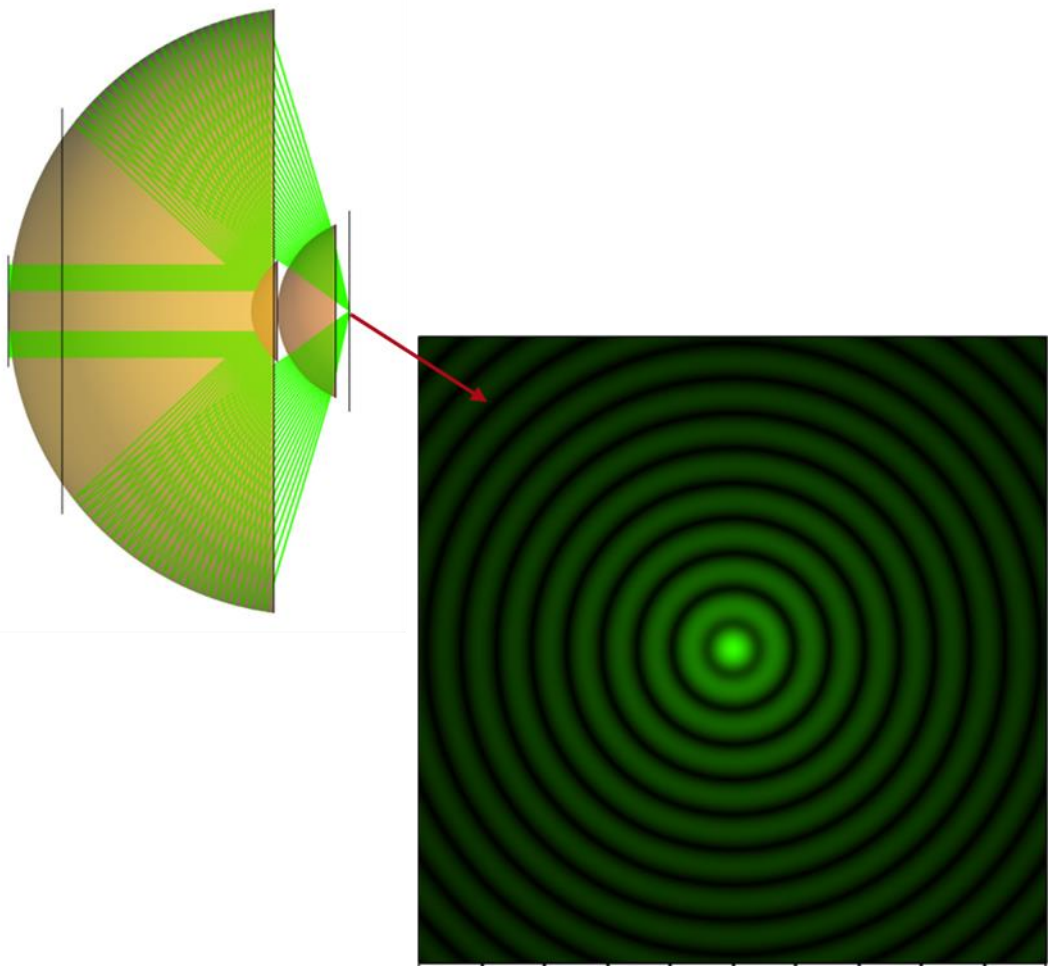
Reflecting Microscope System with very high Numerical Aperture

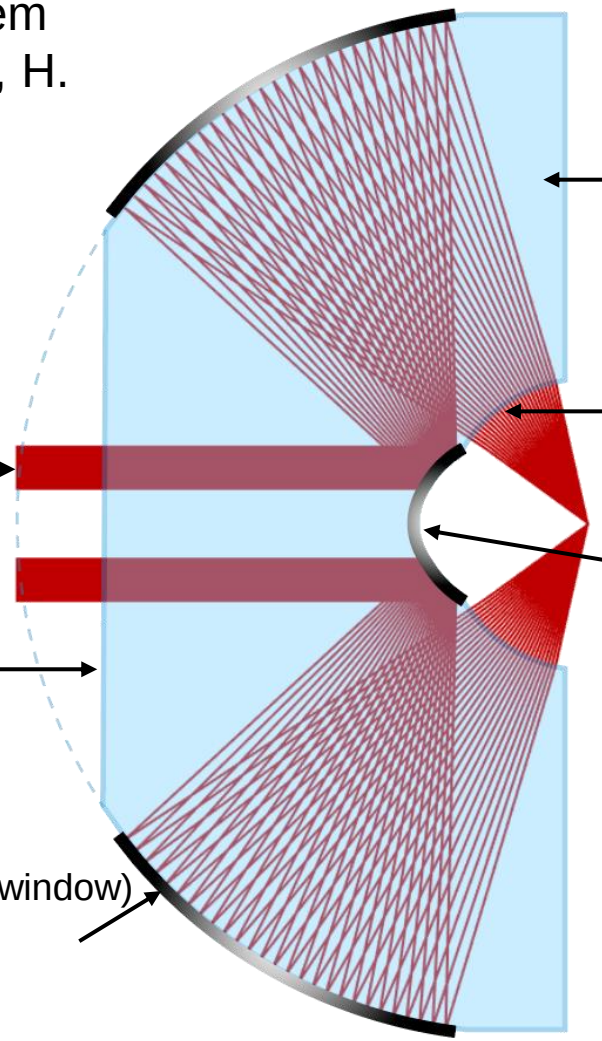
Abstract



In single-molecule microscopy imaging applications, localization precision is a critical issue. Since the localization precision in a certain direction is proportional to the width of the point spread function (PSF) of the image in the same direction, a microscope with a higher numerical aperture (NA) can reduce the width of the PSF and thus improve the localization precision. In this use case, we demonstrate the modeling of very compact reflecting microscope system with an NA of 0.99 (Inagawa et al., 2015), and compare the results obtained with VirtualLab Fusion's fast physical optics technology to the reference.

Task Description

Modeling of the reflecting microscope system with high numerical aperture from Inagawa, H. et al., Sci Rep 5, 12833 (2015).



source
- Plane Wave
- wavelength: 532 nm
- diameter: 4.5 mm
- circularly polarized

plane window
- radius of curvature: ∞

spherical mirror
- inner diameter: 16.9 mm (plane window)
- outer diameter: 29.75 mm
- radius of curvature: 15.0 mm

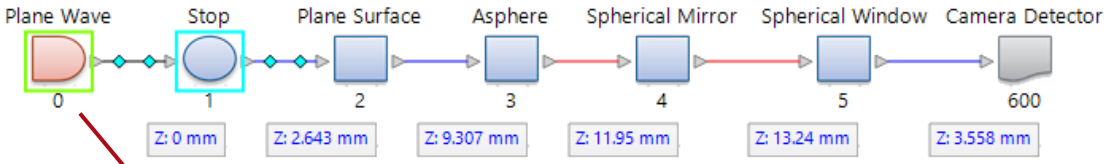
fused silica

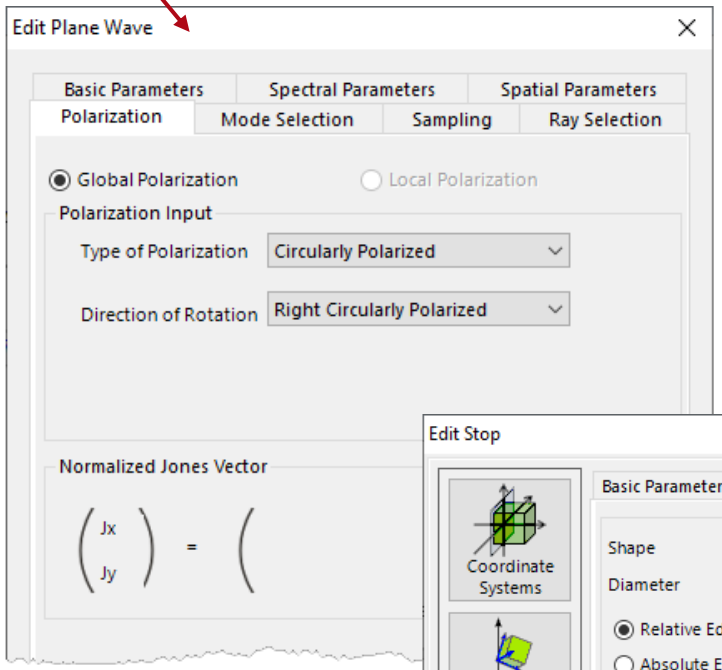
spherical window
- diameter: 29.75 mm
- radius of curvature: 4.61 mm

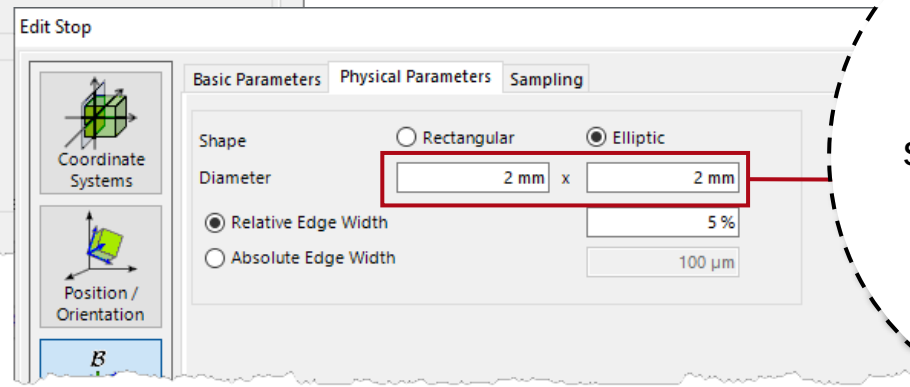
aspherical mirror
- diameter: 5.0 mm
- radius of curvature: 2.1 mm
- conical constant: –0.67
- coefficient 2: $-5.981 \cdot 10^{-2}\,\mathrm{mm}^{-1}$
- coefficient 4: $1.022801 \cdot 10^{-4}\,\mathrm{mm}^{-3}$
- coefficient 6: $-3.409849 \cdot 10^{-5}\,\mathrm{mm}^{-5}$
- coefficient 8: $-3.45471 \cdot 10^{-5}\,\mathrm{mm}^{-7}$

Parameters from Inagawa, H. et al., Sci Rep 5, 12833 (2015).

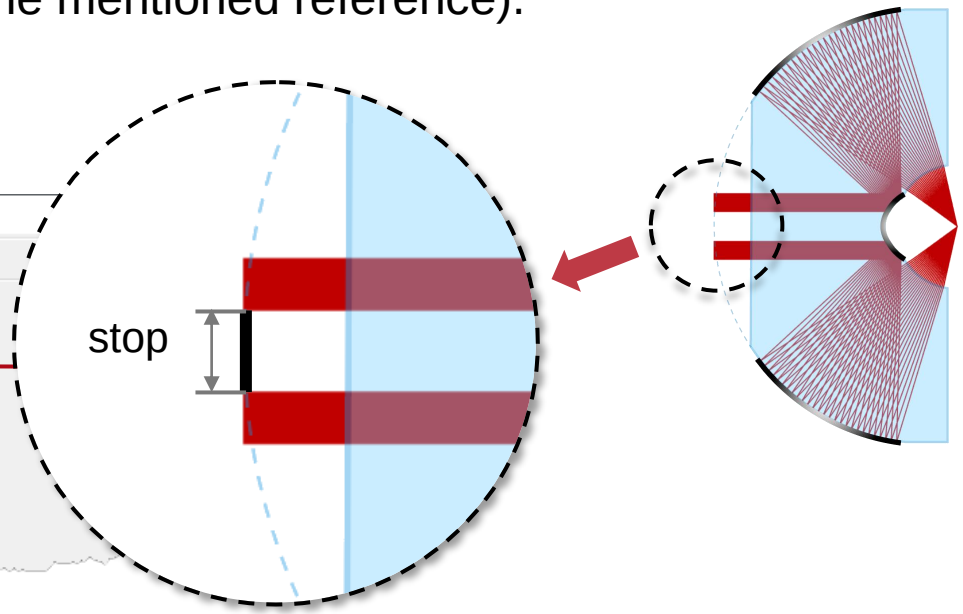
System Building Blocks – Source



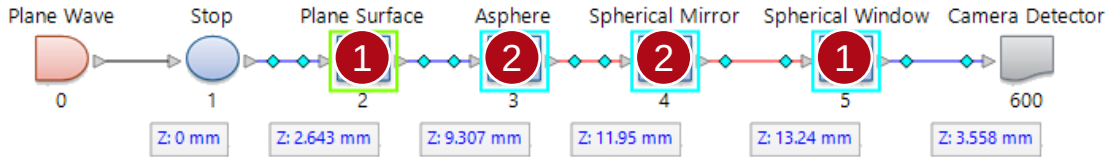




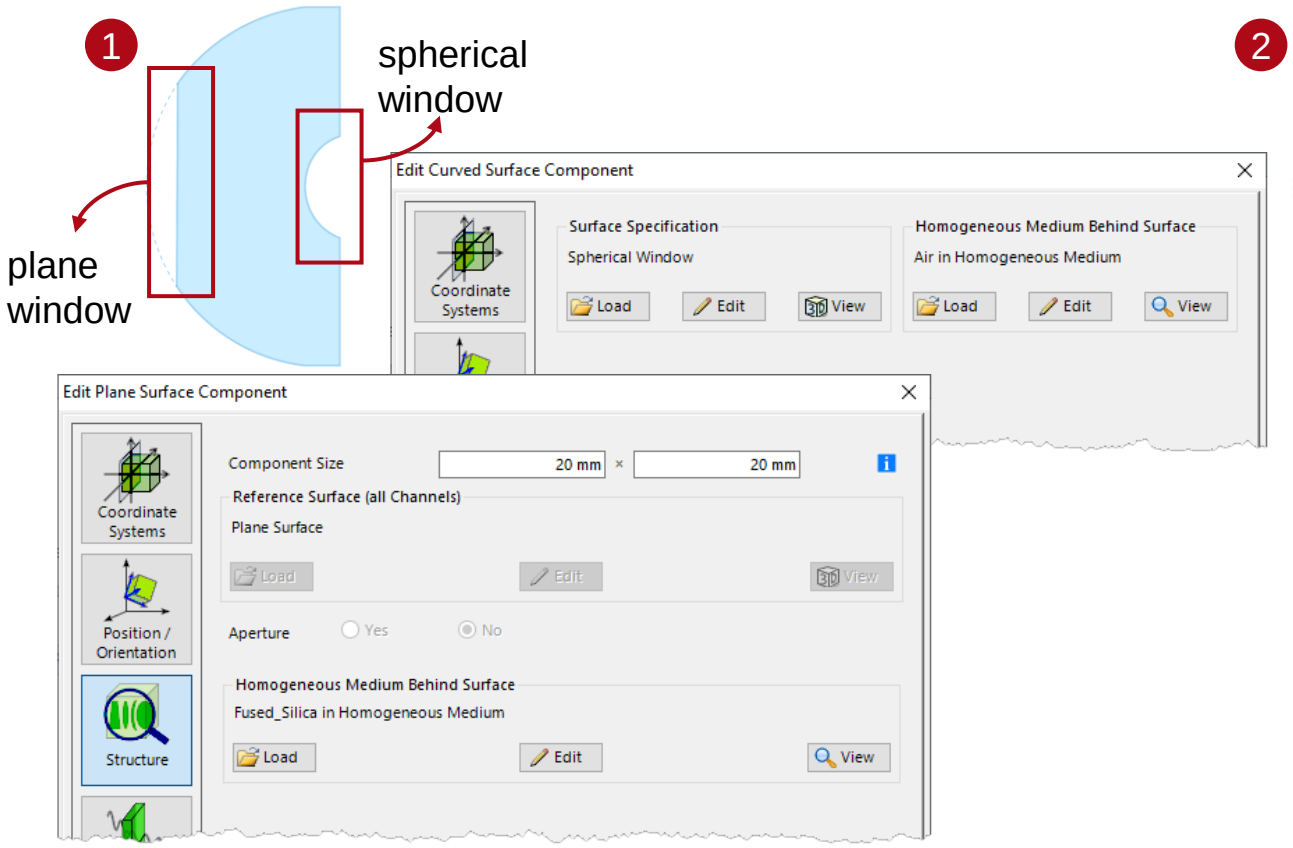
- In order to avoid additional effects introduced by an asymmetrical polarization state, the input plane wave is circularly polarized (right-hand oriented).
- An additional *Stop* component is applied to block light that would be reflected by the aspheric mirror but never reach the spherical mirror (as shown in the mentioned reference).

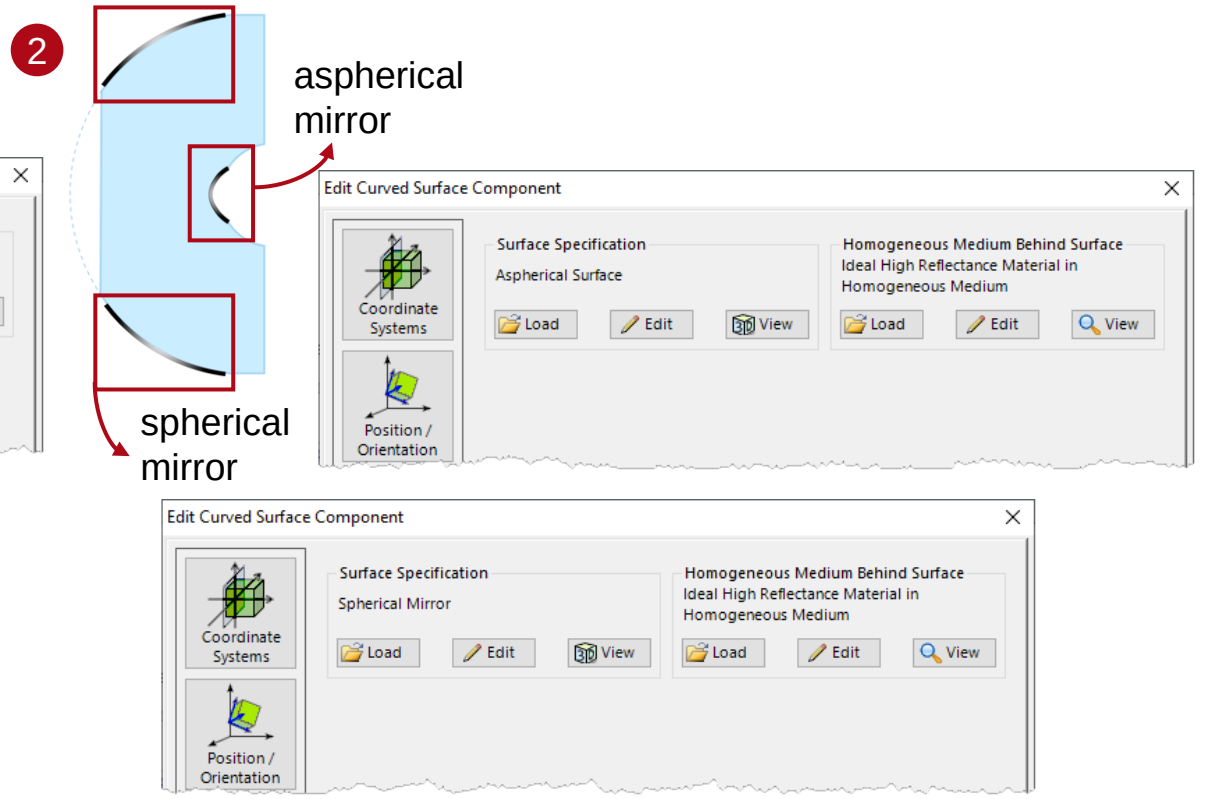


System Building Blocks – Objective Lens

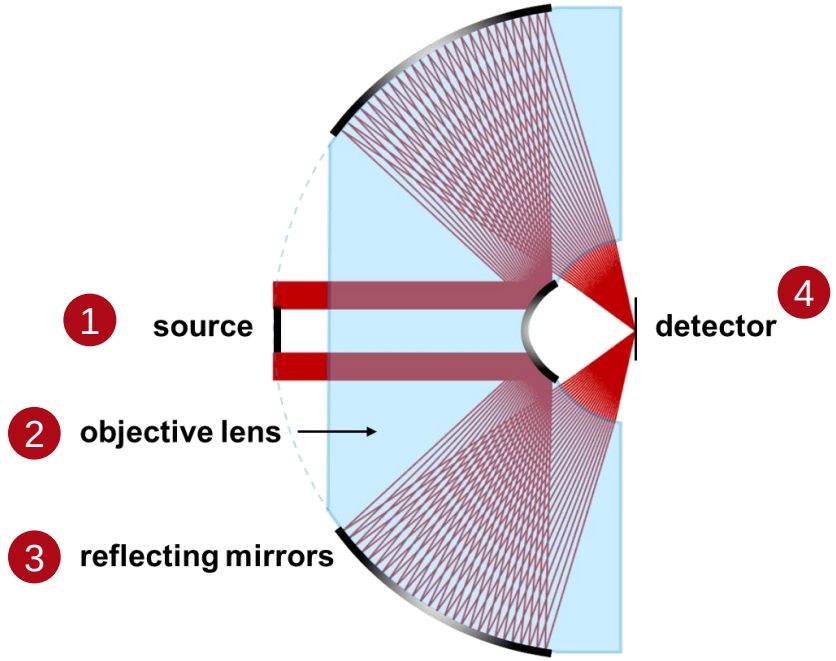


The complex and partially coated lens consists of two parts: 1. the fused silica lens component itself and 2. the ideally reflecting coatings that provide the aspherical and spherical mirror functions.





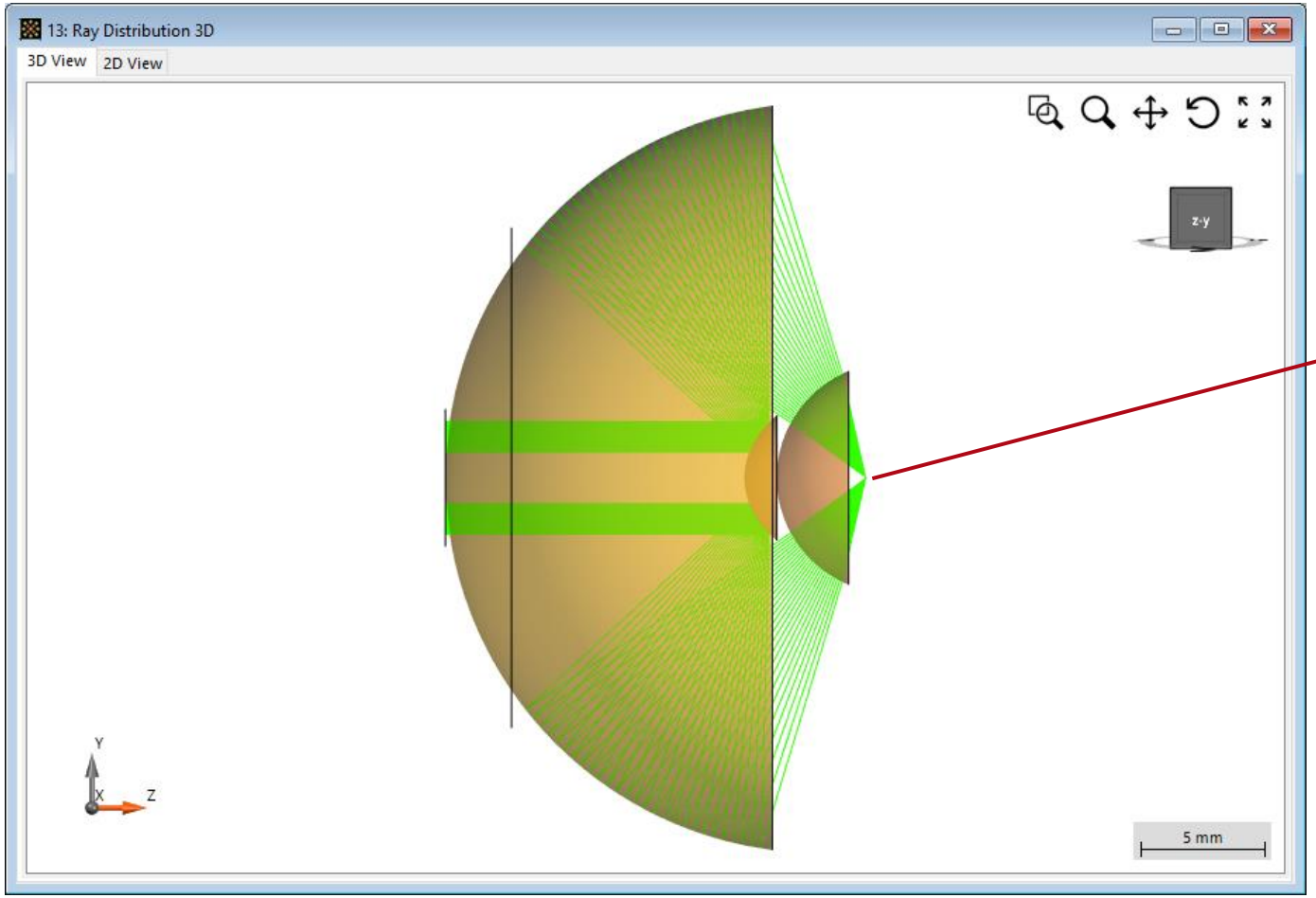
Summary of Model



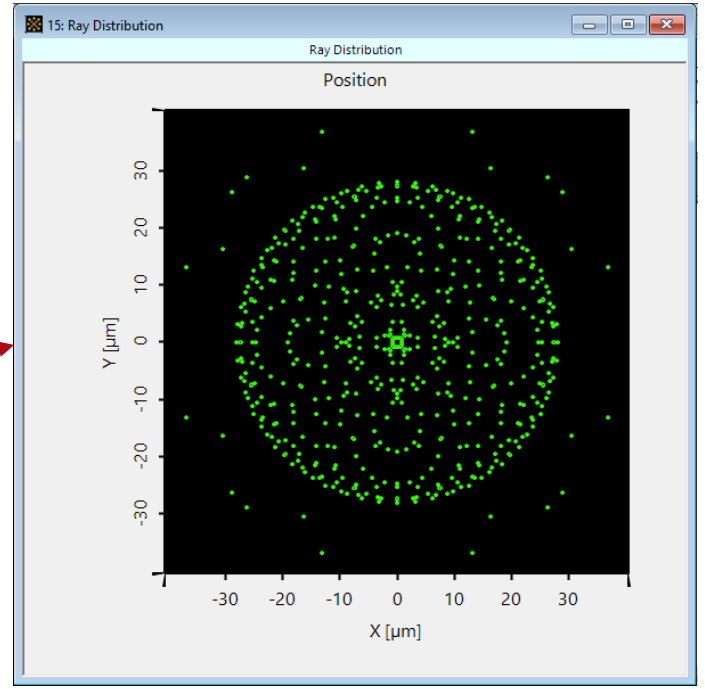
Optical System	Elements in VirtualLab Fusion	Model/Solver/Detected Value
1. source	*Plane Wave* source & *Stop*	truncated ideal plane wave
2. objective lens	• *Plane Surface* • *Conical Surface*	• Fresnel Matrix • Local Plane Interface Approximation
3. reflecting mirrors	*Conical Surface*	Local Plane Interface Approximation
4. detector	*Camera Detector*	energy density measurement

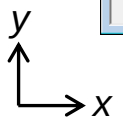
Ray Tracing Result

rays in system:

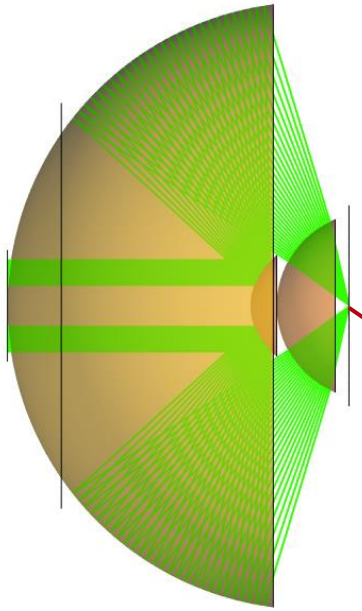


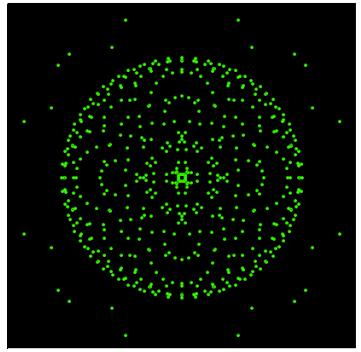
ray distribution on detector plane:





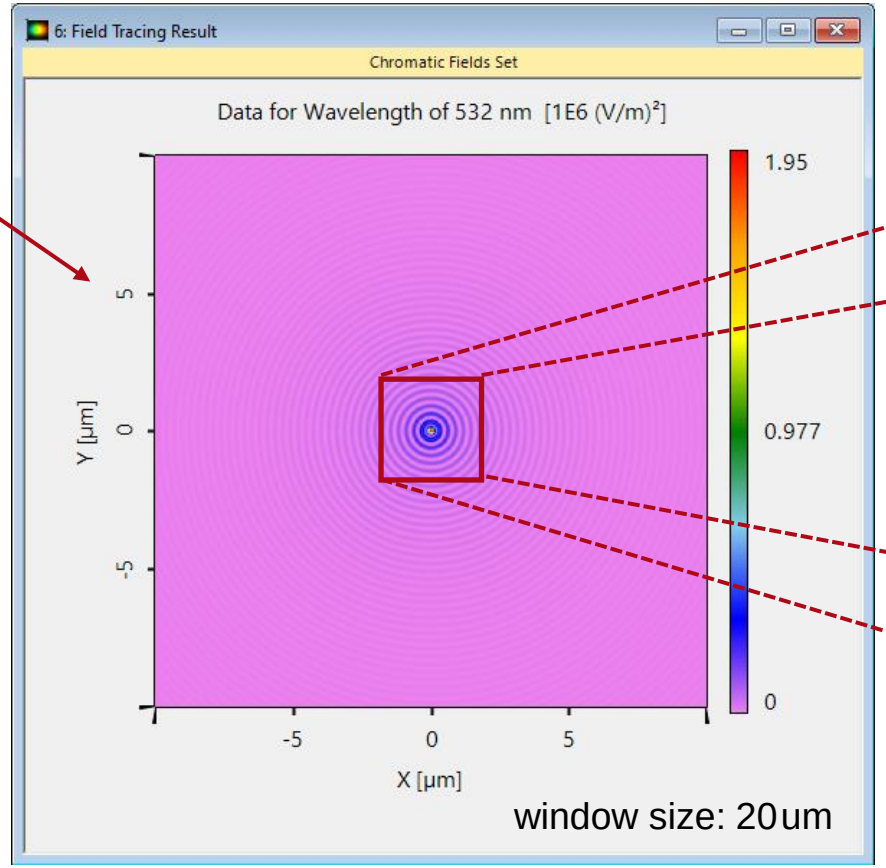
Result: Field Tracing (False Color)



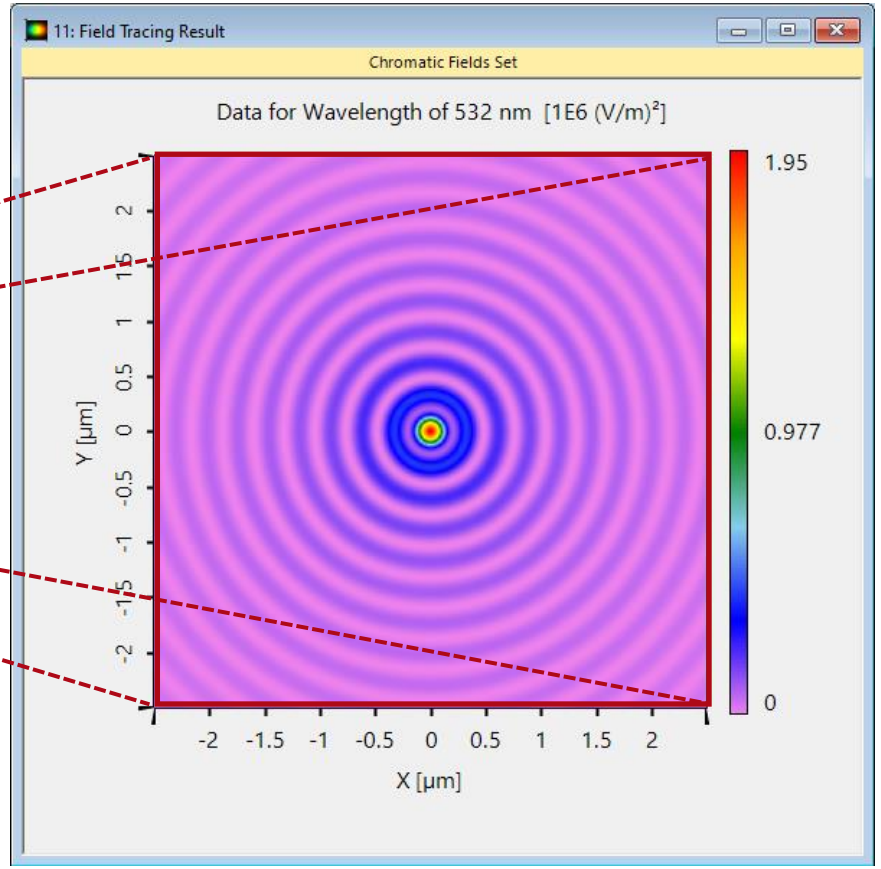


window size: 80um

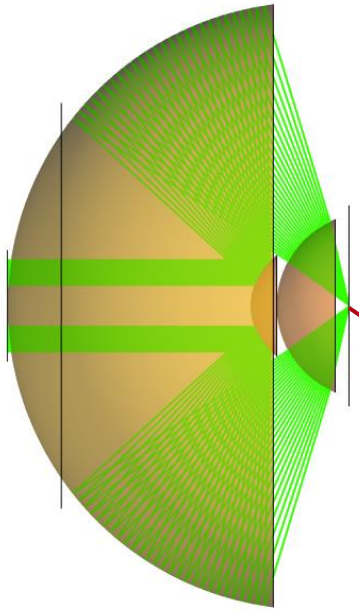
The width of the PSF is much smaller than the diameter obtained in the ray tracing spot diagram due to the strong diffraction effects introduced by the very high NA.



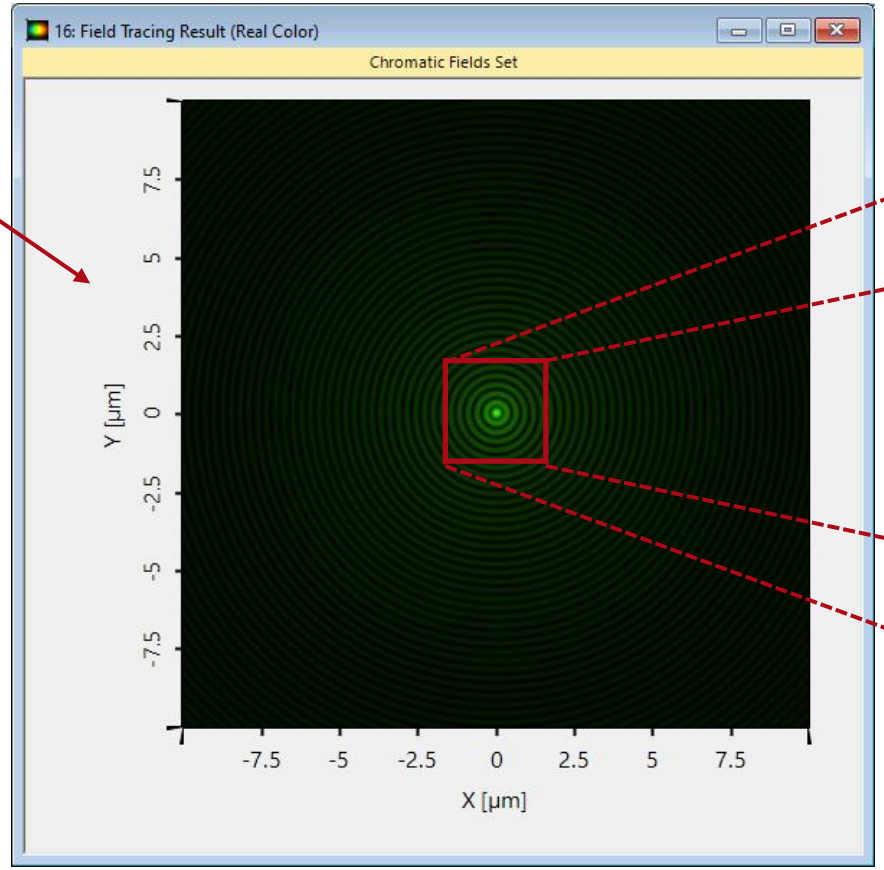
window size: 20um

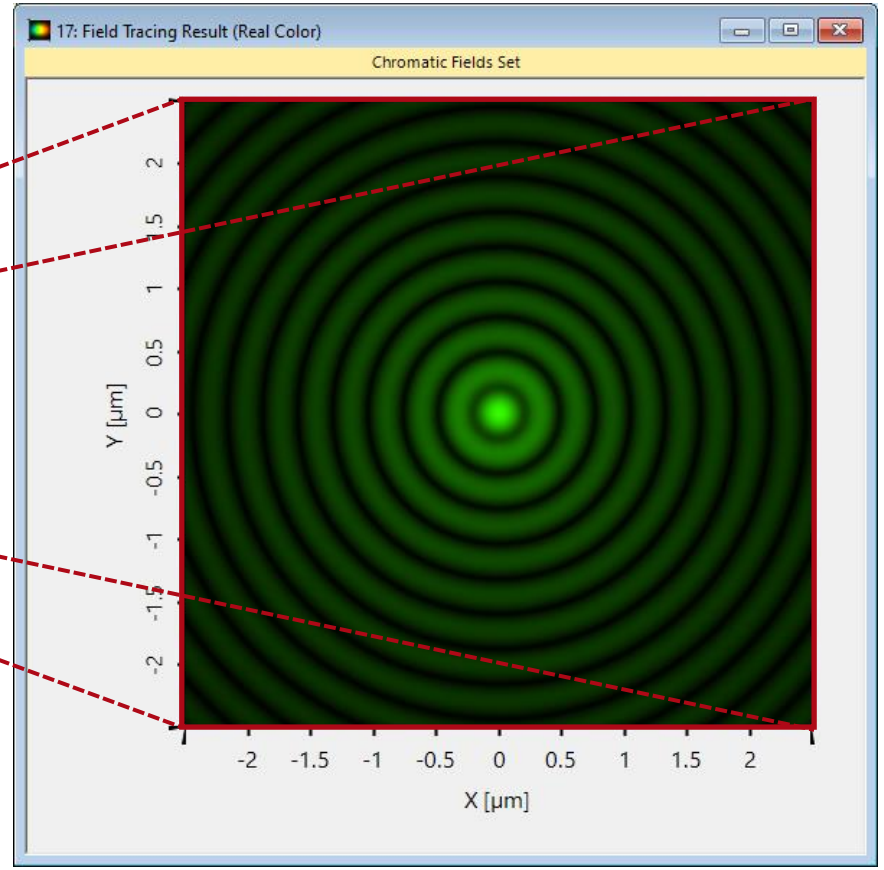


Result: Field Tracing (Real Color)

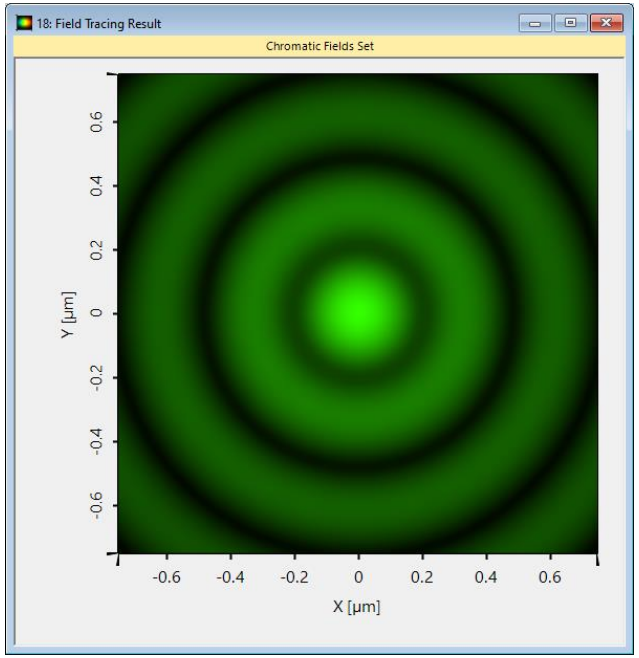


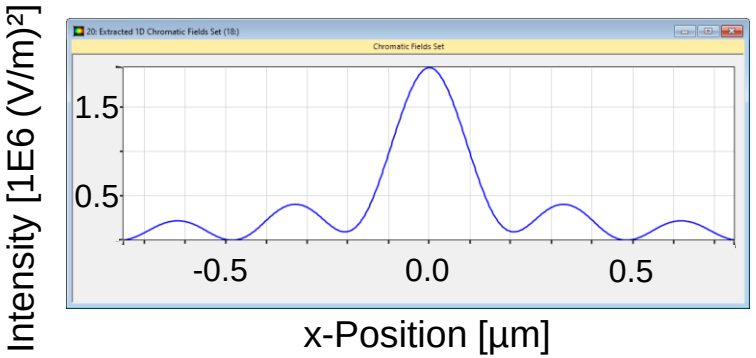
The width of the PSF is much smaller than the diameter obtained in the ray tracing spot diagram due to the strong diffraction effects introduced by the very high NA.

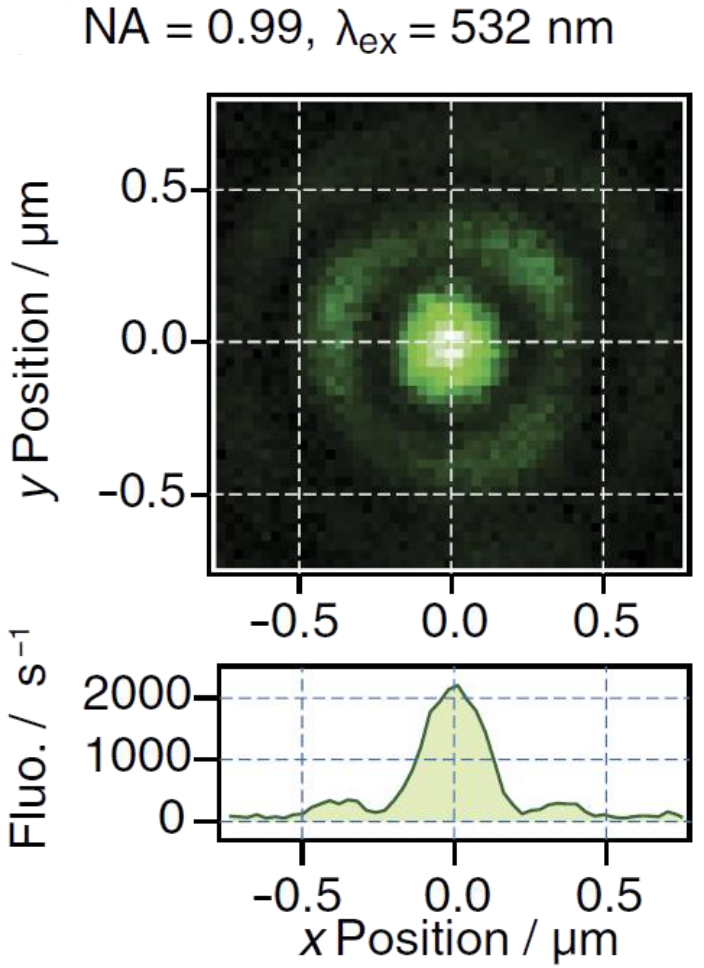




Comparison with Experimental Results

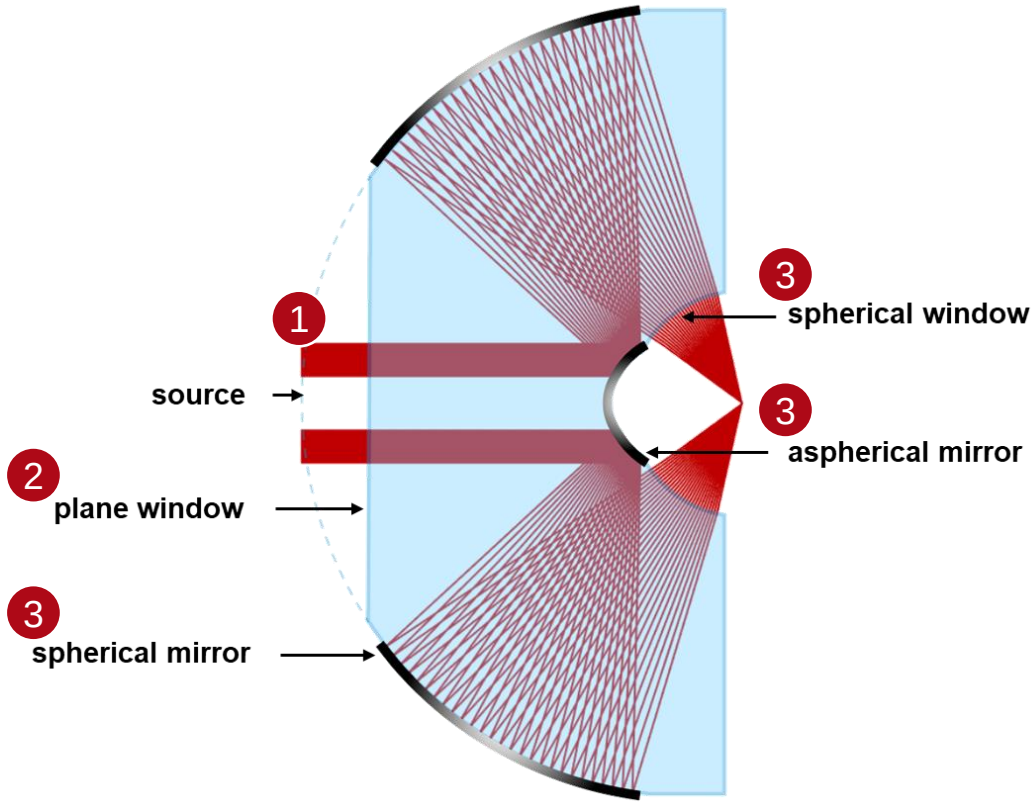


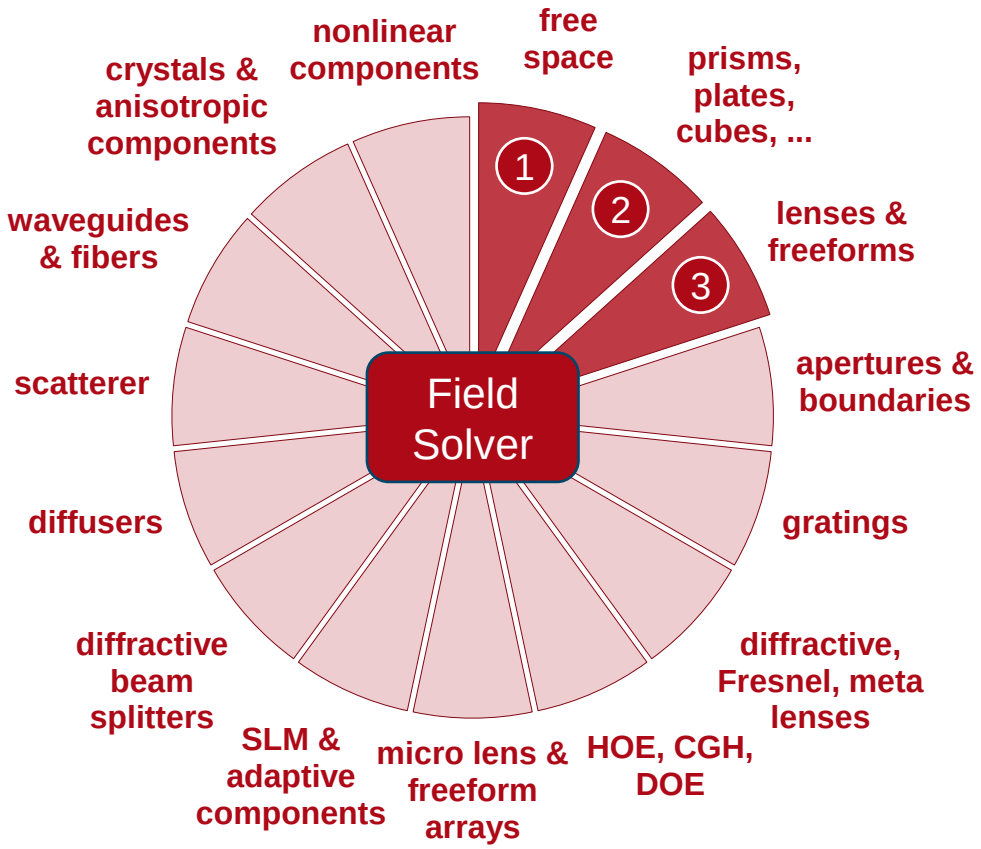




Experimental measurements from Inagawa, H. et al., Sci Rep 5, 12833 (2015).

VirtualLab Fusion Technologies





Document Information

title	Reflecting Microscope System with very high Numerical Aperture
document code	MIC.0022
document version	1.0
software edition	VirtualLab Fusion Basic
software version	2021.1 (Build 1.180)
category	Application Use Case
further reading	- Analysis of Off-Axis Imaging by a High-NA Microscope - Analysis of PSF of a Dipole Source by a High-NA Microscopy System - Single Molecule Imaging by High-NA Fourier Microscope