Report on Raytum Photonics 200 W Laser Tests

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1 Introduction

We have tested a Raytum prototype 200 W laser at Jefferson Lab and William & Mary. The laser is designed for optical pumping of a high-density Rb vapor used to polarized the nucleus of the ^{3}He atom for studies of the structure of the neutron at Jefferson Lab. It contains four 50 W modules operated in parallel to produce up to 200 W and includes a spectrometer feedback system to stabilize the wavelength. The laser is CW with a typical line width of ≤ 0.2 nm.

The intrinsic properties of the laser were first measured at Jefferson Lab including calibrating the input current to output power, analyzing the stability of the laser's output power, wavelength, and line width during operation, and characterizing the beam intensity profile. Each of these parameters must meet the specifications necessary for optical pumping in the ^{3}He target system.

The second round of tests occurred at William & Mary to ascertain the efficacy of the laser in a polarized ^{3}He target system of the type used at Jefferson Lab.

2 Laser Characterization at Jefferson Lab

2.1 Setup & Testing

The beam divergence from the end of the fiber was such that a collimating lens was necessary in order to adjust the beam size for the subsequent optics. Various lenses were then put into place in order to adjust the beam size throughout the setup. Due to the high output power of the laser, the setup for characterization had to include a reduction in the power such that a power meter could handle the wattage. Initially, the experimental setup was to include only power meter 2 (PM2), as seen in Figure 1, since it was capable of receiving the high output power of the laser system. When testing input current versus output power, PM2 was used directly at the fiber output (FO). It was found that 40 A would produce 100 W, with 54 A and 70.8 A producing 150 W and 200 W respectively. However once the test moved to the final setup of Figure 1, the meter failed to work, so a wedge was inserted to measure a relative power in the much smaller power meter 1 (PM1).

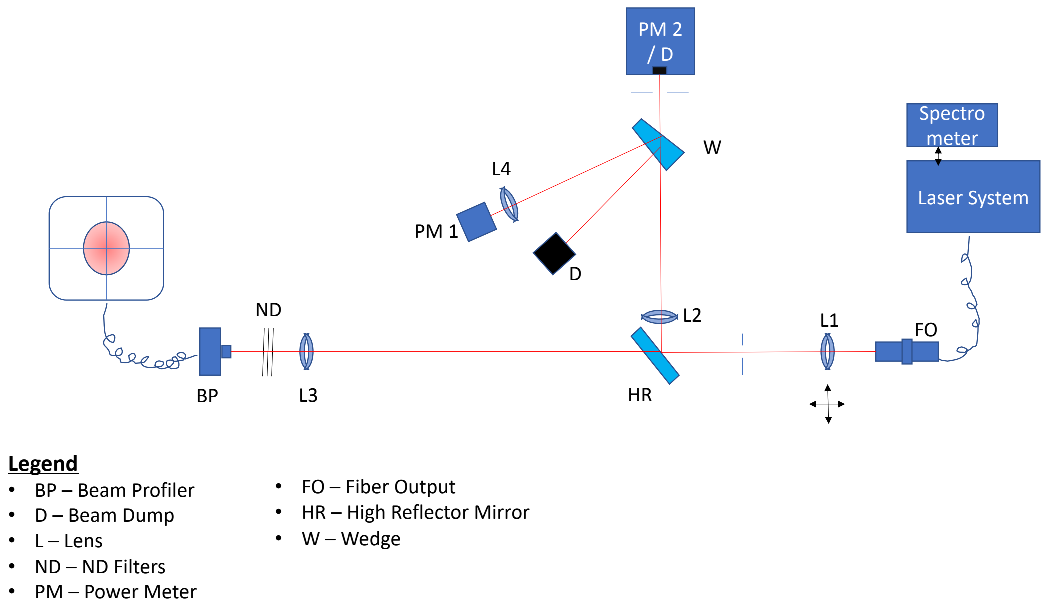

Figure 1: A schematic of the laser characterization setup.

Once the input current to output power relationship was measured, PM1 was cross-calibrated and was found to receive 3% of the total power. The remaining power was sent to a beam dump and PM2, now acting as a beam dump.

To measure the intensity profile of the beam, multiple ND filters were inserted to block all but of a few mW for compatibility with the beam profiler. The images in Figure 2 show a stable profile independent of power as well as shape stability over time.

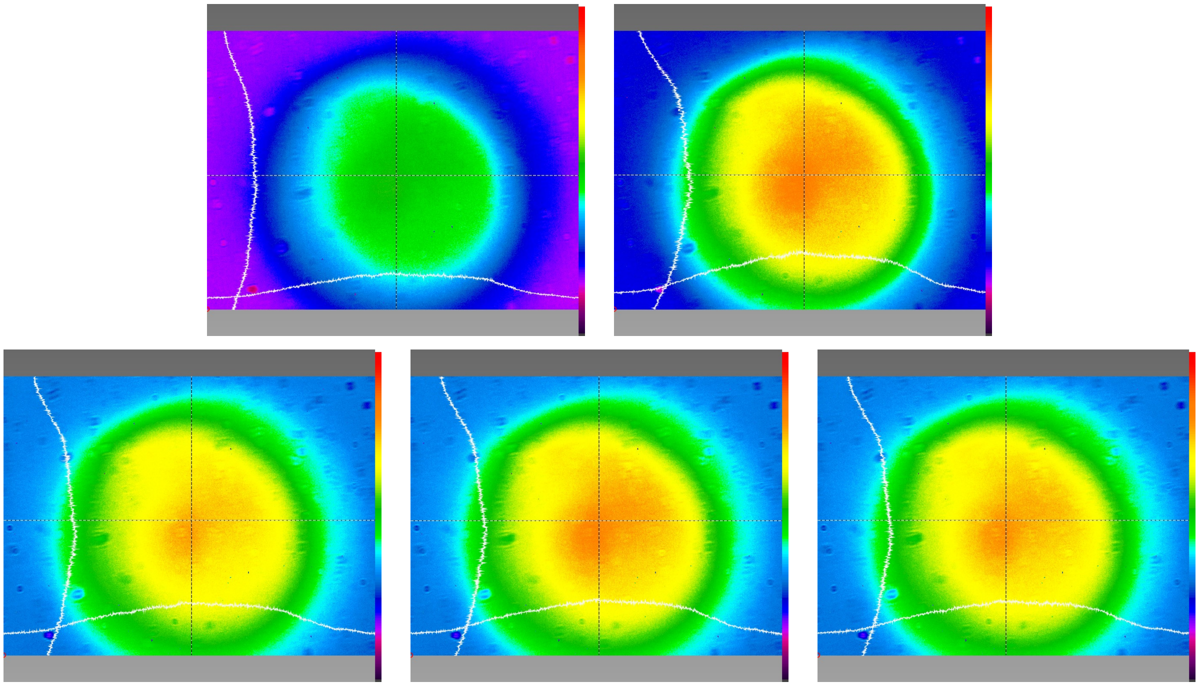

Figure 2: Top left: 40 A (100 W) Beam Profile. Top right: 54 A (150 W) Beam Profile. The bottom row features the 70.8 A (200 W) Beam Profile at various times throughout the test. Only beam shapes were observed. Intensities (the color scaling) were not measured in the initial test. The relative intensity as a function of position are shown by the white horizontal and vertical lines

Over the course of the tests, the three power outputs observed were 100 W, 150 W, and 200 W. Power meter 1 was used to record the stability of the power versus time. Results are shown in Figure 3. The power was relatively stable though slowly decreasing during the 200 W test. This could possibility be due to instability in the temperature or current control or due to the wavelength stabilization system over time. The spikes observed were due to manual corrections to the input current in order to achieve the desired output power.

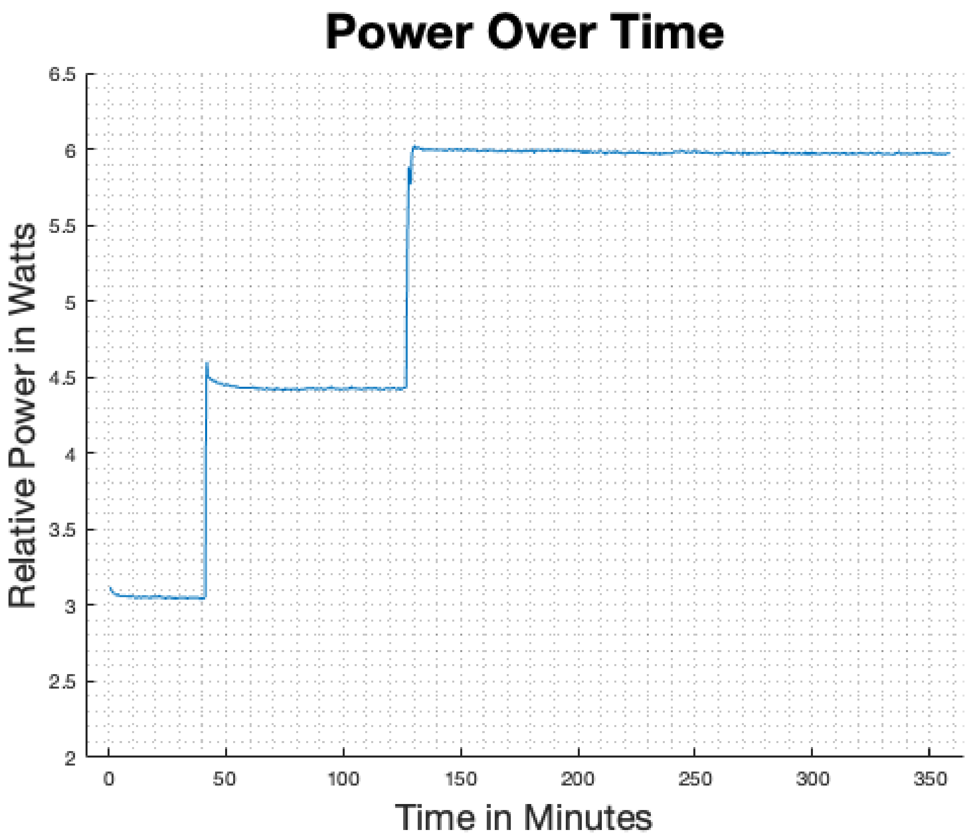

Figure 3: Relative laser power over time.

We then checked each of the internal modules' ability to achieve and sustain a desired wavelength. Figure 4 shows each of the modules' wavelength as read by the on-board spectrometer, and how it varied over the characterization time.

Each of the four modules performed as advertised, adjusting their wavelengths relative to one another as well as themselves, in order to achieve an overall output wavelength of approximately $\lambda = 794.7$ nm.

The next aspect of the beam we wished to examine was the linewidth achieved. The linewidth values were taken from the onboard spectrometer's data and evaluated. We have concentrated on the 40 A and 70.8 A input currents' linewidth values which correspond to 100 W and 200 W respectively.

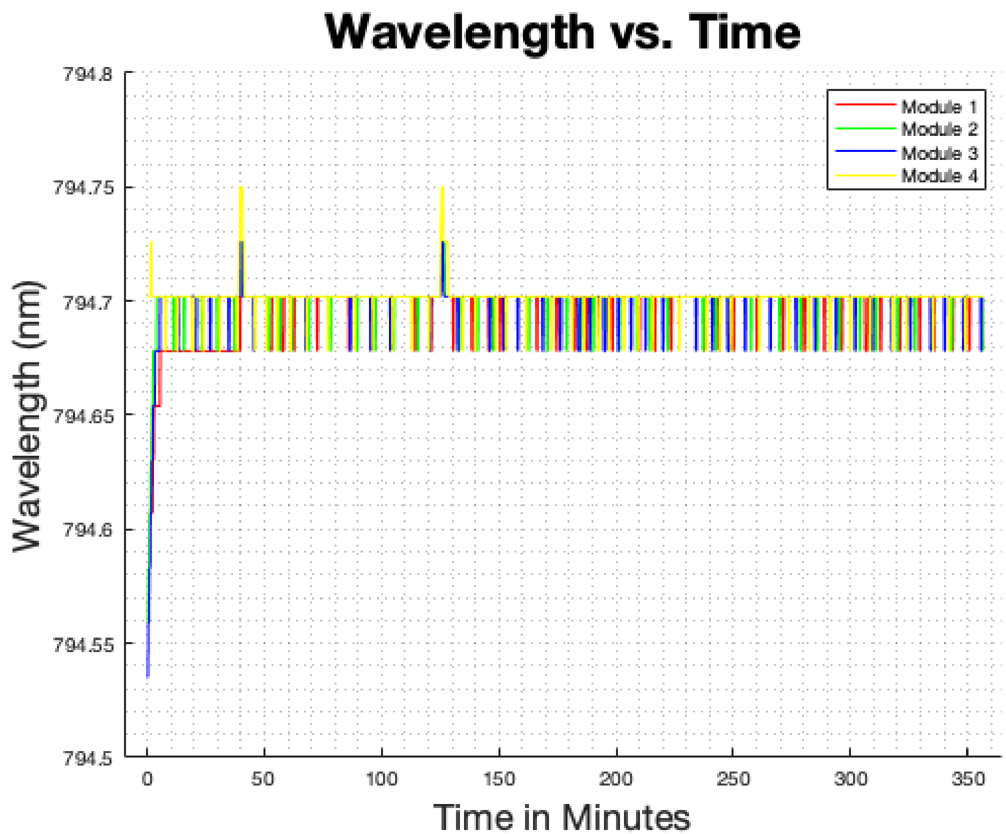

Figure 4: The measured wavelength in nanometers for each of the four modules versus time.

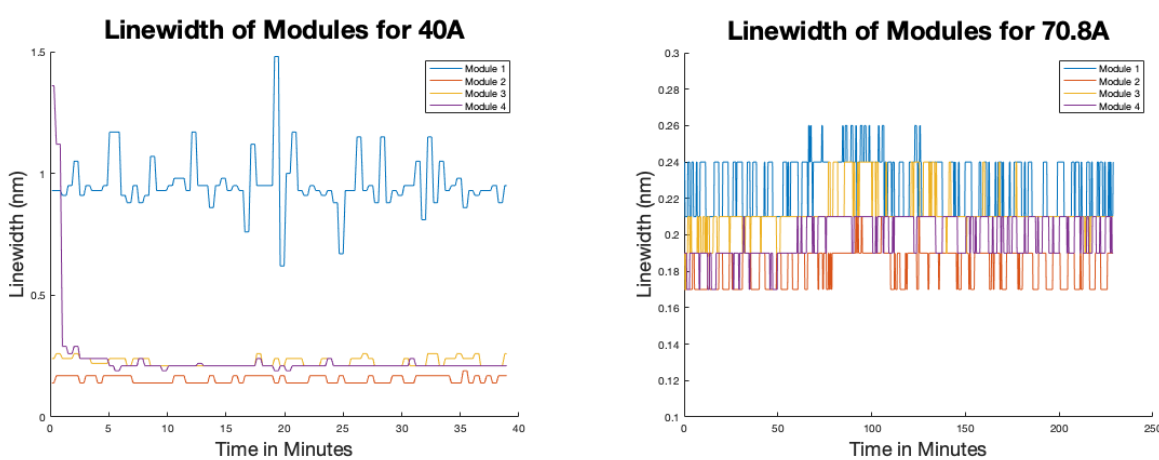

Figure 5: Linewidth values for the time at 100 W (left) and 200 W (right). One of the modules during the lower power output duration never achieved the proper linewidth value. The ability to lock at lower values was improved based on this test.

As seen in the 40 A plot in Figure 5, one of the modules never achieved the desired line width that the other components achieved. As time went on and the power output was adjusted, this resolved itself as seen through the plot at the 70.8 A value. Once the input current was changed to 54 A the higher value for this components' linewidth returned to the values achieved by the other modules. From these measurements we learned that the modules have a harder time locking and obtaining small linewidths at lower current. After improvements by RAYTUM this is no longer an issue at the power levels needed for our research. The linewidths of the remaining three modules were stable at 100 W and 200 W at the desired value of ~ 0.2 nm.

Next we measured the average wavelength and linewidth for the laser system as a whole. Again note that the initially large linewidth of module 1 affects the average calculated by the onboard spectrometer during the first 40 minutes. The plots of the average wavelength and average linewidth versus time are shown in Figure 6. The spikes in the average wavelength plot are due to the manual changes of the input current.

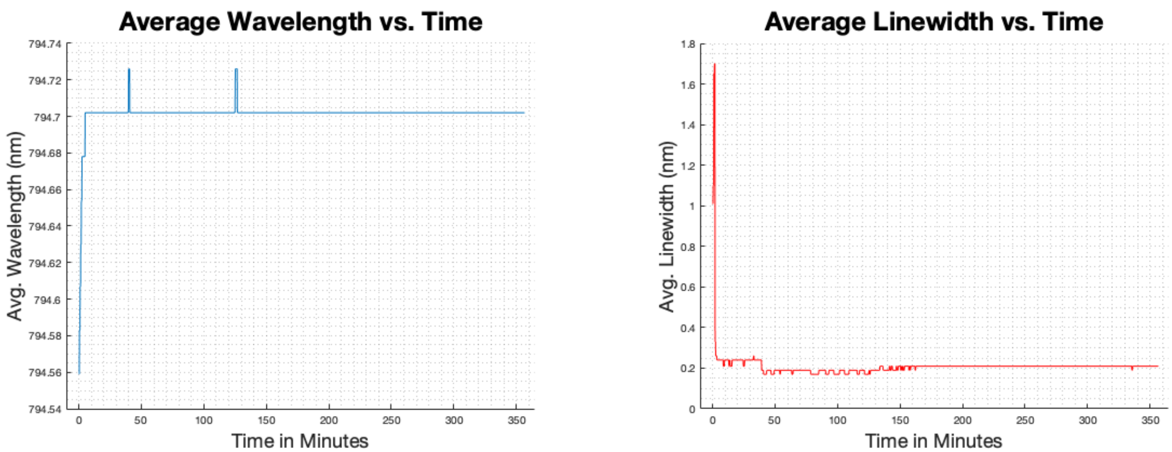

Figure 6: Plots of the onboard spectrometer's reading of the average wavelength (left) and average linewidth (right).

2.2 Summary

- The laser system's power was stable above 99.6% for the hours tested.
- The individual and average wavelengths were stable to 99.3%.
- Average wavelength values computed by the internal spectrometer took 5 minutes to reach the set value of 794.7 nm.
- The linewidth average for the four was 0.21 nm during the 54 A and 70.8 A time periods was stable to 99.1%.

3 Studies of the Laser System for Polarized ^{3}He

3.1 Motivation

The typical need for successful optical pumping requires up to four 35-50 W lasers incident on a glass target cell, see Figure 7 from only one direction. The optics required for multiple lasers is difficult to align and expensive to outfit. In addition, the large cell volume and large alkali vapor density make it difficult for the laser light to penetrate the alkali. The next polarized ^{3}He experiment at Jefferson Lab will see an doubling in the volume of the cells to 6 STP liters while the alkali density remains the same. This increase requires us to pump from both sides of the cell in order to penetrate the thick alkali inside.

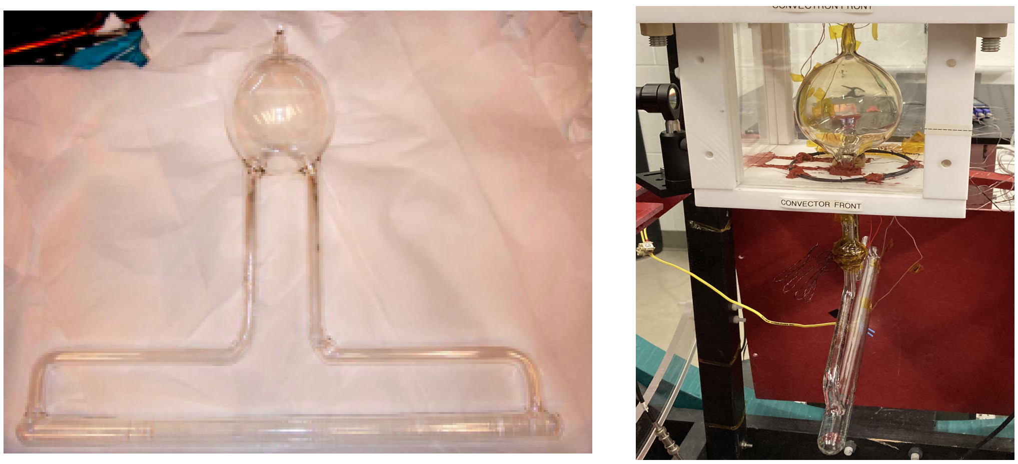

Figure 7: This figure shows cells with similar geometry to cells used at Jefferson Lab. The image on the right shows the cell mounted in the oven at William & Mary ready for polarization tests. Optical pumping takes place in the upper spherical chamber where the alkali is heated to produce a thick vapor. The other cell tested (not shown) consists of only the spherical chamber.

In an effort to simplify the optics for double-sided high power pumping, we would like to use a single laser source. This is the first area in which the single 200 W laser excels. By having only one optical setup, we can minimize both the costs and losses associated with many pieces of specialized optics. It also makes the alignment and optical polarization control much simpler which is essential to maximizing target performance.

Having a single laser and one set of optics reduces the cost per watt by approximately 50% which is certainly important as the cell size grows and requires more power. Finally, the current laser system at Jefferson Lab requires approximately 6 very long (100 ft) and expensive cladded optical fibers to transport the light to the target. The 200 W system will need only one fiber plus a spare, again significantly reducing the cost associated with running these experiments.

One final benefit afforded through the 200 W laser is the wavelength locking and adjustability provided by the on-board spectrometer. This allows for real time feedback of the output wavelength which must remain locked to the atomic transition level for the alkali. Again, having an on-board spectrometer that locks to wavelength allows for less cost in external equipment and the need to manually tune the wavelength.

3.2 William & Mary Lab Experimental Procedure

We assembled a new laser and optics system at W&M using Averett's polarized target laboratory. In addition to developing a system using this laser we were able to monitor the power, wavelength and line width stability for many months and were found to maintain the stability observed at Jefferson Lab in the initial tests. Tests were done using two of the modules (100 W total) or all four (200 W total) with no difference in performance.

We next turned our attention to polarizing two different cells, one spherical and one convection-type similar to the design of the Jefferson Lab cells, both with similar ^{3}He density. The geometry of the convection cells can be seen in the Figure 7.

We began by circularly polarizing and sending the light to the front of the target. We ran polarization studies for this single side pumping and then changed the setup to pump from both sides. Figure 8 shows a schematic of our two sided pumping experiment:

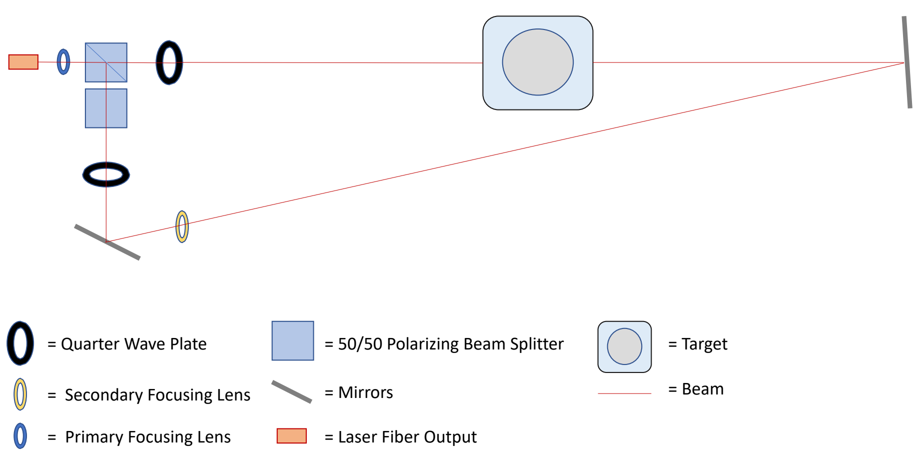

Figure 8: This is the setup for 2-sided pumping. The beam size is focused such that it slowly diverges to the same diameter as the cell once it reaches the target. The figure is not to scale.

As the beam exited the fiber, we collimated the spot size to a one inch diameter (primary focusing lens on a translation table) onto a polarizing beam splitter cube. The transmitted intensity was then sent through a quarter wave plate (QWP) to achieve circular polarization before the beam spot size diverged to the diameter of the target cell. The reflected intensity was sent through a rotated beamsplitter cube producing approximately the same intensity as the transmitted beam. The beam then passed through a QWP and then reflected from a mirror and through a secondary focusing lens which allowed us to set the beam divergence to match the cell diameter as it entered the oven from the back. The beam was then reflected by a 4 inch mirror and onto the target, allowing us to pump from both sides. Note that we were able to pump from two directions with a total of 200 W of laser power with a single set of optics. None of these things has been previously achieved and truly represents the state-of-the-art for next-generation experiment with polarized ^{3}He.

We found, in both cell geometries, slight improvement in the polarization for two-sided pumping versus single side pumping. We did not expect to improve the polarization dramatically since the alkali was already close to its maximum polarization during single side pumping. But for the next generation cells using a pumping chamber with twice the volume of alkali vapor this two-sided pumping is essential.

3.3 Summary and Moving Forward

This laser system is truly a next generation device with the potential to make a measurable improvement in polarized target performance at a lower cost compared to existing technology. Further simplification and savings will be realized through the much simpler fiber and optics systems required. Finally, the wavelength locking is a new and highly desired feature we have long wished for.

The next step in testing the 200 W laser is to run the same tests on multiple cells with a volume of 6 STP liters. These cells require the large laser power and two-sided pumping possible with this new laser. Tests will be conducted at William & Mary, the University of Virginia and Jefferson Lab to polarize both spherical and Jefferson Lab convection style cells. Tests will be conducted using this 200 W system as well as multiple 50 W systems, investigating one- and two-sided pumping.