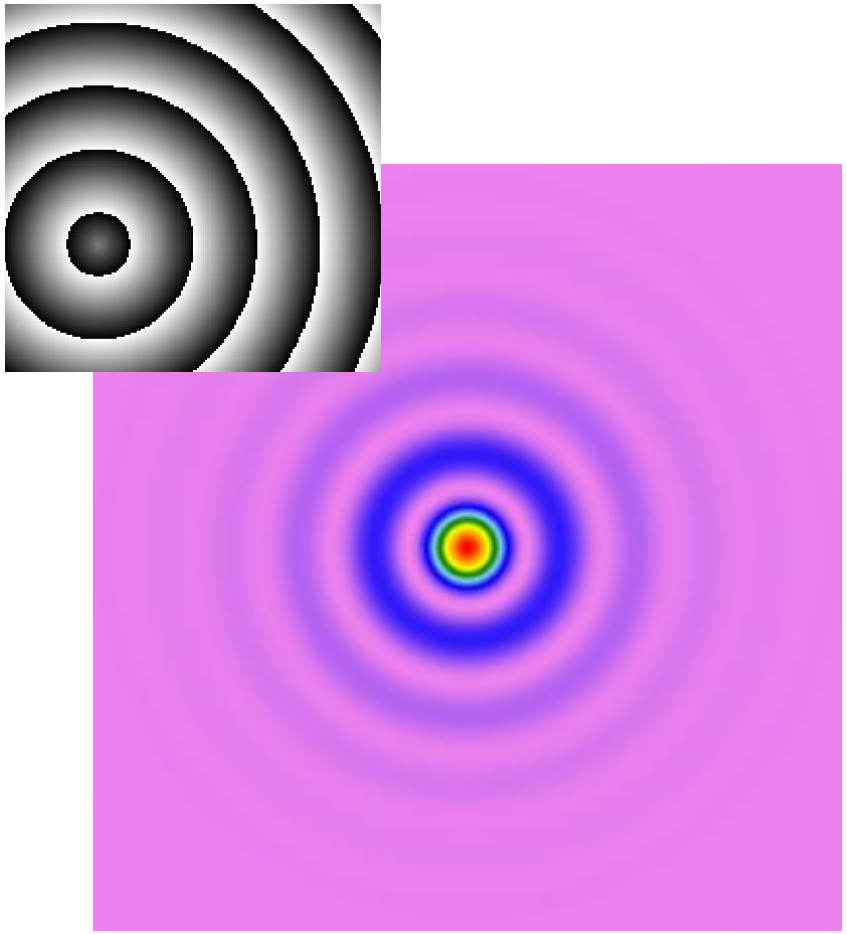
Gauss-Bessel Beam Shaper via Axicon Function

From Gaussian to Non-Diffracting Bessel Beams



Part of the Beam Shaping Solution Guide

Document ID:	UC-BESSEL-AXICON-FUNC
Version:	1.1
Date:	May 20, 2026
Author:	LightTrans International GmbH

Executive Summary

Bessel Beam Generation via Axicon Based Phase Function

Key Achievements

Comparison for different

- deflection cone angles
- topological vortex charges
- quantization levels

Twins Used

`SF-GAUS01:` Gaussian Beam Mode

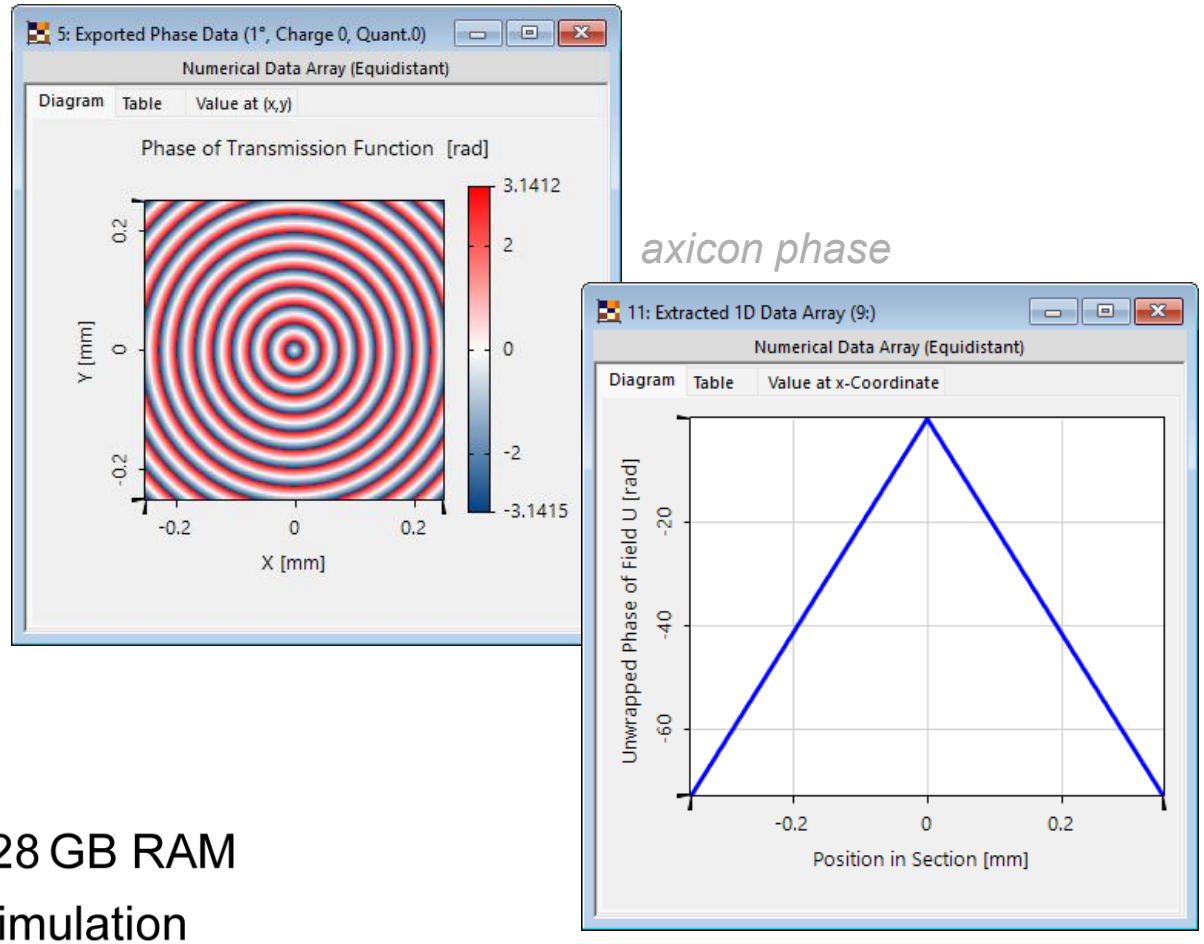
`CF-BESA01:` Gauss-Bessel Beam Shaper [Axicon]

`DF-CAMD01:` Camera Detector

Hardware & Performance

Hardware: Intel i9-11950H @ 2.60 GHz • 8 cores • 128 GB RAM

Simulation time: < 1 second to a few seconds per simulation



axicon phase

Application Scenario

The Challenge

Generating Bessel beams with and without orbital angular momentum (vortex) — beams that maintain their transverse profile over an extended depth of focus. Essential for laser processing, optical trapping, and super-resolution microscopy.

Physical Lab Setup

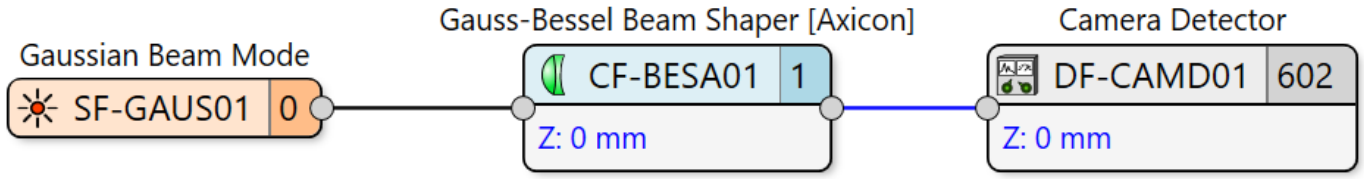
Component	Specification
Laser source	532 nm, Gaussian, waist 100 μm
Axicon phase mask	Conical phase with optional vortex
Translation stage	Moves camera along optical axis (0 to 8 mm)
Camera	CCD, 300 μm × 300 μm, 501 × 501 pixels

From Real Asset to Digital Twin

Digital Twin Mapping

Real Asset	Digital Twin	Parameter Settings
Laser (Gaussian)	`SF-GAUS01`	$\lambda = 532\,\text{nm},\ w_0 = 100\,\mu\text{m}$
Axicon phase mask	`CF-BESA01`	$\theta = \{1^\circ, 1.5^\circ\}$ $\text{charge} = \{0,\ 1,\ 5\}$ $\text{quantization} = \{\text{continuous},\ \text{8-level},\ \text{4-level}\}$
(Moving) camera	`DF-CAMD01`	$300 \times 300\,\mu\text{m},\ 501 \times 1\,\text{px}\ (\text{axial sweep})$ $200 \times 200\,\mu\text{m},\ 501 \times 501\,\text{px}\ (\text{2D})$

System Layout



Axicon Relations

Axicon Phase Function

This twin is a function-based component, which applies phase values according to a 2π-modulated axicon surface. Thus, it corresponds to a phase mask with the transmission function

$$t(\mathbf{r}, \phi) = \exp(i\Phi_{\text{total}})$$

$$\text{where} \quad \Phi_{\text{total}}(\mathbf{r}, \phi) = -k_0 \sin\theta \cdot \rho + l\phi$$

with $k_0 = 2\pi/\lambda$, $\rho = |\mathbf{r}|$, and ϕ the azimuthal angle. The first term is the standard axicon phase and the second is the optional vortex with the charge (l).

Deflection Angle and Apex Angle

The deflection cone angle θ created by the axicon transmission function relates to the apex angle α_0 of the corresponding plano-conic axicon as follows:

$$\theta = \arcsin\left(\frac{n_i}{n_o}\sin\alpha_0\right) - \alpha_0$$

conversely

$$\alpha_0 = \arctan\left(\frac{\sin\theta}{\frac{n_i}{n_o} - \cos\theta}\right)$$

or for small angles:

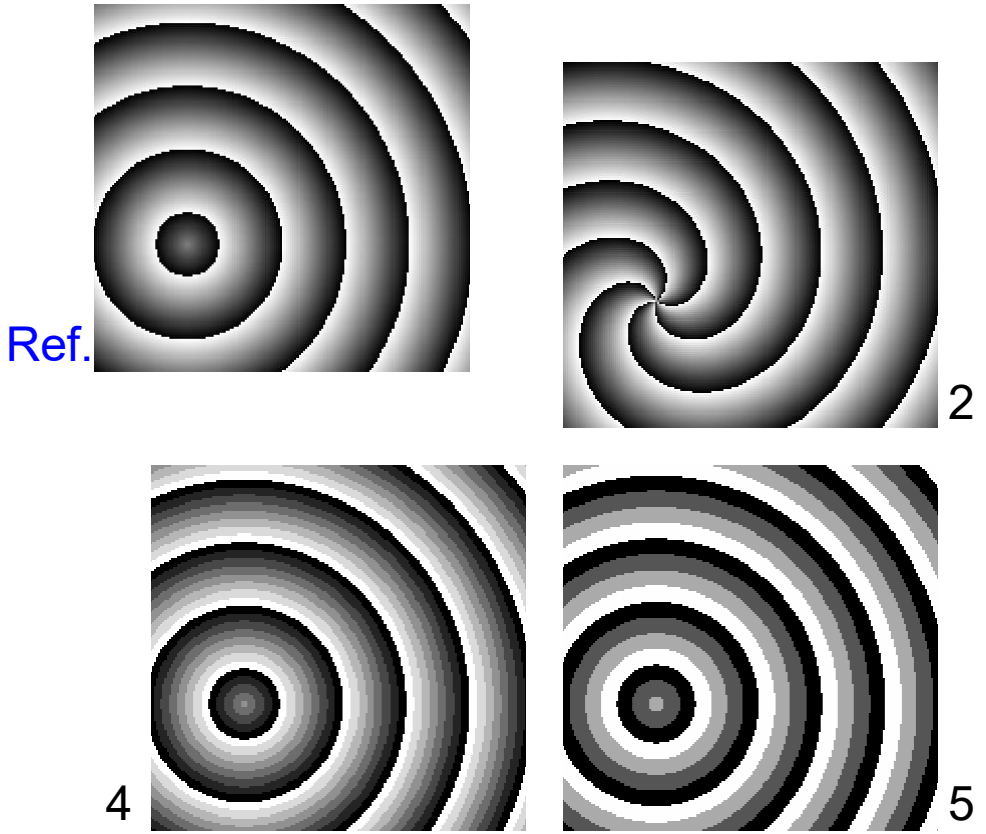
$$\theta \approx \left(\frac{n_i}{n_o} - 1\right)\alpha_0$$

with n_i and n_o as the refractive indices inside and outside the axicon.

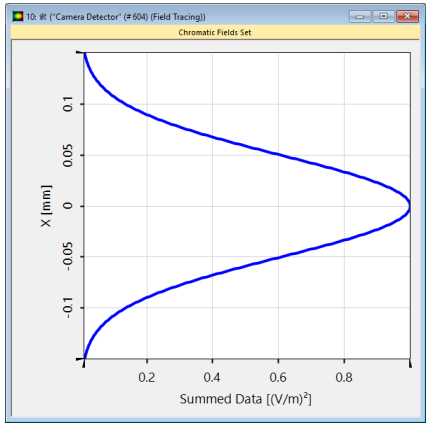
Summary of Varied Parameters

Performed Comparison Simulations

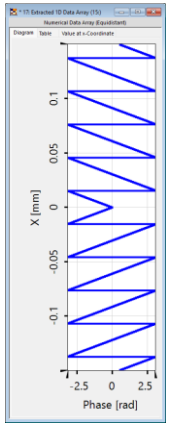
No.	angle	charge	quantization
Ref.	1.0°	0	0
1	1.5°	0	0
2	1.0°	1	0
3	1.0°	5	0
4	1.0°	0	8
5	1.0°	0	4



Scenario Illustration

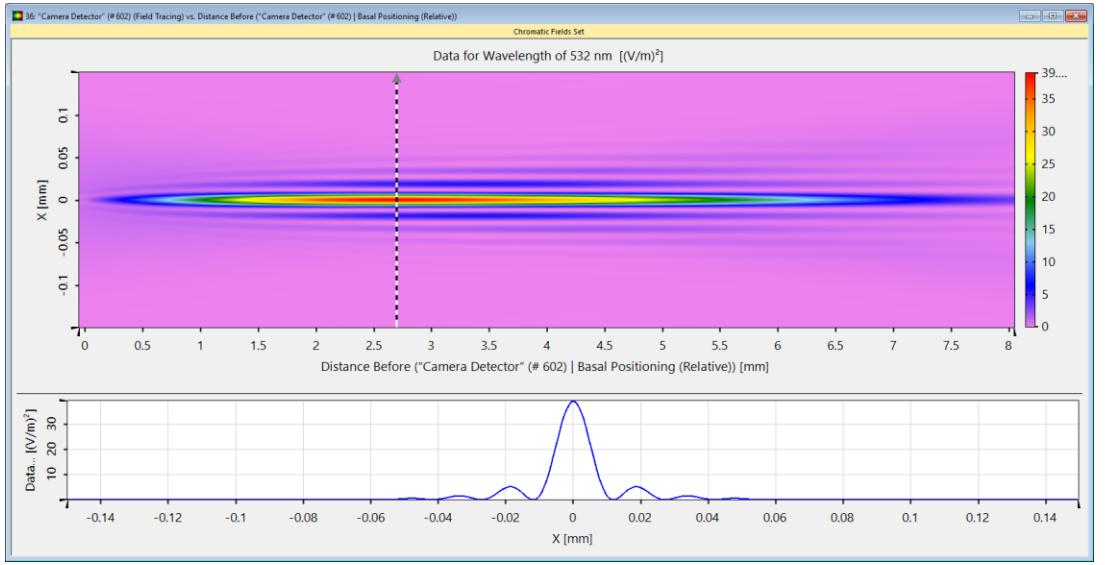


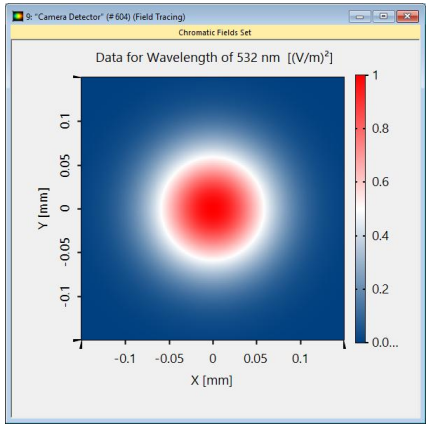
Gausian input beam

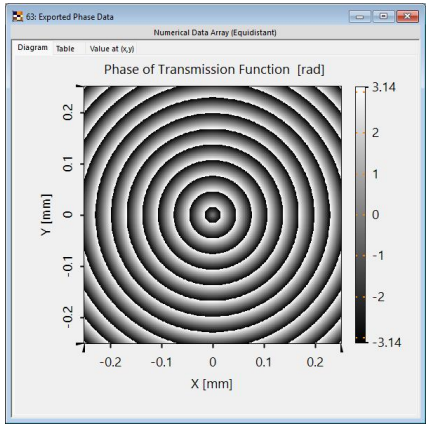


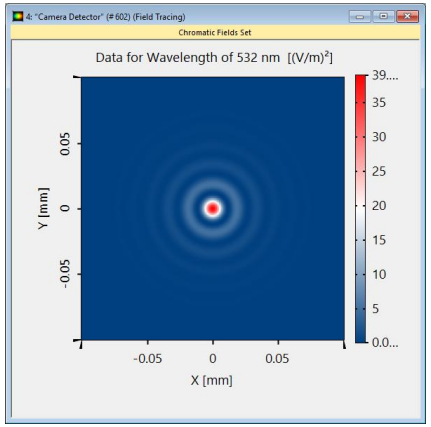
2π-modulated axicon phase mask

Diffracted beam evolution (Bessel-like beam profile)





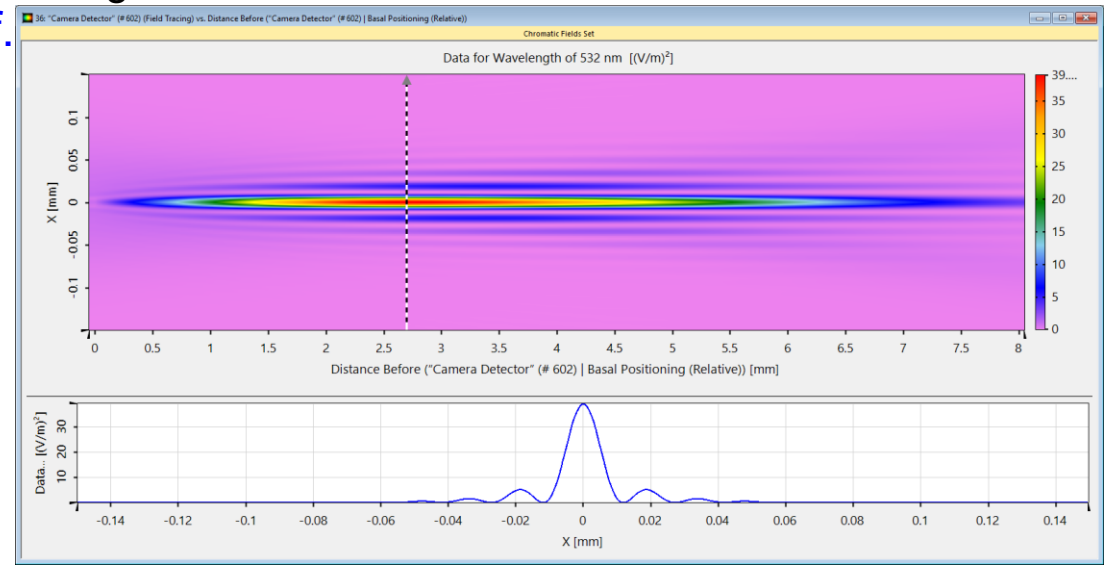


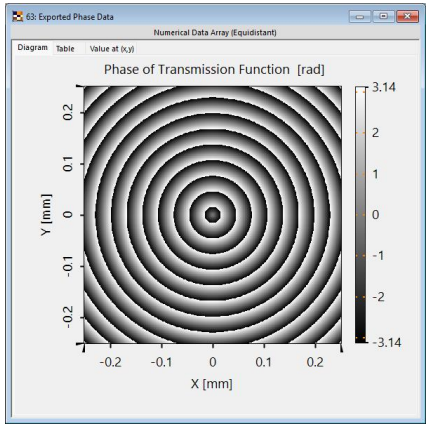


Sim#1 Results: Angle 1° vs 1.5° (charge = 0, quantization = 0)

Ref.

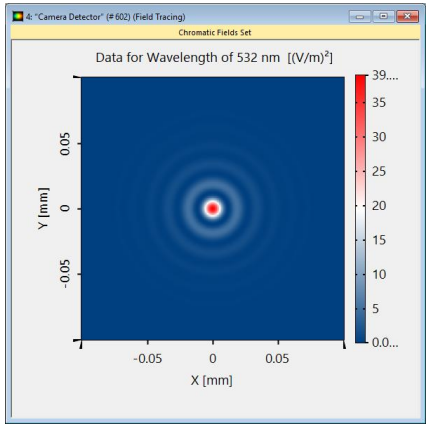
angle = 1°



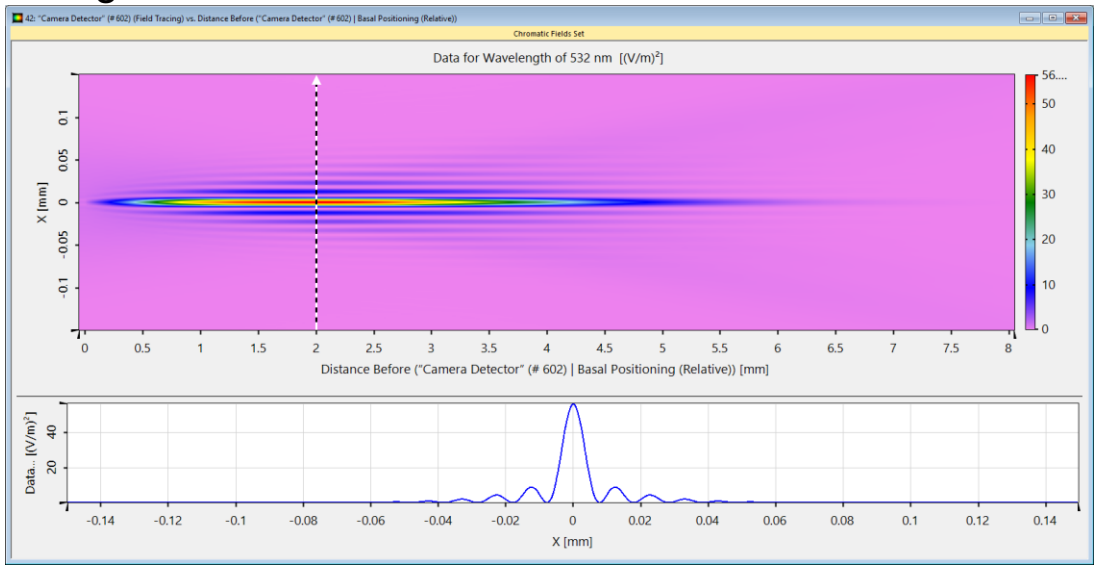


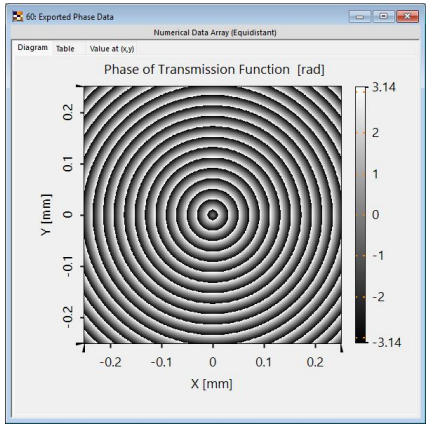
phase function

Bessel beam profile at 2.7mm



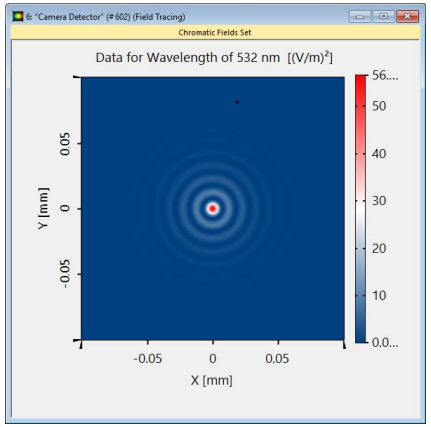
angle = 1.5°





phase function

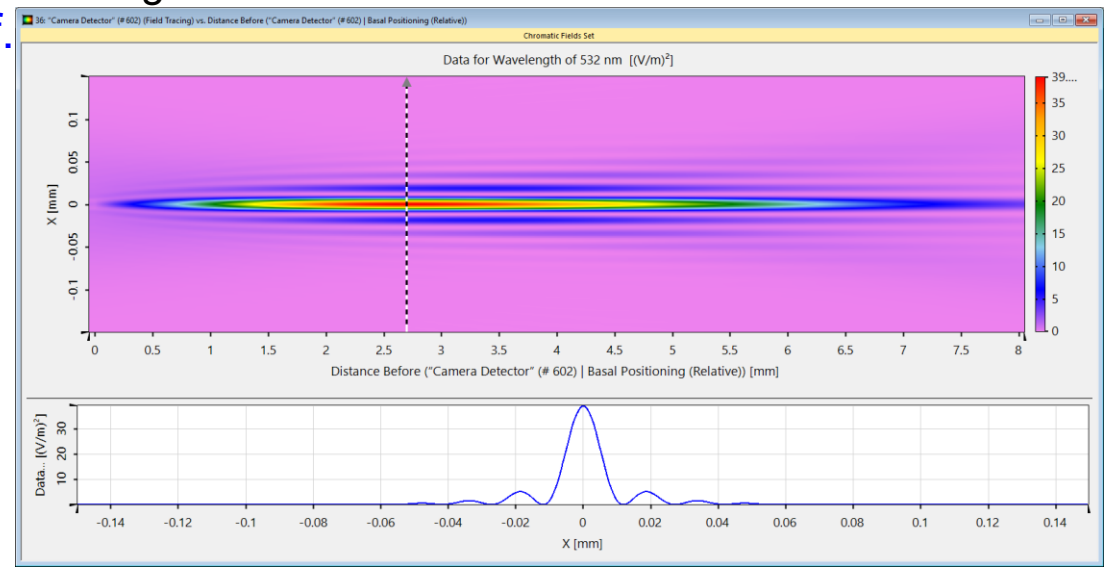
Bessel beam profile at 2.0mm

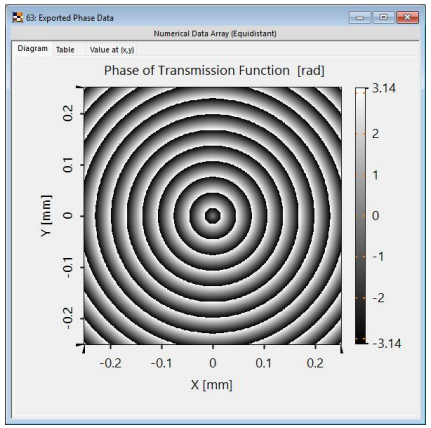


Sim#2 Results: Charge 0 vs 1 (angle = 1°, quantization = 0)

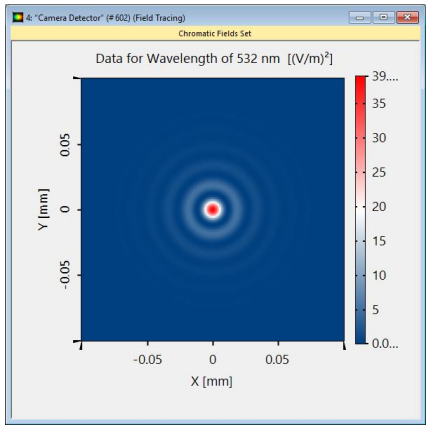
Ref.

charge = 0



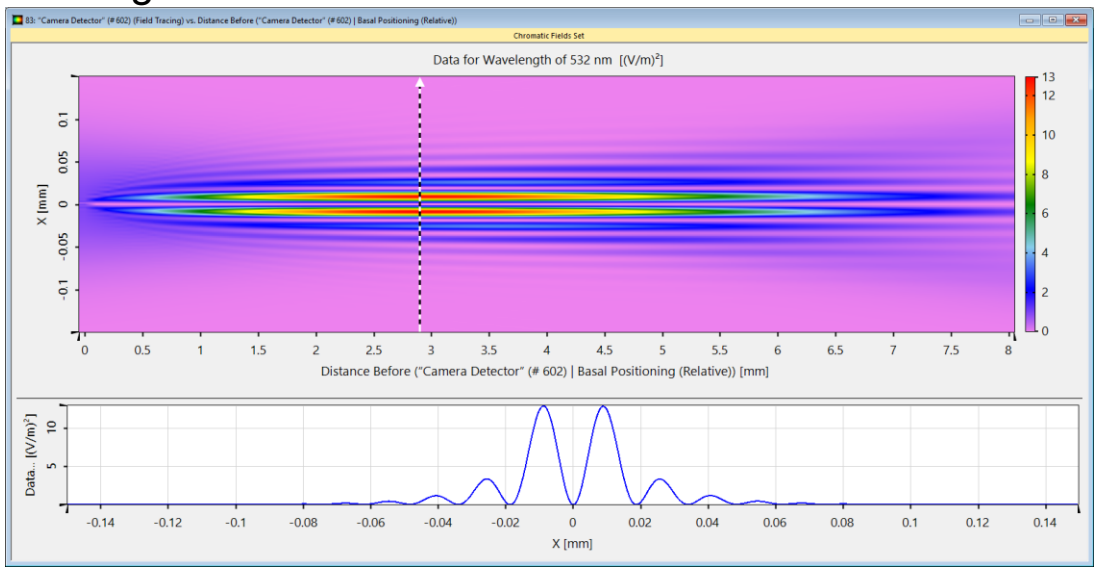


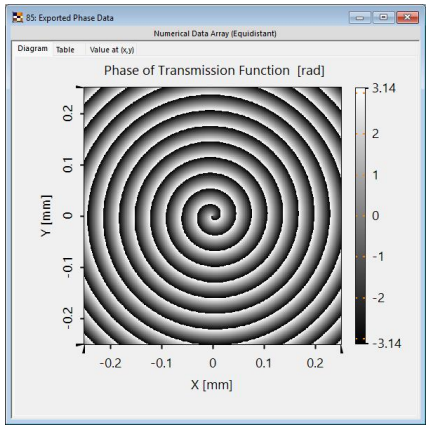
phase function



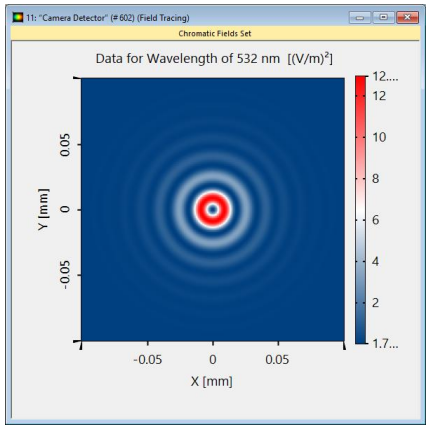
Bessel beam profile at 2.7mm

charge = 1





phase function

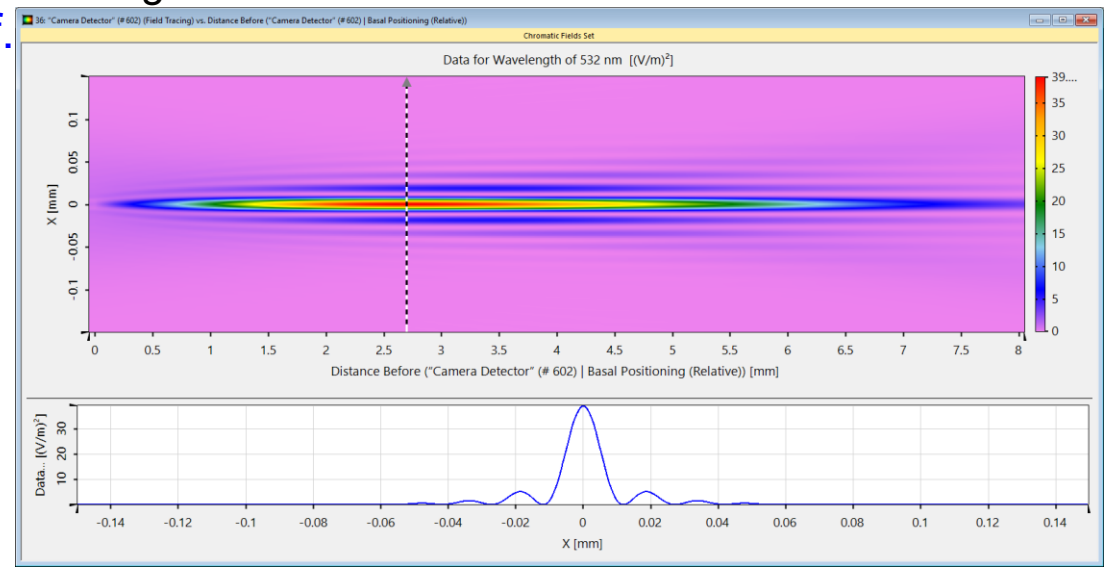


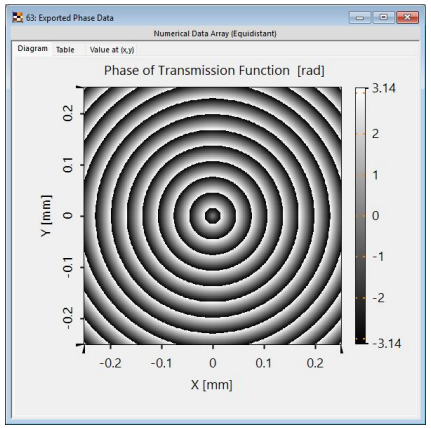
Bessel beam profile at 2.9mm

Sim#3 Results: Charge 0 vs 5 (angle = 1°, quantization = 0)

Ref.

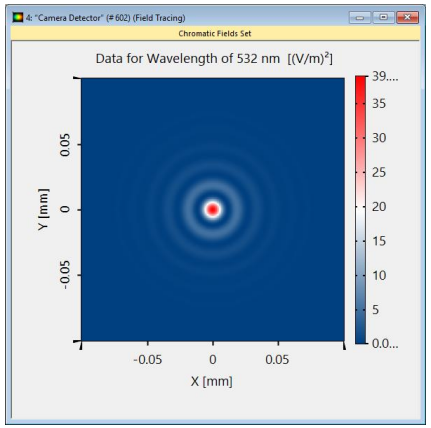
charge = 0



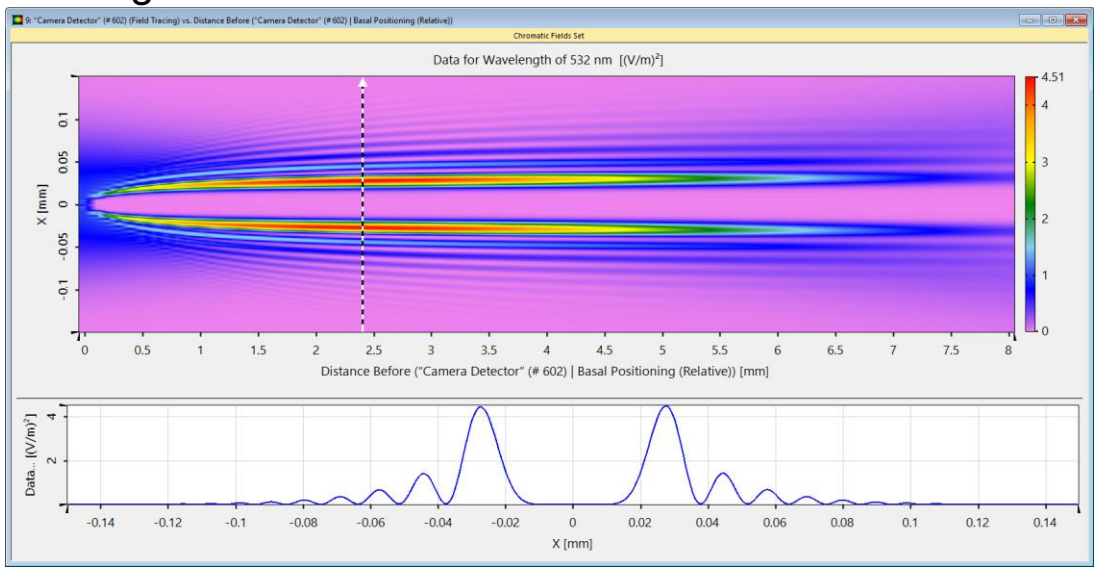


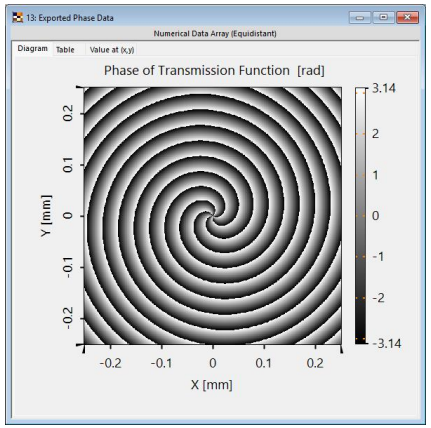
phase function

Bessel beam profile at 2.7mm



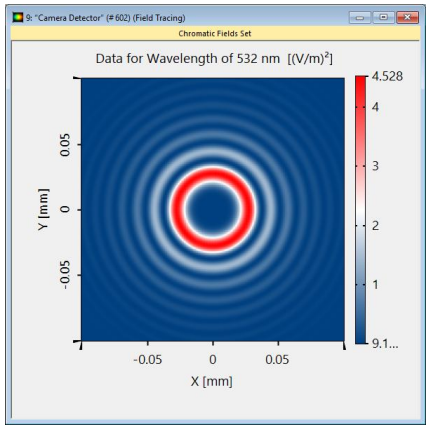
charge = 5





phase function

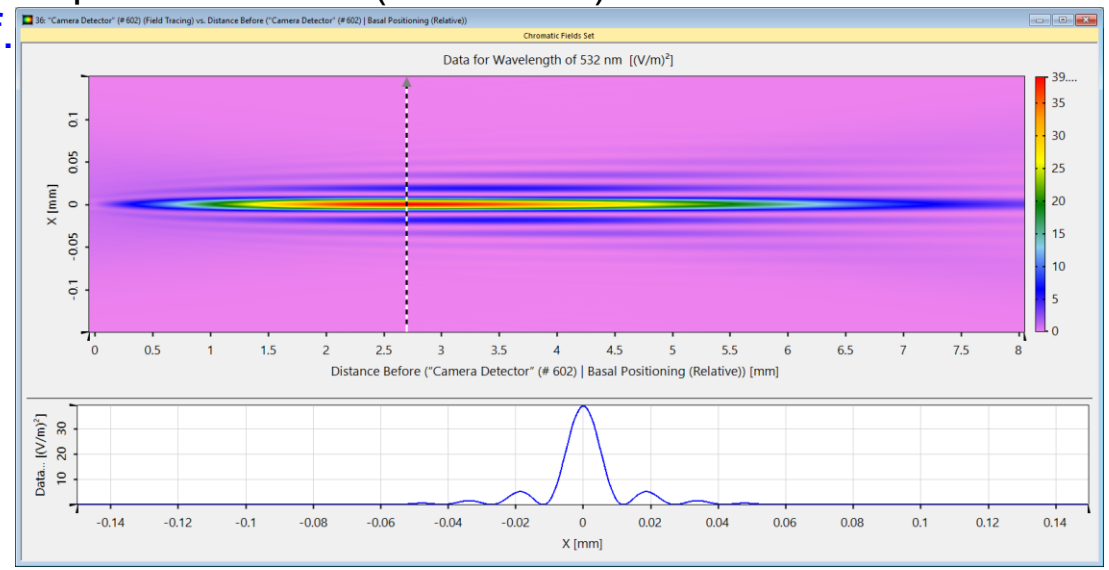
Bessel beam profile at 2.4mm



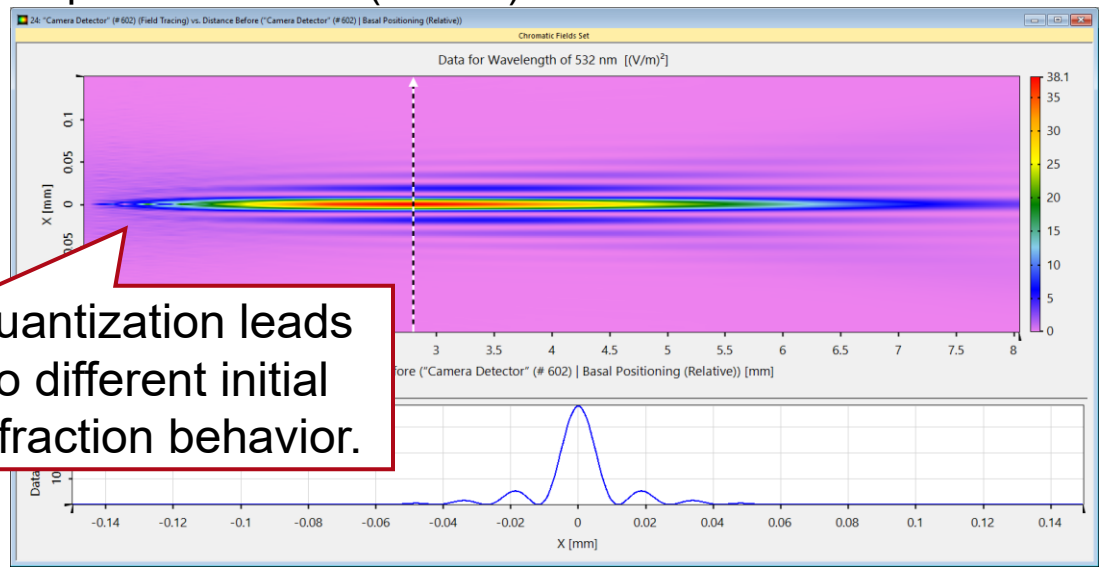
Sim#4 Results: Quantization 0 vs 8 (angle = 1°, charge = 0)

Ref.

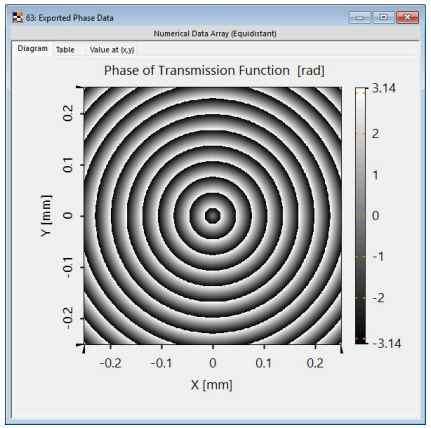
▾ quantization = 0 (continuous)



▾ quantization = 8 (8-level)

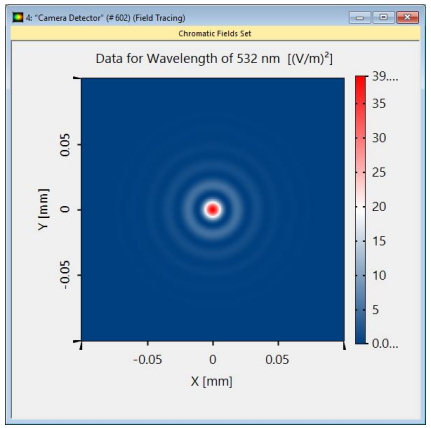


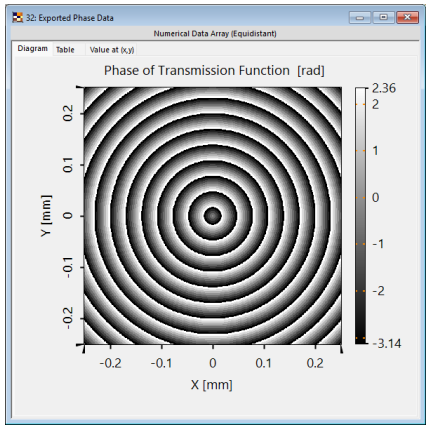
Quantization leads to different initial diffraction behavior.



◂ phase function

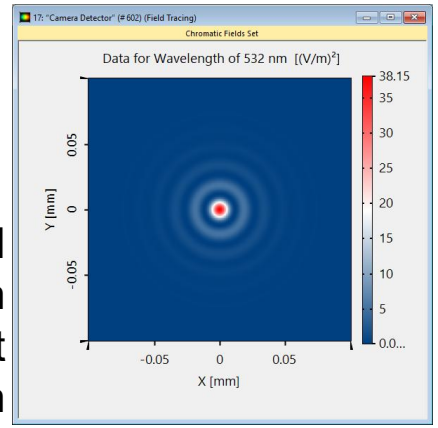
▸ Bessel beam profile at 2.7mm





◂ phase function

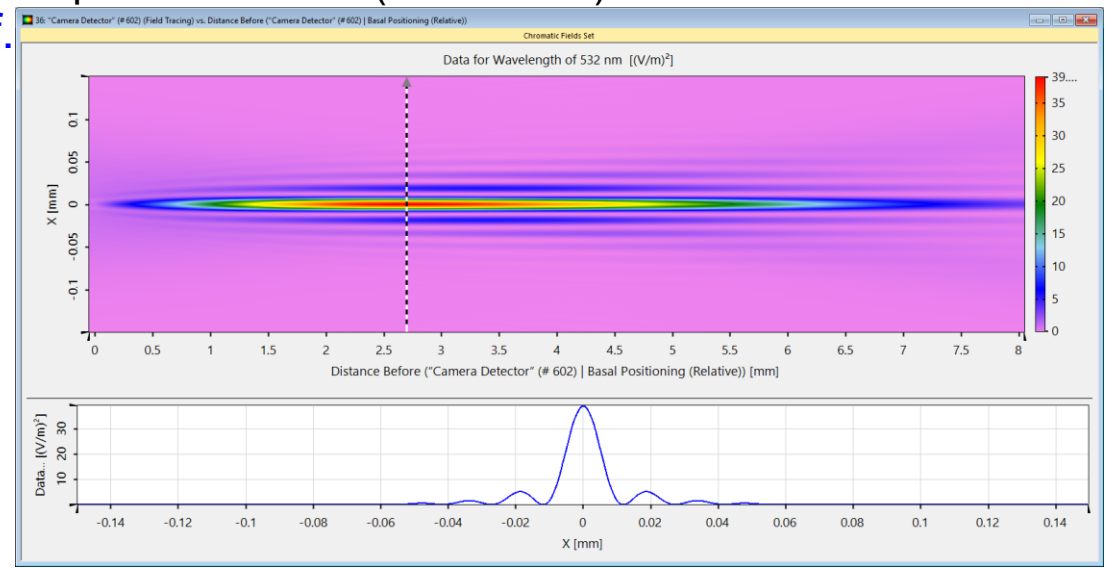
▸ Bessel beam profile at 2.8mm



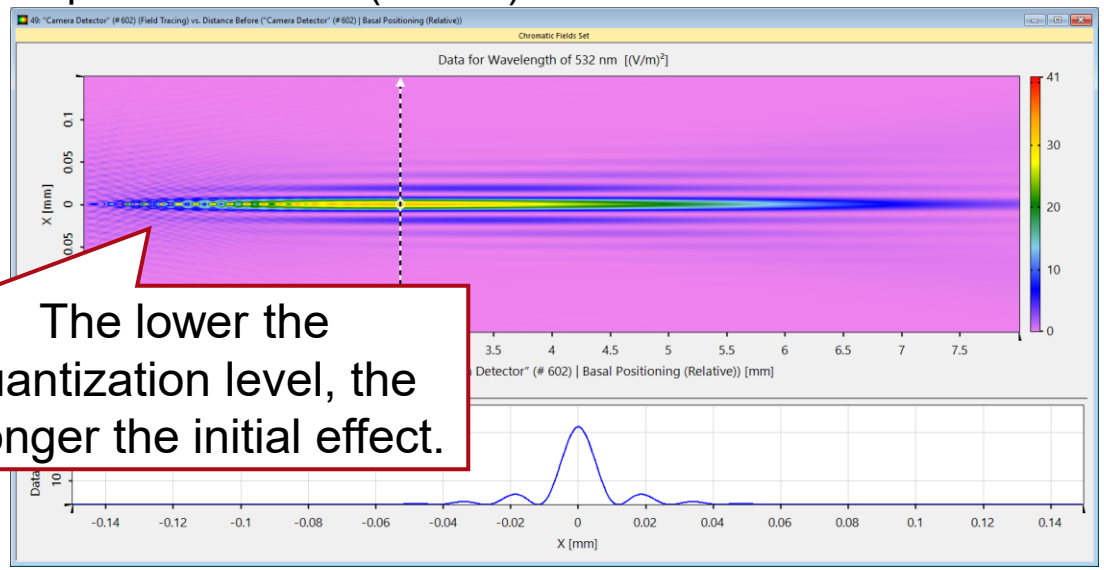
Sim#5 Results: Quantization 0 vs 4 (angle = 1°, charge = 0)

Ref.

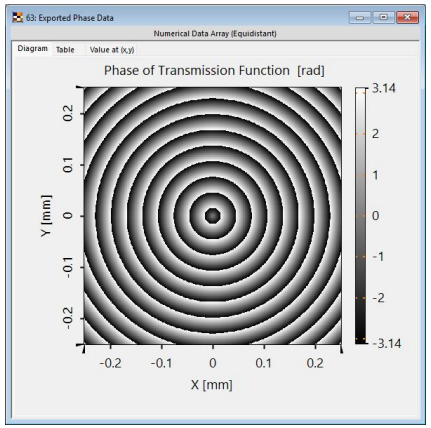
▾ quantization = 0 (continuous)



▾ quantization = 4 (4-level)

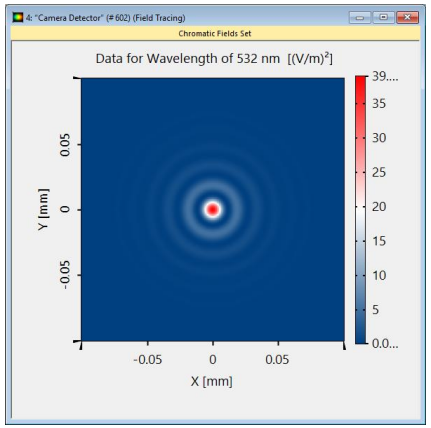


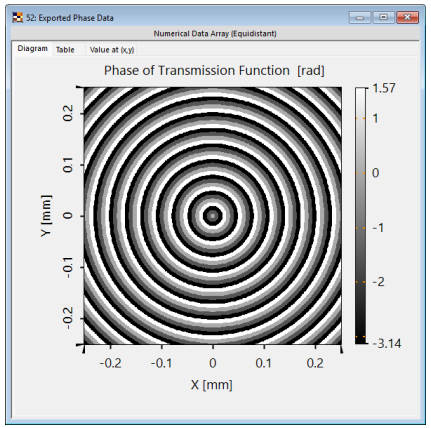
The lower the quantization level, the stronger the initial effect.



◂ phase function

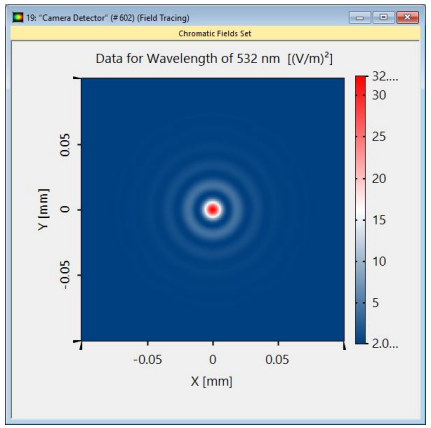
▸ Bessel beam profile at 2.7mm





◂ phase function

▸ Bessel beam profile at 2.7mm



Suggested Steps

Step-by-Step Workflow

1. **Setup:** Place Gaussian Beam Mode, Gauss-Bessel Beam Shaper [Axicon], and Field Monitor and Camera Detectors.
2. **Phase Resolution:** Enable the export option in the Shaper twin and use it with default settings to visualize the phase function applied. Adjust the sampling accuracy if needed.
3. **Performance:** To speed up some simulations (while keeping reasonable accuracy) the gridded sampling limit has been reduced from 10,000 to 3,000 points squared. (The sampling rate used by VLF by default is usually chosen to allow for a safety margin.)
4. **Axial sweep:** Perform parameter run for position z across the specified range; record intensity profiles in 1D for combined 2D output showing the changing cross sections.
5. **Export:** The export option in the Shaper twin generates the phase function with customizable size and resolution.

Conclusion

Key Takeaways

- Axicon function produces Bessel-like beam profile, the axial location and size of which can be controlled with the cone angle.
- Introduction of integer vortex charges produces ”dark core” leading to typical ring profile.
- The effect of quantization of the phase values can be evaluated.