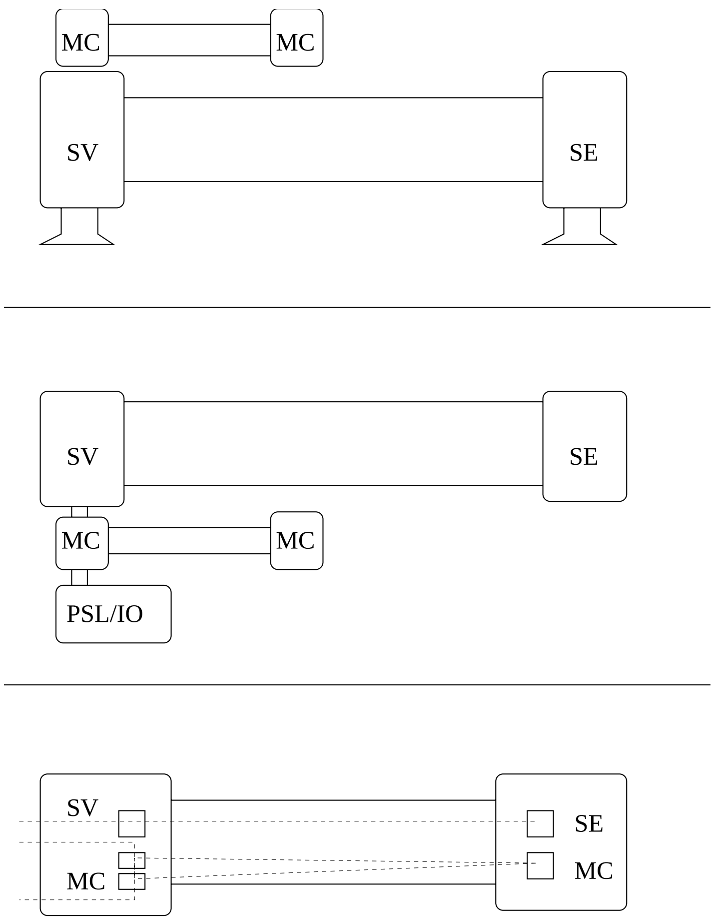
- LIGO: pockels cell → mode cleaner → IFO.
  Mode cleaner filters pockels cell noise (AM).
  Can keep pockels cell in air (on PSL table)
  to minimize heat-related failures.

- Although IR pockels cell may be more robust,
  may want to keep pockels cell in air
  in *either case.*

Details: Long Mode Cleaner Location

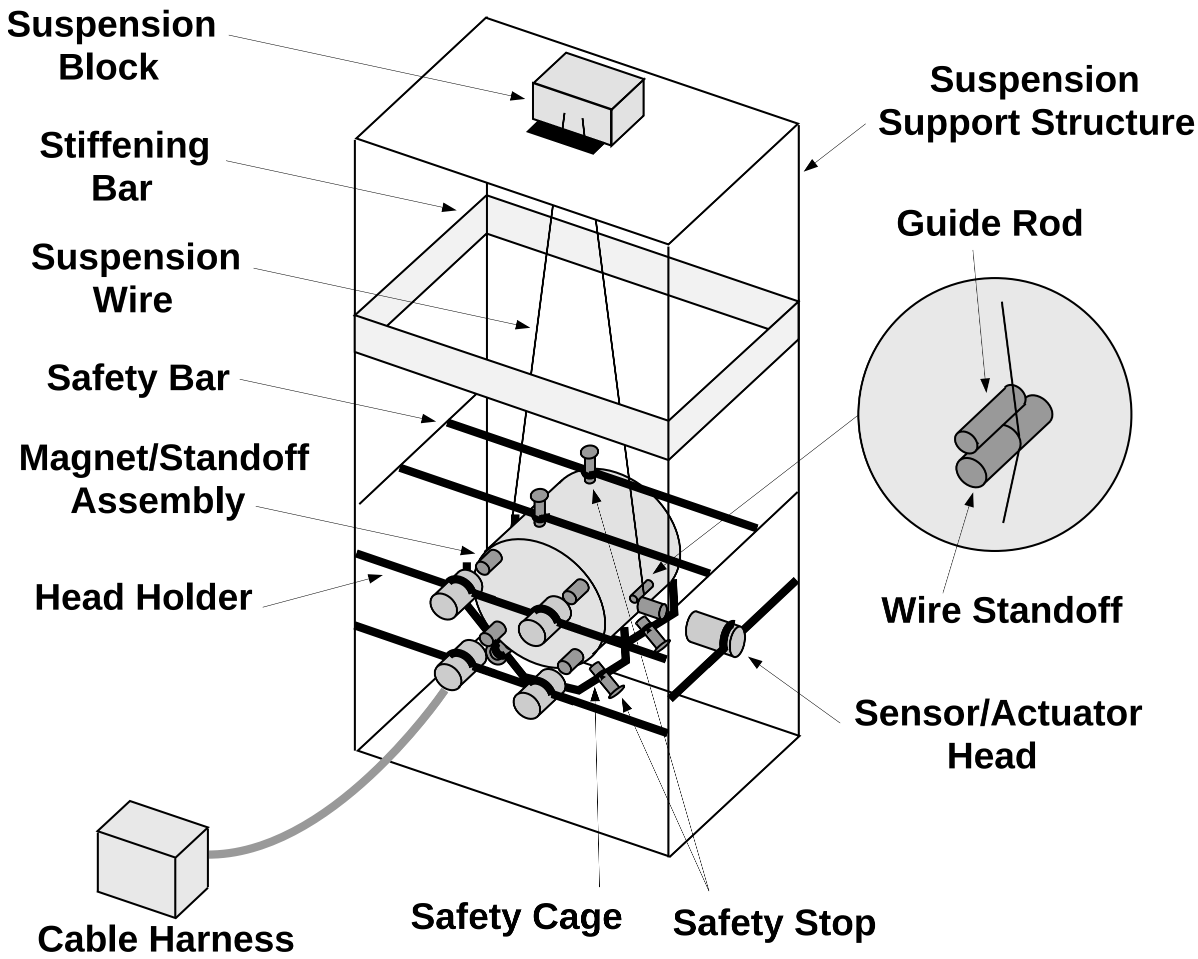
Possible locations for a long suspended-mass MC:

- above one or the other existing beam tube
- along side one or the other existing beam tube
- inside one or the other existing beam tube



Details: Suspension engineering

- Currently, the 40m has 4 types of suspensions.
  LIGO SOS suspensions support the BS and RM.
  Scaled/prototype LIGO LOS for the EV.
- Build new, scaled-LOS suspensions and LIGO OSEMS.
- Build a suspension and controller
  (but no actual optical element, yet)
  for a signal recycling mirror.



Optical levers

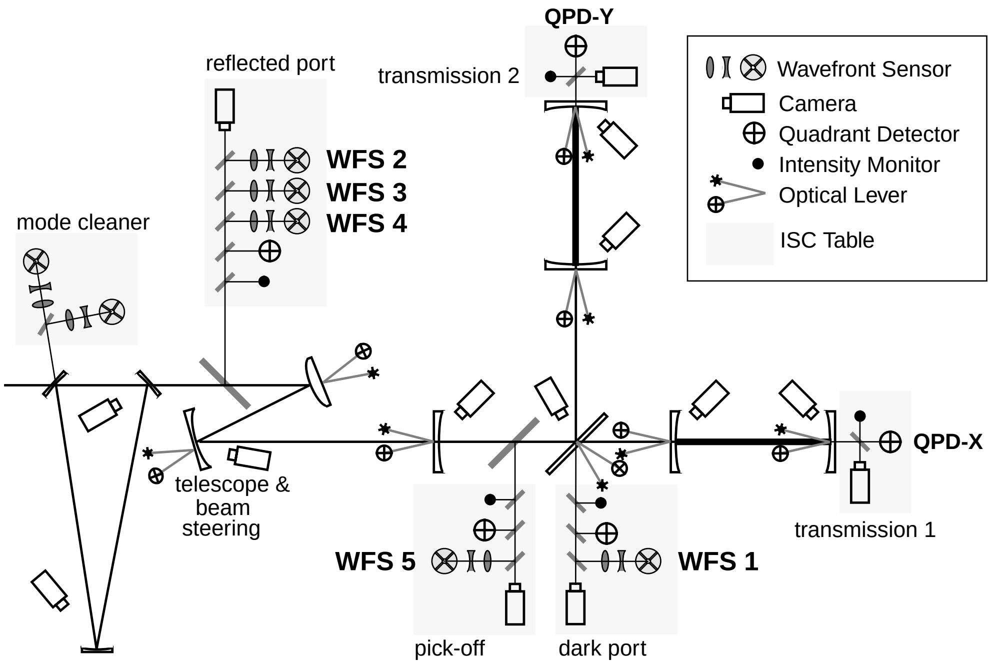
- LIGO uses local suspension controllers and WFS to damp angular motion.
  Local (few meter) optical levers exist but are not used for alignment control (at least, initially).

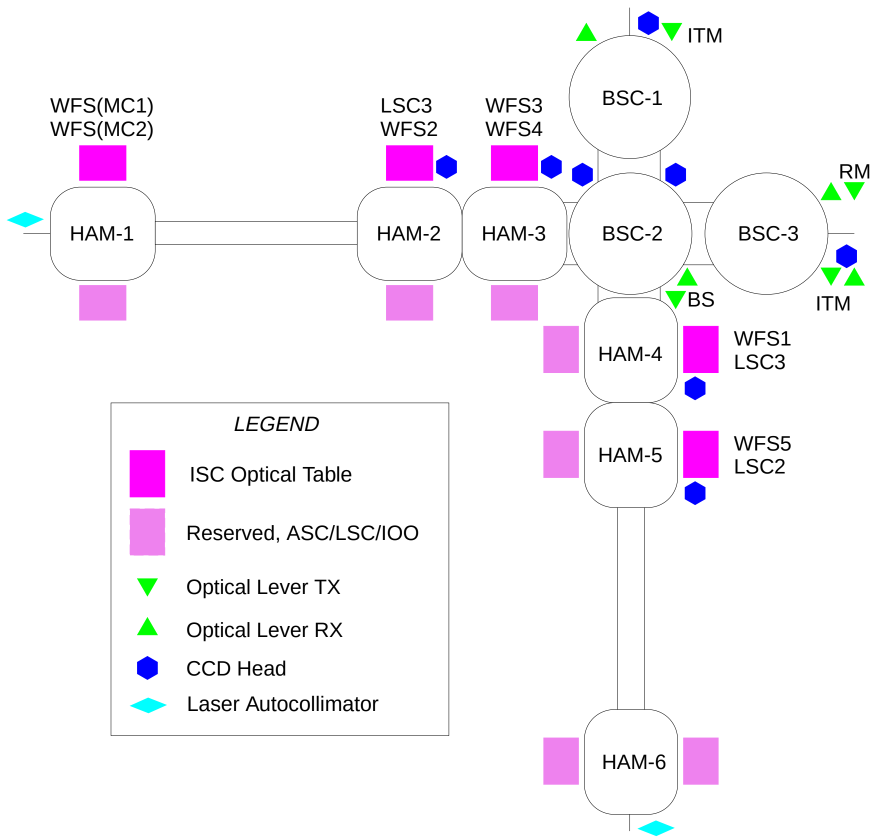
- At 40m: local (∼1 meter) and global (40 meter) optical levers (reflection only).
  Used for coarse alignment, and alignment control.
  The global loops are more stable and useful;
  Limited by stability of the optical platforms.

- With LIGO suspensions, do we need the oplevs?
  - PRO: The more instrumentation, the better (motherhood). And it's already there.
    And, CDS says intrumentation is straightforward.
  - CON: What's it good for? "A man with one watch knows what time it is, a man with two watches is never sure". Simpler to maintain a system without unneccesary instrumentation.

- Propose to retain the global optical levers, but abandon the local ones (for simplicity).

LIGO ASC

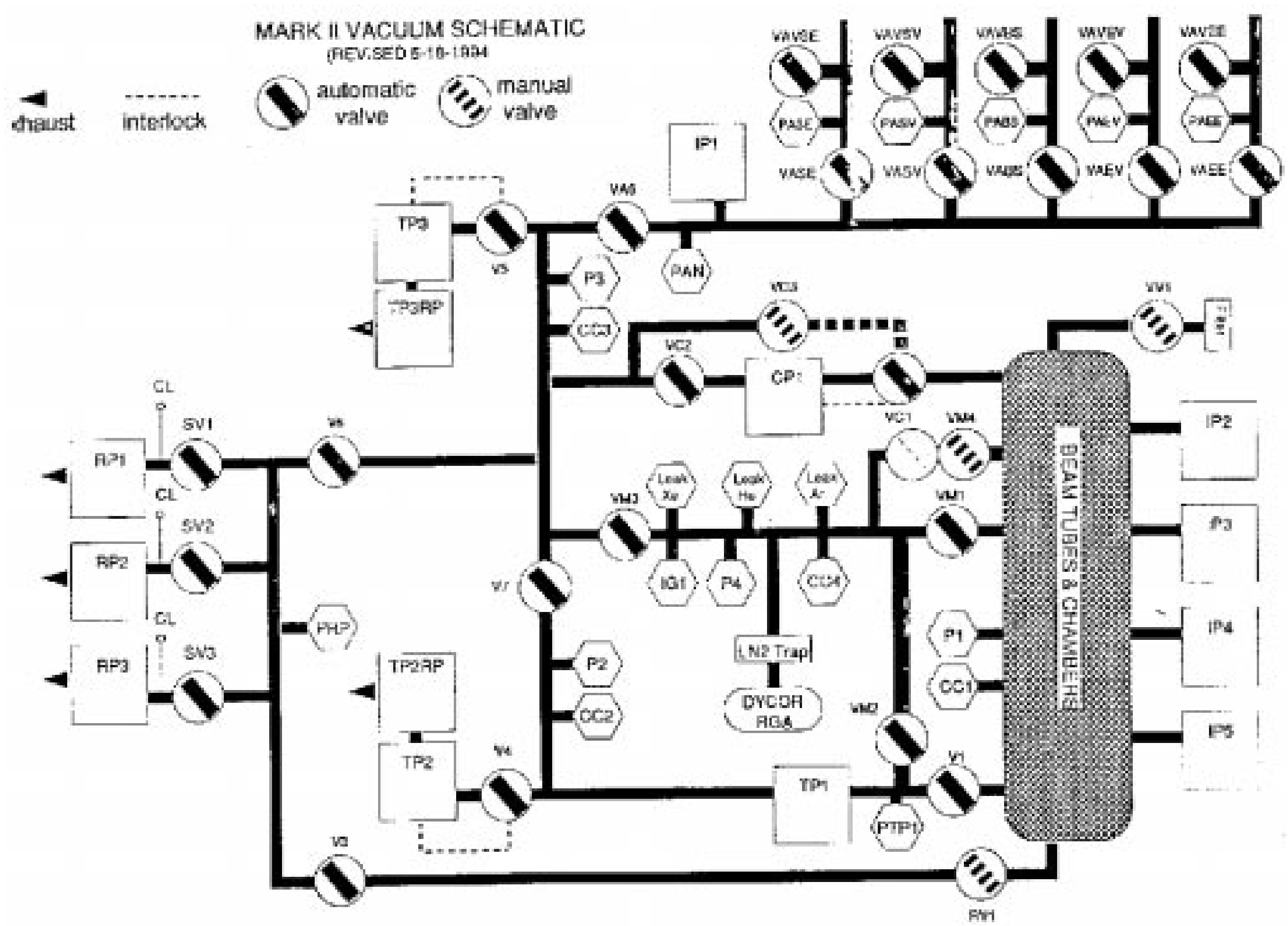

QPD-Y
reflected port
transmission 2
Wavefront Sensor
Camera
Quadrant Detector
Intensity Monitor
Optical Lever
ISC Table
WFS 2
WFS 3
WFS 4
mode cleaner
QPD-X
telescope &
beam
steering
transmission 1
WFS 5
WFS 1
pick-off
dark port


ITM
BSC-1
WFS(MC1)
WFS(MC2)
LSC3
WFS2
WFS3
WFS4
RM
HAM-1
HAM-2
HAM-3
BSC-2
BSC-3
BS
ITM
HAM-4
WFS1
LSC3
LEGEND
ISC Optical Table
Reserved, ASC/LSC/IOO
Optical Lever TX
Optical Lever RX
CCD Head
Laser Autocollimator
HAM-5
WFS5
LSC2
HAM-6

Vacuum system and control

- Vacuum chambers: Need to add output optics chamber. Chamber exists; no optics table / seismic stack.
- Vacuum control: 12 pumps, 25 controllable valves, and 20 gauges.
  40m uses old (1992) vacuum control system, with a state machine enforcing safe sequences.
- Need LIGO-like monitoring, EPICS-based interface, controls. Hardware↔computer interface supplied by CDS. Custom state machine software and GUI required.
- Maglev turbo pump is not vibration free. It would be desireable to use, instead, the existing ion pumps.
- Ion pumps unused (contaminated with hydrocarbons each time we vent). To make them useful, install gate valves. They would then need to be baked out.
- Bake-out of tubes, pumps, stacks

Current 40m vacuum system

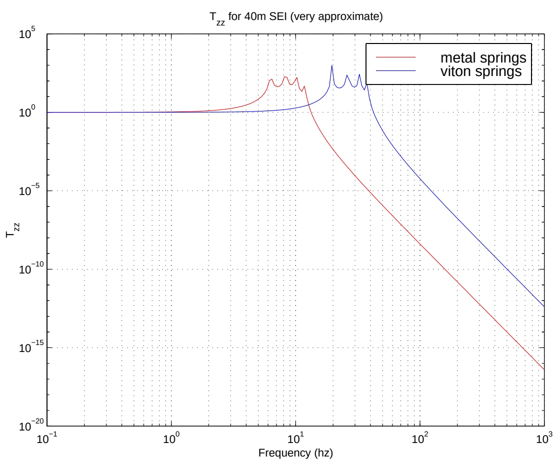


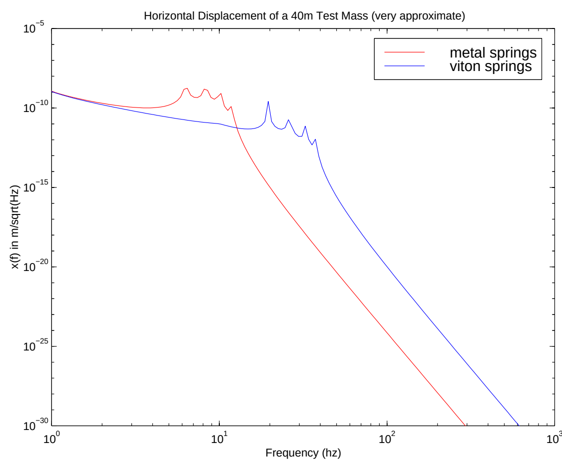
DETAILS: SEISMIC ISOLATION STACKS

Do we need to upgrade the existing stacks?

- Existing viton spring stacks →
  seismic noise wall @ 100-120 Hz

- Upgrading to LIGO-like damped metal springs →
  much less stiff: noise wall @ 40-50 Hz





- Is that extra bandwidth necessary?

- What level of thermal noise be revealed?

- In the course of prototyping narrow-banding configurations, is there a good reason to explore that band?

Details: Seismic isolation stacks

- Fluorocarbons in 40m RGA (Stan):
  existing viton springs contaminating the vacuum.
  Will want to disassemble, and bake and clean,
  the existing stacks (2-3 months?).
- Upgrade to LIGO-like metal springs:
  Procuring the 200 springs: not expensive.
  Remachining leg mass elements to seat springs, and
  then thorough cleaning. Is it worth it?
- Last opportunity to do it, until the next major rebuild.
- Active seismic isolation, outside vacuum chamber.
- Bake-out stacks, tubes, pumps

Details: Electronics and control system (CDS)

- Suspension controllers: Heefner
  LIGO SOS controllers may be able to do the job.
  Re-engineering to 40m specs
  (tolerances, ranges, noise, filtering)
- PSL control system. Rich Abbott.
  LIGO PSL control system can be duplicated.
- LSC hardware and software: Ouimette.
  LIGO LSC control system can be duplicated.
  Re-engineering to 40m specs
  (tolerances, ranges, noise, filtering)
- ASC/WFS hardware and software. Jay Heefner.
  Same comments as for LSC.
- DAQS hardware and software: Bork.
  DAQS currently installed at 40m is already LIGO-like.
  Expect improvements.
- The existing cpus and ethernet network possibly
  adequate for the DAQ task.

Details: CDS, cont.

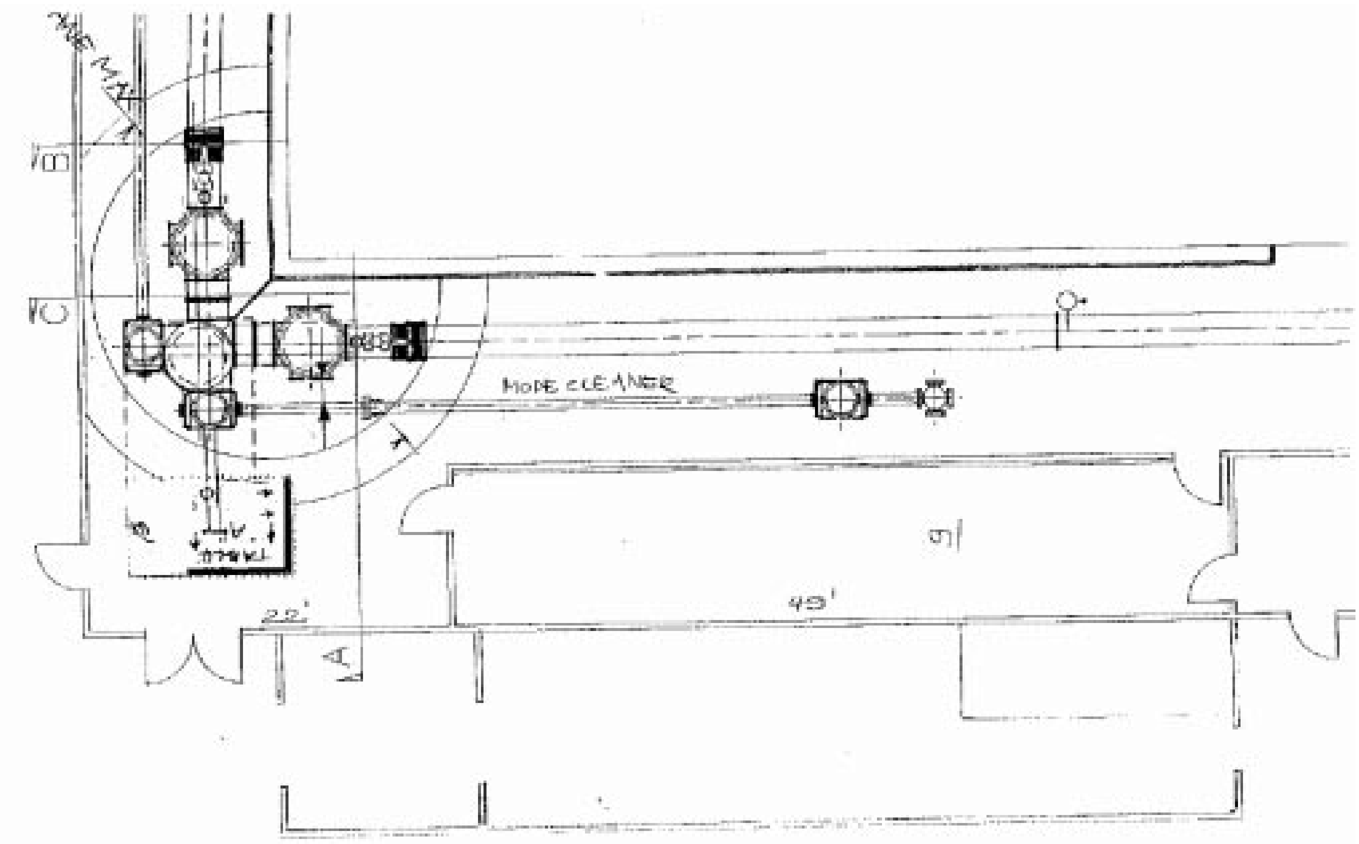
- IR Cameras: at all appropriate places (each core optic, sym and asym ports, *etc.*).
- PEM: minimal system, OTS → CDS patch panel.
- Racks required for totally rebuilt CDS for 40m: one for PSL, one for all (∼10) SOS suspension controllers, one each for ASC and LSC, two for DAQS (including disk farm), one for vacuum. total: 7.
  Built new, accomodate CDS cross wiring.
  All signals, even those from the end stations, can be brought 40m to vertex area.
- CDS for LIGO is $13M. Obviously, we need to cut lots of corners! Est: between $500K and $1M.
- 40m team depend on the availability of knobs and diagnostics for alignment, ASC, LSC, *etc.*, right up next to the IFO. We must ensure that *all* of the useful tools are available, right from the start.

Building modifications

- Rebuild roof, seal doors, to eliminate leaks
- Convert part of north annex for operator space
- Convert current operating room to electronics racks; possibly remove partition wall
- maintain/enhance access to vertex region
- upgrade clean room standards

Other issues

- Safety: High-power IR laser
- Education, tours, outreach.


MODE CLEANER
B
C
A
22'
49'
9'

Schedule

- April 1999: Upgrade plan, exploration of potential advanced configurations.
- 2nd Q, 1999: Top level requirements:
  establish science goals; sensitivity; bandwidth; workable optical configuration
- 2nd Q, 1999: decisions on some important items:
  - 1m fixed-mirror mode cleaner ... ?
  - Seismic stacks - rebuild (+ one extra) with LIGO springs, clean & bake
  - bake 40m tubes and pumps
  - mode cleaner $\rightarrow$ pockels cell (air) $\rightarrow$ IFO (?)
  - 4" core optics with re-engineered SOS suspensions, SOS for everything else
  - CDS engineering? budget?
  - building modifications

Schedule, contin.

- 2nd Q, 1999: Prelim design, schedule, budget; first orders placed.
- 3rd Q, 2000: Preliminary design review
- 3th Q, 2000: Begin Glasgow 10m experiment
- 4th Q, 2002: Completion of Glasgow 10m experiment
- 4th Q, 2002: 40m Operating as IFO, ready for RSE

Budget

40m Upgrade – FY 1999 Operations Budget Detail

WBS	Desc	Category	FTE	Total
2.8	Group Leader	Scientist	1.00	
2.8	Technician	Technician	0.50	
2.8	Technician	Technician	1.00	
2.8	Engineer	Engineer	0.25	
2.8	Optical Engineer	Engineer	0.25	
2.8	Susp Engineer	Technician	0.25	
2.8	CDS Engineer	Technician	0.17	
2.8	Scientist	Scientist	0.25	
2.8	Technician	Technician	0.50	
	Total		4.17	513,576
2.8	Equipment	Equipment		160,000
2.8	Travel	Travel		12,480
2.8	Materials	supplies		62,400
2.8	Laser	Subcontracts		110,000
2.8	Glass blanks	Subcontracts		50,000
2.8	Control systems	Subcontracts		250,000
2.8	Total			1,158,456

Personnel

- Project Managers: Alan Weinstein and Bill Althouse.
- Electrical Engineer: ($\simeq$ 1 FTE).
- General Technician: 1 FTE (Vass).
- Electrical Technician: 1 FTE (TBD).
- One postdoc (w/ GW IFO experience) $\rightarrow$ scientific staff
- Graduate students (2 or 3), undergrads
- Long-term ($\sim$ 1 year) LSC visitors – to be invited!
- Scientific consultants from LIGO:
  Whitcomb, Sanders, Mavalvala, Kells, Camp,
  Gustafson, *etc.*
- Engineering consultants from LIGO:
  Optical, suspension, seismic, CDS
- Computing/software consultants from LIGO.
- Your name here!

Is there sufficient manpower/expertise to pursue this task?