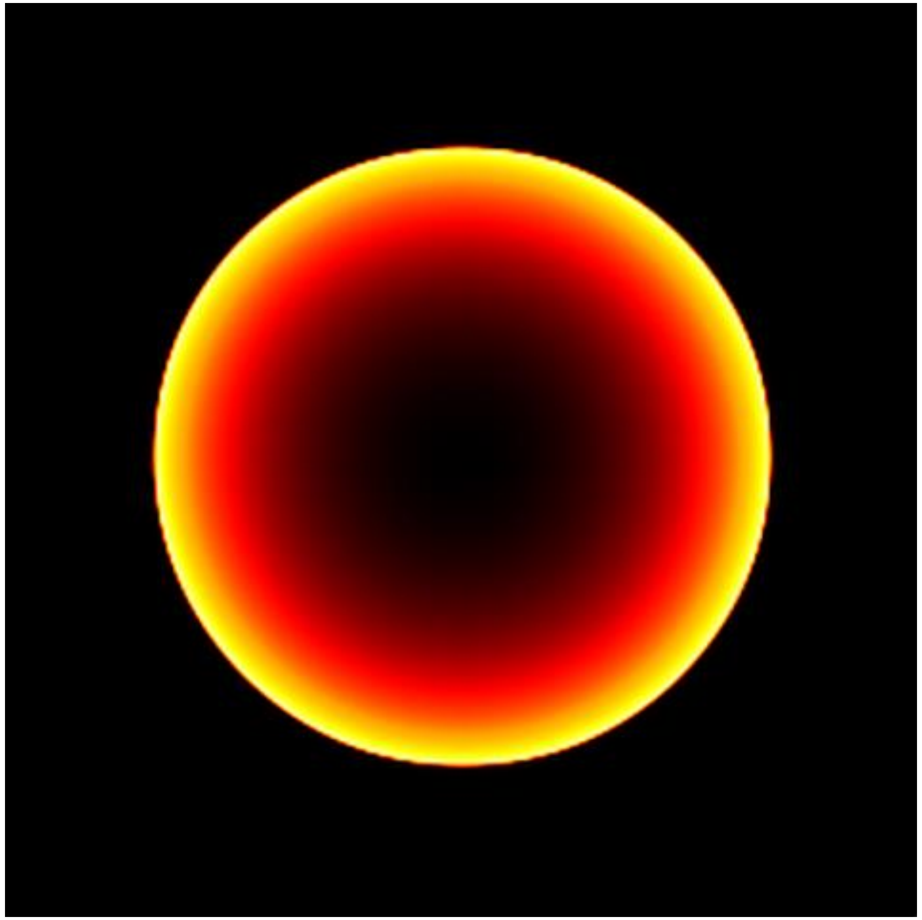
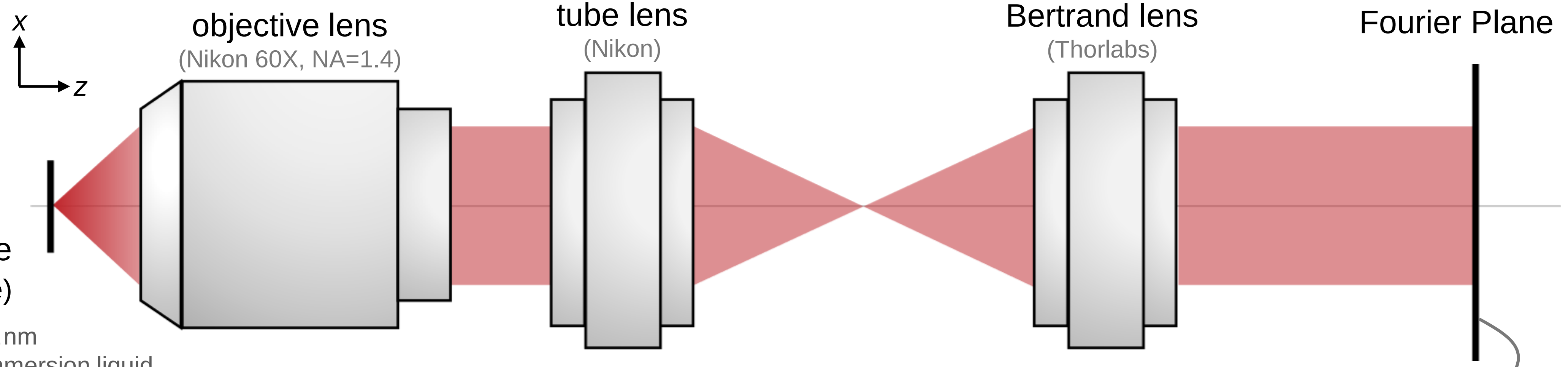
Single-Molecule Imaging with High-NA Fourier Microscope

Abstract



Fourier microscopy is widely used for single-molecule imaging, surface plasma observation, photonic crystal imaging, etc. It enables the direct observation of the spatial frequency distribution. Different effects in the high-NA Fourier microscope (angle-dependent Fresnel losses at each lens surface, diffraction, etc.) can affect the final image quality obtained for the single molecule. The fast physical optics software VirtualLab Fusion can model the entire system with its powerful Field Tracing engine, including the Fresnel losses and aperture diffraction effects. An example is presented, and we compare the simulation results with experimental results from literature.

Modeling Task



single molecule
(dipole source)

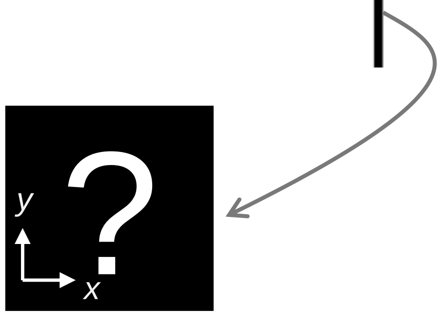
- wavelength 532 nm
- embedded in immersion liquid (n = 1.53)
- dipole orientations:

$[1,0,0]^T$ ↕

$[0,1,0]^T$ ⊗

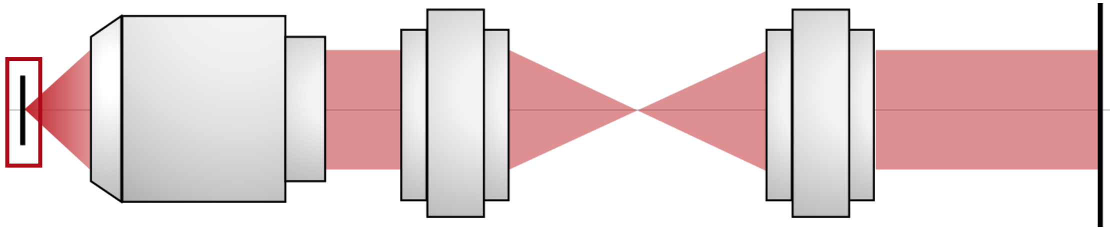
$[1,0,1]^T$ ↗

$[0,0,1]^T$ ↔



How does the Fourier plane image change with the orientation of the molecule?

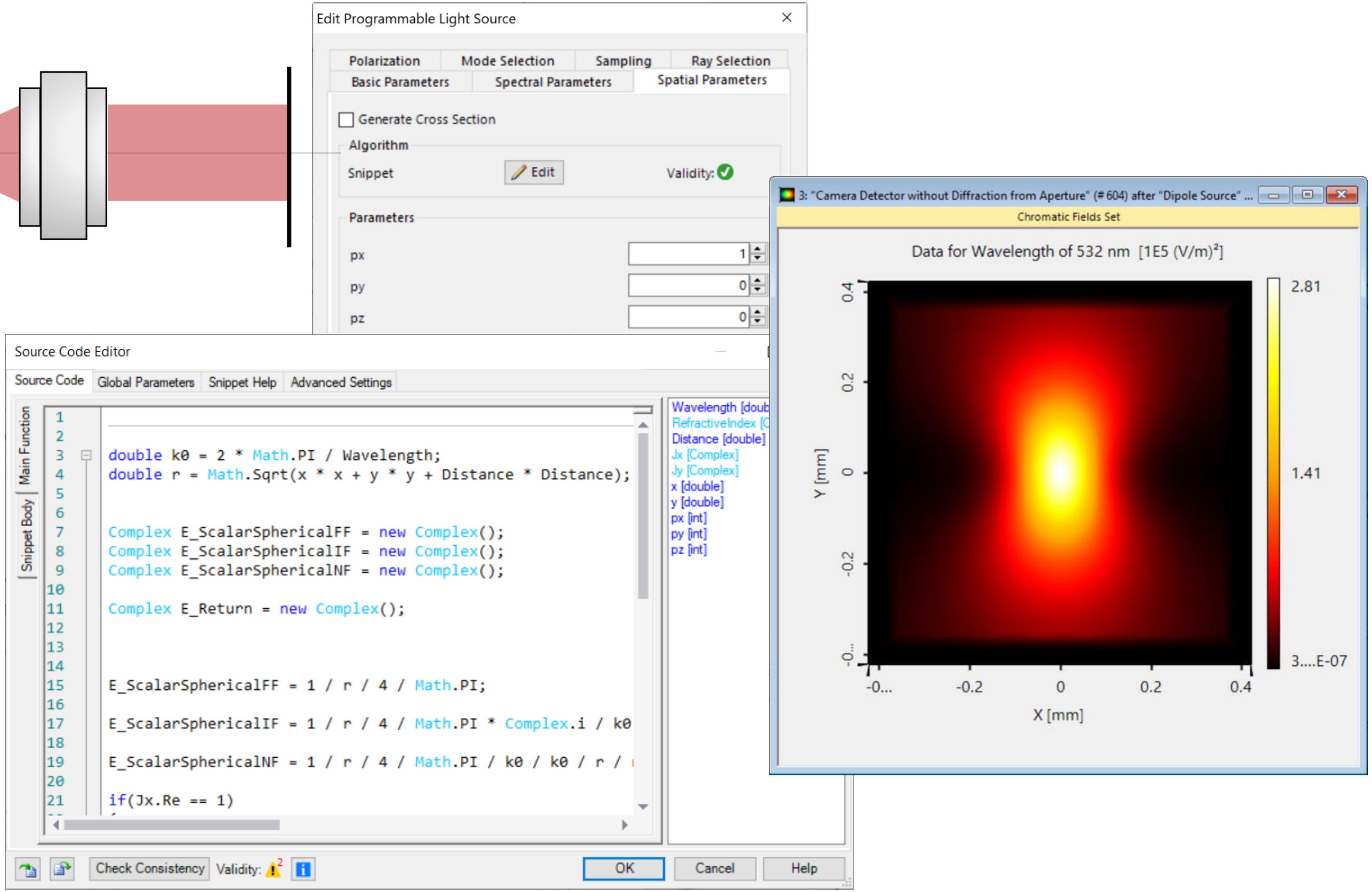
System Building Blocks: Dipole Source



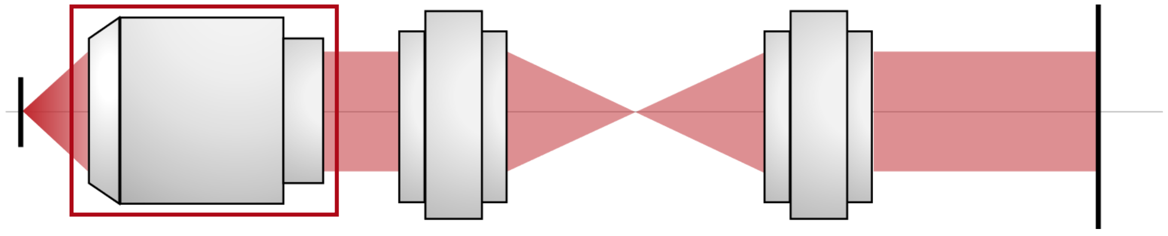
- The *Programmable Light Source* allows for the specification of an arbitrary lateral field distribution. In our case, we specify the field generated by a dipole.

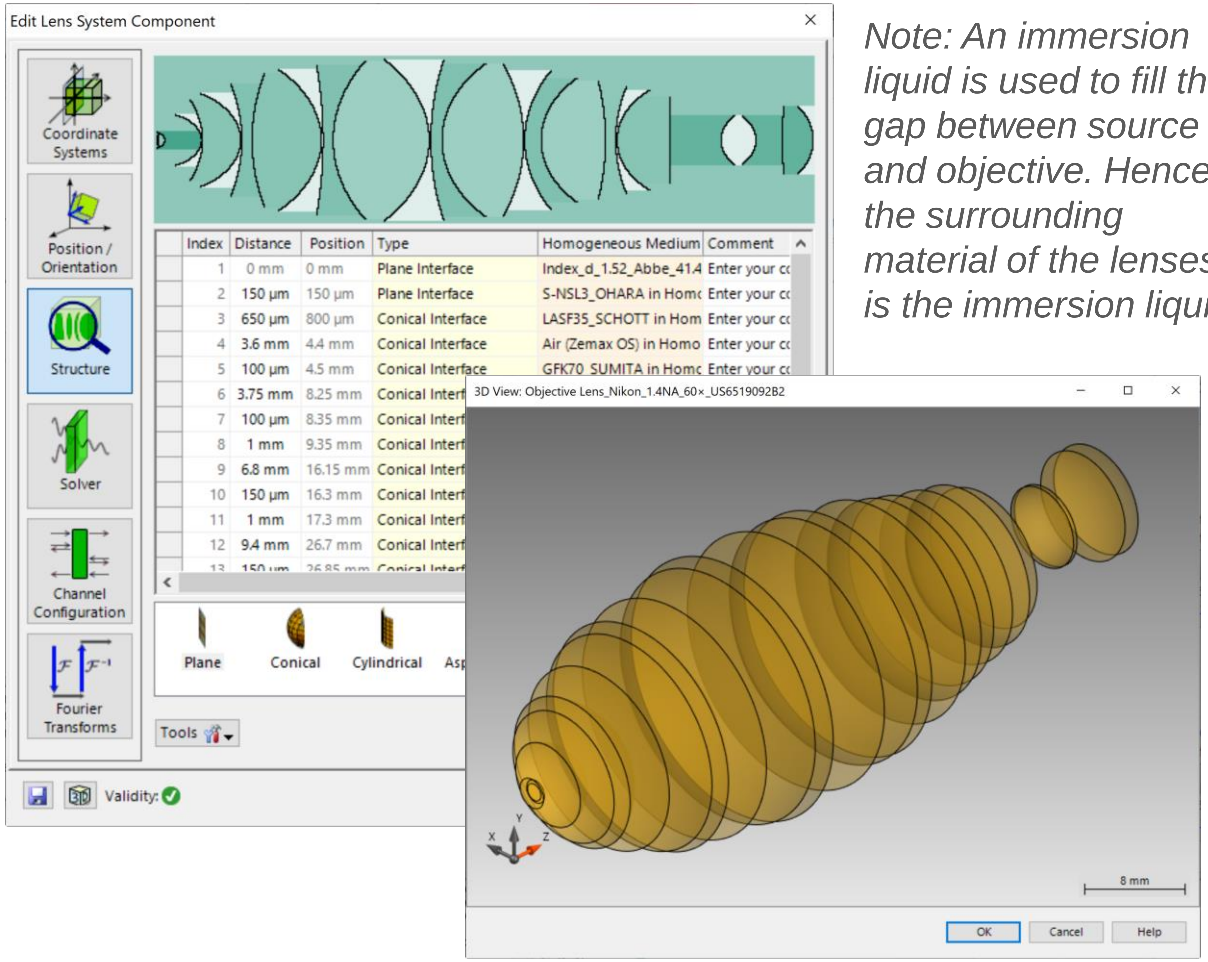
- The dipole source emits a locally polarized field (meaning that the spatial profile of the E_x and E_y components at the source plane is fundamentally different and therefore cannot be expressed with a single function).

- In order to accurately model the polarization characteristics, we employ a *Multiple Light Source,* that allows us to define the different profiles for the different components.



System Building Blocks: Objective Lens



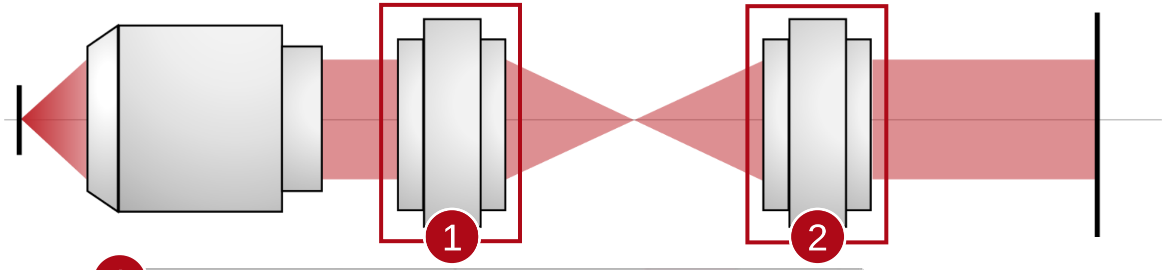


Note: An immersion liquid is used to fill the gap between source and objective. Hence the surrounding material of the lenses is the immersion liquid.

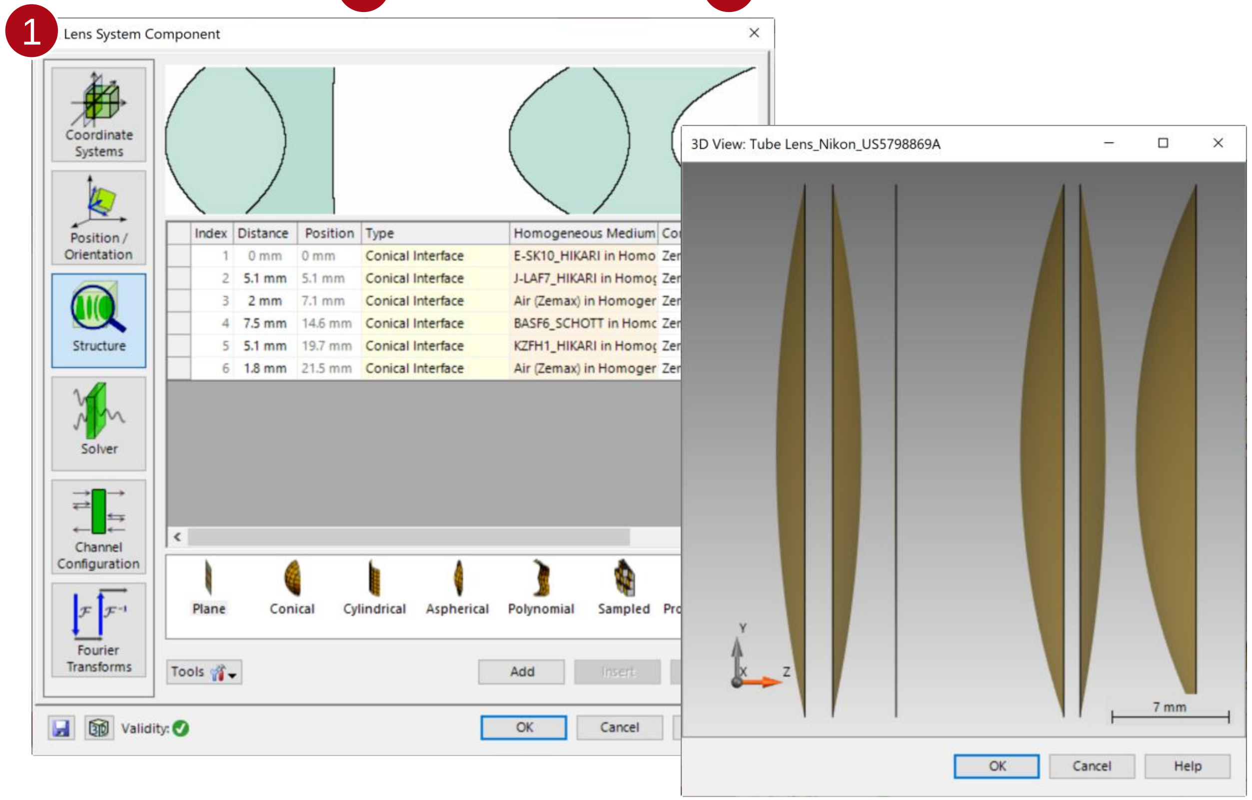
Objective lenses, such as the one used in this system, are usually quite complex structures, containing many interfaces and dispersive materials.

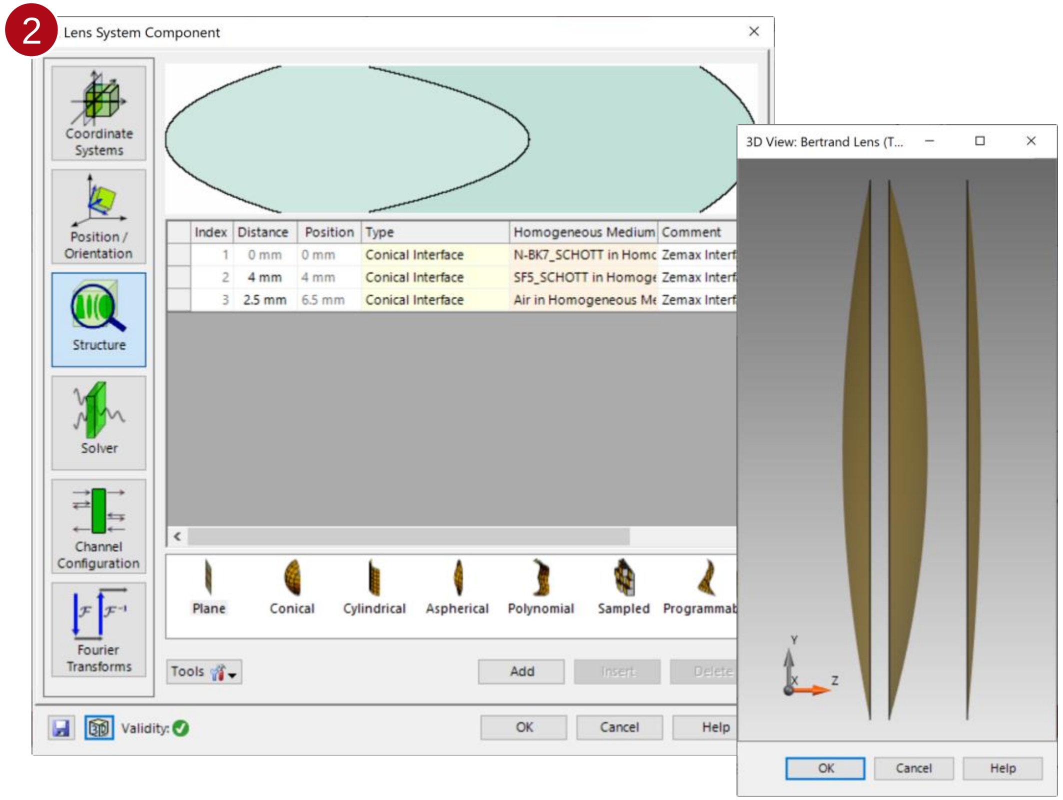
In VirtualLab Fusion, this can be modeled using the *Lens System Component*. There, the optical engineer can build up a component from a sequence of interfaces and materials.

System Building Blocks: Tube & Bertrand Lenses

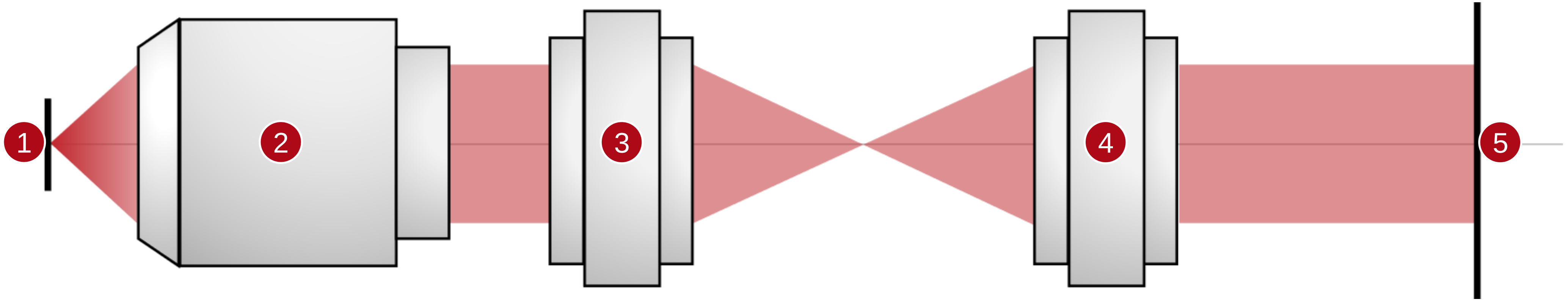


Tube lenses and Bertrand lenses are commonly used in microscopes to reproduce the image from the objective lens to the eye-piece. They can be imported into VirtualLab Fusion. We use the same modeling strategy as for the objective lens.





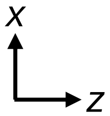
Summary of Model



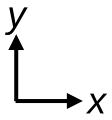
Optical System	Elements in VirtualLab Fusion	Model/Solver/Detected Value
1. dipole source	*Programmable & Multiple Light Source*	lateral field distribution
2. objective lens	*Lens System Component*	Local Plane Interface Approximation
3. tube lens	*Lens System Component*	Local Plane Interface Approximation
4. Bertrand lens	*Lens System Component*	Local Plane Interface Approximation
5. detector	*Camera Detector*	energy density measurement

Image at the Fourier Plane

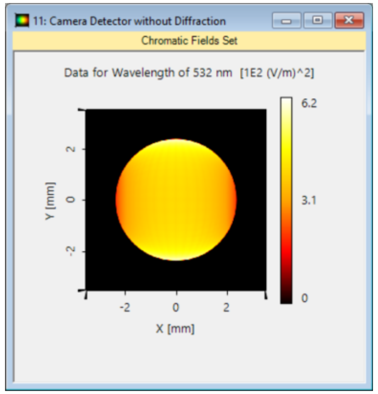
Dipole moment $[p_x, p_y, p_z]^T$

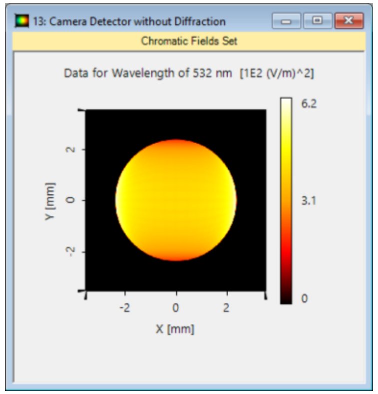


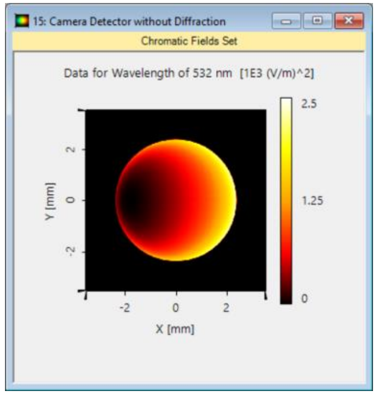
$[1,0,0]^T$	$[0,1,0]^T$	$[1,0,1]^T$	$[0,0,1]^T$

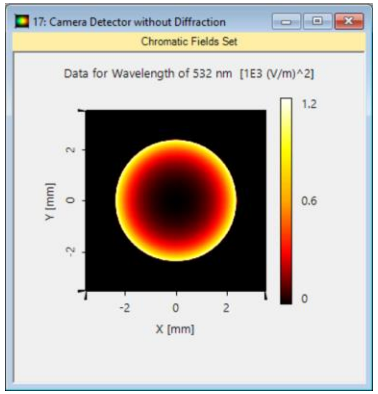


- without diffraction from aperture

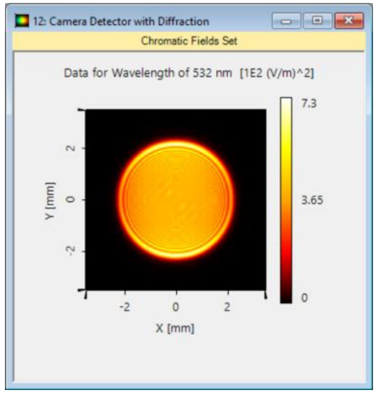


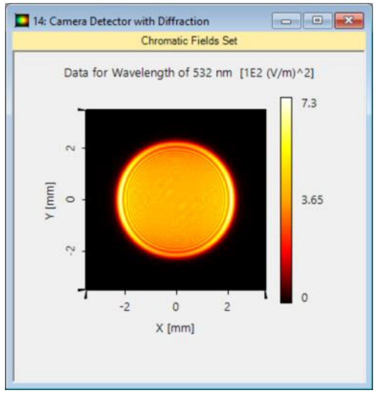


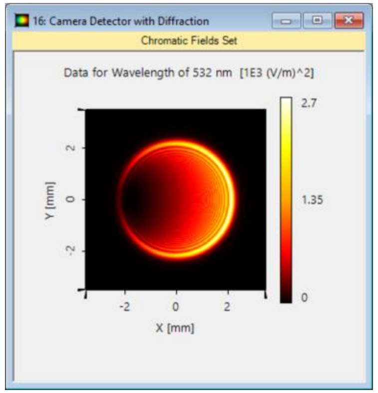


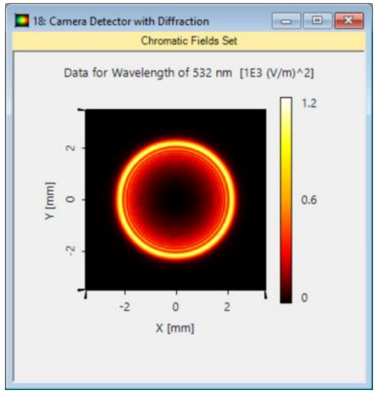


- with diffraction from aperture

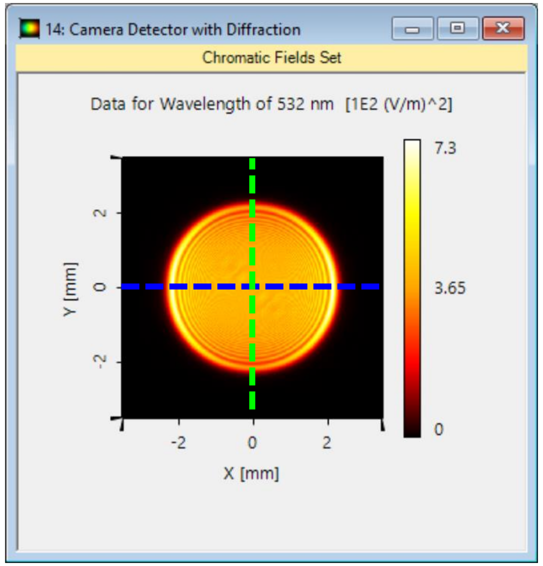




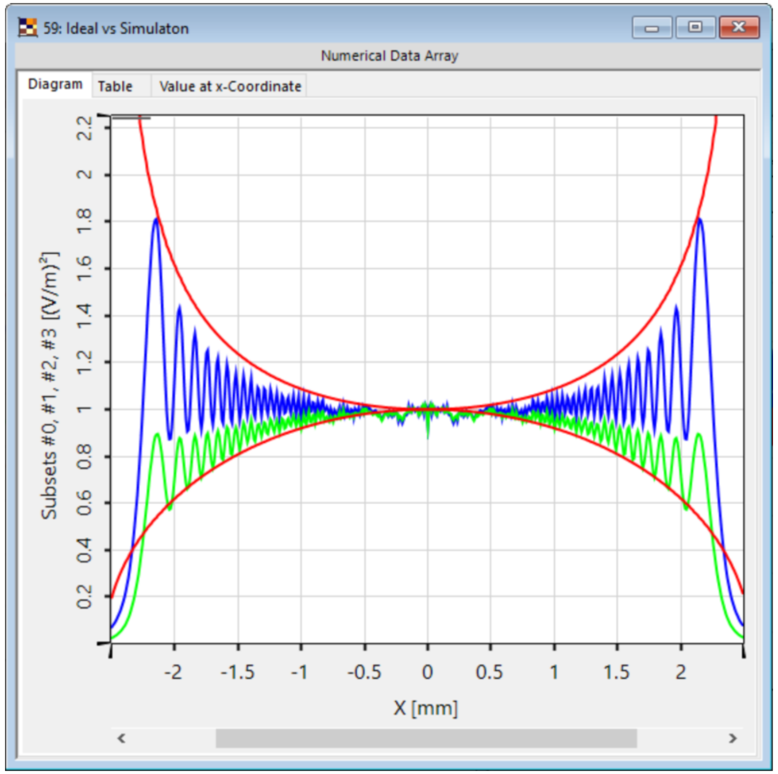




Simulation Comparison for Orientation [0,1,0]

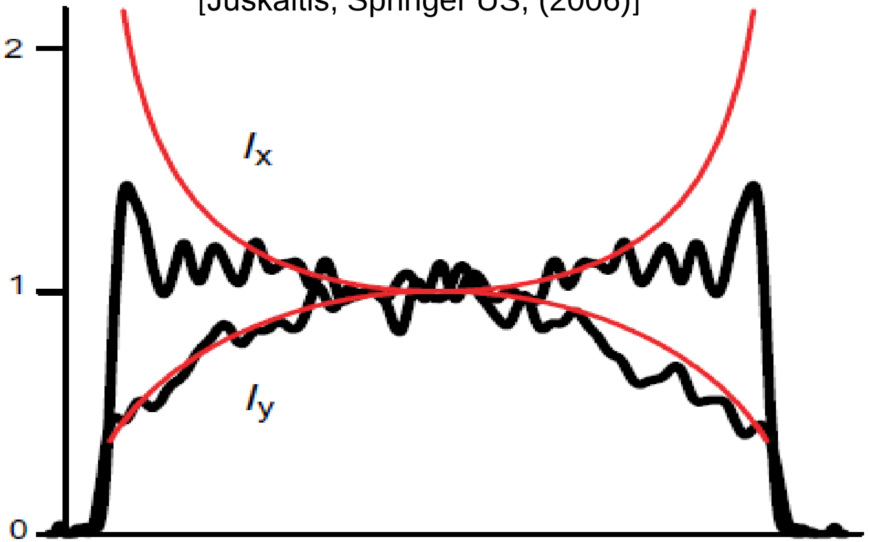


[0,1,0] ^{T} ⊗



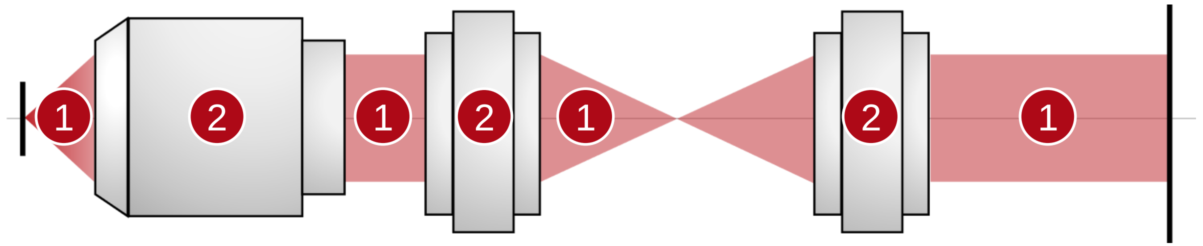
Reference

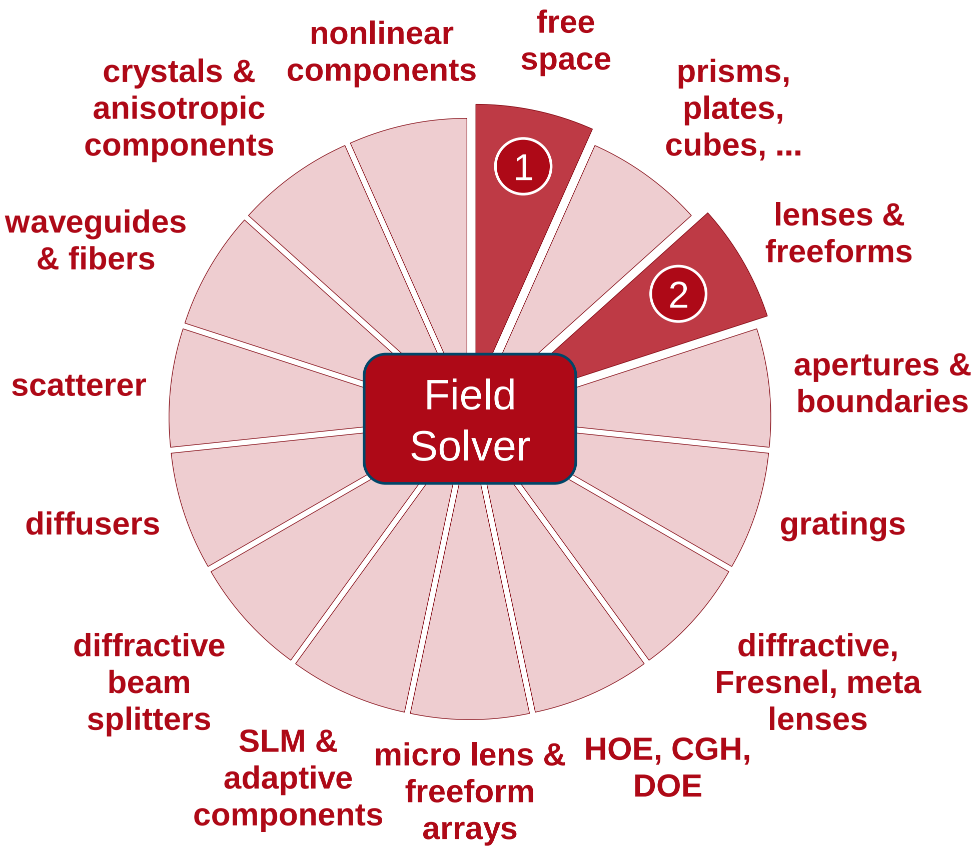
[Juškaitis, Springer US, (2006)]



In order to further investigate the physical effects, we took dipole orientation [0,1,0] and compared the obtained results to an experimental measurement [Juškaitis, Springer US, (2006)]. The blue and green curves are taken from the corresponding 1D cross-sections of the simulation result. Cross-sectional references of an idealized case (diffraction neglected) are depicted in red. The data of the reference curves was calculated analytically by applying formulas given in the reference publication and finally imported into VirtualLab Fusion.

VirtualLab Fusion Technologies





Document Information

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further reading	- Analyzing High-NA Objective Lens Focusing - Resolution Investigation for Microscope Objective Lenses by Rayleigh Criterion - Reflecting Microscope System with Very High Numerical Aperture