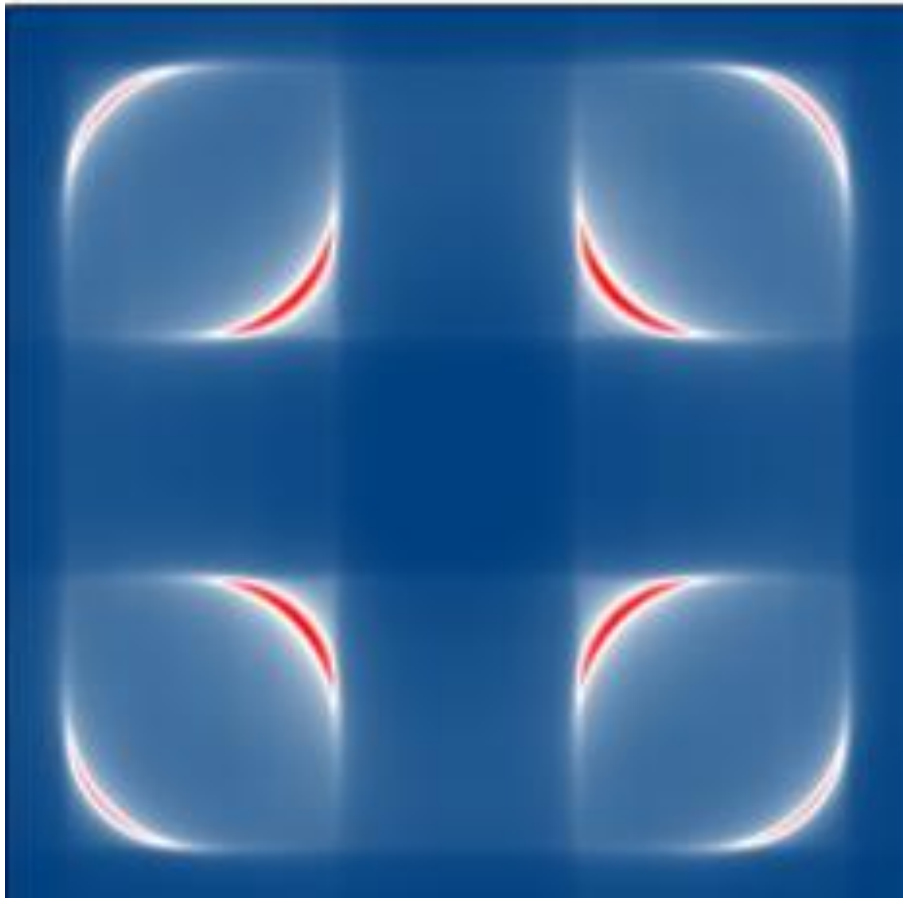
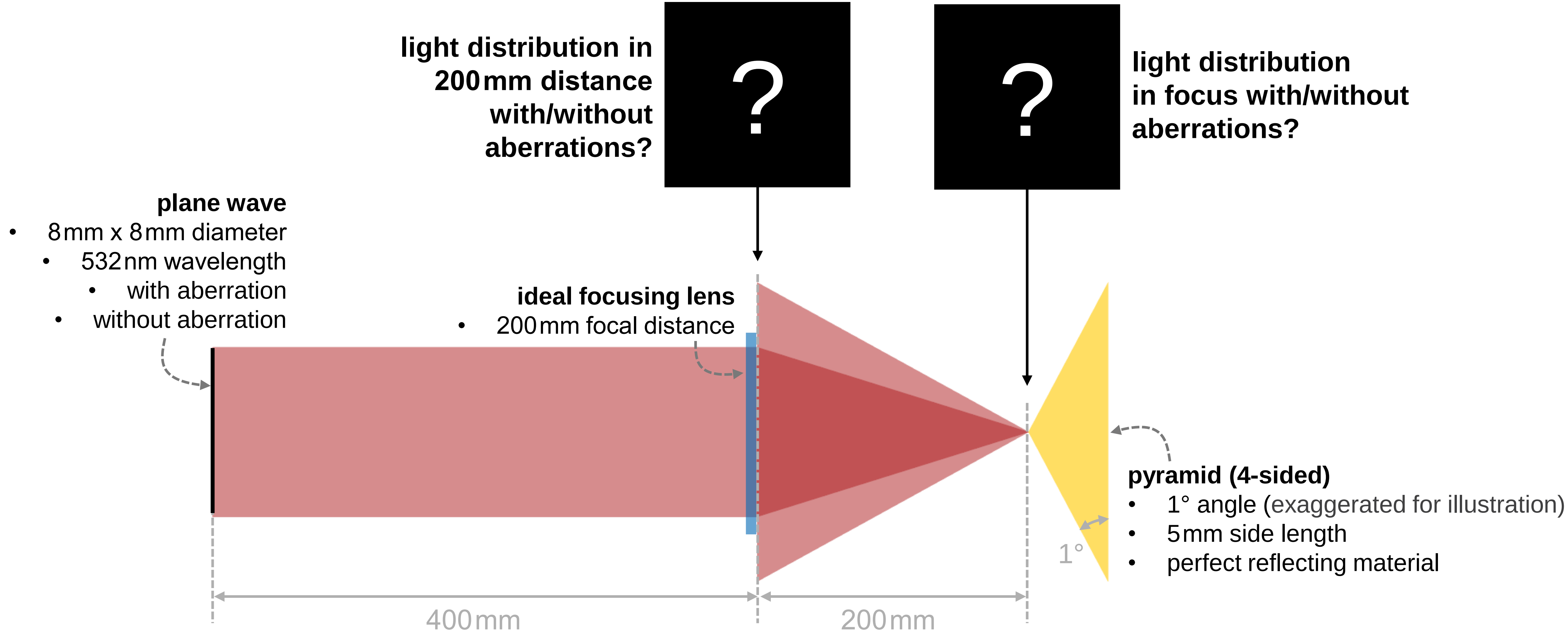
Simulation of Reflective Pyramid Wavefront Sensor

Abstract

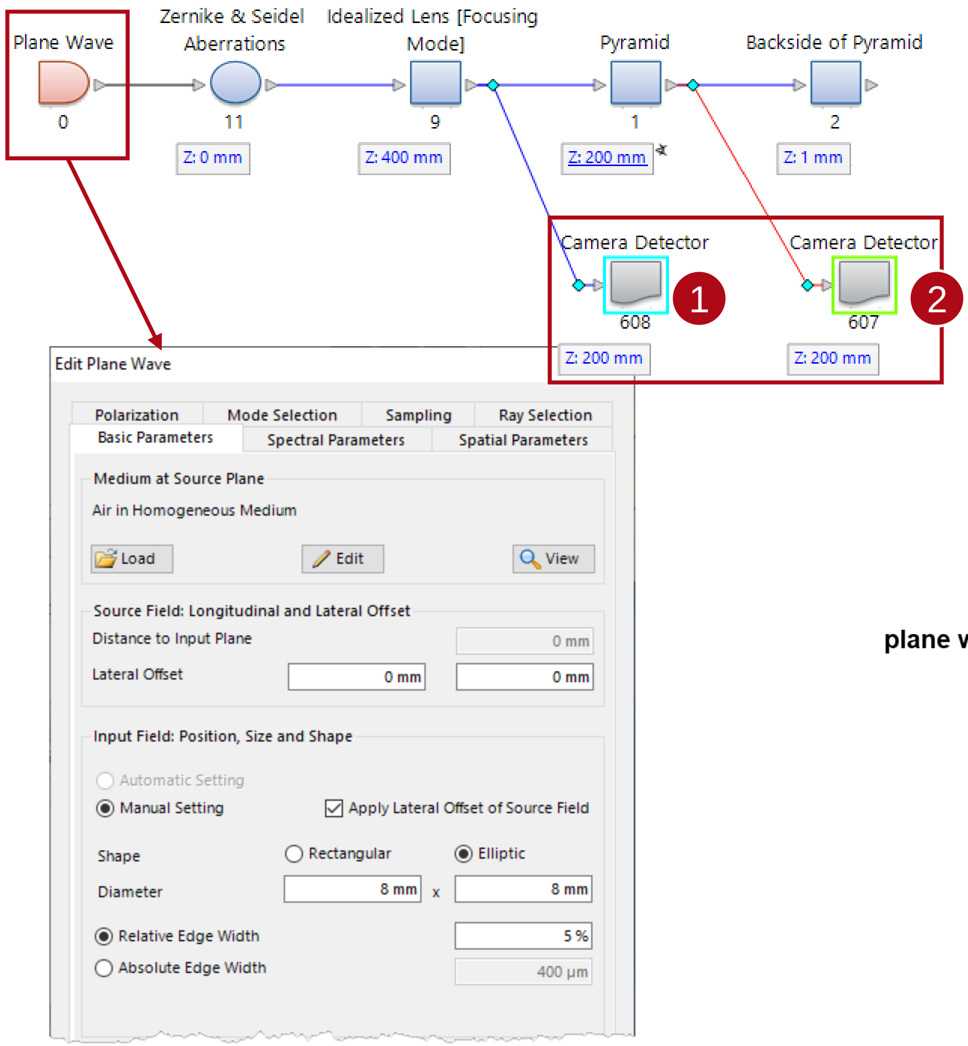


Wavefront sensors that use a pyramid shaped prism or reflector (PyWFS, for *pyramid wavefront sensor*) are known for their high contrast and better wavefront sensitivity compared to conventional Shack-Hartmann sensors, e.g., for the search for extrasolar planets in astronomy. Hence, this type of wavefront sensors are used in special telescopes (e.g., at *Keck Observatory*), usually in the infrared (IR) spectral range. A PyWFS typically consists of a four-sided prism, re-imaging optics, and an appropriate detector. In this example, we show the modeling of the characteristic light pattern of such a pyramid-shaped prism for different types of aberrations, by applying VirtualLab Fusion's fast physical optics Field Tracing technology.

Modeling Task

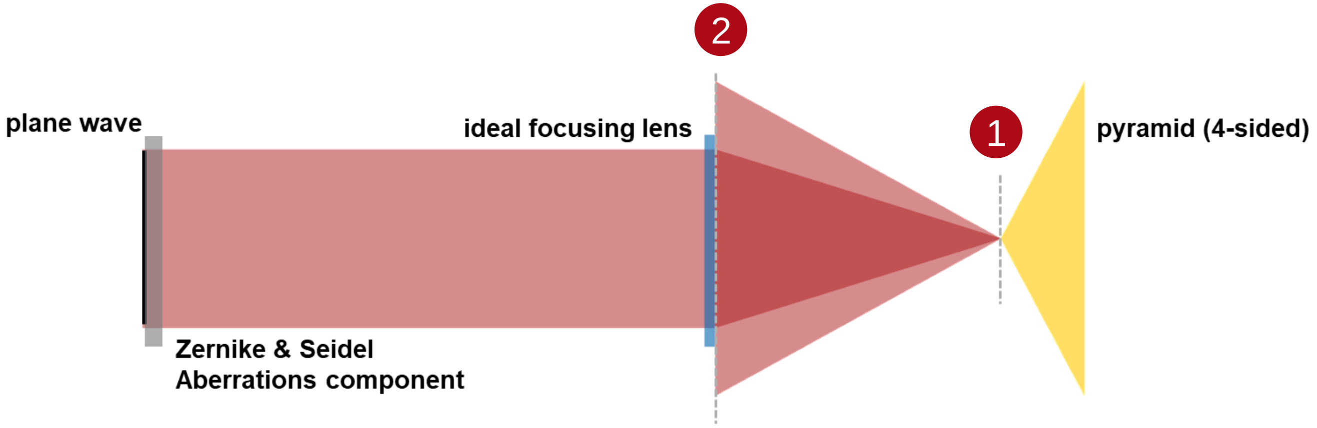


System Building Blocks – Source & Detectors

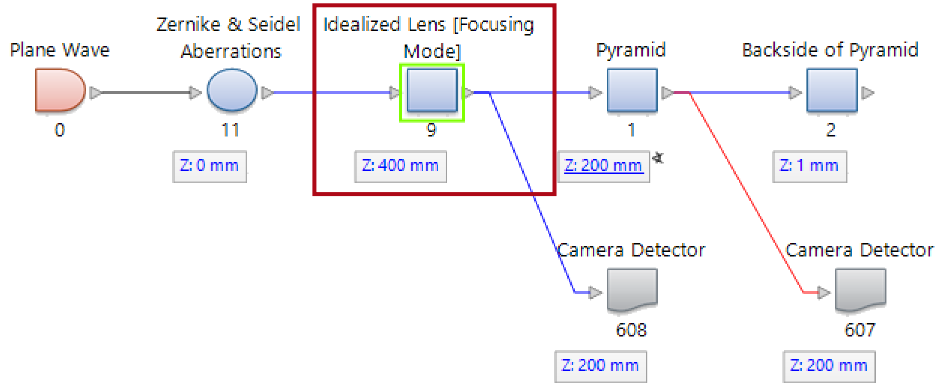


A plane wave is used as source. Due to the absence of aberrations in this model, a *Zernike & Seidel Aberrations* element is added (pls. see slide 7).

In the shown setup, the beam is focused on the tip of the pyramidal-shaped prims and reflected towards the detectors (focal plane and image plane).



System Building Blocks – Idealized Focusing Lens



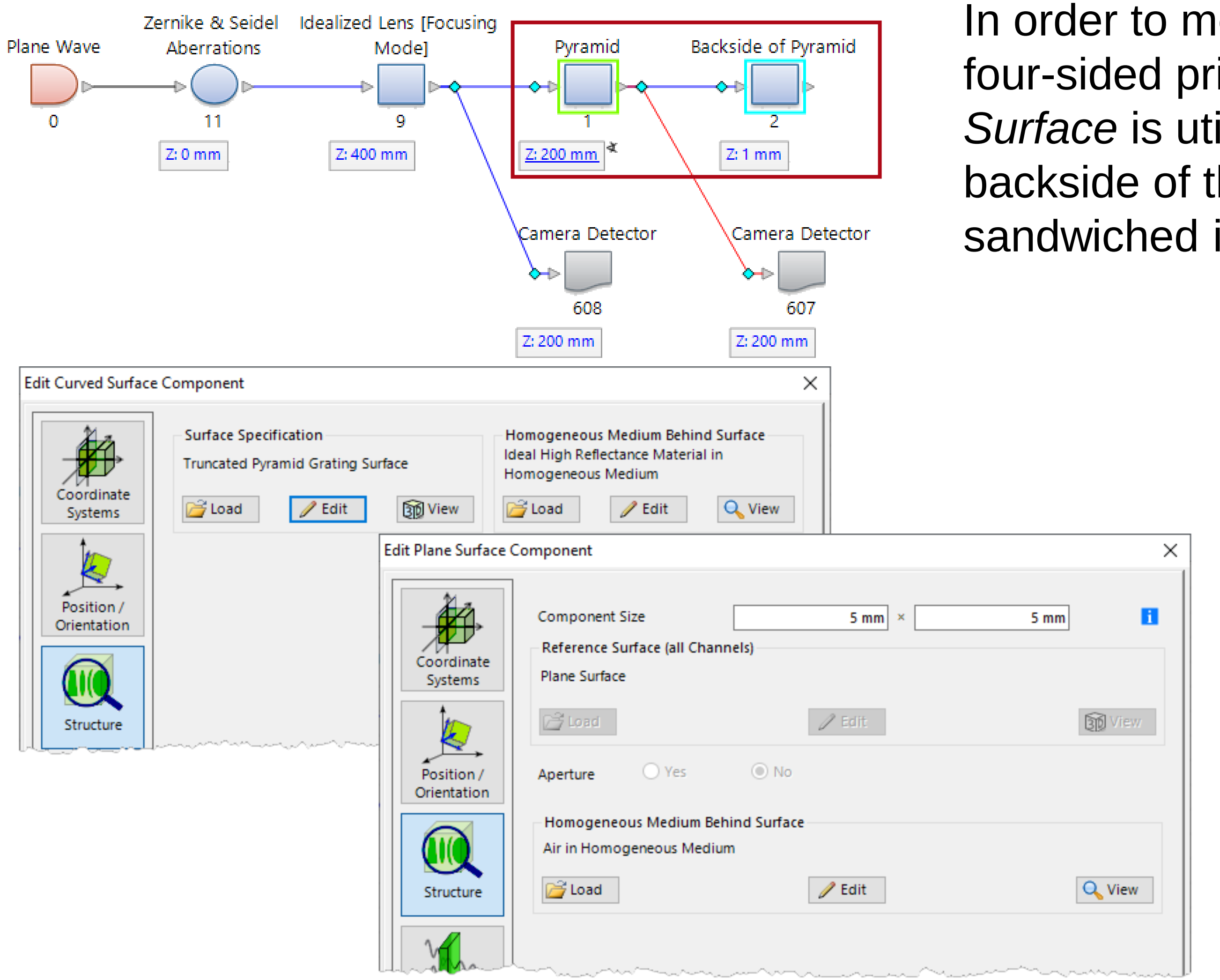
For the purposes of concentrating on the main effects, the focusing lens is simplified with an idealized lens model, which provides an idealized lens function.

Parameter	**Description**
DesignWavelength	Design wavelength given in vacuum
DesignNin	Refractive index of the design working medium in front of lens
DesignNout	Refractive index of the design working medium behind lens
FocalLength	Design focal length
LensType	Lens mode options: 0: F-TanTheta mode 1: F-SinTheta mode 2: F-Theta mode
OutputMaterial	Material on the transmission side

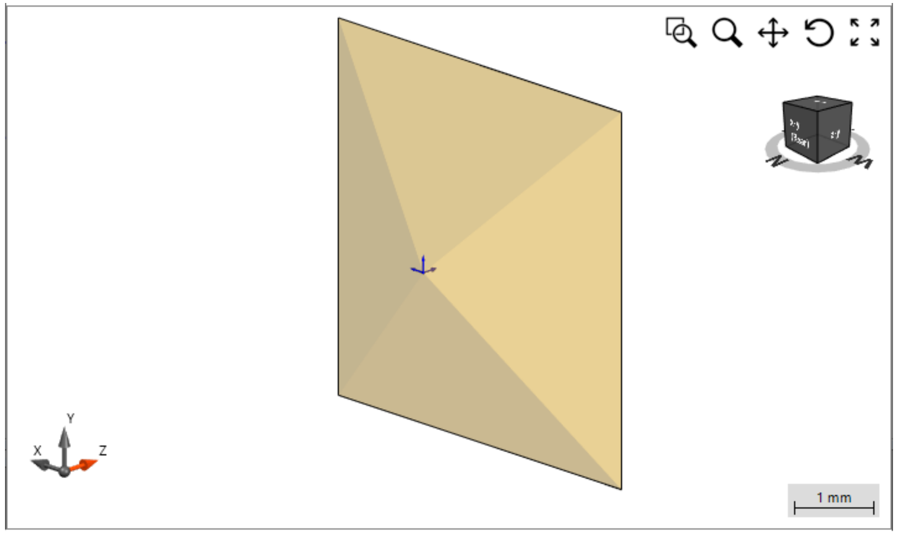
Learn more about this function via:

Idealized Lens Functions.

System Building Blocks – Pyramid Prism

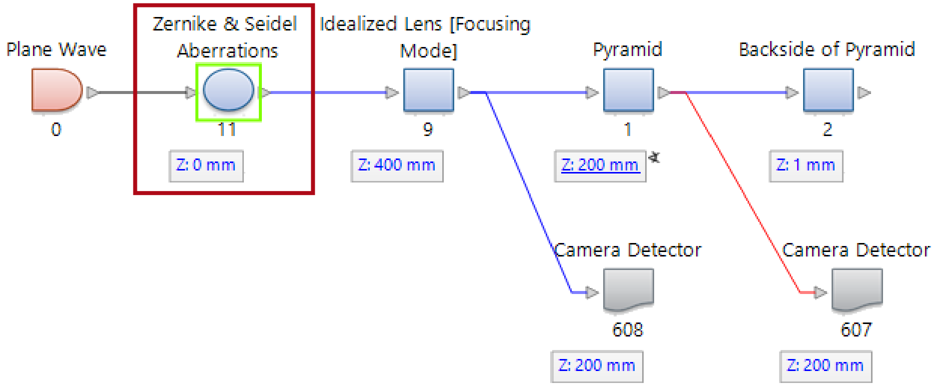


In order to model the reflective pyramid wavefront sensor, a four-sided prism is constructed. The *Truncated Pyramid Surface* is utilized as front side, and a planar interface as the backside of the prism, with an ideal high reflectance material sandwiched in between.

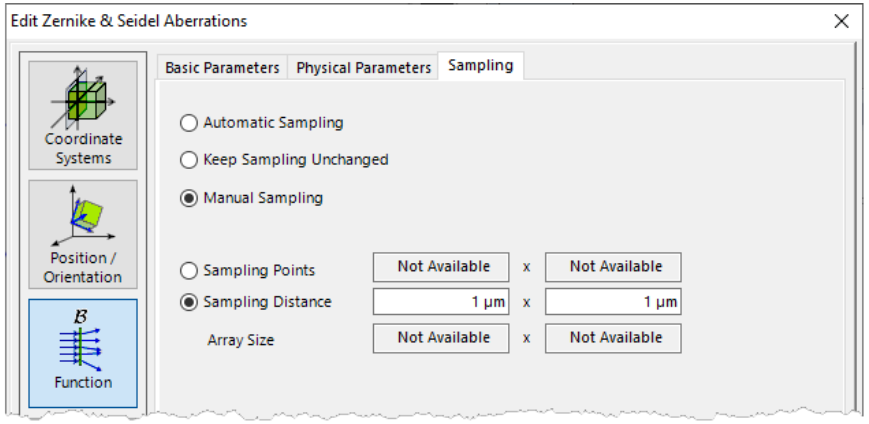


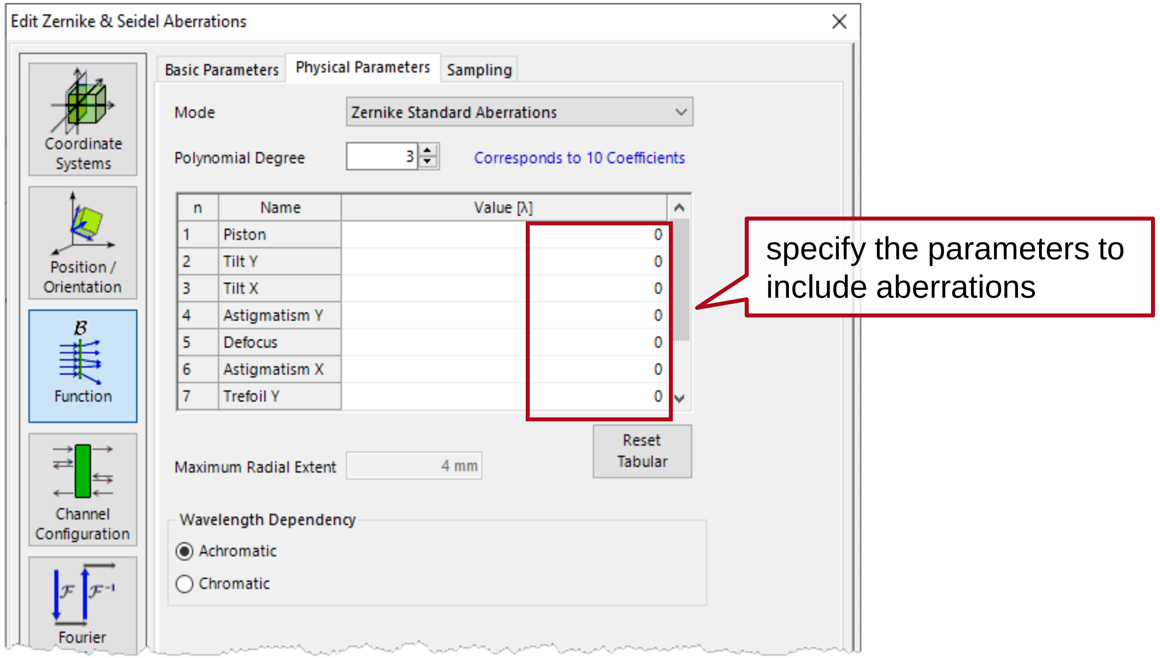
3D structure of the pyramid surface (height exaggerated for illustration)

System Building Blocks – Aberration Component

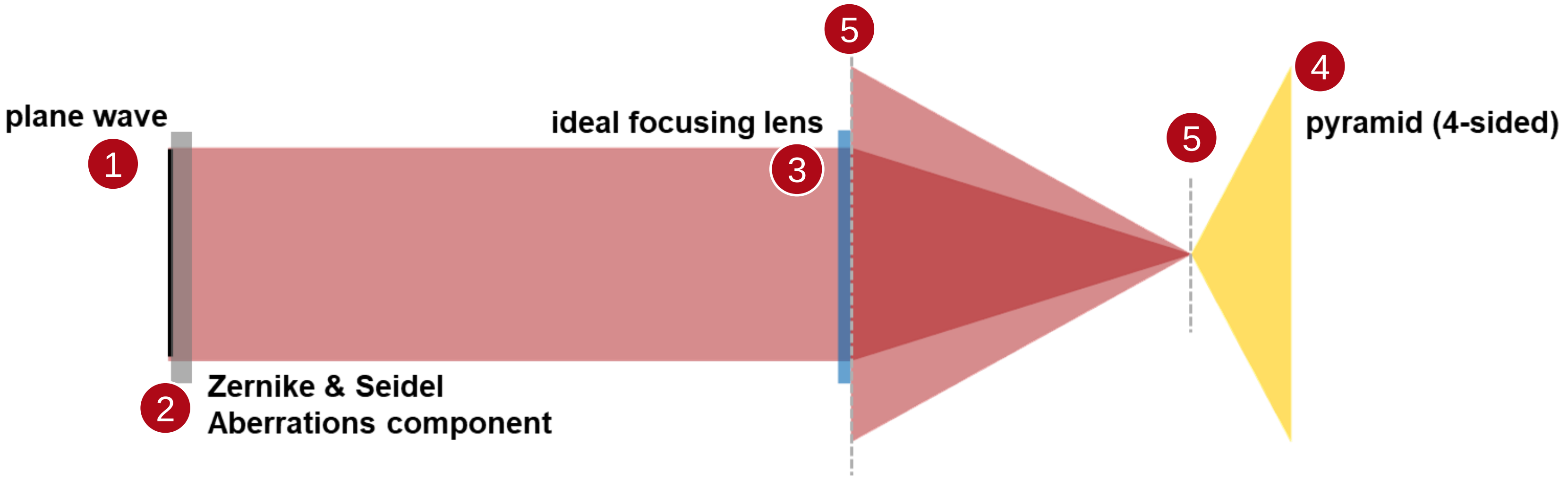


A *Zernike & Seidel Aberrations* component is applied to superimpose the aberrations on the field. In the actual experiment the aberrated wavefront would be unknown; here, to demonstrate the principle, we simply specify the coefficients of different types of aberrations.





Summary of Model

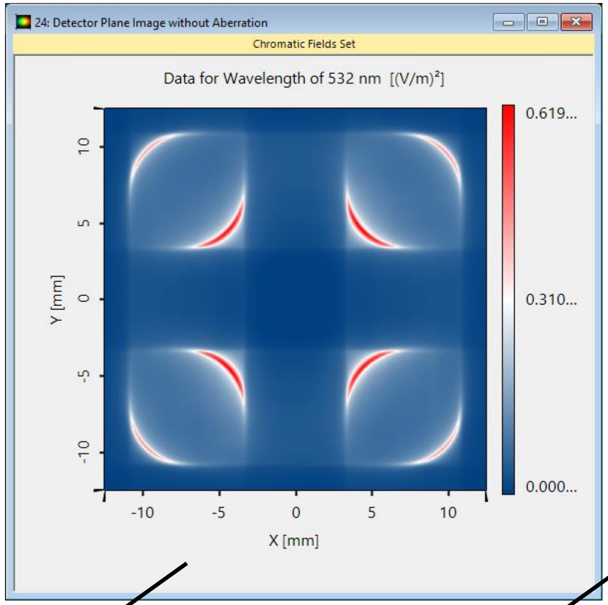


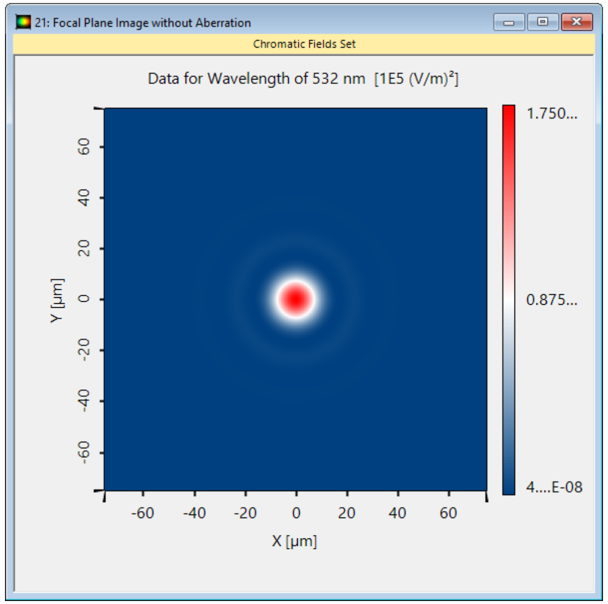
Optical System	Elements in VirtualLab Fusion	Model/Solver/Detected Value
1. source	*Plane Wave* source	truncated ideal plane waves
2. aberrations	*Zernike & Seidel Aberrations Component*	Zernike standard polynomial
3. focusing lens	*Idealized Lens [Focusing Mode]*	idealized focusing
4. pyramid prism	*Truncated Pyramid surface & Plane Interface*	Local Plane Interface Approximation & Fresnel Matrix
5. detector	*Camera Detector*	energy density measurement

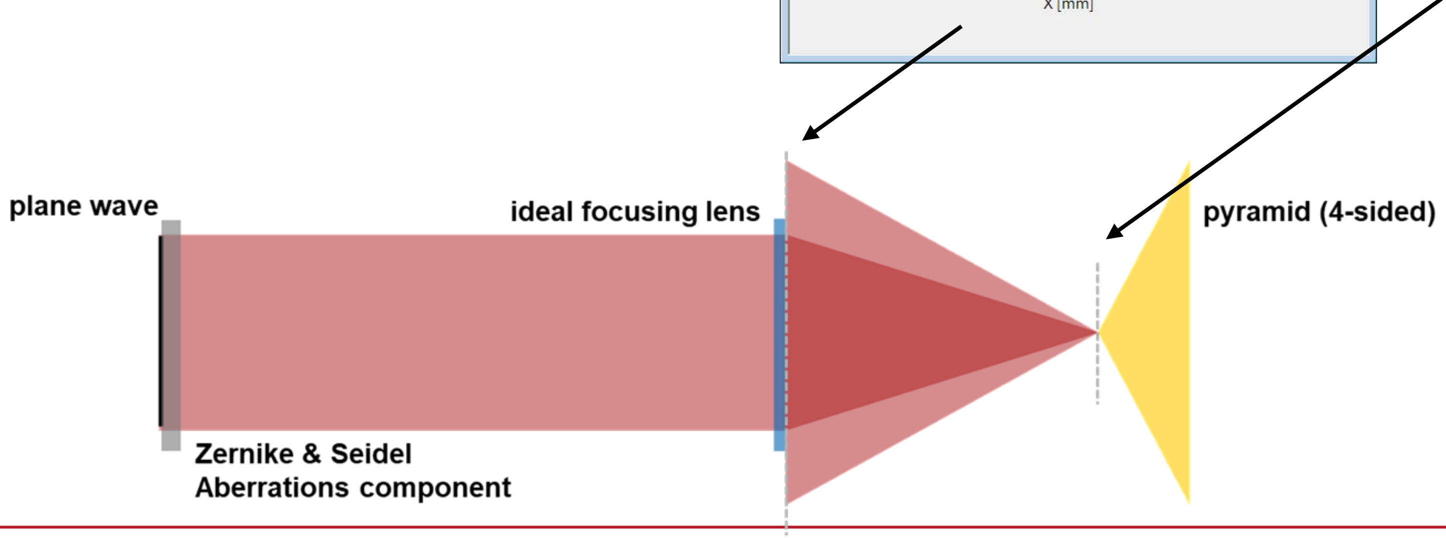
Field Tracing Result

reflected image without aberration

focal plane image without aberration







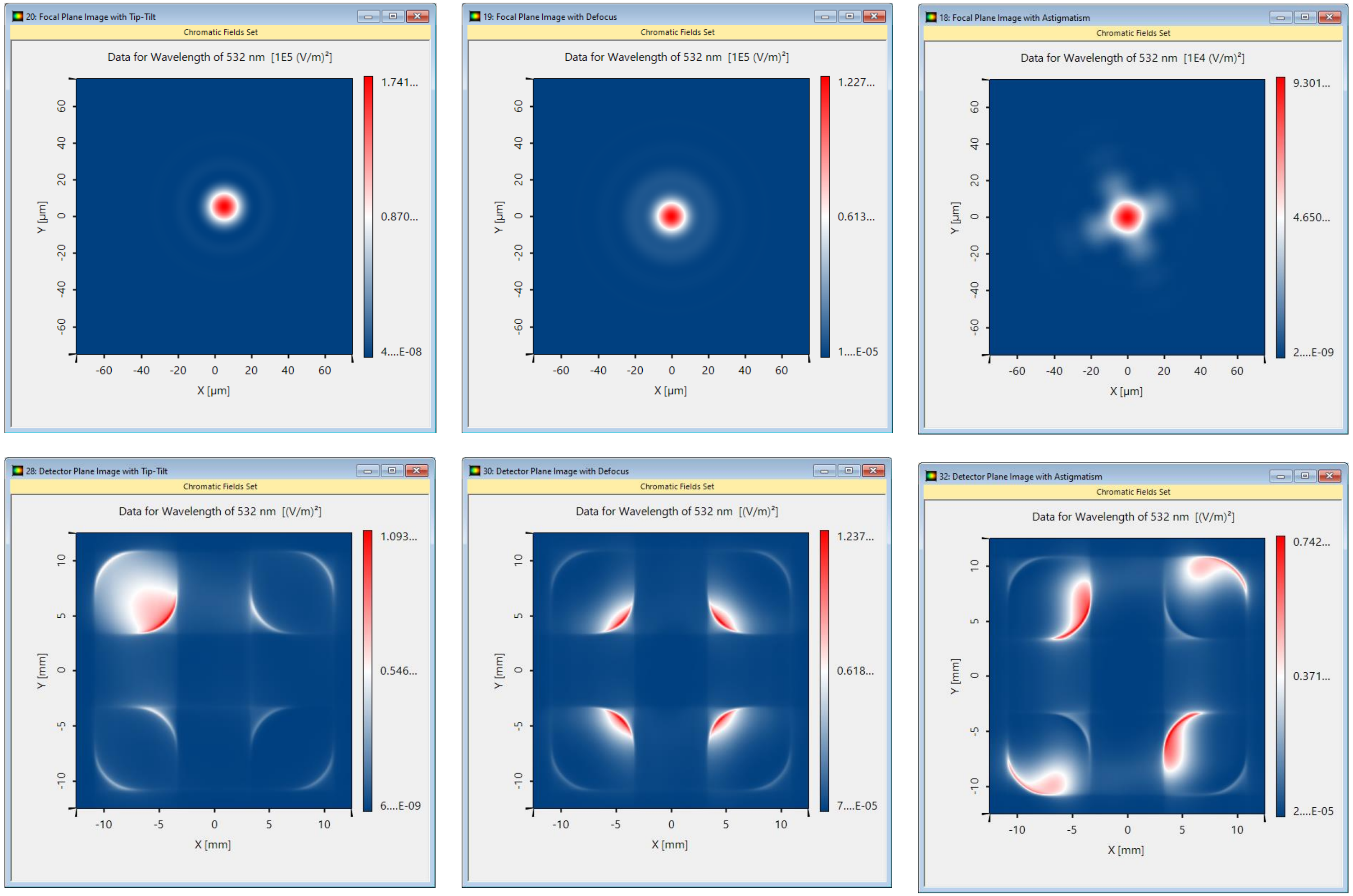
Simulation of Aberration Effects on the Wavefront

By specifying the coefficients of the aberrations in the aberration component, different types of aberrations can be modeled. In this example, we applied three first-order aberrations: tilt, defocus and astigmatism. The aberrations have a distinct impact on the size and shape of the focus.

After re-imaging the light, the pyramid wavefront sensor reveals its beneficial sensitivity: Compared to conventional sensors, e.g., Shack-Hartmann sensors, the PyWFS not only detects the change of the wavefront, but also makes it easy to distinguish the type of aberration from the resulting quadrant-divided pattern.

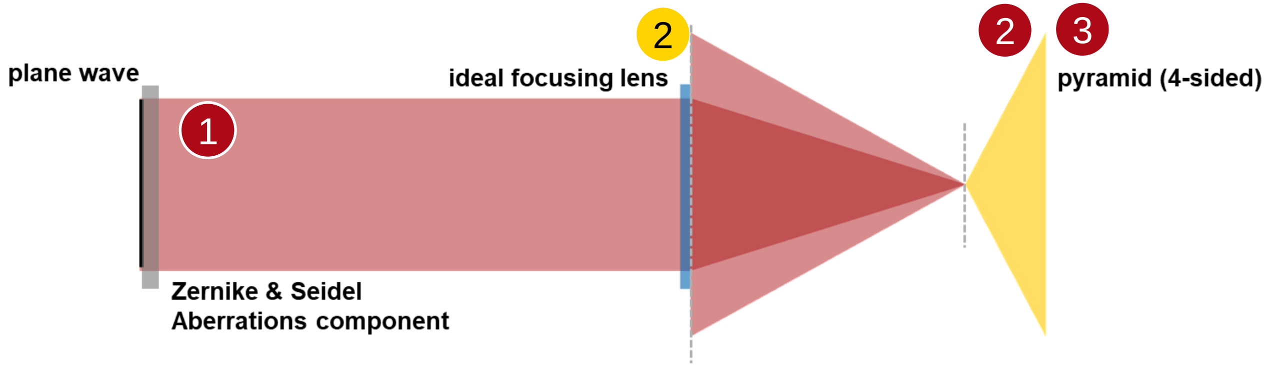
focused image

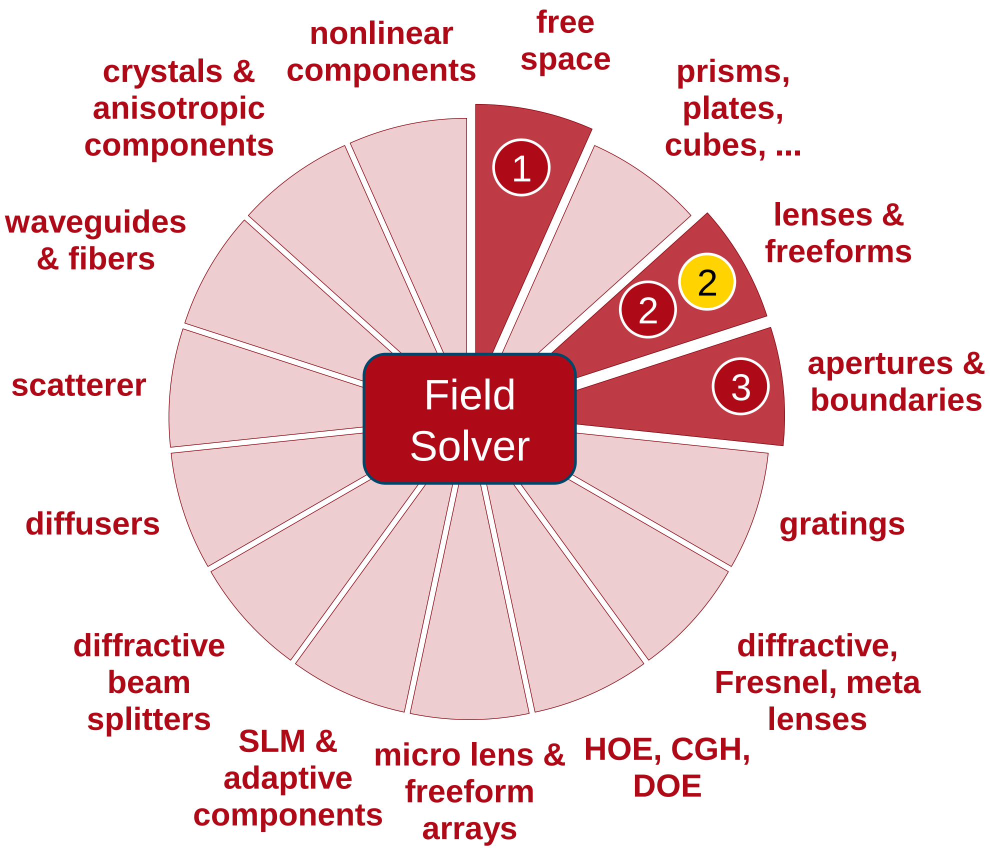
reflected image



from left to right: field tracing images with tip-tilt, defocus, astigmatism aberration

VirtualLab Fusion Technologies





idealized component

Document Information

title	Simulation of Reflective Pyramid Wavefront Sensor
document code	MISC.0092
document version	1.0
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software version	2021.1 (Build 1.180)
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further reading	- How to Work with the Programmable Interface & Example (Spherical Surface) - Analyzing High-NA Objective Lens Focusing - Programming a Truncated Cone Surface - Modeling of Foucault Knife-Edge Test