COMSOL CONFERENCE 2018 BOSTON

Generation of Divergence-Free Bessel-Gauss Beam from an Axicon Doublet for km-long Collimated Laser

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NanoPhotonics

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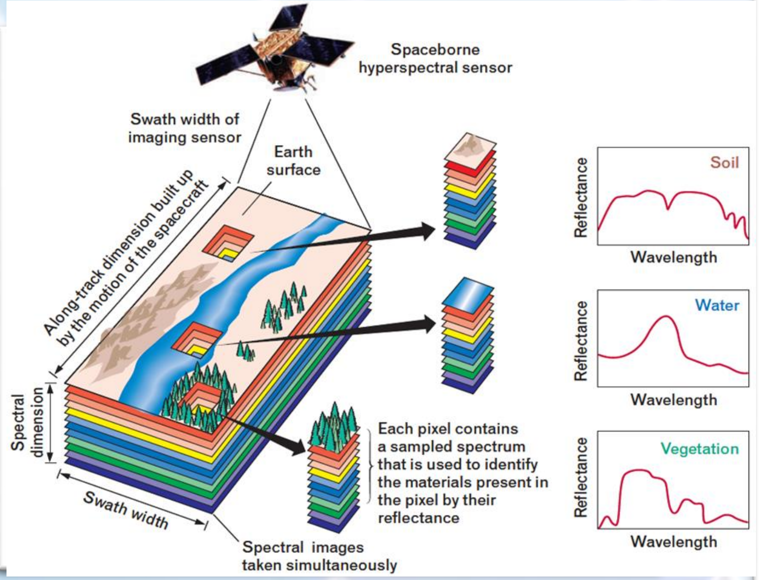
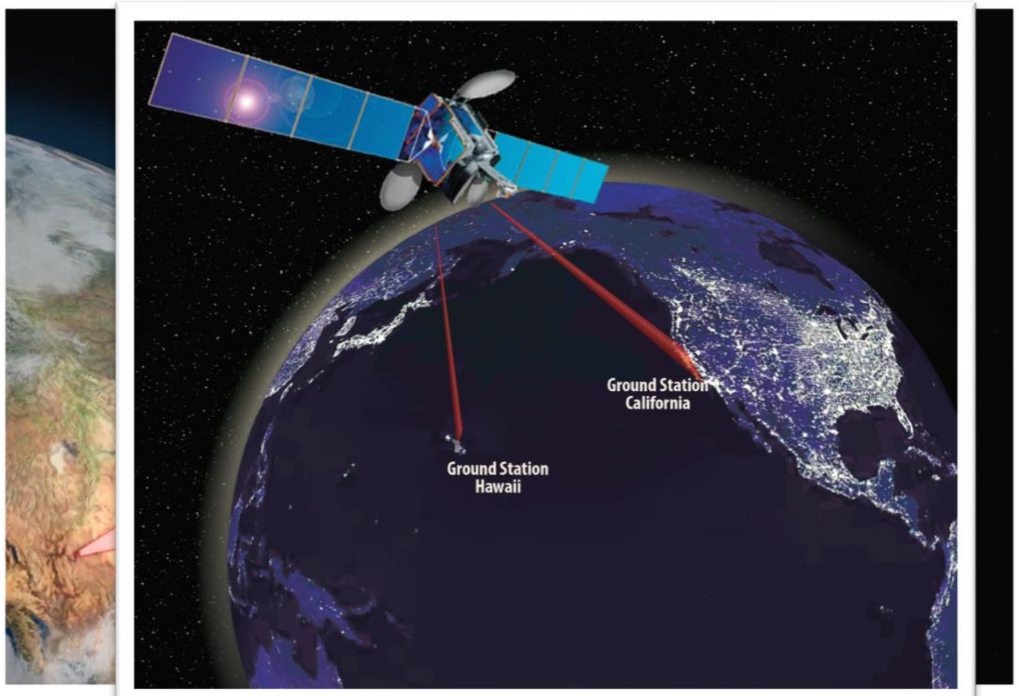
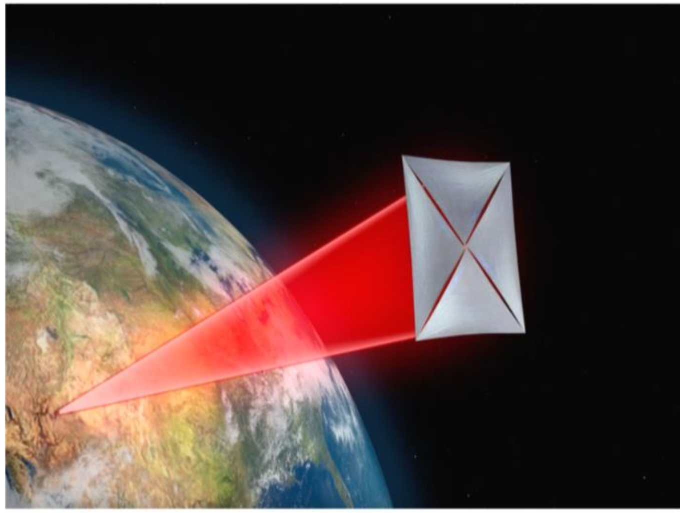






Vermont Center for Geographic Information

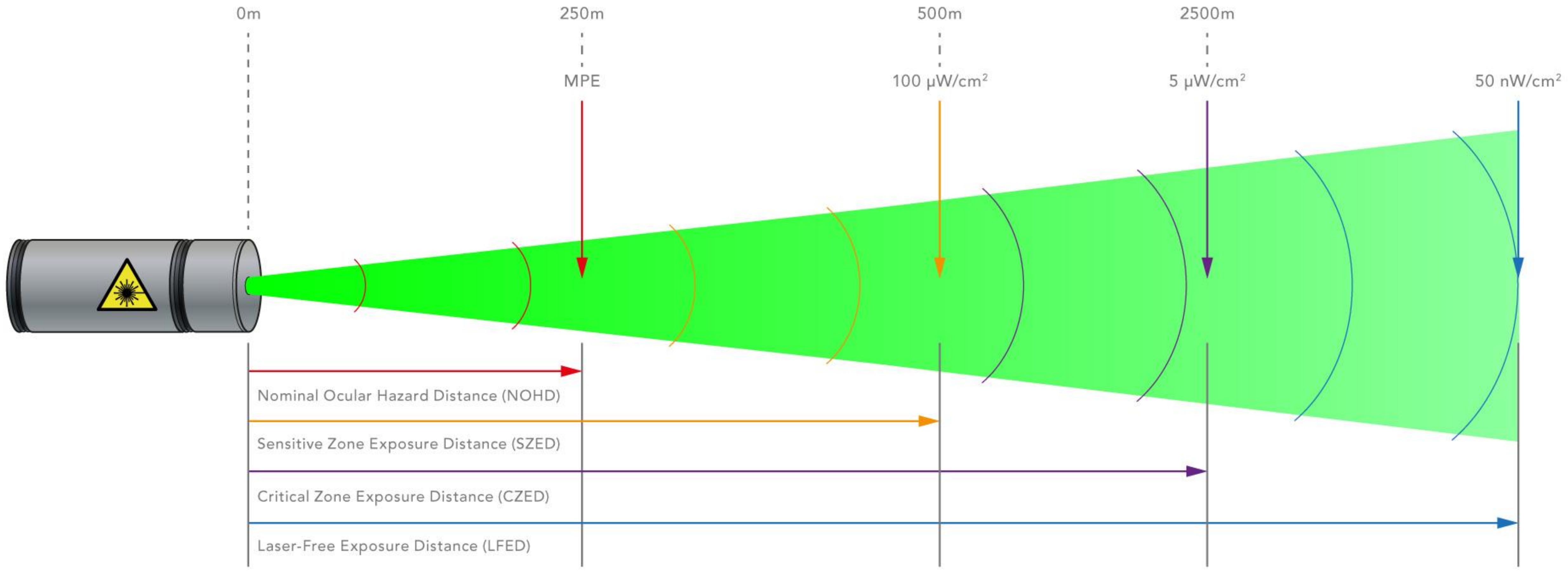
Lori Keesey, JPL/NASA 2011

R. Mark Elowitz

HYPERSPECTRAL IMAGING

SPACE COMMUNICATION

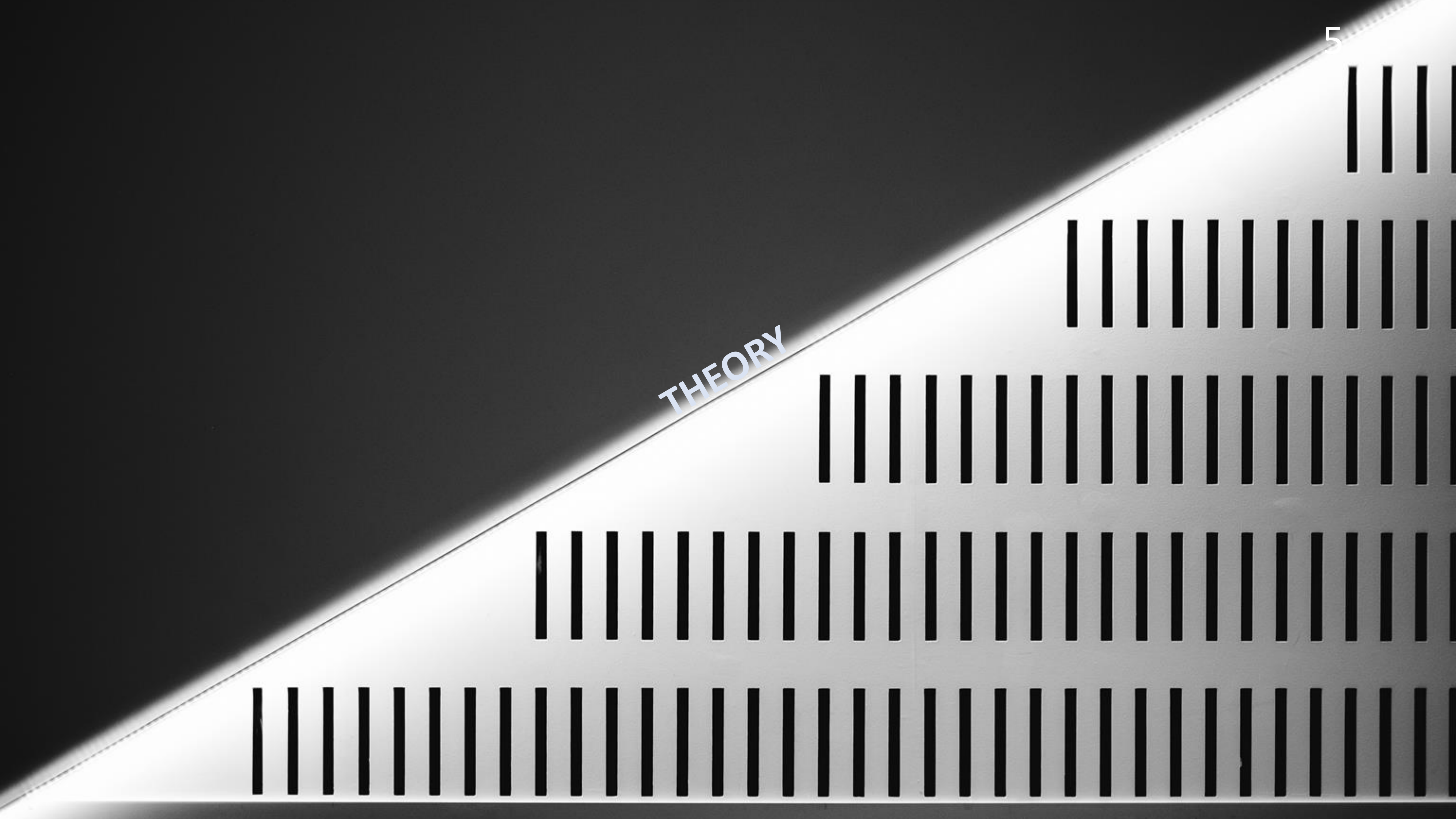
Beam divergence



Nibby Williams, ST Laserstrike 2017

Objective

- To perform finite-element simulation to study effect of compound axicon parameters and beam waist radius on the propagation distance of the Bessel-Gauss in comparison to normal Gaussian beam.


THEORY

Equation of Gaussian beam

Amplitude factor

$$E_G(x,y) = E_{G0}\frac{w_0}{w(y)}e^{-\frac{x^2}{w(y)^2}}e^{-i\varphi}$$

phase

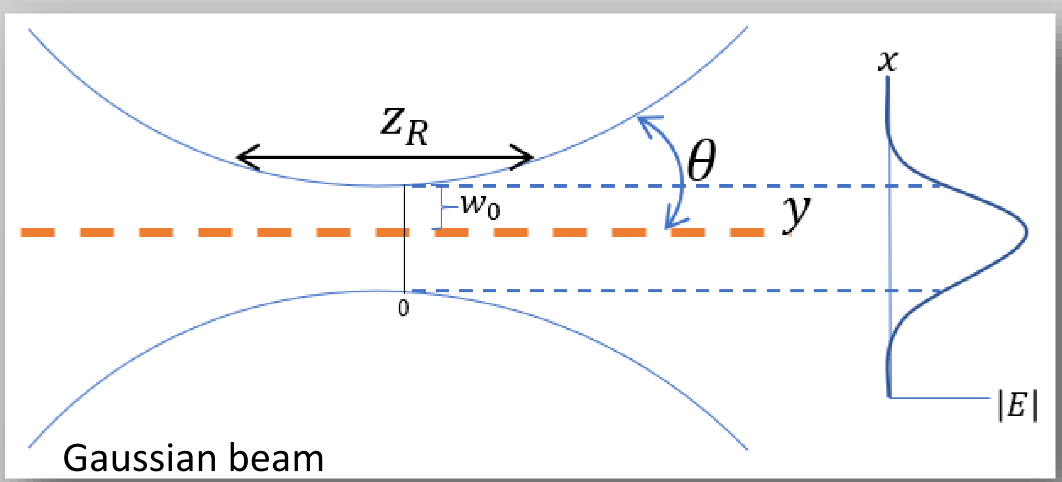
where $w(y) = w_0\sqrt{1+\frac{y^2}{Z_R^2}}$ Spot size

$$Z_R = \frac{\pi {w_0}^2}{\lambda}$$ Rayleigh

$$R(y) = y\left[1+\left(\frac{\pi w_0^2}{\lambda y}\right)^2\right]$$ Radius of curvature

$$\varphi = \mathrm{ky} - atan\frac{y}{z_R} + \frac{kx^2}{2R(y)}$$ Gouy phase shift

$$\theta = \frac{\lambda}{\pi w_0}$$ divergence



w_0 :beam waist

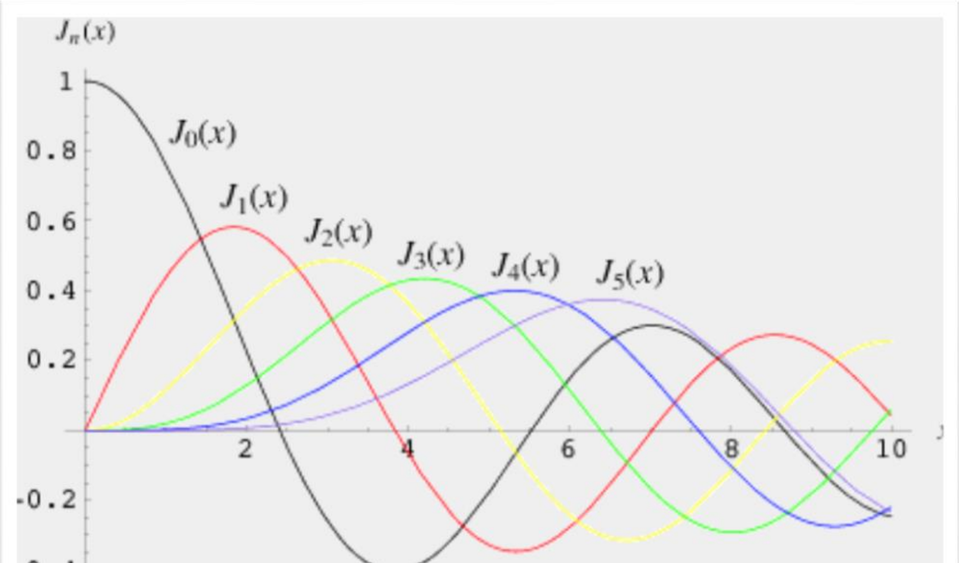
Equation of Bessel beam

$$E_B(x,y) = E_{B0} J_\nu(k_x x) e^{-ik_y y}$$

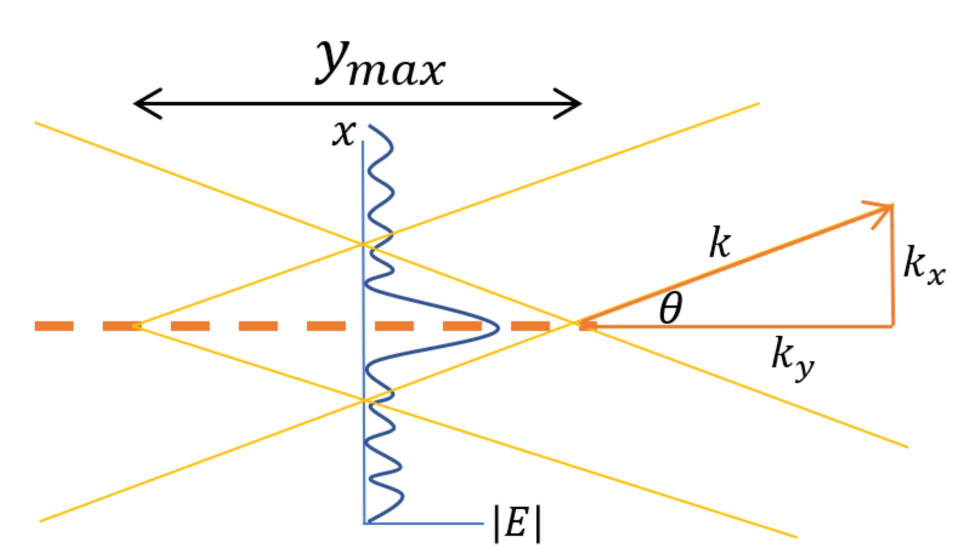
where $J_\nu(k_x x)$ is Bessel function of the first kind

For $\nu = 0$ $E_B(x,y) = J_0(k_x x) e^{-ik_y y}$

"Diffracting-free beam"



Bessel function Eric W. and Weisstein

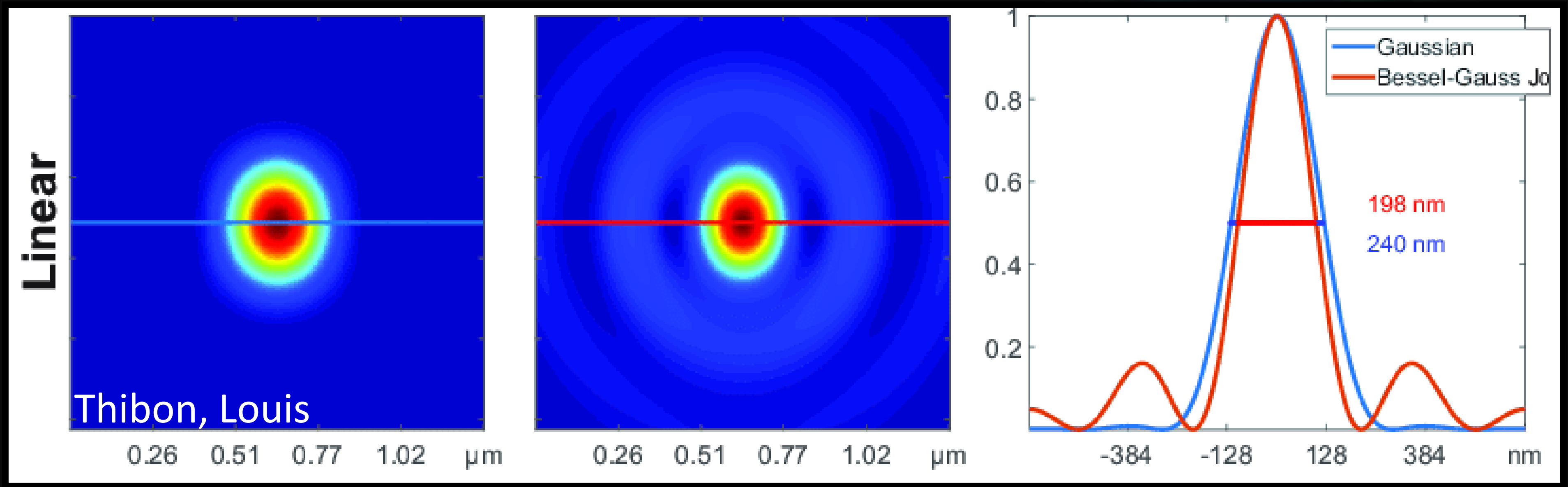


Bessel beam

Equation of Bessel-Gauss beam

$$E_{BG}(x,y) = E_0 J_0(k_x x)\frac{w_0}{w(y)}e^{-\frac{x^2}{w^2}}e^{-i\emptyset}$$

CROSS SECTION

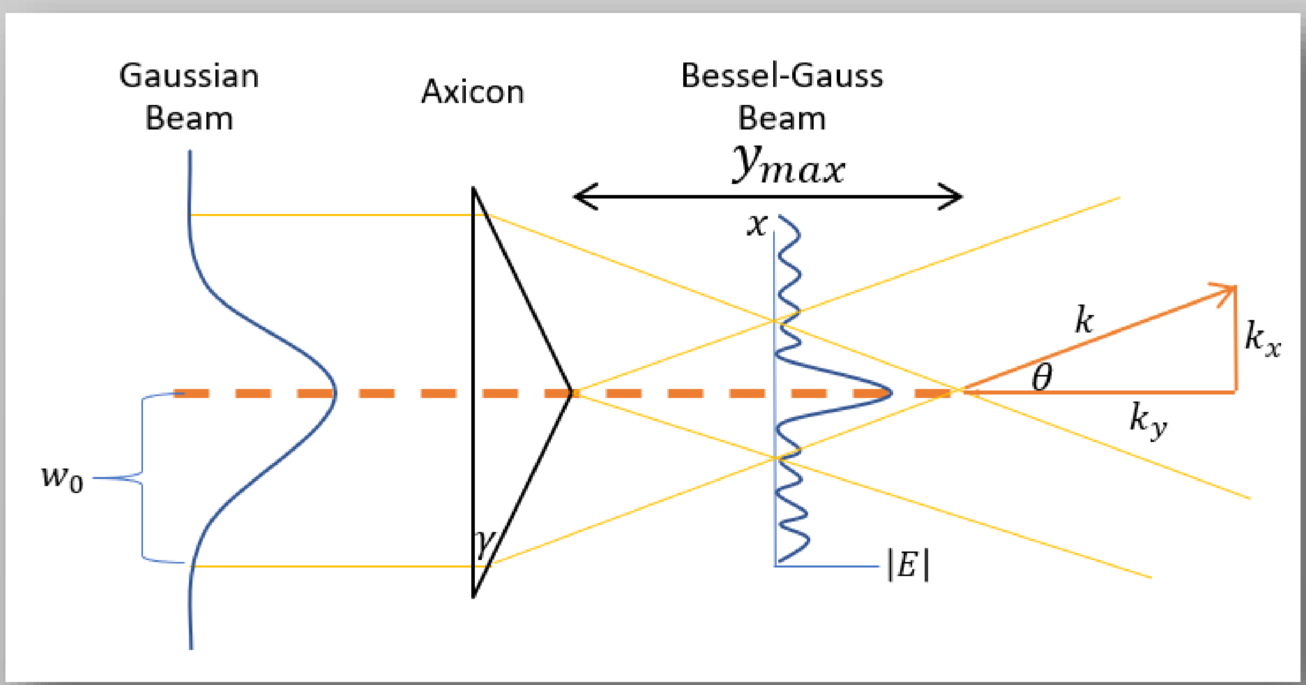


Gaussian beam profile

Bessel-Gauss beam profile

Axicon

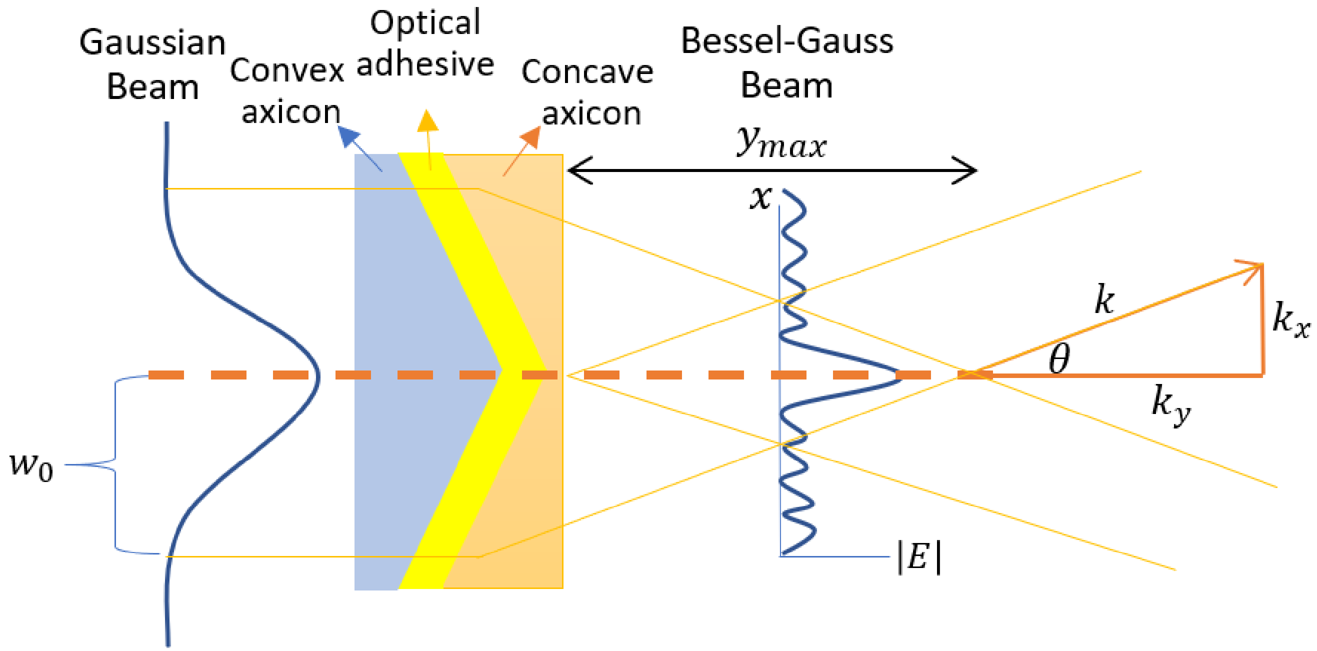
Axicons



How axicon work

COMSOL MULTIPHYSICS

+



Gaussian Beam
Convex axicon
Optical adhesive
Concave axicon
Bessel-Gauss Beam
y_{max}
x
k
k_x
θ
k_y
w_0
$|E|$

Choose the module

Optics

↓

Wave Optics

↓

EMW BEAM ENVELOPES

$$(\nabla - i\mathbf{k}_1) \times \mu_r^{-1}((\nabla - i\mathbf{k}_1) \times \mathbf{E}1) - k_0^2(\epsilon_r - \frac{j\sigma}{\omega\epsilon_0})\mathbf{E}1 = 0$$

Finite element method (FEM)

Define parameters

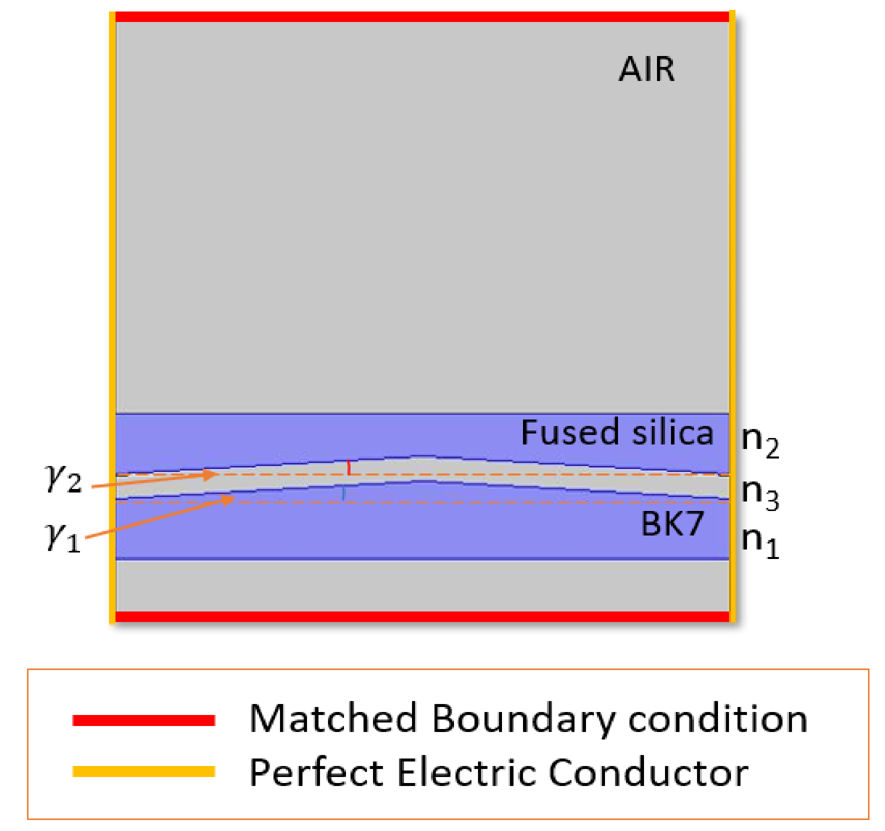
Variable	Expression	Description
w_l	0.532 µm	Wavelength
w_0	25 mm	Beam waist
E_p	0.150 J	Laser Pulse energy
t_p	6 ns	Laser pulse duration

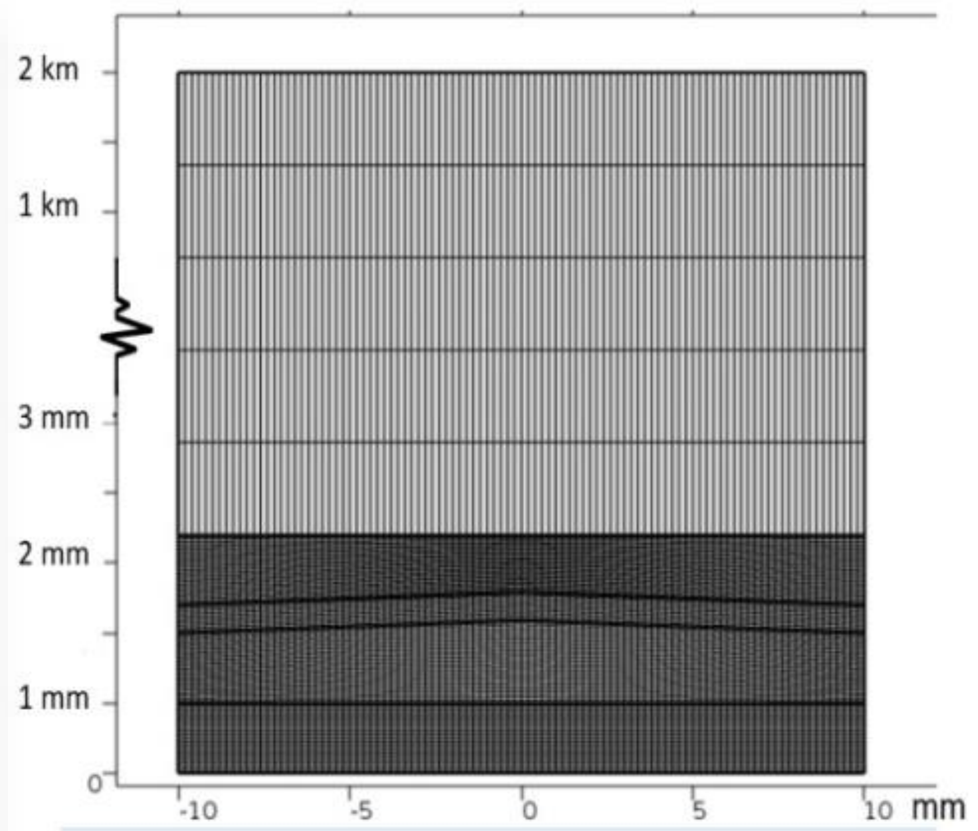
parameters of YAG laser

Create Geometry

Include material

Inject the beam



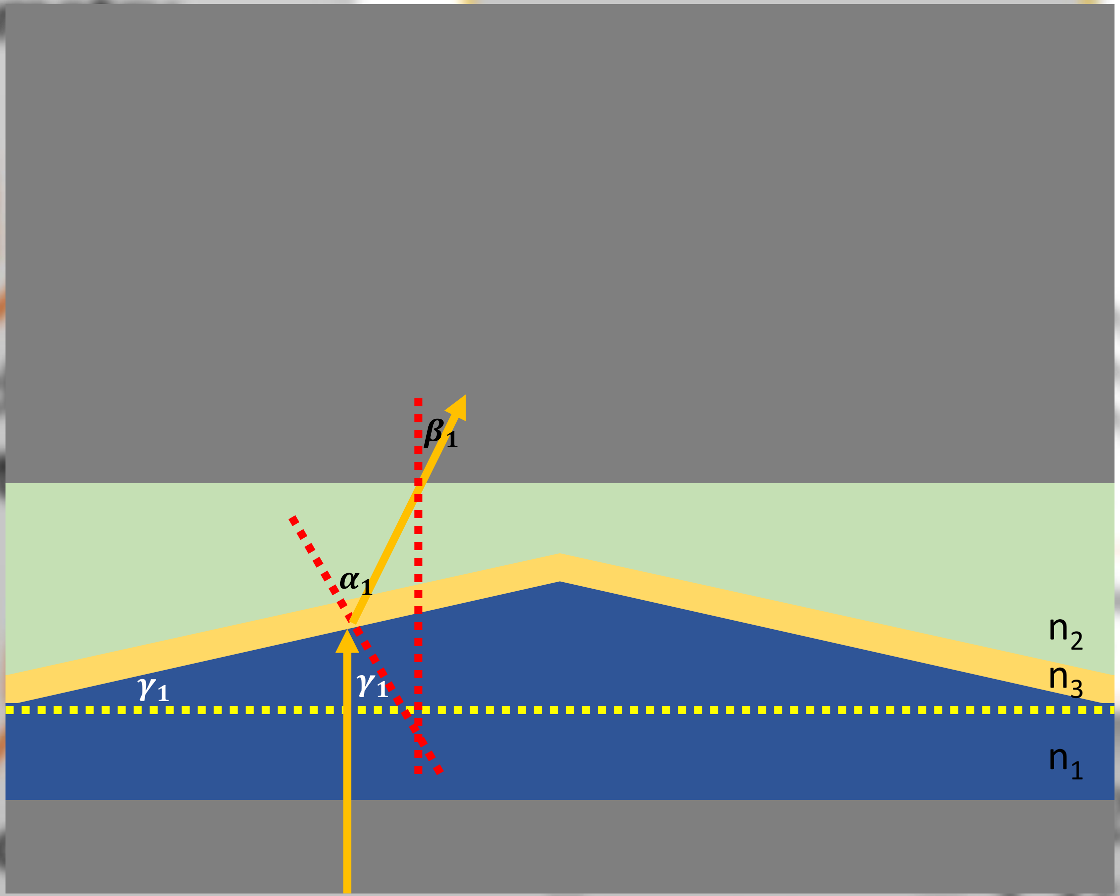


$$n_{BK7} = 1.520$$

$$n_{fusedsilica} = 1.461$$

$$n_{glue} = 1.573 - 1.580$$

$$\gamma_1 = 1.0° \quad \gamma_2 = 0.5°$$



Propagation constant

$$\beta_1 = \pi - \left(\frac{\pi}{2} - \alpha_1\right) - \left(\frac{\pi}{2} + \gamma_1\right)$$

$$k = k_x + ky = k\sin\beta_1 + k\cos\beta_1$$

$n_{fusedsilica} = 1.461$

$n_{glue} = 1.573 - 1.580$

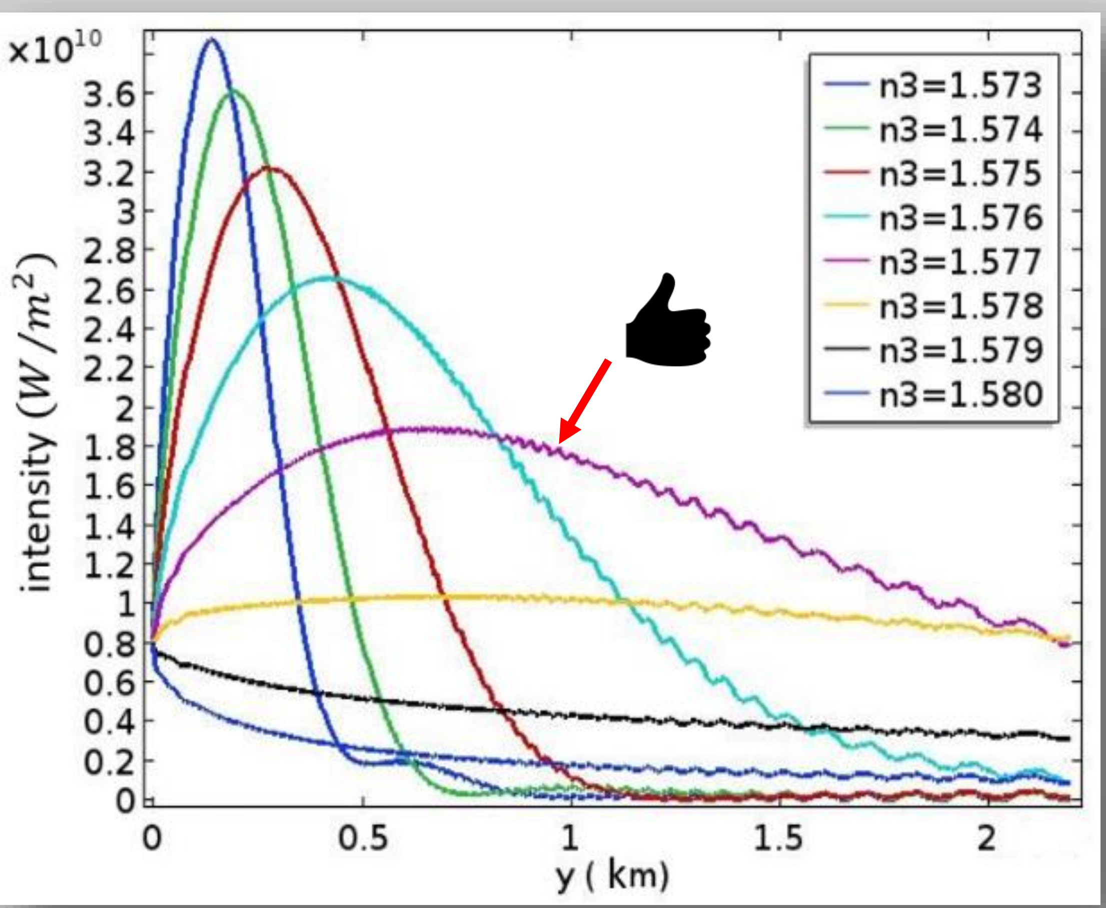
Section I

-Sweep the parameter n_3 (the interlayer refractive index) from 1.573-1.580 and find the optimum n_3.

Result I

Effect of n_3 on longitudinal intensity of Bessel-Gauss beam with w_0 = 25 mm

n_3 = 1.577

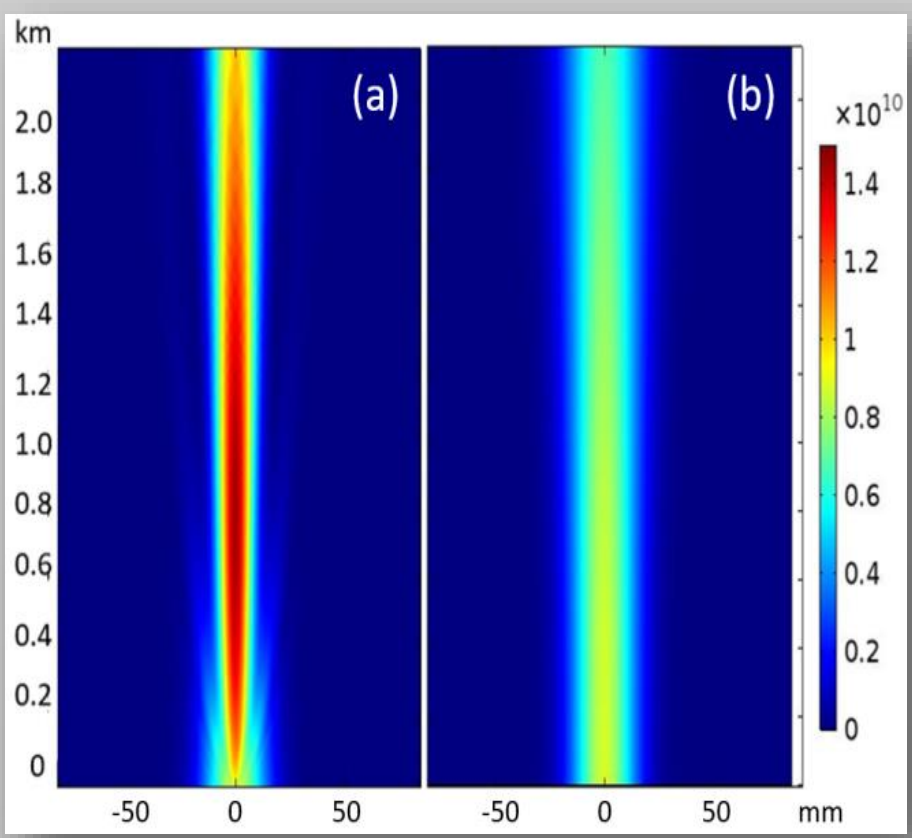


Section II

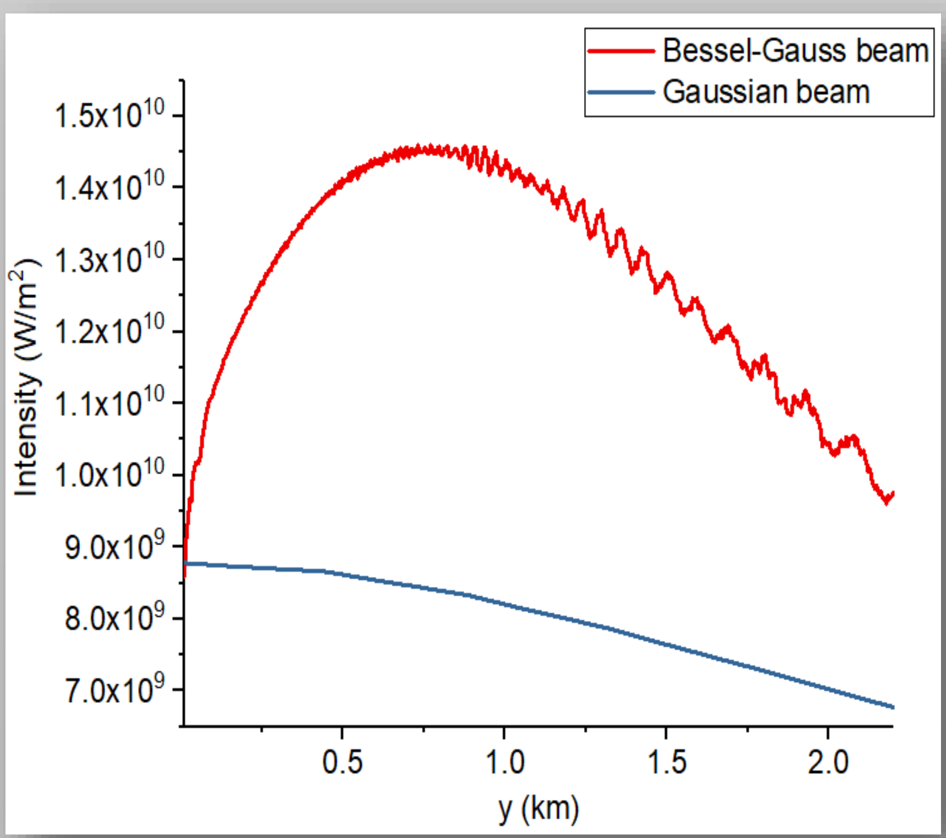
-Using the result from sec.I to contribute a Bessel-Gauss beam and compare to normal Gaussian beam with the same beam waist.

Results II

$n_3 = 1.5775$



Comparison of intensity profile

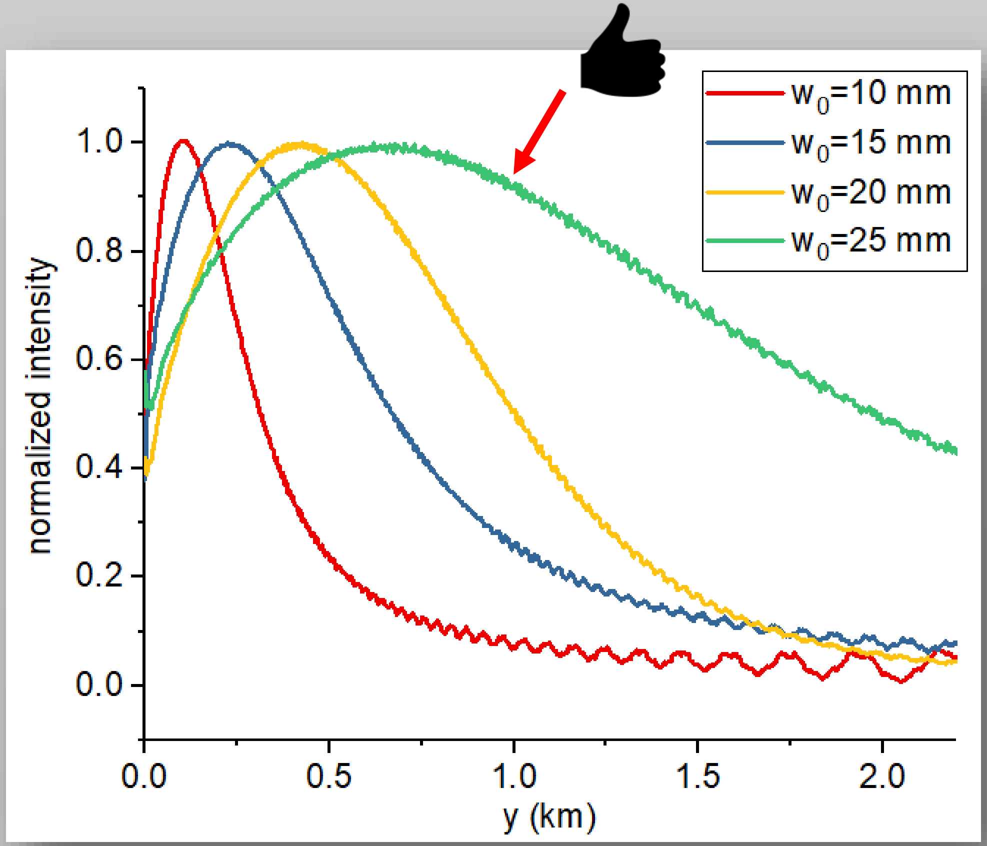


Longitudinal beam intensity for w_0 = 25 mm

Section III

-Sweep the waist diameter input of the beam from 10-25 mm.

Results III



Effect of input beam waist on longitudinal beam intensity of a produced Bessel-Gauss beam

Conclusions

- ✓ It is possible to generate a Bessel-Gauss beam by using numerical method from COMSOL® program.

- ✓ For an input beam waist 25 mm , a compound axicon can generate a beam output that can be delivered over a distance at least 2 km.

Future work

- ❑ Need to compare the results with the experiment.

Acknowledgements

- Assist. Prof. Dr.Chalongrat Daengngam Ph.D
- NanoPhotonics Research Group
- Development and Promotion of Science and Technology Talents Project (DPST)
- Department of Physics, Faculty of Science, Prince of Songkhla University
- COMSOL ® Multiphysics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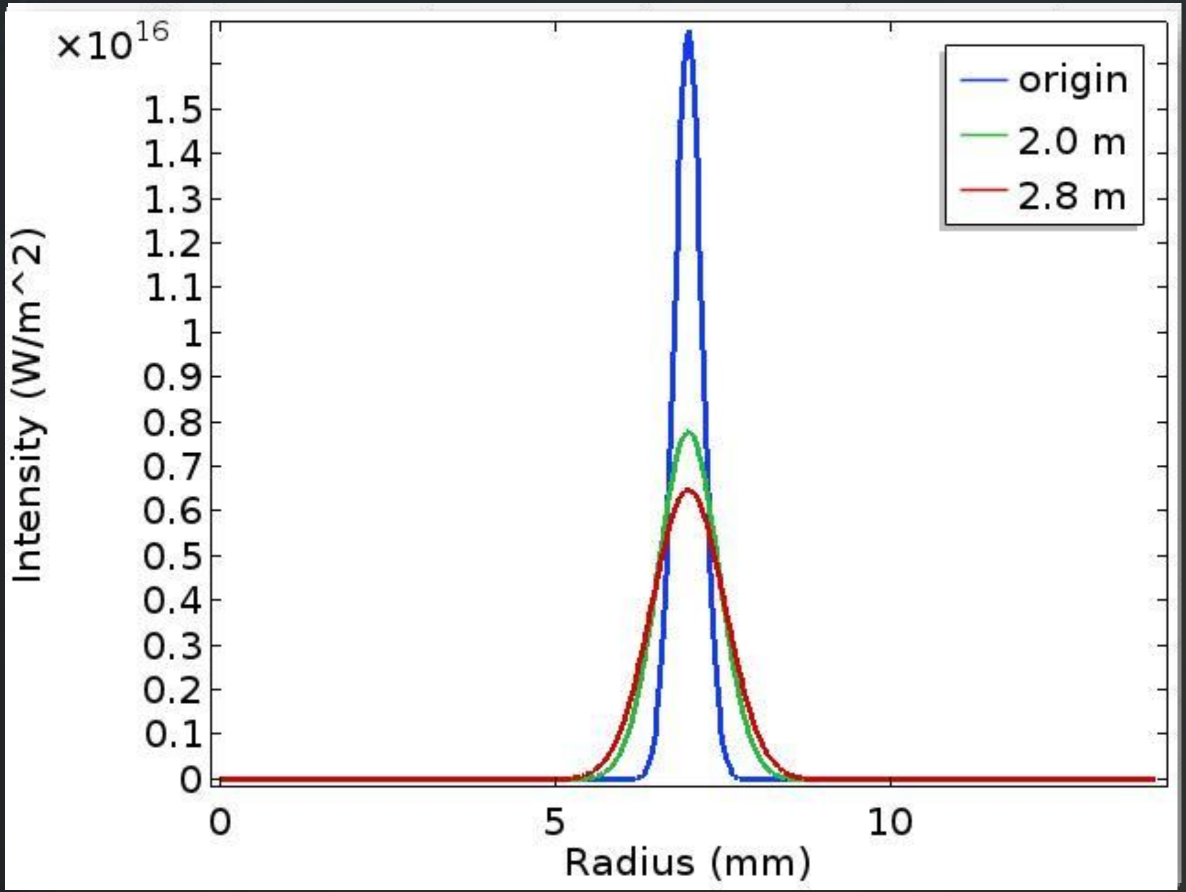
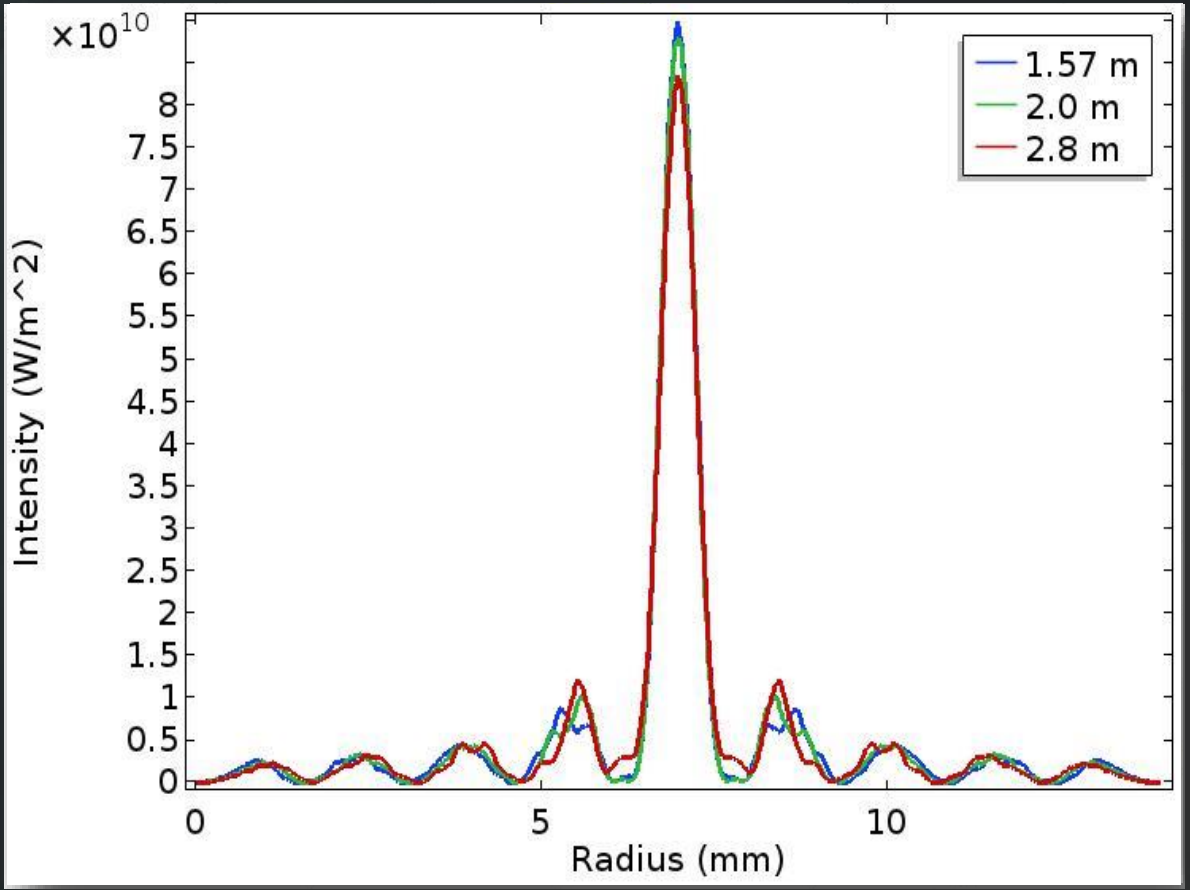
Complete Install

Thank You



Gaussian Beam



Bessel Gauss Beam

Single Axicon

$\tan\gamma = \frac{x}{a}$, $\tan\alpha = \frac{a}{z} \rightarrow \tan\alpha =$

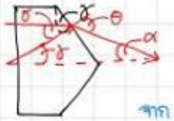
$n_1 \sin\gamma = n_2 \sin\theta$

$\sin\theta = \left(\frac{\sin\gamma}{n}\right) \longrightarrow \theta = \sin^{-1}\left(\frac{1}{n}\sin\gamma\right)$

$$z_{max} = \frac{a}{(n-1)\gamma}$$

$\frac{a}{z} = \tan\alpha \rightarrow z = \frac{a}{\tan\alpha}$ ต้องการ z_{max} ดังนั้น α_{min}

หาค่า α_{min} ;



$\alpha = \pi - \{\gamma + (\pi - \theta)\}$

$\alpha = \theta_1 - \gamma$

จาก $n_1 \sin\theta_1 = n_2 \sin\theta_2$

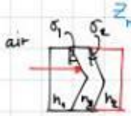
$n \sin\gamma = \sin\theta$

when $\alpha_{min} \rightarrow \theta_{min} \sim n\gamma$; $\alpha_{min} \sim n\gamma - \gamma = (n-1)\gamma$

$$z_{max} = \frac{a}{(n-1)\gamma} \; \#$$

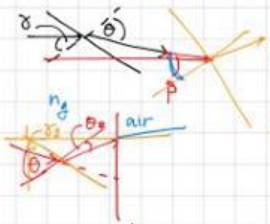
where a = waist radius, γ = axicon angle.

our model ;



After passing convex axicon ; $n_1 \sin\theta_1 = n_2 \sin\theta_2$

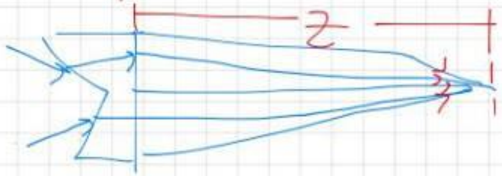
$n_1 \sin\gamma = n_g \sin\theta \rightarrow \theta = \sin^{-1}\left\{\left(\frac{n_1}{n_g}\right)\sin\gamma\right\}$



incident angle II ; $\theta = \beta + \gamma_2$

using $n_g \sin(\beta + \gamma_2) = n_2 \sin\theta_2$

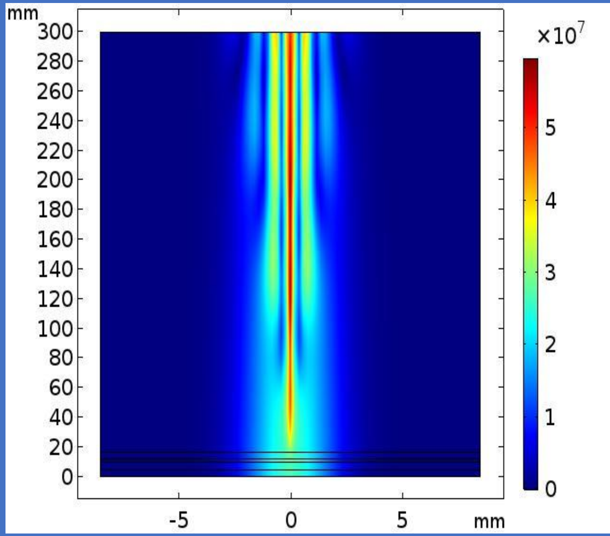
$\sin\theta_2 = \frac{n_g}{n_2}\sin(\beta + \gamma_2)$



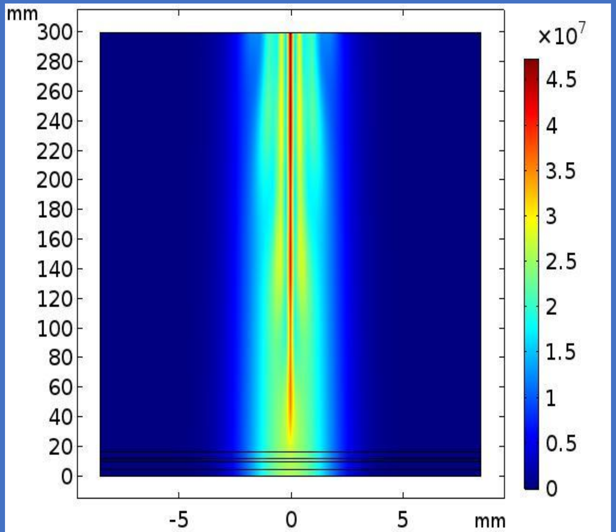
FOR $\gamma_1 = 1.0°$

$\gamma_2 = 0.5°$

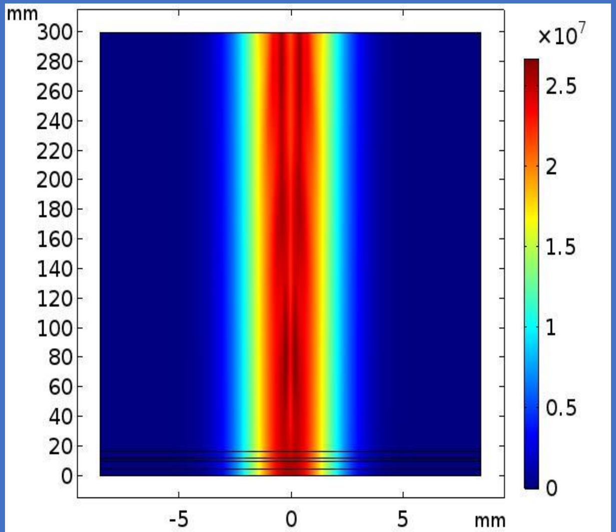
$n_g = 1.4$



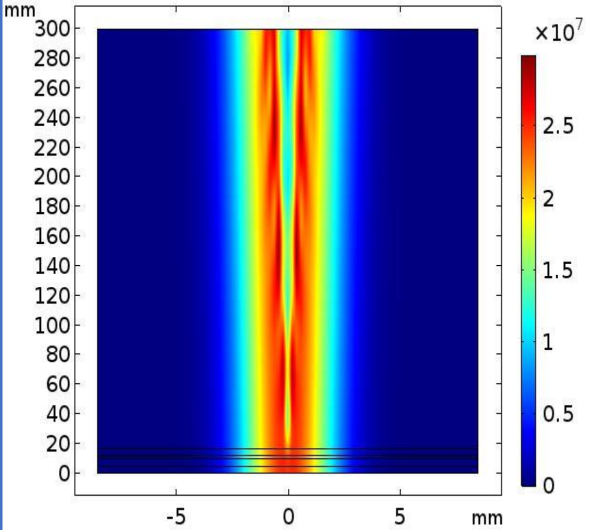
$n_g = 1.5$



$n_g = 1.6$



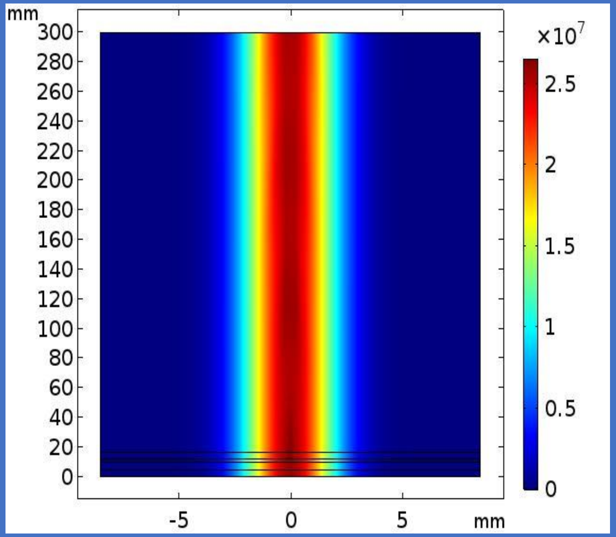
$n_g = 1.7$



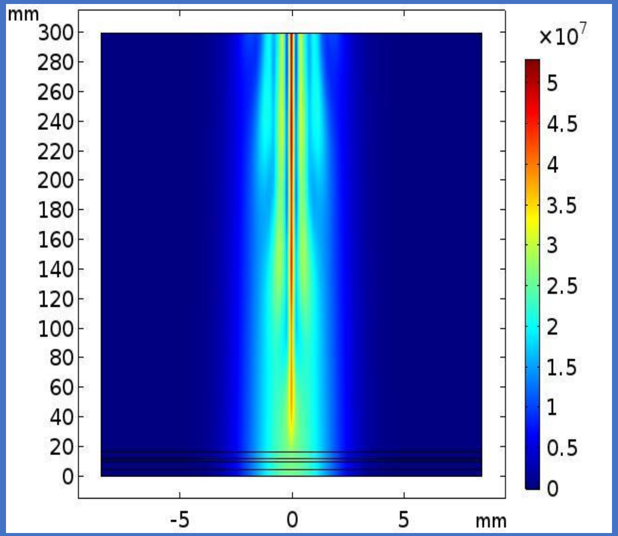
FOR $\gamma_1 = 0.5°$

$\gamma_2 = 1.0°$

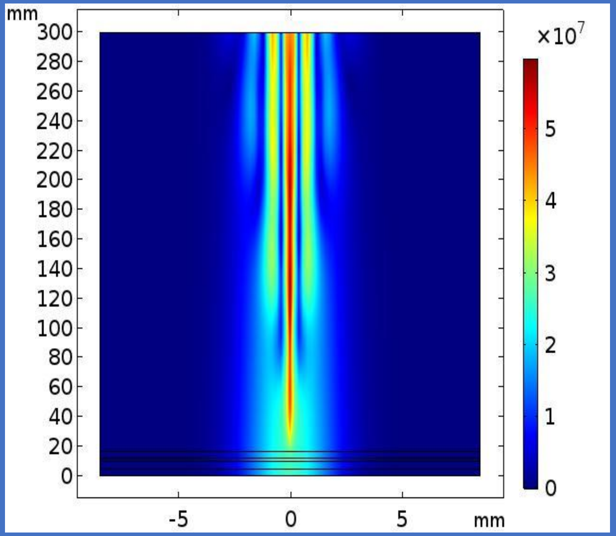
$n_g = 1.4$



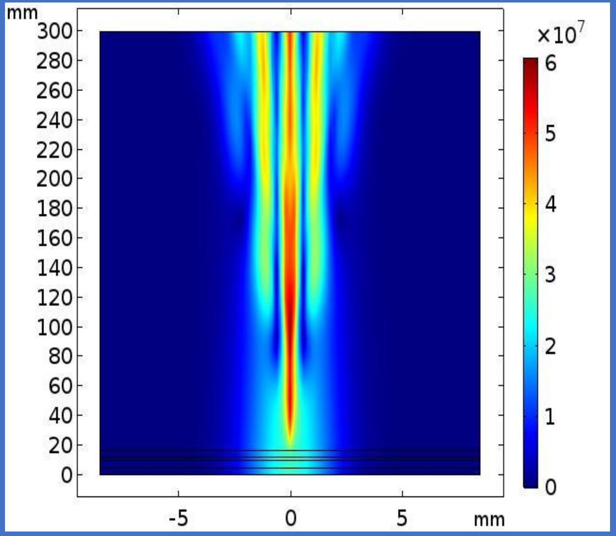
$n_g = 1.5$



$n_g = 1.6$



$n_g = 1.7$



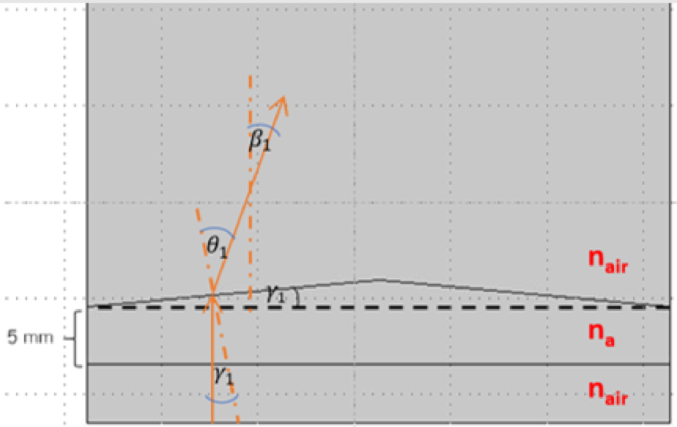


Figure 3.3 (b) Direction of the beam from a single axicon

First, we use Snell's law to calculate for refracted angle θ_1.

Hence, the value of $\theta_1 = sin^{-1}(n_a sin(\gamma_1))$

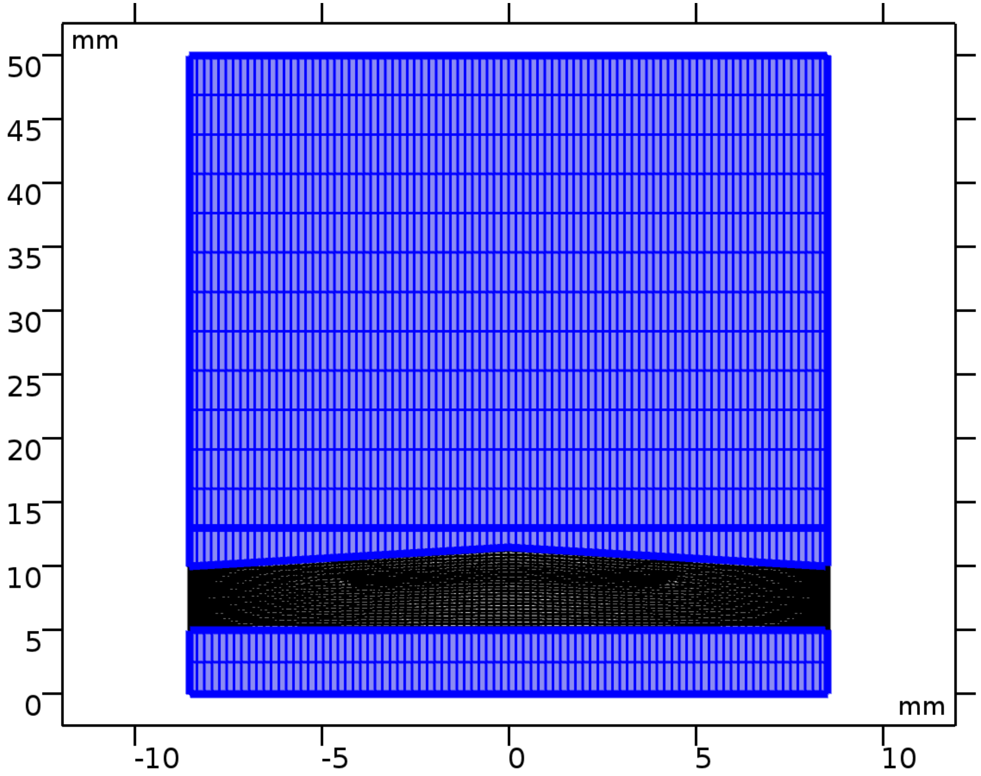
$$\theta_1 = sin^{-1}(1.52 sin(1.74e^{-4} rad)) = 2.62e^{-4}\text{rad.}$$

Then we calculate the refracted angle (θ_1) with respect to the y-axis (β_1) by using mathematics on geometry. After that, we obtained the angle of the beam:

$$\beta_1 = \pi - \left(\frac{\pi}{2} - \theta_1\right) - \left(\frac{\pi}{2} + \gamma_1\right) = 8.73e^{-5}\text{rad.}$$

We define the propagation constant when the beam pass through the axicon:

$$k = k_x + k_y = ksin\beta_1 + kcos\beta_1.$$



For the total power of the Gaussian beam across an arbitrary plane at z,

$$P = 2nc\epsilon_0 \iint E \cdot E^* dA$$

$$P = 2nc\epsilon_0 \frac{w_0^2 E_0^2}{w^2(z)} \int_0^{2\pi} \int_0^{\infty} e^{\left(-\frac{2r^2}{w^2(z)}\right)} r dr d\theta$$

$$P = 2nc\epsilon_0 \frac{\pi w_0^2}{2} E_0^2,$$