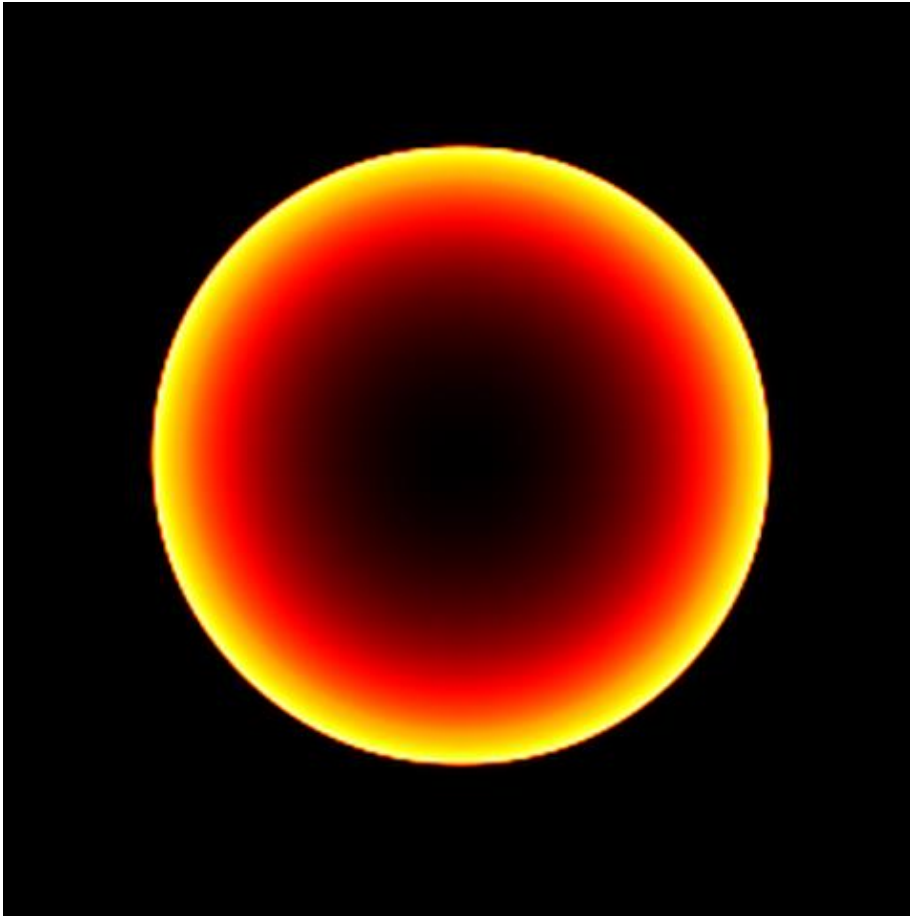


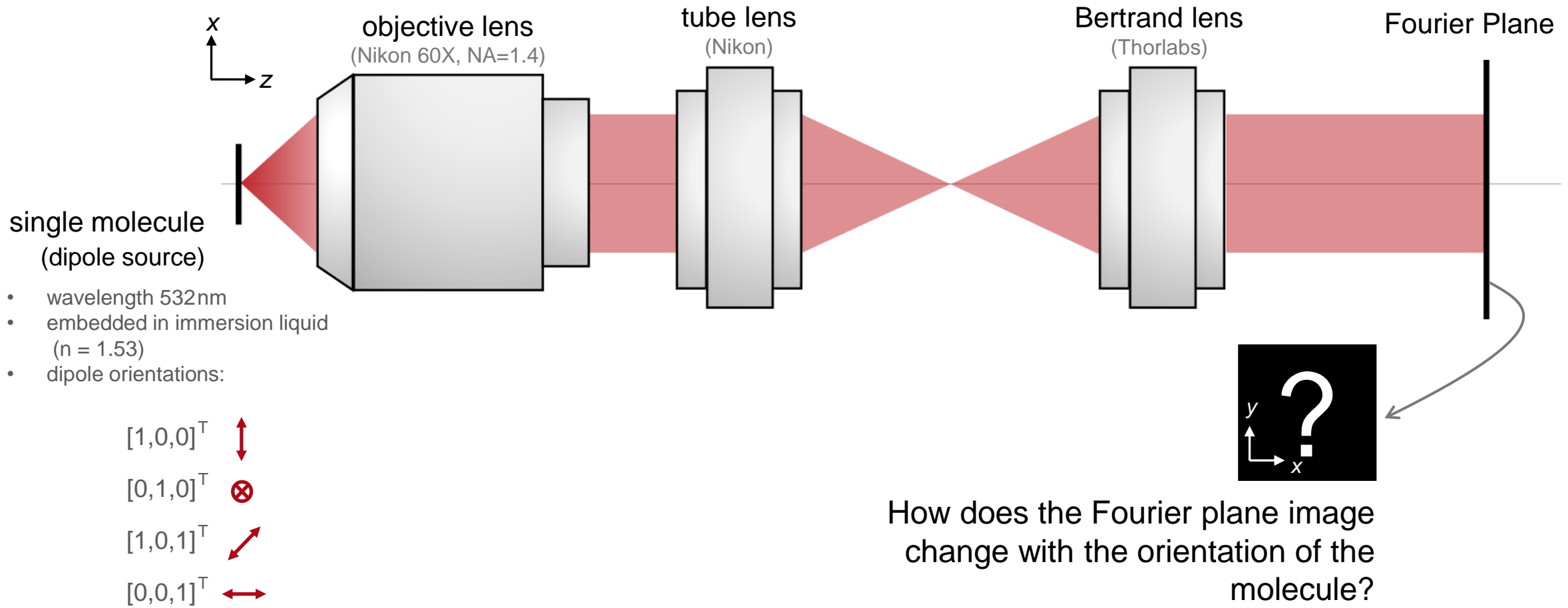
Single-Molecule Imaging with High-NA Fourier Microscope

Abstract

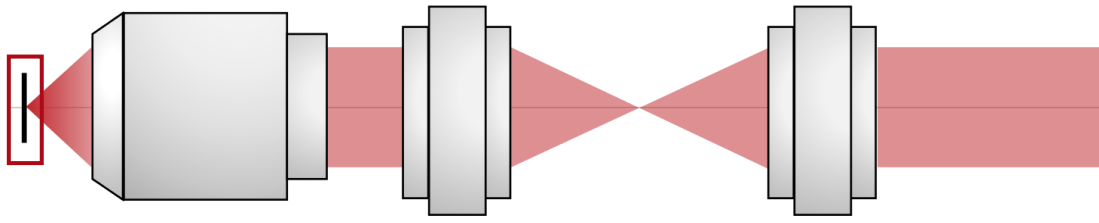


Fourier microscopy is widely used for single-molecule imaging, surface plasma observation, photonic crystal imaging, etc. It enables the direct observation of the spatial frequency distribution. Different effects in the high-NA Fourier microscope (angle-dependent Fresnel losses at each lens surface, 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



System Building Blocks: Dipole Source

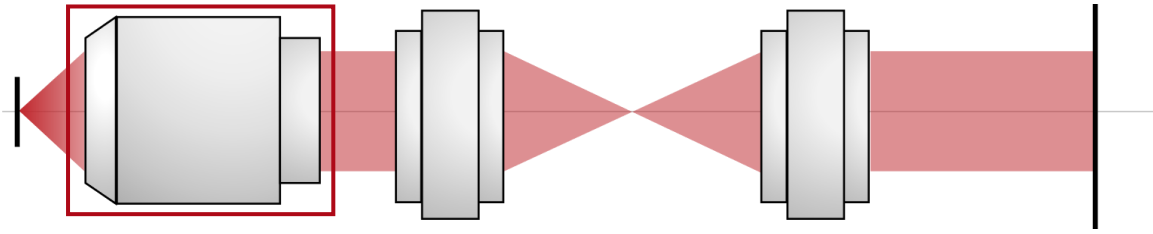


- The *Programmable Light Source* allows for the specification of an arbitrary lateral field distribution. In our case, we specify the field generated by a dipole.
- The dipole source emits a locally polarized field (meaning that the spatial profile of the E_x and E_y components at the source plane is 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.

The software interface consists of three main windows:

- Edit Programmable Light Source:** A dialog box with tabs for Polarization, Mode Selection, Sampling, and Ray Selection. It includes sections for Basic Parameters, Spectral Parameters, and Spatial Parameters. A 'Generate Cross Section' checkbox is present. The 'Algorithm' section shows a 'Snippet' with an 'Edit' button and a 'Validity' indicator (green checkmark). The 'Parameters' section has input fields for px (1), py (0), and pz (0).
- Source Code Editor:** A window with tabs for Source Code, Global Parameters, Snippet Help, and Advanced Settings. It displays C# code for calculating the field from a dipole source. The code includes variables for Wavelength, RefractiveIndex, Distance, and complex field components (E_ScalarSphericalFF, E_ScalarSphericalIF, E_ScalarSphericalNF, E_Return).
- Camera Detector without Diffraction from Aperture (#604) after "Dipole Source":** A window titled 'Chromatic Fields Set' showing 'Data for Wavelength of 532 nm [1E5 (V/m)²]'. It displays a 2D intensity plot with X and Y axes in mm, ranging from -0.4 to 0.4. A color scale on the right indicates intensity values from 3...E-07 to 2.81.

System Building Blocks: Objective Lens

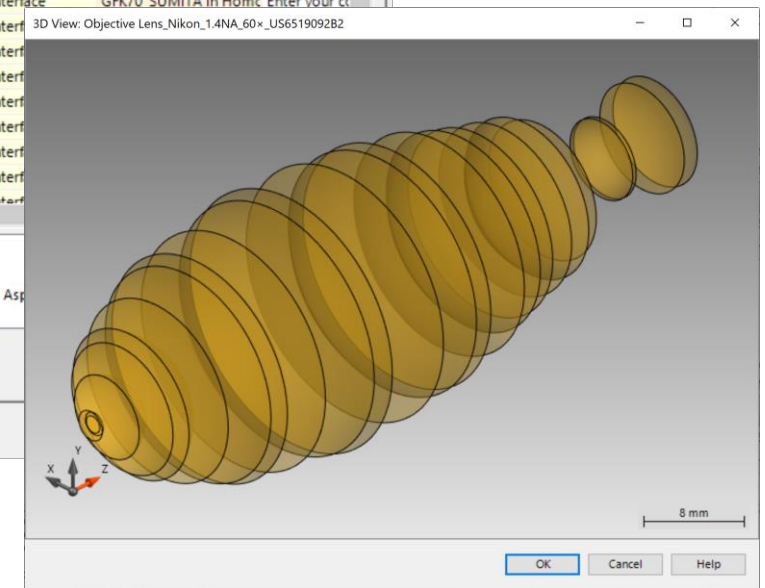


Objective lenses, such as the one used in this system, are usually quite complex structures, containing many interfaces and dispersive materials.

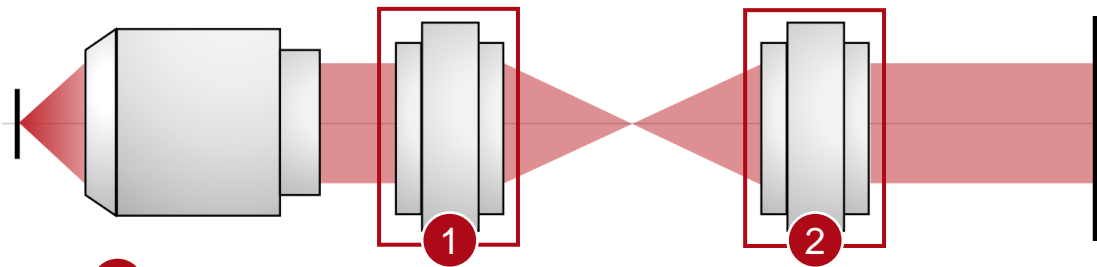
In VirtualLab Fusion, this can be modeled using the *Lens System Component*. There, the optical engineer can build up a component from a sequence of interfaces and materials.

Index	Distance	Position	Type	Homogeneous Medium	Comment
1	0 mm	0 mm	Plane Interface	Index_d_1.52_Abbe_41.4	Enter your co
2	150 μm	150 μm	Plane Interface	S-NSL3_OHARA in Hom	Enter your co
3	650 μm	800 μm	Conical Interface	LASF35_SCHOTT in Hom	Enter your co
4	3.6 mm	4.4 mm	Conical Interface	Air (Zemax OS) in Homo	Enter your co
5	100 μm	4.5 mm	Conical Interface	GFK70_SUMITA in Hom	Enter your co
6	3.75 mm	8.25 mm	Conical Interf		
7	100 μm	8.35 mm	Conical Interf		
8	1 mm	9.35 mm	Conical Interf		
9	6.8 mm	16.15 mm	Conical Interf		
10	150 μm	16.3 mm	Conical Interf		
11	1 mm	17.3 mm	Conical Interf		
12	9.4 mm	26.7 mm	Conical Interf		
13	150 μm	26.85 mm	Conical Interf		

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.



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.

1 Lens System Component

Index	Distance	Position	Type	Homogeneous Medium	Comment
1	0 mm	0 mm	Conical Interface	E-SK10_HIKARI in Homo	Zer
2	5.1 mm	5.1 mm	Conical Interface	J-LAF7_HIKARI in Homo	Zer
3	2 mm	7.1 mm	Conical Interface	Air (Zemax) in Homoge	Zer
4	7.5 mm	14.6 mm	Conical Interface	BASF6_SCHOTT in Homc	Zer
5	5.1 mm	19.7 mm	Conical Interface	KZFH1_HIKARI in Homo	Zer
6	1.8 mm	21.5 mm	Conical Interface	Air (Zemax) in Homoge	Zer

3D View: Tube Lens_Nikon_US5798869A

7 mm

OK Cancel Help

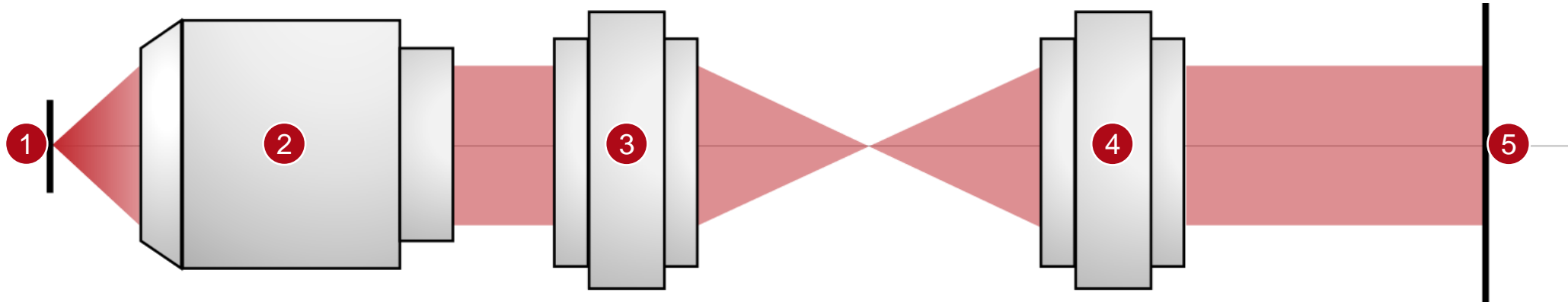
2 Lens System Component

Index	Distance	Position	Type	Homogeneous Medium	Comment
1	0 mm	0 mm	Conical Interface	N-BK7_SCHOTT in Homc	Zemax Interf
2	4 mm	4 mm	Conical Interface	SF5_SCHOTT in Homoge	Zemax Interf
3	2.5 mm	6.5 mm	Conical Interface	Air in Homogeneous M	Zemax Interf

3D View: Bertrand Lens (T...

OK Cancel Help

Summary of Model

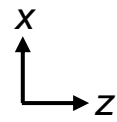


Optical System	Elements in VirtualLab Fusion	Model/Solver/Detected Value
1. dipole source	<i>Programmable & Multiple Light Source</i>	lateral field distribution
2. objective lens	<i>Lens System Component</i>	Local Plane Interface Approximation
3. tube lens	<i>Lens System Component</i>	Local Plane Interface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

Image at the Fourier Plane

Dipole moment

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



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



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



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



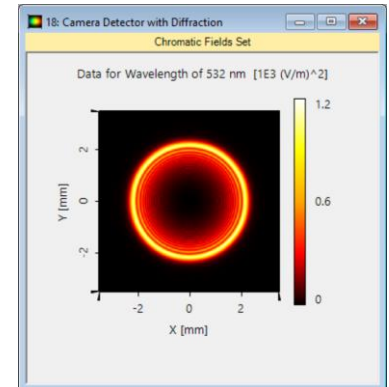
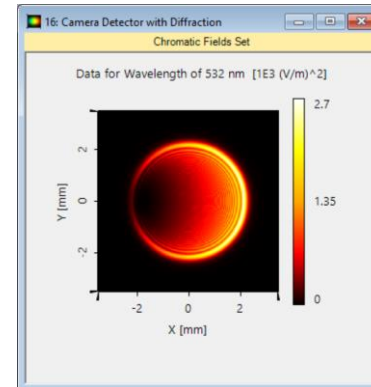
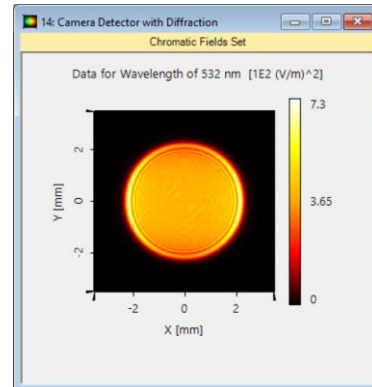
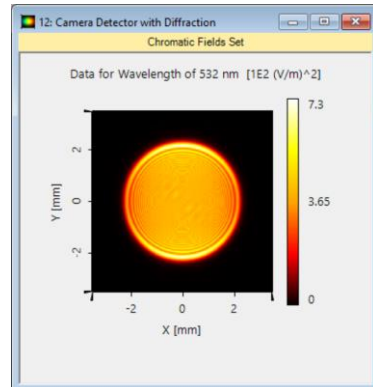
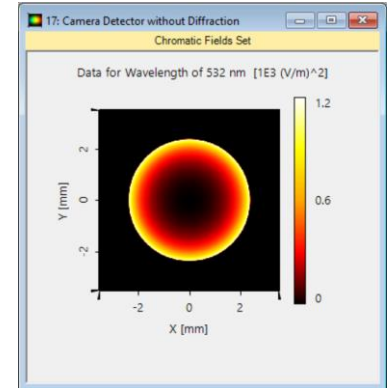
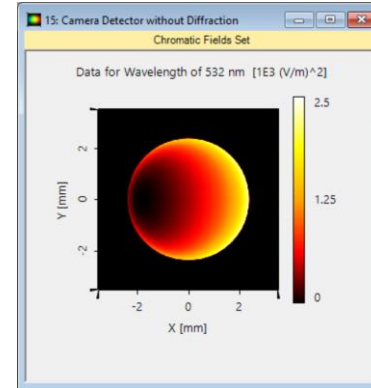
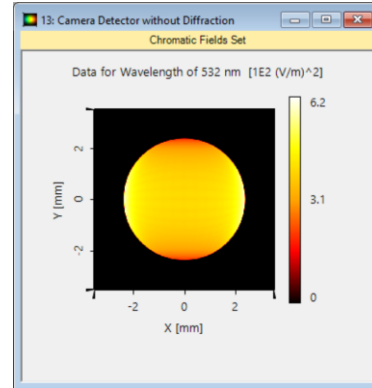
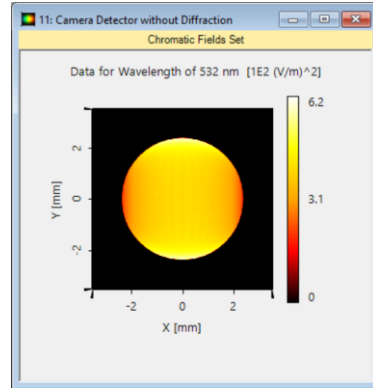
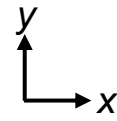
$$[0, 0, 1]^T$$



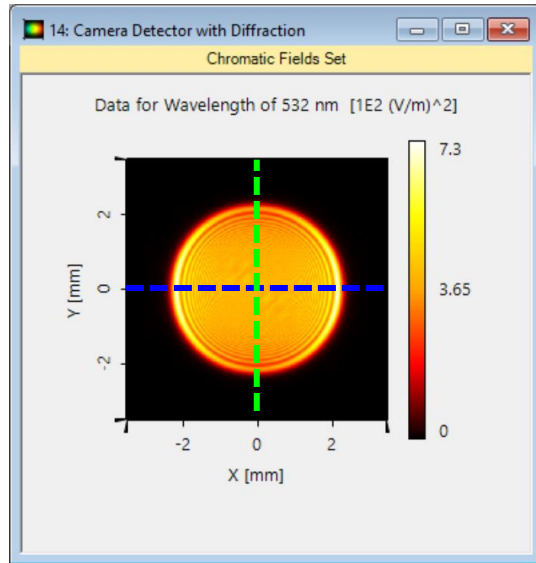
- without diffraction from aperture



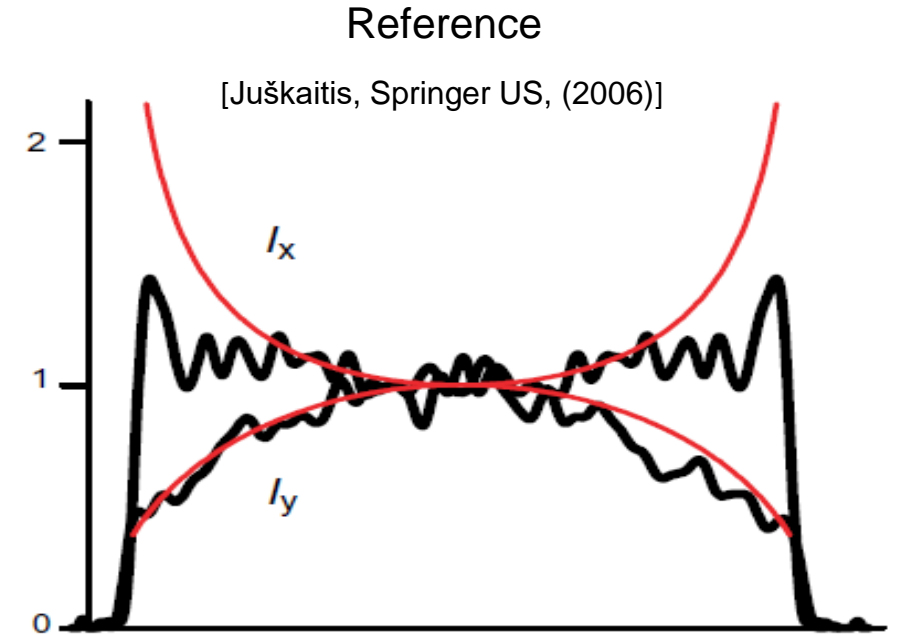
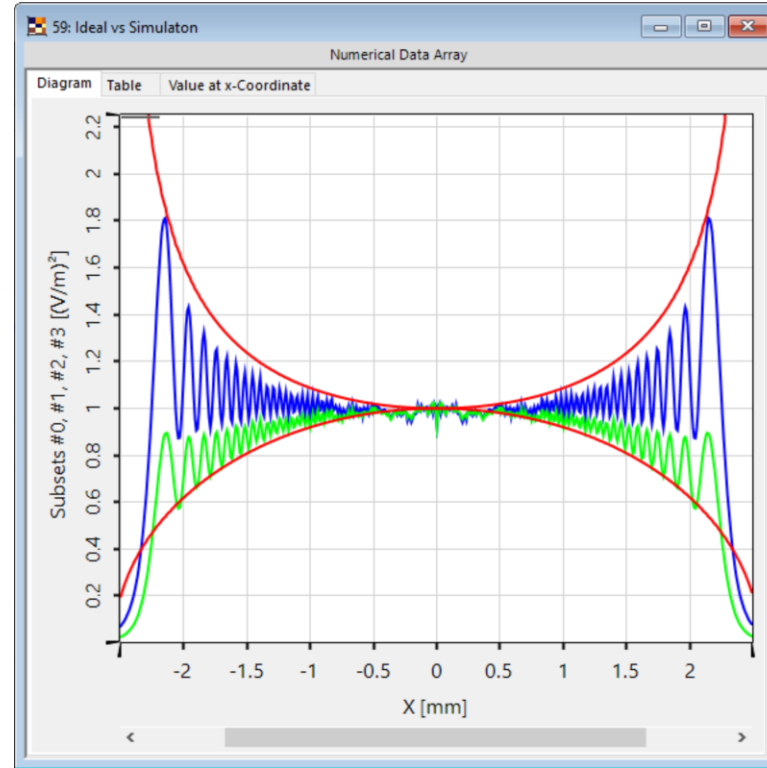
- with diffraction from aperture



Simulation Comparison for Orientation $[0,1,0]$

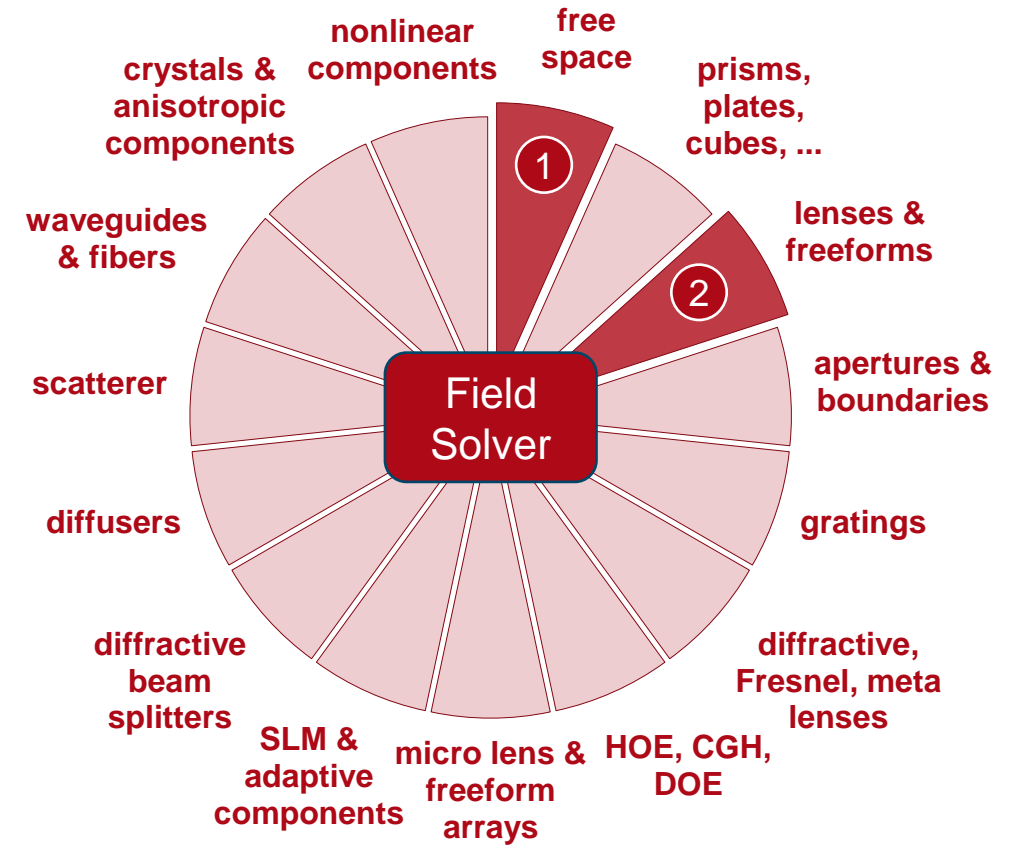
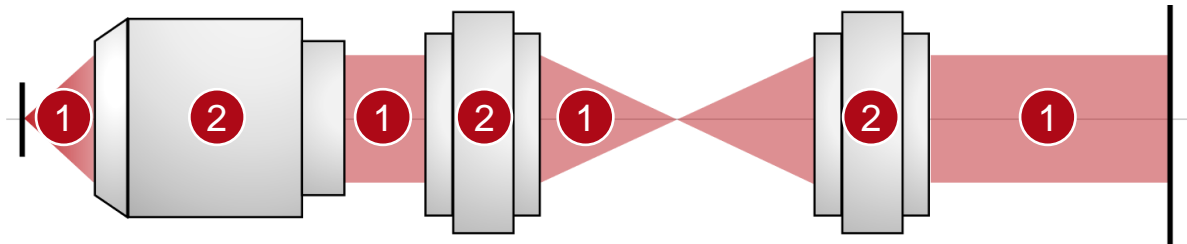


$[0,1,0]^T$ \otimes



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

title	Single-Molecule Imaging with High-NA Fourier Microscope
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