# Analysis of Gaussian Beam Distribution Qualities of a Helium-Neon Laser


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## Abstract

The properties of laser light naturally change as it propagates over any path. Our work intends to verify that the propagation happens in accordance with what is expected for a Gaussian beam, and to make precise measurements of the location, size, and curvature of the beam waist to show that there is indeed a location of smallest spot diameter over the course of the beam. Differential calculus predicts that the beam equation at the waist will have a first derivative equal to zero and a second derivative equal to some maximum curvature. We found that there is indeed a minimum spot radius of the beam, located approximately 14cm away from the aperture of the laser.


## Methods

To verify that the helium-neon laser propagates with Gaussian distribution and that a waist exists, we used a ThorLabs HNL020L 632.8nm Helium-Neon laser and measured its propagation with a Coherent Lasercam-HR camera after filtering the light with a red filter and an appropriate number of neutral density filters based on the propagation distance. The sensor was placed at varying distances from the laser, ranging from 10cm to 201cm. Accompanying measurements were taken at ±1cm from the central locations to provide enough data to calculate the first and second derivatives at that location

There are numerous "accepted" definitions of the beam radius, like $\frac{1}{2}$ and $\frac{1}{e^2}$ of its greatest value. Given the relative imprecision of our measurement techniques, we instead opted to look at a range of beam diameters, starting at $\frac{1}{10}$ of the max up to $\frac{9}{10}$ of the max. Using MATLAB, we processed the image files to find beam diameters and computed first and second derivatives of the beams' equations.

## Results

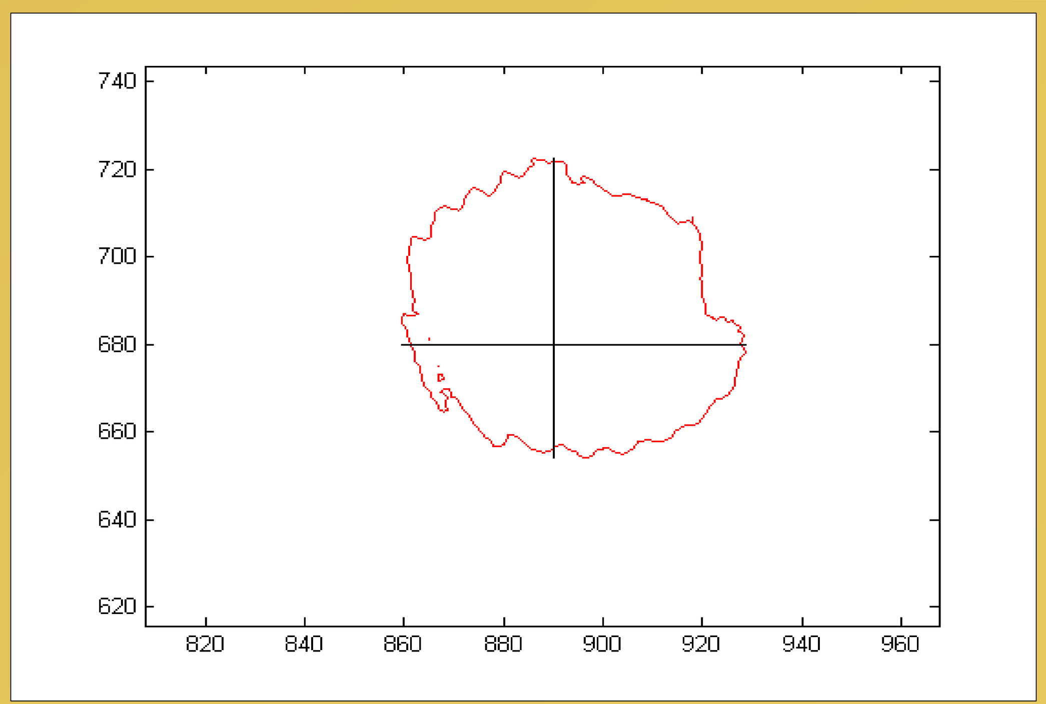



Figure 1: Sample contour of measurement at 14cm at 0.5*max level. The crossing lines connect the minimum and maximum x and y coordinates.

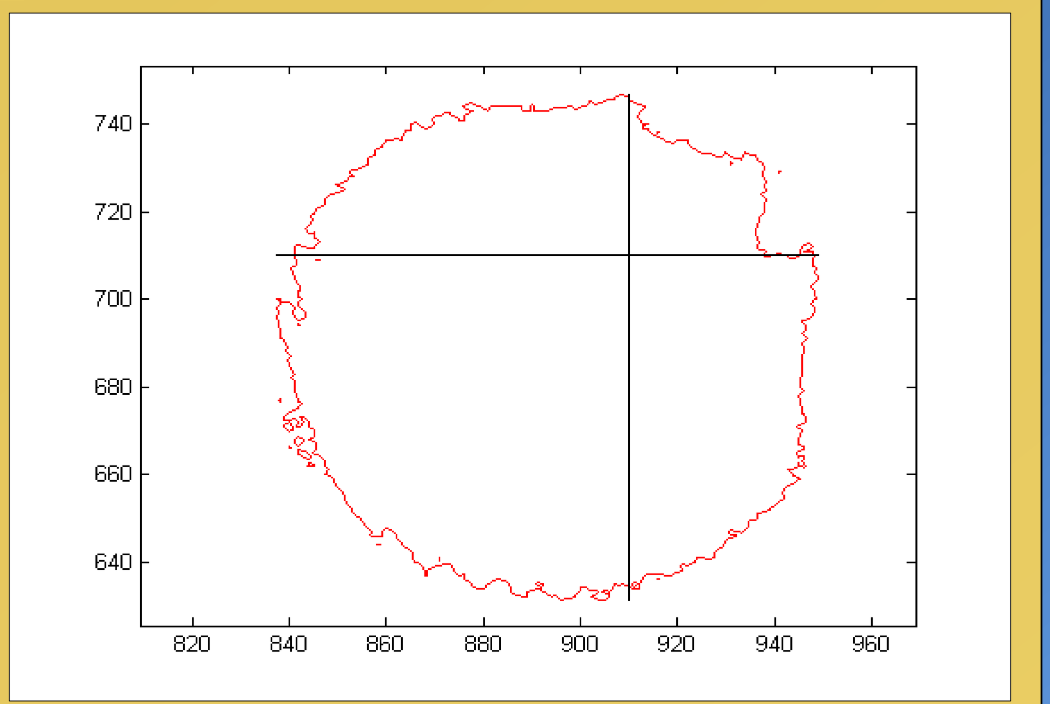
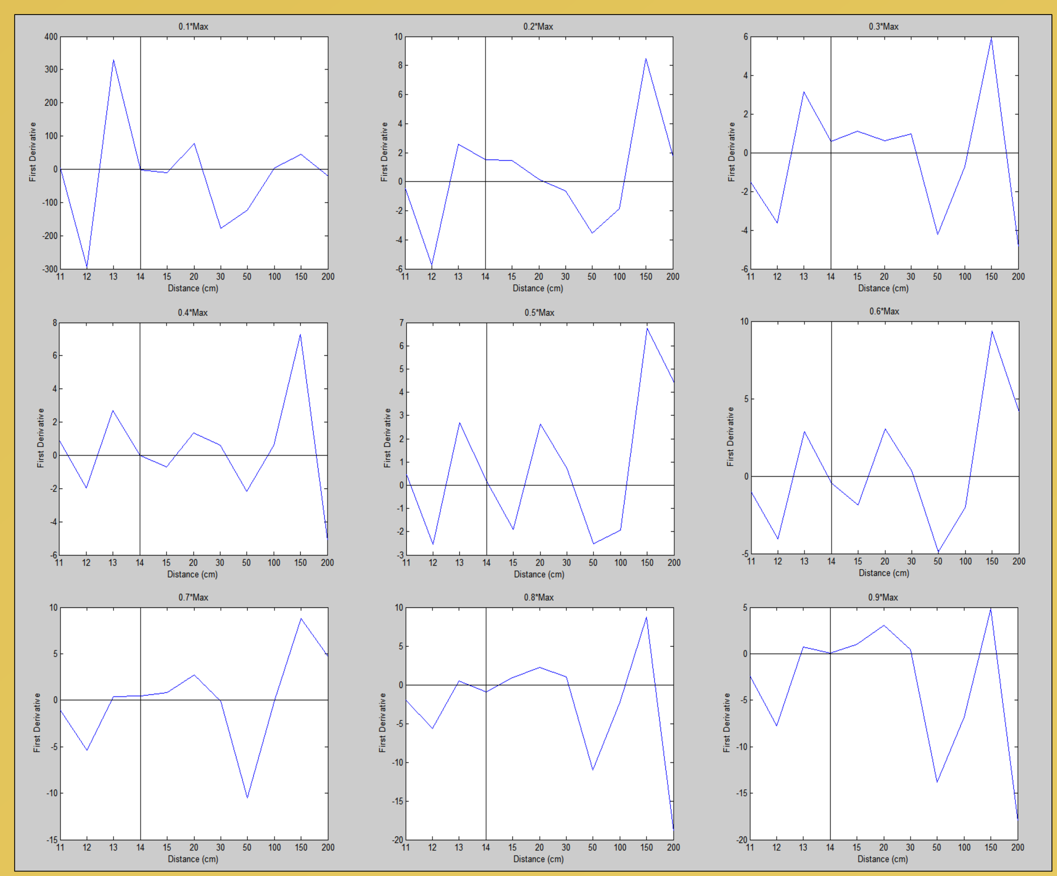
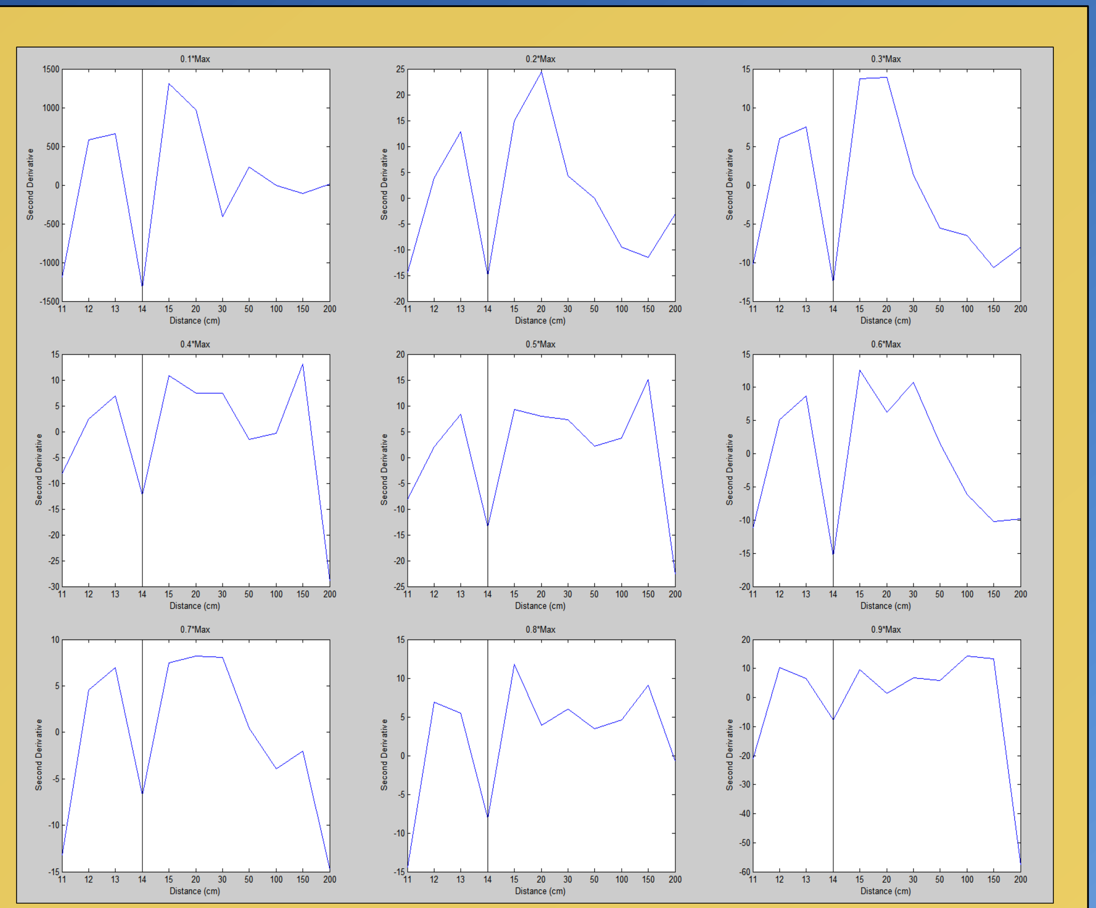



Figure 2: Sample contour of measurement at 14cm at $\frac{1}{e^2}$*max level. The crossing lines connect the minimum and maximum x and y coordinates.





As is evident from these two figures, our measurement of the beam at 14cm from the aperture exhibits precisely the two criteria of first and second derivatives we predicted the beam waist would exhibit. For the first derivative, all graphs show the value at 14 cm to be zero, despite some having zero derivatives at other locations. The minimum second derivative on all graphs is indeed a universal extreme as this particular point was exhibited by graphs over all beam diameter definitions, while any other peaks were unique to one graph or another.

## Conclusions

Based on our data, there is an undisputable minimum size of the beam located around the 14 cm mark. The existence of this minimum is corroborated by both the numerically calculated first and second derivatives of the beam size over numerous definitions of beam diameter and a two dimensional averaged diameter measurement. Since our measurements were only taken at integer distances from the laser's aperture, there is a high likelihood that the exact location of the waist differs from our measurement, though it differs by no more than 1cm in either direction and is most likely within 0.5 cm of the 14cm mark.

## References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3. Klein, Deb. Learning How Laser Beams Propagate. http://laser.physics.sunysb.edu/~wise/wise187/2005/reports/deb/report.html