



LIGO Laboratory

California Institute of Technology
 MC 18-34, 1200 E. California Blvd.
 Pasadena CA 91125 USA
 TEL: 617.395.2129
 FAX: 617.304.9834
 www.ligo.caltech.edu

LIGO Livingston Observatory
 P.O. Box 940
 Livingston LA 70754 USA
 TEL: 225.686.3100
 FAX: 225.686.7189
 www.ligo-la.caltech.edu

LIGO Hanford Observatory
 P.O. Box 159
 Richland WA 99352 USA
 TEL: 509.372.8106
 FAX: 509.372.8137
 www.ligo-wa.caltech.edu

Massachusetts Institute of Technology
 MIT NW22 – 295, 185 Albany St.
 Cambridge MA 02139 USA
 TEL: 617.235.4824
 FAX: 617.253.7014
 www.ligo.mit.edu

Date:	<u>7 May</u> 2008	Refer to:	<u>L080047-01</u>
Subject:	Response to Systems PDR committee comments and questions regarding the Optical Layout and Generic Subsystem Requirements		
To:	Advanced LIGO Systems PDR committee		
From:	Peter Fritschel, Dennis Coyne		

With change tracking from version -00 indicated.

Optical Layout, T010076-02

1. (all); Septum windows are variously also referred to as “Brewster” windows; this is confusing as it is not likely we will place these optics at Brewster’s angle. (MZ)

A decision on whether the windows in the septum plate for AdL will be at Brewster’s angle, or not, will be made at the AOS Preliminary Design Review scheduled for 6/13/2008. (References to Brewster’s windows are in Figure 5 and section 4.5.3)

2. I have some problem with the name of this document “Optical Layout for Advanced LIGO”. First, it doesn’t really present an optical layout, for example, I can’t find recycling cavity lengths in here, which I would expect to find in a real layout. A better title might be “Requirements and Constraints for the Optical Layout of Advanced LIGO”. (I know that the recycling cavity length is available in T080078, but the point of this comment is that when I pick up a document called the optical layout, I expect to get real information about the positions of optics.) (SW)

OK. We will re-title, or combine the two documents.

3. Speaking of titles, I think it is a mistake to have multiple documents (of the same class, in this case T) with the same title. Ref 19 has the same title as this document “Optical Layout for Advanced LIGO”. It can lead to conflicts and confusion. Inside the document, it is a mistake to refer to documents in the text using slangy descriptions that don’t look at all like the real title. Ref 19 is an example of this, referred to in the text as the “system conceptual design” but with the title in the footnote “Optical Layout for Advanced LIGO”. (SW)

Ref. 19 is simply the previous revision of the same document; By definition they must have the same title. The parenthetic “(system conceptual design)” was meant to convey the phase of the effort at the time that the document was issued, not its title. The reference will be removed to avoid further confusion.

4. The first order value of a document like this is that it pulls together the entire layout, ensuring that all parts interface properly and do not interfere. Higher order considerations may make it right to exclude some parts (such as the OMC), but such exclusions should be justified. There should also be some evidence that there is a well-controlled interface between the excluded subsystems and the included ones. (SW)

Section2: Are the interfaces for excepted chambers sufficiently well specified? (all types of interface) (KS)

Good point. You are presumably referring to section 2, "scope" in which it is pointed out that the HAM1/7 and HAM6/12 chambers (ISC in-vacuum optics tables) as well as the PSL/IO table and the ISC exo-vacuum tables are not part of the scope of the document at this time. This is in part due to the fact that ISC has only just gone through a conceptual design review and does not yet have layout designs for these optics tables. However, we do know which beams are going to which tables and where these beams are at the natural interface of the septum windows. In addition the IO group is intimately involved in defining the layouts for the input section. As the design progresses in the final design phase, the integrated layout will include or reference the layouts to these other tables. If referenced, then the beam height, size, direction, etc. will be defined at the interface points. The scope statement will be revised accordingly.

Interfaces for these excepted tables are defined (to the extent practical and needed at the preliminary design level) in appropriate subsystem requirements documents. For example the IO PDD (T060269-02) lists optical, mechanical and cooling water interfaces to PSL in section 3.1, optical and electrical interfaces to ISC in section 3.3, etc.

5. Section 4.4 Signals: The labels in the text do not match Figure 3, for example, in 4.4.5 there is mention of ITM_x, which is not shown on the figure (also it is a little ambiguous whether ITM_x is just the ITM on the X arm or generic for ITM{another character}). Similarly 4.4.7 has optical signals PTX and PTY which are not on the Figure. Please go over this section carefully and fix.

OK. (By the way, ITM_x means the ITM on the x-arm, consistent with the figurative sampling of the back reflection from the ITM on the the x-arm.)

6. Page 12, There is a very nice paragraph which explains that the AOS Conceptual Design Document is not correct. Please tell us your plans to correct this document.

There is no such paragraph on pg. 12. Perhaps you mean footnote 11 on pg. 14, which states: "A significant revision to this report, LIGO-T070062-03, including incorporating stable recycling cavities, will be released soon." Our plans are to release the AOS Stray Light Control (SLC) document (LIGO-T070062-03), revise and incorporate SLC elements in the optical layout (simultaneously) and conduct a preliminary design review of SLC by 18-Nov-2008.

7. Section 4.5.5 Please confirm that this system will be included in the Optical Layout.

We confirm that this system, once sufficiently defined, will be included in the layout. This will happen in the final design phase.

8. Get a LIGO number for Reference 15.

Done. The number is LIGO- L060388-00.

9. Table 1. I am surprised that there are so many Assembly or envelope drawing numbers that are TBD, including many for systems which have already been built for EnLIGO.

There is only one assembly listed with a TBD that was built for eLIGO, the Input Faraday Isolator. For this assembly the TBD should be replaced with D080250-00.

All of the AOS elements are at the conceptual design level and do not yet have drawing numbers assigned.

10. Page 20, why are there different drawing numbers for the OMC at LHO and LLO, given the first sentence of section 4.1.

The OMC units for eLIGO are prototypes. Lessons learned on the first were used to make small changes to the second. The LLO unit was based on using an existing cantilevered maraging steel blade design (and existing spare blades) for the IMC triple suspension. However, the mass of the OMC “payload” increased during the course of the design so that the blade design was no longer optimal. Since we needed to procure new blades for the LHO unit, a more optimal design was purchased. There were also some slight revisions to the upper suspended mass subassembly for improved assembly/alignment access.

11. Table 2: HSTS and HLTS are not defined in the document, as least as far as I can tell. In any event an acronym listing (as an appendix) would be a good idea.

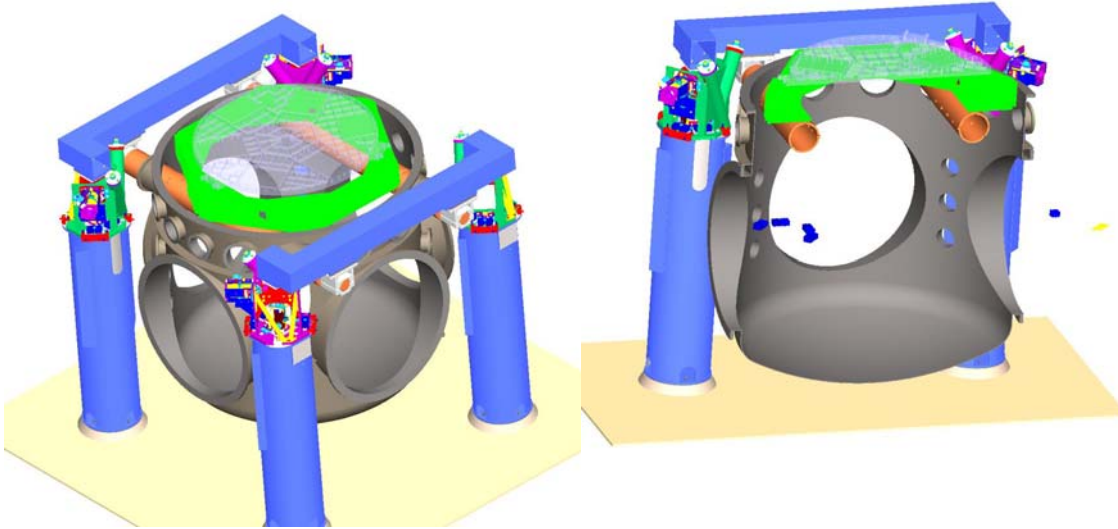
They are defined in Table 1. Nonetheless the suggestion is valid.

12. Caption for the second Figure 6a (which should presumably be Figure 6b). An optical Table will have four quadrants. If the Tall suspension cannot be placed in the four quadrants of the tables, then logically they cannot be used at all. I believe you have some specific exclusion regions in mind, but “quadrants” is not the correct word to use.

True enough; poor wording. There are restrictions in each of the four quadrants, but of course not the whole quadrant. This will be reworded to be clear.

13. Section 5.6 made no sense to me.

I can only guess that it is the second paragraph that is unclear. I suspect that the following images with a transparent BSC optics table in elevation makes clear the fact that the table limits are “hard limits” determined by the support tubes (orange) and the stage-0 support ring (green).



14. Section 6, I don't take a lot of comfort in the statement that the cavity layout in the IO preliminary design is reasonably close to the version in T080078. This seems to be another case where the distributed nature of the requirements statements may lead to confusion and errors.

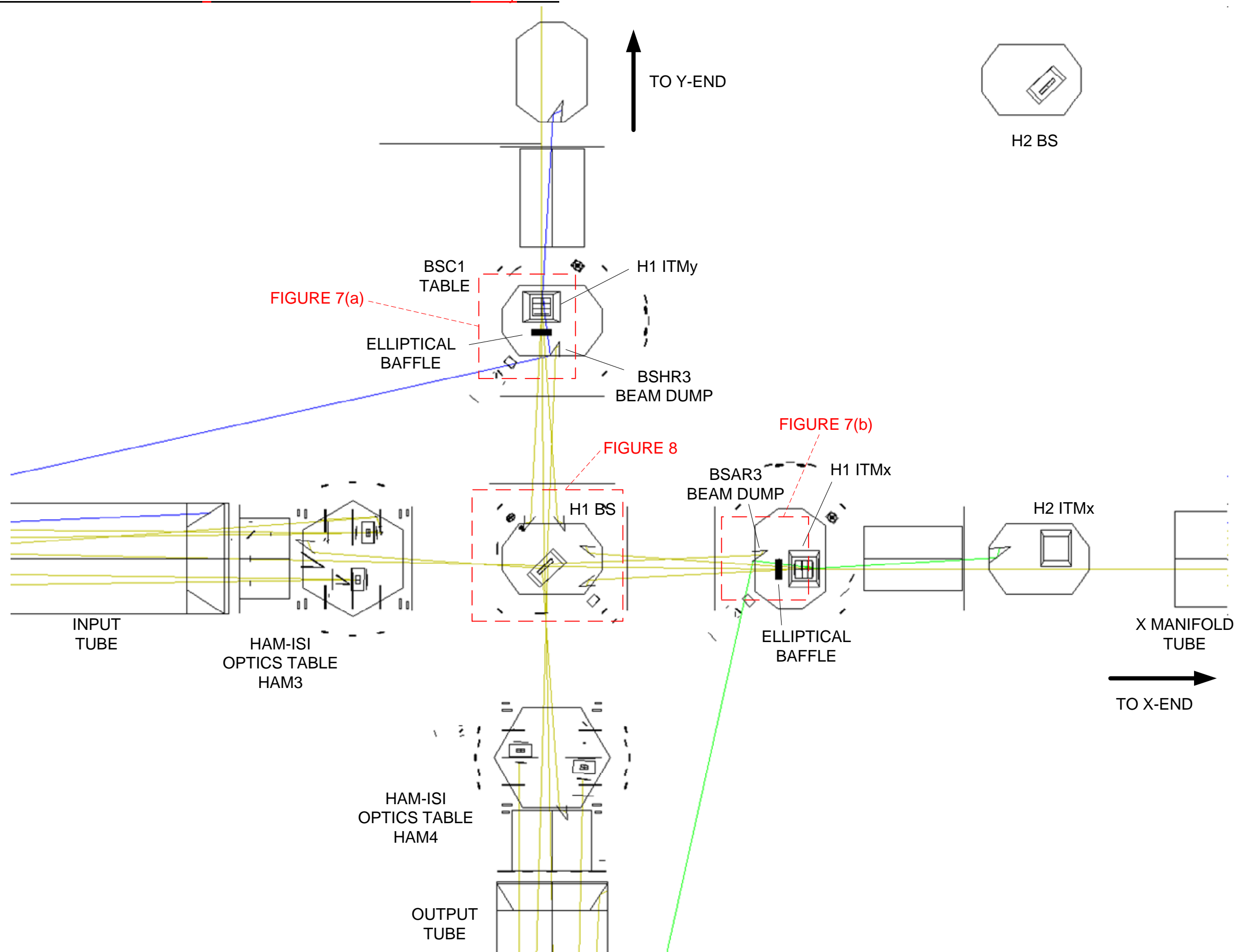
Quite the reverse; IO is performing redundant optical layout work for the input section, since this serves as a check on the overall integrated layout for the input section. The reason that there are differences is that the tentative lengths assumed by the IO group have been revised recently by the ISC as part of their design efforts for their recent CDR. (ISC has responsibility for setting cavity lengths.) AOS and IO are working together to insure that both agree on the layout details.

15. Section 6.1. Are these two independent optomechanical layouts? How are you making sure that they are in sync?

They layouts are not independent. Zemax uses envelope representations of the payload elements in 3D whereas SolidWorks uses the actual 3D CAD models used to create the drawings. Zemax determines the positions of the optics making rough checks that there are no interferences (physical or lines of sight). These optical positions are used to set the locations of assemblies in SolidWorks where more accurate checks of interference are made. In addition the Zemax optical rays are imported into SolidWorks.

16. Figure 7. show orientation. This figure is (for me, impossible to decipher).

The following figure will be added to the document. It shows the vertex section of the H1 interferometer layout and indicates where Figures 7(a), 7(b) and 8 are in the context of the overall layout.



17. Section 7. We need to hear from the system team how they plan to resolve these open design issues, what the schedule is for their resolution, and what systems are impacted by their outcomes.

- a) Astigmatism resulting from BS wedge: May require reduction of the BS wedge angle, requiring the layout to be "squeezed" a bit (reduction of a factor of ~2 is possible). Alternatively we might provide a compensating polish or astigmatic corrector in the recycling cavities.

Issue is now closed. Muzammil and Hiro have studied the effect. Muzammil using the modal model and Hiro using the FFT code. Causes a tolerable shift in Gouy phase and detuning for the intended BS wedge angle (0.8 deg). However it should be noted that there are other wedge angle options under consideration which need to be concluded soon (see item (e) below).

- b) Definitively set the minimum FM and ITM separation: There is a RODA being prepared. We know that we can separate the FM and ITM suspension structures. However, we need to establish the minimum required separation distance so that the suspension envelopes can be finalized.

We have finalized the minimum separation between the FM and ITM. A Record of Decision or Agreement (RODA) is being prepared and should be completed (signed off) within about 1 week.

- c) Consider laterally shifted BSC-ISI design?: Given that the BSC optical layouts are less complex, less massive and less cluttered than originally estimated (no pick-off mirrors, no E/ITM outriggers), one could shift the BSC-ISI system laterally to reduce the required balance mass. This change could add some small additional Schnupp asymmetry range, but reduces the total available optics table area. The reduction in stage 2 mass may also increase the influence of the E/ITM structural resonances on the ISI control. This change would require a redesign of the stage-0 structure and the blade flexures for both stages.

Note that this is a lower priority trade-off consideration; We have a design that appears to work and the benefits of this change do not appear significant. We need to make a determination in time to support the SEI PDR scheduled for 18-Jul-2008; A decision should be made by at least mid-June to allow SEI to consider the likely changes to be pursued in the final design phase which ends 6-Jan-2009.

- d) Resolve whether outriggers are required for the BS and FM suspensions
A revised finite element model approach will be undertaken soon (and completed before the end of May 2008) by the UK group to validate their model/approach against the LASTI coupled quad suspension and BSC-ISI platform. In addition, a BS/FM structure prototype is being fabricated currently at RAL. This unit will then undergo structural dynamics testing (to be completed in May 2008) to determine if the structure without the outriggers is stiff enough.

- e) Define acceptable wedge angle tolerances and/or evaluate the layout for realizable tolerances.

We must first finalize the basic layout before considering wedge angle tolerances. We originally set the wedge angles for the ETM/ITM to be vertical in the ICD (1.1 deg TBC). With further work on the layout design, we are now able to implement an all-horizontal beam solution with the stable recycling cavity, but with 1.3 deg ETM/ITMs. However this may present problems for the quad suspension design which is quite advanced (we are currently conducting an E/ITM FDR and Fab readiness review). The principal issue is accommodating relative yaw between the main and reaction chains. We plan to explore an alternate approach using quite small horizontal wedge angles (~0.1 deg) wherein the ghost beams are dumped into the arm tubes in one direction and separated by the mode-matching telescopes in the opposite direction. Our target date for finalizing the ETM/ITM wedge angle is within the next ~two weeks (longer causes a day-for-day slip in the E/ITM mechanical parts procurement for the UK and risks their program extended beyond their project end date). Our target for finalizing all COC wedge angles and wedge angle tolerances is late Jun-2008 to support the COC FDR.

- f) Seismic Platform Interferometer: Resolve the approach to be used for an arm length stabilizer system for lock acquisition. Implement in the integrated optomechanical layout.

See the response under the Systems Design Document question on the same topic.

- g) Refine and complete the detailed 3D layout in SolidWorks™ to insure that there are no interferences. To date most of the layout has been done in Zemax™ using simplified 3D representations of the payloads and infrastructure.

SolidWorks models of the installed assemblies in the input optics sections as well as some of the BSC chambers have been built. We expect to complete the initial full SolidWorks layouts by late summer at which point they will go into a maintenance/update mode. They are useful even now in support of subsystem assembly design to address fit, interference and line of sight questions

- h) Reduce the Optical Lever quantity or scheme (currently trying to monitor every suspended optic) to a more practical approach.

Optical levers are an AOS responsibility, which is by necessity closely coordinated with IO for layout implementation. The capability to diagonalize the suspension controllers used for cavity length control is important and enabled by optical lever systems. The angular stability of the other suspended optics can be monitored by using their OSEM sensors together with an optical lever used to monitor the HAM optics table. A decision will be made by the time of the AOS Optical Lever CDR which is scheduled for 22-Sep-2008.

- i) Revised ETM Hartmann Sensing approach: The AOS/TCS group has an alternative wavefront sensing approach under evaluation for the ETMs. Instead of a Hartmann probe beam reflected off of the HR surface of each ETM, a **two-point optical lever system (points separated by ~ the beam diameter at the optic center)** would be used plus a temporary Hartmann sensor used to probe the ETM HR surface through the AR side.

The baselined TM Hartmann sensing approach seems to us to be 'overkill'. We are basically just looking for radius of curvature information. This alternative (or possibly just a beam

diameter sensor) would reduce cost and complexity. The TCS group will propose the alternative for review at their PDR scheduled for 8-Aug-2008.

- j) Determine if the **vacuum-manifold arm cavity** baffles are sufficient to address high angle backscatter from the test mass optics.

The arm cavity baffle intercepts scattered light out to ~40 deg. A determination of whether baffling measures need to be taken for light scattered from the test mass at angles > 40 deg, will be made on the basis on measurements of the high angle scatter from iLIGO spare test masses. Analysis of these BRDF measurements will determine whether the BRDF of the chamber walls (with amplified ground motion) is sufficient or whether lower BRDF surfaces, possibly isolated by a simple pendulum (like the arm cavity baffle) are needed. This work will be accomplished by the Stray Light Control (SLC) PDR scheduled for 18-Nov-2008, or shortly thereafter as an update to the PDR. (The SLC FDR is scheduled to be completed by Dec-2009).

18. 4.5; The layout is complicated and frighteningly interconnected. Can Systems provide brief rationale for some of the less obvious "auxiliary" beam real estate drivers, e.g., Hartmann sensors, photon calibrator beams, Faraday rotator diagnostic beams, and SPI beams? For each, is there a persuasive sense that overt and hidden costs (viewports, mechanical resonances, complications to scattered light control, vacuum loads and particulate cleanliness) have been evaluated and are outweighed by added functionality? (MZ)

The auxiliary optical signals are as follows:

- a) CO2 heating beams for the Thermal Compensation System (TCS): obvious and limited to only the compensation plates
- b) Hartmann Wavefront Sensing Beams for TCS: The most significant thermal aberrations are in the ITM/CP pairs, and dedicated sensors to determine these aberrations are critical to effective feedback control. By contrast the phase cameras will determine the overall effect on the interferometer, but do not (directly) determine the contribution from a single ITM/CP pair. The usefulness of wavefront sensing monitors for the HR faces of the TMs is less beneficial; a radius of curvature sensor might be adequate (see comments under 17.i).
- c) Optical Lever Beams (OptLevs): perhaps obvious, but also see the comments under 17.h
- d) Ghost Beam and scattered light control: obvious
- e) Seismic Platform Interferometer (SPI) beams: The main aim of the system is to reduce the test mass arm length fluctuations by a factor of ~100x in times scales of up to a few 10 of seconds, to aid in the lock acquisition. An initial goal for the residual arm length fluctuations is ~1nm in these time scales. Experience in iLIGO indicates that reduction in the number and duration of lock losses and reducing the time to re-acquire lock would be beneficial. Moreover, when AdL is in high power operation, loss of lock will cause a thermal drift from the optimal, compensated condition and require a comparable amount of time for the TCS system to re-establish the compensated condition.
- f) Diagnostic beams for the thermal-birefringence, compensated Faraday isolator: a few small diameter beams that require a few small fixed mirror mounts to send beams through shared windows to either the HAM1 optics table. Further bench and eLIGO

testing will determine if there is value in having these beams, but the costs are minimal.

Generic Requirements, E010613-02

1. 1.4.2; Given the number of superseded/revised iL standards, it might be reasonable to incorporate the revised standards in this document itself. The proliferation of modular policies and specs which have overlapping domains (e.g., configuration management plan, DCN/ECN, documentation requirements, drawing requirements, ...) seems an impediment to coherent maintenance. (MZ)

I respectfully disagree. Maintaining a document that spans all domains from software to welding to EMI is too comprehensive to manage and maintain in a single document; this requires the coordination of multiple authors maintaining sections of a common document. I would prefer to assign ownership and maintenance responsibility to individuals for specific cited and useful documents. This is in fact already the case for many of the useful and cited documents. The Generic requirements document will eventually (and currently does to some extent) point to relevant documents and will include only items not meriting a separate document.

My plan is to weed out all obsolete documents from the DCC. This can be done by explicitly issuing a new single page revision to an obsolete document to stating that it is superseded by document "X", or that it is simply no longer applicable.

2. Along these lines, a schematic Specification Tree would really help orient engineers and scientists needing to determine which specs (and which versions thereof) apply to a given task. Incidentally, it would also help reviewers evaluate compliance. (MZ)

Systems should not define which requirements are applicable; this is the scope of the subsystem design tasks. For example, we can't pre-determine if a part will be welded and therefore must comply with a welding spec. Each subsystem is required to use the Generic Requirements Document to guide them in preparing a list of applicable specifications and requirements. For example see the Universal Suspension Subsystem Design Requirements Document, [T000053-04](#).

3. 3.7.1; I am concerned we are over-specifying welds, at significant potential cost. Recommend Systems and the VRB jointly review experience to date and determine if Class A is a relevant criterion for AdL aluminum alloy applications (OTOH current specs seem reasonable and appropriate for stainless steel). (MZ)

I too am concerned. However, I reduced the requirement to a demonstration of meeting Class A for only weld samples indicative of the welds to be performed and then visual inspection only from that point forward on the production weldments. This is close to the approach used for qualifying the iLIGO SEI aluminum weldments, where samples were examined by x-ray radiography and optical microscopy (of etched and polished cross-sections). For more history and information see the [welding wiki page](#) and linked references. However, I have taken you up on the offer to have the VRB review the welding requirements (I've asked the VRB to review the weld quality specification today in L080046-00).

4. 3.9; We have pursued numerous ad hoc approaches for lubricating clean fasteners in vacuum but continue to suffer from assembly galling, particulate generation, and

strength/modulus compromises. Maybe we should open a task to systematically research and develop a generic “substitute bolt lube” process or set of processes, rather than beating against the problem anew with each assembly task...? (MZ)

Good point. We have samples of [Nedox](#) (a solid lubricant), Tungsten carbide/carbon WC/C ([BALINT C](#)), TiCN ([BALINT B](#)), krytox and Barrierta IS (both low vapor pressure greases) in the queue. (Nedox failed the optical contamination cavity test the first time, but this may have been due to other causes.) In addition I have requested the VRB (in L080045-00) to consider setting limits on the percentage of high vapor pressure elements in metallic alloys which might permit some additional materials into the vacuum system (some brasses, bronzes, phosphor-bronze, etc.)

5. 3.12.2; Somehow the bar code/inventory/tracking stuff ended up in Facilities (?!). I don't understand this; it seems squarely a function of Systems and Project Management. From what I have seen there are also no concise requirements. Can Systems at least specify (presumably herein) the basic functions needed, e.g., to support Configuration Control, Vacuum Compatibility, and other Systems mission elements? (MZ)

I agree that Systems or Program Management would be a logical location for placing the task of procuring/developing an inventory tracking system. However I can also see some logic in placing the effort in FMP since many of the inventory processing steps, control procedures, and storage, assembly spaces and tooling, which handles the inventory, are addressed by FMP. Certainly Systems should at the minimum have input to the definition of the requirements of the system. The draft requirements definition which I've seen (dated 5-Mar-2008) is insufficient/incomplete. I have not had sufficient time to develop a specification of basic requirements. Moreover, being a minimalist (and realist?) I am likely to define a system which falls short of the expectations of others (and perhaps the legitimate requirements of others). As a consequence some manner of review will be needed to canvas potential (or imagined) needs from the AdL managers. Whether the procurement/development of the inventory tracking/control system is under the auspices of FMP or under Systems is likely to matter less than insuring adequate input from all who can contribute properly to its definition. Perhaps the more important question is who is available and capable of working on the procurement.

6. 4.1; E960036 is pretty generic and I think in certain respects deemed “un-followable” by CDS. On the other hand E020986, though well-intentioned, contains a few draconian strictures that were later set aside. For example, no switching power supplies were to be allowed under any circumstances; CDS currently plans to use DC busses with properly shielded and filtered switch-mode terminal power conversion. For another, blind application of EMI feedthrough filters, without consideration of ground path reactances, rendered some legacy equipment dysfunctional and they had to be field bypassed. In the lawless iL Wild West provocative commandments helped motivate positive evolution, but as a working specification, this document should probably be retired. (MZ)

Admittedly the EMI, grounding and shielding section was a place holder. EMI requirements and a basic conceptual approach to EMI, grounding, shielding and DC power distribution will be addressed at the upcoming DAQ PDR scheduled for June 2008.

7. 4.2.4; (minor) Section doesn't seem to be finished (MZ)

This section addresses Commercial-Off-The-Shelf (COTS) modules and components. Cables, connectors, bolts/fasteners are covered in other sections. What other items are worth delineating? Lab & test equipment perhaps? Any input or advice from the committee would be welcome.

8. 5; It might be worth inviting Stuart's group to comment. The number of software authors having influence over front end code will presumably remain small, but arguably, even with the small and well-organized iL group, software configuration issues have caused more downtime than hardware nonconformance. Is this considered an exclusive CDS domain (delete the section...) or should Systems adopt and enforce standards (write it)? (MZ)

Incomplete section (KS)

Software is not in the exclusive domain of CDS. Software for AdL includes:

- o Near real-time code written by the DCS group (what was called LDAS for iLIGO),
- o Realtime (front end and data acquisition) and near-realtime (supervisory control) code by the CDS group,
- o DMT code by the LSC & the LIGO Lab,
- o EPICS scripts written by LIGO Lab,
- o Matlab-based LIGO Data Viewer and diagnostics code by the LSC, and
- o control laws will be written for "Bork-Space" by non-CDS members of the various subsystems (e.g. SEI, SUS, ISC).

Rolf is developing a manual for "Bork-Space" which will include guidelines and requirements for documentation and configuration control. Matt and Lisa developed some tools for auto-logging and updating scripts. Rolf is also in the process of updating the Software Development Plan (SDP) for AdL which will address configuration control, development procedures, testing procedures & requirements, and documentation requirements, for all of the aspects of code development cited above. CDS and DCS have not yet discussed the feasibility, or advisability, of adopting common practices and standards; Systems will encourage a dialog. Rolf plans to have an initial set of software standards and practices defined by the time of the DAQ PDR which is scheduled to complete by June 2008.

9. Section 3.9.1, In-Vacuum Fasteners, addresses in-vacuum requirements, but what about requirements for class B tooling etc., which may well be clean enough to require the same care with fasteners (think of recent problems with lower structure tooling)? (KS)

Good point. A subsection will be added on fasteners for Class-B clean hardware. There are additional options for Class-B hardware and tooling including the use of low vapor pressure lubricants if, and only if, they can be protected from migrating onto Class-A hardware; this will be pointed out.

Interface Control

1. There is no interface document, which is the most important document to allow subsystem design to proceed. How/when will that be done? Once again, I would say without this SYS is not yet at the preliminary design phase. (FR)

There is an interface document (although it is not complete) as well as RODAs (many of which address interfaces). In addition interfaces are also addressed by each subsystem in their design documentation, just as in iLIGO. The interface document can be found here:

<http://www.ligo.caltech.edu/~coyne/AL/Systems%20Site/ICD.html>

The Records of Decisions and Agreements (RODAs) can be found here:

http://www.ligo.caltech.edu/~coyne/AL/project_management/RODA/RODA_status.htm

An example of a subsystem document with interface definition is section 3 of the IO PDD:

<http://www.ligo.caltech.edu/docs/T/T060269-02.pdf>

Miscellaneous

1. T020034-01 is marked as draft - but that should be changed to final - perhaps an oversight (KS)

The "draft" designation on this document will be removed.