1. How does the IO subsystem meet the general requirements of any subsystem? This should be spelled out in a separate Preliminary Design Document.

A: Done, see LIGO-E070170-00-D, "Generic Input Optics Requirements and Standards"

» Covers all of the generic requirements laid out in Dennis's "Generic Requirements" document E010613-01

– Documentation and drawings, testing, transportability, safety, etc…

2. The Design Requirements Document needs a careful reviewing to update it…

Q: The Design Requirements Document needs a careful reviewing to update it…

A: Done, see http://www.ligo.caltech.edu/docs/T/T020020-02-A.pdf

- Obsolete stuff removed / repaired:
  » Active jitter suppression
  » RF readout
  » MC mass

- New scope added
  » IO baffles
  » PRM beam dump parking spot
  » Optical lever beam paths

- However, IO baffles, beam dump will be addressed in a 3rd PDD.
  » Materials issues: black glass, copper, stainless fail 40 W small beam test.
  » SiC is promising, testing underway

3-13,90: Several typos and mislabeling in the original PDR document should be fixed.

3-9 Several typos and mislabeling in the original PDR document should be fixed.
- Fixed in the new PDD.

10. Equation 7.1 is the equation for the transmission of a Fabry-Perot not a ring cavity.
- Right, fixed
  - » For s-polarized light, there's a $-\pi$ phase shift at each of 3 mirrors,
  - » Hence there needs to be an additional +/- λ/2 in optical path.
  - » Include reflectivity of MC2 and renumber mirrors.

11-13 More typos, mislabeling, significant figures in the original PDR document should be fixed.
- Yes, fixed

90. In Section 13.1.2.2, it is SUS not ISC who is responsible for providing OSEMs as well as other suspension electronics.
- Yes, fixed

14. Safety, hazard analysis and remediation not addressed. Can you say something about your plans to implement safety during installation?

A: It is our understanding that laser safety protocols and laser SOPs will be developed at the SYS level

- However, the IOO has specific safety issues.
  - » Laser power
  - » Magnet safety

- See Section 15 of LIGO-E070170-00-D "Generic Input Optic Requirements and Standards"
  - » Special plans for magnet handling, adoption of LLO High Power Test Laser Lab plans

A: Polarization control at the input to the MZ will be used as manual power control. During alignment, the set-up will be covered and locked and tagged to prevent adjustment.

> » Alignment of the upstream mirrors will be done by adjusting the PSL power down
> » PSL power locked in software

In addition, the laser power control at the input to the periscope will be disconnected to prevent remote adjustment
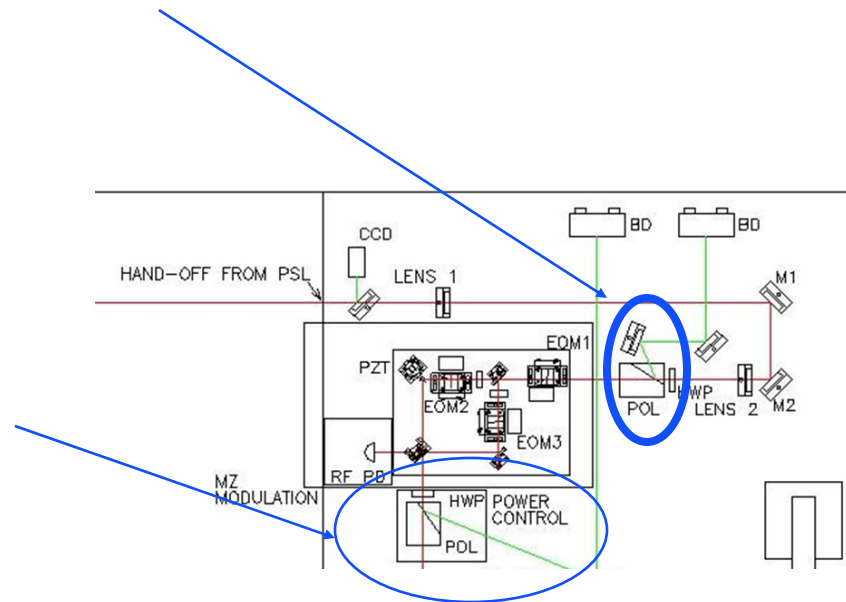
16. What plans are there to cover and control access to viewing ports which are mentioned for "observing" the laser?

- **Viewports will be covered for safety.**
  - » With appropriate material for the covers
- **Covers not in the IO scope.**
- **SYS should define whose scope this is.**

LIGO R&D
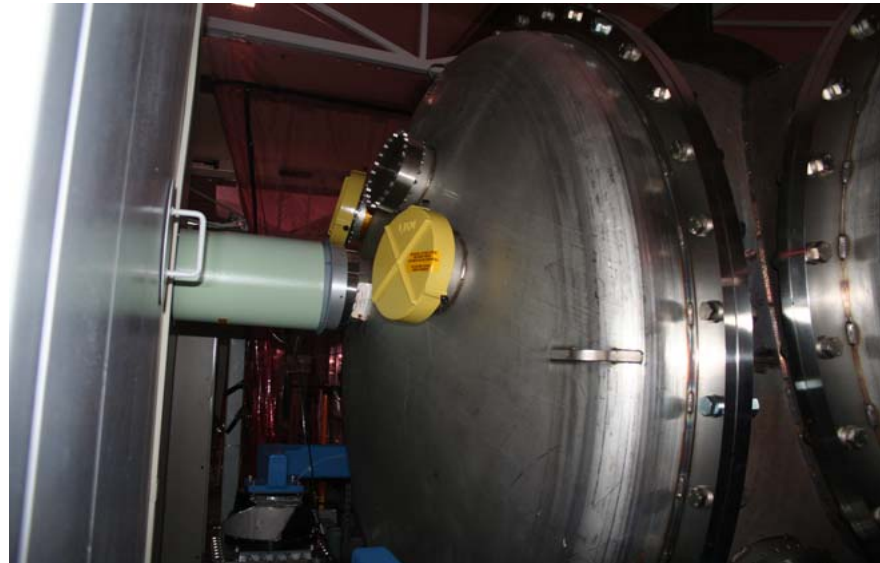
17. Where will heat be dissipated from beam dumps?
AND
87. In Section 3.1.3 can you specify the tube for water better than just giving the OD?

A: Specs:

» Beam dumps are water cooled
» Beam dumps can be connected to same water supply as PSL
» Flow rate: 0.5 GPM
» 3/8" outside diameter
» 1/4" inside diameter
» Poly tubing; NPT fittings

- **Specs are included in the PDR interface section**

18. Would it be better to have these alternate schemes in an appendix or possibly a different document?

➢ Yes, posted in an alternative document, with DCC number LIGO-T070197-00-R currently only available on the aLIGO wiki:

http://lsc-grid.phys.ufl.edu/ligo-uf/PDR/complex_modulation.doc

19. Has the spectrum of the driving pulses used been measured? Will the active drive units be shielded so that any pulses will not induce other circuits to ring?

A: This question was probably aimed at the complex modulation scheme.

- ➢ There are no 'pulses' in either MZ or complex-modulation
- ➢ MZ uses sinusoidal modulation

➢ Crosstalk and EM radiation will be investigated with the eLIGO modulators.

LIGO R&D

20. Will the Peltier controllers for temperature stabilization of the EOMs be PWM devices? If so, shielded appropriately?

**21. How reliable are Peltier cooler in vacuum?**

A: No Peltier coolers in vacuum

- Even though we will continue our investigations if temperature stabilization for the EOMs is needed, we will avoid PWM for the power control of the peltier current should the need arise.

22. Can you explain more why temperature stabilization of modulators is needed? Why is this not necessary in enhanced LIGO?

A: Initial designs showed temperature to RF/AM coupling but this effect is greatly reduced by the use of wedged modulator crystals.
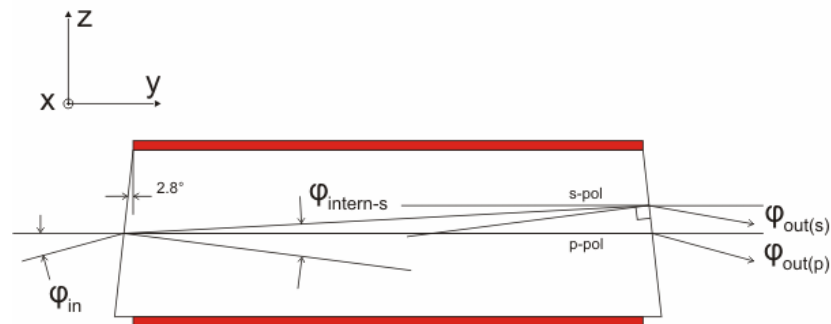
➢ Use eLIGO modulators to measure the remaining RF/AM and verify that a temperature stabilization is not needed.

23. Will there be time and are there plans to review EOM performance in enhanced LIGO before committing to its use in Advanced LIGO?

A: Yes, extensive testing of the eLIGO modulators with the eLIGO 30W laser is underway.

➢ Will look for:
  ➢ RF/AM,
  ➢ EMI spectrum at Ω_m
  ➢ Performance over time
    ➢ Degradation of transmission, mod depth
  ➢ thermal lensing
  ➢ PZT resonances

➢ The Advanced LIGO modulator design may be modified according to our results from these tests.

24. What plans are there for further work on the complex AM/PM modulation ?

A: We will follow up on this research but concentrate on the MZ for the baseline.

➢ The complex modulation scheme is an elegant solution to provide multiple sidebands pairs or single sidebands at with only two modulators, but it also presents some challenges for the stable realization. It is an option to upgrade to this scheme later.

Modulation

25. What is at the normally low power port in Figures 6.2 and 6.9, a photodiode or a wavefront sensor?

   » It's a photodiode

26. What happens when the Mach Zehnder falls out of lock, does 180 W get put on the photodiode? How would this be dealt with?

➤ The illustration in the PDR showed a simplified version of the setup.

➤ The light of the bright port of the MZ is sampled with a photodiode, therefore the PD always sees an adequate power level if the MZ is locked, and less light if it falls out of lock.
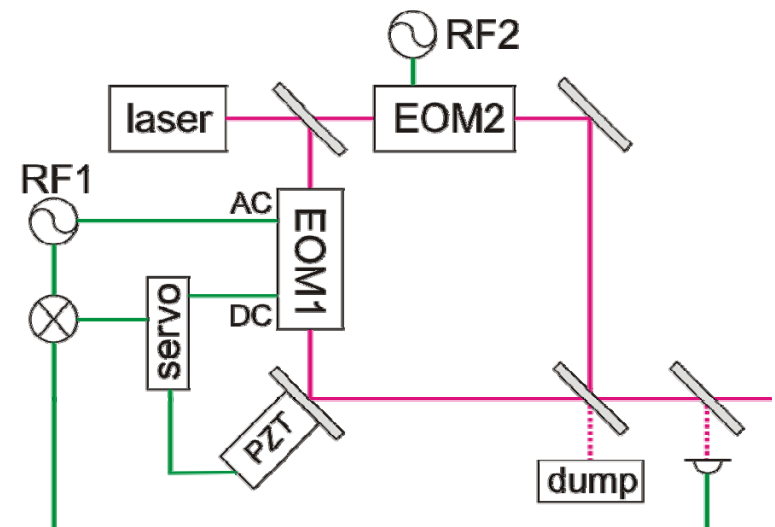
27. Has the experience with the Mach Zender modulation scheme at the 40 m been incorporated into plans for Advanced LIGO? If so, this should be discussed in the PDD, if not, why not?

A: Some input from Rob Ward

➢ The current weaknesses of the MZ at the prototype were analyzed and improved to the required level.

» Mechanical stability

» Quasi monolithic design

» Significantly higher unity gain frequency for length control

28. The modulation frequencies are now 9 and 45 MHz, contrary to Table 4.

- Table 4 removed, and these are listed as "nominal" freqs.
- See "Constraints on Advanced LIGO Cavity Lengths and Modulation Frequencies" LIGO-T070196-00-D.
- Spacing of HAM 2 and 3 and HAM 3 and the BSC's with the ITMs constrain the frequencies.
    1. For straight IFO, marginal recycling cavities a choice of 45 MHz for the second frequency requires the SRC to be 9.855 m in length, 229 mm *longer* than allowed by physical constraints in the SRC HAM.
    2. 63 MHz is lowest second frequency.
    3. For straight IFO, stable recycling cavities, frequencies of 9.4 and 47.0 MHz OK.
    4. For folded interferometer, marginal RCs, 27.8 and 65.0 are the lowest set.
    5. Without physically changing the separation of HAM2 and HAM3, the folded interferometer with stable PRC must be 18.5 and 64.7 MHz.
    6. Case of stable PRC and stable SRC for folded IFO still to be worked.
    7. Won't change conclusions 1-5 however.

29. Who is responsible for the Mach Zehnder servo electronics?

A: CDS will be responsible for fabrication

➢ IOO will be responsible for the design of the servo and provide interfaces and requirements for sensor/actuator signals.

30. What are the plans for pursuing the monolithic Mach Zender design? Is there still enough time to develop this? If the monolithic design isn't pursued, presumably there are improvements to the current design that could be made ... a low-expansion baseplate; vibration isolation; etc. What are the plans?

A: The current MZ design is currently meeting requirements.

- ➢ Needs some additional design work to integrate wedged crystals.
- ● Monolithic MZ will be pursued with lower priority.
  - ● Will be kept at a pace that allows for rapid prototyping in case the current MZ needs to be replaced.
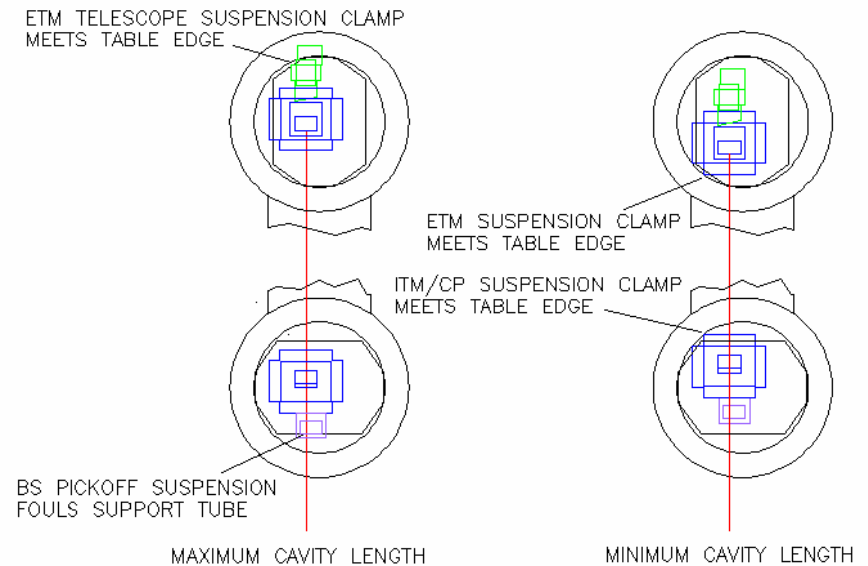
30. UV-cure epoxy might be a simpler option for the bonding, has this been explored?

➢ We have now plenty of experience with bonding glass to SuperInvar, Zerodur, and Silicon Carbide using hydroxide bonding. This technique is as simple if not simpler than UV-cured epoxy.
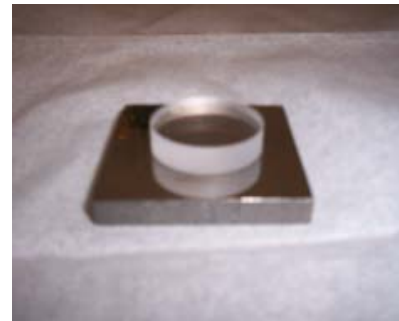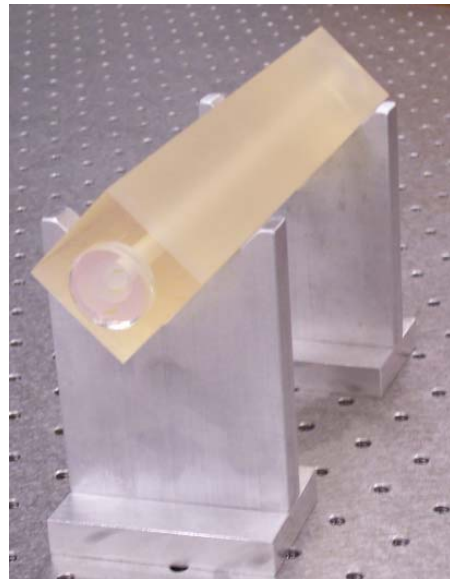
31. Is it correct, as said in Section 7.2.1 Constraints and Assumptions, that the arm cavities are adjustable ± 30 mm?

- There is a range of possible FP cavity lengths, depending on the Schnupp Asymmetry, and where the ETM and ITM suspensions are placed on their respective tables.

- For the straight IFO, and 200mm Schnupp, the length of the FP cavities is 3994744mm +/- 289mm.

- SYS has not determined a baseline FP cavity length

ETM TELESCOPE SUSPENSION CLAMP
MEETS TABLE EDGE

ETM SUSPENSION CLAMP
MEETS TABLE EDGE

ITM/CP SUSPENSION CLAMP
MEETS TABLE EDGE

BS PICKOFF SUSPENSION
FOULS SUPPORT TUBE

MAXIMUM CAVITY LENGTH   MINIMUM CAVITY LENGTH

32. Where does the requirement in Section 7.2.1 that the sidebands be 5-6 Hz away from maximally antiresonant in the arms come from?

- **This is a nominal value, used in initial LIGO.**
  - » Being near antiresonance helps keep sideband amplitudes balanced
  - » If exactly antiresonant, second harmonics of the sidebands, which exist for the high modulation index components, would resonate.

- Criterion is probably better stated as

$$\Delta f > FSR_{arm} / Finesse_{arm}$$

  or about 40 Hz

33. Will there be fiducial marks on the baffles to aid visual alignment of the beam onto the mirror? For example, when it comes to centering the beam, will marks on the baffles indicate where the centre of the axes are?

- **Good idea!**
- **Suspension mounted baffles will have fiducial marks for beam centering**
  - » Conceptual design ←
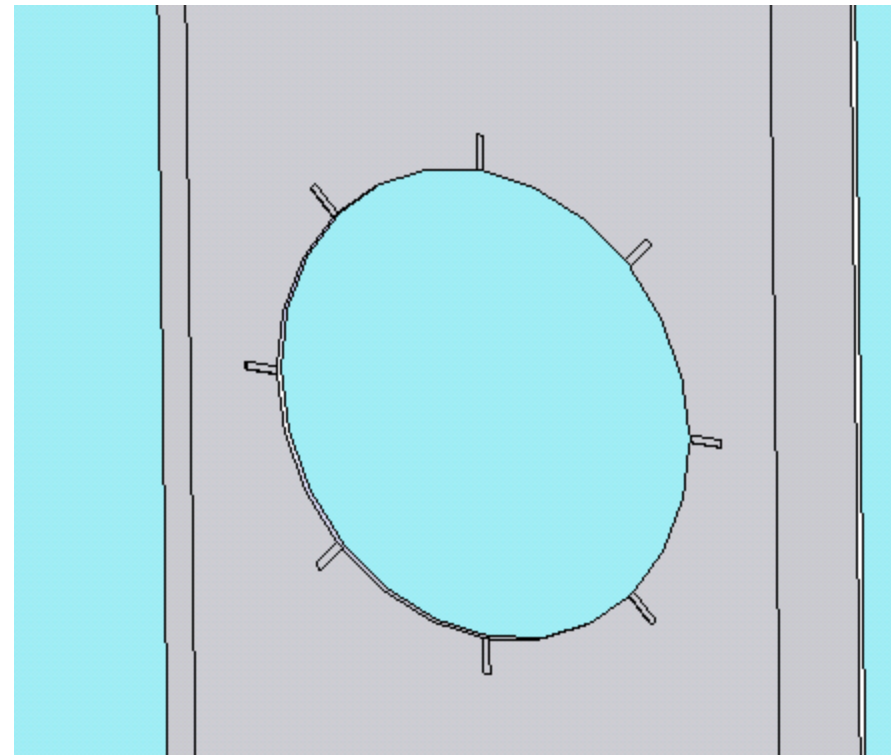
34. What are the normal modes of the MC cleaning baffle, HAM2 baffle and IO baffle? Has the mechanical aspects of this design been approved by SUS? Will these big plates cause low frequency resonances in the suspension structures? Who is responsible for the design and installation of these baffles?

- TBD

- Separate document on baffles and scattered/stray light control in IO system to be presented at later date.

G070591-00-D

LIGO R&D

35. What frequency noise is expected from scattered light off of baffles and other objects? Probably should be a section in Preliminary Design Document on errant beam protection, baffling, and scattered light, possibly like:

Sec 2.4 Beam Dumps and Baffles
3.10 Beam Dumps and Baffles
3.10.1 Errant Beam Baffles
3.10.2 Mode Cleaner, Cleaning Baffle
3.10.3 Parking Beam Dump

- TBD

- Separate document on baffles and scattered/stray light control in IO system to be presented at later date.

36. Should the requirements for the baffle material in Section 4.4.2 include high reflectivity?

- **TBD**
  - » Baffle design too immature to determine if they should be reflective or absorptive.

- **Absorptive reduces stray light, and prevents problem from being passed to new location.**

- **Reflective better for surviving intense beam**
  - » Testing on rough copper surface in vacuum indicates damage at < 50W
  - » Smooth surface survived

- **Candidate materials: copper, aluminum, stainless steel, and silicon carbide.**
  - » Silicon carbide may be the best candidate
    - – High melting temperature
    - – Good thermal conductivity
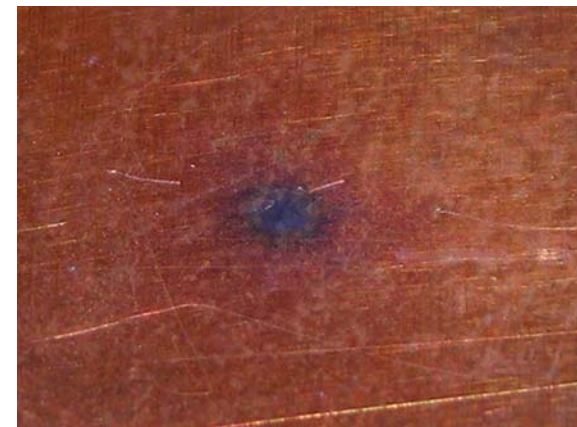
37. How is the aperture for the SOS baffle on MMT1 to be decided? It needs to be as large as possible and still protect the wires.

- **Aperture allows HR face access but protects wires:**
  - » Aperture is 50 mm in diameter
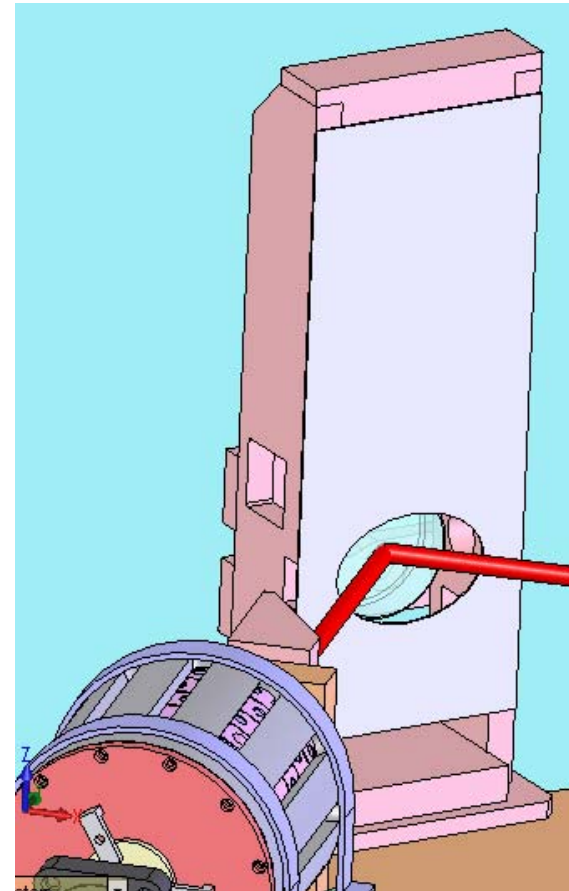
38. In Figures 4.15 and 4.16, where are the MC cleaning baffle and HAM 2 baffles placed, what are their apertures?

- The MC cleaning baffle and HAM2 baffle are placed on the table in HAM2

- In general, the aperture radius of <u>non-cavity baffles</u> will be set to the <u>25ppm</u> clipping level, plus 1cm for alignment purpose. This includes the HAM 2 baffle.
  - » **Will check to make sure that wires are protected**
  - » **To be done in IOO baffle PDR**

- In general, the aperture radius of <u>cavity baffles</u> will be set to the <u>1ppm</u> clipping level, plus 3 mm. This includes the MC cleaning baffle.

MC ERRANT BEAM BAFFLES

MC CLEANING BAFFLE

MODIFIED LOS BAFFLE

SOS BAFFLE

HAM2 BAFFLE
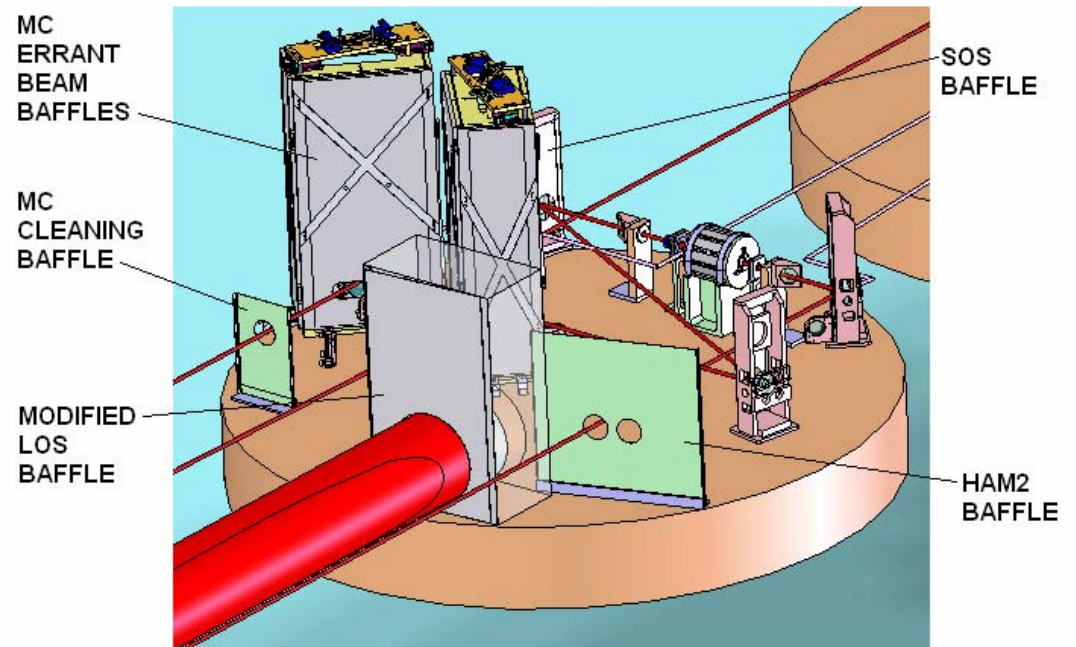
39. In Section 4.4.6, the IO baffle is is not part of IO, it is AOS responsibility.
Should all of the things that are not the responsibility of IO be put together rather than be distributed throughout the document?

- It's section 4.4.9 in the present doc.

- The picture of the IO baffle was included for completeness, because IO part placement will need to be cognizant of this large item.

- IO prefers to keep it in the baffles subsection.

40. Why was the scheme for adaptive mode matching changed from the CO_2 laser system to the ring heater?

Ans:

- RHs are much easier to design and implement
- RHs are much cheaper than CO_2 laser systems
- CO_2 laser system was designed to exploit the huge dynamic range available for adaptive mode matching if required due to thermal lensing in the core optics components.
- TCS will maintain arm cavity mode for IO to the nominal mode of 2076 m ROC and 6 cm beam size at the ITM.
- No need to install adaptive heating system on mode matching system because arm cavity mode will stay relatively same
- Provision is still in the design for future adaptive heating system

41. Why is the thermal compensation needs for the MMT not known well enough that a factor of 10 in absorption difference may be needed?

Ans:

- Not clear from question if MMT or MC substrate is meant

- For MC, the absorption is known and the value is 10 ppm/cm

- So, this might refer to BK7 that has a coefficient of thermal expansion that is 10 times more than fused silica

- This is done in order to exploit huge dynamic range available due to CO_2 heating if required in future.

42. What is the status of checking whether motion sensitivity on MMT_1 warrants a triple suspension?

- The requirement of beam jitter of the beam after mode cleaner in terms of TEM_{10} mode amplitude is given by:

$$|a_{10}| \leq 7 \cdot 10^{-9} \sqrt{1 + \left(\frac{230Hz}{f}\right)^4} \ / \sqrt{\mathrm{Hz}}$$

assuming a misalignment of 1×10^{-9} radian for the ITM (from: Beam jitter coupling in advanced LIGO, G. Mueller).

- At 10 Hz this leads to:

$$|a_{10}| \leq 3.7 \times 10^{-6} / \sqrt{\mathrm{Hz}}$$

- Mode cleaner supplies a suppression of 1/250, i.e., via

$$S \approx \frac{\pi}{2F \sin(1)} = 0.0004$$

42. Contd...

Contribution from Optics

$$\Delta\tilde{\phi}_x = \sqrt{\left|A\cdot\tilde{x}\cdot\tilde{\gamma}_x\right|^2 + \left|B\cdot\tilde{\alpha}\cdot\tilde{\gamma}_\alpha\right|^2 + \left|B\cdot\tilde{x}\cdot\tilde{\gamma}_{x\alpha}\right|^2}$$

$$\Delta\tilde{\phi}_\alpha = \sqrt{\left|C\cdot\tilde{x}\cdot\tilde{\gamma}_x\right|^2 + \left|D\cdot\tilde{\alpha}\cdot\tilde{\gamma}_\alpha\right|^2 + \left|D\cdot\tilde{x}\cdot\tilde{\gamma}_{x\alpha}\right|^2}$$

where $\tilde{\gamma}_x$ is the displacement transfer function (i.e., *x* to *x* coupling mainly), $\tilde{\gamma}_\alpha$ is the angular transfer function (i.e, yaw to yaw mainly), and $\tilde{\gamma}_{x\alpha}$ is the damping to displacement dependent angular motion (i.e, *x* to pitch mainly), and A,B,C,D are the ABCD matrix coefficents.

- The total beam jitter in terms of amplitude of TEM$_{10}$ mode with contribution from PSL and IOO is found to be $1.77\times10^{-6}/\sqrt{\text{Hz}}$ as compared to the $3.7\times10^{-6}/\sqrt{\text{Hz}}$ limit due to the ITM differential tilt limit.
- The total contribution is still a factor of two lower than the proposed limit.
- PSL noise is the main contributing noise source for the beam jitter and the SOSs used for the mode matching optics provide sufficient suppression.

42. Contd…

Table 1: Summary of the Beam Jitter Contribution from Noise Sources

Optical Component	Normalized Contribution	Individual Incoherent Contribution
PSL/MC	1	1
From three Steering Mirror	0.167405665	0.013915508
MMT1	0.053406638	0.001405587
MMT2	0.017634392	0.014068636
MMT3	0.225999332	0.026250352
Total		**1.040318987**

43. Why was a four segment ring heater design chosen, was it to compensate for astigamtic thermal lensing in the MC substrate? Would less substrate absorption remove the need for four segments, and might this be preferable?

Ans:

- Four segment RH design is flexible
- Does not require as much infrastructure
  - » Nichrome wires as opposed to CO_2 lasers and optical components
- Enables control of astigmatism arising from any component

44. In Table 15, is the value of 4 mm for the tolerance of the MC waist a typo? What is the correct tolerance?

Ans: Yes. The correct tolerance is ±20 μm. This is more than twice of the expected change in IMC waist size due to thermal effects.
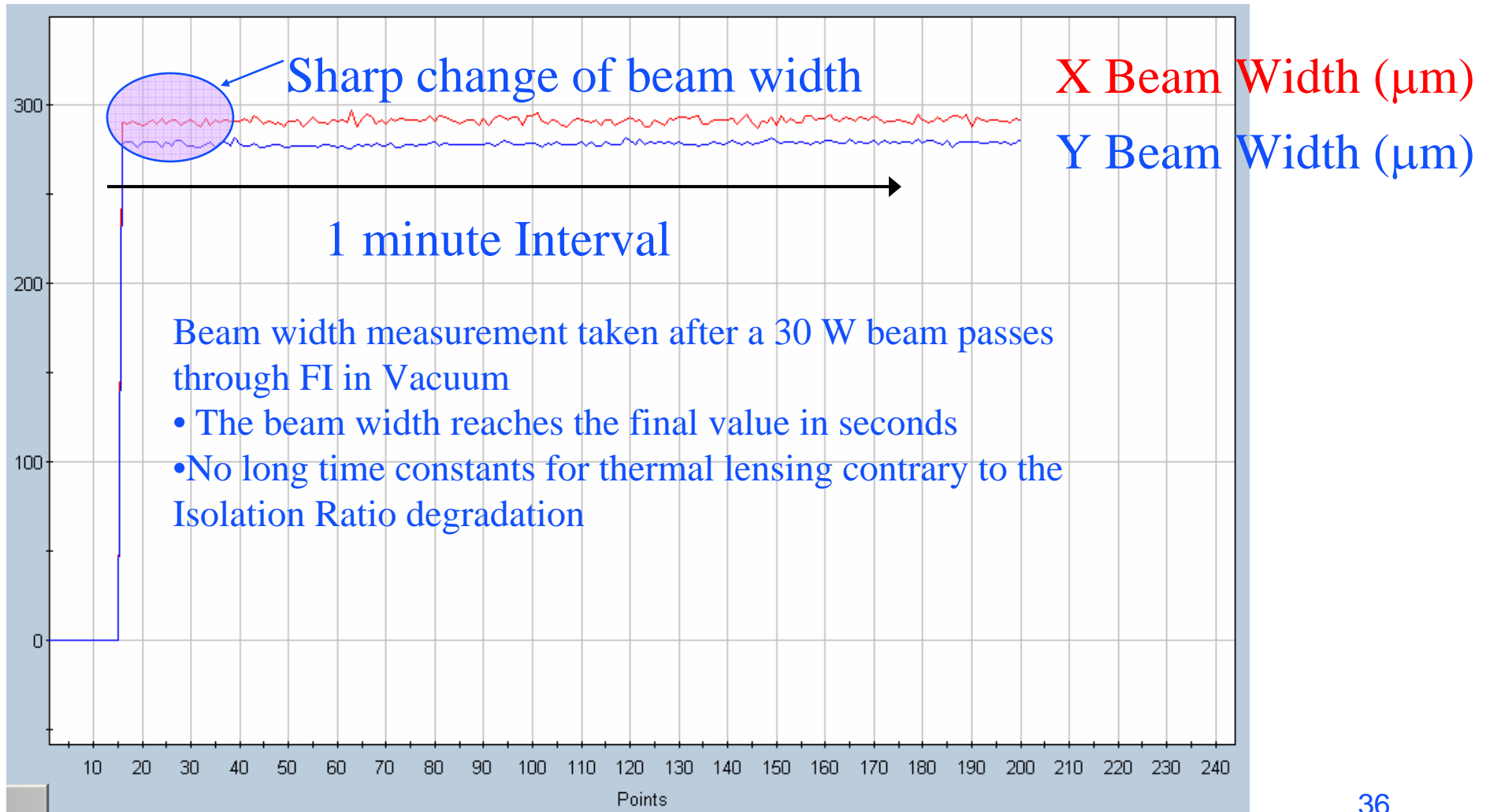
45. How fast will we be able to ramp the laser power and still maintain the mode matching with the adaptive beam control?
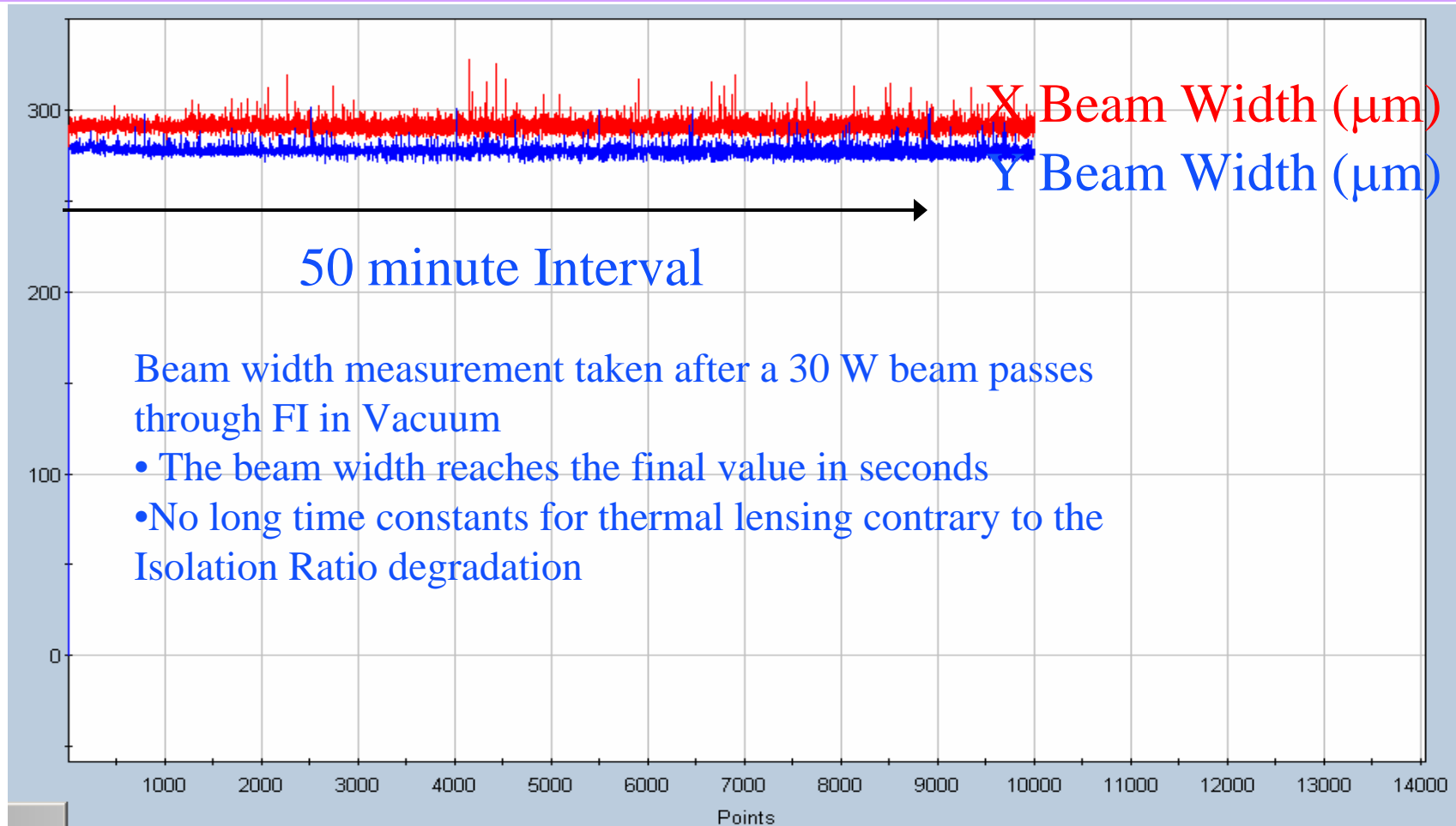
Ans:

- Mode matching changes due to dynamic thermal lensing
    » The thermal time constants for thermal lensing are in the order of seconds for both TGG and DKDP.
- This has been experimentally observed and predicted through FEMLAB analysis (see next slides)
- The transients due to mismatch in thermal conductivity of TGG and DKDP in connection with thermal lensing will last for few seconds
- Thus laser power ramp will mainly be dictated by the cavity dynamics and not the mode matching from IO
- TCS (or the arm cavity thermal lensing) may be the limiting factor in the ramp-up of laser power
- The MMT RH may have a servo around the electrical control that can effectively form a closed loop system

Sharp change of beam width

X Beam Width (µm)

Y Beam Width (µm)

1 minute Interval

Beam width measurement taken after a 30 W beam passes through FI in Vacuum
• The beam width reaches the final value in seconds
•No long time constants for thermal lensing contrary to the Isolation Ratio degradation

300

200

100

0

10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240

Points

45. Power ramp-up (Contd.)

X Beam Width (μm)

Y Beam Width (μm)

50 minute Interval

Beam width measurement taken after a 30 W beam passes through FI in Vacuum
• The beam width reaches the final value in seconds
•No long time constants for thermal lensing contrary to the Isolation Ratio degradation

TGG with radiation enabled on faces and edges

30 W incident power
Time from t = 0s to t = 60s with a line every 1s

FEMLAB analysis
Alice Ohlson, LLO SURF student
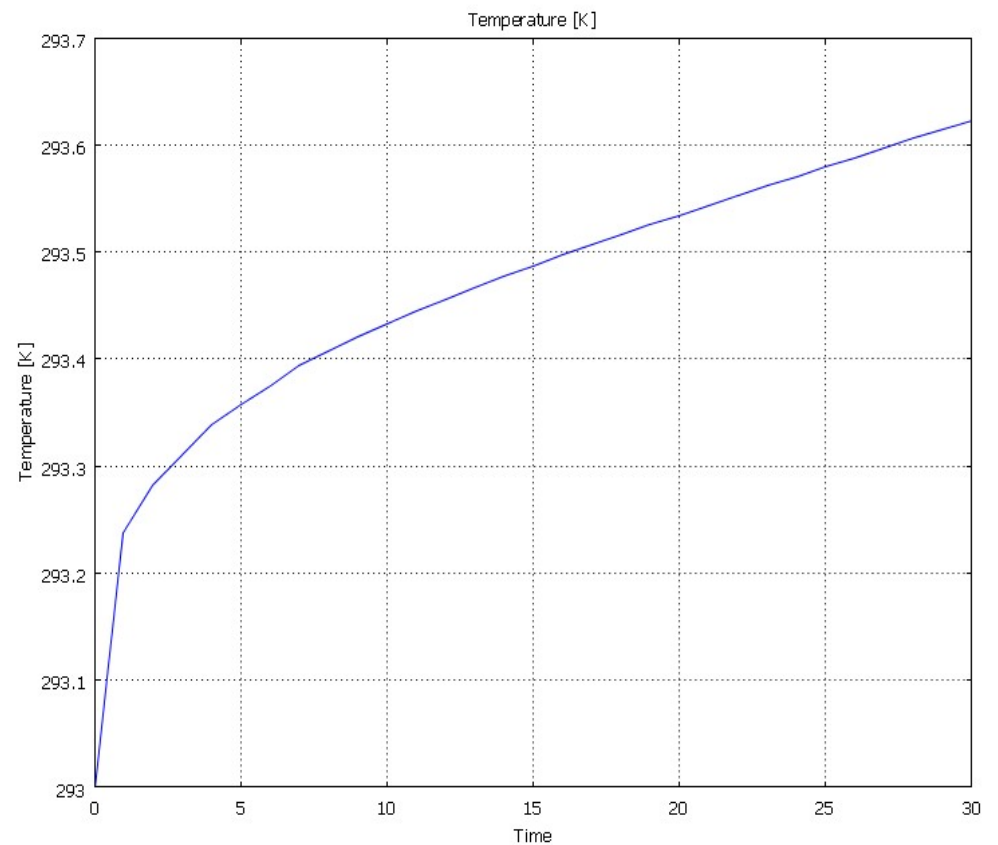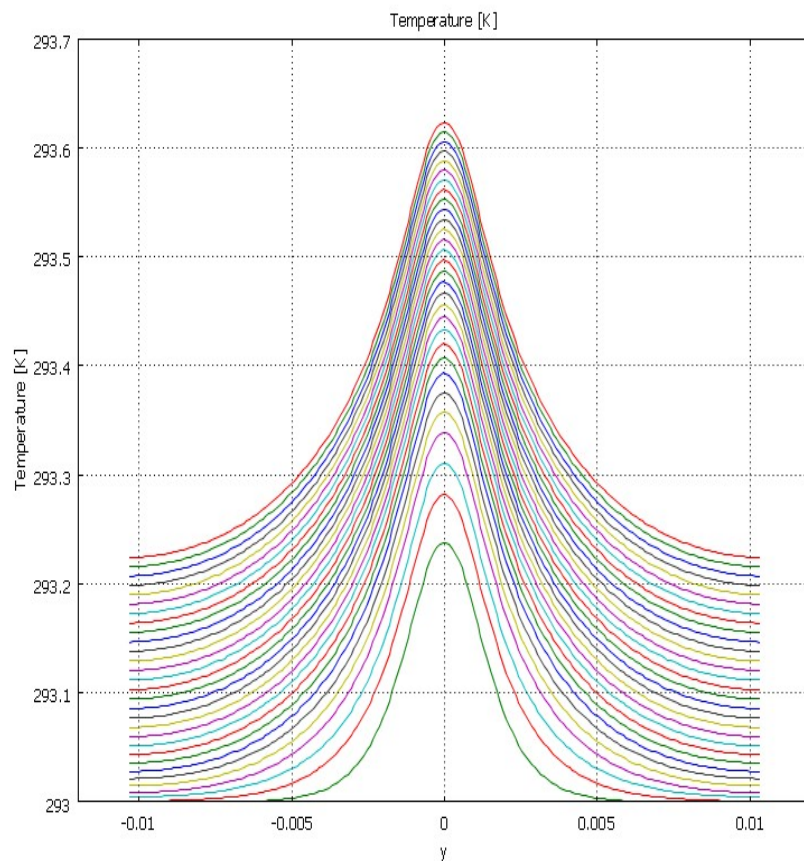
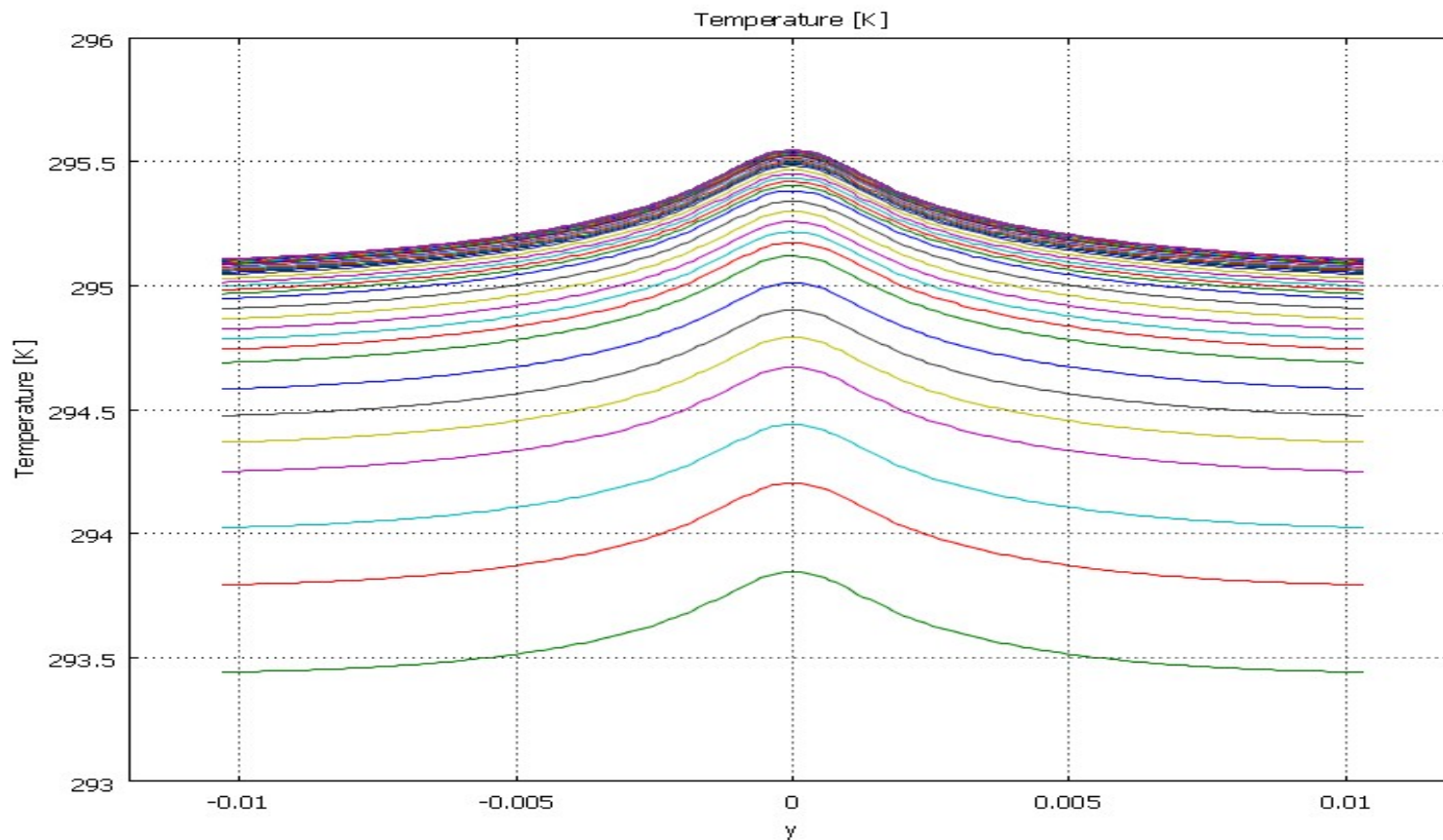TGG with radiation enabled on faces and edges

30 W incident power
Time from t = 0s to t = 3600s (60min) with a line every 60s (1min)

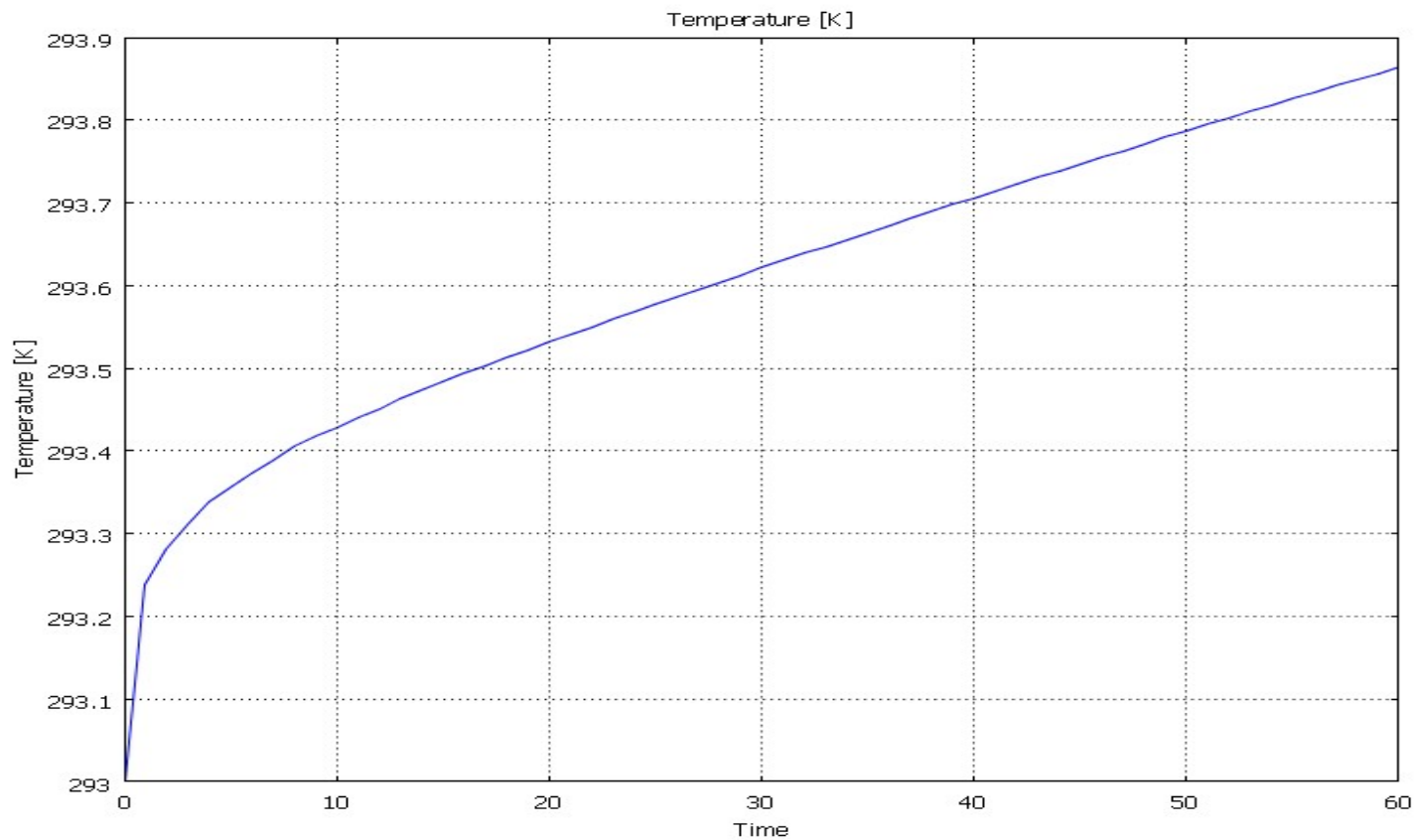**TGG with radiation enabled on faces and edges**

30 W incident power
Time from t = 0s to t = 3600s (60min) with a line every 60s (1min)

45. Power ramp-up (Contd.)

- Differential temperature and not the absolute temperature matters for thermal lensing
  - » Absolute temperature matters for isolation ratio degredation
- Last two slide show that the differential temperature between the center and the edge reaches 90% of final value in one second
- Ratio of density to thermal conductivity is of the same order for TGG and DKDP
- No problem expected in adaptive mode matching
- Isolation ratio degradation depends upon the absolute temperature and plans are there to improve thermal contact

# 46. How likely is it that more jitter suppression will be needed?

- We rely on the reports from LZH of the jitter from the 180 W laser, combined with the expected performance of the PMC.
  - » For MSPRC, should be 2x better than requirement (which has standard 10x technical noise safety factor)

- Stable cavity changes things for the worse
  - » Depends on Gouy phase of stable cavity, expected to be 2x-10x worse w.r.t. jitter.

- This eats up some of the 20x safety margin in the jitter suppression.
  - » Still 2x below, but no safety factor anymore

A: We think so

- ➤ The physics is well understood
- ➤ first measurements have been done
  - ➤ 20 nrad/V
  - ➤ Can get to 200 urad dynamic range with 10 kV

- ➤ **not needed until we have reached a level where Advanced LIGO is limited by beam jitter.**
  - ➤ The installation will only require minor changes in the layout on the PSL table and can be done long after the rest of the IO is installed.

RTP Prism Pointing

204 Vpp
356 Vpp
456 Vpp
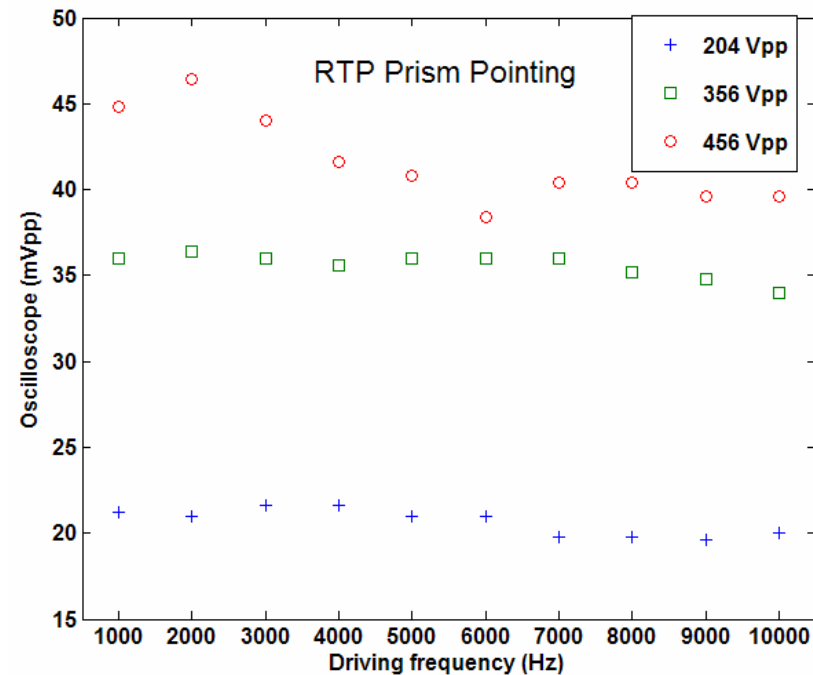
48. How much of the 30 ppm loss is scatter and absorption in Table 10? Is this crucial, does it seem doable with current understanding of scatter in initial LIGO?

- Coating absorption is <1 ppm; scattering nominally 30 ppm.
- Scatter of 200 ppm would give a 10% hit on the MC transmission.
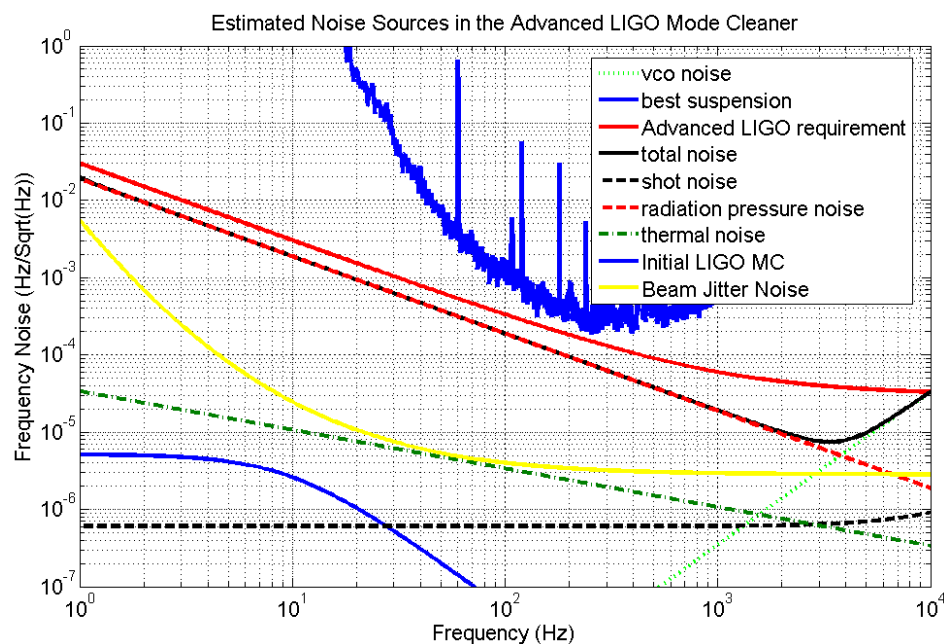 - » Cleanliness is next to godliness.

49. Does the total noise in Figure 7.4 exceeding the requirement above 3 kHz cause concern? Can the VCO noise be improved to increase the crossing frequency?

- ➢ **The initial theoretical model was assuming a very conservative estimate**
  - ➢ Assumed 100% SB phase noise to carrier phase noise coupling.
  - ➢ We relaxed that to 10% SB phase noise coupling requiring a SB amplitude asymmetry of less than 10% (still conservative).

Estimated Noise Sources in the Advanced LIGO Mode Cleaner

Legend:
- vco noise
- best suspension
- Advanced LIGO requirement
- total noise
- shot noise
- radiation pressure noise
- thermal noise
- Initial LIGO MC
- Beam Jitter Noise

x-axis: Frequency (Hz)
y-axis: Frequency Noise (Hz/Sqrt(Hz))

50. What plans are there to insure the IMC coatings will have the required 1 ppm or less absorption?

A: MC pathfinder optic currently being polished; will be coated by REO and characterized for absorption at Caltech in mid-2008

- if coating absorption is higher than 1 ppm, fallback is LMA Virgo
    - » Have demonstrated < 0.5 ppm routinely

51. Section 5.2.1 says the IMC mirrors are 20 times lighter than TMs, is this the right size?

- No
- 13.6x (or IMC mirrors are 7% of TM masses**)**
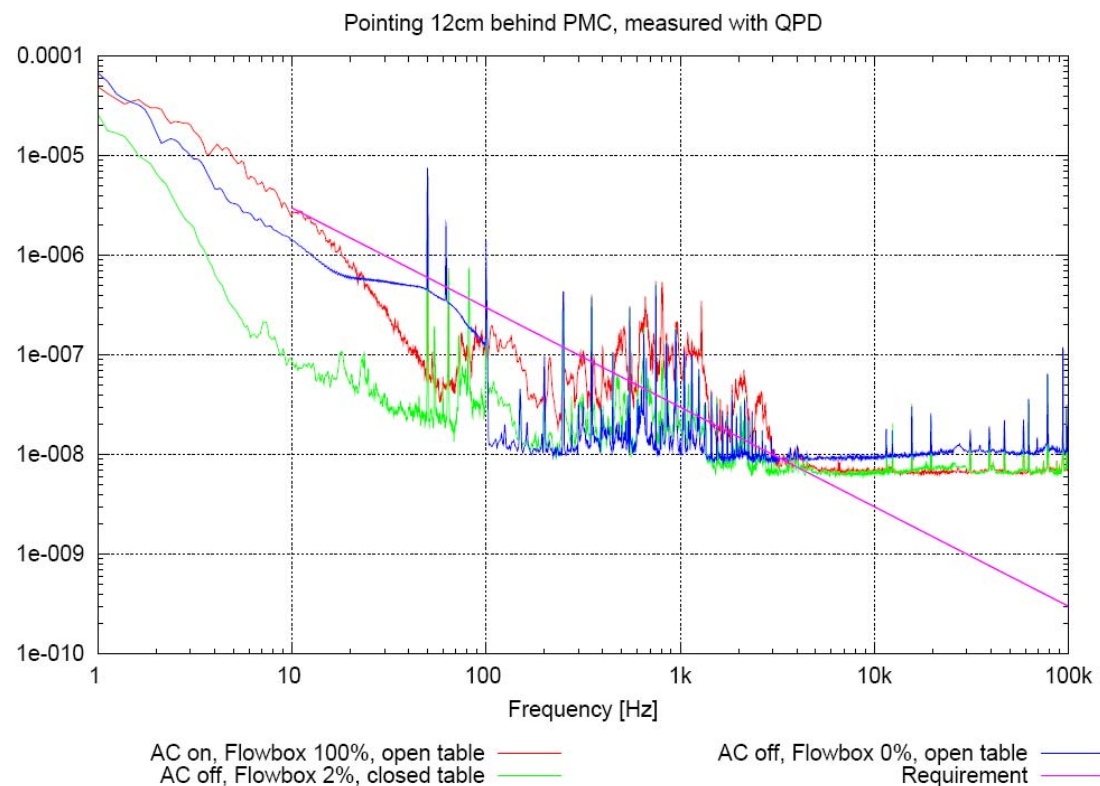- Corrected in the PDR

52. Typos. ... Can you explain what $\Delta\Theta_{ITM}$ is being used here? Is the PSL pointing noise flat from 10 Hz up?

- **Typos corrected**
- **IFO 4×10^{-9}/rtHz beam jitter requirement assumes $\Delta\Theta_{ITM} = 10^{-9}$ rad**
- **PSL jitter specified as 2×10^{-6}/rHz (10 Hz) at**
  http://www.ligo.caltech.edu/advLIGO/scripts/subsystems_psl.shtml
  - » Better results obtained at LZH ("Status of the Advanced LIGO PSL development," Benno Willke, LSC meeting, Baton Rouge March 2007, LIGO-G070137-00-Z).
  - » I-LIGO laser jitter is 1×10^{-6}/rHz and falling as f^{-2} to 100 Hz. (*cf* David Ottaway, Beam Jitter Noise, LSC, 2002; Elogs, Sat, Apr 20, 2002, 20:46:43 UTC and Sat, Apr 20, 2002, 20:48:21 UTC)

- Depends on environment.

- Best result is 1×10^{-7}/rHz at 10 Hz

- Falls as $1/f$ to 1×10^{-8} /rHz at 100 Hz.

- Appears to be measurement limited above 100 Hz.

Pointing 12cm behind PMC, measured with QPD

AC on, Flowbox 100%, open table
AC off, Flowbox 2%, closed table
AC off, Flowbox 0%, open table
Requirement

[svn://pat/diss/Data/2007-02-16/behindpmcparticles.plt, rev. 791, 13 Mar 2007, Patrick Kwee, kwee@bigfoot.de]

Mode Cleaner…

54. Why do the ROC numbers on page 64 and 67 disagree, which are the correct numbers?

Ans: The numbers have been updated. The correct numbers are 26.769 for MC2 cold ROC and 26.9116 for MC2 hot ROC.

55. Where does the 10 ppm/cm number for substrate absorption come from? Why not use Suprasil 311 with about 4 ppm to get rid of the (astigmatic) thermal lensing?

Ans:
- This is done on the suggestion of the reviewers' comment during conceptual design review.
- Suprasil 311 is more expensive
- Helps in reducing adaptive heating on DKDP

56. In description of purposes of Faraday isolator, should include that it is used to create the REFL signal.

A: Done, added to section 8 of the PDR

57. What is current understanding of the Fizeau effect in the Faraday isolator?
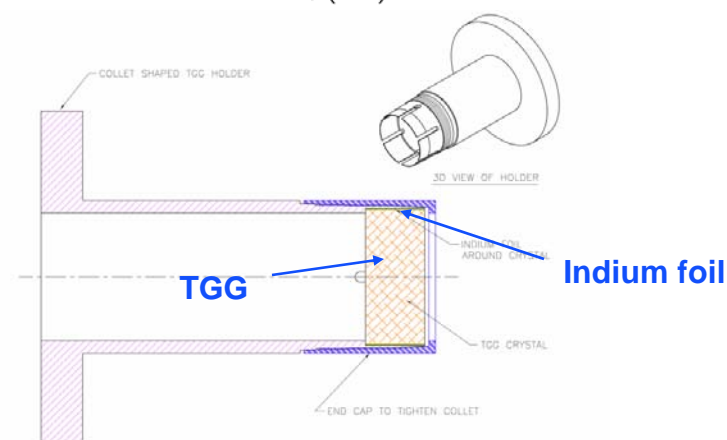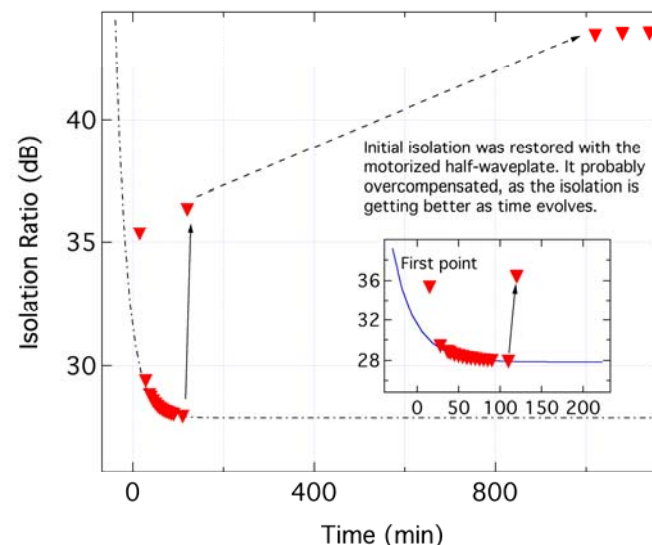
A: Frequency noise from Fizeau effect:

$$\delta f = 1.5 x 10^{-12} \frac{Hz}{\sqrt{Hz}} \left(\frac{f}{10}\right)^2 \left(\frac{\delta x_{seismic}(f)}{2 x 10^{-13}}\right)$$

- The HAM seismic isolation requirements have relaxed since the IOO DRR:
  - » Old: δx = 2 x 10^{-13} m/rHz @ 10 Hz
  - » New: δx = 4 x 10^{-11} m/rHz @ 10 Hz; 1.5 x 10^{-11} m/rHz, f > 20 Hz
- Leading to…
  - » Old: δf =1.5 x 10^{-12} (f/10)^2 Hz/rHz
  - » New: δf = 3 x 10^{-10} (f/10)^2 Hz/rHz @ 10 Hz; 1.13 x 10^{-10} (f/10)^2 Hz/rHz f > 20 Hz
- Compare to IOO requirement of δf = 3 x 10^{-5} Hz/rHz above 1 kHz
  - » fine below 5 kHz, slightly higher than requirement above 5 kHz
    - – requirement has 10x safety factor
    - – 1.1 x 10^{-4} Hz/rHz at 10 kHz

LIGO R&D

58. What is the status of investigating the degradation of isolation ratio in vacuum? What is the prognosis for solving it?

A: Isolation degrades in vacuum:

- at 10-5 Torr, the isolation reduces by ~ 8 dB…
- …due to T dependence of the Verdet constant

  » Isolation can be restored with a motorized HWP

  - stable after about 12 hr.

- New TGG holders designed to improve conduction channels and reduce ΔT in the TGG crystals

  » Currently under test for E-LIGO

- In Advanced LIGO we will insert a picomotor controlled HWP to restore the isolation.

Initial isolation was restored with the motorized half-waveplate. It probably overcompensated, as the isolation is getting better as time evolves.

First point

TGG

Indium foil

59. What plans are there to investigate transients immediately after lock from thermal mismatches between TGG and DKDP?

A: This is closely related to question 45…

- Preliminary work already done at 30 W for E-LIGO.
  - » Transient effect has been studied in both air and vacuum
  - » Measured time constants for thermal lensing are essentially same for TGG and DKDP

- Will continue at 100 levels through the FDR phase. Also, E-LIGO will allow us to look at dynamical effects
  - » Three of the four FI ports will be monitored; will be able to measure FI performance *in situ* at 30 W
- Ultimately, segmented ring heater will minimize transients

60. What is the status of rechecking the thermal lensing and passive compensation on "normal" low loss TGG?

A: Not sure what this question is really asking…

- The current Russian fabricated TGGs does not have higher absorption losses

- The newly ordered TGGs have a similar absorption loss

- Current TGGs have the lowest absorption values commercially available we have found so far.

61. Can you explain more about the Faraday isolation spec of 35 dB. Where does this come from?

A: It's an educated guess based on initial LIGO

- » iLIGO FI's provide ~ 25 dB isolation at 3 W[1]
  - – parasitic interferometers seen at these power levels in iLIGO
- » Scale to AdvLIGO powers (125W/3W) and lower MC finesse:
  - – 12 dB of additional isolation at least is needed to achieve the same performance assuming same mirror quality
  - – 40 dB is not so hard to get
- Bottom line: isolation should be as good as we can make it
- Will be looked at experimentally in eLIGO

[1]http://ilog.ligo-wa.caltech.edu/ilog/pub/ilog.cgi?
group=detector&date_to_view=03/06/2002&anchor_to_scroll_to=2002:03:06:20:43:27-stan

62. How is the 3 W that is rejected by the second polarizer dumped in vacuum? Is there any way to tweak the B-field to maximize transmission as well?

- **All FI port beams are collected and analyzed for diagnostic purposes**
  - » All beams from the polarizers are directed to HAM 1
  - » Layout issues TBD between IO/ISC

- **No current plans to adjust B-field**
  - » An electromagnet (e.g., a coil) could be added to the FI for fine control.
    - – This is not in the baseline.
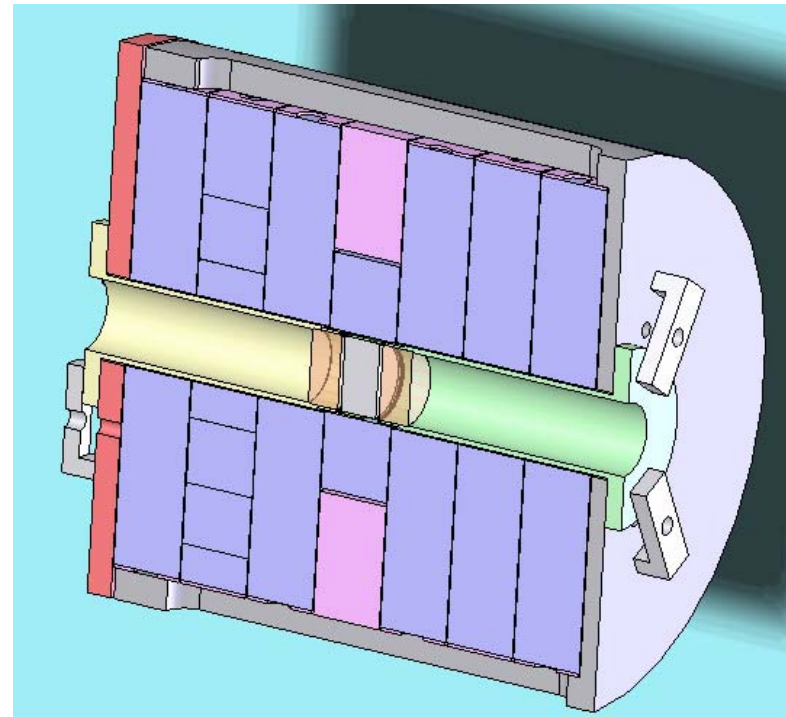
63.In Section 8.2.3, is the 40 m focal length including compensation? Why is this so large? What was the compensation factor?

Ans:

- Yes, the 40 m focal length was after compensation
- The thickness of the DKDP can be reduced accordingly to improve the compensation
  - » But we haven't done it yet…
- Current measurements gave new insight into thermal lensing performance
- We are planning to buy DKDP from US sources so the thermal compensation will be much improved

64. In Section 8.4.1, why was the phase noise estimated at the second order point, rather than with a reasonable (say 1 mm) offset of the beam from the lens center?

A: That section looks at the effects of "shaking" the Faraday Isolator and the lens that is investigated is a thermal lens that is "self-centered".

65. In Section 8.4.2, why were estimates made at 10 Hz but not above this frequency, since the HAM ISI vibration level won't be rolling off very quickly above 10 Hz? It would be useful to see numbers up to 100 Hz.

➢ Fixed in PDR.

➢ The frequency noise requirement is most stringent at 30 Hz with 3×10^{-6} Hz/rHz. The worst vibration level is found at 10 Hz and leads to:

$$1.8 \cdot 10^{-15} \frac{\text{Hz}}{\sqrt{\text{Hz}}}$$

➢ We meet the strongest requirement for the worst vibration, i.e. we meet the requirement everywhere in the measurement band.

66. The description on page 36 of the PDD for the initial LIGO power control system seems not quite right. Perhaps the Advanced LIGO design should start from the lessons learned in initial LIGO…

Ans:
- Input from various folks (Rana, Rick S.) on this problem
- Fixed ramping step of 1- dB is the main concern
- In new set-up, variable step is possible through software control
- A step resolution of better than 2.1 mW is available

67. Why is the "worst case" for the radiation power kick considered in Section 5.2.1.1 82.5 W rather than 180 W?

Ans:
- 82.5 W. i.e, 165 W/2 is selected because this provides the largest step change in the power due to HWP+Polarizer $\cos^2\theta$ behavior.
- The derivative of power with rotation of HWP is maximum at half power point.

68. Are the plans to deal with radiation power kicks consistent with the initial LIGO experience with this problem?

A: The software controlling the power was set to adjust in 1 dB increments[1]

[1]Rana, personal communication

- » 1 dB is a ~25% increase
- » This could have caused power kicks in Initial LIGO but this has never been proved
- » For diagnostics purposes sometimes a small power step is required
- » The current power ramp procedure of starting at 1 W, moving to 2 W and then going to 7 W should be changed where the ramp speed should be controllable parameter

- Solution is to have software provide finer adjustment
  - » Possible using proposed stepper motor controller
  - » Simple and easy, no?
  - » Much smaller (maximum of 2.1 mW) power step induced power kicks can be handled by the same electronics being used in Initial LIGO.

LIGO R&D

Power Control…

69. There will be long periods of time (commissioning and low power operation) when the power from the PSL will be 30-35 W, not 180 W. Will the IO work at that power level for sustained periods?

Ans: The system is designed to operate better at low power without any adaptive correction needed.

70.   How long will it take to ramp the laser from 0 to full power?

Ans:

- The minimum time required for power to be ramped from 0 to full load in about 5 seconds.
    - Set by speed of stepper stage
- Maximum time can be set through software
    - And can be ◎

Transmissive optical components

71. In Section 4.2.1.1.2 Optical Components it is said that fused silica is used for transmissive components to minimize thermal distortion.

Ans:

- Yes. The power level at various reflective optical components does not warrant changing the material.
- Proposed BK7 has 10 times more thermoelastic deformation than fused silica
- No problems expected even for stable cavity power levels
- IOO performance is not compromised.

72. Are polarizers planned to be made from fused silica?

Ans: Yes.

73,75: Additional Optics…Beam Dump

73. What contamination plan is there is for a leak from the water cooled beam dumps?

- There are no water-cooled beam dumps in the vacuum system.
- For the PSL table, will install flow meter watchdawgs on cooling lines tied to shut off valves.
    - » Beam dumps can handle full laser power without damage
        - – They just get real hot…
- IOO beam dumps located on edge of PSL table; leaks can easily be diverted off the table

75. Should the alternate beam dump discussed in Section 5.3.1 be in an appendix or even a different document if it is not the baseline?

Ans: This has been moved to an appendix.

74. Why is there no spec for backscatter off of the beam dump? Should there be one, and if so how will one be determined?

Ans:

- Light can scatter into vacuum or back to PSL
  - » Into vacuum?
    - – MC filters scattered light by 500x
  - » Into PSL?
    - – Faraday isolator attenuates by >1000x
- Experimentally, the maximum amount of back scattered light at 18.5 cm from the beam dump was found to be 1 mW/cm^2 (with 100W input)
  - » Closest optics is about 1 m from the beam dump
  - » The beam size at the closest optics is about 1 mm
  - » The scattering from beam dump to a 1 mm x 1 mm area will be 33 μW
  - » This corresponds to 0.3 ppm of the incident power at the beam dump
  - » In absence of cavity this is several order of magnitude lower than the reflections from the AR coatings and comparable to small angle BRDF for optical surfaces
- Therefore beam dump back scattering was neglected
- Will be addressed in a IOO baffle PDD in greater detail

76. Can you show an optical lever layout and explain who is responsible for optical levers on IO optics? Should be included in requirements and as Section 2.2.5 in PDD.

- IOO is responsible for routing optical levers to all suspended optics.
  - » In the IOO layouts already…

- AOS is responsible for the OL transmitters, receivers,
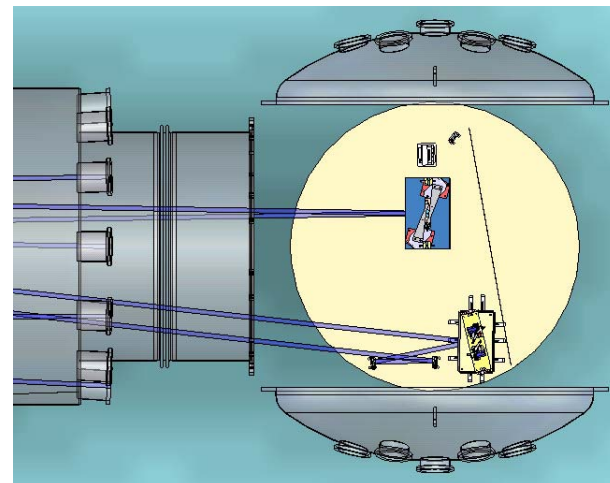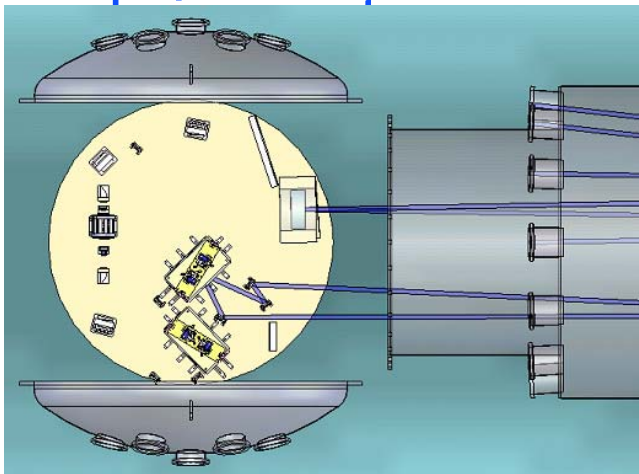
77. Can you explain confusion over polarization in 3.1.1.1, it might be clearer if it said horizontal or vertical.

A: Horizontal

- Fixed in PDR

78. Many of the components have 50 mm diameters. We don't seem to need larger than 25.4 mm optics in initial LIGO, why would we in Advanced LIGO?

A: Might be able to use 1" optics, but…

» For some IOO components on PSL table, beam waist is large enough that 2" is required

– Eg, MC MMT mirrors.

» Our HPTF experience tells us that 2" optics are safer to work with

79. Will the injection periscope used be identical to one used in initial LIGO? Why or why not? Has Robert Schofield been consulted about the comparison between the tubular ISC periscope to the PSL one? What is the motivation to improve the existing PSL periscope?

- PSL injection into vacuum is still TBD!
- We assume through HAM1
- There are two choices for injection periscope: LIGO 1 (oil derrick) or ISC (tubular)
- Heights are not the same, so tubular periscope needs to be modeled at correct height with FEA to check first resonance
  - » Will do for FDR
- Tubular design has smaller footprint, which is useful on crowded PSL table (current preferred choice)
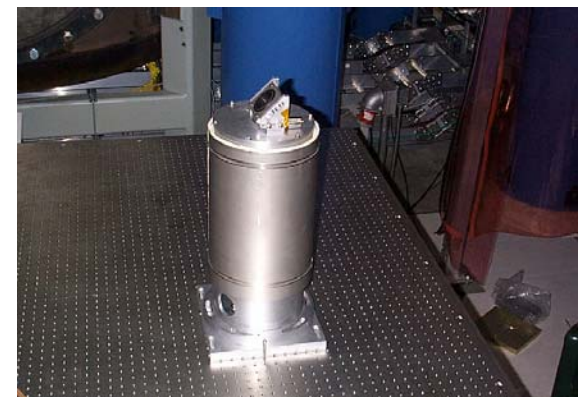
80. Has the layout in Figures 3 and 4.1 been approved by PSL? It appears that this layout needs to be mirrored along the Y-axis due to some cabling issues associated with high power laser.

- Initial response from PSL team was positive, but
  - » PSL group has not developed a detailed layout yet,
  - » does not yet know if it can fit in the baseline layout shown below
- Some space can be saved in the IO area by using tubular periscope, changing the 12' dimension to 13'.
- A larger table may be required.
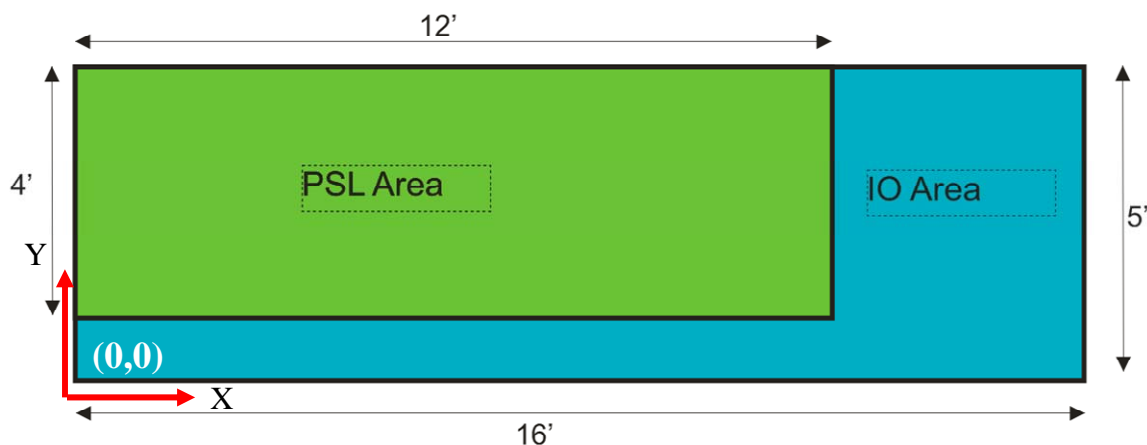
81. Why are such long beam paths needed in Figure 4.1? This is not consistent with what is done in initial LIGO, why is it needed here? Will it cause problems with beam pointing stability?

Ans:

- Long beam paths are not a requirement for mode matching
- A long path telescope helps in reducing the sensitivity to optical path length changes
- The long path telescope also provides flexibility to adjust the mode matching of the PSL layout is changed without disturbing the earlier optical system
- These telescope reduce the angular pointing stability at the expanse of beam displacement, thus it will not increase the beam pointing
- However, if we have to use small distances due to PSL layout constraints, then an afocal system (in a traditional f1:f1+f2:f2 distance configuration) with f1 = 335.4 mm and f2= 802.2 mm can be used.

82-83: Additional Optics

82. What is the purpose of of the beam tubes? If it is to stop air conditioner wind that is OK. If it is to stop buoyancy driven convection the tubes should have a small diameter and if it is to stop dust, how will they do that if the dust is already in the air?

A: Mainly for safety

  » Define 'hard' stay clear areas for people working on the table
    – Even though all alignment will be performed at low powers, we feel this is prudent
    – Keeps cables and tools out of the beam
  » Some environmental protection against air flow

83. What plans are there to leak test cooling/fluid lines inside the vacuum?

A: Not relevant, no cooling lines in vacuum

84. Are their any concerns with lifetime for electronic parts which will be located in vacuum?

A: IO components
- » Ring Heaters
  - – Simple (wires, connectors), should be reliable with external fuse
  - – Will run a test during the FD phase
- » Picomotor will be tested in e-LIGO

● OSEMS are SUS responsibility

85. There is discussion about using picomotors in the vacuum system to rotate the waveplate. Have we looked into the reliability of picomotors in vacuum?

A: Will be tested in E-LIGO

86. Who is responsible for the design, fabrication and testing of electronics? Is it planned to do this at UF?

A: CDS is responsible for the design, fabrication and testing of IOO electronics

- IOO electronic components include:
    - EOM RF drive
        - EOM temperature control if needed
    - MZ length controls
    - PSL power control
    - MC centering/alignment system
    - MMT auto-alignment system
        - Servo
        - diagnostics
    - Adaptive MMT
        - Ring heater current
        - MMT diagnostics
    - Faraday diagnostics
        - HWP adjustment for isolation control
        - FI Port monitoring
- IOO will meet with CDS very soon to discuss CDS conceptual design for IOO electronics

88. In Section 3.2.1, coordinates and cosines are TBD, depend upon the choice of BS wedge which is TBD. Also the cosines are specified to too many significant figures.

- OK, this has been changed to TBD.

89. Is the plan to re-use the existing SOS suspensions? Probably replace OSEMs, but otherwise it makes sense just to re-use, if no design changes are needed. Statement in 3.6 is not clear on this.

- **IO will re-use SOSs, including OSEMs**

- **LIGO 1 OSEMs have comparable sensitivity/noise performance to Birmingham OSEMs**