LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Laser Safety Plan
UF High Power Laser Facility
at the LLO

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1 Purpose

This document outlines the laser safety and standard operating procedures that are implemented at UF High Power Laser Facility (HPLF) at the LLO and is a supplement to the LIGO Livingston Observatory Laser Safety Plan (LIGO-M990148). This document has been written to ensure the safety of personnel and equipment in and around the area of High Power Laser Facility.

2 UF-High Power Laser Description

The primary laser in the HPLF is a 100W, continuous wave, class IV Ytterbium fiber device. Built by IPG Photonics, the YLR-100-LP laser is a diode pumped device and delivers near-infrared radiation (1064 nm). This radiation is not visible by the unaided human eye. Only one fiber coupled output port exists and is used for all operating powers.

Additional laser systems employed in the HPLF and their hazards may be added as amendments to this document.

3 Hazards

Radiation from Class 3B or Class 4 lasers is a hazard to eyesight, skin, and equipment constructed from flammable materials. This hazard is observed in the form of both direct beam and specular reflection. Infrared lasers such as the HPLF 100W laser pose an additional risk since they are not readily observed without infrared sensors or cameras. Furthermore, it should be noted that highly focused high power lasers can generate micro-plasma reactions on nearly any irregular surface. This may result in the ignition of painted surfaces or even substrate materials. Therefore, care must be exercised in analyzing what materials are to be placed in the beamline before they are placed into the beamline.

After emission from their respective lasers, laser light propagates through free space over the experiment table. Due to the nature of the high power test facility, the trajectory of the beamline changes during experiment conversion. Diffuse, specular, or possibly direct beam may depart the table and impact the lab walls. Users must check for and control this health hazard prior to increasing laser power to requested running power.

The HPLF is also frequently involved in optical component failure testing (often called destructive testing). In addition to the above health hazards, destructive testing can result in rapid vaporization of substrates resulting in an explosive failure of the material under test. Preventative steps must be taken to contain any flying debris and eliminate injury to humans and damage to equipment.

4 Controls

Controls for operation of this laser lab conform to guidelines provided in ANSI Z136.1 for lasers used without protective housings, in research and development environments, and by highly trained personnel.

4.1 Administrative Controls

For purposes of laser safety, two conditions are defined for the UF High Power Laser Facility at the LLO. These conditions are LASER SAFE and LASER HAZARD.

The LASER SAFE condition exists only when all Class 3B or Class 4 laser power supplies have been shut down, removed from their respective energy sources, and are therefore incapable of being energized.

The LASER HAZARD condition exists any time a Class 3B or Class 4 laser in the HPLF is capable of being energized.

4.2 UF High Power Laser Test Facility Status Controls

The procedure for transitioning between the various conditions is documented in section 7. The devices used for status control are documented below.

One laser warning sign adjacent the primary entrance provides total lab hazard status. It is controlled by a key switch inside the lab that also controls laser system power outlets. Responsible laser personnel should verify the operation of this sign prior to activation of any class 3B and class 4 laser in the facility. Only after the sign is verified as operational and indicating LASER HAZARD may Class 3B or Class 4 lasers be engaged.

All Class 3B or Class 4 power supplies are to be locked and tagged out in the "off" position and verify that the hazard status sign has switched to LASER SAFE before entering the LASER SAFE condition.

4.3 UF High Power Laser Test Facility Emergency Laser OFF Switches

A "BEAM OFF" interlock circuit is connected to the large access doors and initial foyer door accessing the lab. If these doors are forced open, all properly equipped Class 3B or Class 4 lasers' interlocks or shutters will activate. This implies that various laser power supplies will enter a standby state or a physical automatic beam block will block the laser output aperture. Lasers without the proprietary power supply interlock will be equipped with a laser shutter.

This physical barrier must close upon forced entry. There may be no uncontained beam between the output port and the shutter. The lab officially remains in LASER HAZARD and the use of protective apparel remains mandatory. Furthermore, a forced door will set off an alarm in the Entrapass LLO security computer. This alarm must be reset by the LSO for the lasers to be reactivated.

The second and third types of emergency switches are connected to the main power bus. The main power bus on/off switch is located inside the HPLF adjacent the large egress doors. Two EMERGENCY STOP buttons are also located around the HPLF. One EMERGENCY STOP button is located at the main entrance below the status sign, while a second button is located adjacent the aforementioned on/off key switch. Pressing either of these buttons or turning the key switch to the "off" position will shutdown all HPLF lasers regardless of classification by disconnecting the HPLF's electrical power.

A total shutdown can result in equipment damage. Once the lasers are turned off, the lab immediately transitions to the LASER SAFE state. This is noted on the lab's laser hazard sign. This form of shutdown is not recommended for normal operations. Resetting the EMERGENCY STOP buttons following a emergency shutdown will not reactivate Class 3B or Class 4 lasers. A shunt trip mechanism inside the lab's circuit breaker box prevents immediate reactivation. This shunt trip must be reset for main power to be restored.

Emergency personnel (paramedics, firefighters, and such) are authorized to use the EMERGENCY STOP BUTTONS to secure lab safety when forcing the main or egress doors. As indicated above, pressing the EMERGENCY STOP BUTTON will permit entry without the need for safety eyewear.

No prior communication is required with the LSO or control room for an emergency shutdown. Following any emergency shutdown, the responsible operator must communicate the reason for the shutdown to either the LSO, SSO, LLO facility director, and/or UF-LIGO. Restart of laser operation will proceed only after the responsible operator has defined and declared new operating parameters to prevent further incidents should it be needed. New operating parameters will be added as amendments to this SOP.

4.4 UF High Power Laser Test Facility Warning and Access Controls

A single warning sign is placed adjacent the lab entrance. It is controlled by a key switch inside the HPLF. This warning sign is powered through dedicated AC power lines parallel to those providing power for the laser power supplies. This sign is also connected to the "EMERGENCY OFF" switch (section 4.3). It is the responsibility of the persons working within the UF High Power Laser Facility to verify the operation of the signs prior to energizing any facility Class 3B or Class 4 lasers.

4.5 The Restricted Lab Condition

A restricted lab condition exists any time a Class 3B or Class 4 laser device is activated within the UF High Power Laser Facility and is emitting radiation. The access doors must be kept closed at all possible times with the laser warning signs on during this type of laser operation. Access to this area will be restricted to Laser Operators of LIGO-M990151L who have obtained HPLF clearance through UF-LIGO and the LLO Laser Safety Officer. This master list of Laser Operators is found on LIGO Livingston Observatory Laser Safety website, http://www.ligo.caltech.edu/laser/registered_laser_personnel.pdf.

Only Laser Operators who have UF-LIGO clearance are authorized to work on the UF High Power Laser Facility tables.

The safety of the UF High Power Laser Facility tables also relies on the following:

- Training—Personnel must be a Laser Operator for both LIGO-M990151, SOP: LIGO 10 W Laser for the 4 km Interferometer Operating in the LVEA (with Laser Area Enclosure) and LIGO-M030100 for the HPLF 100 W laser.
- Lab doors are always closed during LASER HAZARD operation.
- A number of physical barriers and beam dumps exist to intercept all beams.
- IR viewing equipment is used to identify potentially hazardous reflections and/or stray light upon entrance and exit to the HPLF and during routine operations.
- Appropriate laser safety eyewear is used by individuals working in the HPLF.
- A written and approved LLO work permit exists.

A copy of this laser safety plan is on hand in the UF High Power Laser Facility.

4.6 UF High Power Laser Facility Mechanical Beam Controls

The UF High Power Laser Facility table utilizes several beam containment layers to prevent direct beams and specular reflections from escaping the tables. Beam stops and beam dumps are used to intercept direct radiation. Black anodized, sandblasted aluminum plates installed at the table's perimeter form a second layer of protection. This perimeter belt is at least twice the height of the 100 W laser output port and serves to stop completely stray laser light. As indicated above, the entrance doors to the lab must remain closed and locked throughout the operation of any Class 3B or Class 4. A laser interlock attached to the entry doors provides instant safing of all high-energy lasers. The responsible operator must be certain that the beams are contained on the table, that safety protocols are followed, and that the lab doors are locked when the lab is unattended and lasers are operating.

For scenarios involving destructive testing, all the above mechanical safeties must be in place. Additionally, a set of secured beam blocks must be arranged around the component under test close enough to prevent debris from leaving the test area on the table and injuring

users. Explosive containment apparatus must be constructed of non-flammable materials capable of handling direct beams for extended periods.

4.7 Eye Protection

Required protective eyewear for work with the UF High Power Laser Facility must be LASER SAFETY GLASSES and have an optical density (OD) of 6.0 or greater for 1000-1100 nm wavelength radiation. Particular care must be taken to ensure that the side shields of the laser glasses properly fitted to the user's face; goggles are recommended. Neither glass nor plastic protective eyewear is designed for protection from high power direct beams. These lenses are only capable of attenuating diffuse and/or scattered light.

Due to the high optical power levels available in the UF High Power Laser Facility, extreme care must be taken into consideration when redirecting the beam, directing the beam through lenses, and/or onto mirrors.

5 Operating Procedures

5.1 Transitioning from the Laser Safe to the Laser Hazard Condition

5.1.1 UF-LIGO and LLO must grant approval to the laser operator(s). If destructive testing is to be conducted, permissions from UF-LIGO and LLO must be posted on the outer lab door.

5.1.2 Anyone who will be working in the lab must don appropriate laser safety goggles prior to entering the lab's nominal hazard zone.

5.1.3 Signs must be inspected for laser status prior to entry. Signs must be illuminated in the LASER HAZARD condition prior to Class 3B or Class 4 laser activation.

5.1.4 Watches and jewelry worn on hands must be removed to reduce specular reflections. Users with long hair and/or sleeves shall roll up and restrain these materials to reduce fire hazards.

5.1.5 Lab users must check and if necessary close manual shutters on lasers. If the shutter is electronically controlled, then the control switch shall be set to the closed position. Also a beam block should be placed in front of the 100 W laser output port if and when it will be activated.

5.1.6 If a laser's emitted power cannot be reduced below 10 W, a power attenuator composed of a polarizer, half-wave plate, and beam dump must be installed prior to laser start. (See figure 1)

5.1.7 Once inspection of all interlocks is complete, laser operations may proceed.

5.2 Operating in the Laser Hazard Condition (Normal Operations)

5.2.1 Prior to altering a beamline, laser power of the applicable laser must be reduced to safe levels. Safe levels are designated as being below 2.0 W.

5.2.2 During alignment of any beamline, beam blocks must be installed to prevent free space beam propagation across large table distances. During alignment, all beams must be mapped out using appropriate detectors (IR cameras and/or IR sensors). See section 5.3 for further details.

5.2.3 All unused beamlines (strays included) must be terminated by beam dumps, beam blocks, power meters, photodiodes, or sensors. The perimeter belt is NOT to be used as a primary beam block for direct radiation during data runs; it is only for stray and scattered light. The perimeter belt is a reserve safety and is permitted to catch direct beam during alignment only.

5.2.4 Beams are forbidden from traveling out of the operating volume (10 x 4 x 1 ft.) on the table.

5.2.5 Use diffuse reflectors or beam dumps wherever possible to contain reflections. Dark materials are not always absorptive in the near-IR. Care must be taken to use appropriate beam blocks and diffusers to intercept radiation.

5.2.6 Reduce scattered light by eliminating unnecessary items in the beamline.

5.2.7 Once steps 3) through 7) are complete and all stray beams accounted, high power running may proceed.

5.3 Alignment Procedures

Beam alignment will inevitably require the responsible operator to defeat multiple safe guards. This makes alignment a hazardous activity. Therefore, all optical equipment (mirrors, lenses, and beam blocks) will be oriented to minimize scatter to or below MPE (maximum permissible exposure) to eyes, skin, and equipment not in the beamline.

During complicated alignments, the following procedure must be followed when practical.

Pre-alignment Checklist

- Only authorized personnel are permitted entry during realignment in order to reduce potential exposure to personnel.
- Watches, rings, jewelry, dangling bandages, and long neckwear (ties and necklaces) must be removed prior to laser activation in order to reduce accidental reflections.
- When working in the HPLF, working with a partner is strongly encouraged.

- Prepare in advance. Have all of the equipment needed for alignment on hand.
- Remove all unnecessary stuff from the table during alignment, flammable or not.
- Persons performing alignments must be authorized by the responsible operator.
- During unusual operating circumstances, a warning sign must be installed at the HPLF entrance that details any additional hazards.

Alignment Procedures in the HPLF

- DO NOT LOOK INTO A LASER. REGARDLESS OF THE LASER WAVELENGTH OR POWER, NO DIRECT BEAM VIEWING IS PERMITTED WITH ONE'S EYE!
- Direct beam viewing is permitted ONLY through CCD camera or similar electronic devices.
- Beam must be reduced to low class IV levels until alignment is complete
- For mode verification, full operating power may be used if a tomographic device is installed to intercept the direct beam.
- The LLO-LSO has authorized OD 6.0 eyewear to be used in the HPLF. Eye protection below said rating is not considered sufficient to cope with high power scatter or specular reflections.
- All optical equipment (beam blocks included) must be secured using either bolts or clamps.
- The beam must be kept parallel to the table surface. Regions where the beamline is directed out of the horizontal will be marked.
- Stray/unused beams will be terminated before commencing with the experiment.
- Invisible radiation used in the HPLF may be observed with either IR sensor cards, second harmonic ceramics, IR cameras, silicon based cameras, mobile beam blocks. For low power visible lasers, white card stock (i.e., business cards) is acceptable. The operators are aware that some of the above sensors WILL smoke if exposed to radiation exceeding their thermal breakdown.
- Once alignment is complete, all normal shield barriers will be reinstalled, and the table surveyed for strays and scattered light.
- IF THE LASER CAVITY MUST BE REALIGNED, OPERATORS MUST UNDERSTAND THAT THE HOUSING WILL BE OPEN AND 300+ W BEAMS WILL BE ACCESSIBLE. Extreme care must be taken when retuning the HPLF's main laser housing.

In addition to the aforementioned alignment procedures, the operator will announce the opening of a laser shutter so others in the room may secure themselves or aid in beam surveillance.

5.4 Operating in the Laser Hazard Condition (Destructive Testing)

5.4.1 All procedures of Section 5.3 must be completed.

5.4.2 Multiple beam blocks or debris containment devices must be placed around the material under test and secured.

5.4.3 A sign indicating destructive testing in-progress must be placed on the outer lab door. This sign must be signed and dated by the responsible operator.

5.4.4 High power running may now proceed.

5.4.5 If long-term exposures are required, the test area on the table must be covered to prevent laser light from entering a possible upwards-inclined trajectory.

5.4.6 In order for operators to exit and re-enter the lab area during extended running, only vestibule doors are to be used. Swipe cards in conjunction with swipe card readers will unlock the main foyer door without disrupting the laser.

5.5 Transitioning from the Laser Hazard to the Laser Safe Condition

5.5.1 At the conclusion of an experiment, the user must make all lasers safe and place a beam block in front of the100 W laser output port.

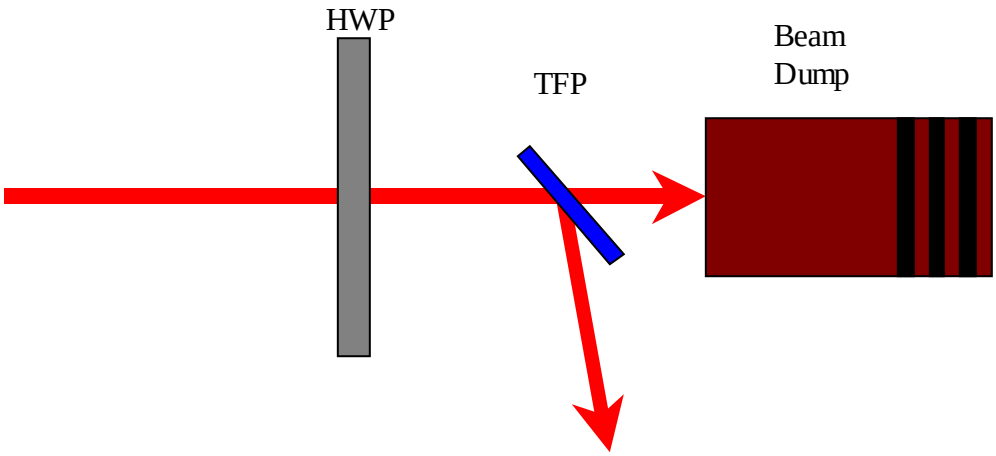
5.5.2 The user must disengage all laser power supplies.

5.5.3 Finally, the power supplies for all Class 3B or Class 4 lasers must be shutdown and the lasers disconnected from their respective power sources.

5.5.4 The laboratory may then be placed in the LASER SAFE condition by turning off the main power and transitioning the laser warning signs.

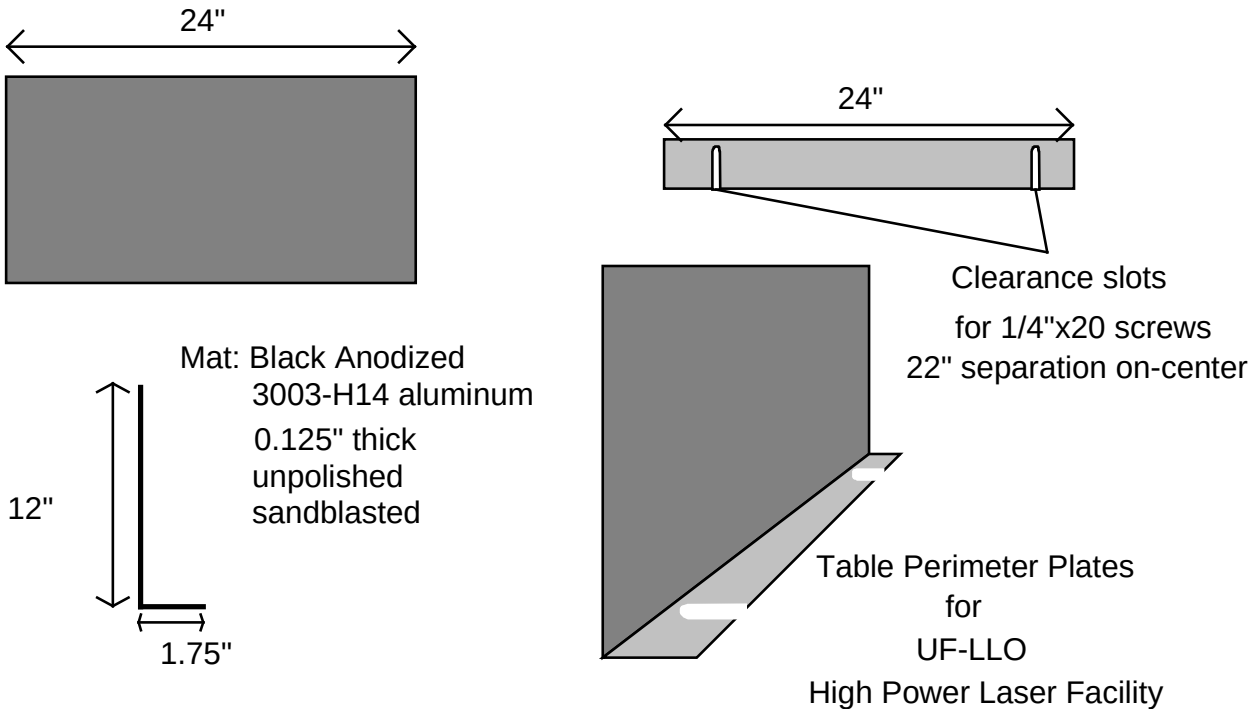
6 Figure 1: High Power Beam Regulator

6.1 This depicts the physical layout of high power beam regulator. HWP = half-wave plate; TFP = Thin Film Polarizer. The orientation of the half-wave plate controls polarization and thereby beam power sent to the experiment. The remaining power enters the beam dump.



7 Figure 2: (Laser) table perimeter plates

7.1 These aluminum plates are to be placed around the perimeter of high power experiment table during high power laser operation. These plates are unpolished and sandblasted to decrease the specular reflection upon laser impact. Although these plates are not meant to observe direct high power beams, they can contain direct high power radiation for extended periods without substantial deterioration of performance.



8 Figure 3: Mobile beam block.

8.1 These beam blocks are the used to intercept direct radiation from all lasers in the HPLF. Above is an example design based on the 10 W laser's beam blocks. Mobile blocks are designed and permitted to handle focused radiation for extended periods during laser operation.

8.2

HPLF Beam Block

1/4"x20 Clearance Slots
1.5" wide

Mat: Black Anodized
3003-H14 Aluminum
Sand Blasted

Vertical Plate:

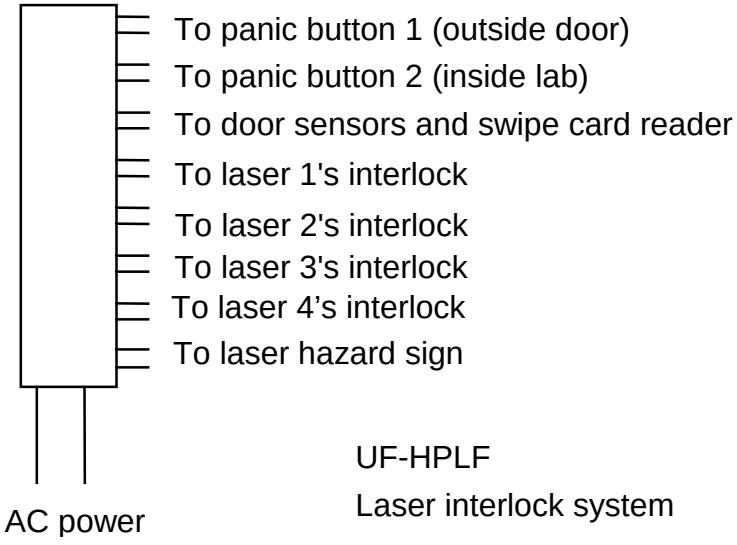
Height: 10"
Width: 5"
Thickness: 0.125"

Base Plate:

Height: 0.5"
Width: 5"
Thickness: 0.75"

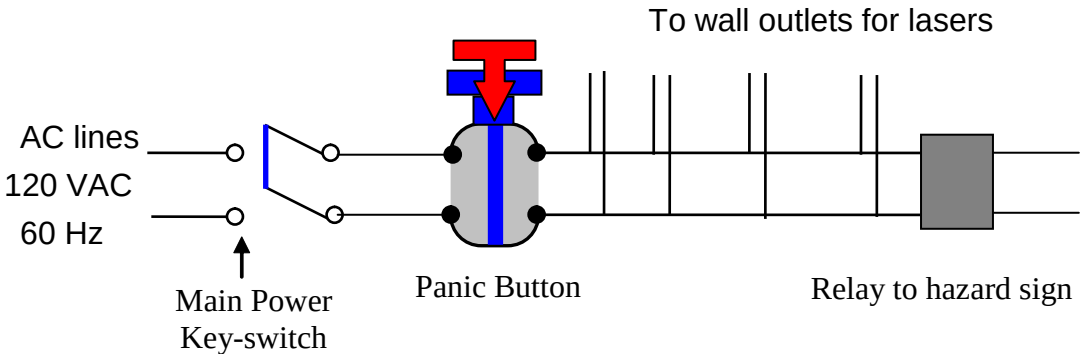
9 Figure 4: Interlock system.

9.1 The HPLF interlock is based on a Kantech Controller. It is designed to permit laser operation only when the when the egress doors are closed, EMERGENCY STOP buttons are out, and lasers power supplies are correctly interlocked. If any of the sensors indicate a fault in the circuit either through forced entry, or panic button depression, laser apertures will close and/or power supplies will enter stand-by conditions, and an alarm will inform the Laser Safety Officer of a protocol failure.

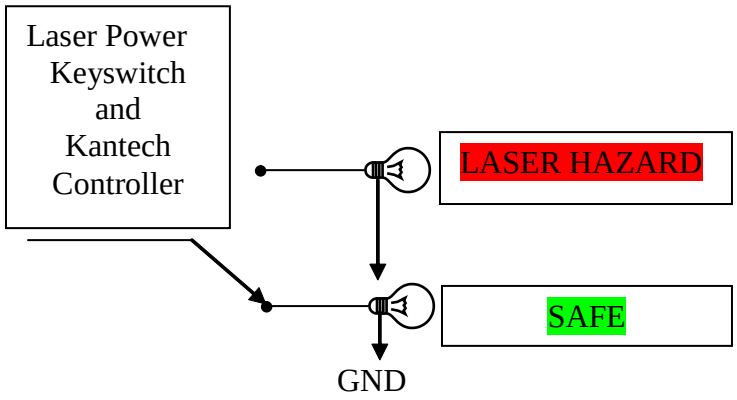


10 Figure 5: Laser power bus control.

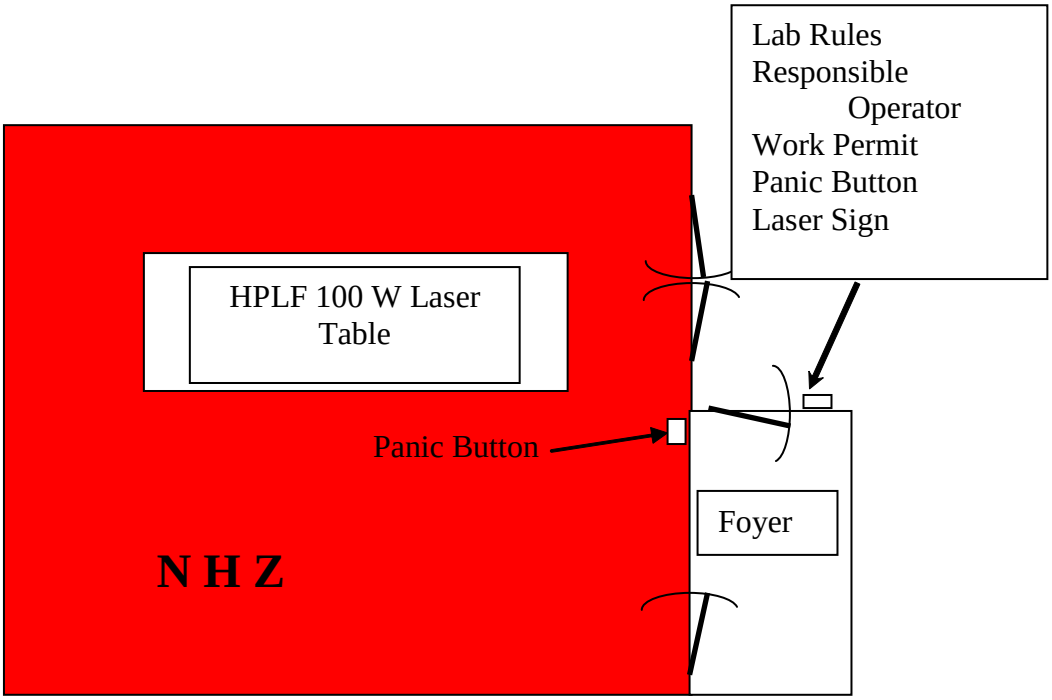
10.1 A single key switch is located inside the HPLF. Turning this switch to the “on” position activates wall outlets specific to each laser’s power supply. EMERGENCY STOP buttons inside and outside the HPLF must be in their “out” position to permit current flow. Depressing the panic button will break the circuit and abruptly deactivate all laser electrical power. The warning sign will transition to LASER SAFE. Also a shunt trip (not shown) in the lab circuit breaker will activate. The shunt, EMERGENCY STOP, and key switch must all be reset for main power to be re-established.



11 Figure 6: A diagram of the lab status sign.



12 Figure 7: ALL of HPLF is a Nominal Hazard Zone.



12.1 This is a depiction of the NHZ (Nominal Hazard Zone), table position, and information signs. During the LASER HAZARD status condition, users must wear approved laser eyewear when in the NHZ.

12.2 Note: The HEPA Enclosure Assembly that encases the Higher Power Laser Facility optics table is NOT a laser containment device. It is not a safety feature. It is meant to provide clean air for HPLF experiments. Its intent and purpose is to reduce dust counts on the HPLF optics table through positive pressure HEPA filtered air in the vicinity of the optics table.

13 Application Documents

13.1 ANSI Z136.1-2007, American National Standard for the Safe Use of Lasers American National Standards Institute (2007)

13.2 LIGO-M960001, LIGO Laser Safety Program

13.3 LIGO-M990148, LIGO Livingston Laser Safety Plan

13.4 LIGO-M990151, SOP LIGO 10-W Laser Operating in the LVEA

13.5 LIGO-M000324, SOP: ISC Table Infrared Alignment Laser Operation in LLO LVEA and Optics Lab

14 Amendments

14.1 LightWave Model 126-700-1064 NPRO

The NPRO resident in the LIGO Livingston Optics Laboratory, falling under the LIGO Standard Operating Procedures document LIGO-M990150 (SOP 700mw NPRO Laser in Optics Laboratory), shall be permitted operation in the HPLF. Note: Laser operators of the NPRO will abide by these safety procedures and standard operating procedures adopted by the HPLF.