VirtualLab Fusion Applications, Technology & Workflows

Extended Hands-on Training with VirtualLab Fusion

LightTrans International UG
Presenter: Sohrab Sangini & Hartwig Craisheim

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Quick Index:

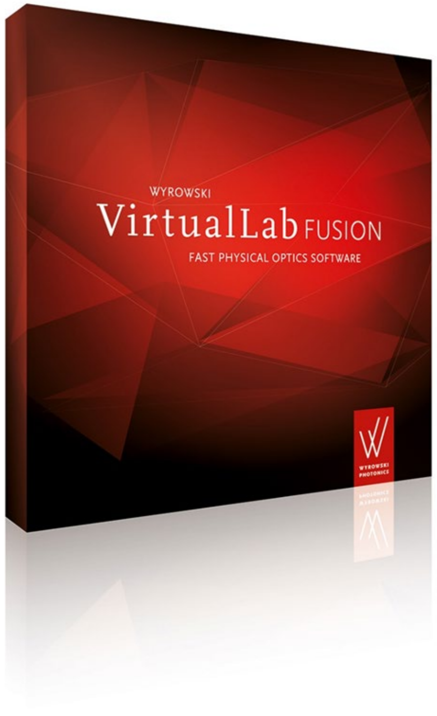
Introduction to the Teams

Who We Are

LIGHTTRANS

Founded 1999

General Distributor of the
Fast Physical Optics Software
VirtualLab Fusion

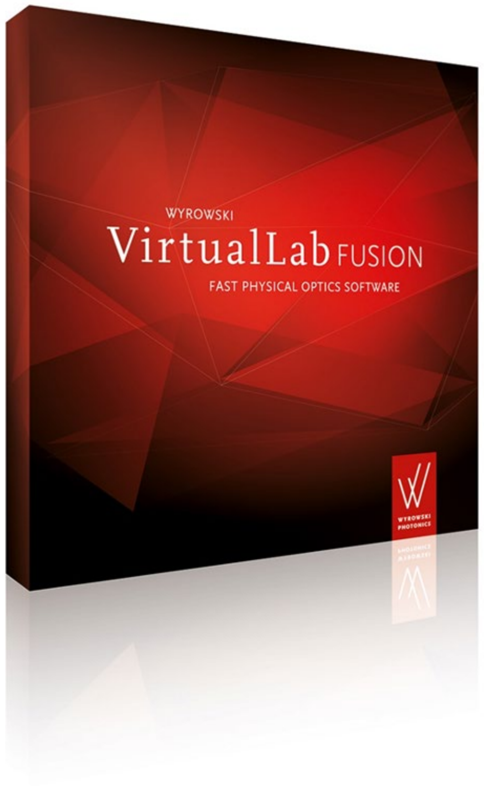


WYROWSKI PHOTONICS

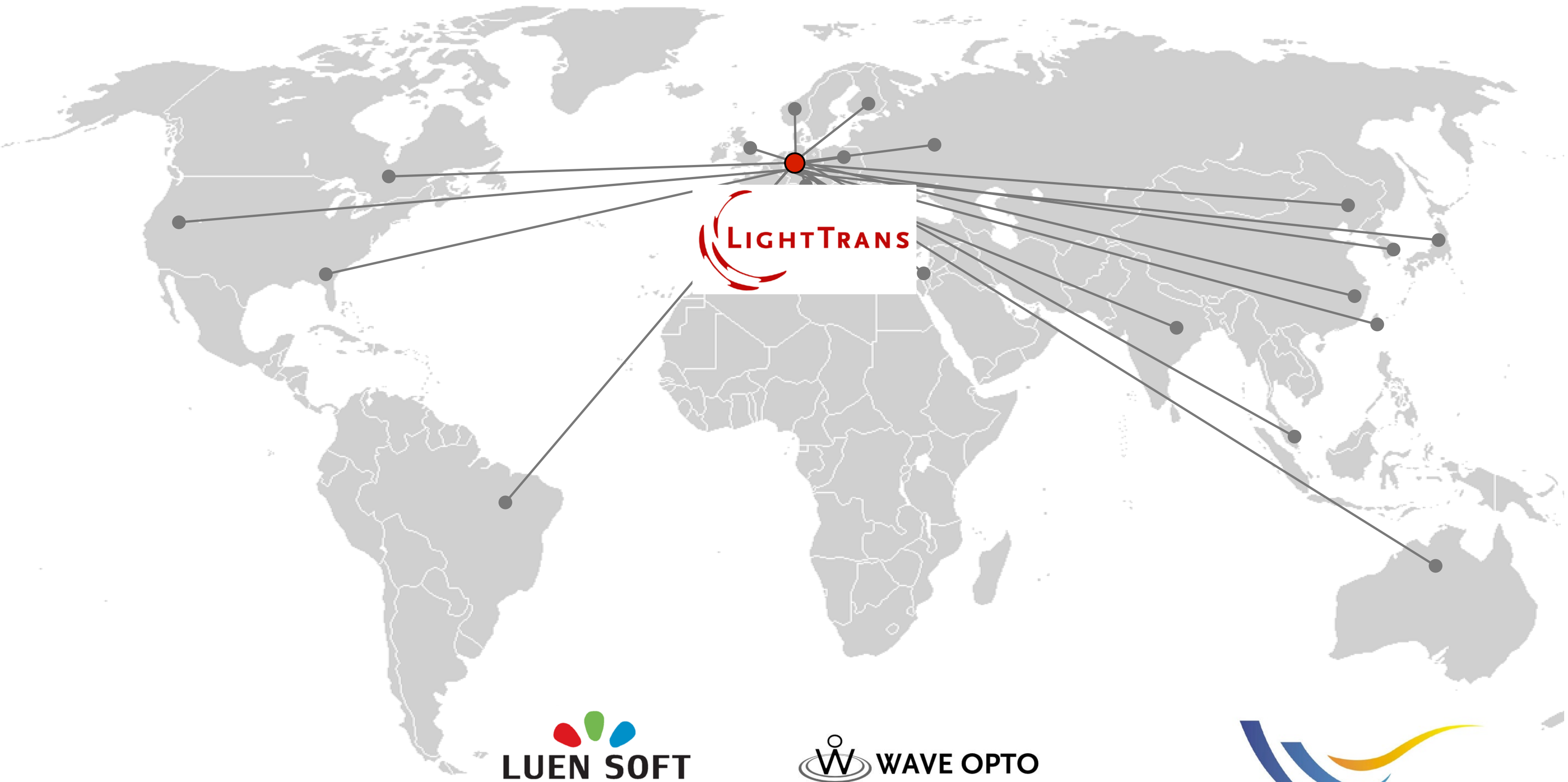
Founded 2014

Developer of the
Fast Physical Optics Software
VirtualLab Fusion

Fast Physical Optics Modeling and Design Software



Fast Physical Optics Modeling and Design Software

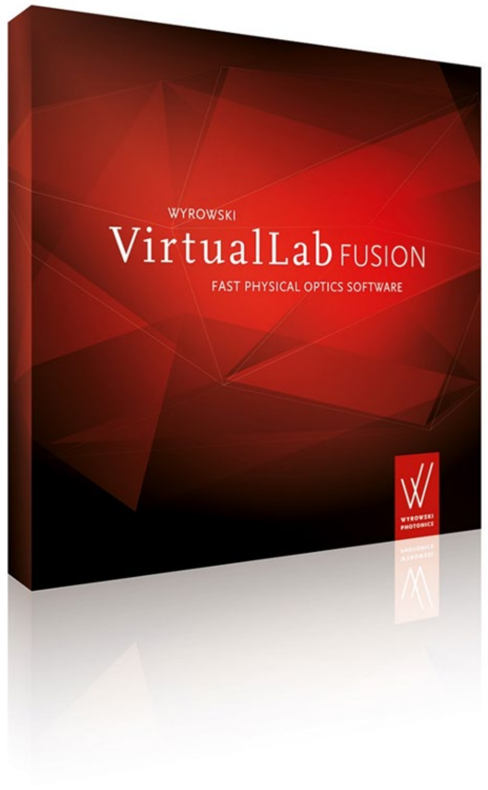


LUEN SOFT

WAVE OPTO

T.E.M. Incorporated

INFOTEK



Part 1

Light as an Electromagnetic Field

The Objective Behind VirtualLab Fusion

To perform physical optics simulations of arbitrary optical systems

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

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

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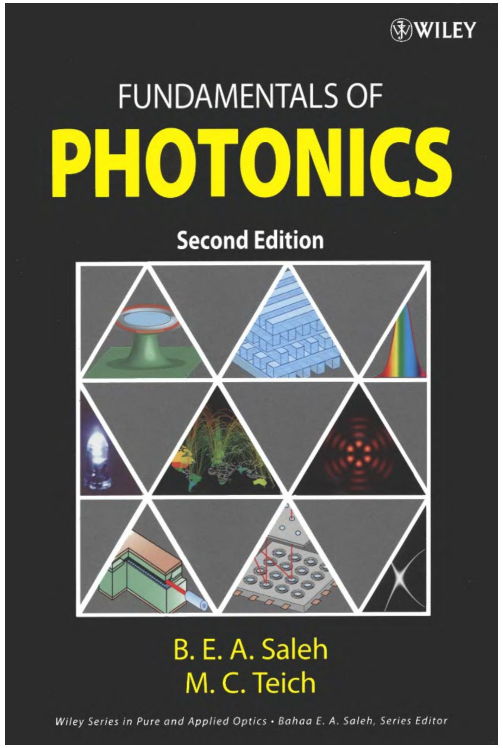

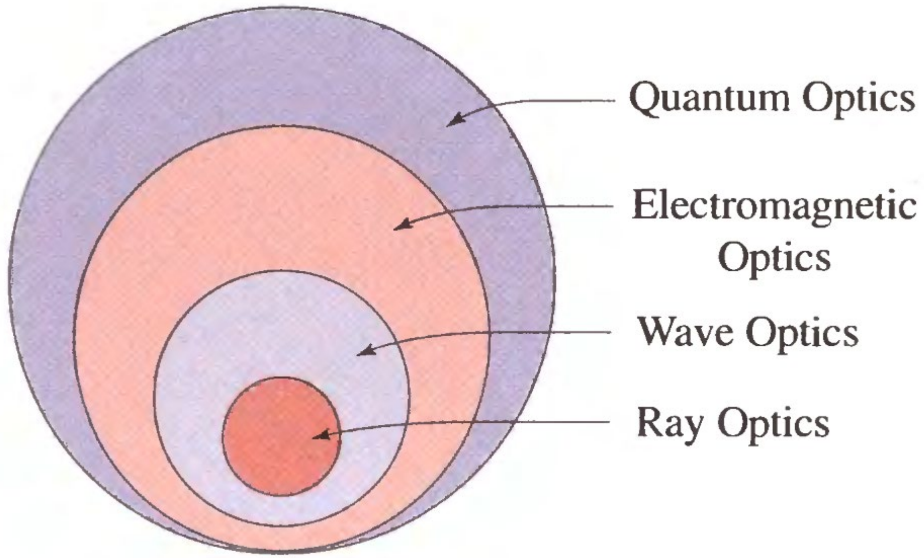

Image reference: “Fundamentals of Photonics”, B. E. A. Saleh and M. C. Teich, 2ndEdition, Wiley

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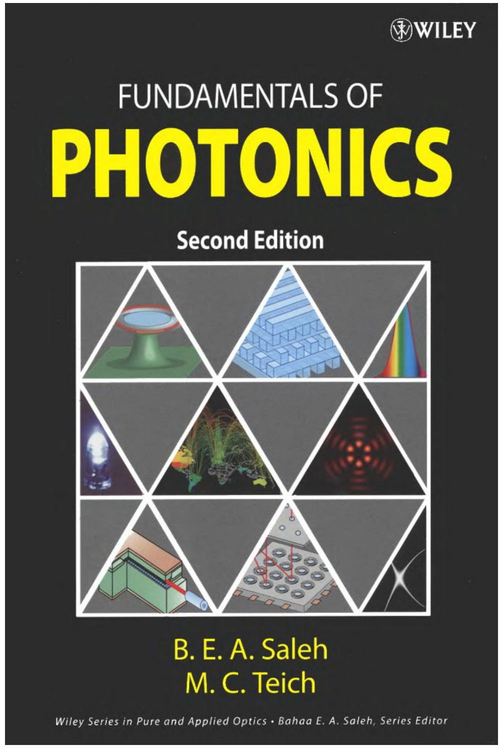

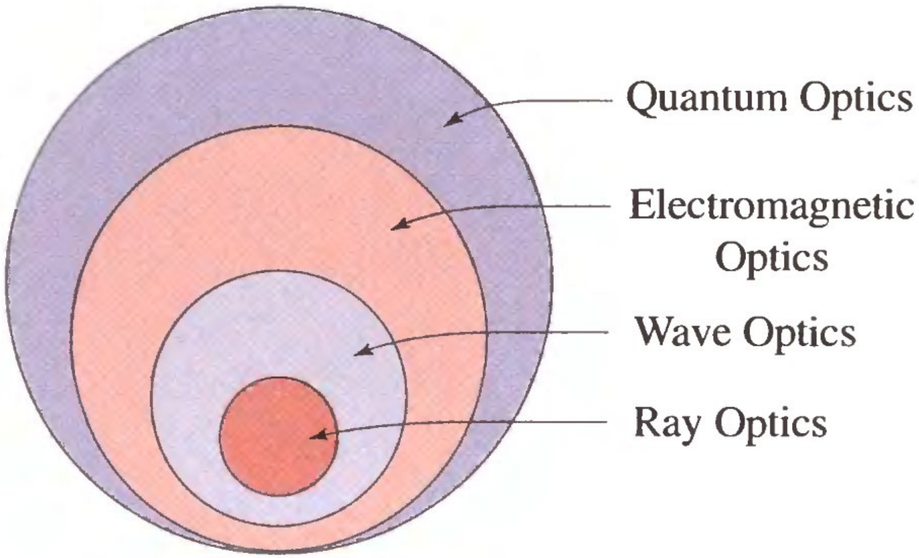

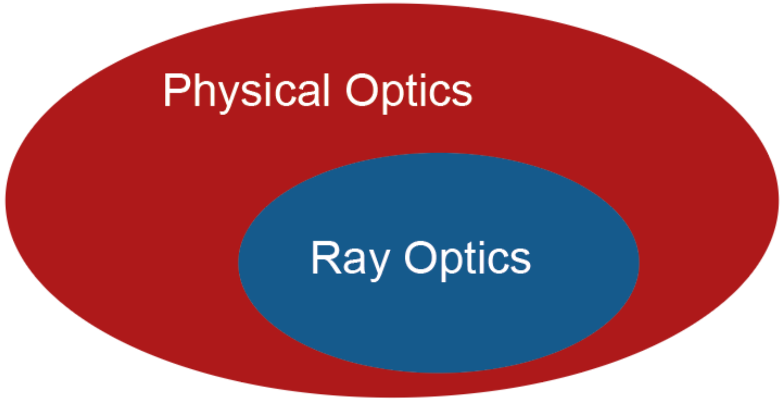

… in VirtualLab Fusion

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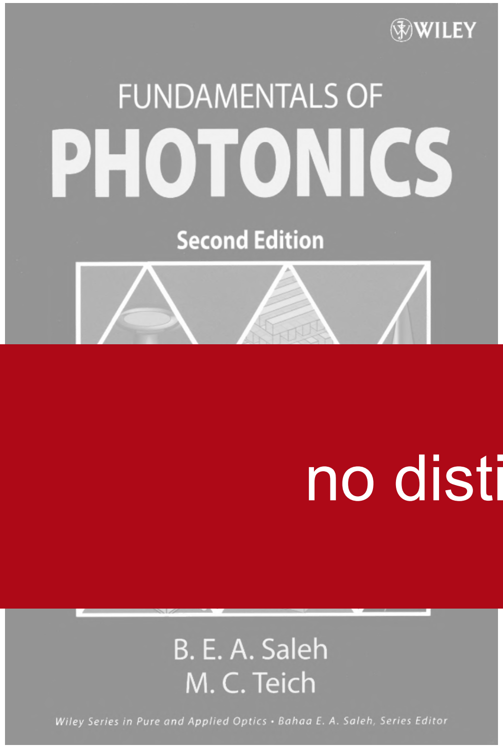
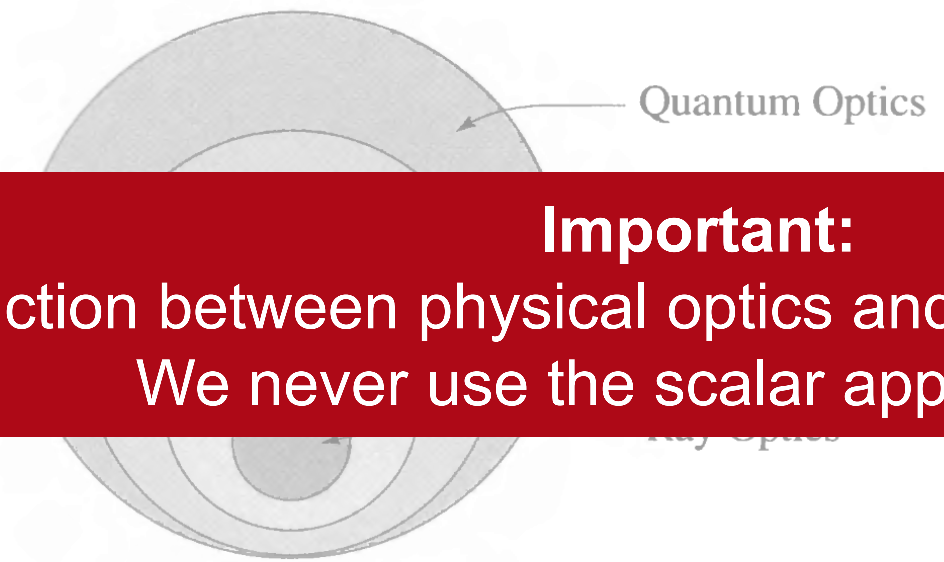
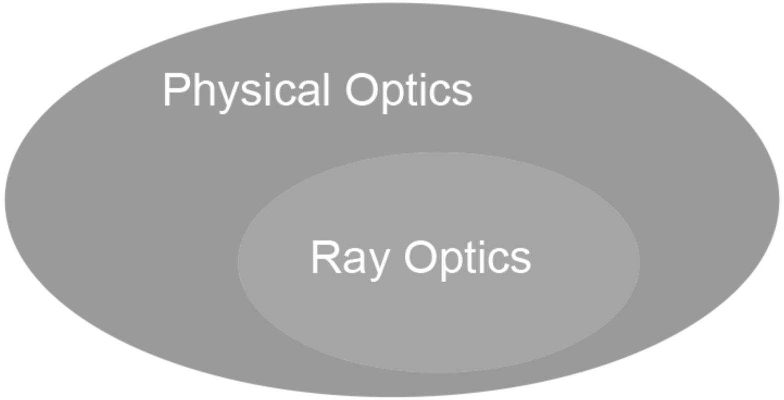




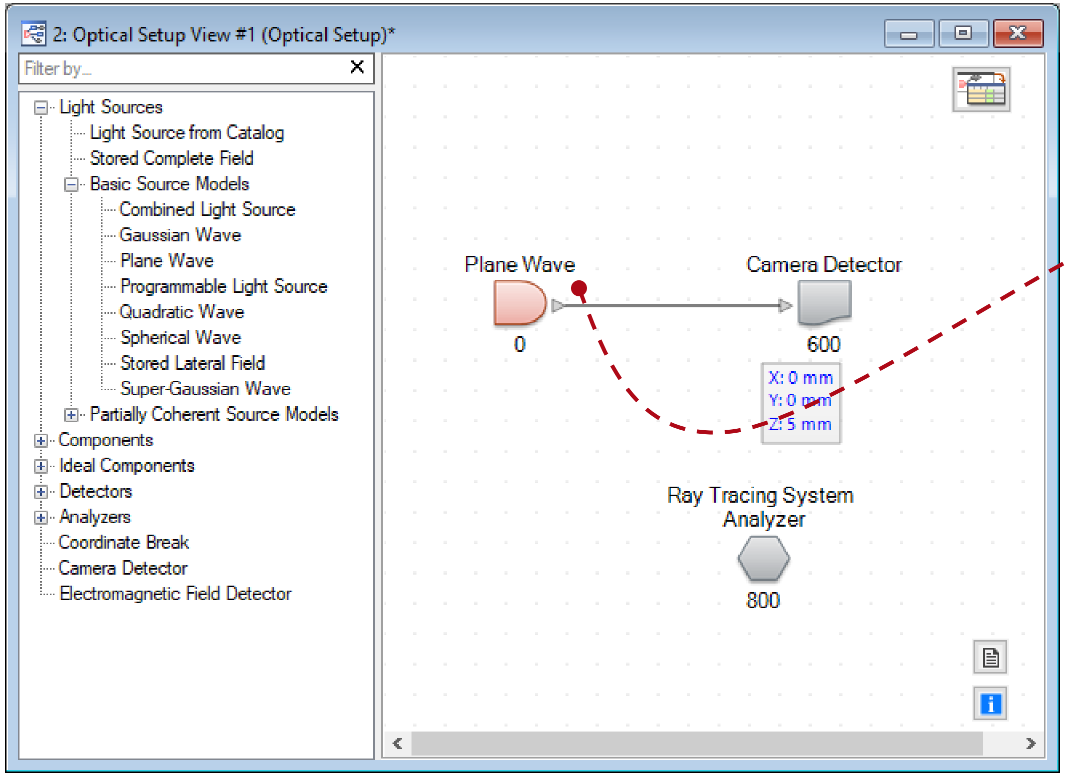


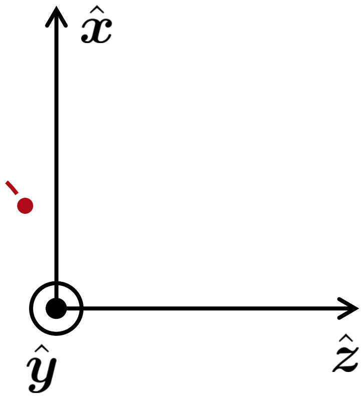
Important:
no distinction between physical optics and electromagnetic optics.
We never use the scalar approximation!

… in VirtualLab Fusion

Image reference: “Fundamentals of Photonics”, B. E. A. Saleh and M. C. Teich, 2ndEdition, Wiley

How Is Light Generated in the System? (Basics)





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

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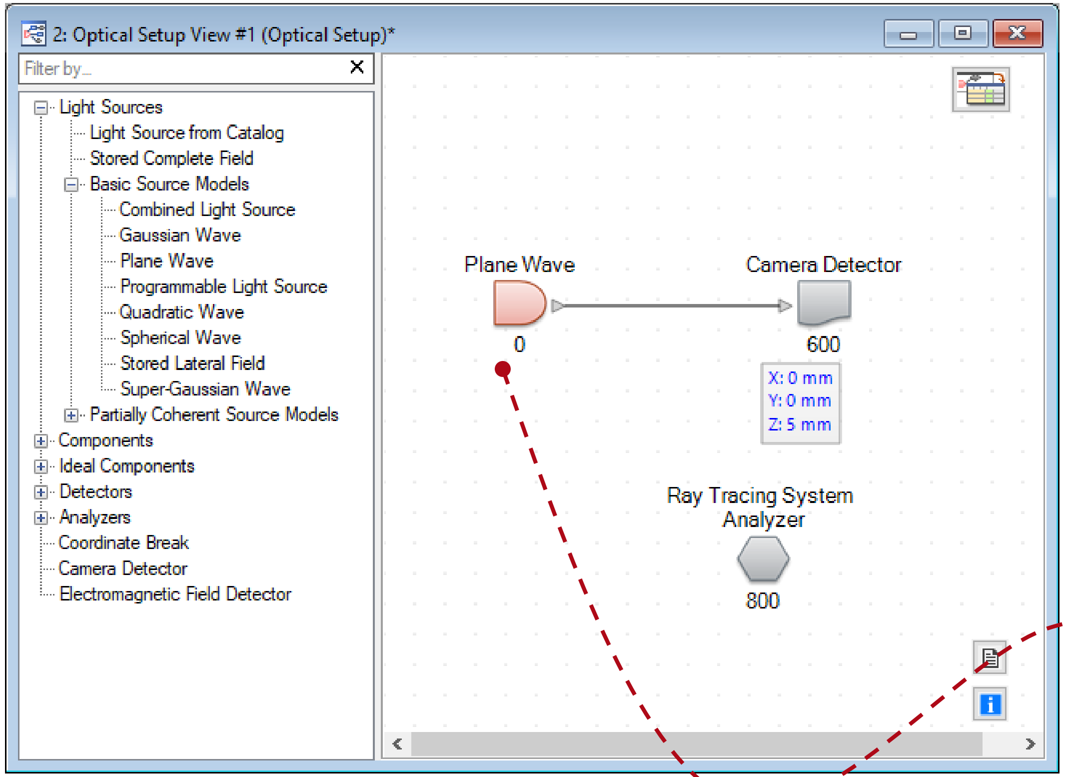

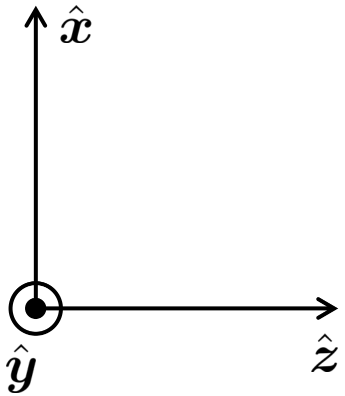

In VirtualLab Fusion, the source establishes the **global coordinate system** of the optical setup

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

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

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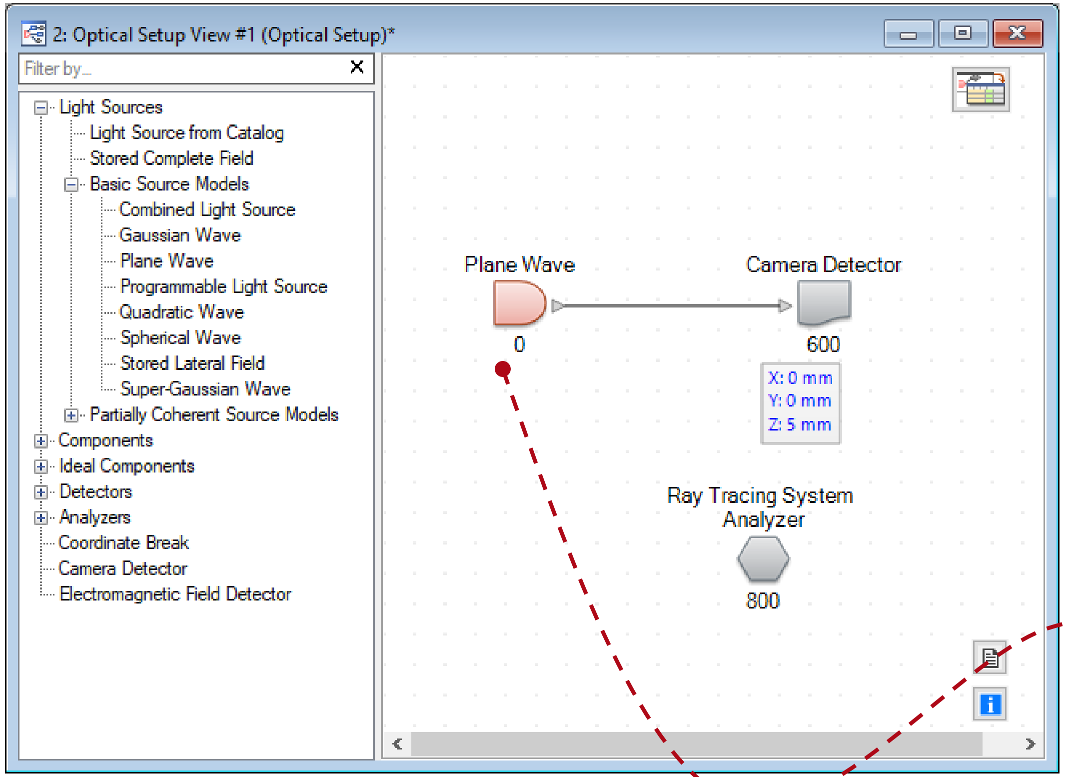

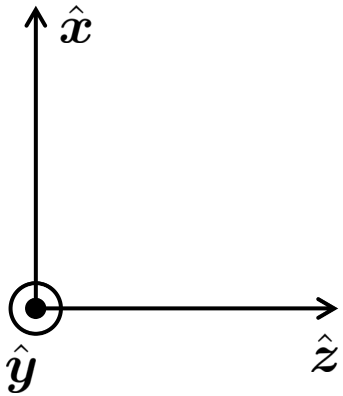

In VirtualLab Fusion, the source establishes the **global coordinate system** of the optical setup

$$\begin{cases} \boldsymbol{E}_x(x,y) \\ \boldsymbol{E}_y(x,y) \end{cases}$$

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

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

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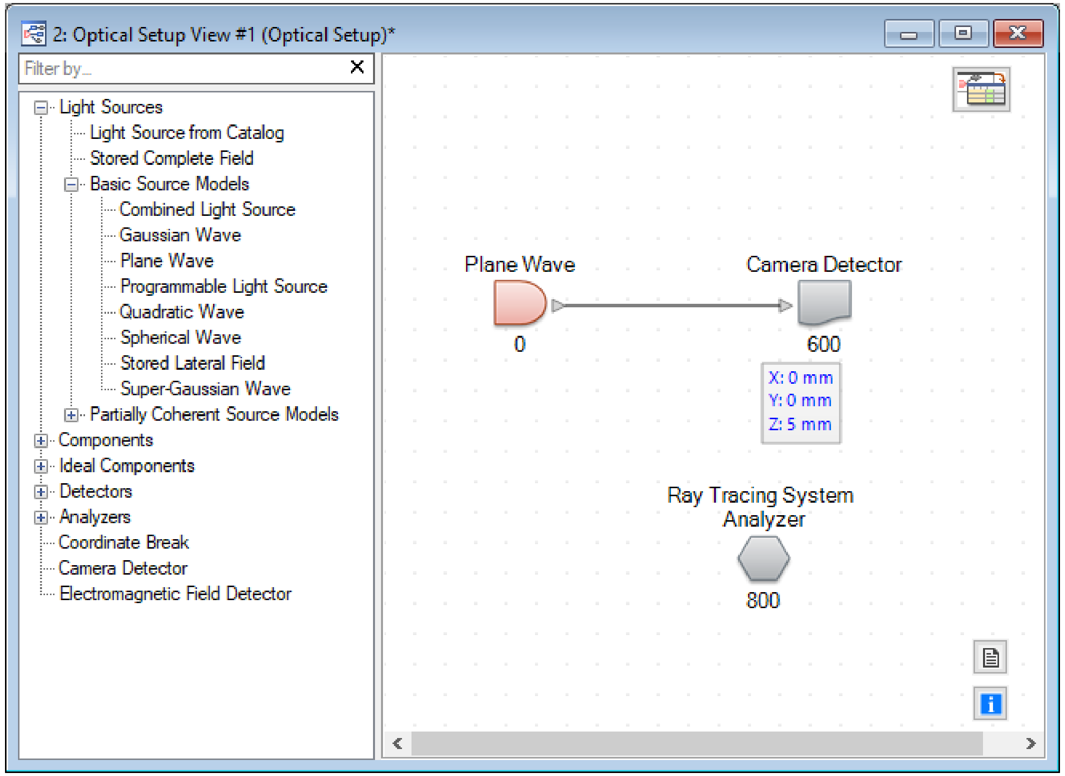

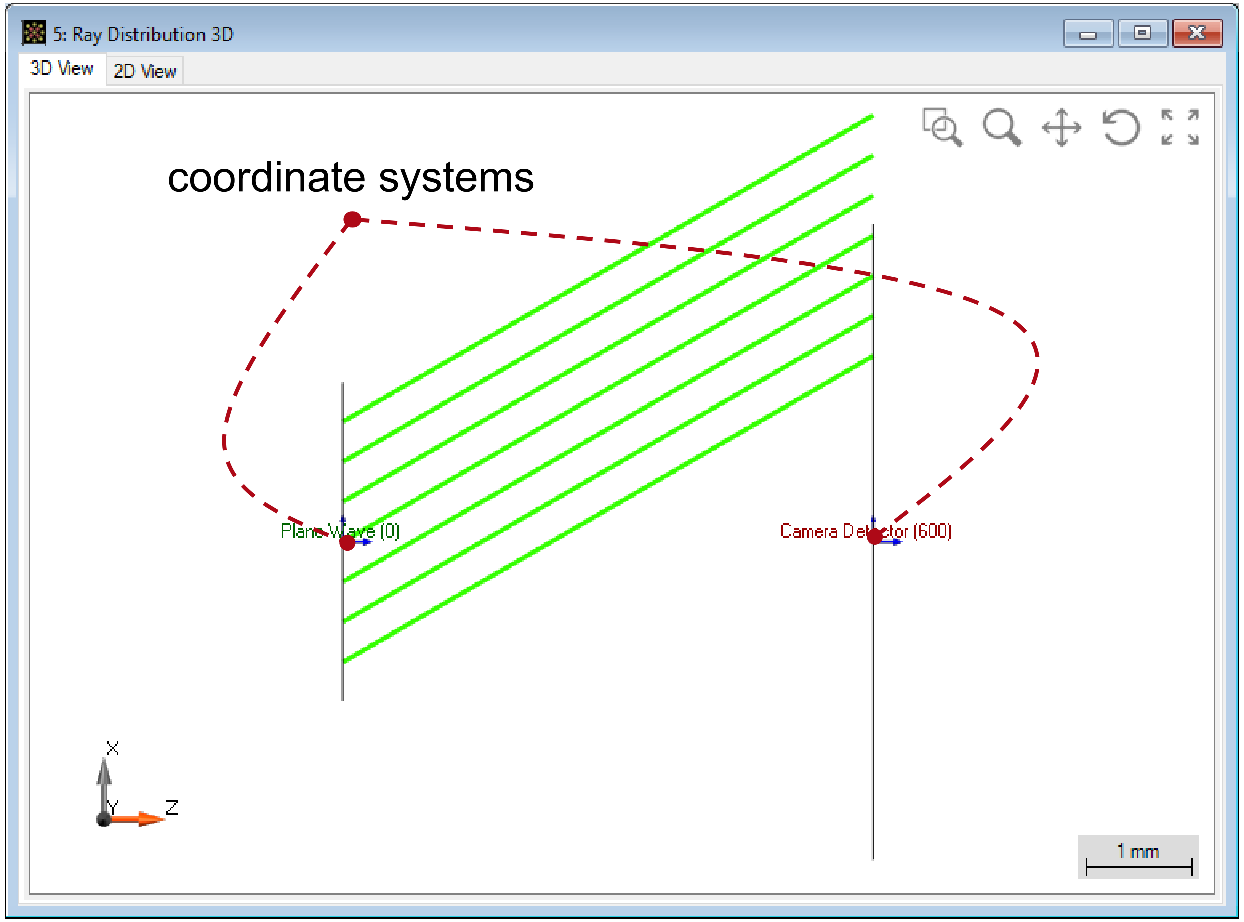

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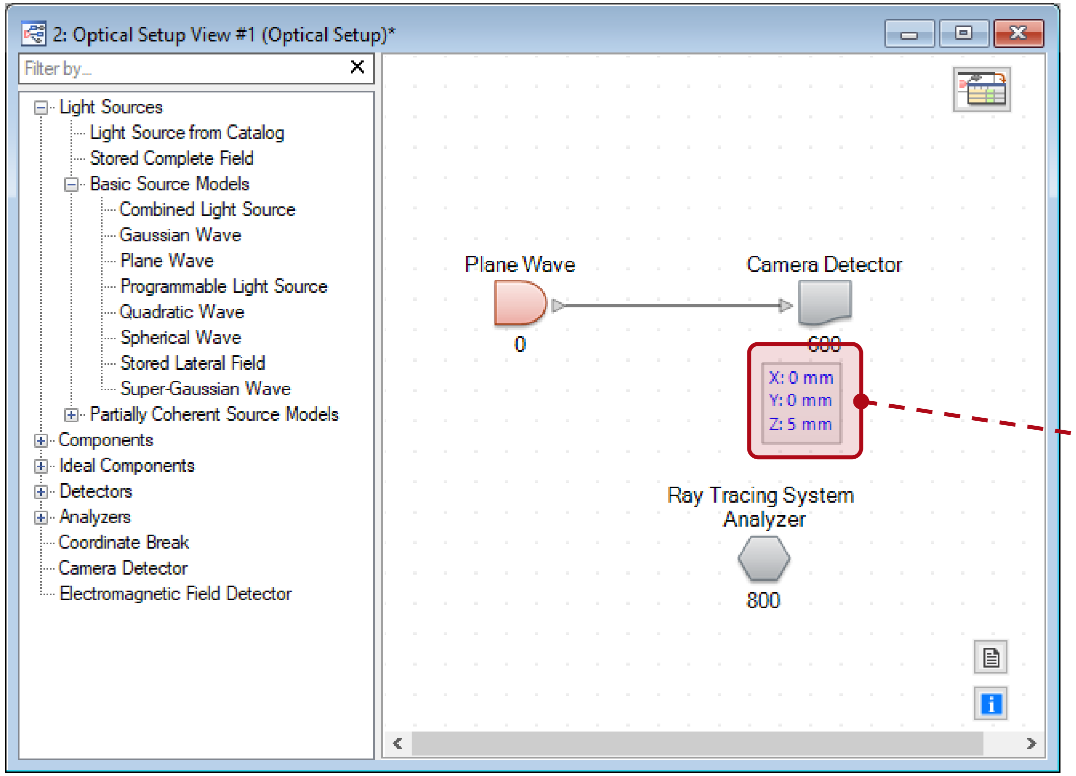

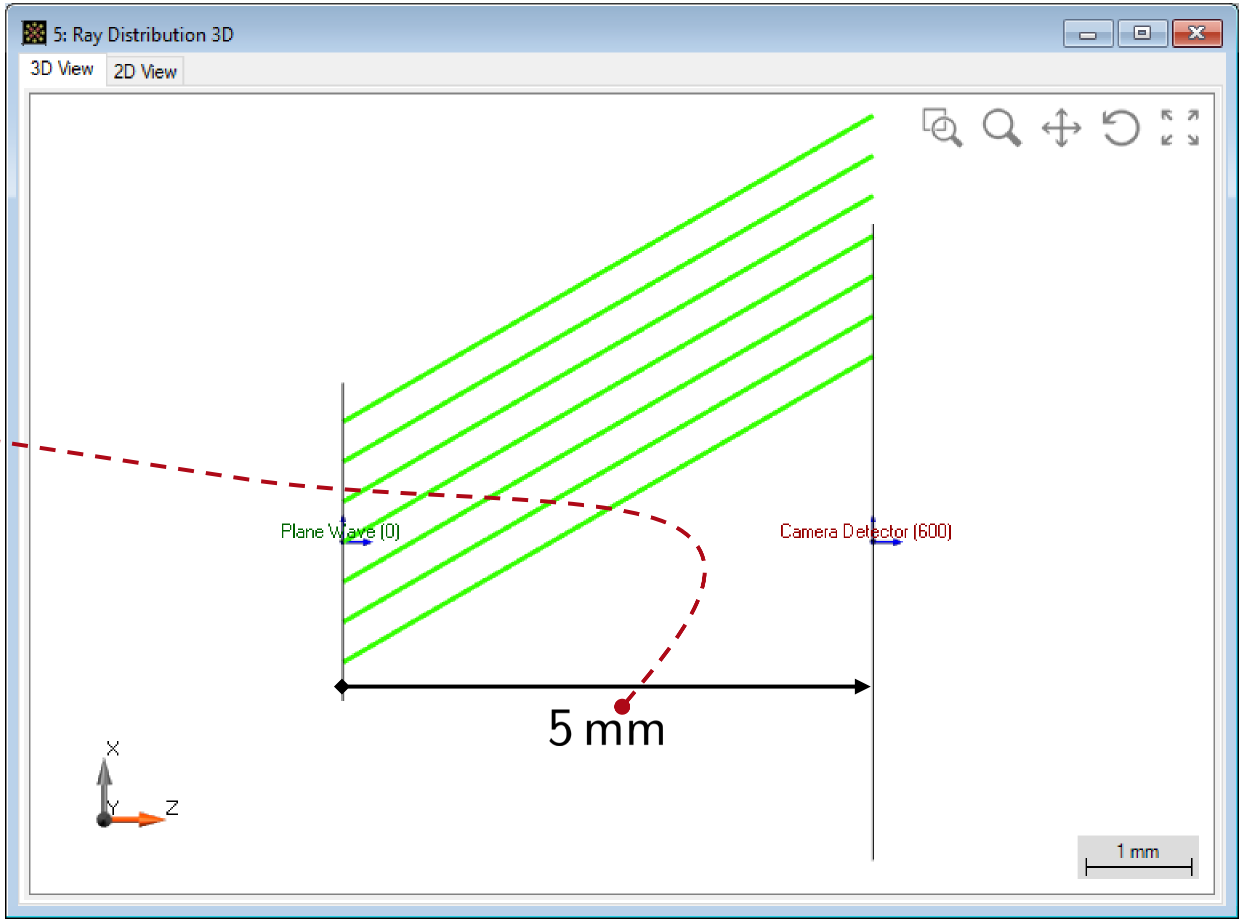

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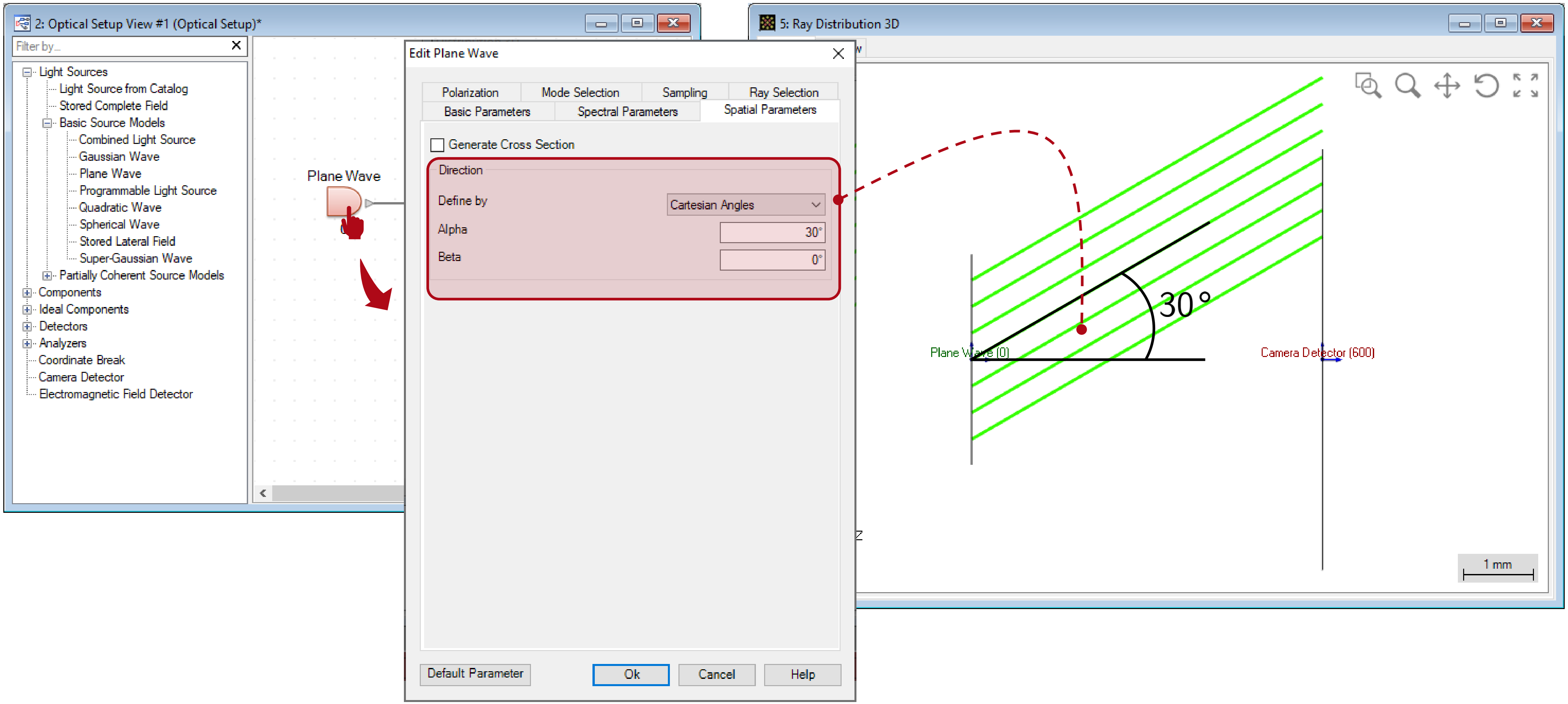

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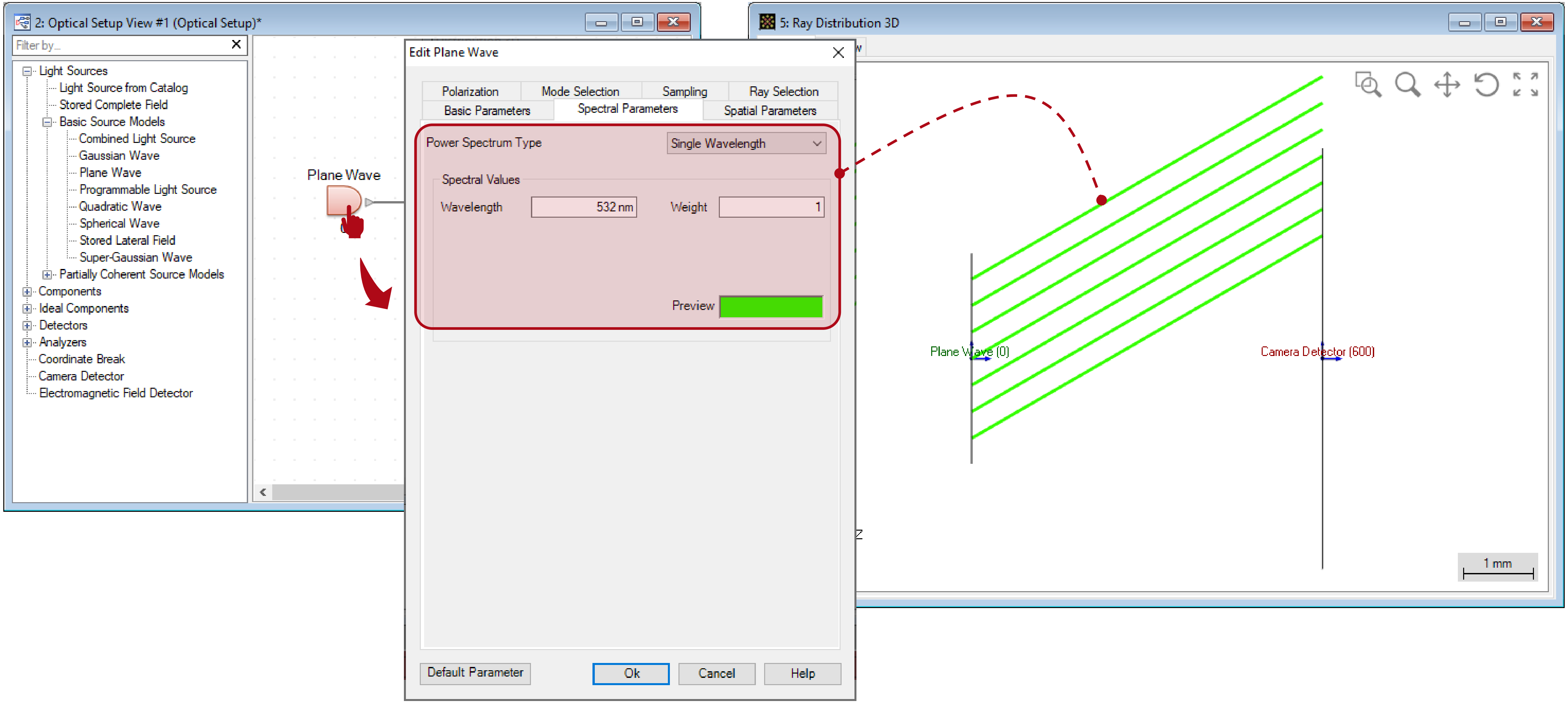

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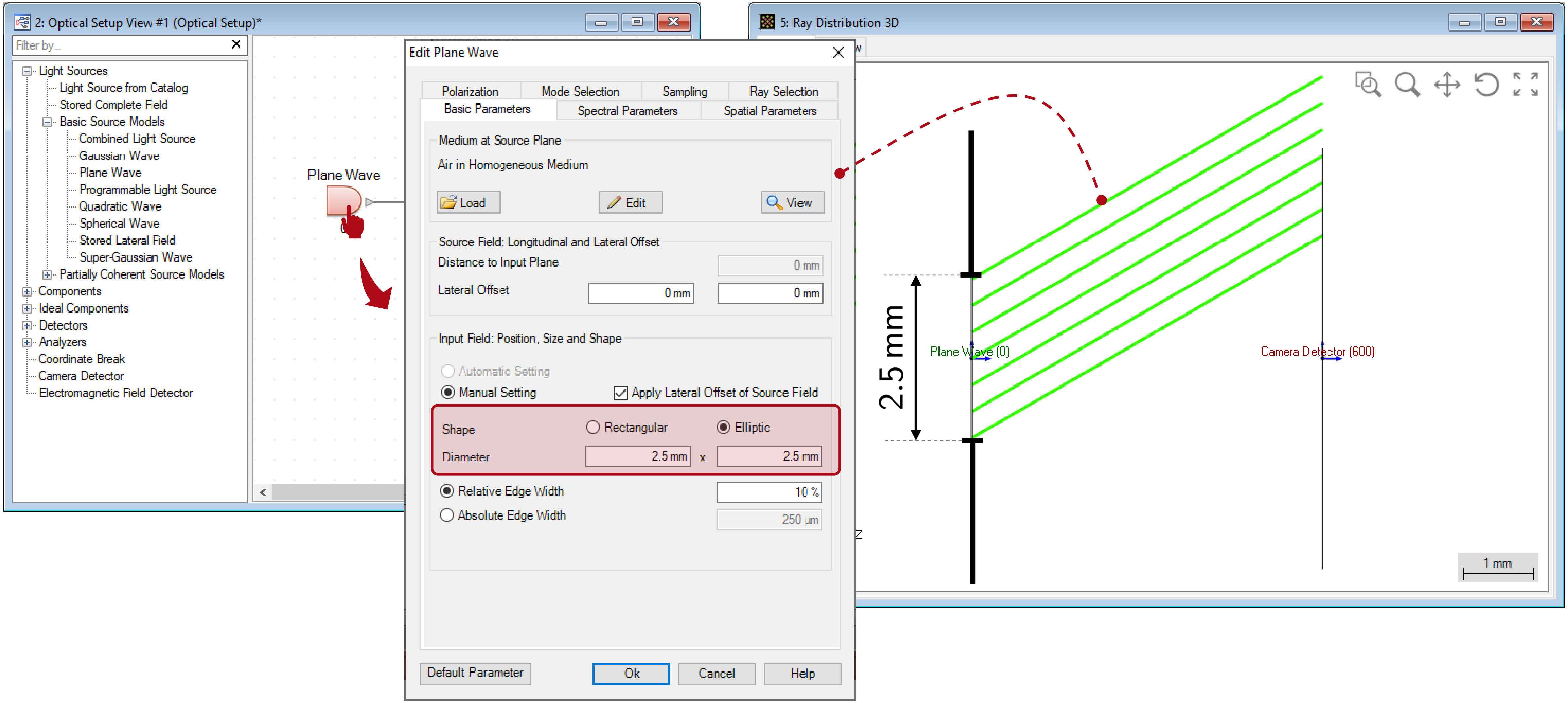

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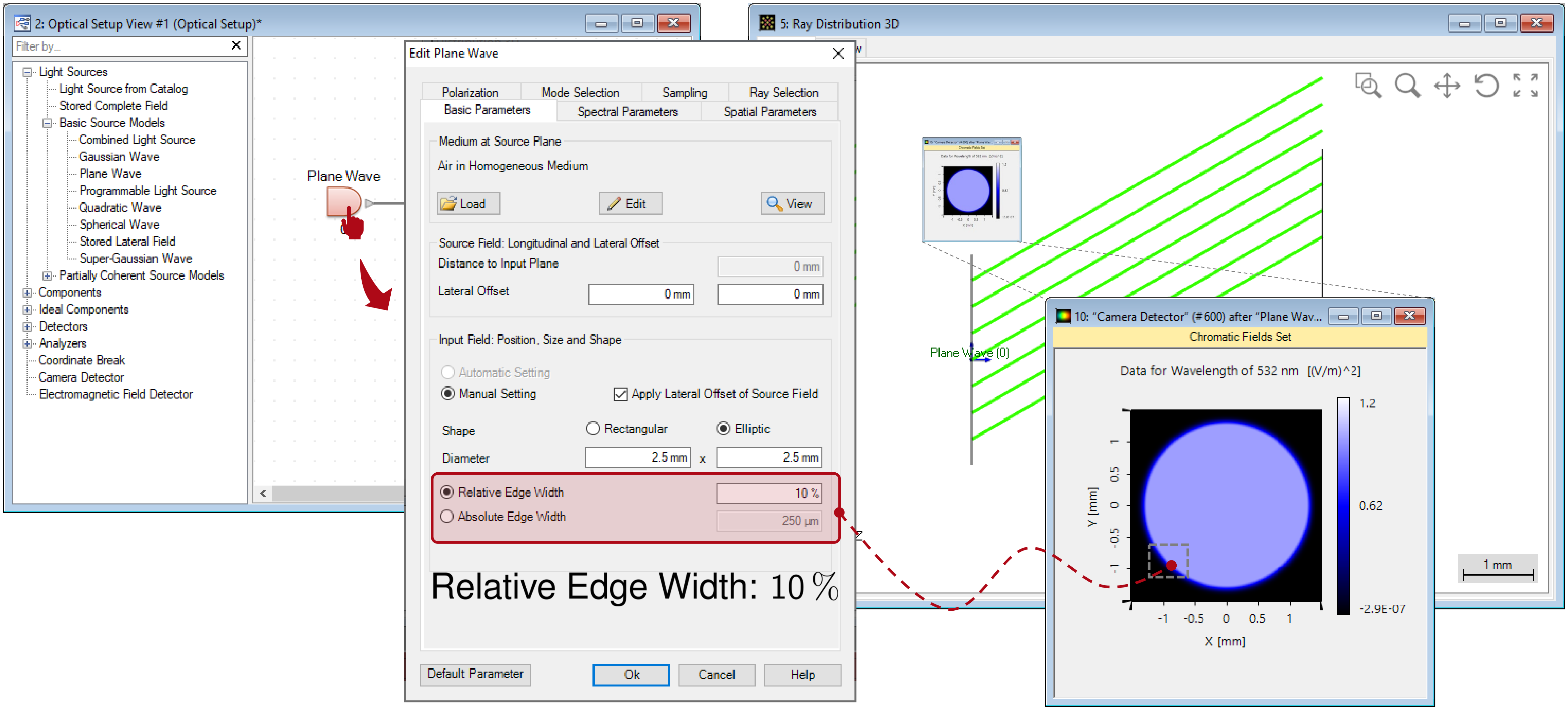

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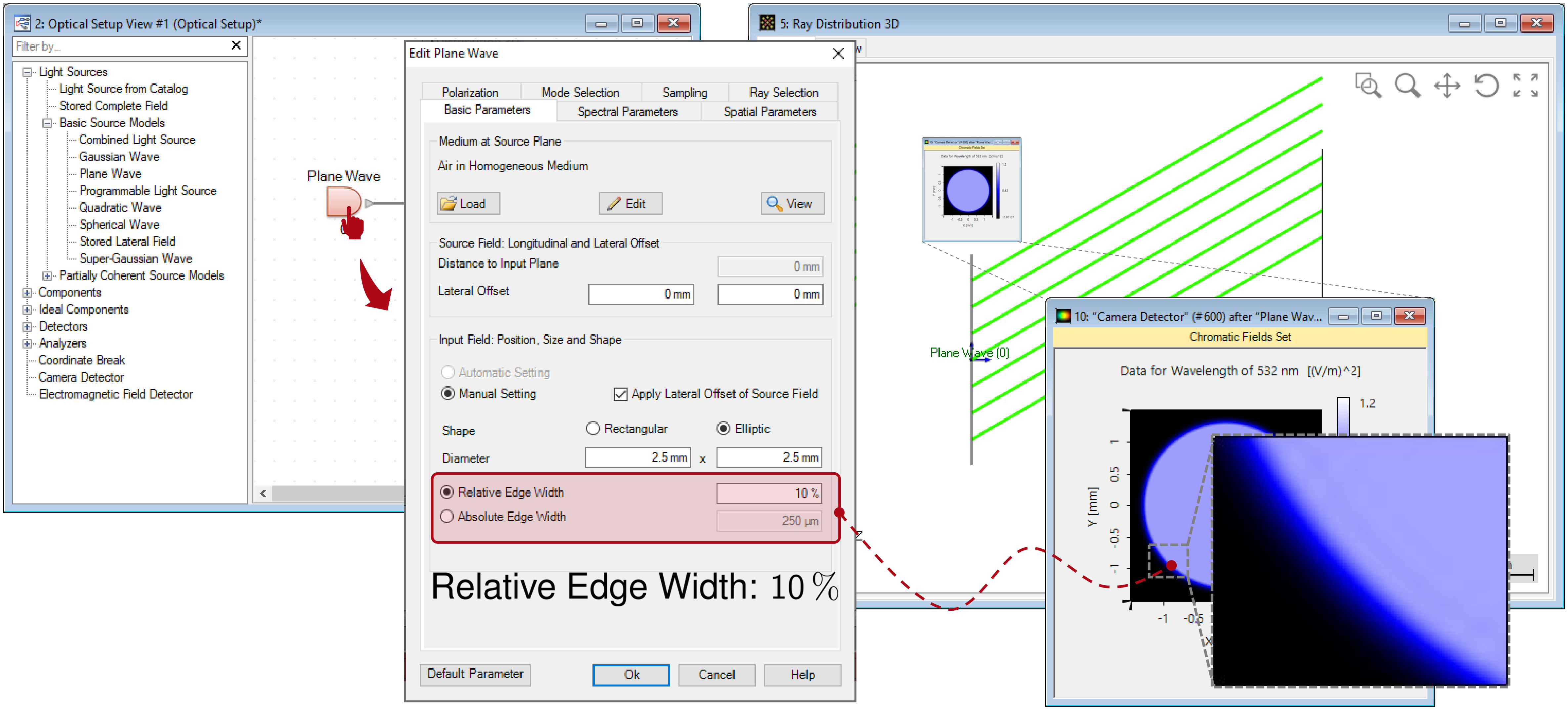

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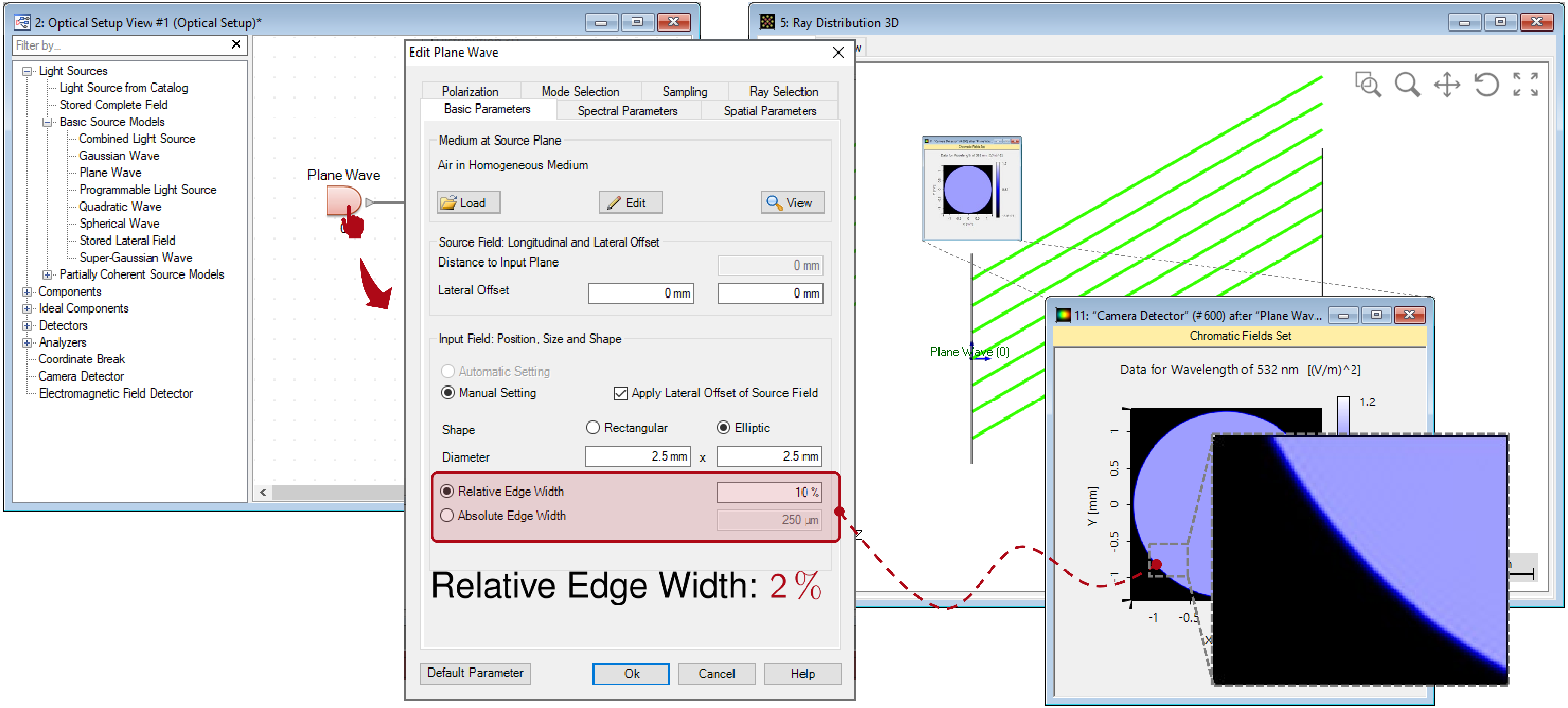

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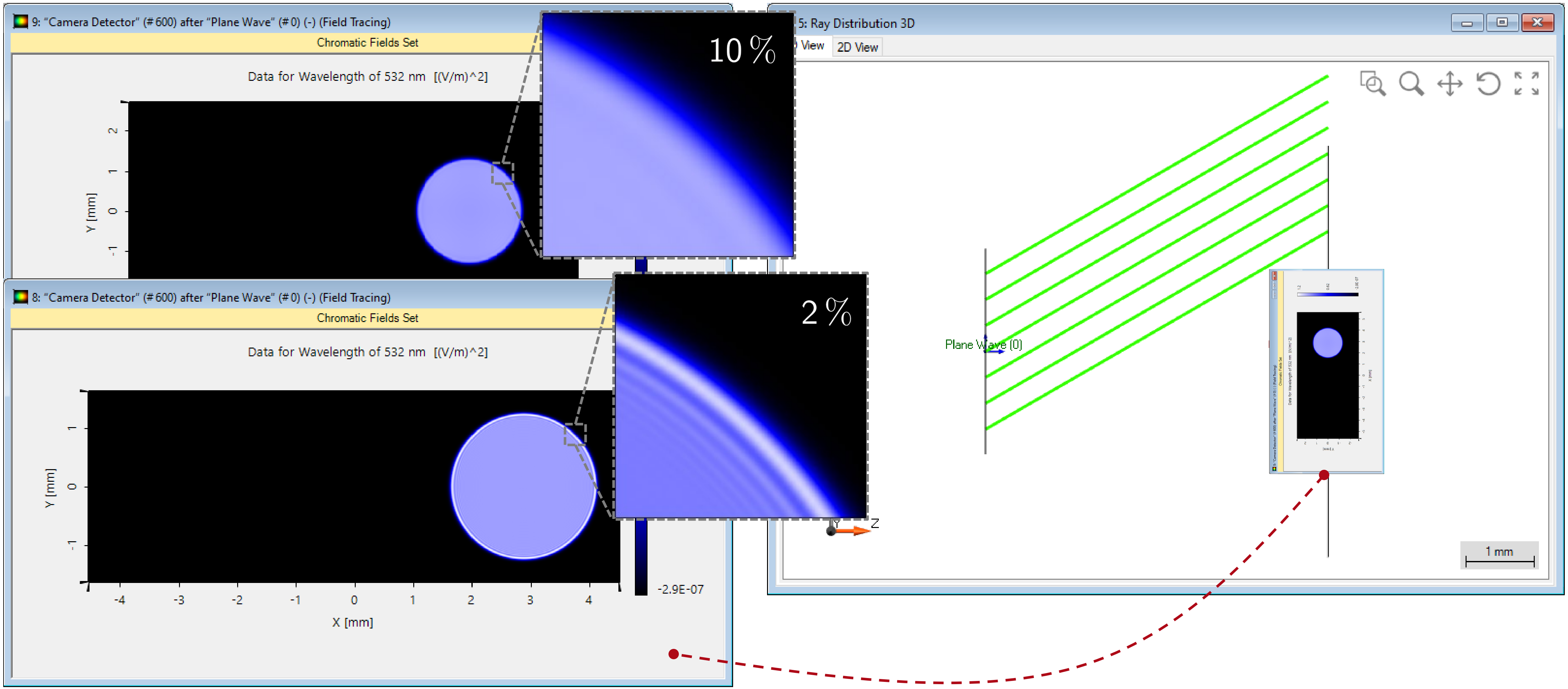

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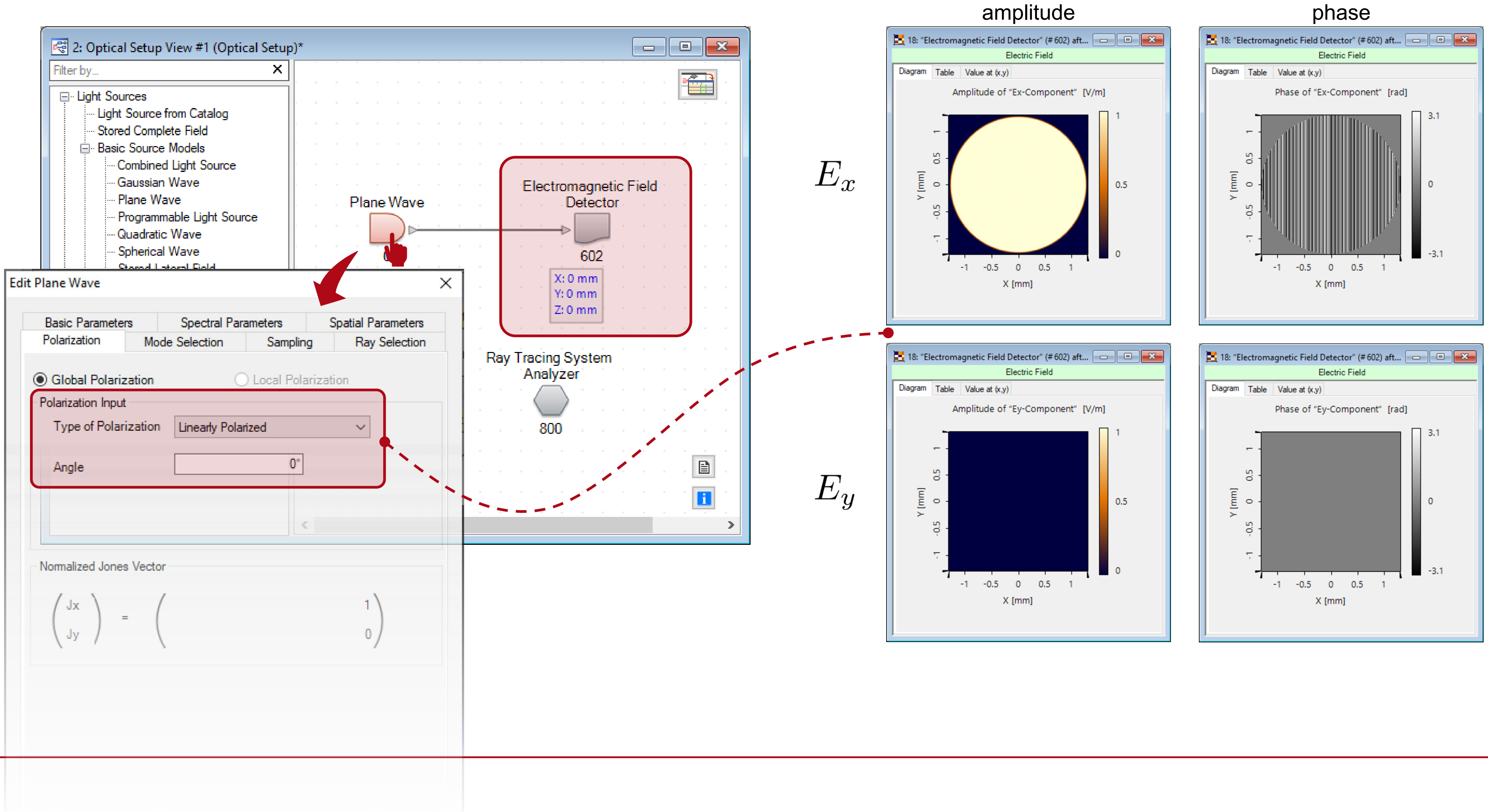
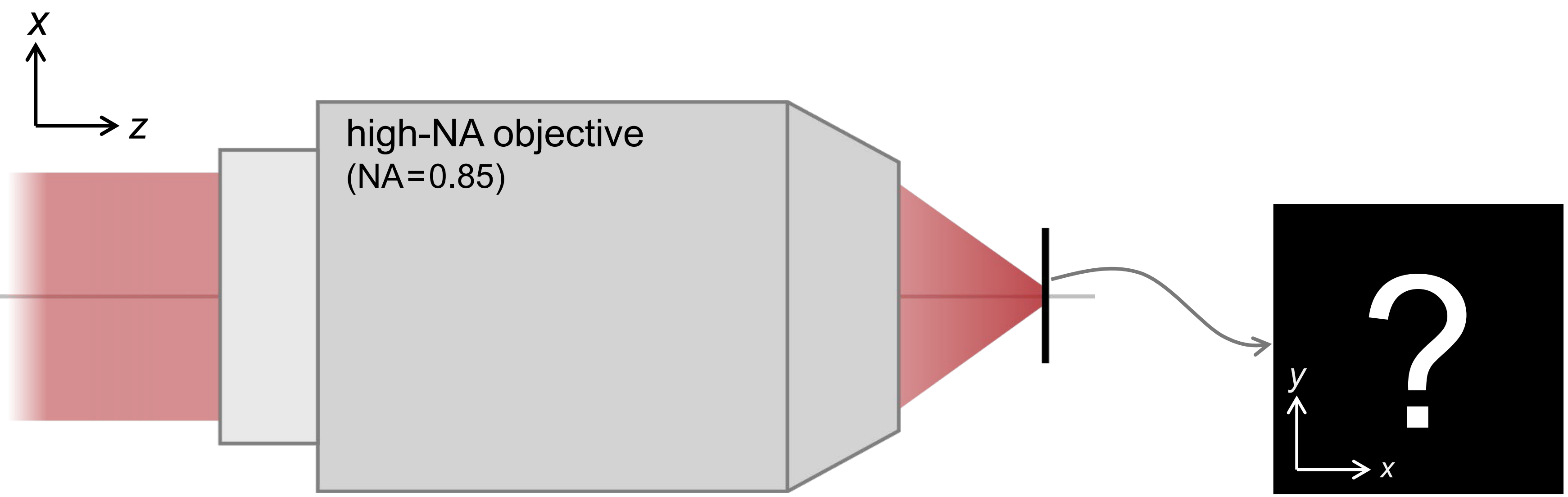


Example 1

Analyzing High-NA Objective Lens Focusing

see the full Application Use Case

Modeling Task

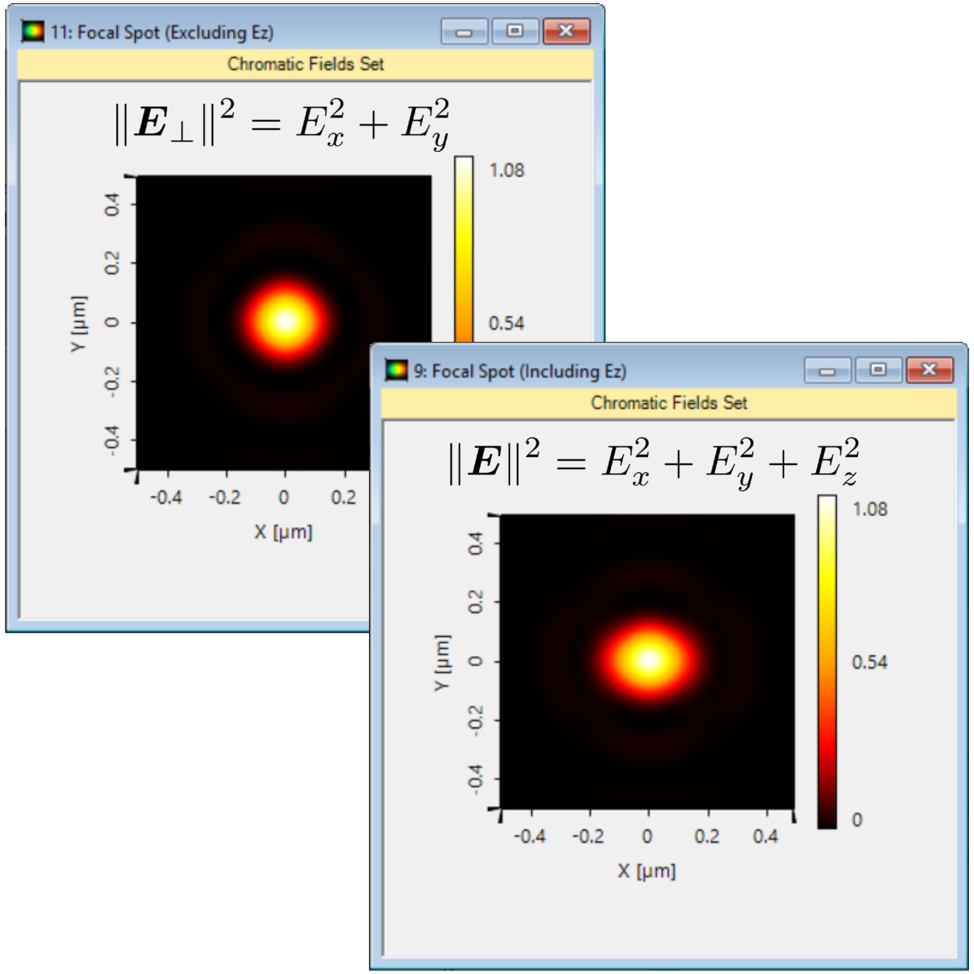


input plane wave

- wavelength 266.08 nm
- beam diameter 3 mm
- linearly polarized in *x* direction

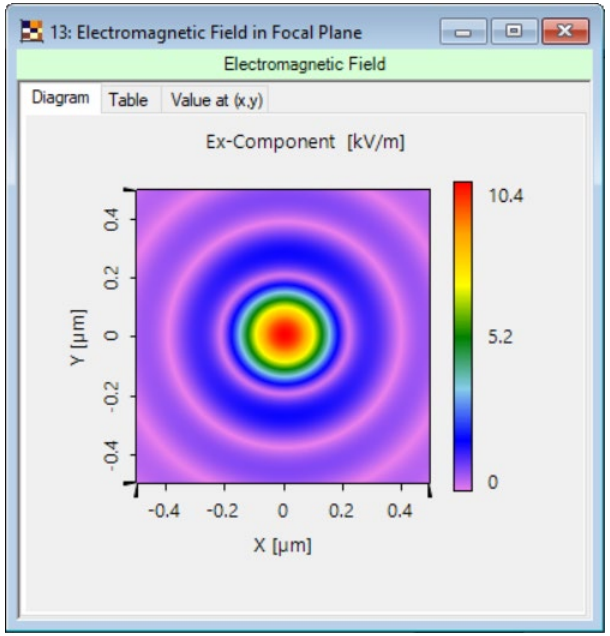
Field Tracing Results (Camera Detector)

- 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.

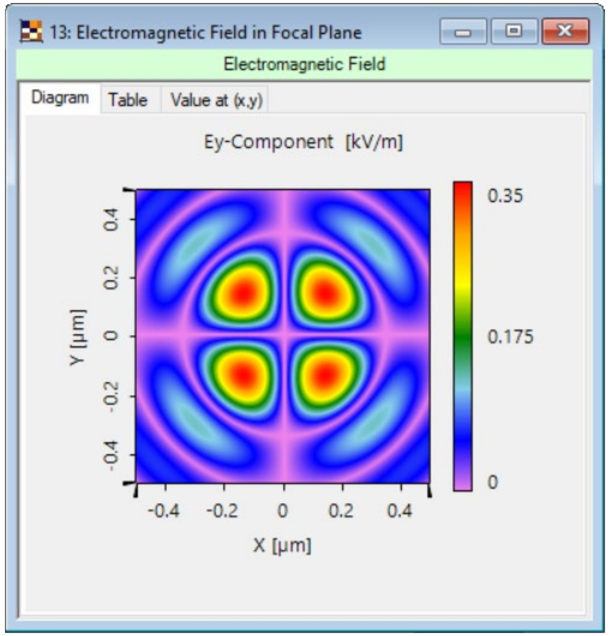


Field Tracing Results (Electromagnetic Field Detector)

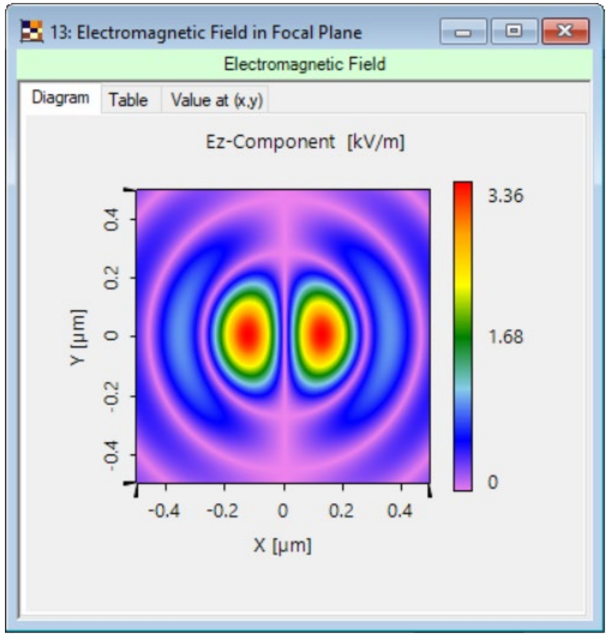
- All electromagnetic field components are obtained by using the Electromagnetic Field Detector.



amplitude of E_x



amplitude of E_y



amplitude of E_z

Field Tracing Results (Electromagnetic Field Detector)

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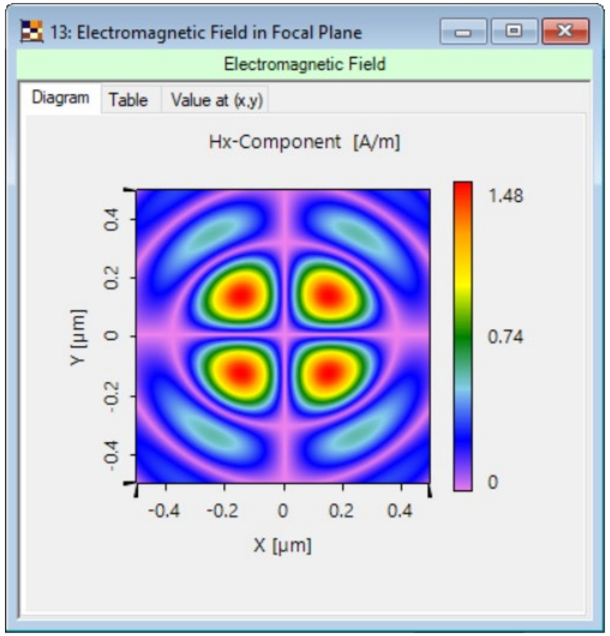
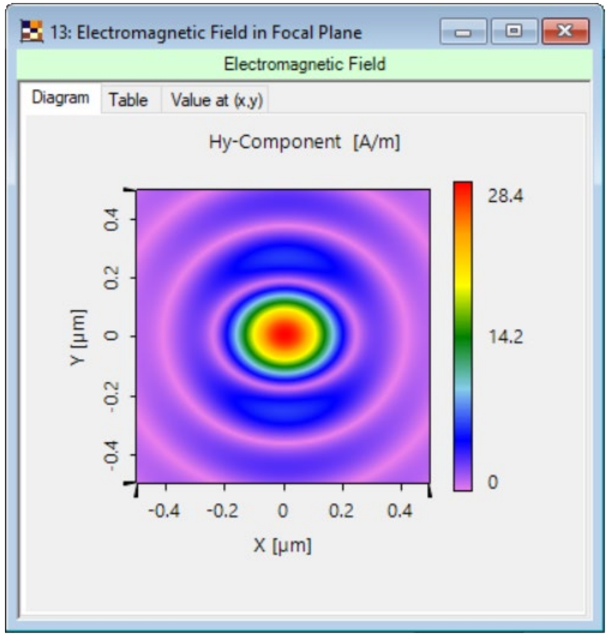
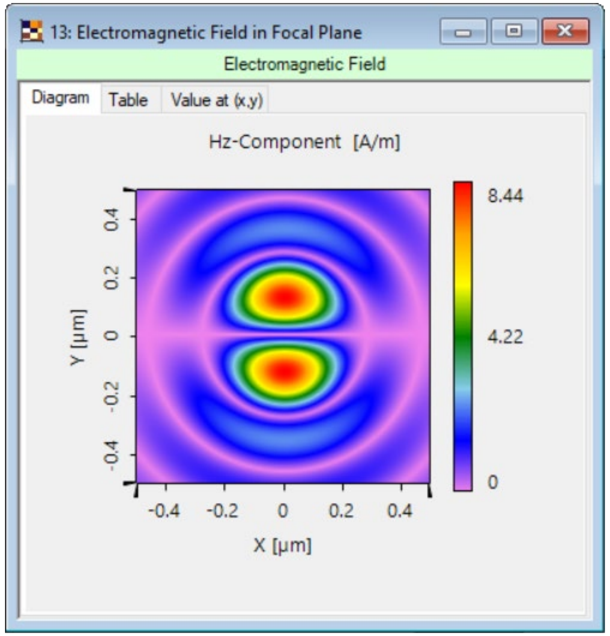


amplitude of H_x



amplitude of H_y



amplitude of H_z

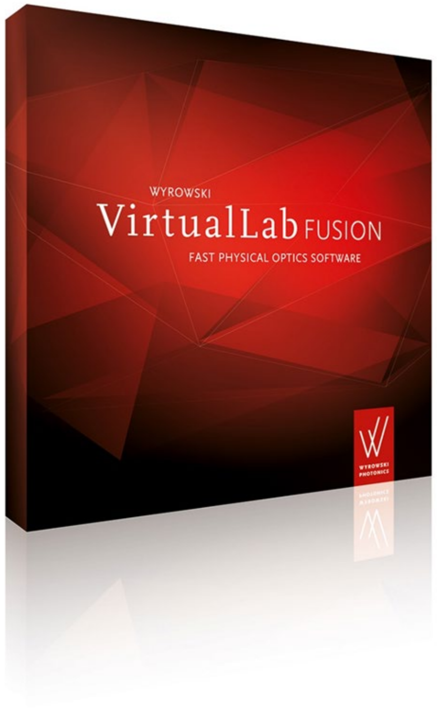
Part 2

The Electromagnetic Field Solvers

One Platform, Many Solvers

Fast physical optics simulations…

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

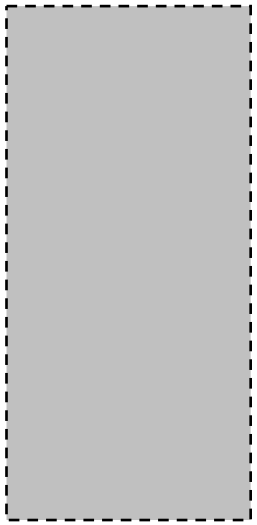


VirtualLab Fusion acts a software platform to connect electromagnetic field solvers in a **seamless, fully non-sequential manner**

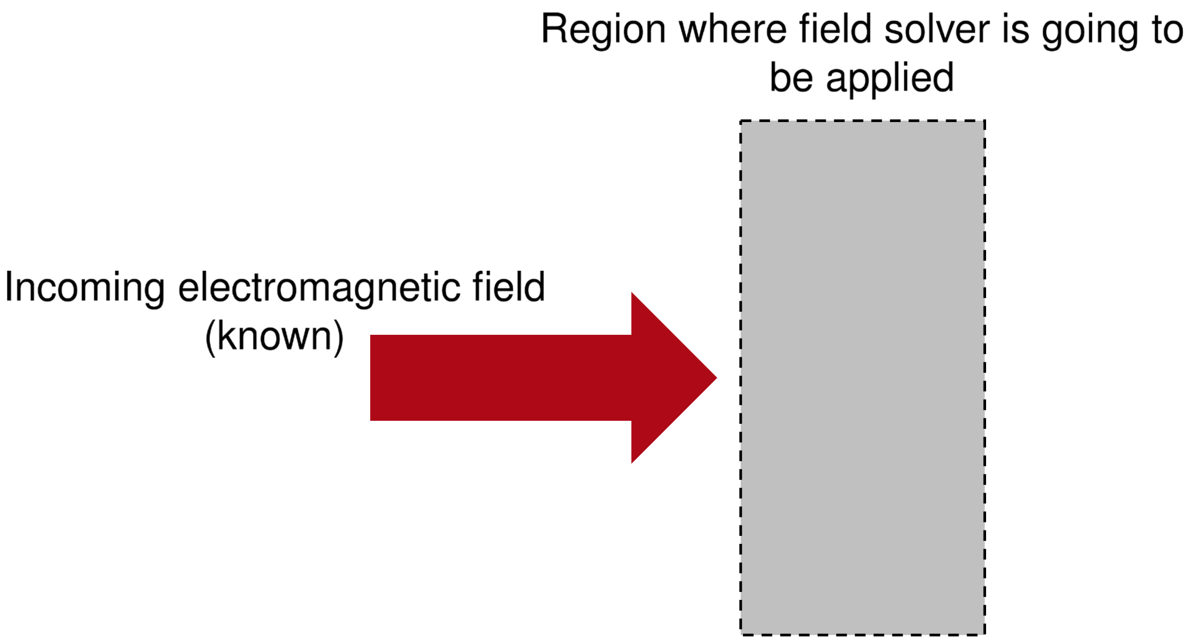
→ **solving Maxwell's equations for the whole system!**

Electromagnetic Field Solvers

Region where field solver is going to be applied



Electromagnetic Field Solvers



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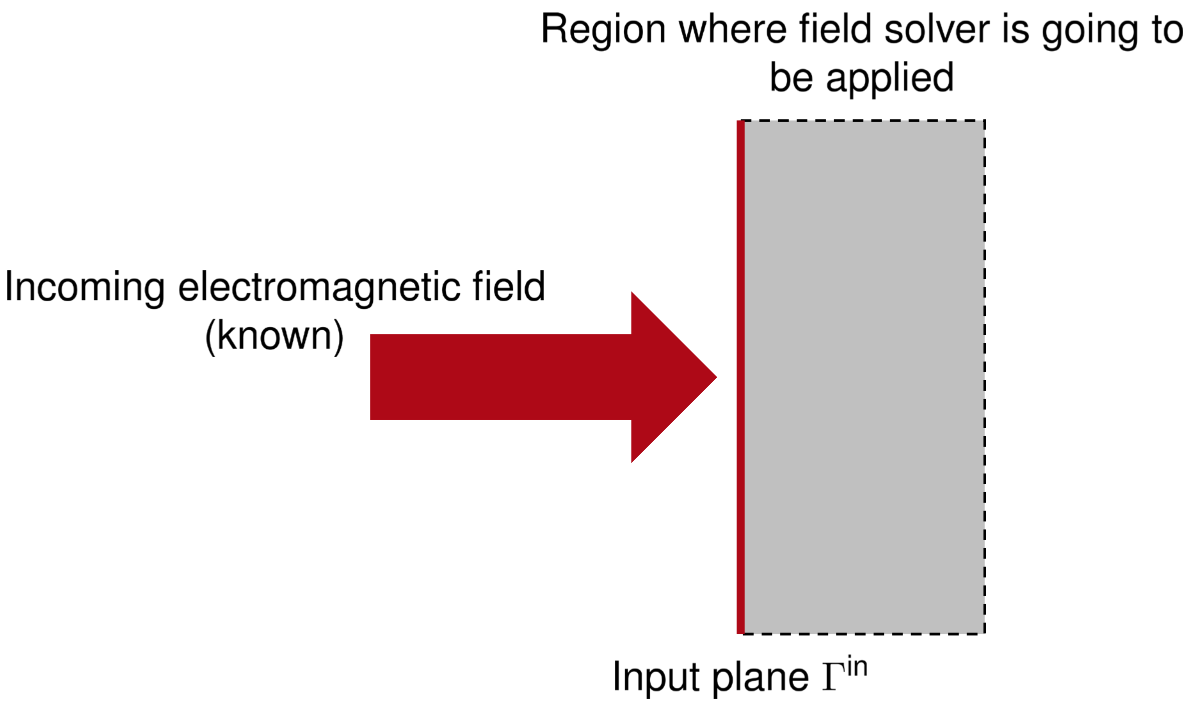

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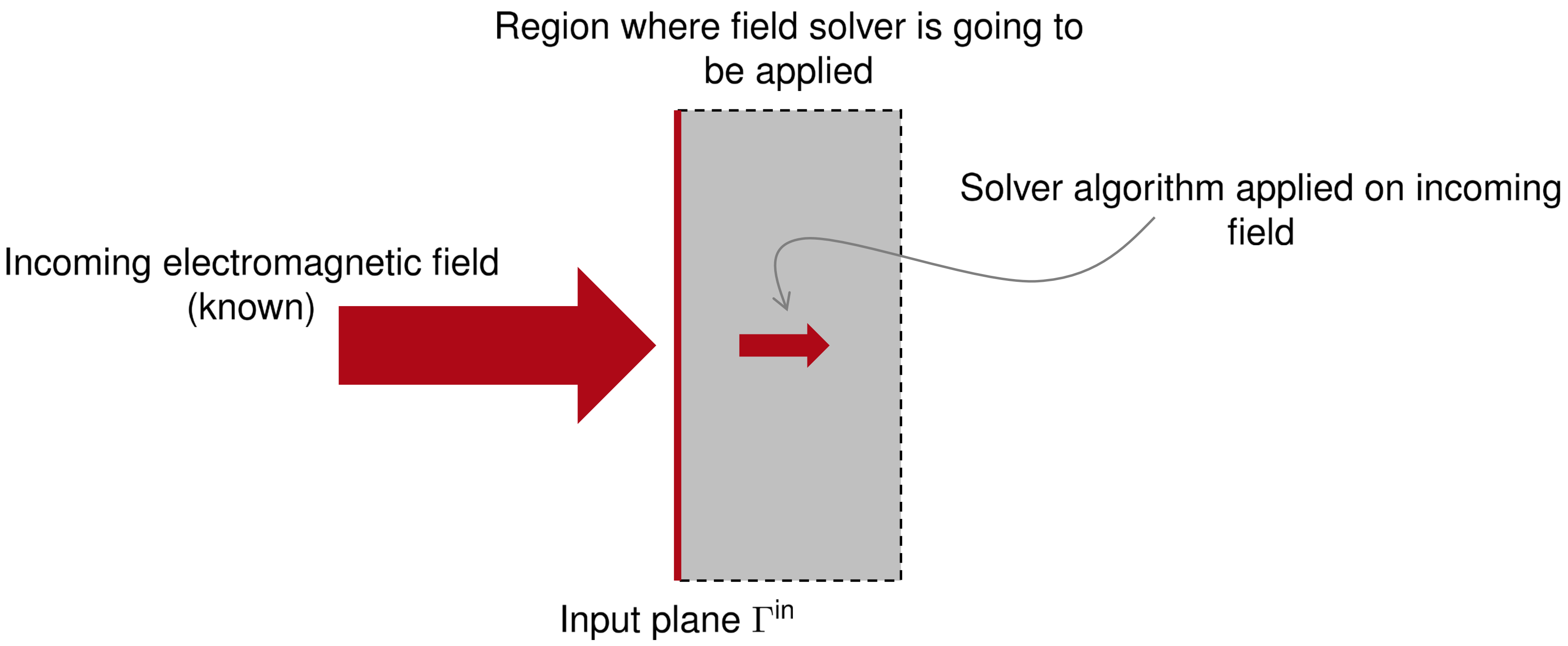

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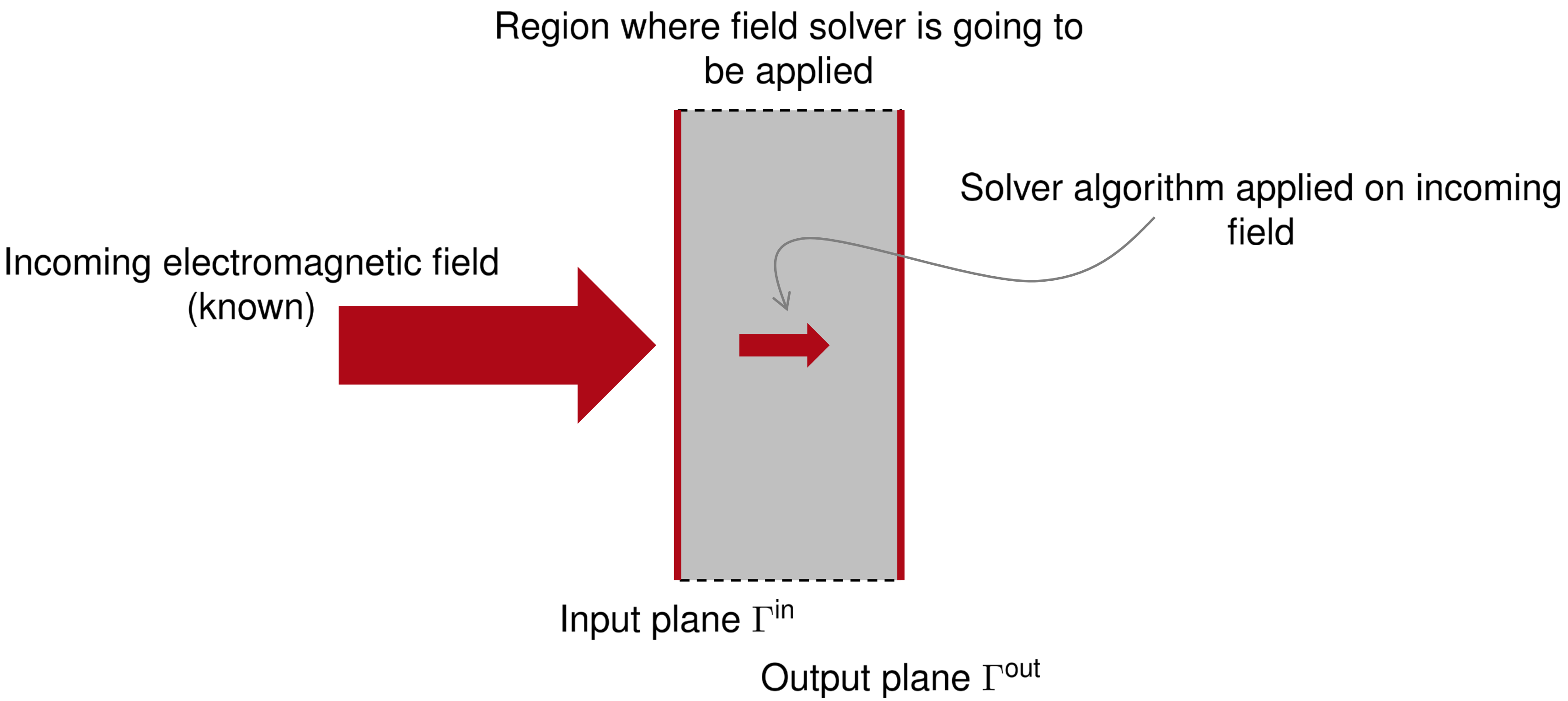

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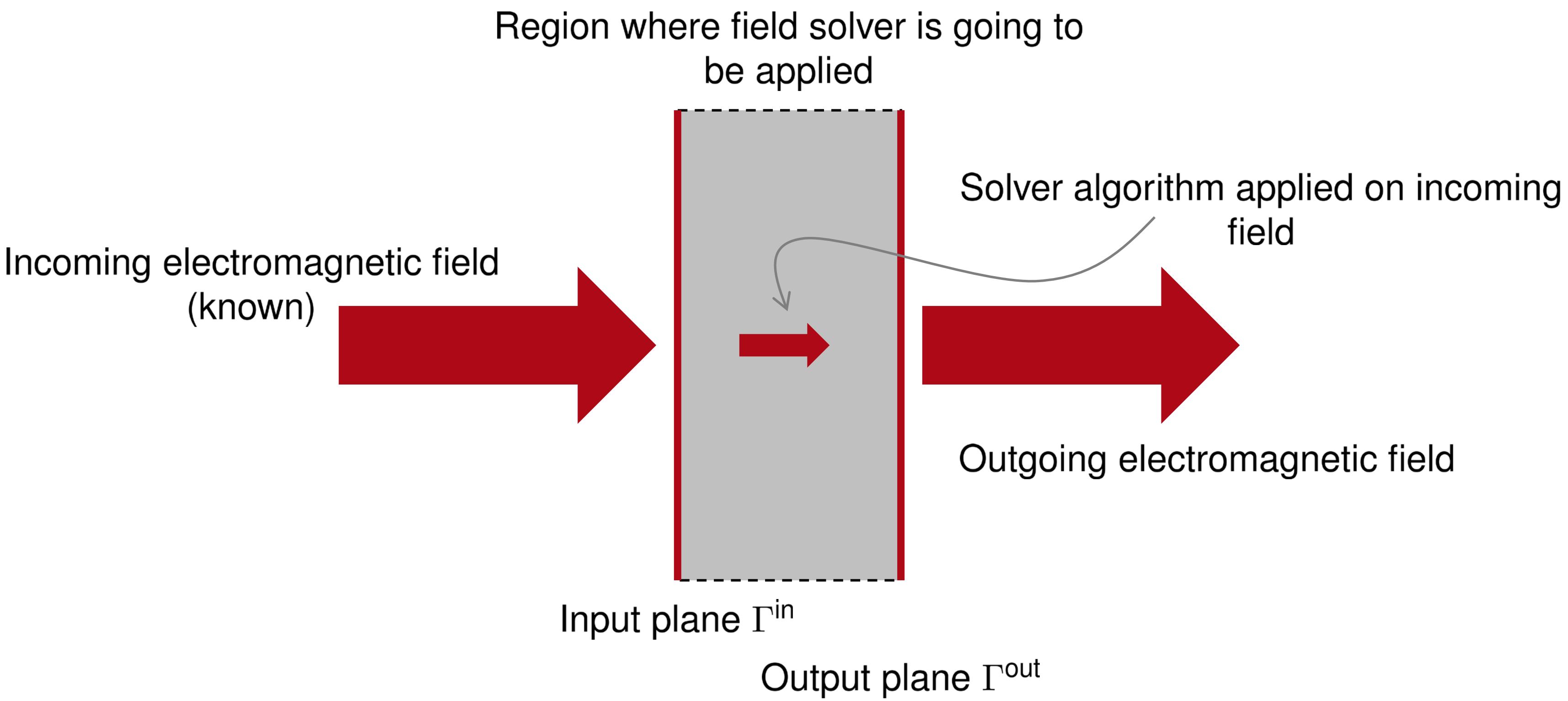

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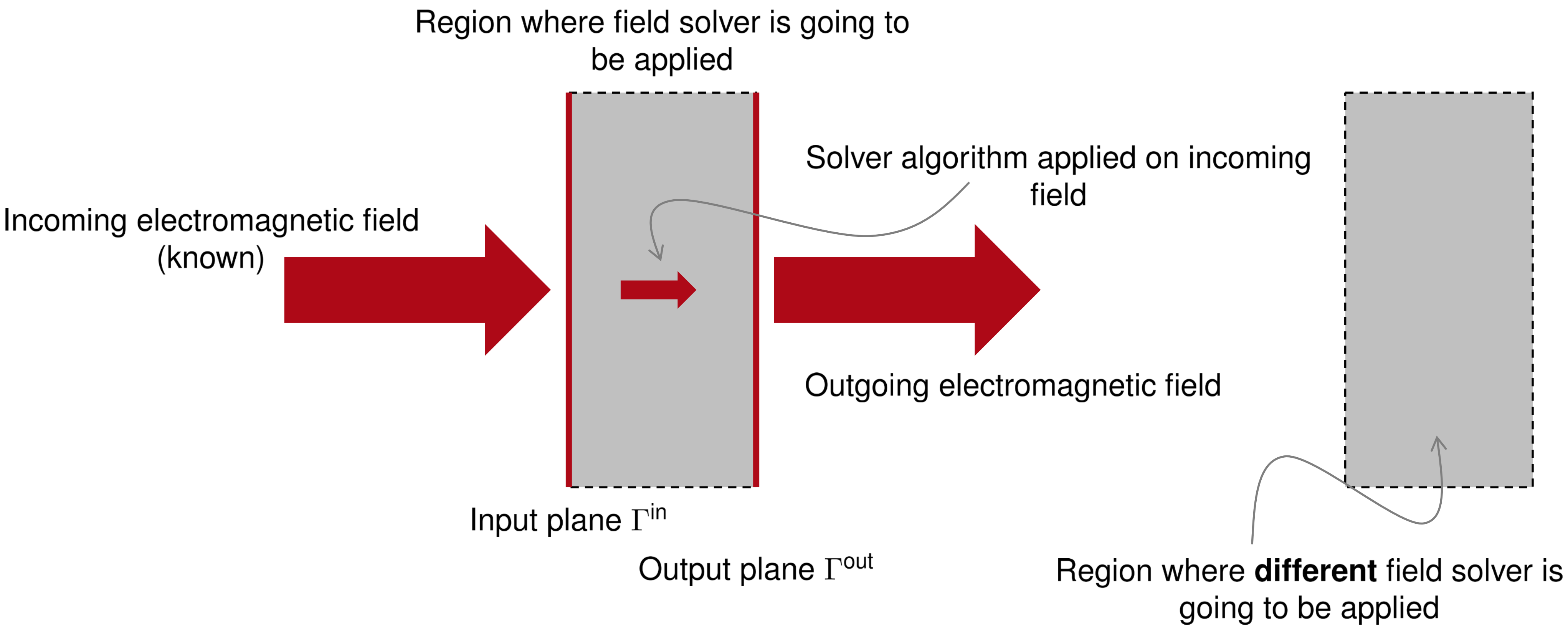

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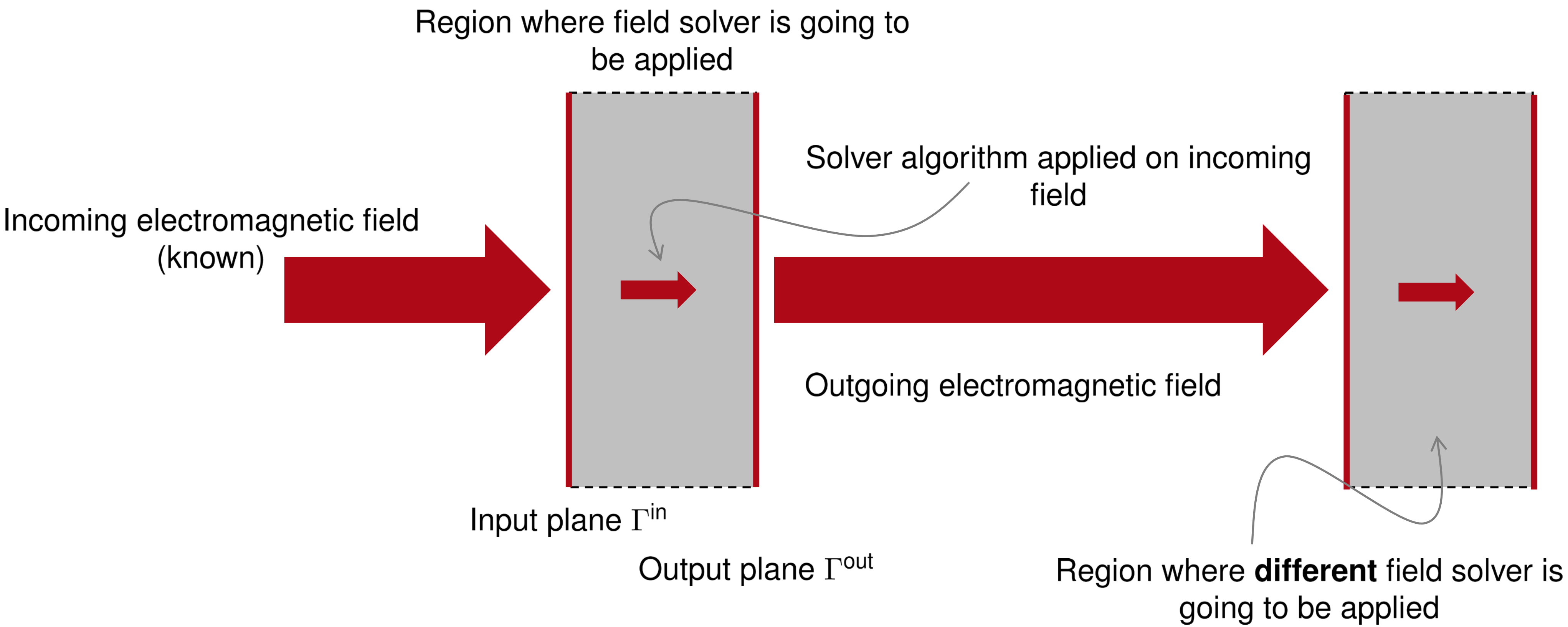
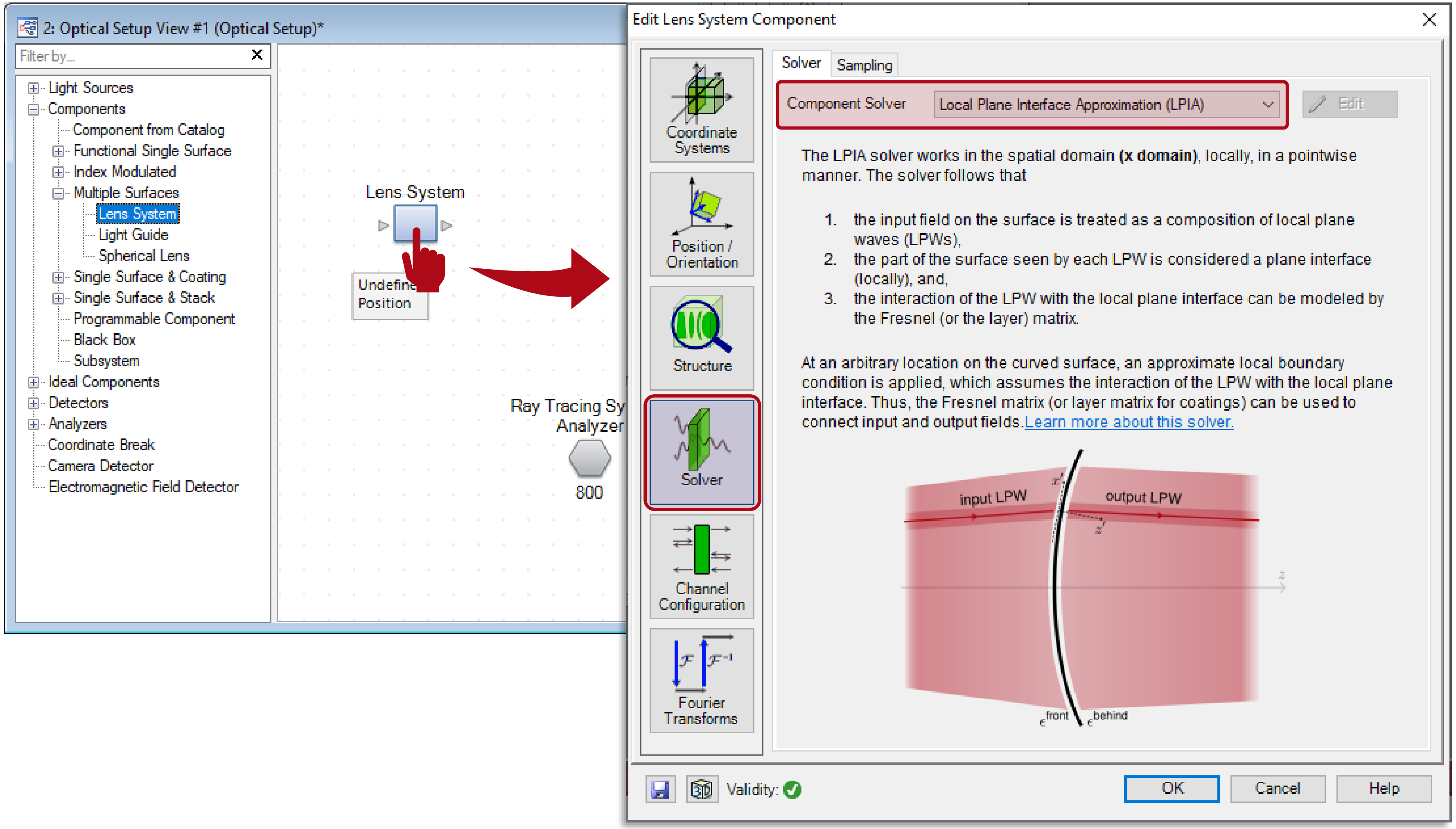
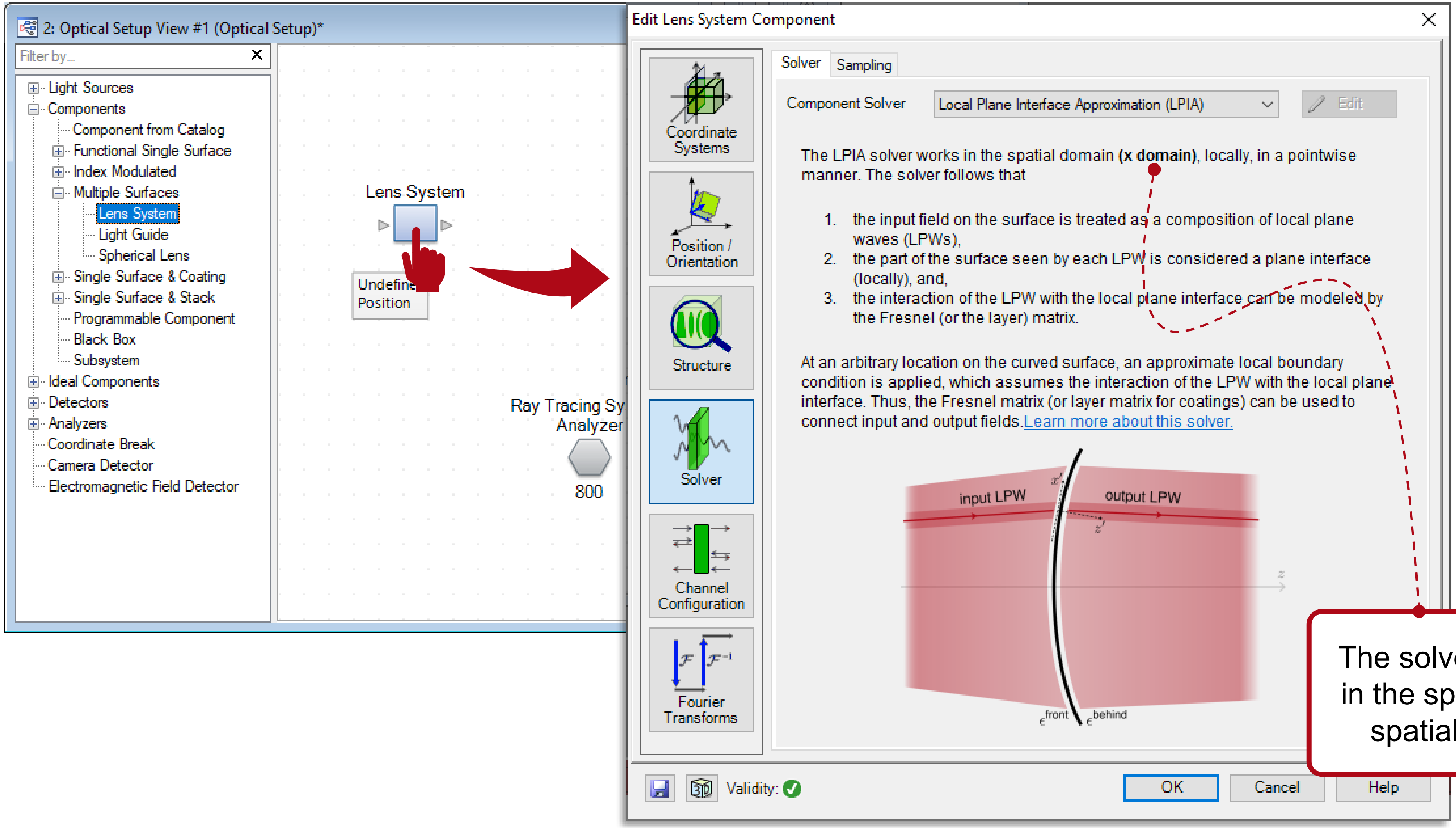


Components & Solvers



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

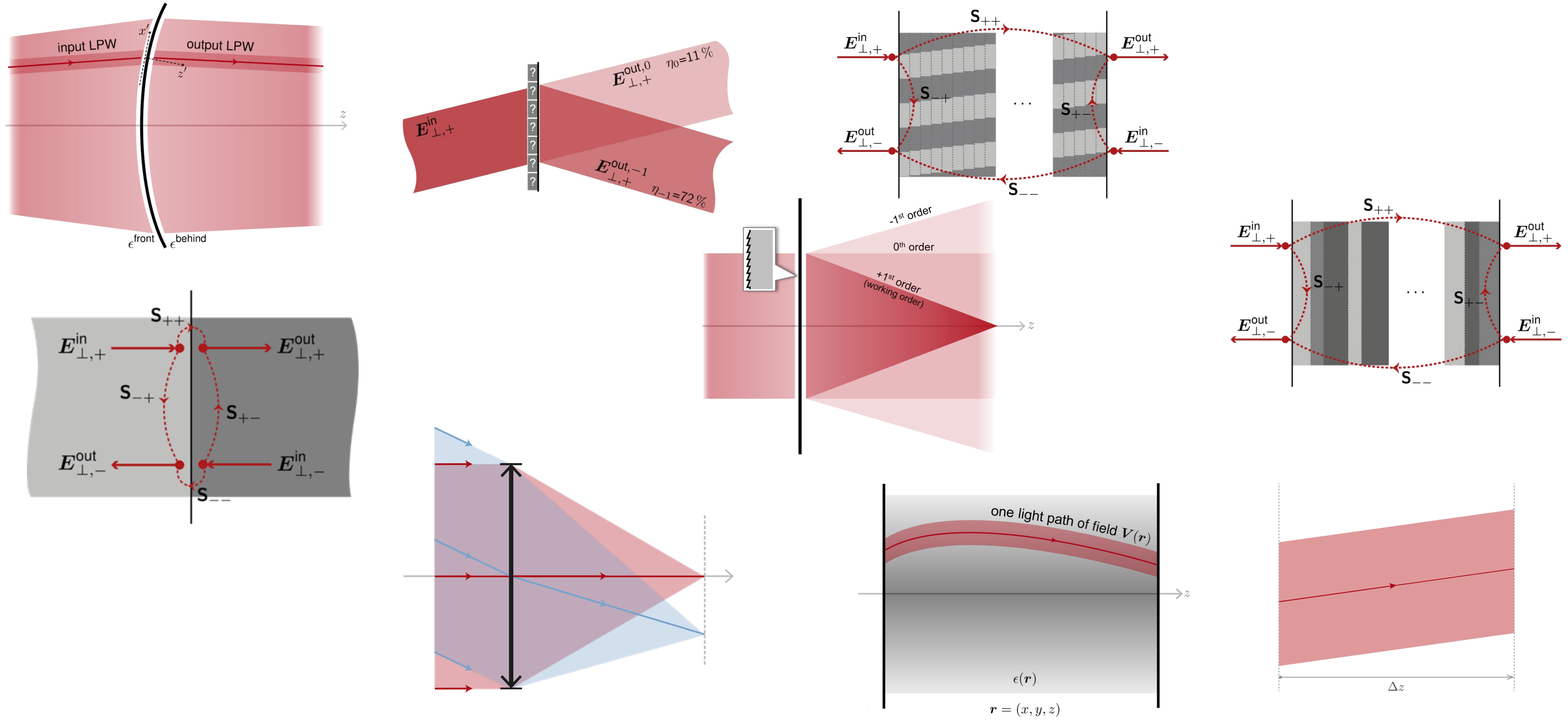
Components & Solvers



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

Why Different Domains?



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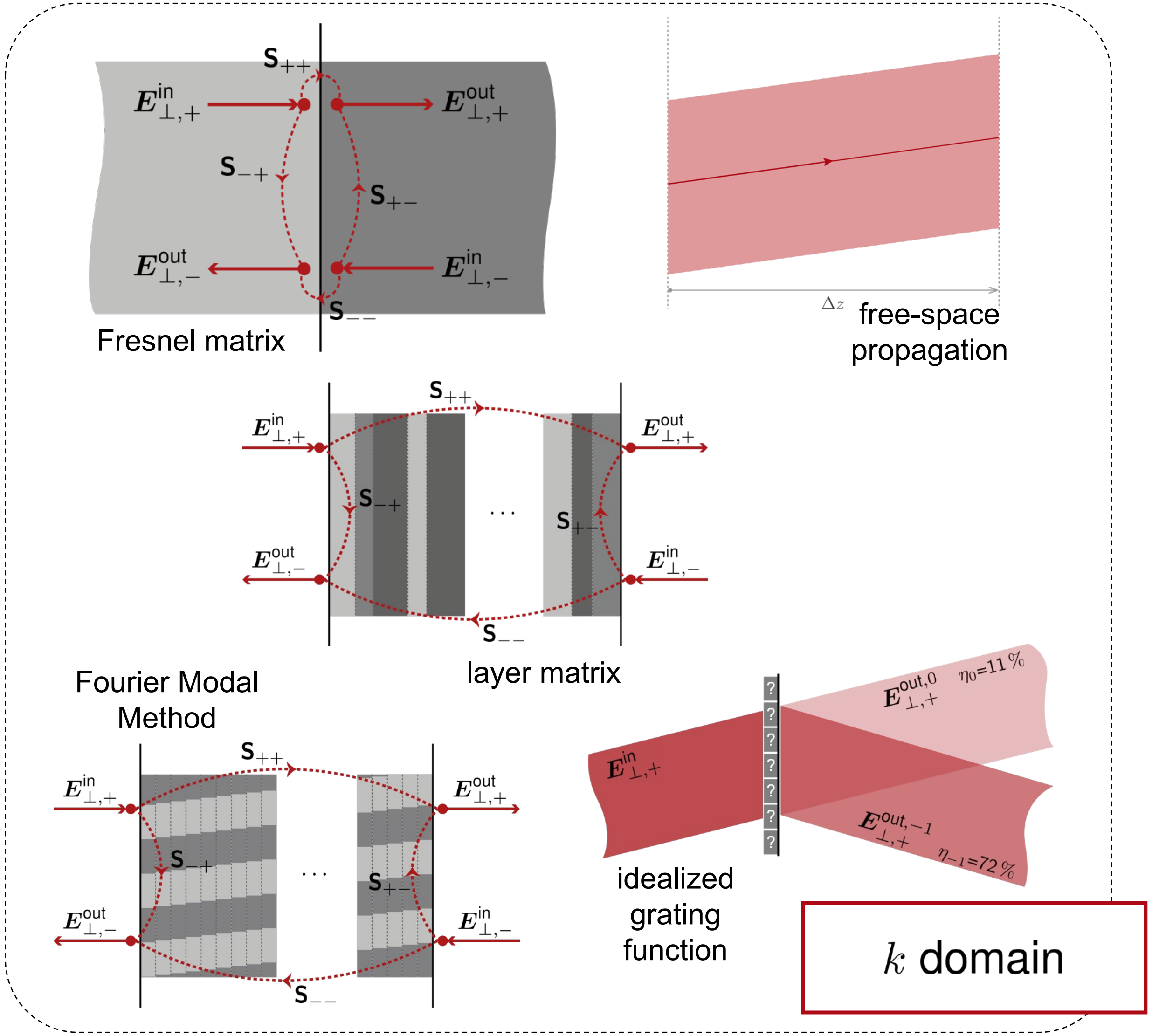
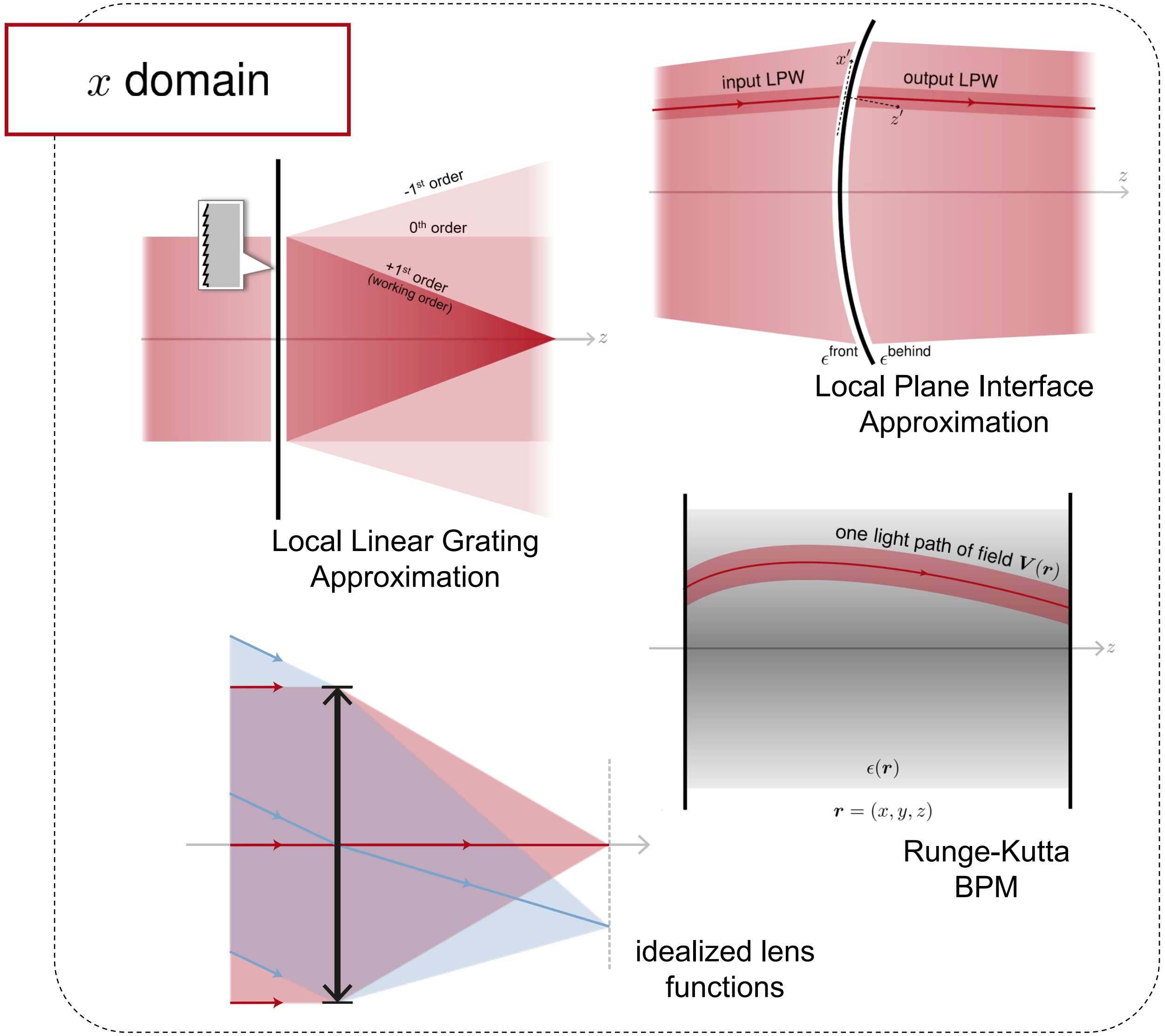
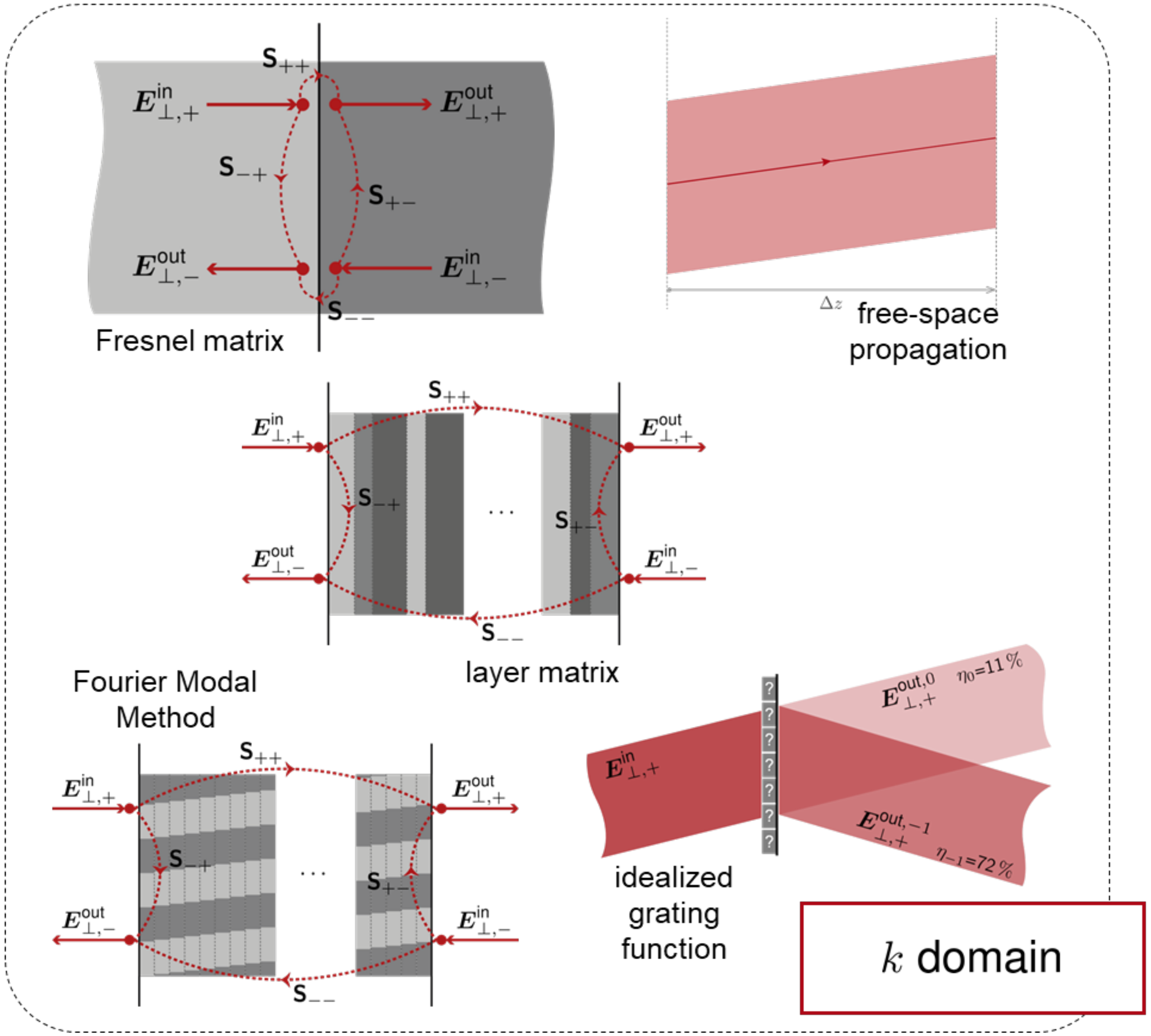
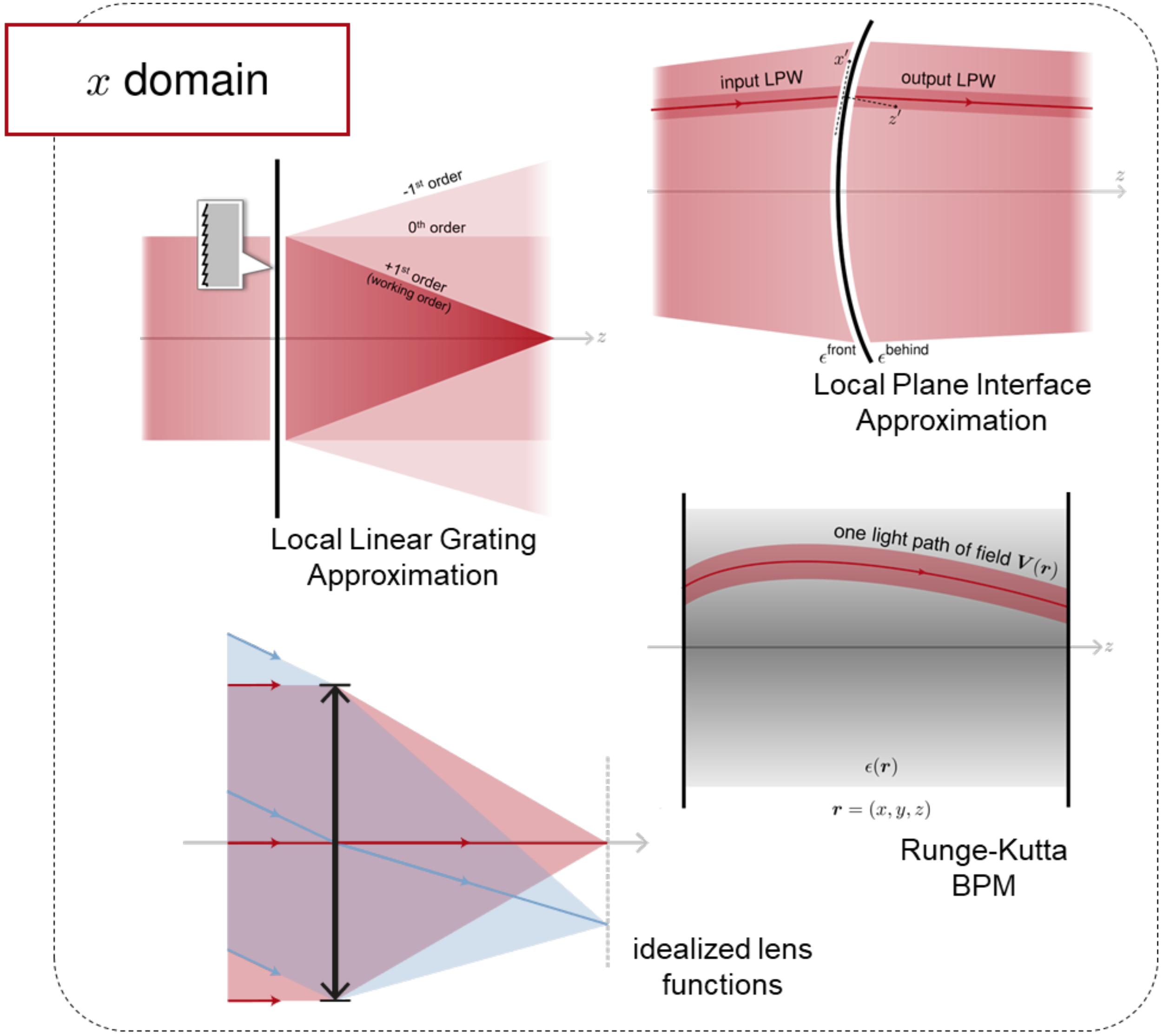




Hint: click on the logos for additional documentation on the solvers!

Why Different Domains?





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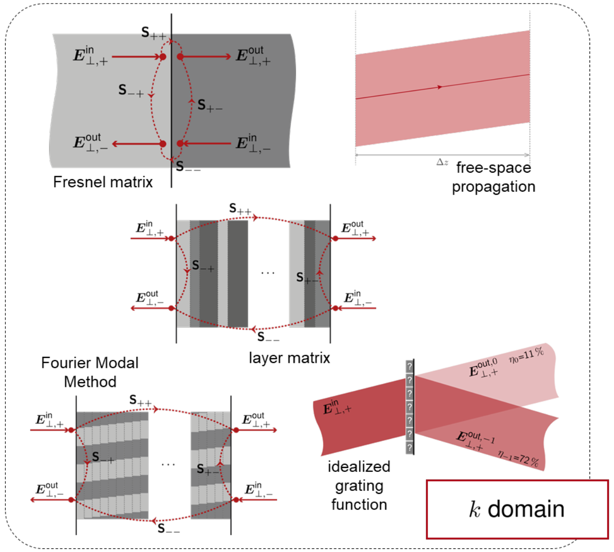
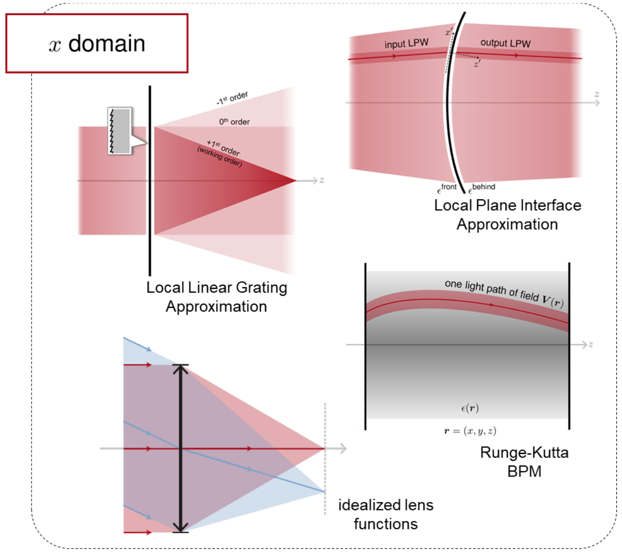
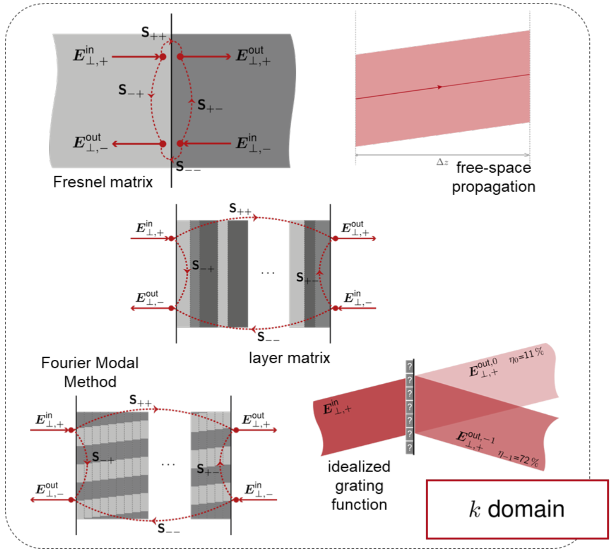
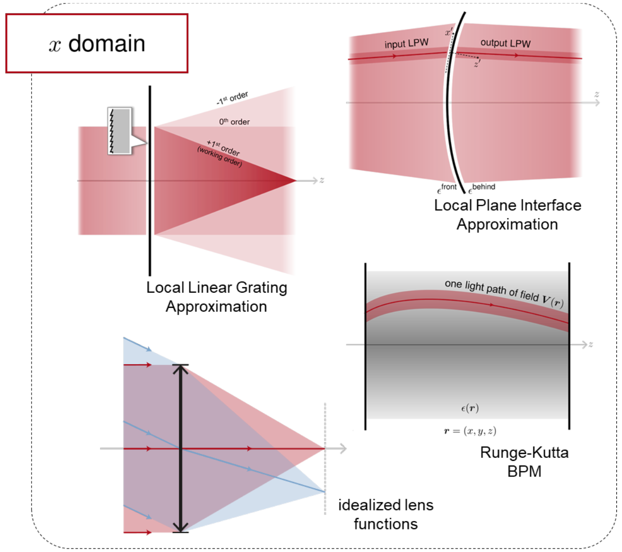




Why Different Domains?

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**!





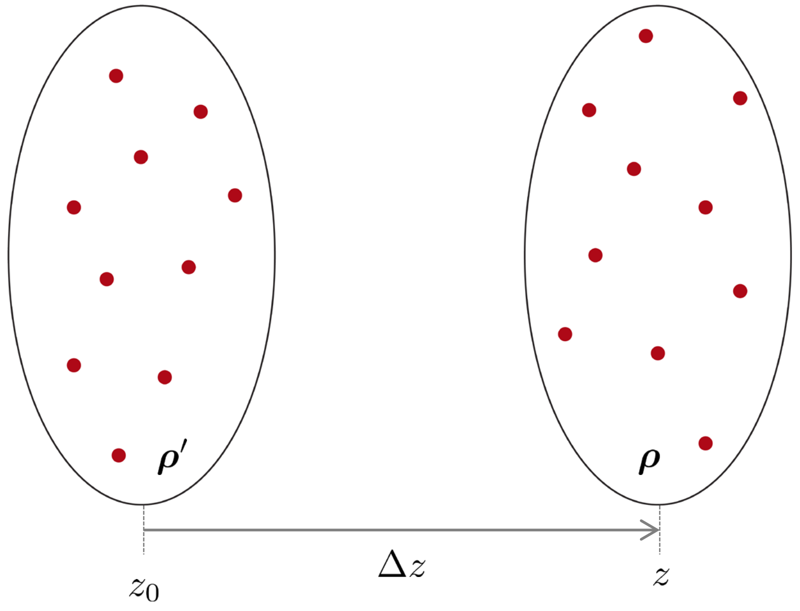
Example: Free-Space Propagation

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



Example: Free-Space Propagation

Space domain

Rayleigh-Sommerfeld integral:

$$V_\ell^{\mathsf{out}}(\boldsymbol{\rho}, z) \propto \iint_{-\infty}^{+\infty} V_\ell^{\mathsf{in}}(\boldsymbol{\rho}', z_0) \frac{\mathrm{e}^{\mathrm{i}k_0 n R}}{R}\left(\mathrm{i}k_0 n - \frac{1}{R}\right)\frac{\Delta z}{R}\mathrm{d}^2\rho'$$

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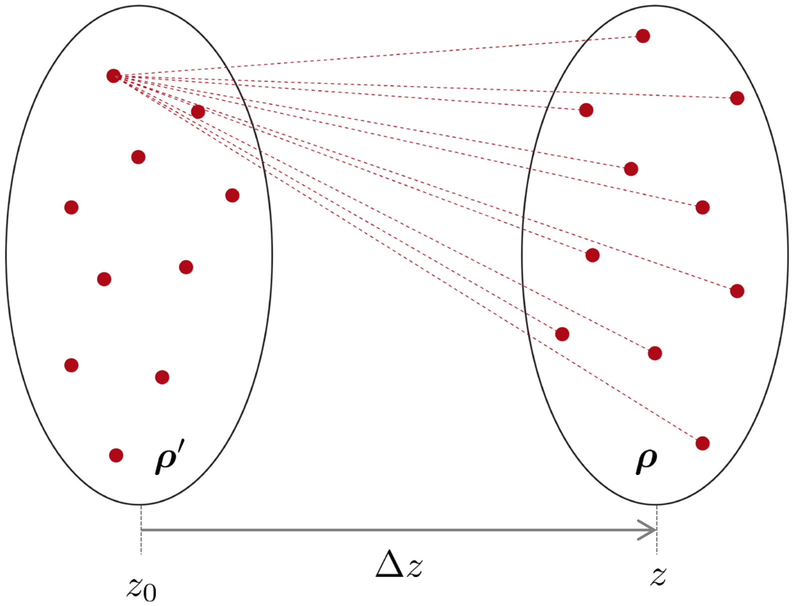

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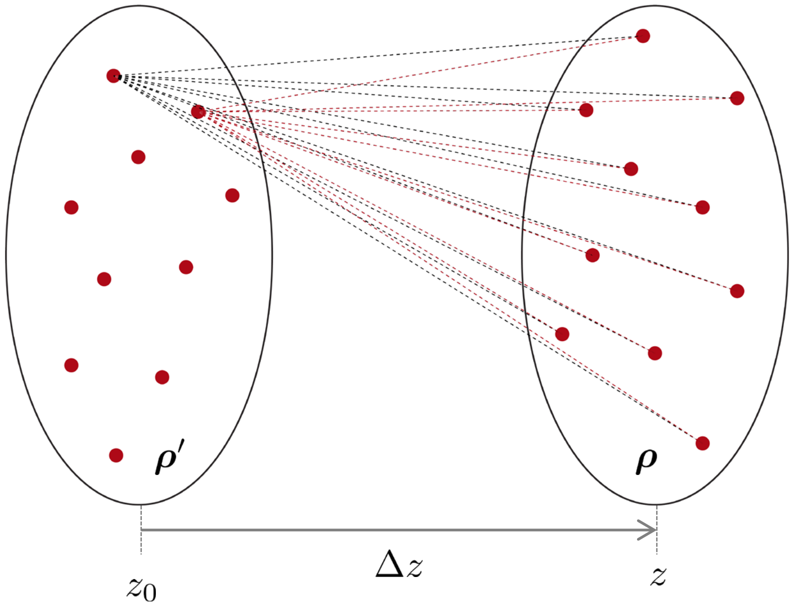

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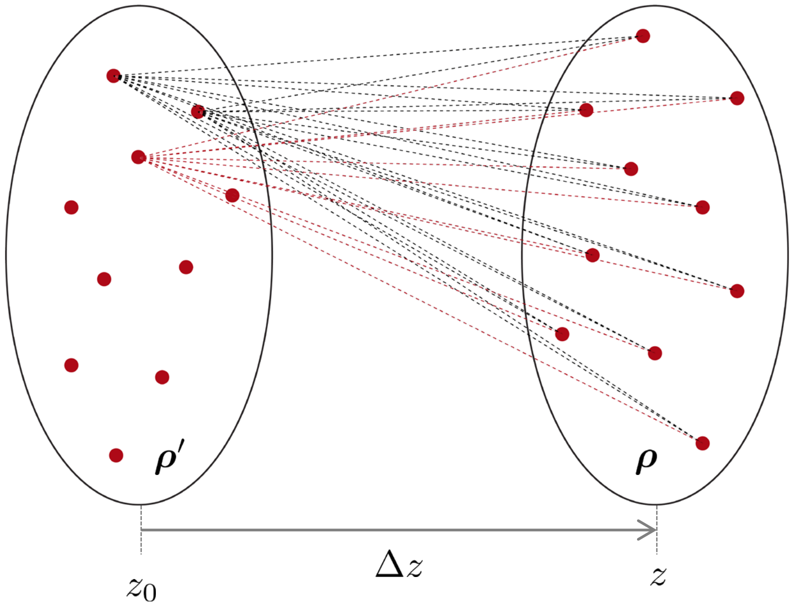

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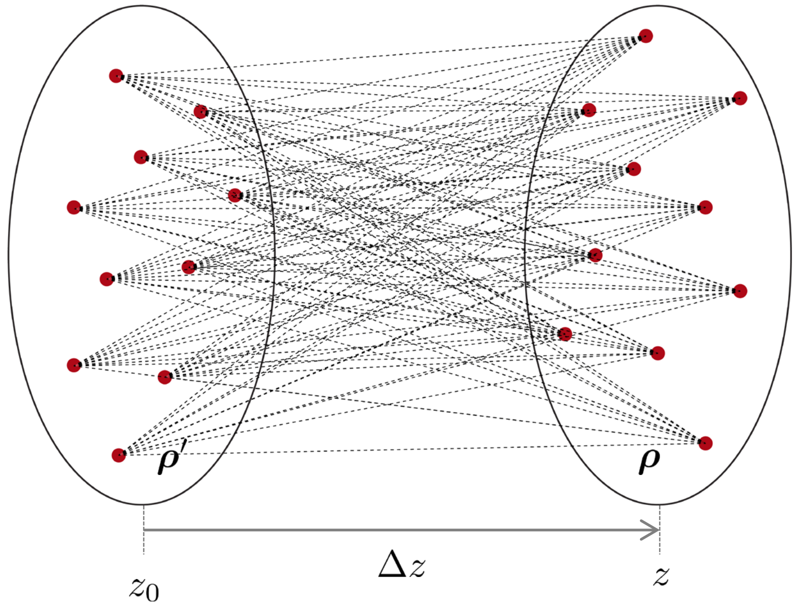

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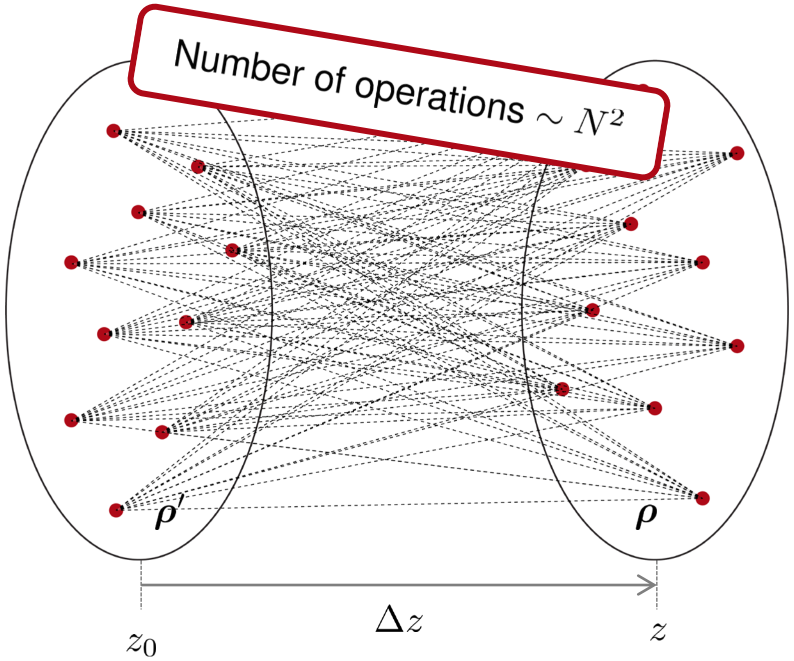

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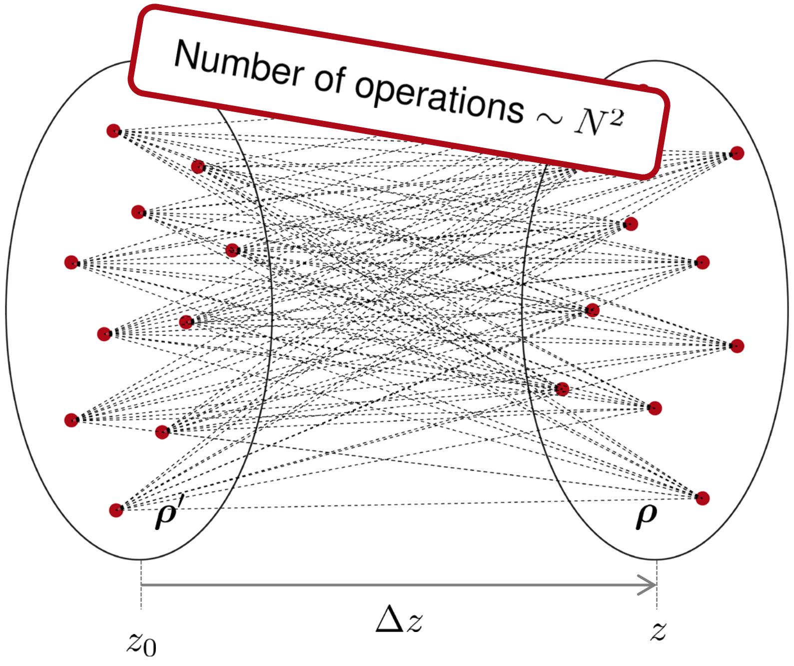

Spatial-frequency domain

Plane-wave propagation operator:

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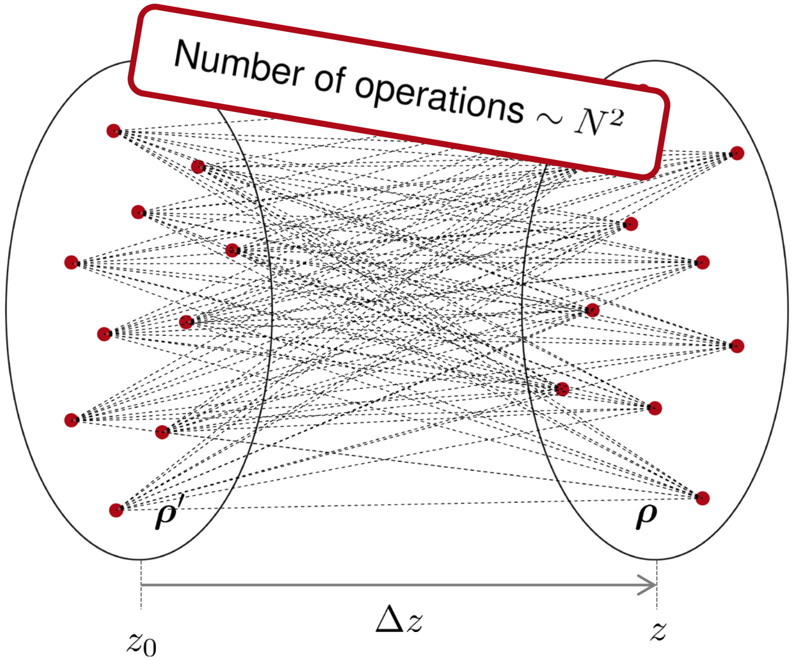

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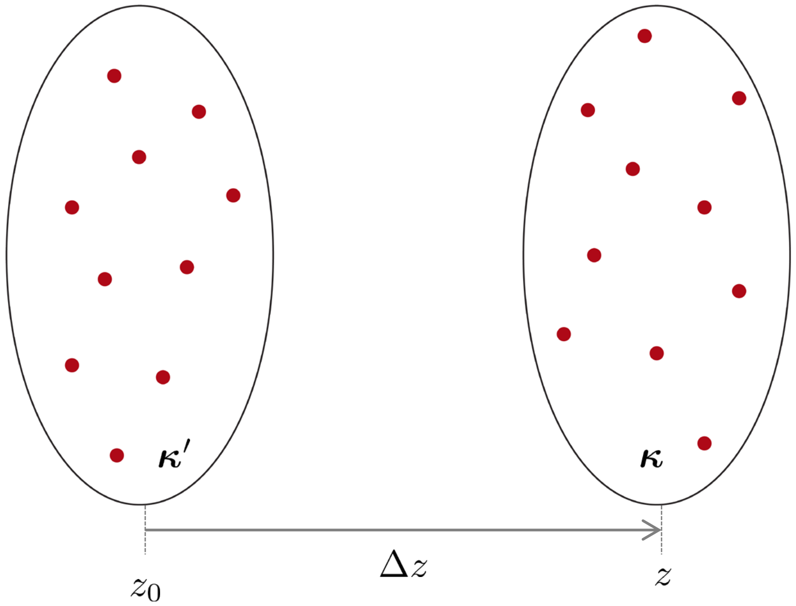

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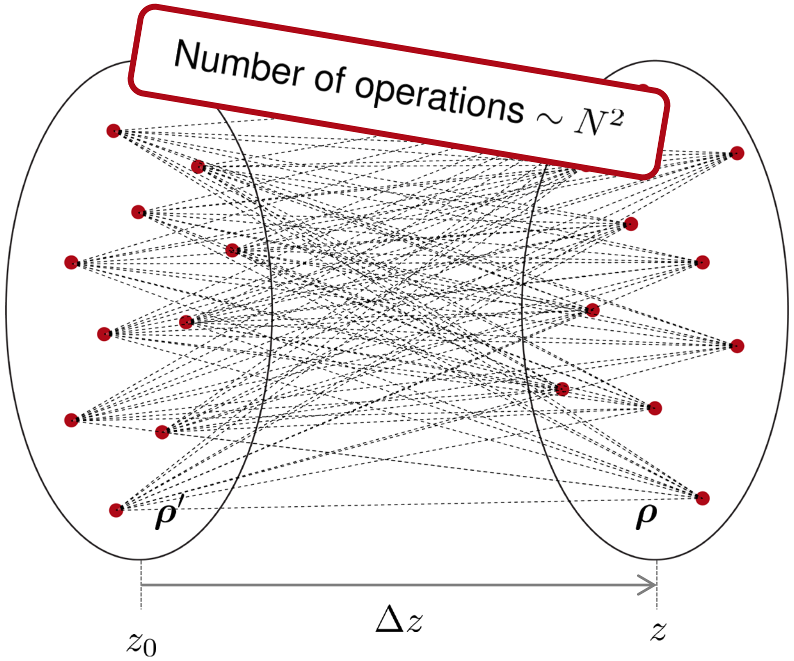

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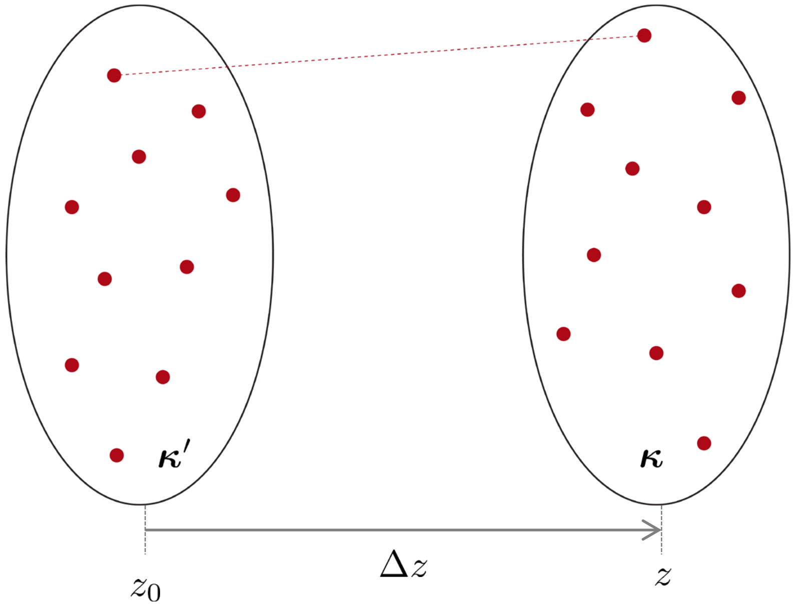

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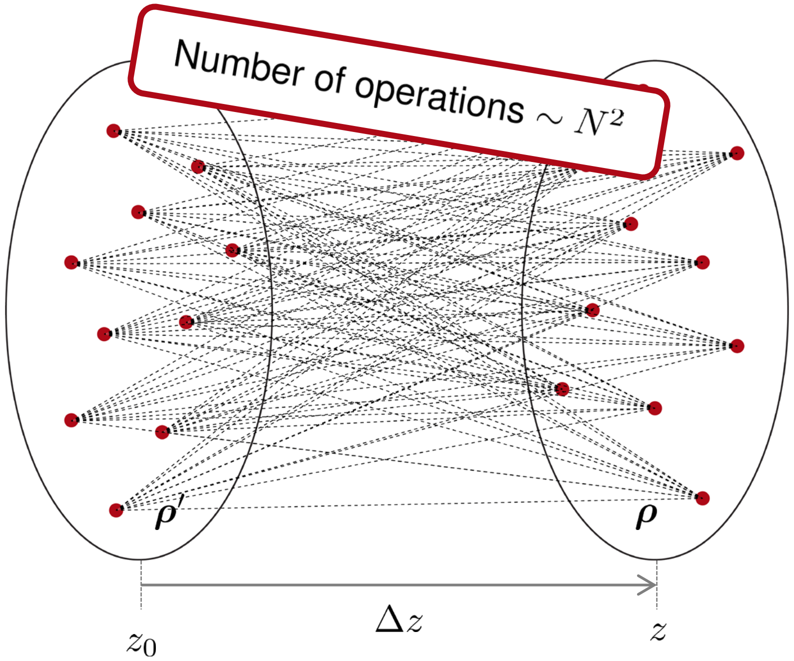

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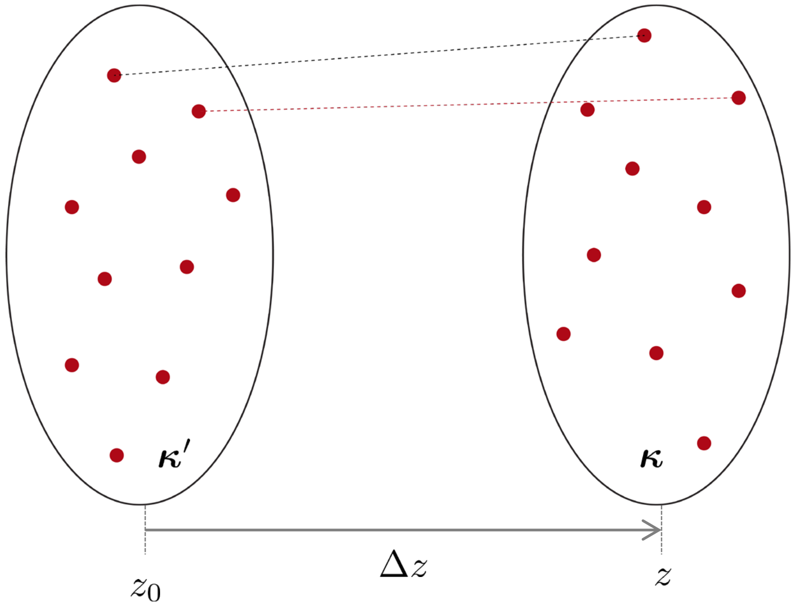

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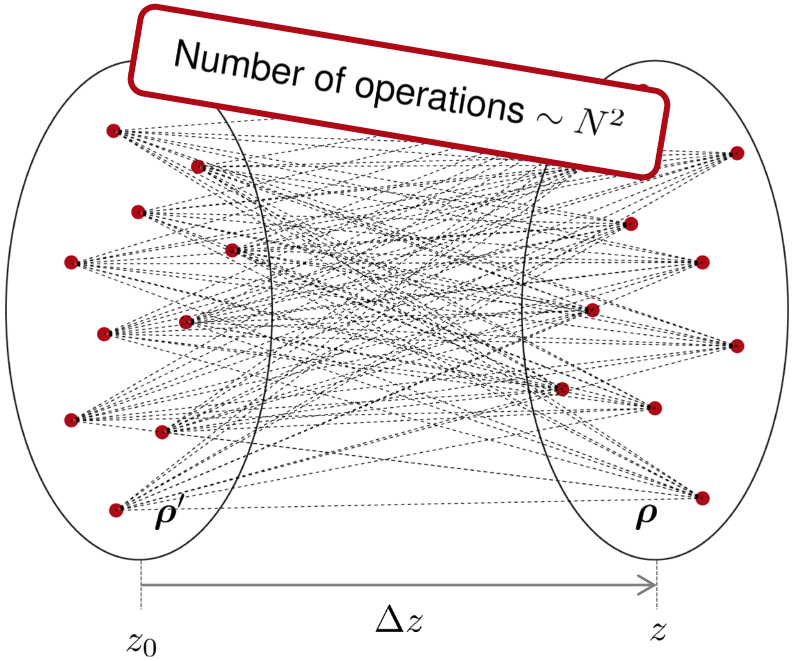

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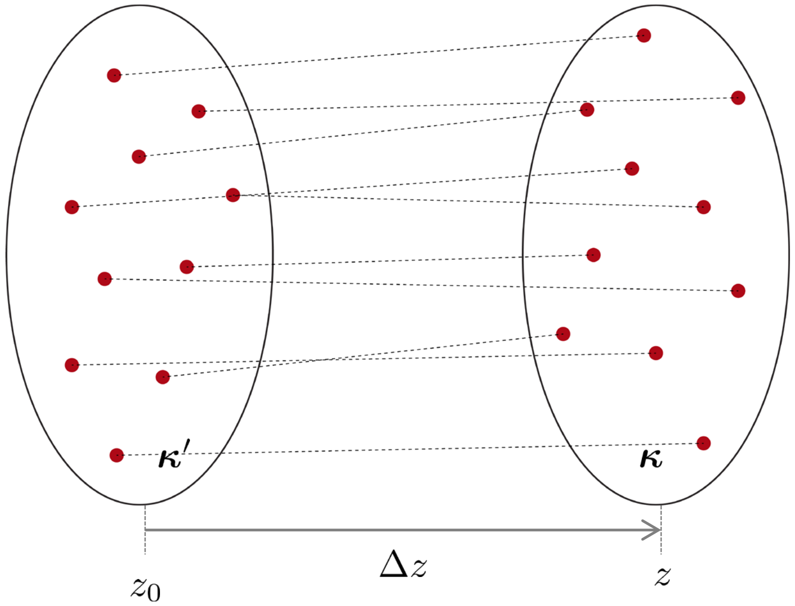

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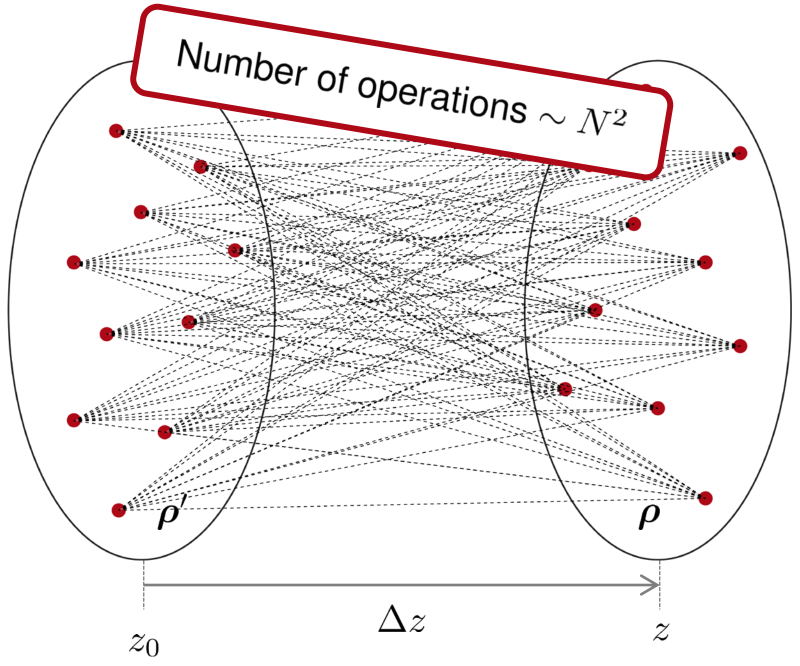

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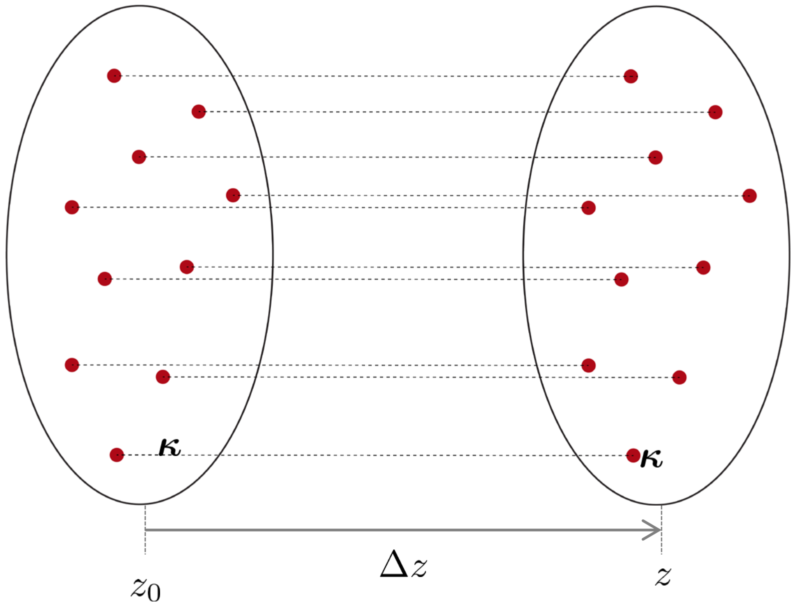

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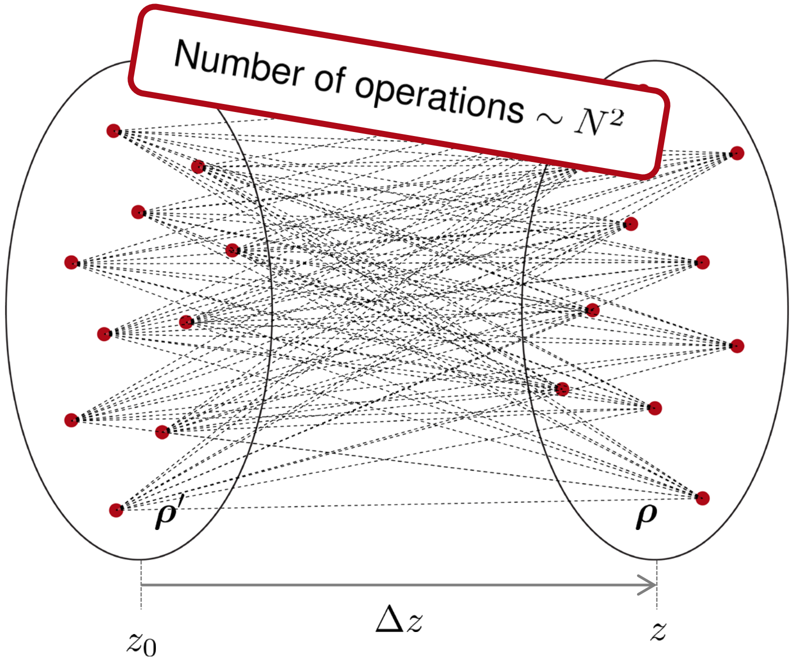

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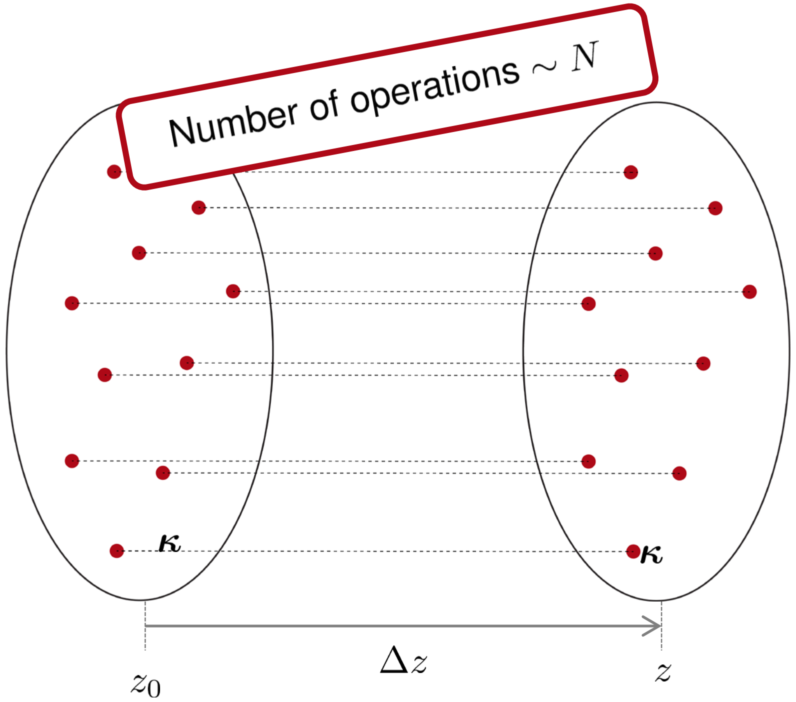
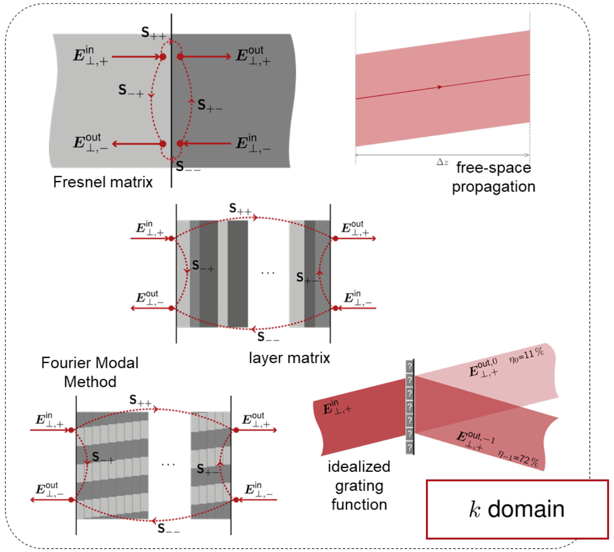
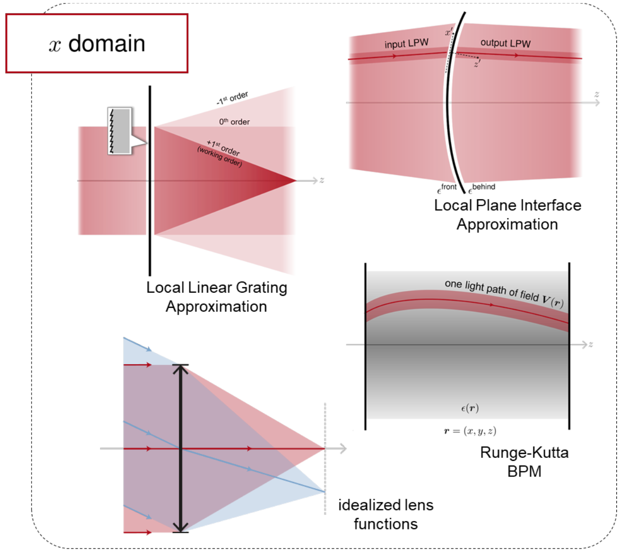


Why Different Fourier Domains?

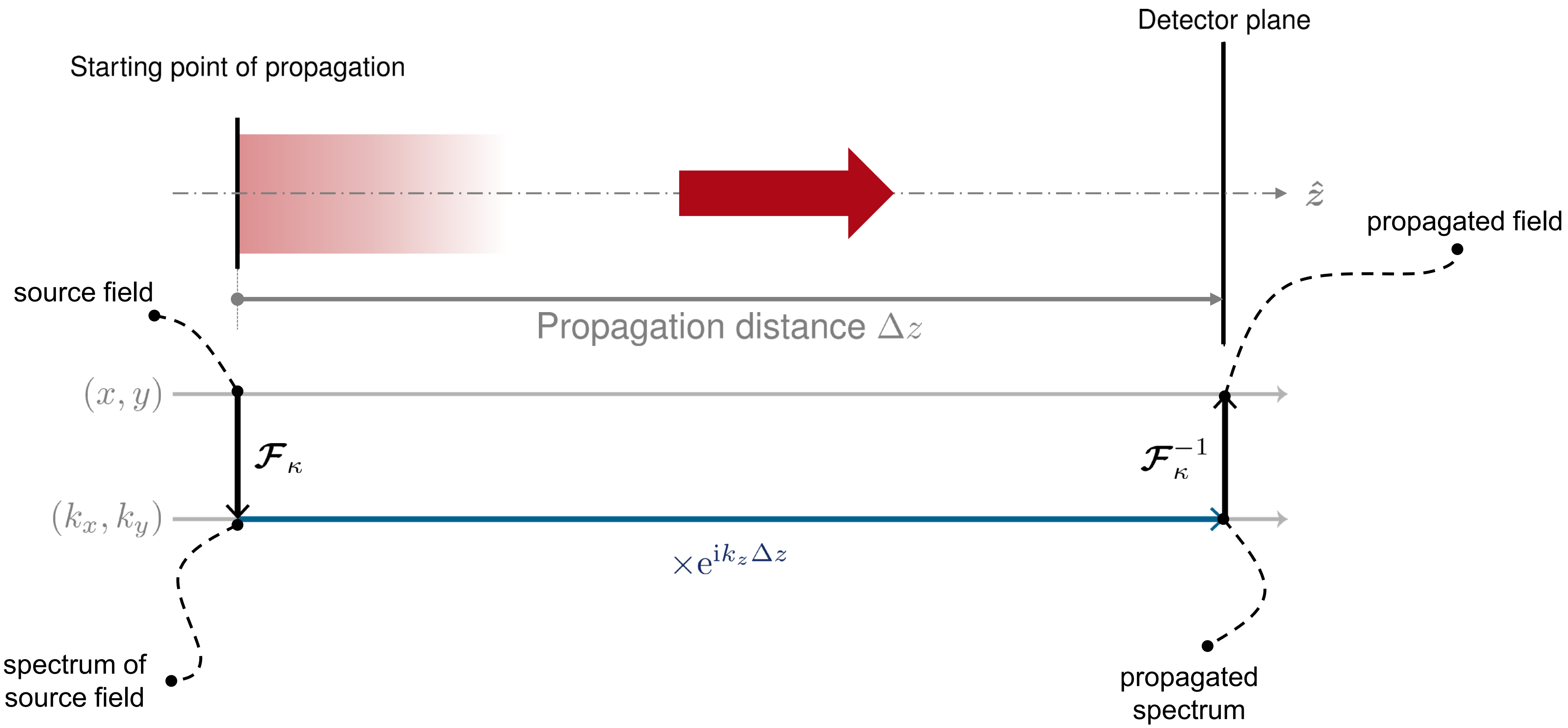
Although, in general, electromagnetic field solvers have an **integral** behaviour, with the resulting high numerical complexity, the characteristics of some of the most common optical components mean they can be modeled with **pointwise** operators in one of the Fourier domains – when this happens,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





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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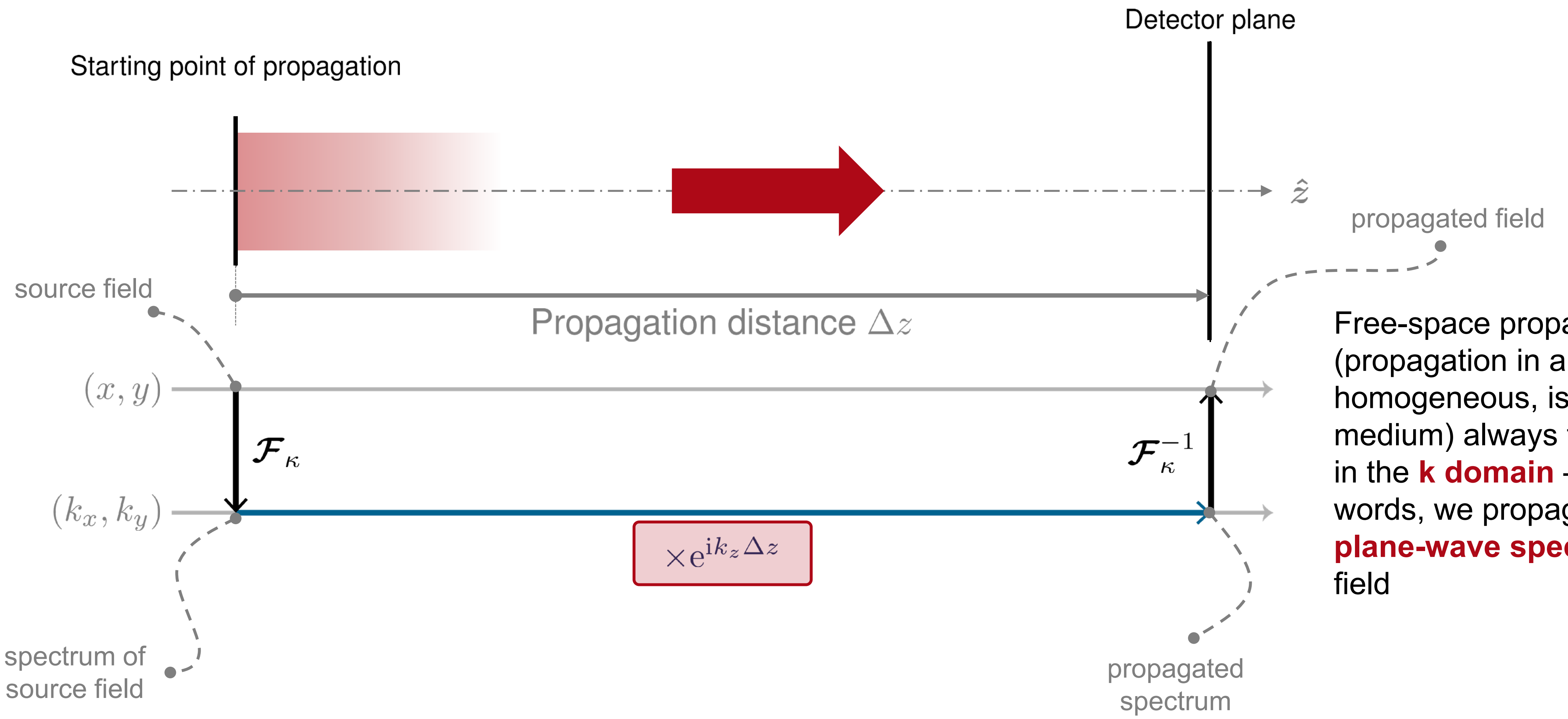

Free-space propagation (propagation in a homogeneous, isotropic medium) always takes place in the **k domain** – in other words, we propagate the **plane-wave spectrum** of the field

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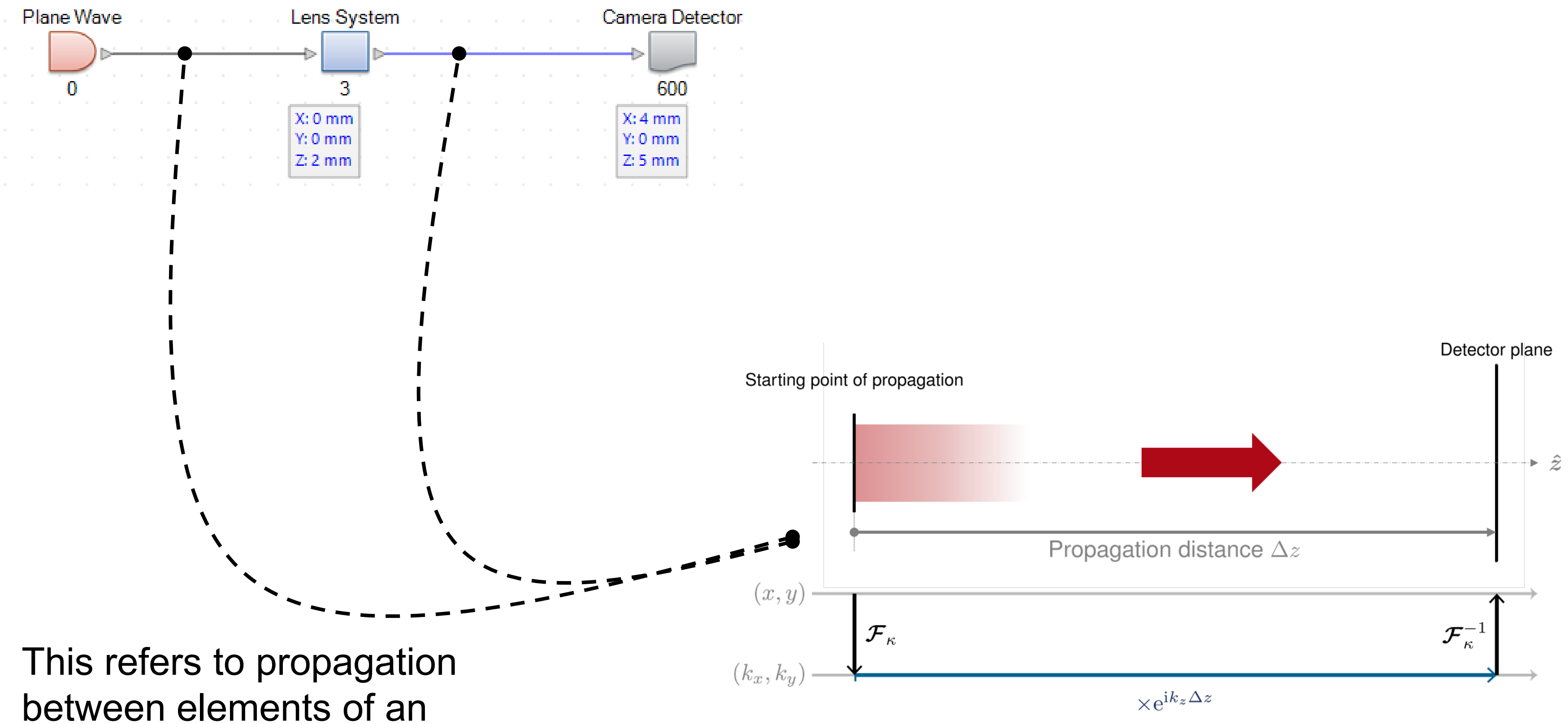

This refers to propagation between elements of an optical system…

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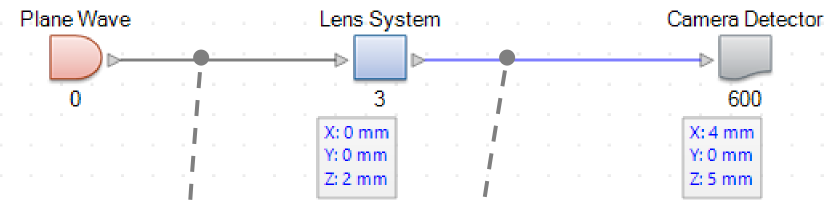

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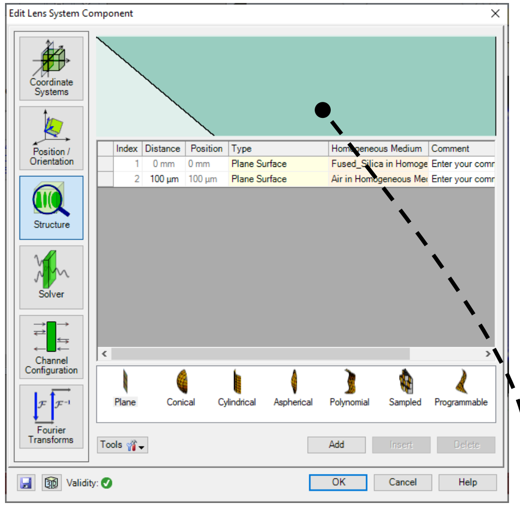
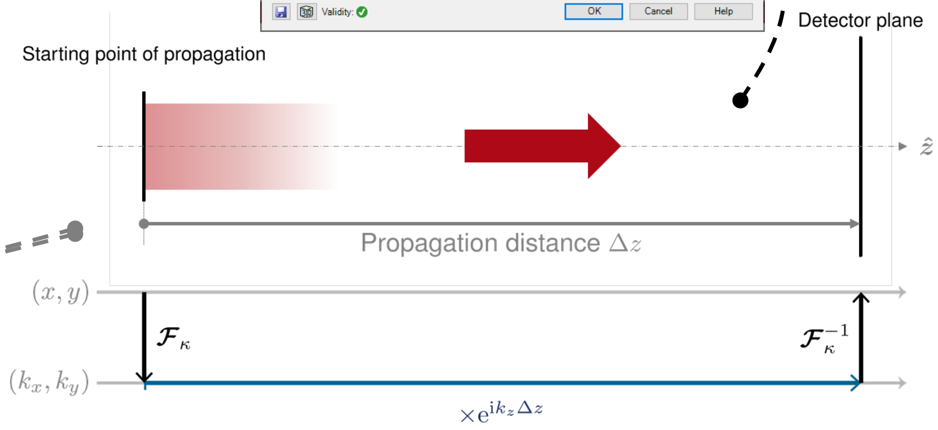


… as well as to internal propagation between surfaces in some cases, like the *Lens System* component



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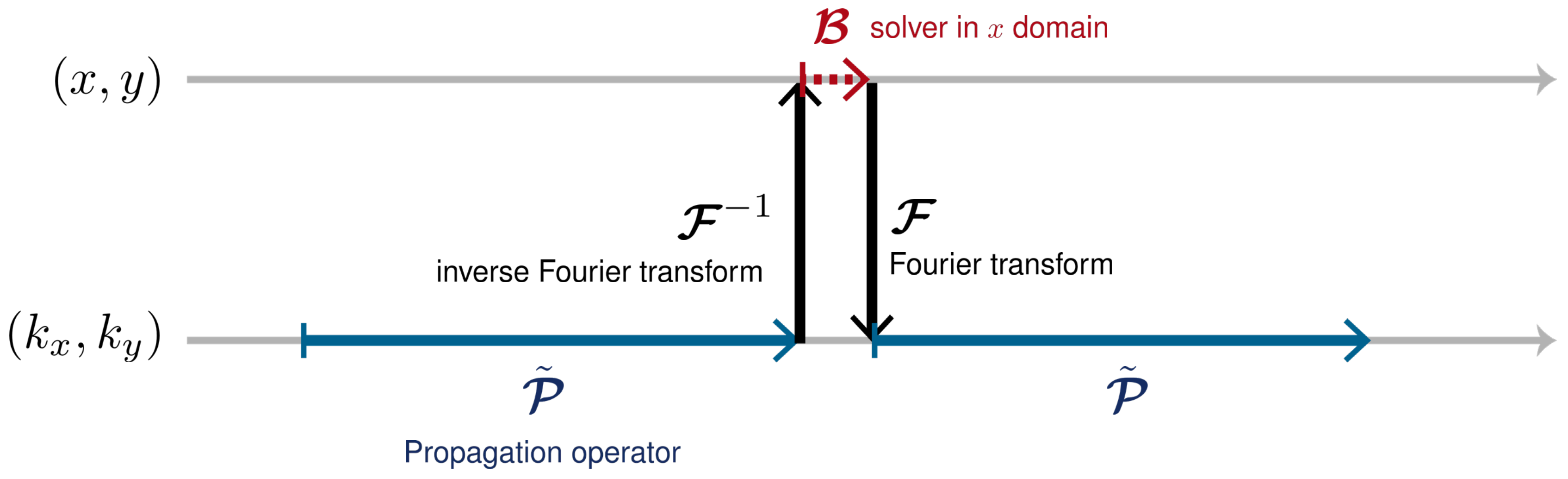
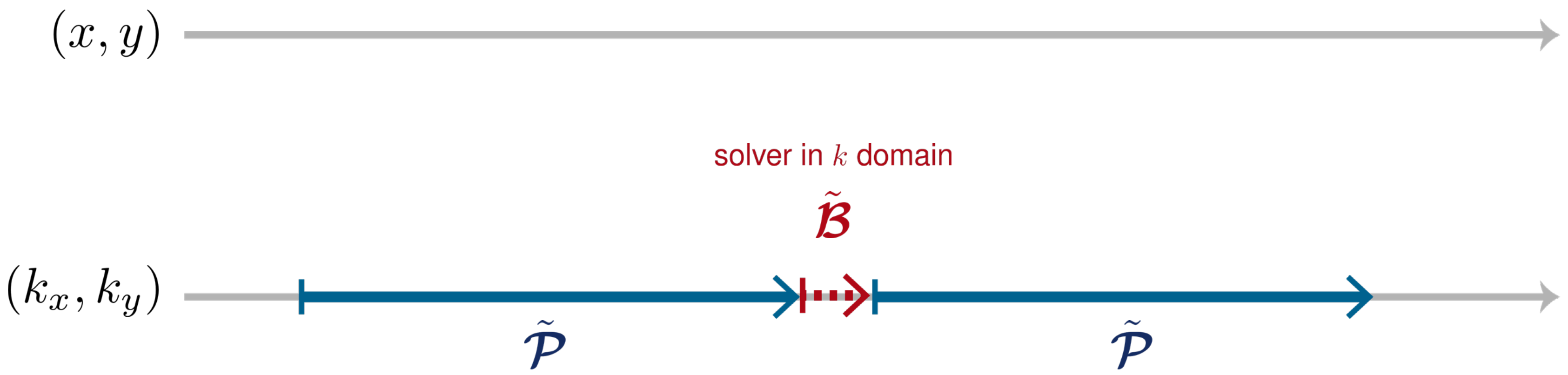
Domain of Application of the Solvers



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



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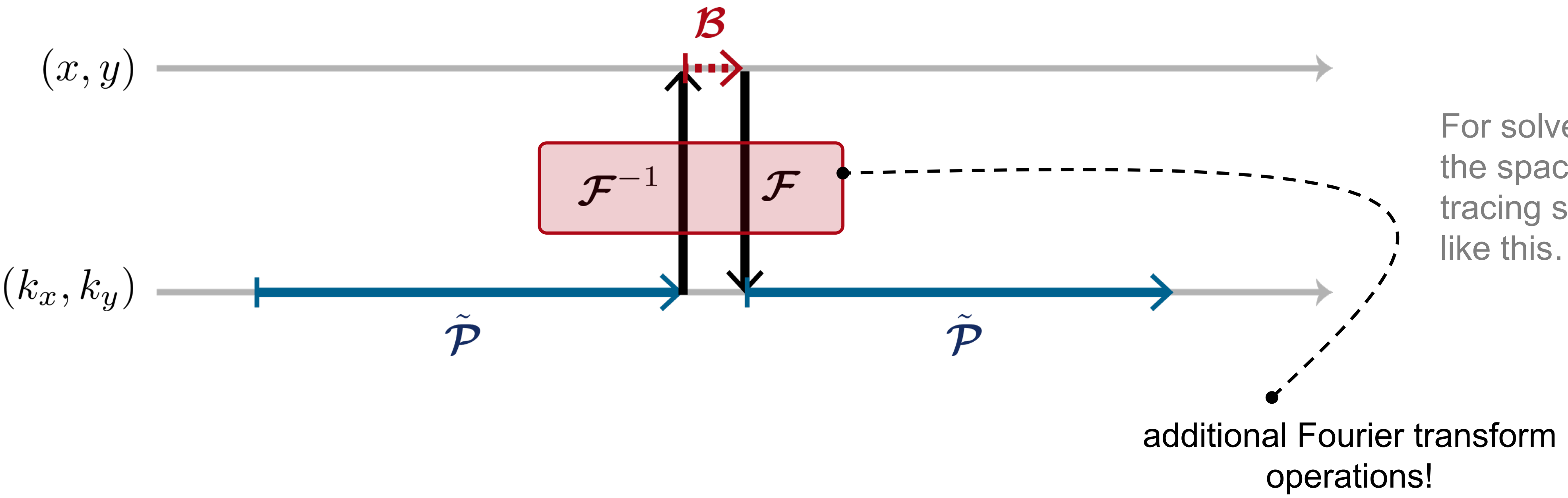

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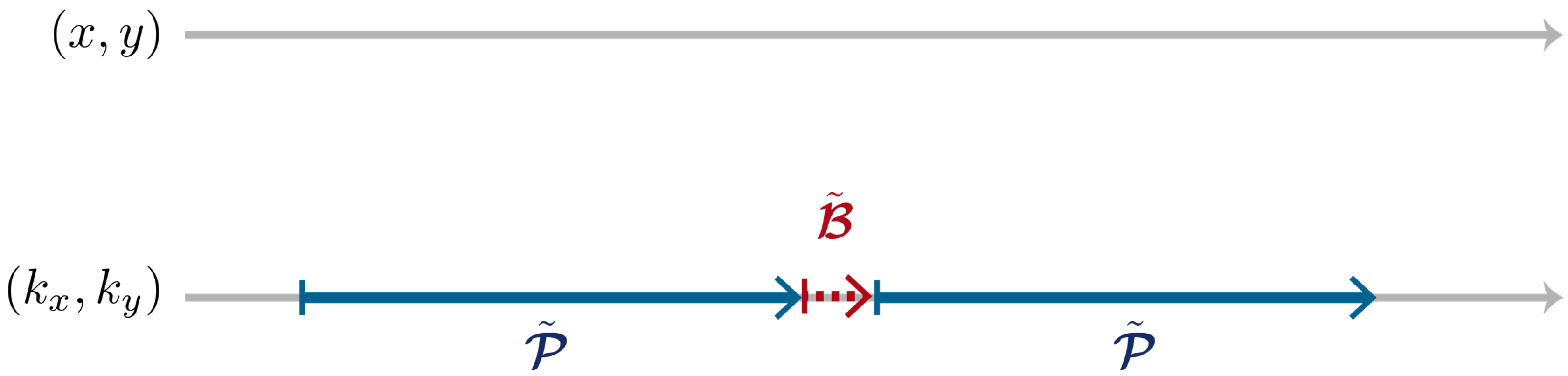
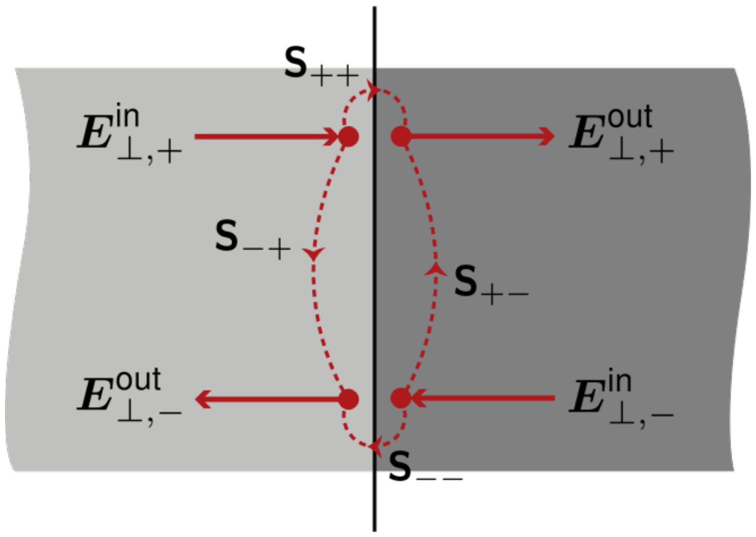


The Special Case of the Plane Surface

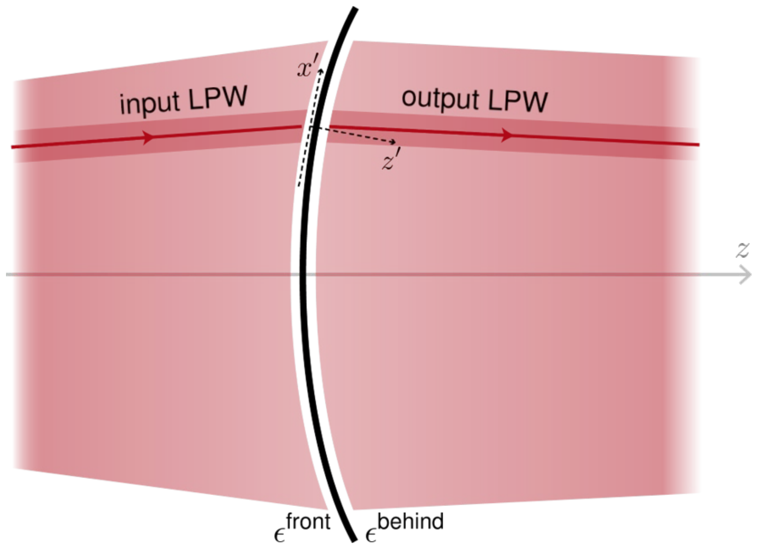
Possible Field Solvers for Plane Surfaces

- As an infinitely extended ideal plane surface ➔ **Fresnel Matrix**
- Solver in **k domain**



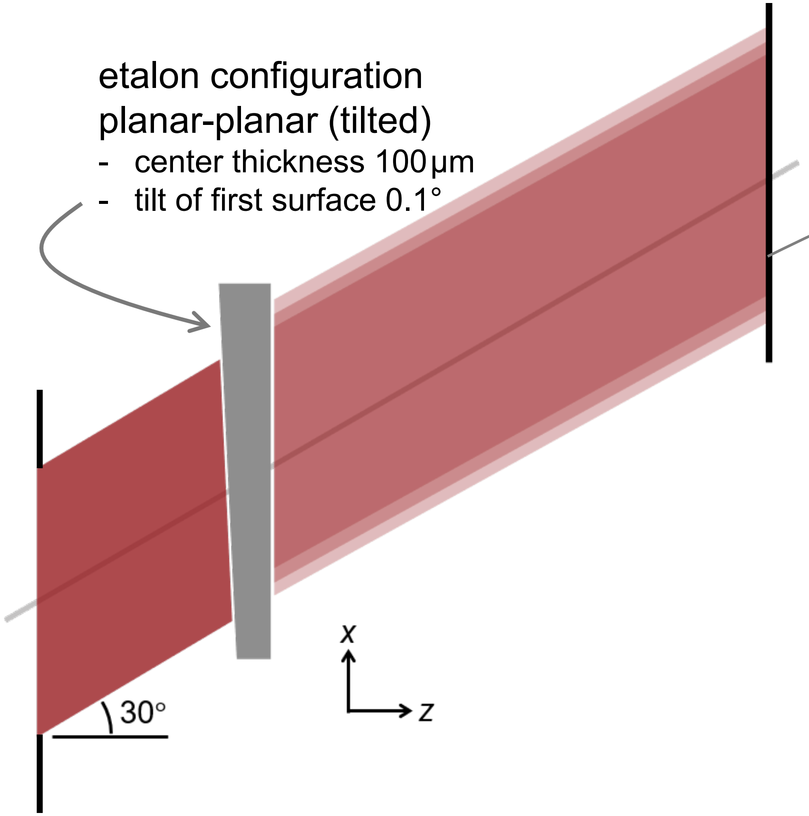
- Implemented in *Plane Surface* component

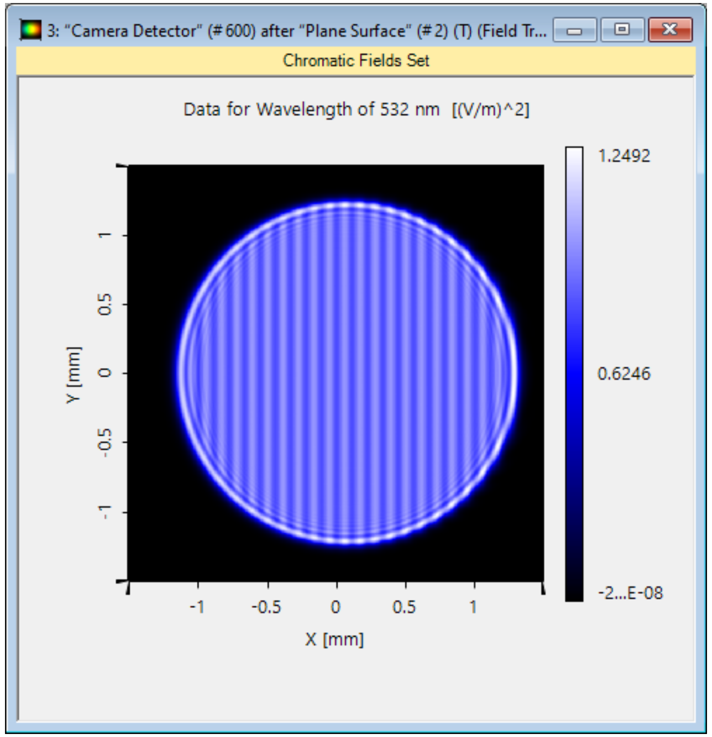
- As a curved surface without curvature ➔ **Local Plane Interface Approximation (LPIA)**
- Solver in **x domain**



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

Modeling an Etalon with Plane Interfaces…

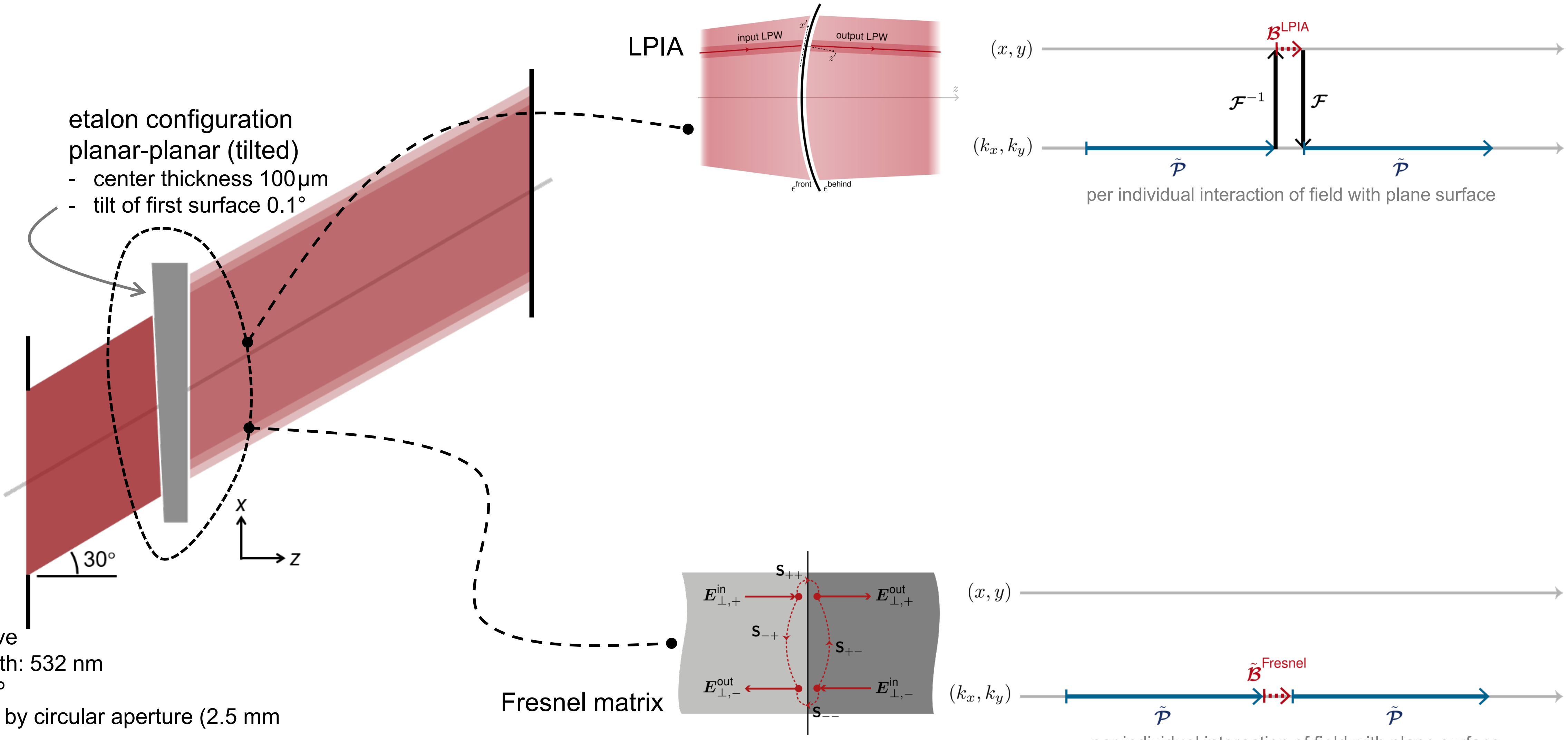




source
- plane wave
- wavelength: 532 nm
- angle: 30°
- truncated by circular aperture (2.5 mm diameter)

see the full Application Use Case:
"Modeling of Etalon with Planar or Curved Surfaces"

… Two Ways



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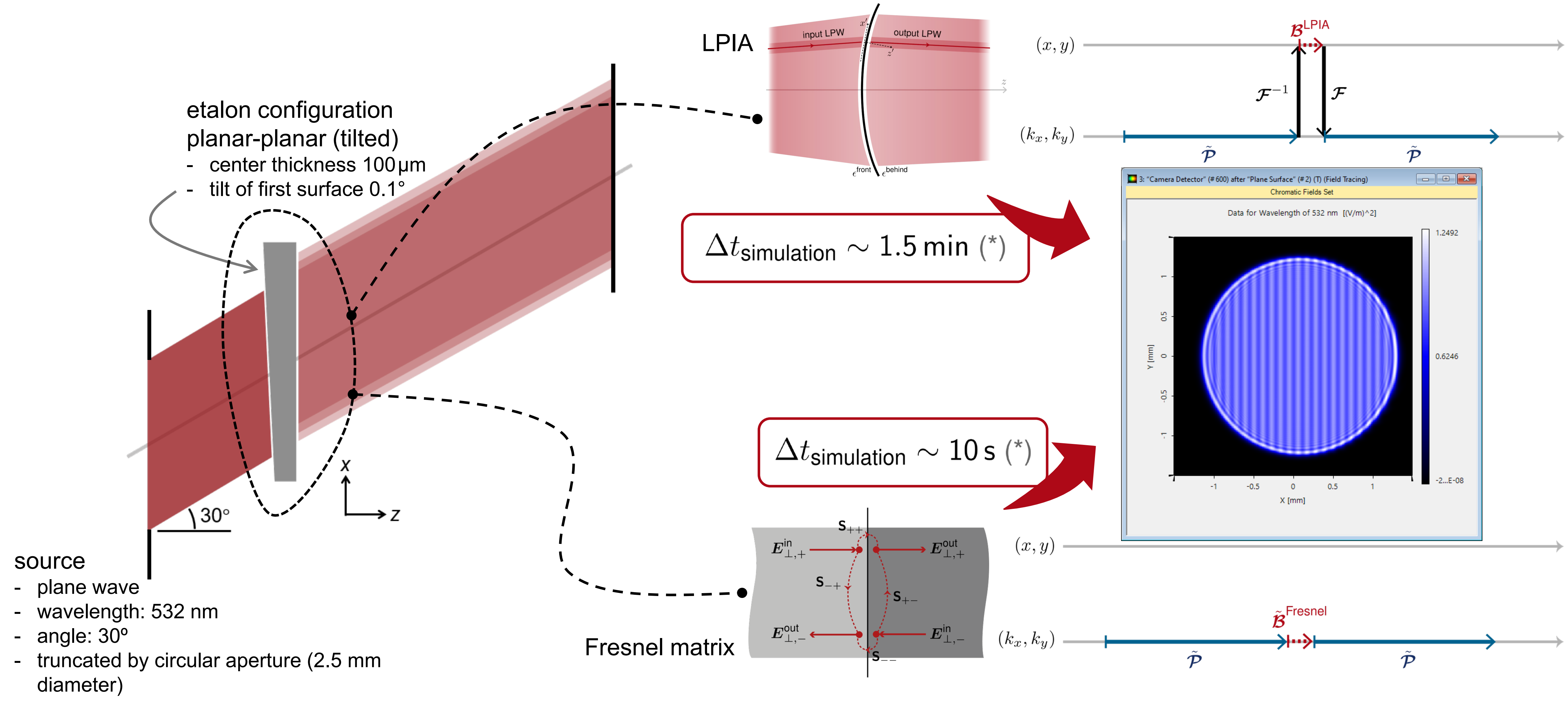
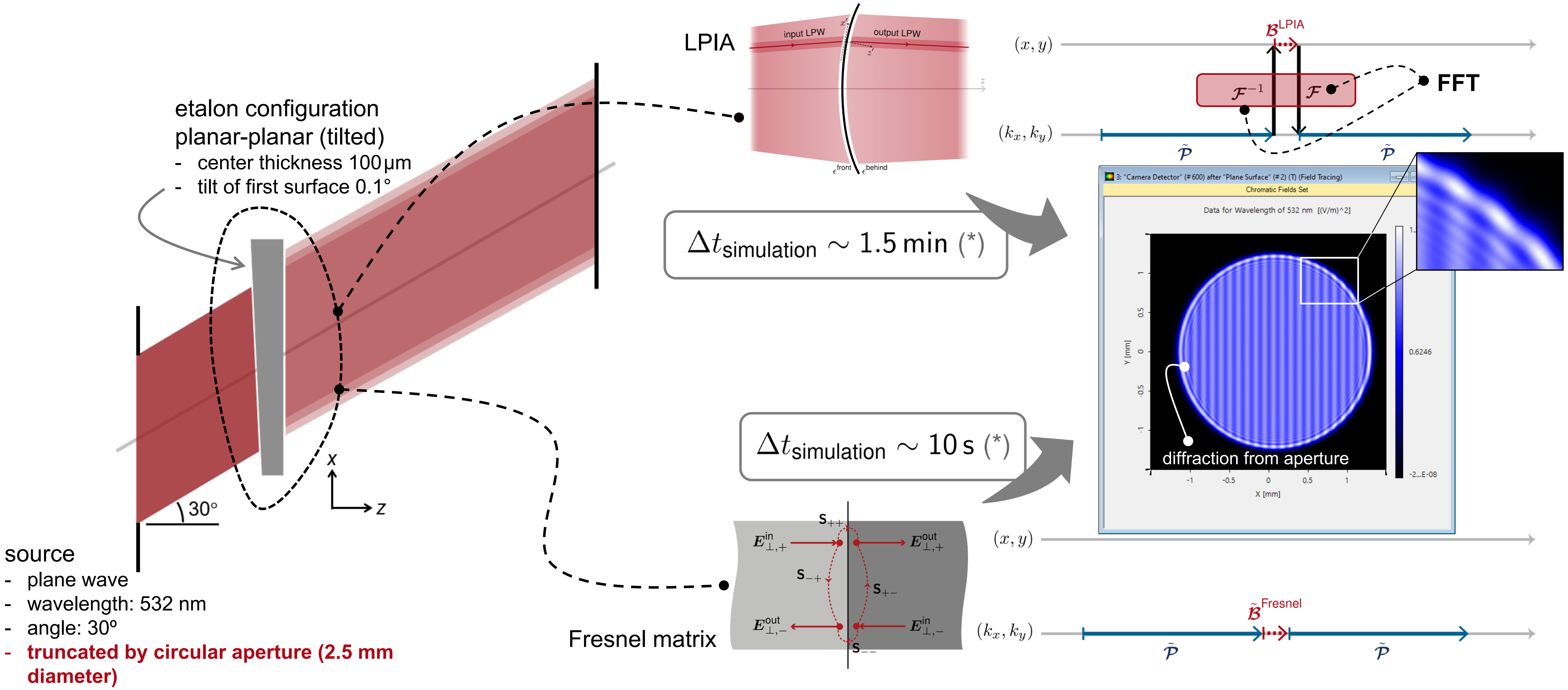


(*) Approximate simulation times on a PC with the following technical specs: processor Intel(R) Core(TM) i7-7700HQ CPU @ 2.80GHz and 32 GB RAM

The Importance of the Fourier Transform



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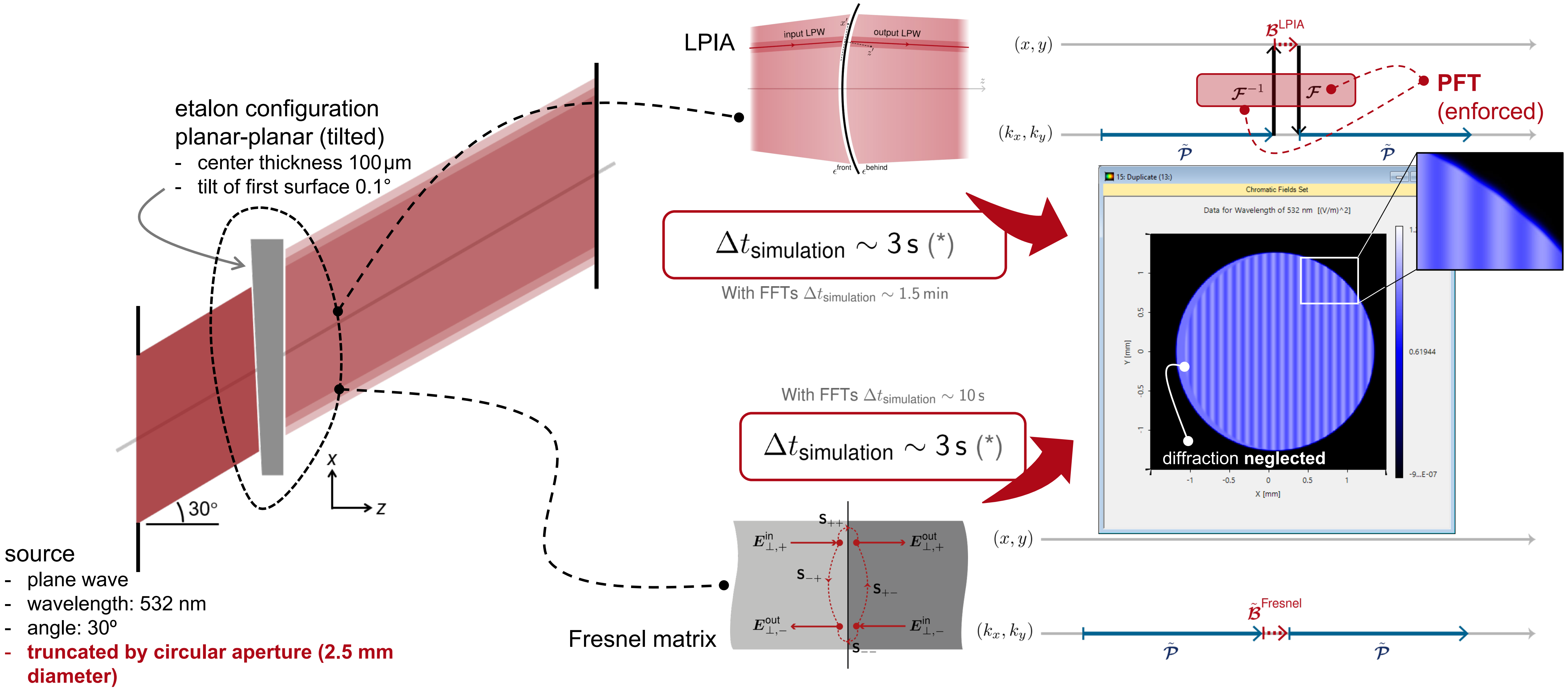

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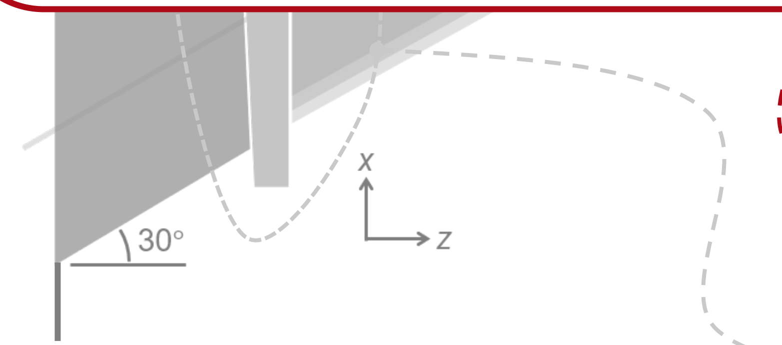
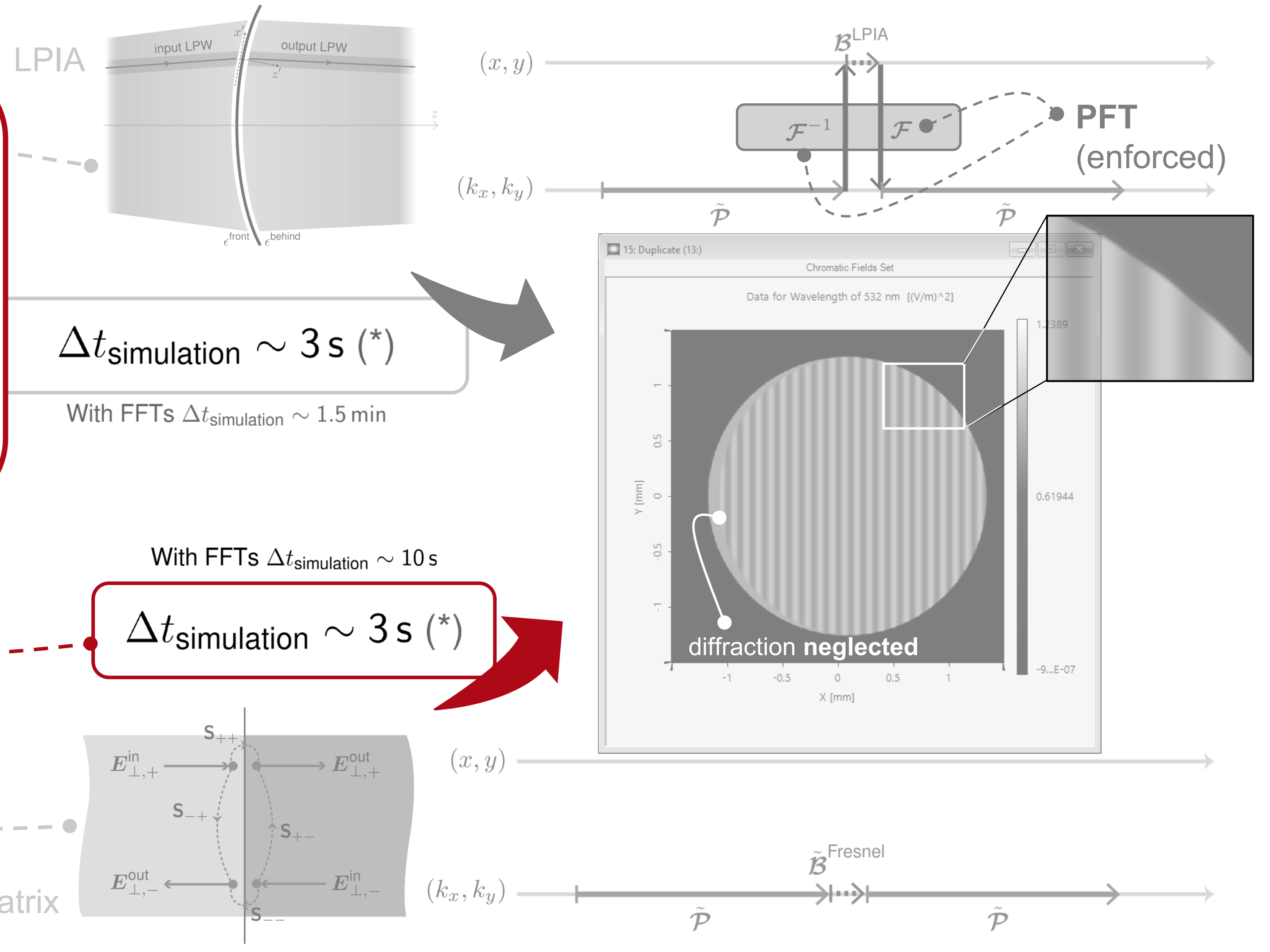
The Importance of the Fourier Transform

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*"]

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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

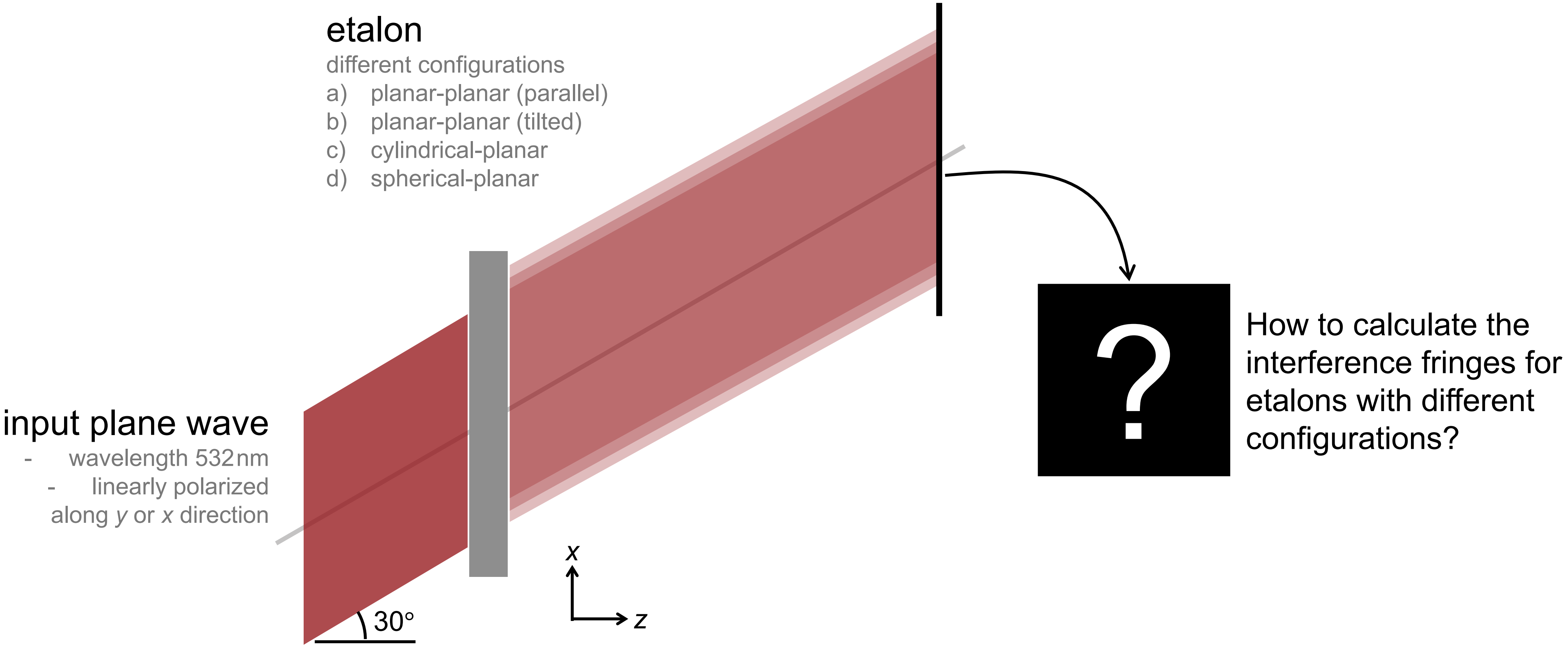
LPIA:

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

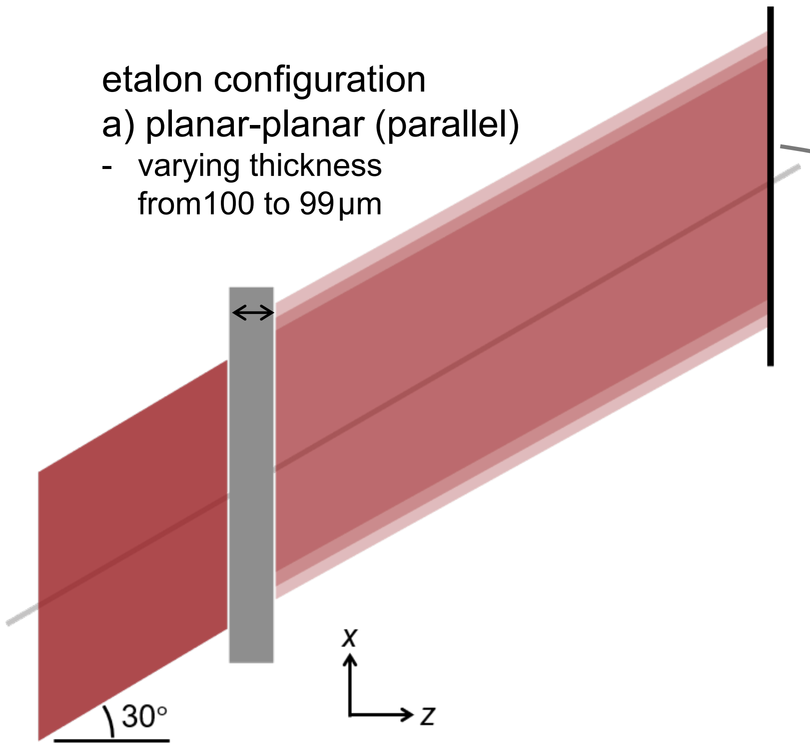
Modeling of Etalon with Planar or Curved Surfaces

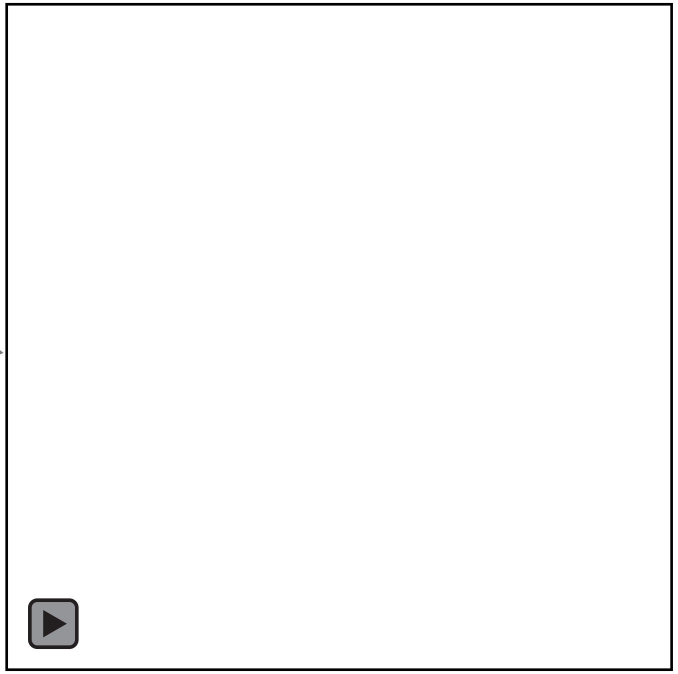
see the full Application Use Case

Modeling Task



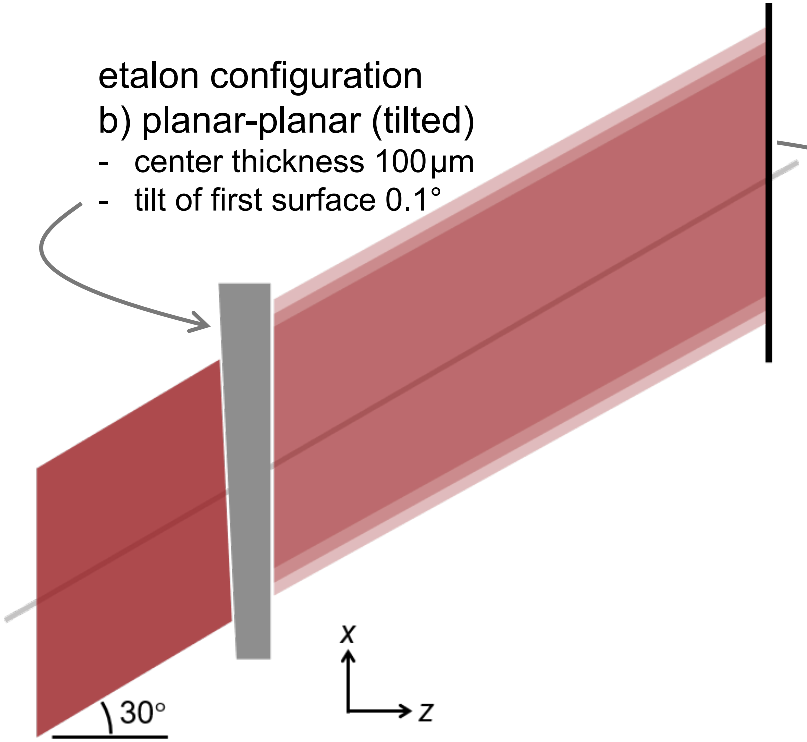
Parallel Planar-Planar Surfaces

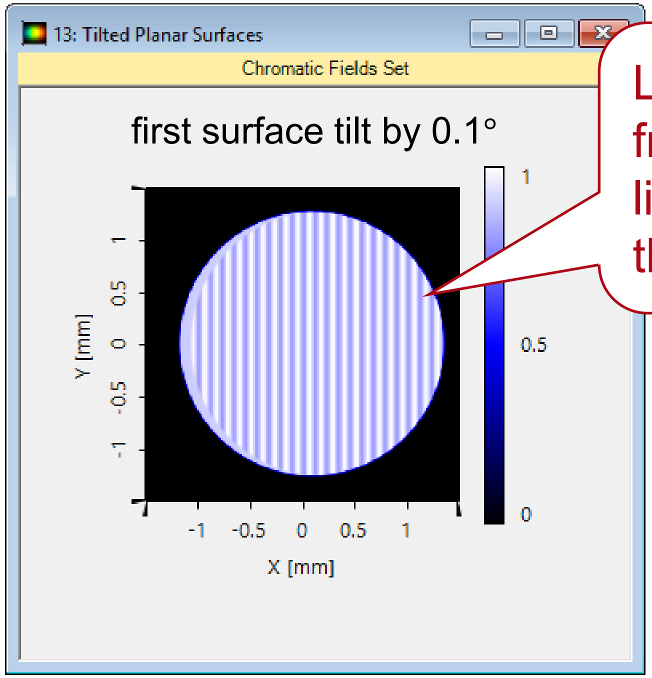




Constructive and destructive interference alternatively shows up when the thickness of etalon varies.

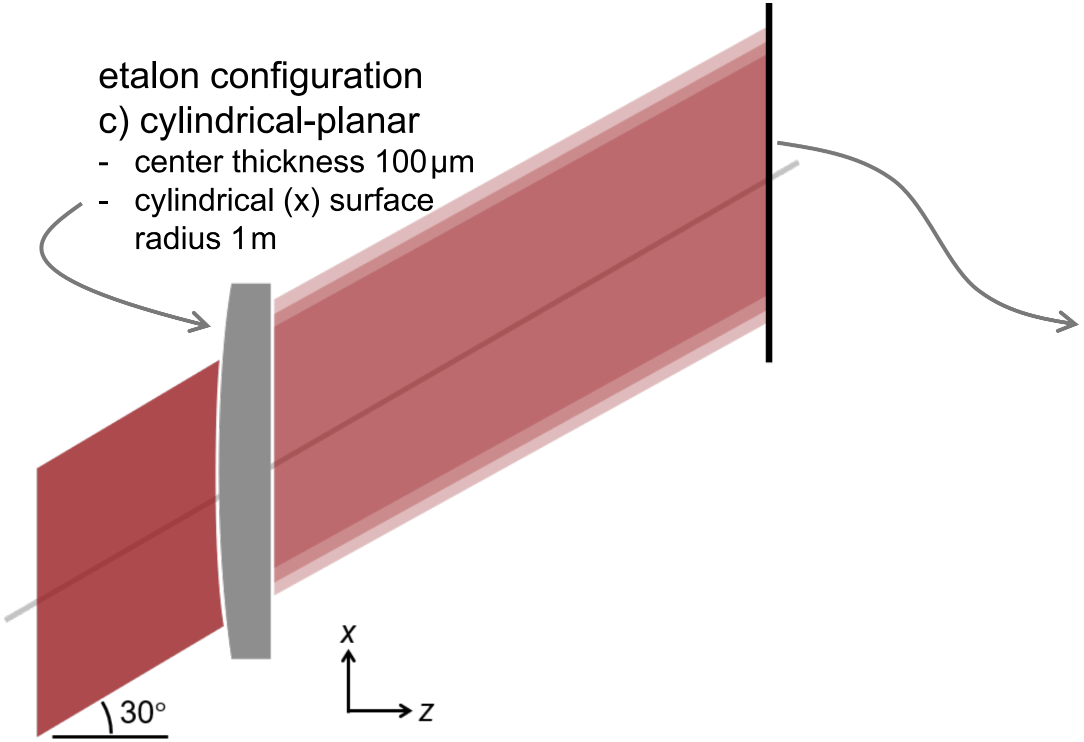
Tilted Planar-Planar Surfaces

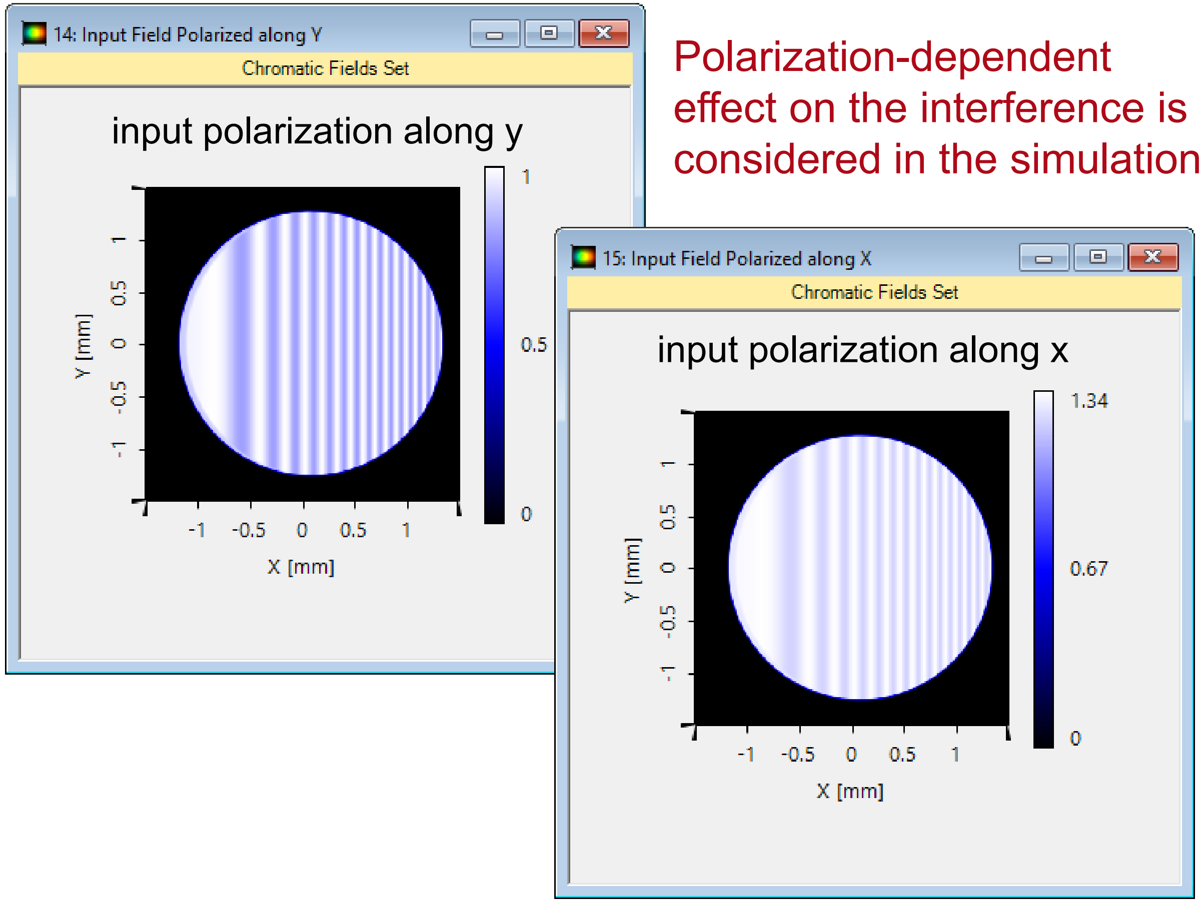




Linear interference fringes appear due to linear change of etalon thickness.

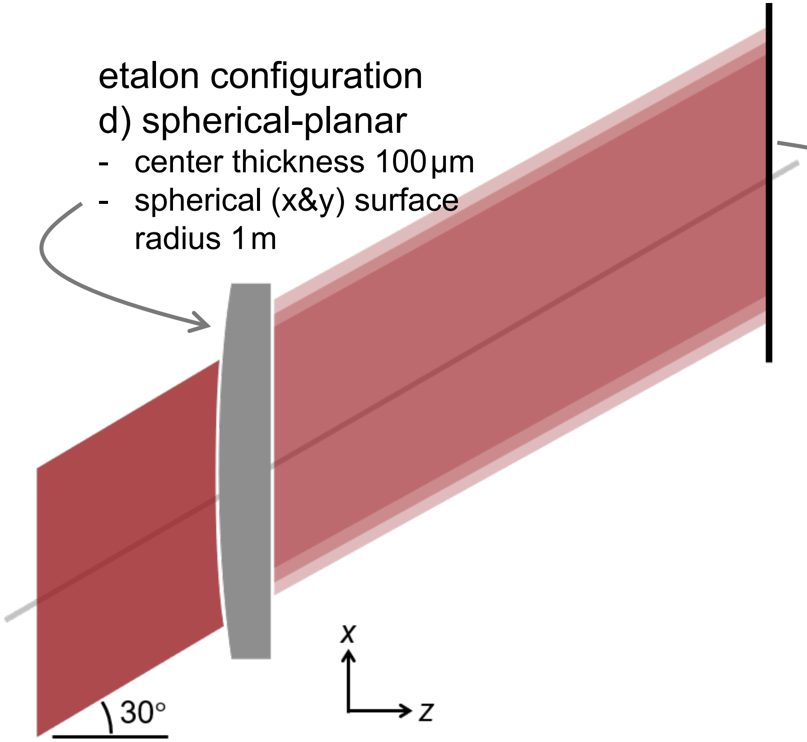
Cylindrical-Planar Surfaces

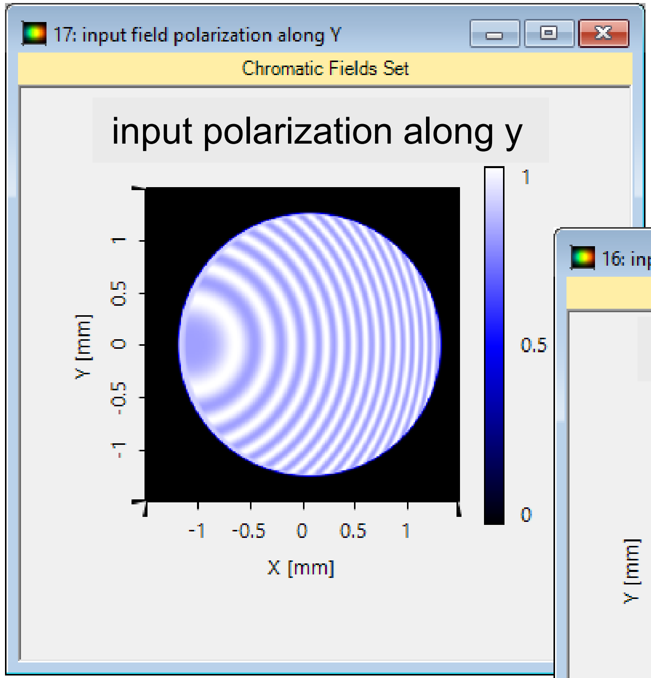


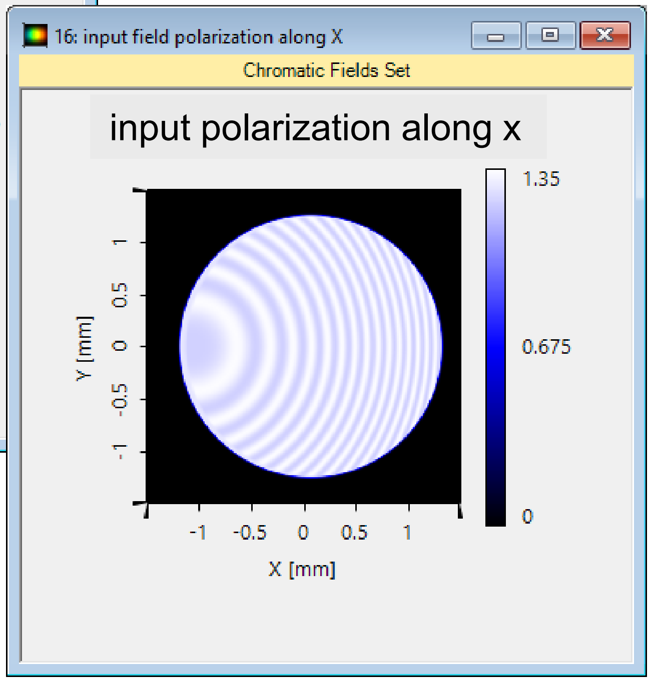


Polarization-dependent effect on the interference is considered in the simulation.

Spherical-Planar Surfaces

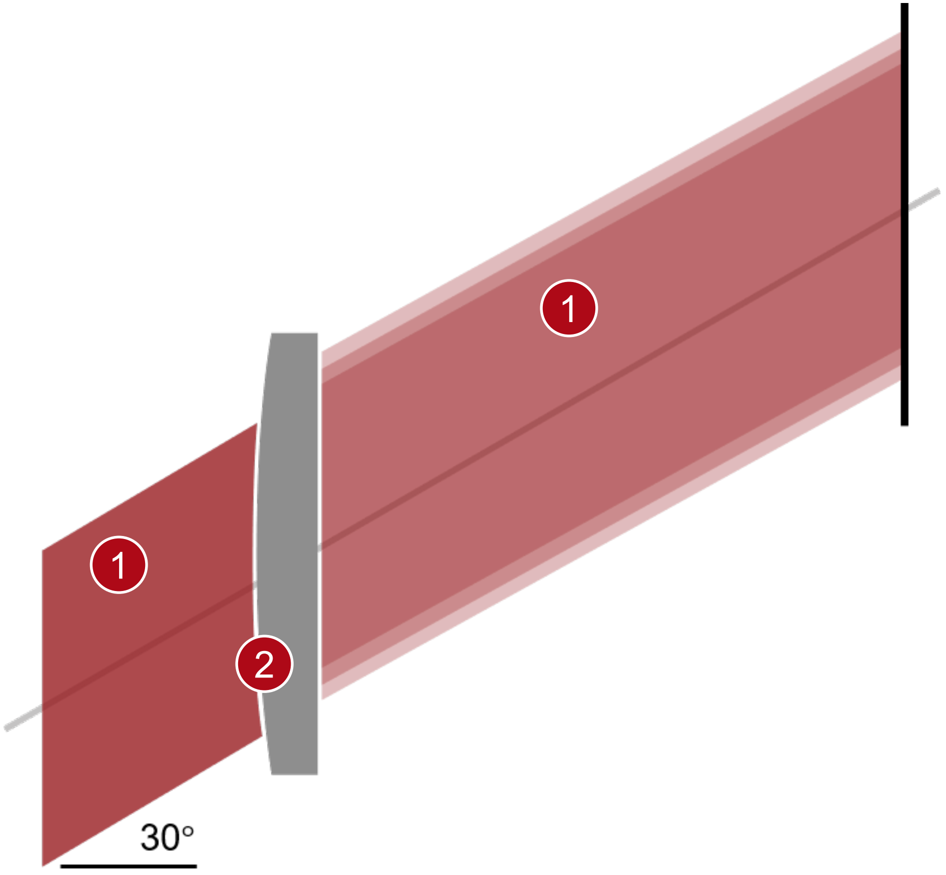


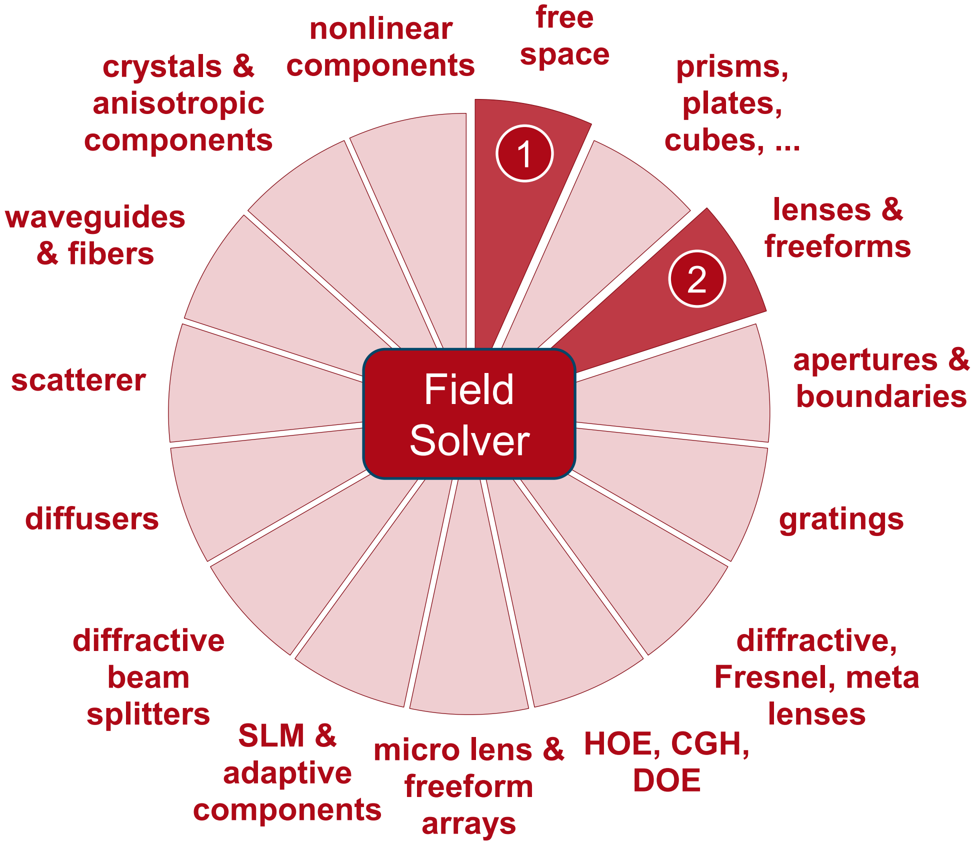




Non-sequential field tracing simulation of etalons allows the consideration of arbitrary surface types.

VirtualLab Fusion Technologies

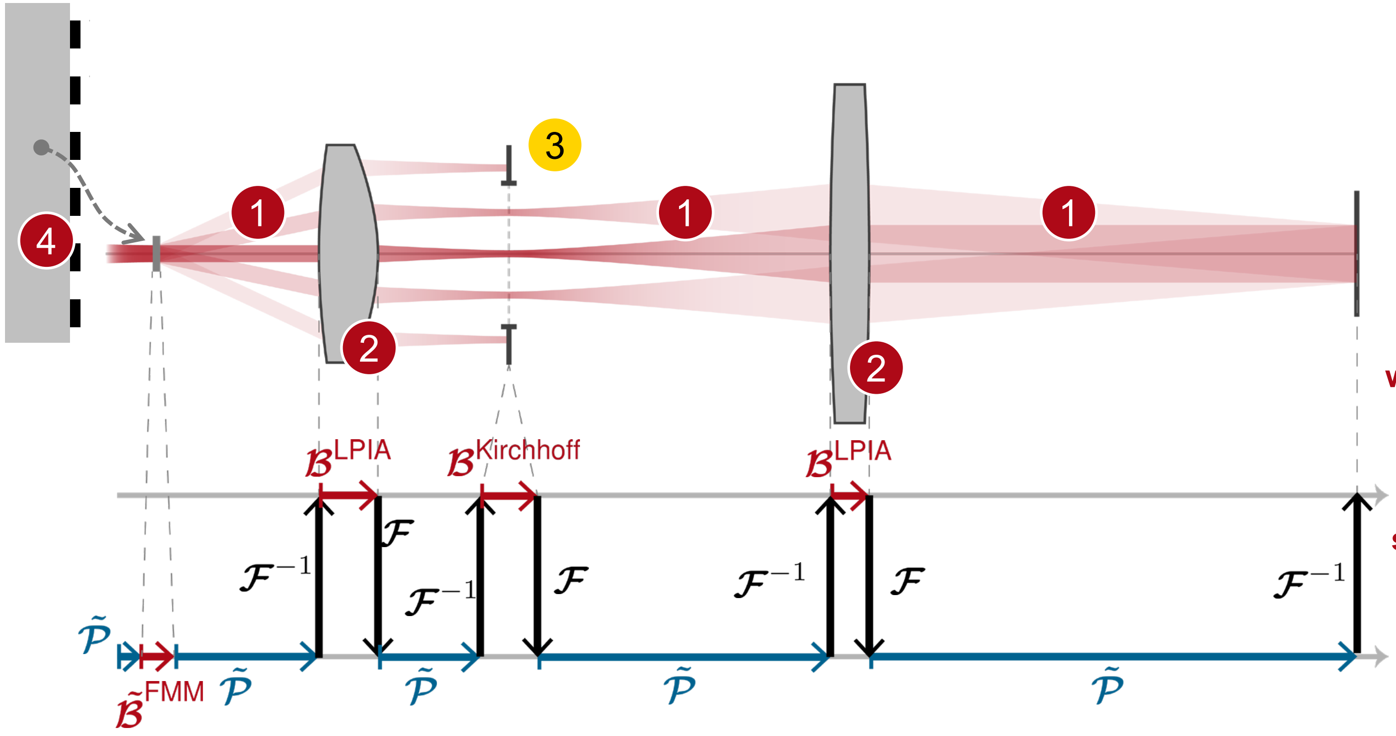


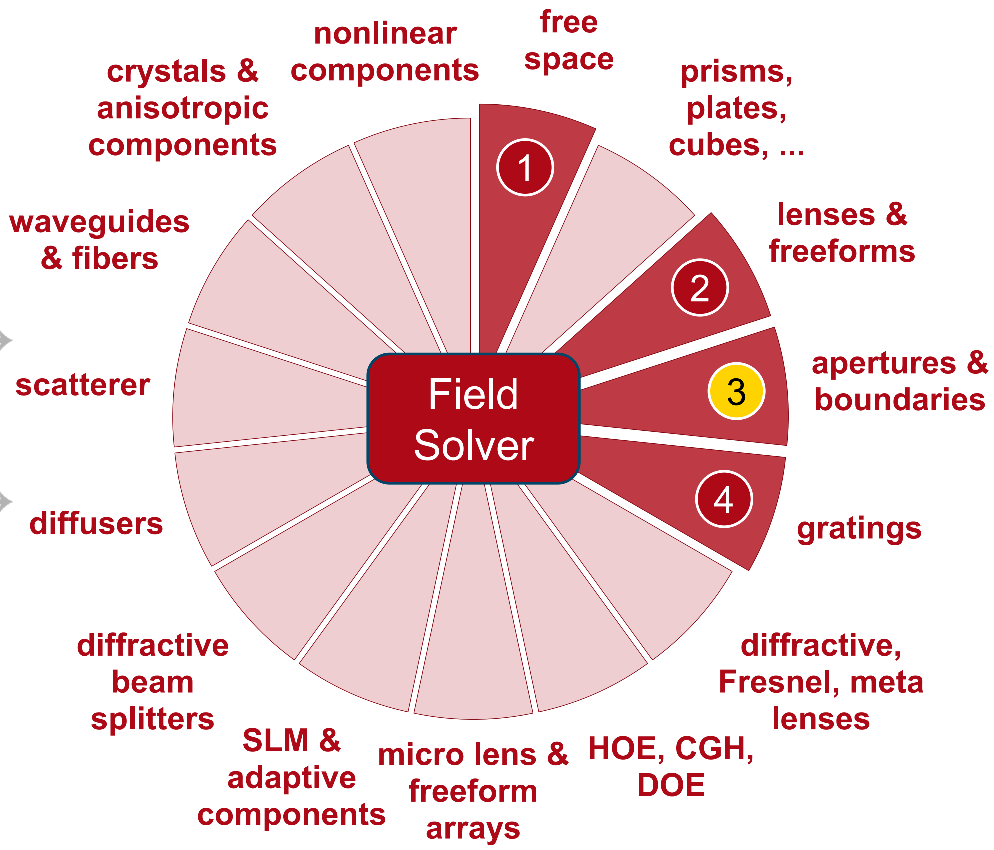


Part 3

The Fourier Transform

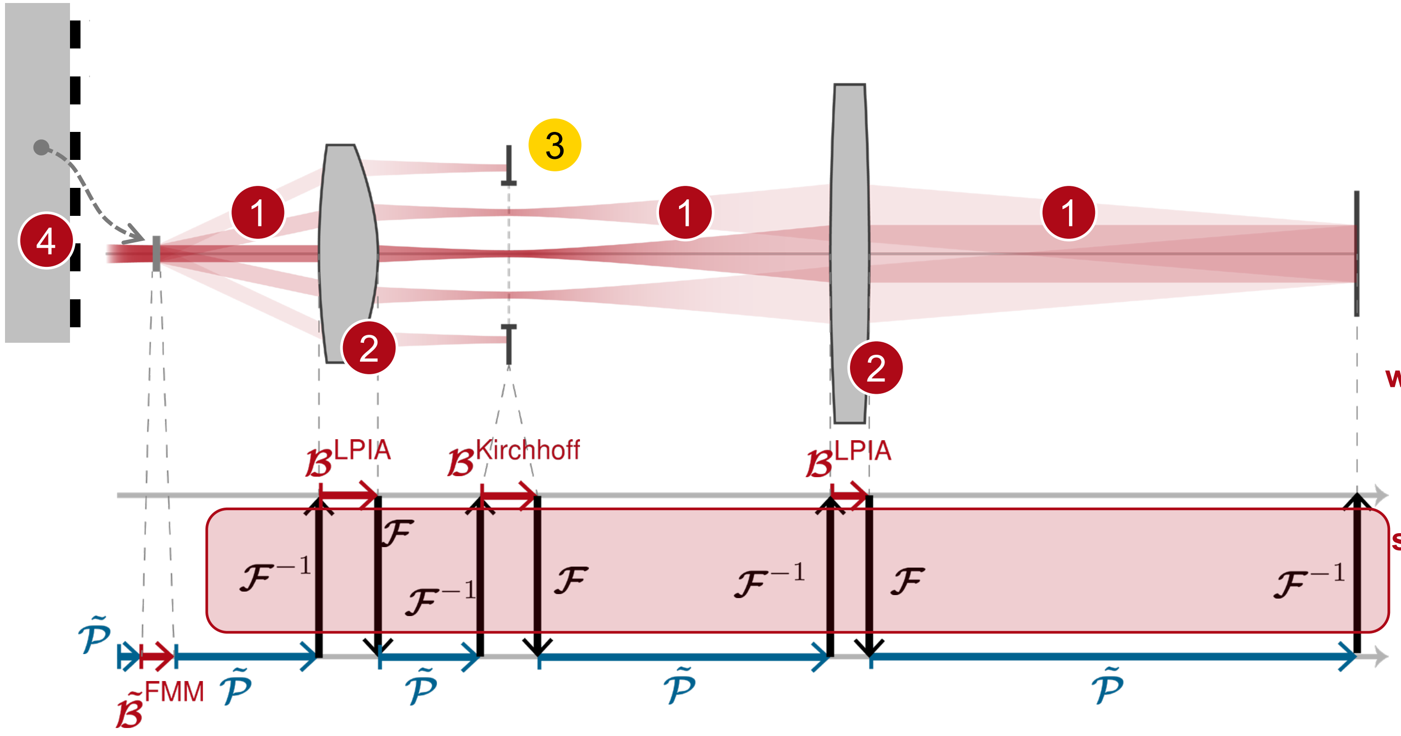
Field Tracing Diagram

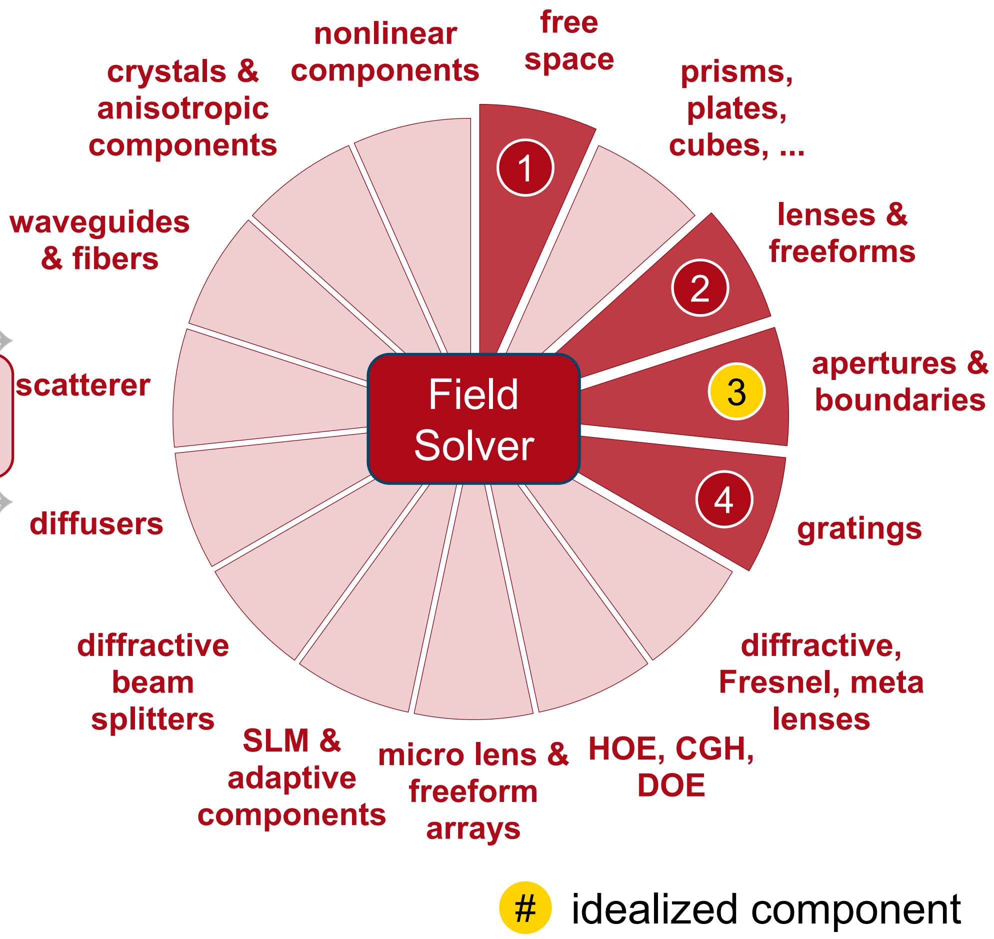




idealized component

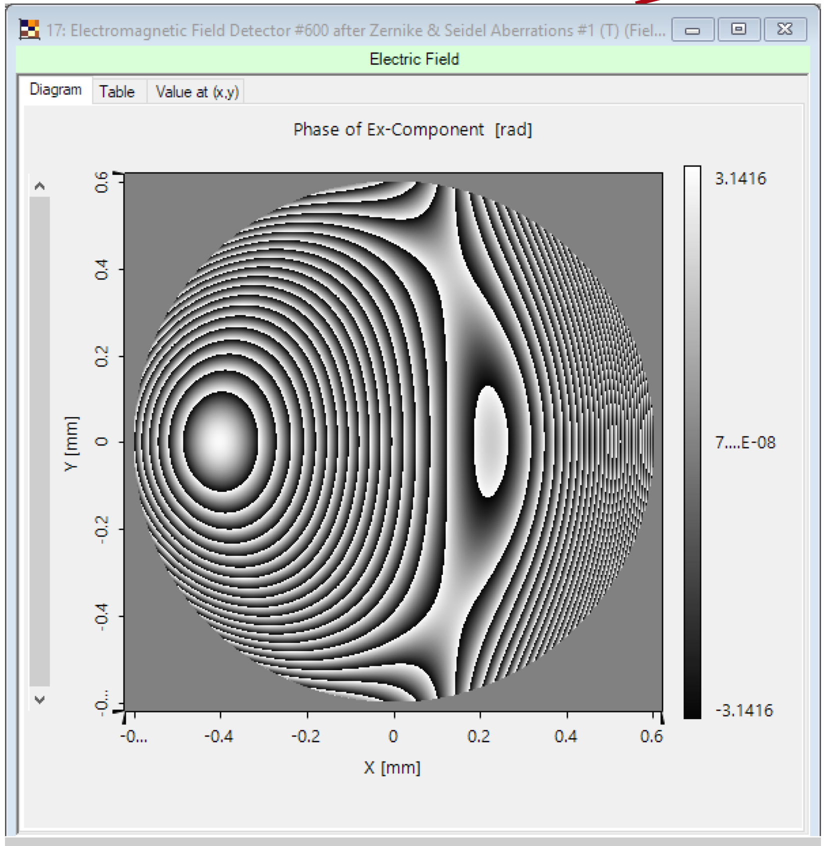
Field Tracing Diagram

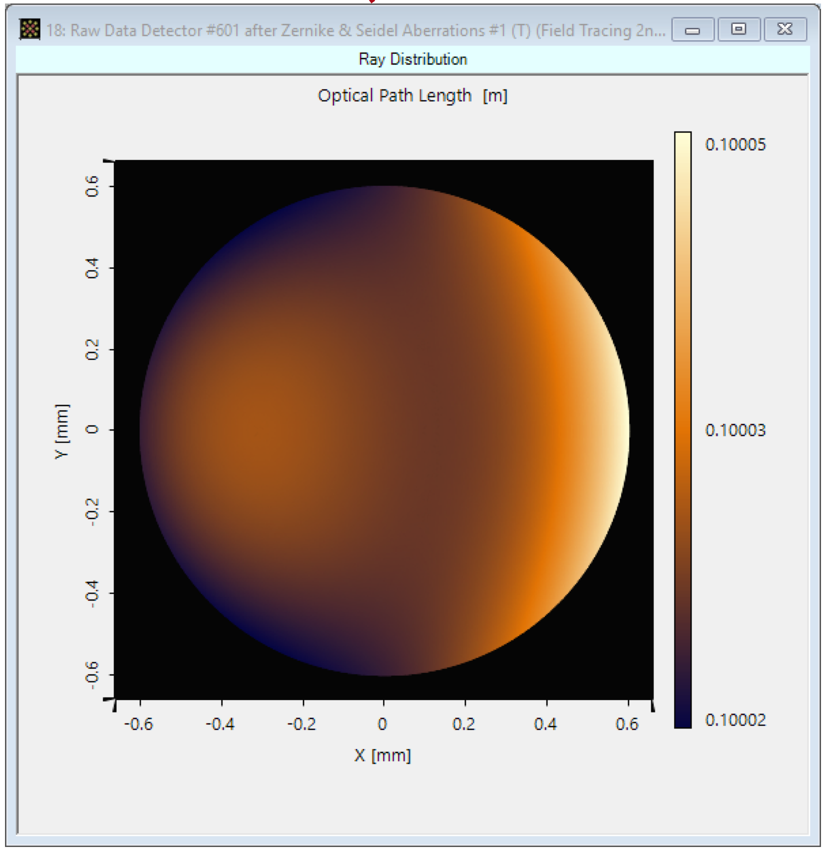




Fourier-Transforming an Arbitrary Field

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





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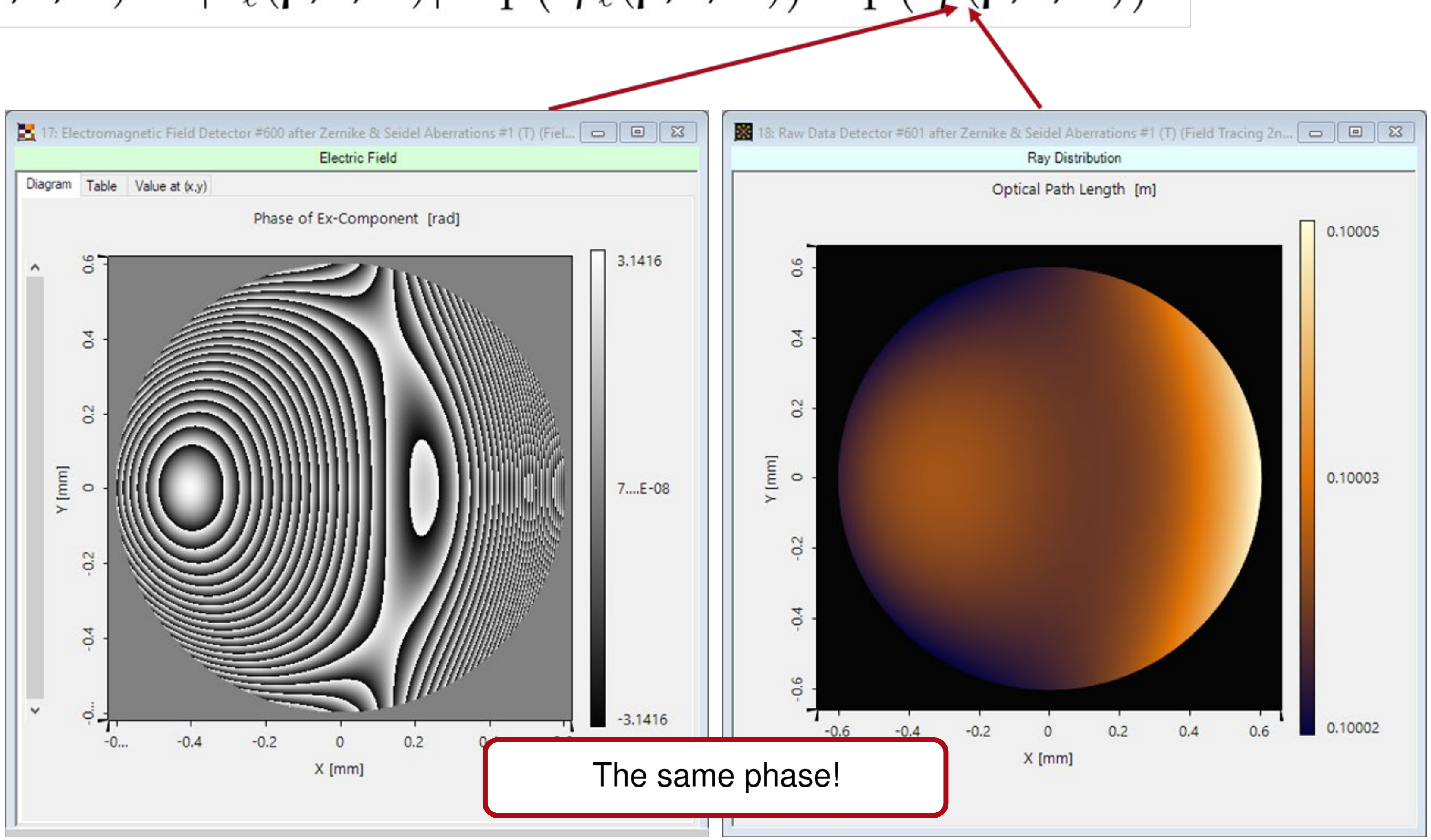

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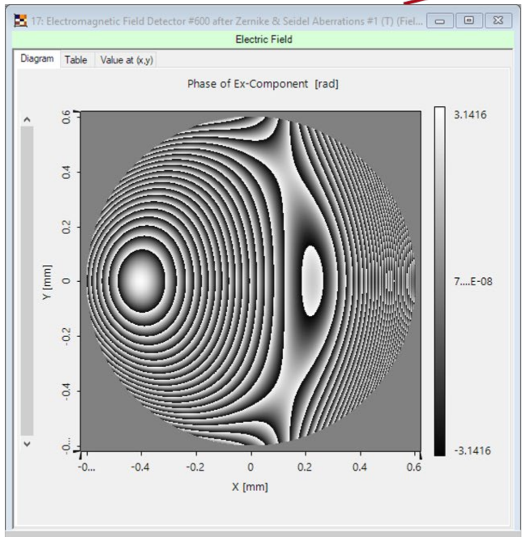

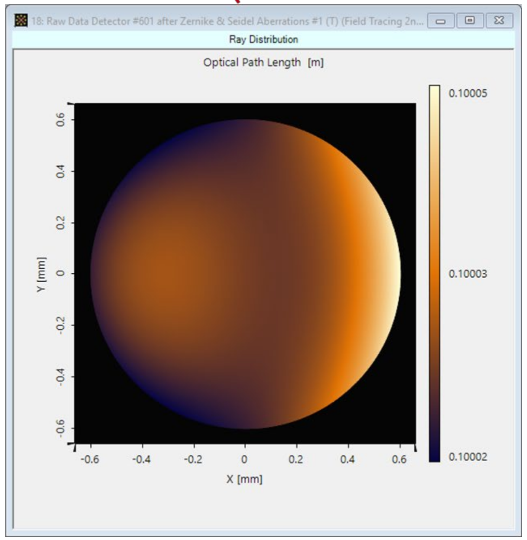

Fourier-Transforming an Arbitrary Field

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

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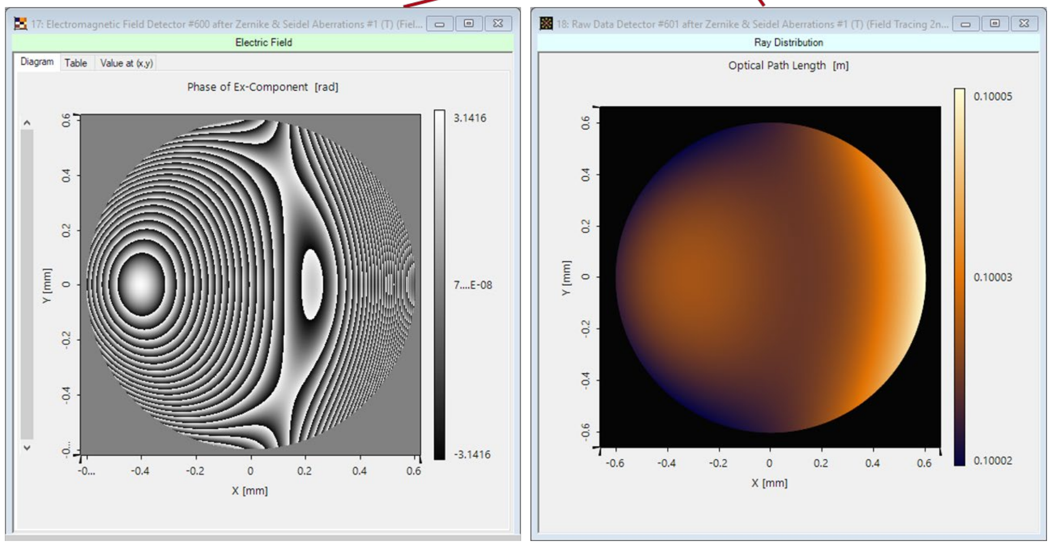

Fourier-Transforming an Arbitrary Field

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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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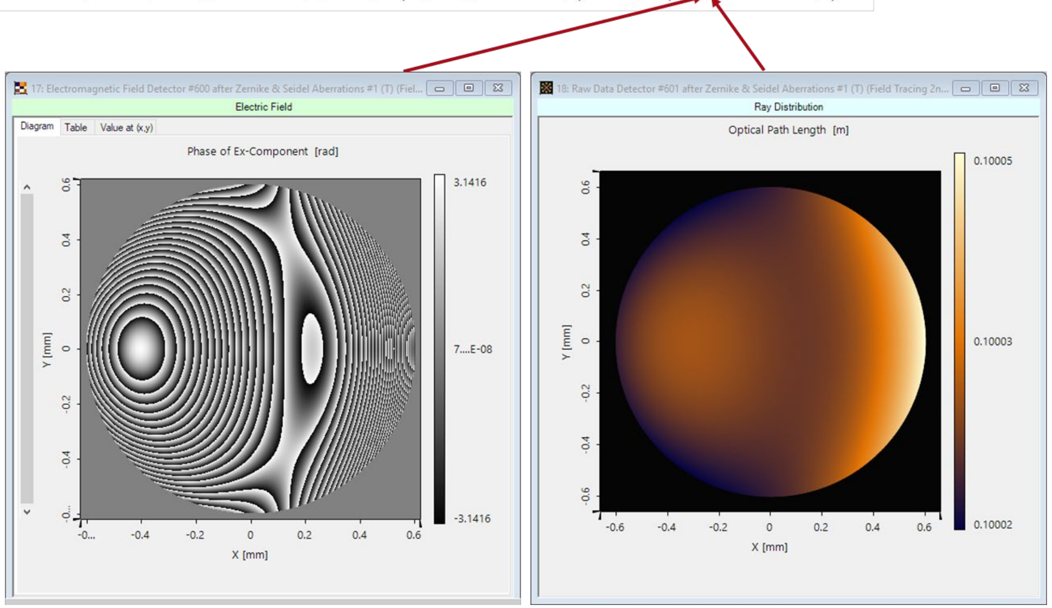

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This already means **pointwise** operation, right? Job done! ✓

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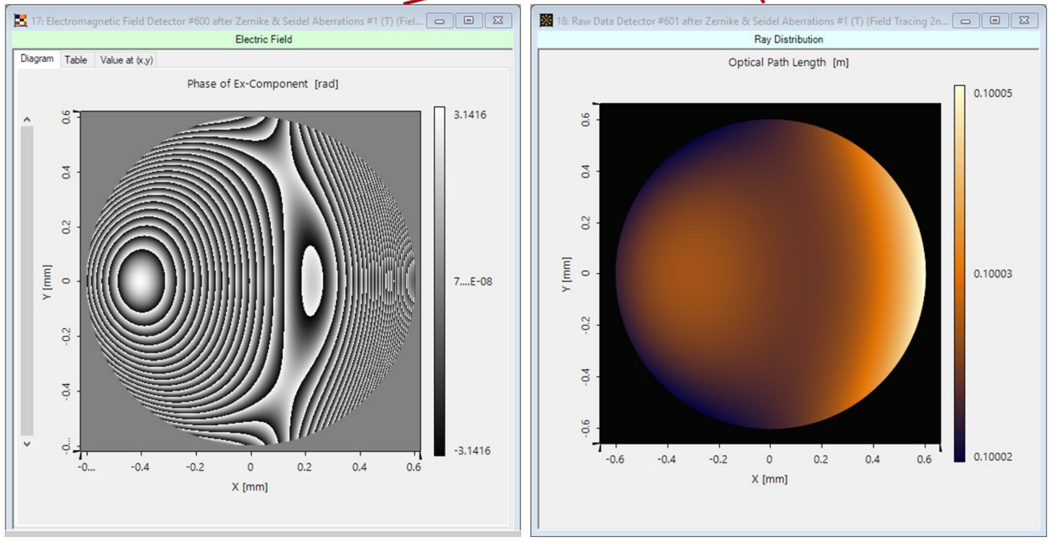

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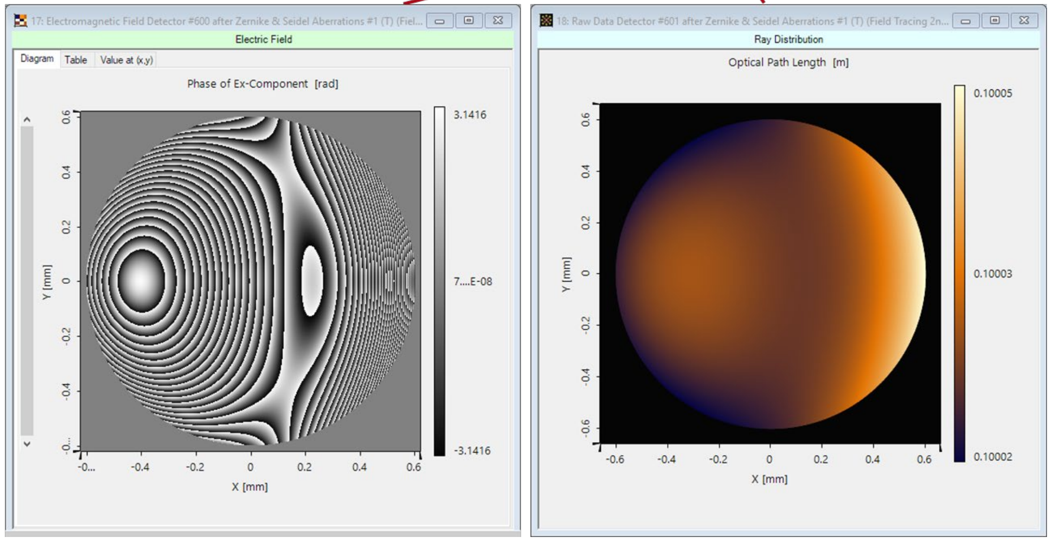

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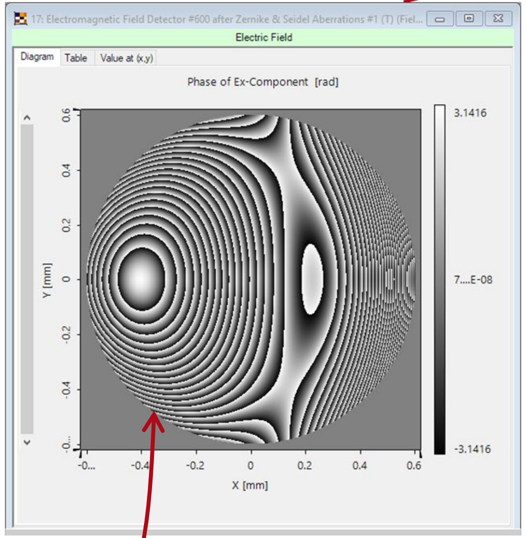
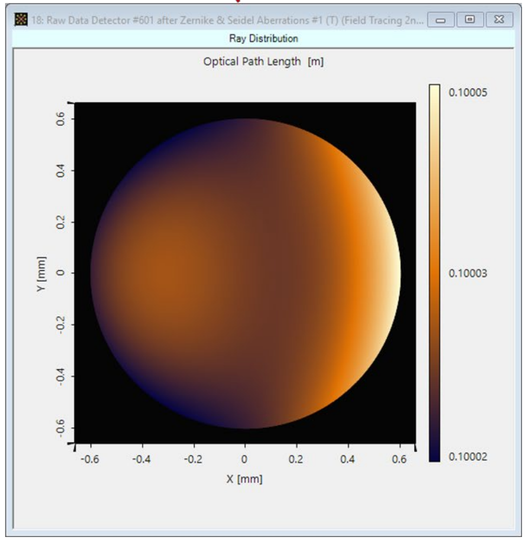


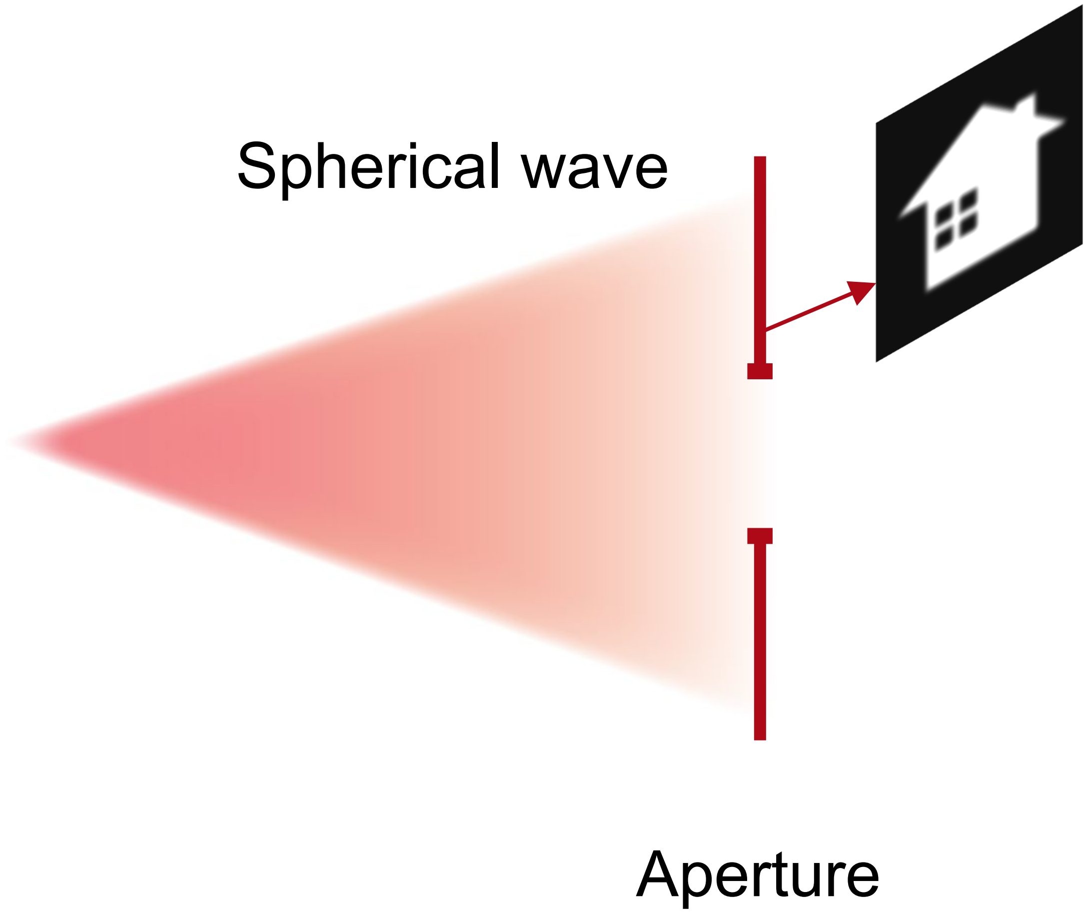


The FFT requires fulfilment of the Nyquist-Shannon sampling theorem $\Rightarrow$ wrapped phase **must** be well resolved!

$\Downarrow$

Huge sample number N

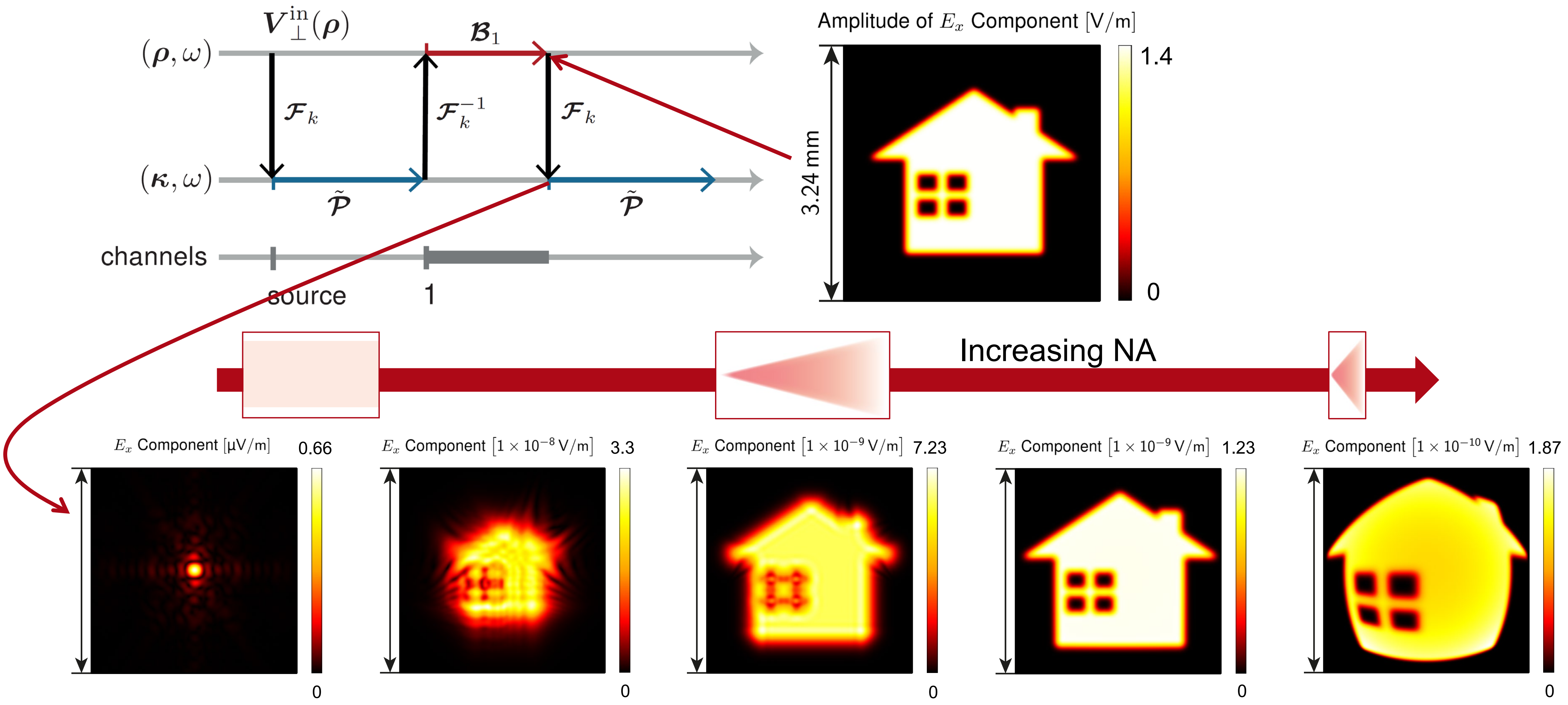
Modeling the Propagation Through an Aperture



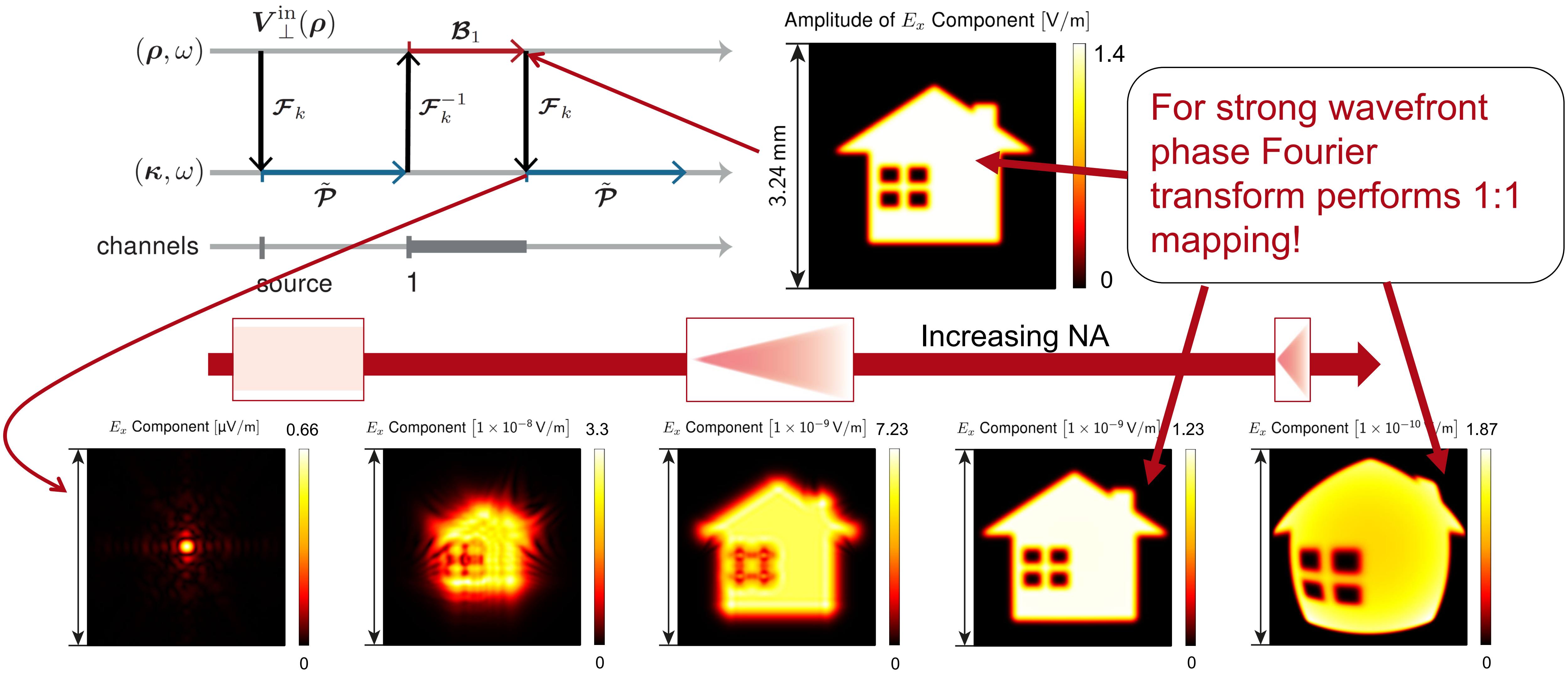
Field after the aperture

Amplitude of E_x Component $[\mathrm{V/m}]$

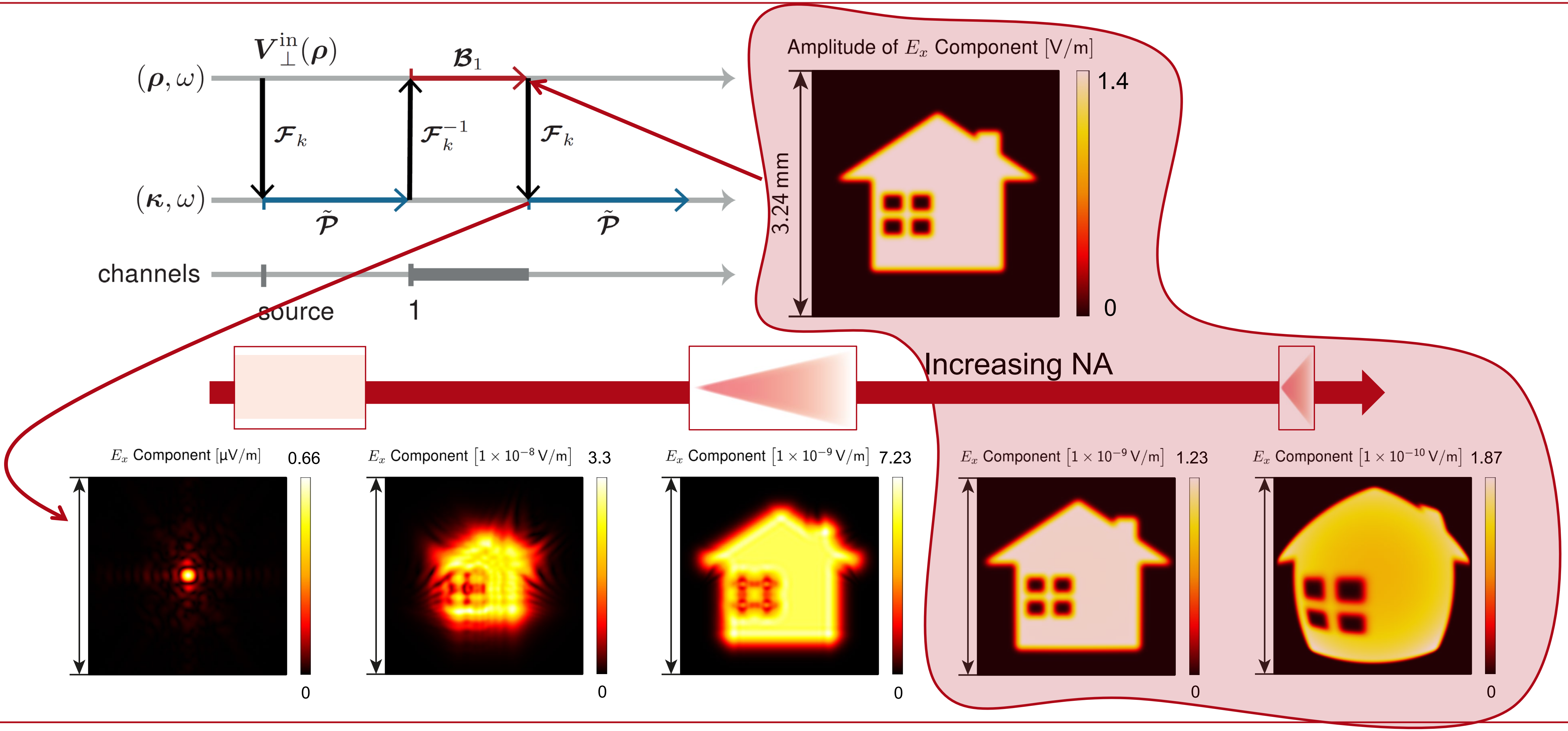
Results of Fourier Transform



Results of Fourier Transform



Results of Fourier Transform



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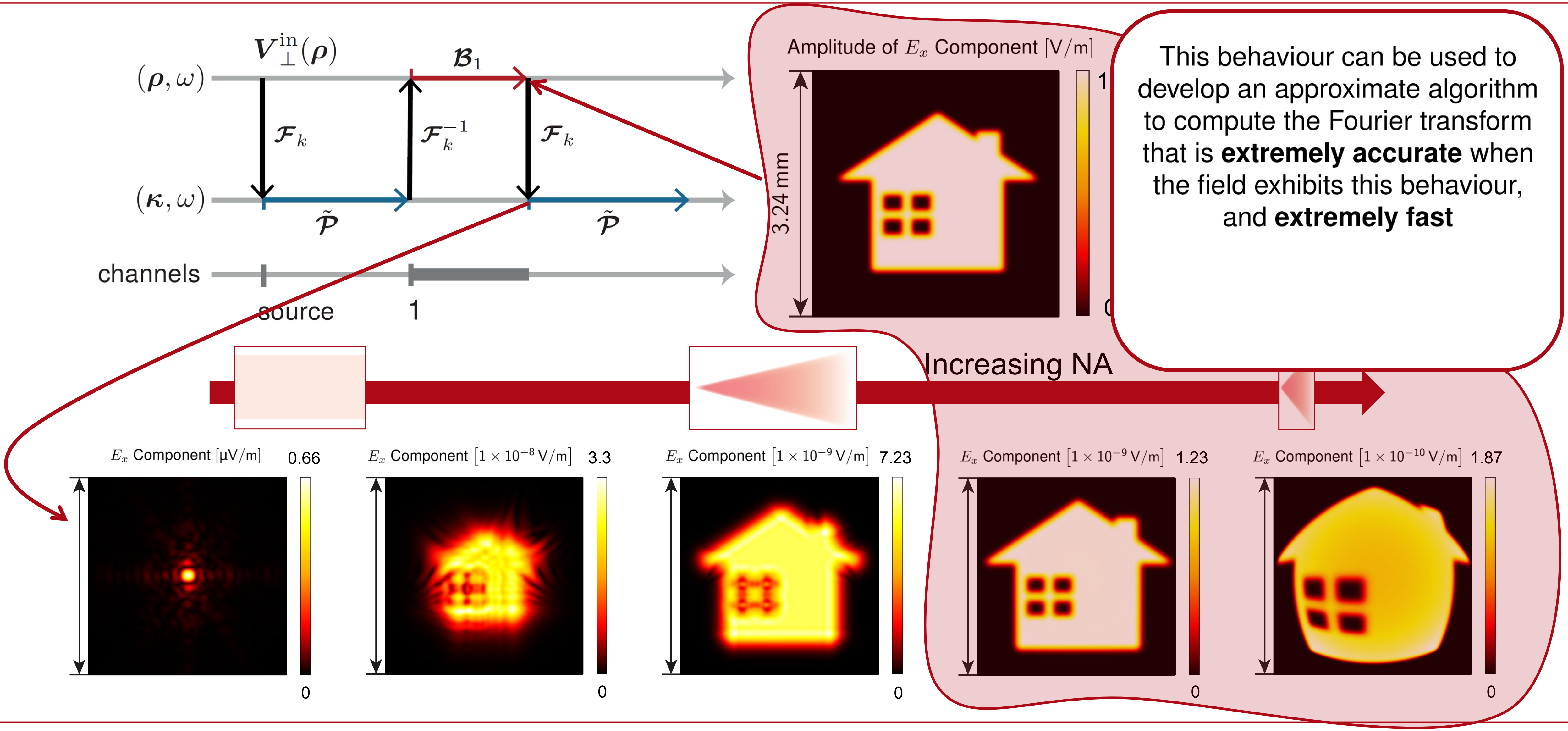
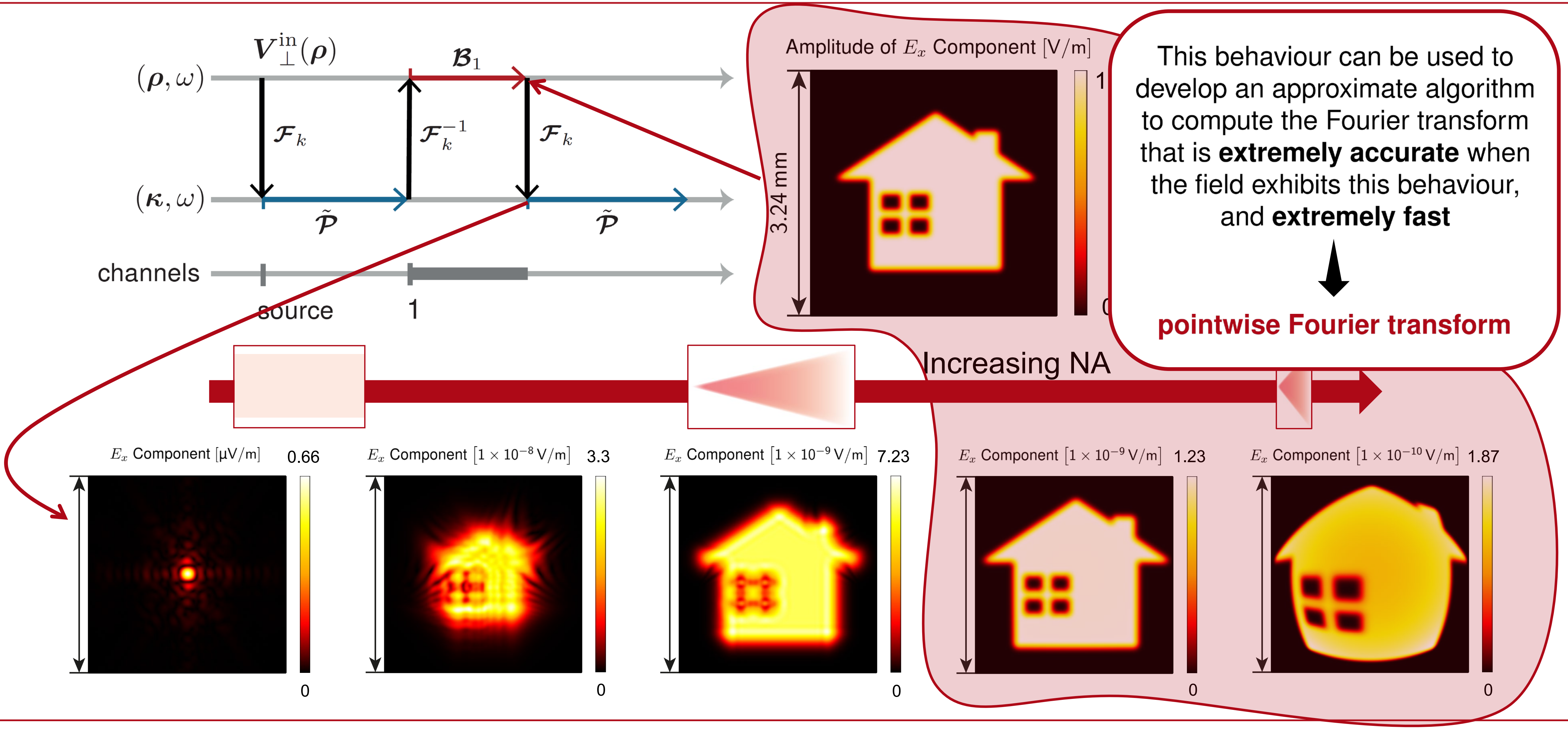


This behaviour can be used to develop an approximate algorithm to compute the Fourier transform that is **extremely accurate** when the field exhibits this behaviour, and **extremely fast**

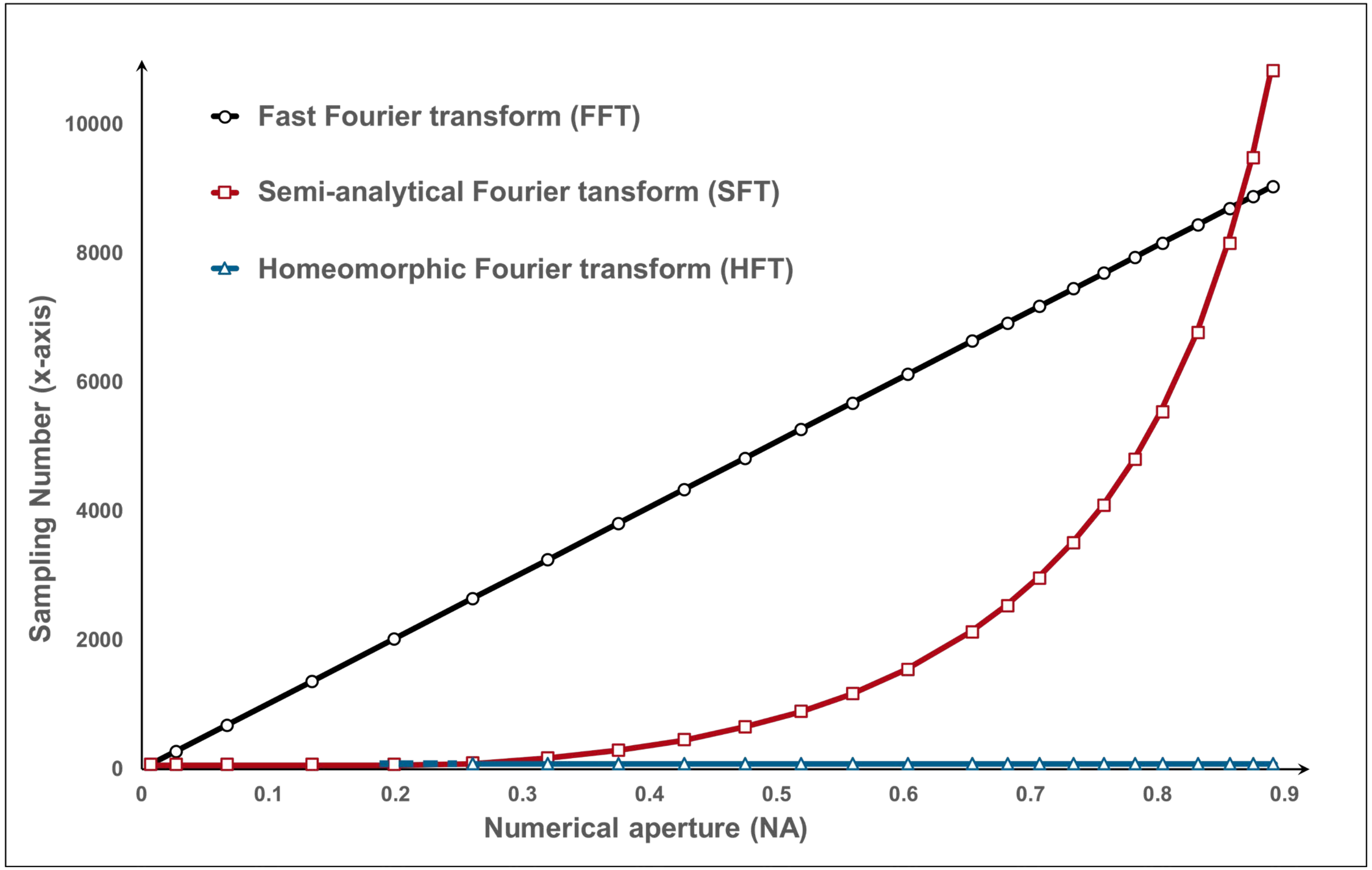
Results of Fourier Transform

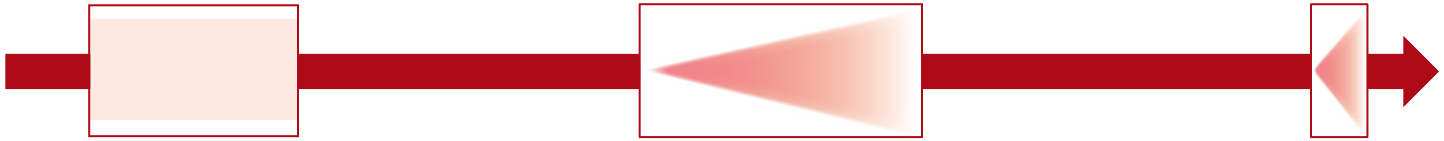


This behaviour can be used to develop an approximate algorithm to compute the Fourier transform that is **extremely accurate** when the field exhibits this behaviour, and **extremely fast**

pointwise Fourier transform

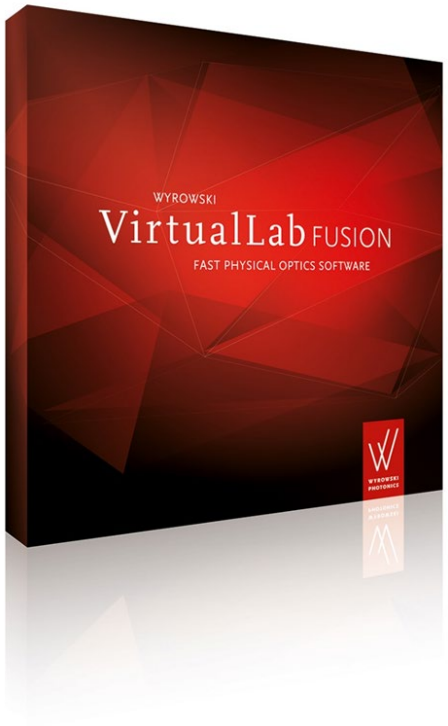
Comparison of the Sampling Effort





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 (PFT)
  - Accurate for strong wavefront phase



→ Combination of Fourier transform algorithms essential for fast physical optics!

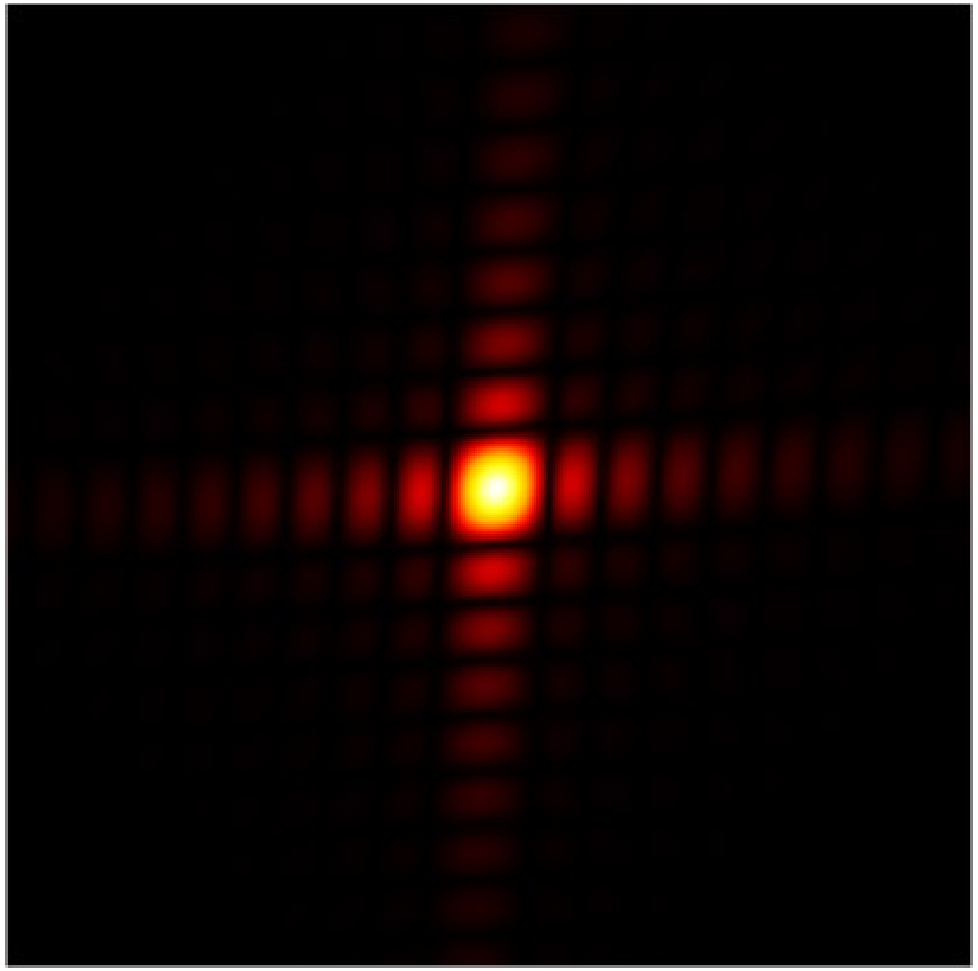
References to Our Fourier Transform Publications

- *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

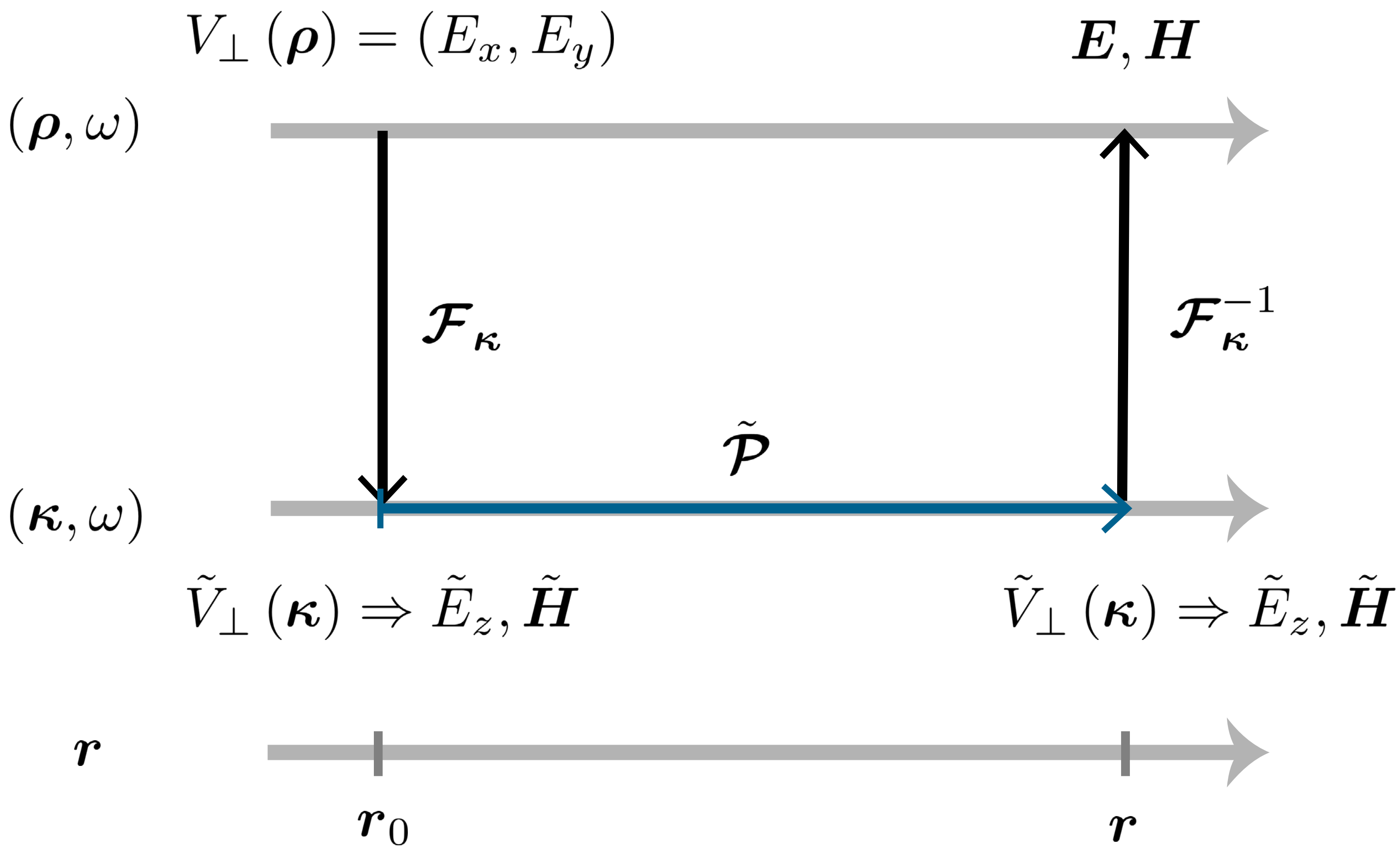
Automatic Selection of Fourier Transform Techniques in Free-Space Propagation Operator

Abstract



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.

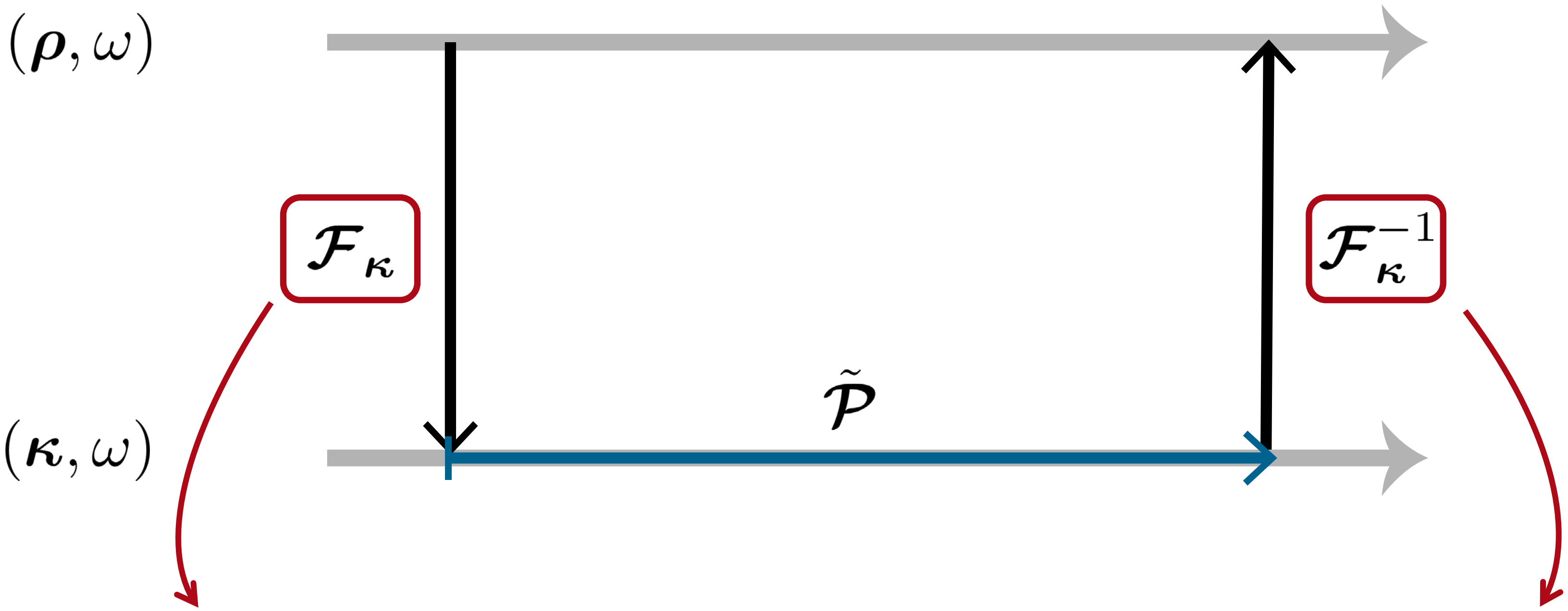
Concept of Free-Space Propagation Operator



- 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

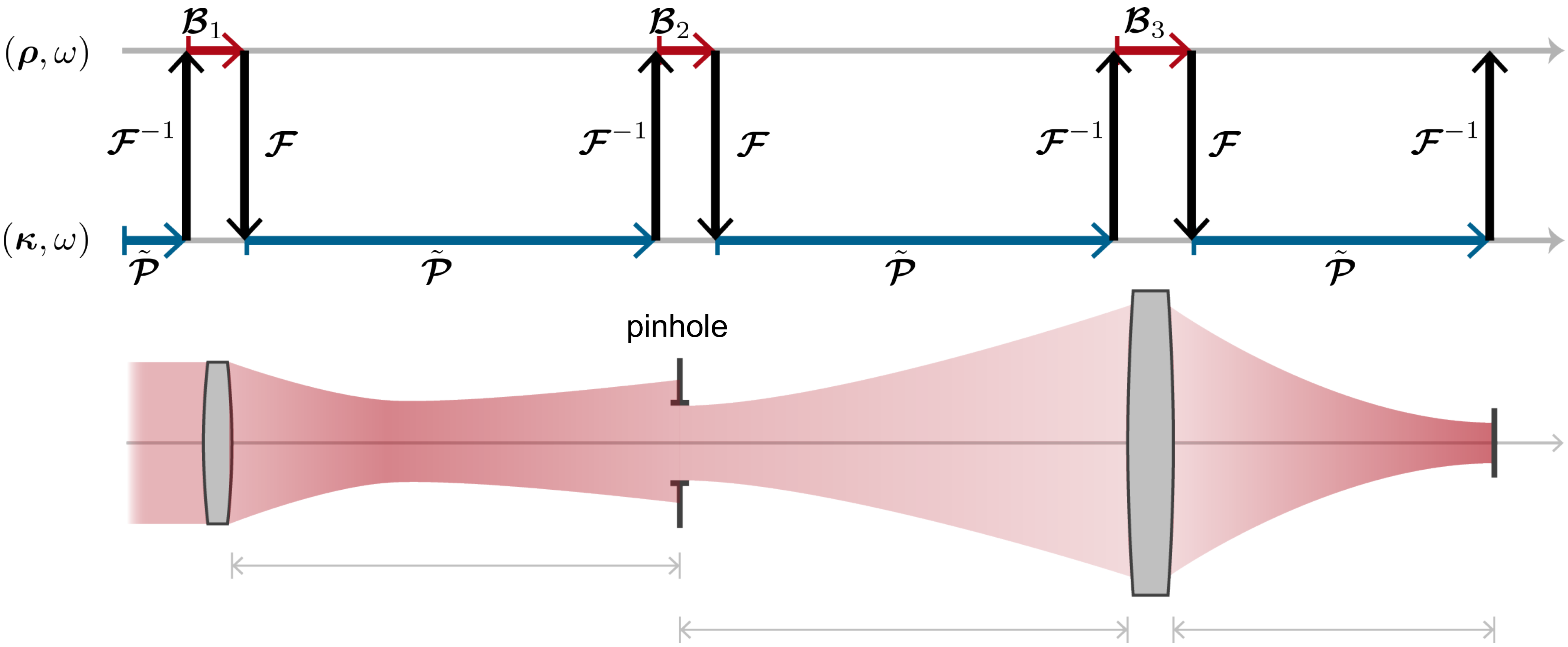


- $\mathcal{F}_{\boldsymbol{\kappa}}$: fast Fourier transform (FFT)
- $\mathcal{F}_{\boldsymbol{\kappa}}^{\text{semi}}$: semi-analytical Fourier transform (SFT)
- $\mathcal{F}_{\boldsymbol{\kappa}}^{\text{h}}$: homeomorphic Fourier transform (HFT)

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

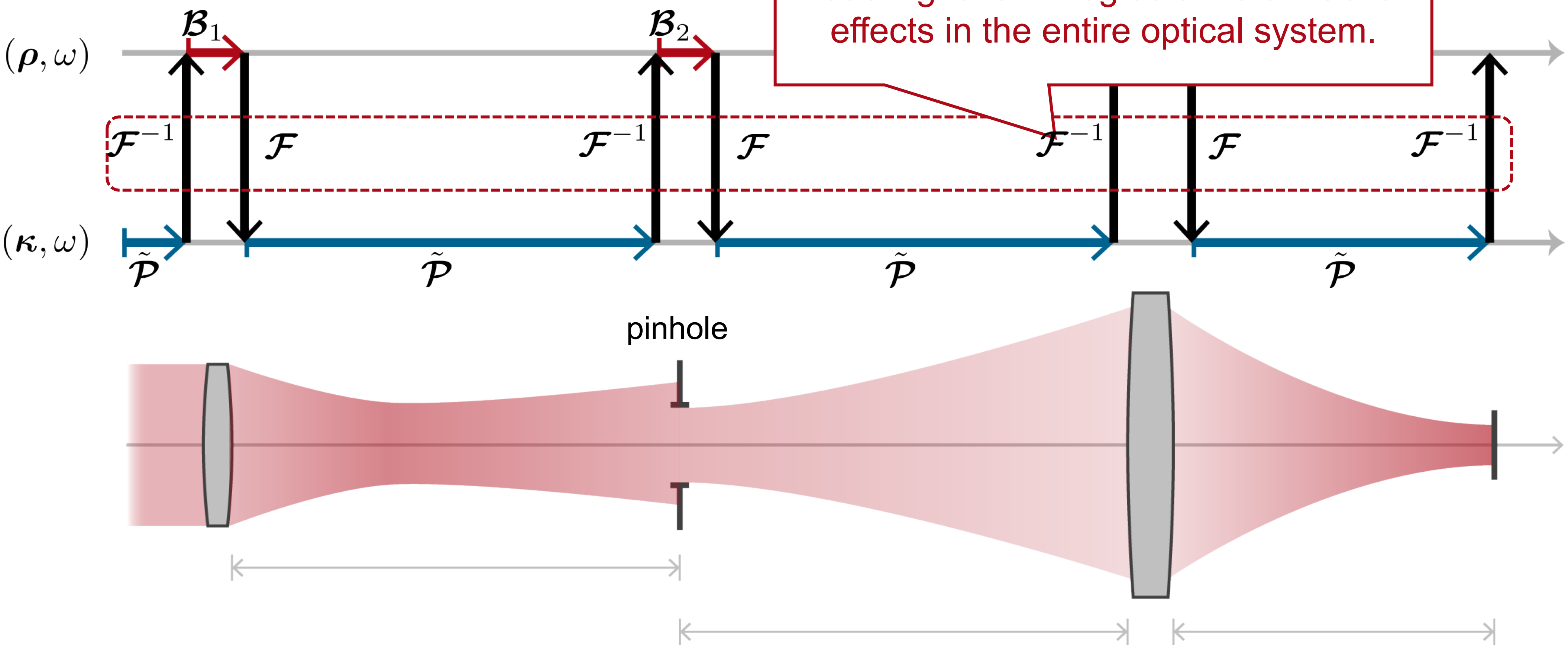
Modeling Levels Definitions

Available Modeling Levels For an Arbitrary System



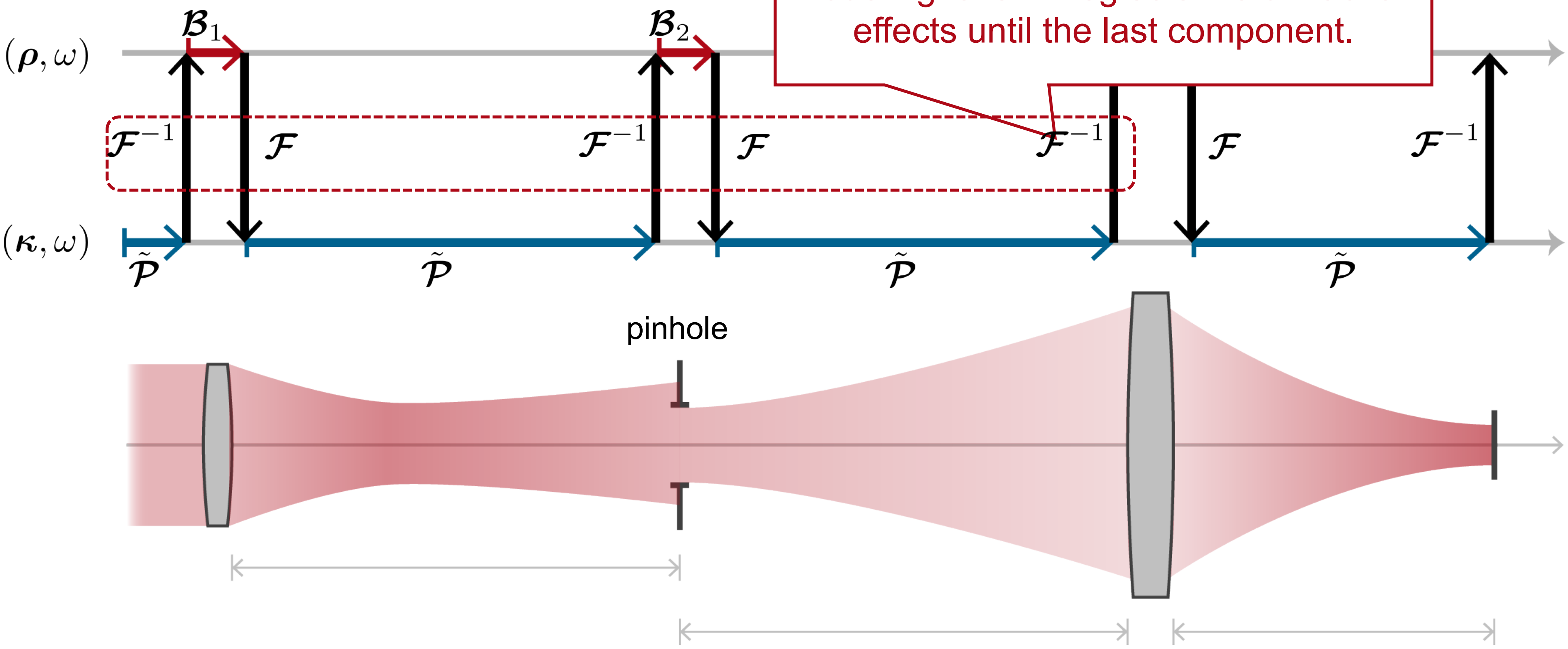
Modeling Level 1

Modeling level 1 neglects the diffraction effects in the entire optical system.

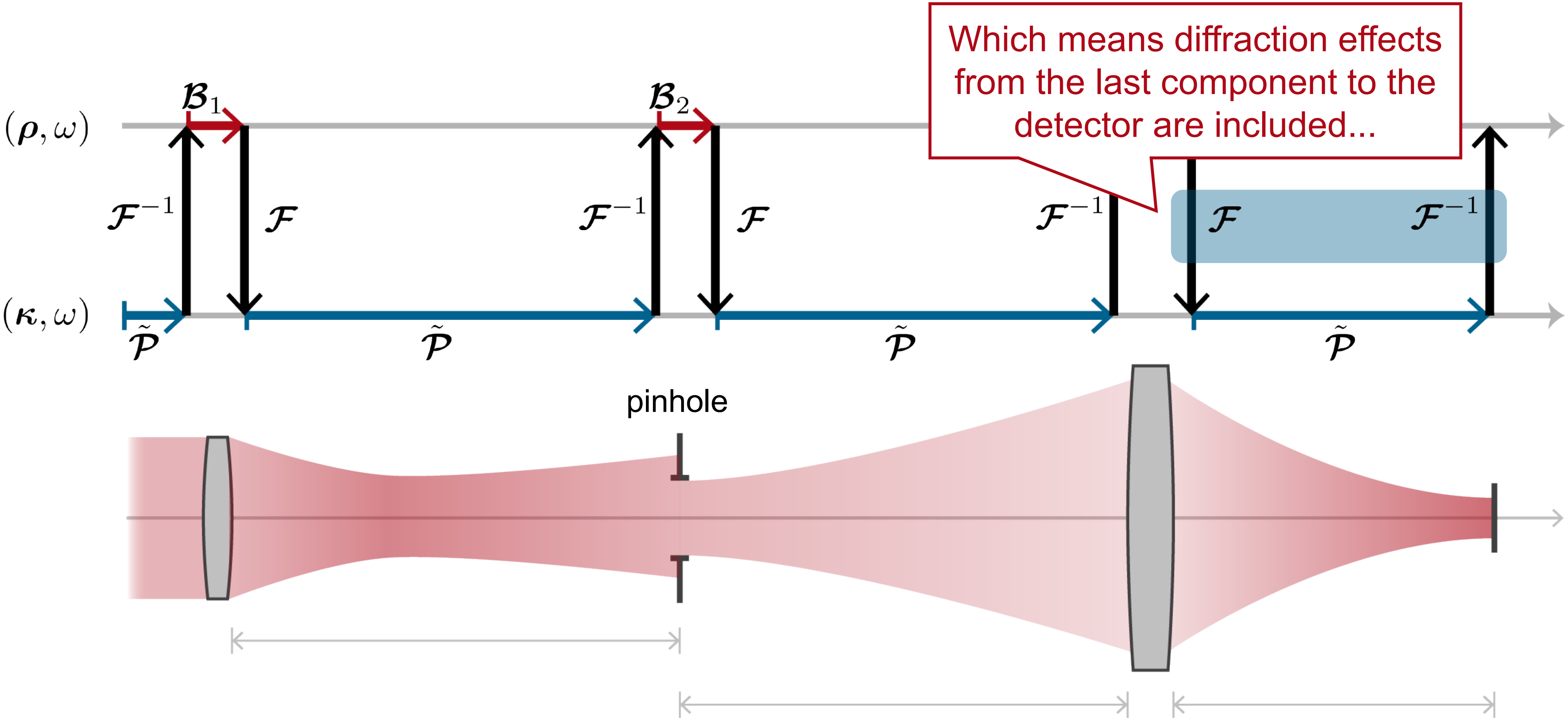


Modeling Level 2

Modeling level 2 neglects the diffraction effects until the last component.



Modeling Level 2



Modeling Level 3

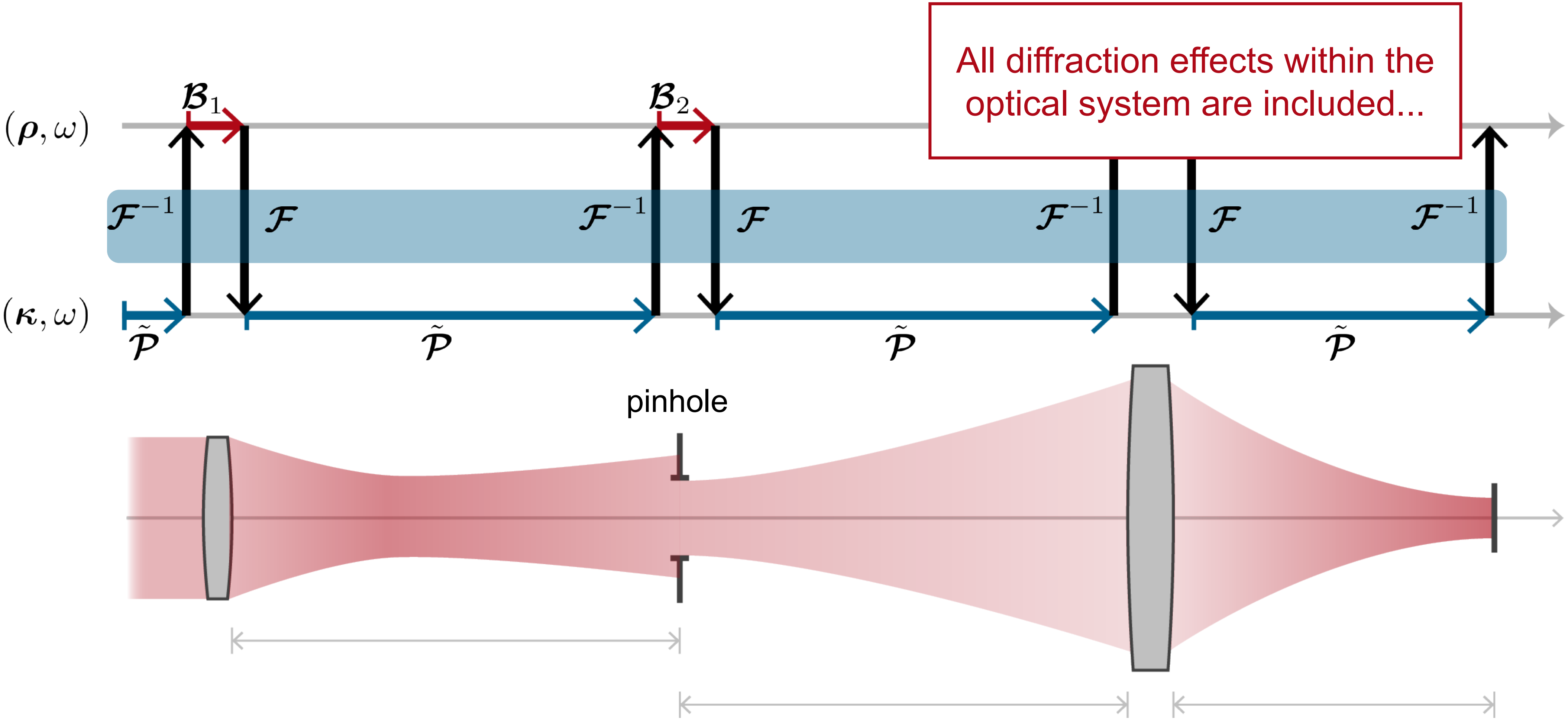
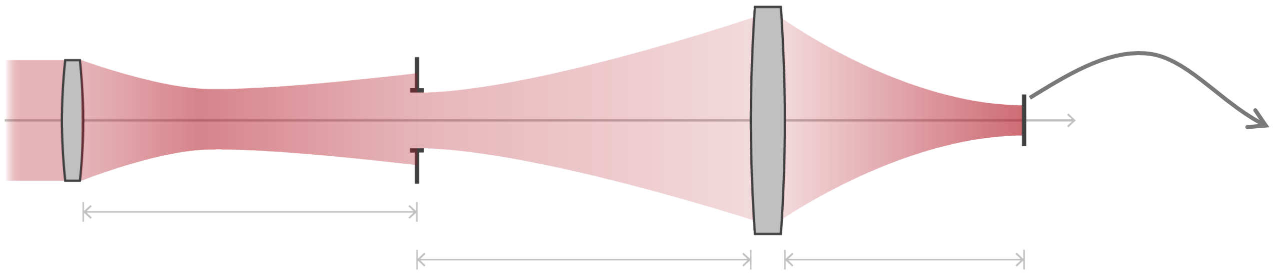
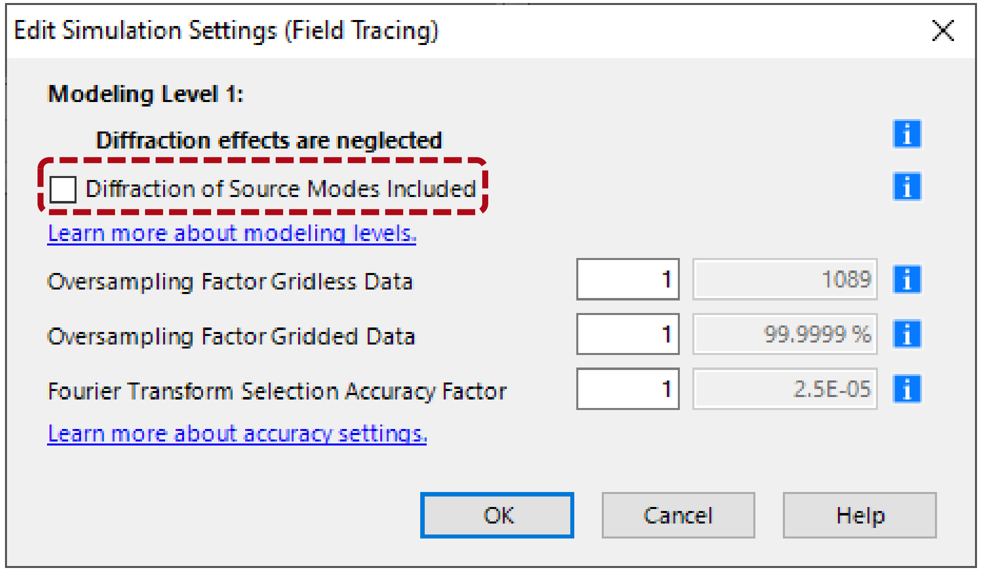
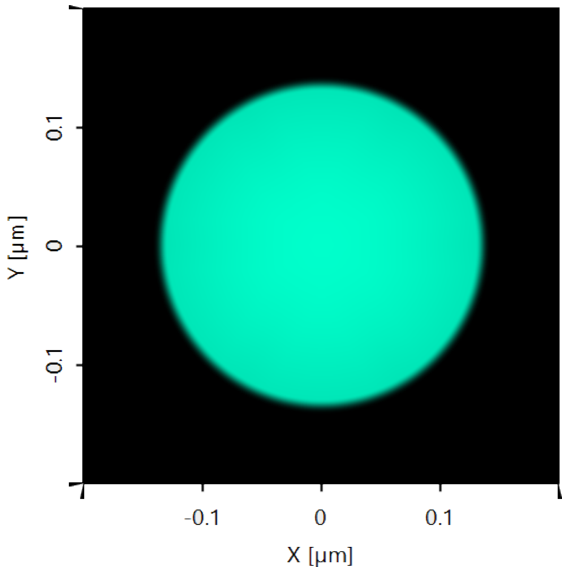


Image Evaluation by Modeling Level 1

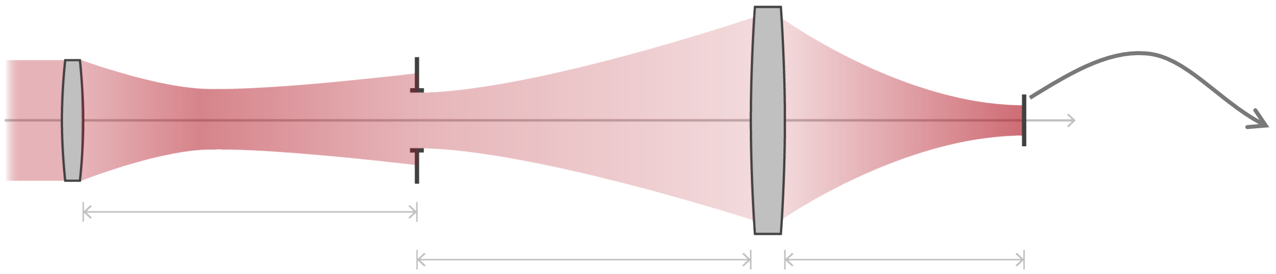


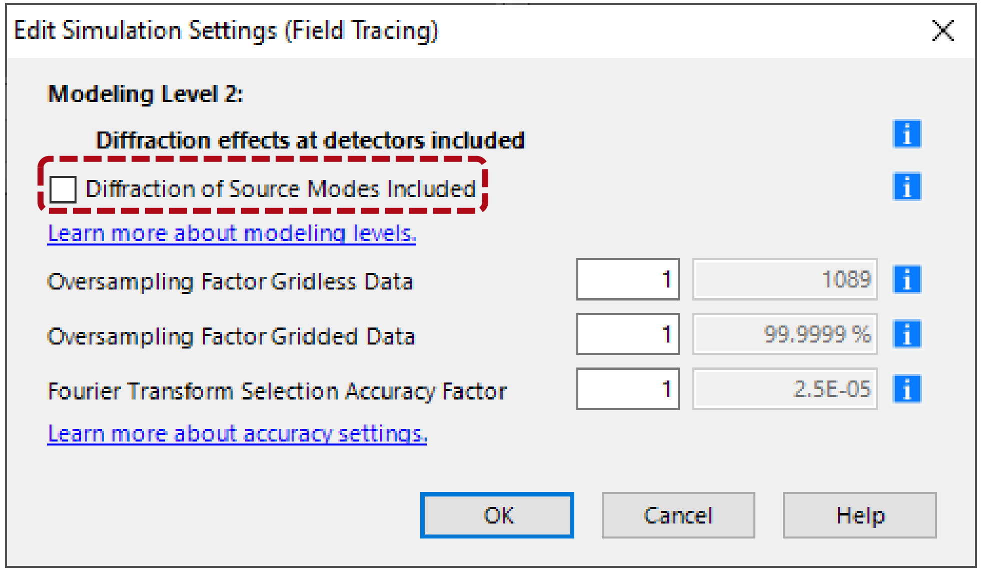


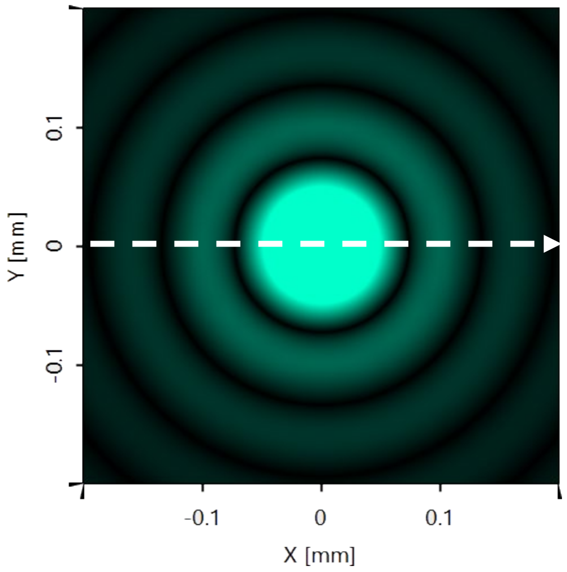


Focal spot

Image Evaluation by Modeling Level 2







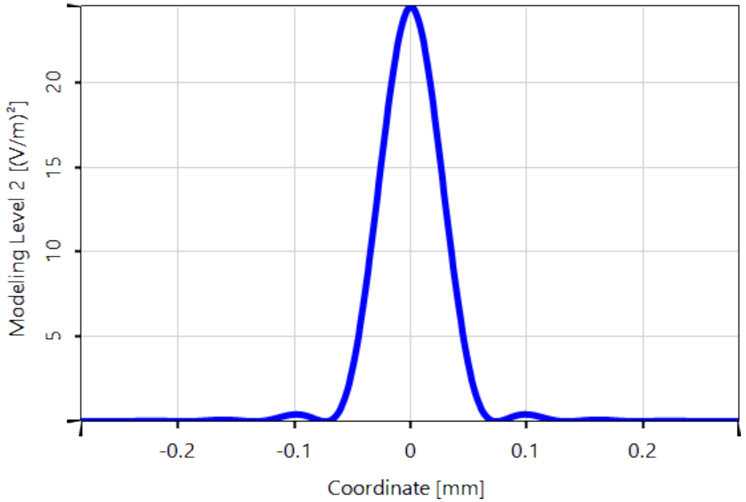
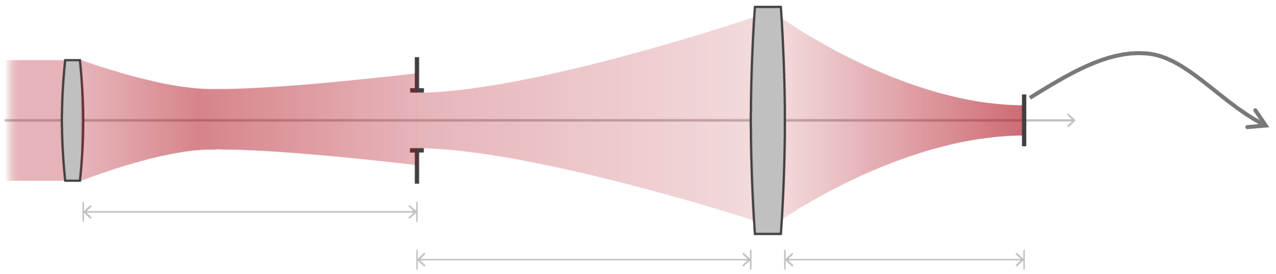
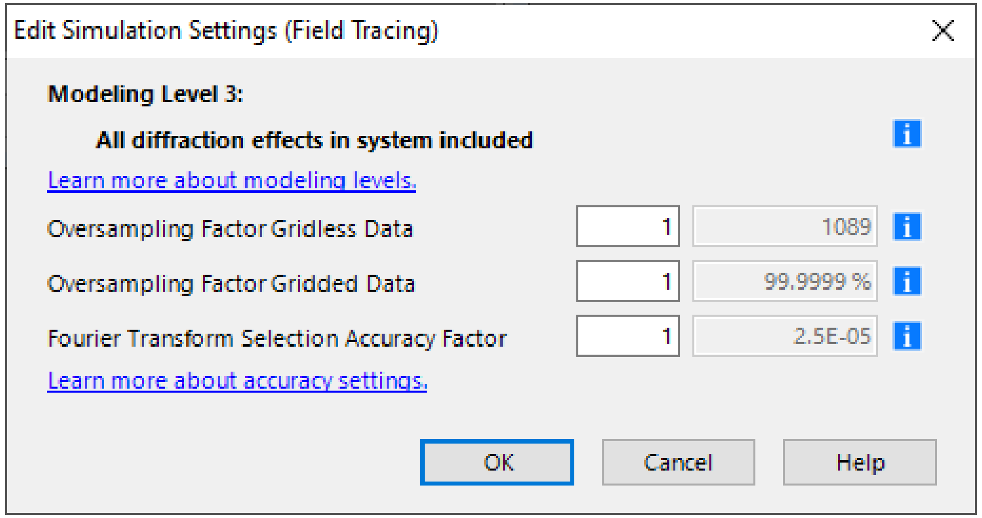
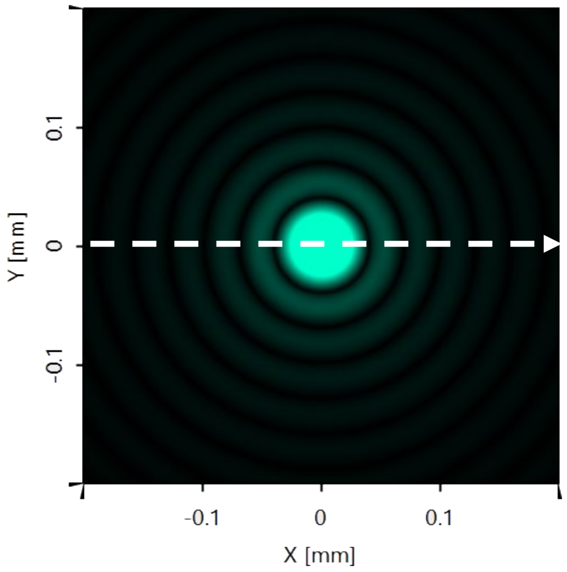
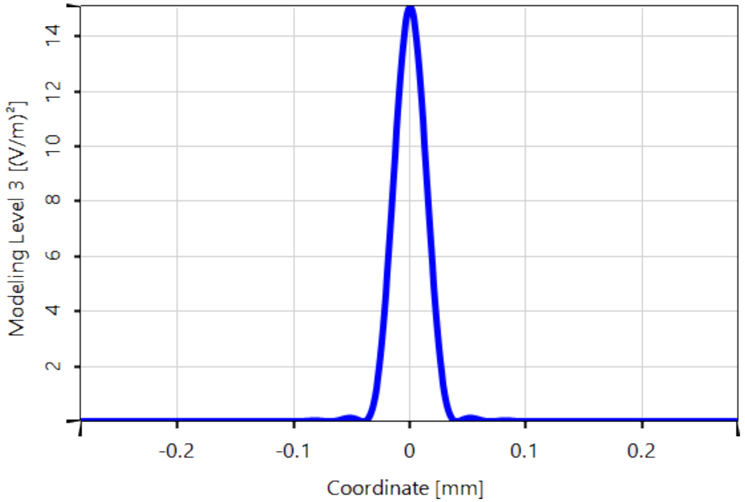


Image Evaluation by Modeling Level 3

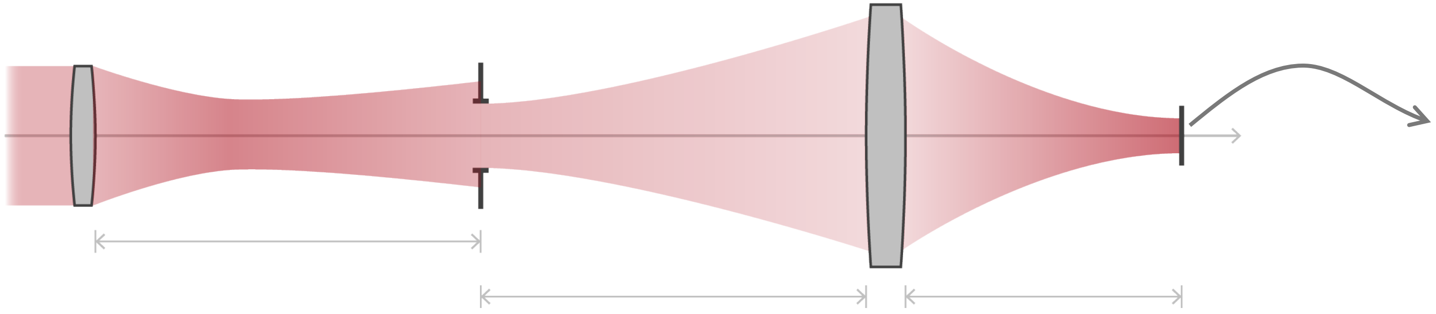




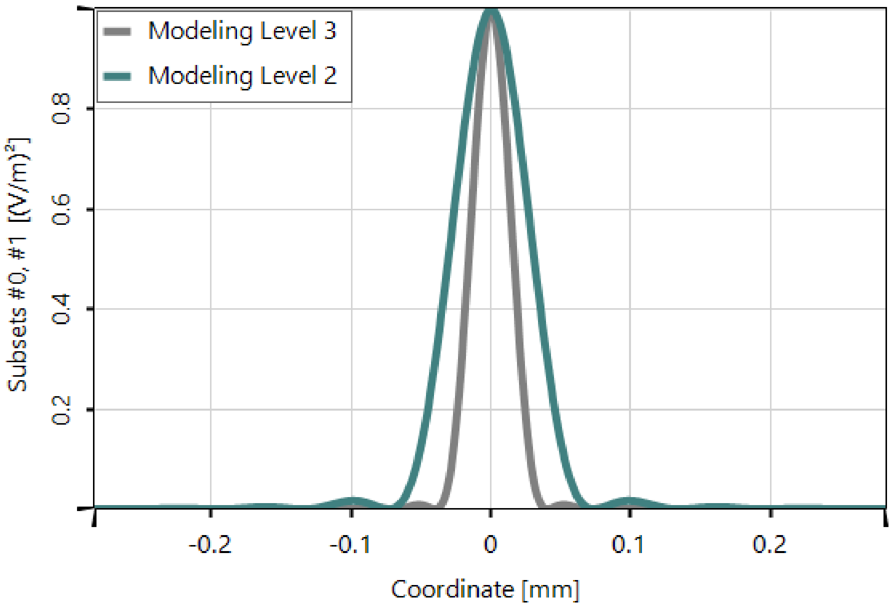




Comparison between Modeling Level 2 & 3



Values are normalized

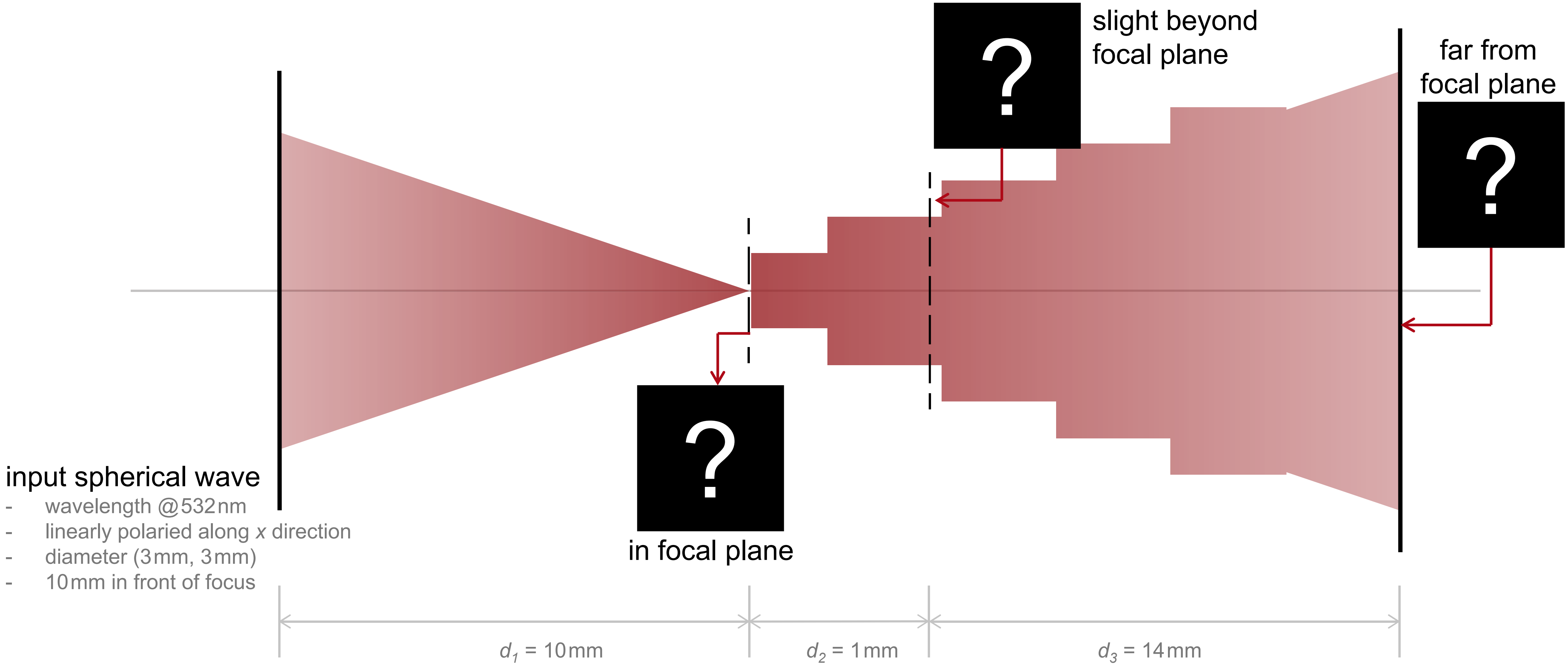


Using rigorous Fourier transform in the whole system results in truncation of a large amount of energy by the pinhole!

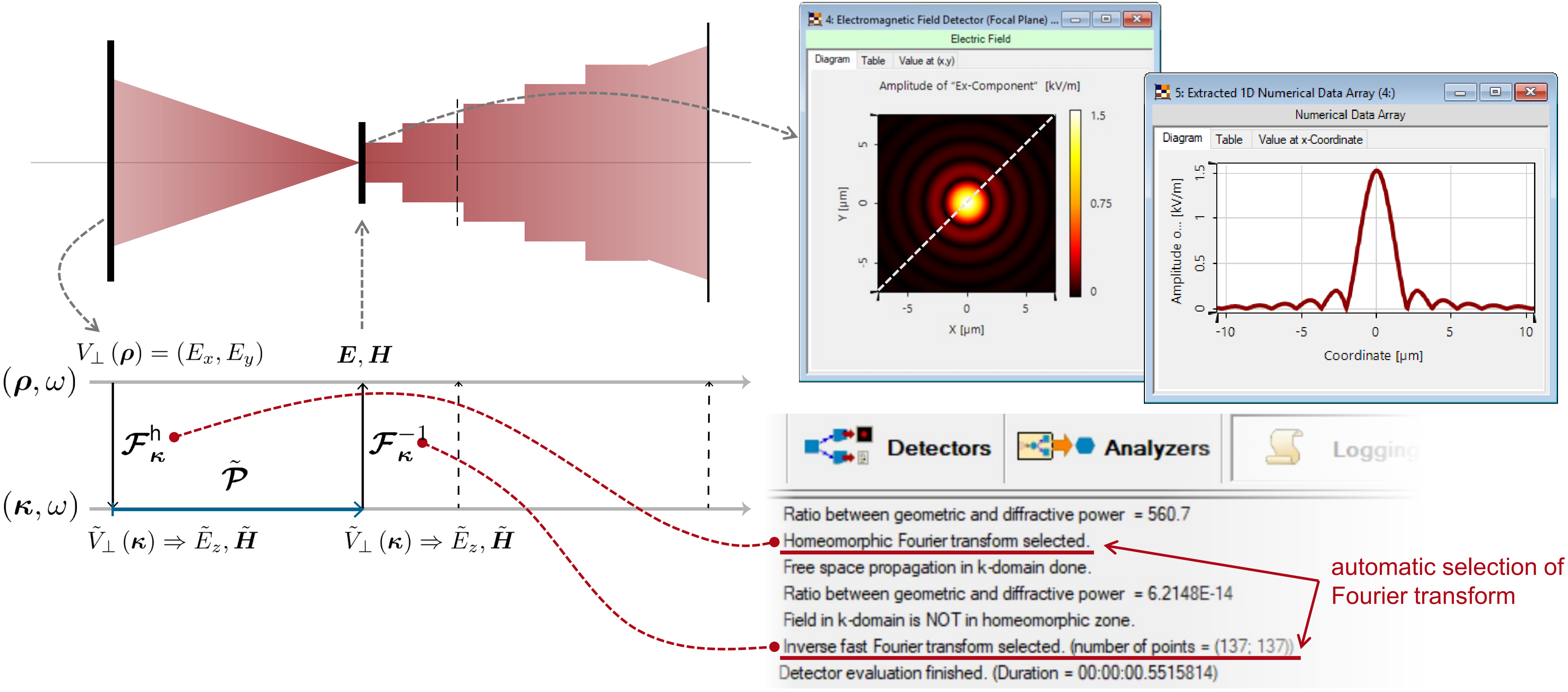
Example 1: Propagation of a Spherical Wave

see the full Application Use Case

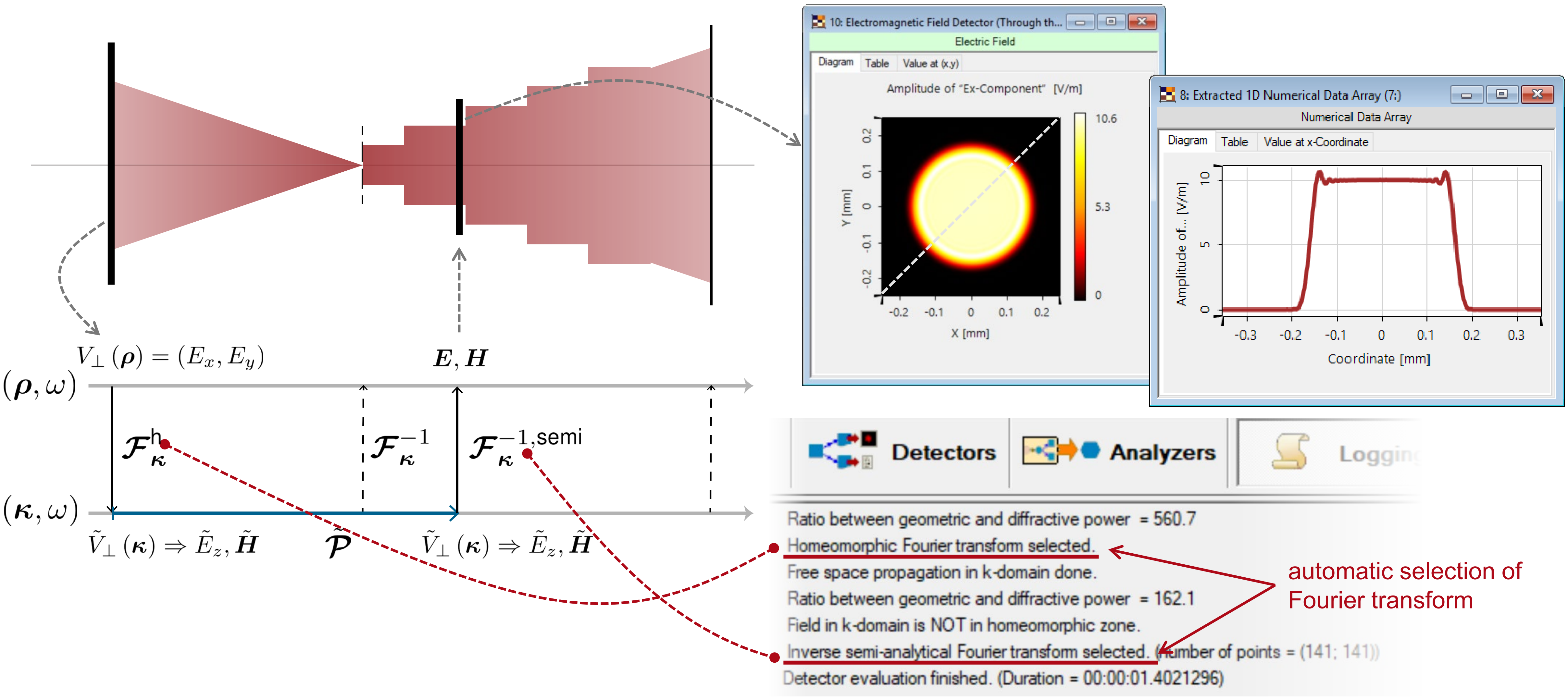
Modeling Task



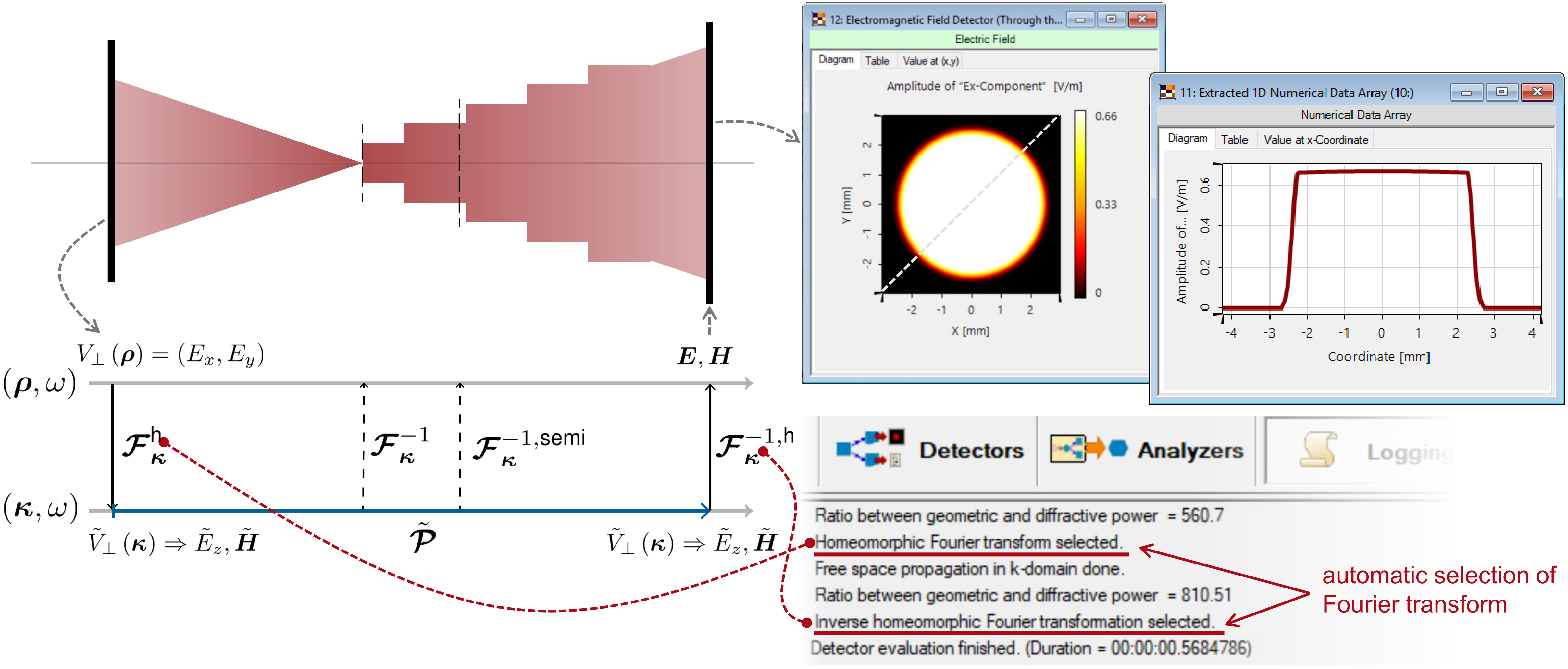
Simulation Result: in Focal Plane



Simulation Result: Slightly beyond Focal Plane



Simulation Result: Far from Focal Plane



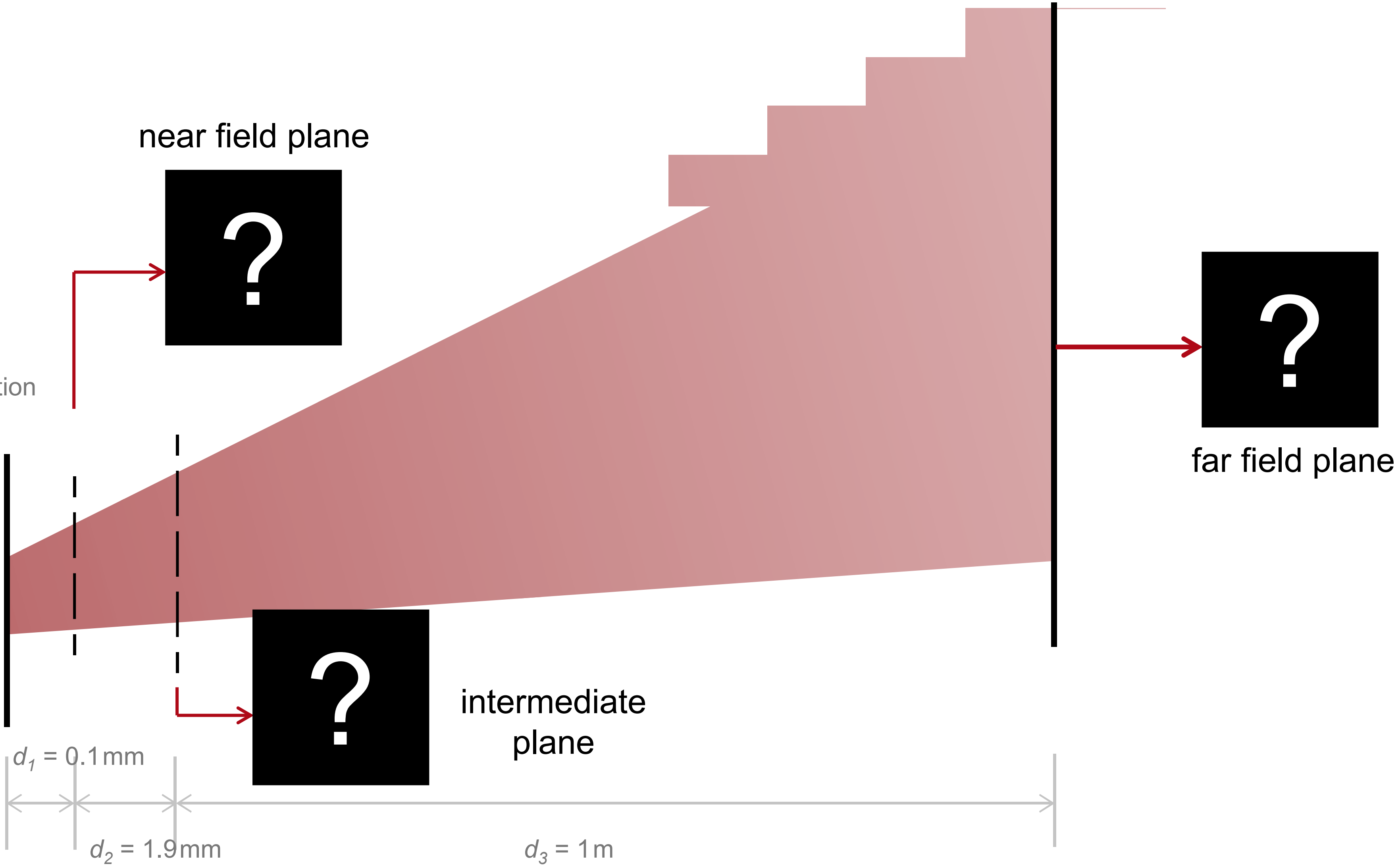
Example 2: Propagation of a Truncated Plane Wave

see the full Application Use Case

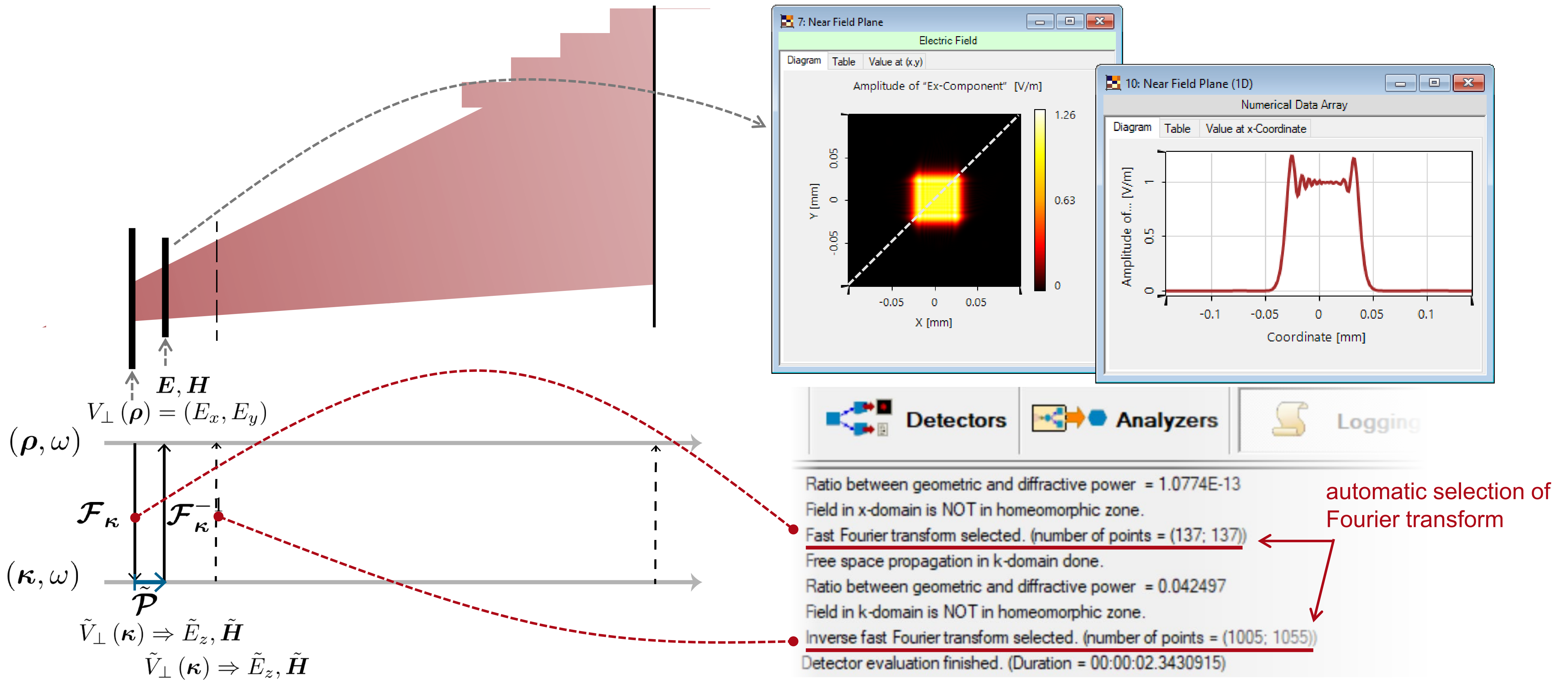
Modeling Task

truncated plane wave

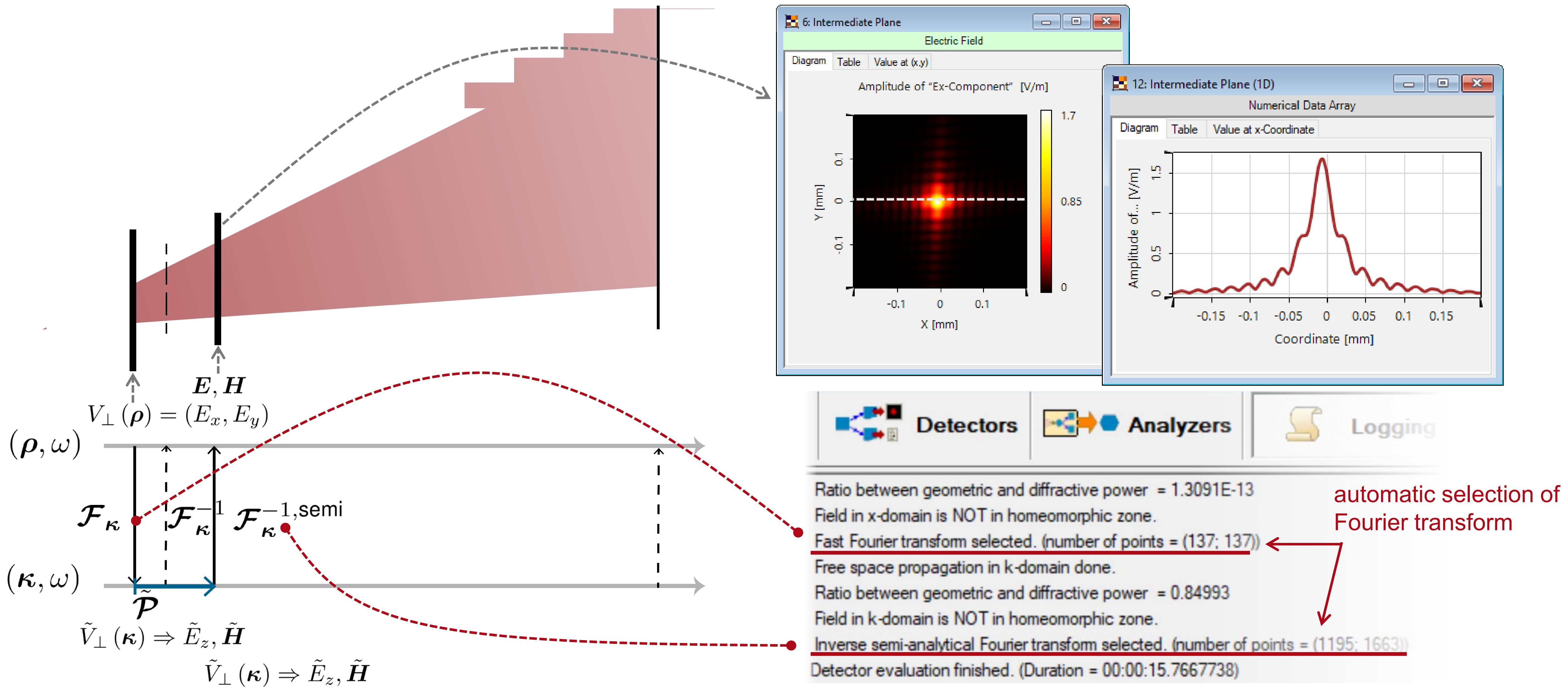
- wavelength @532nm
- linearly polaried along *x* direction
- shape: rectangular
- diameter: (50um, 50um)
- inclination(10°, 20°)



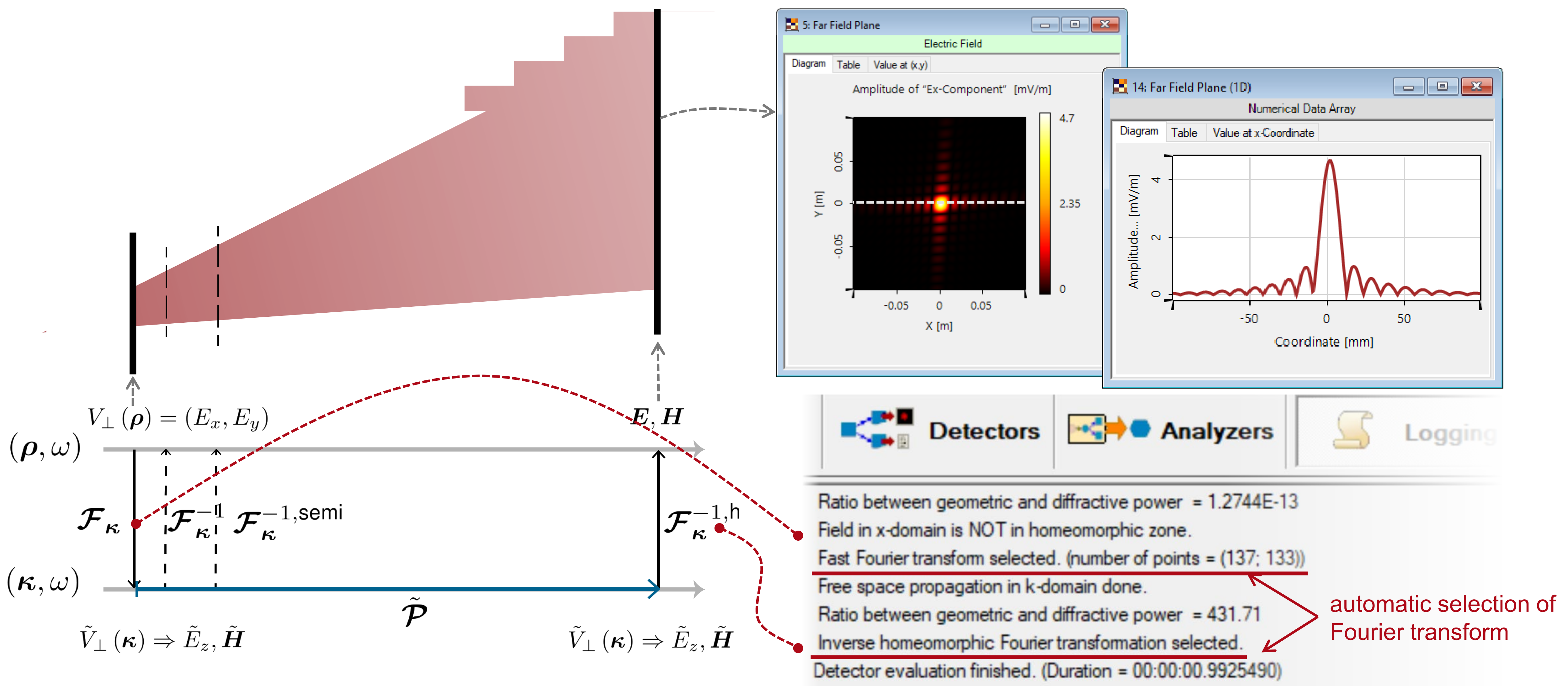
Simulation Result: Near Field Plane



Simulation Result: Intermediate Plane



Simulation Result: Far Field Plane

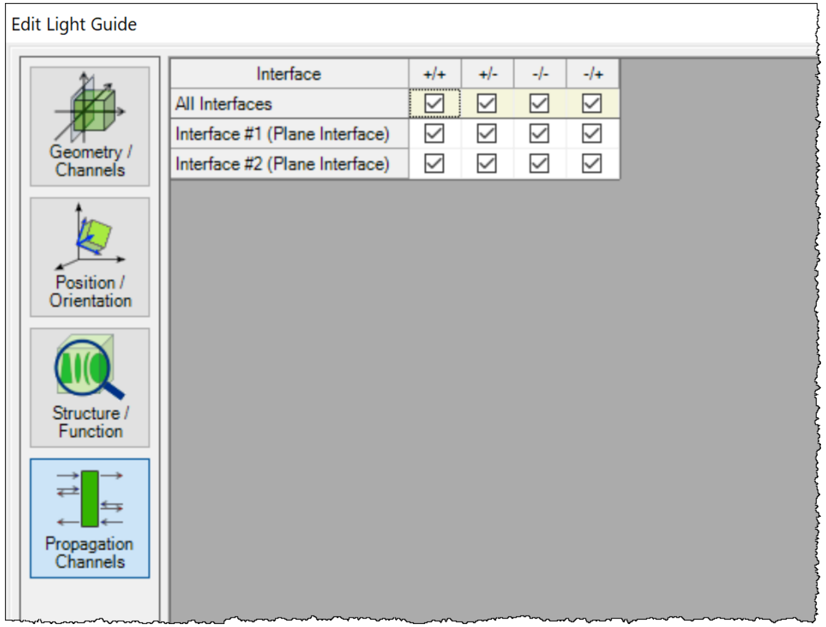


Part 4

The Channel Concept

Surface Channels

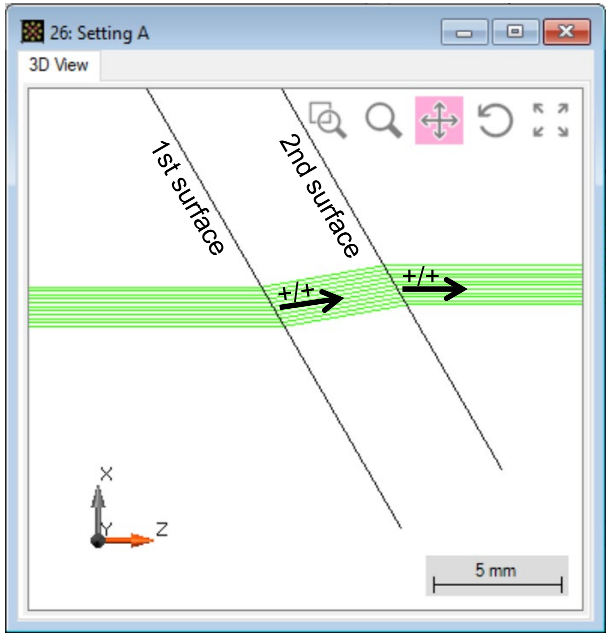
- Channel definition
  - There are four possible channels for each surface, at least one should be activated for the tracing.
  - Channels can be defined for each surface individually.
  - Different settings on channels leads to different modeling schemes.



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

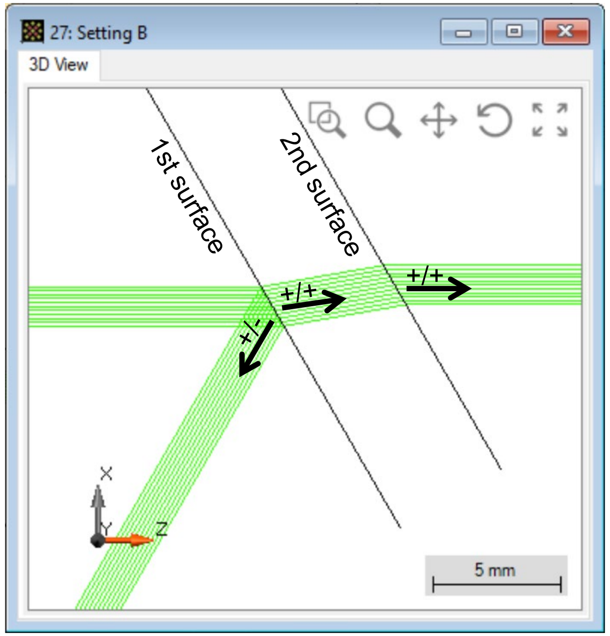
Surface Channels

Setting A



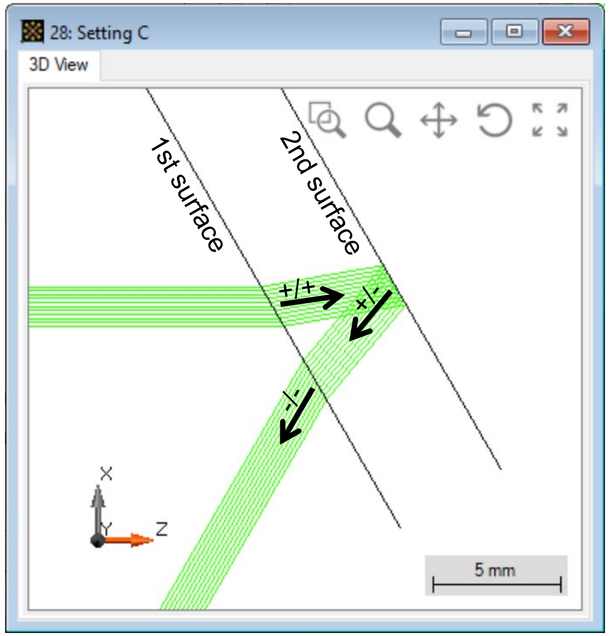
Surface	+/+	+/-	-/-	-/+
1st	×			
2nd	×			

Setting B



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

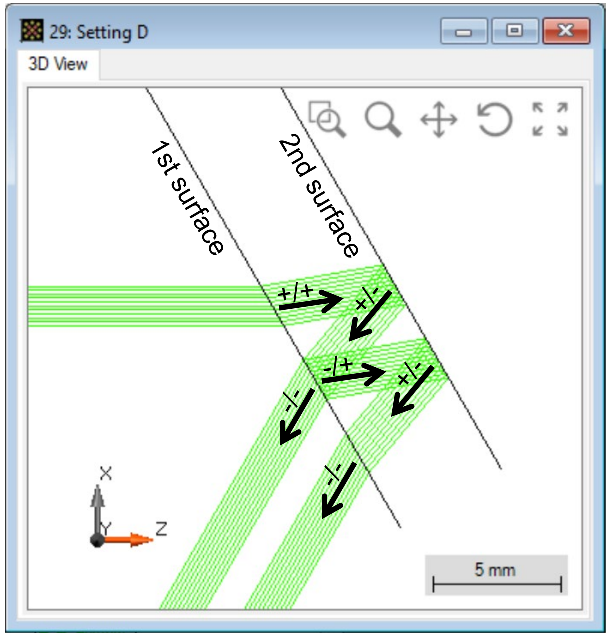
Setting C



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

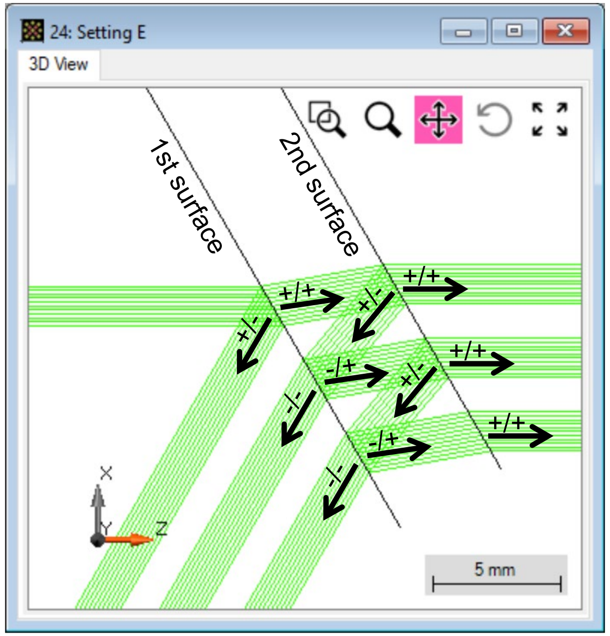
Surface Channels

Setting D



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

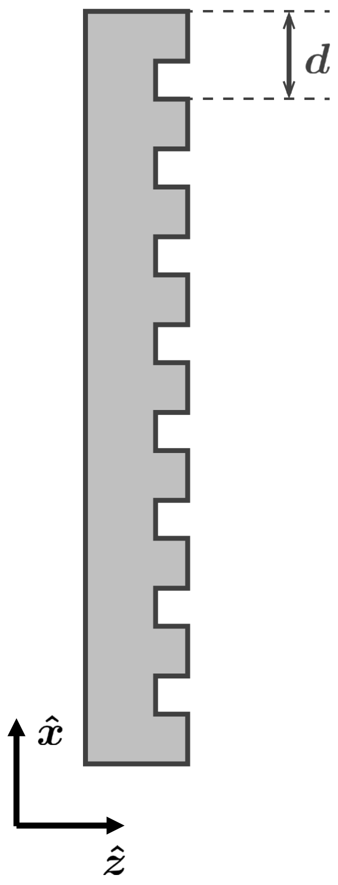
Setting E



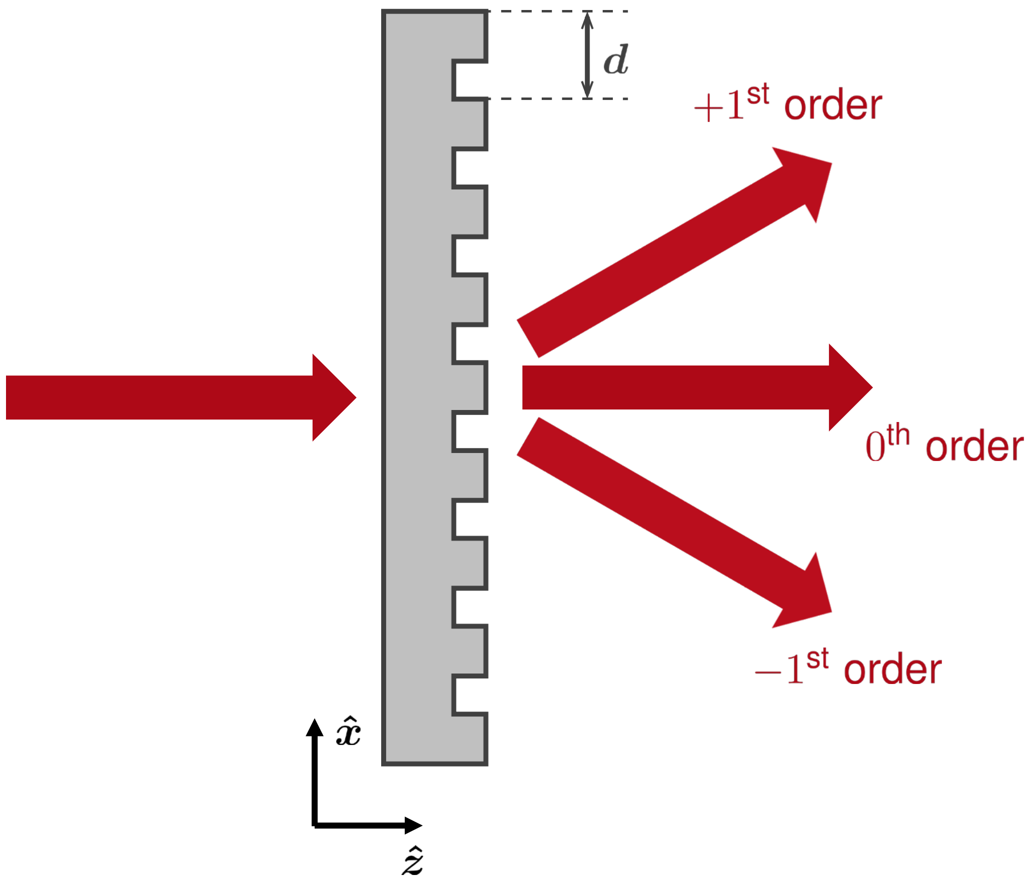
Surface	+/+	+/-	-/-	-/+
1st	×	×	×	×
2nd	×	×	×	×

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

Grating Channels



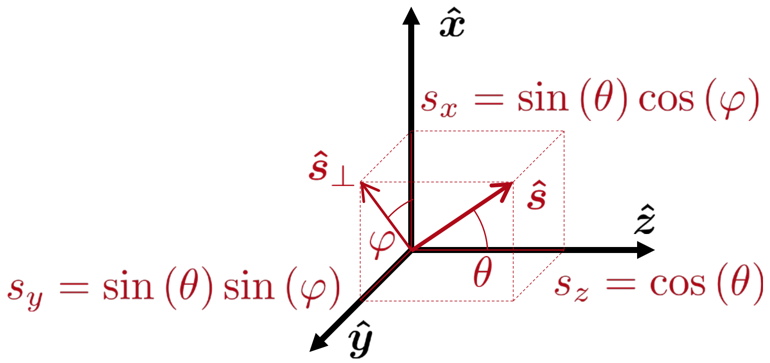
Grating Channels

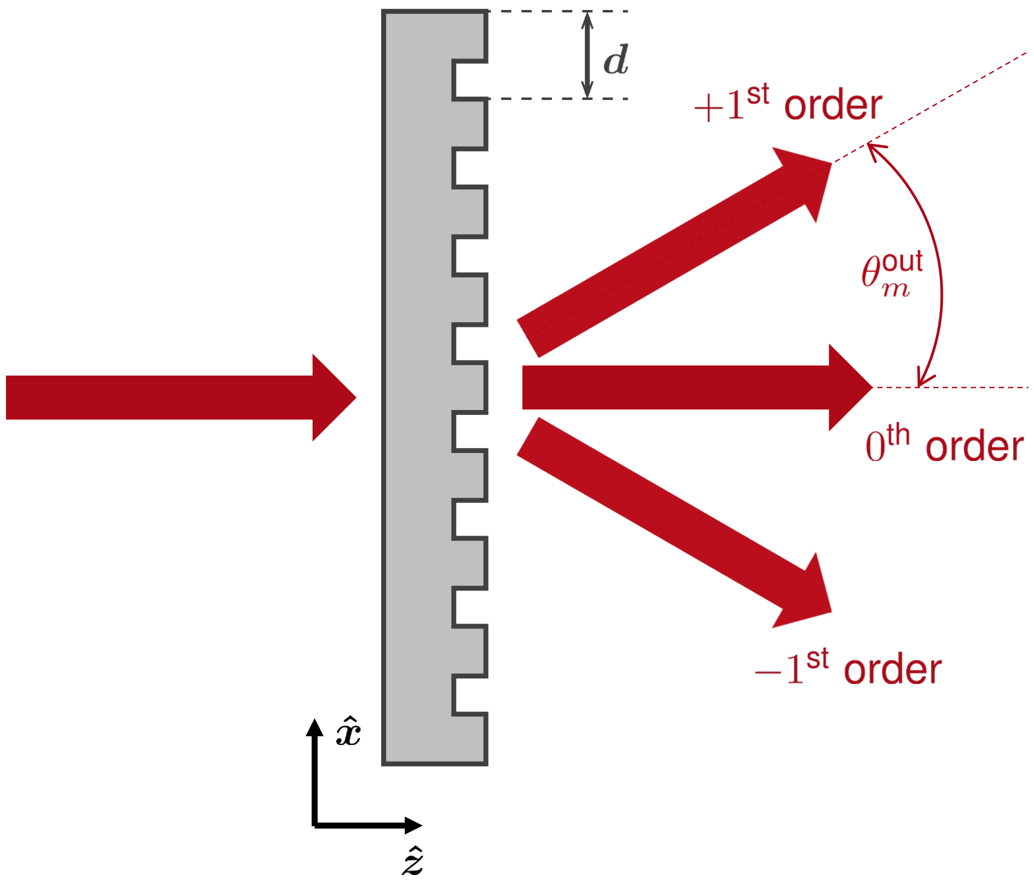


Grating Channels

Grating equation:

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

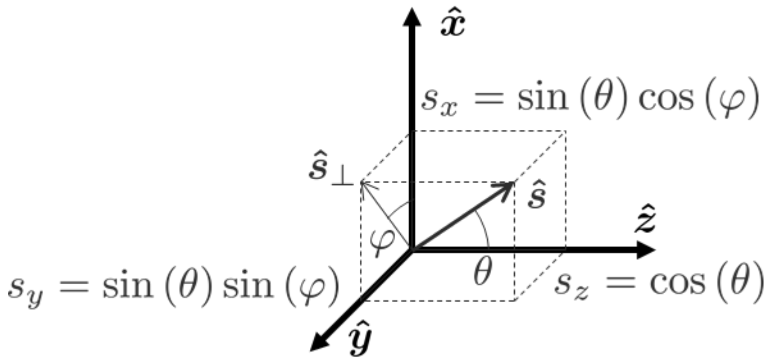


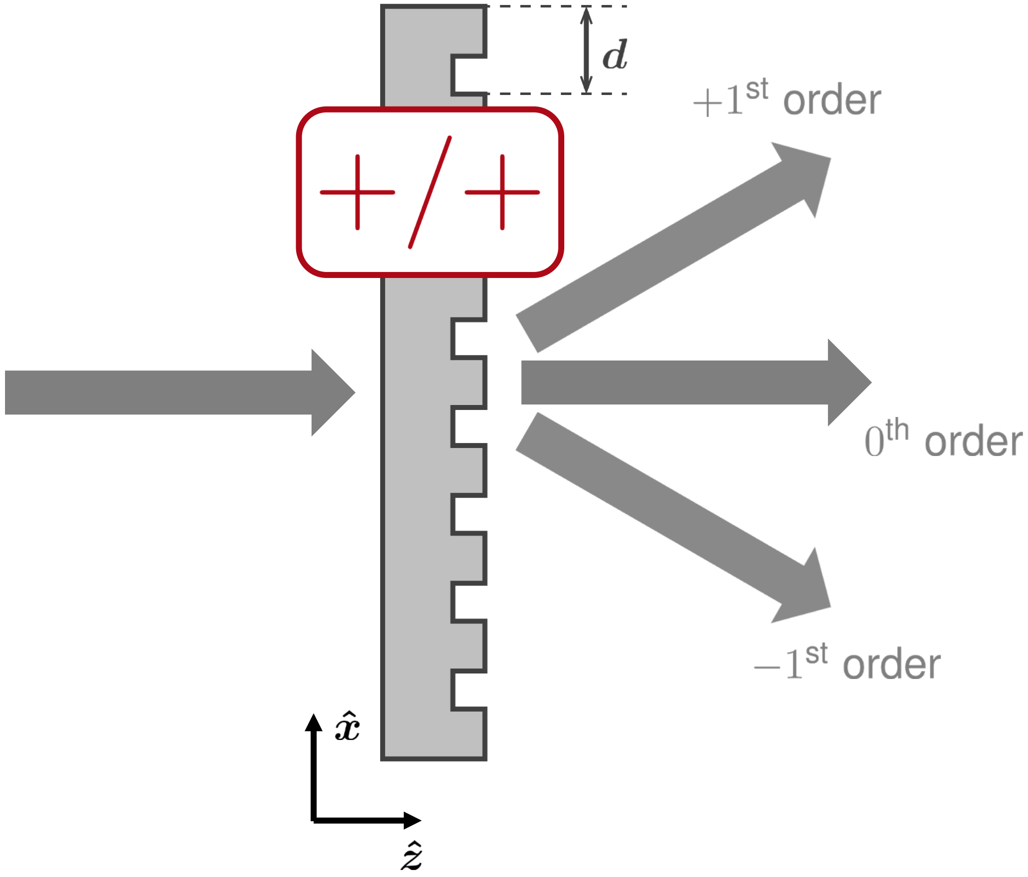


Grating Channels

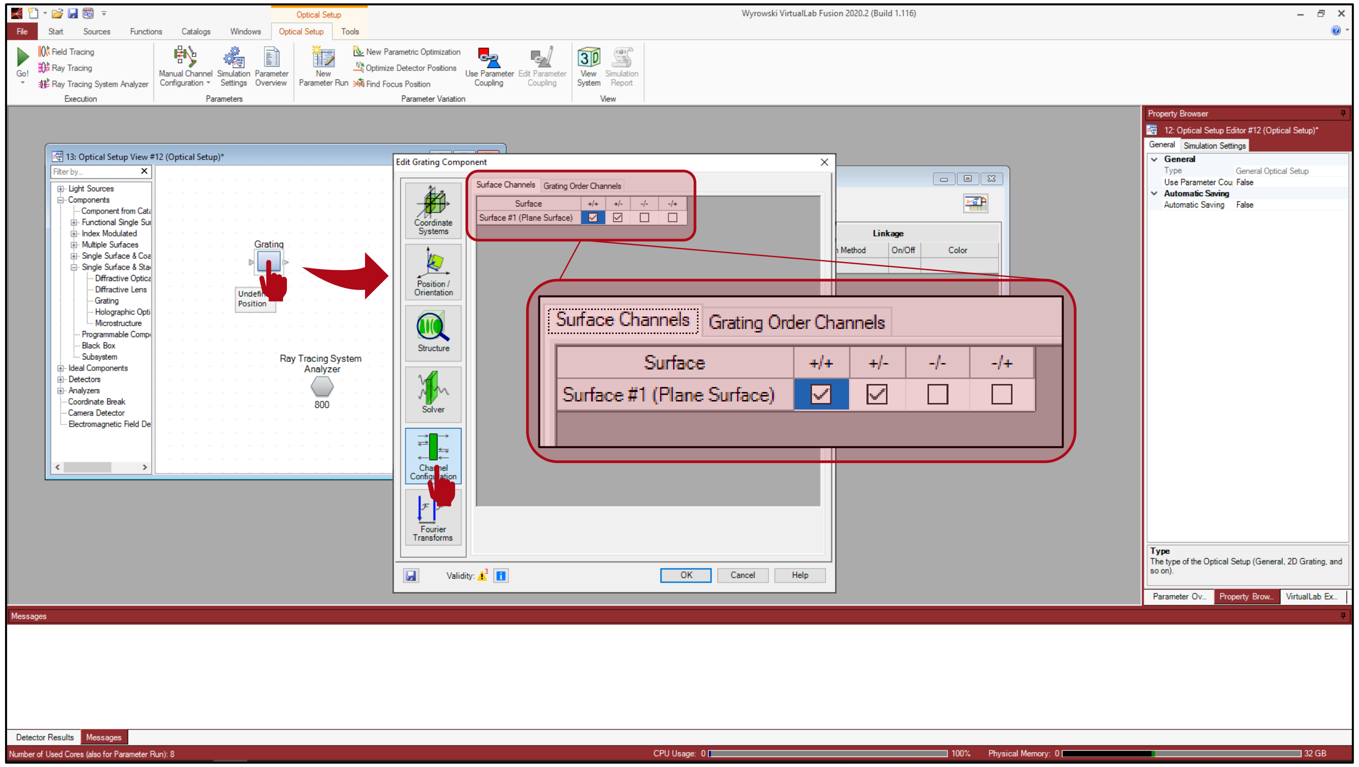
Grating equation:

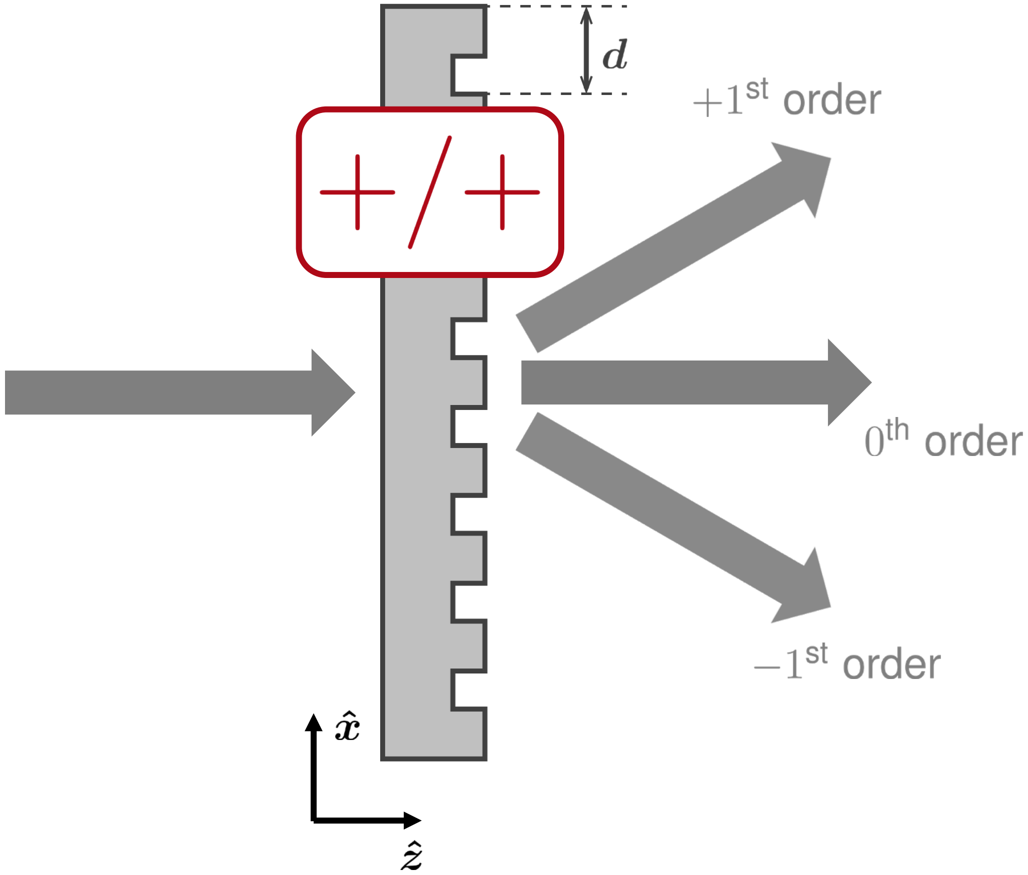
- $\boldsymbol{\kappa}_m^{\text{out}} = \boldsymbol{\kappa}^{\text{in}} + m\boldsymbol{\Delta\kappa}$,
- where $\boldsymbol{\kappa}_m^{\text{out}} = \boldsymbol{k}_{m,\perp}^{\text{out}} = \left(k_{m,x}^{\text{out}}, k_{m,y}^{\text{out}}\right) = nk_0\hat{\boldsymbol{s}}_{m,\perp}^{\text{out}}$ (with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



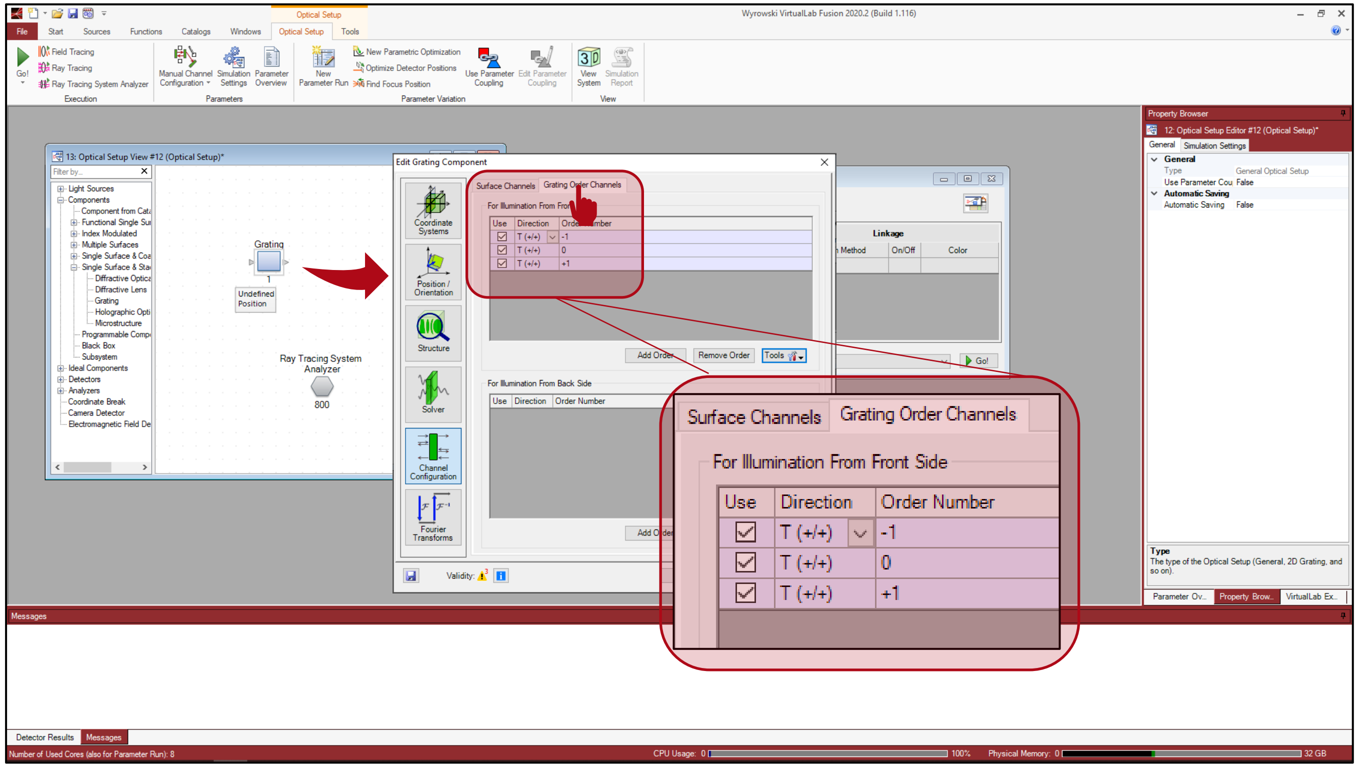


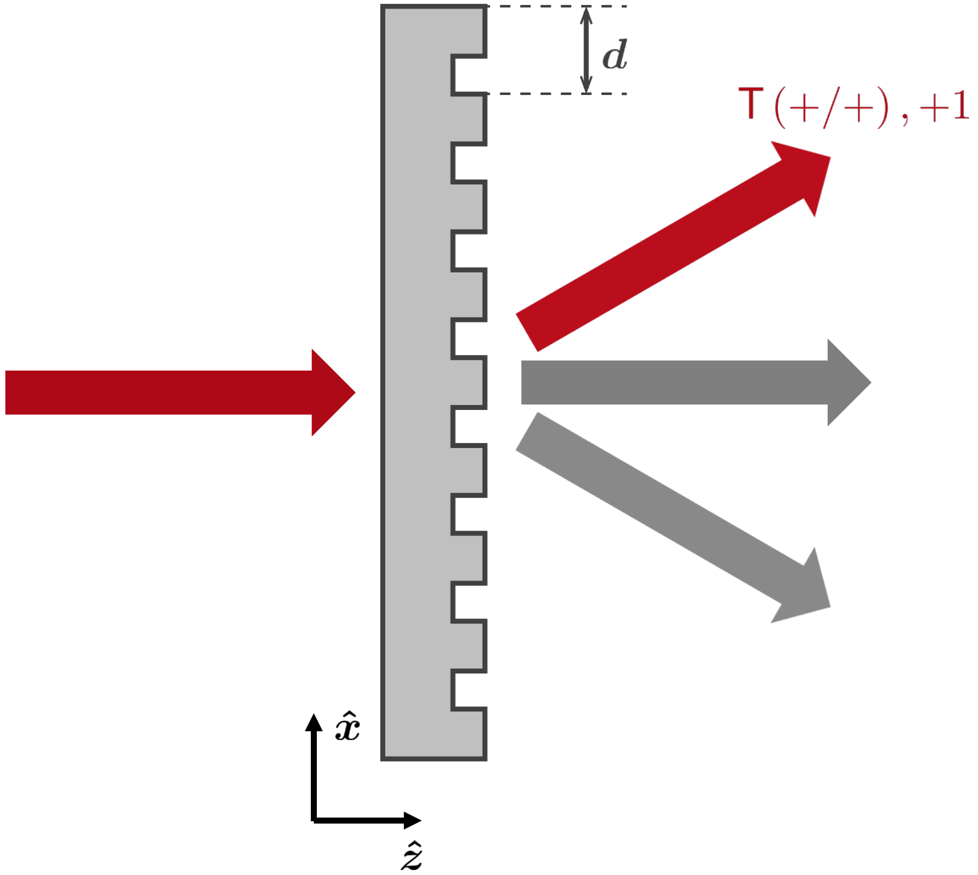
Grating Channels



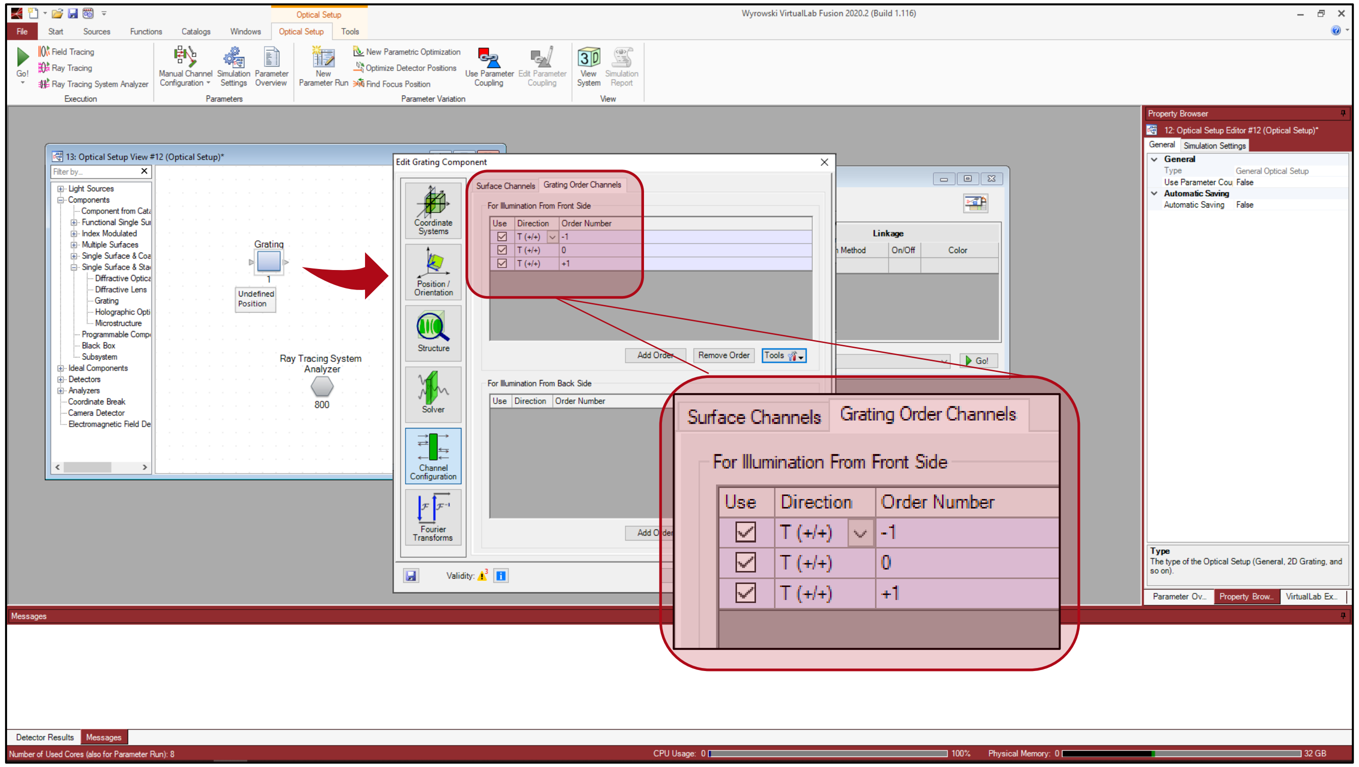


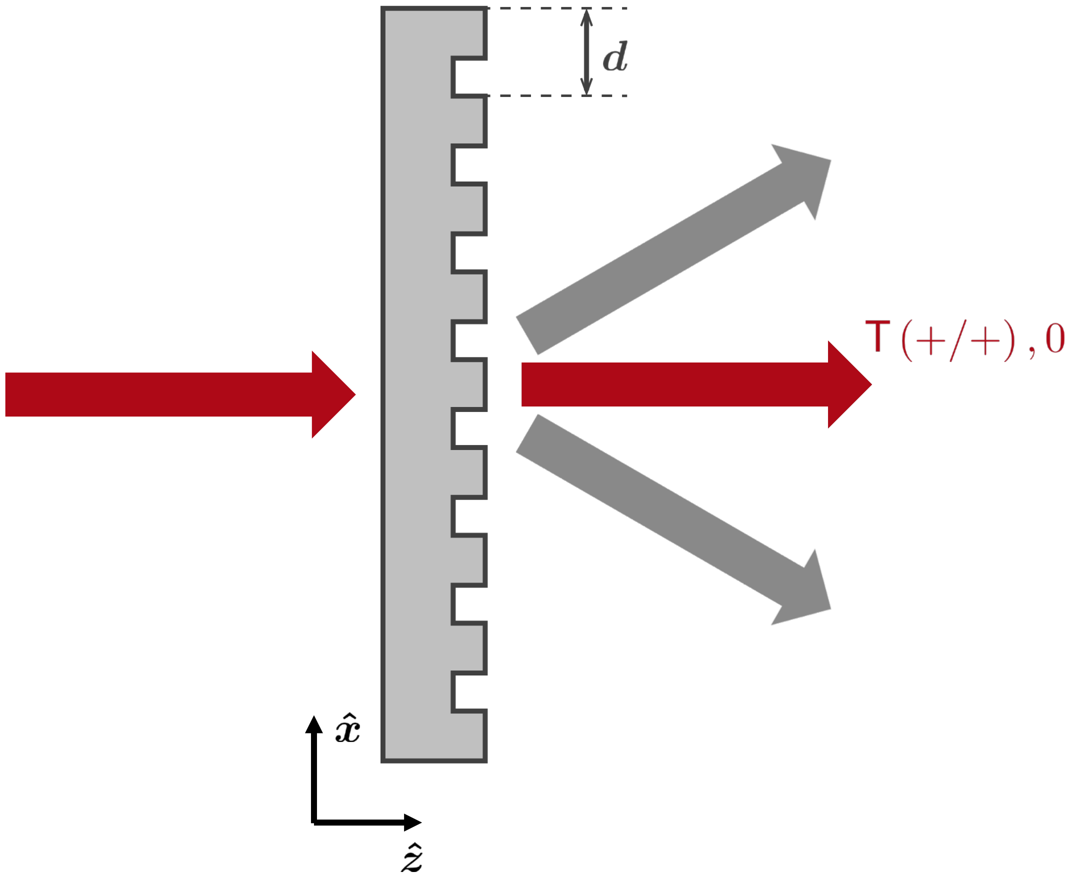
Grating Channels



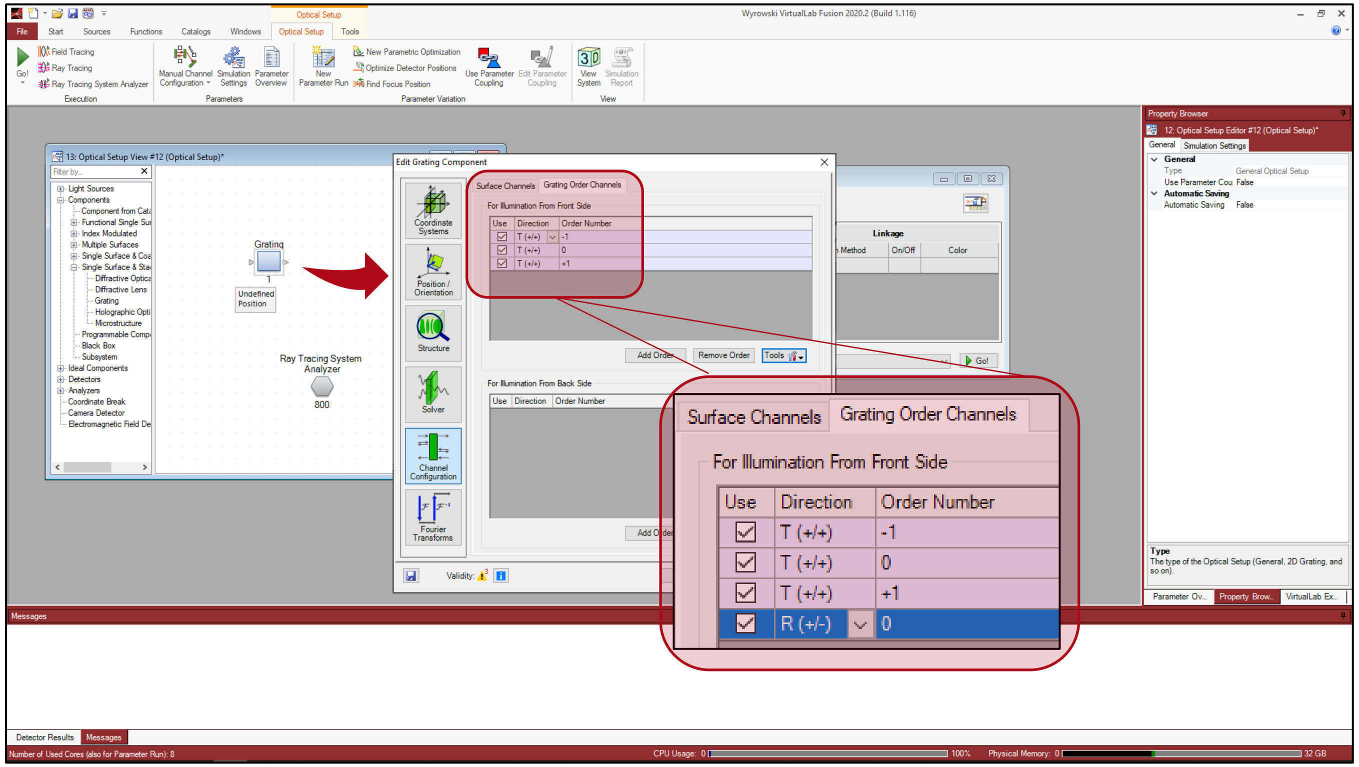


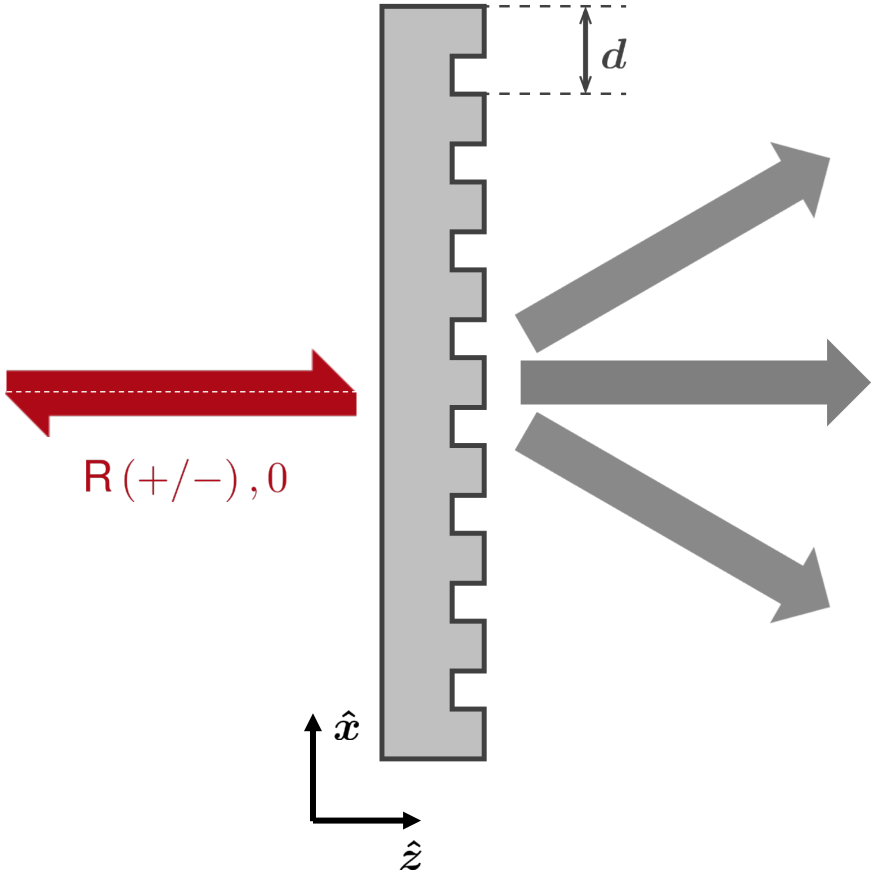
Grating Channels



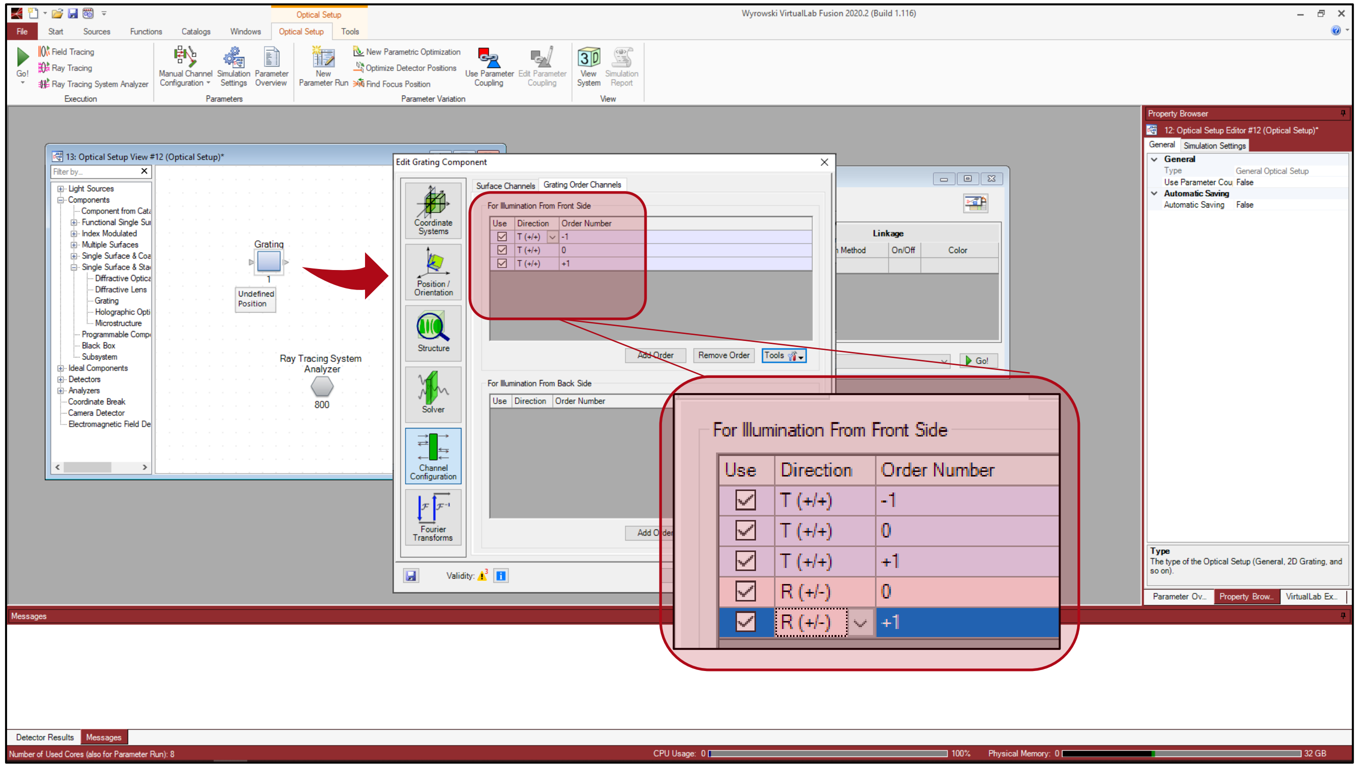


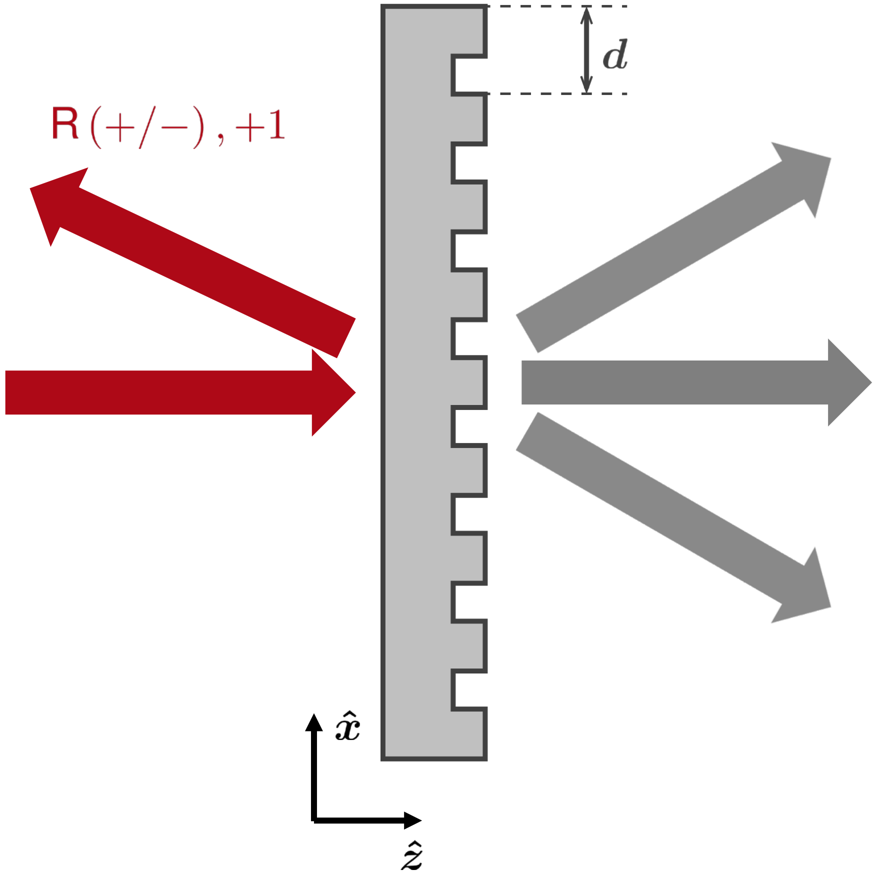
Grating Channels



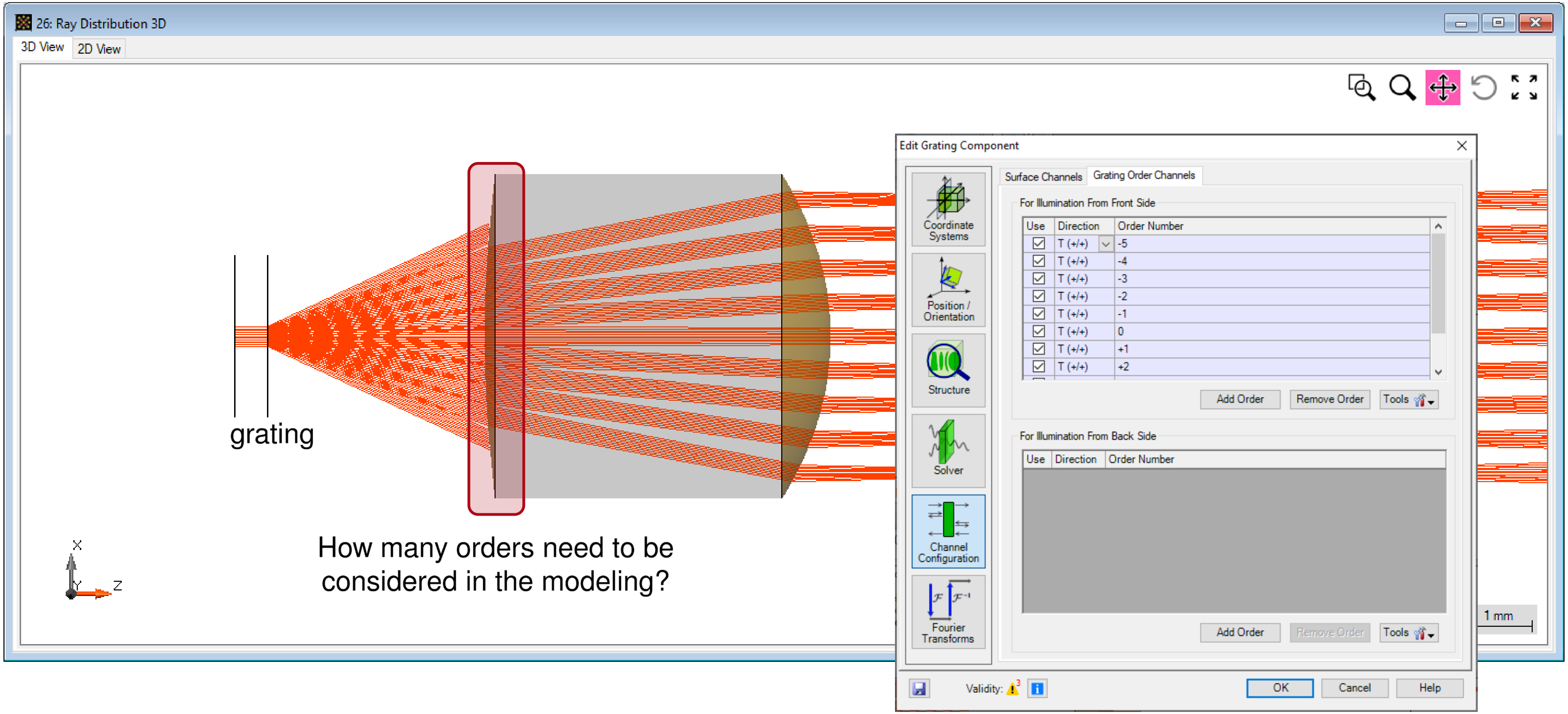


Grating Channels



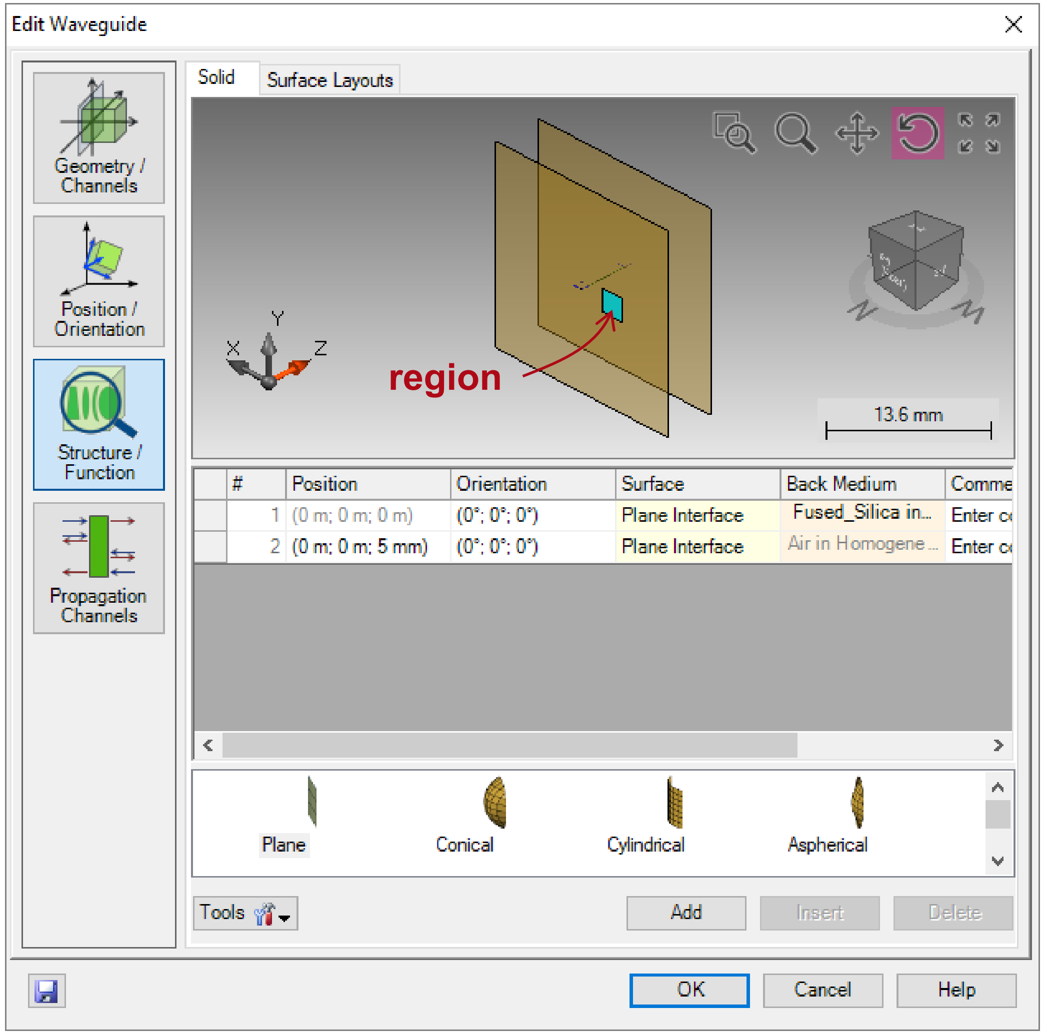


Grating Channels in Abbe's Experiment



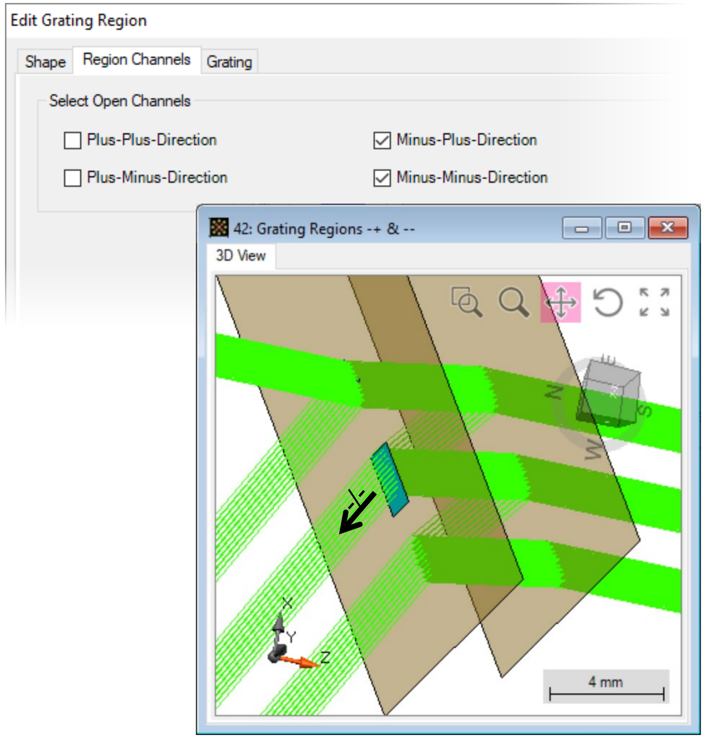
Lateral Channels

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



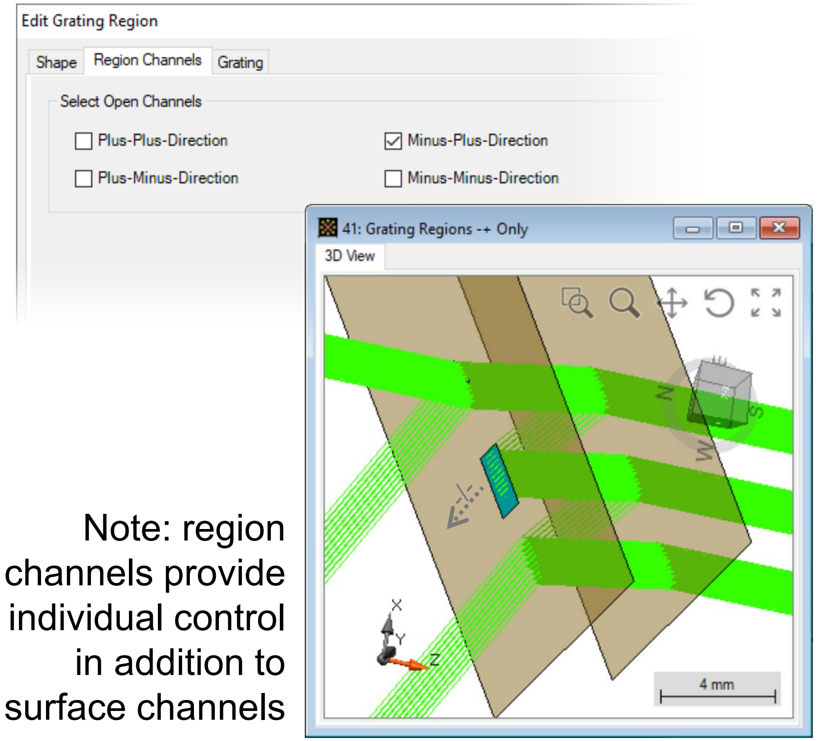
Lateral Channels

- 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



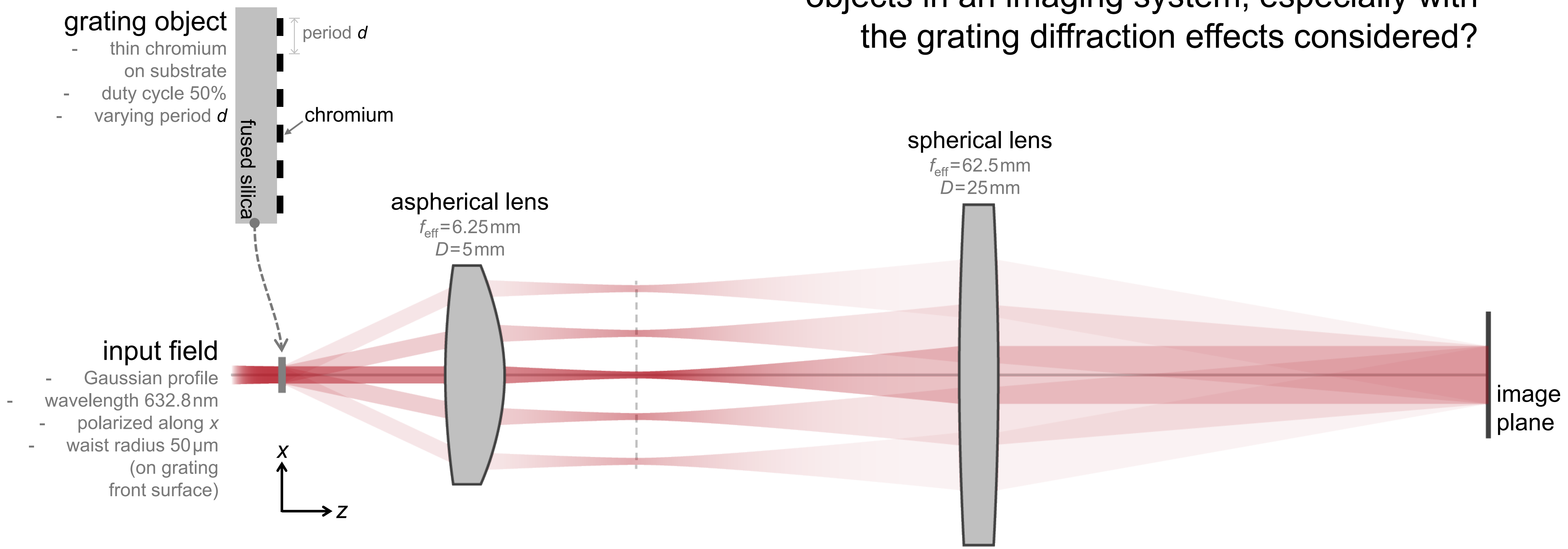
region channel -/+ on

Demonstration of Abbe's Theory of Image Formation

see the full Application Use Case

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

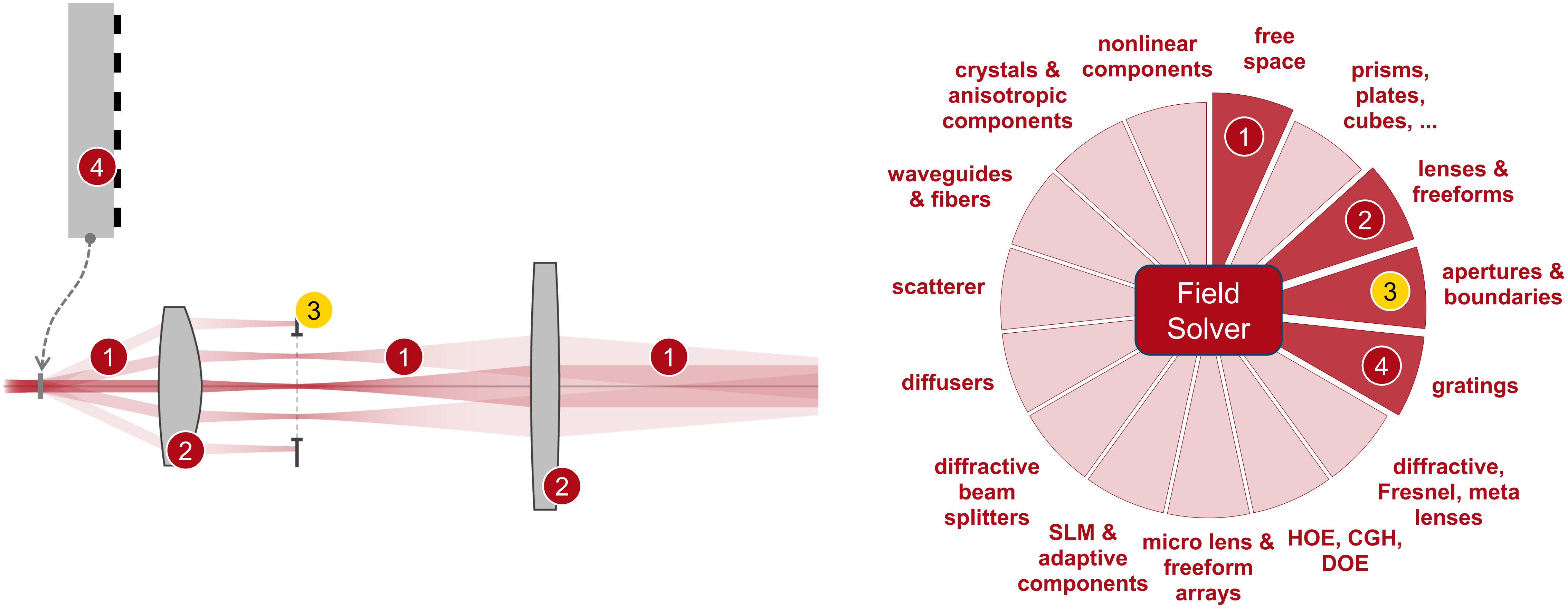
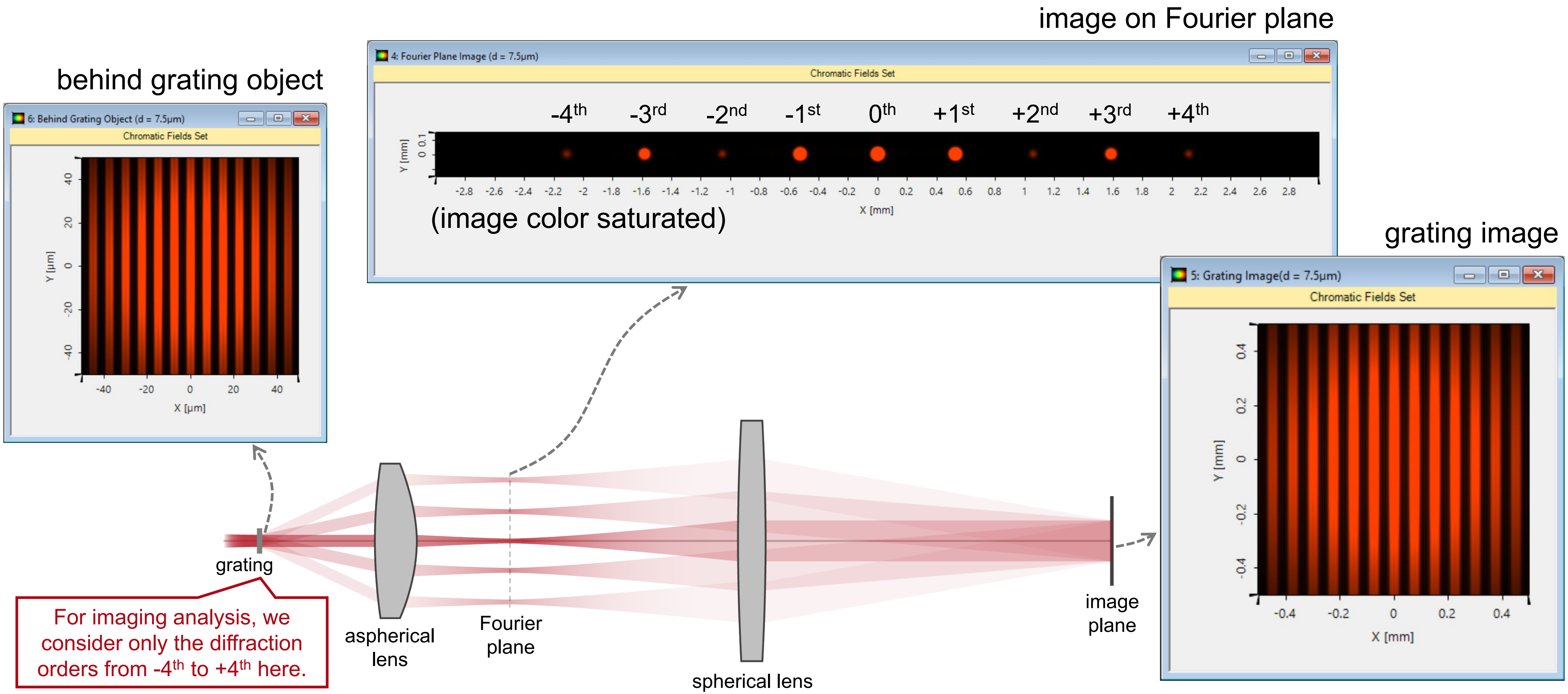
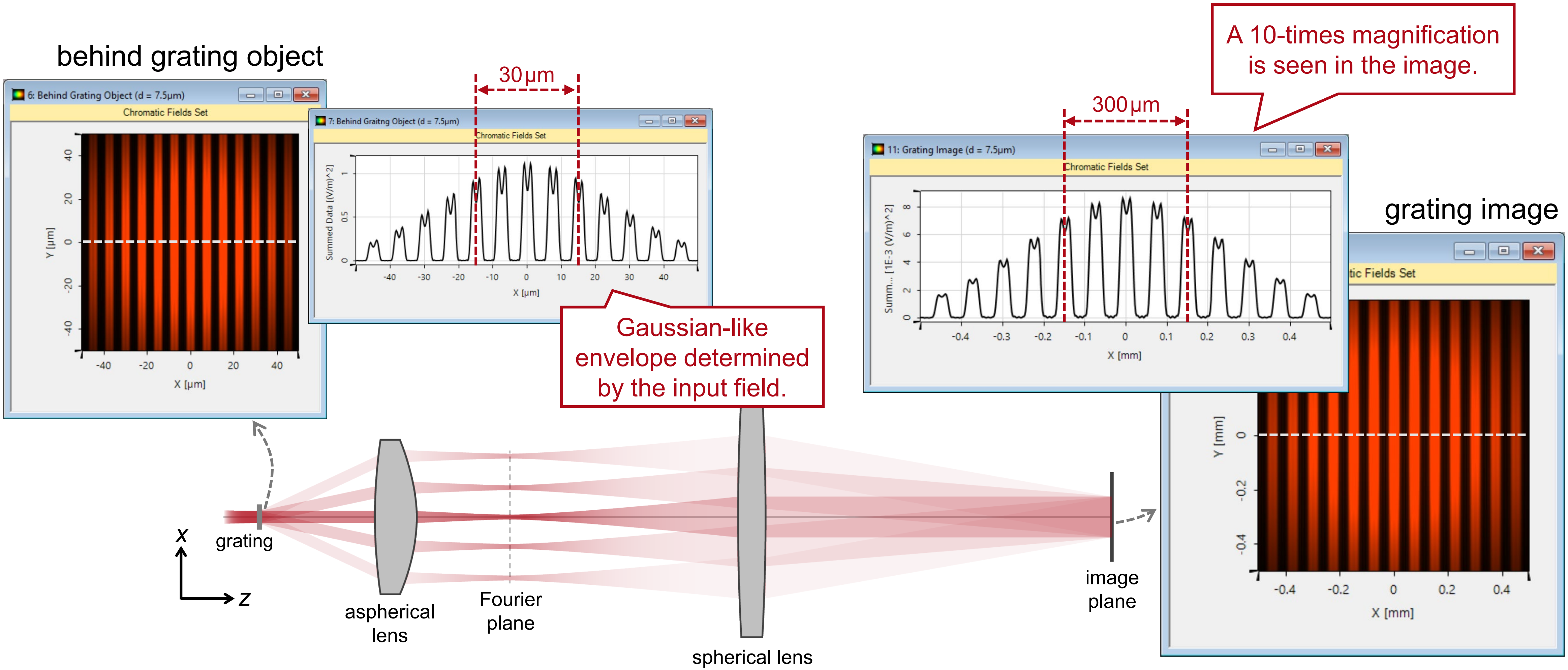


Image Formation Analysis

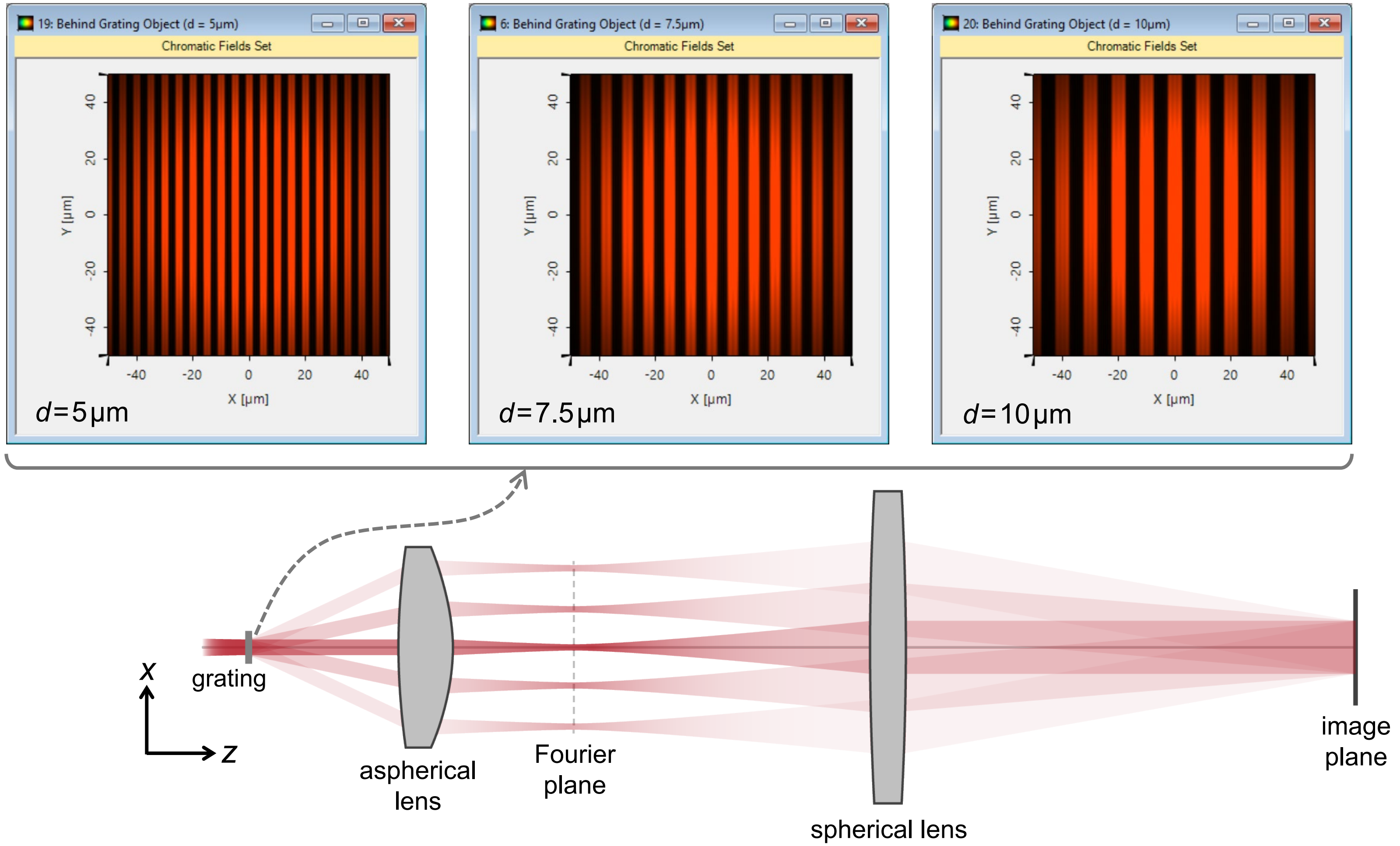


For imaging analysis, we consider only the diffraction orders from -4th to +4th here.

Image Formation Analysis



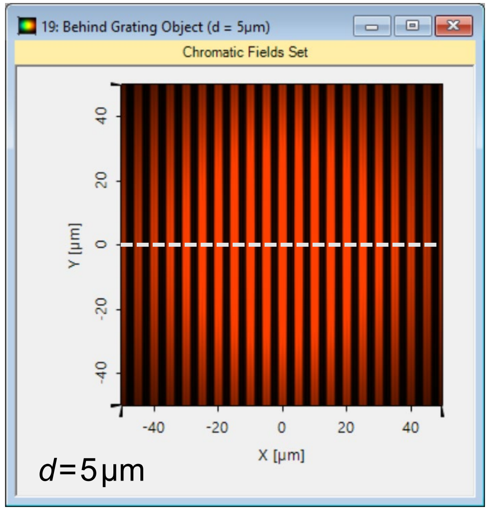
Behind Grating Objects with Different Periods

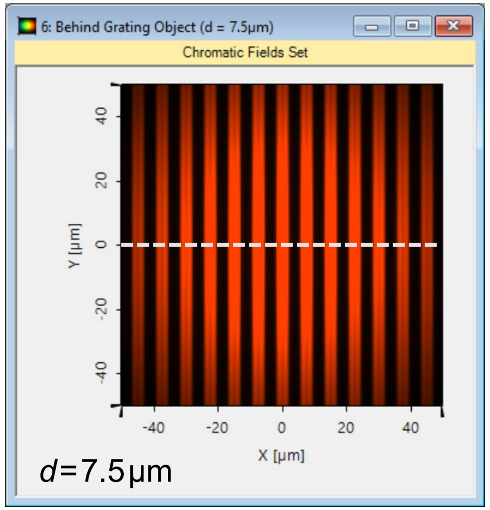


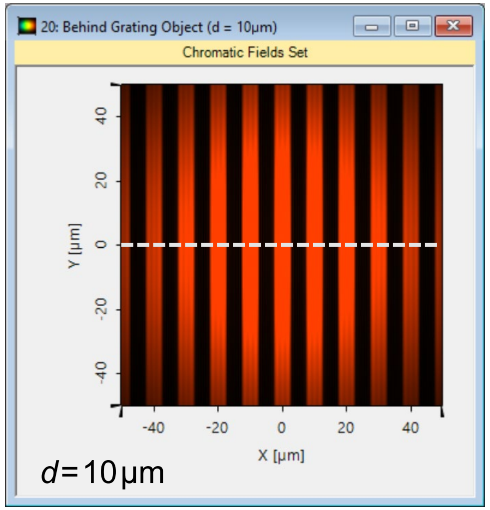
For imaging analysis, we consider only the diffraction orders that will enter the subsequent system:

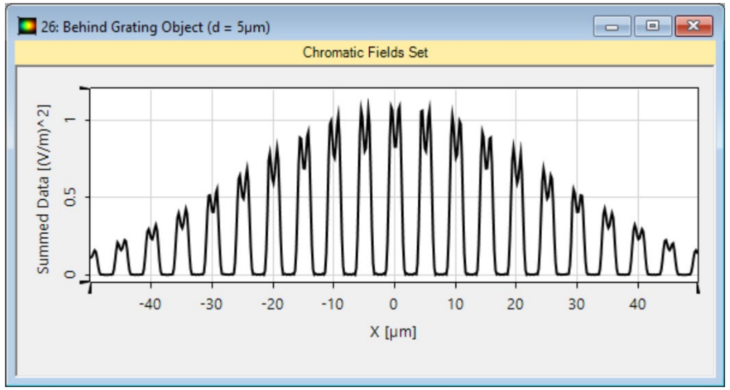
- d=5µm: -3rd to +3rd orders
- d=7.5µm: -4th to +4th orders
- d=10µm: -6th to +6th orders

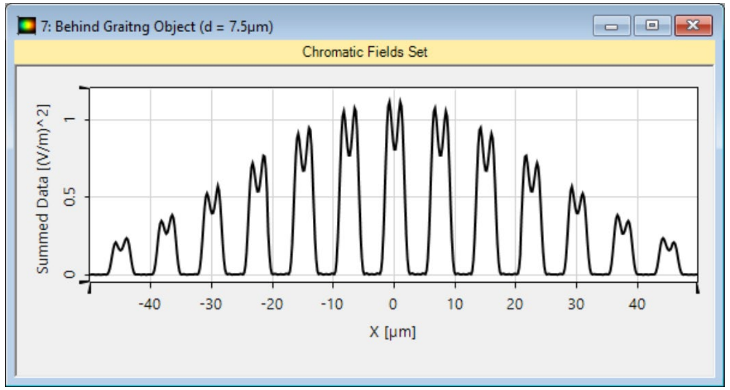
Behind Grating Objects with Different Periods

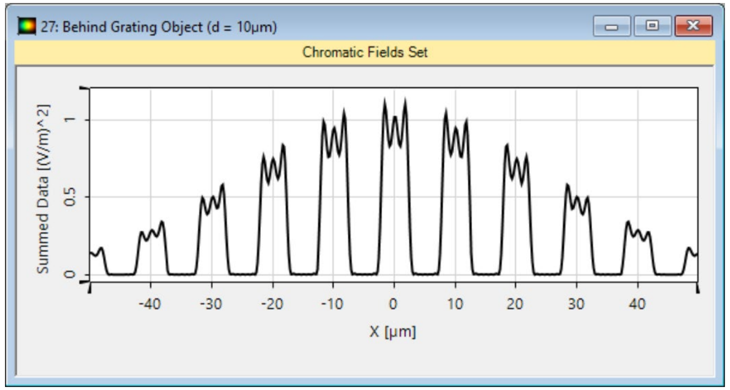






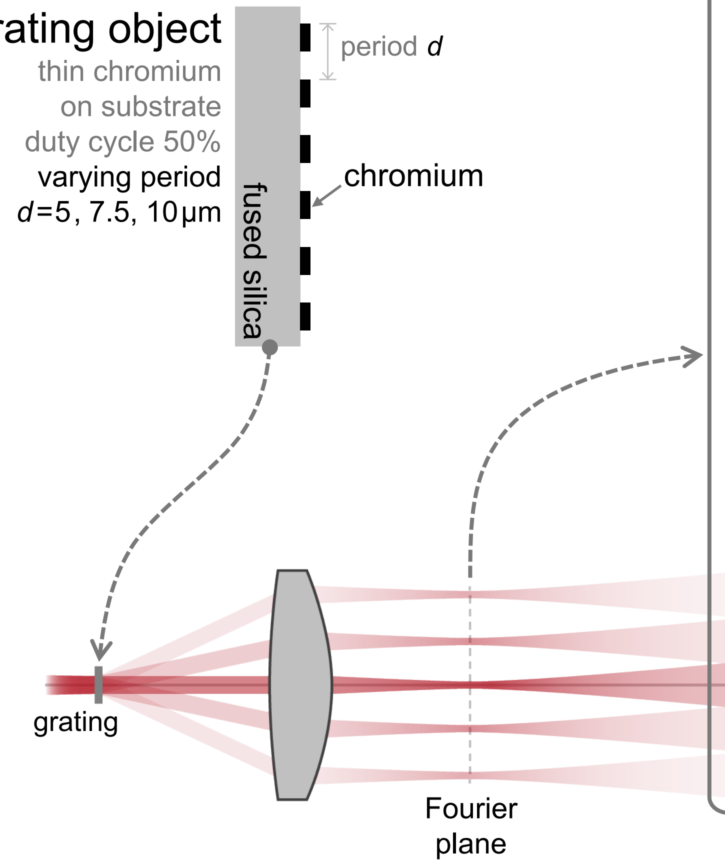






Fourier Plane Images for Different Periods

grating object
- thin chromium on substrate
- duty cycle 50%
- varying period d=5, 7.5, 10 µm



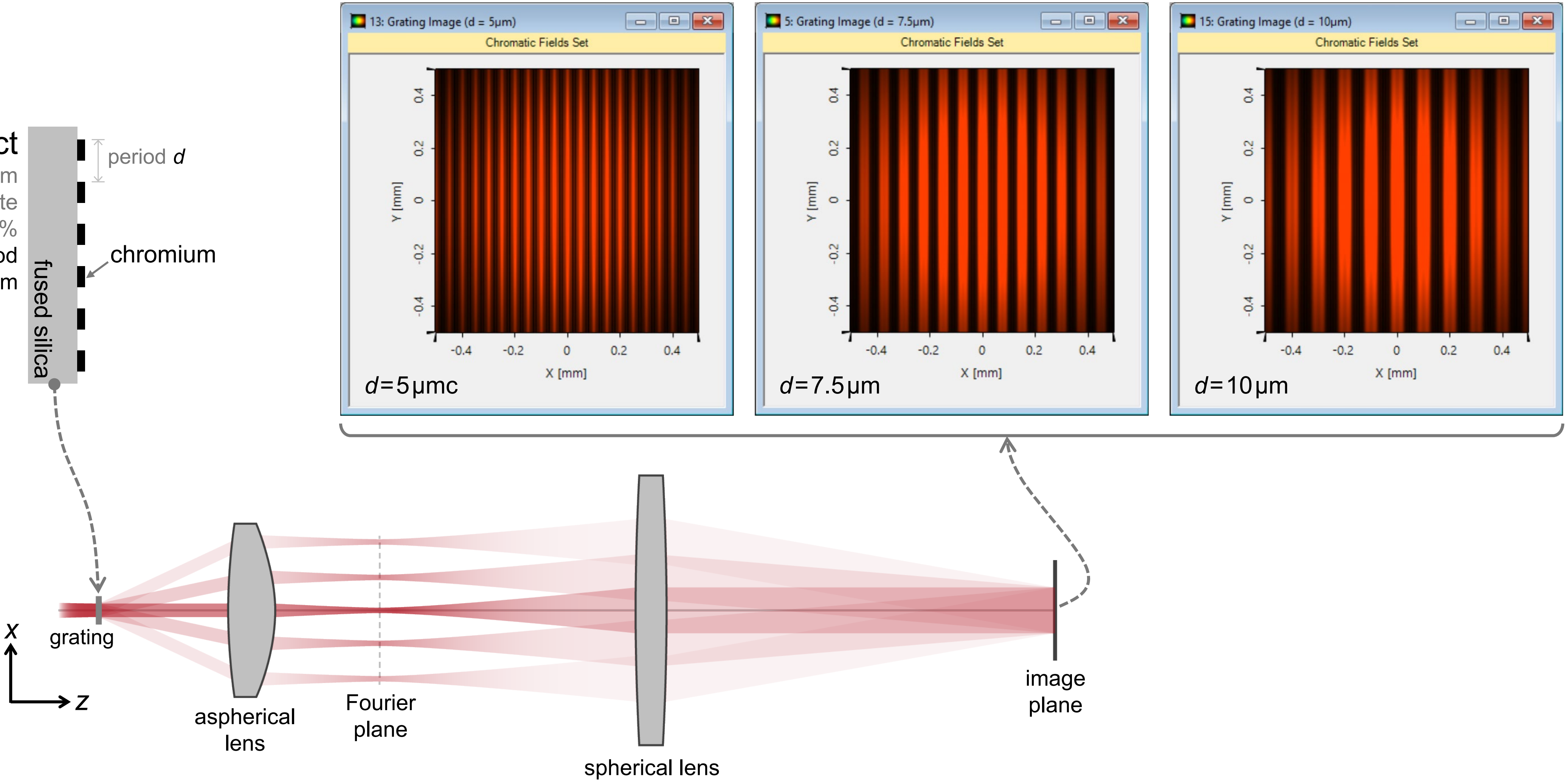
images on Fourier plane

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

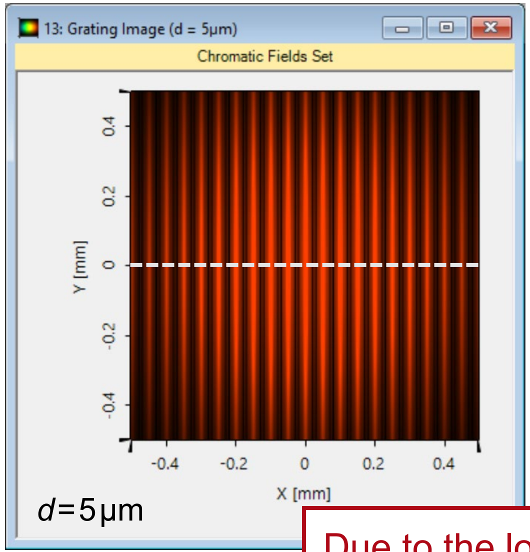
Grating Images for Different Periods

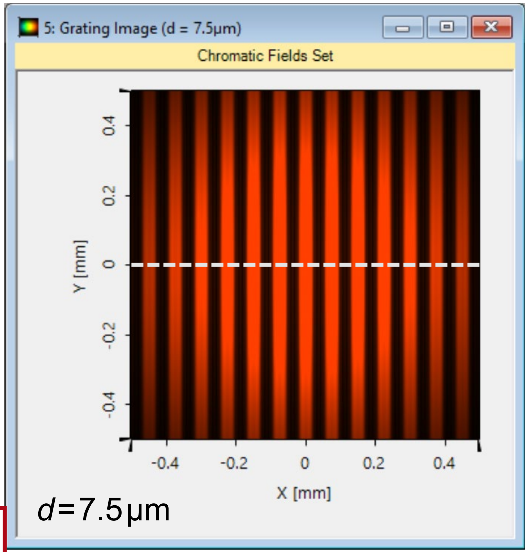
grating object

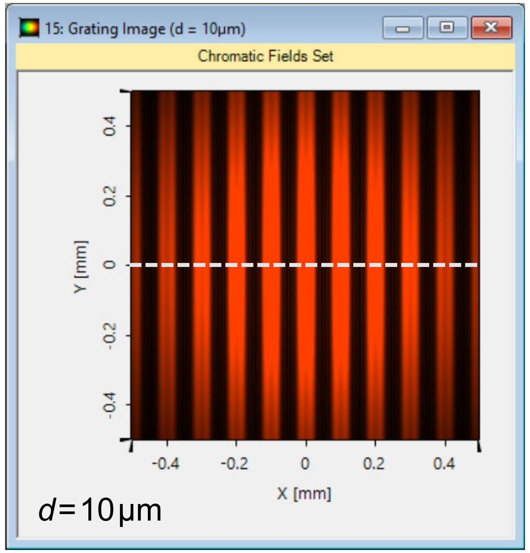
- thin chromium on substrate
- duty cycle 50%
- varying period d=5, 7.5, 10μm



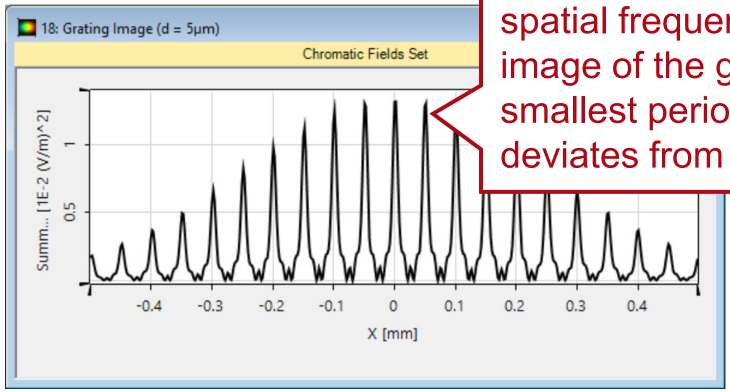
Grating Images for Different Periods

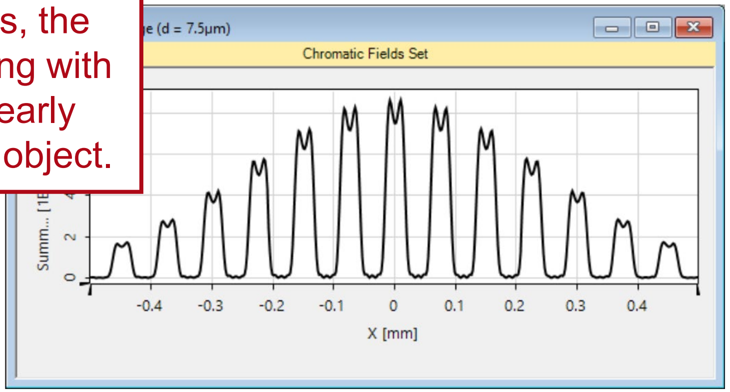


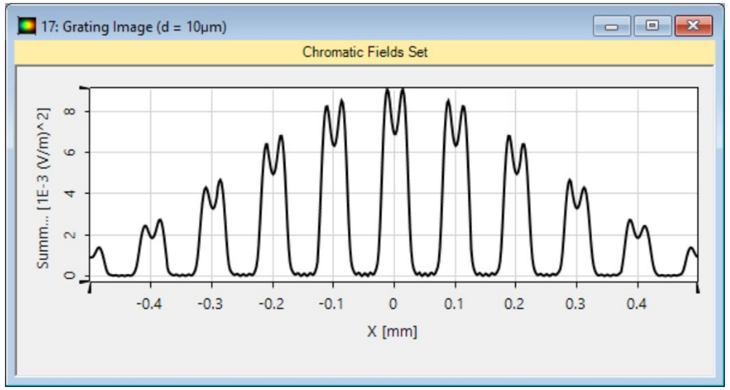




Due to the loss of high spatial frequencies, the image of the grating with smallest period clearly deviates from the object.

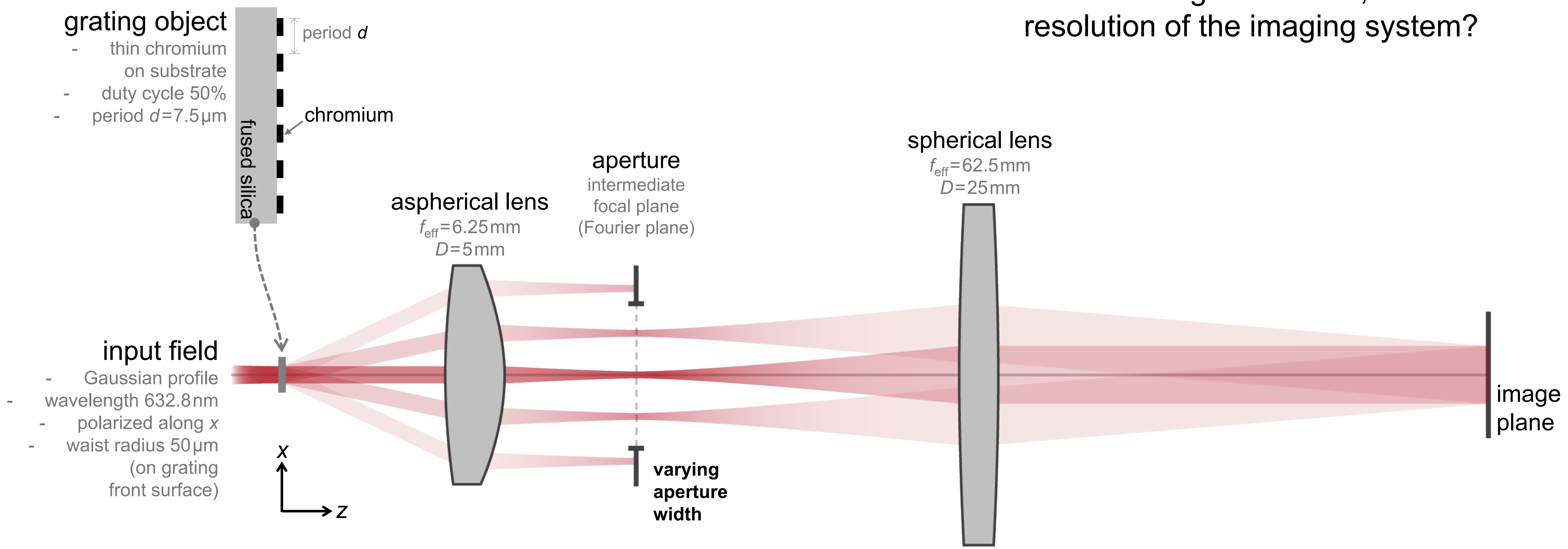






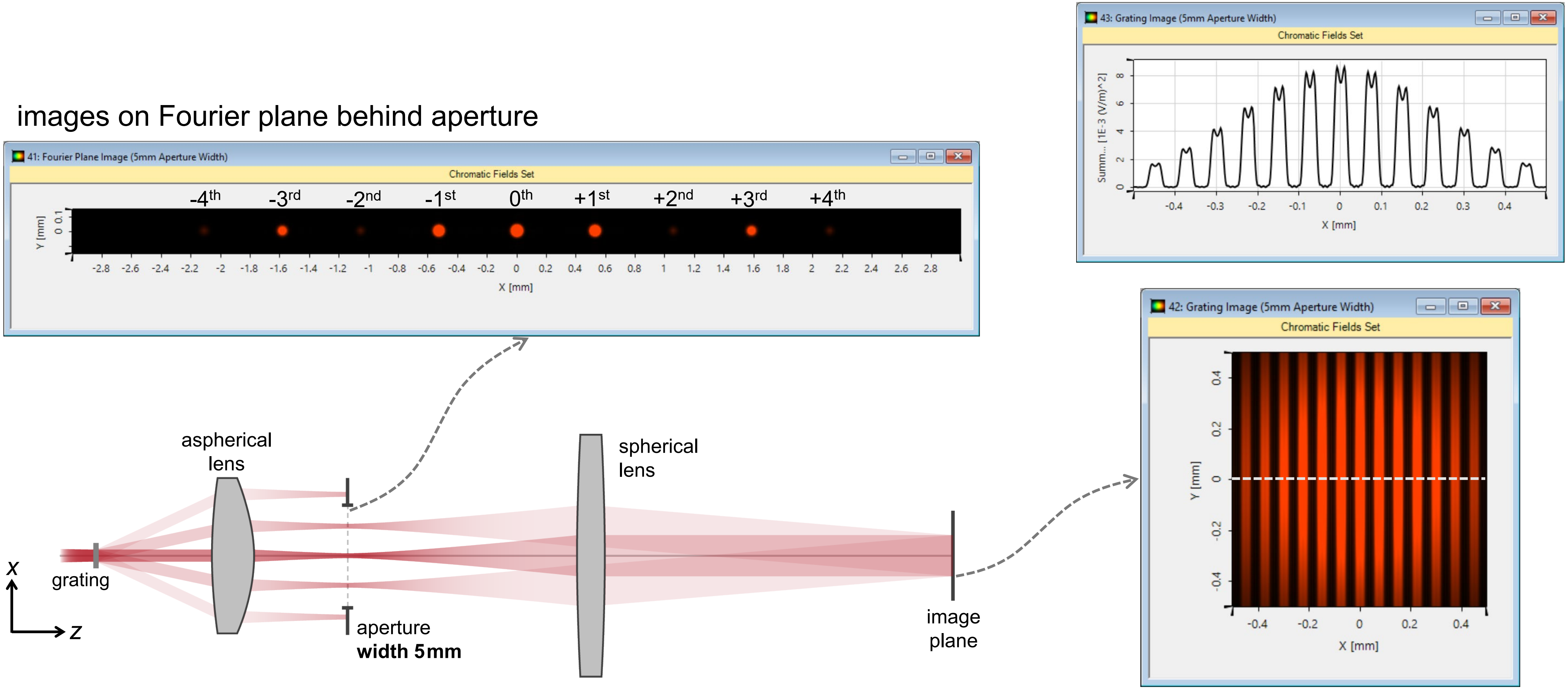
Modeling Task – Aperture Effect in Fourier Plane

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



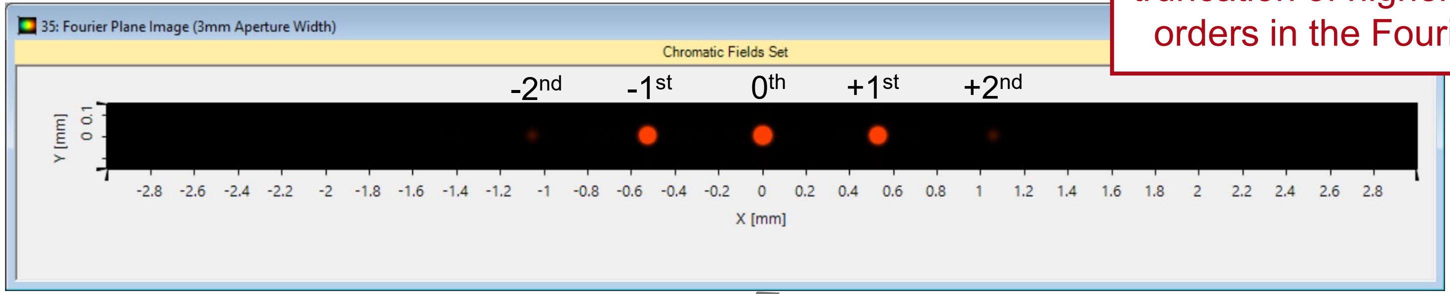
Aperture Width 5mm

images on Fourier plane behind aperture

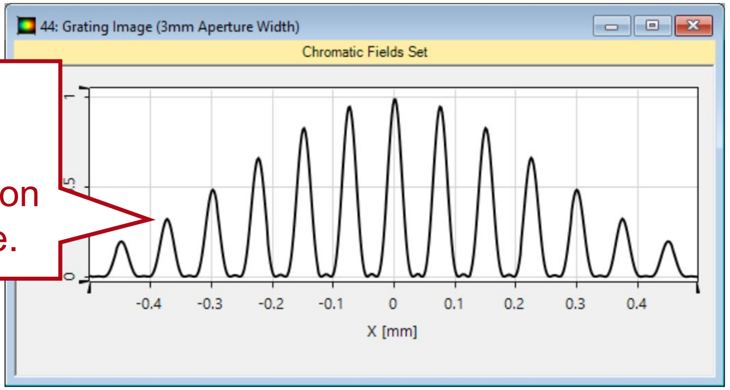


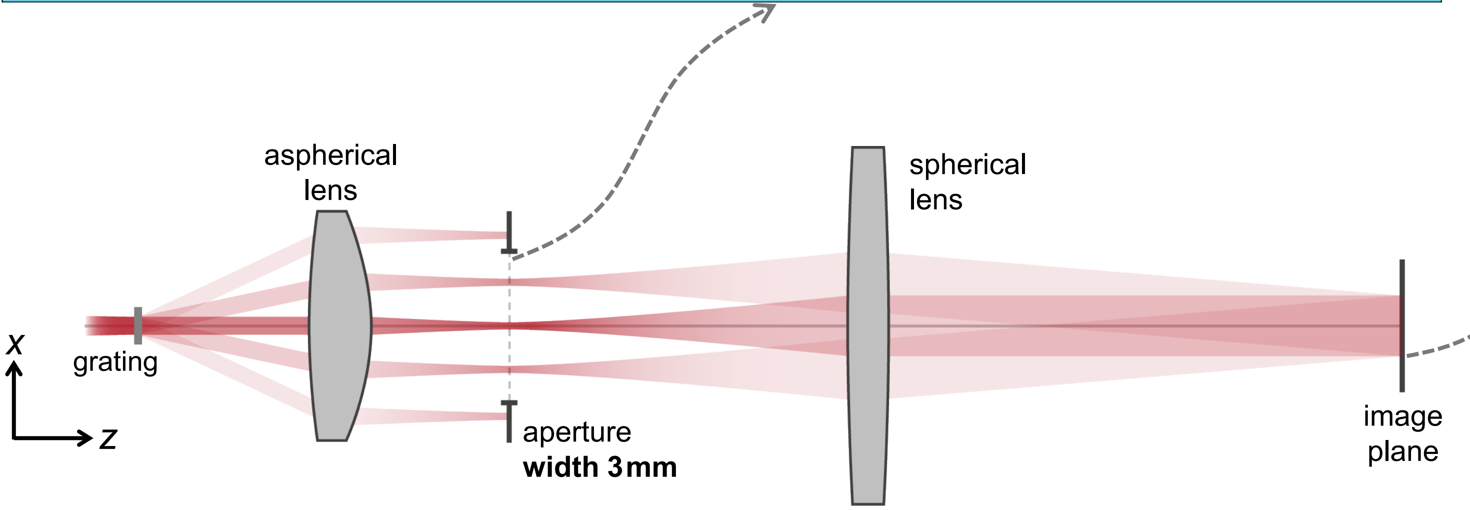
Aperture Width 3 mm

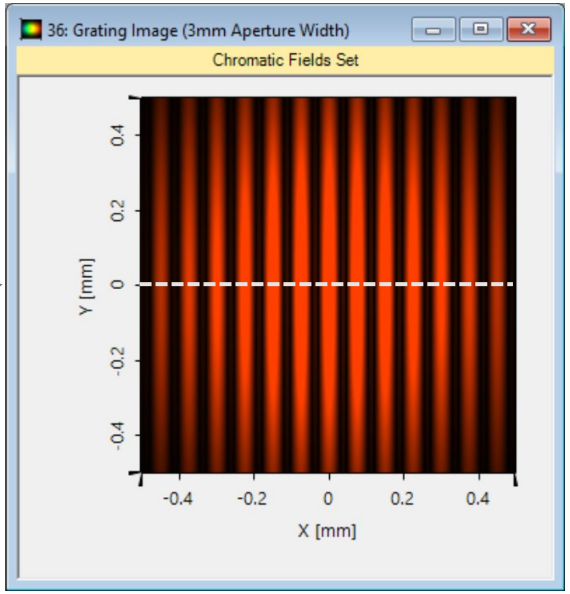
images on Fourier plane behind aperture



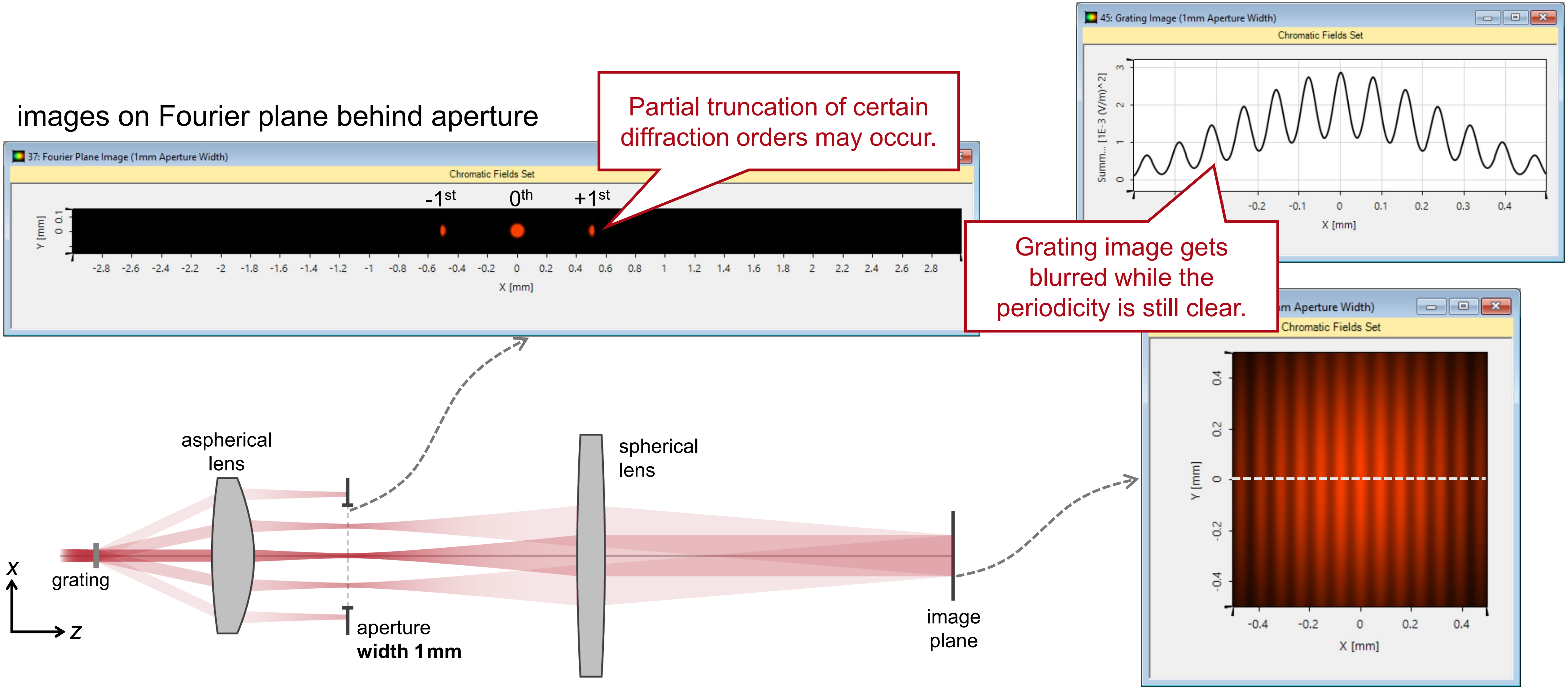
The grating image gets smoother because of the truncation of higher diffraction orders in the Fourier plane.





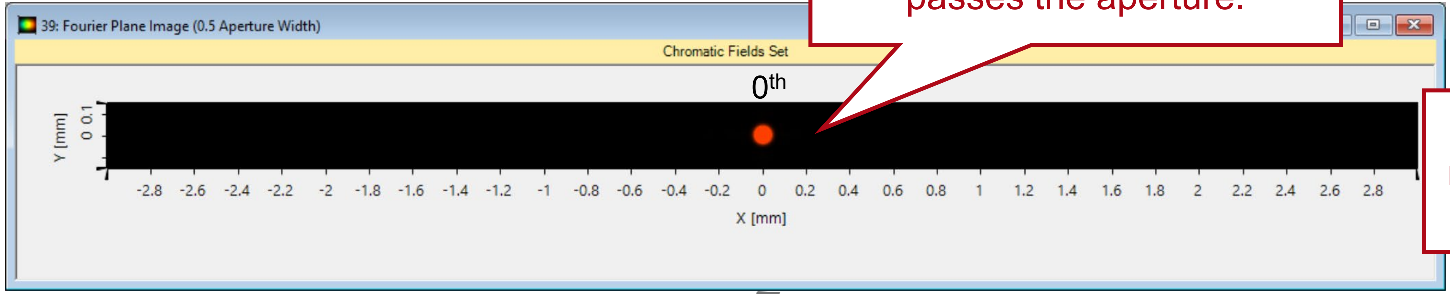


Aperture Width 1 mm

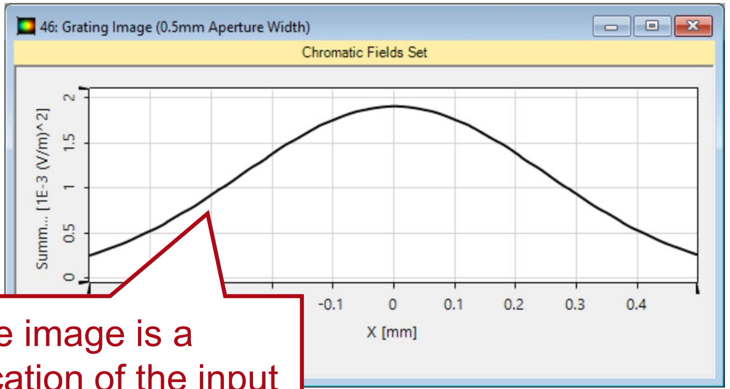


Aperture Width 0.5mm

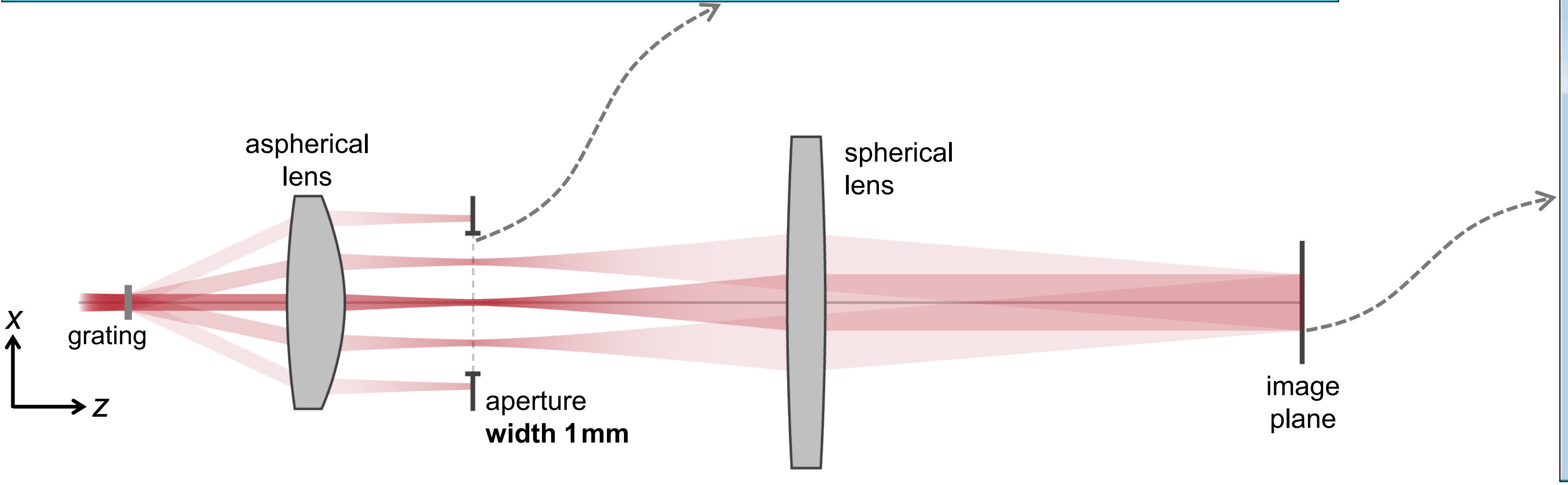
images on Fourier plane behind aperture

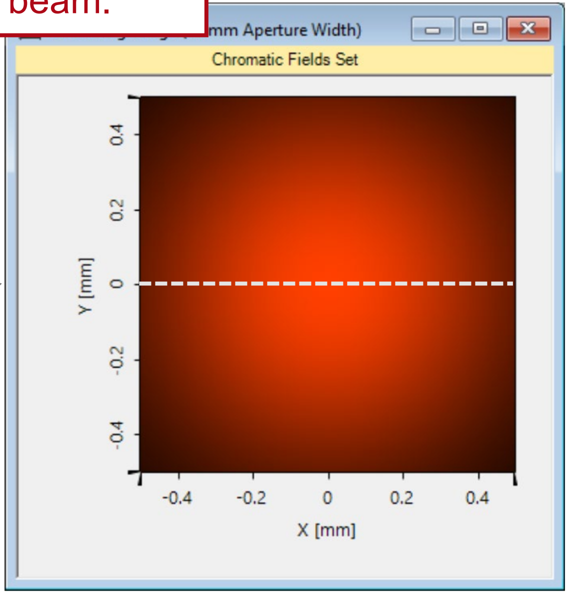


Only the 0th diffraction order passes the aperture.



The image is a magnification of the input Gaussian beam.



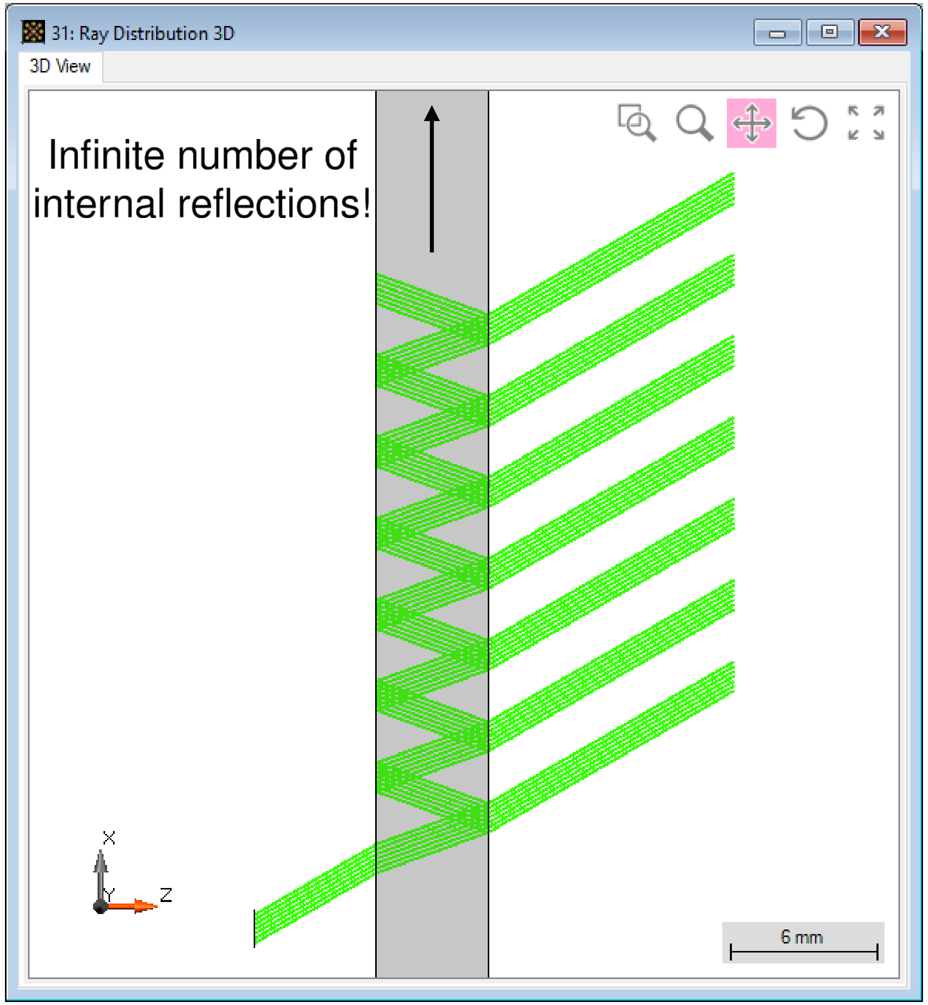


Part 5

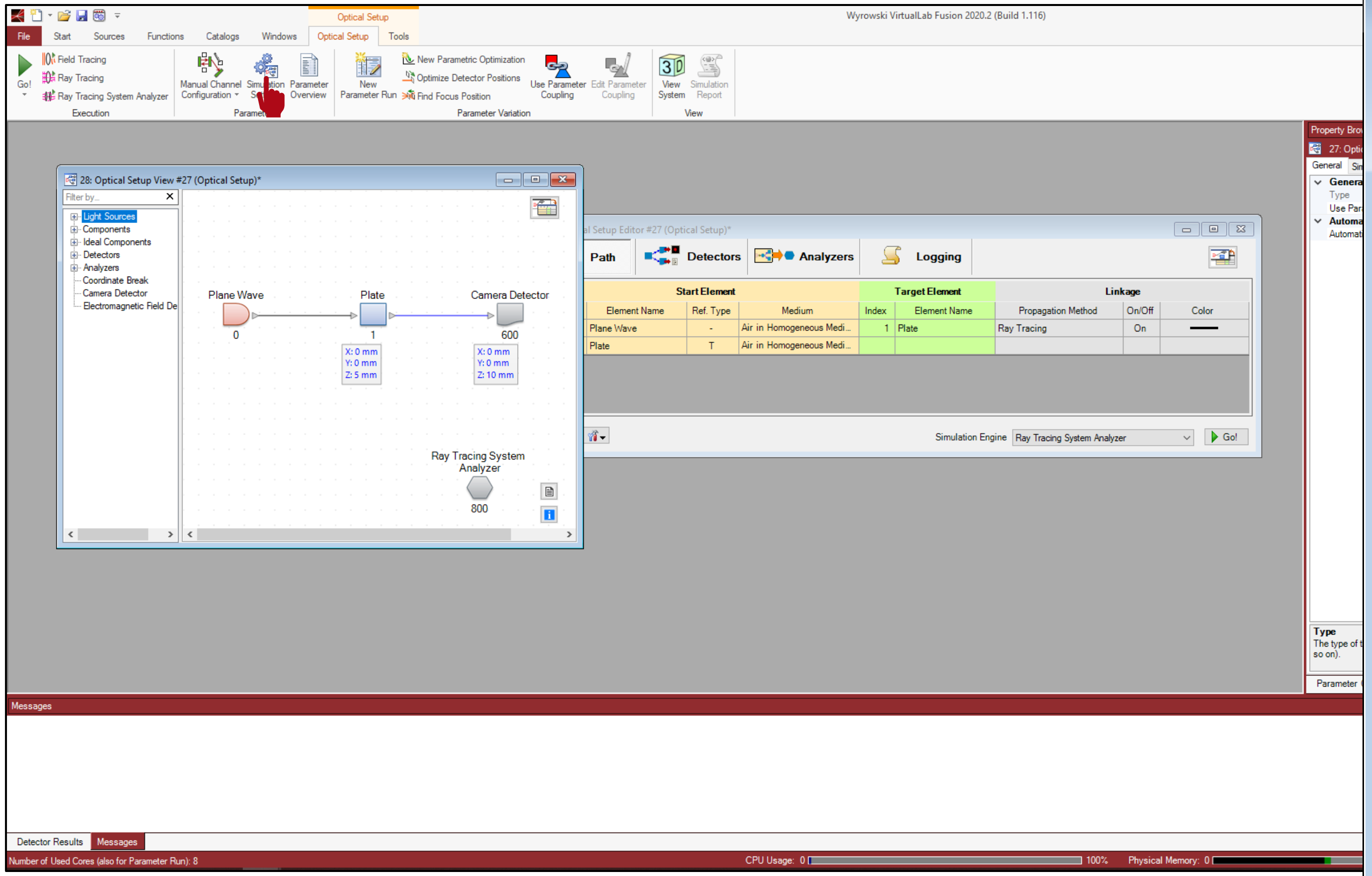
The Light Path Finder

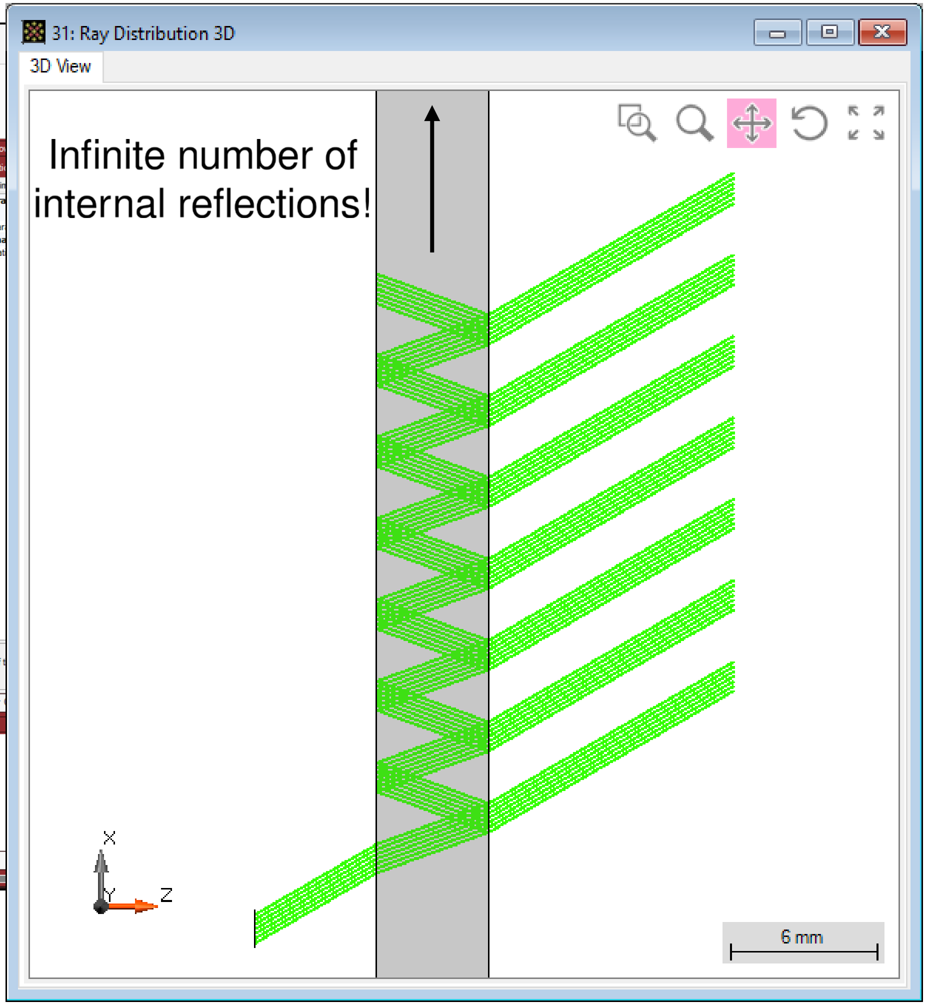
The Light Path Finder

- 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.

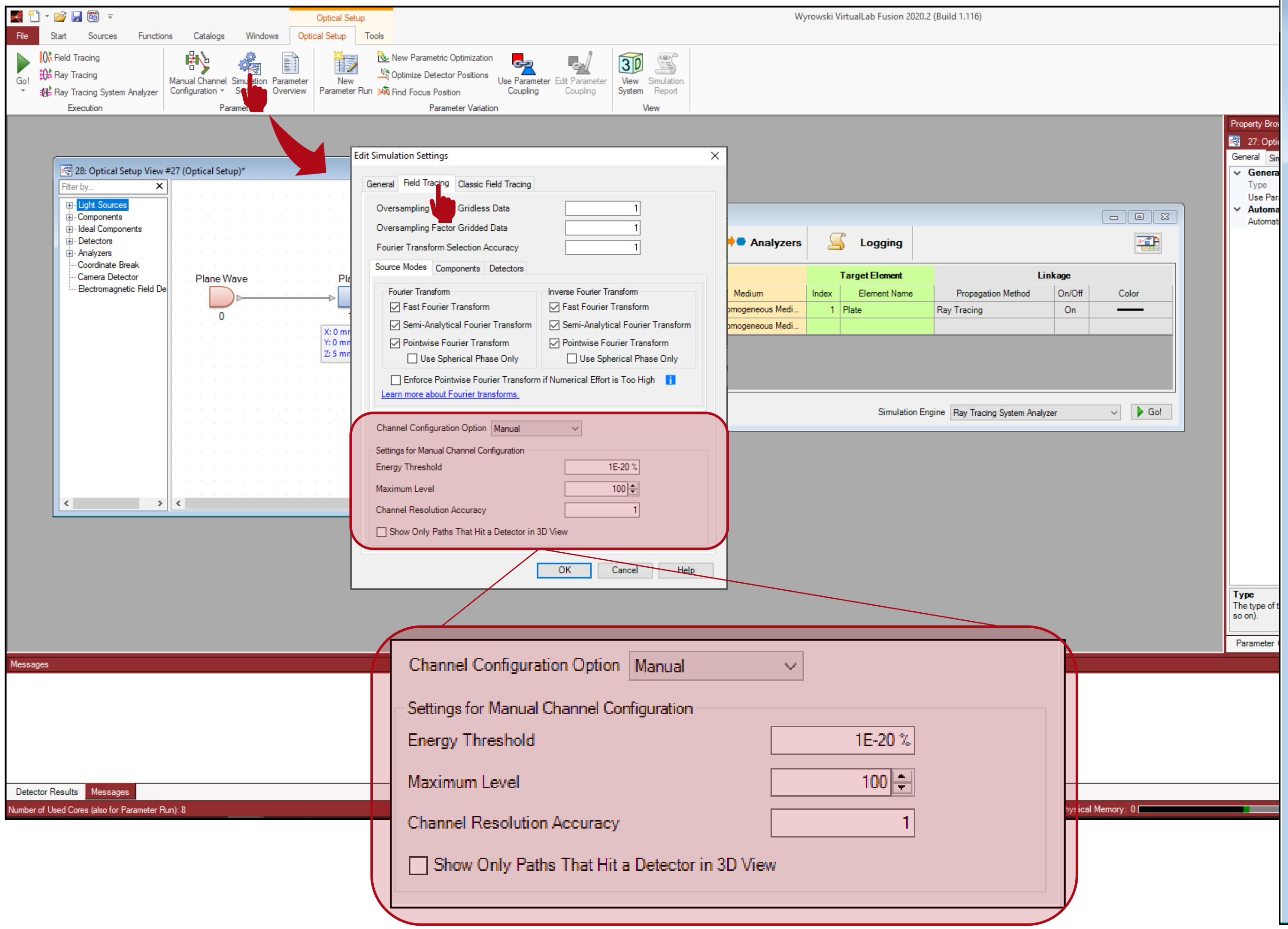


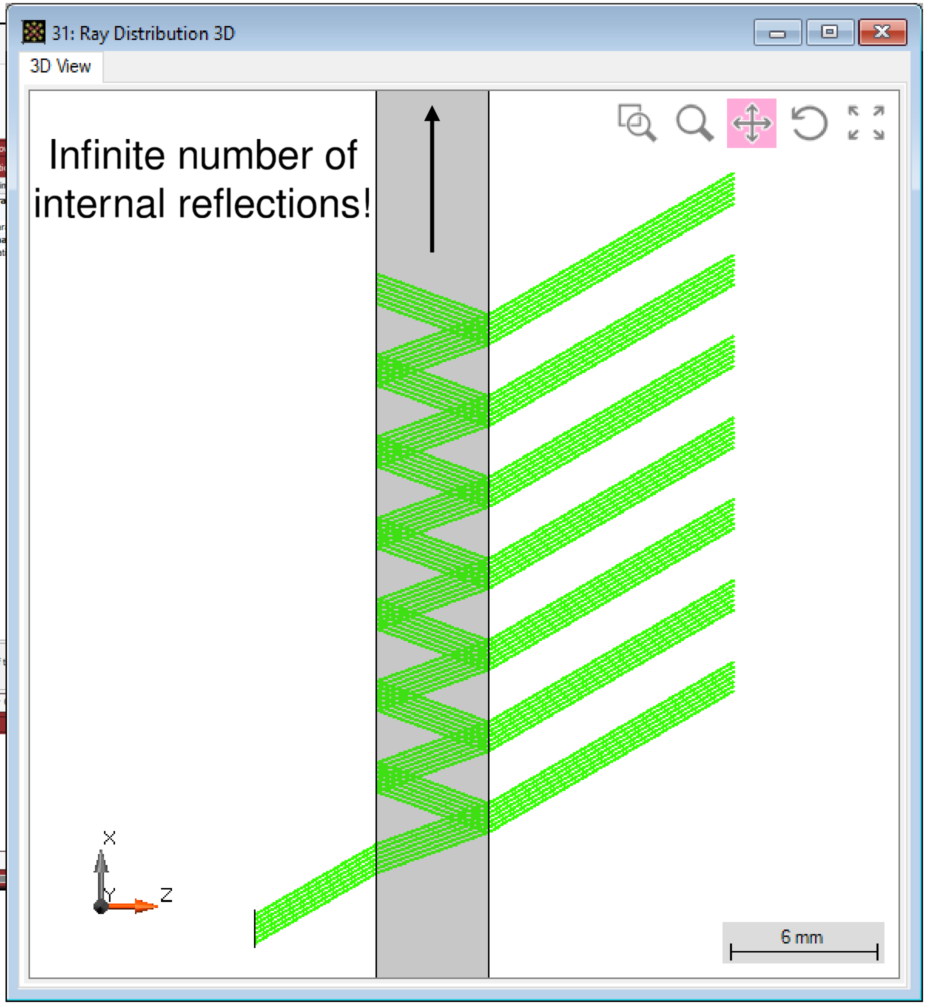
The Light Path Finder



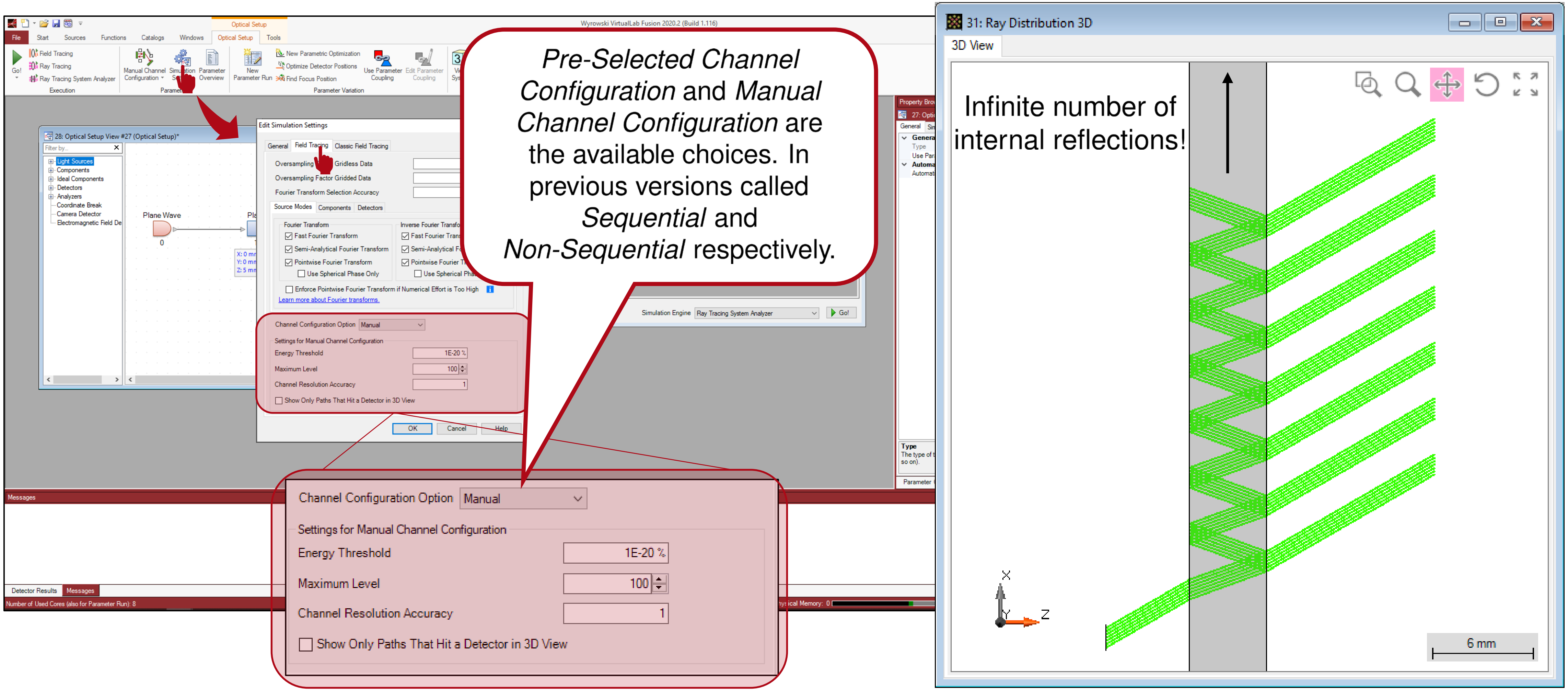


The Light Path Finder

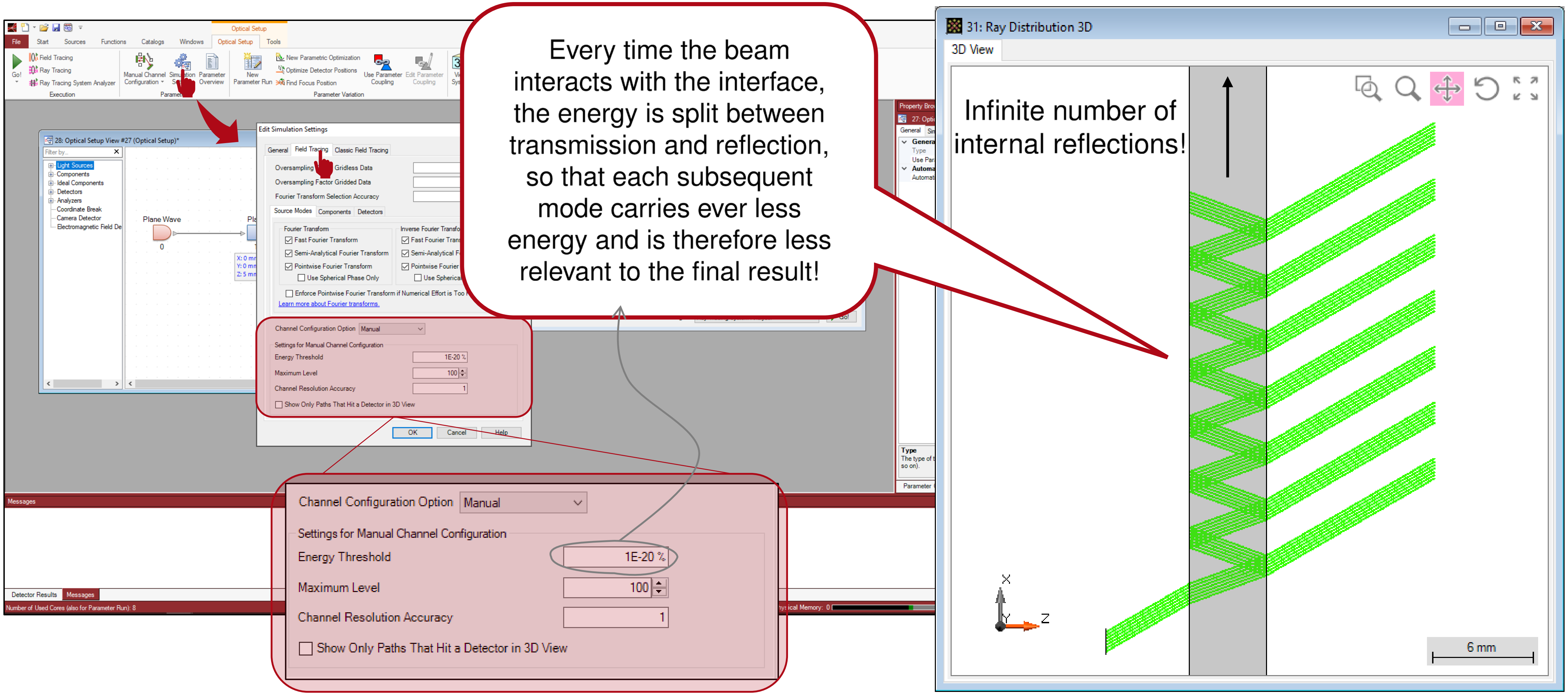




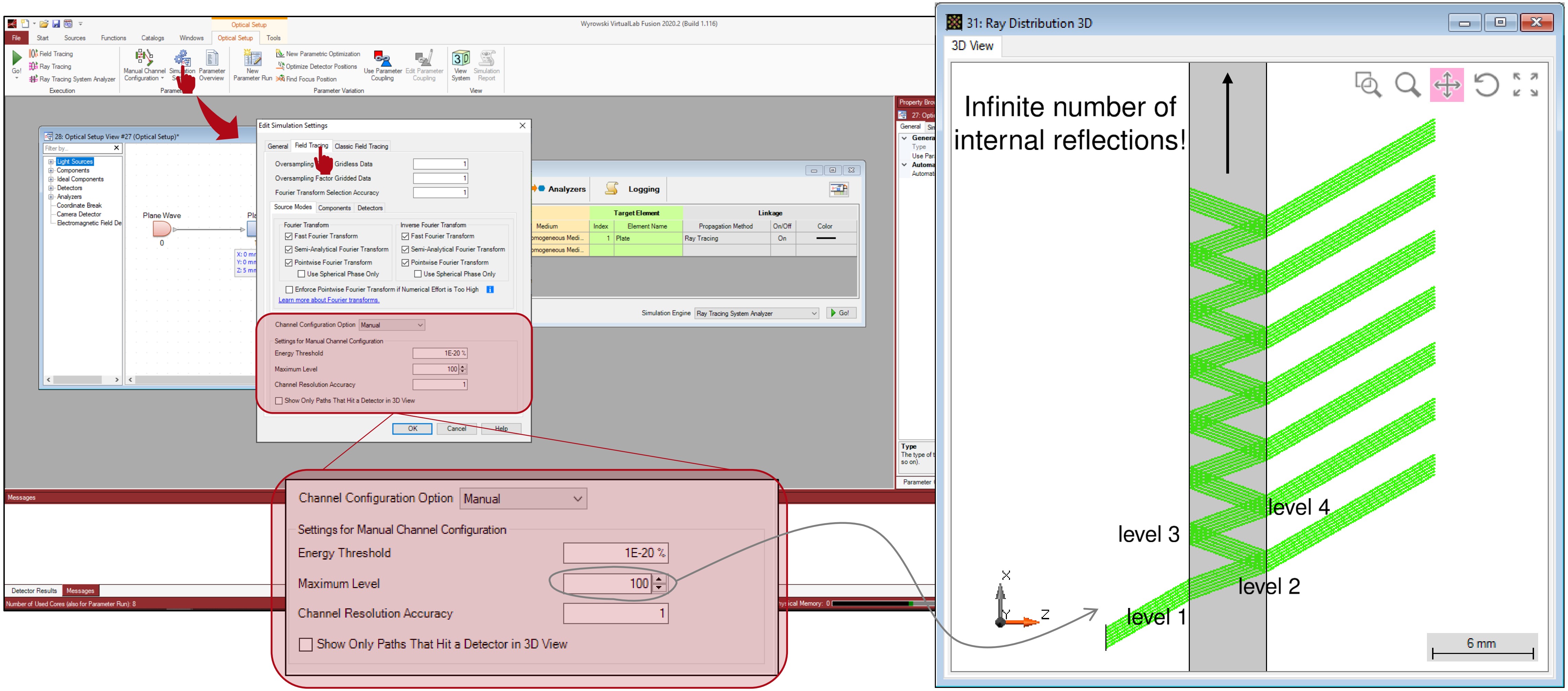
The Light Path Finder



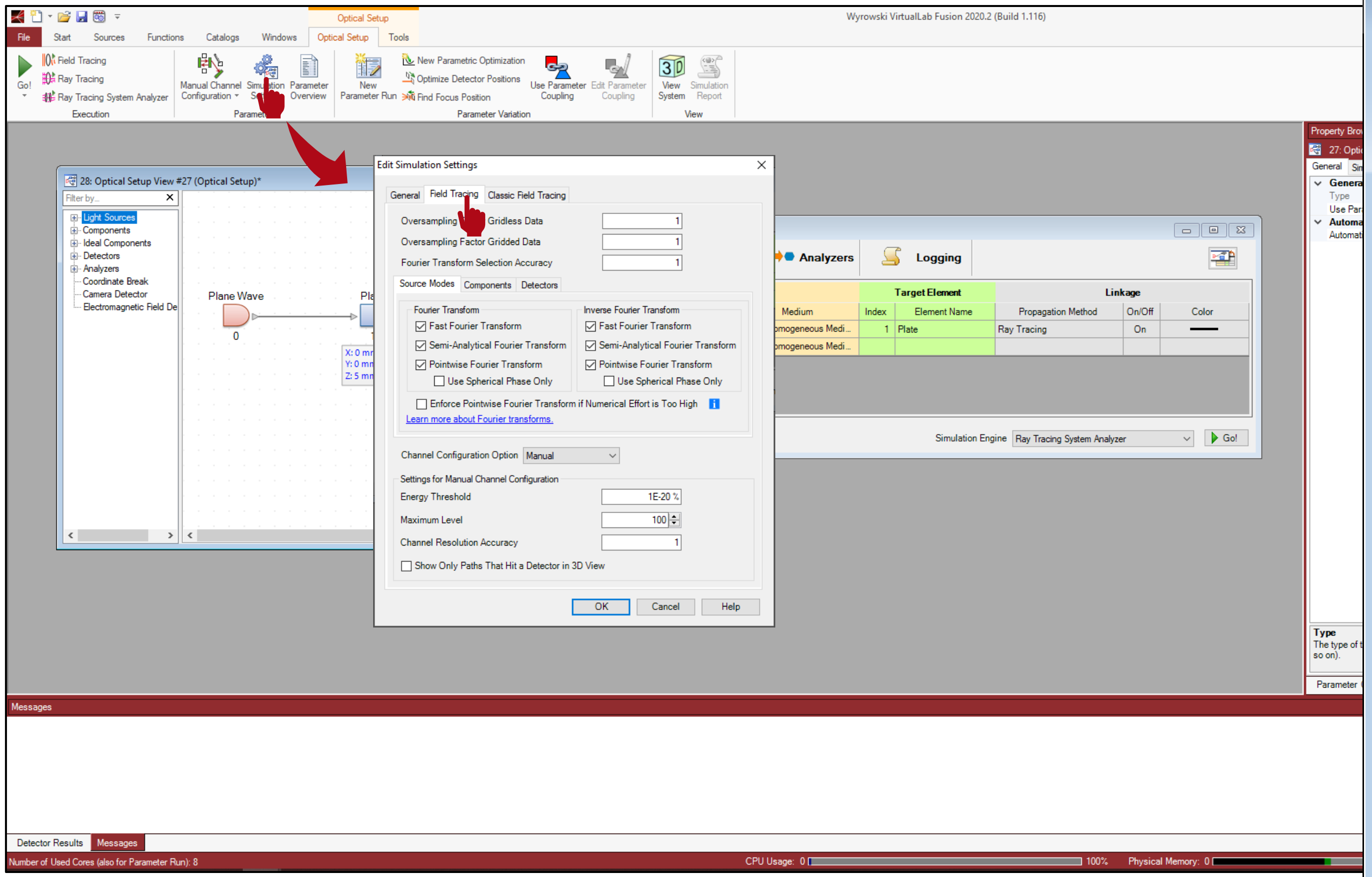
The Light Path Finder

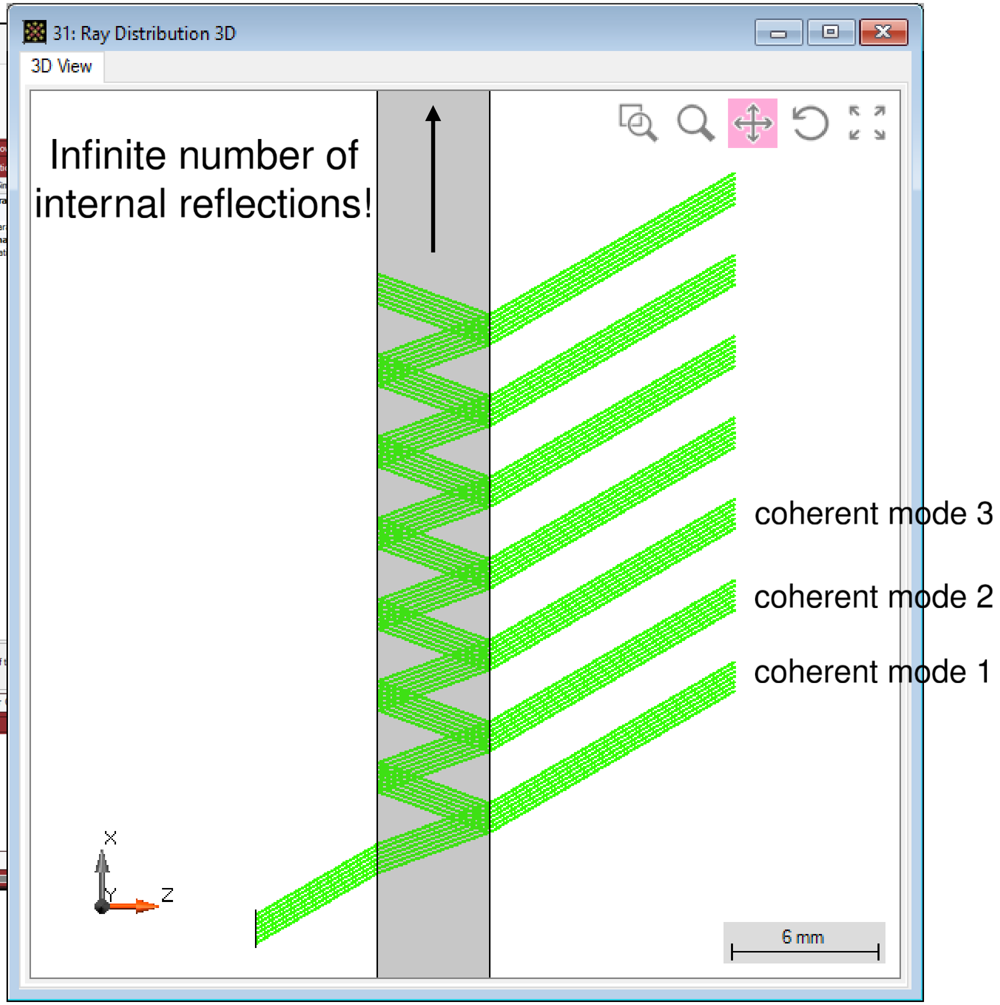


The Light Path Finder



The Light Path Finder and the Modes Reaching the Detector

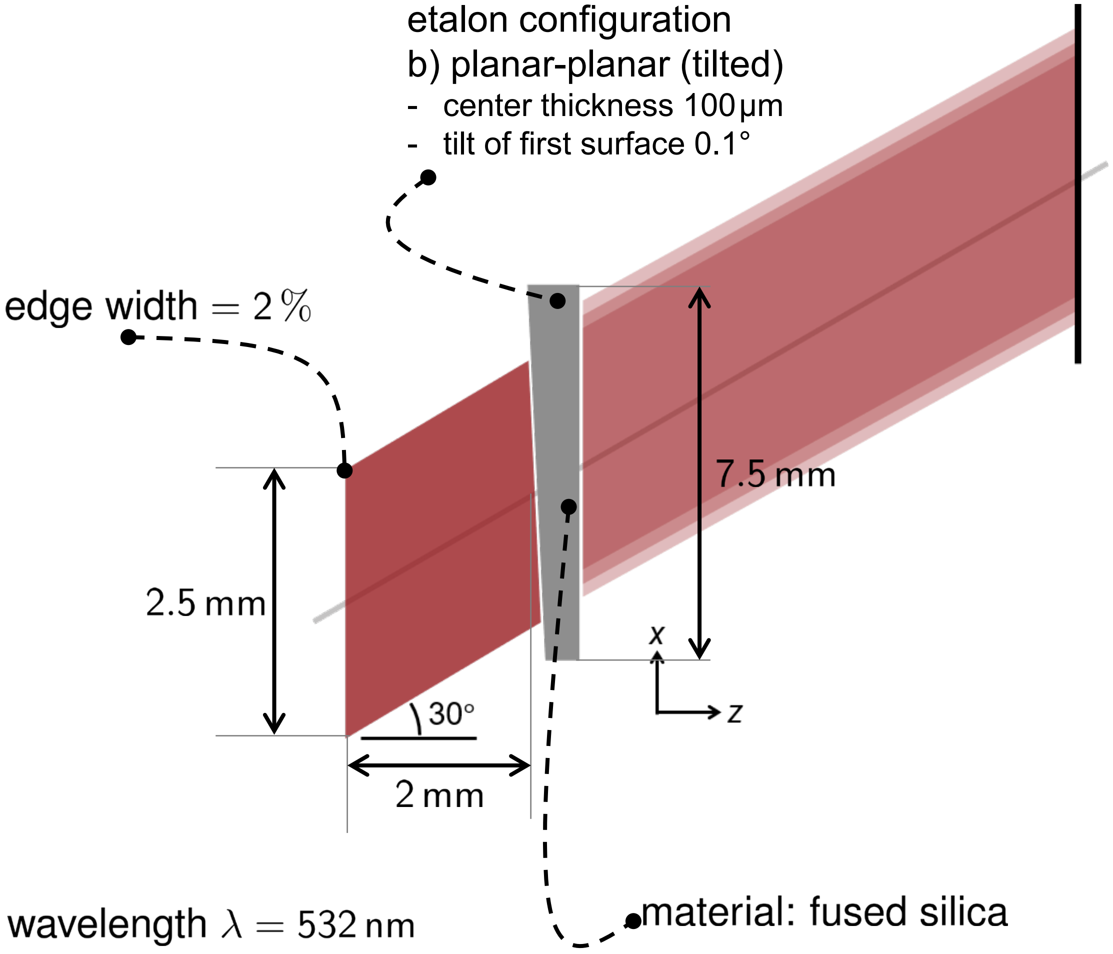




Exercise 1

Building an Etalon

Build the Following System in VirtualLab Fusion



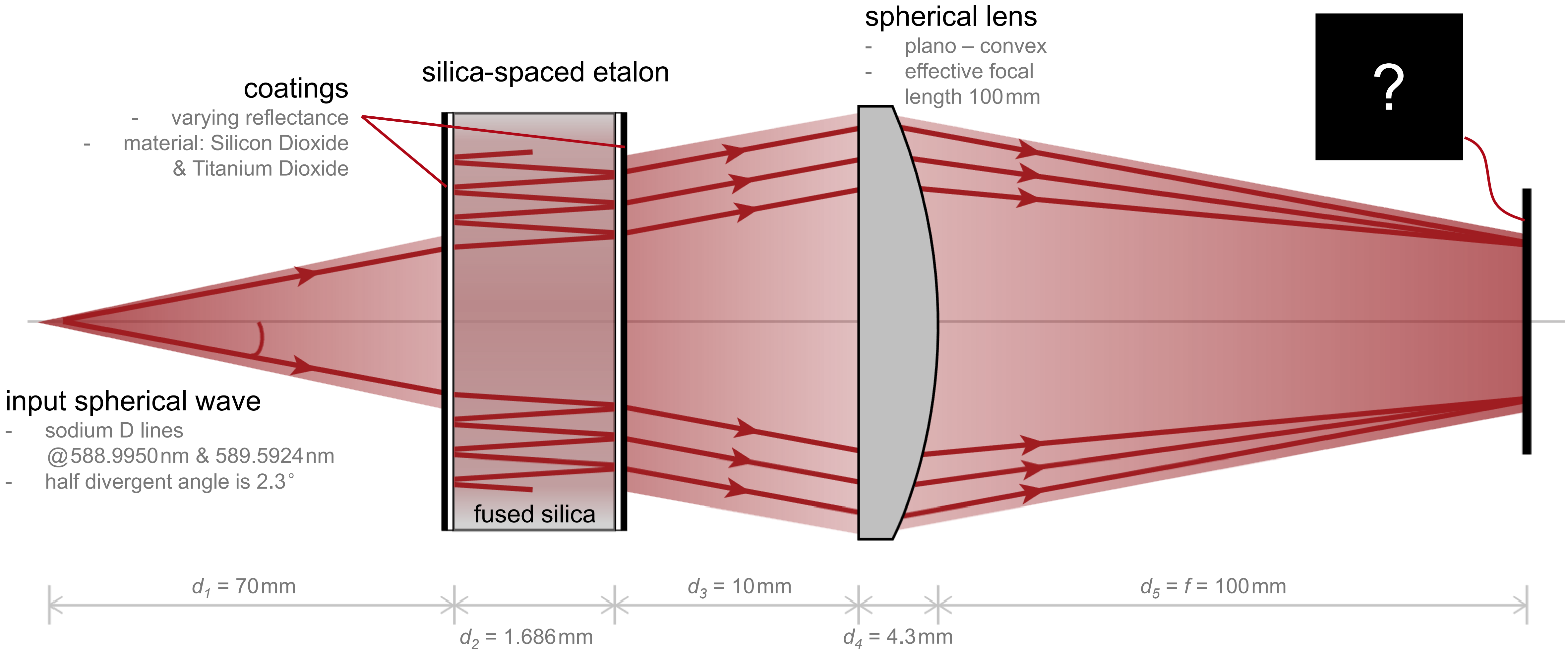
camera detector
- position $x = 4$ mm, $z = 5$ mm
- window size 3 mm × 3 mm
- components to integrate E_x, E_y and E_z
- false colour (cold colours) to better visualize interference

Note:
- Non-sequential simulation – adjust *Channel Configuration Options* to the *Manual* setting and configure surface channels in components.
- Diffraction in the system: play with the Fourier transforms (*Simulation Settings*) to see the role of diffraction.
- Investigate the effects of using different polarization in the source.
- Replace the first surface with others of different shape: spherical, cylindrical... (suggested radius of curvature 1 m).

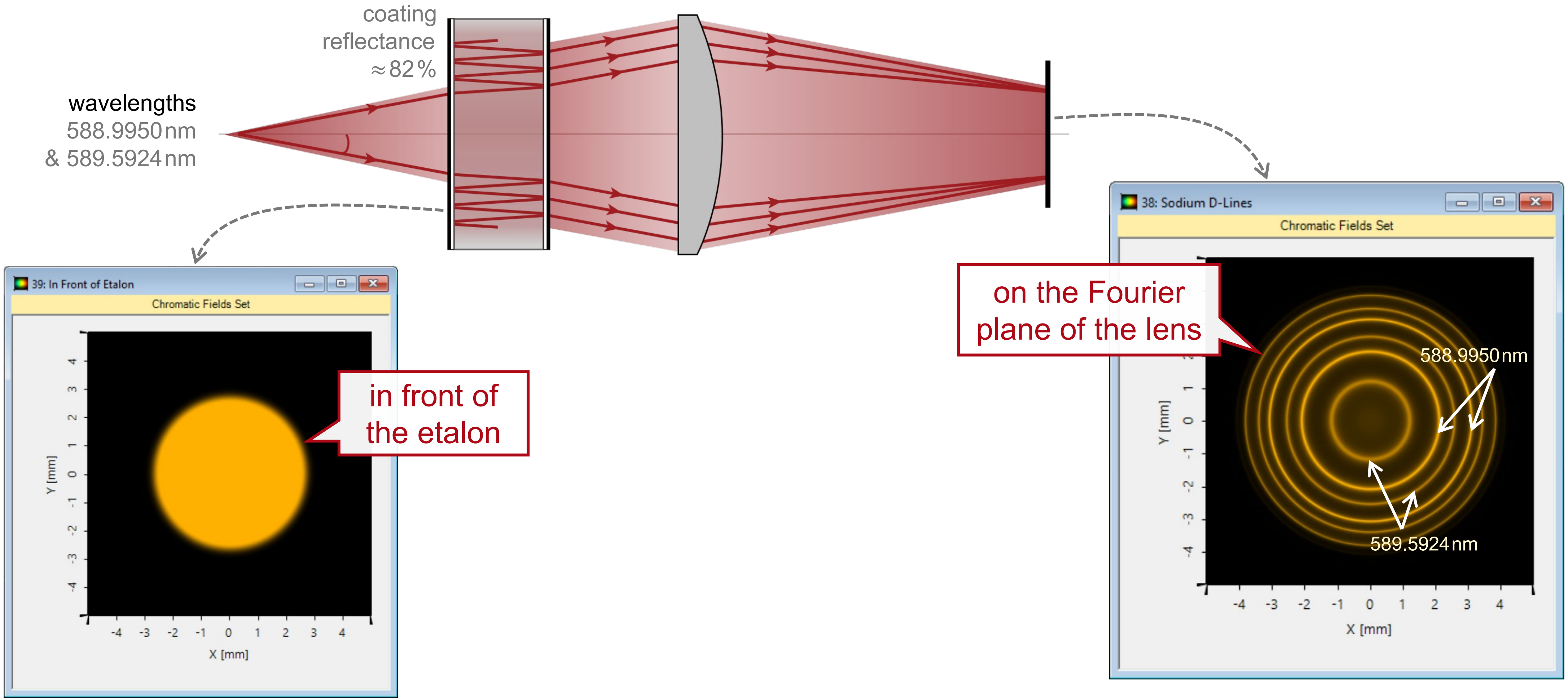
Examination of Sodium D Lines with Fabry-Pérot Etalon

see the full Application Use Case

Modeling Task

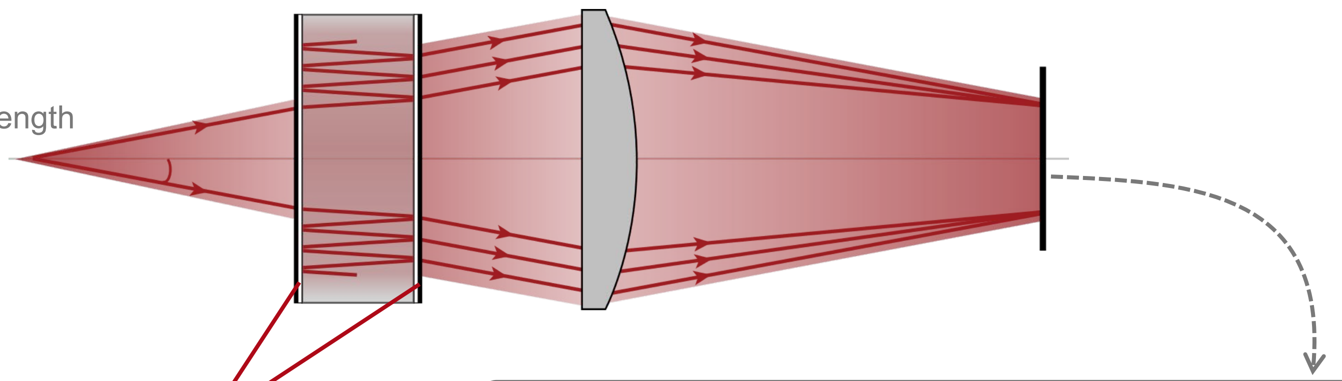


Visualization of Both Spectrum Lines



Finesse vs. Coating Reflectance

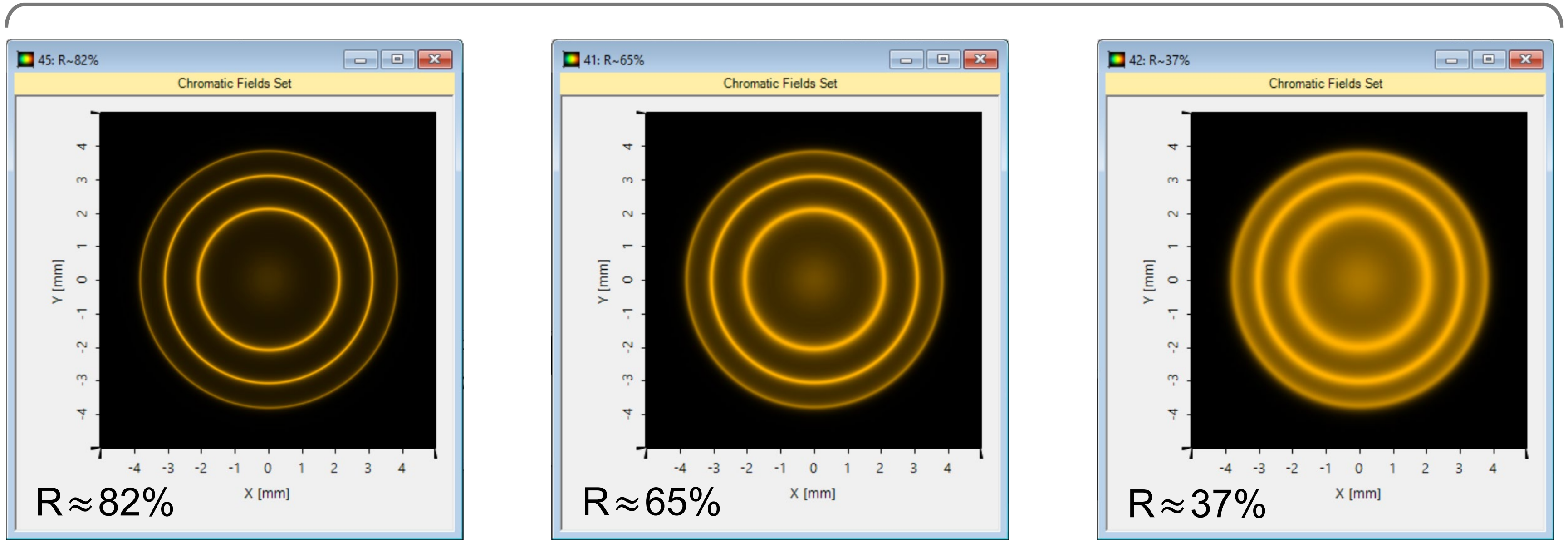
single wavelength
589.9950 nm



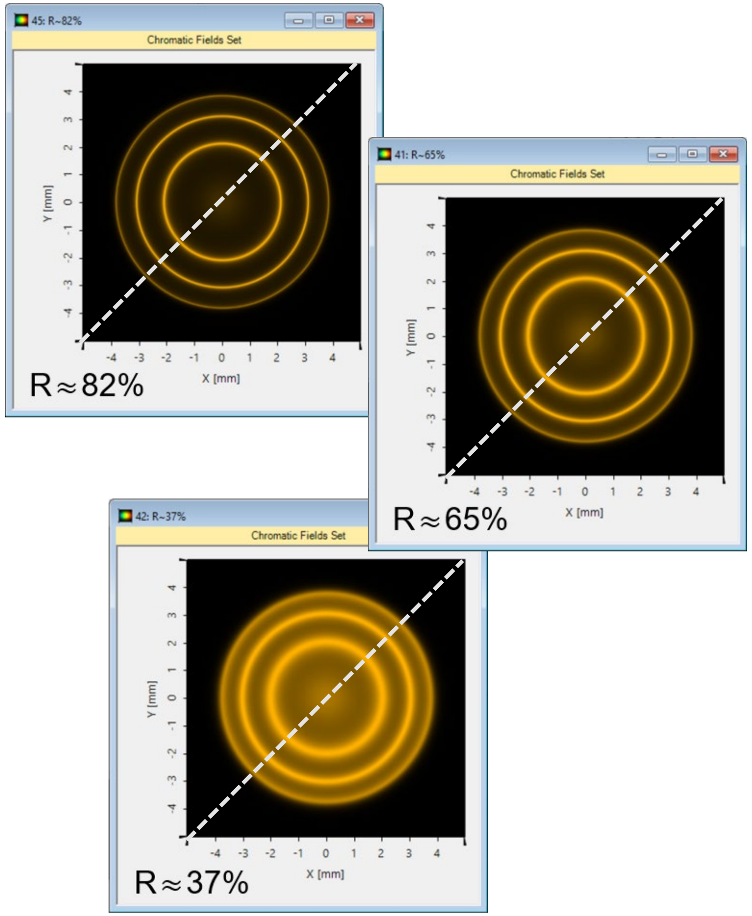
coatings

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

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

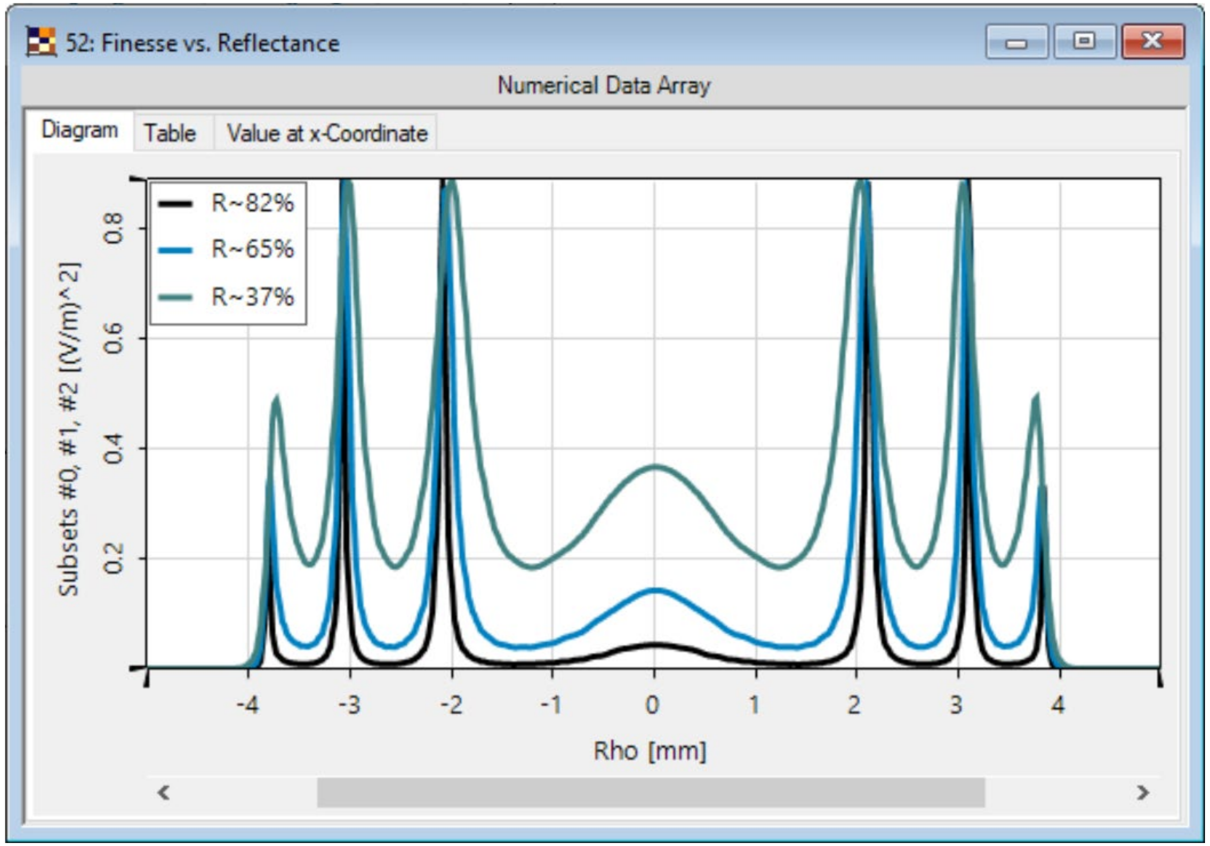


Finesse vs. Coating Reflectance

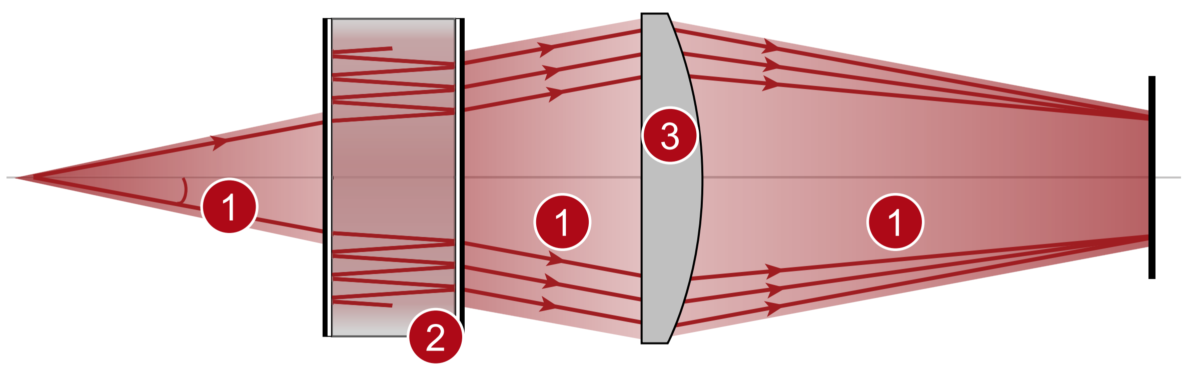


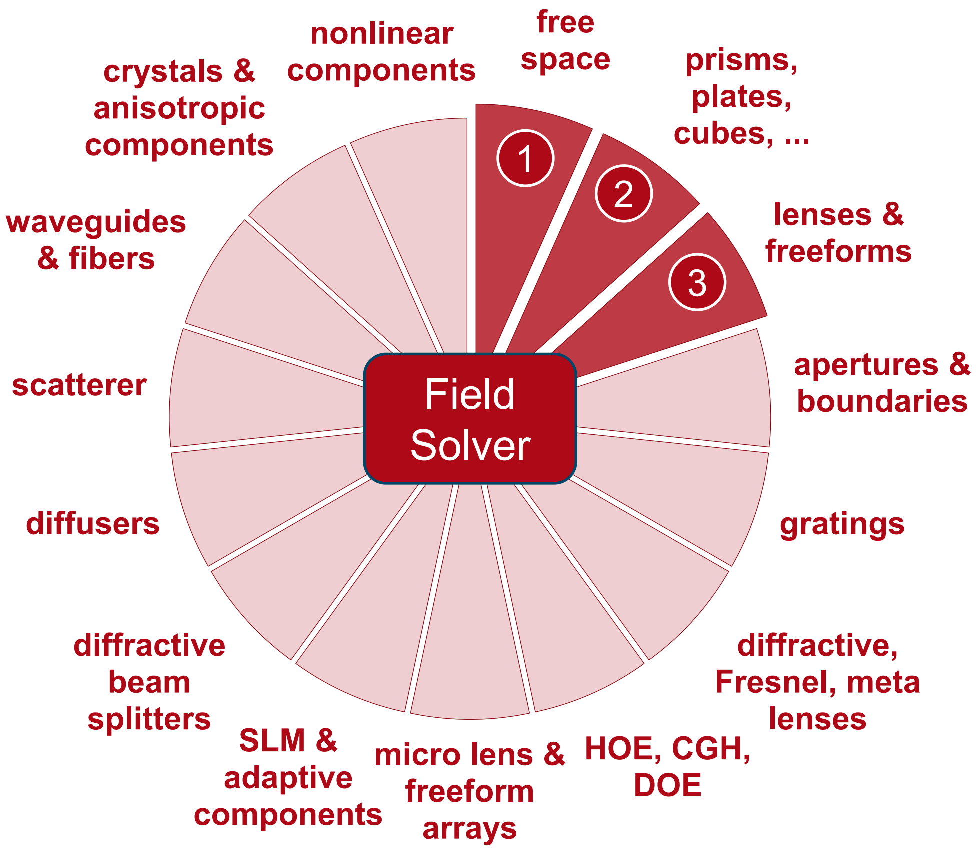
1D measurements along the radial direction

the higher the reflectance, the higher the finesse



VirtualLab Fusion Technologies



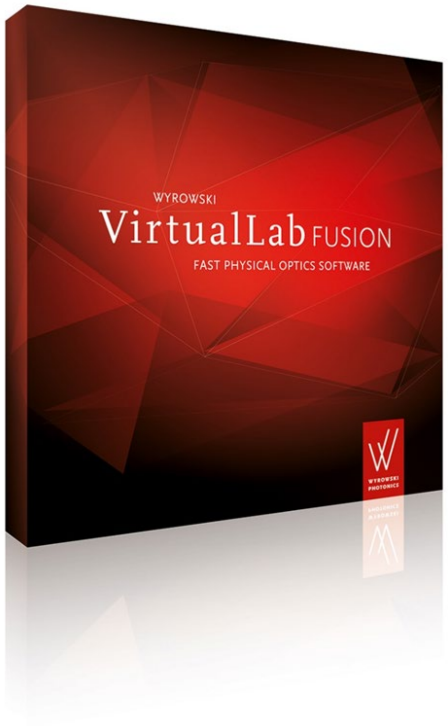


Part 6

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!**

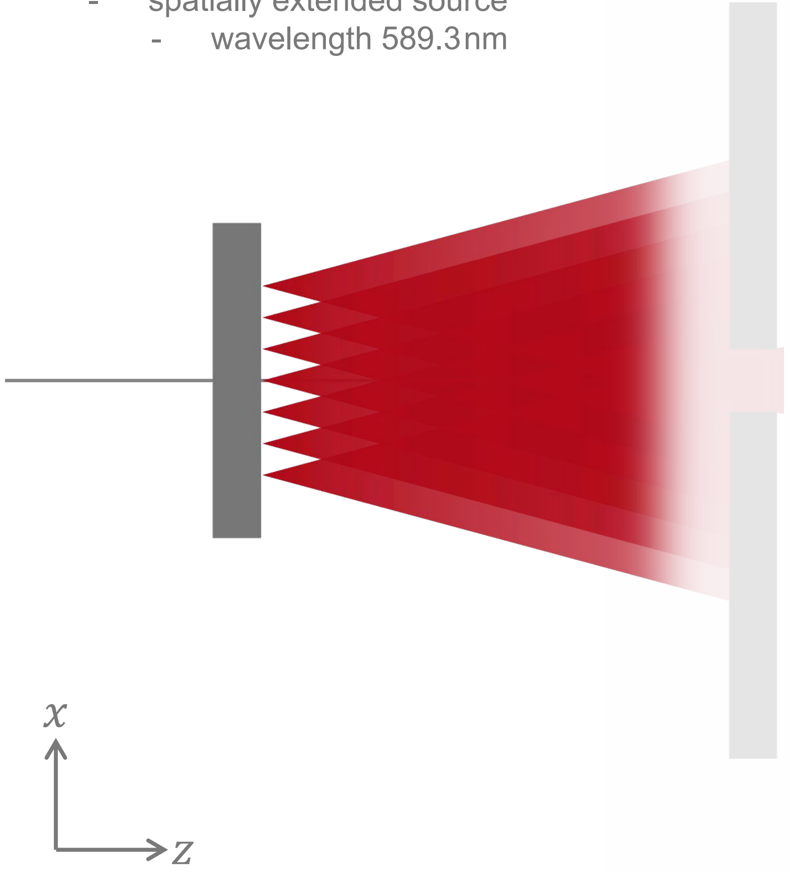
Partial Spatial Coherence with Shifted Elementary Field Method

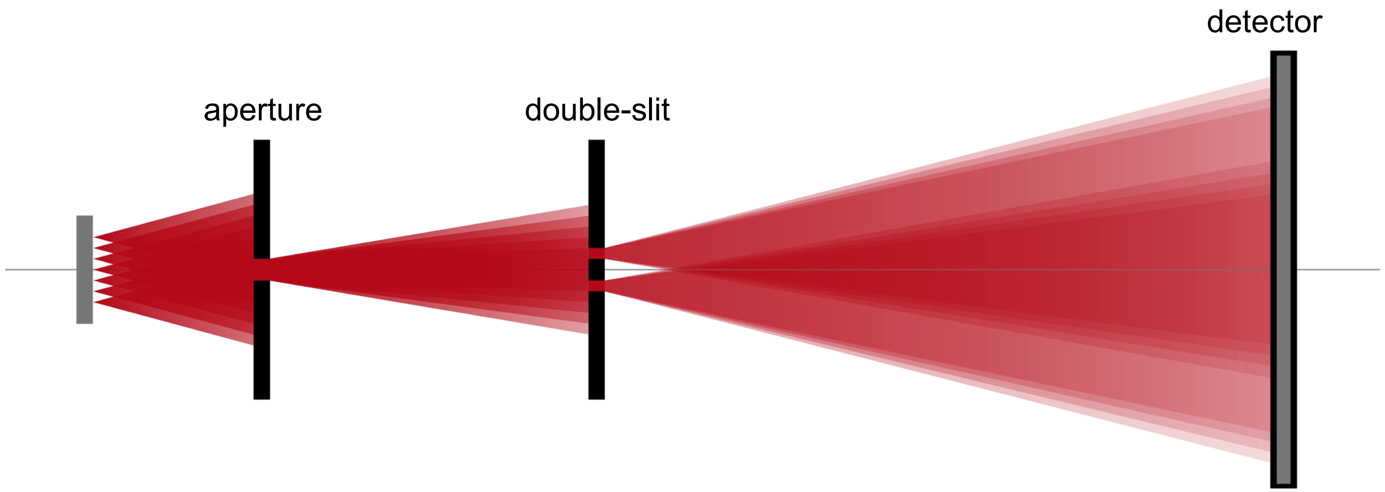
see the full Application Use Case

Shifted Elementary-Field Method

input field

- spatially extended source
- wavelength 589.3nm

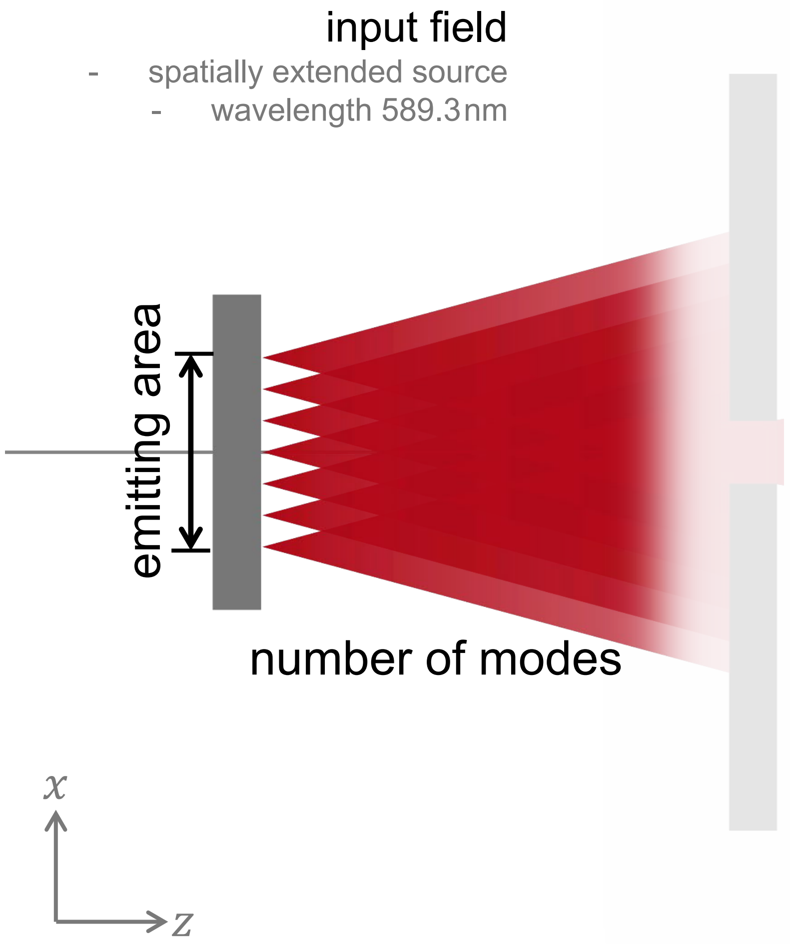




The source is represented by a superposition of spatially identical, but mutually uncorrelated and transversely displaced, fully coherent fields [J. Opt. Soc. Am. A 27 (9), 2010].

This means that each elementary field (mode) is fully coherent with itself, but fully incoherent with all the other elementary fields in the source. In this case the elementary fields are spherical fields each generated by a different point source.

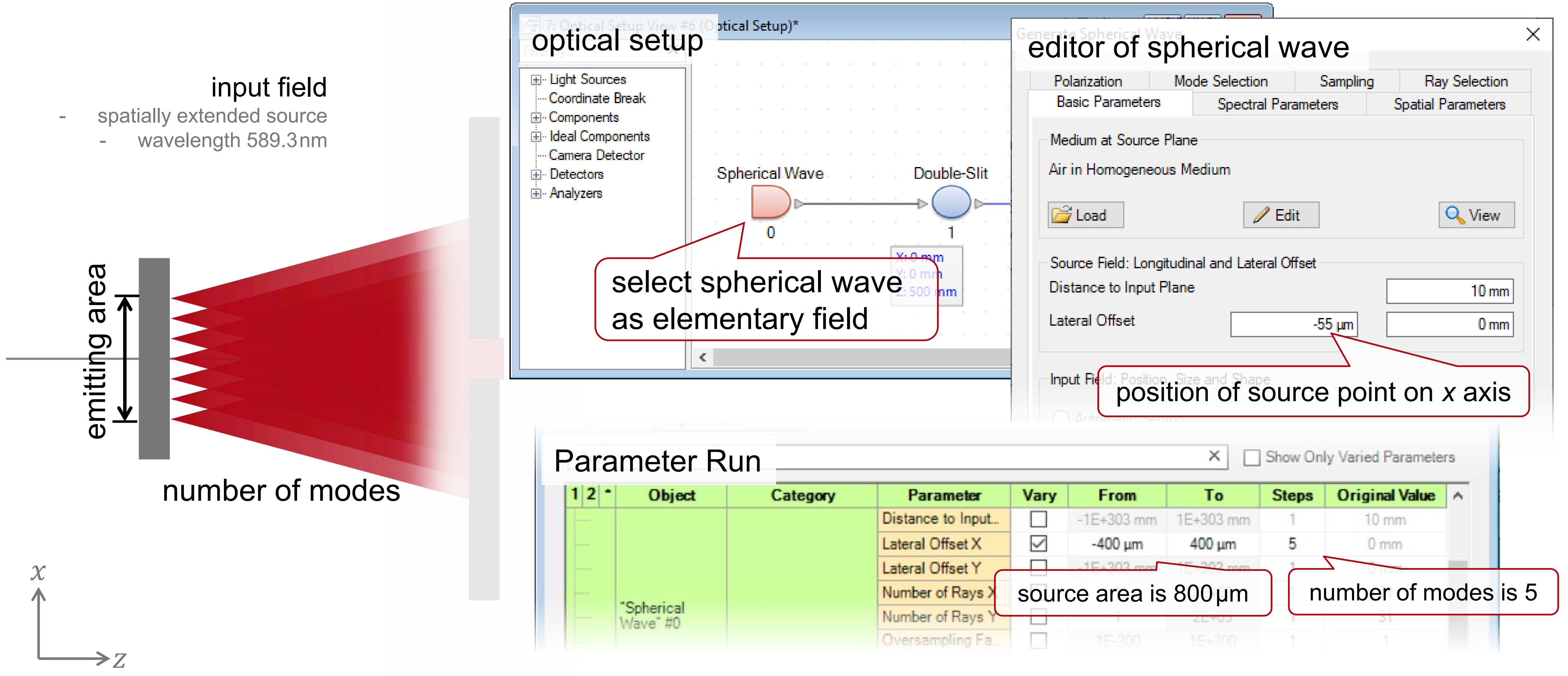
Number of Elementary-Fields (Modes)



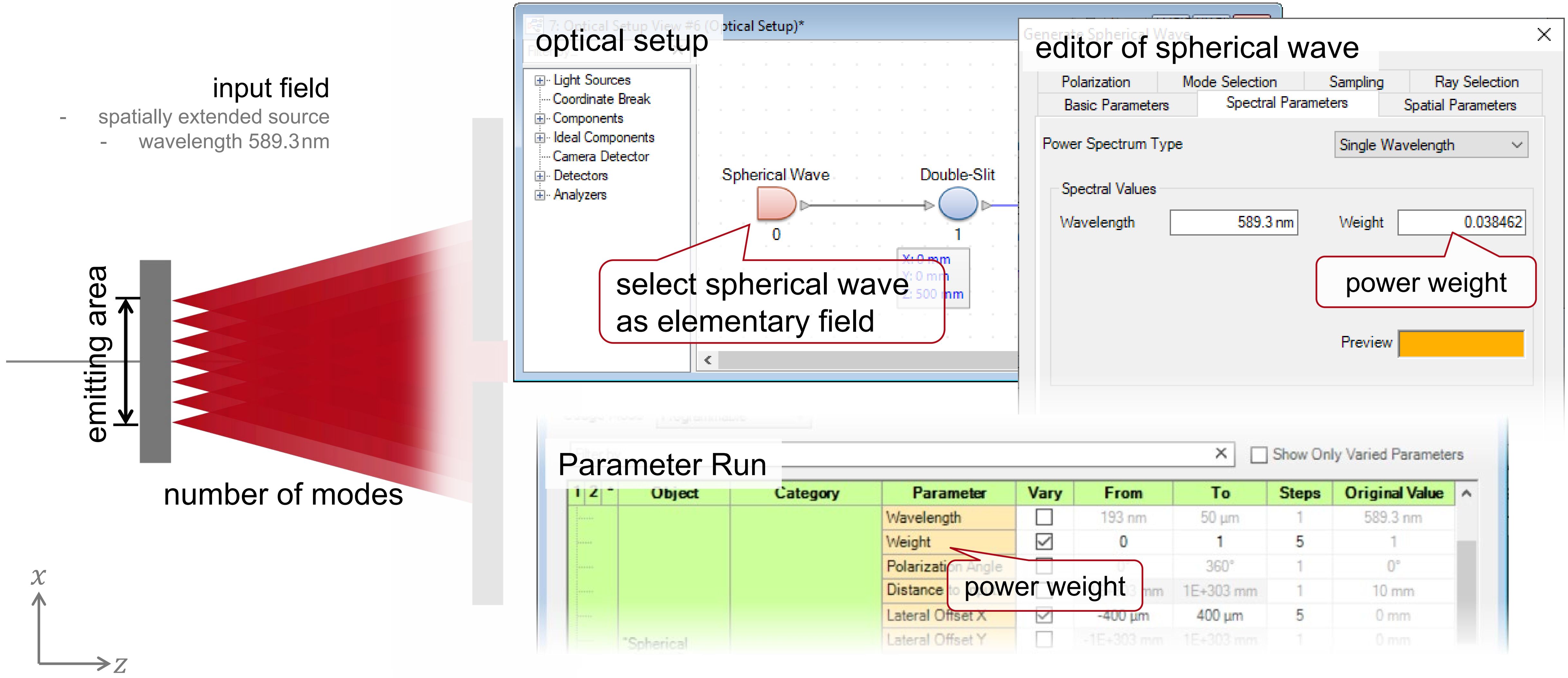
- The emitting area is fixed at 800 µm. The point source at the edge of this emitting area gives a weak interference pattern, which is negligible.
- The number of elementary fields (modes) should be large enough to achieve convergent and reliable results.
- So before performing the simulation, **we use 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



Configuration of Parameter Variation

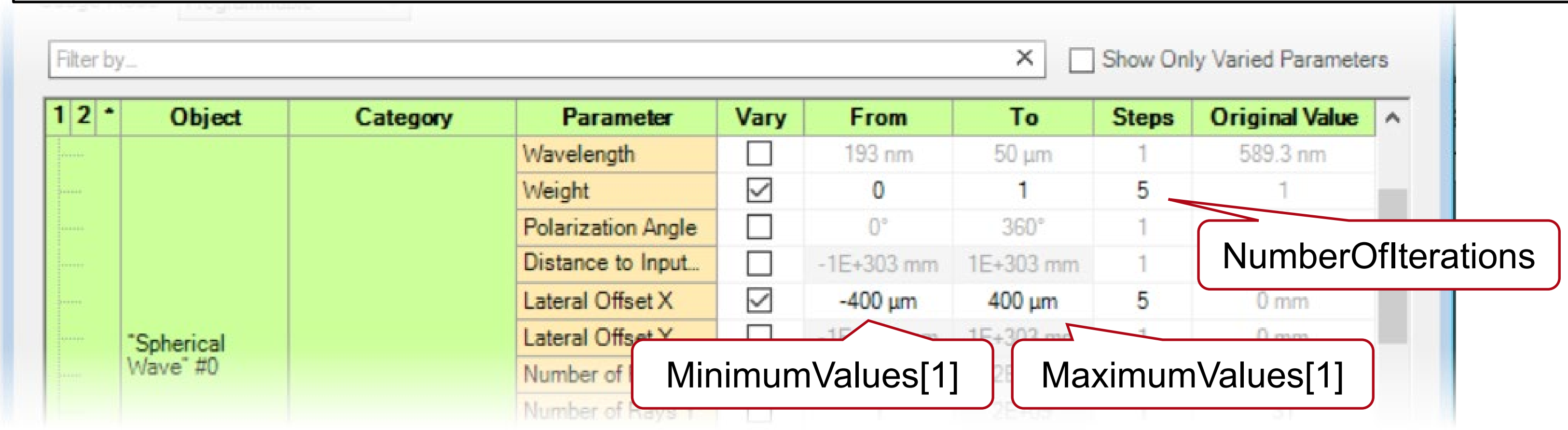


Programmable Mode of Parameter Run

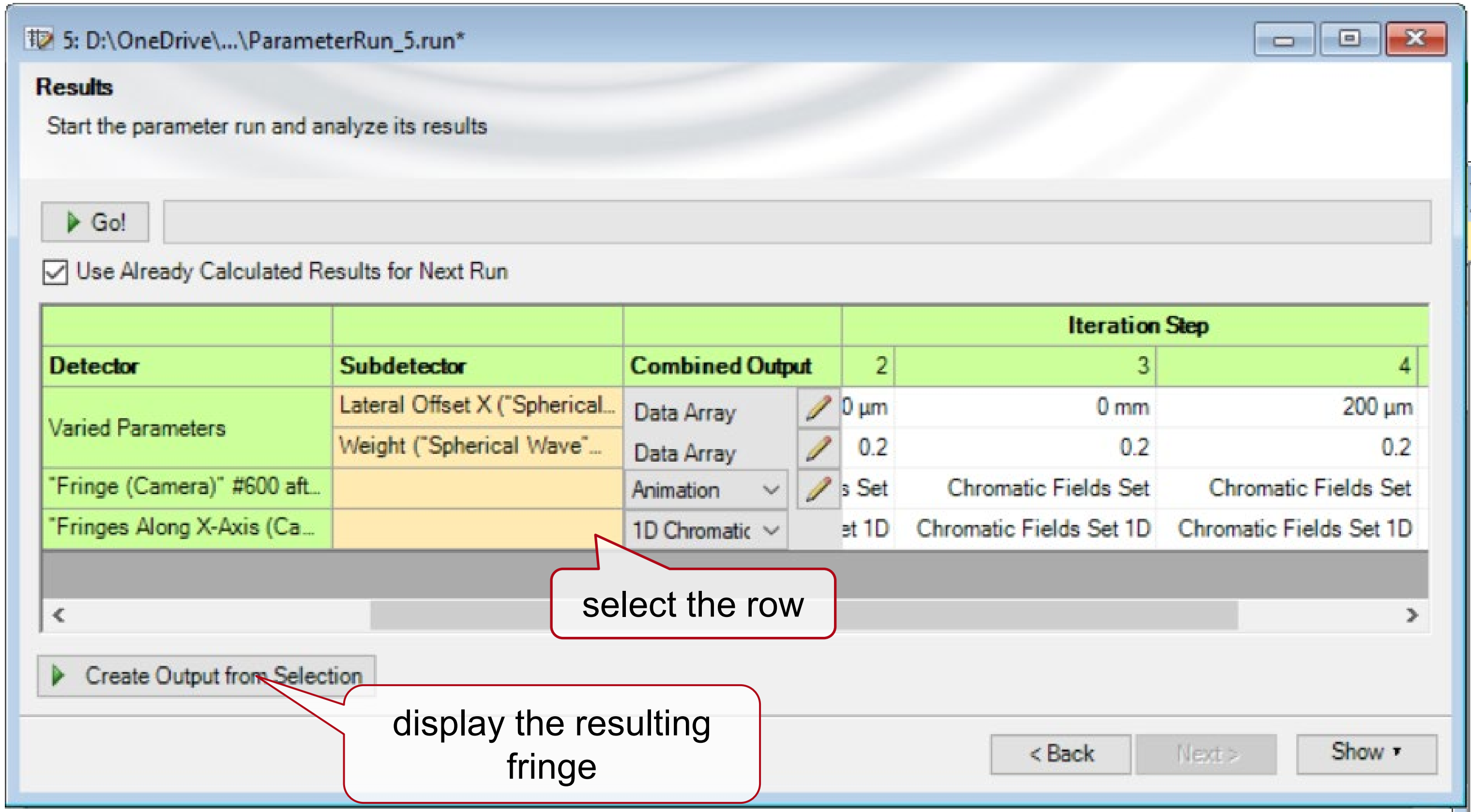
Main Function

```
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;
```

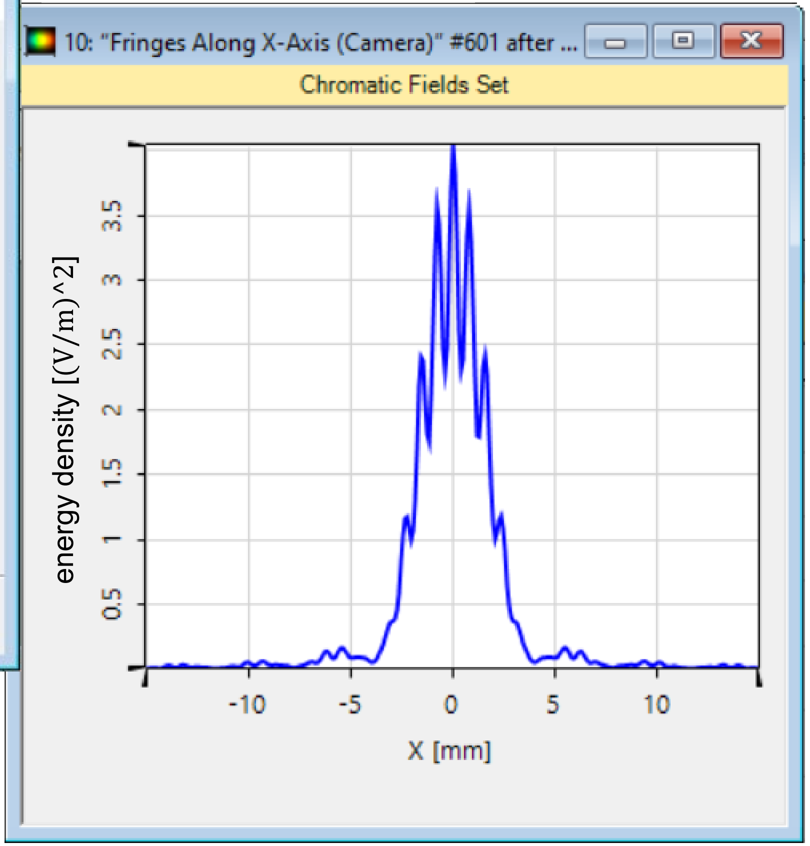
$$\text{weight} = \frac{1.0}{\text{number of modes}}$$



Display of Resulting Fringe along *x* Axis

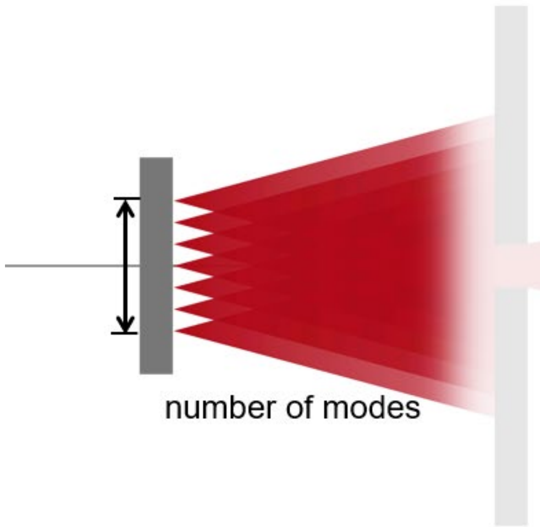


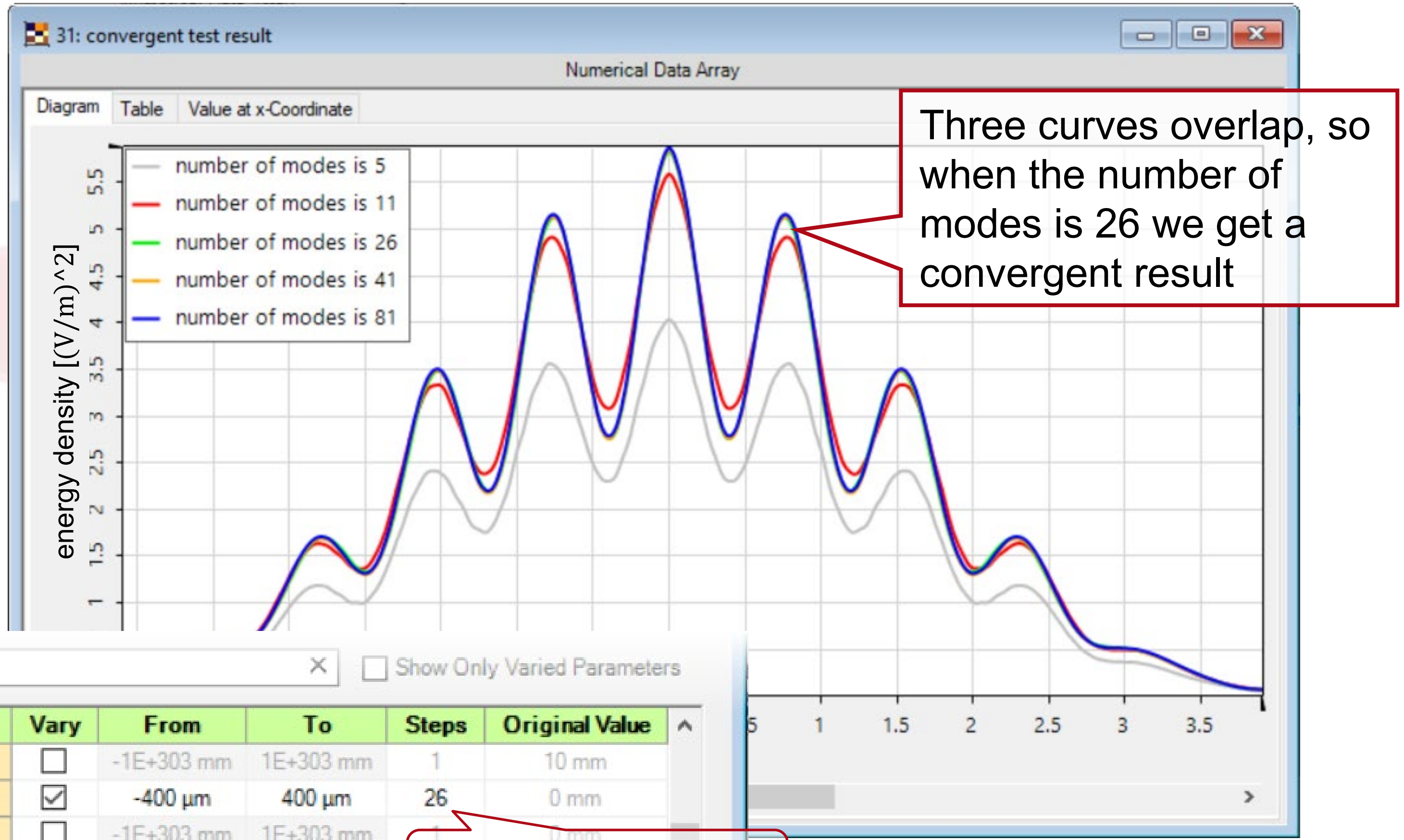
fringe along *x* axis

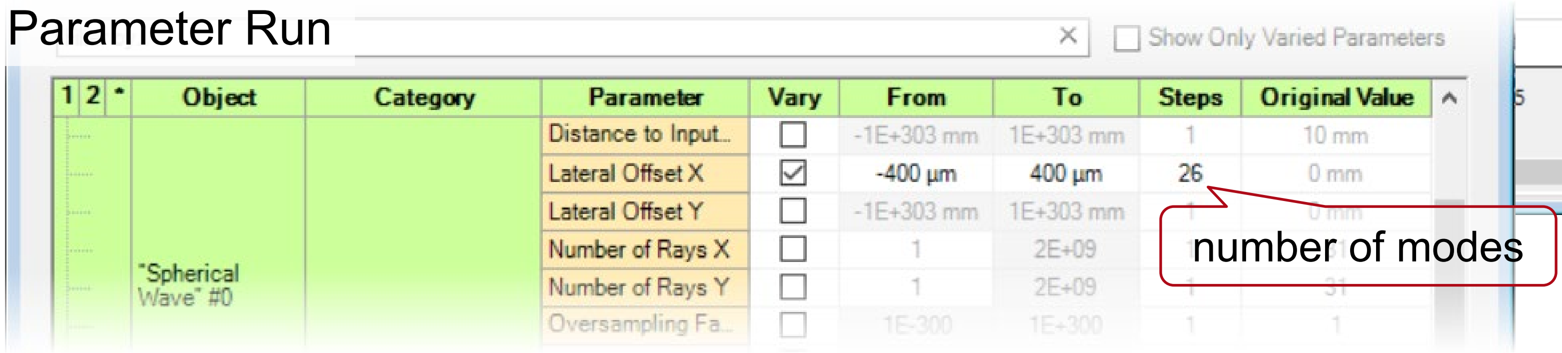


superposition of energy density
from different point sources

Fringes with Different Number of Modes





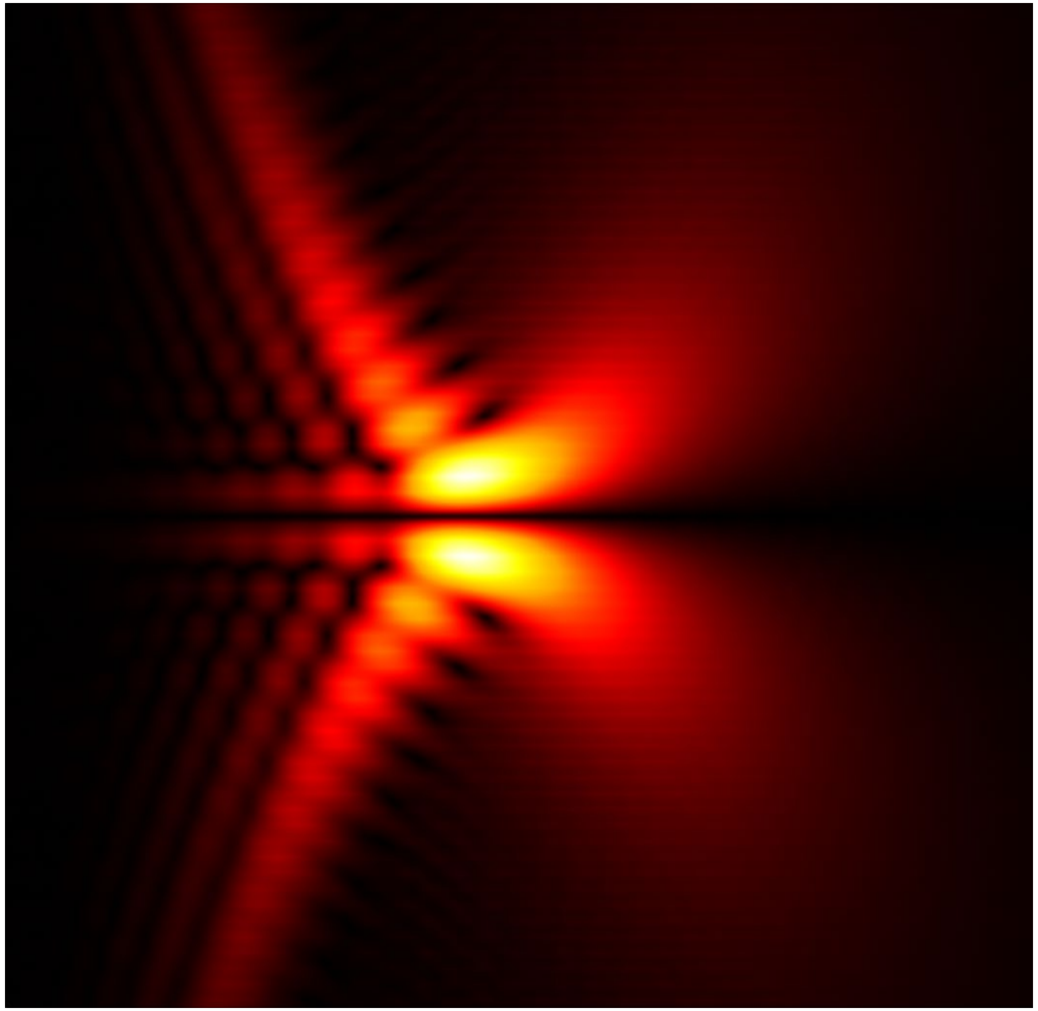


Object	Category	Parameter	Vary	From	To	Steps	Original Value
"Spherical Wave" #0		Distance to Input...	☐	-1E+303 mm	1E+303 mm	1	10 mm
		Lateral Offset X	☑	-400 µm	400 µm	26	0 mm
		Lateral Offset Y	☐	-1E+303 mm	1E+303 mm	1	0 mm
		Number of Rays X	☐	1	2E+09		
		Number of Rays Y	☐	1	2E+09	1	31
		Oversampling Fa...	☐	1E-300	1E+300	1	1

Pulse Focusing with High-NA Lens

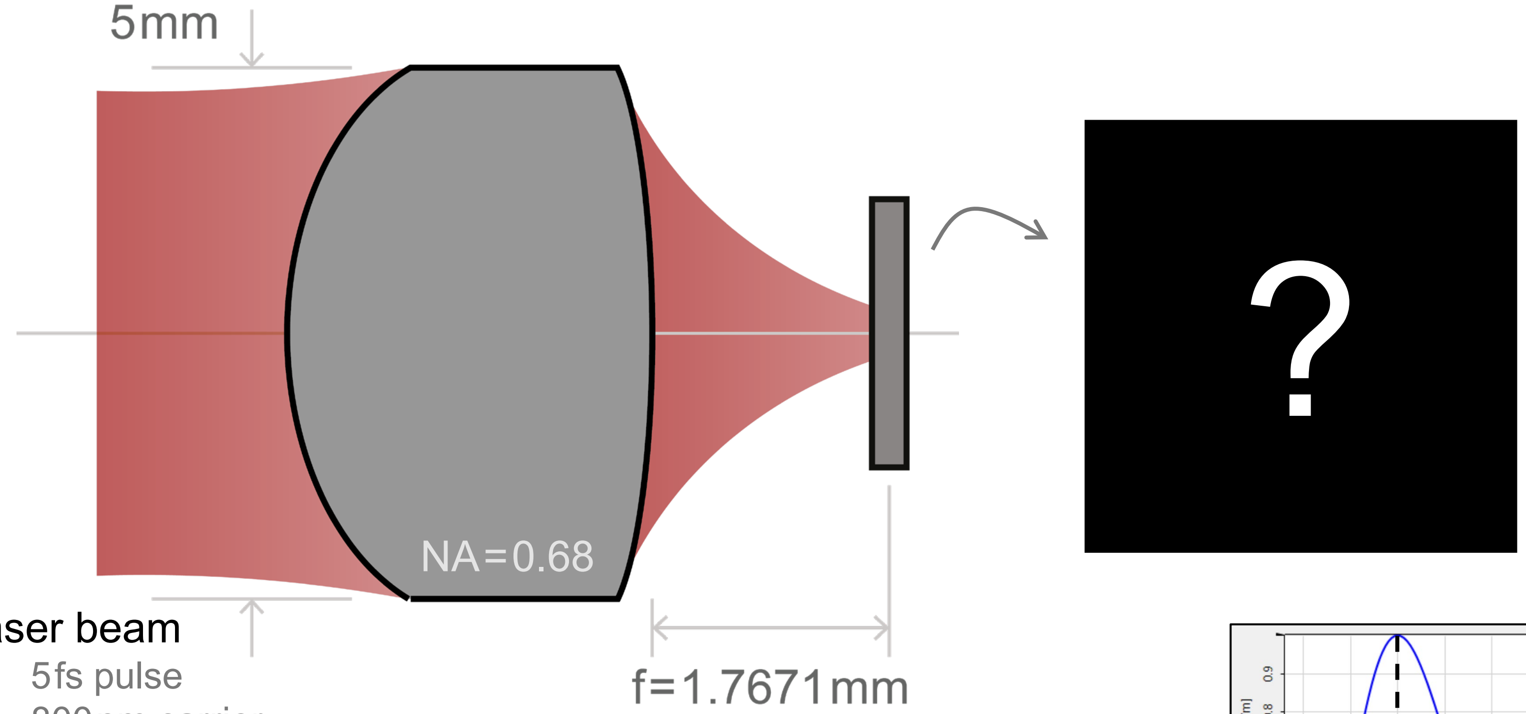
see the full Application Use Case

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

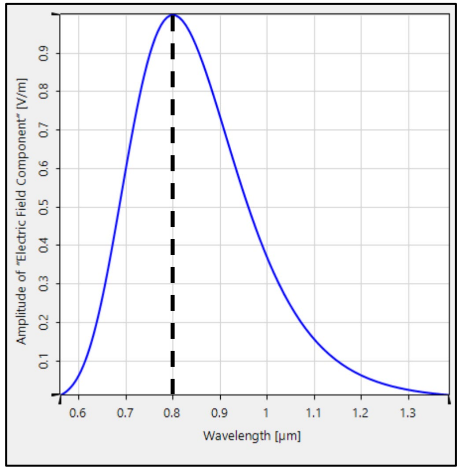


pulse evaluation

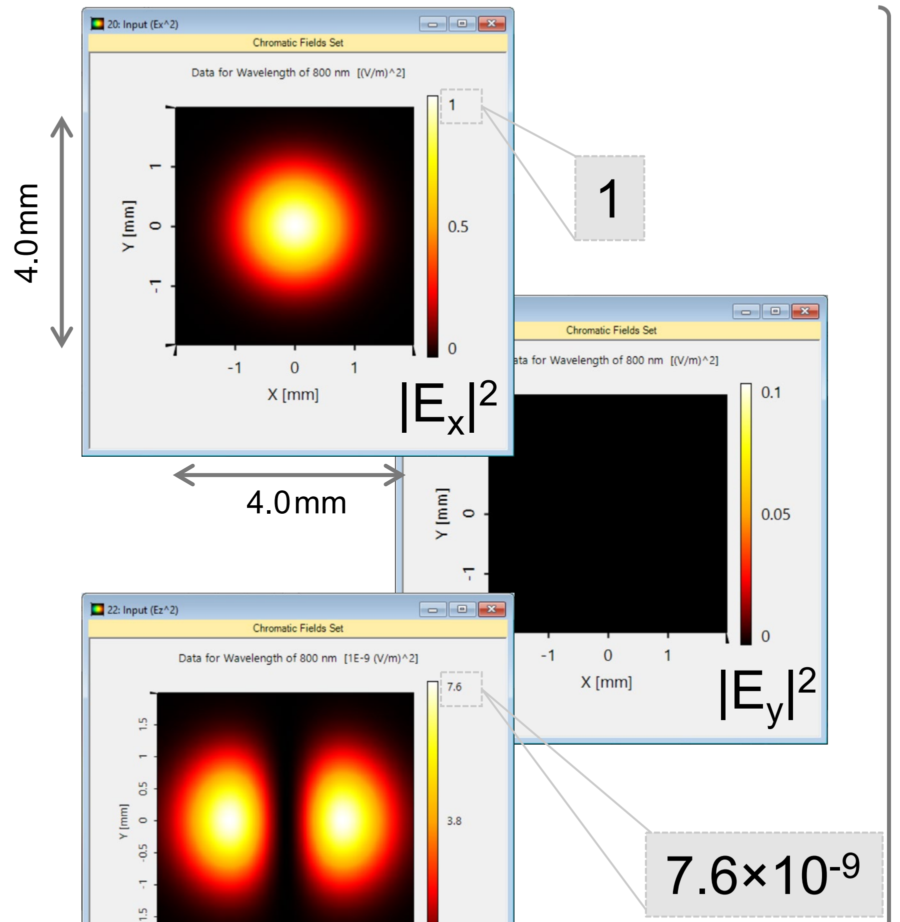
- spatial
- temporal

laser beam

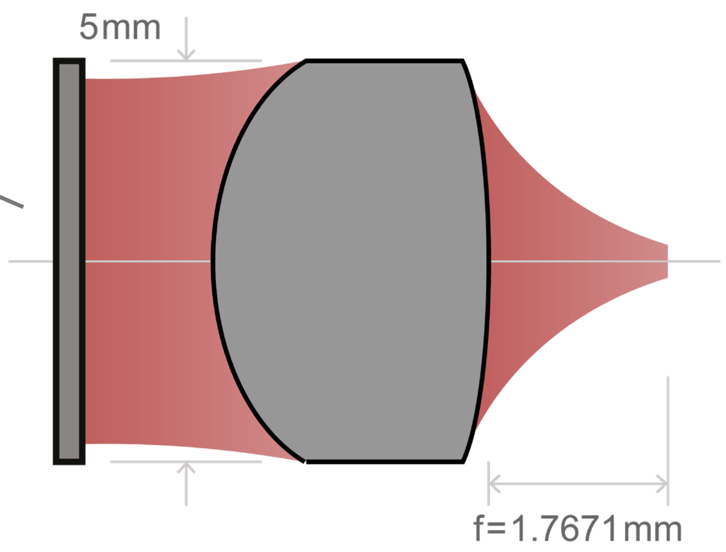
- 5fs pulse
- 800nm carrier wavelength
- linearly polarized along *x*

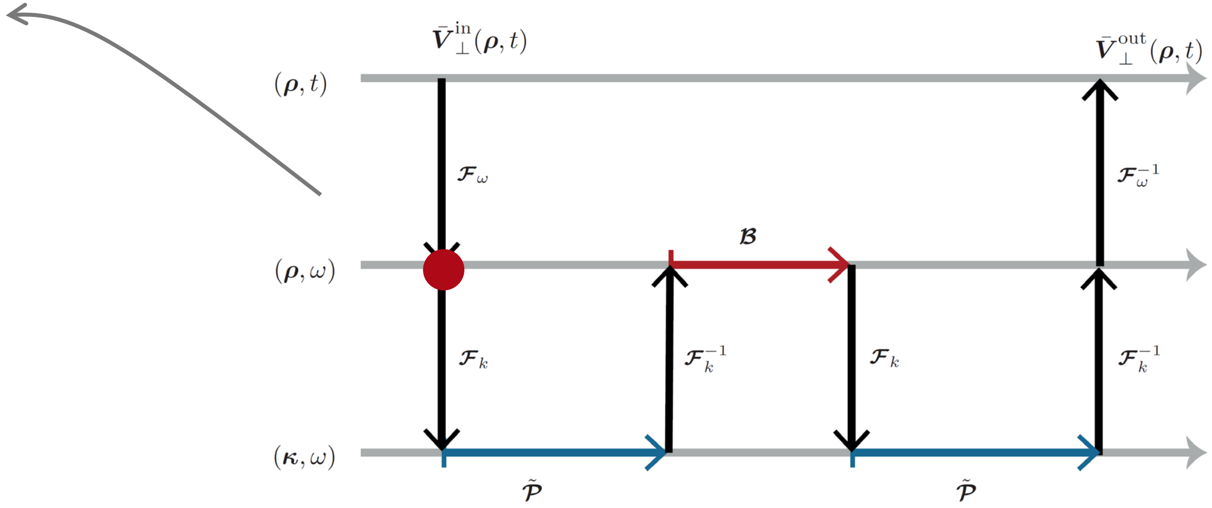


Purely Spatial Analysis: Input Field (Carrier λ)

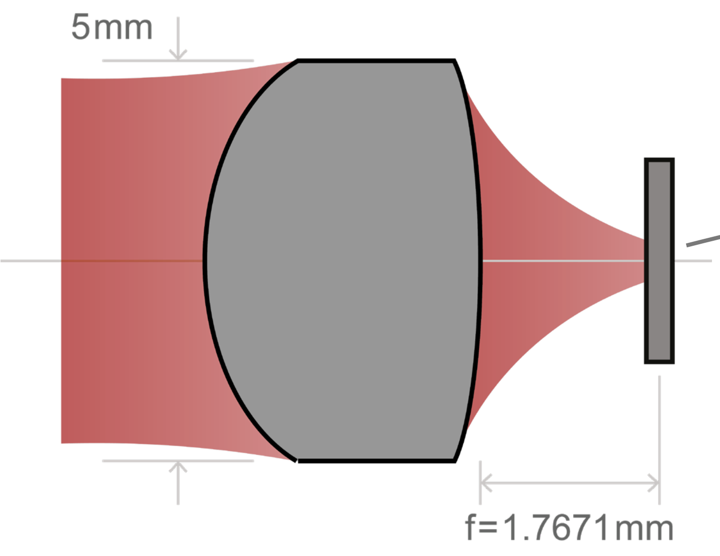


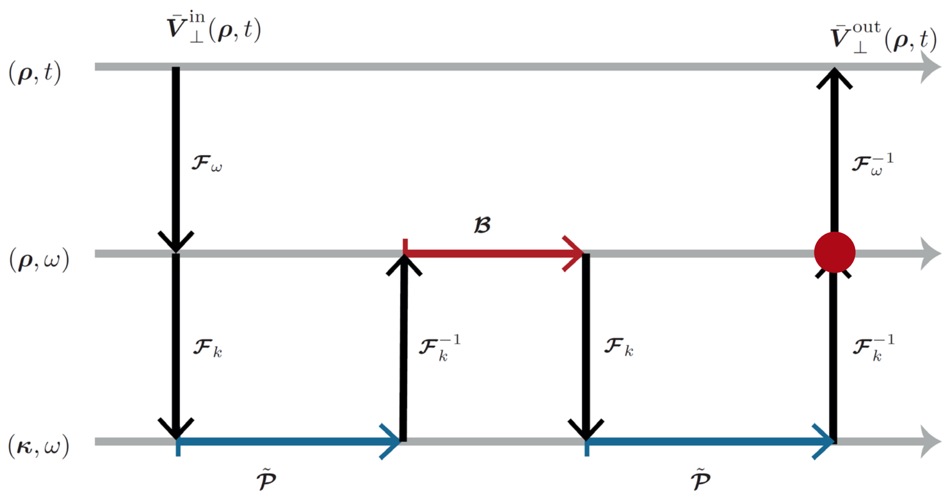
Negligible E_z component hints at collimated nature of beam





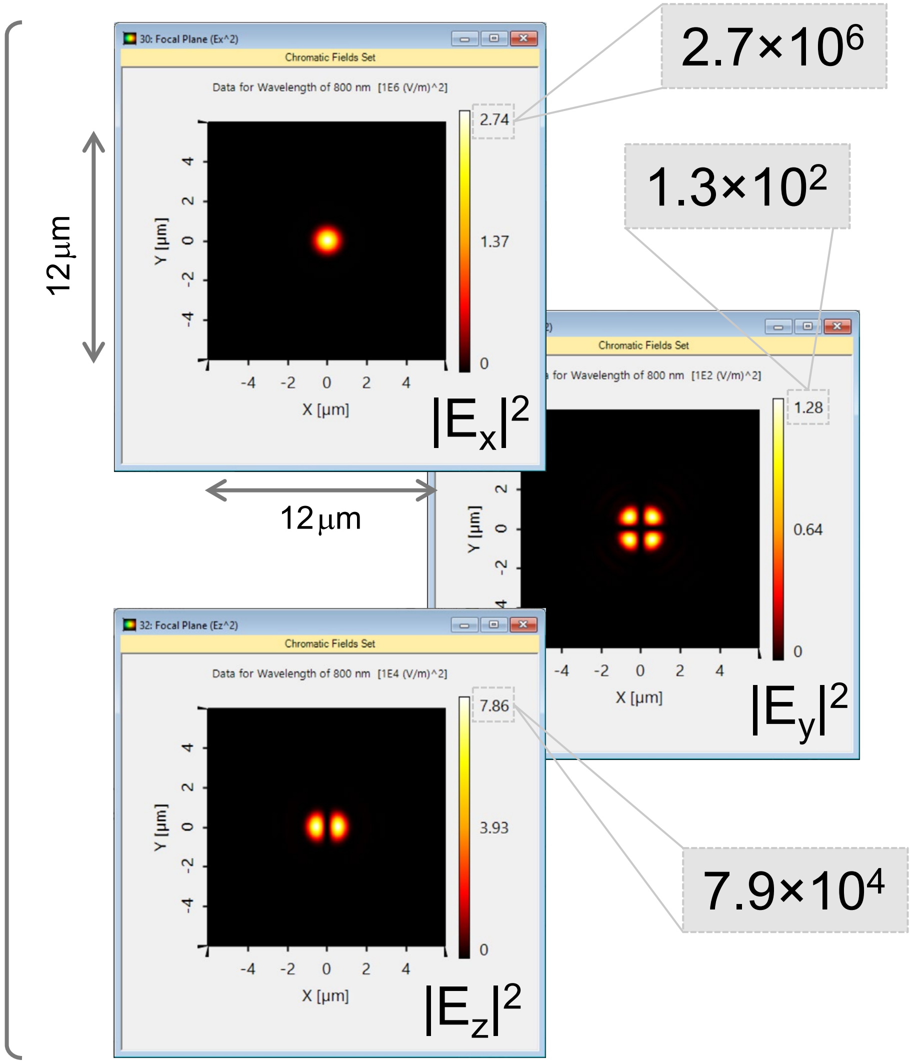
Purely Spatial Analysis: Field at Focal Plane (Carrier λ)





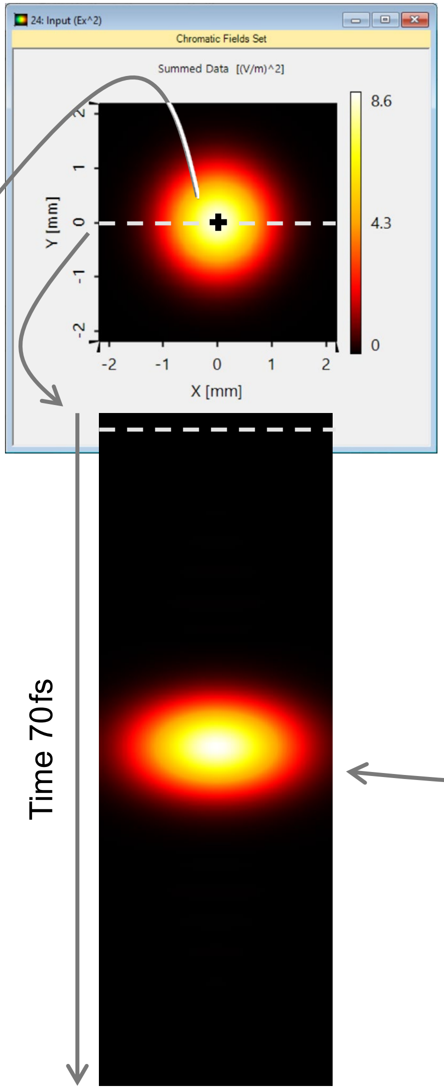
Note focusing effect on the size!

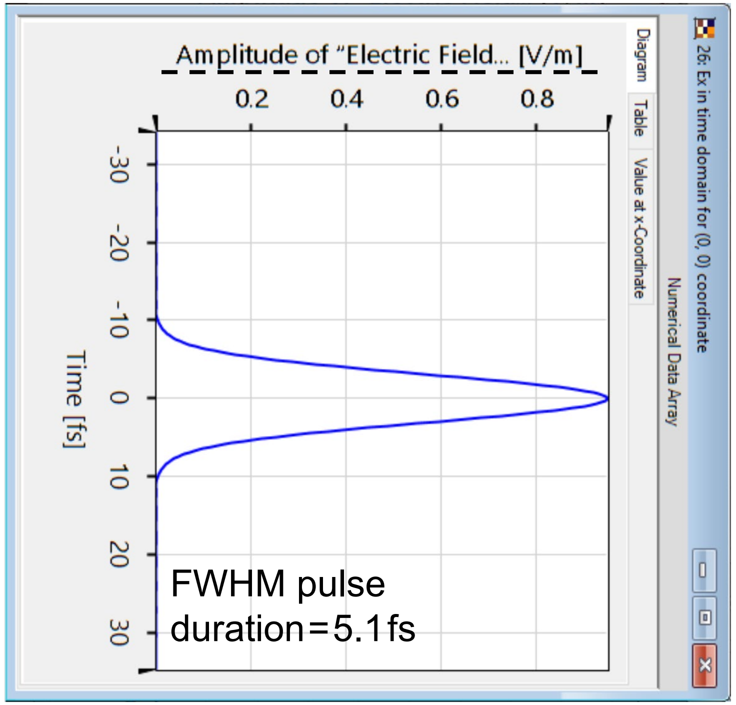
A small E_y component appears from the cross-talk effected by the surfaces of the lens. The tangible E_z component is the result of the high focusing of the beam

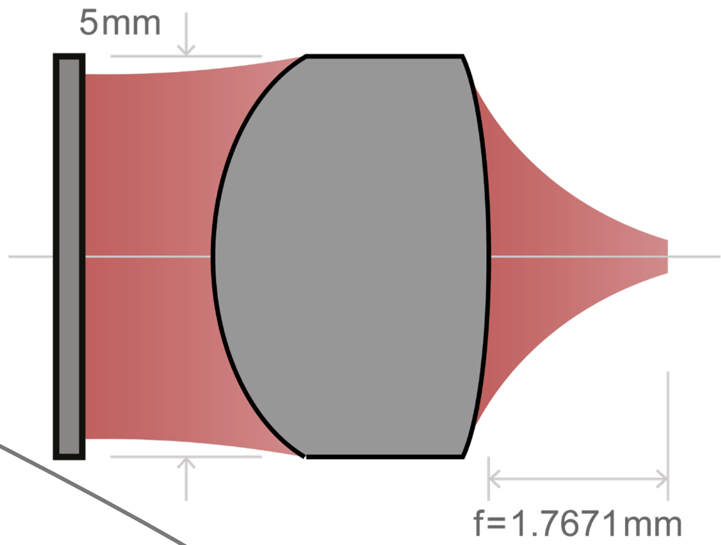


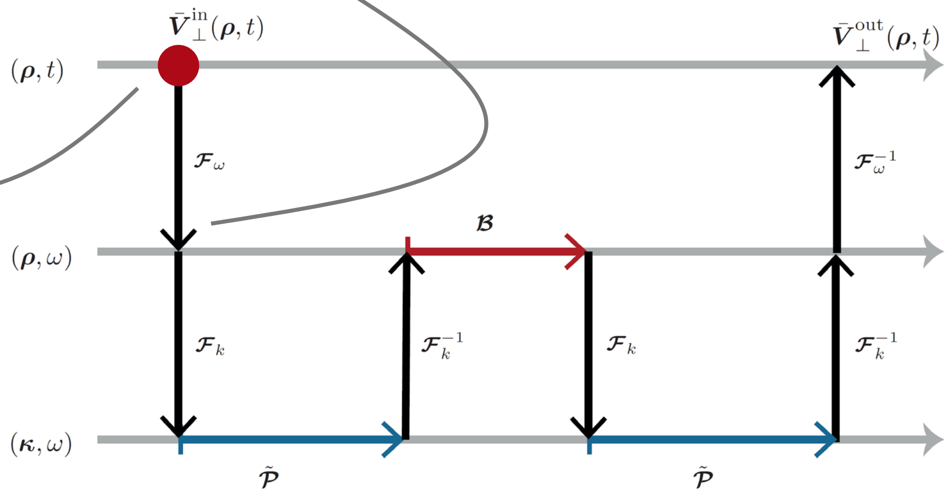
Spatio-Temporal Analysis: Input Field (E_x Component)

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



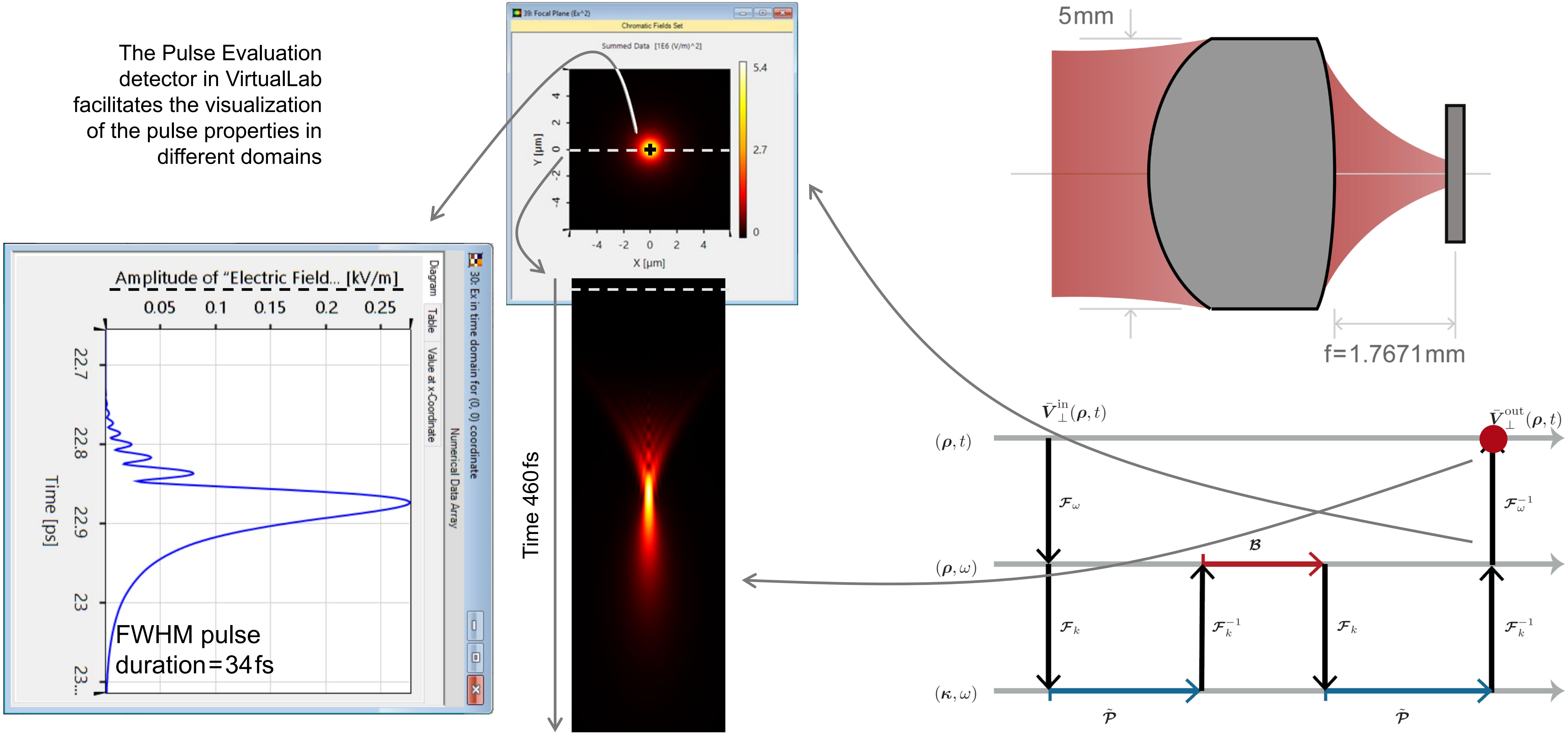




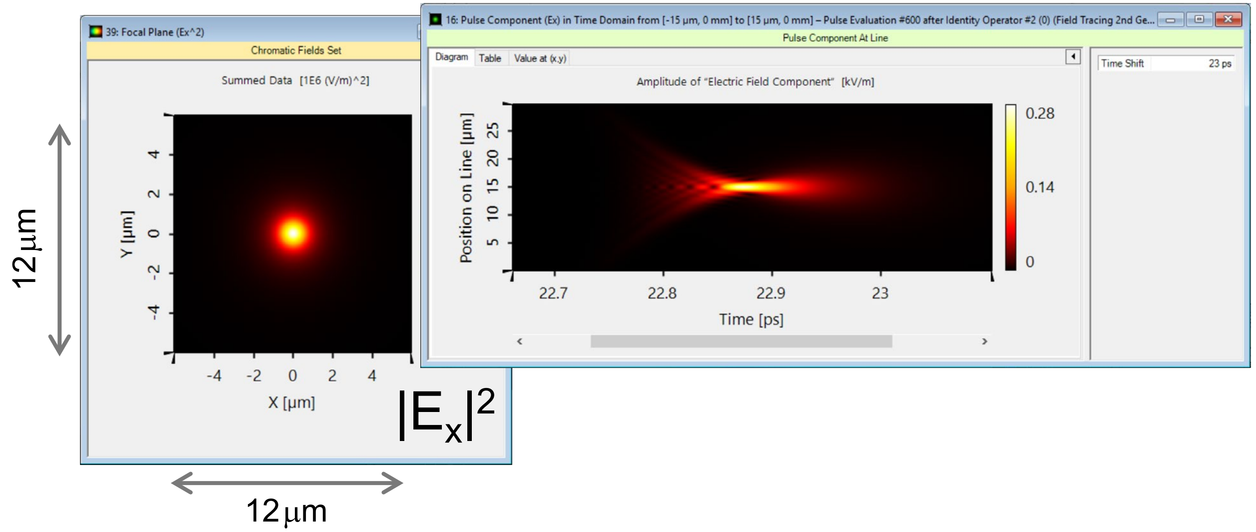


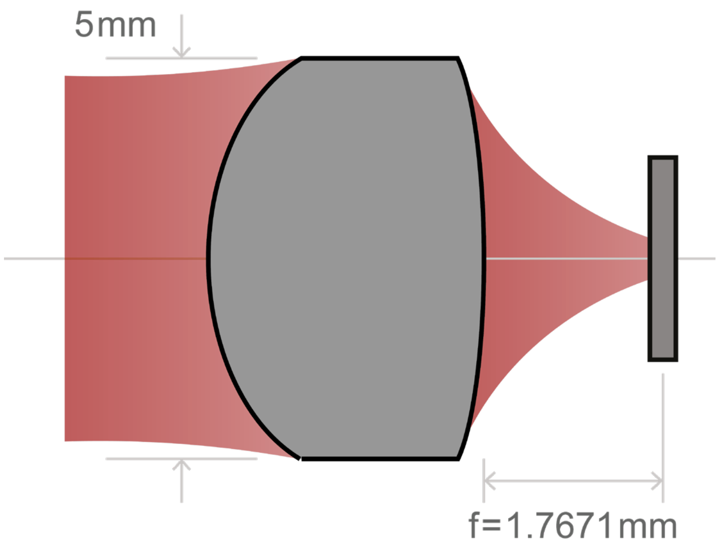
Spatio-Temporal Analysis: Focus (E_x Component)

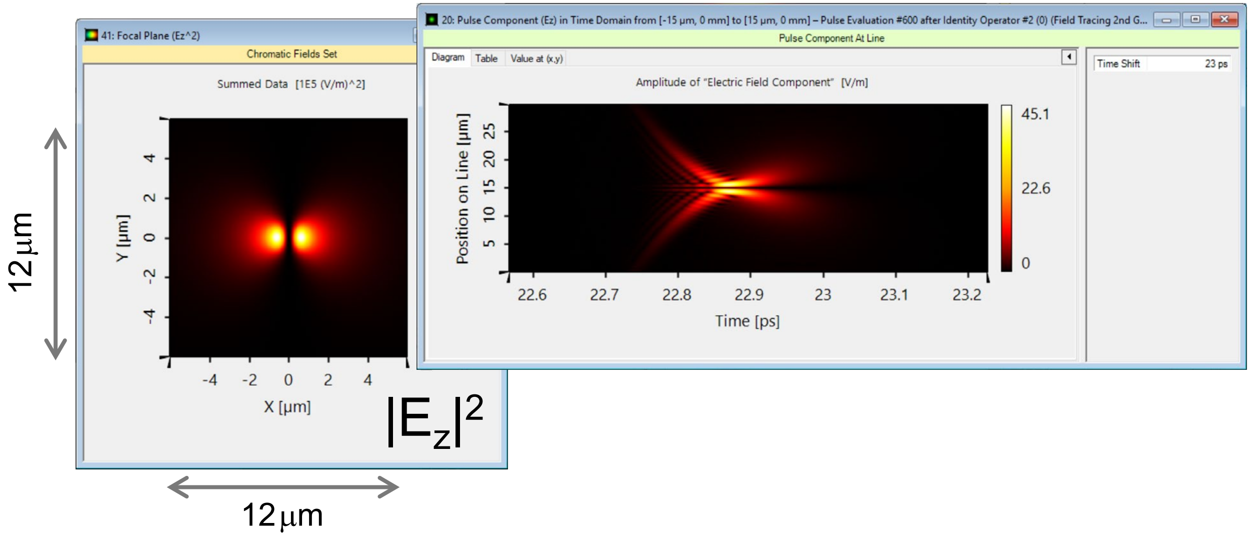
The Pulse Evaluation detector in VirtualLab facilitates the visualization of the pulse properties in different domains



Spatio-Temporal Analysis: Focus (E_x and E_z)

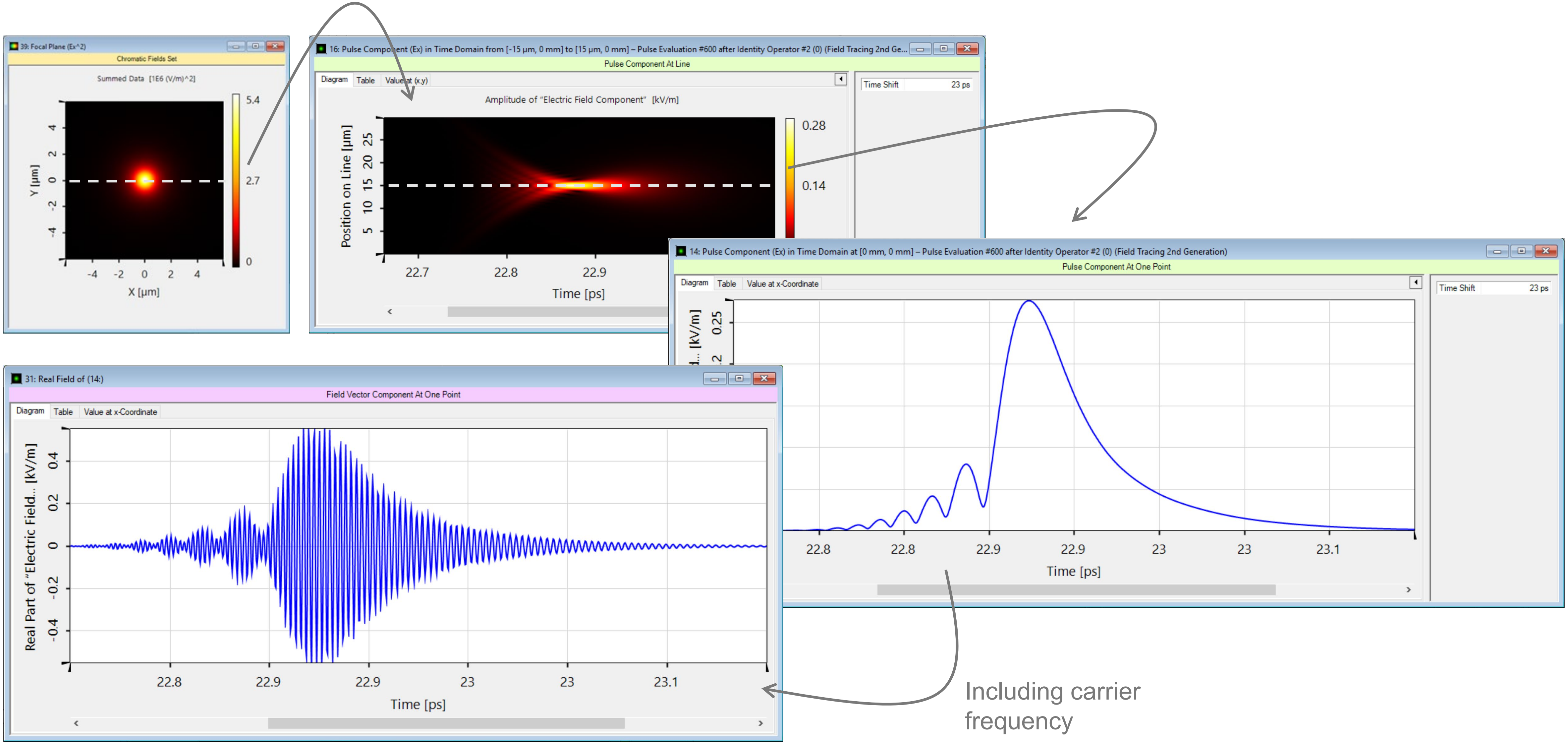






As always, consistent electromagnetic treatment in VirtualLab Fusion allows for the analysis of vectorial effects, also for ultra-short pulses

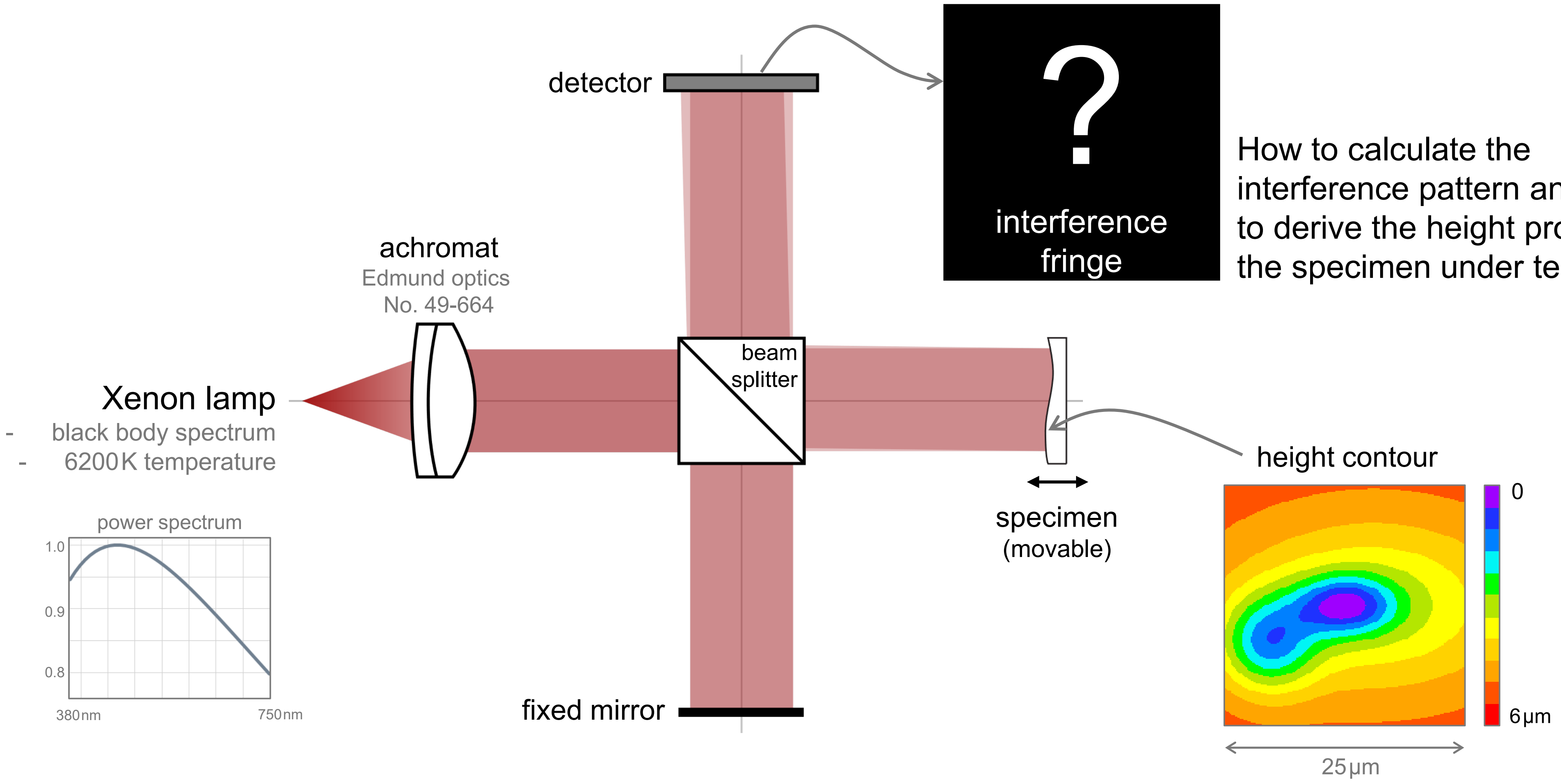
Temporal Analysis: E_x Component with Carrier Frequency



Full-Field Optical Coherence Scanning Interferometry

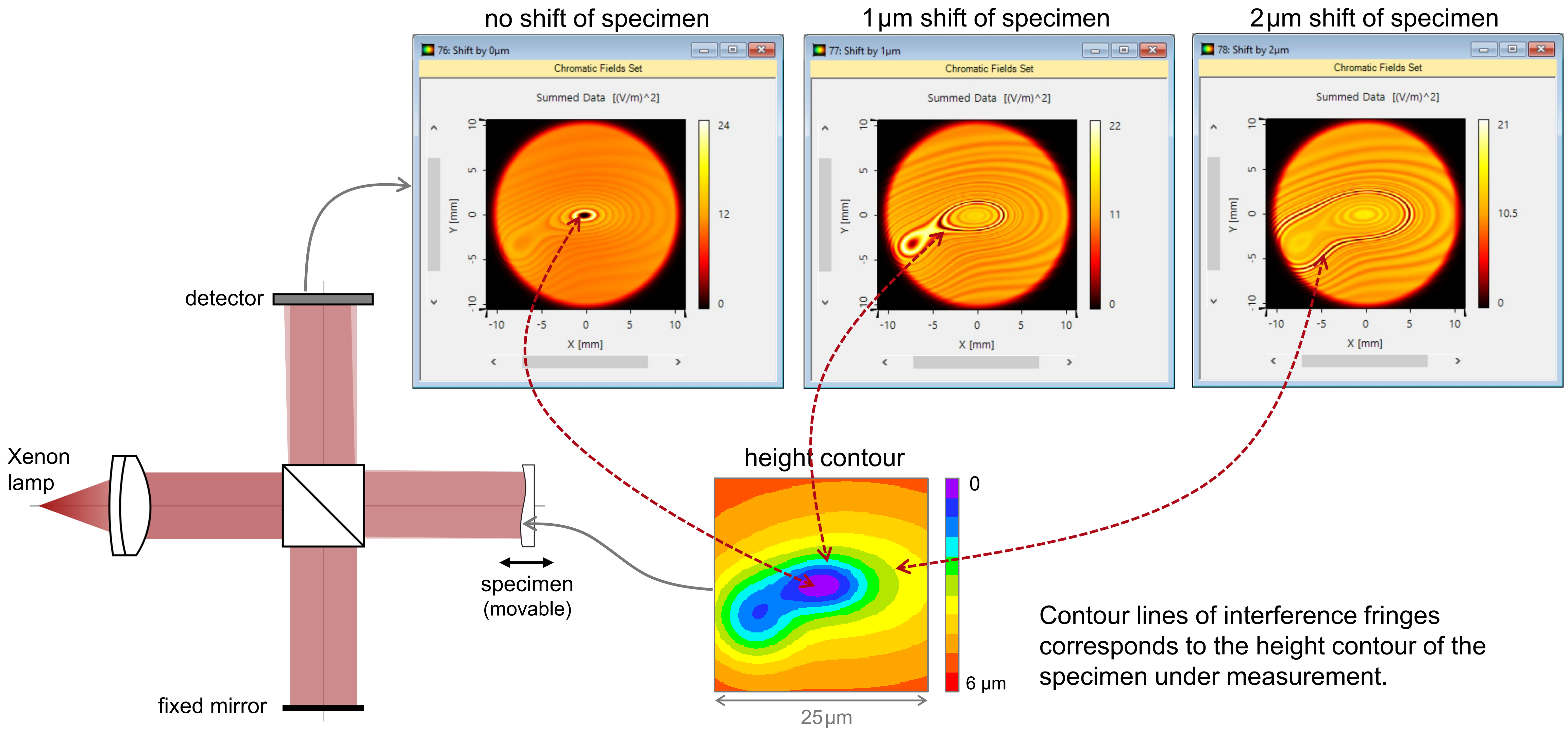
see the full Application Use Case

Modeling Task



How to calculate the interference pattern and even to derive the height profile of the specimen under test?

Simulated Interference Fringes

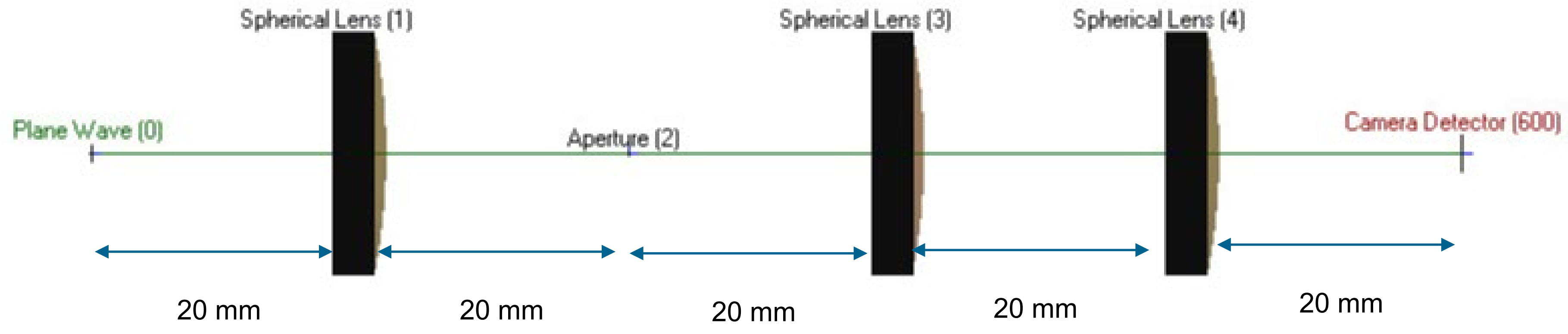


Contour lines of interference fringes corresponds to the height contour of the specimen under measurement.

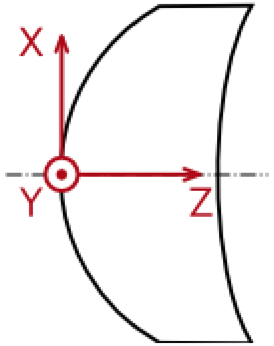
Part 7

Position and Orientation

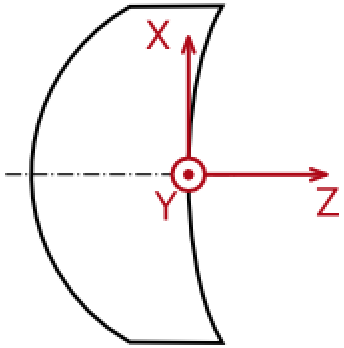
Illustration: Position and Orientation



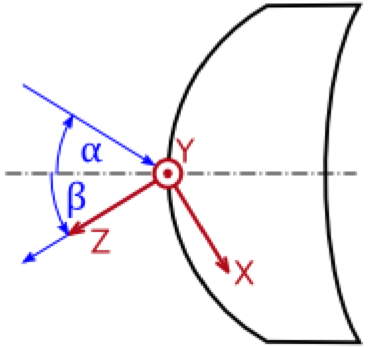
Coordinate Systems



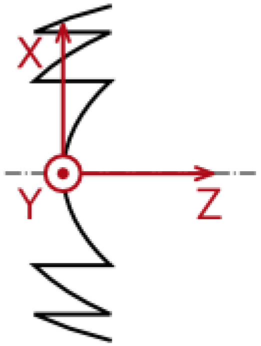
Input coordinate system



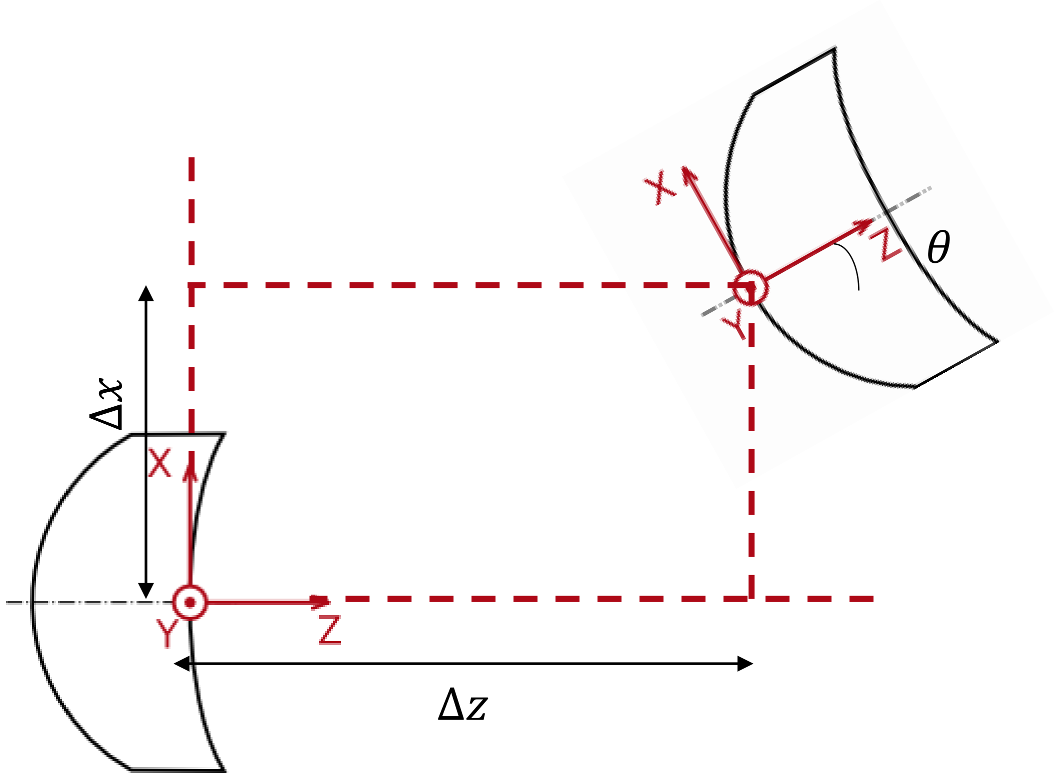
Transmission coordinate system



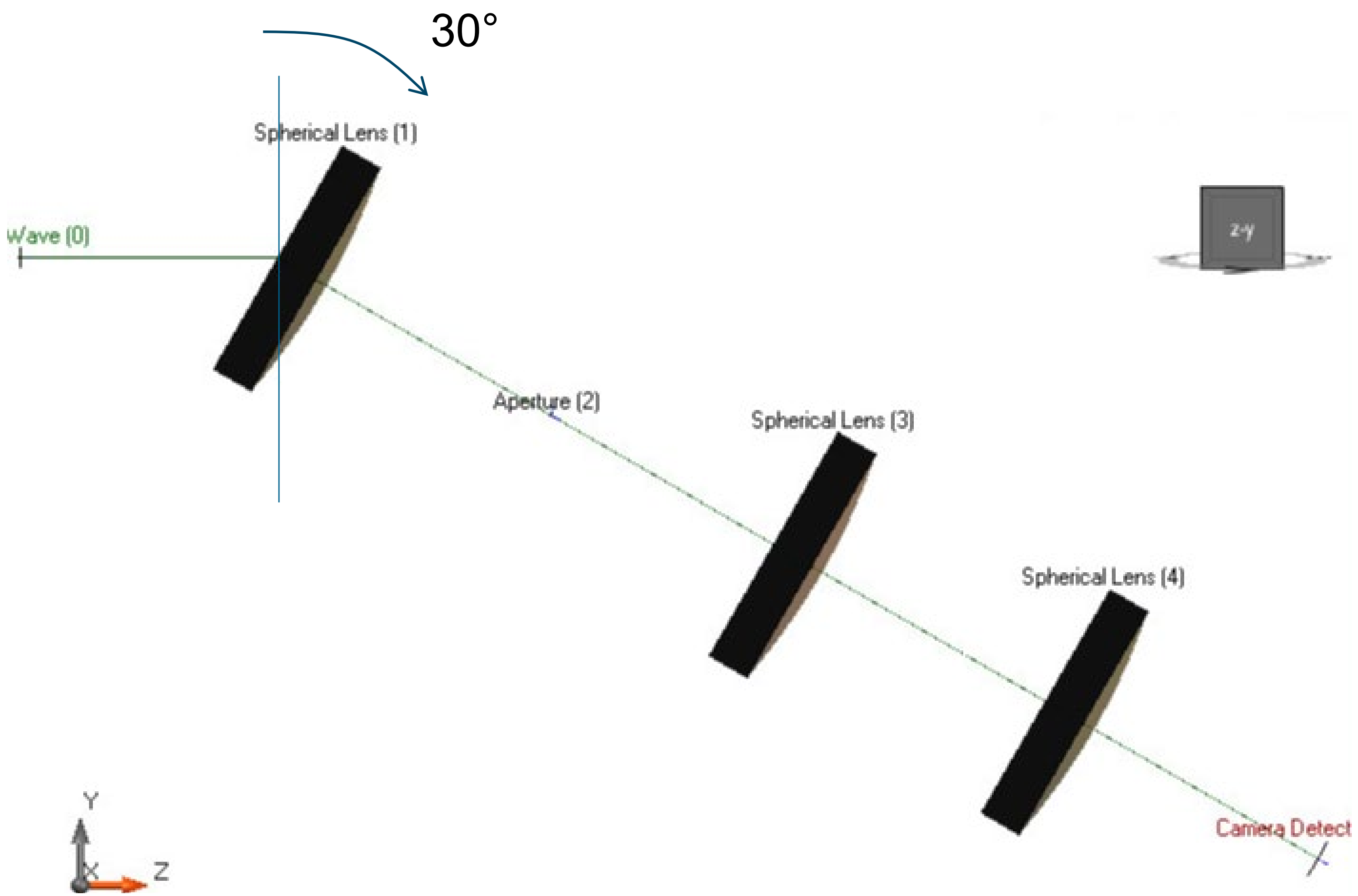
Reflection coordinate system



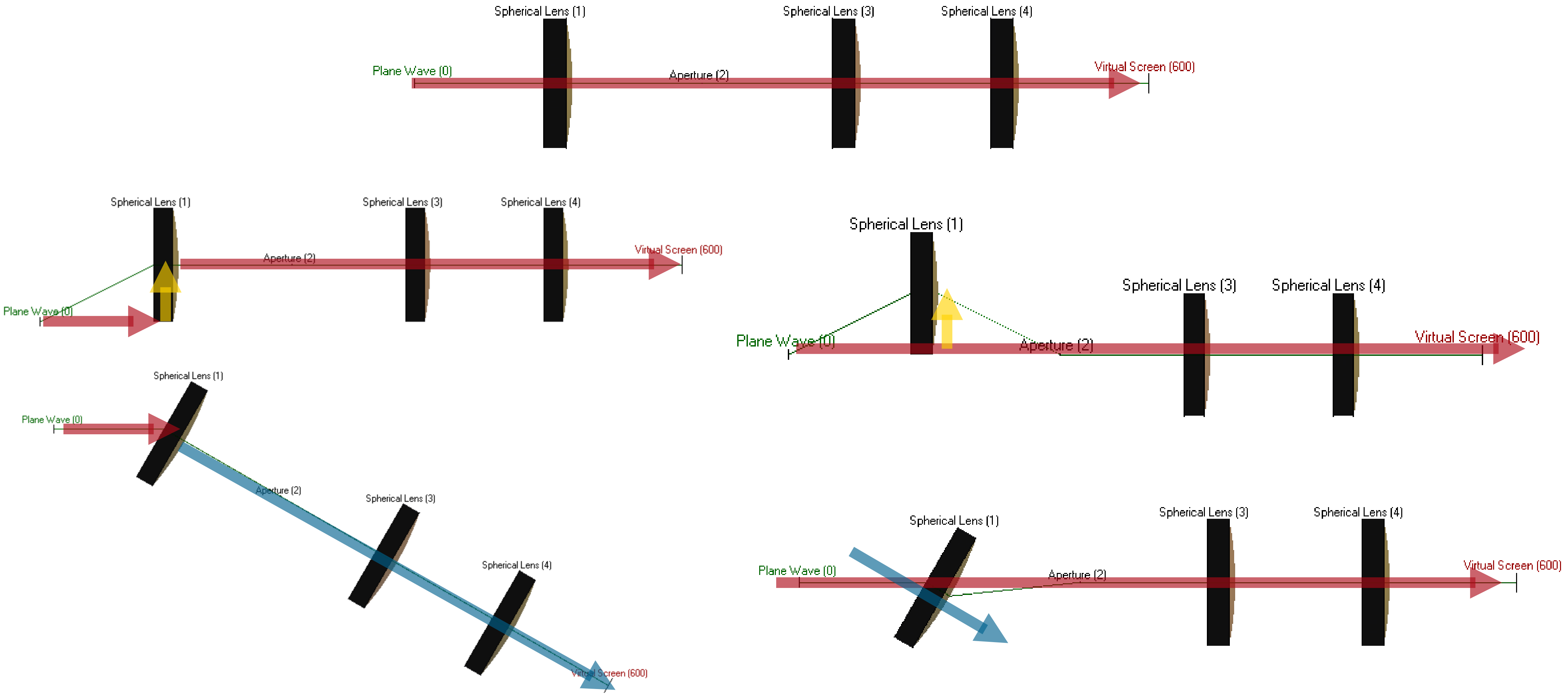
Basal Positioning



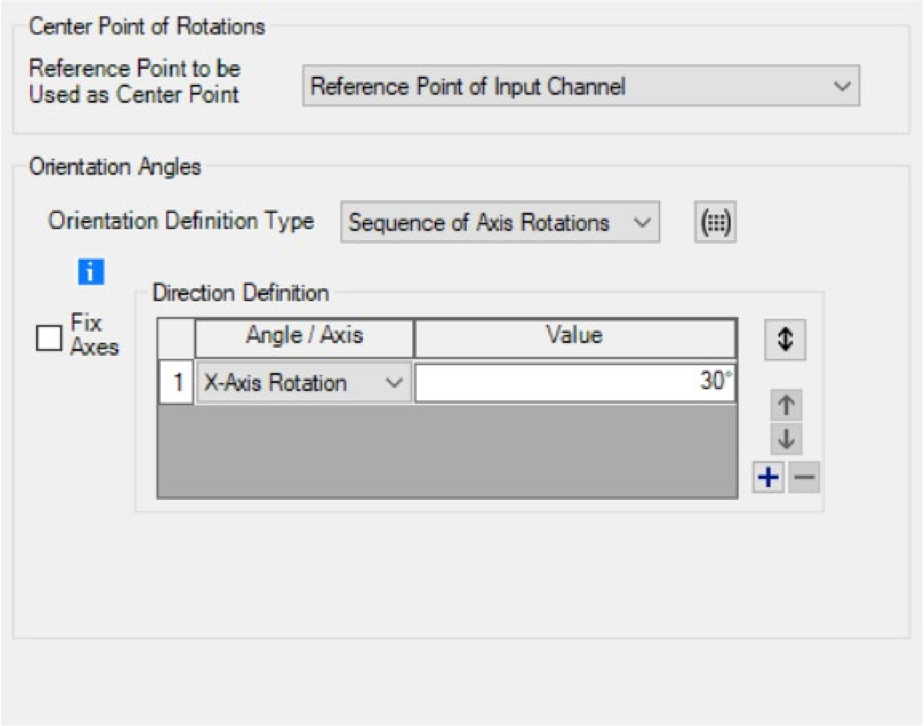
Optical Setup

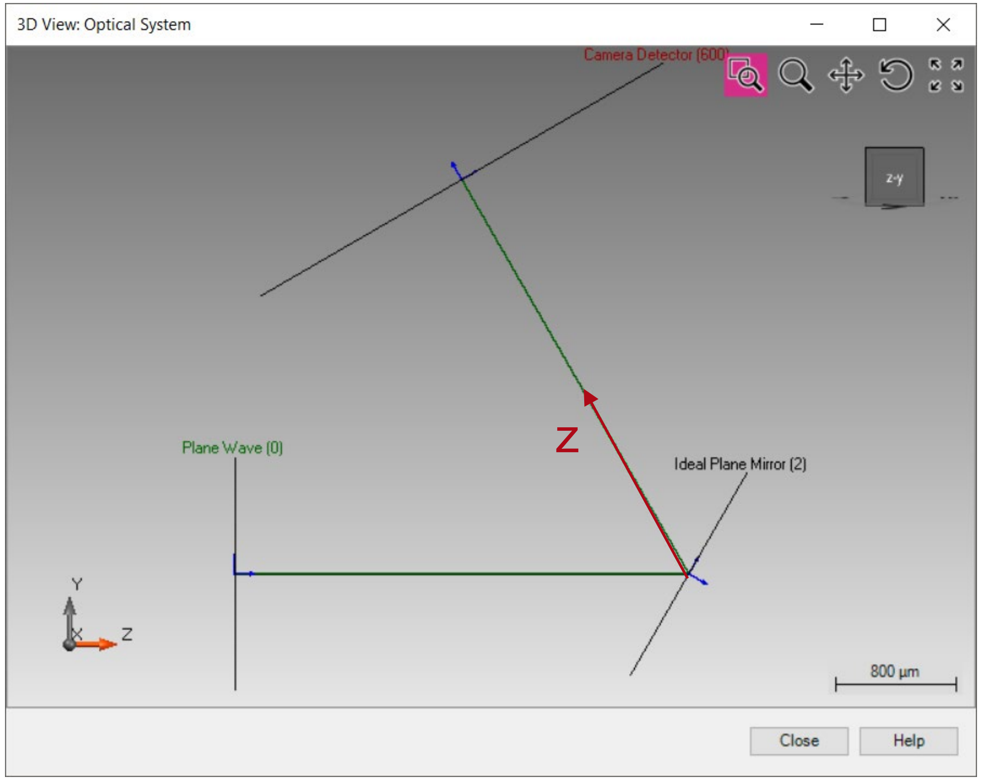


Basal Positioning and Isolated Positioning



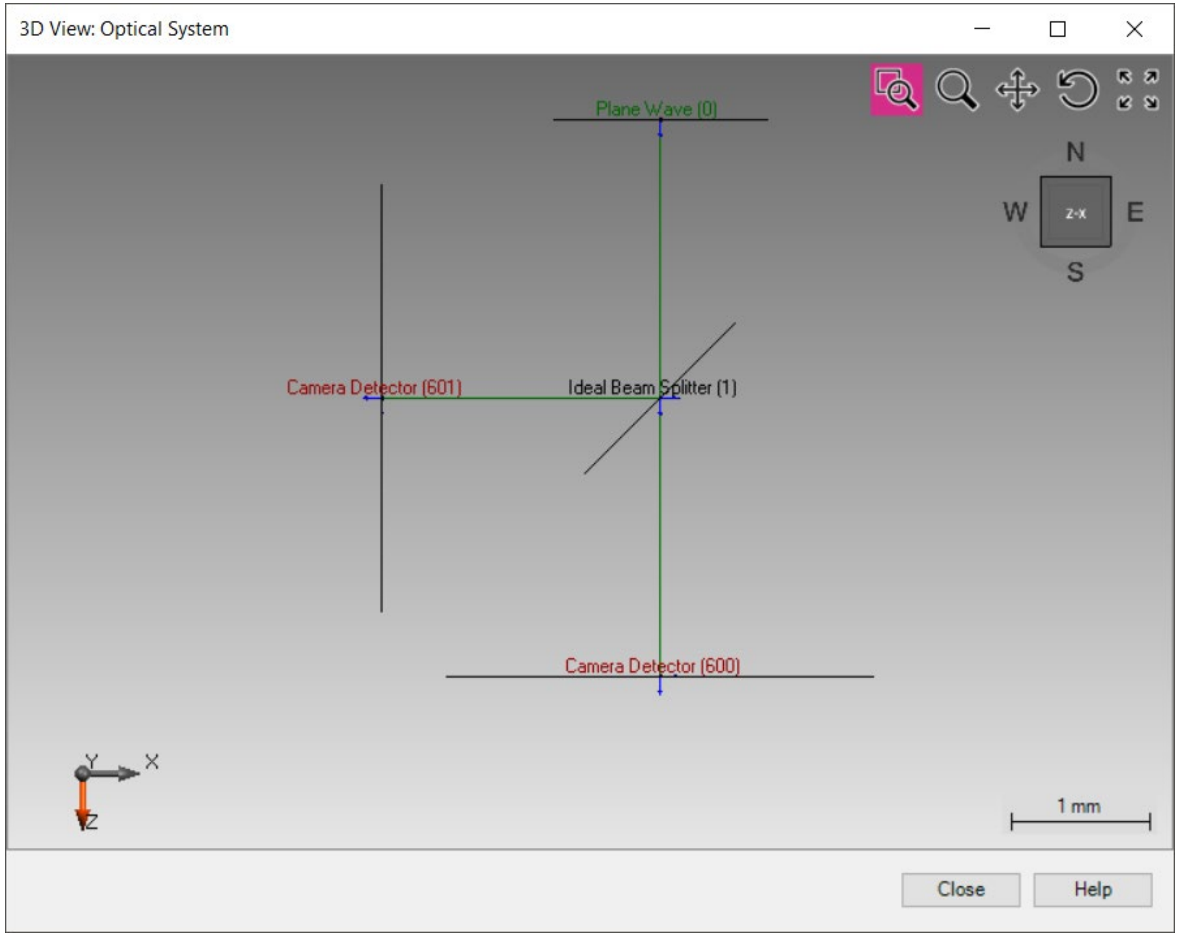
Special Components: Mirror





Special Components: Ideal Beam Splitter

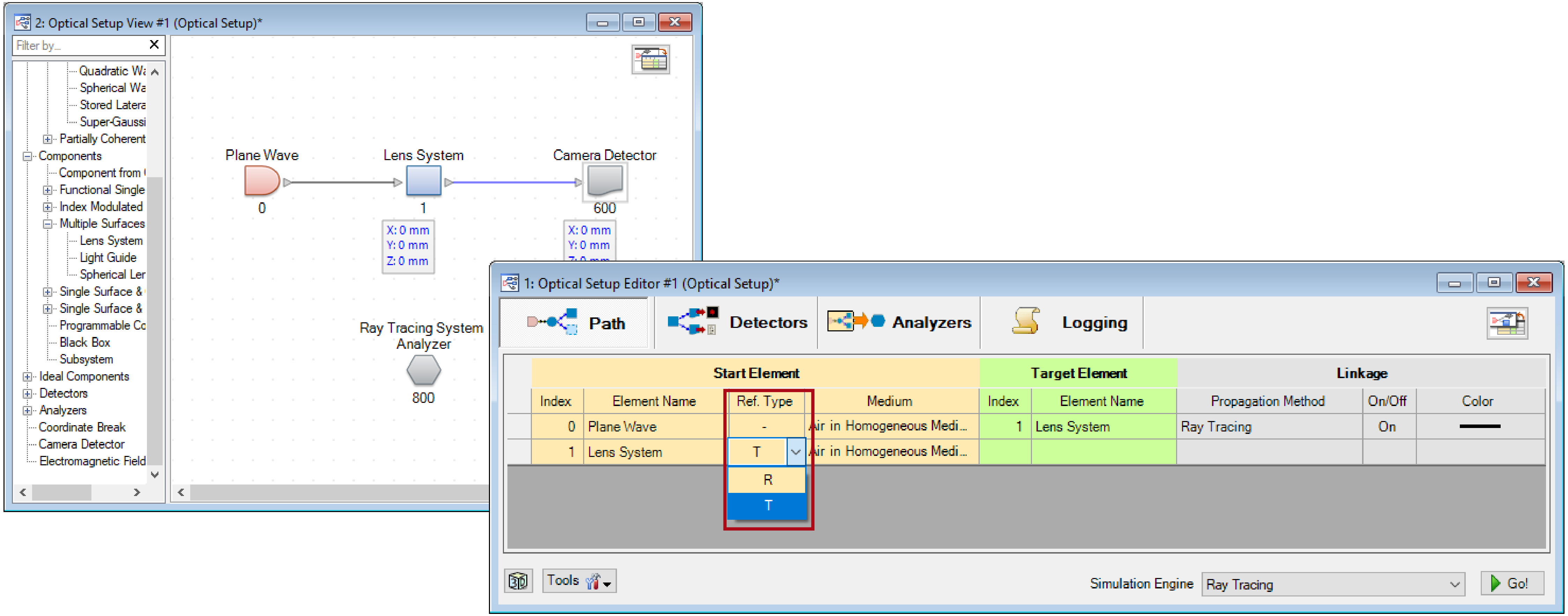
Two perpendicular output channels are automatically defined.



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

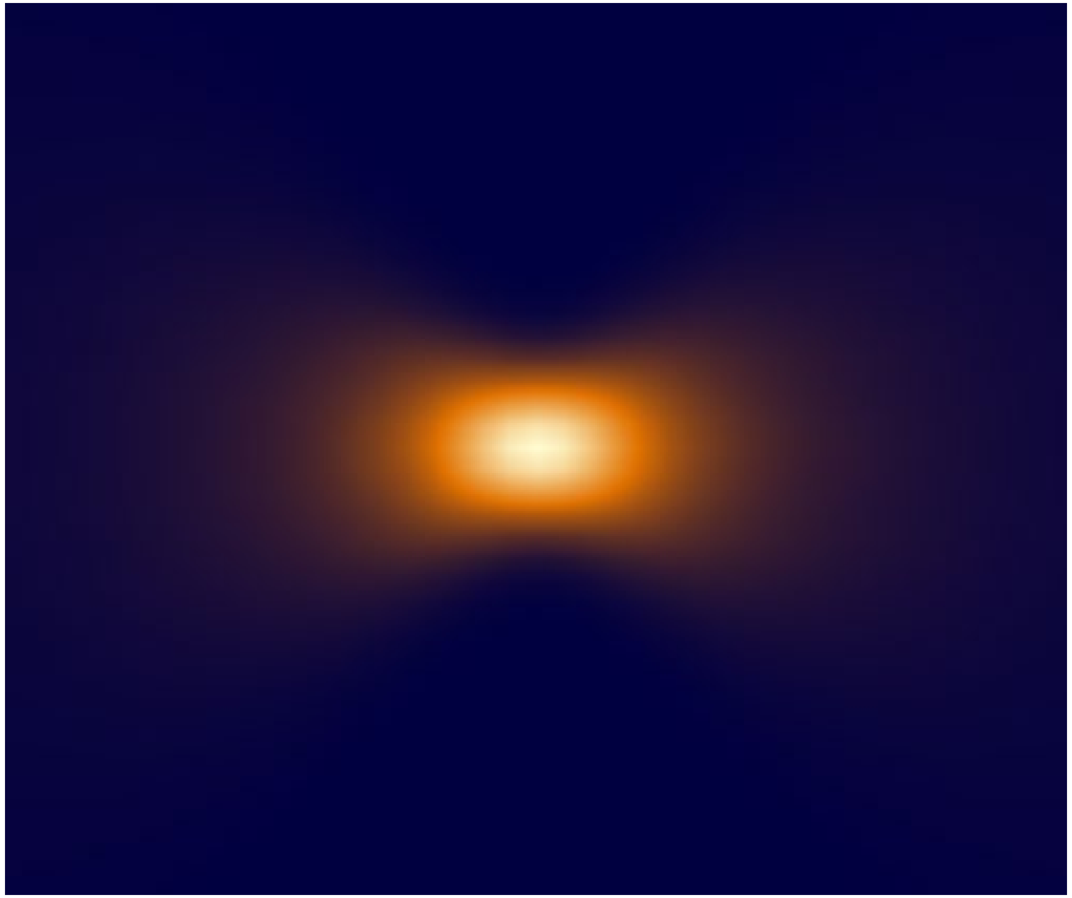
Configuring Reference Type in VirtualLab Fusion



Tolerance Analysis of a Fiber Coupling Setup

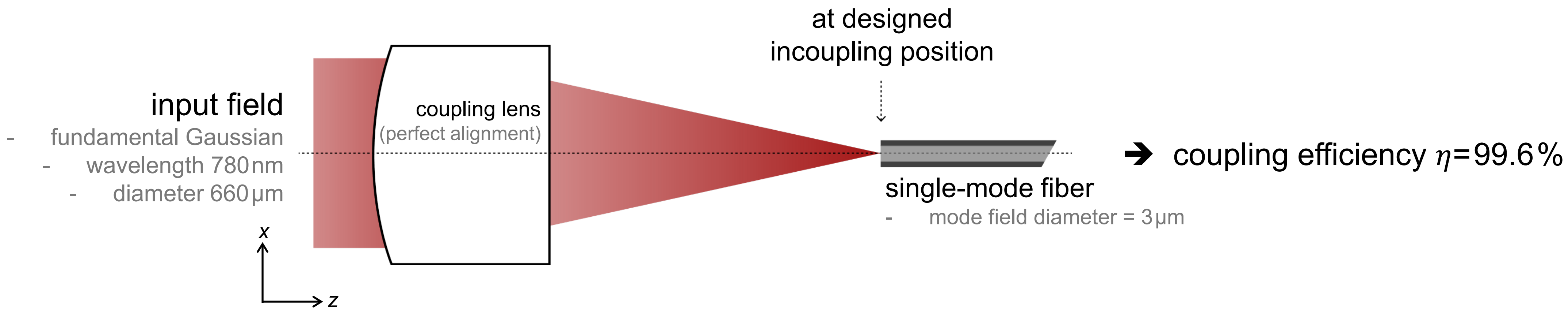
see the full Application Use Case

Abstract

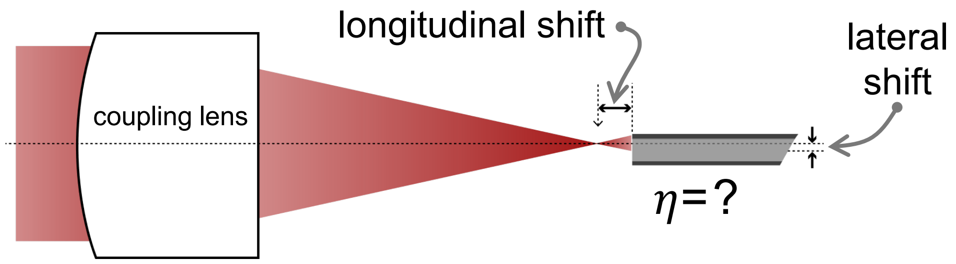


In modern optics, fibers can be found in various optical system, and it is usually of concern how much light can be coupled into fibers. The coupling efficiency can be sensitive to the system alignment, especially for single-mode fibers with relatively small core diameters. In this example, a well-designed 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.

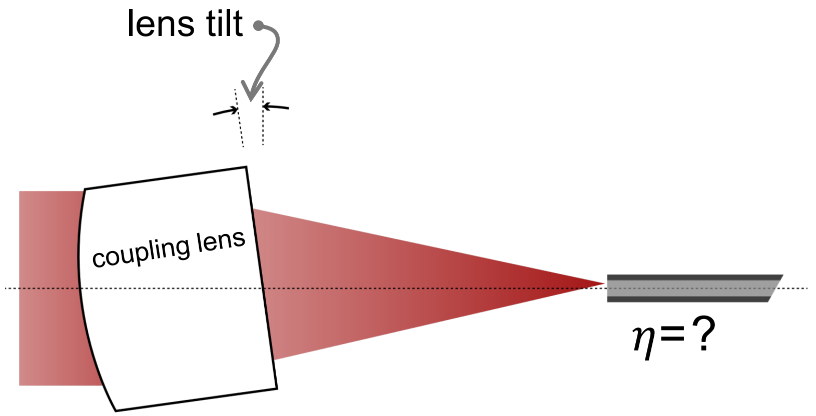
Modeling Task



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

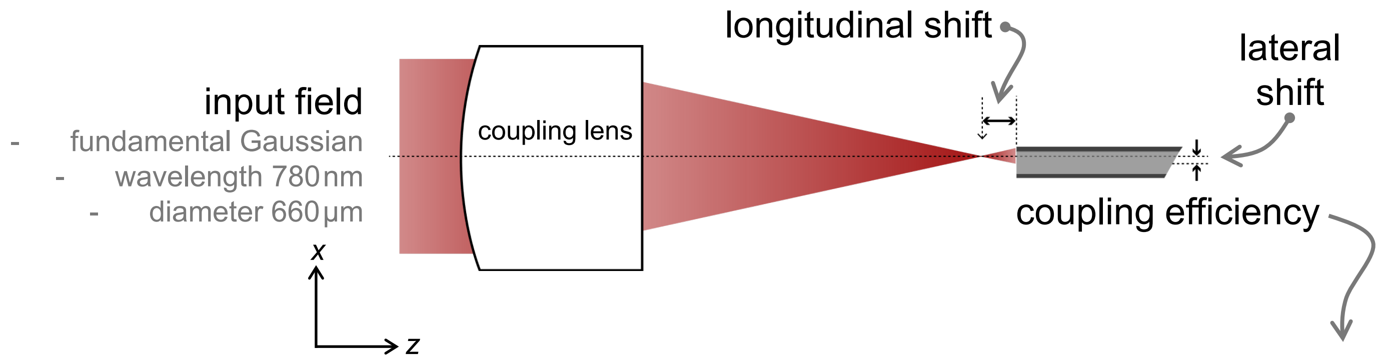


(a) shift of fiber end position

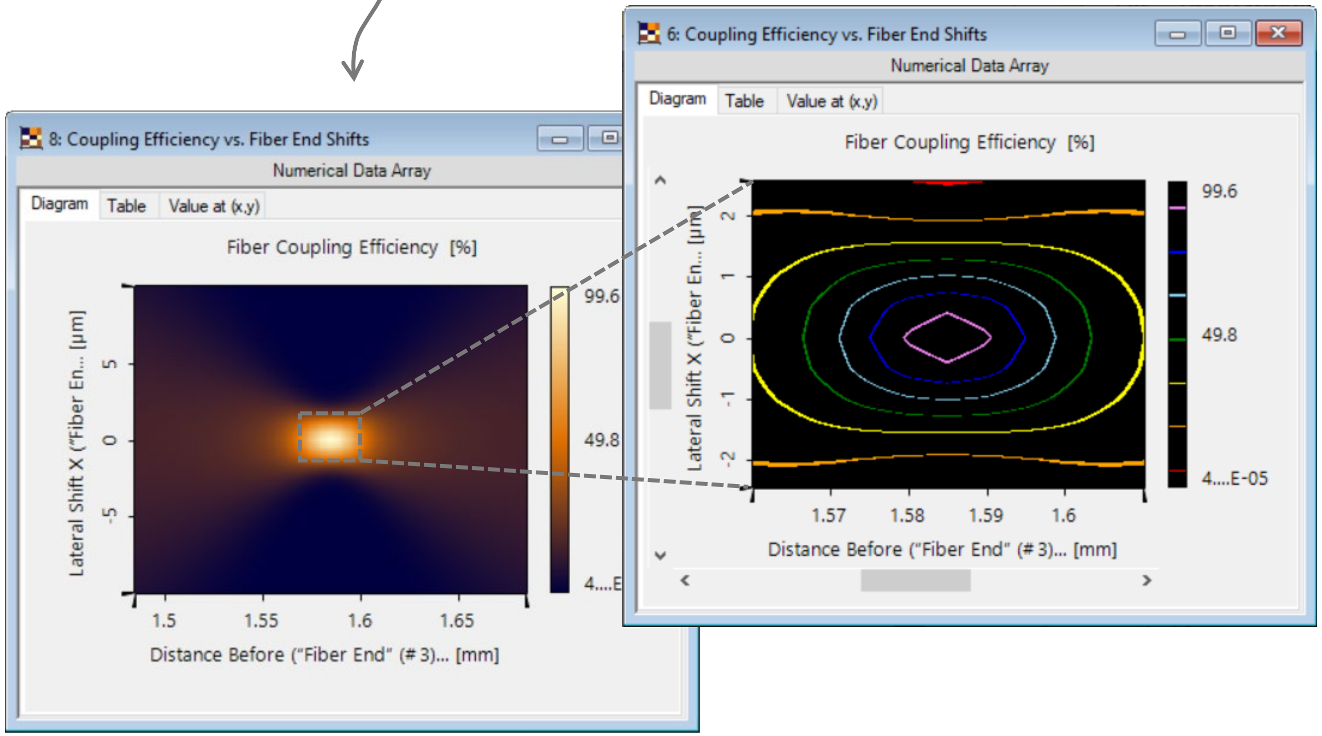


(b) tilt of coupling lens

Coupling Efficiency vs. Fiber End Position Shift

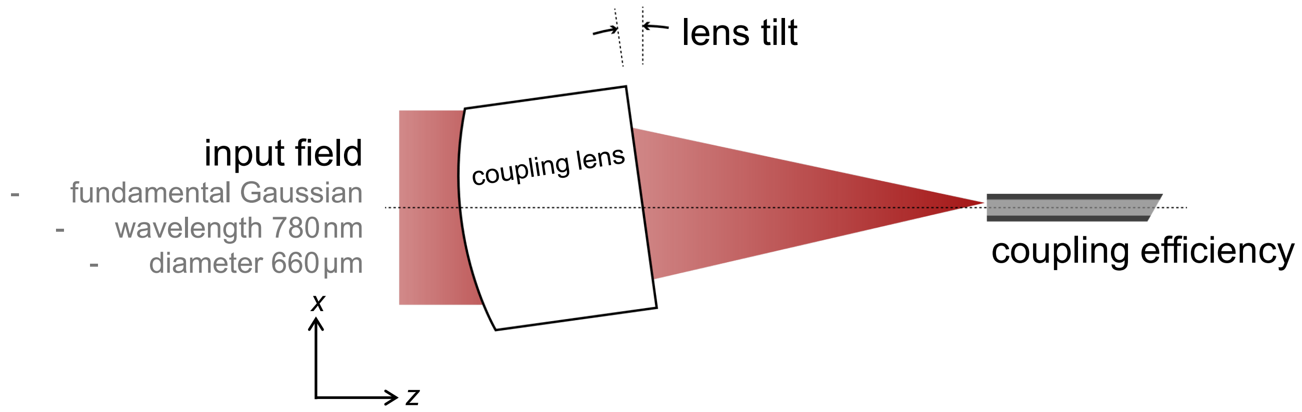


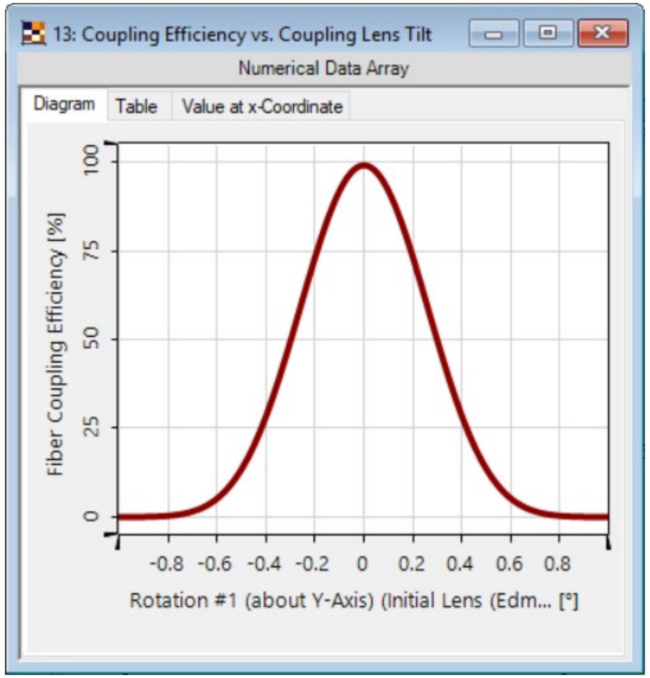
Contour plot helps with the identification of the parameter range for desired coupling efficiency threshold.



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

Coupling Efficiency vs. Coupling Lens Tilt



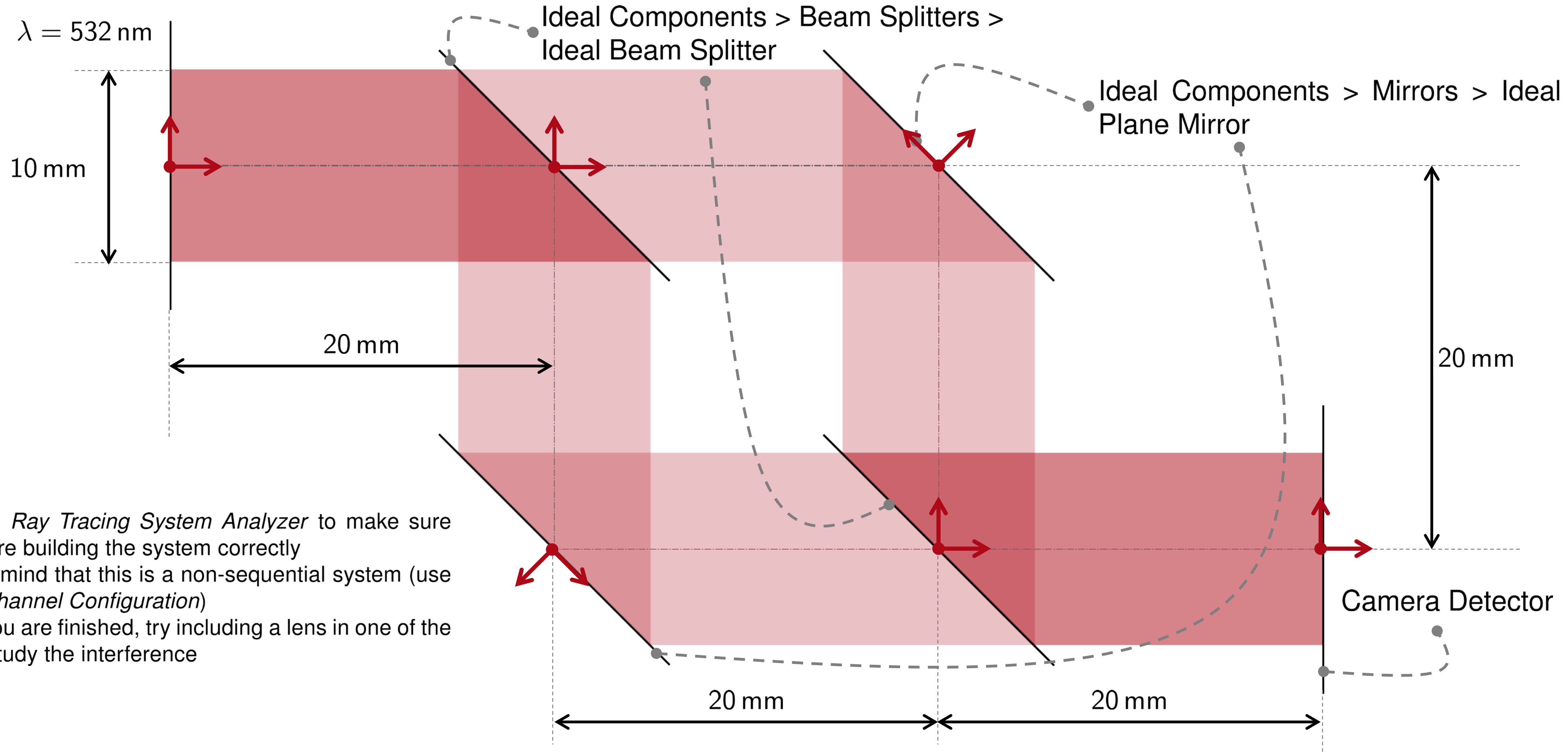


Physical-optics analysis of the coupling efficiency with respect to lens tilt. When lens tilt angle is within 0.1°, the coupling efficiency is still higher than 90%

Exercise 2

Build a Mach-Zehnder Interferometer

Build the Following System in VirtualLab Fusion

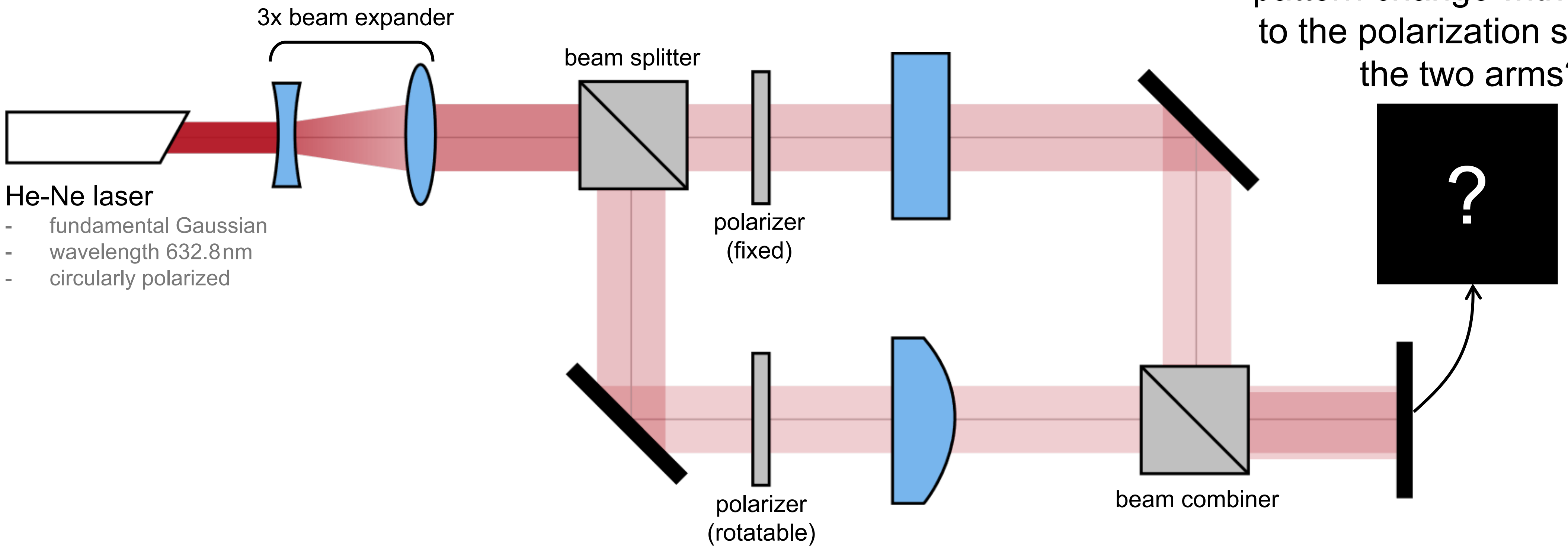


- Use the *Ray Tracing System Analyzer* to make sure that you are building the system correctly
- Keep in mind that this is a non-sequential system (use *Manual Channel Configuration*)
- When you are finished, try including a lens in one of the paths to study the interference

Generation of Spatially Varying Polarization by Interference with Polarized Light

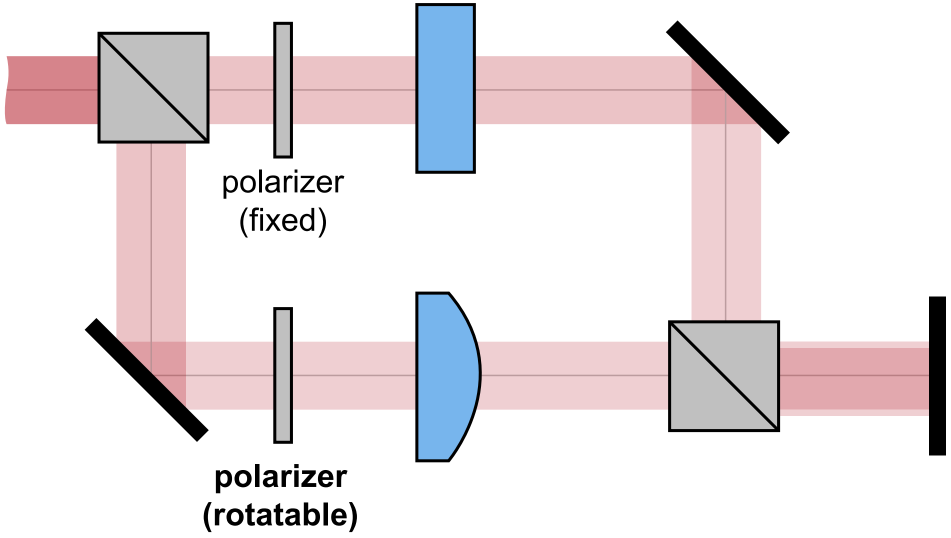
see the full Application Use Case

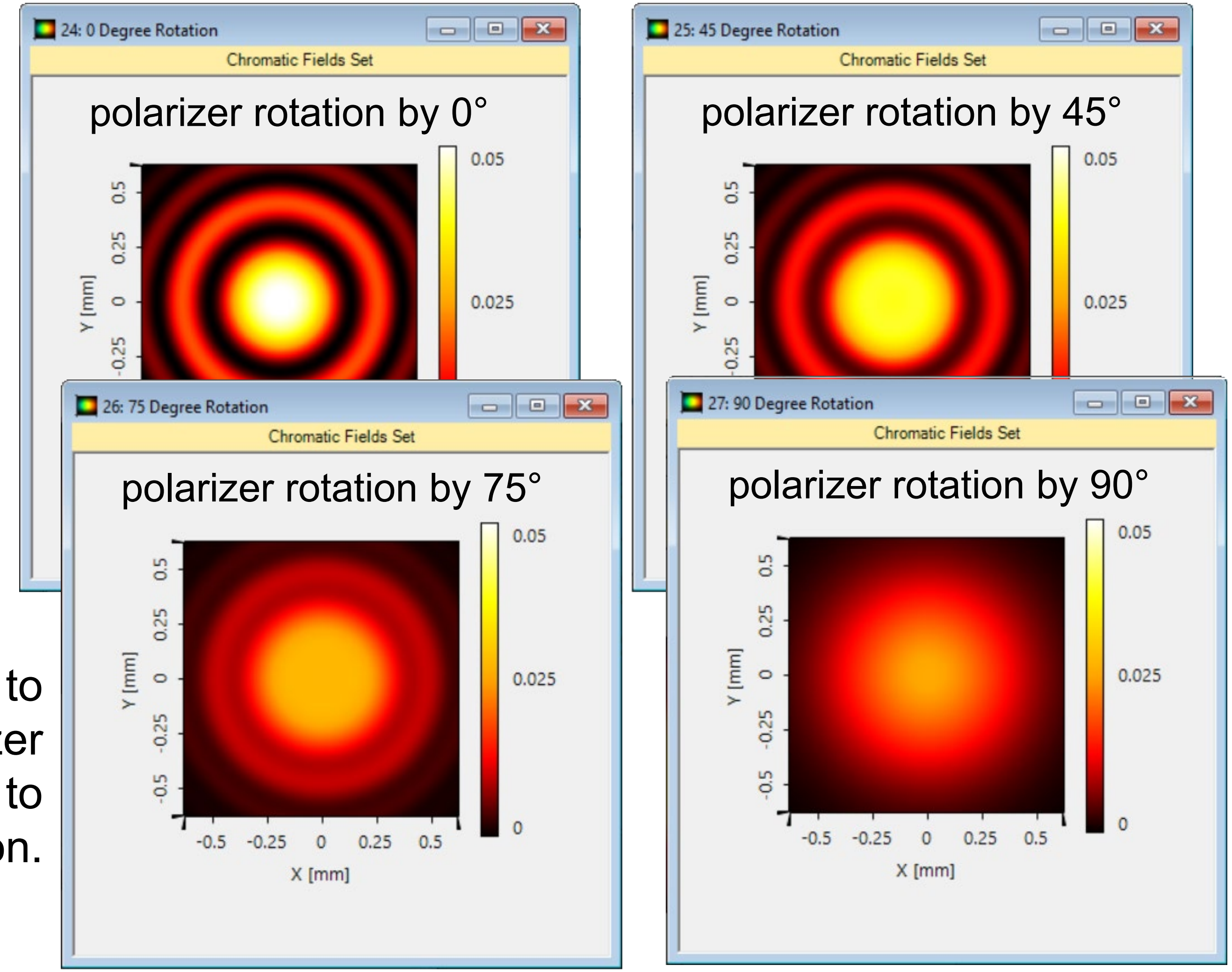
Modeling Task



How does the interference pattern change with respect to the polarization states of the two arms?

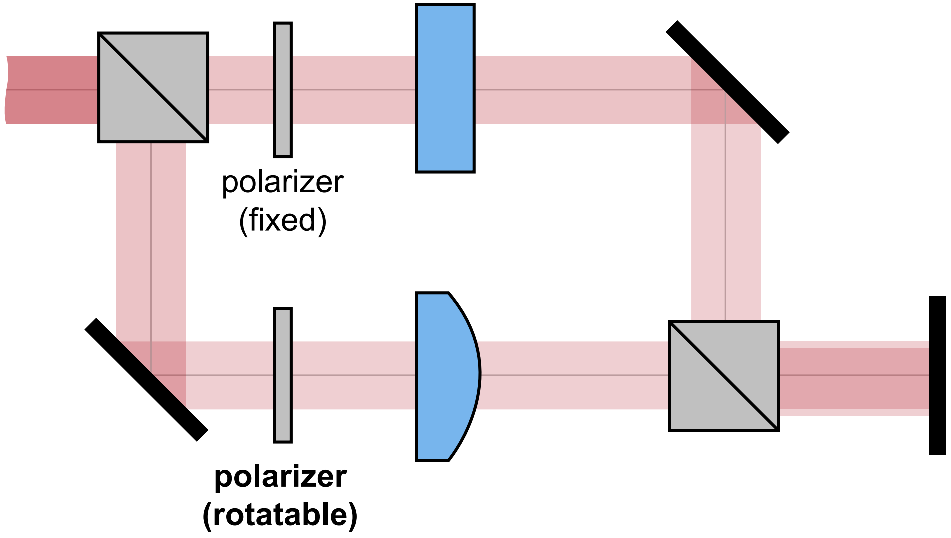
Interference Pattern Changes with Polarizer Rotation

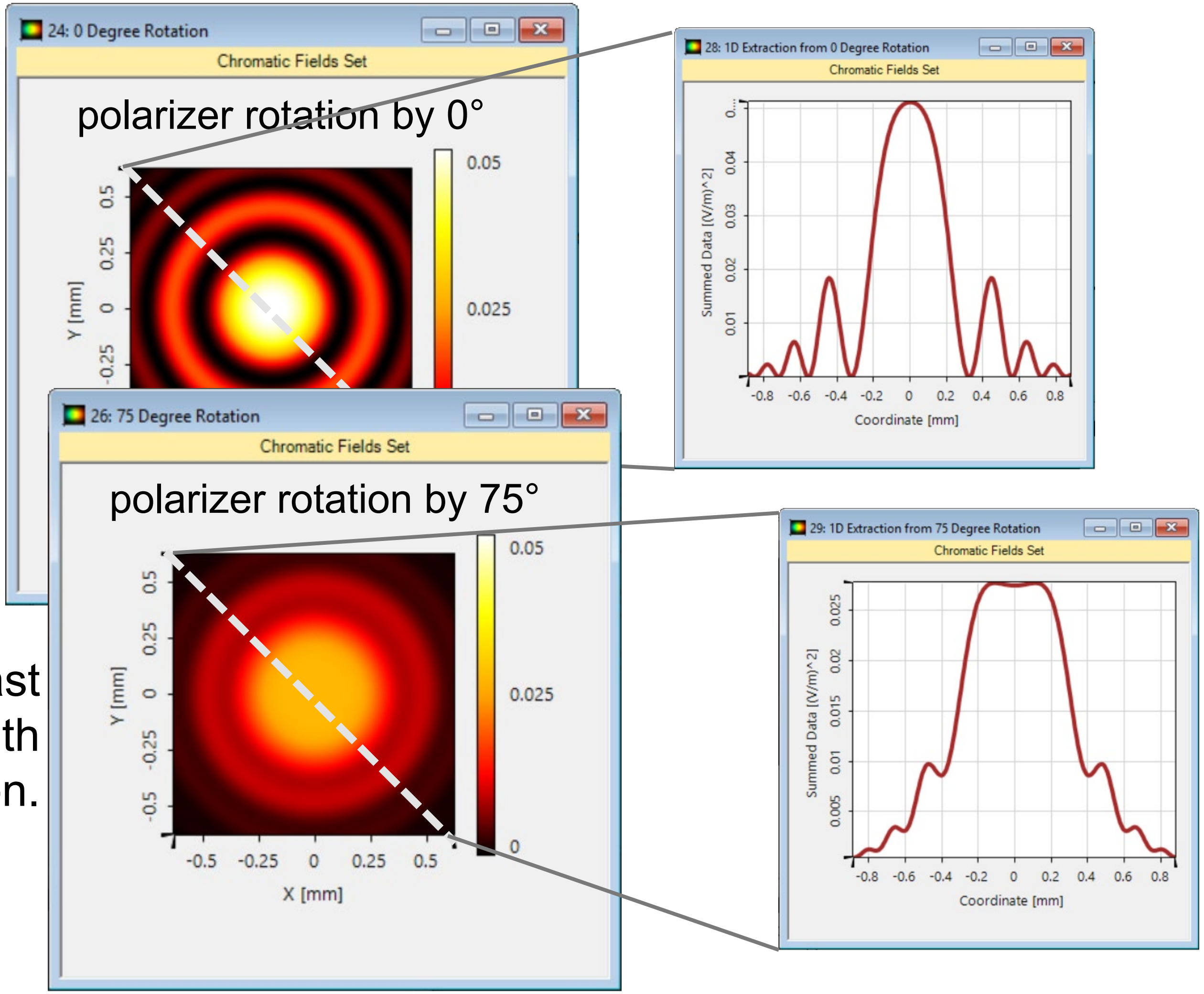




Interference fringes start to disappear, when polarizer rotates from parallel to orthogonal orientation.

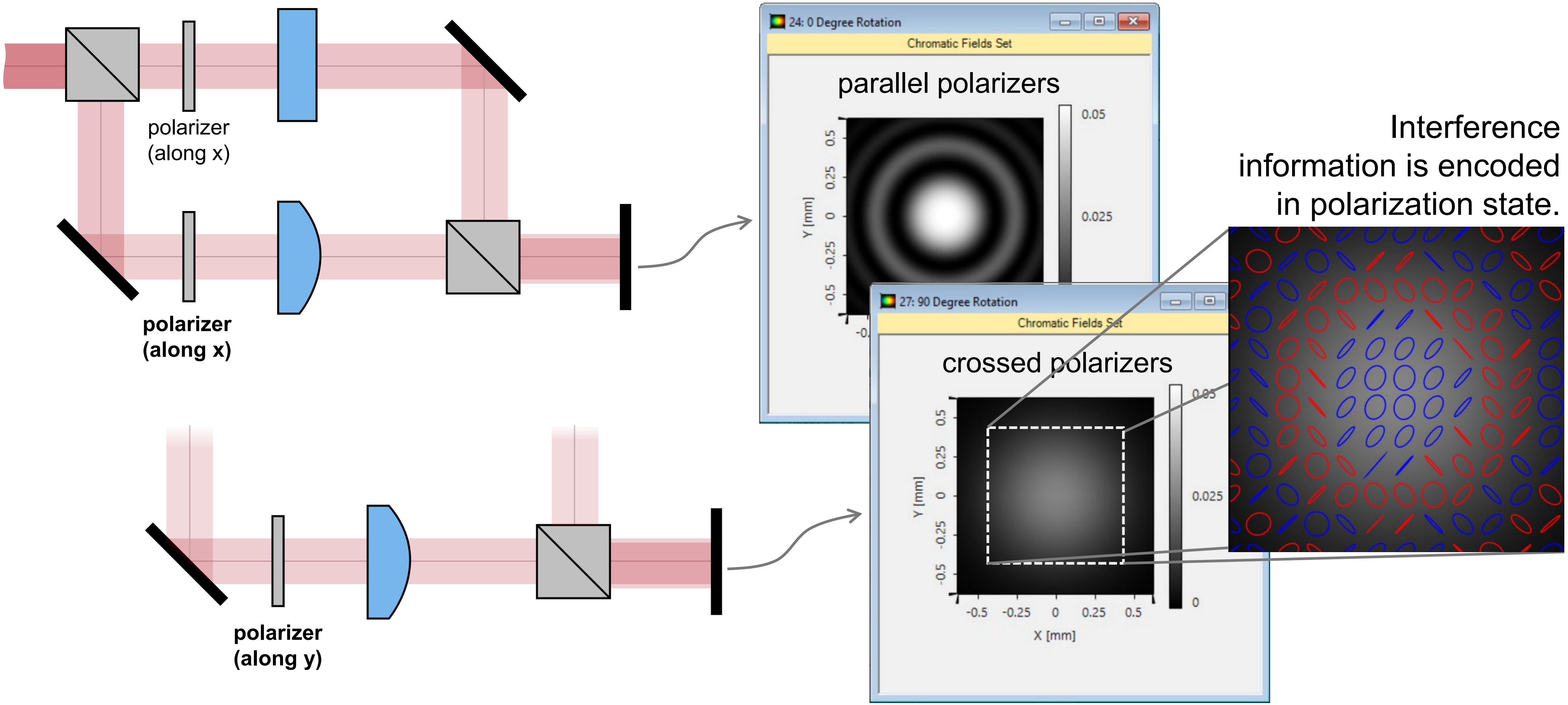
Interference Pattern Changes with Polarizer Rotation





Fringe contrast changes with polarizer rotation.

Interference Pattern



Interference information is encoded in polarization state.

Hands-on Sessions Exercises

Exercise1

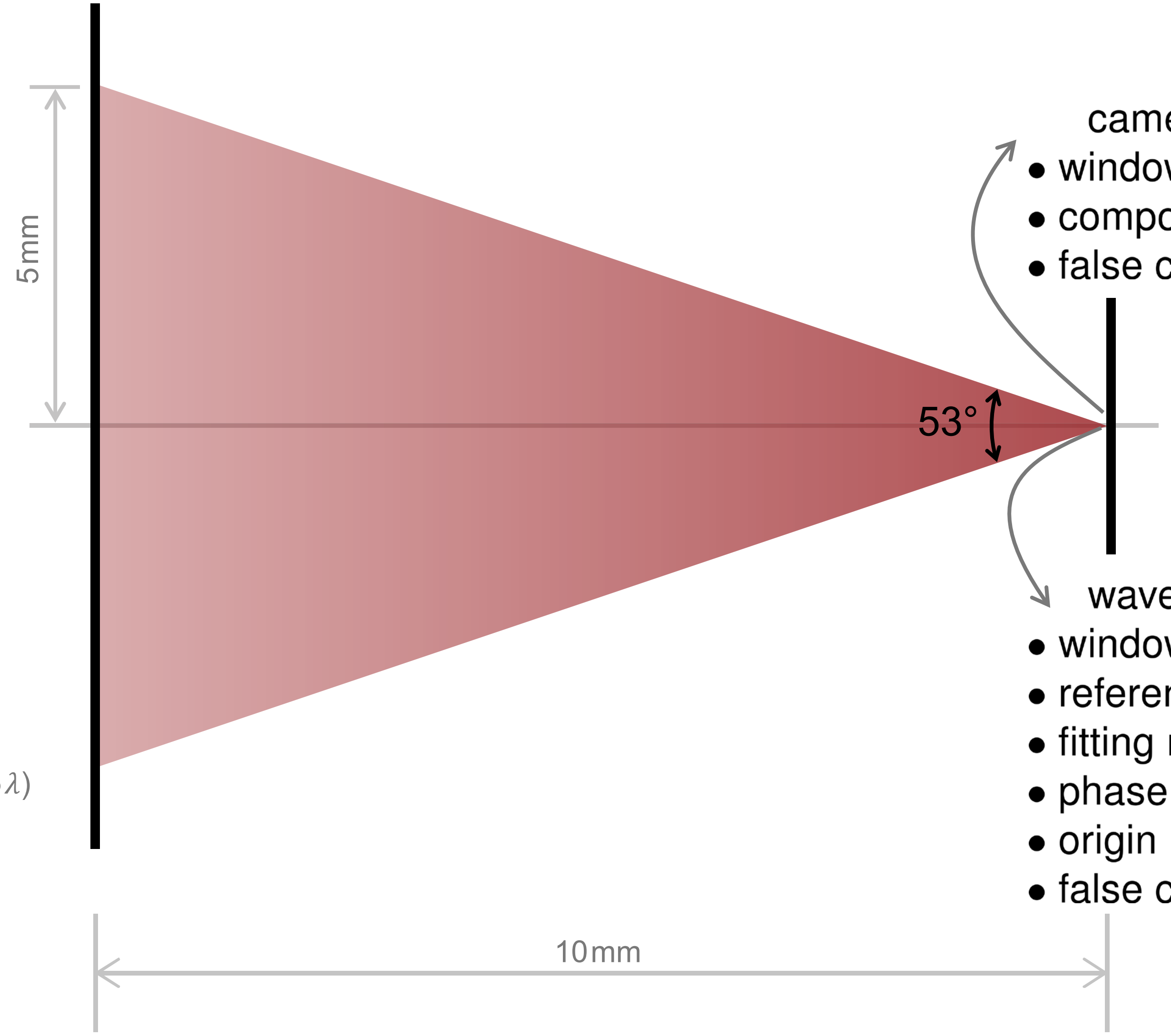
Evaluate the Focal Spot for Different Aberrations

see the full Application Use Case

Build the Following System in VirtualLab Fusion

input spherical wave with different aberration

- wavelength @532nm
- type of aberration:
  1. defocus (0.2λ- 0.5λ)
  2. spherical (0.2λ- 0.5λ)
  3. astigmatism (0.2λ- 0.5λ)
  4. coma (0.2λ- 0.5λ)
  5. secondary coma (0.2λ- 0.5λ)
  6. trefoil (0.2λ- 0.5λ)



camera detector

- window size 15 μm $\times$ 15 μm
- components to integrate E_x, E_y and E_z
- false colour for better visualization

wavefront error detector

- window size 11 mm $\times$ 11 mm
- reference wavefront: spherical phase
- fitting method: user-defined radius & origin
- phase radius: -10 mm
- origin (x,y): (0,0)
- false colour for better visualization

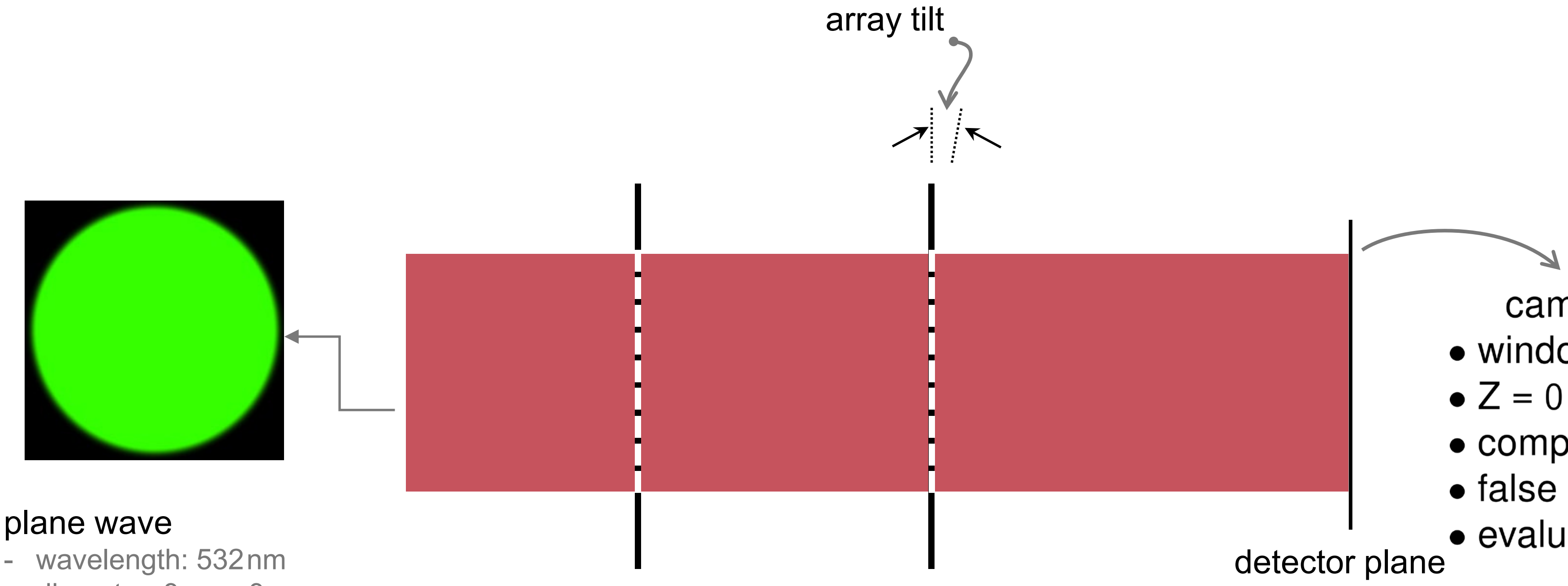
Note: The aberrations can be introduced to the wavefront by using the “Zernike & Seidel Aberrations” component.

Exercise 2-a

Generate Moiré Fringes with Periodic Apertures

see the full Application Use Case

Build the Following System in VirtualLab Fusion



camera detector

- window size 5 mm $\times$ 5 mm
- Z = 0 mm
- components to integrate E_x and E_y
- false colour for better visualization
- evaluate the interference pattern

plane wave

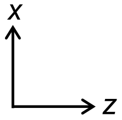
- wavelength: 532 nm
- diameter: 3 mm × 3 mm
- relative edge width: 5 %

1D periodic aperture

- aperture component
- periodicity: along-X
- aperture size: 50 µm
- period size: 100 µm

1D periodic aperture

- aperture component
- periodicity: along-X
- aperture size: 50 µm
- period size: 100 µm
- array tilt angle: 5°

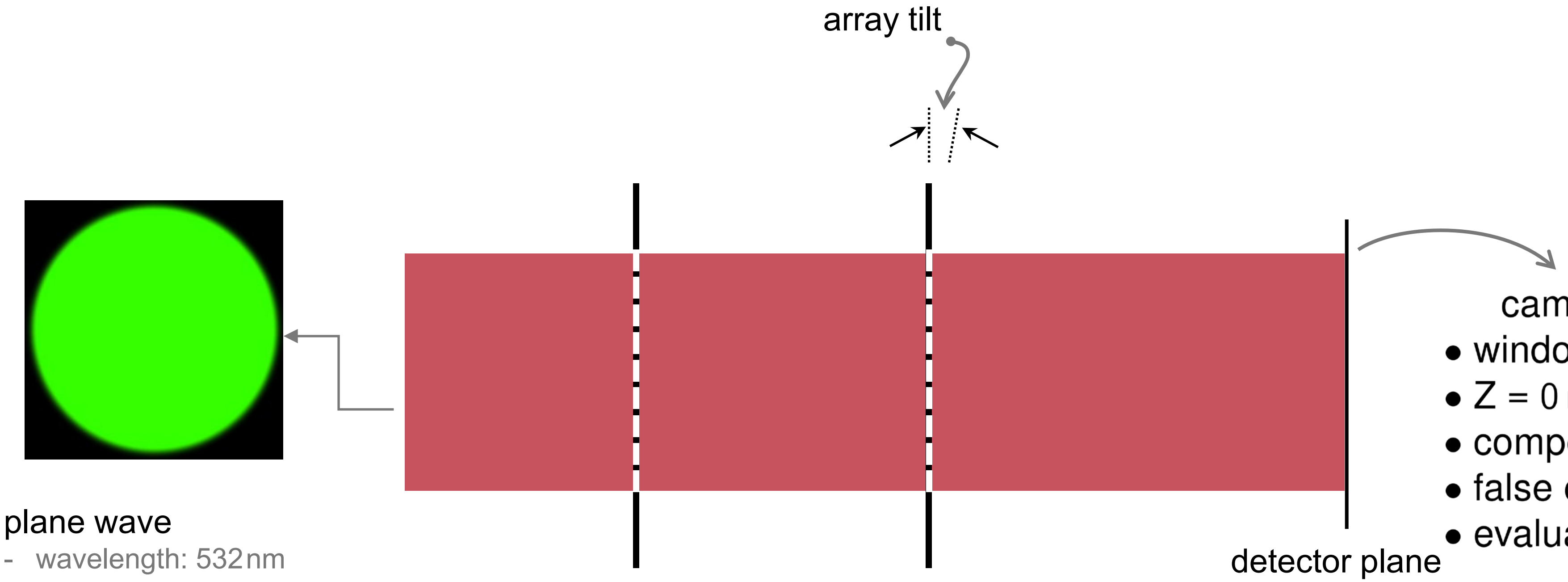


Exercise 2-b

Generate Moiré Fringes with Sinusoidal Gratings

see the full Application Use Case

Build the Following System in VirtualLab Fusion



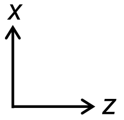
plane wave
- wavelength: 532 nm
- diameter: 3 mm × 3 mm
- relative edge width: 5 %

1D periodic grating
- Sinusoidal grating transmission
- periodicity: along-X
- period size: 100 µm
- modulation depth: 1 V/m

1D periodic grating
- Sinusoidal grating transmission
- periodicity: along-X
- period size: 100 µm
- modulation depth: 1 V/m
- array tilt angle: 5°

camera detector
- window size 5 mm × 5 mm
- Z = 0 mm
- components to integrate E_x and E_y
- false colour for better visualization
- evaluate the interference pattern

Vary the tilt angle to observe the corresponding influence on the interference fringes...

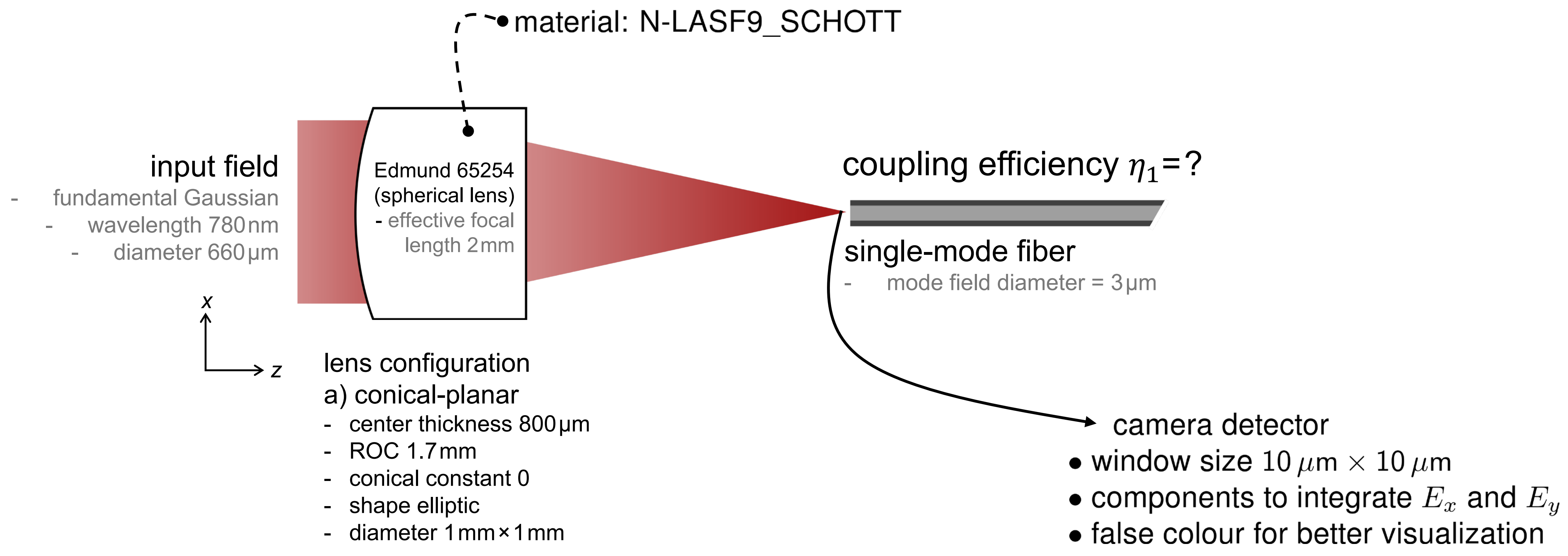


Exercise 3-a

Evaluate The Coupling Efficiency of Different Lenses

see the full Application Use Case

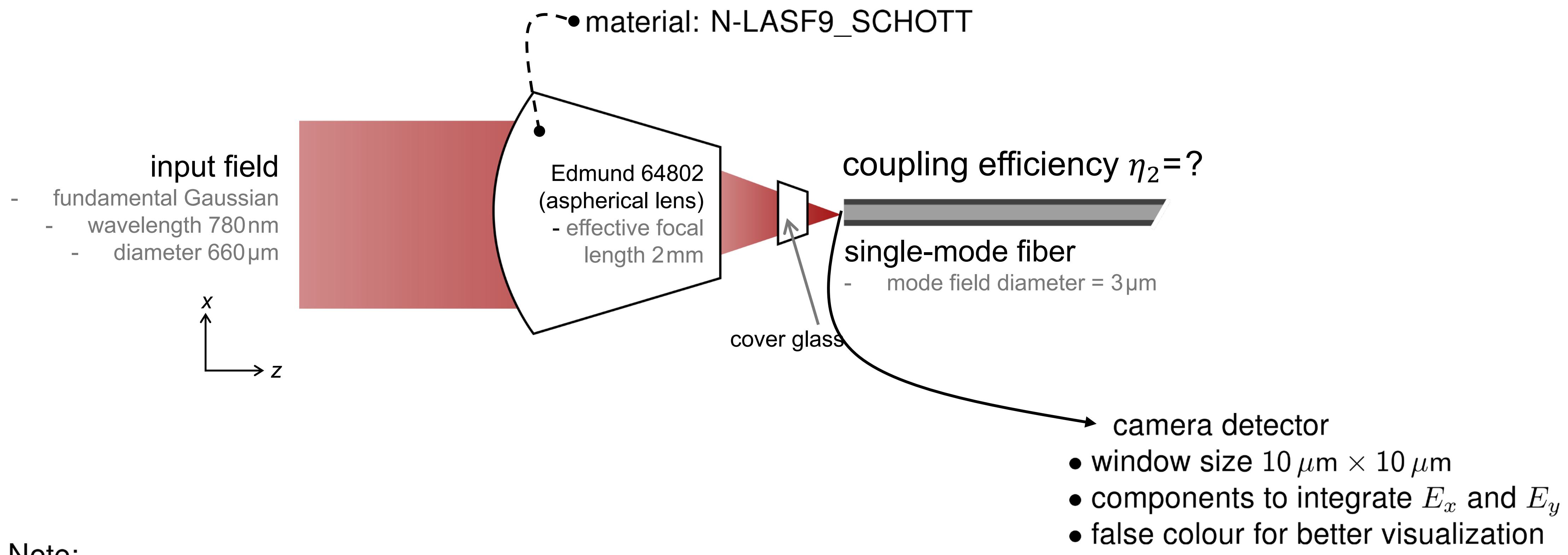
Build the Following System in VirtualLab Fusion



Note:

- Take care of the diffraction in the system.
- Use Single-mode Fiber Coupling Efficiency detector.

Build the Following System in VirtualLab Fusion



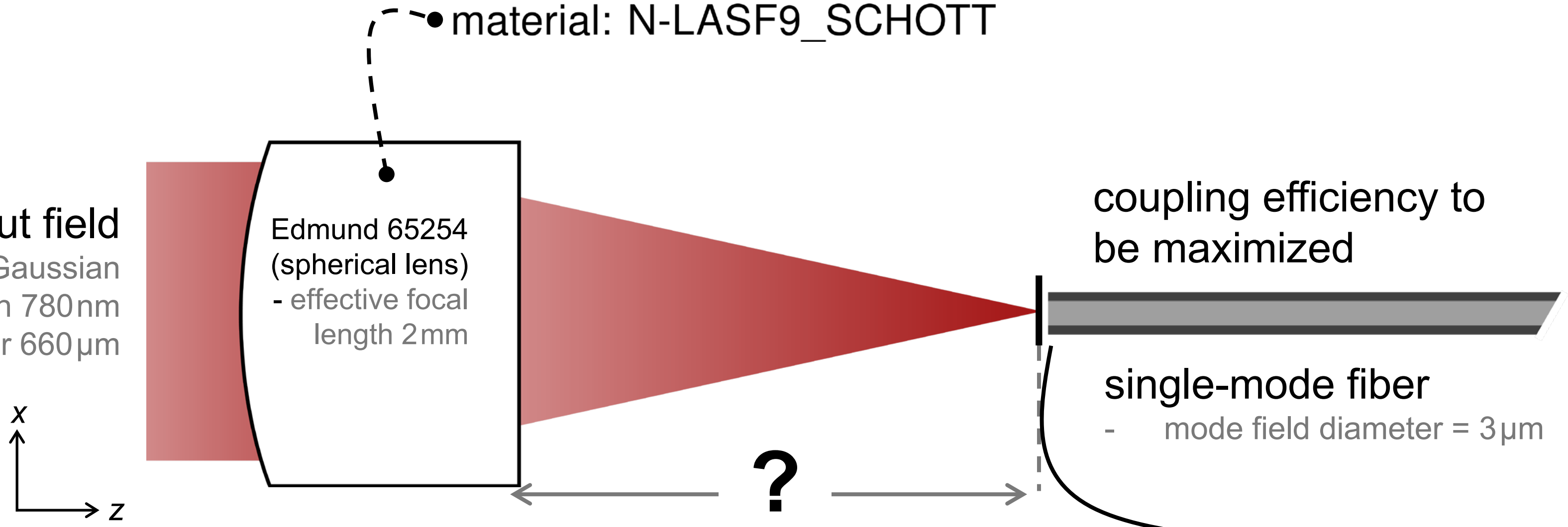
Note:
- Take care of the diffraction in the system.
- The lens configuration can be imported into VirtualLab Fusion components catalog. (file name: Edmund_64802_Aspherical Lens.ctlg)
- Use Single-mode Fiber Coupling Efficiency detector.

Exercise 3-b

Find The Optimal Working Distance For Coupling Light into a Single-Mode Fiber

see the full Application Use Case

Schematic View of The Optical Setup



Note:

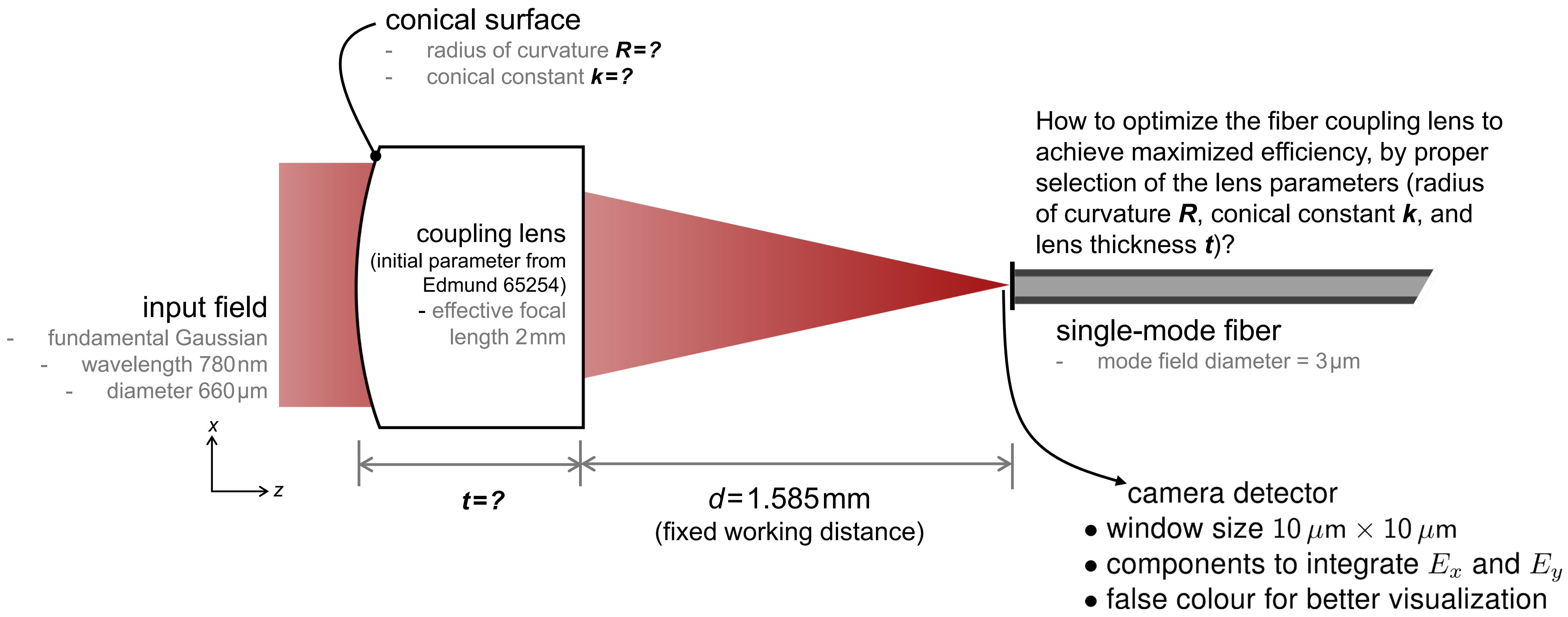
- Take care of the diffraction in the system.
- Use Single-mode Fiber Coupling Efficiency detector.
- First, use ray tracing to find the focal distance of the spherical lens.
- Second, use field tracing to find the optimal focal length and compare it with the ray tracing result.

Exercise 3-c

Apply Parametric Optimization to The Fiber Coupling Lens

see the full Application Use Case

Build the Following System in VirtualLab Fusion

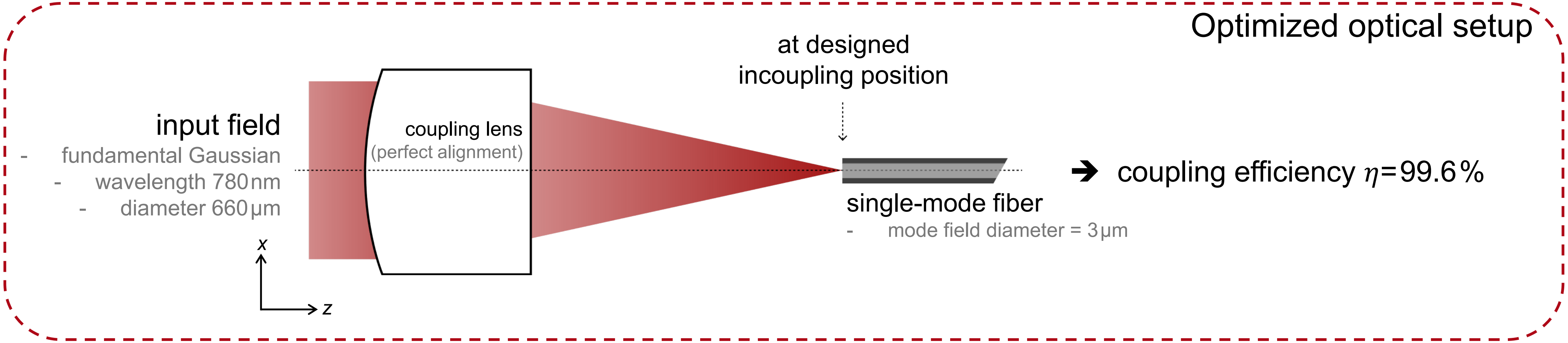


Exercise 3-d

Analyze The Tolerances Induced to The Fiber Coupling Lens

see the full Application Use Case

Schematic View of The Optical Setup



misalignment configuration

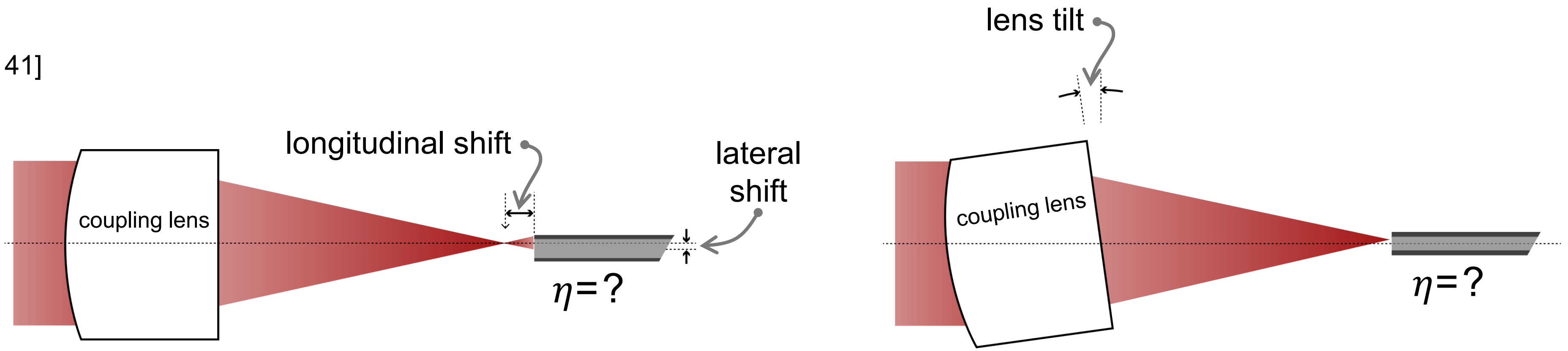
a) longitudinal* & lateral shift**

- shift range* [1.485 mm, 1.485 mm, 41]
- shift range**[-10 µm, 10 µm, 41]

b) tilt along Y-axis

- tilt range [-1°, +1°, 201]

Number of steps



(a) shift of fiber end position

(b) tilt of coupling lens

Exercise 4-a

Build A Mach-Zehnder Interferometer with Ideal Beam Splitters

see the full Application Use Case

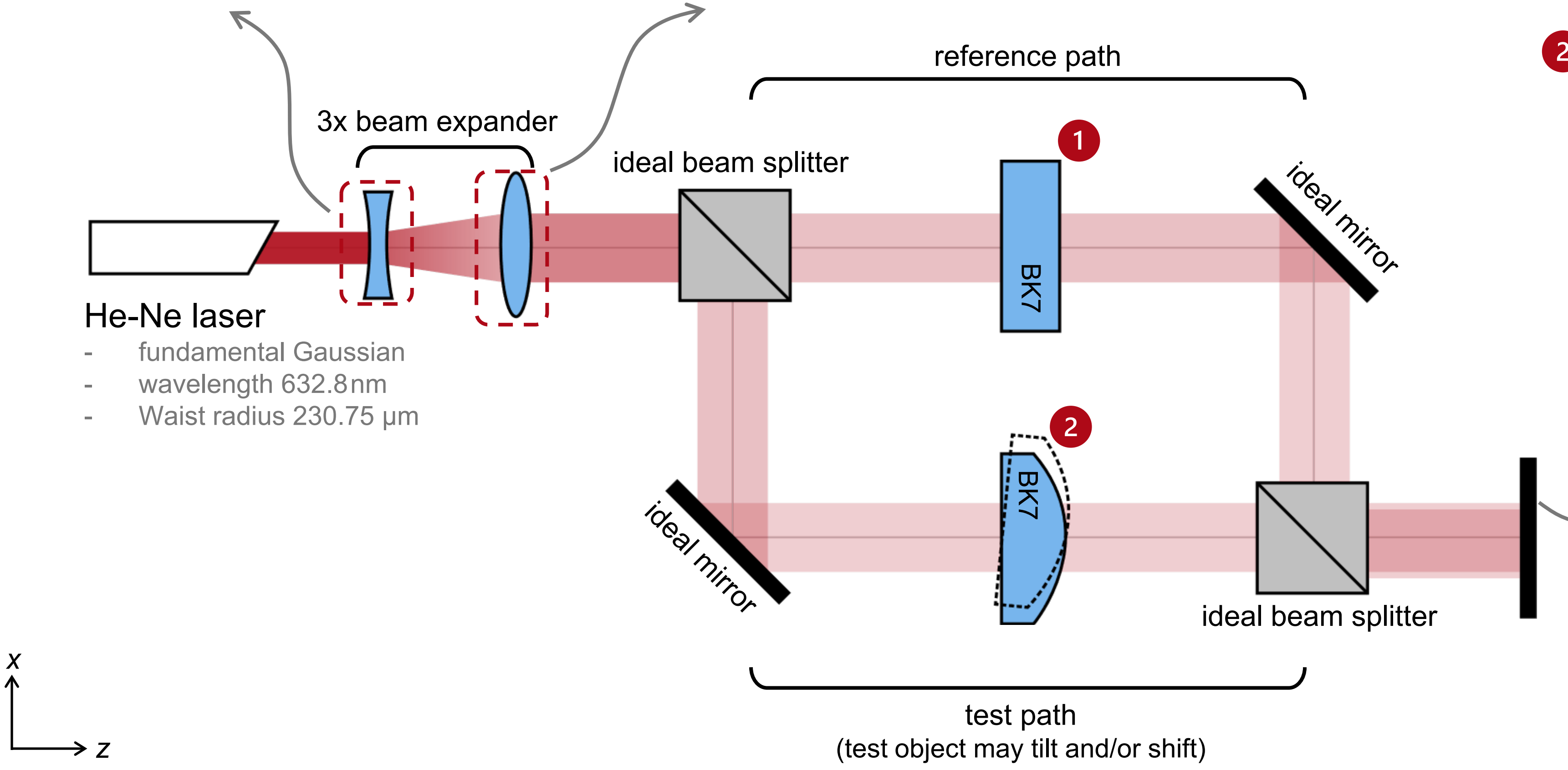
Build the Following System in VirtualLab Fusion

beam expander configuration (part 1)

a) ROC -20.772 mm & ROC +20.772 mm
b) material: N-BK7_SCHOTT
c) diameter 5 mm × 5 mm
d) thickness 1 mm

beam expander configuration (part 2)

a) ROC 61.072 mm & ROC -61.072 mm
b) material: N-BK7_SCHOTT
c) diameter 10 mm × 10 mm
d) thickness 4.3 mm



① glass plate configuration

a) thickness 2 mm
b) material: N-BK7_SCHOTT
c) diameter 10 mm × 10 mm

② test object configuration (spherical lens)

a) thickness 2 mm
b) material: N-BK7_SCHOTT
c) diameter 10 mm
d) plano-convex (radius 100 mm)

misalignment configuration

a) lateral shift
- shift range [0 mm, 1 mm, 5]

b) tilt along Y-axis
- tilt range [3°, 10°, 3]

camera detector

- window size 2 mm × 2 mm
- Z = 20 mm
- components to integrate E_x, E_y and E_z

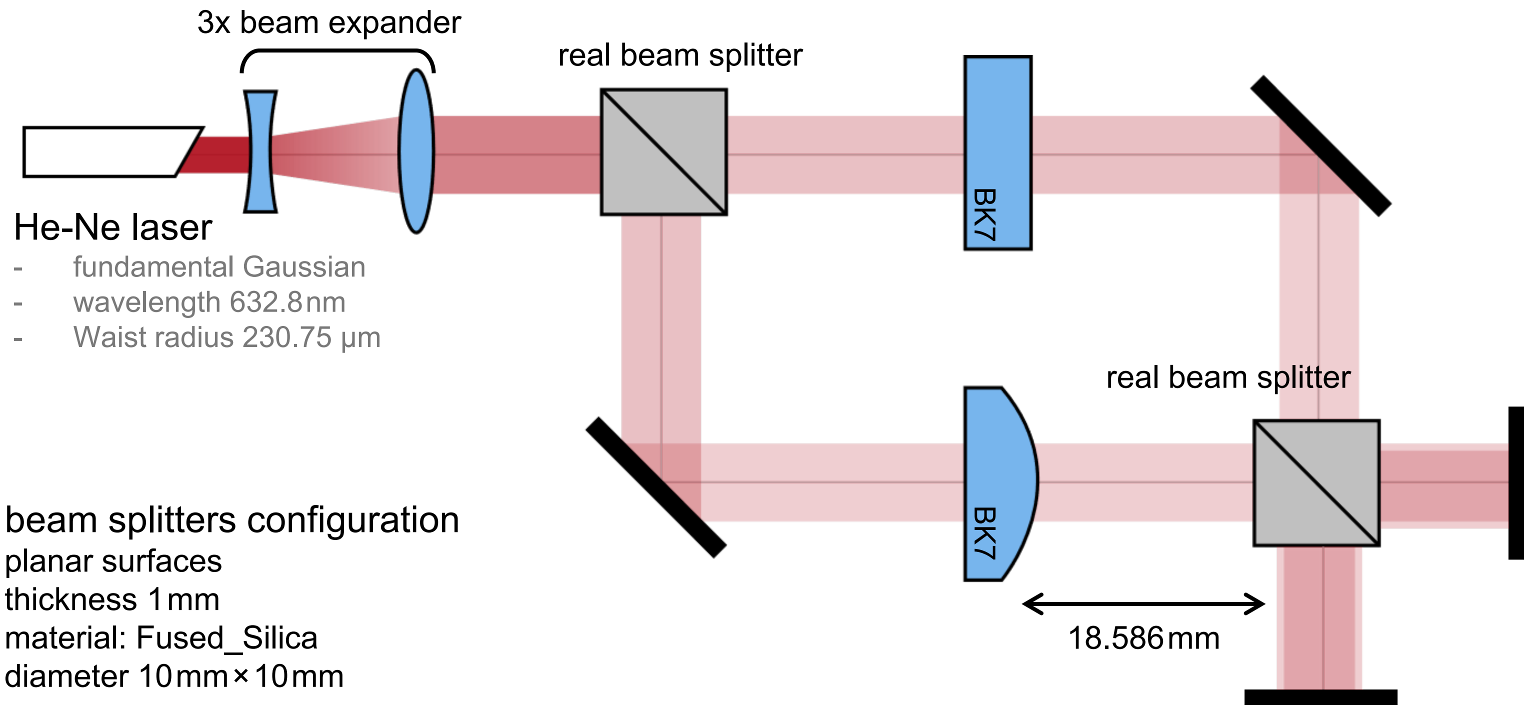
Note: The distances between the components are 20 mm.

Exercise 4-b

Build A Mach-Zehnder Interferometer with Real Beam Splitters

see the full Application Use Case

Build the Following System in VirtualLab Fusion



He-Ne laser
- fundamental Gaussian
- wavelength 632.8 nm
- Waist radius 230.75 µm

real beam splitters configuration
a) planar surfaces
b) thickness 1 mm
c) material: Fused_Silica
d) diameter 10 mm × 10 mm

camera detector
- window size 2 mm × 2 mm
- X = 315 μm , Z = 20 mm
- components to integrate E_x, E_y and E_z

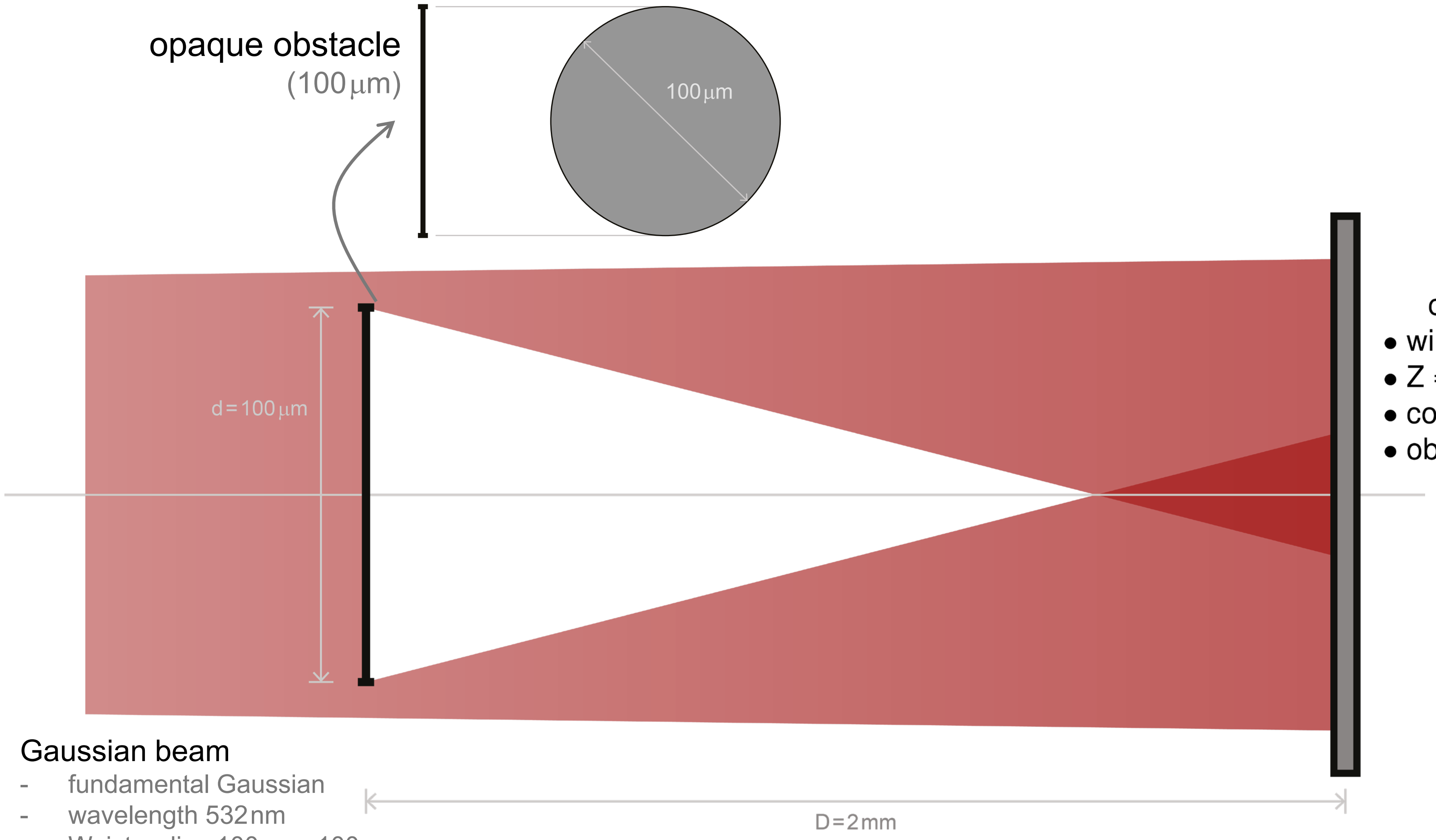
camera detector
- window size 2 mm × 2 mm
- X= 20 mm , Z = -785 μm
- components to integrate E_x, E_y and E_z

Exercise 5

Observation of the Poisson Spot

see the full Application Use Case

Build the Following System in VirtualLab Fusion



camera detector

- window size 304.73 μm $\times$ 304.73 μm
- Z = 2 mm
- components to integrate E_x and E_y
- obtain the 1D and 2D energy distributions

Gaussian beam

- fundamental Gaussian
- wavelength 532 nm
- Waist radius 100 µm × 100 µm

$$\frac{d^2}{D\lambda} > 1$$

Condition of observation
(Fresnel number)

see the full Application Use Case

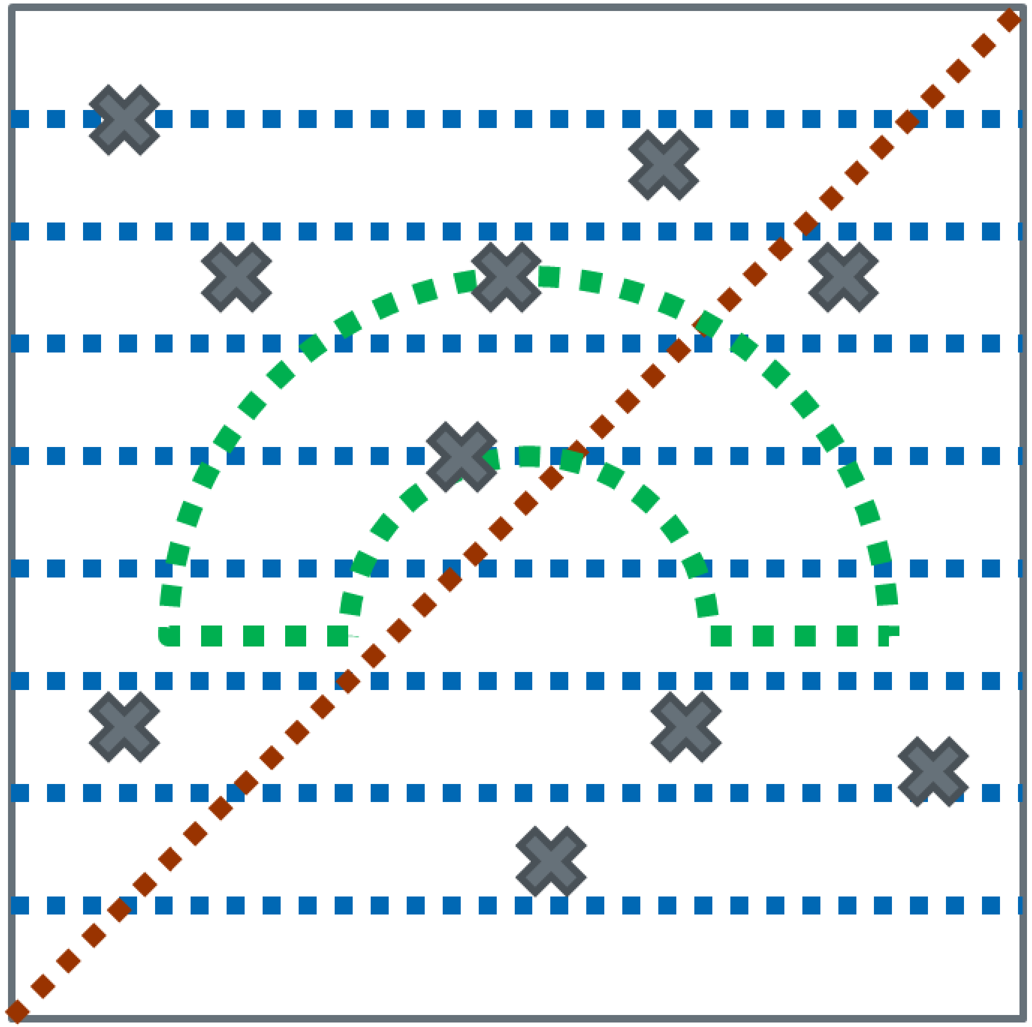
Build the Following System in VirtualLab Fusion

Annex

Some brief guides to useful features

Parameter Run

Abstract



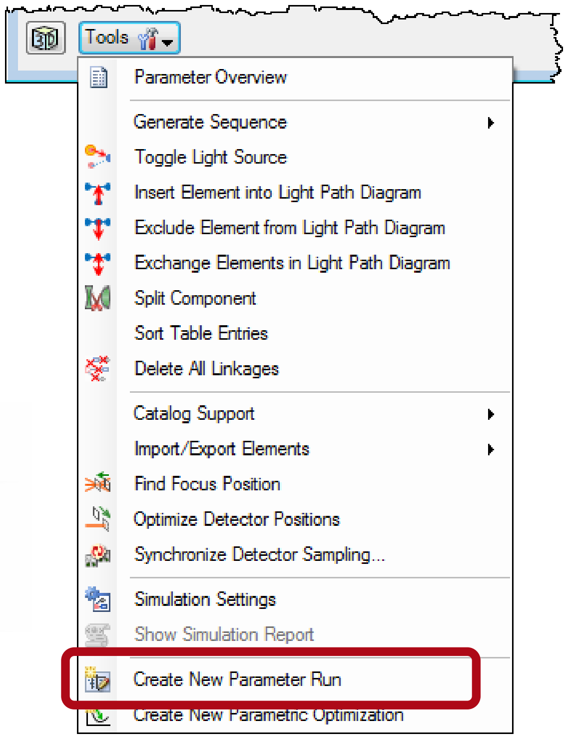
For a given optical system, it is helpful to check its performance by controlling and varying selected parameters. VirtualLab Fusion provides a fully flexible and computationally efficient (via parallelization) Parameter Run, which enables the user specify different manners of parameter variations. As 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.

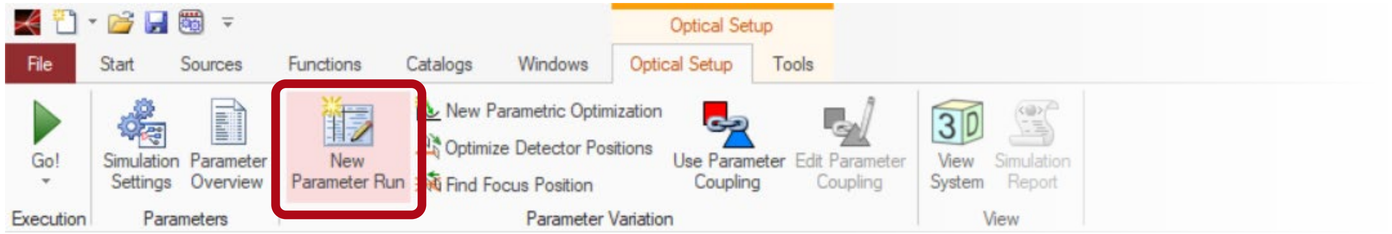
Parameter Run Document

- 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.

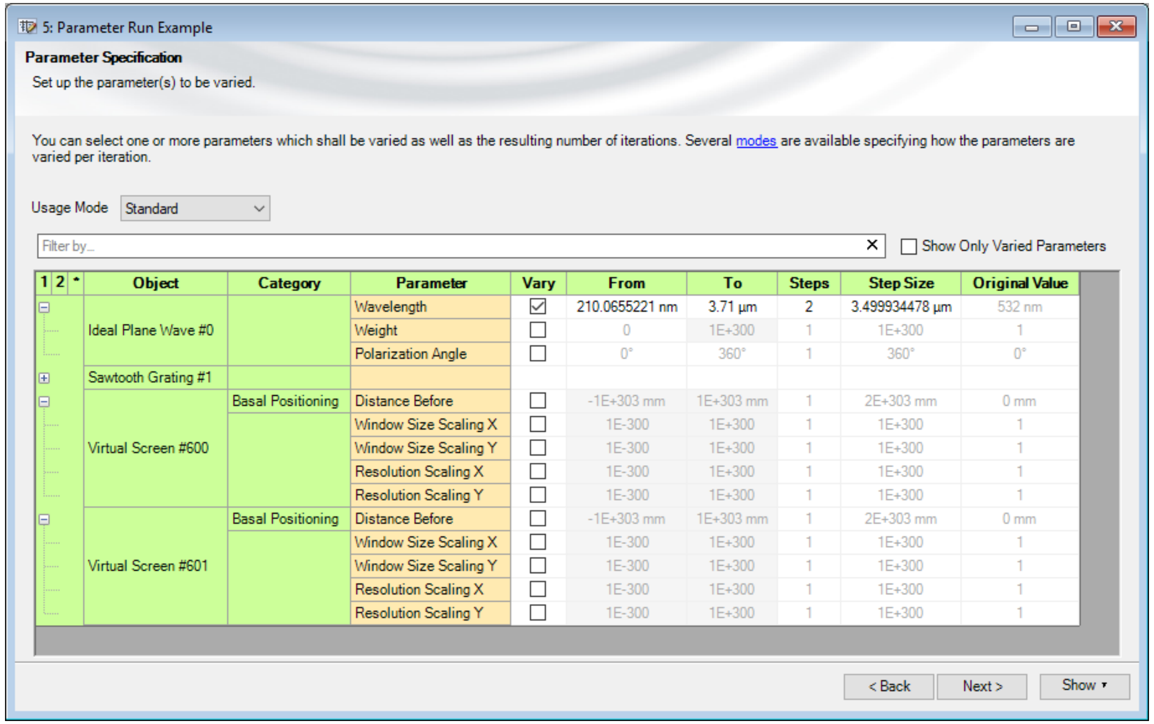
New Parameter Run

- 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





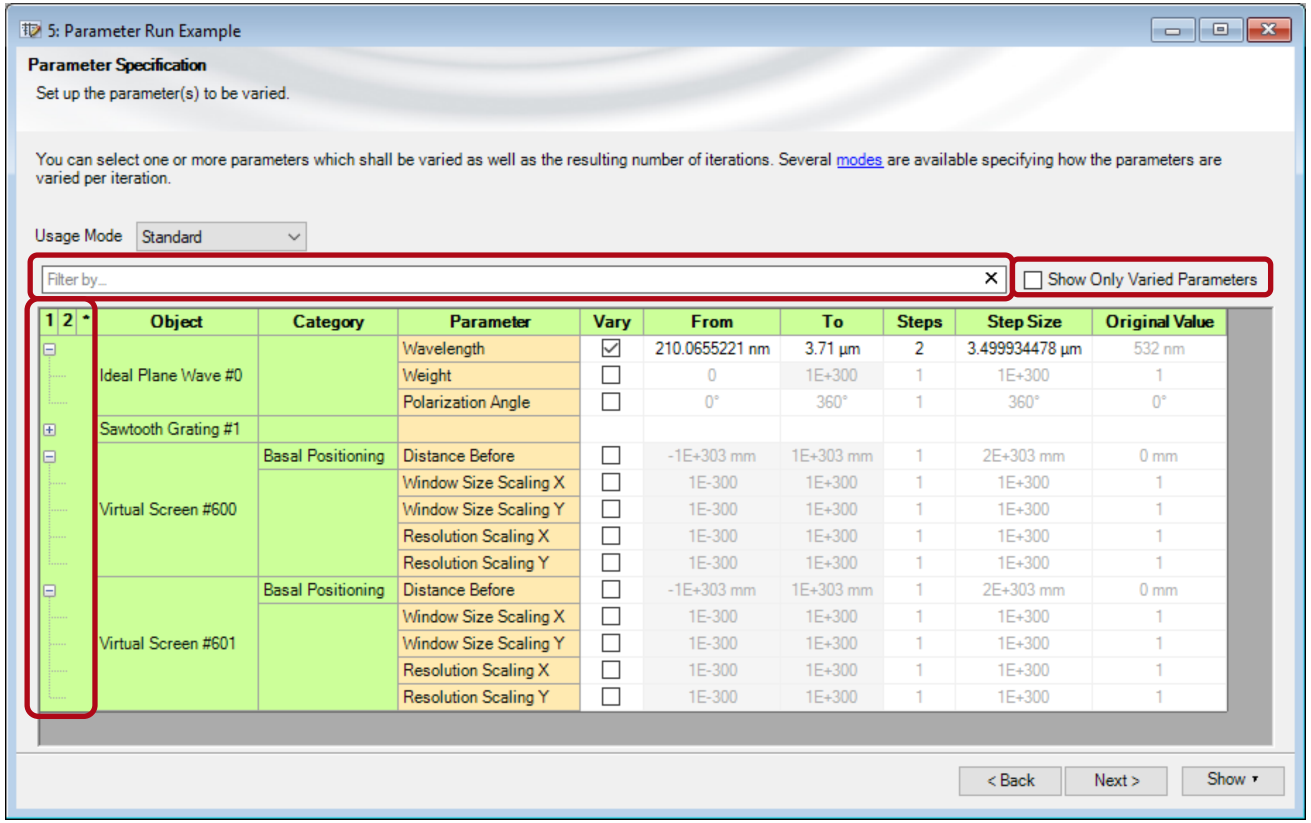
Parameter Specification Page



- 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



Object	Category	Parameter	Vary	From	To	Steps	Step Size	Original Value
Ideal Plane Wave #0		Wavelength	☑	210.0655221 nm	3.71 µm	2	3.499934478 µm	532 nm
		Weight	☐	0	1E+300	1	1E+300	1
		Polarization Angle	☐	0°	360°	1	360°	0°
Sawtooth Grating #1								
Virtual Screen #600	Basal Positioning	Distance Before	☐	-1E+303 mm	1E+303 mm	1	2E+303 mm	0 mm
		Window Size Scaling X	☐	1E-300	1E+300	1	1E+300	1
		Window Size Scaling Y	☐	1E-300	1E+300	1	1E+300	1
		Resolution Scaling X	☐	1E-300	1E+300	1	1E+300	1
		Resolution Scaling Y	☐	1E-300	1E+300	1	1E+300	1
Virtual Screen #601	Basal Positioning	Distance Before	☐	-1E+303 mm	1E+303 mm	1	2E+303 mm	0 mm
		Window Size Scaling X	☐	1E-300	1E+300	1	1E+300	1
		Window Size Scaling Y	☐	1E-300	1E+300	1	1E+300	1
		Resolution Scaling X	☐	1E-300	1E+300	1	1E+300	1
		Resolution Scaling Y	☐	1E-300	1E+300	1	1E+300	1

Usage Modes

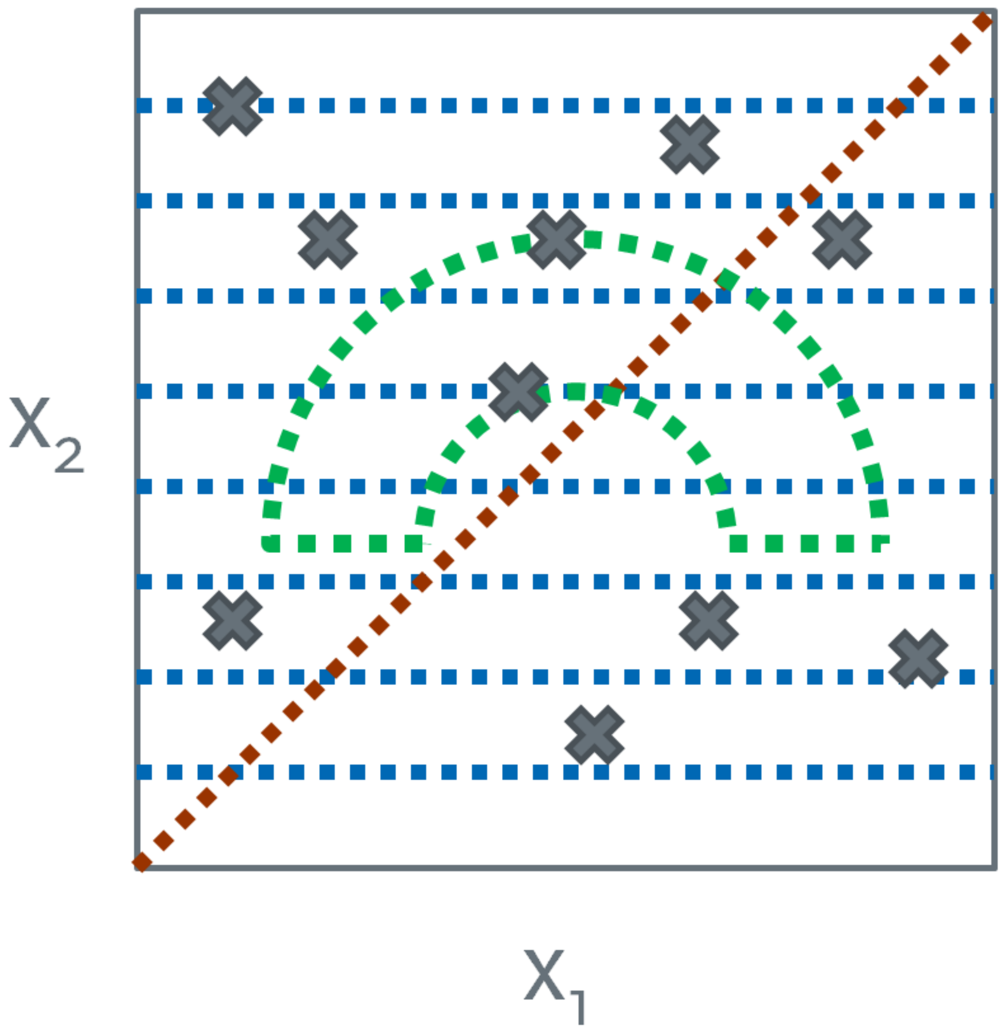
- Standard Mode:
  Linear variation of all selected parameters between minimum and maximum value.

- 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.

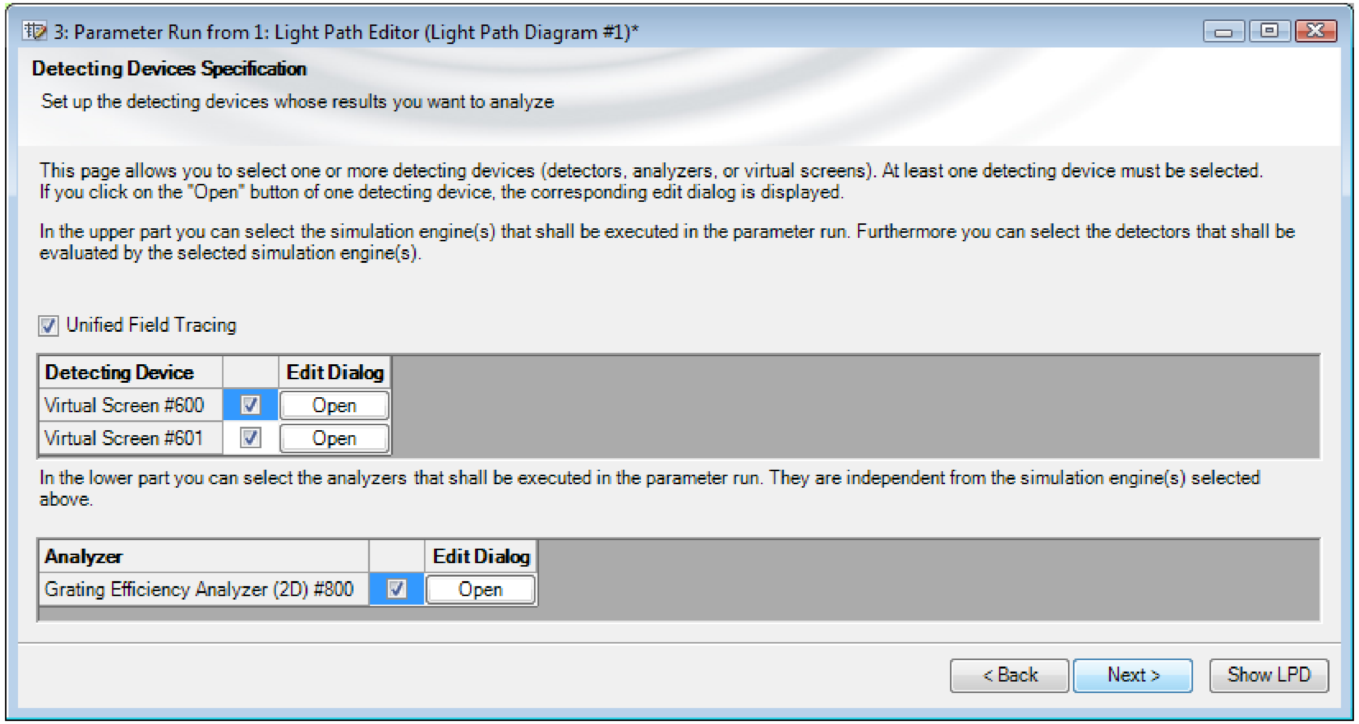
- Random Mode:
  Random variation of parameters between minimum and maximum value. Sometimes also called Monte-Carlo-Simulation. A seed can be used for reproducible results.

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.

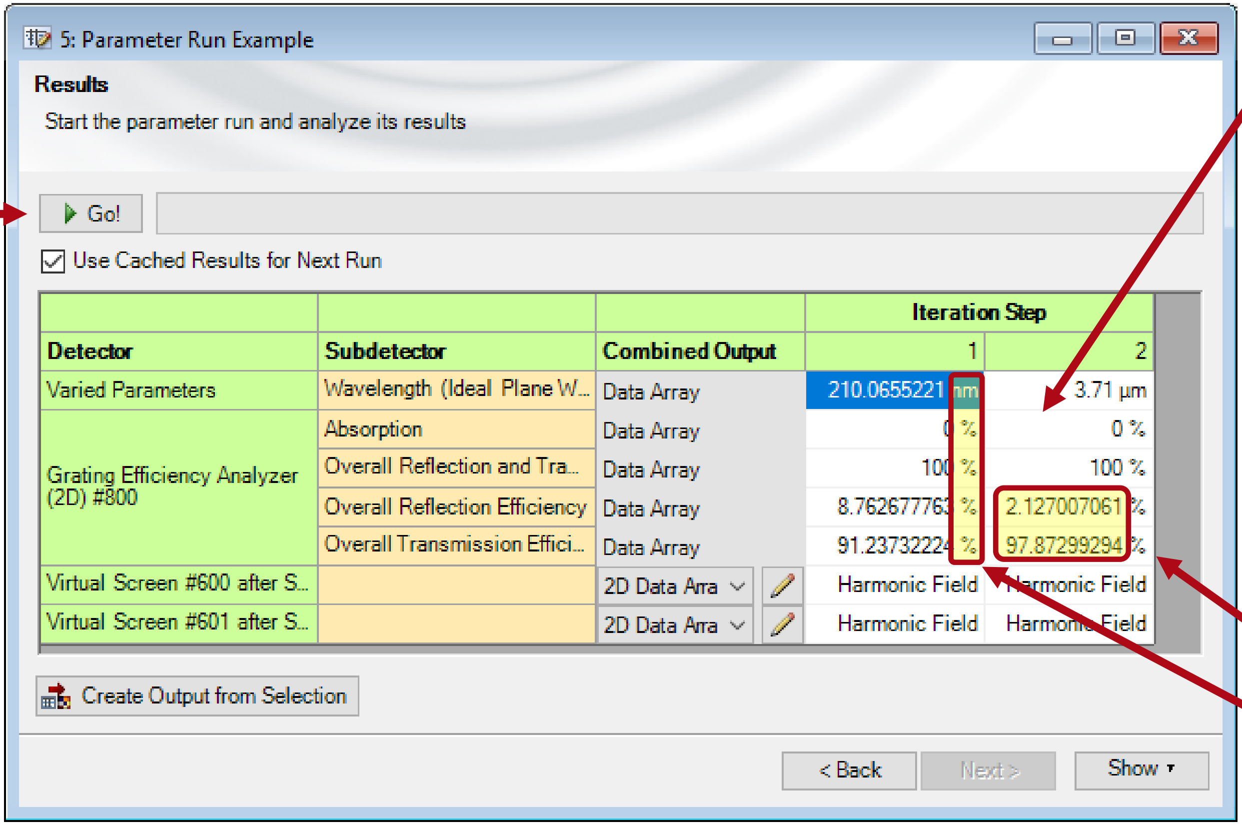
Detecting Devices Specification Page



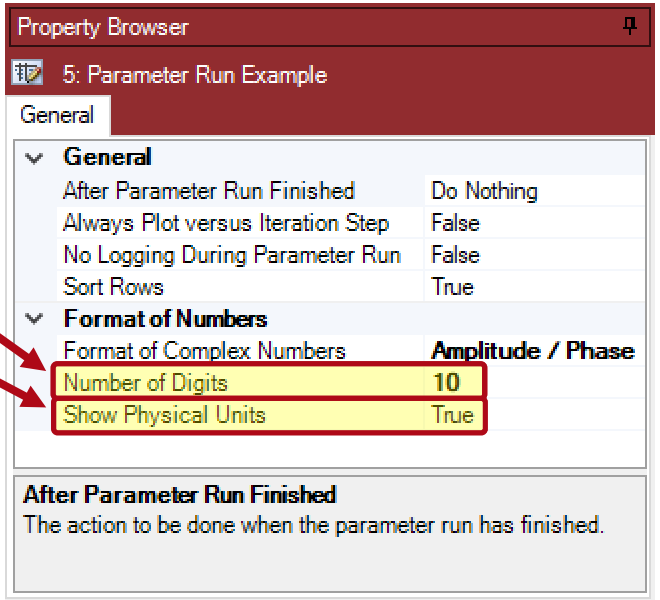
- This page allows to select which simulation engines, detectors, screens and analyzers are evaluated.
- The detecting devices can be configured after clicking Open to get to the edit dialog.

Results Page

Starts and stops the parameter variation.

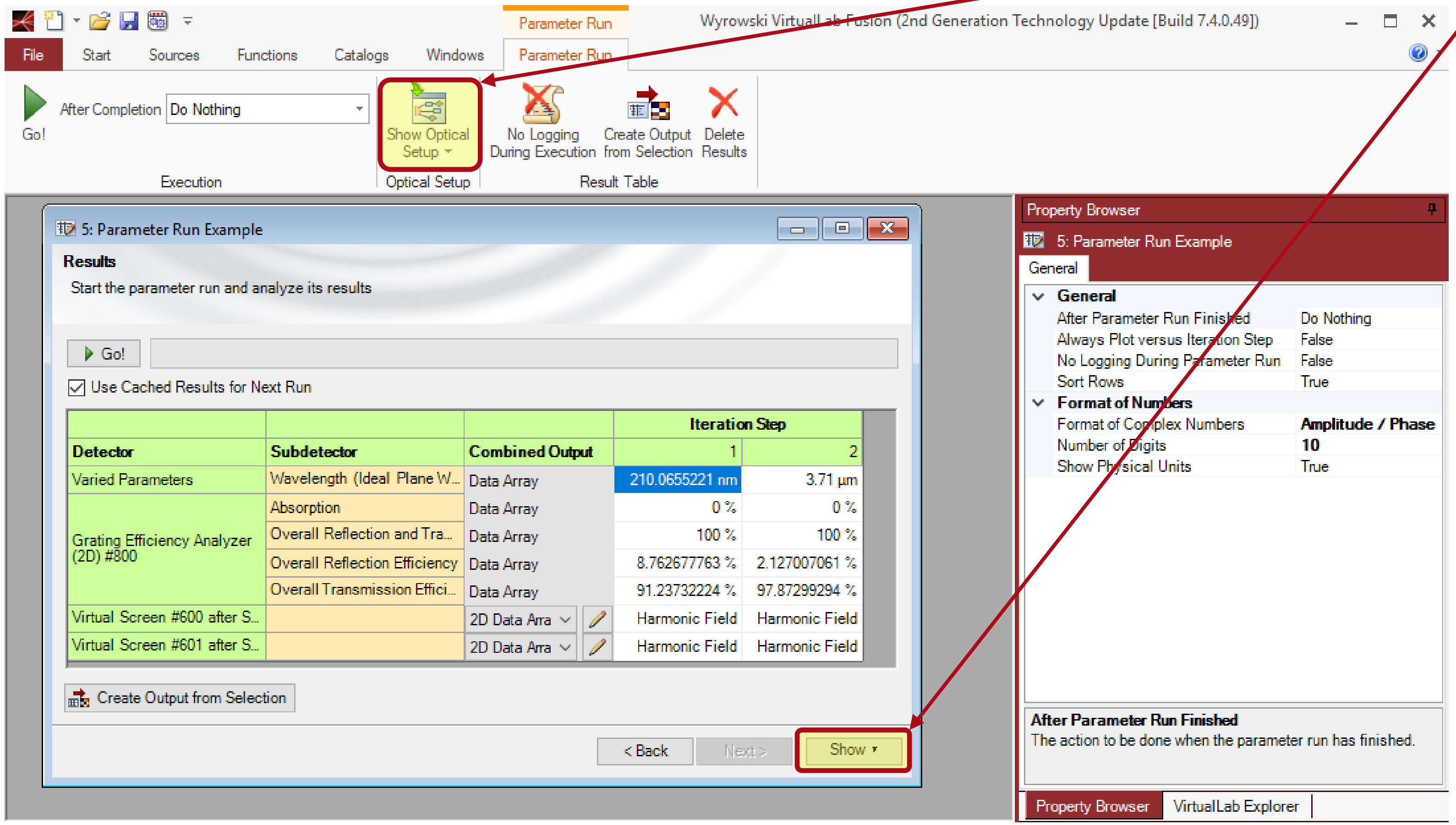


Simulation results: Double click on a document to view it in a separate window.



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.

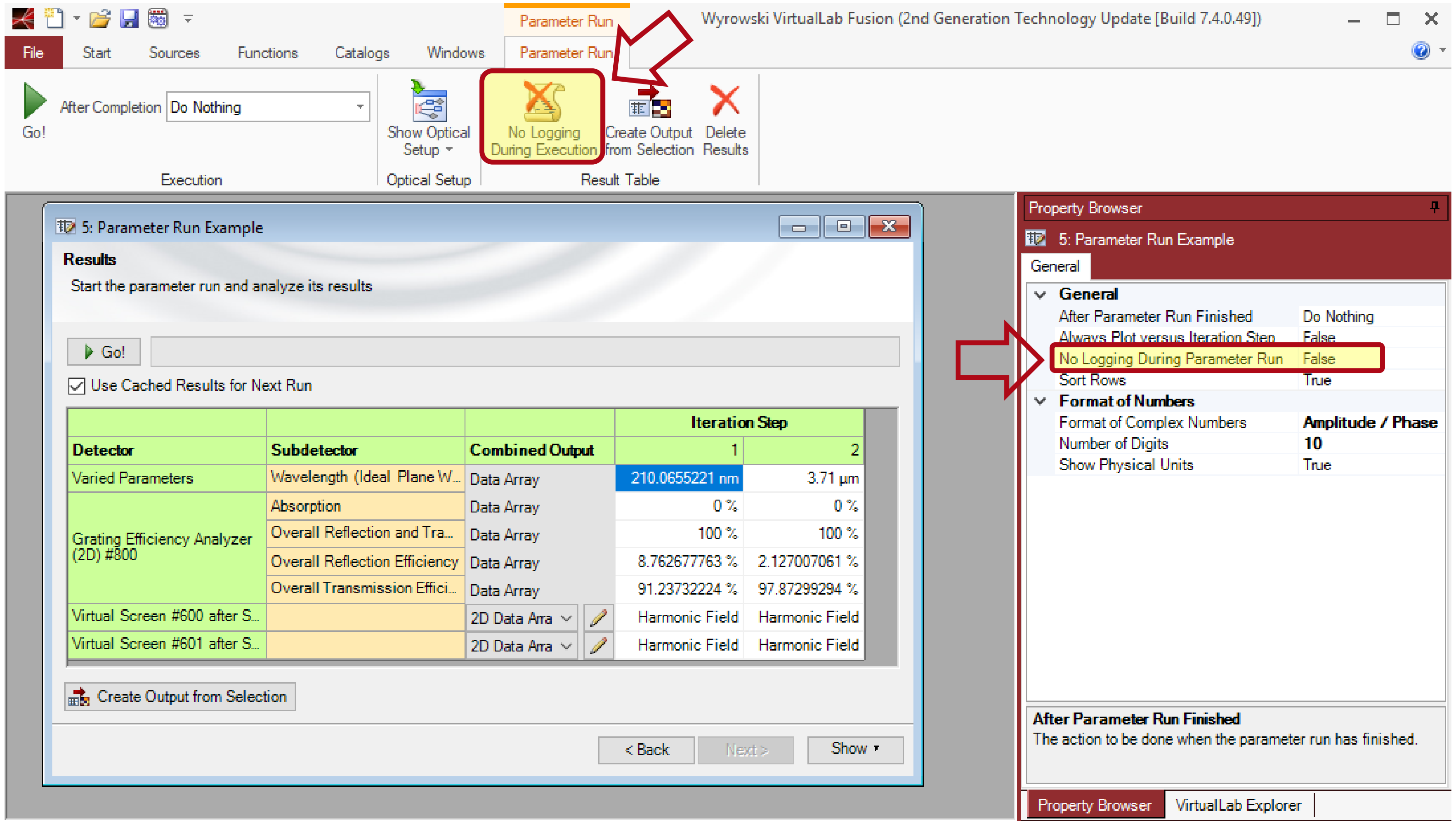
Optical Setups within Parameter Run



Displays the optical setup:

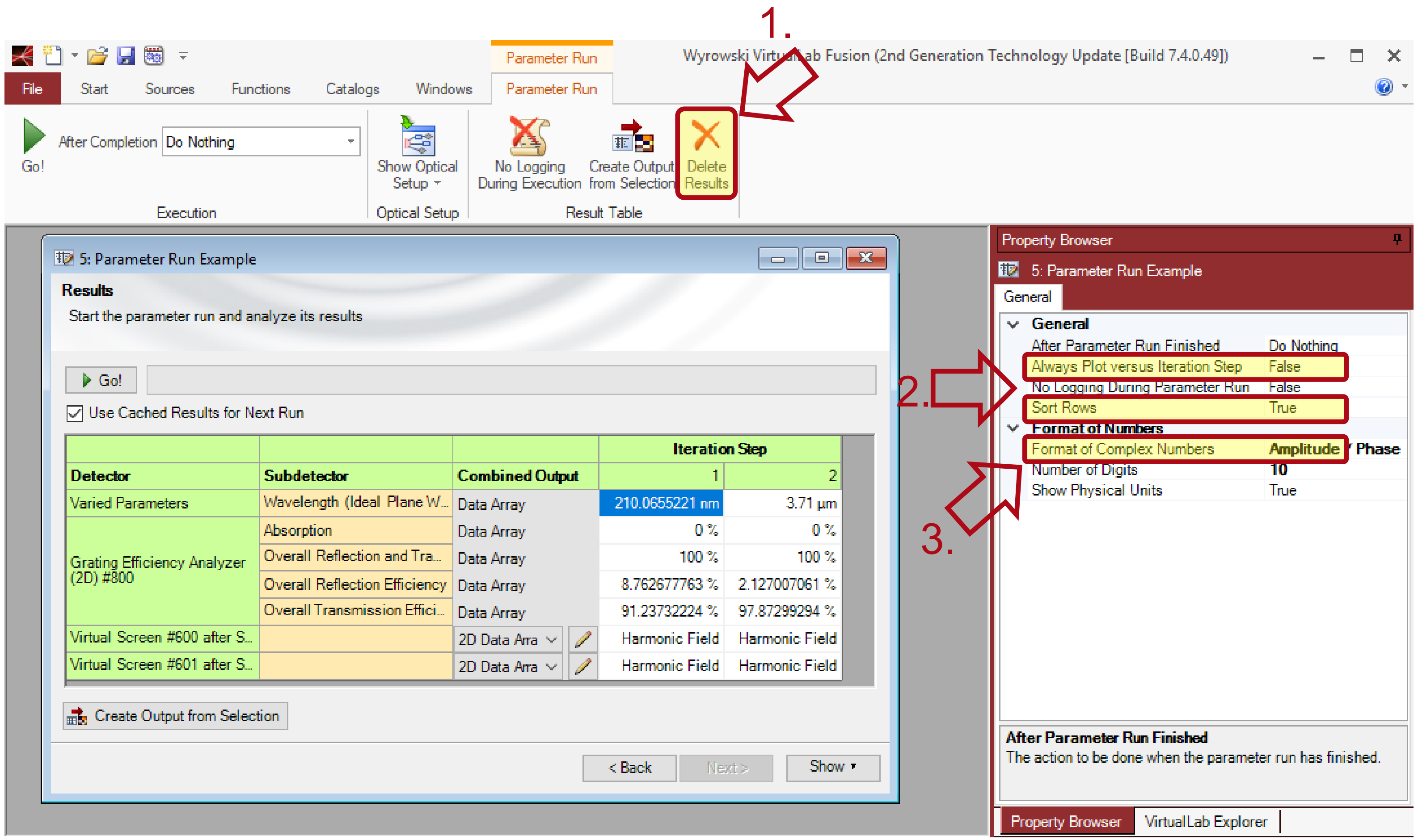
- initial
- from any iteration

Logging of Parameter Run Results



- 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 Paramter Run document of the current status with all already calculated results.

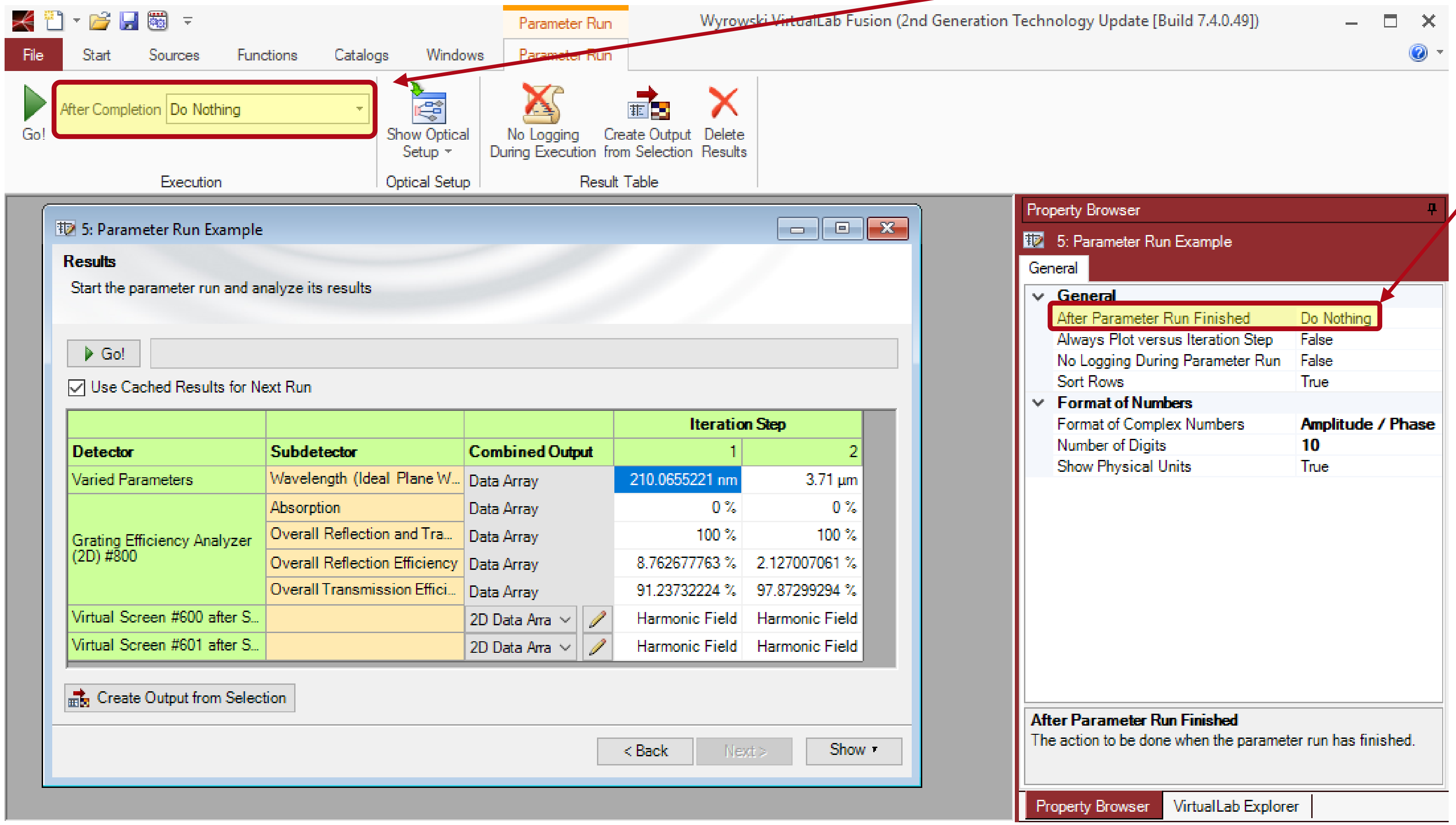
Display of Parameter Run Results



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 compex numbers.

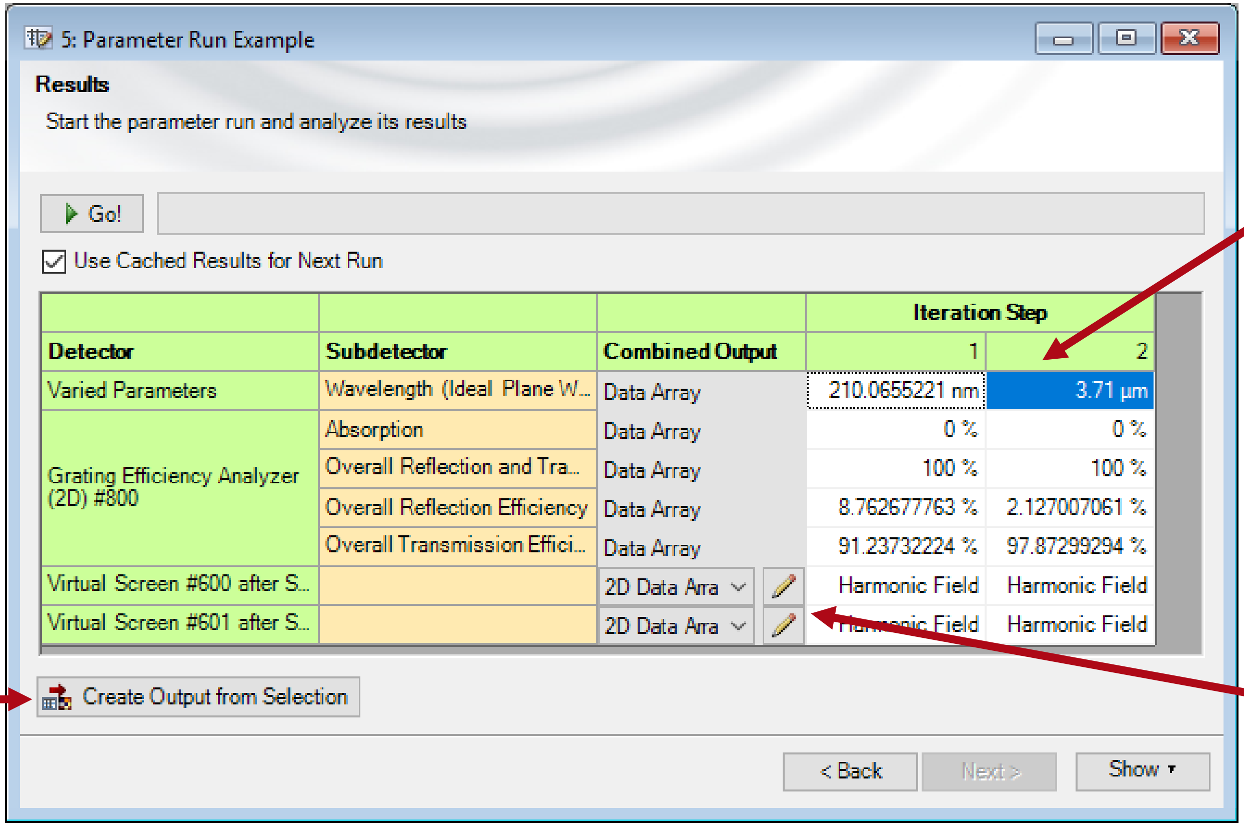
Saving (& Shutdownd) after Parameter Run Completion?

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



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.

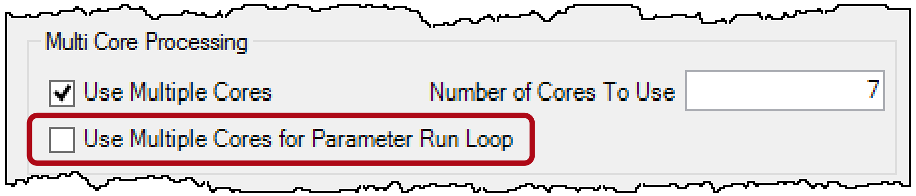
- Select the results to combine.
- Clicking on a cell in the Detector or Subdetector column selects the whole row.

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

Parallelization & Amount of Data

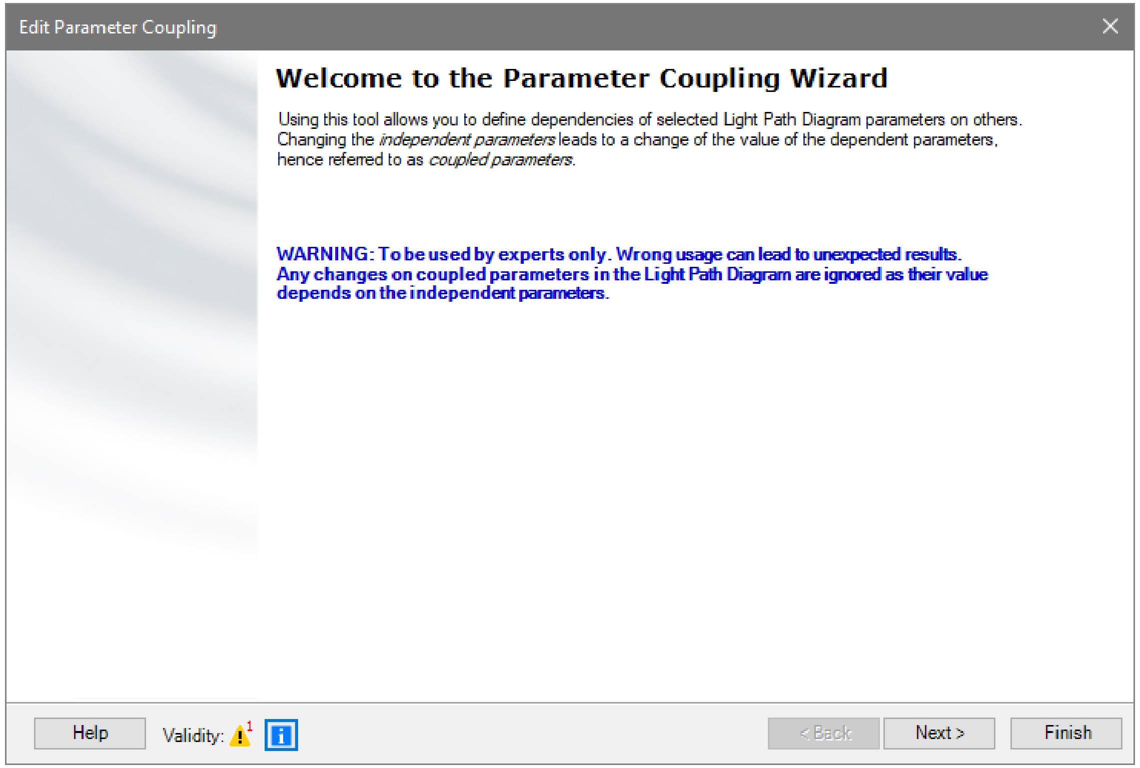
- The execution of the different iterations of a Parameter Run simulation is very well parallelized. Thus it represents a very efficient method to simulate many different settings very fast.

- 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

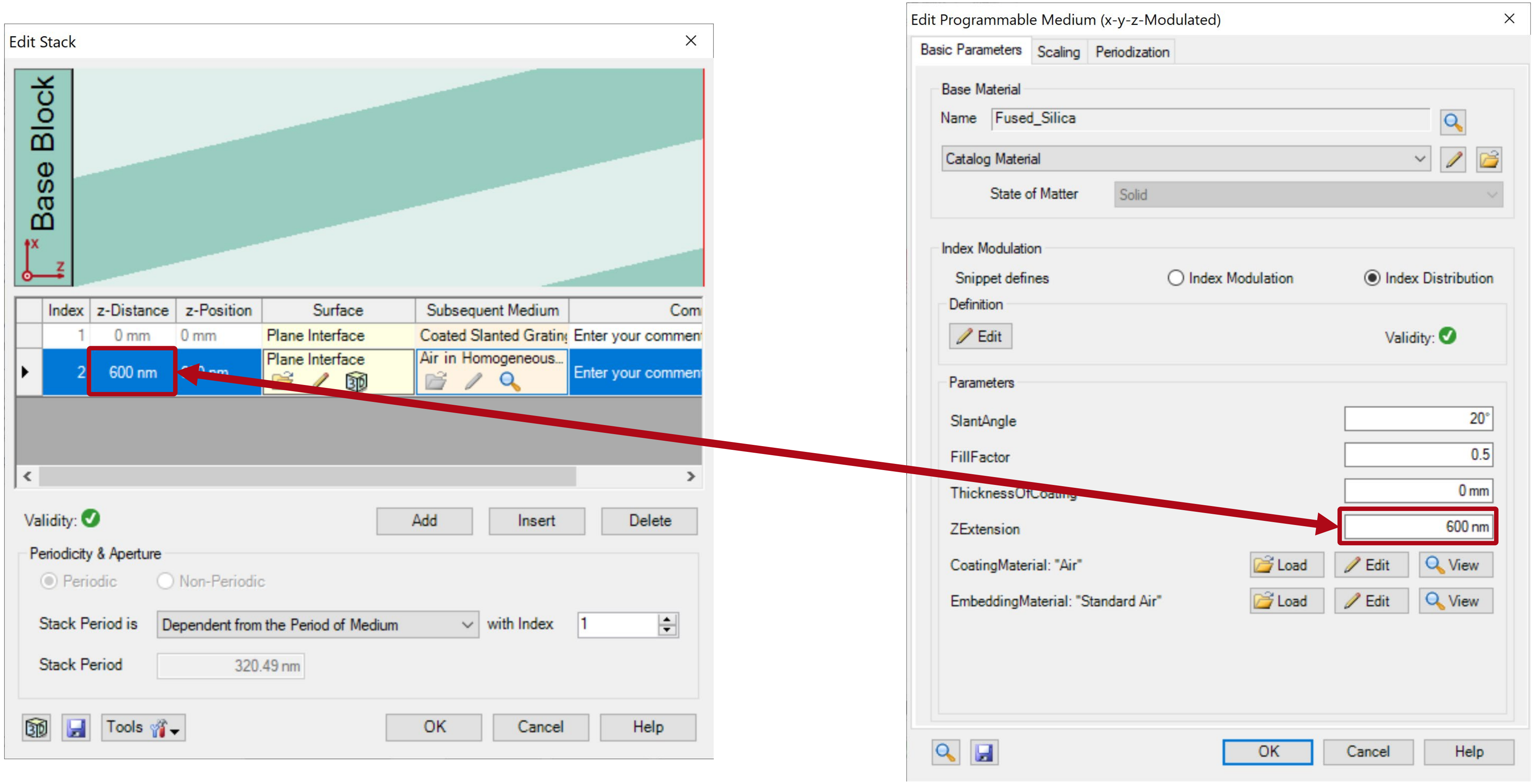
Abstract



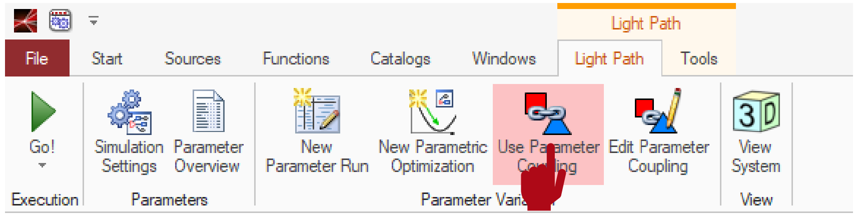
The parameter coupling feature of VirtualLab Fusion enables the coupling of parameters in an optical setup. The values can also be used to re-calculate other parameters of the system, so that a certain relationship between them is automatically maintained. Hence, this feature allows the user to instate 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

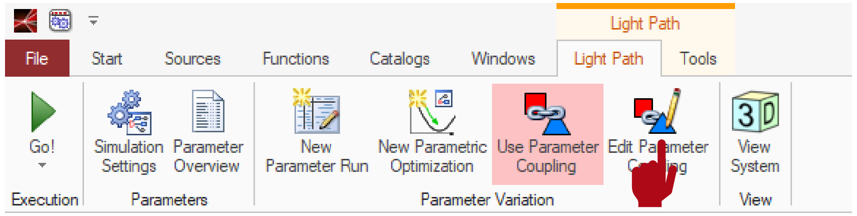
We wish to link two parameters of an optical system, so that they automatically take the same value. For this purpose, VirtualLab's Parameter Coupling feature is used.



Set Up Parameter Coupling

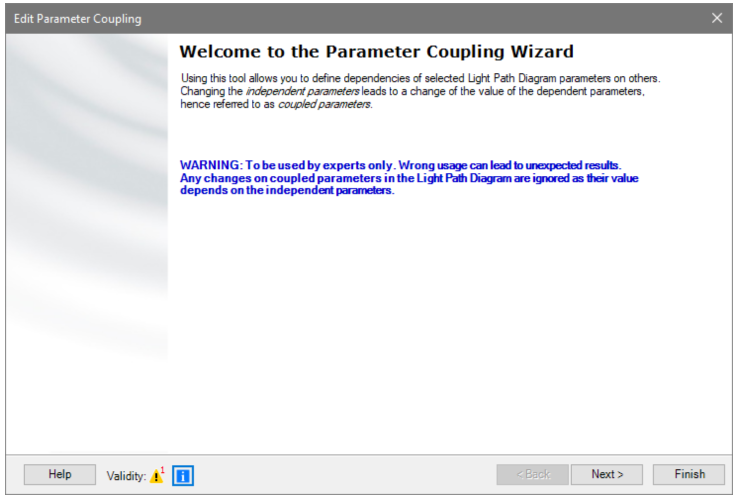


In order to use the parameter coupling feature of VirtualLab Fusion activate the option “*Use Parameter Coupling*” for the optical setup in question.



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

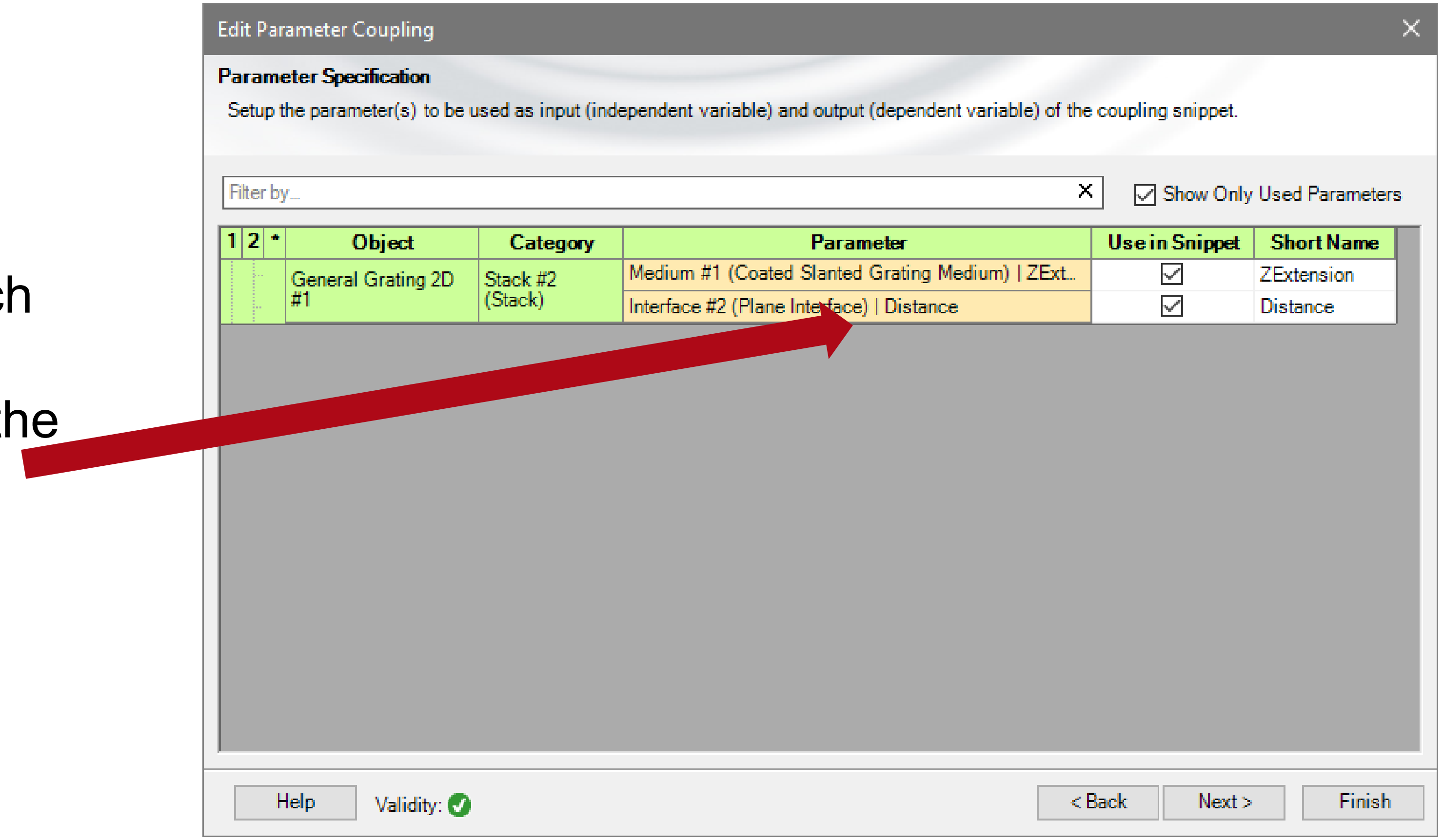
Clicking on the “*Edit Parameter Coupling*” button causes the parameter coupling wizard to appear.



Choose Parameters Involved

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

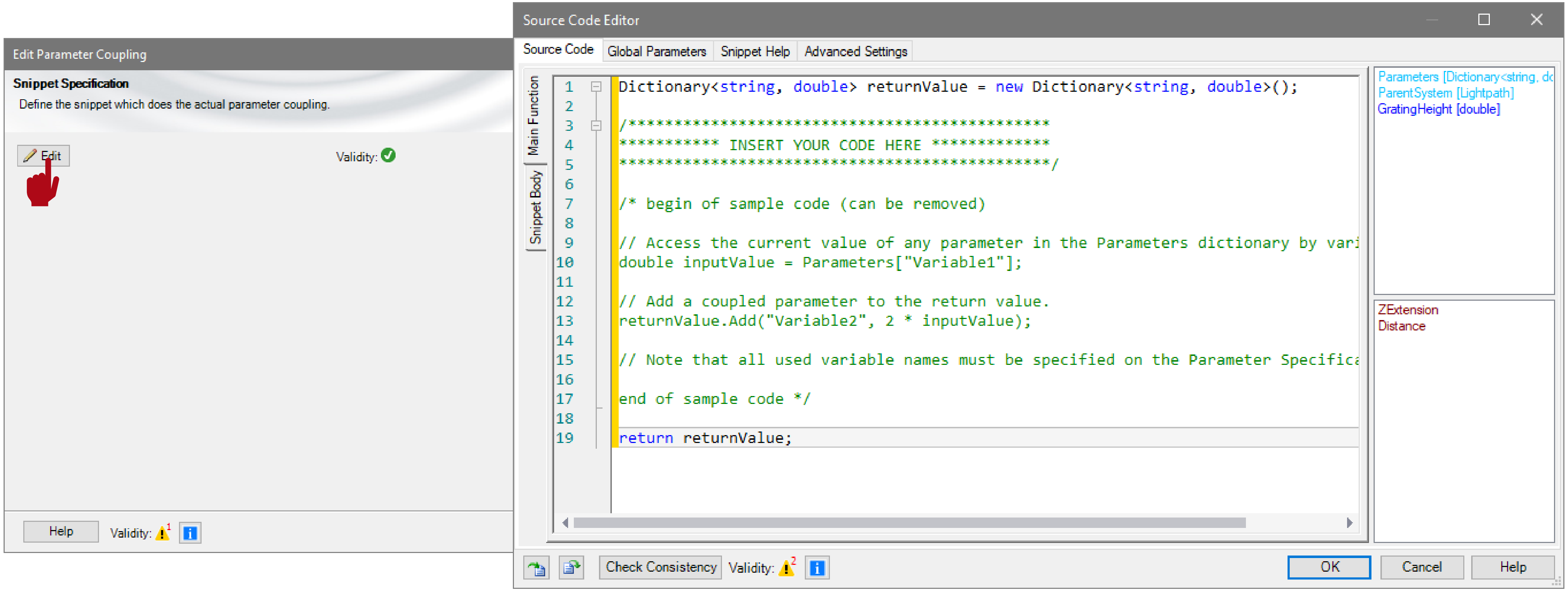
Please select all the parameters which are relevant for the coupling and necessary calculation. For instance, the parameters “*ZExtension*” and “*Distance*” are chosen in this case.



Configure the Coupling of the Parameters

After choosing the parameters, the snippet which controls the coupling has to be set.

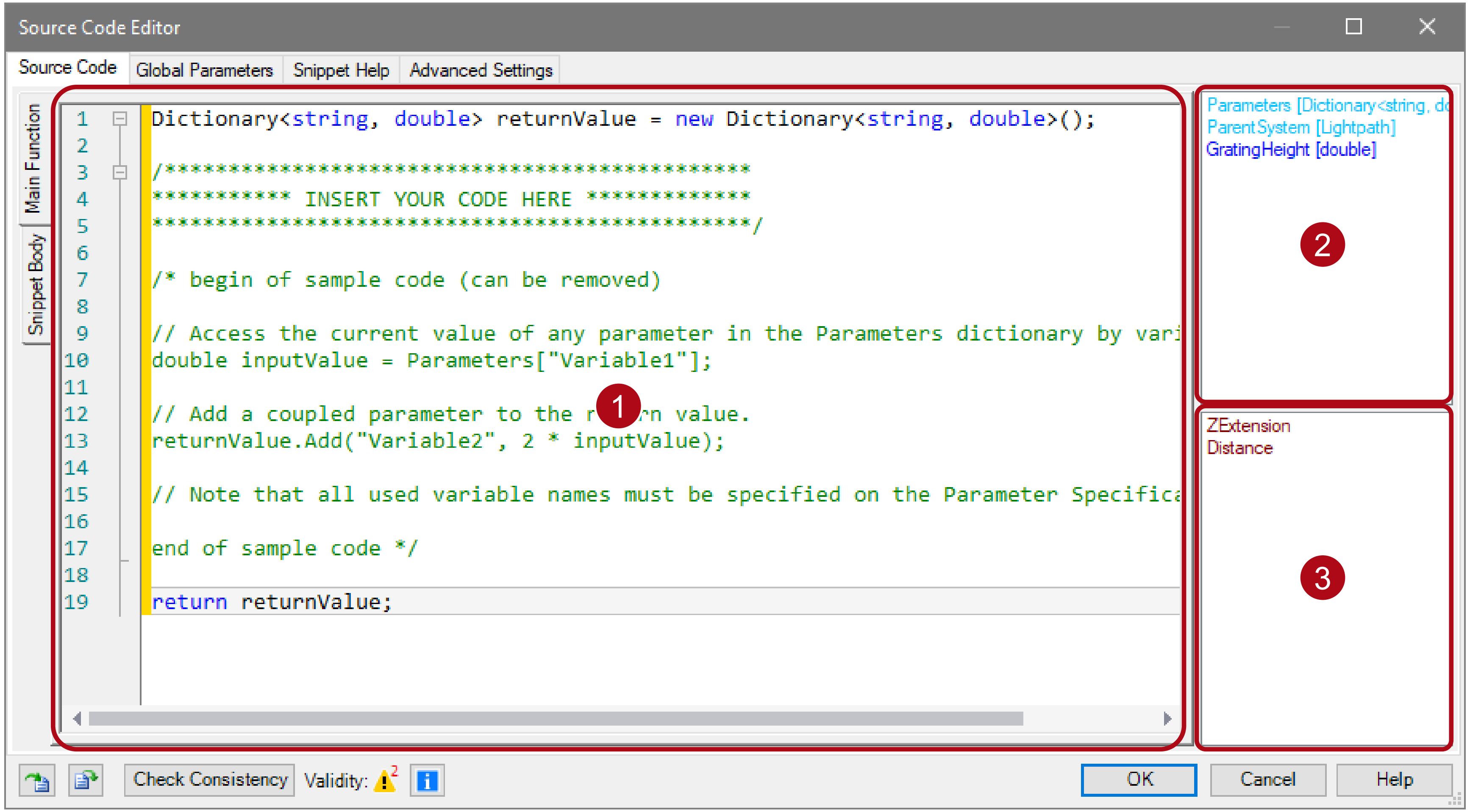
By clicking on “*Edit*” the source code editor opens.



Configure the Coupling of Parameters

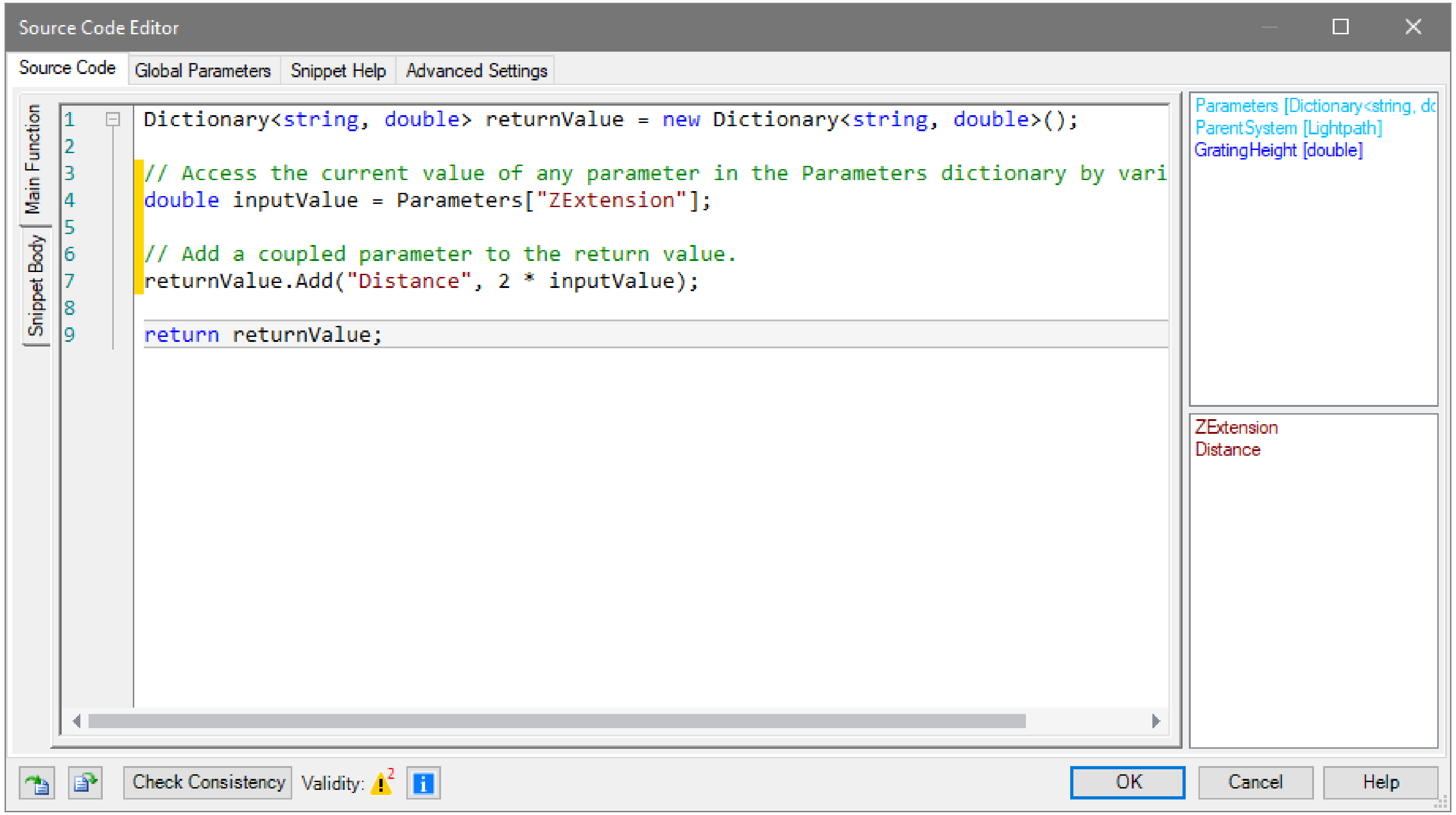
The source code tab contains three areas:

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



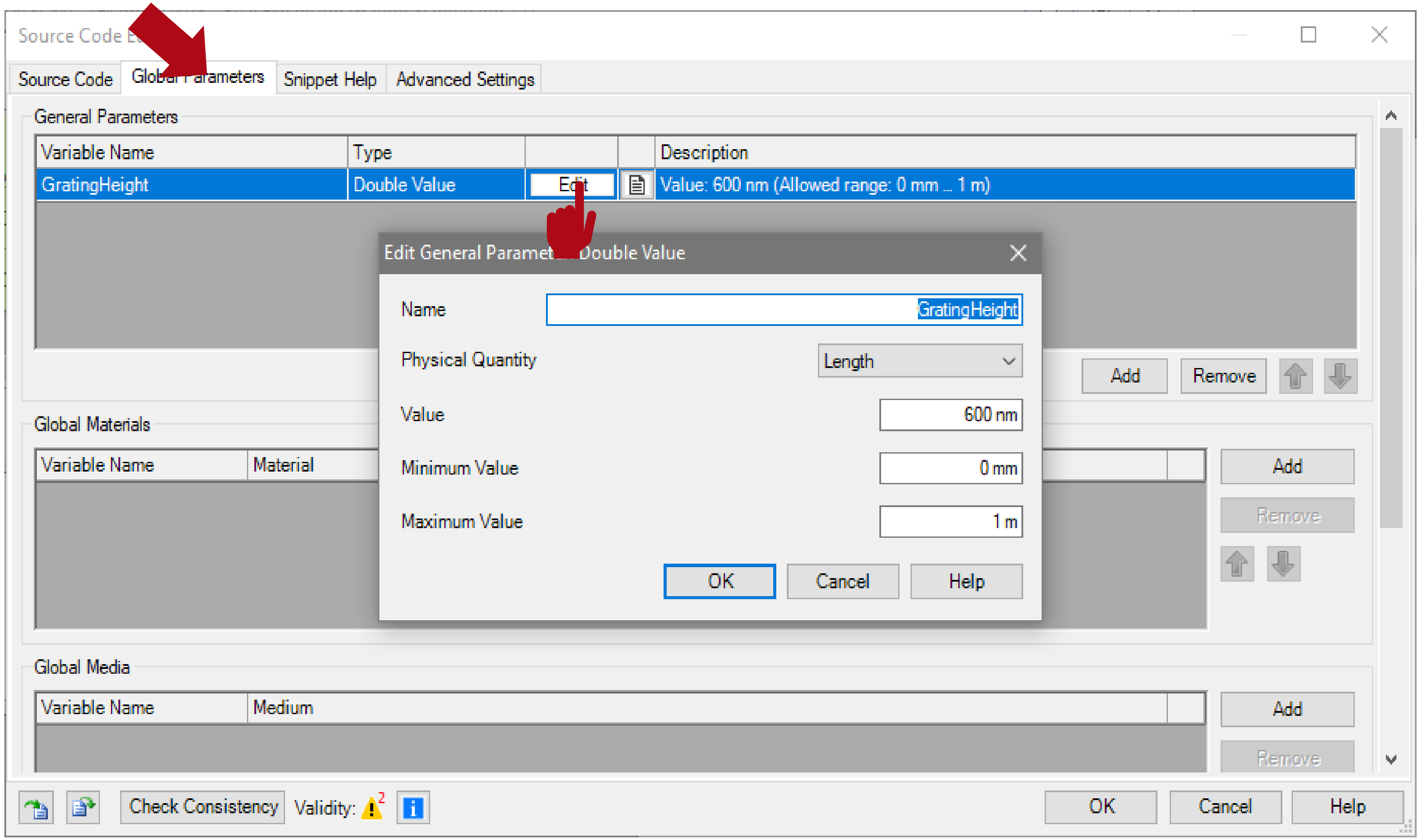
General Example of Parameter Coupling

- 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

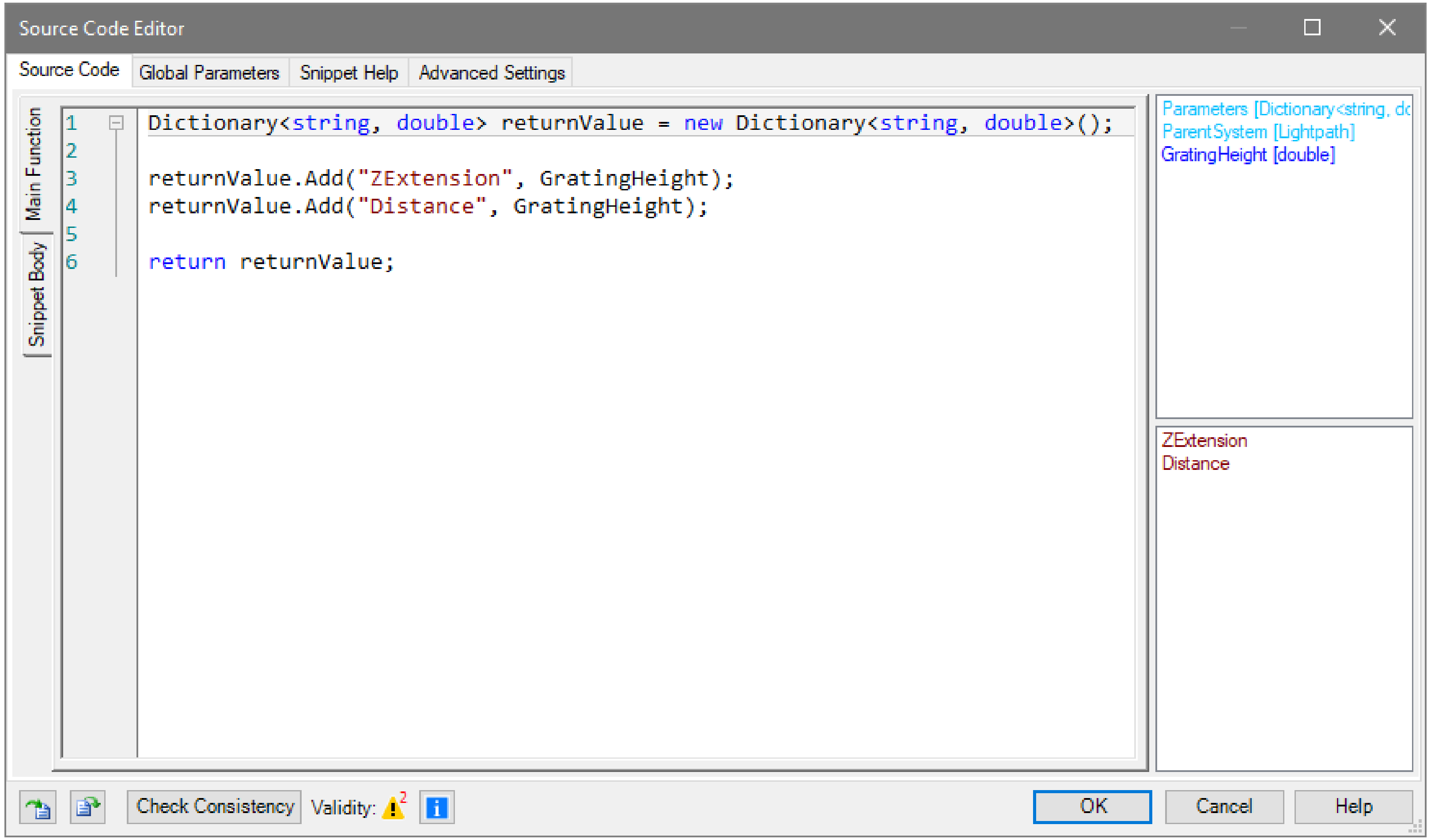
- In this particular example, it is helpful to define a new global variable, which later appears on the parameter coupling window.
- This can be done in the "*Global Parameters*" tab.
- The variable can be of different types and have different physical quantities attached.



Particular Example of Parameter Coupling

- In this example, the global variable is used to return its value to both chosen parameters of the system.

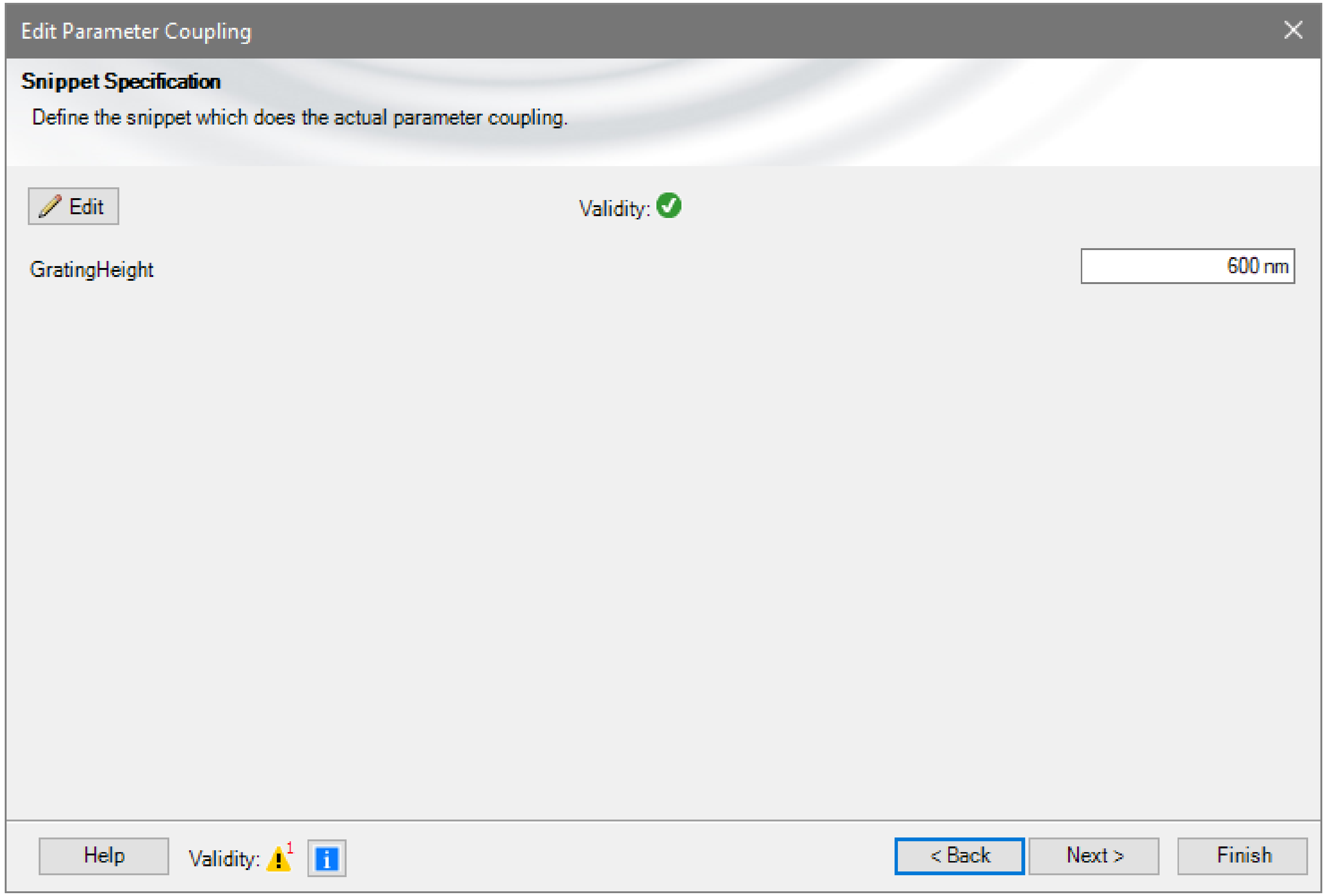
- Thus, no parameter has to be read from the dictionary or re-calculated.



Particular Example of Parameter Coupling

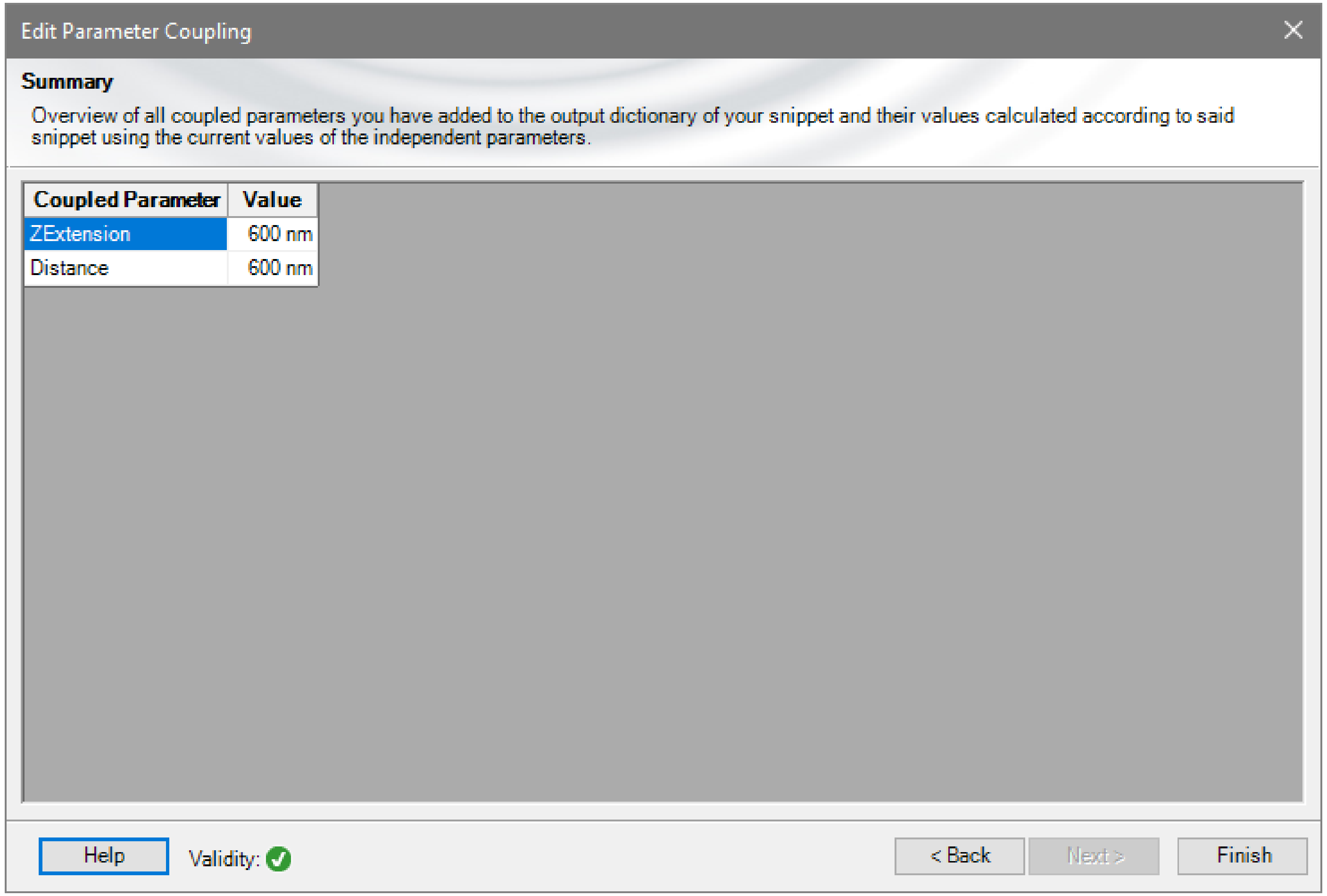
- After closing the source code editor, the defined global variable “*GratingHeight*” appears.

- 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.



Final Check of the Set-up Parameter Coupling

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

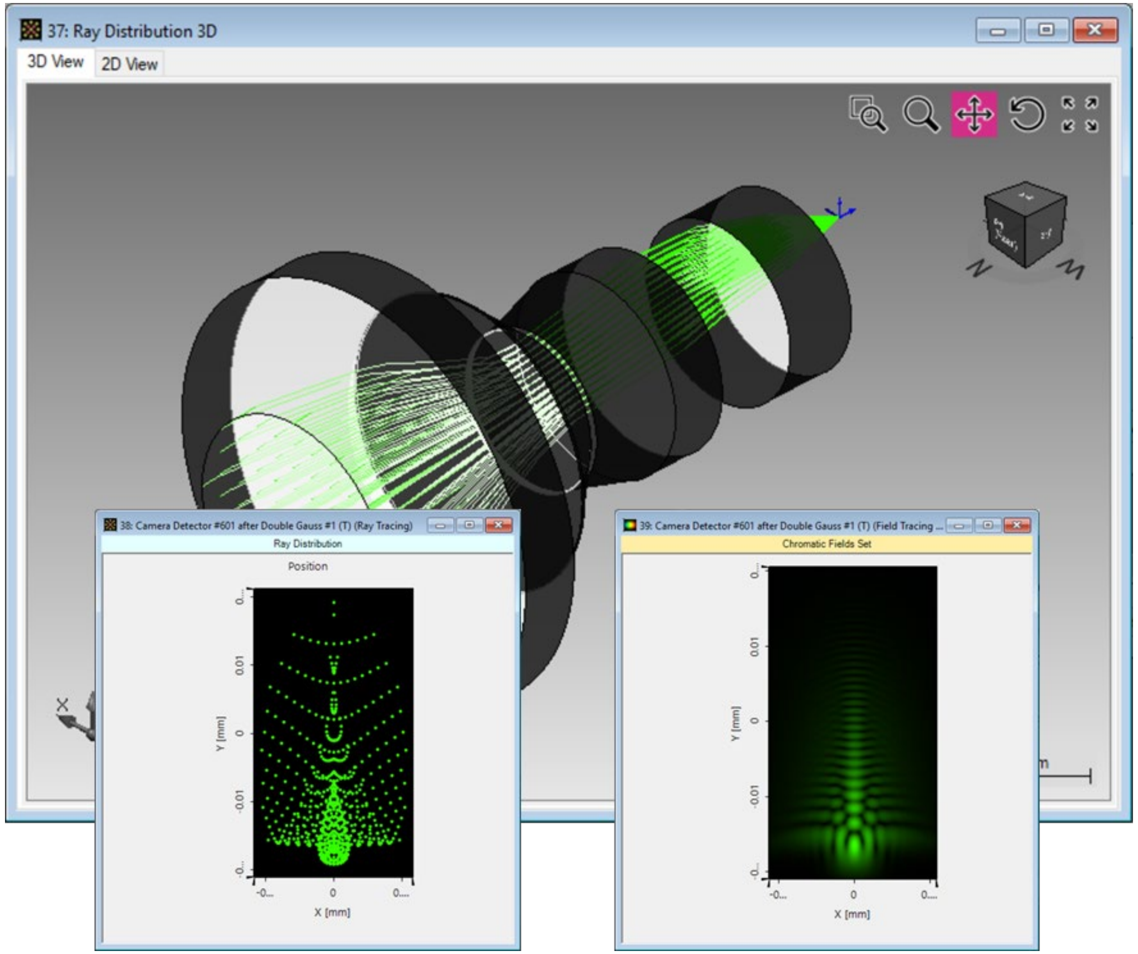


Zemax Import

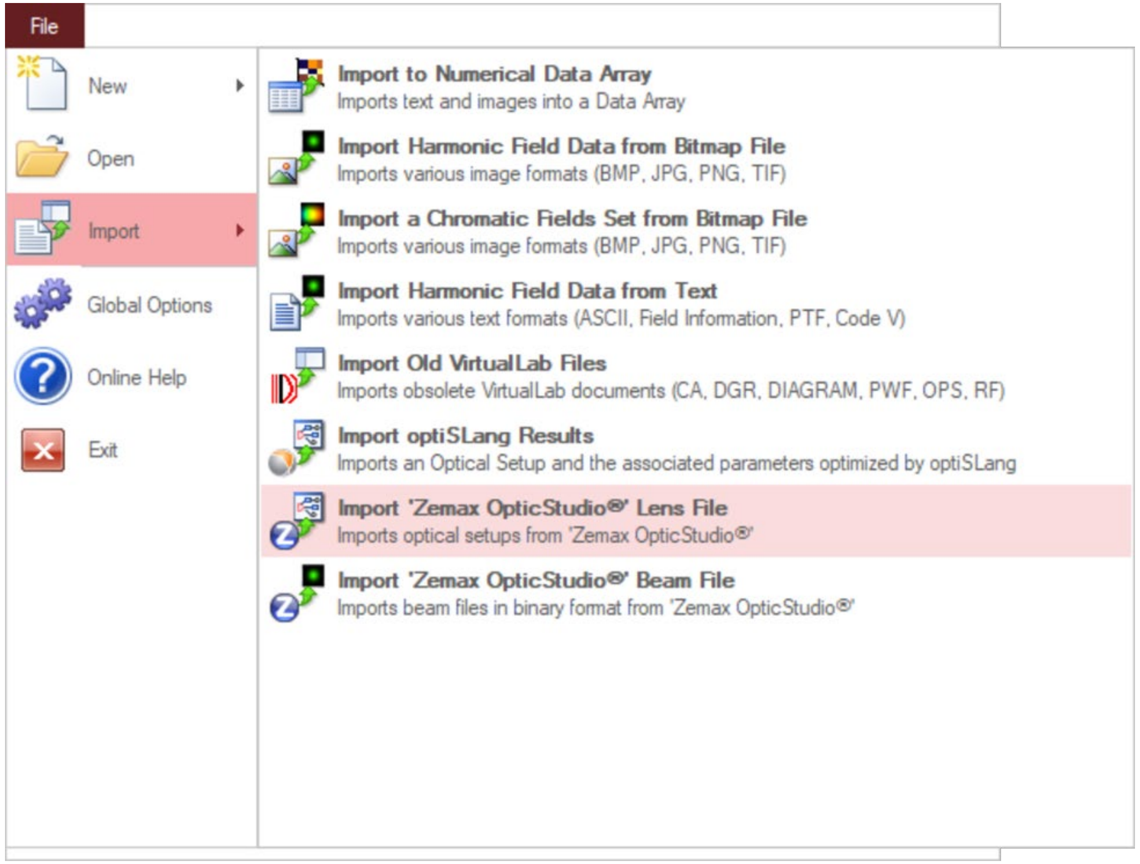
Importing Zemax Files

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



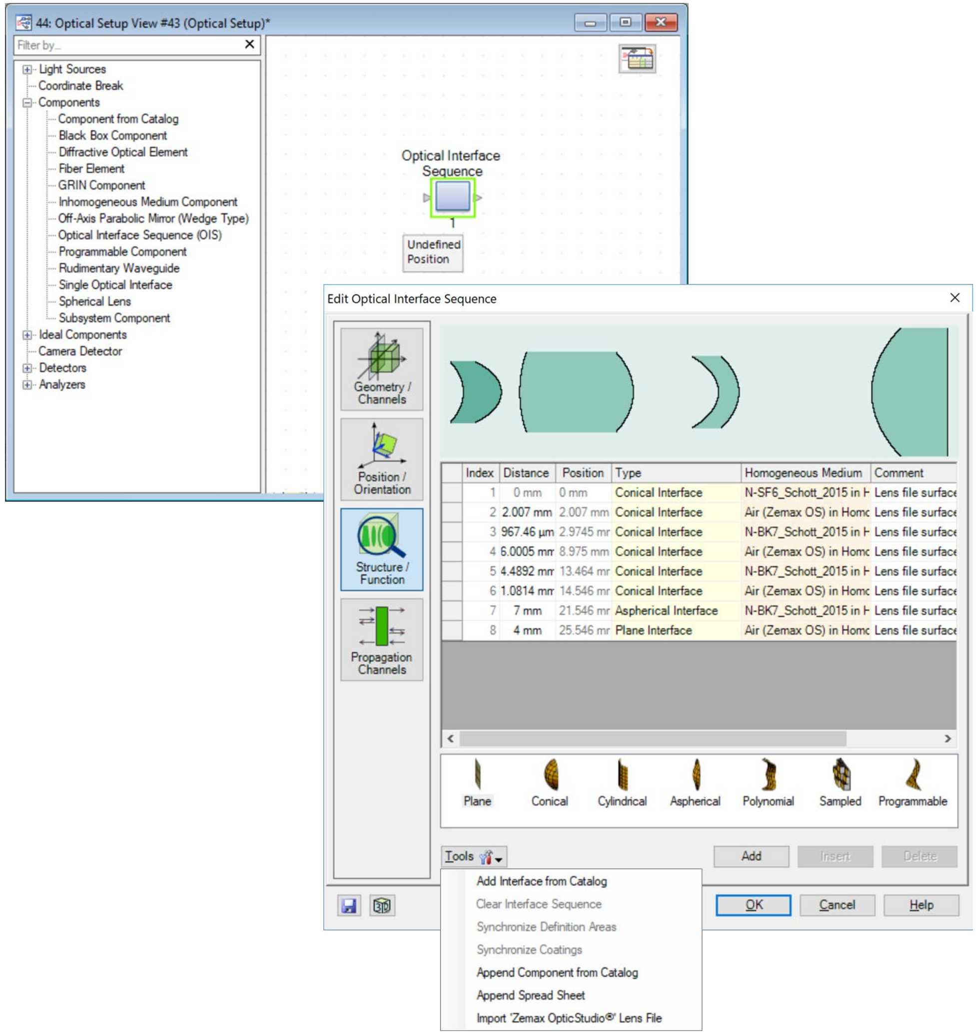
Importing Zemax Files



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

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

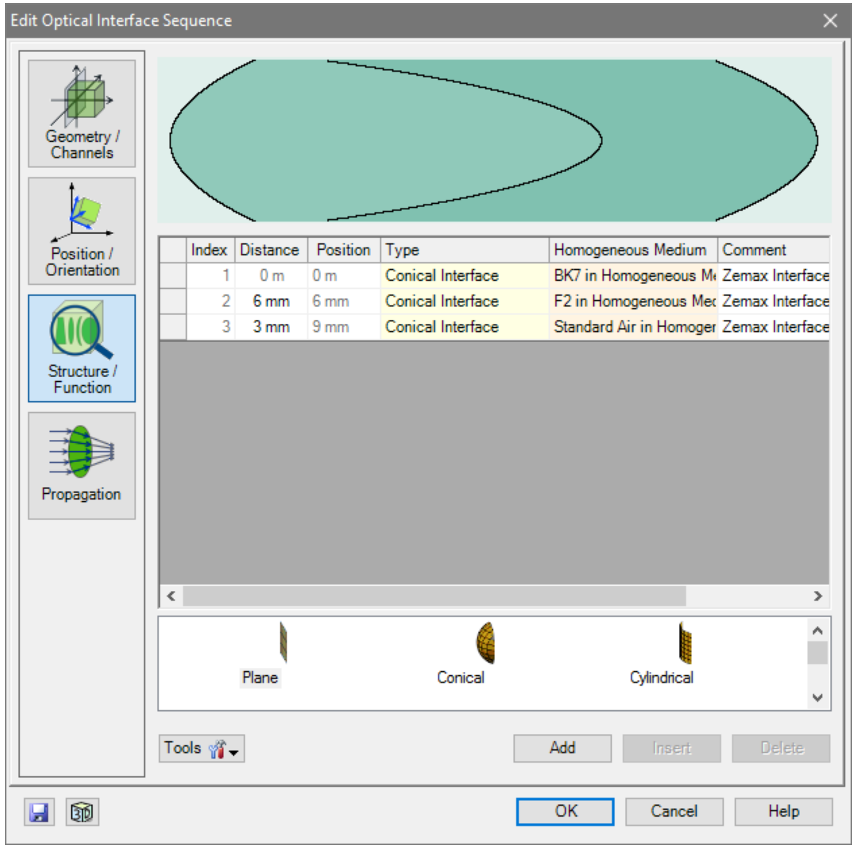
Elementary Zemax Import

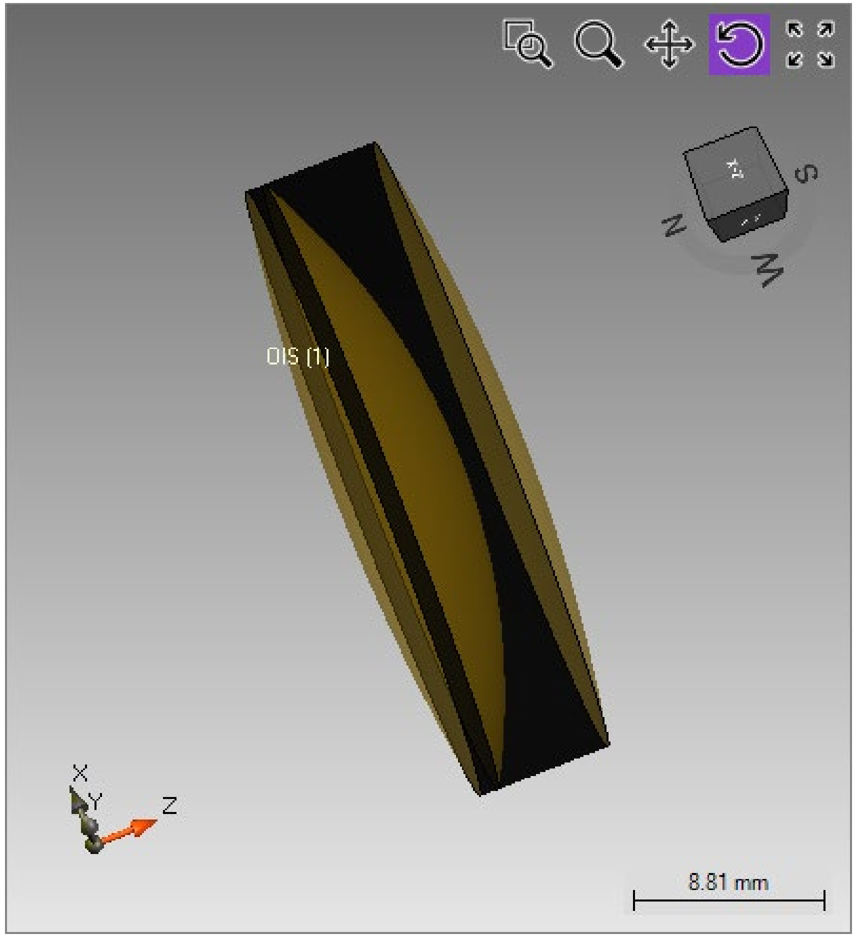
The **elementary Zemax** import is fully **sufficient** for the **import of most lens data** that is provided on manufacturers‘ websited via Zemax files.

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

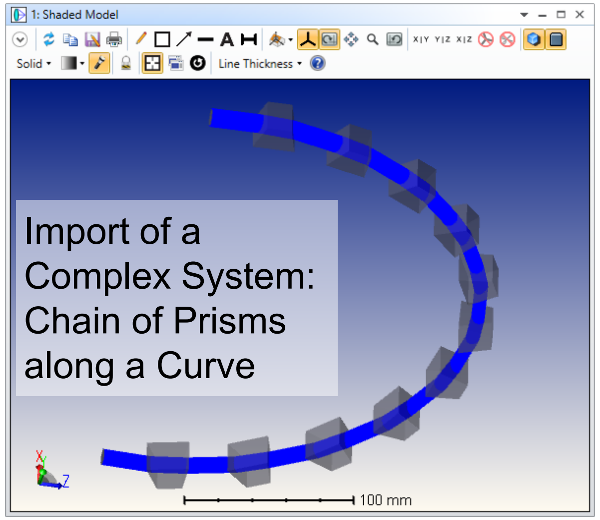
Elementary Zemax Import

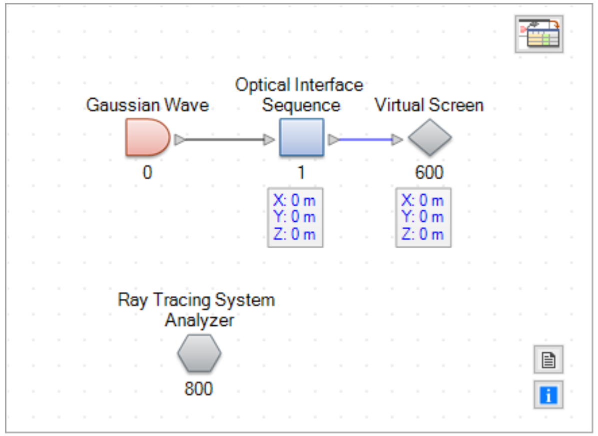
After the import some manual adaptions are needed, then the result looks like the following:

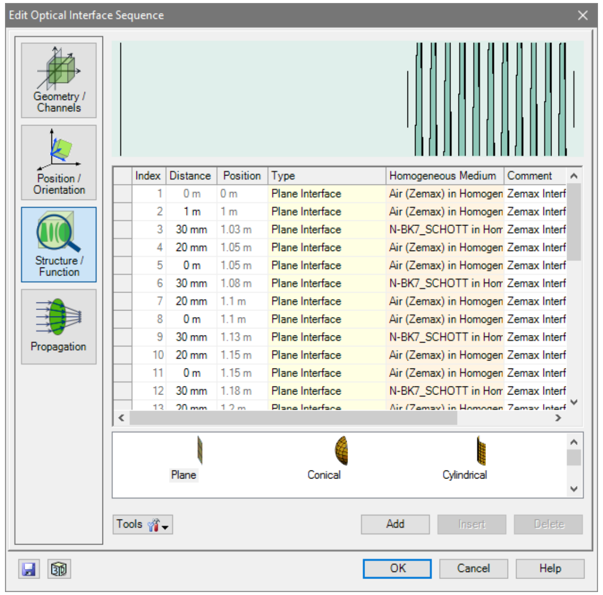




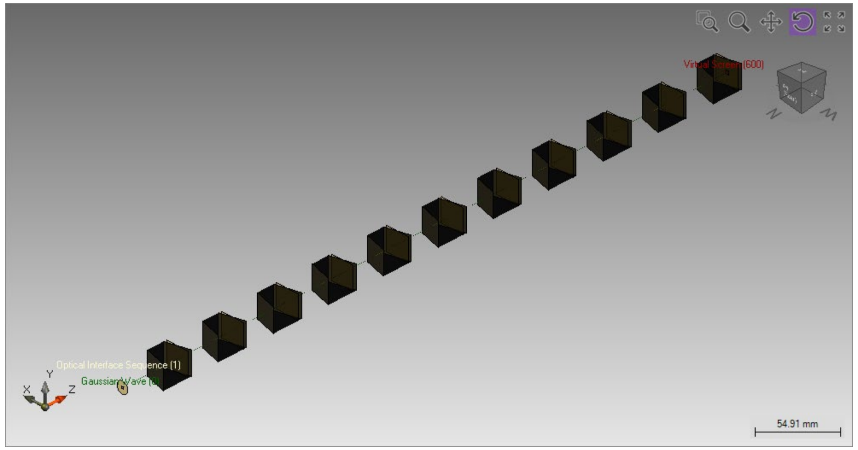
Limits of the Elementary Zemax Import



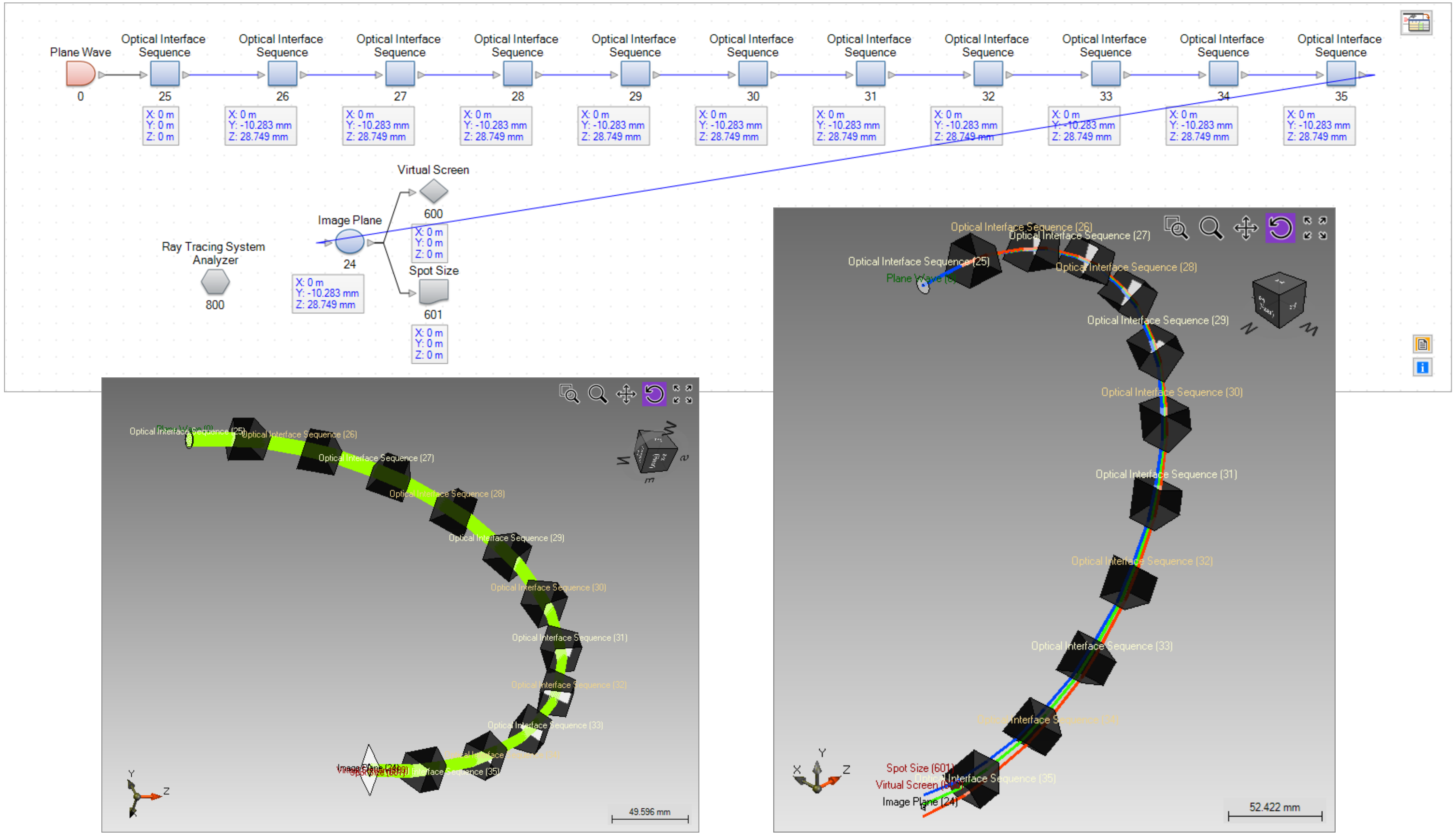




Messages
[08/09/2016 17:55:07] === Starting Zemax import ===
[08/09/2016 17:55:07] Warning: DISZ INFINITY detected at Zemax interface 0
[08/09/2016 17:55:07] Warning: Aperture diameter ZERO detected at Zemax interface 0 (default will be used).
[08/09/2016 17:55:07] Zemax Interface #4: unsupported type 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

- 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.