Advanced LIGO PSL

presentation of the PSL team at the preliminary design review

LIGO-G080539-00-Z

opening remarks

- we thank committee for early posting of questions
- we would like to start DBB and 35W front-end fabrication
  - people with expertise available now
  - we would like committee to assess
    - maturity of design
    - risk involved in early fabrication
    - possible refurbishments required for these items after PSL final design review
- we have not answered the QA questions
  - need to understand the questions/suggestions better
  - we have to assess which of the suggestions we can follow with the given resources

A: Please give us a complete picture of what is being reused from initial LIGO (including electronics). Not only actual hardware, but also if there are designs that are being reused. This info should be included in the PD document too.

- initial LIGO hardware
  - reference cavity including vacuum container, pumps, pressure gauges
    - do Ion pumps need to be regenerated ?
  - frequency shifter (EOM, AOM, VCO)
    - VCO might undergo revision
  - tidal actuator (including electronics)
  - 4 x 6HU crates
  - electronic racks
  - optical table
- enhanced LIGO design
  - table top frequency servo –TT-FSS
- enhanced LIGO hardware
  - 35W front end (after refurbishment)
  - chiller


front
back
PSL control chassis 1
servo ILS
FB ILS
LO ILS
LO PMC
only phase
shifter
FB PMC
servo PMC
ILS LO
stand alone
optinal
to Beckhoff
from Beckhoff
to AI
to AA
to AI
to AA
servo ILS
FB ILS
LO ILS
LO PMC
only phase
shifter
FB PMC
servo PMC
ILS LO
stand alone
optional
power
power in
LO
LO
ILS bus
PMC bus
PSL control chassis 2
FB FSS
LO FSS
FB ISS
to table top
TT FSS
to table top
TT ISS
to AI
to AA
to AI
to AA
FB FSS
LO FSS
FB ISS
power
power in
FSS bus
ISS bus
PSL control chassis 3
FB DBB
DBB module
DBB module
DBB module
DBB module
DBB module
DBB module
to AI
to AA
table top boxes
TT FSS
power
to front of
FB FSS
TT ISS
power
to front of
FB ISS

B: Give us a complete list and/or diagram of what is in the US scope and what is in the Germany scope. Where does maintenance fall? This info should be included in the PD document too.

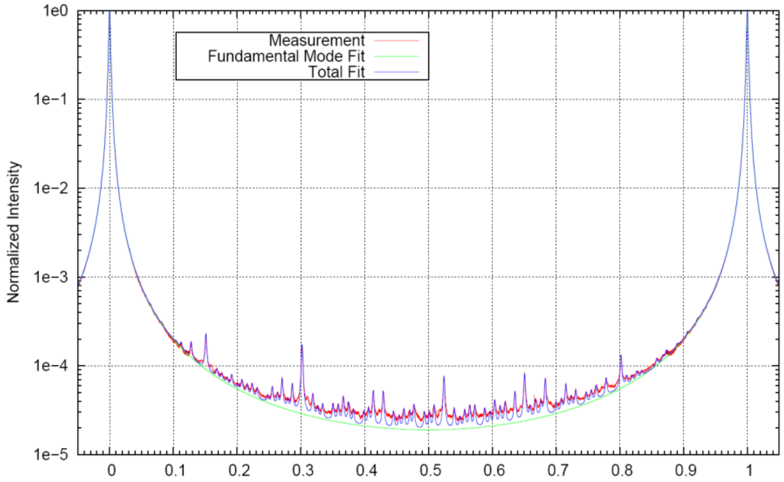
- scope is defined in the attachment of the LIGO-AEI MOU and in the WBS
- US scope
  - outer-loop power stabilization
  - RT control system (field boxes AEI, AA / AI LIGO)
  - Racks, measurement equipment (FFT analyzer, scopes portable power meters, beam analyzer, IR viewer, IR cards, ...)
  - rooms, tubes for cooling water, communication fibers
  - cleanroom equipment, flow boxes, air shower, clothes
  - laser safety equipment (access control, safety glasses)
- maintenance is US scope (according to MOU)
- we do not understand why this should go into PDD

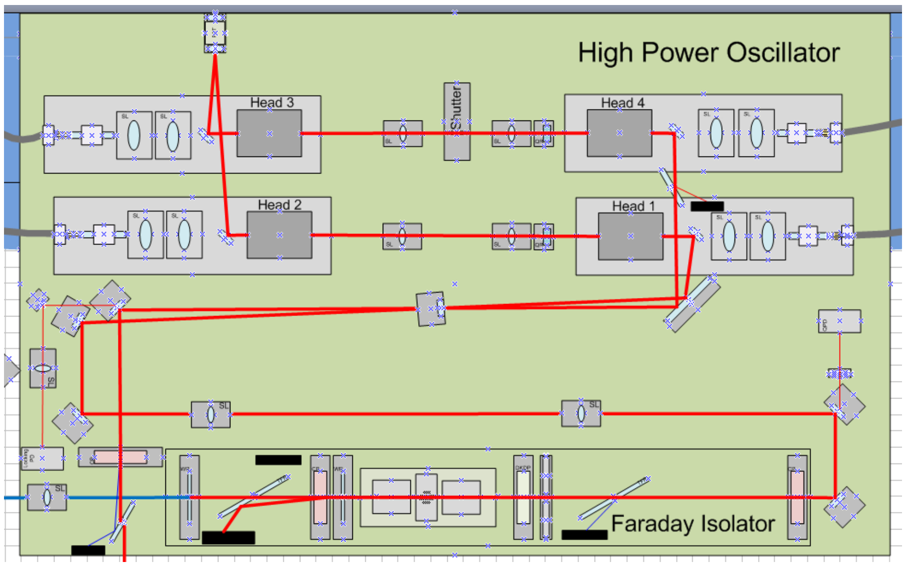
Appendix AEI-LIGO MOU (LIGO- M060296-01-M)

- **PSL No 1**
  - **NPRO**
    - 2W Mephisto Lasersystem (Innolight) including laser head, power supply and control electronic
    - miscellaneous (cables, fiber, mounts, mirrors, auxiliary electronics, ...)
  - **35W Amplifier**
    - laser head
    - laser head temperature controller
    - laser diode (LD) box
    - optical fibers for pump-light delivery
    - LD power supply
    - LD current and temperature controller
    - front-end breadboard including beam conditioning components
    - miscellaneous (cables, fiber, mounts, mirrors, auxiliary electronics, ...)
  - **200W high power oscillator**
    - laser oscillator including laser heads, polarization and birefringence control
    - crystal temperature controller
    - laser diode boxes
    - optical fibers for pump-light delivery
    - LD power supply
    - LD current and temperature controller
    - optical isolator
    - miscellaneous (cables, fiber, mounts, mirrors, auxiliary electronics, ...)

- **injection locking system**
  - optomechanical components
  - electro optical components
  - injection locking control electronics
  - miscellaneous (cables, computer control equipment, ...)
- **spatial filtering system (PMC)**
  - ring resonator
  - optomechanical components
  - electro optical components
  - length and alignment control electronics
  - miscellaneous (cables, computer control equipment, ...)
- **diagnostic breadboard**
  - beam diagnostic breadboard
  - diagnostic and control electronics
  - miscellaneous (cables, computer control equipment, ...)
- **power stabilization system**
  - optomechanical components
  - electro optical components
  - power stabilization electronics miscellaneous (cables, computer control equipment, ...)
- **frequency stabilization system**
  - optomechanical components
  - electro optical components
  - frequency stabilization electronics
- **laser safety equipment**
  - laser beam shutter
  - optomechanical components
  - electro optical components
  - laser safety electronics
  - miscellaneous (cables, computer control equipment, ...)

…. C: How could we get something like a 1 W beam, with the right spatial parameters, out of the PSL? Also, in the 16 W low power mode, how is the 20 W transmitted beam dumped



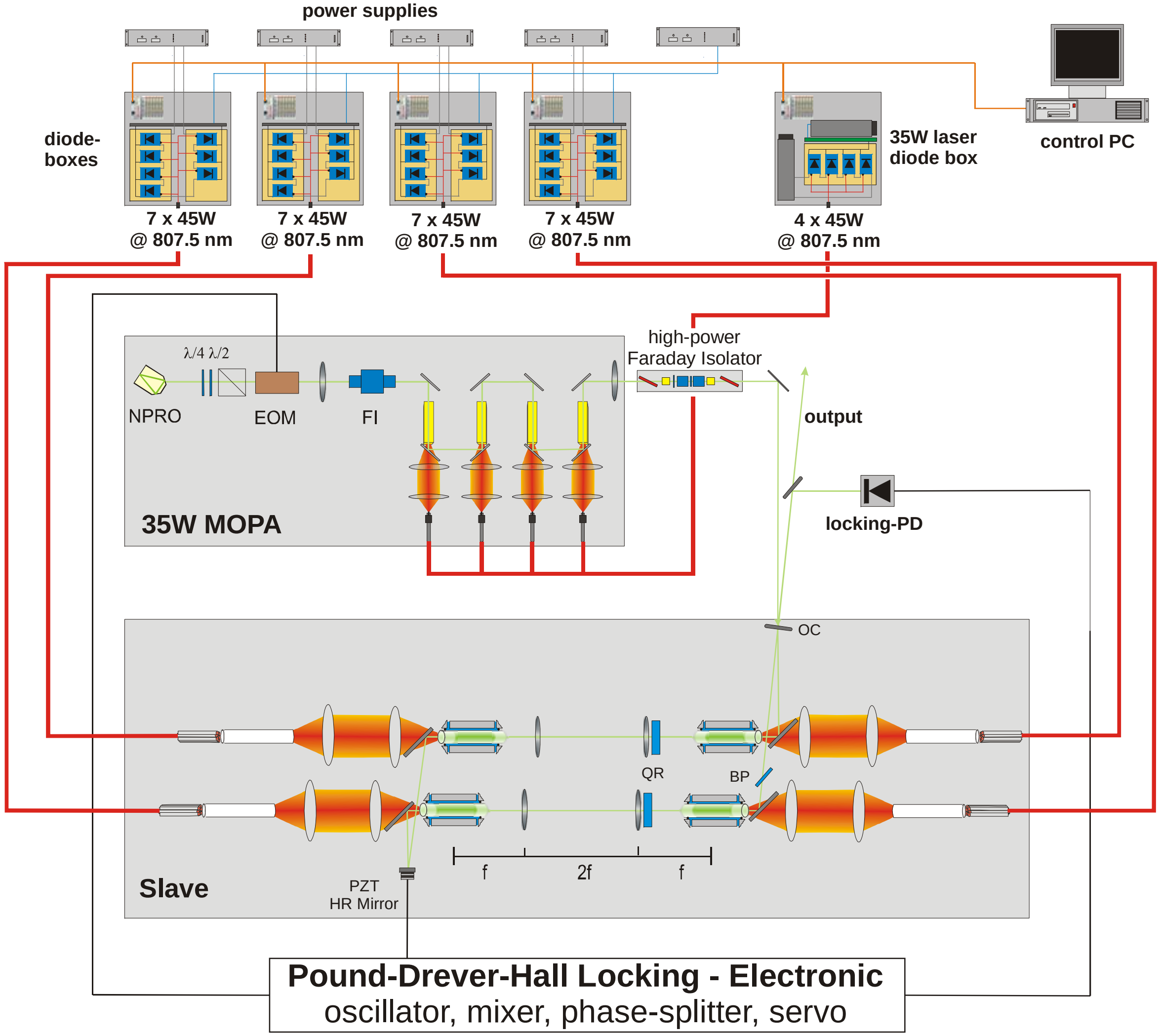


- the spatial mode of the PSL is defined by the PMC and we do not see any thermal effects in the high power PMC
- one could put a partially reflecting mirror into the path before the PMC and dump the reflection of this mirror on a power meter
- the shutter in the oscillator will be able dump more than 20W
  - either the shutter itself will be water cooled or
  - the light will be reflected by the shutter to a water cooled power meter

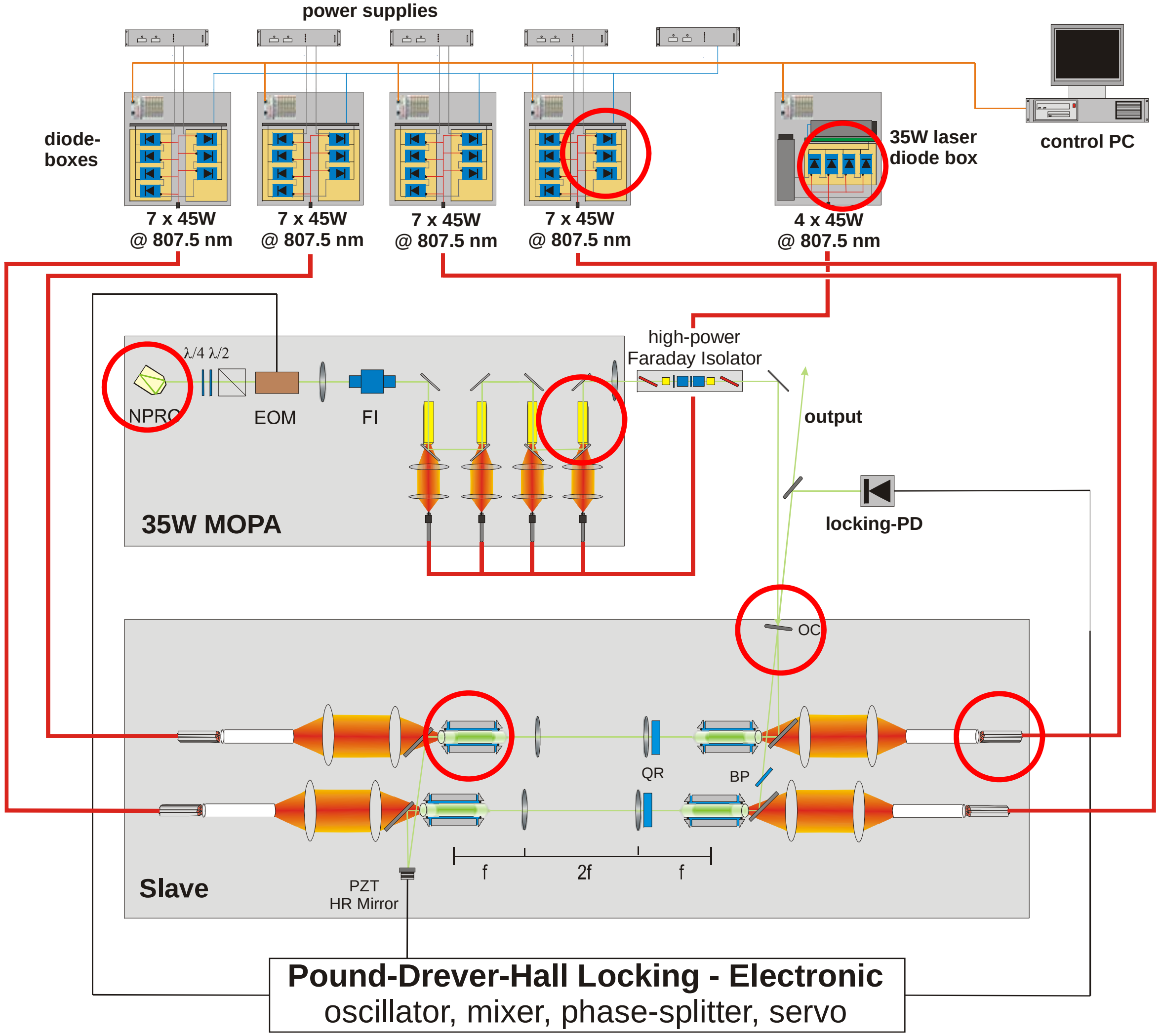
D: Repair. What are the more likely failure modes for the PSL, and the estimated time to repair for those modes?

- PMC transmission degrades
  - mitigation
    - replace PMC
    - degradation should appear slowly -> replacement can be done in scheduled maintenance time
- PSL electronics fails
  - mitigation
    - replace with spare
    - replacement and tuning should be possible within 1 day

HPL – system overview



HPL – more likely failures



More likely failures:

- NPRO
- Pump diodes
- 35W MOPA:
  - Laser crystal
- High power slave:
  - Output coupler
  - Laser crystal
  - Fiber bundle
- Water leakage

NPRO failure

Cause:	?
Action:	• Replace 35W MOPA with spare • Realign spare 35W MOPA • Verify 35W MOPA beam parameters • Check mode-matching to slave laser
Duration:	~ 2 days

Pump diode failure (35W MOPA / Slave laser)

Cause:	Natural degradation of emitter material / electrical or optical failure
Action:	• Depending on age of pump diodes: • „Young“ diodes: replace single diode • „Old“ diodes: replace complete diode box with spare • Verify output power and spectrum parameters
Duration:	~ 1 day

35W MOPA: laser crystal failure

Cause:	Dust on crystal surface

Action:	• Replace 35W MOPA with spare
	• Realign spare 35W MOPA
	• Verify 35W MOPA beam parameters
	• Check mode-matching to slave laser
	• Repair: depending on expertise of on-site staff:
	    • Well trained staff: exchange crystal, realign MOPA
	    • Inexperienced staff: send MOPA for repair

Duration:	~ 2 days

Slave: Output coupler failure

Cause:	Dust on mirror surface
Action:	• Exchange output coupler • Align output coupler • Check high power slave laser cavity alignment • Verify beam position and quality with PMC
Duration:	~ 1 day

Slave: Laser crystal failure

Cause:	Dust on laser crystal surface

Action:	• Depending on expertise of on-site personnel:
	  • Well trained staff: exchange crystal, spare pump-chamber with mounted crystal or exchange complete laser head (prealigned)
	  • Inexperienced staff: Replace slave laser with spare
	• Realign high power slave laser cavity following documented procedure
	• Check operating point (output power, beam profile, beat signal on PD)
	• Lock laser system to front-end (check error signals)
	• Check mode matching to PMC

Duration:	~ 3 days (exchange crystal etc.) ~ 5 days (replace slave laser with spare)

Slave: Fiber bundle failure

Cause:	Absorption at fiber bundle tip / broken fiber / damaged SMA fiber connector at pump end
Action:	• Replace fiber bundle with spare • Replace homogenizer • If pump optics are contaminated: replace pump lenses • Realign fiber bundle / pump optics • Check operating point • Check mode matching to PMC • Disassemble damaged fiber bundle and send it for rework
Duration:	~ 1 day

Water leakage

Cause:	?

Action:	• Seal leak and replace leaking component
	• If leakage outside of laser box: nothing more to do
	• If inside laser box: check which component got wet
	• Depending on severity:
	    • Clean components
	    • Exchange MOPA/Slave with spare

Duration:	< 1 day (outside) ~ 3-5 days (inside of amplifier or slave box)

E: Risks. Go through the PSL risk registry items and review their status

Risk Value	Probability	Scope Consequence	Cost Consequence	Schedule Consequence	Performance Consequence
5	Extremely Likely – 90% probability of occurrence over the project	Unacceptable	> $3M	> 4 mos.	Unacceptable
4	Highly Likely – 70% probability of occurrence over the project life	Major overall Consequence	$500K to $3M	2 - 4 mos.	Doesn't meet SRD
3	Moderately Likely – 50% probability of occurrence over the projec	Some major areas Consequenceed	$250K to $500K	1 - 2 mos.	Doesn't meet SRD in some areas
2	Unlikely – 30 % probability of occurrence over the project life	Minor Consequence	$50K to $250K	<1 mon.	Doesn't meet high goals
1	Highly Unlikely – 10% probability of occurrence over the project l	Negligible	<$50K	Negligible	Negligible

							Residual Risk Evaluation						
Risk ID	Risk Contri-butor	Risk Event	Affected System or WBS Level	Prob-ability	Completed Mitigation Actions	Major Threat List	Prob-ability	Consequence: Cost	Consequence: Sched-ule	Consequence: Perform	Consequence: Scope	Resi-dual Risk Score	Open Mitigation Actions
06-055	P. Fritschel	If foreign funding is lost or delayed, then schedule delays and cost increases will be incurred.	PSL	1	N/A – Accept risk		1	5	3	-	4	Low	N/A – Accept risk
06-056	P. King	If pre-stabilized lasers are limited to operating at less than 200W, then final sensitivity and performance will be lowered.	PSL	3		Y	3	-	1	3	2	Med	Determine final need date for full power during operations. Have back-up R&D plan to increase power. Maintain capability in back-up technologies. Continue R&D
06-057	P. King	If pump diode manufacturer goes out of business or discontinues the current pump diode model, then .	PSL	3	The design involving coupling the pump power to the laser rods via optical fibres does not depend on the particular hardware interface used by the pump diode manufacturer.		2	-	-	-	-	Low	Accept risk.
06-058	P. King	If key staff leave Laser Zentrum Hannover, then there will be a lack of vital knowledge.	PSL	3	Training sesions for LIGO personnel included in plan.	Y	2	-	3	1	1	Med	Knowledge will be propagated to many staff members so that a continuation of knowledge is always present.
06-059	P. King	If damage occurs to a laser component (either the laser rods, pump beam homogenizers, pump fibers or laser mirrors), then negative Consequences to the project will ensue.	PSL	4	Keep sufficient numbers of spare components on hand, especially those most prone to damage.		3	2	1	-	-	Med	Additional spare parts available at LASTI and Hannover.
06-060	P. King	If beam and mode quality do not meet requirements, then modifications to system may be required.	PSL	2	The use of a spatial filter cavity reduces the likelihood of this event.		1	1	-	1	-	Low	Accept risk.
06-061	P. King	If cooling water for the pump diodes fails, then negative project Consequences ensue.	PSL	2	Install temperature sensors and monitoring to automatically shutdown the laser if the temperature gets too high.		1	1	1	1	-	Low	Accept risk..
06-062	P. King	If facility electrical power fails, then damage will occur due to improper shutdown or mains glitches.	PSL	3	Install mains filters and power conditioning.		1	2	2	1	-	Low	Accept risk.
06-063	P. King	If project cannot transport the required pump power over the proposed distances (100 m) by optical fibers, then negative project Consequences	PSL	3			2	2	2	2	1	Low	monito long term behavior during EnL phase
06-064	P. King	If staff from LZH or MPG encounter visa problems to enter the US, then negative project Consequences ensue..	PSL	3	Keep abreast of current immigration issues.	Y	2	2	4	-	2	Med	Keep abreast of current immigration issues.

AdL risk registry – PSL part

	Risk Value	Probability	Scope Consequence	Cost Consequence	Schedule Consequence	Performance Consequence
	5	Extremely Likely – 90% probability of occurrence over the project	Unacceptable	> $3M	> 4 mos.	Unacceptable
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Risk ID	Risk Contri-butor	Risk Event	Affected System or WBS Level	Prob-ability	Completed Mitigation Actions	Major Threat List	Residual Risk Evaluation: Prob-ability	Consequence: Cost	Consequence: Sched-ule	Consequence: Perform	Consequence: Scope	Resi-dual Risk Score	Open Mitigation Actions
06-064	P. King	If staff from LZH or MPG encounter visa problems to enter the US, then negative project Consequences ensue..	PSL	3	Keep abreast of current immigration issues.	Y	2	2	4	-	2	Med	Keep abreast of current immigration issues.
06-065	P. King	If pre-modecleaner cannot handle the high power for long periods of time, then negative project Consequences	PSL	4	Keep sufficient numbers of spares on hand. Spares in plan.		1	2	1	1	-	Low	Accept risk.
06-066	P. King	If frequency noise does not meet the design specification.	PSL	2	This is unlikely given that the design specification is relaxed from initial LIGO.		1	1	1	1	-	Low	Accept risk
06-067	P. King	If intensity noise does not meet the design specification, then specification will not be met.	PSL	5	Intensity noise demonstrated to meet risk. - Accept risk.		2			2	-	Low	Accept risk.
06-068	P. King	If the high power photodetector is damaged, significant rework and repaires will be required.	PSL	4	Keep sufficient numbers of spares on hand. Spares included in plan.		1	1	1	1	-	Low	Accept risk.
06-069	P. King	If the high power photodetector fails vacuum qualification, then performance of the system will be reduced.	PSL	3			2	1	2	-	1	Low	Keep note of vacuum processing procedures.
06-070	P. King	If mix up occurs over metric or imperial units, then parts will not interface and significant rework will be required.	PSL	1	Settle on working units and clearly note the working units in all design documents.		1	1	1	-	-	Low	Accept risk.
06-071	P. King	If the reference cavity is contaminated during assembly into its vacuum chamber, then reassembly will be required.	PSL	2	Add schedule contingency to plan. Keep sufficient assembly instructions and handling procedures.		1	1	1	-	-	Low	Accept risk.
06-072	P. King	If the pre-modecleaner is contaminated during installation, then reinstallation will be required.	PSL	2	Add schedule contingency to plan. Keep sufficient assembly instructions and handling procedures.		1	1	1	-	-	Low	Accept risk.
06-073	P. King	If pump diode optical fibres get damaged after installation, spares will	PSL	2	Install fibres in a protective conduit or sleeve.Include in install instructions.		1	1	1	-	-	Low	Accept risk.
06-074	P. King	If Incompatibility of laser controls arises due to differences in mains frequencies, I & C modifications may be	PSL	2	During the design stages, check that the equipment selection is compatible.		2	1	2	-	1	Low	During the design stages, check that the equipment selection is compatible.
06-075	P. King	If laser safety related incident, as opposed to an injury, occurs, then significant delay and cost increases will occur.	PSL	4	Ensure proper training and procedures are maintained and reinforced.		4	1	1	-	1	Low	Ensure proper training and procedures are maintained and reinforced.

AdL risk registry – PSL part

Risk Value	Probability	Scope Consequence	Cost Consequence	Schedule Consequence	Performance Consequence
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Risk ID	Risk Contributor	Risk Event	Affected System or WBS Level	Probability	Completed Mitigation Actions	Major Threat List	Residual Risk Evaluation: Probability	Consequence: Cost	Consequence: Schedule	Consequence: Perform	Consequence: Scope	Residual Risk Score	Open Mitigation Actions
06-075	P. King	If laser safety related incident, as opposed to an injury, occurs, then significant delay and cost increases will occur.	PSL	4	Ensure proper training and procedures are maintained and reinforced.		4	1	1	-	1	Low	Ensure proper training and procedures are maintained and reinforced.
06-076	P. King	If items are either lost or damaged during shipping, then negative Consequences to the project will	PSL	2	Accept risk		2	3	3	-	1	Med	Accept risk.
06-095	B. Willke	If cooling water of laser crystals get contaminated the laser performance might degrate. Cooling tubes and Xtals have to be replaced	PSL	2								Low	monitor cooling water quality during EnL phase
06-096	B. Willke	If fibers or cooling tubes get damaged during refurbishment or movement of HAM1 they need to be renewed.	PSL	1								Low	protect fibers and tubes during this operation

F: Go through the testing plan from here through final design phase. Point out what happens at LZH, AEI, Caltech, etc.

engineering prototype (final design phase) (The original plan was to test this laser at LASTI).

1. test full cooling concept (long water tubes, use same chiller models as planned for the observatories, these chillers will later be used for the reference system)
2. test performance with long fibers
3. test full PSL computer control system (Beckhoff, RTLinux control and Beckhoff-Linux interface) at AEI
4. run for several month in 24/7 mode with regular DBB runs similar to NPRO long term testing
5. test for obvious glitches in temporal behavior (power, frequency, PMC transmission)
6. test all elements of system for support of the PSL Safety Plan
7. install and test outer power stabilization loop with servo and diodes provided by LIGO, two diodes similar to the ones to be used as the observatories are required as in-loop and out of loop detector
8. measure pointing-RIN coupling of outer loop diodes
9. test sensing noise performance of outer loop photodiode downstream of suspended cavity (either at AEI in Hannover, LASTI, Hanford 2k or 40m)
10. test of a power outage and re-supply to check for an orderly shut down and no accidental re-appearance of light
11. test for cross couplings and possible instabilities of FSS and ISS during simultaneous operation (including couplings due introduced by the PMC)

35W front end test

a. operate for several weeks 24/7 mode at LZH to test stability of output power and general performance
b. test shipment procedure (boxes, agents, customs declarations, FDA, ...) (may perform some shaking tests to identify critical components)
c. test 110V operation
d. long term test of laser at Caltech
e. adapt and test initial LIGO ISS with new laser and actuator
f. test first version of the power stabilization outer-loop photodiode
g. measure noise performance

F: Go through the testing plan from here through final design phase. Point out what happens at LZH, AEI, Caltech, etc.

reference system

1. initial performance test with internal DBB
2. long term test in Hannover

a. characterize spatial beam profile and pointing with diagnostic breadboard (DBB)
b. measure frequency noise with DBB
c. measure power noise with DBB

observatory lasers

1. initial performance test with internal DBB after fabrication in Hannover
2. acceptance test at observatory after shipment
3. performance test after installation on PSL table in LEVA (only if acceptance test was performed in optics lab)

a. performance test with DBB after fabrication in Hannover

Test Report

Enhanced LIGO MOPA System

Version: observatory 1

Destination: Livingston observatory

Test Report

Enhanced LIGO MOPA

Observatory Laser 2

S/N: OB2-1207

Advanced LIGO Pre-stabilized Laser

Watch
Move
Delete
Protect
History
Edit
Discussion
Article

DBB 0207

From AdvancedPSL

- Location: LZH
- Contact: Sascha Wagner (S.Wagner@lzh.de)
- Serial number: DBD 02/07
- Date of delivery: 25.07.2008

Contents

- 1 Components
  - 1.1 RMT Test
  - 1.2 PMC
  - 1.3 DBB Test
  - 1.4 Calibration Data
  - 1.5 Packing List
  - 1.6 Photos

G: Are some or all of the high power PSL beam paths to be enclosed with tubes? Have the pros and cons of doing so been considered ?

- no final decision yet
- pros:
  - avoids passing the high power beam with hand or equipment
  - however, table layout designed such that high power beam is in center of table,
- cons:
  - additional complexity, risk to damage components while handling tubes
  - scattering
  - vibrations coupled to table due to tube resonances /organ pipes
- unknowns:
  - Is particle count small enough such that glitch rate is negligible ?
  - To reduce particle count purged air system is better than tubes. Does it introduce too high refractive index fluctuations?

? What is the main driver for tubes?

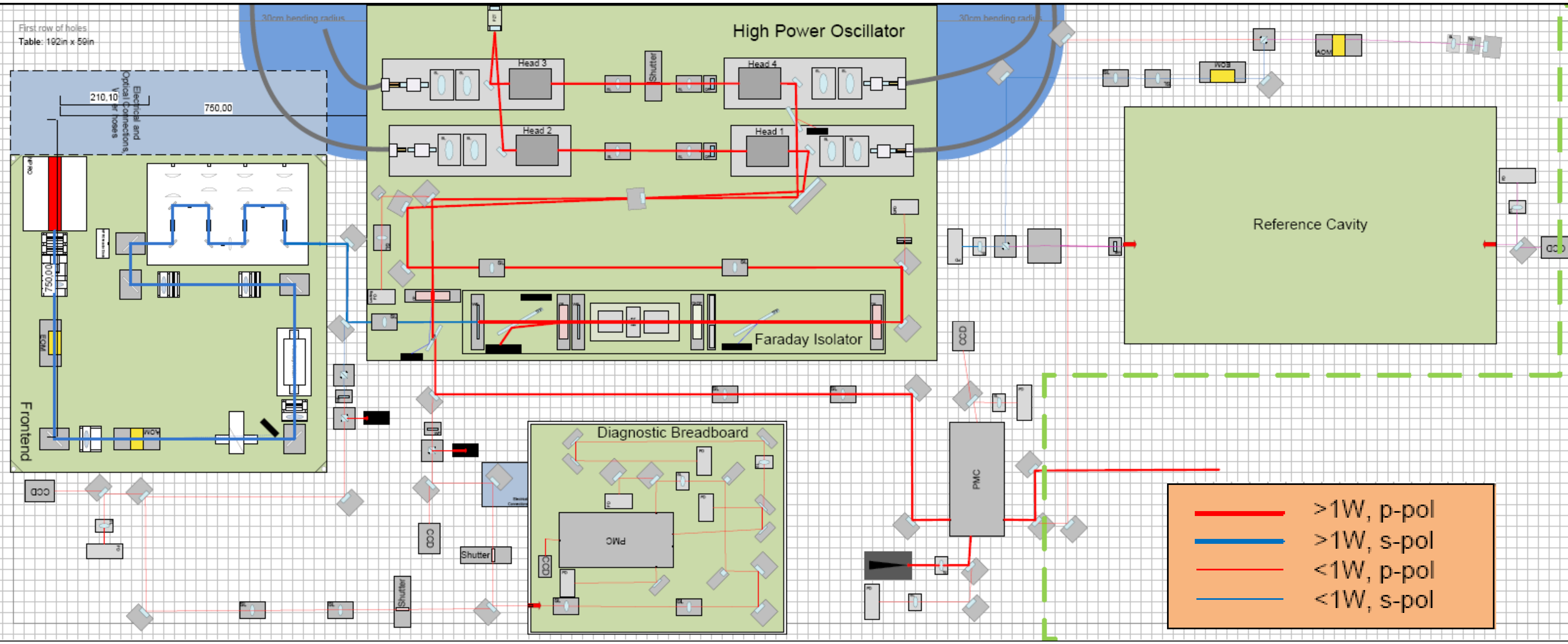
H: Loop gain monitors. We find we need to adjust the gain of the FSS every few months or so to maintain the desired ugf for this loop….Similarly, loop gain monitors for the ISS and PMC servos should also be implemented. We can discuss more what we have in mind at the review.

- we will provide three function generators (with option to lock to master clock) for calibration lines to be injected into FSS, ISS, and PMC servo
  - frequencies within loop bandwidth, TBD
  - amplitude TBD
  - additional AWG lines can be used during maintenance intervals during automatic “health-monitoring runs”

I: List all the locations where PSL beam power is monitored (include this in thePDD too).

- NPRO power
  - right before injection into 35W amplifier (relaxation oscillation monitor diode)
- 35W laser
  - continuously in DBB path
  - optional with DBB
- 200W laser:
  - injection locking diode (in laser box)
  - optional with DBB
  - PMC transmission (RPN diode)
  - PMC locking

PSI layout



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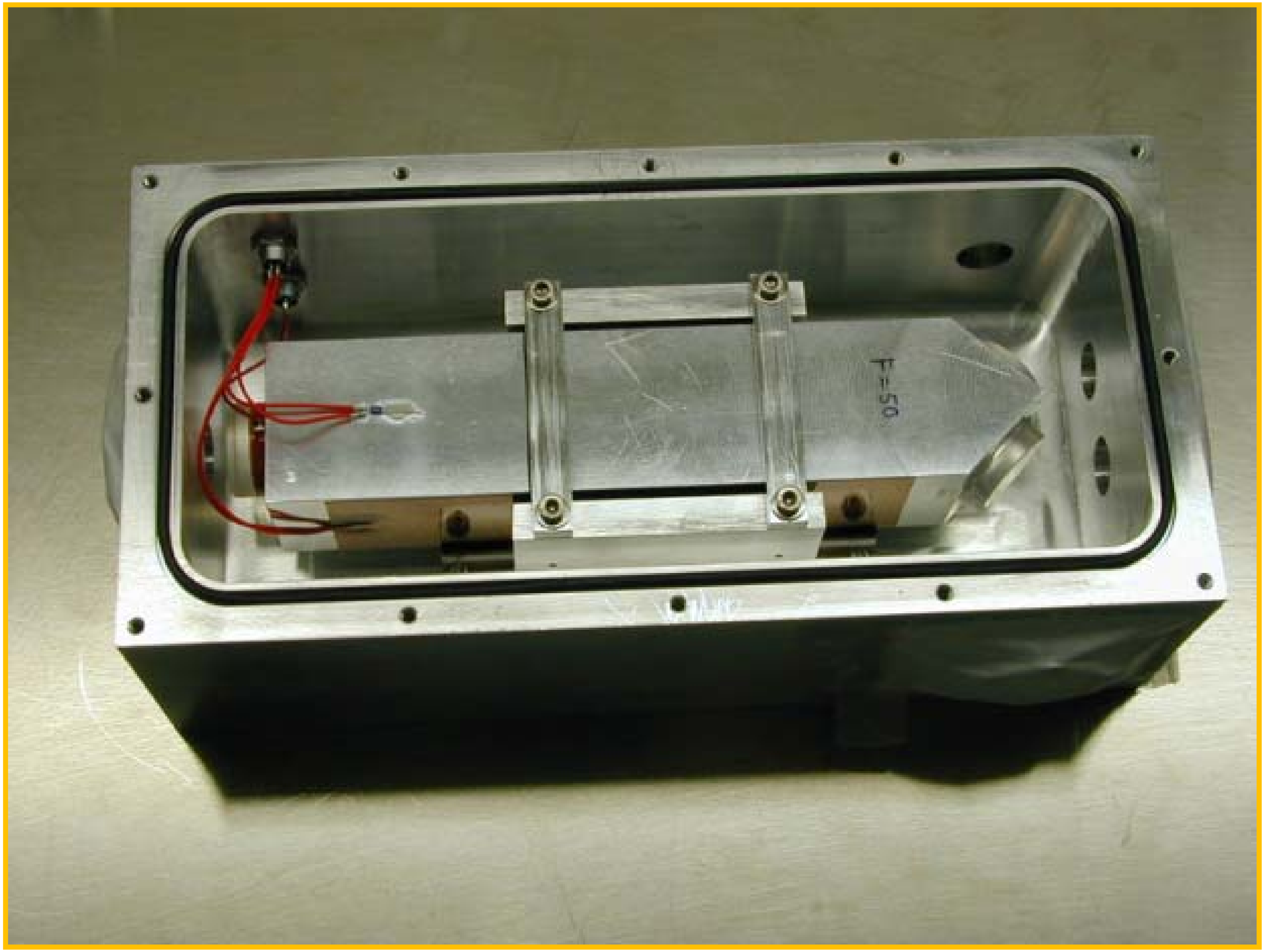
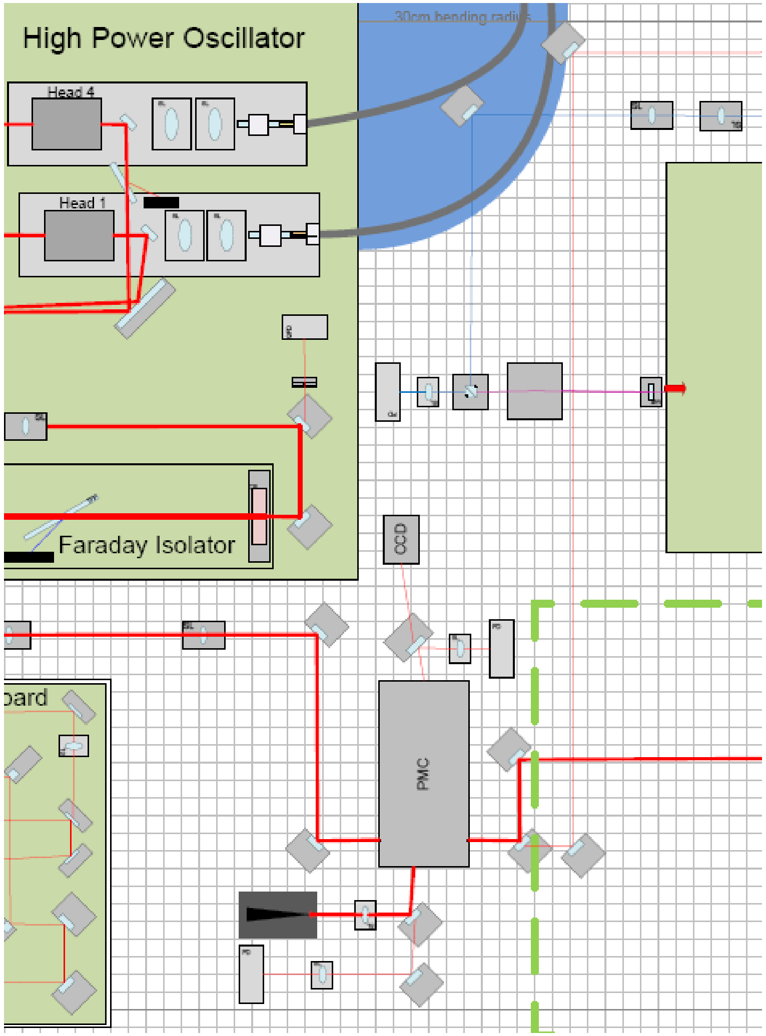
J: PMC design. Give us a more detailed look at the PMC design (e.g., what is the body made of? What is its shape? What does the chamber look like? Thermal actuator design).

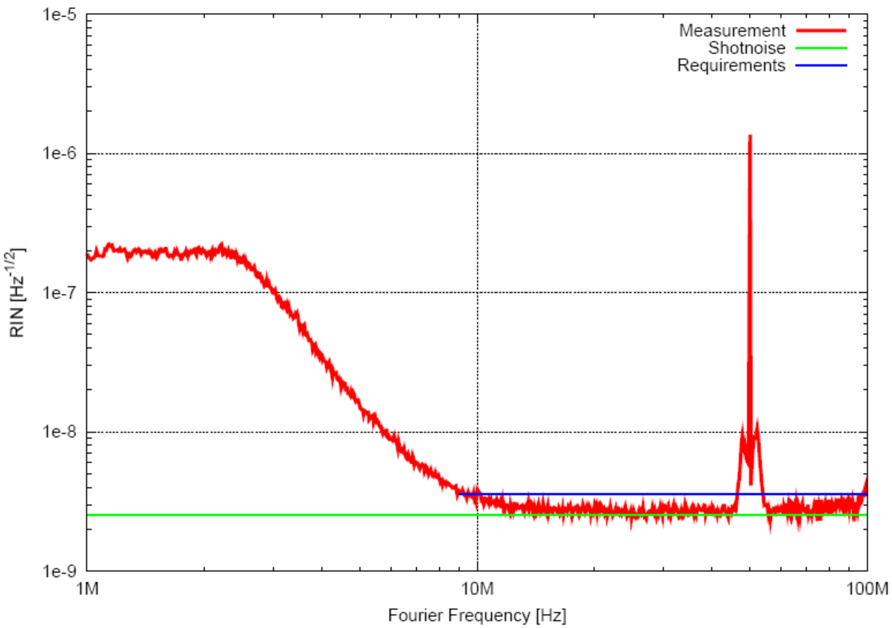


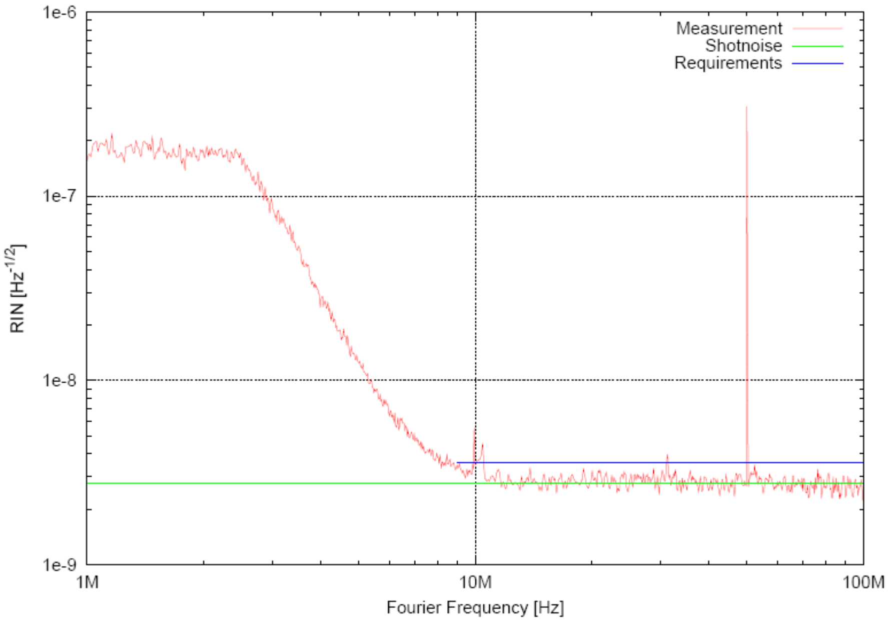
J: The ISC design is now working with 100 ma of detected power on some of their photodetectors, and at the level the RF noise looks a little marginal. Could the PMC be designed to give another factor of 2-3 filtering at 9 MHz? : How about using a 4-mirror bowtie design, where the optical path can be essentially doubled in the same physical space?

- constraints on length with current table layout, if we want to allow for IO beam measurements with DBB
- 4 mirror bowtie might be possible
  - astigmatism higher
  - additional and test effort
- could try to increase Finesse by factor 2
  - thermal loading experiments with 180 FPT and DBB



FPT- before and after PMC





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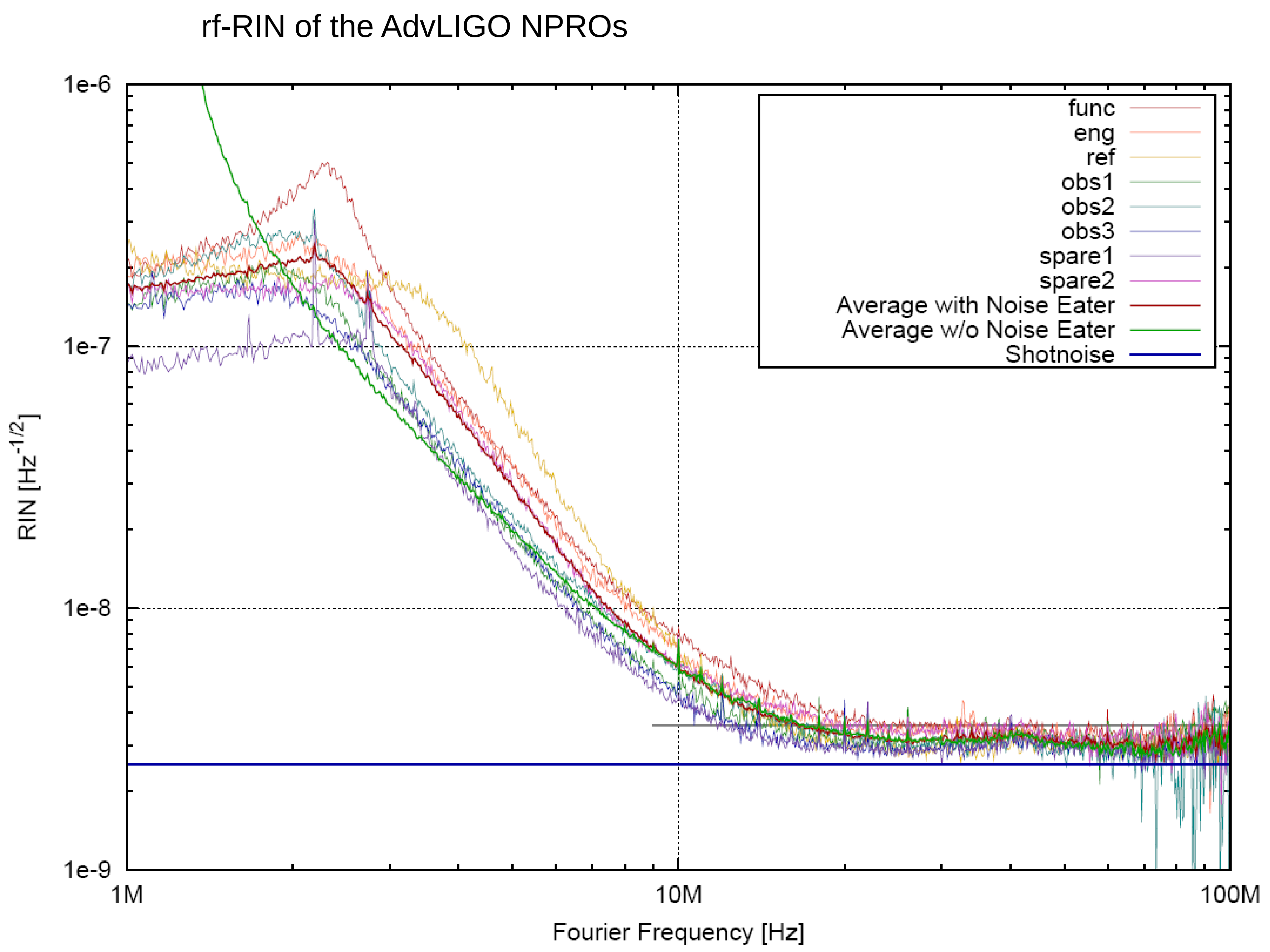
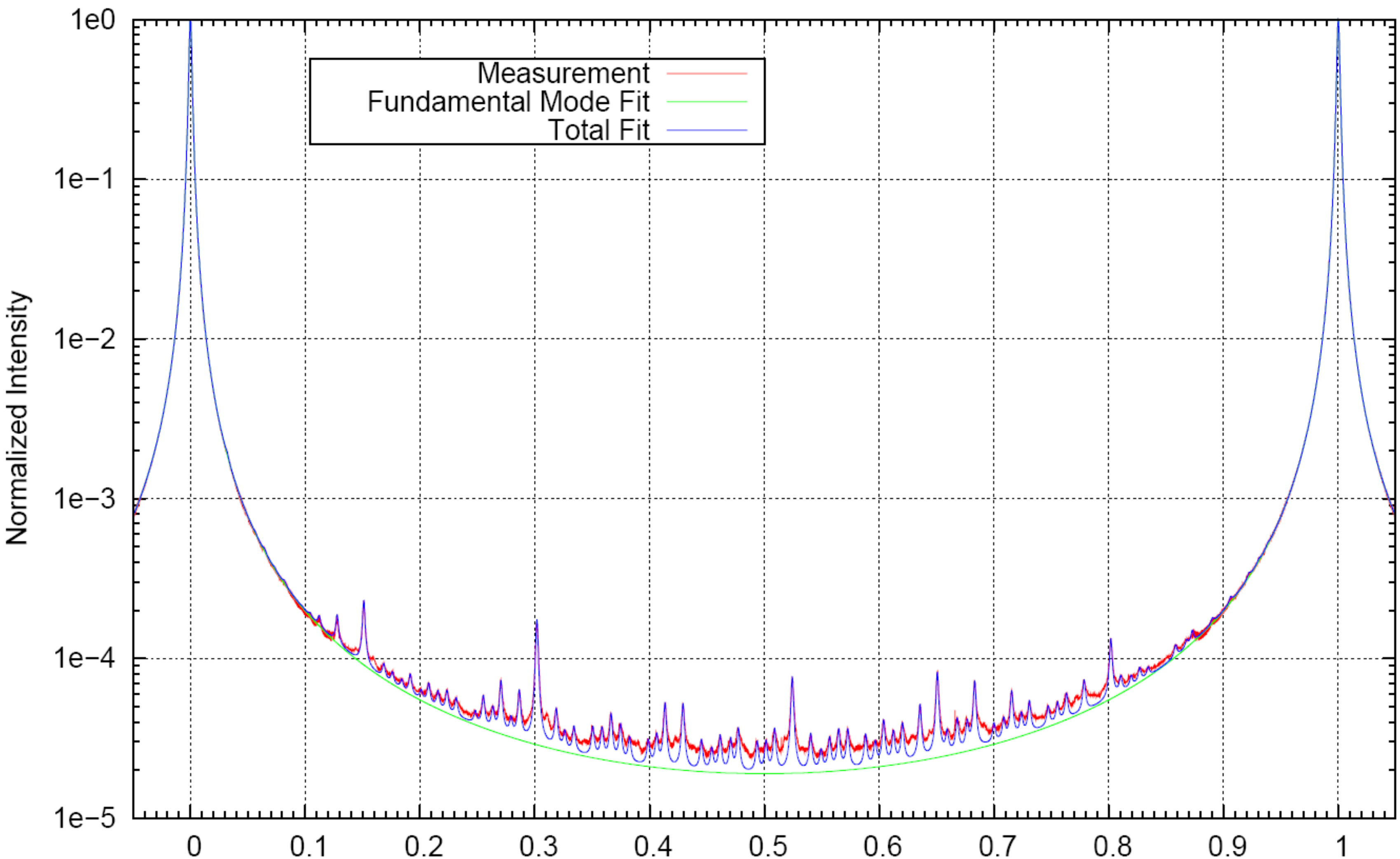
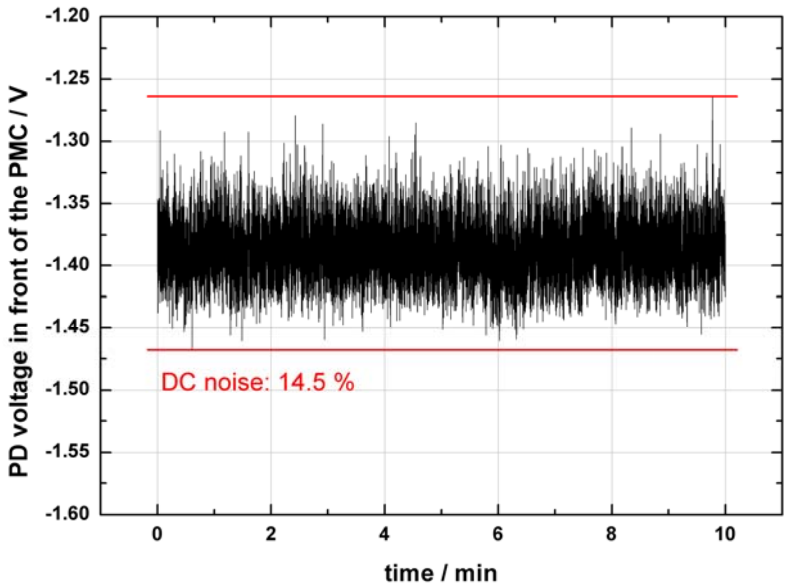

rf-RIN of the AdvLIGO NPROs
1e-6
1e-7
1e-8
1e-9
RIN [Hz^-1/2]
1M
10M
100M
Fourier Frequency [Hz]
func
eng
ref
obs1
obs2
obs3
spare1
spare2
Average with Noise Eater
Average w/o Noise Eater
Shotnoise

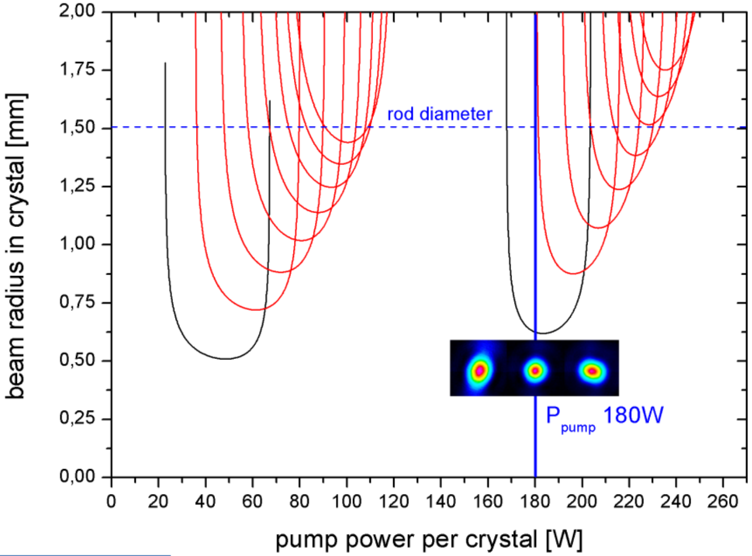
J: Will the PMC output beam parameters change much in going from low to high power modes?



35 W laser behind F=380 PMC

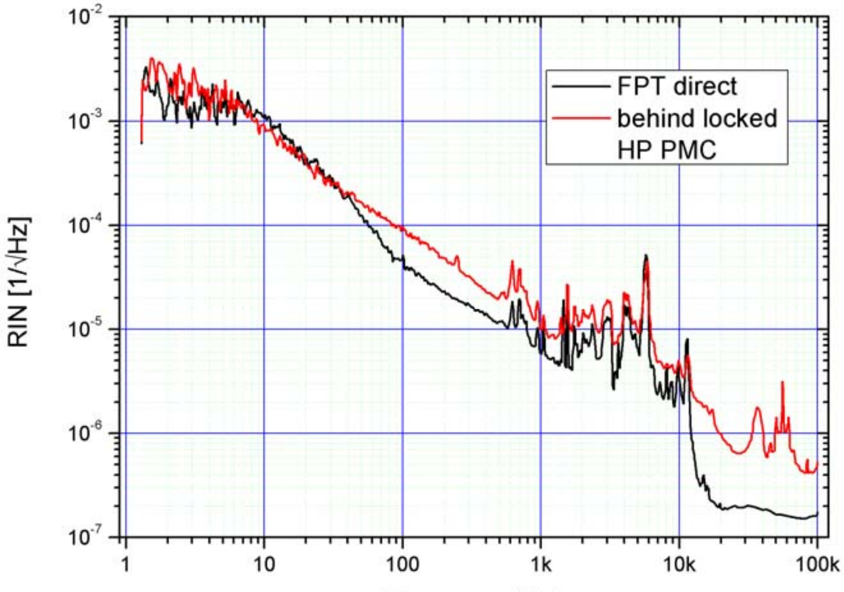
K: Power fluctuations. Fig. 18 shows 15% pk-pk variations compared with the target of 1e-4; how do you get from here to there?



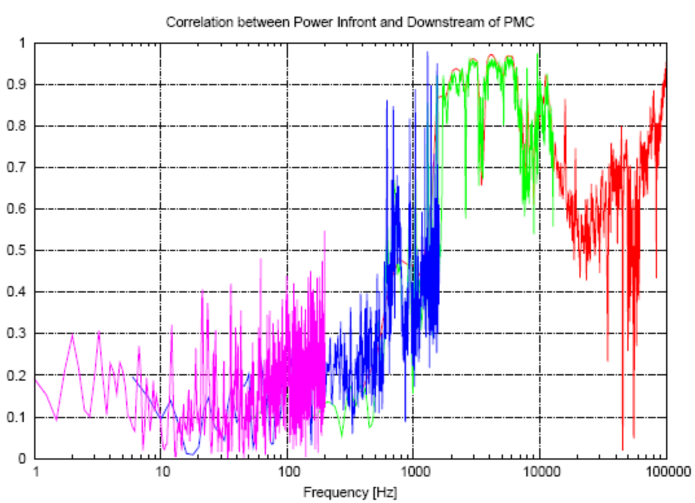


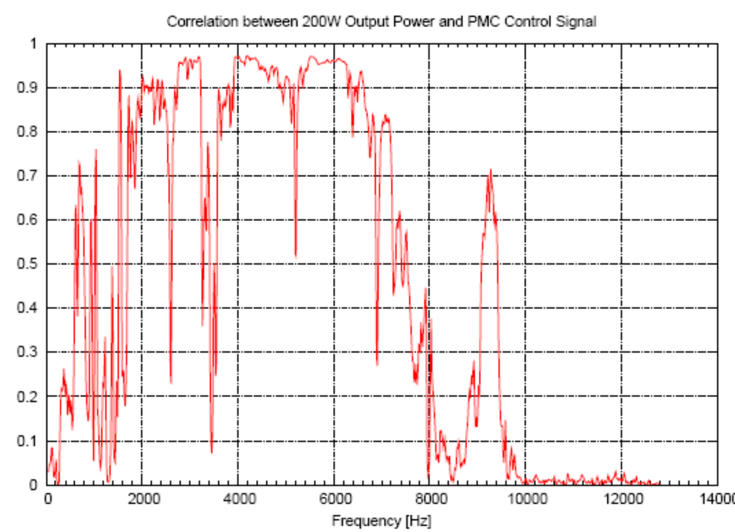
- reduce the free running noise
  - improved diagnostics to find main noise source
  - choose more stable operation point
- use feedback control
  - actuator with large enough range
    - 180W pump source
    - PMC
    - AOM
    - evanescent field prism

K: Fig. 17 seems to show higher noise after the PMC than before; what is going on here? Fig. 37 has a spectral peak with some wide shoulders at 50 MHz; what are these due to and will they be eliminated? Also longer term: did you look at effects of environment temperature and humidity?

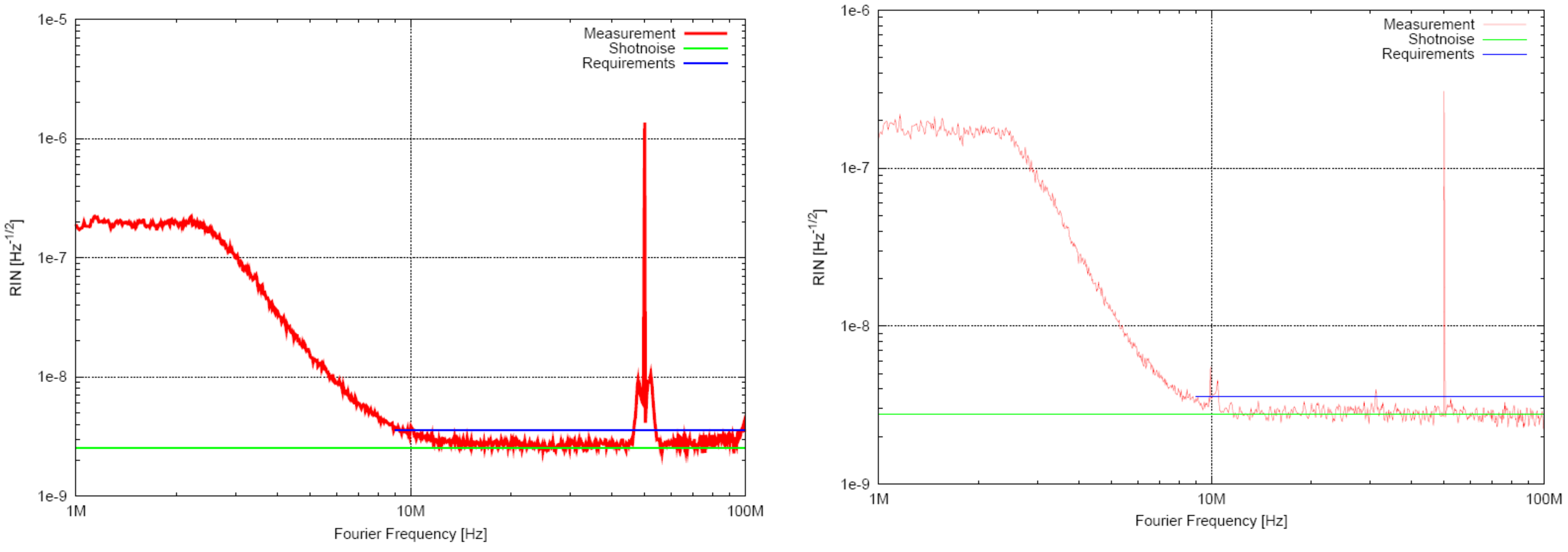


- higher RPN after PMC due to cross coupling
- strong coupling between 180W RPN and PMC error signal
- strong coupling between RPN and IJL error signal
- needs further investigaions





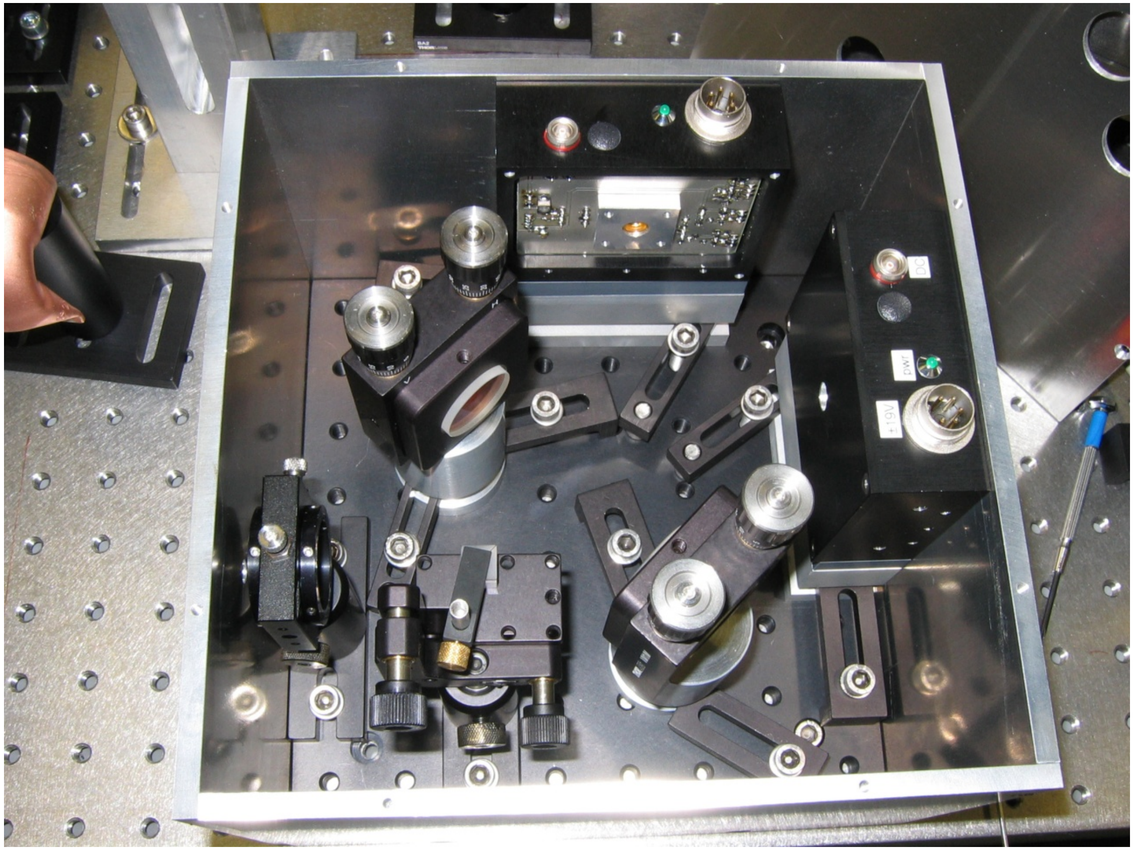
K: Fig. 37 has a spectral peak with some wide shoulders at 50 MHz; what are these due to and will they be eliminated? Also longer term: did you look at effects of environment temperature and humidity?



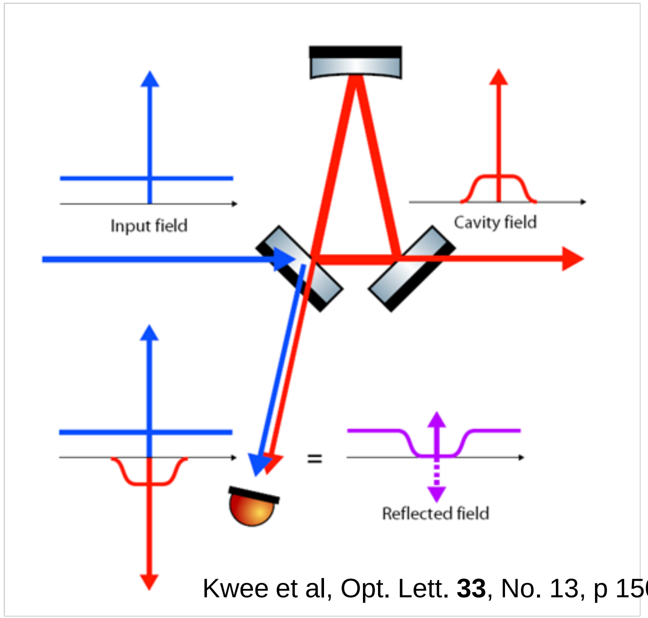
- we have strongly increased diagnostic on laser table to understand the temperature dependence of the 180W laser
- dedicated long term tests are planned for in schedule

L:ISS outer loop sensing. Is this (in-vac) sensor planned to be one or two PDs? We suggest this be two PDs with a 50/50 splitter, so comparisons can be made.

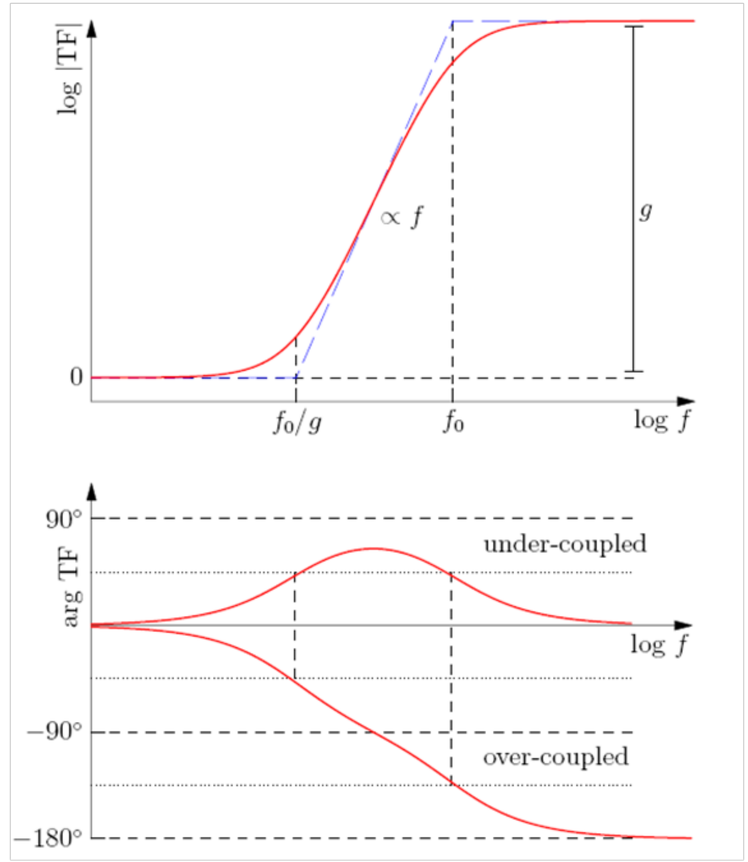
- the plan is to use two diode for out-of-loop sensing



L:There is also the more recent idea of using the IFO reflected report beam for the outer loop. Can the ISS be made to accept the sensor/s at either location?



Kwee et al, Opt. Lett. **33**, No. 13, p 1509f (2008)



- OAC sensing has to be investigated for AdL baseline
- could be DC signal of IFO common-mode sensing diode
- gain factor depends on mode/impedance matching / sideband power
- modecleaner cavity to get rid of SBs ?
- could be tested in EnL already

$$|G(f)| = \sqrt{\frac{1 + g^2 \cdot f^2 / f_0^2}{1 + f^2 / f_0^2}}$$

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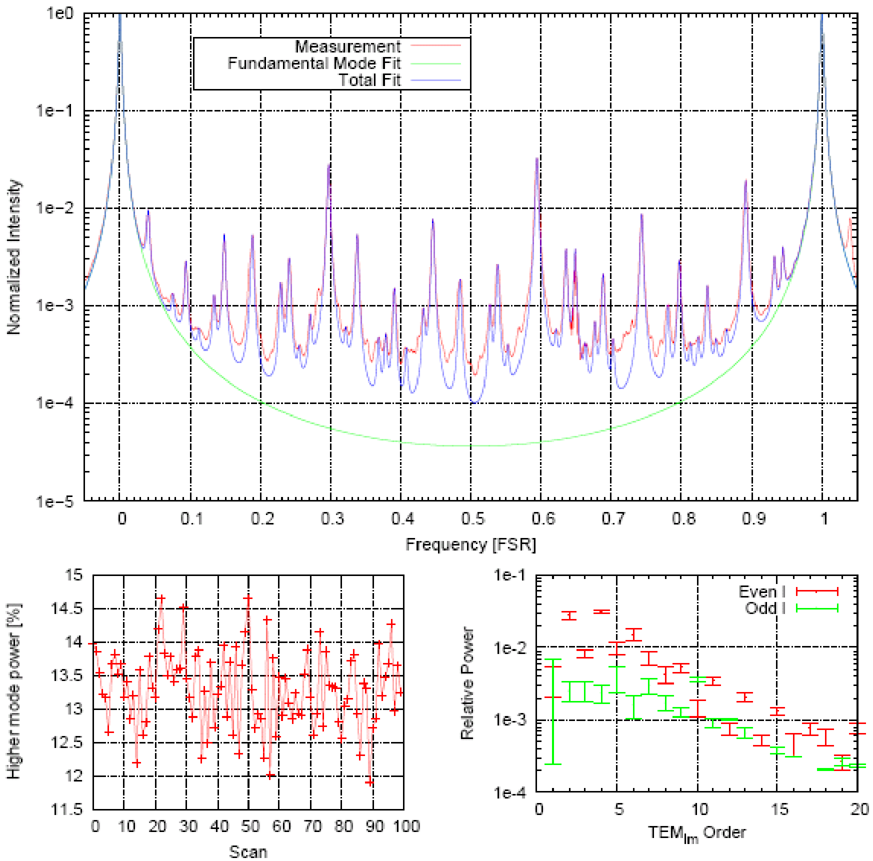
LZH LASER ZENTRUM HANNOVER e.V.

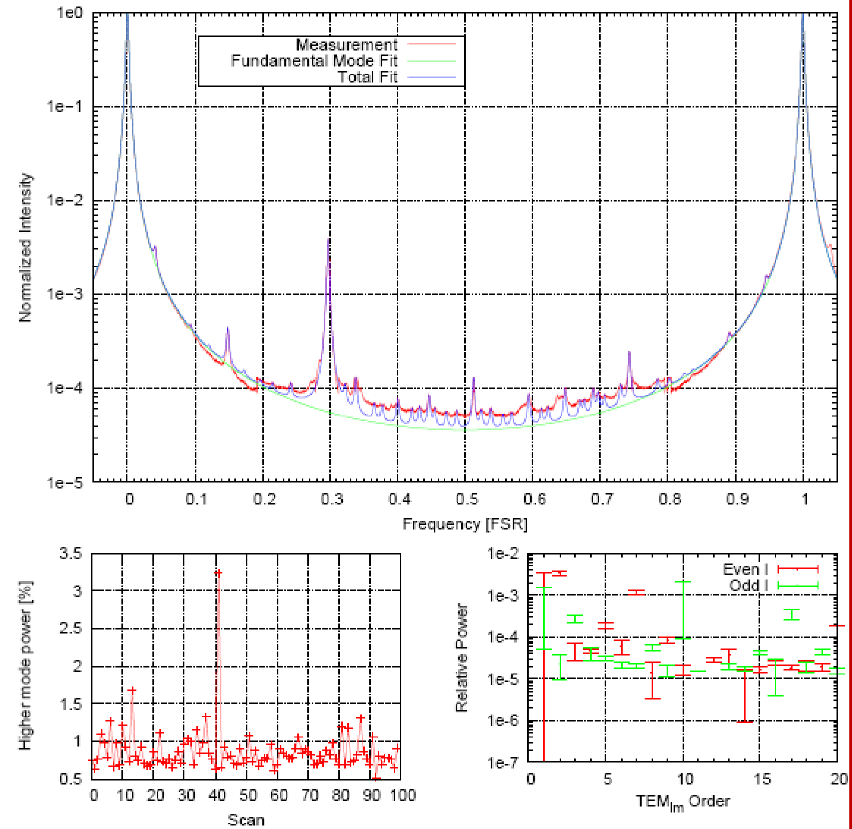
M:How do you plan on reducing the higher order mode content of the high power output beam (p15 of PDD)? How well do you think you can do?



Number of scans:	100	Relative power of one sideband:	-1 ± 0
Measurement duration:	100 s	Significant modes:	25.67 ± 2.95315
Measurement start:	Wed Jun 18 13:14:12 2008	Average deviation:	-0.000912052 FSR
PD signal:	0.00146765 V . . . 8.1071 V	Relative horizontal (X) misalignment:	0.0484971 ± 0.0130575
Samples per FSR:	22426.9 ± 19.3117	Relative vertical (Y) misalignment:	0.0594115 ± 0.0128894
Calibration deviation:	-4.51391% ± 0.310545%	Relative mismodematching:	0.16575 ± 0.00977483
Finesse:	259.435 ± 0.654622	Roundtrip Gouy phase:	0.148497 FSR ± 3.74447e-05 FSR
Higher mode count:	42.08 ± 2.26133		
Higher mode power:	13.2971% ± 0.570173%		

Notes:

180W, June 08 before PMC



Number of scans:	100	Relative power of one sideband:	-1 ± 0
Measurement duration:	100 s	Significant modes:	26.4545 ± 3.95753
Measurement start:	Thu Jun 19 12:20:22 2008	Average deviation:	-0.000802868 FSR
PD signal:	0.000309964 V . . . 6.98466 V	Relative horizontal (X) misalignment:	0.0226088 ± 0.00658679
Samples per FSR:	22367.2 ± 28.2193	Relative vertical (Y) misalignment:	0.0330419 ± 0.00963598
Calibration deviation:	-4.04593% ± 0.0833528%	Relative mismodematching:	0.0577833 ± 0.00306683
Finesse:	257.306 ± 0.494433	Roundtrip Gouy phase:	0.14853 FSR ± 6.3151e-05 FSR
Higher mode count:	42.12 ± 2.24624		
Higher mode power:	0.863677% ± 0.299826%		

Notes:

180W, June 08 after PMC

2. DRD. Table 3 gives the RIN requirement and the corresponding induced motion in the 0.1-10 Hz band, but Table 2 gives the seismic motion only in a limited part of this band, so it is not clear how consistent these are. Then sec 5.2 of the PDD gives a different set of control band requirements. So this all needs to be made consistent

Optic	δx	*RMS seismic/local damping motion*
TM	$6\times10^{-11}\cdot\delta P$ (m/W)	~0.2 nm (f > 1 Hz)
MC	$4\times10^{-10}\cdot\delta P$ (m/W)	~10 nm (f > 0.4 Hz)

Table 2. Optic motion from radiation pressure, assuming dP(f) = constant in the 0.1-10 Hz band, and K = 3. The third column is an estimate of the optic motion, under local damping, due to SEI platform motion and local damping noise.

get rms$_{[0.1\text{-}1\text{Hz}]}$ for MC and TM

The nominal incident power is 800 kW for a TM, and 75 kW for a MC mirror, thus in terms of the relative power fluctuations (RIN), the optic motion is $\delta x \sim (3-5)\times10^{-5}\cdot RIN$. We set the following requirements on power stability:

use this formula to calculated requirement

Frequency band	*RIN requirement (dP-rms/P)*	*Induced motion*
0.1 – 10 Hz	$< 10^{-4}$	< 3-5 nm

Table 3. Power stability requirements in the control band.

5.2 Control Band Fluctuations

The control band is defined as the frequency range from 0.1 to 10 Hz. The relative intensity noise requirements for this band are summarized in the following table.

Frequency [Hz]	$\delta P_{rms}/P$
0.1 to 0.4	$<10^{-3}$
0.4 to 10	$<10^{-4}$

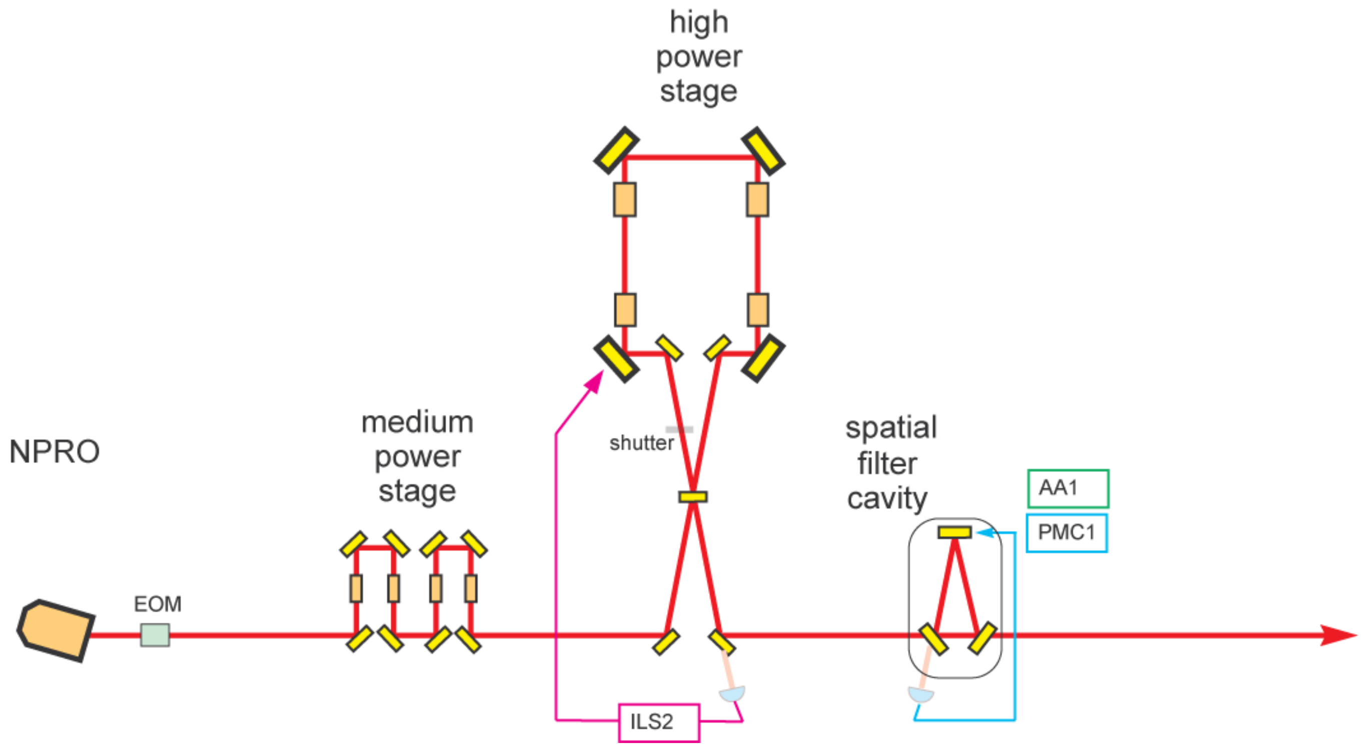
update PDD numbers accordingly

8. Pointing spec (p8 DRD and Table 5 PDD); the formula should use beam size and theta = lambda/pi/omega, instead of waist and far field divergence angle.

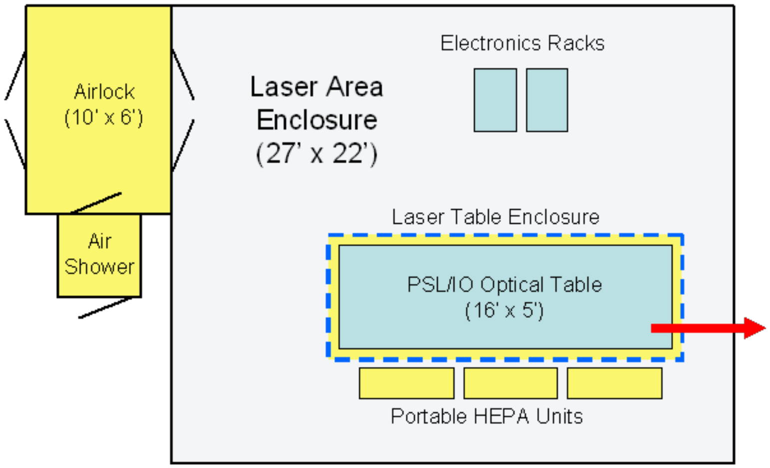
$$U(\delta x, \delta\alpha) \approx \Phi_{0,0} + \epsilon\Phi_{1,0} \quad \text{with} \quad \epsilon = \frac{\delta x}{w_0} + i\frac{\delta\alpha}{\theta_D}$$

21. RF modulation frequency for oscillator PDH locking (p19 of PDD). Given the potential for higher order modes in the 30-50 MHz region, it seems prudent to choose something outside that band (ie, not 35.5 MHz). Perhaps 25 MHz, since we use that in iLIGO

Is there an advantage in using the same modulation frequency as in initial LIGO?

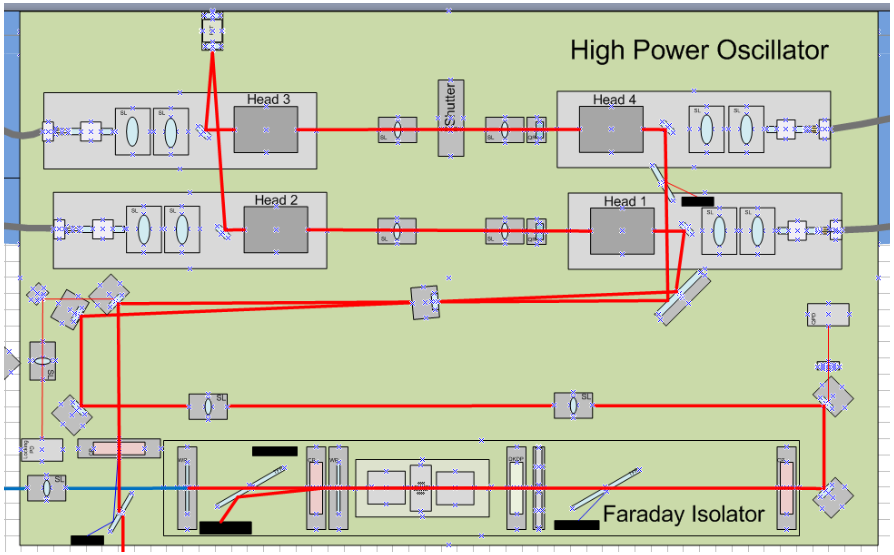


22. Enclosures and such. …What's the plan for deciding whether to include acoustic enclosures for the PSL tables? …



- main goal of enclosure is cleanliness and laser safety (808nm radiation)
- we plan to take precautions in the room design to allow for a later installation of acoustic shielding
- include acoustic damping measures in room design
- find acoustic coupling paths during EnL -> reduce coupling
- limit acoustic noise sources in LAE

23. Low power mode. Somebody is going to come up with a reason to want more than 16 W. Consider a way to make the full MOPA power (35 W) available



- we do not see a good way to make 35W available for fast turn-arounds between 200W and 35W
- with a one day effort output coupler of high power stage can be change to HR mirror if 35W will be required for longer periods of time
- in case 35W are required with fast turn-arounds use IO attenuator

QA questions (1)

1: I noticed there was a statement on investigating effects of temp and humidity. Do we have a specifics on the ranges for test? We should ensure that all the test plans written for this system has statements of temp and humidity requirements.

When we do the test we will of course try to test the relevant range to be expected at the sites. If we can not change humidity / temp far enough we will project the results.

2: I received some info from Benno on the breadboard, need to ensure we setup periodic tests on this as well and certify it is functioning properly prior to laser tests. Function generators, arbitrary waveform generators, scopes, signal analyzers all need to be calibrated at all test sites, and verified.

How many layers do we need to certify? The DBB is only provided to test the PSL to recognize trends / drifts and to get a quick info in case of a failure. The main functionality of the PSL will be tested by the IFO.

3: Do we have any data on RF interference? High mHz to low gHz ranges, do these have any measureable effect on the PSL system?

We do not have data. How should we test RF interference?

QA questions (2)

4: Audits need to be done for calibration programs, cleanliness. Will need to work with Benno to design audits, and schedule. Is there an expectation with the teams in Hannover that we may perform these audits? How sensitive would they be to this? Timing?

We can't set hard requirements on cleanliness. What kind of audits has Mick in mind?

5: Clearly outline a section on Inspection processes, participants. What inspections will be required at what stage? Who will attend inspections? What are the focus areas of each inspection? What is the follow up process for deficiencies? Ensure we generate an inspection report and post to DCC.

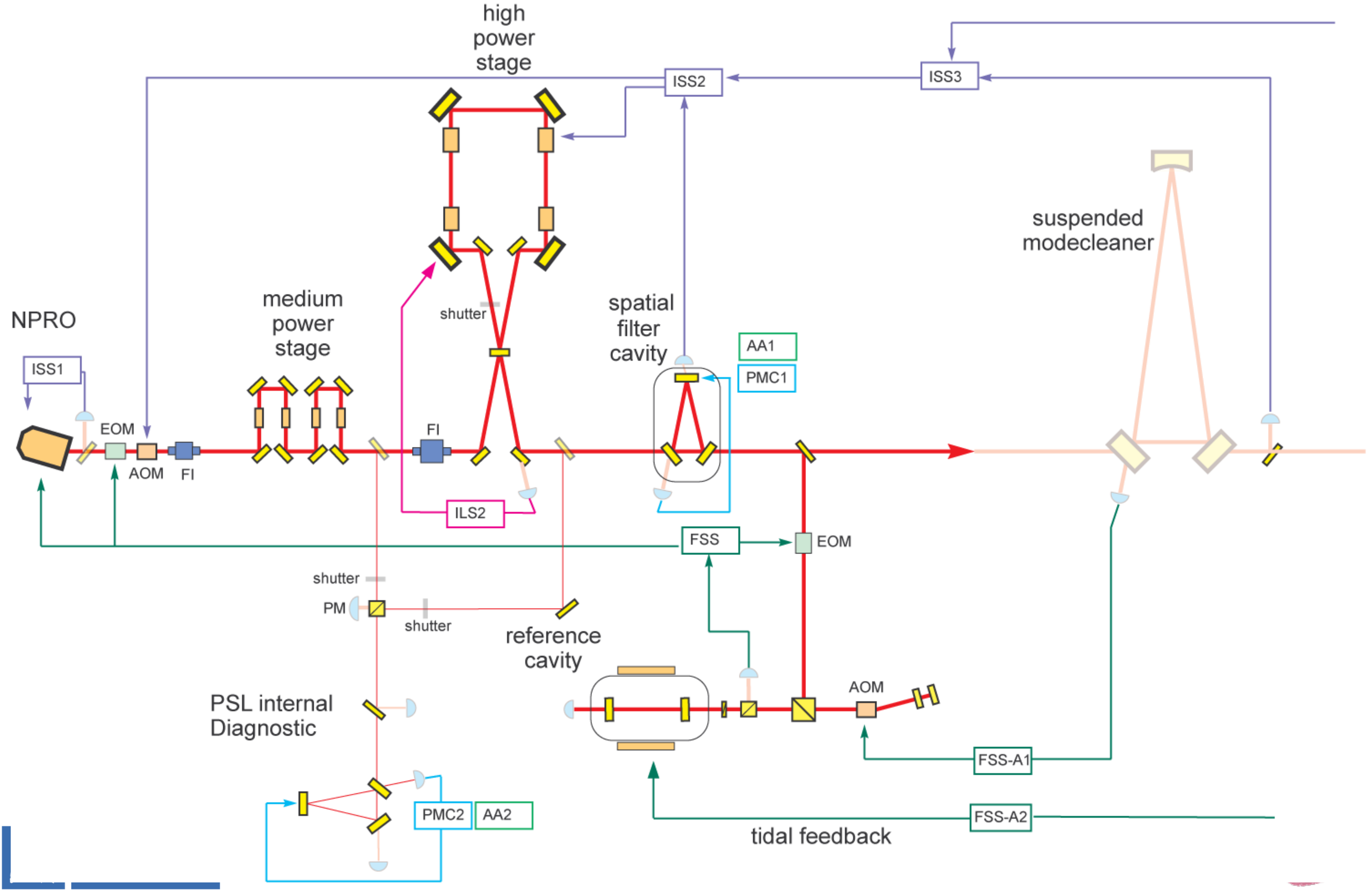
We kind of inspections?

QA questions (3)

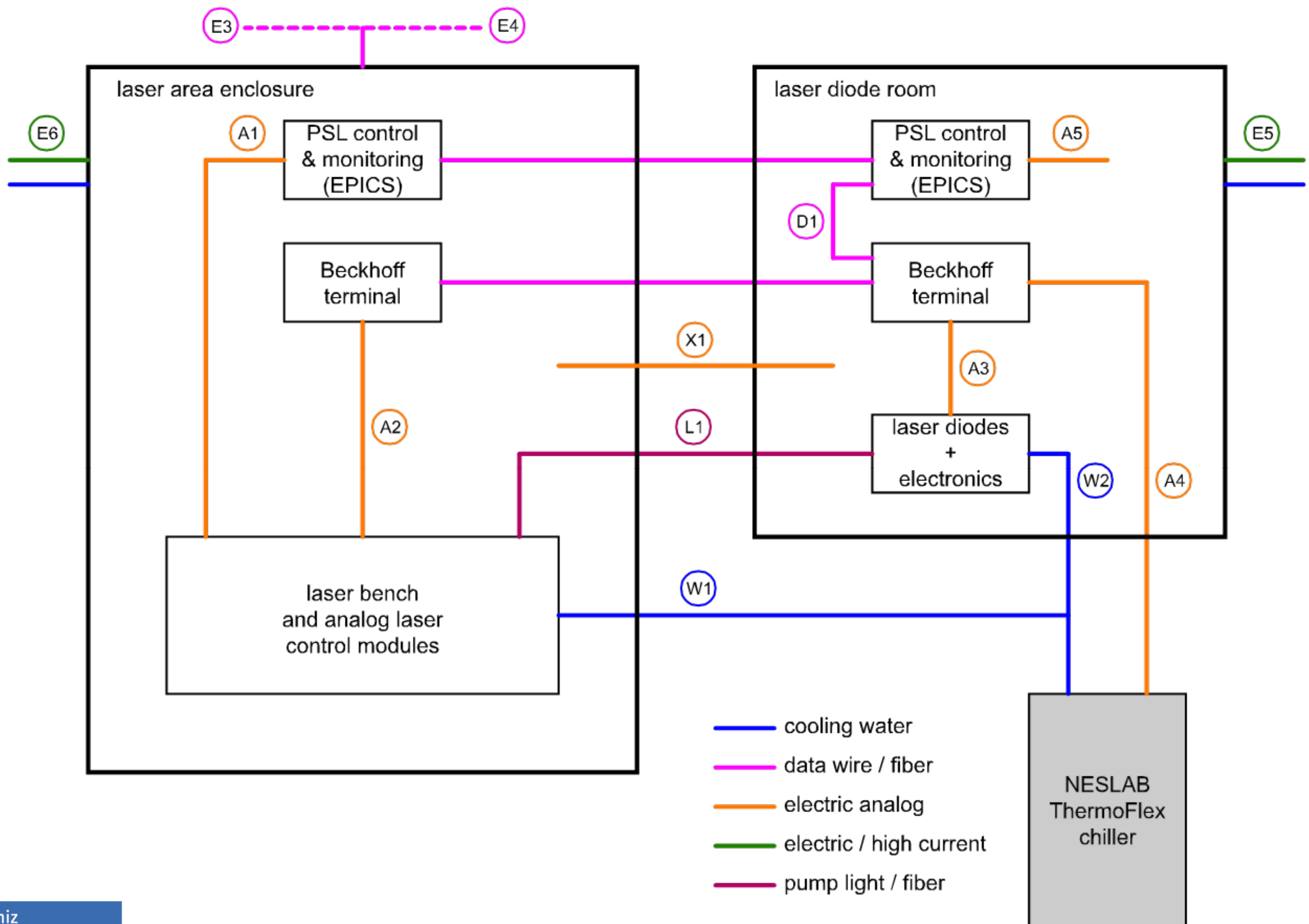
6: We are developing a defect tracking system and I would like to have the test and inspection teams all use this tool to track issues through final disposition. As the system is being developed I would like to interface with a team member to ensure we capture fields needed for PSL. We will write a brief instruction manual, and I will provide tracking support, moderation, to ensure we dispose of issues in a timely manner, whether it is repair, replace, defer, etc. It will be important to use this for even human errors so we can generate a "Lessons Learned" document on the fly.

Might be a good thing. Who is the test and inspection team. What is a defect?

Advanced LIGO pre-stabilized laser system

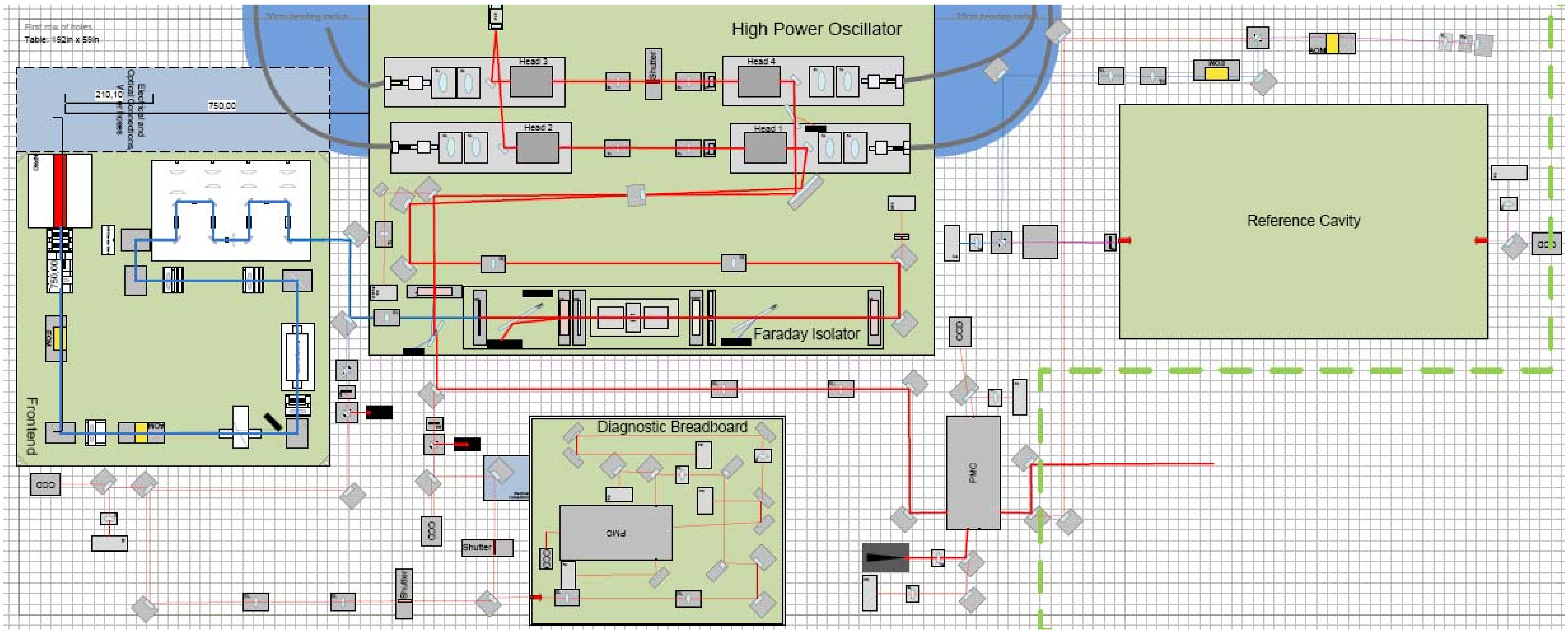


Interfaces



E3
E4
laser area enclosure
laser diode room
E6
A1
PSL control & monitoring (EPICS)
PSL control & monitoring (EPICS)
A5
E5
D1
Beckhoff terminal
Beckhoff terminal
X1
A3
A2
L1
laser diodes + electronics
W2
A4
laser bench and analog laser control modules
W1
cooling water
data wire / fiber
electric analog
electric / high current
pump light / fiber
NESLAB ThermoFlex chiller

PSL table layout



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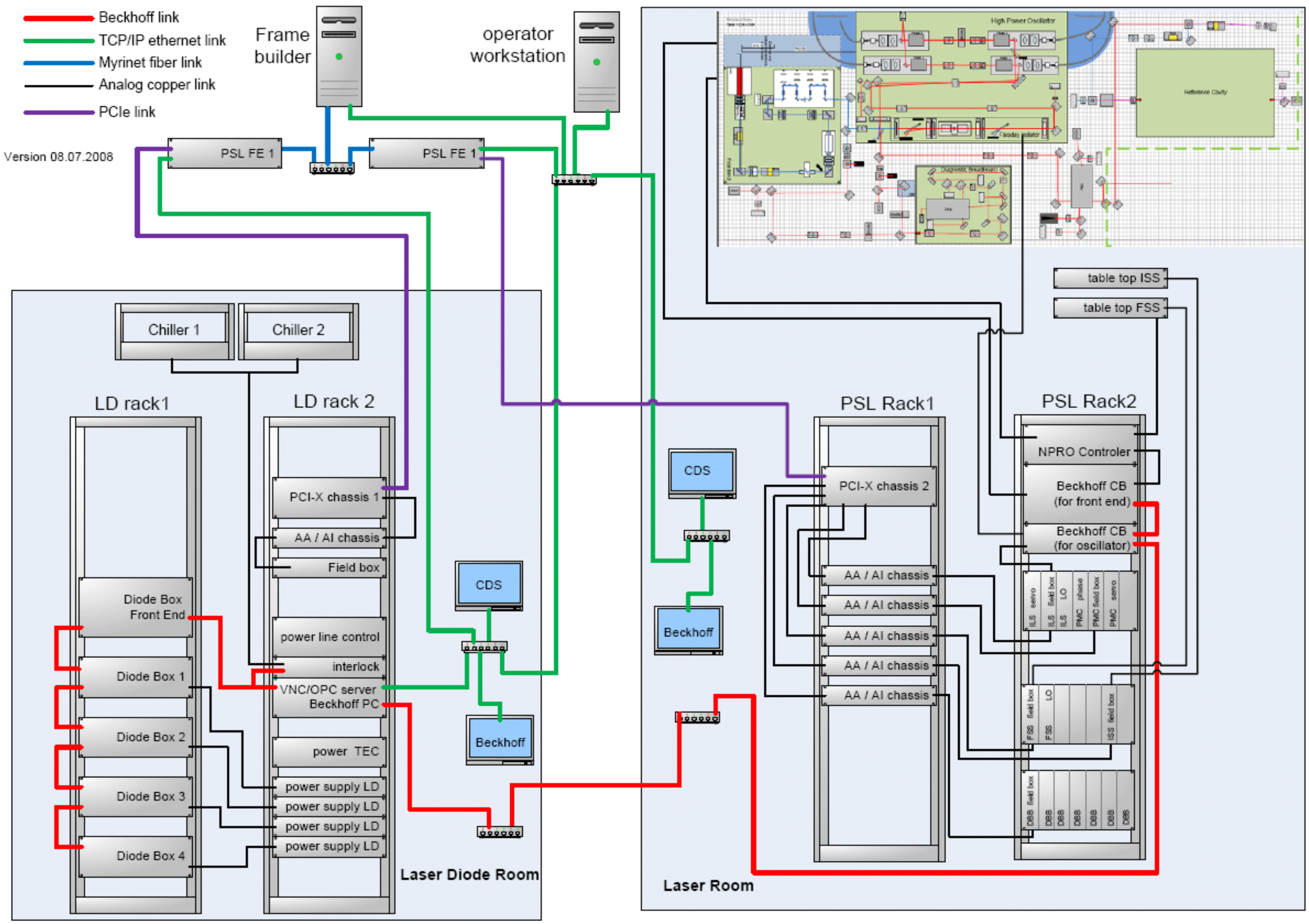
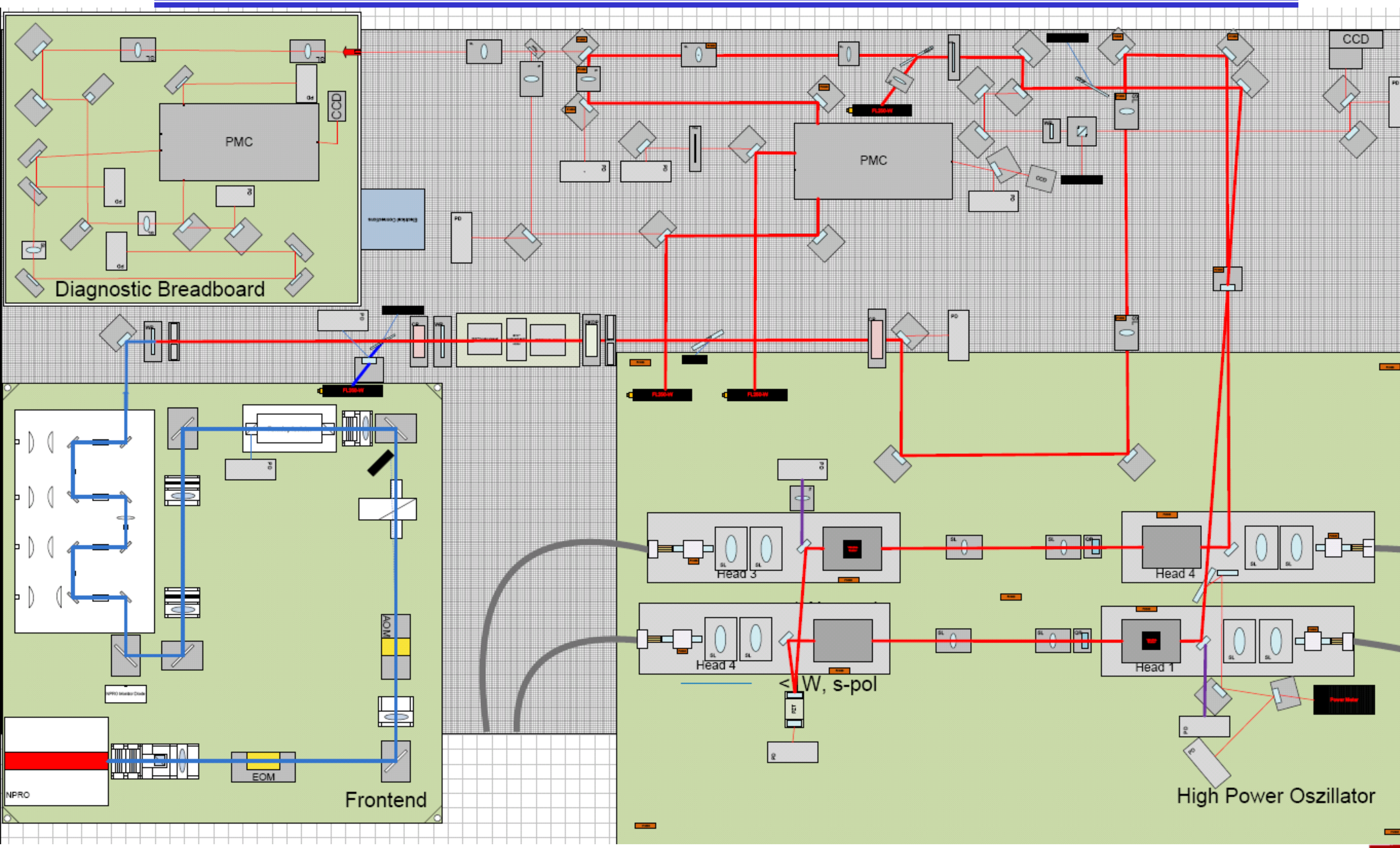
computer control - overview



Functional PT at LZH



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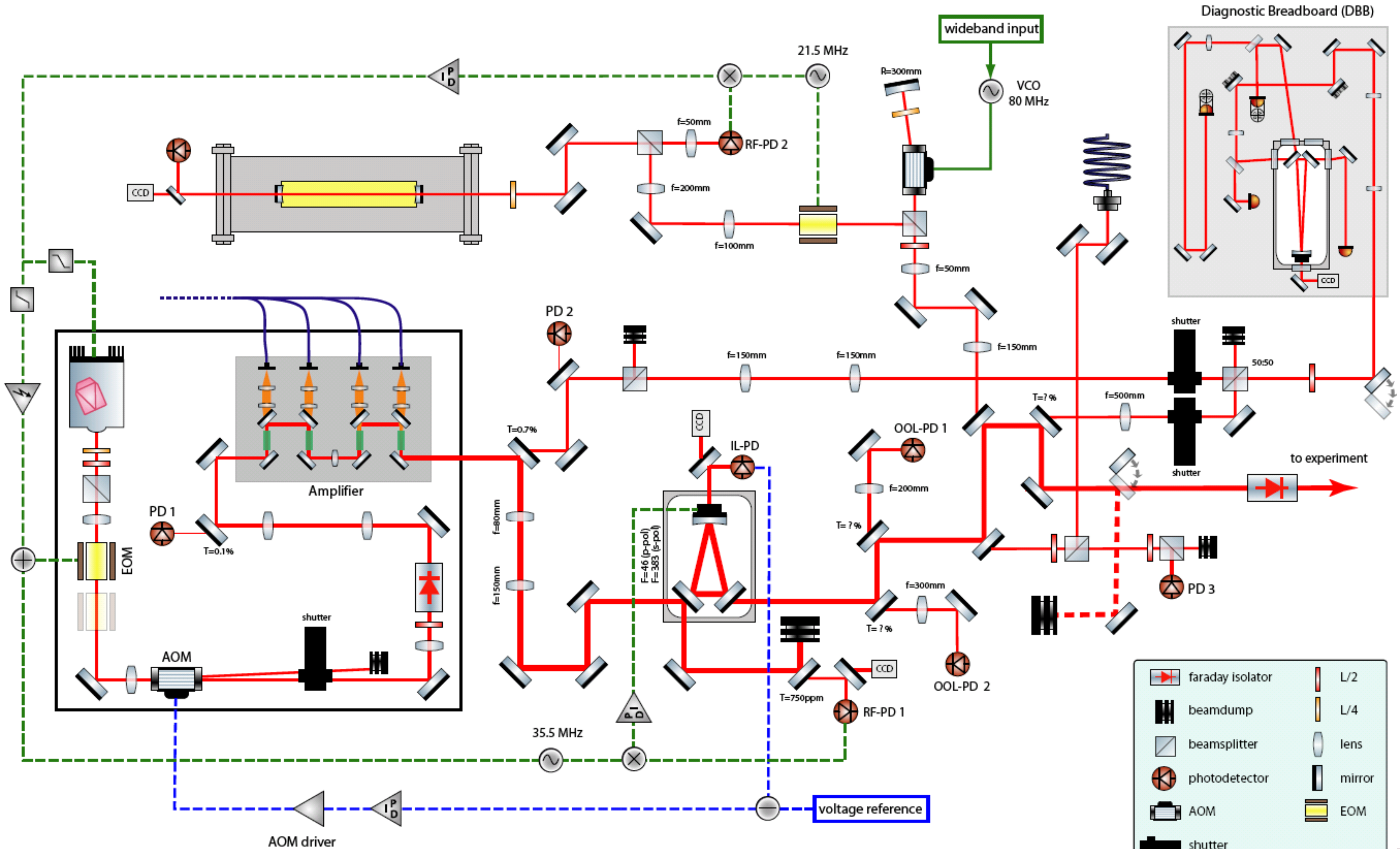
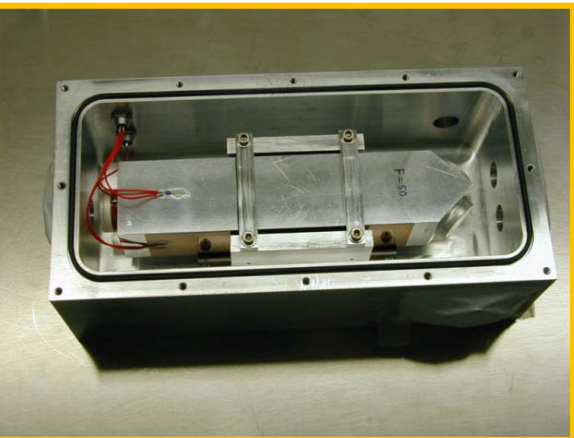
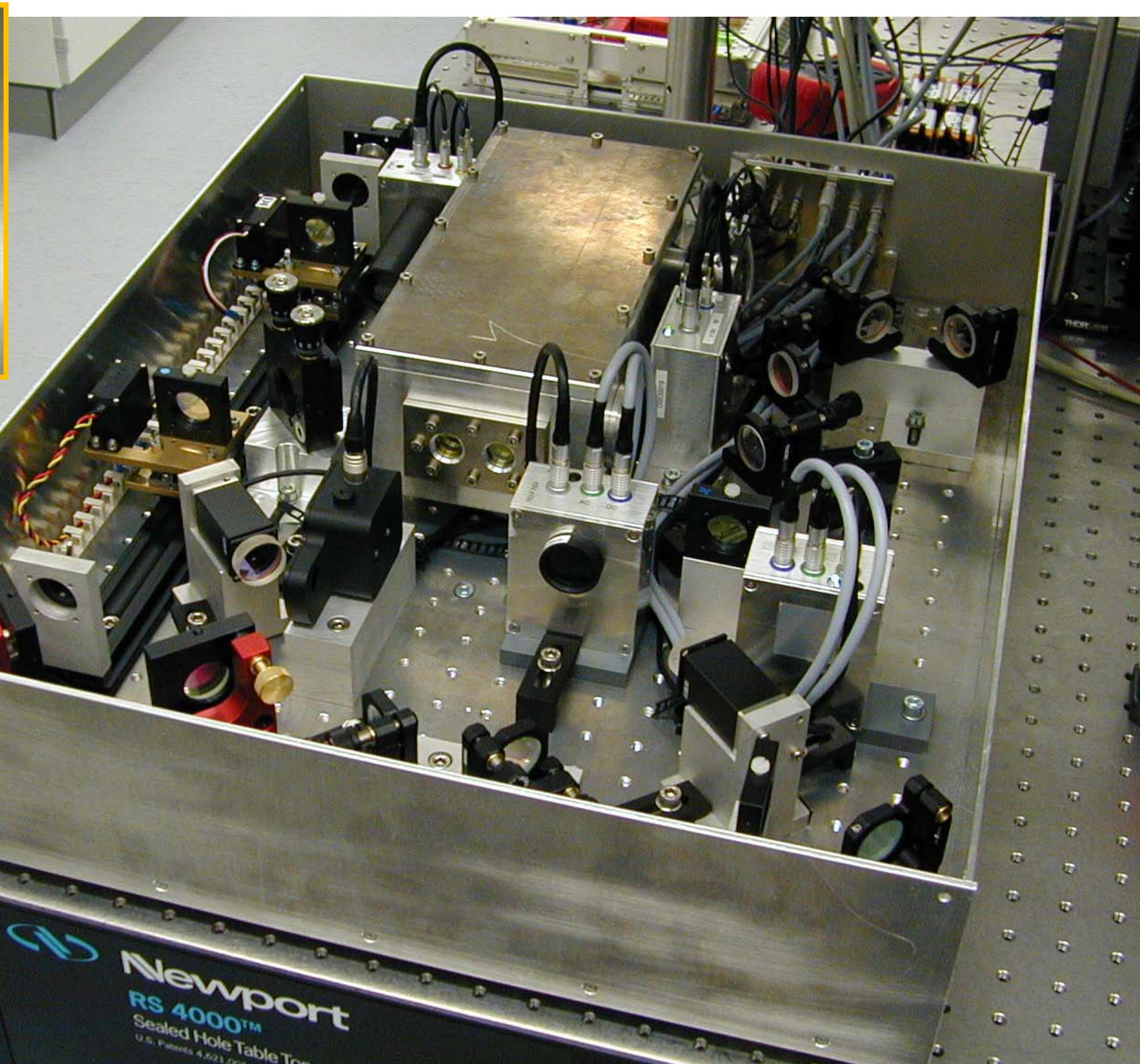
35W reference system at AEI

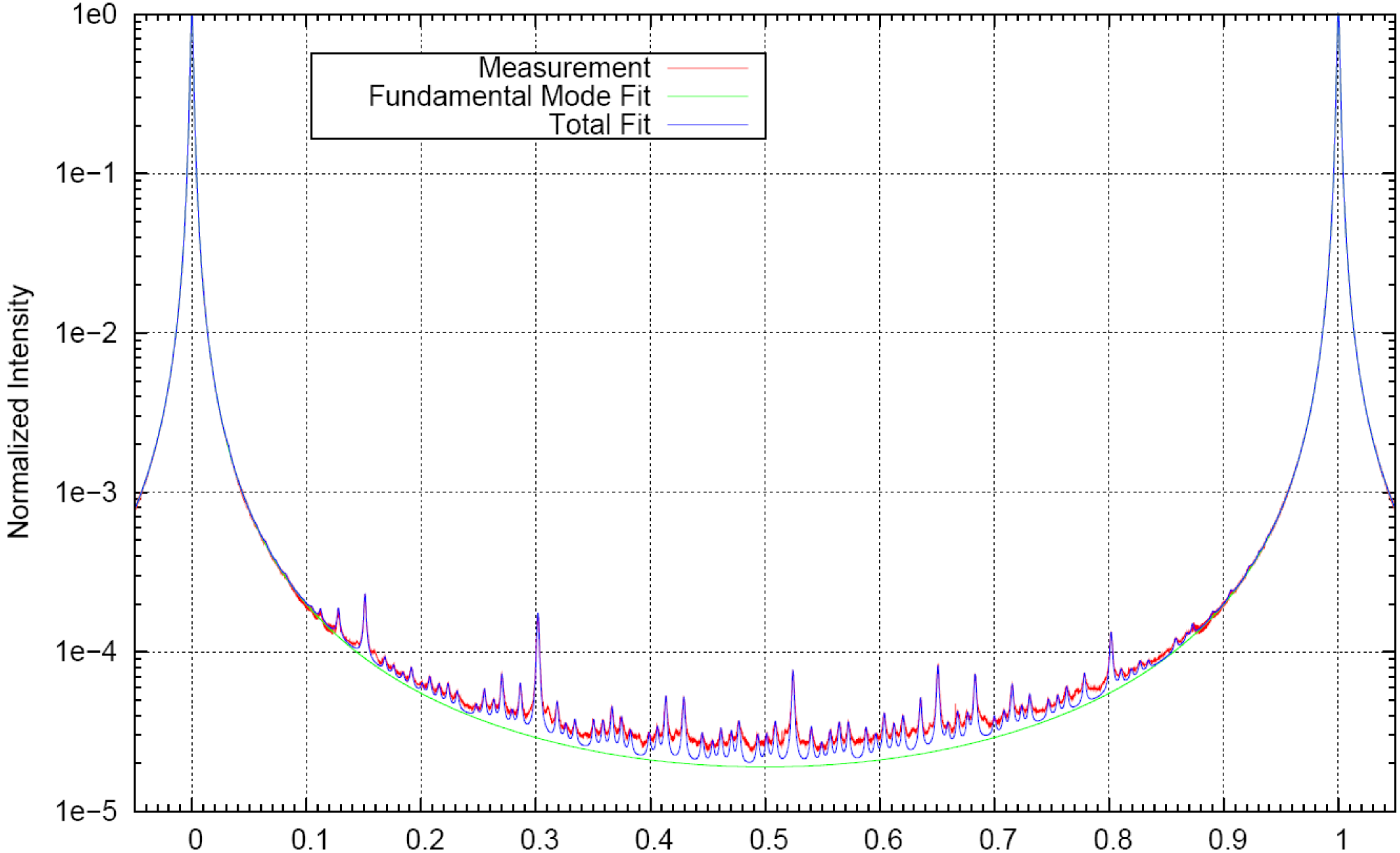


beam diagnostic setup





beam scan of 35W laser filtered by PMC



Finesse: 361 ± 0.5
higher order mode power: 0.18% ±0.01%

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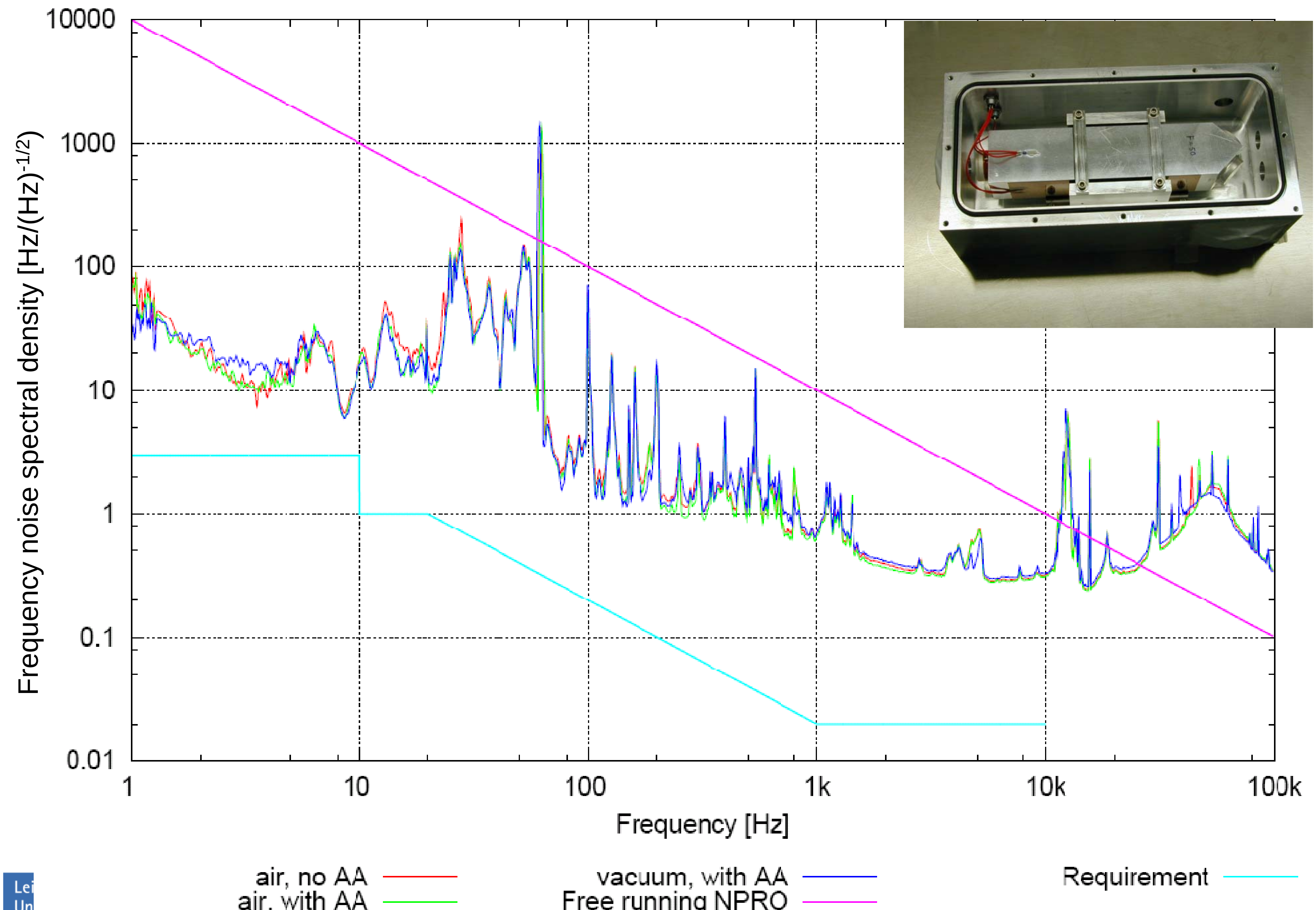
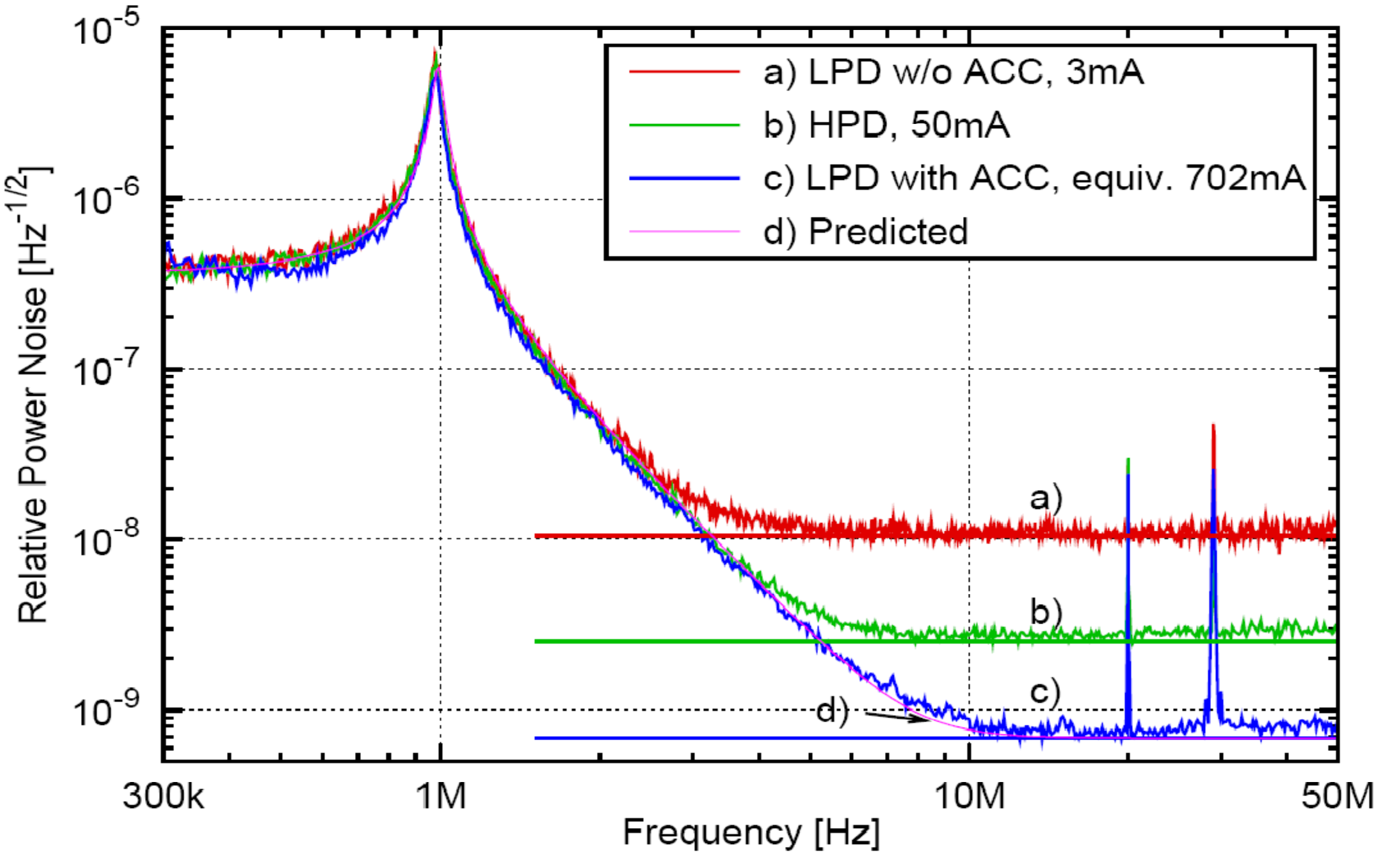
Frequency Fluctuations PMC

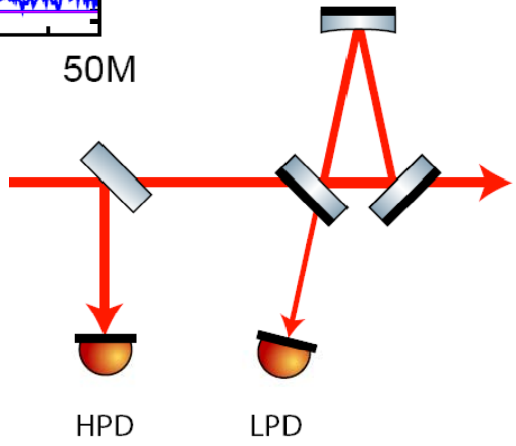


Power noise measurement



Detected photo current: 3mA

Equivalent photo current: 702mA



DBB – acceptable beam parameters