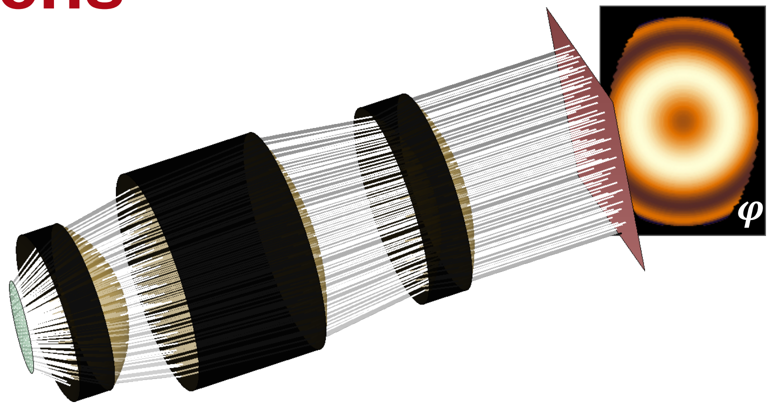
Beam Delivery Systems (BDS.0001 v1.5)

Collimation of Diode Laser Beam by Objective Lens



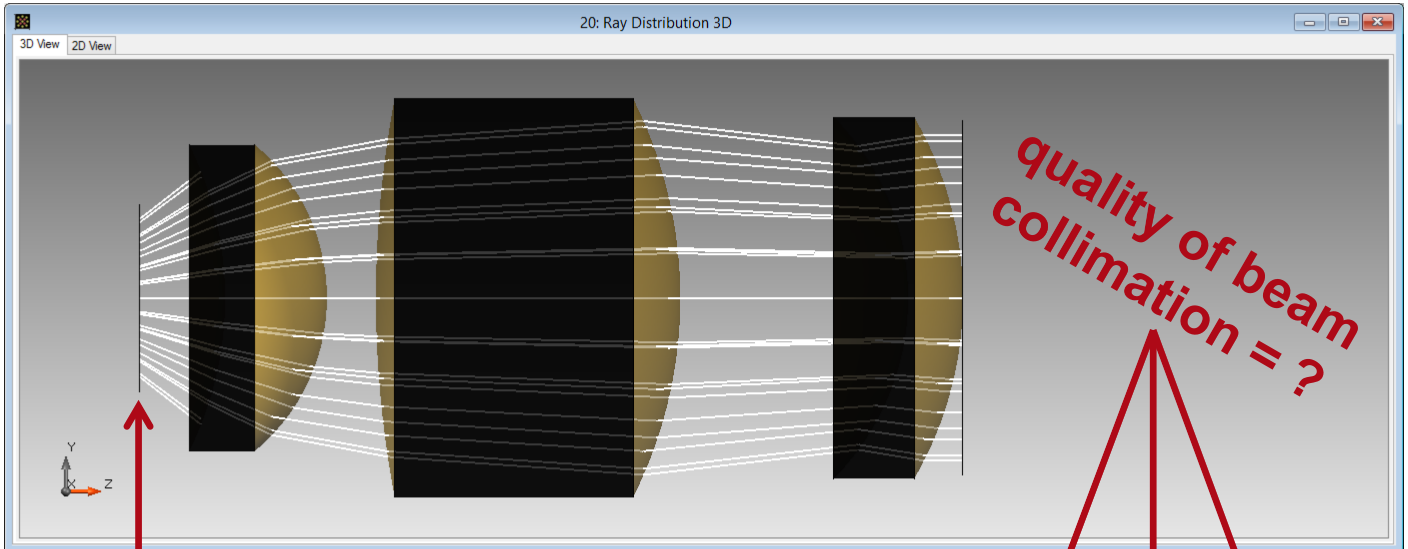
Application Example in a Nutshell

System Details

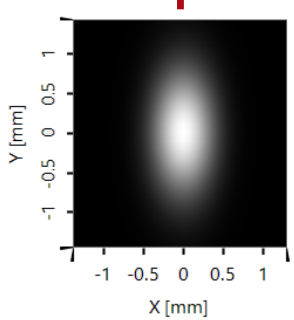
- Source
  - astigmatic IR laser diode
- Components
  - refractive lens system to collimate the divergent laser diode
- Detectors
  - visual check of rays (3D display)
  - ray directions (dot diagram)
  - wavefront error detection
  - phase aberrations after lens
  - beam parameters (M^2, divergence)

  (visual check, ray directions, wavefront error detection: **ray tracing**; phase aberrations, beam parameters: **field tracing**)
- Modelling/Design
  - ray tracing: First insight into system and **wavefront error calculation**
  - **field tracing: Influence of laser beam clipping on beam quality**

System Illustrations



collimation objective lens



asymmetric Gaussian beam of IR laser diode ($M^2 = 1$)

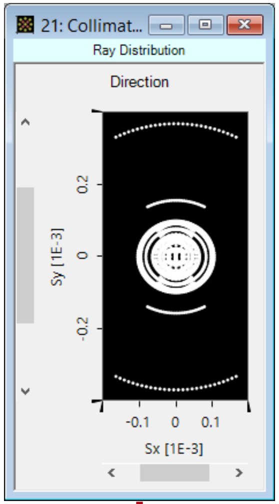
dot diagram

wavefront error

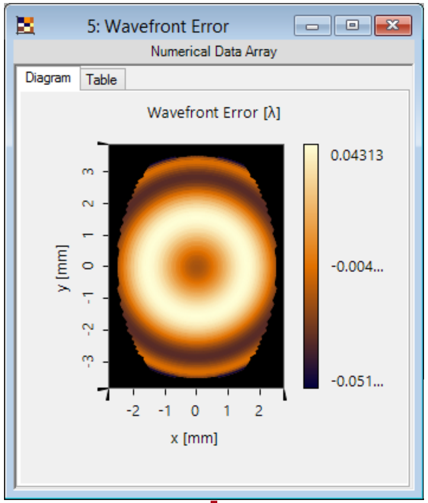
phase view

beam parameters

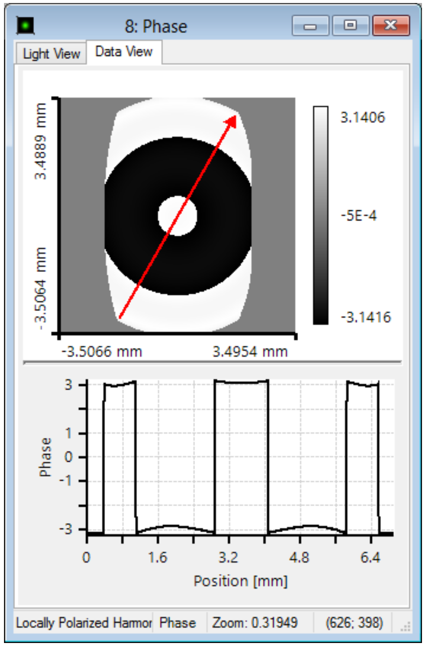
Modeling & Design Results



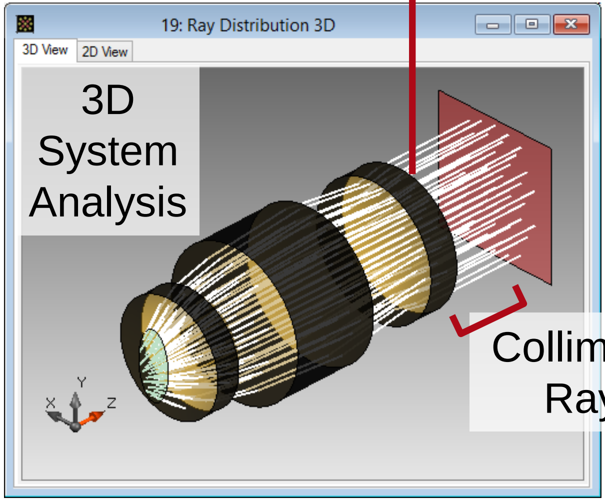
Ray Directions



Wavefront Error



Phase Analysis



3D System Analysis

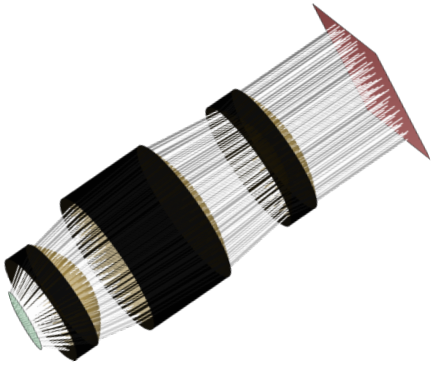
Collimated Rays

Numerical Detector Results

Quantity	Value & Unit
wavefront error (RMS)	0.03λ
divergence Angle X x Y	0.02° × 0.01°
M^2 parameter in X x Y direction	1.0180 × 1.1802

Summary

The performance of a lens system for the collimation of an astigmatic laser diode was investigated by:

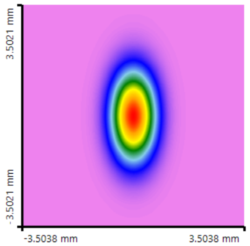


1st step

Ray tracing evaluation for wavefront error calculation

2nd step

Field tracing evaluation to check **beam clipping induced diffraction effects** and their influence on the **beam quality**.



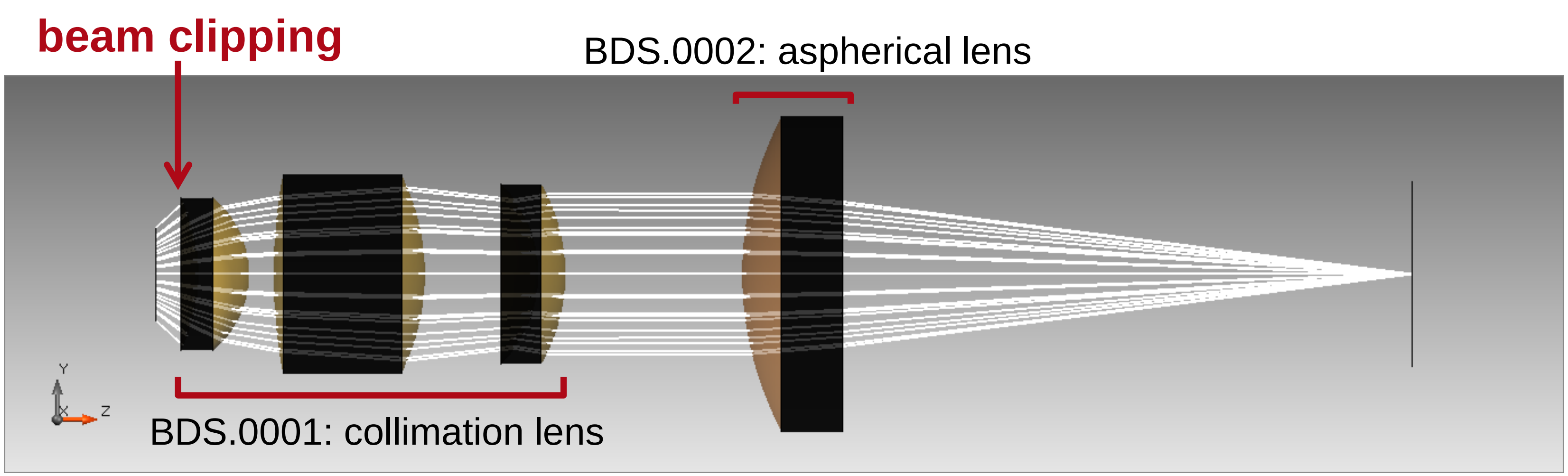
Quantity	Value & Unit
M^2 parameter in X direction	1.0180
M^2 parameter in Y direction	1.1802

Application Example in Detail

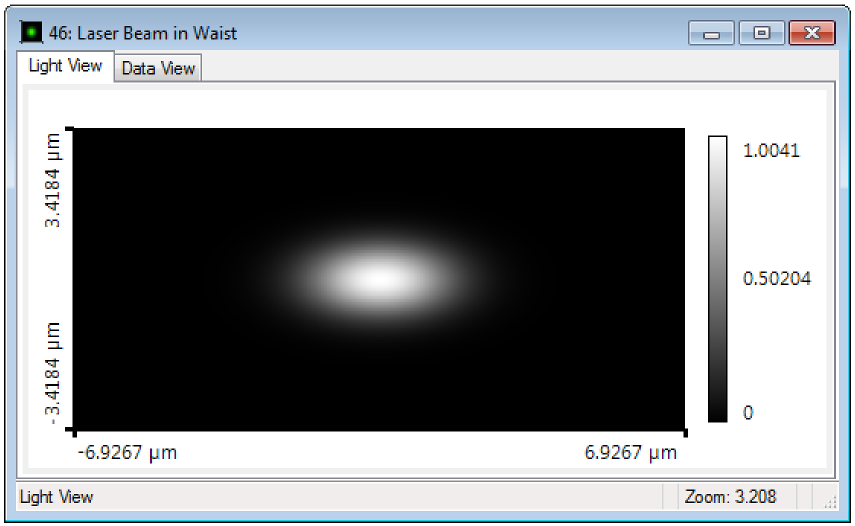
System Parameters

Context of this Application Example

- BDS.0001, BDS.0002 and BDS.0003 deal with a **refractive beam delivery system**.
- In this example the collimation lens system is analyzed. Especially the influence of beam truncation (**beam clipping**) at the aperture of the collimation optics is investigated.
- BDS.0002 and BDS.0003 deal with light focusing.



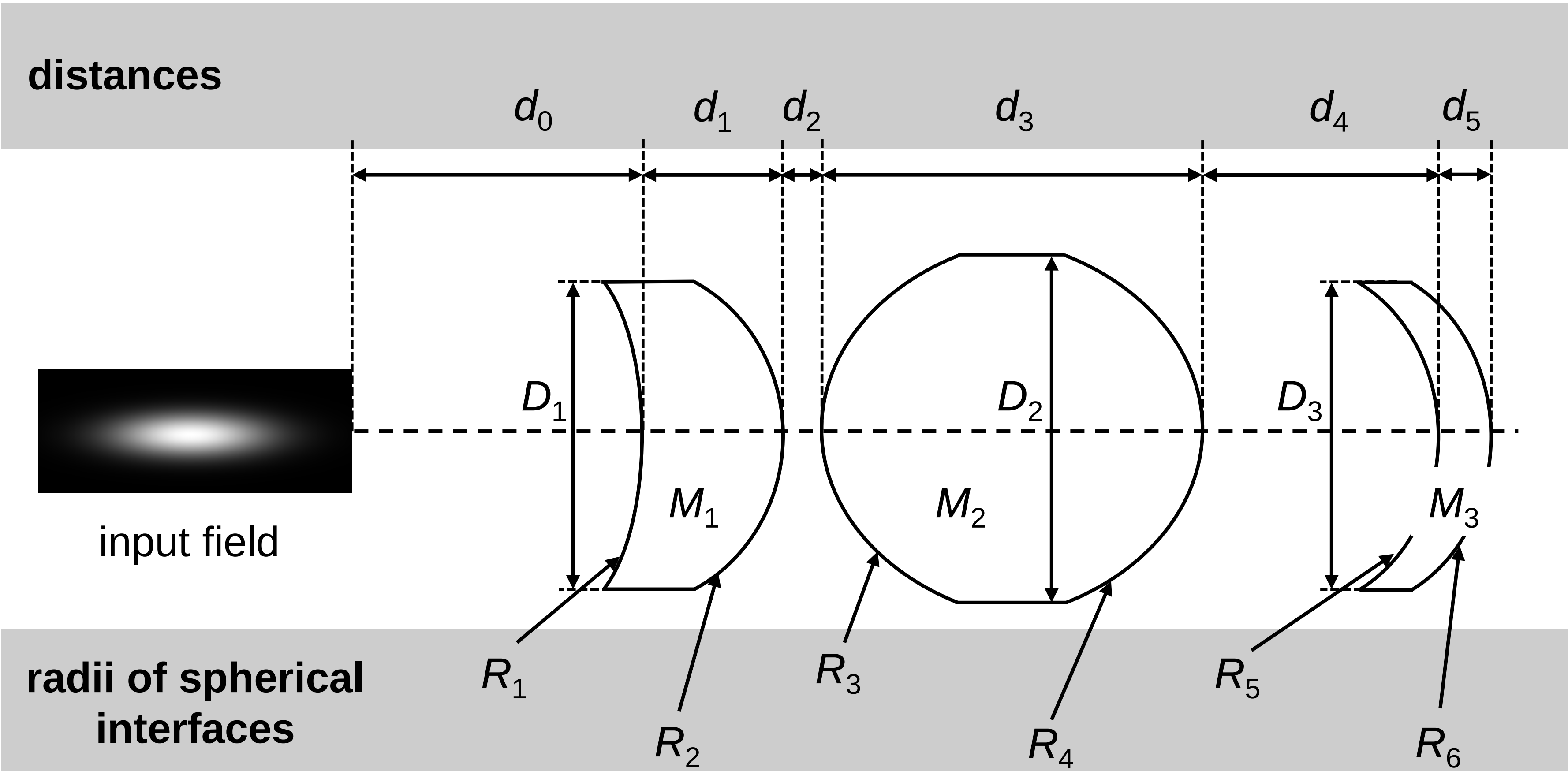
Specs: Uncollimated Input Laser Beam



Single Mode IR Diode Laser from Laser Components

Parameter	Value (& Unit)
name/type	WSLD-1064-050m-1-PD
wavelength	1064 nm
FWHM angle divergence of beam intensity	**10° × 20°** i.e. 8.49° × 16.97° (referring to the 1/e^2 waist radius)
polarization	linear (e.g. parallel to x-axis)
initial M^2 in X- and Y direction	1.0 × 1.0

Specs: Collimation Objective Lens Overview



Specs: Collimation Objective Lens Parameters

Parameter	Value & Unit
distance d_0	3.6915 mm
distance d_1	2.007 mm
distance d_2	967.46 µm
distance d_3	6.0005 mm
distance d_4	4.4892 mm
distance d_5	1.0814 mm
diameter D_1	6.04 mm
diameter D_2	7.8576 mm
diameter D_3	7.1226 mm

Parameter	Value & Unit
conical radius R_1	−6.799 mm
conical radius R_2	−3.9068 mm
conical radius R_3	21.051 mm
conical radius R_4	−8.7395 mm
conical radius R_5	−5.0489 mm
conical radius R_6	−7.0837 mm
material M_1	N-SF6*
material M_2	N-BK7*
material M_3	N-BK7*

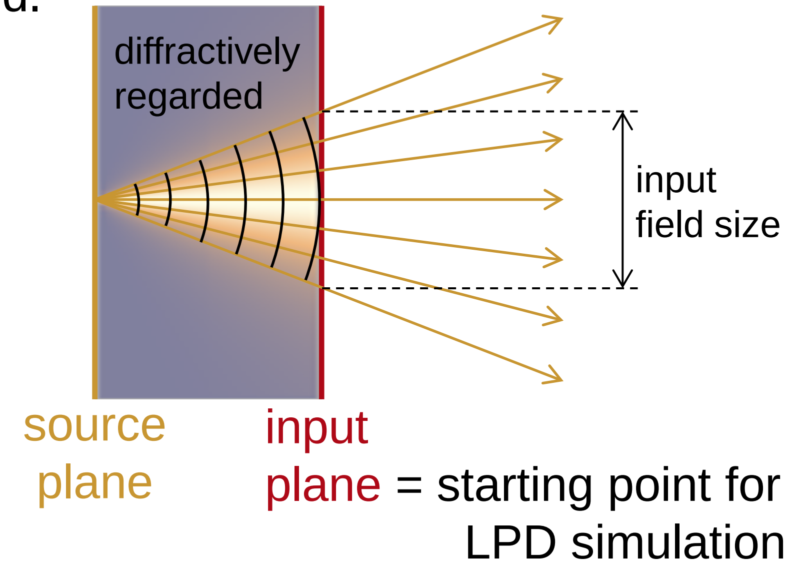
* from catalog Schott_2014

Application Example in Detail

Simulations & Results

First Simulation Distance: Astigmatic Gaussian

Because of the **astigmatic shape** of the used **Gaussian input beam** a **special handling of the first simulation distance** is required if Ray Tracing or Geometric Field Tracing Plus (GFT+) is used.



Background Information

- For the light source modeling it is possible to specify a **distance between source and input plane** (see figure) directly in the edit dialog of the source.
- No matter the set simulation engine, this **internally regarded distance** will be handled by a **physical optics algorithm that includes diffraction effects**. It also **allows for an astigmatic consideration**.

First Simulation Distance: Gaussian Beam

Normally if a **Gaussian beam** was modeled by **Ray Tracing** and is propagated via geometric optics from its waist, the light will show **no divergence** as the divergence is solely defined by the Gaussian‘s waist size, thus by diffraction.

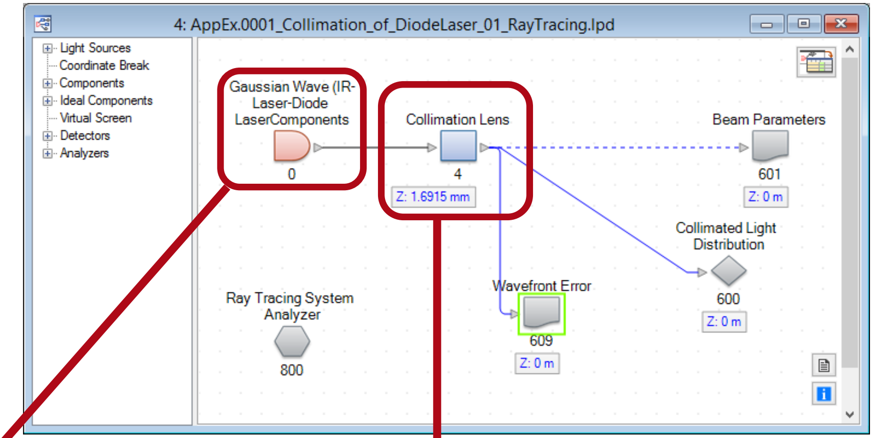
- For **symmetric Gaussian** beams VirtualLab provides an **algorithm that calculates the divergence even if Ray Tracing or Geometric Field Tracing Plus** is used as simulation engine.
- But for **astigmatic Gaussian** beams, it is still **necessary to propagate the light out of the so-called diffractive zone first**, before a geometric optics propagation may continue.

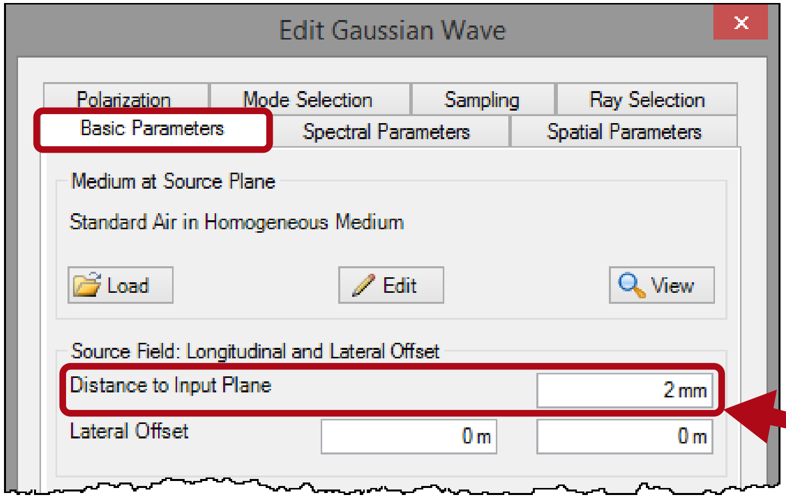
  → **Rule of Thumb**
  Thus for a astigmatic Gaussian a distance to input plane of at least >10x the Rayleigh length should be set in the source‘s edit dialog.

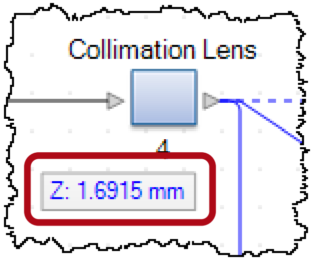
For almost collimated Gaussians the divergence can be neglected, as the light can be regarded as plane with just a Gaussian modulation. So here now special regard is required.

Ray Tracing: Laser Beam Simulation

- Diffractive propagation part is done within light source.
- By using the option *Distance to Input Plane* (Basic Parameters) the corresponding curvature is calculated automatically.
- The subsequent propagations can now be done by ray tracing.

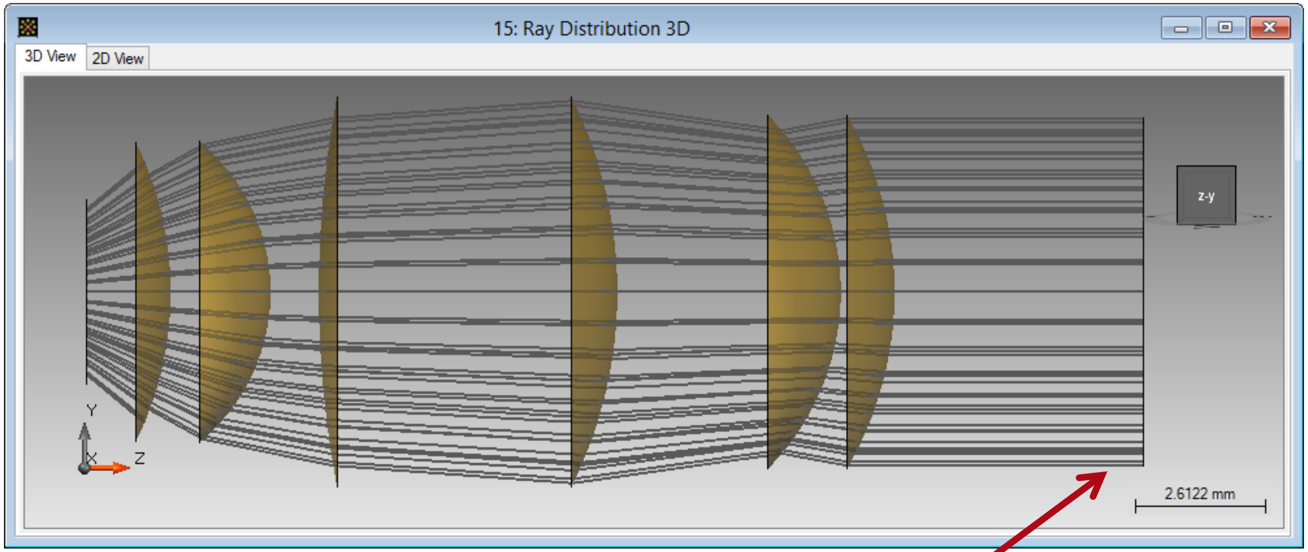


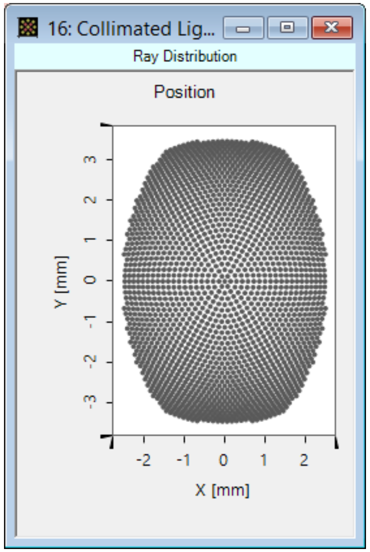




3.6915 mm – 2 mm = 1.6915 mm

First System Evaluation by using Ray Tracing



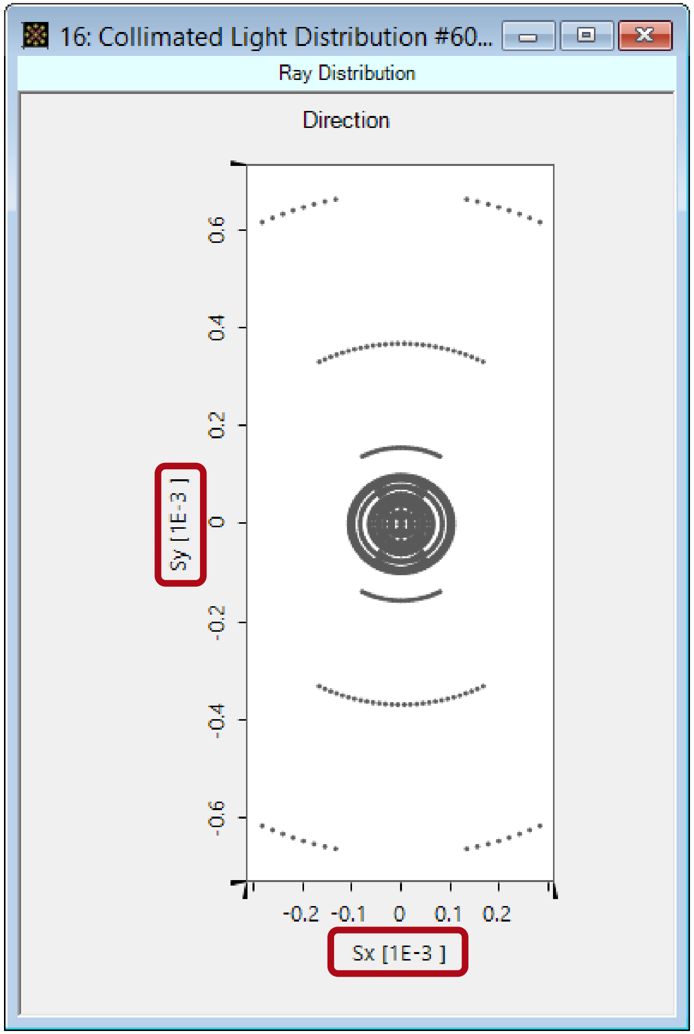


screen 5mm after last lens, for better ray view

Via **Ray Tracing System Analyzer** the propagation of the rays through all desired parts of the system can be displayed in 3D.
→ Visible evaluation: Finally rays have all same **collimated** direction

Via **Ray Tracing** classic spot diagrams can be generated.
→ No information about the modulation of the light distribution

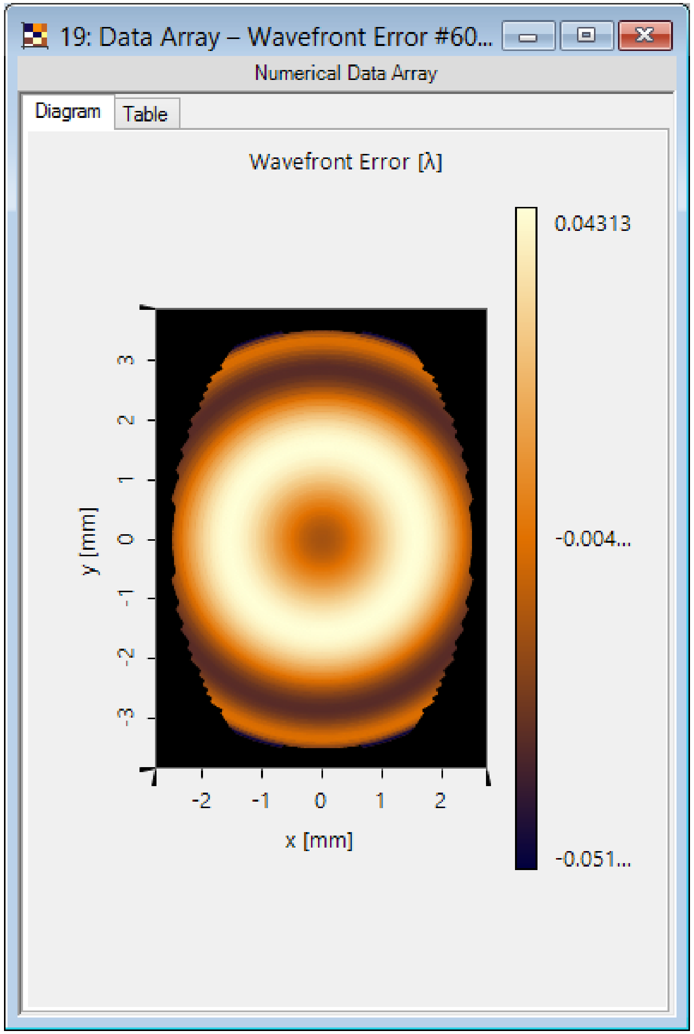
Ray Tracing: 2D Direction Spot Diagram



- VirtualLab allows to provide **diverse display options** for spot diagrams.
- E.g. adjacent the X and Y component **(S_x, S_y)** of the normed direction vectors of each ray is shown (after last lens).
- The small scale indicates that the S_z component is approximately 1, thus all rays are **very well collimated**.

 file used: BDS.0001_Collimation_of_DiodeLaser_01_RayTracing.lpd

Ray Tracing: Wavefront Error Detection

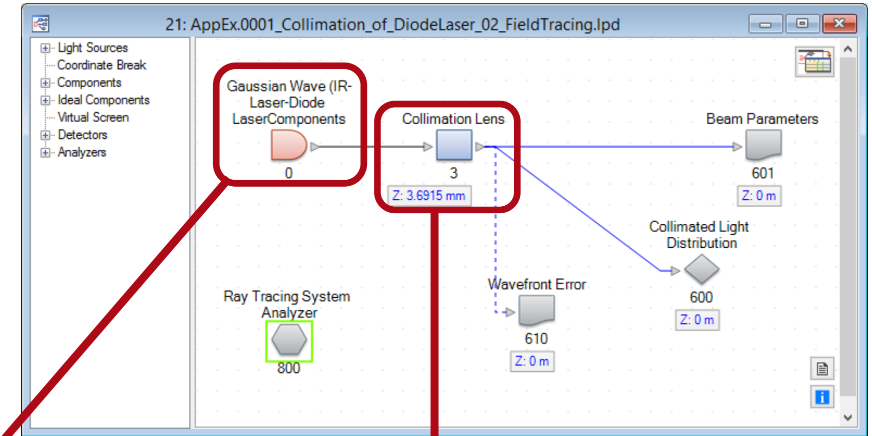


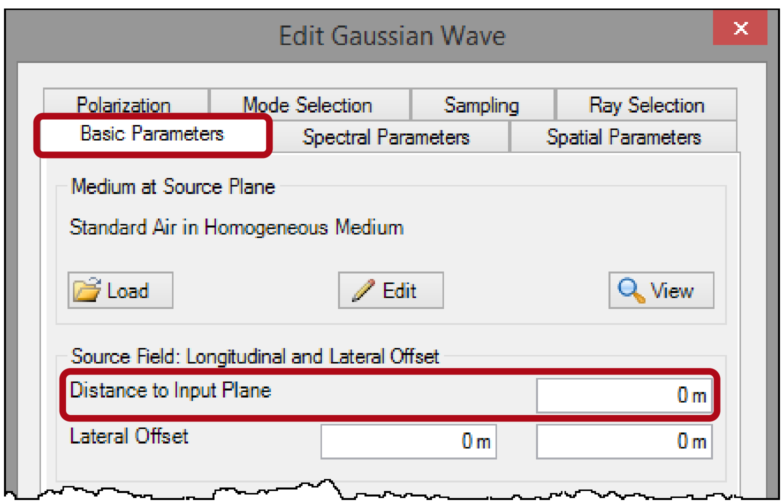
- The dedicated **Wavefront Error** detector allows you to see the remaining differences of the optical path lengths which is proportional to the phase aberrations.
- Additionally this detector outputs the **RMS** value of the Wavefront Error: **~0.03λ**
- This also proves the **successful collimation**.

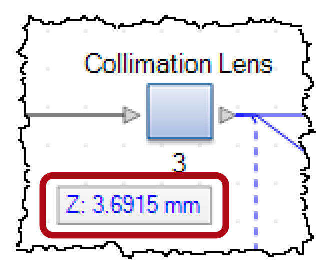
 file used: BDS.0001_Collimation_of_DiodeLaser_01_RayTracing.lpd

Field Tracing: Laser Beam Simulation

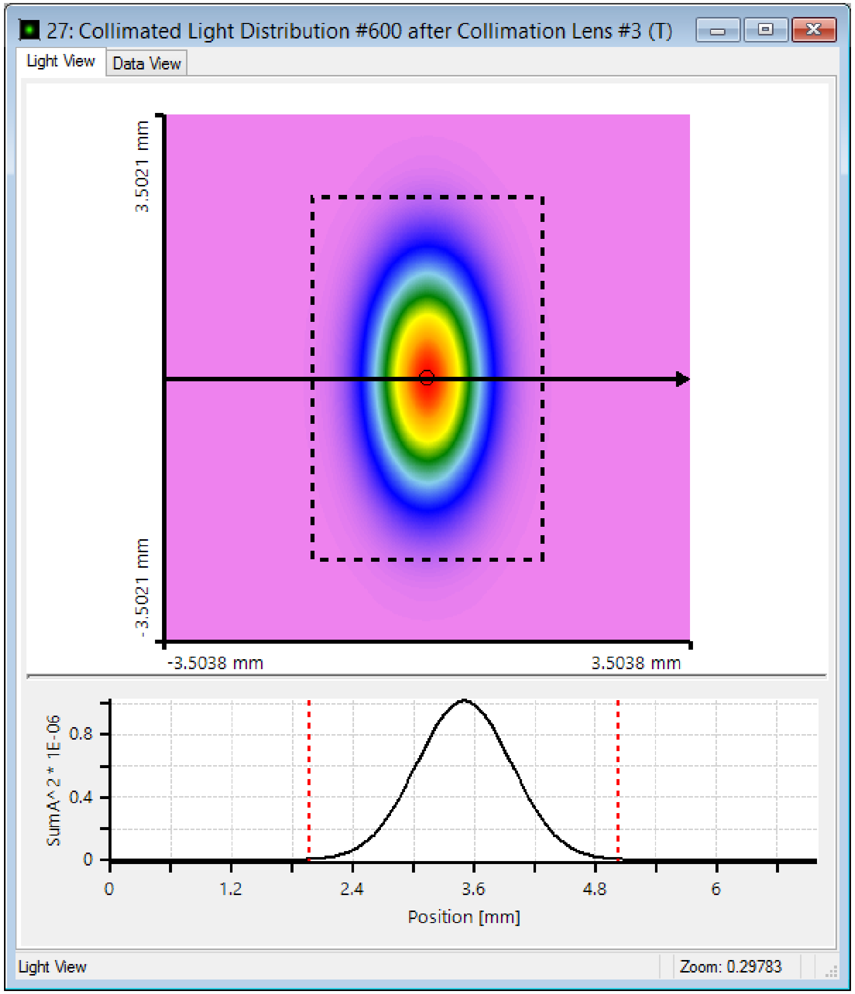
- The Classic Field Tracing engine allows an **automatic regard of the diffractively induced divergence**.
- So we specify the **total free space propagation distance** of 3.6915 mm from waist to lens surface directly **via element position**.







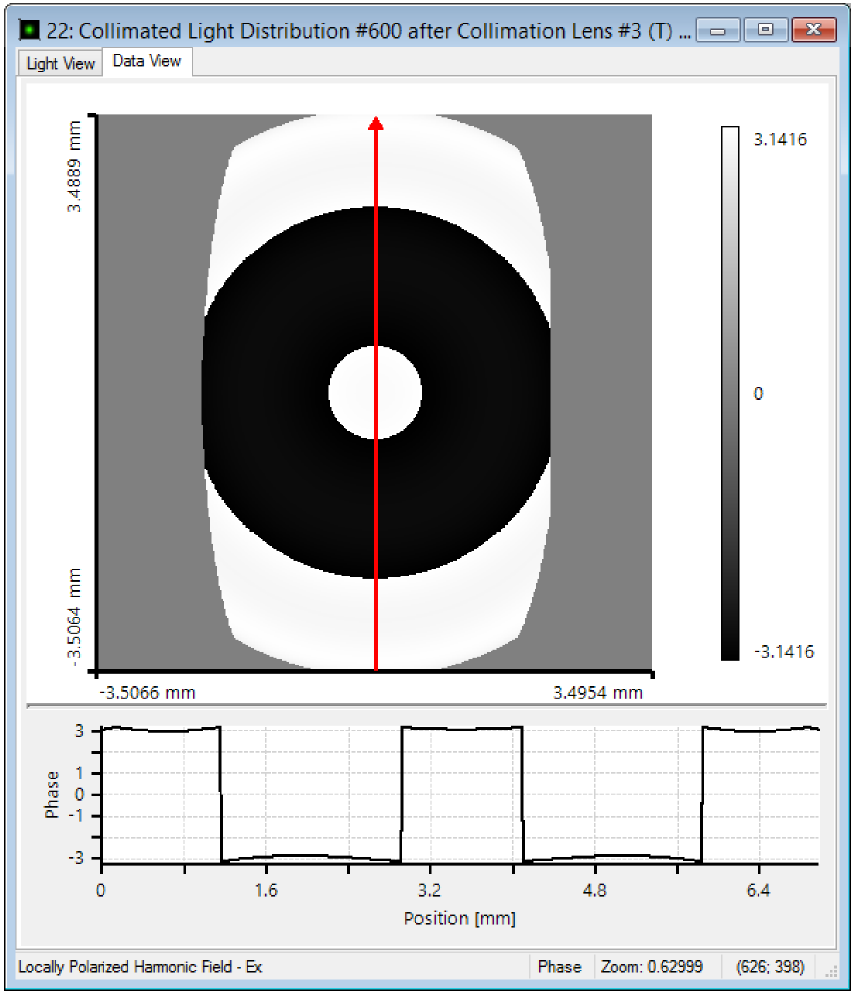
Field Tracing: Intensity Distribution



- By tracing the complete electromagnetic field you are able to evaluate the **intensity distribution**.
- Adjacent the squared amplitude values are shown in false color (inverse rainbow) and in a **1D cross section** (along X axis) display.
- Additionally VirtualLab can calculate the area in which a certain percentage of the full field's power is located. E.g. while being collimated, the beam is enlarged such, that **99% of the power** is located within about 3.1mm x 4.8mm.

file used: BDS.0001_Collimation_of_DiodeLaser_02_FieldTracing.lpd

Field Tracing: Phase Distribution



- Typically VirtualLab shows the light‘s **phase values in a 2π modulo display** mode.
- Due to **smart sampling** VirtualLab is able to store parts of the phase analytically (e.g. spherical phase factor).
- The 1D and 2D evaluations demonstrate that the final phase (including spherical phase factor) exhibits only very small modulations, thus the wavefront is almost plane
  → **very well collimated**

file used: BDS.0001_Collimation_of_DiodeLaser_02_FieldTracing.lpd

Field Tracing: Beam Parameter Detector Results

Evaluated Quantity	Value & Unit
radius X	936.22 µm
radius Y	1.8607 mm
waist radius X	929.81 µm
waist radius Y	1.8474 mm
divergence angle X	0.021245°
divergence angle Y	0.012396°
waist distance X	294.88 mm
waist distance Y	1.0259 m
M^2 parameter in X direction	1.0180
M^2 parameter in Y direction	1.1802

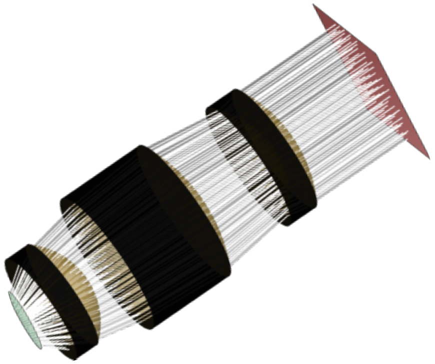
- VirtualLab provides diverse numerical detectors.
- Adjacent the results from the so-called **beam parameter detector**, whose evaluations are based on the **second momentum method**.
- The resulting **small divergence angles** also prove that the beam is **well collimated**.
- Due to **beam clipping** the beam quality (**M^2**) is slightly reduced. This reduction is different for X- and Y- direction due to the **astigmatic laser beam.**

Summary

The performance of a lens system for the collimation of an astigmatic laser diode was investigated by:

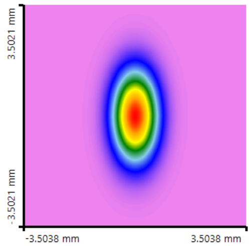
1st step

Ray tracing evaluation for wavefront error calculation



2nd step

Field tracing evaluation to check **beam clipping induced diffraction effects** and their influence on the **beam quality**.



Quantity	Value & Unit
M^2 parameter in X-direction	1.0180
M^2 parameter in Y-direction	1.1802

Further Readings

Further Readings

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