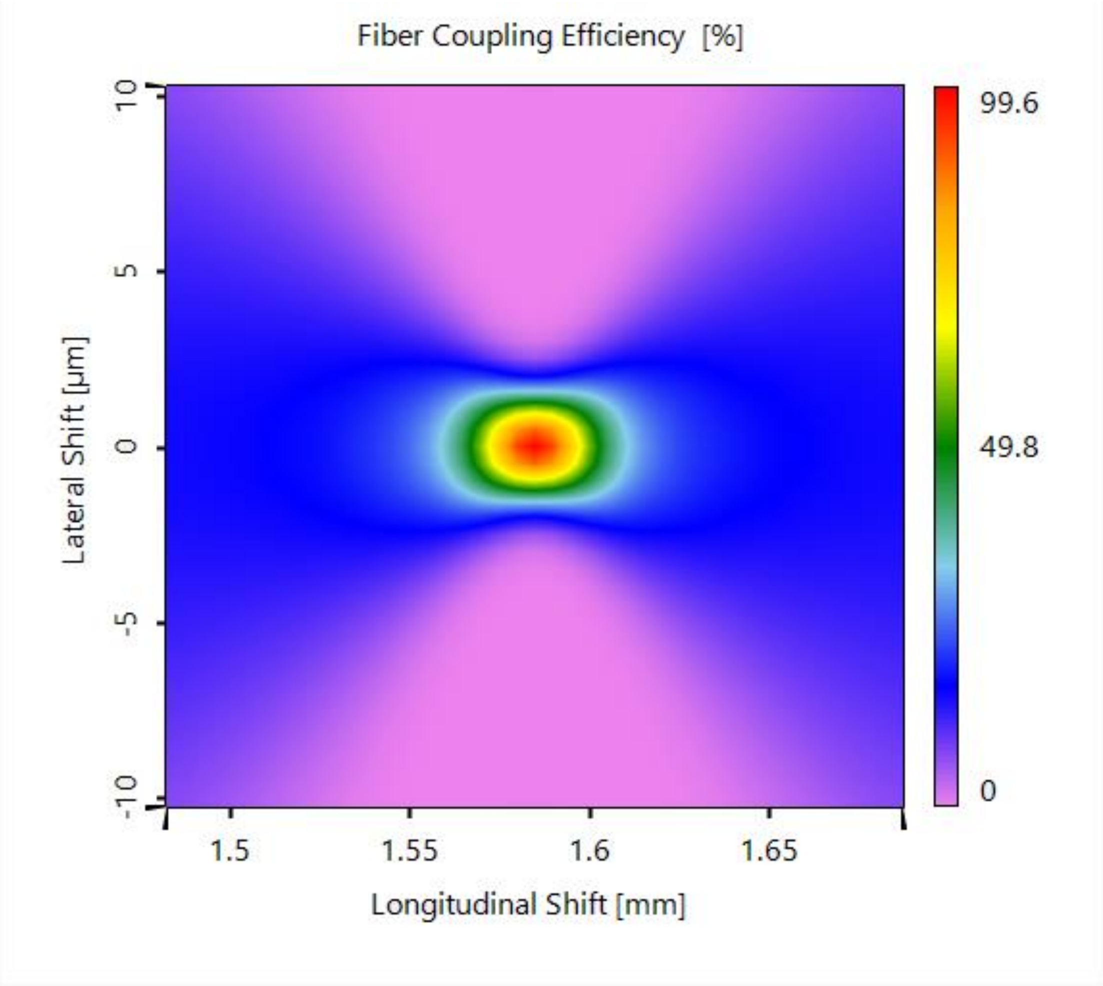
Tolerance Analysis of a Fiber Coupling Setup

Abstract

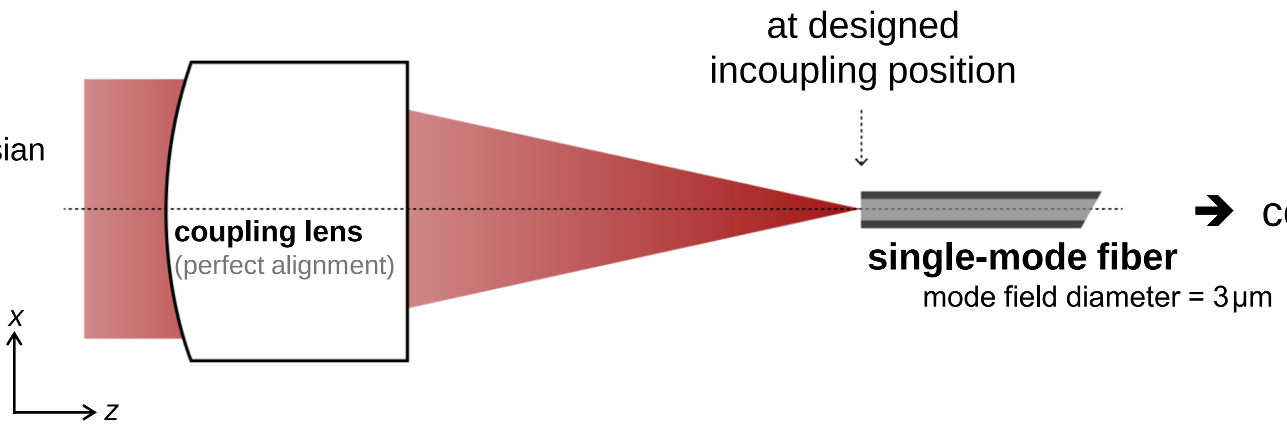


The capacity of optical fibers to transport light over long distances with hardly any losses is one of the characteristics that makes them such popular components. However, the coupling efficiency is often extremely sensitive to the system alignment, especially for single-mode fibers with relatively small core diameters. In this example, a well-designed fiber-coupling lens is selected, and the coupling efficiency is evaluated with respect to different tolerance factors, such as the shift of the fiber end position and the tilt of the coupling lens.

Modeling Task

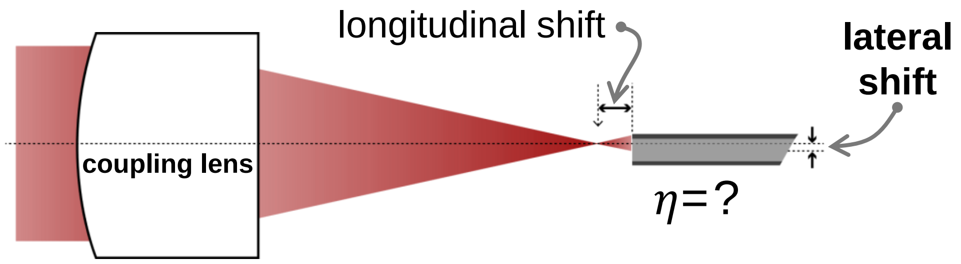
input field

- fundamental Gaussian
- wavelength 780 nm
- diameter 660 µm

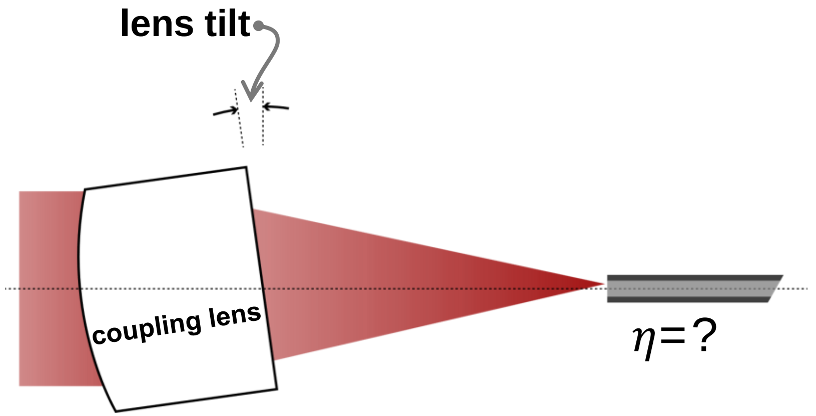


➔ coupling efficiency η=99.6%

How does the coupling efficiency change
with respect to alignment tolerance factors?

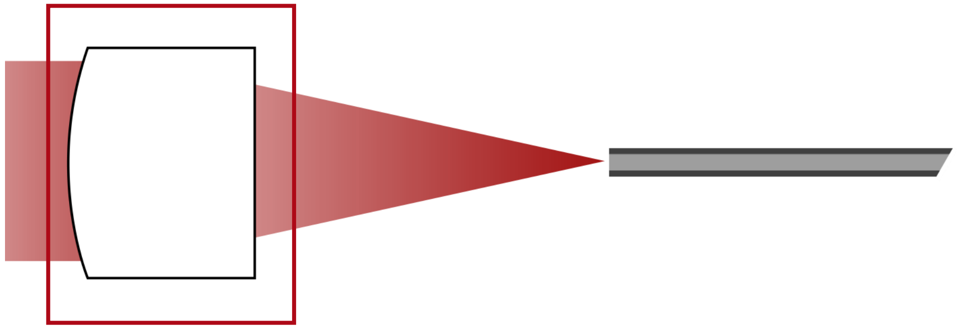


(a) shift of fiber end position

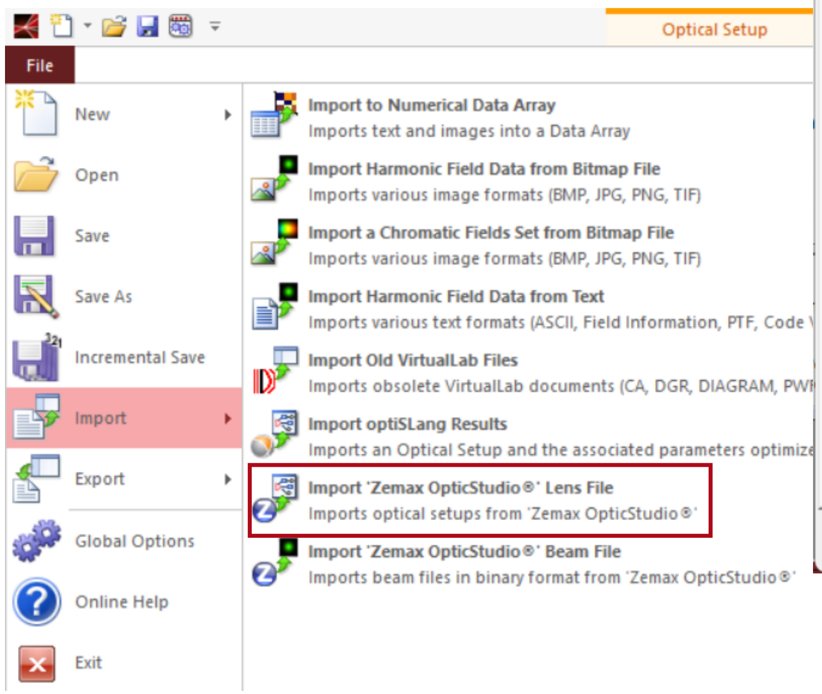


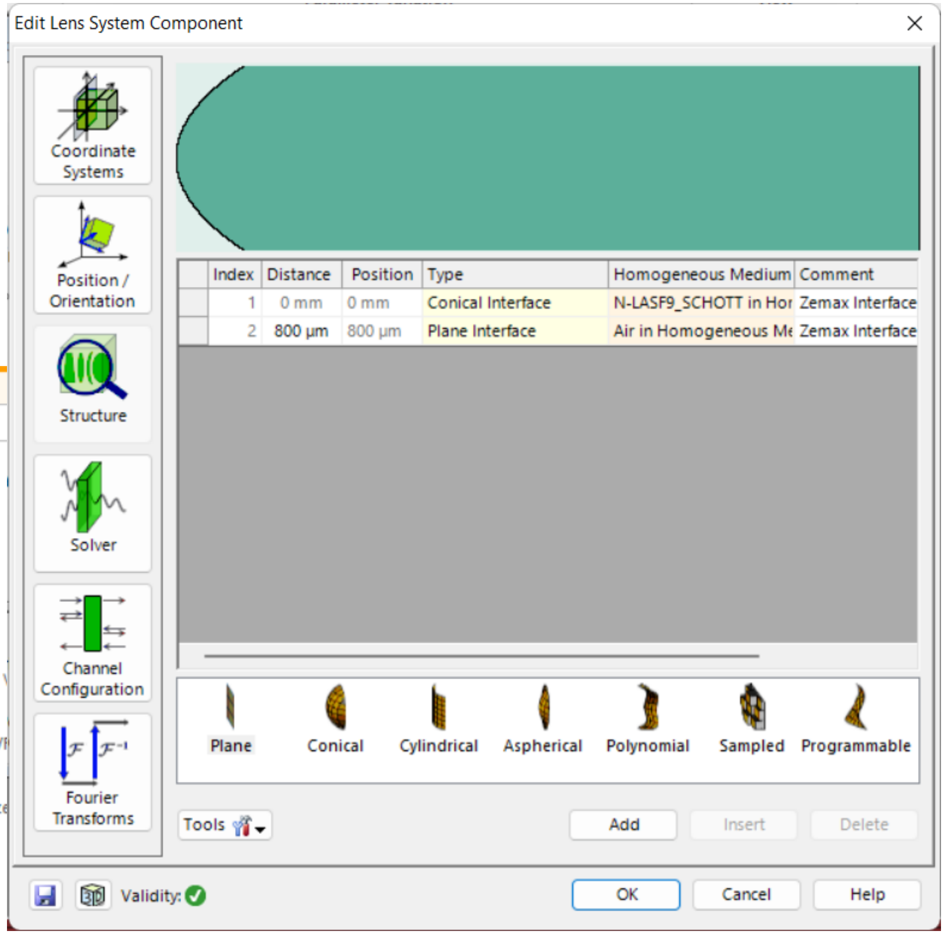
(b) tilt of coupling lens

Imported Lens File

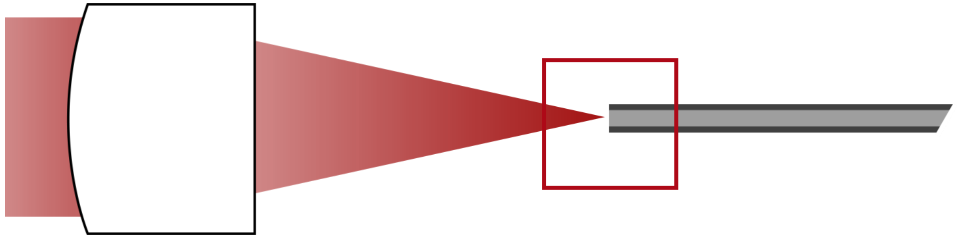


Lens systems, such as the coupling lens in this application, can either be configured by the user from scratch or imported from information provided by the manufacturer.





Fiber Coupling Efficiency Detector



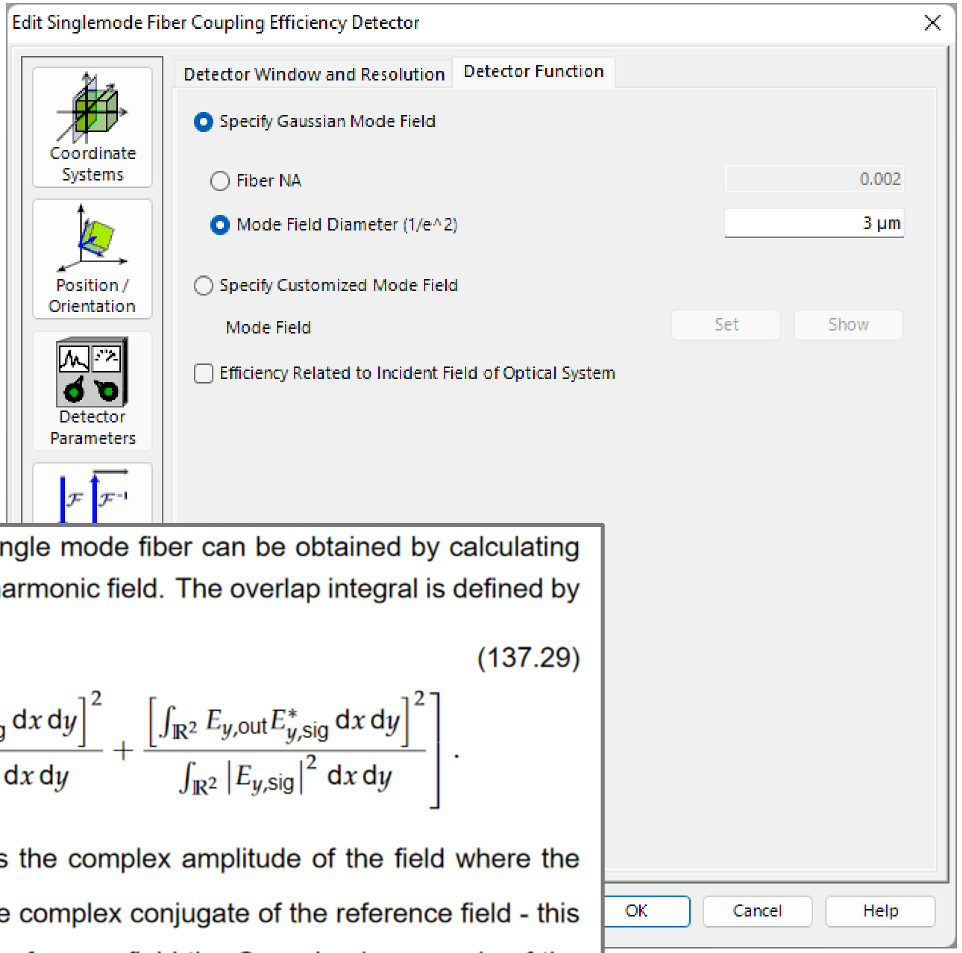
The *Singlemode Fiber Coupling Efficiency Detector* calculates the efficiency as the normalized overlap integral of the incoming field and the (single) eigenmode of the fiber. Please note that, as its name implies, this detector only works for a singlemode fiber.

From VirtualLab Fusion Manual:

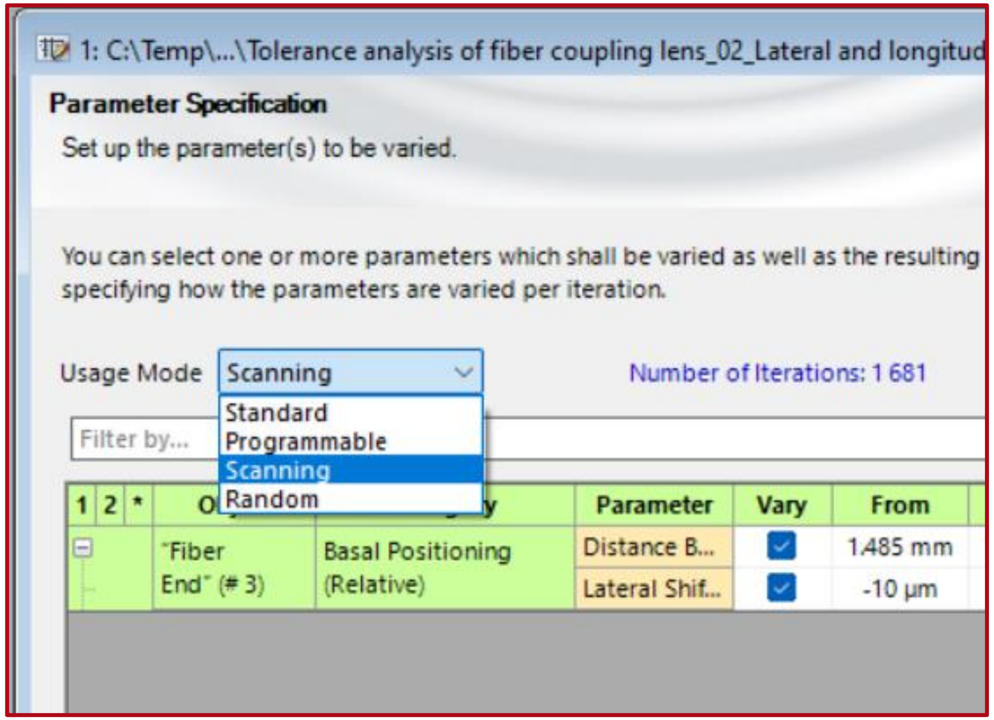
The coupling efficiency of an arbitrary harmonic field into a single mode fiber can be obtained by calculating the complex overlap integral between the fiber mode and the harmonic field. The overlap integral is defined by

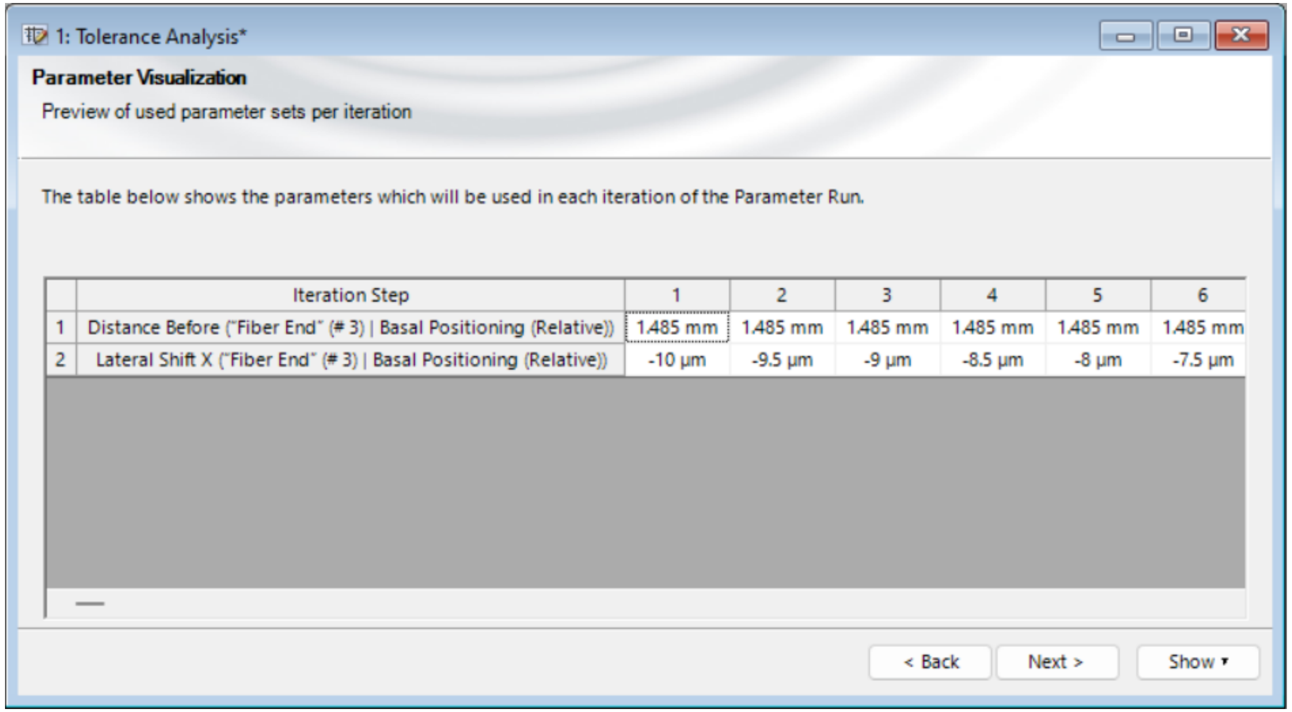
$$\begin{aligned}\eta_{\text{coupl}} &= \eta_{\text{x,coupl}} + \eta_{\text{y,coupl}} \\ &= \frac{1}{\int_{\mathbb{R}^2} |E_{\text{xy,in}}|^2 \,\mathrm{d}x\,\mathrm{d}y} \left[\frac{\left[\int_{\mathbb{R}^2} E_{x,\text{out}} E^*_{x,\text{sig}} \,\mathrm{d}x\,\mathrm{d}y\right]^2}{\int_{\mathbb{R}^2} |E_{x,\text{sig}}|^2 \,\mathrm{d}x\,\mathrm{d}y} + \frac{\left[\int_{\mathbb{R}^2} E_{y,\text{out}} E^*_{y,\text{sig}} \,\mathrm{d}x\,\mathrm{d}y\right]^2}{\int_{\mathbb{R}^2} |E_{y,\text{sig}}|^2 \,\mathrm{d}x\,\mathrm{d}y} \right].\end{aligned} \tag{137.29}$$

$E_{\text{xy,in}}$ is the complex amplitude of the incident field, $\binom{E_{x,\text{out}}}{E_{y,\text{out}}}$ is the complex amplitude of the field where the coupling efficiency should be calculated from and $\binom{E^*_{x,\text{sig}}}{E^*_{y,\text{sig}}}$ is the complex conjugate of the reference field - this means the harmonic field of the fiber mode. Typically as the reference field the Gaussian base mode of the fiber should be used.



Parameter Run

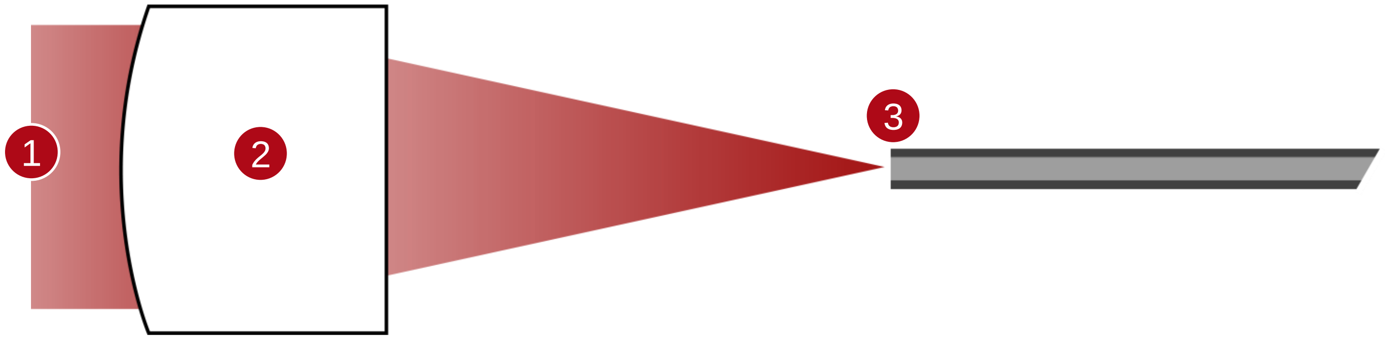




The scanning mode of VirtualLab Fusion's *Parameter Run* document allows you to perform a parameter sweep over a multi-dimensional (often 2D) region of the parameter space. More information under:

Scanning Mode of Parameter Run

Summary – Components...

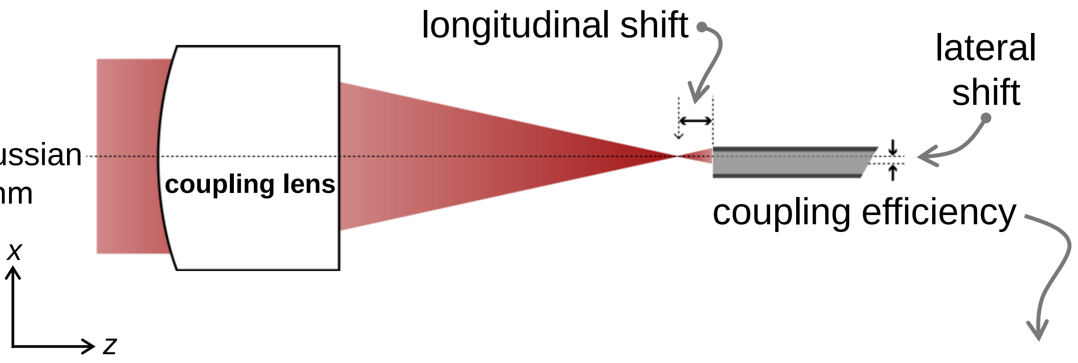


… of Optical System	… in VirtualLab Fusion	Model/Solver/Detected Value
1. source	*Gaussian Wave*	spatial Gaussian function
2. coupling lens	*Lens System Component*	Local Plane Interface Approximation (LPIA)
3. fiber	*Fiber Coupling Efficiency*	overlap integral calculation

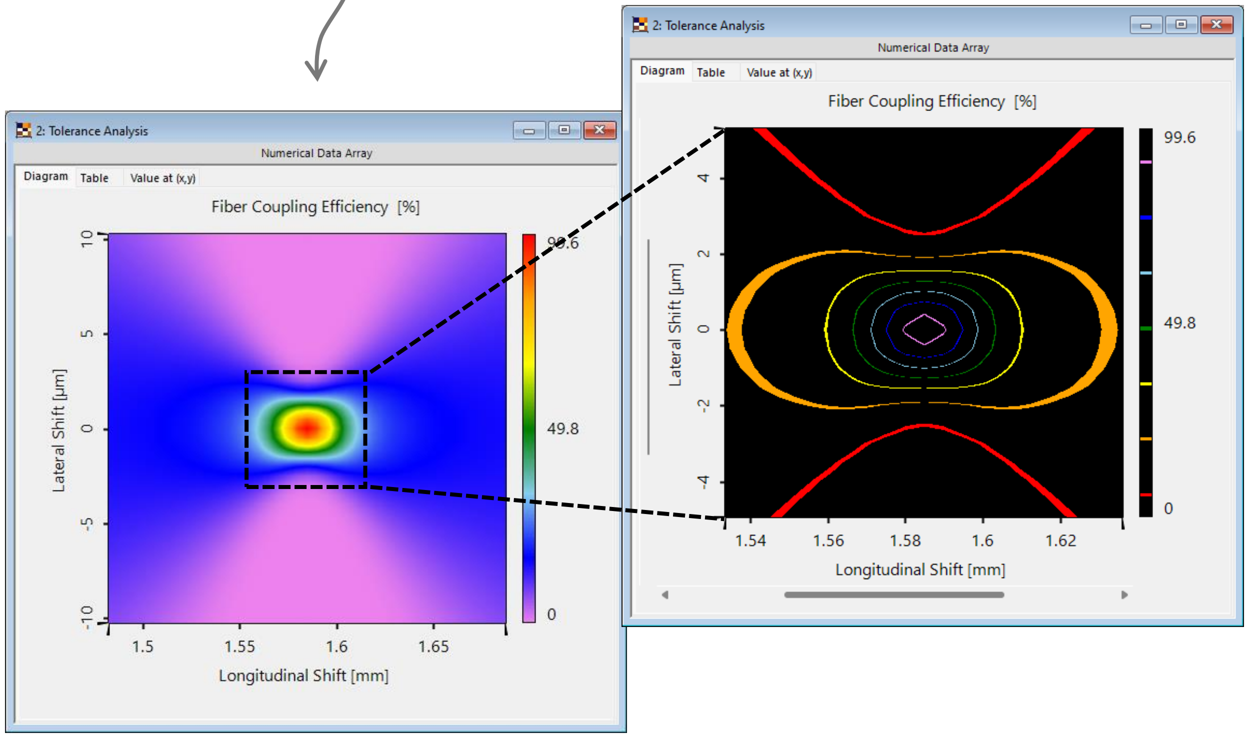
Coupling Efficiency vs. Fiber End Position Shift

input field

- fundamental Gaussian
- wavelength 780 nm
- diameter 660 μm



Contour plots help with the identification of the parameter range that provides the desired coupling efficiency threshold.

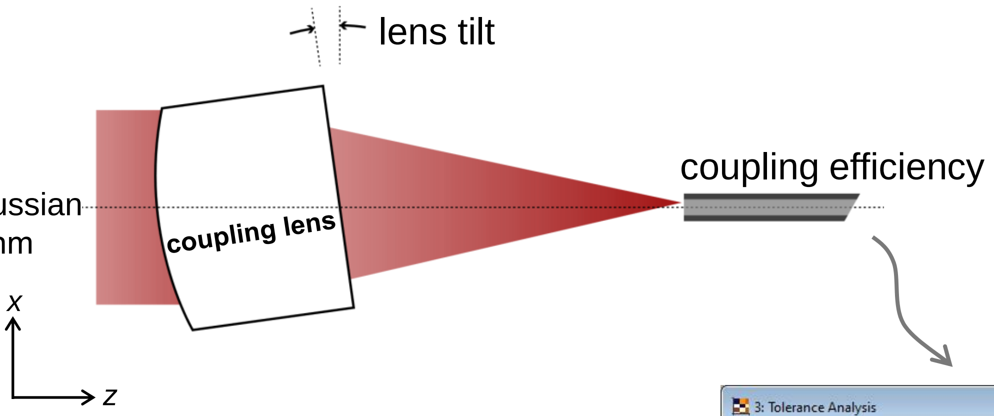


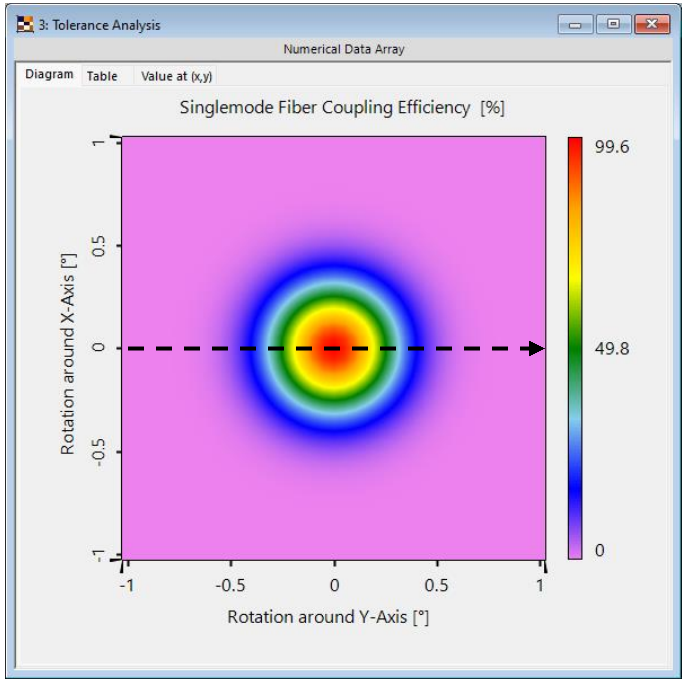
The coupling efficiency is scanned with respect to the fiber position shifts along both longitudinal and lateral directions.

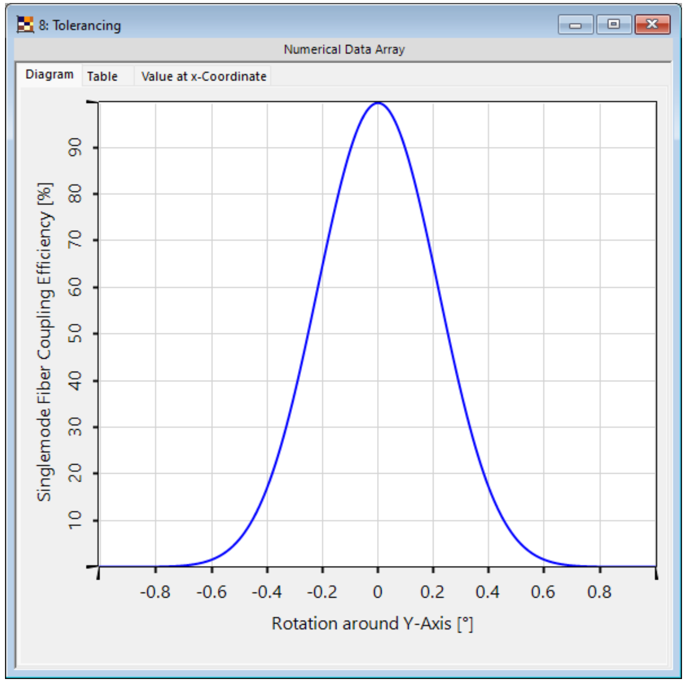
Coupling Efficiency vs. Coupling Lens Tilt

input field

- fundamental Gaussian
- wavelength 780 nm
- diameter 660 µm

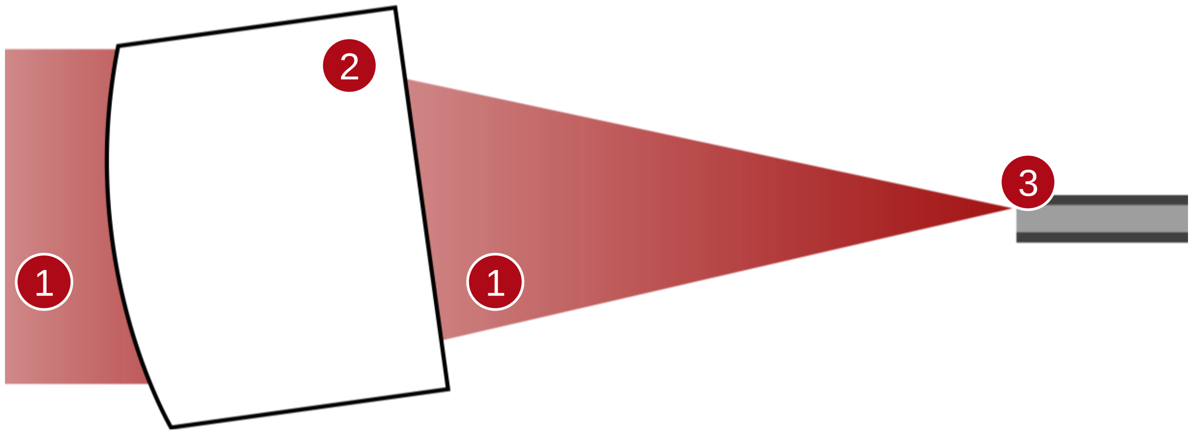


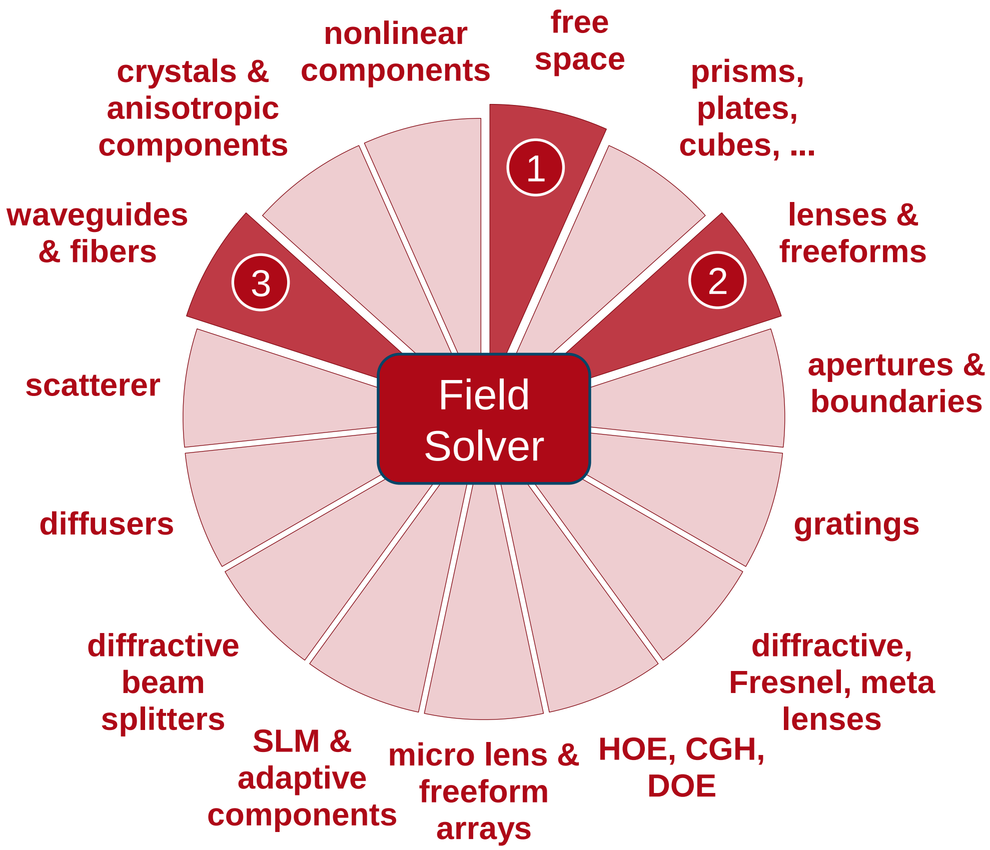




Physical-optics analysis of the coupling efficiency with respect to lens tilt. As long as the lens tilt angle is within 0.1°, the coupling efficiency remains higher than 90%.

VirtualLab Fusion Technologies





Document Information

title	Tolerance Analysis of a Fiber Coupling Setup
document code	FCP.0004
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software version	2021.1 (Build 1.180)
category	Application Use Case
further reading	- Comparison of Different Lenses for Fiber Coupling - Parametric Optimization of Fiber Coupling Lens - Scanning Mode of Parameter Run