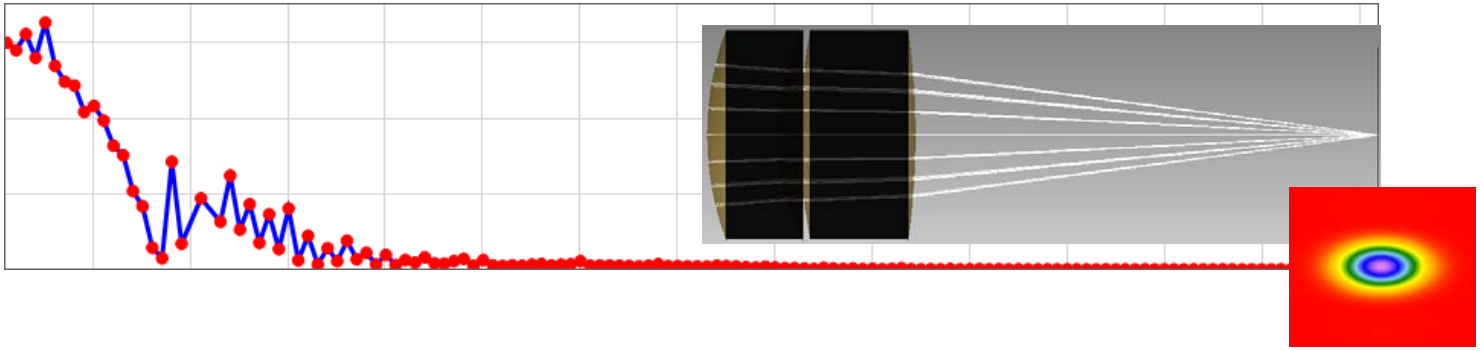
LightTrans

Beam Delivery Systems (BDS.0003 v1.4)

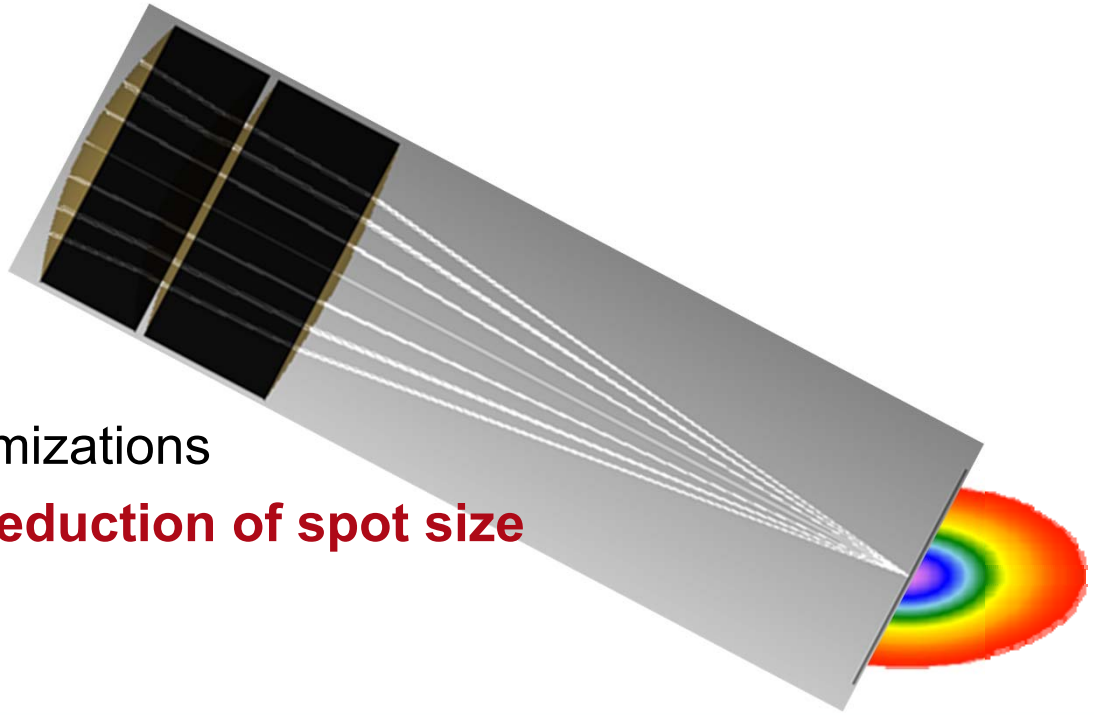
Optimization of a Lens Doublet for Laser Beam Focusing



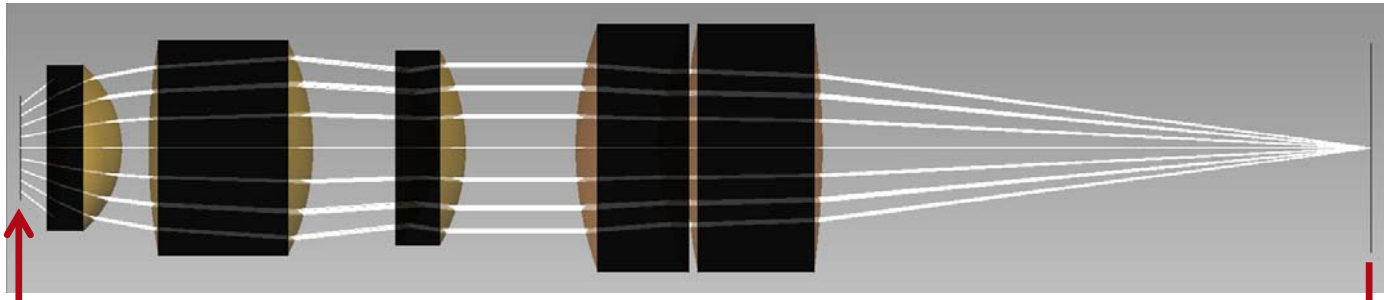
Application Example in a Nutshell

System Details

- Source
  - astigmatic IR laser diode
- Components
  - refractive lens system to collimate then focus with doublet
- Detectors
  - spot diagram
  - intensity distribution
  - beam parameters
- Modelling/Design
  - ray tracing: initial optimizations
  - field tracing: **further reduction of spot size**

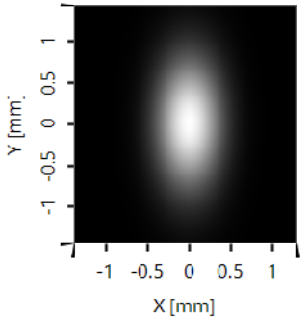


System Illustrations

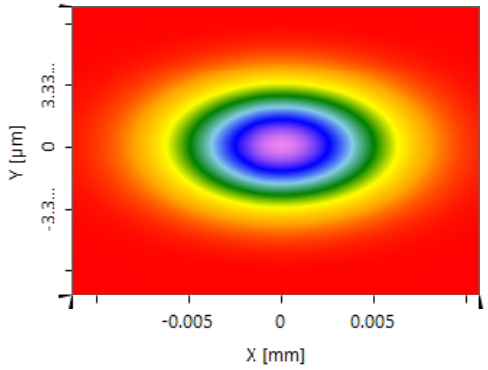


collimation
objective lens

focusing
doublet lens
to be optimized

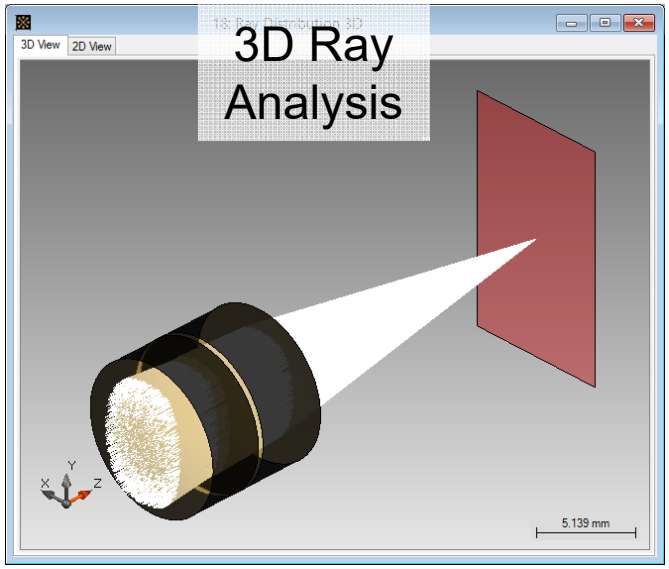


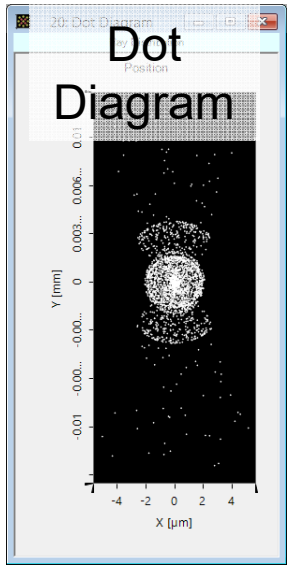
asymmetric
Gaussian beam of
IR laser diode

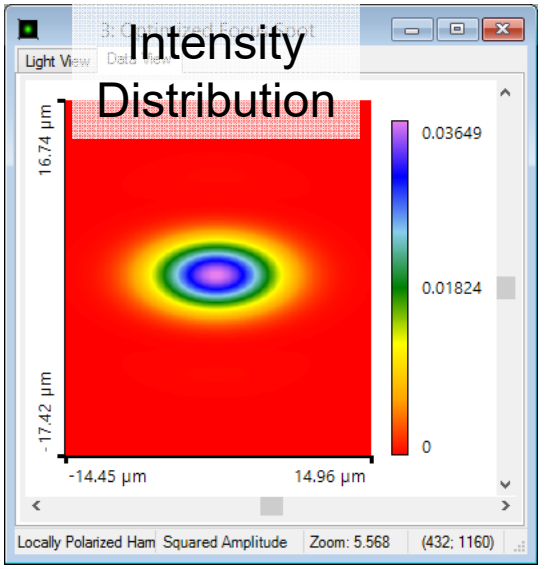


focused
intensity distribution

Modelling & Design Results







Parametric Optimization of Beam Parameters

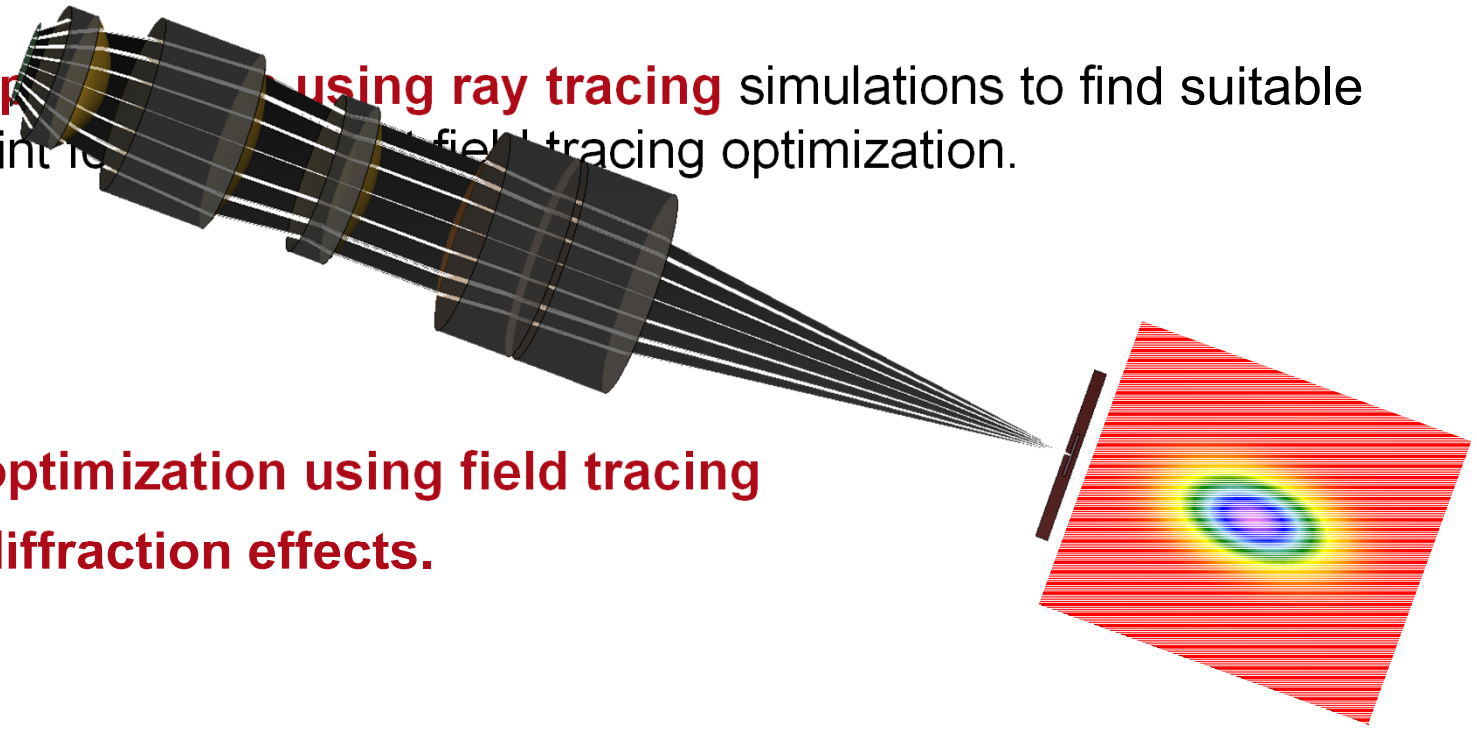
Parameter	Ray Tracing Optimization Result	Field Tracing Optimization Result
radius X	8.57 µm	8.45 µm
radius Y	5.01 µm	4.77 µm

Summary

Improving a lens design obtained by ray tracing using an additional optimization step based on **field tracing**.

1st step

Fast **pre-op** **using ray tracing** simulations to find suitable starting point f field tracing optimization.



2nd step

Refining optimization using field tracing

including **diffraction effects.**

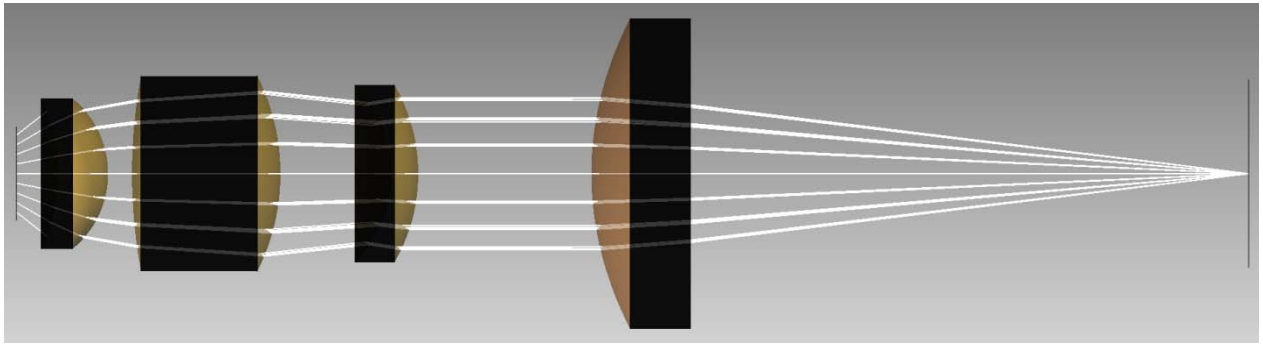
Application Example in Detail

System Parameters

Context of this Application Example

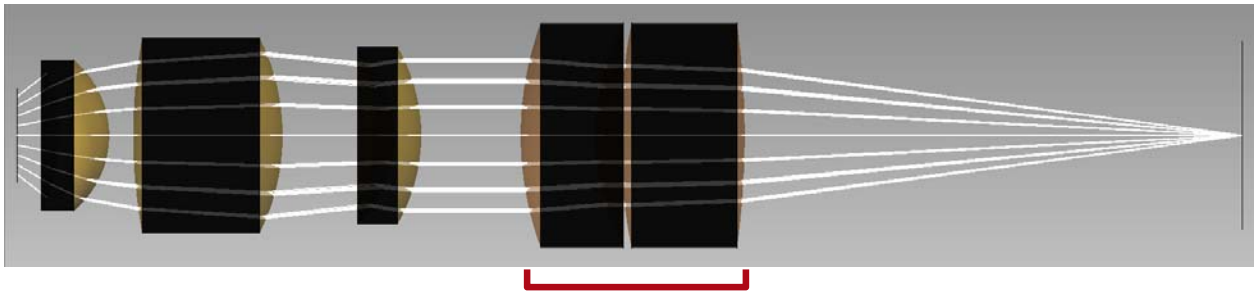
This application example is part of a larger group of related examples:

BDS.0001, BDS.0002 and BDS.0003 deal with a **refractive beam delivery system**.



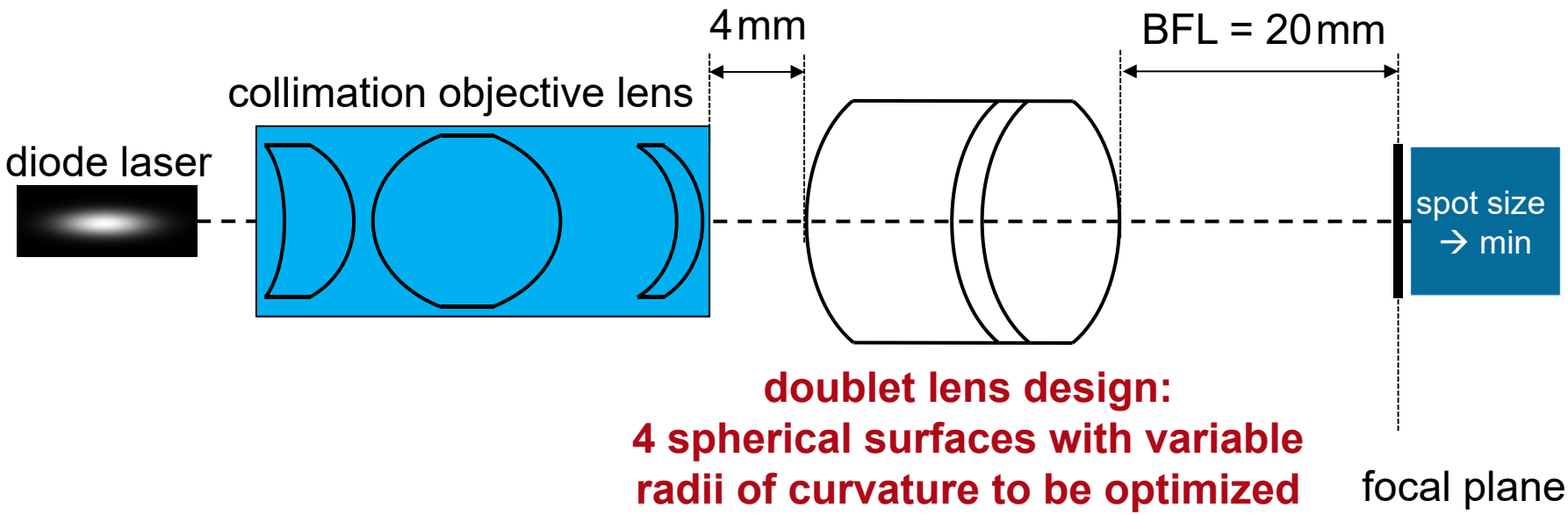
BDS.0001: collimation lens

In BDS.0002 we have used an aspherical catalog lens. In this example we replace it by our own lens design.

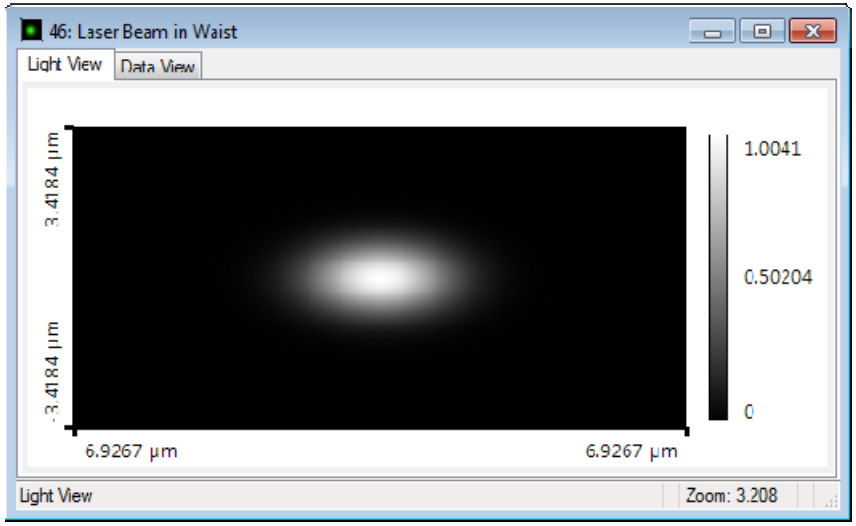


BDS.0003: **design of doublet lens** for focusing

Design Task


4 mm
BFL = 20 mm
collimation objective lens
diode laser
spot size
→ min
doublet lens design:
4 spherical surfaces with variable
radii of curvature to be optimized
focal plane

Specs: Uncollimated Input Laser Beam

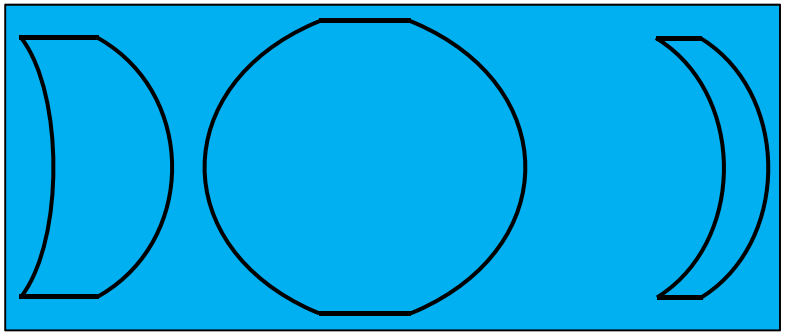


Single Mode IR Diode Laser from Laser Components

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

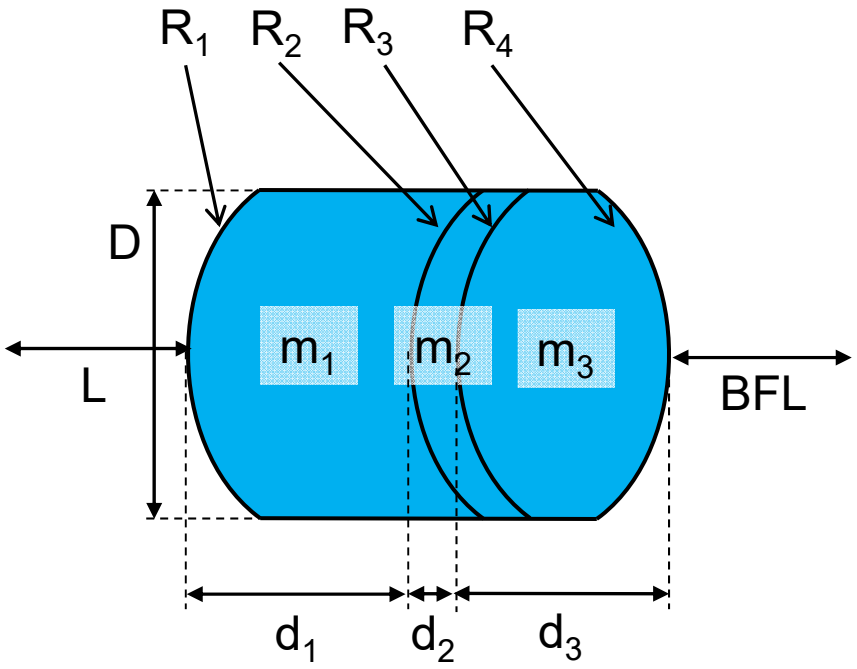
Specs: Collimation Lens and Subsequent Light



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	1.0180 × 1.1802
RMS of wavefront error	~0.03 λ

Specs: Doublet Lens



Parameter	Value & Unit
distance collimation to doublet lens L	4 mm
distances (d1, d2, d3)	(3, 1, 5) mm
desired back focal length (BFL)	20 mm
diameter D of all surfaces	9 mm
material m1	N-BK7 (*)
material m2	air
material m3	SF6 (*)
initial radii of curvatures (R1, R2, R3, R4)	each 10 mm
allowed range of modulus of radii of curvature $\|R_i\|$ for optimization	[5 mm; 50 mm]

(*) from catalog Schott 2014

Application Example in Detail

Simulations & Results

How to Optimize (Presettings)

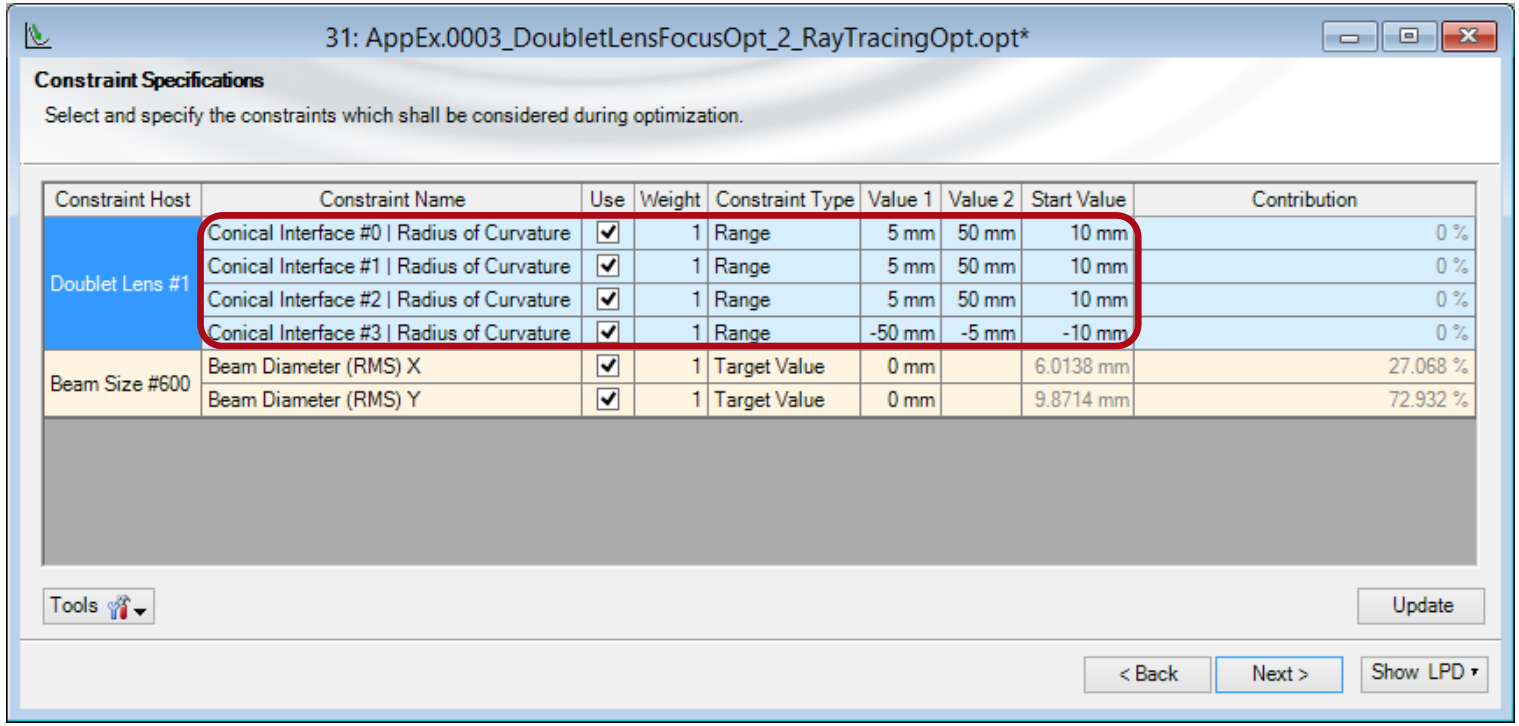
- The doublet lens should be optimized such, that the collimated **input beam is focused** under the given conditions at a distance of **20 mm behind the lens**.

- We apply the **parametric optimization document** to automatically perform iterative **simulations with varying radii of curvature** until a minimized focus spot is achieved.

- As the first part of the whole setup is not altered, we use the calculated **light distribution directly in front of the doublet lens as starting point**.

- For the **evaluation** of the focus spot we put a **beam size or a beam parameter detector** at the target focal plane.

Ray Tracing: Pre-Optimization

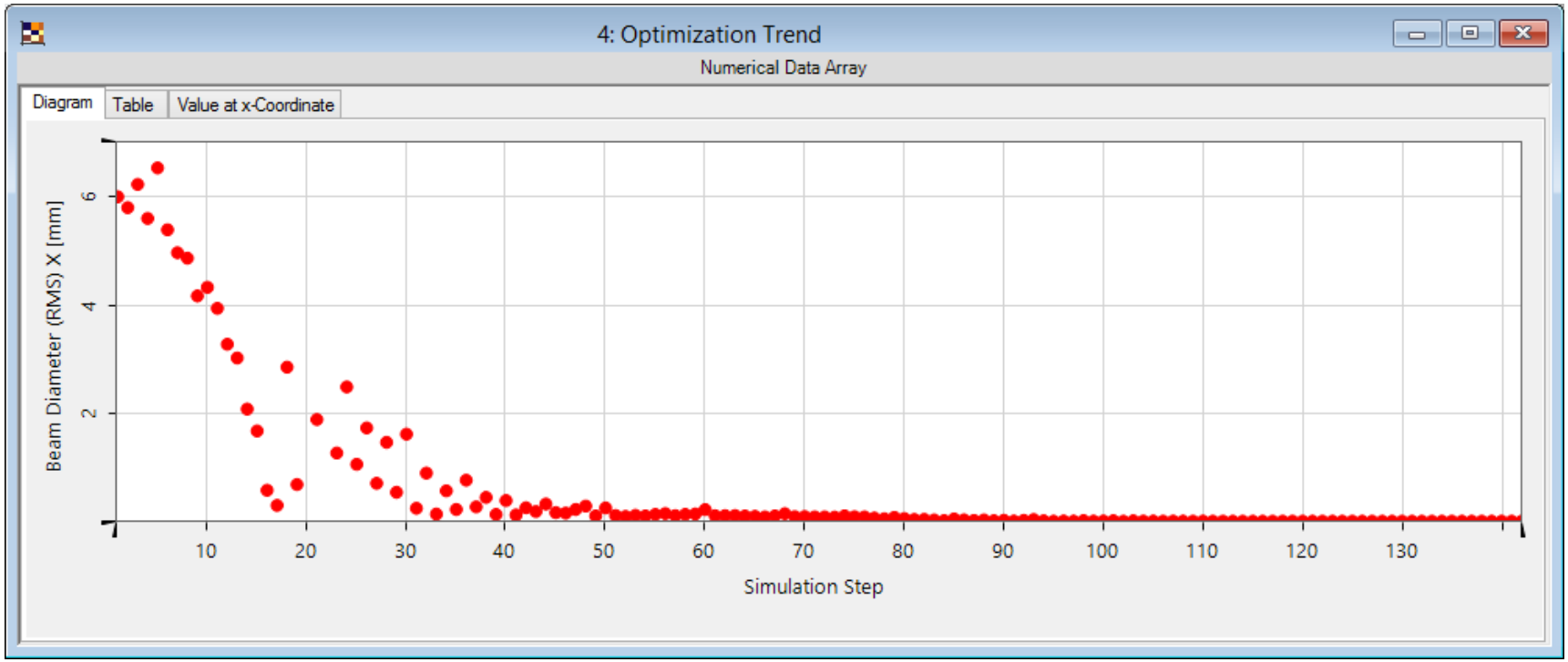


Constraint Host	Constraint Name	Use	Weight	Constraint Type	Value 1	Value 2	Start Value	Contribution
Doublet Lens #1	Conical Interface #0 | Radius of Curvature	☑	1	Range	5 mm	50 mm	10 mm	0 %
	Conical Interface #1 | Radius of Curvature	☑	1	Range	5 mm	50 mm	10 mm	0 %
	Conical Interface #2 | Radius of Curvature	☑	1	Range	5 mm	50 mm	10 mm	0 %
	Conical Interface #3 | Radius of Curvature	☑	1	Range	-50 mm	-5 mm	-10 mm	0 %
Beam Size #600	Beam Diameter (RMS) X	☑	1	Target Value	0 mm		6.0138 mm	27.068 %
	Beam Diameter (RMS) Y	☑	1	Target Value	0 mm		9.8714 mm	72.932 %

- **Ray tracing simulations** often have the advantage to be **faster**.
- Thus we are using VirtualLab‘s Ray Tracing Engine for a first pre-optimization step. Subsequently we **refine the results via the Classic Field Tracing Engine**.

Ray Tracing: Optimization Process

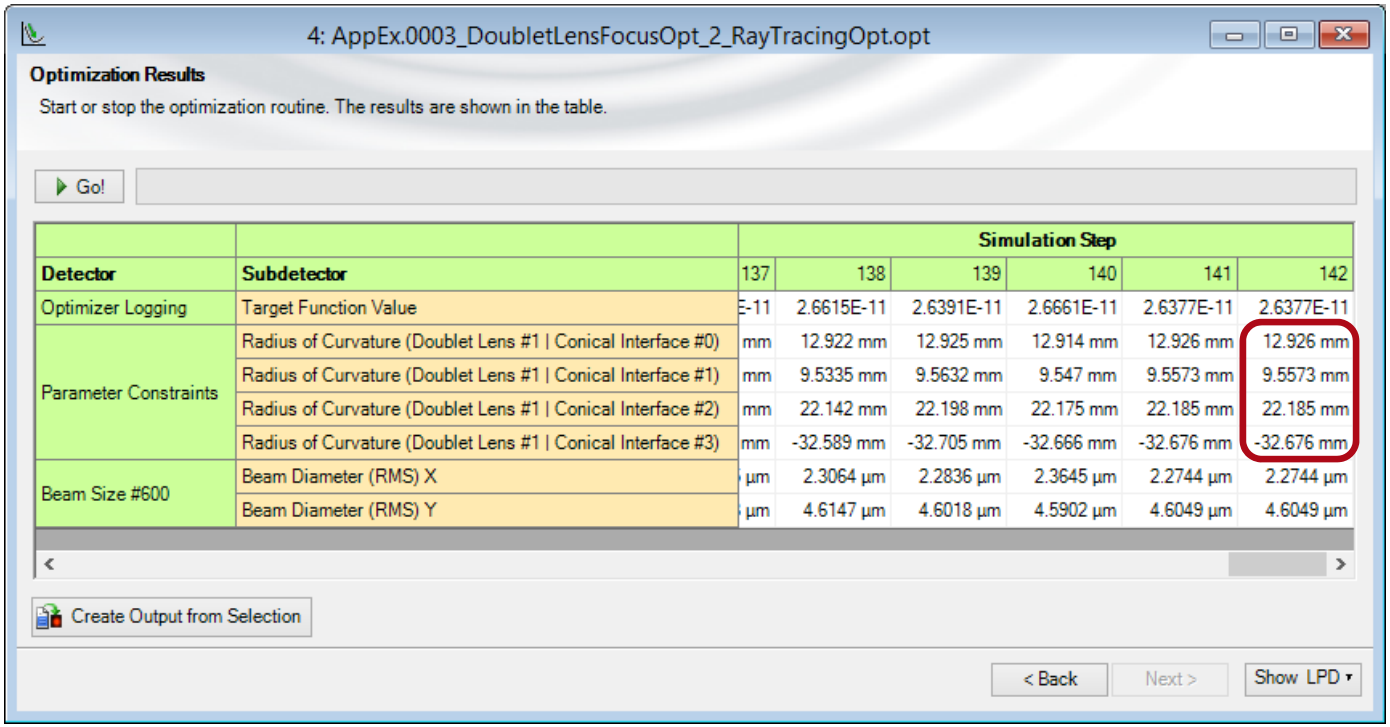
Within 142 optimization steps VirtualLab varied the four surface radii and found a **minimal focus diameter** via ray tracing simulations.



file used: BDS.0003_DoubletLensFocusOpt_2_RayTracingOpt.lpd

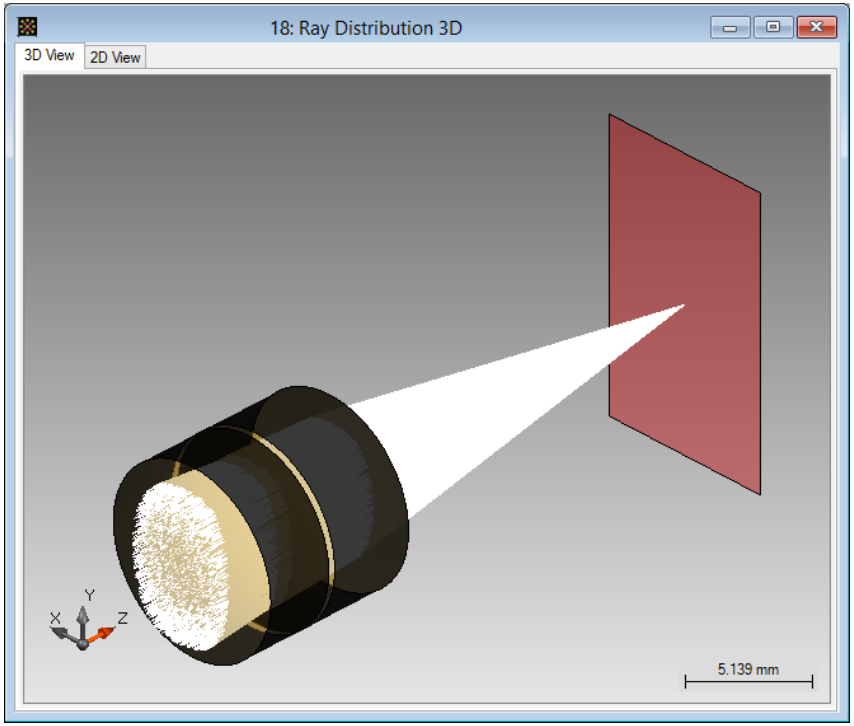
Ray Tracing: Pre-Optimized Focusing Surfaces

VirtualLab lists all parameters and results of the optimization. In the last column the **pre-optimized radii of curvature** of the four surfaces are displayed.



		Simulation Step					
Detector	**Subdetector**	137	138	139	140	141	142
Optimizer Logging	Target Function Value	E-11	2.6615E-11	2.6391E-11	2.6661E-11	2.6377E-11	2.6377E-11
Parameter Constraints	Radius of Curvature (Doublet Lens #1 | Conical Interface #0)	mm	12.922 mm	12.925 mm	12.914 mm	12.926 mm	12.926 mm
	Radius of Curvature (Doublet Lens #1 | Conical Interface #1)	mm	9.5335 mm	9.5632 mm	9.547 mm	9.5573 mm	9.5573 mm
	Radius of Curvature (Doublet Lens #1 | Conical Interface #2)	mm	22.142 mm	22.198 mm	22.175 mm	22.185 mm	22.185 mm
	Radius of Curvature (Doublet Lens #1 | Conical Interface #3)	mm	-32.589 mm	-32.705 mm	-32.666 mm	-32.676 mm	-32.676 mm
Beam Size #600	Beam Diameter (RMS) X	µm	2.3064 µm	2.2836 µm	2.3645 µm	2.2744 µm	2.2744 µm
	Beam Diameter (RMS) Y	µm	4.6147 µm	4.6018 µm	4.5902 µm	4.6049 µm	4.6049 µm

Ray Tracing: 3D Evaluation

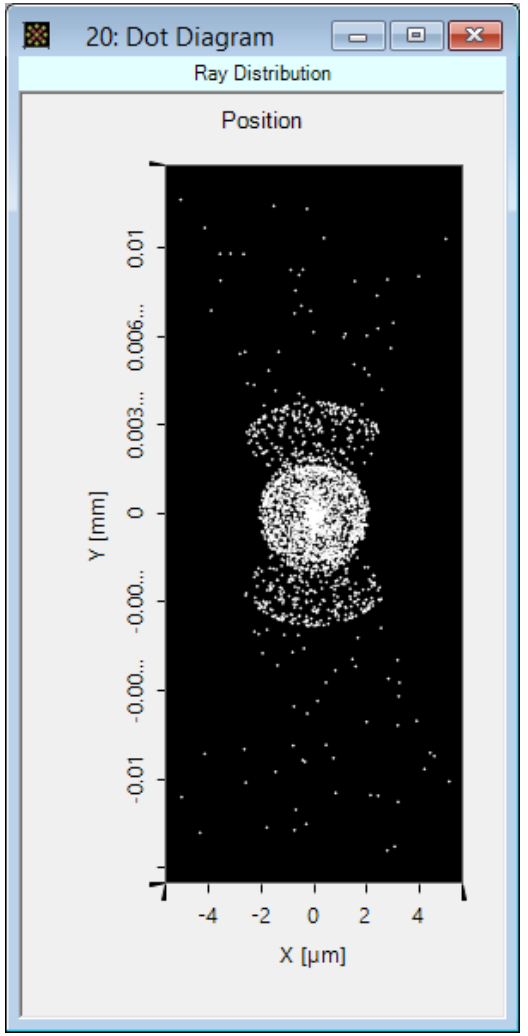


3D ray tracing system analysis exhibits expected focusing behavior.

Ray Tracing: Focus Spot Size

- We have used the **beam size detector** to evaluate the spot size during the ray tracing optimization.

- The resulting **beam diameters in X and Y** direction according to the RMS values (referring to the centroid) are:
  2.27 µm × 4.60 µm (smaller than the diffraction limit)



via optimized LPD from: BDS.0003_DoubletLensFocusOpt_2_RayTracingOpt.lpd

Improvement: From Ray to Field Tracing

- Simulations based on **geometric optics cannot evaluate the light distribution realistically where diffraction effects play a major role**.

- This is the case in the **focal region**.

- **Field tracing** simulations **allow** the consideration of **all wave optical effects**.

Thus you can
check and improve
your **ray tracing designs** by using **field tracing simulations!**

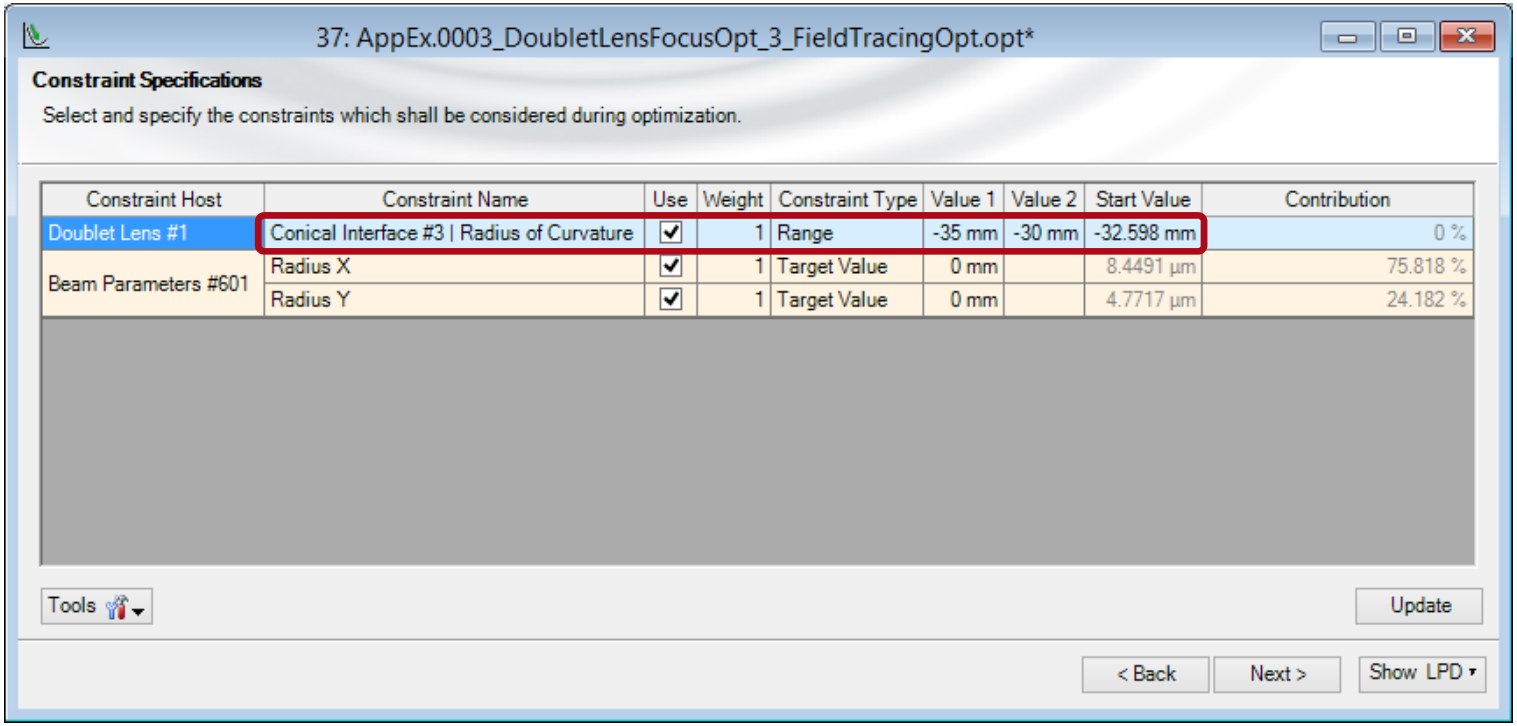
Field Tracing: Interim Results

- So, to get a more meaningful result, we perform **physical optical field tracing simulations** considering also the **diffraction effects** and apply the **beam parameter detector** which is based on the second momentum theory.
- The field tracing result values „**Waist Distances X × Y**“ already reveal that the optimal focus positions after the ray tracing optimization are not at the desired distance of 20 mm due to diffraction effects.
- Thus we do the **second optimization step** based on **field tracing** and the pre-optimized surface data as initial values.

Parameter	Value & Unit
radius in X x Y	8.57 µm × 5.01 µm
waist distances in X x Y	-40.08 µm × -19.71 µm

via optimized LPD from: BDS.0003_DoubletLensFocusOpt_2_RayTracingOpt.lpd

Field Tracing: Final-Optimization



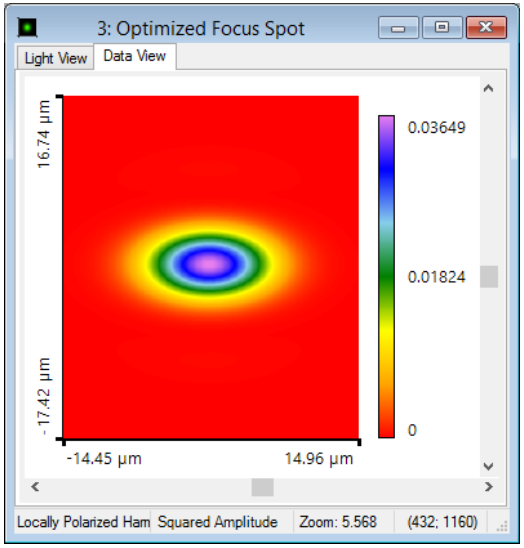
- For a refining optimization step it‘s not necessary to vary all surfaces. Here we decide only to **modify the last surface** such, that we really get the optimal focus at 20 mm distance.
- Furthermore, this fine tuning requires typically only slight changes, thus we specify a **smaller range for the radius of curvature**.

Field Tracing: Final Results

- By optimizing the last surface we **shifted** the **beam waists closer to the desired position**. Thus the **focus spot is further decreased**.

- Even for this low NA system field tracing enabled us to improve (decrease) the final **focus spot** radii by: **0.12µm × 0.24µm** (1.4% × 4.8%)

Parameter	Value & Unit
radius in X × Y	8.45µm × 4.77µm
waist distances in X × Y	-17.10µm × 3.51µm

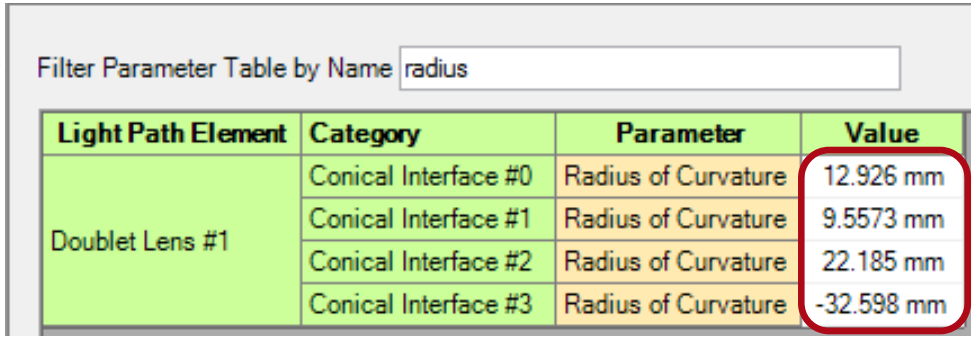


file used: BDS.0003_DoubletLensFocusOpt_4_FinalSystemOptimized.lpd

Result Comparison (1st vs 2nd step) & Radii

Parameter	After Ray Tracing Optimization (1st Step)	After Field Tracing Optimization (2nd Step)
radius X	8.57 µm	8.45 µm
radius Y	5.01 µm	4.77 µm
waist distance X	-40.08 µm	-17.10 µm
waist distance Y	-19.71 µm	+3.51 µm

The *Parameter Overview* shows the final radii of curvature of the four conical interfaces, building the lens doublet.

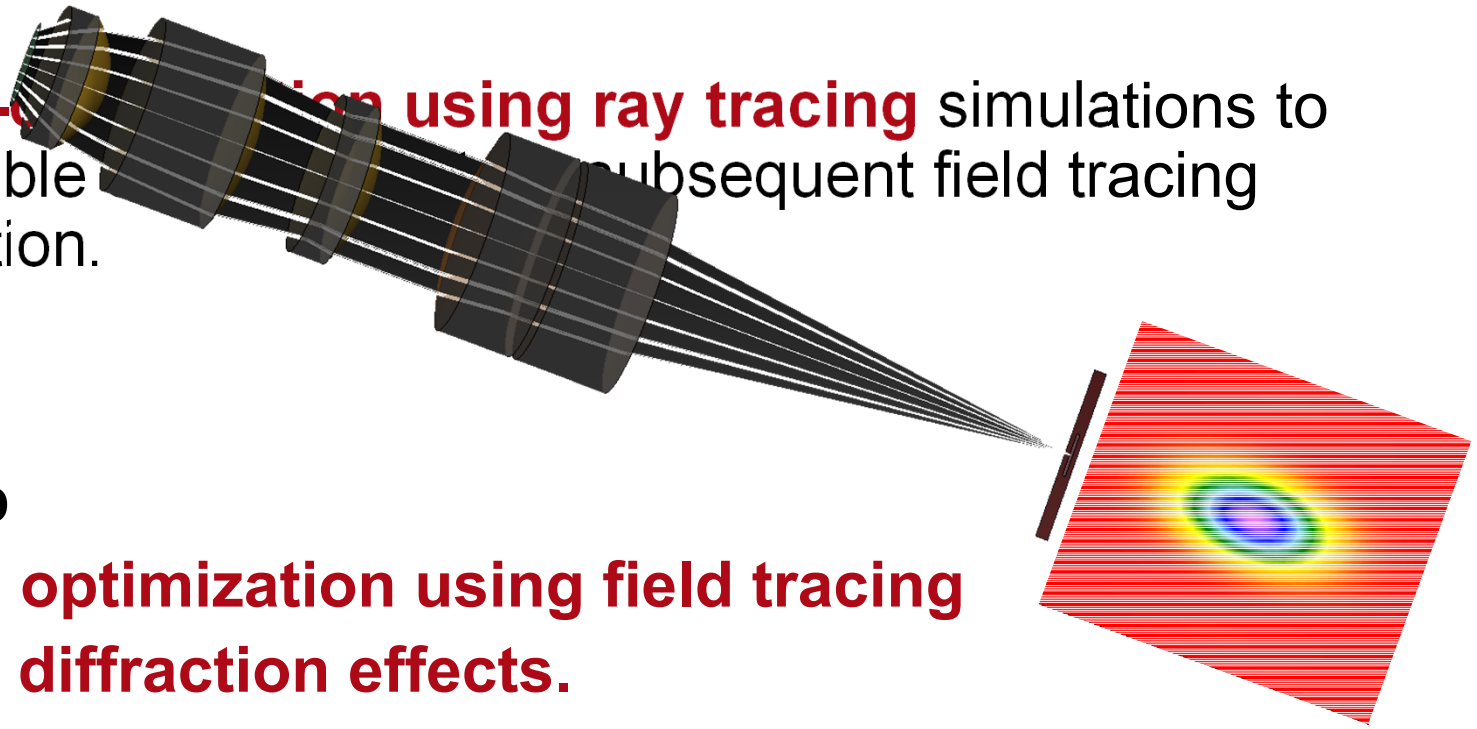


Summary

Improving a lens design obtained by ray tracing using an additional optimization step based on **field tracing**.

1st step

Fast **pre-o** **using ray tracing** simulations to find suitable ubsequent field tracing optimization.



2nd step

Refining optimization using field tracing

including **diffraction effects.**

Further Readings

Further Readings

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