Chapter 1

Polarized ^{3}He Target [1]

1.1 General Description

1.1.1 Physics Principle

This target system provides a high-density ($\approx 2.5 \times 10^{20}$ nuclei/cm^3) polarized ^{3}He gas target for spin physics experiments at JLab. The JLab polarized ^{3}He target system was first constructed in 1998 and had been used for over a dozen experiments in Hall A during 6 GeV era. This Hall C polarized target is upgraded from the last version used in the transversity series of experiments in Hall A (2008).

The target employs the so-called spin-exchange technique. In the traditional spin–exchange technique ^{3}He is polarized in a two-step process. First, rubidium vapor is polarized by optical pumping with circularly polarized 795 nm laser light. Second, the polarization of the Rb atoms is transferred to the ^{3}He nucleus in spin-exchange collisions, in which ^{3}He nuclei are polarized via the hyperfine interaction. Recently,a novel technique of hybrid pumping has been used. In addition to the direct spin exchange, it also happens indirectly for the hybrid Rb-K cells: spin-excahnge first happens between rubidium and potassium atoms (very fast) and then between potassium atoms and ^{3}He nuclei, which is more efficient than the direct Rb-^{3}He spin exchange. The target cell contains high pressure ^{3}He gas and a small amount of vapor of Rb-K mixture. In addition, it also contains a small amount of nitrogen to increase the pumping efficiency.

1.1.2 Apparatus

High power infrared (795 nm) diode lasers (up to 120 W) provide an intense monochromatic light beam for optical pumping. The lasers are housed in a laser room outside the hall next to the counting house. Laser light goes to the hall through an optical fiber

[1] Authors: Revised by J. P. Chen, 2018/2/23. 2008 Revision by: T. Averett, J. P. Chen, C. Dutta, J. Katich, Y. Qiang. Earlier versions: T. Black, J. P. Chen, P. Chevtsov, H. Gao, O. Hansen, S. Incerti, S. Jensen, M. G. Jones, K. Kramer, M. Liang, N. Liyanange, K. McCormick, Z.-E. Meziani, X. Zheng. jpchen@jlab.org

system. An overview of a typical arrangement of the target components in the Hall is shown in Fig. 1.1.

The polarized target comprises several components beyond its target cell (see Fig. 1.1) related to its operation, they are in subsection:

1. Two sets of orthogonal Helmholtz coils provide the target spins with a holding magnetic field of few tens of Gauss as well as define the orientation of the polarization in any required direction on the horizontal plane.

2. One pair of RF coils which allow for the measurement of the target polarization using the Adiabatic Fast Passage (AFP) technique, the pulsed NMR technique and the Electron Paramagnetic Resonance (EPR) technique.

3. A multi-purpose enclosure which is part of the laser light enclosure and provides a containment of the target cell in case of explosion. It also provides a containment volume for the ^{4}He gas to cool the target windows with cooling jets, minimizing the radiation length crossed by the electron beam.

4. An oven with all its related components for providing the necessary temperature to the pumping cell in order to bring Rb and K in their vapor phase and control their number densities.

5. A target ladder subassembly which supports a target cell, a reference cell, (which can be filled with Hydrogen, ^{3}He or Nitrogen gas with pressure up to 10 atmospheres for calibration or to study dilution, density or background), a multi-foil ^{12}C optics target, a single ^{12}C foil and a ^{12}C foil with a hole(for beam centering), and an oven. It also includes a full mechanism for positioning the targets and bears the target cell viewing mirrors and the optical beam line mirrors.

6. A laser and optical fiber system in the laser room bring up to ten laser beams, each from a 40 Watt diode laser, to the hall. These laser beam lines are used for optical pumping of the rubidium-potassium alkali atoms in two different directions: along the electron beam (longitudinal), perpendicular to the electron beam line but on the horizontal plane (transverse). They can also be re-directed to any direction on the horizontal plane as needed.

1.1.3 Control System

The control (including monitoring and measurement) system for the target Helmholtz coil magnet power supplies, the NMR polarimetry, the pulzed NMR polarimetry and the EPR polarimetry are based on the LabView system on a PC. The control system for the target vertical motion, the lasers, the oven heater, and temperature and pressure monitoring runs under the EPICS [?] environment utilizing an IOC in a VME crate. The LabView system records data on disk and communicates with the EPICS system through the network. Information from the EPICS IOC is logged on disk and selected information passed on to the event data stream.

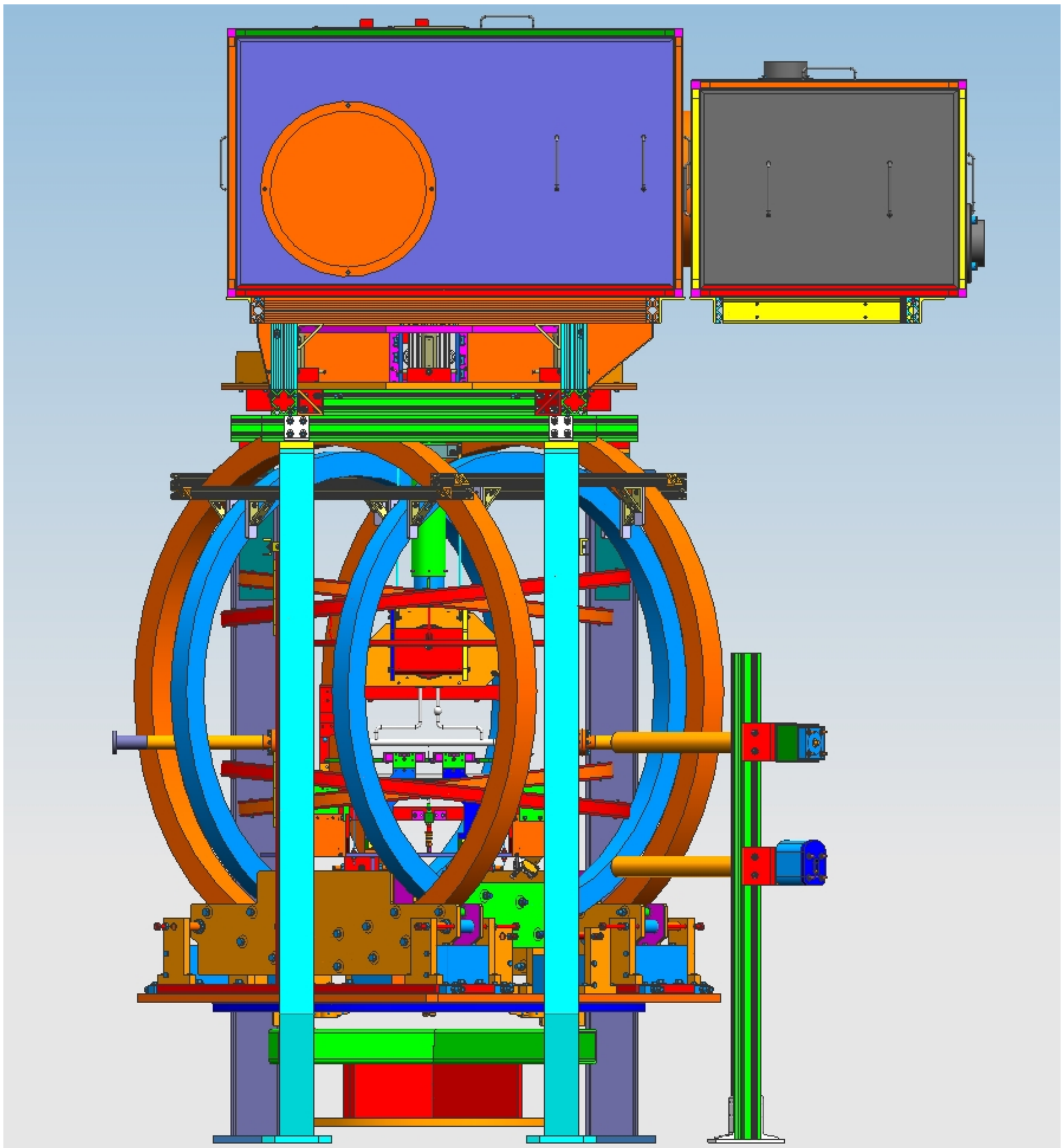

Figure 1.1: Overview of the target setup. Shown are the laser beam pipes covering the laser beam line on top of the target area, and the two sets of Helmholtz coils with the support sub-assembly.

1.2 Operation Overview

In normal operation the target will be under one of the following situations described below.

1. The target is in "beam position", the fast raster set to a nominal 5 mm diameter circular area coverage and the experiment is running to collect physics data. In this configuration the monitoring of the target consists of reading a set of temperatures of the pumping cell, target cell and reference cell. The temperature in the pumping cell provides feedback for the temperature controller. A spectral-analyzer is monitoring the laser wavelength and the relative intensity. All interlocks of electron beam and laser beam shall be on.

2. The beam is turned off and the target is moved to "Pickup Coil Position" (polarized ^{3}He target in a position between the NMR pickup coils) and a polarization measurement is performed using the NMR (AFP) method. The laser beam will be stopped first. If the polarization is in the transverse mode, a rotation of the polarization to the longitudinal direction is performed (procedure described in Section 1.9). Once the measurement is completed the target cell will be moved back to the "beam position". If the next running is in transverse mode, a rotation of the polarization to the transverse direction is performed. The laser beam will be turned on. The beam interlock is reset and the fast raster enabled before turning the beam back on target. The physics data taking can resume.

3. The "Polarized ^{3}He Target" is either in "beam position" or in "pick-up coil position". The data taking is stopped and the beam is turned off. An EPR (or pulsed NMR) measurement is performed (procedure described in Section 1.11). After the measurement is completed and the fast raster enabled, the beam is put back on and data taking resumes.

4. The multi-foil or single ^{12}C "Optics Target" is in "beam position". Data on the optics target are taken for spectrometer optics study or detector calibration.

5. The "hole" target is in "beam position". The "hole" target is a single ^{12}C foil with a 2mm diamtere hole at the center. It is used for center the beam with respect to the target ladder.

6. The target ladder "Empty Target" frame is moved to "beam position" whenever beam tuning is performed, and when checking for possible beam halo background.

7. The "Reference Cell Target" is in "beam position" with the beam fast raster on and data on the reference cell are taken for calibration.

1.3 Laser System

The laser system provides 795 nm circularly polarized light for optical pumping of the target. The light is generated by several solid-state diode lasers, which are located in a laser room outside the hall. Each laser emits 30 W of power and is transported into the hall with an 110 meter long optical fiber (which causes about 10% loss in power). Up to four laser beams are combined to one through a 4-to-1 combiner. It is then polarized by passing through a polarizer (beam splitter) followed by standard $\lambda/4$ waveplates. Because of the invisibility and high intensity of the laser beam, the lasers present a significant safety hazard. The system generates two independent laser beams for optical pumping of two different target spin directions: parallel, perpendicular, or vertical to the electron beam. In the standard configuration, up to five lasers are used for each direction. Further, the laser polarization direction can be reversed by rotating the $\lambda/4$ waveplates by 90 degrees.

1.3.1 Laser Room & Beam Path

To protect the lasers from radiation damage due to the electron beam and shield personnel from accidental exposure to hazardous laser light, all laser systems are located in a laser room outside the hall.

Up to 10 infrared diode lasers (five for each pumping direction) and the related interlock control box are located on two 19" racks in the laser room. Light is guided out of each laser and goes into the hall via an optical fiber. Four beams combined to one with a 4-to-1 combiner. The combined beam is focused by two 2" diameter convex lens then divided by a polarizing beam splitter cube into two linearly polarized rays. Because the laser light is initially unpolarized, both the direct and the split beam carry approximately half the power. To utilize the full laser power it is necessary to combine both beams and focus them onto the optical pumping cell. This is accomplished as follows:

The direct beam is reflected by a 3" diameter dielectric mirror which can be adjusted to steer it towards the pumping cell. The split beam passes through a $\lambda/4$ waveplate, is reflected by a 2" diameter dielectric mirror, and passes through the $\lambda/4$ waveplate again. The fast and slow axes of this $\lambda/4$ waveplate should be oriented at an angle of 45° to the horizontal or vertical direction. The linear polarization of this beam is thus rotated by 90°, and is able to pass through the beamsplitter, essentially without reflection. The second passing through the splitter is necessary to achieve a very high degree of linear polarization for the split beam since the splitter only gives high polarization for direct beam ($T_P > 95\%$,$R_S > 99.8\%$).

Now both beams from each laser have identical linear polarizations. Each passes through a $\lambda/4$ waveplate that transforms its polarization from linear to circular. The orientation of each $\lambda/4$ waveplate is shown in Fig. 1.2, note that all $\lambda/4$ waveplates should have the same orientation.

The resulting beams are reflected twice by a pair of adjustable 6" diameter mirrors mounted on top or next to the target pumping chamber. These mirrors can be standard dielectric ones since they will be in a polarization-preserving compensating configuration (one mirror rotated by 90° with respect to the other). The laser beams are carefully aligned to coincide on the pumping chamber of the cell. They enter the target chamber via transparent windows on the oven wall.

Under normal conditions, laser light will be mostly absorbed by the rubidium in pumping cell. There are additional windows on the oven to allow lights to be collected for the EPR measurement and for spectral-analyzer to monitor laser spectrum and intensity. For the ERP measurement, light is focused by two lenses (mounted on the oven) into an optical fiber to be transported to the EPR photodiode which is located behind a shielding wall. At the meantime some light will be viewed by the spectral-analyzer through an optical fiber.

The laser beam line is protected by beam pipes that extend from the laser room to the target area. A laser enclosure with interlock covers the laser optics system and the target. It is important to point out that the complete laser beam lines and optics system are fully enclosed with laser intrelock system from the rest of the hall.

The entire laser room is a laser controlled area that requires special safety precautions (see Section 13 and Appendix A).

1.3.2 Diode Lasers & Controls

The laser light for experiments is provided by multi (up to 10) 30 Watt, 795 nm solid-state diode lasers. The primary lasers used during the experiment are made by Coherent Semiconductor Inc. The diode lasers consist of a main enclosure which contains the diode, power supplies, fans and control systems for the laser. The laser light from the diode is sent into a flexible optical fiber which extends out of the main enclosure and goes into Hall A. The fiber is 110 m long in a stainless steel jacket.

The lasers operate at diode temperature from 15° C to 26.5° C depending on the system. They are run at output power of up to 30 Watts which uses an operating current of 35-40 Amps. The output laser light has a central wavelength of 795 nm with a spectral width of less than 0.3 nm. The fiber diamter is 600 microns. The beam divergence is < 0.20 N.A.

The lasers have a computer (PC) control system. The control allows adjustments in operating current (and therefore the laser power), diode temperature and the wavelength within a small range.

During the experiment the lasers will be controlled remotely through EPICS. There is an MEDM [?] GUI interface for each of the lasers, which allows remote control, monitoring of current, temperature and wavelength as well as being able to turn each laser on and off.

1.3.3 Alignment

Basic procedure for laser alignment

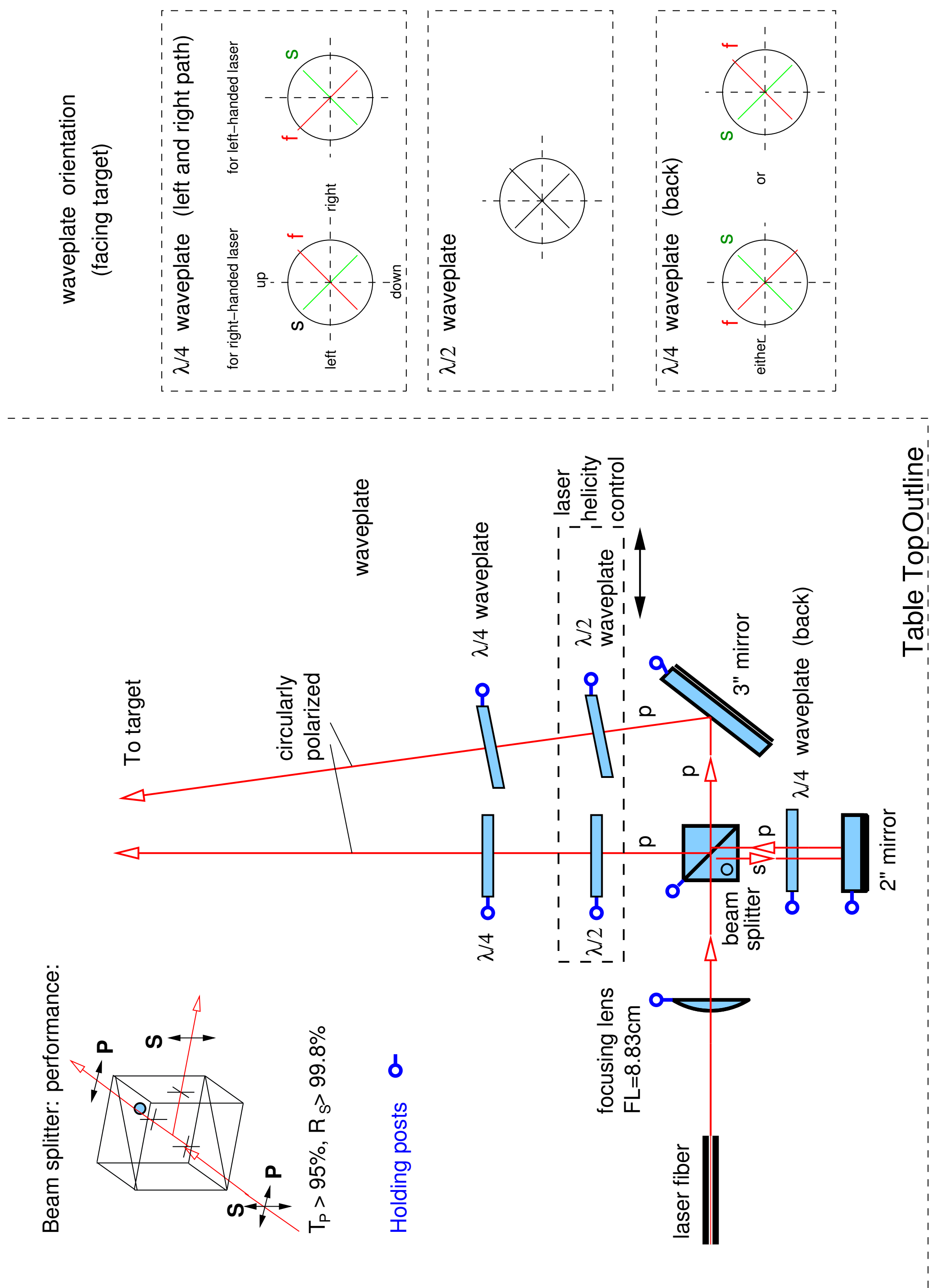

Figure 1.2: Top view of the optics setup.

1. Set the height of the diode laser, the center of the polarizing cube (beam splitter), the two-inch mirror, the quarter wave plates, the lens, and the three-inch mirror to be at the same height.
2. Viewing along the direction of the cube, the mirror and the wave plates, you should be able to see the target. Here target refers to the 6” mirror on top of the oven.
3. Place diode alignment laser such that it passes through the center of the polarizing cube and the center of the target.
4. Rotate the cube and change the angle such that the back reflection hits the alignment laser and such that the reflection hits the diode laser simultaneously.
5. Place the two focusing lens in its mount with the flat side away from the diode laser. Adjust them so that the back reflection goes back on itself.
6. Turn the diode laser on at LOW POWER.
7. Adjust the head of the diode laser such that the light goes through the center of the lens.
8. Rotate the cube mount such that the light passes through the center. Be sure that the cube is mounted so that the light enters the marked side and is reflected towards the two-inch mirror.
9. Turn off the diode laser.
10. Place the two-inch mirror into its mount and move such that the alignment laser hits the center.
11. Place a quarter wave plate between the cube and the two-inch mirror.
12. Turn the laser on at LOW POWER.
13. Adjust the position of quarter wave plate so that the laser passes through the center.
14. Adjust the two-inch mirror so that the reflected light hits the target.
15. If you know the axes of quarter wave plate, rotate it according to Fig. 1.2. If not,
    - Rotate the quarter wave plate so that the light which passes through the cube from the two-inch mirror is a minimum.
    - Rotate the quarter wave plate forty-five degrees.
16. Adjust the two-inch mirror so that the light hits the target.
17. Check to see where the back reflection of the diode is hitting. It shall be near the head of the diode laser but not directly on top of it. If it is then rotate the cube slightly and realign the two-inch mirror. Repeat if necessary. It is important to keep the back reflection away from the fiber since a small amount of back reflected laser could reach the diode through fiber and will damage the laser.
18. Place the three-inch mirror in its mount.
19. Check to see that the diode light is hitting the mirror.

20. Adjust the three-inch mirror so that the light is hitting the target.
21. Center a quarter wave plate in the path of each beam.
22. If you know the axes of quarter wave plate, rotate it according to Fig. 1.2. If not, you need to do bench test first to find the axes of each quarter wave plate.
23. Repeat for all beams heading towards the target.
24. Be sure that the helicity of each beam line is the same.

Testing quarter wave plates

- Find the direction of the axes:

  1. Use the laser beam which passes through the polarizing cube (beam splitter).
  2. Place the unknown wave plate in the beam.
  3. Place a polarizing cube after the unknown wave plate.
  4. Place a power meter perpendicular to the polarizing cube such that it measures the power of reflected light.
  5. Rotate the unknown wave plate such that the reflected light coming from the second cube is at a minimum.
  6. Now one of the axes is in horizontal direction and the other is in vertical direction.

- Make sure the axes of all quarter wave plates are identical (either fast or slow):

  1. Use the laser beam which passes through the polarizing cube (beam splitter).
  2. Measure the laser beam power P.
  3. Place the 1st quarter wave plate in the beam, rotate it such that one of the axes (marked axis) is in vertical direction.
  4. Rotate the 1st quarter wave plate by 45° clockwise.
  5. Place a 2nd quarter wave plate after the 1st one, rotate it such that one of the axes (marked axis) is in vertical direction.
  6. Rotate the 2nd quarter wave plate by 45° clockwise.
  7. Place a polarizing cube after the 2nd quarter wave plate.
  8. If the reflected light coming from the cube is at a minimum, then the marked axes of these two quarter wave plates are opposite (one is fast and the other is slow);
  9. If the reflected light coming from the cube is at a maximum and equals roughtly the full power P, then the marked axes of these two quarter wave plates are identical (both are fast or both are slow);

10. If the reflected light coming from the cube is at a maximum and equals roughtly the half power P/2, one of the two wave plates is a half wave plate.

Some technical details

- One needs to be careful about backscattering light since it may damage the laser diode if it is right on top of the fiber. However, if the backscattering light is far away from the fiber, it indicates that the system is not optimized and will affect the quality (intensity and polarization) of laser light to the target. The major part of backscattering light comes from the P light reflected from the 2" mirror and the beam-splitter. To check position of backscattering light, one shall use a backscattering test plate. Never use paper or any flammable material around fiber. Always turn off the laser when putting on or taking off the test plate.
- Adjust position of back-scattering spot vertically: Probably the reflecting surfact of beam-splitter is not exactly perpendicular to the laser beam. Make sure the fiber, focuing lens and cube(beam-splitter) are at the same level, then rotate cube, at the same time adjust the 2" mirror if necessary.
- Adjust position of back-scattering spot horizontally:
    1. Moving spot to the left (viewing towards fiber): Rotate cube holder clockwisely (viewing from the top), then rotate cube (relative to its holder) anticlockwisely. Keep the spot at the center of 2" mirror. See Fig. 1.3
    2. Moving spot to the right (viewing towards fiber): Rotate cube holder anticlockwisely, then rotate cube anticlockwisely. Keep the spot at the center of 2" mirror.

1.3.4 Operation I: Local Mode

To turn a laser on:

1. Be sure to connect the laser control box to the interlock and to the correct laser.
2. Turn on the switch on the back panel of the laser.
3. Turn the key on the front panel to turn on the power.
4. Set the current through the computer.
5. Press the On/Off button. The screen should show 'laser enabled'.
6. Press the On/Off button again. The screen should show 'laser on'. The laser should be on now.

To turn a laser off:

- Press the On/Off button. The screen should show 'laser disabled'.

Table 1.1 lists the optimum parameter determined for the 30 W lasers used in early experiments.

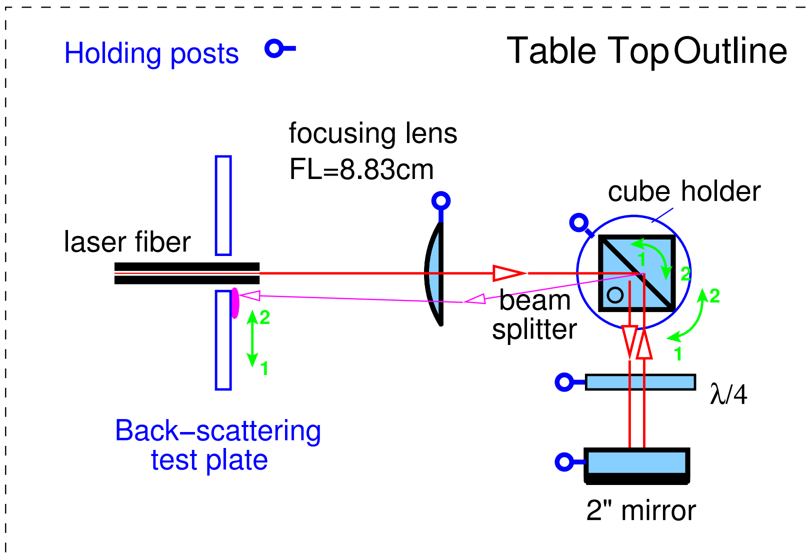

Figure 1.3: Adjusting back-scattering light

Laser	Max Current(A)	Max Power(W)
Raytum #1	40	30
Raytum #2	40	30
Raytum #3	40	30
Raytum #4	40	30
Raytum #5	40	30

Table 1.1: Operational parameters for the 30 W lasers.

1.3.5 Operation II: Remote Mode

For the remote mode to work, the lasers must be connected to the interlock box, the interlock system must be engaged and the laser key turned on as described above. The lasers can then be controlled through the MEDM GUIs:

To turn a laser on:

1. Set the desired temperature and current in the “Set Temp” and “Set Current” enter boxes.
2. Press the “Enable” button. If you have a camera pointing at the laser box in the Hall then you should see ’laser enabled’.
3. Press the “Start” button. If you have a camera pointing at the laser box in the Hall then you should see ’laser on’. The laser should now be on.

To turn a laser off:

- Press the “Stop” button. If you have a camera pointing at the laser box in the Hall then you shall see ’laser disabled’.

In addition to cameras pointing at the lasers boxes in the Laser room to monitor lasers on or off, there is a spectral-analyzer which monitors both the relative power and the waveform of the lasers. The spectral-analyzer has remote readback. Alarm will be set when the readback deviate from the regular running condition by more than 10%. This will enable us to know when there is one laser goes off or when the cell ruptured.

1.4 Target Cell

1.4.1 Description

The target cell is usually a 40 cm long aluminosilicate glass (GE180) high pressure (about 10 atm) double chamber cell. Typical dimensions for a 40 cm cell are shown in Fig. 1.4. It is a closed system filled with a gas mixture which consists of ^{3}He, rubidium and nitrogen.

The cell volume is about 3 l for a 40 cm cell with 3.5 inch diameter sphere pumping chamber.. The interior pressure of the cell at room temperature is between 7 and 10 times atmospheric pressure. The cells contain approximately 70 torr of nitrogen to help with the spin-exchange process. There is usually 0.1-0.3 g of Rb-K mixture with a mixing ratio of 1:5 in the pumping chamber. The tritium contamination of the ^{3}He gas used to fill the cell is less than 10^{-11}% according to the specifications from the manufacturer, Spectra Gases.

The glass walls of the cell vary in thickness from cell to cell and from chamber to chamber. The end windows of the target chamber are 120-150 microns thick and are therefore the thinnest part of the cell. The walls of the target chamber and transfer tube are over a millimeter thick and the pumping chamber walls are up to 2 mm thick.

The cell is installed on a target ladder and then this ladder is mounted to the bottom of the oven. The cell is attached to the target ladder with a high-temperature elastomer, GE RTV106. The ladder is then bolted onto the oven.

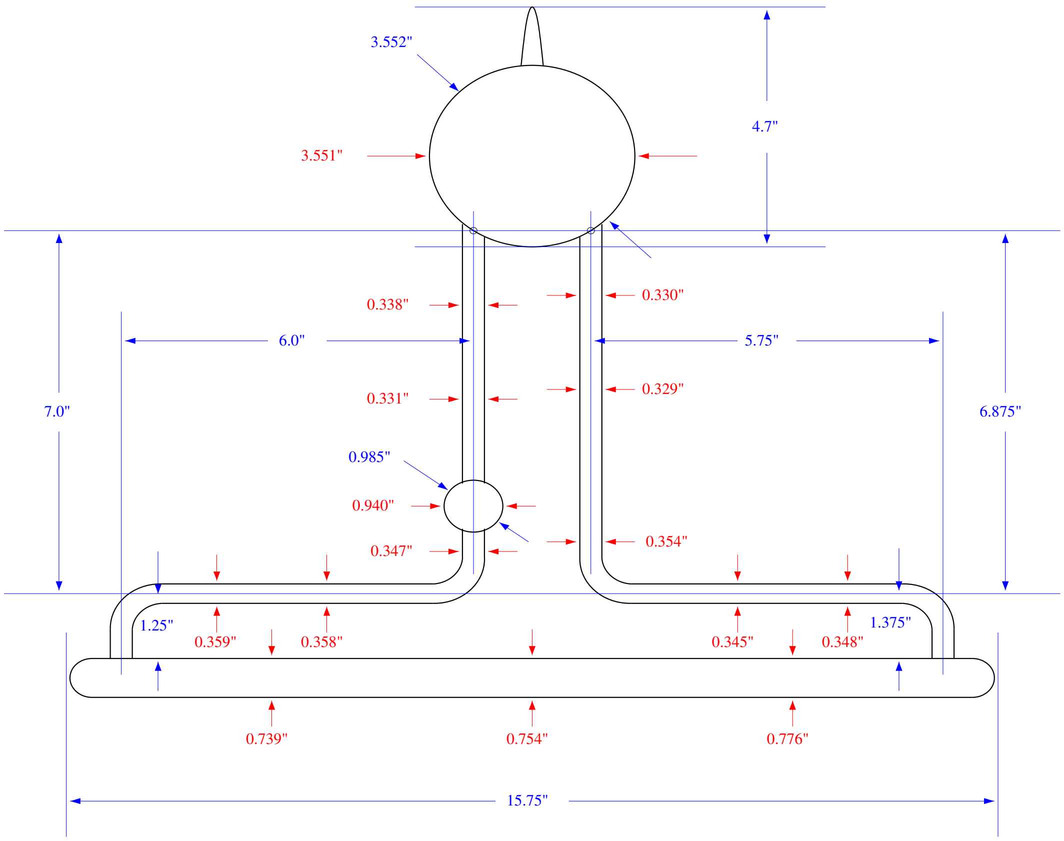

Figure 1.4: Typical 40 cm polarized ^{3}He target cell used in this experiment.

1.4.2 Installation & Replacement

The target installation is a delicate procedure and shall be performed only by qualified personnel. A minimum requirement is Radiation Worker II training. Only the first time installation does not require the monitoring of radiation around the pivot area. After the cell has been exposed to the electron beam, any replacement of the cell must be done under strict observation of possible radiation and contamination hazards.

The cells are fragile and under high pressure so they can cause damage not only to exposed skin and eyes, but also hearing. It is therefore important to wear hearing protection in the vicinity of an exposed cell and also to wear a face shield and a safety glasses when handling or in the vicinity of someone handling a cell.

In the following we describe the procedure for cell replacement. The procedure applies both to a routine replacement and a replacement after a cell explosion.

- If the replacement of the cell follows the explosion of a previous target, a new Q curve of the pickup coils shall be measured. If the pickup coils have deteriorated, they shall be replaced as well.

- Lasers shall all be turned off. Laser fibers be disconnected from the lasers and be lock-away following the lock-and-tag procedure.
- Prepare the replacement target and, if necessary, a new set of pickup coils. Request Hall access from MCC, and wait for a member from the RADCON team to accompany the group of qualified people authorized to change a target cell.
- The member of the RADCON group will evaluate the radiation level around the target area. If safe levels of radiations are observed, the work can proceed. Otherwise a Radiation Work Permit will have to be written. The member of the RADCON group will either clean up the glass pieces or, after determining that there is no contamination, informs us that we can proceed to clean up the glass pieces.
- All personnel within the target area platform must wear hearing protection, a face shield, a pair of safety glasses and buttonned cotton jacket during any access to the inside of the target enclosure when the pressurized glass cell is or will be exposed.
- Remove the side enclosure to provide sufficient access to the target. Monitor the radiation level close to the target ladder and oven. Determine what conditions are required to comply with a radiation safe work condition.
- Qualified personnel shall proceed to replace the target and align it according to well defined reference lines of the target ladder. The motion of the target and the clearance between the pickup coils shall be tested. When finished, the enclosure shall be put back in place.
- If an intact target cell was removed, it shall be stored in a wooden or plastic box with a lid or a metal box specially designed for store target cell. It must be left in the hall with "Pressurized Glass Cell, Open By Authorized Personnel Only" warning sign on the box. It can only be removed from the hall after approval from RADCON.

1.5 Target Ladder & Motion System

1.5.1 Description

The polarized ^{3}He target system has six target positions: the actual polarized target cell, which can be replaced by a water cell for NMR calibration (see Section 1.9), a seven-foil Carbon target and a single carbon target for optics calibration, a "hole" target for alignment, an empty target position that contains no target and allows the beam to pass undisturbed through the apparatus, and a reference cell position (see Section 1.12). These targets are mounted on a target ladder as shown in Fig. 1.5.

The target ladder can be positioned vertically using a stepper-motor-driven motion control system. The controller can drive the ladder to sever different fixed positions, five of which correspond to the five targets, the sixth to the empty (no target) configuration,

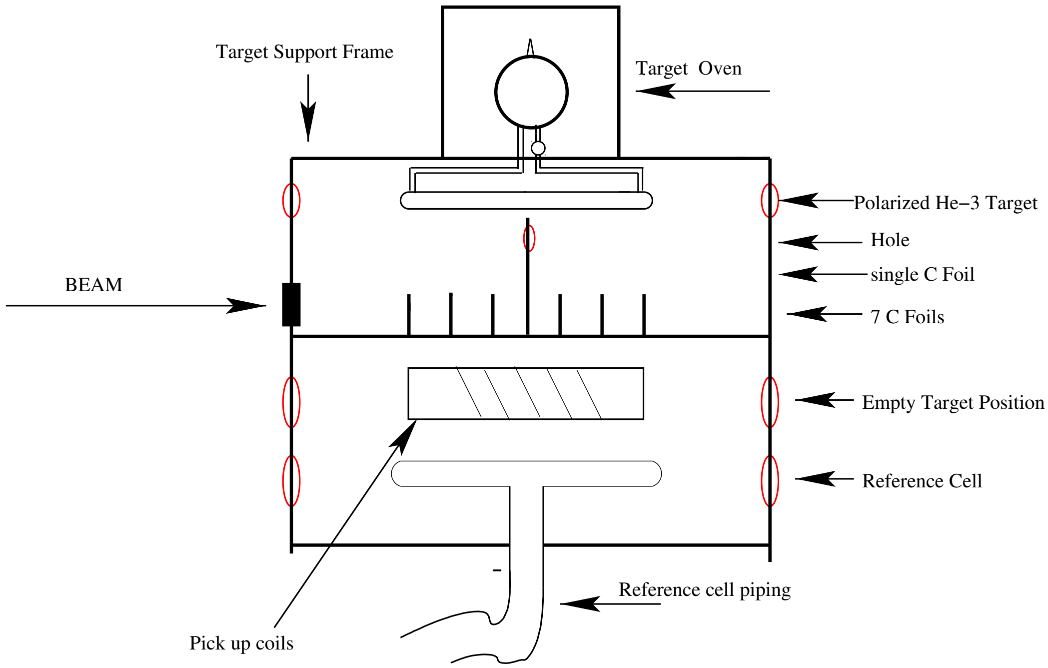

Figure 1.5: Schematic diagram of the target ladder and target positions.

and the seventh to the position used for NMR measurements where the target cell is surrounded by the pick-up coils.

The motion controller employed was developed at JLab and has been used for previous experiments. Vertical target motion is provided by a screw-driven cylinder (Industrial Devices Corporation model N2P22V1205A12MF1MT1L). The cylinder incorporates a 200 step/rev stepper motor with a 1:12 gear, resulting in a position repeatability of about $\pm 13\,\mu$m at a maximum load of 600 lbs (272 kg). The maximum range of motion is 31.5 cm. Mechanical position sensors are mounted on the target support frame to indicate motion limits. These switches are wired normally closed and fail open. A magnetic position sensor (Reed Sensor, PSR-1Q) mounted on the motor cylinder serves as the home switch. This switch is wired normally open, using only two of its three wires (12 V is not connected for this type of switch). Additionally, a linear potentiometer provides independent readback of the cylinder position.

1.5.2 Operation

The motor can be controlled locally and remotely. Local control is provided through the SmartStep 23 keypad controller. The keypad allows the target to be jogged into position. It also allows for small codes to be saved which will move the target ladder into preset target positions. Remote control is provided through the EPICS environment. During norml operation, target motion is controlled through the lifter MEDM GUI running on one of the computers in the Hall C counting house. The GUI has buttons for preset target positions, as well as lights indicating the status of the controller (i.e. any faults, at a limit, etc.). The velocity, acceleration time, deceleration time and position can also be manually set from the GUI, but the defaults should be correct for all but special situations. The position of the motor is readback on the GUI. This position is displayed in revolutions from the home position and can be compared with preset target positions.

The electronics provide a Fast Shutdown (FSD) interlock signal to the accelerator that is triggered whenever the target is moved with the beam on. This prevents damage to the target cell and ladder due to the electron beam. The FSD signal is generated by the SmartStep controller and sent to an FSD node in the Hall. Target changes require Hall personnel to telephone MCC and request temporary masking of this FSD channel.

1.6 Target Enclosure & Windows

The target is surrounded by an enclosure. . The enclosure serves three purposes: First, it is part of the laser light enclosure. Second, it provides a containment volume in case of explosion of the target cell and so limits the potential hazard working area. Third, it allows the region around the target to be filled with helium gas, minimizing ionization and energy loss of the electron beam crossing the target area.

The enclosure is made fiber glass material and part of the middle section is removable for access to work in the target area. The material at the forward part where the scattered particles passing through is 0.762 mm thick. The other parts are thicker.

If the middle section is open, people working anywhere on the *target platform* must wear double ear protection and a face shield. Lasers should have been turned off and optics fiber ends be locked away following the lock-and-tag procedure. This region is designated as the “target area”. Signs will be posted indicating that the enclosure is open and that work is in progress. If the enclosure is closed the target area is no longer restricted except for possible reasons of radiation safety.

The electron beam line is under vacuum and separate from the target enclosure for both upstream and down-stream of the target enclosure with the enclosure windows. The beam inlet and outlet windows of the target enclosure are made of 0.254 mm and 0.508 mm thick Be and are strong enough to stop any flying glass shards in case of a target cell explosion. Each Be window has an additional 0.076 mm thick aluminum foil cover to protect it from exposing to air.

1.7 Target Cell Heater

The target pumping cell must be kept at a temperature of about 230°C for optical pumping of Rb-K to be effective. This is accomplished by flowing hot air through a special temperature-resistant enclosure (“oven”) around the pumping cell and regulating the temperature of the air using a process controller. The system is described in detail in the following.

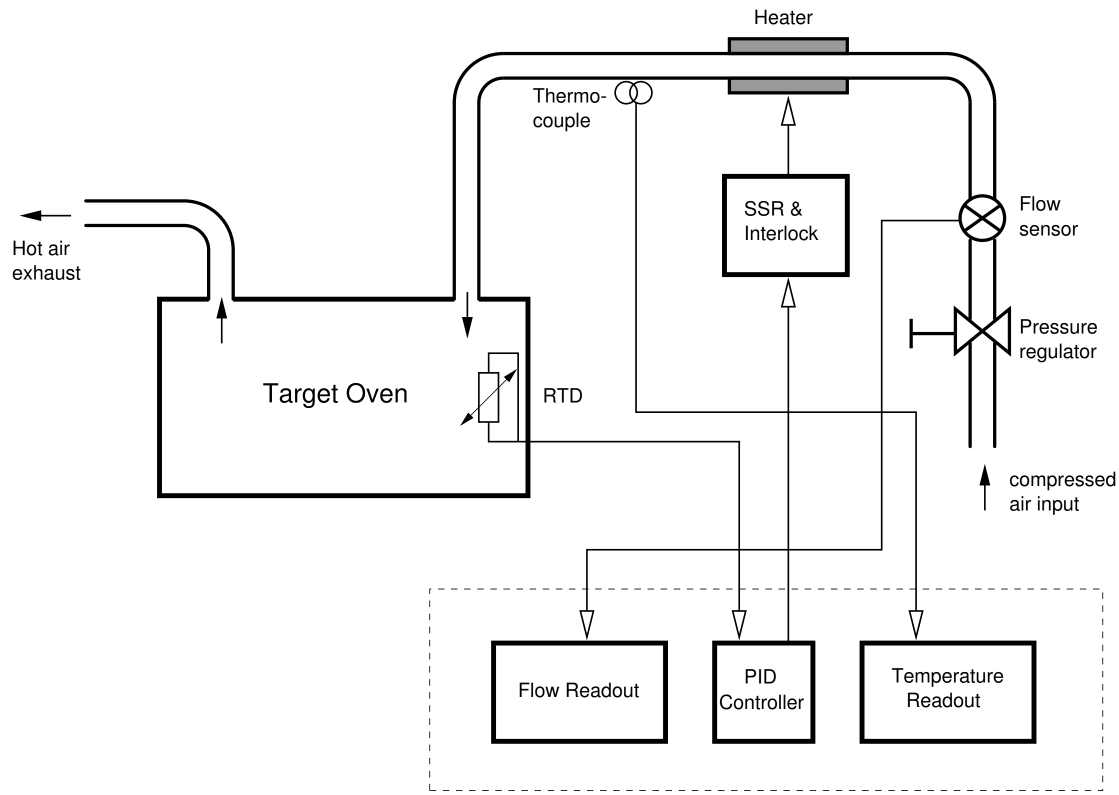

Figure 1.6: Schematic diagram of the target cell oven control system. The instruments in the dashed box are located upstairs, while the remaining components are located in the Hall in the vicinity of the target. For clarity, the interlock circuitry is not shown (see Fig. 1.7).

1.7.1 Description

Fig. 1.6 shows a schematic diagram of the heater system and the associated controls. Pressurized dry and filtered air at room temperature is provided by a dedicated compressor in the Hall. The air enters the system through a shut-off valve and a pressure regulator, which is typically set to an output pressure of 15 psi. The flow rate is measured with a gas velocity sensor (Omega model FMA-905) connected to a display unit (Omega DP41-E-S2R) that provides an alarm to indicate insufficient flow. The air then passes through two resistive heaters (120 VAC, 1200 W) and continues through insulated copper tubing into the target oven. The oven material is ceramic which can withstand a temperature of at least 300°C continuously. The air finally exits the system through an exhaust pipe where it can cool down. Both inlet and exhaust pipes are inside the oven supporting tube filled with insulation material.

A 100Ω Pt RTD (Omega model F3105) measures the temperature inside the oven. A process controller (Omega CN77540-C2) operating in PID mode drives the heater

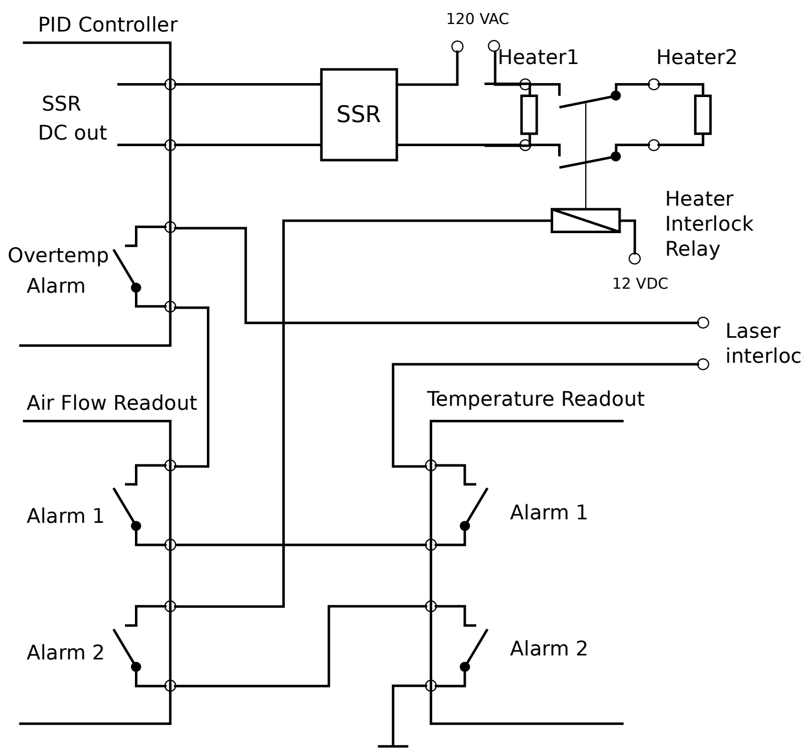

Figure 1.7: Schematic diagram of the oven heater interlock system. The switches represent relays. In normal operation, the relays are energized (contacts closed). An alarm condition (or instrument power failure) will de-energize (open) the corresponding relays, interrupting the interlock circuit. The instruments are programmed such that their dual alarm outputs operate simultaneously.

via a solid-state relay (SSR) regulating the heater power dependent on the temperature detected by the RTD. The SSR (Omega model SSR240DC10) accepts a low-voltage (3 − 32 VDC) control signal of about 30 mA. A mechanical relay between the SSR and the heater allows interruption of the 120 VAC heater power in case of a malfunction (see subsection 1.7.2).

A thermocouple (Omega 5SC-GG-K-30-36) is mounted on the tubing right after the heater to allow monitoring of the temperature of the air exiting the heater. Another display unit (Omega DP41-TC-S2R) reads the thermocouple and generates an alarm if the temperature exceeds a preset threshold.

The PID controller as well as the two display units are installed in a 19" chassis in the electronics racks on the second floor of the counting house where they can be manually operated if necessary. All other components are located in the Hall in the vicinity of the target. The instruments can be monitored and programmed remotely via serial RS-232 communications, which allows convenient control via an EPICS/MEDM graphical user interface (GUI) in the counting house.

1.7.2 Safety Considerations

The heater system represents a significant fire hazard and therefore requires good failsafe protection. Possible failure modes include:

1. Insufficient air flow. Possible causes: Compressor failure; obstruction in filter; operator error. Possible harzards: Overheating of heater element, resulting in equipment damage and/or fire. Protection: Air flow is monitored; insufficient flow disables heater (and laser) via hardware interlock.

2. Heater overtemperature. Possible causes: Insufficient airflow; temperature controller failure; RTD failure; operator error. Possible hazards: Damage to heater element and/or tubing; fire. Protection: Heater temperature is monitored; excessive temperature disables heater (and laser) via hardware interlock.

3. Oven overtemperature. Possible causes: Temperature controller failure; RTD failure; insufficient air flow; excessive laser power; operator error. Possible hazards: Explosion of target cell; damage to oven enclosure and/or optical elements; fire. Protection: Temperature controller will generate alarm if RTD indicates excessive temperature, disabling heater via internal logic and and laser via hardware interlock.

A schematic diagram of the interlock system is shown in Fig. 1.7. The instruments are programmed such that their dual alarm relays operate simultaneously if a value is out of range. An interlock condition disables the heater as well as puts the lasers in standby mode. Interlocking the lasers is important as the laser light contributes significantly to the heating of the target oven.

1.7.3 Operation

The oven can be controlled from a GUI running on one of the Hall C counting house computers, or manually using the front panel controls.

1.7.3.1 Local Operation

A brief description of the manual operating procedure is given here:

1. The oven controller and temperature and flow displays are located in a 19” chassis in one of the racks upstairs. Make sure power to this chassis is on. The green light on the front panel should be lit.

2. Verify the alarm set points for the flow meter and temperature indicator. Press the `SETPTS` button until the display shows `SP3`. After about 1 second, the setpoint value appears. It should be 250 for the air flow display and 220 for the temperature display. Press `SETPTS` again and check setpoint `SP4`. It should be identical to `SP3`.

   To change any of the values use the `MIN` and `MAX` buttons. The `MIN` button selects the digit to be changed whereas the `MAX` button changes the value of the currently selected digit. Press `SETPTS` again to store the new value. When finished, press `SETPTS` until `RUN` appears in the display.

3. Verify the current temperature of the oven. It is shown in the upper (red) display of the temperature controller and is labeled `PV` for “Process Value”. The units are °C. The value should be reasonable, *e.g.* around room temperature if the oven has been off for several hours or more. If the value does not make sense, either the controller is misconfigured (see below) or the RTD in the oven is broken or incorrectly connected. Do not proceed before you have a sensible reading.

4. (Optional) Verify the correct configuration of the controller. Use the `MENU` button on the controller to scroll through the various configuration menus. To inspect parameters within a menu, press `ENTER` followed by `MENU` again. The suggested default parameters are listed in Tables 1.2 and 1.3. This step is time-consuming and can be skipped if you are relatively certain that the configuration is ok. A detailed description of the controller parameters is given in the controller manual.

5. Verify that air is flowing. The air flow readout should indicate a value of 350–450. These are arbitrary units. As long as the heater is off, the reading should not fluctuate by more than about ±10 units.

6. Verify the current temperature of the heater. It should be close to room temperature. If the value is unreasonable, either the readout is misconfigured or the thermocouple is broken. Do not proceed before the problem is corrected.

7. Verify that alarms are reset. Underneath the main display there are four LEDs, one for each alarm 1–4. If either LED `3` or `4` is on on either instrument, it indicates

that an alarm has been triggered and that the system is interlocked. You must reset the alarms before you can continue. To do so, first correct the problem (*e.g.* turn the air flow on) then press `RESET` once on the affected instrument(s). If the LEDs stay on despite correct setpoints and readings, the instrument is probably misconfigured.

8. Begin heating. To avoid damage to the oven, the temperature must be increased to the final value slowly. A good final operating temperature is 170°C, and a good ramping rate is 60°C/h, *i.e.* heating of the oven will take about three hours to complete.

   In manual mode, you must enter a new temperature setpoint by hand at fixed time intervals. ("Ramp and Soak" does not seem to work reliably with this controller.) You should increase the value by 10°C every 10 minutes. For example, if the current oven temperature is 35°C, start with a setpoint of 45°C and increase this value by 10°C in approximately 10 minute intervals.

   To enter a new setpoint, do the following

   (a) Press `MENU` on the temperature controller. A little green light marked `SP1` in the upper left corner of the display will start to blink. Also, the first digit of the green numerical display, labeled `SV` for "Setpoint Value", will blink.

   (b) Use `MIN` to select the digit you wish to change and `MAX` to modify the value.

   (c) When done, press `ENTER`. The display will briefly show `run` when the controller enters normal operating mode. This starts the heating process.

9. Check correct operation of the controller. A little green light marked `SP1` in the upper left corner of the temperature controller display indicates that the heater is active. This light should blink slowly, being mostly on while the oven is heating up and being mostly off (or even completely off for periods of up to a few minutes) when the oven temperature has reached the setpoint.

   The heater temperature should increase proportionally to the fraction of time that the `SP1` indicator is on. Note that the temperature reading is *not* directly related to the oven temperature. In particular, the heater may become significantly hotter than the oven, and its temperature might fluctuate from almost room temperature to high values over short periods of time as the heater power is automatically cycled on and off by the controller. As long as the temperature stays below the alarm threshold (220°C) there is no reason for concern.

10. Check stability of the final temperature. The temperature might overshoot slightly. If the overshoot is less than about 5°C then this is normal. If the stability is poor it is probably due to incorrectly set PID parameters in the controller. Changing these parameters is best done by an expert since this requires in-depth understanding of the system.

The laser contributes significantly to the heating of the oven. Therefore, you will notice sudden temperature instabilities when the laser is turned off or on. It will take several minutes for the controller to compensate for such changes.

11. The air flow rate is slightly dependent on the heater power applied (conductance varies with temperature). Therefore, the flow rate will fluctuate by some 10-20%. This is normal.

12. At any time you can place the controller in standby mode by pressing `ENTER` twice. The display will show a blinking text `STBY`. This will turn the heater off completely and can be used when the system appears to malfunction. However, exercise some caution if the oven is at an elevated temperature since it will quickly cool down if heater power is disabled and you will lose time bringing it back up to operating temperature.

13. In an emergency, simply turn the power to the chassis off completely. This will open the interlock loops, thereby cutting power to the heater and placing the laser in standby mode.

1.7.3.2 Remote Operation

1. Make sure the power is on to the Oven Heater Controller Chassis as described above. Also verify the alarm set points for the oven air flow and heater temperature as above.

2. Verify the current temperature of the oven. It is shown on the GUI on the blue HacOMEGA_RTD readback. It's shown on the meter and also in the readback box. Also, a plot of oven temperature vs time is shown on the stripchart in the bottom-left of the GUI (labelled oven temperature). The units are °C. The value should be reasonable, *e.g.* around room temperature if the oven has been off for several hours or more. If the value does not make sense, either the controller is misconfigured (see directions for manual control above) or the RTD in the oven is broken or incorrectly connected. Do not proceed before you have a sensible reading.

3. Verify that air is flowing. The air flow readout should indicate a value of 350–450. These are arbitrary units. As long as the heater is off, the reading should not fluctuate by more than about ±10 units.

4. Verify the current temperature of the heater. It should be close to room temperature. If the value is unreasonable, either the readout is misconfigured or the thermocouple is broken. Do not proceed before the problem is corrected.

5. Verify that alarms are reset. The alarms are reset by pressing the "Reset" button in the upper-left of the GUI.

Menu	Submenu	Setting
Output Redirection		S1.o1
Input Type		RTD
	RTD Type	385.3
	RTD Value	100_
RDG Configuration	Decimal Point	FFF.F
	Temperature Units	°C
	Filter Constant	0004
Alarm 1		Enabled
	Type	Absolute
	Latched	Latched
	Contact	n.c.
	Setup	Above
	Power On	Enabled
	Low Value	(anything)
	Hi Value	210.0
Alarm 2		Not Installed
Loop Break		Disabled
Output 1	Self	Disabled
	% Low	0000
	% High	0095
	Control Type	PID
	Action Type	Reverse
	Auto PID	Disabled
	Adaptive Control	Disabled
	Anti Integral	Enabled
	Start PID	Disabled
	Proportional Band	0038
	Reset Setup	0050
	Rate Setup	0000
	Cycle Time	0001
	Damping Factor	0001
Output 2	(any)	(anything)

Table 1.2: Suggested default parameters for the temperature controller.

Menu	Submenu	Setting
Ramp & Soak	Ramp	Disabled
	Soak	Disabled
Analog Output		Not installed
Communication Option	Baud	9600
	Parity	Odd
	Data Bits	7bit
	Stop Bits	1bit
Bus Format	Checksum	no
	Line Feed	no
	Echo	no
	Standard	232C
	Mode	Command
	Separator	Space
Data Format	Status	yes
	Reading	yes
	Peak	no
	Valley	no
	Unit	yes
	ID	no
Address Setup	(any)	(anything)
Transmit Time	(any)	(anything)
Remote Setpoint		Not installed

Table 1.3: Suggested default parameters for the temperature controller (continued).

6. Begin heating. To avoid damage to the oven, the temperature must be increased to the final value slowly. A good final operating temperature is 230°C, and a good ramping rate is 60°C/h, *i.e.* heating of the oven will take about four hours to complete.

   In controlling the Oven Temperature from the GUI, you must enter a new temperature setpoint by hand at fixed time intervals. Enter the desired setpoint in the "SP1" enter box in the lower right of the GUI. You should increase the value by 10°C every 10 minutes. For example, if the current oven temperature is 35°C, start with a setpoint of 45°C and increase this value by 10°C in approximately 10 minute intervals. The heater is controlled in PID (proportional, integral, derivative) mode. It approaches the setpoint according to the PID parameters defined in the "Prop. Band", "Reset" and "Rate" boxes in the lower-right of the GUI. These values can be changed, but the defaults should be fine except for special circumstances.

7. Check stability of the final temperature. The temperature might overshoot slightly. If the overshoot is less than about 5°C then this is normal. If the stability is poor it is probably due to incorrectly set PID parameters on the GUI. Changing these parameters is best done by an expert since this requires in-depth understanding of the system.

   The laser contributes significantly to the heating of the oven. Therefore, you will notice sudden temperature instabilities when the laser is turned off or on. It will take several minutes for the controller to compensate for such changes.

8. The air flow rate is slightly dependent on the heater power applied (conductance varies with temperature). Therefore, the flow rate will fluctuate by some 10-20%. This is normal.

9. At any time you can place the controller in standby mode by pressing the "Standby" button in the upper-left of the GUI. This will turn the heater off completely and can be used when the system appears to malfunction. However, exercise some caution if the oven is at an elevated temperature since it will quickly cool down if heater power is disabled and you will lose time bringing it back up to operating temperature.

10. In an emergency, simply turn the power to the chassis off completely. This will open the interlock loops, thereby cutting power to the heater and placing the laser in standby mode.

1.8 Helmholtz Coils

The Helmholtz coils are six large rings of coils that provide a large constant magnetic field. Three sets are necessary so that the magnetic field can point in any direction in the horizontal plane. The larger pair horizontal coils each has an inner diameter of 1.45

m and consists of 272 turns of coil. The smaller set of coils each has an inner diameter of 1.27 m and is made of 256 turns of coil. Each pair of the horizontal coils has a resistance of 3 Ohms. The vertical coils each has an inner diameter of 1.83 m and consists of 355 turns of coil. The pair of vertical coils has resistance of 4.4 ohms.

The normal holding field for the target is 25 Gauss which corresponds to approximately 7.2 Amps of current and 25 Volts in the horizontal coils and 7.4 Amps and 33 Volts in the vertical coils. However, when doing an NMR measurement the field gets as high as 32 Gauss, which corresponds to 9.2 Amps and 32 Volts. The maximum field will not exceed 35 Gauss, which corresponding to 10.0 Amps and 35 Volts.

The coils are powered by two Agilent 6675A power supplies. The maximum range of power supply is 18A and 120 V. The operation condition for the magnet is typically 25-32 Gauss. The maximum field will not excced 35 Gauss, which corresponding 10 A and max 35 V. The power supplies are controlled by a LabView Vi running on a PC.

Hazards associated with the operation of the target magnet include exposure to voltage and exposure to magnetic field. All Hazards are mitigated by the use of the engineering and administrative controls detailed below.

The power supplies are located in an electronics rack. Two insulated cables connect each power supply to the magnet. The voltage hazards are electrical shock or burns.The hazards are mitigated by:

- Engineering control:
  - Connectors are covered with insulated material.
  - Magnet is grounded.
  - Electronic rack is grounded.
- Administrative controls:
  - Warning signs in front of the power supply and on the magnet wall.
  - Voltage to be used is not to exceed 48 V for the Agilent power supply.

In addition, there is a hazard associated with magnetic field. The maximum magnetic field is 35 Gauss inside the magnet. A warning sign will be posted around the target area. No person with pace maker will be allowed around the target area.

The following personnel have received the proper training. They are the only ones authorized to operate the power supply and the magnets. Names may be added with authorization from the supervisor of the system (Jian-ping Chen, x7413).

Name (first,last)	Institute	Phone	e-mail	Comment
JianPing Chen	JLab	7413	jpchen@jlab.org	*Contact*

Table 1.4: Polarized ^{3}He target: personnel authorized to operate the power supply and the target magnets

Attached to the horizontal Helmholtz coils are two smaller sets of coils. These consist of 20 loops of 16 AWG wire attached to smaller DC power supplies. In addition there are two pairs of small coils in the vertical direction connecting to two smaller DC power supplies. These coils can be used to compensate for field gradient to minimize AFP polarization loss. These coils can also be used to introduce a field gradient to reduce masing effect.

1.9 NMR Polarimetry

This guide explains briefly how to perform safely an NMR AFP sweep on the polarized ^{3}He target. Figure. 1.8 shows the target setup and explaining the angle conventions of the polarized target system.

1.9.1 NMR polarization measurement

An automatic NMR measurement will be performed every time the target spin gets flipped. Each of these measurement includes:

- AFP flip of ^{3}He triggered by RF frequency sweep;
- Laser polarization change by rotating Q-wave plates;
- NMR data recording and automatic polarization calculation;
- Spin state determination;
- Automatic log entry.

For a manual NMR measurement, it has the following steps:

- Turn OFF the lasers (optional).
- Make sure the target is in the Helium 3 (beam) position.
- Make sure the correct RF coil is connected to the impedance match box output: use Longitudinal RF coil for Transverse or Vertical polarization and use Vertical RF coil for Longitudinal polarization.
- Make sure corresponding impedance is selected in the impedance match box.
- Turn ON the NMR RF amplifier.
- Make sure the Pumping chamber Lock in amplifier get the signal from correct pick up coil: use Vertical pickup coil for Transverse polarization and use Transverse pickup coil for Vertical or Longitudinal polarization.
- Make sure the coil current and oven temperature readings are normal.

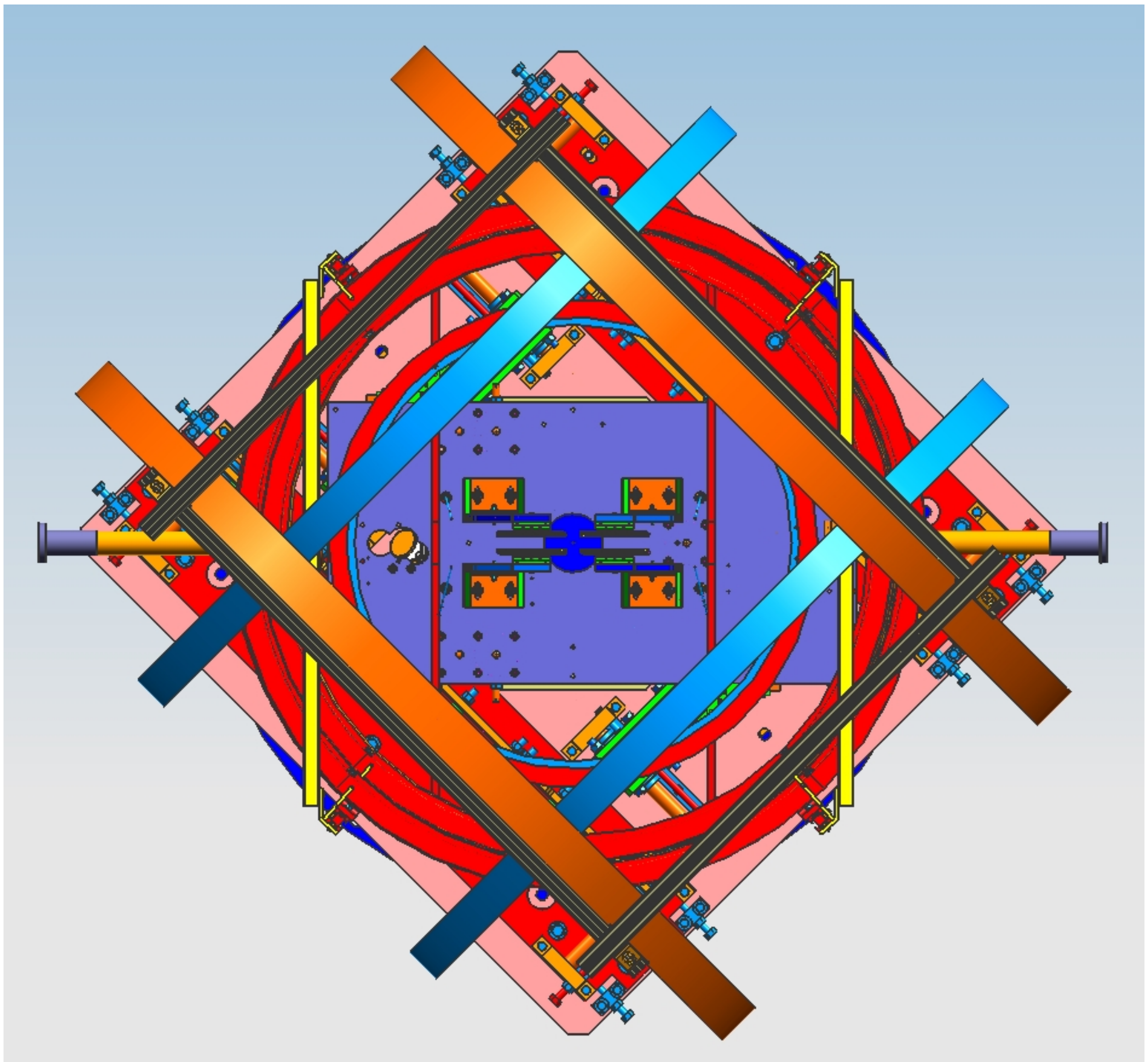

Figure 1.8: Top view of the coils used in the ^{3}He target setup. The combinations of the 3 pairs of Helmholtz coils power the main holding field to either longitudinal, transverse or vertical directions while 3 lines of lasers are available as well in these three directions to polarize the target. The two sets of RF coils are needed to flip the target spin for NMR and EPR measurements with different setups field direction. Four pairs of NMR pick up coils are used during the flips to read out the polarization strength. Two of the pairs are located below the beam line to measure the NMR signal from upstream and downstream part of the target chamber. The other two of the pairs are fixed in the target oven to measure the NMR signal from the pumping chamber.

Coil	Radius (m)	Turns	Power Supply	I_{Max} (A)	V_{Max} (V)
Small	0.667	256	HP6675A	18	49
Large	0.758	272	HP6675A	18	49

Table 1.5: Maximum condition of the power supplies during ^{3}He target system operation (35 Gauss).

- Call MCC to mask the beam and make sure the target is masked before doing anything further. In case NMR signals from target chamber are wanted (only for Vertical and Longitudinal polarization), move the target down to the pick-up coils.
- Run the NMR Measurement VI.
- Load appropriate parameters by clicking "Load Default" button.
- Start NMR Measurement.
- Check result and submit log entry by inputing required info.
- Exit the NMR VI.
- Move the target back to beam position if previously moved to pickup coil position.
- Call MCC, tell them you have measured the polarization and that the target is back to its beam position. Be sure to follow the beam back procedure before sending the beam back to the target (beam position, raster ON and beam current.)

1.9.2 Warnings

- Never stop a running LabVIEW VI (Normally you can't but don't try to hack it);
- Never put CW beam ON the target without raster;
- Every target operator must read and sign the Target Operation and Safety Procedure;
- If the target ruptures, turn OFF the lasers immediately, and then turn off the heaters;
- The lasers must be OFF before rotating the holding field;
- Do not manually change the voltage of the HP6675A;
- We indicate on Table 1.5 the voltage and current values for each coils power supply.

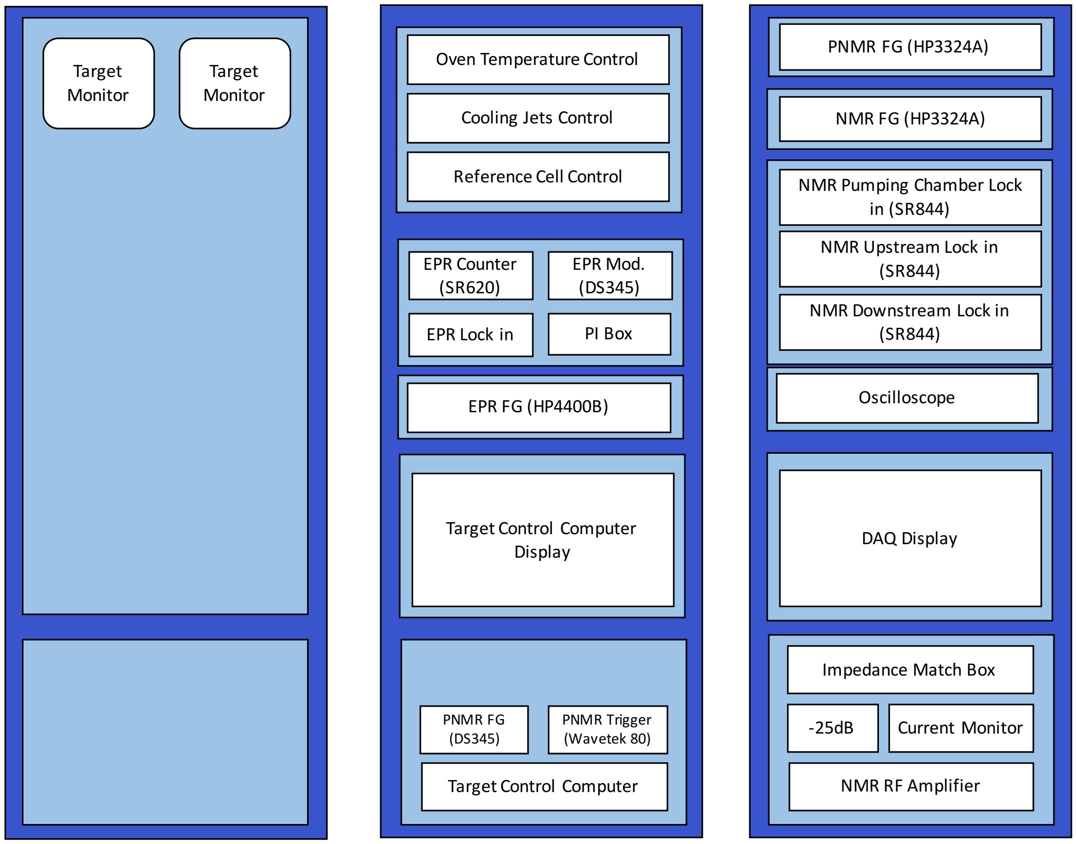

Figure 1.9: The electronics located in the Hall C Counting House.

1.9.3 NMR AFP Safety

The NMR AFP system provides the DC current in the holding coils (up to 18 A) and the AC current in the RF coils (usually 1 A rms) of the target setup. Any human contact with the wires could be fatal and shall therefore be avoided. The electronic devices and the PC used to sweep are located in the Counting House and Hall C. Refer to Fig. 1.9 and Fig. 1.10 for a description of the electronics.

1.9.3.1 The DC current

The DC currents are produced by two Agilent power supplies located in a rack behind the shielding wall in Hall C. One power supply drives the large horizontal coils, and the other drives the small ones, as stamped on their front panel. The output of each power supply consists of two wires. The output plugs are located on the back panel of each power supply which can only be reached through the back panel of the rack. All connections are protected either by plastic strips or covers and can not be touched directly by hands. At the coil end, simple metal screws are used to connect those wires to the coils. They shall never be touched while power is ON. All power supplies are grounded to the ground

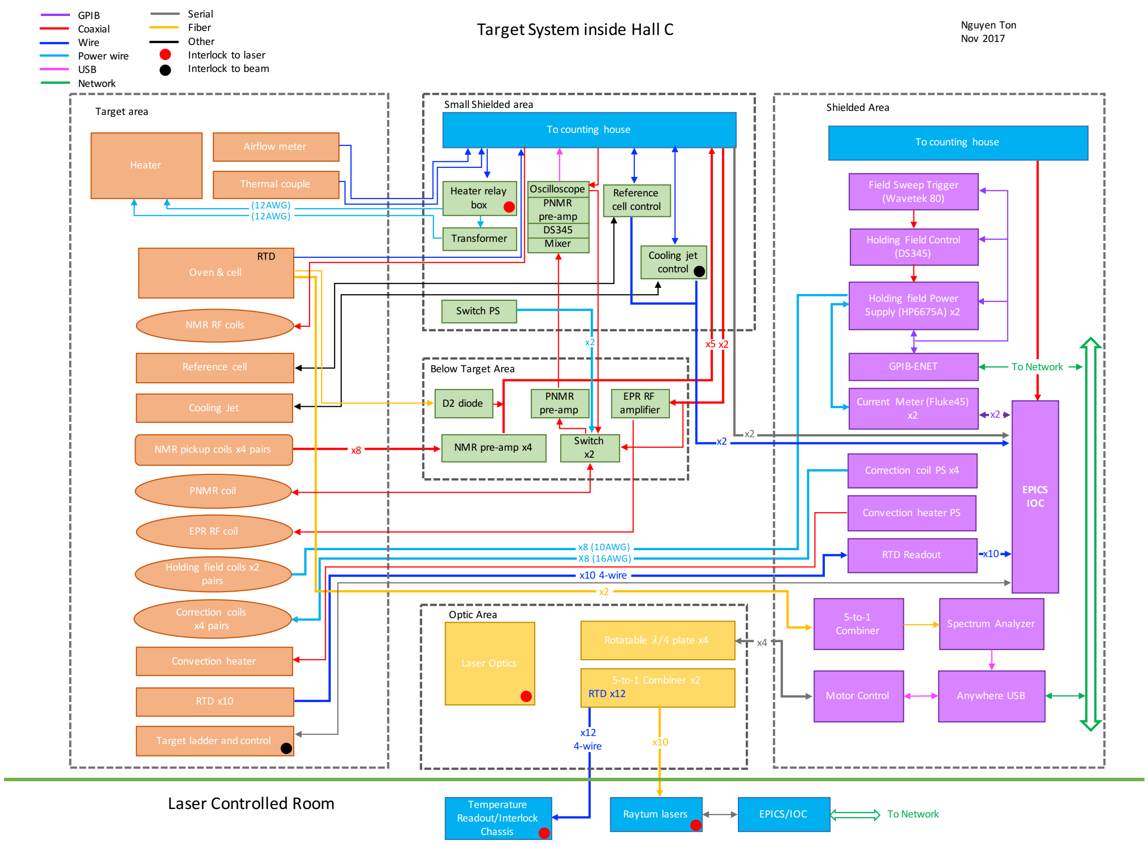

Figure 1.10: Complete diagram of Hall C ^{3}He target system.

of the hall.

1.9.3.2 How to turn the Power Supplies OFF in an emergency?

1. Turn the Function Generators SRS DS345 OFF (one for each coil) by pressing the ON/OFF switch.

2. Turn the Agilent ON/OFF switches to OFF.

1.9.3.3 The AC current

It is produced by the AG Series Power Amplifier located at the bottom of the right rack in counting house. When it is running, the power switch is set to the ON position, the yellow LED is steady and the display shows loaded power above zero. The AC current comes out from the BNC OUTPUT plug, goes through a current monitor (looks like a small toroid) and finally goes to the RF coils. In the hall, the cable is connected to the RF coils along the RF mounting using simple connectors with screws. Those are protected by electrical black tape. They shall never be touched when the RF Power Amplifier is running. The grounding of the system is provided by the RF Power Amplifier.

1.9.3.4 How to turn the RF Power Amplifier OFF in an emergency?

1. Turn the Function Generator HP 3324A connected to the RF Power Amplifier OFF.

2. Turn the RF Power Amplifier OFF by setting the power ON/OFF switch to the OFF position. All LEDs should turn OFF.

Detailed description of the NMR system is contained in the Hall A wiki page: http://hallaweb.jlab.org/wiki

1.10 PNMR Polarimetry

This guide explains briefly how to perform safely a PNMR sweep on the polarized ^{3}He target.

1.10.1 PNMR polarization measurement

An automatic PNMR measurement will be performed every time the target spin gets flipped. For a manual PNMR measurement, it has the following steps:

- Make sure the target is in the Helium 3 (beam) position.

- Make sure the coil current and oven temperature readings are normal.

- Run the PNMR Measurement VI.

- Load appropriate parameters by clicking “Load Default” button.
- Start PNMR Measurement.
- Check result and submit log entry by inputing required info.
- Exit the PNMR VI.

1.10.2 Warnings

- Never stop a running LabVIEW VI (Normally you can’t but don’t try to hack it);
- Never put CW beam ON the target without raster;
- Every target operator must read and sign the Target Operation and Safety Procedure;
- If the target ruptures, turn OFF the lasers immediately, and then turn off the heaters;
- The lasers must be OFF before rotating the holding field;
- Do not manually change the voltage of the HP6675A;
- We indicate on Table 1.5 the voltage and current values for each coils power supply.

1.10.3 PNMR Safety

The electronic devices and the PC used to sweep are located in the Counting House and Hall C. Refer to Fig. 1.9 and Fig. 1.10 for a description of the electronics.

1.10.3.1 The AC current

It is produced by the function generator (DS345) located at a rack in counting house. When it is running, the power switch is set to the ON position. The AC current comes out from the BNC OUTPUT plug and then goes to the RF coils. The current is very small (∼20 mA).

1.11 EPR Polarimetry

In what follows we describe two methods to setup and perform an EPR measurement of the target polarization.

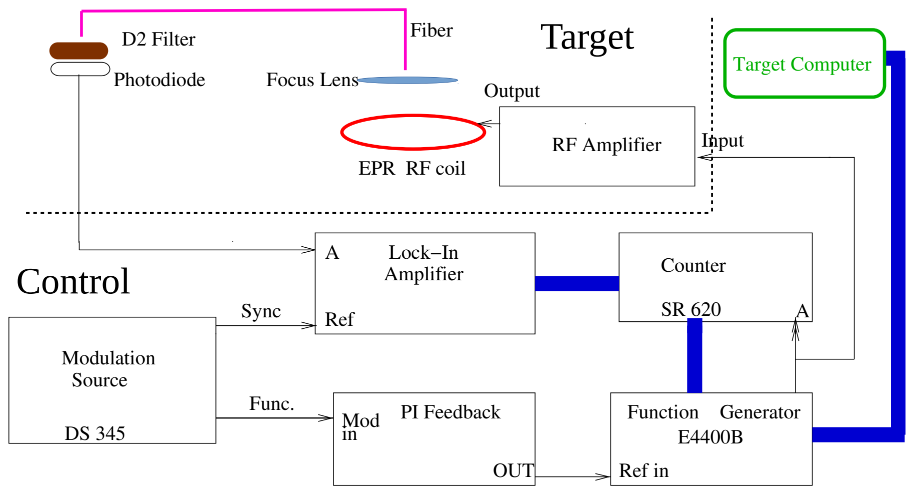

Figure 1.11: Circuit for EPR lineshape measurement

1.11.1 EPR Lineshape Measurement – Frequency Modulation Sweep:

Use this configuration when you wish only to find the Electron Paramagnetic Resonance (EPR) frequency, not actually track its position. This method allows the user to observe the lineshape of the EPR transition (Rb D2 line or K lines) light emitted from the cell as a function of applied frequency to the EPR coil.

First, construct the circuit described in Fig. 1.11.1 by following these steps:

1. Position the EPR optical fiber so that it looks directly at the light beam coming from the cell. Adjust and align the focusing lenses such that most of the light is collected through the optical fiber and reaches the PIN diode.

2. Measure PIN diode output, it should be a DC signal with an amplitude of -100 mV to -150 mV (could be as high as -230 mV). If the signal is less than -100mV, check the light and PIN diode again.

3. Set Lock-in amplifier parameters:
   AC Gain: 50 dB; Input Limit: 10 mV;
   Sensitivity: 1 mV; DR 16;
   Time Constant: 100 ms; Osc: 0.000 Hz;

4. Connect PIN diode to input A of the Lock-in amplifier.

5. Set Modulation source DS345 parameters:
   Function: sine wave;

Sweep/modulate: LIN SWP.

6. Connect DS345 'output' to PI circuit 'mod in', DS345 'sync output' to Lock-in Amplifier 'ref in'.
7. Set PI circuit Integration off, make sure the input is disconnected.
8. Set the parameters for the function generator E4400: FM: ON, RF: ON, Source:External DC, Dev: 20 KHz, Gain: -5dB (range is from 0 to -10 dB depending on the sintuation), Frequency: 10 MHz to 24 MHz (you need to set the frequency limit according to Rb or K resonance. At this monent this is controlled by the EPRFM.VI. So dont have to worry about it).
9. Connect the RF output of E4400B to the RF amplifier and also to the A input of the counter SR620.
10. Do not connect the lock-in back output to the INPUT of the PI box. Leave that INPUT OPEN.
11. Connect the OUTPUT of the PI box to the INPUT of the E4400.
12. Turn INT GAIN OFF.
13. Turn the RF amplifier ON.
14. Make sure you have exactly the same circuit as in the figure.

Now that the circuit is in place, open the LabView program "EPRFM.VI".

1. RUN it.
2. Set the Start Freq and stop frequency according to your wish .i.e. the range mentioned above.
3. Set the step size to 0.01 MHz for a quick scan. Or 0.005 MHz for a nominal scan.
4. Set the lockin time constant to 100 or 200 ms (should try both).
5. Set the lockin sensitivity to 200 uV/ 500 uV/ 1mV nominal.
6. Set the FM dev to 20 KHz first. Later need to be adjusted and make it larger depending on the signal.
7. Set the gain to -5 dB (might need to adjust later, but no less than -12 dB otherwise the counter will not register signals).
8. Do not worry about the phase of the lock-in now.

9. Set the modulator frequency to 100 Hz and the amplitude to 1.5 Vpp.
10. START SWEEP.
11. Once you have the lineshape signal, PLOT it. Choose /select the linear regions of both channels (X and Y). FIT with order 3 unless it is really linear. Once you fit, take a look at the calculated PHASE (Just take a look, nothing needs to be done).
12. SET PARAMETER and click on I KNOW I KNOW.
13. START SWEEP again. This time you should see all the signal is in one channel (X usually unless the program is broken) and you have the correct phase.
14. Repeat steps 9 to 11 again. In step 10, this time you probably can use FIT ORDER 1. When you are done with the SET PARAMETER and I KNOW I KNOW, record the number of turns for the gain in the PI box. Make sure that the overall gain we are shooting for is -0.5. It is the default value in the VI . But if you find its different, SET IT TO -0.5 and RECALCULATE the number of turns again. This NUMBER OF TURNS in the PI gain is the heart of our measurement.
15. Save the datafile if the data look reasonable to lock the signal in the next AFP step. Usually K signals are larger than the Rb signal at a temperature of ≈ 230°C. Anything above 20 mV is good enough for AFP.

1.11.2 Common Problems

1. The plot shows no peak/dip.
   - Check the PIN diode and light, make sure there is enough light.
   - If the PIN diode signal amplitude is above 100 mV already, try changing the Lock-in Amplifier phase by 90°.
   - If still no peak is detected, try changing the start sweep frequency and the number of steps such that the program will cover larger region.
2. The plot shows multiple peaks. It might be the signal is mixed with background (cable resonance, noise etc.). The solution might be complicated and will not be discussed here. Contact target experts on call.
3. How do I use the output data? The data is saved in a text file consisting of two columns. The first column contains the frequency of the EPR coil, while the second column holds the corresponding signal from the Lock-in Amplifier. Its format can be read by programs such as SigmaPlot, Excel, and Paw.

1.11.3 EPR Polarization Measurement – AFP Sweep

This configuration uses the lock-in amplifier with a PI feedback box to lock into the EPR resonance frequency and then track its behavior. With AFP spin-flip, a shift in EPR resonance frequency will be measured, which is proportional to the pumping cell polarization.

Once you are done with the FM sweep and have the number for the turns for the GAIN for the PI box, follow the procedure below to get the AFP sweep done.

1. Refer to the circuit diagram. Start from the configuration as you were doing FM sweep.
2. Connect the lockin output from the back of the lockin to the INPUT of the PI box.
3. SET the GAIN to the number you have got from the FM sweep vi.
4. Open EPRAFP.VI
5. RUN it. SET the DEFAULT parameters. Frequency 78 to 92 KHz. V_rms to 0.8 V.
6. Set it to MANUAL or AUTO. If AUTO, SET the wait time to 15 sec/20 sec.
7. POWER ON. You will see the frequency (GREEN) in the first plot, frequency fluctuation in the second plot and lockin signal in the third plot. Just dont worry about those at this moment.
8. SET the Integration gain at knob to 1 first in the PI box. Usually between 1 to 2 should be okay. But you have to play around. (The magic numbers we found is 1 to 1.2 for 100ms time constant and 1.5 to 1.7 for 200ms time constant)
9. TURN the INT GAIN ON in the PI box. You should see in the third plot the lockin signal approaching 0 ± 5 mV is okay. If not, try to increase the INT GAIN slowly till you feel comfortable.
10. WAIT for a couple of seconds.
11. START SWEEP. You should hear a "click" and see a drop or rise in the frequency ("well" or "hat" shape) in the first plot.
12. If you are doing it MANUALLY, wait for 10 to 15 sec in that flipped state and hit "START SWEEP" again to get back to the original state. If you feel you need more data in that flipped state, wait for another 10 sec.
13. Repeat the above two steps one more time or two.
14. Make sure you end up in the original state. Then POWER OFF. SAVE the data.
15. *Never stop the program during sweeping, this could cause the ^{3}He to stay at the wrong state and hence a big loss in target polarization.*

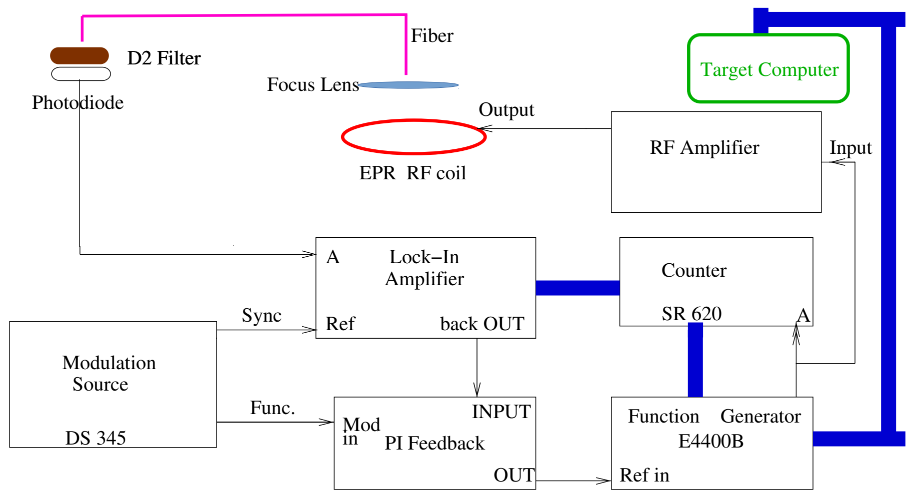

Figure 1.12: Circuit for EPR measurement with AFP spin flip

1.11.4 Common Problems

1. The lock-in does not remain stable. Or the lock-in but does not seem to track the resonance.

   You may see a big fluctuation in either lock-in signal or resonance frequency. This effect can be caused by several things.

   First, it is possible that the frequency to which you are locked is not the true resonance, or you are completely out of resonance region. The solution is again to find manually the resonance, looking for the most pronounced signal.

   The problem could also be caused by a wrong lock-in amplifier phase. Please refer to Section 1.11.1.

   Finally, it could be that the PI Feedback box is improperly set. Adjust the gains until the lock-in becomes more stable. Admittedly this method is not very quantitative. Based on experience, at high polarization (>40%), both gains should be adjusted anti-clockwisely nearly to the end. At lower polarization (∼20%), both gains should be adjusted by about 4∼5 turns clockwisely. These numbers may also vary at a higher or lower EPR D2 signal amplitude.

   You may also optimize the PI circuit gains by observing how fast the circuit follows the resonance. When counter reading is stablized, change Wavetek frequency manually by 0.04 MHz (which is close to the real jump during sweeping, at a target polarization ∼ 40%). If the counter goes back to resonance in roughly 3 5 seconds, then the circuit is working well. If less than 2 seconds and counter reading is not stable, decrease both the relative and absolute gain. If longer than 6 seconds or lose the signal, increase both the relative and absolute gain.

2. The lock-in does not track the resonance when doing AFP flips. This is common, since the frequency shift during the spin flip can be quite large, on the order of 20-40kHz.

   First, it is possible that the PI feedback is not strong enough for the circuit to follow the resonance shift. Try increasing the absolute gain of PI circuit if possible. Second, it could be that the modulation DS 345 amplitude is too small. The size of this amplitude determines how far from the central frequency the circuit looks for the resonance. Try increasing the modulation amplitude (but do not increase too much, usually it is less than 0.8 Vpp). This will cause the counter reading less stable and you need to compromise between stablizing the circuit and following the frequency shift.

1.12 Reference Cell

1.12.1 Description of the Reference Cell System

The reference cell system is comprised of three subsystems—the reference target cell, the gas handling system, and the control electronics. The reference target cell is mounted inside the target enclosure, which is located in the beam path immediately upstream of the spectrometers. The gas handling system consists of a gas manifold, which is located in the electronics rack near passageway under beam line, and a series of gas lines that connect the manifold to the reference cell. A control box consisting of electronics that control the solenoid valves of the gas system is also located in the electronics rack. A remote control box, identical to the one in the hall, is located in the counting house. A schematic of the entire system is shown in Fig. 1.13. The individual subsystems are depicted in Fig. 1.14–1.15.

Under normal operating conditions, the manifold, the reference cell, and the intervening gas lines will be filled with either H_2, ^{3}He, or N_2 gas at high pressure (typically ≈ 10 atm). The system may be operated either locally (at the panel) or remotely (via switches mounted in the counting house). A switch on the remote gas panel itself allows one to toggle between local and remote control. All switches, local and remote, are equipped with LED displays so that one can readily determine the status of any switch.

The reference cell consists of a very thin-walled glass flask. An outlet at the opening is joined to a Copper tube by means of a glass-to-metal seal. This Copper tube is connected to a 1/8" dia. Copper tube with quick-plug-on gas fittings. High pressure ^{3}He gas bottle is mounted near the target chamber and is connected to the other end of the 1/8" Copper tube through solenoid valve **V3**. The rest of the gas system is connected to the 1/8" copper tube by a long 1/2" Copper tube. The reference cell is mounted at the gas fitting. A special coupling tool has been designed to facilitate the coupling/de-coupling the reference cell at the quick-plug-on gas joint.

The gas handling system consists of 7 solenoid-controlled, air-actuated valves, one hand-set needle valve, two baratron pressure gauges (0–1000 torr and 0–1000 psia), two

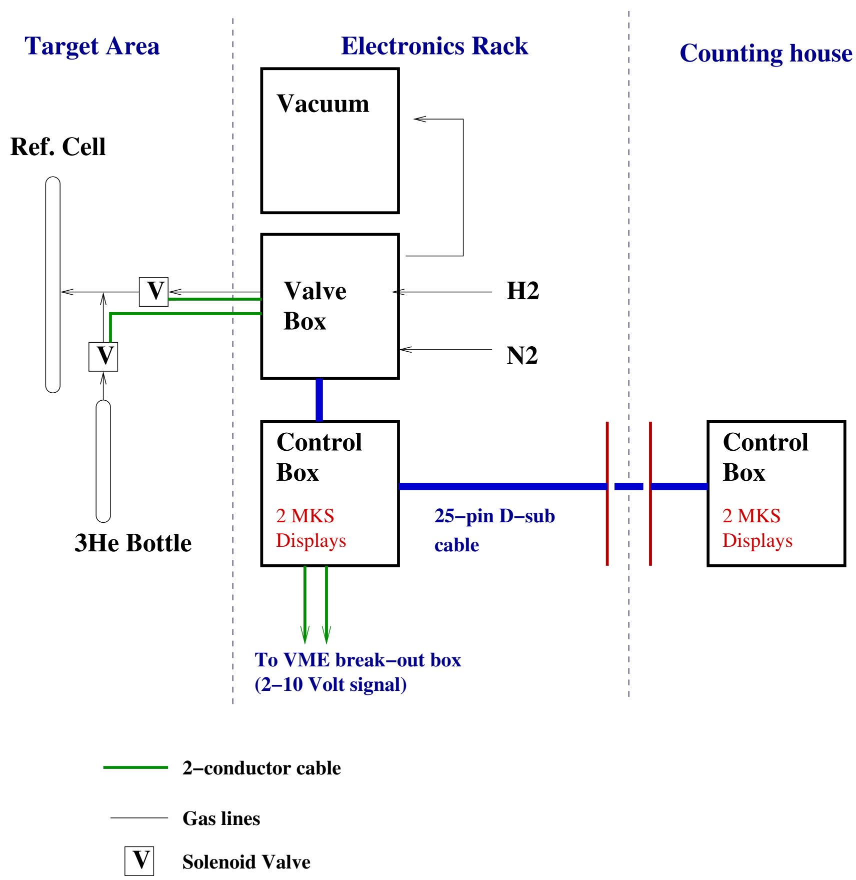

Figure 1.13: Schematic of reference cell system

Condition	Action	Valves activated (open)
C1	**Evacuate**	V1+V4+V5
C2	**Vent**	V4+V5+V7
C3	**^{3}He fill**	V3
C4	**N_2 fill**	V2+V4+V5
C5	**H_2 fill**	V4+V5+V8

Table 1.6: Action of the remote-control switch panel

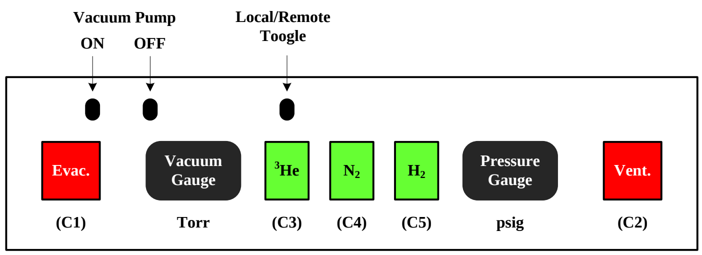

Figure 1.14: Valve configuration of the reference cell gas system

pressure relief valves, a bottle of high-pressure ^{3}He gas, a bottle of high pressure N_2 gas, a bottle of high pressure H_2 gas, an oil-free MD pump backed up by a backing pump, and sufficient tubing and pipe fittings to connect them all together. There are 5 basic actions that the gas handling system must accomplish; pump-out, vent, fill with H_2, N_2, or fill with ^{3}He.

The reference cell control panel (shown in Fig. 1.15) is comprised of 5 pushbutton switches, which activate the 5 possible valve setting conditions, a baratron high-pressure gauge which reads between 0-1000 psia, a baratron low-pressure gauge which reads between 0-1000 torr, two toggle switches to turn on and off the vacuum pump and a toggle switch to select local or remote operation. The valve configurations for the five actions are described in Table 1.6.

1.12.2 Operation

The following operational sequences will allow the filling of the reference cell with the three gases:

- Fill with N_2
  - Step 1: Vent to 16 psia.
  - Step 2: Evacuate until vacuum reaches 1 mtorr.

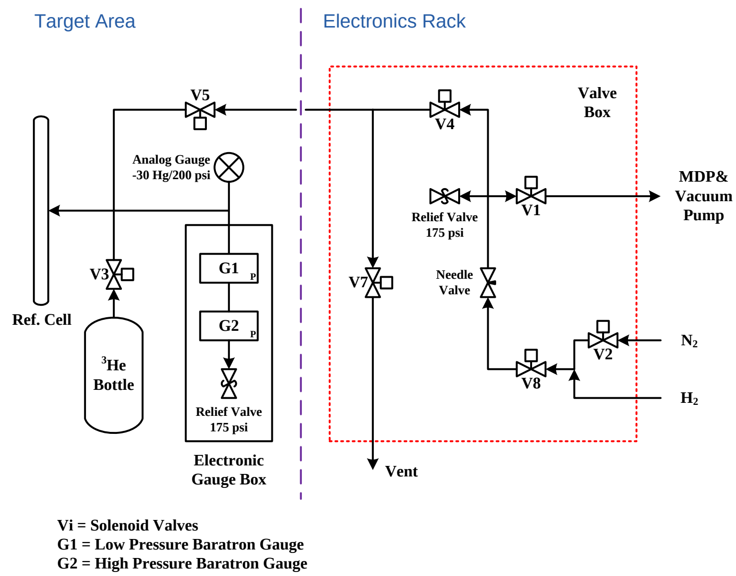

Figure 1.15: Control panel

  - Step 3: Hold the N_2 button down while checking the high-pressure gauge, until the desired pressure is established.
  - Repeat steps 2,and 3 three times.

- Fill with H_2
  - Step 1: Vent to 16 psia.
  - Step 2: Evacuate until vacuum reaches < 10 mtorr.
  - Step 4: Hold the H_2 button down while checking the high-pressure gauge, until the desired pressure is established.
  - Repeat steps 2, and 3 three times.

- Fill with ^{3}He
  - Step 1: Vent to 16 psia.
  - Step 2: Evacuate until vacuum reaches < 1 mtorr.
  - Step 4: Hold the ^{3}He button down while checking the high-pressure gauge, until the desired pressure is established.

The pressure at the location of the gas manifold is measured by a baratron gauge. The baratron pressure is read into the data stream and is also output to a remote sensing unit located in the counting house.

1.12.3 Cautions

1. Be careful with the ^{3}He, we have a limited supply.
2. If the system is above atmospheric pressure, always vent it before pumping.
3. Always monitor the high-pressure gauge when filling. Do not exceed 150 psia.

1.12.4 Potential Hazards

The principal hazards associated with the reference cell are flying material and loud noise if the gas panel or reference cell fails catastrophically under high pressure. Of the two subsystems, the reference cell subsystem presents the greater hazard, both because it is more likely to fail, and because it is likely to be more dangerous if it does. The target enclosure is designed to contain all the debris in case of a cell explosion.

1.12.5 Hazard Mitigation

After testing the reference cell system to 200 psia and to protect the cell from rupturing during normal operation, the relief valves have been set to 175 psia.

All personnel shall wear double hearing protection when accessing the platform area while the cell is under high pressure and no windows are on the target enclosure.

Special care must be taken when accessing the region inside the target enclosure. Full face shielding, safety glasses and buttoned cotton jacket shall be worn under these conditions. Before working in the vicinity of any of the reference cell components, personnel shall check the pressure in the manifold from the baratron readout in the remote control area.

1.13 Hazards and Safety Issues

The main potential hazards encountered in the overall operation of the target are listed below. As we address the operation of each subsystem, a description on how to alleviate the potential hazards is reported.

- Personnel eye sight damage due to exposure to infrared laser light;
- Fire due to the operation of the high power lasers;
- Fire due to the operation of the target oven;
- Explosion of the high pressure target cell;
- Explosion of the reference cell;
- Activation of the target caused by the electron beam.

For personnel safety to be effective all personnel authorized to operate any subsystem of the target will be required be familiar with that specific subsystem as well as read this target OSP.

A target operator is on shift usually when the target laser system is on. A training session is required of any target operator.

1.14 Laser Safety

1.14.1 Laser Safety

1. Always have your safety goggles on when the laser is on!
2. When the yellow beacon is flashing, have goggles on when you enter the hut.
3. Alignment should be done at low power.
4. Be sure that the beam is hitting the target.
5. Do not turn the beam up to full power unless the oven temperature is at least 150 degrees Celsius.
6. Do not look directly into the beam even with safety goggles on.
7. Do not stand in the way of a beam that is at full power.
8. Understand where the beam is and where the reflections are.

1.14.2 Fire Hazards and Safety

The fire and safety in the laser room is covered in the LOSP for the laser room, however, in the target area where the laser beam is directed, there is a case where a potential fire hazard exists.

In case the target cell explodes during optical pumping, the temperature sensors mounted on the target and pumping cells will respond immediately and an alarm will be triggered. The alarm will be triggered whenever a temperature reading of any sensor is 10% out of its norminal range. The target operator shall shut off all the lasers immediately. Based on the tests performed, the target oven will sustain on the order of 10 minutes with full laser power incident and no rubidium atoms to absorb the laser power.

1.14.3 Personnel Safety/ Working in the Hall

When the installation of the full target setup is finished, working in the hall shall be safe from laser light hazards or target explosion hazards, because laser light as well as the target cell will be safely enclosed. Therefore when considering the overall aspects of the safety of personnel working in the Hall two distinct periods are to be considered.

1. One period is during the laser beam alignment because the laser beam pipes from the laser hut to the target need to be removed. During this time period we will ensure that no other person except those people who are laser trained are in the hall. This will be arranged by using a controlled access to the Hall provided by the CANS system. This alignment will be performed usually during the night time and (or) weekend. Clear warning signs will be posted at the entrances of the Hall when the alignment is under progress.

2. One period is during the setup of the high pressure target cell in its final position, or when replace a target cell, or perform target related work requiring opening the enclosure. In this case the "target platform" which is a natural perimeter around the target area will be marked and signs posted requiring the wearing of ear protection and faceshield. Lasers shall be tuned off and fibers be disconnected and locked away following the lock-and-tag procedure. Beyond that defined perimeter all personnel working in the hall will not be affected in case of explosion of the cell if they are not wearing a faceshield. Nevertheless, it is strongly recommended to have ear protection when working anywhere in the Hall.

1.15 Appendix: Laser Standard Operation Procedure

1.15.1 Introduction

A polarized ^{3}He target system was built and used for several JLab experiments. A number of new experiments will continue use the polarized ^{3}He target system in the future. The polarized ^{3}He target is based on the principle of spin exchange between optically pumped vapor of Ru-K mixture and ^{3}He gas. Several high power (30 Watts) 795 nm diode lasers will be used for the optical pumping. A laser room outside the hall is built to house the lasers. This LSOP describes the setup of the laser system in the laser room and at the target area, details the potential hazards associated with the operation of this setup and provides instructions for the safe and effective use of the equipment. In addition, this manual provides information about the functioning of the various safety systems installed to protect personnel and equipment.

1.15.2 Personnel and Required Training

The 30 watts infrared diode lasers (Coherent FAP-System and Newport Comet lasers) may only be operated by personnel who have :

- completed a Laser Safety course administrated by the laser safety officers at Jefferson Laboratory (Bert Manzlak).
- read the Laser Safety section of the EH&S Manual(6410);

- completed and passed an opthalmological exam;
- had a safety walkthrough by the Laser Safety Supervisor of the Polarized ^{3}He Target System (Jian-ping Chen);
- read this document;
- been added to the authorized list of Laser Personnel, included as the last page of this LSOP.

Jefferson Lab personnel or outside visitors, who have not completed all of above training, are only allowed to enter the laser control area under the following conditions :

- have permission of the Laser Safety Supervisor of the Polarized ^{3}He target system
- be accompanied by a laser authorized personnel
- if the laser is operational, with required safety goggles
- if any equipment, including the laser, is operational, no touching of equipment due to electrical hazards.

1.15.3 Laser

The main Laser specifications are outlined in Table 1.15.3 and Table ??. For more specific information, we refer to the Raytum diode laser users manual which will be available in the lab.

1.15.4 Optical setup

The optical setup is shown in Fig. 1.17, and is made of:

- Up to 15 infra-red diode lasers (five for each pumping direction) located on two racks in the laser room;
- Fifteen long (75 m) optical fiber to transport laser beam from the lasers into the hall;
- Three 5-to-1 optical fiber combiners, one for each pumping direction;
- Six lens, two lenses for each laser beam to have it focused at the pumping cell;
- Three beam splitters to split each laser beam to two beams with linear polarization;
- Nine $\lambda/4$ waveplates, six with rotating motors, to transform each beam from linear polarization to right or left circular polarization;
- Twelve dielectric mirrors to reflect each split beam back into the pumping cell;

Specifications	**Raytum Laser System**
Operational Specifications	
Output power	30 W
Mechanical Specifications	
Weight	60 pounds
Cooling Requirements	None required
Delivery Optical Fiber Bundle	0.6 mm diameter
Delivery Fiber Length	5.0 meter nom.
Delivery Fiber Termination	SMA 905 conn.
Operational Specifications	
Typical Operating Temperature	15°C to 35°C
Typical Storage Temperature	−20°C to 65°C
Humidity (non-condensing)	20% to 80%
Electrical Specifications	
Input Power	115 Vac 60 Hz
Optical Specifications	
Beam Characteristic	Semiconductor, multimode
Beam Divergence	< 0.20 N. A.
Diode Laser Center Wavelength	794.7 nm, wavelength tuning 0.8 nm
Wavelength Temp Coefficient	0.27 to 0.30 nm/°C
Emission Bandwidth (FWHM)	±0.2 nm

Table 1.7: Raytum laser specifications

- Three transparent windows on the oven to allow the combined laser beams to pass through;
- One pumping cell to absorb all the laser beam power;
- One mirror and three optical fibers with lenses for spectral-analyzer and for EPR;
- One spectral-analyzer for monitoring the pumping cell.

For each pumping direction, up to five diode lasers will be used. After passing through the 75 m long fibers, they will be combined to be one beam with a 5-to-1 optical fiber combiner. The combined beam, after passing through two lenses, will be split into two beams. Each one will go through a $\lambda/4$ waveplate to transform linear polarization to circularly right or left polarization. All beams, after passing some windows and being reflected by some mirrors, will shoot into a glass pumping cell filled with mixture of Rb-K vapor and ^{3}He gas. The laser beams will be mostly absorbed by the pumping cell. The total path length from the output of 5-to-1 combiner to the pumping cell is about 5 meters. The pumping cell is inside an oven and connected to a target cell. The whole target assembly is inside three pairs of Helmholtz coils, which provide a magnetic field for the polarization of the target. A NMR system with a set of RF drive coils and a set of separate pickup coils, and an EPR system are used to measure the polarization of the target.

1.15.5 Hazards

The primary beam hazards associated with Class IV lasers consists of eye and skin injuries. The most severe eye injuries are caused by viewing the beam either directly or through specular reflection. At an infra-red wavelength of 795 nm most of the laser light entering the eye is absorbed in the retina. The primary adverse effects from direct or specular viewing are blindness and severe retinal burns. The primary adverse effects from accidental viewing are retinal burns. The retina is most sensitive to radiation of this wavelength, and if the laser energy incident to the eye is too high, it can cause an irreversible retinal burn.

Laser radiation of the intensity associated with Class IV diode lasers 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.

The normal Hazard Zone for the 30 Watts FAP system is 78.5 meters for intrabeam and 6.7 meters for fiber-optic output.

1.15.6 Laser environment

The diode lasers and the associated devices will be located in the laser room outside Hall A. The entire laser room is a laser controlled area (see Fig. 1.16).

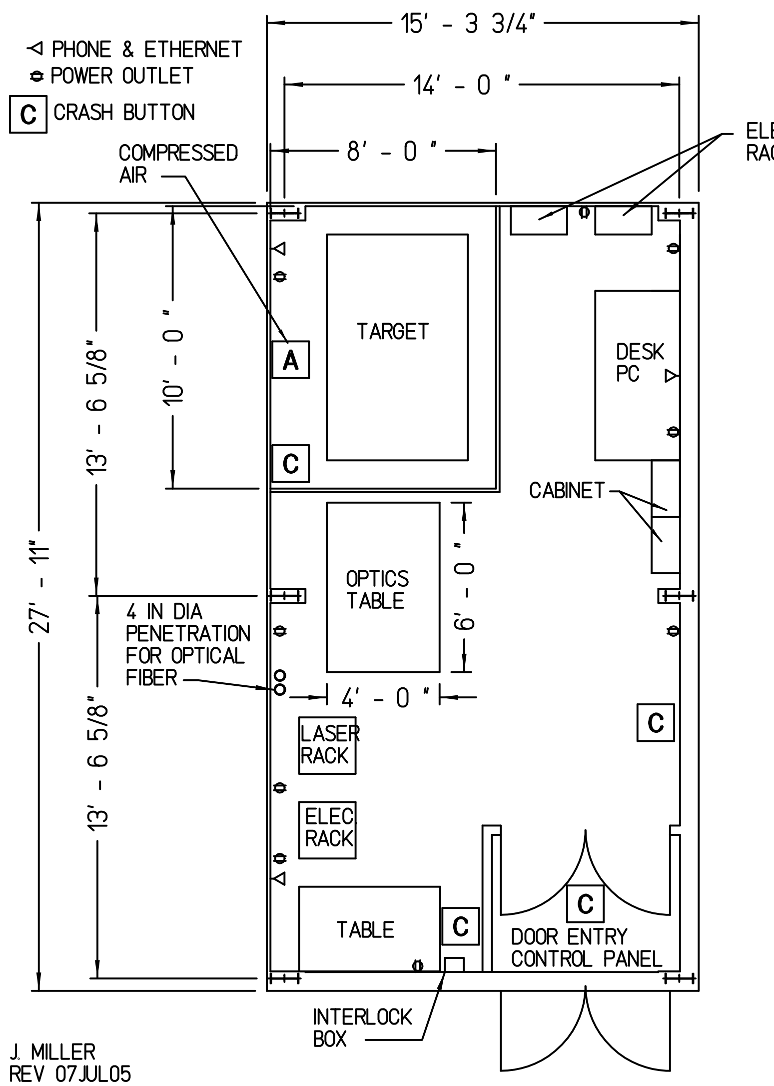

Figure 1.16: The Polarized ^{3}He Target Laser Room Layout

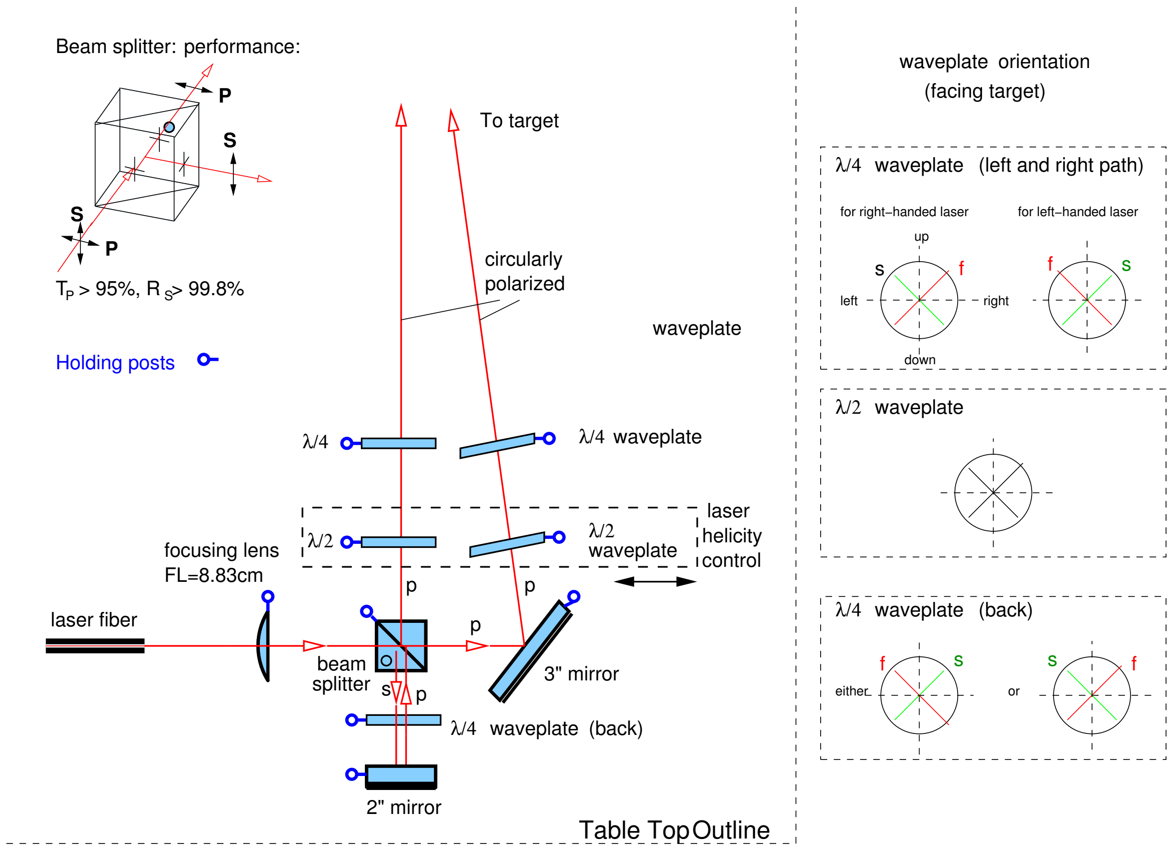

Figure 1.17: The Polarized ^{3}He Target Laser Optics Setup

Laser beams go into the hall via long optical fibers and then combined to form desired polarized lights for optical pumping. The setup is shown in Fig. 1.17. After passing through the optical setup, the laser beams are directed into the pumping cell and terminated there.

Outside the laser room, the laser beam path is completely enclosed with beam pipe between the laser room and the target pivot and an enclosure on top of the the target.

Apart from direct beam hazards to eyes and skin, since the diode lasers are Class IV lasers, there exists a potential fire hazard. Flammable material shall not be brought into the laser area.

1.15.7 Procedures

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 laser beams are switched on. During tests, maintenance, upgrades and/or alignment, beam hazards are more likely.

At all times, when operating the diode lasers in lasing mode, safety goggles are required.

1.15.7.1 Normal procedure

In the operation mode, each diode laser is in lasing mode rendering an output power of approximately 30 W. The laser beam is already aligned, properly focused and directed into the pumping cell. The lasers are interlocked with the entrance door of the laser hut. All the laser beam pipes and the laser enclosure on top of the target are securely installed.

Working with the lasers in normal operational mode will require protective eye wear with a minimum optical density (OD) of 4.7 at wavelength of 795 nm. Before starting the laser in its normal operation mode personnel have to enable the laser safety interlock box. This will cause access to the laser room to be in a controlled mode. Authorized personnel with an access code can bypass the interlock for 45 seconds when entering the laser room. Unauthorized personnel entering the room will cause the lasers switching to stand-by mode when the door is opened. If the laser is to be unattended for a long time, the power should be switched off.

Thus the general procedures for normal operation of the diode lasers in the target lab are:

- Enable laser safety interlock box;;
- Wear protective eyewear;
- Switch on AC power;
- Turn on the control box with a key;
- Turn laser to Ready and then On.

1.15.7.2 Alignment procedure

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). Initial setup of laser and optical system will be done while the laser hut window is closed (such that no laser beam will come out the laser hut). Initial alignment will be done with a standard class 3 HeNe laser (class 3A after attenuation, 650 nm) or a laser pointer (class 3A). Laser safety goggles are mandatory for all procedures except for alignment using class 3A HeNe laser. Use precaution for class 3A laser when using the HeNe laser: Do not look directly into the beam or use collecting optics. The final alignment will be done with the diode laser but at a reduced laser power (less than 10 amps, when the laser spot on a card can be clearly seen with IR viewer). The alignment is performed with one laser beam line at a time. The beam can be tracked by the use of either an IR viewing card or an IR viewer. The photosensitive card can be displaced along the beam, and the

IR viewer allows the tracking by the light slightly diffused on the optical components. During this final alignment, the laser hut window will be opened and the laser beam will be directed to the target, while the laser beam pipes and the laser enclosure on top of the target will be taken off. Therefore the whole hall will be classified as laser area. We will use the CANS system to have controlled access. Before the laser alignment starts, a sweep will be performed to clear the Hall. Then the CANS system will be programmed to only allow authorized laser trained persons to have access to the hall. The door to the BSY tunnel will be magnetically locked with a toggle push-button switch. The "laser danger" warning sign will be posted at all the entrances. The doors will be checked by pulling the door handle. In addition, a red flashing light will be put at the BSY side of the door. Most of the final laser alignment will be performed during night time to minimize interference with other work going on in the hall. When the alignment stops, all signs will be take off and the CANS system will be disabled and the door to BSY will be unlocked.

1.15.7.3 Maintenance procedure

Replacement of used or damaged optical components of the setup will be made with the laser off (power switched off and unplugged). The positions and orientations of the new components will be mechanically surveyed and extensively checked before turning to any procedure needing the laser on.

When the target enclosure windows need to be opened (such as to inspect the target or to replace a target cell) and the hall is not in laser controlled access, the lasers must be turned off before opening the target enclosure. The keys for all of the laser power supplies optical fibers will be disconnected and the connection ends will be secured in a lock box. All staff working in the vicinity of the target enclosure must apply personal locks to this box in accordance with JLab lockout/tagout procedures. The vicinity area will be determined from the power measurement and with clear danger sign posted.

In case of the failure of any electromechanical or electrical or electronical device, the lasers and the other power supplies will be turned off. The Laser power can simply be unplugged.

1.15.7.4 Off-normal and emergency procedure

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

- Push the Crash button;
- Turn off the control key on the laser power supply;
- Pull the plug from the power outlet.

In the event of a fire, the users shall leave the laser room and pull the nearest fire alarm. Then leave the hall.

In case anybody is accidentally exposed to the laser beam (direct or indirect) without eye protection, he or she shall immediately contact the Jefferson Lab medical center (phone: 7539, page: 584-7539). If it is off business hours, please contact local hospital emergency. At the mean time, please inform the laser system superviser (Jian-ping Chen, phone: 7413, page: 584-7413) and/or laser safety officer (Bert Manzlak, phone: 7556, page: 584-7556).

1.15.8 Controls

Several controls have been added as preventive measures to the laser room and to the direct laser area. We will enumerate these controls here.

1. The laser control area will have danger signs posted and will have a yellow beacon indicating the presence of Class IV diode lasers. Danger sign will also be posted near the target enclosure area.

2. A controlled access interlock system will limit the entrance to the laser room with a coded number pad. The code is given only to the authorized laser users listed in section 10 with currently valid training.

3. The laser switches are interlocked to allow an opening of the door to turn off the laser (to stand-by).

4. The main power plug to the laser can be easily pulled. It is plugged into a power strip with a on/off switch which can be easily switched off.

5. Protective safety goggles (minimum OD 4.7 at 795 nm) have to be worn when the laser is operational.

6. All laser beam paths outside the laser hut are enclosed with beam pipe or other enclosure (except during laser alignment process).

7. All personnel need to fulfill the training requirements as indicated in Section 1 of this document.

8. the LSOP will be posted on the outside door of the laser room to inform personnel about the hazards associated with the setup and the proper procedures.

All controls will be inspected every six months and the inspection will be documented.

1.15.9 Laser safety calculations

1. Maximum Permissible exposure The Coherent FAP-System emit nominal continuous beams of 30 W at a wavelength of $795nm$. With a limiting aperture size of 7 mm and exposure time of 10 seconds, the calculated MPE is $1.51mW/cm^2$.

2. Optical Density The minimum Optical Density is calculated for the beam diameter of 0.64 mm with maximum CW power of 30 watts (the worst case) to be 4.70. OD of 5 safety goggles for the wavelength of 795 nm were selected to be used in the lab.

   With all 4 lasers, when the beams overlap, the combined beam will have a size larger than 2.75 inches. The power density will be lower than the maximum power density with one laser.

3. Nominal Hazard Zone

   The nominal hazard zone is calculated for 3 conditions:

   (a) intrabeam: 78.5 meters
   (b) after lens: 5 meters
   (c) fiber-optic output: 6.7 meters

   The condition of use will always be fiber-optic output with nominal hazard zone of 6.7 meters.

   The laser hazard zone is nimized by confining operation to an interlocked laboratory or interlocked enclosure.

1.16 List of authorized personnel

The personnel showed in Table 1.8 is authorized to operate the Coherent FAP-system diode lasers and the associated polarized ^{3}He target facility, under the assumptions, they have completed the training requirements defined in Sec. 1.15.2. Names can be added to this list by the Laser System Supervisor.

Other authorized personnel is shown in Tables 1.9, 1.10 and 1.11.

Names can be added to the lists after proper training and authorized by Jian-Ping Chen, phone 7413 and jpchen@jlab.org.

Name (first,last)	Institute	Phone	e-mail	Comment
JianPing Chen	JLab	7413	jpchen@jlab.org	*Contact*
Kai Jin	UVa	5510	kai@jlab.org	
Nguyen Ton	UVa	5013	ton@jlab.org	

Table 1.8: Polarized ^{3}He target: authorized personnel

Name (first,last)	Institute	Phone	e-mail	Comment
JianPing Chen	JLab	7413	jpchen@jlab.org	*Contact*
Kai Jin	UVa	5510	kai@jlab.org	
Nguyen Ton	UVa	5013	ton@jlab.org	

Table 1.9: Polarized ^{3}He target: laser trained personnel

Name (first,last)	Institute	Phone	e-mail	Comment
JianPing Chen	JLab	7413	jpchen@jlab.org	*Contact*
Kai Jin	UVa	5510	kai@jlab.org	
Nguyen Ton	UVa	5013	ton@jlab.org	

Table 1.10: Polarized ^{3}He target: personnel authorized to change target cells

Name (first,last)	Institute	Phone	e-mail	Comment
JianPing Chen	JLab	7413	jpchen@jlab.org	*Contact*
Kai Jin	UVa	5510	kai@jlab.org	
Nguyen Ton	UVa	5013	ton@jlab.org	

Table 1.11: Polarized ^{3}He target: personnel authorized to perform laser alignment