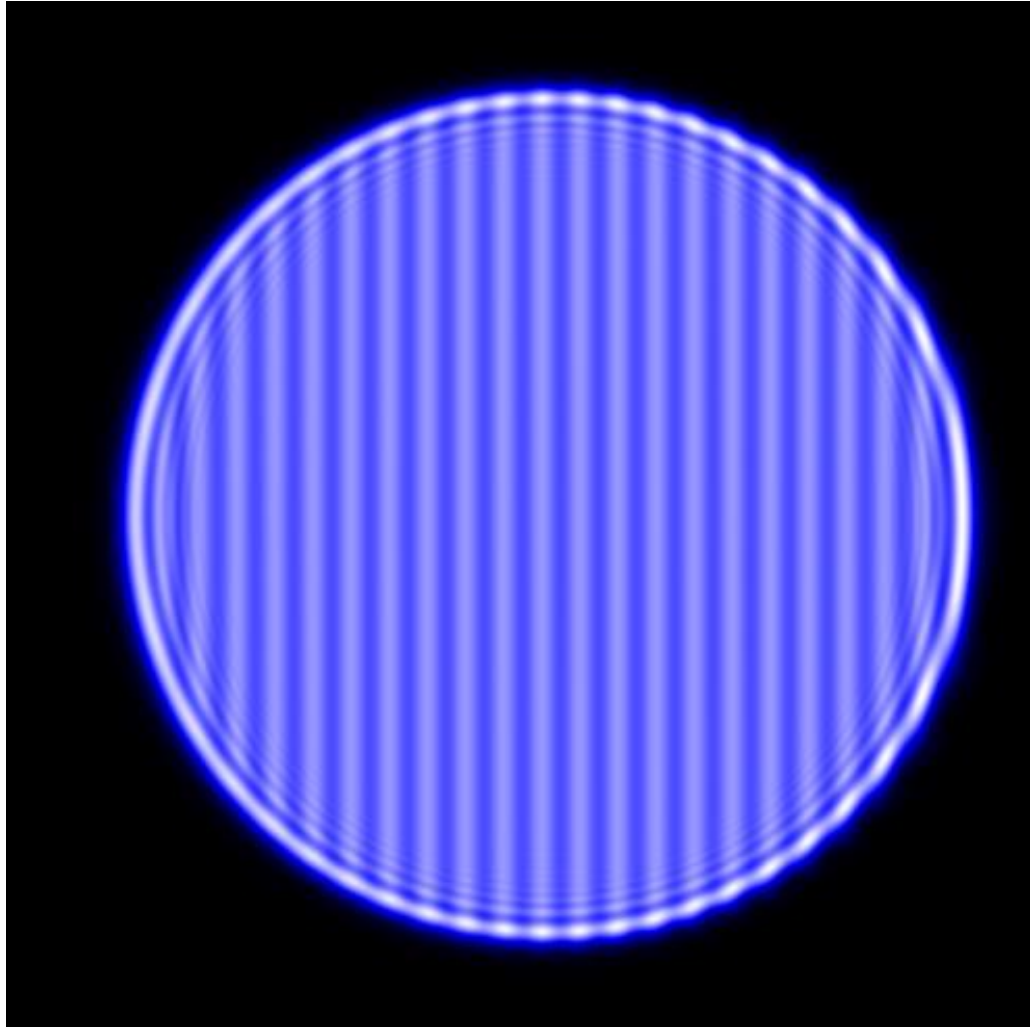


# Components, Solvers and Fourier Domains – Plane Surface

# Abstract



The field-tracing technology in VirtualLab Fusion rests on the philosophy of “connecting field solvers”: using different solvers for different components inside a single system, so that the best-suited option is applied to each part of the system. The choice exists for each solver to be implemented in the space domain or in the spatial-frequency domain. One or the other will be selected depending on the mathematical characteristics of said solver – for many of the most common components, the corresponding solver is going to be much lighter numerically in one domain than in the other, and therefore faster. This results in a simulation sequence that must move back and forth between the Fourier domains.

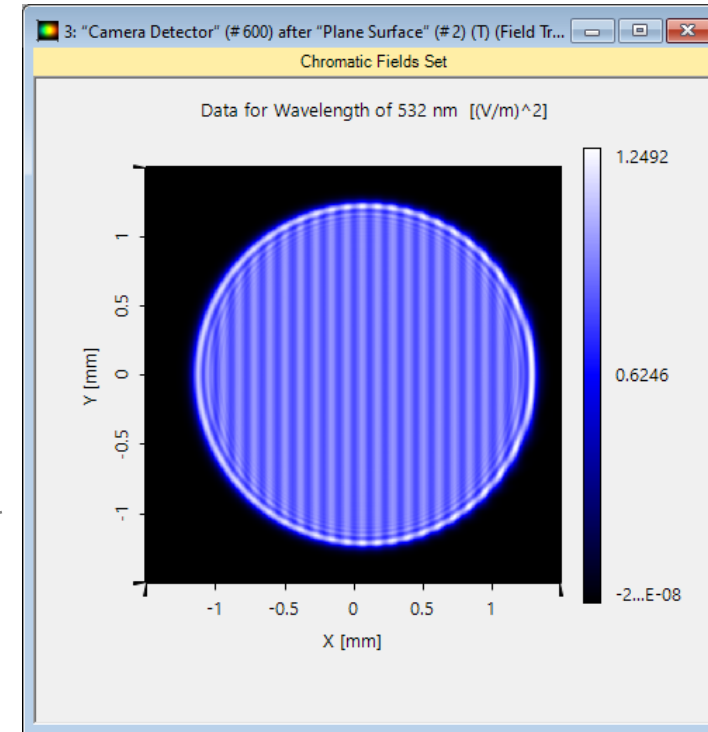
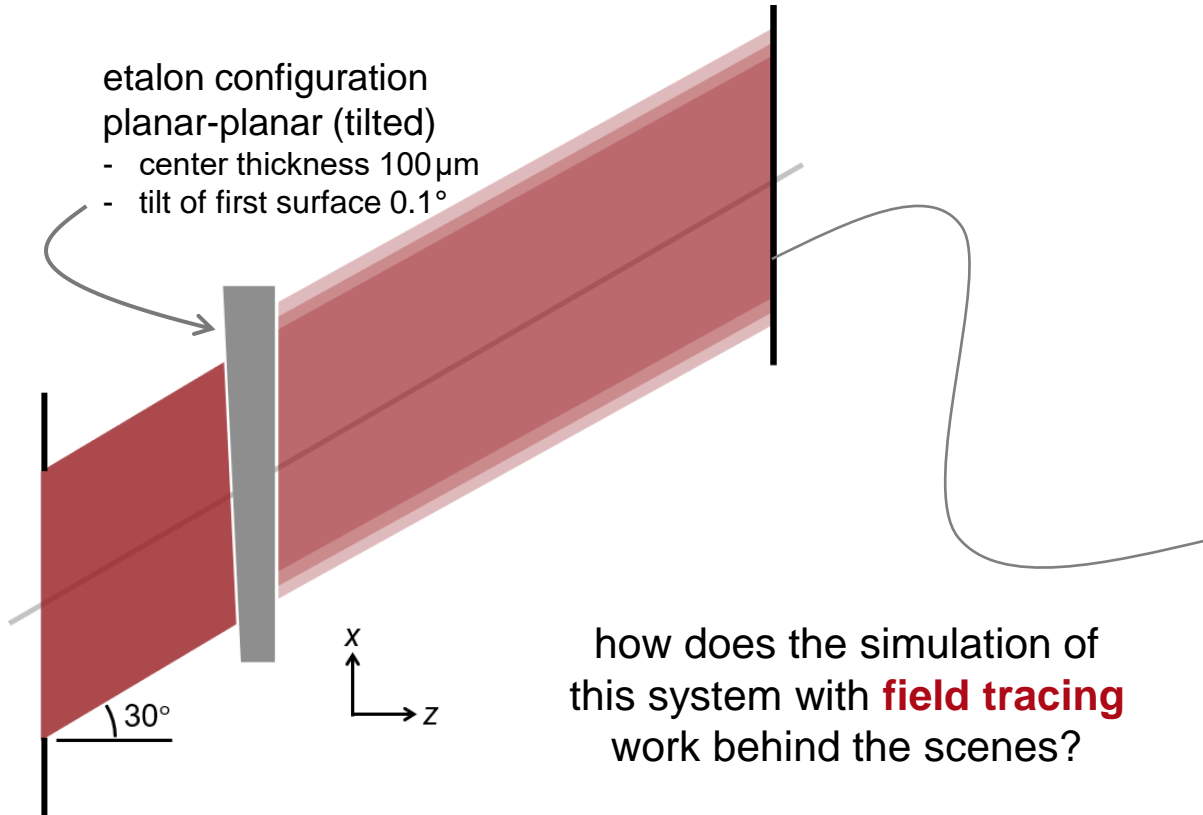
# Modeling Task

etalon configuration  
planar-planar (tilted)

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

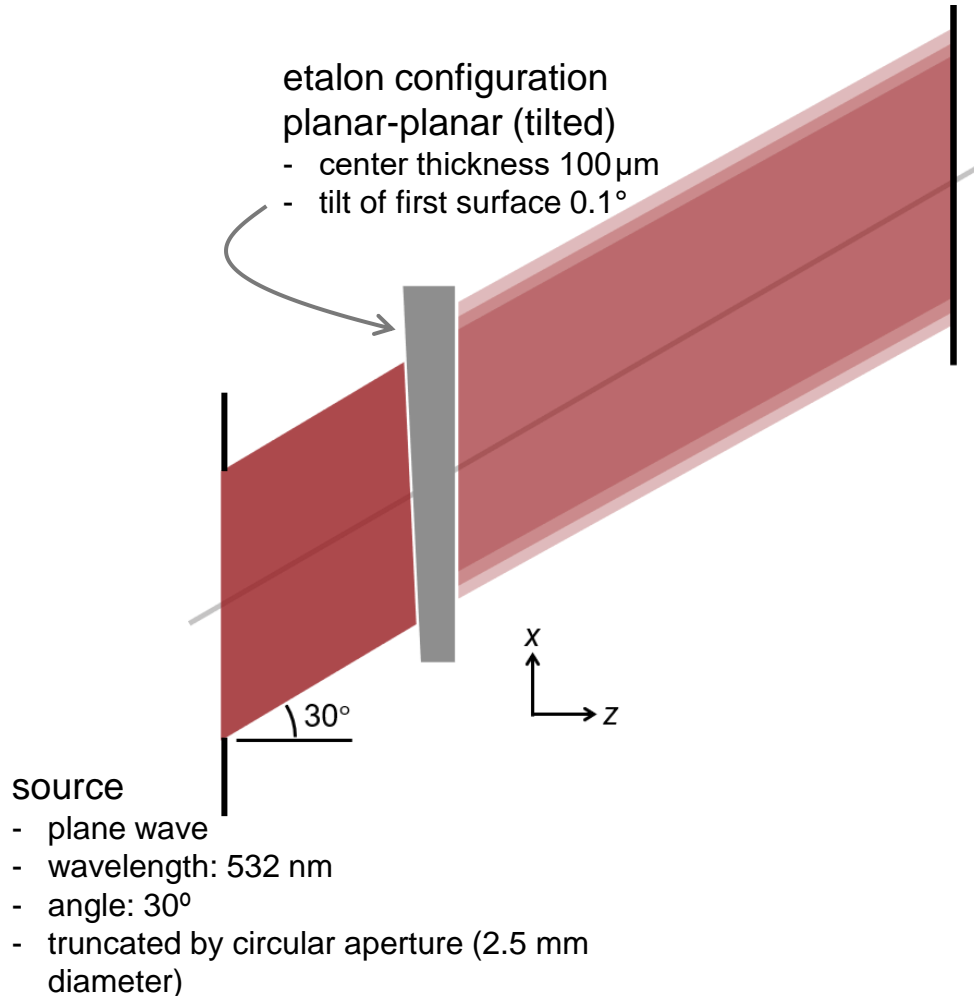
source

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



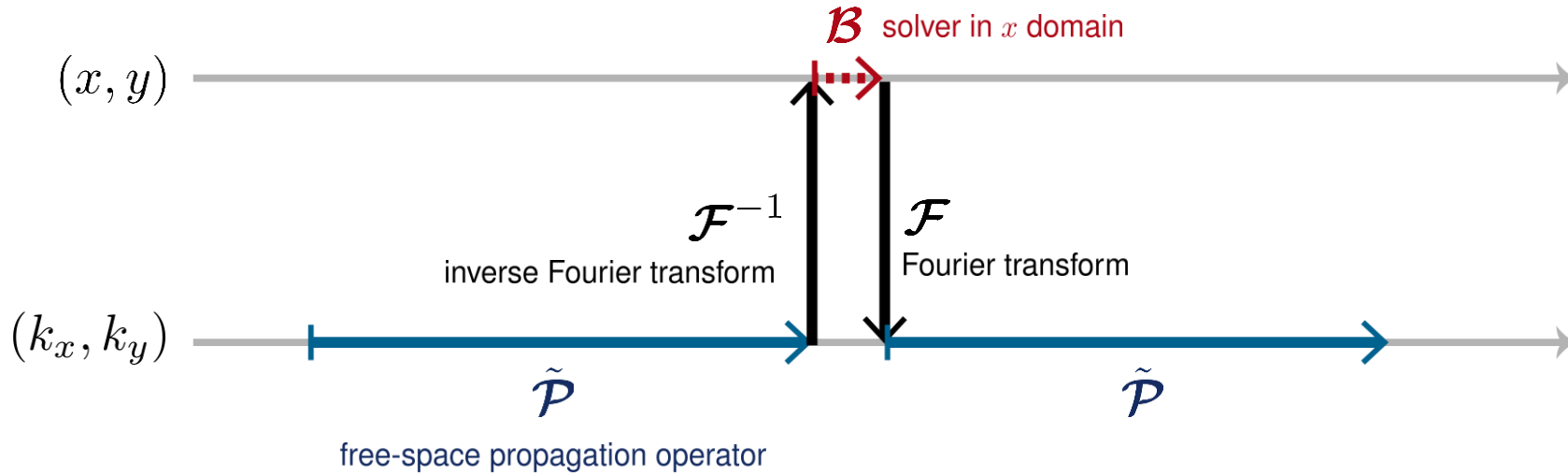
 [see the full Application Use Case:  
"Modeling of Etalon with Planar or Curved Surfaces"](#)

# Connecting Solvers!



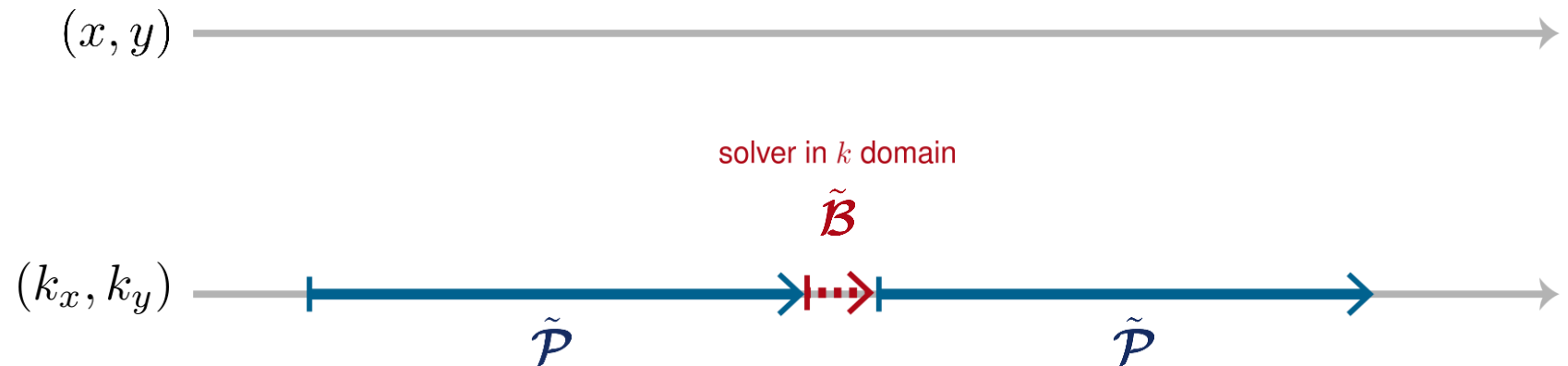
- Field tracing connects electromagnetic field solvers!
- An optical system is broken up into its different constituent parts.
- Each part is modeled with a specific field solver.
- In general, these solvers can be implemented in the space (x) domain or in the spatial-frequency (k) domain.
- **VirtualLab Fusion connects all the solvers in a seamless, non-sequential way, to provide a fully electromagnetic solution to the system!**

# Domain of Application of the Solvers

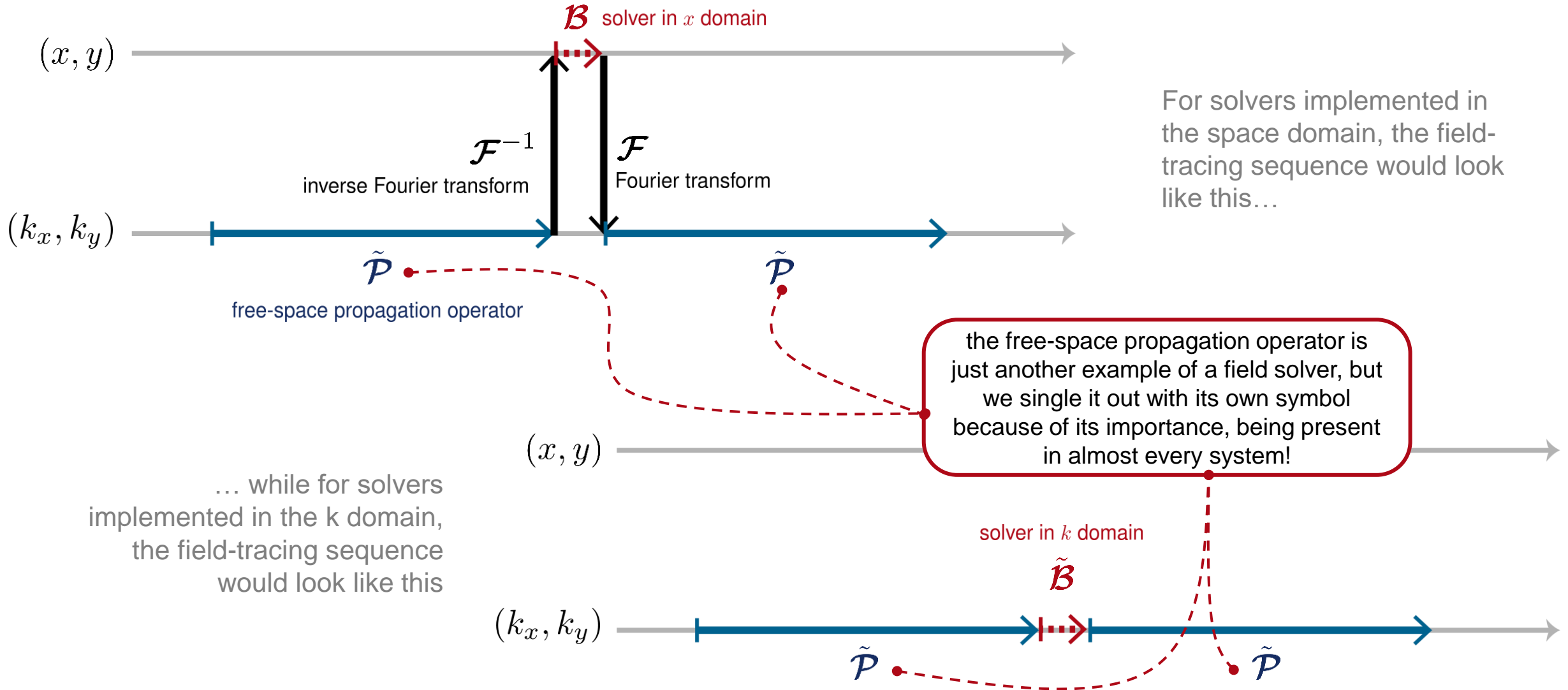


For solvers implemented in the space domain, the field-tracing sequence would look like this...

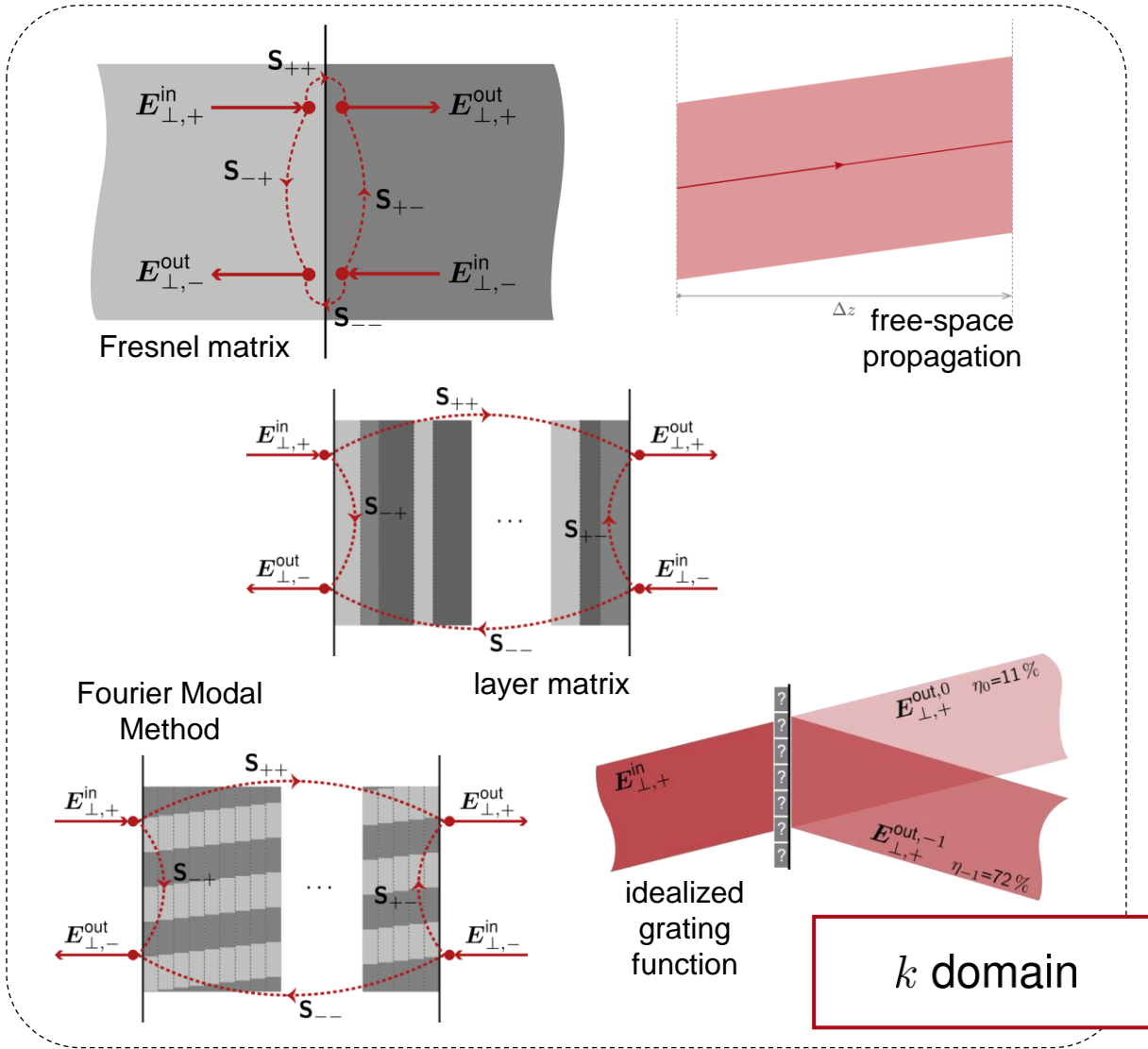
... while for solvers implemented in the  $k$  domain, the field-tracing sequence would look like this



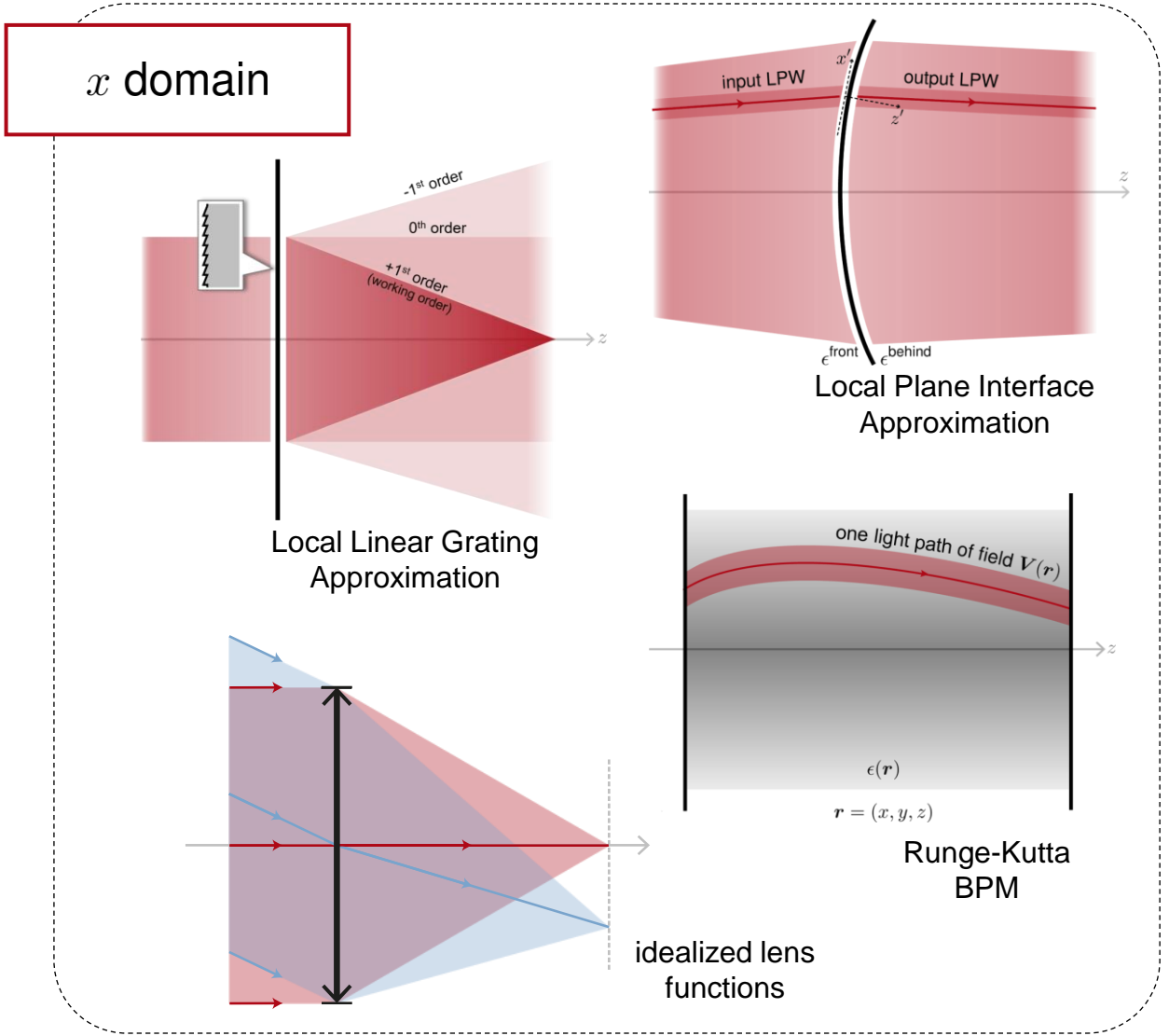
# Domain of Application of the Solvers



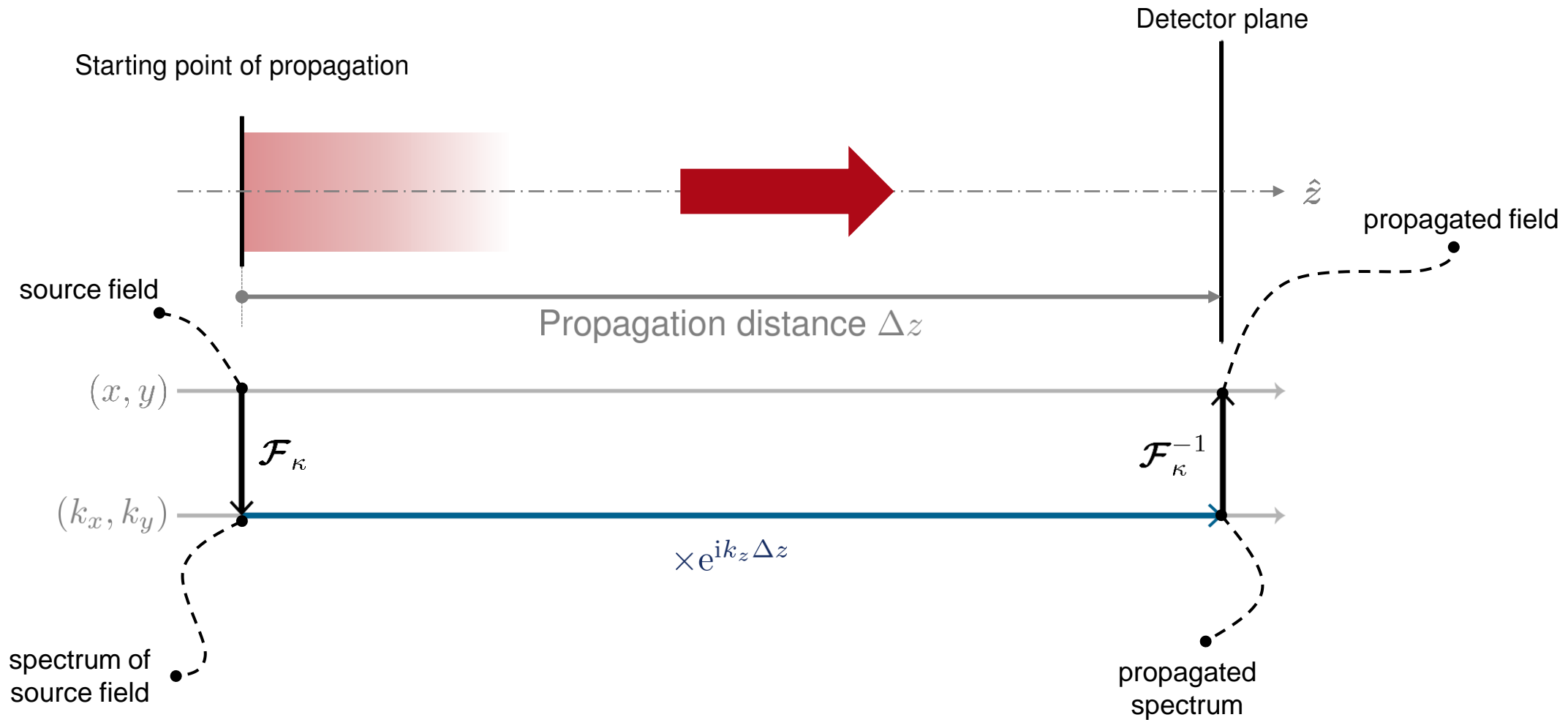
# Some Solvers and Their Domains



**$k$  domain**

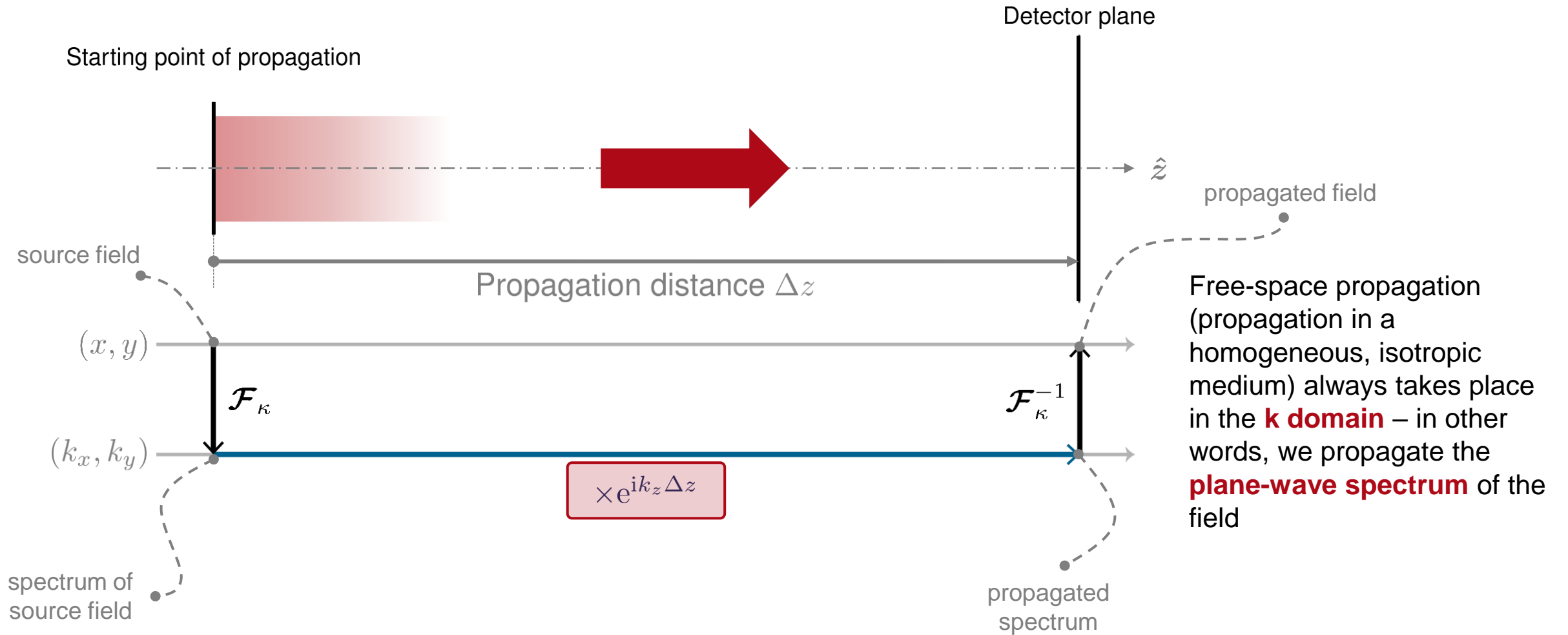


# Free-Space Propagation

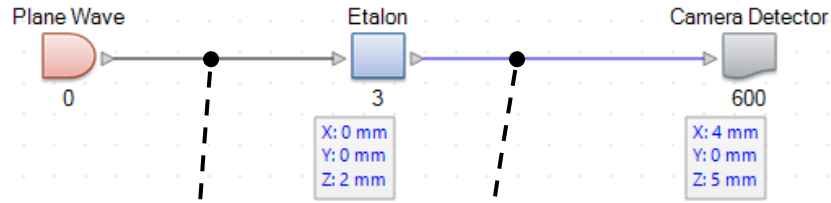




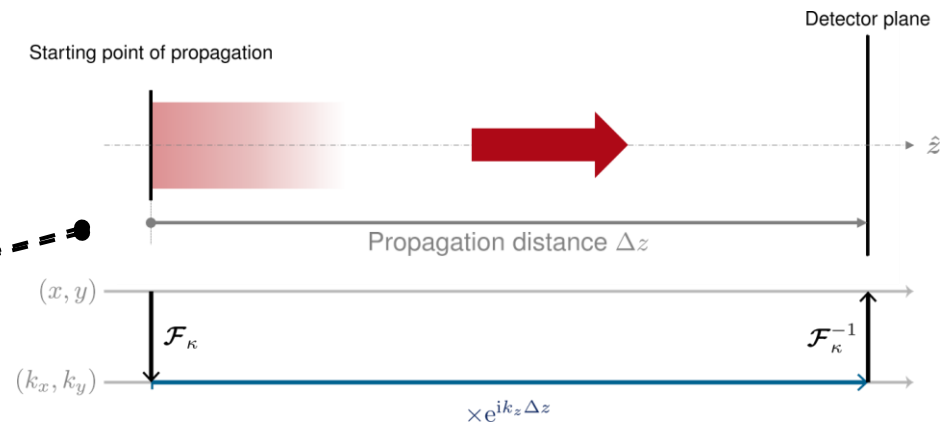
# Free-Space Propagation



# Free-Space Propagation

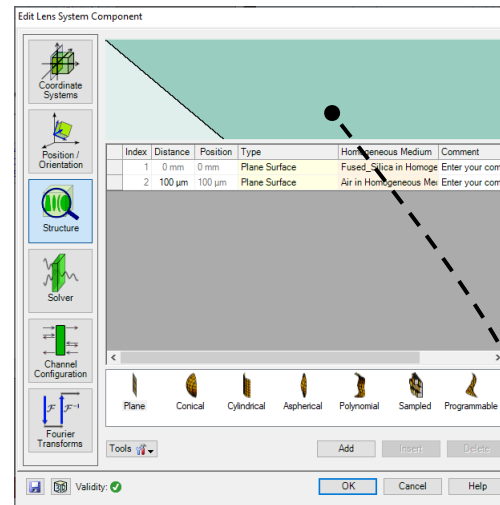
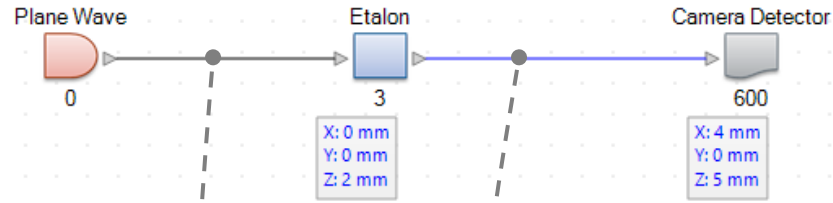


This refers to propagation between elements of an optical system...



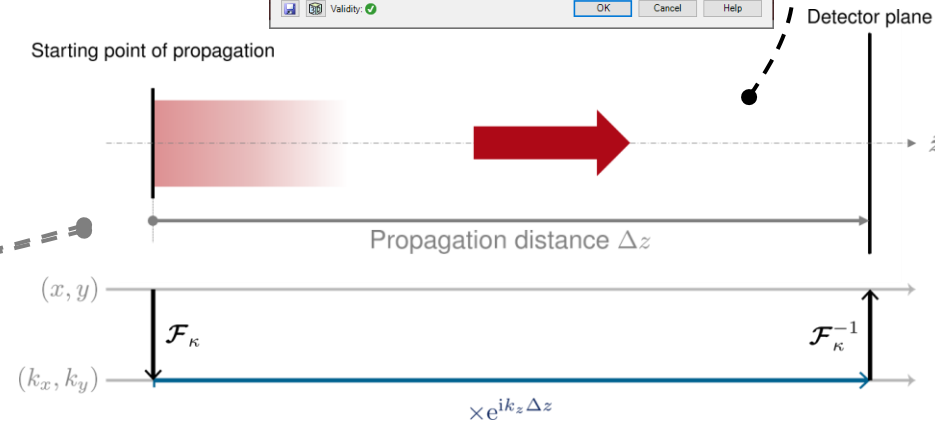
Free-space propagation (propagation in a homogeneous, isotropic medium) always takes place in the **k domain** – in other words, we propagate the **plane-wave spectrum** of the field

# Free-Space Propagation



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

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



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

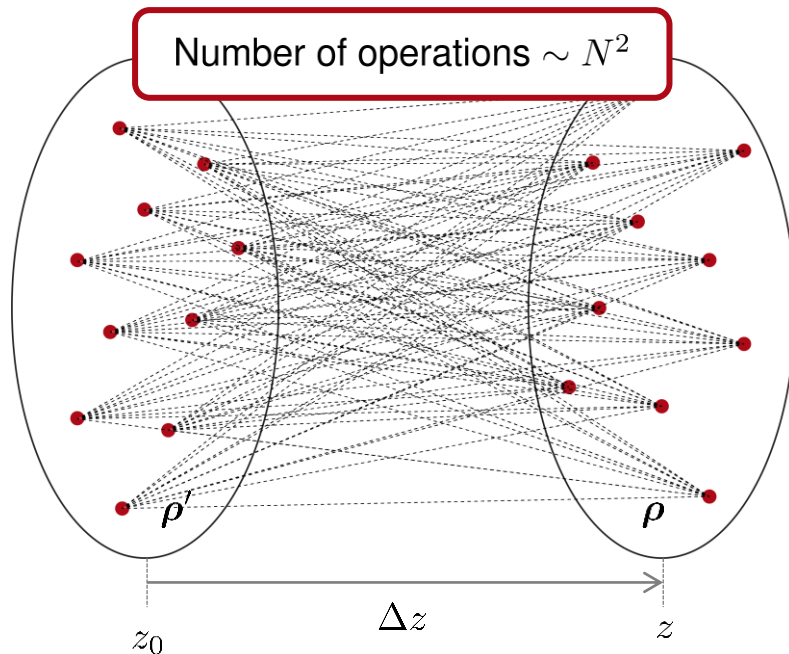
# Free-Space Propagation: Why K Domain?

## Space domain

Rayleigh-Sommerfeld integral:

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

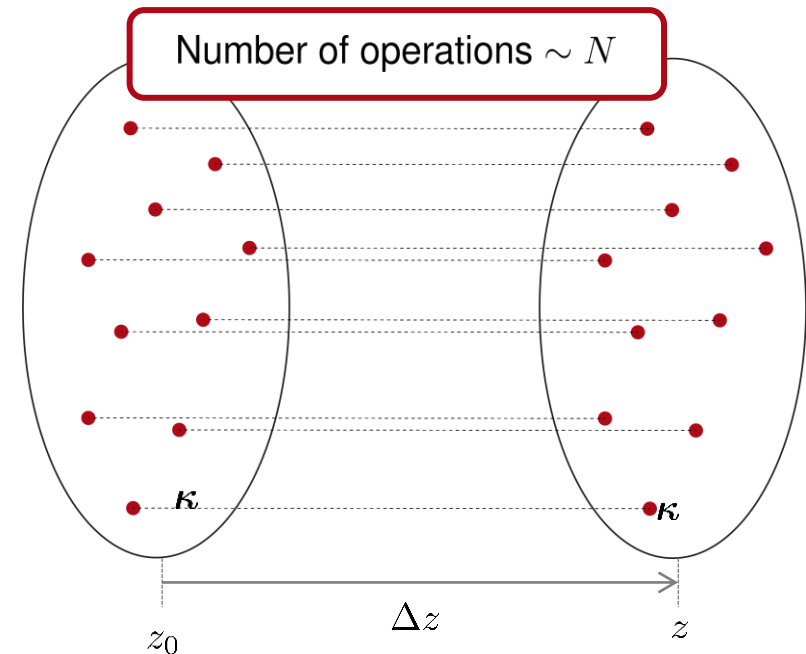
with  $R = \sqrt{(x - x')^2 + (y - y')^2 + (\Delta z)^2}$



## Spatial-frequency domain

Plane-wave propagation operator:

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



$N$ : number of samples

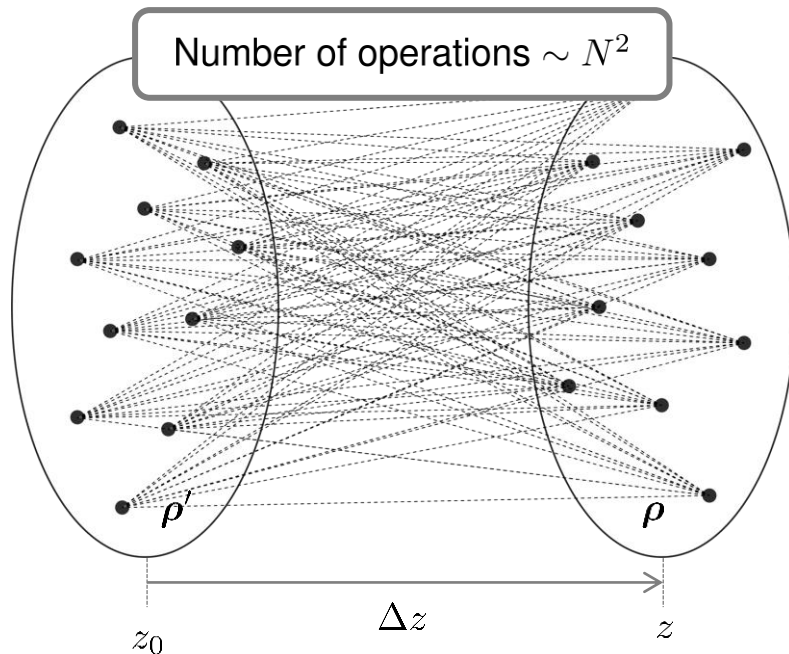
# Free-Space Propagation: Why K Domain?

## Space domain

Rayleigh-Sommerfeld integral:

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

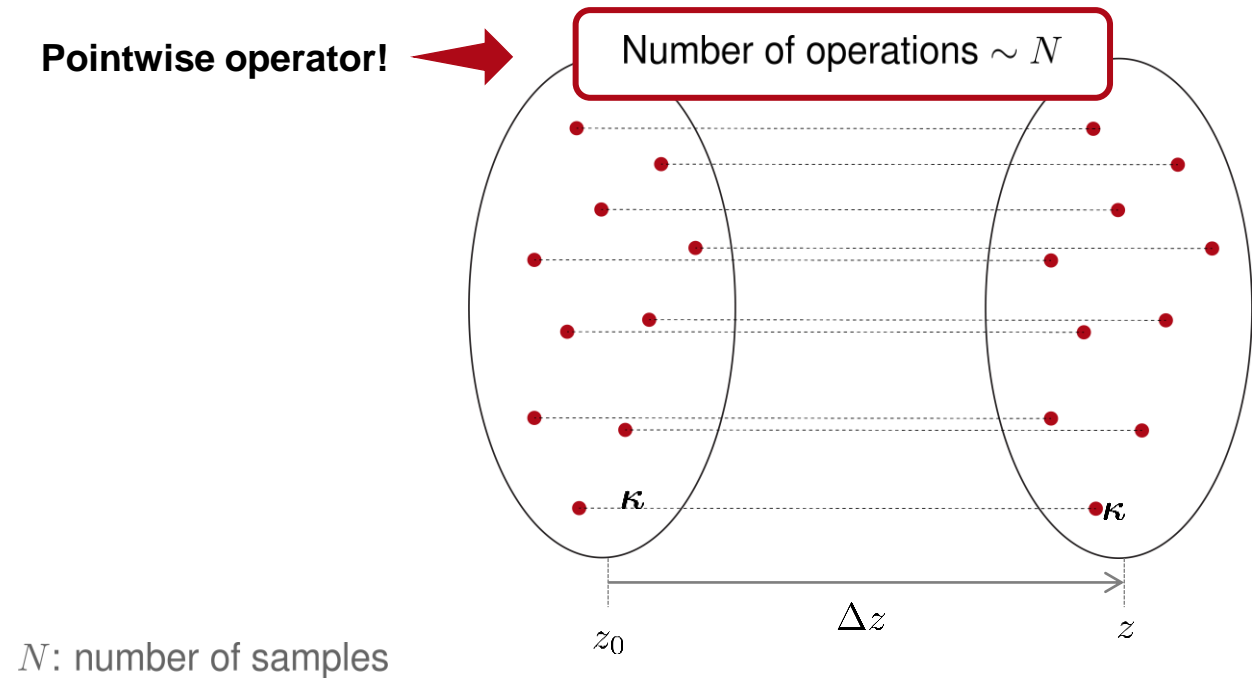


## Spatial-frequency domain

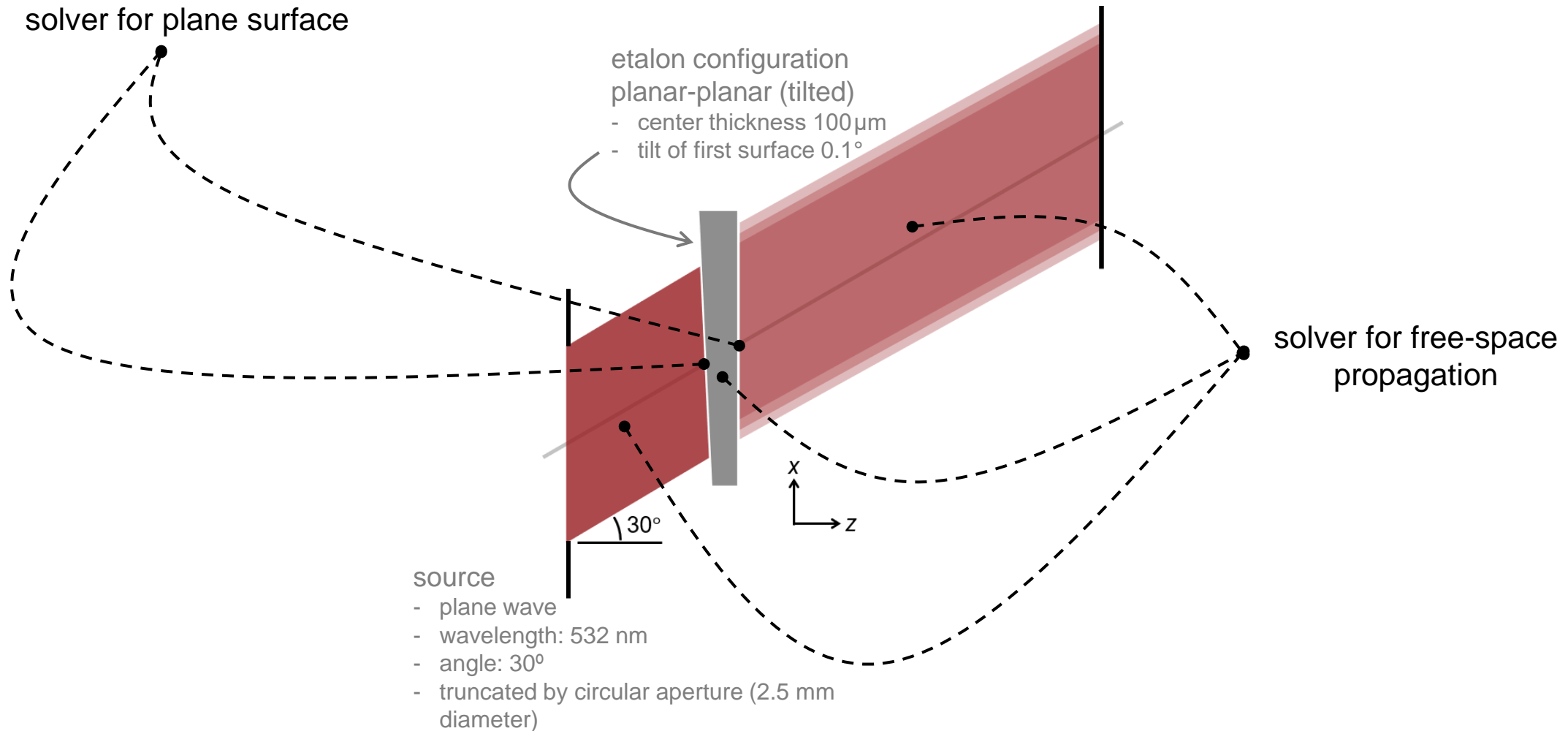
Plane-wave propagation operator:

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

Pointwise operator!  $\rightarrow$



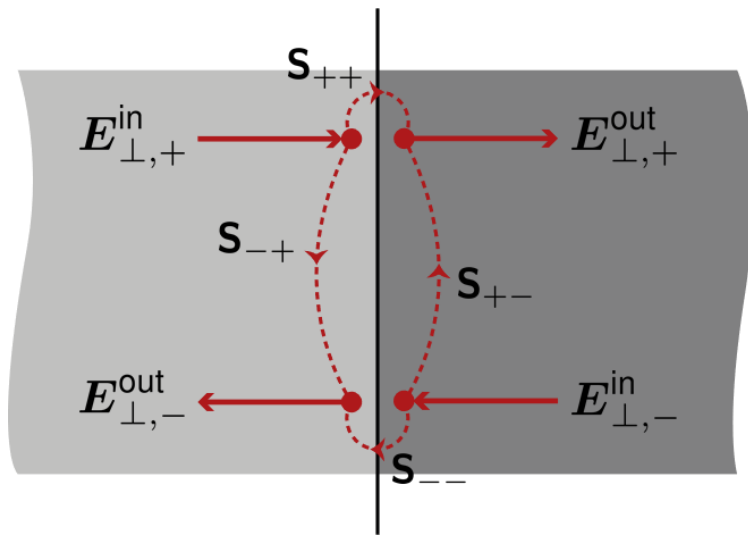
# What Solvers Do We Need in This System?



# Possible Field Solvers for Plane Surfaces

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

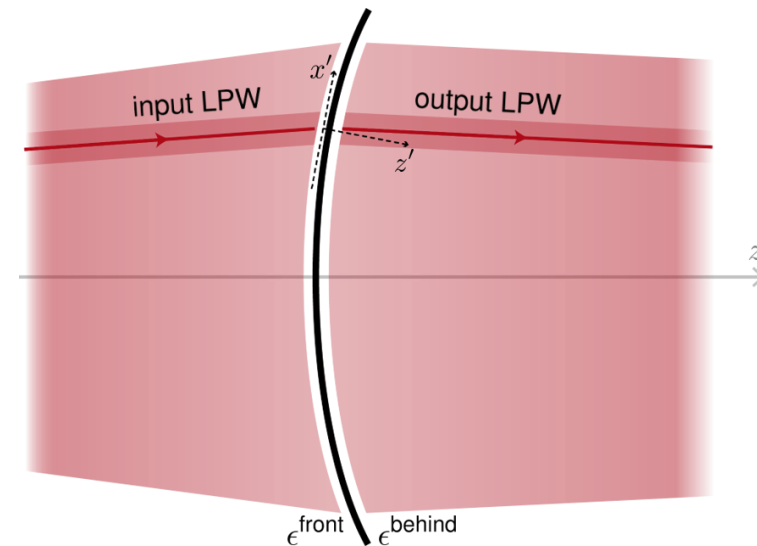
- Solver in **k domain**



- Implemented in *Plane Surface* component

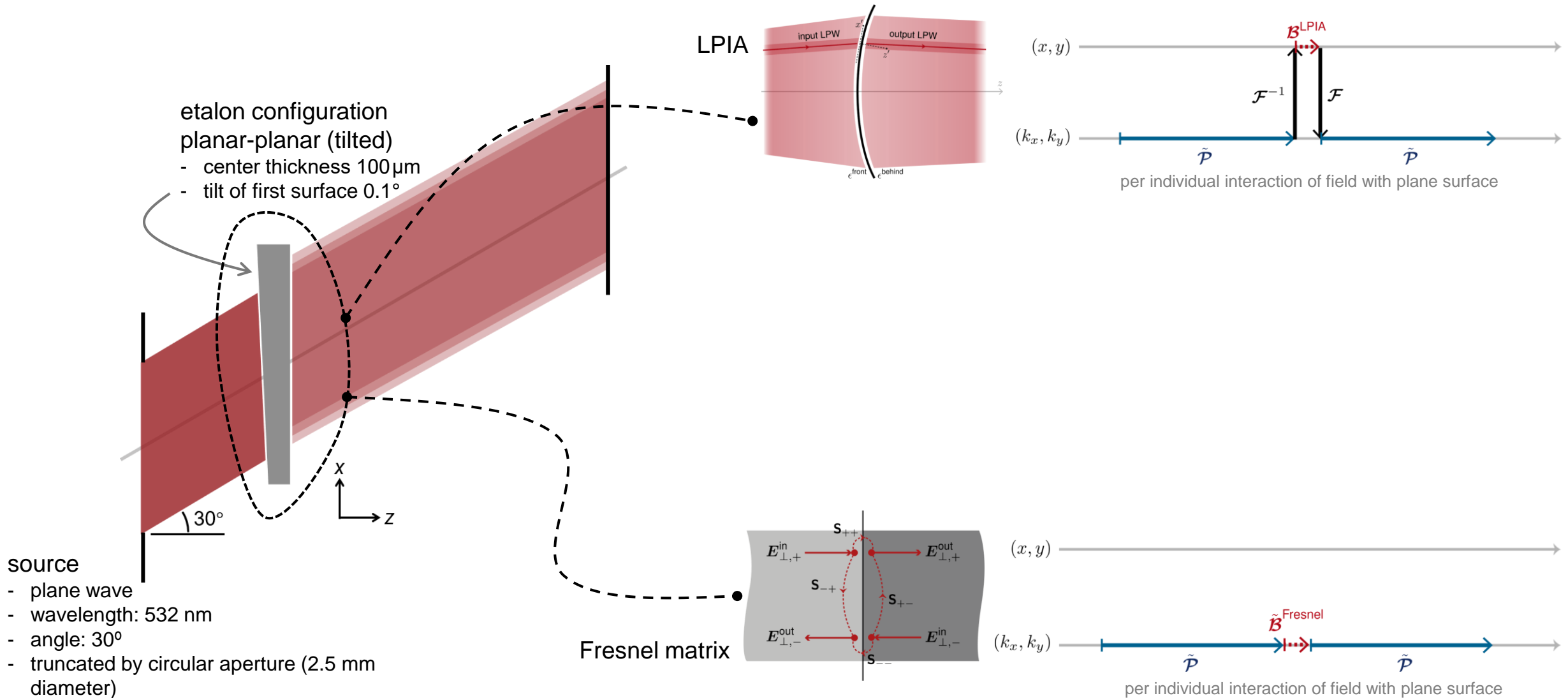
- As a curved surface without curvature → **Local Plane Interface Approximation (LPIA)**

- Solver in **x domain**



- Implemented in *Lens System*, *Curved Surface*, *Spherical Lens* and *Light Guide* components, among others.

# Possible Field Solvers for Plane Surfaces





# Possible Field Solvers for Plane Surfaces

The screenshot shows the VirtualLab Fusion interface. On the left, a component list includes Light Sources, Components, Ideal Components, Detectors, and Analyzers. The main workspace displays an optical setup: a Plane Wave (0) incident on Etalon Surface 1 (X: 0 mm, Y: 0 mm, Z: 2 mm), followed by Etalon Surface 2 (X: 0 mm, Y: 0 mm, Z: 100 μm), and a Camera Detector (600) at X: 4 mm, Y: 0 mm, Z: 5 mm. A Ray Tracing System Analyzer (800) is also present. A red hand icon points to Etalon Surface 1, and a red arrow points to Etalon Surface 2. A text label 'Plane Surface component (Fresnel Matrix)' is positioned below the setup. On the right, the 'Edit Plane Surface Component' dialog box is open, showing the 'Solver' tab. The 'Component Solver' is set to 'Fresnel Matrix'. The dialog box contains the following text:

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

1. an eigenmode solver for the homogeneous media on both sides of the interface and
2. matching of the boundary conditions at the plane interface separating those two media.

The eigenmode solver computes the field solution in the **k domain** for the homogeneous medium in each layer, and then boundary conditions are applied to compute the matrix of reflection and transmission coefficients. In contrast to the traditional Fresnel coefficients (typically given for TE and TM, or s- and p-polarization), our solver gives the result corresponding to the  $E_x$  and  $E_y$  field components directly. [Learn more about this solver.](#)

The diagram shows a vertical plane interface. On the left side, incident electric field components are  $E_{\perp,+}^{in}$  (pointing right) and  $E_{\perp,-}^{in}$  (pointing left). On the right side, transmitted components are  $E_{\perp,+}^{out}$  (pointing right) and  $E_{\perp,-}^{out}$  (pointing left). A dashed red ellipse encircles the interface, with scattering matrix elements  $S_{++}$ ,  $S_{+-}$ ,  $S_{-+}$ , and  $S_{--}$  labeled at the top, right, left, and bottom respectively.

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

# Possible Field Solvers for Plane Surfaces

The image shows a screenshot of the VirtualLab Fusion software interface. On the left, the 'Optical Setup View #1 (Fresnel Matrix)\*' window displays a ray tracing system with components: Plane Wave (0), Etalon Surface 1 (X: 0 mm, Y: 0 mm, Z: 2 mm), Etalon Surface 2 (X: 4 mm, Y: 0 mm, Z: 100 μm), and Camera Detector (600). A red hand icon points to Etalon Surface 1, and a red arrow points to Etalon Surface 2. A dashed line connects Etalon Surface 1 to a 'Curved Surface component (LPIA)' (800). On the right, the 'Edit Curved Surface Component' dialog box is open, showing the 'Solver' tab. The 'Component Solver' is set to 'Local Plane Interface Approximation (LPIA)'. The dialog box contains the following text:

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

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

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

The diagram shows a curved surface with an 'input LPW' and an 'output LPW'. The surface is defined by a coordinate system with  $x$  and  $z$  axes. The surface is labeled  $c_{front}$  and  $c_{behind}$ . The diagram illustrates the local plane interface approximation (LPIA) solver.

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

# Possible Field Solvers for Plane Surfaces

The image shows a screenshot of the VirtualLab Fusion software interface. On the left, the 'Optical Setup View #3 (LPIA)\*' window displays a ray tracing diagram. A 'Plane Wave' (0) is incident on an 'Etalon' component. The Etalon is positioned at  $X: 0 \text{ mm}$ ,  $Y: 0 \text{ mm}$ , and  $Z: 2 \text{ mm}$ . A red hand icon points to the Etalon. A red arrow points from the Etalon to a 'Camera Detector' (600) located at  $X: 4 \text{ mm}$ ,  $Y: 0 \text{ mm}$ , and  $Z: 5 \text{ mm}$ . A 'Ray Tracing System Analyzer' (800) is also present. The 'Lens System component (LPIA)' is highlighted in the diagram.

On the right, the 'Edit Lens System Component' dialog box is open. The 'Component Solver' is set to 'Local Plane Interface Approximation (LPIA)'. The dialog box contains the following text:

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

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

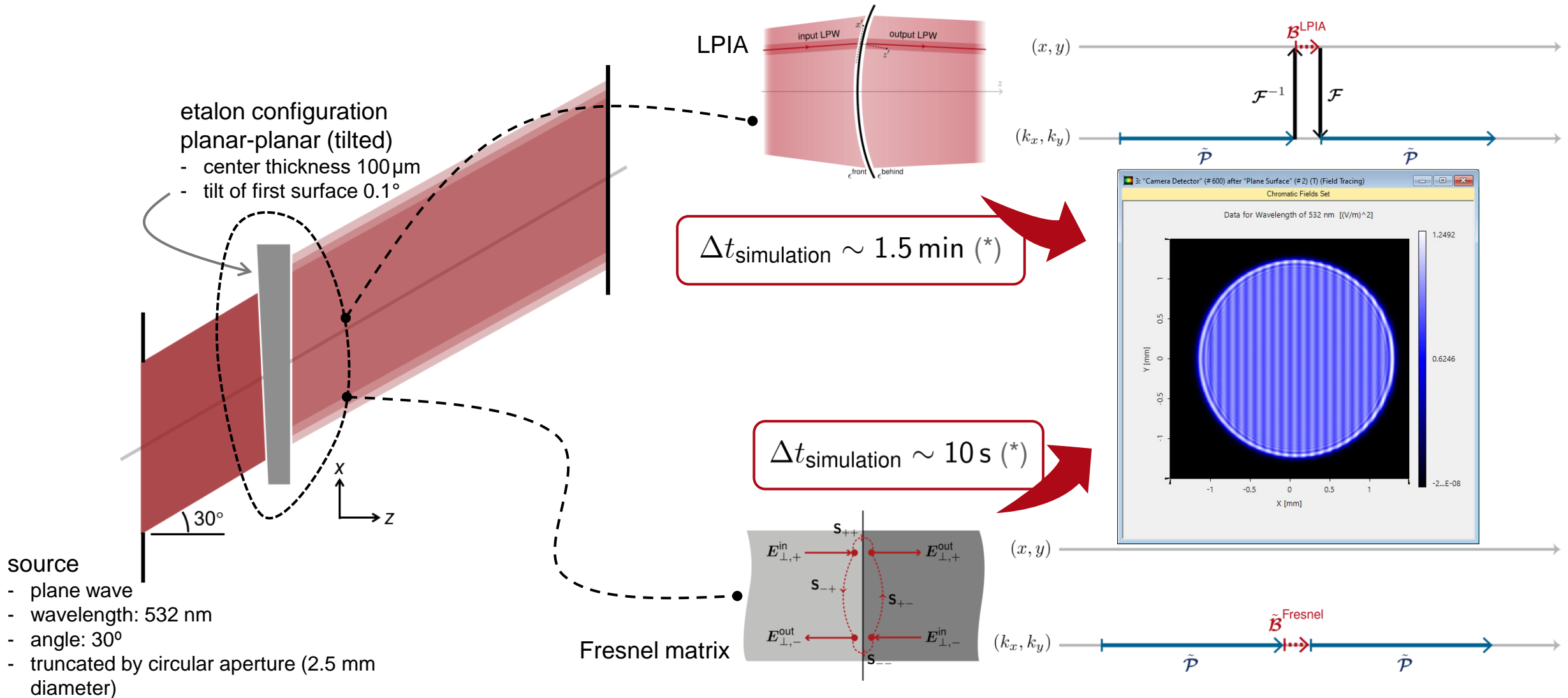
At an arbitrary location on the curved surface, an approximate local boundary condition is applied, which assumes the interaction of the LPW with the local plane interface. Thus, the Fresnel matrix (or layer matrix for coatings) can be used to connect input and output fields. [Learn more about this solver.](#)

The diagram below the text shows a curved surface with an 'input LPW' and an 'output LPW'. The surface is defined by  $x'$  and  $z$  coordinates. The front and back surfaces are labeled  $c_{\text{front}}$  and  $c_{\text{behind}}$ .

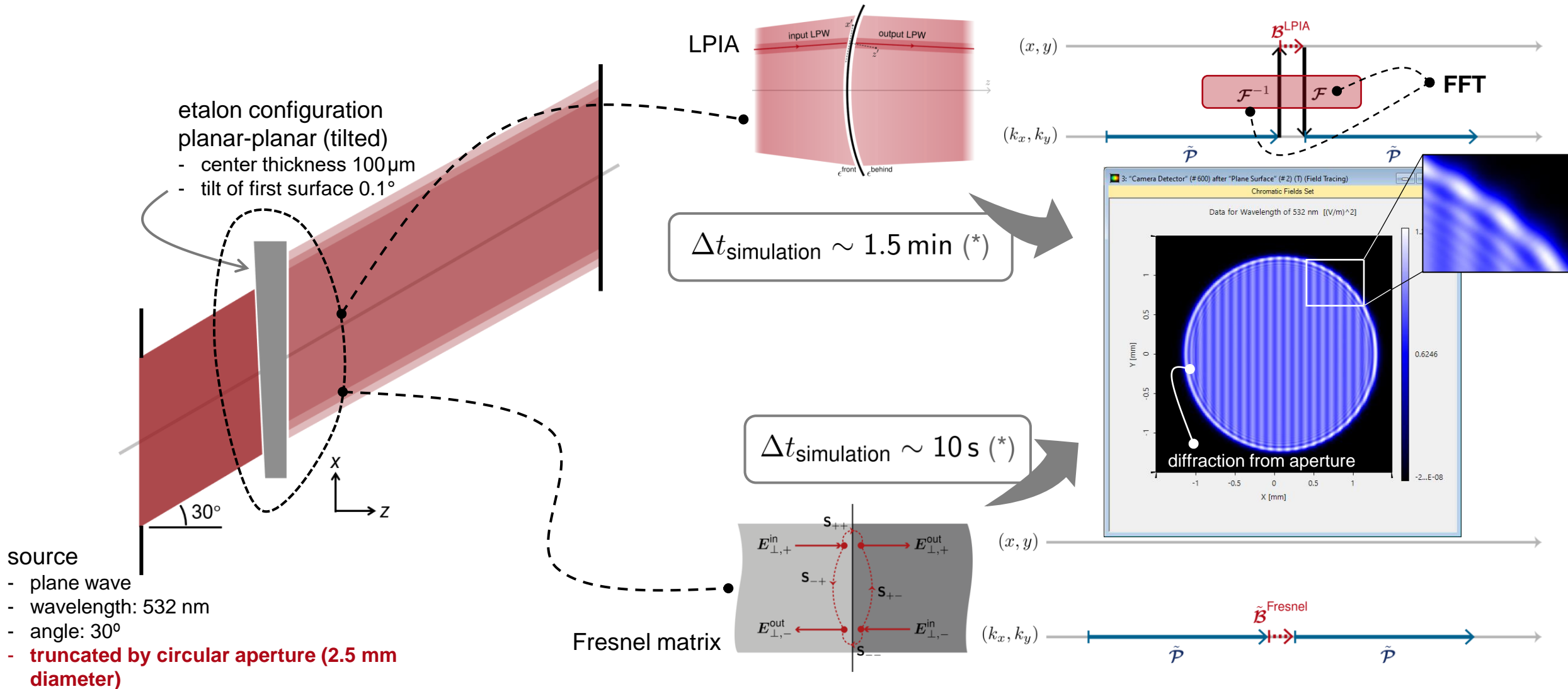
The 'Edit Lens System Component' dialog box also includes a 'Solver' section with icons for 'Coordinate Systems', 'Position / Orientation', 'Structure', 'Solver', 'Channel Configuration', and 'Fourier Transforms'. The 'Solver' icon is highlighted with a red box. The dialog box has 'OK', 'Cancel', and 'Help' buttons at the bottom.

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

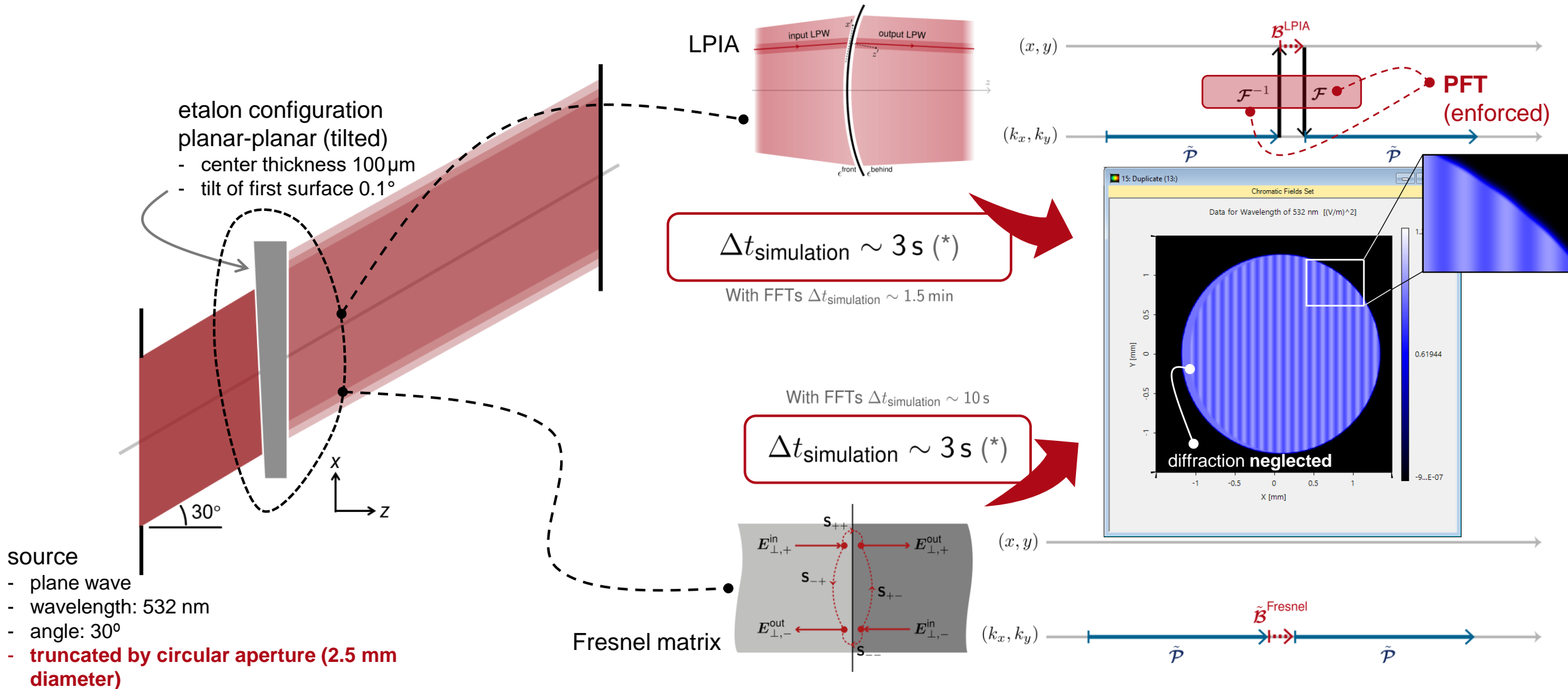
# Possible Field Solvers for Plane Surfaces



# The Importance of the Fourier Transform

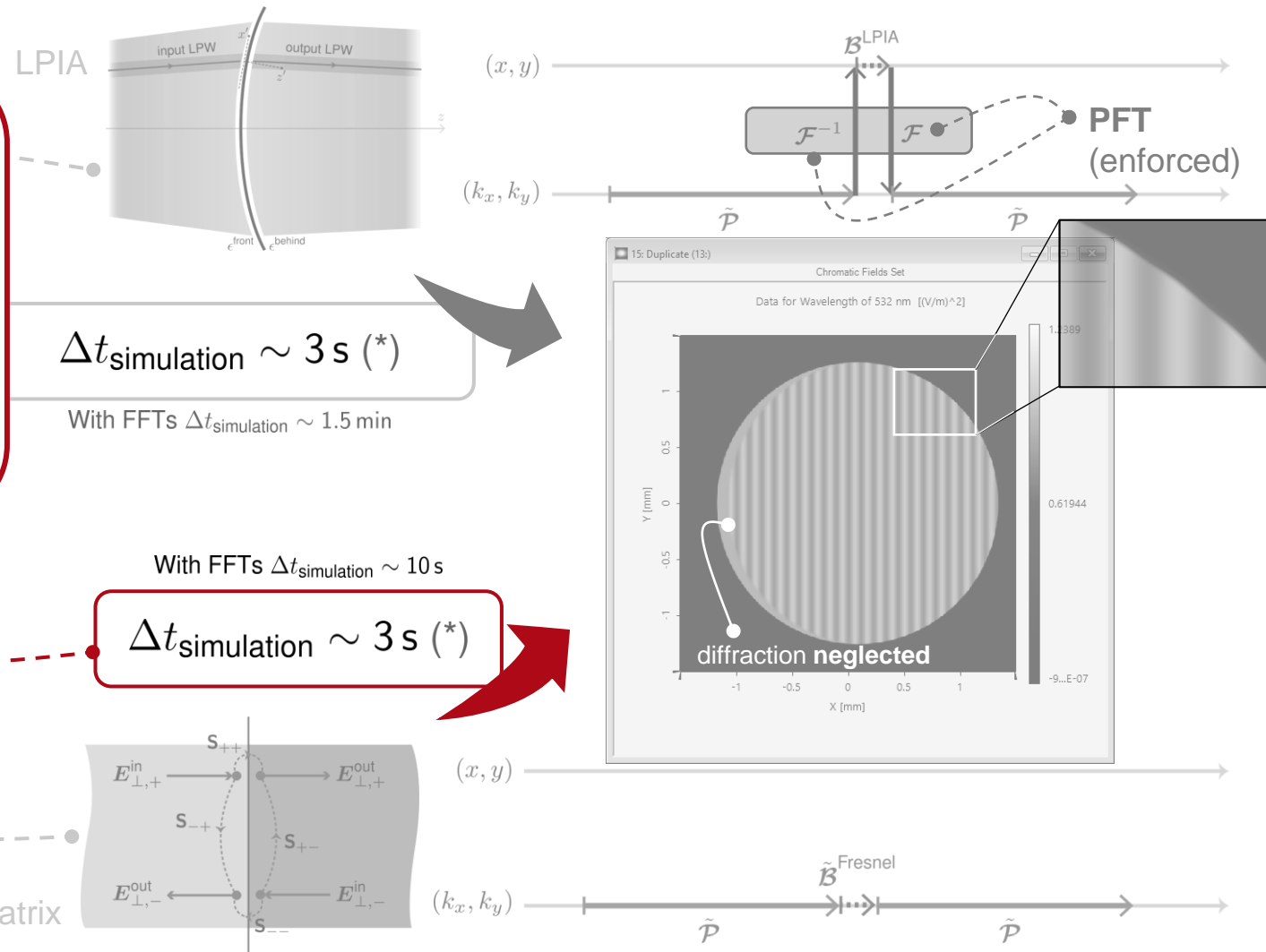


# The Importance of the Fourier Transform



# The Importance of the Fourier Transform

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



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

# Practical Conclusions: Which Solver Do I Use?

---

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

## **Fresnel Matrix:**

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

## **LPIA:**

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



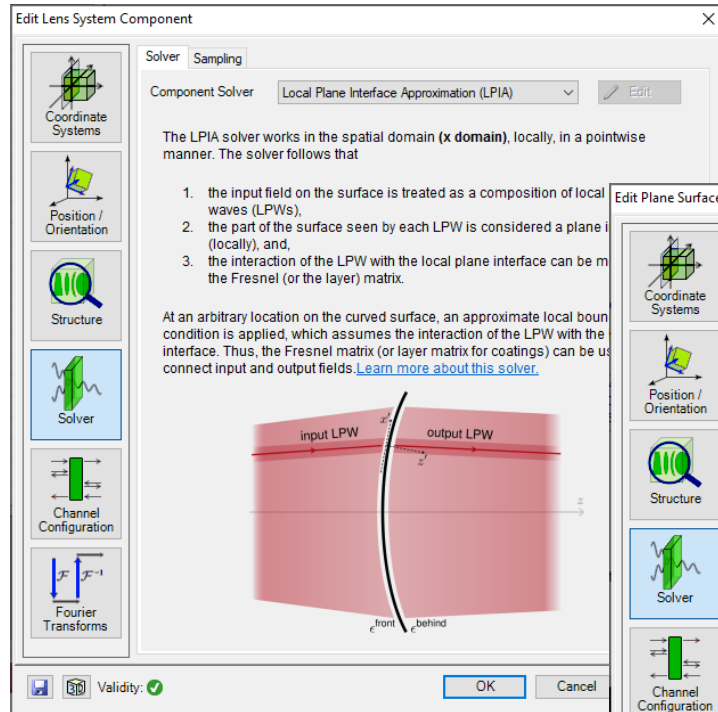
# Practical Hint: Component Substitution

The screenshot shows the VirtualLab Fusion interface. At the top, the 'Tools' menu is open, with 'Split Component' highlighted. Below it, a 'Split Component' dialog box is displayed, showing 'Component to Split' set to 3, 'Split After Each Surface' selected, and 'Split After Surface #' set to 1. The 'OK' button is highlighted. In the background, the 'Optical Setup View #15 (LPIA)' shows a 'Lens System' component (Etalon) being substituted with individual surfaces: 'Plane Wave' (0), 'Etalon (Surface #1)' (4), 'Etalon (Surface #2)' (5), and 'Camera Detector' (600). A 'Plane Surface' (6) is also added at an 'Undefined Position'. A 'Ray Tracing System Analyzer' (800) is also present. A 'Filter by...' window is open, showing 'Plane Surface' selected under 'Components'. A red box highlights the 'Plane Surface' component in the 'Filter by...' window.

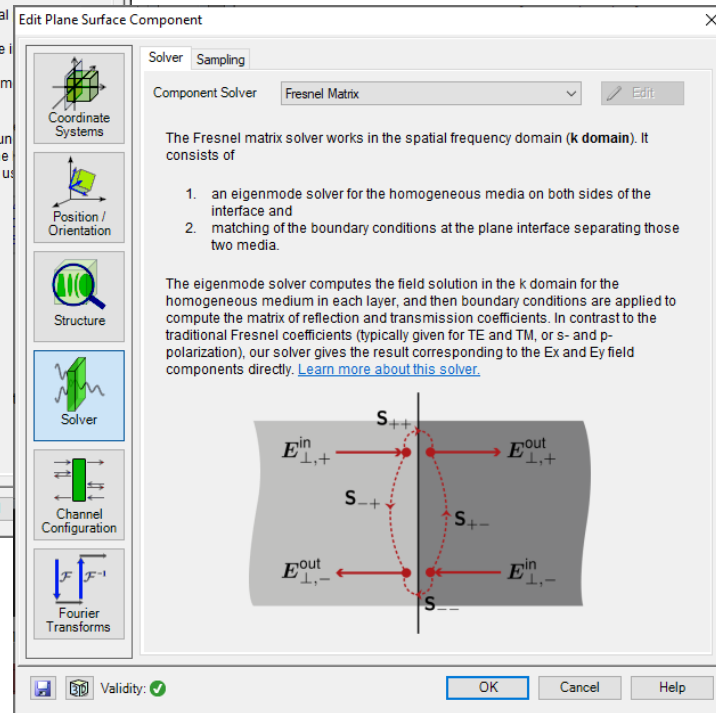
How to modify your *Optical Setup* if you have imported a *Lens System* component in VirtualLab Fusion, but you would like to use the Fresnel Matrix solver for a plane surface inside that system?

Do not forget to include and configure the *Plane Surface* component (inclination, material behind surface, etc.)

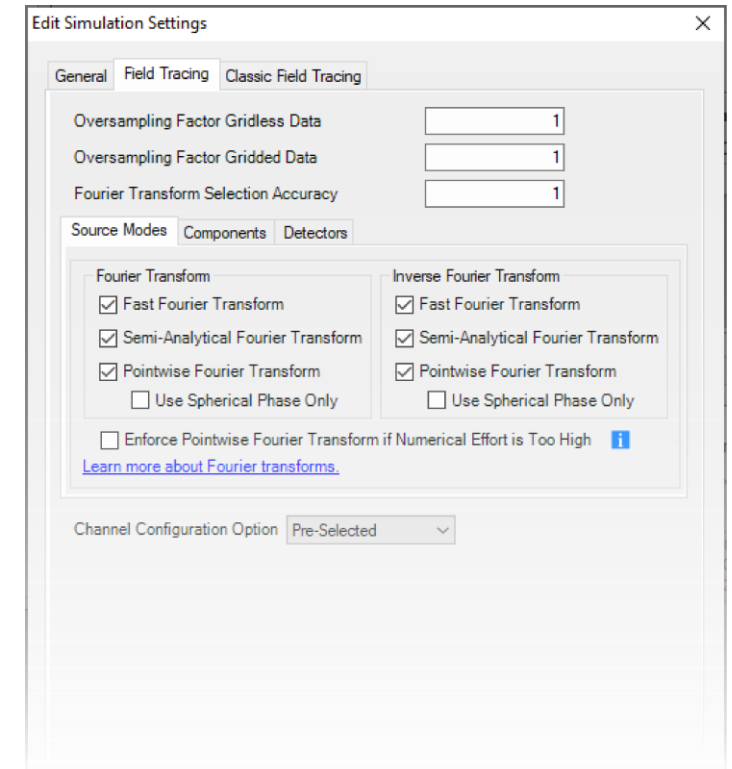
# Peek into VirtualLab Fusion



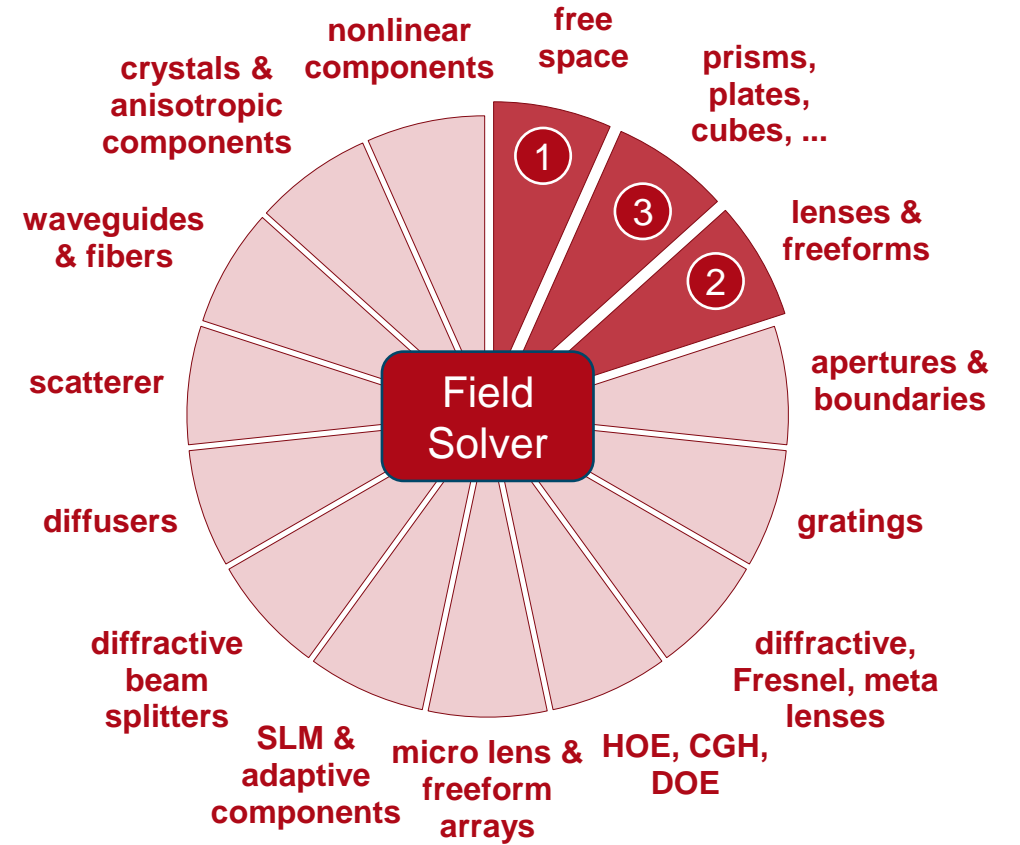
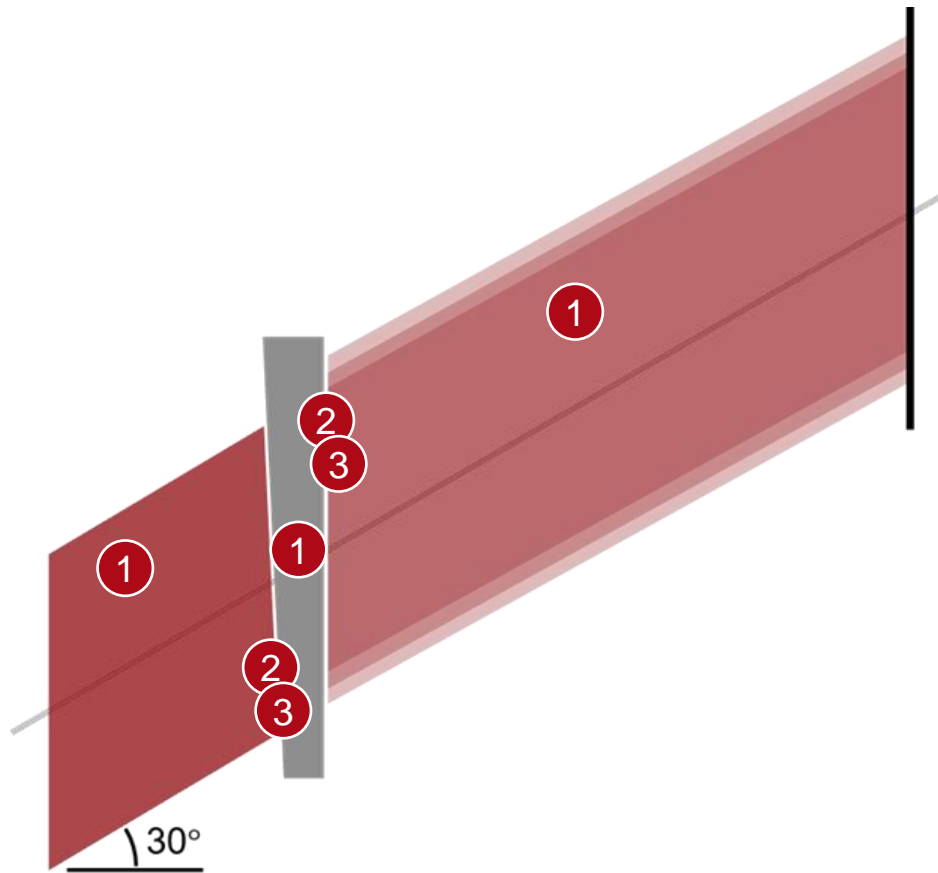
solver information panel in components



## catalog of Fourier transform algorithms



# VirtualLab Fusion Technologies



# Document Information

title	Components, Solvers and Fourier Domains – Plane Surface
document code	MISC.0090
version	1.0
edition	VirtualLab Fusion Basic
software version	2020.2 (Build 2.22)
category	Feature Use Case
further reading	<ul style="list-style-type: none"><li>- <a href="#">Modeling of Etalon with Planar or Curved Surfaces</a></li><li>- <a href="#">Fourier Transform Settings – Discussion at Examples</a></li><li>- <a href="#">The Local Plane Interface Approximation (LPIA)</a></li><li>- <a href="#">The Fresnel Matrix</a></li><li>- <a href="#">Channel Configuration for Surfaces and Grating Regions</a></li></ul>