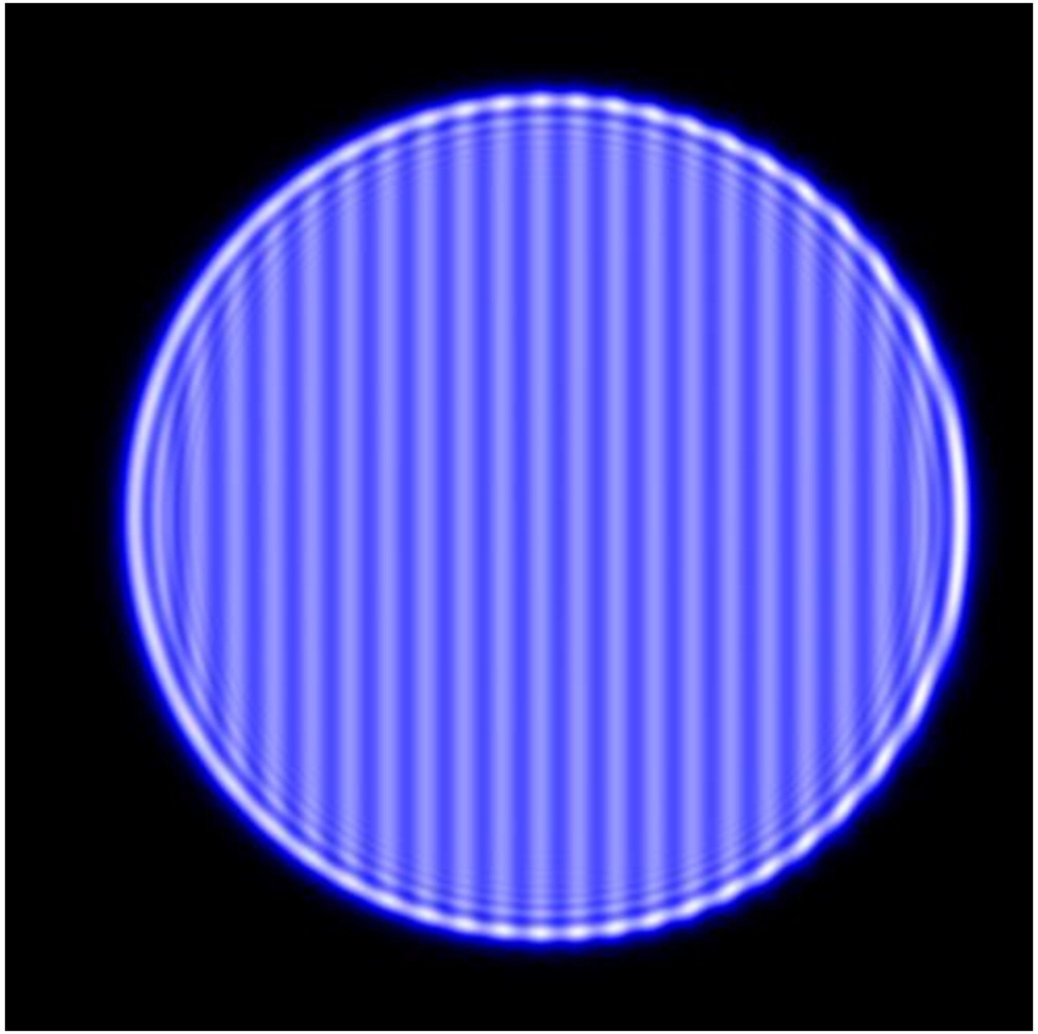
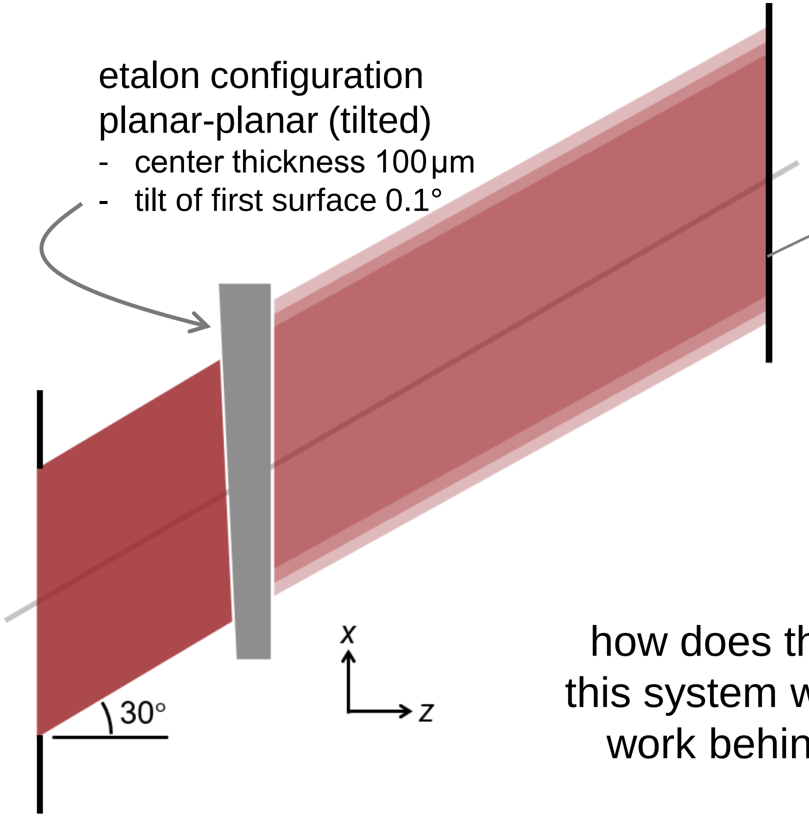
Components, Solvers and Fourier Domains – Plane Surface

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.

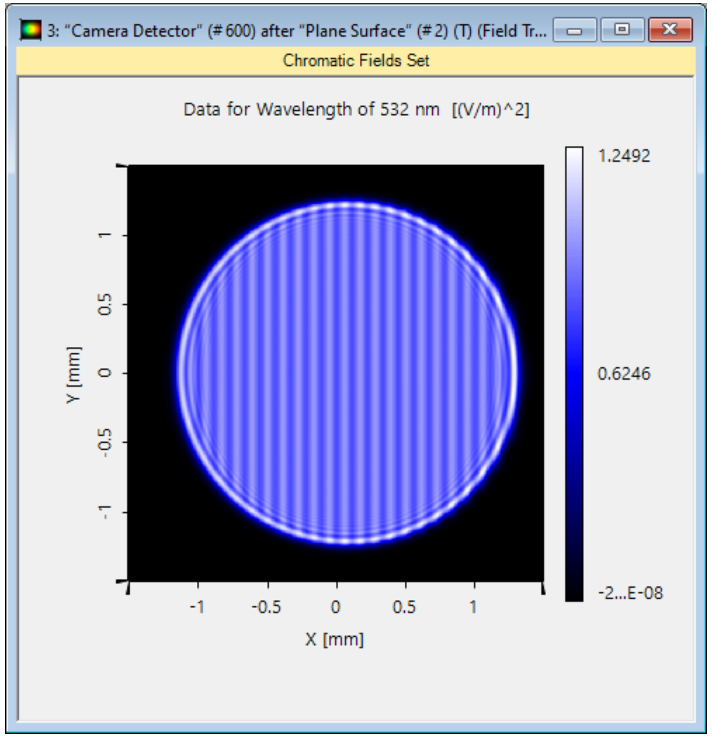
Modeling Task



etalon configuration
planar-planar (tilted)
- center thickness 100 µm
- tilt of first surface 0.1°

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

how does the simulation of this system with **field tracing** work behind the scenes?

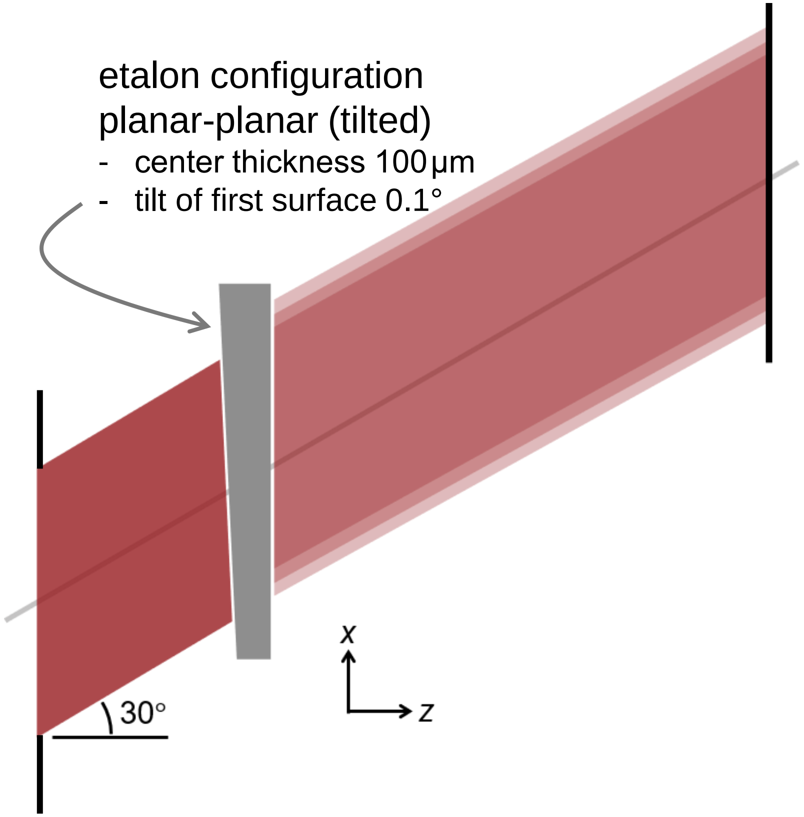


see the full Application Use Case:
"Modeling of Etalon with Planar or Curved Surfaces"

Connecting Solvers!

etalon configuration
planar-planar (tilted)

- center thickness 100 μm
- tilt of first surface 0.1°

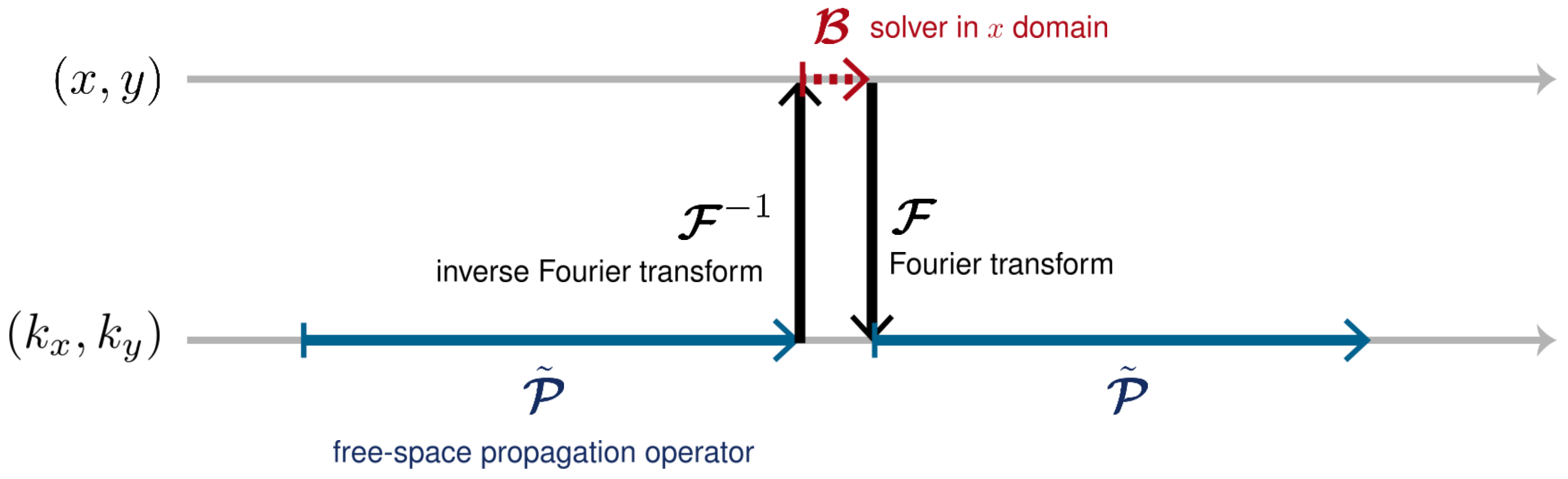


source

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

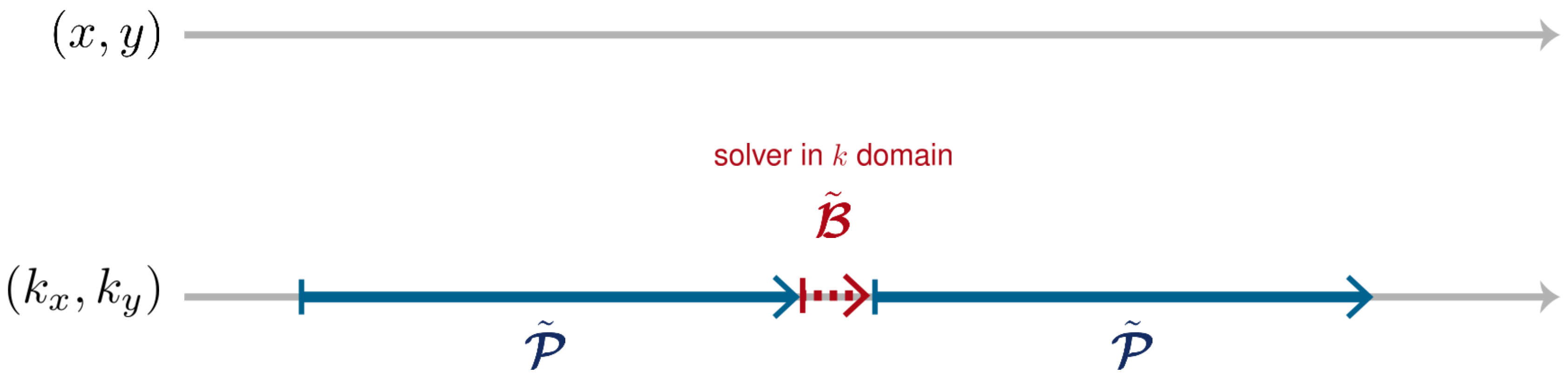
- Field tracing connects electromagnetic field solvers!
- An optical system is broken up into its different constituent parts.
- Each part is modeled with a specific field solver.
- In general, these solvers can be implemented in the space (x) domain or in the spatial-frequency (k) domain.
- **VirtualLab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



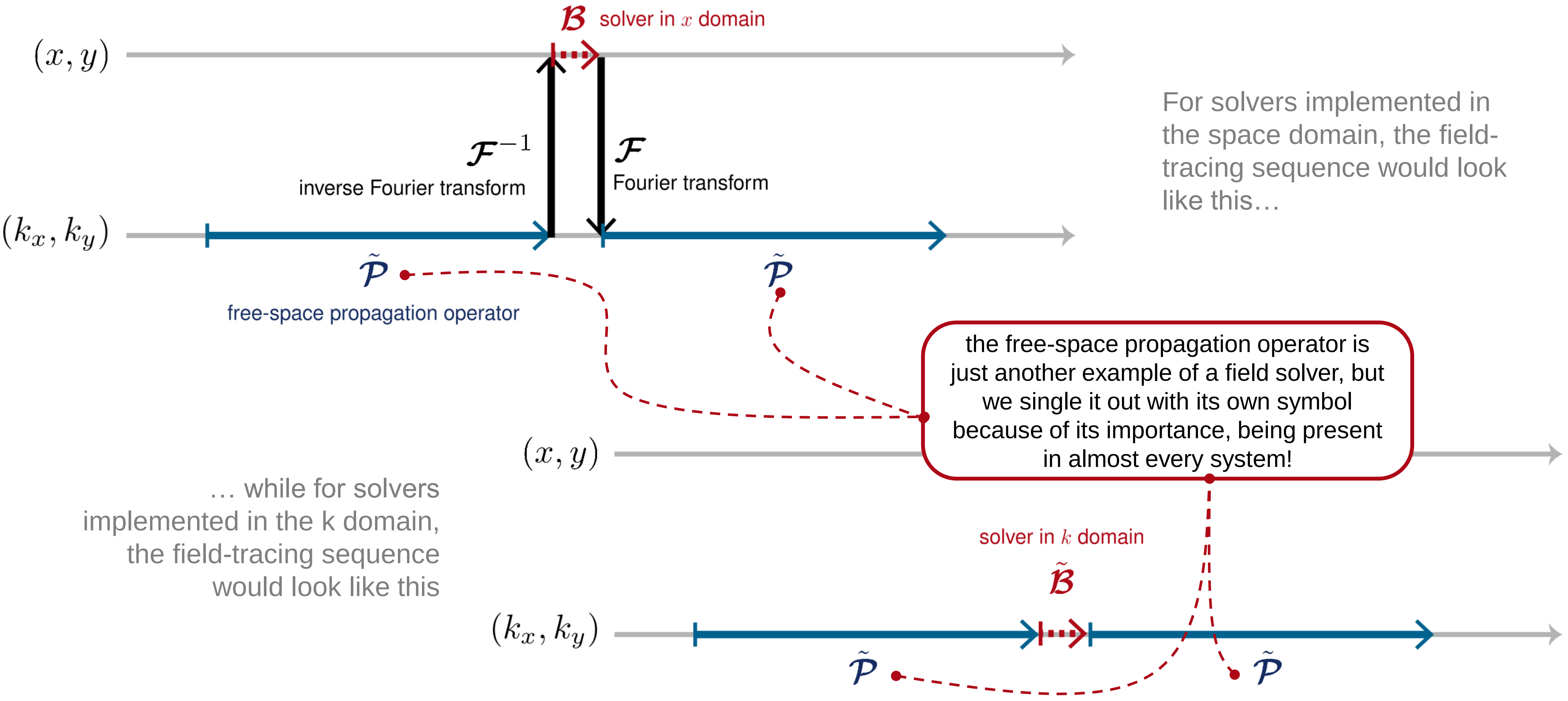
For solvers implemented in the space domain, the field-tracing sequence would look like this…

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



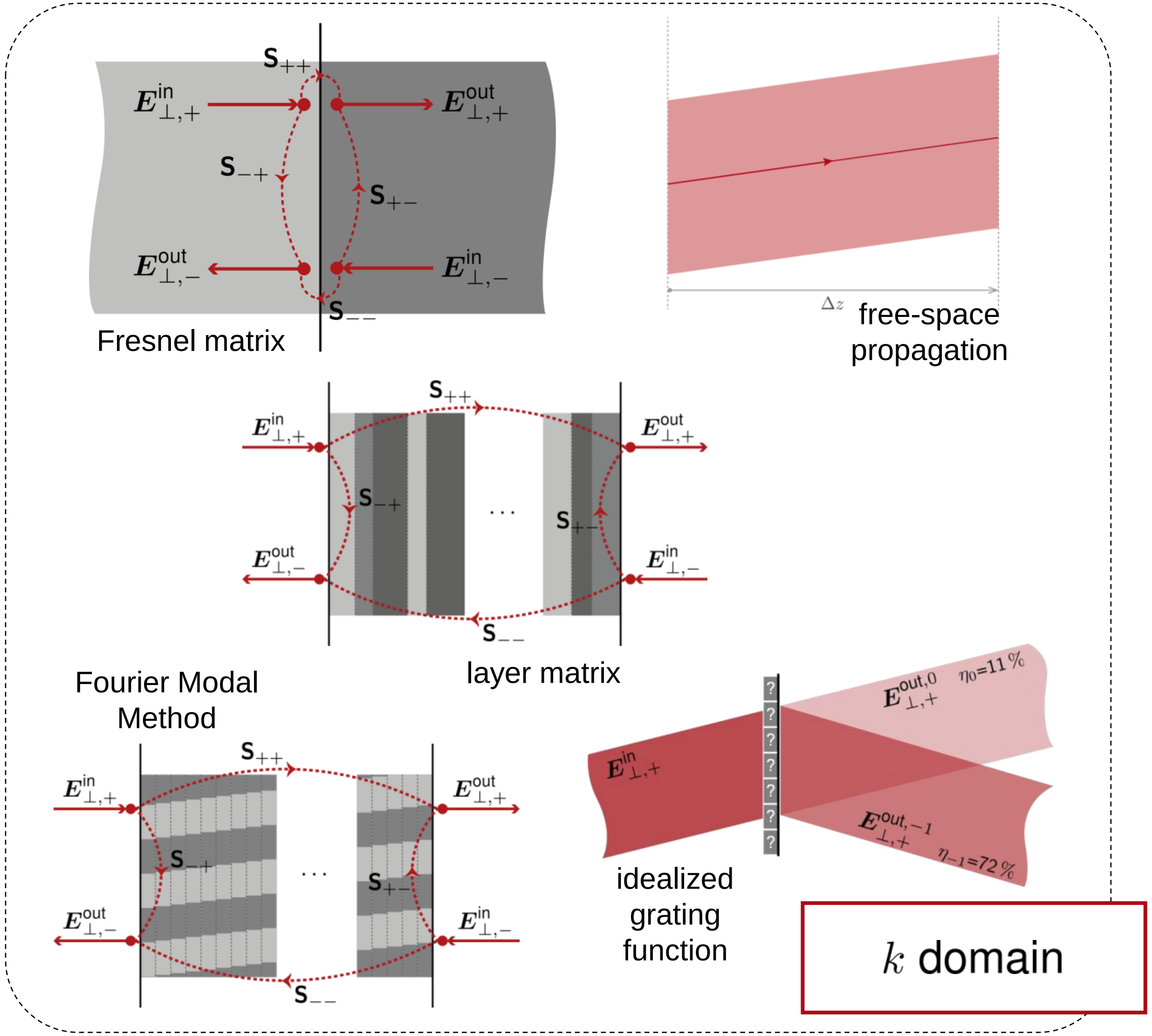
Domain of Application of the Solvers

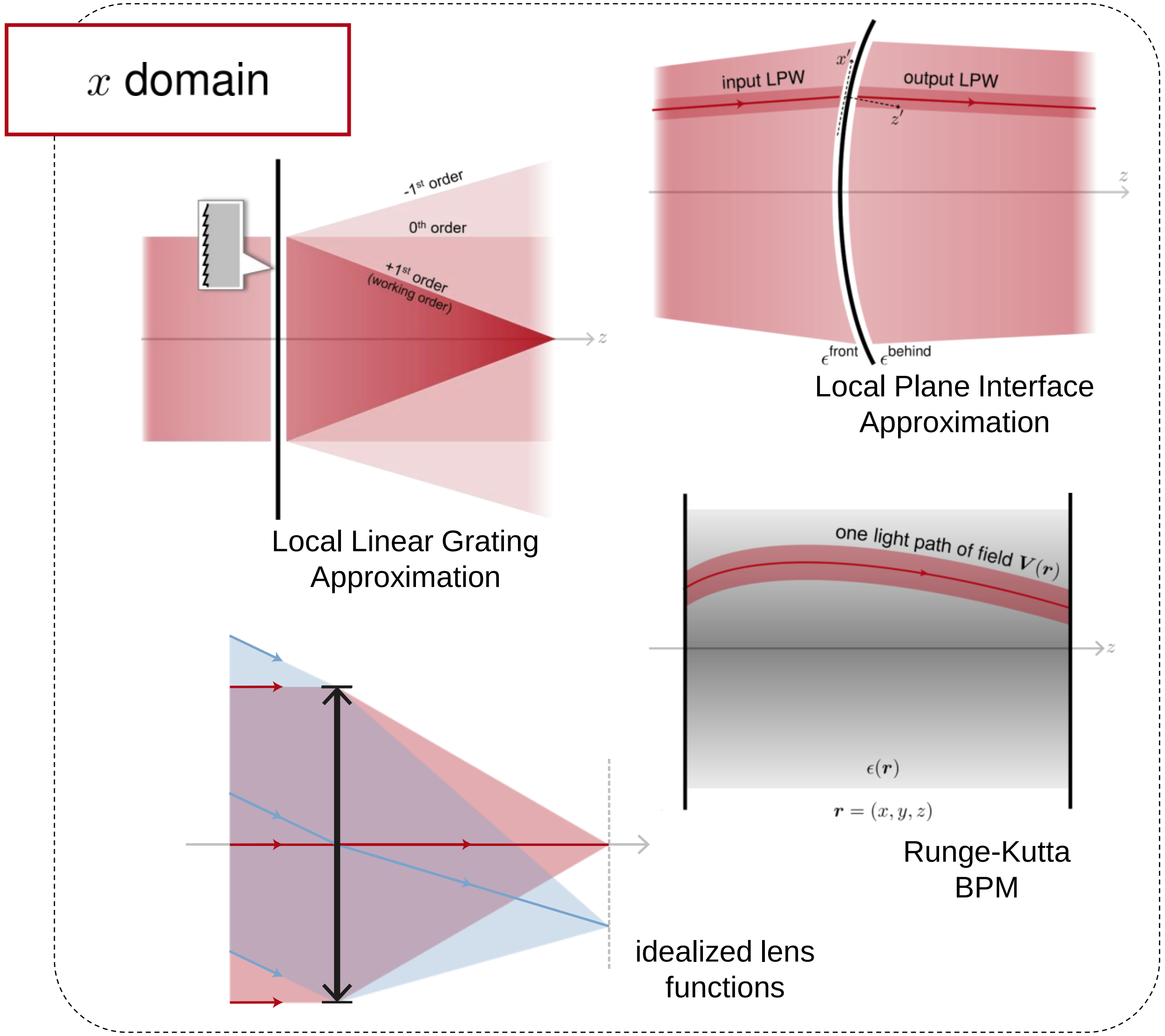
For solvers implemented in the space domain, the field-tracing sequence would look like this…



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

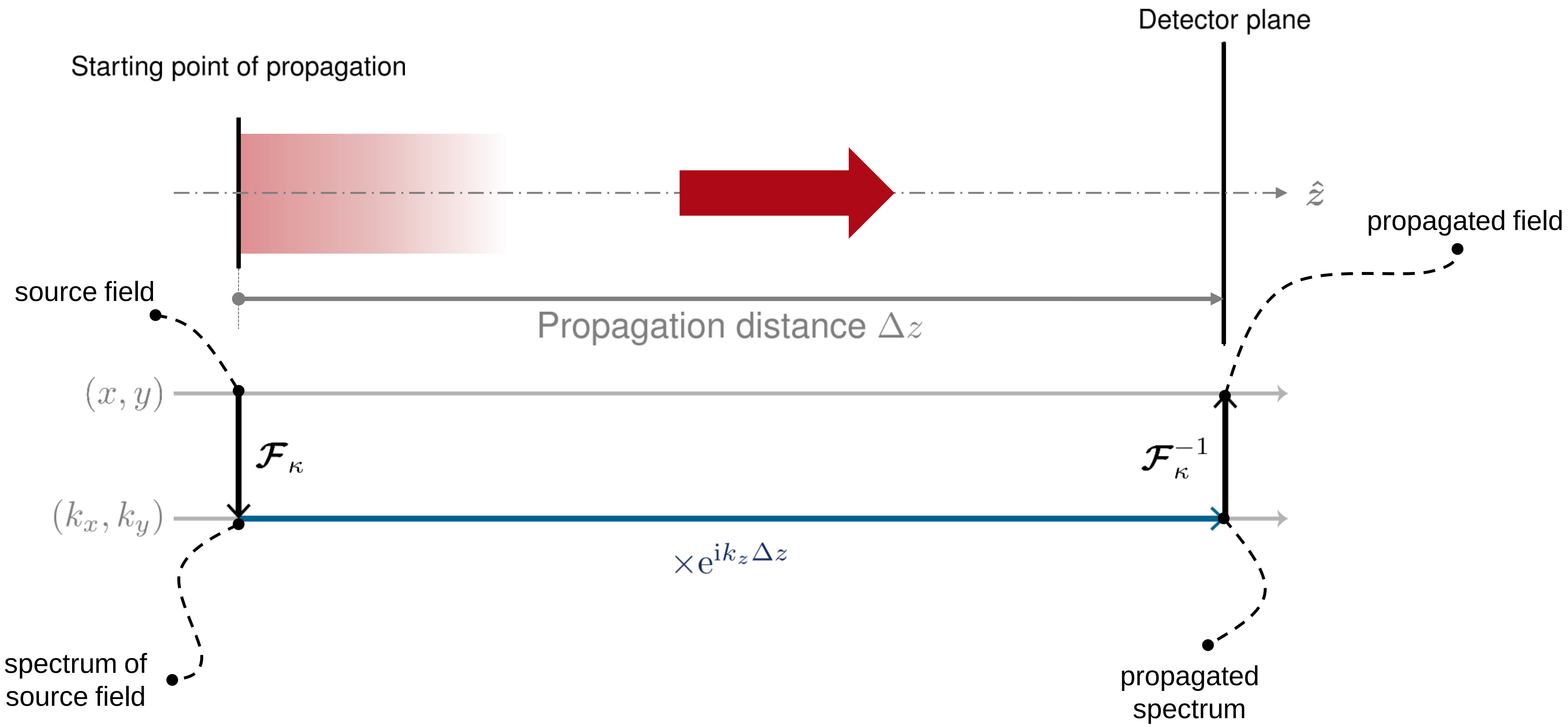
Some Solvers and Their Domains



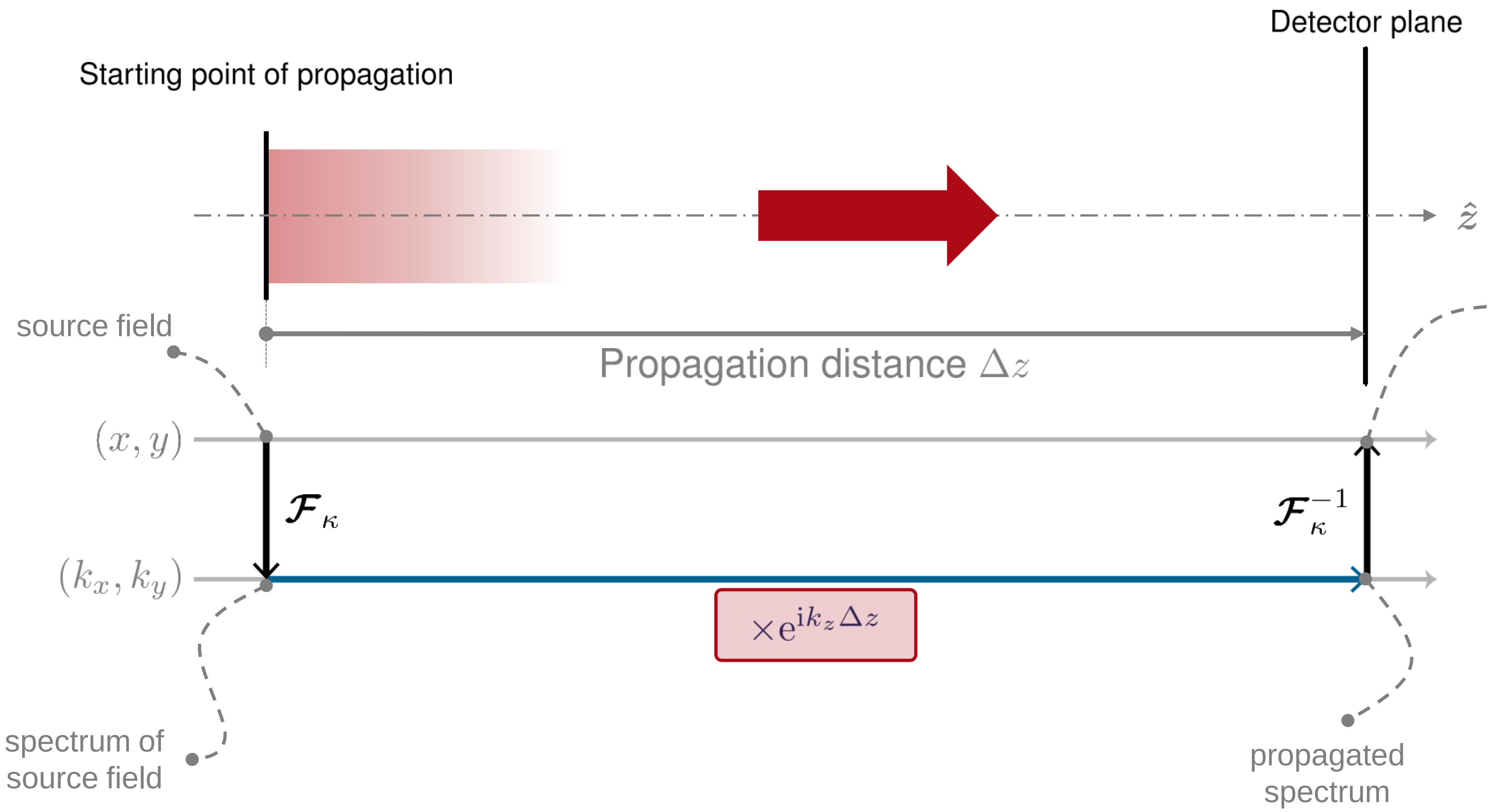


Hint: click on the logos for additional documentation on the solvers!

Free-Space Propagation

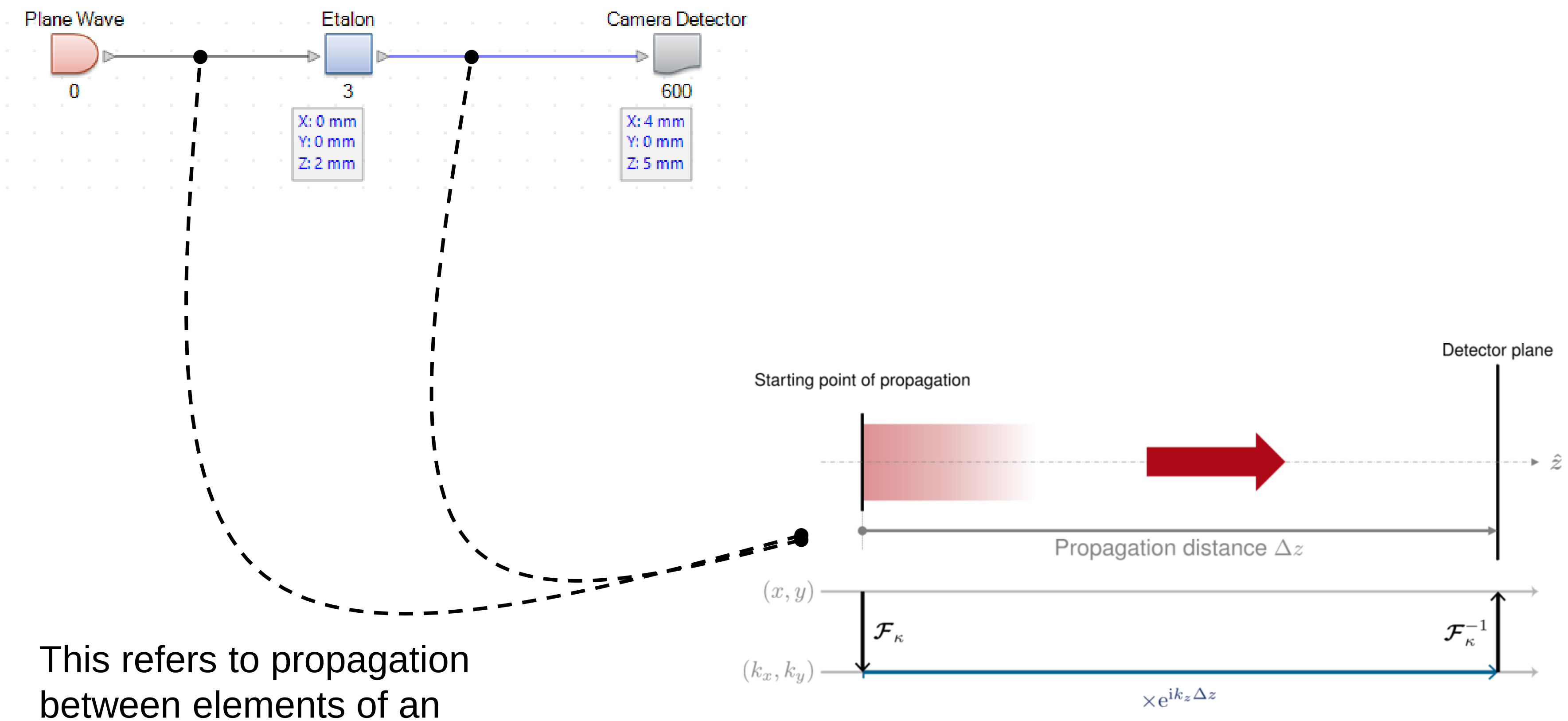


Free-Space Propagation



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

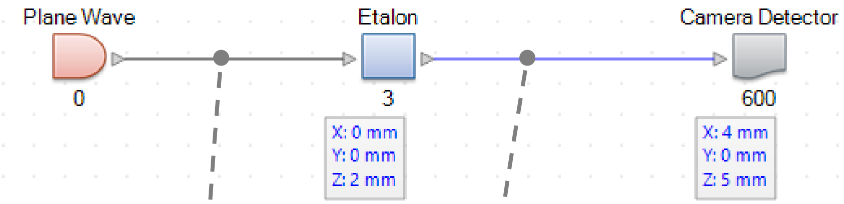
Free-Space Propagation



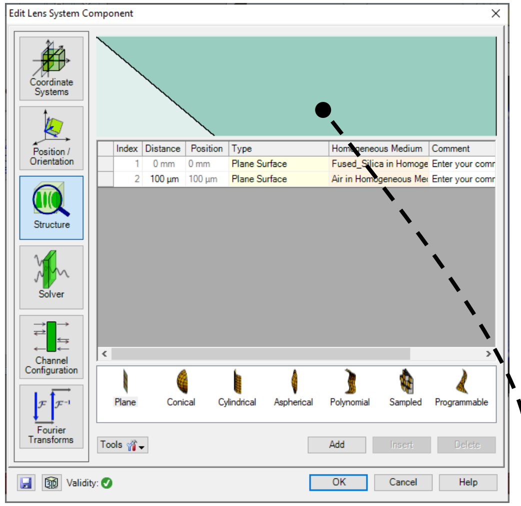
This refers to propagation between elements of an optical system…

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

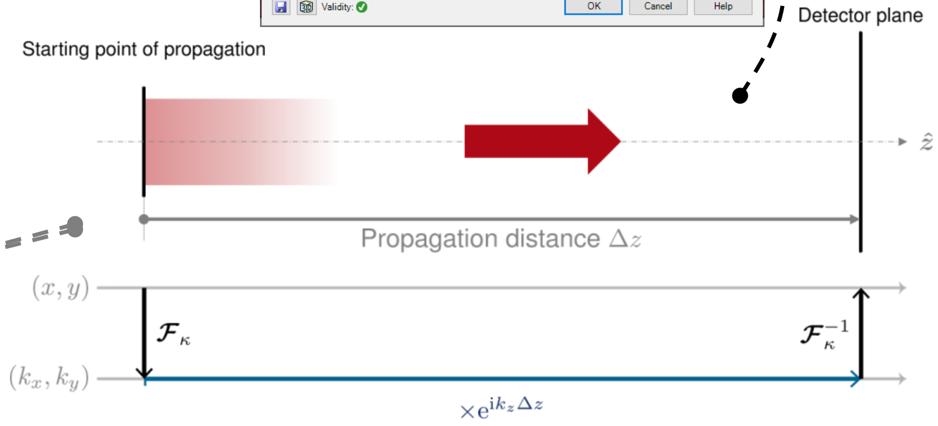
Free-Space Propagation



This refers to propagation between elements of an optical system…



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



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

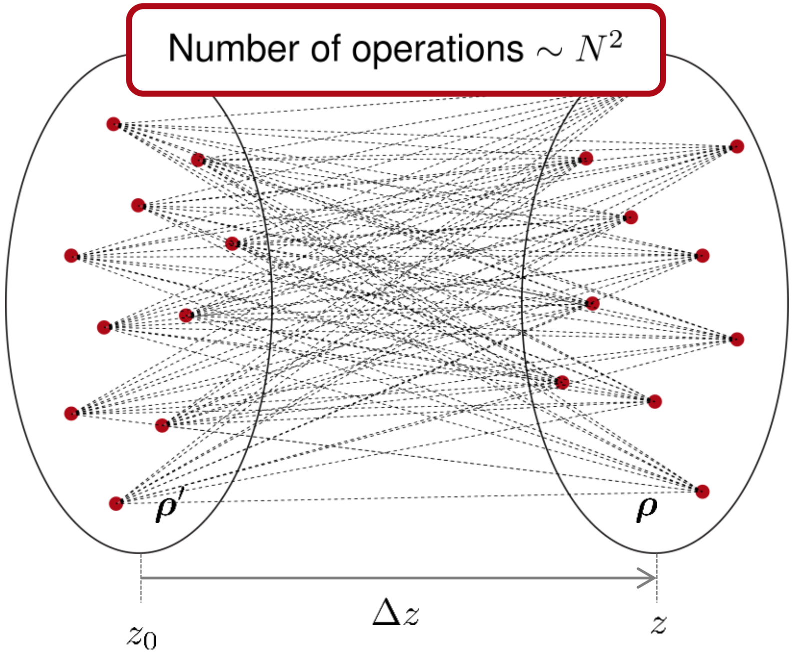
Free-Space Propagation: Why K Domain?

Space domain

Rayleigh-Sommerfeld integral:

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

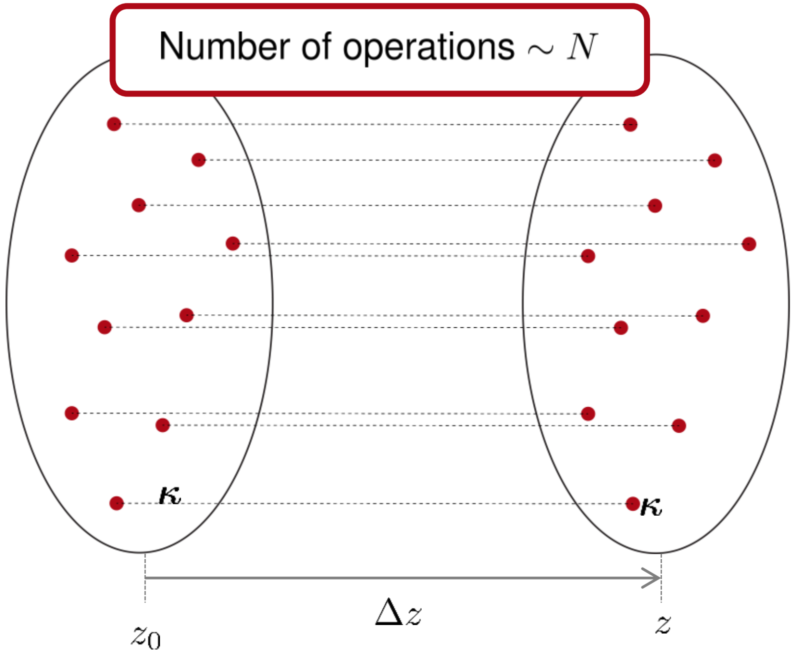
with $R = \sqrt{(x-x')^2 + (y-y')^2 + (\Delta z)^2}$



Spatial-frequency domain

Plane-wave propagation operator:

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



N: number of samples

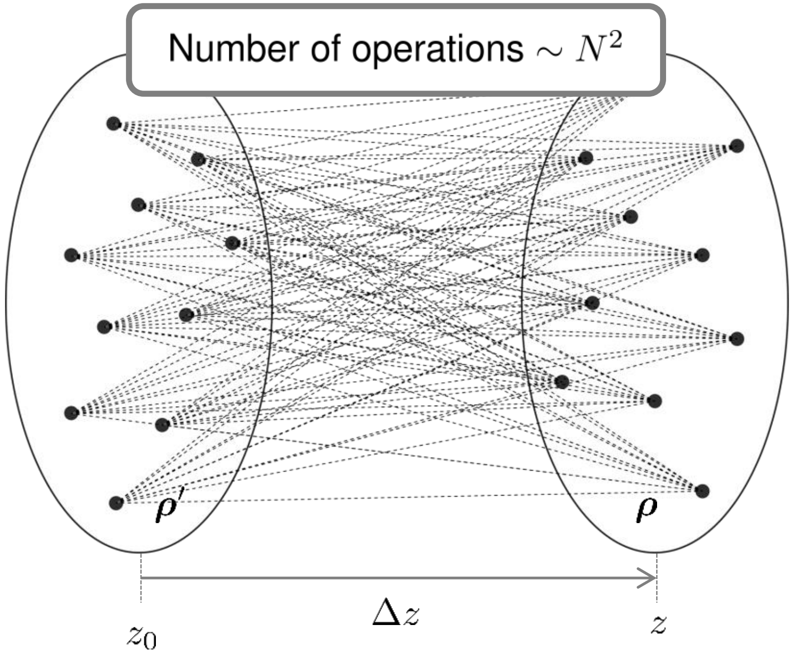
Free-Space Propagation: Why K Domain?

Space domain

Rayleigh-Sommerfeld integral:

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

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

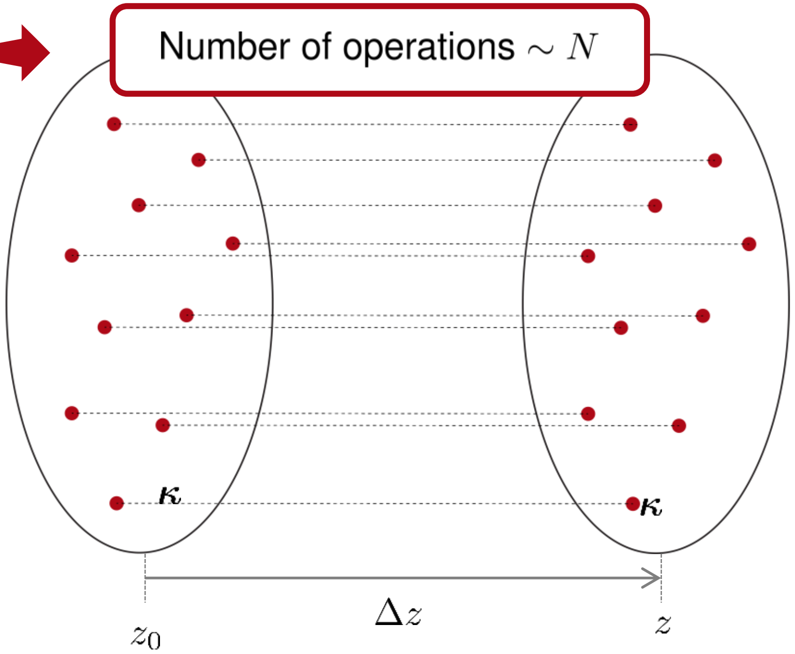


Spatial-frequency domain

Plane-wave propagation operator:

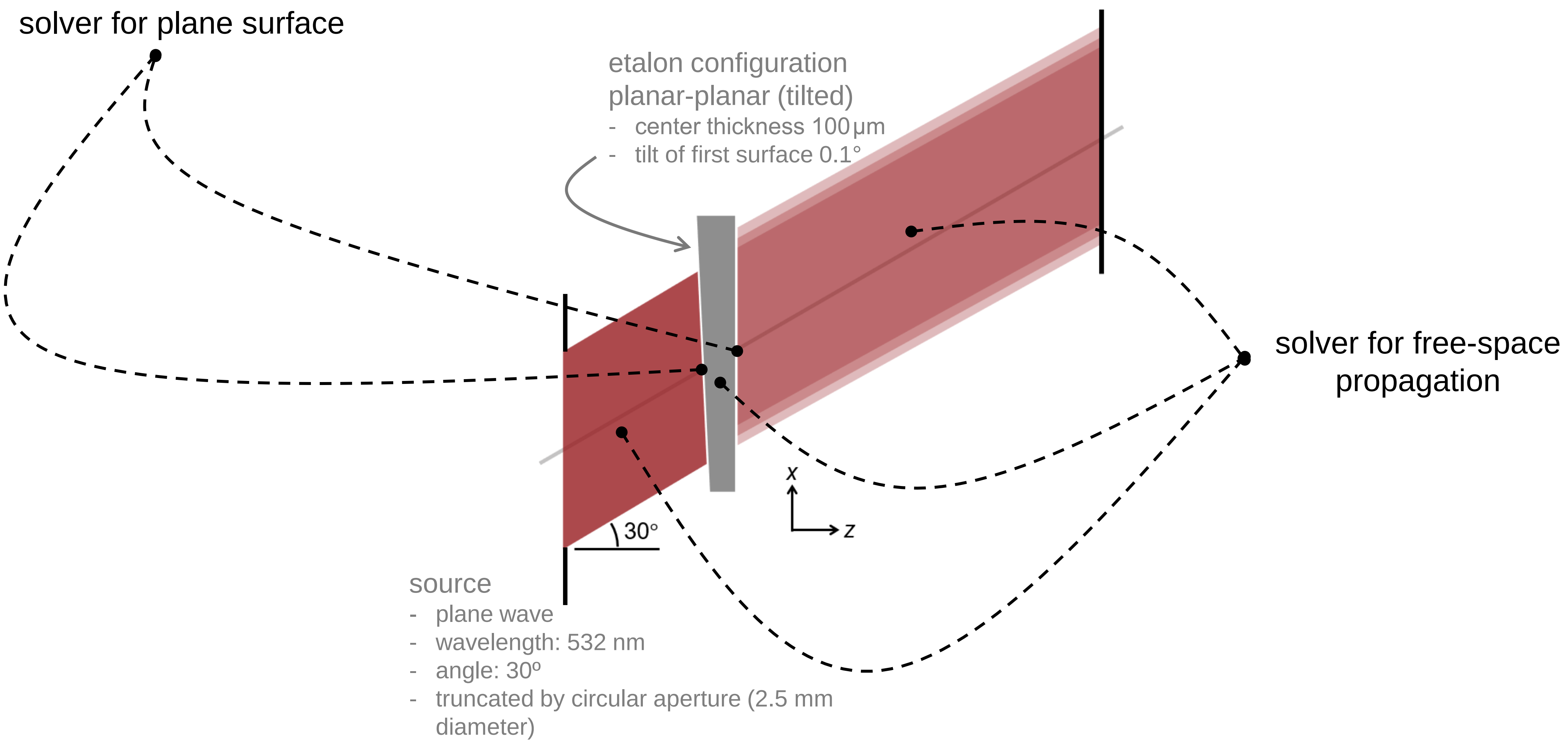
$$\tilde{V}_\ell^{\text{out}}(\boldsymbol{\kappa}, z) = \tilde{V}_\ell^{\text{in}}(\boldsymbol{\kappa}, z_0) \times \mathrm{e}^{\mathrm{i}k_z(\kappa)\Delta z}$$

Pointwise operator!



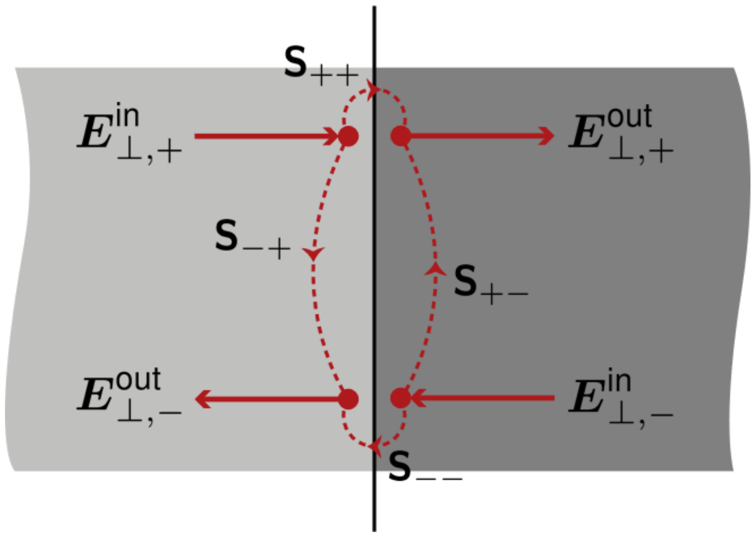
N: number of samples

What Solvers Do We Need in This System?



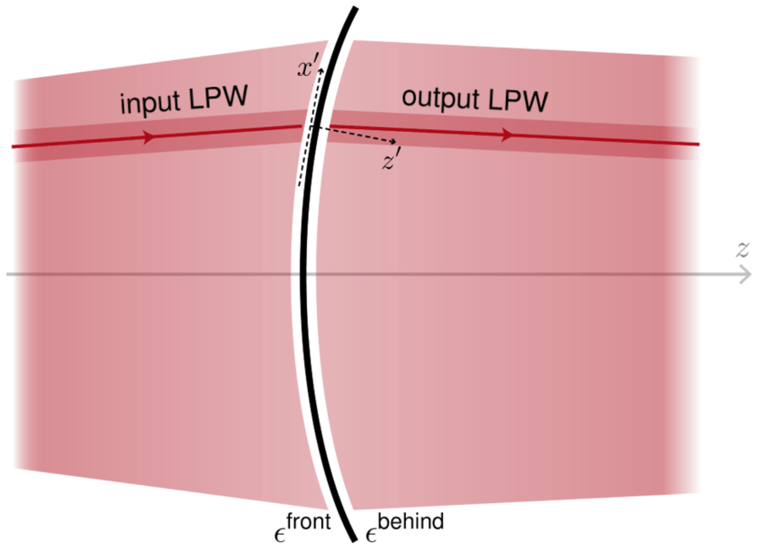
Possible Field Solvers for Plane Surfaces

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



- Implemented in *Plane Surface* component

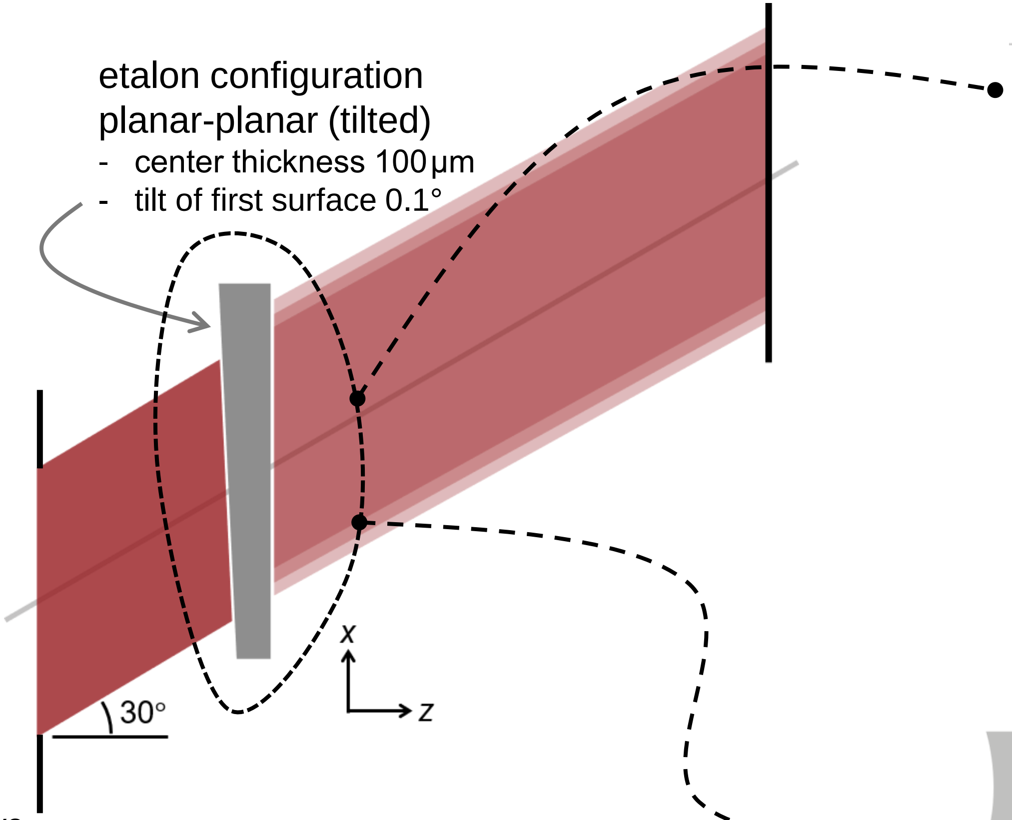
- As a curved surface without curvature ➔ **Local Plane Interface Approximation (LPIA)**
- Solver in **x domain**



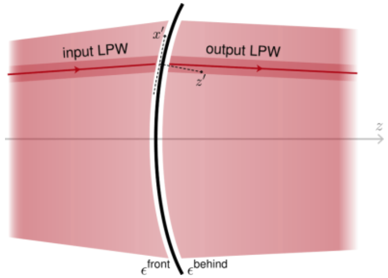
- Implemented in *Lens System*, *Curved Surface*, *Spherical Lens* and *Light Guide* components, among others.

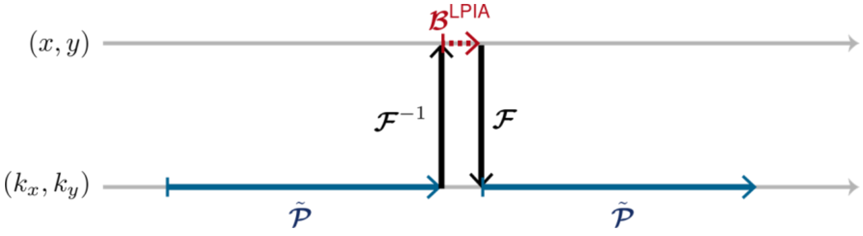
Possible Field Solvers for Plane Surfaces

etalon configuration
planar-planar (tilted)
- center thickness 100 µm
- tilt of first surface 0.1°



LPIA

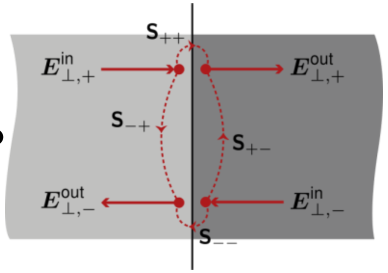


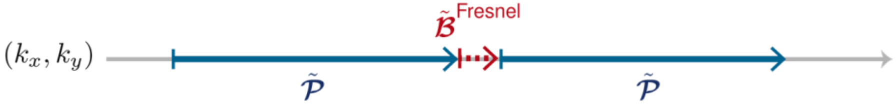


per individual interaction of field with plane surface

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

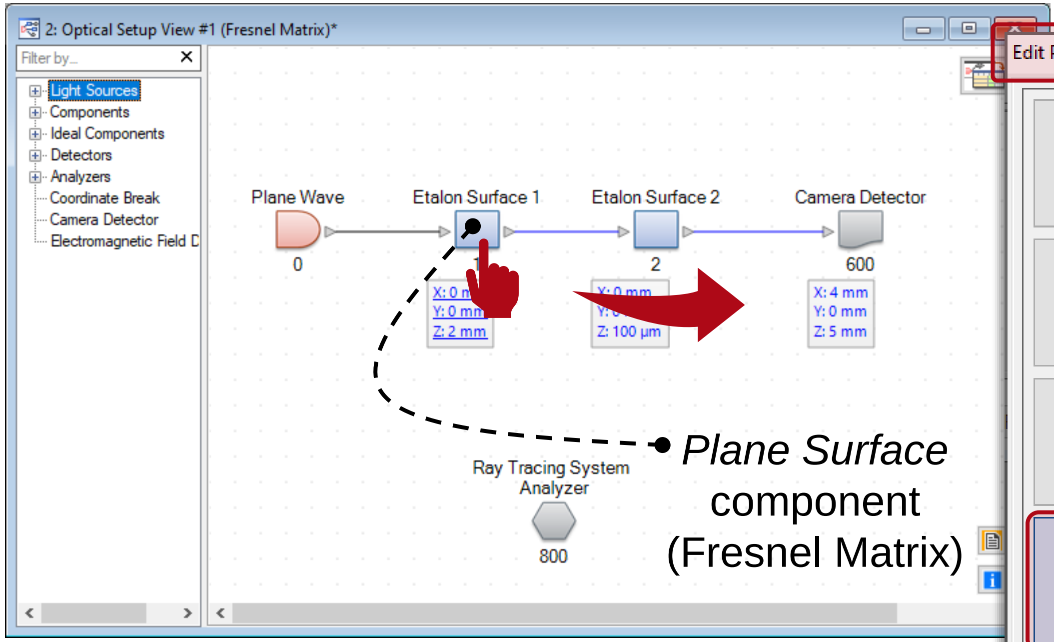
Fresnel matrix

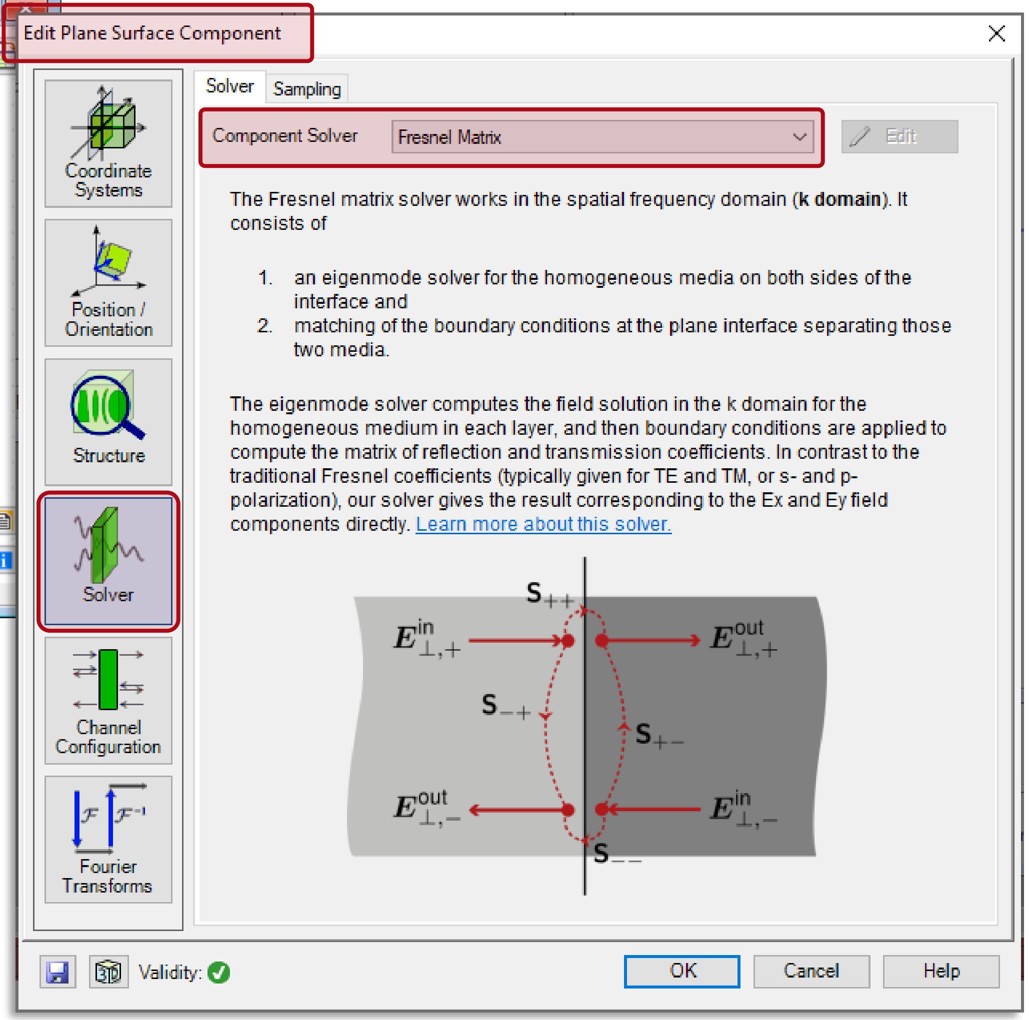




per individual interaction of field with plane surface

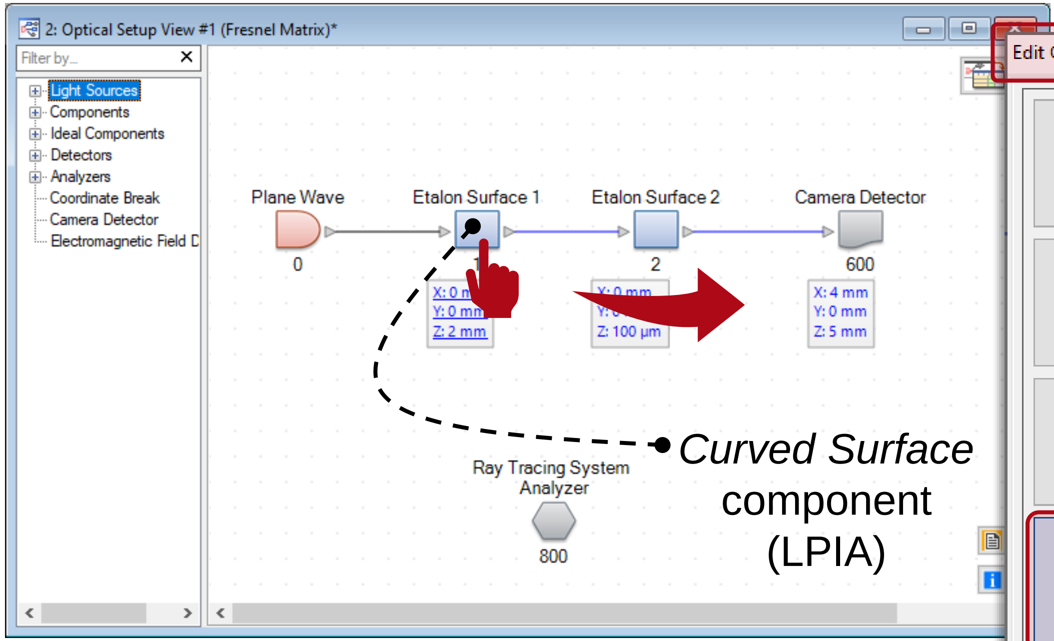
Possible Field Solvers for Plane Surfaces



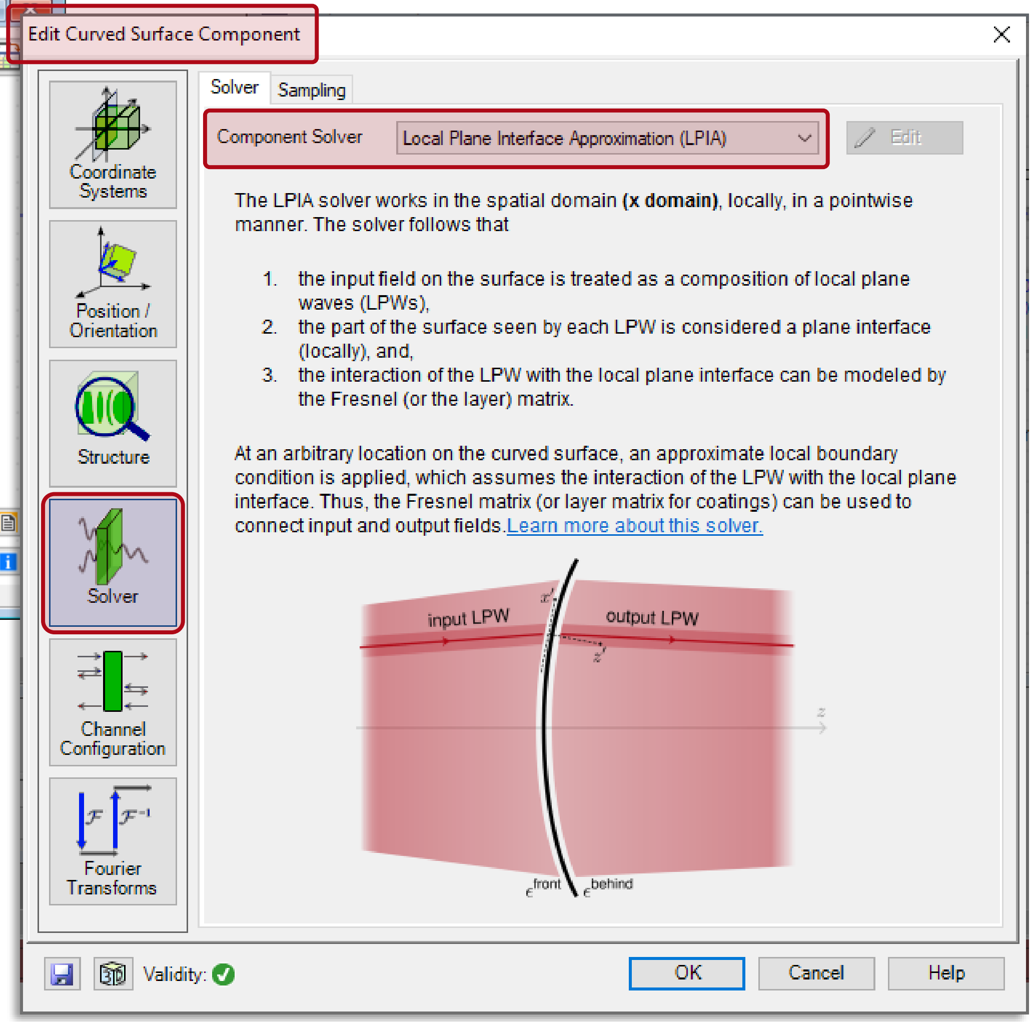


In VirtualLab Fusion, including a certain type of component in your system means, in practice, selecting an **electromagnetic field solver** to model that part of the system

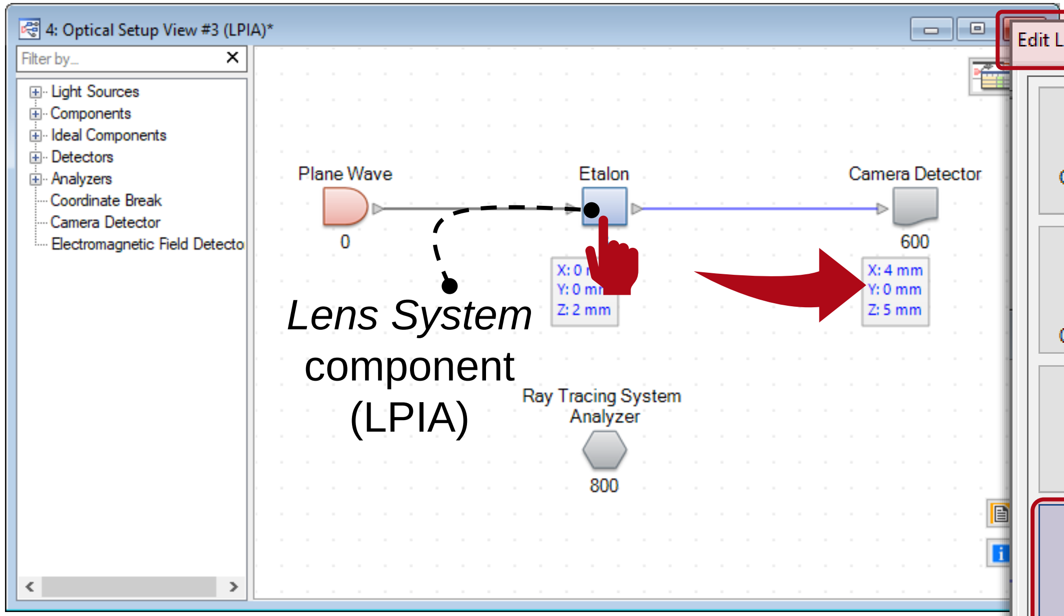
Possible Field Solvers for Plane Surfaces

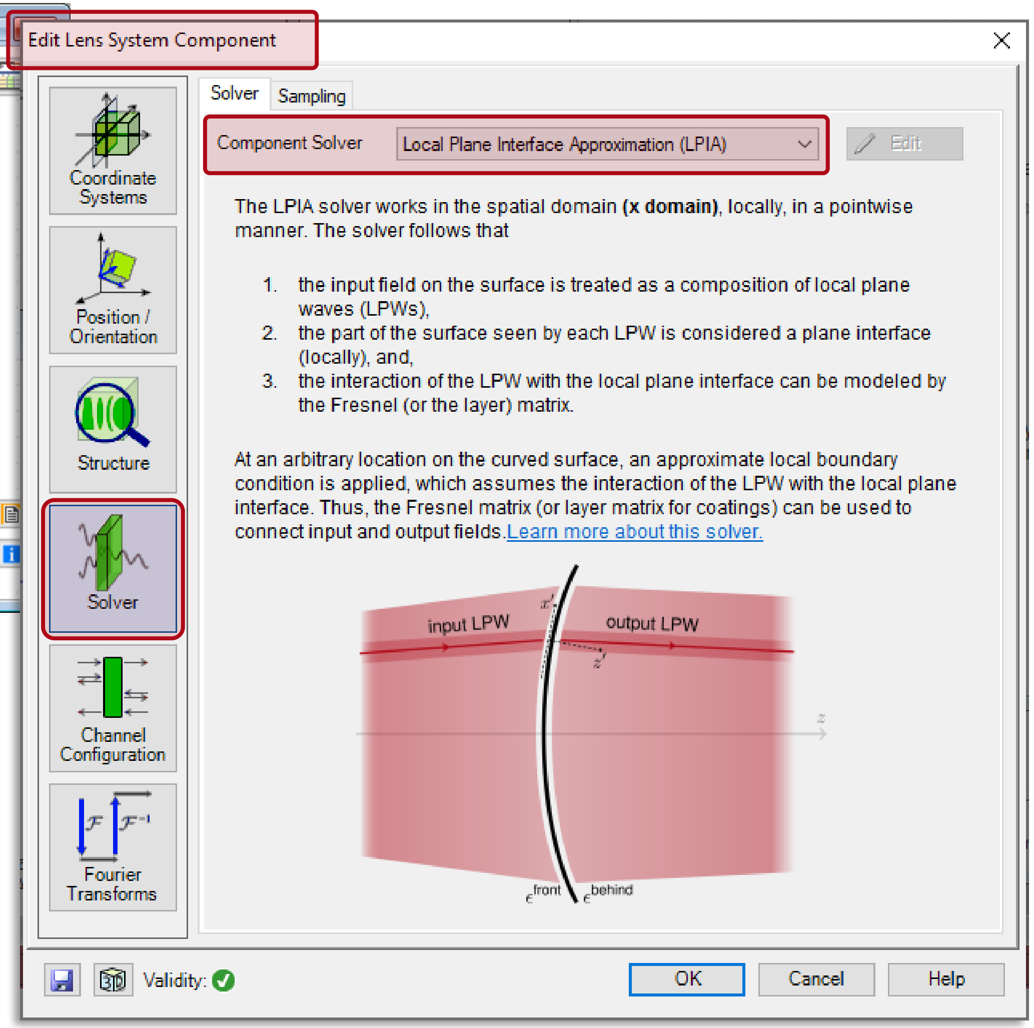


In VirtualLab Fusion, including a certain type of component in your system means, in practice, selecting an **electromagnetic field solver** to model that part of the system



Possible Field Solvers for Plane Surfaces

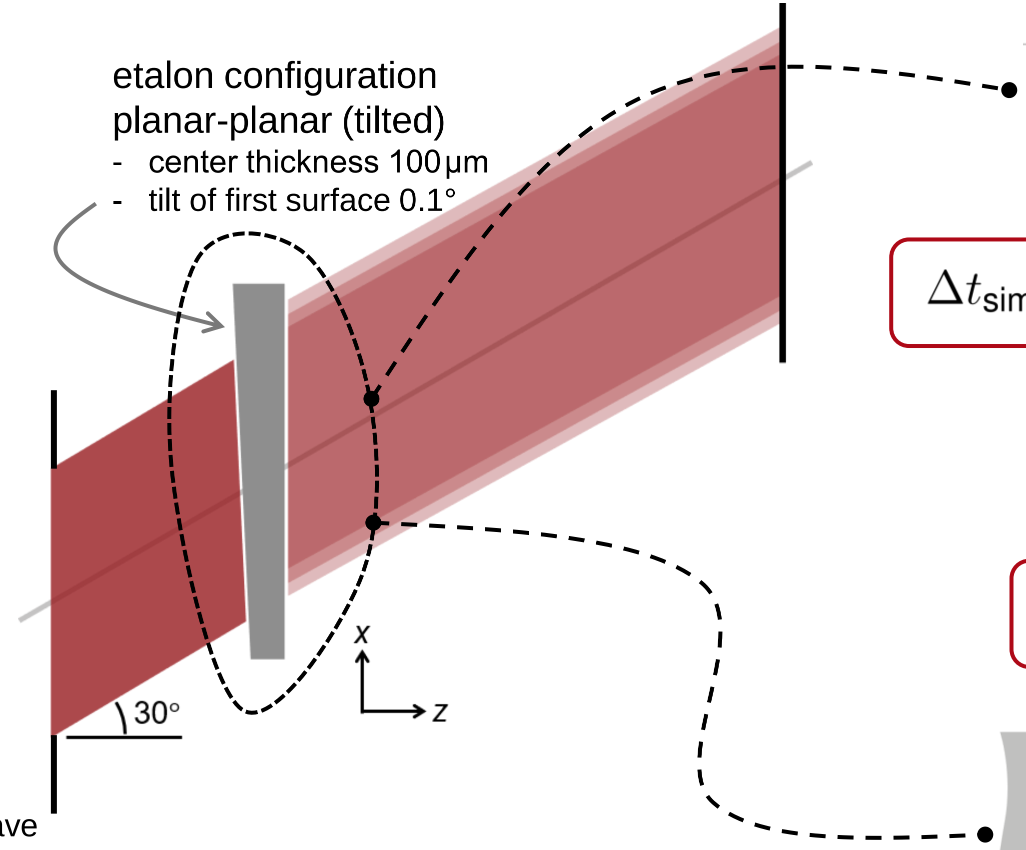




In VirtualLab Fusion, including a certain type of component in your system means, in practice, selecting an **electromagnetic field solver** to model that part of the system

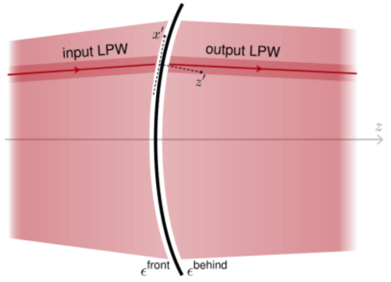
Possible Field Solvers for Plane Surfaces

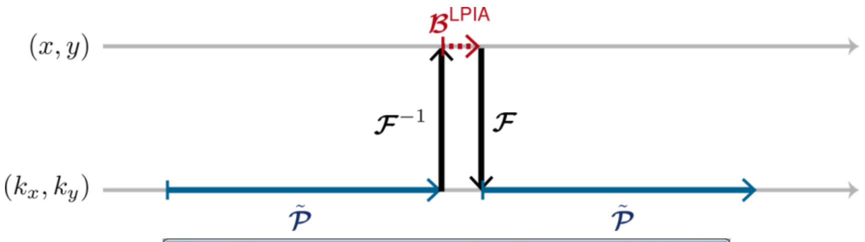
etalon configuration
planar-planar (tilted)
- center thickness 100 µm
- tilt of first surface 0.1°



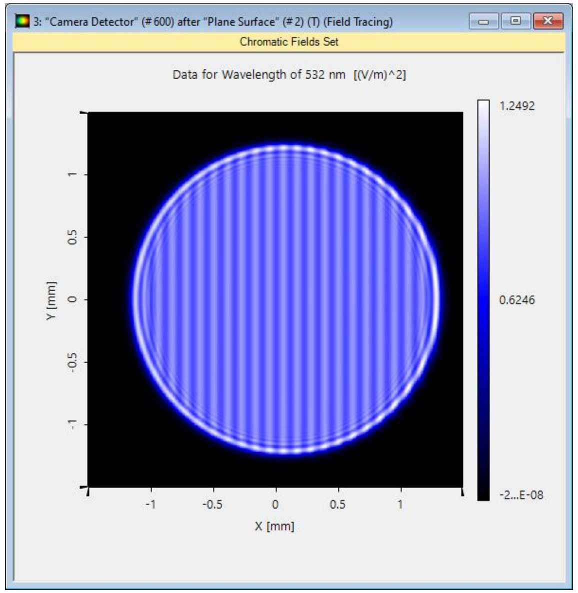
source
- plane wave
- wavelength: 532 nm
- angle: 30°
- truncated by circular aperture (2.5 mm diameter)

LPIA



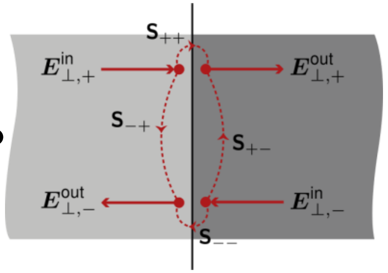


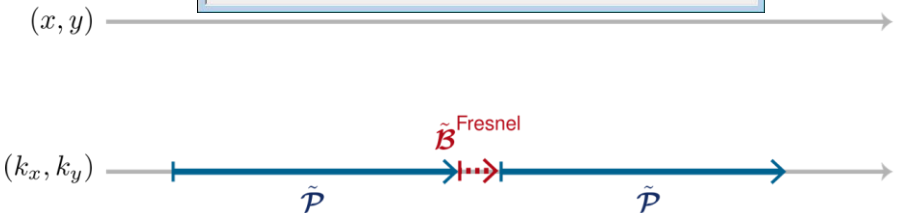
$\Delta t_{\text{simulation}} \sim 1.5\,\text{min}$ (*)



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

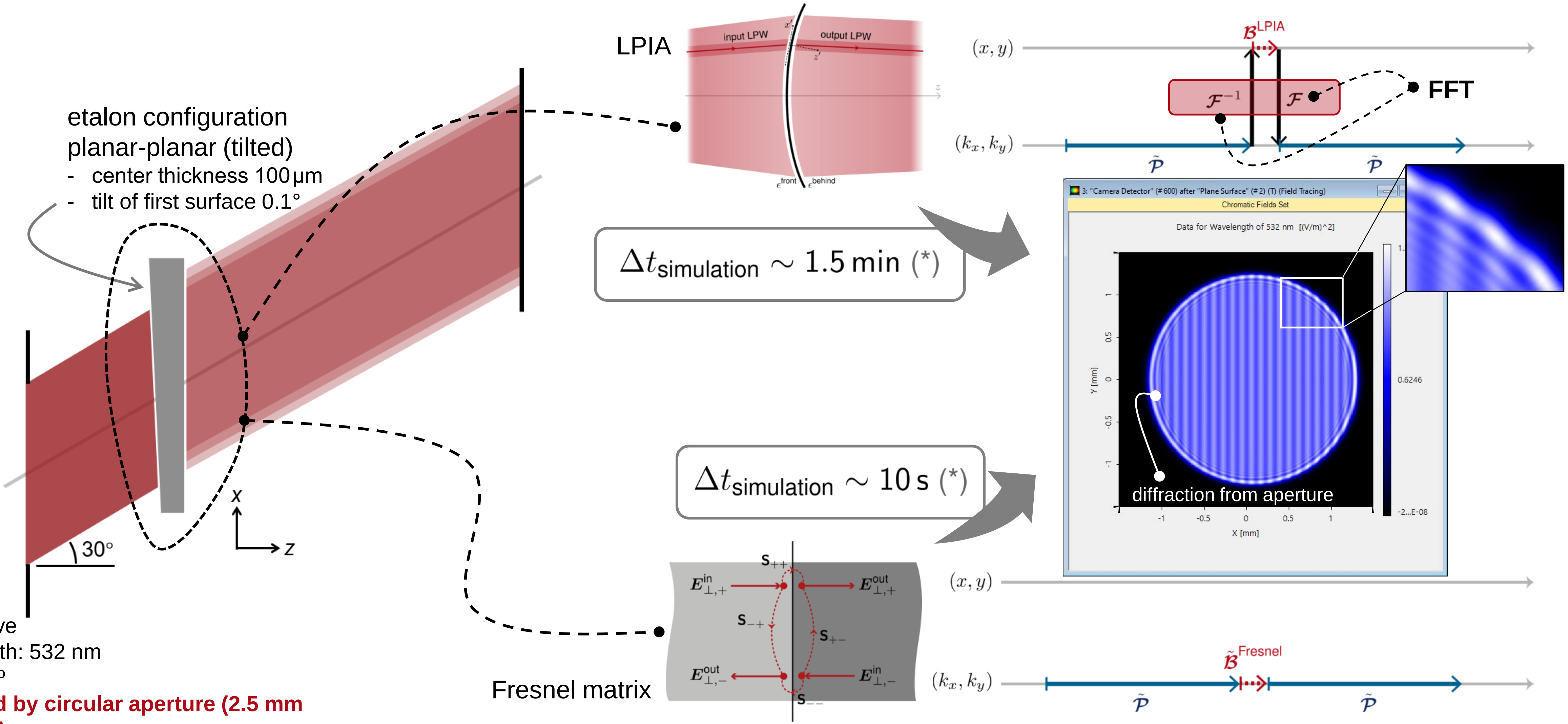
Fresnel matrix





(*) 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

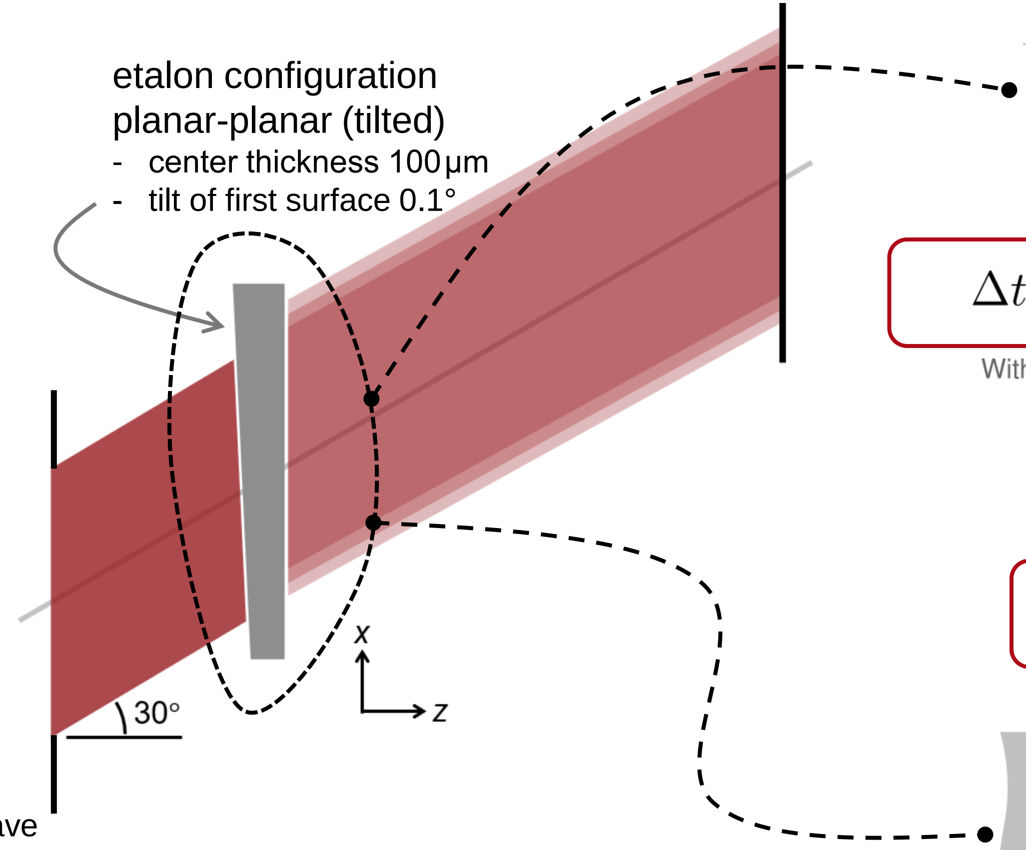


source
- plane wave
- wavelength: 532 nm
- angle: 30º
- **truncated by circular aperture (2.5 mm diameter)**

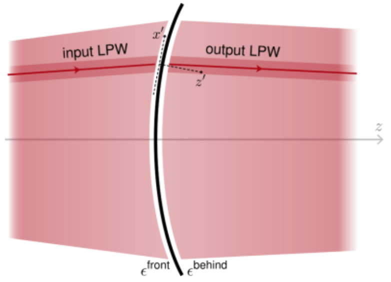
(*) Approximate simulation times on a PC with the following technical specs: processor Intel(R) Core(TM) i7-7700HQ CPU @ 2.80GHz and 32 GB RAM

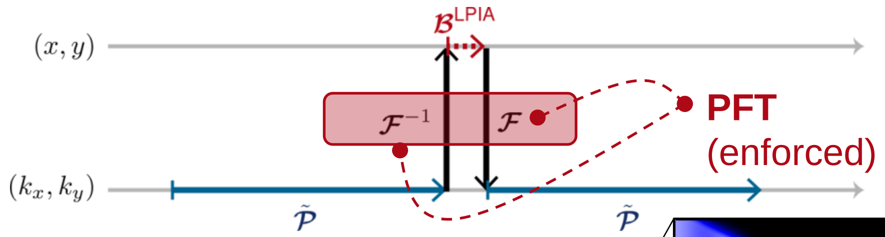
The Importance of the Fourier Transform

etalon configuration
planar-planar (tilted)
- center thickness 100 µm
- tilt of first surface 0.1°



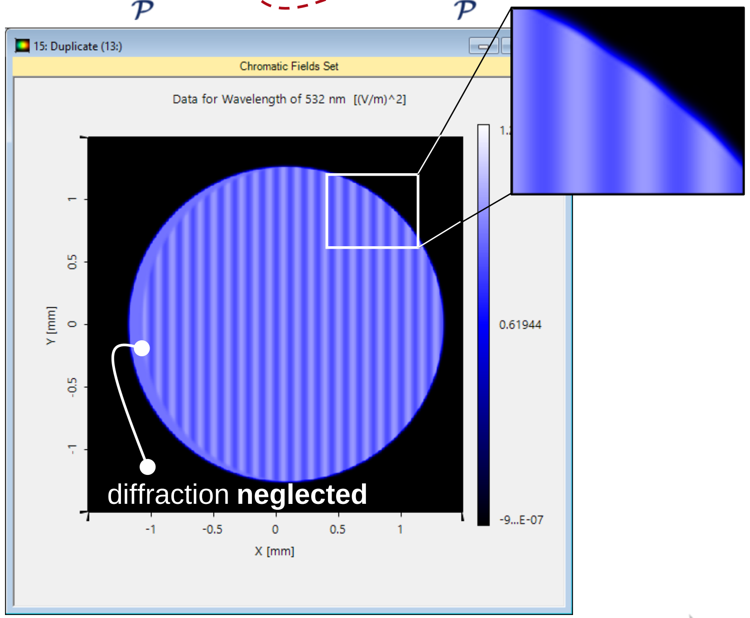
LPIA





$\Delta t_{\text{simulation}} \sim 3\,\text{s}$ (*)

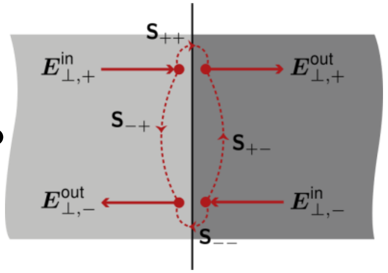
With FFTs $\Delta t_{\text{simulation}} \sim 1.5\,\text{min}$

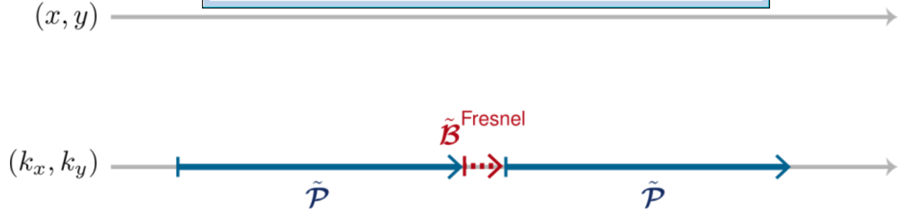


With FFTs $\Delta t_{\text{simulation}} \sim 10\,\text{s}$

$\Delta t_{\text{simulation}} \sim 3\,\text{s}$ (*)

Fresnel matrix



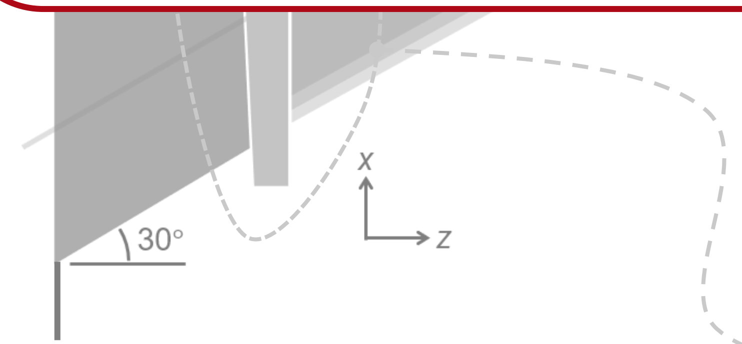


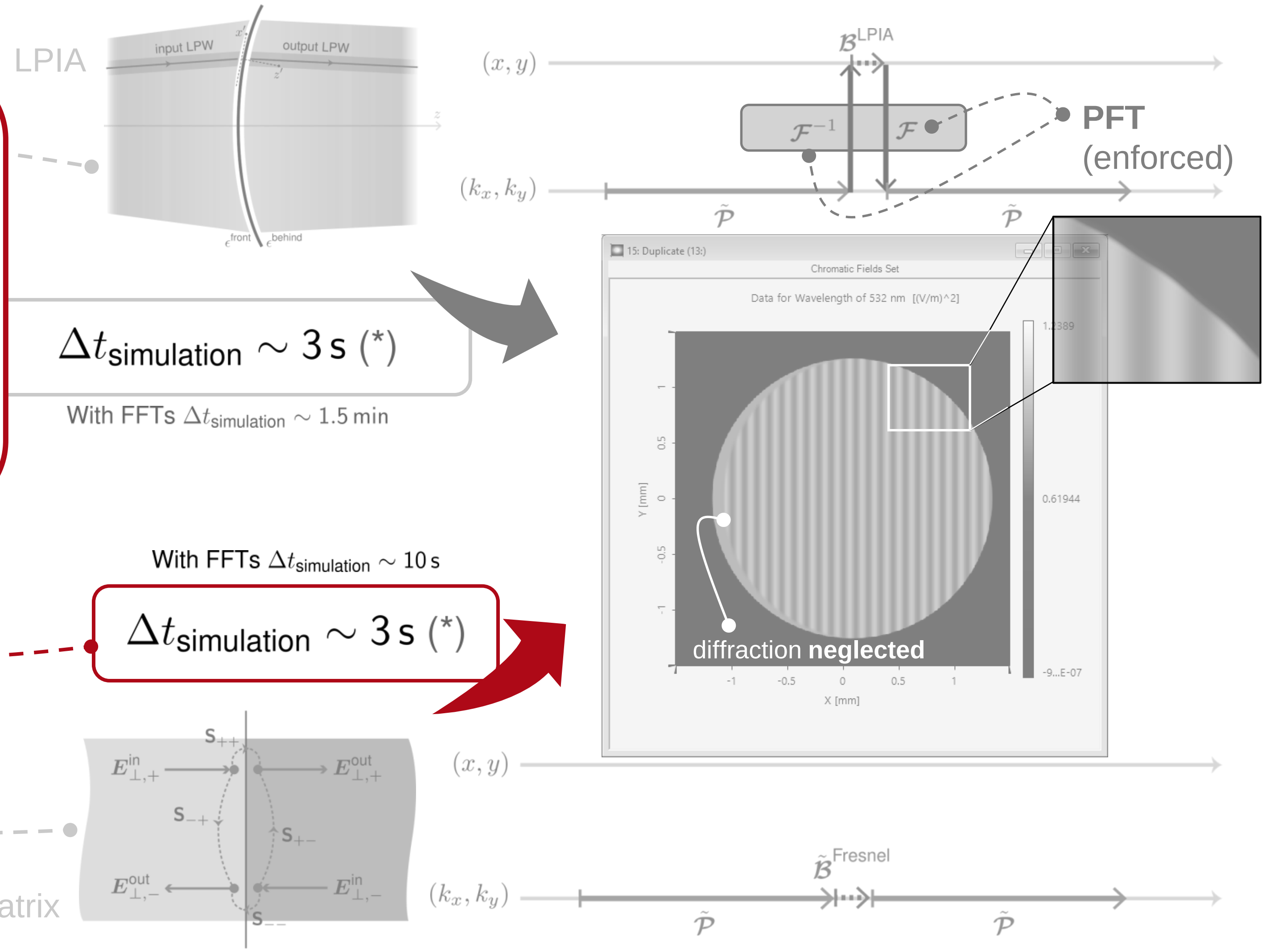
source
- plane wave
- wavelength: 532 nm
- angle: 30º
- **truncated by circular aperture (2.5 mm diameter)**

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

The Importance of the Fourier Transform

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





[More information about our catalog of Fourier transform algorithms in our use case “*Fourier Transform Settings – Discussion at Examples*”]

(*) 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

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:

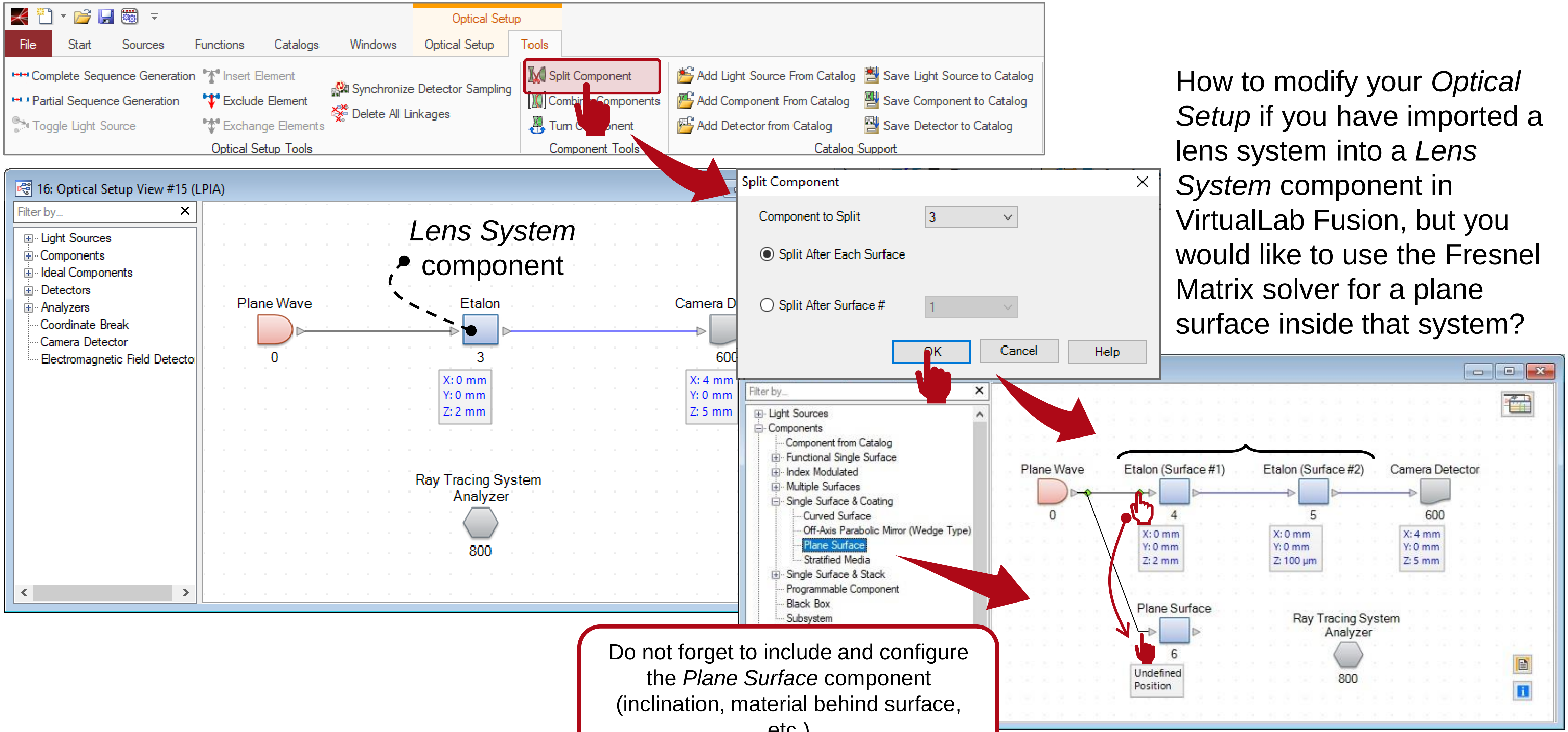
- Rigorous solver for ideal plane surface
- Works in spatial-frequency (k) domain
- Fewer Fourier transforms to be calculated
  ➔ potential numerical gain
- Assumes infinite surface

LPIA:

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

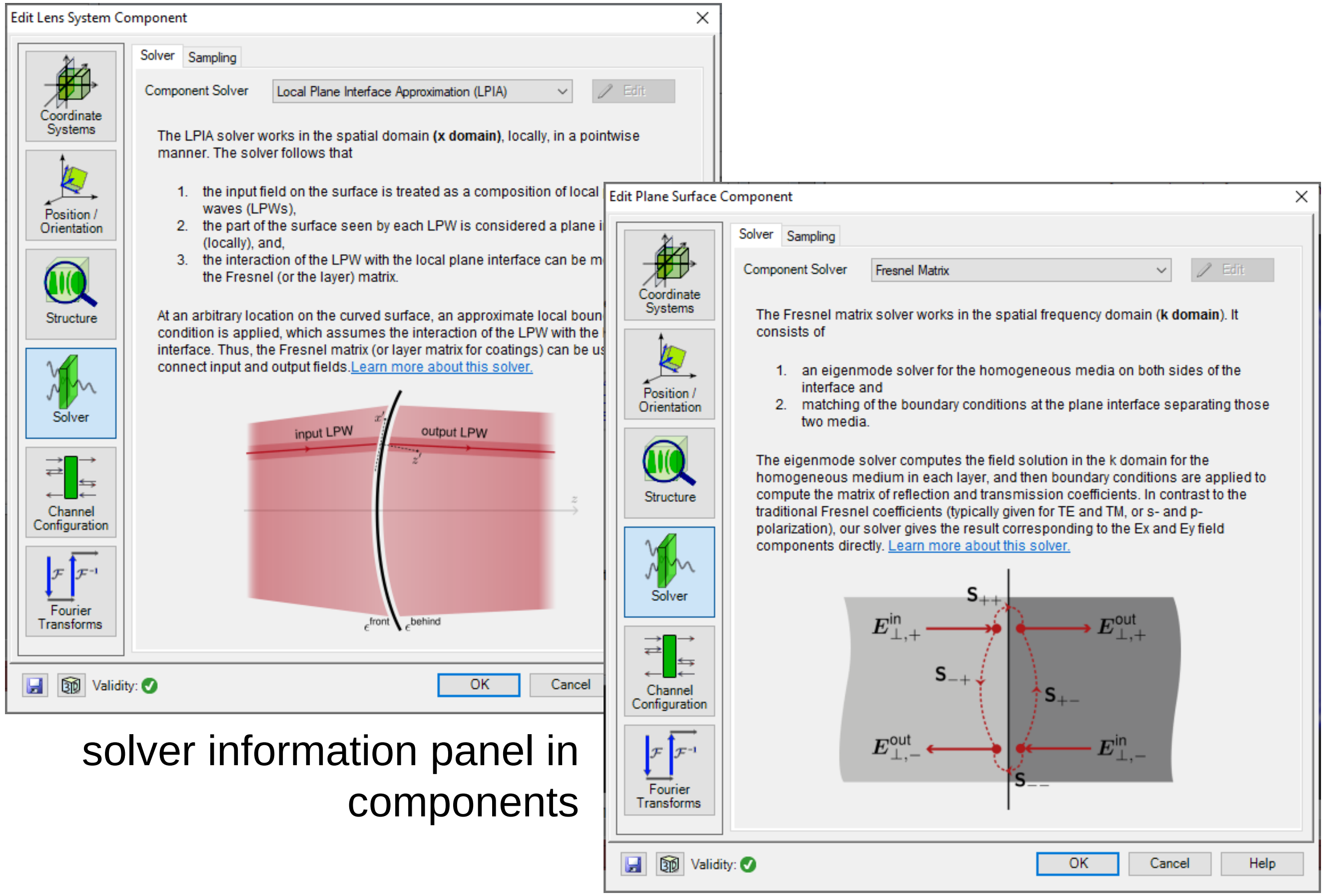
Practical Hint: Component Substitution

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



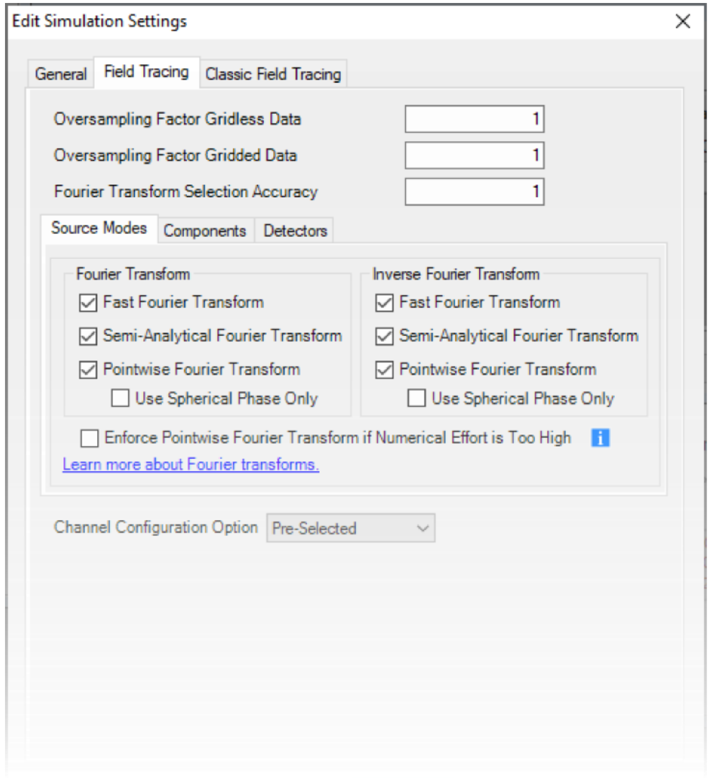
Do not forget to include and configure the *Plane Surface* component (inclination, material behind surface, etc.)

Peek into VirtualLab Fusion

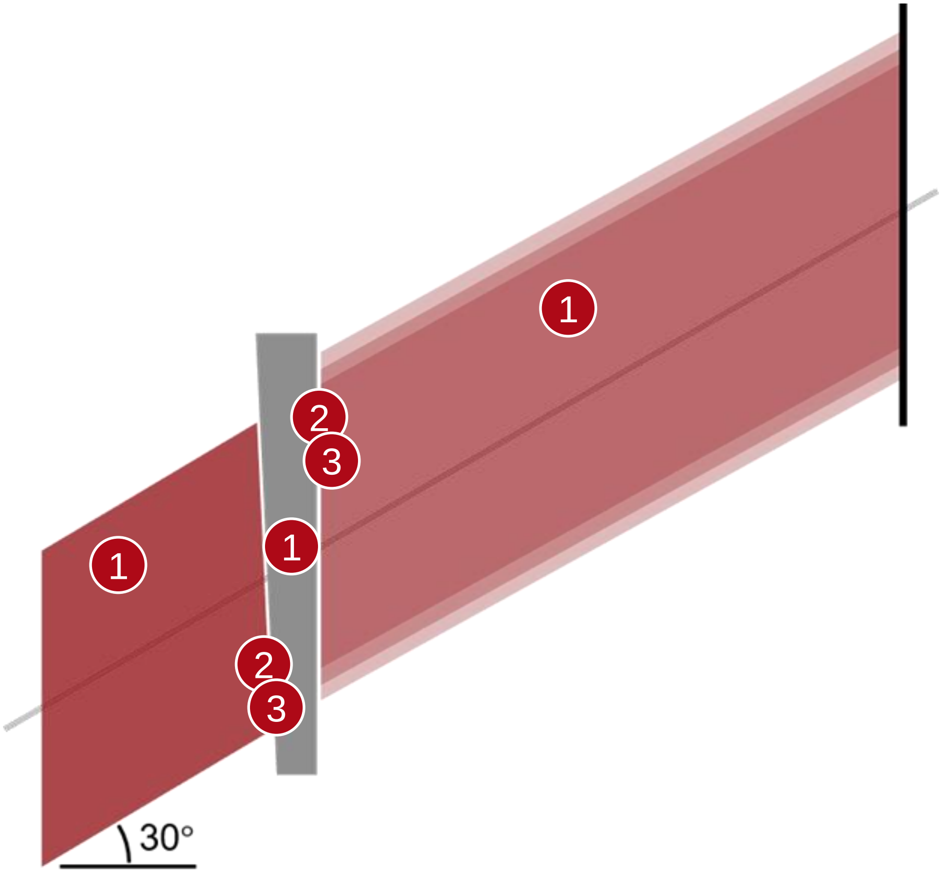


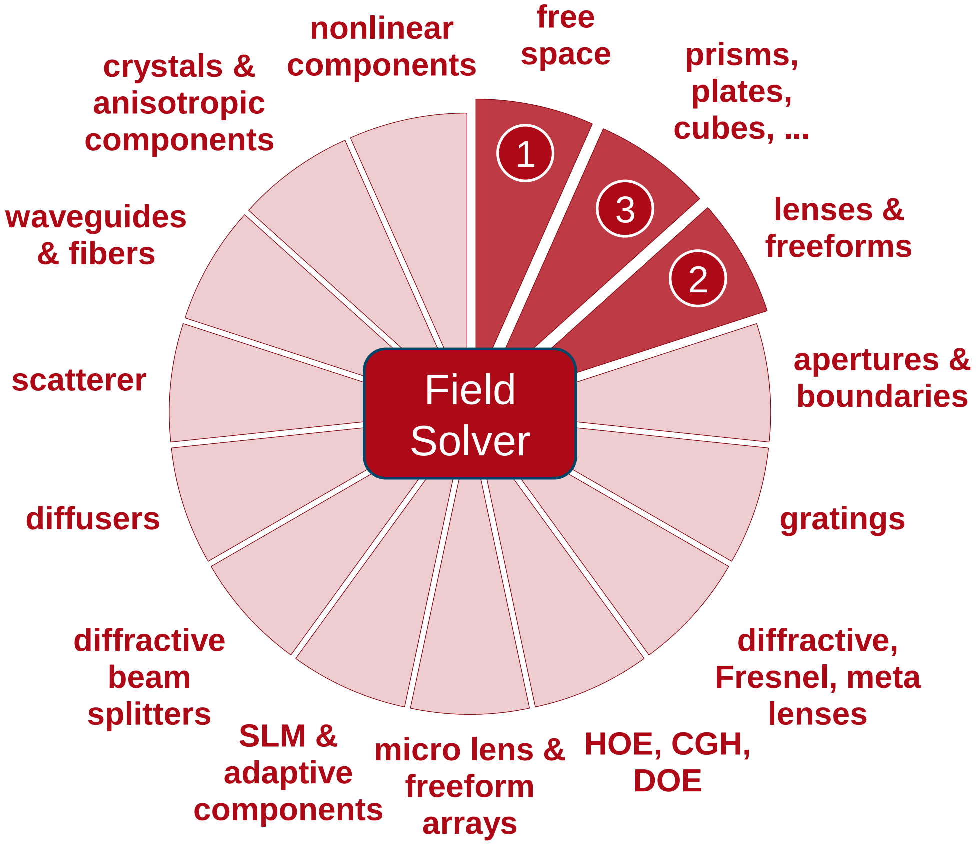
solver information panel in components

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	- Modeling of Etalon with Planar or Curved Surfaces - Fourier Transform Settings – Discussion at Examples - The Local Plane Interface Approximation (LPIA) - The Fresnel Matrix - Channel Configuration for Surfaces and Grating Regions