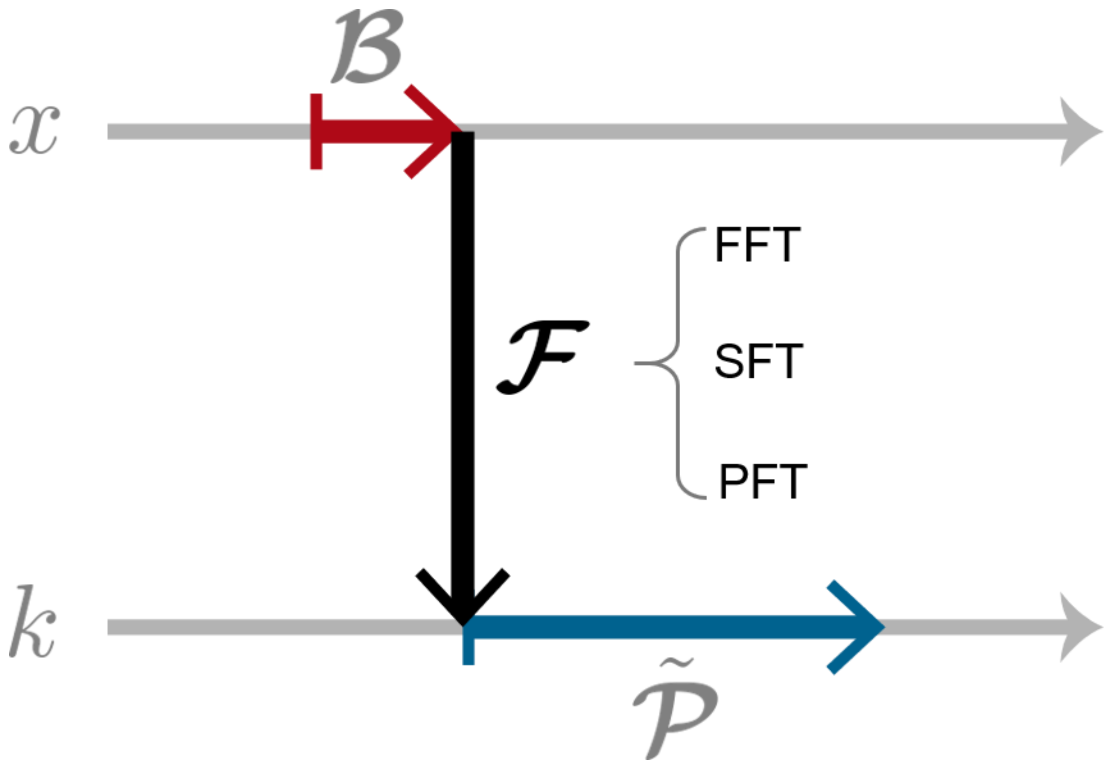
Fourier Transform Settings – Discussion at Examples

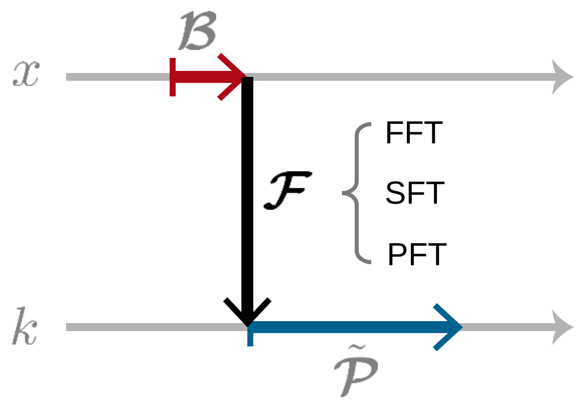
Abstract



Many field solvers and functions are included in VirtualLab Fusion. They may either working in the space (x) domain or the spatial frequency (k) domain. To use different solvers and functions in connection, so to enable the modeling of complex systems, the transforming between x and k domain is a crucial step. Three Fourier transform algorithms are available in VirtualLab Fusion, and, with this document, we show how to set the options by discussing at different examples.

The Three Fourier Transforms

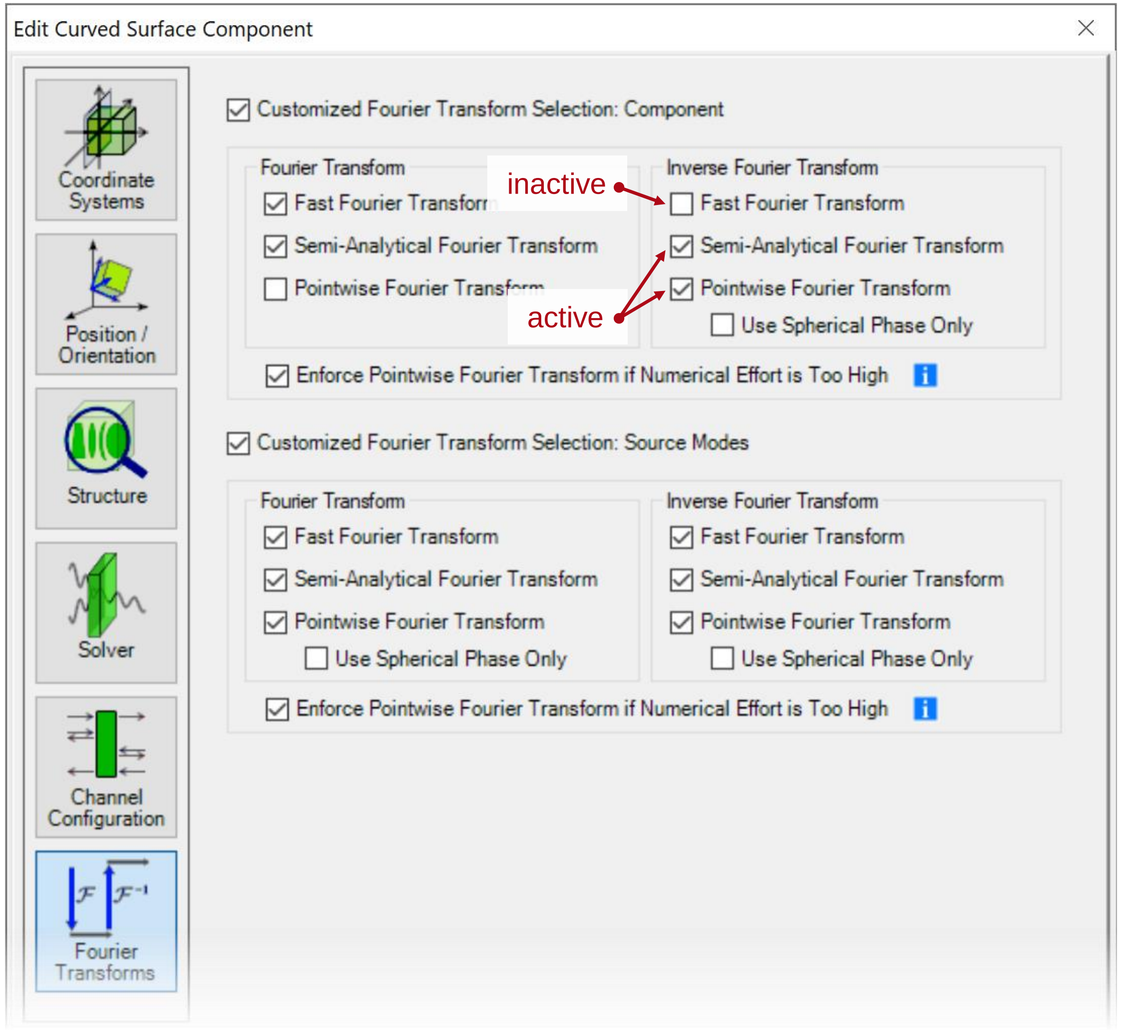
- The fast Fourier transform (FFT)
  - Standard and efficient algorithm for various numerical computations
- The semi-analytical Fourier transform (SFT)
  - An efficient reformulation without approximation
  - Analytical handling of quadratic phases, like the chirp-z transform
  - Read more in Z. Wang, *et al*., Opt. Express 27, 15335-15350 (2019)
- The pointwise Fourier transform (PFT)
  - An approximate approach, inspired by the stationary phase theory, but formulated in purely mathematical form
  - Highly efficient and accurate for strong wavefront phase
  - Read more in Z. Wang, *et al*., Opt. Express 28, 10552-10571 (2020)



Settings for Each Component

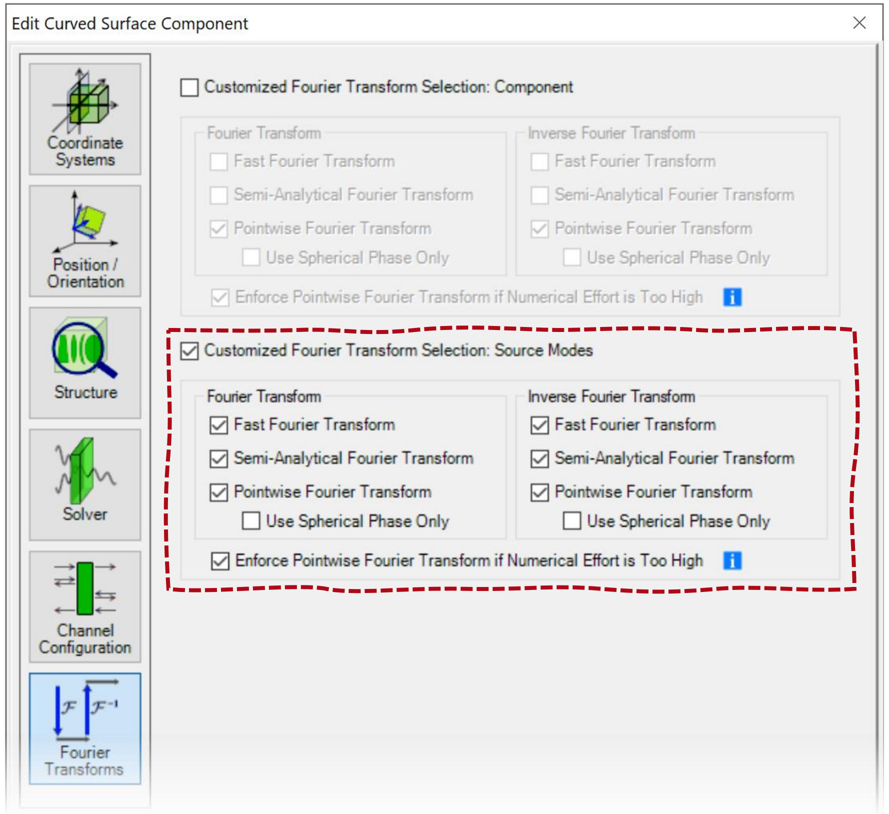
- Fourier transform setting
  - For each component and detector, a tab Fourier Transforms is available.
  - VirtualLab Fusion selects automatically from all the active Fourier transform options; inactive ones not for choice.
  - The combination of Fourier transforms affects the modeling of the preceding propagation step in free space

This is not only meant for the free space in front of the component – it applies to cases with complicated channel configurations too.

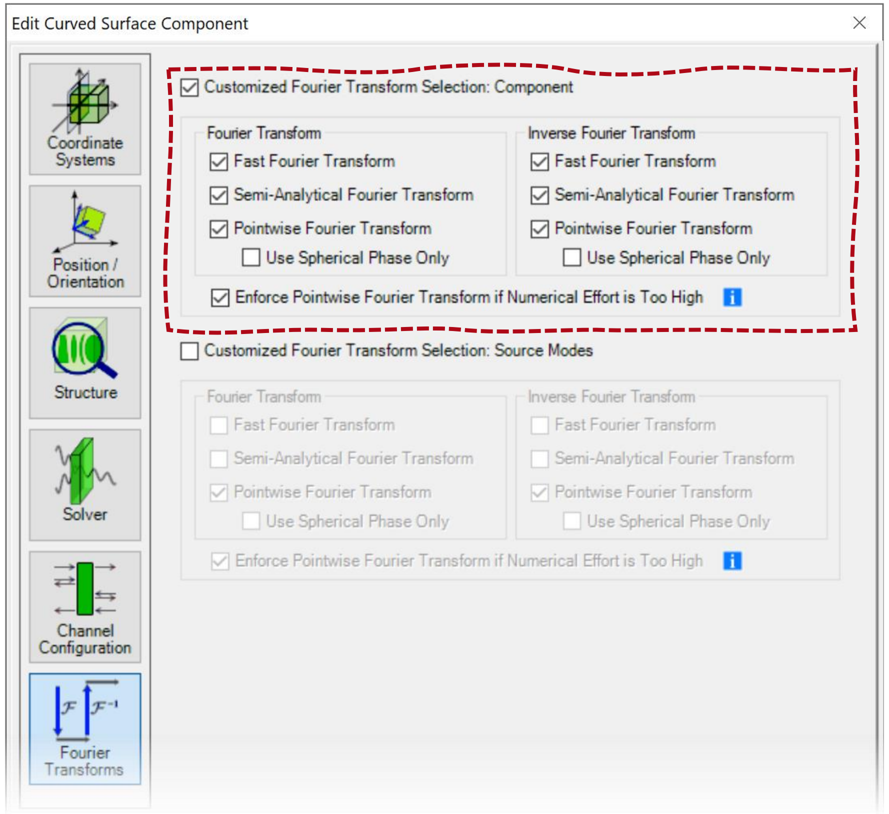


Settings for Each Component

- Fourier transform setting
  - For the preceding propagation step from the light source …

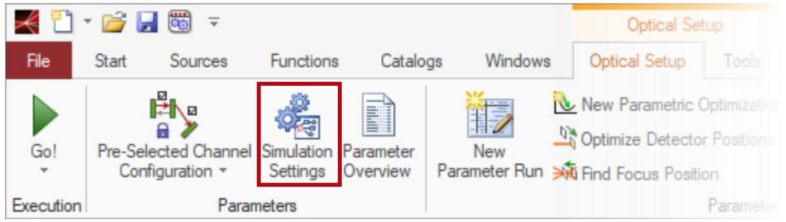


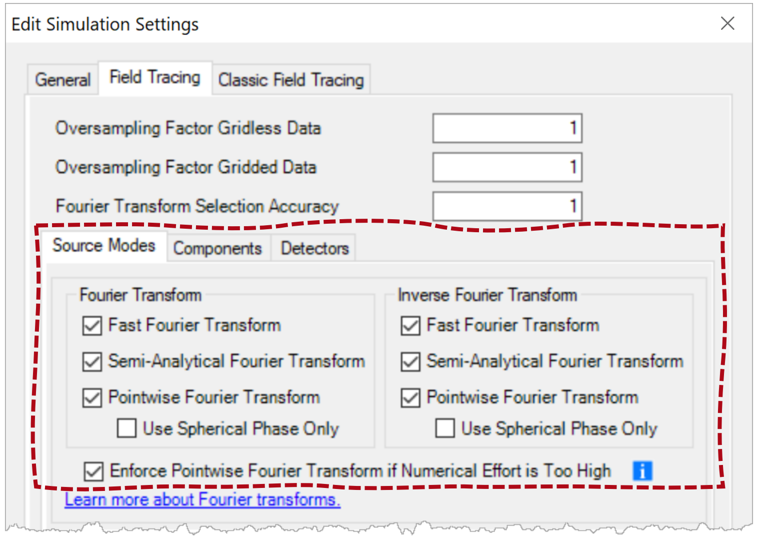
- For the preceding propagation step from another component …

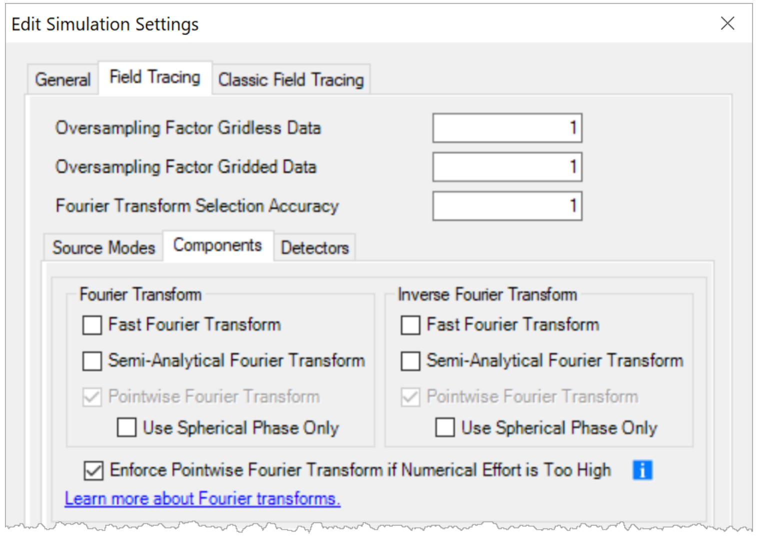


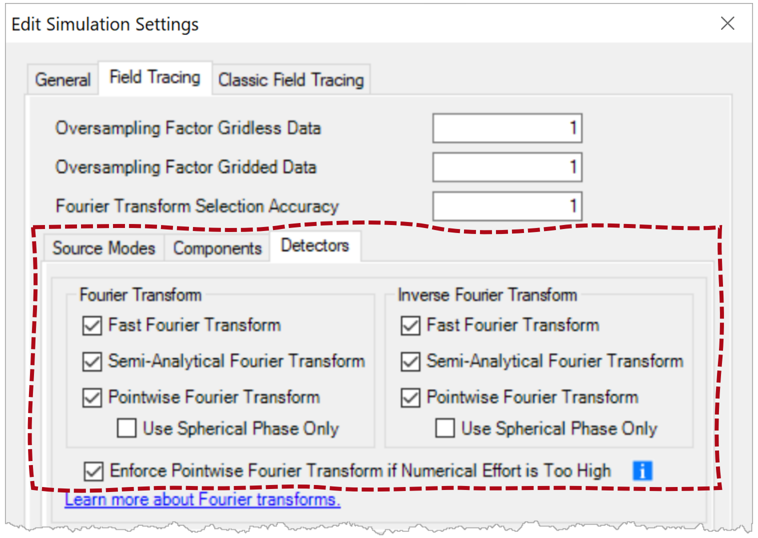
Default Fourier Transform Settings

- Settings for source modes and detectors
  - For source modes and detectors, all three Fourier transform options are activated by default.
  - As special cases, diffraction might be not of concern for source modes or detectors. We will discuss such cases in Example #1 and #3 in the following.



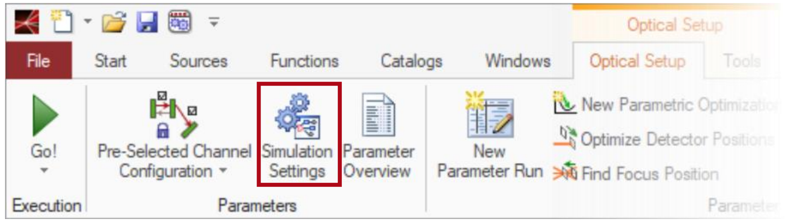


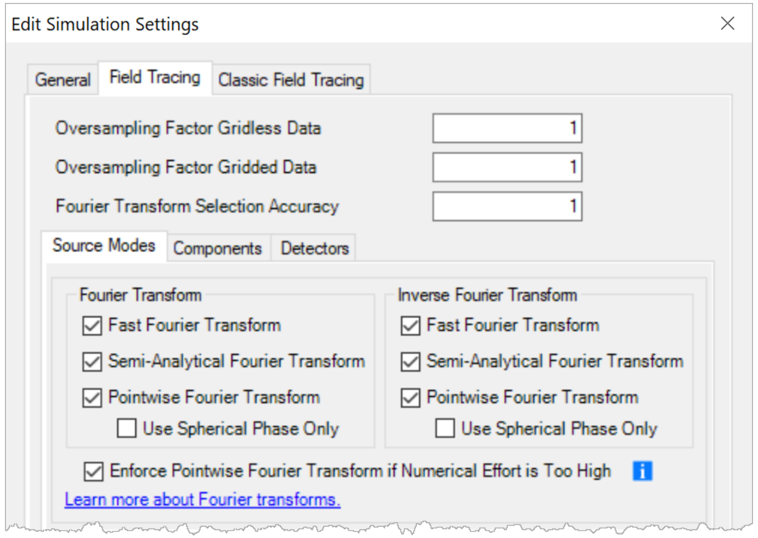


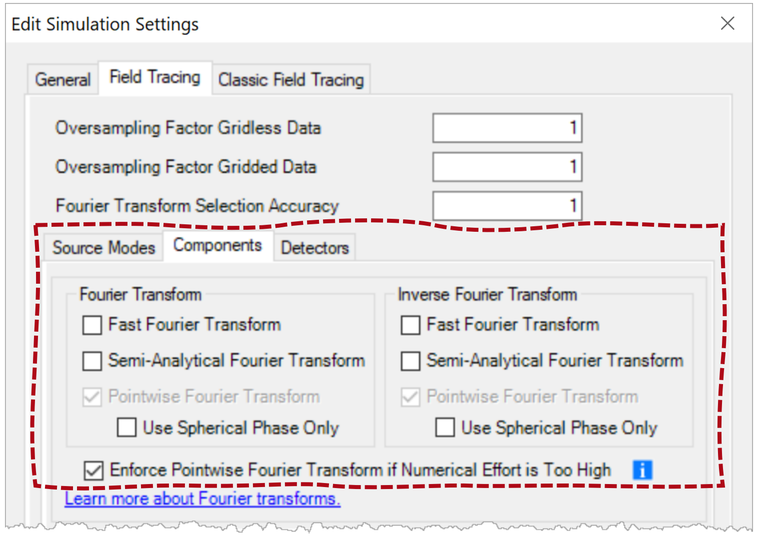


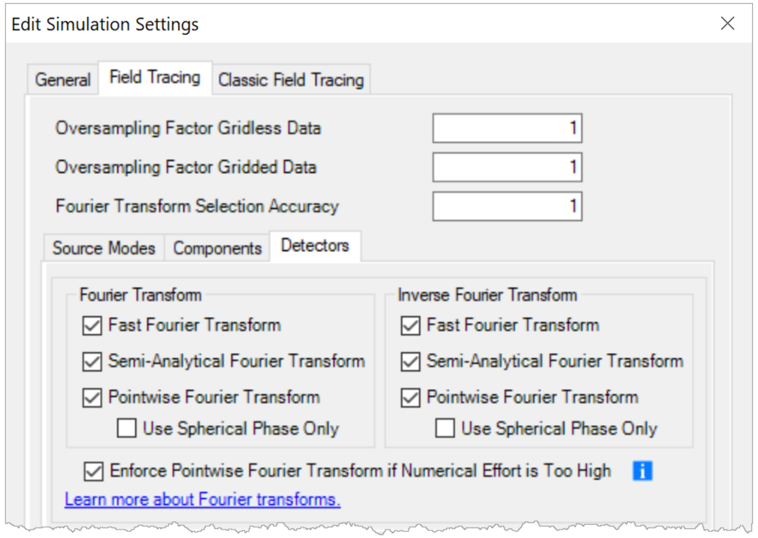
Default Fourier Transform Settings

- Settings for components
  - For components, only the pointwise Fourier transform option is activated by default for performance consideration.
  - That will neglect possible diffraction effects and often needs additional care in different cases. Typical examples are discussed in Example #1 and #2.



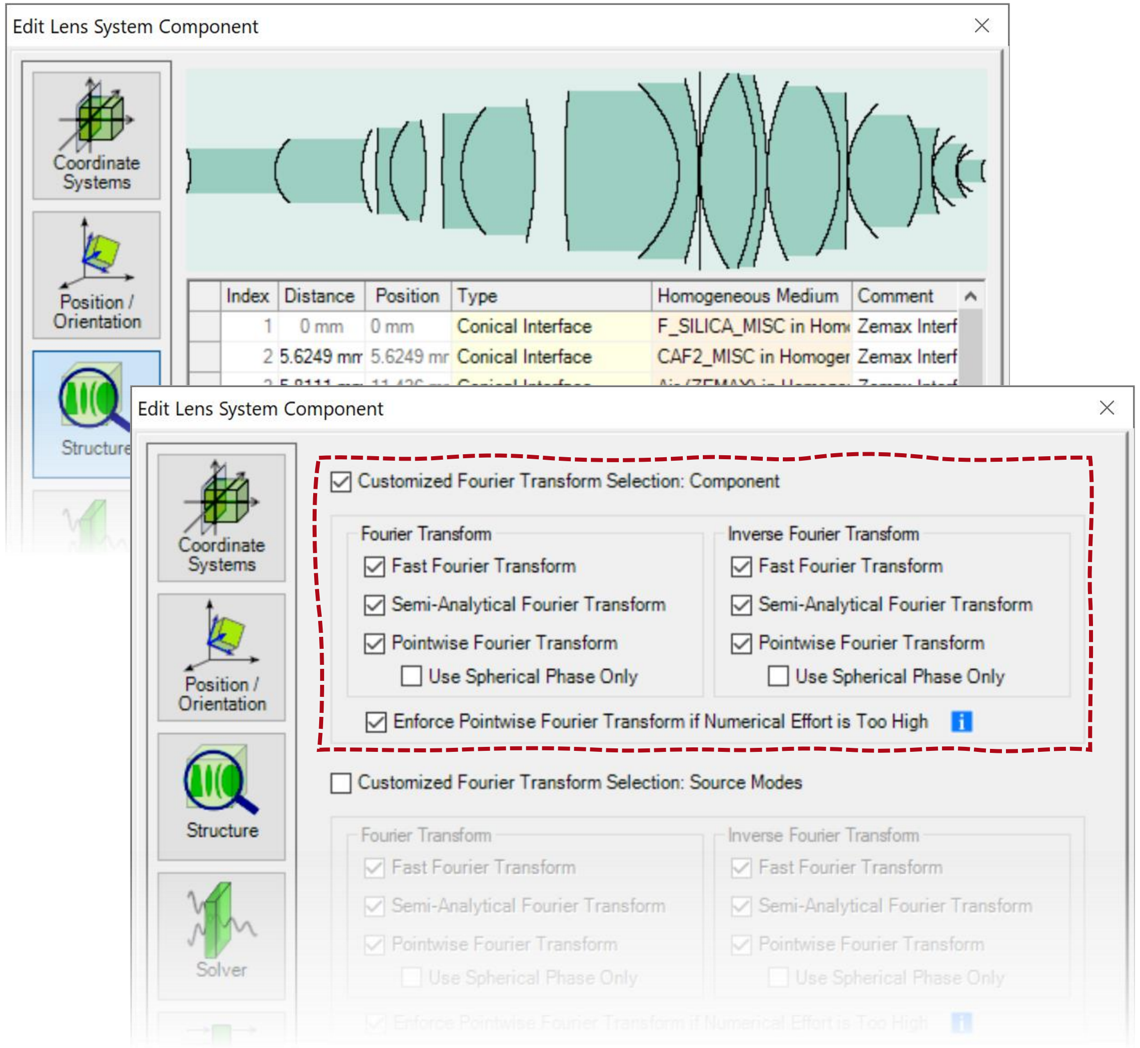






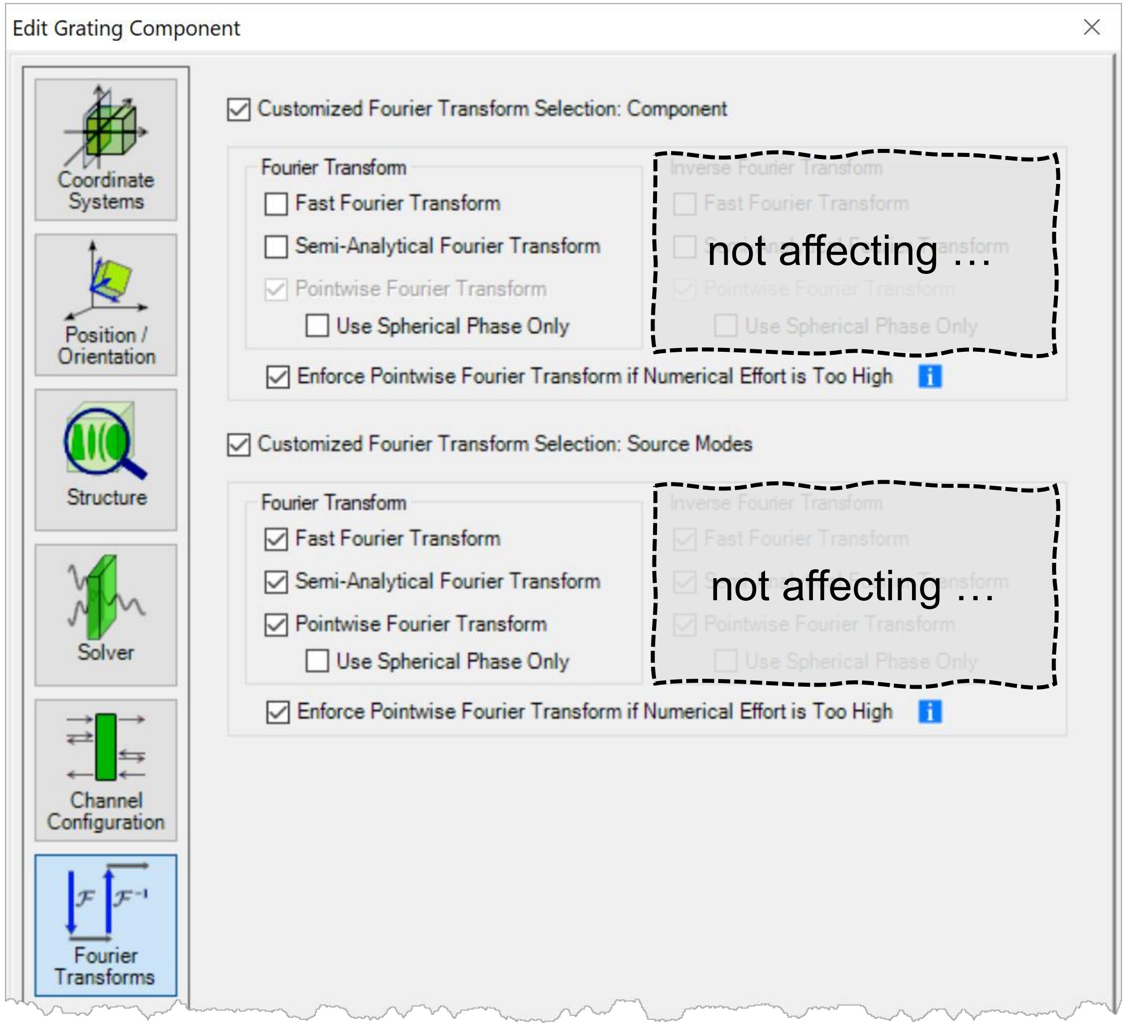
Special Cases

- Multiple-surface components
  - Special considerations shall be given to the following cases
    - Lens System Component
    - Spherical Lens Component
  - Such components can be understood as a convenient composition of
    - Set of curved surface components, and
    - Pieces of free spaces in between
  - The Fourier transform option also affects the free-space propagation steps in between.



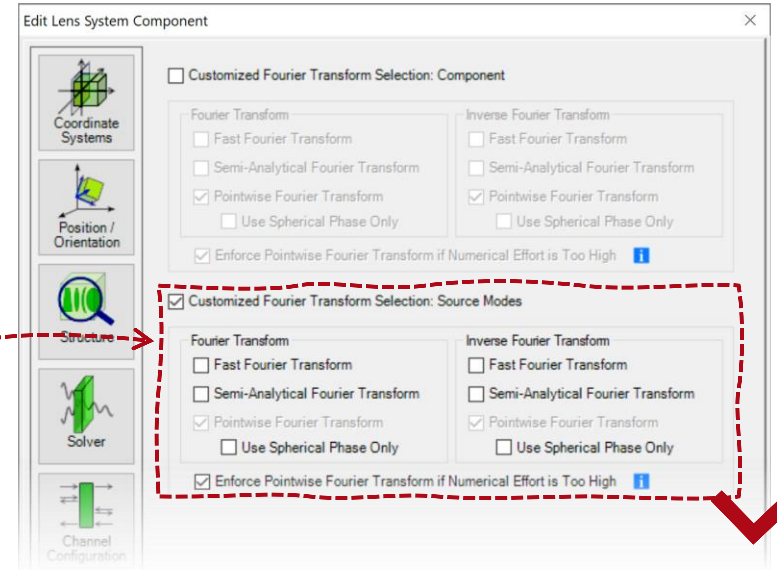
Special Cases

- Components in k domain
  - When the solver / function of a component works in the k domain, the inverse Fourier transform option does not affect anything.
  - This applies to the following cases
    - Plane Surface Component
    - Stratified Medium Component
    - Grating Component
    - Functional Grating Component



Example #1: Pinhole in a Low-Fresnel-Number System

Example #1: Source Modes for Imaging



For typical imaging applications, with

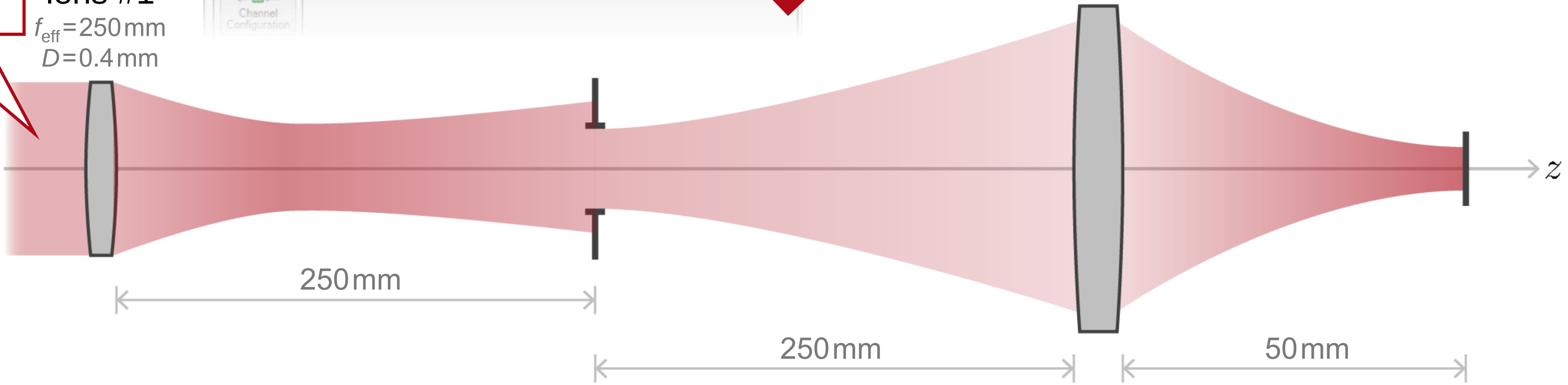
- plane waves source in different directions coming from infinity, or
- point sources emitting spherical waves covering large angular range,

diffraction effect is not of concern and therefore a PFT-PFT combination is chosen.

diffraction consideration not needed

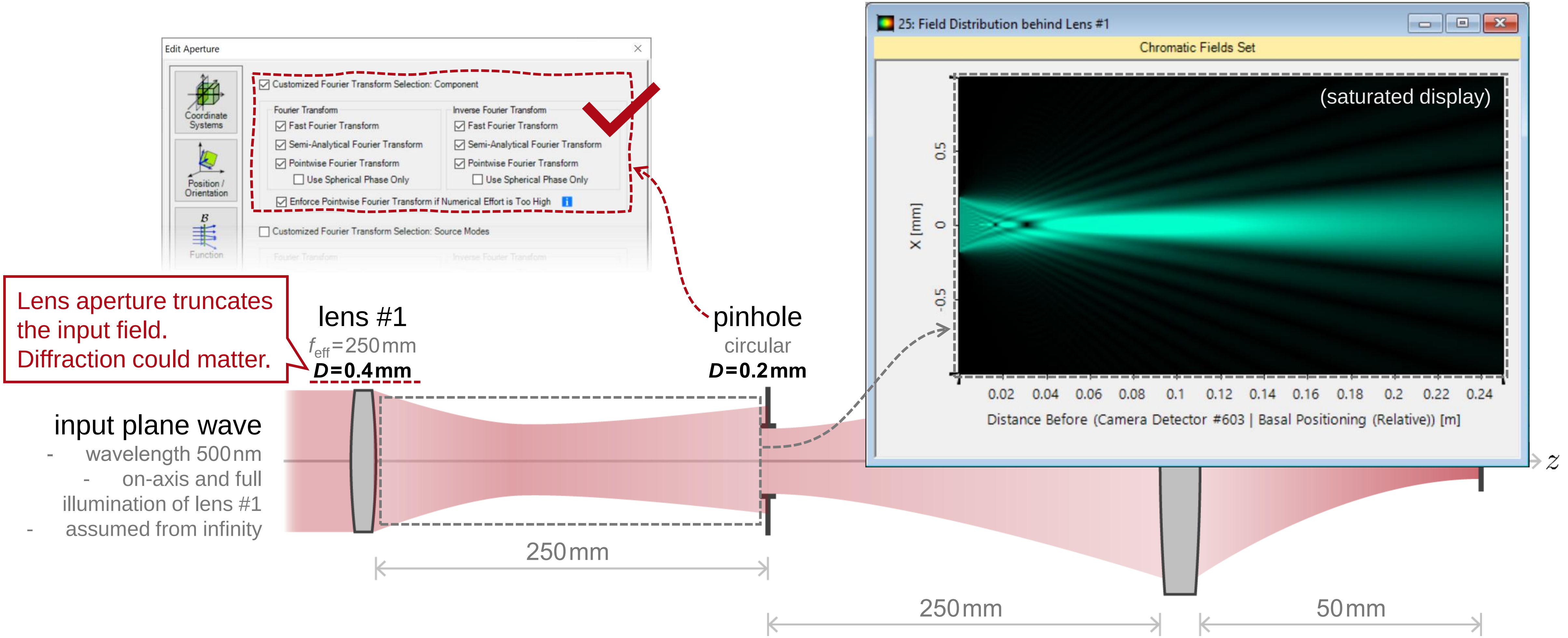
lens #1
$f_{\mathrm{eff}} = 250\,\mathrm{mm}$
$D = 0.4\,\mathrm{mm}$

input plane wave
- wavelength 500 nm
- on-axis and full illumination of lens #1
- **assumed from infinity**

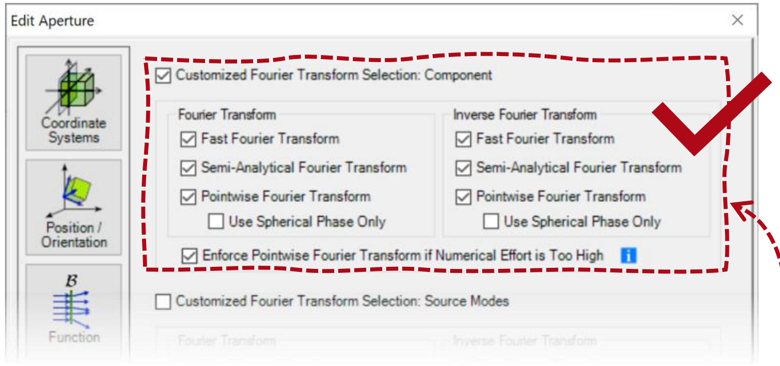


see the full Application Use Case

Example #1: Diffraction inside System Inclusion



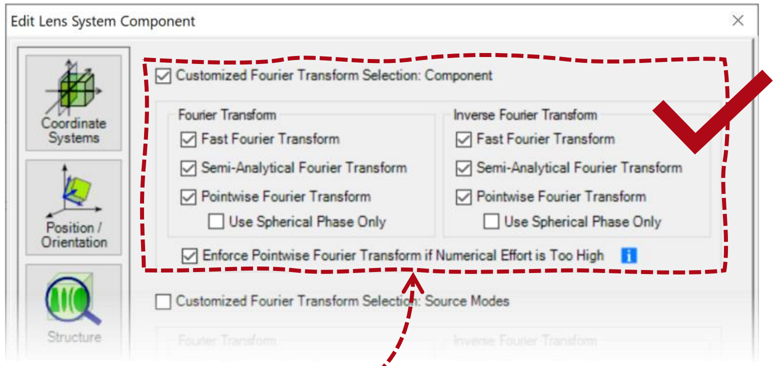
Example #1: Diffraction inside System Consideration

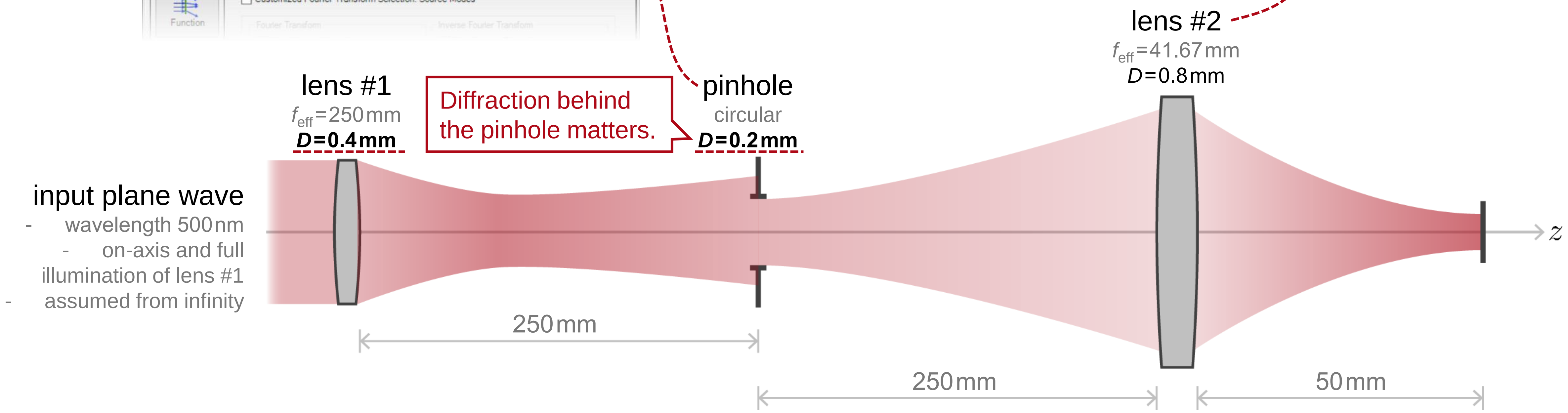


When diffraction starts to matter, e.g., behind

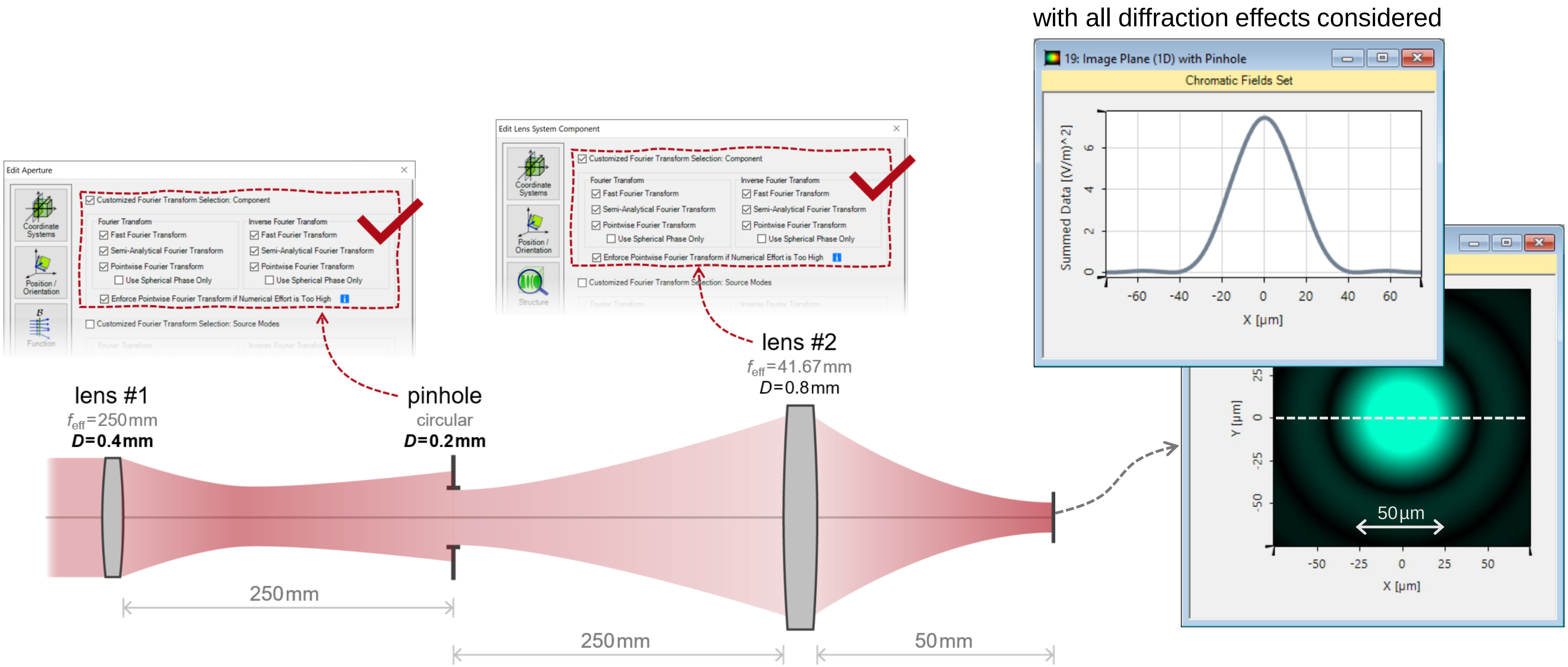
- pinhole, aperture/stop, or
- boundary truncating component,

we recommend to activate FFT and SFT for such cases.

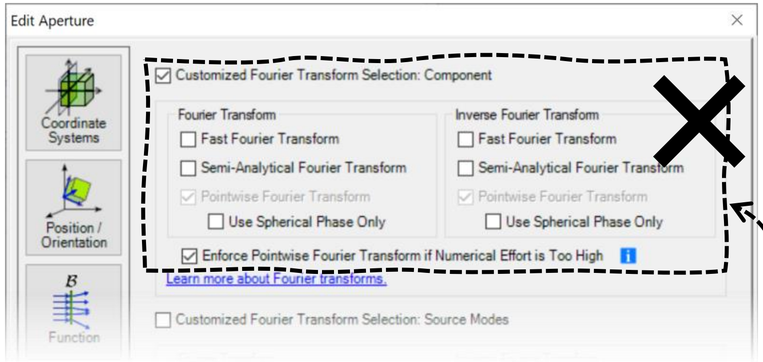




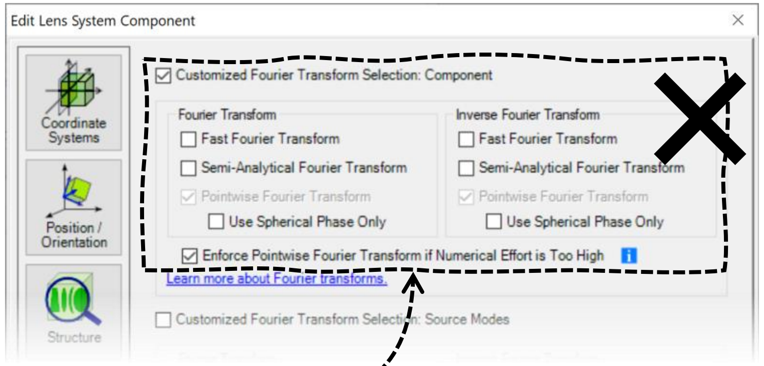
Example #1: Diffraction inside System Consideration

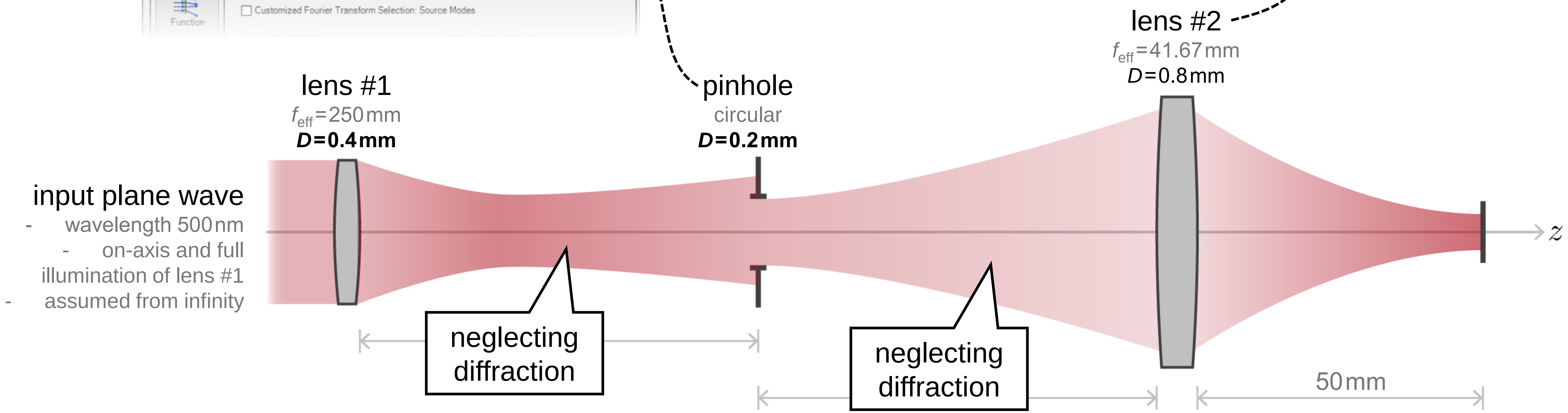


Example #1: Exit Pupil Diffraction Approach

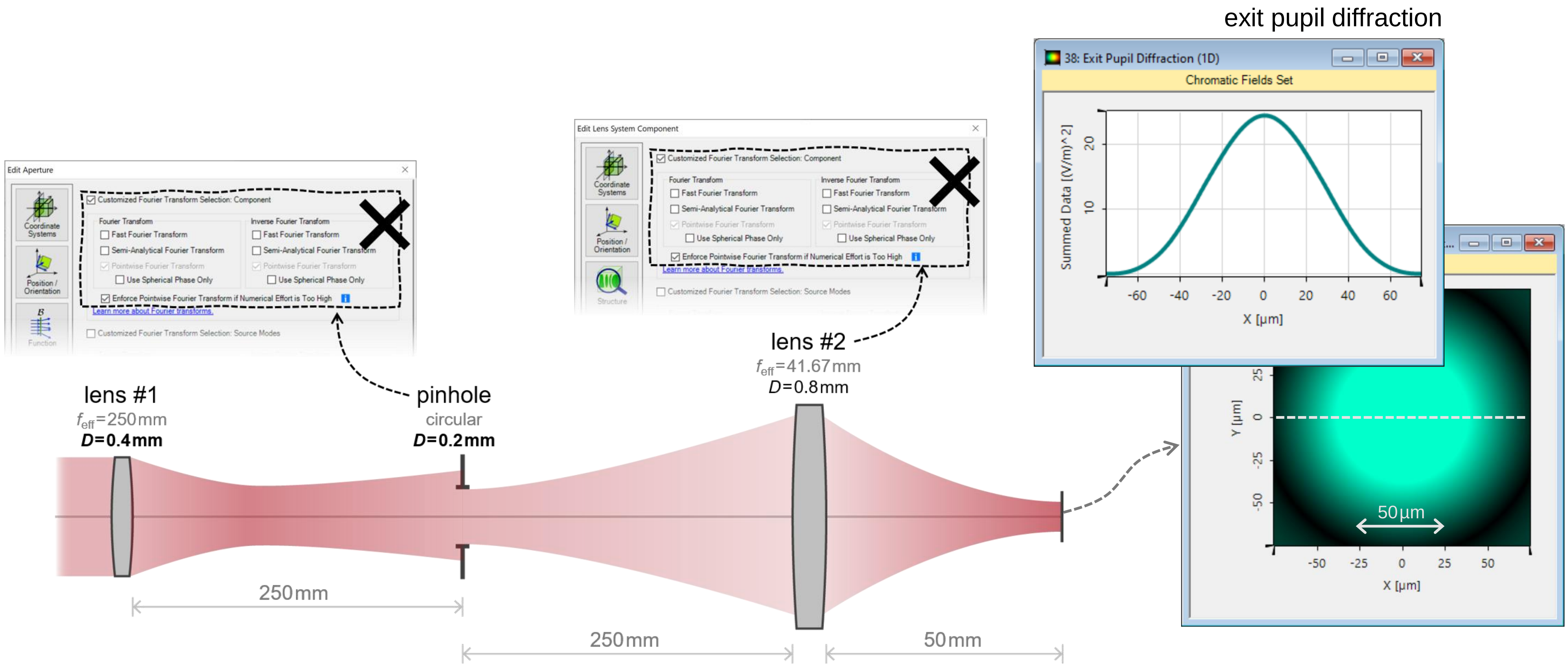


One can neglect the diffraction by enforcing to the PFT-PFT combination. This is a negative example.



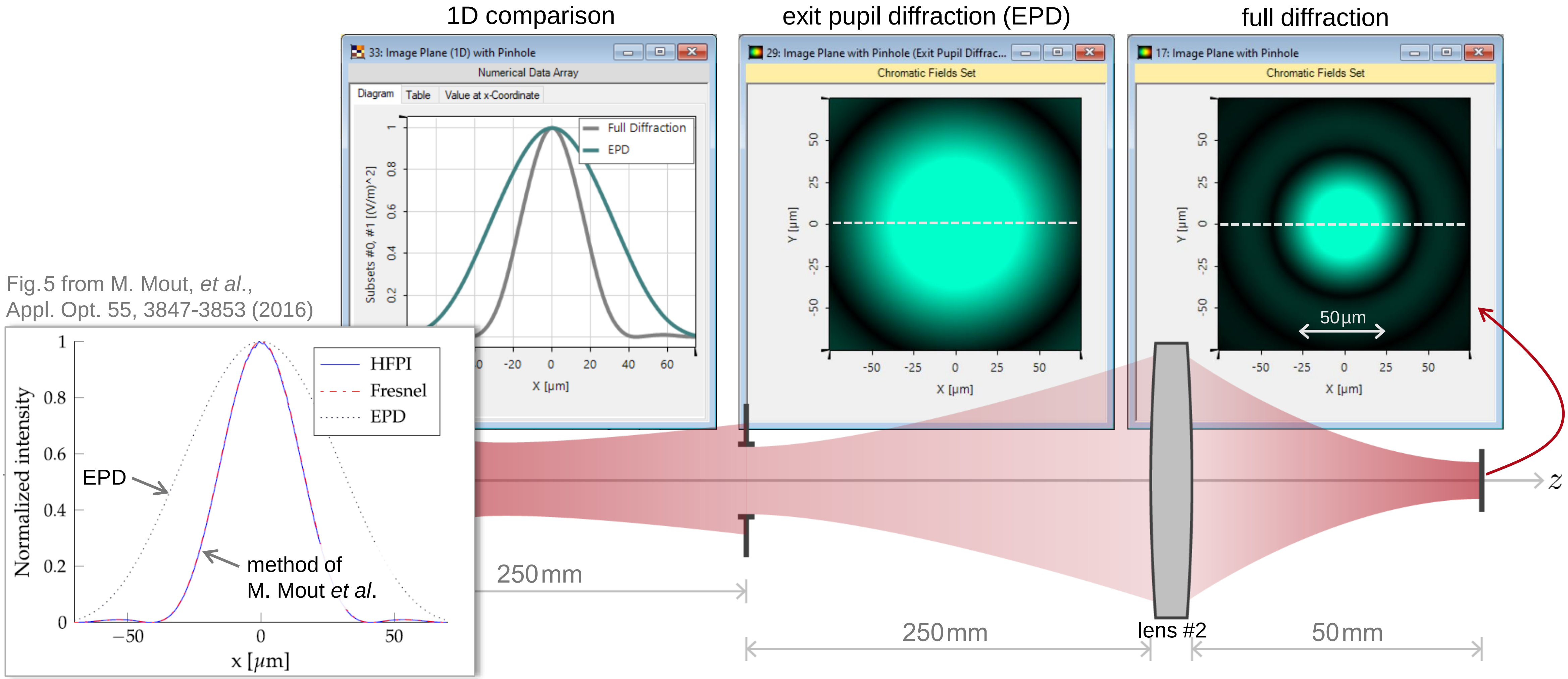


Example #1: Exit Pupil Diffraction Approach



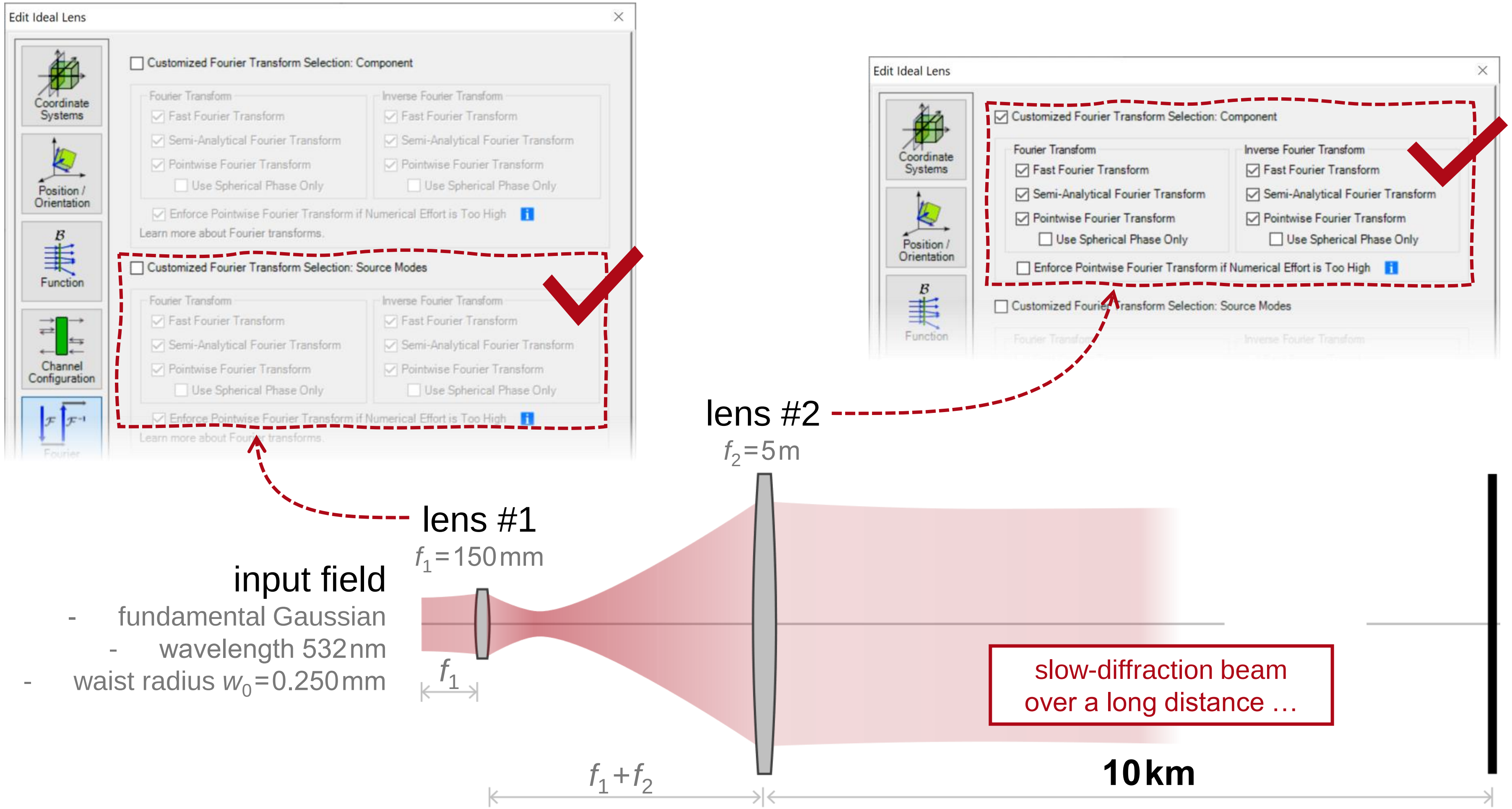
Example #1: Exit Pupil Diffraction & Comparison

Fig.5 from M. Mout, *et al.*, Appl. Opt. 55, 3847-3853 (2016)



Example #2: Afocal System for Laser Guide Stars

Example #2: All Possible Diffraction Included



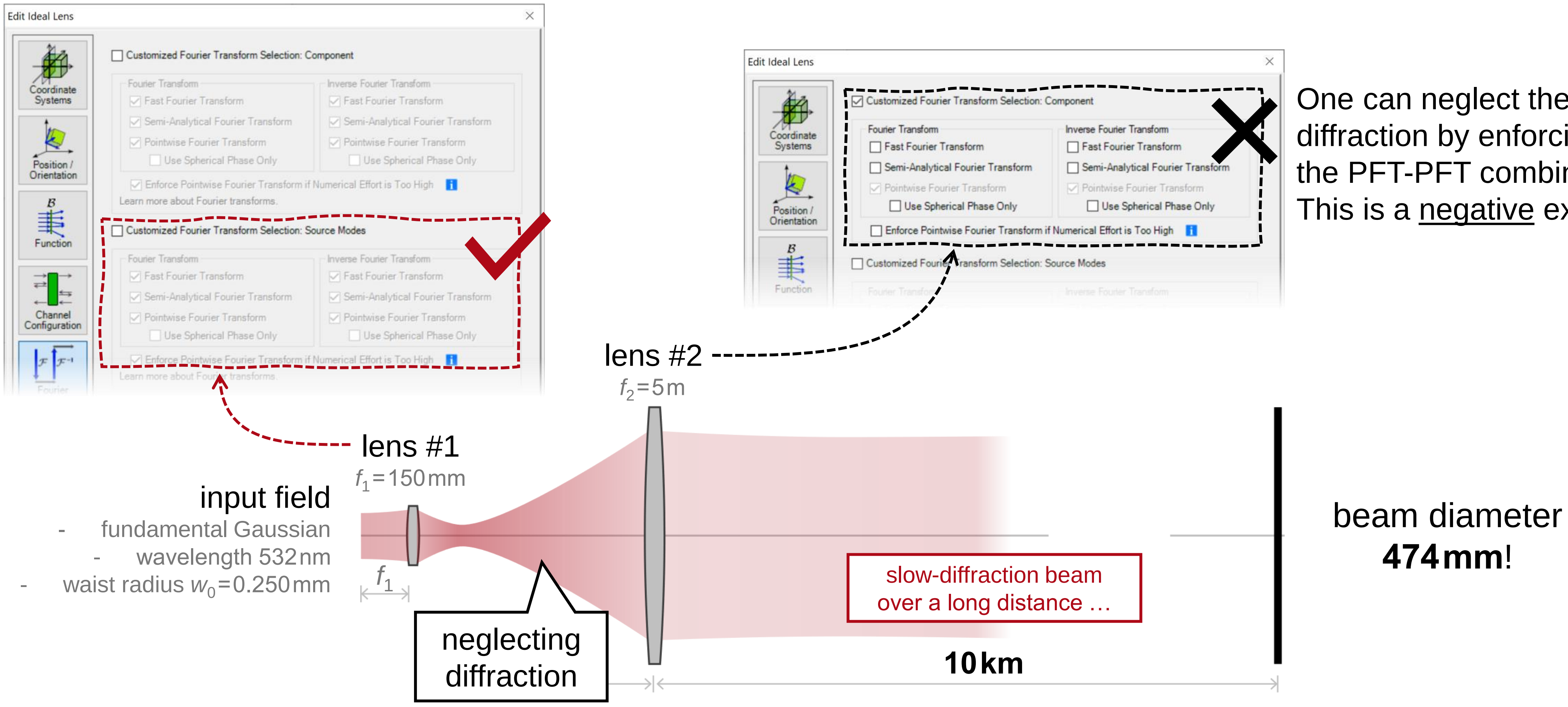
For the accurate analysis of slow-diffraction beams, we recommend to active FFT and SFT, especially for Parameter Run and Optimization.

This is the correct modeling result.

beam diameter 406mm

see the full Application Use Case

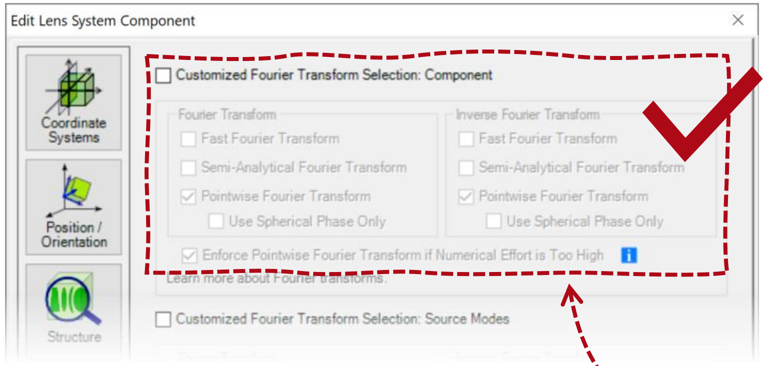
Example #2: Neglecting Diffraction between Lenses



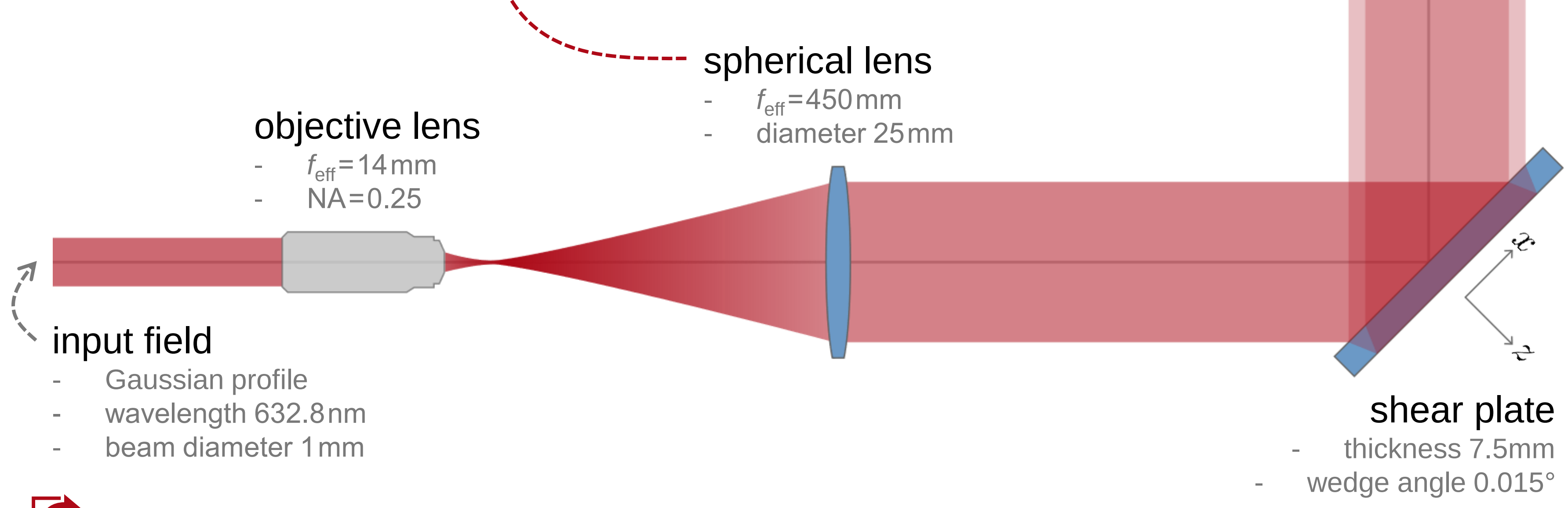
One can neglect the diffraction by enforcing to the PFT-PFT combination. This is a negative example.

Example #3: Collimation Testing with Shearing Interferometry

Example #3: Neglecting Diffraction on Purpose



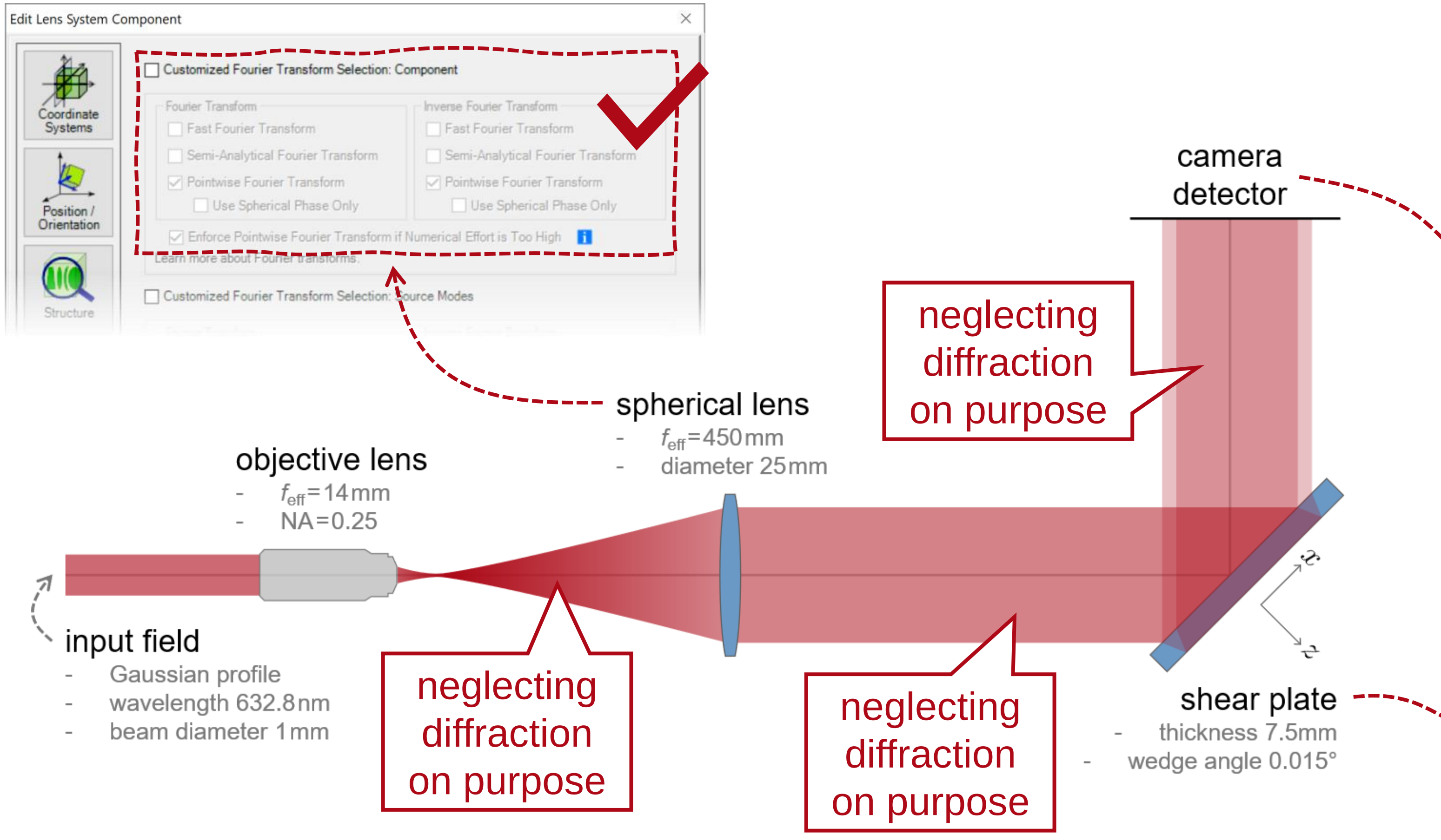
For lens systems beyond paraxial / parabasal situation (in contrast to Example #1 and #2), the intra-system diffraction effect is often negligible. Thus, a PFT-PFT combination (default) is appropriate.

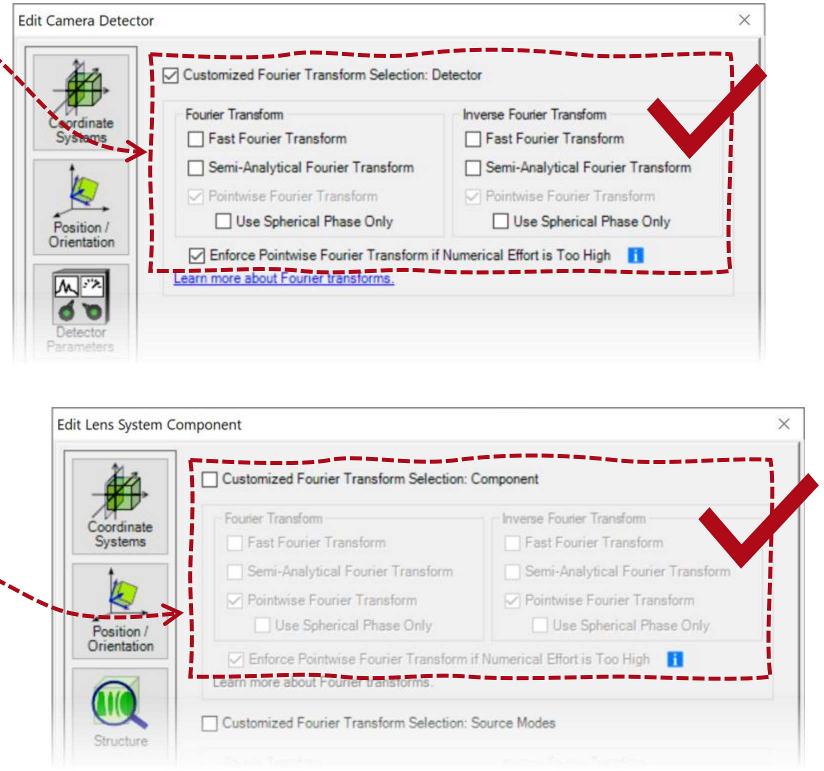


see the full Application Use Case

Example #3: Neglecting Diffraction on Purpose

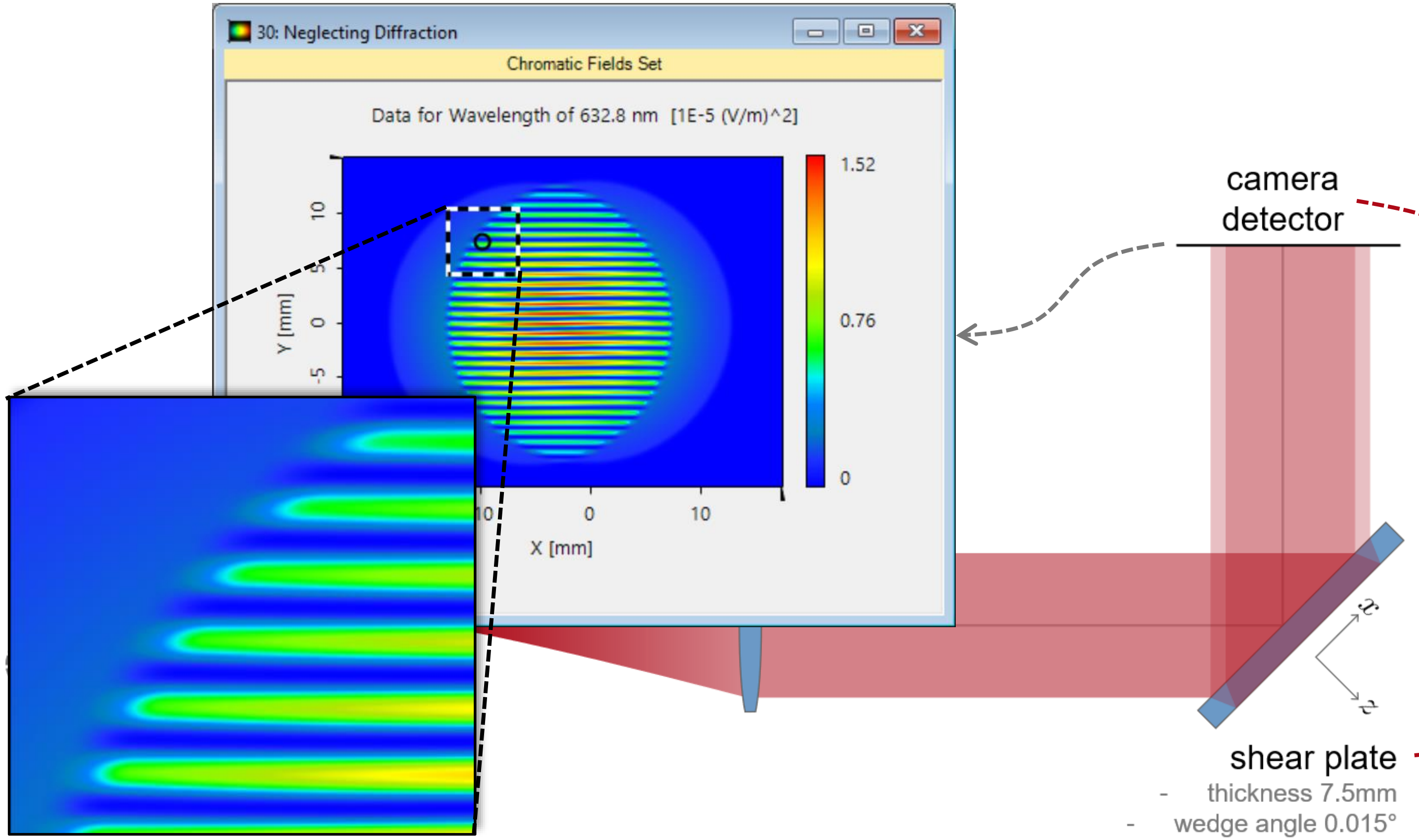
For collimated beams with relatively large diameter, and for relatively short-distance propagation, we often neglect the diffraction as a minor effect, since the major modeling goal in this example is the interference.

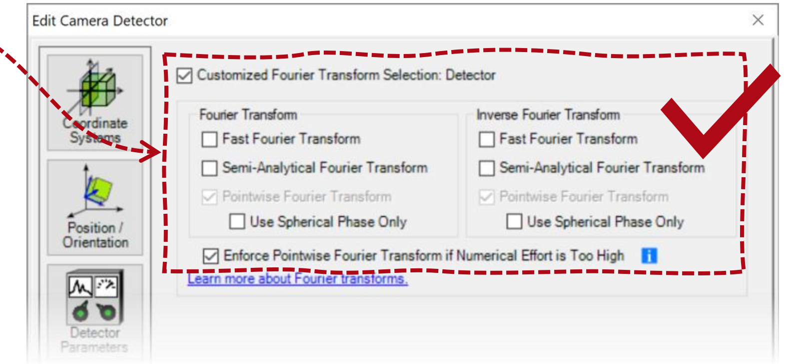


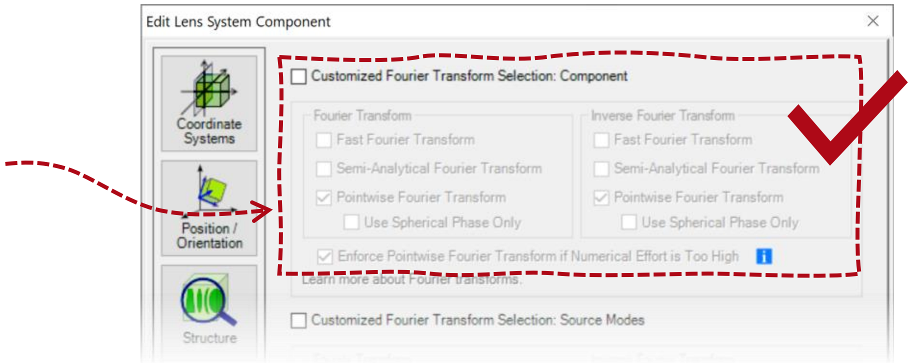


Example #3: Neglecting Diffraction on Purpose

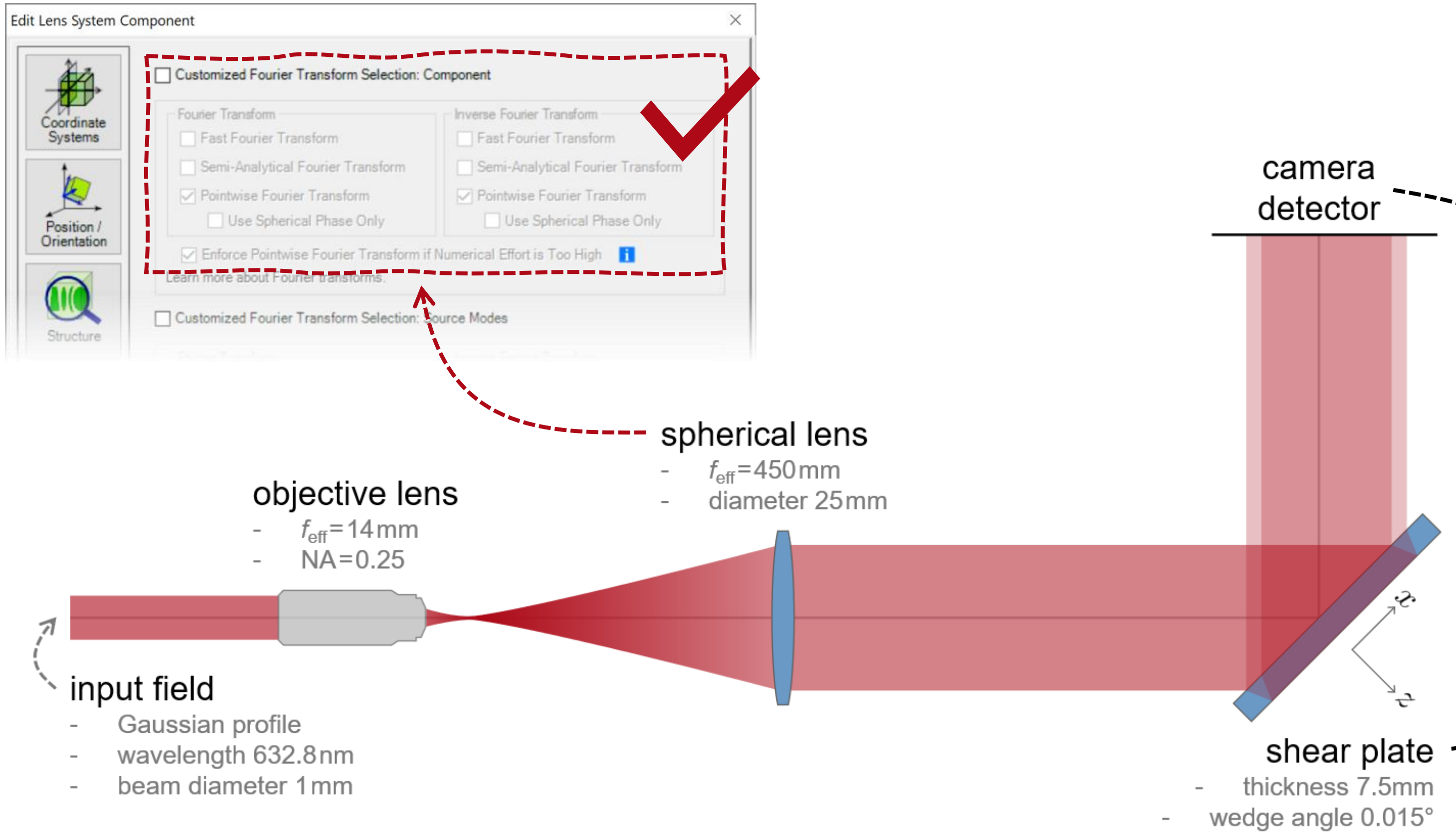
For collimated beams with relatively large diameter, and for relatively short-distance propagation, we often neglect the diffraction as a minor effect, since the major modeling goal in this example is the interference.



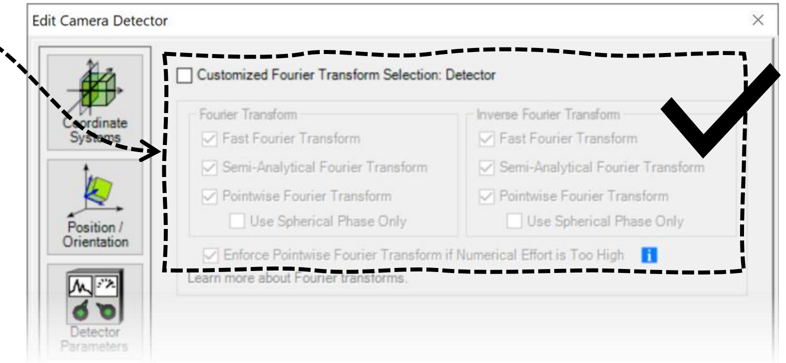


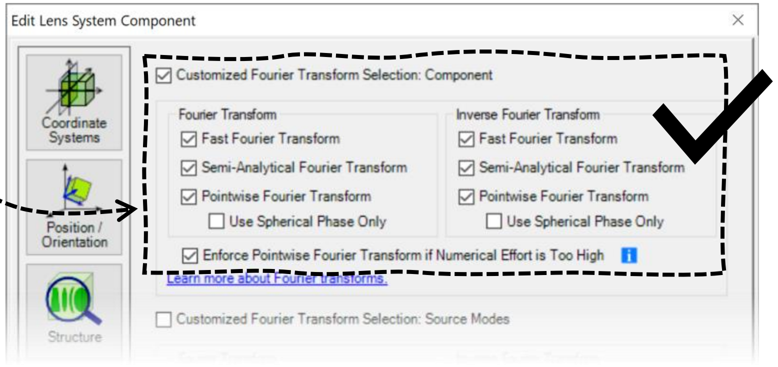


Example #3: Including Diffraction

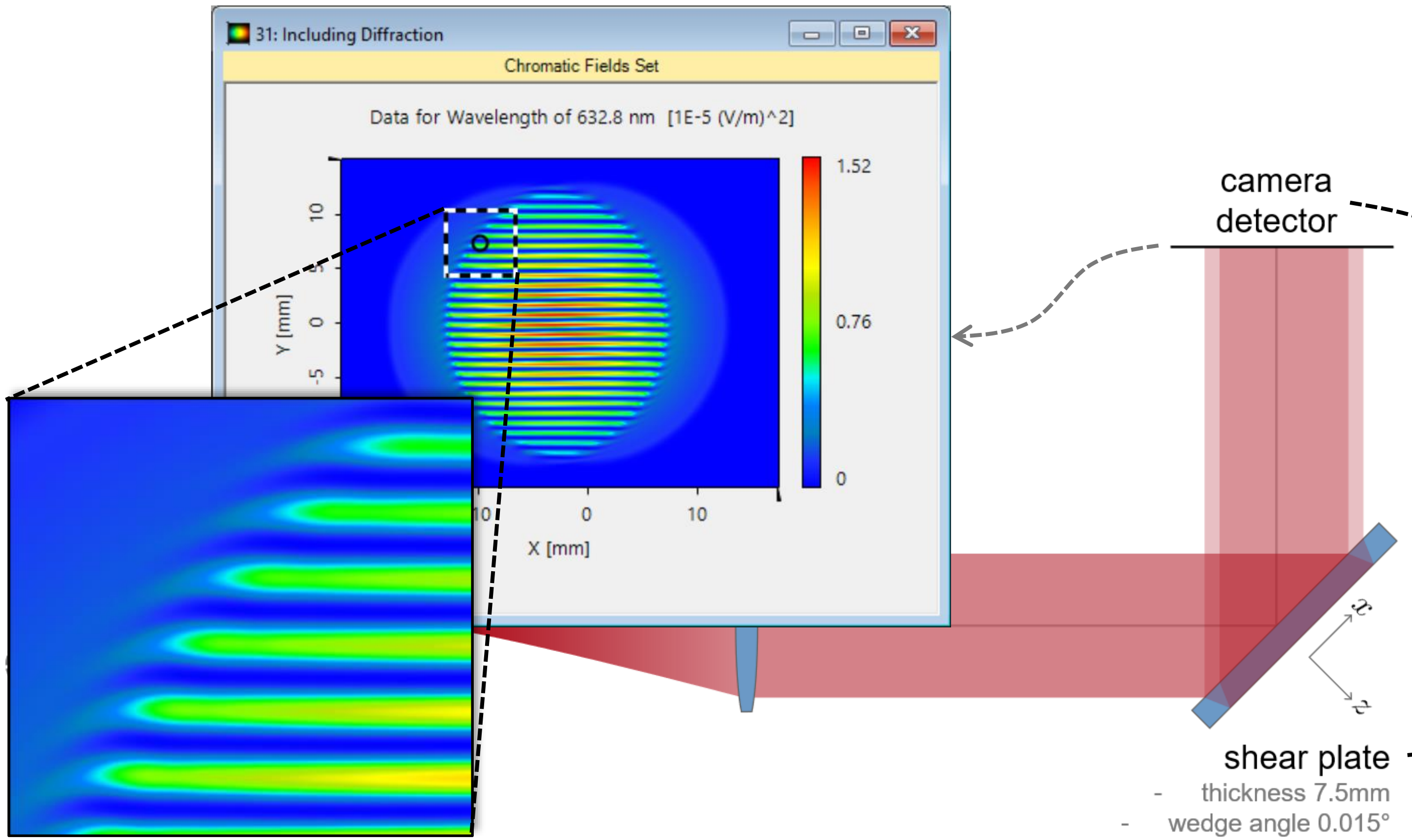


To check the minor influence on the result from diffraction, we perform the simulation with the following alternative settings.

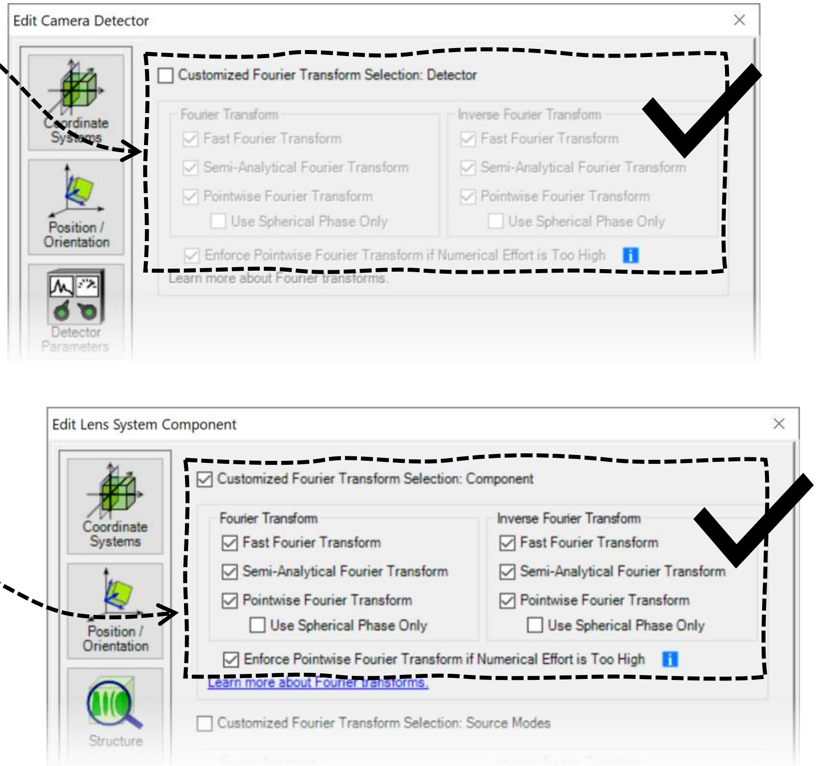




Example #3: Including Diffraction



To check the minor influence on the result from diffraction, we perform the simulation with the following alternative settings.



Only minor changes appear in the “tails” of the fringes, while the simulation takes longer time than before.

Document Information

title	Fourier Transform Settings – Discussion at Examples
document code	MISC.0003
version	1.0
edition	VirtualLab Fusion Basic
software version	2020.1 (Build 1.238)
category	Feature Use Case
further reading	- Automatic Selection of Fourier Transform Techniques in Free-Space Propagation Operator - Pinhole Modeling in a Low-Fresnel-Number System - Analysis and Design of Afocal Systems for Laser Guide Stars - Collimation Testing with Shearing Interferometry