Fidelity Verification of an Apodized Gaussian Beam for Photoinjector Laser at LCLS II

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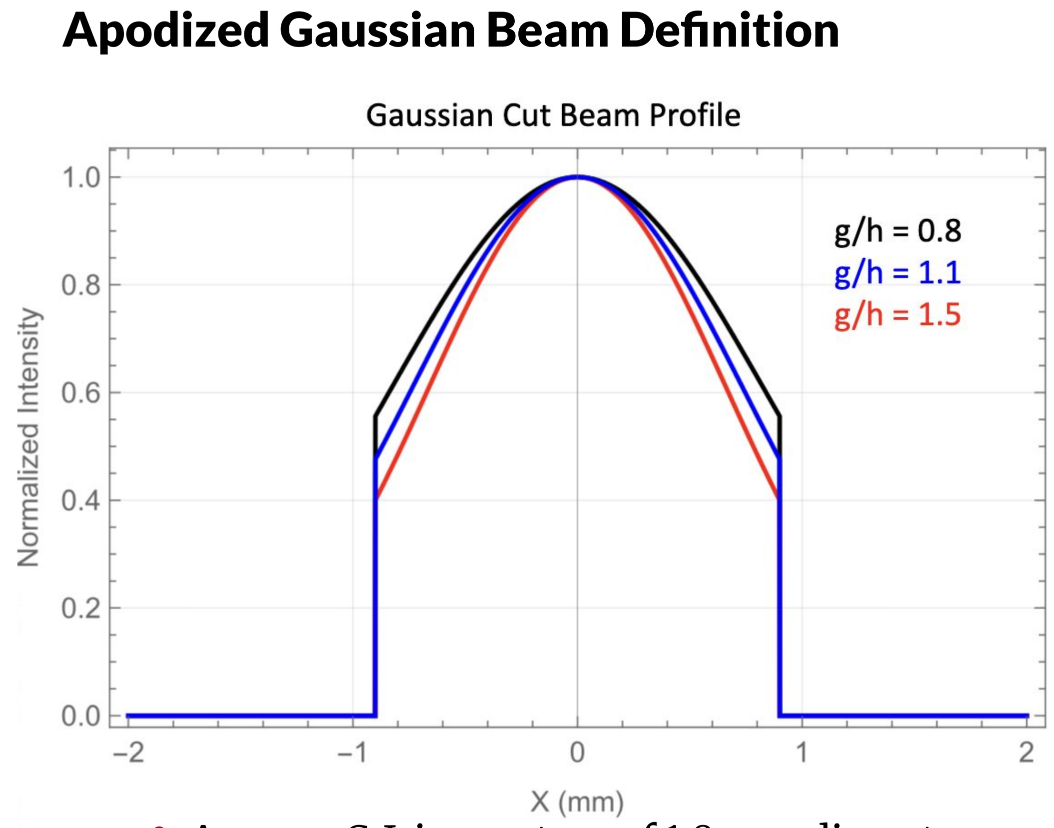
Background/ Motivations

- The electron beam quality generated by the photoinjector is crucial for FEL performance[1].
- To minimize electron emittance from the photoinjector, an Apodized Gaussian beam must be delivered to the photocathode

While the mathematical model of the Apodized Gaussian assumes ideal conditions, experimental fidelity testing ensures that we can confidently deploy the beam profile to the photocathode in practise. The fidelity of the beam is evaluated by how well the physical beam profile ($I_{real}(x,y)$) preserves its structured spatial shape relative to the theoretical prediction ($I_{ideal}(x,y)$), verifying that the hard aperture cut and the edge steepness are maintained without spatial degradation.

Apodized Gaussian Beam Definition



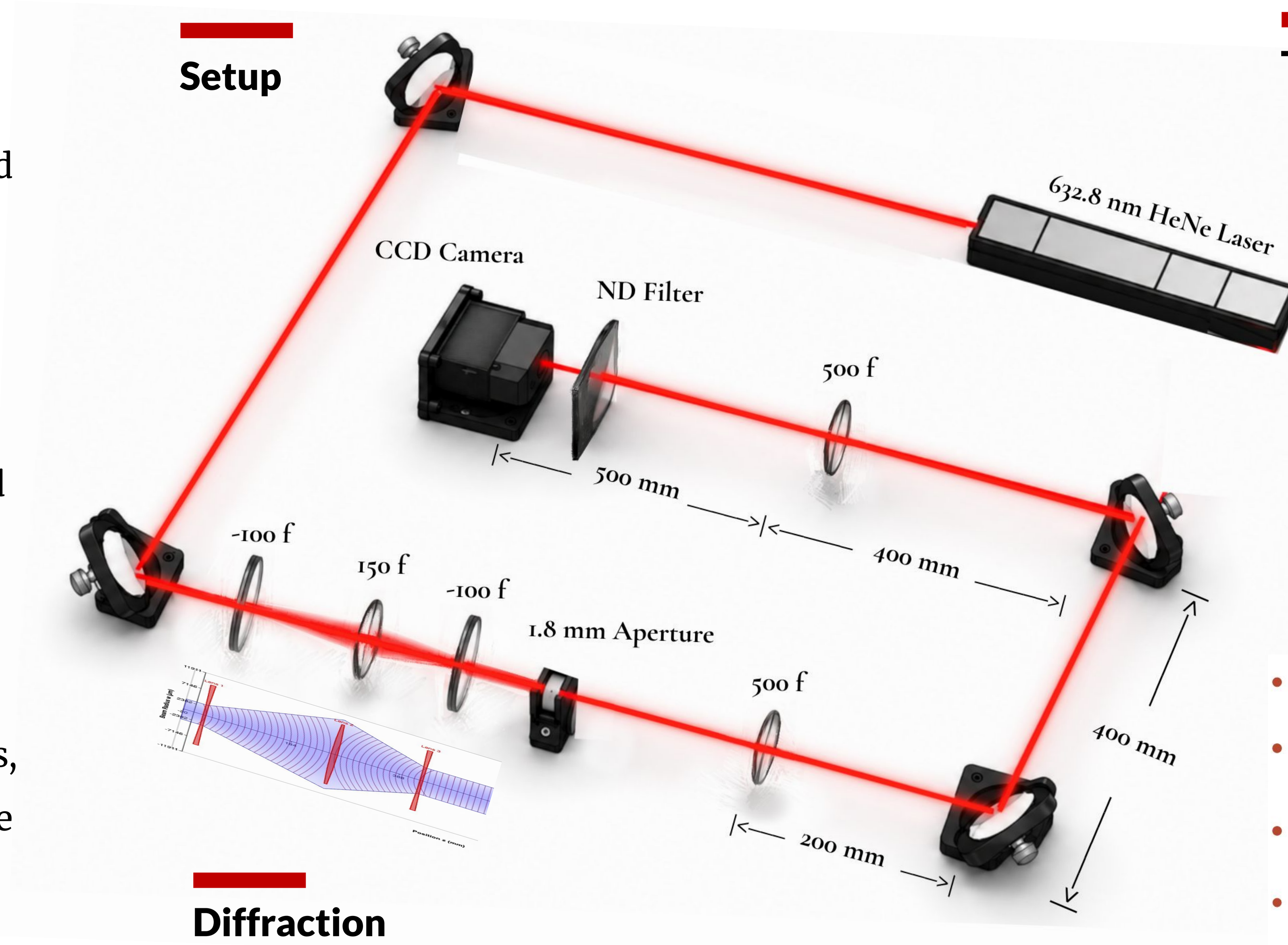
- Assume C-Iris aperture of 1.8 mm diameter

Courtesy of A. Ropak

	Normalized Gaussian Height	Normalized Pedestal Height	Ratio of 1/e² diameter to cut diameter		1/e^2 diameter needed to generate for each g/h
g/h	**g**	**h**	**(1/e²Ø)/(cut Ø)**	**cut Ø**	**1/e²Ø**
0.8	0.444	0.556	1.8445	1.800	3.320
0.9	0.474	0.526	1.7650	1.800	3.177
1	0.500	0.500	1.6985	1.800	3.057
1.1	0.524	0.476	1.6420	1.800	2.956
1.2	0.545	0.455	1.5925	1.800	2.867
1.3	0.565	0.435	1.5495	1.800	2.789
1.4	0.583	0.417	1.5115	1.800	2.721
1.5	0.600	0.400	1.4775	1.800	2.660

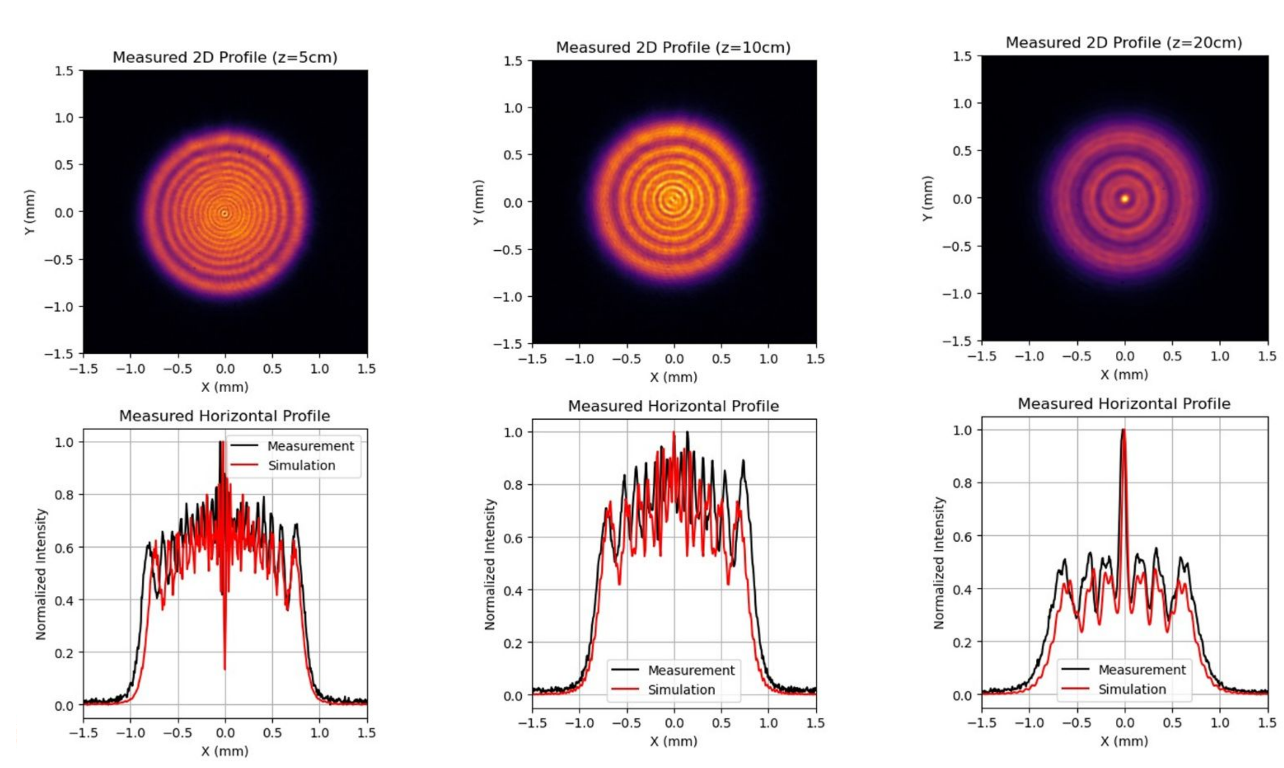
h is the normalized irradiance at the cut point

Setup

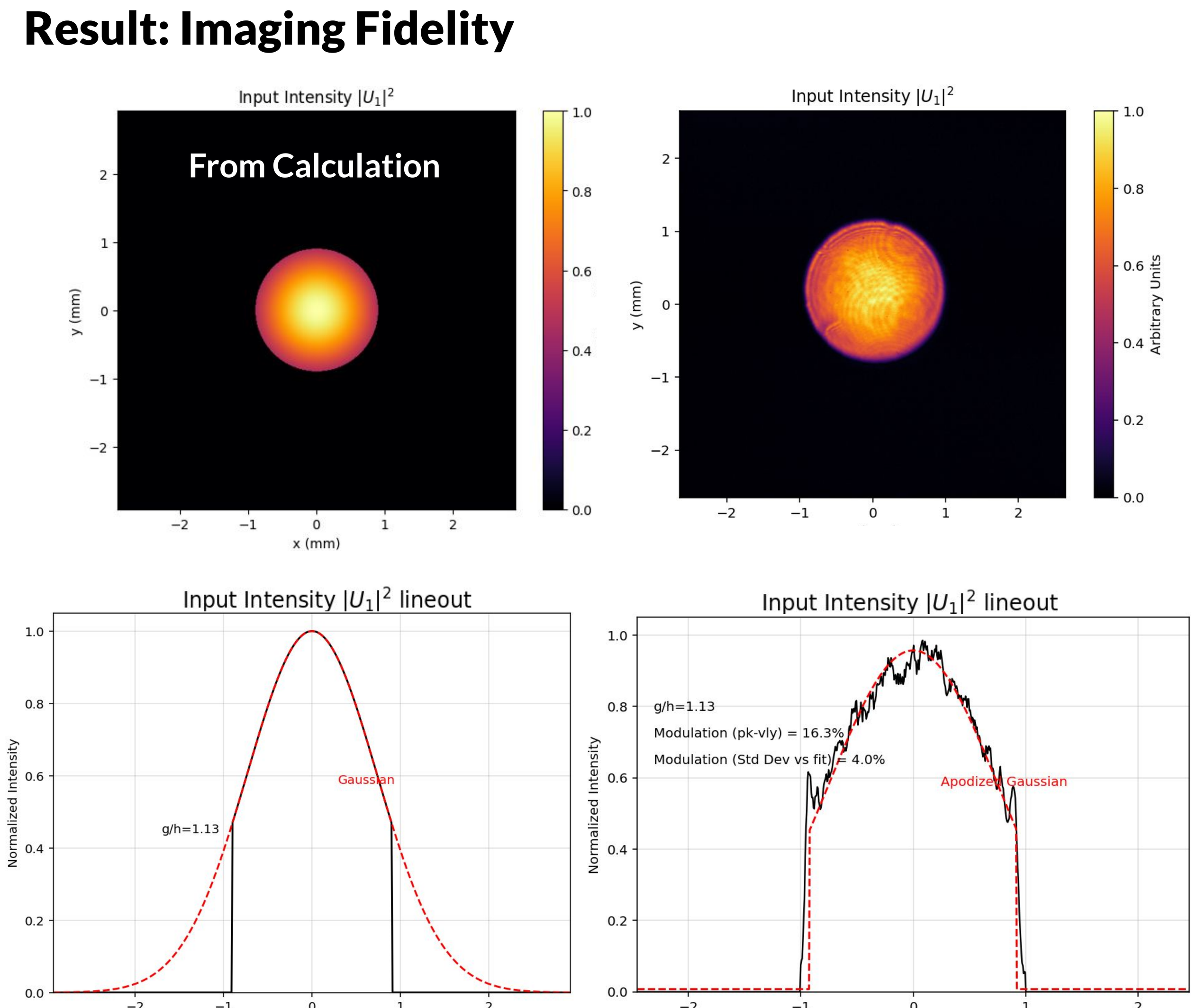


Diffraction

Diffraction of the Apodized Gaussian at Different Distances



Result: Imaging Fidelity



Modulation *pk-vly* (%) = $[(I_{max} - I_{min})/ I_{peak}] \times 100$ = 16.3%

Modulation σ (%) = $\frac{\sqrt{\frac{1}{N}\sum(y_i - f_i)^2}}{I_{peak}} \times 100$ = 4.0%

Theory

- **Diffraction** – *Fresnel diffraction expression*

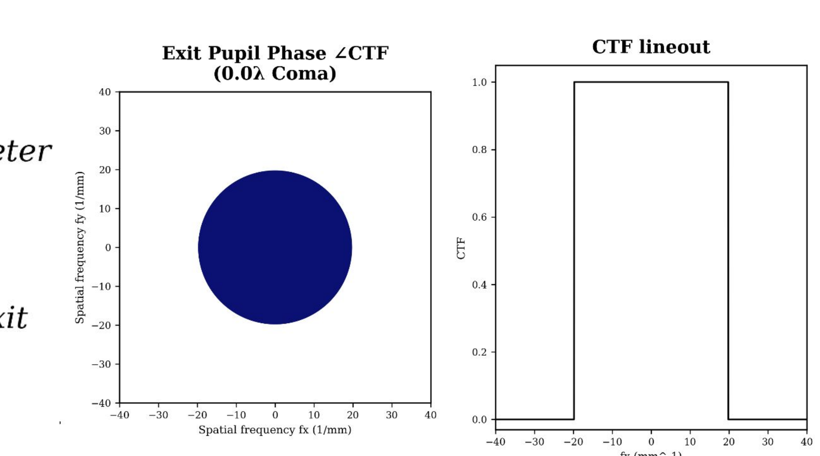
$$U_2(x,y) = \frac{e^{jkz}}{j\lambda z}\iint U_1(\xi,\eta)\exp\left\{j\frac{k}{2z}\left[(x-\xi)^2+(y-\eta)^2\right]\right\}d\xi d\eta .$$

- **Imaging** – *Coherent Transfer Function (CTF)*

$$\underbrace{I(f_x,f_y)}_{ImageSpectrum} = \underbrace{O(f_x,f_y)}_{ObjectSpectrum} \underbrace{\cdot H(f_x,f_y)}_{CTF}$$

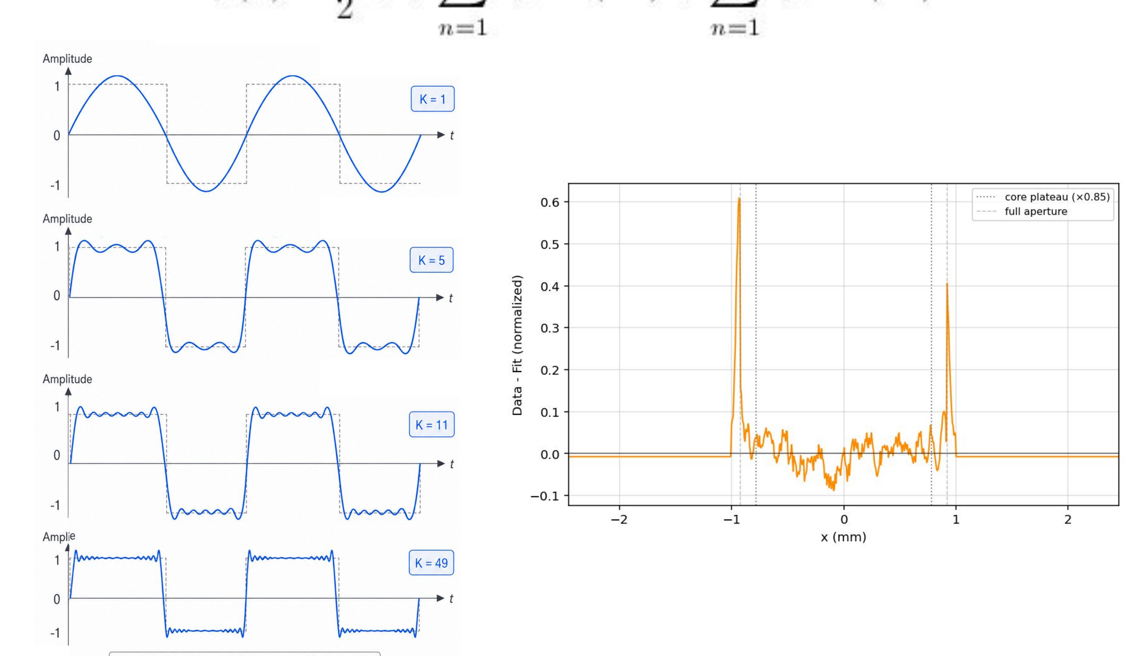
$$f_{cut} = \frac{D_{exit}}{2\lambda L_{exit}}$$

- D_{exit} = *Exit pupil diameter*
- λ = *wavelength*
- L_{exit} = *distance from exit pupil to image plane*
- Numerical example: $D_{exit} = 25\,mm,\ \lambda = 632.8\,nm,\ L_{exit} = 1\,meter$ $\rightarrow\ f_{cut} = 19.8\ mm^{-1}$



- **Gibbs phenomenon** – *Fourier Series*

$$f(x) = \frac{1}{2}a_0 + \sum_{n=1}^{\infty} a_n\ cos(nx) + \sum_{n=1}^{\infty} b_n\ sin(nx)$$



Conclusion

- The diffraction propagation of the Apodized Gaussian beam measured matches will with the theoretical calculations
- Verified that the relay imaging preserved the fidelity of the Apodized Gaussian beam across different cut ratios.

What's Next?

With this fidelity verification, we can use the same principle to construct the new relay imaging and test it in Sector 0. We will use this information to further optimize the beam size used in the new beam transport.

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REFERENCES

1. Feng Zhou, et al, "Impact of the spatial laser distribution on photocathode gun operation", *PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 15, 090701 (2012)*
2. David Voelz, Computational Fourier Optics, Copyright © 2011 Society of Photo-Optical Instrumentation Engineers (SPIE).