Laser Beam Profiling and Crystallographic Analysis

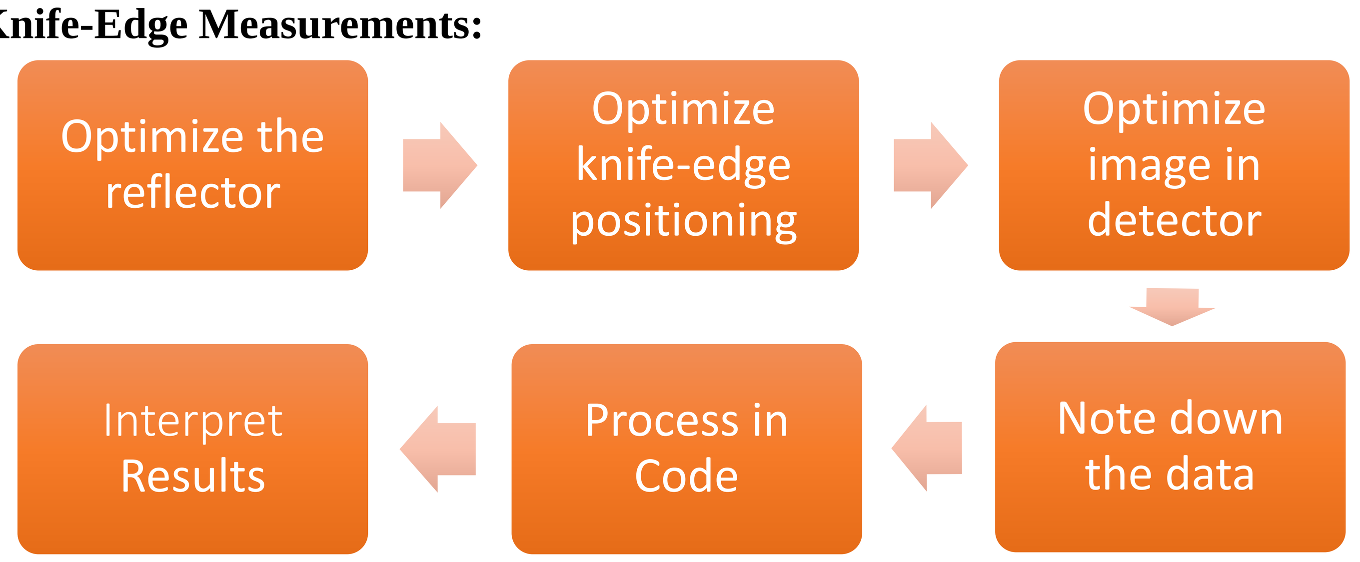
Tim Kaltenberger, Jacob McDowell, Karissa Carlson, Eric Jones, Emily Grace
PHOEBE Laser Research Group, Physics Department, Northwestern College

Abstract

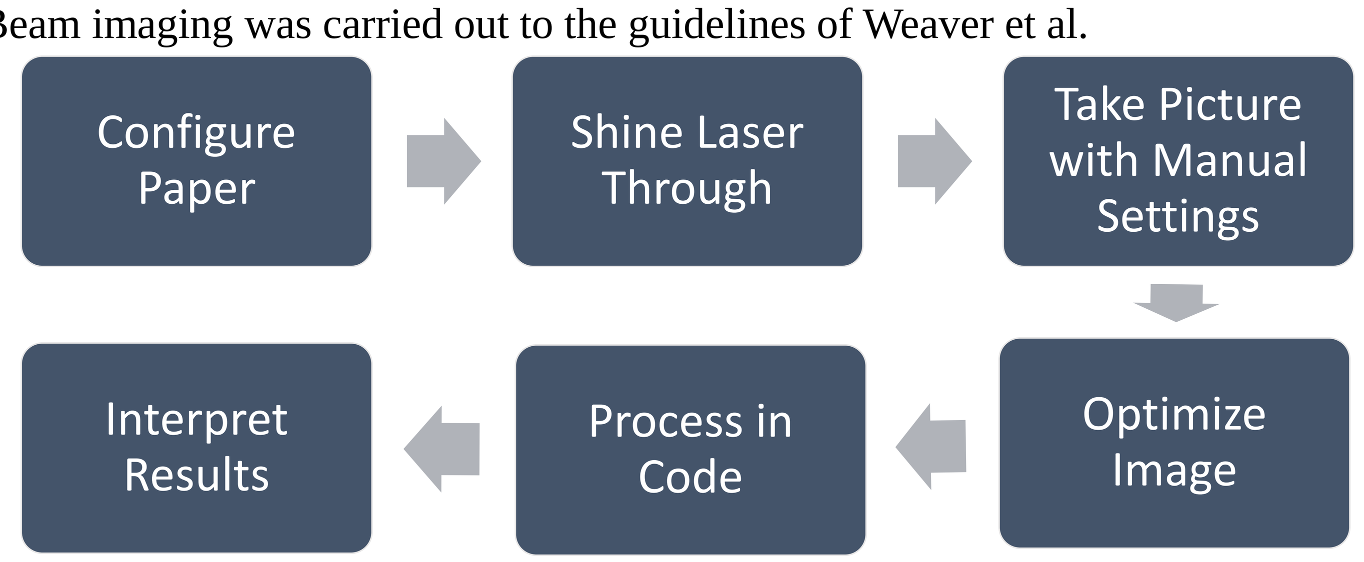
Lasers and x-rays are widely used in the modern world for studying biomolecules. For the purposes of the physics department, future research requires certainty that lasers have Gaussian profiles, though the lasers used often deviate from this ideal. In this project, we investigate methods to measure and analyze laser beam profiles. We first reviewed the theory of Gaussian beams and their properties. We then measured our laser's profile using two techniques: a knife-edge method and a cell phone photography method. The first involved moving a razor edge across the beam to measure transmitted light, while the second involved visualizing the profile through photographs. The second part of the project involved x-ray crystallography, a powerful technique for determining the three-dimensional structure of molecules. Crystallography analysis involves growing crystals of the molecule of interest and exposing them to x-rays. By analyzing the diffraction pattern, it is possible to reconstruct the molecule's electron density and determine its precise atomic coordinates. However, crystallography analysis can be challenging due to the data processing and modeling required to interpret the diffraction data. We compared open-source crystallography software and practiced data analysis using publicly available sample diffraction patterns. In summary, we investigated methods to measure and analyze laser beam profiles, including hands-on techniques and imaging. We also discussed x-ray crystallography, a key technique in studying molecular structures. Our work provides the foundation for future optics and crystallography projects.

Methods & References

Knife-Edge Measurements:



Beam Image Measurements:
Beam imaging was carried out to the guidelines of Weaver et al.



Weaver, T. M.; Cortez, L. M.; Khoang, T. H.; Washington, M. T.; Agarwal, P. K.; Freudenthal, B. D. Visualizing Rev1 catalyze protein-template DNA synthesis. *Proc. Natl. Acad. Sci. U.S.A.* **2020**, *117, 25494– 25504*, DOI: 10.1073/pnas.2010484117.

Mgpullen, •. (2016, August 26). [python] lasers and non-linear regression – part 2. Data and Science. Retrieved March 24, 2023, from https://mgpullen.wordpress.com/2016/08/26/python-lasers-and-non-linear-regression-part-2/

Expectations and Results

Coding:
Many improvements were made to the Jupyter Notebook Gaussian image analysis code, particularly in the areas of importing files, analyzing both monochromatic and color images, calculating R-squared values for Gaussian fits, and creating 3D images of beam intensity.

Beam Photography:
As mentioned earlier, "ideal" beams have a characteristic bell-shaped intensity profile that can be modeled by a Gaussian curve. Note that HENE lasers (Helium-Neon) should produce Gaussian profiles because of a variety of reasons. First, the nature of the gain medium (the mixture of gases) favors an intensity profile highest in the center and dropping off toward the edges. Second, cavity mirrors used by HENE lasers are typically spherical, which do not modify intensity profiles to a significant extent (thereby not influencing the Gaussian-like nature of the profile). Finally, the lenses and apertures used by HENE lasers tend to preserve the profile rather than modify it. As such, the expected result for most typical HENE lasers (see Figure 2) is Gaussian, which can be observed in figures 1 and 3 - the intensity profile is concentrated in the center and drops off toward the edges.

Knife-Edge Profiling:
A knife-edge beam profile can also be modeled in a two-dimensional graph, with the razor position in millimeters as the x-axis and the laser intensity as the y-axis (in volts). As the razor is moved out of the path of the laser beam (Figure 6), the resulting graph is a Gaussian curve, as shown in Figure 7. This is consistent with the results of the beam photography profiling, which also showed a Gaussian beam profile. The HENE laser used in this experiment is designed to produce a Gaussian beam, and the results of both experiments support this. Therefore, the Gaussian fit of the knife-edge beam profiling data is a valid representation of the beam profile.

X-Ray Crystallography:
The crystallography portion of the project was potentially the most interesting and most challenging, as we did not have an "expected result" – the goal was to prepare for future data (like the reflection data of Figure 4) obtained by the physics department by exploring ways of analyzing crystallography software.

Figure 1

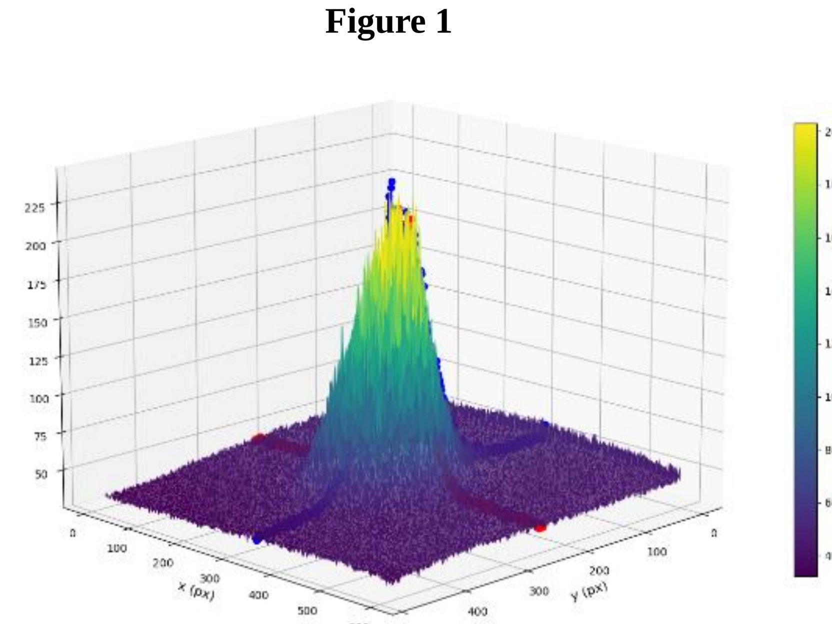


Figure 2

Figure 3

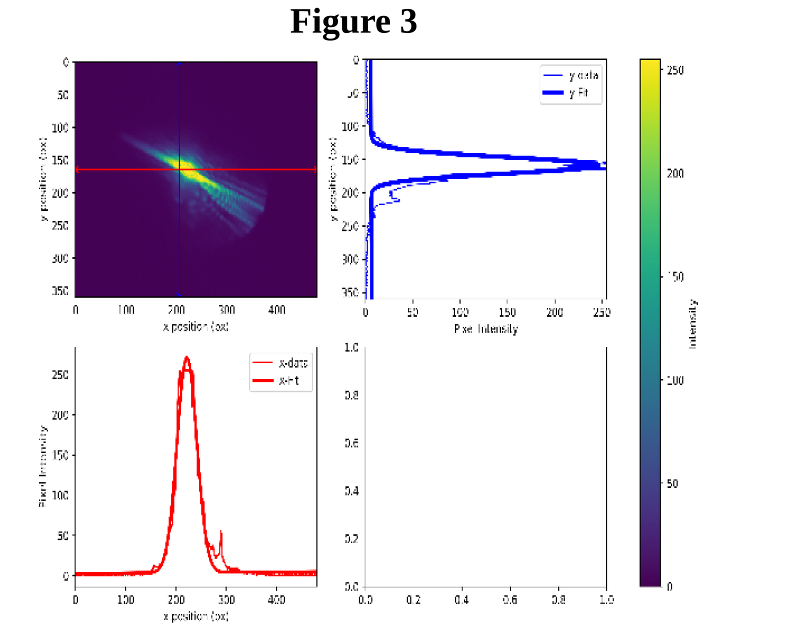
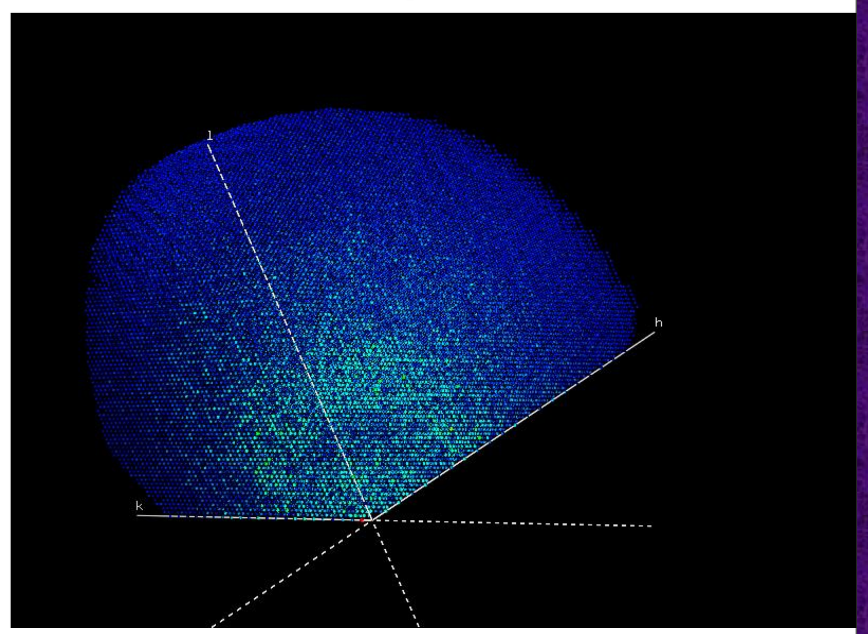


Figure 4



Results (cont.)

Figure 5

S	y1	x2	y2
1.27	2.24	1.21	2.15
1.14	2.24	1.07	2.15
1.016	2.22	0.94	2.12
0.889	2.15	0.82	2.05
0.76	2.08	0.7	1.97
0.63	1.8	0.58	1.7
0.127	1.37	0.07	1.15
0	0.98	0	0.91

Figure 6

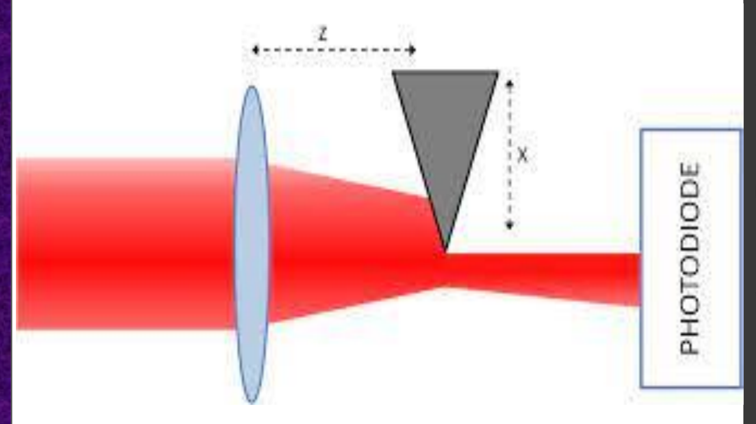
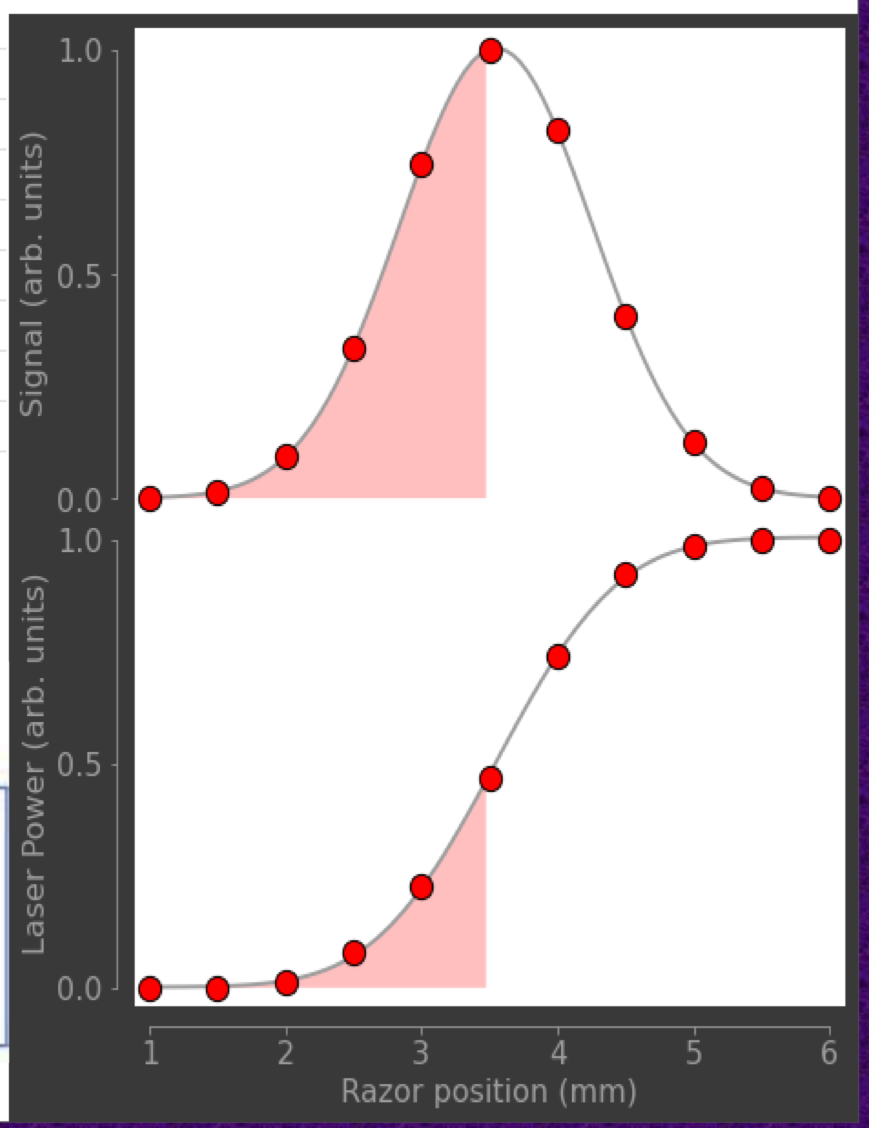


Figure 7



Discussion and Conclusions

In this project, we investigated how to profile lasers using knife-edge and photography techniques. We also analyzed the results and discussed the applications of X-ray crystallography and analysis in determining the molecular structures of various materials.

- The results of our experiments showed that both the knife-edge and photography methods are effective in profiling lasers. The knife-edge method produced a Gaussian beam profile, as expected. The cell-phone photography method also produced a Gaussian beam profile, but the results were not as accurate as the knife-edge method.
- The main complications were the ambiguity of the photograph angle and phone settings with respect to the accuracy of the photography method, the difficulty of applying code to knife-edge data, and the uncertainty of the desired X-ray crystallography results.
- X-ray crystallography analysis was challenging, but preliminary results were obtained. The Phenix software was explored and used with sample data sets to set up and prepare for future students' efforts.

In conclusion, we have successfully demonstrated how to profile lasers using knife-edge and photography techniques. We have also shown that we are able to use X-ray crystallography to study the structures of molecules.

Going forward, we could use a more accurate knife-edge profiling method, such as a laser interferometer. We could also use a more precise cell-phone photography method, such as a DSLR camera, and obtain access to a high-quality X-ray crystallography system for procuring crystallography data.