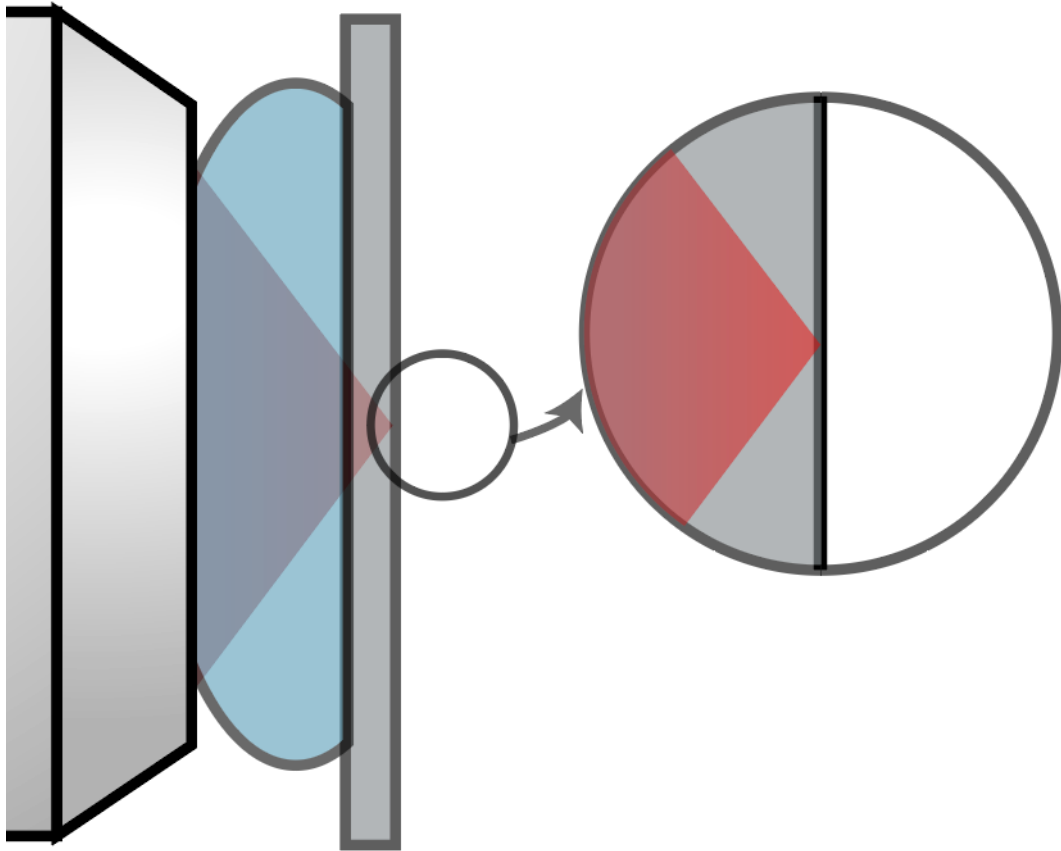


Tight Focusing by a High-NA Immersion Microscope

Abstract



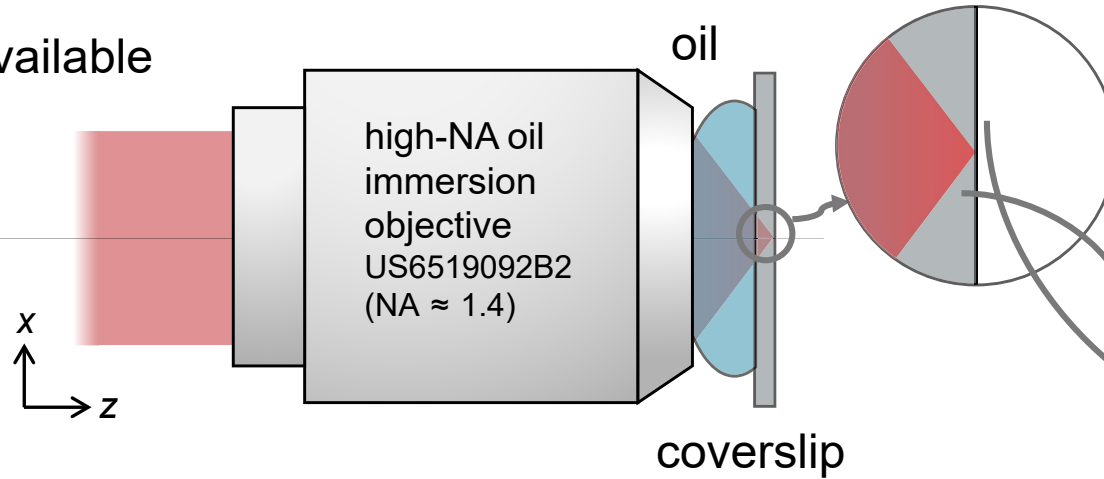
In an immersion microscope, there is often a coverslip which separates the immersion liquid and the specimen. Therefore, the PSF could be distorted by the interface of the coverslip at the focal plane, which is not very often considered well in the design procedure. In VirtualLab Fusion, the influence of the PSF by the interface of the coverslip can be analyzed straightforwardly. The distortion of the focal spot behind the coverslip is demonstrated and analyzed in a fully vectorial manner.

Scenario

1. real lens data available

plane wave

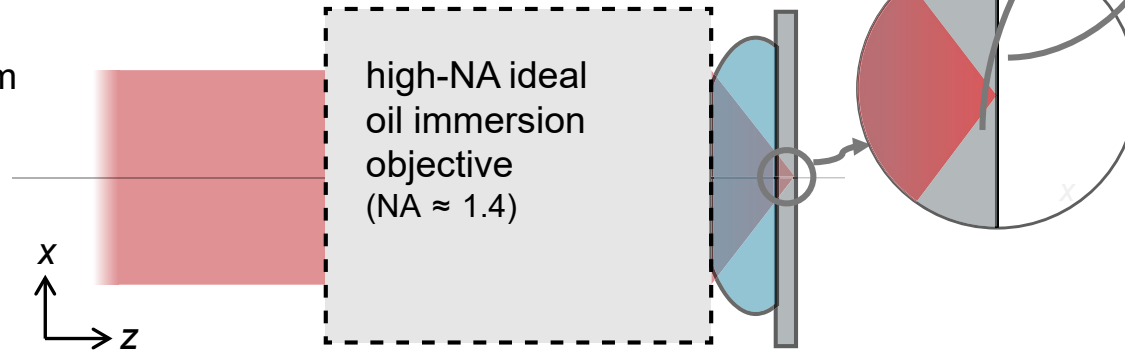
- wavelength 532nm
- linearly polarized in x direction



2. no real lens data available

plane wave

- wavelength 532nm
- linearly polarized in x direction



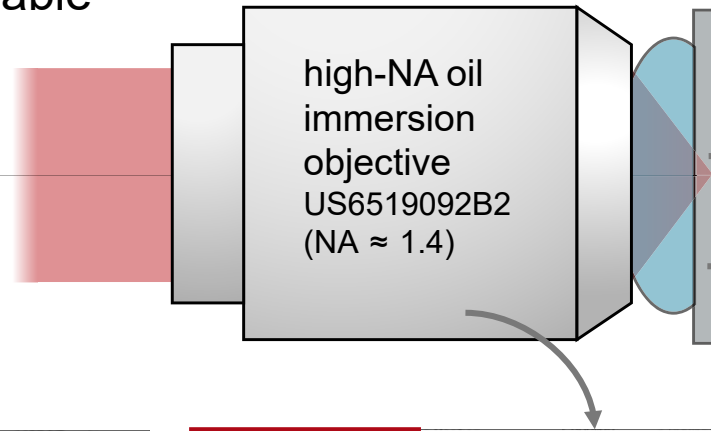
PSF & electric field?

Comparison of the PSF and electric field before and behind the last surface of the coverslip to investigate how the PSF and the electric field are influenced?

Building the System in VirtualLab Fusion

System Building Blocks

1. real lens data available



Edit Plane Wave
✕

Basic Parameters

Polarization

Global Polarization Local Polarization

Polarization Input

Type of Polarization: Linearly Polarized

Angle: 0°

Spectral Parameters

Mode Selection

Sampling

Ray Selection

Normalized Jones Vector

$$\begin{pmatrix} J_x \\ J_y \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

Edit Lens System Component
✕

Coordinate Systems

Position / Orientation

Structure

Solver

Channel Configuration

Index	Distance	Position	Type	Homogeneous Medium	Comment
1	0 mm	0 mm	Conical Interface	FD60-W_HOYA in Homc	Enter your c
2	3 mm	3 mm	Conical Interface	S-LAH63_OHARA in Hoi	Enter your c
3	2.6 mm	5.6 mm	Conical Interface	Air (Zemax OS) in Homc	Enter your c
4	3.4 mm	9 mm	Conical Interface	S-LAH63_OHARA in Hoi	Enter your c
5	5 mm	14 mm	Conical Interface	GFK70_SUMITA in Homc	Enter your c
6	5.2 mm	19.2 mm	Conical Interface	Air (Zemax OS) in Homc	Enter your c
7	150 μm	19.35 mm	Conical Interface	Index_d_1.53_Abbe_51	Enter your c
8	1 mm	20.35 mm	Conical Interface	LITHOTEC-CAF2_SCHC	Enter your c
9	6.3 mm	26.65 mm	Conical Interface	J-KZFH1_HIKARI in Hor	Enter your c
10	1.6 mm	28.25 mm	Conical Interface	Air (Zemax OS) in Homc	Enter your c
11	100 μm	28.35 mm	Conical Interface	LITHOTEC-CAF2_SCHC	Enter your c
12	8 mm	36.35 mm	Conical Interface	J-KZFH1_HIKARI in Hor	Enter your c
13	1.1 mm	37.45 mm	Conical Interface	Air (Zemax OS) in Homc	Enter your c

Edit Stratified Media Component
✕

Coordinate Systems

Position / Orientation

Structure

Solver

Channel Configuration

Component Size: 6 mm × 6 mm

Reference Surface (all Channels)

Plane Surface

Aperture: Yes No

Coating

Name: No Coating

Homogeneous Medium Behind Surface

Water-H2O_(1997+1991) in Homogeneous Medium

Edit Camera Detector
✕

Detector Window and Resolution

Detector Window

Scale Window Size by Factor

Set Window Size: 2 μm × 2 μm

Edit Electromagnetic Field Detector
✕

Detector Window and Resolution

Detector Window

Scale Window Size by Factor

Set Window Size: 2 μm × 2 μm

Copy from ... Center Position: 0 mm × 0 mm

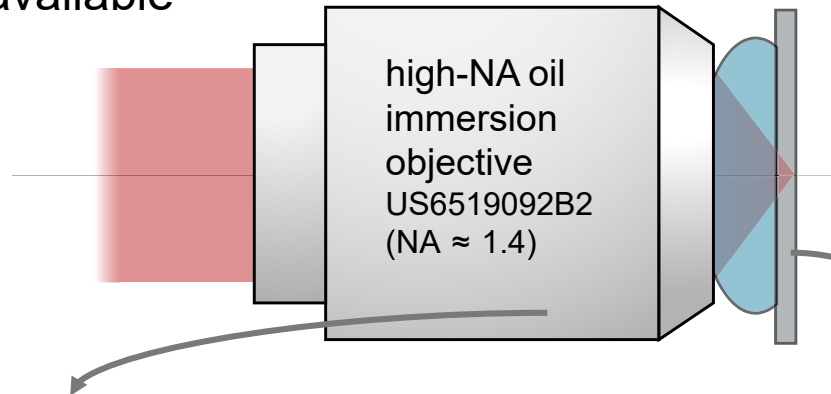
Detector Resolution

Scale Sampling Distance by Oversampling Factor

5

Solvers for Components

1. real lens data available



Edit Lens System Component

Solver | Sampling

Component Solver: **Local Plane Interface Approximation (LPIA)**

The LPIA solver works in the spatial domain (**x domain**), locally, in a pointwise manner. The solver follows that

1. the input field on the surface is treated as a composition of local plane waves (LPWs),
2. the part of the surface seen by each LPW is considered a plane interface (locally), and,
3. the interaction of the LPW with the local plane interface can be modeled by the Fresnel (or the layer) matrix.

At an arbitrary location on the curved surface, an approximate local boundary condition is applied, which assumes the interaction of the LPW with the local plane interface. Thus, the Fresnel matrix (or layer matrix for coatings) can be used to connect input and output fields [Learn more about this solver](#).

The diagram shows a curved surface with an 'input LPW' and an 'output LPW'. The surface is divided into 'front' and 'behind' regions. The z-axis is shown.

Edit Stratified Media Component

Solver | Sampling

Component Solver: **Layer Matrix [S-Matrix]**

The layer matrix solver works in the spatial frequency domain (**k domain**). It consists of

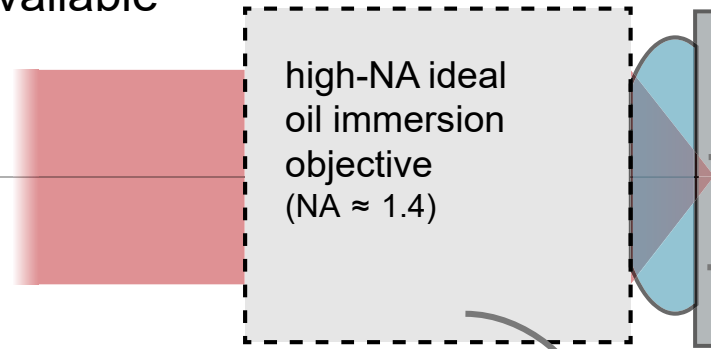
1. an eigenmode solver for each homogeneous layer and
2. an S-matrix for matching the boundary conditions at all surfaces.

The eigenmode solver computes the field solution in the k domain for the homogeneous medium in each layer. The S-matrix algorithm calculates the response of the whole layer system by matching the boundary conditions in a recursive manner. It is well-known for its unconditional numerical stability since, unlike the traditional transfer matrix, it avoids the exponentially growing functions in the calculation steps. [Learn more about this solver](#).

The diagram shows a stratified media component with multiple layers. The S-matrix is shown as a series of blocks labeled S₊₊, S₋₊, ..., S₋. The input and output fields are labeled E_{⊥,+}ⁱⁿ, E_{⊥,+}^{out}, E_{⊥,-}^{out}, and E_{⊥,-}ⁱⁿ.

System Building Blocks

2. no real lens data available



Edit Plane Wave

Basic Parameters | Spectral Parameters | Spatial Parameters

Polarization | Mode Selection | Sampling | Ray Selection

Global Polarization Local Polarization

Polarization Input

Type of Polarization: Linearly Polarized

Angle: 0°

Normalized Jones Vector

$$\begin{pmatrix} J_x \\ J_y \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

Edit Idealized Lens [Focusing Mode] Component

Bounding Box | Component Specification

Input Field Preparation (for Classic Field Tracing)

Relative Position of Field to Position of Input Transface

Keep Stored in the Field's Coordinate System

Resolve via Zero Padding

Algorithms

Input Transface	Edit	Validity: ✓
Snippet for Equidistant Field Data	Edit	Validity: ✓
Snippet for Non-Equidistant Field and Ray Data	Edit	Validity: ✓

Parameters

DesignWavelength	532 nm
DesignNin	1.5222
DesignNout	1.5222
FocalLength	3 mm

Edit Stratified Media Component

Component Size: 6 mm x 6 mm

Reference Surface (all Channels)

Plane Surface

Aperture: Yes No

Coating

Name: No Coating

Homogeneous Medium Behind Surface

Water-H2O_(1997+1991) in Homogeneous Medium

Edit Camera Detector

Detector Window and Resolution | Detector Function

Detector Window

Scale Window Size by Factor

Set Window Size: 2 μm x 2 μm

Edit Electromagnetic Field Detector

Detector Window and Resolution | Detector Function

Detector Window

Scale Window Size by Factor

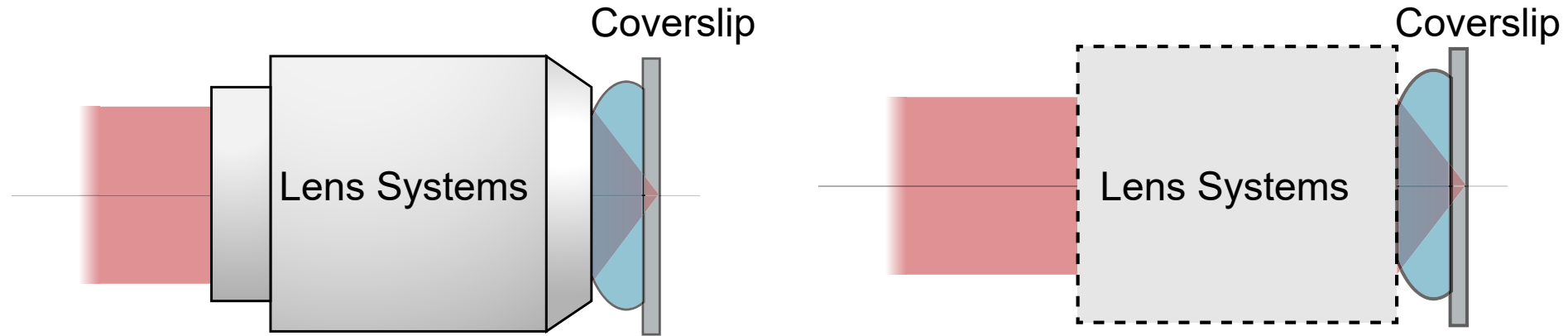
Set Window Size: 2 μm x 2 μm

Copy from ... Center Position: 0 mm x 0 mm

Detector Resolution

Scale Sampling Distance by Oversampling Factor

Summary



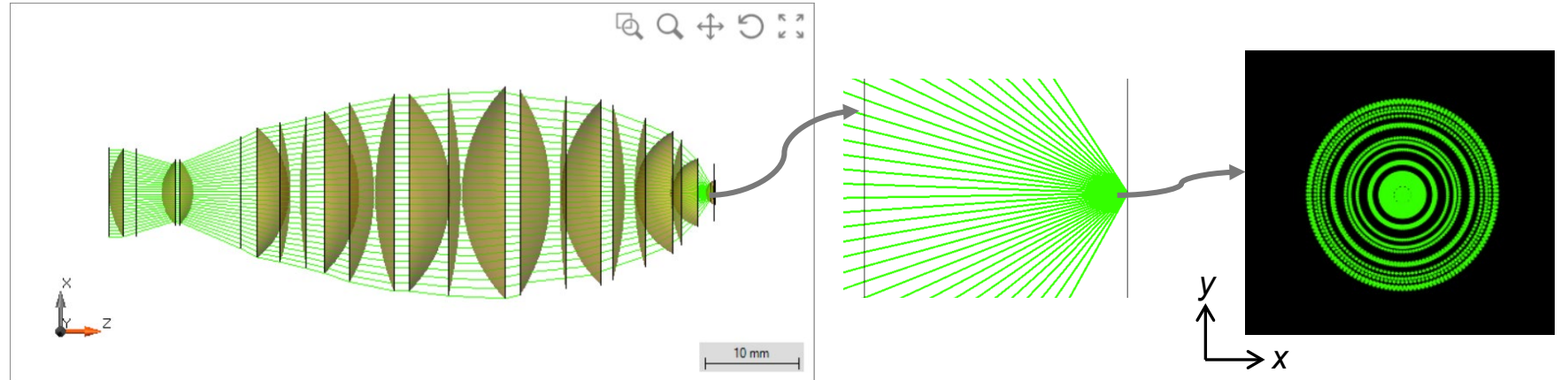
Components	Solvers
Lens Systems	Local Plane Interface Approximation (LPIA)
Coverslip	S-matrix for stratified medium

Geometric-Optics Simulations

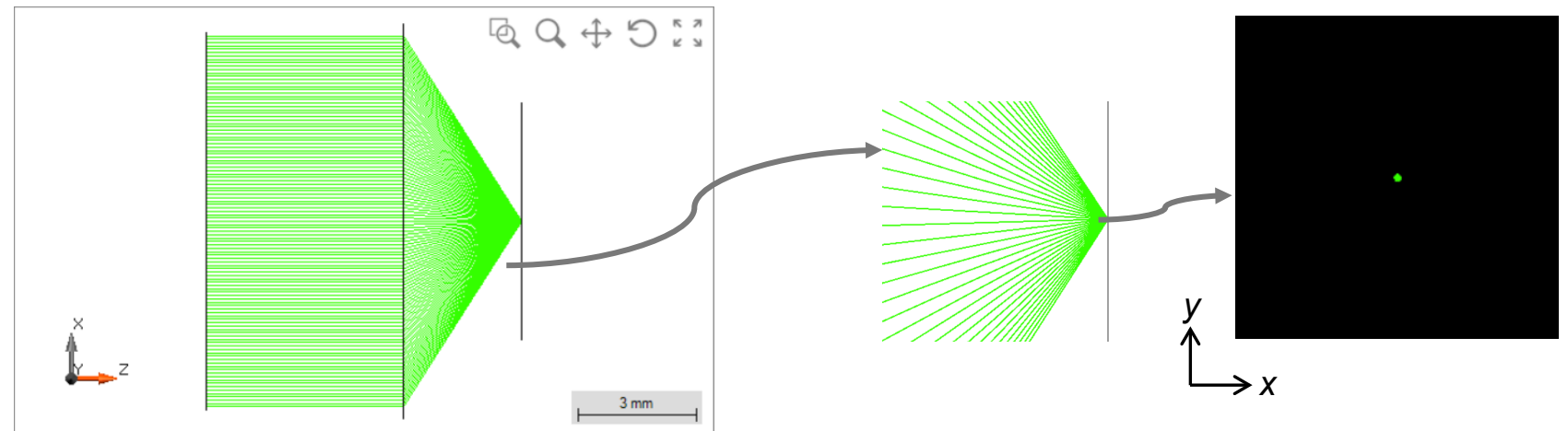
by Ray Tracing

Results: Ray Tracing

1. real lens data available



2. no real lens data available



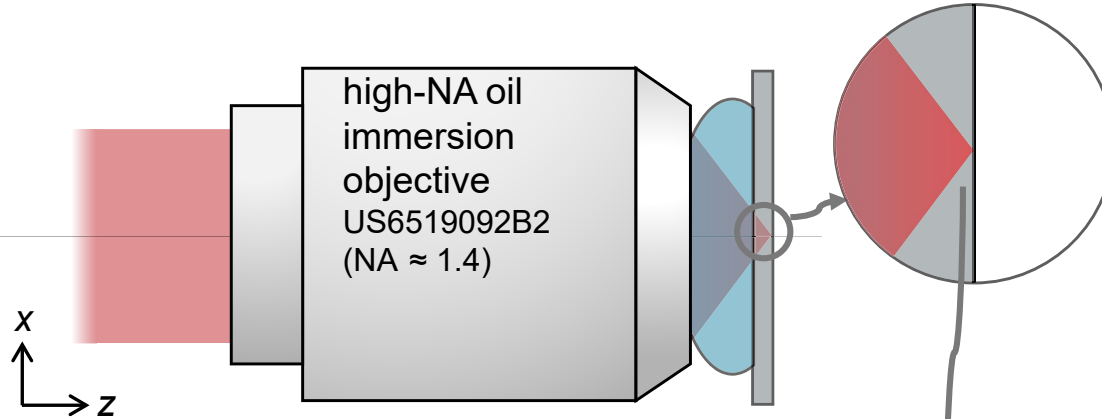
Fast Physical-Optics Simulations

by Field Tracing

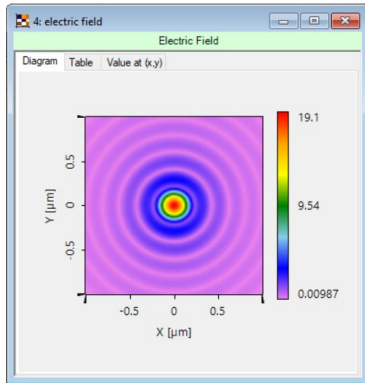
Focusing Before Last Interface of Coverslip

plane wave

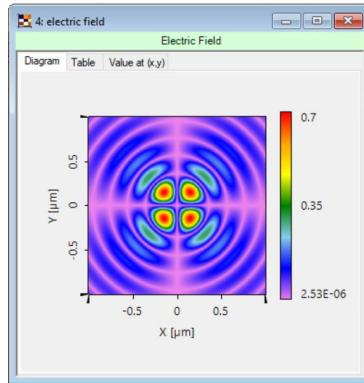
- wavelength 532 nm
- linearly polarized in x direction



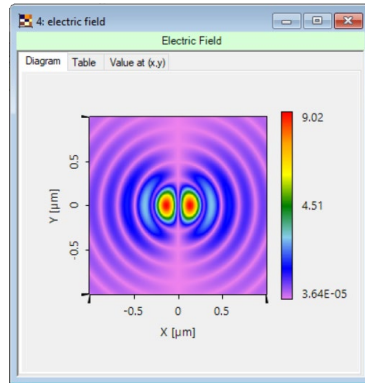
$$|E_x|$$



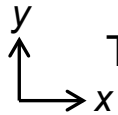
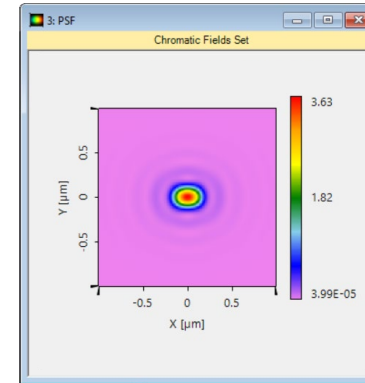
$$|E_y|$$



$$|E_z|$$



$$|E_x|^2 + |E_y|^2 + |E_z|^2$$



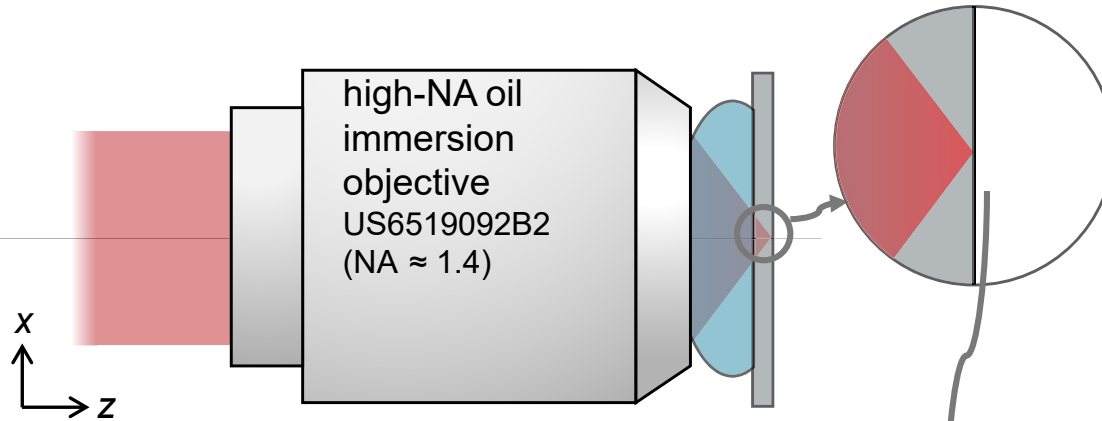
The cross-talk of different components of electric field is demonstrated.

The asymmetry of the PSF is observed.

Focusing Behind Last Interface of Coverslip in Water

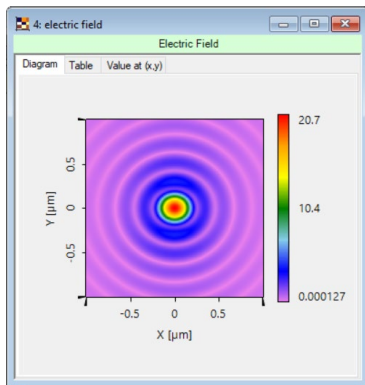
plane wave

- wavelength 532 nm
- linearly polarized in x direction

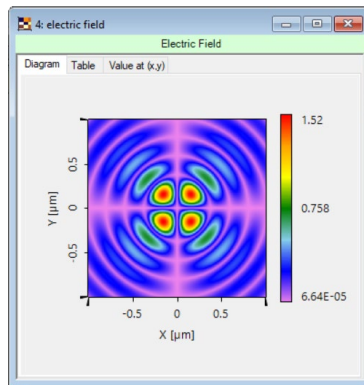


The PSF is elongated in x direction propagating through the interface.

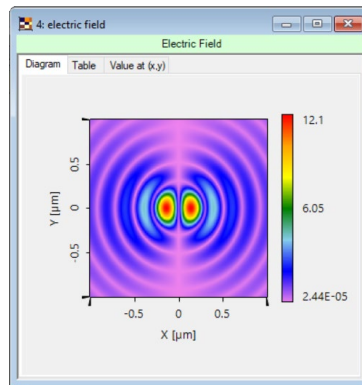
$$|E_x|$$



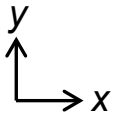
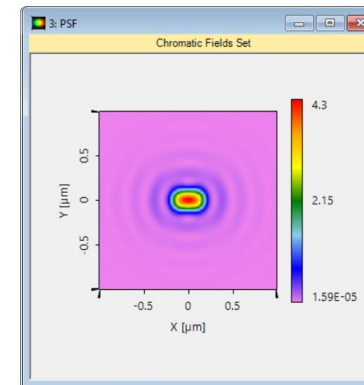
$$|E_y|$$



$$|E_z|$$



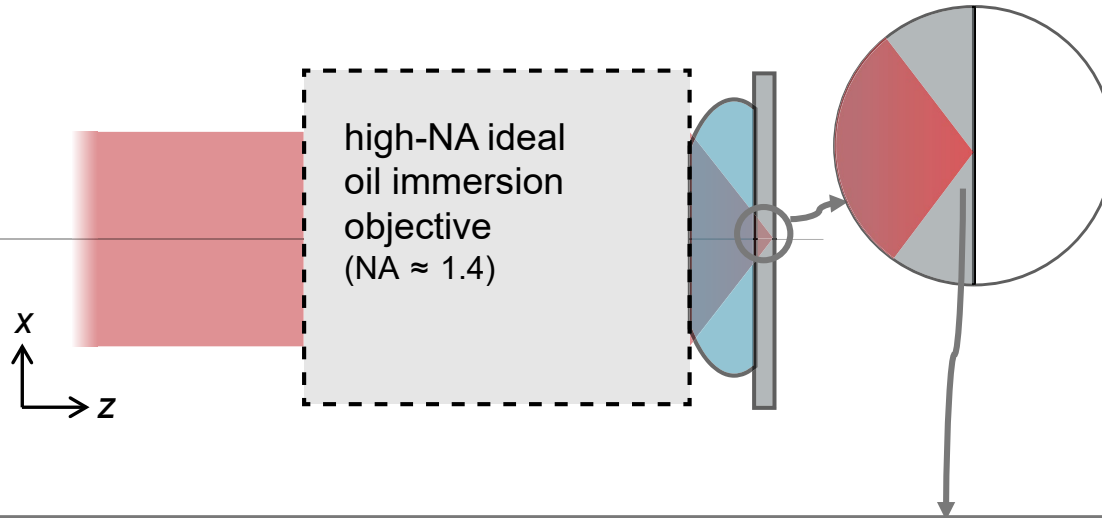
$$|E_x|^2 + |E_y|^2 + |E_z|^2$$



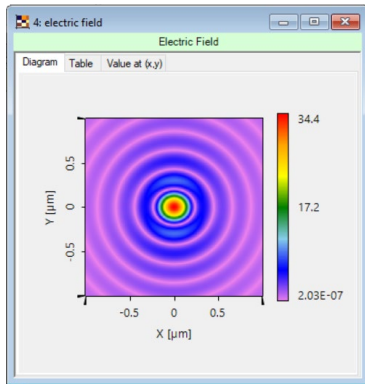
Focusing Before Last Interface of Coverslip

plane wave

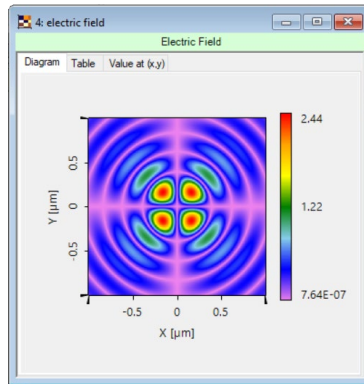
- wavelength 532 nm
- linearly polarized in x direction



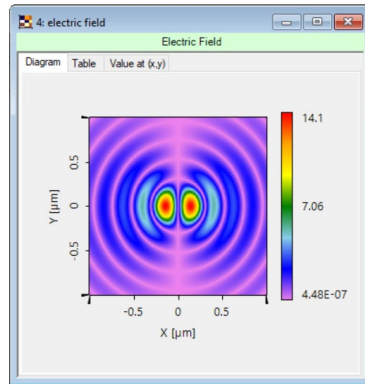
$$|E_x|$$



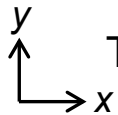
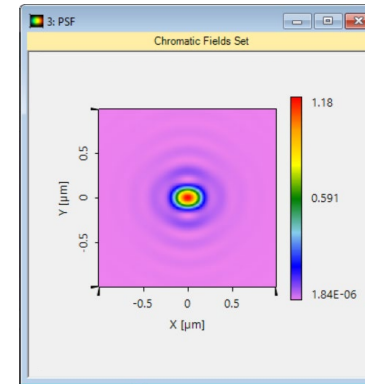
$$|E_y|$$



$$|E_z|$$



$$|E_x|^2 + |E_y|^2 + |E_z|^2$$



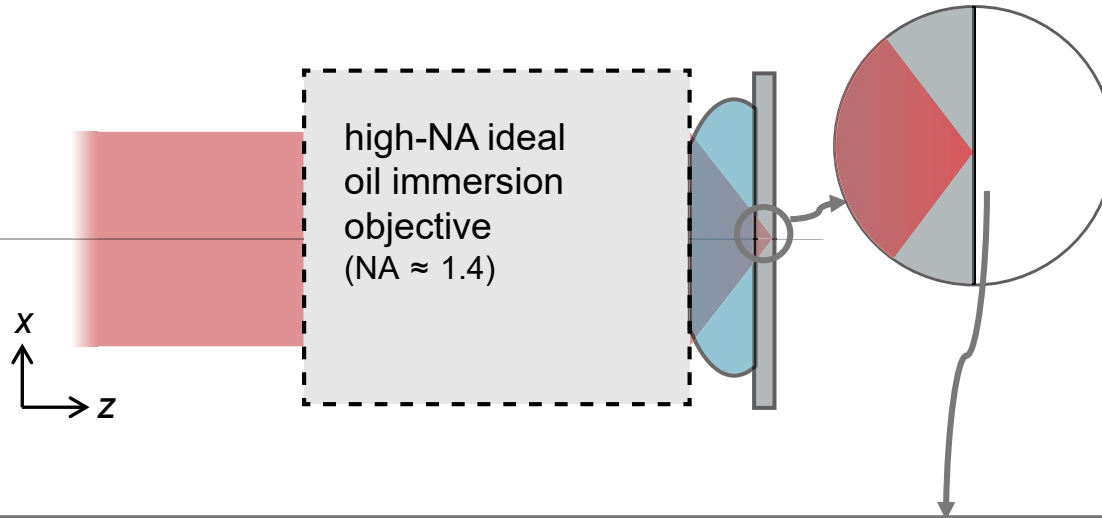
The cross-talk of different components of electric field is demonstrated.

The asymmetry of the PSF is observed.

Focusing Behind Last Interface of Coverslip in Water

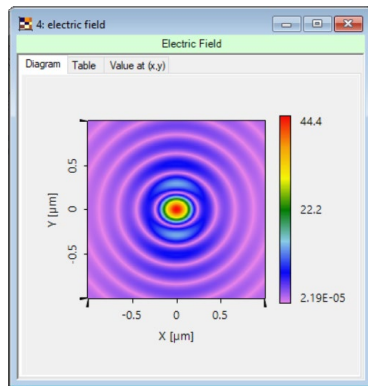
plane wave

- wavelength 532 nm
- linearly polarized in x direction

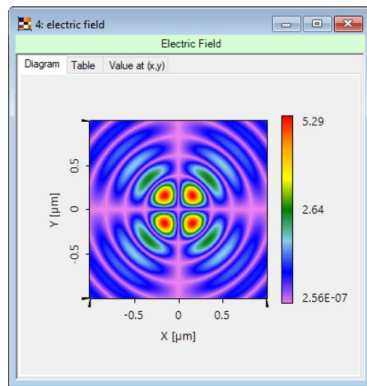


The PSF is elongated in x direction propagating through the interface.

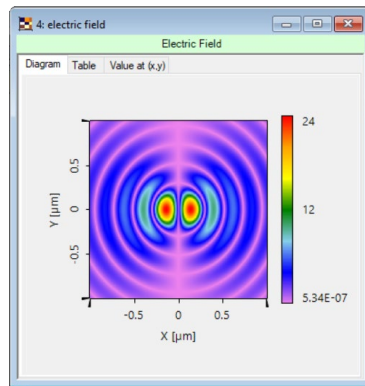
$$|E_x|$$



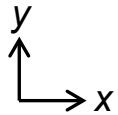
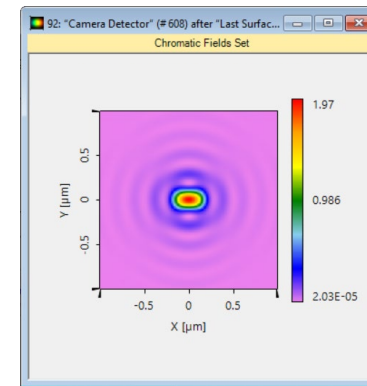
$$|E_y|$$



$$|E_z|$$



$$|E_x|^2 + |E_y|^2 + |E_z|^2$$



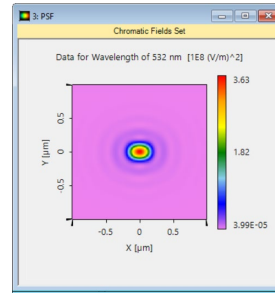
Summary

before the last interface

behind the last interface

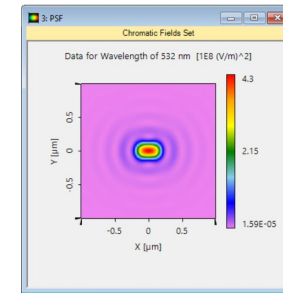
1. real lens data available

$$|E_x|^2 + |E_y|^2 + |E_z|^2$$



The asymmetry of the PSF is observed.

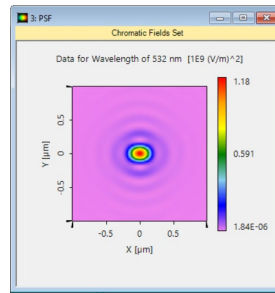
$$|E_x|^2 + |E_y|^2 + |E_z|^2$$



The PSF is elongated in x direction.

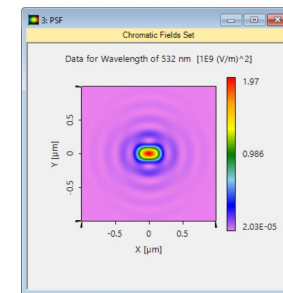
2. no real lens data available

$$|E_x|^2 + |E_y|^2 + |E_z|^2$$



The asymmetry of the PSF is observed.

$$|E_x|^2 + |E_y|^2 + |E_z|^2$$



The PSF is elongated in x direction.

Document Information

title	Tight Focusing by a High-NA Immersion Microscope
document code	MIC.0011
version	1.0
edition	VirtualLab Fusion Basic
software version	2020.2 (Build 1.116)
category	Application Use Case
further reading	<ul style="list-style-type: none">- <u>Debye-Wolf Integral Calculator</u>- <u>Analyzing High-NA Objective Lens</u>- <u>Resolution Investigation for Microscope Objective Lenses by Rayleigh Criterion</u>