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**VirtualLab Fusion Applications, Technology & Workflows**

# **Getting Started with VirtualLab Fusion**

LightTrans International UG

Presenter: Olga Baladron-Zorita

# Links of Interest

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- LightTrans website: [www.LightTrans.com](http://www.LightTrans.com)
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  - You have further questions? Drop us a line at [info@LightTrans.com](mailto:info@LightTrans.com)
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    - YouTube ([www.youtube.com/LightTransInternational](http://www.youtube.com/LightTransInternational))
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## Introduction to the Teams

# Who We Are



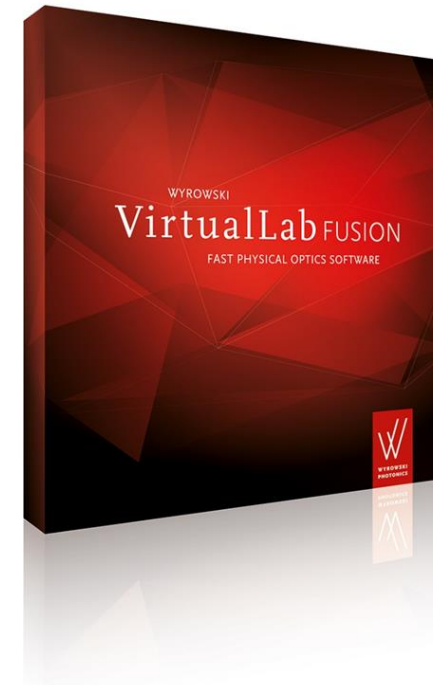
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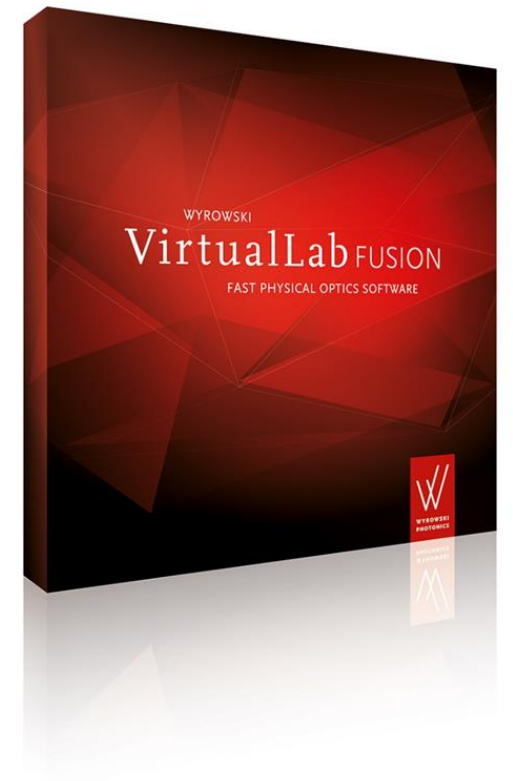
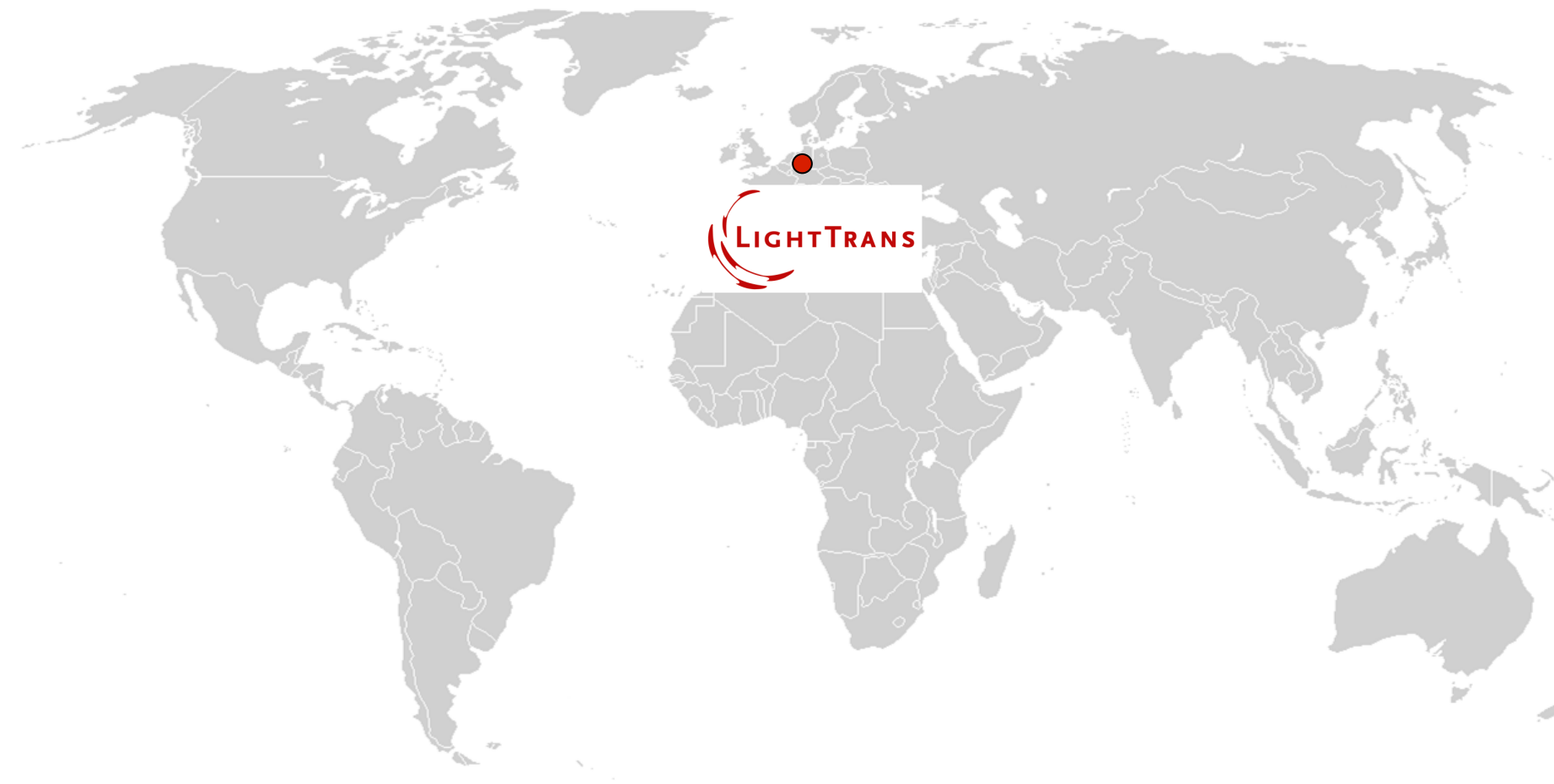
Founded 2014

General Distributor of the  
Fast Physical Optics Software  
**VirtualLab Fusion**

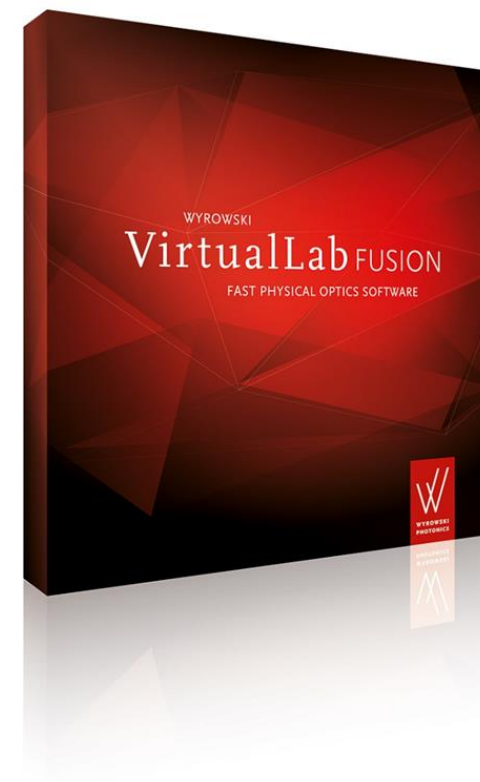
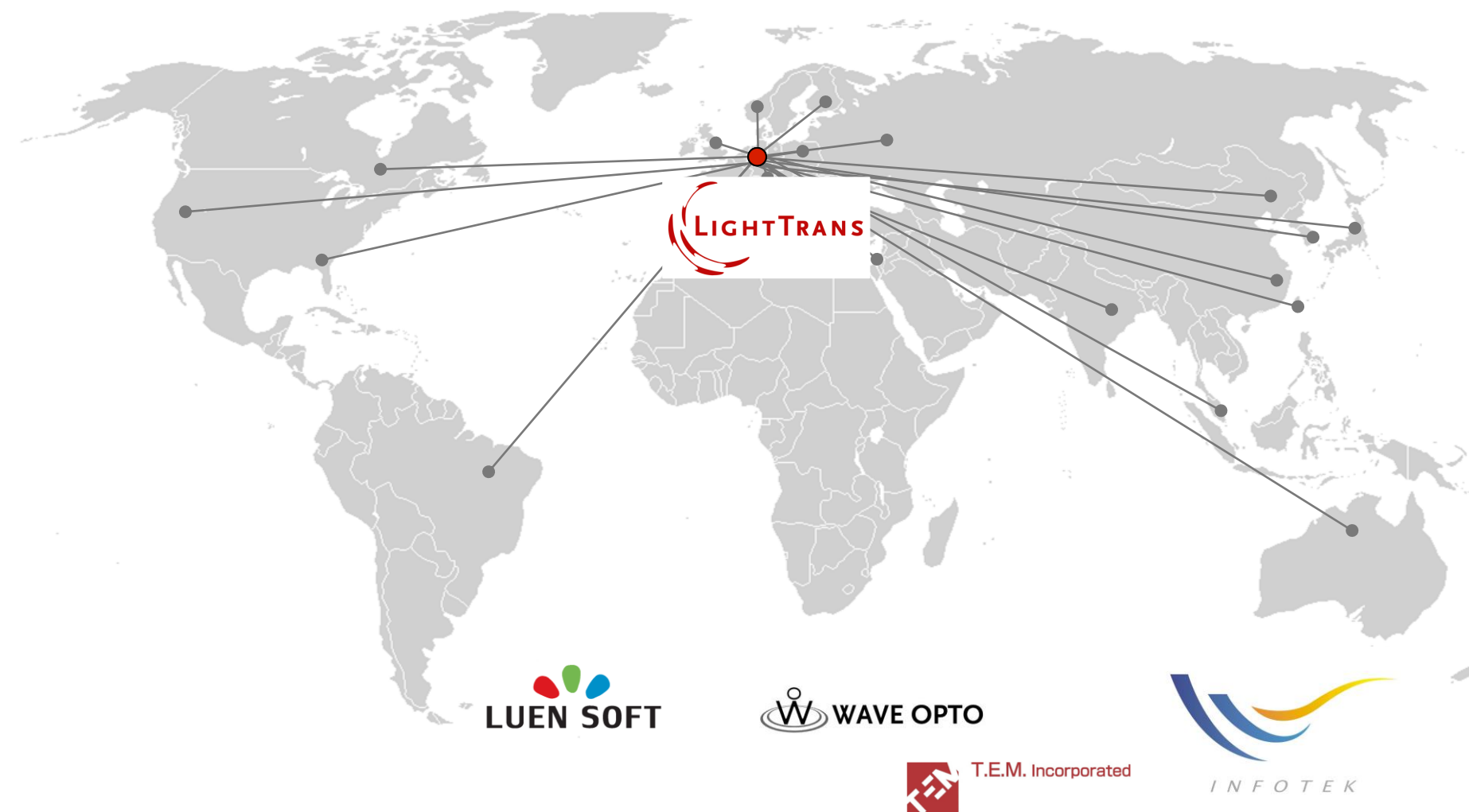
Developer of the  
Fast Physical Optics Software  
**VirtualLab Fusion**



# Fast Physical Optics Modeling and Design Software



# Fast Physical Optics Modeling and Design Software



Part 1

# Light as an Electromagnetic Field



# The Objective Behind VirtualLab Fusion

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To perform physical optics simulations of arbitrary optical systems

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# The Objective Behind VirtualLab Fusion

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To perform **physical optics simulations** of arbitrary optical systems

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# The Objective Behind VirtualLab Fusion

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To perform **physical optics simulations** of arbitrary optical systems

Finding the expression of the **six-dimensional vector field that solves Maxwell's equations** under the conditions imposed by the system in question



# The Objective Behind VirtualLab Fusion

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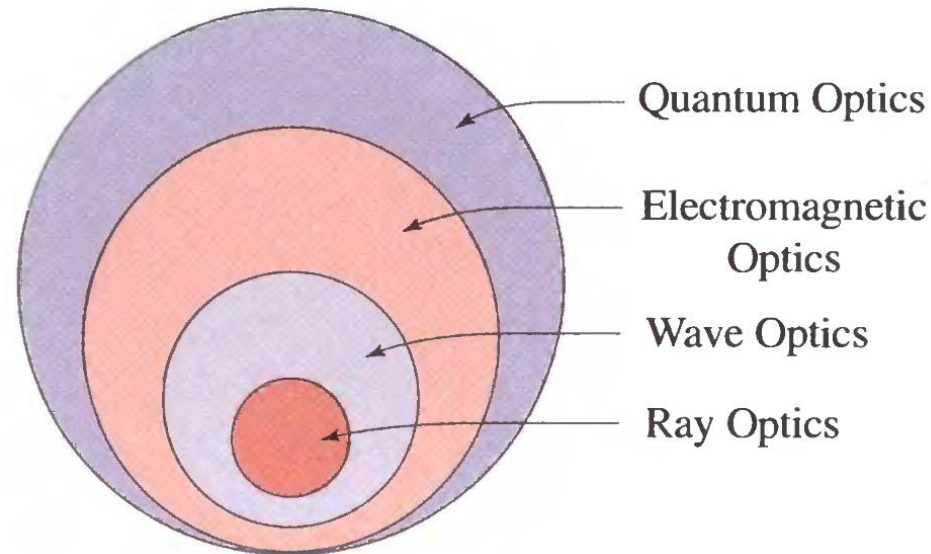
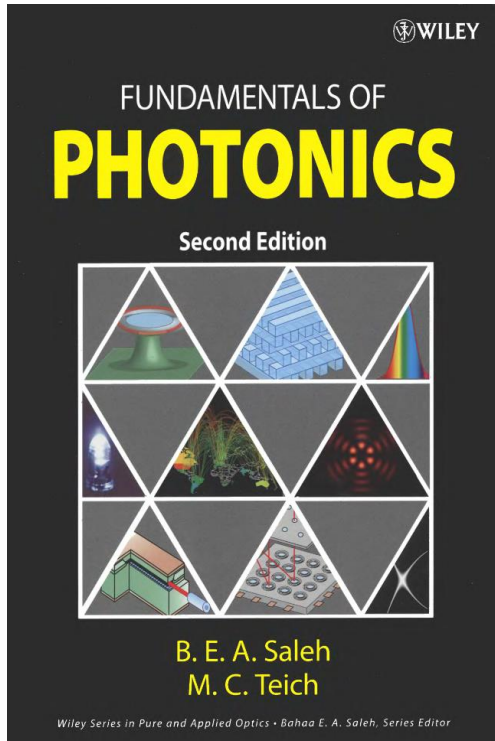
To perform **physical optics simulations** of arbitrary optical systems

Finding the expression of the **electromagnetic field** for the system in question

# The Objective Behind VirtualLab Fusion

To perform **physical optics simulations** of arbitrary optical systems

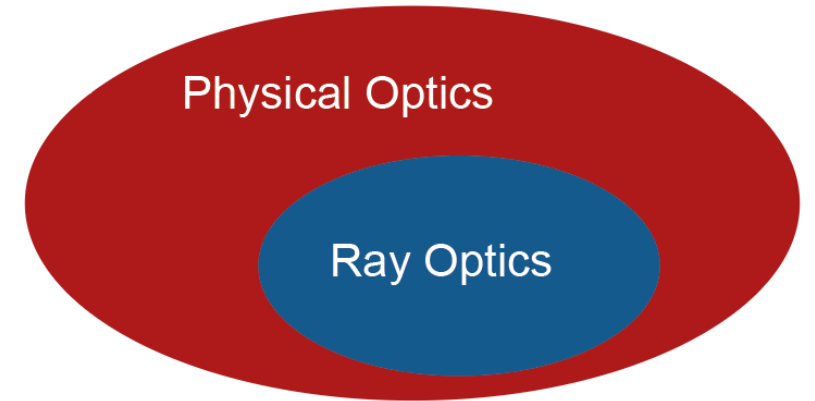
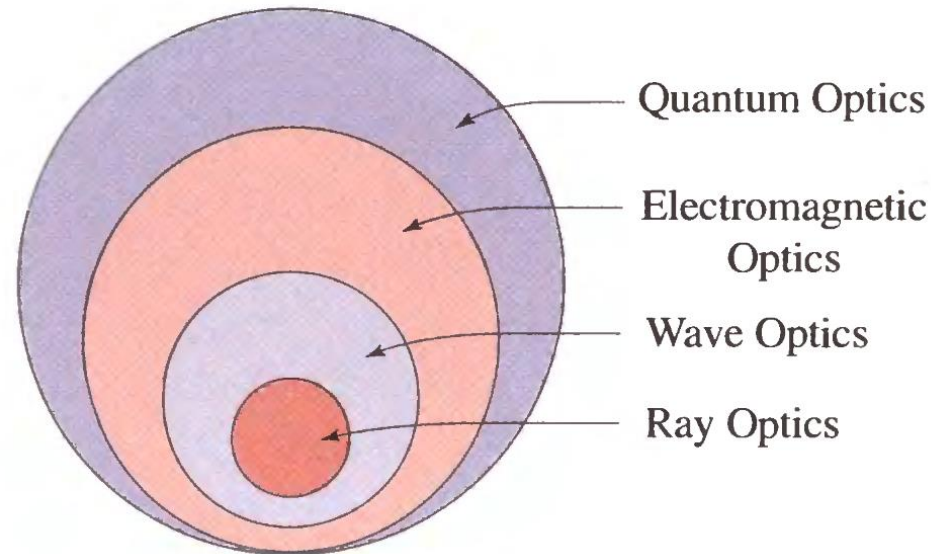
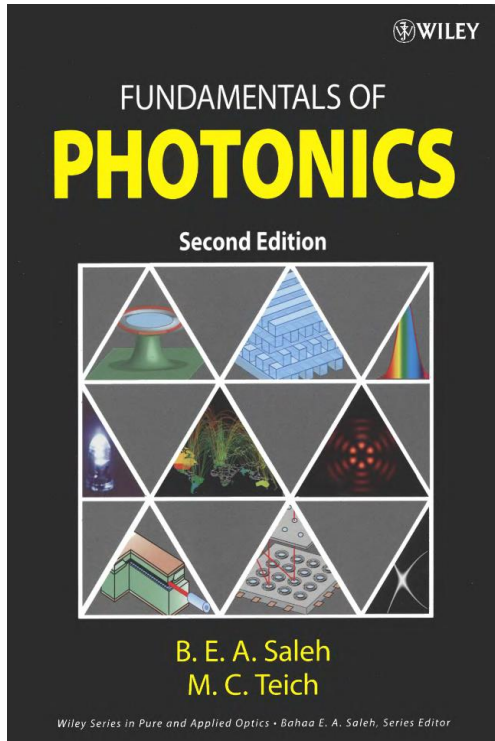
Finding the expression of the **electromagnetic field** for the system in question



# The Objective Behind VirtualLab Fusion

To perform **physical optics simulations** of arbitrary optical systems

Finding the expression of the **electromagnetic field** for the system in question



... in VirtualLab Fusion

# The Objective Behind VirtualLab Fusion

To perform **physical optics simulations** of arbitrary optical systems

Finding the expression of the **electromagnetic field** for the system in question

Quantum Optics

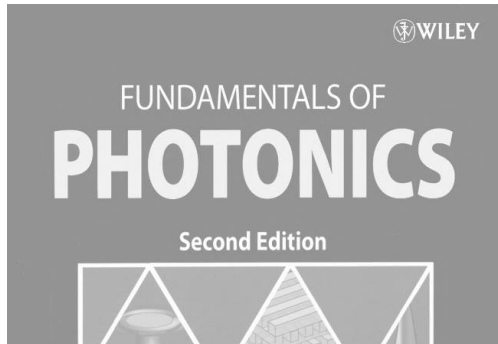
Physical Optics

Ray Optics

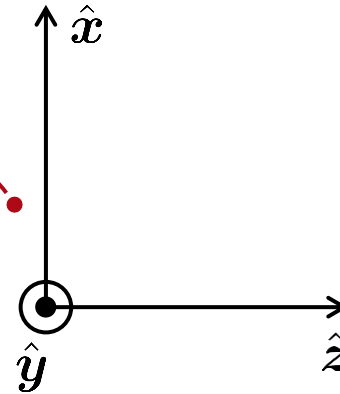
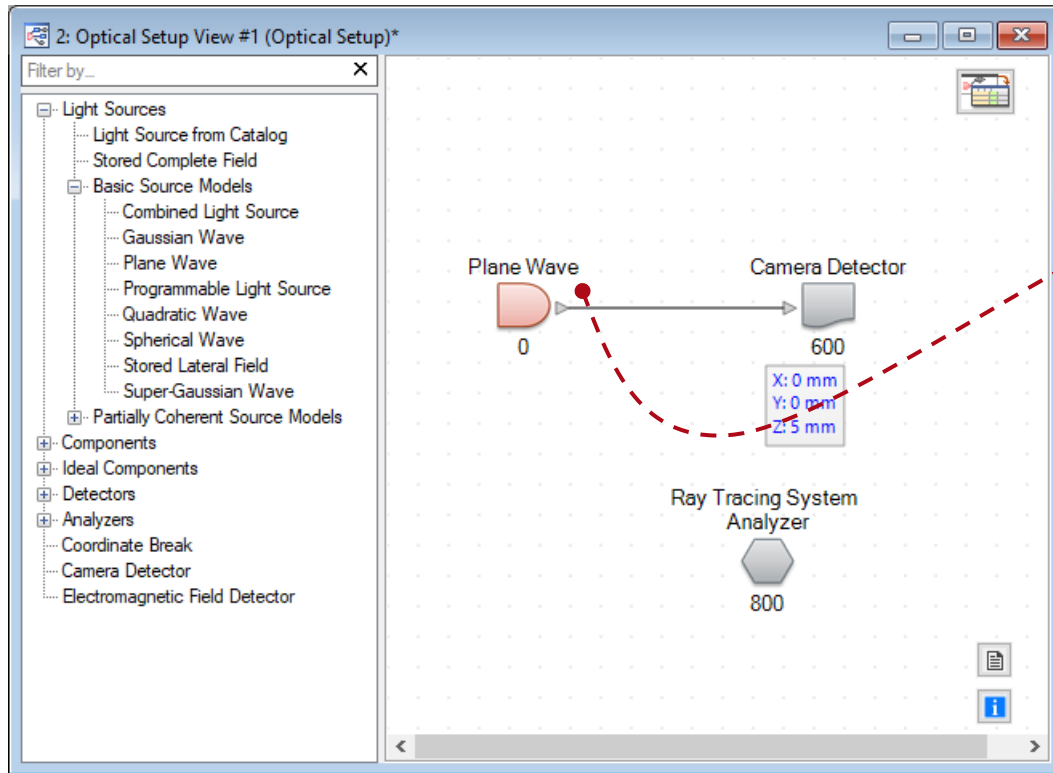
**Important:**

no distinction between physical optics and electromagnetic optics.  
We never use the scalar approximation!

... in VirtualLab Fusion

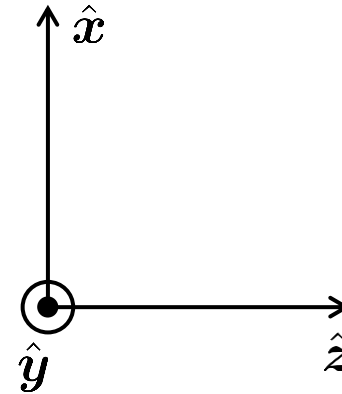
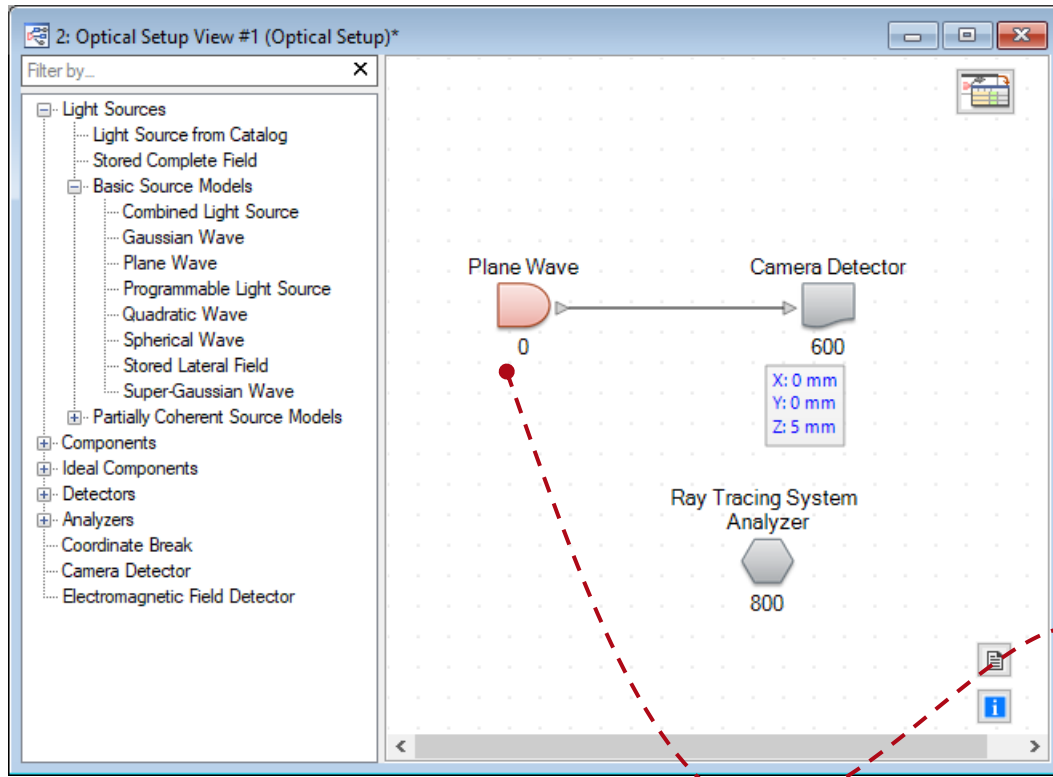


# How Is Light Generated in the System? (Basics)



In VirtualLab Fusion, the source establishes the **global coordinate system** of the optical setup

# How Is Light Generated in the System? (Basics)

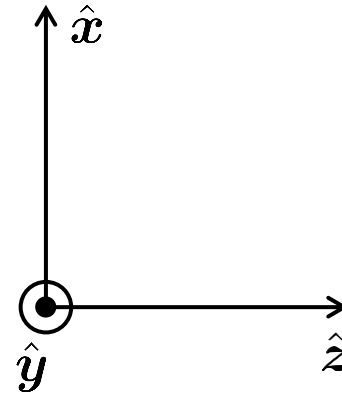
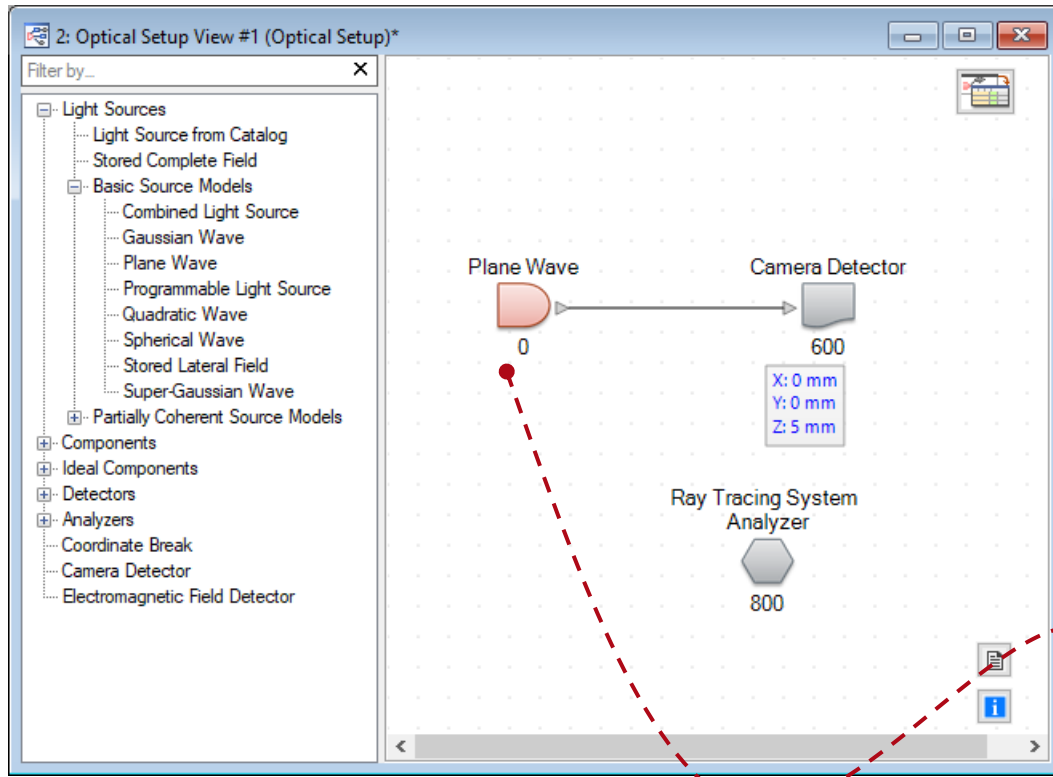


In VirtualLab Fusion, the source establishes the **global coordinate system** of the optical setup

$$\begin{cases} E_x(x, y) \\ E_y(x, y) \end{cases}$$

The source needs to define, per wavelength, the **function that spatially describes the x and y components** of the electric field at the input plane

# How Is Light Generated in the System? (Basics)



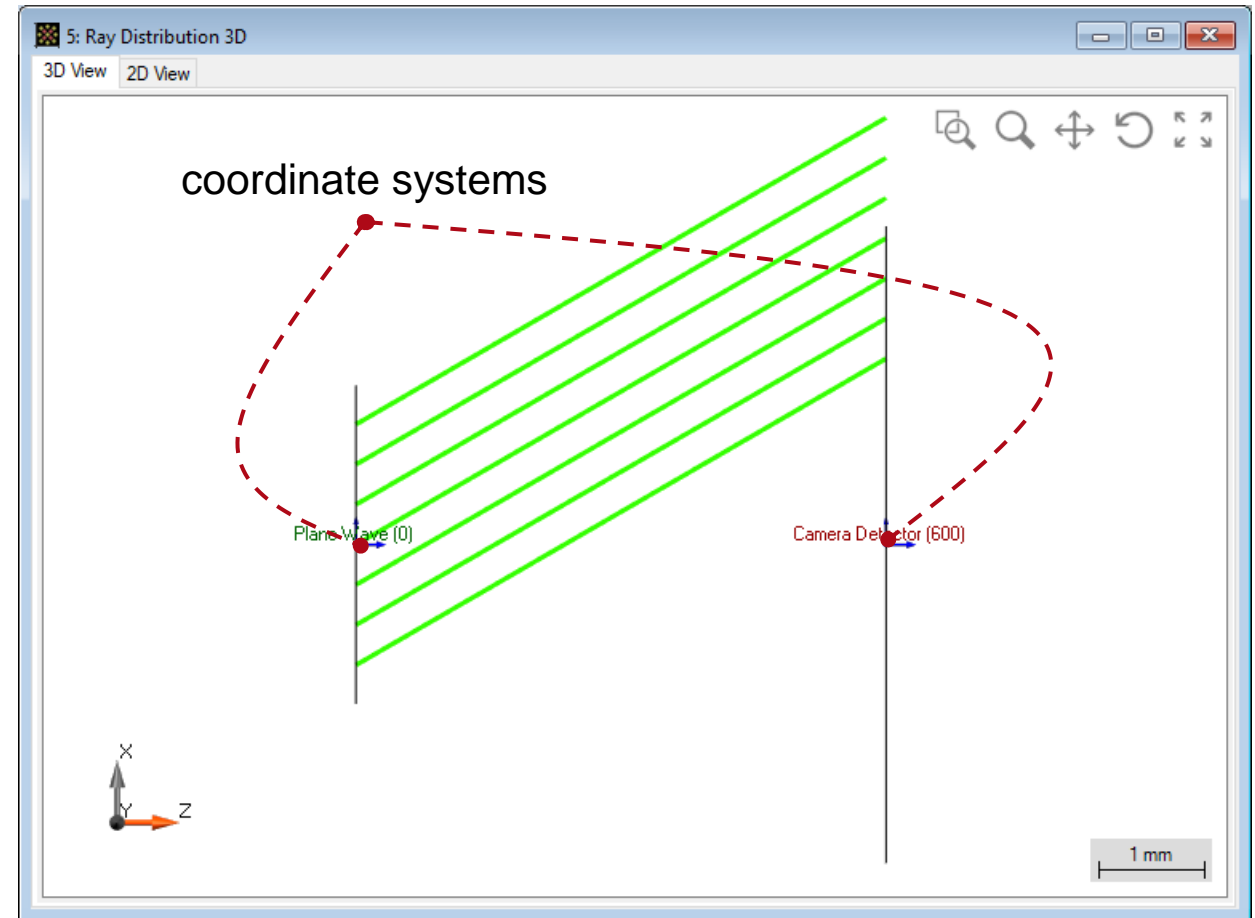
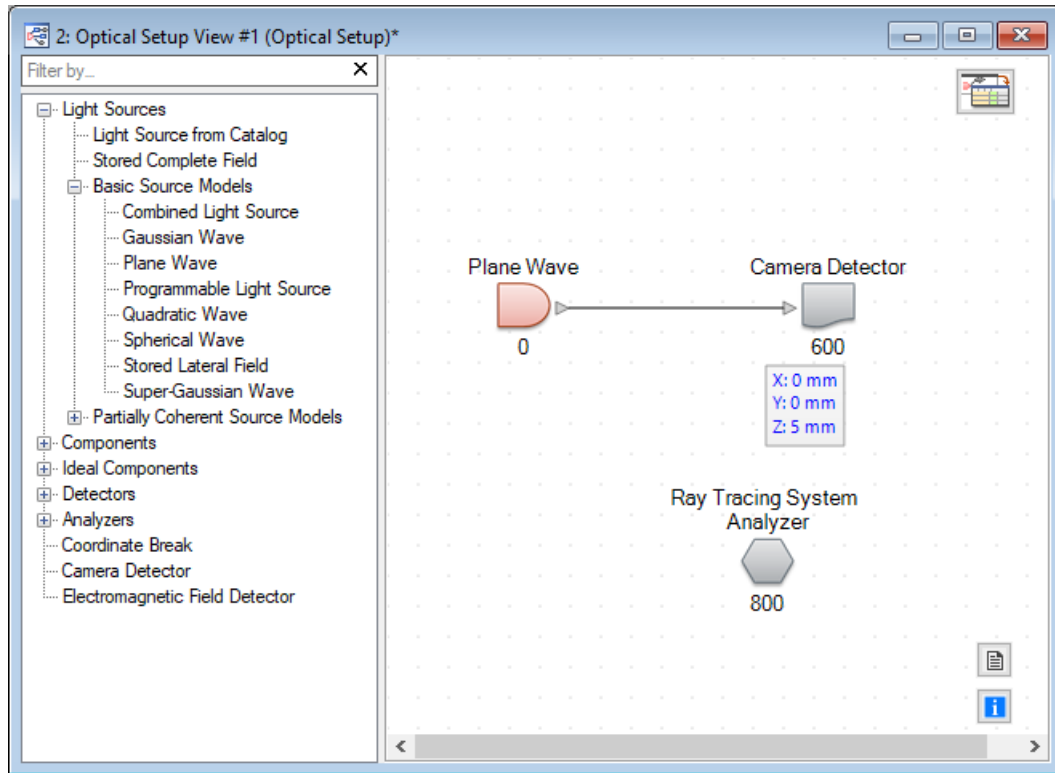
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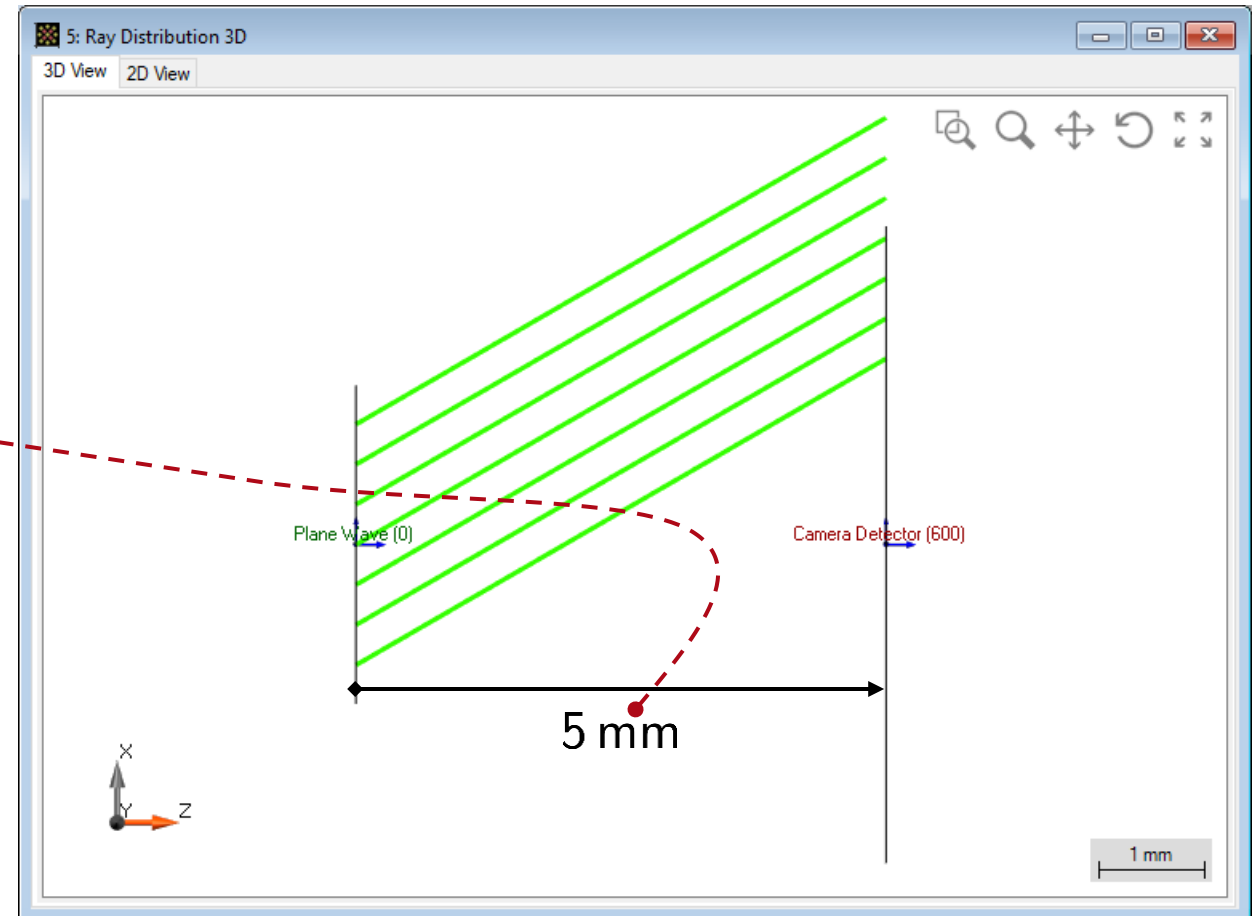
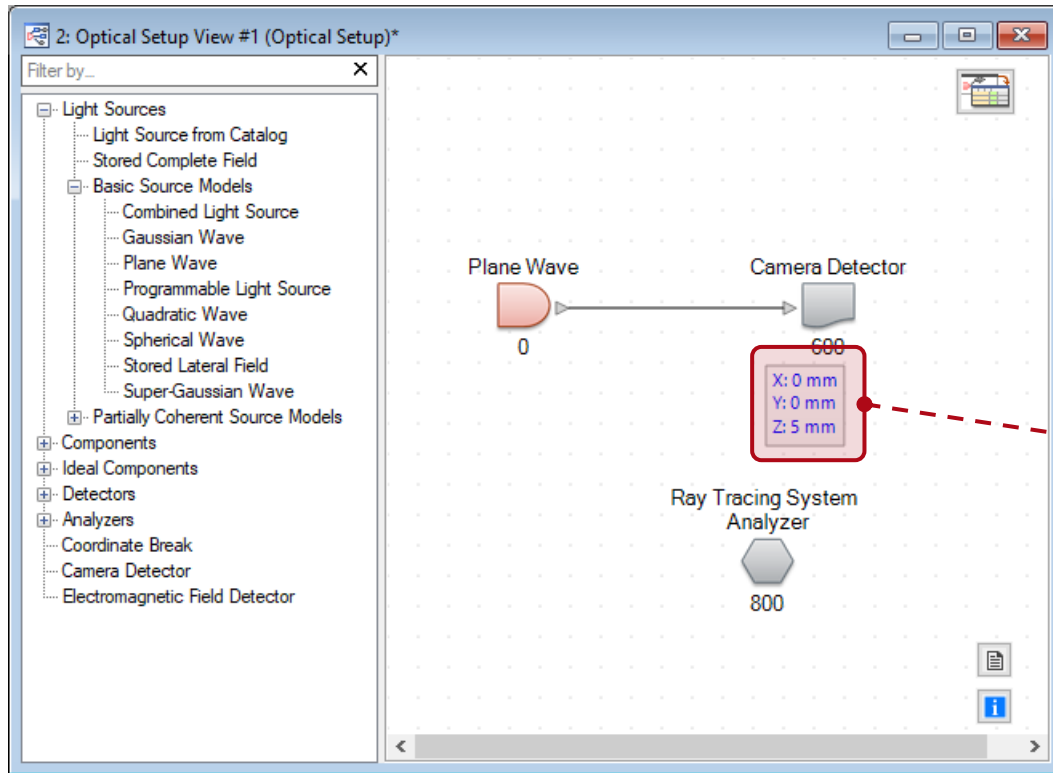
According to Maxwell's equations, **only two of the six electromagnetic components are independent** in a homogeneous, isotropic medium → we arbitrarily select  $E_x$  and  $E_y$ ; other components calculated on demand

# How Is Light Generated in the System? (Basics)

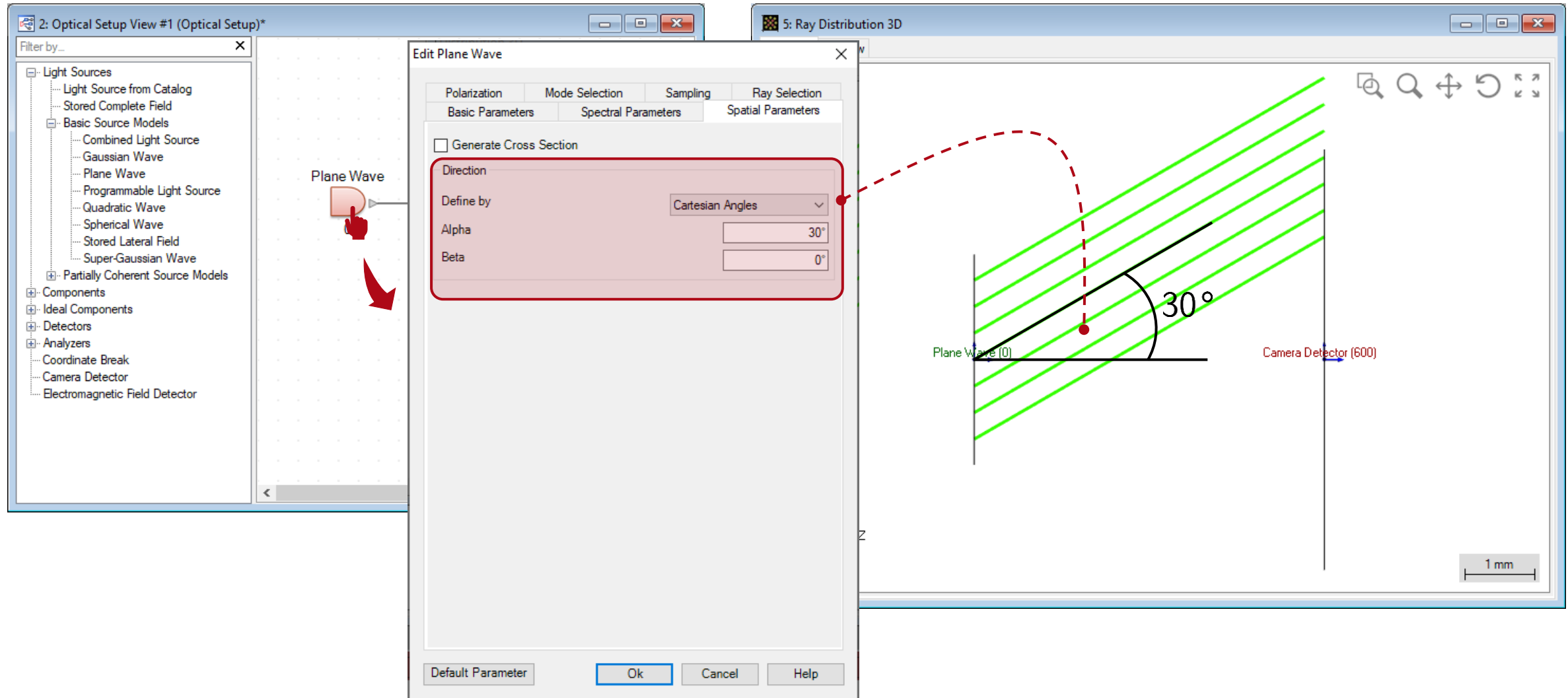




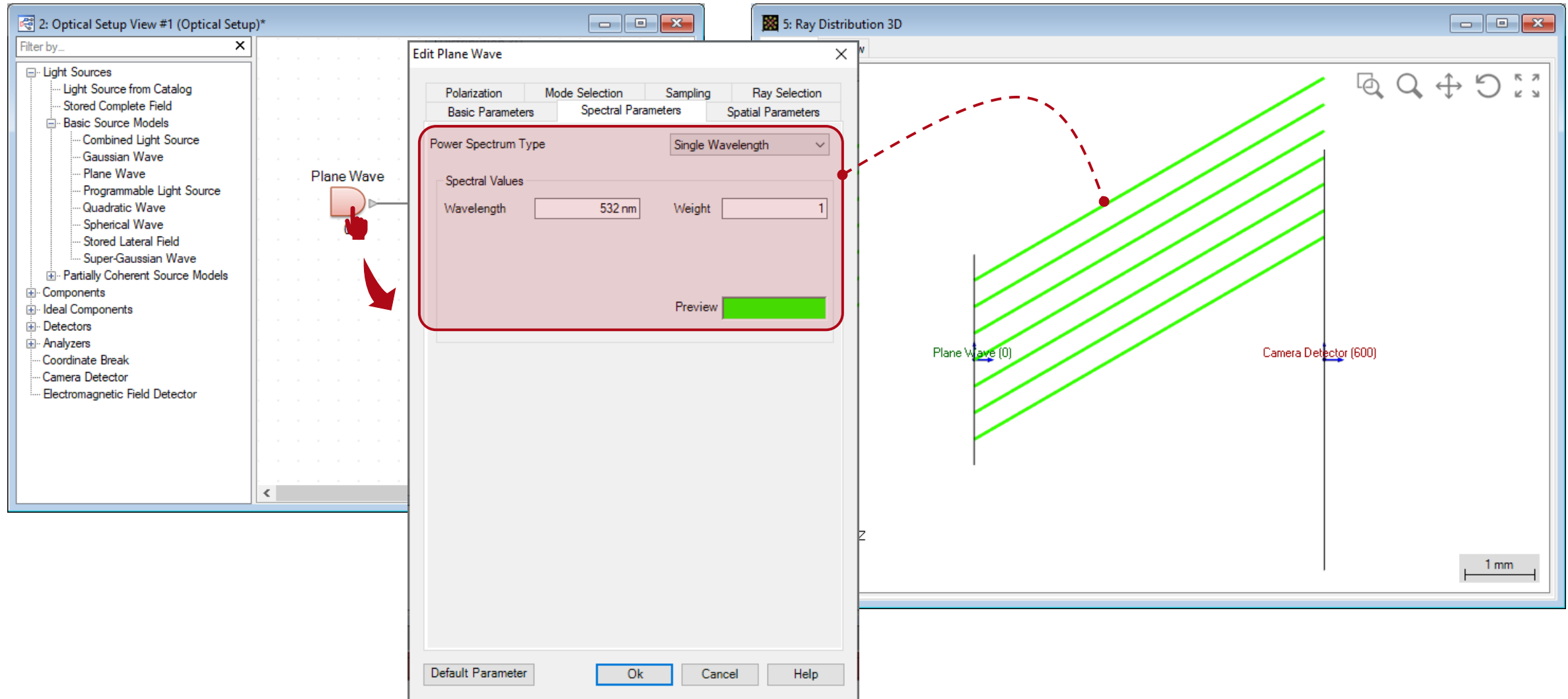
# How Is Light Generated in the System? (Basics)



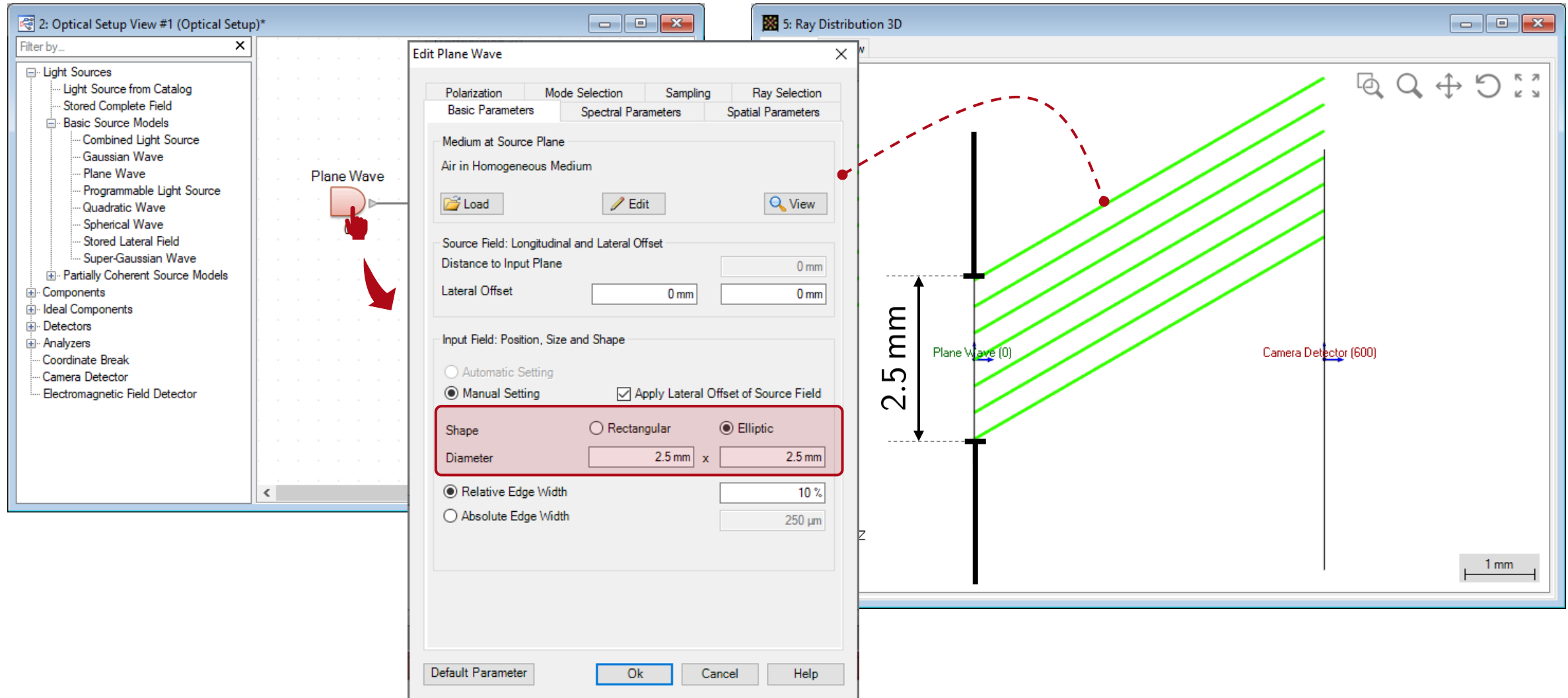
# How Is Light Generated in the System? (Basics)



# How Is Light Generated in the System? (Basics)



# How Is Light Generated in the System? (Basics)



# How Is Light Generated in the System? (Basics)

The image displays a software interface for optical simulation, consisting of several windows:

- 2: Optical Setup View #1 (Optical Setup)\***: A tree view on the left lists components under categories like "Light Sources", "Basic Source Models", "Partially Coherent Source Models", "Components", "Ideal Components", "Detectors", and "Analyzers". A red arrow points from the "Plane Wave" option in the "Basic Source Models" list to the "Edit Plane Wave" dialog box.
- Edit Plane Wave**: A dialog box with tabs for "Polarization", "Mode Selection", "Sampling", "Ray Selection", "Basic Parameters", "Spectral Parameters", and "Spatial Parameters". The "Basic Parameters" tab is active, showing:
  - Medium at Source Plane: Air in Homogeneous Medium
  - Source Field: Longitudinal and Lateral Offset (Distance to Input Plane: 0 mm, Lateral Offset: 0 mm)
  - Input Field: Position, Size and Shape (Automatic Setting, Manual Setting, Apply Lateral Offset of Source Field)
  - Shape: Rectangular, Elliptic (selected)
  - Diameter: 2.5 mm x 2.5 mm
  - Edge Width: **Relative Edge Width: 10 %** (highlighted with a red box and a red dashed line pointing to the detector window)
  - Absolute Edge Width: 250  $\mu\text{m}$
- 5: Ray Distribution 3D**: A 3D visualization showing a series of parallel green lines representing light rays. A label "Plane Wave (0)" is visible.
- 10: "Camera Detector" (# 600) after "Plane Wav..."**: A window showing the "Chromatic Fields Set" for a wavelength of 532 nm. It displays a 2D intensity plot (color map) of the light field on the detector. The plot shows a circular region of high intensity (blue) on a black background. The axes are labeled X [mm] and Y [mm], ranging from -1 to 1. A color bar on the right indicates intensity values from -2.9E-07 to 1.2. A scale bar of 1 mm is shown at the bottom right.

# How Is Light Generated in the System? (Basics)

The image displays a software interface for optical simulation, showing the configuration of a light source and the resulting ray distribution and camera detector output.

**2: Optical Setup View #1 (Optical Setup)\***

- Filter by...
- Light Sources
  - Light Source from Catalog
  - Stored Complete Field
  - Basic Source Models
    - Combined Light Source
    - Gaussian Wave
    - Plane Wave
    - Programmable Light Source
    - Quadratic Wave
    - Spherical Wave
    - Stored Lateral Field
    - Super-Gaussian Wave
  - Partially Coherent Source Models
- Components
  - Ideal Components
  - Detectors
  - Analyzers
  - Coordinate Break
  - Camera Detector
  - Electromagnetic Field Detector

**Edit Plane Wave**

Polarization | Mode Selection | Sampling | Ray Selection

Basic Parameters | Spectral Parameters | Spatial Parameters

Medium at Source Plane  
Air in Homogeneous Medium

Load Edit View

Source Field: Longitudinal and Lateral Offset  
Distance to Input Plane 0 mm  
Lateral Offset 0 mm 0 mm

Input Field: Position, Size and Shape

☐ Automatic Setting ☒ Manual Setting ☒ Apply Lateral Offset of Source Field

Shape ☐ Rectangular ☒ Elliptic

Diameter 2.5 mm x 2.5 mm

☒ Relative Edge Width 10 %  
☐ Absolute Edge Width 250  $\mu\text{m}$

Default Parameter Ok Cancel Help

**5: Ray Distribution 3D**

Plane Wave (0)

**10: "Camera Detector" (# 600) after "Plane Wav..."**

Chromatic Fields Set

Data for Wavelength of 532 nm  $[(V/m)^2]$

Y [mm] 1 0.5 0 -0.5 -1

X [mm] -1 -0.5 0 0.5 1

1.2

# How Is Light Generated in the System? (Basics)

The image displays a software interface for optical simulation, showing the configuration of a light source and the resulting ray distribution and camera detector output.

**2: Optical Setup View #1 (Optical Setup)\***

- Filter by...
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  - Partially Coherent Source Models
- Components
  - Ideal Components
  - Detectors
  - Analyzers
  - Coordinate Break
  - Camera Detector
  - Electromagnetic Field Detector

**Edit Plane Wave**

Polarization | Mode Selection | Sampling | Ray Selection

Basic Parameters | Spectral Parameters | Spatial Parameters

Medium at Source Plane  
Air in Homogeneous Medium

Load | Edit | View

Source Field: Longitudinal and Lateral Offset  
Distance to Input Plane: 0 mm  
Lateral Offset: 0 mm

Input Field: Position, Size and Shape

☐ Automatic Setting  
☒ Manual Setting ☒ Apply Lateral Offset of Source Field

Shape: ☐ Rectangular ☒ Elliptic  
Diameter: 2.5 mm x 2.5 mm

☒ Relative Edge Width: 10 %  
☐ Absolute Edge Width: 250  $\mu\text{m}$

Relative Edge Width: 2 %

Default Parameter | Ok | Cancel | Help

**5: Ray Distribution 3D**

Plane Wave (0)

**11: "Camera Detector" (# 600) after "Plane Wav..."**

Chromatic Fields Set

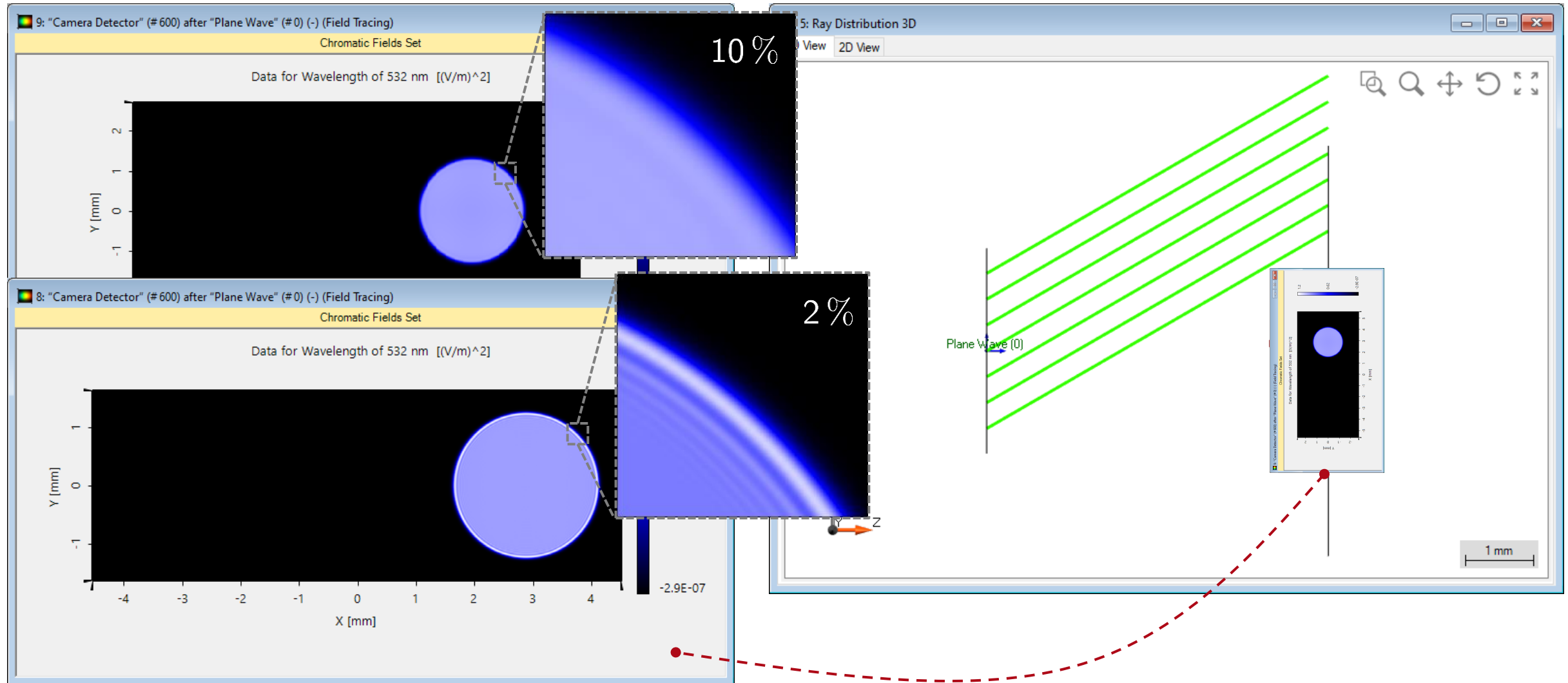
Data for Wavelength of 532 nm  $[(V/m)^2]$

Y [mm]: -1, -0.5, 0, 0.5, 1

X [mm]: -1, -0.5, 0, 0.5, 1

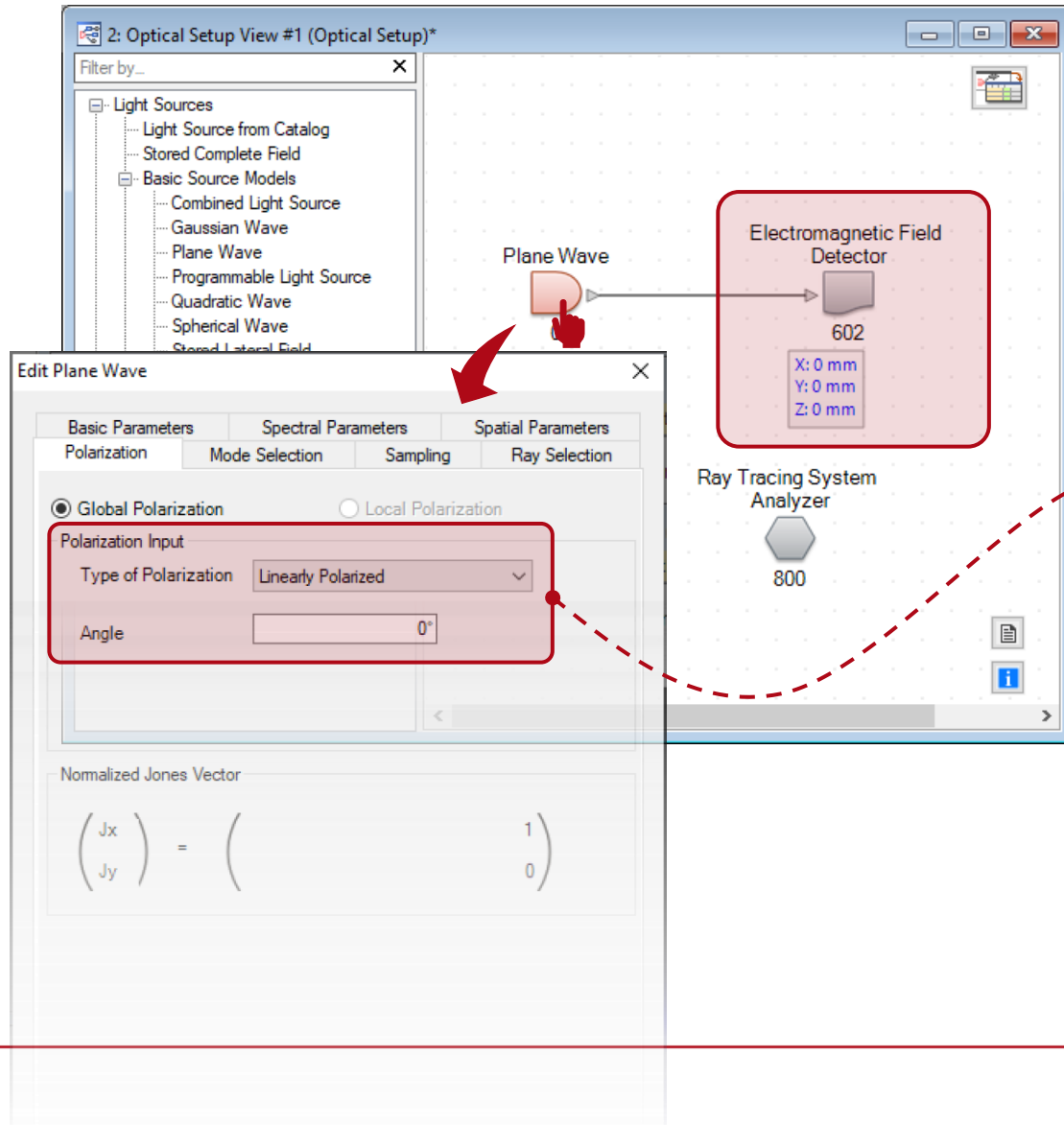
1.2

# How Is Light Generated in the System? (Basics)

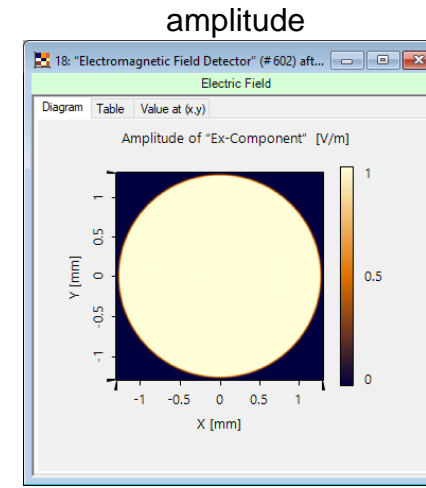




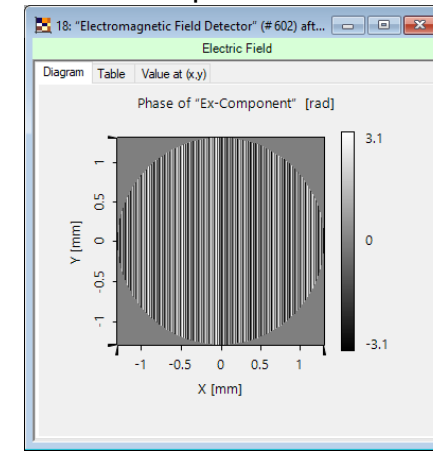
# How Is Light Generated in the System? (Basics)



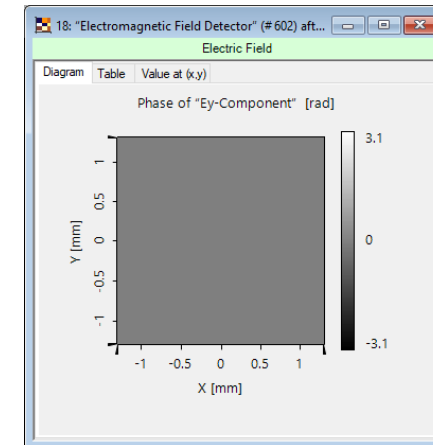
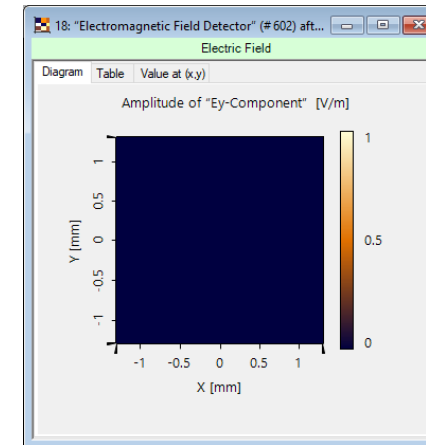
$E_x$



phase



$E_y$

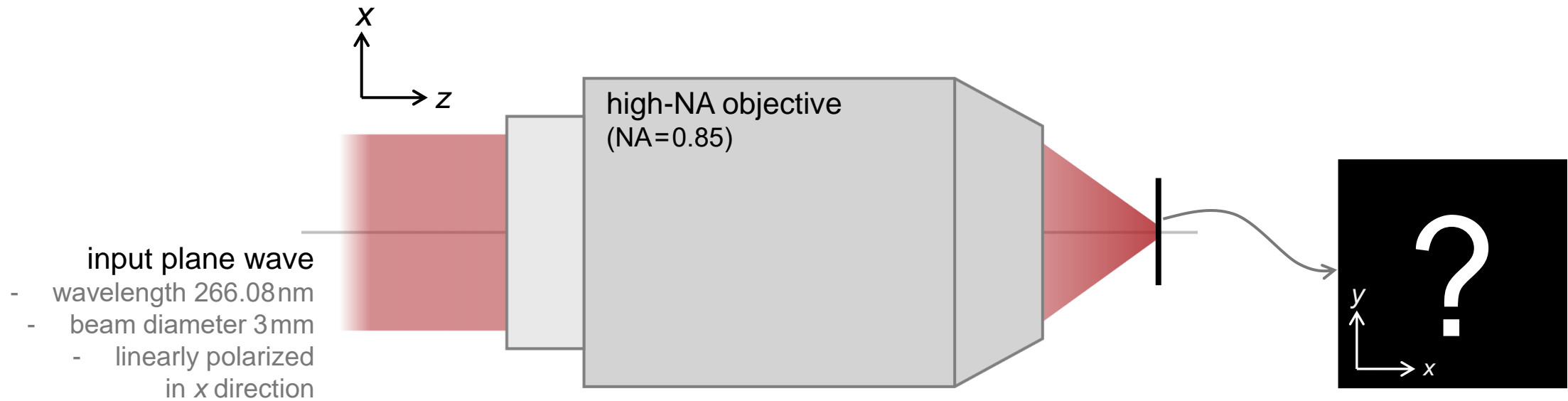


Example 1

## Analyzing High-NA Objective Lens Focusing

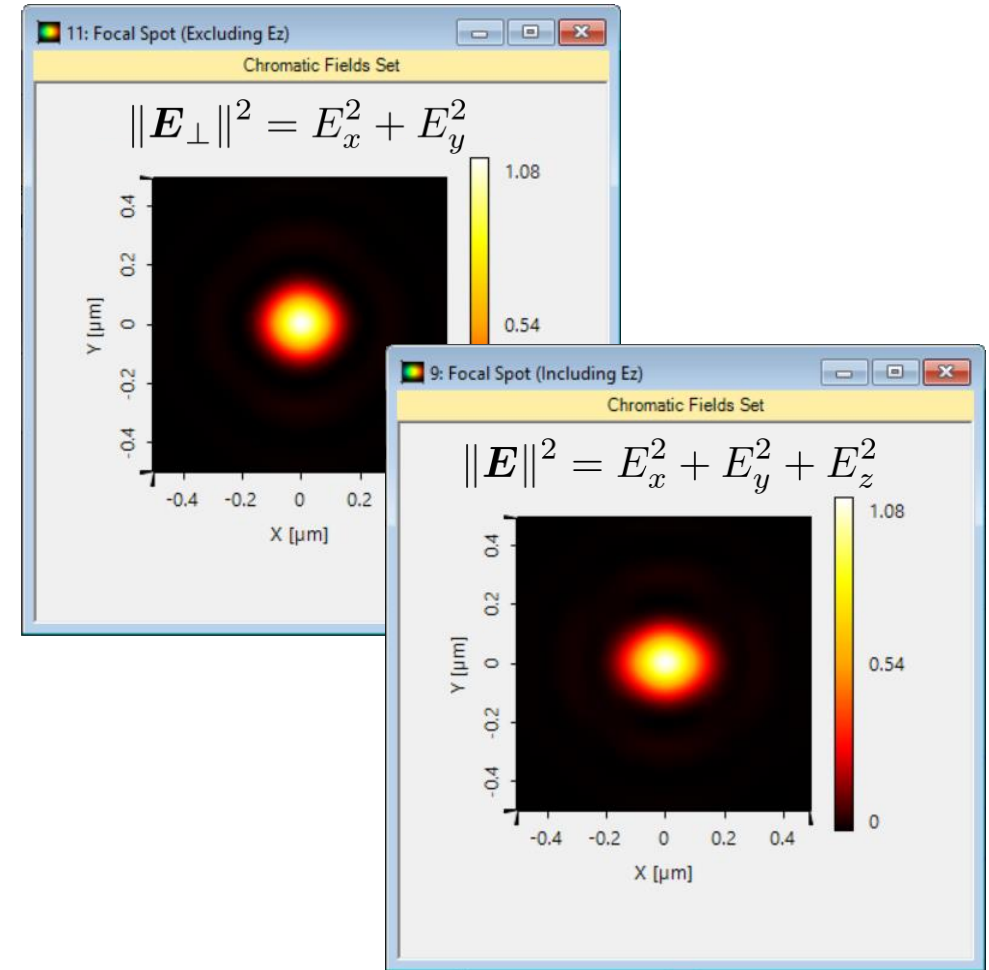


# Modeling Task



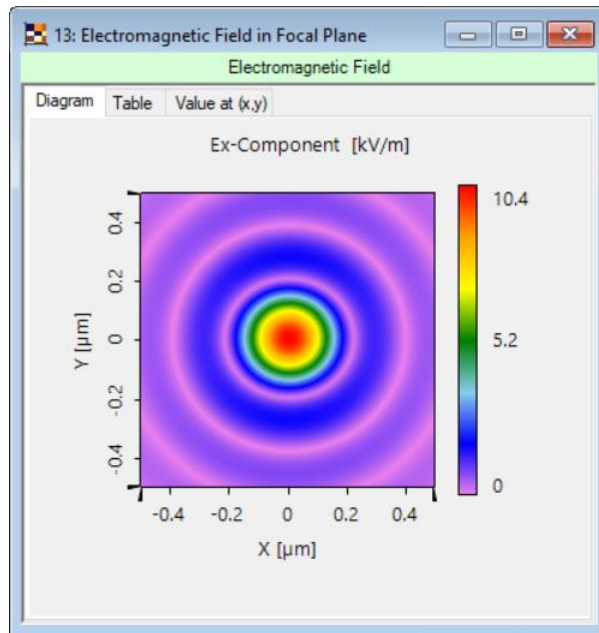
# Field Tracing Results (Camera Detector)

- The top figure shows the intensity by integrating  $E_x$  and  $E_y$  field components only.
- The bottom figure shows the intensity by integrating  $E_x$ ,  $E_y$  and  $E_z$  components: an obvious asymmetry is seen due to the relatively large  $E_z$  component in high-NA situation.

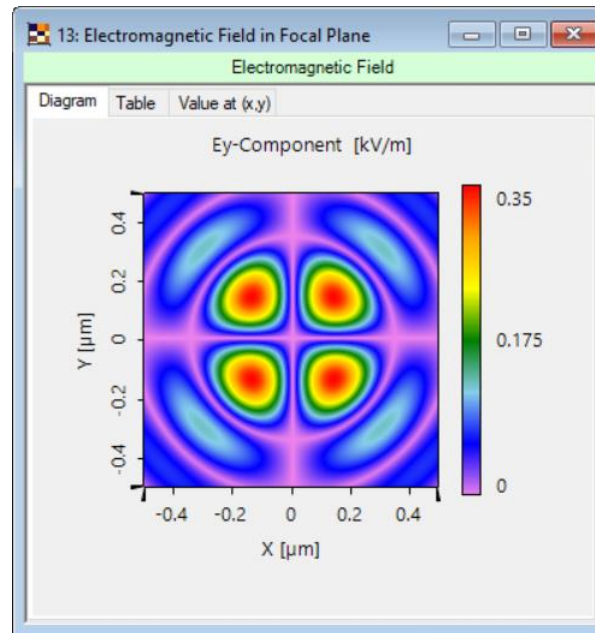


# Field Tracing Results (Electromagnetic Field Detector)

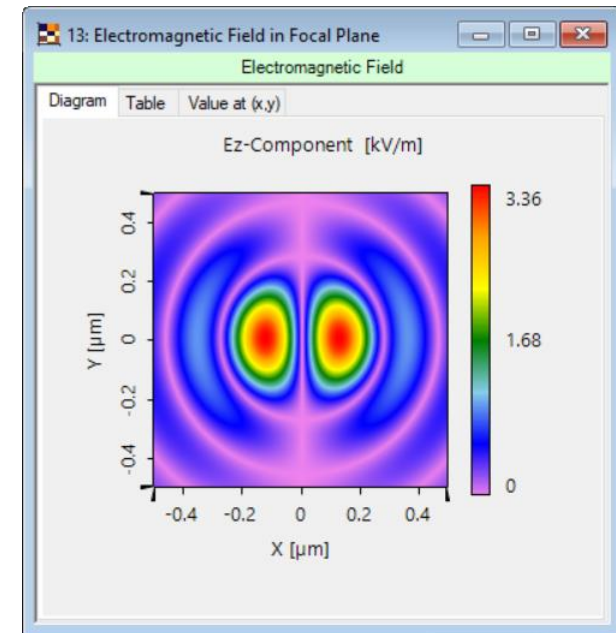
- All electromagnetic field components are obtained by using the Electromagnetic Field Detector.



amplitude of  $E_x$



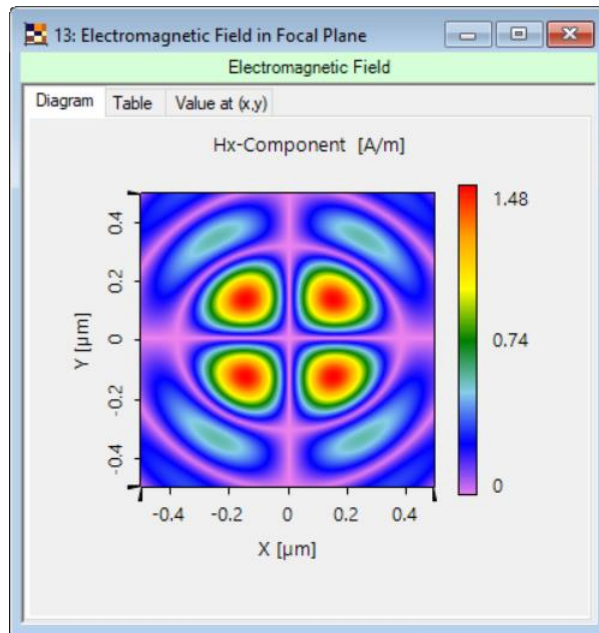
amplitude of  $E_y$



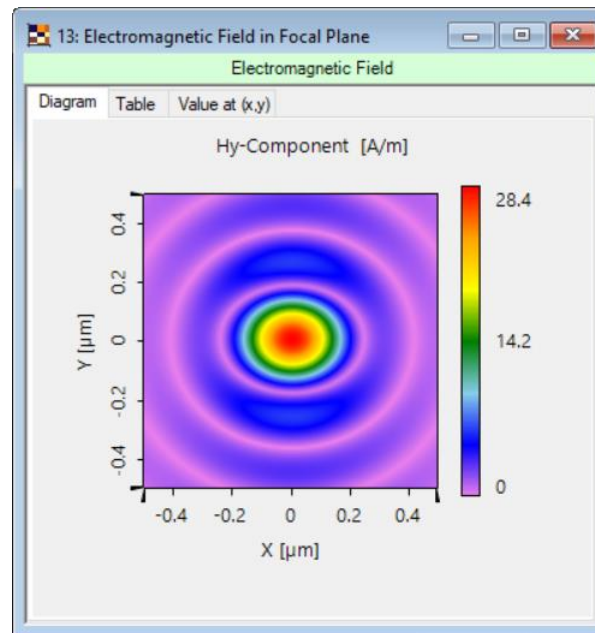
amplitude of  $E_z$

# Field Tracing Results (Electromagnetic Field Detector)

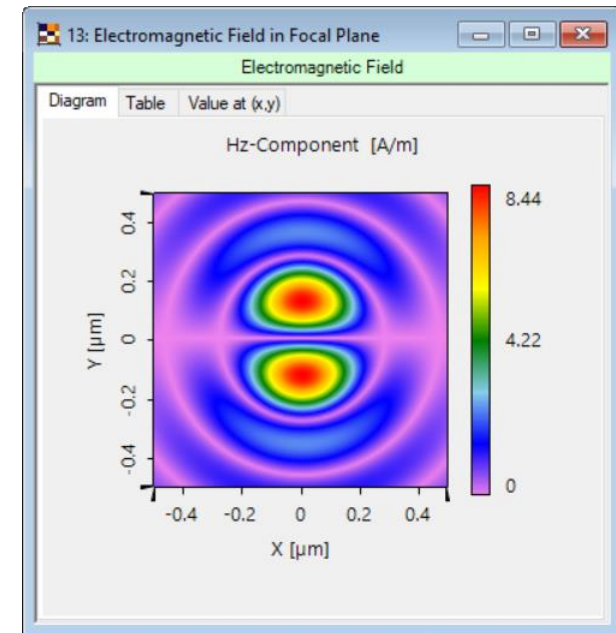
- All electromagnetic field components are obtained by using the Electromagnetic Field Detector.



amplitude of  $H_x$



amplitude of  $H_y$



amplitude of  $H_z$

Part 2

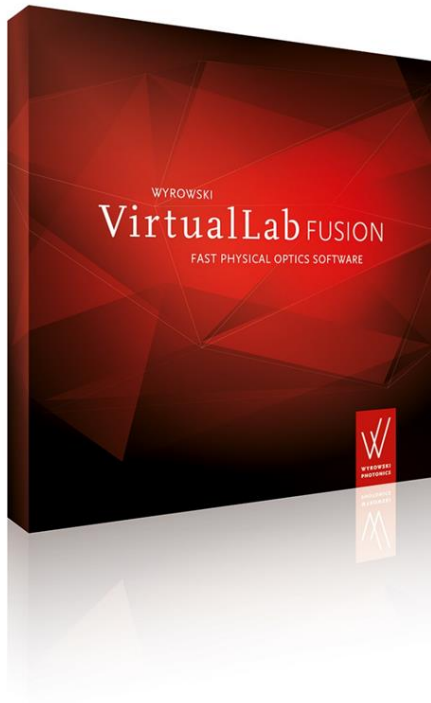
# The Electromagnetic Field Solvers



# One Platform, Many Solvers

Fast physical optics simulations...

... made possible by **connecting field solvers!**



VirtualLab Fusion acts a software platform to connect electromagnetic field solvers in a **seamless, fully non-sequential manner**



**solving Maxwell's equations for the whole system!**



# Electromagnetic Field Solvers

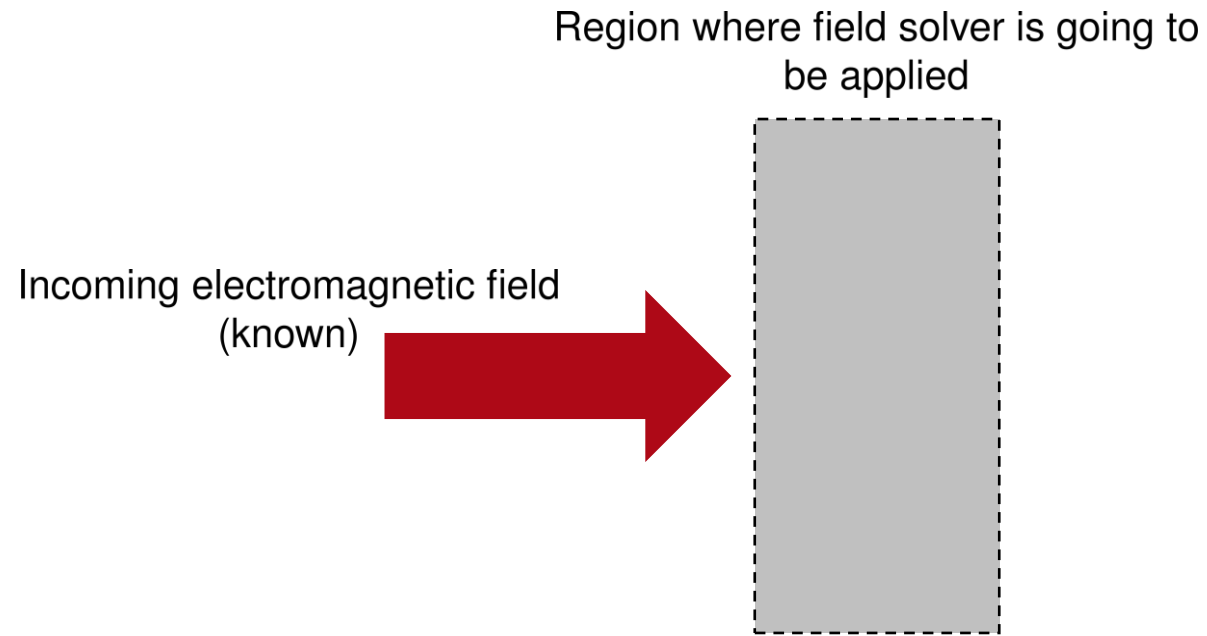
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Region where field solver is going to  
be applied



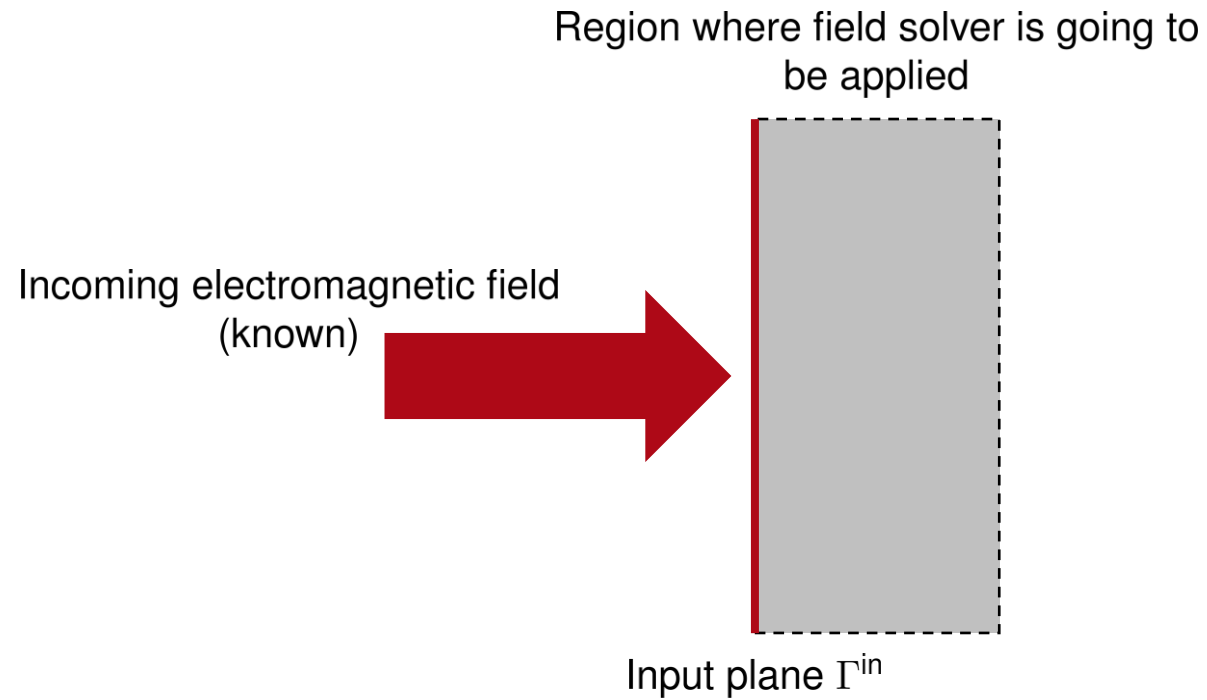
# Electromagnetic Field Solvers

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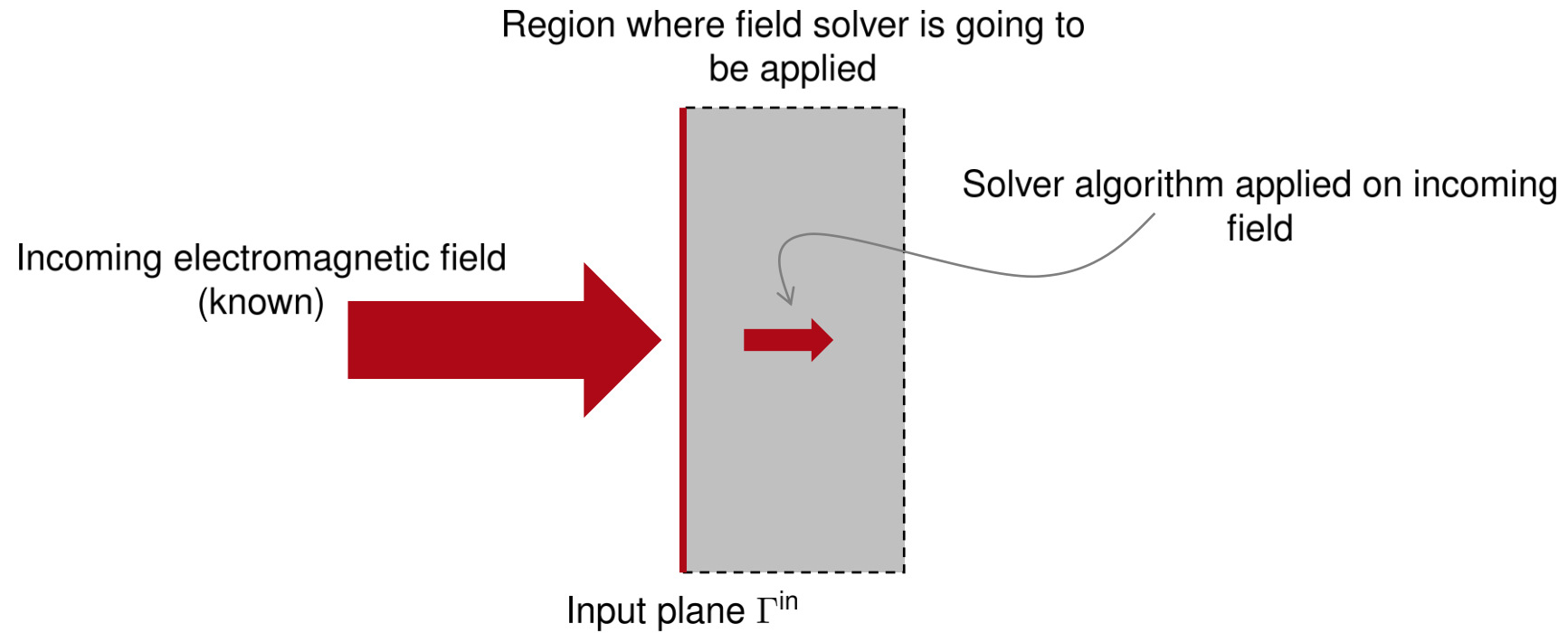


# Electromagnetic Field Solvers

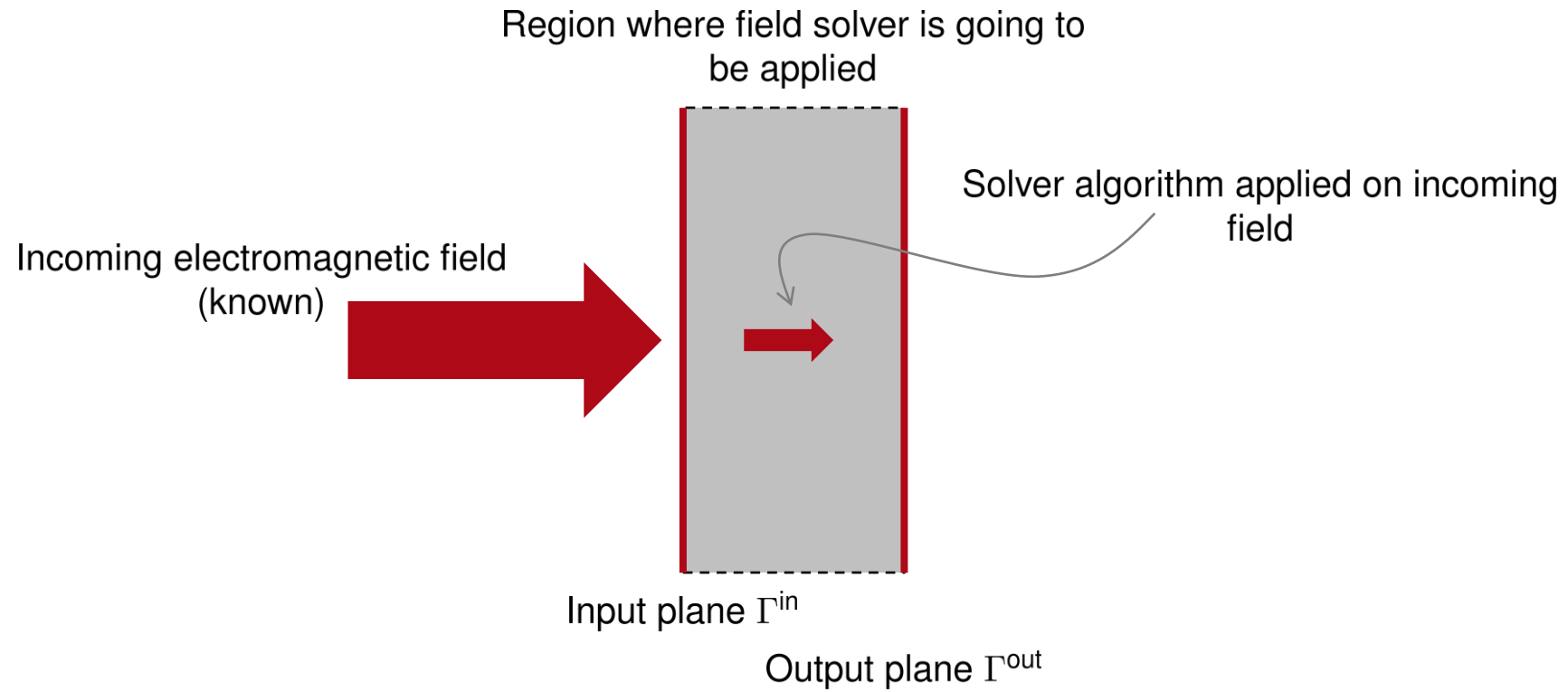
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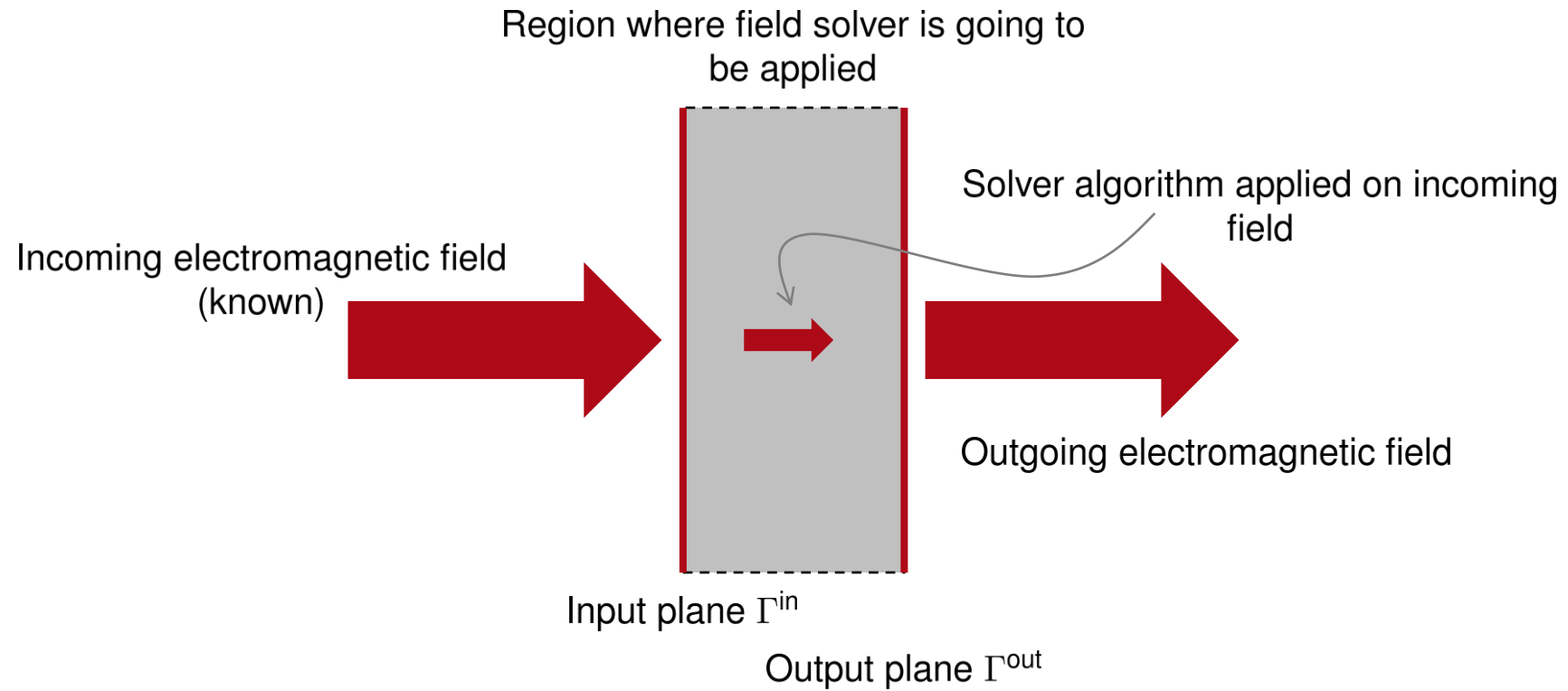
# Electromagnetic Field Solvers



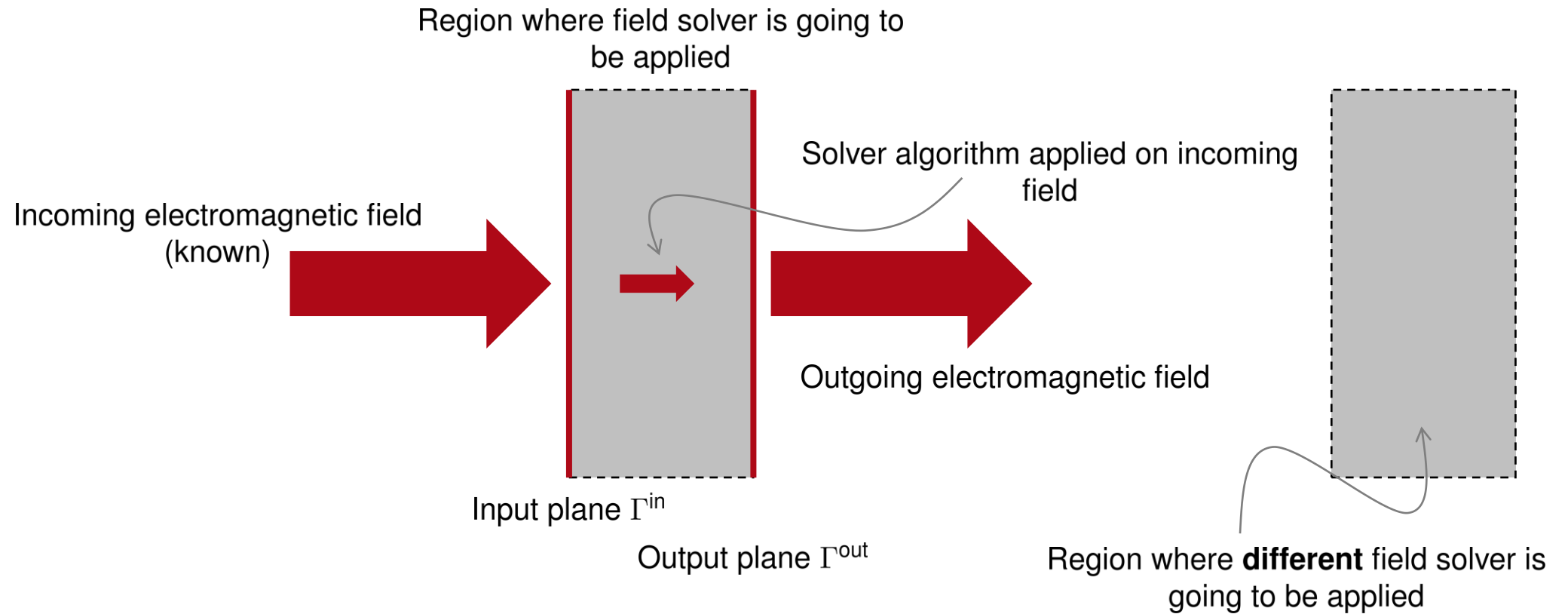
# Electromagnetic Field Solvers



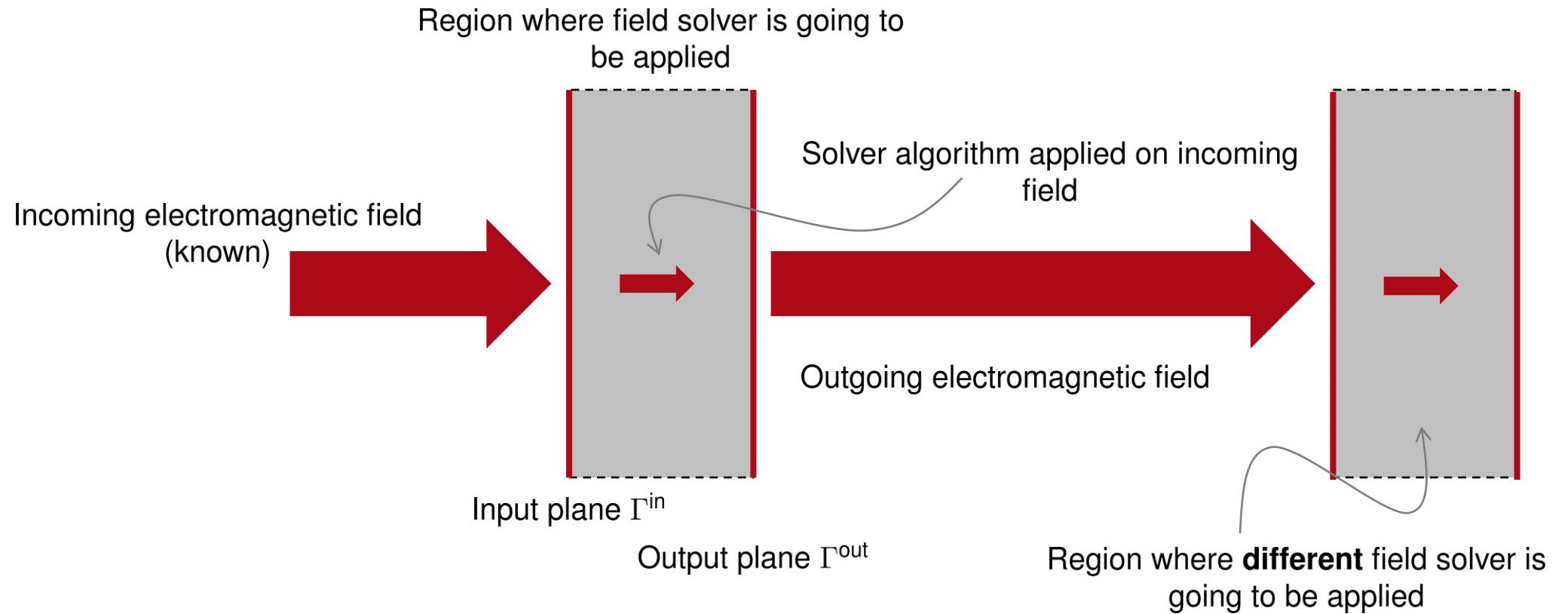
# Electromagnetic Field Solvers



# Electromagnetic Field Solvers

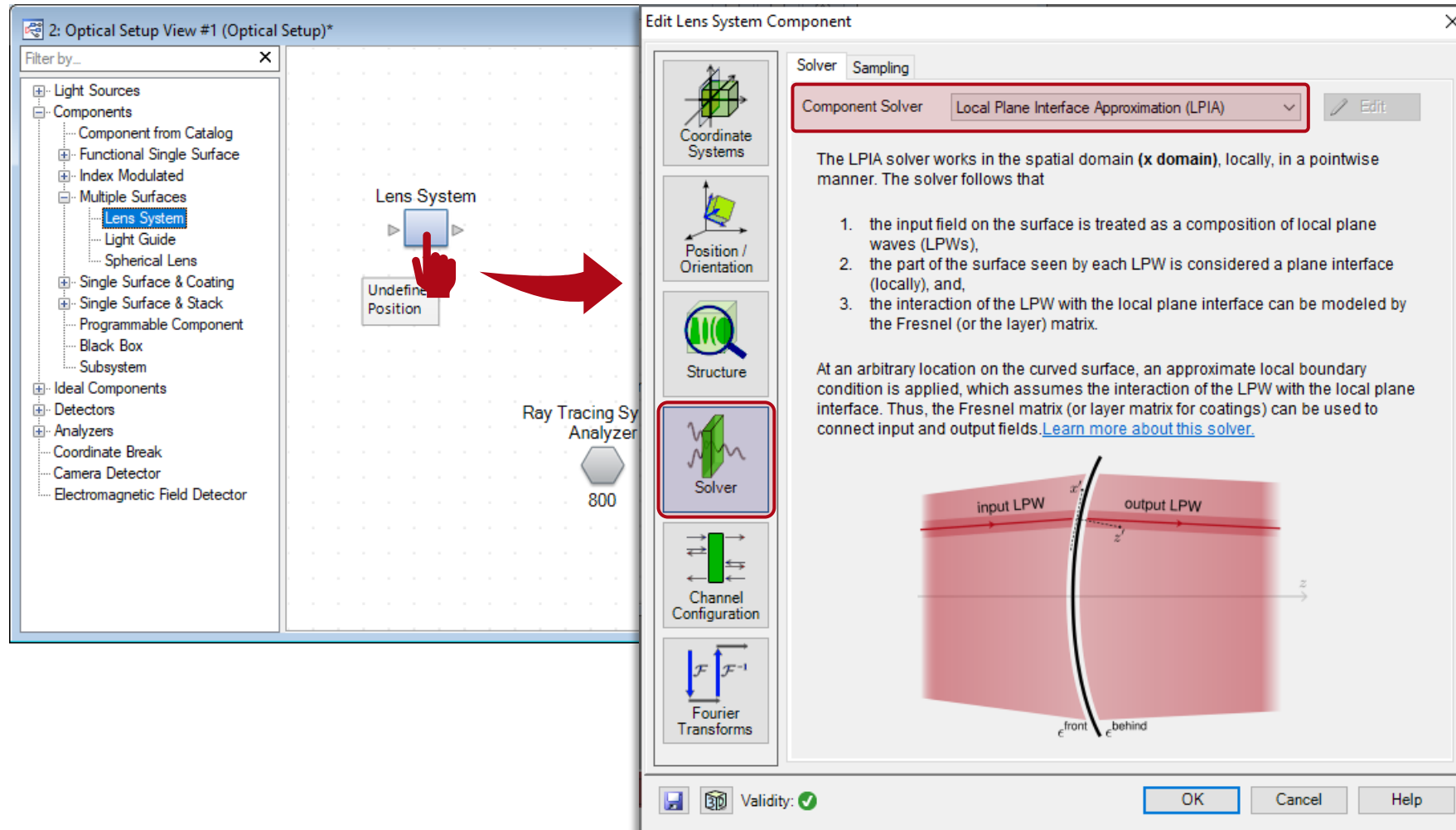


# Electromagnetic Field Solvers



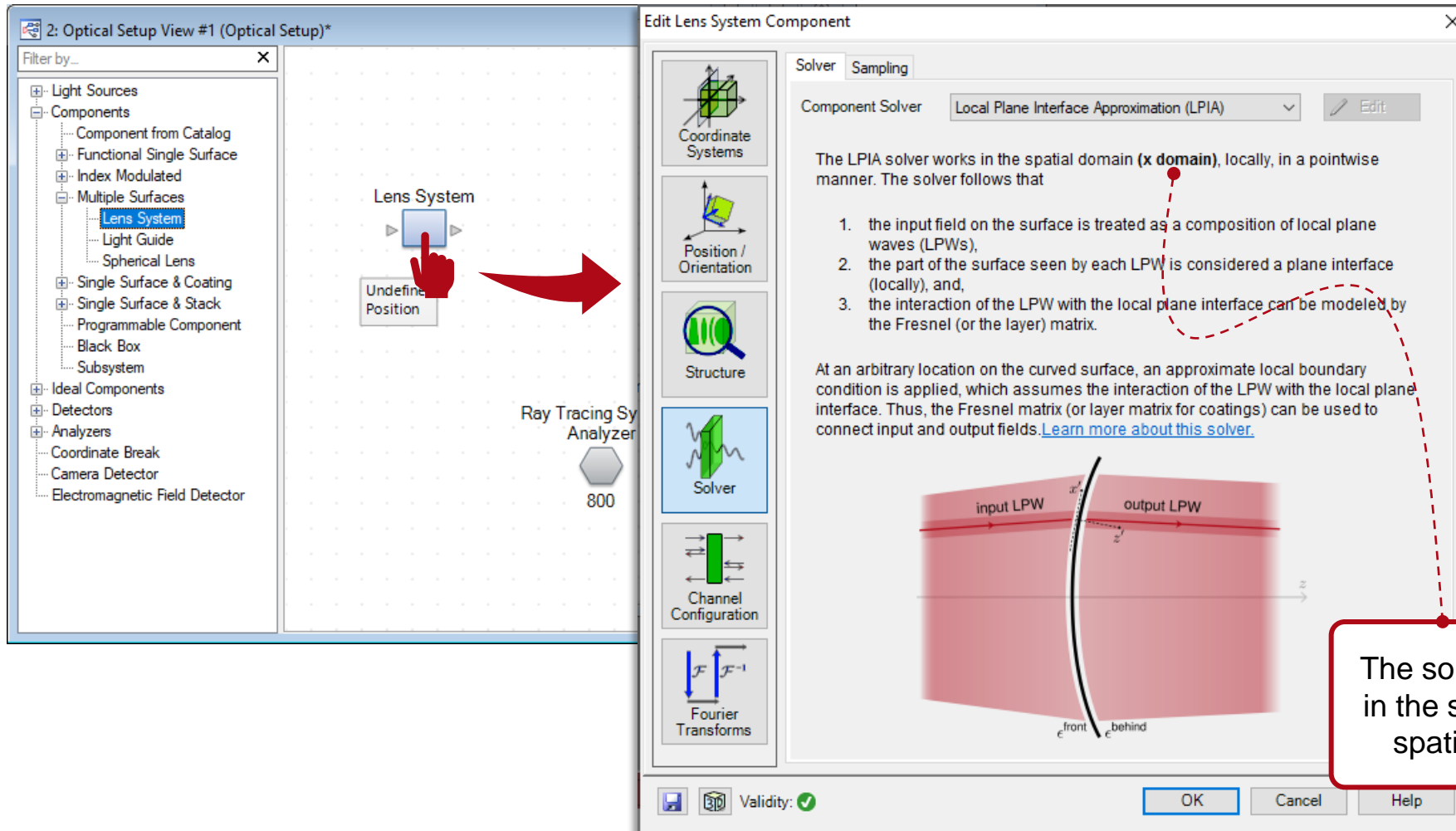


# Components & Solvers



In VirtualLab Fusion, including a certain type of component in your system means, in practice, selecting an **electromagnetic field solver** to model that part of the system

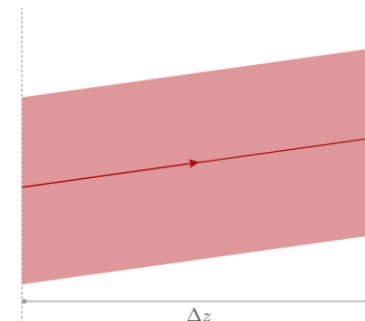
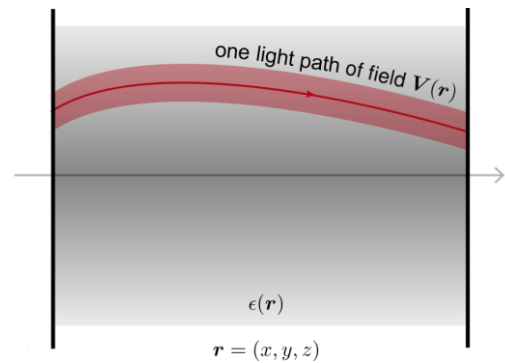
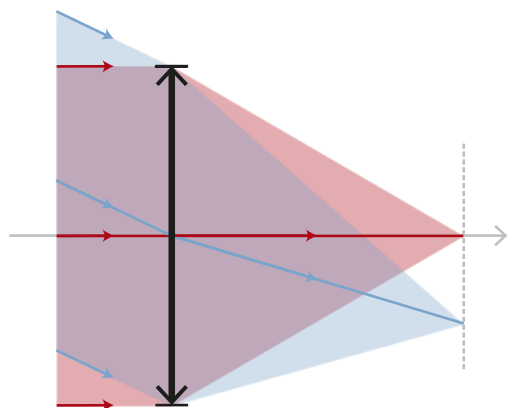
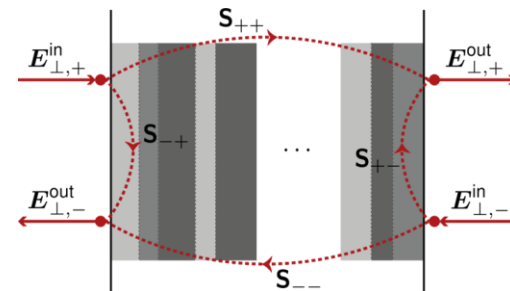
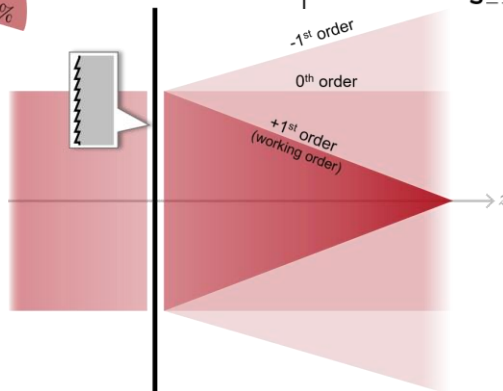
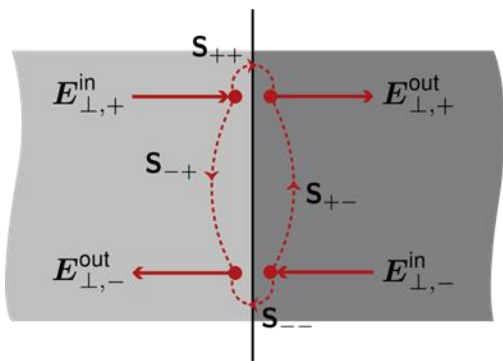
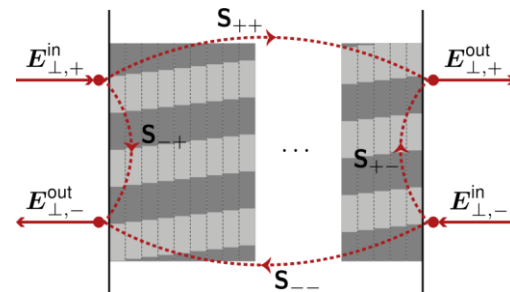
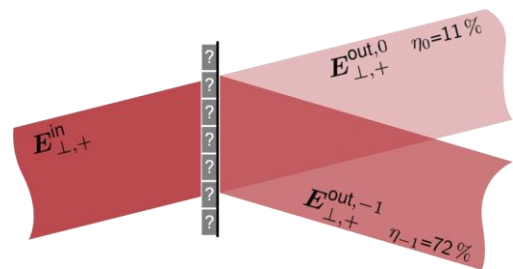
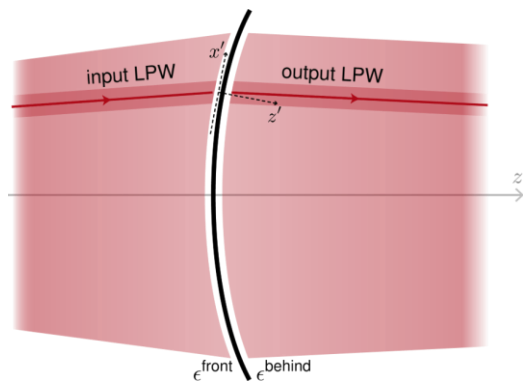
# Components & Solvers



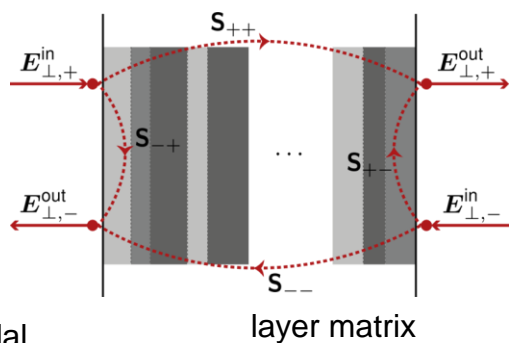
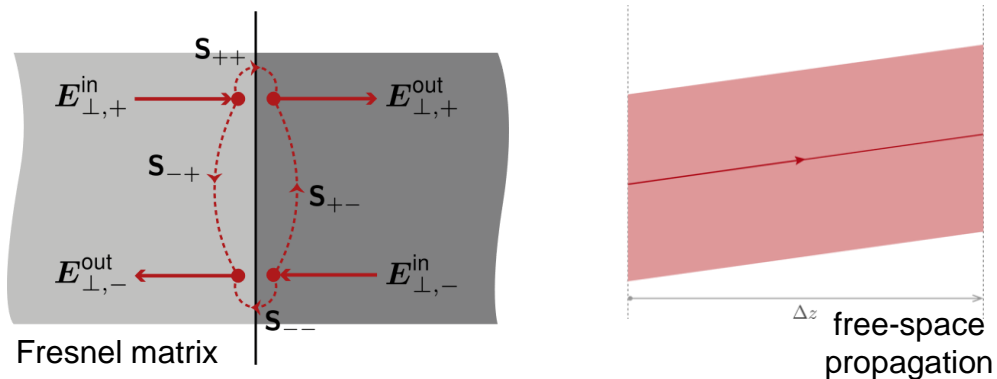
In VirtualLab Fusion, including a certain type of component in your system means, in practice, selecting an **electromagnetic field solver** to model that part of the system

The solvers may be implemented in the space ( $x$ ) domain, or in the spatial-frequency ( $k$ ) domain

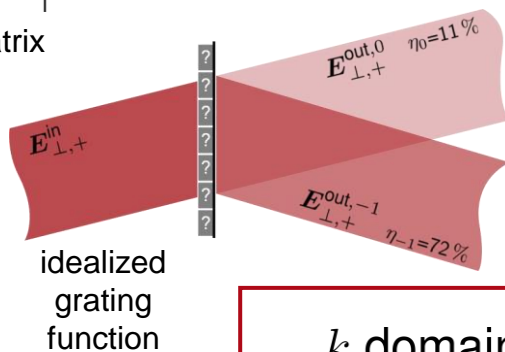
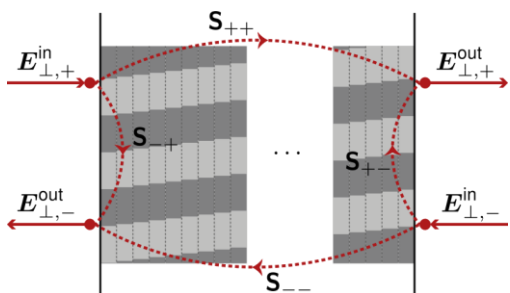
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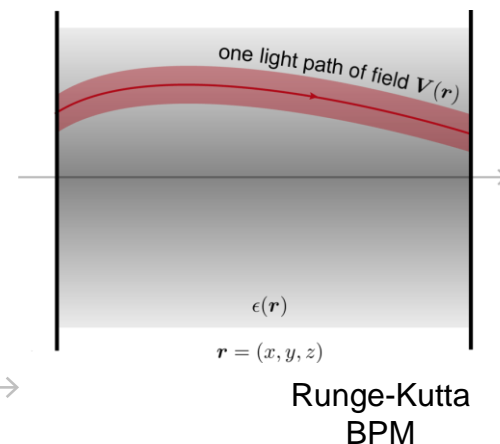
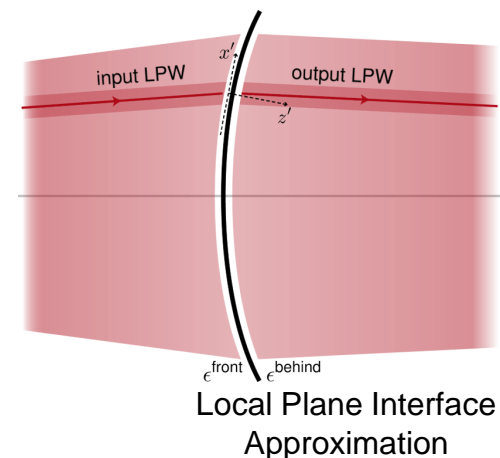
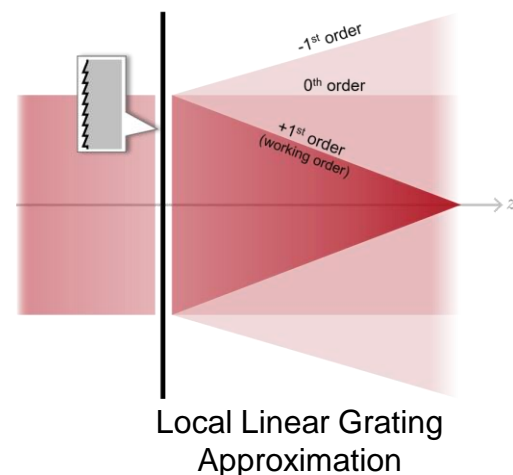


Fourier Modal Method



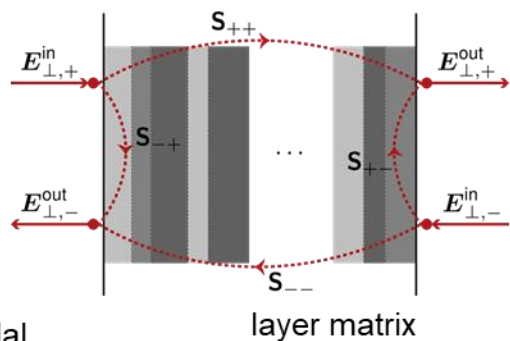
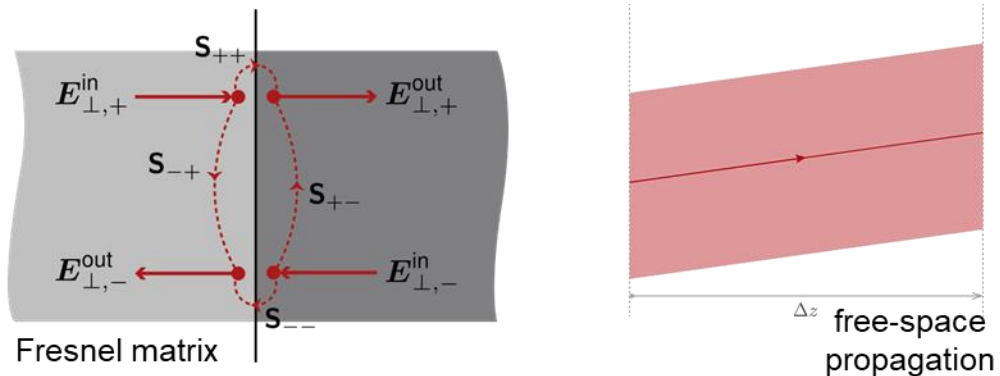
$k$  domain

$x$  domain

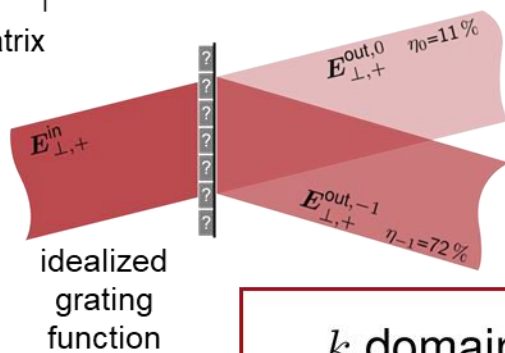
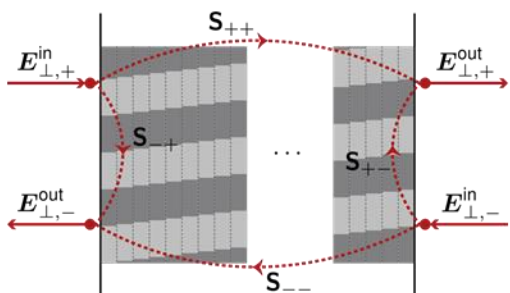


idealized lens functions

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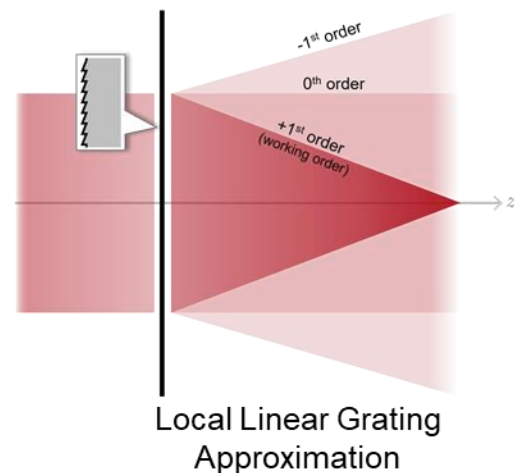
Fourier Modal Method



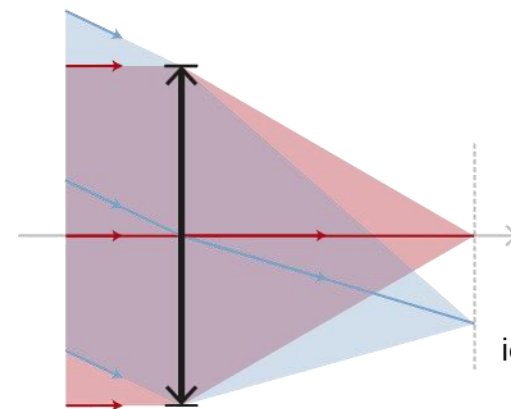
idealized grating function

$k$  domain

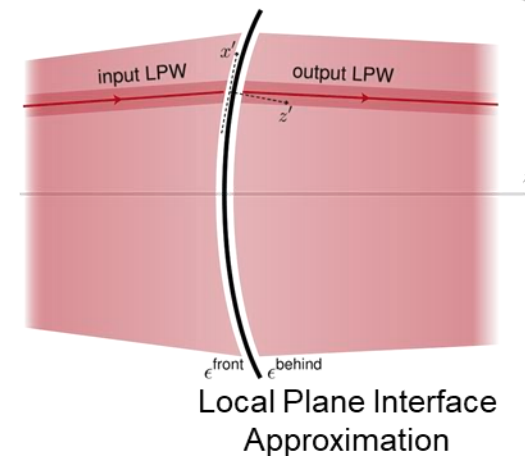
$x$  domain



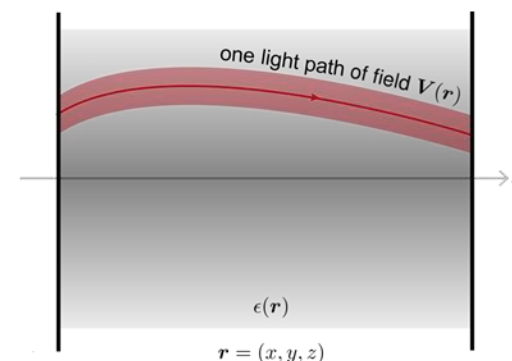
Local Linear Grating Approximation



idealized lens functions

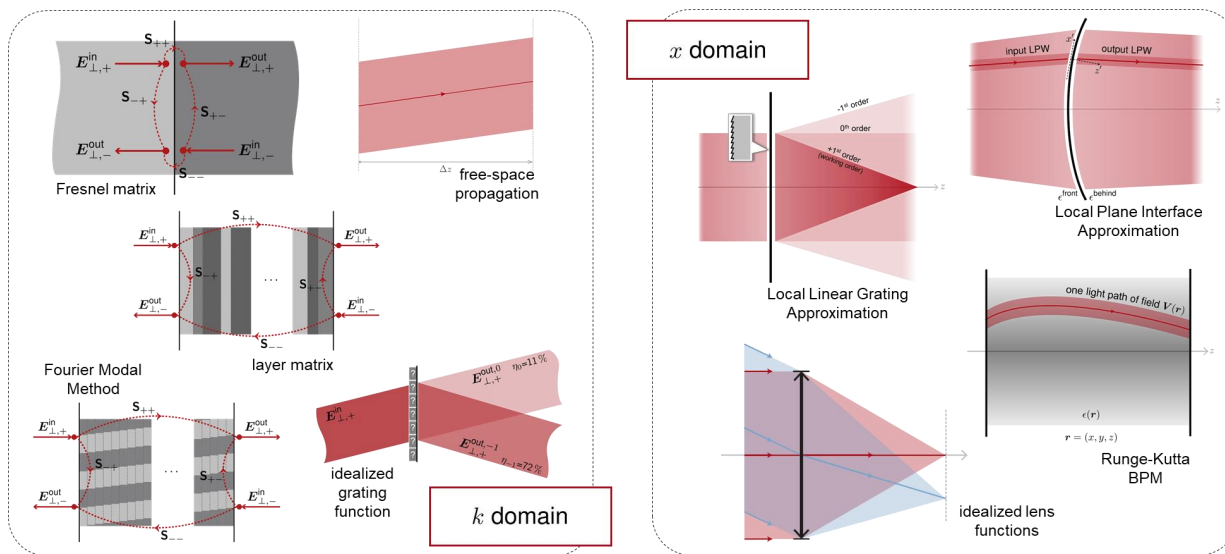


Local Plane Interface Approximation



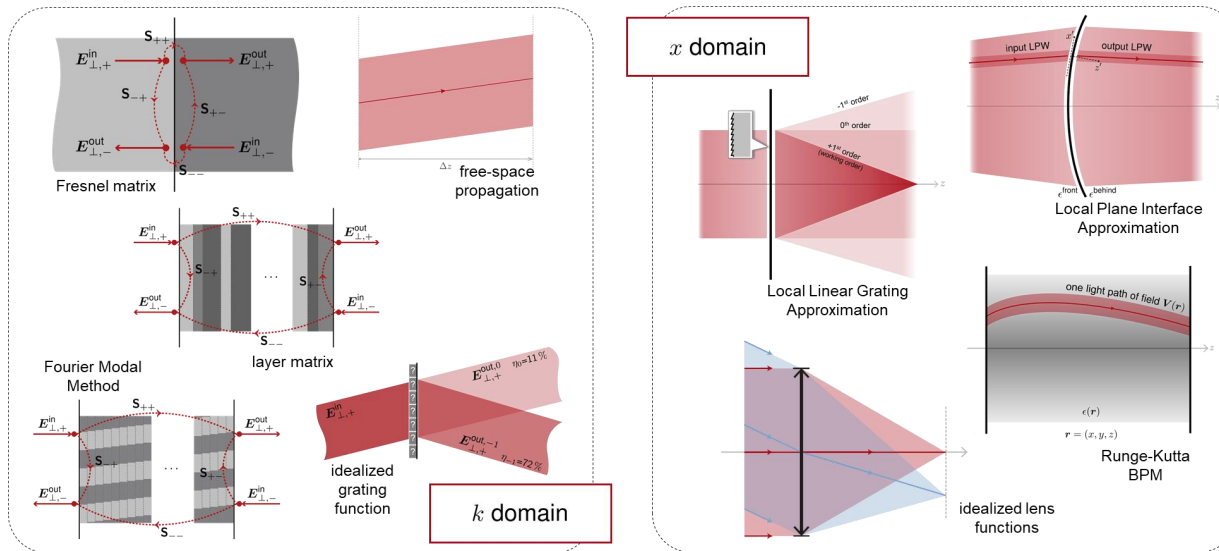
Runge-Kutta BPM

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Although, in general, electromagnetic field solvers have an **integral** behaviour, with the resulting high numerical complexity, the characteristics of some of the most common optical components mean they can be modeled with **pointwise** operators in one of the Fourier domains – when this happens, it entails a **massive computational advantage**!



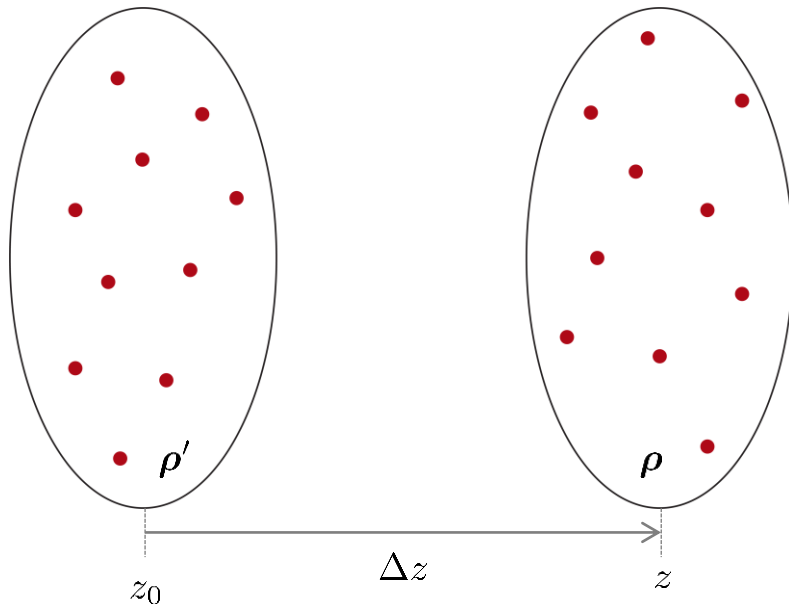
# Example: Free-Space Propagation

## Space domain

Rayleigh-Sommerfeld integral:

$$V_{\ell}^{\text{out}}(\boldsymbol{\rho}, z) \propto \iint_{-\infty}^{+\infty} V_{\ell}^{\text{in}}(\boldsymbol{\rho}', z_0) \frac{e^{ik_0 n R}}{R} \left( ik_0 n - \frac{1}{R} \right) \frac{\Delta z}{R} d^2 \rho'$$

with  $R = \sqrt{(x - x')^2 + (y - y')^2 + (\Delta z)^2}$





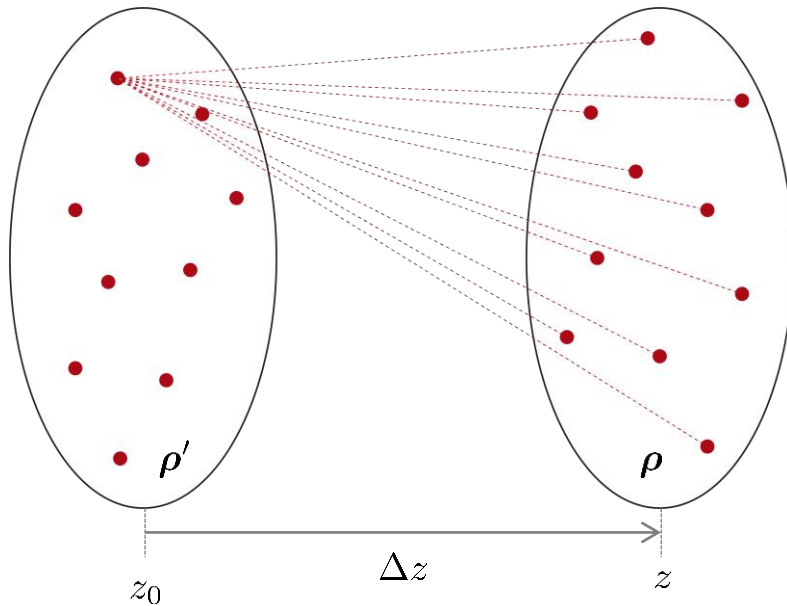
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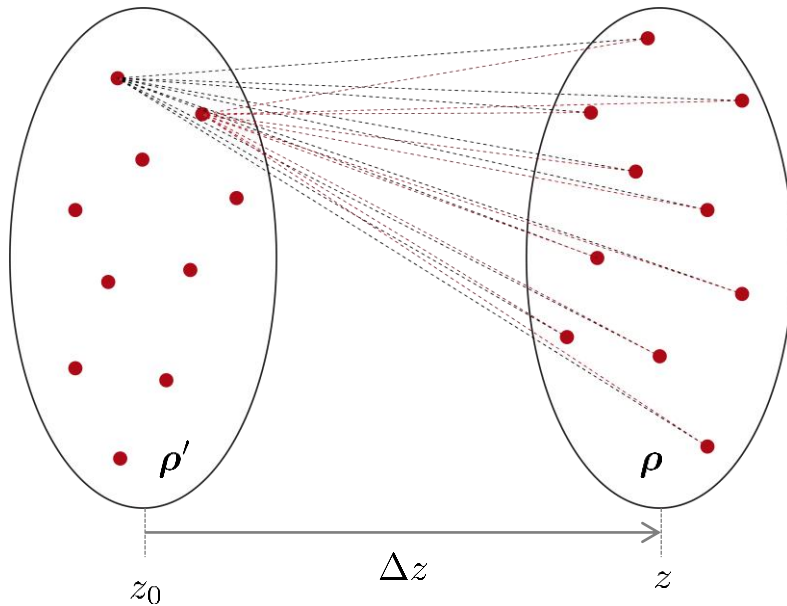
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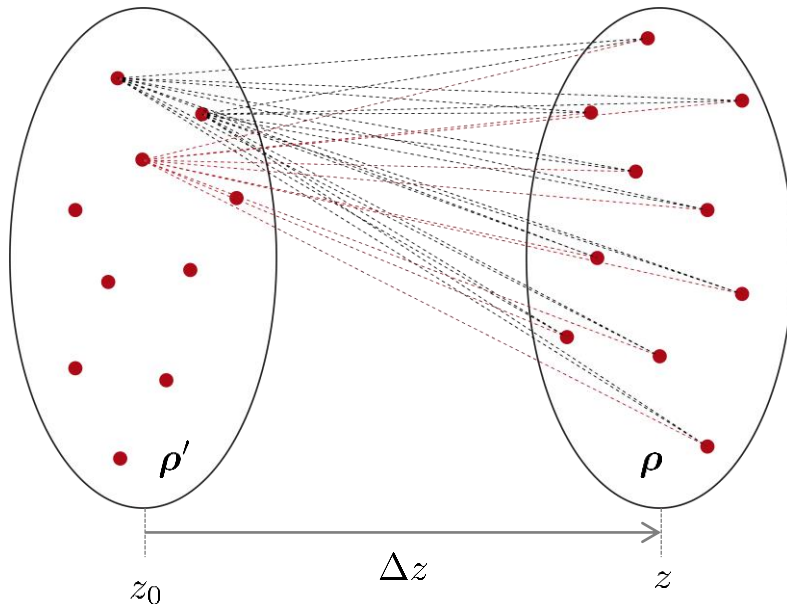
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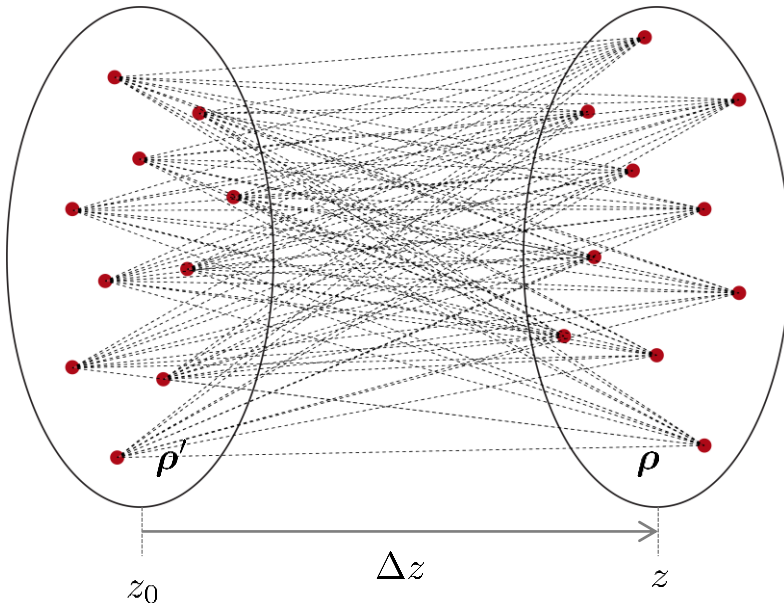
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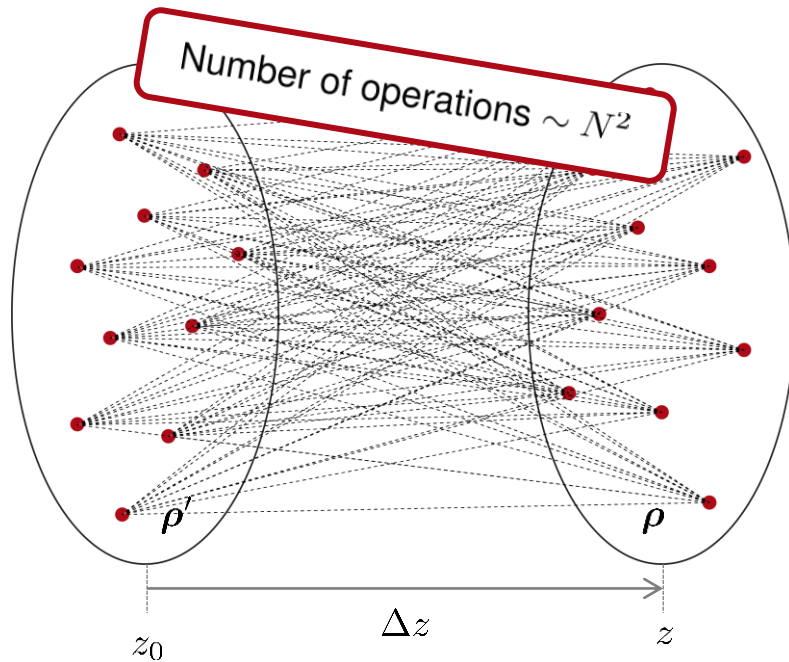
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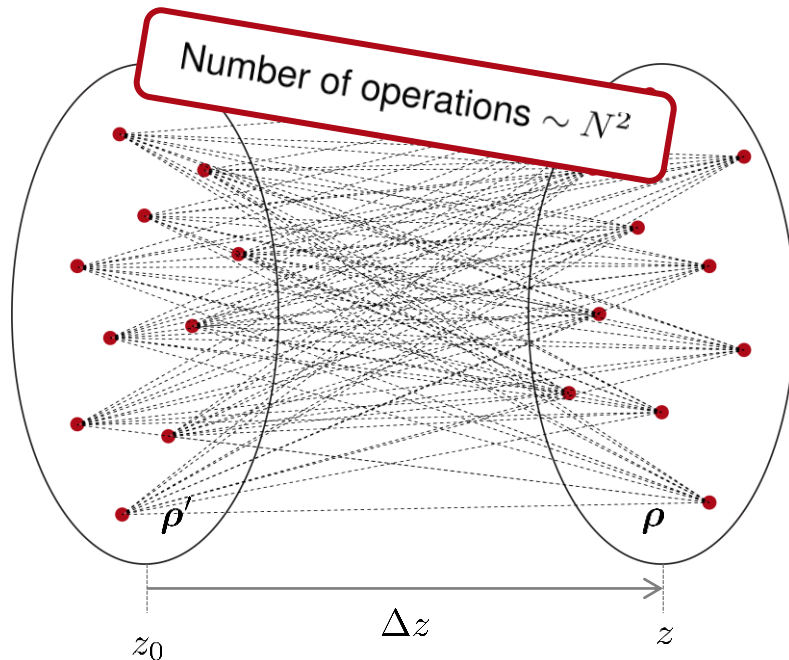
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## Spatial-frequency domain

Plane-wave propagation operator:

$$\tilde{V}_{\ell}^{\text{out}}(\boldsymbol{\kappa}, z) = \tilde{V}_{\ell}^{\text{in}}(\boldsymbol{\kappa}, z_0) \times e^{ik_z(\boldsymbol{\kappa})\Delta z}$$

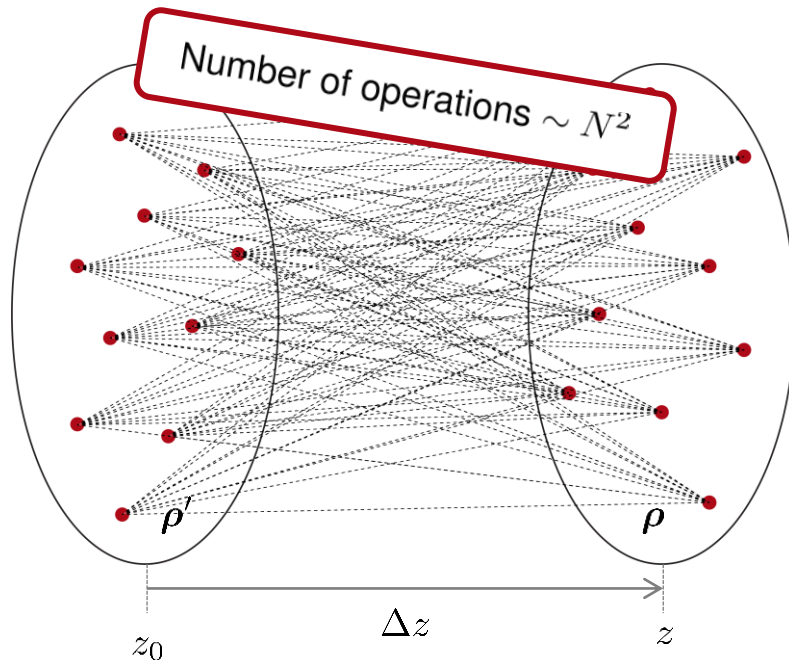
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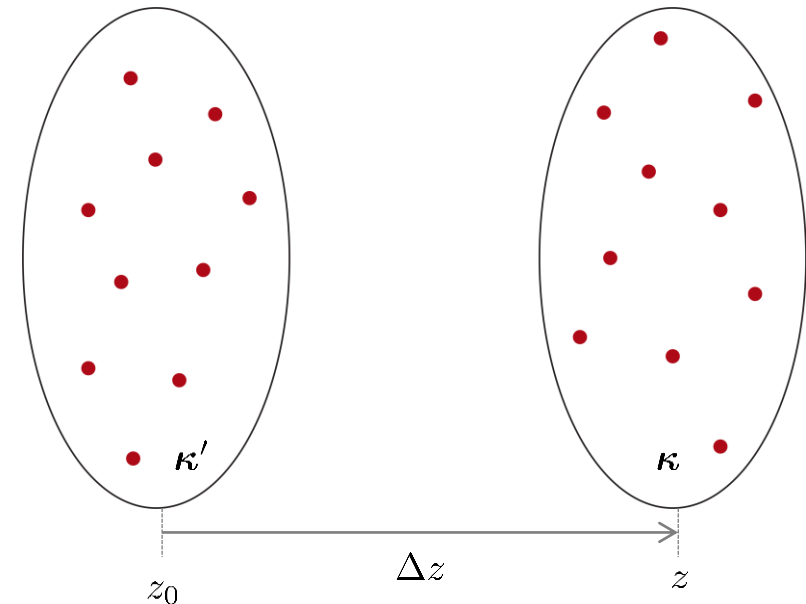
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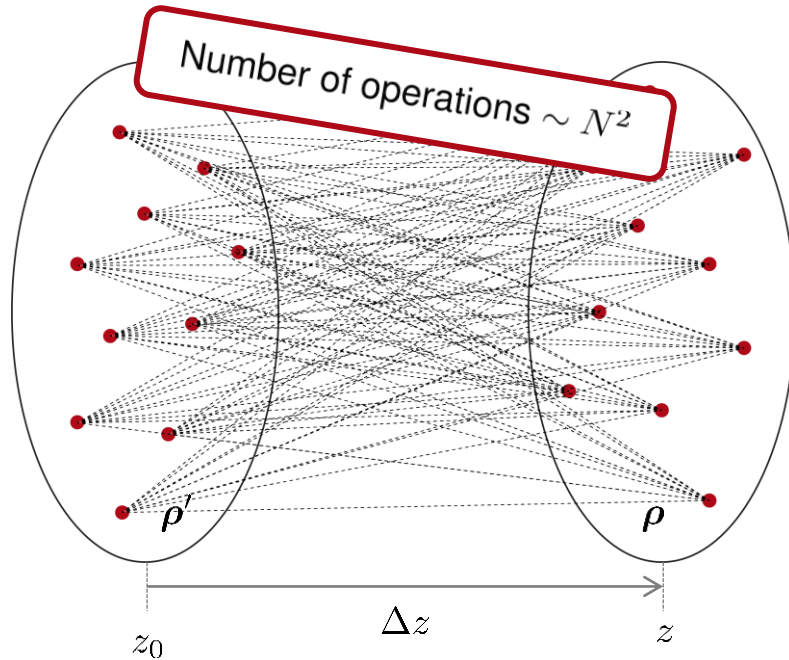
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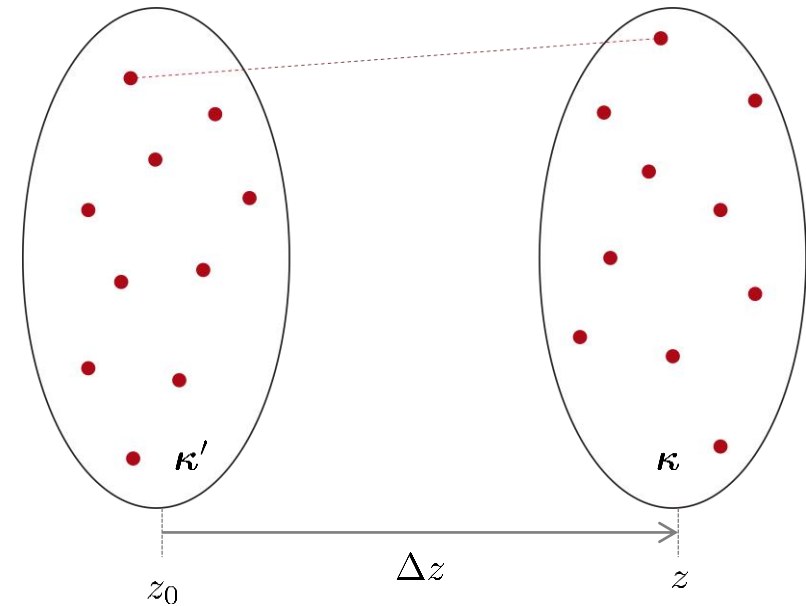
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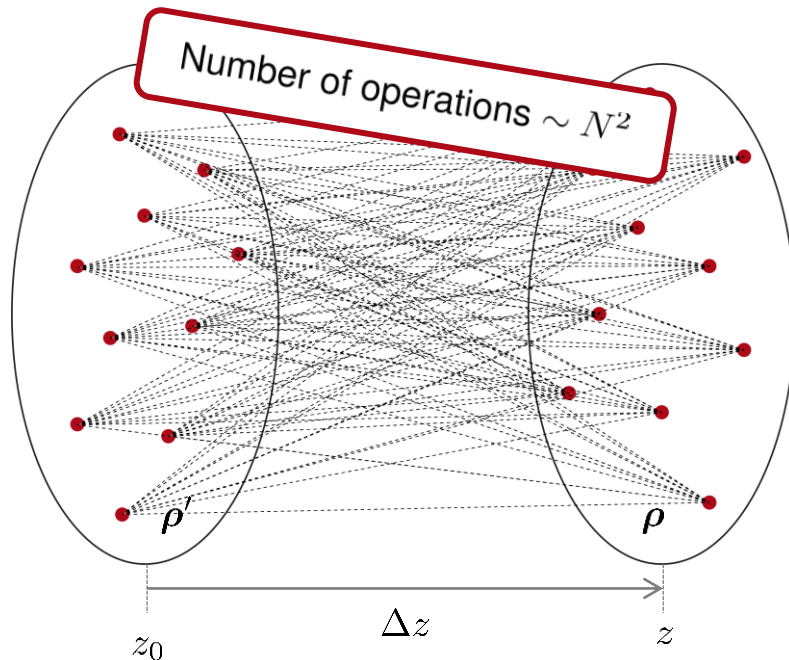
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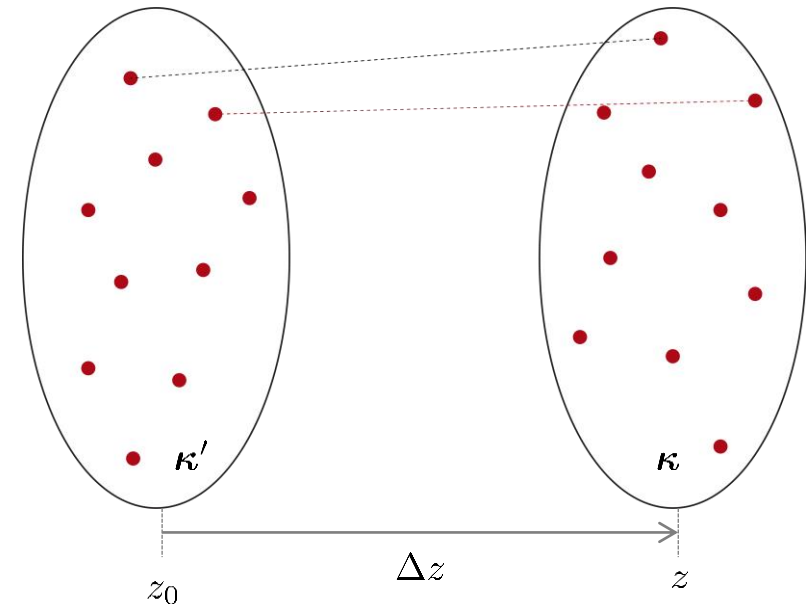
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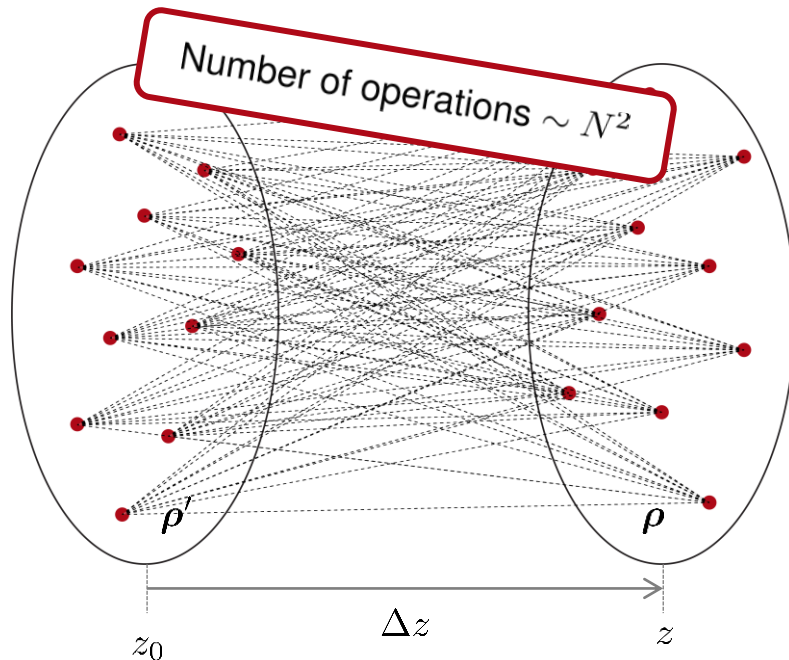
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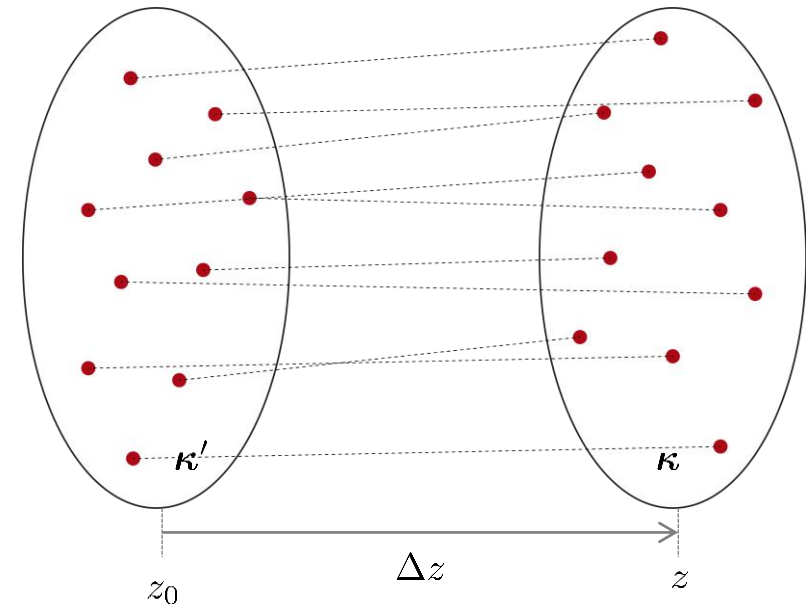
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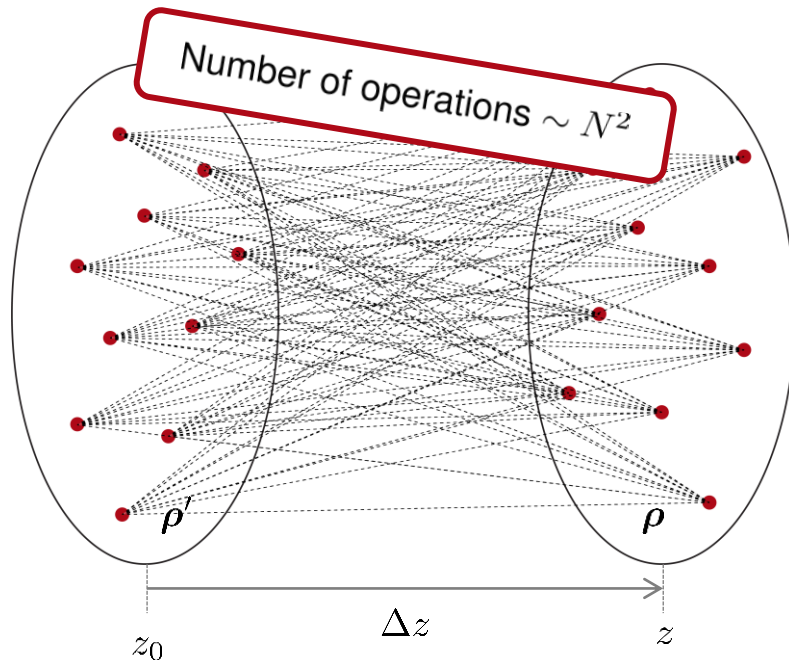
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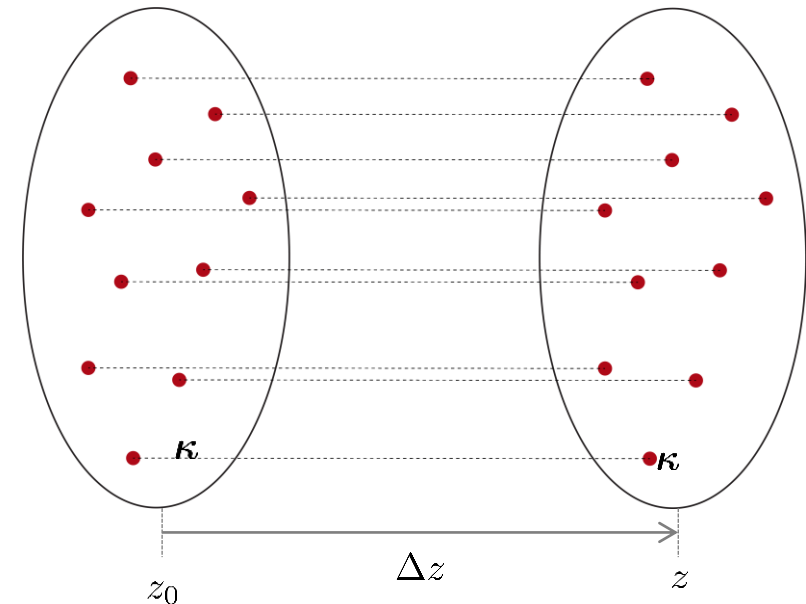
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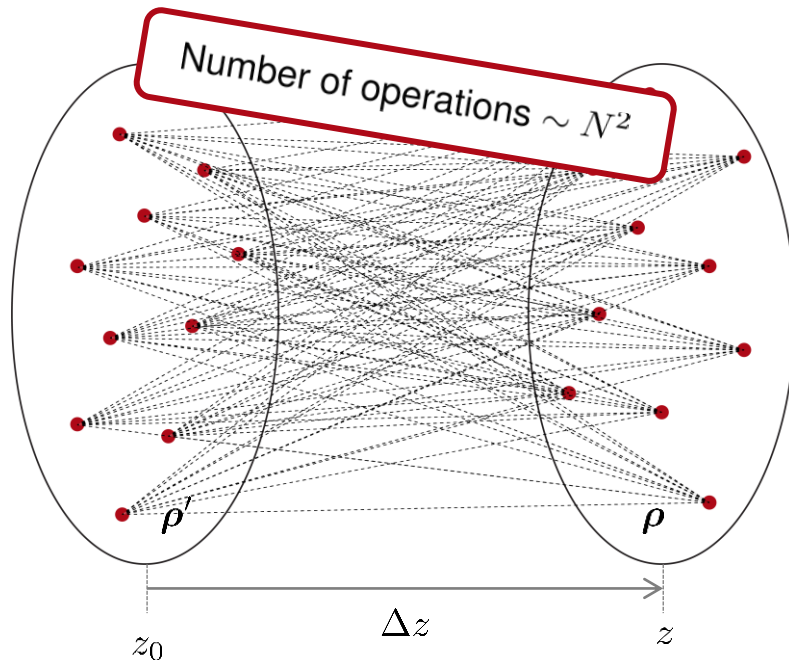
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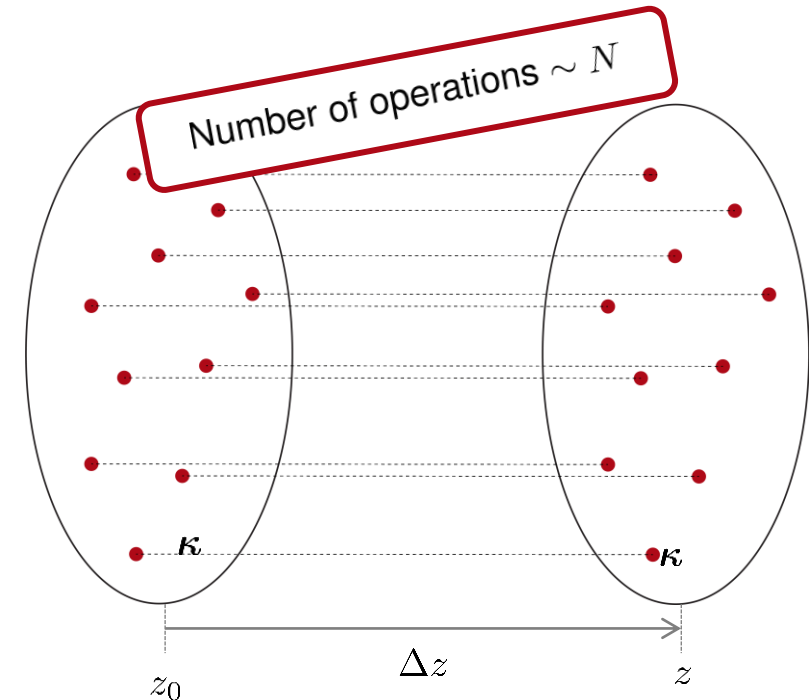
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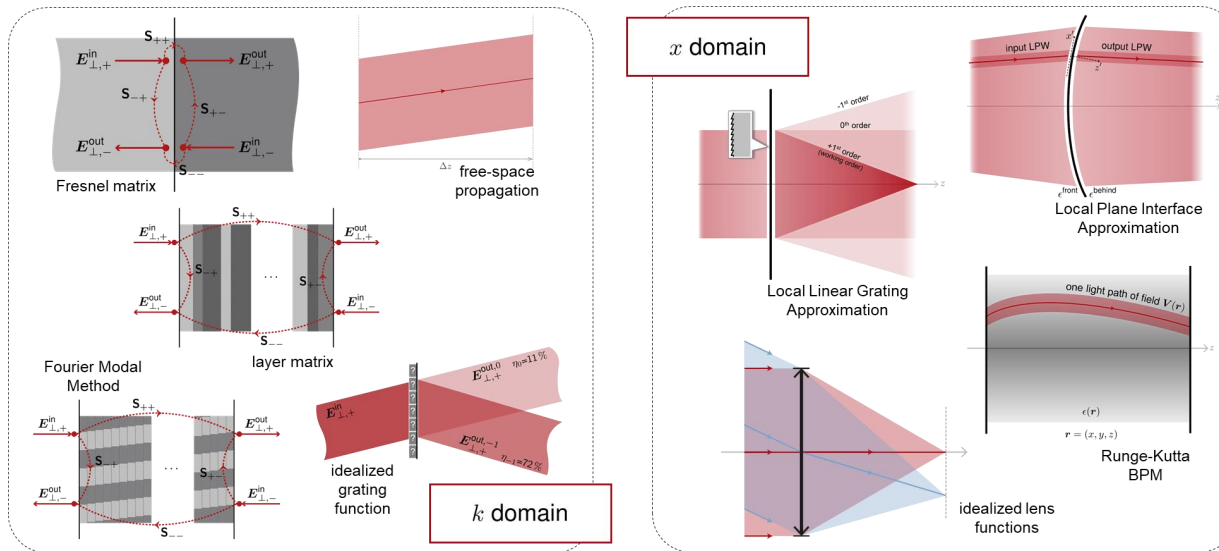
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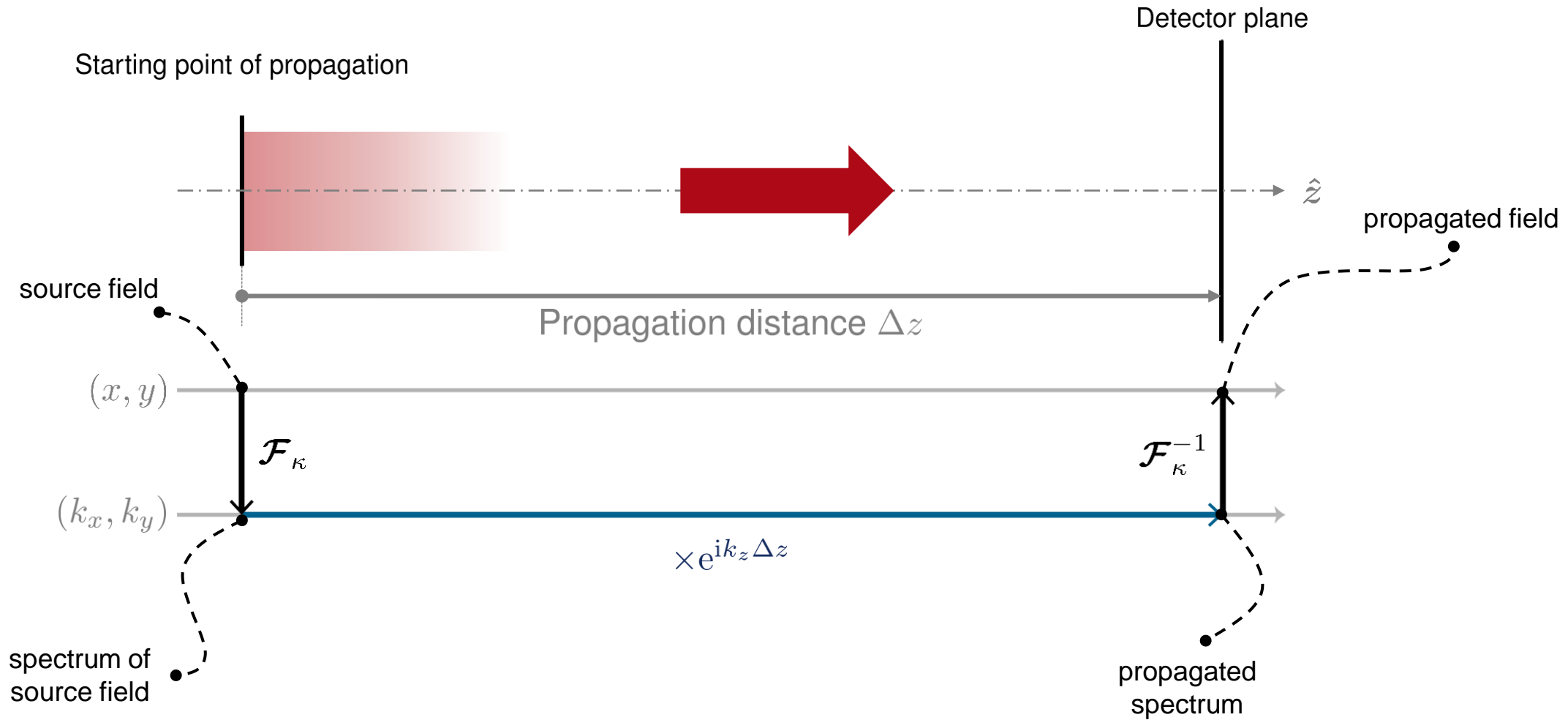
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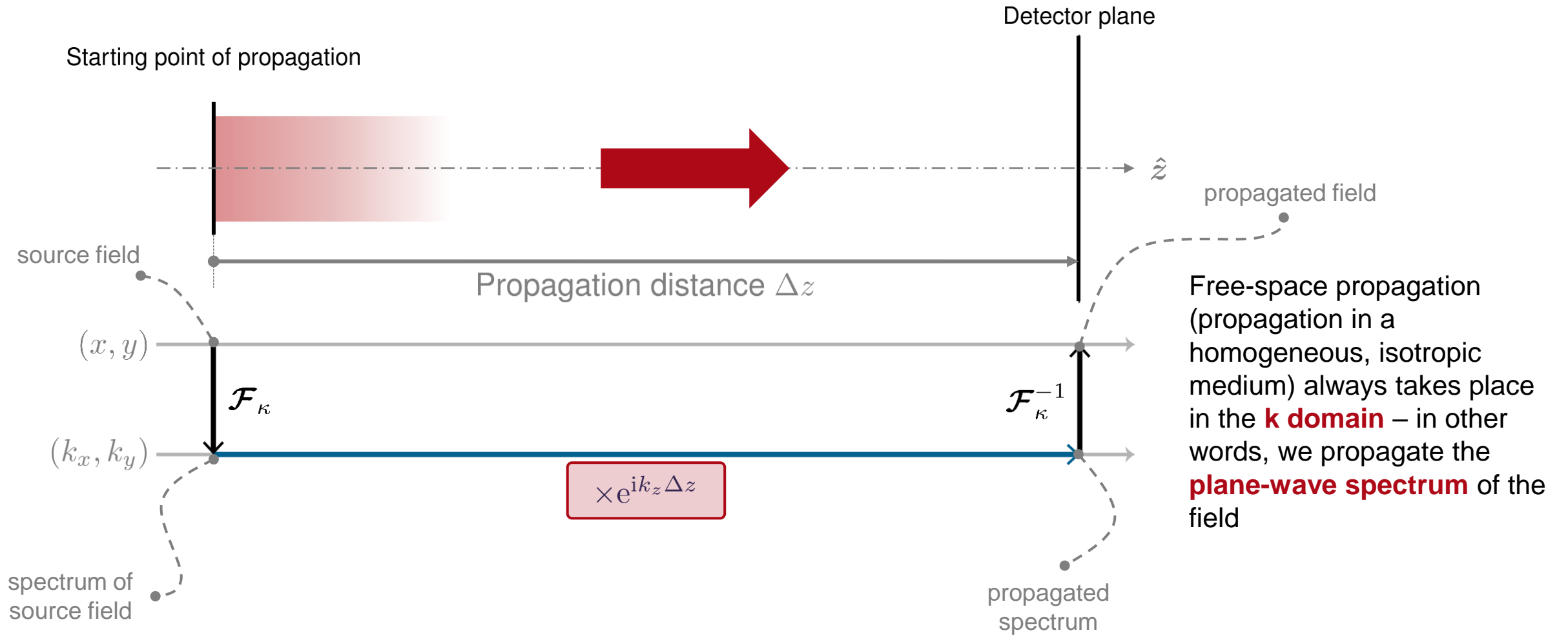


**Conclusion:** Whenever this mathematical property presents itself, we implement the solver in the domain where it exhibits **pointwise behaviour**!

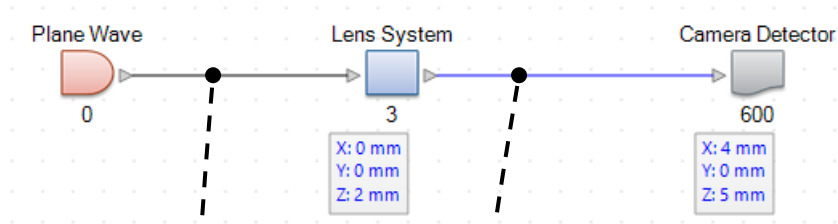
# Free-Space Propagation



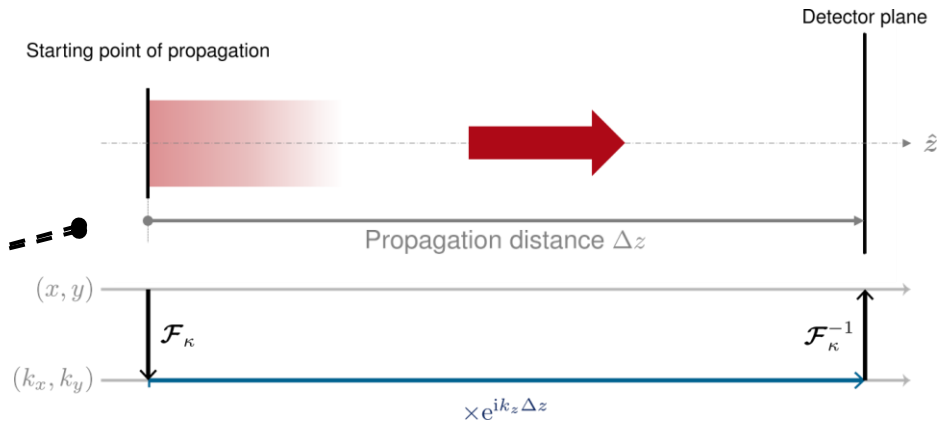
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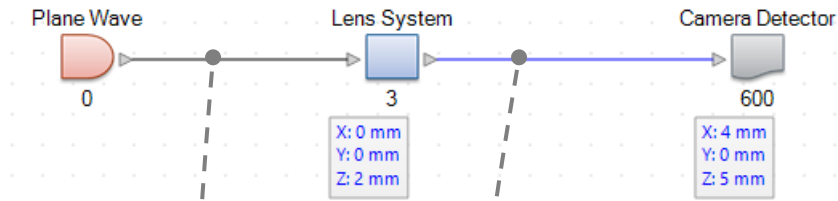
This refers to propagation between elements of an optical system...



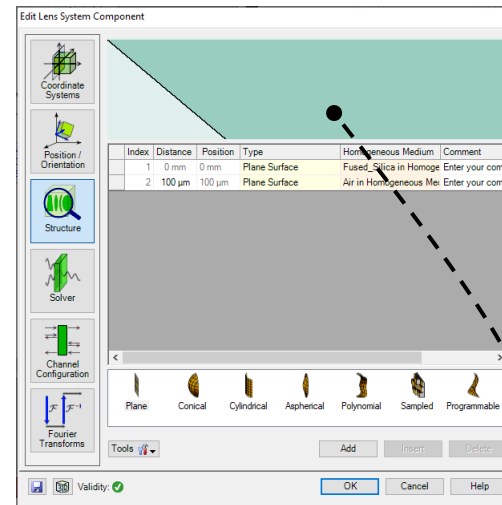
Free-space propagation (propagation in a homogeneous, isotropic medium) always takes place in the **k domain** – in other words, we propagate the **plane-wave spectrum** of the field



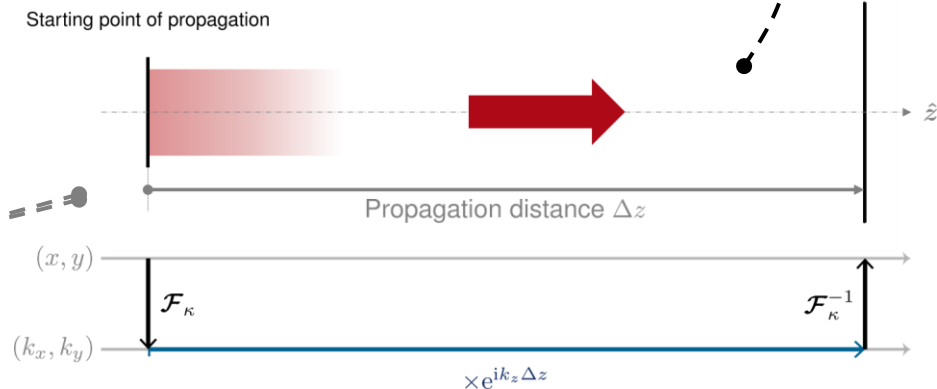
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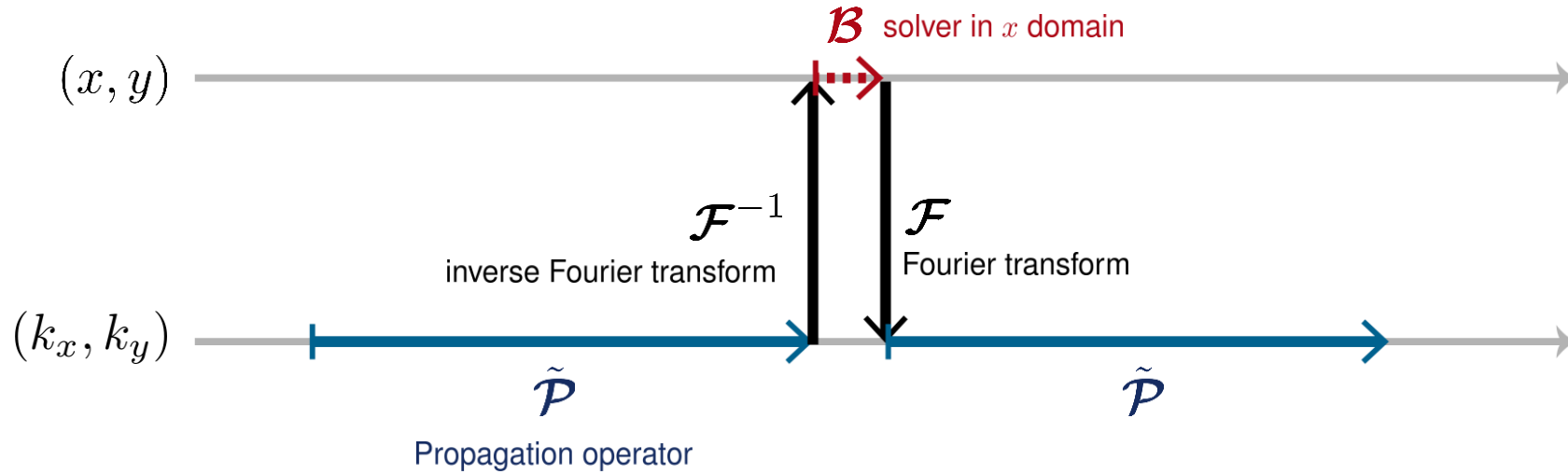


... as well as to internal propagation between surfaces in some cases, like the *Lens System* component



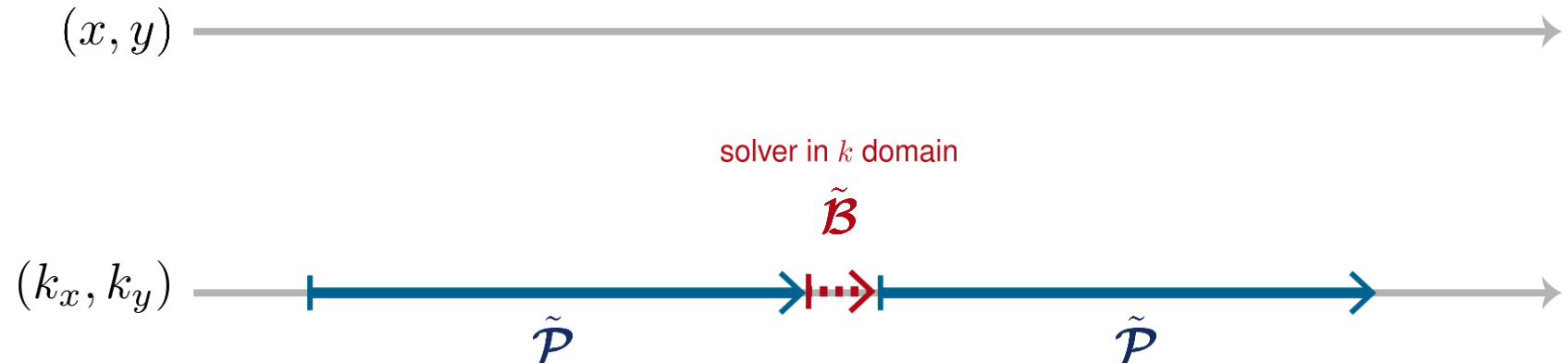
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# Domain of Application of the Solvers

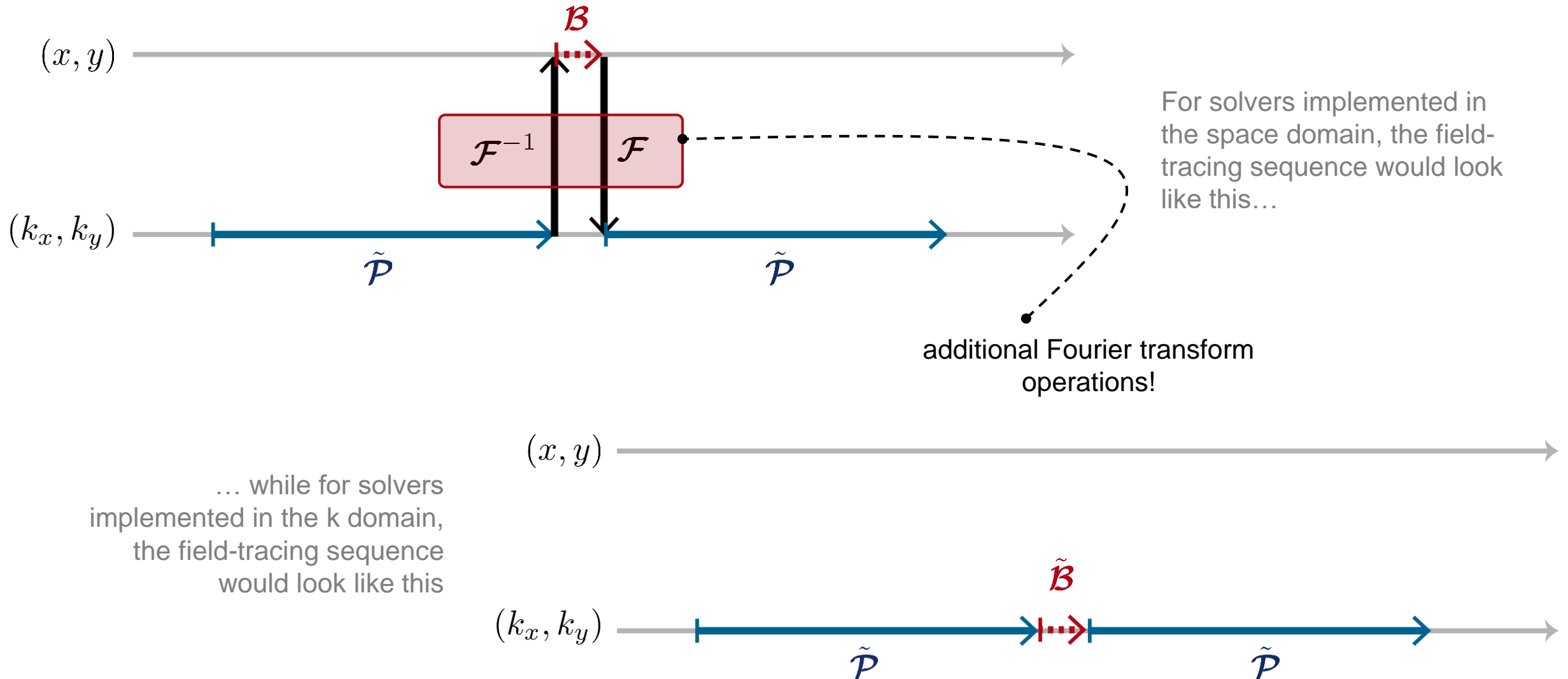


For solvers implemented in the space domain, the field-tracing sequence would look like this...

... while for solvers implemented in the  $k$  domain, the field-tracing sequence would look like this



# Domain of Application of the Solvers

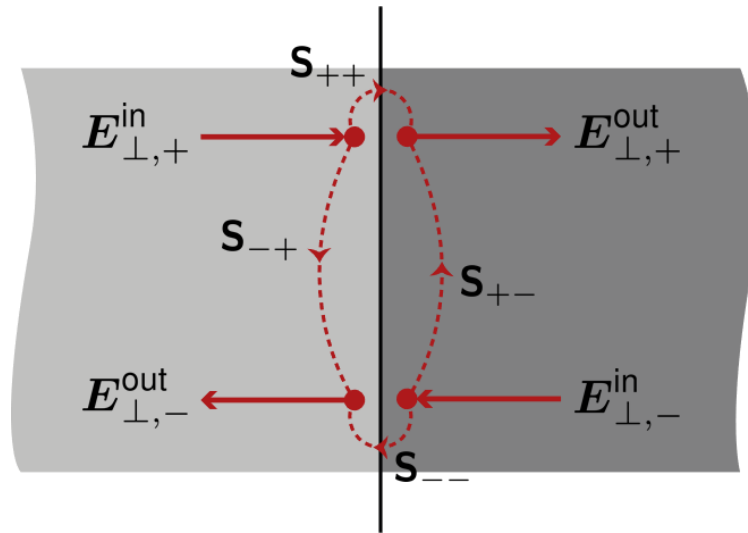


## **The Special Case of the Plane Surface**

# Possible Field Solvers for Plane Surfaces

- As an infinitely extended ideal plane surface → **Fresnel Matrix**

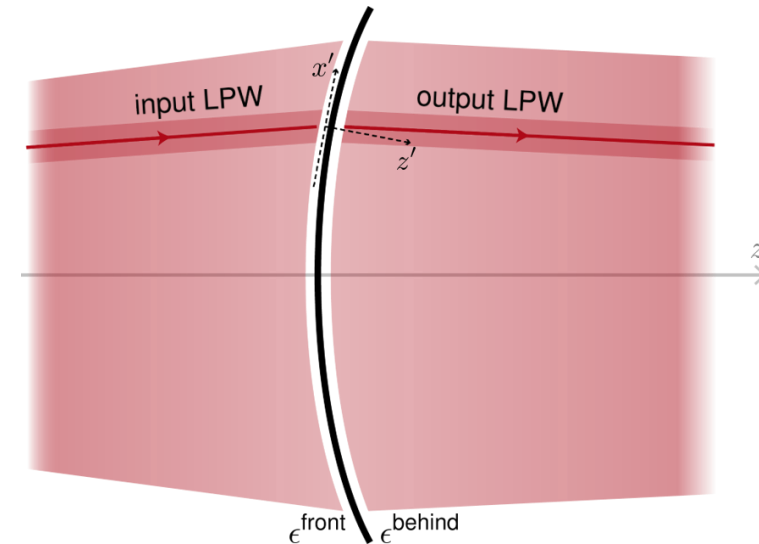
- Solver in **k domain**



- Implemented in *Plane Surface* component

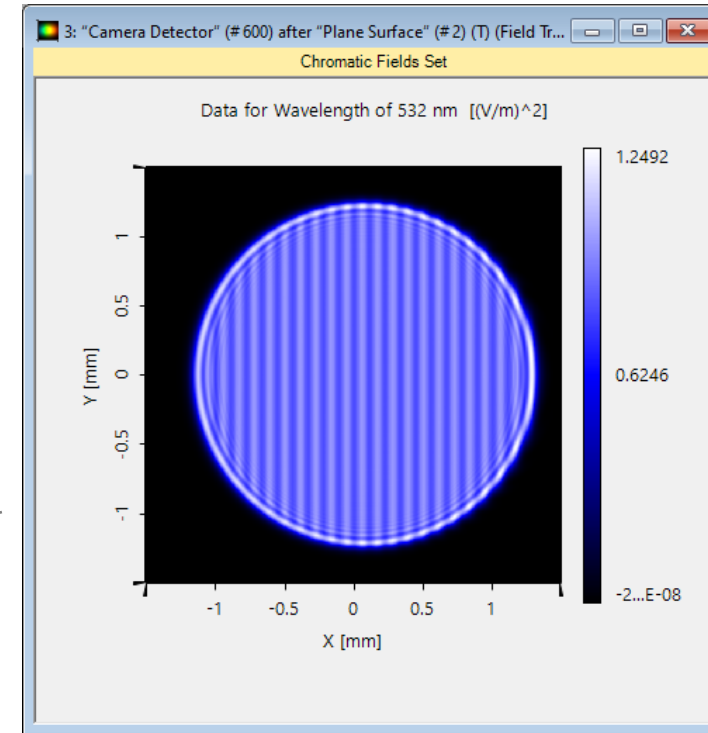
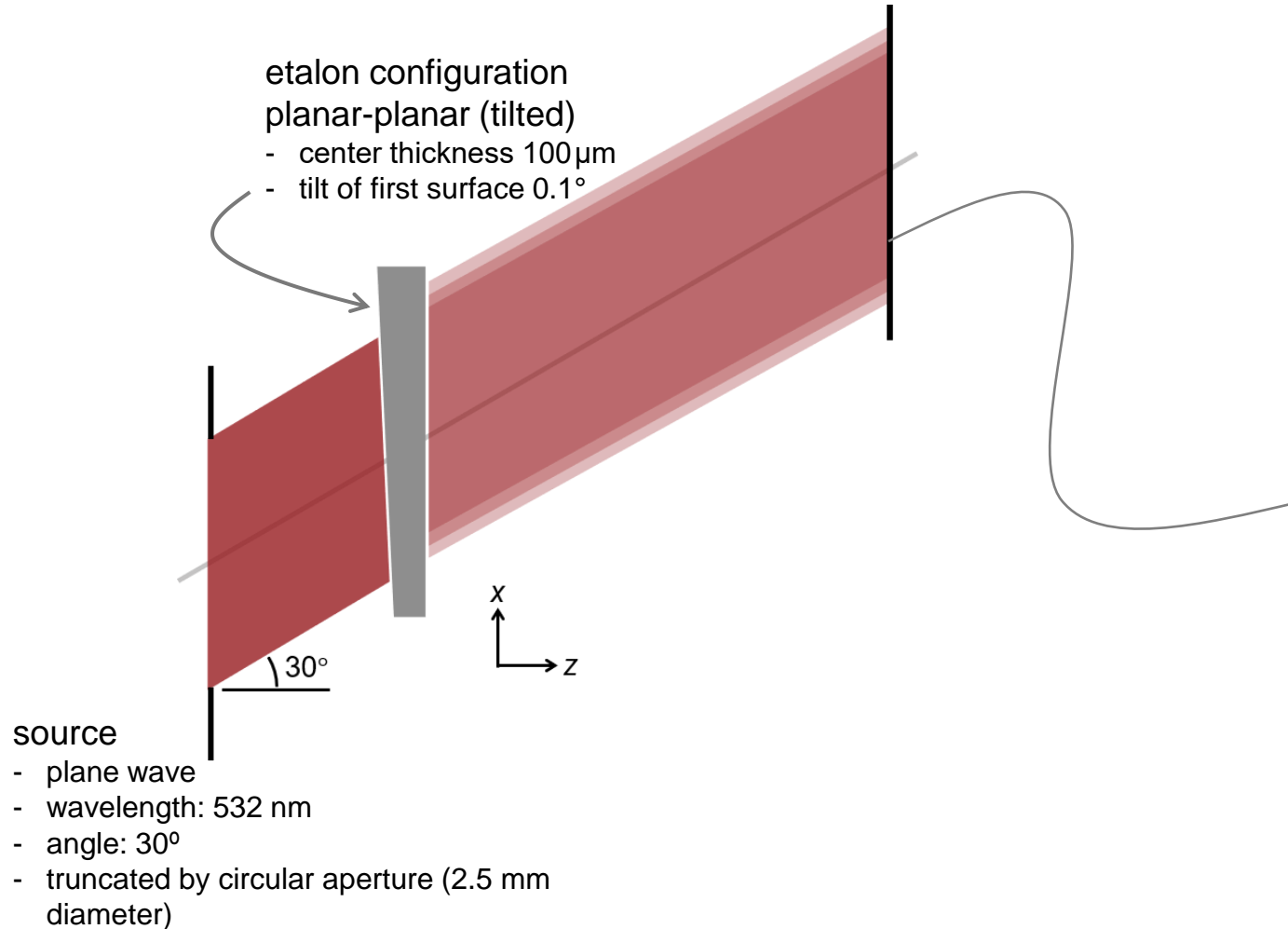
- As a curved surface without curvature → **Local Plane Interface Approximation (LPIA)**

- Solver in **x domain**



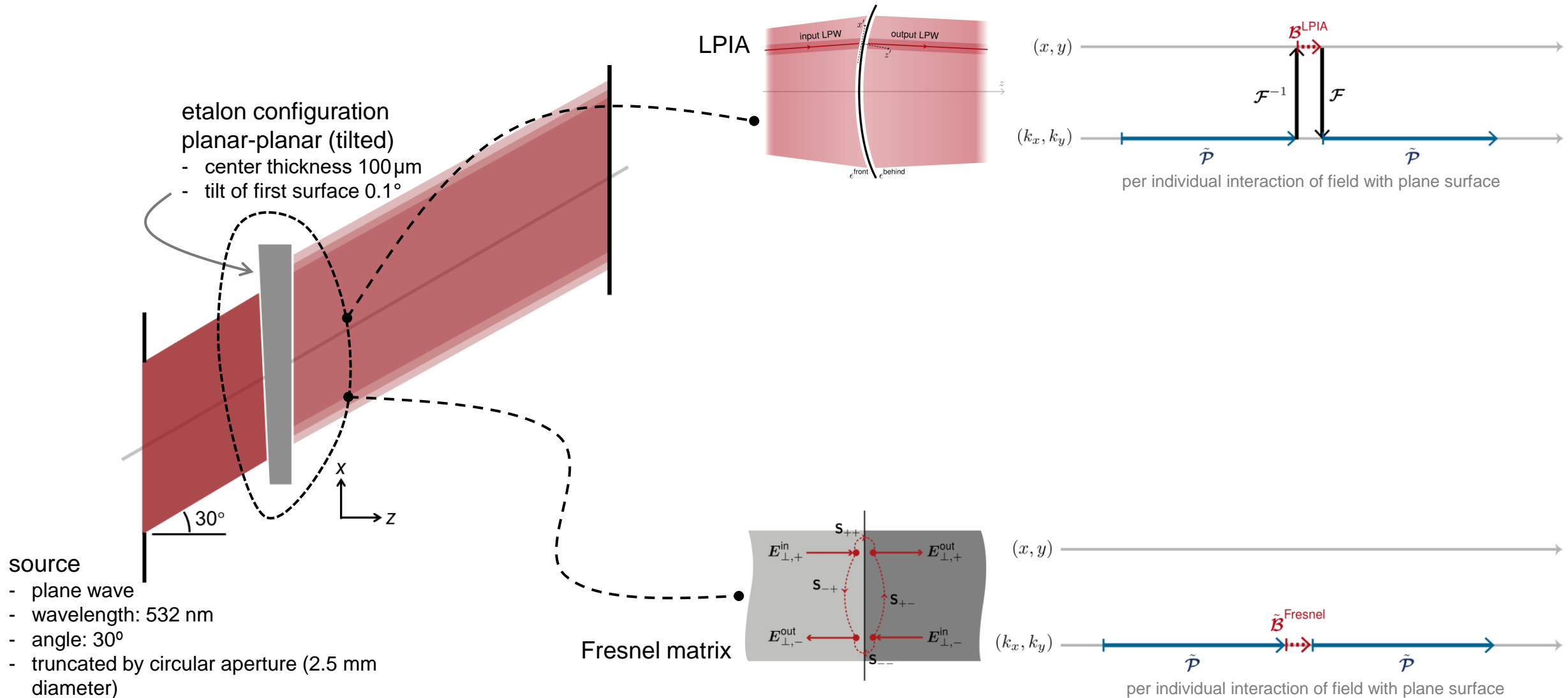
- Implemented in *Lens System* and *Curved Surface* components, among others

# Modeling an Etalon with Plane Interfaces...



 [see the full Application Use Case:  
"Modeling of Etalon with Planar or Curved Surfaces"](#)

# ... Two Ways



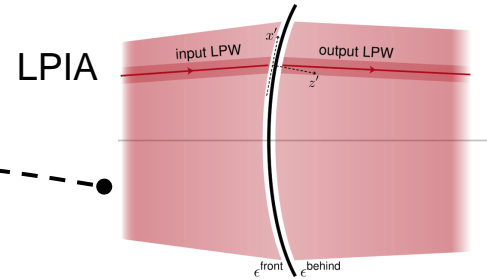
# ... Two Ways

etalon configuration  
planar-planar (tilted)

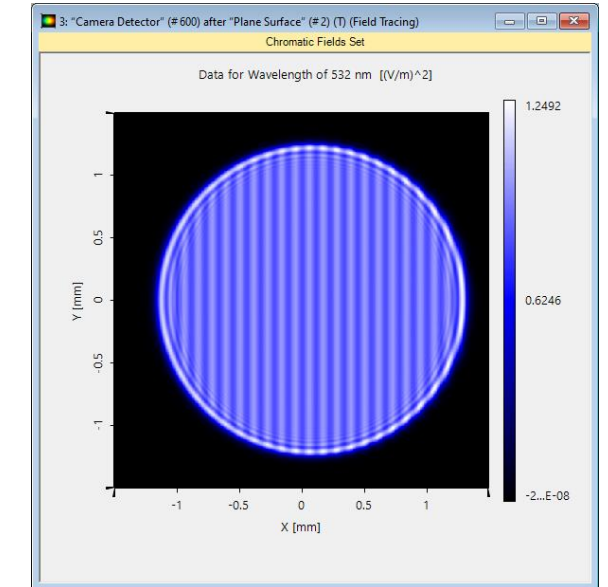
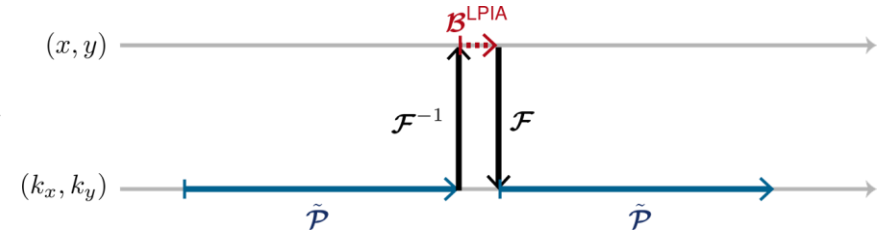
- center thickness  $100\mu\text{m}$
- tilt of first surface  $0.1^\circ$

source

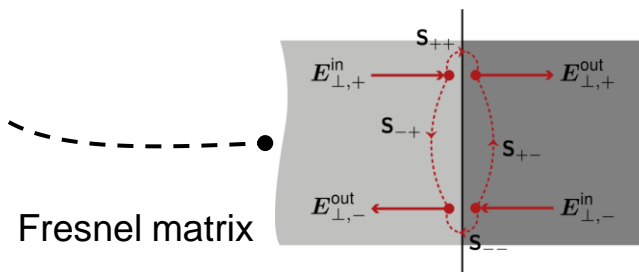
- plane wave
- wavelength:  $532\text{ nm}$
- angle:  $30^\circ$
- truncated by circular aperture (2.5 mm diameter)



$\Delta t_{\text{simulation}} \sim 1.5\text{ min (*)}$



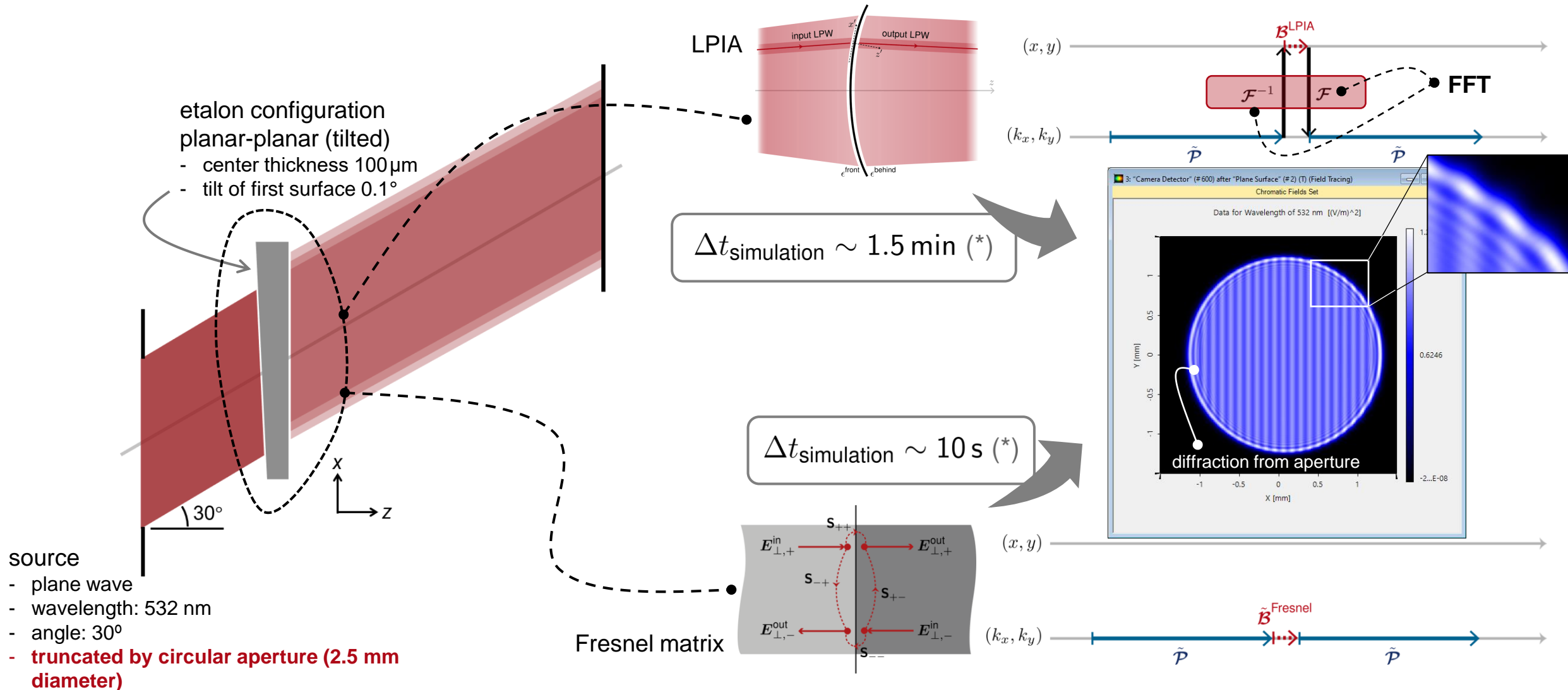
$\Delta t_{\text{simulation}} \sim 10\text{ s (*)}$



(\*) Approximate simulation times on a PC with the following technical specs: processor Intel(R) Core(TM) i7-7700HQ CPU @ 2.80GHz and 32 GB RAM

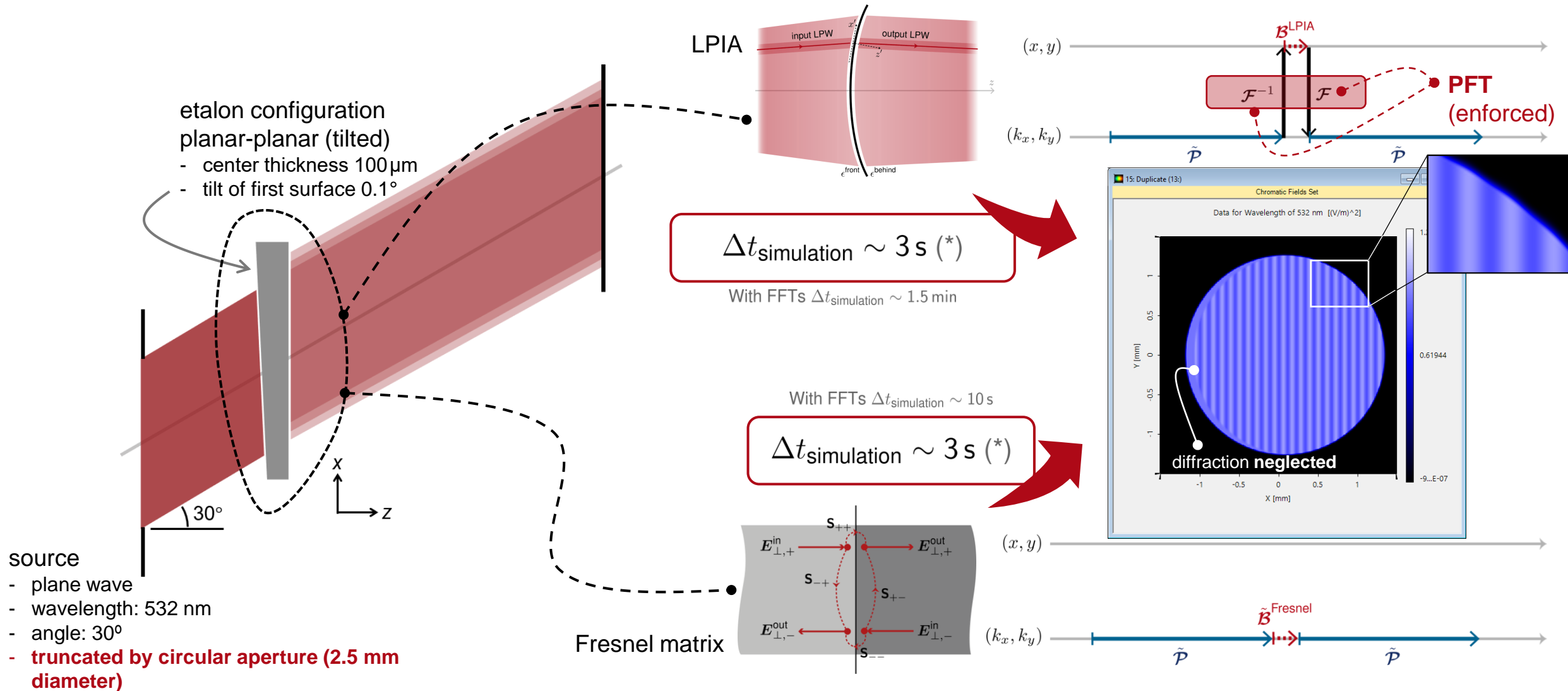


# The Importance of the Fourier Transform



(\*) Approximate simulation times on a PC with the following technical specs: processor Intel(R) Core(TM) i7-7700HQ CPU @ 2.80GHz and 32 GB RAM

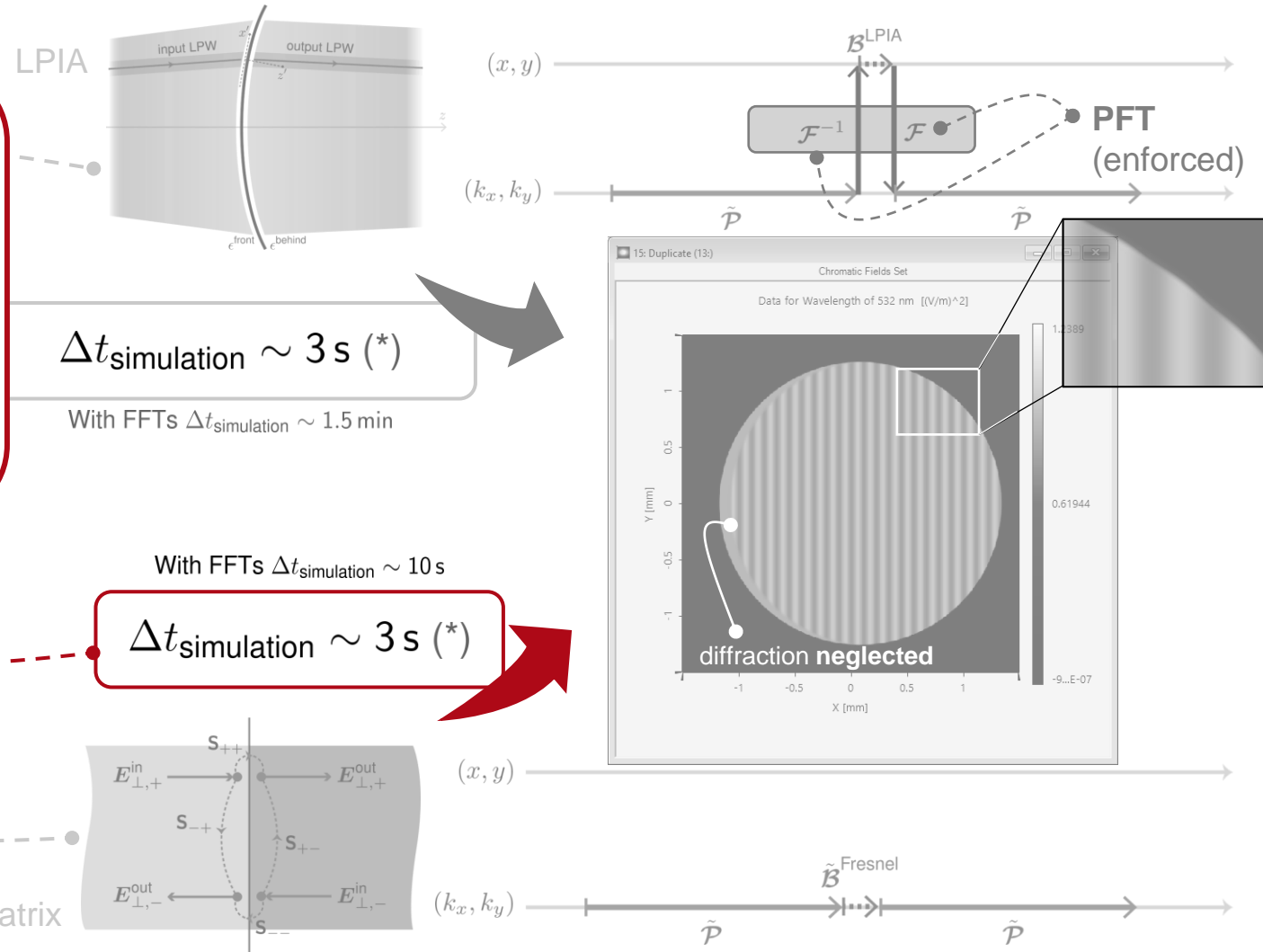
# The Importance of the Fourier Transform



(\*) Approximate simulation times on a PC with the following technical specs: processor Intel(R) Core(TM) i7-7700HQ CPU @ 2.80GHz and 32 GB RAM

# The Importance of the Fourier Transform

Note: Fourier transforms are also performed at the source and detector planes, hence there is also a slight time improvement in the Fresnel Matrix case when the **Pointwise Fourier transform is enforced** across the system



More information about our catalog of Fourier transform algorithms in our use case "[Fourier Transform Settings Discussion at Examples](#)"

# Practical Conclusions: Which Solver Do I Use?

---

Two possible solvers for plane interfaces in an optical system: the Fresnel Matrix and the Local Plane Interface Approximation (LPIA). Which one is more appropriate for your system depends on the circumstances:

## **Fresnel Matrix:**

- Rigorous solver for ideal plane surface
- Works in spatial-frequency ( $k$ ) domain
- Fewer Fourier transforms to be calculated  
→ potential numerical gain
- Assumes infinite surface

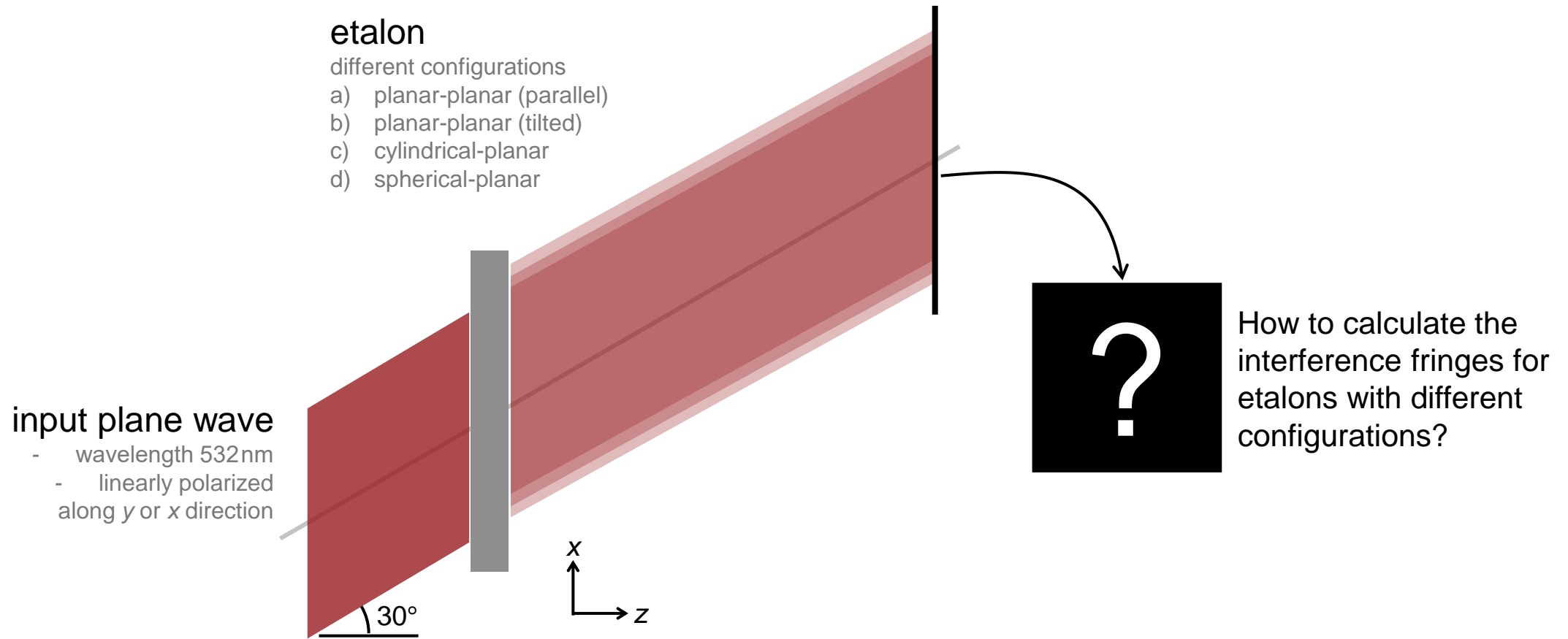
## **LPIA:**

- Solver for curved surfaces
  - Works in space ( $x$ ) domain
  - Requires computation of additional Fourier transforms
  - Considers finite size (aperture) of surface
-

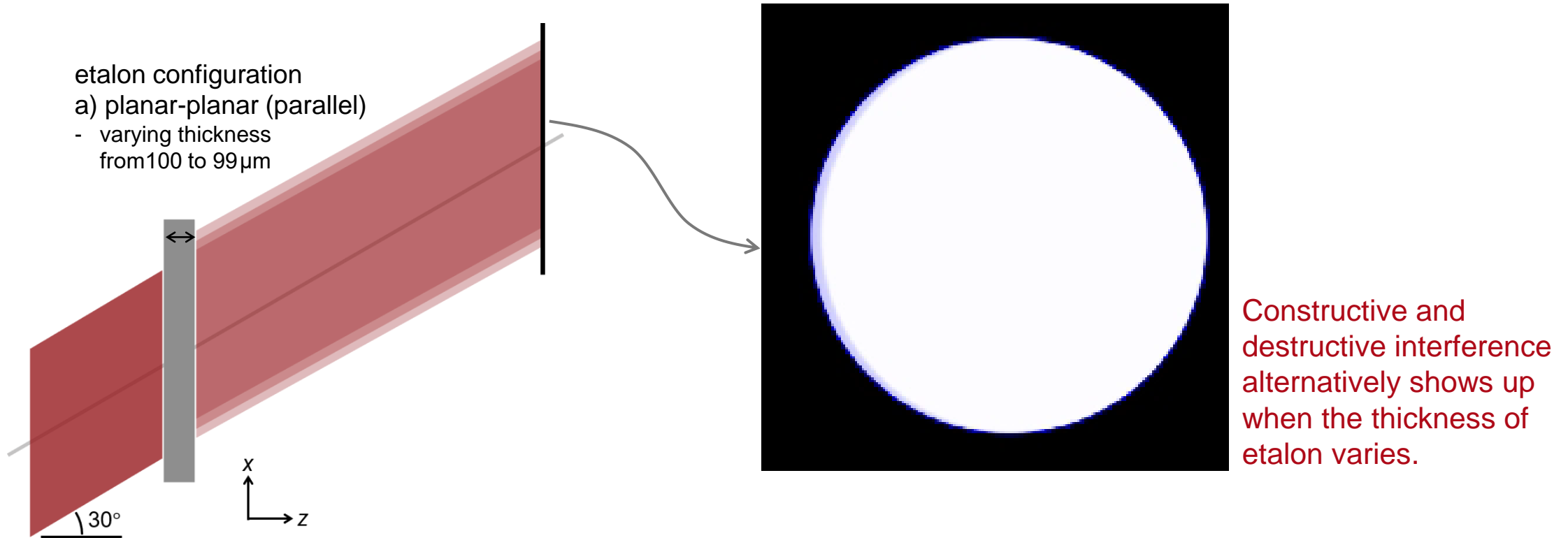
# Modeling of Etalon with Planar or Curved Surfaces



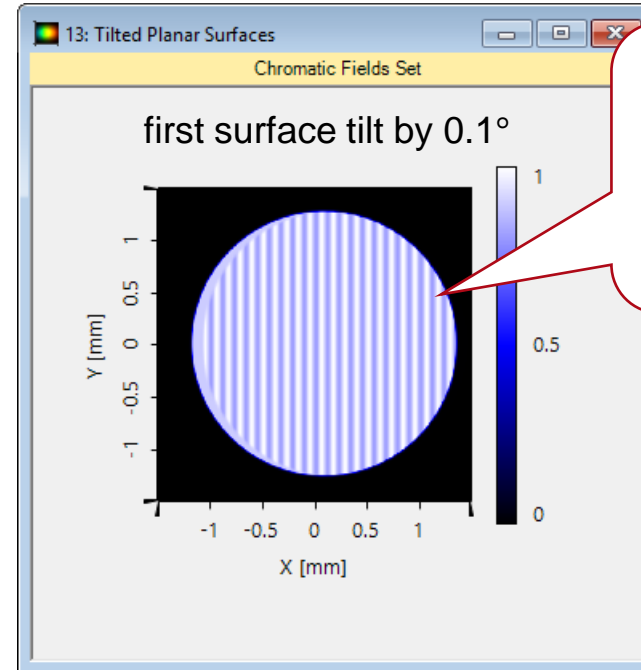
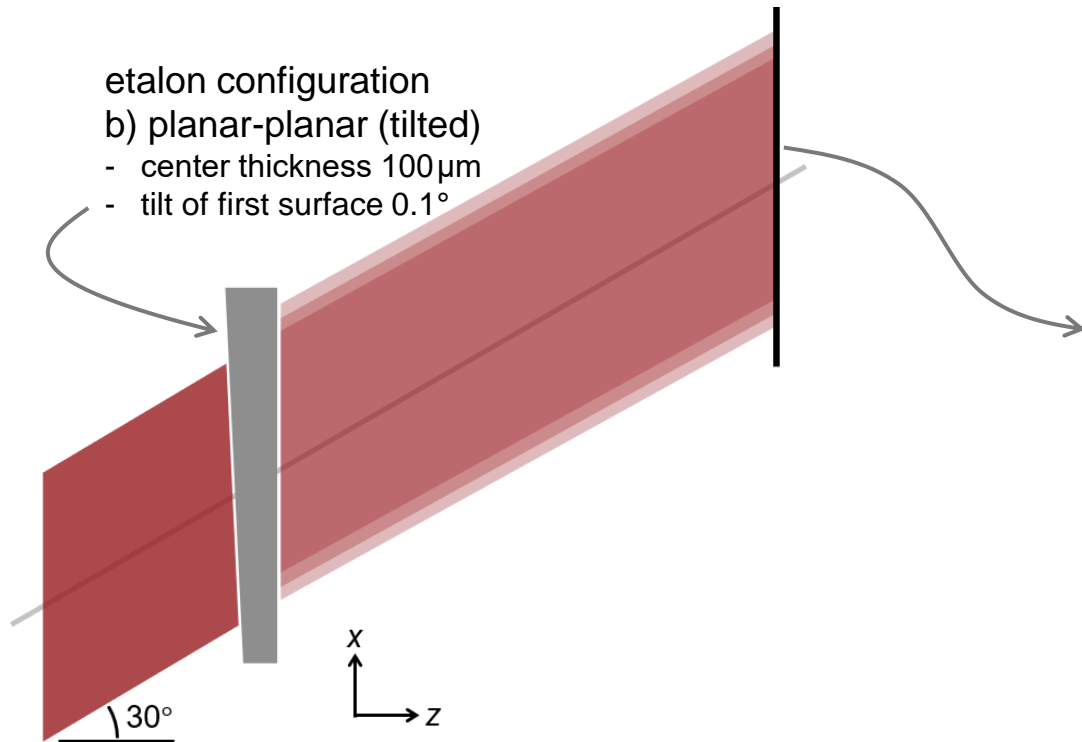
# Modeling Task



# Parallel Planar-Planar Surfaces



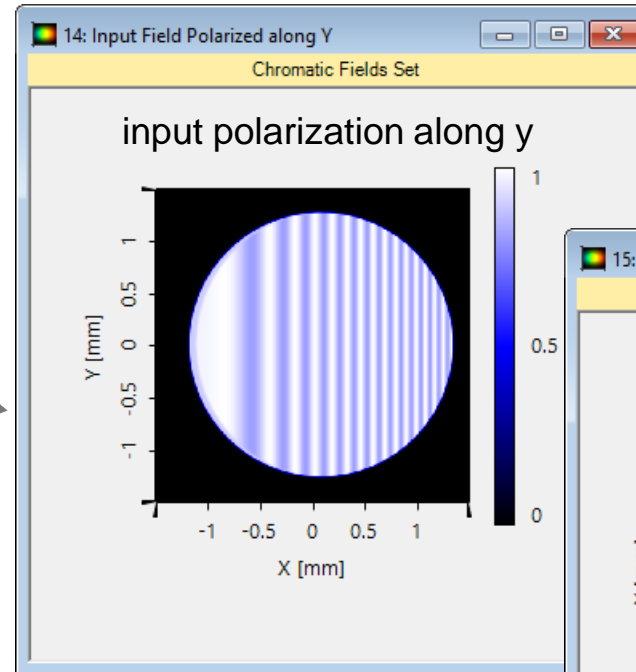
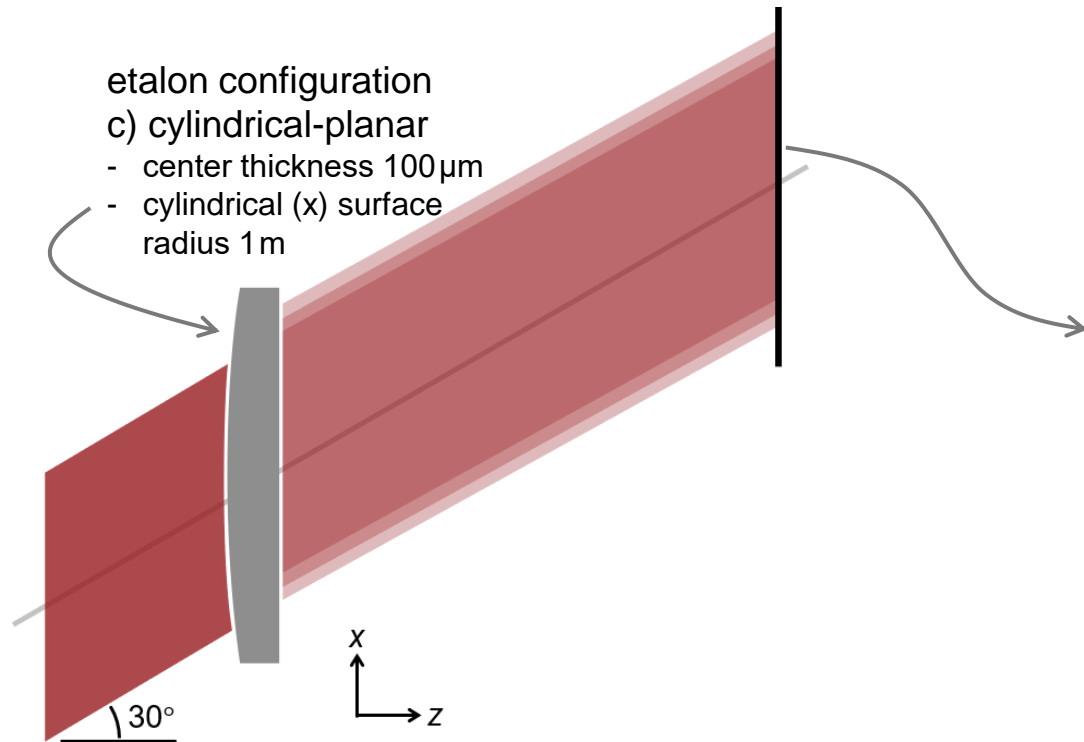
# Tilted Planar-Planar Surfaces



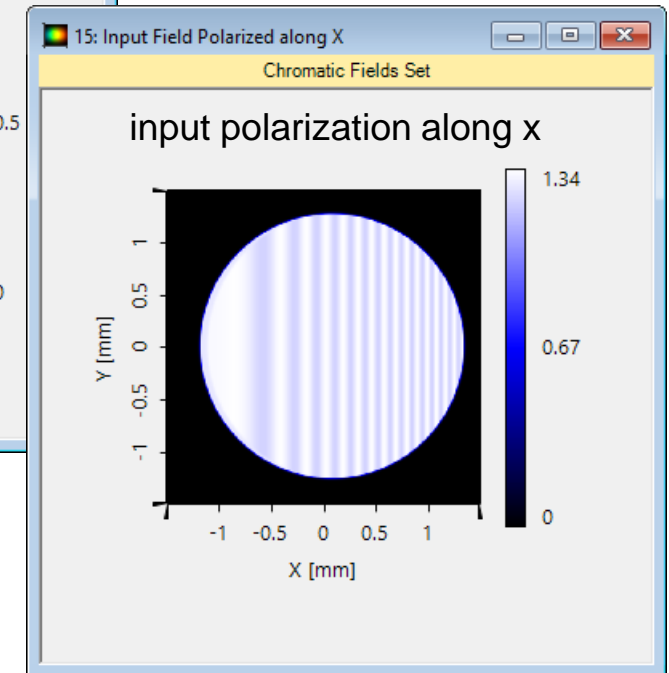
Linear interference fringes appear due to linear change of etalon thickness.



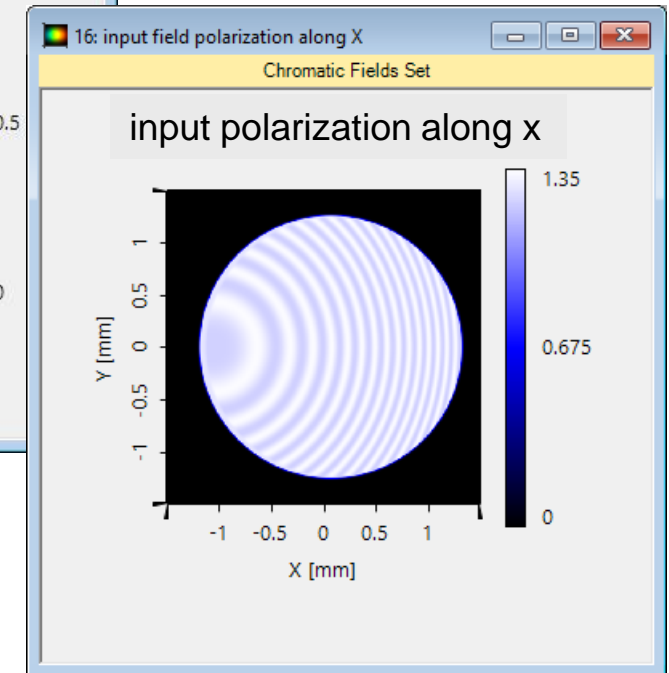
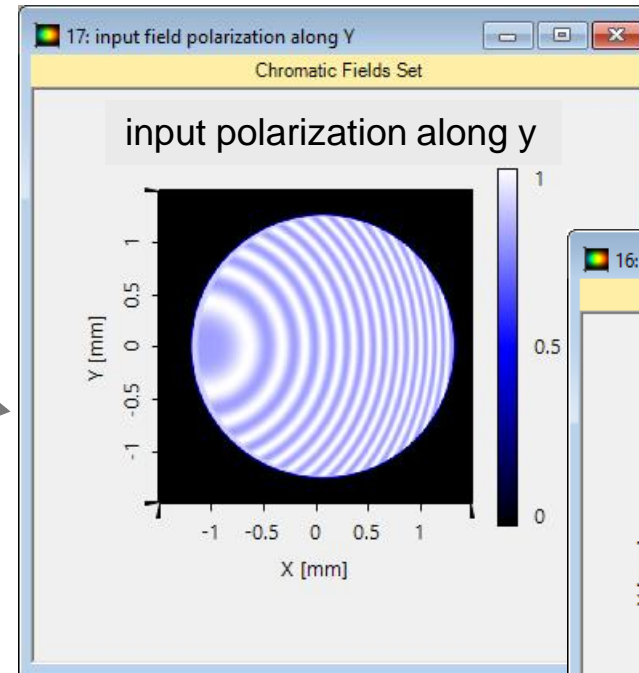
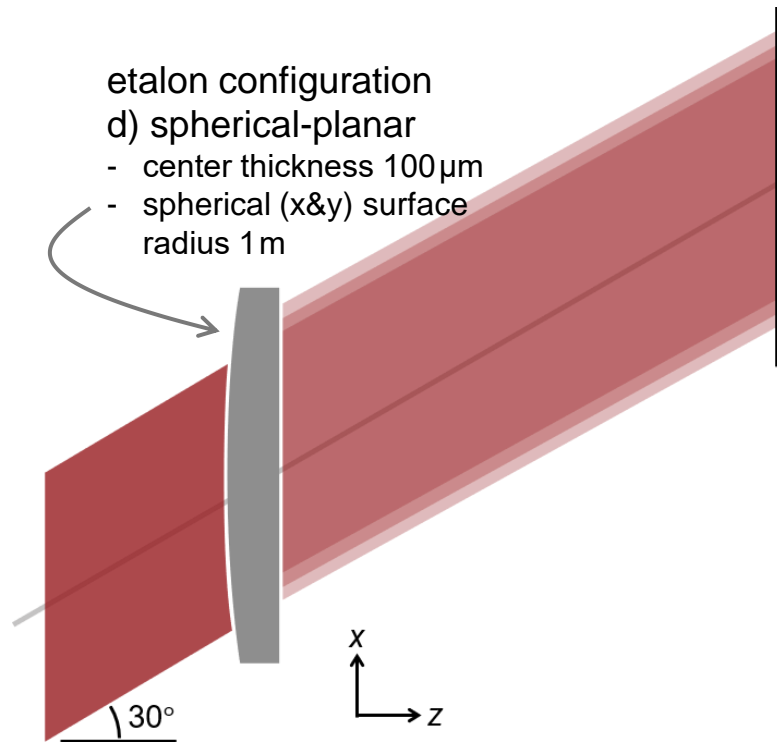
# Cylindrical-Planar Surfaces



Polarization-dependent effect on the interference is considered in the simulation.

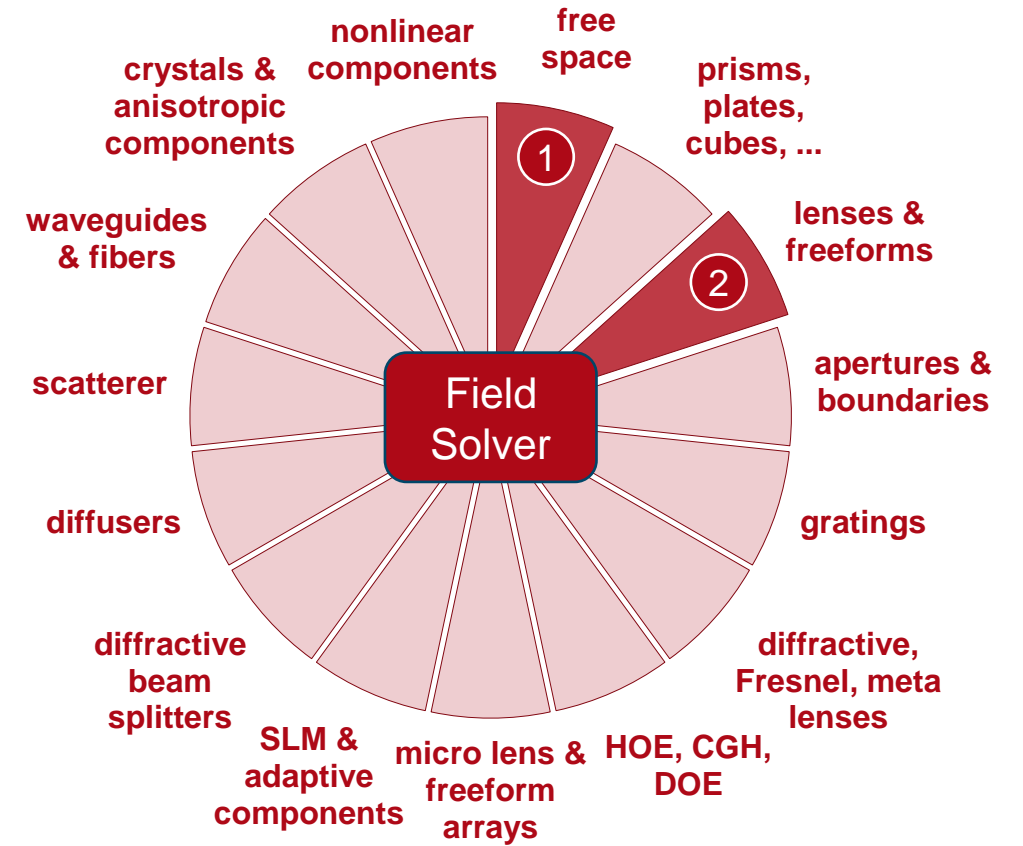
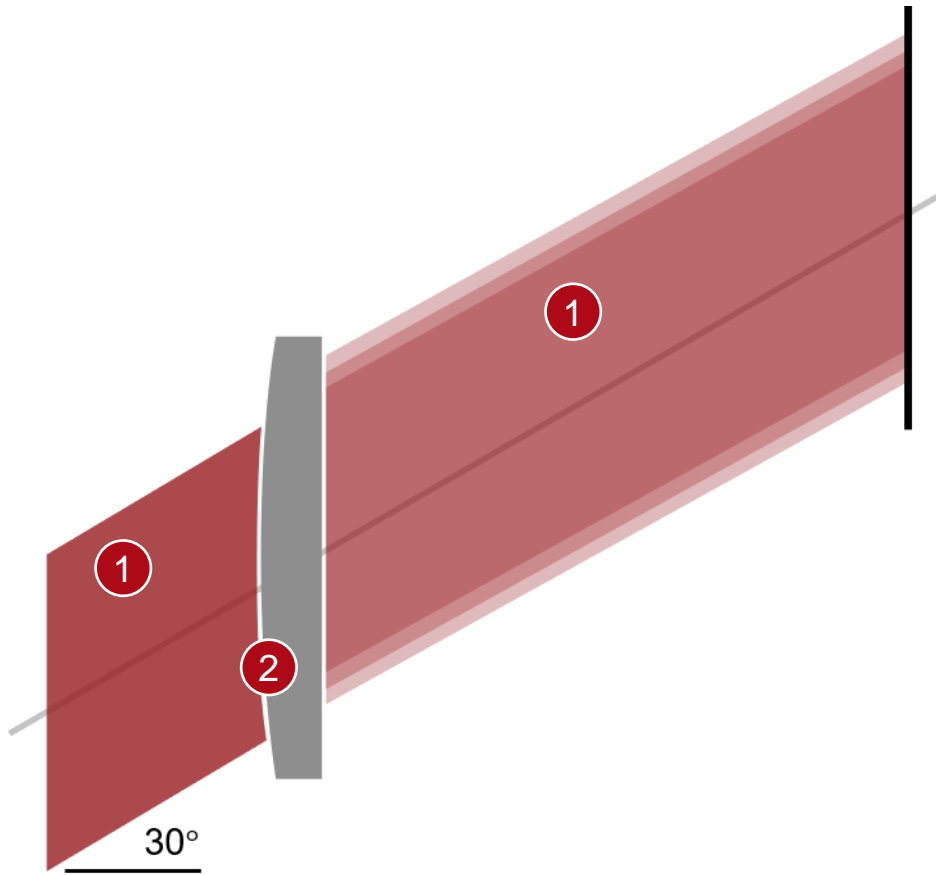


# Spherical-Planar Surfaces



Non-sequential field tracing  
simulation of etalons allows  
the consideration of arbitrary  
surface types.

# VirtualLab Fusion Technologies

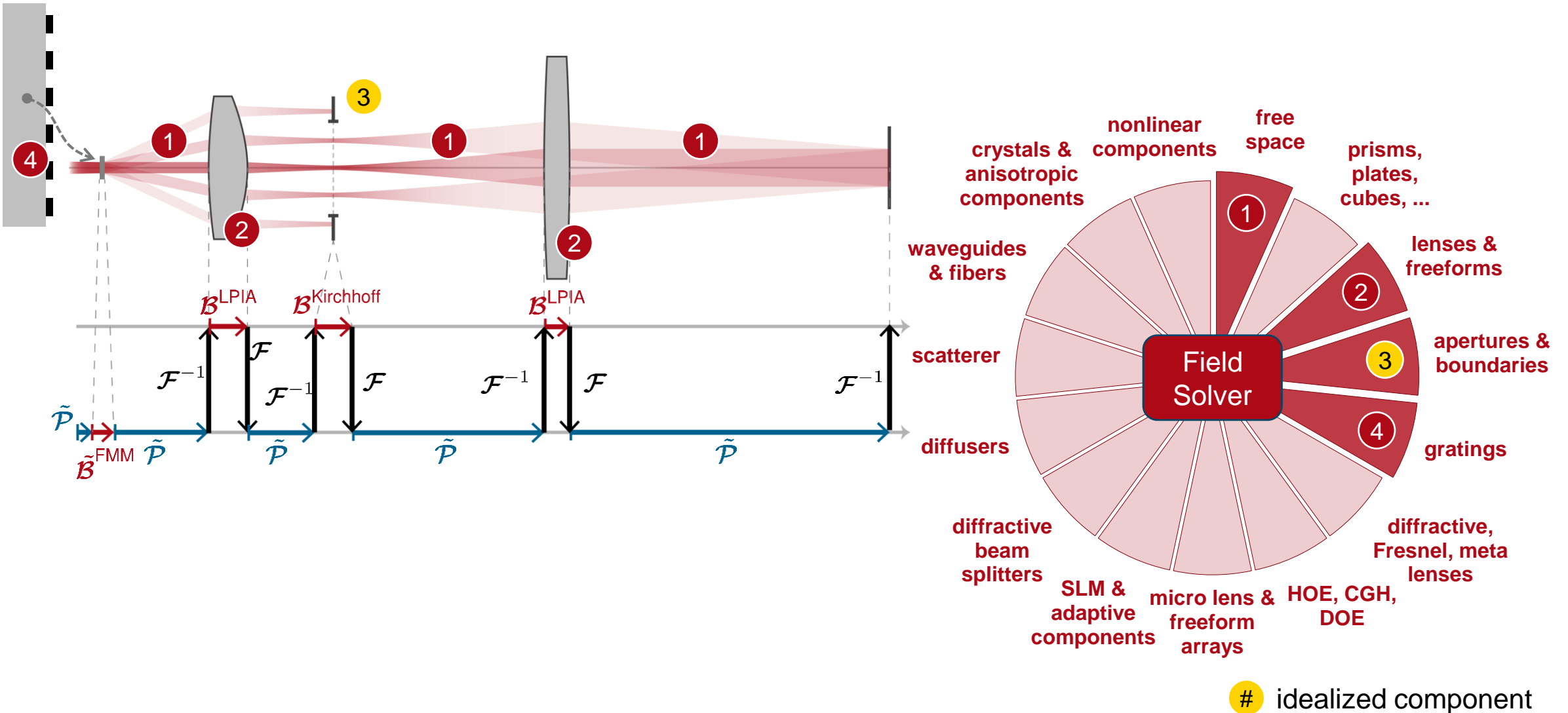


Part 3

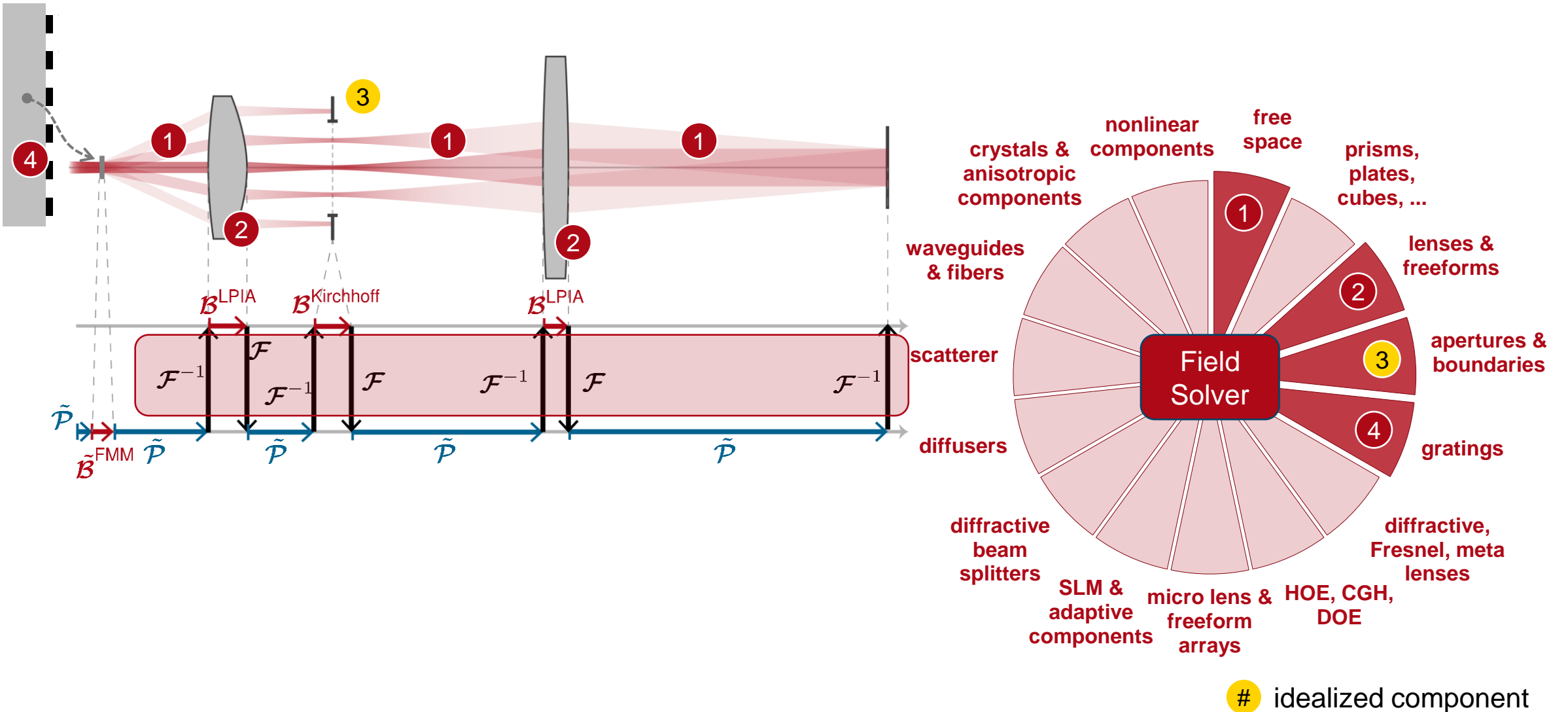
# The Fourier Transform



# Field Tracing Diagram

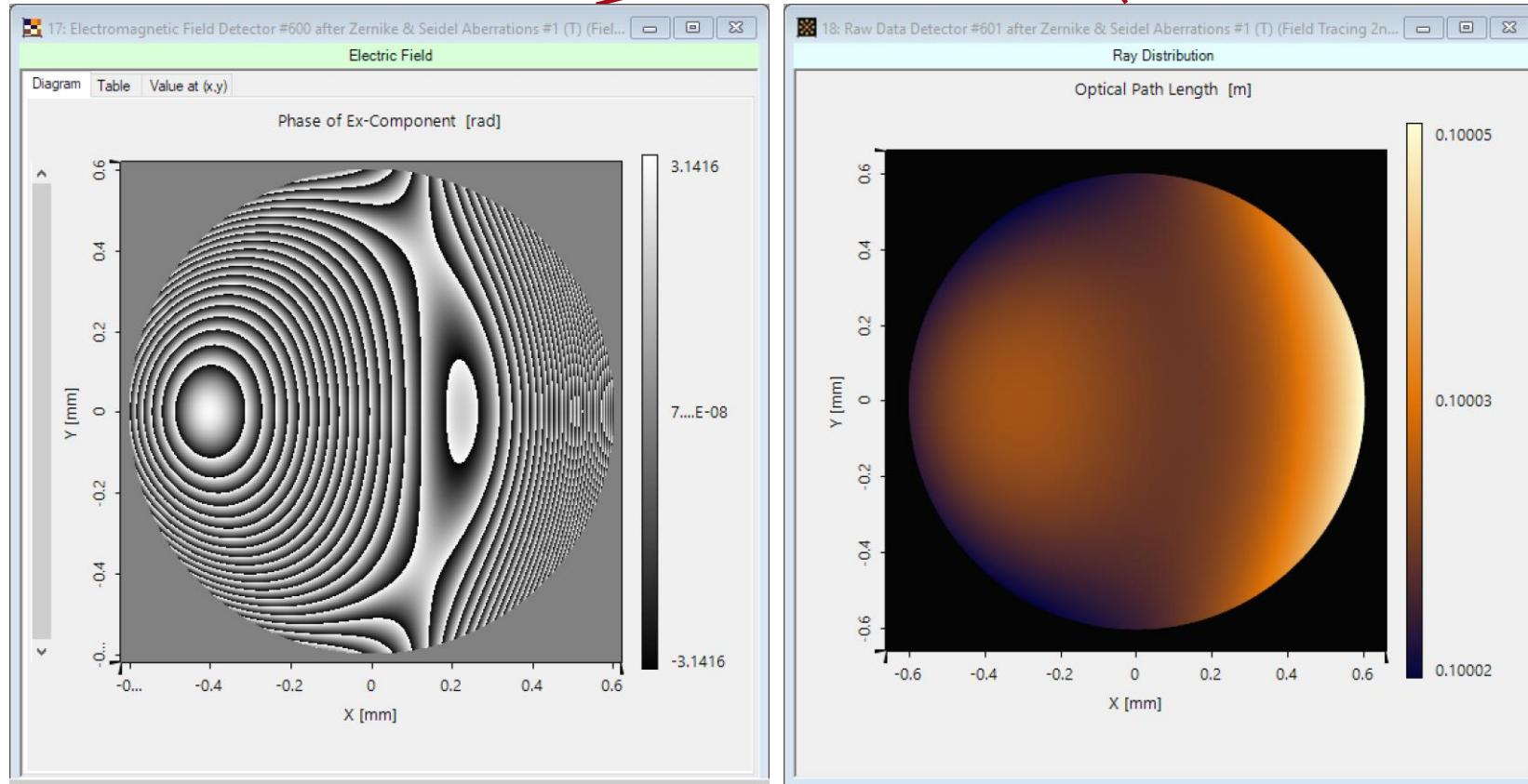


# Field Tracing Diagram



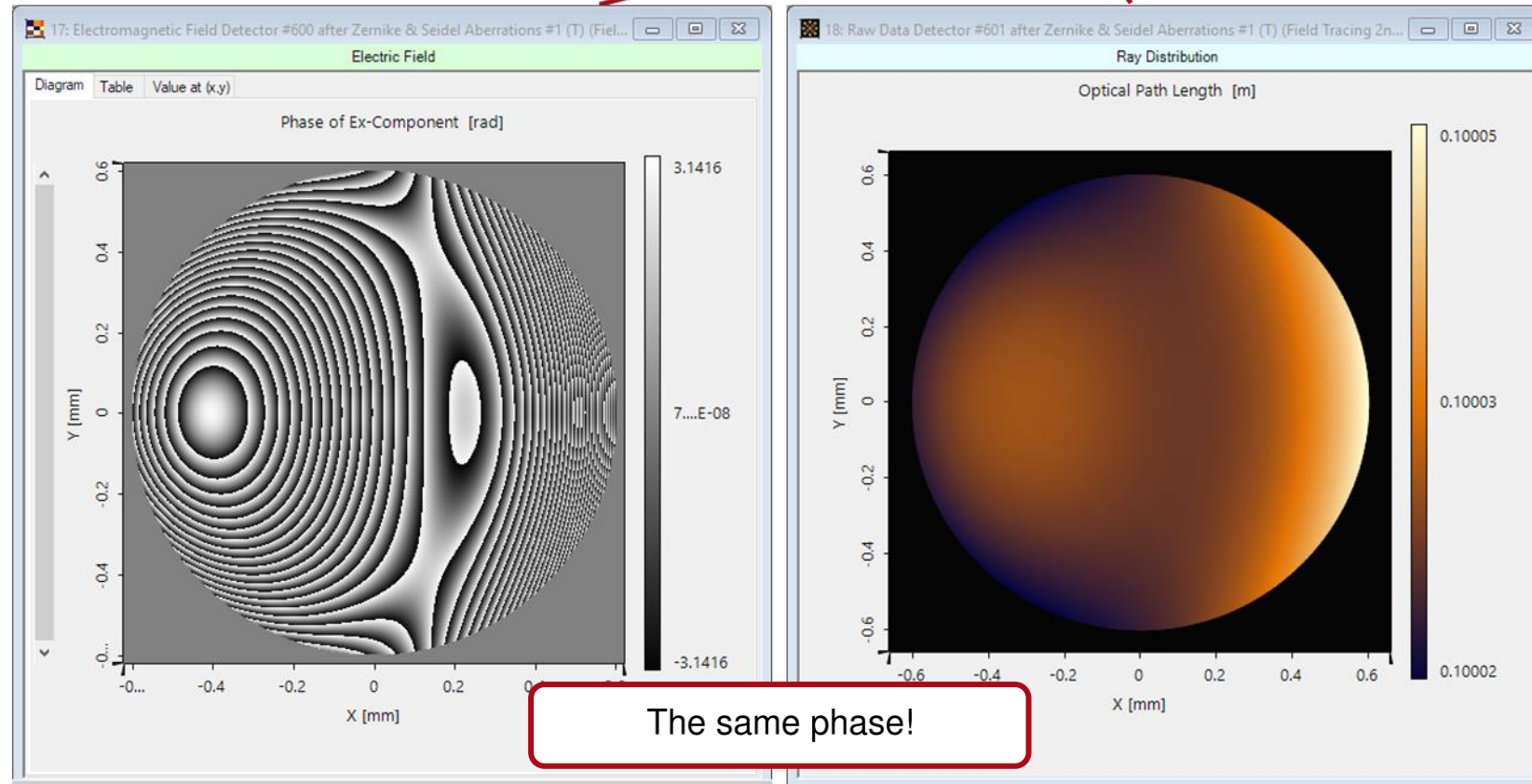
# Fourier-Transforming an Arbitrary Field

$$V_\ell(\rho, z, \omega) = |V_\ell(\rho, z, \omega)| \exp(i\phi_\ell(\rho, z, \omega)) \exp(i\psi(\rho, z, \omega))$$



# Fourier-Transforming an Arbitrary Field

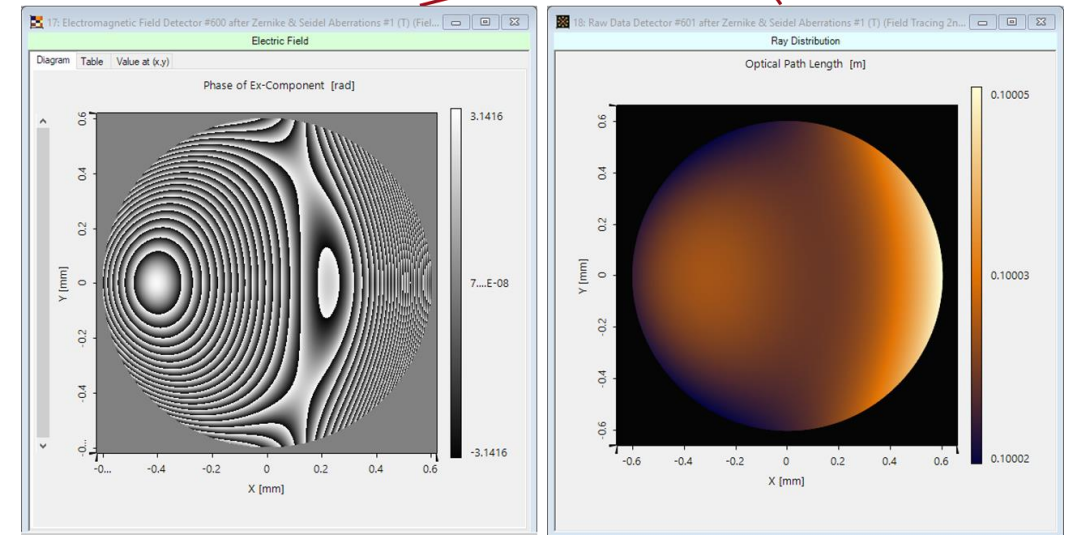
$$V_\ell(\rho, z, \omega) = |V_\ell(\rho, z, \omega)| \exp(i\phi_\ell(\rho, z, \omega)) \exp(i\psi(\rho, z, \omega))$$





# Fourier-Transforming an Arbitrary Field

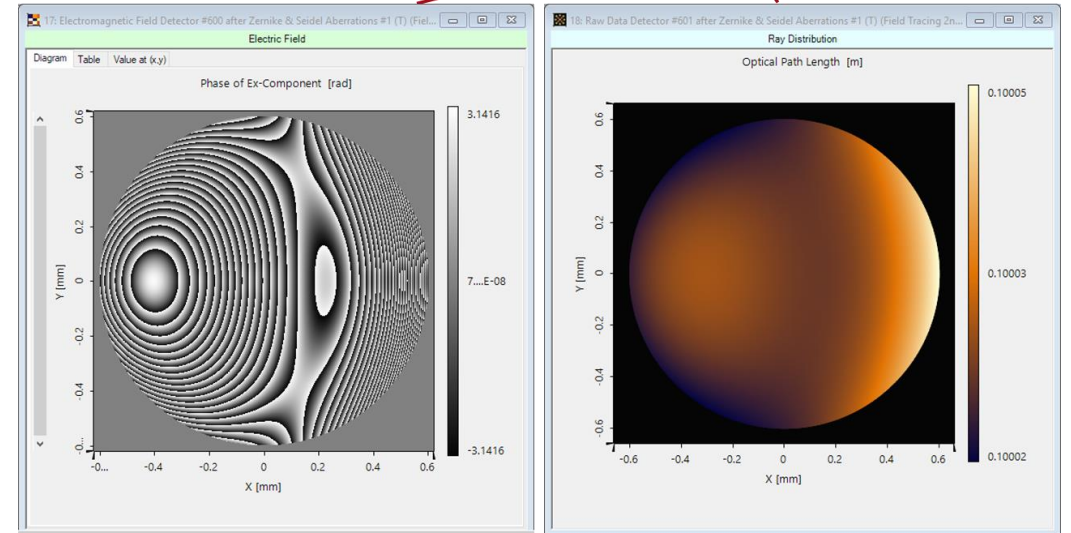
$$V_\ell(\boldsymbol{\rho}, z, \omega) = |V_\ell(\boldsymbol{\rho}, z, \omega)| \exp(i\varphi_\ell(\boldsymbol{\rho}, z, \omega)) \exp(i\psi(\boldsymbol{\rho}, z, \omega))$$



# Fourier-Transforming an Arbitrary Field

- Direct discretization of Fourier integral  $\rightarrow$  DFT (Discrete Fourier Transform): numerical complexity  $\sim N^2$

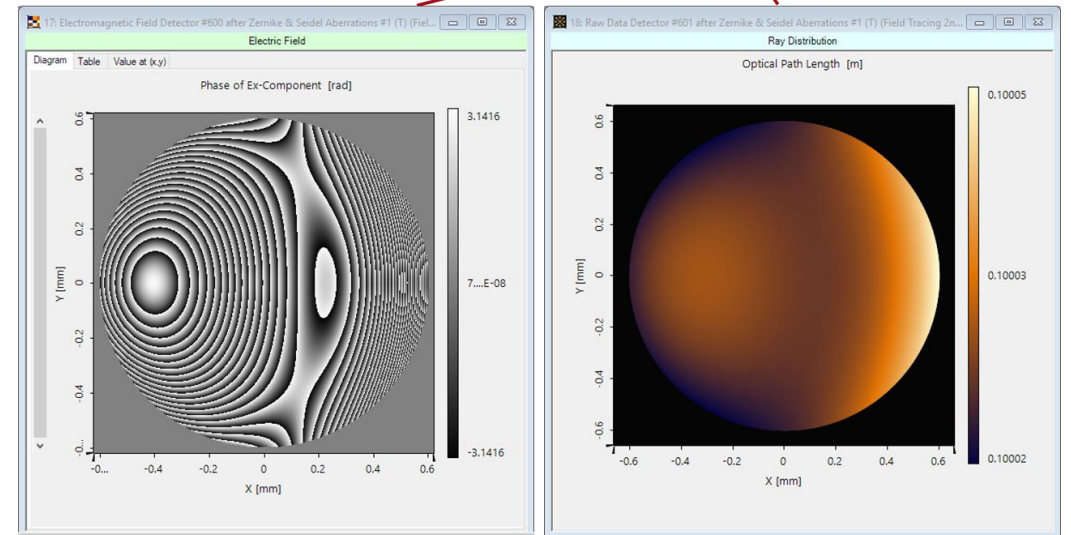
$$V_\ell(\boldsymbol{\rho}, z, \omega) = |V_\ell(\boldsymbol{\rho}, z, \omega)| \exp(i\varphi_\ell(\boldsymbol{\rho}, z, \omega)) \exp(i\psi(\boldsymbol{\rho}, z, \omega))$$



# Fourier-Transforming an Arbitrary Field

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- Numerical trick in Fast Fourier Transform (FFT) brings down computational effort to  $\sim N \log N \rightarrow \sim N$

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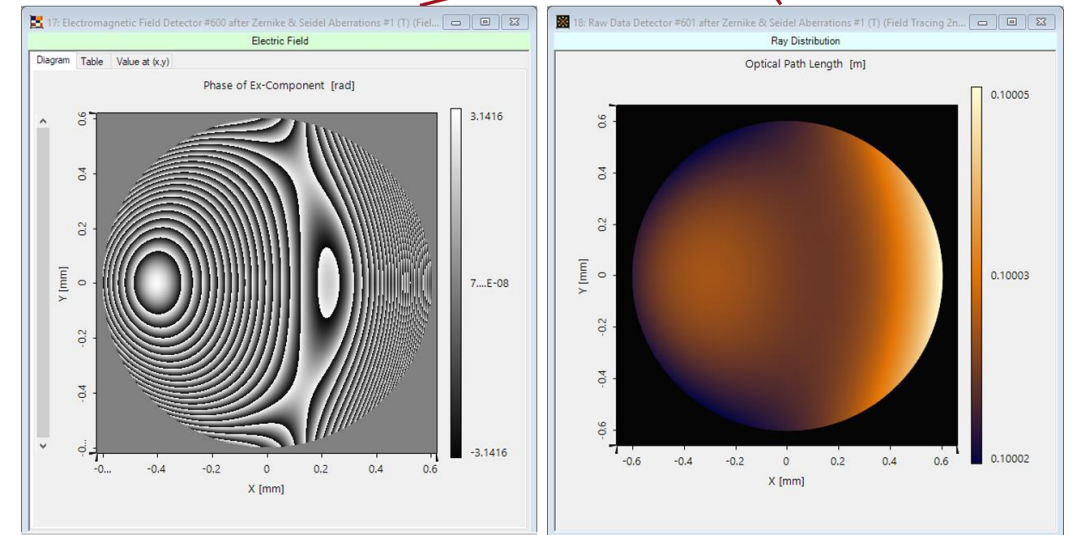


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This already means **pointwise** operation, right?  
Job done! ✓

$$V_\ell(\boldsymbol{\rho}, z, \omega) = |V_\ell(\boldsymbol{\rho}, z, \omega)| \exp(i\varphi_\ell(\boldsymbol{\rho}, z, \omega)) \exp(i\psi(\boldsymbol{\rho}, z, \omega))$$

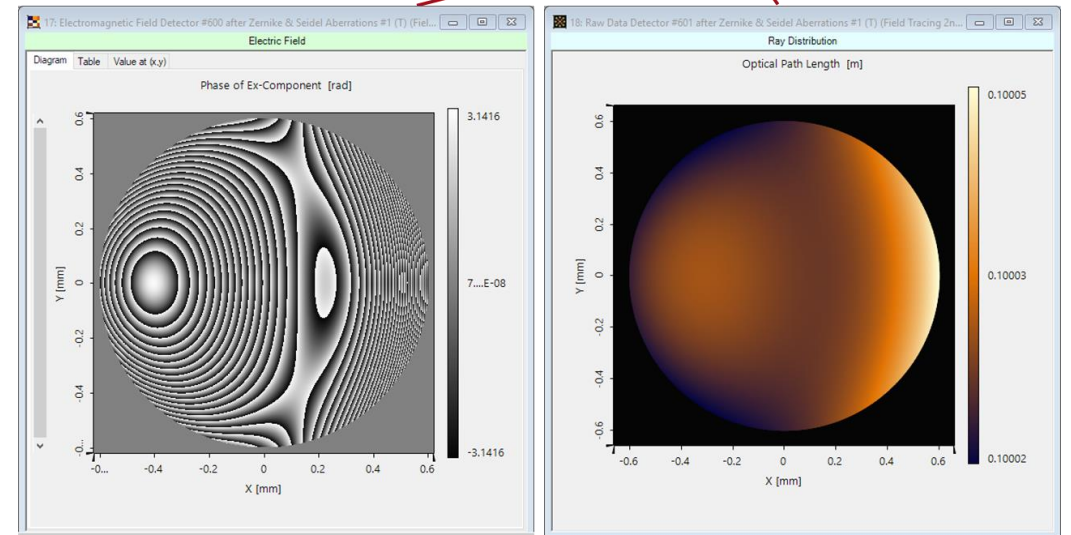


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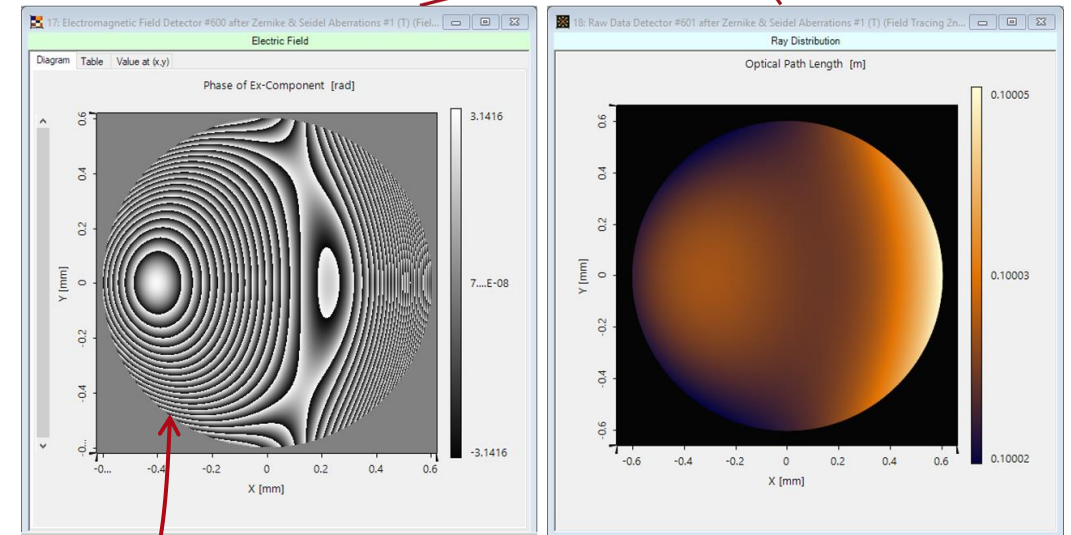
# Fourier-Transforming an Arbitrary Field

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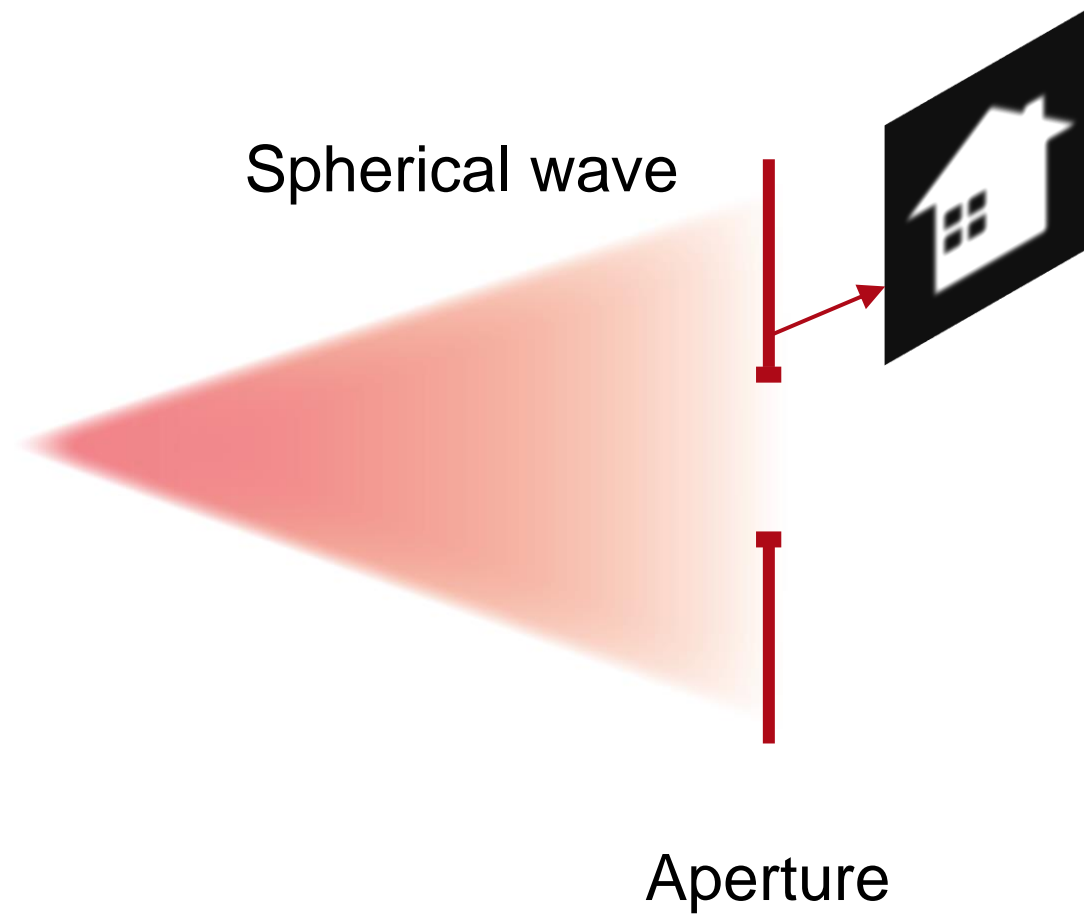
$$V_\ell(\boldsymbol{\rho}, z, \omega) = |V_\ell(\boldsymbol{\rho}, z, \omega)| \exp(i\varphi_\ell(\boldsymbol{\rho}, z, \omega)) \exp(i\psi(\boldsymbol{\rho}, z, \omega))$$

The FFT requires fulfilment of the Nyquist-Shannon sampling theorem  $\Rightarrow$  wrapped phase **must** be well resolved!

$\Downarrow$   
**Huge sample number  $N$**



# Modeling the Propagation Through an Aperture

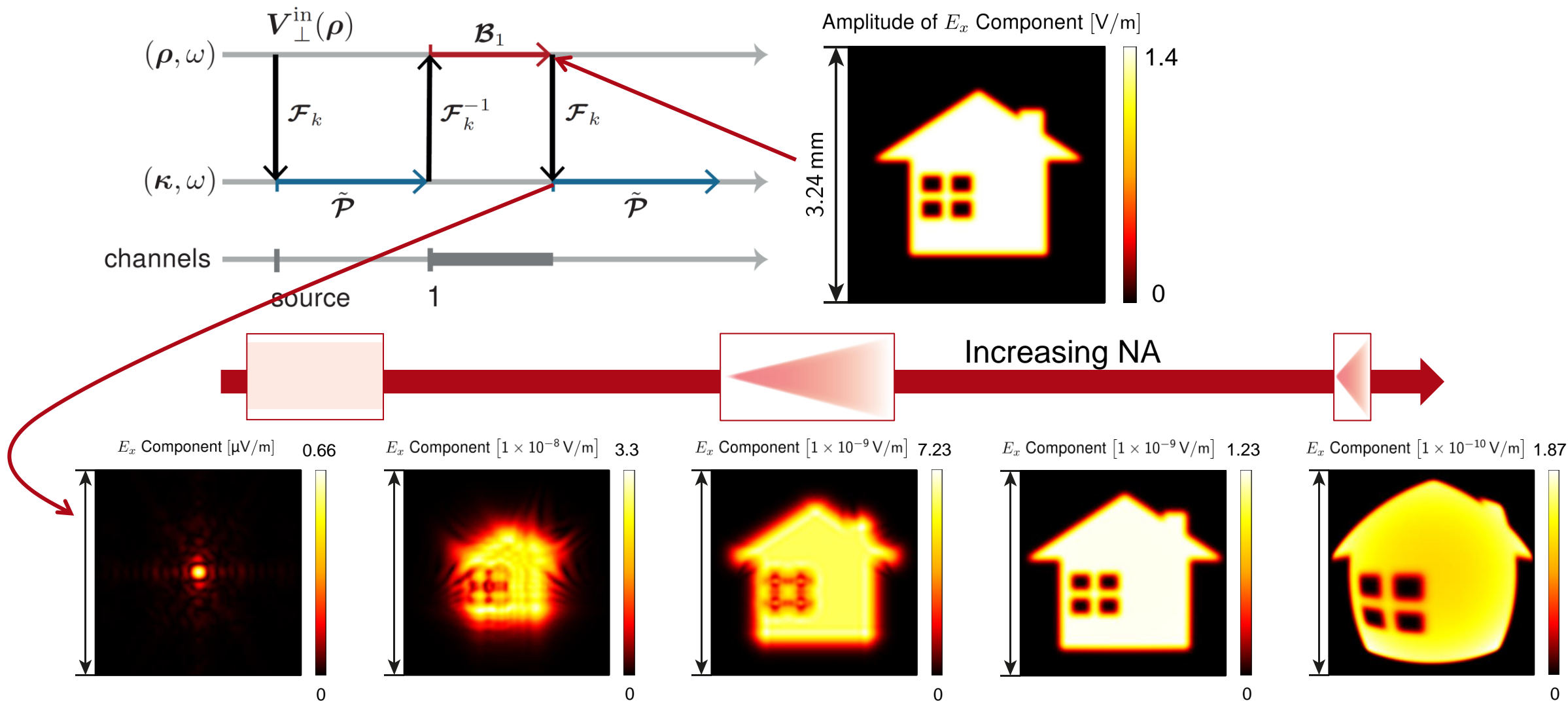


## Field after the aperture

Amplitude of  $E_x$  Component [V/m]

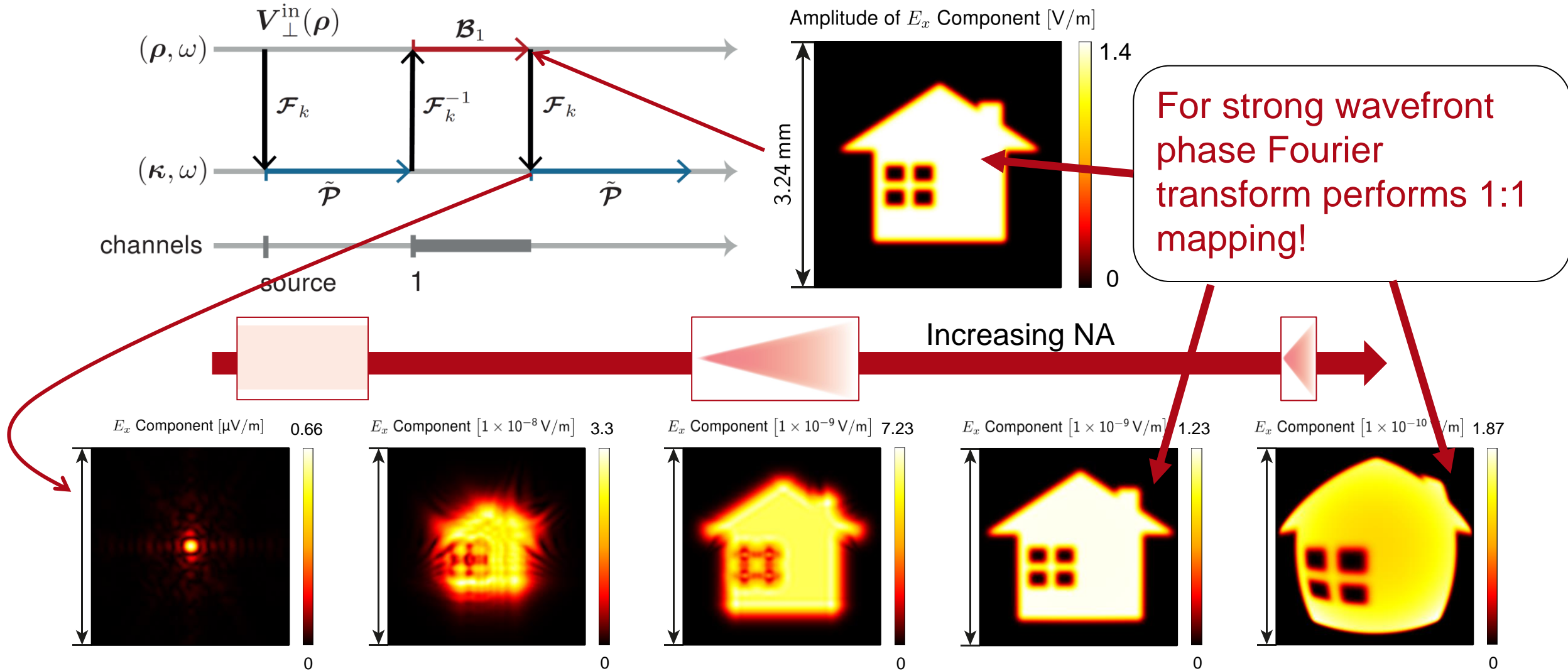


# Results of Fourier Transform

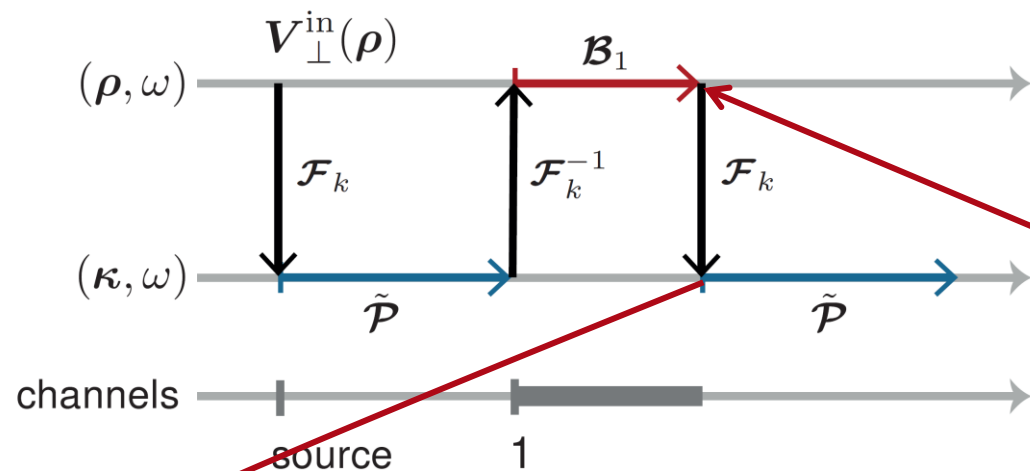




## Results of Fourier Transform



# Results of Fourier Transform

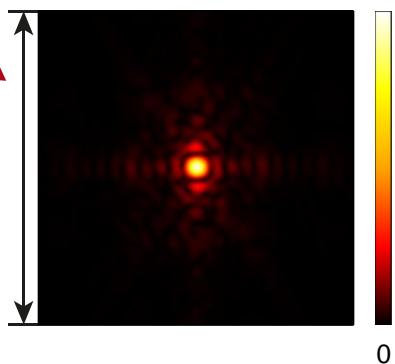


Amplitude of  $E_x$  Component [V/m]

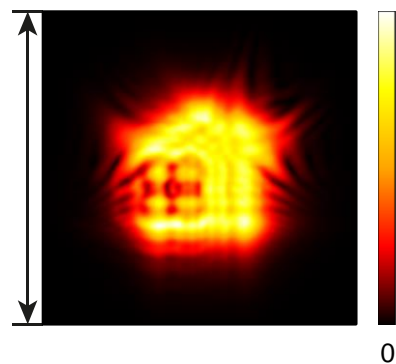


Increasing NA

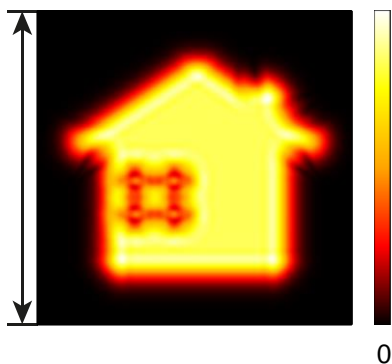
$E_x$  Component [ $\mu\text{V/m}$ ] 0.66



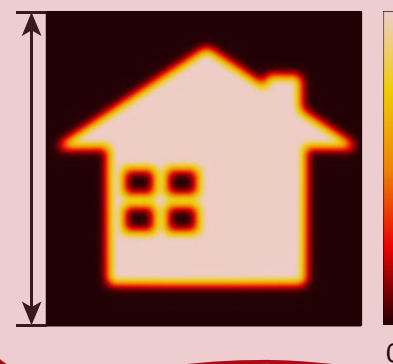
$E_x$  Component [ $1 \times 10^{-8} \text{ V/m}$ ] 3.3



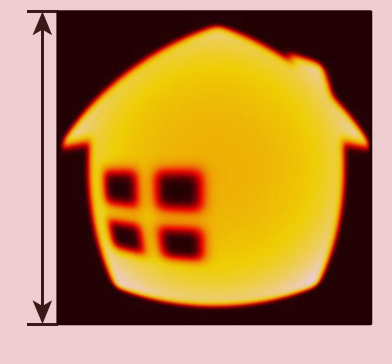
$E_x$  Component [ $1 \times 10^{-9} \text{ V/m}$ ] 7.23



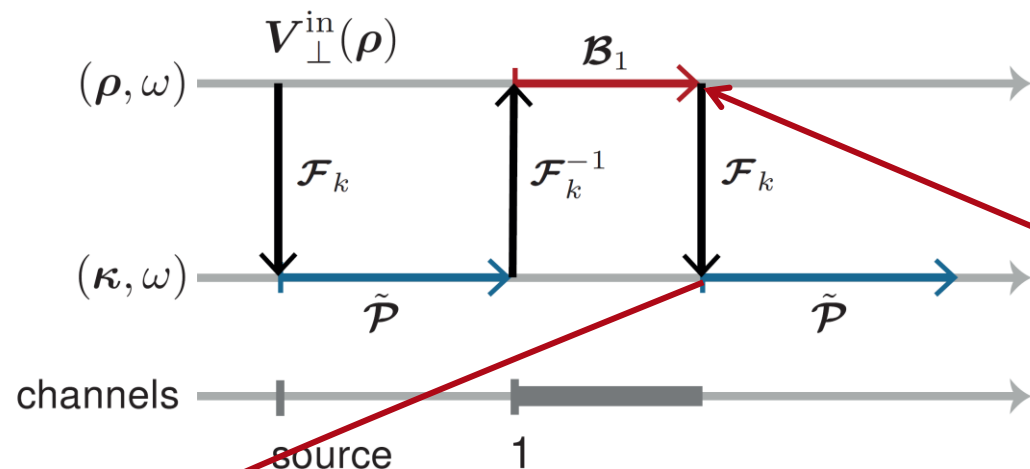
$E_x$  Component [ $1 \times 10^{-9} \text{ V/m}$ ] 1.23



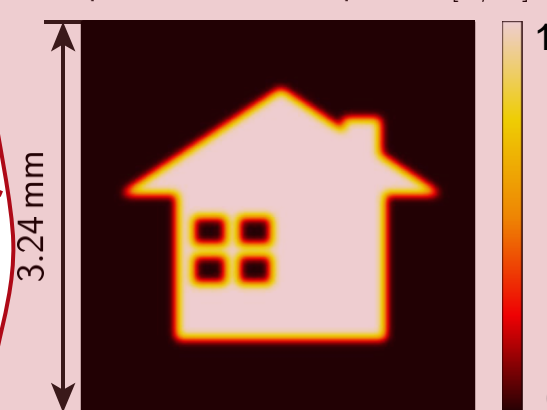
$E_x$  Component [ $1 \times 10^{-10} \text{ V/m}$ ] 1.87



# Results of Fourier Transform



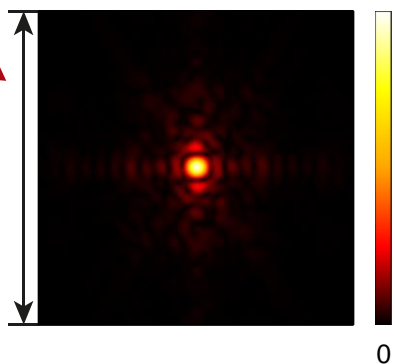
Amplitude of  $E_x$  Component [V/m]



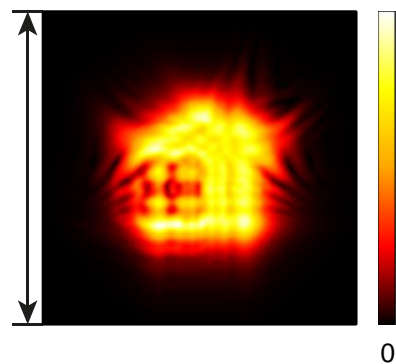
This behaviour can be used to develop an approximate algorithm to compute the Fourier transform that is **extremely accurate** when the field exhibits this behaviour, and **extremely fast**

Increasing NA

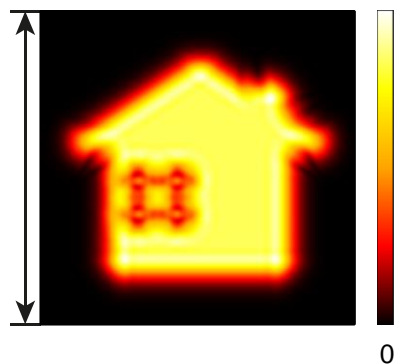
$E_x$  Component [ $\mu\text{V/m}$ ] 0.66



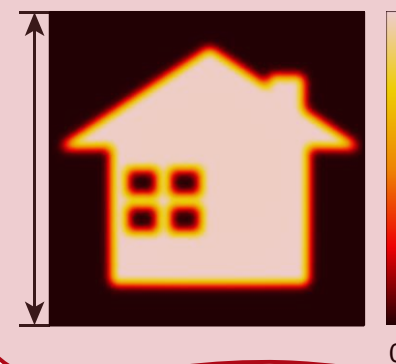
$E_x$  Component [ $1 \times 10^{-8} \text{ V/m}$ ] 3.3



$E_x$  Component [ $1 \times 10^{-9} \text{ V/m}$ ] 7.23



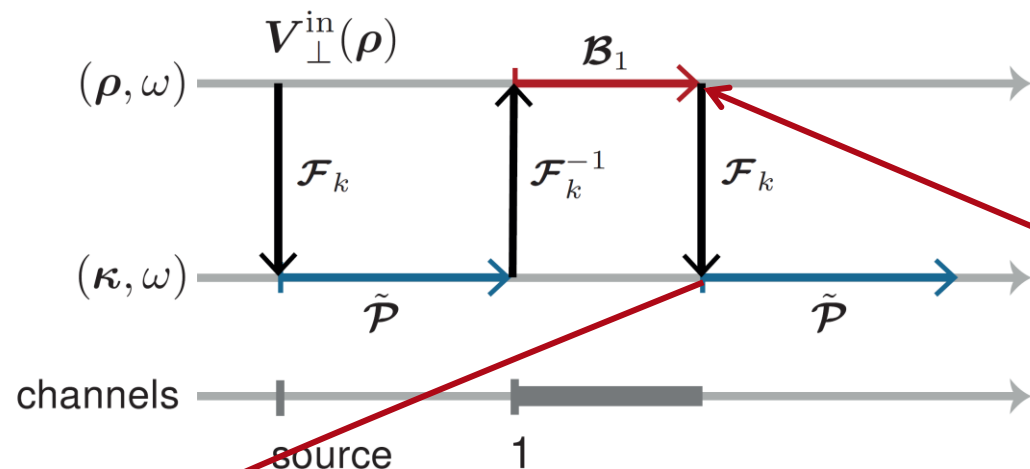
$E_x$  Component [ $1 \times 10^{-9} \text{ V/m}$ ] 1.23



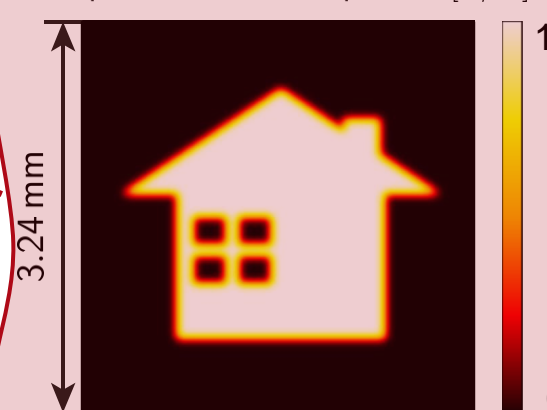
$E_x$  Component [ $1 \times 10^{-10} \text{ V/m}$ ] 1.87



# Results of Fourier Transform



Amplitude of  $E_x$  Component [V/m]

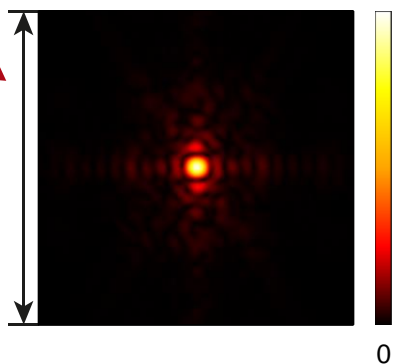


This behaviour can be used to develop an approximate algorithm to compute the Fourier transform that is **extremely accurate** when the field exhibits this behaviour, and **extremely fast**

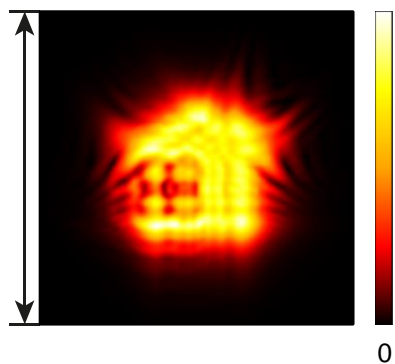
**pointwise Fourier transform**

Increasing NA

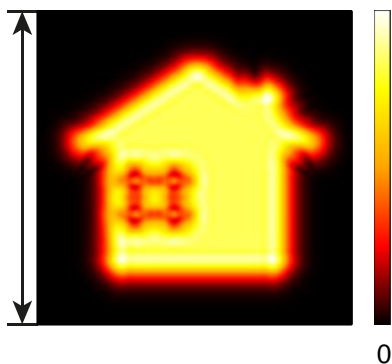
$E_x$  Component [ $\mu\text{V/m}$ ] 0.66



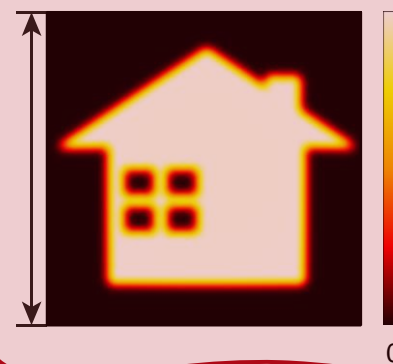
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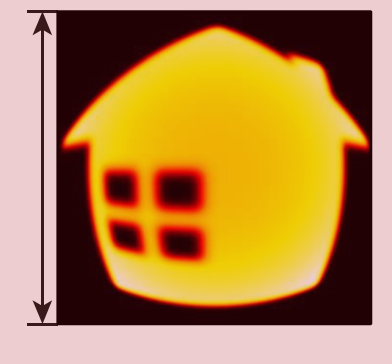
$E_x$  Component [ $1 \times 10^{-9} \text{ V/m}$ ] 7.23



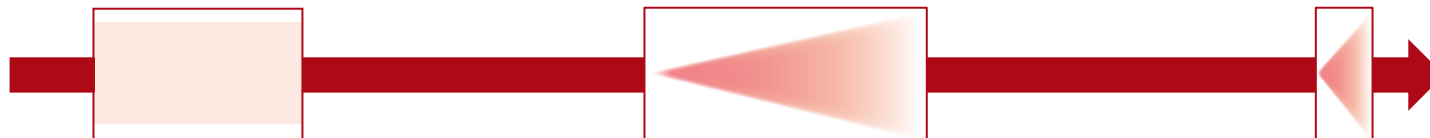
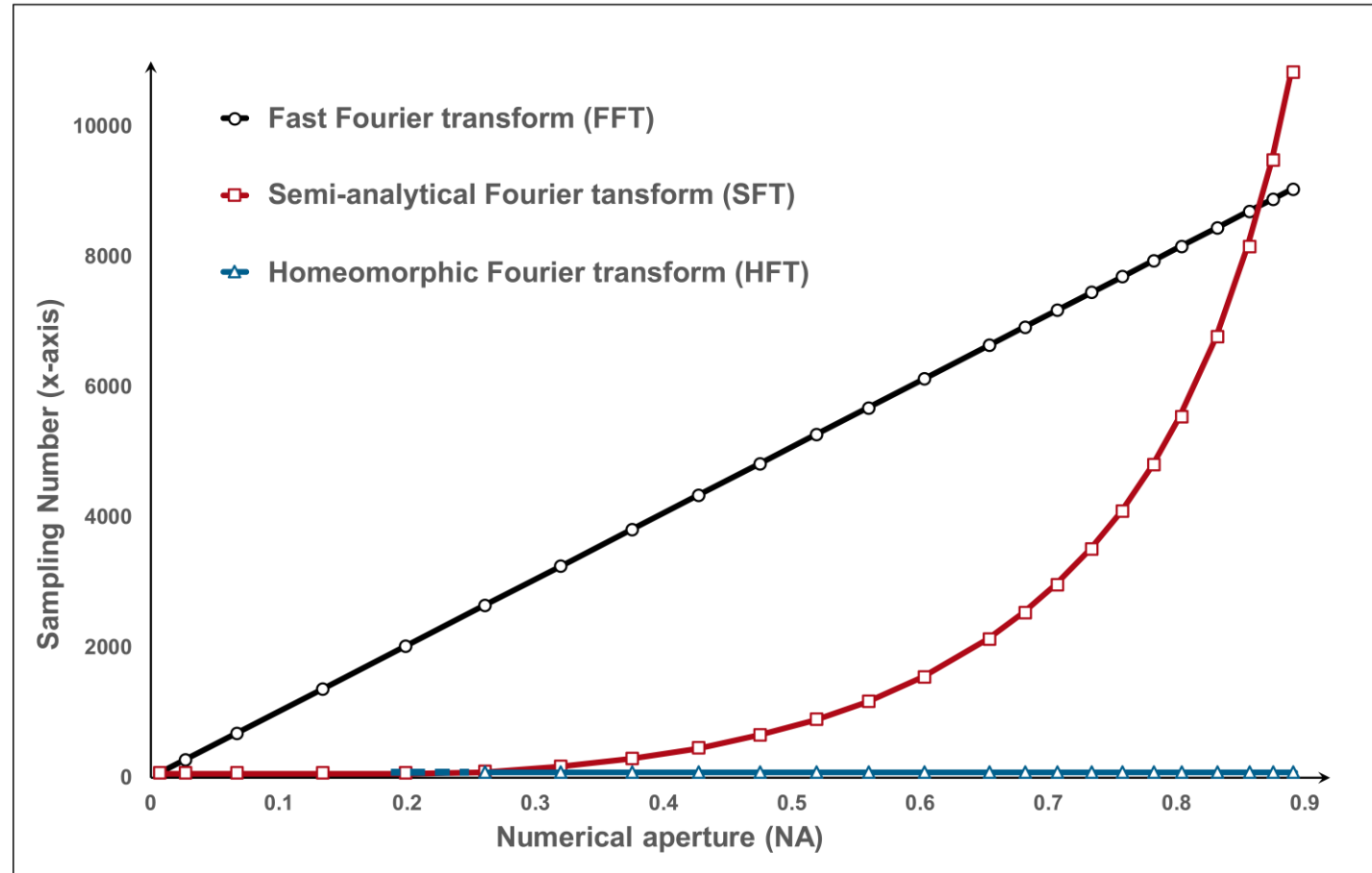
$E_x$  Component [ $1 \times 10^{-9} \text{ V/m}$ ] 1.23



$E_x$  Component [ $1 \times 10^{-10} \text{ V/m}$ ] 1.87

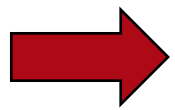


# Comparison of the Sampling Effort



# Types of Fourier Transform Algorithms in VirtualLab Fusion

- Fast Fourier Transform (FFT)
  - Fast for weak wavefront phase
- Semianalytical Fourier transform (SFT)
  - Fast for wavefront phase with medium local gradient
- Pointwise Fourier transform (HFT)
  - Accurate for strong wavefront phase



Combination of Fourier transform algorithms essential for fast physical optics!



## References to Our Fourier Transform Publications

---

- *Theory and algorithm of the homeomorphic Fourier transform for optical simulations*, Z. Wang et al, Optics Express, **28**, 7, 2020
- *Application of the semi-analytical Fourier transform to electromagnetic modeling*, Z. Wang et al, Optics Express, **27**, 11, 2019

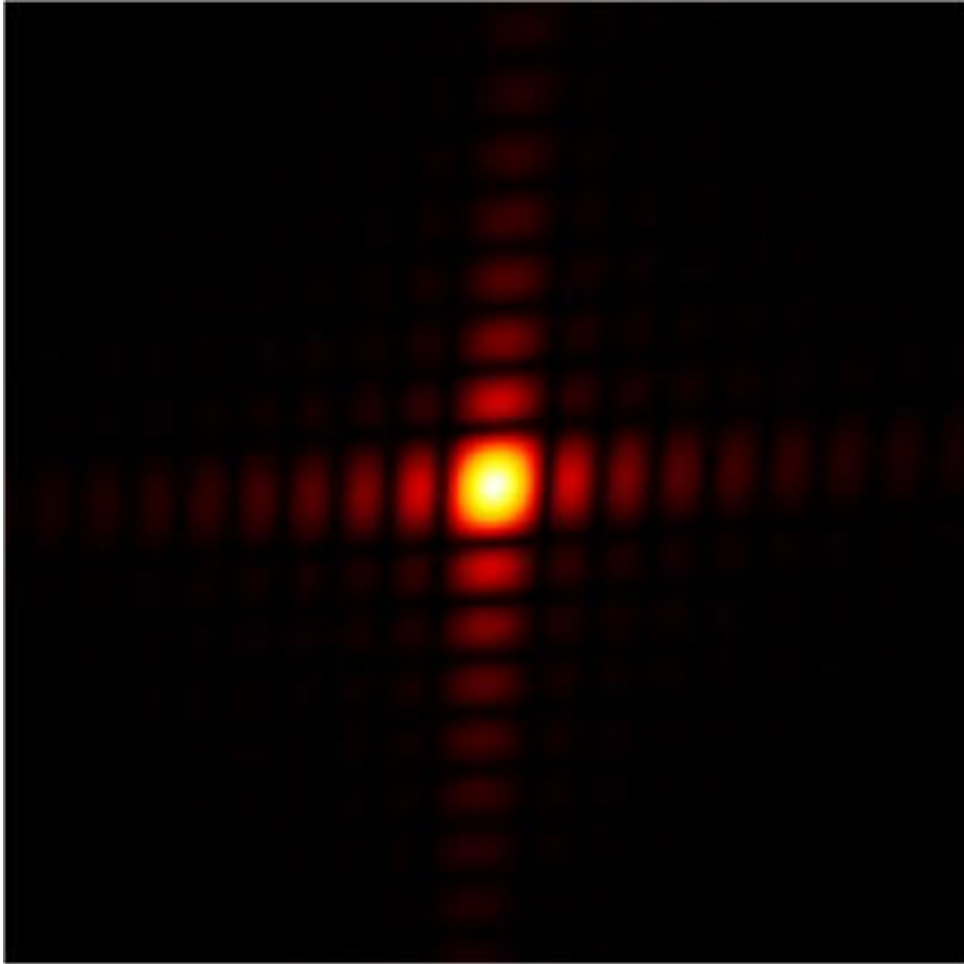
# Automatic Selection of Fourier Transform Techniques in Free-Space Propagation Operator





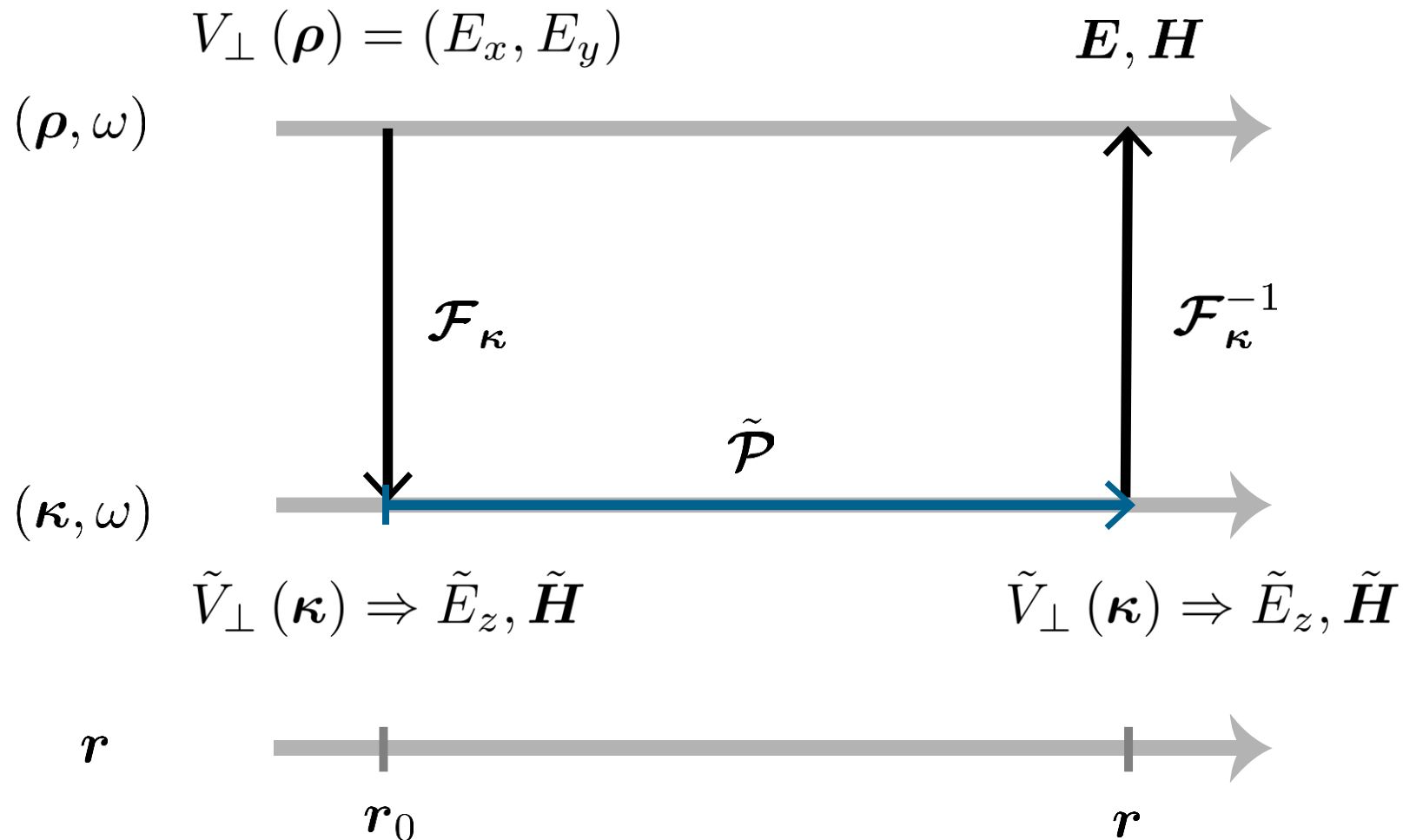
# Abstract

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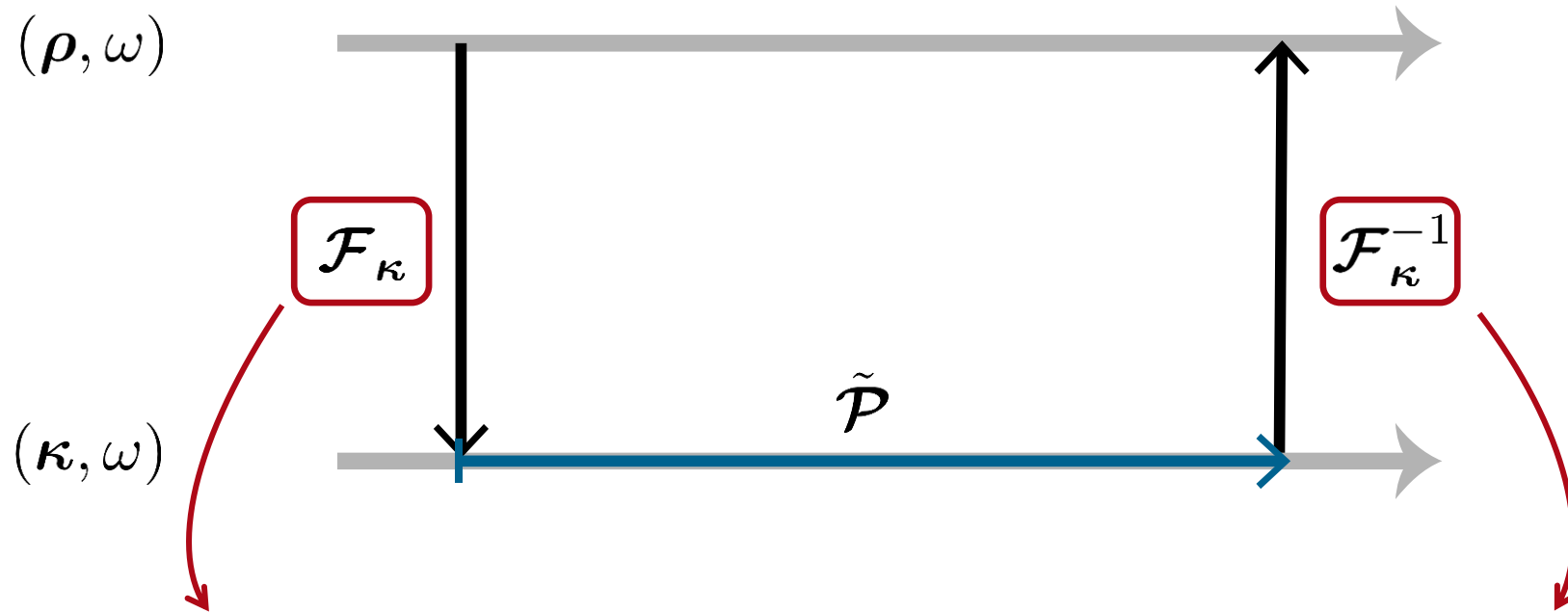
Accurate and efficient simulation of free-space propagation of electromagnetic fields is essential for physical optics modeling and design. VirtualLab Fusion has a unified free-space propagation concept. It is based on the spatial-frequency domain (k-domain) analysis. In combination with different Fourier transform techniques, it delivers numerical efficient solutions for different situations of free-space propagations. The selection of appropriate Fourier transform is automatic according to the situation.

# Concept of Free-Space Propagation Operator



- Unified propagation operator in the k-domain
- Applicable for arbitrarily oriented planes
- Switching between two domains via Fourier transform
- References
  - F. Wyrowski, "Unification of the geometric and diffractive theories of electromagnetic fields" Proc. DGaO, (2017)
  - Z. Wang *et al.*, „Application of the semi-analytical Fourier transform to electromagnetic modeling,“ Opt. Express 27, 15335-15350 (2019)

# Available Fourier Transform Techniques in VirtualLab Fusion

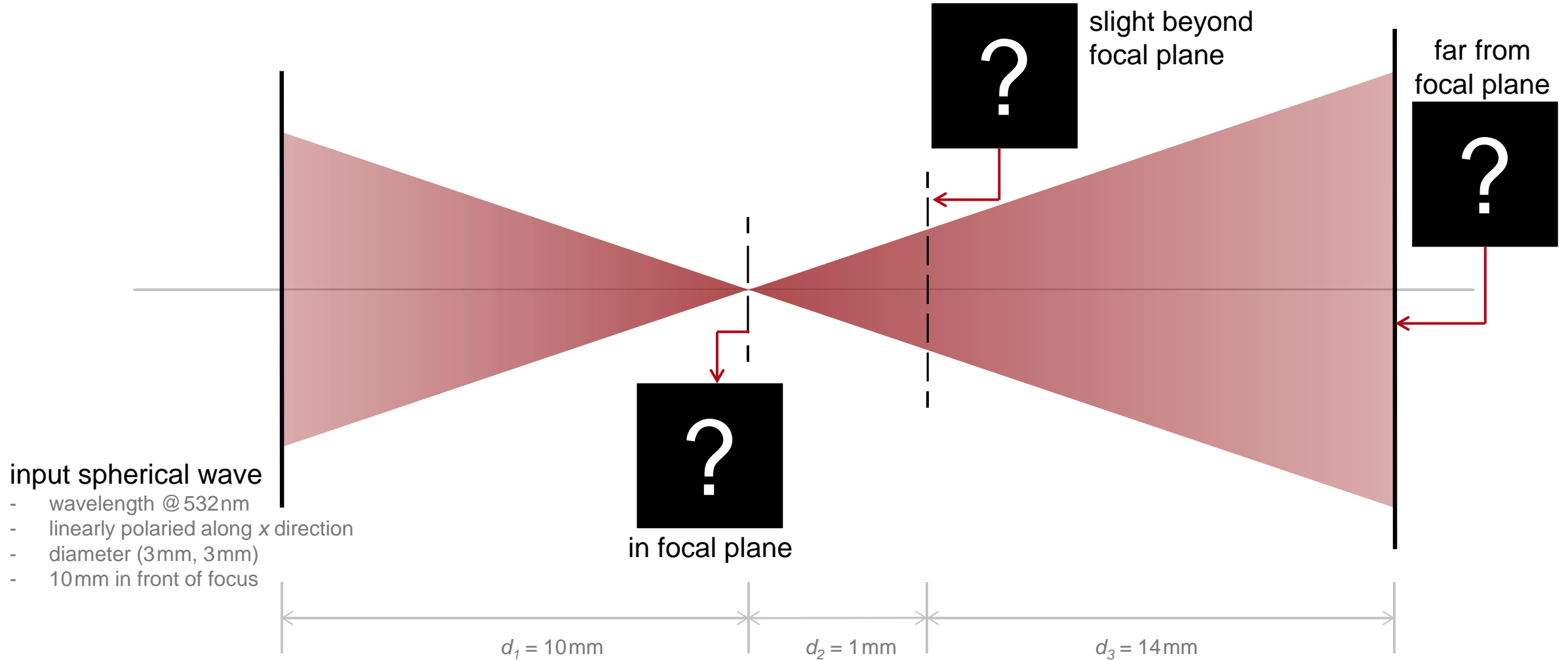


- $\mathcal{F}_\kappa$ : fast Fourier transform (FFT)
- $\mathcal{F}_\kappa^{\text{semi}}$ : semi-analytical Fourier transform (SFT)
- $\mathcal{F}_\kappa^{\text{h}}$ : homeomorphic Fourier transform (HFT)

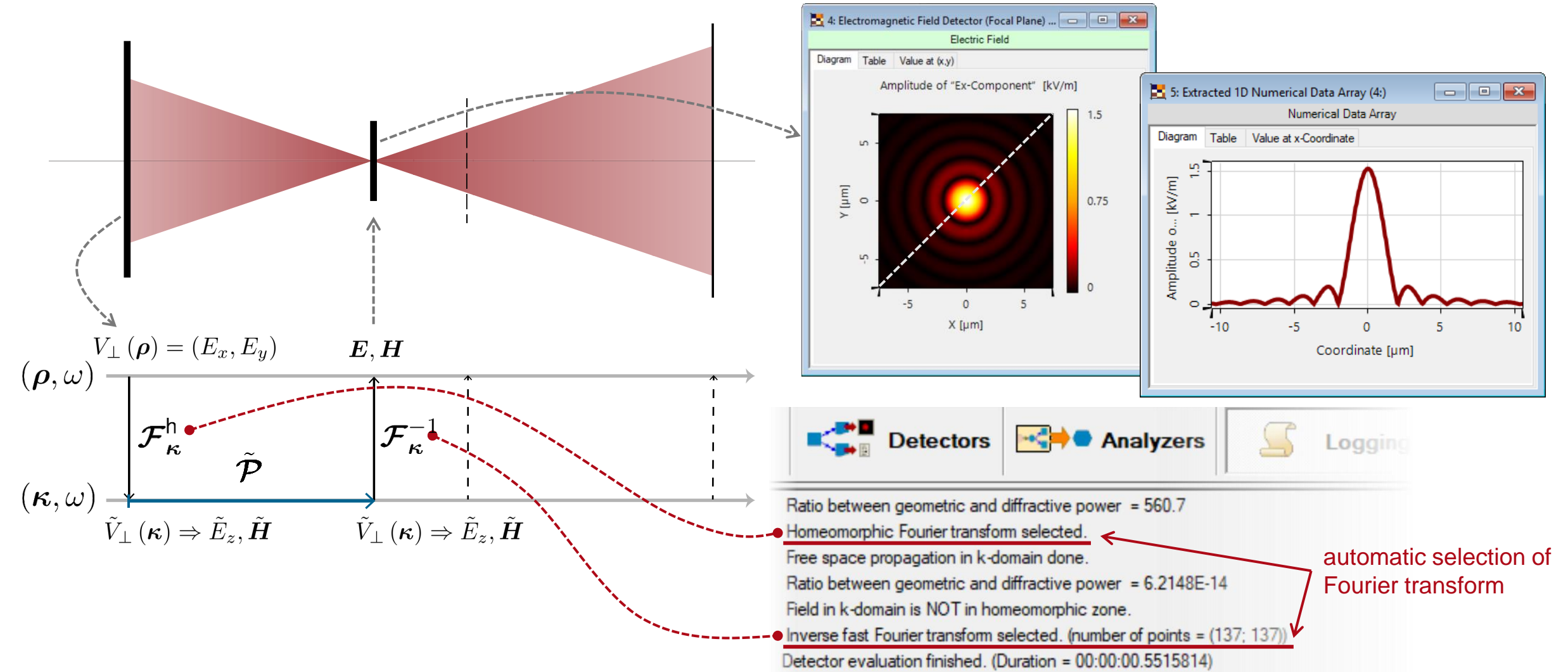
- $\mathcal{F}_\kappa^{-1}$ : inverse fast Fourier transform (IFFT)
- $\mathcal{F}_\kappa^{-1, \text{semi}}$ : inverse semi-analytical Fourier transform (ISFT)
- $\mathcal{F}_\kappa^{-1, \text{h}}$ : inverse homeomorphic Fourier transform (IHFT)

## **Example 1: Propagation of a Spherical Wave**

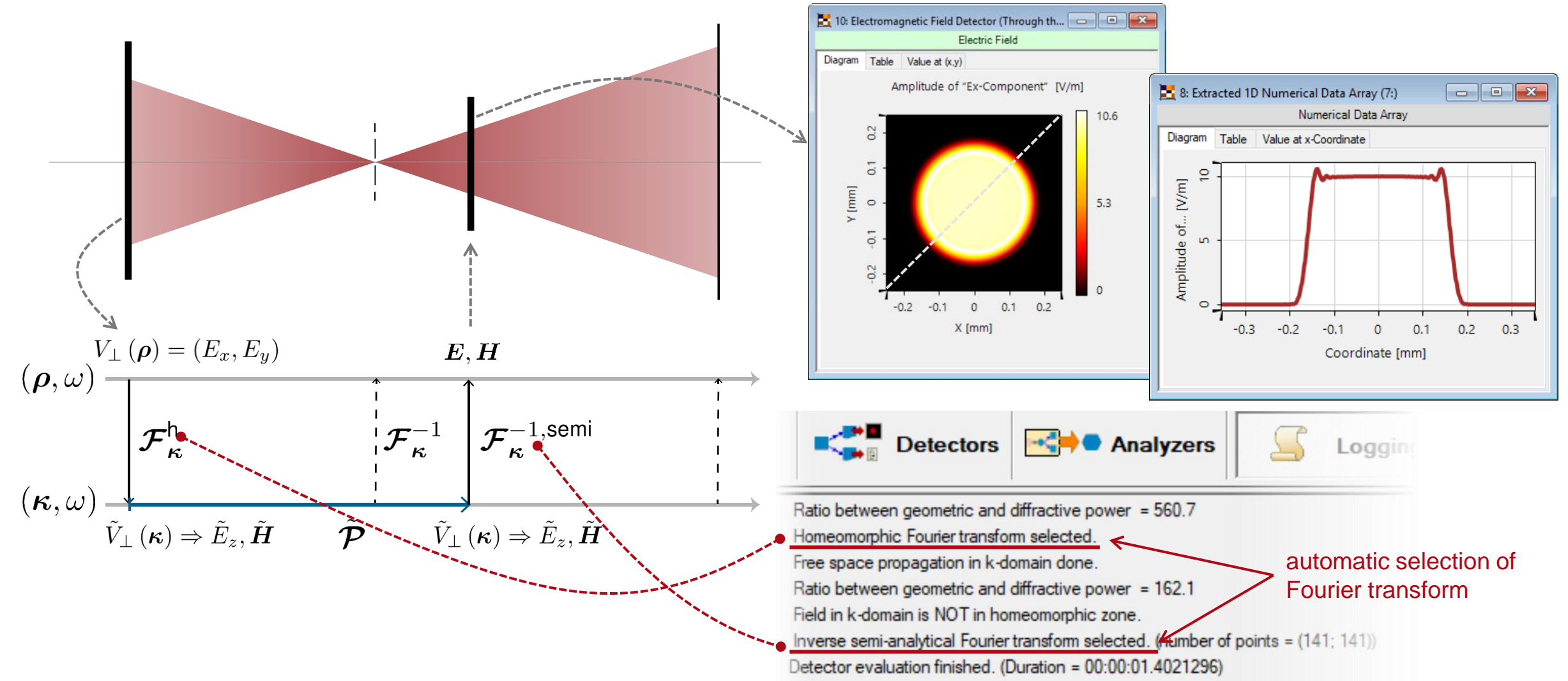
# Modeling Task



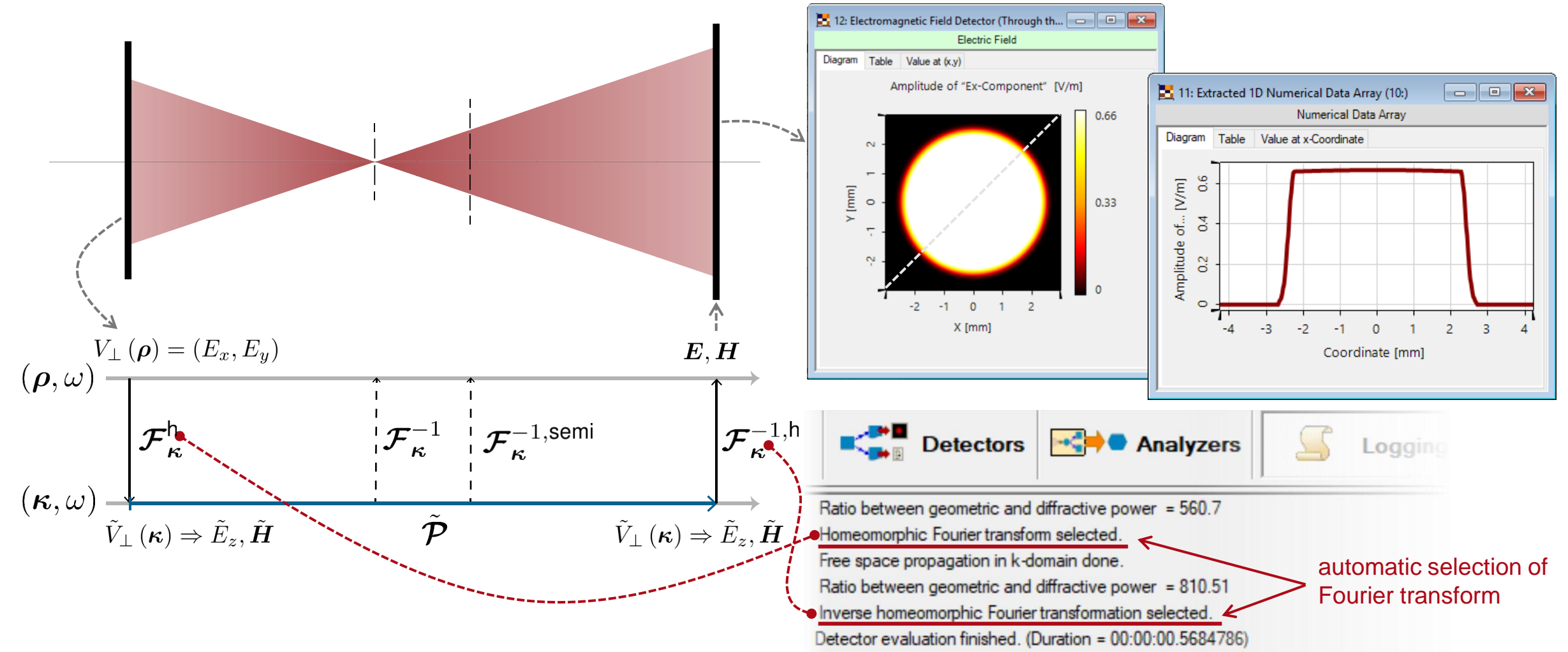
# Simulation Result: in Focal Plane



# Simulation Result: Slightly beyond Focal Plane



# Simulation Result: Far from Focal Plane



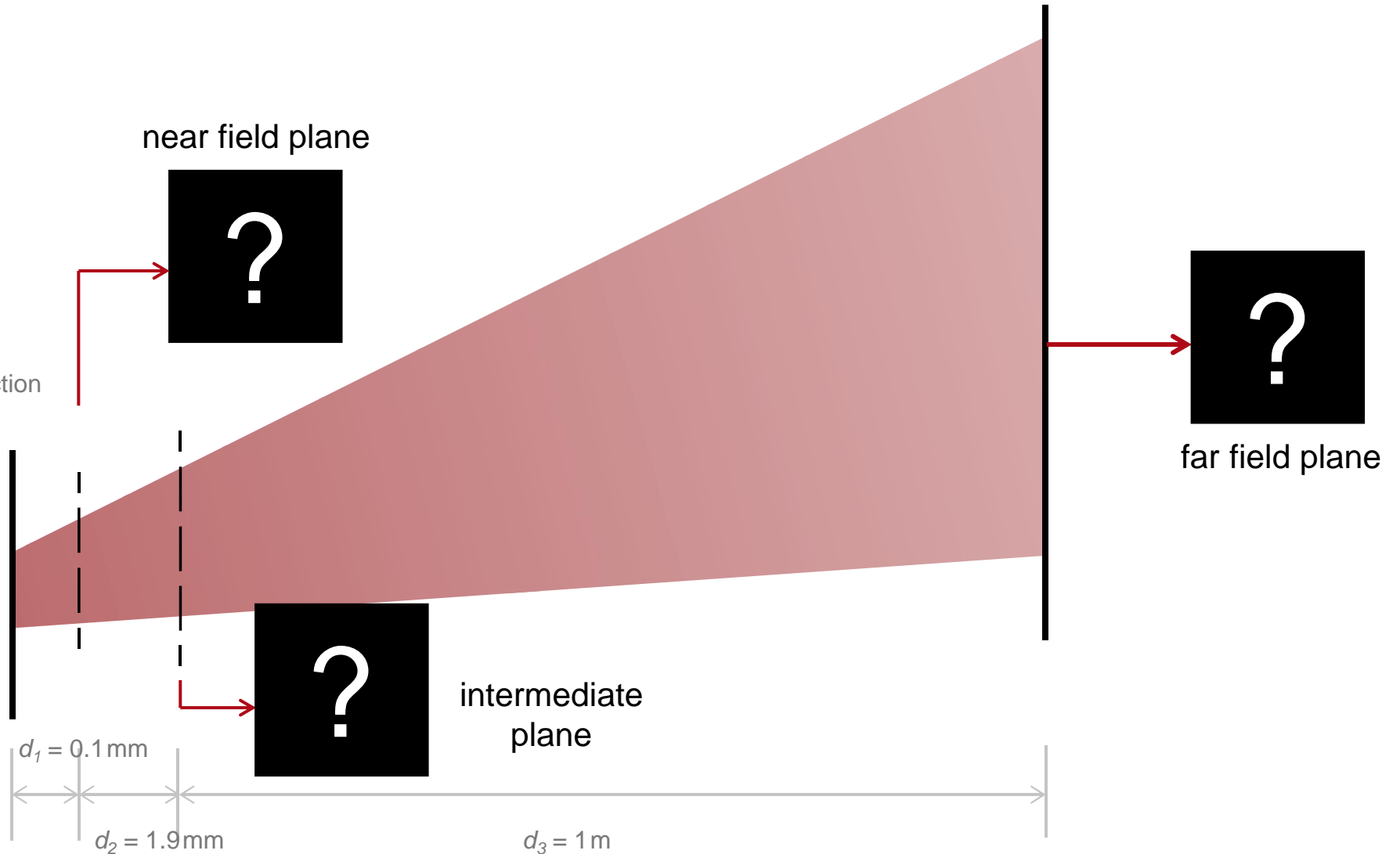


## **Example 2: Propagation of a Truncated Plane Wave**

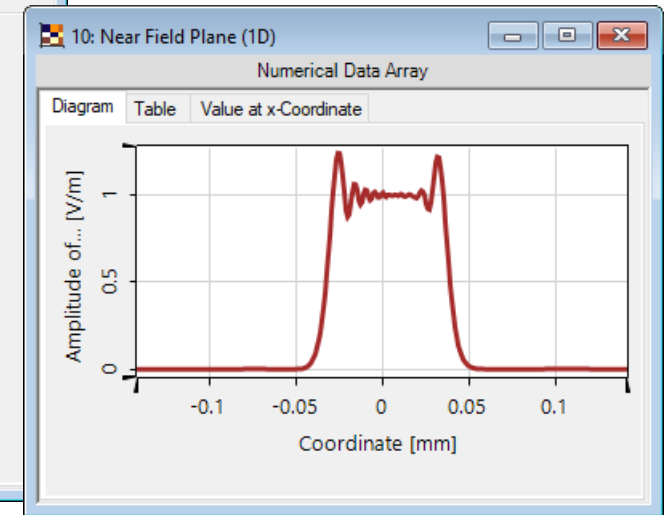
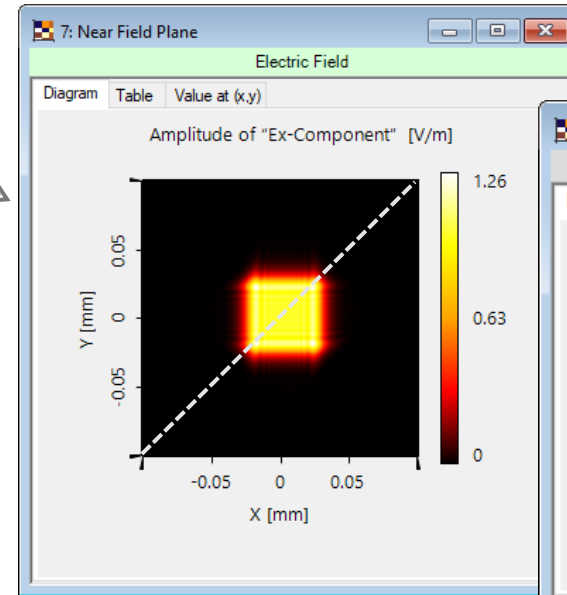
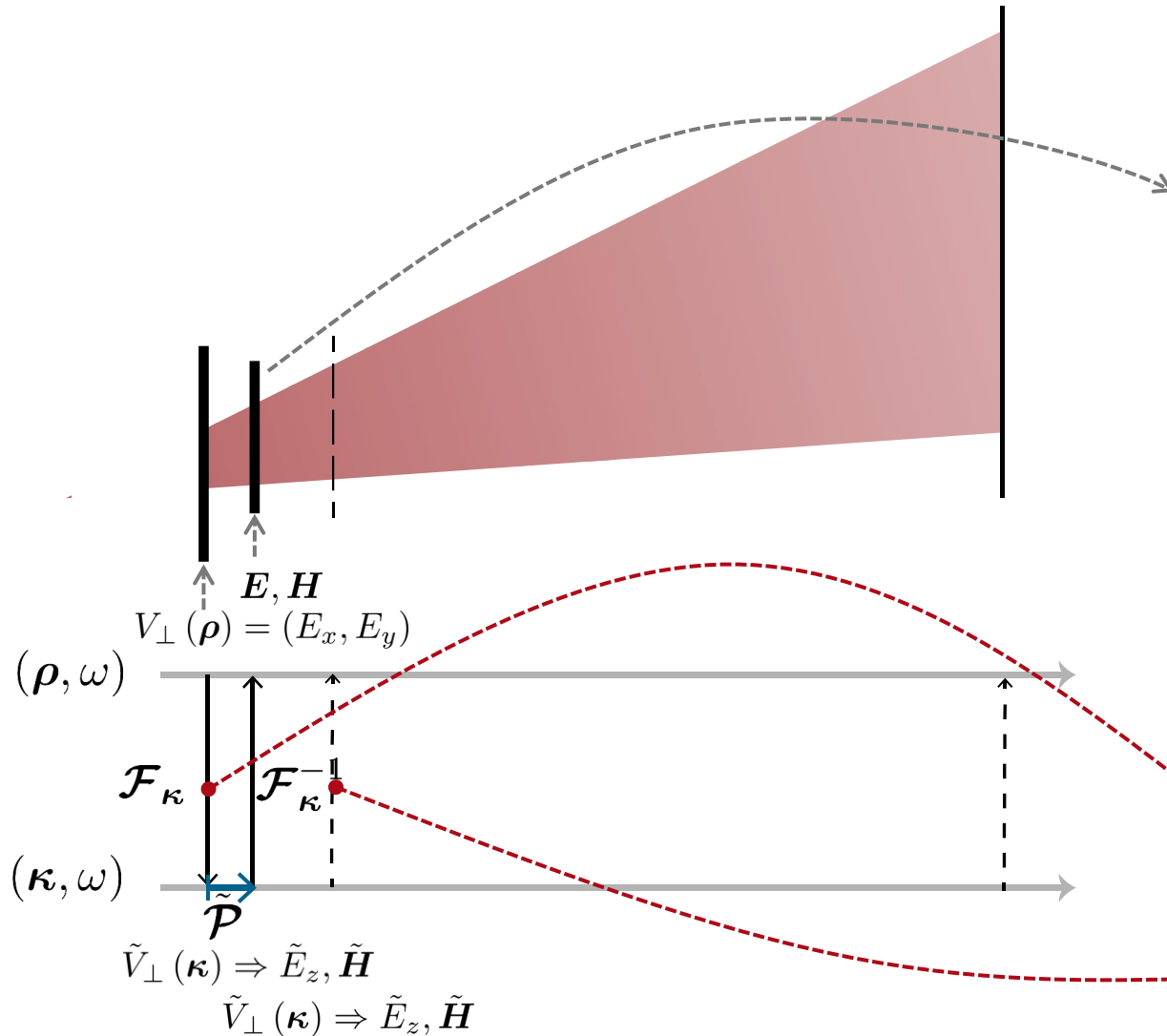
# Modeling Task

## truncated plane wave

- wavelength @ 532nm
- linearly polarized along x direction
- shape: rectangular
- diameter: (50  $\mu\text{m}$ , 50  $\mu\text{m}$ )
- inclination (10°, 20°)



# Simulation Result: Near Field Plane



Detectors Analyzers Logging

Ratio between geometric and diffractive power = 1.0774E-13

Field in x-domain is NOT in homeomorphic zone.

Fast Fourier transform selected. (number of points = (137; 137))

Free space propagation in k-domain done.

Ratio between geometric and diffractive power = 0.042497

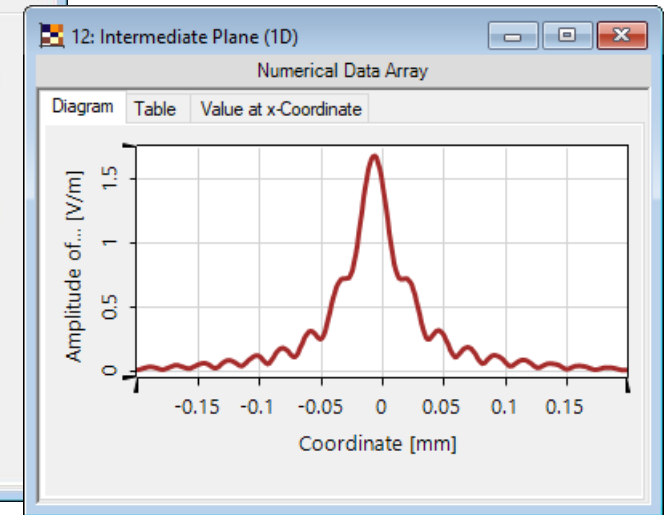
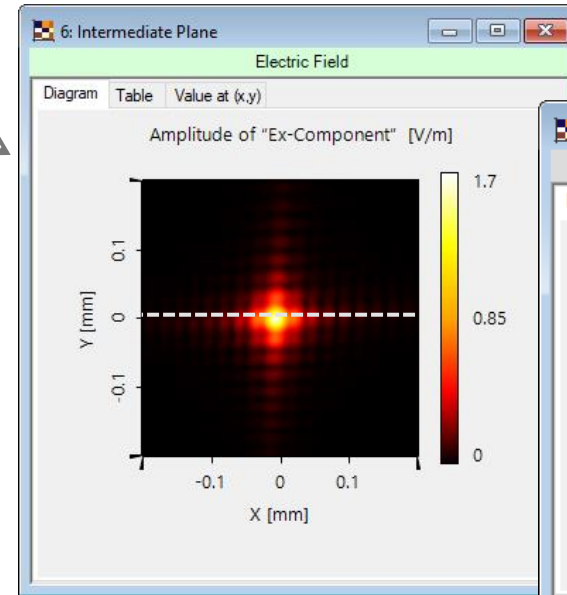
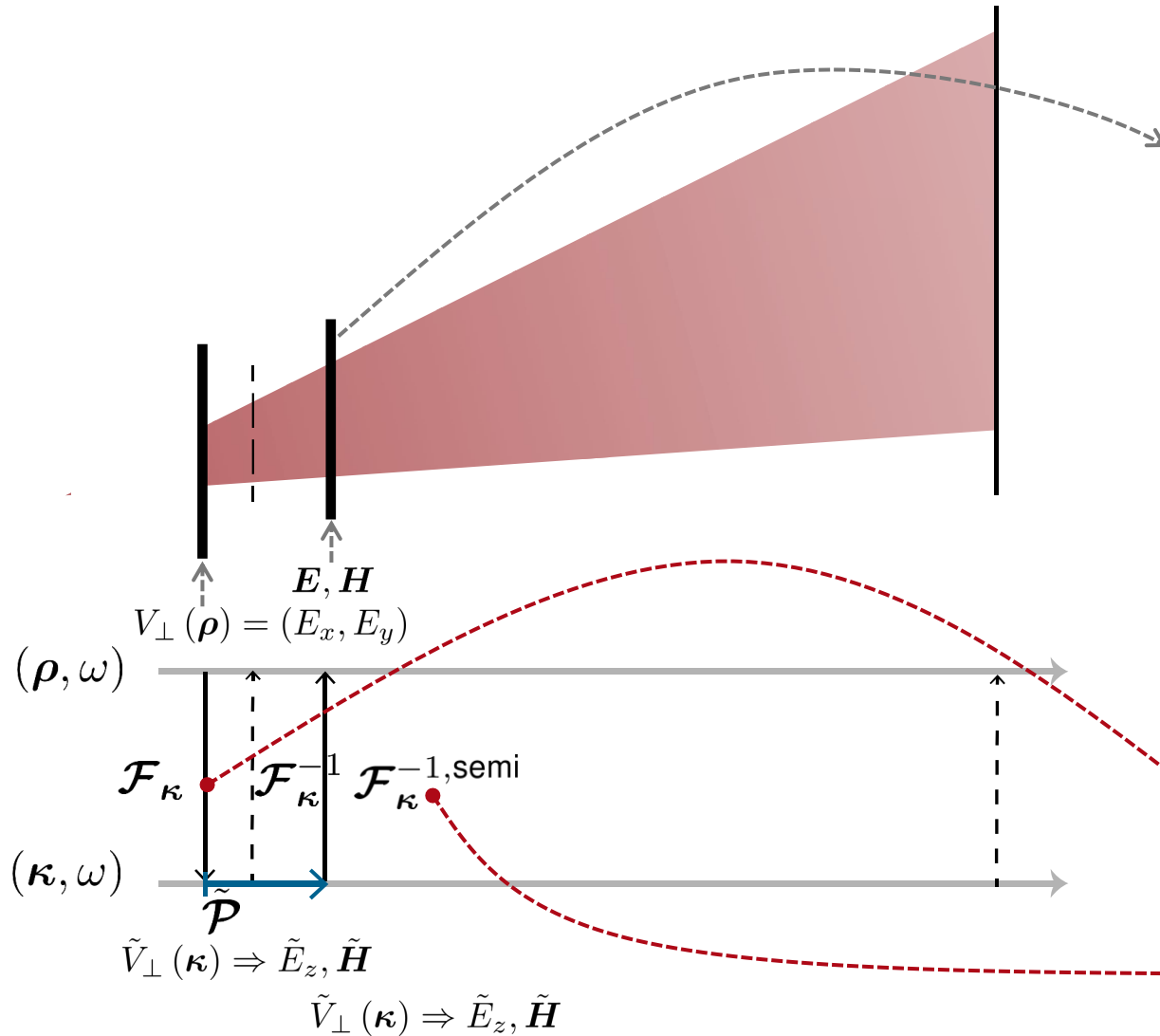
Field in k-domain is NOT in homeomorphic zone.

Inverse fast Fourier transform selected. (number of points = (1005; 1055))

Detector evaluation finished. (Duration = 00:00:02.3430915)

automatic selection of  
Fourier transform

# Simulation Result: Intermediate Plane



Detectors Analyzers Logging

Ratio between geometric and diffractive power = 1.3091E-13

Field in x-domain is NOT in homeomorphic zone.

Fast Fourier transform selected. (number of points = (137; 137))

Free space propagation in k-domain done.

Ratio between geometric and diffractive power = 0.84993

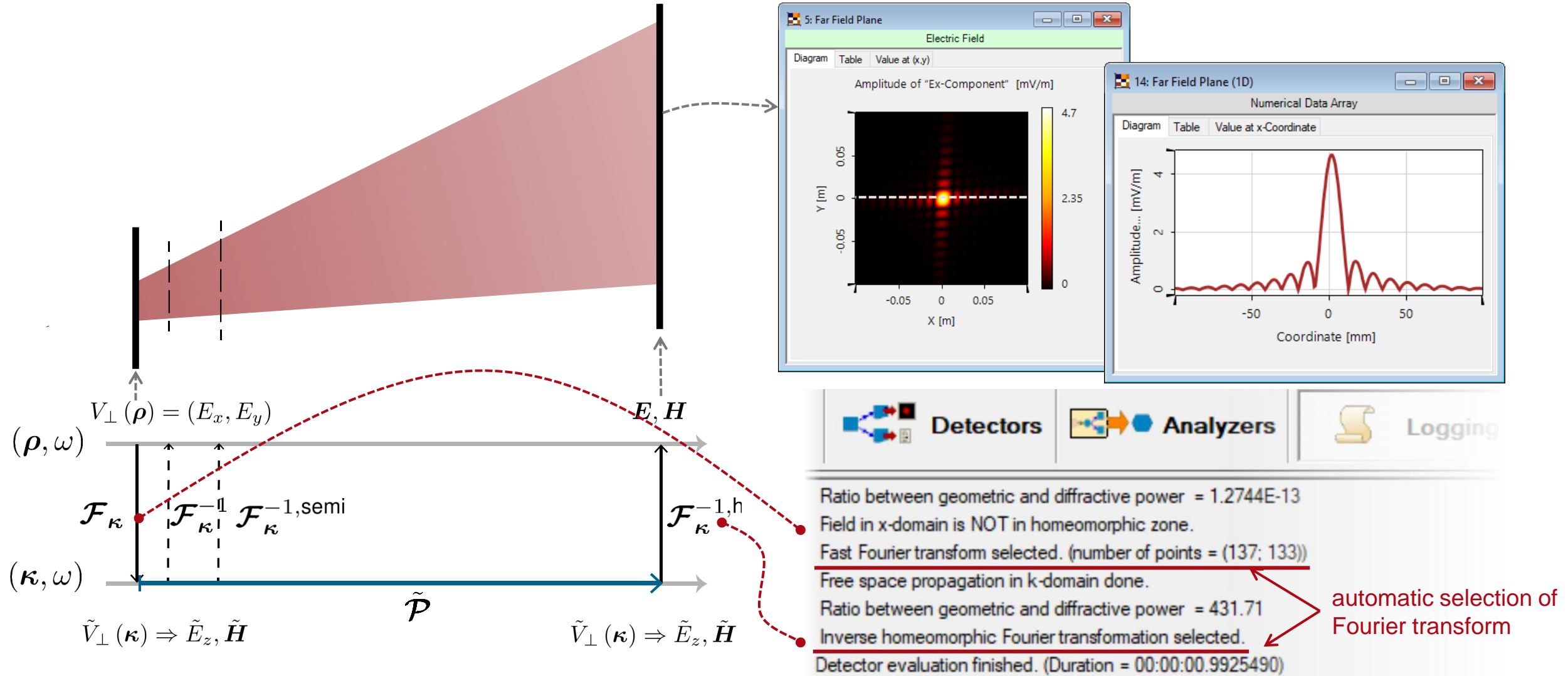
Field in k-domain is NOT in homeomorphic zone.

Inverse semi-analytical Fourier transform selected. (number of points = (1195; 1663))

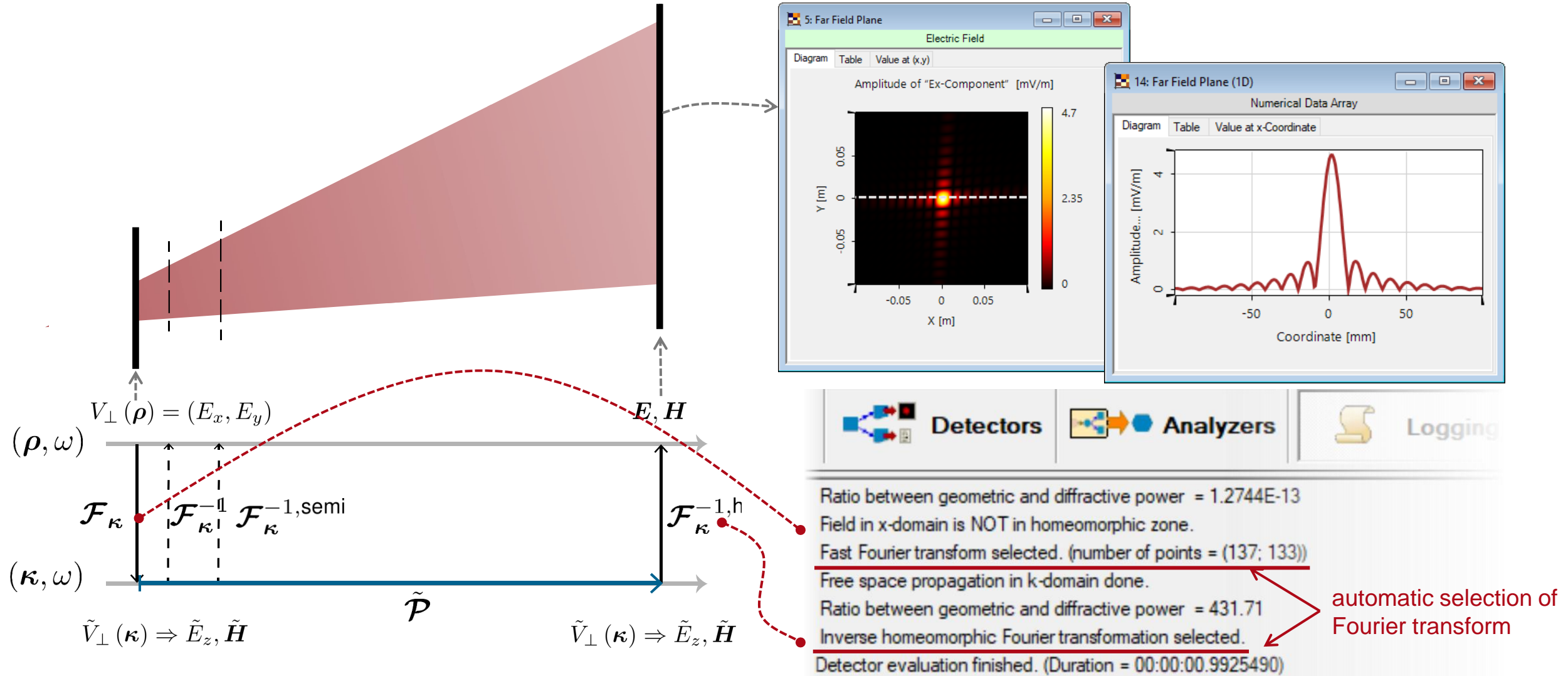
Detector evaluation finished. (Duration = 00:00:15.7667738)

automatic selection of Fourier transform

# Simulation Result: Far Field Plane



# Simulation Result: Far Field Plane



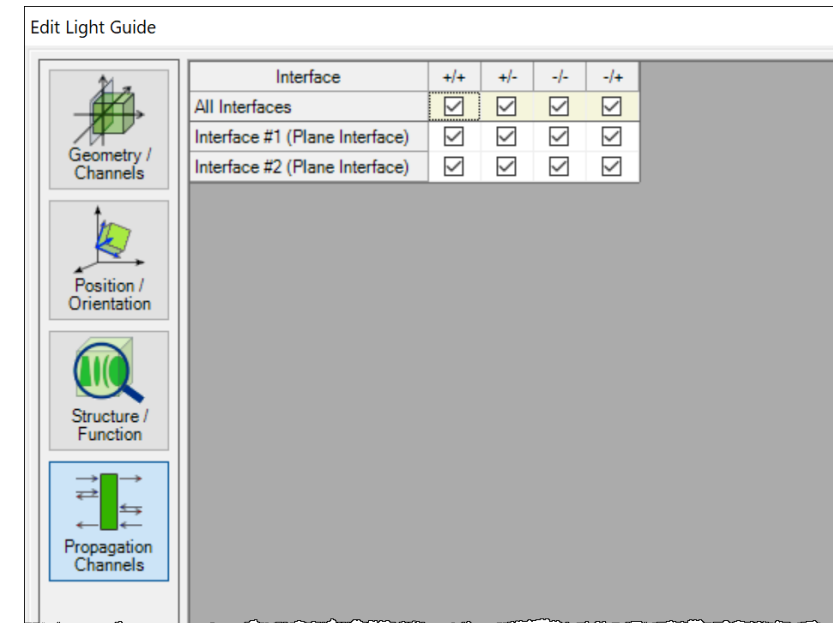
Part 4

## The Channel Concept



# Surface Channels

- Channel definition
  - There are four possible channels for each surface, at least one should be activated for the tracing.
  - Channels can be defined for each surface individually.
  - Different settings on channels leads to different modeling schemes.



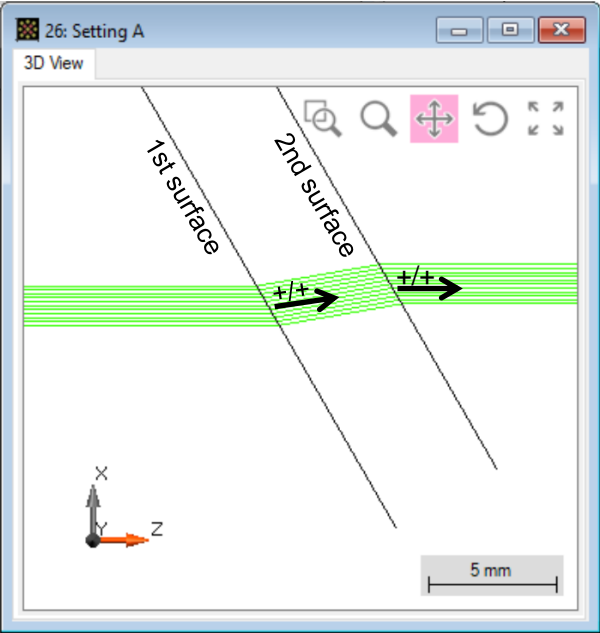
## Channel Description

+/+	transmission (forward)
+/-	reflection (forward)
-/+	reflection (backward)
-/-	transmission (backward)



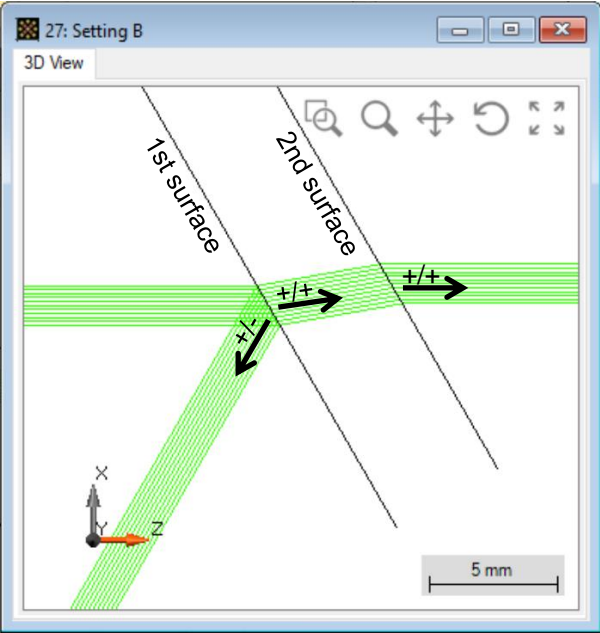
# Surface Channels

Setting A



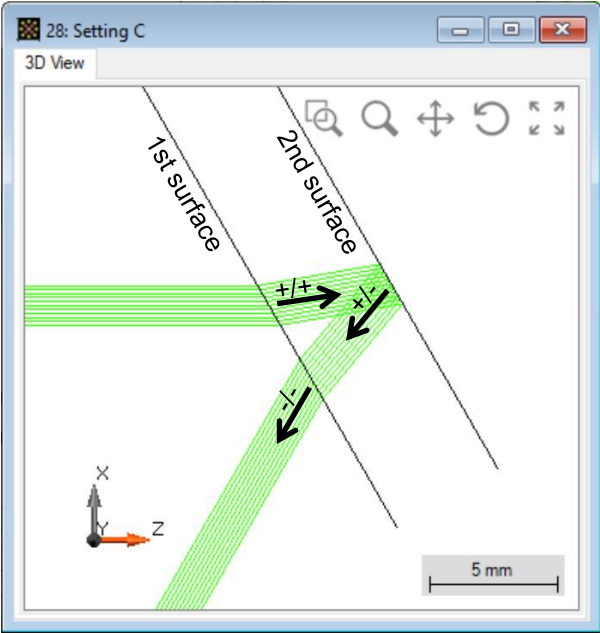
Surface	+/+	+/-	-/-	-/+
1st	×			
2nd	×			

Setting B



Surface	+/+	+/-	-/-	-/+
1st	×	×		
2nd	×			

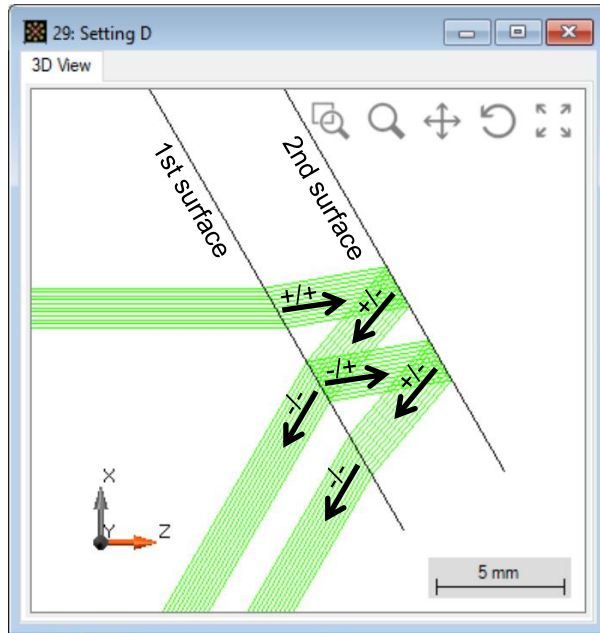
Setting C



Surface	+/+	+/-	-/-	-/+
1st	×		×	
2nd		×		

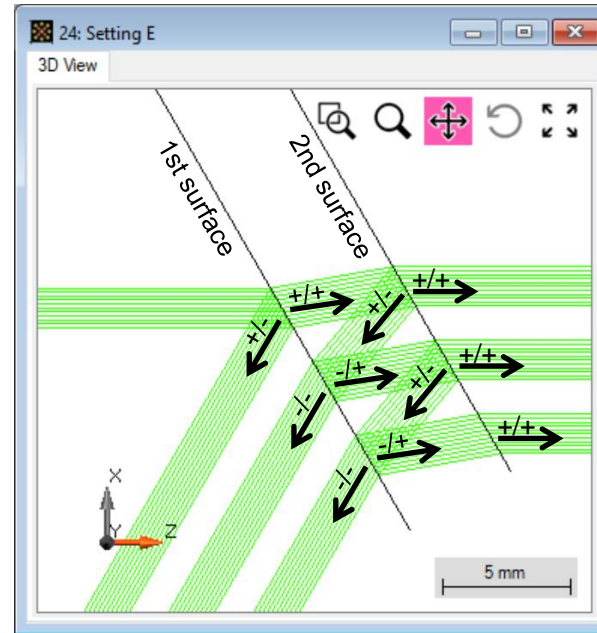
# Surface Channels

## Setting D



Surface	+/+	+/-	-/-	-/+
1st	×		×	×
2nd		×		

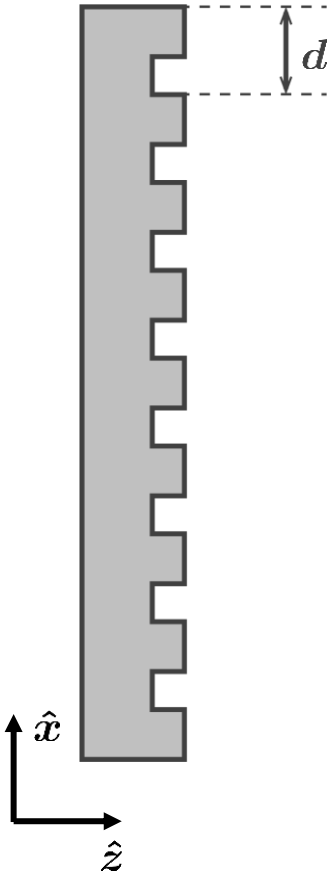
## Setting E



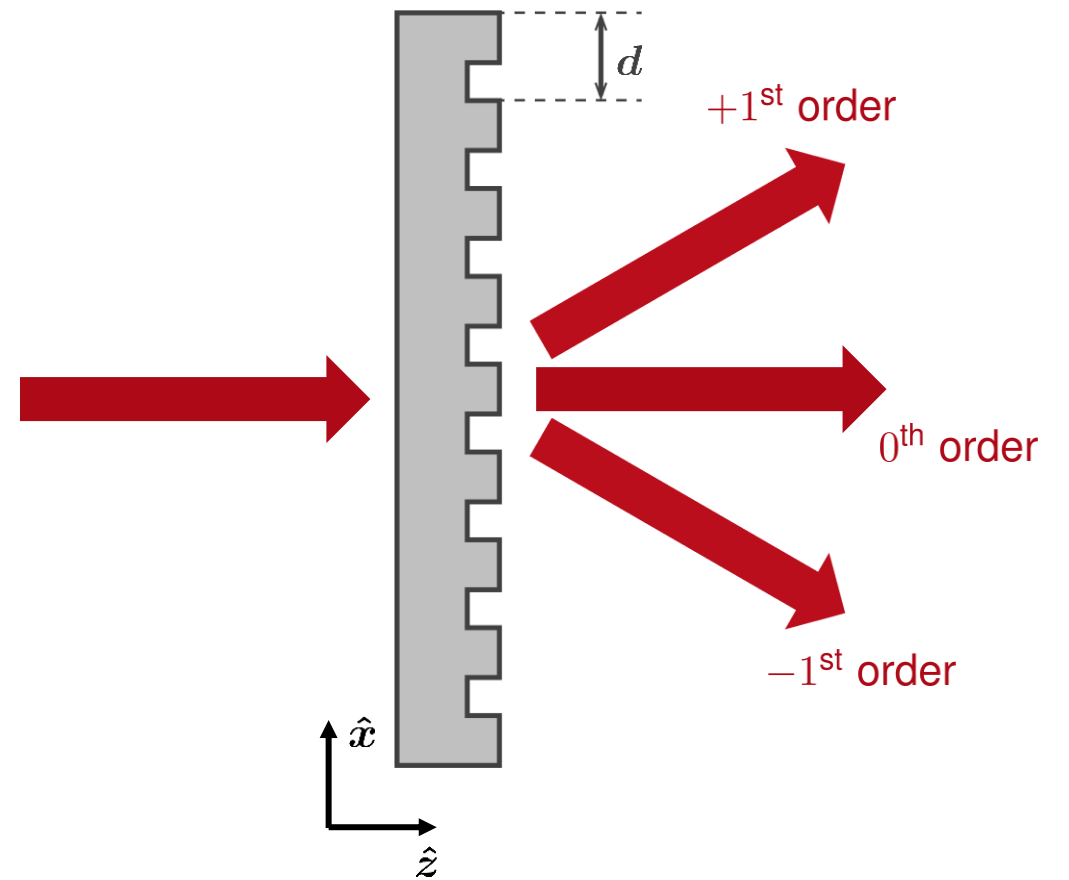
Surface	+/+	+/-	-/-	-/+
1st	×	×	×	×
2nd	×	×	×	×

Note: an activated channel does not necessarily lead to corresponding light path(s). E.g., the -/- and -/+ channel of 2<sup>nd</sup> interface do not influence the tracing, because there is no backward incidence.

# Grating Channels



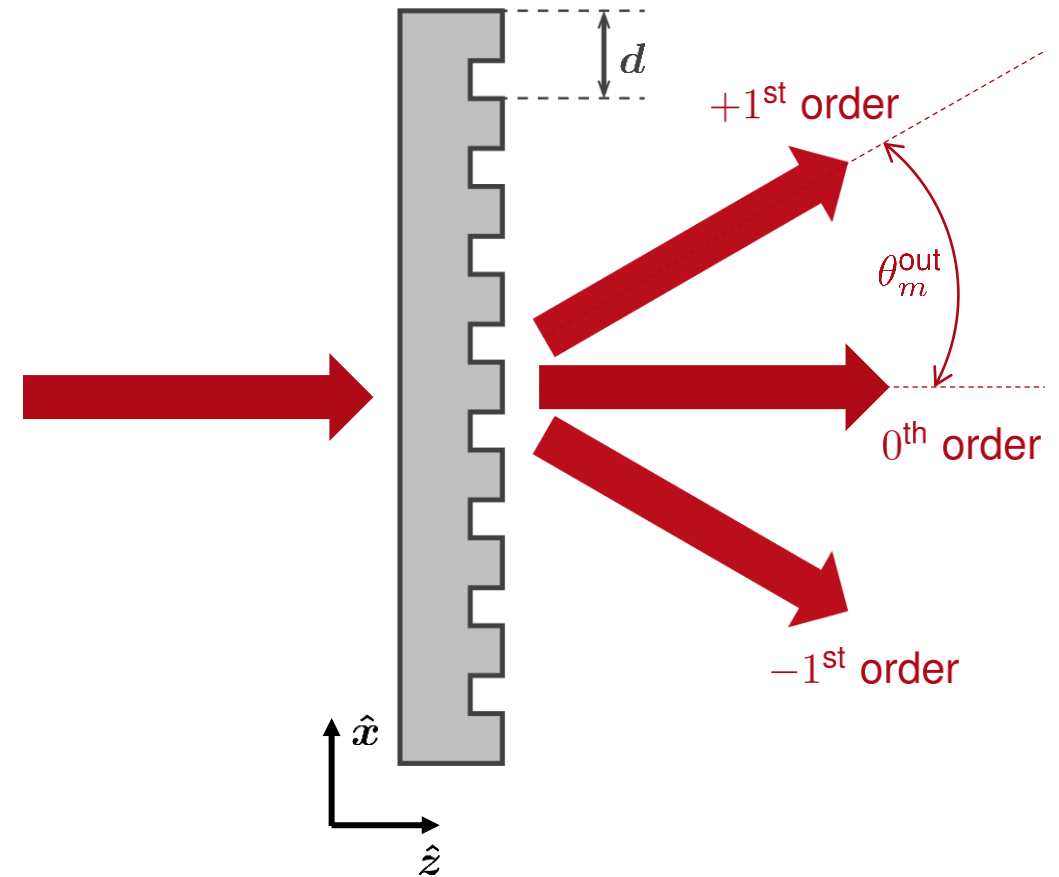
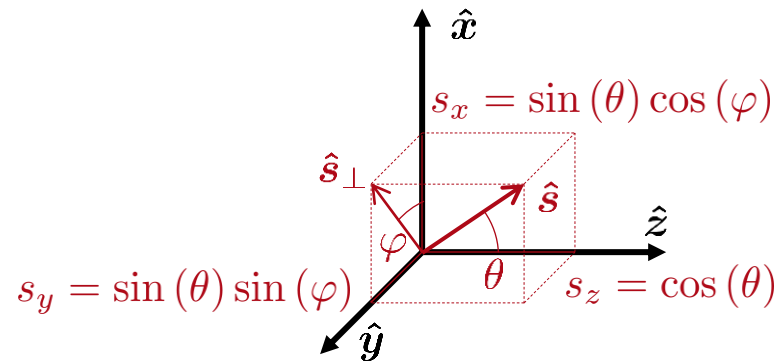
# Grating Channels



# Grating Channels

Grating equation:

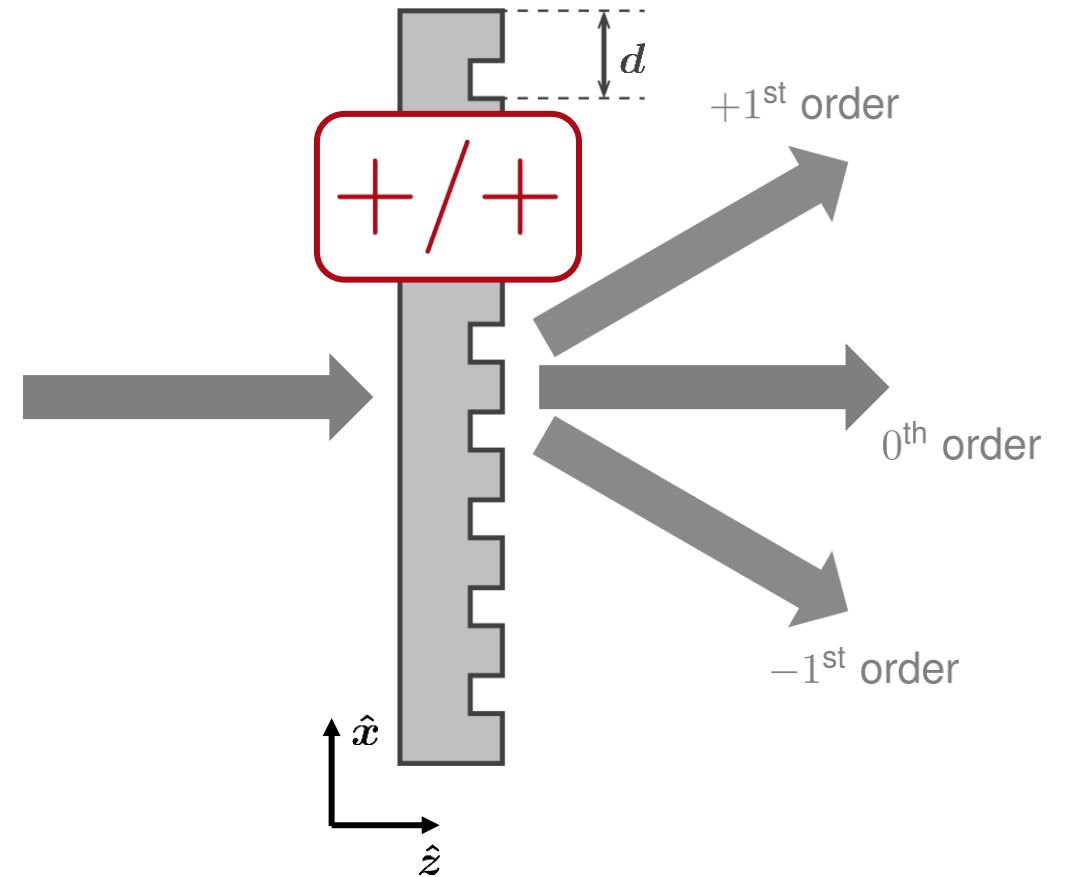
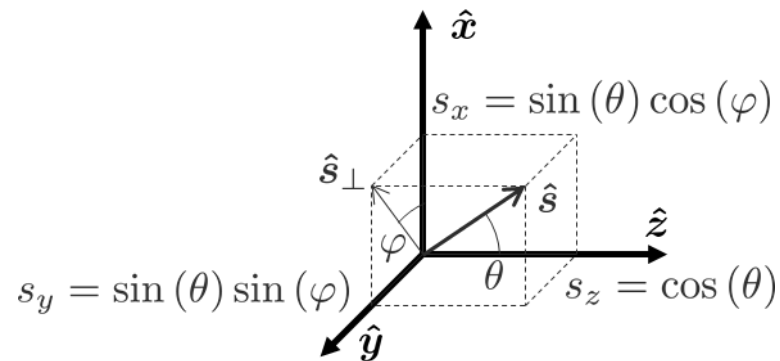
- $\kappa_m^{\text{out}} = \kappa^{\text{in}} + m\Delta\kappa$ ,
- where  $\kappa_m^{\text{out}} = \mathbf{k}_{m,\perp}^{\text{out}} = (k_{m,x}^{\text{out}}, k_{m,y}^{\text{out}}) = nk_0\hat{\mathbf{s}}_{m,\perp}^{\text{out}}$  (with  $m$  the order),
- $\kappa^{\text{in}} = \mathbf{k}_{\perp}^{\text{in}} = (k_x^{\text{in}}, k_y^{\text{in}}) = nk_0\hat{\mathbf{s}}_{\perp}^{\text{in}}$  and
- $\Delta\kappa = \frac{2\pi}{d}$



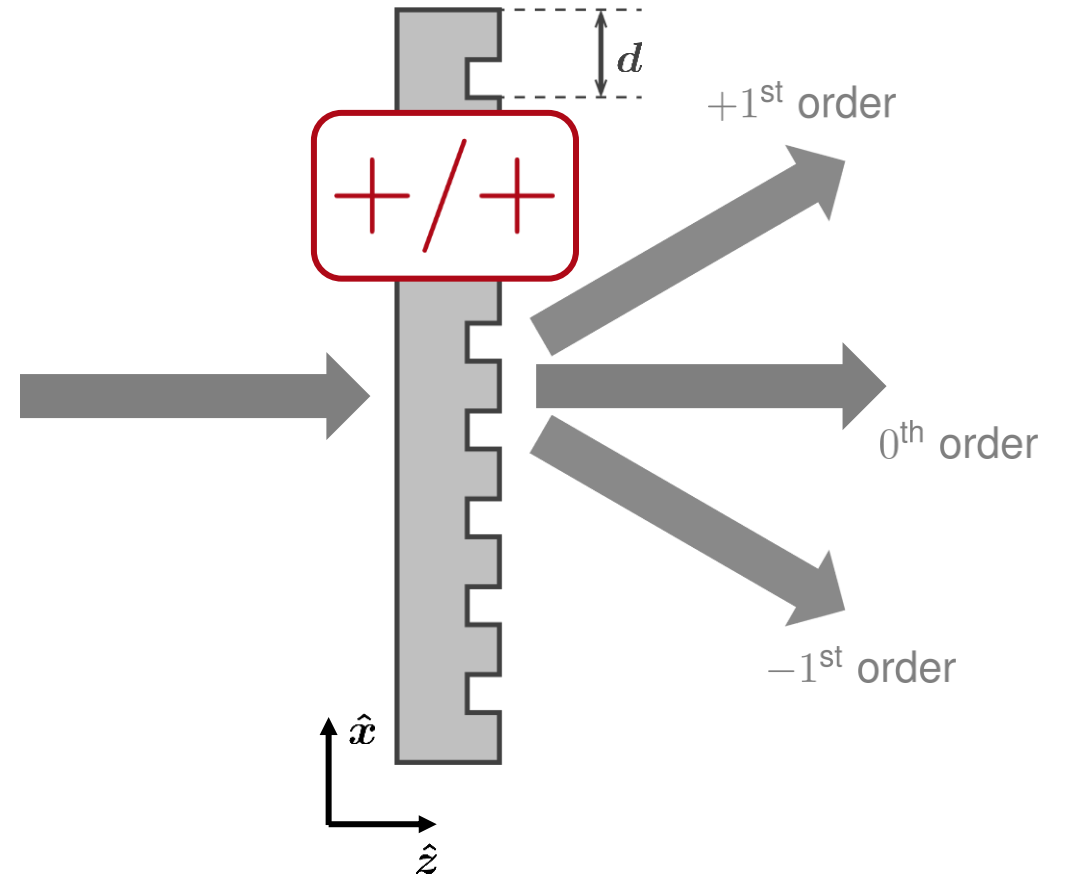
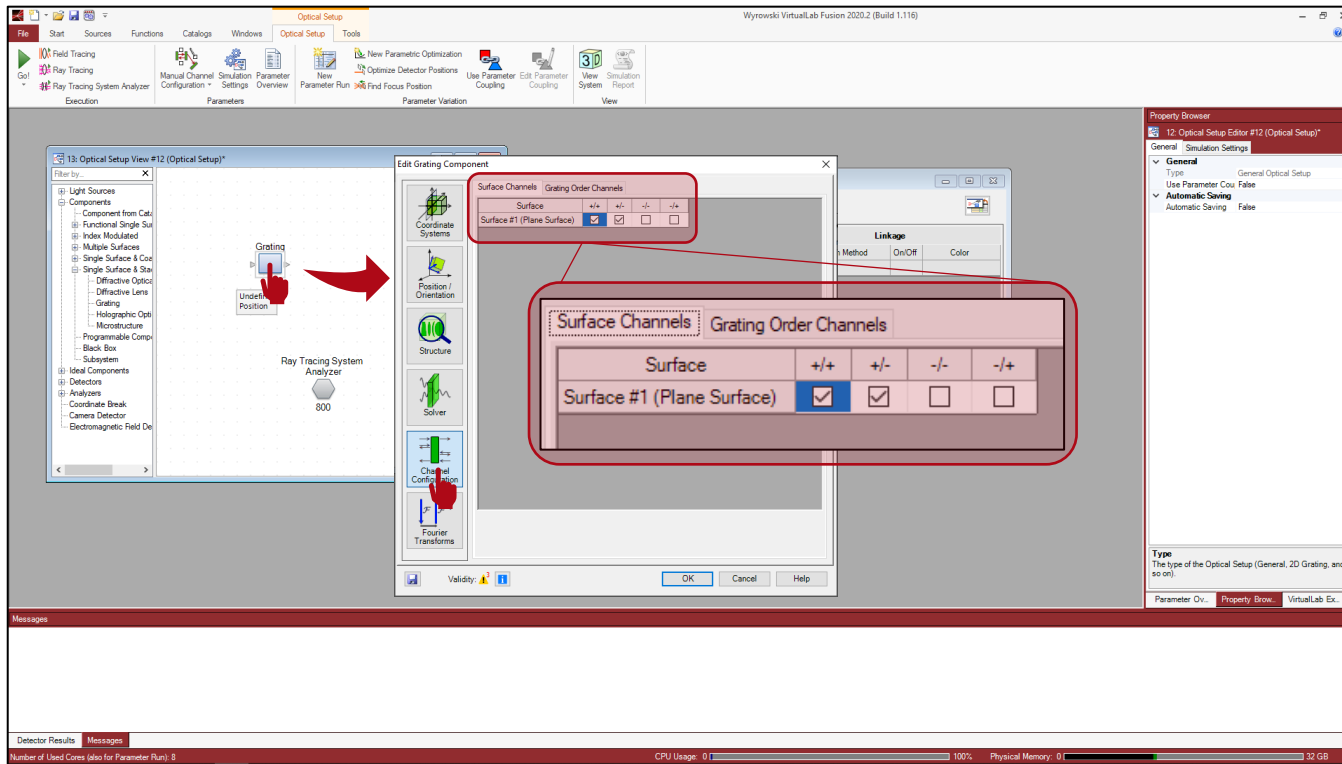
# Grating Channels

Grating equation:

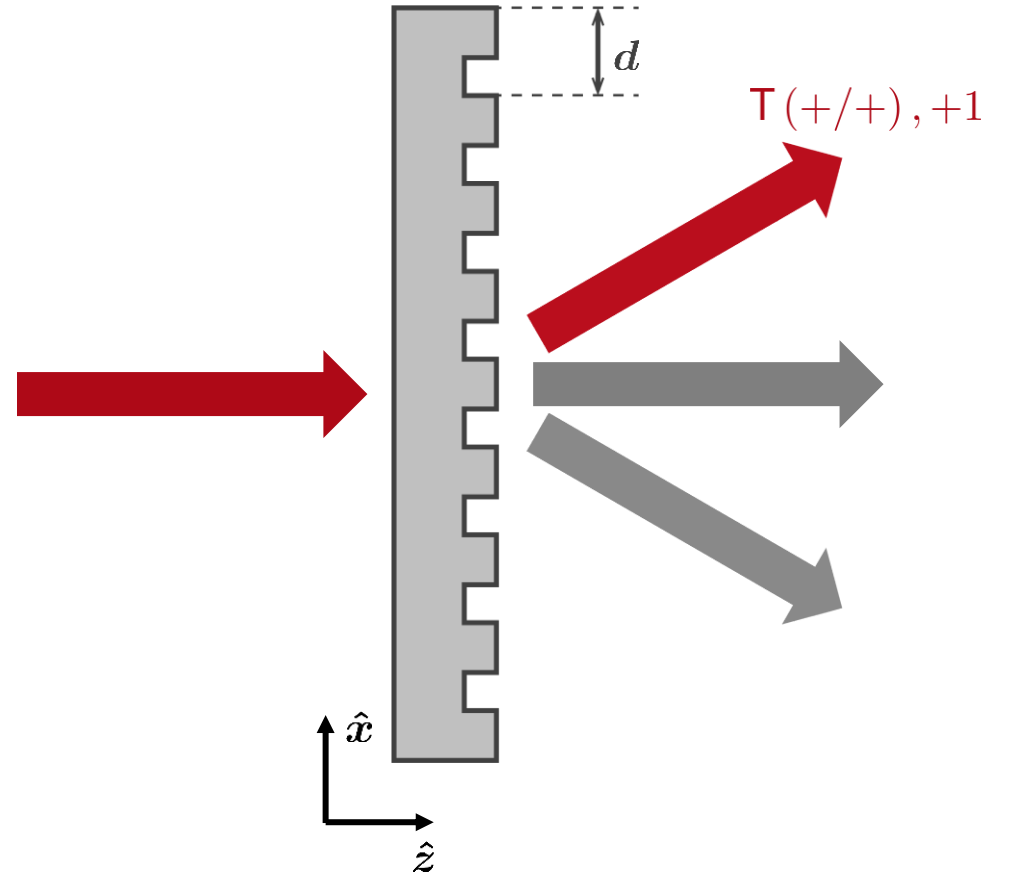
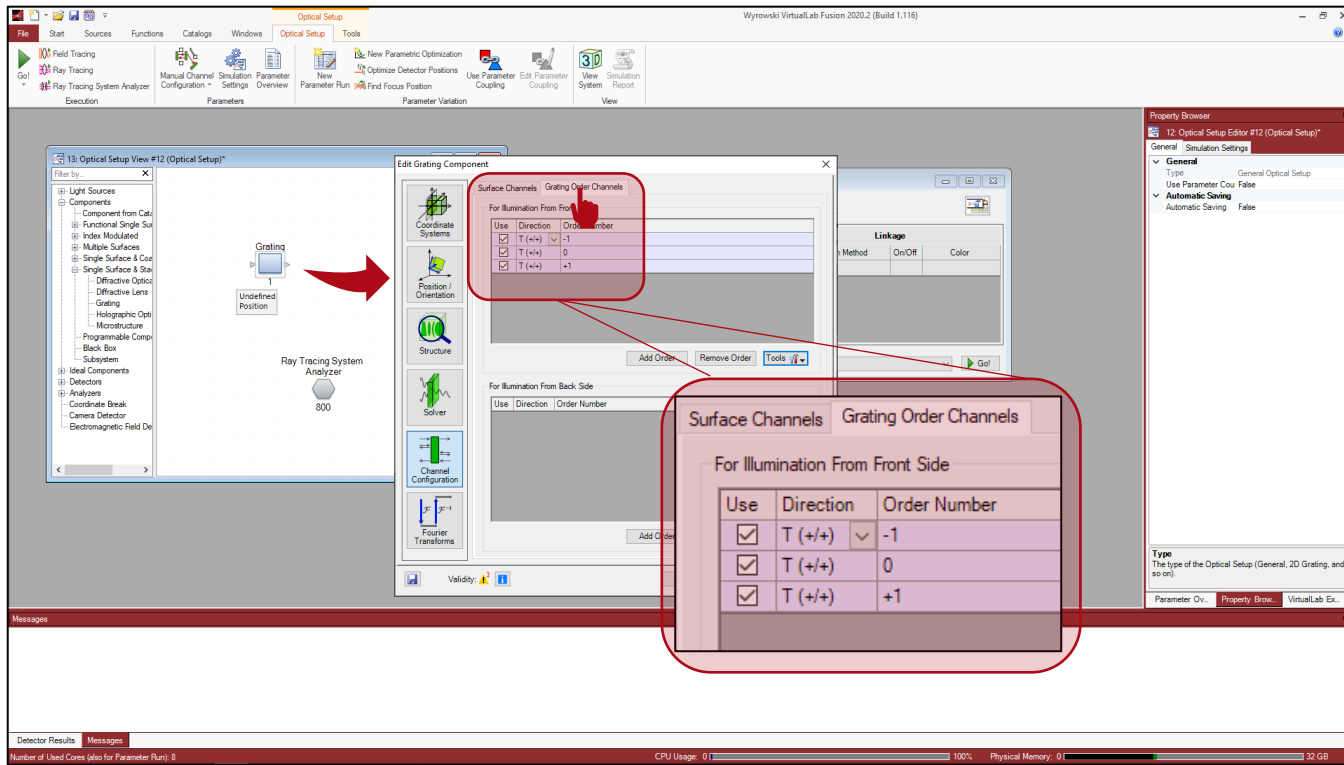
- $\kappa_m^{\text{out}} = \kappa^{\text{in}} + m\Delta\kappa$ ,
- where  $\kappa_m^{\text{out}} = \mathbf{k}_{m,\perp}^{\text{out}} = (k_{m,x}^{\text{out}}, k_{m,y}^{\text{out}}) = nk_0 \hat{\mathbf{s}}_{m,\perp}^{\text{out}}$  (with  $m$  the order),
- $\kappa^{\text{in}} = \mathbf{k}_{\perp}^{\text{in}} = (k_x^{\text{in}}, k_y^{\text{in}}) = nk_0 \hat{\mathbf{s}}_{\perp}^{\text{in}}$  and
- $\Delta\kappa = \frac{2\pi}{d}$



# Grating Channels

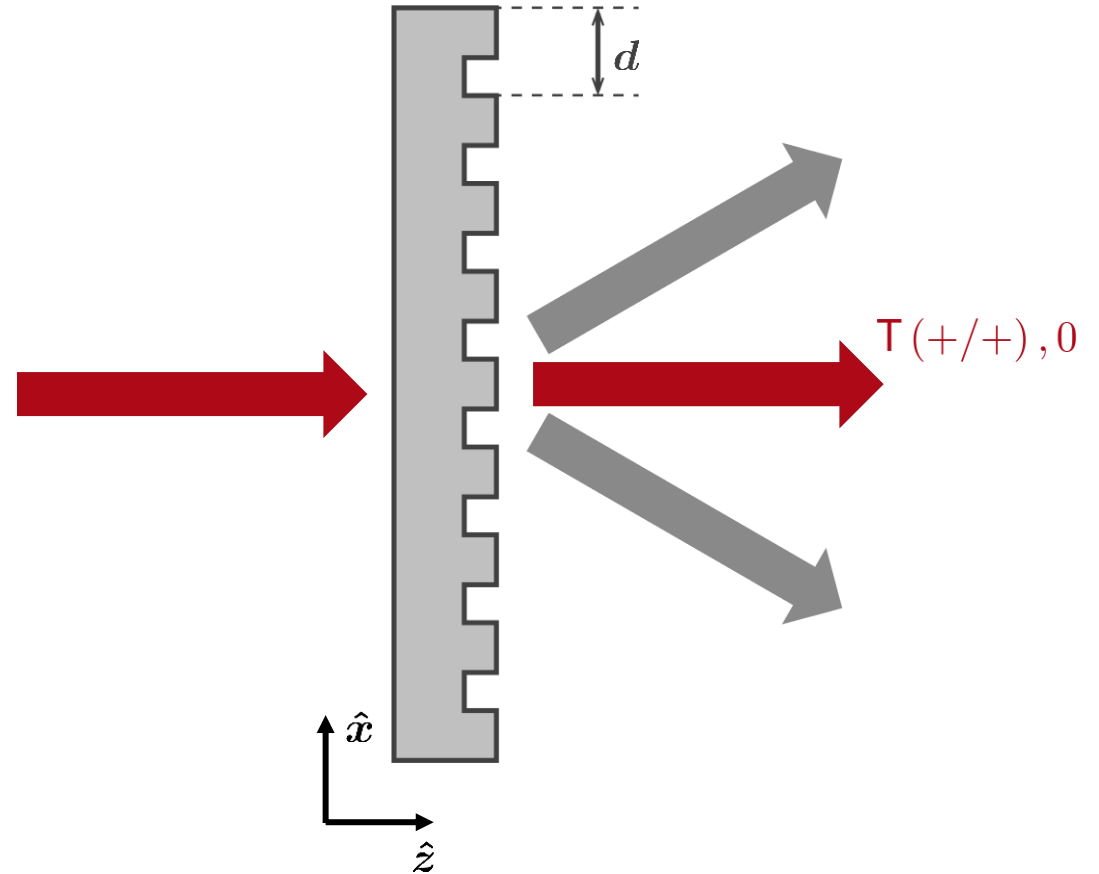
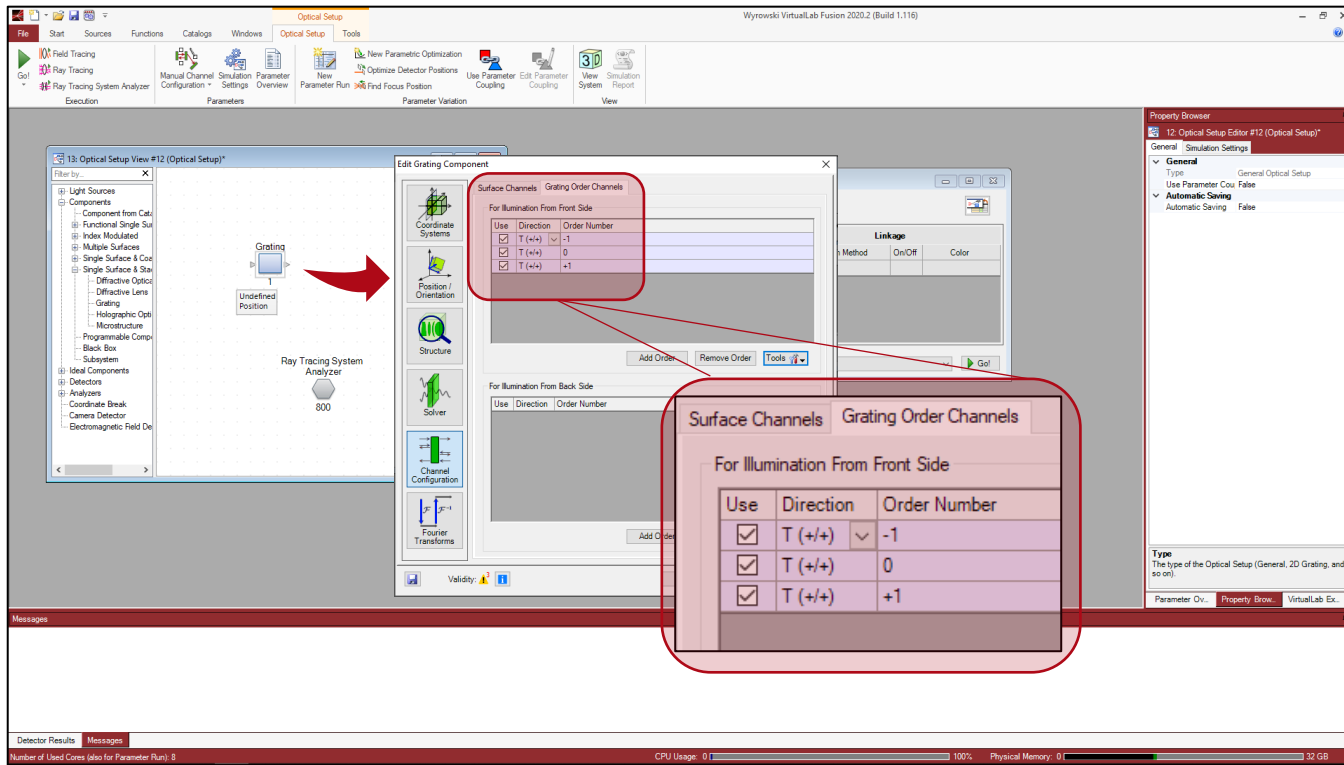


# Grating Channels

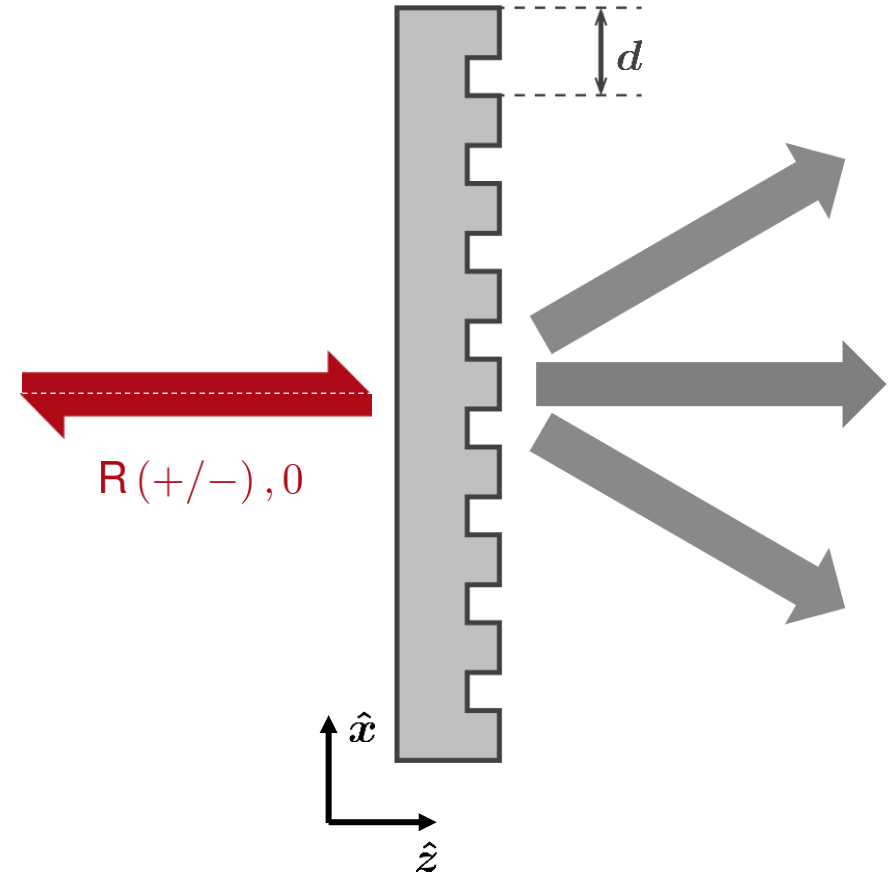
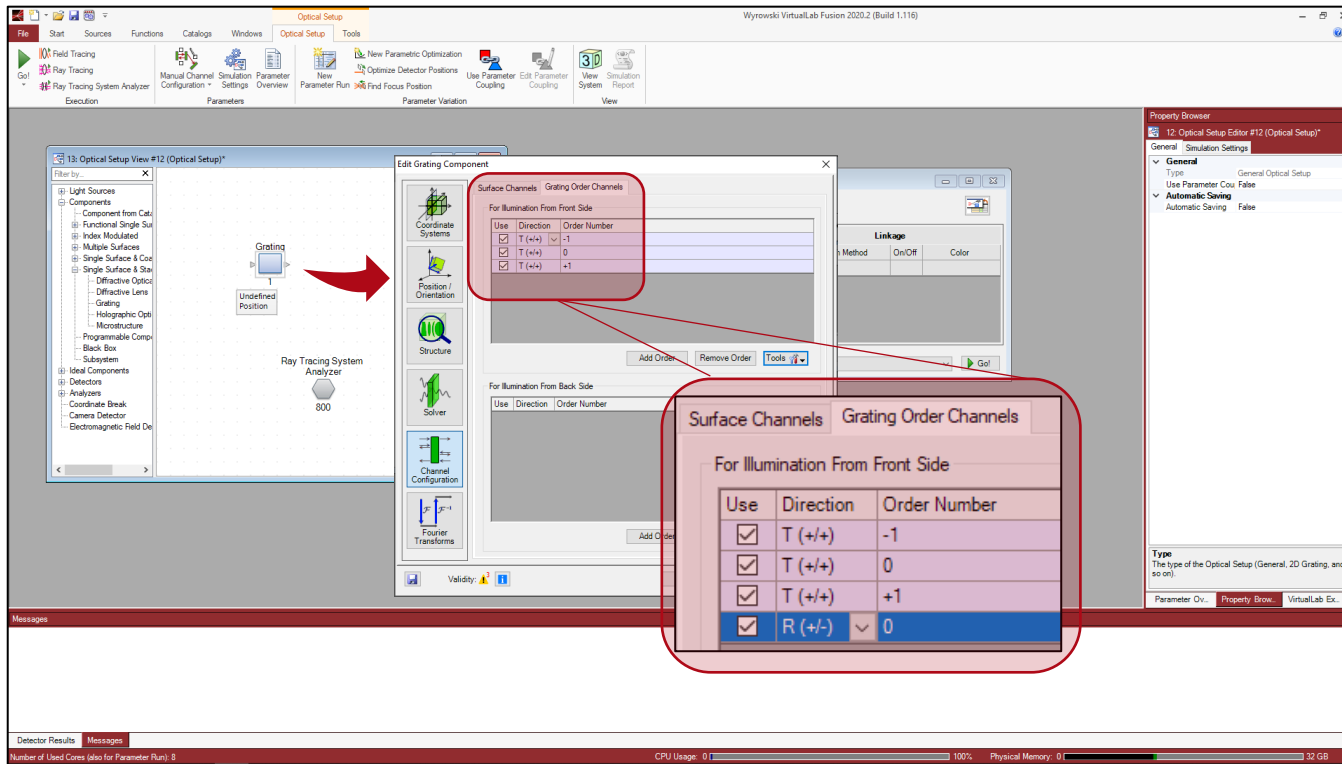




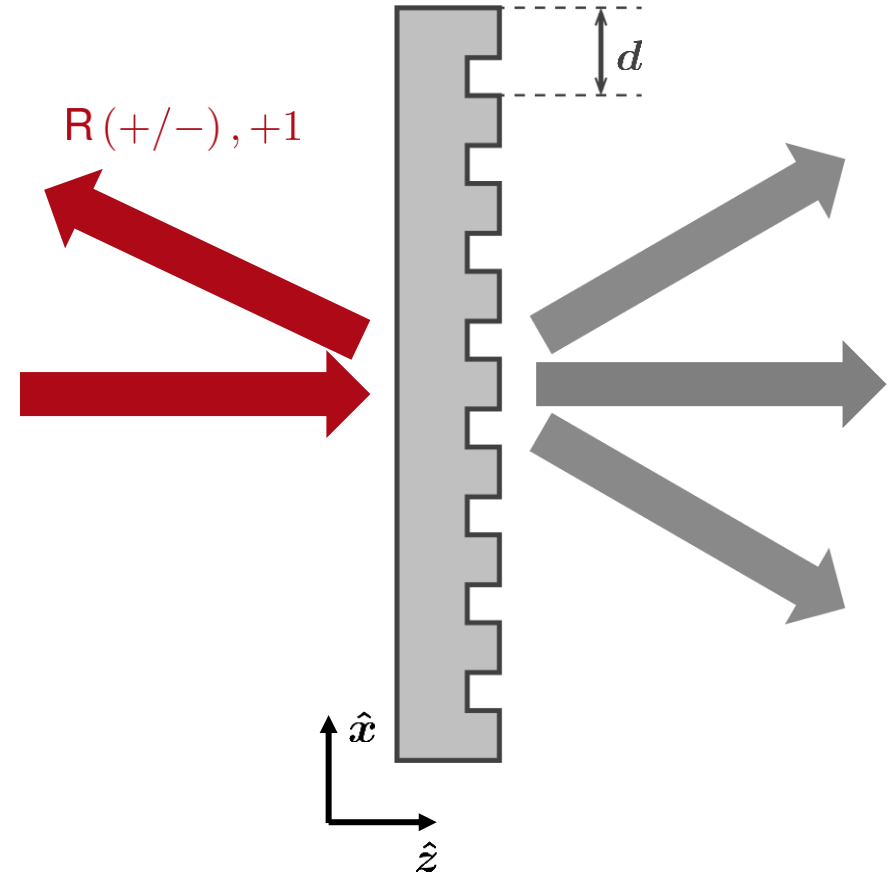
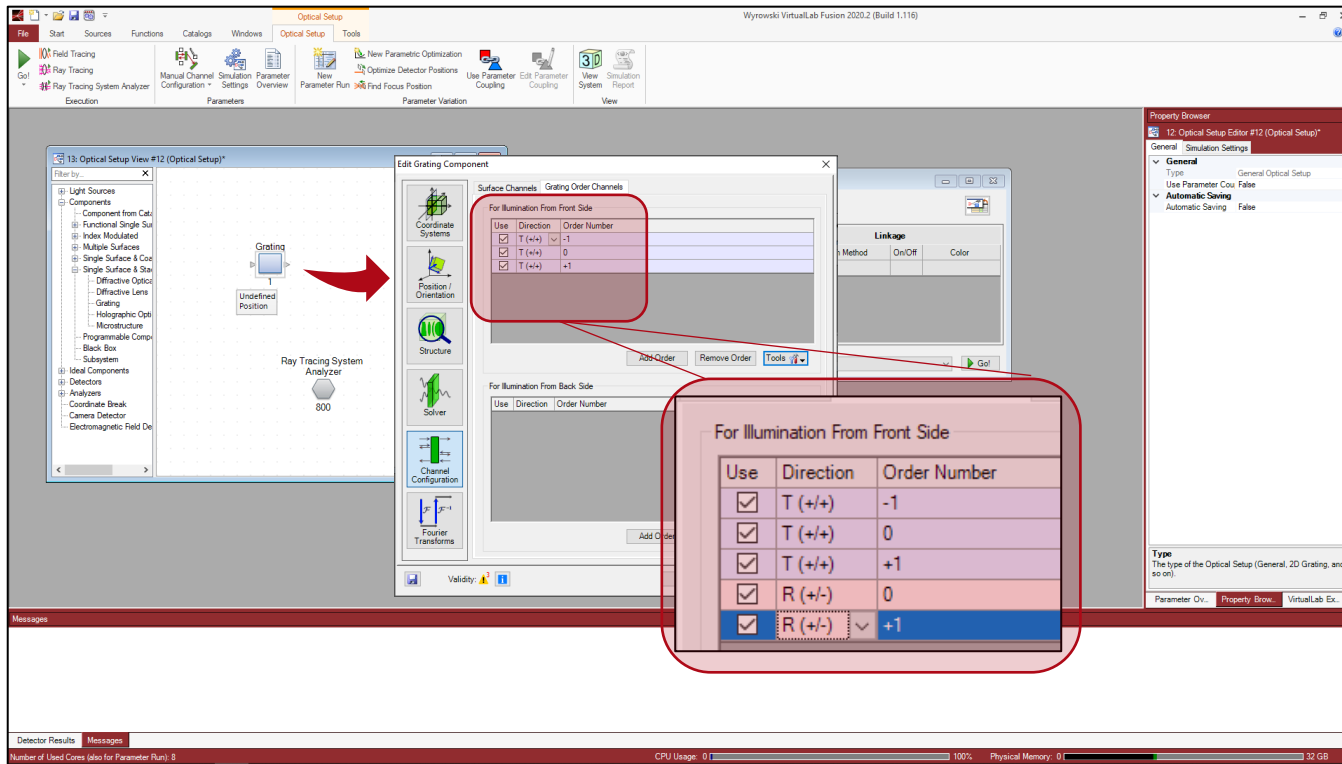
# Grating Channels



# Grating Channels



# Grating Channels



# Grating Channels in Abbe's Experiment

26: Ray Distribution 3D

3D View 2D View

grating

How many orders need to be considered in the modeling?

Edit Grating Component

Surface Channels Grating Order Channels

For Illumination From Front Side

Use	Direction	Order Number
<input checked="" type="checkbox"/>	T (+/+)	-5
<input checked="" type="checkbox"/>	T (+/+)	-4
<input checked="" type="checkbox"/>	T (+/+)	-3
<input checked="" type="checkbox"/>	T (+/+)	-2
<input checked="" type="checkbox"/>	T (+/+)	-1
<input checked="" type="checkbox"/>	T (+/+)	0
<input checked="" type="checkbox"/>	T (+/+)	+1
<input checked="" type="checkbox"/>	T (+/+)	+2

Add Order Remove Order Tools

For Illumination From Back Side

Use	Direction	Order Number
-----	-----------	--------------

Add Order Remove Order Tools

Coordinate Systems  
Position / Orientation  
Structure  
Solver  
Channel Configuration  
Fourier Transforms

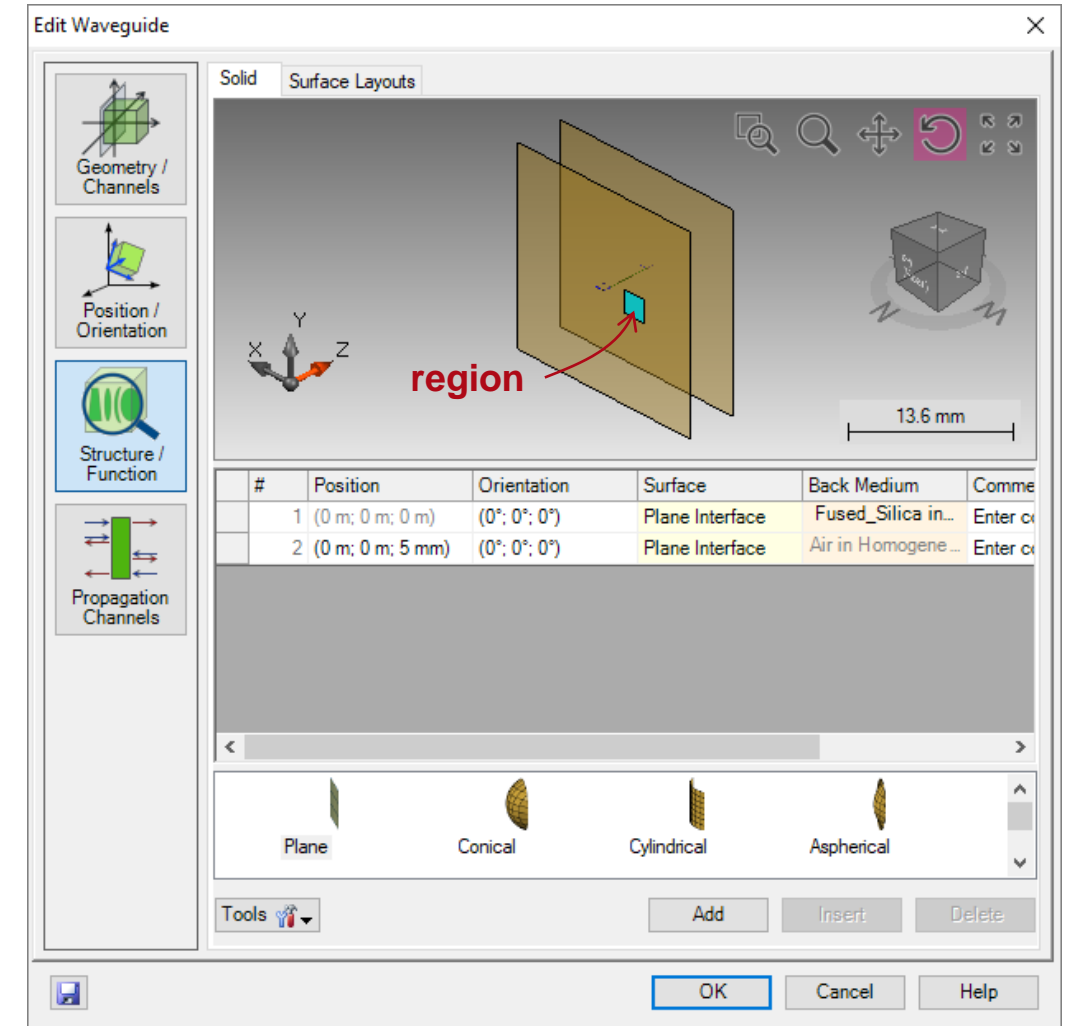
Validity: 3

OK Cancel Help

1 mm

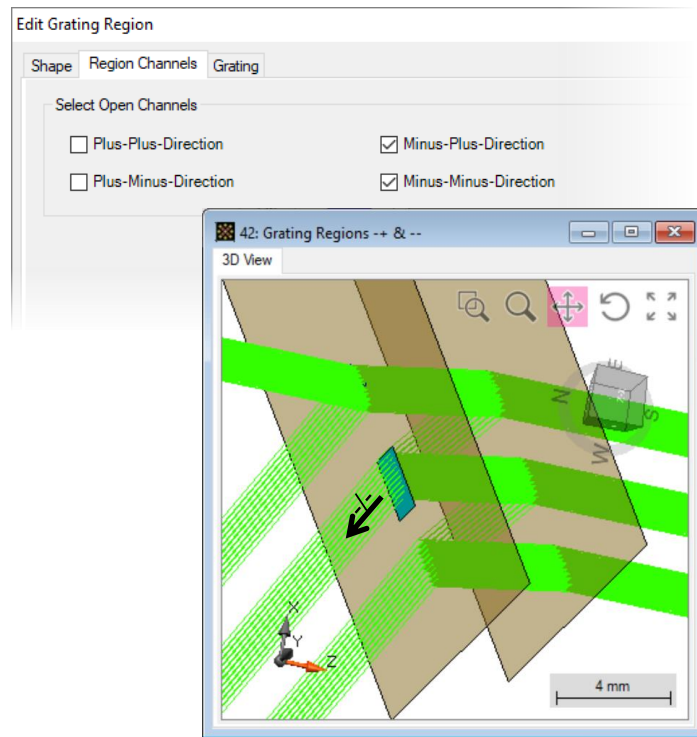
# Lateral Channels

- Region(s) on surface
  - It is possible to define individual Regions on a surface and define their optical properties individually, including the channel settings.

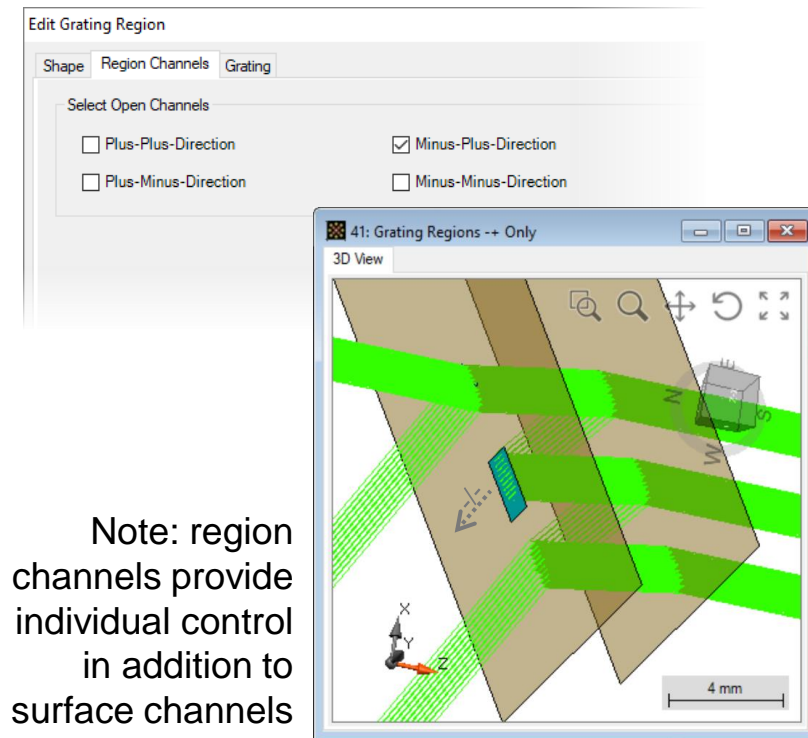


# Lateral Channels

- Region definition
  - Set up the channels for this region, following the same rule as for the surfaces.



region channels -/+ , -/- on



Note: region channels provide individual control in addition to surface channels

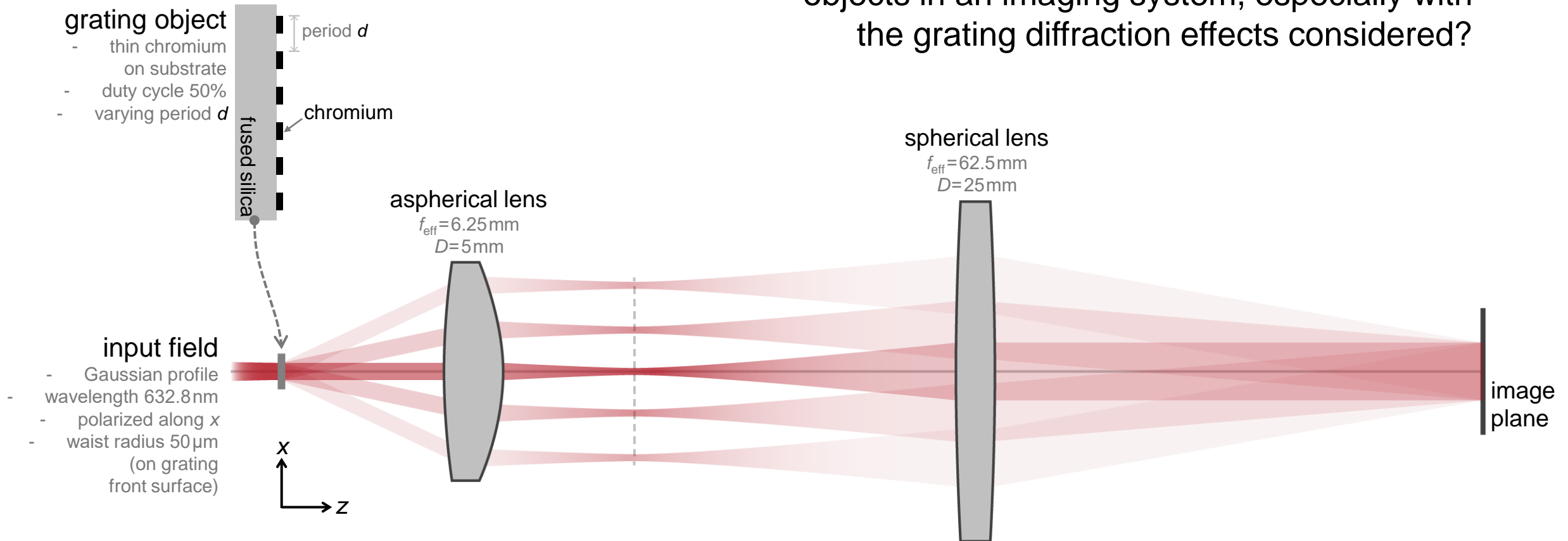
region channel -/+ on

# Demonstration of Abbe's Theory of Image Formation



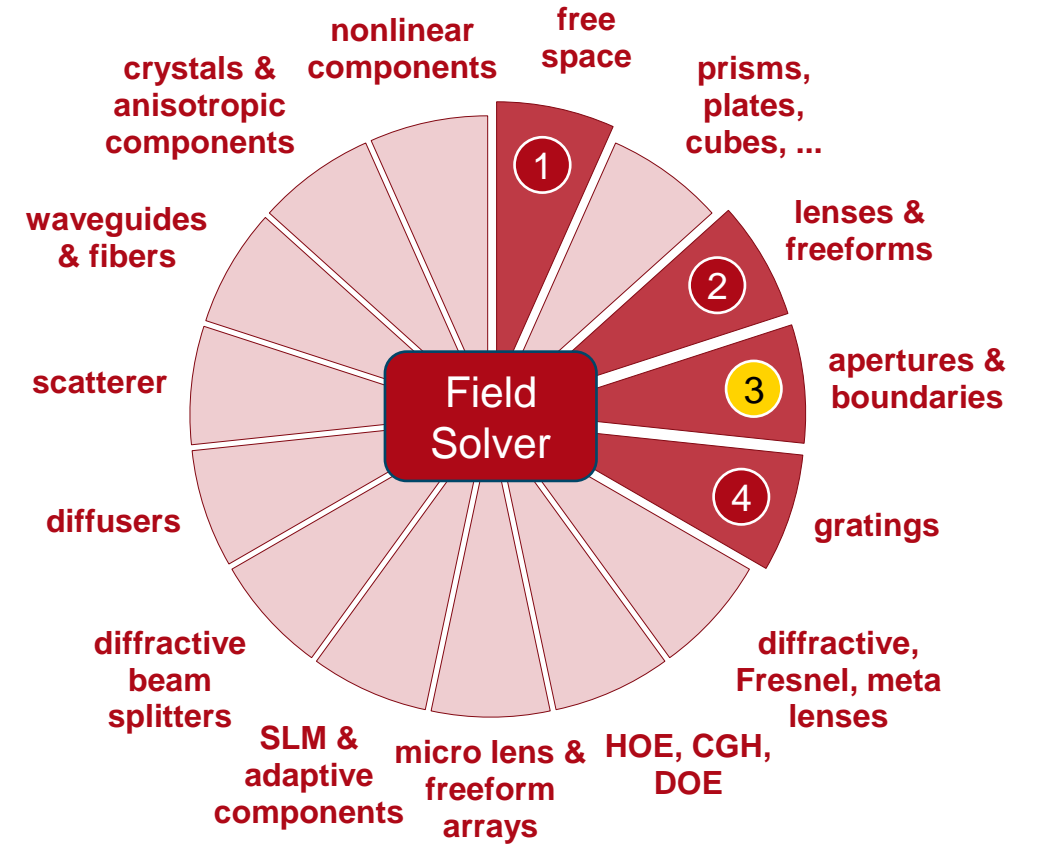
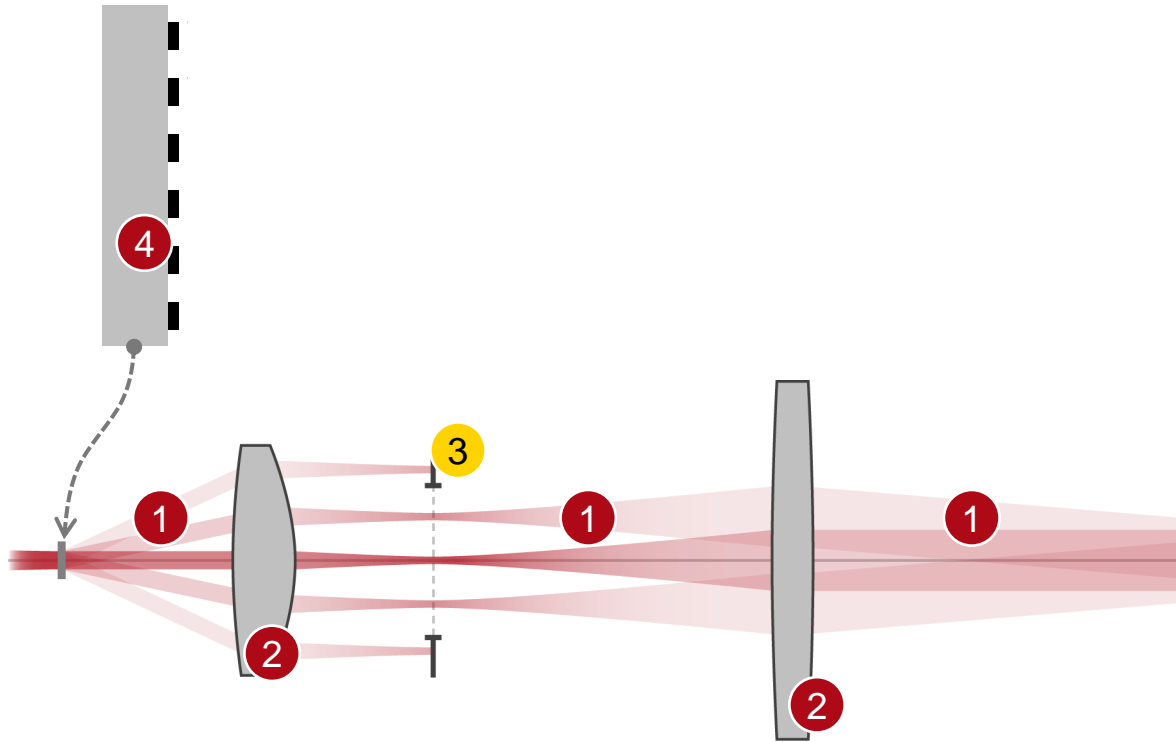
# Modeling Task – Imaging with Varying Grating Period

How to simulate the image formation for grating objects in an imaging system, especially with the grating diffraction effects considered?



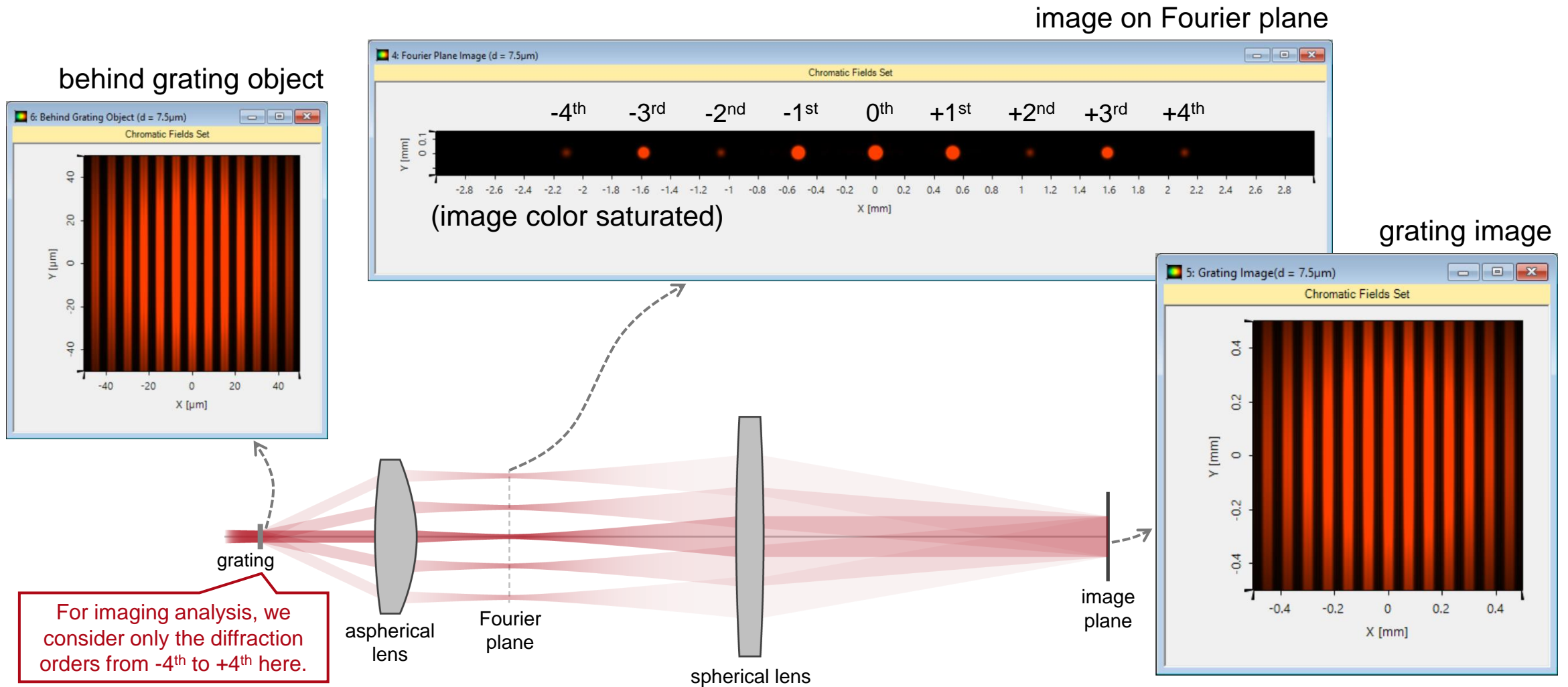


# VirtualLab Fusion Technologies

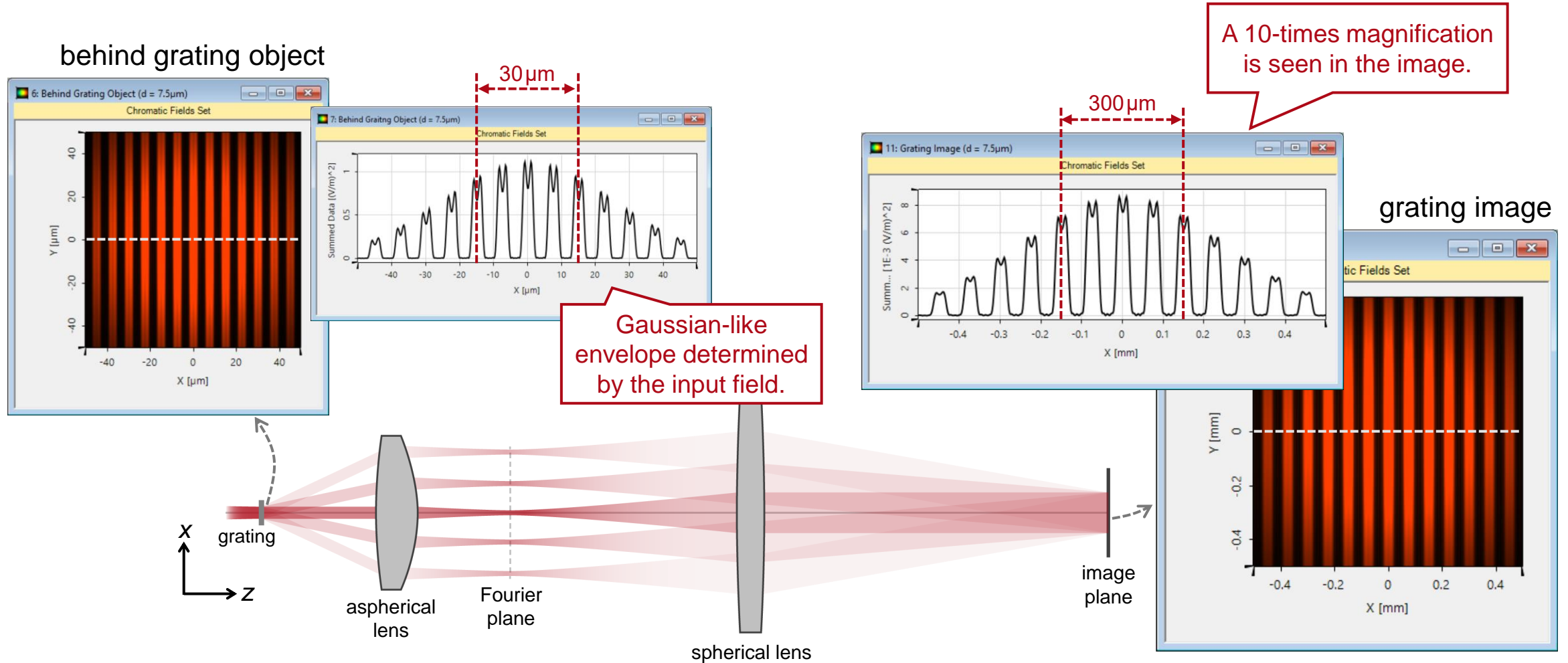


# idealized component

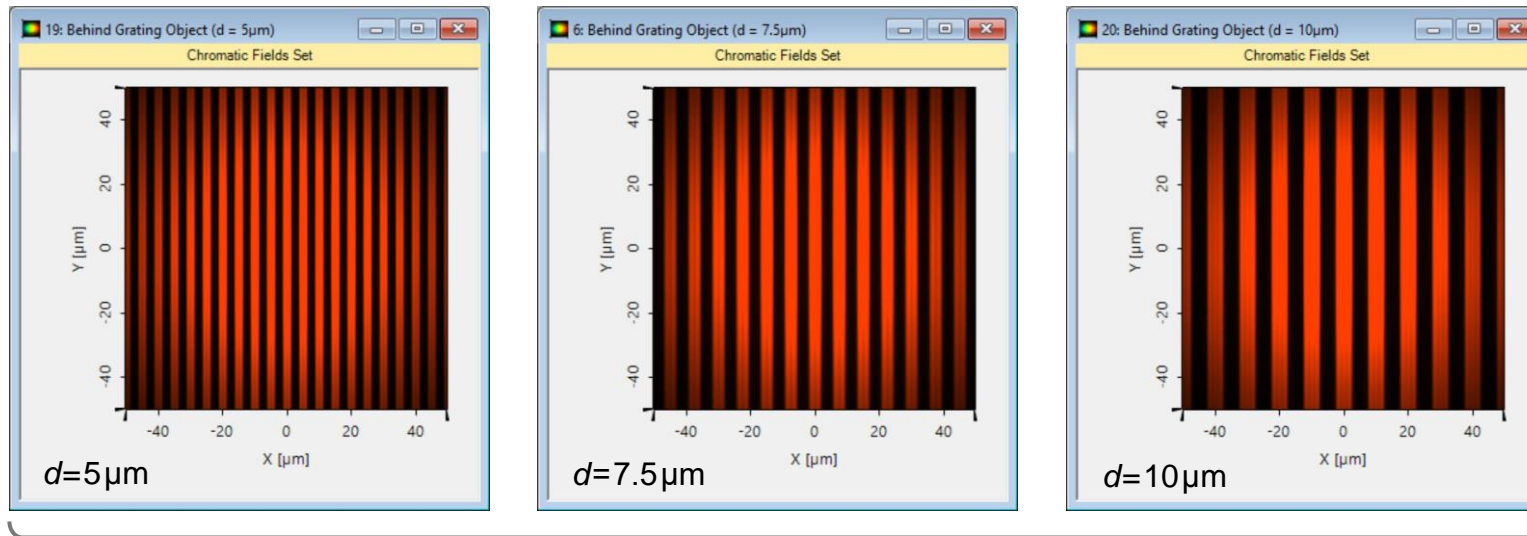
# Image Formation Analysis



# Image Formation Analysis

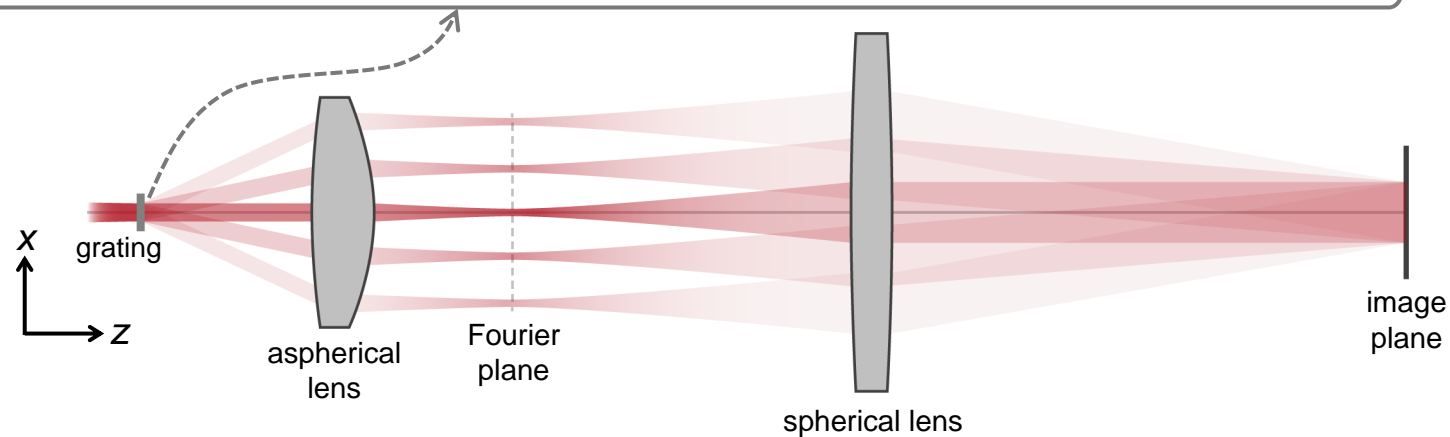


# Behind Grating Objects with Different Periods

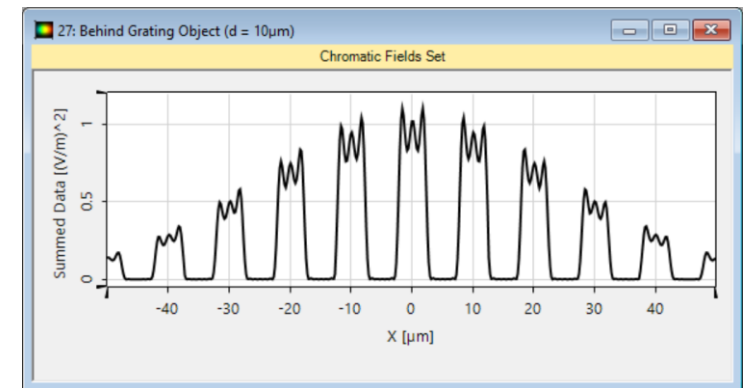
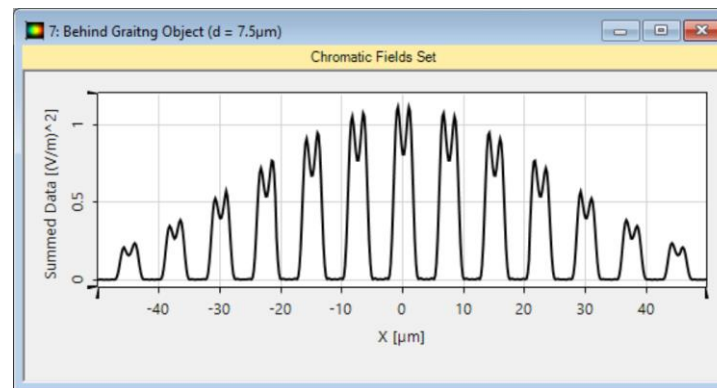
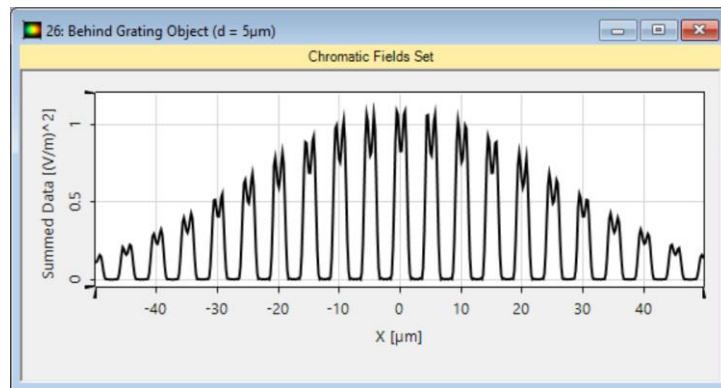
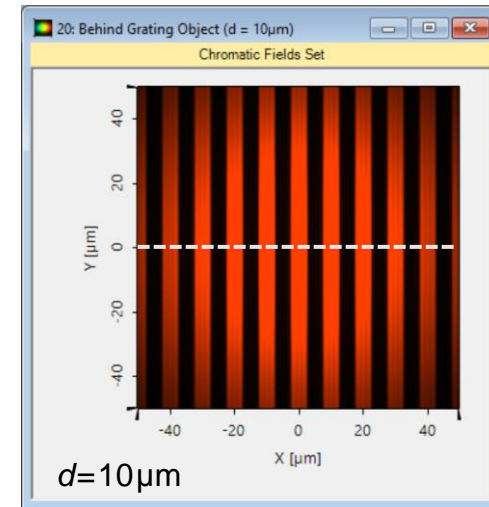
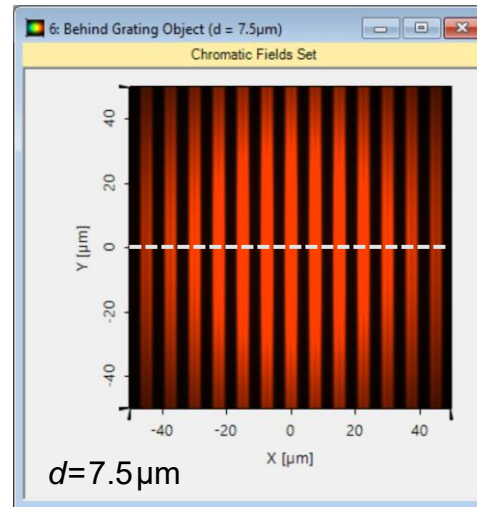
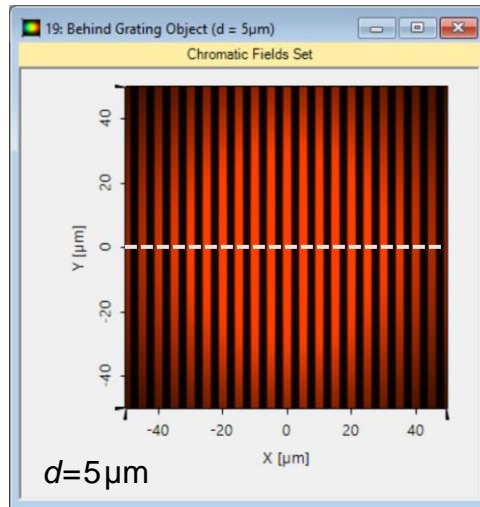


For imaging analysis, we consider only the diffraction orders that will enter the subsequent system:

- $d=5\mu\text{m}$ :  $-3^{\text{rd}}$  to  $+3^{\text{rd}}$  orders
- $d=7.5\mu\text{m}$ :  $-4^{\text{th}}$  to  $+4^{\text{th}}$  orders
- $d=10\mu\text{m}$ :  $-6^{\text{th}}$  to  $+6^{\text{th}}$  orders



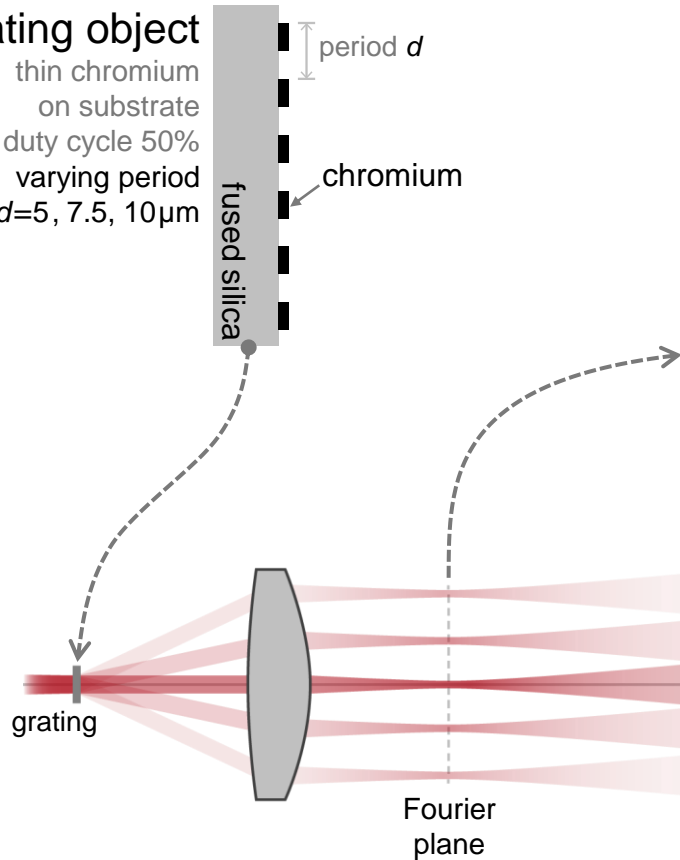
# Behind Grating Objects with Different Periods



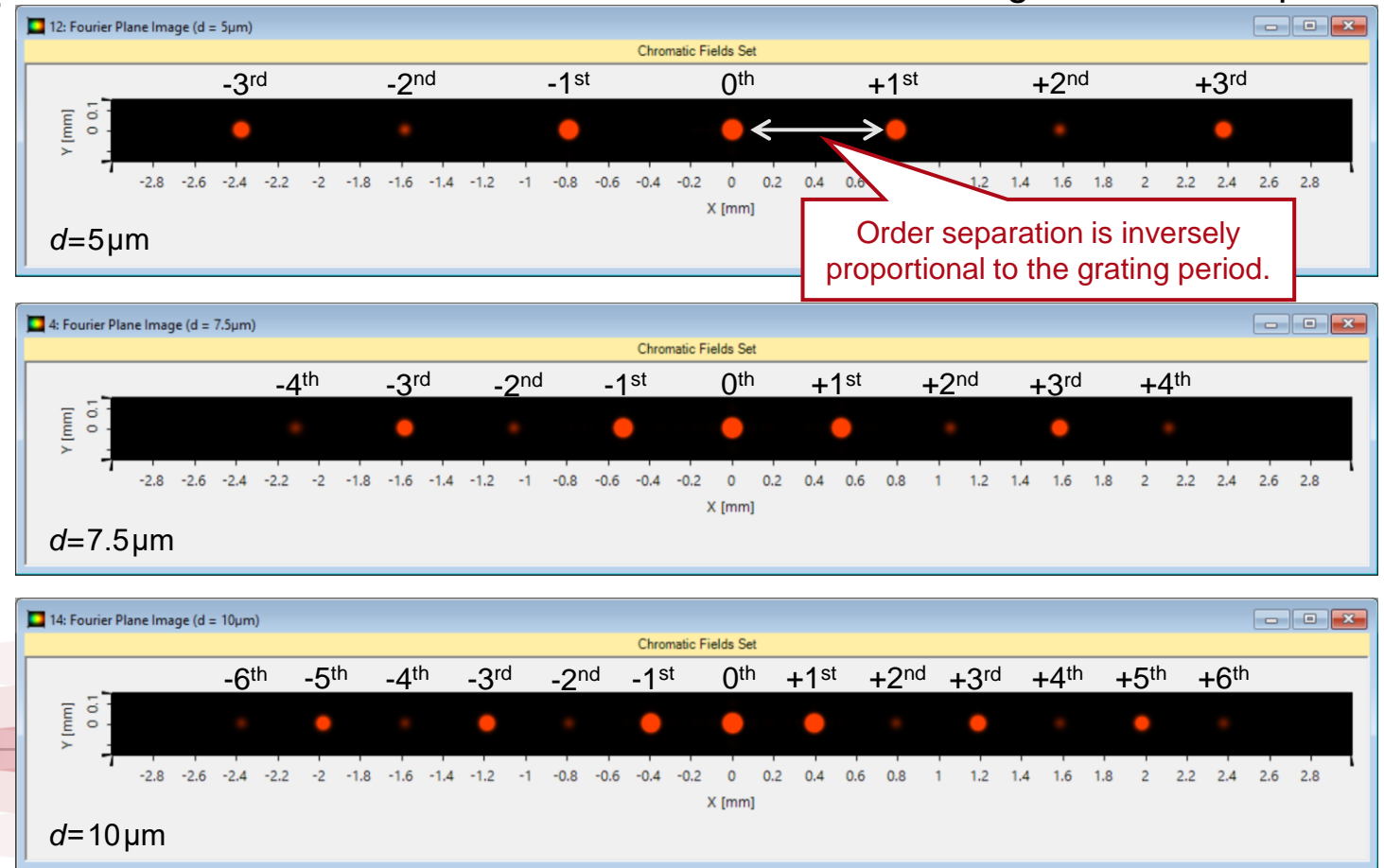
# Fourier Plane Images for Different Periods

## grating object

- thin chromium on substrate
- duty cycle 50%
- varying period  $d=5, 7.5, 10\mu\text{m}$



images on Fourier plane

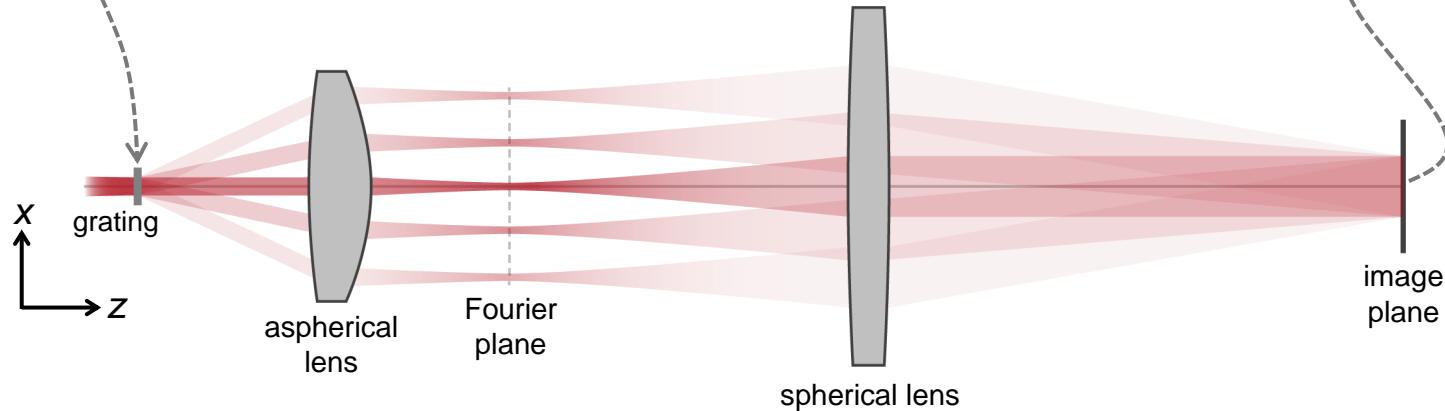
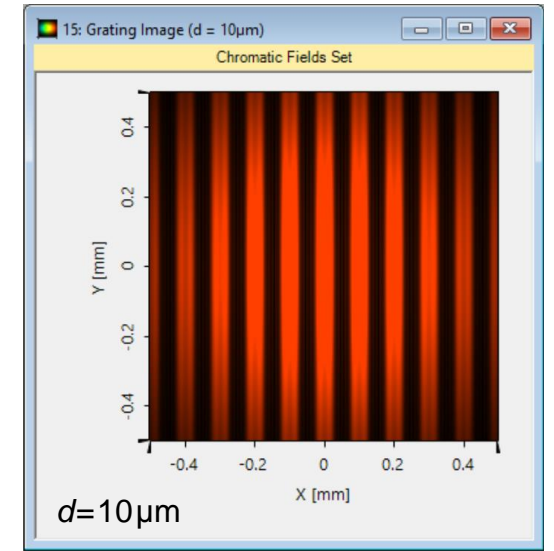
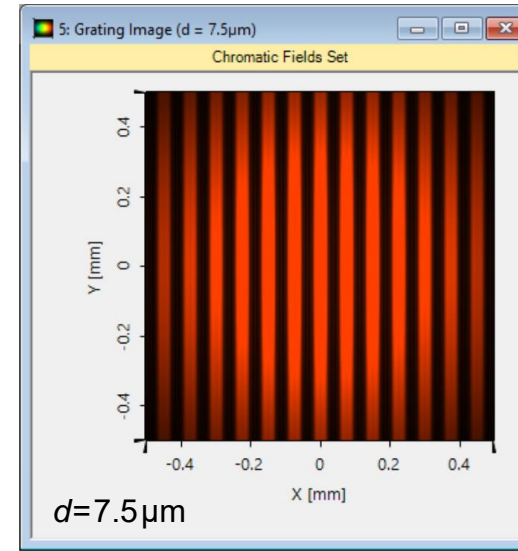
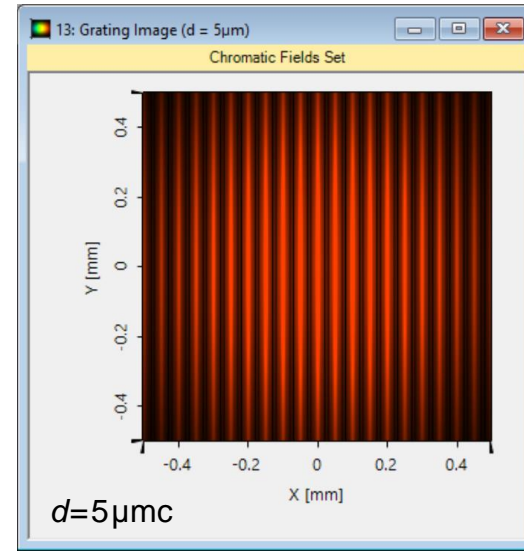
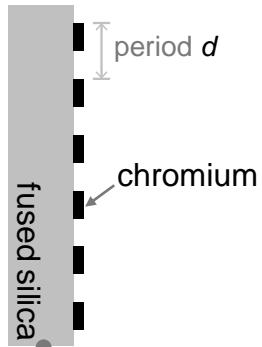


Grating efficiencies – corresponding to the spot brightness – are calculated by Fourier modal method (FMM, also known as RCWA).

# Grating Images for Different Periods

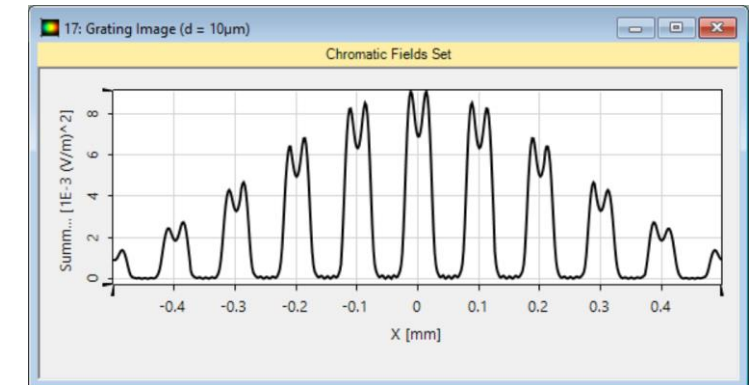
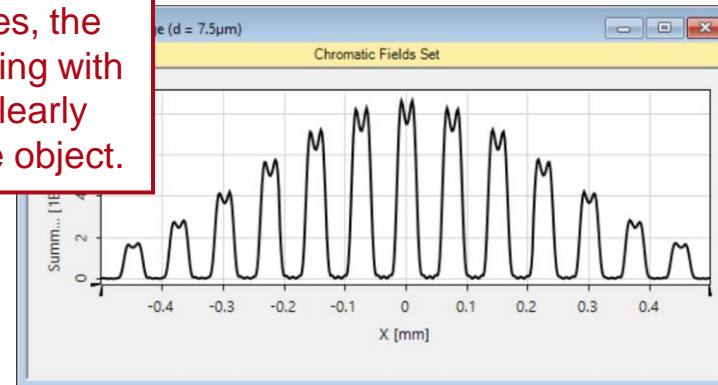
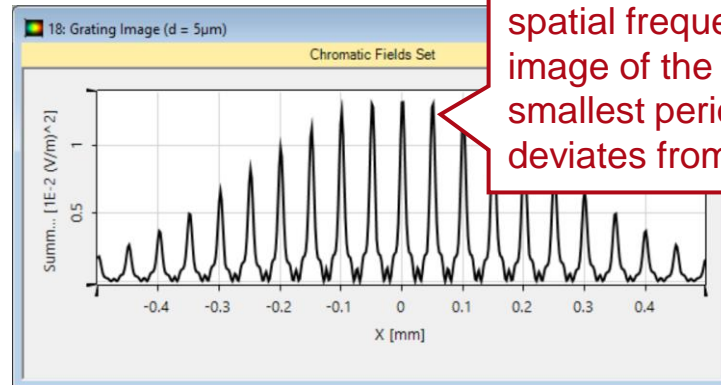
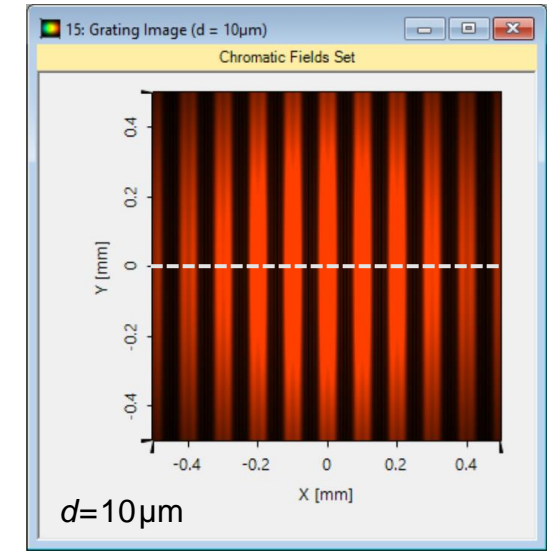
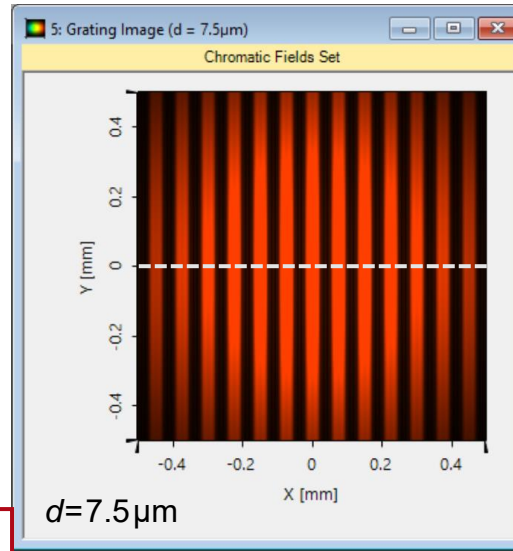
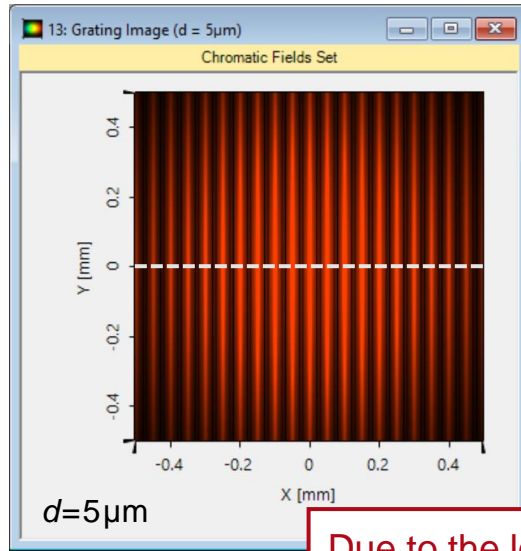
## grating object

- thin chromium on substrate
- duty cycle 50%
- varying period  $d=5, 7.5, 10\mu\text{m}$





# Grating Images for Different Periods

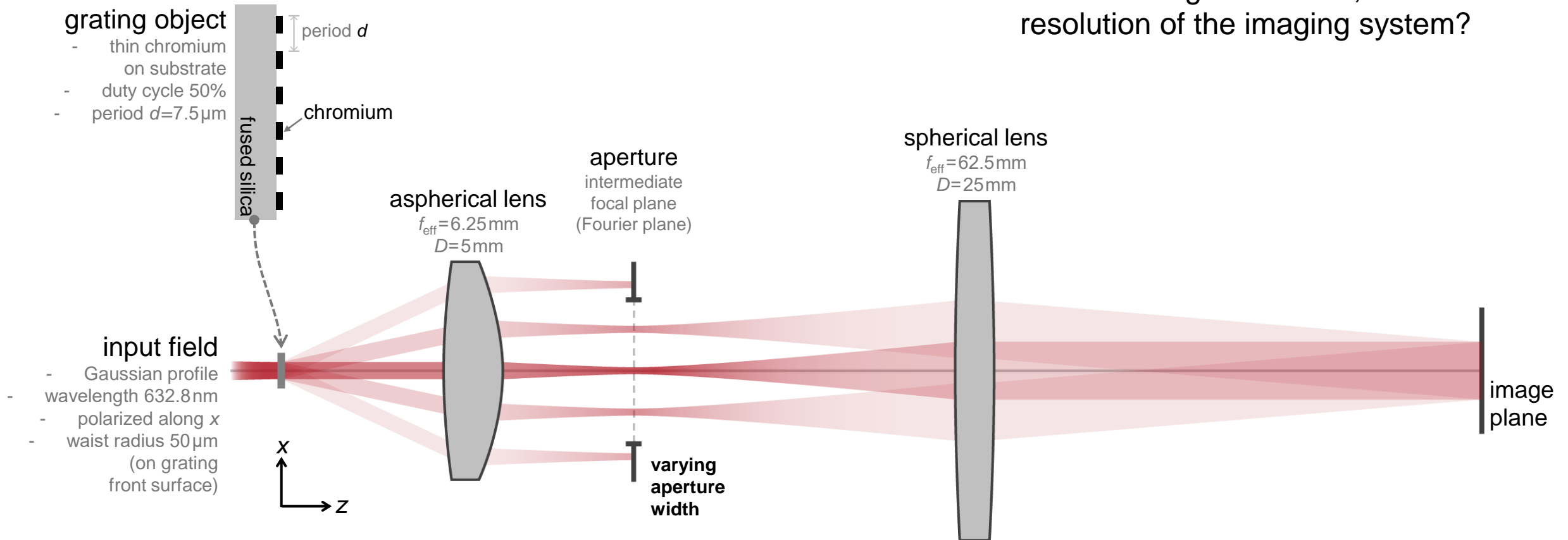


Due to the loss of high spatial frequencies, the image of the grating with smallest period clearly deviates from the object.



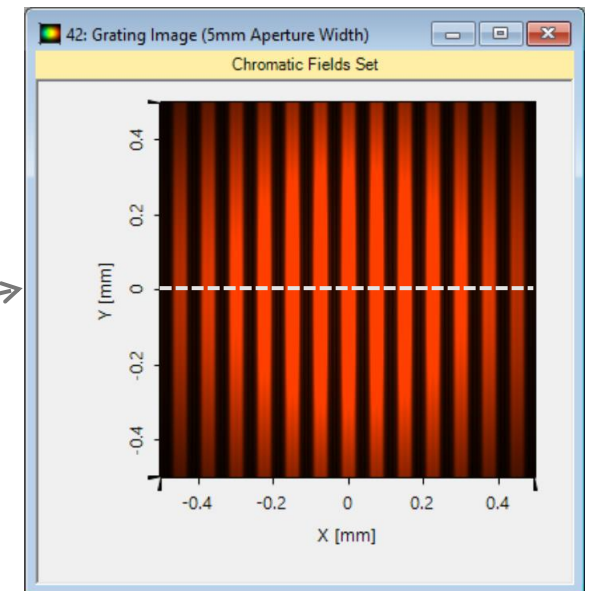
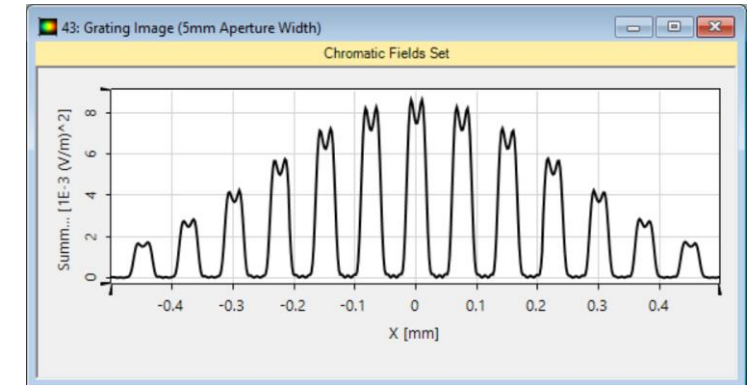
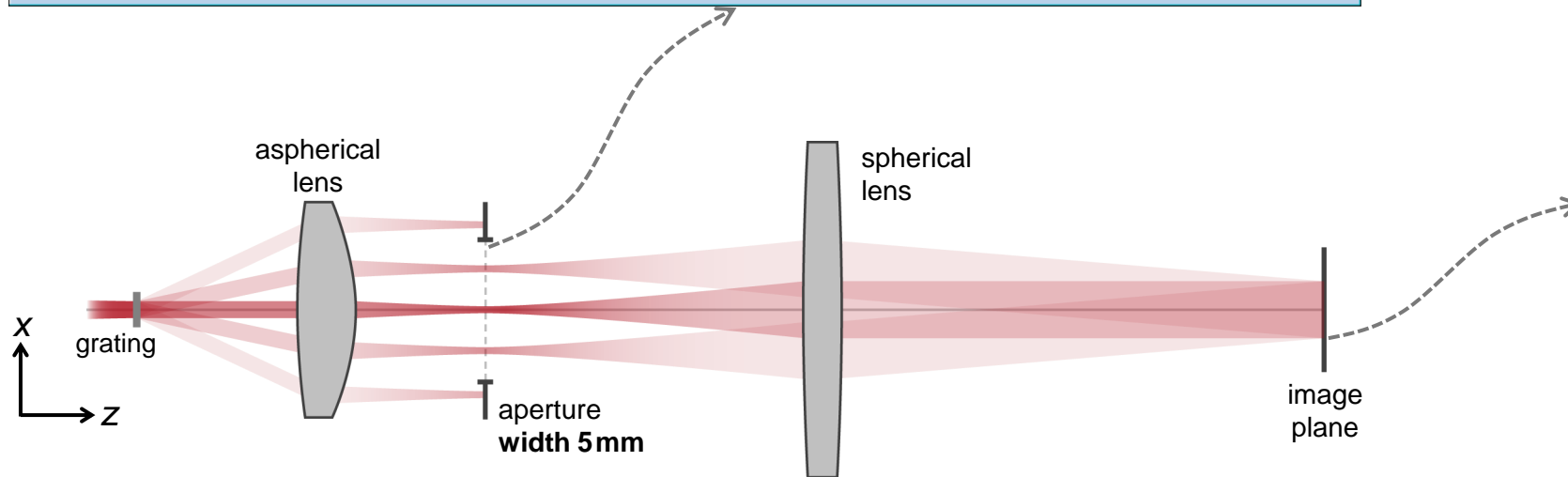
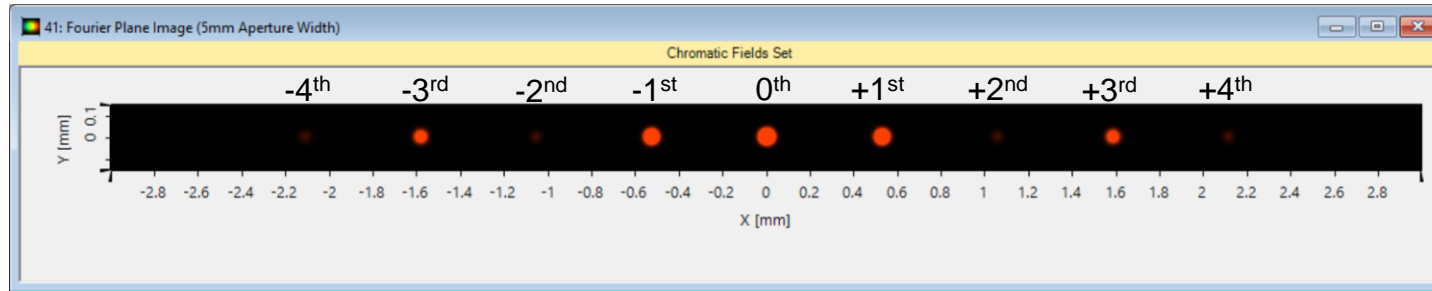
# Modeling Task – Aperture Effect in Fourier Plane

How can the aperture in the Fourier plane affect the image formation, and the resolution of the imaging system?



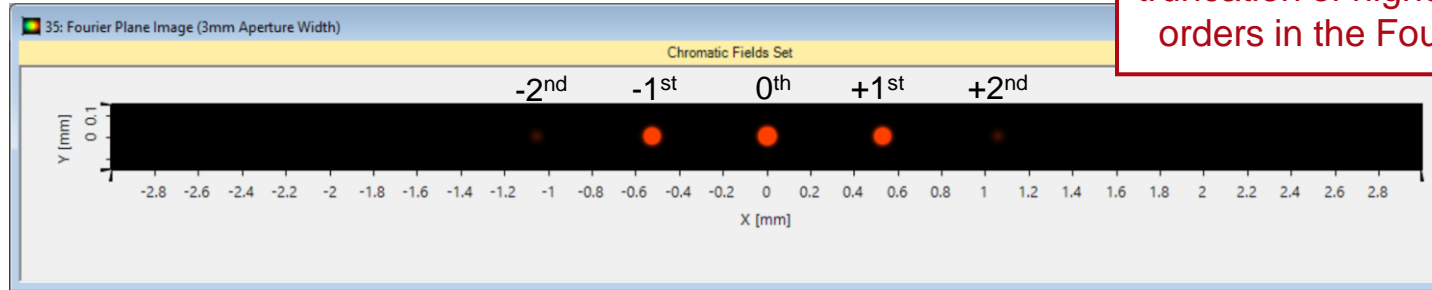
# Aperture Width 5mm

images on Fourier plane behind aperture

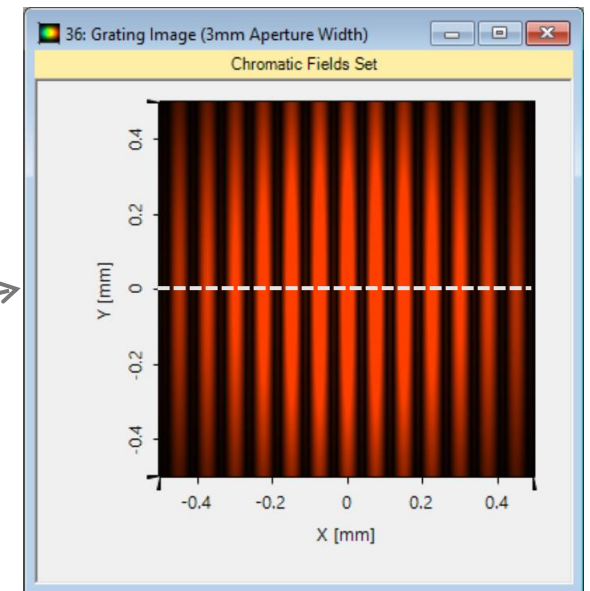
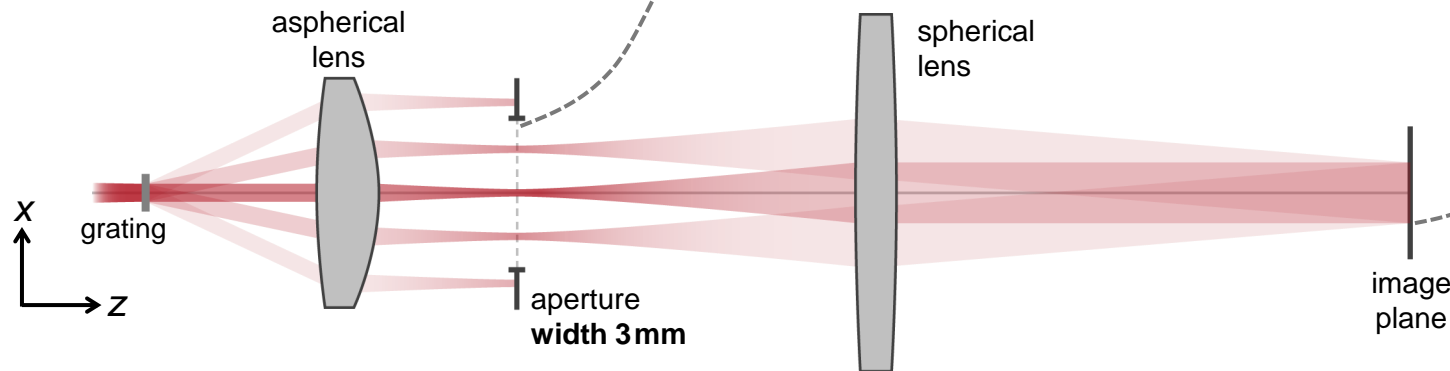
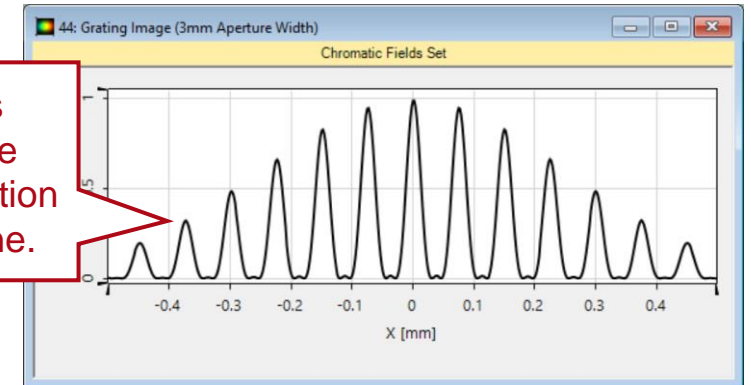


# Aperture Width 3mm

images on Fourier plane behind aperture

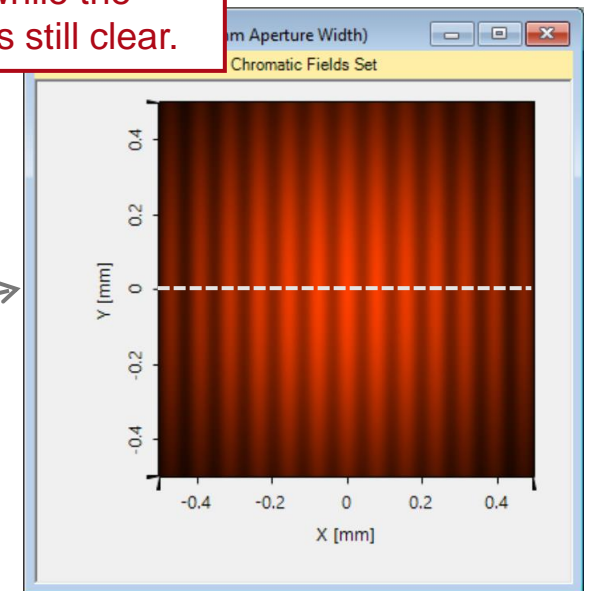
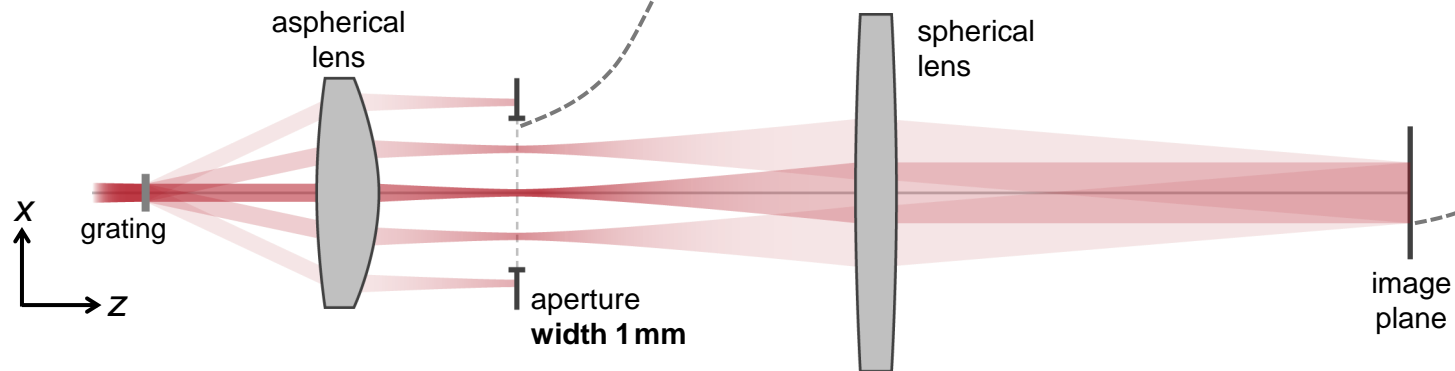
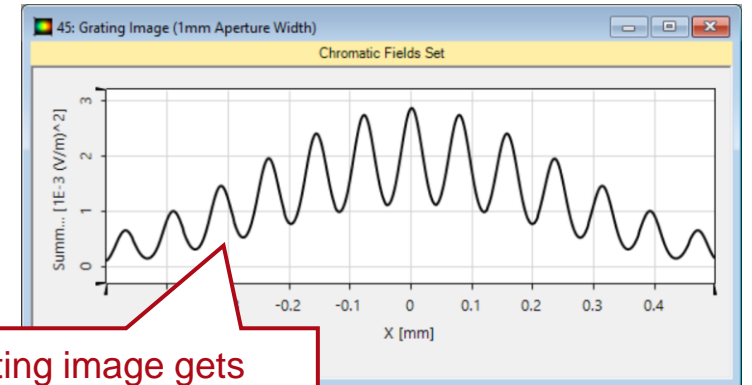
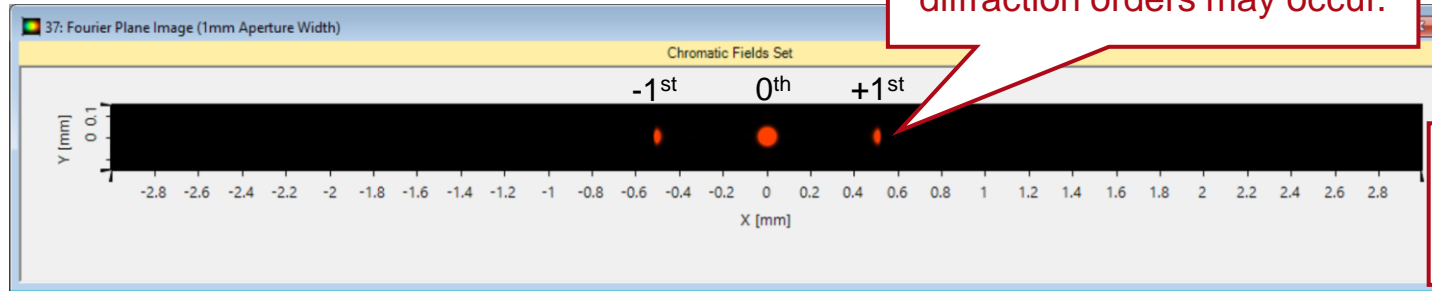


The grating image gets smoother because of the truncation of higher diffraction orders in the Fourier plane.



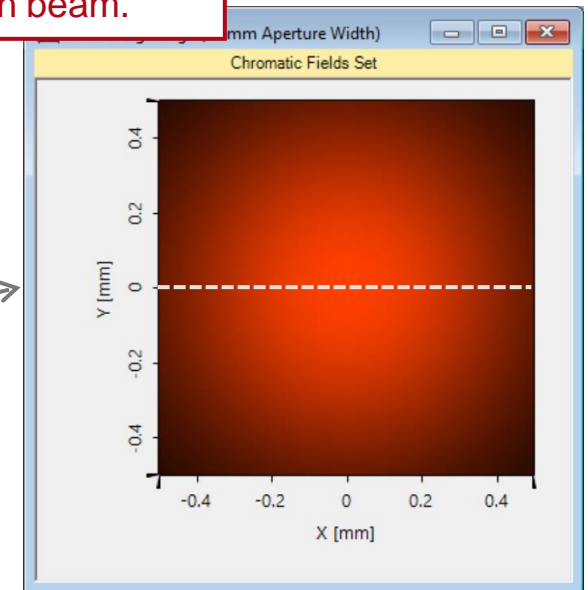
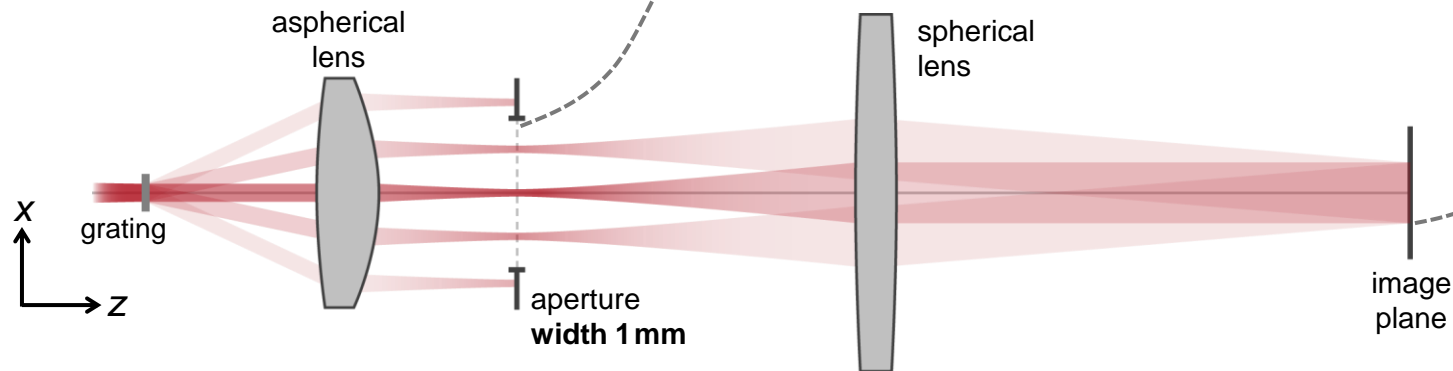
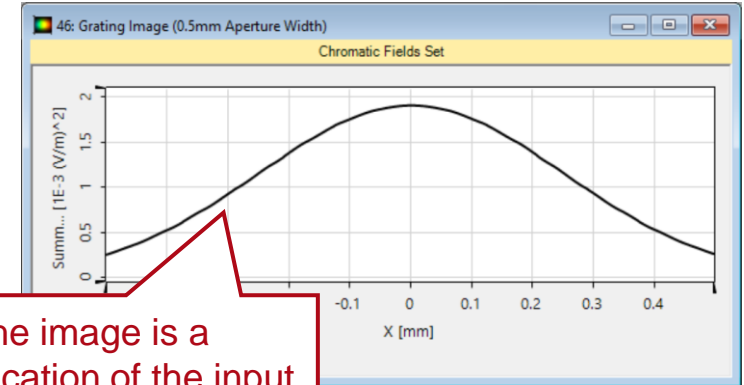
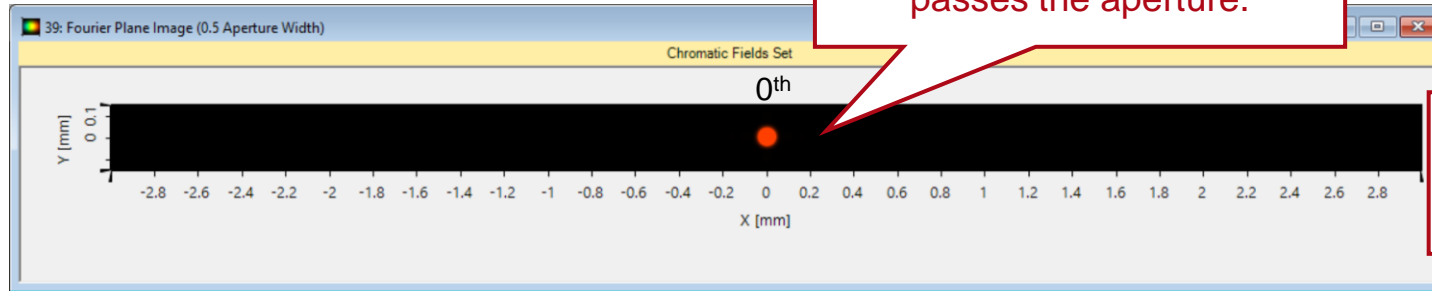
# Aperture Width 1 mm

images on Fourier plane behind aperture



# Aperture Width 0.5mm

images on Fourier plane behind aperture



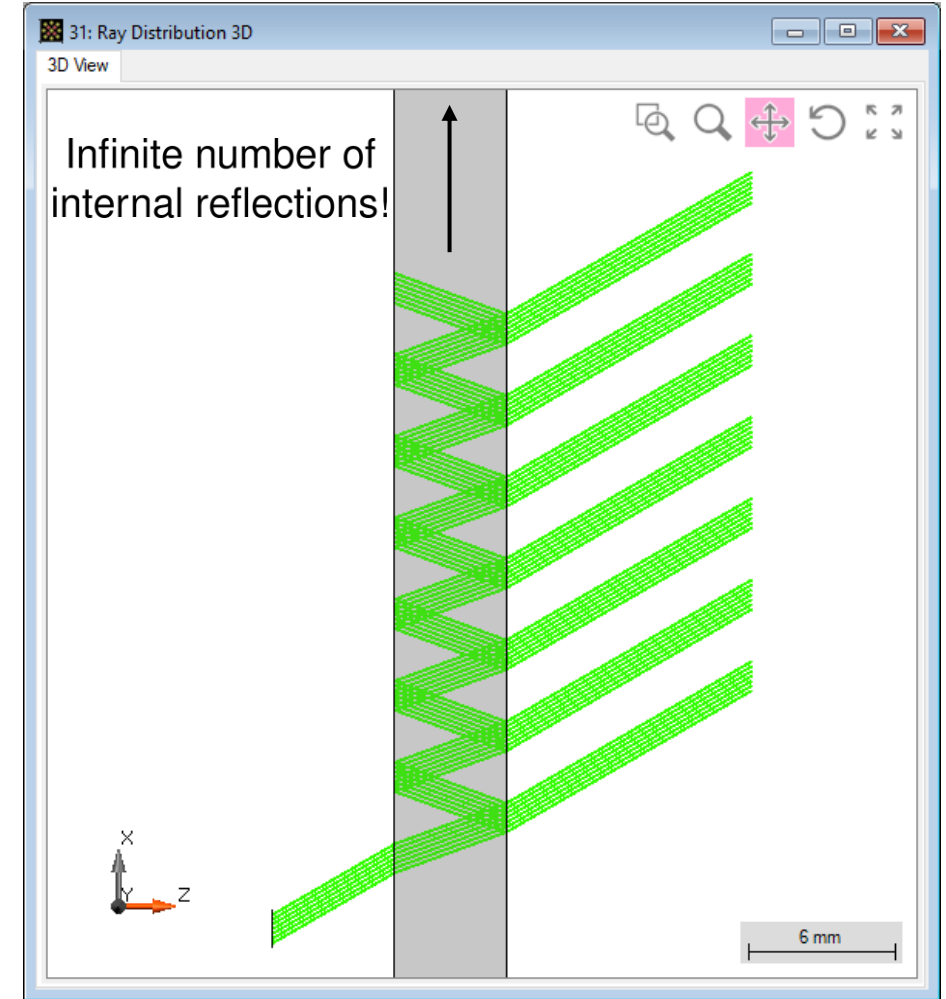
Part 5

## The Light Path Finder

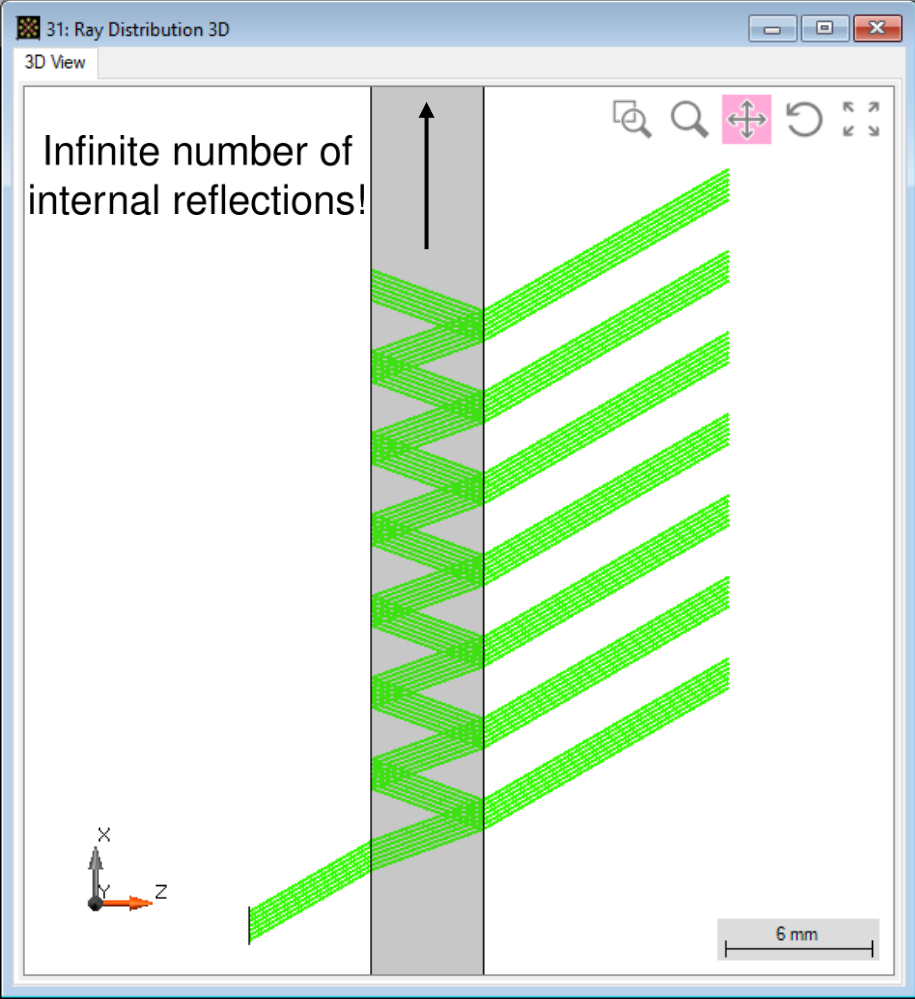
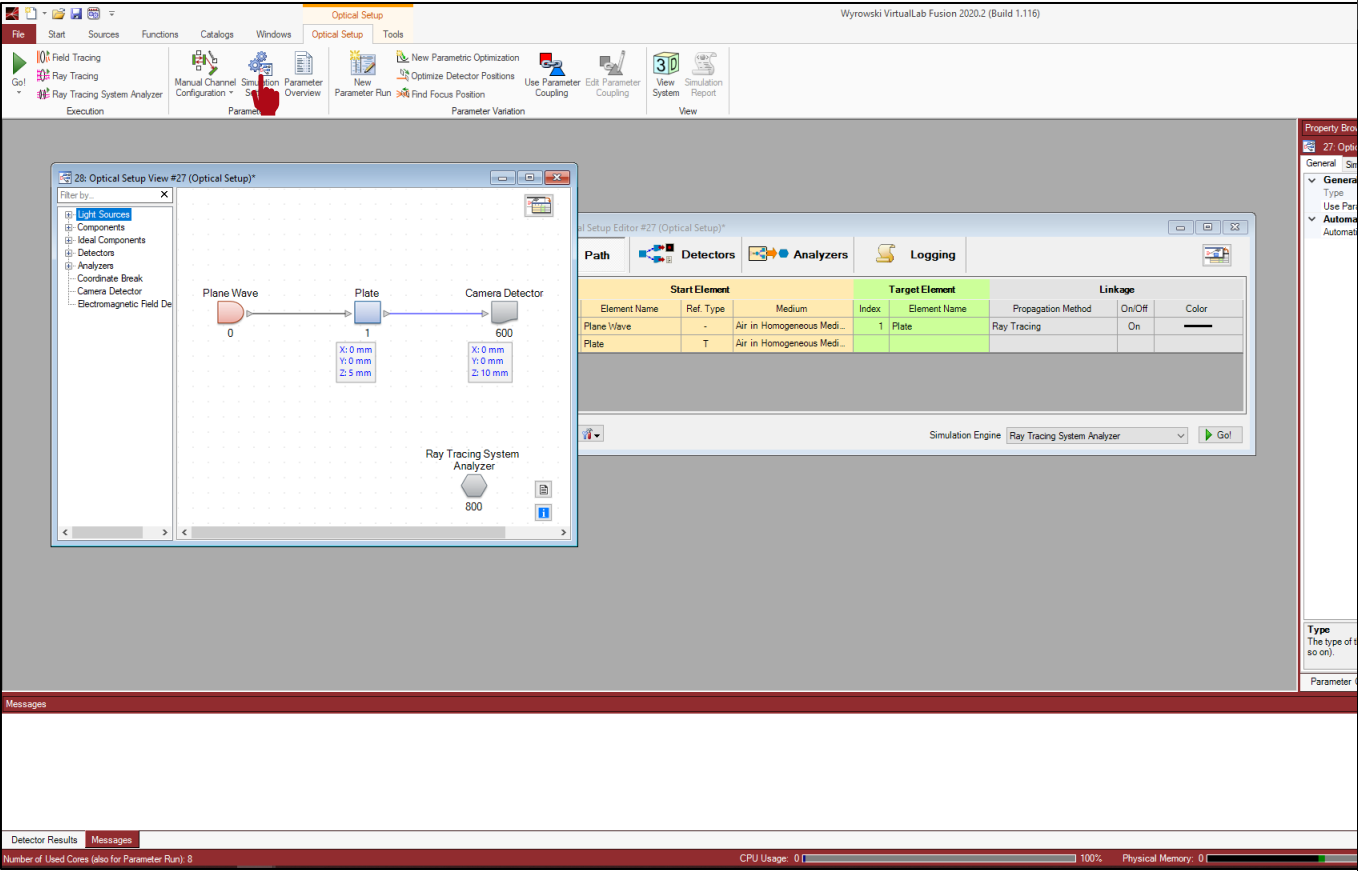


# The Light Path Finder

- The Light Path Finder performs a preliminary analysis of the open channels in the system and determines through which of them light will propagate and how.
- The Light Path Finder uses a physical-optics model without diffraction to analyse the system.
- After the Light Path Finder has determined the light paths that the field is going to follow, the Field Tracing engine takes over and simulates the fully fledged physical-optics propagation of the field along those paths.

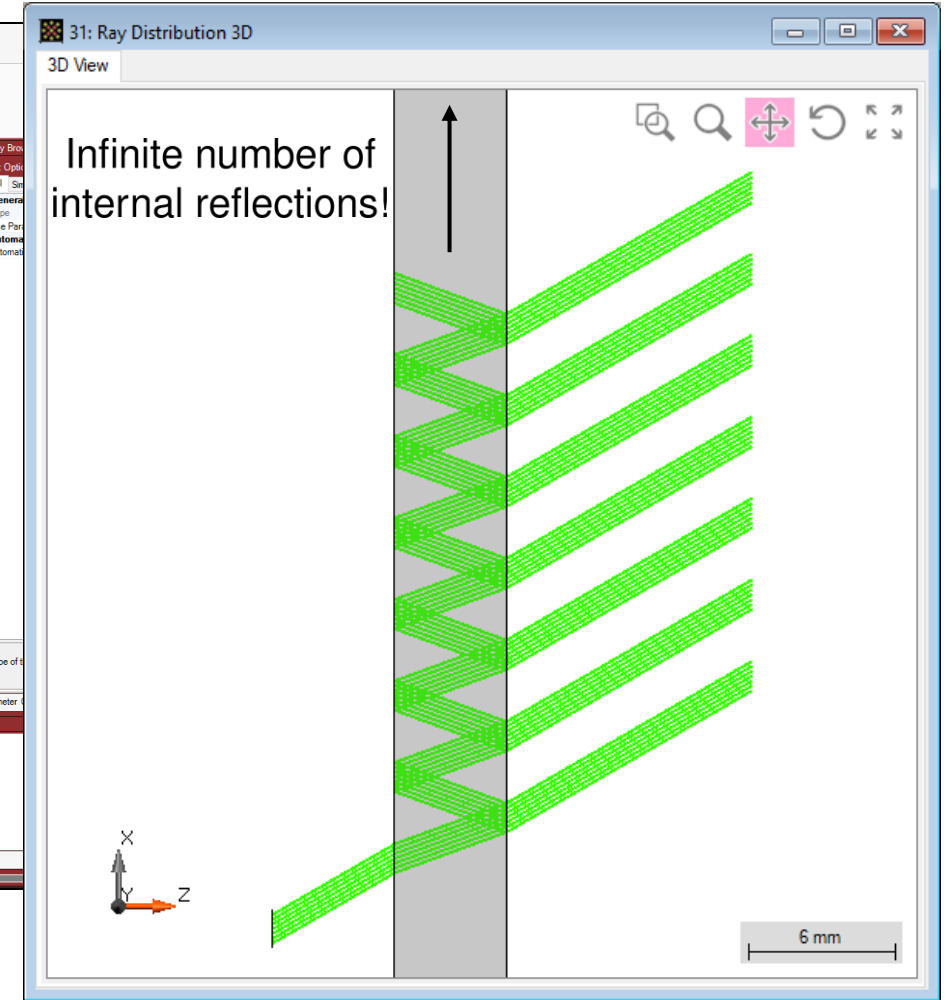
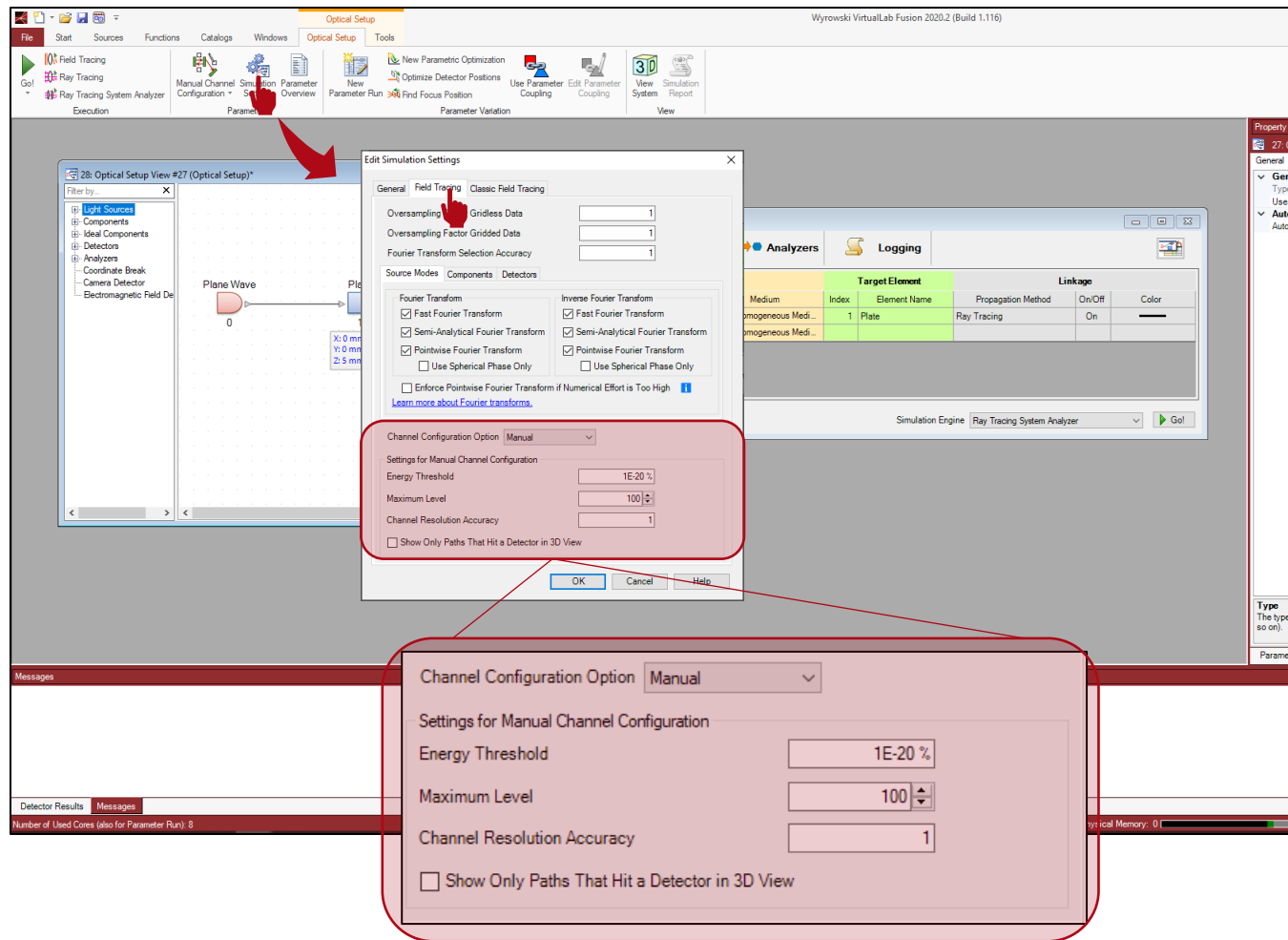


# The Light Path Finder

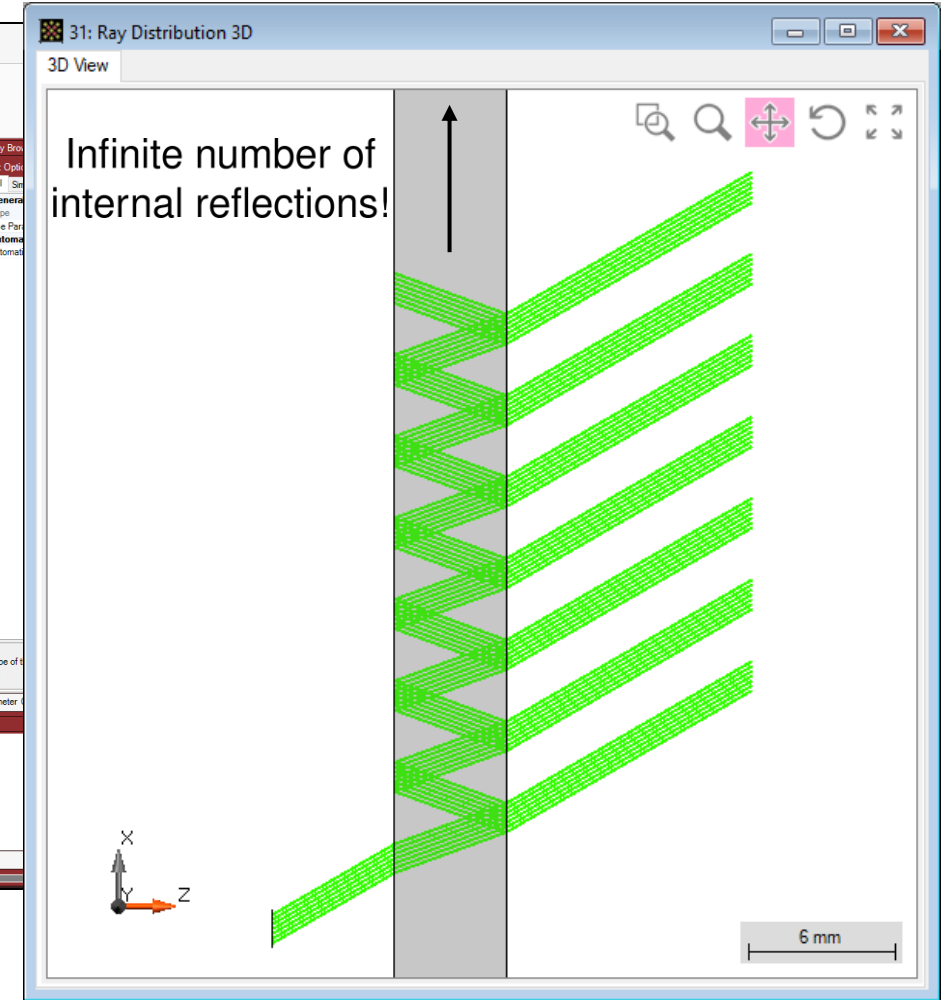
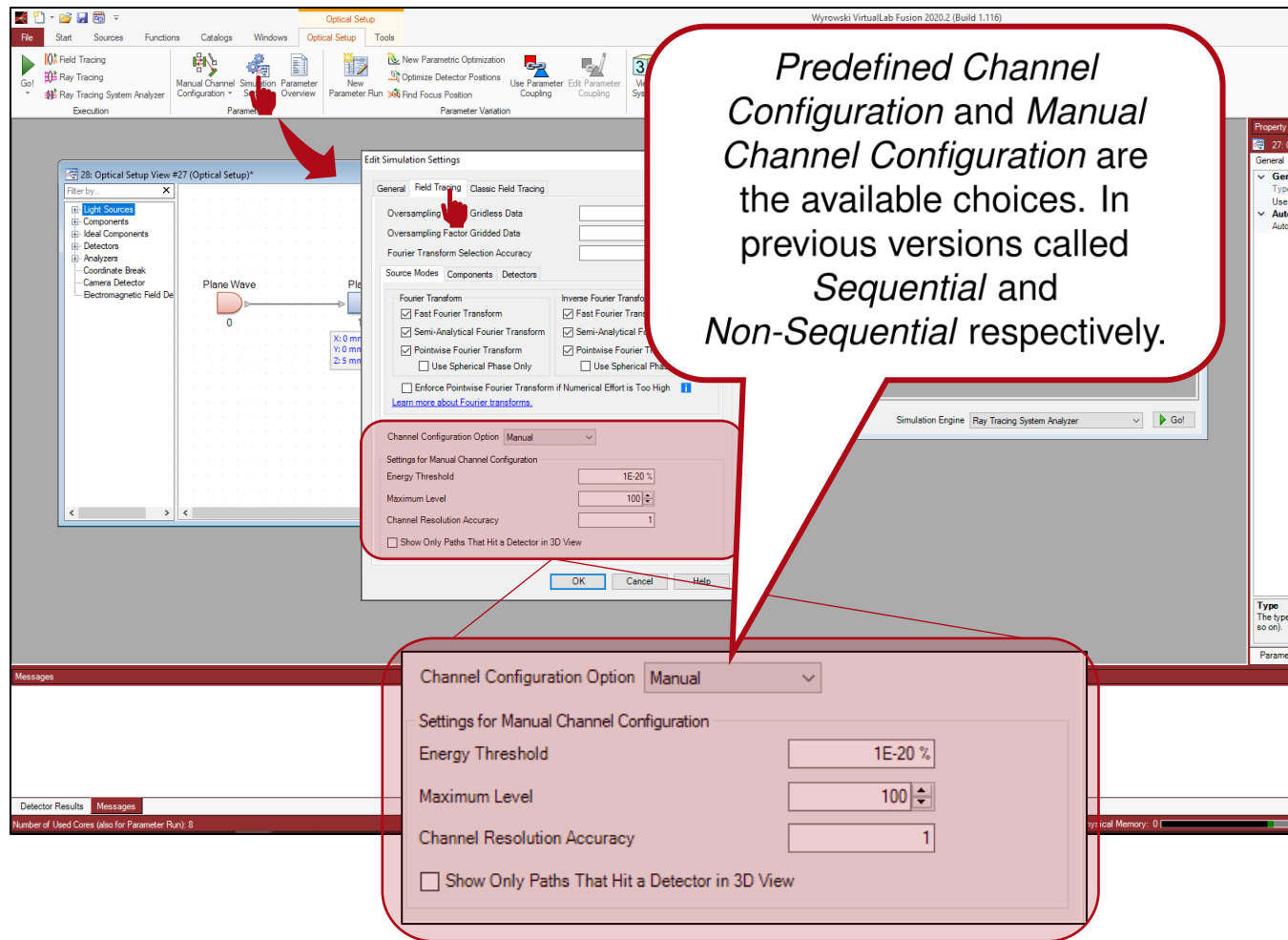




# The Light Path Finder



# The Light Path Finder



# The Light Path Finder

Every time the beam interacts with the interface, the energy is split between transmission and reflection, so that each subsequent mode carries ever less energy and is therefore less relevant to the final result!

Infinite number of internal reflections!

Channel Configuration Option: Manual

Settings for Manual Channel Configuration

Energy Threshold: 1E-20 %

Maximum Level: 100

Channel Resolution Accuracy: 1

☐ Show Only Paths That Hit a Detector in 3D View

31: Ray Distribution 3D

3D View

6 mm

# The Light Path Finder

The screenshot displays the Wyrowski VirtualLab Fusion 2020.2 (Build 1.116) interface. The 'Edit Simulation Settings' dialog is open, showing the 'Field Tracing' tab. The 'Channel Configuration Option' is set to 'Manual'. The 'Maximum Level' is set to 100, which is circled in red. The 'Energy Threshold' is set to 1E-20 % and the 'Channel Resolution Accuracy' is set to 1. The '31: Ray Distribution 3D' window shows a 3D view of the light path, with a zigzag pattern labeled 'level 1', 'level 2', 'level 3', and 'level 4'. The text 'Infinite number of internal reflections!' is displayed in the 3D view. A scale bar indicates 6 mm.

**Edit Simulation Settings**

General Field Tracing Classic Field Tracing

Oversampling Gridless Data 1

Oversampling Factor Gridded Data 1

Fourier Transform Selection Accuracy 1

Source Modes Components Detectors

Fourier Transform

☒ Fast Fourier Transform ☒ Fast Fourier Transform

☒ Semi-Analytical Fourier Transform ☒ Semi-Analytical Fourier Transform

☒ Pointwise Fourier Transform ☒ Pointwise Fourier Transform

☐ Use Spherical Phase Only ☐ Use Spherical Phase Only

☐ Enforce Pointwise Fourier Transform if Numerical Effort is Too High [Learn more about Fourier transforms.](#)

Channel Configuration Option Manual

Settings for Manual Channel Configuration

Energy Threshold 1E-20 %

Maximum Level 100

Channel Resolution Accuracy 1

☐ Show Only Paths That Hit a Detector in 3D View

**31: Ray Distribution 3D**

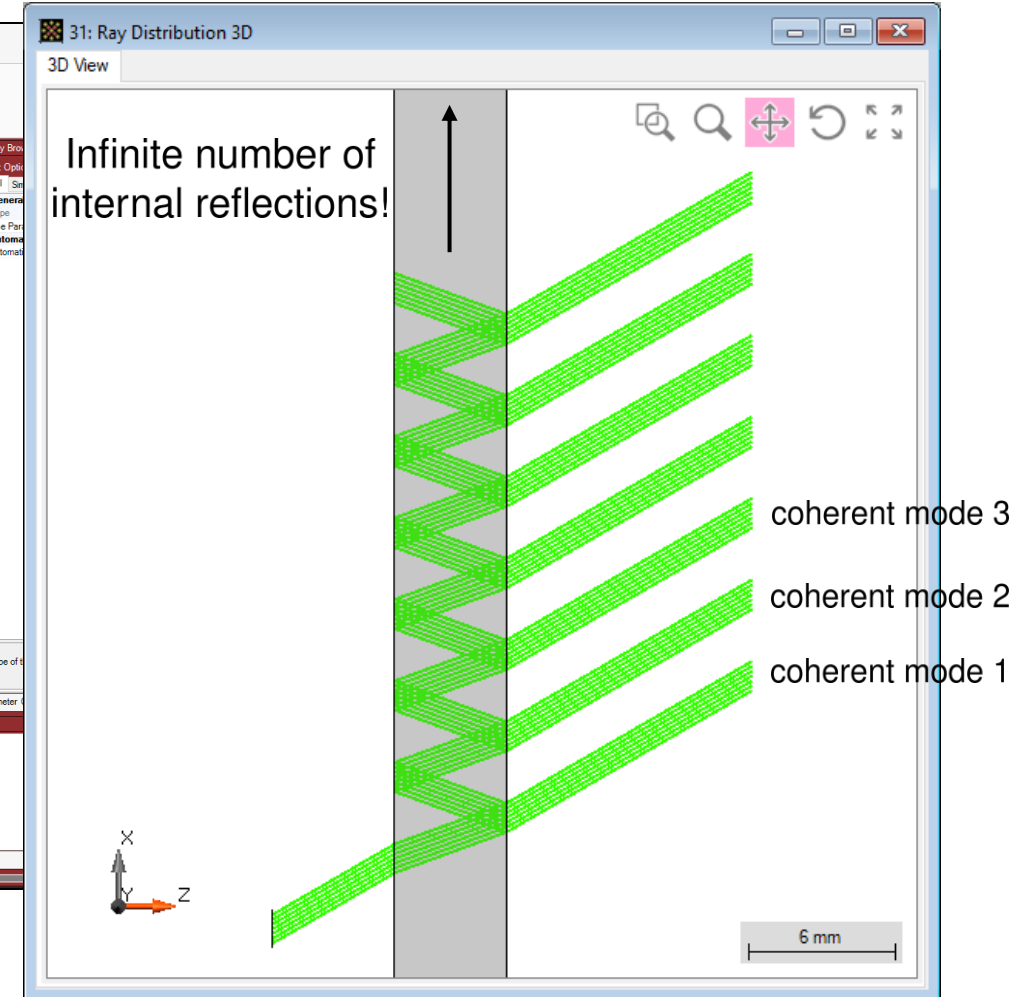
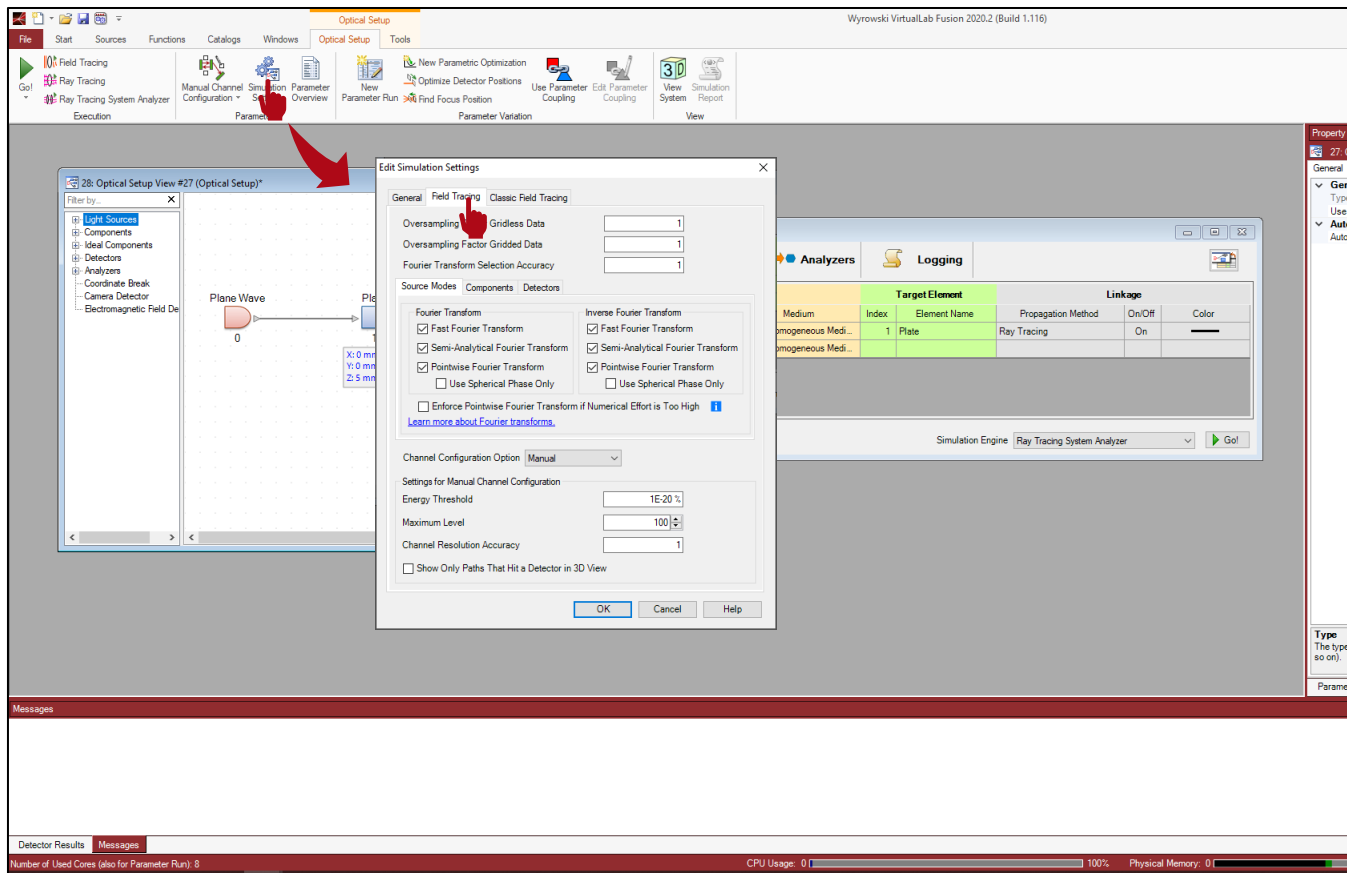
3D View

Infinite number of internal reflections!

level 1 level 2 level 3 level 4

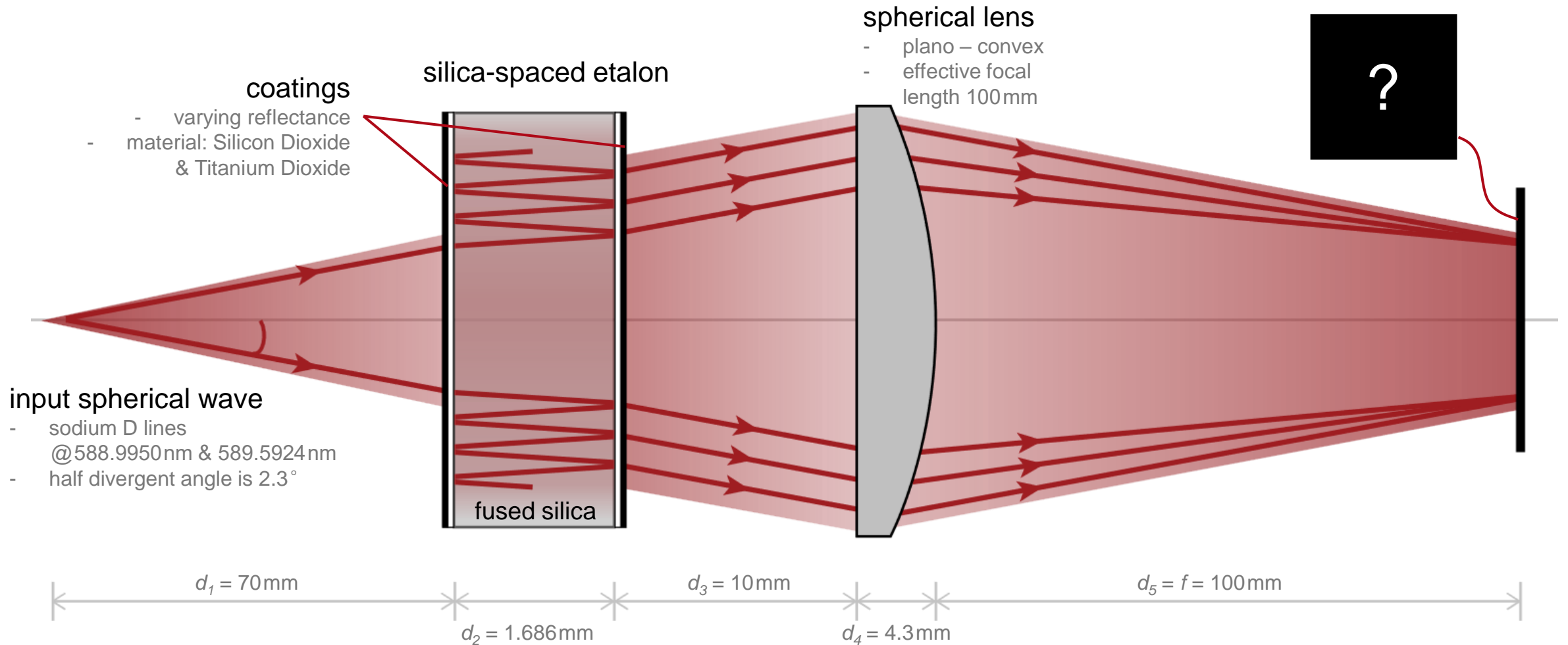
6 mm

# The Light Path Finder and the Modes Reaching the Detector

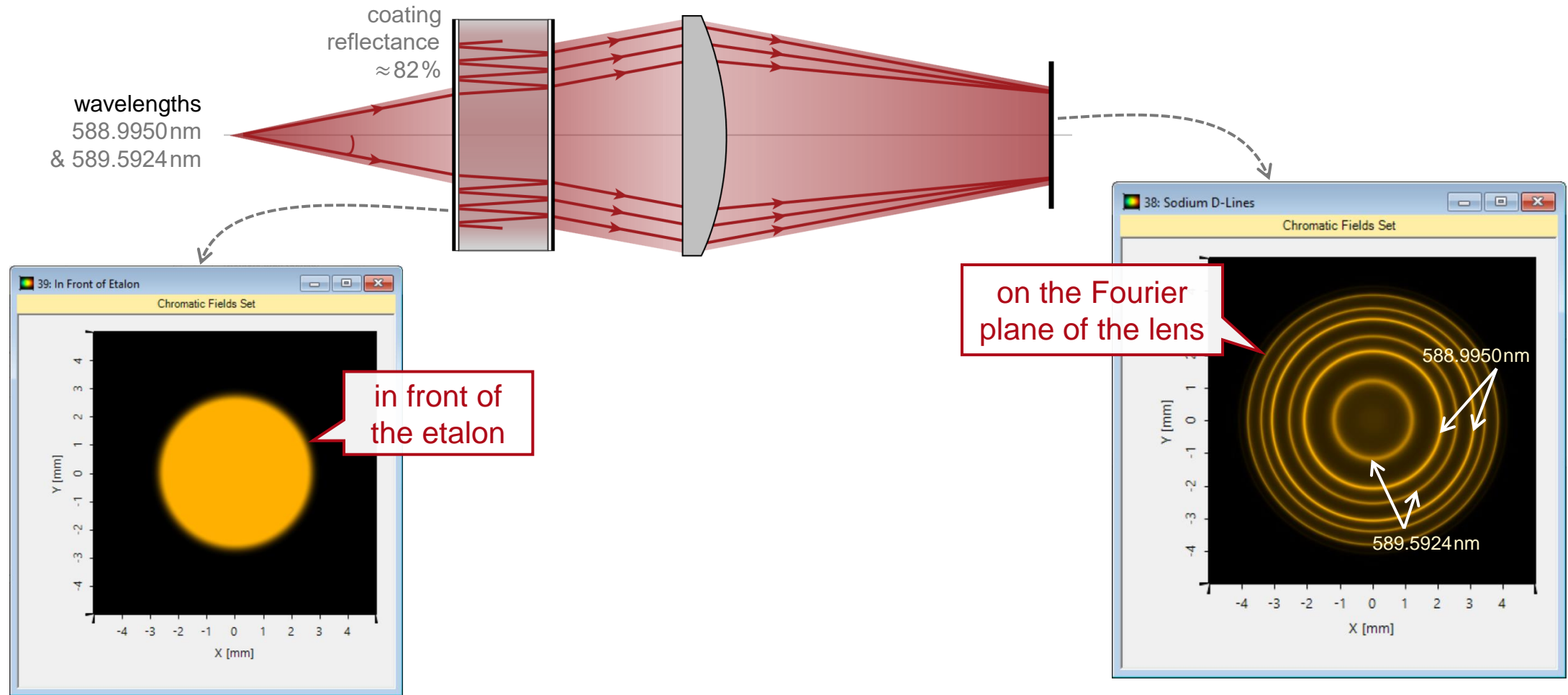


# Examination of Sodium D Lines with Fabry-Pérot Etalon

# Modeling Task

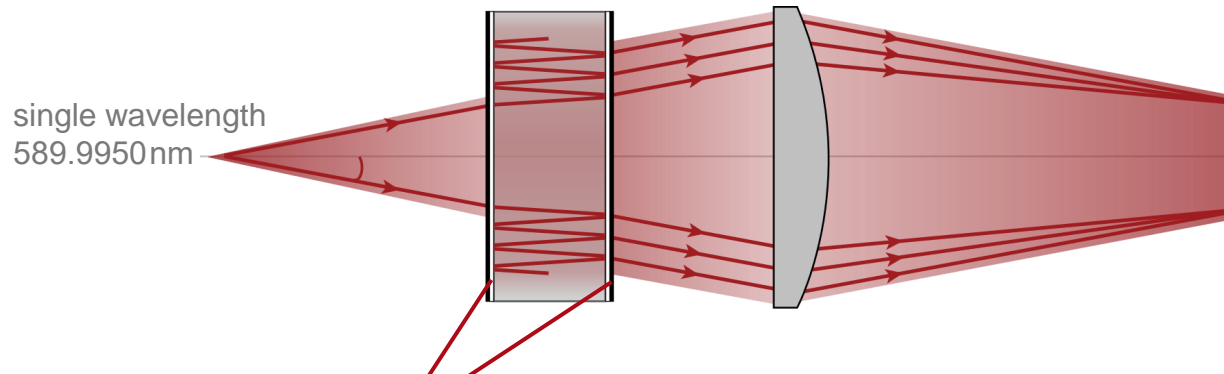


# Visualization of Both Spectrum Lines





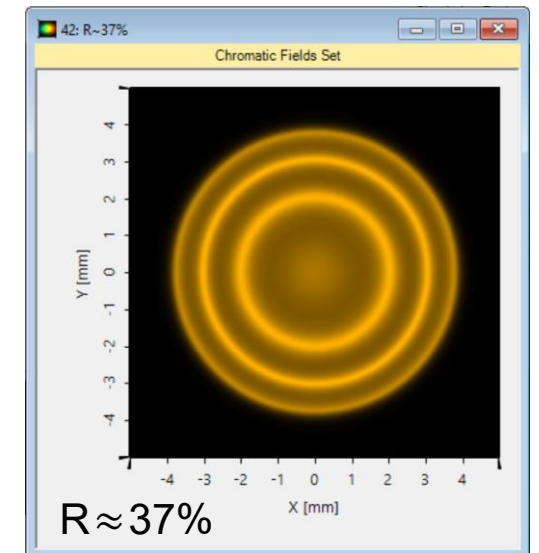
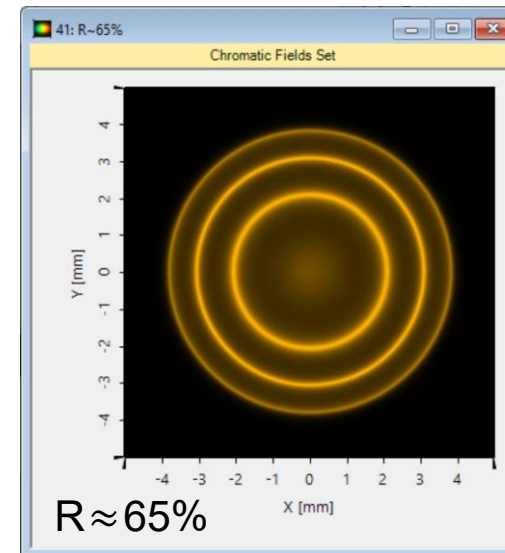
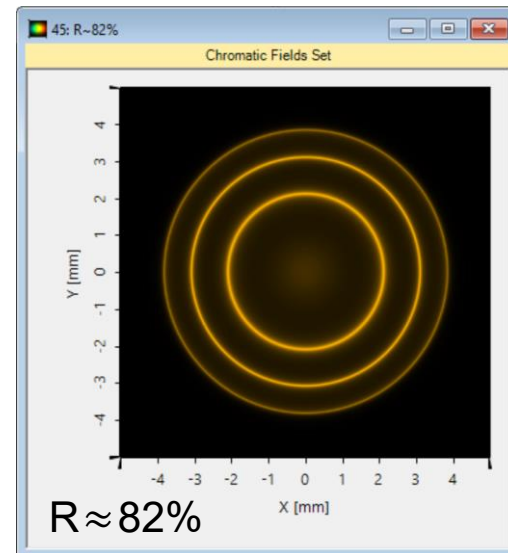
# Finesse vs. Coating Reflectance



Sharpness of the interference fringes depends on the reflectance of the coatings on the etalon.

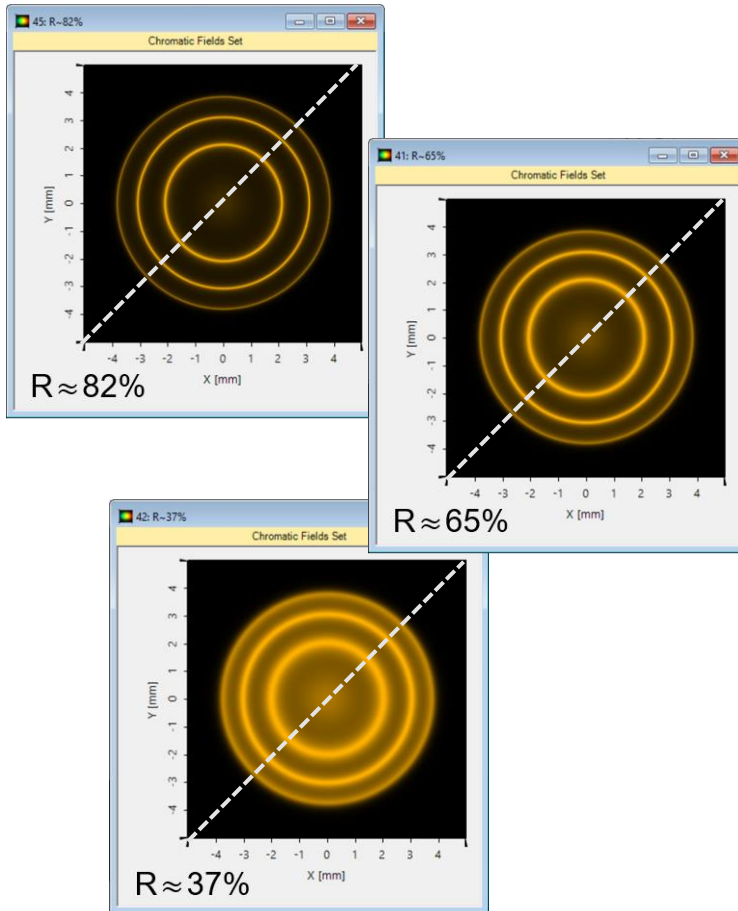
coatings

- varying reflectance:  
82%, 65%, 37%

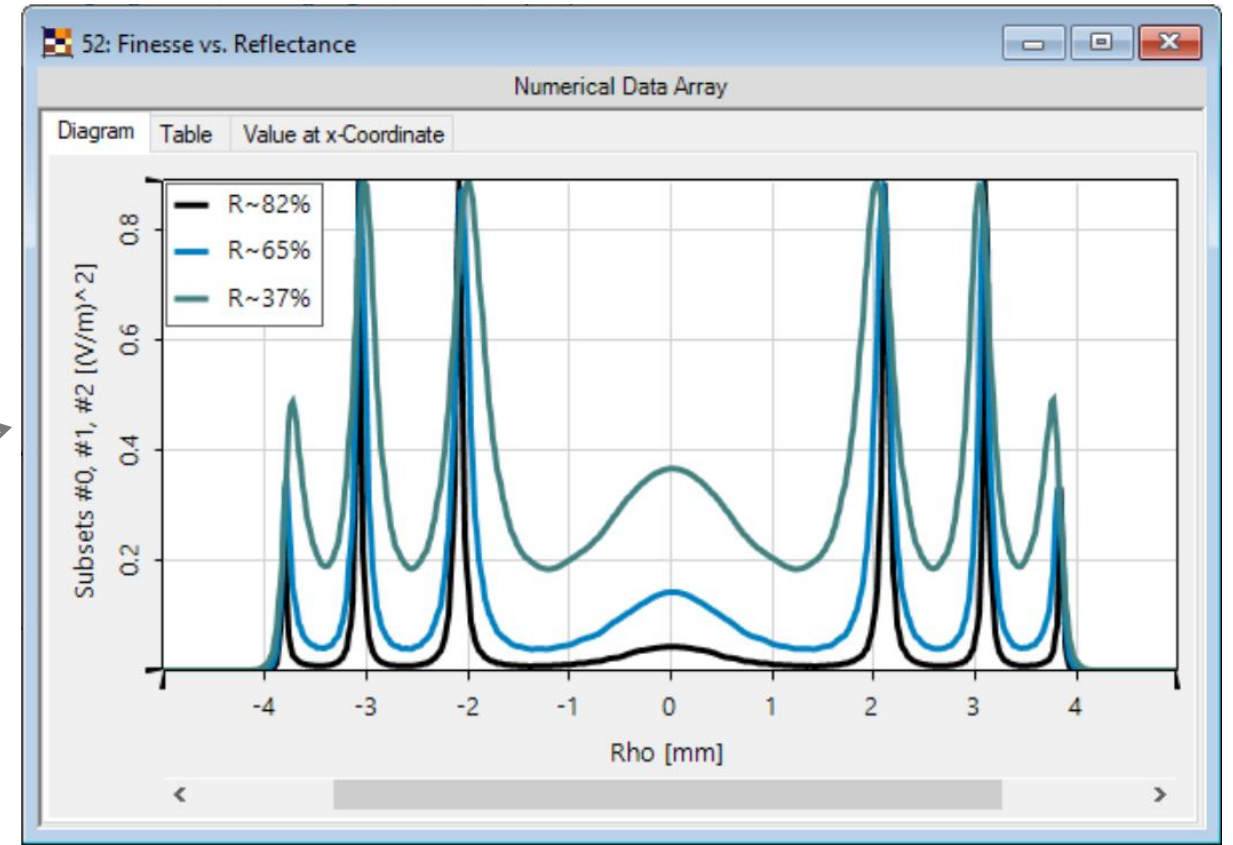


# Finesse vs. Coating Reflectance

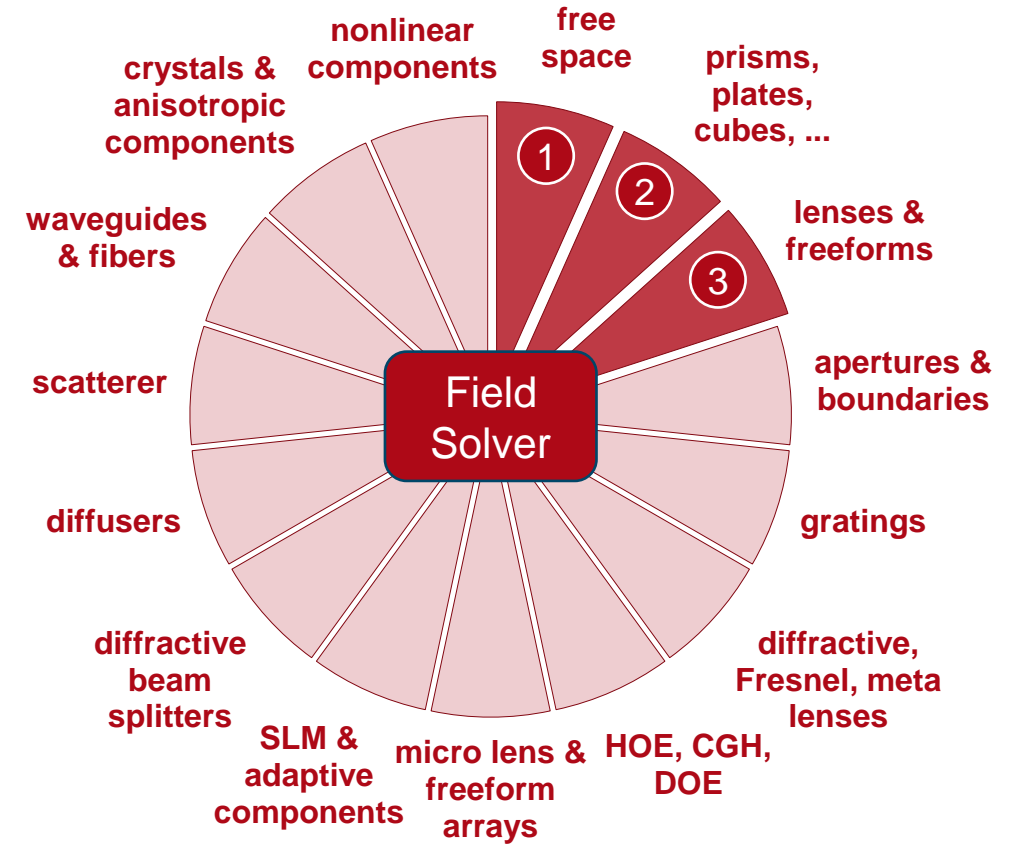
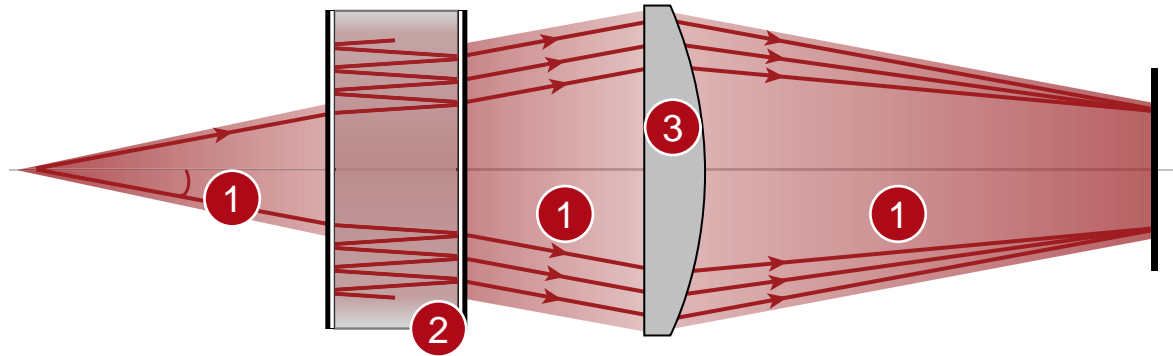
the higher the reflectance, the higher the finesse



1D measurements along the radial direction



# VirtualLab Fusion Technologies



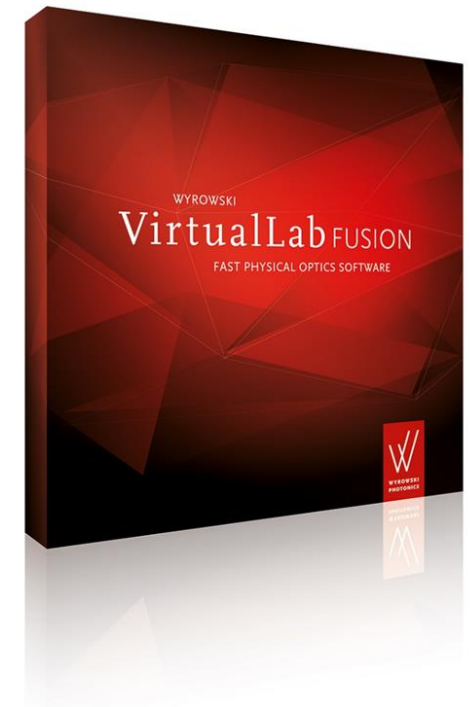
Part 6

## The Source Mode Concept



# How to Model the Different Properties of Light?

- Being able to replicate the physical **properties of the light** that enters a system is just as important for an optical simulation as being able to model the effect of the different components on the field.
- We are mainly talking about **polarization**, partial **temporal coherence**, partial **spatial coherence**.
- There are different mathematical strategies available.
- In VirtualLab Fusion we follow a single general approach which can be applied to the simulation of all these characteristics: the **source-mode concept**.



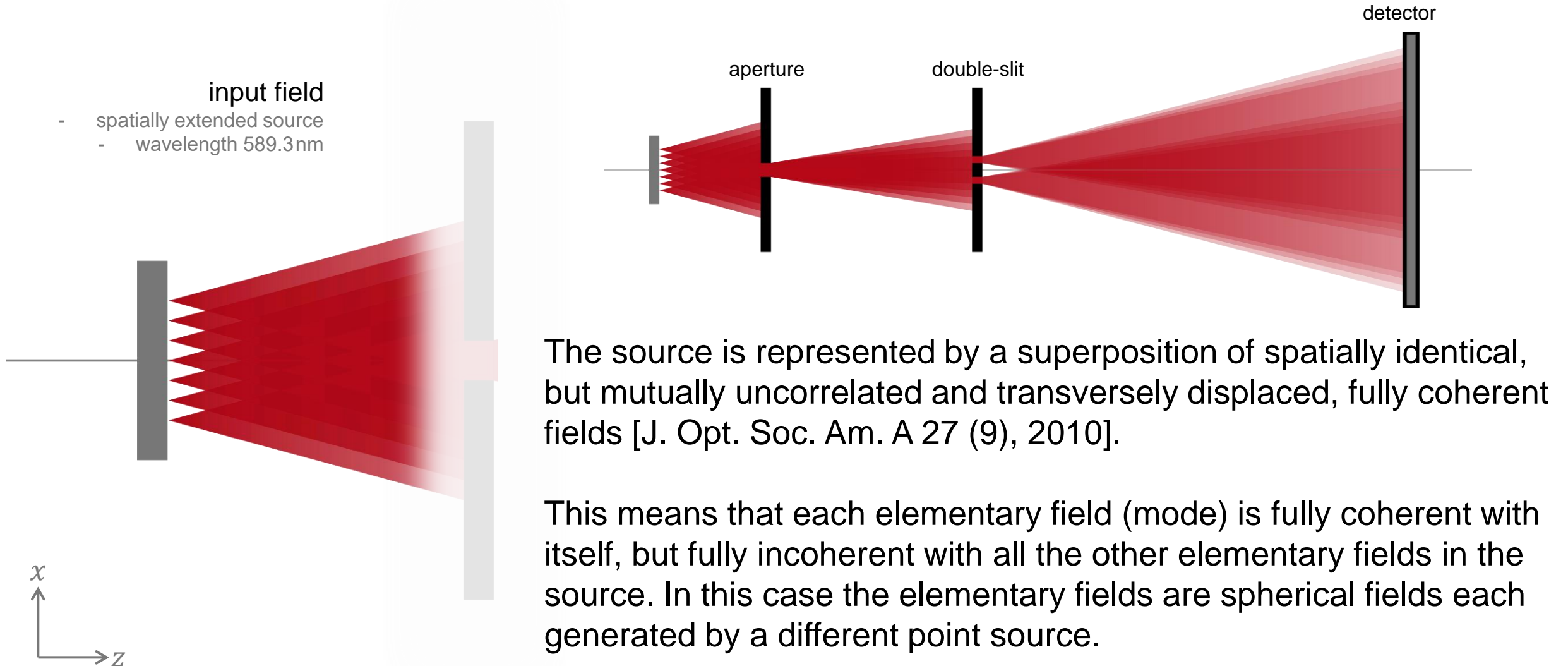
# The Source Mode Concept

---

- The light at the input plane of the system is represented by a finite set of modes.
  - **Each of the modes is fully self-correlated.** This means that, if a source mode is split on its way through the system (for instance, by being partly transmitted and partly reflected at an interface) each of the resulting modes will be coherent to each other, and therefore capable of generating an interference pattern.
  - **Each of the source modes can be coherent or incoherent to each of the other source modes,** depending on the property to be modelled and the characteristics of the source.
  - There are different types of modes: spectral (wavelength) and spatial.
  - **Finding the best set of modes for a given source in a given system is in general not a trivial task!**
-

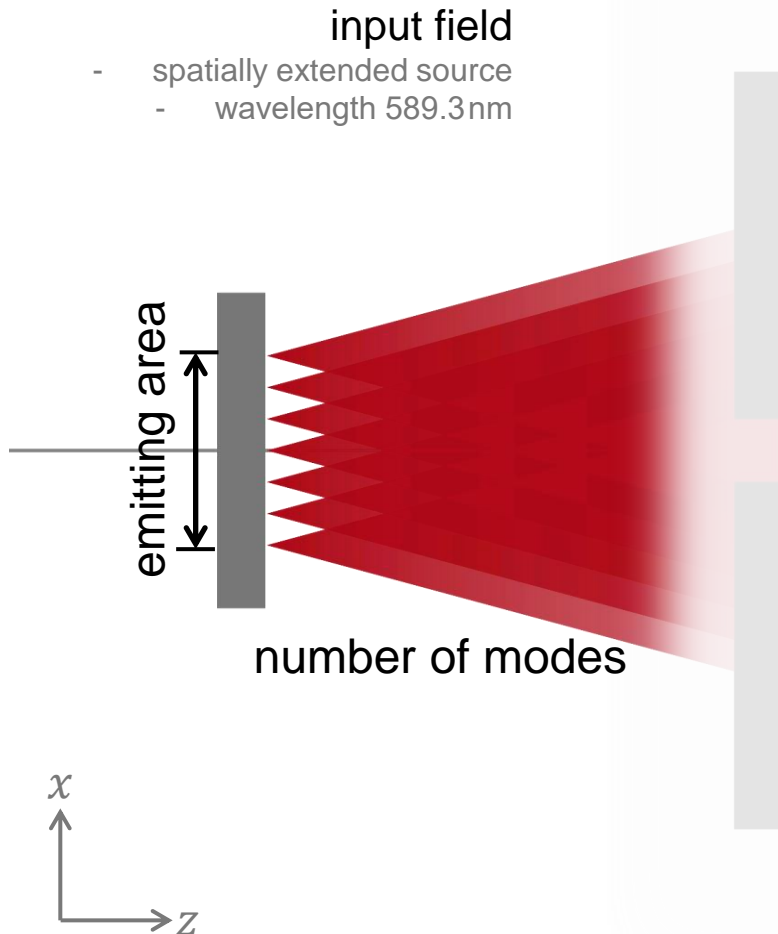
# **Partial Spatial Coherence with Shifted Elementary Field Method**

# Shifted Elementary-Field Method





# Number of Elementary-Fields (Modes)



- The emitting area is fixed at  $800\mu\text{m}$ . The point source at the edge of this emitting area gives a weak interference pattern, which is negligible.
- The number of elementary fields (modes) should be large enough to achieve convergent and reliable results.
- So before performing the simulation, **we use a one-dimensional (1D) list of point sources along the x axis to check how many modes give convergent fringes along said axis in the detector.**
- To keep the power of the source constant, the power weight of each point source decreases as the number of modes increases.

$$\text{weight} = \frac{1.0}{\text{number of modes}}$$

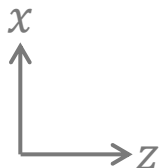
# Configuration of Parameter Variation

input field

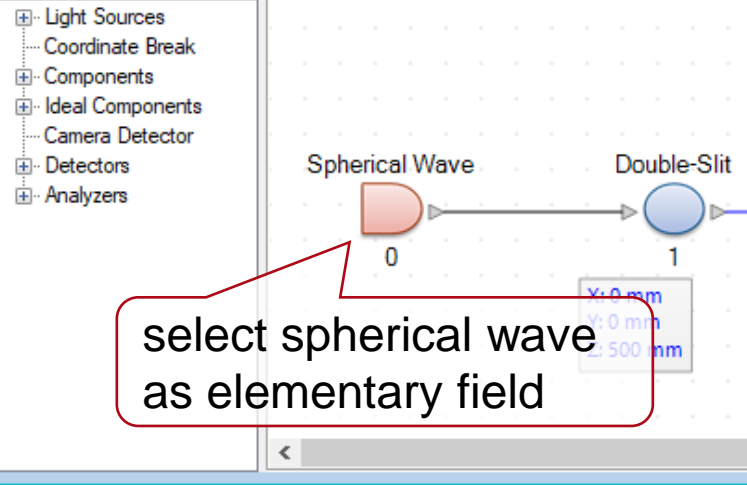
- spatially extended source
- wavelength 589.3nm

emitting area

number of modes



optical setup



editor of spherical wave

The dialog box has tabs for Polarization, Mode Selection, Sampling, and Ray Selection. The 'Basic Parameters' tab is active. It shows 'Medium at Source Plane' as 'Air in Homogeneous Medium'. The 'Source Field: Longitudinal and Lateral Offset' section has 'Distance to Input Plane' set to 10 mm and 'Lateral Offset' set to -55 μm. A red callout box points to the Lateral Offset field with the text 'position of source point on x axis'.

Parameter Run

1	2	*	Object	Category	Parameter	Vary	From	To	Steps	Original Value
					Distance to Input...	<input type="checkbox"/>	-1E+303 mm	1E+303 mm	1	10 mm
					Lateral Offset X	<input checked="" type="checkbox"/>	-400 μm	400 μm	5	0 mm
					Lateral Offset Y	<input type="checkbox"/>	1E+303 mm	1E+303 mm	1	0 mm
					Number of Rays X	<input type="checkbox"/>	1	2E+03	1	31
					Number of Rays Y	<input type="checkbox"/>	1	2E+03	1	31
					Oversampling Fa...	<input type="checkbox"/>	1E-300	1E+300	1	1

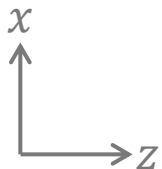
A red callout box points to the 'Lateral Offset X' row with the text 'source area is 800μm'. Another red callout box points to the 'Steps' column for 'Lateral Offset X' with the text 'number of modes is 5'.

# Configuration of Parameter Variation

- input field
  - spatially extended source
  - wavelength 589.3 nm

emitting area

number of modes



optical setup

editor of spherical wave

select spherical wave as elementary field

power weight

Parameter Run

	Object	Category	Parameter	Vary	From	To	Steps	Original Value
1			Wavelength	<input type="checkbox"/>	193 nm	50 $\mu$ m	1	589.3 nm
2			Weight	<input checked="" type="checkbox"/>	0	1	5	1
3			Polarization Angle	<input type="checkbox"/>		360°	1	0°
4			Distance to	<input type="checkbox"/>		1E+303 mm	1	10 mm
5			Lateral Offset X	<input checked="" type="checkbox"/>	-400 $\mu$ m	400 $\mu$ m	5	0 mm
6			Lateral Offset Y	<input type="checkbox"/>	-1E+303 mm	1E+303 mm	1	0 mm

\*Spherical

# Programmable Mode of Parameter Run

## Main Function

```
double[,] parameters = new double[NumberOfParameters,NumberOfIterations];

double weight = 1.0 / NumberOfIterations;
for(int Index = 0; Index < NumberOfIterations; Index++)
{
    //power weight
    parameters[0, Index] = weight;
    //position of point source
    parameters[1, Index] = MinimumValues[1] + (MaximumValues[1] - MinimumValues[1]) / (NumberOfIterations - 1.0) * Index;
}

return parameters;
```

$$\text{weight} = \frac{1.0}{\text{number of modes}}$$

Filter by... X ☐ Show Only Varied Parameters

1	2	*	Object	Category	Parameter	Vary	From	To	Steps	Original Value
					Wavelength	<input type="checkbox"/>	193 nm	50 μm	1	589.3 nm
					Weight	<input checked="" type="checkbox"/>	0	1	5	1
					Polarization Angle	<input type="checkbox"/>	0°	360°	1	
					Distance to Input...	<input type="checkbox"/>	-1E+303 mm	1E+303 mm	1	
					Lateral Offset X	<input checked="" type="checkbox"/>	-400 μm	400 μm	5	0 mm
					Lateral Offset Y	<input type="checkbox"/>	1E+303 mm	1E+303 mm	1	0 mm
					Number of					
					Number of Rays					

"Spherical Wave" #0

NumberOfIterations

MinimumValues[1]

MaximumValues[1]

# Display of Resulting Fringe along x Axis

5: D:\OneDrive\...\ParameterRun\_5.run\*

**Results**  
Start the parameter run and analyze its results

Go!

☒ Use Already Calculated Results for Next Run

Detector	Subdetector	Combined Output	Iteration Step		
			2	3	4
Varied Parameters	Lateral Offset X ("Spherical...	Data Array	0 $\mu\text{m}$	0 mm	200 $\mu\text{m}$
	Weight ("Spherical Wave"...	Data Array	0.2	0.2	0.2
"Fringe (Camera)" #600 aft...		Animation	s Set	Chromatic Fields Set	Chromatic Fields Set
"Fringes Along X-Axis (Ca...		1D Chromatic	et 1D	Chromatic Fields Set 1D	Chromatic Fields Set 1D

< >

Create Output from Selection

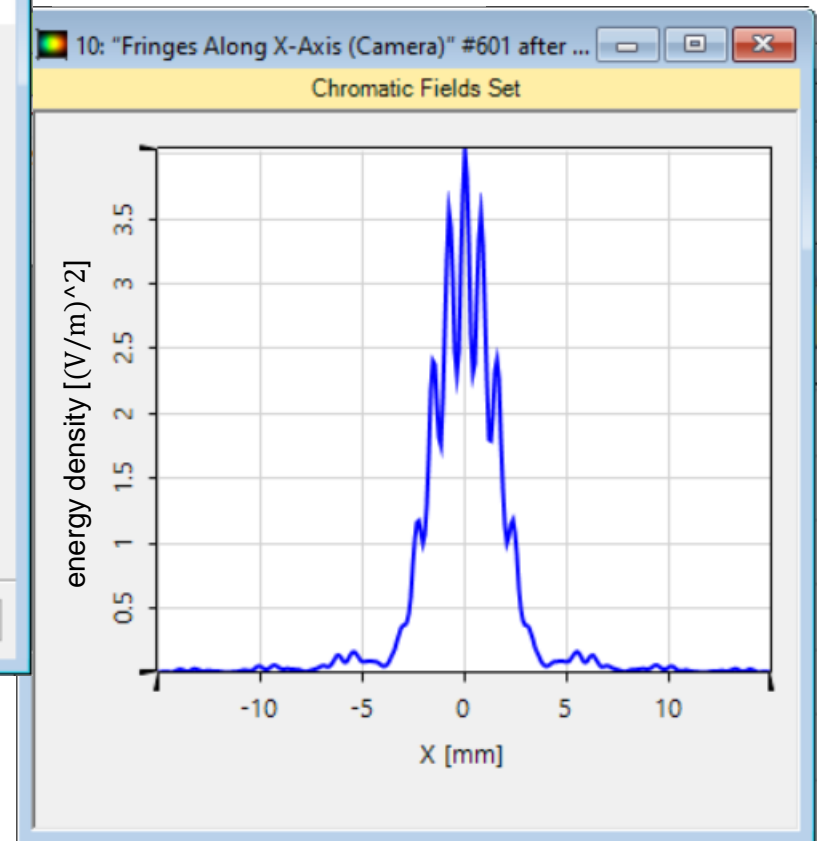
< Back Next > Show

select the row

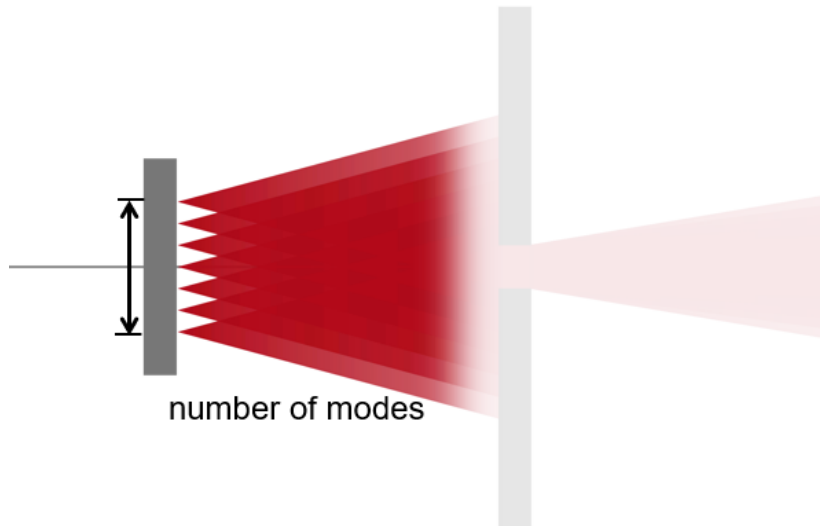
display the resulting fringe

superposition of energy density  
from different point sources

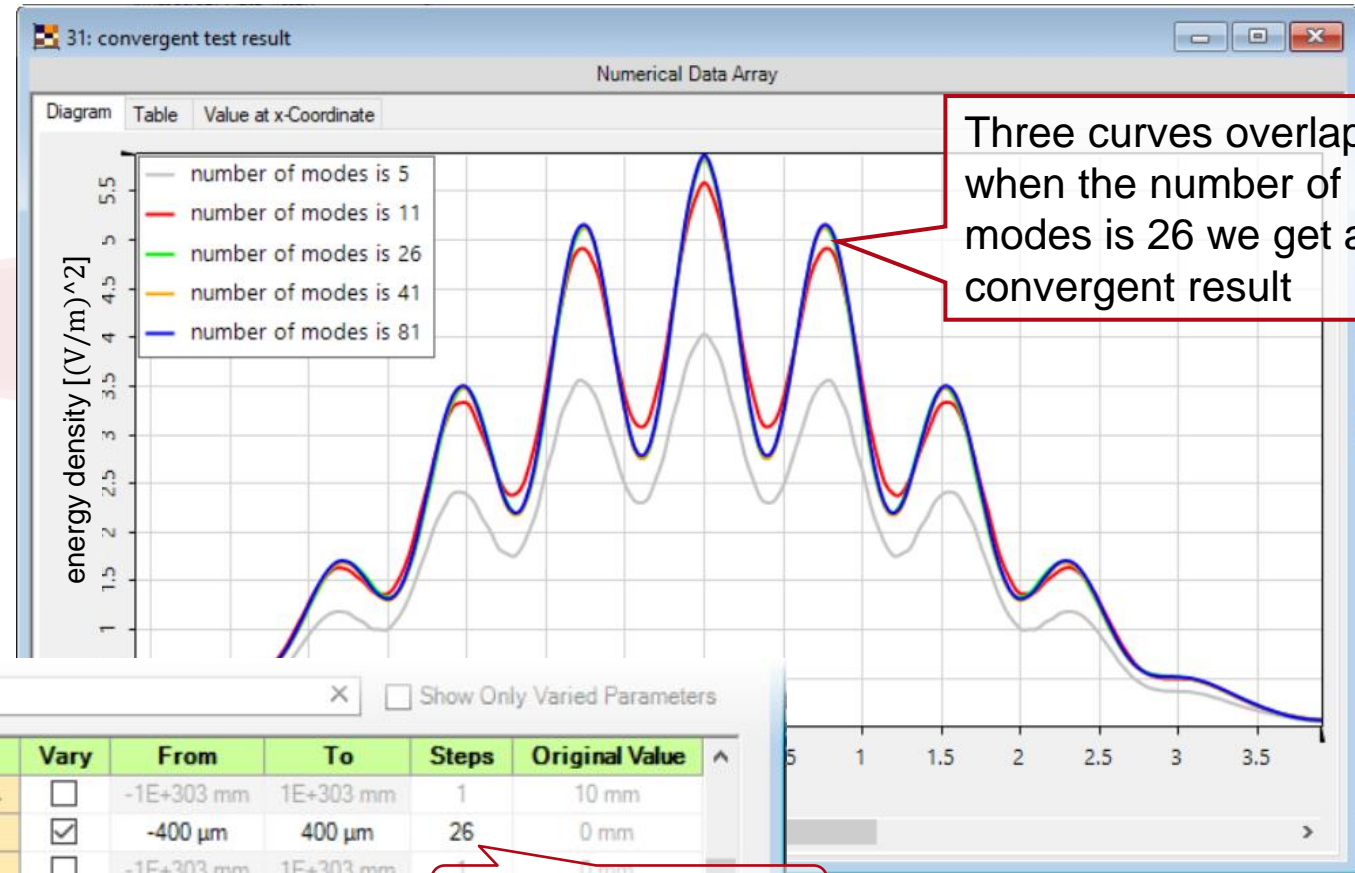
fringe along x axis



# Fringes with Different Number of Modes



number of modes



## Parameter Run

1	2	*	Object	Category	Parameter	Vary	From	To	Steps	Original Value
					Distance to Input...	<input type="checkbox"/>	-1E+303 mm	1E+303 mm	1	10 mm
					Lateral Offset X	<input checked="" type="checkbox"/>	-400 $\mu$ m	400 $\mu$ m	26	0 mm
					Lateral Offset Y	<input type="checkbox"/>	-1E+303 mm	1E+303 mm	1	0 mm
					Number of Rays X	<input type="checkbox"/>	1	2E+09	1	31
					Number of Rays Y	<input type="checkbox"/>	1	2E+09	1	31
					Oversampling Fa...	<input type="checkbox"/>	1E-300	1E+300	1	1

number of modes

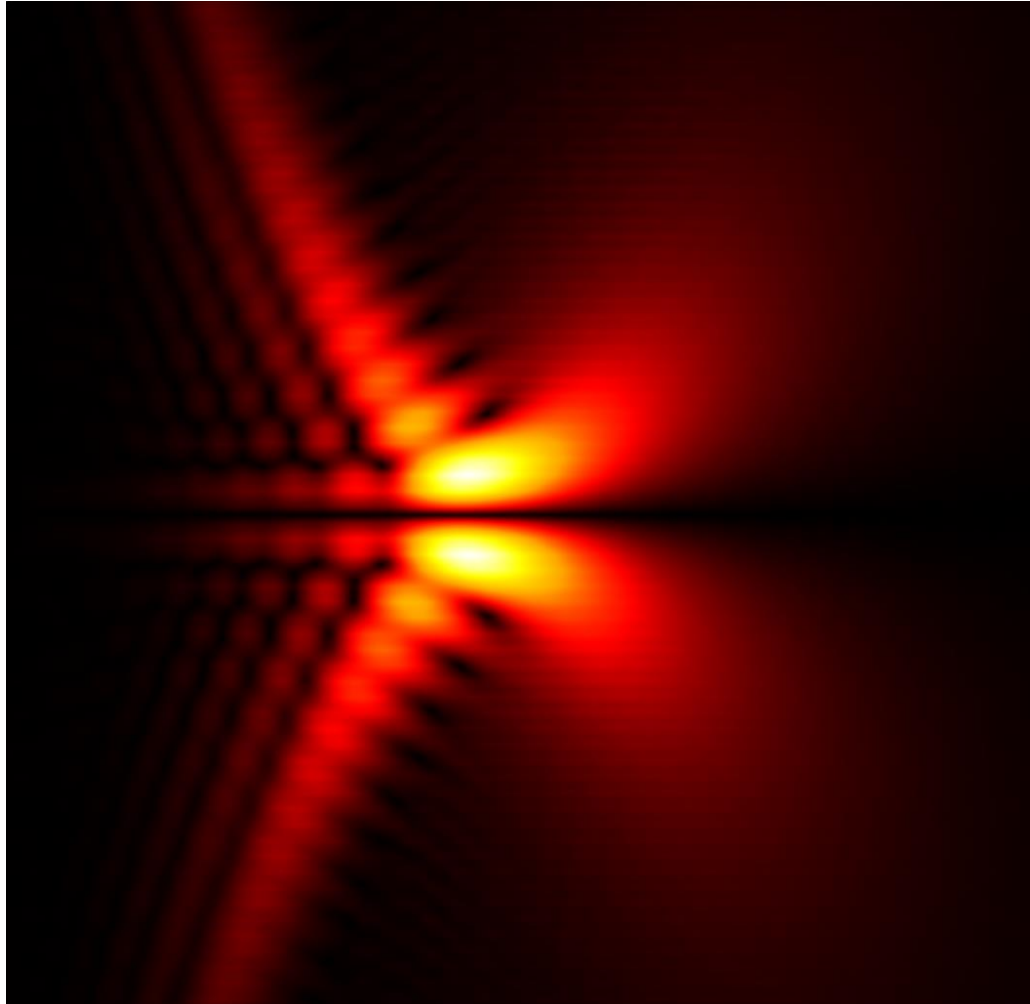
## Pulse Focusing with High-NA Lens





# Abstract

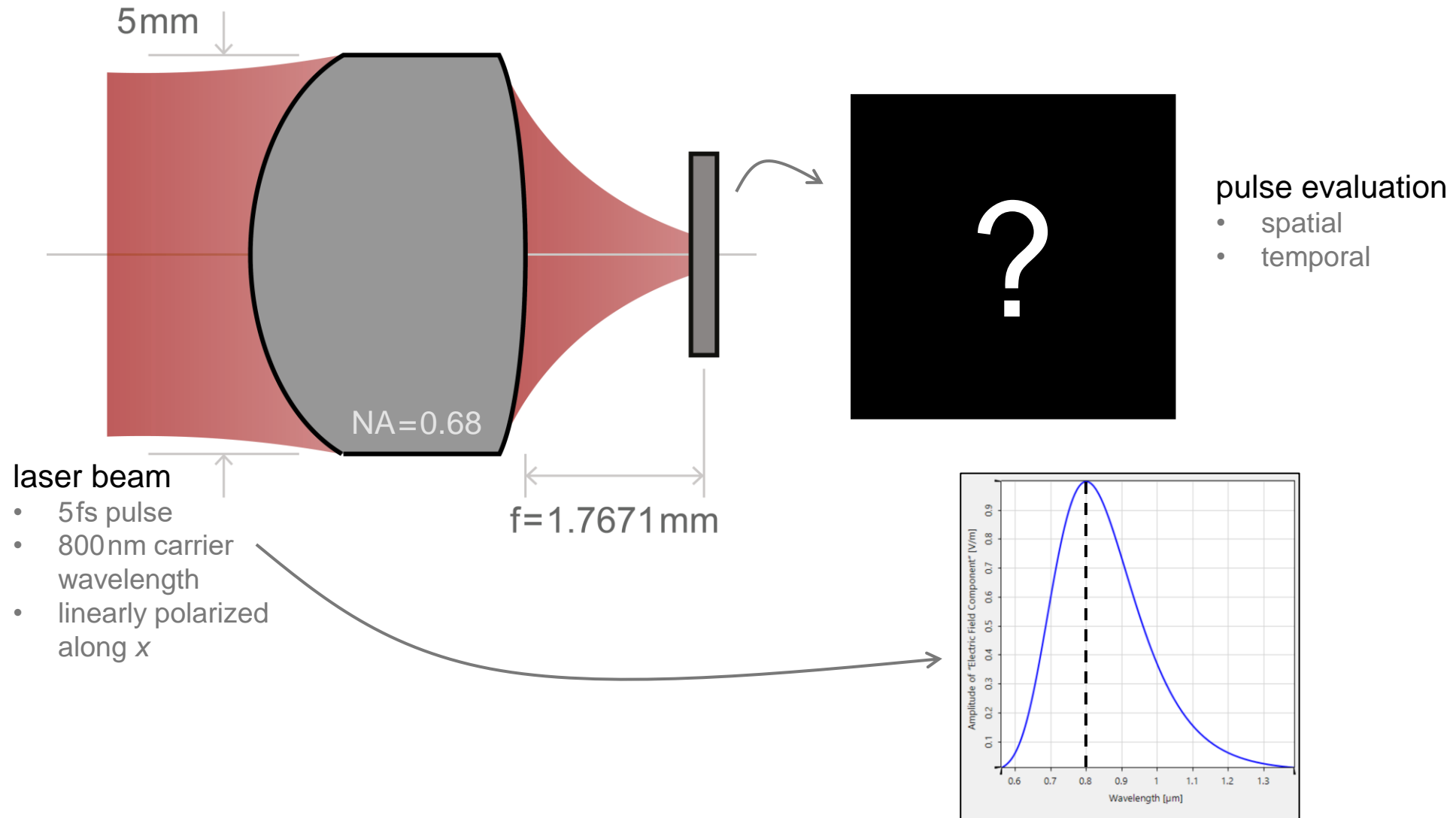
---



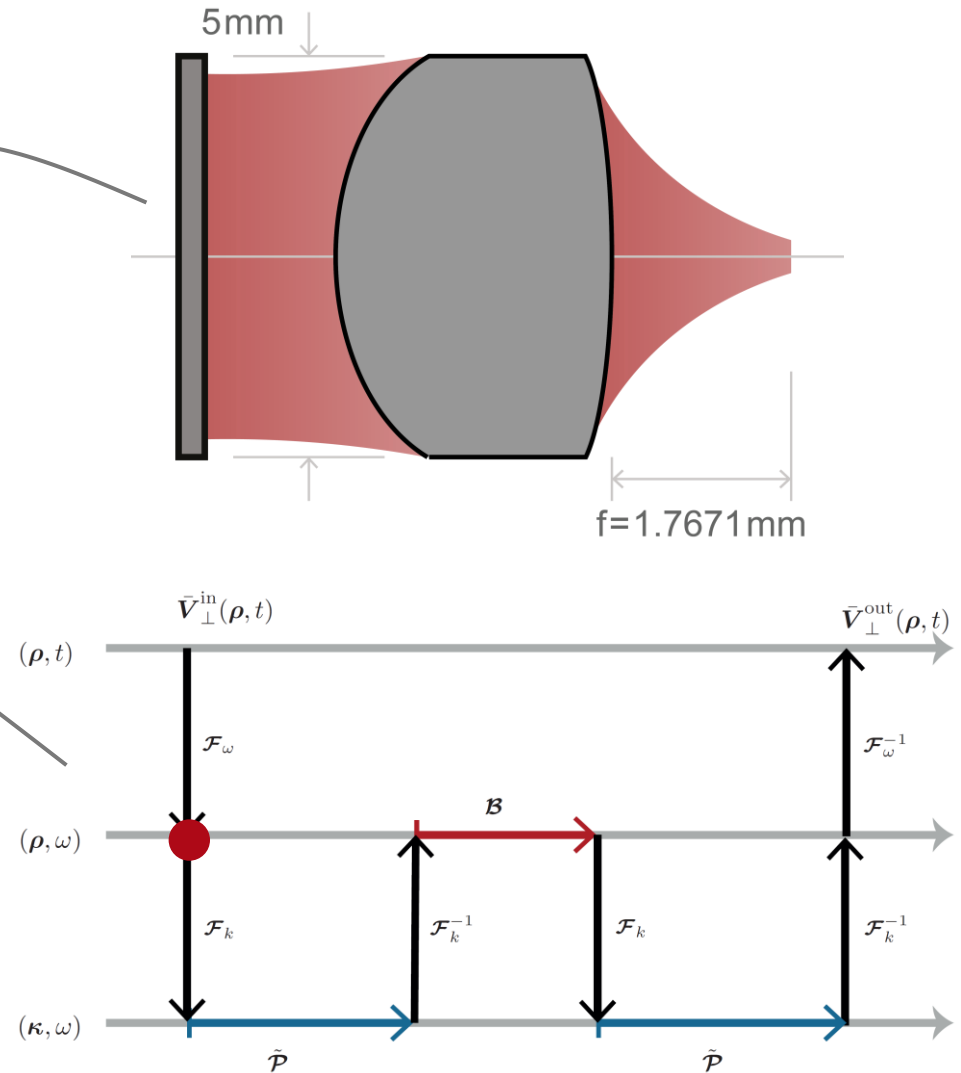
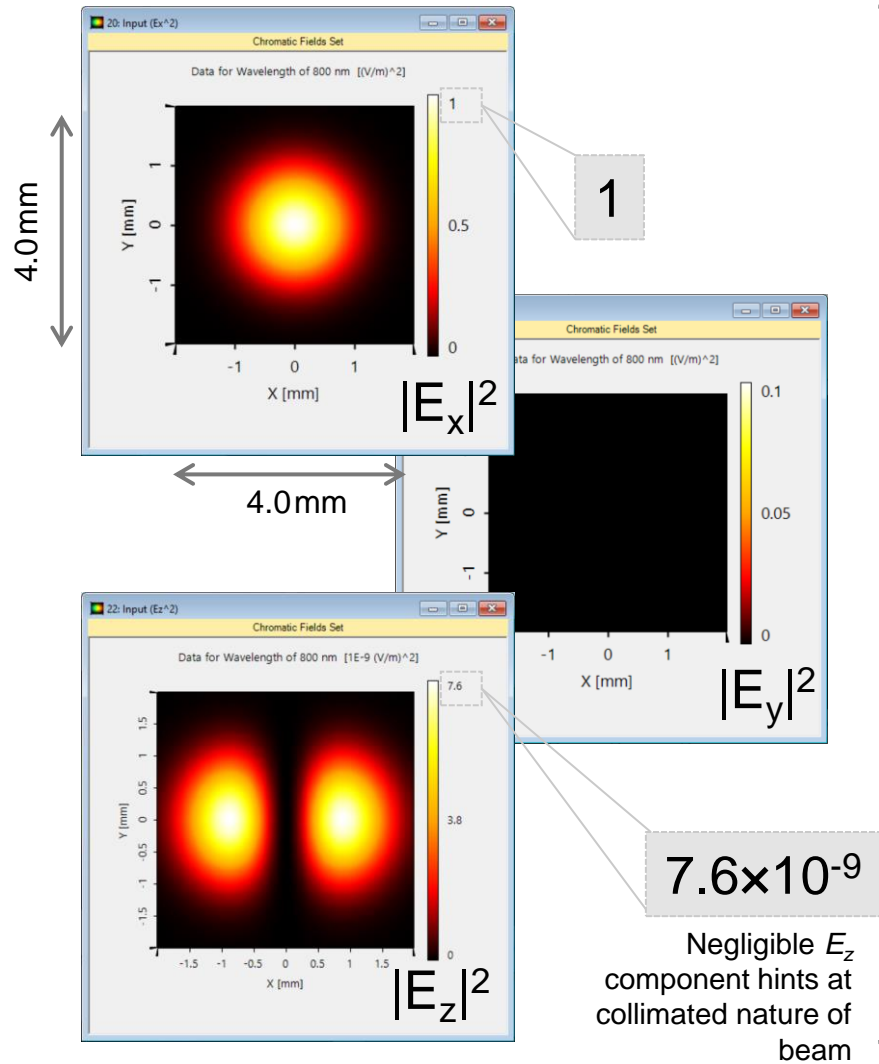
While for most other types of sources it is often accurate enough to labour under the stationary approximation, ultrashort pulses require a somewhat more nuanced approach, where the correlation between the different spectral modes is taken into account. We investigate here the effects of subjecting one such pulse to propagation through a lens with high numerical aperture, in terms of its spatial, as well as of its temporal, profile.



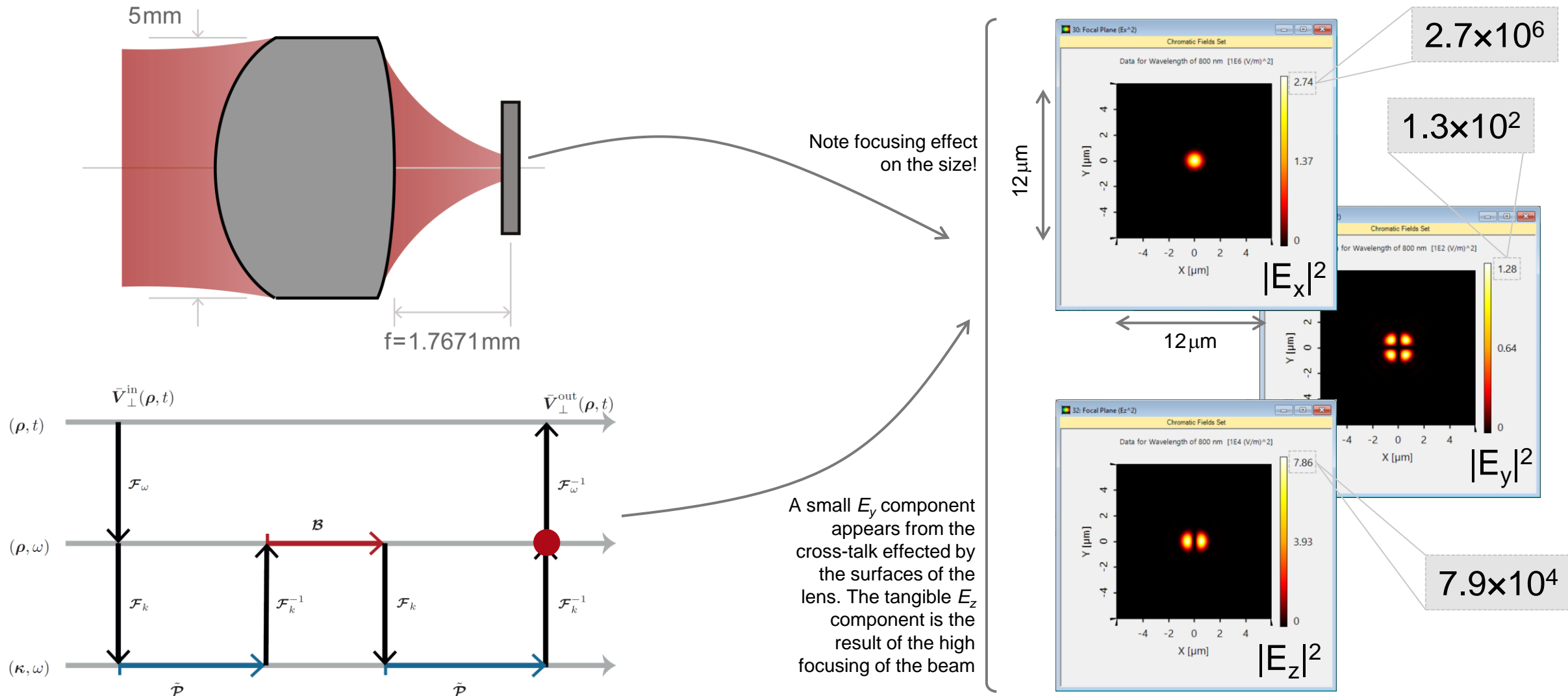
# Modeling Task



# Purely Spatial Analysis: Input Field (Carrier $\lambda$ )

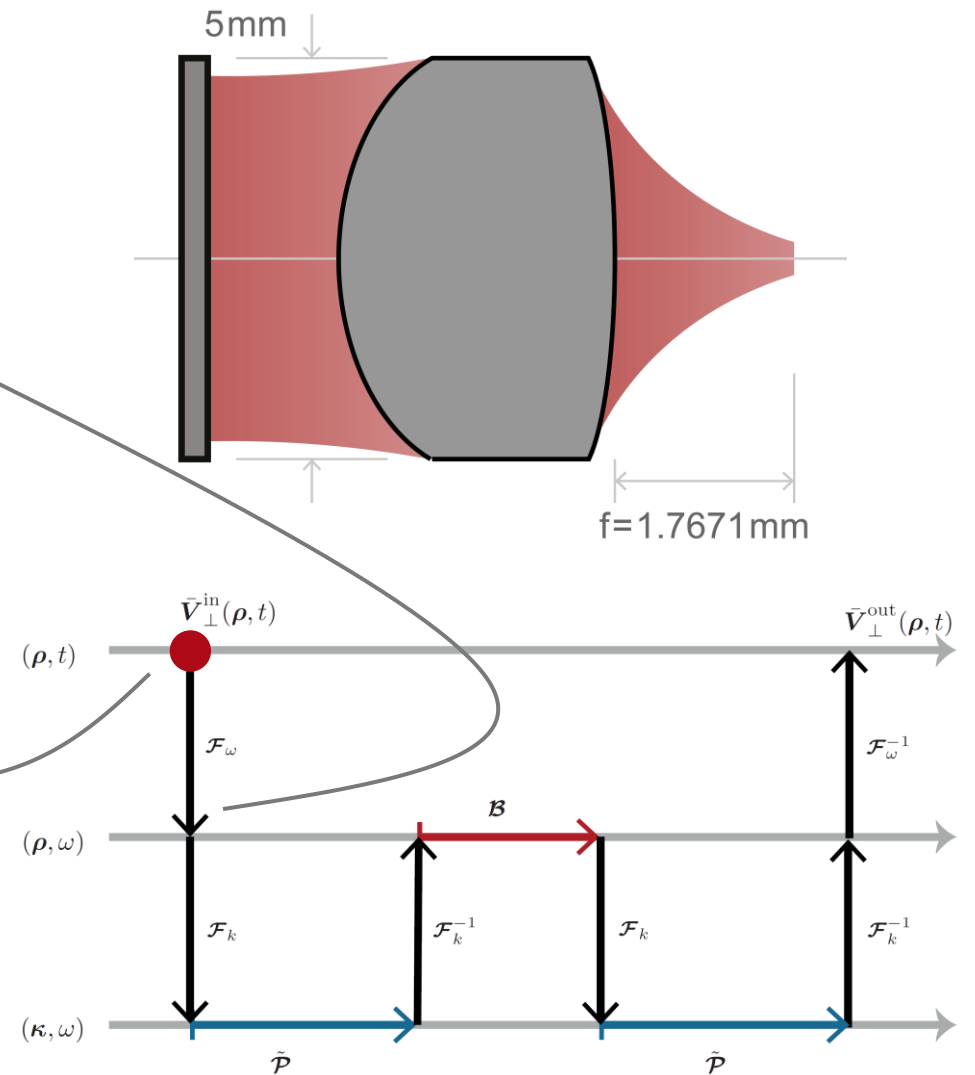
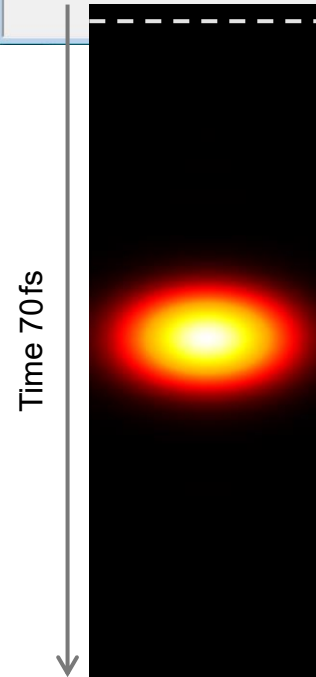
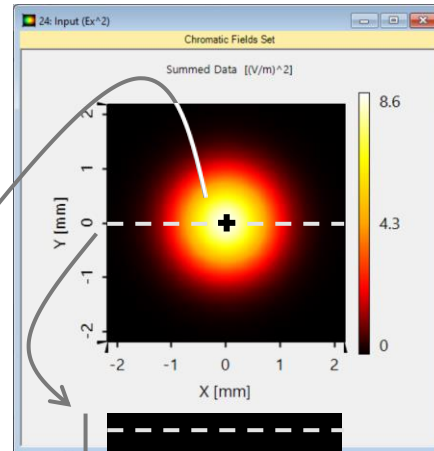
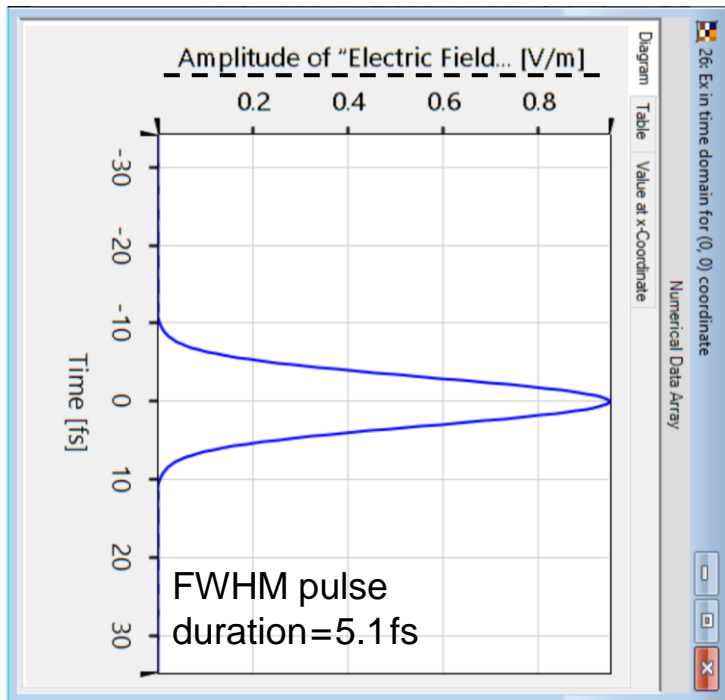


# Purely Spatial Analysis: Field at Focal Plane (Carrier $\lambda$ )



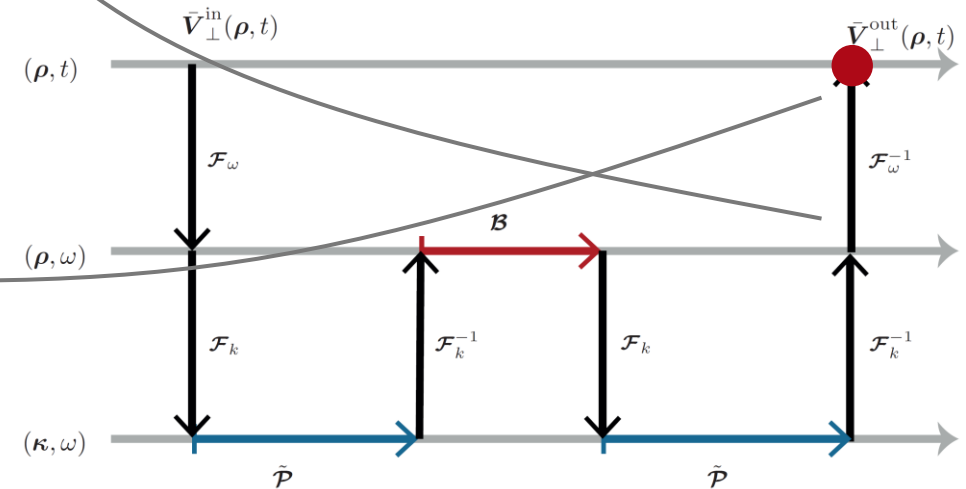
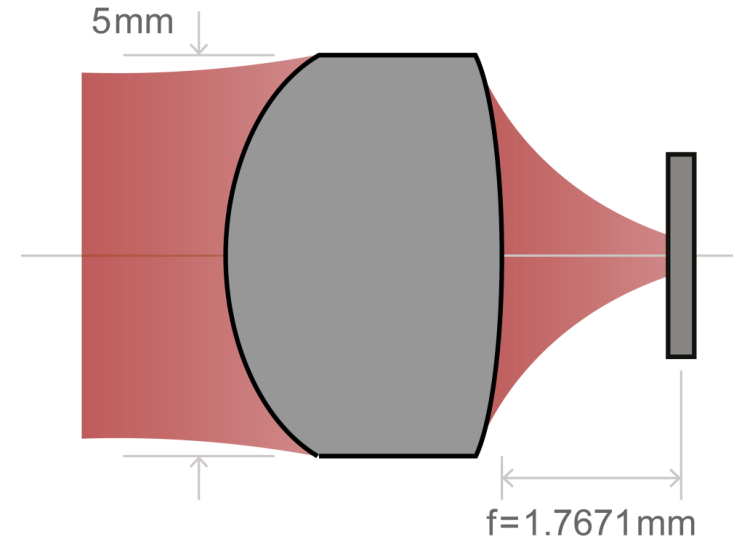
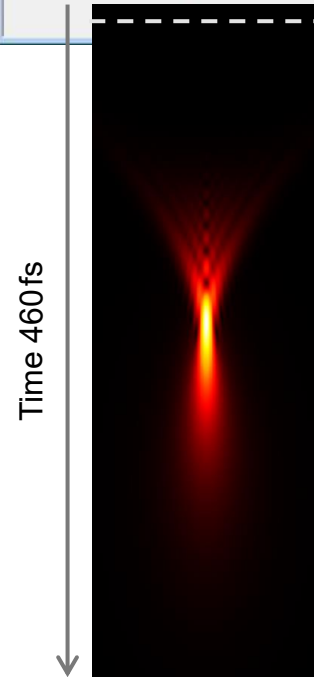
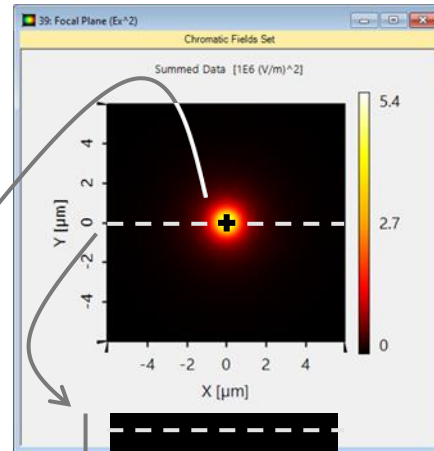
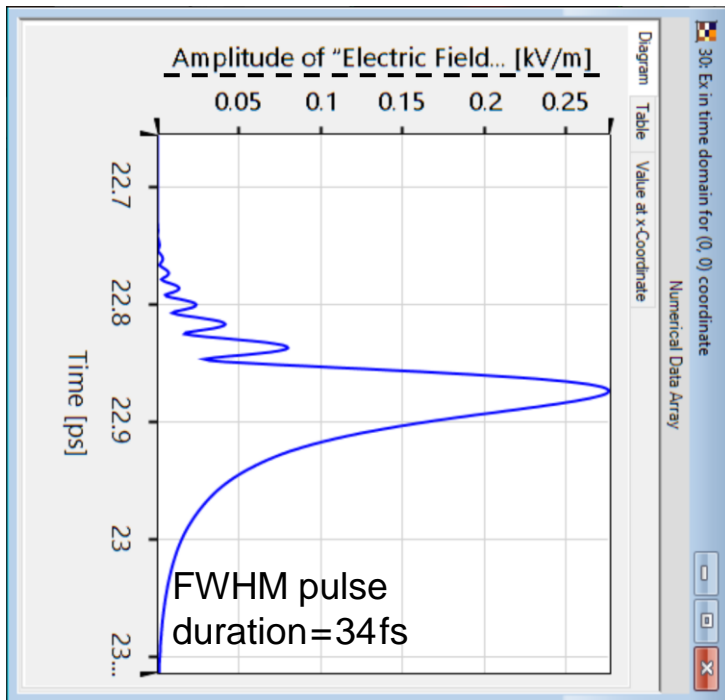
# Spatio-Temporal Analysis: Input Field ( $E_x$ Component)

The Pulse Evaluation detector in VirtualLab facilitates the visualization of the pulse properties in different domains

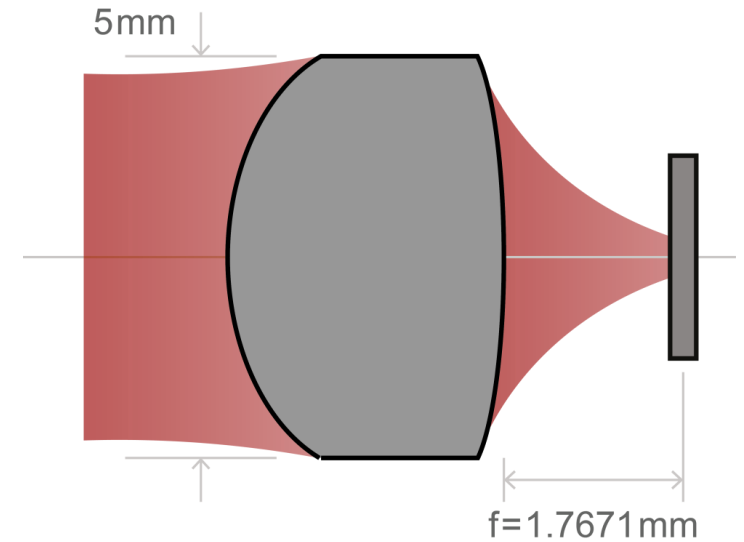
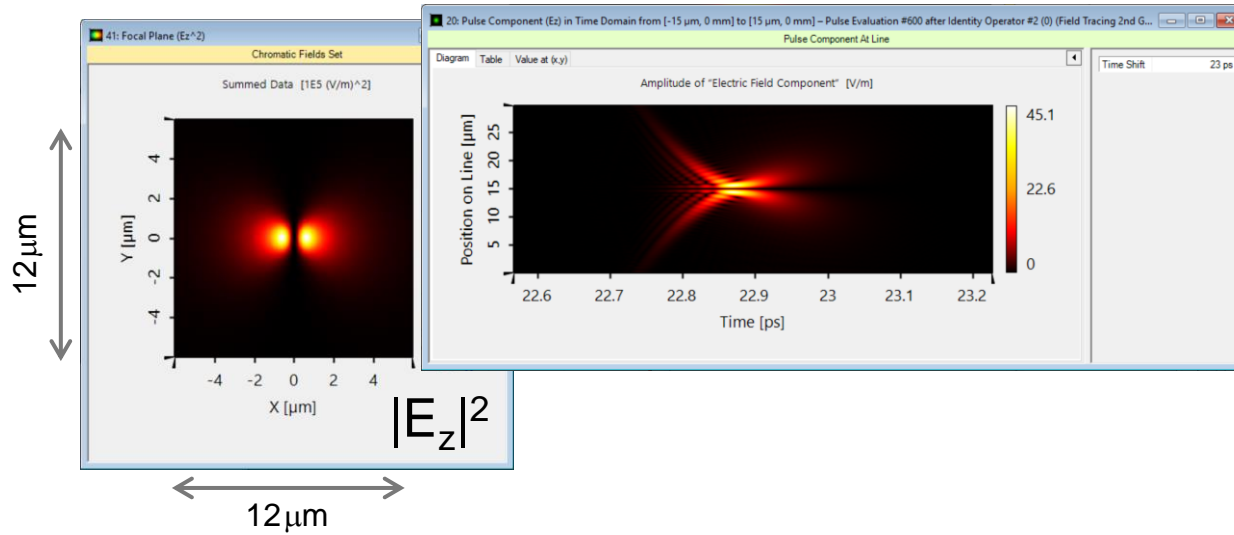
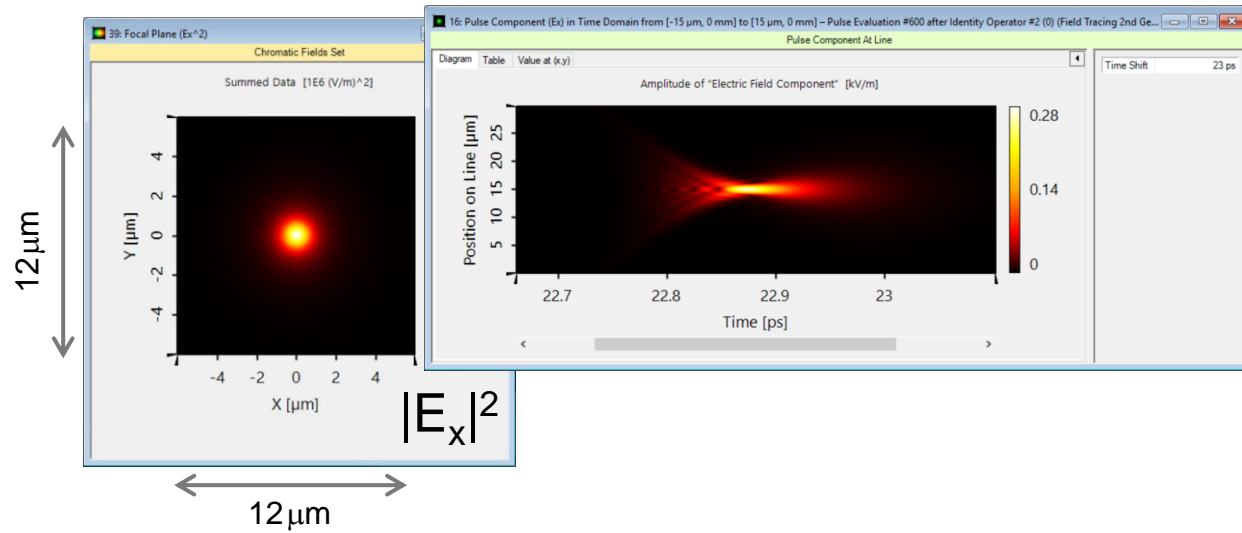


# Spatio-Temporal Analysis: Focus ( $E_x$ Component)

The Pulse Evaluation detector in VirtualLab facilitates the visualization of the pulse properties in different domains

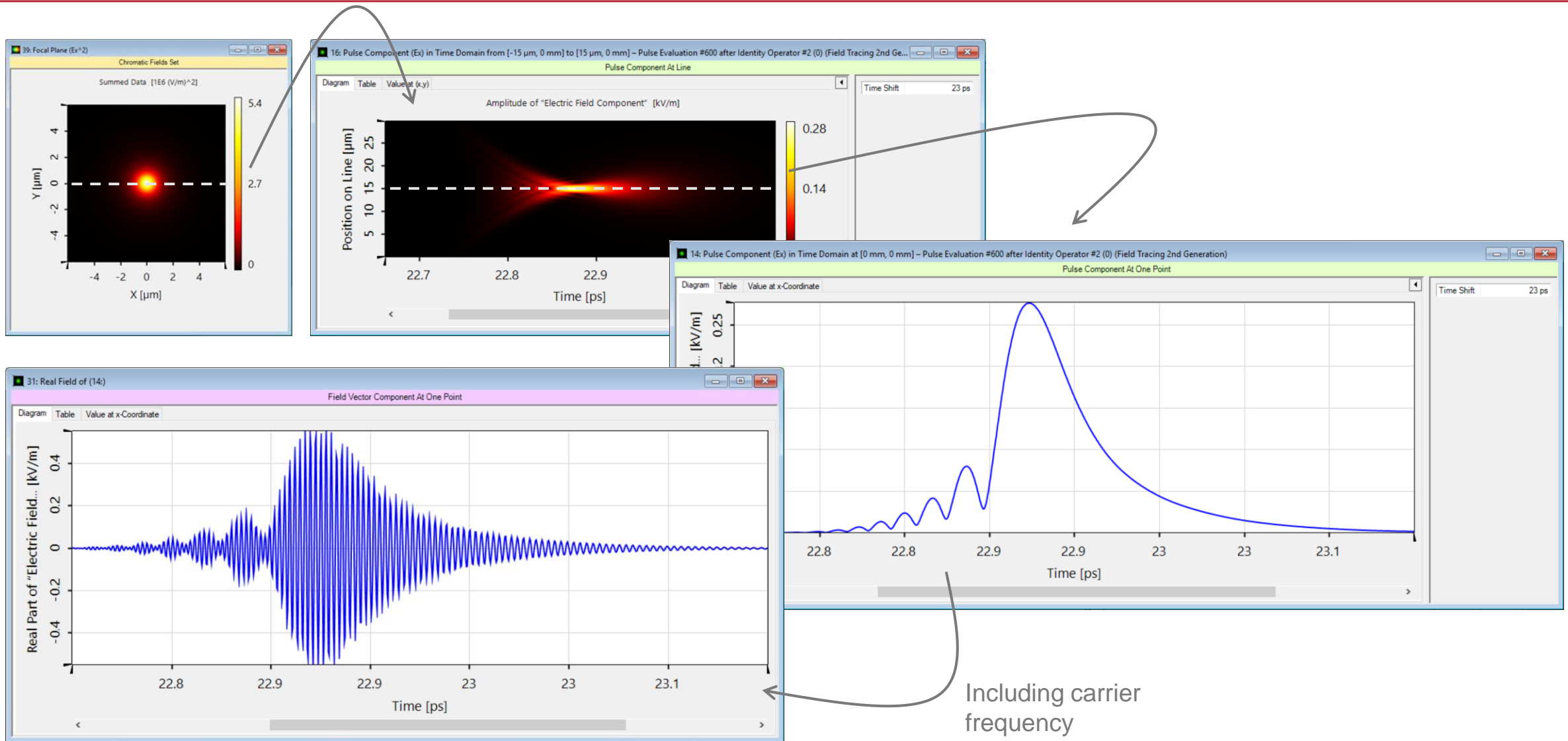


# Spatio-Temporal Analysis: Focus ( $E_x$ and $E_z$ )



As always, consistent electromagnetic treatment in VirtualLab Fusion allows for the analysis of vectorial effects, also for ultra-short pulses

# Temporal Analysis: $E_x$ Component with Carrier Frequency

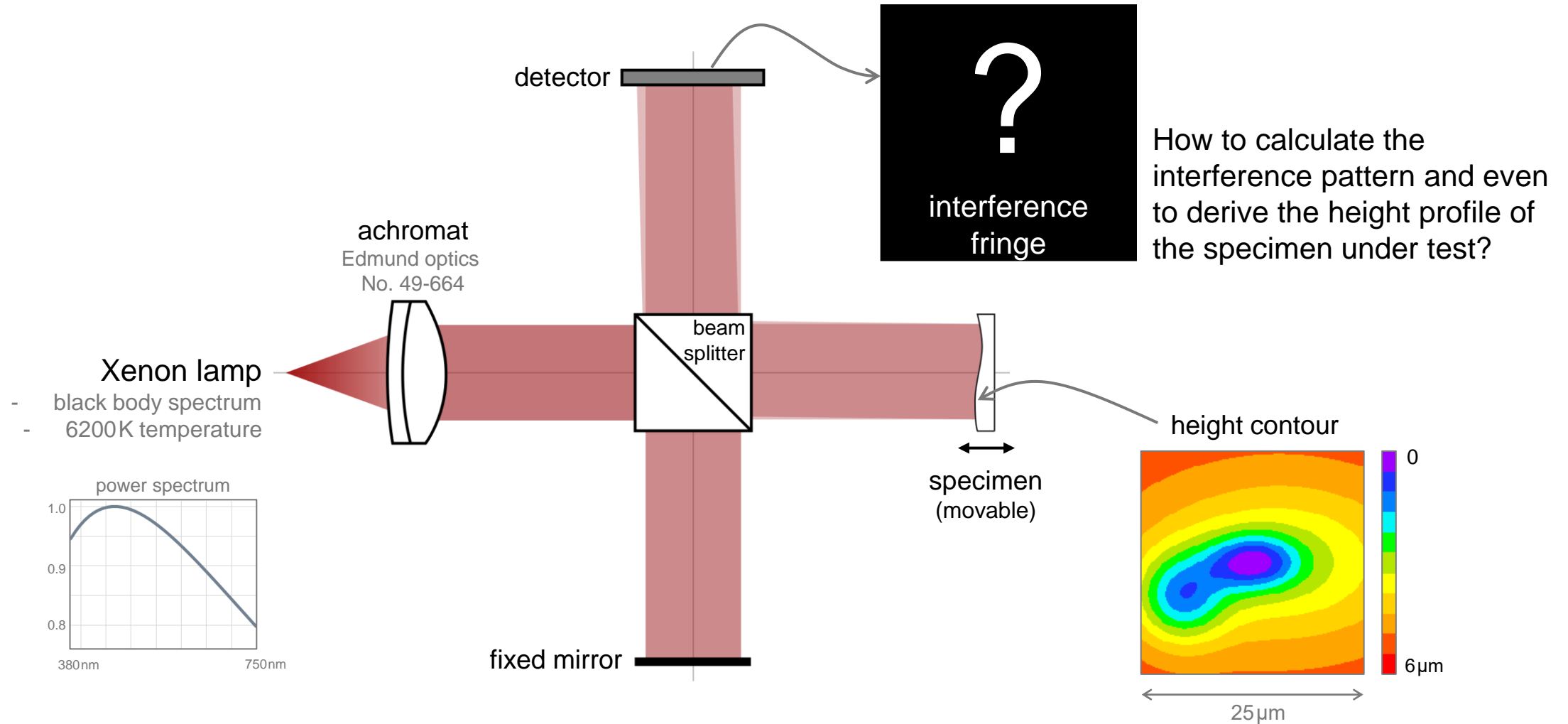


# Full-Field Optical Coherence Scanning Interferometry

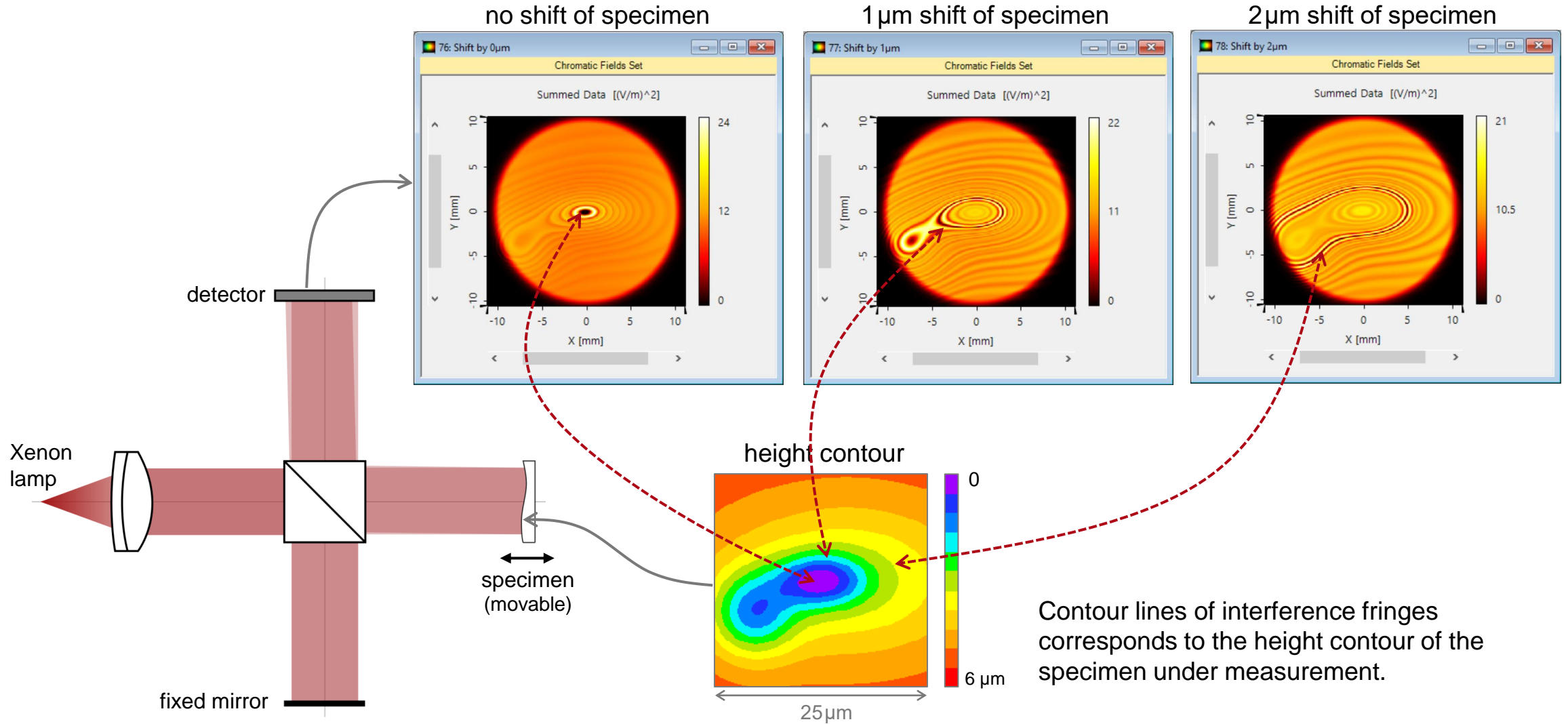




# Modeling Task



# Simulated Interference Fringes

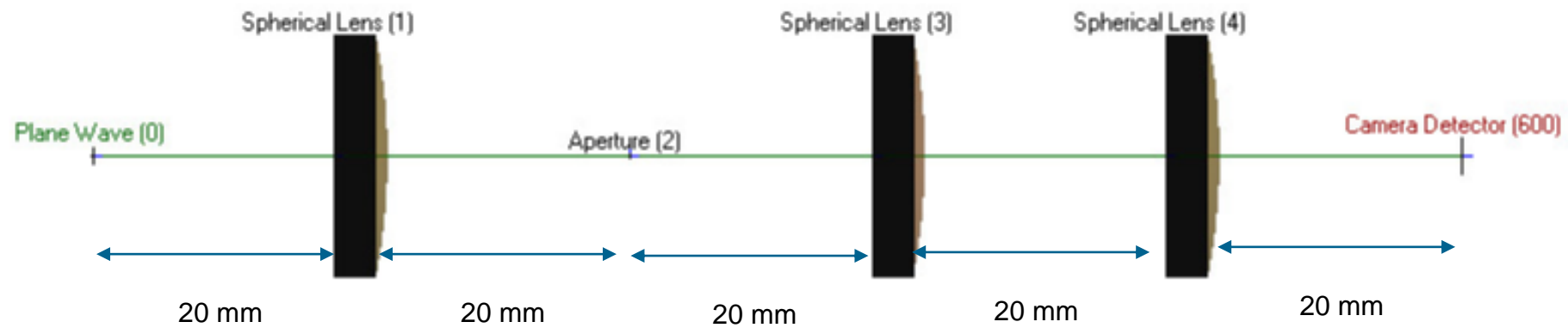


Part 7

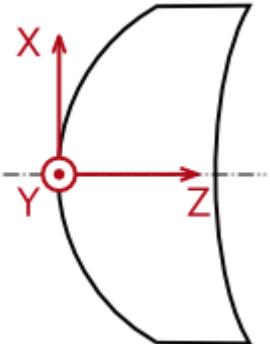
## Position and Orientation



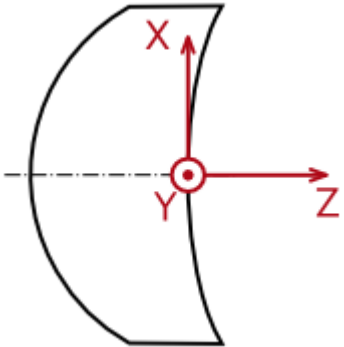
# Illustration: Position and Orientation



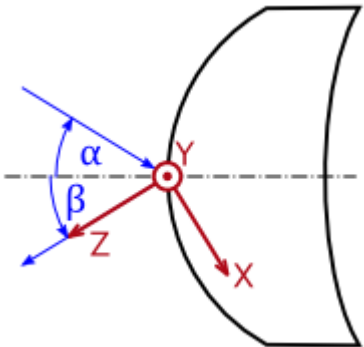
# Coordinate Systems



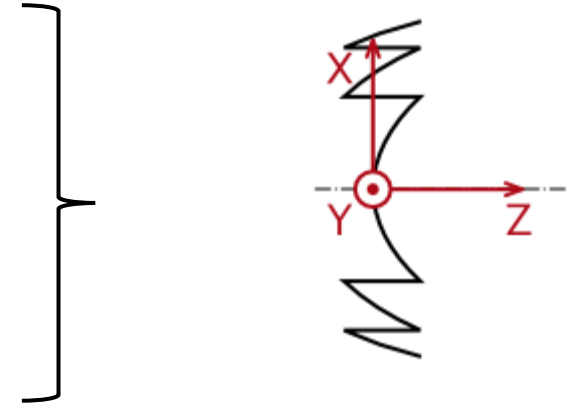
Input coordinate system



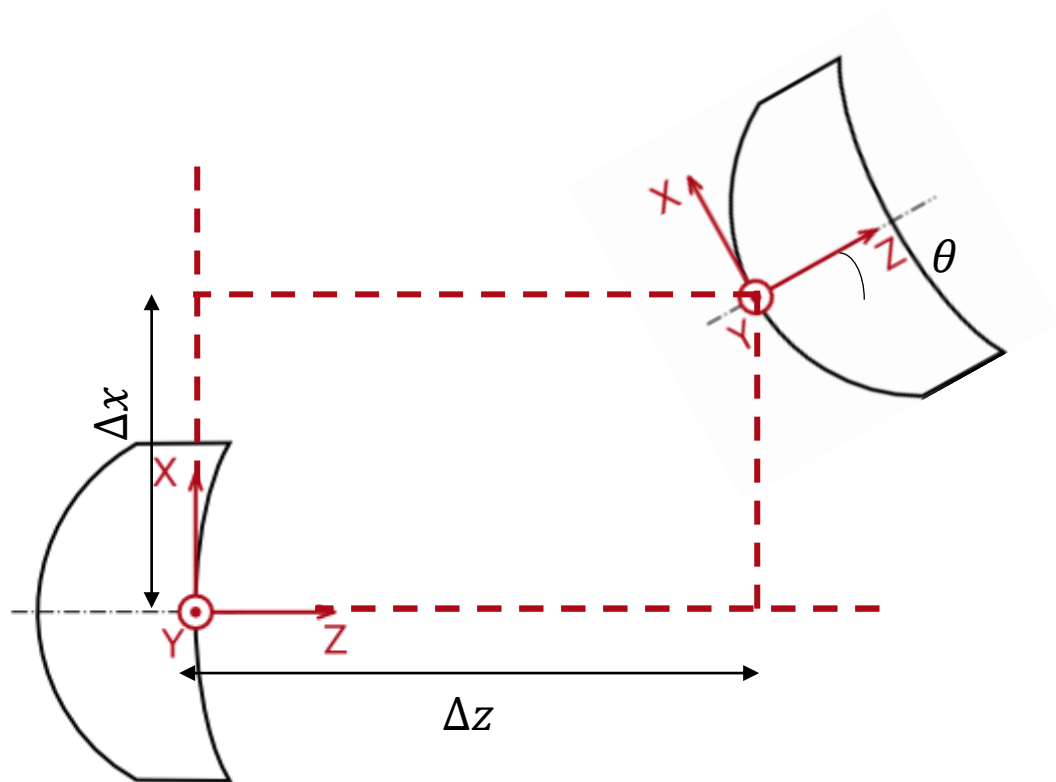
Transmission coordinate system



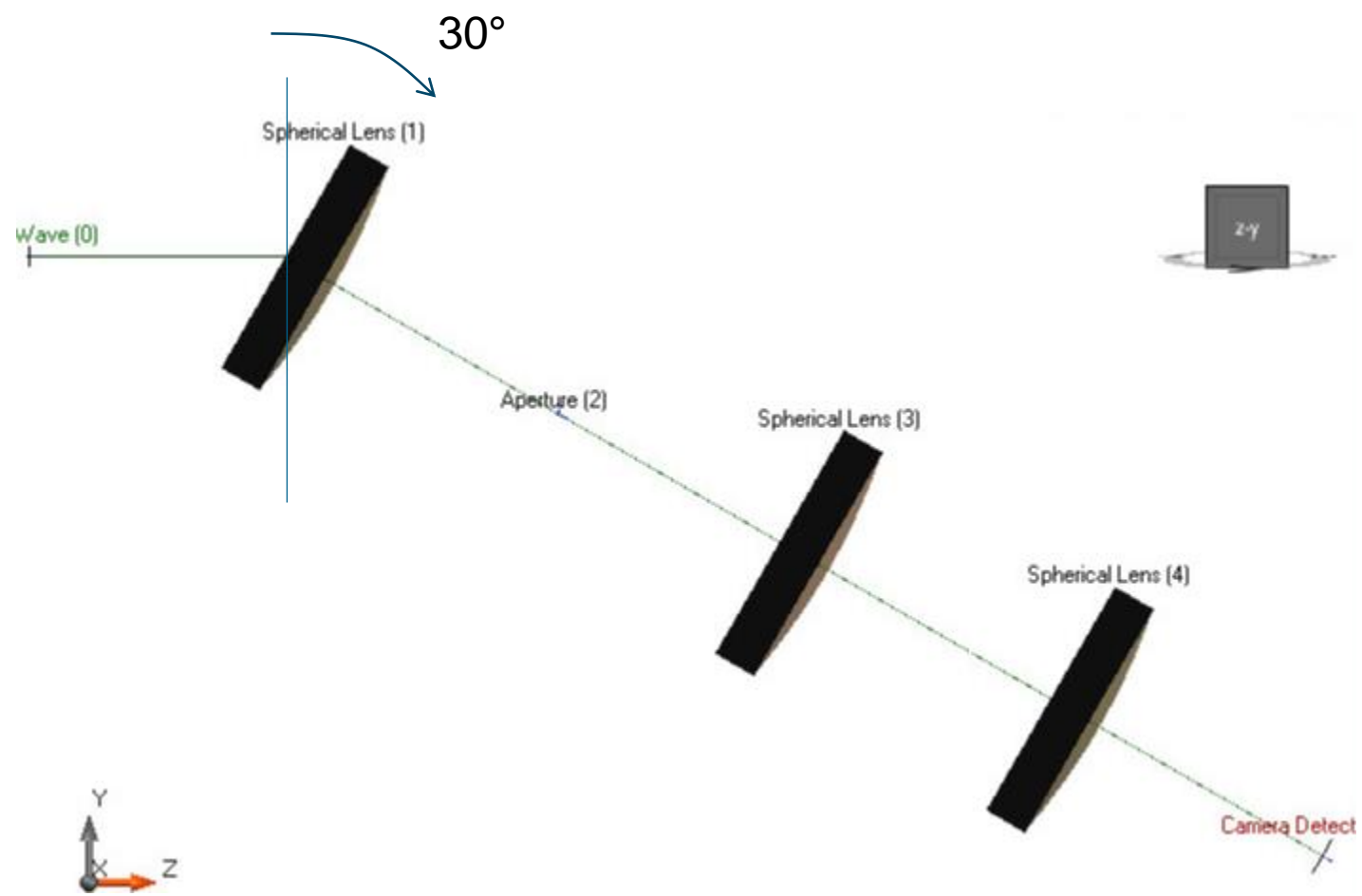
Reflection coordinate system



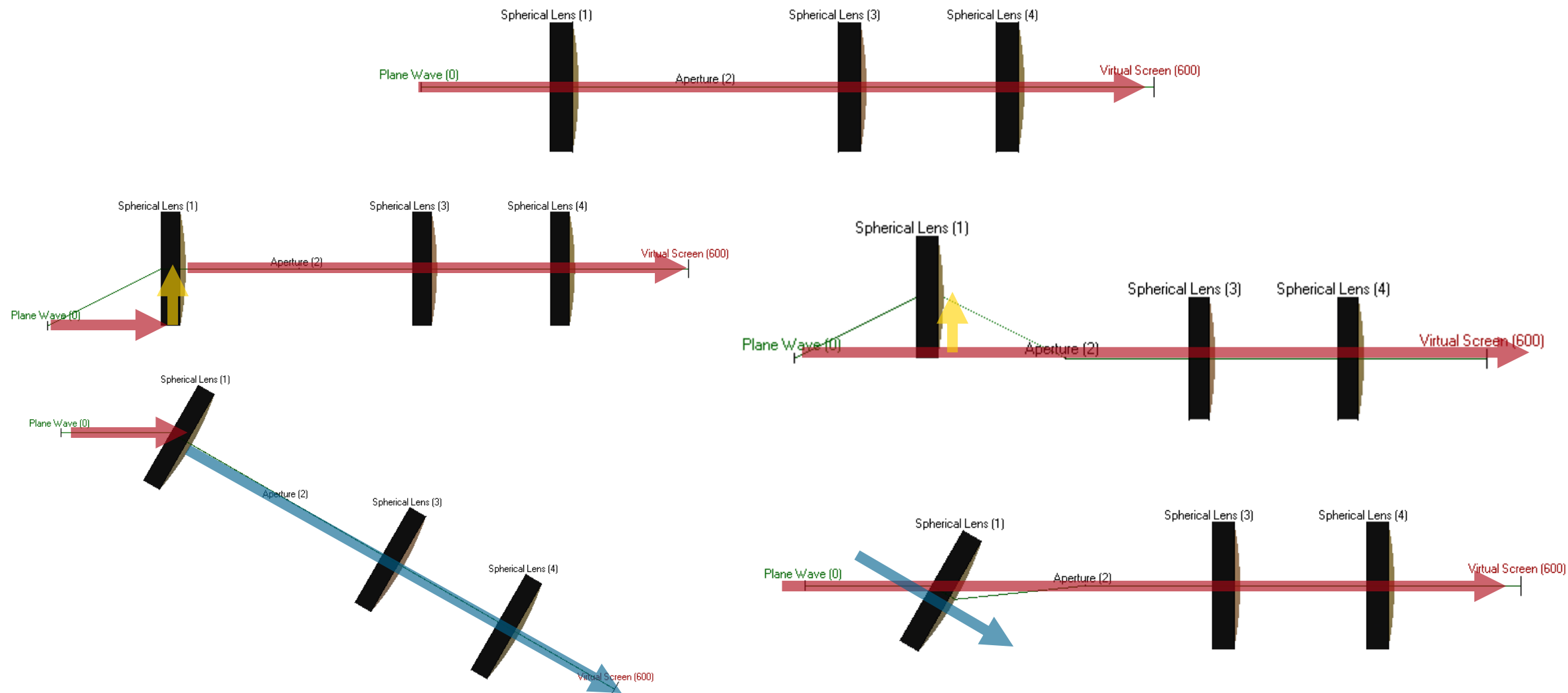
# Basal Positioning



# Optical Setup



# Basal Positioning and Isolated Positioning





# Special Components: Mirror

Center Point of Rotations

Reference Point to be Used as Center Point: Reference Point of Input Channel

Orientation Angles

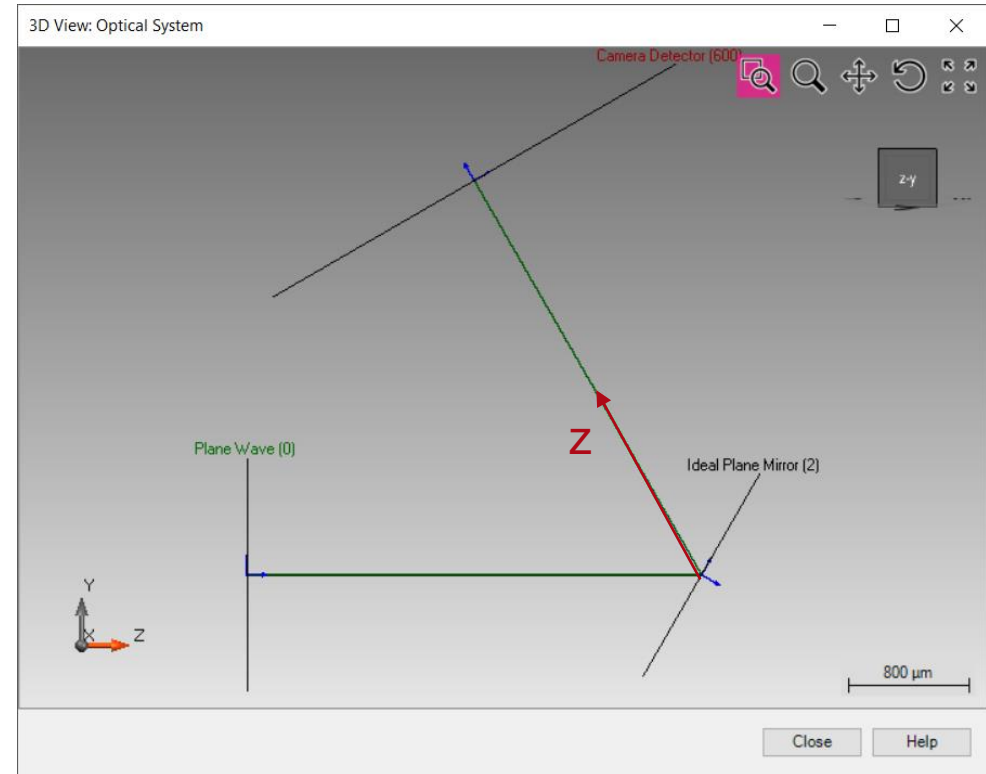
Orientation Definition Type: Sequence of Axis Rotations

☐ Fix Axes

Direction Definition

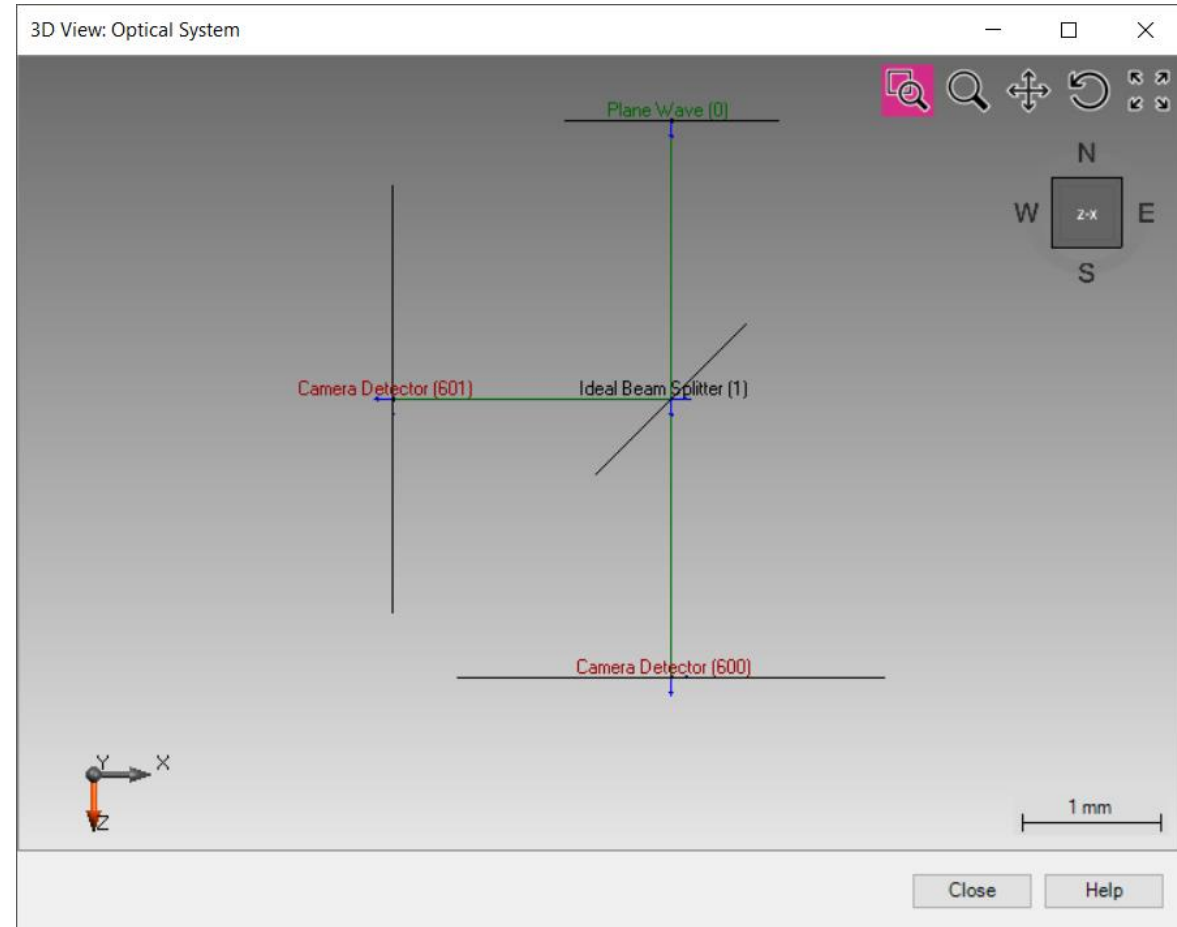
	Angle / Axis	Value
1	X-Axis Rotation	30°

800  $\mu\text{m}$



# Special Components: Ideal Beam Splitter

Two perpendicular output channels are automatically defined.



# Several Points about Positioning

---

- Set position of one component: put the input CS in the output CS of previous component (Basal Positioning)
- Basal position: if one component shift or rotate, all the following path changes
- Isolated position: basal output CS doesn't change
- Special case:
  - Reflection CS: z-axis is calculated by component normal vector and input path
  - Beam splitter: two output CSs  $> 0$  is transmission CS, 1 is reflection CS. Two z-axes are perpendicular

# Configuring Reference Type in VirtualLab Fusion

The image displays two windows from the VirtualLab Fusion software. The background window, titled "2: Optical Setup View #1 (Optical Setup)\*", shows a schematic of an optical setup. It includes a "Plane Wave" source (labeled 0), a "Lens System" (labeled 1), and a "Camera Detector" (labeled 600). A "Ray Tracing System Analyzer" (labeled 800) is also present. The foreground window, titled "1: Optical Setup Editor #1 (Optical Setup)\*", provides a detailed configuration table for the elements. The table has columns for "Start Element" (Index, Element Name, Ref. Type, Medium) and "Target Element" (Index, Element Name), along with "Linkage" settings (Propagation Method, On/Off, Color). The "Ref. Type" column for the "Lens System" is highlighted with a red box, showing a dropdown menu with options "T" and "R".

Start Element				Target Element		Linkage		
Index	Element Name	Ref. Type	Medium	Index	Element Name	Propagation Method	On/Off	Color
0	Plane Wave	-	Air in Homogeneous Medi...	1	Lens System	Ray Tracing	On	—
1	Lens System	T	Air in Homogeneous Medi...					

Simulation Engine: Ray Tracing

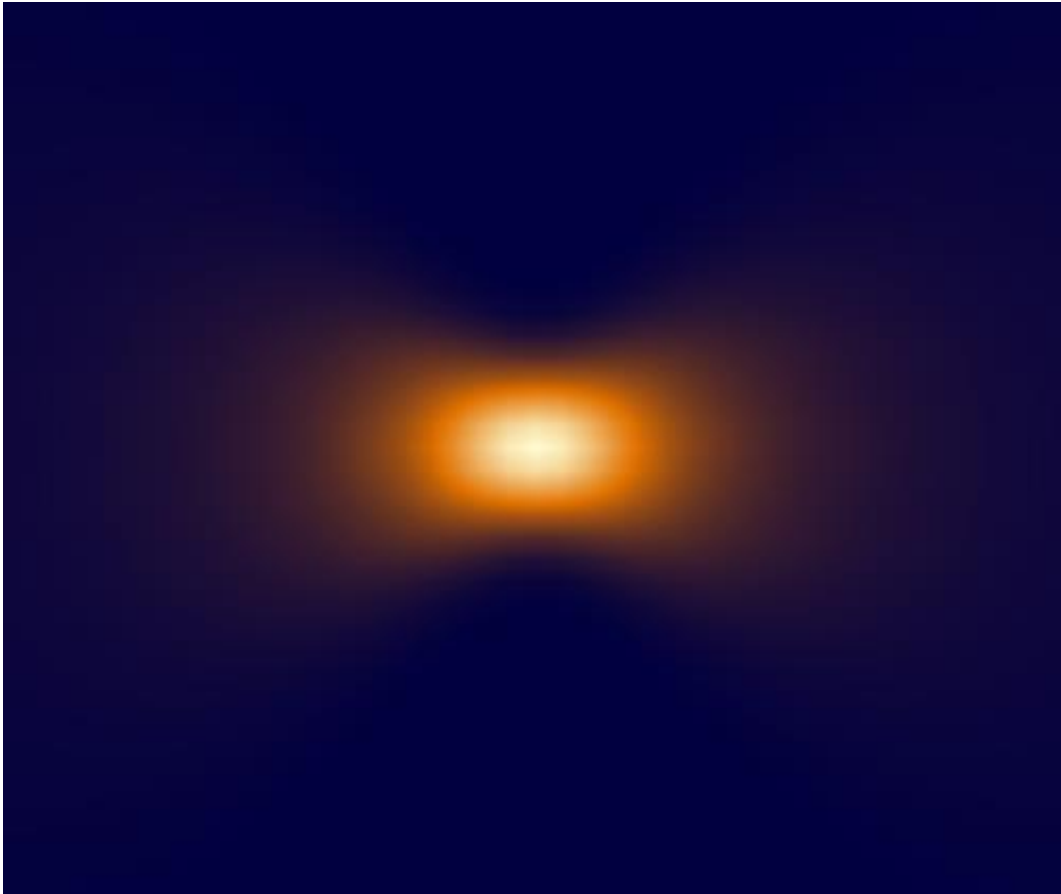
Go!

# Tolerance Analysis of a Fiber Coupling Setup



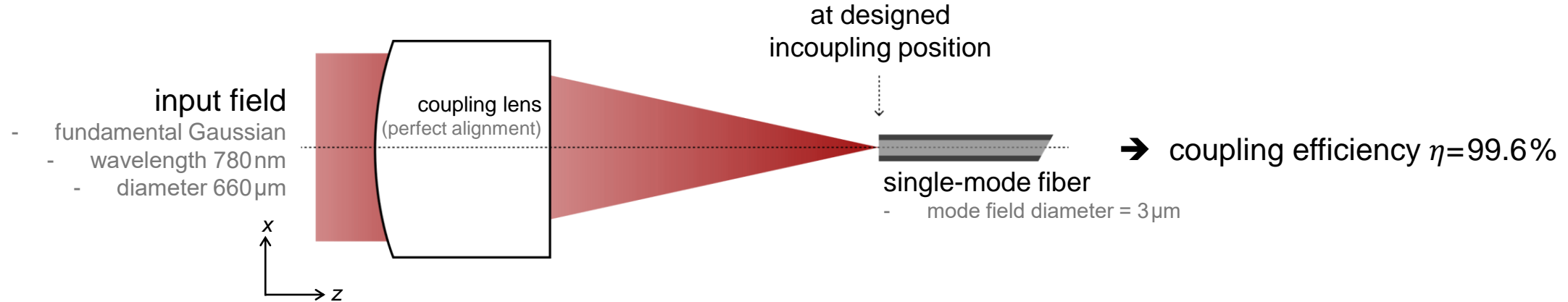
# Abstract

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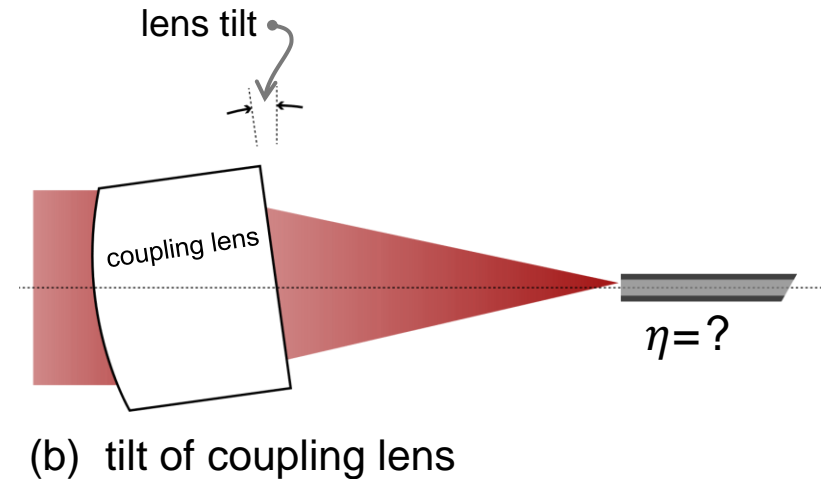
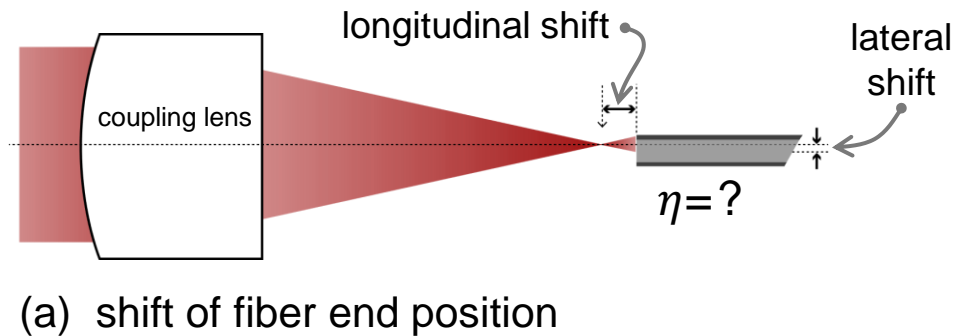


In modern optics, fibers can be found in various optical system, and it is usually of concern how much light can be coupled into fibers. The coupling efficiency can be sensitive to the system alignment, especially for single-mode fibers with relatively small core diameters. In this example, a well-designed fiber coupling lens is selected, and the coupling efficiency is evaluated with respect to different tolerance factors, such as the shift of fiber end position and the tilt of coupling lens.

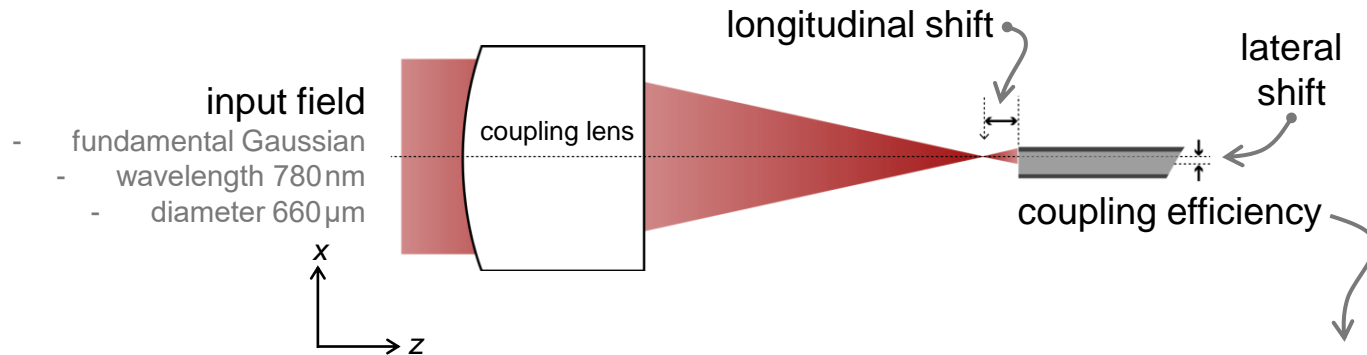
# Modeling Task



How does the coupling efficiency change with respect to alignment tolerance factors?

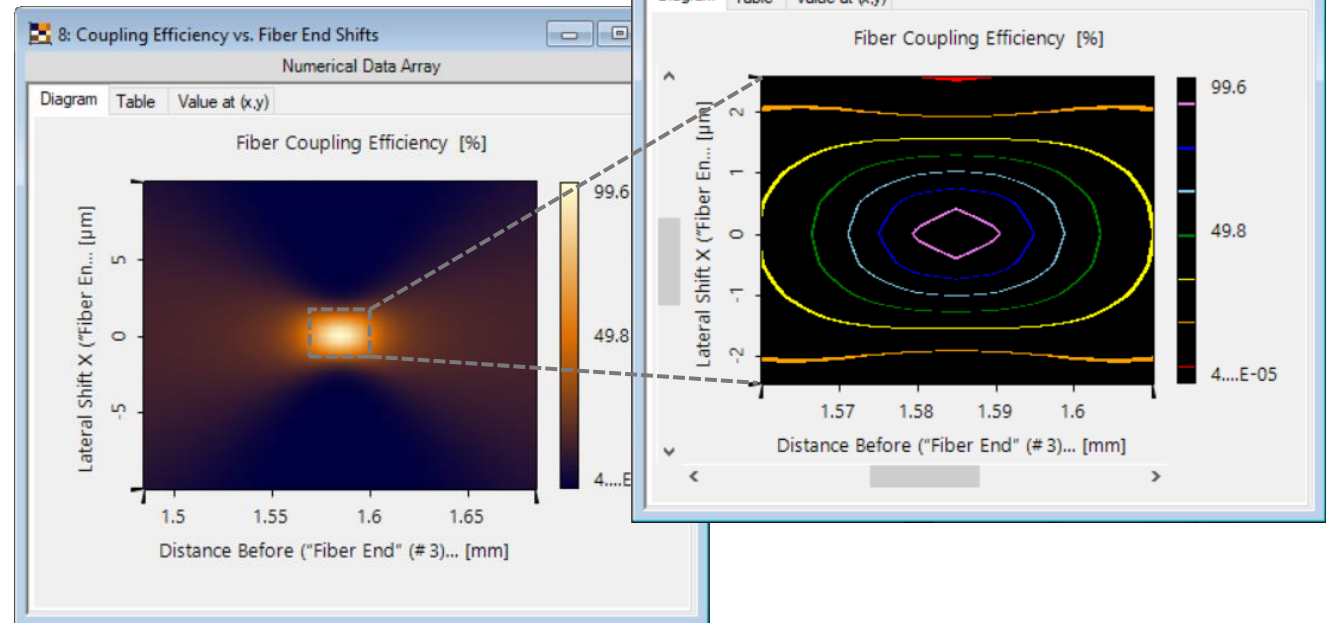


# Coupling Efficiency vs. Fiber End Position Shift



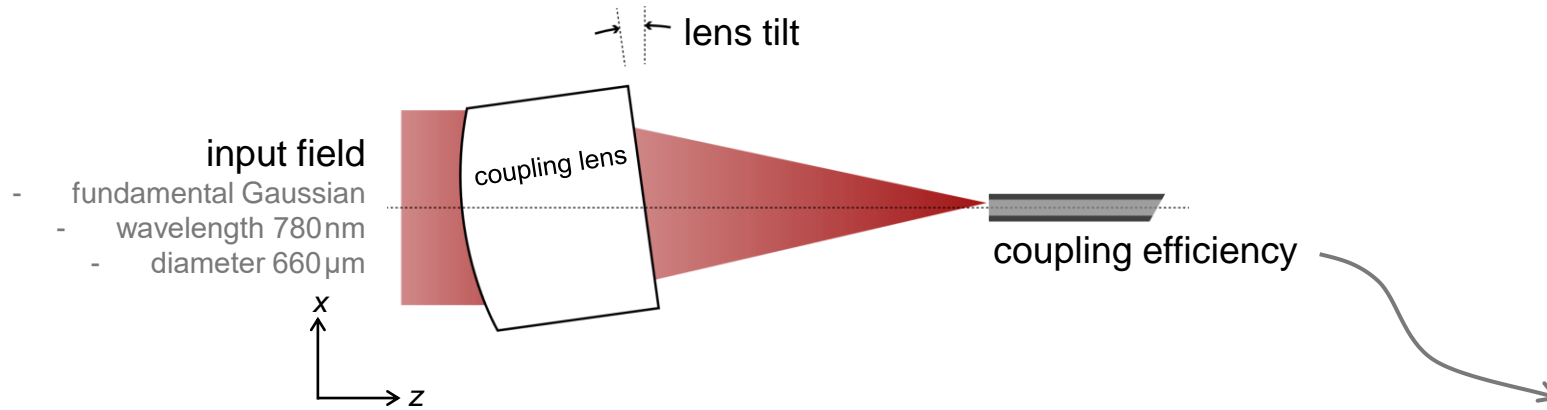
Contour plot helps with the identification of the parameter range for desired coupling efficiency threshold.

The coupling efficiency is scanned with respect to the fiber position shifts along both axial and lateral directions.

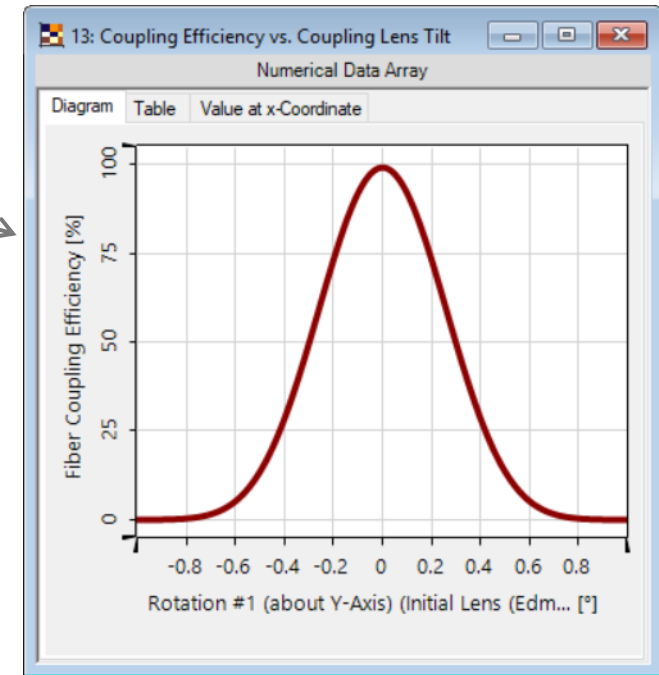




# Coupling Efficiency vs. Coupling Lens Tilt



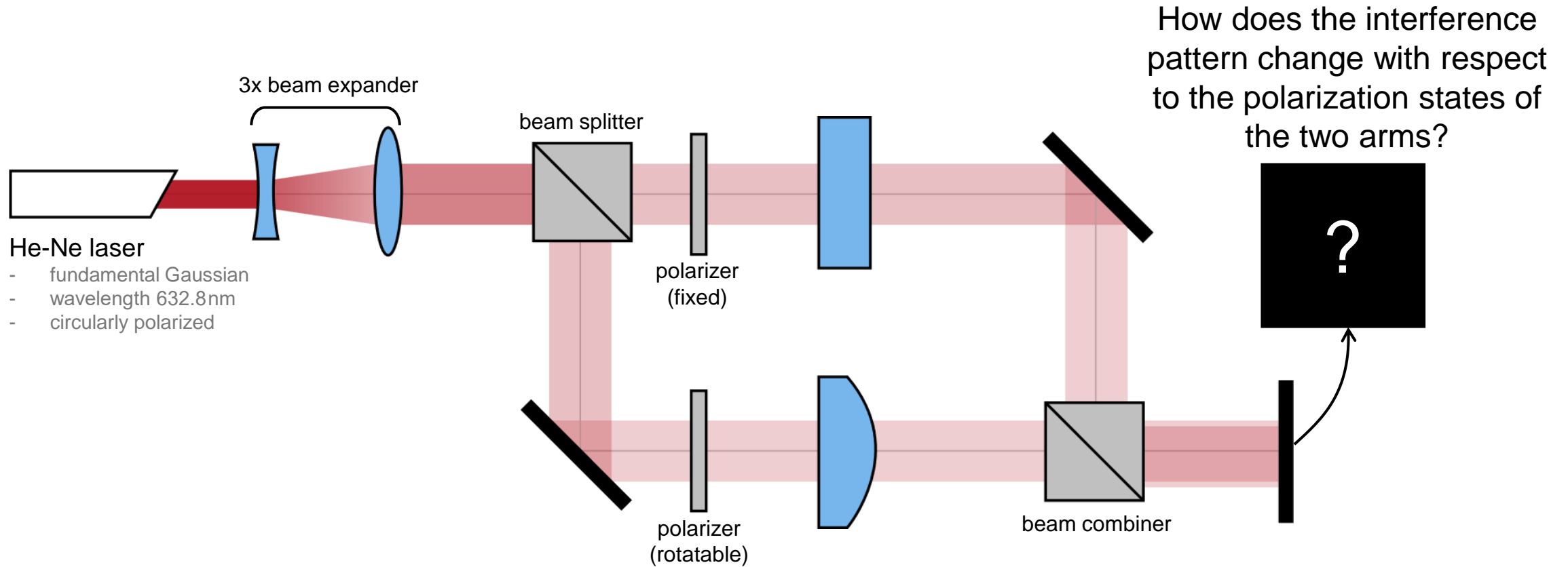
Physical-optics analysis of the coupling efficiency with respect to lens tilt. When lens tilt angle is within  $0.1^\circ$ , the coupling efficiency is still higher than 90%



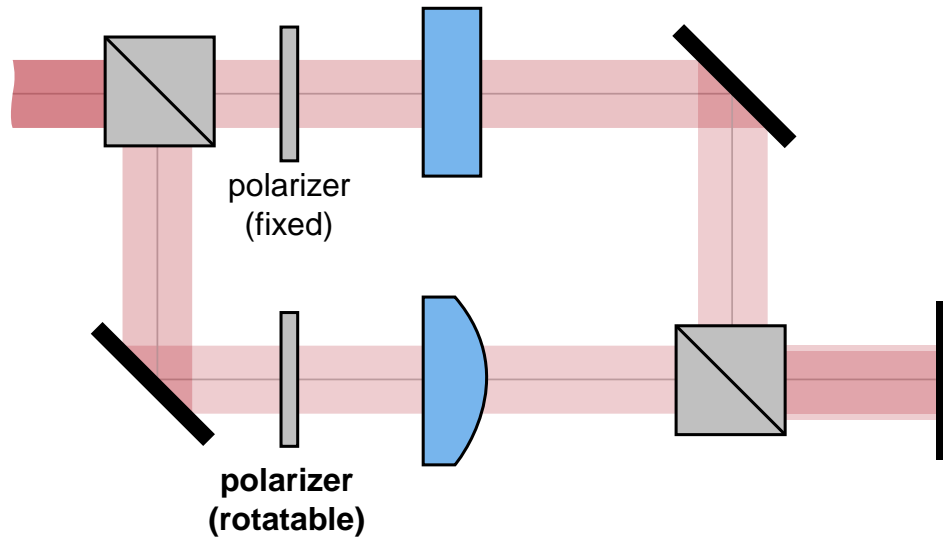
# Generation of Spatially Varying Polarization by Interference with Polarized Light



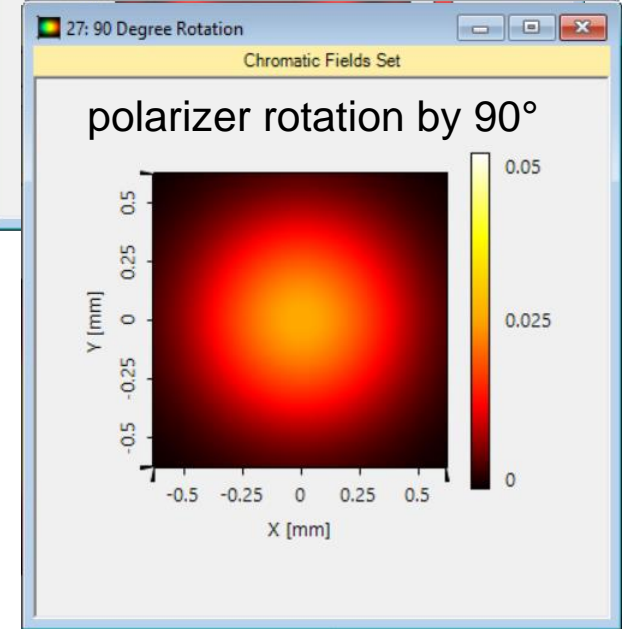
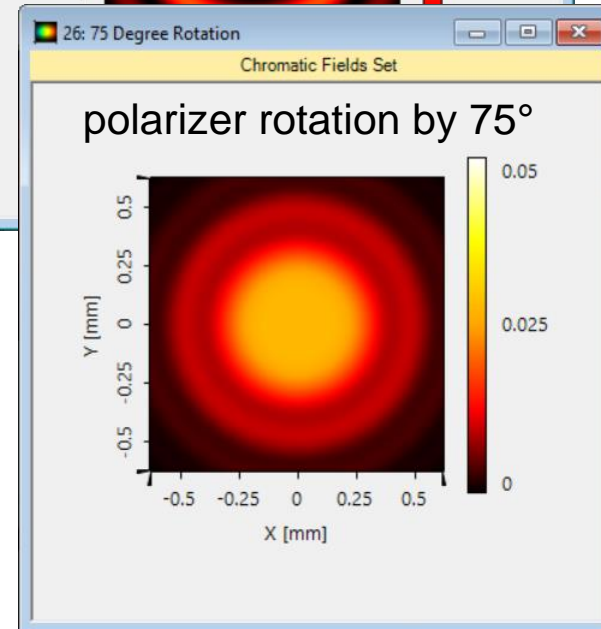
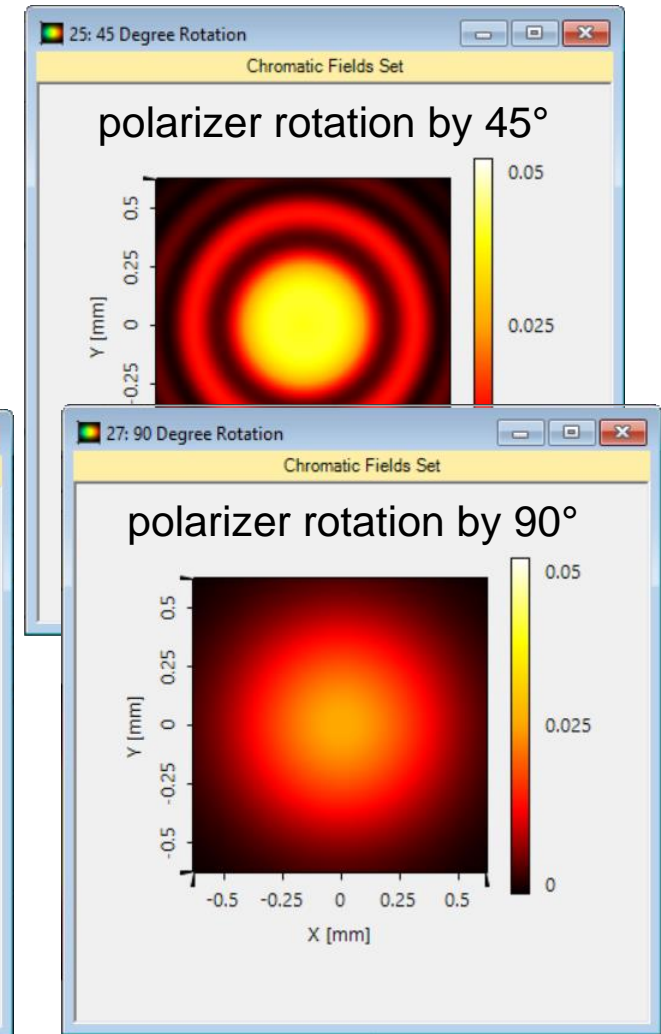
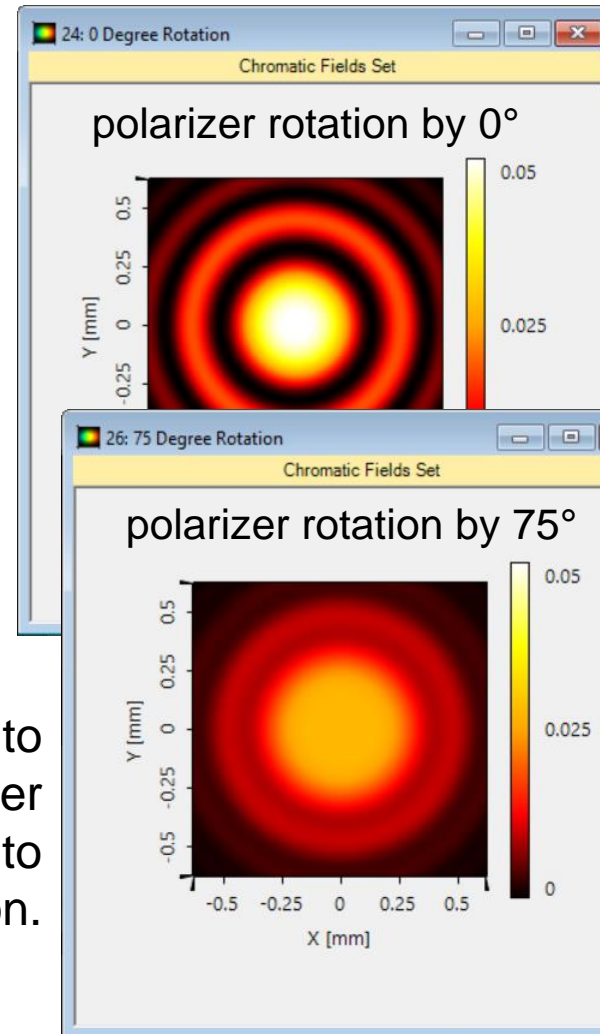
# Modeling Task



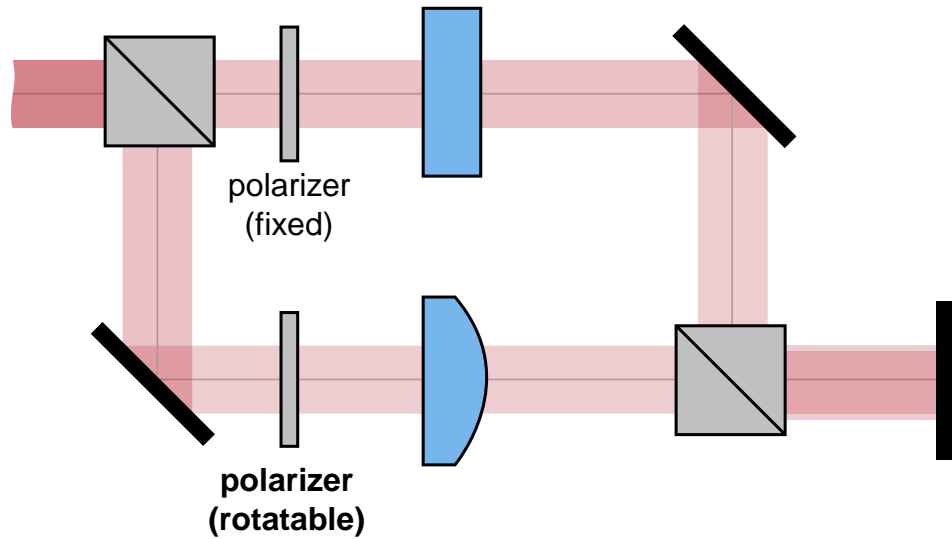
# Interference Pattern Changes with Polarizer Rotation



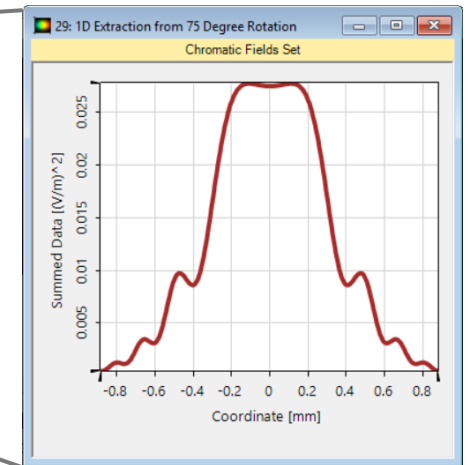
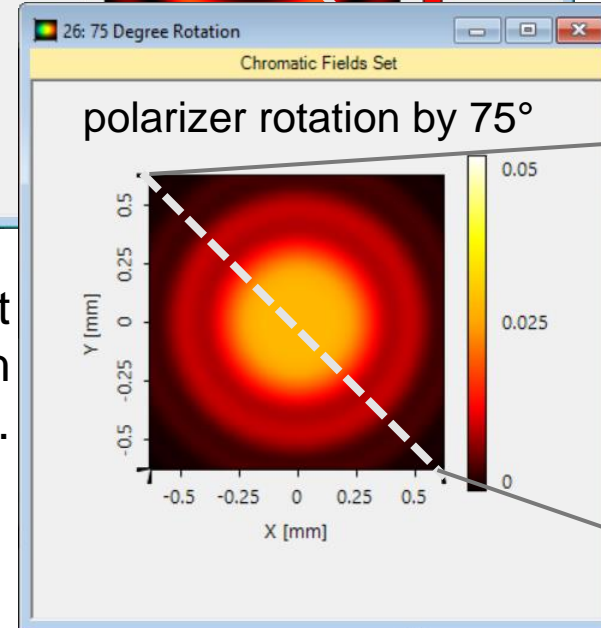
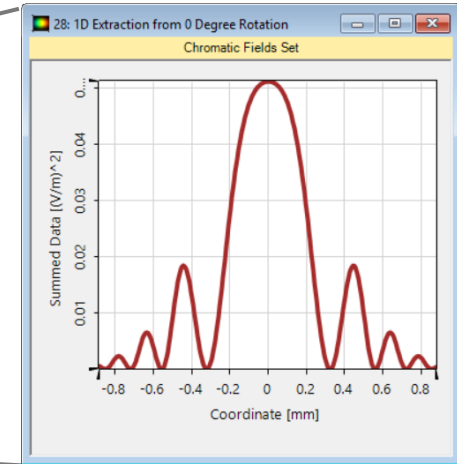
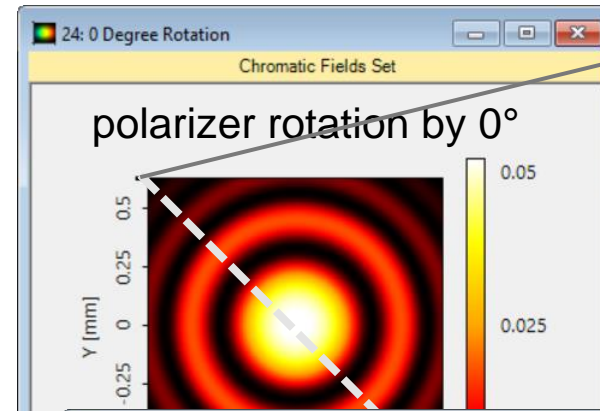
Interference fringes start to disappear, when polarizer rotates from parallel to orthogonal orientation.



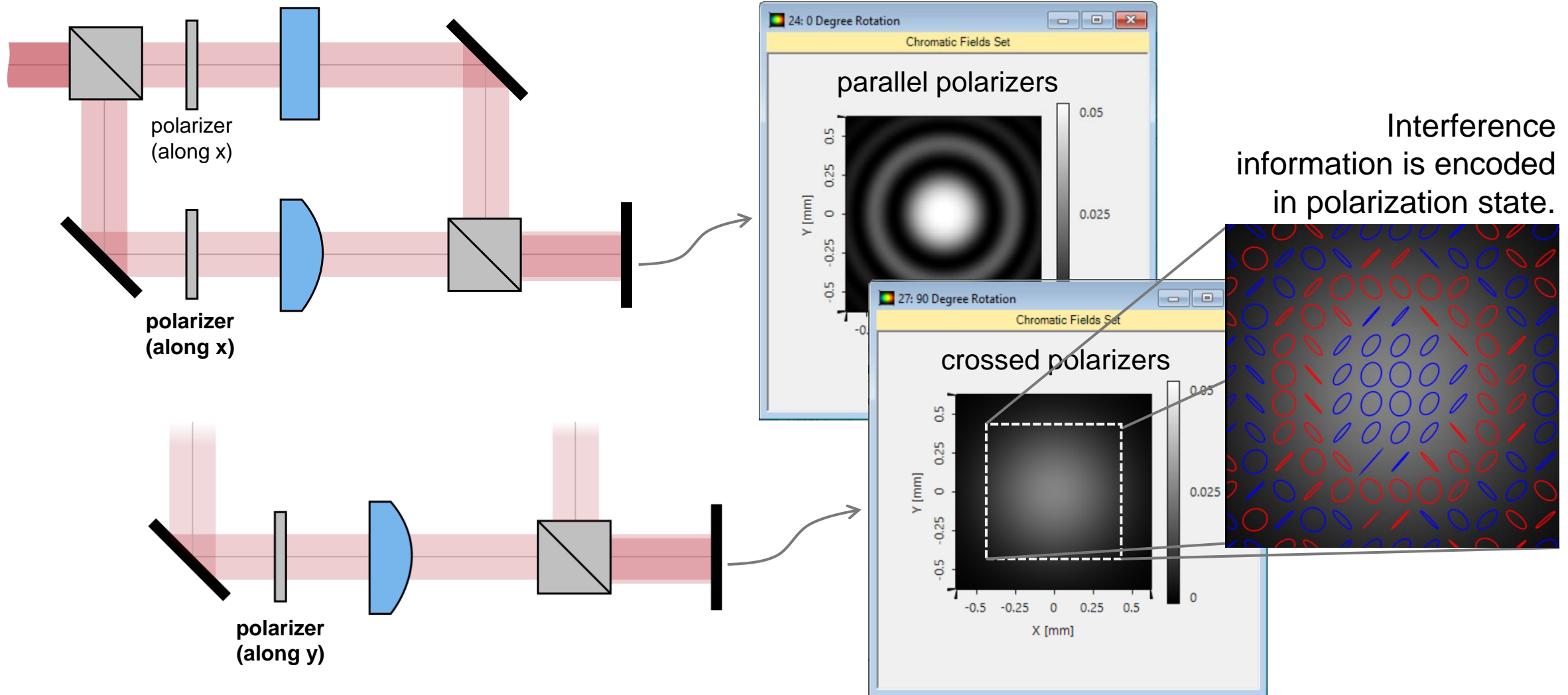
# Interference Pattern Changes with Polarizer Rotation



Fringe contrast  
changes with  
polarizer rotation.



# Interference Pattern



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# Annex

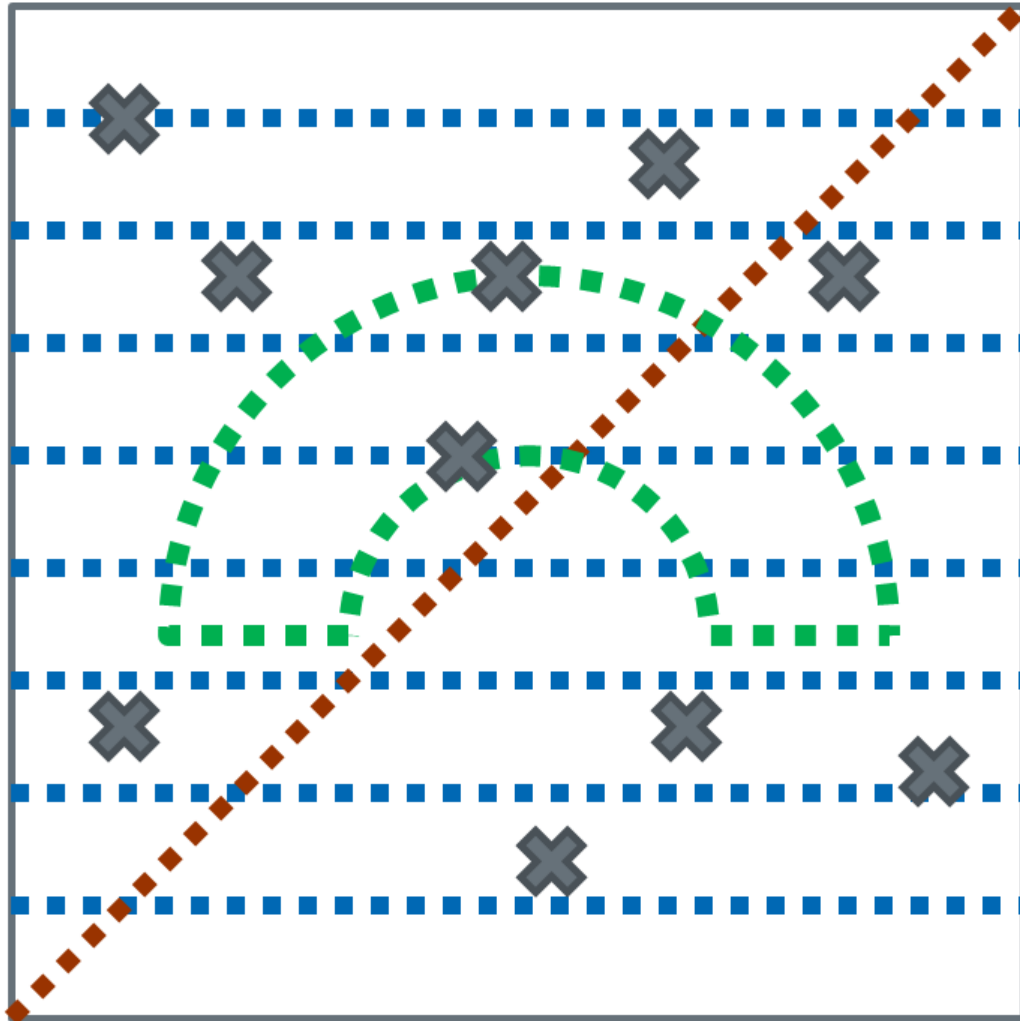
Some brief guides to useful features

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## Parameter Run



# Abstract



For a given optical system, it is helpful to check its performance by controlling and varying selected parameters. VirtualLab Fusion provides a fully flexible and computationally efficient (via parallelization) Parameter Run, which enables the user specify different manners of parameter variations. As an example, it can be used for the tolerance analysis with respect to any system parameters under investigation. The analysis result can be visualized in different ways, such as single numbers, graphs, or even animations.

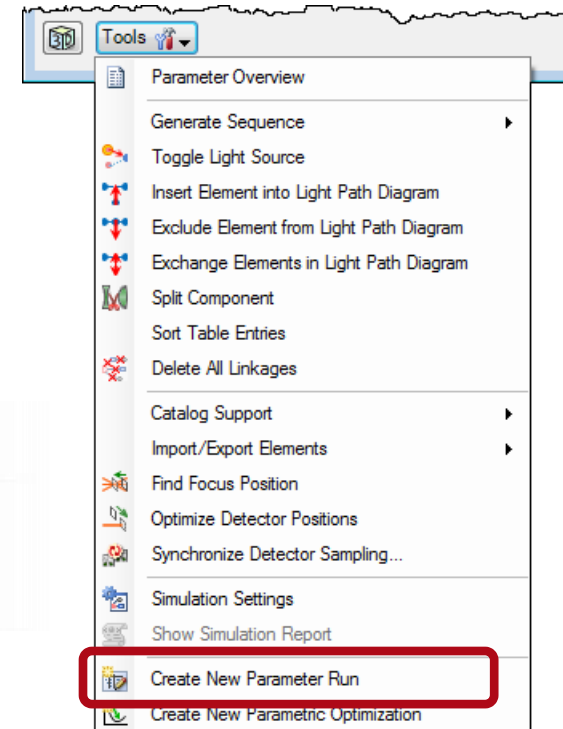
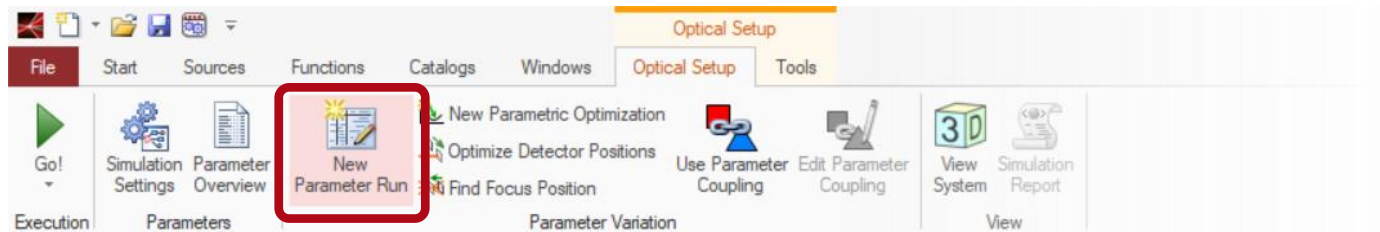
# Parameter Run Document

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- The Parameter Run document allows the variation of the numerical parameters of an Optical Setup.
  - It can be used e. g.
    - to investigate the system's sensitivity for parameter tolerances
    - to optimize parameters
    - to evaluate the changing profile of a beam in the vicinity of a focus
    - ...
  - One or multiple parameters can be varied.
  - Detector results are recorded within the Parameter Run document.
  - A copy of the original Optical Setup is stored in the Parameter Run document.
-

# New Parameter Run

- To generate a new Parameter Run an open and activated Optical Setup window is required.
- A new Parameter Run document can be generated via
  - ribbon
  - Optical Setup Tools
  - shortcut Ctrl + P



# Parameter Specification Page

**Parameter Specification**  
Set up the parameter(s) to be varied.

You can select one or more parameters which shall be varied as well as the resulting number of iterations. Several [modes](#) are available specifying how the parameters are varied per iteration.

Usage Mode: Standard

Filter by... Show Only Varied Parameters

1 2 *	Object	Category	Parameter	Vary	From	To	Steps	Step Size	Original Value
	Ideal Plane Wave #0		Wavelength	<input checked="" type="checkbox"/>	210.0655221 nm	3.71 $\mu$ m	2	3.499934478 $\mu$ m	532 nm
			Weight	<input type="checkbox"/>	0	1E+300	1	1E+300	1
			Polarization Angle	<input type="checkbox"/>	0°	360°	1	360°	0°
	Sawtooth Grating #1								
	Virtual Screen #600	Basal Positioning	Distance Before	<input type="checkbox"/>	-1E+303 mm	1E+303 mm	1	2E+303 mm	0 mm
Window Size Scaling X			<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1	
Window Size Scaling Y		<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1		
Resolution Scaling X		<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1		
Resolution Scaling Y		<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1		
	Virtual Screen #601	Basal Positioning	Distance Before	<input type="checkbox"/>	-1E+303 mm	1E+303 mm	1	2E+303 mm	0 mm
Window Size Scaling X			<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1	
Window Size Scaling Y		<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1		
Resolution Scaling X		<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1		
Resolution Scaling Y		<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1		

< Back   Next >   Show ▾

- This page allows you to select the parameters that should be varied.
- The parameter range and the number of steps can be specified.
- Four different Usage Modes (Standard, Programmable, Scanning, Random) will be Explained later.

# Parameter Specification Page

You can

- filter for specific parameters
- show only the ones that are already set for variation
- fold/unfold the parameter list for a clearer representation by using the first three columns

5: Parameter Run Example

**Parameter Specification**  
Set up the parameter(s) to be varied.

You can select one or more parameters which shall be varied as well as the resulting number of iterations. Several [modes](#) are available specifying how the parameters are varied per iteration.

Usage Mode: Standard

Filter by:  ☐ Show Only Varied Parameters

1 2	Object	Category	Parameter	Vary	From	To	Steps	Step Size	Original Value
<input type="checkbox"/>	Ideal Plane Wave #0		Wavelength	<input checked="" type="checkbox"/>	210.0655221 nm	3.71 $\mu\text{m}$	2	3.499934478 $\mu\text{m}$	532 nm
			Weight	<input type="checkbox"/>	0	1E+300	1	1E+300	1
			Polarization Angle	<input type="checkbox"/>	0°	360°	1	360°	0°
<input type="checkbox"/>	Sawtooth Grating #1								
<input type="checkbox"/>	Virtual Screen #600	Basal Positioning	Distance Before	<input type="checkbox"/>	-1E+303 mm	1E+303 mm	1	2E+303 mm	0 mm
			Window Size Scaling X	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1
			Window Size Scaling Y	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1
			Resolution Scaling X	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1
			Resolution Scaling Y	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1
<input type="checkbox"/>	Virtual Screen #601	Basal Positioning	Distance Before	<input type="checkbox"/>	-1E+303 mm	1E+303 mm	1	2E+303 mm	0 mm
			Window Size Scaling X	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1
			Window Size Scaling Y	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1
			Resolution Scaling X	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1
			Resolution Scaling Y	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1

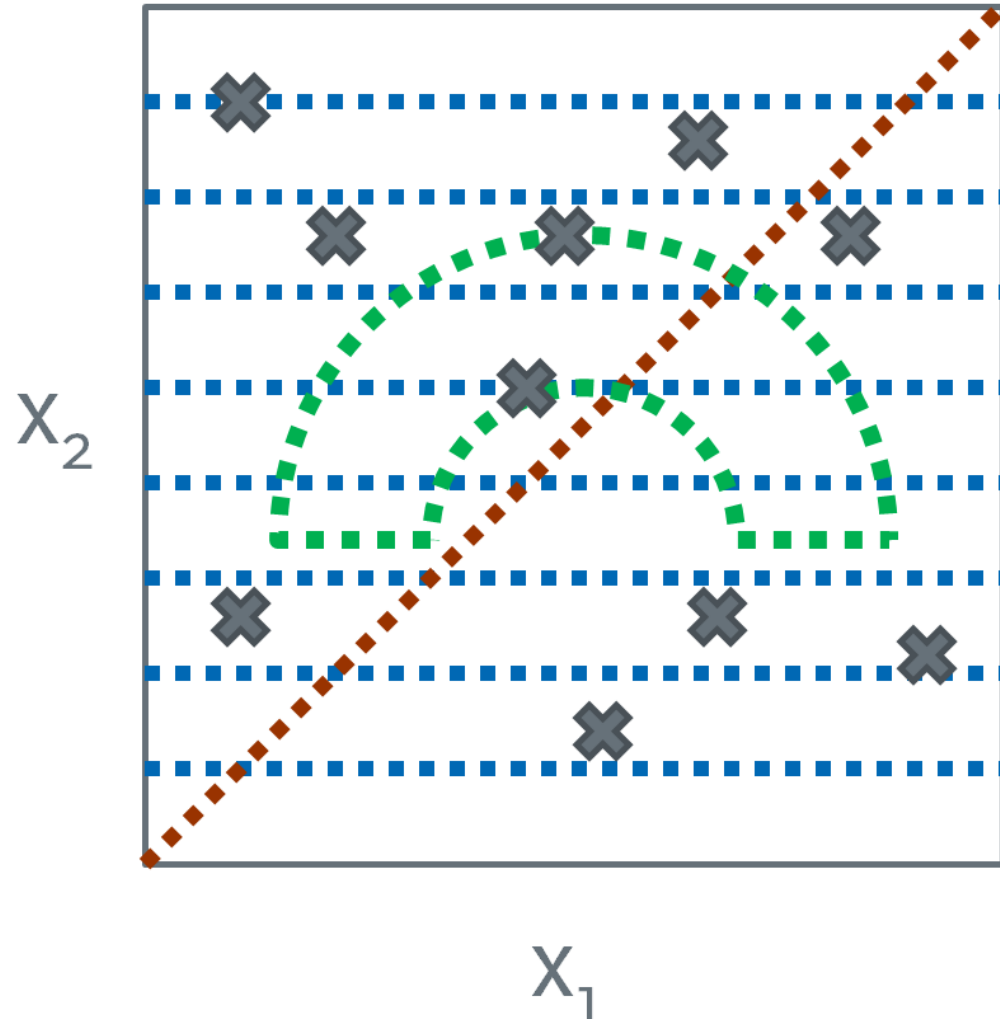
< Back   Next >   Show ▾

# Usage Modes

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- **Standard Mode:**  
Linear variation of all selected parameters between minimum and maximum value.
  - **Programmable Mode:**  
Customized parameter values per variation step. A table with the parameter values per variation step is filled by a snippet.
  - **Scanning Mode:**  
Scan of parameter space – all possible parameter combinations are simulated.
  - **Random Mode:**  
Random variation of parameters between minimum and maximum value. Sometimes also called Monte-Carlo-Simulation. A seed can be used for reproducible results.
-

# Usage Modes



- Illustration of the different usage modes for the parameter run. A two-dimensional parameter space defined by two parameters  $X_1$  and  $X_2$  is shown.
- **Red:** Resulting parameter sets for the standard mode.
- **Green:** Example how the parameter sets can be generated by a snippet in the programmable mode.
- **Blue:** Resulting parameter sets for the scanning mode.
- **Grey:** Some randomly generated parameter sets.

# Detecting Devices Specification Page

**Detecting Devices Specification**  
Set up the detecting devices whose results you want to analyze

This page allows you to select one or more detecting devices (detectors, analyzers, or virtual screens). At least one detecting device must be selected. If you click on the "Open" button of one detecting device, the corresponding edit dialog is displayed.

In the upper part you can select the simulation engine(s) that shall be executed in the parameter run. Furthermore you can select the detectors that shall be evaluated by the selected simulation engine(s).

☒ Unified Field Tracing

Detecting Device		Edit Dialog
Virtual Screen #600	<input checked="" type="checkbox"/>	Open
Virtual Screen #601	<input checked="" type="checkbox"/>	Open

In the lower part you can select the analyzers that shall be executed in the parameter run. They are independent from the simulation engine(s) selected above.

Analyzer		Edit Dialog
Grating Efficiency Analyzer (2D) #800	<input checked="" type="checkbox"/>	Open

< Back   Next >   Show LPD

- This page allows to select which simulation engines, detectors, screens and analyzers are evaluated.
- The detecting devices can be configured after clicking Open to get to the edit dialog.



# Results Page

Starts and stops the parameter variation.

**Results**  
Start the parameter run and analyze its results

☒ Use Cached Results for Next Run

Detector	Subdetector	Combined Output	Iteration Step	
			1	2
Varied Parameters	Wavelength (Ideal Plane W...	Data Array	210.0655221 nm	3.71 $\mu$ m
	Absorption	Data Array	0 %	0 %
Grating Efficiency Analyzer (2D) #800	Overall Reflection and Tra...	Data Array	100 %	100 %
	Overall Reflection Efficiency	Data Array	8.762677763 %	2.127007061 %
	Overall Transmission Efficiency	Data Array	91.23732224 %	97.87299294 %
Virtual Screen #600 after S...		2D Data Arra	Harmonic Field	Harmonic Field
Virtual Screen #601 after S...		2D Data Arra	Harmonic Field	Harmonic Field

Simulation results:  
Double click on a document to view it in a separate window.

In the Property Browser you can change the formatting of the shown physical values (number of digits and whether physical units are shown) so that you can better export them to e.g. spread sheet programs via copy & paste.

**Property Browser**

5: Parameter Run Example

**General**

After Parameter Run Finished	Do Nothing
Always Plot versus Iteration Step	False
No Logging During Parameter Run	False
Sort Rows	True

**Format of Numbers**

Format of Complex Numbers	Amplitude / Phase
Number of Digits	10
Show Physical Units	True

**After Parameter Run Finished**  
The action to be done when the parameter run has finished.

# Optical Setups within Parameter Run

The screenshot shows the 'Parameter Run' window in Wyrowski VirtualLab Fusion. The 'Execution' tab is active, showing a 'Go!' button and a dropdown menu for 'After Completion' set to 'Do Nothing'. Below this, there are buttons for 'Show Optical Setup', 'No Logging During Execution', 'Create Output from Selection', and 'Delete Results'. The 'Optical Setup' button is highlighted with a red box. The 'Results' tab is also visible, showing a table of results for a 'Grating Efficiency Analyzer (2D) #800'. The table has columns for 'Detector', 'Subdetector', 'Combined Output', and 'Iteration Step' (1 and 2). The 'Show' button at the bottom right of the 'Results' tab is also highlighted with a red box.

Detector	Subdetector	Combined Output	Iteration Step	
			1	2
Grating Efficiency Analyzer (2D) #800	Wavelength (Ideal Plane W...	Data Array	210.0655221 nm	3.71 $\mu$ m
	Absorption	Data Array	0 %	0 %
	Overall Reflection and Tra...	Data Array	100 %	100 %
	Overall Reflection Efficiency	Data Array	8.762677763 %	2.127007061 %
	Overall Transmission Effici...	Data Array	91.23732224 %	97.87299294 %
Virtual Screen #600 after S...		2D Data Arra	Harmonic Field	Harmonic Field
Virtual Screen #601 after S...		2D Data Arra	Harmonic Field	Harmonic Field

Displays the optical setup:

- initial
- from any iteration

# Logging of Parameter Run Results

The screenshot shows the Wyrowski VirtualLab Fusion (2nd Generation Technology Update [Build 7.4.0.49]) interface. The 'Parameter Run' window is active, displaying a table of results for a 'Grating Efficiency Analyzer (2D) #800'. The 'Property Browser' on the right shows the 'General' tab with the 'No Logging During Parameter Run' option set to 'False'.

**Parameter Run Results Table:**

Detector	Subdetector	Combined Output	Iteration Step	
			1	2
Grating Efficiency Analyzer (2D) #800	Wavelength (Ideal Plane W...	Data Array	210.0655221 nm	3.71 μm
	Absorption	Data Array	0 %	0 %
	Overall Reflection and Tra...	Data Array	100 %	100 %
	Overall Reflection Efficiency	Data Array	8.762677763 %	2.127007061 %
	Overall Transmission Effici...	Data Array	91.23732224 %	97.87299294 %
Virtual Screen #600 after S...		2D Data Arra	Harmonic Field	Harmonic Field
Virtual Screen #601 after S...		2D Data Arra	Harmonic Field	Harmonic Field

- For time critical simulations especially for Parameter Runs with many iterations, the simulation time can be reduced by **deactivating the logging**.
- Thus the results are only shown after all iterations are finished.
- In order to see the results of a running Parameter Run document that have been produced so far, you can duplicate the document via the Windows ribbon; then VirtualLab creates a Parameter Run document of the current status with all already calculated results.

# Display of Parameter Run Results

1. Delete Results

2. Always Plot versus Iteration Step

3. Format of Complex Numbers

Property Browser

5: Parameter Run Example

General

General

After Parameter Run Finished Do Nothing

Always Plot versus Iteration Step False

No Logging During Parameter Run False

Sort Rows True

Format of Complex Numbers Amplitude

Number of Digits 10

Show Physical Units True

After Parameter Run Finished

The action to be done when the parameter run has finished.

Property Browser VirtualLab Explorer

Detector	Subdetector	Combined Output	Iteration Step	1	2
Varied Parameters	Wavelength (Ideal Plane W...	Data Array		210.0655221 nm	3.71 μm
Grating Efficiency Analyzer (2D) #800	Absorption	Data Array		0 %	0 %
	Overall Reflection and Tra...	Data Array		100 %	100 %
	Overall Reflection Efficiency	Data Array		8.762677763 %	2.127007061 %
	Overall Transmission Effici...	Data Array		91.23732224 %	97.87299294 %
Virtual Screen #600 after S...		2D Data Arra		Harmonic Field	Harmonic Field
Virtual Screen #601 after S...		2D Data Arra		Harmonic Field	Harmonic Field

1. It is possible to delete the results in order to save a smaller Parameter Run document (e.g. for email sending).  
(Sometimes the saving or opening of a Parameter Run document with many and/or huge results takes longer than the simulation of all iterations.)
2. The user can select different orders for the display of the results.
3. There are different options to display complex numbers.

# Saving (& Shutdown) after Parameter Run Completion?

Allows you to save the results after the simulation has finished and then shut down your computer.

The screenshot displays the Wyrowski VirtualLab Fusion software interface. The main window is titled '5: Parameter Run Example'. It features a 'Results' section with a 'Go!' button and a checkbox for 'Use Cached Results for Next Run'. Below this is a table showing simulation results for various detectors and parameters. The 'Property Browser' on the right shows the 'General' tab with a dropdown menu set to 'Do Nothing'.

**Table 1: Results**

Detector	Subdetector	Combined Output	Iteration Step 1	Iteration Step 2
Varied Parameters	Wavelength (Ideal Plane W...	Data Array	210.0655221 nm	3.71 $\mu$ m
Grating Efficiency Analyzer (2D) #800	Absorption	Data Array	0 %	0 %
	Overall Reflection and Tra...	Data Array	100 %	100 %
	Overall Reflection Efficiency	Data Array	8.762677763 %	2.127007061 %
	Overall Transmission Effici...	Data Array	91.23732224 %	97.87299294 %
Virtual Screen #600 after S...		2D Data Arra	Harmonic Field	Harmonic Field
Virtual Screen #601 after S...		2D Data Arra	Harmonic Field	Harmonic Field

**Table 2: Property Browser - General**

Property	Value
After Parameter Run Finished	Do Nothing
Always Plot versus Iteration Step	False
No Logging During Parameter Run	False
Sort Rows	True
Format of Complex Numbers	Amplitude / Phase
Number of Digits	10
Show Physical Units	True

# Results Page – Combined Outputs

The results for each (sub-)detector can be combined into a Data Array, Animation, Harmonic Fields Set or Ray Distribution. Which combined outputs are available depends on the type and dimensionality of the original documents.

Create the combined output – or stop the creation if it takes too long. Clicking/Double clicking on a cell in the Detector or Subdetector column is a shortcut to selecting the whole row and start the output creation with the current combined output.

5: Parameter Run Example

**Results**  
Start the parameter run and analyze its results

☒ Use Cached Results for Next Run

Detector	Subdetector	Combined Output	Iteration Step	
			1	2
Varied Parameters	Wavelength (Ideal Plane W...	Data Array	210.0655221 nm	3.71 $\mu$ m
Grating Efficiency Analyzer (2D) #800	Absorption	Data Array	0 %	0 %
	Overall Reflection and Tra...	Data Array	100 %	100 %
	Overall Reflection Efficiency	Data Array	8.762677763 %	2.127007061 %
	Overall Transmission Effici...	Data Array	91.23732224 %	97.87299294 %
Virtual Screen #600 after S...		2D Data Arra	Harmonic Field	Harmonic Field
Virtual Screen #601 after S...		2D Data Arra	Harmonic Field	Harmonic Field

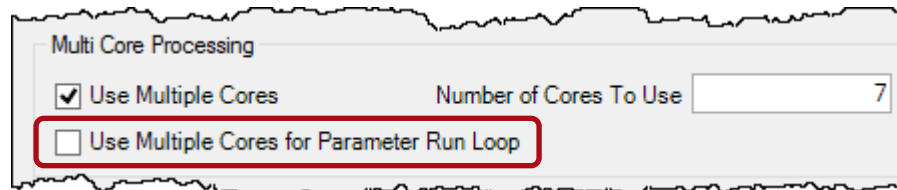
< Back    Next >    Show ▾

- Select the results to combine.
- Clicking on a cell in the Detector or Subdetector column selects the whole row.

- Choose the desired combined output.
- Several combined outputs can be configured by clicking on the pencil icon.

# Parallelization & Amount of Data

- The execution of the different iterations of a Parameter Run simulation is very well parallelized. Thus it represents a very efficient method to simulate many different settings very fast.
- But in case already one simulation is extremely memory consuming, parallel executions are out of the question. They would not be possible or slow down the whole process if VirtualLab may swap such large data on hard disc instead of keeping it in the RAM.
- Then the parallelization should be switched off for Parameter Run Loop.
- VirtualLab will still do parallel computations, as parallelization is also used within single system simulations.



## Parameter Coupling



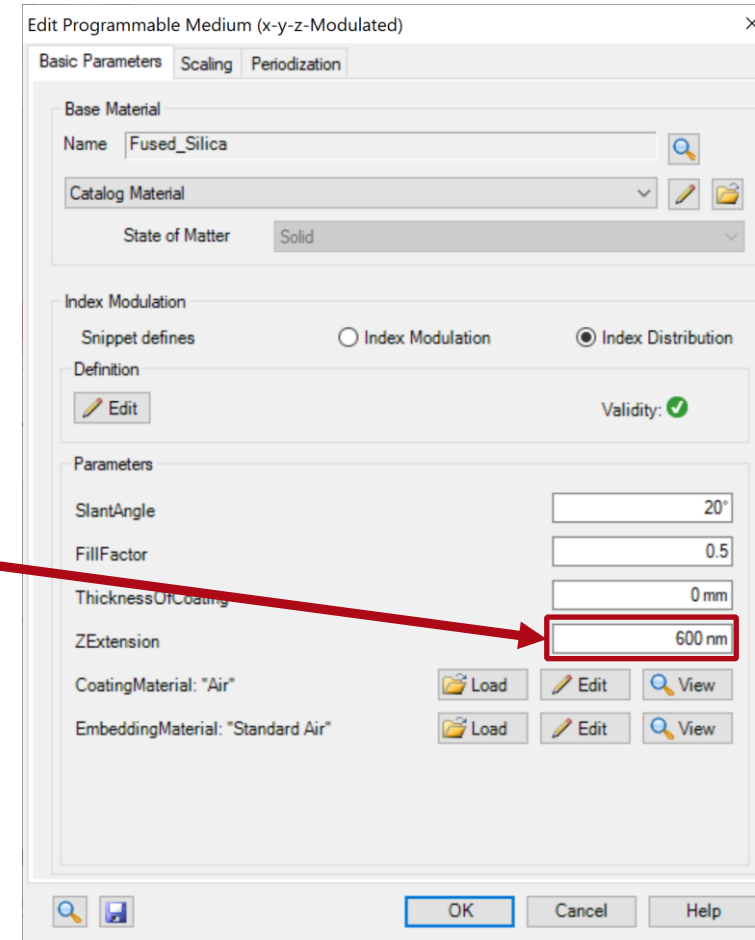
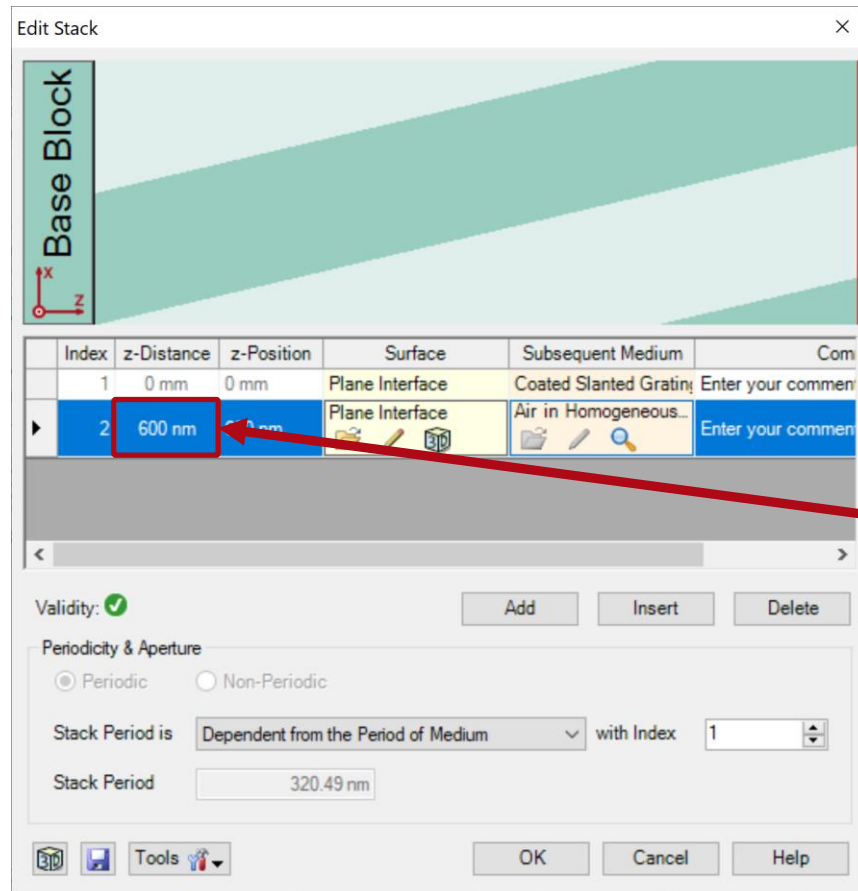
# Abstract



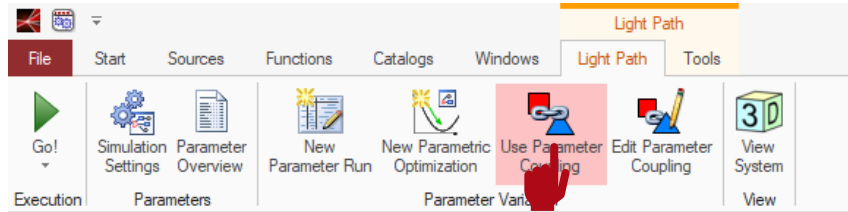
The parameter coupling feature of VirtualLab Fusion enables the coupling of parameters in an optical setup. The values can also be used to re-calculate other parameters of the system, so that a certain relationship between them is automatically maintained. Hence, this feature allows the user to instate complex dependencies for these parameters. For instance, in this example we use the Parameter Coupling to ensure that the z extension of a user-programmed slanted grating medium coincides with the thickness of the structured layer where it is contained.

# Task

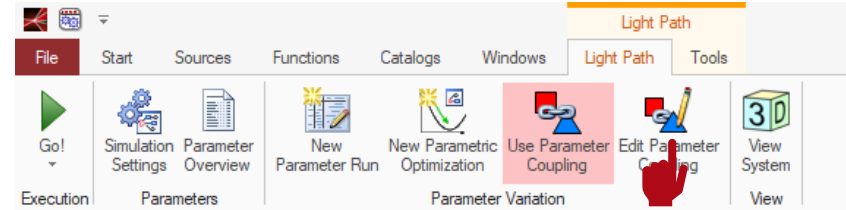
We wish to link two parameters of an optical system, so that they automatically take the same value. For this purpose, VirtualLab's Parameter Coupling feature is used.



# Set Up Parameter Coupling

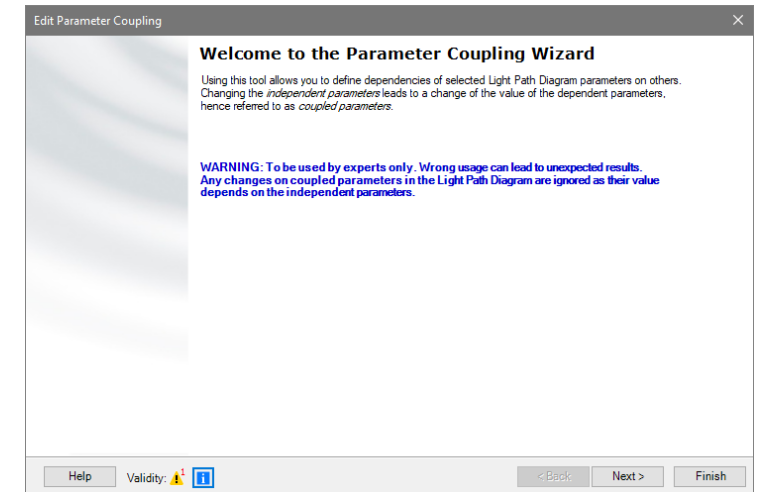


In order to use the parameter coupling feature of VirtualLab Fusion activate the option “*Use Parameter Coupling*” for the optical setup in question.



Afterwards, the “*Edit Parameter Coupling*” button is available.

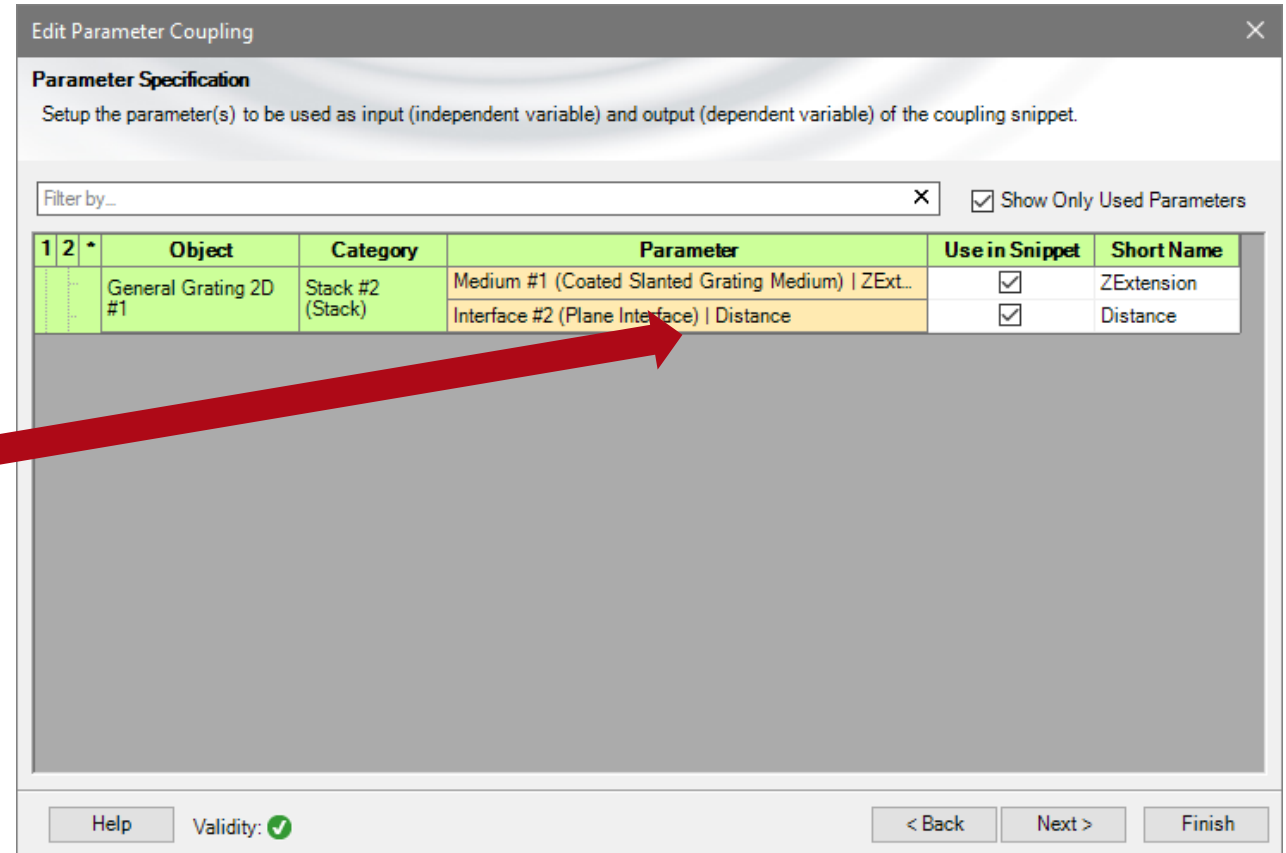
Clicking on the “*Edit Parameter Coupling*” button causes the parameter coupling wizard to appear.



# Choose Parameters Involved

By clicking “*Next*”, a table is shown which contains all parameters of the current optical setup.

Please select all the parameters which are relevant for the coupling and necessary calculation. For instance, the parameters “*ZExtension*” and “*Distance*” are chosen in this case.



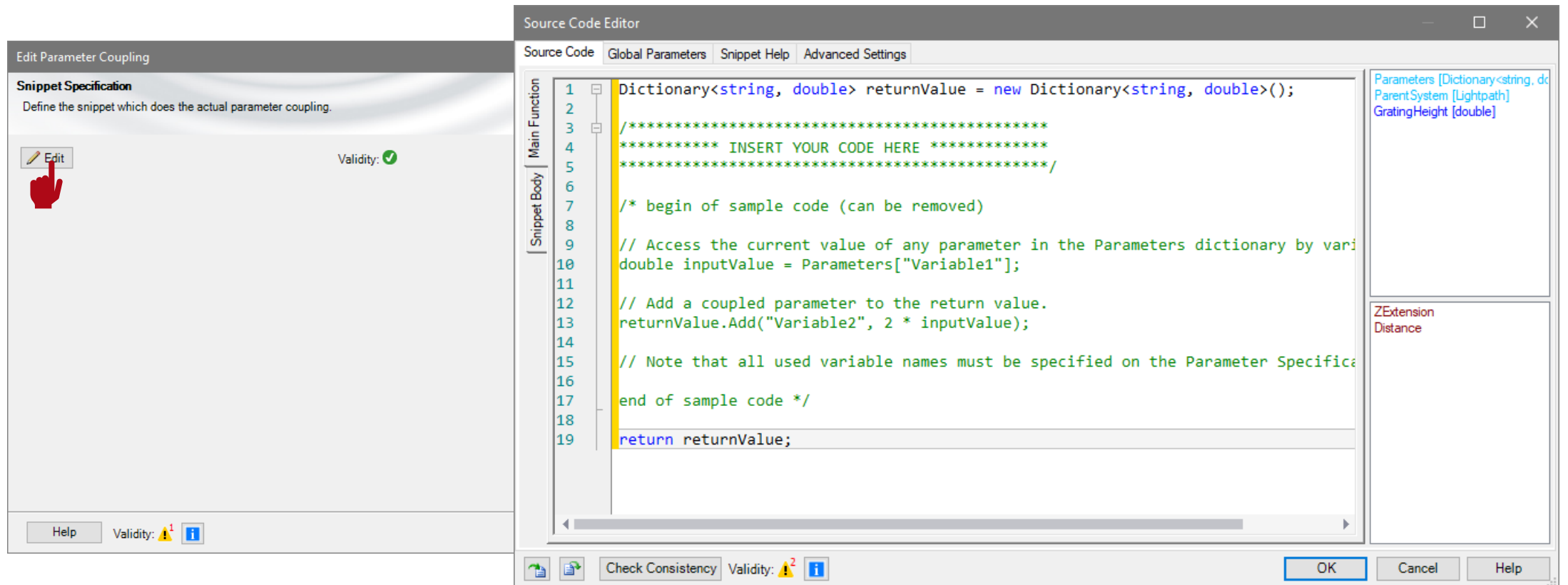
The screenshot shows the 'Edit Parameter Coupling' dialog box. It has a title bar with a close button. Below the title bar is the 'Parameter Specification' section with a subtitle: 'Setup the parameter(s) to be used as input (independent variable) and output (dependent variable) of the coupling snippet.' There is a 'Filter by...' search bar and a checkbox labeled 'Show Only Used Parameters' which is checked. Below this is a table with the following data:

1	2	Object	Category	Parameter	Use in Snippet	Short Name
		General Grating 2D #1	Stack #2 (Stack)	Medium #1 (Coated Slanted Grating Medium)   ZExt...	<input checked="" type="checkbox"/>	ZExtension
				Interface #2 (Plane Interface)   Distance	<input checked="" type="checkbox"/>	Distance

A red arrow points from the text 'Distance' in the paragraph to the 'Distance' parameter row in the table. At the bottom of the dialog box, there is a 'Help' button, a 'Validity: ✓' indicator, and three buttons: '< Back', 'Next >', and 'Finish'.

# Configure the Coupling of the Parameters

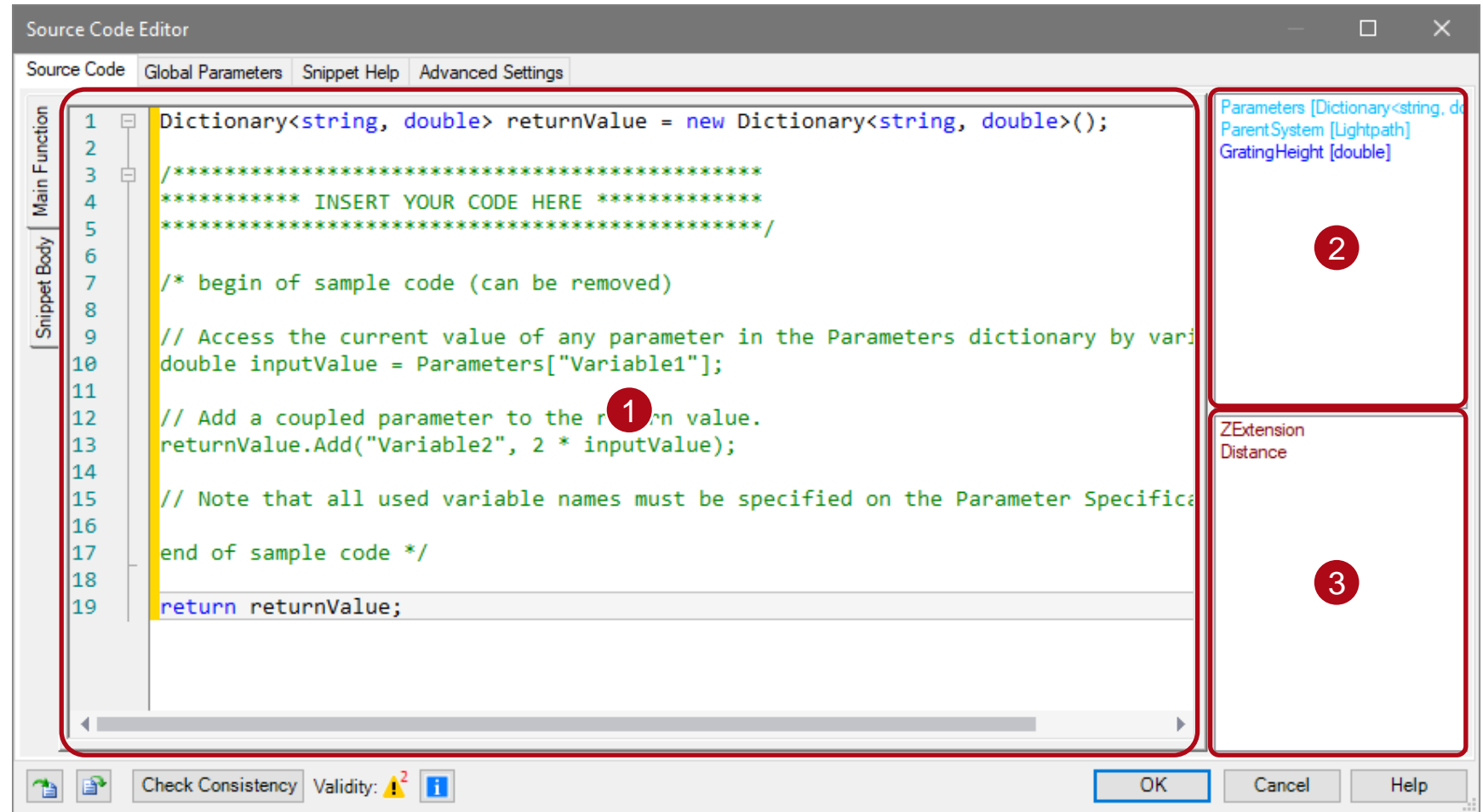
After choosing the parameters, the snippet which controls the coupling has to be set. By clicking on “*Edit*” the source code editor opens.



# Configure the Coupling of Parameters

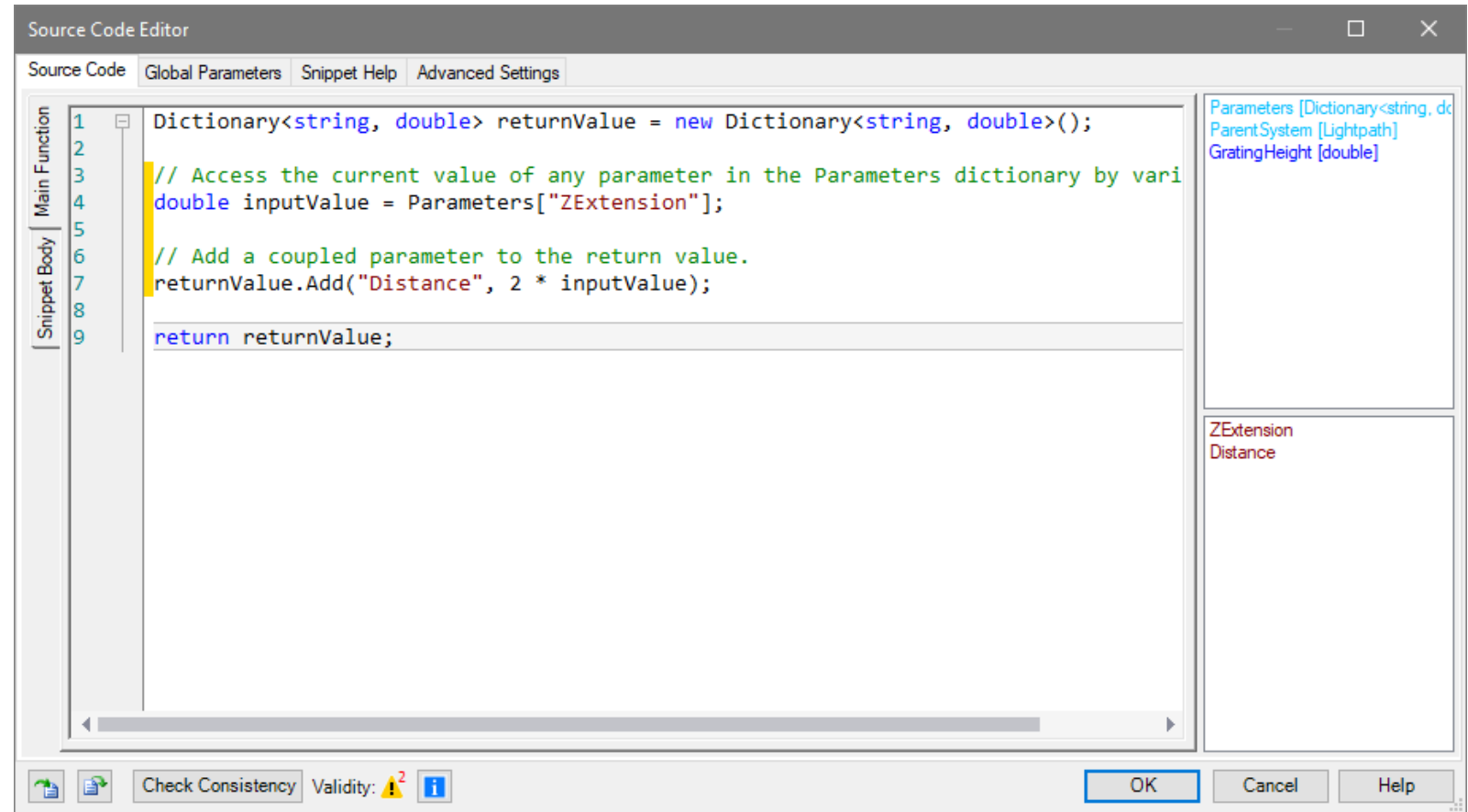
The source code tab contains three areas:

- 1 the source code (center area)
- 2 global variables/parameters (upper right area)
- 3 chosen system parameters (lower right)



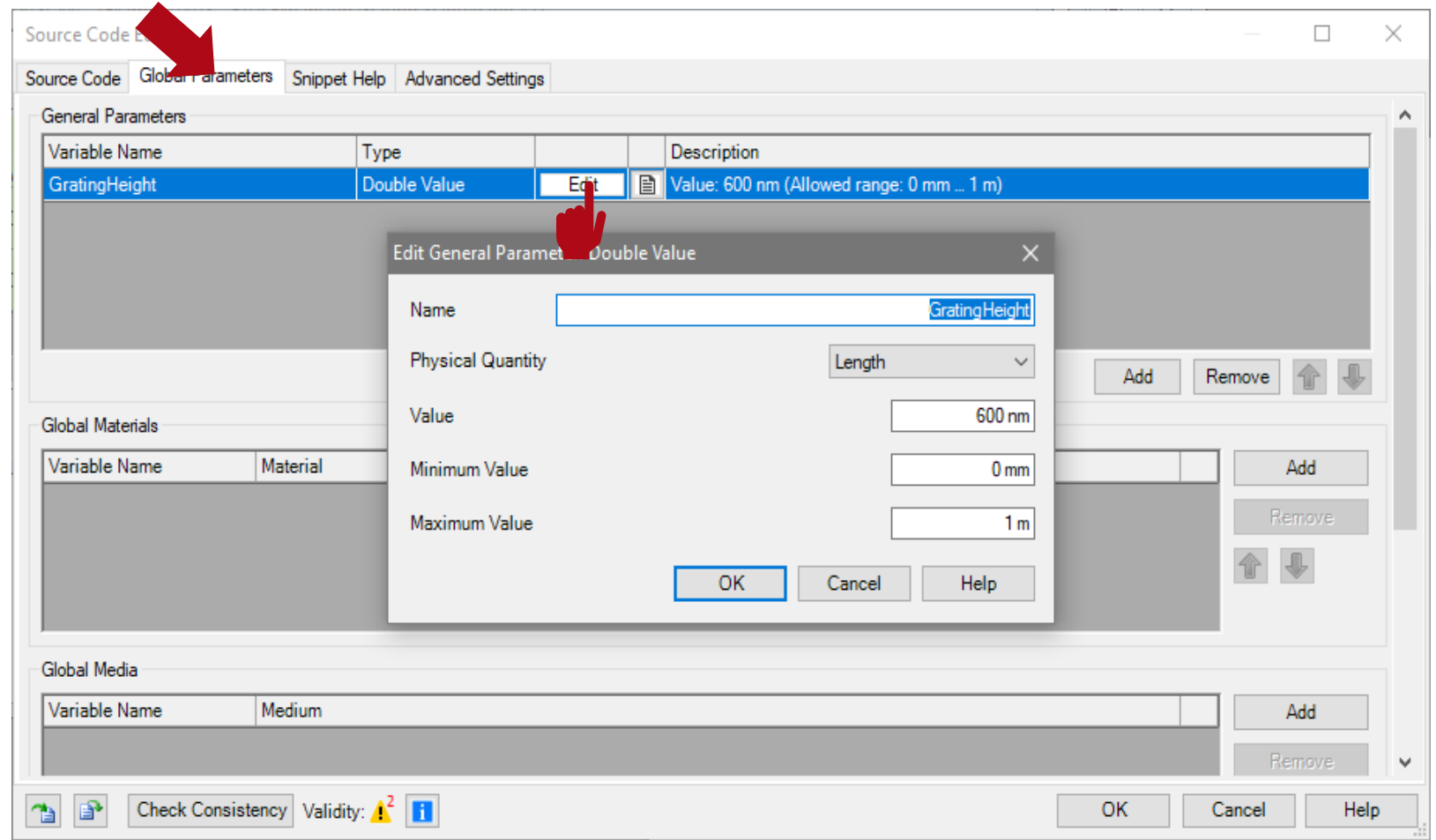
# General Example of Parameter Coupling

- In general, the chosen parameters have to be read from the dictionary and saved to a variable (line 4).
- Afterwards, that value can be used as output for another parameter, or play a role in its calculation, e.g. be doubled (line 7).



# Definition of Global Parameters

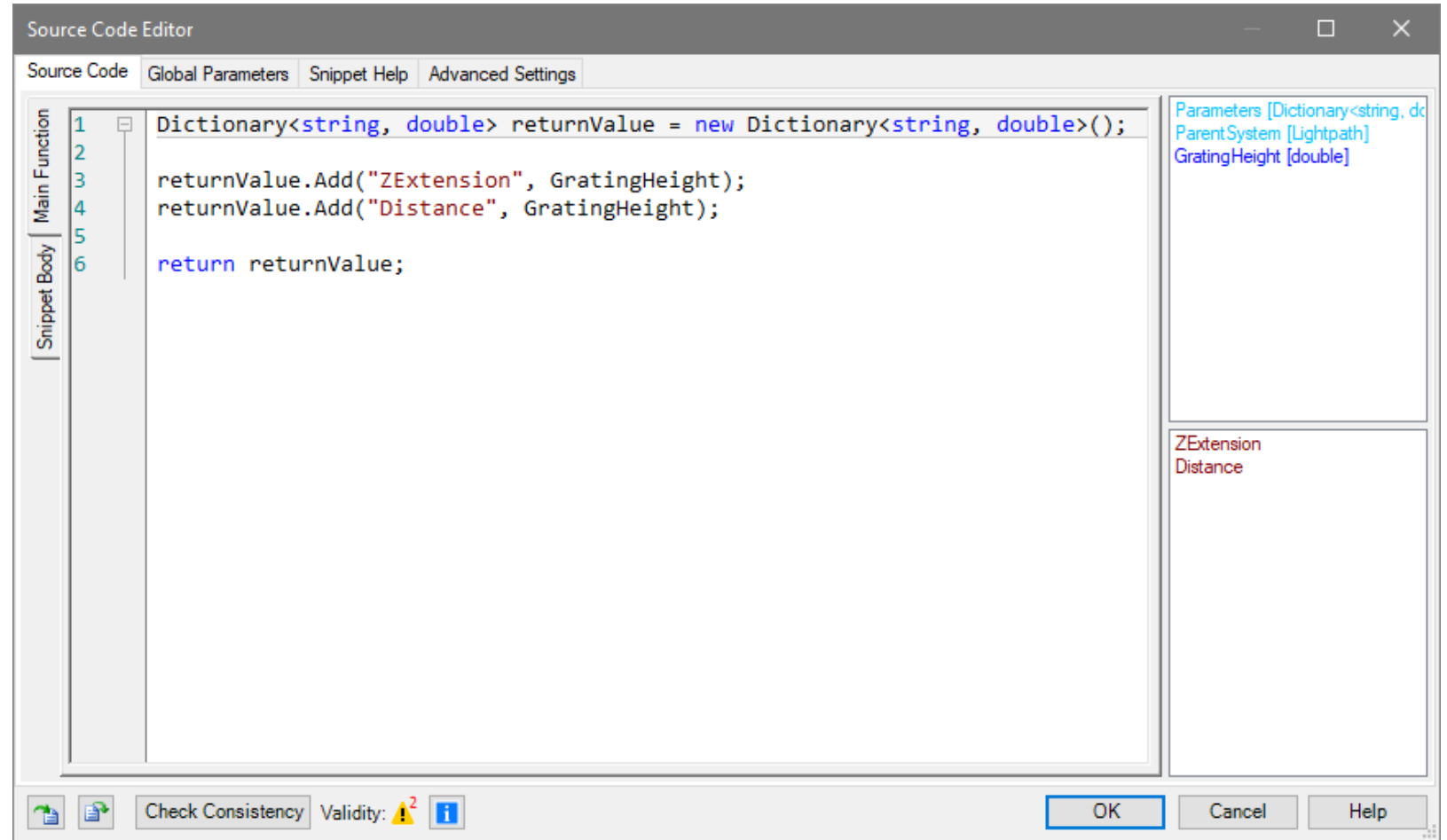
- In this particular example, it is helpful to define a new global variable, which later appears on the parameter coupling window.
- This can be done in the “*Global Parameters*” tab.
- The variable can be of different types and have different physical quantities attached.





# Particular Example of Parameter Coupling

- In this example, the global variable is used to return its value to both chosen parameters of the system.
- Thus, no parameter has to be read from the dictionary or re-calculated.



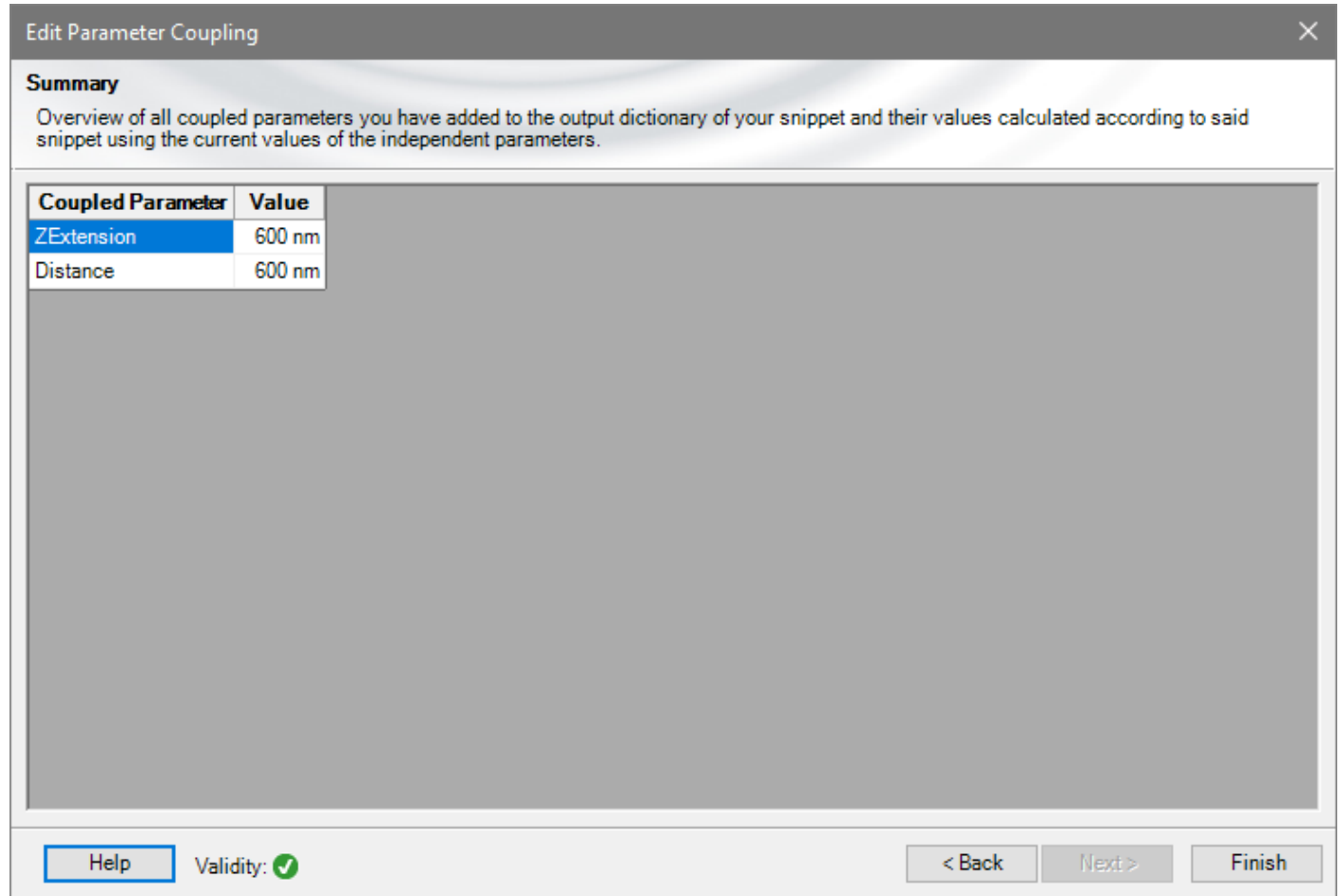
# Particular Example of Parameter Coupling

- After closing the source code editor, the defined global variable “*GratingHeight*” appears.
- When working with the system later on, the user will only be able to modify the value of this variable, which will in turn automatically affect the value of the system parameters. Trying to modify the value of the parameters themselves will have no effect.

The screenshot shows a software window titled "Edit Parameter Coupling". Inside, there is a section labeled "Snippet Specification" with the instruction "Define the snippet which does the actual parameter coupling." Below this, there is an "Edit" button with a pencil icon. To the right of the button, it says "Validity: ✓". In the center, the variable name "GratingHeight" is displayed next to a text input field containing the value "600 nm". At the bottom of the window, there is a footer bar containing a "Help" button, a "Validity: ⚠️ 1" indicator, an information icon, and three navigation buttons: "< Back", "Next >", and "Finish".

# Final Check of the Set-up Parameter Coupling

- On the last page of the wizard, the returned parameters and values can be checked.



The screenshot shows a software window titled "Edit Parameter Coupling". It contains a "Summary" section with a descriptive text and a table of coupled parameters. The table has two columns: "Coupled Parameter" and "Value". Two parameters are listed: "ZExtension" and "Distance", both with a value of "600 nm". The "ZExtension" row is highlighted. At the bottom, there is a "Help" button, a "Validity" status with a green checkmark, and navigation buttons for "< Back", "Next >", and "Finish".

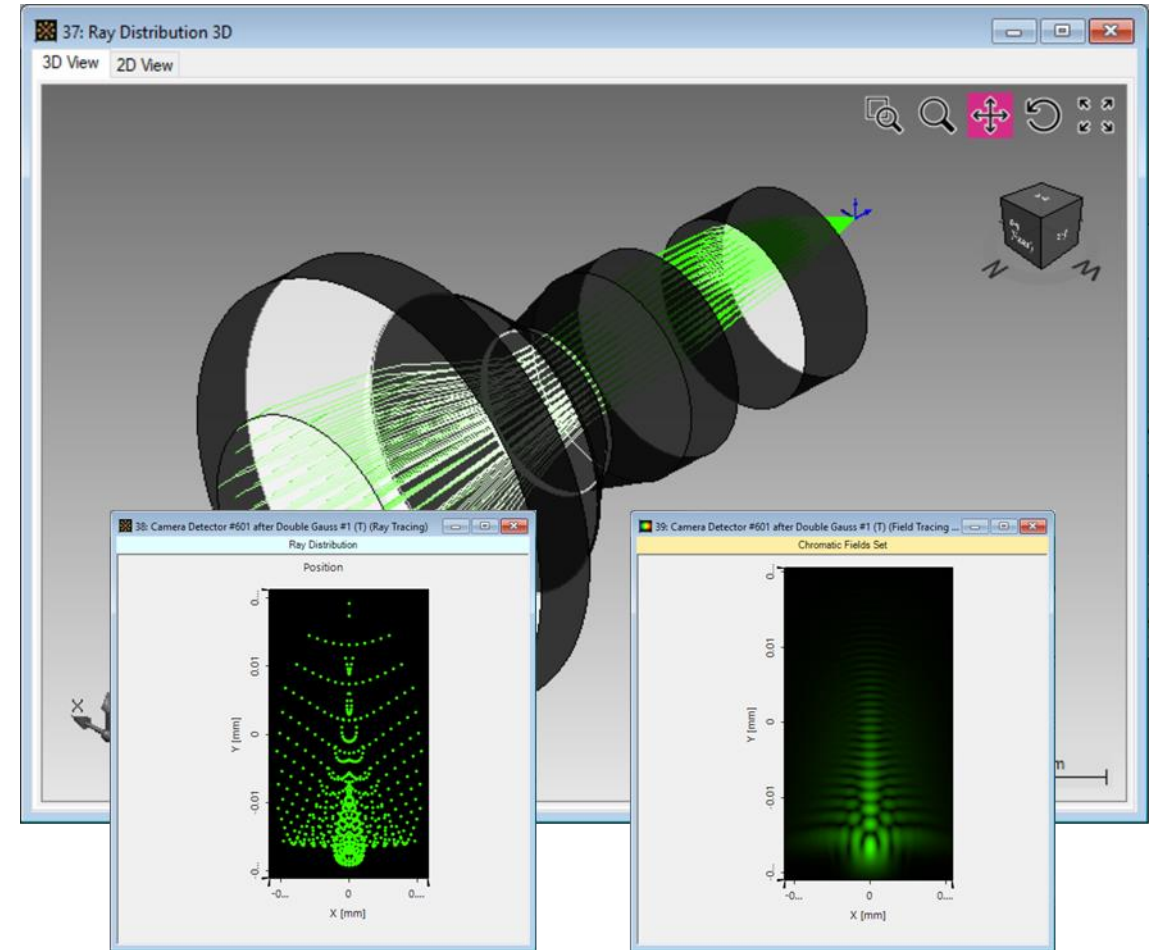
Coupled Parameter	Value
ZExtension	600 nm
Distance	600 nm

## Zemax Import

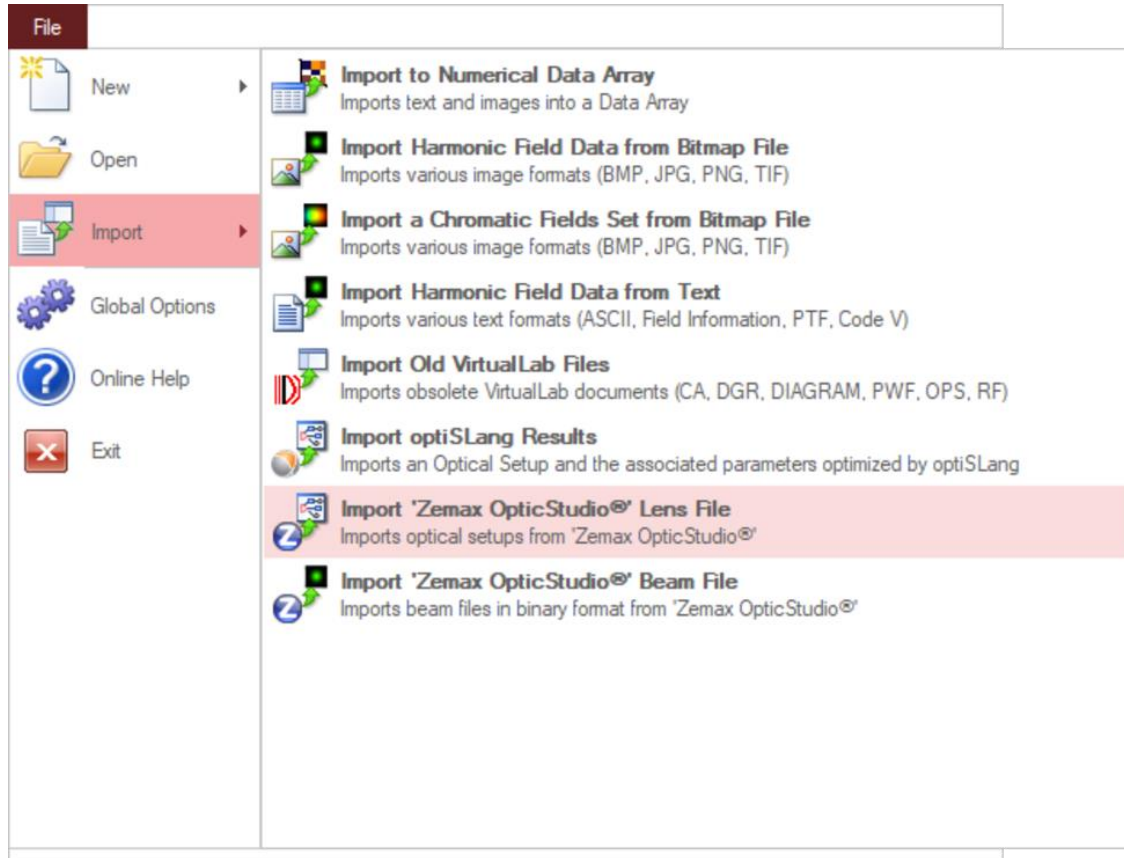
# Importing Zemax Files

Being able to import Zemax files into VirtualLab constitutes an interesting feature for several reasons:

- Using field tracing in VirtualLab to simulate a system previously constructed in OpticStudio
- Some hardware manufacturers provide only Zemax files of their products



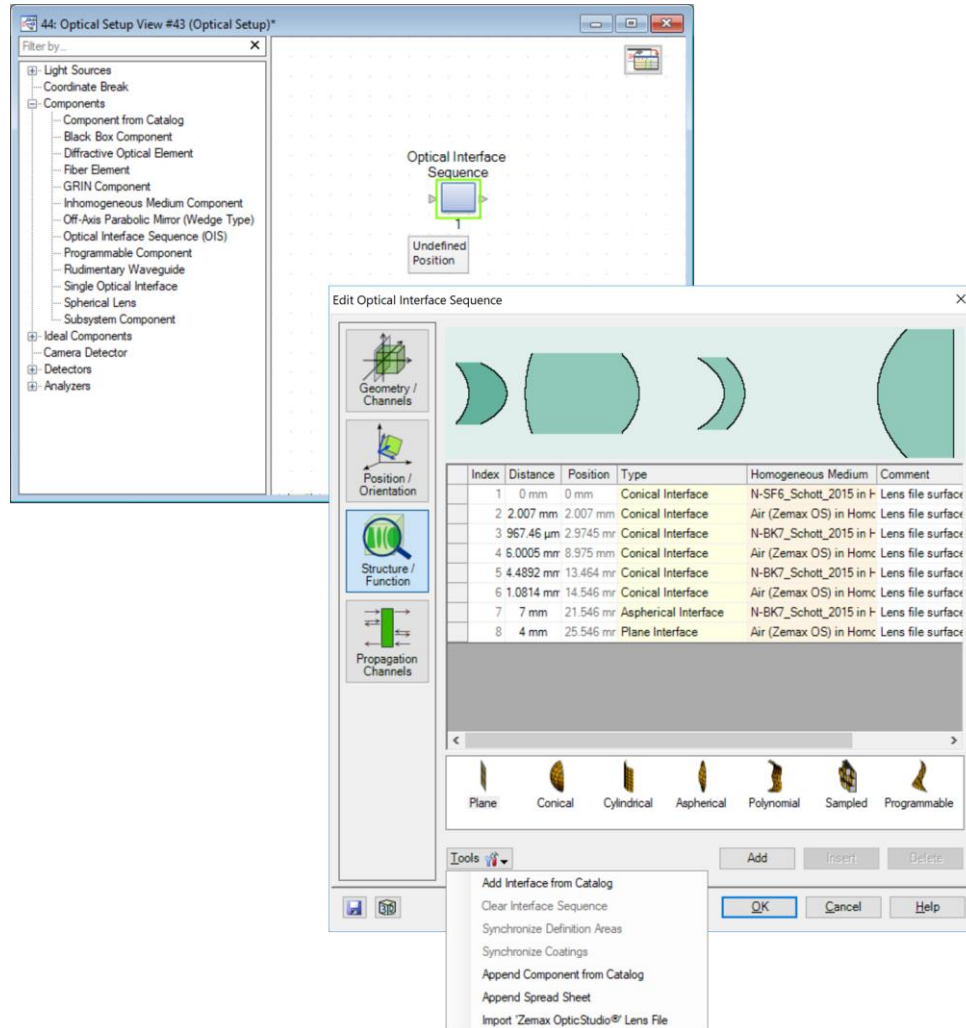
# Importing Zemax Files



There are two ways to go about importing a Zemax OpticStudio file into VirtualLab Fusion:

- Importing the full system file into VirtualLab Fusion

# Importing Zemax Files



There are two ways to go about importing a Zemax OpticStudio file into VirtualLab Fusion:

- Importing the full system file into VirtualLab Fusion
- Importing the system into an Optical Interface Sequence component in VirtualLab Fusion

# Two Zemax Import Mechanisms: Elementary and Advanced

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In general the user has three workflow options to trigger the import:

- drag and drop a ZMX file into your VirtualLab window
- go via File menu → Import → Import Zemax OpticStudio Lens File
- use the Tools button in the configuration dialogue of the Optical Interface Sequence (OIS) component into which the system is to be imported

Which import mechanism is used depends only on whether Zemax is installed on the computer in question and on whether there is a valid running licence or not:

- The advanced import mechanism needs access to the Zemax installation to extract more detailed information of the system which is to be imported
  - The elementary import mechanism needs only the Zemax glass catalogue directory in order to load the pertinent materials for the system
-



# Elementary Zemax Import

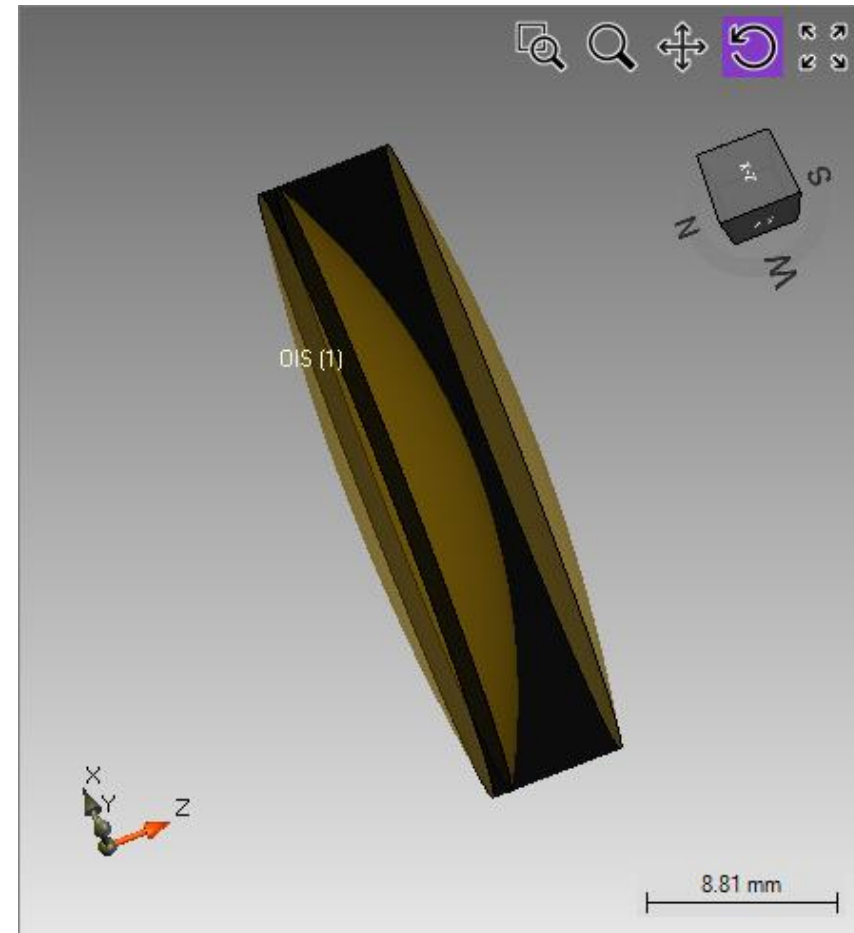
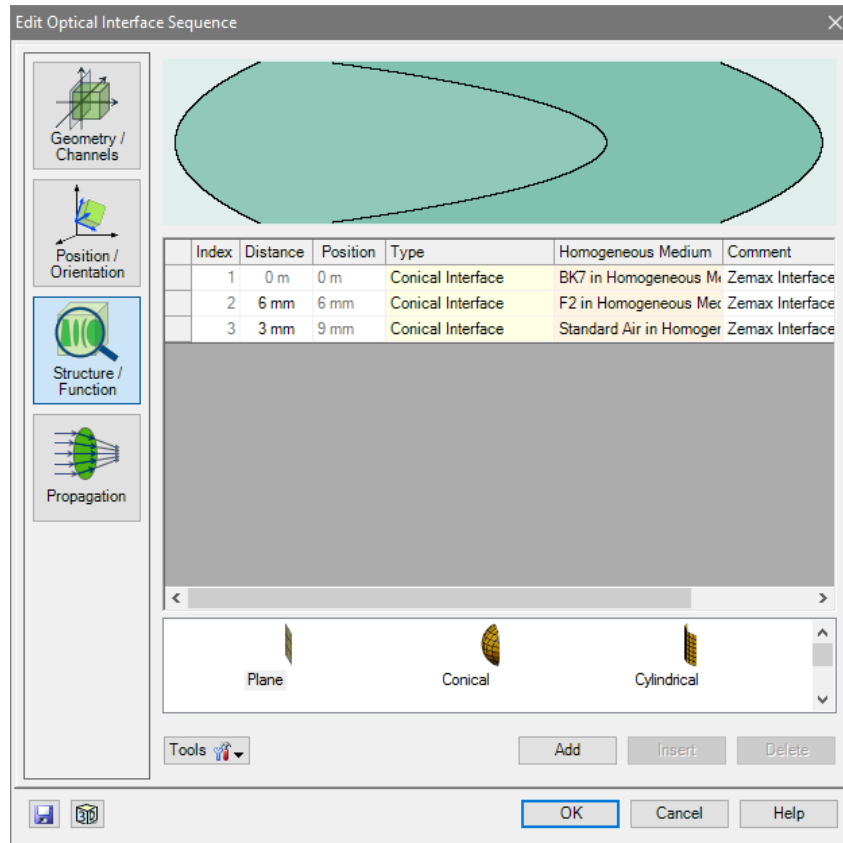
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The **elementary Zemax** import is fully **sufficient** for the **import of most lens data** that is provided on manufacturers' websites via Zemax files.

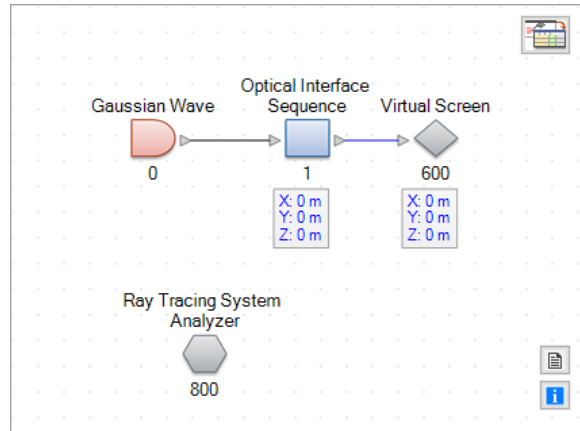
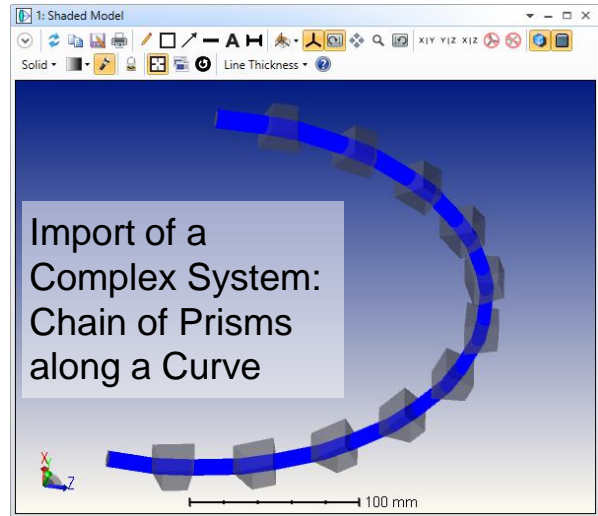
Even though manufacturers also start to provide VirtualLab files, Zemax files are still a standard.

# Elementary Zemax Import

After the import some manual adaptations are needed, then the result looks like the following:



# Limits of the Elementary Zemax Import



Index	Distance	Position	Type	Homogeneous Medium	Comment
1	0 m	0 m	Plane Interface	Air (Zemax) in Homogen	Zemax Interf
2	1 m	1 m	Plane Interface	Air (Zemax) in Homogen	Zemax Interf
3	30 mm	1.03 m	Plane Interface	N-BK7_SCHOTT in Hom	Zemax Interf
4	20 mm	1.05 m	Plane Interface	Air (Zemax) in Homogen	Zemax Interf
5	0 m	1.05 m	Plane Interface	Air (Zemax) in Homogen	Zemax Interf
6	30 mm	1.08 m	Plane Interface	N-BK7_SCHOTT in Hom	Zemax Interf
7	20 mm	1.1 m	Plane Interface	Air (Zemax) in Homogen	Zemax Interf
8	0 m	1.1 m	Plane Interface	Air (Zemax) in Homogen	Zemax Interf
9	30 mm	1.13 m	Plane Interface	N-BK7_SCHOTT in Hom	Zemax Interf
10	20 mm	1.15 m	Plane Interface	Air (Zemax) in Homogen	Zemax Interf
11	0 m	1.15 m	Plane Interface	Air (Zemax) in Homogen	Zemax Interf
12	30 mm	1.18 m	Plane Interface	N-BK7_SCHOTT in Hom	Zemax Interf
13	20 mm	1.2 m	Plane Interface	Air (Zemax) in Homogen	Zemax Interf

Tools: Plane, Conical, Cylindrical

Buttons: Add, Insert, Delete, OK, Cancel, Help

Messages

[08/09/2016 17:55:07] === Starting Zemax import ===

[08/09/2016 17:55:07] Warning: DISZ INFINITY detected at Zemax interface 0

[08/09/2016 17:55:07] Warning: Aperture diameter ZERO detected at Zemax interface 0 (default will be used).

[08/09/2016 17:55:07] Zemax Interface #4: unsupported type COORDBRK, using plane interface

[08/09/2016 17:55:07] Warning: Aperture diameter ZERO detected at Zemax interface 4 (default will be used).

[08/09/2016 17:55:07] Zemax Interface #7: unsupported type COORDBRK, using plane interface

[08/09/2016 17:55:07] Warning: Aperture diameter ZERO detected at Zemax interface 7 (default will be used).

[08/09/2016 17:55:07] Zemax Interface #10: unsupported type COORDBRK, using plane interface

[08/09/2016 17:55:07] Warning: Aperture diameter ZERO detected at Zemax interface 10 (default will be used).

[08/09/2016 17:55:07] Zemax Interface #13: unsupported type COORDBRK, using plane interface

[08/09/2016 17:55:07] Warning: Aperture diameter ZERO detected at Zemax interface 13 (default will be used).

[08/09/2016 17:55:07] Zemax Interface #16: unsupported type COORDBRK, using plane interface

[08/09/2016 17:55:07] Warning: Aperture diameter ZERO detected at Zemax interface 16 (default will be used).

[08/09/2016 17:55:07] Zemax Interface #19: unsupported type COORDBRK, using plane interface

[08/09/2016 17:55:07] Warning: Aperture diameter ZERO detected at Zemax interface 19 (default will be used).

[08/09/2016 17:55:07] Zemax Interface #22: unsupported type COORDBRK, using plane interface

[08/09/2016 17:55:07] Warning: Aperture diameter ZERO detected at Zemax interface 22 (default will be used).

[08/09/2016 17:55:07] Zemax Interface #25: unsupported type COORDBRK, using plane interface

[08/09/2016 17:55:07] Warning: Aperture diameter ZERO detected at Zemax interface 25 (default will be used).

[08/09/2016 17:55:07] Zemax Interface #28: unsupported type COORDBRK, using plane interface

[08/09/2016 17:55:07] Warning: Aperture diameter ZERO detected at Zemax interface 28 (default will be used).

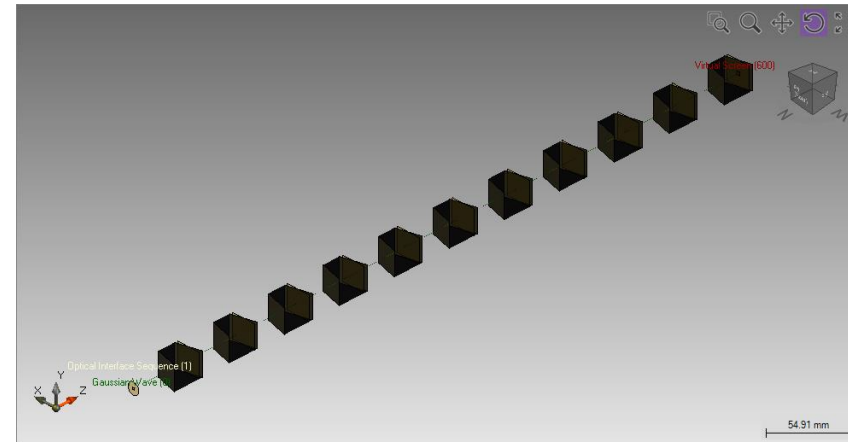
[08/09/2016 17:55:07] Zemax Interface #31: unsupported type COORDBRK, using plane interface

[08/09/2016 17:55:07] Warning: Aperture diameter ZERO detected at Zemax interface 31 (default will be used).

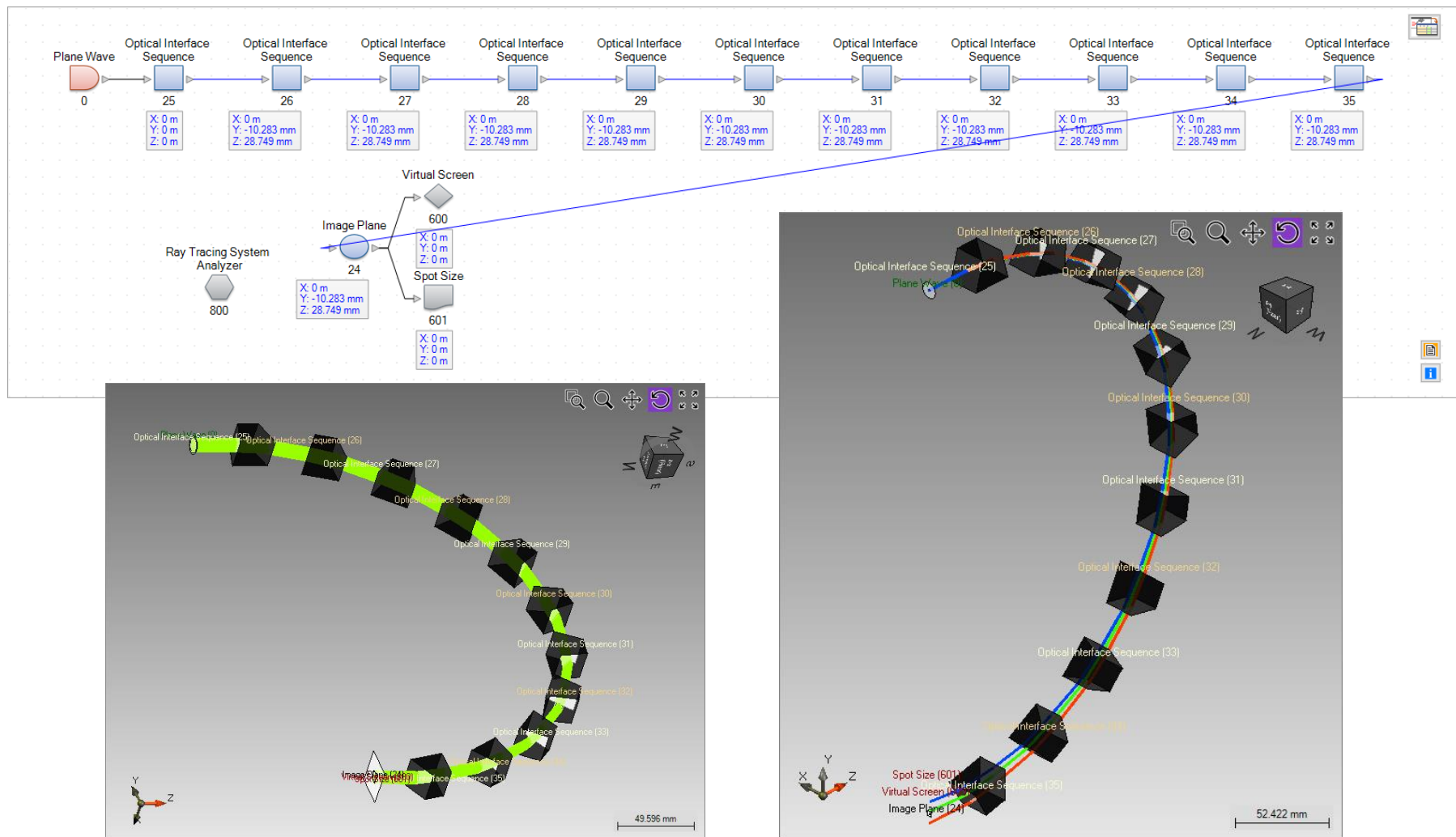
[08/09/2016 17:55:07] Zemax Interface #34: unsupported type COORDBRK, using plane interface

[08/09/2016 17:55:07] Warning: Aperture diameter ZERO detected at Zemax interface 34 (default will be used).

[08/09/2016 17:55:07] === Zemax import finished ===



# Advanced Zemax Import



## Further Info about Advanced Zemax Import

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- Due to the complexity and the differences of both programs (Zemax & VirtualLab) even the advanced import algorithm needs to make certain assumptions and has some limitations.
- **Example assumptions:**
  - The used wavelengths of the Zemax file are used to define the spectrum of the VirtualLab source.
  - The entrance pupil diameter of Zemax defines the input field size of the source in VirtualLab.
- **Example limitation:**

Lateral positions and angles of the fields specified in Zemax are ignored. Such configurations need to be reset manually after the import.

For more detailed information please consult the manual or help file.

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