Hall A Polarized ^{3}He Target Operation and Safety Procedure

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Abstract

We describe in this procedure all aspects of the Polarized ^{3}He target operation in Hall A. We have identified and addressed personnel as well as fire safety issues related to the normal operation of the target during the experiment. We explain how safety issues are alleviated and provide a detailed description of the target operation within the framework of running experiment.

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Chapter 1

General Description

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.

The target employs the so-called spin-exchange technique. In this 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 electronic polarization of the Rb is transferred to the ^{3}He nucleus in spin-exchange collisions, in which ^{3}He nuclei are polarized via the hyperfine interaction. The target cell contains high pressure ^{3}He gas and a small amount of rubidium vapor. In addition, it also contains a small amount of nitrogen to increase the pumping efficiency.

1.2 Apparatus

High power diode lasers (about 100 W) provide an intense monochromatic light beam for optical pumping. The lasers are housed in a large shielding house, known as the "laser hut", which is located about 5m away from the target on one side of the beam line. An overview of a typical arrangement of the target components in the Hall is shown in Figure 1.1.

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

1. A double sets of Helmholtz coils which 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.

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

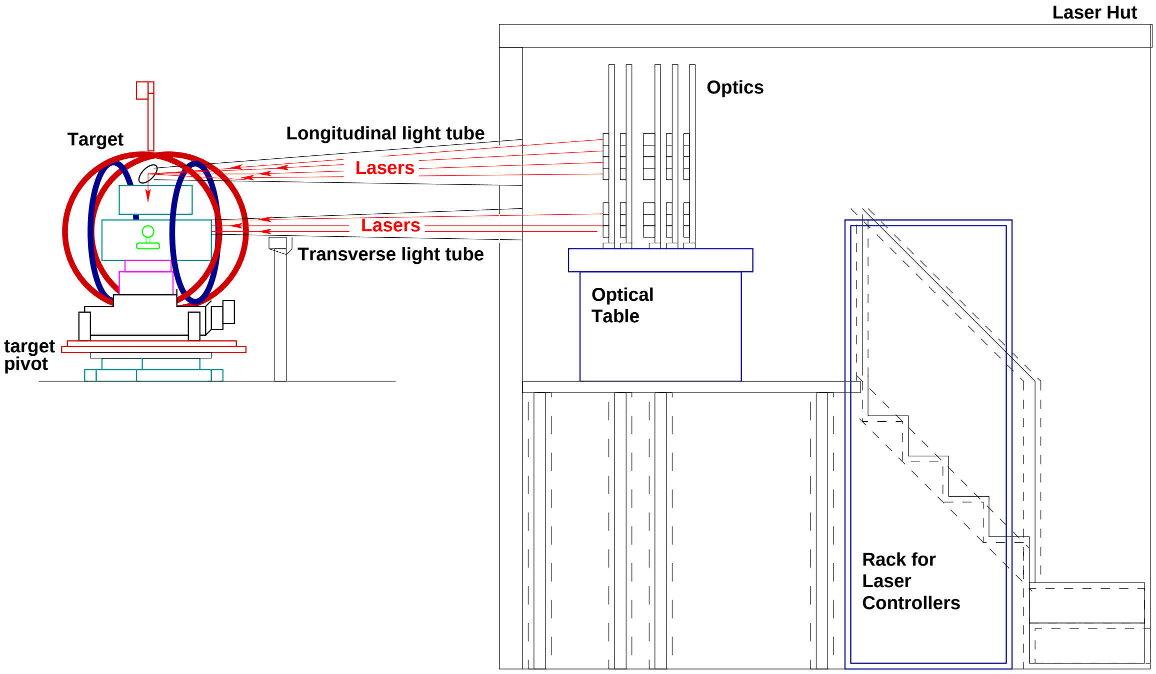


Figure 1.1: Overview of the target setup. Shown are the laser hut, the beam pipes covering the laser beam line extending to the target area, and the Helmholtz coils with the RF assembly and support sub-assembly.

3. A multi-purpose RF enclosure which holds the RF coils but more importantly is crucial for the 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 the rubidium in its vapor phase and control its number density.

5. A target ladder subassembly which supports a target cell, a reference cell, (which can be filled with ^{3}He, Nitrogen or ^{4}He gas with pressure up to 10 atmospheres to study dilution, density or background), a 7-foil ^{12}C optics target, a BeO beam viewer 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 shielding house known as "laser hut" where two laser beam lines are formed by seven 30-Watt diode lasers. These laser beam lines are used for optical pumping of the rubidium alkali atoms in the direction either along the electron beam (longitudinal, 4 lasers) or perpendicular to the electron beam line (transverse, 3 lasers). The nominally longitudinal laser beam can also be directed at a different (specific) direction.

1.3 Control System

The control (including monitoring and measurement) system for the target Helmholtz coil magnet power supplies, the NMR polarimetry and the EPR polarimetry is based on the LabView system on a PC. The control system for the target vertical motion, the half-wave plate 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 to the event data stream.

Chapter 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 4 mm $\times$ 4 mm 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. One viewing camera which looks at the pumping cell will be on. All interlocks of electron beam and laser beam should 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 Chapter 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 should resume.

3. The "Polarized ^{3}He Target" is in "beam position". The data taking is stopped and the beam is turned off. An EPR measurement is performed (procedure described in Chapter 10). After the measurement is completed and the fast raster enabled, the beam is put back on and data taking resumes.

4. The "BeO Target" is moved to "beam position". The electron beam current lowered (to $< 5\ \mu$A with raster-off) as not to damage the BeO target. The monitoring of the

beam position is performed by looking at the TV monitor which displays the view of the target.

5. The 7-foil ^{12}C "Optics Target" is in "beam position". Data on the optics target are taken for spectrometer optics study or detector calibration. Since the BeO and the optics target are in beam at the same time, the above two measurements are often performed at the same time.
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.

Chapter 3

Laser System

The laser system provides 795 nm circularly polarized light for optical pumping of the target. The light is generated by seven solid-state diode lasers, which are located in a shielding hut several meters away from the target, and polarized by passing through a polarizer (beam splitter) followed by standard $\lambda/4$ waveplates. Each laser emits roughly 30W of power. 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 and perpendicular to the electron beam. In the standard configuration, four lasers are used for the parallel and three for the perpendicular direction. Further, it is possible to reverse each of these polarization directions by 180° ("flipping" the target spin). This requires the rotation of the target holding field (see Chapter 8) and reversal of the pumping light helicity. The light helicity can be inverted by inserting a $\lambda/2$ waveplate into the beam path of each laser.

3.1 Laser Hut & 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 shielding house ("laser hut"). It is positioned in Hall A on the right-hand side of the target at a distance of approximately 5 meters as shown in Figures 1.1 and 3.1. This placement limits the maximum angle for the hadron spectrometer to about 45°, which is sufficient for the planned ^{3}He experiments.

Inside the laser hut, an optical table with an anodized aluminum top supports all optics. The setup of the polarizing optics is shown in Figure 3.2.

Seven infrared diode lasers (four for longitudinal pumping and three for transverse pumping) and the related interlock control box are located on a 19" rack. Light is guided out of each laser and goes to an optical table via an optical fiber. Each beam is focused by a 2" diameter convex lens with a focal length of 88.3mm, then divided by a polarizing beam splitter cube into two linearly polarized rays. Because the laser light is initially

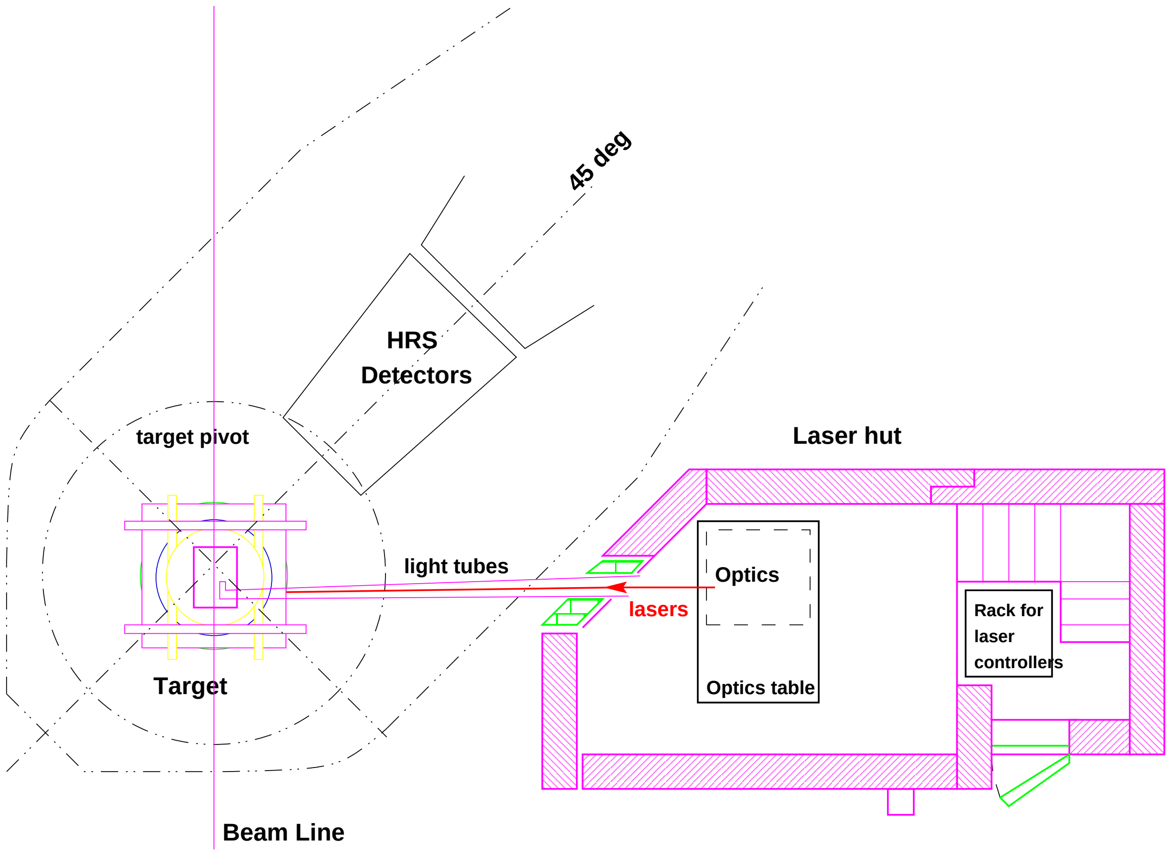


Figure 3.1: A topview of the laser hut shows the location of the interlocked door as well as the position of the laser table where all lasers and optics will be set up.

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 Figure 3.2, note that all eight (or six for transverse pumping) $\lambda/4$ waveplates should have the same orientation.

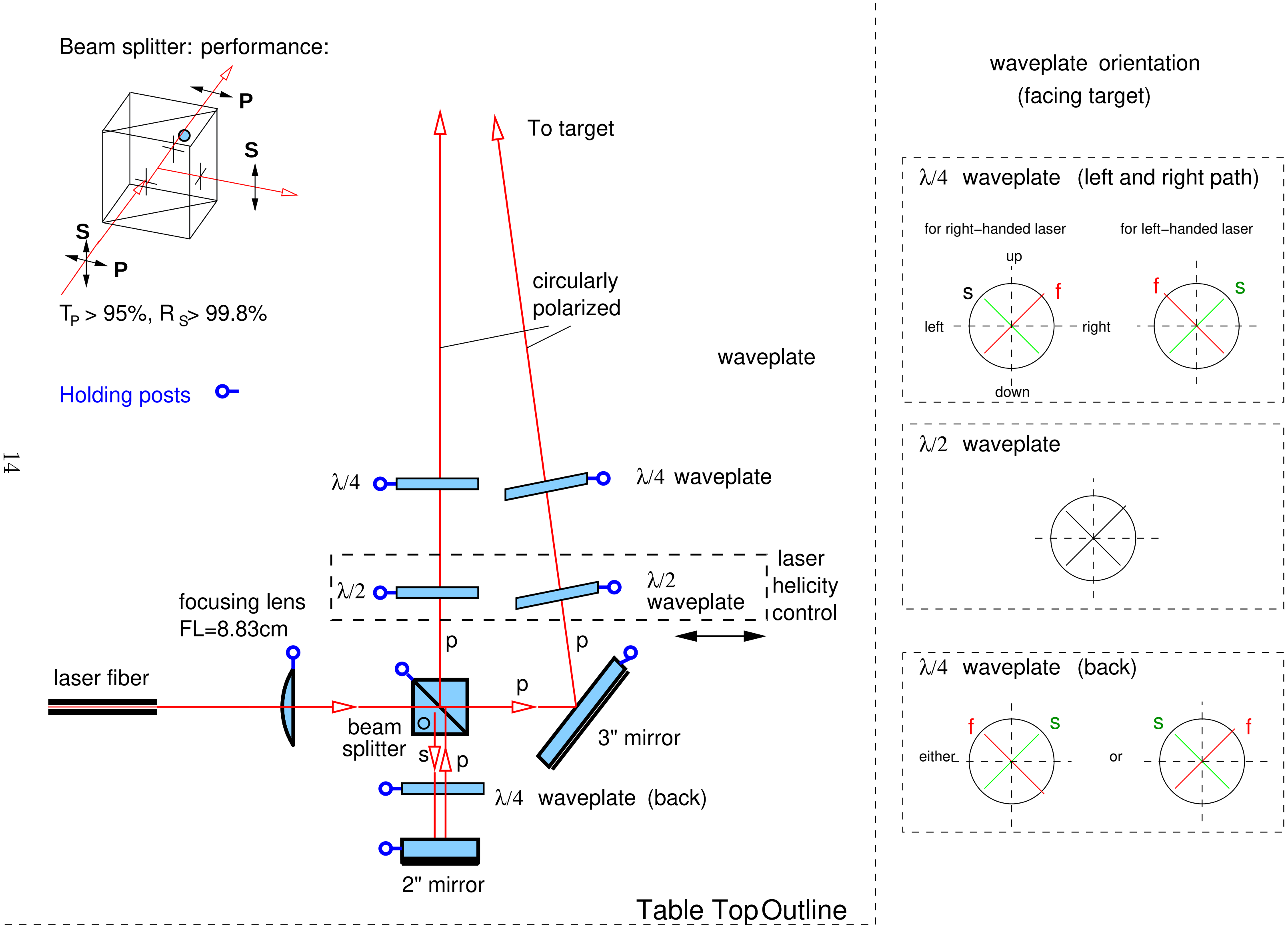
The eight (or six for transverse pumping) resulting beams are carefully aligned to coincide on the pumping chamber of the cell. They enter the target chamber via transparent windows in the target enclosure and oven walls. There is one pair of windows for each polarization direction.

The total path length from the lasers to the pumping cell is about 5 meters. The beam path for transverse pumping is a straight line from the polarizing optics to the pumping cell (via the transparent windows). However, for any other pumping direction, e.g. longitudinal, the beam must be reflected twice such that it goes first down and then horizontally in the desired direction. To this end, a pair of adjustable 4" diameter mirrors is mounted on the outside of the target enclosure. For longitudinal pumping, 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).

Under normal conditions, laser light will be completely absorbed by the rubidium in pumping cell. However, there is small amount of the laser light being reflected by the pumping cell wall or deflected by the pumping cell itself. There is a 4" diameter mirror on the left side (viewing towards downstream direction) to collect the light for the EPR measurement. The light is focused by two lenses (mounted on the oven) first, then guided by a pipe with mirror and additional focusing lenses in it, finally reaches the EPR photodiode which is located a few meters away from the target. At the meantime this light will also be viewed by a fiber and enters the spectral-analyzer, which is used to monitor the spectrum and intensity of the lasers.

The laser beam line is protected by beam pipes that extend from the laser hut to the target top cover. It is important to point out that the laser beam lines are fully enclosed from the rest of the hall.

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


Beam splitter: performance:
P
S
S
P
$T_P > 95\%$, $R_S > 99.8\%$
Holding posts
To target
circularly
polarized
waveplate
λ/4
λ/4 waveplate
λ/2
λ/2
waveplate
laser
helicity
control
focusing lens
FL=8.83cm
laser fiber
p
p
p
beam
splitter
s
p
3" mirror
λ/4 waveplate (back)
2" mirror
Table Top Outline
waveplate orientation
(facing target)
λ/4 waveplate (left and right path)
for right−handed laser
for left−handed laser
up
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left
right
down
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λ/2 waveplate
λ/4 waveplate (back)
f
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3.2 Diode Lasers & Controls

The laser light for this experiment is provided by seven 30 Watt, 795 nm solid-state diode lasers. The seven primary lasers used during the experiment are made by Coherent Semiconductor Inc. There will also be two diode lasers made by the Opto-Power Corporation that will be used as spares. Though there are some minor differences, both companies' laser systems perform the same function. Only the Ceherent lasers and control will be described here. If the Opto-Power lasers are used, readers are refered to the original version of the polarized ^{3}He target OSP manual.

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.The fiber is 5m long in a stainless steel jacket and is removable.

The lasers operate at diode temperature from 15° C to 26.5° C depending on the system. They are run at output power of 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 2 nm. The fiber diamter is 800 microns. The beam divergence is < 0.20 N.A.

The lasers have a local control system, which is integrated into the main enclosure. The local control allows adjustments in operating current (and therefore the laser power) and diode temperature (and therefore the wavelength within a small range).

During the experiment the lasers will be controlled remotely through EPICS. The lasers have a serial IO port on the back of the main enclosure which is connected to a VME RS-232 port. There is an MEDM GUI interface for each of the lasers, which allows remote control and monitoring of current and temperature as well as being able to turn each laser on and off.

3.3 Alignment

Basic procedure for laser alignment

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 4" mirror on top of the oven (for longitudinal laser beam path), or the side window on target (for transverse laser beam path). You might need to adjust the position of each post to compromise between transverse and longitudinal lasers.
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 focusing lens in its mount with the flat side away from the diode laser. Adjust it 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 axises of quarter wave plate, rotate it according to Figure 3.2. 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 should 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 axises of quarter wave plate, rotate it according to Figure 3.2. If not, you need to do bench test first to find the axises 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.

25. Place the half wave plates in mounts, adjust the position of the post and the mounts such that all either (or six) laser beams are able to hit the center of the corresponding half wave plates simutanuously.
26. If you know the axises of half wave plate, rotate each one according to Figure 3.2. If not, you need to do bench test first to find the axises of each half wave plate.

Testing quarter (half) 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 FAP (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 should 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: Probablly 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 Figure 3.3
  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.

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 keypad.
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 3.1 lists the optimum parameter determined for the 30 W lasers used in experiments E99-117 and E97-103 in the summer of 2001.

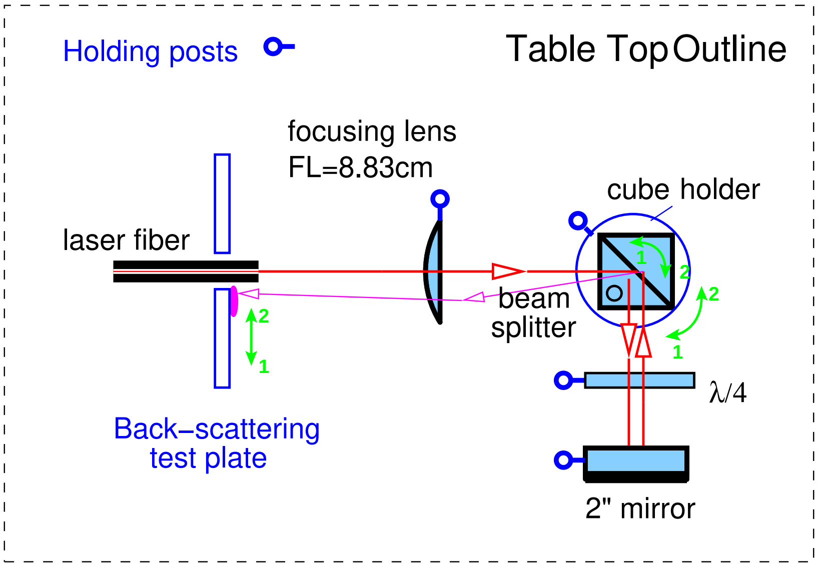

Figure 3.3: Adjusting back-scattering light

Laser	PS #	FAP-I #	Set Current	Set Temperature	Maximum Current ⋆
Coherent 1	3115	V7645	38500 mA	15 °C	45000 mA
Coherent 2	4151	V7250	37000 mA	24 °C	44600 mA
Coherent 3	4157	V7251	40000 mA	26.3 °C	48000 mA
Coherent 4	4206	V8491	40000 mA	15.5 °C	48000 mA
Coherent 5	4209	V8511	36000 mA	19.7 °C	43200 mA
Coherent 6	4208	V8492	40000 mA	14.7 °C	48000 mA
Coherent 7					

⋆ Factory set absolute maximum current

Table 3.1: Operational parameters for the 30 W lasers.

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 should see 'laser disabled'.

In addition to cameras pointing at the lasers boxes in the Laser Hut 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.

3.6 Half-Wave Plate Motion Control

The target polarization can be reversed by insertion or removal of a set of half-wave plates. Before moving the half-wave plates, all lasers must be turned off first.

The half-wave plate positions are controlled through the MEDM GUI running on one of the computers in the Hall A Counting House. The half-wave plates have only two positions: IN (in the laser beam path) and OUT (pulled out of the laser path). The speed, acceleration, deceleration and number of steps can be defined for the half-wave plate motor, but the defaults should be fine except in special circumstances. The GUI allows insertion and removal of the half-wave plates:

To move the half-wave plates IN, click the “Go” button under “Move Half-Wave Plates IN”.

To move the half-wave plates OUT, click the “Go” button under “Move Half-Wave Plates OUT”.

After the motion is finished, you can get the position of the motor by clicking on the “Get Position” button. This button shouldn't be pressed while the motor is moving because the motor likes to perform one operation at a time.

The motor that drives the half-wave plates isn't 100% reliable, so the plates should be checked on the camera monitor to make sure they are in the correct position after a move. If you see a problem with the motion of the motor (i.e. it's driving too far forward or about to drive off the table) then press the Emergency Stop "HALT" button.

Chapter 4

Target Cell

4.1 Description

The target cell is either a 25 cm or 40 cm long aluminosilicate glass (GE180) high pressure (up to 15 atm) double chamber cell. Typical dimensions for a 40 cm cell are shown in Figure 4.1. A 25 cm cell is identical except the target chamber is 25 cm long instead of 40 cm. It is a closed system filled with a gas mixture which consists of ^{3}He, rubidium and nitrogen.

The cell volumes range from 160 ml for a 25 cm cell to 200 ml for a 40 cm cell. The interior pressure of the cell at room temperature is between 8 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 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.

4.2 Installation & Replacement

The target installation is a delicate procedure and should 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.

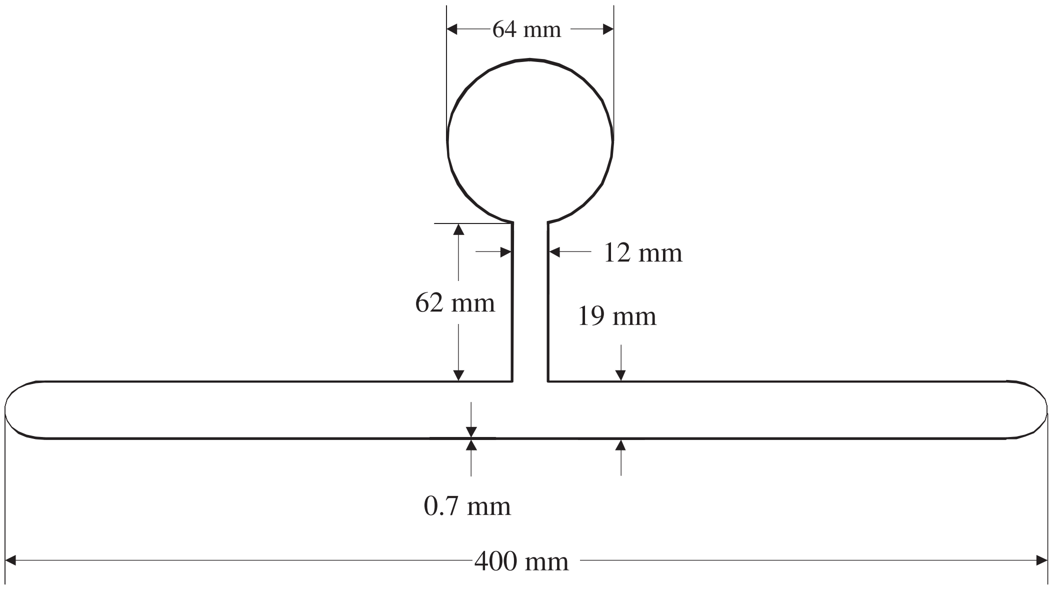

Figure 4.1: Typical 40 cm polarized ^{3}He target cell used in this experiment.

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 protective clothing and a face shield 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 should be measured. If the pickup coils have deteriorated, they should be replaced as well.
- 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 ear protection and a face shield during any access to the inside of the target enclosure.

- Raise the target top assembly support and if necessary remove the scattering windows of the RF 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 should 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 should be tested. When finished, the scattering windows of the RF enclosure should be put back in place.

- If an intact target cell was removed, it should be stored in a wooden box with a screwed 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.

Chapter 5

Target Ladder & Motion System

5.1 Description

The polarized ^{3}He target system has four target positions: the actual polarized target cell (which can be replaced by a water cell for NMR calibration (see Chapter 9), a solid BeO target inline with a seven-foil Carbon target for alignment and optics calibration, an empty target position that contains no target and allows the beam to pass undisturbed through the apparatus and a reference cell position (see Chapter 11). These targets are mounted on a target ladder as shown in Figure 5.1.

The target ladder can be positioned vertically using a stepper-motor-driven motion control system. The controller can drive the ladder to five different fixed positions, three of which correspond to the three targets, the fourth to the empty (no target) configuration, and the fifth to the position used for NMR measurements where the target cell is surrounded by the pick-up coils. The total required vertical motion range is approximately 15 cm.

The motion controller employed was developed at JLab and will be first used in experiment 99-117 (Precision Measurement of the Neutron Asymmetry A_1^n at Large x using CEBAF at 6 GeV). 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.

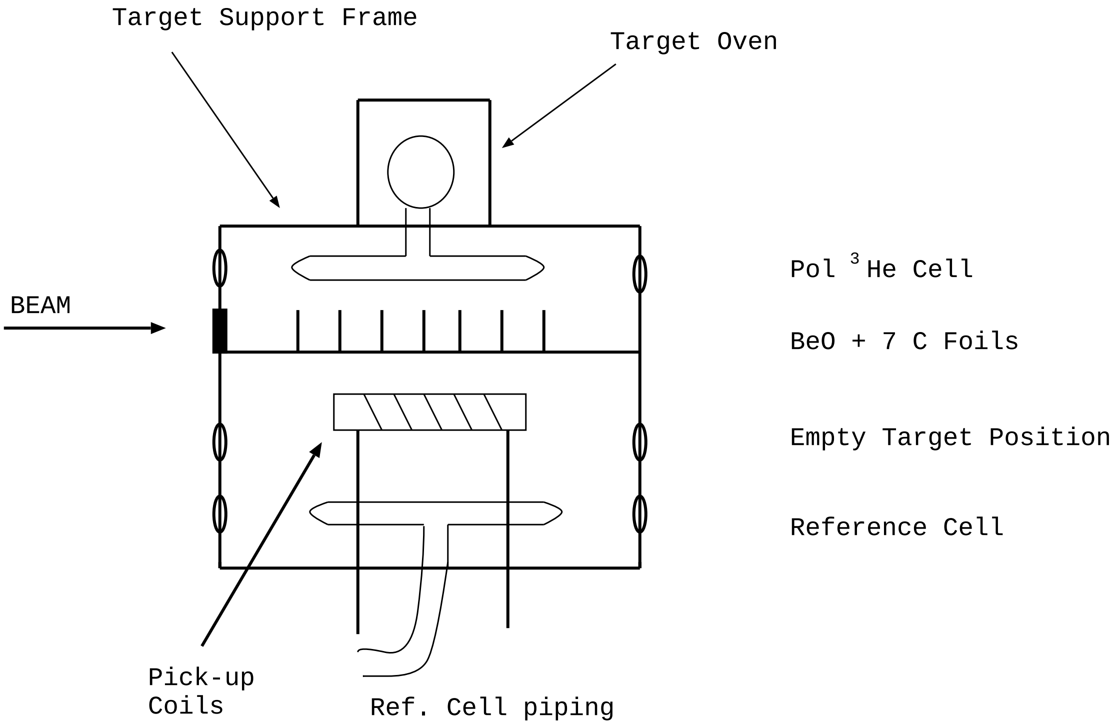

Figure 5.1: Schematic diagram of the target ladder and target positions.

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 A counting house. The final GUI is under developemnt at this time, but it will have 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 A personnel to telephone MCC and request temporary masking of this FSD channel.

Chapter 6

Target Enclosure & Windows

The target is surrounded by an enclosure similar to a scattering chamber. The enclosure serves three purposes: First, it provides a containment volume in case of explosion of the target cell and so limits the potential hazard working area. Second, it holds the RF coils in a stable position and provides a strong frame for the support assembly. 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 of high density polyvinyl (HDPV) material and has several removable windows. The windows are of three types: The incident electron beam entrance and exit windows are 0.127 mm thick aluminum. The windows on the side of the chamber through which the scattered particles pass are 2.54 mm thick aluminum. Five-mm thick optical-perfect windows allow the laser beam to enter the enclosure.

If any windows are open, people working anywhere on the *target platform* must wear ear protection and a face shield. This region is designated as the "target area". Signs will be posted indicating that the windows are open and that work is in progress. If the windows are closed the target area is no longer restricted except for possible reasons of radiation safety.

The electron beam crosses two windows before reaching the target, the electron beam pipe window and the target enclosure beam inlet window. Similarly, it crosses two similar windows as it leaves the target area. The electron beam line is under vacuum and separate from the target enclosure for both upstream and down-stream of the target enclosure. The gap between the upstream beam line and the enclosure inlet window is very narrow. Both upstream and downstream beam lines are terminated with a 0.254mm thick beryllium window. The beam inlet and outlet windows of the target enclosure are made of 0.127mm thick aluminum and are strong enough to stop any flying glass shreds in case of a target cell explosion.

Chapter 7

Target Cell Heater

The target pumping cell must be kept at a temperature of about 170°C (340°F) for optical pumping of Rb 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.

7.1 Description

Figure 7.1 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 a resistive heater element (120 VAC, 700 W) and continues through insulated copper tubing into the target oven. The oven material is Torlon and Vespel plastic which can withstand a temperature of at least 260°C continuously. The air finally exits the system through a several meters long exhaust pipe where it can cool down.

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 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 section 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

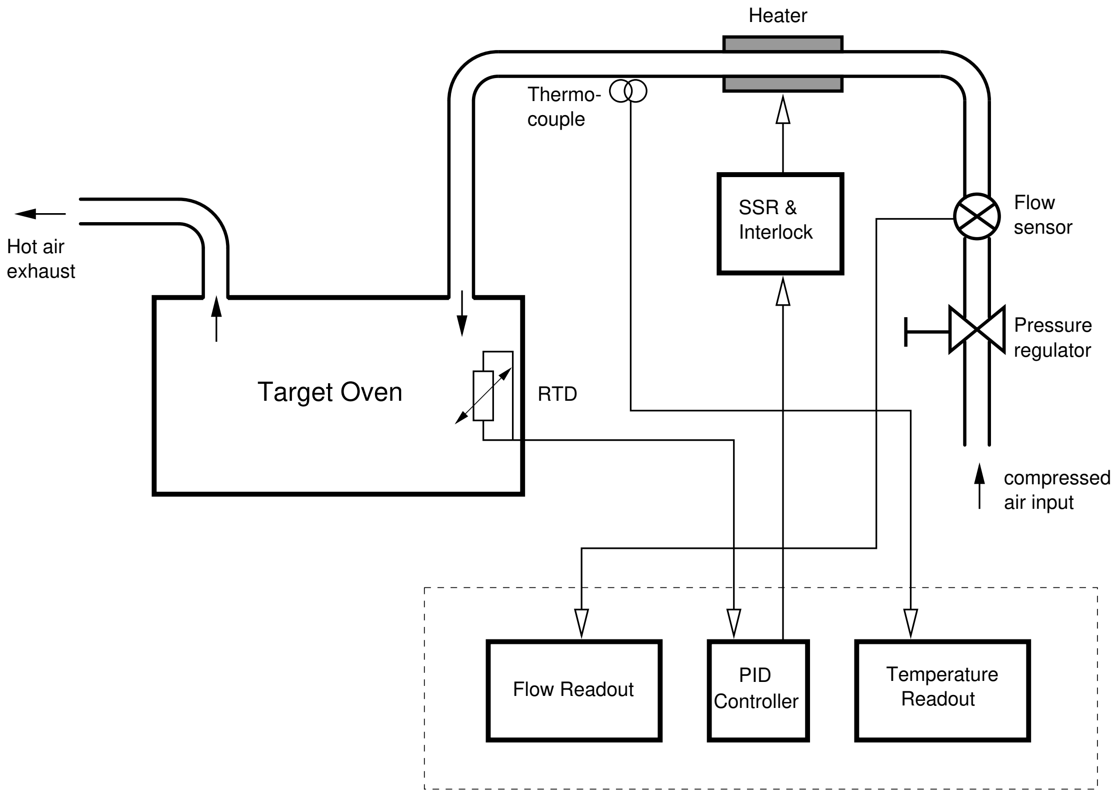

Figure 7.1: Schematic diagram of the target cell oven control system. The instruments in the dashed box are located upstairs, while the remaining components are located in the Hall in the vicinity of the target. For clarity, the interlock circuitry is not shown (see Figure 7.2).

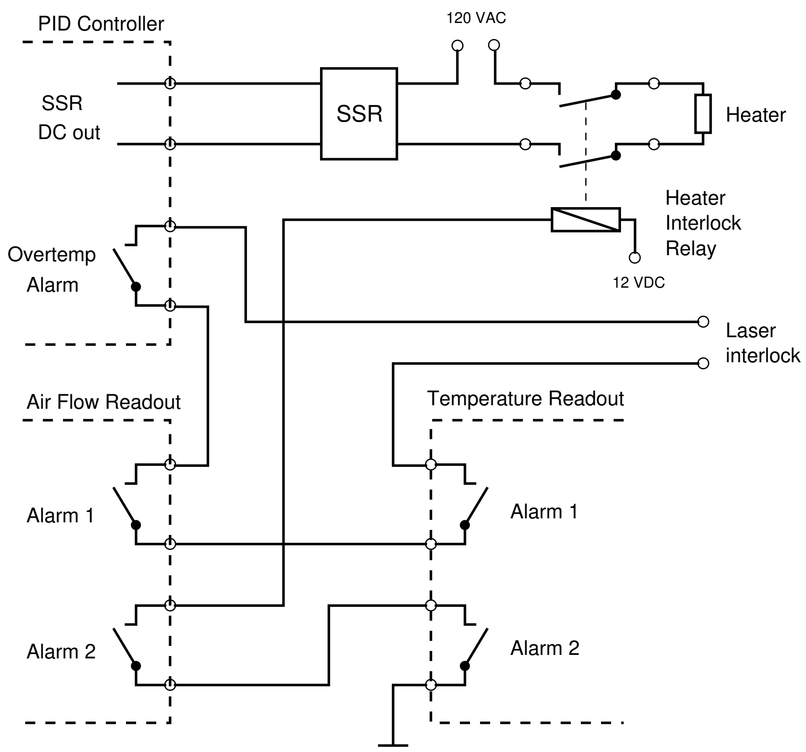

Figure 7.2: Schematic diagram of the oven heater interlock system. The switches represent relays. In normal operation, the relays are energized (contacts closed). An alarm condition (or instrument power failure) will de-energize (open) the corresponding relays, interrupting the interlock circuit. The instruments are programmed such that their dual alarm outputs operate simultaneously.

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.

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 Figure 7.2. 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.

7.3 Operation

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

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 7.1 and 7.2. 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.

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.

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 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 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.

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 7.1: 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 7.2: Suggested default parameters for the temperature controller (continued).

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.

Chapter 8

Helmholtz Coils

The Helmholtz coils are four large interlocking rings of coils that provide a large constant magnetic field. Two sets are necessary so that the magnetic field can point in any direction in the horizontal plane. The larger two coils have an internal diameter of 1.45 m and consist of 272 turns of coil. The smaller set of coils each have a internal diameter of 1.27 m and are made of 256 turns of coil.

The normal holding field for the target is 25 Gauss which corresponds to approximately 7.2 amps of current in the coils. However, when doing an NMR measurement the field gets as high as 32 Gauss, which corresponds to 9.2 amps of current.

The coils are controlled by a DC voltage from two Stanford Research System DS345 Function Generators. These are in turn controlled by a LabView Vi running on a PC. There is a small glitch in the DS345 function generator : there sometimes will be a short drop in voltage before going to the correct voltage. This is a problem when rotating the field, since it causes sudden magnitude shifts which in turn destroy a little of the target polarization. This glitch is compensated for by a specially designed rotation box to which a Wavetek 80 function generator is attached. This function generator compensates for the small decrease in voltage so that the rotation can be performed smoothly.

Attached to the small set of Helmholtz coils are a smaller set of coils. These consist of 20 loops of 16 AWG wire attached to a 150 W power supply. This target occasionally has a problem with a phenomena known as masing. This is a loss of target polarization due to coupling of the helium nuclei in their higher energy states (such as during an NMR measurement) and a coil of wire (the pick-up coils, a Rb ring, or some other source). Masing can be easily identified with EPR, and introducing a small field gradient generally makes it disappear. These coils are used to introduce that field gradient.

Chapter 9

NMR Polarimetry

This guide explains briefly how to perform safely an NMR AFP sweep on the polarized ^{3}He target. Please, refer to Figure 9.1 showing the target setup and explaining the angle conventions. Longitudinal or parallel field configuration is named if the holding field is pointing towards 0°, *i.e.* along the incident electron momentum direction.

9.1 NMR polarization measurement

- Turn off the lasers (3 or 4), rotate the magnetic holding field to the parallel configuration (if the field is in transverse mode).
- Make sure the target is in the Helium 3 (beam) position.
- Make sure you are in the parallel field configuration.
- Run the NMR Record Settings panel. Make sure you get the print out.
- Run the Current Monitoring panel. Print it at the end.
- Call MCC and tell them you are going to move the target down to the pick-up coils to measure its polarization. When the target is masked, move the target down to the pick-up coils.
- Print the RTD screen from the HAC X terminnal.
- Run the NMR Measurement panel and print it when completed.
- Move the target back to its beam 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 with a radius setting $r = 2$ mm, current less than 15 μA)

- Run the NMR Extract Polarization panel and print it.
- Staple the plots together and store them in the target binder.

9.2 Plots to print

For every NMR measurement, print :

- NMR Record settings panel (will be printed by the Vi)
- NMR Measurement panel (print it at the end of the sweep)
- NMR Extract Polarization panel (print it when completed)
- RTD temperatures screen (print it from the X terminal)

Staple the four plots together and store them in the target binder.

9.3 Warnings

- Never stop a running LabVIEW Vi
- 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
- The lasers must be off before rotating the holding field
- We indicate on Table 9.1 the voltage and current values for each KEPCO.

9.4 NMR AFP Safety

The NMR AFP system provides the DC current in the holding coils (up to 10 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 should therefore be avoided. All the electronic devices and the PC used to sweep are located in the Counting House A. Refer to **Figure 9.3** for a description of the electronics.

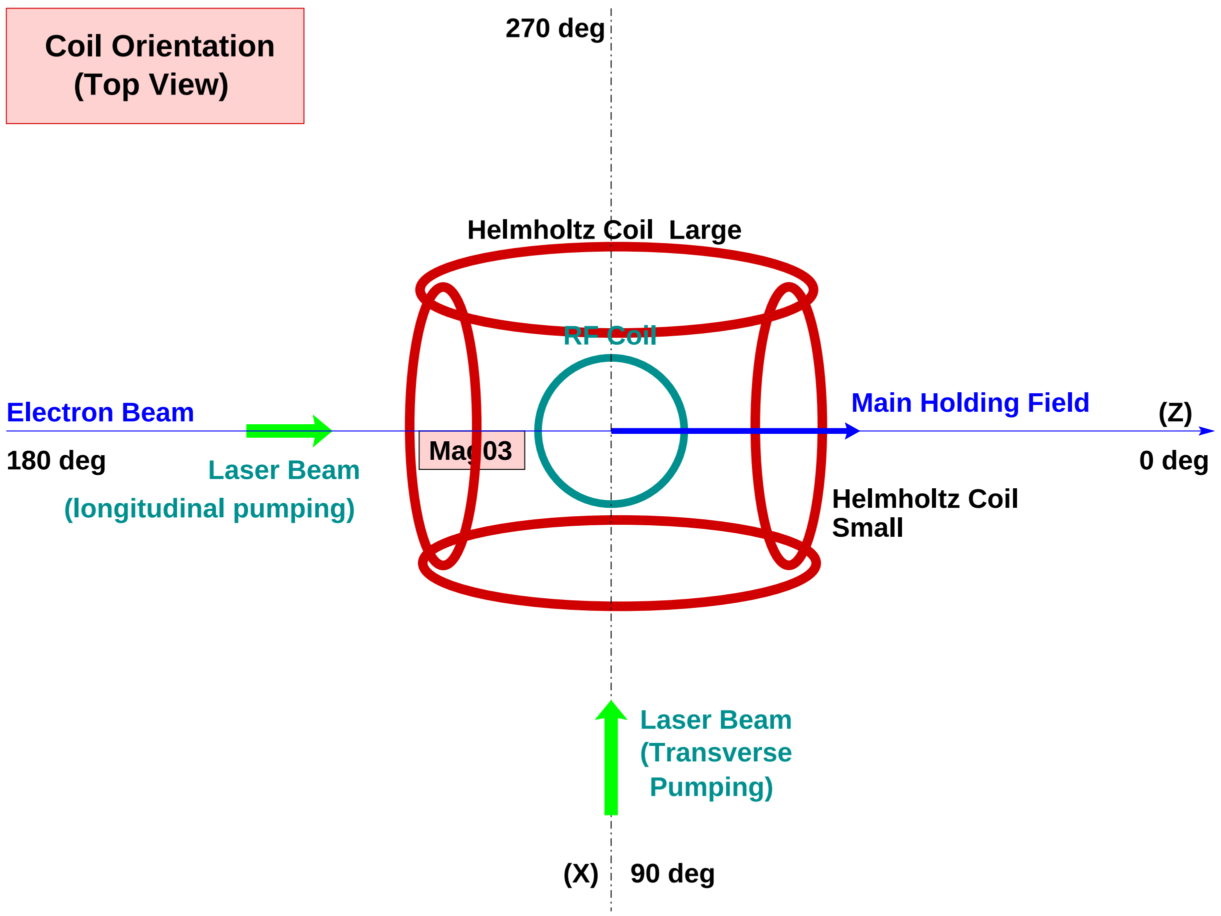

Figure 9.1: Top view of the longitudinal and transverse Helmholtz coils used in the polarized ^{3}He target setup. The RF coils are needed to perform NMR as well as EPR measurements. The 0° angle gives the incident electron beam direction. The dashed lines indicate the coils main axis, the long bold arrow indicates the holding field direction which can be rotated from 0° to 360°. We also show the laser beam longitudinal and transverse directions.

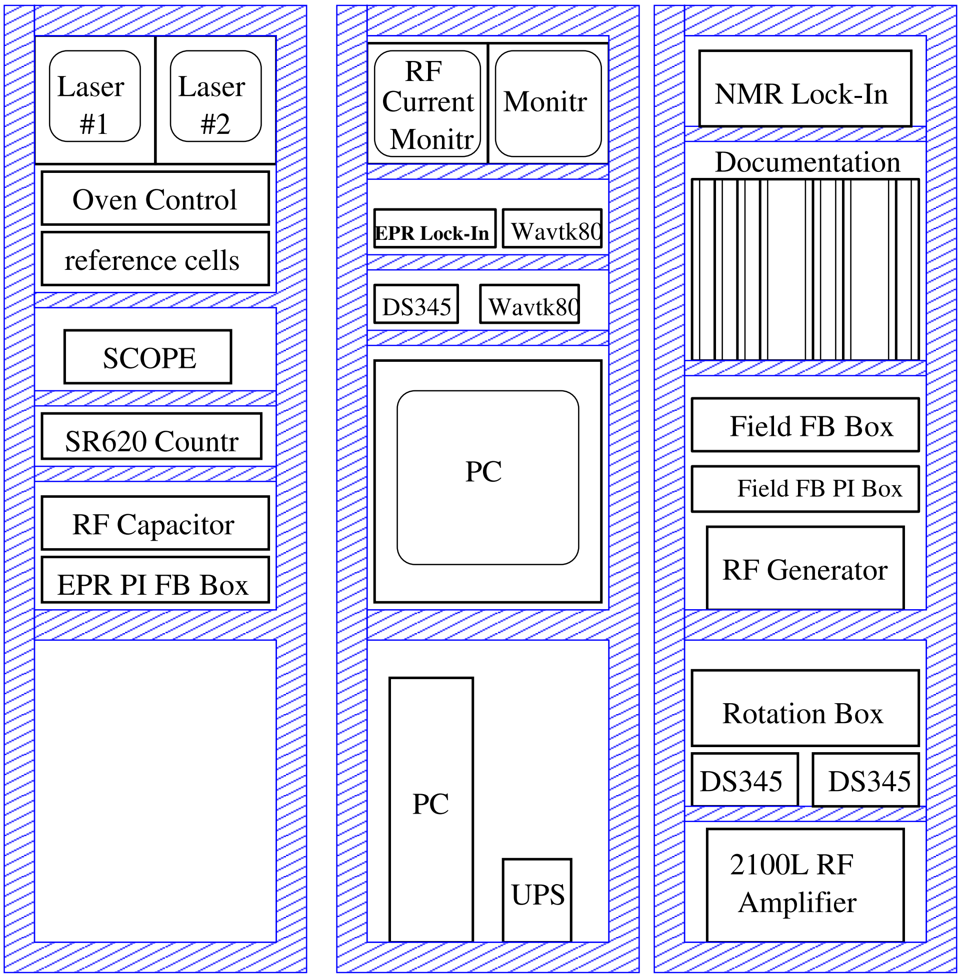

Figure 9.2: The electronics is located in the Counting House A.

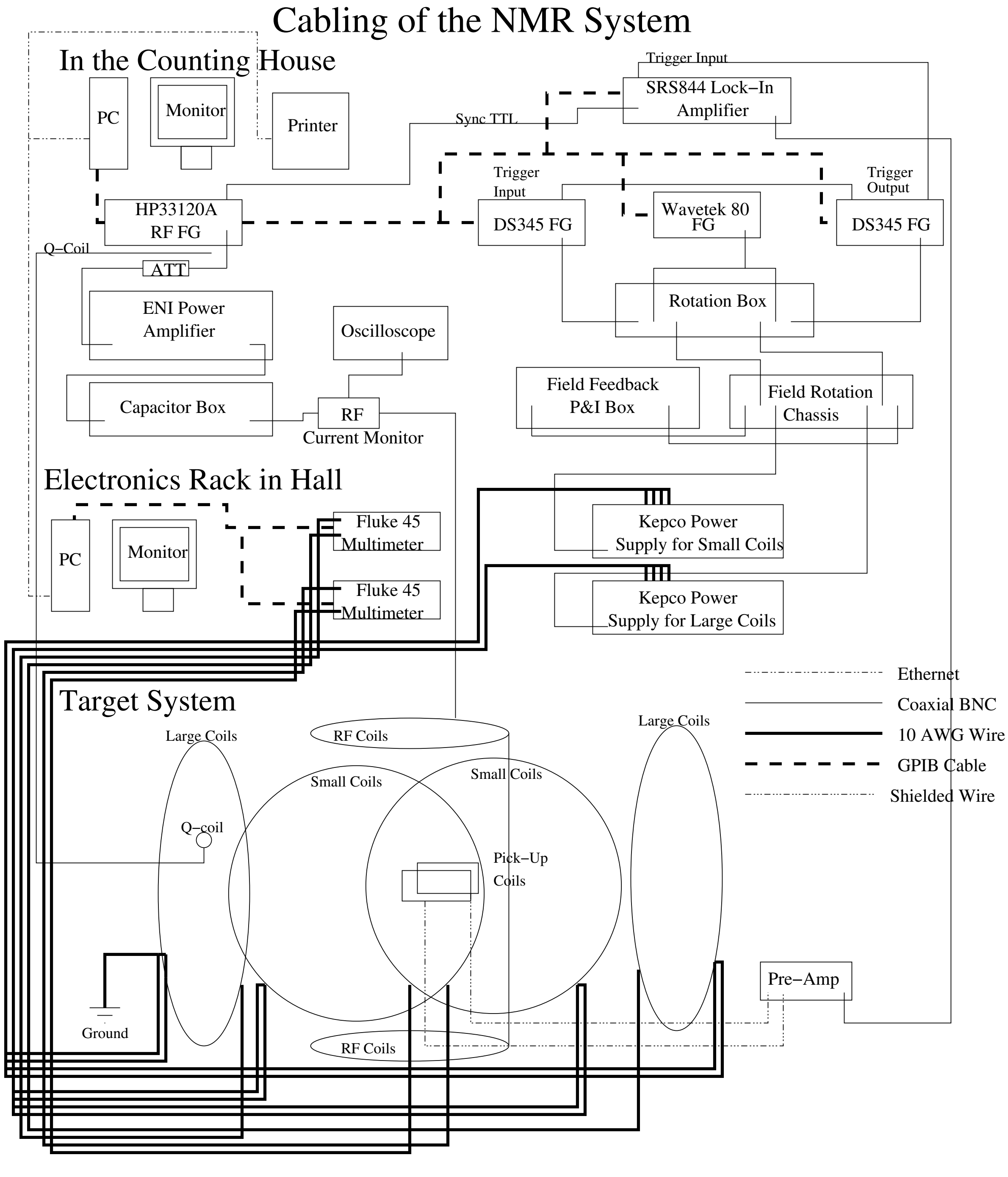

Figure 9.3: Description of the cabling of the NMR system. 10 cables go from the counting house to the target location in the hall : 8 (main+sensing) ESSEX AWG 10 for the Helmholtz coils, 1 RG58A/U for the RF coils and 1 RG58A/U for the pick-up coils.

9.4.1 The DC current

It is produced by the two Kepco power supplies. One drives the large coils, and the other the small ones, as stamped on their front panel. The output of each Kepco consists of four wires, two to lead the current, and the two others used for sensing. The four output plugs are located on the back panel of each power supply which can only be reached through the back panel of the rack. The connections are protected by a plastic strip and can not be touched by hands. In the hall, simple copper screws are used to connect those wires to the coils. They should never be touched. The grounding of the system is achieved in the hall.

How to turn the Kepco Power Supplies off in an emergency ?

1. Turn the Function Generators SRS DS345 off (one for each Kepco) by pressing the on/off switch.

2. Turn the Kepco power supplies off by setting the manual on/off switch to the off position. The digital displays should turn off.

9.4.2 The AC current

It is produced by the EIN RF Power Amplifier located at the bottom of the same rack. When it is running, the manual switch is set to the ON position, the red LED is steady and the needle on the display is 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 should never be touched when the RF Power Amplifier is running. The grounding of the system is provided by the RF Power Amplifier.

How to turn the RF Power Amplifier off in an emergency ?

1. Turn the Function Generator HP 33120A connected to the RF Power Amplifier off.

2. Turn the RF Power Amplifier off by setting the manual ON/OFF switch to the OFF position. The red LED should turn off and the needle should go back to the zero position.

Table 9.1: *KEPCO settings*

Orientation	KEPCO 3 Voltage	KEPCO 3 Current	KEPCO 4 Voltage	KEPCO 4 Current
0 deg	38.0 V	7.1 A	0.0 V	0.0 A
90 deg	0.0 V	0.0 A	38.2 V	7.2 A

Detailed description of the NMR system is contained in the following technical note by S. Incerti: *The NMR system of the Hall A polarized Helium 3 target*, JLab-TN-98-049. A copy of this note is included in the target binder in the Hall A counting house.

Chapter 10

EPR Polarimetry

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

10.1 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) light emitted from the cell as a function of applied frequency to the EPR coil.

First, construct the circuit described in figure 10.1 by following these steps:

1. Position the PIN diode so that it looks directly at the light beam coming from the cell. If pipe is used for guiding the light from the cell to where the PIN diode is located, you may need to adjust the focusing lenses within the pipe such that most of the light is collected 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. 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;

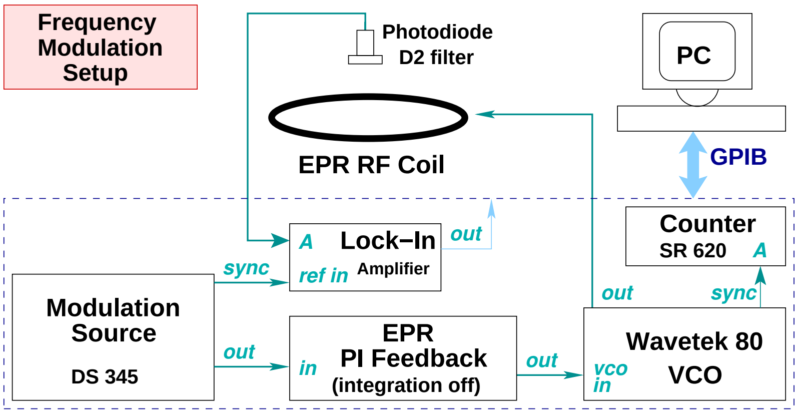

Figure 10.1: Circuit for EPR lineshape measurement

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 Wavetek 80 parameters:

Modulation Mode:	VCO;
Output:	sine wave;
Operating mode:	FUNC.

   Be sure that the VCO indicator is lit. (The VCO is used because it is very sensitive to small changes in voltage. At a carrier frequency of 10MHz, a 1mV input will produce a 400Hz shift in the output frequency.)

9. Connect PI circuit output to Wavetek 80 VCO IN through an 100:1 attenuator. Set the 100:1 attenuator switch to “FMS” (no attenuation).

10. Connect Wavetek 80 sync out to SR 620 Counter. Connect Wavetek 80 output to the cable leading to the EPR coils. Make sure that the Wavetek 80 output is not in standby mode.

11. Bypass the RF capacitor by setting the switch to 'EPR' on RF capacitor box front panel.

Now that the circuit is in place, open the LabView program called "FMSweep.vi" (in windows-diagram).

1. Input the start frequency for your sweep in the upper left of the screen. At the start of pumping, the resonance frequency should be around the number given by this formula:

   EPR base resonance = (466000 * holding field in Gauss)

   Thus, your sweep should begin below and end above this number. However the resonance frequency is different for different Rb polarization directions in the pumping cell. Typically with 25 Gauss holding field the starting sweep frequency is 11.1 MHz for right-handed light, or 11.5 MHz for left-handed light.

2. Input the voltage at which you will run the EPR coils. Typically, this is 8.0 Vpp, but it can go as high as 16.0 Vpp.

3. Next, set the step to be 1KHz and the number of steps to be 500. Keep in mind that the lineshape you are looking for is about 500kHz in width.

4. Set the number of points per sweep, as well as the sweep duration. Typically we take 2 points per sweep and 500ms for each point. The maximum speed should not exceed two points per second.

5. The program will automatically generate the data file to store the data, with a filename related to date and time the program is running. However, you can change the filename and path through the dialog bar located at the right bottom corner.

6. After all of the necessary data has been entered, the sweep may begin. To start the program, simply click on the white arrow in the upper left corner of the screen. You should be able to read the current Lock-in signal amplitude and the EPR coil frequency from the screen.

7. Under normal conditions, in the plot of Lock-in signal vs. EPR coil frequency showed by the program, you should find a dip followed by a peak, or vice versa.

8. You might need to adjust the Lock-in Amplifier phase. You can use "auto-phase" in reference channel menu or you can adjust it manually as follows:

   When the program goes at the maximum of the peak (or mininum of the dip), check the Lock-in Amplifier phase by reading the X and Y signals from Lock-in Amplifier front panel. Since the LabView program only reads X channel, the phase should be adjusted such that X channel has a big signal while Y channel is roughly zero (or only consists noise). If not, adjust the reference channel phase through the front panel menu of the Lock-in amplifier. You don't need to stop the program to do it, it is easier to adjust phase by checking the output of the running program simutaneously. After the phase is optimized, run the program again.

Manual adjustment is useful when the signal is small compared to the background (cable resonance, noise etc.), where "auto-phase" will track the phase of the background.

9. An EPR signal of amplitude higher than 25 μV extracted by FM Sweep will be good enough to do the EPR polarization measurement.

10. Once the measurement is done, disconnect the output of Wavetek 80 to the cable leading to RF coil.

10.2 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.

10.3 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.

Construct the circuit described in figure 10.3:

1. First construct FM Sweep circuit described above.

2. Connect Lock-in amplifier channel 1 output (from rear panel) to PI circuit 'in'.

3. Switch the 100:1 attenuator from "FMS (no attenuation)" to "AFP (100:1)".

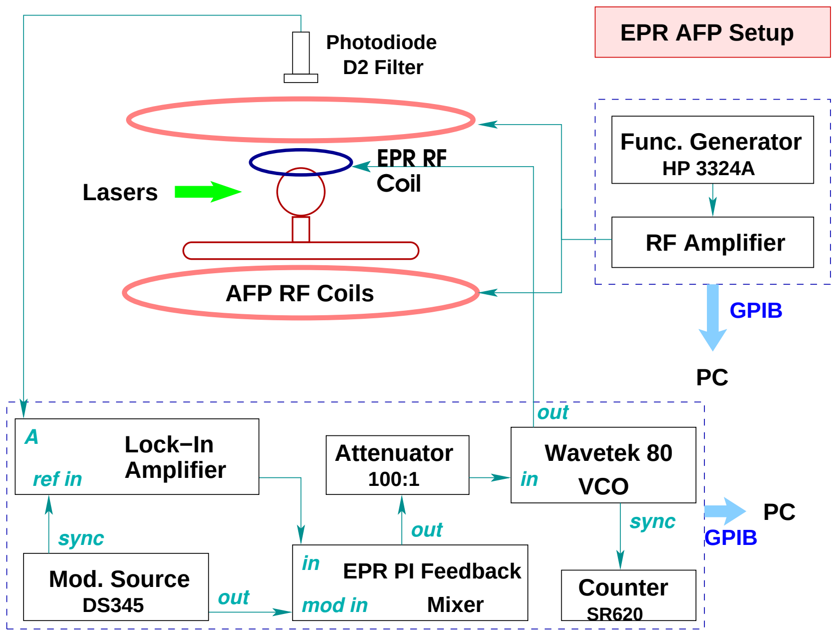

Figure 10.2: Circuit for EPR measurement with AFP spin flip

4. Set Modulation source DS345 parameters:
   Frequency: 200 Hz (This frequency is arbitrary. 200Hz is good since it is far away from most noise sources.)
   Waveform: sine wave

5. Set Wavetek 80 parameters:
   Amplitude: 8.0 V, higher amplitude will be needed if the signal extracted by FM Sweep is less than 25 μV;

6. Bypass the RF capacitor by setting the switch to 'EPR' on RF capacitor box front panel.

Now that the circuit is built, you can begin the initialization of the setup.

1. Set the modulation source DS345 amplitude to approximately 0.6 Vpp. This number can be optimized for different conditions such as different target polarization and EPR D2 signal amplitude. At an EPR D2 signal amplitude of 25 μV the optimized DS345 amplitude is roughly 0.05 Vpp for P$<$ 20%, between 0.05 and 0.6 Vpp for 20% $<$P$<$ 40%, and 0.6 Vpp or higher for P$>$ 40%.

2. Find the EPR resonance frequency:

   If you have done a FM Sweep measurement, then you already know the EPR resonance frequency, continue to the next step.

   If you don't know where the resonance frequency is, you may want to do a FM sweep measurement, or you can find the current resonance frequency by hand, To do this,

   - Temporarily remove the connection to Vin on the PI feedback box, turn off the integration function, set the 100:1 attenuator switch to "FMS (short)". Now you are back to the FM Sweep circuit setup. Manually adjust the Wavetek 80 frequency with the smallest step 0.01 MHz, while observing the lock-in. Look in the area given by the formula:

     EPR base resonance = (466000 * holding field in Gauss)

     This is typically about 11MHz.
   - You should be able to observe the lock-in signal changing when adjusting the frequency. It should show a maximum (>0, peak) followed by a minimum (<0, dip), or vice versa, and the resonance is between them when the lock-in signal is small. Keep in mind that the lock-in will read zero when you are far from resonance as well, so be sure to look for this characteristic resonance behavior.
   - Reconnect the Vin input, and set the 100:1 attenuator switch from "FMS (short)" back to "AFP (100:1)".

3. Set the Wavetek 80 frequency to be 0.1 MHz lower than the current resonance frequency if the light is right-handed polarized, or 0.15 MHz lower than the current resonance frequency if the light is left-handed polarized. The lock-in signal should be large since you are not at the resonance frequency.

4. Turn on the integration on the PI feedback box.

5. Observe the Vout of PI circuit on an oscilloscope. If it is "jumping around" erratically, or looks as if the Opamps have been saturated, you must adjust the gains. The best advice is to begin with the relative gain, and if this does not rectify the problem, move on to the absolute gain. Basically, adjust these parameters such that the feedback signal is not too strong, neither too weak.

6. Once this is done, the circuit should track the resonance frequency and the counter reading should change towards it. The lock-in signal should be stablized to minimum.

7. Wait until the counter reading is stablized, change Wavetek frequency manually by 0.01 MHz. You can observe a jump of 0.01 MHz in counter reading, but then it should change back to the resonance frequency, which means the circuit is following

the resonance. If not, then the frequency it was stablized before is not the true resonance frequency, check the circuit and try again.

8. Once this is done, the circuit should take care of itself. Left alone, it will track the movement of the resonance peak.

To measure the shift in resonance frequency due to AFP spin-flip, open the LabView program AFPSweep.vi. Enable the program by clicking on the large white arrow in the upper left corner of the panel.

1. Set the sweeping time to be 6 seconds and the waiting time to be 20 seconds. Set the number of sweeps to be 2.

2. Run the program.

3. Download parameters by clicking the corresponding button, you should read "downloading parameters" on the program status dialog.

4. Wait until the program status shows "waiting for data taking to start".

5. Start data taking by clicking the "pause :: run" button. Now the program should read resonance frequency from counter, and the lock-in amplifier signal. The program status should show "waiting for sweep trigger".

6. Wait for roughly 20 seconds, start sweeping by clicking on the "start sweeping" button. The program status should show "sweeping...".

7. You should then be able to see the jump in resonance frequency. When the light is right-handed polarized, this should be a positive jump, while for left-handed light it is negative.

8. After the sweeping is completed, wait until the program status shows "waiting for sweep trigger", now you can stop the program.

9. Disconnect the output of Wavetek 80 to the cable leading to RF coil.

10. *Never stop the program during sweeping, this will cause the ^{3}He to stay at the wrong state and hence a big loss in target polarization.*

10.4 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 10.1.

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 $\sim$ 40to 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.

10.5 EPR Continuous Monitoring with Field Feedback

This configuration uses the lock-in amplifier with PI feedback circuit to lock into the EPR resonance frequency and then track its behavior. At the same time a field feedback system is used to stablize the main holding field to a level of 10^{-5}. The EPR resonance frequency is the central frequency proportional to the main holding field plus (or minus) a field originated from the ^{3}He polarization. By measuring the EPR resonance frequency and the main holding field, one is able to monitor the pumping cell polarization continuously.

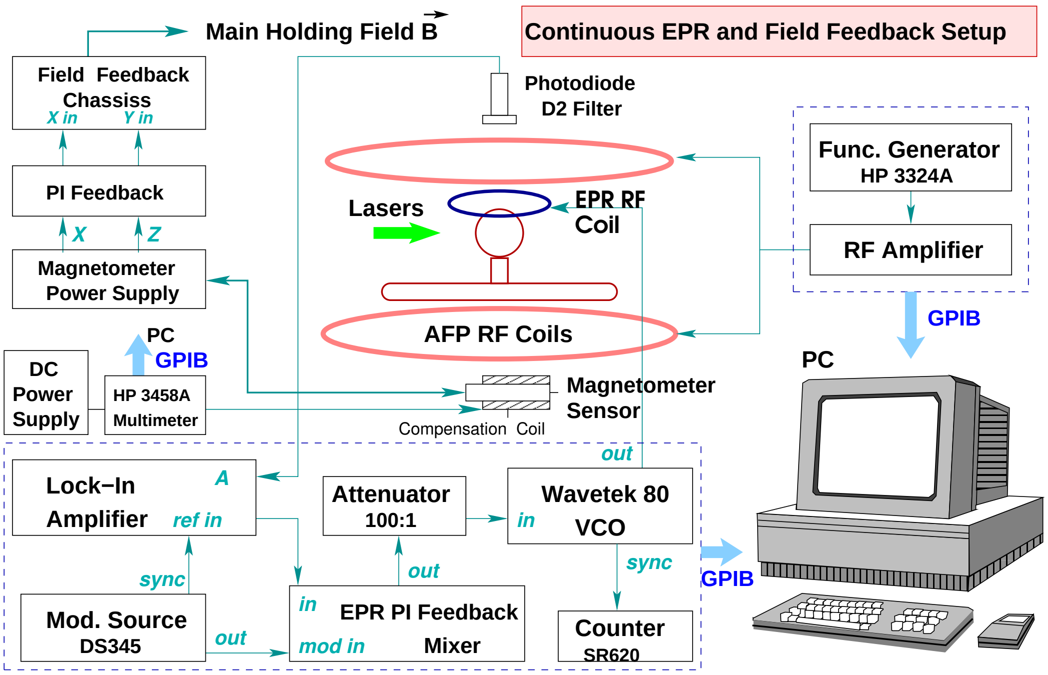

Figure 10.3: Circuit for continuous EPR measurement with field feedback

The circuit and labview program are the same to that are used for AFP Sweep measurement described in Section 10.3, except that field feedback system is needed, as shown in Figure 10.5

1. Construct circuit and set parameters. To track the resonance frequency, the only difference between EPR AFP measuremen and EPR continous monitoring is that the modulation source DS 345 amplitude does not need to be large. Typically 0.05 Vpp is enough.

2. Make sure the circuit is tracking the resonance frequency.

3. Use a scope or multimeter to measure the two field feedback signals, the amplitude should be less than 500 mV. If either of them is larger than 500 mV, you must adjust the position of magnetometer sensor such that the signal perpendicular to the main holding field is back to 200 mV or lower. Then adjust the power supply for the compensation coil such that the signal parallel to the main holding field is back to 200 mV or lower.

4. Enable the field feedback system by setting the switch 'bypass/through' on field

feedback chassiss to 'bypass'. You should observe that both field feedback signals are stablized to zero.

5. Run LabView program HP3458A_read.vi on computer downstairs to record the current of compensation coil.
6. Open LabView program AFPSweep.vi, enable the program by clicking the white arrow in the upper left corner.
7. Set the paramters, download parameters and start data taking. Do not do sweeping (AFP spin flips).
8. After enough data is collected, stop the program.
9. Disconnect the output of Wavetek 80 to the cable leading to RF coil.

10.6 Common Problems

1. See the problems in the previous section.
2. The field feedback signals jump to +10V or -10V when enabling the field feedback system, and stay there afterwards.

   This is usually caused by a wrong state of the field feedback system. For example, wrong sign of the feedback settings (XCOS, YCOS) can cause a positive feedback such that the signals are stablized to the satuated values.
3. The field feedback signals oscillate between +10V or -10V when enabling the field feedback system.

   This is also caused by a wrong state of the field feedback system. Because we are using two dimensional field feedback, wrong sign of the feedback settings (XSIN, YSIN) will cause the longitudinal and transverse components of the field interfering with each other through a positive feedback so both are not stablized.
4. The field feedback signals are stablized at a small but non-zero value.

   This means the field feedback system is working properly and in principle should not affect the measurement. However, a non-zero offset of either of the signals may cause a non-linearity between holding field and the compensation coil current, which should be avoided in high precision polarization measurements. With the field feedback system in 'Bypass' mode, you can adjust the screws on field feedback chassiss to adjust the 'XOFFSET' and 'YOFFSET', meanwhile use a scope to measure the two field feedback signals from magnetometer sensor until they are stablized to zero.

Chapter 11

Reference Cell

11.1 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 behind the laser hut, 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 figure 11.1. The individual subsystems are depicted in figures 11.2–11.3.

Under normal operating conditions, the manifold, the reference cell, and the intervening gas lines will be filled with either ^{3}He, N_2, or ^{4}He gas at high pressure (typically $\approx$ 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 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 8 solenoid-controlled, air-actuated valves, one hand-set needle valve, two baratron pressure gauges (0–1000 torr and 0–1000 psia), two pressure relief valves, a bottle of high-pressure ^{3}He gas, a bottle of high pressure N_2 gas, a bottle of high pressure ^{4}He gas, an oil-free turbo pump backed up by a pre-pump, and

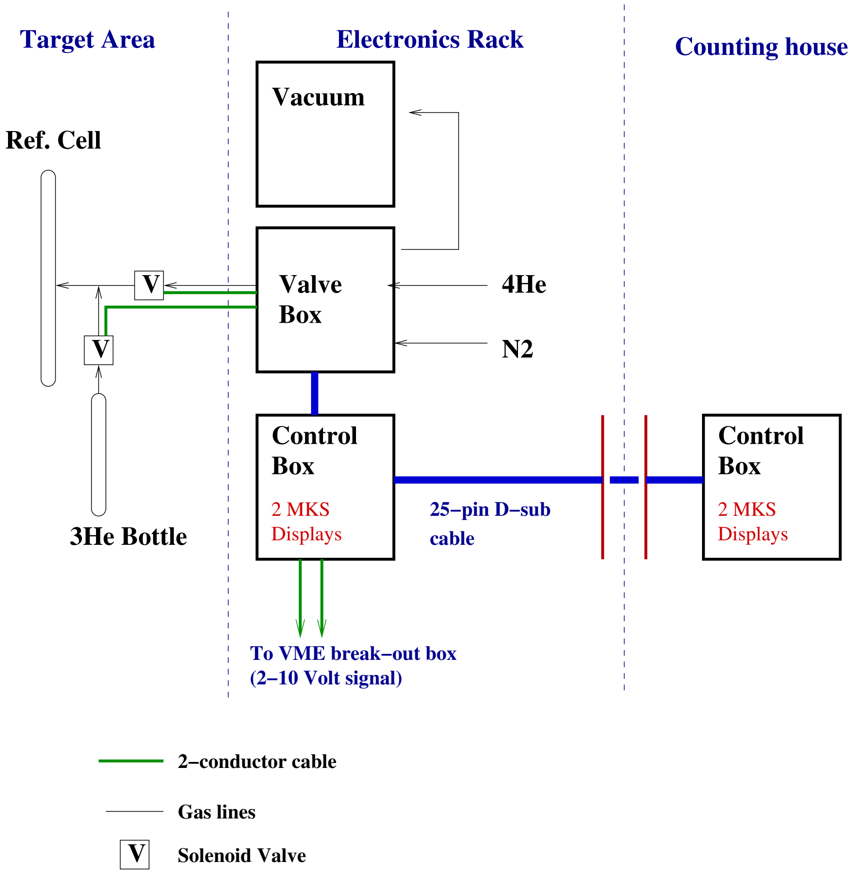

Figure 11.1: Schematic of reference cell system

Condition	Action	Valves activated (open)
C1	**Evacuate**	V1+V4+V5+V6
C2	**Vent**	V4+V5+V6+V7
C3	**^{3}He fill**	V3+V4+V6
C4	**N_2 fill**	V2+V4+V6
C5	**^{4}He fill**	V2+V4+V6+V8

Table 11.1: Action of the remote-control switch panel

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 N_2 or ^{4}He, and fill with ^{3}He. The selection between N_2 and ^{4}He is done by a special directional solenoid valve (**V8**).

The reference cell control panel (shown in Fig. 11.3) 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 11.1.

11.2 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.
  - 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 ^{4}He
  - Step 1: Vent to 16 psia.
  - Step 2: Evacuate until vacuum reaches < 10 mtorr.
  - Step 4: Hold the ^{4}He button down while checking the high-pressure gauge, until the desired pressure is established.
  - Repeat steps 2, and 3 three times.

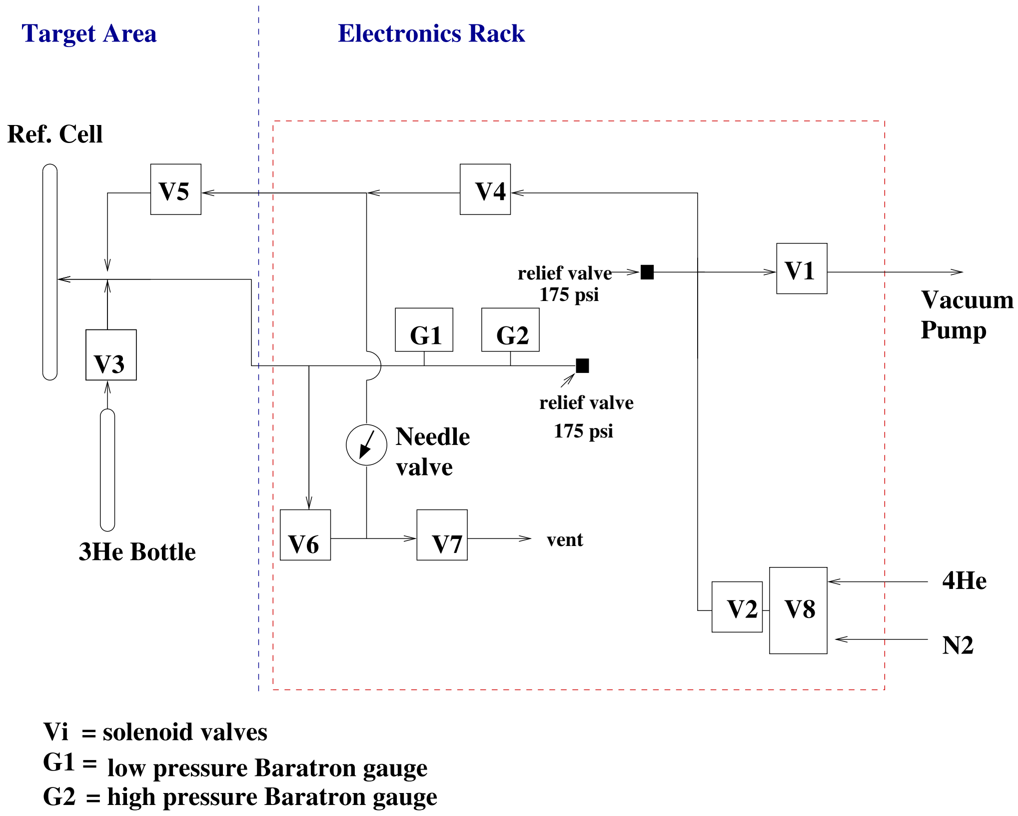

Figure 11.2: Valve configuration of the reference cell gas system

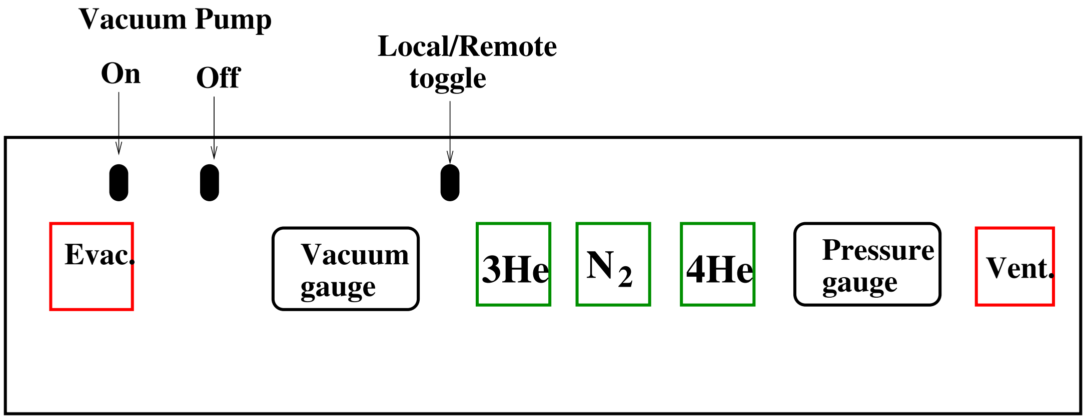

Figure 11.3: Control panel

- 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.

11.3 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.

11.4 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 RF enclosure is designed to contain all the debris in case of a cell explosion.

11.5 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 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, long sleeve shirt and long pants should 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.

Chapter 12

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 a laser light exposure;
- 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;
- Irradiation of the target 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 the target OSP.

Chapter 13

Laser Safety

13.1 Laser Safety

1. Always have your safety goggle on when the laser is on!
2. When the yellow beacon is flashing, have goggle 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 goggle 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.

13.2 Fire Hazards and Safety

The fire and safety in the laser hut is covered in the LOSP for the laser hut area, 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 should 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.

13.3 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 and qualified for laser beam alignment 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 only during the night time and weekend. Clear warning signs will be posted at the entrance 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. 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. 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.

Appendix A

Laser Standard Operation Procedure

A.1 Introduction

A polarized ^{3}He target system was built and used for JLab experiments E94-010 and E95-001. Several approved experiments will use the polarized ^{3}He target system this summer and in the future. The polarized ^{3}He target is based on the principle of spin exchange between optically pumped Rubidium vapor and ^{3}He gas. Several high power (30 Watts) 795 nm diode lasers will be used for the optical pumping. A laser hut has been built and installed in Hall A. This LSOP describes the setup of the laser system in the laser hut 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.

A.2 Personnel

The 30 watts infrared diode lasers (Coherent FAP-System and OPC-D030-795-HBPS) may only be operated by personnel who have :

- completed a Laser Safety course administrated by the laser safety officers at Jefferson Laboratory (Patty Hunt).
- 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.

A.3 Laser

The main Laser specifications are outlined in Table 1. For more specific information, we refer to the Coherent FAP-system and OPTO POWER CORPORATION models OPC-D030-795-HBPS diode laser users manual, which will be available in the lab.

A.4 Optical setup

The optical setup is shown in figure 1, and is made of:

- A optical table (stainless steel) supporting one breadboard (anodized aluminum);
- Seven infra-red diode lasers (four for longitudinal pumping and three for transverse pumping) located on one side of the table, with optical fiber bundles.
- Seven lens to have each laser beam focused at the pumping cell;
- Seven beam splitters to split each laser beam to two beams;
- Fourteen $\lambda/4$ waveplates to transform each beam from linear polarization to right or left circular polarization;
- Fourteen dielectric mirrors to reflect each split beam back into the pumping cell;
- One transparent window on the RF enclosure and one transparent window on the oven to allow the combined transverse laser beam to pass through;
- Two dielectric mirrors to reflect the combined longitudinal laser beam into the pumping cell;
- One pumping cell to absorb all the laser beam power;
- Three mirrors for monitoring the pumping cell;

Specifications	**COHERENT FAP-System**
Operational Specifications	
Output power	30 W
Mechanical Specifications	
Weight	60 pounds
Cooling Requirements	None required
Delivery Optical Fiber Bundle	0.8 mm diameter
Delivery Fiber Length	5.0 meter nom.
Delivery Fiber Termination	SMA 905 conn.
Operational Specifications	
Typical Operating Temperature	0°C to 35°C
Typical Storage Temperature	−20°C to 65°C
Humidity (non-condensing)	5% to 95%
Electrical Specifications	
Input Power	115 Vac 60 Hz, < 1200 W (500 W typical)
Optical Specifications	
Beam Characteristic	Semiconductor, multimode
Beam Divergence	< 0.20 N. A.
Diode Laser Center Wavelength	780 to 840 nm
Wavelength Temp Coefficient	0.27 to 0.30 nm/°C
Emission Bandwidth (FWHM)	±2 nm

Table A.1: Laser specifications

Specifications	**OPC-D030-795-HBPS**
Operational Specifications	
Output power	30 W, minimum
Mechanical Specifications	
Weight	17 pounds
Cooling Requirements	None required
Delivery Optical Fiber Bundle	1.5 mm diameter
Delivery Fiber Length	1.0 meter nom.
Delivery Fiber Termination	SMA 905 conn.
Operational Specifications	
Typical Operating Temperature	15°C to 35°C
Typical Storage Temperature	-30°C to 80°C
Humidity (non-condensing)	5% to 95%
Electrical Specifications	
Input Power	115 Vac 60 Hz, 6A ($<$ 300 W)
Optical Specifications	
Beam Characteristic	Semiconductor, multimode
Beam Divergence ($1/e^2$)	12° cone
Diode Laser Center Wavelength	795 to 980 nm
Center Wavelength Tolerance	±5 nm
Center Wavelength User Adjustable	±3 nm
Wavelength Temp Coefficient	0.27 to 0.30 nm/°C
Emission Bandwidth (FWHM)	$<$ 3 nm

Table A.2: Laser specifications

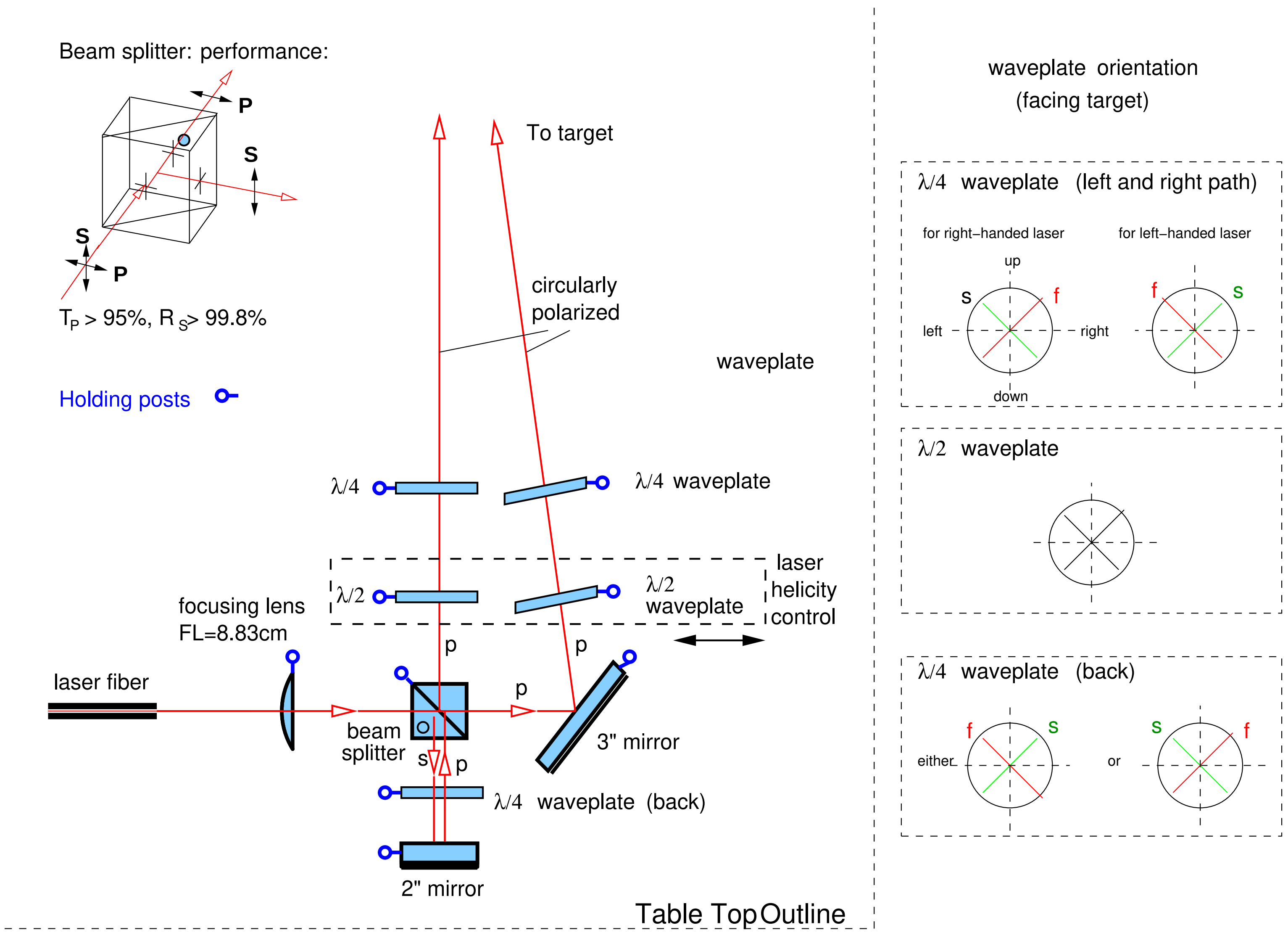

Figure A.1: Optical Setup in the Laser Hut

- One spectral-analyzer for monitoring the pumping cell.

The optical table will be about 2 meters from the platform. The laser beams will be from about 15 cm to 105 cm above the table Each of the 795 nm diode laser light, after passing through the lens, 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 vapor and ^{3}He gas. The laser beams will be completely absorbed by the pumping cell. The total path length from the lasers 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 two 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.

A.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 $795nm$ 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.

A.6 Laser environment

The diode lasers and the associated devices will be located in the polarized ^{3}He target laser hut in Hall A. The entire hut is a laser controlled area. Its organization is shown in figure 2. The setup will be on the second floor and the direct laser light will not be visible from the entrance of the room.

The laser beams are horizontal and are pointing away from the entrance door. After passing through the optical setup, the laser beams are directed into the pumping cell and terminated there.

Outside the laser hut, the laser beam path is completely enclosed with beam pipe between the laser hut and the target pivot and an enclosure on top of the the target. Since the beam path is not enclosed inside the laser hut, any partially reflective surface may

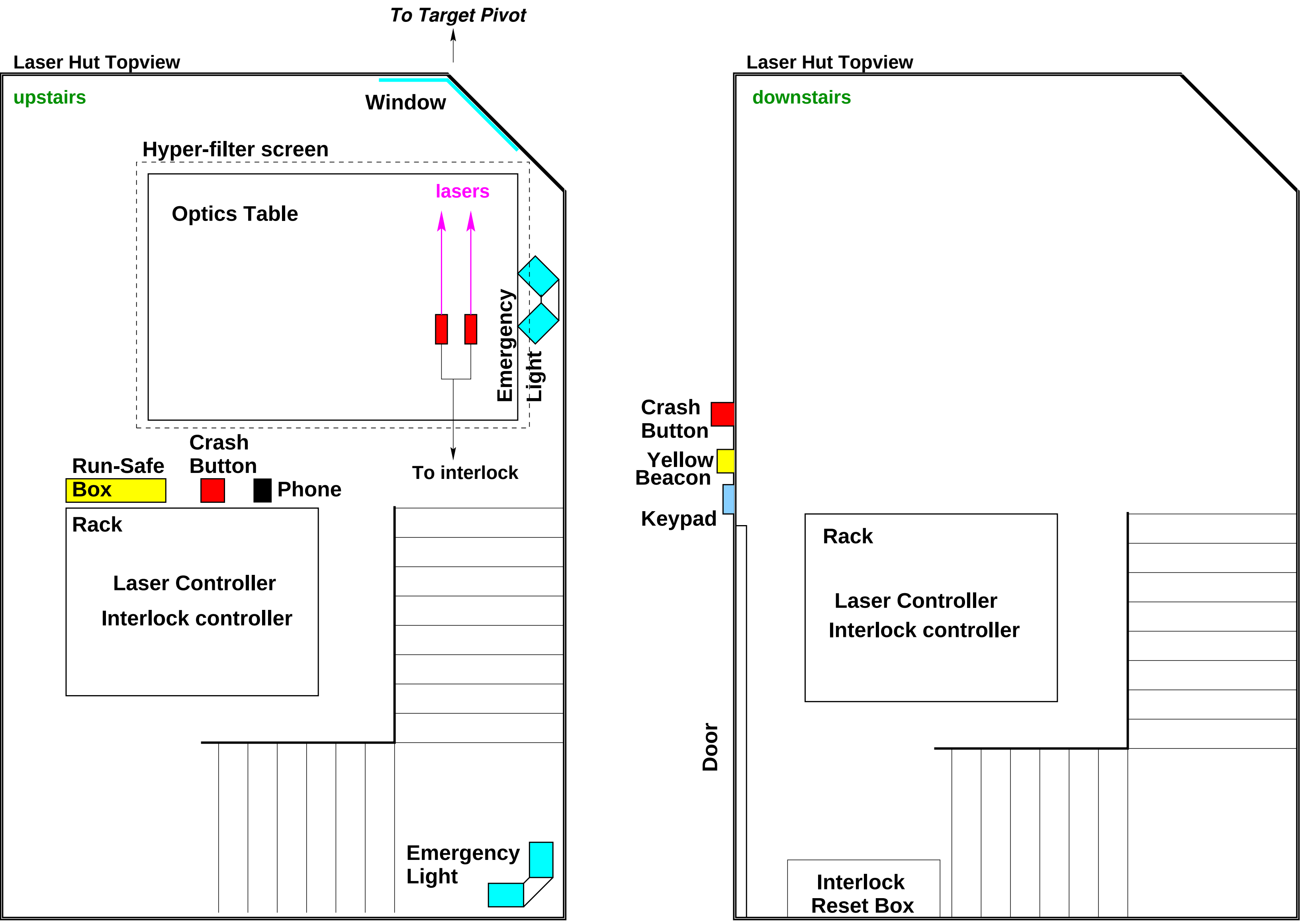

Figure A.2: The Polarized ^{3}He Target Laser Hut Setup cause deflection of the beam path. When operating the diode laser, safety goggles are required at all times.

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 should not be brought into the laser area.

A.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.

A.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 hut 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.

A.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). The final alignment will be done with the diode laser. 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.

A.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 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 and the out of order devices will be fixed by Coherent or Opto Power service personnel. The Laser power can simply be unplugged.

A.7.4 Off-normal and emergency procedure

In case of an emergency, power to the laser should 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 should 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 should immediately contact the Jefferson Lab medical center (Mary Gibson, phone: 7539, page: 875-3363). 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: 872-5736) and/or laser safety officer (Patty Hunt, phone: 7039, page: 820-8254).

A.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 hut 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 hut to inform personnel about the hazards associated with the setup and the proper procedures.

A.9 Maximum permissible exposure

The Coherent FAP-System and the Opto Power OPC-D030-795-HBPS infra-red diode lasers emit nominal continuous beams of 30 W at a wavelength of $795nm$. With a limiting aperture size of $0.385cm^2$ ($7mm$ pupil size), this gives an irradiance at the eye of $39W/cm^2$. With one 30 W laser, the maximum irradiance at the eye is $78W/cm^2$ As this wavelength is not visible, no blink reflex can occur, and we thus assume a 10 second exposure time. With a correction factor of $CA = 1.55$ the calculated MPE is $1.57mW/cm^2$.

The required filter transmittance is thus 0.000020 , which gives a minimum Optical Density of 4.7. We chose to use safety goggles of Optical density 5, for the wavelength of $795nm$.

A.10 List of authorized personnel

The following personnel are authorized to operate the Coherent FAP-system and OPC-D030-795-HBPS diode lasers and the associated polarized ^{3}He target facility, under the assumptions, they have completed the training requirements defined in Section 1:

Vincent Breton	William and Mary
Gordon Cates	University of Virginia
Jian-Ping Chen	Jefferson Lab (Laser system Supervisor)
Alexandre Deur	Jefferson Lab
Gary Dezern	Jefferson Lab
Ed Folts	Jefferson Lab
Haiyan Gao	MIT
Ole Hansen	Jefferson Lab
Wolfgang Korsch	University of Kentucky
Kevin Kramer	William and Mary
Nilanga Liyanage	Jefferson Lab
Zein-Eddine Meziani	Temple University
Karl Slifer	Temple University
Scot Spiegel	Jefferson Lab
Mark Stevens	Jefferson Lab
Xiaochao Zheng	MIT
Xiaofeng Zhu	William and Mary

Names can be added to this list by the Laser System Supervisor, Jian-ping Chen, phone 269-7413, pager 872-5736, email jpchen@jlab.org.

Appendix B

List of Authorized Personnel

B.1 List of Laser Trained Personnel

See the list at the end of Appendix A.

B.2 List of Authorized Polarized ^{3}He Target Operators

Todd Averett	William and Mary
Vincent Breton	William and Mary
Gordon Cates	Princeton University
Jian-ping Chen	Jefferson Lab (Laser system Supervisor)
Alexandre Deur	Jefferson Lab
Haiyan Gao	MIT
Ole Hansen	Jefferson Lab
Wolfgang Korsch	University of Kentucky
Kevin Kramer	William and Mary
Nilanga Liyanage	Jefferson Lab
Kathy McCormick	Kent State University
Zein-eddine Meziani	Temple University
Karl Slifer	Temple University
Xiaochao Zheng	MIT
Xiaofeng Zhu	William and Mary
Piotr Zolnierczuk	University of Kentucky

B.3 List of Authorized People to Change Target Cells

Jian-ping Chen	Jefferson Lab
Alexandre Deur	University of Virginia
Kevin Kramer	College of William and Mary
Nilanga Liyanage	Jefferson Lab
Karl Slifer	Temple University
Xiaochao Zheng	MIT
Xiaofeng Zhu	College of William and Mary

B.4 List of Authorized People to Perform Laser Alignment

Jian-ping Chen	Jefferson Lab
Kevin Kramer	College of William and Mary
Wolfgang Korsch	University of Kentucky
Xiaochao Zheng	MIT
Xiaofeng Zhu	College of William and Mary

Names can be added to the above lists after proper training and authorized by Jian-ping Chen, pager 872-5736, phone 7413 and email:jpchen@jlab.org.