LIGO Advanced System Test Interferometer

PAC meeting 16 Nov 98
David Shoemaker

Initial steps

- System proposed at PAC MIT June 97
- Plan for vacuum system adopted by LIGO in Fall 97
- Space approved by MIT in Fall 97
- order placed Fall 97 with PSI (LIGO Vacuum Equipment vendor)

Since last PAC meeting

- envelope completed in May 98
- MIT Lab, high bay completed; Lab moved 15 July 98
- vacuum equipment in high bay 5 Nov 98
- seismic isolation equipment ordered; some delivered

Update on research and infrastructure

- activities at MIT, in LIGO Lab, in Ligo Science Collaboration
- LASTI: where it stands, where it is going

LSC Suspension/Isolation Working Group

2004: First opportunity for significant changes

- first science run finishing in ~2003
- allows a ~5 year cycle of research, development, engineering, test

Low-Frequency Performance goals dictated by thermal noise

- target materials (quartz, sapphire) loss characterized
- practical techniques needed for assembly
- isolation goal: let optimistic level for thermal noise dominate
- only moderate improvements in isolation required

Leads to near-term plan for research:

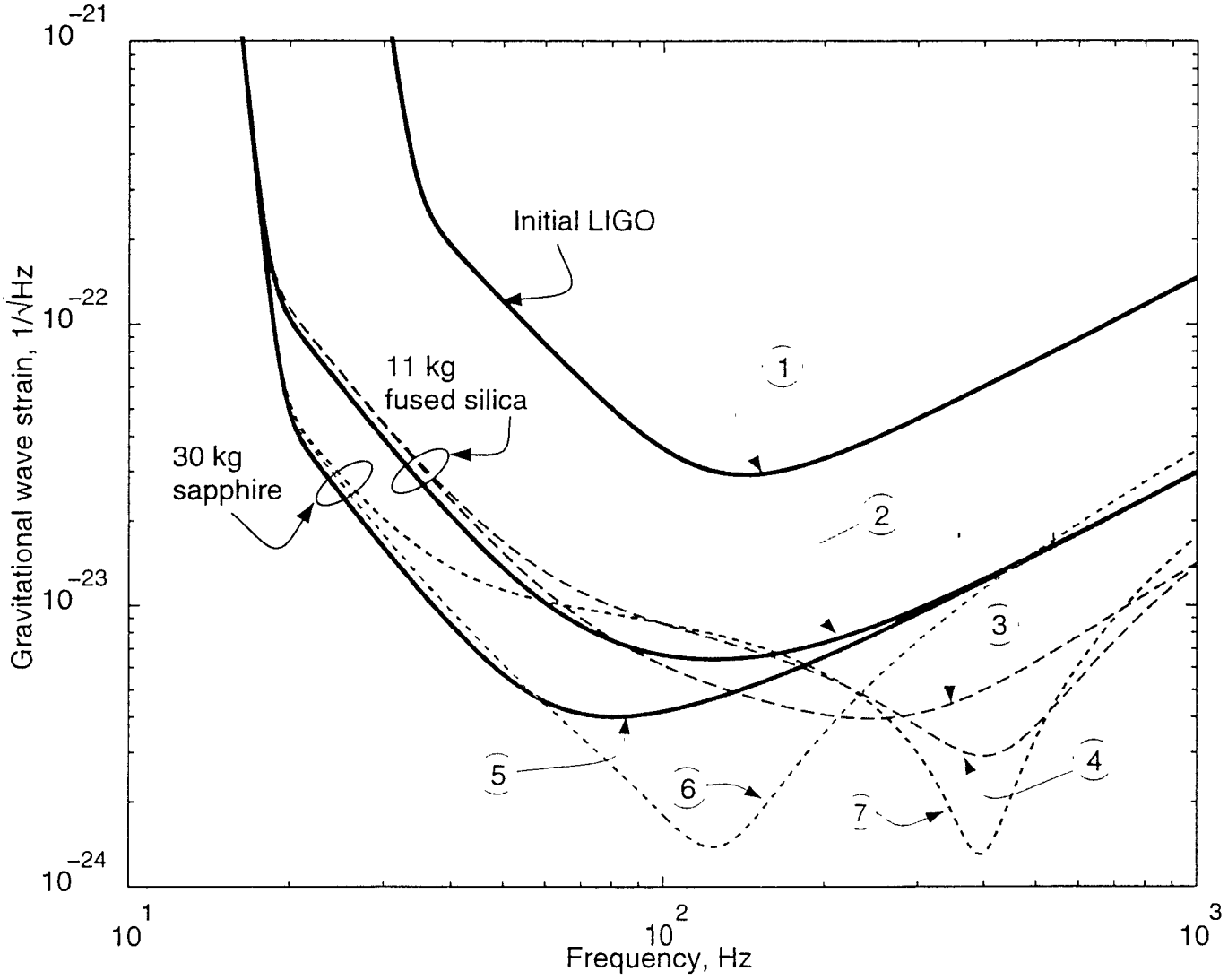
- model and plan the system: requirements, trades
- leave LIGO I passive isolation in place, augmented by...
- multiple-pendulum suspension, and
- modest active isolation system

Long-term goal: gravity gradient limited performance

- probably rather limited by pendulum thermal noise

interest in LIGO and community for aggressive application of sensing/servo techniques, but all approaches to be considered

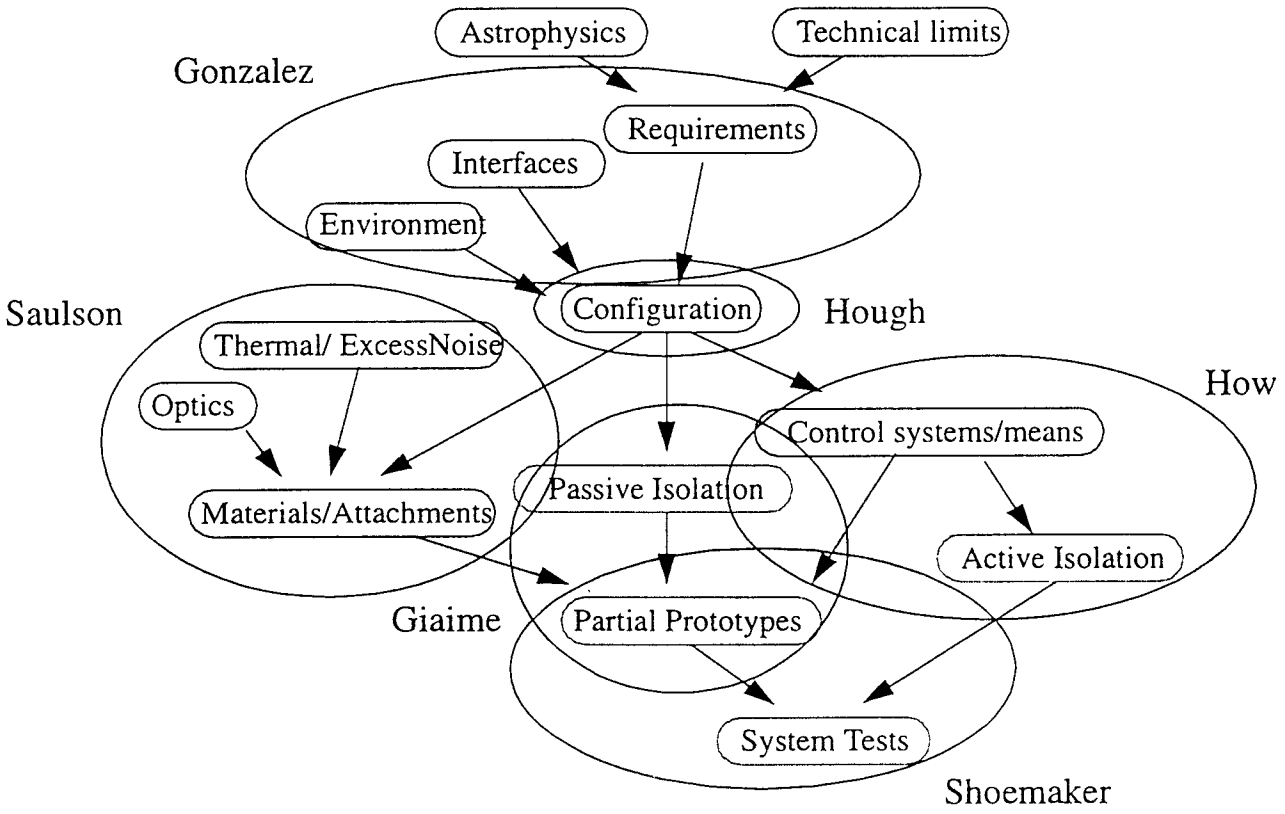
Performance goals



Considerable progress in defining strawman and models

- realistic parameters for losses
- design concepts for control hierarchy, mechanical assembly
- some staging of implementation possible (test mass material)

Roadmap to Stochastic forces research



LIGO Science Collaboration Suspension Working Group

- important force in planning for LASTI
- steering group meeting monthly, larger physical meetings ~2-3 months
- coordinated effort to develop near, far-term solutions
- here, discuss ways that the Full-Scale Test Interferometer contributes

Active Seismic Isolation

Plan to re-use the bulk of LIGO I passive isolation system

- with double pendulum, allows thermal noise to dominate in GW band
- considerable cost/complexity savings if incorporated in new design
- will be well-understood and characterized system
- changes (e.g., damping of springs) if indicated by experience

Active pre-isolation system

- Objective: to reduce required dynamic range in suspension; goal: factor 30 reduction, 0.1-10 Hz
- target design is (principally) external to vacuum
  - › may include sensors in vacuum to control stack dynamics
- MIT contributing commercial system for test to help make MIT LIGO campus site workable

Servo-control aspects

- fuly digital system
- payload sensors, internal sensors, ground sensors
- commercial system comes with expert control development help

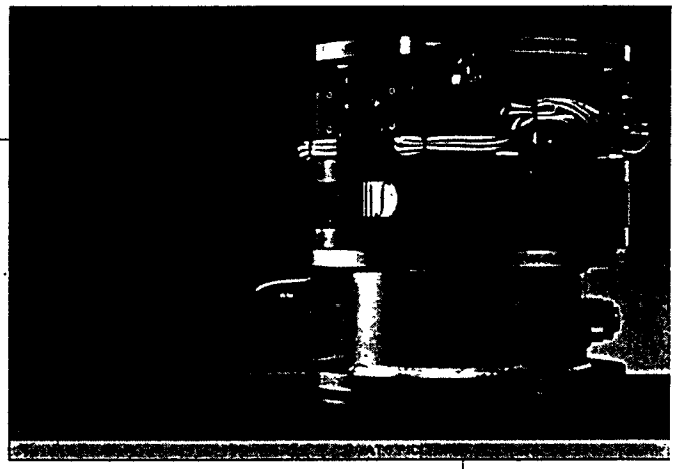
Goal: element of LIGO II isolation system

- off-load actuators on test mass (to zero!)

Active Isolation

Status

- working relationship established with Integrated Dynamics Engineering (IDE)
- in design, with some funcamental choices still unresolved
- MIT staff/faculty working with IDE to reduce noise in air-bearings
- possible change in design to horizontal-only air bearing
- December: fix the basic design choices



Passive Isolation

LIGO II objective: thermal/quantum noise to dominate

- put 'seismic wall' intercept >10x above sensitivity limit
- combination of LIGO I stack, multiple pendulum, pre-isolator sufficient for horizontal isolation

Additional vertical isolation required

- earth's curvature gives vertical-horizontal coupling
  - › best case: 3×10^{-4}; difficult to measure, and likely greater
  - › LIGO I passive isolation ~1000x worse in vertical than horizontal
- simple pendulum has ~10-15 Hz 'bounce mode'; no real isolation
- additional isolation must be close to test mass to filter passive stack internally generated thermal noise
- development work in GEO and LIGO/Caltech

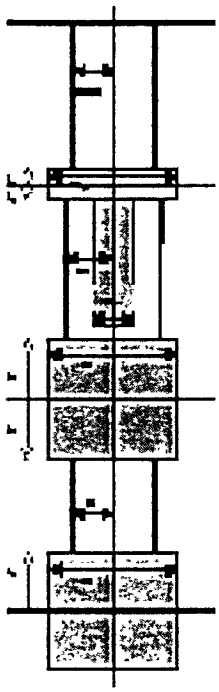
LASTI activities

- modify test-mass chamber isolation/suspension interface
- raise optics table without modification of stack
  - › spacers between support tubes and support table
  - › spacers between support table and first stack element
- tests in LASTI of target system for vertical isolation (once integrated with suspension)

Suspension Prototypes

Transfer of GEO double pendulum to MIT Lab

- fused-quartz system with masses comparable to LIGO II
- requires vertical compliant member
- requires instrumentation for testing



Separate test setup

- in Phase Noise Interferometer tank
- allows early start
- allows 'dirty' tests and instrumentation

Measurement of transfer functions, cross coupling

- looking at particularities of fused quartz connections
- difficulties/improvements in static alignment strategy

Charge monitoring and control

- need to track static charge and time varying charge
- electrometer with oscillating probe near surface
- will probably need means to discharge in situ, non-destructively
- ultraviolet probably not permissable solution

System tests

Once design well developed, need end-to-end testing

- tests of modifications of interfaces to LIGO Seismic Isolation
- acquisition with coupled cavities; alignment control
- noise performance

Complete LASTI to enable this research

- isolation systems in Test Mass Chamber, HAMs
- active isolation customized for suspension, isolation designs
- fabrication of suspension systems

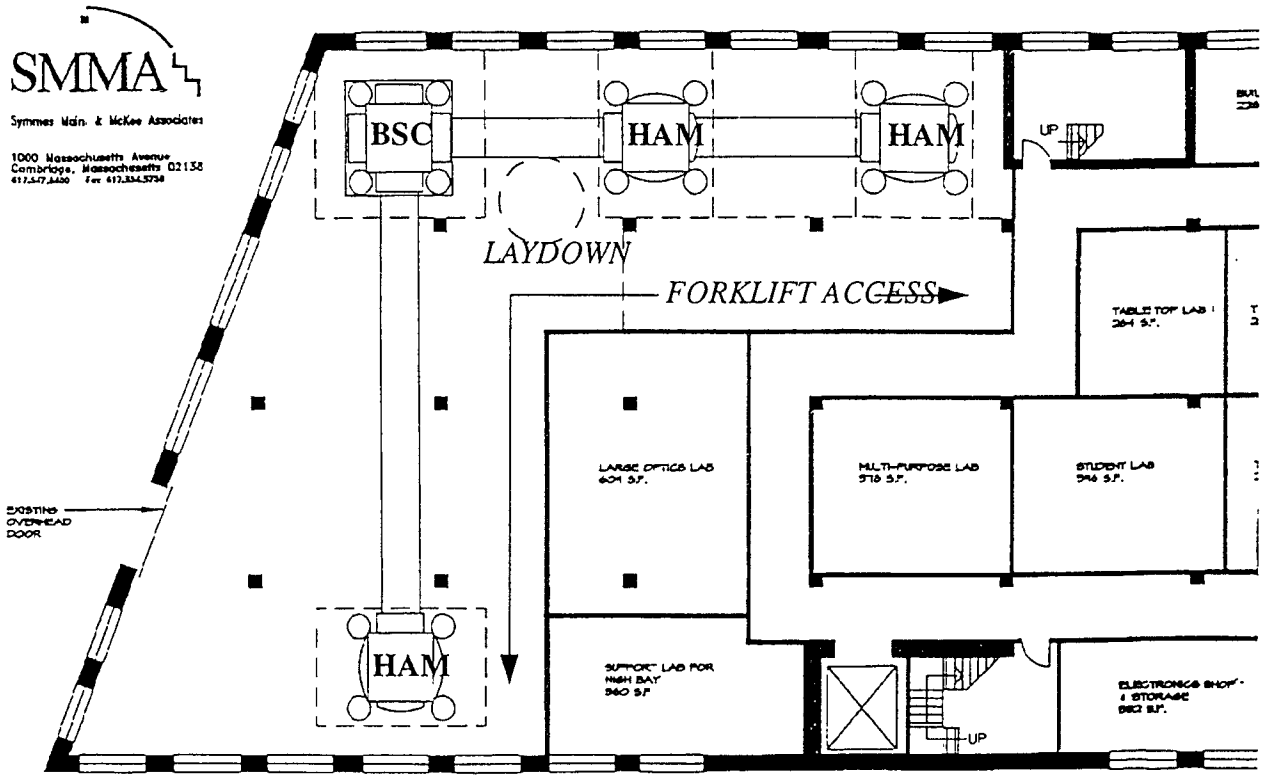
Tests as required to qualify design

- transfer functions
- control issues: length [distribution of authority], alignment
- thermal noise (upper limits---small laser beam diameters)
- internally-generated noise
- installation problems/procedures
- reliability

Any optics/configurations issues

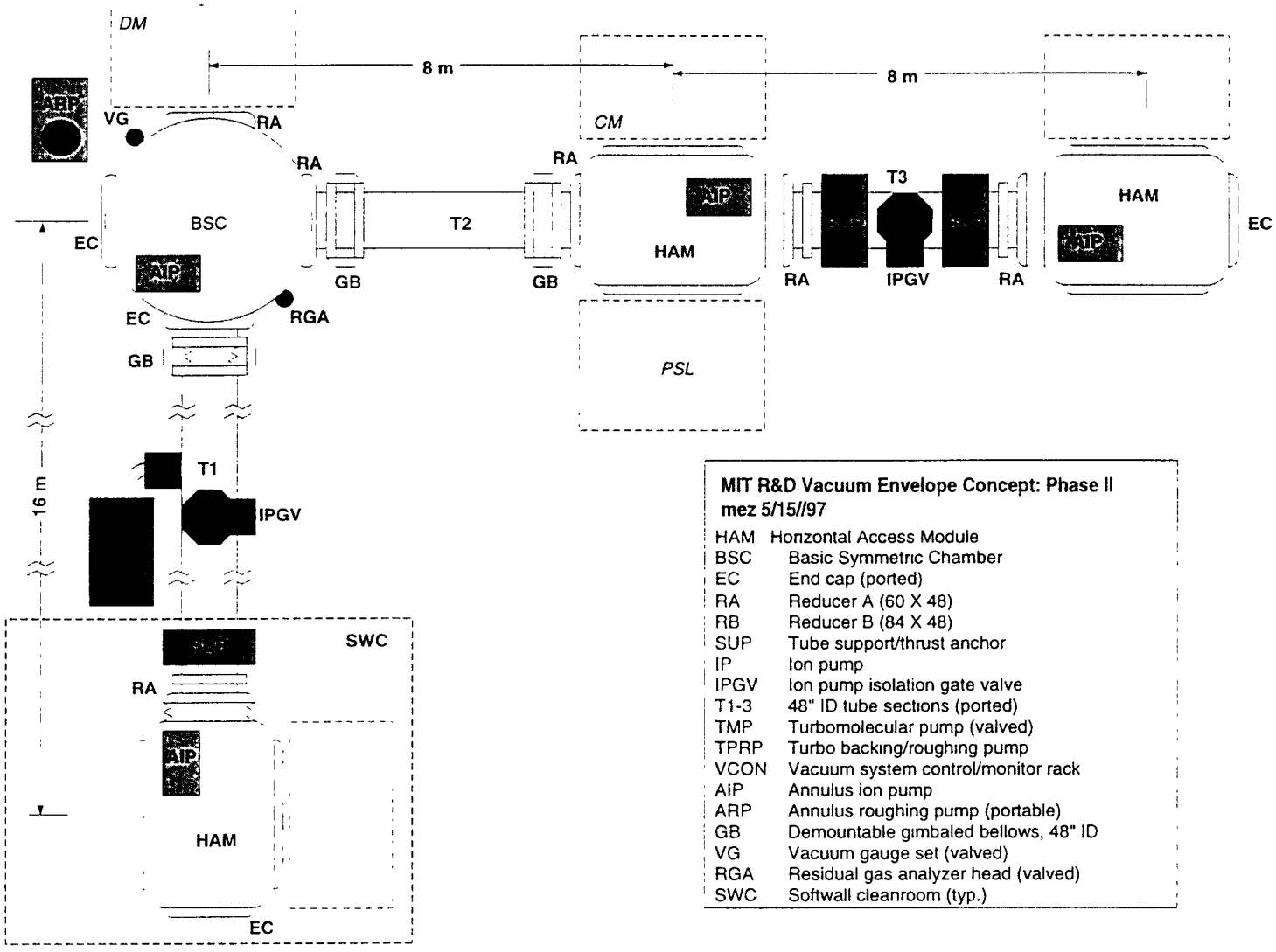
- as lab, LSC see appropriate

Test Interferometer



- Shown in place in new MIT Lab high-bay
  - › overhead clearance ~4' less than LIGO sites
  - › would require segmenting Test Mass Chamber cover for internals of maximum height; PSI sees no problem
  - › no problem with LIGO I/II seismic installation
- overhead crane for manipulating covers, tops
- control room, supporting labs on same floor
- staff, visitors' offices on two floors above

Vacuum system layout



MIT R&D Vacuum Envelope Concept: Phase II
mez 5/15//97

HAM	Horizontal Access Module
BSC	Basic Symmetric Chamber
EC	End cap (ported)
RA	Reducer A (60 X 48)
RB	Reducer B (84 X 48)
SUP	Tube support/thrust anchor
IP	Ion pump
IPGV	Ion pump isolation gate valve
T1-3	48" ID tube sections (ported)
TMP	Turbomolecular pump (valved)
TPRP	Turbo backing/roughing pump
VCON	Vacuum system control/monitor rack
AIP	Annulus ion pump
ARP	Annulus roughing pump (portable)
GB	Demountable gimbaled bellows, 48" ID
VG	Vacuum gauge set (valved)
RGA	Residual gas analyzer head (valved)
SWC	Softwall cleanroom (typ.)

LASTI Seismic Isolation elements

Objectives:

- give LIGO-like environment for tests (LIGO II, possibly LIGO I)
- keep costs for re-engineering/startup minimal (add on to LIGO orders)
- not interfere with LIGO fab/install (put at end of queue)

BSC (test mass chamber):

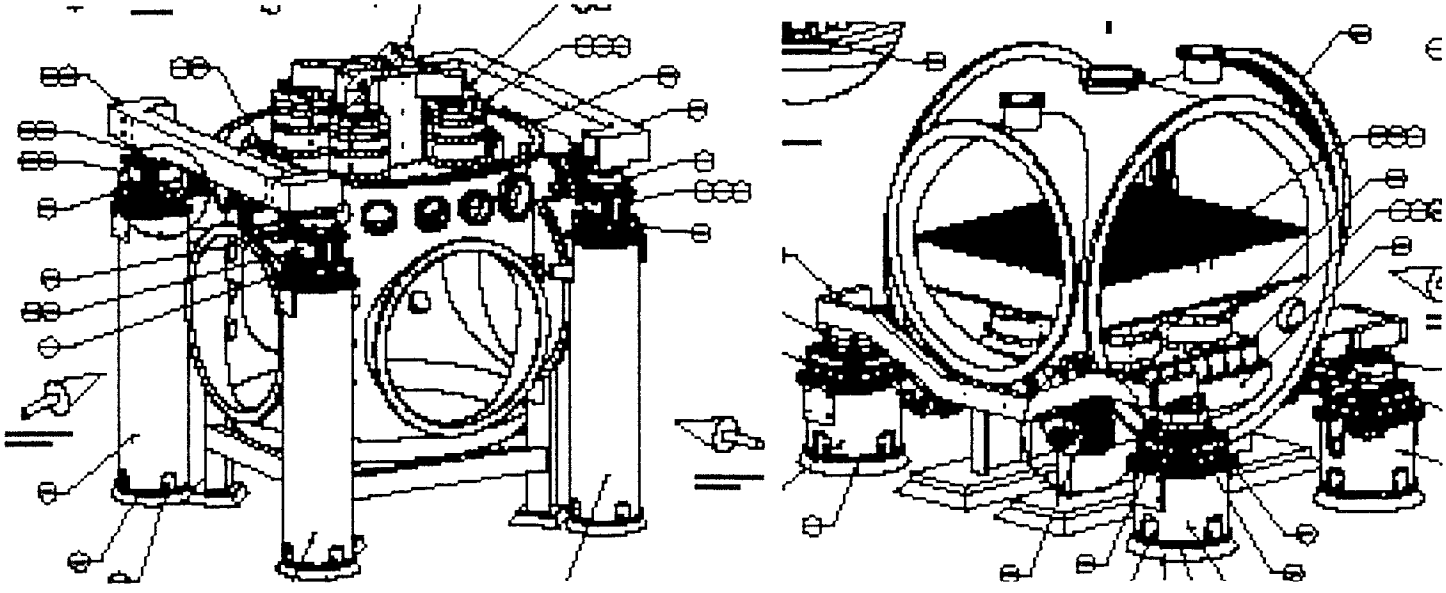
- complete support and isolation system, except
- no 'fine actuator' or 'coarse actuator' (replaced by IDE system)
- additional spacers to create headroom for multiple suspension

HAM #1:

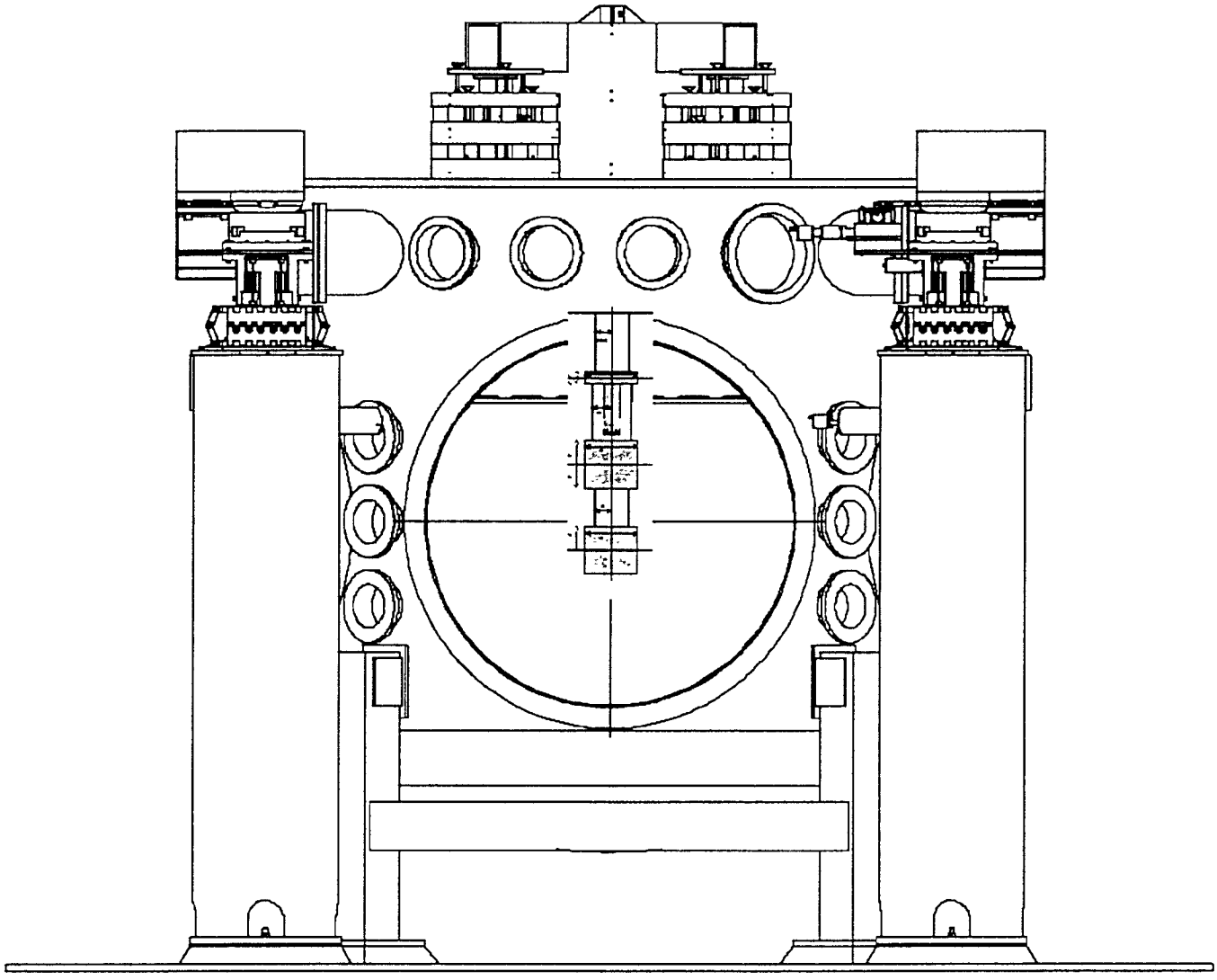
- complete support and isolation system

HAM #2, 3:

- complete support system and optics table; no masses, springs
- could retrofit if indicated, or substitute alternative designs



View of BSC, GEO Suspension



Scheduling/staffing

LASTI schedule tied to LSC Suspension development plans:

LSC Suspension Group	Epoch	LASTI
Top-level Requirements review	4th qtr '98	start envelope installation
Conceptual design; **Design summit**	1st qtr '99	complete envelope installation; start pier installation
Internal requirements, component research, configuration trades; **Preliminary Design Review**	2nd qtr '99	start seismic isolation installation; start prototype fab
	4th qtr '99	pre-isolation functional; start partial prototype tests
Component Prototypes; **Test Review**	3rd qtr '00	add isolation/infrastructure as needed for system tests
Fabrication of Engineering Prototypes	1st qtr '01	install engineering prototypes
System tests; **Final Design Review**	3rd qtr '02	...start to plan for LIGO III

Staff

- Joe Giaime (50%), Andrea Stolte (grad), post-doc (search), dhs
- Mike Zucker, tech help on vacuum envelope design/install/shakedown

State of the Art