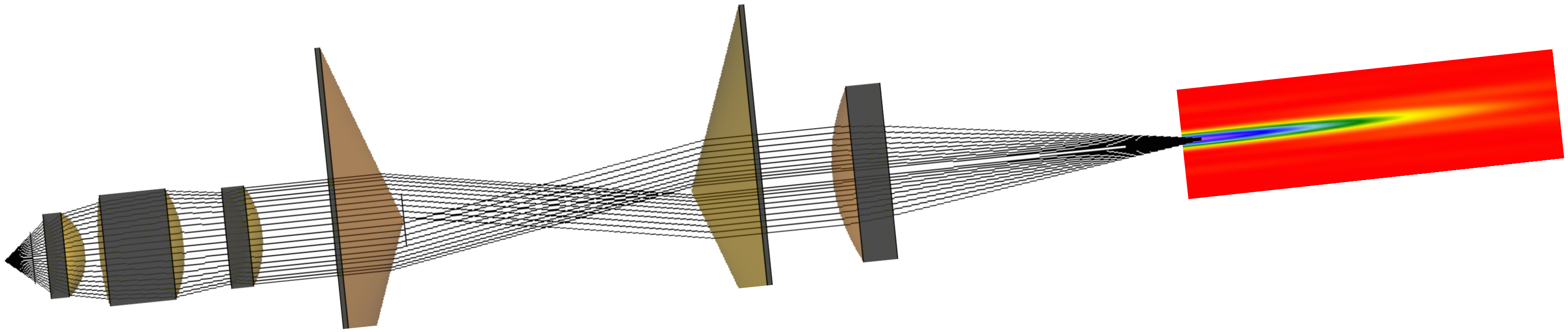
Beam Delivery System (BDS.0004 v1.2)

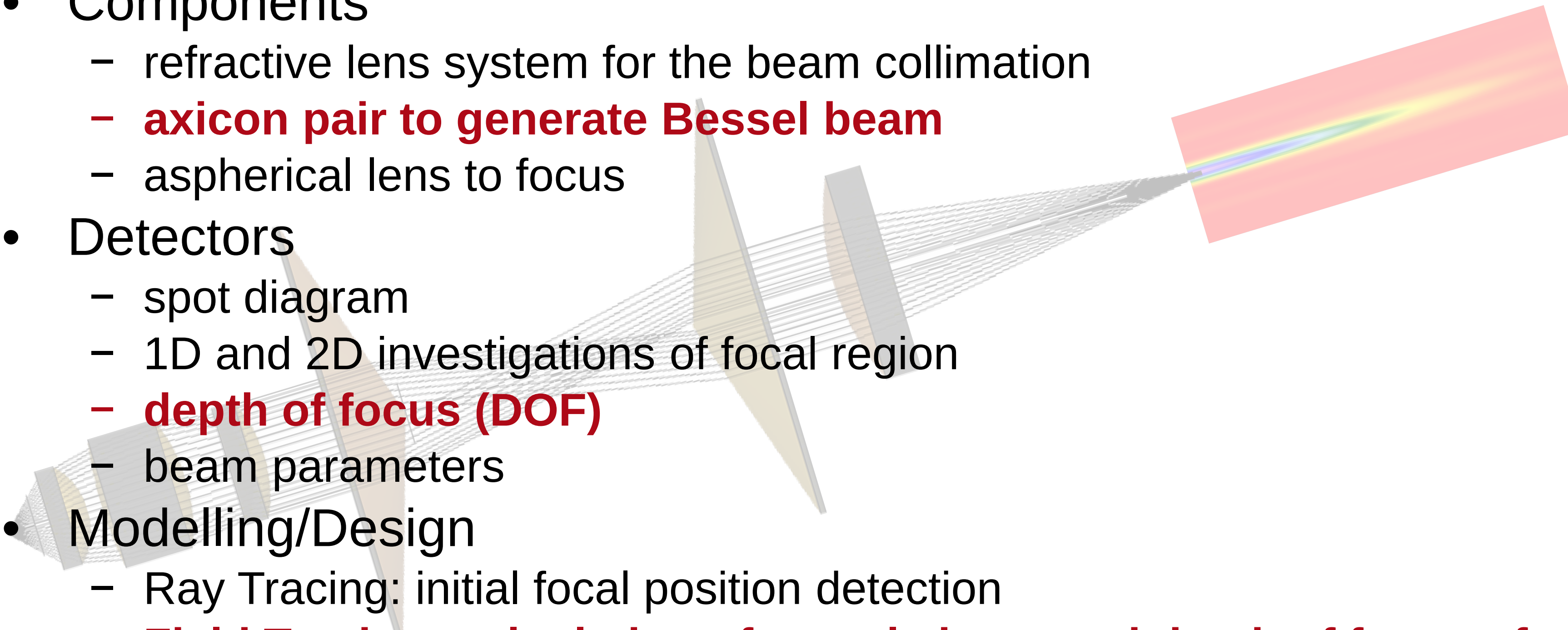
Optimization of Focal Spot Size and Depth of Focus by Generating a Bessel Beam Using an Axicon Pair



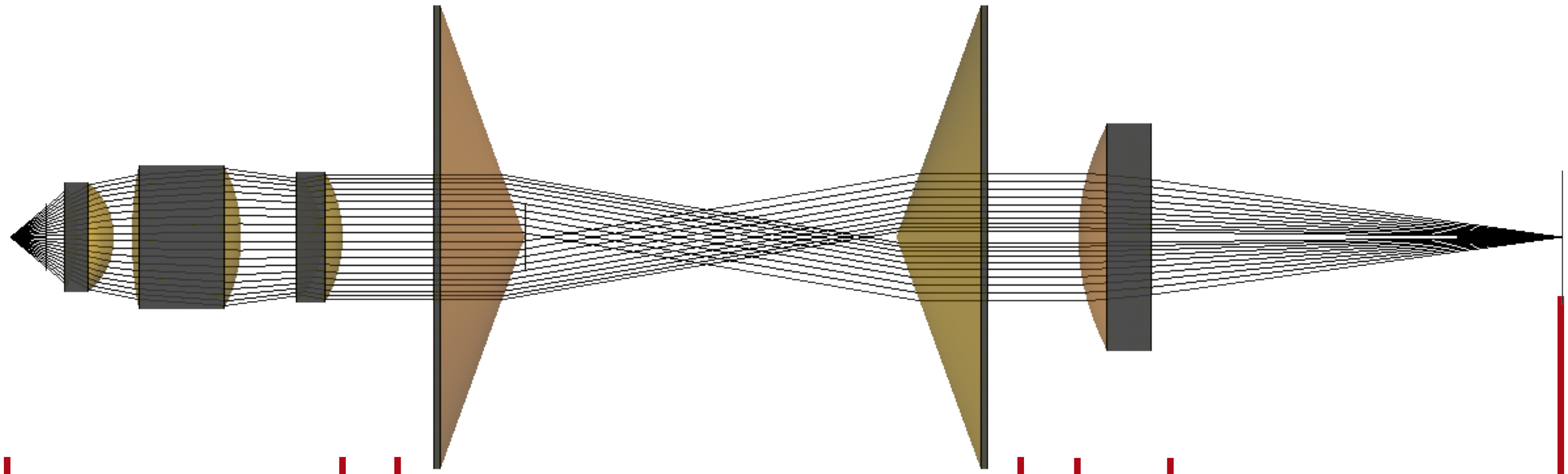
Application Example in a Nutshell

System Details

- Source
  - astigmatic IR laser diode
- Components
  - refractive lens system for the beam collimation
  - **axicon pair to generate Bessel beam**
  - aspherical lens to focus
- Detectors
  - spot diagram
  - 1D and 2D investigations of focal region
  - **depth of focus (DOF)**
  - beam parameters
- Modelling/Design
  - Ray Tracing: initial focal position detection
  - **Field Tracing: calculation of actual shape and depth of focus of the Bessel beam**



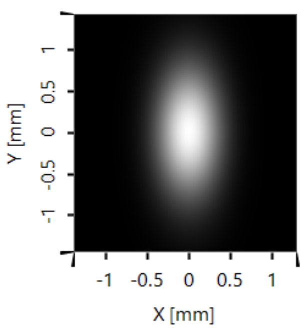
System Illustrations



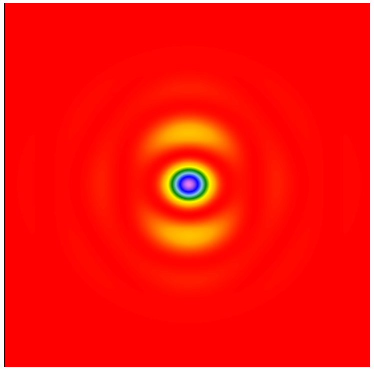
collimation objective lens

axicon pair **generating Bessel beam**

focusing asphere from catalog

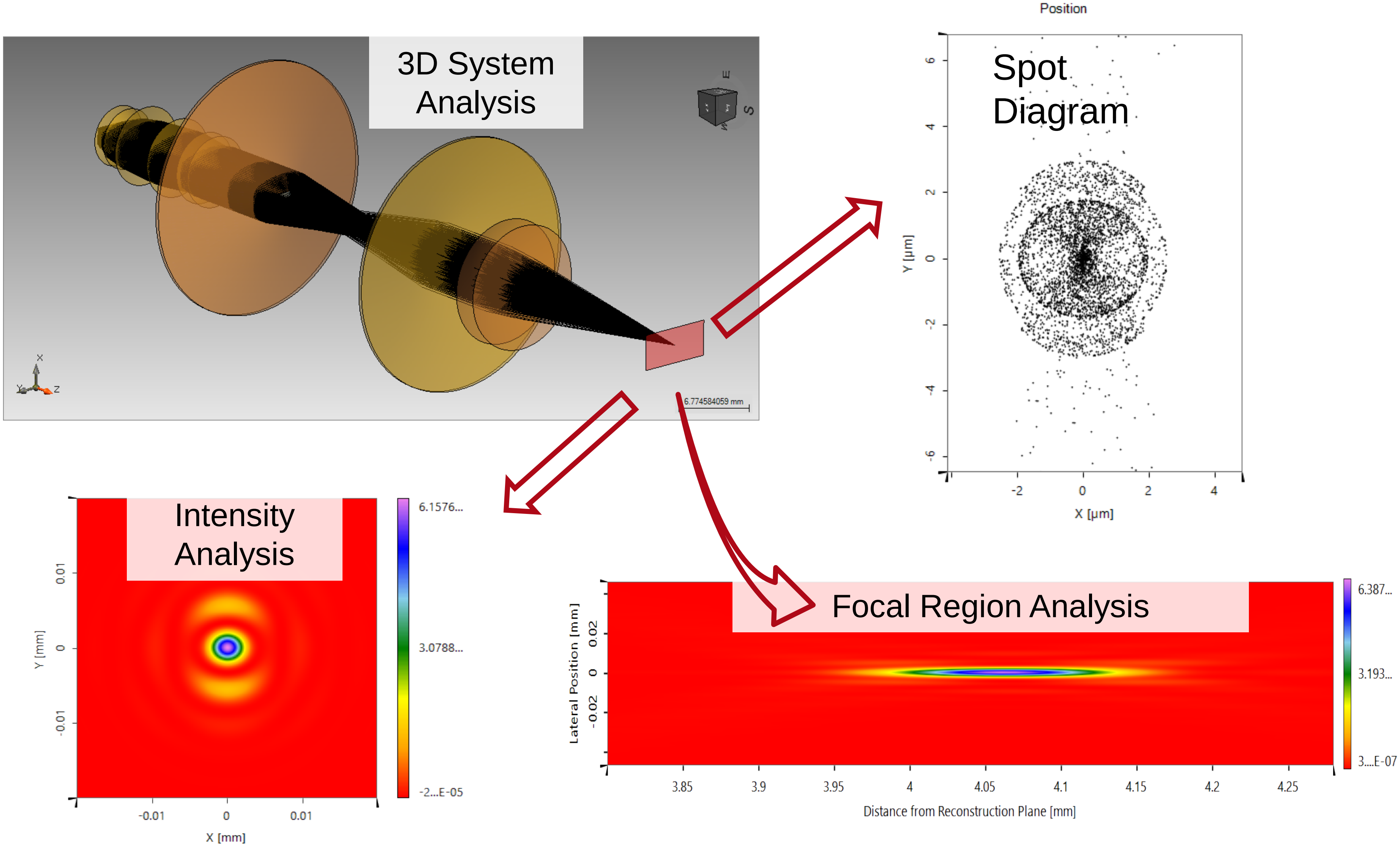


asymmetric Gaussian beam of IR laser diode



focused intensity distribution

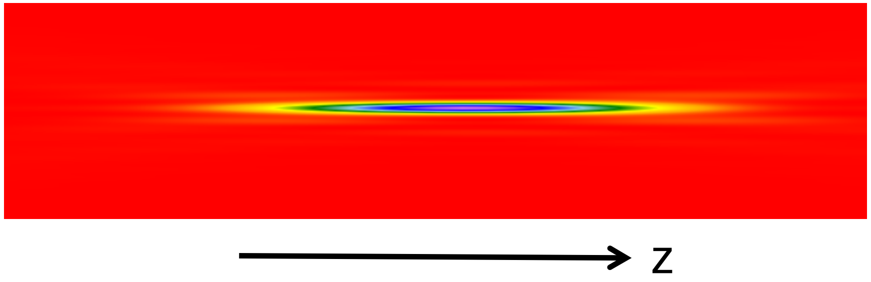
Modelling & Design Results



Additional VirtualLab Features

In this example you benefit from the following selected features:

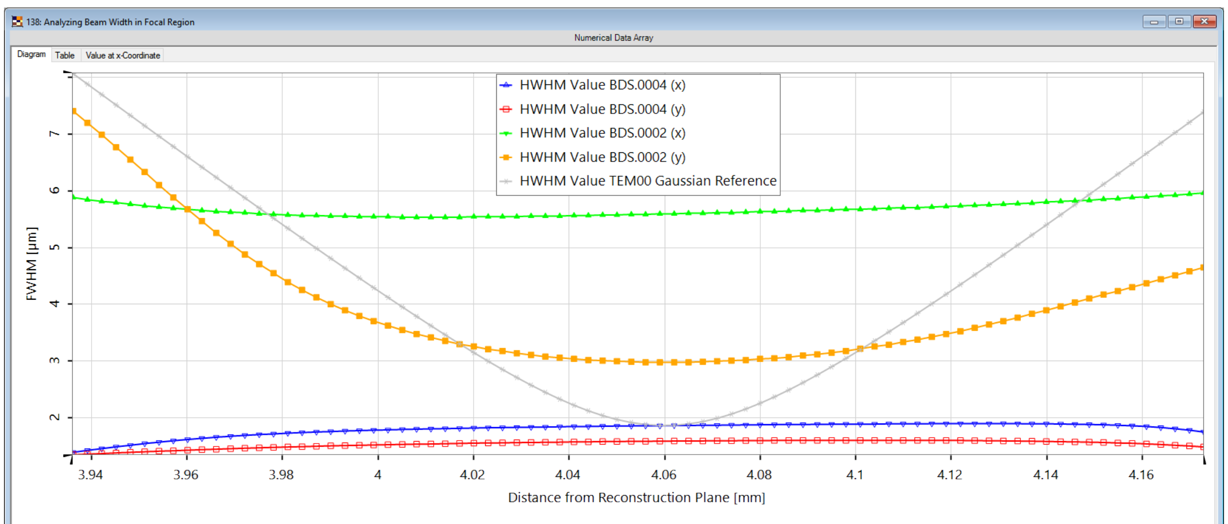
- focal region analysis by:
  - profile line detector
  - parameter run document
  - HWxM detector

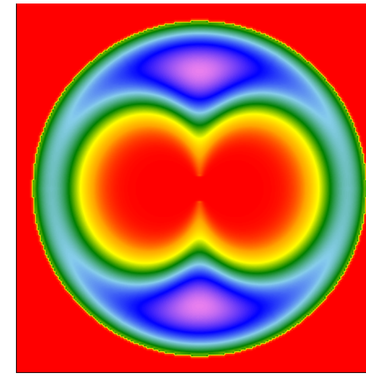


- get different informative/illustrative results such as
  - quality of beam: beam size and shape
  - depth of focus
  - diverse 2D & 3D diagrams demonstrating the beam propagation along the optical axis within the focal region

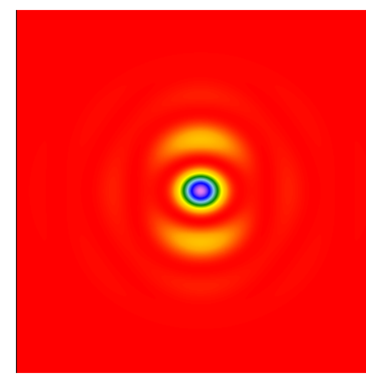
Summary

- In this example it was shown how the **focal spot size** can be reduced and the **depth of focus** can be increased by a **pair of axicon lenses**.
- The propagation of a **Bessel beam within the focal region** was analyzed.
- VirtualLab enables the **physical optics based profile and focus analysis** of beams generated by **special components like e.g. axicons**.





Beam after Aspherical Lens



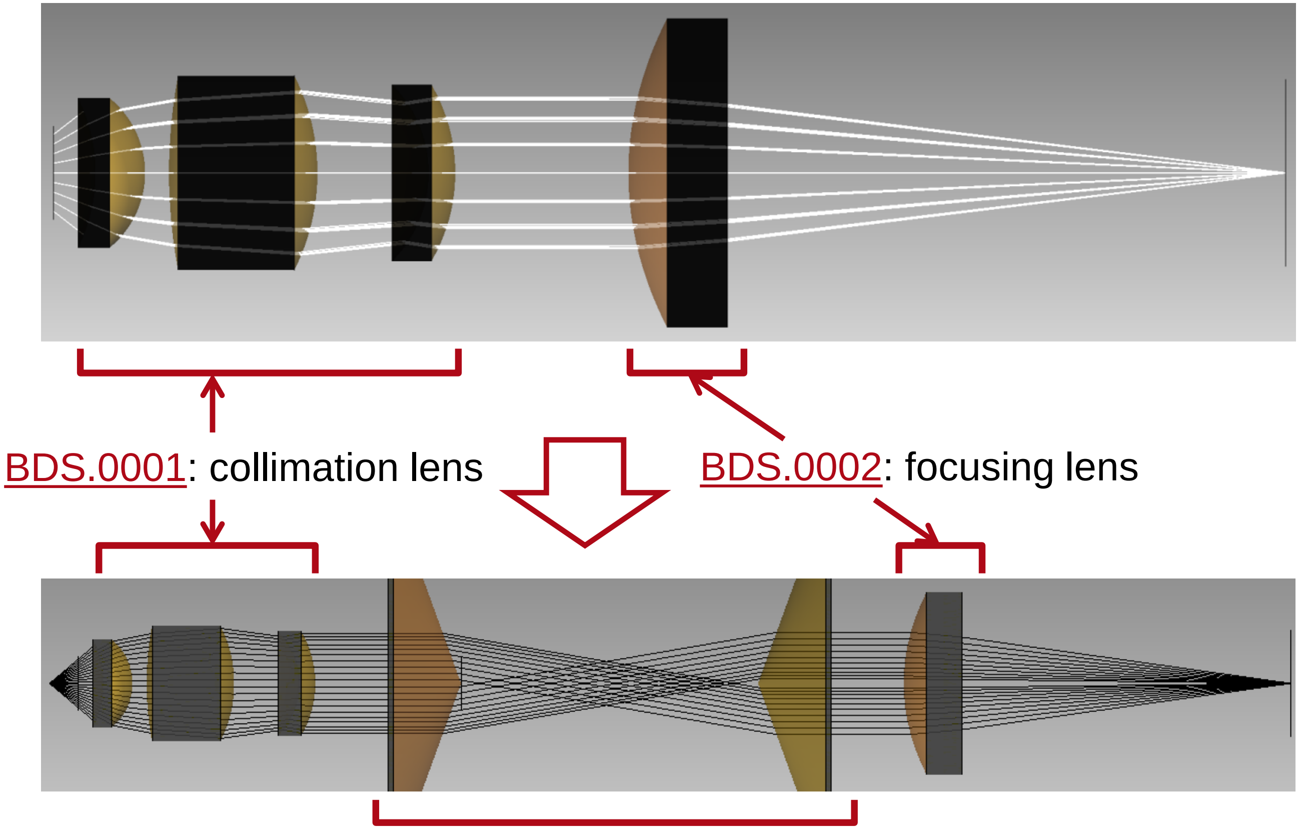
Beam at Focus

Application Example in Detail

System Parameters

Context of this Application Example

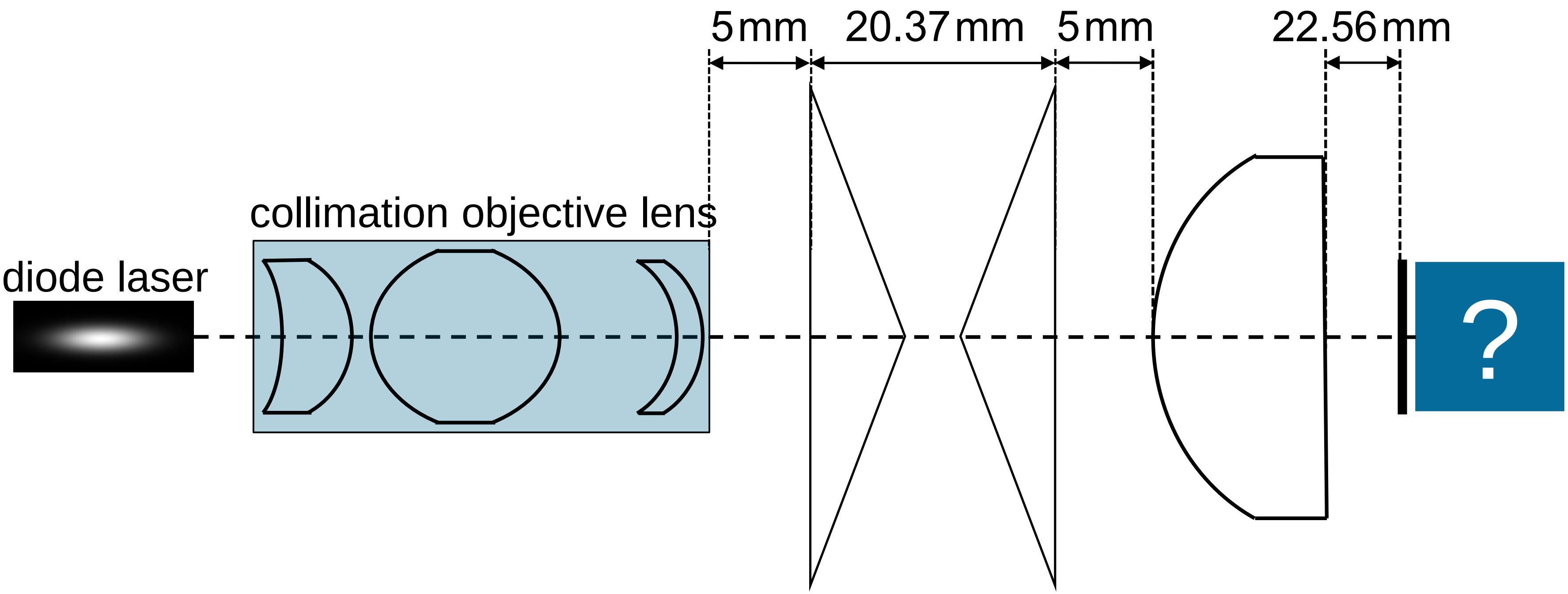
This application example demonstrates the **generation of a “non-diffractive” Bessel beam by an axicon lens** pair to **reduce the focal spot size** and to **increase the depth of focus**.



BDS.0004: **axicon lens pair** for Bessel beam generation

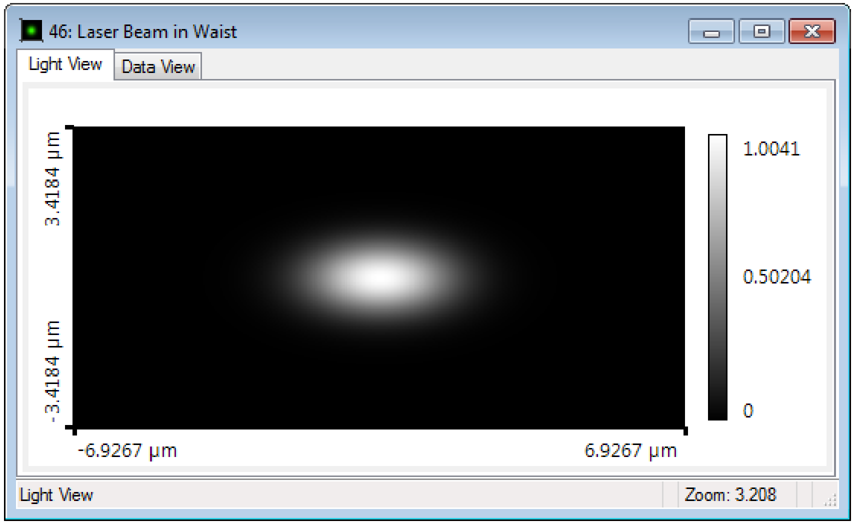
In BDS.0002 we have used an aspherical lens to focus the beam. In this example we include an axicon lens pair in front of the aspherical lens.

Modeling Task



axicon lens pair:
two identical axicon lenses are used to reduce the focal spot size and to increase the depth of focus

Specs: Uncollimated Input Laser Beam

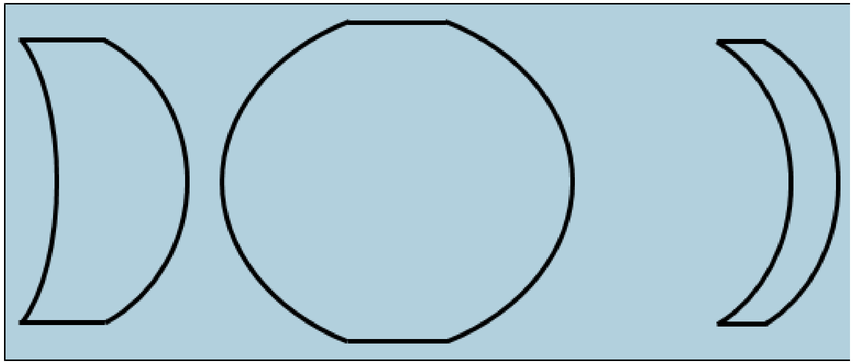


Single Mode IR Diode Laser from Laser Components

Parameter	**Value (& Unit)**
name/type	WSLD-1064-050m-1-PD
wavelength	1064 nm
divergence of beam intensity	**10° × 20°** (FWHM) i.e. 8.49° × 16.99° (referring to $1/e^2$)
polarization	linear (e.g. parallel to x-axis)

same as in BDS.0001

Specs: Collimation Lens and Subsequent Light

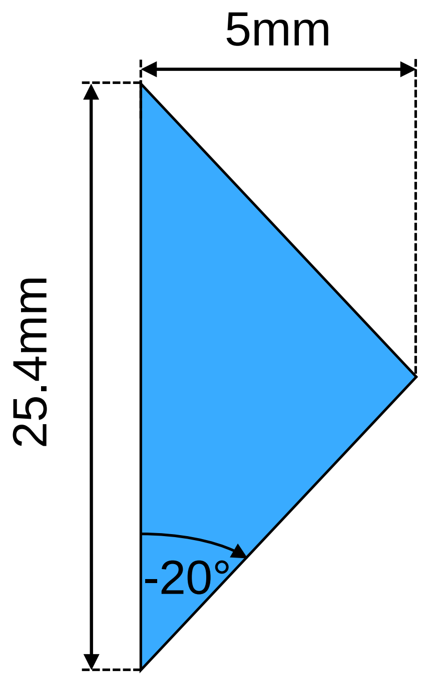


Lens from BDS.0001;
Beam Parameters behind it:

Parameter	Value & Unit
$1/e^2$ radius X × Y	936.22 µm × 1.8607 mm
$1/e^2$ divergence angle X × Y	0.021245° × 0.012396°
M^2 in X × Y direction	1.018 × 1.1802
RMS of wavefront error	~0.03λ

Specs: Axicon Lens Pair

- The axicon pair consists of two identical axicon type lenses.
- The opening angles are usually defined counter clockwise.

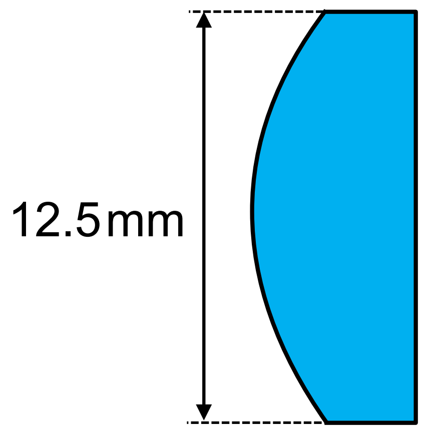


Parameter	Value & Unit
diameter	25.4 mm
width	5 mm
opening angle	-20°
material	N-BK7

The second axicon is placed parallel to the first axicon along the optical axis at a relative distance of 20.3672 mm. The opening angle is +20°. As a result the axicon pair acts like a beam expander with a ratio of 1.0.

Specs: Aspherical Focusing Lens

- A convex-plano aspherical lens from Asphericon is chosen from catalog.
- Model: ALL12-25-S-U
  (A12-25LPX)



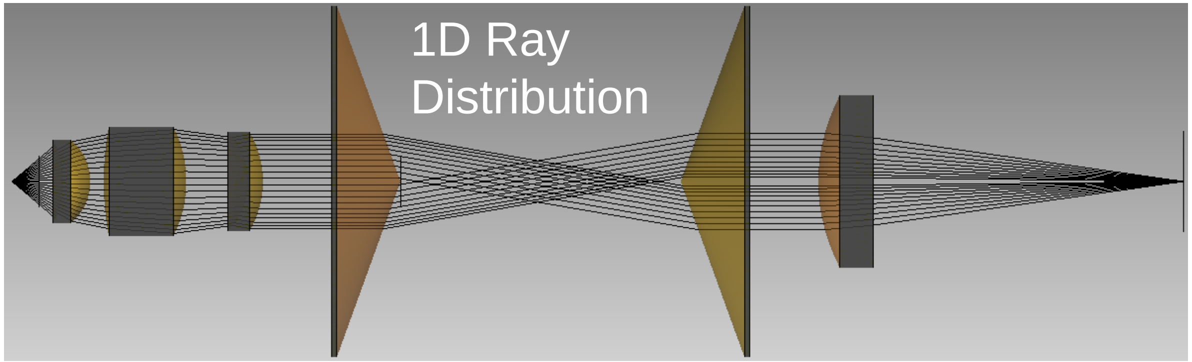
Parameter	Value & Unit
diameter	12.5mm
effective focal length	25mm
back focal length	22.354mm
numerical aperture	0.23
center thickness	4.0mm
marginal thickness	2.4mm
material	N-BK7

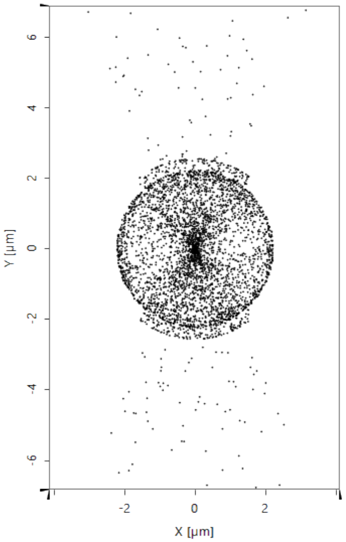
In BDS.0002 the back focal length of 22.576mm was determined for the laser diode with 1064nm wavelength.

Application Example in Detail

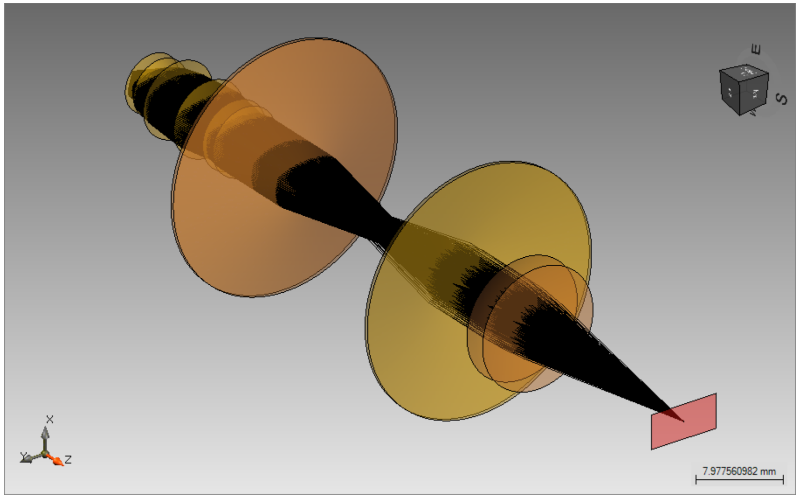
Simulations & Results

Ray Tracing: Analysis of the Beam Focus



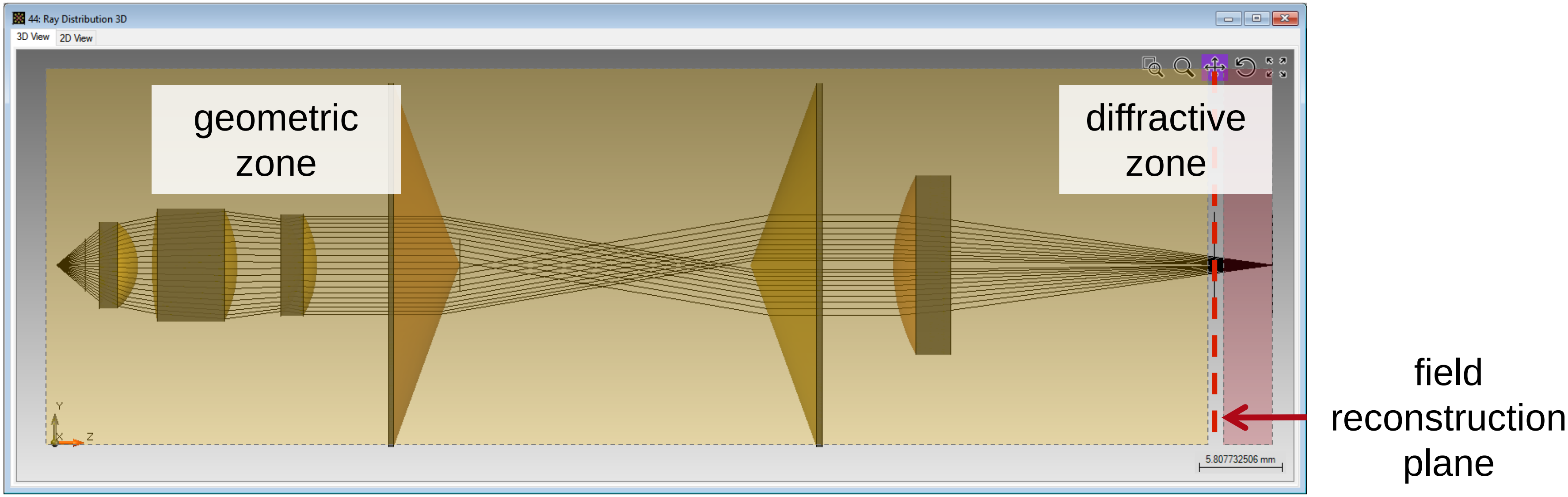


Spot
Diagram



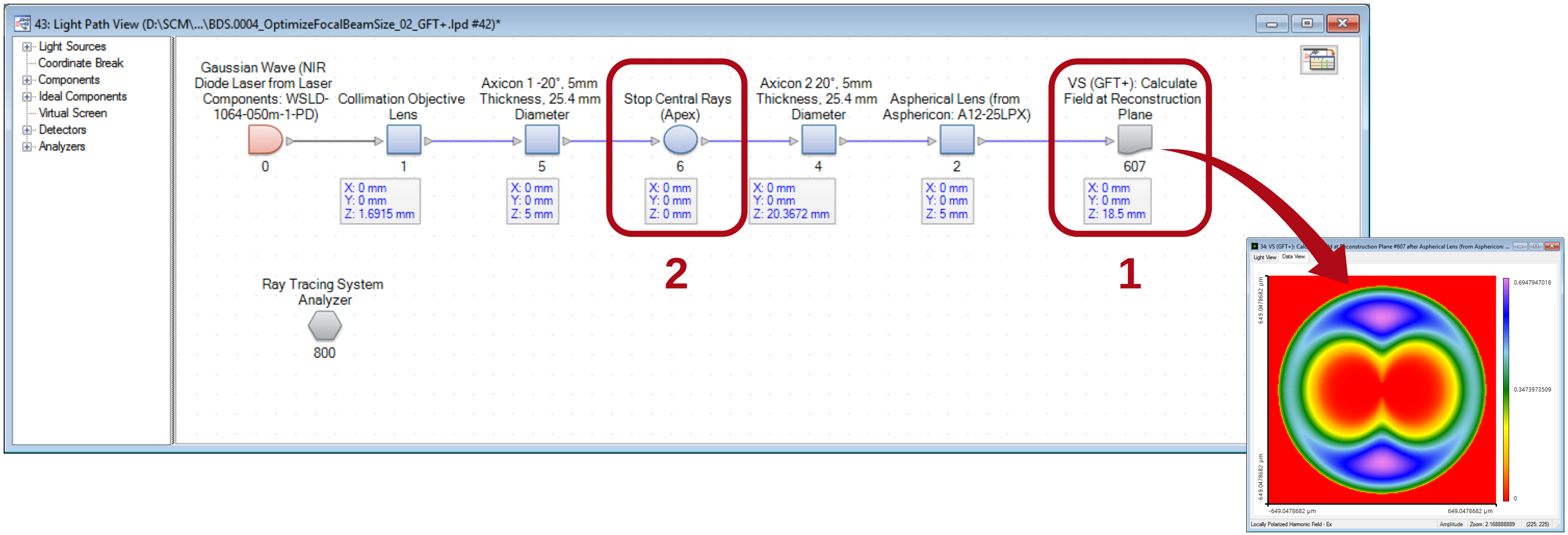
 file used: BDS.0004_OptimizeFocalBeamSize_01_RayTracing.lpd

Field Tracing: Calculate Field within Diffractive Zone



- Nevertheless, the **propagation of light by Geometric Field Tracing Plus (GFT+) engine is accurate outside the focal region.**
- Due to the fact, that the **geometrical approach is not valid in the diffractive region**[2], the propagation with GFT+ has to be stopped before beam diffraction becomes significant. At this position (field reconstruction plane) the field data is passed on appropriately to a more suitable propagation technique.
- The **reconstructed field** at this plane can be used to **propagate into the focal region (= diffractive zone) using Classic Field Tracing**.

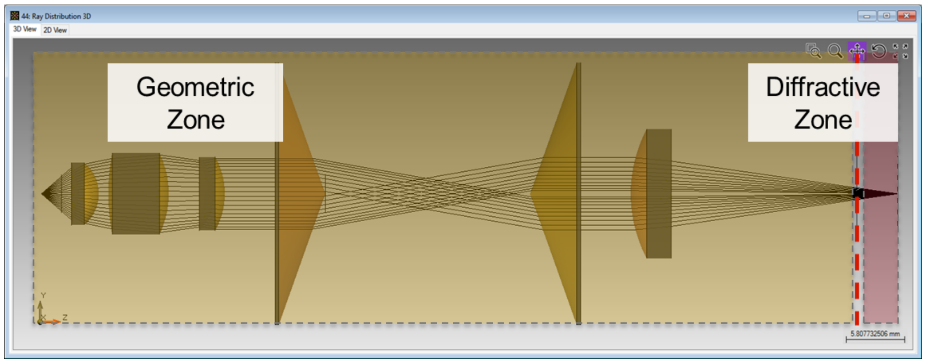
Field Tracing: Calculate Field at Reconstruction Plane

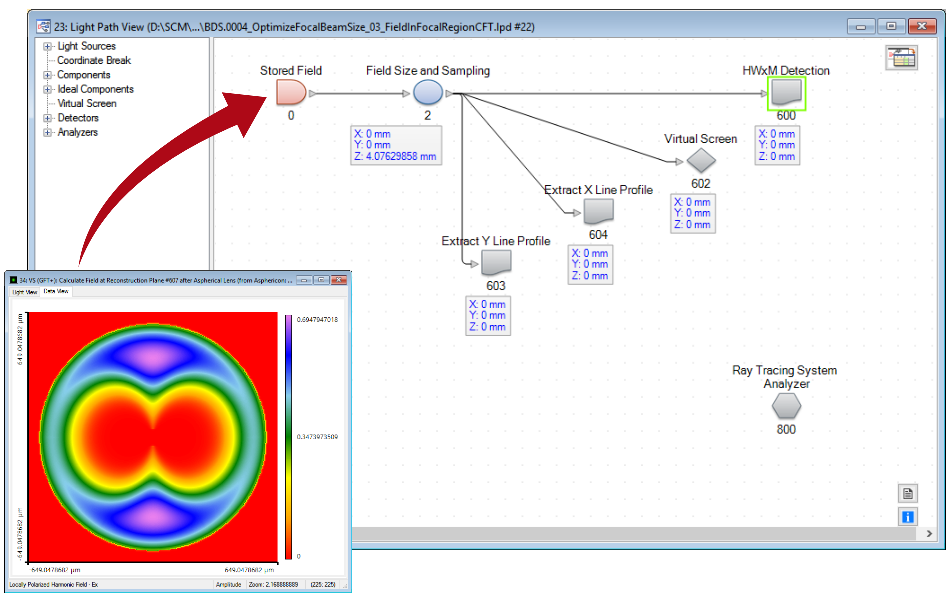


- To calculate the field within the diffractive zone the **Virtual Screen for Geometric Field Tracing (1)** is used at the end of the geometric zone (= field reconstruction plane) at 18.5mm distance from the asphere.

- **Light hitting the discontinuous apex of the axicon perturb the reconstruction of the field** numerically and hence, should be blocked by a stop (2).

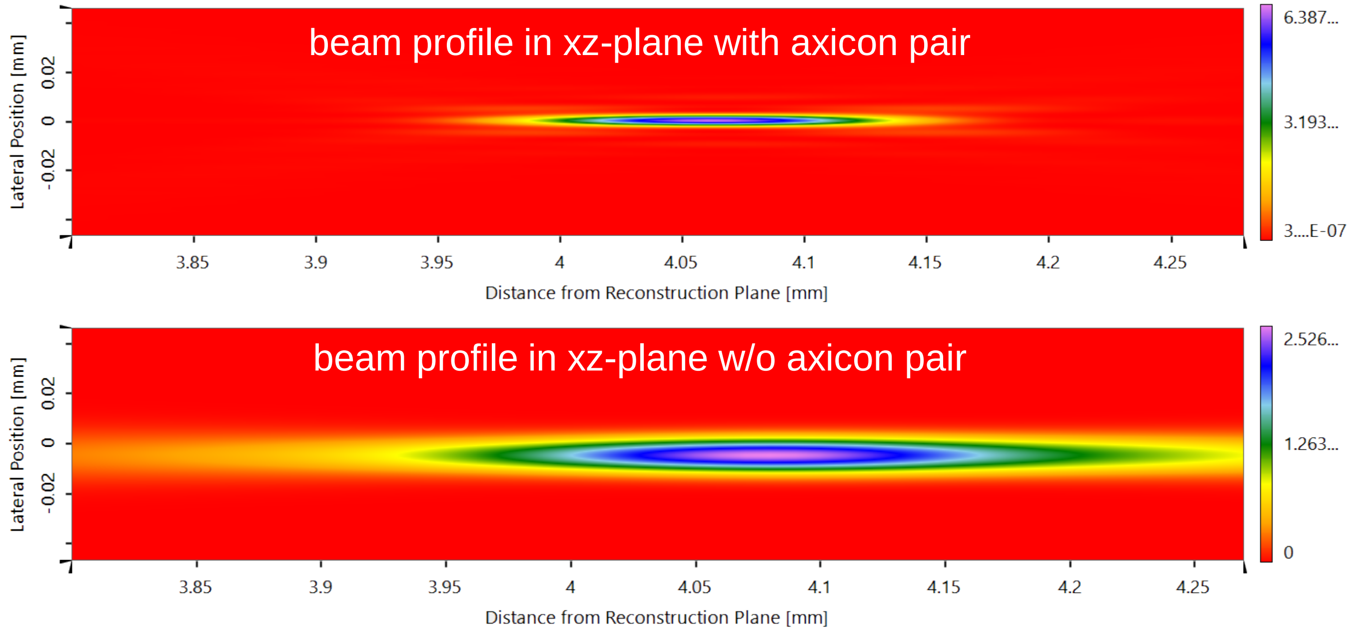
Propagation within Diffractive Zone by Field Tracing





- Now the reconstructed field can be used to **calculate the field in the diffractive zone using Classic Field Tracing**.
- For this purpose the generation of a new LPD is recommended to store the reconstructed field in a **Stored Field Component**.
-
- Then various elements can be added, e.g. optical components or detectors, where **Classic Field Tracing provides more accurate evaluation of the field**.
- This LPD can be used for optimization and automation tools like a **Parameter Run to investigate the focal region of the beam** by varying the distance to the detectors.

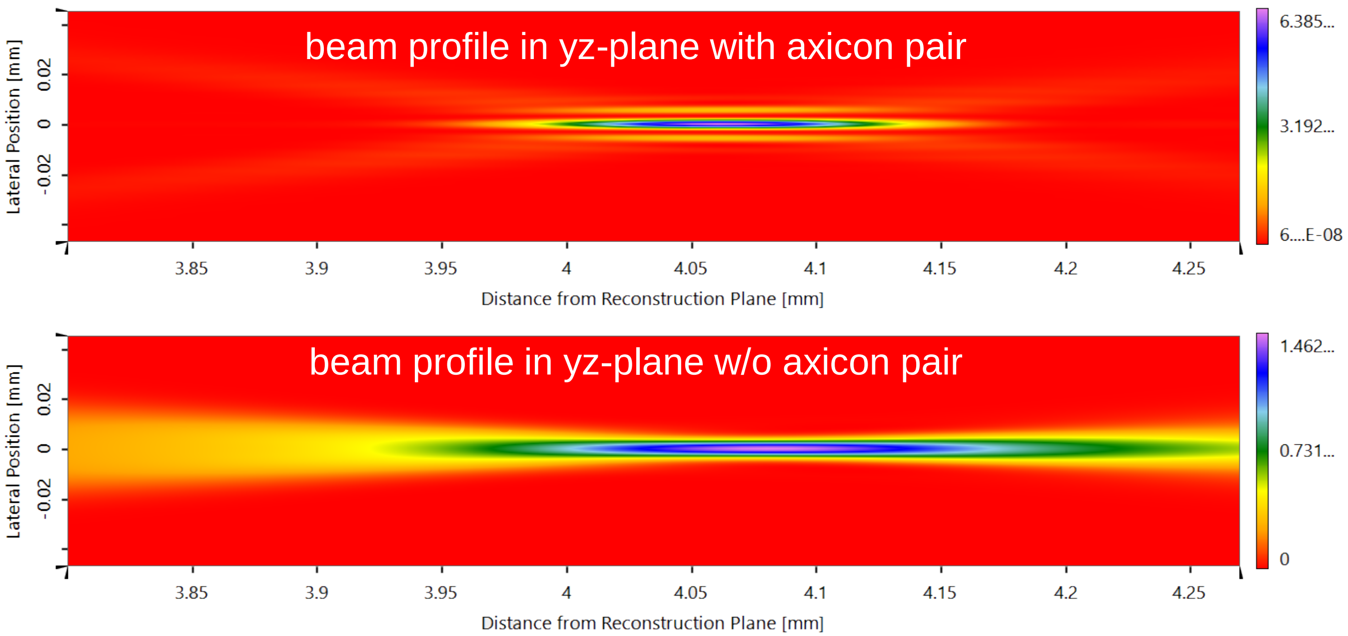
Investigating the Focal Region in the XZ-Plane



- The previous LPD was used to perform a **parameter run**, in order to vary the **distance between focal and reconstruction plane from 3.8 mm to 4.3 mm** (corresponds to a distance from asphere between 22.3 mm and 22.8 mm) to **investigate the focal region**.
- Both figures show the squared amplitude of the beam along the x-axis within the focal region with (BDS.0004) and without the axicon pair (BDS.0002).
- In comparison, **the axicon pair provides a smaller focus of the beam within the xz-plane**.

 file used: BDS.0004_OptimizeFocalBeamSize_04_InvestiateFocalRegion.run

Investigating the Focal Region in the YZ-Plane

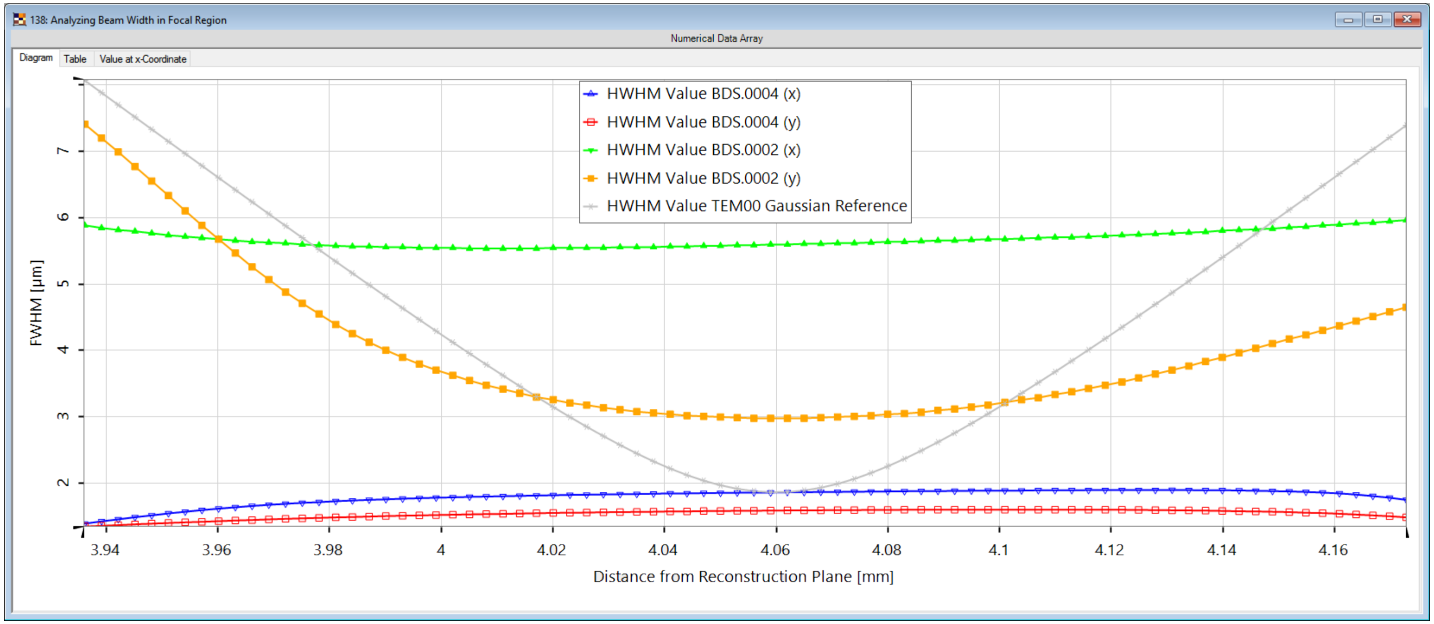


- Both figures show the squared amplitude of the beam along the **y-axis** within the focal region with (BDS.0004) and without the axicon pair (BDS.0002).
- In comparison, **the axicon pair provides also a smaller focus of the beam within the yz-plane**.

The Beam Width in Focal Region

- For a more detailed evaluation of the beam within the focal region, the **half width at half maximum (HWHM)** was calculated for the system without (BDS.0002), with an axicon pair (BDS.0004) and for a Gaussian TEM_{00} mode as comparison reference. The results are shown in the diagram below.

- It can clearly be seen that the **focal spot size and the depth of focus are measurably improved by using an axicon pair.**



The Beam Width in Focal Region

- In theory, an **axicon generates an ideal Bessel beam**. These beams have the property of being **“non-diffracted” along a certain distance in the focal region**.[1]
- Consequently, **Bessel beams** have a **higher depth of focus** and a **reduced divergence** within the focal region as Gaussian beams with similar beam size.
- For a comparison the **depth of focus** is defined as the distance, where the beam waist (defined as HWHM) has increased by a factor of $\sqrt{2}$.

$$\mathrm{DOF} = \sqrt{2} \cdot \mathrm{HWHM}$$

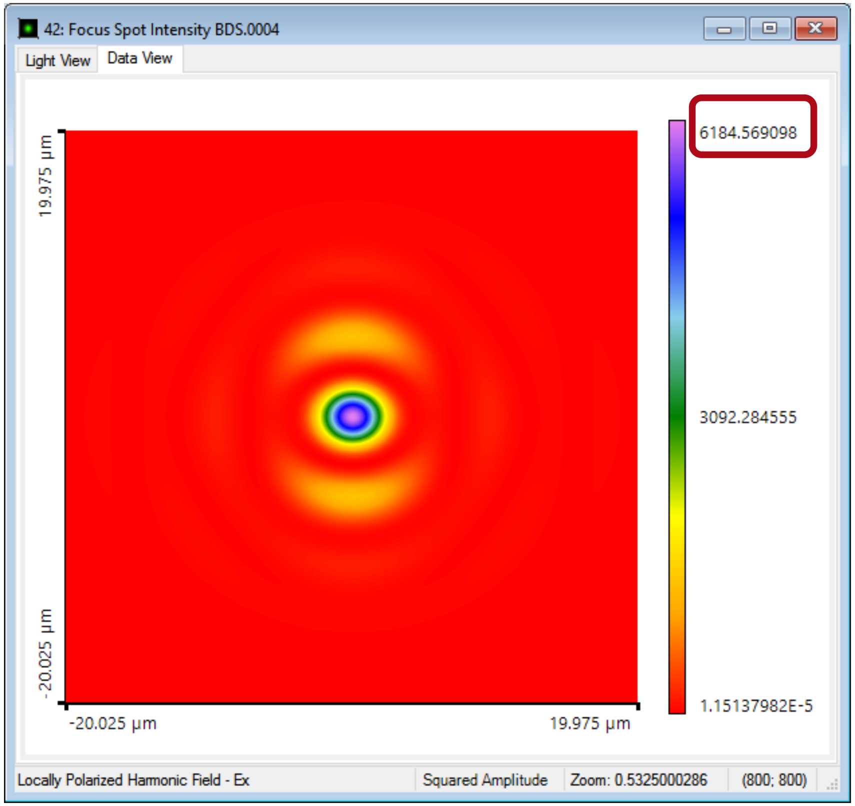
- For comparison of the depth of focus a **Gaussian $\mathbf{TEM_{00}}$ mode** was calculated **as reference**, where the beam waist is similar to the beam waist of the Bessel beam in a comprehensive focal plane of all the beams.

The Beam Width in Focal Region

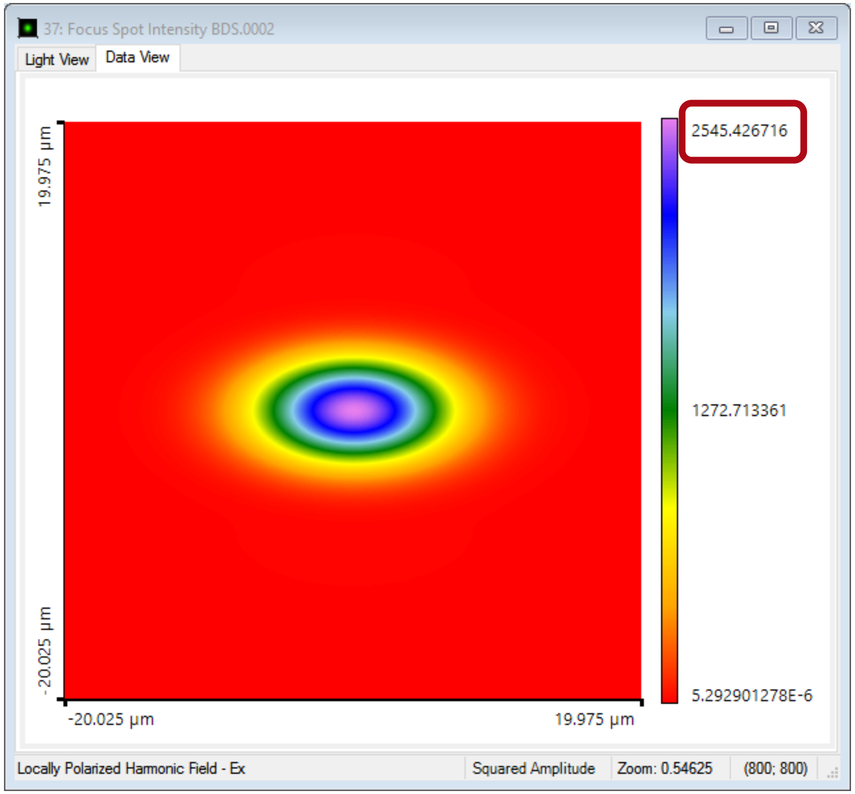
- In comparison the calculated **beam waist** and the **depth of focus** are listed in the table below.
- Please note that the generated beam cannot be an ideal **Bessel beam** as the **incident light** of the axicon is an **aberrated and astigmatic Gaussian**.
- Interestingly, the **astigmatic beam behavior of the beam in the focal region is significantly improved by the axicon pair**. This can be seen especially on the parameters for the y-profile of the beam.
- Furthermore, the **depth of focus** of the generated Bessel beam **is increased by a factor of 4** compared to a Gaussian beam with a similar beam waist.

	Beam Width (HWHM) [µm]	Depth of Focus [µm]
BDS.0002 X-Profile	5.54	> 300
BDS.0002 Y-Profile	2.97	165
BDS.0004 X-Profile	**1.55**	**249**
BDS.0004 Y-Profile	**1.40**	**240**
Gaussian TEM_{00} mode	1.85	58

Focus Spot Intensity in 22.576mm after Lens



focal spot using a pair of axicons



focal spot without using axicons (BDS.0002)

 file used: BDS.0004_OptimizeFocalBeamSize_03_FieldInFocalRegionCFT.lpd

Additional VirtualLab Features

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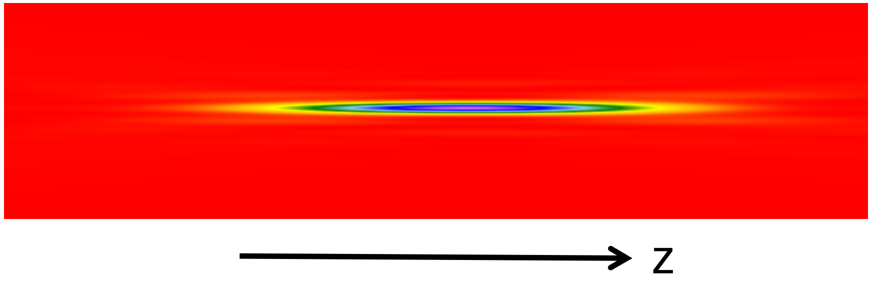
  - HWxM detector



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  - diverse 2D & 3D diagrams demonstrating the beam propagation along the optical axis within the focal region

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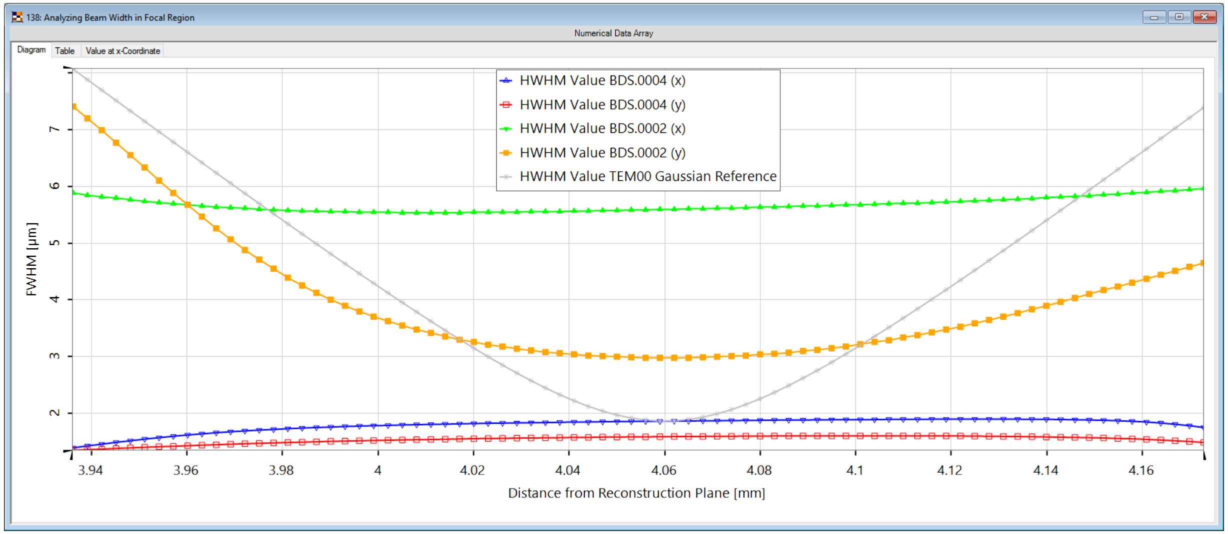
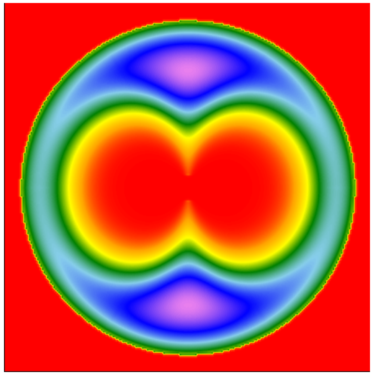
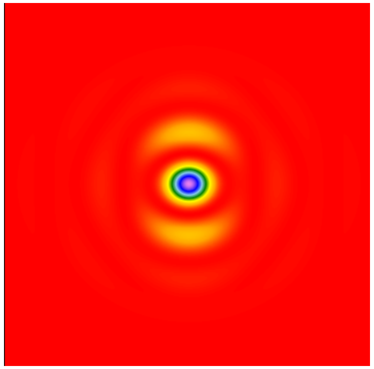




Beam after Aspherical Lens



Beam at Focus

Further Readings

References

[1] D. McGloin, K. Dholakia, “Bessel Beams: diffraction in a new light”, Contemporary Physics, Vol. 4615 – 28, 2005.

[2] Frank Wyrowski, Huiying Zhong, Site Zhang, Christian Hellmann, „Approximate solution of Maxwell’s equations by geometrical optics“, Proc. SPIE 9630, Optical Systems Design 2015: Computational Optics, 963009, 2015.

Further Readings

- Get Started Videos
  - Introduction to the Light Path Diagram
  - Introduction to the Parameter Run
  - Introduction to Parametric Optimization

- Documents Related with This Application Example
  - BDS.0001: Collimation of Diode Laser Beam by Objective Lens
  - BDS.0002: Focus Investigation behind Aspherical Lens
  - UseCase.0047: Settings and Result Displays of the Ray Tracing Engine
  - UseCase.0065: Usage of the Parameter Run Document
  - UseCase.0083: High NA Lens System - Analysis by Geometric Field Tracing Plus