Person: Gaskell, Dave (gaskelld@jlab.org)
Org: PHALLC

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Jefferson Lab — Thomas Jefferson National Accelerator Facility

Operational Safety Procedure Review and Approval Form # 90881
(See ES&H Manual Chapter 3310 Appendix T1 Operational Safety Procedure (OSP) and Temporary OSP Procedure for Instructions)

Type:	***LOSP*** Click for OSP/TOSP Procedure Form Click for LOSP Procedure Form Click for LTT-Individual Information Click for LTT-Group Information
Serial Number:	***ENP-19-90881-LOSP***
Issue Date:	***10/21/2019***
Expiration Date:	***8/21/2022***
Title:	***Hall A Compton Polarimeter Laser System***
Location: (where work is being performed) Building Floor Plans	***101 - Experimental Hall A - A100*** — Location Detail: (specifics about where in the selected location(s) the work is being performed): ***Compton polarimeter in Hall A beam tunnel***
Risk Classification: (See ES&H Manual Chapter 3210 Appendix T3 Risk Code Assignment)	Without mitigation measures (3 or 4): ***3*** With mitigation measures in place (N, 1, or 2): ***1***
Reason:	This document is written to mitigate hazard issues that are : ***Determined to have an unmitigated Risk code of 3 or 4***
Owning Organization:	***PHALLA***
Document Owner(s):	***Gaskell, Dave (gaskelld@jlab.org)*** Primary

Supplemental Technical Validations

Lasers Class 3B or 4 (Ultraviolet, Infrared, and Visible Light) (Jennifer Williams, Paul Collins)
Lock, Tag, Try (Bill Rainey, Tim Fitzgerald)
Fire Protection (Tim Minga)
ESH&Q Liasion (Bert Manzlak)

Document History

Revision	Reason for revision or update	Serial number of superseded document
1	***Renewal - update to include new lasers that might be used in system.***	***ENP-17-66136-LOSP***

Lessons Learned	Lessons Learned relating to the hazard issues noted above have been reviewed.
Comments for reviewers/approvers:	***Updated version to clarify LTT procedure.***

Attachments

Procedure: ***LOSP_Hall_A_Compton_oct14_2019_v2.pdf LOSP_Hall_A_Compton_oct14_2019_v2.pdf LOSP_Hall_A_Compton_oct8_2019.pdf LOSP_Hall_A_Compton_oct14_2019_v2.pdf***

THA: ***HallA_ComptonLaser_THA.pdf***

Additional Files:

Review Signatures

Additional Authorization : Fire Protection - other than current engineered safeguards or fire watch	**Signed** on 10/15/2019 8:09:02 AM by Tim Minga (minga@jlab.org)
Subject Matter Expert : Lasers Class 3B or 4 (Ultraviolet-> Infrared-> and Visible Light)	**Signed** on 10/15/2019 5:51:24 AM by Paul Collins (paulc@jlab.org)
Subject Matter Expert : Lock-> Tag-> Try	**Signed** on 10/15/2019 7:24:22 AM by Tim Fitzgerald (tfitzger@jlab.org)

Approval Signatures

Division Safety Officer : PHALLA	**Signed** on 10/21/2019 7:10:15 AM by Ed Folts (folts@jlab.org)
ESH&Q Division Liasion : PHALLA	**Signed** on 10/15/2019 8:50:55 AM by Bert Manzlak (manzlak@jlab.org)
Org Manager : PHALLA	**Signed** on 10/15/2019 4:01:37 PM by Cynthia (Thia) Keppel (keppel@jlab.org)
Person : Lock, Tag, Try Coordinator	**Signed** on 10/15/2019 9:19:11 AM by Dave Gaskell (gaskelld@jlab.org)
Safety Warden : Experimental Hall A - A100	**Signed** on 10/15/2019 4:33:38 PM by Jessie Butler (jbutler@jlab.org)

Laser Operational Safety Procedure (LOSP) Form

(See ES&H Manual Chapter 6410 Appendix T1 Laser Operational Safety Procedure)

Serial Number: ______________________________

(Assigned by ESH&Q Document Control x7277)

*Attach the Task Hazard Analysis (THA) related to this procedure

Issue Date:		**Expiration Date:**	
Title:	**Hall A Compton Polarimeter Laser System**		
Location:	Hall A Compton Polarimeter		
Description of Project	Compton Polarimetry of electron beam with laser back-scattering		
Document Owner(s):	Dave Gaskell	**Date:**	

Laser Inventory

Laser Serial #	Laser Class	Wavelength(s)	Maximum Power/Energy
1. 1903	3B	1064 nm	0.2 W
2. 1425	4	1064 nm /532 nm	2 W/ 0.1 W
3. 121	3B	1064 nm	0.3 W
4. 279	4	1064 nm	0.7 W
5. 8940	3B	1064 nm	0.2 W
6. AY-Y60405-21-5	4	532 nm	3 W
7. 1BKSL5P2069050020050Y003	4	532 nm	3 W
8. AC-Y150802-32-02	4	532 nm	3 W
9. PA0605581	4	1064 nm	5 W
10. PA0706598	4	1064 nm	10 W
11. PA1910003	4	1064 nm	10 W
12. PA1910004	4	1064 nm	10 W
13. PA0907863	4	1064 nm	30 W

Approval Signatures:	**Print**	**Signature**	**Date:**
Laser System Supervisor:			
Laser Safety Officer:			
Division Safety Officer			
Department or Group Head:			
Other Approval(s):			

Document History:

Revision:	Reason for revision or update:	Serial number of superseded document

Distribution: ESH&Q Document Control (x7277, MS6B); affected area(s); Document Owner; Division Safety Officer

Introduction – In areas containing more than one laser, define operational sequence or parameters.

Many Hall A experiments at Jefferson Lab using polarized electrons beams require accurate knowledge of the polarization of the beam. The Hall A Compton Polarimeter utilizing the principle of Compton backscattering of electrons from circularly polarized photons measures the polarization of the electron beam from the cross section asymmetry of scattered photons and electrons. Unlike other methods of beam polarimetry that interfere with beam delivery due to placement of an intrusive target in the beam path, Compton Polarimetry provides continuous non-destructive measurements of the electron beam polarization.

A green laser at 532 nm from a frequency doubling crystal, pumped by a fiber amplifier seeded with a 1064 nm infrared laser, is used to generate the circularly polarized photon beam. This 532 nm laser beam is then amplified in a high gain Fabry-Perot cavity, which serves as an intense source of photons for Compton scattering for the CEBAF polarized electron beam. The scattered electrons and photons are detected using electron and photon detectors. All the devices of the setup are installed on an enclosed optical table, and are controlled and operated in accordance with the requirements of this document. The optical table (1200 x 1800 mm^2) is located in the middle of the Compton Polarimeter magnetic chicane between dipoles 2 and 3 as shown in Figure 1. The laser systems and optical devices are located in an enclosure, the laser hut, to shield from accidental exposure to hazardous laser light. The laser hut drawing is shown in Figure 2.

This Laser Operational Safety Procedure (LOSP) addresses the safe operating procedure for the optical equipment used in the Hall A Compton Polarimeter.

Personnel Only those authorized by the LSS are permitted to enter the location noted on the cover sheet of this document.	List: • Training and qualification requirements (including refresher training). • Medical requirements. • Spectator protection requirements.

The laser system may only be operated by personnel who have

- Completed ESH-333DE, DOE Laser Worker Training,
- Read the Laser Safety section of the EH&S Manual (6410 - Laser Safety Program),
- Completed and passed an ophthalmologic exam (MED 02 – Laser Eye Exam),
- Completed Lock, Tag, and Try training (SAF104),
- Had a safety walkthrough by the Laser Safety Supervisor (LSS) and completed training SAF153 (Compton Polarimeter Laser Safety),
- Read this document,
- Been added to the authorized list of Laser Personnel by the LSS, included as the last page of this LOSP.

Since this laser system is in experimental Hall A, operators of the Compton laser system must have also completed all required training for working in Hall A. These requirements are:

- EH&S Orientation (SAF100)
- Radiological Worker Training I (SAF801F)
- Oxygen Deficiency Hazards Training (SAF103)
- Hall A Safety Walkthrough Training (SAF110)

If working on the laser system during a running experiment, it is also necessary to read and sign the relevant experiment-specific safety documentation (Conduct of Operations, etc.) This documentation can be found in the Hall A Counting House.

Note that at Jefferson Lab, an employee or user who is a student and works with Class 3B or Class 4 lasers is required to be in a mentor program. This laser safety mentor program is to continue until the employee/user is considered adequately trained by the equipment/area LSS and no longer considered to be a "student." In particular, those users or employees participating the mentor program should only perform laser-related work with the LSS or another trained laser system user designated by the LSS.

There shall be no access to the laser system while it is in use for personnel who have not satisfied the above requirements. Exceptions may be made for personnel (laser service technicians or personnel from other labs) who have received equivalent laser safety certification elsewhere. In this case, such personnel are only allowed to enter the laser control area under the following conditions:

- Have permission of the Jefferson Lab laser safety officer (LSO)
- Have permission of the Laser Safety Supervisor (Dave Gaskell)
- Be accompanied by a laser authorized personnel
- Laser eye protection is required when the laser system is on. This protection must cover both the infrared (1064 nm) and the green (532 nm) lasers.
- Briefed on the potential hazards and appropriate controls in place.

Additionally, this area periodically requires access by Jefferson Lab personnel for non-laser related work (vacuum, survey and alignment, etc.). In this case, such personnel will be briefed on the laser system and the appropriate procedures to guarantee control of the potentially hazardous energy associated with the laser system. This can be most simply accomplished by maintaining control of the keys for the laser system power supplies.

In the case of a single user, JLab LTT requirements for control of hazardous energy can be met by maintaining personal control of laser power supply key. In the case of multiple users, the laser power supply keys will be placed in a lock-box, and all workers can then place their personal locks on the lock-box.

Laser	Define: • Laser system specifications. • Define laser system components. • Copy of laser operating manuals or reference the location of the manual(s).

The 532 nm green laser beam used in the Compton Polarimeter is generated in a three-stage process. A low power fiber-coupled infrared laser at 1064 nm seeds an Ytterbium doped fiber amplifier. The fiber amplifier produces a high power 1064 nm beam which pumps a doubling crystal to produce the 532 nm green beam using second harmonic generation (SHG).

The primary seed laser is the 126-1064-700 laser, manufactured by JDSU (now Lumentum). The JDSU laser is a diode-pumped Nd:YAG non-planar ring oscillator (NPRO) laser. Specifications for the 126-1064-700 laser are shown in Table 4. Backup lasers for the seed are the Innolight Prometheus (Table 2), the Innolight Mephisto (Table 1), and the Lumentum Model 126-1064-200 (Table 5).

The fiber amplifier is the YAR-10K-1064-LP-SF manufactured by IPG Photonics. It produces up to 10 Watts of 1064 nm CW infrared laser power. The beam is delivered through a fiber collimator. The specifications for the 10 W fiber amplifier are given in Table 7. There are also two fiber amplifiers available for use as spares; the YAR-5K-1064-LP-SF (maximum power 5 W) and YAR-30K-1064-LP-SF (maximum power 30 W) described in Tables 6 and 8 respectively.

The doubling crystal is a 50 mm long Periodically Poled Lithium Niobate (PPLN) crystal, supplied by HC Photonics. Pumped with a 1064 nm beam, the PPLN produces the green beam via second harmonic generation (SHG) at 532 nm. When properly tuned, the PPLN setup can produce up to 3 Watts of CW power at 532 nm in a single pass. The specifications of the PPLN green laser are given in Table 9.

In addition, a low power (< 5 mW) 635 nm fiber-coupled laser will occasionally be used for alignment of fiber couplers, required for using the free-space seed lasers with fiber amplifiers. Properties of this laser are summarized in Table 10.

Copies of the manuals for lasers deployed in the Hall A Compton laser system will be kept on the 2nd floor for the Counting House in the Hall A Compton rolling tool chest.

Table 1: Innolight Mephisto laser properties.

Type of Laser/Class	*NPRO Nd:YAG / Class IIIb*
Manufacturer	*Innolight*
Model Number	*Mephisto S*
Serial Number	*1903*
Wavelength range	*1064 nm*
Power range	*200 mW*
Mode (i.e., time structure)	*CW*

Table 2: Innolight Promethues laser properties.

Type of Laser/Class	*NPRO Nd:YAG (frequency doubled)/ Class IIIb*
Manufacturer	*Innolight*
Model Number	*P100*
Serial Number	*1425*
Wavelength range	*1064/532 nm*
Power range	*2000/100 mW*
Mode (i.e., time structure)	*CW*
Beam diameter (collimated, typical)	*0.4 mm*
Divergence (uncollimated, typical)	*3.5 mRad*

Table 3: JDSU-300 laser properties.

Type of Laser/Class	*NPRO Nd:YAG/ Class IIIb*
Manufacturer	*JDSU*
Model Number	*126-1064-300*
Serial Number	*121*
Wavelength range	*1064 nm*
Power range	*300 mW*
Mode (i.e., time structure)	*CW*
Beam diameter (collimated, typical)	*0.5 mm*
Divergence (uncollimated, typical)	*2.7 mRad*

Table 4: JDSU-700 laser properties.

Type of Laser/Class	*NPRO Nd:YAG/ Class IV*
Manufacturer	*JDSU*
Model Number	*126-1064-700*
Serial Number	*279*
Wavelength range	*1064 nm*
Power range	*300 mW*
Mode (i.e., time structure)	*CW*
Beam diameter (collimated, typical)	*0.5 mm*
Divergence (uncollimated, typical)	*2.7 mRad*

Table 5: Lumentum-200 laser properties.

Type of Laser/Class	*NPRO Nd:YAG/ Class IV*
Manufacturer	*Lumentum*
Model Number	*126-1064-200*
Serial Number	*8940*
Wavelength range	*1064 nm*
Power range	*300 mW*
Mode (i.e., time structure)	*CW*
Beam diameter (collimated, typical)	*0.5 mm*
Divergence (uncollimated, typical)	*2.7 mRad*

Table 6: IPG 5W fiber amplifier properties.

Type of Laser/Class	*Ytterbium Fiber Amplifier/ Class IV*
Manufacturer	*IPG*
Model Number	*YAR-5K-1064-LP-SF*
Serial Number	*PA0605581*
Wavelength range	*1064 nm*
Power range	*5 W*
Mode (i.e., time structure)	*CW*
Beam diameter (collimated, typical)	*0.9 mm*

Table 7: IPG 10W fiber amplifier properties.

Type of Laser/Class	*Ytterbium Fiber Amplifier/ Class IV*
Manufacturer	*IPG*
Model Number	*YAR-10K-1064-LP-SF*
Serial Numbers	*PA0605581, PA1910003, PA1910004*
Wavelength range	*1064 nm*
Power range	*10 W*
Mode (i.e., time structure)	*CW*
Beam diameter (collimated, typical)	*0.9 mm*

Table 8: IPG 30W fiber amplifier properties.

Type of Laser/Class	*Ytterbium Fiber Amplifier/ Class IV*
Manufacturer	*IPG*
Model Number	*YAR-30K-1064-LP-SF*
Serial Number	*PA0907863*
Wavelength range	*1064 nm*
Power range	*30 W*
Mode (i.e., time structure)	*CW*
Beam diameter (collimated, typical)	*0.9 mm*

Table 9: PPLN, frequency doubling crystal properties (3 crystals).

Type of Laser/Class	*PPLN/ Class IV*
Manufacturer	*HC Photonics Corp.*
Model Number	*PPLN*
Serial Number	*AY-Y60401-21-5, 1BKSL5P2069050020050Y003, AC-Y150802-32-02*
Wavelength range	*532 nm*
Power range	*Up to 3 W*
Mode (i.e., time structure)	*CW*
Beam diameter (collimated, typical)	*Same as pump*

Table 10: Thorlabs alignment laser

Type of Laser/Class	*Handheld alignment laser/ Class 3R*
Manufacturer	*Thorlabs*
Model Number	*HLS635*
Serial Number	*TP02050059-13893*
Wavelength range	*635 nm*
Power range	*< 5mW*
Mode (i.e., time structure)	*CW*
Beam diameter (collimated, typical)	*Fiber coupled*

Hazards and Mitigation	Define: • Laser-specific hazards. • Occupational exposure hazards beyond laser light (e.g. fumes, noise, etc.). • Credible non-beam hazards (e.g. environmental hazards). • Describe all required personal protective equipment ES&H Manual Chapter 6410 Appendix T2 Laser Personal Protective Equipment (PPE) (include: clothing requirements (e.g.: no reflective jewelry, etc.). • Control of Hazardous Energy (includes beam and non-beam hazards such as electrical)

The primary adverse effects from direct or specular viewing of the laser are blindness and severe retinal burns. The retina is most sensitive to radiation of this wavelength.

Laser radiation of the intensity associated with Class IV PPLN green laser (532 nm) can also cause irreversible damage to the skin. The damage caused is either associated with temperature rise of the skin tissue following the absorption of laser energy (skin burns) or with surface reactions resulting from photon interactions at the molecular level (photochemical effect), disrupting the normal functionality of the skin tissue. MPE calculation results are provided in the "Required Calculations" section.

The laser eye and skin hazards are mitigated by following the detailed procedures in "Written Procedures for Use and Alignment." These procedures specify the appropriate eyewear based on the MPE calculations and provide guidance to avoid skin exposure. Hazard mitigation for non-affected personnel is provided by engineered safety controls in the form of an interlocked laser safety system, and administrative controls in the form of signage and warning lights.

The fiber amplifier provides a unique hazard in the case that the output fiber is damaged. This is unlikely since the output fiber is protected by a thick protective cover. However, care should be taken to maintain a large bend radius when handling the fiber. The fiber should be inspected before initial use, and the output power checked for consistency with the expected power. If the fiber is broken or damaged, the output power will be reduced and the protective cover may be damaged. If the damage to the fiber is too severe, the fiber may be exposed, perhaps resulting in sharp fragments.

Apart from direct beam hazards, two potential non-beam hazards exist in the Laser area described. Firstly, since the PPLN green laser is a Class IV laser, there exists a potential fire hazard. Use of combustible materials in the laser enclosure is minimized, and a smoke detector (connected to the laser interlock system) is present. Secondly, there exist electrical hazards due to the high voltage needed to operate the laser, the micro-motors controllers of the remote-controlled mirrors and all the measurement devices (110V, 40A). The lasers contain no user serviceable parts so the covers of the laser or the different power supplies should not be opened. If for some reason it is deemed necessary to open the power supply housing, the system must be turned off and the electrical hazard controlled appropriately, using the JLab Lock, Tag, and Try procedure if needed.

Laser Environment System designs, including interlocks, require hazard evaluation review by SME.	Define: • Layout of the laser controlled area and/or table. (Show beam location in relation to user (waist height preferable).) • Interlock schematic (or similar) (including smoke detector interlocks). • Room lighting conditions during laser use and alignment procedure(s). • Targets. • Primary and all likely beam paths (open or enclosed).

The optical setup is described in Figures 1 and 2 and made of three breadboards and the optical cavity on an optical table. The laser beam is provided in three steps: the seeding laser (1064 nm) through the fiber laser amplifier to the PPLN doubling crystal for the green laser beam (532 nm). The seed laser and PPLN laser sit on the optical table, while the fiber amplifier, its controller, as well as the seed laser controller, sit under the optics table.

The laser path and optical setup is as follows:

- The laser exits the PPLN laser head on the first, "laser breadboard" (1200 mm x 300 mm) pointing downstream, parallel to the table. The beam then passes through:
  - 1 λ/2 plate to turn the axis of the linear polarization in order to get it parallel to the table, prior to the faraday isolator.
  - 1 faraday isolator to protect the laser from optical feedback from downstream optical elements.
  - A second λ/2 plate to turn the axis of the linear polarization in order to get it parallel to the table.
  - 1 convergent lens to optimize waist at the polarizing stage.

- A mirror then steers the beam across the table, toward the second breadboard.
  - On its way to the 2nd breadboard, the beam passes through a polarizing prism (at 90 degrees, there is an integrating sphere with a fast photodetector on the side).

- The laser beam then passes to the second "beam shaping breadboard" (600 mm × 300 mm) where we have:
  - Remote-controlled rotating λ/4 and λ/2 plates which allow switching between circularly right or left polarization in the Fabry-Perot cavity.
  - A telescope made of 2 lenses (divergent, convergent) to tune the waist at the Compton Interaction Point (CIP).
  - A two-axis remote-controlled turning mirror.
- The beam is then steered by 90 degrees so that it is now pointing upstream and leaves the "beam shaping breadboard.

- The beam is then rotated by a fixed mirror by 90 degrees in the vertical plane and points toward the ceiling.

- Above is a second remote-controlled turning mirror – the beam then points towards the tunnel walkway.

- The beam enters the vacuum pipe (when it is in place, i.e. in operational running procedure) and is pointing left to right. The beam goes through the cavity.

- After 1152 mm, a new rotation over 90 degrees in the vertical plane makes the beam point to the floor (actually, the optical table). The beam leaves the beam pipe.

- After exiting the pipe, the beam is steered by a turning mirror toward the tunnel walkway where it enters the third, “diagnostic breadboard” (600 mm x 300 mm), where we have:
  - 1 harmonic beam splitter to separate the laser beam in order to provide two diagnostic beams (these two deviated beams carrying 1% of the initial energy). One of these beam paths is sent to a CCD camera and the other to a fast photodetector.
  - 1 remote-controlled rotating $\lambda/4$ plate to transform between circularly right or left polarization.
  - 1 Calcite Wollaston prism to separate the right and left polarization components. Note that this will likely be replaced in the future with a polarizer to facilitate laser polarizations measurements using the “rotating waveplate” technique.
  - 2 Integrating spheres with photodetectors - the beam is stopped here.

The total path length from the laser to the integrating spheres is around 4 m. The “mother” optical table will be at 0.81 m from the floor of the tunnel. There will be three beam heights with respect to the table: 132 mm, 300 mm, and 120 mm.

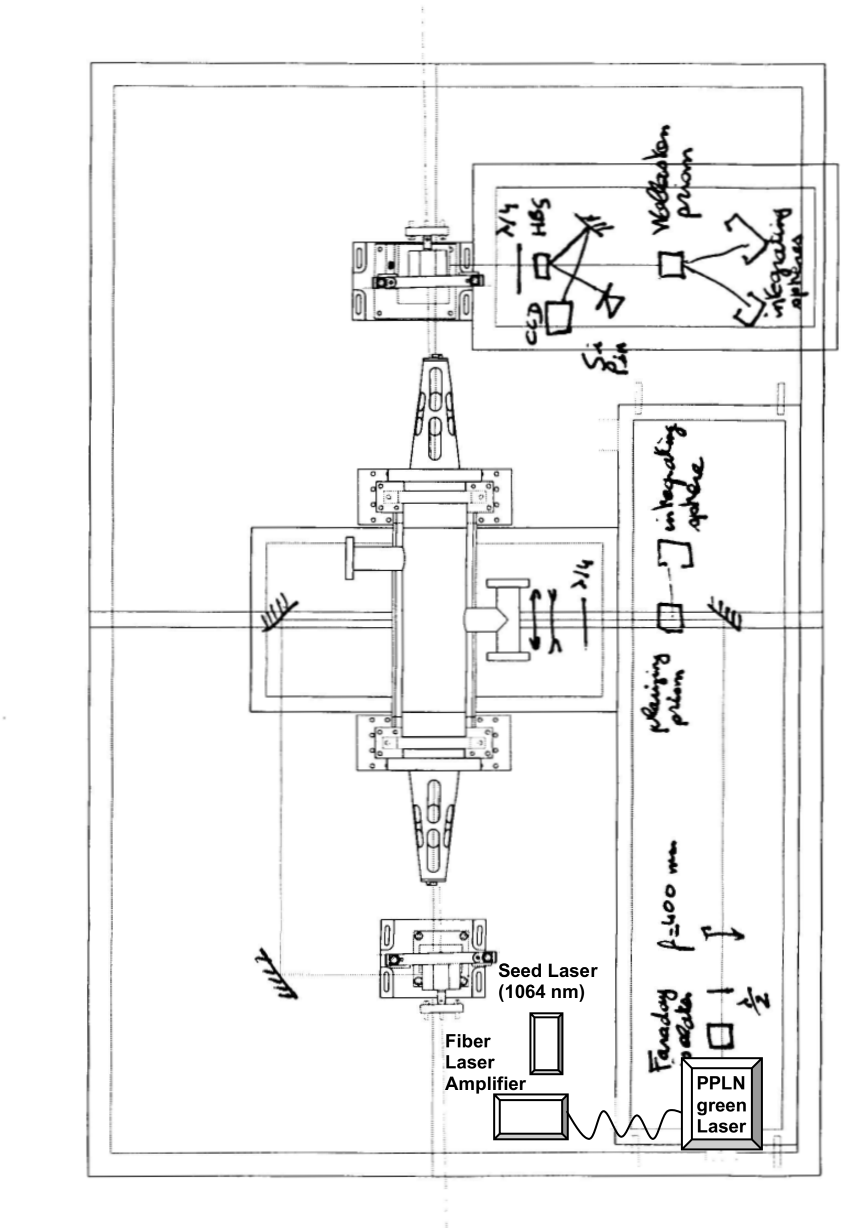


Figure 1: Top view of the Compton Polarimeter optical table.

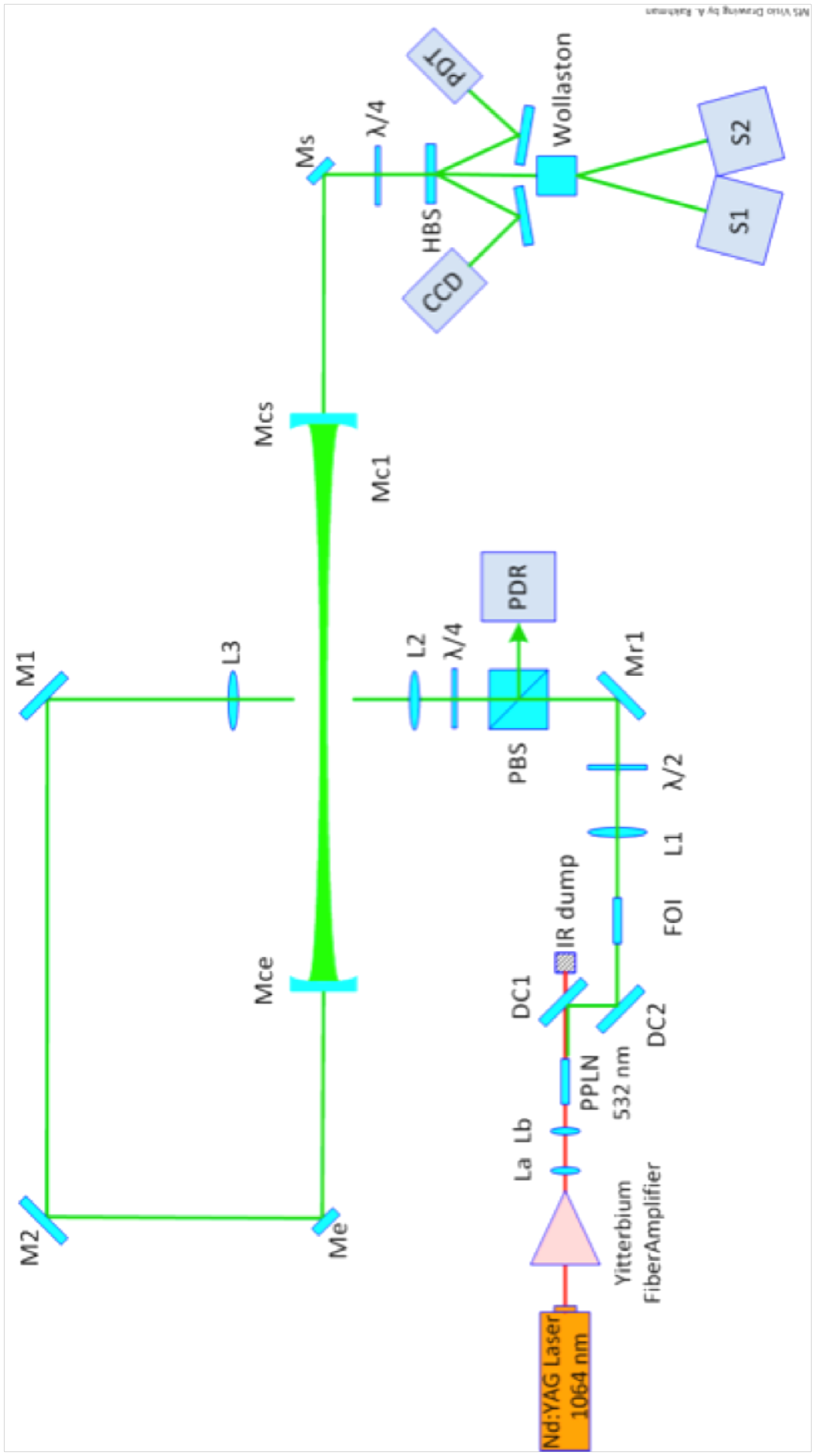


Figure 2: Schematic view of the Compton Polarimeter optical setup. The laser beam starts with a 1064 nm seed laser feeding a fiber amplifier. The amplified beam pumps a PPLN crystal producing the 532 nm green laser beam.

The PPLN green laser and the associated devices are located in the tunnel, about 7 meters before the entrance of Hall A. During normal operations, the Compton laser table is totally enclosed in a special laser enclosure between dipoles 2 and 3. The only access to the laser table is through an interlocked accordion door (from the walkway side) or from a small interlocked door on the upstream side of the enclosure. When access to the table is required for alignment, the door interlock can be bypassed and the walkway door opened. However, in this case, additional curtains are dropped into the tunnel walkway area to prevent any laser light from escaping the enclosure area. In addition, the laser interlock system includes floor mats immediately upstream and downstream of the laser area in the beam tunnel walkway. These floor mats trigger the interlock system and turns off the lasers if stepped on while the laser system/interlock box are in alignment mode.

In addition, the laser beam enters a part of the beam pipe, and could potentially exit the laser safety enclosure through the pipe. Note that this particular hazard is only relevant if part of the beamline either upstream or downstream of the laser enclosure is disassembled. To prevent inadvertent exposure, blank flanges are installed on the beampipes upstream of dipole 2 and downstream of dipole 3. On these flanges, signs will be posted to indicate "DANGER, Class IV Laser Hazard." In addition, valves on the upstream and downstream side of the laser table will be closed during any laser alignment, especially when work on the Hall A beamline is anticipated.

The laser enclosure area is shown schematically in Figure 3.

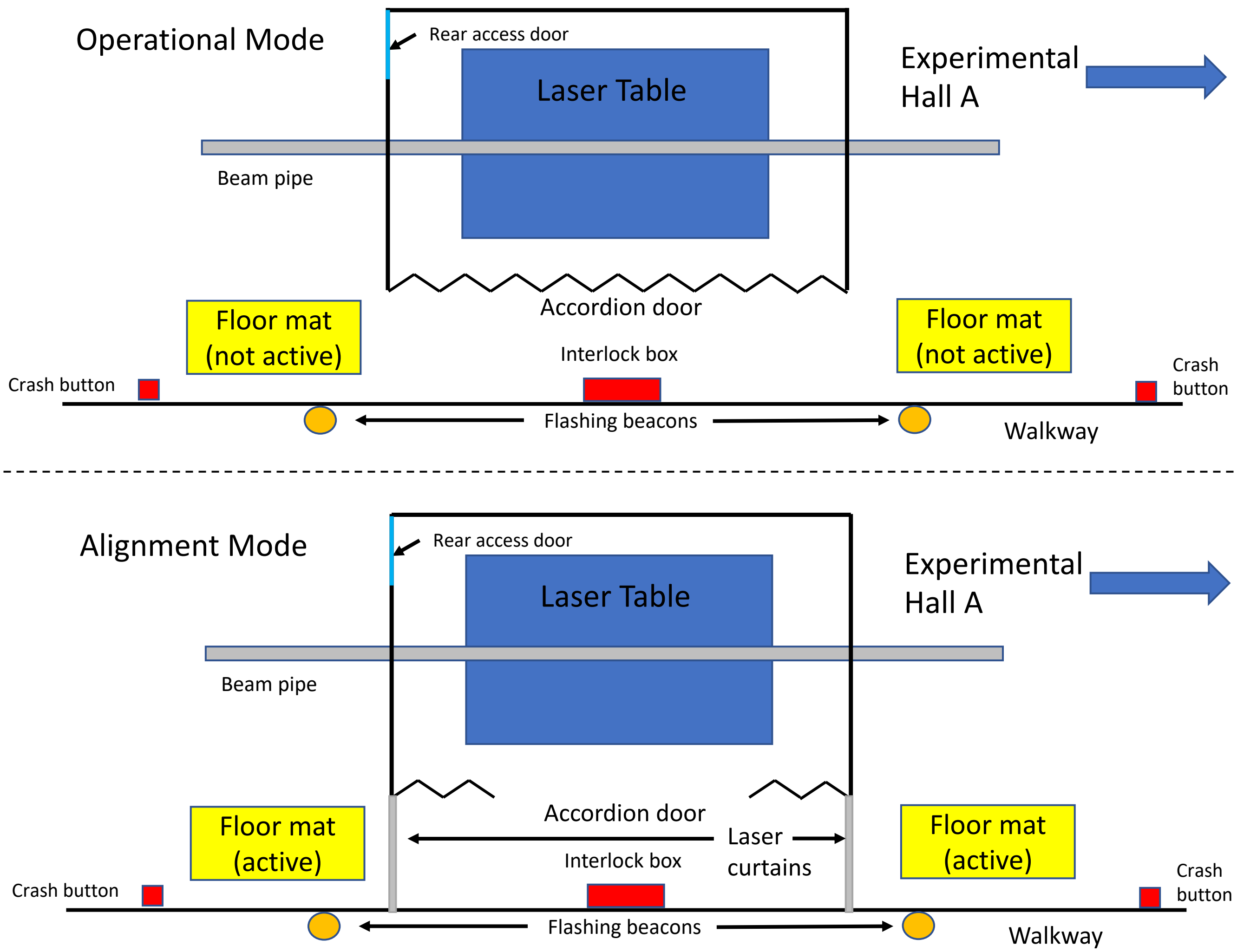


Figure 3: Laser enclosure area.

Written Procedure for Use and Alignment	Provide: • All process steps – including unattended operation controls. • All process steps for detailed alignment – Include manufacturer's protocols for alignment. • Maintenance and service. • Off-normal and emergency procedures (e.g. beam loss, fire).

In this section, we review the various procedures that are required to operate the laser and optical devices. Hazards are least likely to occur during normal operation when the laser is switched on. During tests, maintenance, upgrades and/or alignment, beam hazards are more likely to occur.

At all times, when operating the lasers in lasing mode, laser safety goggles, that have an optical density (OD) appropriate for that wavelength and energy, are required to be worn. The appropriate OD is given in Table 11.

Operational running procedure

The most common normal procedure, when the beam is already aligned and properly focused, is electron beam polarization measurements and polarization measurements of the laser beam transmitted through the Fabry-Perot cavity. Laser polarization measurements are made with a rotating quarter-wave plate and Wollaston prism – this activity requires no laser alignment or changes. Occasionally, alignment of the laser input to the Fabry-Perot cavity must also be optimized. This generally requires only a few small steps with the remote mirror controls.

In operational running mode, use of the optical setup safety is insured by:

- laser safety enclosure
  - A black metallic panel encloses the entire optical setup.
  - The front and the side doors are interlocked with the laser.
  - The blank flanges on each side of the beam line with signs posted to indicate their laser safety enclosure function and that anyone needs the agreement of laser supervisor before removing the flanges.
- A yellow warning beacon, indication the possible presence of laser light inside the optical enclosure

Alignment procedure

In alignment mode, laser safety eyewear is required at all times when lasers may be active, i.e., whenever the interlock system is enabled. Lasers should be assumed to be active until the individual worker has verified that all lasers are off and the interlock disabled.

General guidelines for safe alignment procedure of laser setups are given in Appendix A. These general procedures must be adhered to during alignment work of the Compton Polarimeter Optical setup. In addition, the following specific procedure must be followed.

When performing alignment of the optical devices on the table (unlikely to occur often), the access to the area of the tunnel near the laser table will only be allowed for authorized people working, with laser safety goggles, on the optical setup. The curtains will be extended to the wall of the tunnel. Outside the laser controlled area delimited by the curtains, the two blank flanges on each side of the beam pipe close the laser safety enclosure. The upstream and downstream valves on the beam line will be closed (the photon beam won't be able to be reflected far in the main electron beam pipes if it is lost). The connectors on the valves will be disconnected in the tunnel. Then, the accordion door may be opened and the interlock placed in "alignment" mode. All the mechanical stands supporting the optical components have been designed and surveyed in order to achieve a preliminary safe alignment of the entire setup (laser off). Laser on, the beam can be tracked by the use of either a photosensitive screen or a beam viewer (a cell phone camera works well for observing the green light). In alignment mode, output power should be limited 100-200 mW. Final testing of alignment with no optics manipulation can be at full power.

The last fine alignment is electro-mechanically achieved by the two 2 axes mirror micro-actuators under the control of the two position-sensitive 4 cells photodiodes. The fine focusing is electro-mechanically achieved by the translation micro-actuators under the control of a beam analyzer. Alignment is attended conditions and may occur during limited access permit. Alignment power for the IPG fiber amplifier should be limited to 200mW when possible. Fine alignment of the PPLN crystal relative to the IPF fiber amplifier output beam can be performed at higher power once rough alignment through the crystal has been achieved. Note that any manipulation of the output fiber (de-installation, re-positioning for tests, etc.) of the fiber amplifier requires that the amplifier be turned off and power controlled via the JLab LTT protocols.

Detailed alignment procedure of Compton laser system:

1. Alignment of seed laser to fiber collimator

   The free-space 1064 nm seed laser must be aligned to achieve good translation through a free-space -to-fiber collimator for use with the fiber amplifier. This is achieved with a 2-mirror "chicane" that allows alignment of the laser into the stationary coupler. The seed laser will run at 100-200 mW normally, so is attenuated, either with an ND filter, or a combination half-wave plate + polarizing cube. In the latter case, care must be taken to dump the non-transmitted beam appropriately. An optical isolator will also be used to minimize back reflection. The isolator may also emit beams from the initial and final polarizing cubes – these beams must also be properly controlled.

   Transmission through the fiber coupler is checked with a PM fiber connected to the collimator and incident on a power meter. Once good transmission is achieved (typically 5-10 mW), the system is ready to be connected to the fiber amplifier.

2. Connection to the fiber amplifier

   Once good transmission through the fiber collimator has been achieved, one may connect the fiber that provides the input to the fiber amplifier. Once connected, turn on the seed laser at nominal power – then turn on power to the fiber amplifier. Verify from the front-panel readback that the input seed power is appropriate (typically 5-10 mW). At this point, the fiber amplifier is ready to be turned on and used.

   Note: Prior to the connection/disconnection to the fiber amplifier LOTO shall be applied at the laser source to prevent inadvertent personnel exposure from an un-terminated fiber.

3. Alignment of the PPLN crystal

The output of the fiber amplifier is passed through two lenses and is incident on a PPLN doubling crystal. The crystal sits on a 4-axis stage so that it can be aligned to the fiber amplifier output. The PPLN crystal is aligned by monitoring the output green power for fixed fiber amplifier output. In addition, the shape of the frequency doubled output is monitored on a CCD camera. There will be some compromise between output green power and making the beam "round".

4. Alignment of the laser across the table to the cavity

Once green light has been achieved, the laser must pass through an optical isolator. Initial rough alignment of the isolator centers the beam on the input and output apertures. To achieve maximum isolation, the input polarizer should be rotated to provide maximum transmission in the "forward direction. The isolator is then spun to face the opposite direction – rotate the output polarizer (now upstream) to minimize transmission. The isolator can then be returned to its normal direction. As noted above, rejected beams may be emitted from the input and output polarizers – these beams must be controlled. In addition, the optical isolator has a strong magnetic field. Care must be taken when using metal tools in the vicinity of the isolator.

After the isolator, the beam is transported through a half-wave plate, lens, turning mirror, and polarizing cube. The half wave plate should be adjusted to provide maximum transmission through the cube. A beam dump on the left side of the cube captures any rejected (vertically polarized) light.

After the cube, the laser passes through a quarter-wave plate, half-wave plate and two lenses as it crosses the table. The laser should be aligned to pass through the center of these elements as much as possible. Note that before operation at high power, the quarter and half wave plates should be aligned to provide the proper polarization configuration such that the amount of light back-reflected through the polarization cube is not too large. Large back-reflection can cause possible damage to the fiber amplifier, even with the use of an optical isolator.

On the far side of the table, the laser is steered sideways in the "upstream direction" with a remotely movable mirror (M1). The laser is then aligned through a periscope with a fixed bottom mirror, and another remote mirror (M2) at the top. Note that the periscope presents a vertical beam hazard, so care should be taken in its vicinity. At the top of the periscope, the laser is steered through a window into the vacuum system.

5. Alignment of beam into cavity and cavity mirrors

At this point, the remaining steps depend on whether the cavity mirrors have been installed and aligned or not:

a) Cavity mirrors installed and aligned: M2 should be used to make the back-reflected beam coincident with the initial beam. This can be most easily observed by looking at the bottom periscope mirror with a viewer (cell phone camera).
b) Cavity mirrors not installed/aligned: The trajectory through the cavity region can be set using "pinhole" targets in the Fabry-Perot cavity mirrors. The incoming beam alignment can be set iteratively by maximizing transmission through the upstream pinhole using M1, and the downstream pinhole using M2. Once the incoming trajectory is set, the high-reflectivity mirrors can be installed. The upstream mirror should be adjusted to make the back-reflected and initial beams coincident at the bottom periscope mirror.

Then the downstream mirror can be adjusted until "flashes" of transmitted power are seen (this happens as the cavity drifts in and out of resonance).

6. Alignment of elements after the cavity
7. After the cavity, the laser exits the vacuum system vertically down through a window (note: another vertical beam path) and is reflected by a steering mirror across the table (in the direction of the tunnel walkway). It passes through a quarter wave plate, a harmonic beam sampler (HBS), and Wollaston prism on its way to two integrating spheres used for monitoring the beam power when the cavity is locked. The HBS also provides low power samples of the laser to be sent to a CCD camera and fast photodiode. Alignment of these elements can be done using the "flashes" of transmitted power as the cavity passes through resonance, or with the cavity locked at low power.

Maintenance procedure

The lasers in use in the Hall A Compton polarimeter have no user serviceable components. All maintenance will be performed by the vendor, either on-site or at the vendor location.

Replacement of used or damaged optical components of the setup will be made with the laser power controlled using the JLab Lock, Tag, and Try (LTT) protocols. The positions and orientations of the new components will be mechanically surveyed and extensively checked before turning to any procedure needing the laser on.

Off-normal and emergency procedure

Fire: In the event of a fire, the laser system should be turned off and the nearest fire alarm pull box should be pulled to start an evacuation of the hall. If the fire is small enough, a fire extinguisher may be used if properly trained and if the escape route is clear. If the fire cannot be extinguished of condition deteriorate, the user should leave the hall, exit the building and gather at the muster point. The user should call 911 to report the fire.

Accidental Eye Exposure: Accidental eye exposure to a laser beam requires ***immediate medical attention*** whether injury is apparent or not. In case of exposure, immediately contact Jefferson Lab Medical Services (x7539, pager: 584-7539). If after business hours, proceed to the Emergency Room. Please also contact the LSS (Dave Gaskell, x6092, cell: 757-719-5482) and Paul Collins (JLab Laser Safety Officer). If possible, the individual should remain and be transported in the upright position.

In case of an emergency, power to the laser should be shut off if easily accomplished. This can be performed in three ways.

- Change the position of the control key on the laser power supply.
- Push the crash button.
- Use the control panel of the EPICS slow control in the counting room.

Laser Controls	• Describe all controls (administrative and engineering). (If a different control is recommended the rationale for not using a typical/recommended control.)

Several controls have been added as preventive measures to the Compton polarimeter chicane area and to the direct laser area. The controls will be checked before initial start-up by the LSS and the LSO, and every six months by the LSS. We will enumerate these controls here. A schematic view of the safety interlock controls is shown in Appendix B.

1. The laser control area is posted with danger signs indicating the presence of Class IIIb and IV lasers.

2. A yellow beacon will illuminate to indicate operation "Power ON" status.

3. In "normal" mode, the laser interlock system will turn off both the seed laser and fiber amplifier when either the beam-side accordion door or the small upstream door are opened.

4. A crash button is on the interlock control box situated in the laser safety enclosure when in alignment procedure (laser curtains extended up to the opposite wall and no more pathway in the tunnel).

5. Floor mats immediately upstream and downstream of the laser area will trip the laser interlock and turn off the lasers. These floor mats are only active when the system is in alignment mode.

6. On each side of the laser safety enclosure, upstream and downstream the enclosure, there will be another crash button. So, in case of emergency, somebody (knowing the laser activity by the yellow beacon) can turn off the laser and go through the laser tent.

7. The main power switch to the laser interlock box on wall can be easily pulled.

8. Protective safety goggles with OD values as shown in Table 11 have to be worn before turning the laser on when working in the tunnel in the alignment procedure.

9. All personnel need to fulfill the training requirements as indicated in this document.

10. The LOSP will be posted near the laser area to inform personnel about the hazards associated with the setup and the proper procedures.

11. No reflective jewelry is to be worn.

12. Smoke detector interlocked to laser power for class IV laser operations.

Required Calculations	• Maximum permissible exposure. • Optical density. • Nominal hazard zone.

The maximum permissible exposure (MPE), optical density of protective eyewear (OD) and Nominal Ocular Hazard Distance (NOHD) for the lasers are summarized in Table 11. Reference Lazan Laser Hazard Analysis is attached separately. An OD of 5 at least is required for IR (1064 nm) and an OD of 4 is required for green (532 nm). Since both wavelengths may be present at the same time, safety glasses suitable for both wavelengths will be employed. Note that since the Thorlabs alignment laser is Class 3R (< 5mW) safety glasses are not required for use of this laser.

Manufacturer	Model	λ (nm)	MPE (mW/cm^2)	OD	NOHD (m)	Power (W)
Innolight	Mephisto	1064	2.55	2.017	99.8	0.2
Innolight	Prometheus	1064/532	5/2.55	3.017/2.009	319/101	2/0.1
JDSU	126-1064-300	1064	5	2.193	123	0.3
JDSU	126-1064-700	1064	5	2.561	189	0.7
Lumentum	126-1064-200	1064	5	2.017	101	0.2
HC Photonics	PPLN	532	2.5	3.486	548	3
IPG Photonics	YAR-5K-1064-LP-SF	1064	5	3.415	505	5
IPG Photonics	YAR-10K-1064-LP-SF	1064	5	3.716	714	10
IPG Photonics	YAR-30K-1064-LP-SF	1064	5	4.193	1240	30
Thorlabs	HLS635	635	2.55		22.3	0.005

Table 11: Laser safety calculations and the appropriate OD for Safety Goggles.

Labeling/Posting (See ES&H Manual Chapter 6410 Appendix T5 Laser Labeling/Posting Requirements	• Equipment/area labeling/posting requirements. • Area signs.

Signs will be posted on the tunnel wall upstream and downstream of the Compton polarimeter laser area indicating the presence of Class IIIb and IV lasers. Similar signs will be posted on the upstream and downstream sides of the enclosure itself. Additional signs will be installed near the flanges upstream of dipole 2 and downstream of dipole 3 noting "DANGER, Class IV Laser Hazard."

On the laser table, near the coupling of the free space seed laser to the fiber amplifier input, there will be a label stating "Hazardous Laser Radiation when Disconnected." Additionally, signs will note the presence of vertical beams at appropriate points along the beam path.

Authorized/Trained Individuals	
Print Name/Signature	**Date**

Authorized/Trained Individuals	
Print Name/Signature	**Date**

APPENDIX A – GENERAL ALIGNMENT GUIDELINES

The techniques for laser alignment listed below will be used to help prevent accidents during alignment of this/these laser system(s).

The requirements for alignment procedures for class 2 and above lasers and laser systems, found in the EH&S chapter 6410 (Laser Safety Program) and ANSI Z136.1 (Safe Use of Lasers), do not apply to laser pointers, surveying equipment, barcode readers, hand held laser diagnostic equipment or similar general industry equipment.

Procedural Considerations:

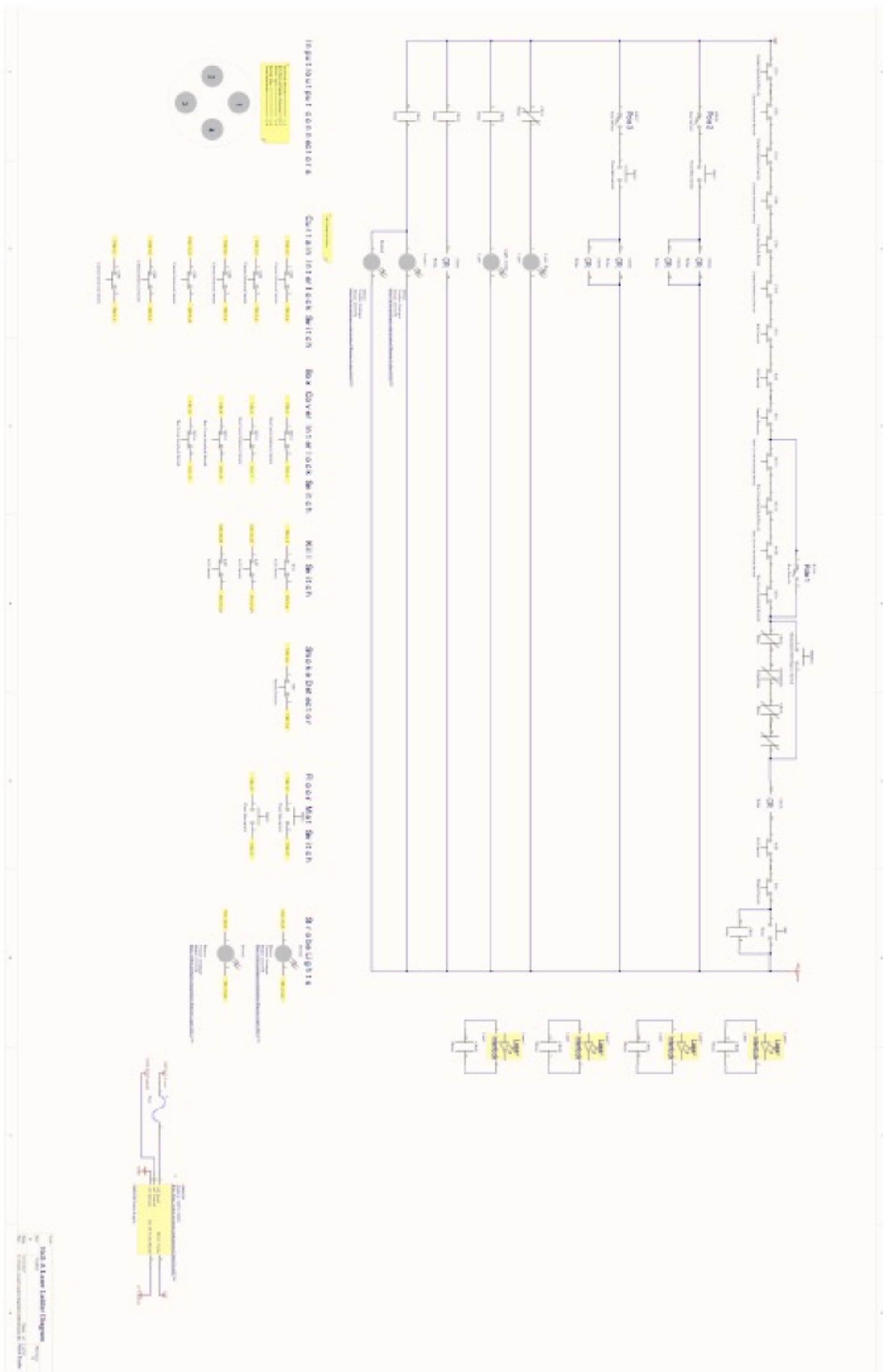
1. To reduce accidental reflections, watches, rings, dangling badges, necklaces, reflective jewelry are taken off before any alignment activities begin. Use of non-reflective tools should be considered.
2. Access to the room/area is limited to authorized personnel only.
3. Consider having someone present to help with the alignment.
4. All equipment and materials needed are present prior to beginning the alignment
5. All unnecessary equipment, tools, combustible material (if fire is a possibility) have been removed to minimize the possibility of stray reflections and non-beam accidents.
6. Persons conducting the alignment have been authorized by the LSS
7. A NOTICE sign is posted at entrances when temporary laser control areas are setup or unusual conditions warrant additional hazard information is available to personnel wishing to enter the area.

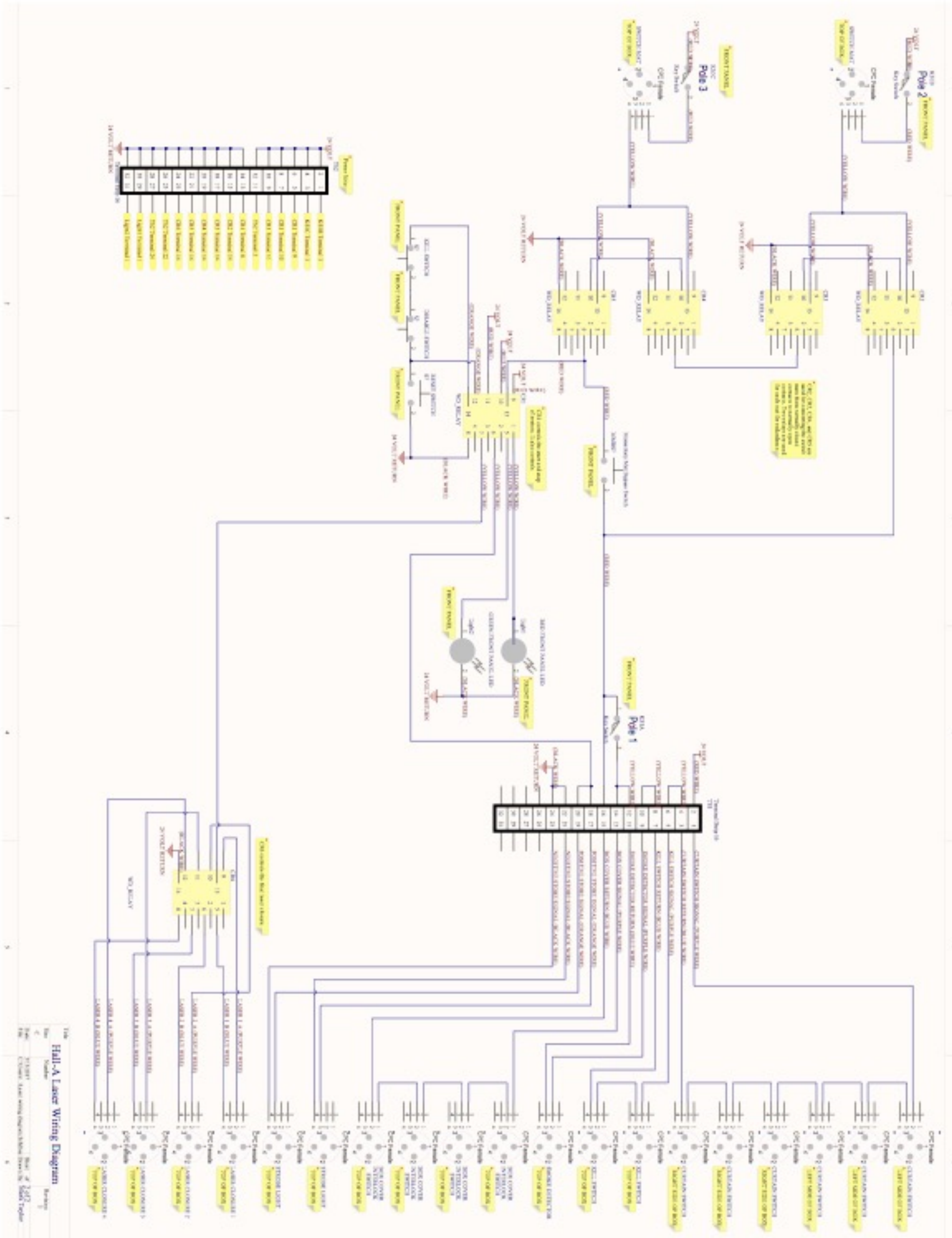
Alignment Methods to be used for this laser:

1. There shall be no intentional intrabeam viewing with the eye. Co-axial low power lasers should be used when practical for alignment of the primary beam.
2. Reduce the beam power through the use of ND filters, beam splitters and dumps, or reducing power at the power supply. Avoid the use of high-power settings during alignment as much as is practical.
3. Laser Protective Eyewear shall be worn at all times during the alignment, within the parameters and notes established on the accompanying laser table.
4. Skin protection should be worn on the face, hands and arms when aligning at UV wavelengths.
5. Beam Control- the beam is enclosed as much as practical, the shutter is closed as much as practical during course adjustments, optics/optics mounts are secured to the table as much as practical, beam stops are secured to the table or optics mounts.

6. Areas where the beam leaves the horizontal plane shall be labeled.
7. Any stray or unused beams are terminated.
8. Invisible beams are viewed with IR/UV cards, business cards or card stock, craft paper, viewers, 3x5 cards, thermal fax paper, Polaroid film or similar technique. Operators are aware that specular reflections off some of these devices is possible, and that they may smoke or burn.
9. Pulsed lasers are aligned by firing single pulses when practical.
10. No intra-beam viewing is allowed unless specifically evaluated and approved by the LSO/LSS. Intrabeam viewing is to be avoided by using cameras or fluorescent devices.
11. Normal laser hazard controls shall be restored when the alignment is completed. This includes enclosures, covers, beam blocks/barriers have been replaced, and affected interlocks checked for proper operation.

APPENDIX B – LASER INTERLOCK SCHEMATICS





1.0 Revision Summary

Revision 1.2 – 09/05/19 – Updated TPOC from B.Manzlak to P.Collins per B.Rainey
Periodic Review – 12/22/15 – No changes per TPOC
Revision 1.1 – **07/01/14** – TechPOC changed from D. Owen to B. Manzlak.
Revision 1.0 – 12/05/10 – Updated to reflect current laboratory operations.

ISSUING AUTHORITY	TECHNICAL POINT-OF-CONTACT	APPROVAL DATE	REVIEW DATE	REV.	
ESH&Q Division	Paul Collins	09/05/19	09/05/21	1.2	

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Task Hazard Analysis (THA) Worksheet

(See ES&H Manual Chapter 3210 Appendix T1
Work Planning, Control, and Authorization Procedure)

Click For Word

Author:	Dave Gaskell	**Date:**	9/10/19	**Task #:** If applicable	

Complete all information. Use as many sheets as necessary

Task Title:	Hall A Compton Laser Operation and Alignment			**Task Location:**	Hall A Beam Tunnel
Division:	Hall A	**Department:**	Physics	**Frequency of use:**	Intermittent
Lead Worker:	Dave Gaskell				
Mitigation already in place: Standard Protecting Measures Work Control Documents	LOSP, Laser safety interlocks, PPE (laser safety glasses).				

Sequence of Task Steps	Task Steps/Potential Hazards	Consequence Level	Probability Level	Risk Code (before mitigation)	Proposed Mitigation (Required for Risk Code >2)	Safety Procedures/ Practices/Controls/Training	Risk Code (after mitigation)
1	General optical element alignment (seed laser, PPLN, and green laser)/Laser exposure above MPE to eyes or skin	M	M	3	PPE (laser safety glasses), proper alignment procedures as outlined in LOSP.	See LOSP for detailed laser alignment practices.	1
2	Laser alignment through vertical chicanes/ Laser exposure above MPE to eyes or skin	M	M	3	PPE (laser safety glasses), proper alignment procedures as outlined in LOSP.	In addition to good alignment practices, vertical beam areas are marked.	1
3	Laser alignment through optical isolators	M	M	3	PPE (laser safety glasses), proper alignment procedures as outlined in LOSP.	In addition to good alignment practices, awareness and control of beams rejected by isolator is required.	1
4	Operation of Class IV laser at high power/Laser induced fire	M	L	2	Eliminate flammables from laser enclosure. Smoke alarm in laser enclosure shuts off laser.	The enclosure is designed to prevent laser exposure to any flammable material.	1

Sequence of Task Steps	Task Steps/Potential Hazards	Consequence Level	Probability Level	Risk Code (before mitigation)	Proposed Mitigation (Required for Risk Code >2)	Safety Procedures/ Practices/Controls/Training	Risk Code (after mitigation
5	Operation of fiber amplifier with possible damage to output fiber	M	L	2	PPE (laser safety glasses). Output fiber enclosed in thick protective covering.	Visual inspection of fiber, check output power relative to expected to check for losses	1
6	Connecting/disconnecting fibers/ Laser exposure above MPE to eyes or skin	M	M	3	LTT when connecting/disconnecting fibers	Seed laser power must be controlled when connecting and disconnecting fiber to coupler	1
7	Use of laser power supplies and remote mirror motors/Electrical shock	M	L	2	LTT when attempting to service electrical components	All devices are in closed housing without user serviceable components	1

Highest Risk Code before Mitigation:	3	**Highest Risk Code after Mitigation:**	1

When completed, if the analysis indicates that the Risk Code before mitigation for any steps is "medium" or higher (RC≥3), then a formal Work Control Document (WCD) is developed for the task. Attach this completed Task Hazard Analysis Worksheet. Have the package reviewed and approved prior to beginning work. (See ES&H Manual Chapter 3310 Operational Safety Procedure Program.)

Form Revision Summary

Periodic Review – 08/13/15 – No changes per TPOC
Revision 0.1 – 06/19/12 - Triennial Review. Update to format.
Revision 0.0 – 10/05/09 – Written to document current laboratory operational procedure.

ISSUING AUTHORITY	TECHNICAL POINT-OF-CONTACT	APPROVAL DATE	REVIEW DATE	REV.
ESH&Q Division	Harry Fanning	08/13/15	08/13/18	0.1

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By signing this page, you testify that you have read, understand, and agree to abide by the procedure specified in the above referenced work control document:

Serial Number: ENP-19-90881-LOSP

Title: Hall A Compton Polarimeter Laser System

Name	**Signature**	**Date**