Precision Laser Beam Profiling: Using Optical Lenses and the Knife-Edge Method

Thomas Campagna

Dr. Donev

September 20, 2025

Understanding the spatial distribution of light is fundamental in modern optics. Most stable laser beams exhibit a Gaussian intensity distribution, characterized by the beam radius, w, defined as the radius where the intensity drops to $1/e^2$ of its peak value. This experiment employs the knife-edge method to accurately measure w and determine the magnification factor, M, of a $5\times$ Galilean telescope beam expander by comparing the radius before and after the expansion.

The setup to complete this task was composed of a laser whose beam is expanded using a system of three lenses with focal lengths $f = -50$ mm, $f = 250$ mm, and $f = 100$ mm. These lenses were configured to achieve the target $5\times$ magnification.

The transverse intensity profile of a laser beam was measured using the knife-edge (razor-blade) scanning method before and after passing through a $5\times$ beam expander, as illustrated in Figure 1. The integrated intensity profile, $G(x)$, was fitted to the complementary error function, $\mathrm{erfc}(x)$, and the resulting Gaussian beam profile, $g(x) = dG/dx$, was fitted to a Gaussian function. The complete set of fitted beam parameters, including beam radii and magnification analysis, is summarized in Table 1, while the visual results of the curve fits are presented across the figures in Figure 2.

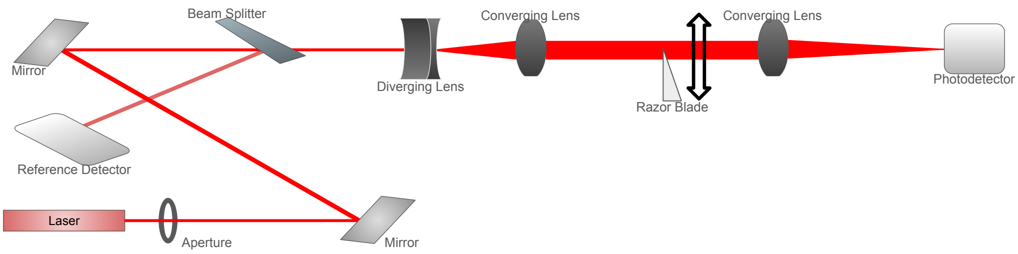


Figure 1: The setup utilizes a Galilean telescope configuration for $5\times$ beam expansion and the knife-edge method for intensity measurement. Figure was made using Google Sheets.

The intensity measured by a detector as a razor blade is scanned across a Gaussian beam corresponds to the integrated intensity, $G(x)$, modeled by the complementary error function in Equation (1). The true spatial intensity profile, $g(x)$, is then obtained as the derivative of $G(x)$, yielding the expected Gaussian function in Equation (2):

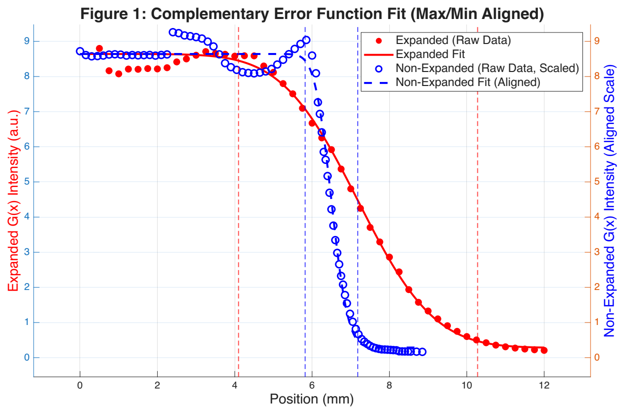
$$G(x) = I_0 \cdot \mathrm{erfc}\left(\frac{\sqrt{2}(x - x_0)}{w}\right) + I_b \qquad (1)$$

$$g(x) = A \cdot \exp\left(-2\frac{(x - x_0)^2}{w^2}\right) \qquad (2)$$

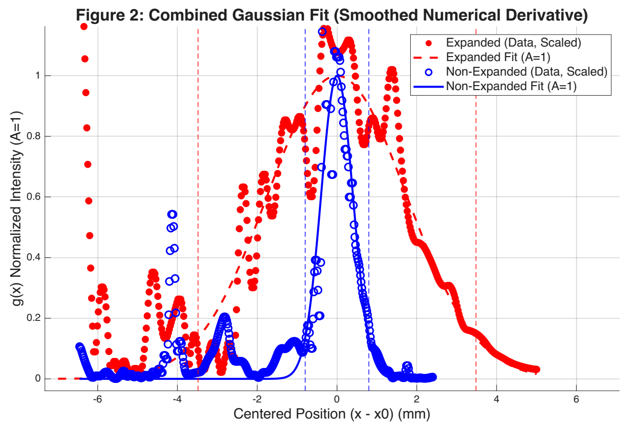
The experimental integrated intensity data, $G(x)$, was processed in MATLAB. The resulting $g(x)$ data (derived via the numerical derivative) was fitted to the Gaussian function to extract the beam radius, w, and its uncertainty (δw). The R^2 values for both fits exceeded 0.99, demonstrating a strong correlation between the data and the theoretical model.

Table 1: Summary of Final Gaussian Beam Radius (w) and Magnification ($\mathbf{M}$) Analysis

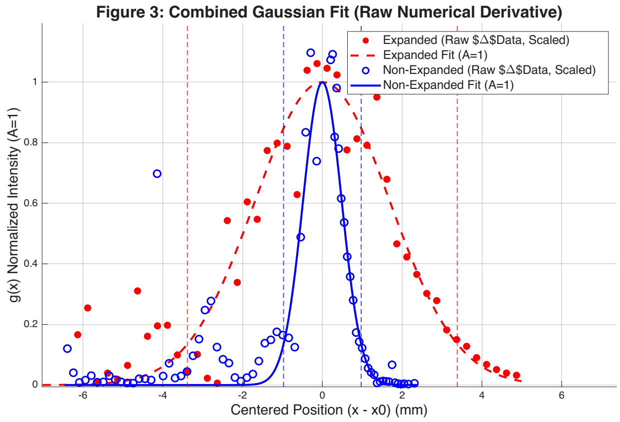
Beam State	**Beam Radius** $\mathbf{w} \pm \delta\mathbf{w}$ (mm)	**Goodness of Fit** ($\mathbf{R^2}$ of ERFC)	**Center Position** ($\mathbf{x_0}$, mm)
Unexpanded	0.680 ± 0.005	**0.9925**	6.500
Expanded	3.091 ± 0.010	**0.9895**	7.189
Magnification $\mathbf{M_{exp}}$	4.543 ± 0.036	–	
Percent Error (vs. $5\times$**)**	9.15 %	–	



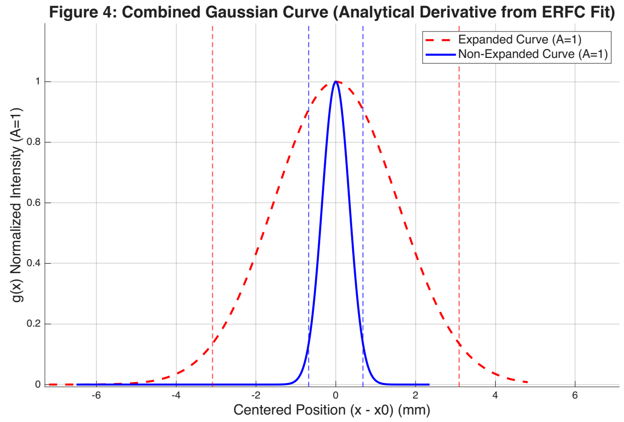
(a) Integrated Intensity $\mathbf{G(x)}$ Fits (ERFC, Aligned Max/Min)



(b) Spatial Intensity $\mathbf{g(x)}$ (Method 1: Smoothed Numerical Derivative)



(c) Spatial Intensity $\mathbf{g(x)}$ (Method 2: Raw Numerical Derivative)



(d) Spatial Intensity $\mathbf{g(x)}$ (Method 3: Analytical Derivative)

Figure 2: **Comparison of Beam Profile Analysis Methods.** **(a)** Shows the primary integrated intensity $G(x)$ fits using the Complementary Error Function (ERFC). **(b)-(d)** Compare the derived Gaussian spatial profiles $g(x)$ obtained via three different methods: **(b)** Smoothed Numerical Derivative (M1), **(c)** Raw Numerical Derivative (M2), and **(d)** Analytical Derivative from the ERFC fit (M3), which yields the most reliable results.

References

1. Optics Laboratory Manual, Fall 2025, Austin Peay State University.
2. *Gaussian Laser Beams*, course handout, Austin Peay State University, 2025.
3. E. Hecht, *Optics*, 5th Edition, Pearson, 2017.