Aberration Control via Metalens

Spherical Aberration Correction

Part of the Meta Optics Solution Guide

`SF-PLAW01` `CS-MPCA01` `CS-CSFP01` `DF-FMON01` `DK-SDKD01`

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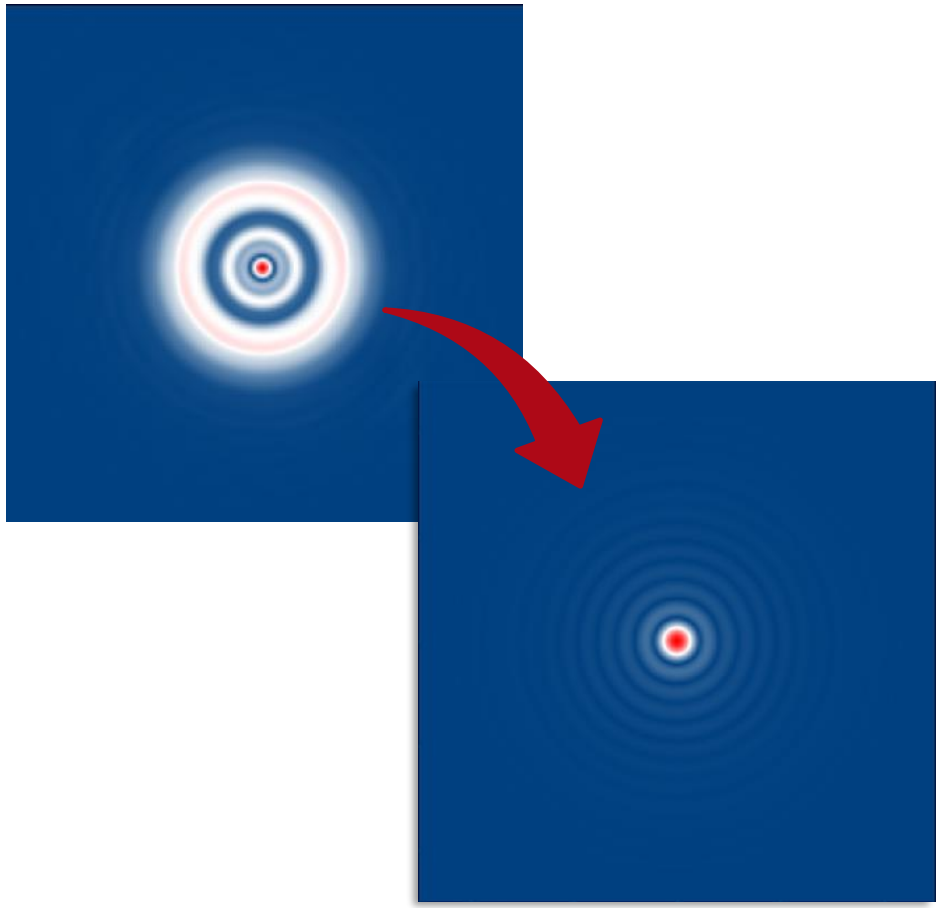
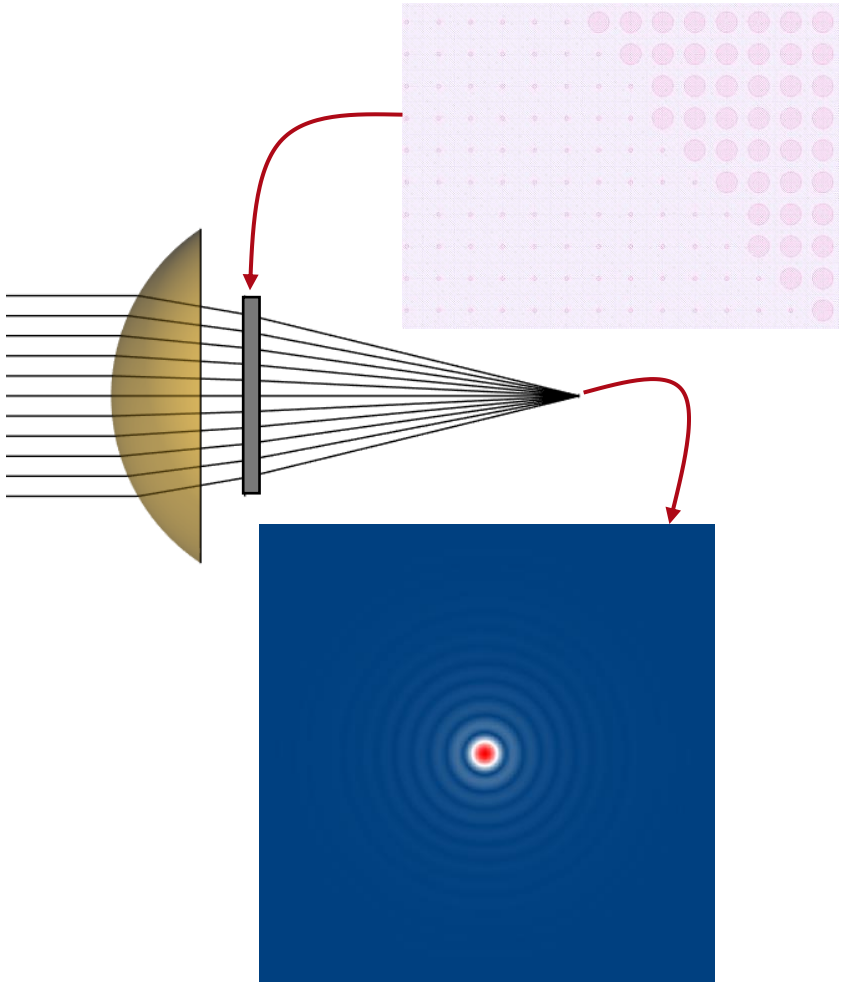


Executive Summary

Spherical aberration correction using a metalens.

Key Achievements

- Reference spherical-plano lens shows significant focal spot broadening due to spherical aberration.
- Metalens with calculated radial phase profile corrects aberration and restores diffraction-limited focusing.
- Correction demonstrated for both plane wave and Laguerre mode input.



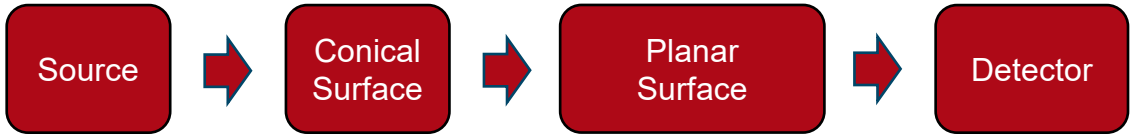
Hardware & Performance

- Hardware: AMD Ryzen Threadripper 3970X 32-Core Processor, 256 GB DDR4 SDRAM
- Simulation time: 5 s (without metalens), 1:20 min (with metalens).

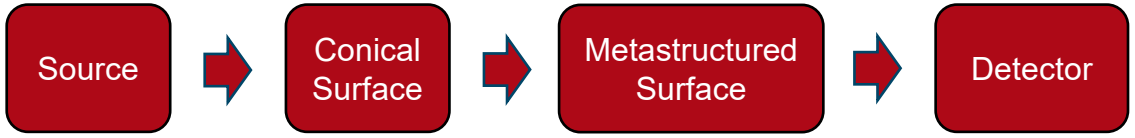
Application Scenario

What We Did A metastructure compensating spherical aberration was designed. Focal spots of a spherical-plano lens were analyzed with and without the metastructure on the plano side, for a plane wave and a Laguerre-Gaussian (0,1) donut mode sources.

Scenario 1: Reference spherical-plano lens



Scenario 2: Metalens with aberration correction



Physical Lab Setup

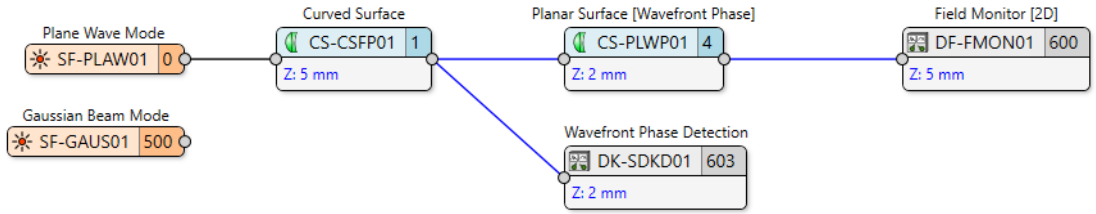
Component	Specification
Source 1	Plane wave, 940 nm
Source 2	Laguerre-Gaussian, 940 nm, mode (0,1)
Spherical Lens	Radius of Curvature 3 mm, size 5 mm x 5 mm
Metalens	Nanopillars, n = 3.8, f = 5 mm, diameter 3 mm
Meta-atom	Height 465 nm, period 400 nm × 400 nm
Detector 1	Wavefront phase before metalens
Detector 2	EM field in focal spot

Digital Twins of the System

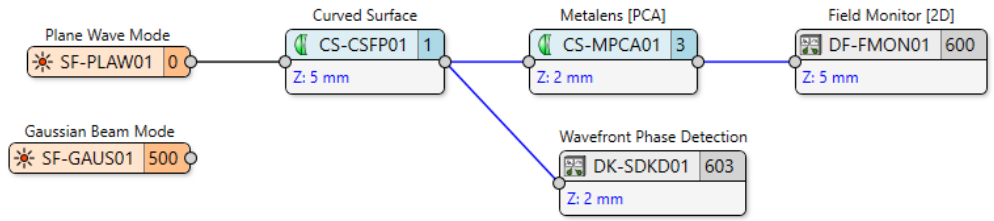
Digital Twin Mapping

Real Asset	Digital Twin	Description
Source 1	SF-PLAW01	Plane wave, 940 nm
Source 2	SF-GAUS01	Laguerre-Gaussian, 940 nm, mode (0,1)
Curved surface	CS-CSFP01	Radius of Curvature 3 mm, size 5 mm × 5 mm, medium fused silica
Metalens surface	CS-MPCA01	Nanopillars, n = 3.8, f = 5 mm, diameter 3 mm, only present in scenario 2
Planar surface	CS-PLWP0101	Only present in scenario 1
Detector 1	DK-SDKD01	1D wavefront phase evaluation
Detector 2	DF-FMON01	EM field in focal spot

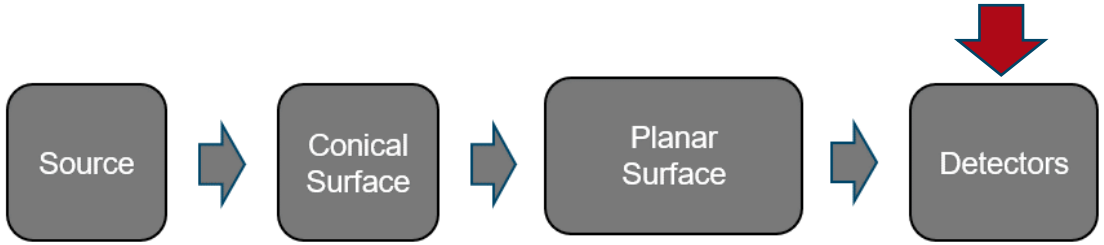
Scenario 1: Reference spherical-plano lens



Scenario 2: Metalens with aberration correction

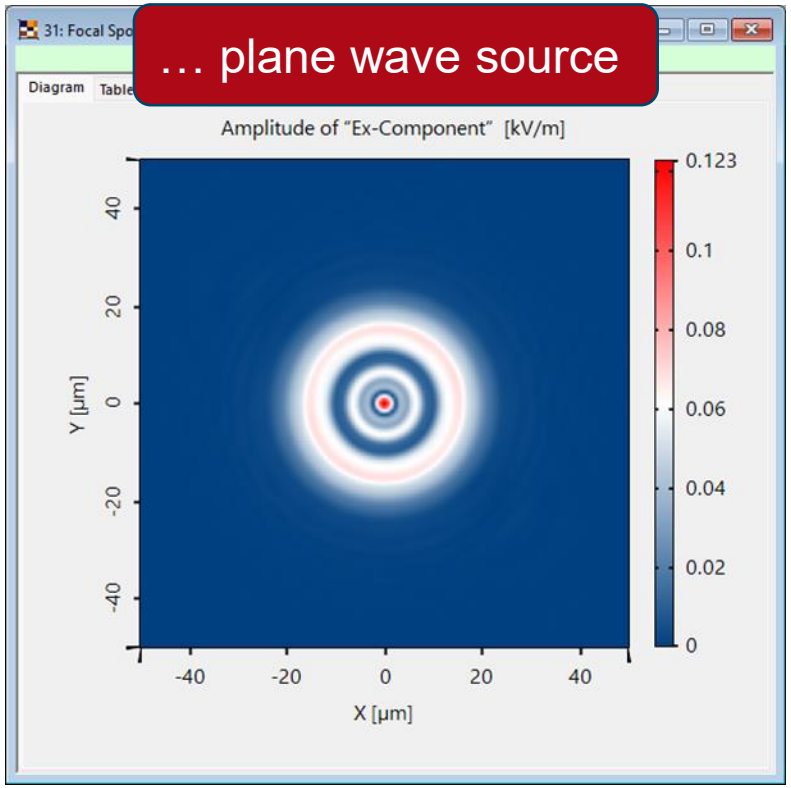


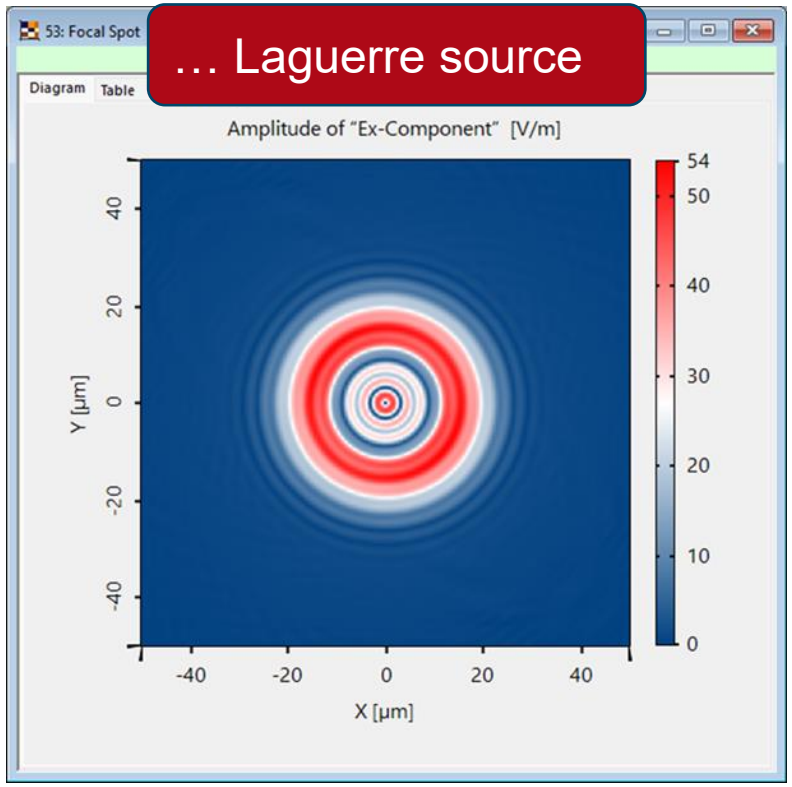
Results – Reference System with Planar Surface



Performance Simulation time: 5 s
Hardware: AMD Ryzen Threadripper 3970X 32-Core Processor, 256 GB DDR4 SDRAM

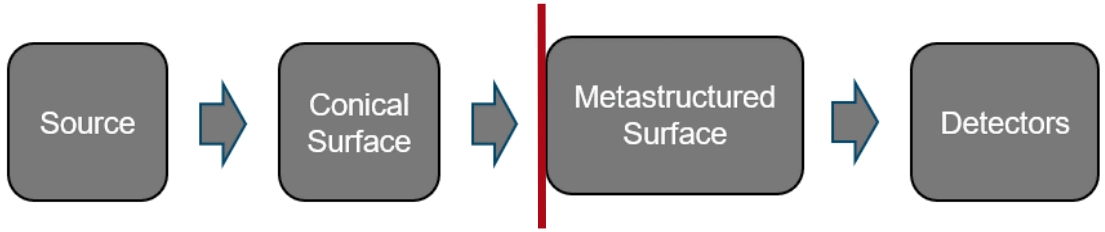
Focal spot with …





Sample file: AberrationCorrection_PW_noMeta.os

Wavefront Phase Profile Definition



What We Did To define the wavefront phase profile of the metastructure we use the following steps:

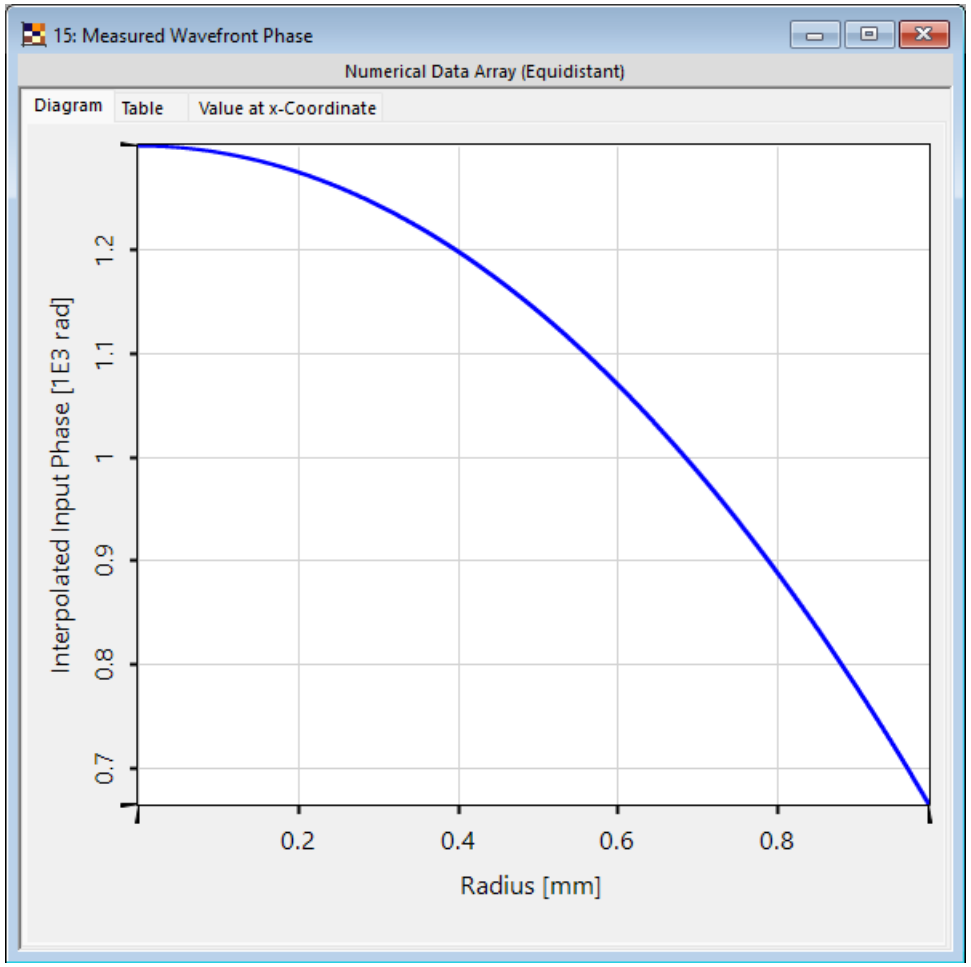
1. Determine the incident phase

Use *Radial Wavefront Phase Detector* to obtain $\phi_{\text{lens}}(r)$ in front of the metasurface — this phase includes the lens's spherical aberration.

2. Calculate the required metalens phase via difference

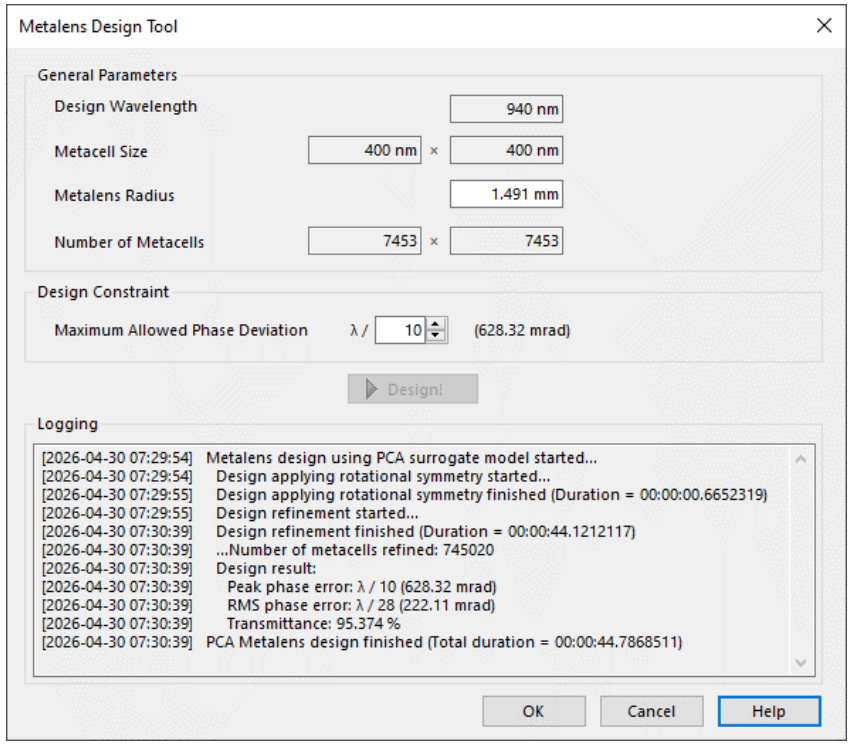
The target phase behind the lens is a perfect spherical wave $\phi_{\text{target}}(r)$. The metalens must impart the difference:

$$\phi_{\text{metalens}}(r) = \phi_{\text{target}}(r) - \phi_{\text{lens}}(r)$$



Calculated Radial Wavefront Phase

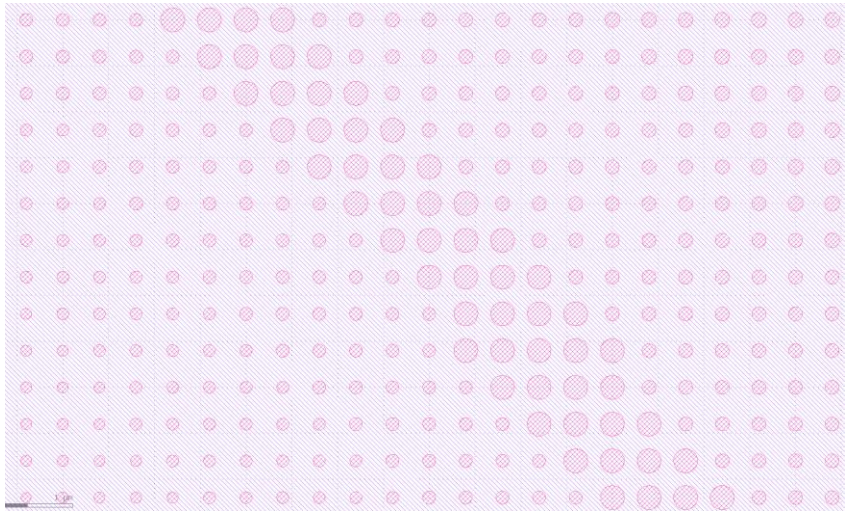
Metalens Design



Hardware & Performance

- Hardware: AMD Ryzen Threadripper 3970X 32-Core Processor, 256 GB DDR4 SDRAM
- Design time: 45 s for > 55 million meta-atoms

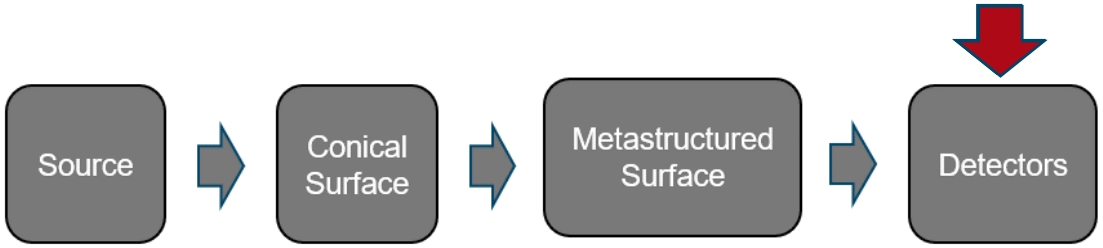
Detail view of designed metalens



Design Results

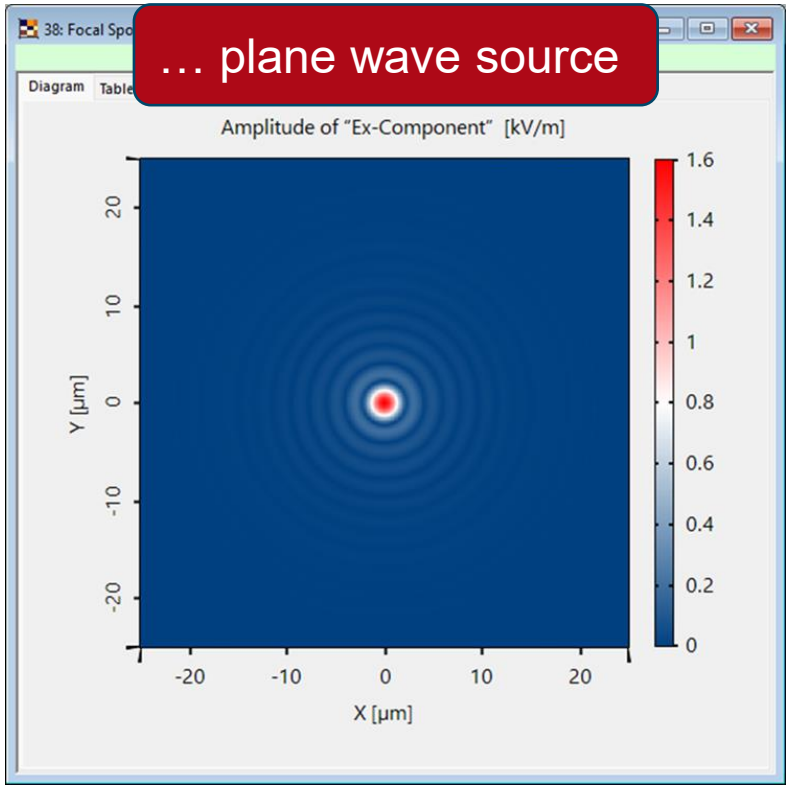
Parameter	Value
Peak phase error	$\lambda/10$
RMS phase error	$\lambda/28$

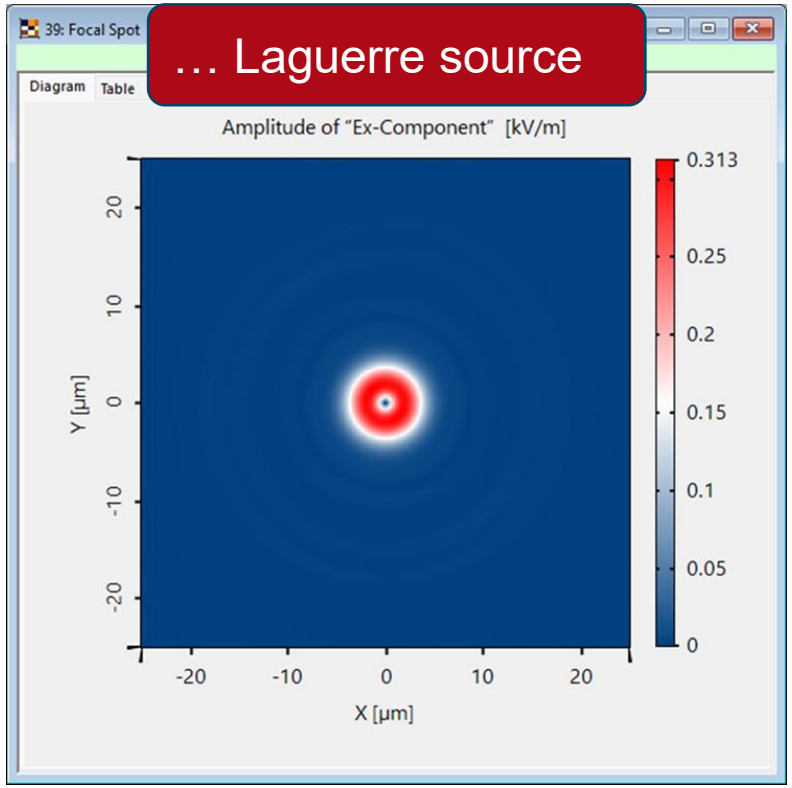
Results – System with Metalens Surface



Performance Simulation time: 1:20 min
Hardware: AMD Ryzen Threadripper 3970X 32-Core Processor, 256 GB DDR4 SDRAM

Focal spot with …





Sample file: AberrationCorrection_PW_noMeta.os

Demonstrated Workflow

Step-by-Step Workflow

1. **Train surrogate model:** Load the provided sample file — preset parameters are included and training has been performed.
2. **System setup:** Add digital twins — *Plane Wave Mode*, *Metalens [PCA]*, *Planar Surface*, *Curved Surface*, *Field Monitor [2D]*, *Wavefront Aberrations [Error]* and *Radial Wavefront Phase*. Set parameters and connect them according to the *Application Scenario* page.
3. **Bind surrogate model:** In the *Metalens [PCA]* component, navigate to the *Simulation Model* page and click *Bind*. Select the trained surrogate model.
4. **Calculate 1D radial wavefront phase:** Calculate the result of the *Radial Wavefront Phase* detector.
5. **Define wavefront phase profile:** Import *Focusing Metalens with Wavefront Phase Correction* snippet from sample files into *Metalens [PCA]* component. Use the calculated 1D radial wavefront profile as *Input Wavefront Data*.
6. **Field tracing:** For the reference system: Use field tracing to simulate. For the metalens system: On first use, the metalens design process starts automatically. Change Maximum Allowed Phase Deviation to $\lambda/10$. Click *Design*, then *OK* after completion — field tracing proceeds automatically.

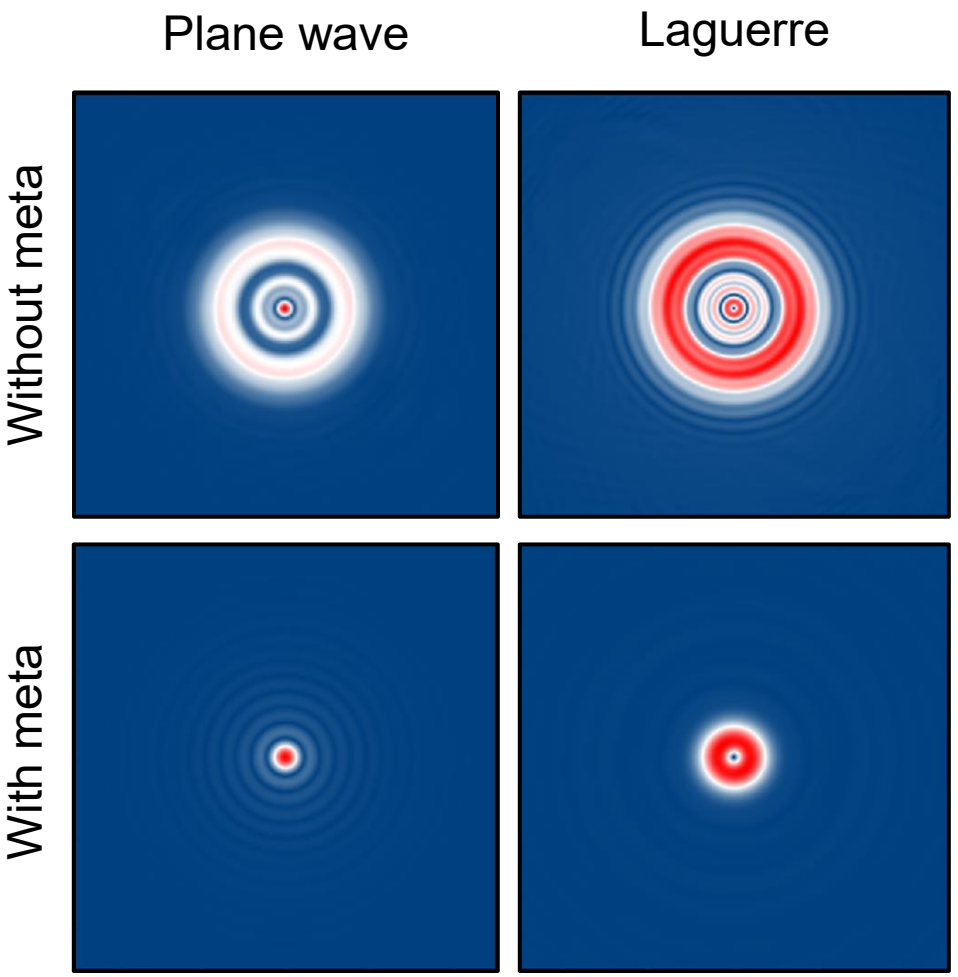
Conclusion

Key Takeaways

- The metastructure successfully compensates spherical aberrations of a conical surface.
- For plane wave illumination: Aberration-free focal spot — clean Airy pattern achieved.
- For Laguerre-Gaussian (0,1) mode: Iconic donut structure fully restored.

→ Next Steps

- Download the sample files and reproduce the results.
- Export the designed metastructure for manufacturing.



Resources Used

White Papers

- WP-META-PCA - PCA: The Foundation for Metalens Design
- WP-META-PHASE - Designing and Analyzing the Phase Response of Metasurfaces

Tutorials

- Define Metalens Functionality
- Designing a Metalens in VirtualLab Fusion

Related Use Cases

- Surrogate Model Training for Nanopillars
- Focusing Metalens Based on Nanopillars

🚀 Step-by-Step Tutorial

Step 1: Metalens Configuration

After adding the metalens component to your system, configure the basic properties: the medium after the component and the aperture diameter (shape is always circular). Then define the wavefront phase profile – the phase transformation to be applied by the metalens.

VirtualLab Fusion provides two methods for defining the phase profile:

- **Even Order Radial Polynomials:** Define spherical, aspherical, or freeform phase profiles using polynomial coefficients (r^2, r^4, ...). Coefficients can also be imported automatically from a Zemax Binary 2 surface.
- **User Defined Formula:** Define the phase profile using a mathematical expression in C# via VirtualLab's snippet technology.