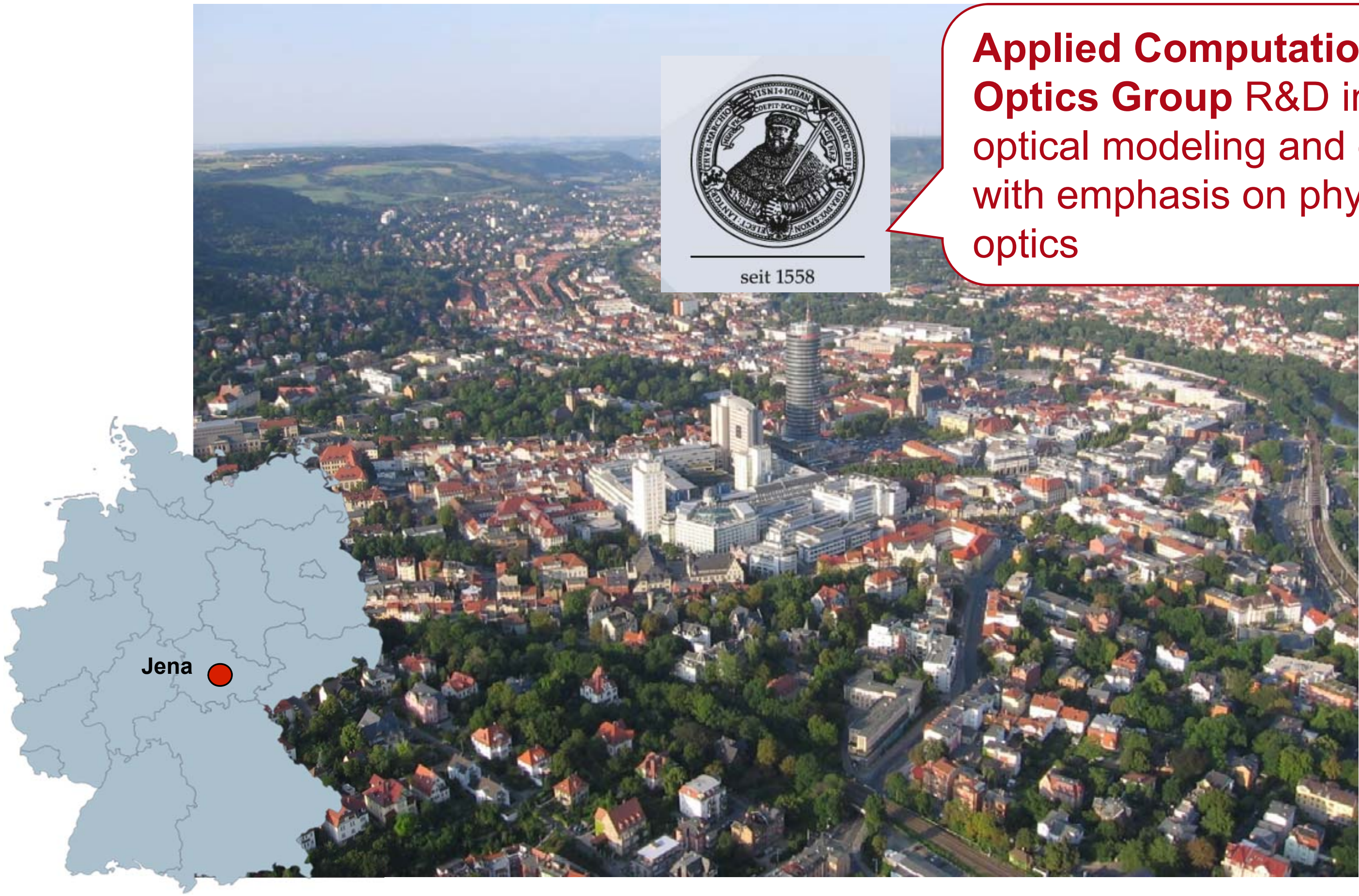
Optatec 2018, 15.05.2018

Optical design of diffractive and freeform solutions for light shaping with VirtualLab Fusion

Frank Wyrowski

- University of Jena, Applied Computational Optics
- LightTrans International UG
- Wyrowski Photoncis UG

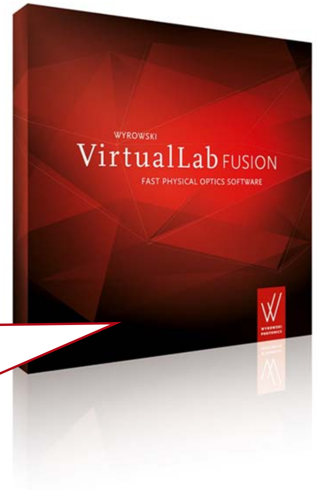
Who, Where, What?



Applied Computational Optics Group R&D in optical modeling and design with emphasis on physical optics

Who, Where, What?

Wyrowski Photonics
Development of fast physical optics software VirtualLab Fusion



All examples shown in this talk were done with **VirtualLab Fusion** software.

Who, Where, What?

LightTrans

- Distribution of VirtualLab Fusion, together with distributors worldwide
- Technical support, seminars, and trainings
- Engineering projects

Who, Where, What?

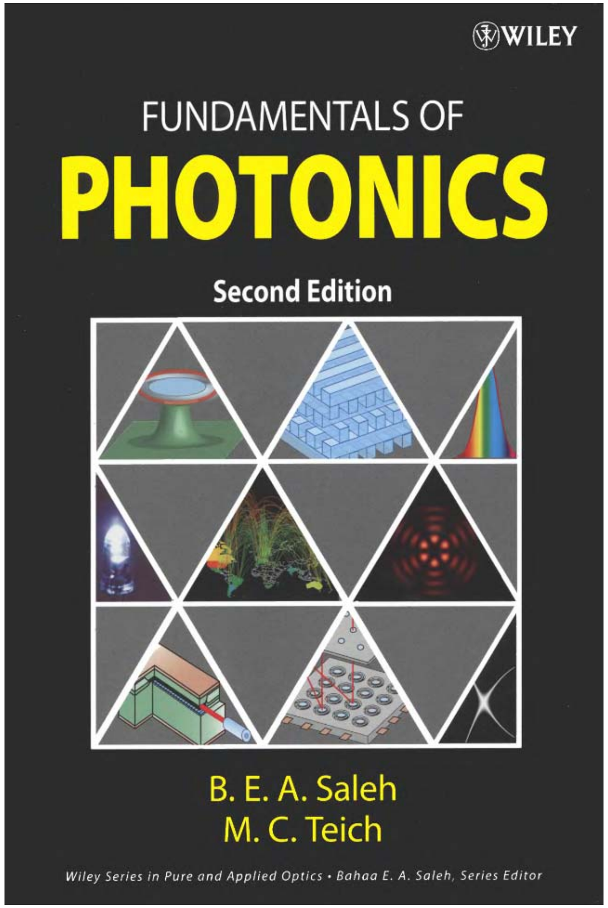
All techniques shown in this talk are available in **VirtualLab Fusion Software** or/and as **Consulting & Engineering Services!**

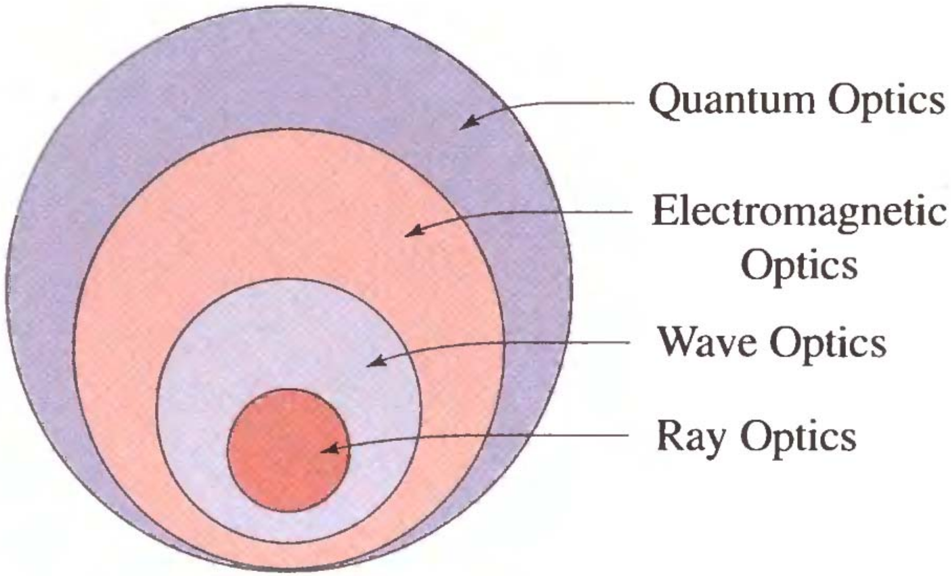
Hall 3.0, Booth B63

Optical design of diffractive and freeform solutions for light shaping with VirtualLab Fusion

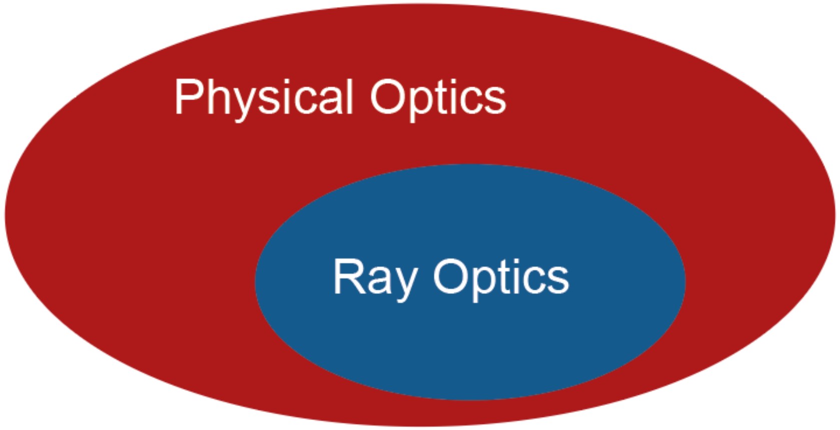
Diffractive and geometric branches of physical optics

Physical and Geometrical Optics: Traditional Understanding





Physical and Geometrical Optics: Traditional Understanding



- Physical optics:
  - Light represented by electromagnetic fields which
  - are governed by Maxwell's equations.

- Geometrical/ray optics:
  - Light is represented by mathematical rays (with energy flux) which
  - are governed by Fremat's principle which is mathematically expressed by ray equation.

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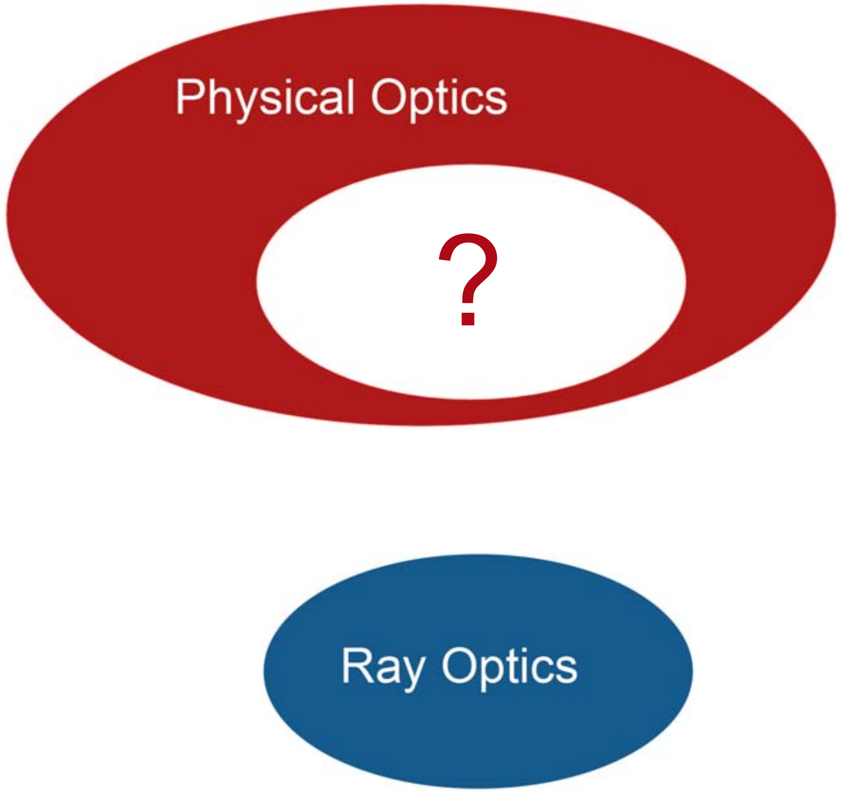

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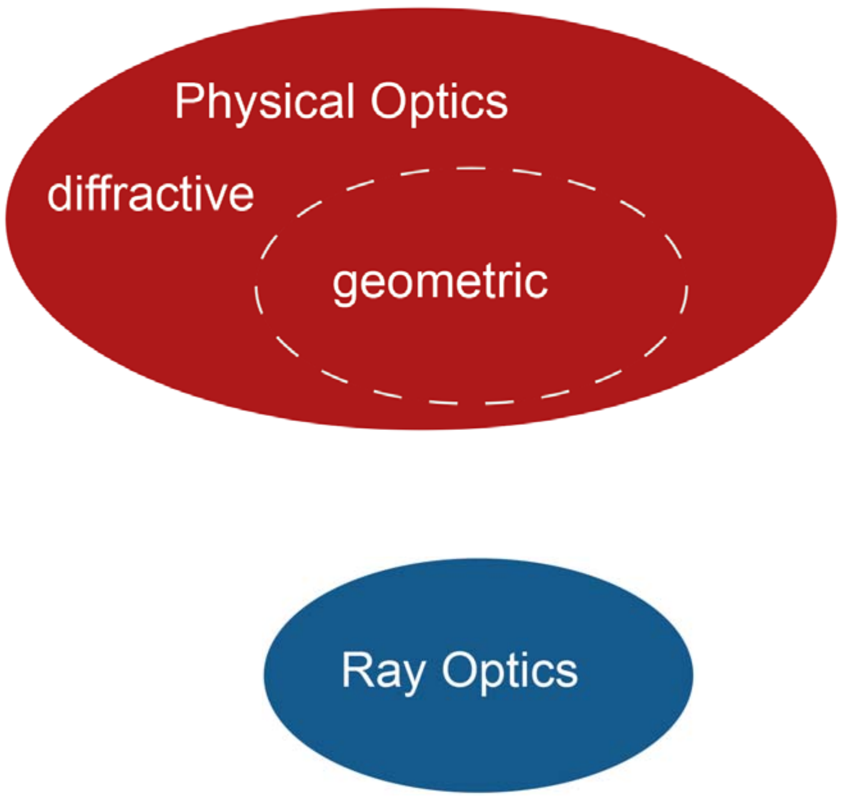

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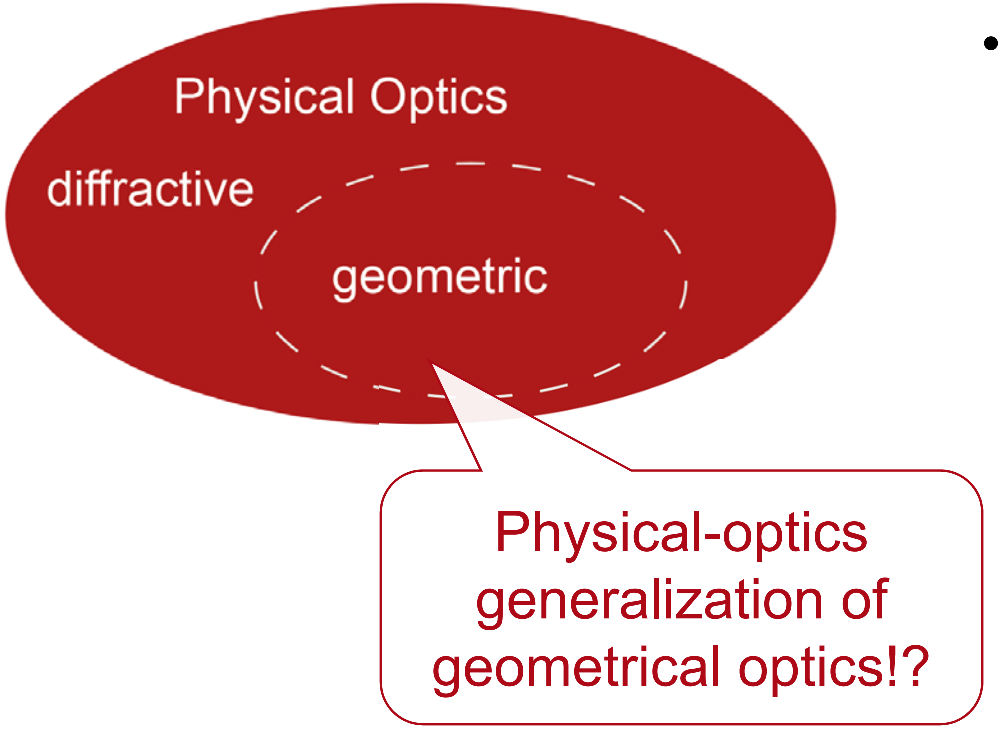
Physical and Geometrical Optics: Unified Theory



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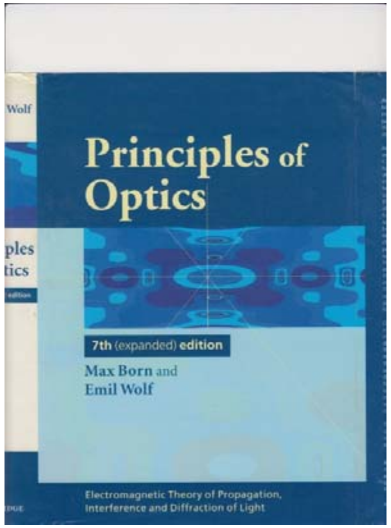

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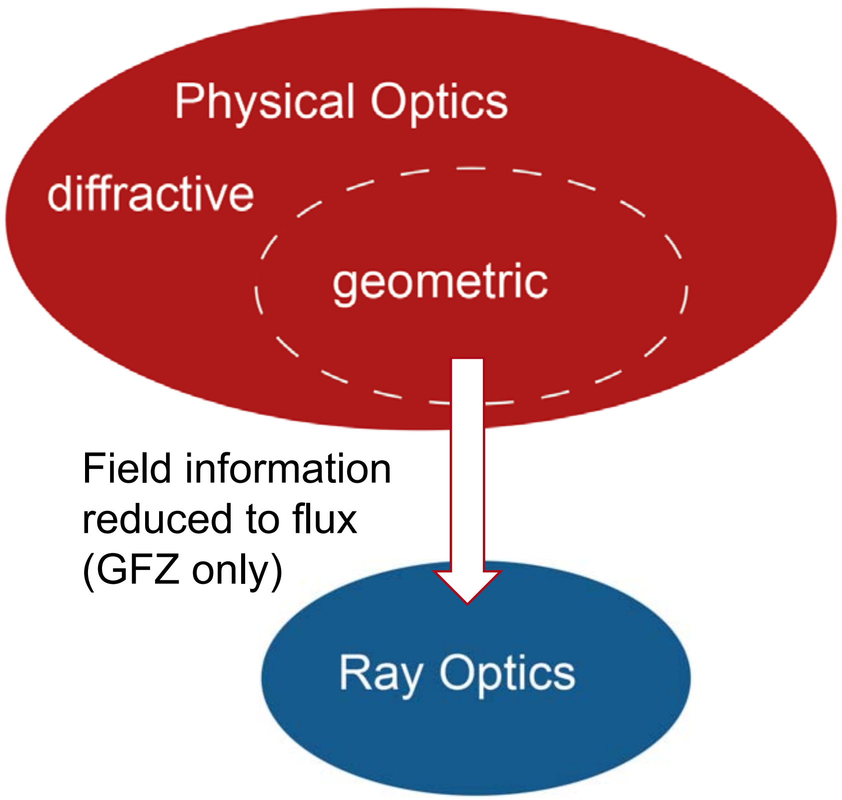

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  - Diffractive and geometric field zones

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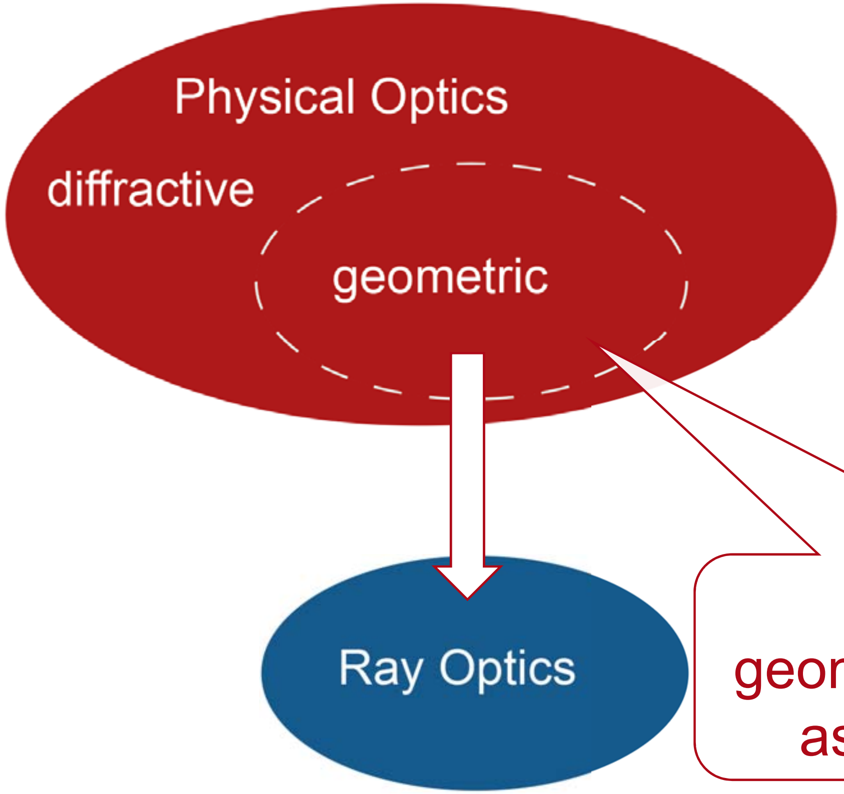

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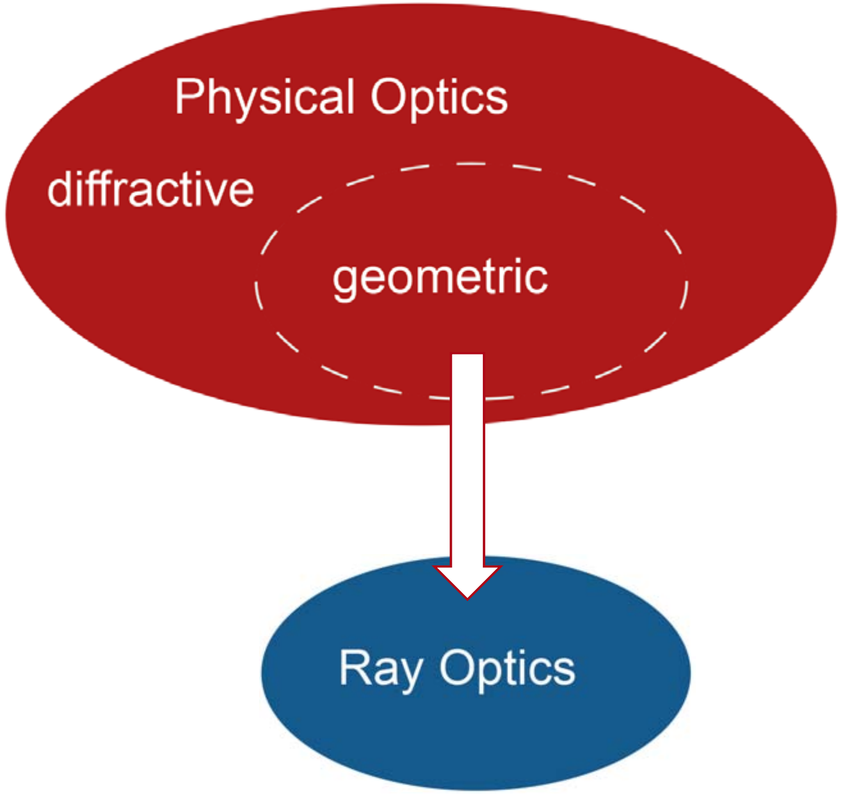
Physical optics in geometric zones is at least as fast as ray tracing!

Physical and Geometrical Optics: Unified Theory

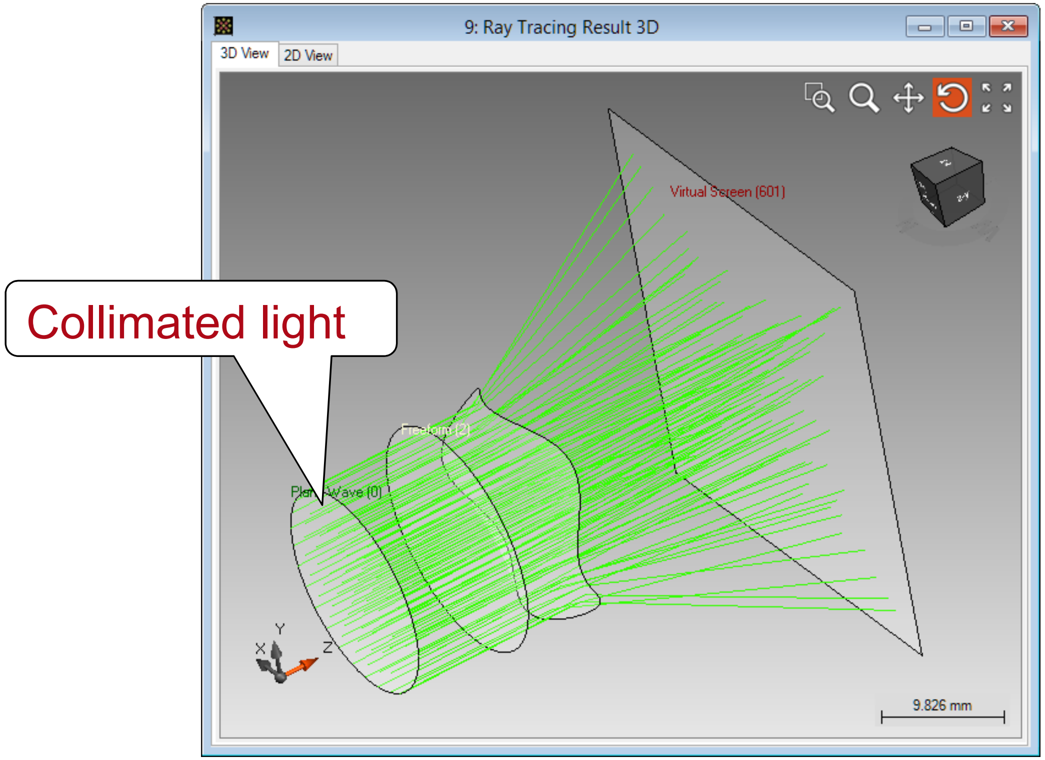


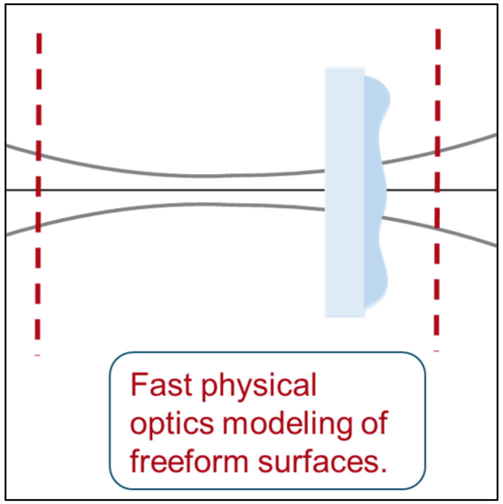
- Physical optics:
  - Light represented by electromagnetic fields which
  - are governed by Maxwell's equations
  - Transition between diffractive/geometric branch fully specified and controlled by mathematical concepts
  - Diffractive and geometric field zones
- VirtualLab Fusion deals with the transitions between diffractive and geometric branches of physical optics automatically (steady development).

Modeling and Design with Fast Physical Optics

- Compared to ray tracing You do not lose anything by fast physical optics
- Ray tracing is included in VirtualLab Fusion software on a solid base knowing about limitations of ray optics

Fast Physical Optics: Freeform Surfaces





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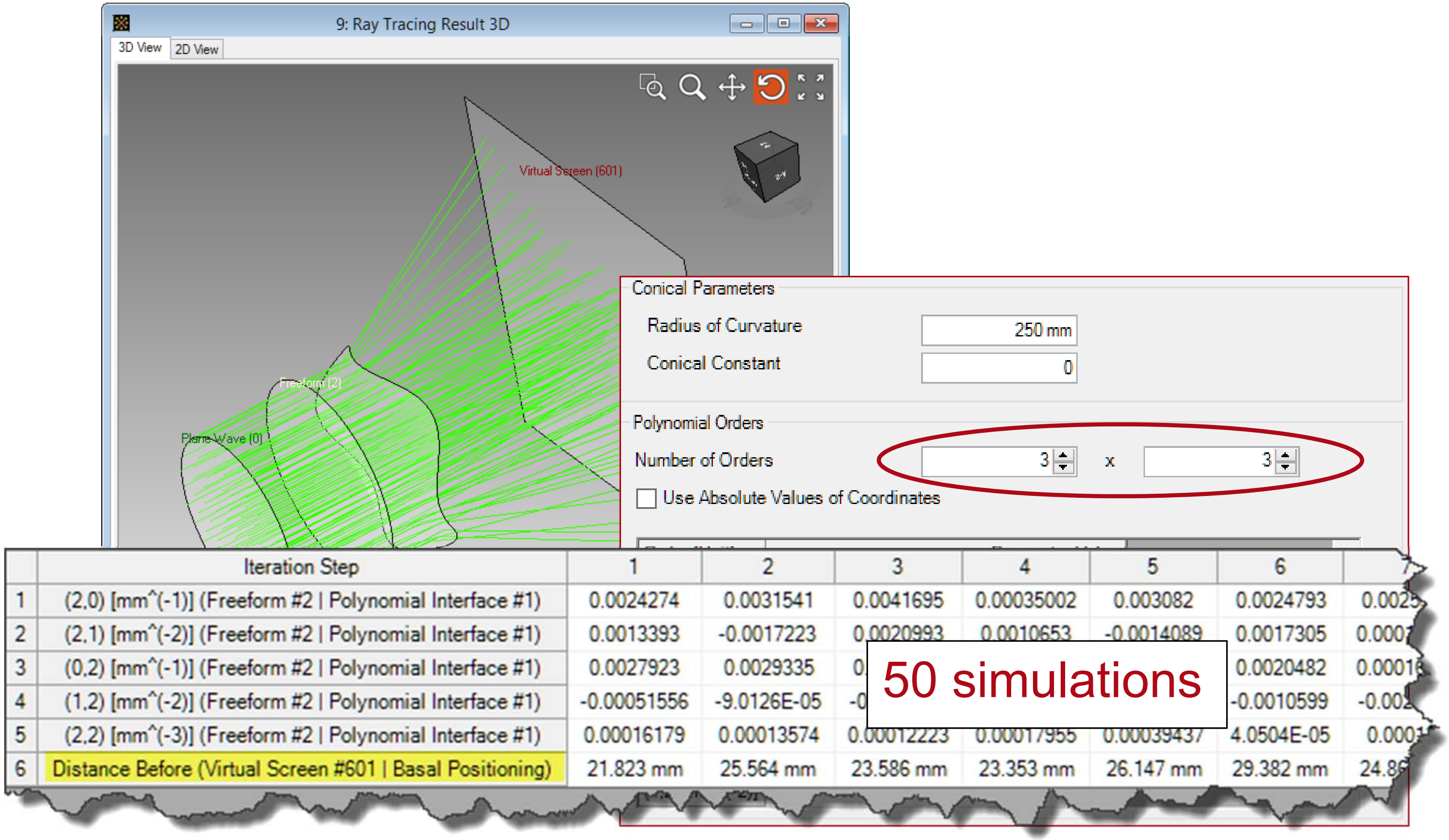
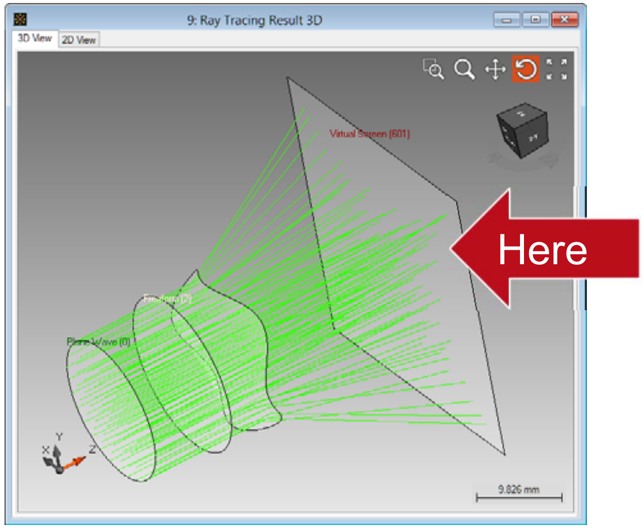
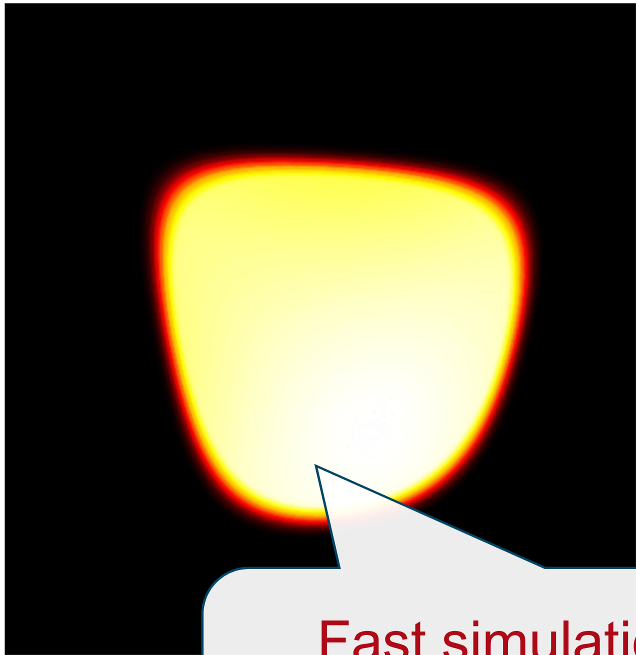


	Iteration Step	1	2	3	4	5	6	7
1	(2,0) [mm^(-1)] (Freeform #2 | Polynomial Interface #1)	0.0024274	0.0031541	0.0041695	0.00035002	0.003082	0.0024793	0.0025
2	(2,1) [mm^(-2)] (Freeform #2 | Polynomial Interface #1)	0.0013393	-0.0017223	0.0020993	0.0010653	-0.0014089	0.0017305	0.0007
3	(0,2) [mm^(-1)] (Freeform #2 | Polynomial Interface #1)	0.0027923	0.0029335	0.			0.0020482	0.00016
4	(1,2) [mm^(-2)] (Freeform #2 | Polynomial Interface #1)	-0.00051556	-9.0126E-05	-0			-0.0010599	-0.002
5	(2,2) [mm^(-3)] (Freeform #2 | Polynomial Interface #1)	0.00016179	0.00013574	0.00012223	0.00017955	0.00039437	4.0504E-05	0.000
6	Distance Before (Virtual Screen #601 | Basal Positioning)	21.823 mm	25.564 mm	23.586 mm	23.353 mm	26.147 mm	29.382 mm	24.8

Fast Physical Optics: Freeform Surfaces



Amplitude $E_x(x,y)$

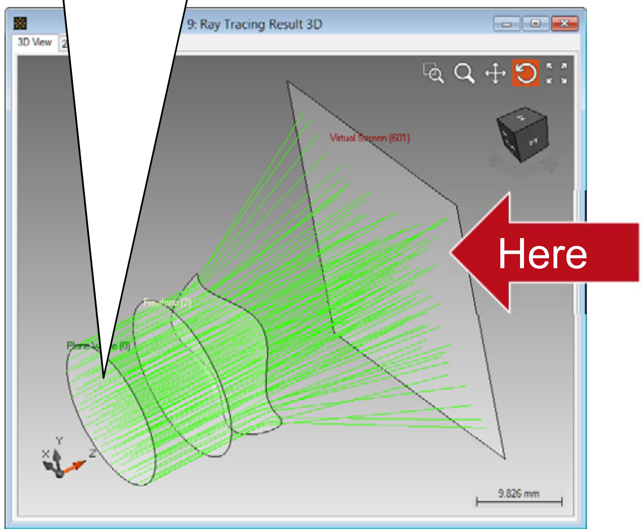


Fast simulation with low number of wavefront samples but noise-free detector signal!

cpu time per simulation < 1 sec

Fast Physical Optics: Freeform Surfaces

Input: Gaussian beam
Diameter 10 mm



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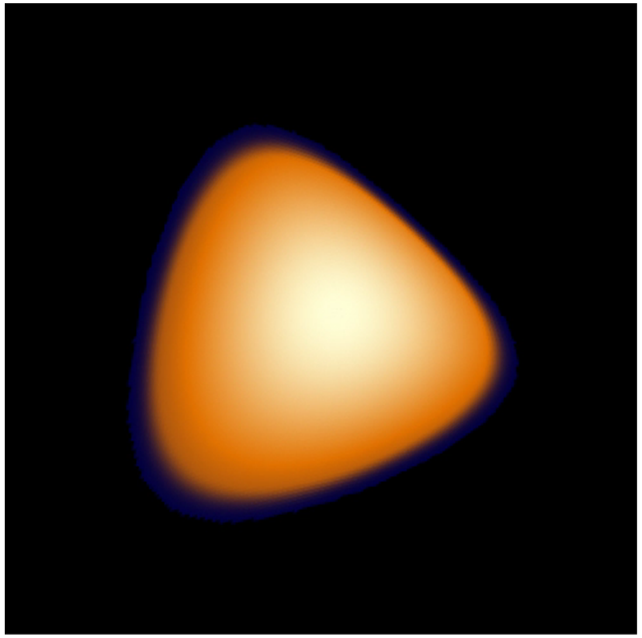

cpu time per simulation < 1 sec

Modeling and Design with Fast Physical Optics

- Compared to ray tracing You do not lose anything by fast physical optics
- Ray tracing is included in VirtualLab Fusion software on a solid base knowing about limitations of ray optics
- **By going beyond ray tracing**
  - You win more information about the light in your system
  - You get better insight into the performance of your system
  - You can include and investigate more effects
  - You can model with higher accuracy
  - You are ready for new optical design concepts and by that for innovative optical solutions

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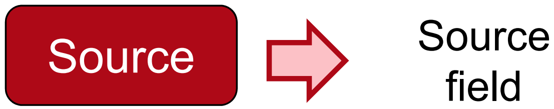
Light Shaping Task

… from a physical-optics perspective

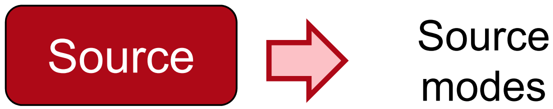
Light Shaping Task: Source Modes



- Laser
- Laser diode
- LED
- OLED
- Lamp
- Natural light

- Any source field can be decomposed into harmonic and mutually incoherent modes

Light Shaping Task: Source Modes



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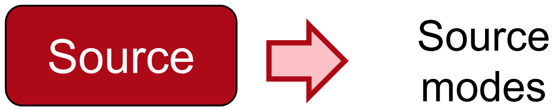
- Any source field can be decomposed into harmonic and mutually incoherent modes
    - Gaussian modes

Light Shaping Task: Gaussian Modes (Hermite)



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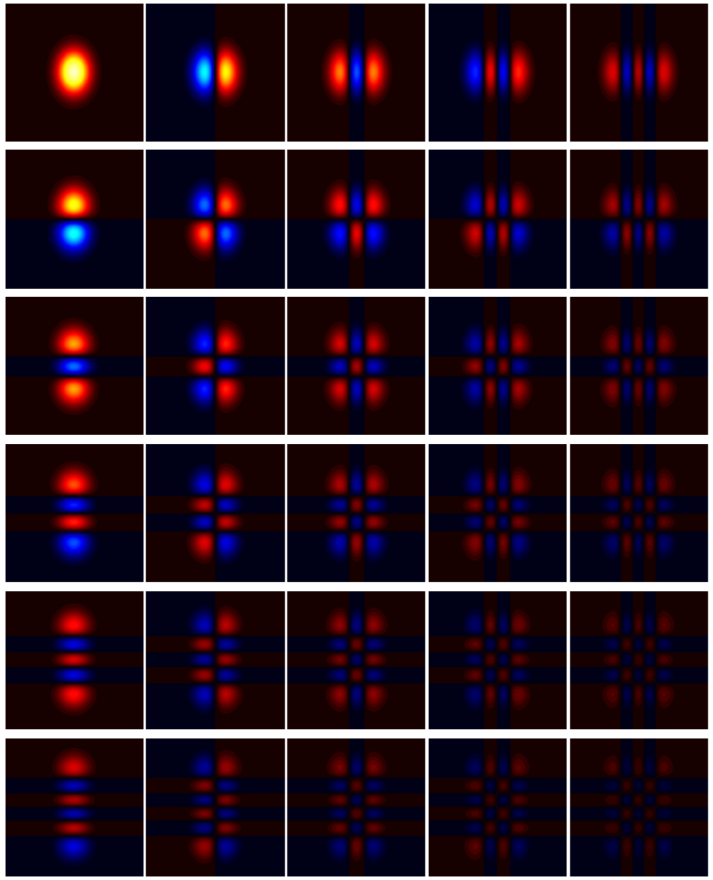
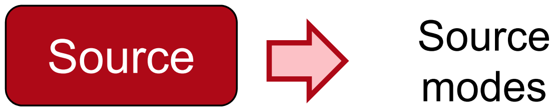


Light Shaping Task: Source Modes



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- Any source field can be decomposed into harmonic and mutually incoherent modes
  - Gaussian modes
  - Plane wave modes
  - Shifted modes, e.g.
    - Spherical wave
    - Lambertian mode

Light Shaping Task: Shifted Modes

Source → Source modes

- Laser
- Laser diode
- LED
- OLED
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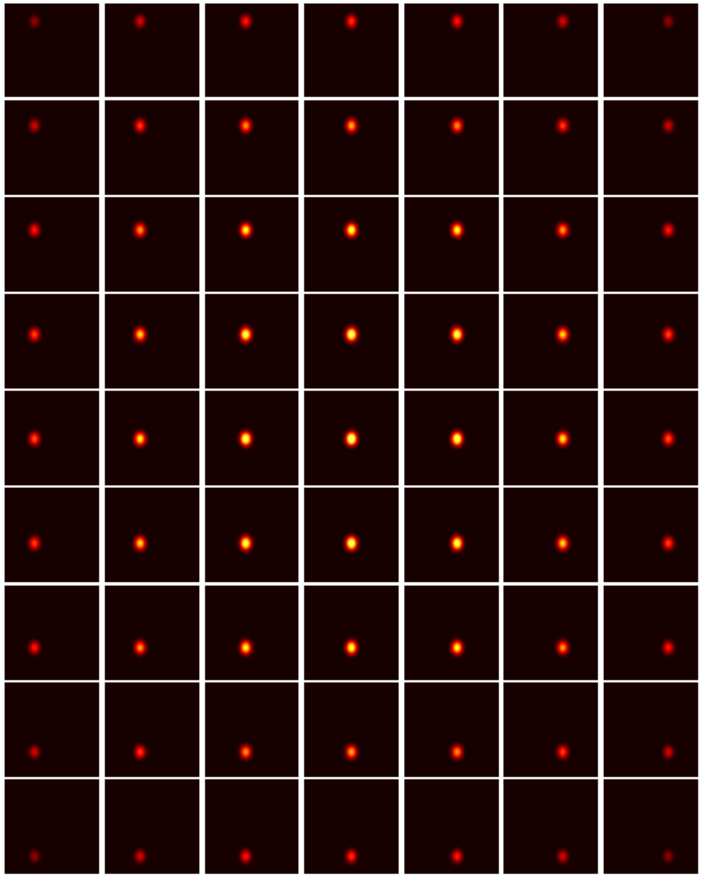
- Natural light



Light Shaping Task: Modes from Ray Data

Source → Source modes

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- **LED**
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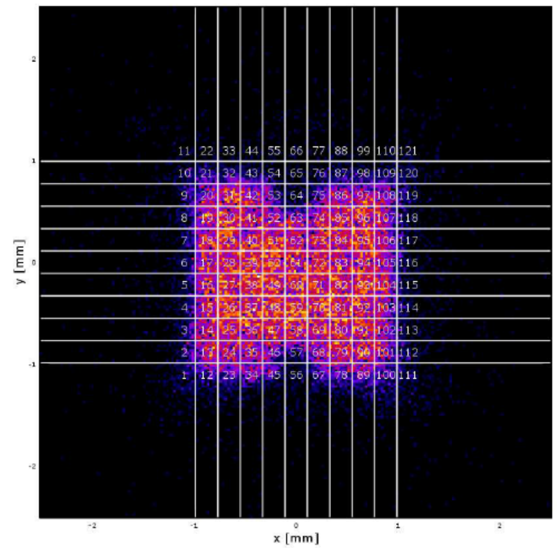
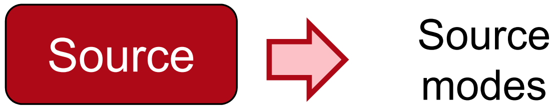
- Any source field can be decomposed into harmonic and mutually incoherent modes
- Modes from ray data



Osram GW CSSRM2pm LED (dome lens)

Light Shaping Task: Modes from Ray Data



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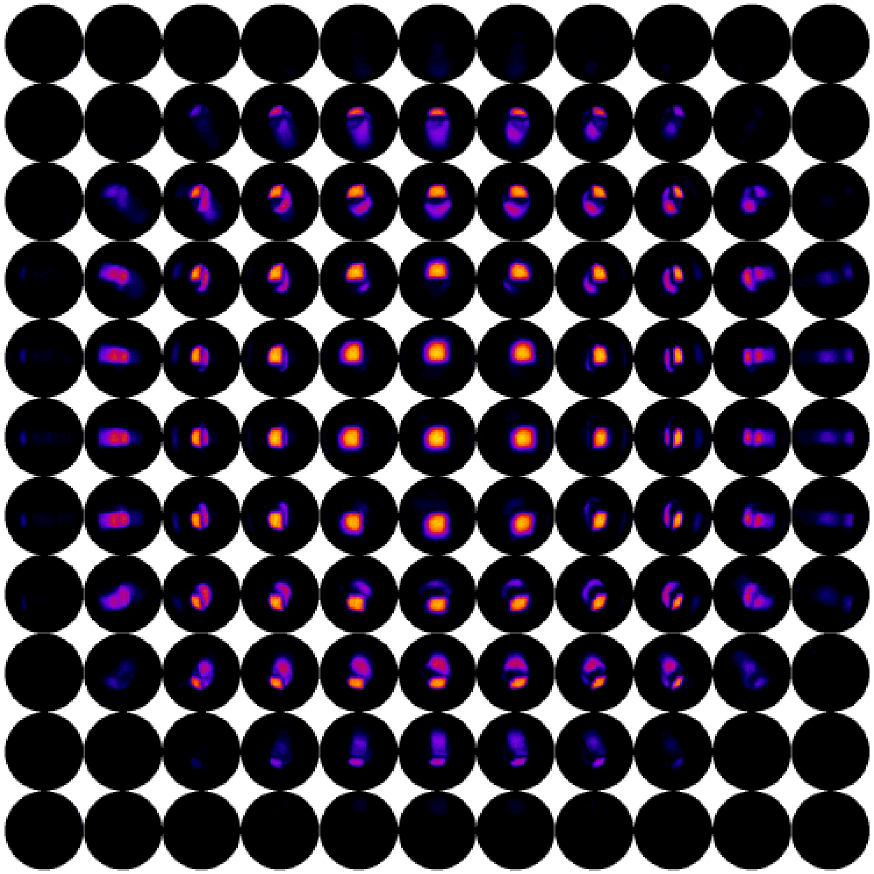
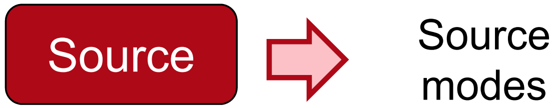


Light Shaping Task: Design



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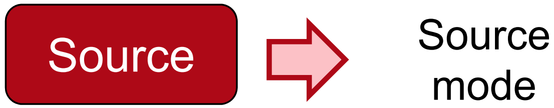
- Any source field can be decomposed into harmonic and mutually incoherent modes
- Design:
  - For one mode only (+ far field of source)
  - For one mode only and then optimization for other modes
  - Simultaneous design for few modes
  - Multichannel techniques
  - Diffuser

Light Shaping Task: Design



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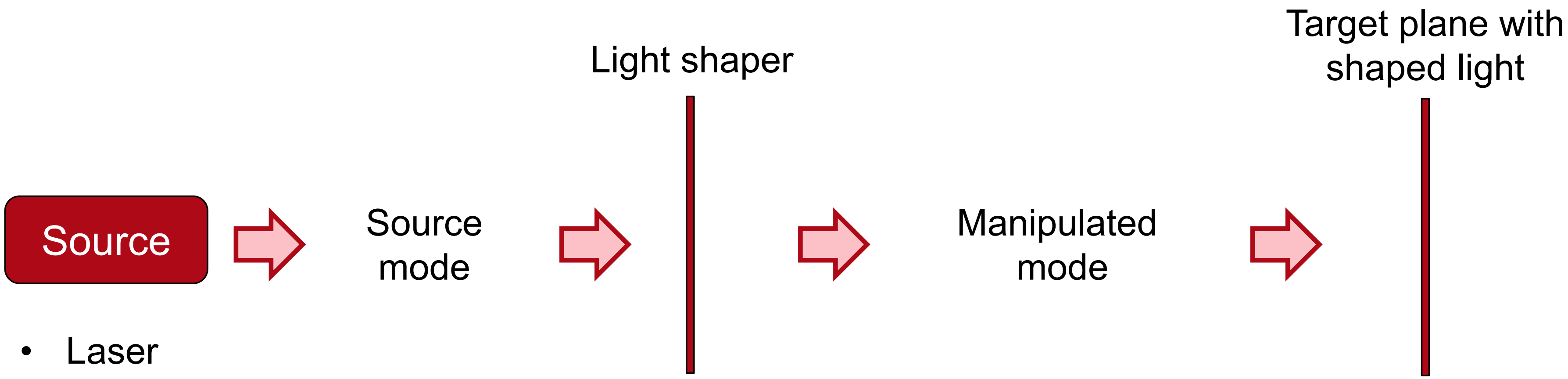
Light Shaping Task



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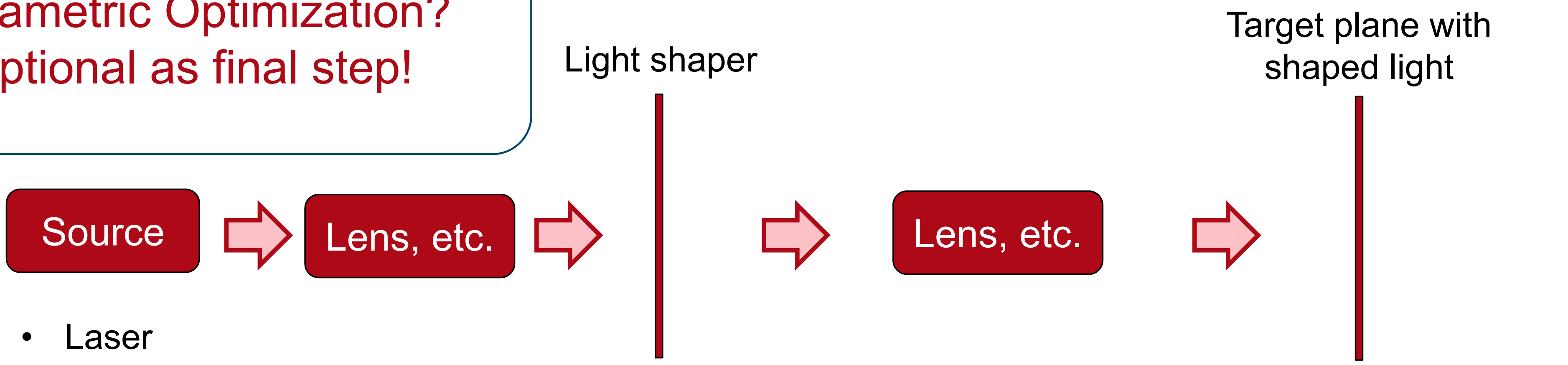
Manipulation of
- Amplitude
- Wavefront (rays: direction)
- Other phase terms, e.g. vortexes
- Irradiance

Shaped field quantities
- Complex field
- Irradiance
- Polarization
- Temporal pulse shape

Light Shaping Task

Parametric Optimization?
Optional as final step!



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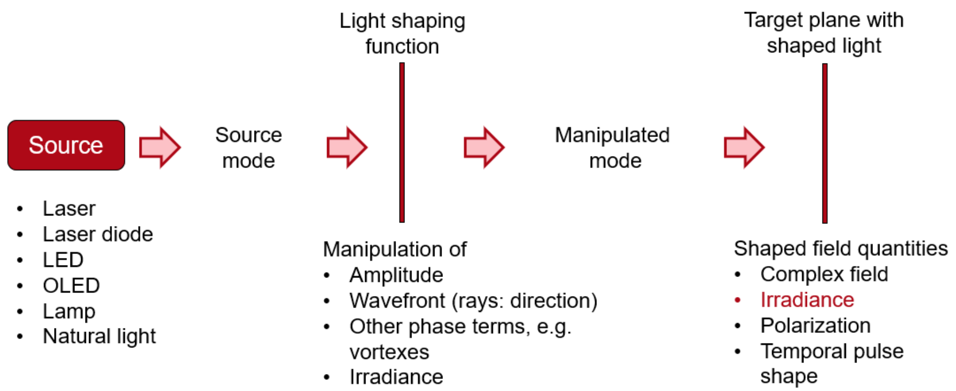
Light Shaping Design: Functional

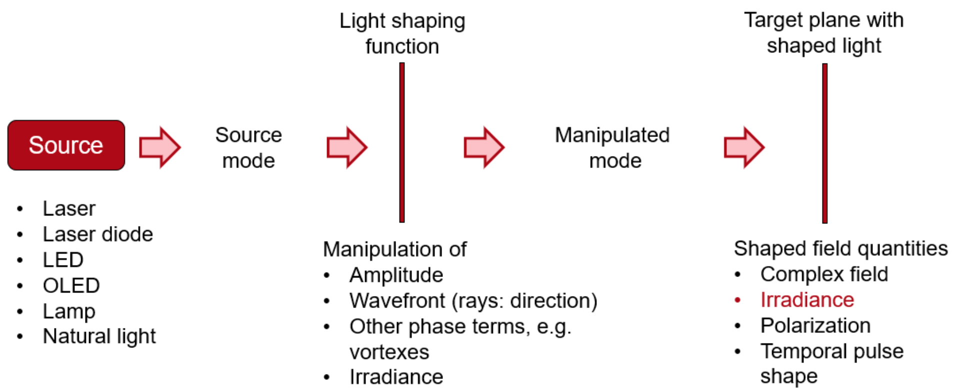


We need to answer the following questions:

- What kind of light manipulation is needed in order to obtain the demanded shaping result?
- Do I need more components and which are the required distances?

Light Shaping Design: Functional

Physical optics enables strategies for functional design!



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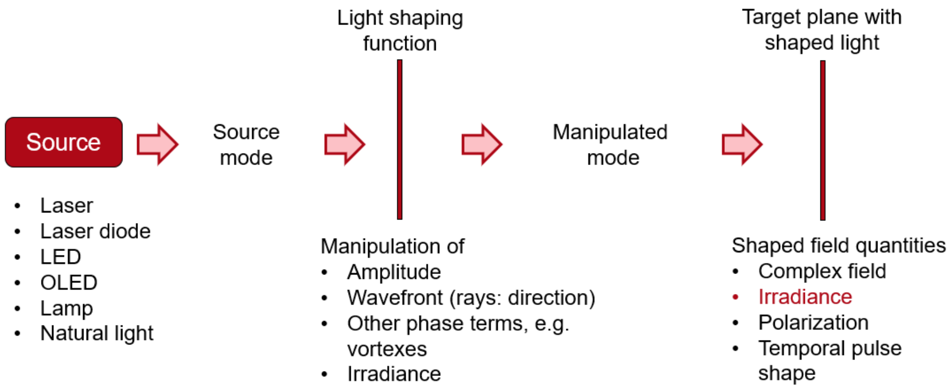
Light Shaping Design: Structural



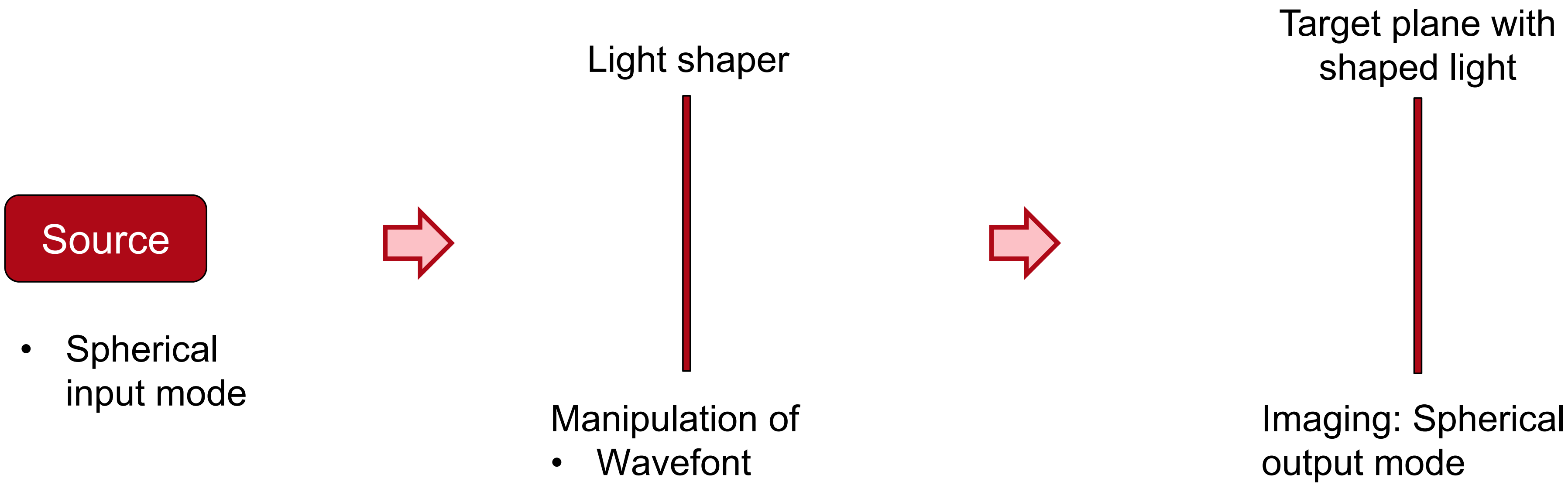
Functional design provides a strong foundation for the subsequent structural design.

We need to answer the following questions:

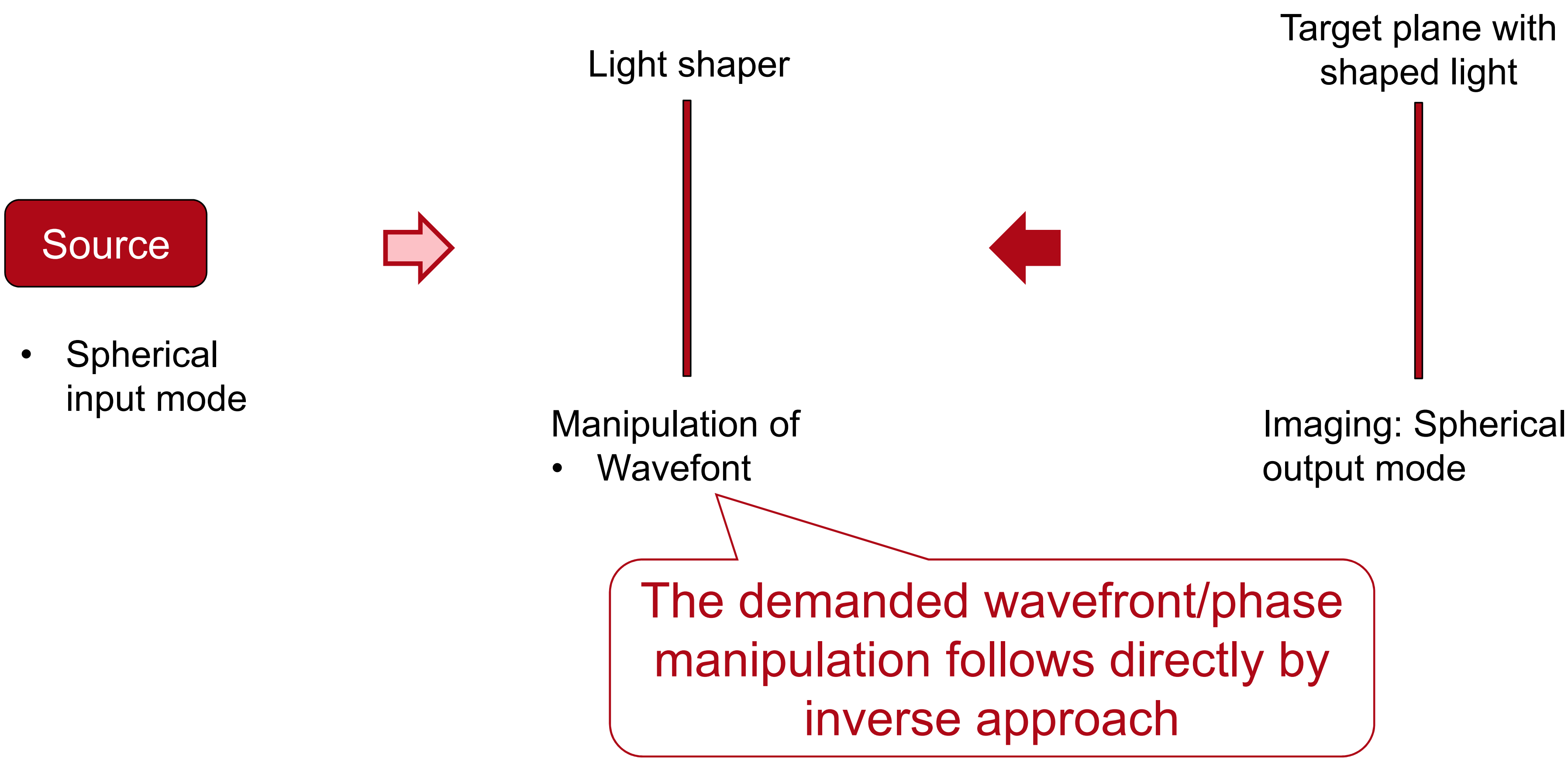
- What kind of light manipulation is needed in order to obtain the demanded shaping result?
- Do I need more components and which are the required distances?
- What kind of components can be used to obtain the required light manipulations?
  - Spherical, aspherical, freeform
  - Diffractive
  - GRIN components
  - Metasurfaces

Examples from lens design: Imaging

Basic Imaging Task



Functional Design: Inverse Approach



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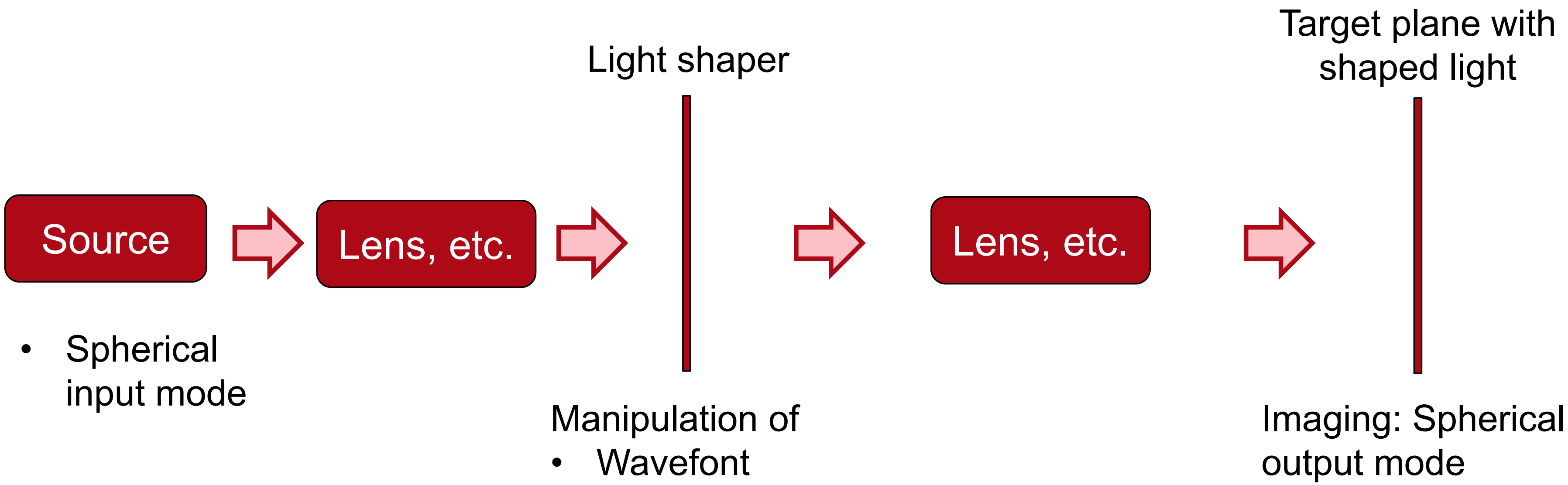

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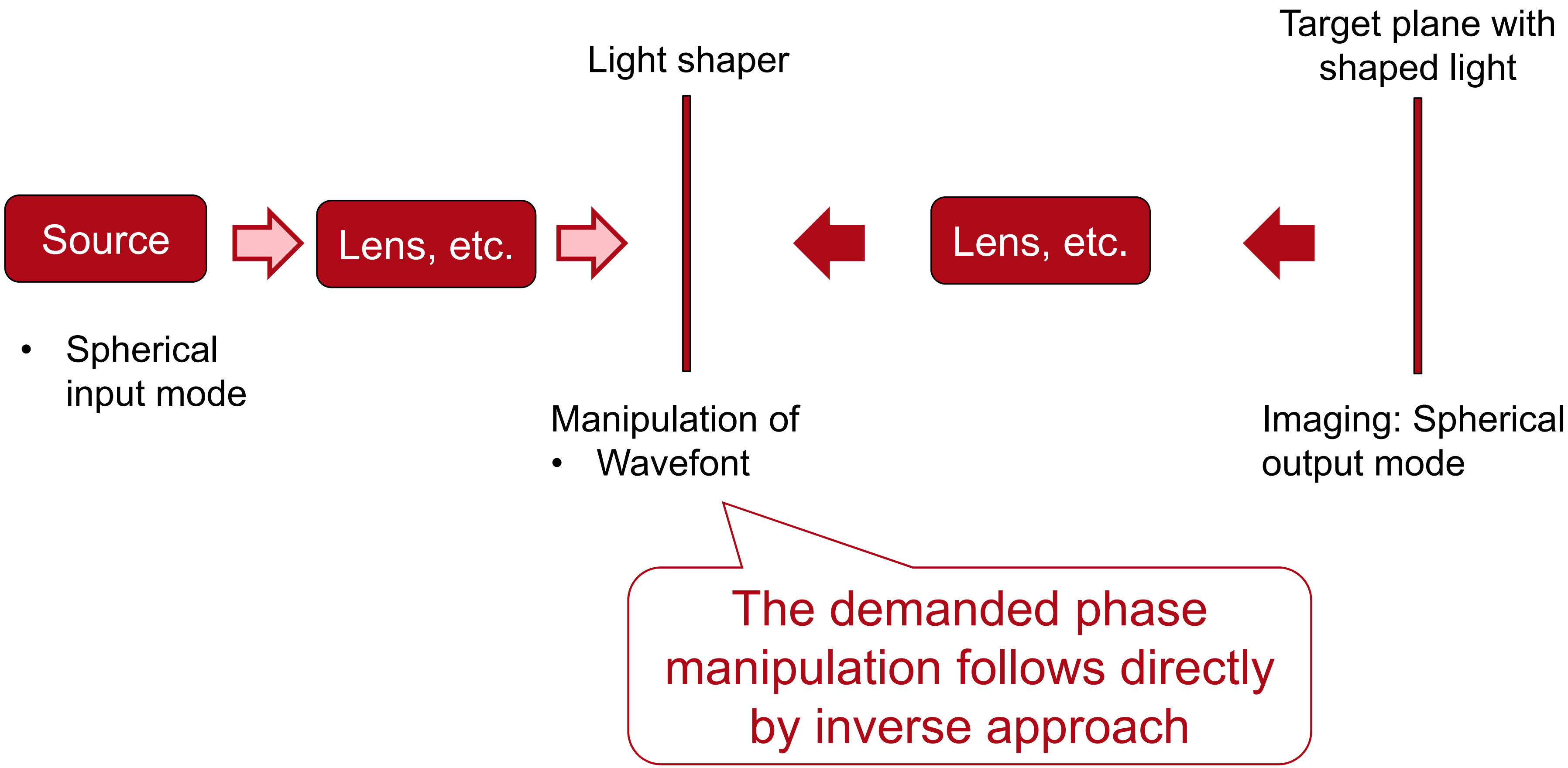
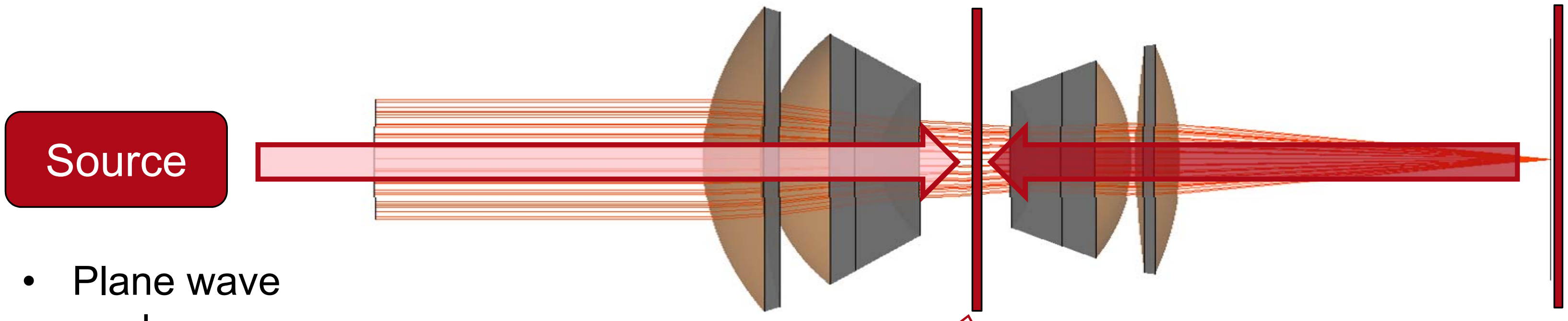


Example: Correction of Lens System

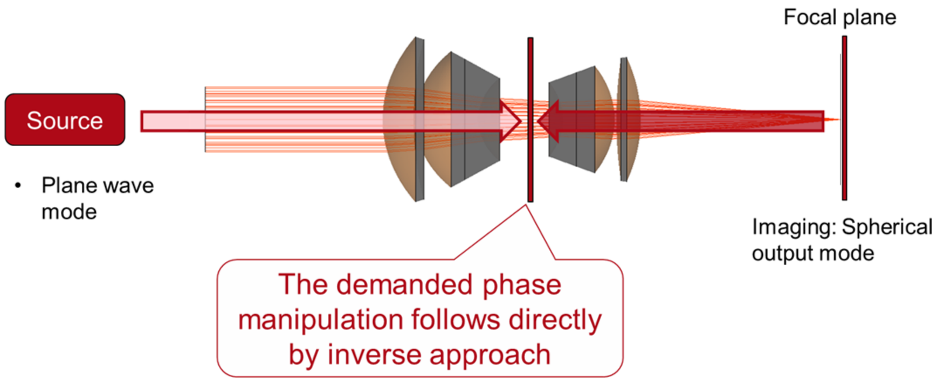


- Plane wave mode

Imaging: Spherical output mode

The demanded phase manipulation follows directly by inverse approach

Light Shaping Design: Functional



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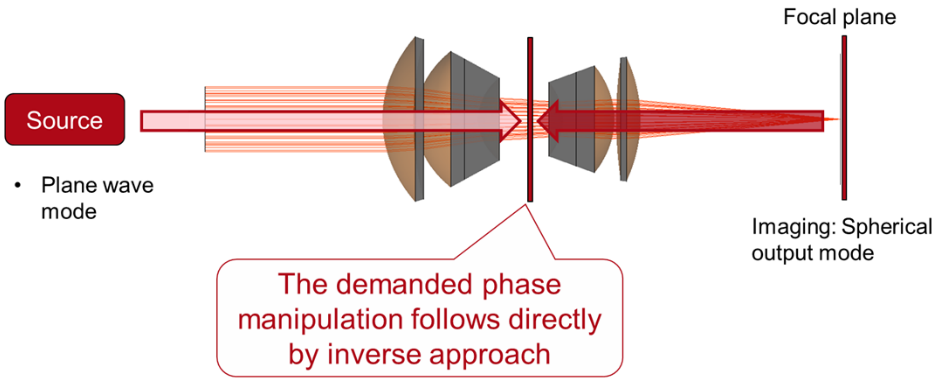
Light Shaping Design: Structural



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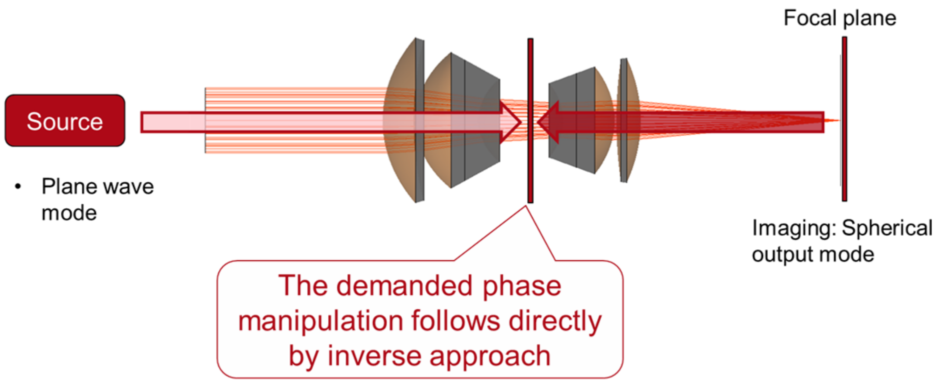

- We have developed a fast freeform surface design algorithm.
- It is based on the phase information from functional design step.
- No parametric optimization!

We need to answer the following questions:

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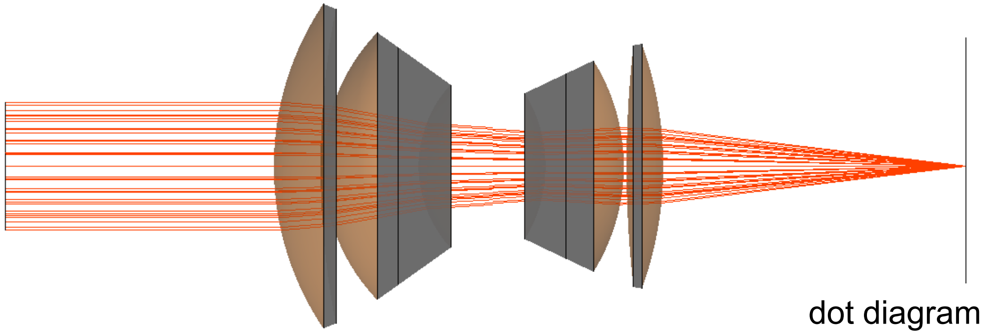
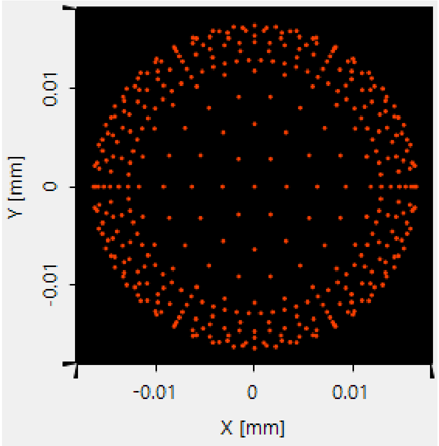
Example: Focusing Lens w/o Freeform

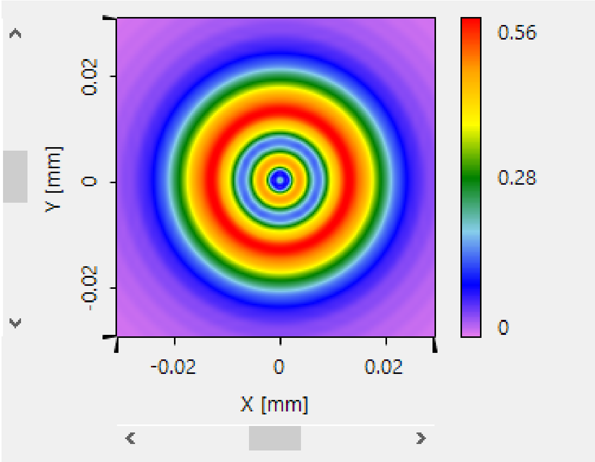


dot diagram



Size $= 42.27\mu m$

PSF



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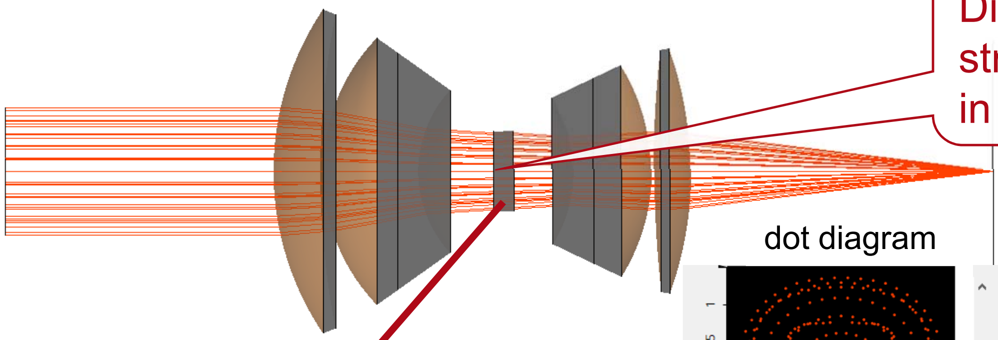
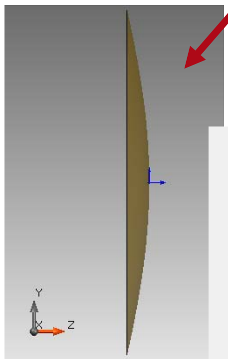
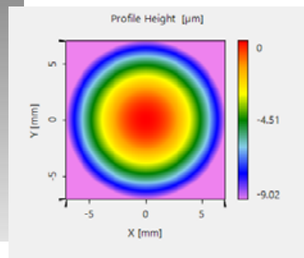


Direct design (functional + structural) without optimization in a few seconds!

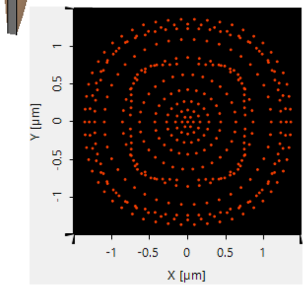


Height Profile (3D view)



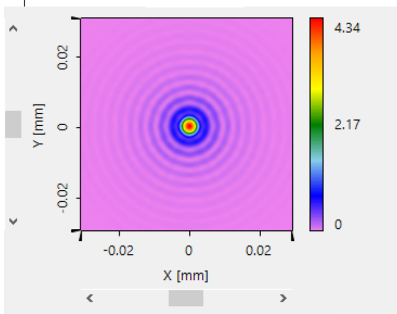
Height Profile (2D view)

dot diagram

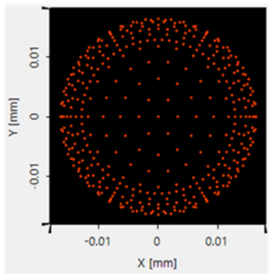


Size $= 2.08\mu m$

PSF

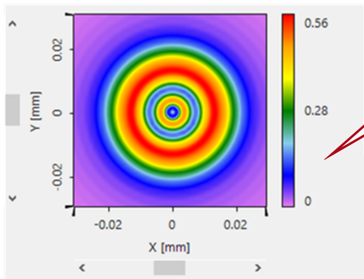


dot diagram



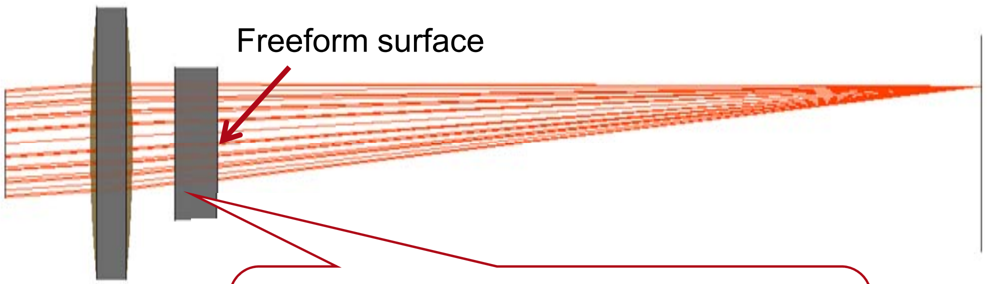
Size $= 42.27\mu m$

PSF



Result without correction with freeform surface!

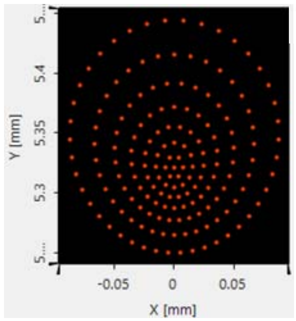
Example: Focusing Lens Off-Axis



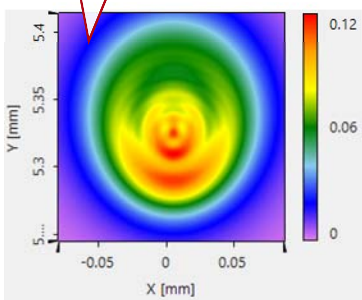
Direct design (functional + structural) without optimization in a few seconds!

Result without correction with freeform surface!

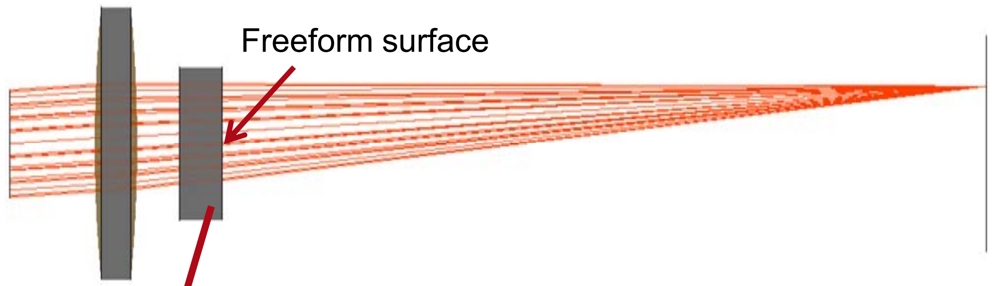
Size $= 0.76\mu$m

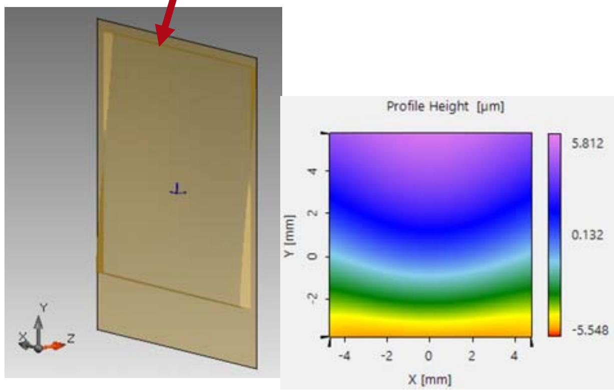


Size $= 127.9\mu$m



Example: Focusing Lens Off-Axis

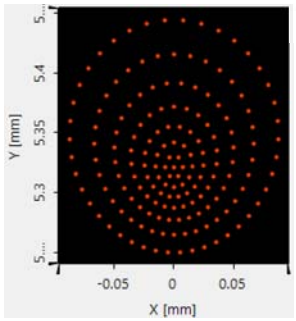




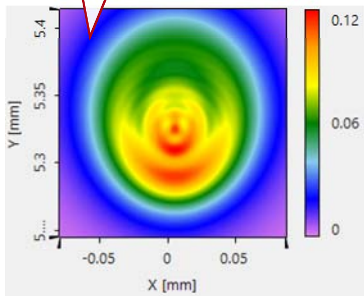
3D view 2D view

Result without correction with freeform surface!

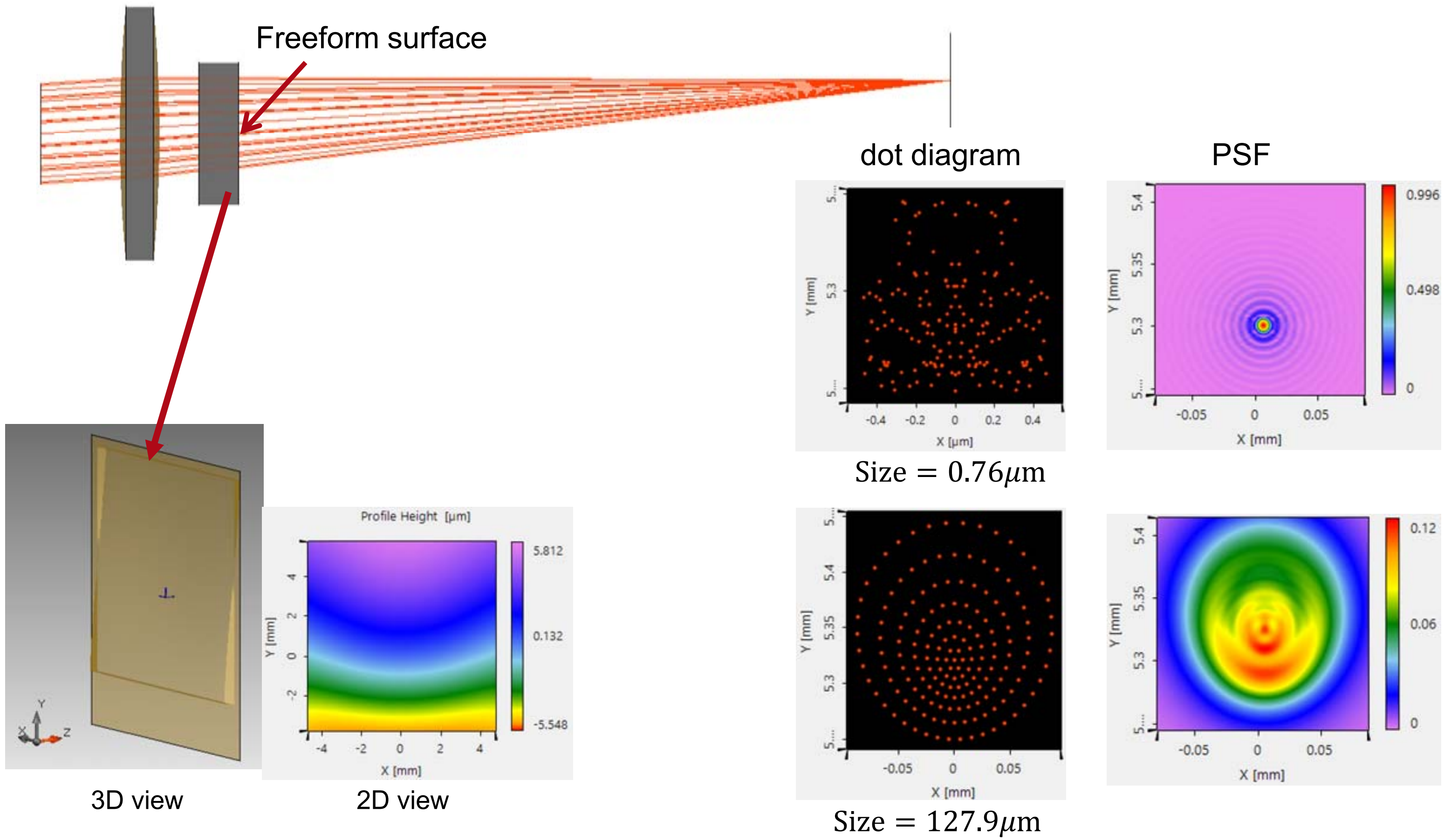
Size $= 0.76\mu$m



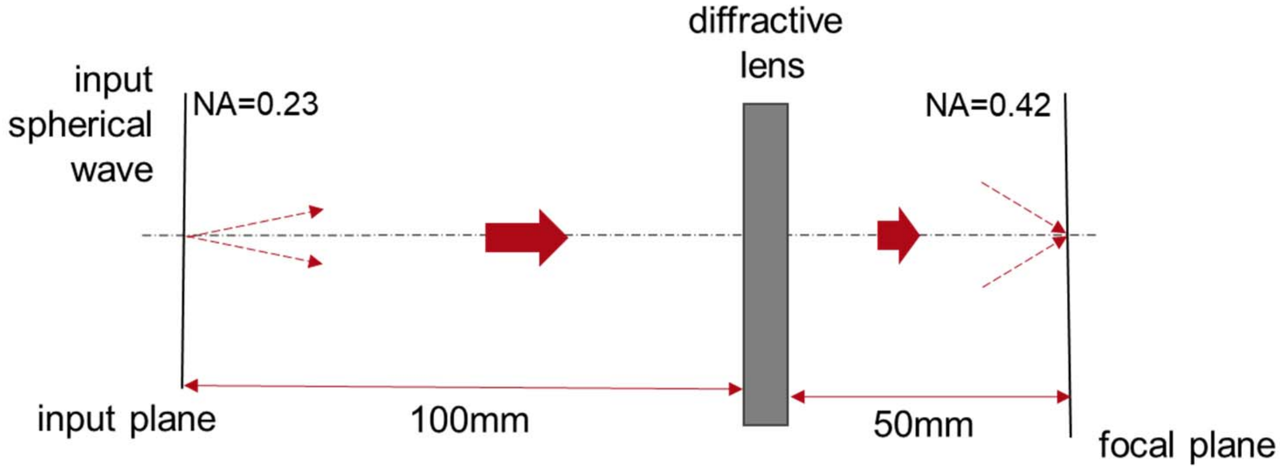
Size $= 127.9\mu$m



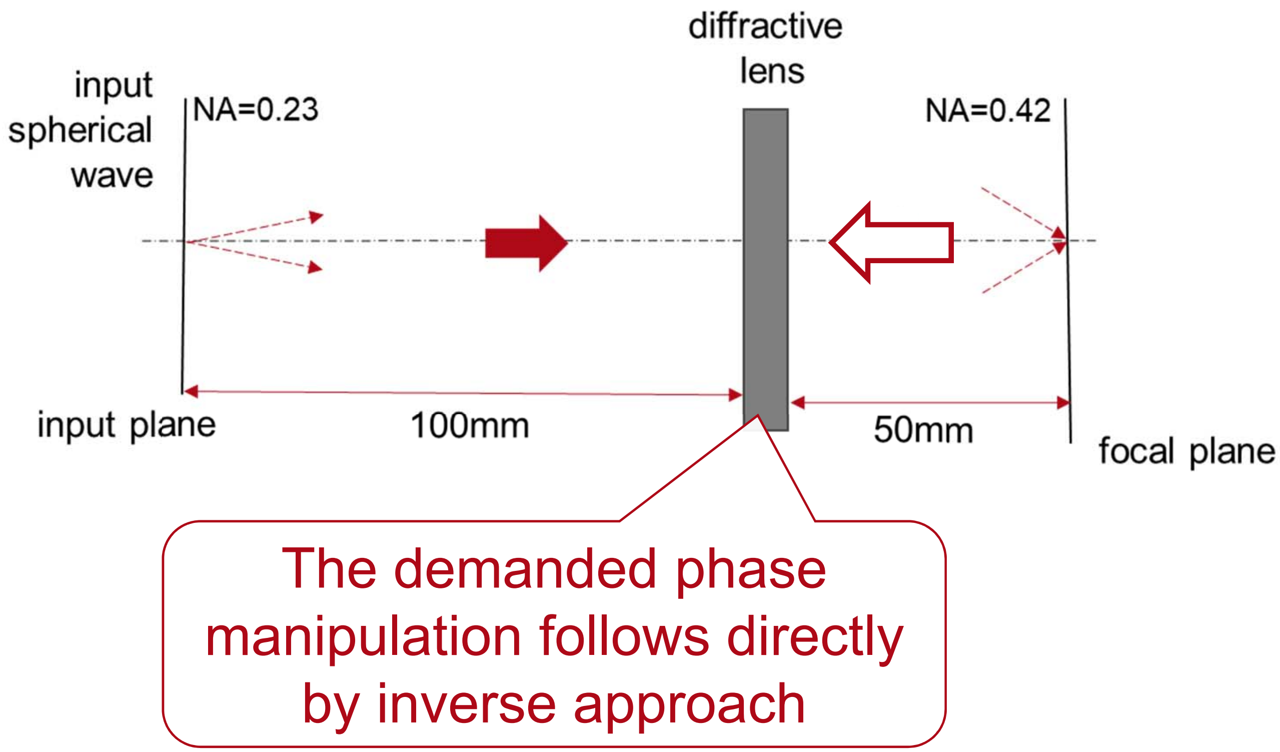
Example: Focusing Lens Off-Axis



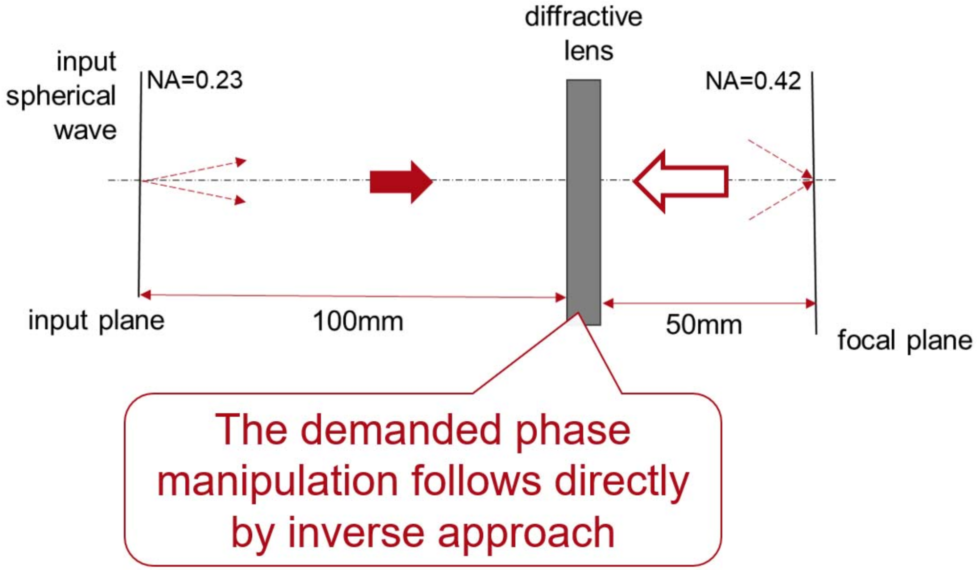
Imaging with Diffractive Lens



Imaging with Diffractive Lens: Functional Design



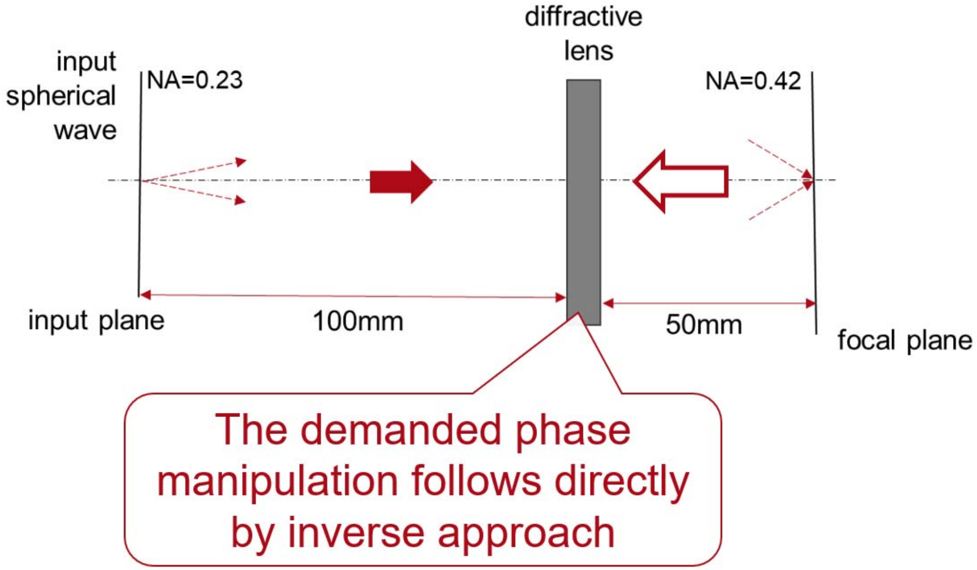
Light Shaping Design: Structural



We need to answer the following questions:

- **What kind of light manipulation is needed in order to obtain the demanded shaping result?**
- Do I need more components and which are the required distances?
- What kind of components can be used to obtain the required light manipulations?
  - Spherical, aspherical, freeform
  - Diffractive
  - GRIN components
  - Metasurfaces

Light Shaping Design: Structural



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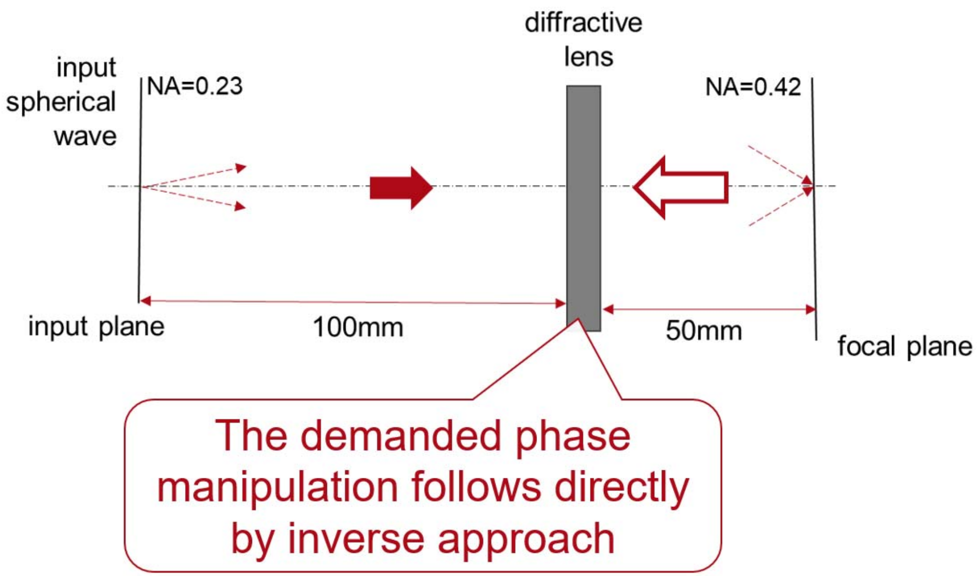
  - GRIN components
  - Metasurfaces

Light Shaping Design: Structural



- Local periods of diffractive lens follow directly from phase design in functional design step.

We need to answer the following questions:

- **What kind of light manipulation is needed in order to obtain the demanded shaping result?**
- Do I need more components and which are the required distances?
- What kind of components can be used to obtain the required light manipulations?
  - Spherical, aspherical, freeform
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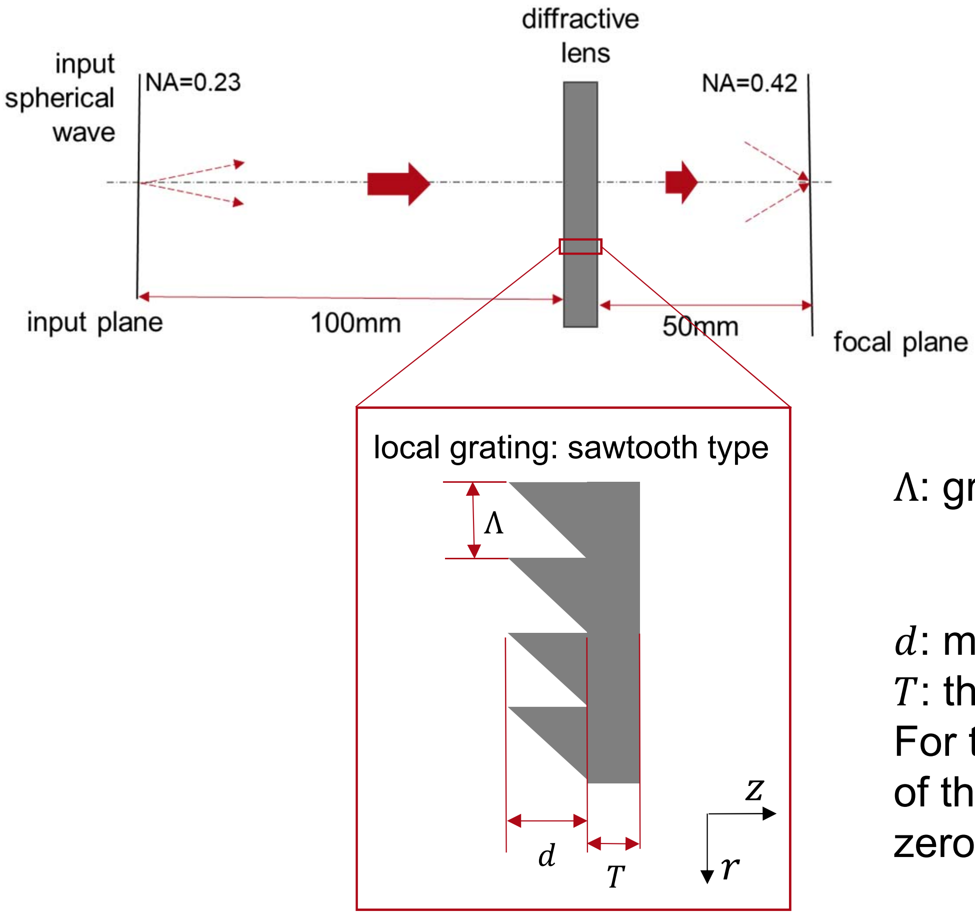
Imaging with Diffractive Lens



Λ: grating period

$$\Lambda(x, y) = \frac{2\pi}{|\nabla\varphi(x, y)|}$$

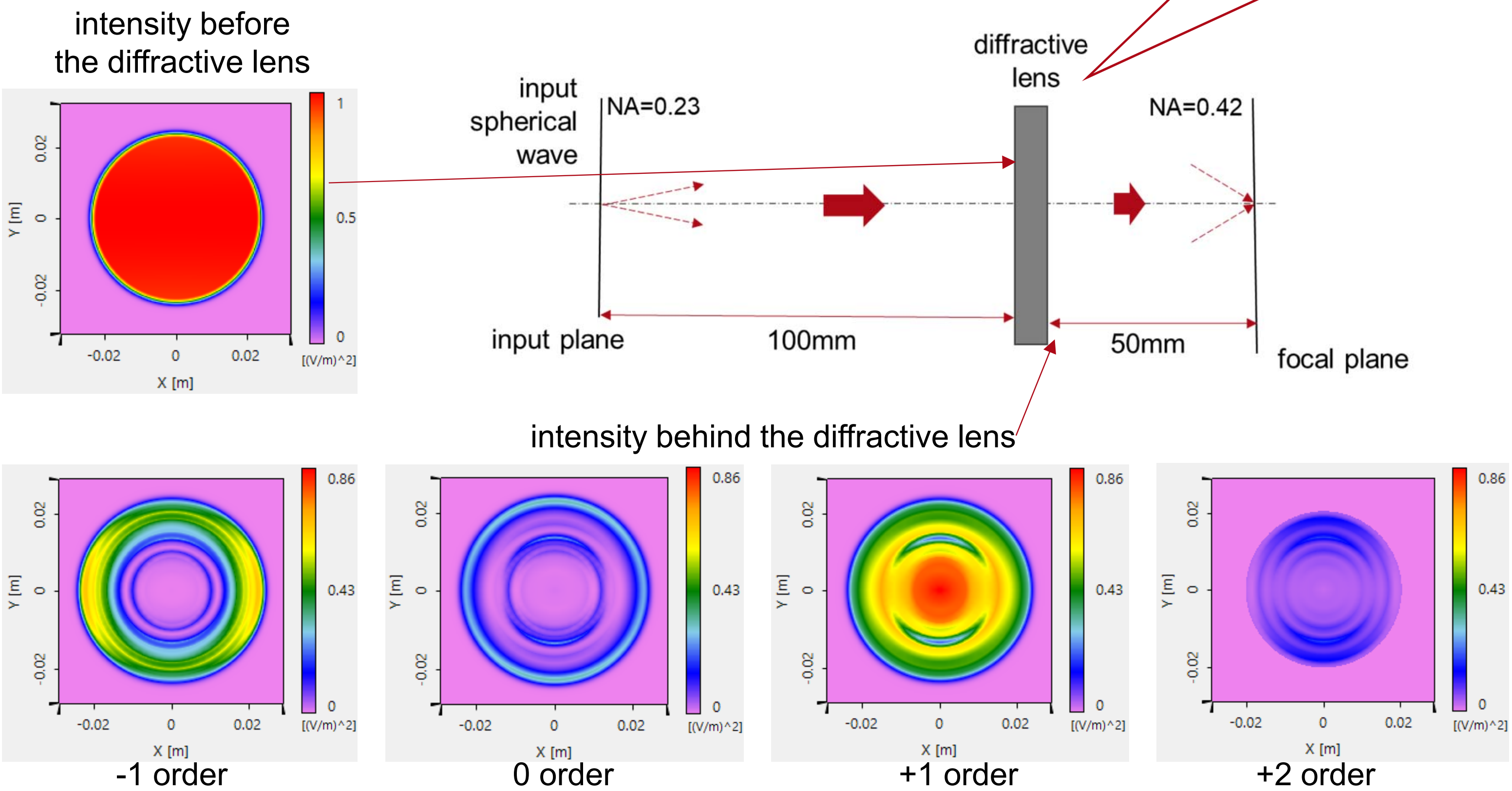
d: modulation depth

T: thickness of base block.

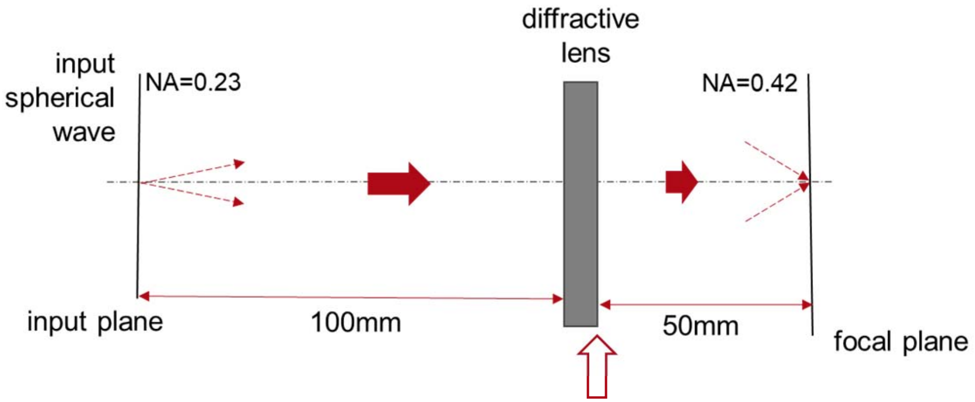
For the design, the thickness of the base block is set as zero, $T = 0$

Imaging with Diffractive Lens

Modeling with rigorous RCWA/FMM

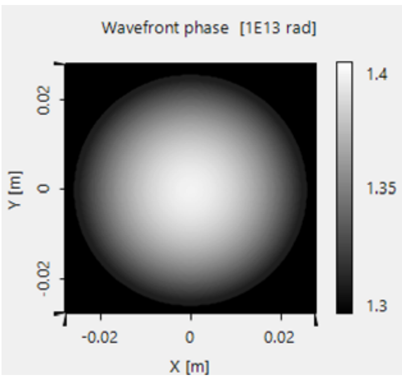


Imaging with Diffractive Lens

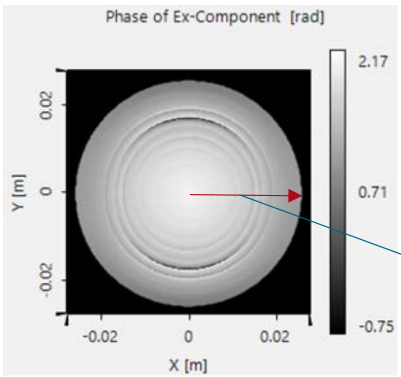


phase of the working order behind the diffractive lens

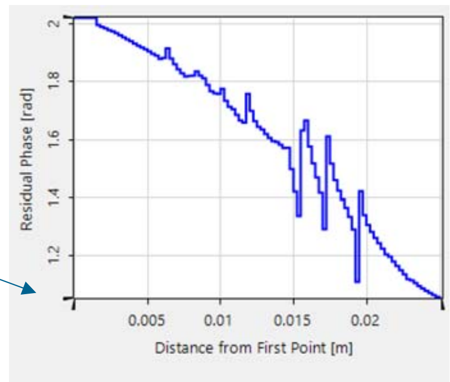
calculated phase of Rayleigh coefficient of Ex



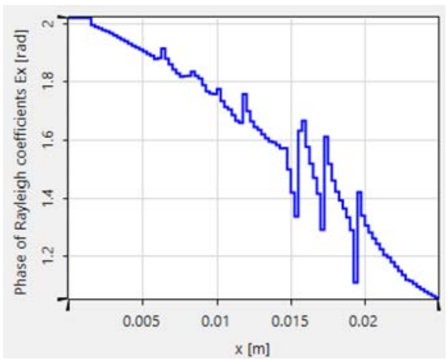
wavefront phase



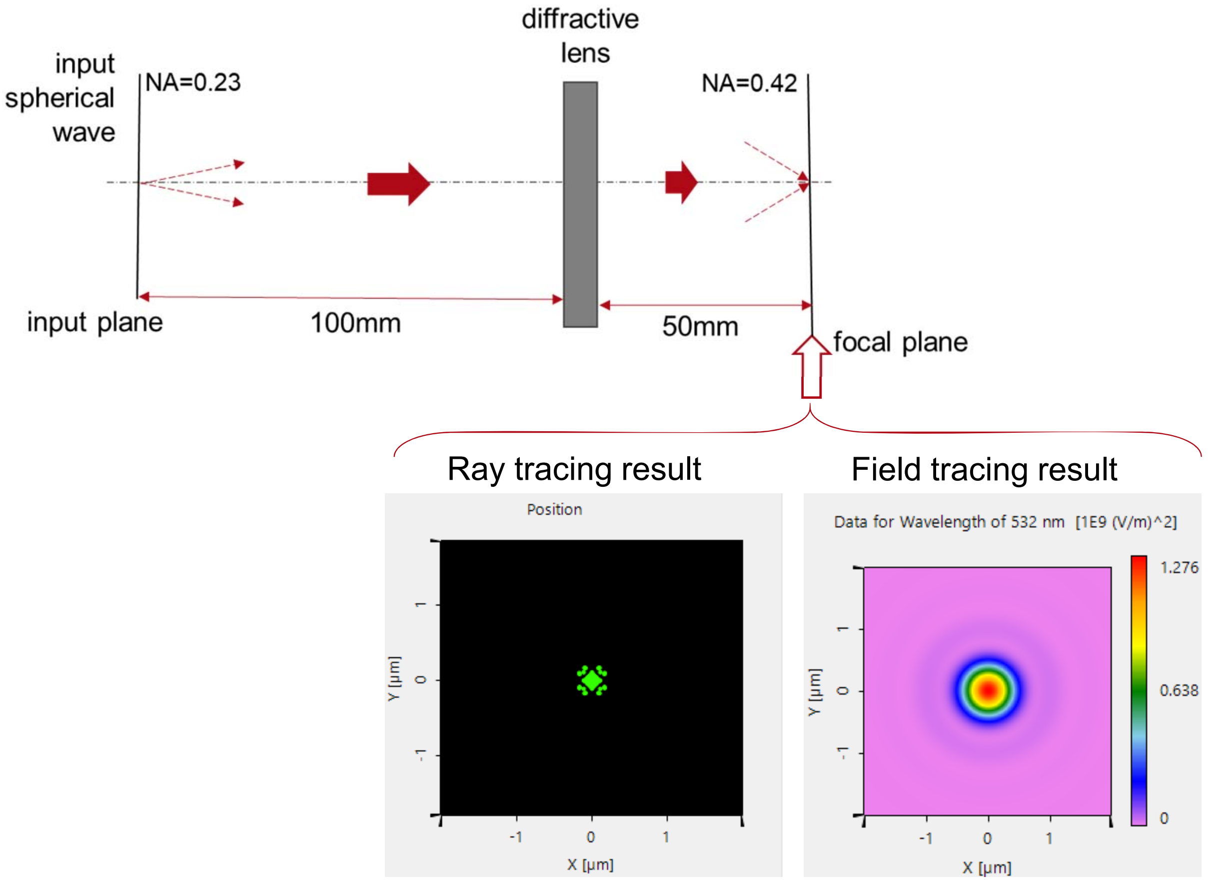
residual phase



residual phase along cross-section



Imaging with Diffractive Lens



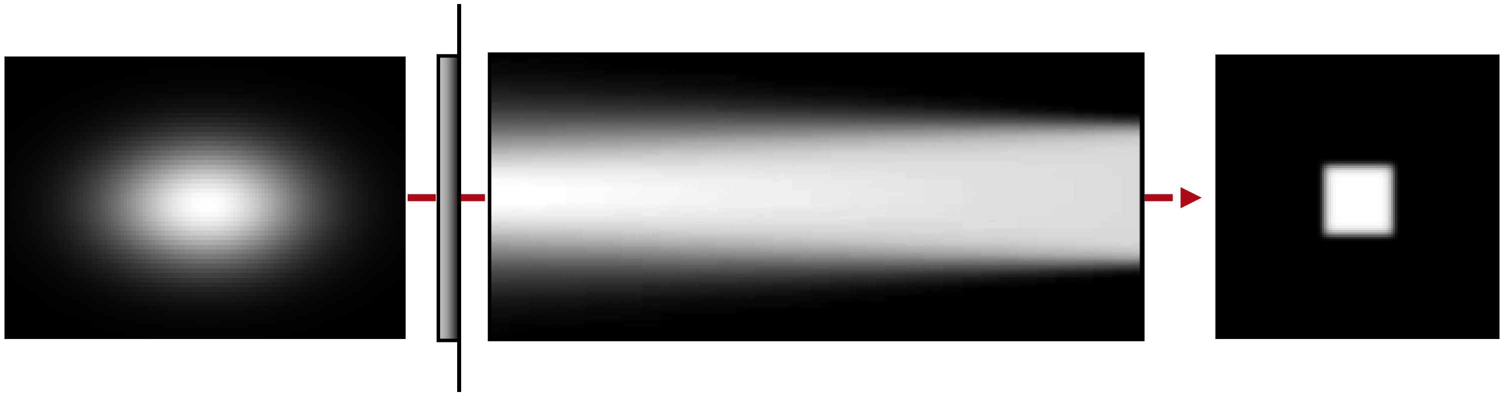
Dot pattern of the working order

PSF

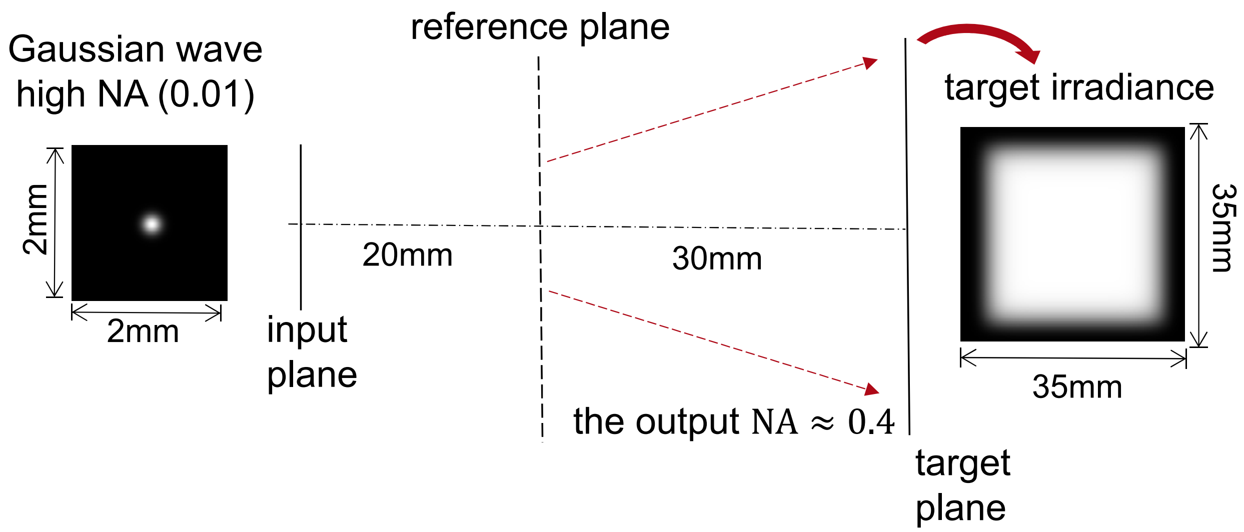
Light shaping by wavefront control

Laser beam shaping and more

Laser beam shaping: Paraxial

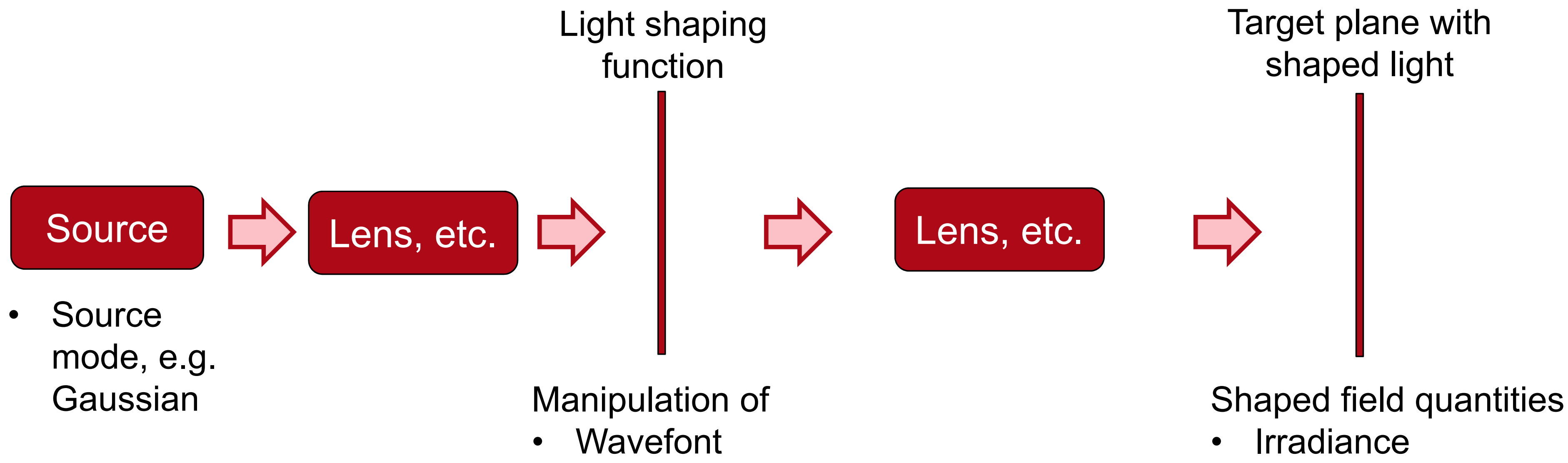


Gaussian to Top-Hat (Non-paraxial)

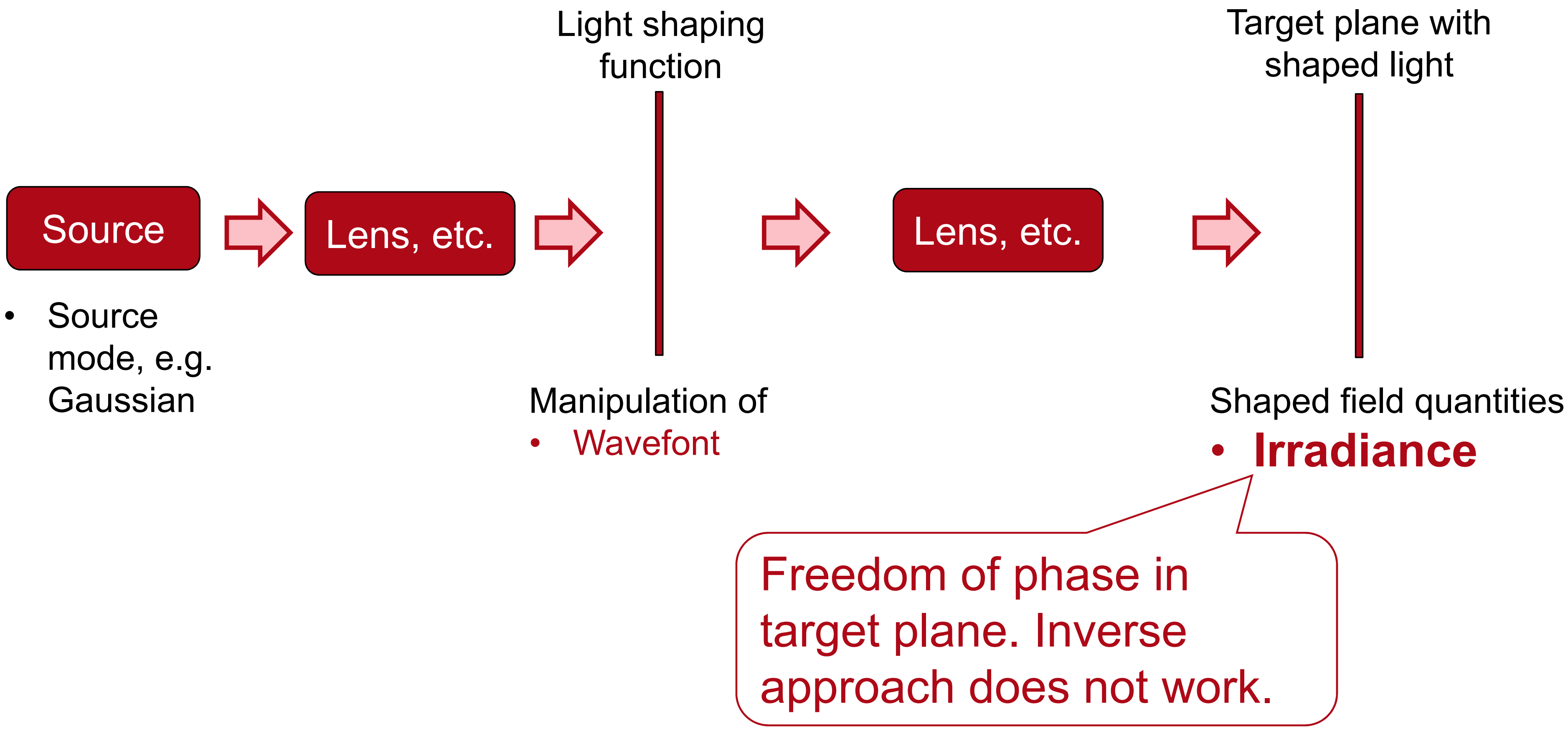


The Rayleigh lengths of the input Gaussian is $555.6\mu m$

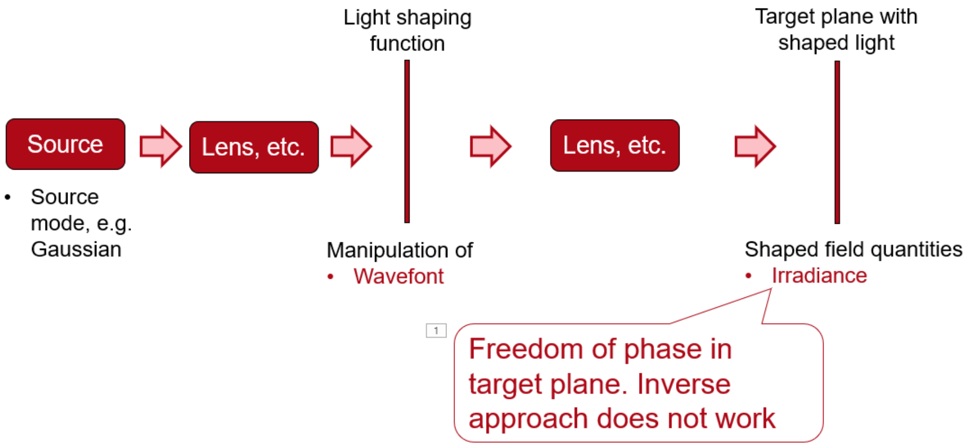
Light Shaping by Wavefront Control



Light Shaping by Wavefront Control



Light Shaping Design: Functional



We need to answer the following questions:

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- Do I need more components and which are the required distances?
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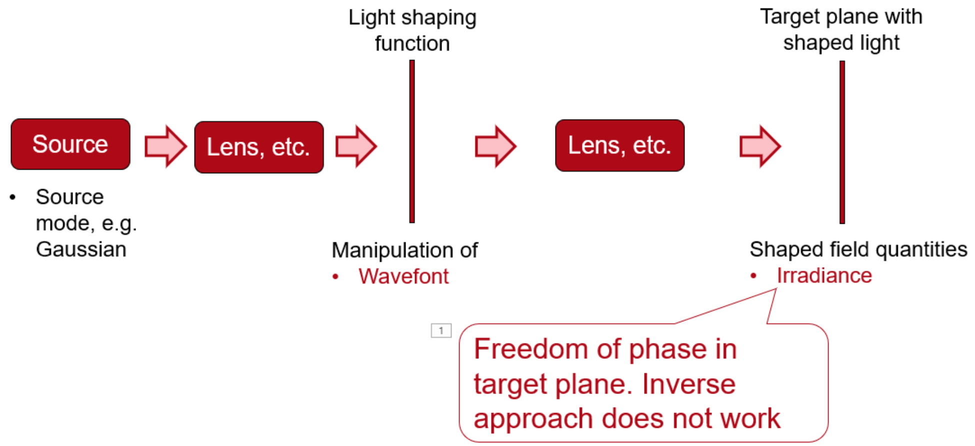
  - Diffractive
  - GRIN components
  - Metasurfaces

Light Shaping Design: Functional



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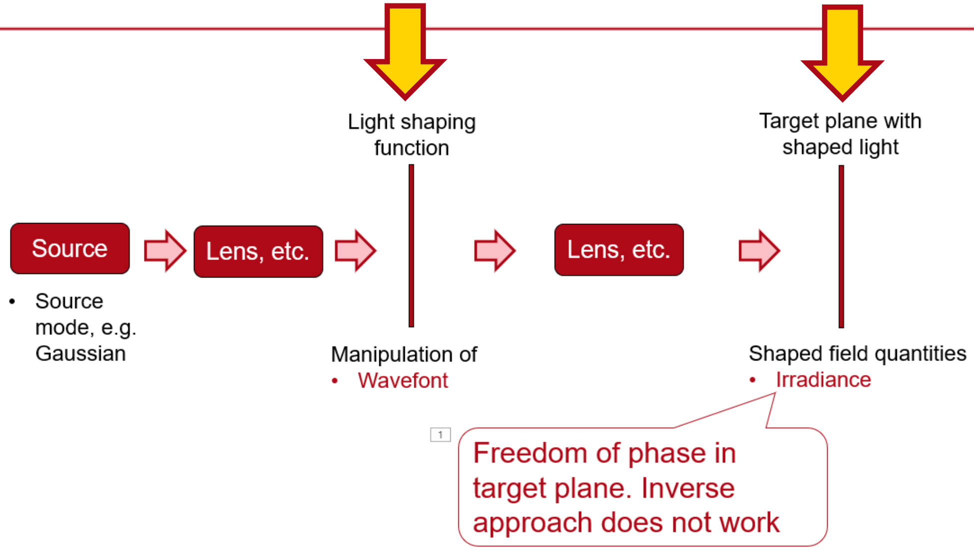
Light Shaping Design: Functional

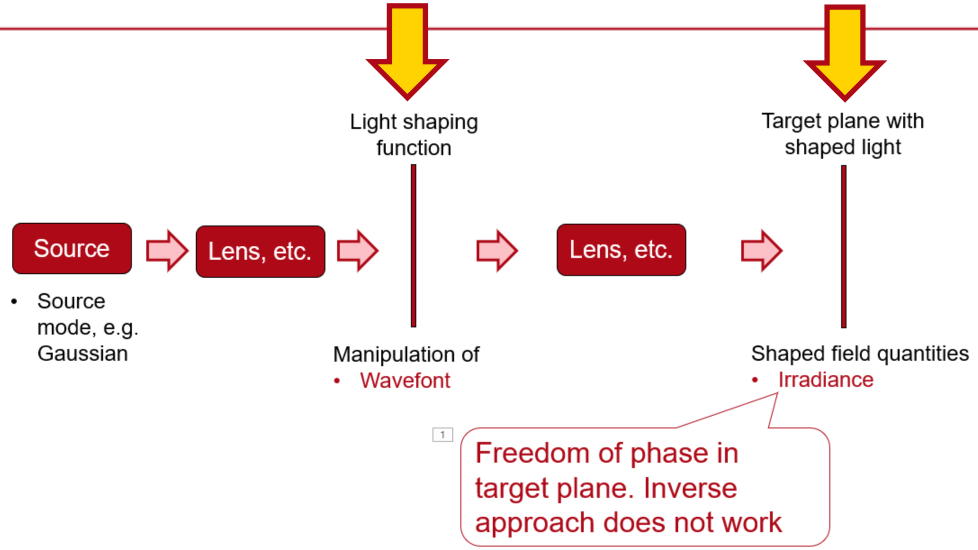


We need to answer the following questions:

- **What kind of light manipulation is needed in order to obtain the demanded shaping result?**

- Energy conservation leads to identity of integral over irradiances in shaper and target planes.
- Together with geometric zone assumption phase for wavefront manipulation can be designed.

Light Shaping Design: Functional



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- Energy conservation leads to identity of integral over irradiances in shaper and target planes.
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Analytical beam shaping with application to laser-diode arrays

Harald Aagedal, Michael Schmid, Sebastian Egner, Jörn Müller-Quade, and Thomas Beth

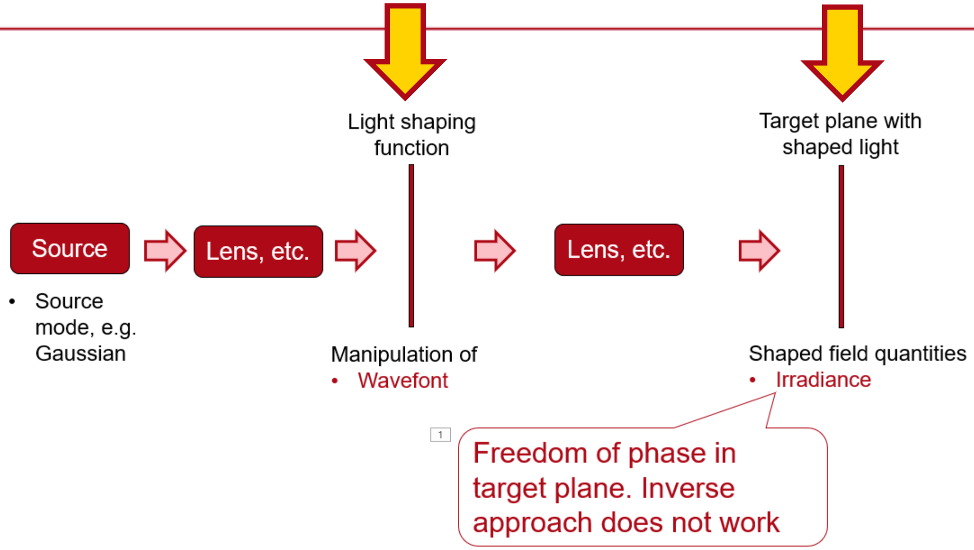
Institut für Algorithmen und Kognitive Systeme, Universität Karlsruhe, Am Fasanengarten 5, D-76128 Karlsruhe, Germany

Frank Wyrowski

Institut für Angewandte Physik, Friedrich-Schiller-Universität, Max-Wien-Platz 1, D-07743 Jena, Germany

Vol. 14, No. 7/July 1997/J. Opt. Soc. Am. A 1549

Light Shaping Design: Functional



We need to answer the following questions:

- **What kind of light manipulation is needed in order to obtain the demanded shaping result?**

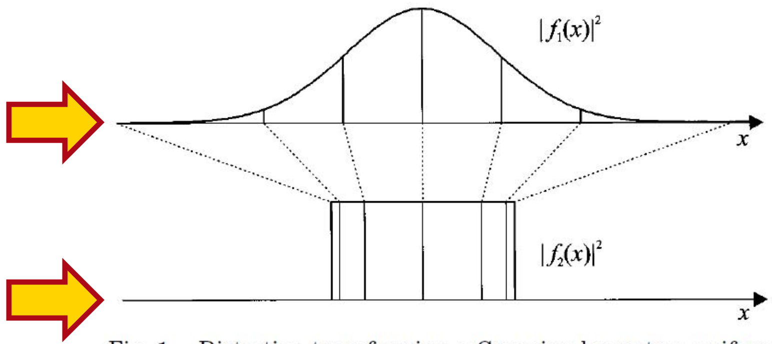
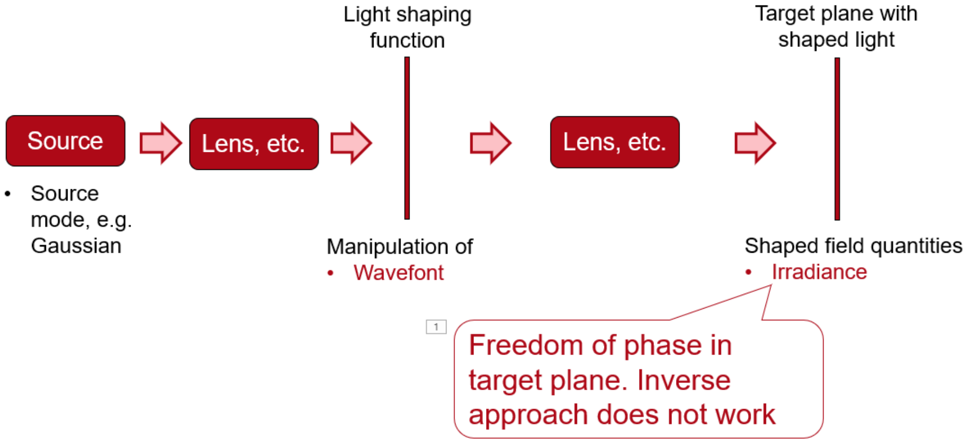


Fig. 1. Distortion transforming a Gaussian beam to a uniform distribution.

- Energy conservation leads to identity of integral over irradiances in shaper and target planes.
- Together with geometric zone assumption phase for wavefront manipulation can be designed.

Light Shaping Design: Functional



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- Together with geometric zone assumption phase for wavefront manipulation can be designed.

We need to answer the following questions:

- **What kind of light manipulation is needed in order to obtain the demanded shaping result?**

Design of diffractive beam-shaping elements for non-uniform illumination waves

Andreas Hermerschmidt and Hans J. Eichler

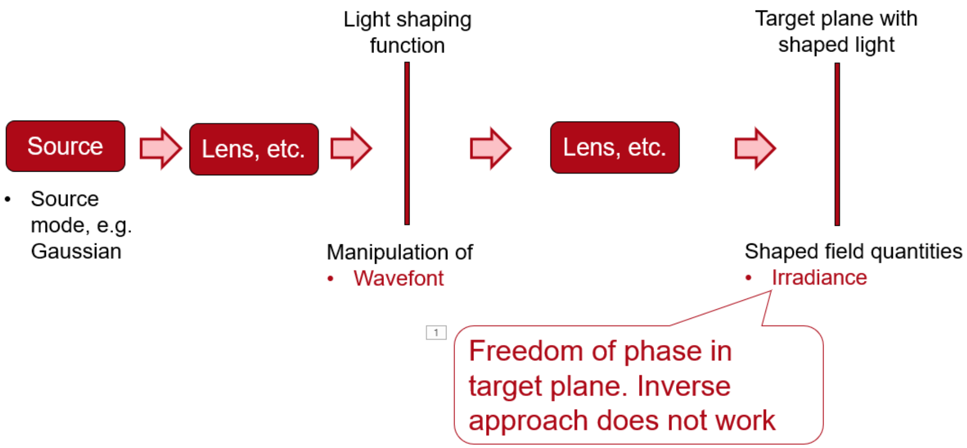
Technical University of Berlin, Optisches Institut P11
Strasse des 17. Juni 135, 10623 Berlin, Germany

Stephan Teiwes and Joerg Schwartz

Berlin Institute of Optics (BIFO), Department of Diffractive Optics
Rudower Chaussee 6, 12484 Berlin, Germany

Proc. SPIE 1998

Light Shaping Design: Functional



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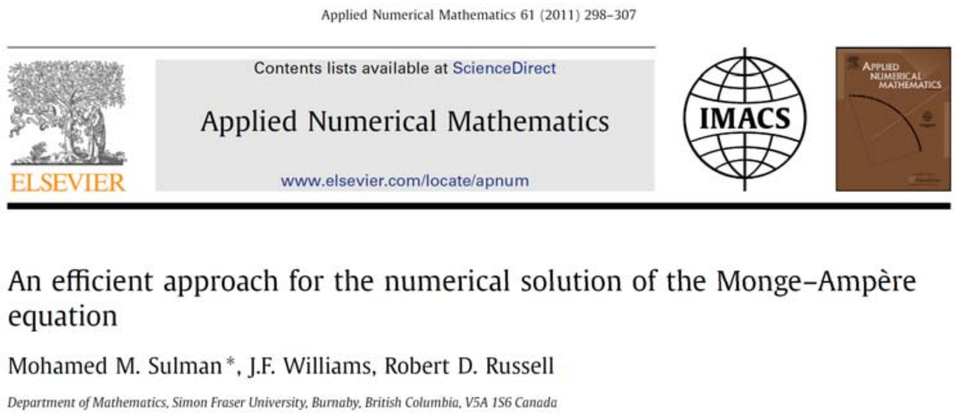
Applied Numerical Mathematics 61 (2011) 298–307

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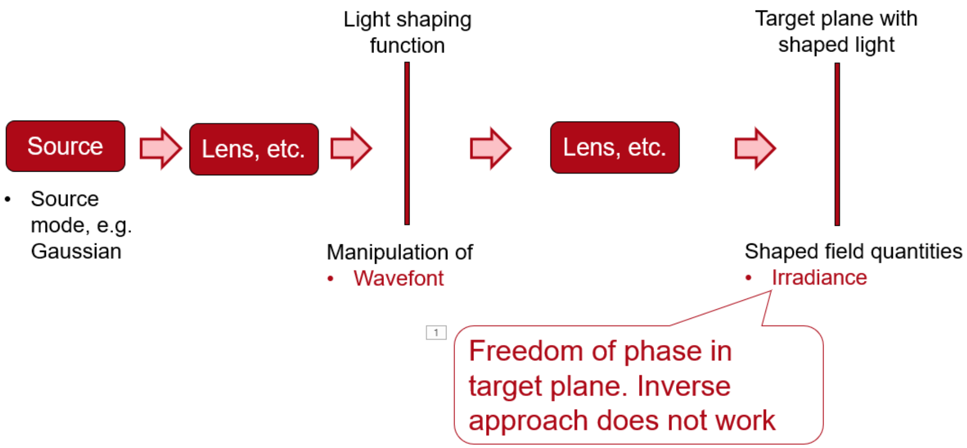
An efficient approach for the numerical solution of the Monge–Ampère equation

Mohamed M. Sulman *, J.F. Williams, Robert D. Russell

Department of Mathematics, Simon Fraser University, Burnaby, British Columbia, V5A 1S6 Canada

Light Shaping Design: Functional



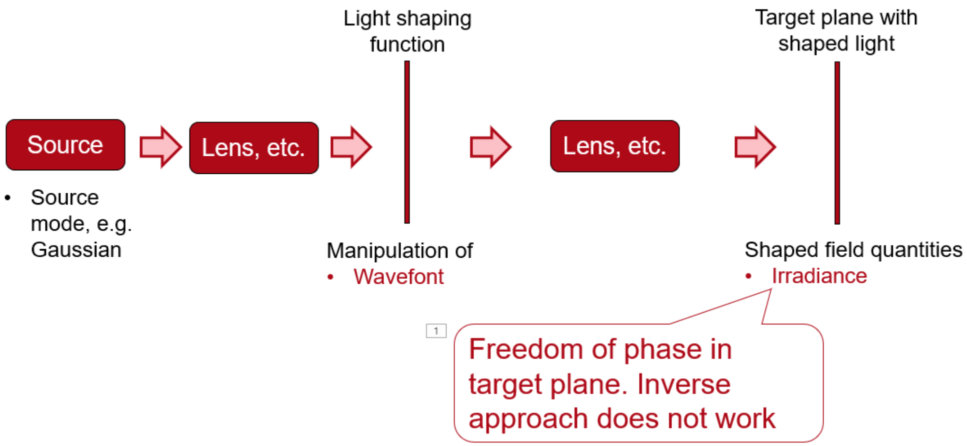
We need to answer the following questions:

- **What kind of light manipulation is needed in order to obtain the demanded shaping result?**

- VirtualLab Fusion provides technique for functional design in light shaping.

- Demanded phase for wavefront change is known.

Light Shaping Design: Structural



- **Structural design available**
  - Spherical, aspherical, freeform
  - Diffractive (HOE)
  - GRIN components (soon!)
  - Metasurfaces (soon!)

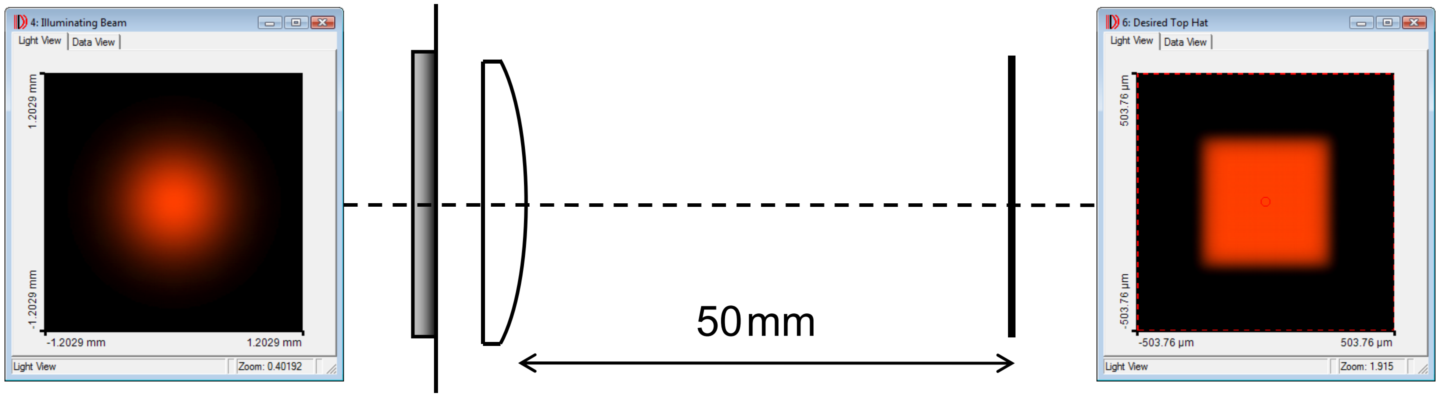
We need to answer the following questions:

- **What kind of light manipulation is needed in order to obtain the demanded shaping result?**
- Do I need more components and which are the required distances?
- What kind of components can be used to obtain the required light manipulations?
  - Spherical, aspherical, freeform
  - Diffractive
  - GRIN components
  - Metasurfaces

Paraxial Laser Beam Shaping

Diffractive beam shaper
shape, size: round, 2 mm × 2 mm
phase levels: 16

target
plane



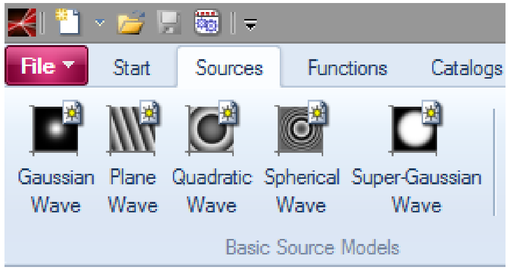
illuminating beam
intensity

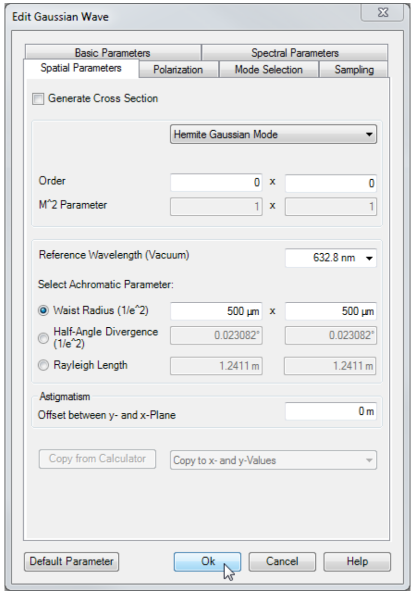
1f-setup

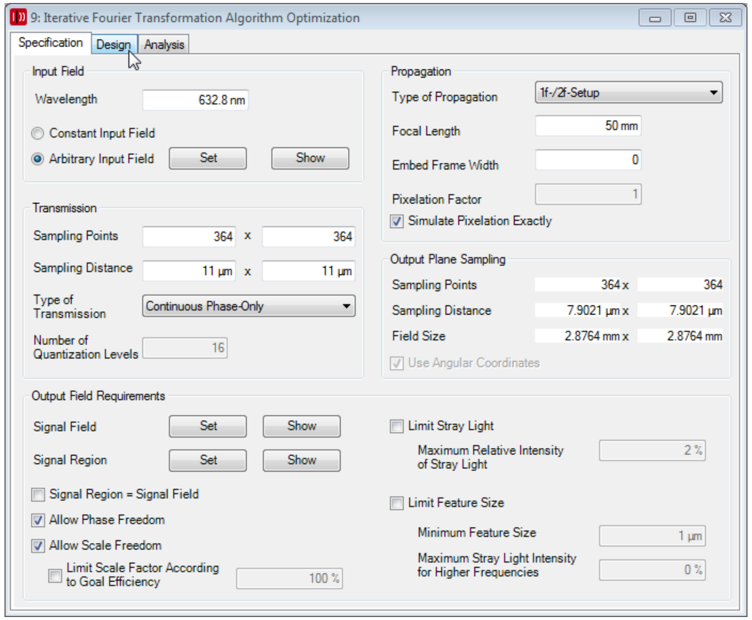
top hat intensity
(free of speckles)

surrounding medium: vacuum

All Tools Available in VirtualLab Fusion

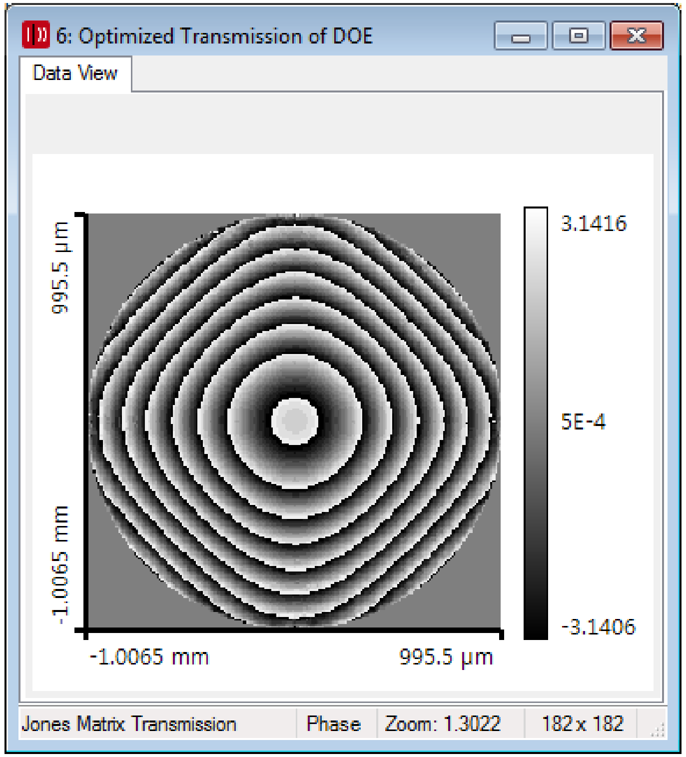


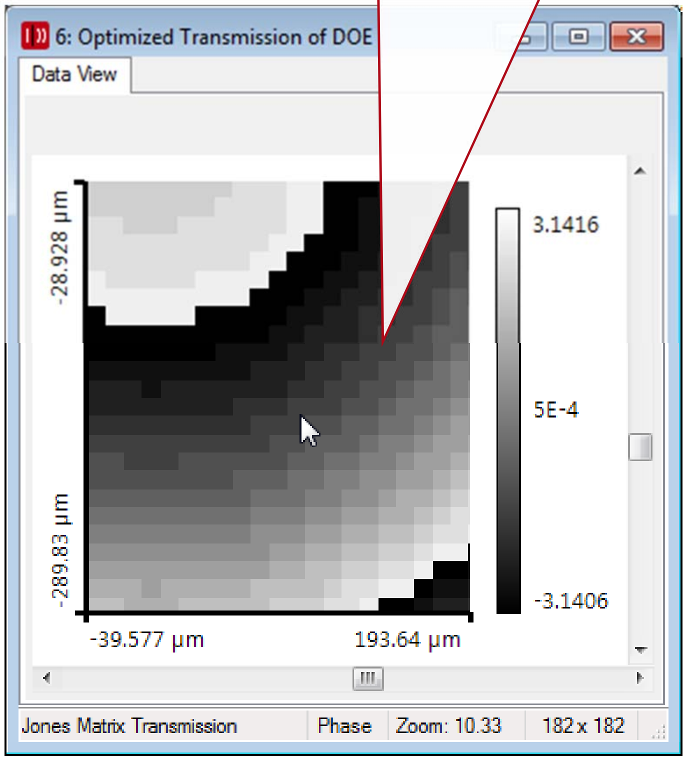




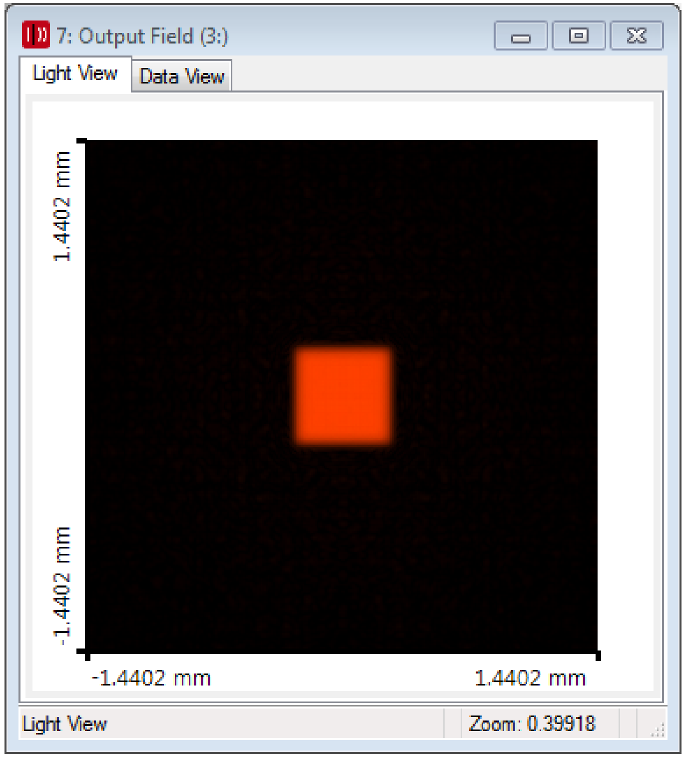
IFTA Optimized Transmission

Quantized to 16 levels to enable lithographic fabrication.



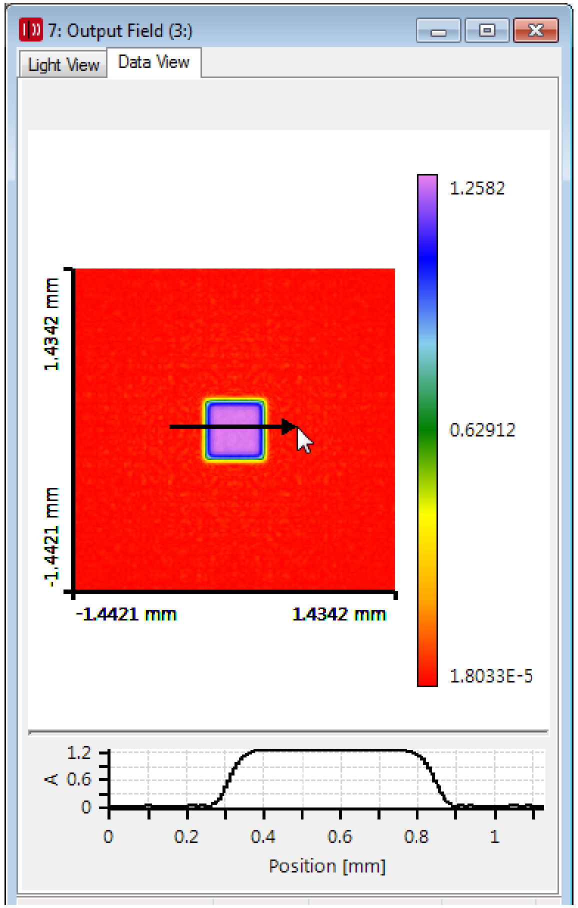


Result of Design



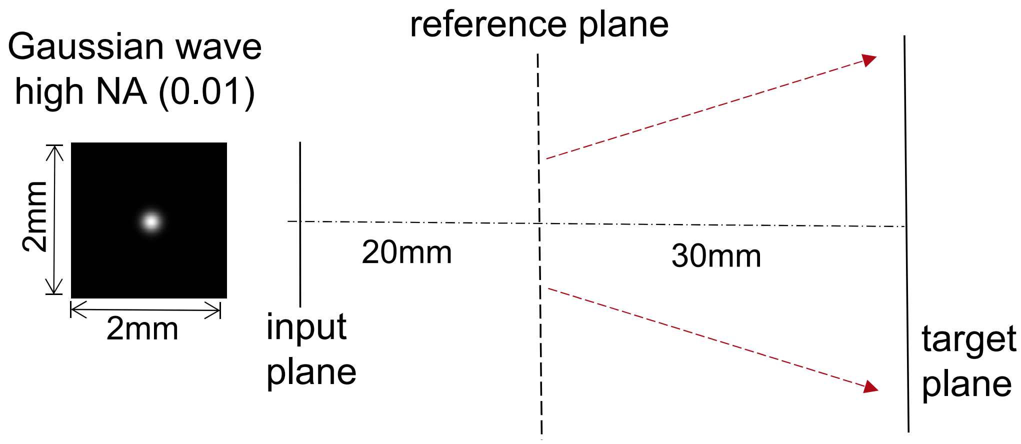
☐	Window Efficiency [%]	
☑	Conversion Efficiency [%]	96.897799114995138
☑	Signal-to-Noise Ratio / dB	48.467698617696094
☑	Uniformity Error [%]	15.433530790091091
☐	Zeroth Order Intensity [%]	
☐	Zeroth Order Efficiency [%]	
☑	Maximum Relative Intensity of Stray Light [%]	1.5324463437275169

Result of Design

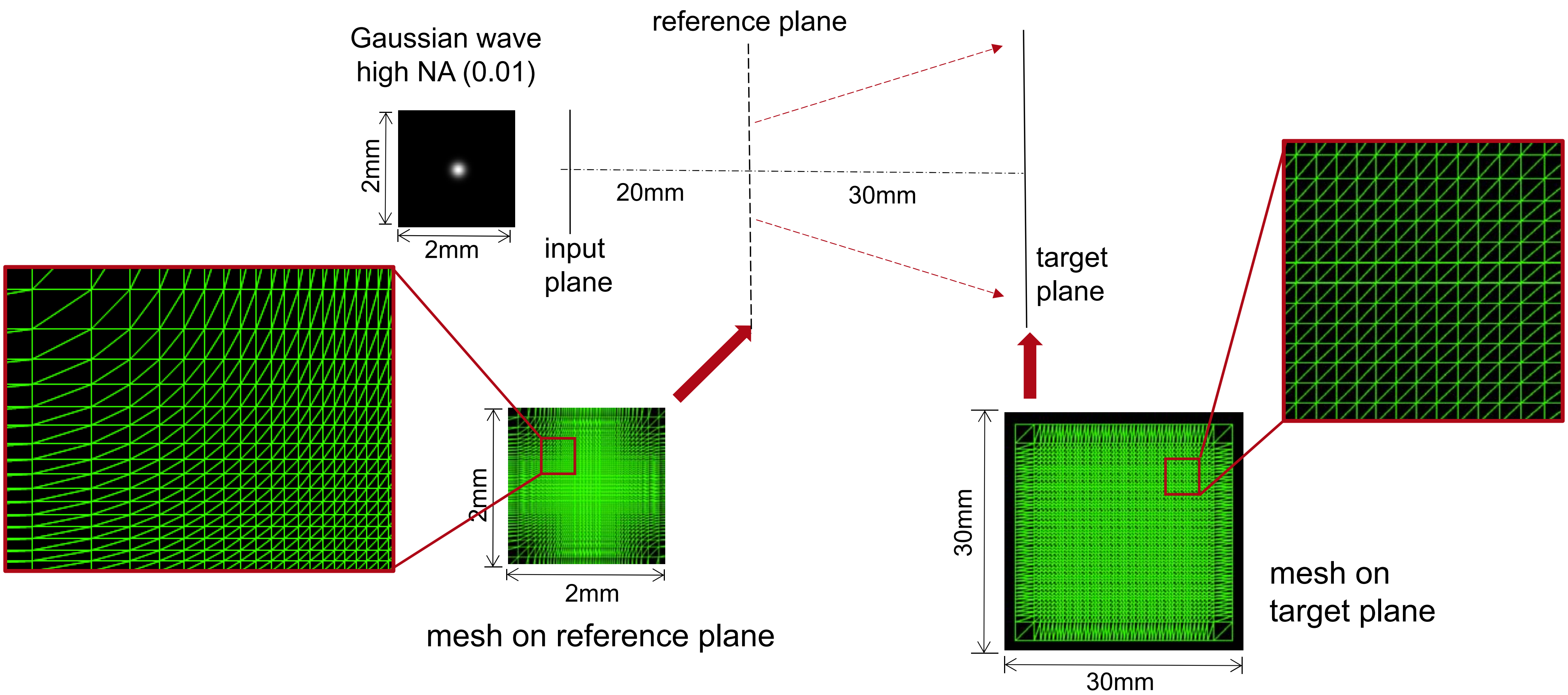


Window Efficiency [%]	
Conversion Efficiency [%]	96.897799114995138
Signal-to-Noise Ratio / dB	48.467698617696094
Uniformity Error [%]	15.433530790091091
Zeroth Order Intensity [%]	
Zeroth Order Efficiency [%]	
Maximum Relative Intensity of Stray Light [%]	1.5324463437275169

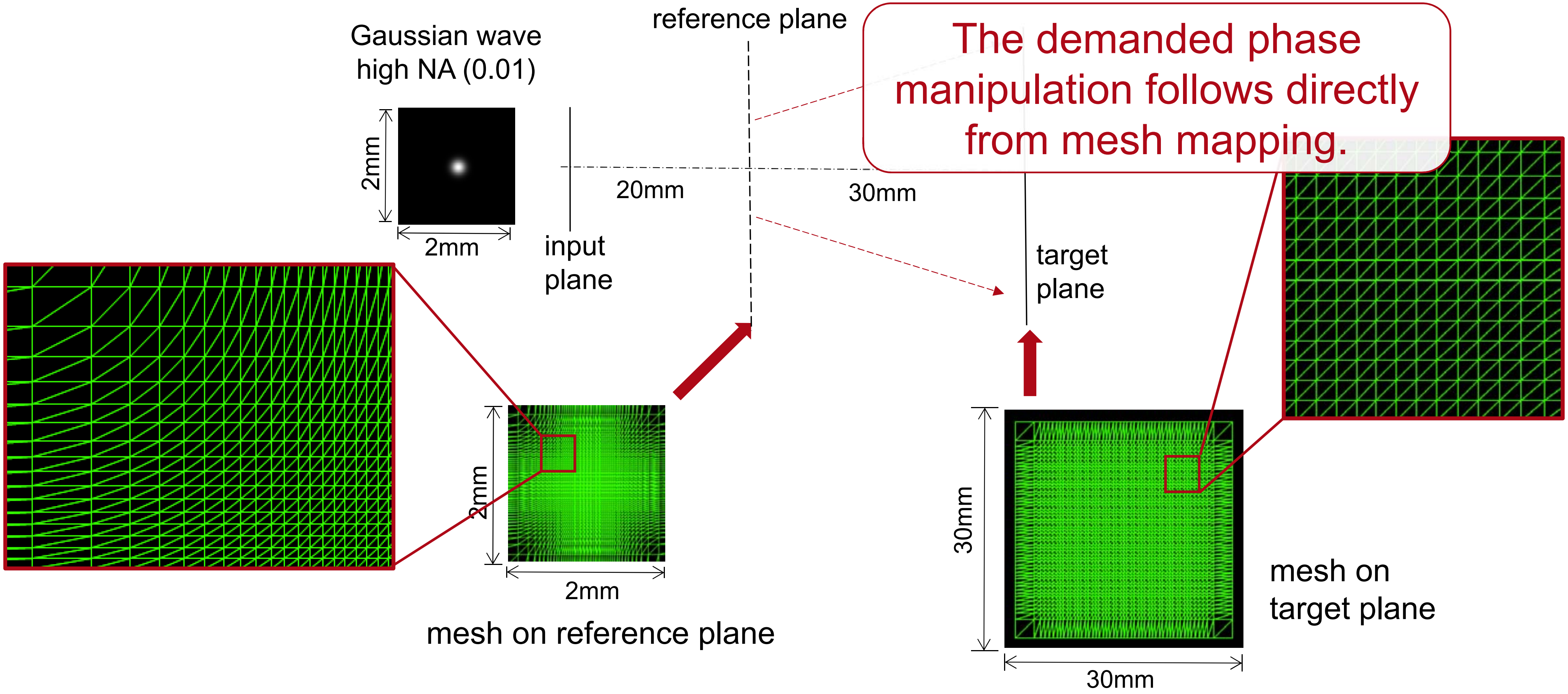
Gaussian to Top-Hat (Non-paraxial): Functional Design



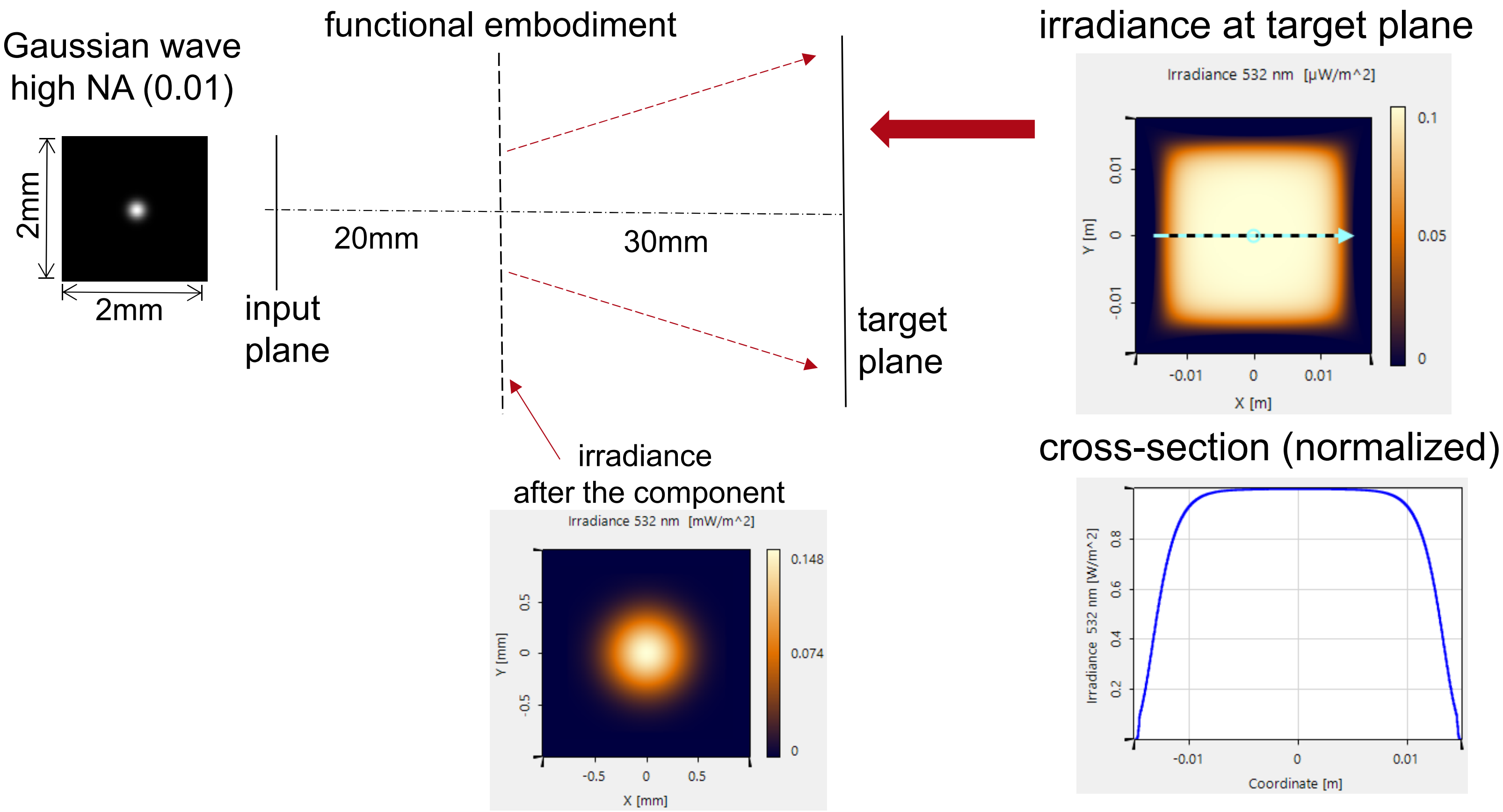
Gaussian to Top-Hat (Non-paraxial): Functional Design



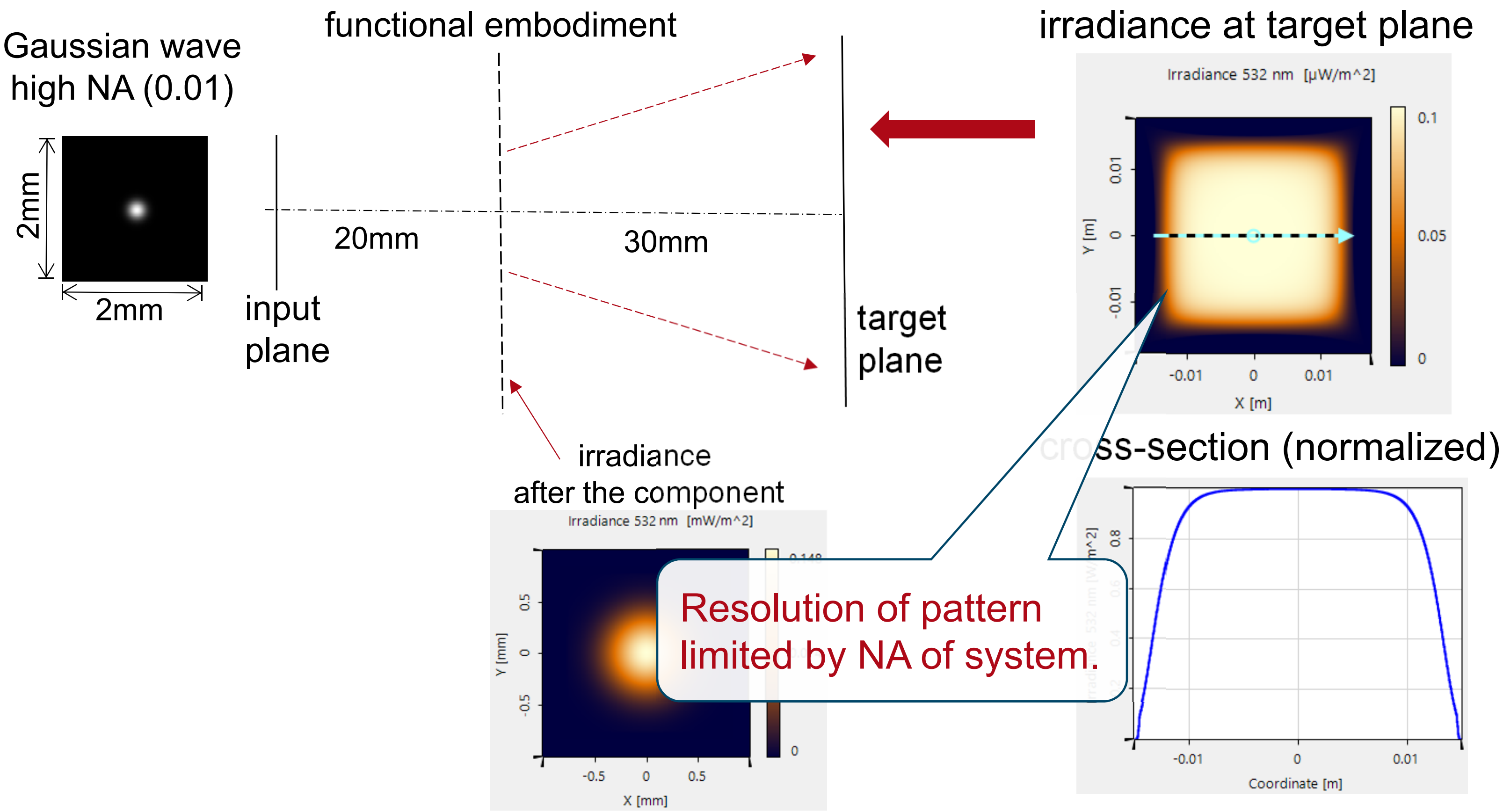
Gaussian to Top-Hat (Non-paraxial): Functional Design



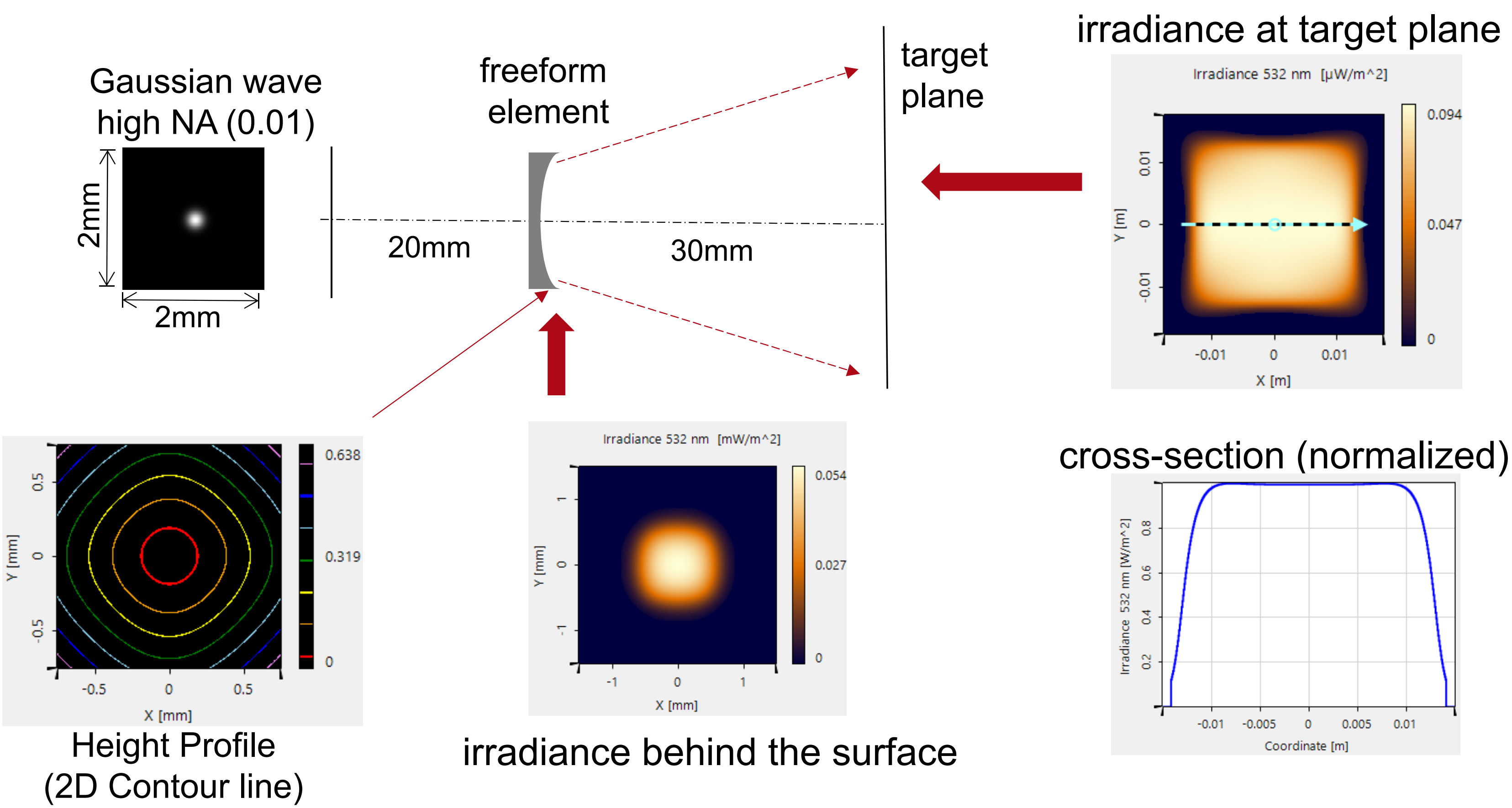
Gaussian to Top-Hat (Non-paraxial): Functional Design



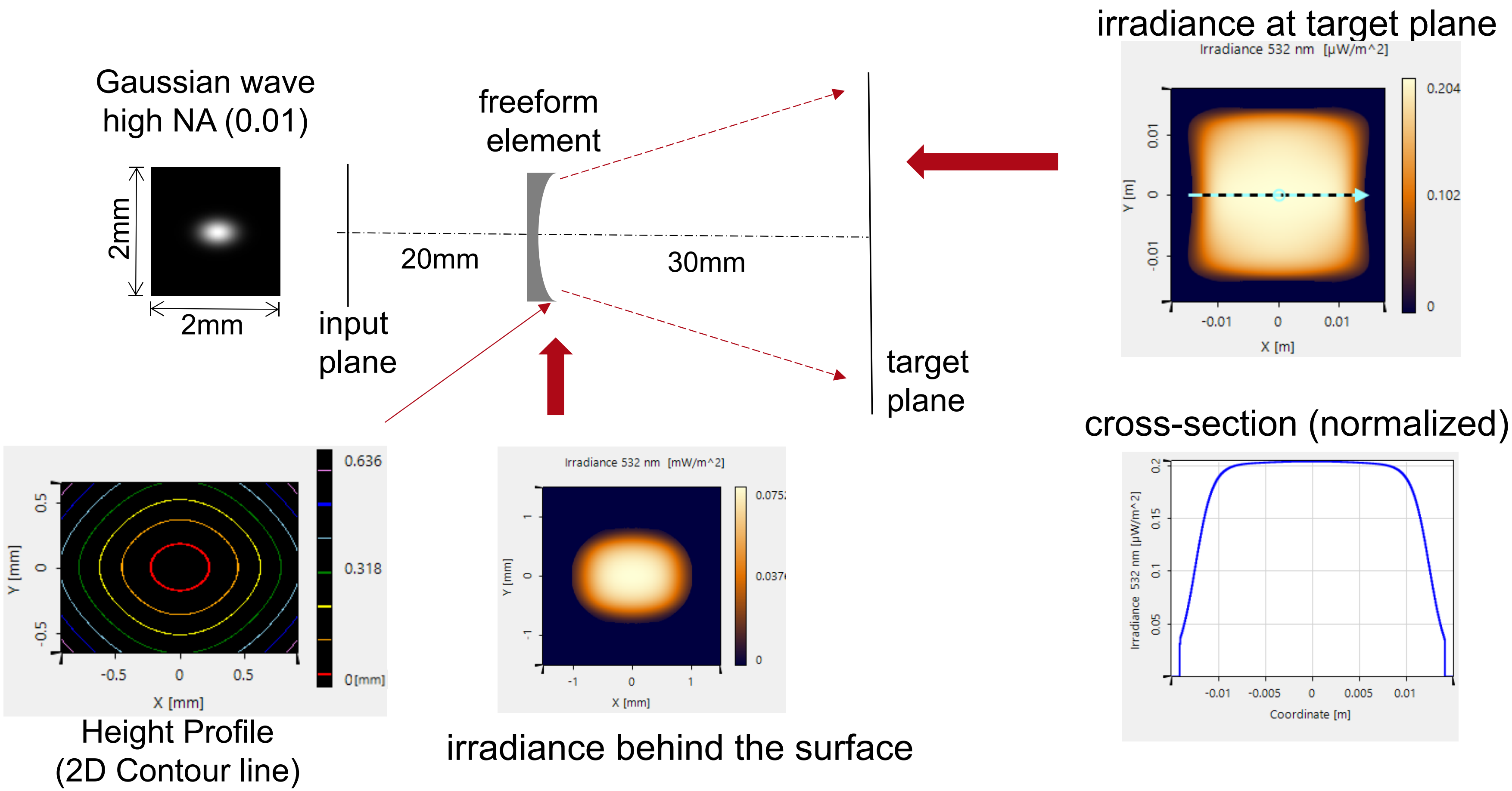
Gaussian to Top-Hat (Non-paraxial): Functional Design



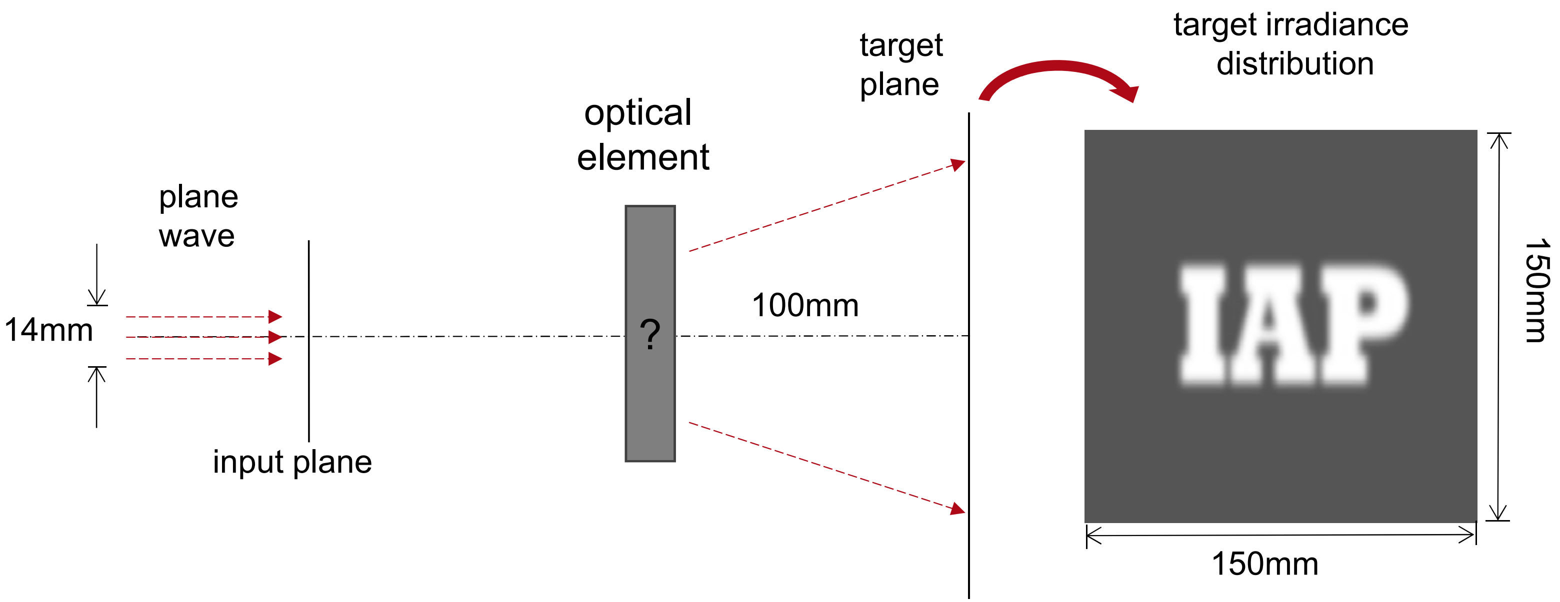
Gaussian to Top-Hat (Non-paraxial): Freeform Surface Design



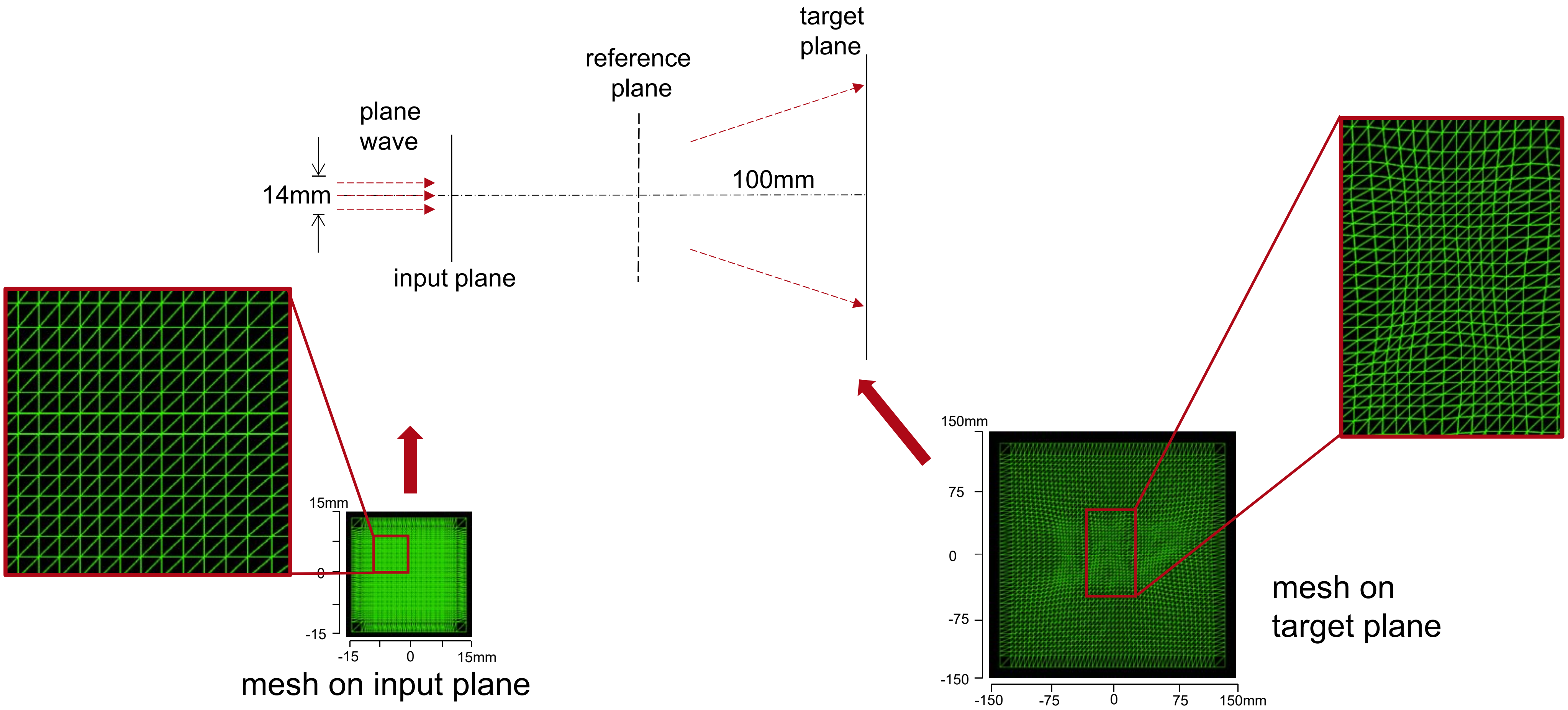
Elliptical Gaussian to Top-Hat: Freeform Surface Design



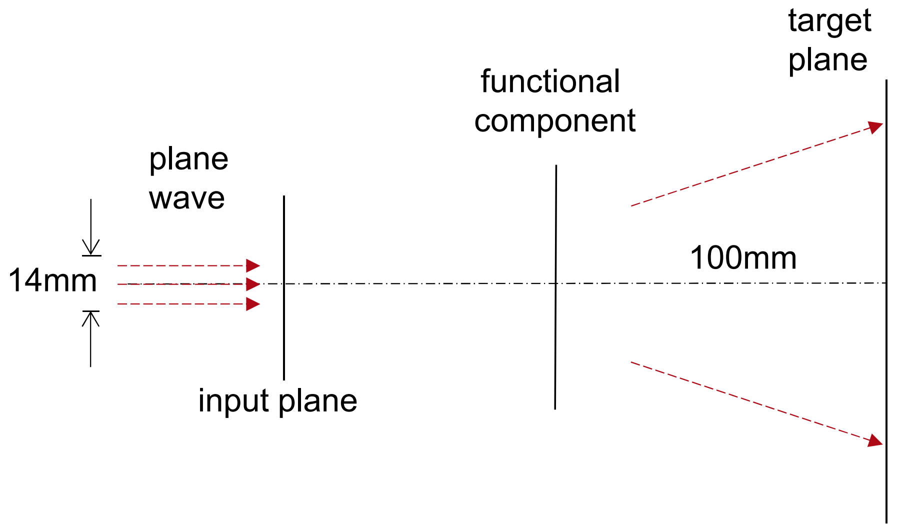
Plane Wave to Far Field Pattern (Non-paraxial)

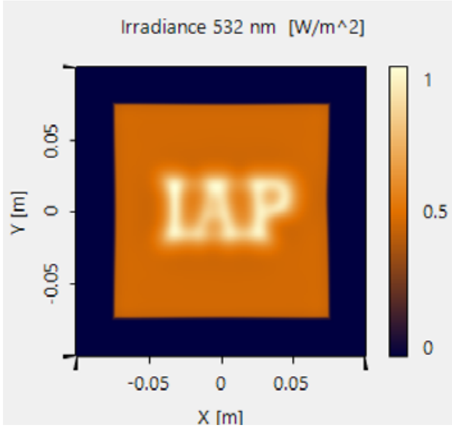


Plane Wave to Far Field Pattern: Functional Design

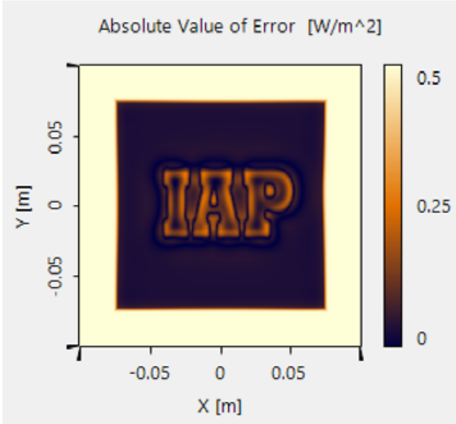


Plane Wave to Far Field Pattern: Functional Design



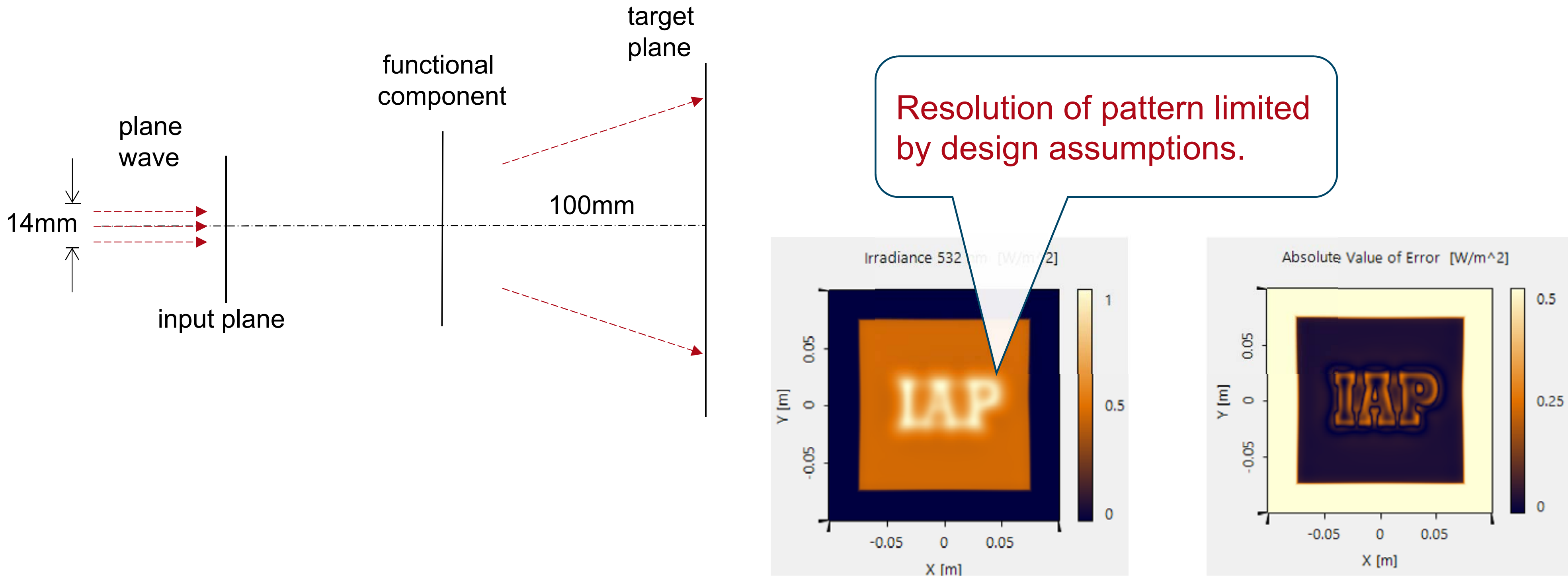


irradiance at target plane (normalized)



error from target irradiance

Plane Wave to Far Field Pattern: Functional Design

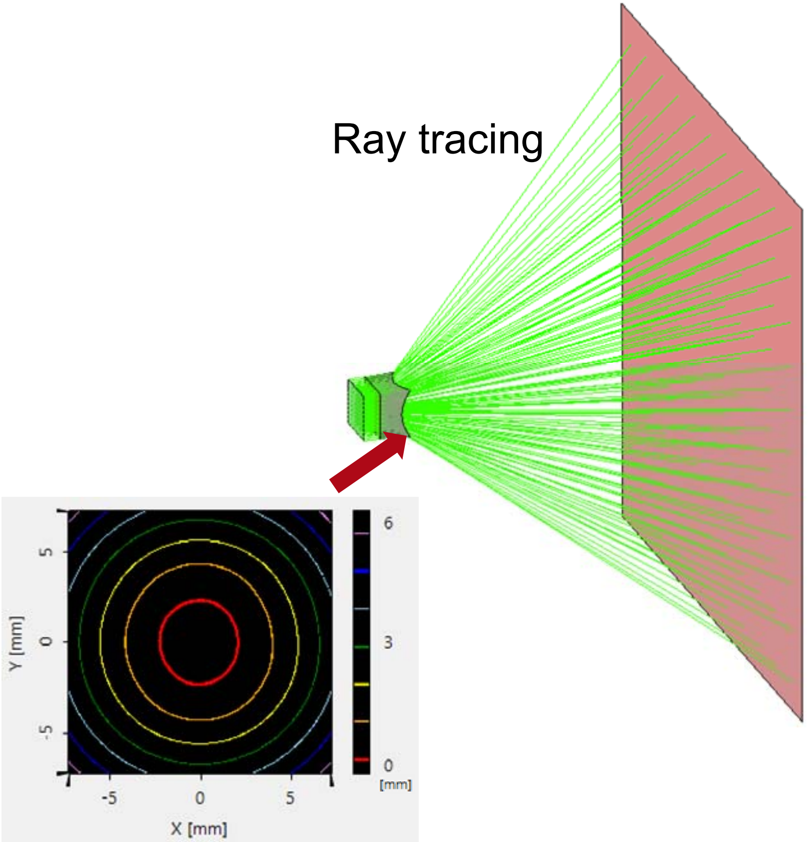


irradiance at target plane (normalized)

error from target irradiance

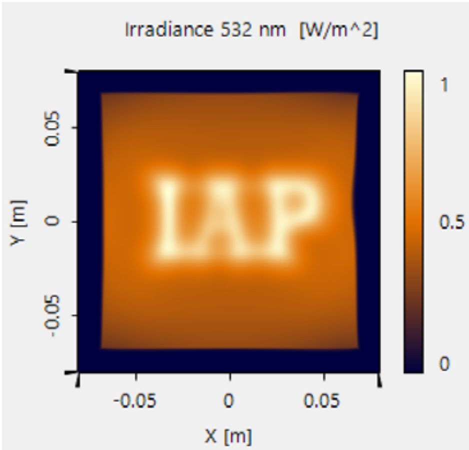
Plane Wave to Far Field Pattern: Freeform Surface

Ray tracing



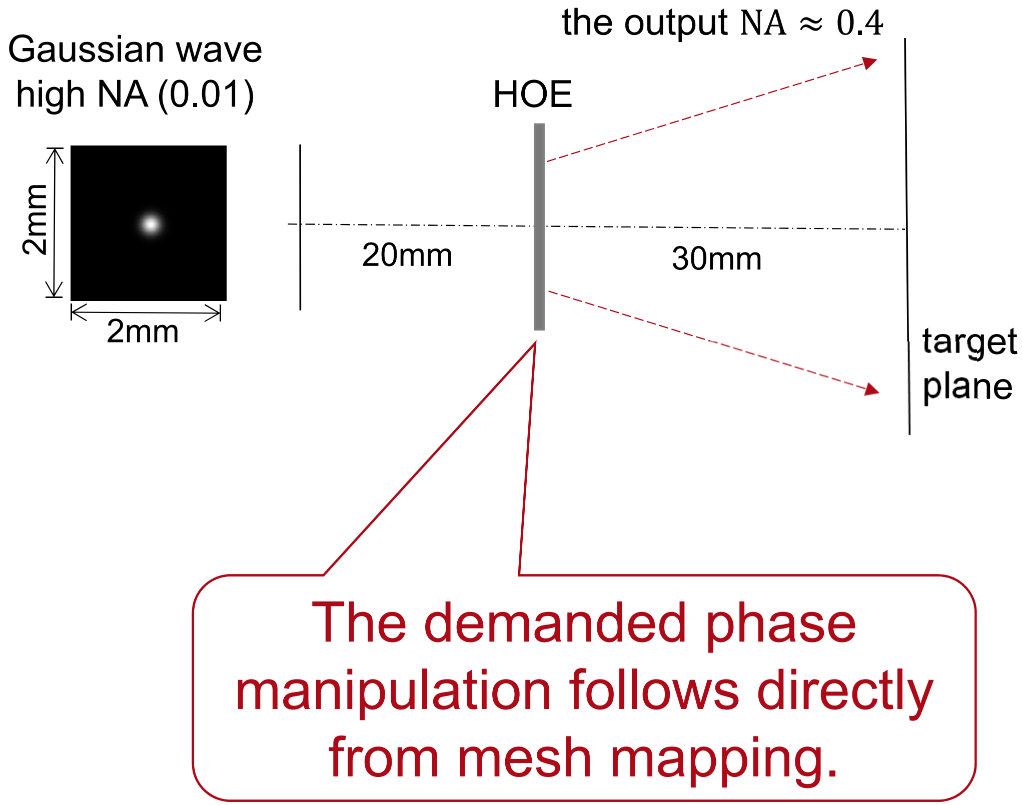
Height Profile
(2D Contour line)

Field tracing

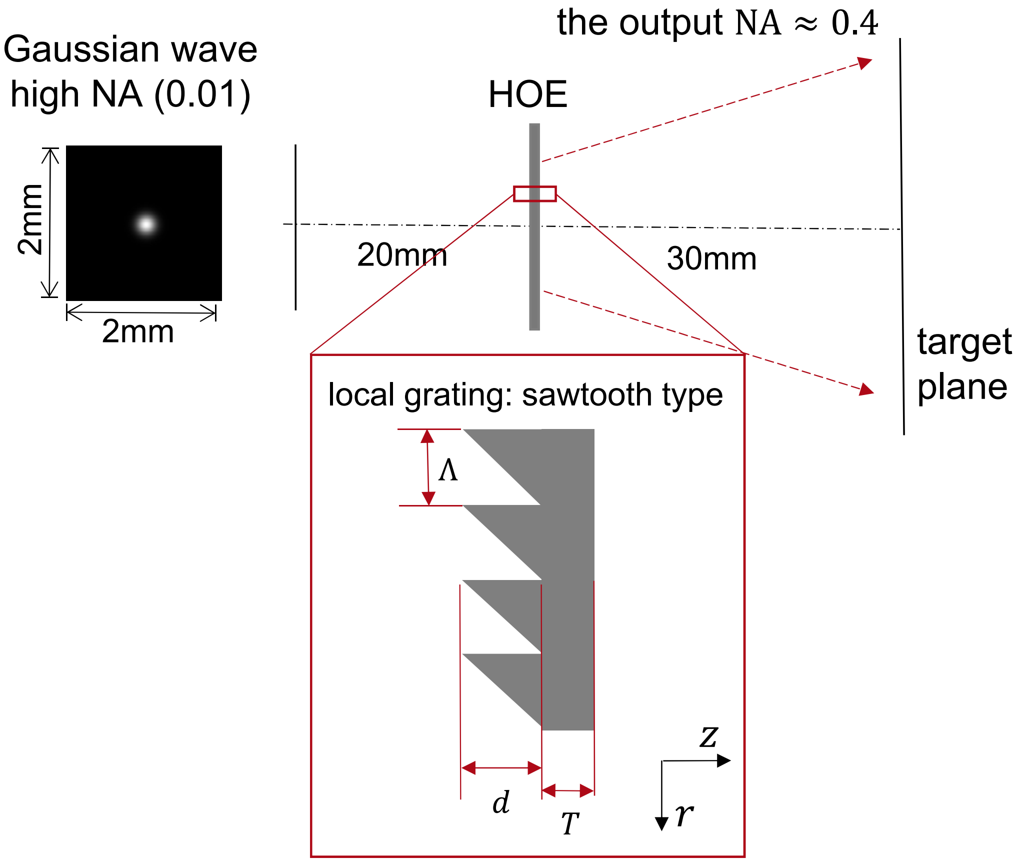


irradiance at target plane
(normalized)

Gaussian to Top-Hat: Functional Design

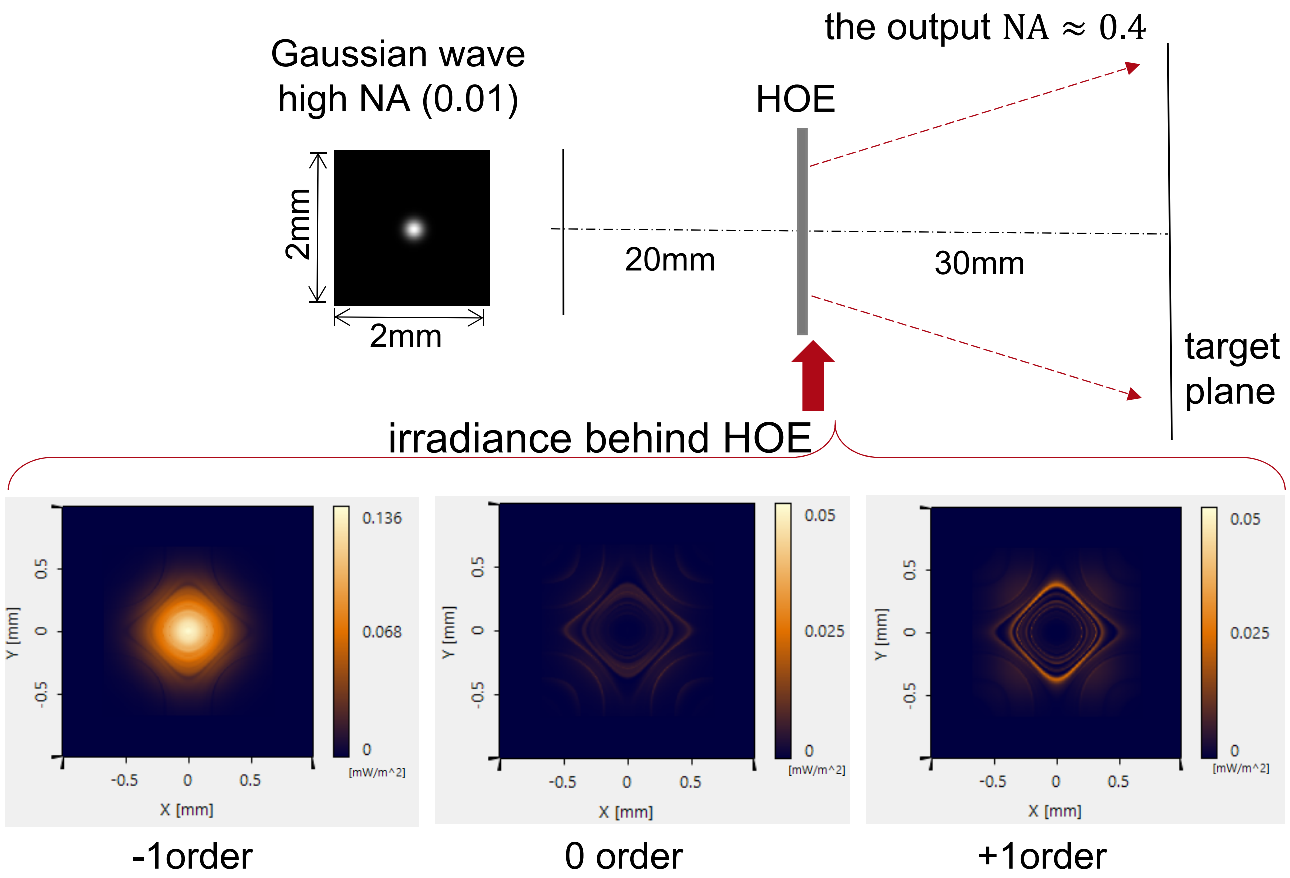


Gaussian to Top-Hat: Structural Design by HOE



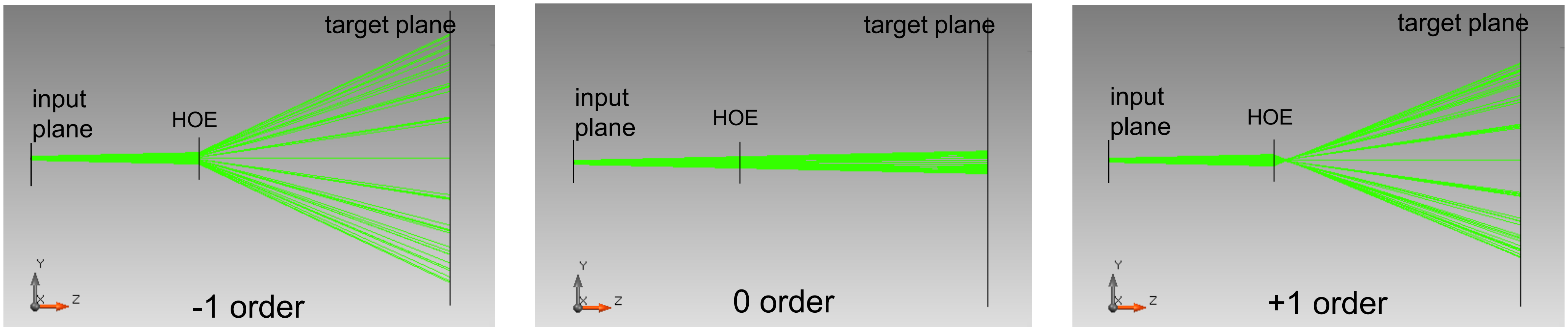
HOE: Holographic Optical Elements

Gaussian to Top-Hat: Structural Design by HOE

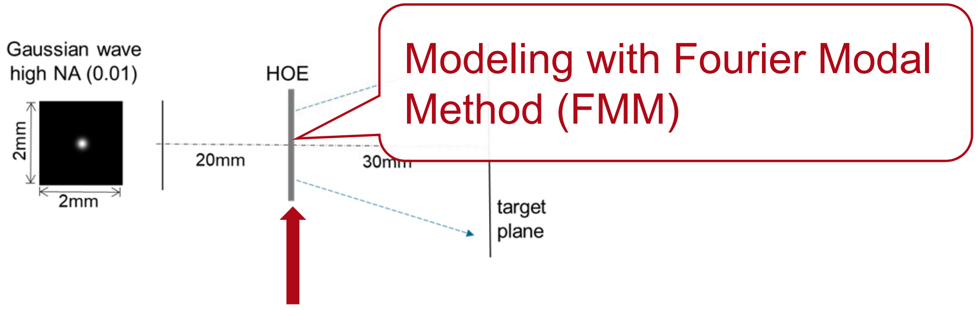


Gaussian to Top-Hat (Non-paraxial): HOE

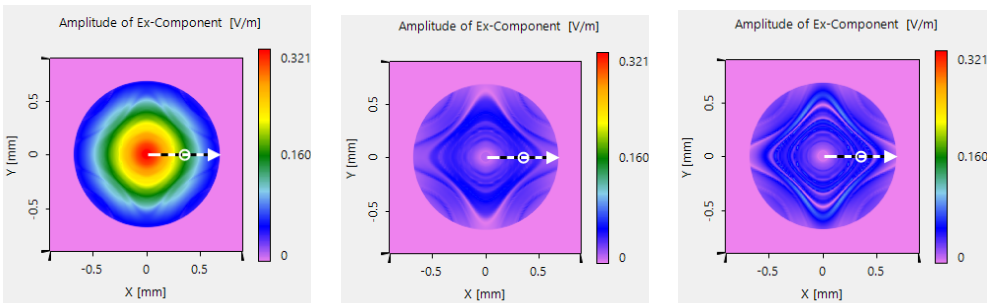
ray tracing result with HOE (with the working order of -1 order)



Investigate Rayleigh Coefficient

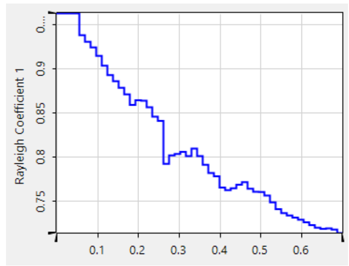
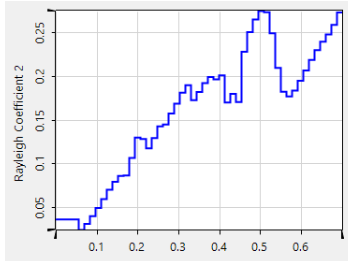
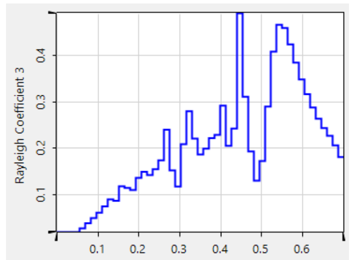


Ex Component behind HOE

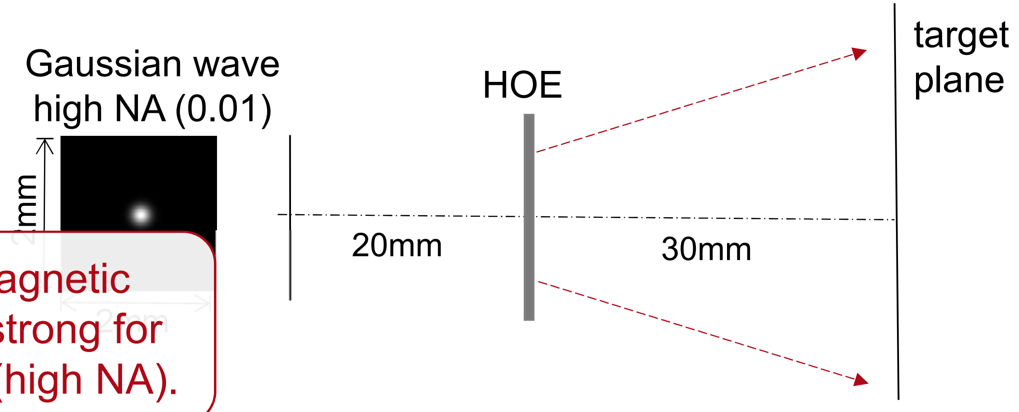


-1order | 0 order | +1order

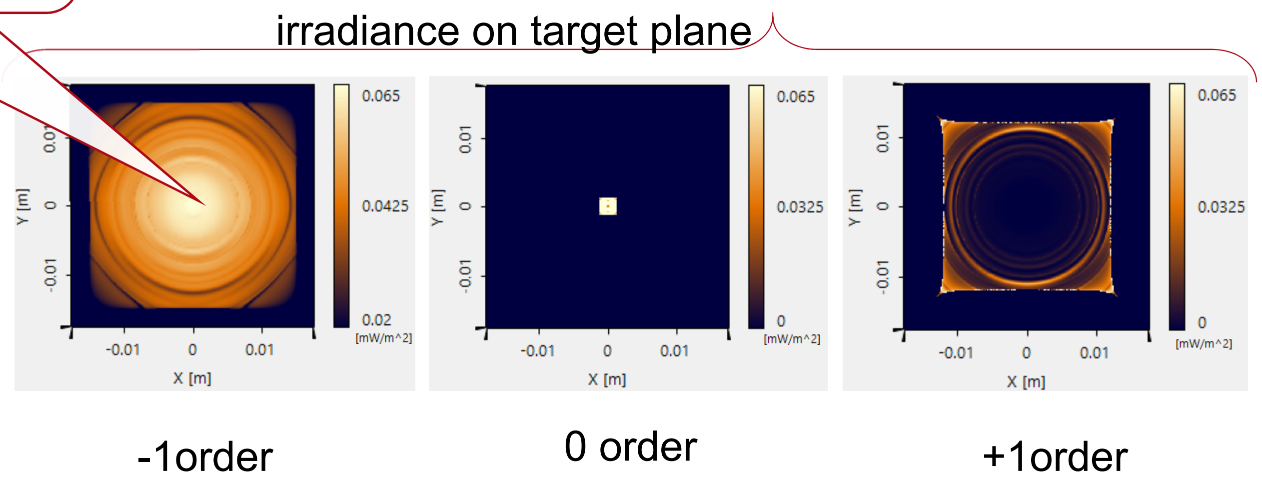
the Rayleight coefficient along the cross-section is compared with the result from Grating Toolbox

	cross-section profile
-1 order	
0 order	
+1 order	

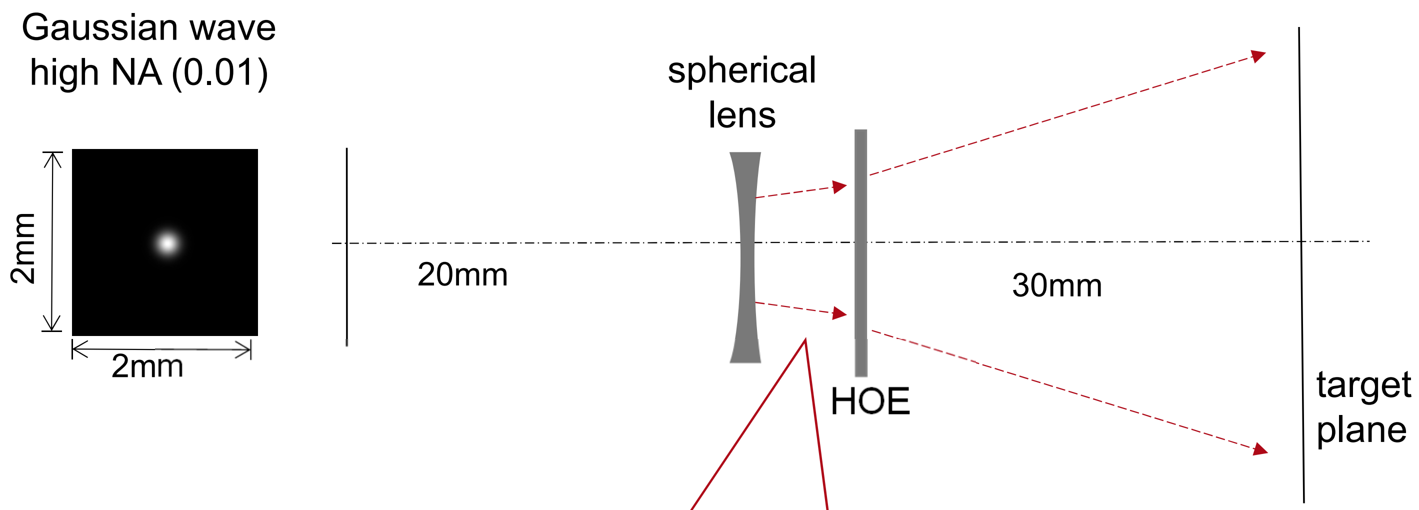
Gaussian to Top-Hat (Non-paraxial): Structural Design by HOE



Unwanted electromagnetic effects in HOE too strong for small local periods (high NA).



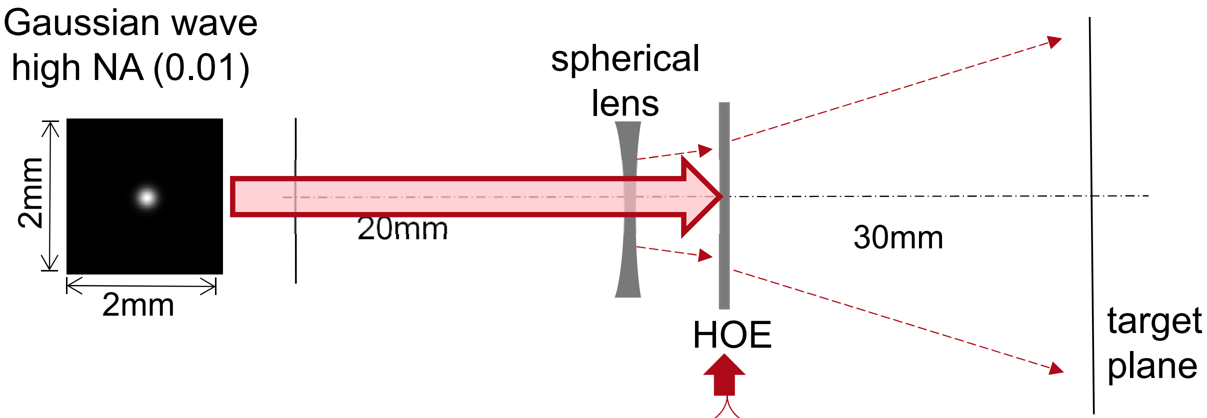
Gaussian to Top-Hat (Non-paraxial): Lens + HOE

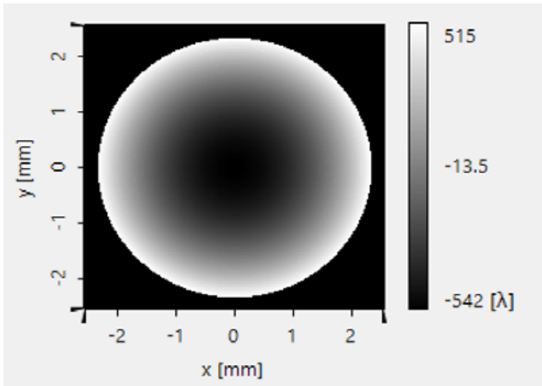


Hybrid solution:

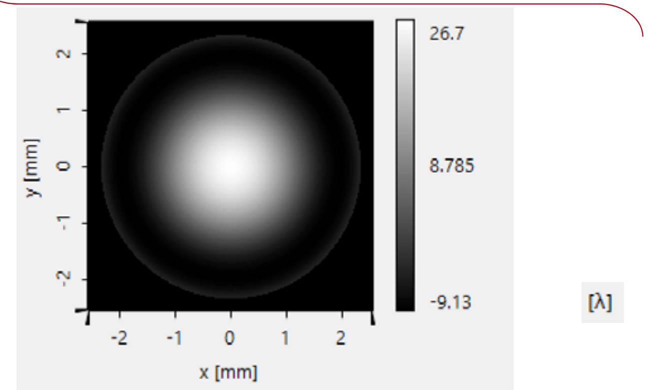
- Spherical lens provides major divergence power
- HOE controls/introduces aberrations

Gaussian to Top-Hat (Non-paraxial): Functional Design





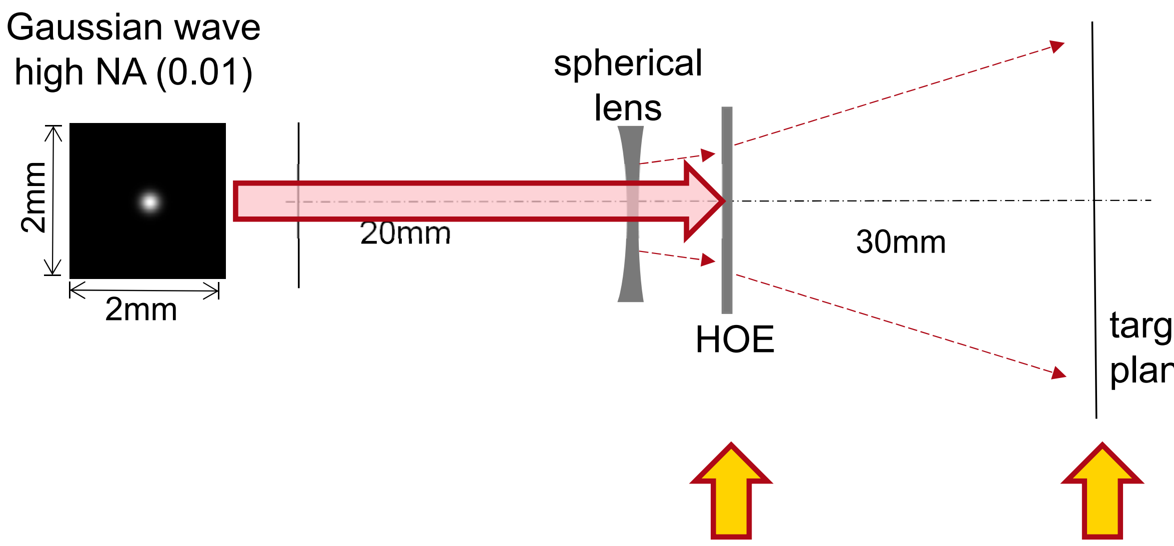
wavefront behind spherical lens



wavefront error
with respect to spherical wavefront

the Peak-to-Valley wavefront error is 35.83λ

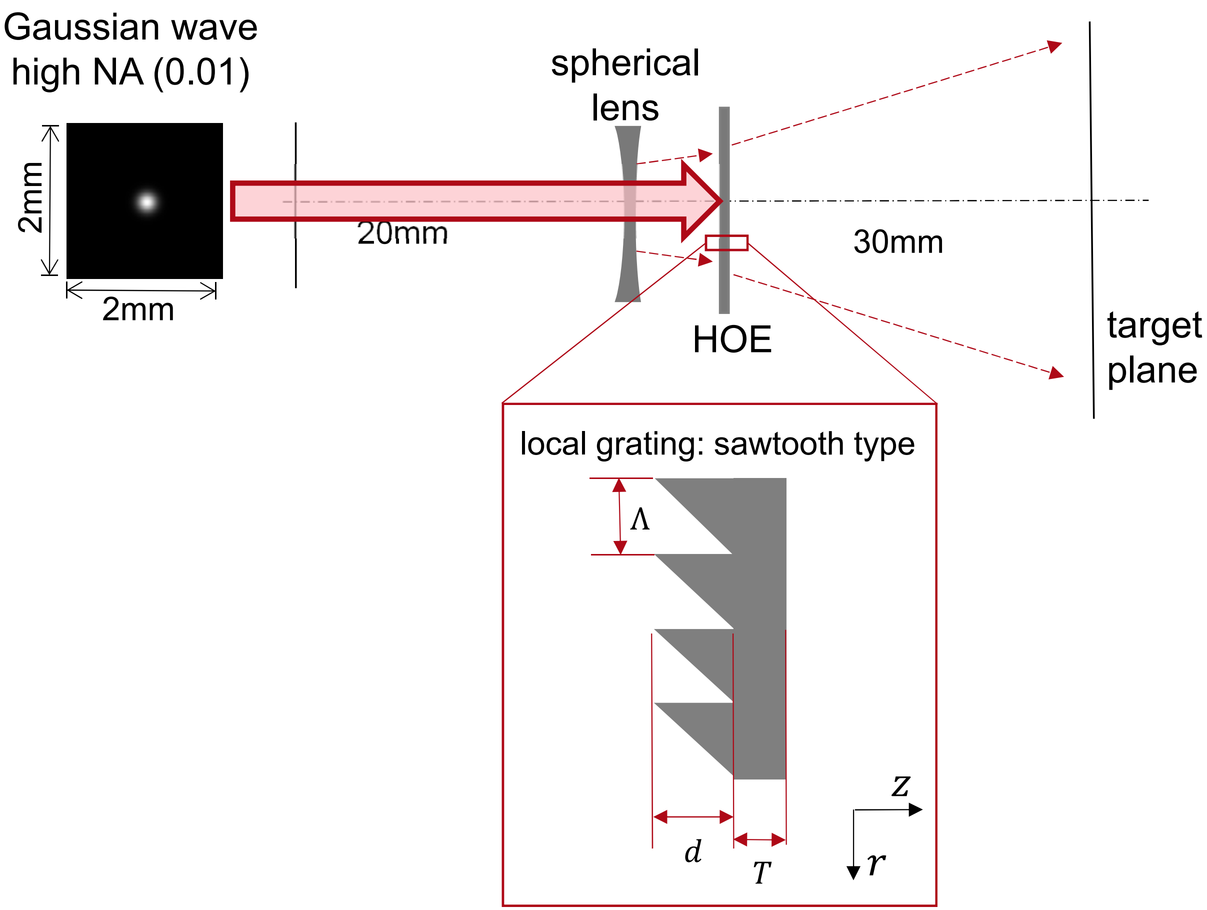
Gaussian to Top-Hat (Non-paraxial): Functional Design



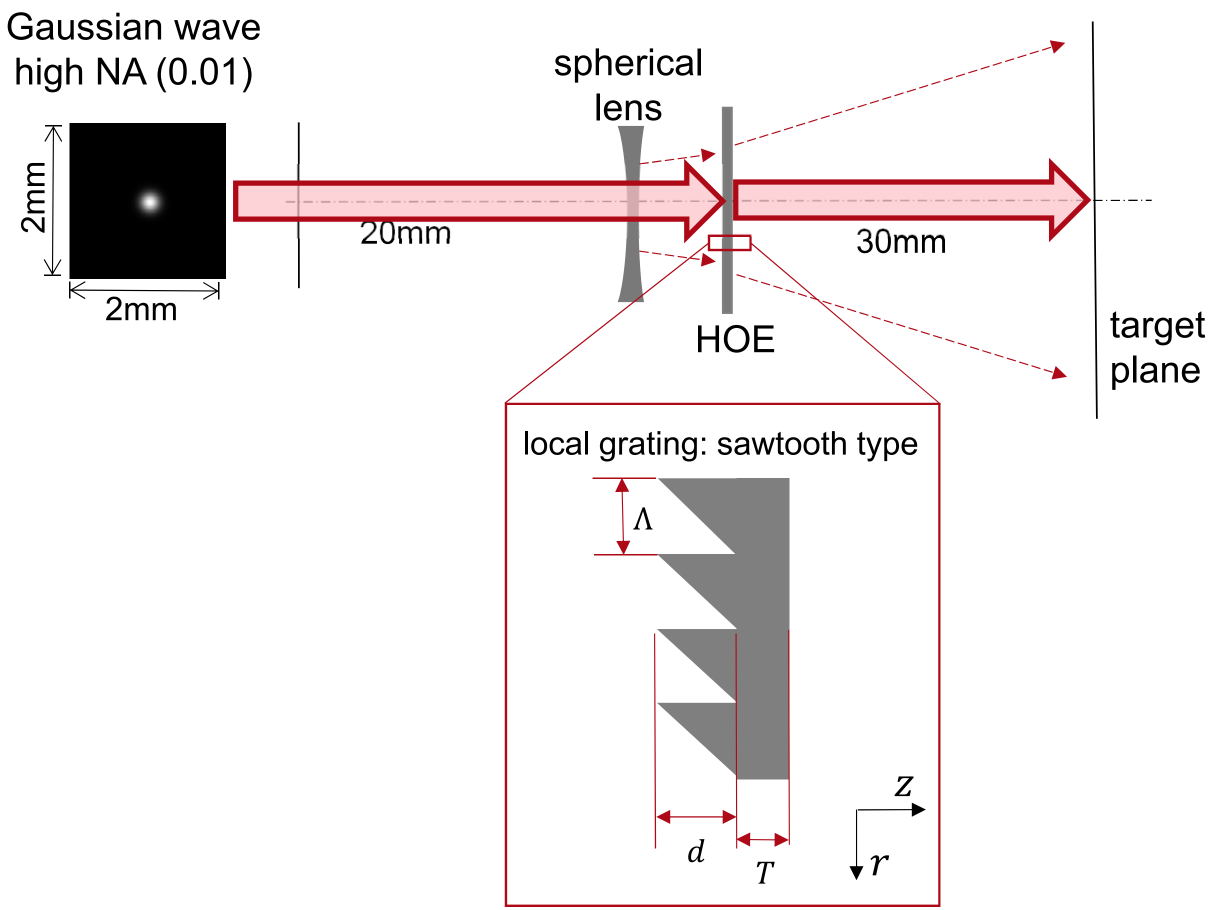
- Energy conservation: mesh mapping

- Demanded phase for wavefront change is known.

Gaussian to Top-Hat (Non-paraxial): Structural Design



Gaussian to Top-Hat (Non-paraxial): Structural Design

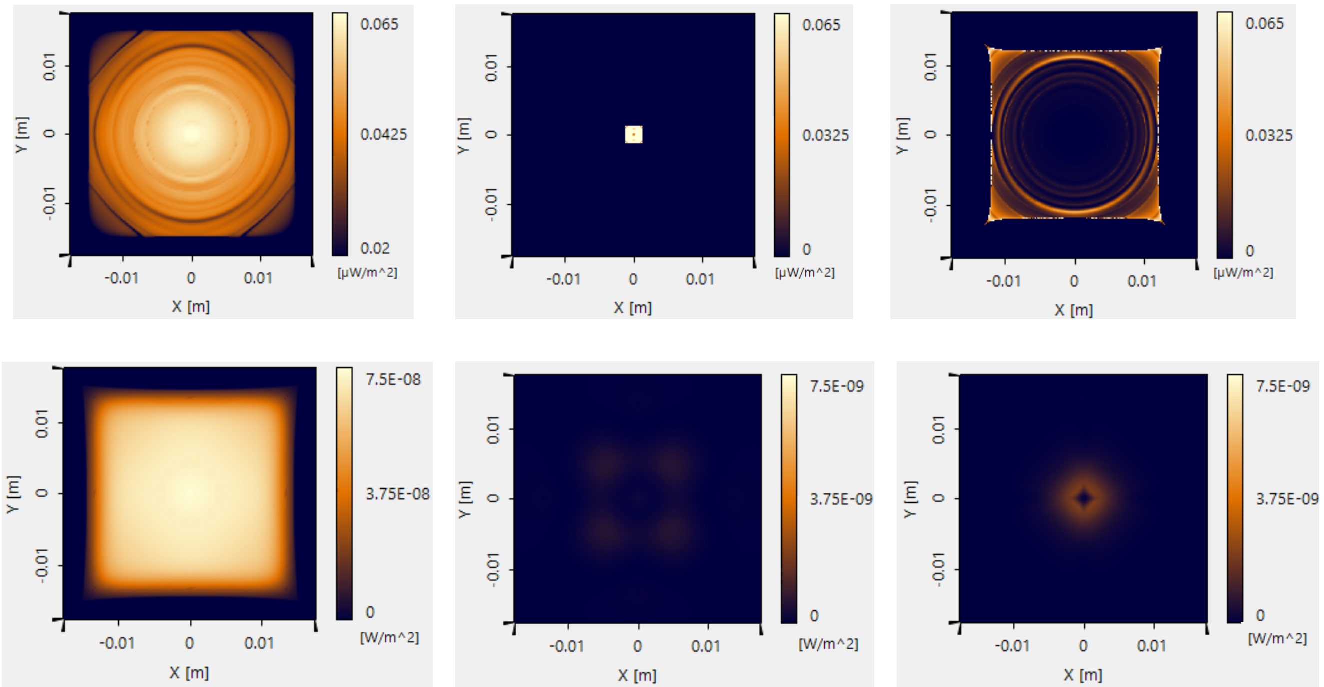


Gaussian to Top-Hat (Non-paraxial): Lens + HOE

The result irradiance on target plane is compared with the previous case without the lens.

without the lens

with the lens



-1order

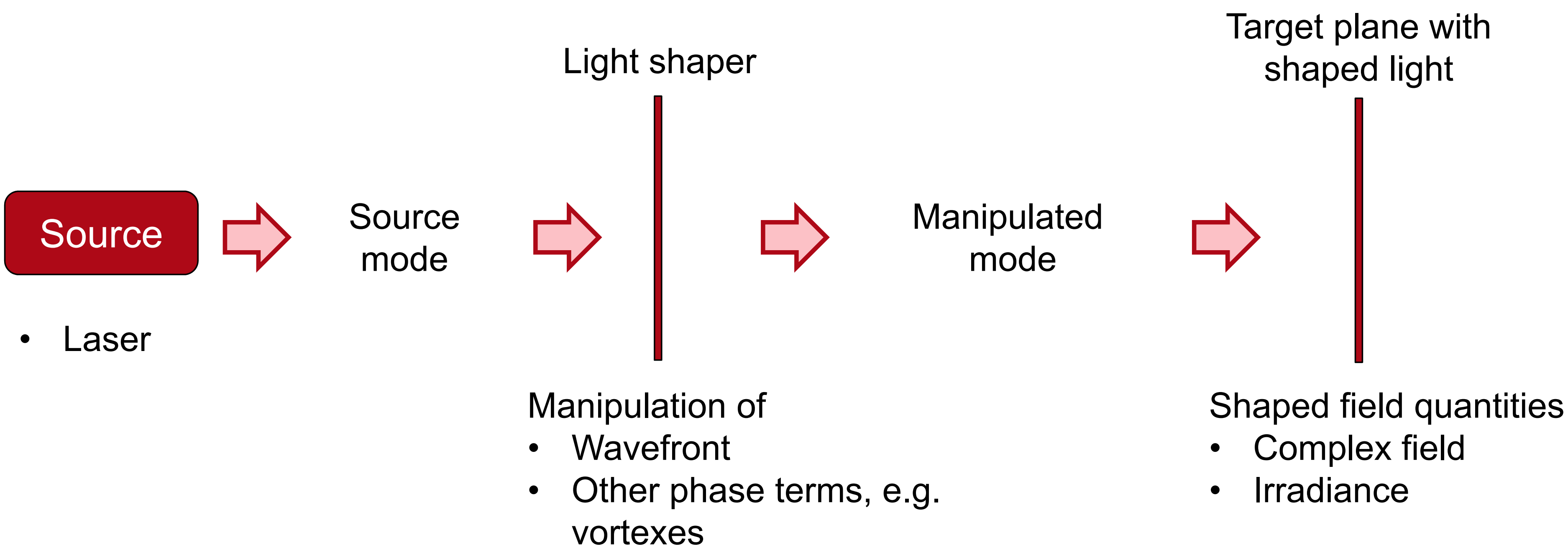
0 order

+1order

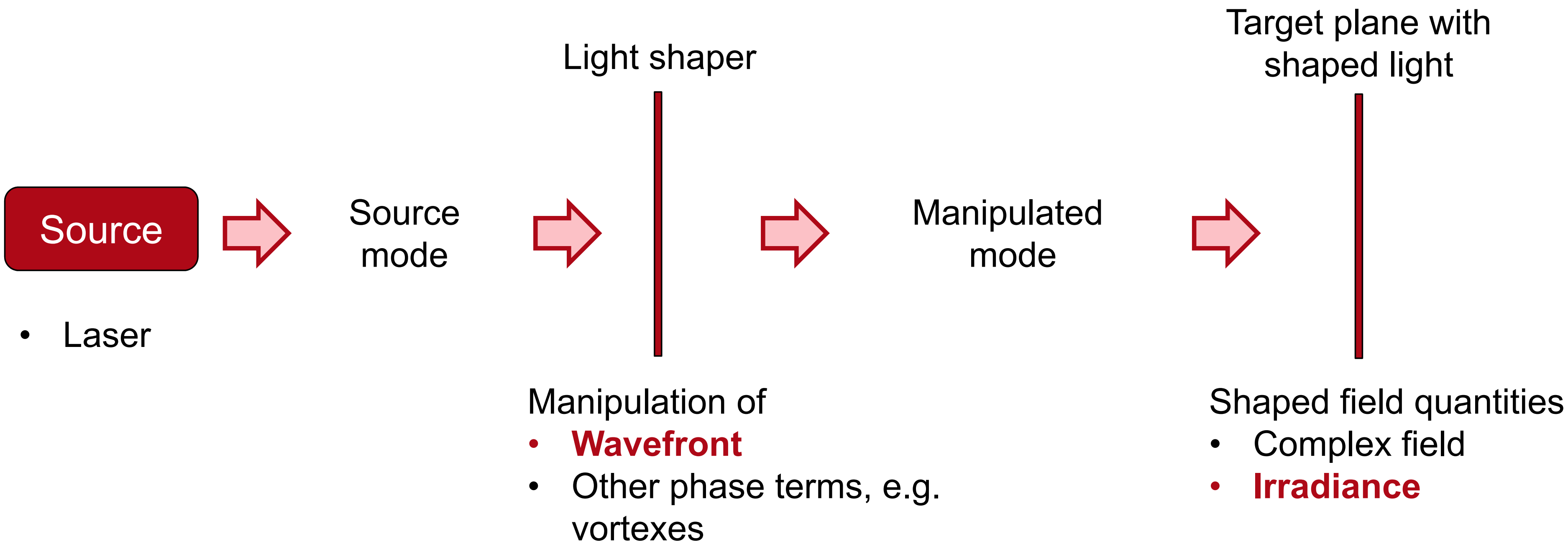
Diffractive light shaping by vortexes

Shaping by diffraction

Light Shaping Task: Donut Mode



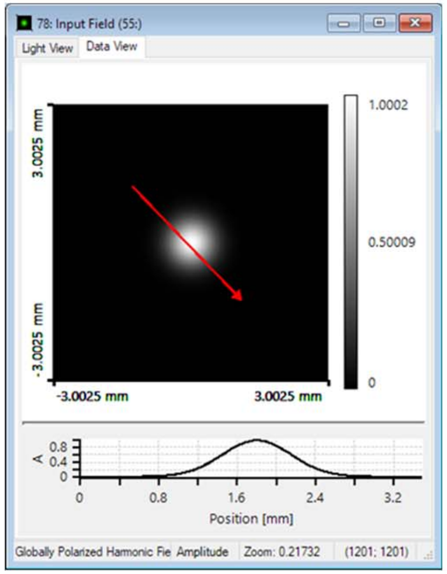
Light Shaping Task: Donut Mode



Light Shaping Task: Donut Mode

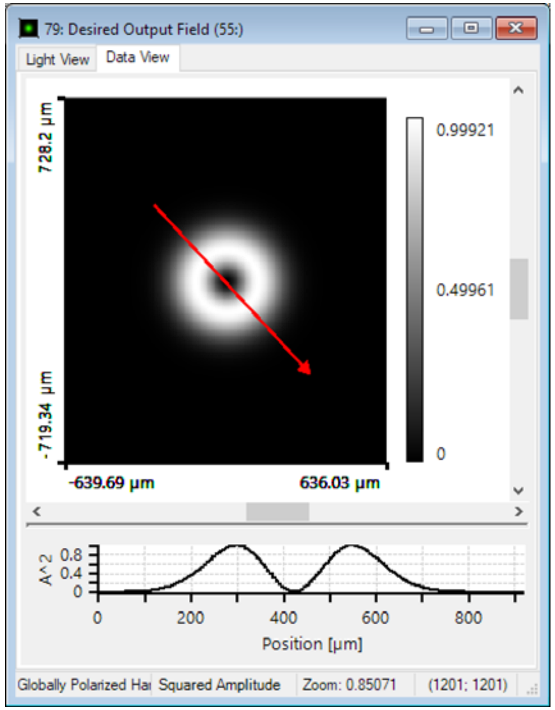
Source → Source mode → Light shaper → Manipulated mode → Target plane with shaped light

- Laser



Manipulation of
- **Wavefront**
- Other phase terms, e.g. vortexes

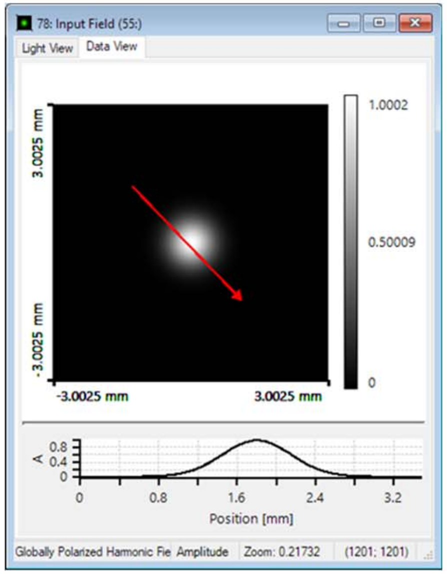
Shaped field quantities
- Complex field
- **Irradiance**



Light Shaping Task: Design by Wavefront Control

Source → Source mode → Light shaper → Manipulated mode → Target plane with shaped light

- Laser

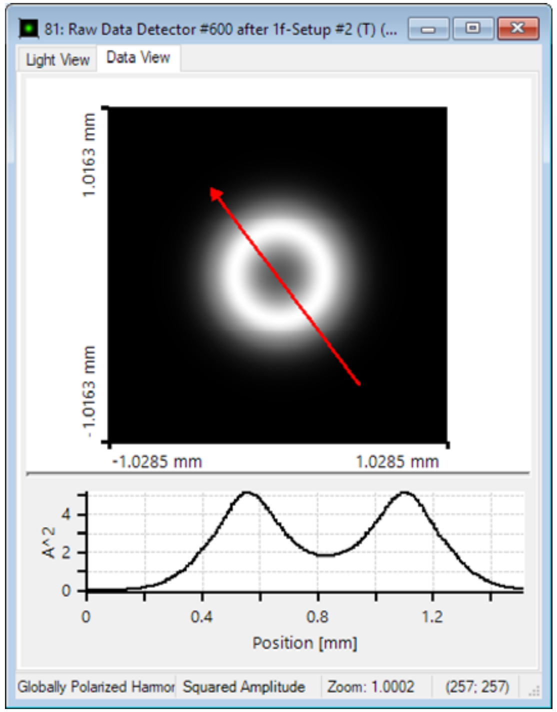


Light shaper

Manipulation of
- **Wavefront**
- Other phase terms, e.g. vortexes

Target plane with shaped light

Shaped field quantities
- Complex field
- **Irradiance**

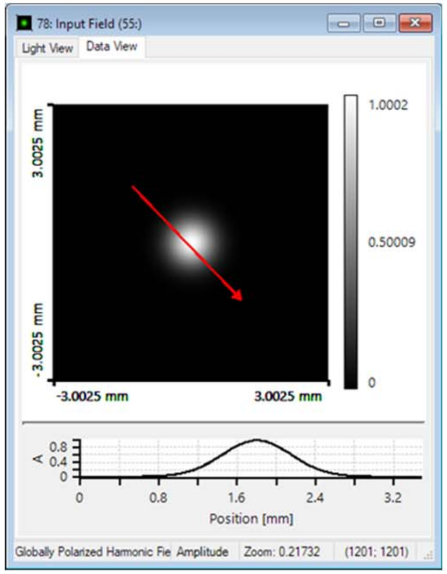


Change to diffractive phase for manipulation

Light Shaping Task: General Phase Control

Source → Source mode → Light shaper → Manipulated mode → Target plane with shaped light

- Laser



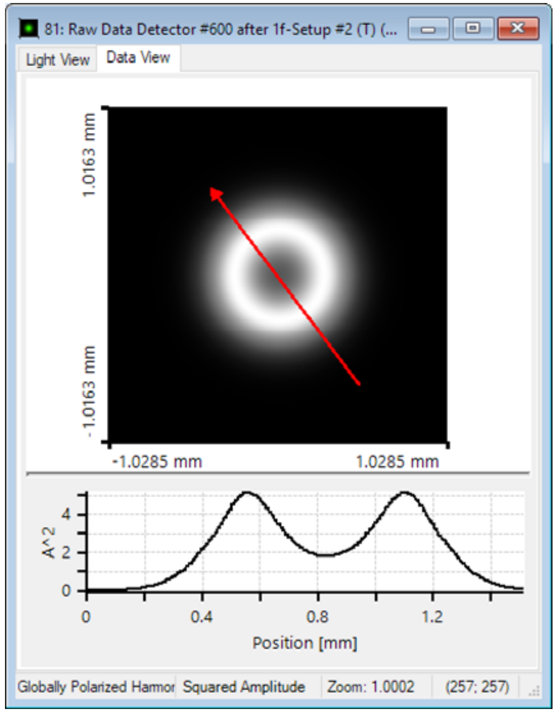
Manipulation of

- **Wavefront**
- Other phase terms, e.g. vortexes

Shaped field quantities

- Complex field
- **Irradiance**

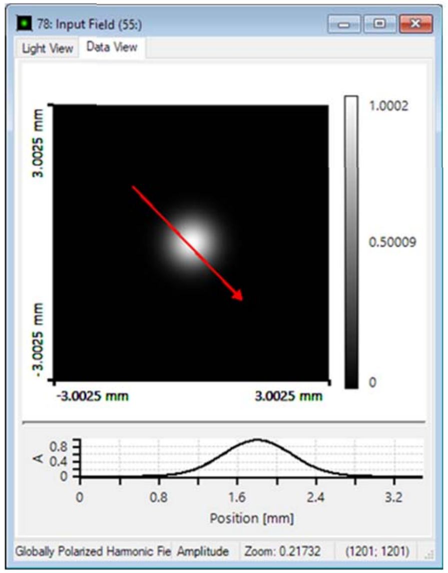
Change to complex amplitude in target



Light Shaping Task: General Phase Control

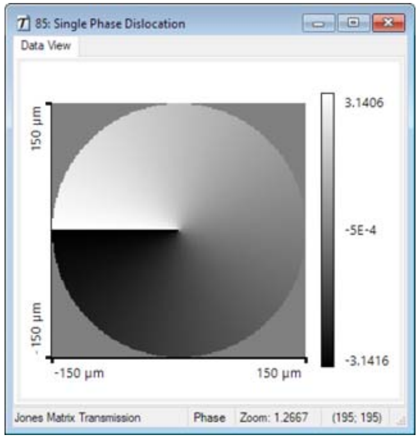
Source → Source mode → Light shaper → Manipulated mode → Target plane with shaped light

- Laser



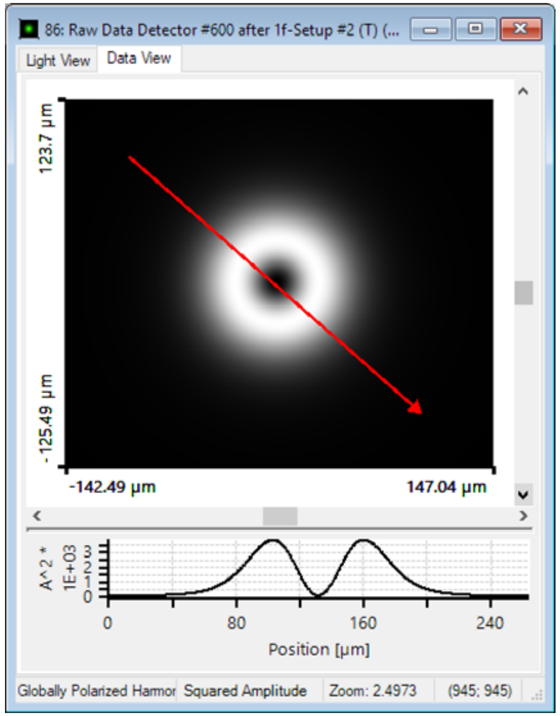
Light shaper

Manipulation of
- Wavefront
- Other phase terms, e.g. **vortexes**



Target plane with shaped light

Shaped field quantities
- **Complex field**
- Irradiance

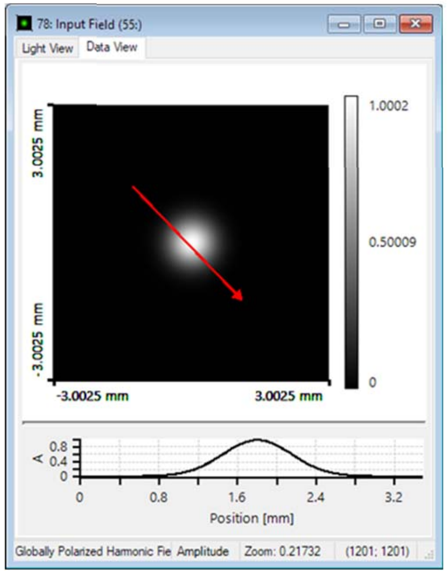


Light Shaping Task: General Phase Control

Source → Source mode → Light shaper → Manipulated mode → Target plane with shaped light

Source

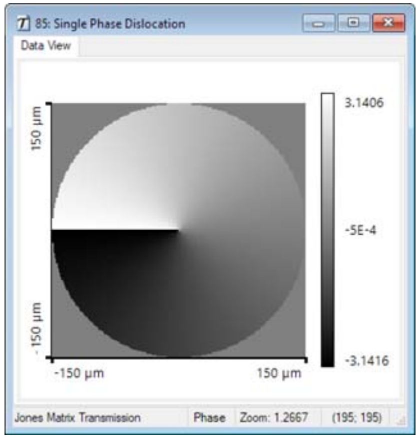
- Laser



Light shaper

Manipulation of

- Wavefront
- Other phase terms, e.g. **vortexes**

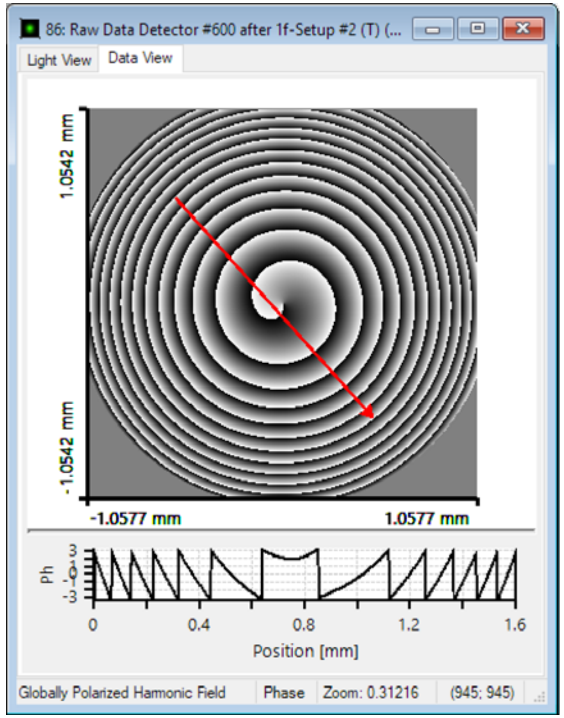


Manipulated mode

Target plane with shaped light

Shaped field quantities

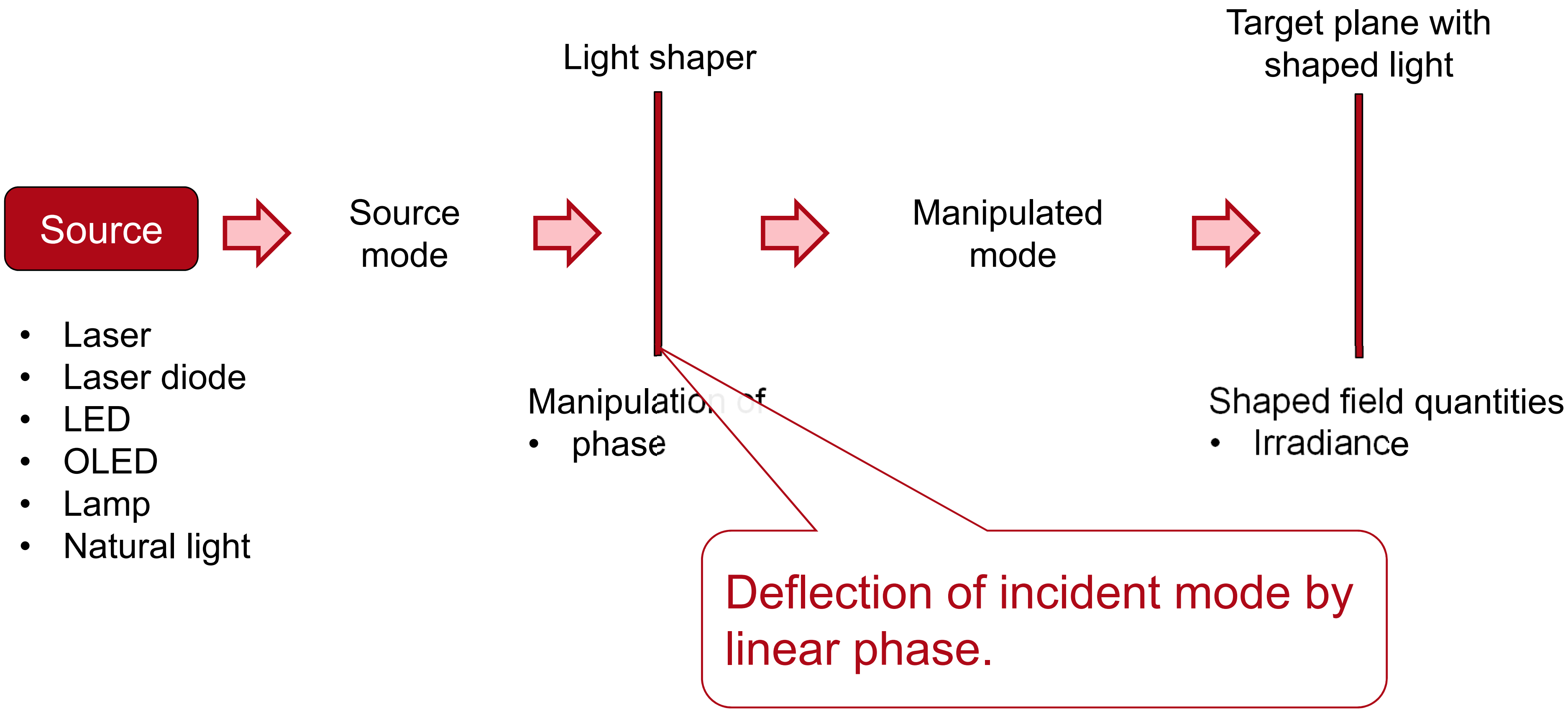
- **Complex field**
- Irradiance



Diffractive light shaping by coherent superposition

Diffractive beam splitter and diffuser

Light Shaping Task: Functional Design



Light Shaping Task: Functional Design

Source → Source mode → Light shaper → Manipulated mode → Target plane with shaped light

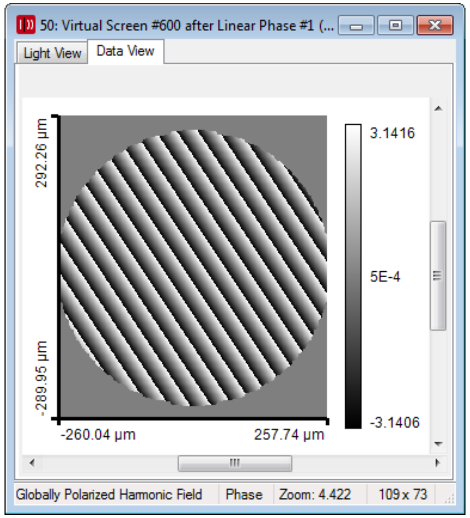
Source

- Laser
- Laser diode
- LED
- OLED
- Lamp
- Natural light

Light shaper

Manipulation of
- phase

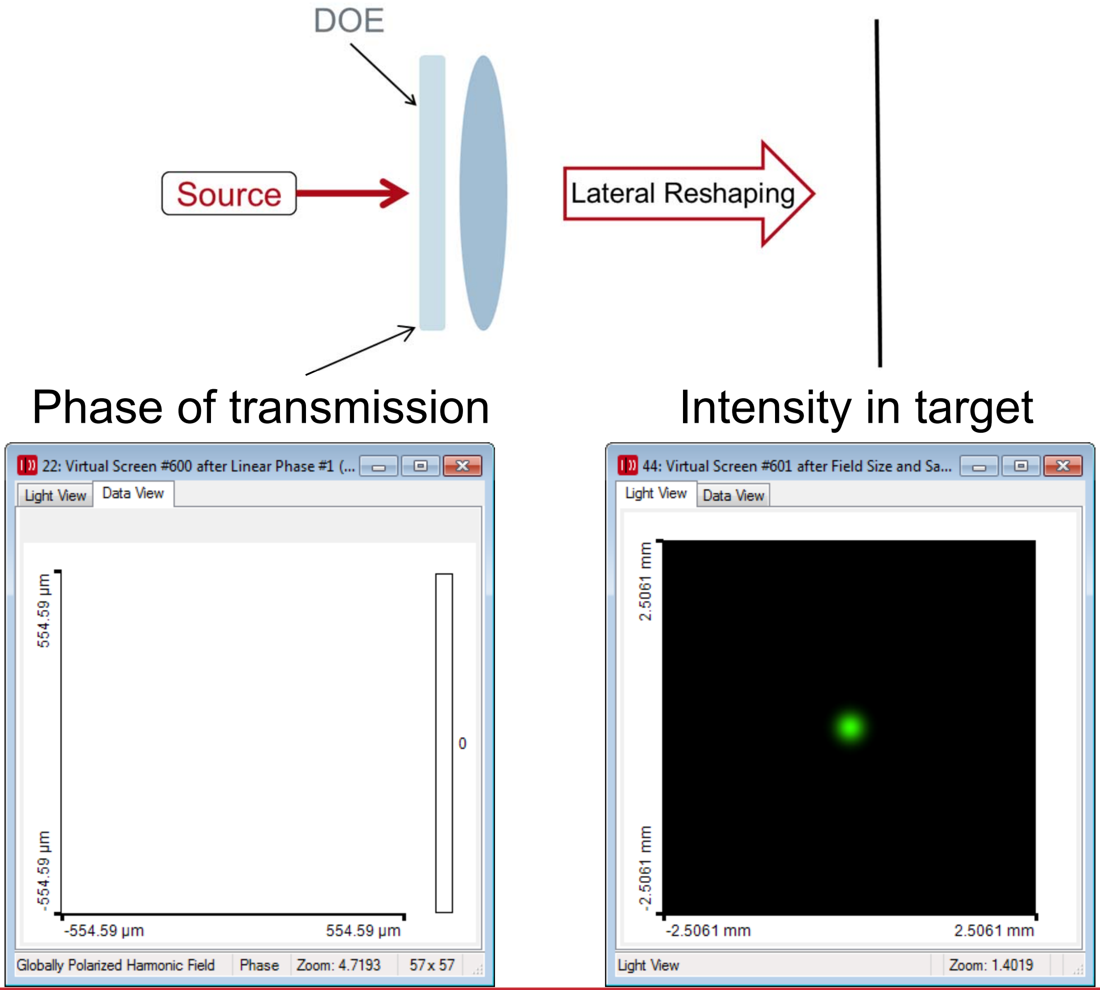
Manipulated mode



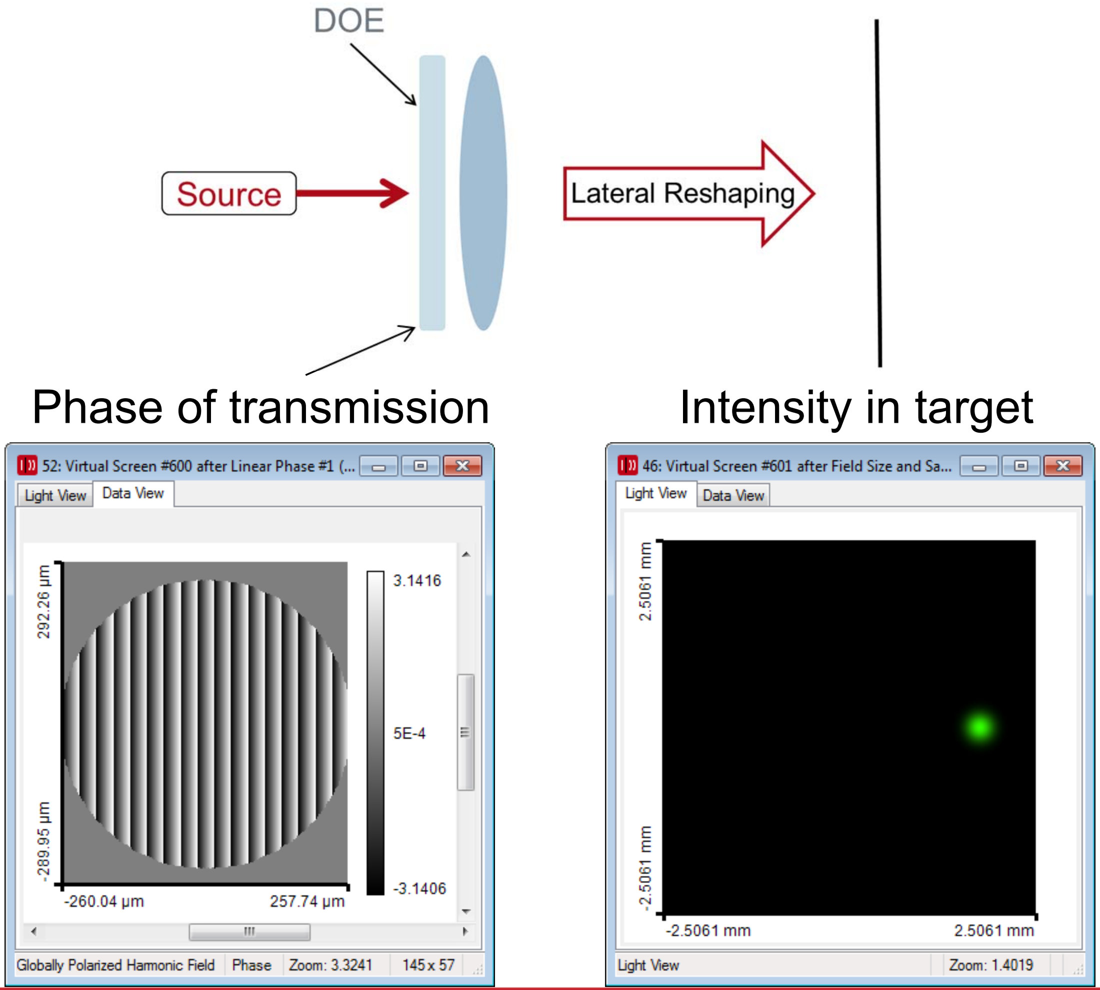
Target plane with shaped light

Shaped field quantities
- Irradiance

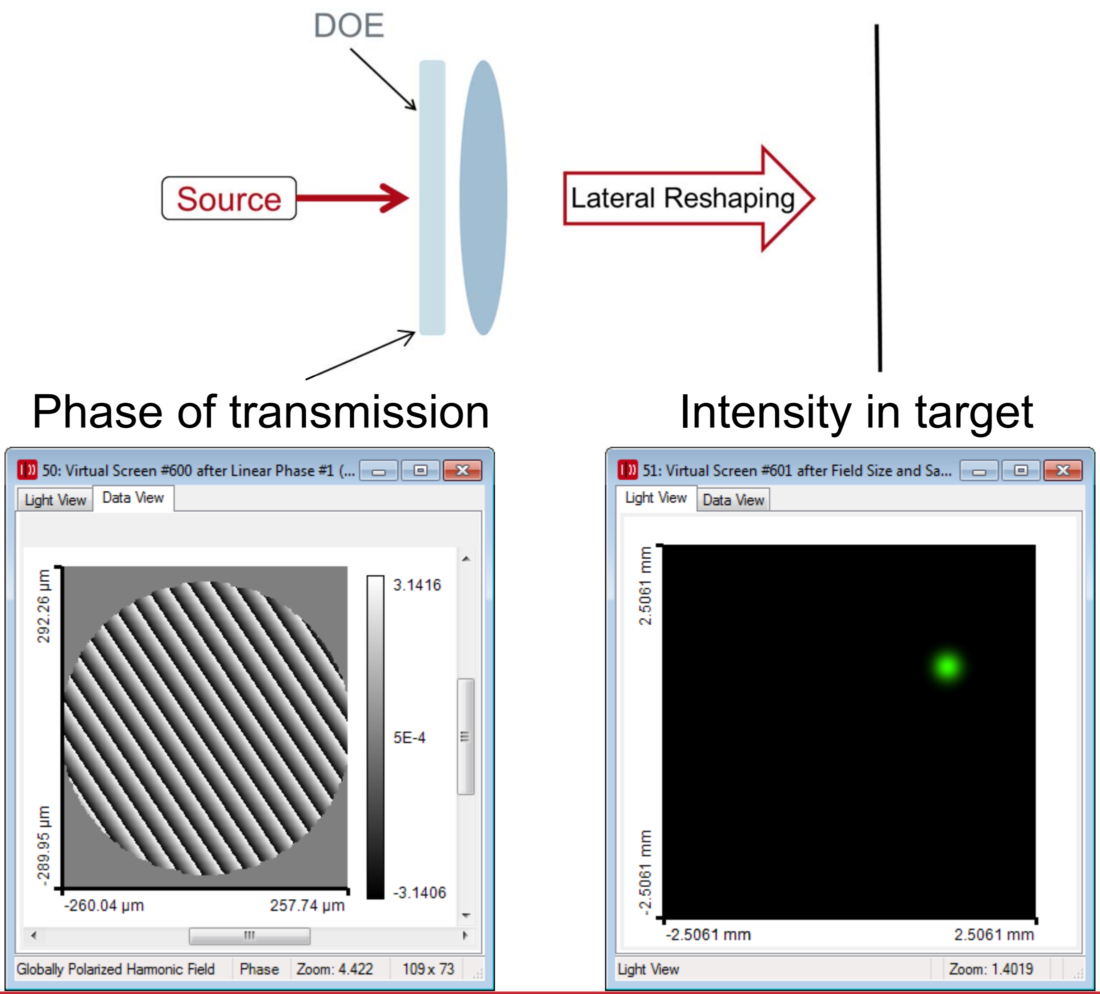
Functional Design: Illustration of Deflection



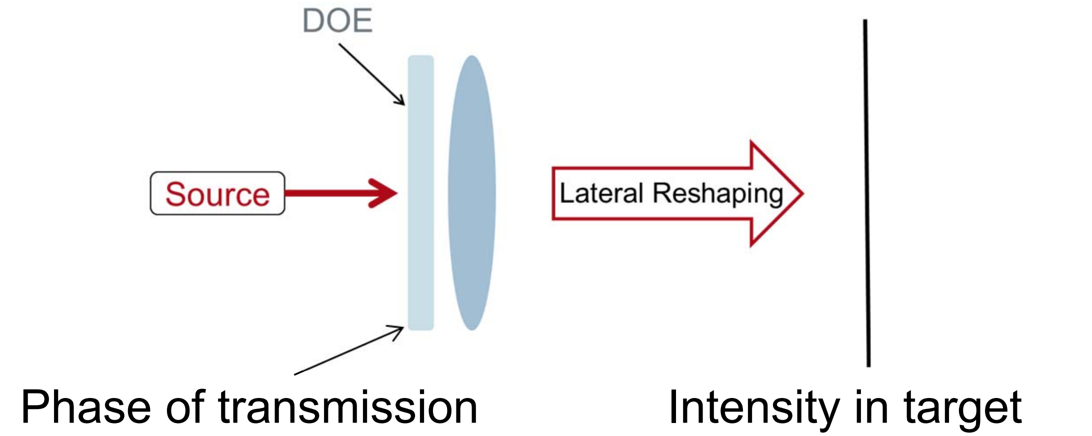
Functional Design: Illustration of Deflection

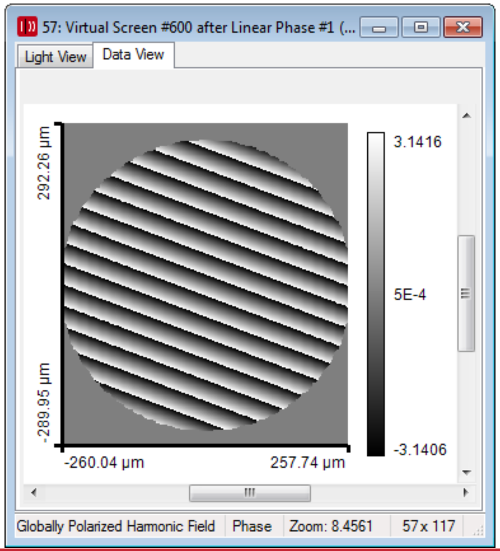


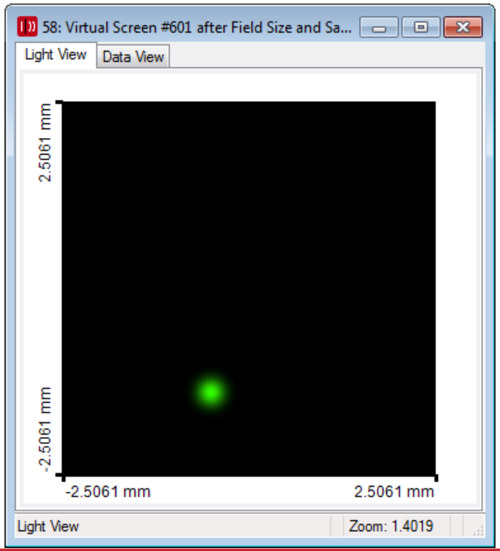
Functional Design: Illustration of Deflection



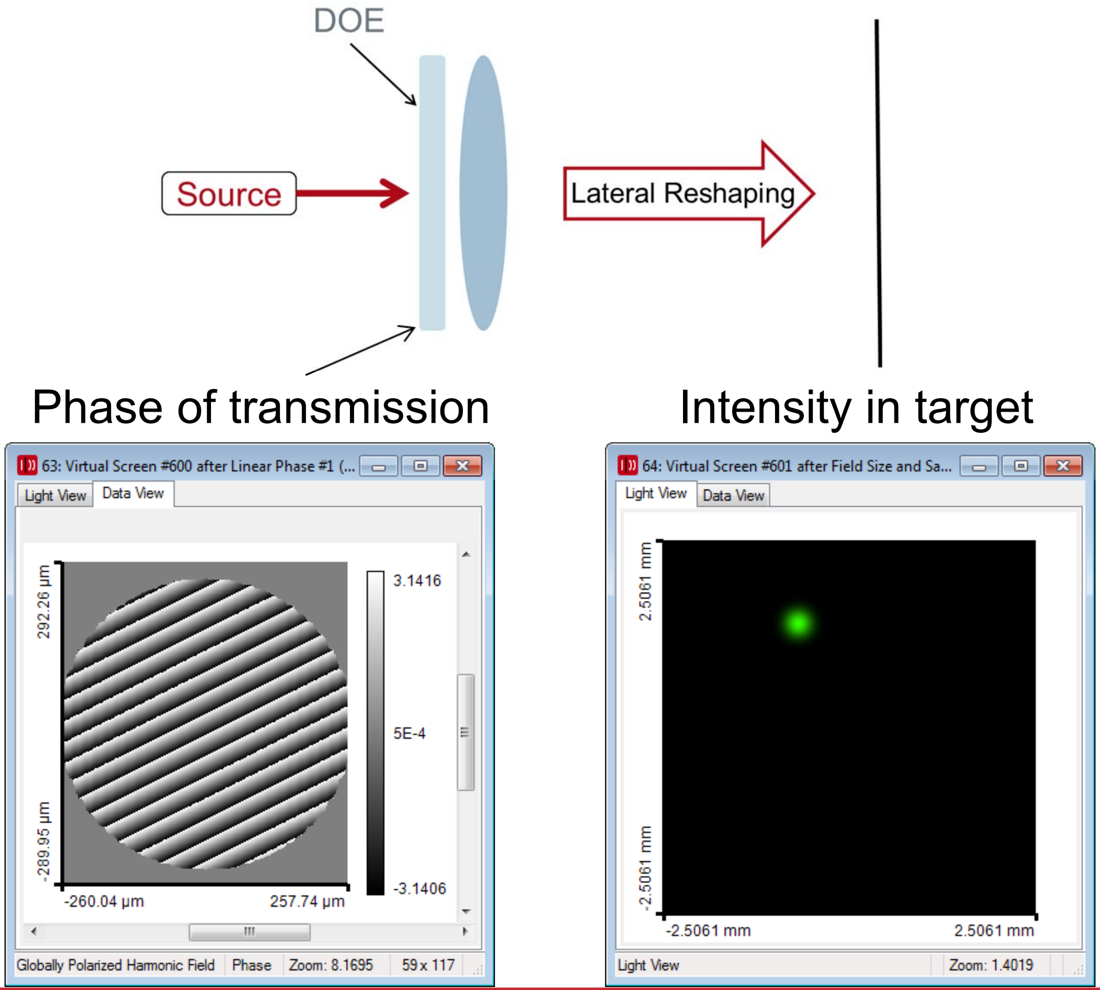
Functional Design: Illustration of Deflection



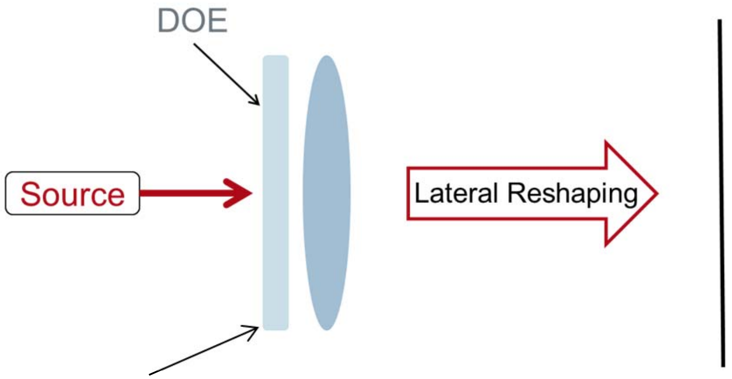




Functional Design: Illustration of Deflection

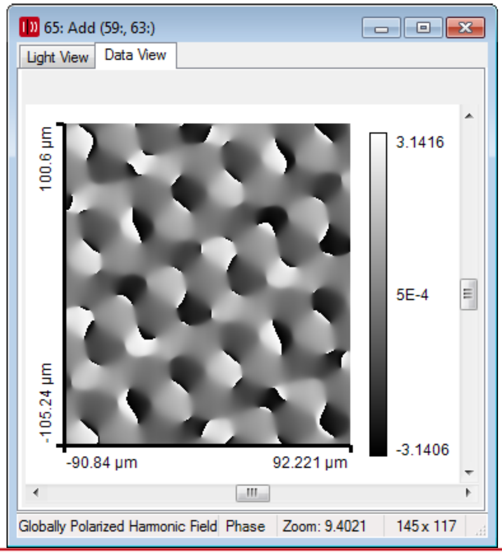


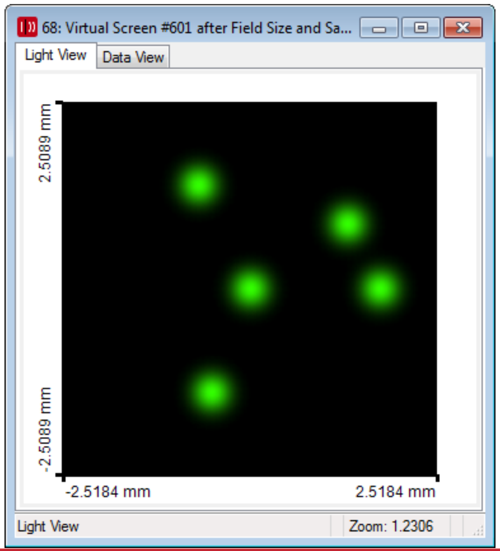
Functional Design: Coherent Sum of Linear Phases



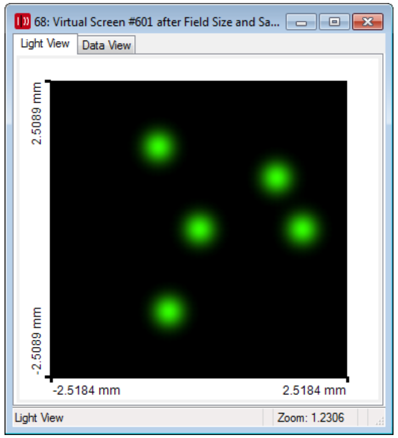
Phase of transmission

Intensity in target

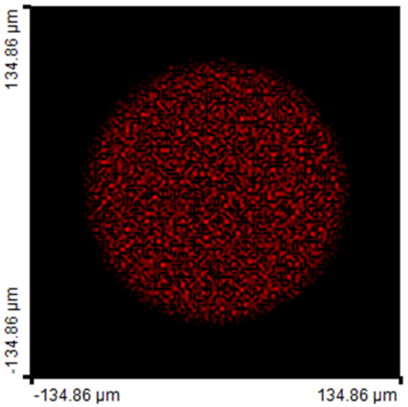




Basic Design Situations: Splitting

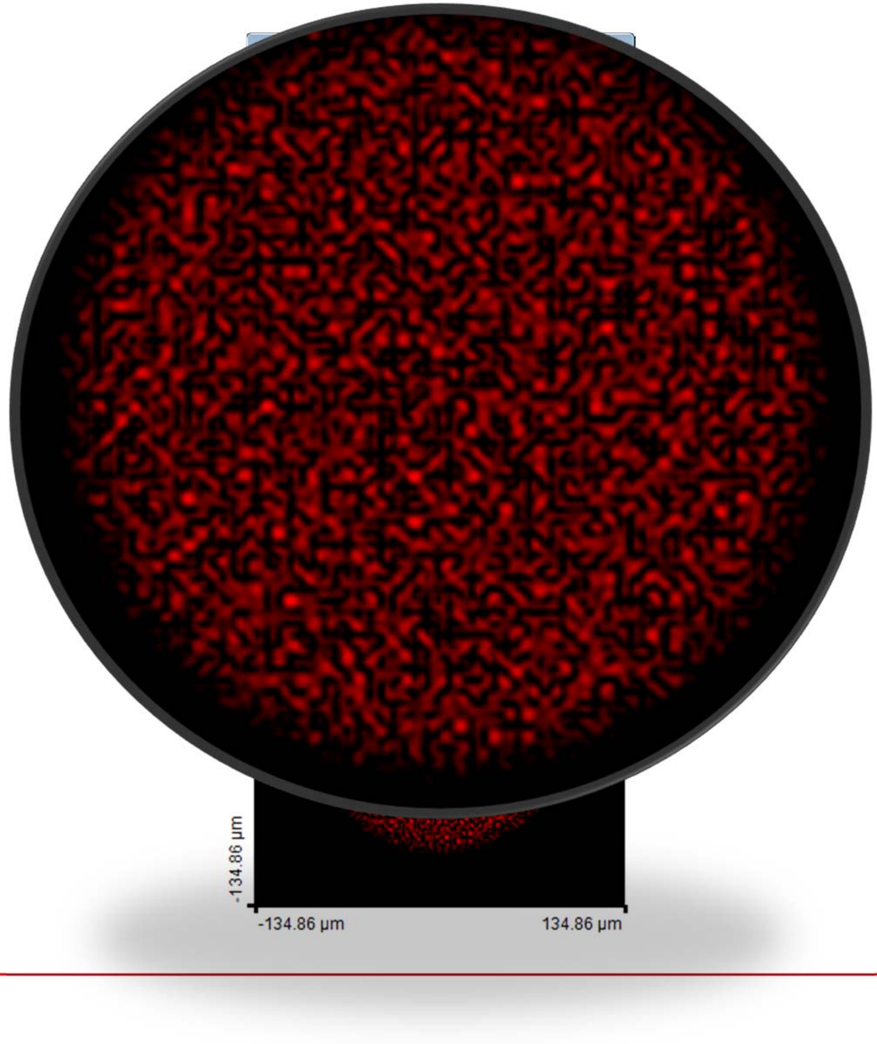


- Spots in target pattern do not overlap: diffractive beam splitter



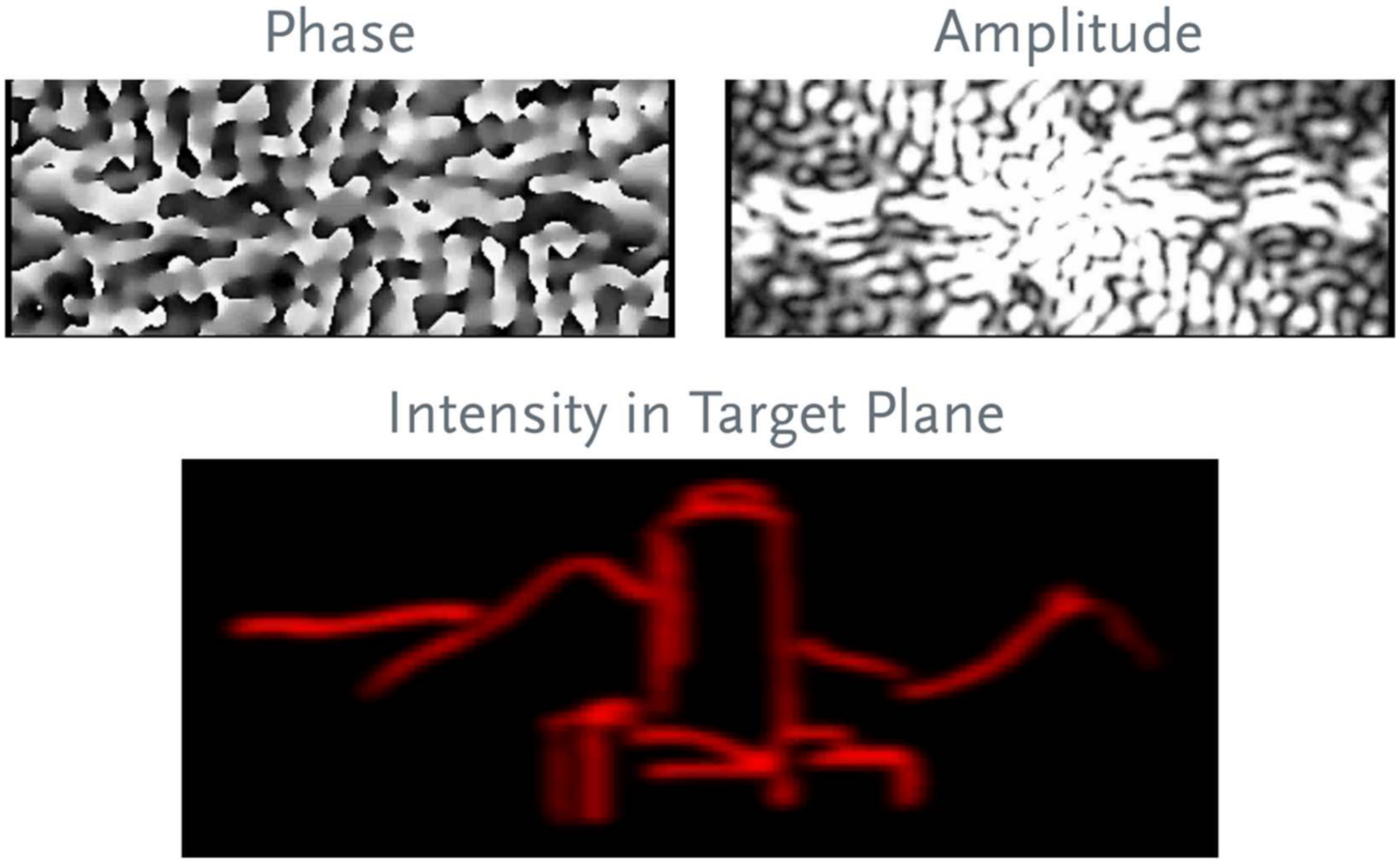
- Spots overlap in target patten: diffractive diffuser

Basic Design Situations: Splitting



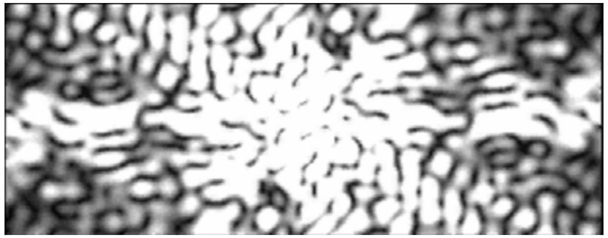
- Spots in target pattern do not overlap: diffractive beam splitter
- Spots overlap in target patten: diffractive diffuser

Shaping by “Beam Scanning”

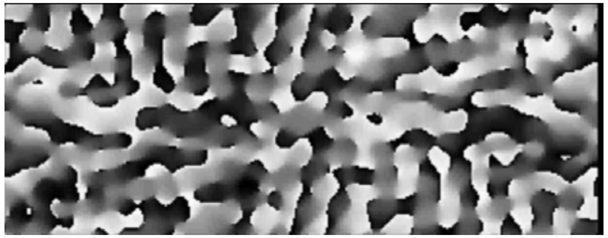


Functional Design: Iterative Fourier Transform Algorithm

Amplitude



Phase



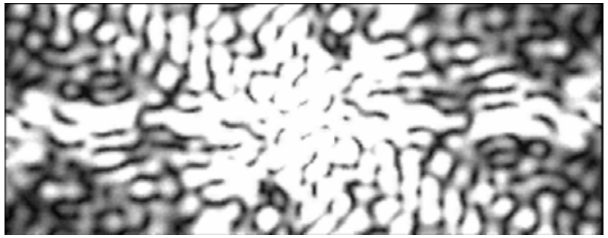
Advanced diffractive optics design techniques

Design technique (IFTA) implemented in VirtualLab

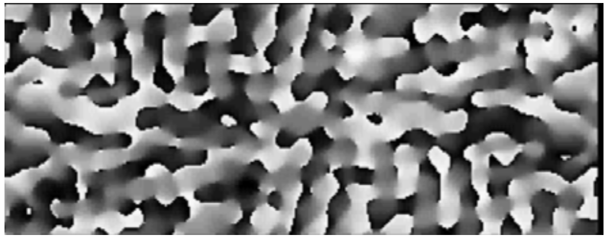
- Satisfaction of phase-only constraint
- Quantization of phase values for lithographic fabrication

Structural Design: Height Profile Calculation

Amplitude

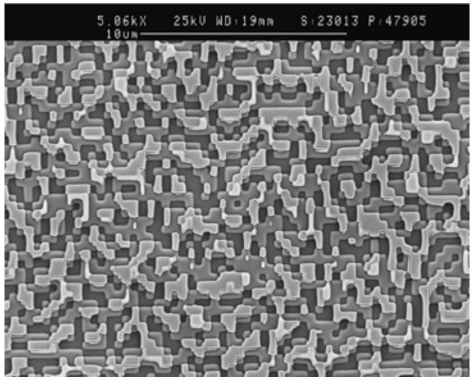


Phase



Advanced diffractive optics design techniques

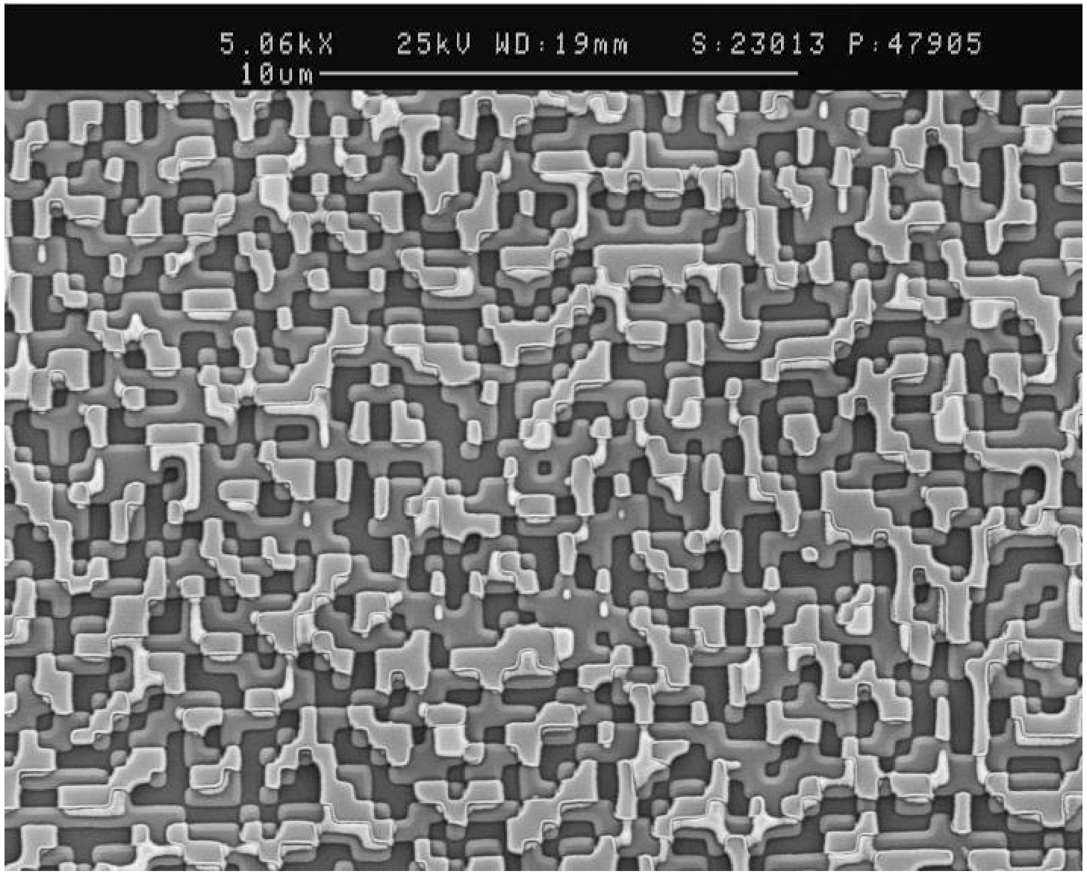
Design technique (IFTA) implemented in VirtualLab



Micro-structured surface profile

Fabricated at IAP, University of Jena

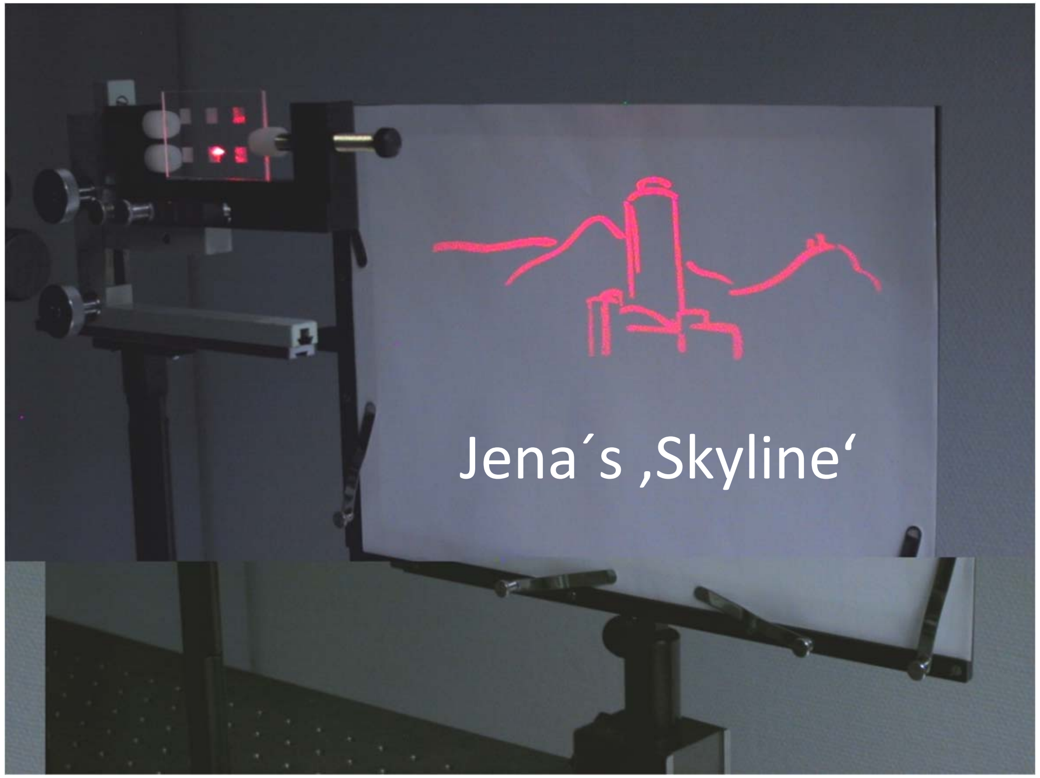
Feature Sizes of Element



Feature size
about 400 nm

4 height levels

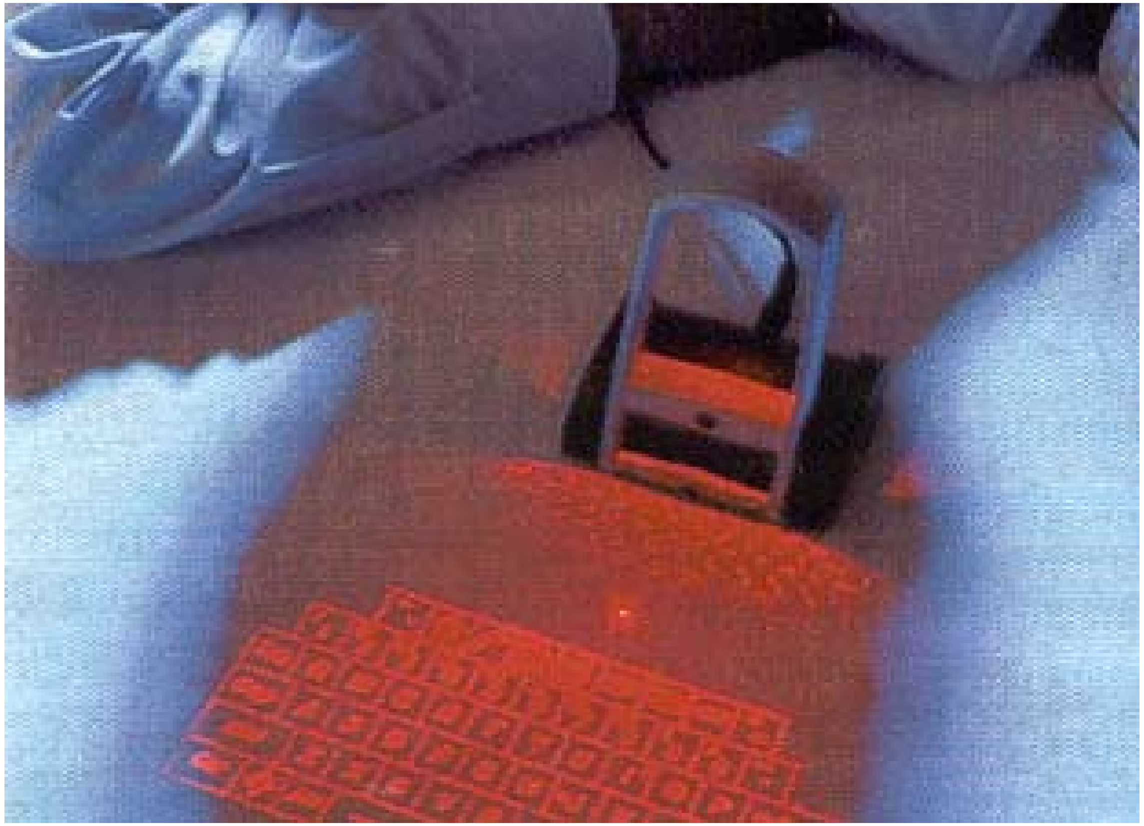
Optical Experiment



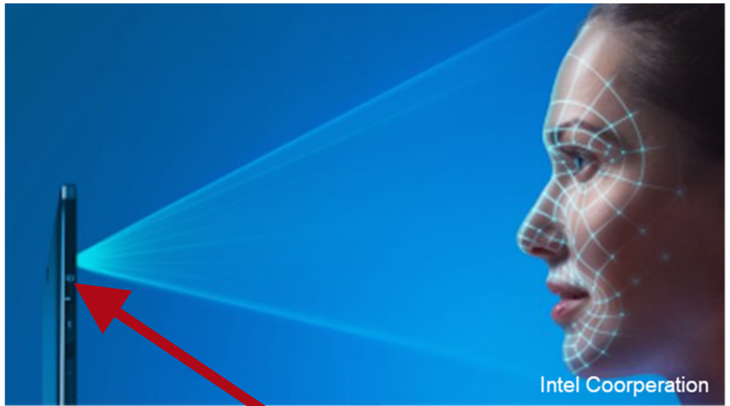
Comments on Diffuser Technology

- Very flexible in light pattern generation
- Robust against adjustment problems
- Coherent light leads to speckle pattern
- Diffusers work for partially coherent beams
- Partially coherent beams smooth the speckle pattern; effect can be simulated with VirtualLab™

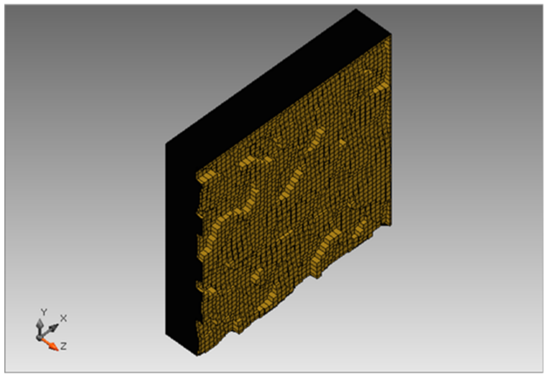
Illumination: Virtual Keyboard for PDA's



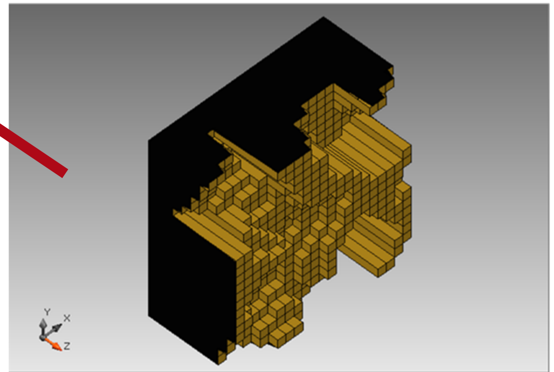
Face ID and General 3D Sensing

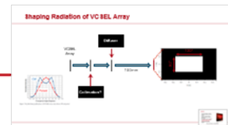


Paraxial Beam Splitter

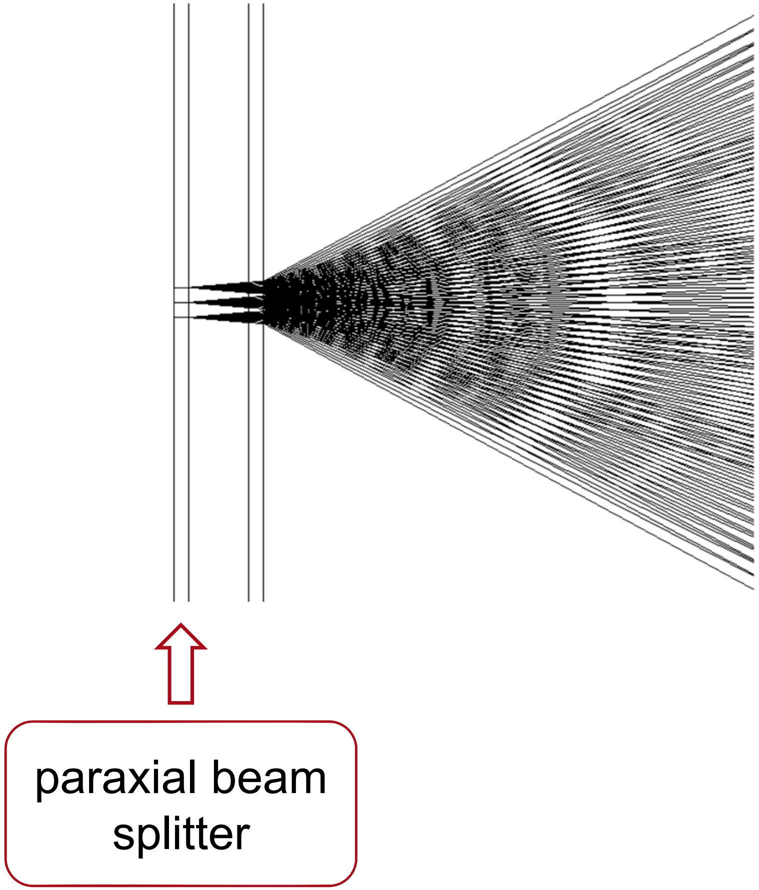


Non-Paraxial Beam Splitter



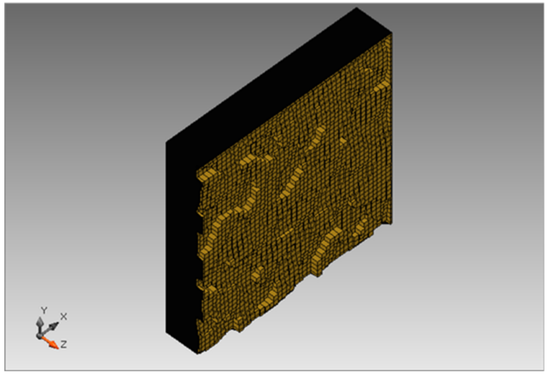


High NA Beam Splitter by Two DOE‘s

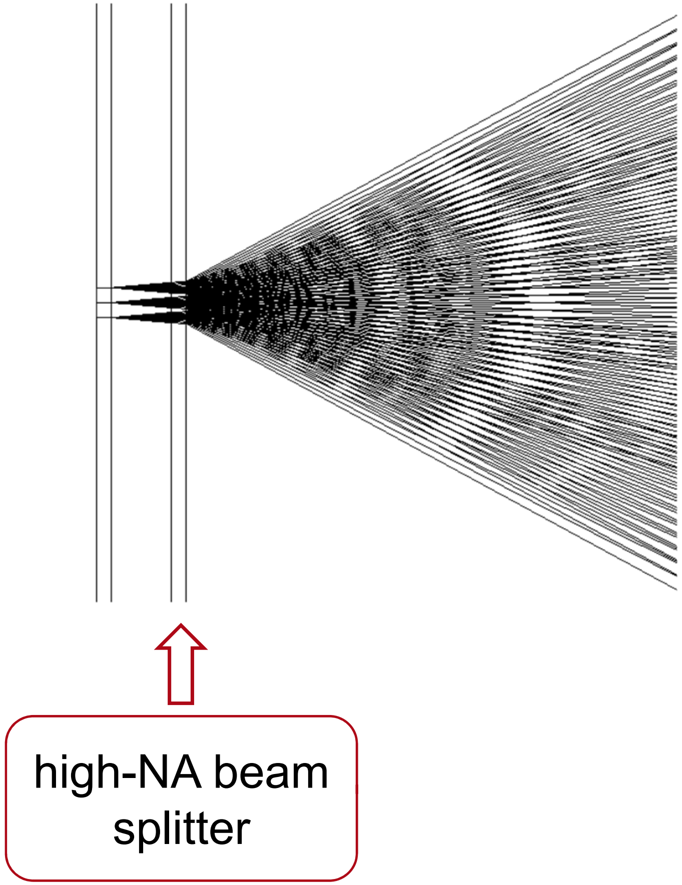


Parameter	Value & Unit
number of orders	11x11
order separation	1x1°
period	30.35x30.35µm
pixel size	690x690nm
discrete height levels	8
material	fused silica

Paraxial Beam Splitter

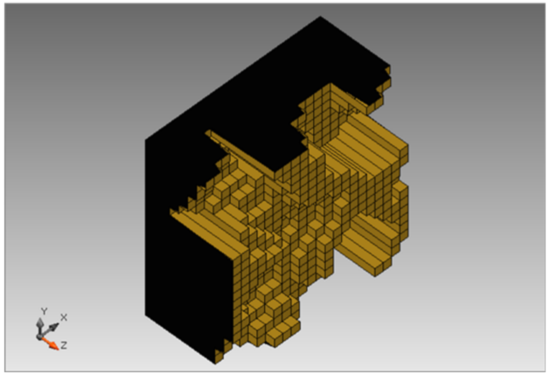


Specification: Second Beam Splitter

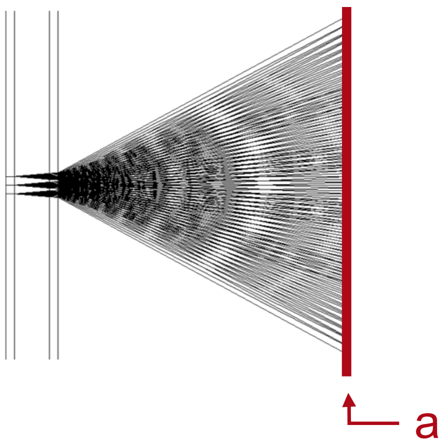


Parameter	Value & Unit
number of orders	5x5
order separation	11x11°
period	2.73x2.73μm
pixel size	130x130nm
discrete height levels	8
material	fused silica

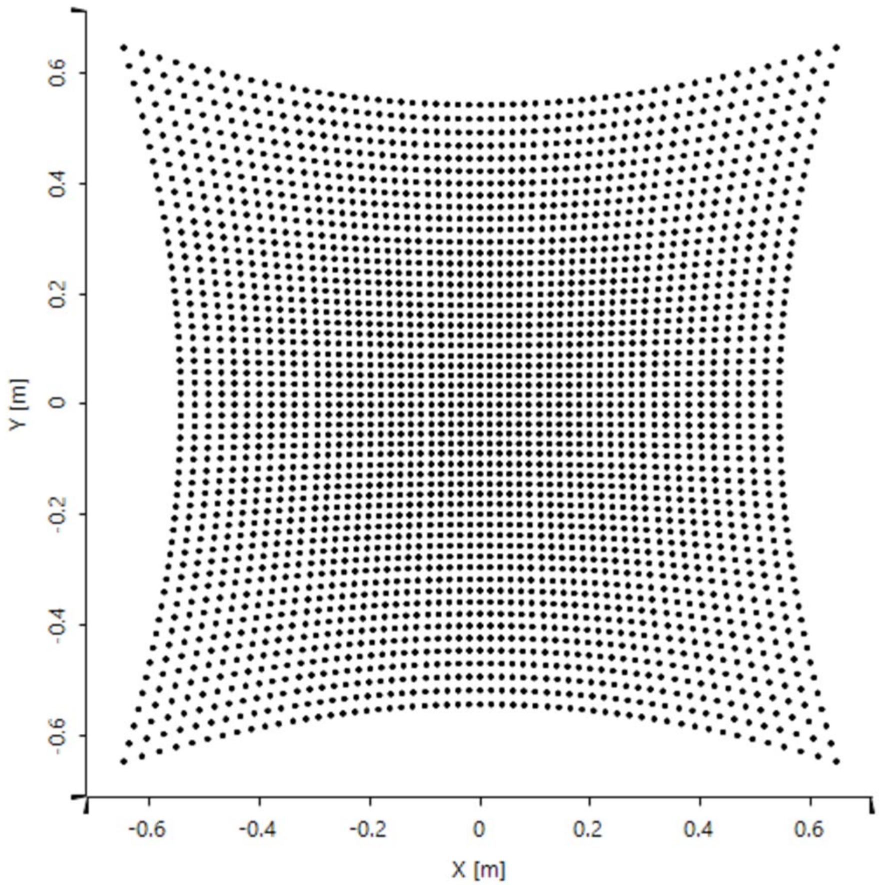
Non-Paraxial Beam Splitter



Results: Spot Diagram

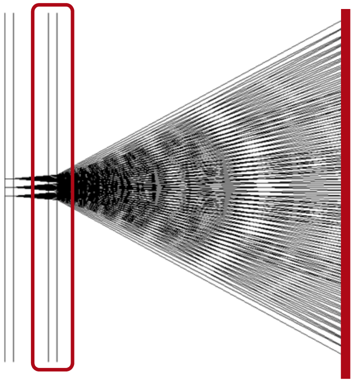


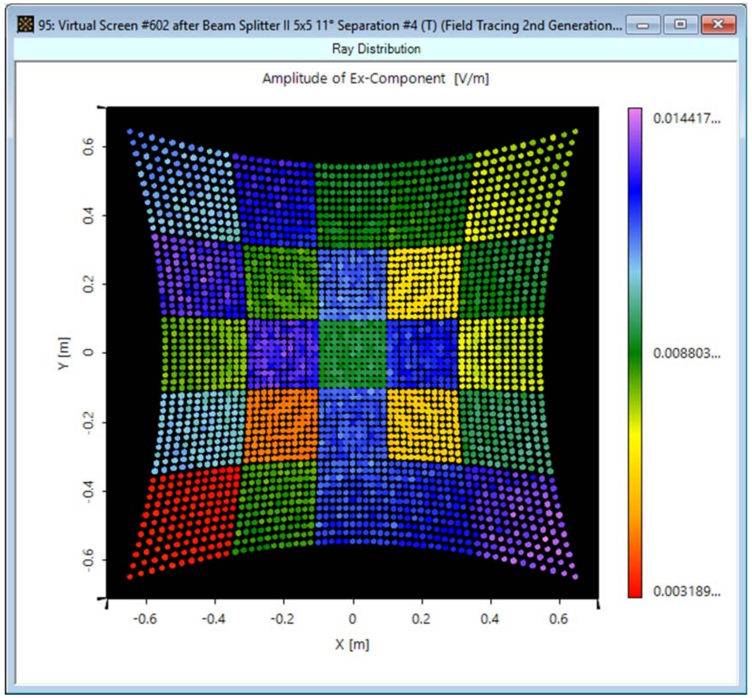
combination of both beam splitter generate **55x55 order** with **55x55° full opening spread**



spot diagram

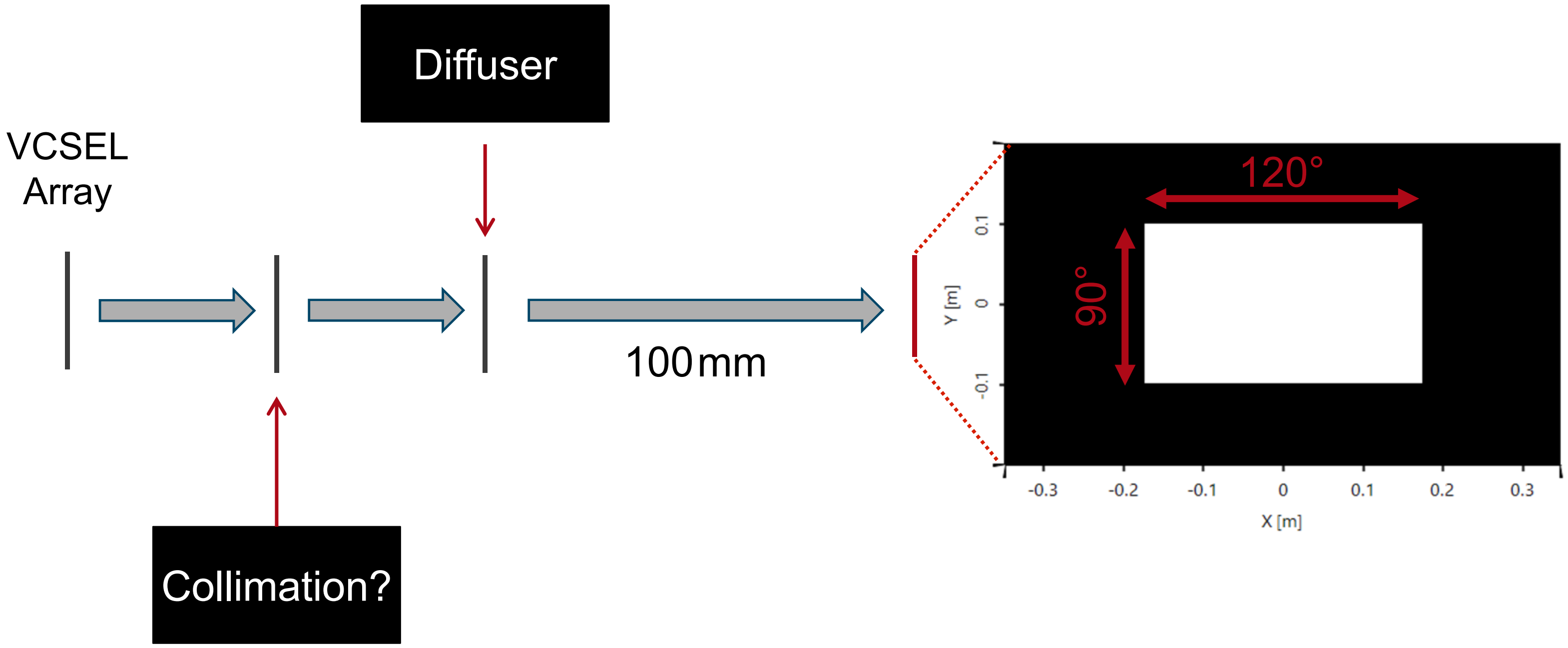
Results: Output Evaluation with FMM





VirtualLab Fusion enables the design and full analysis

Shaping Radiation of VCSEL Array



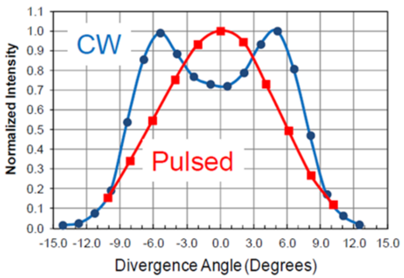
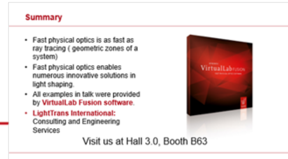
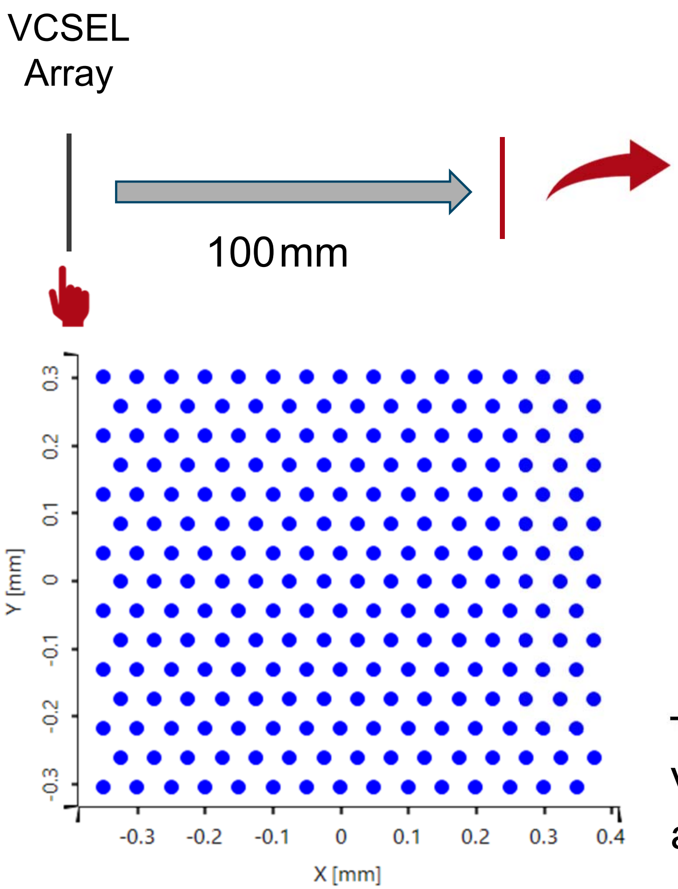
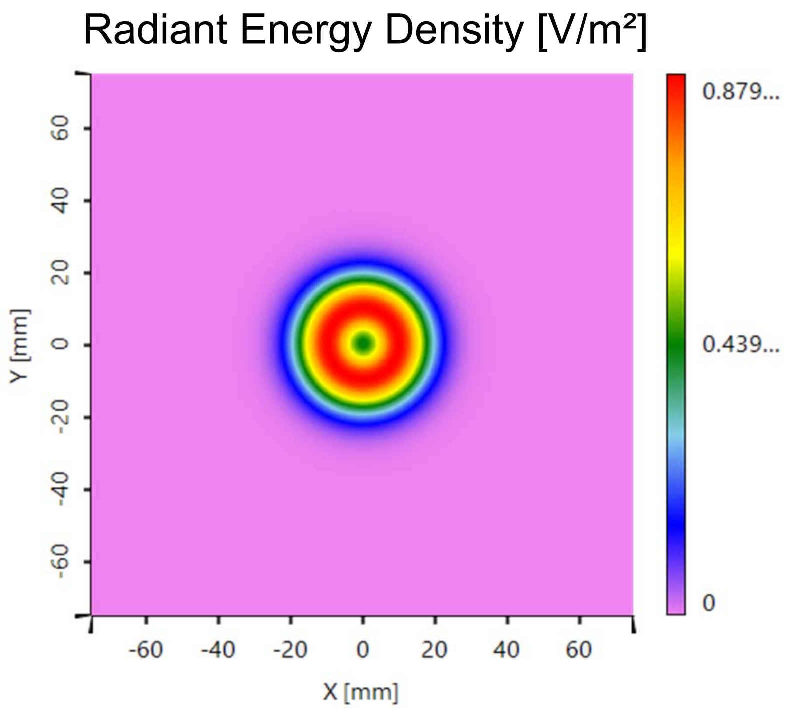


Figure 7 Far field beam profile from a 2D VCSEL array when driven CW and pulsed



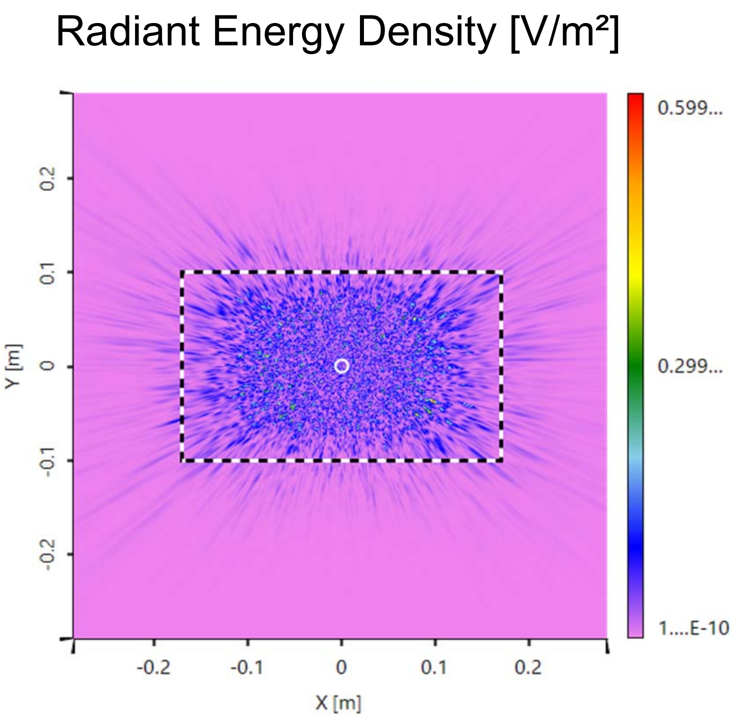
Simulation of a VCSEL Array

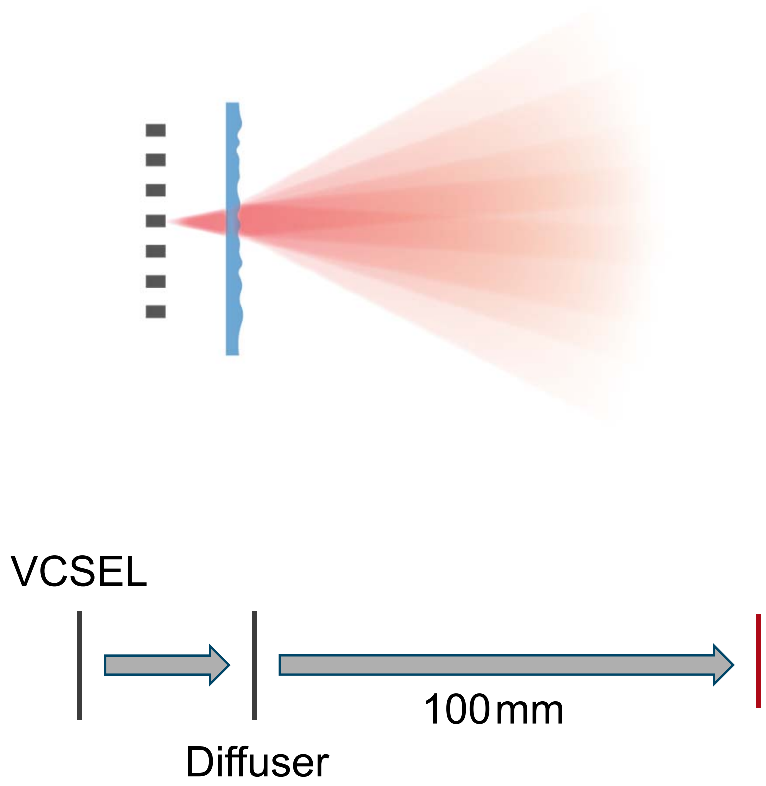




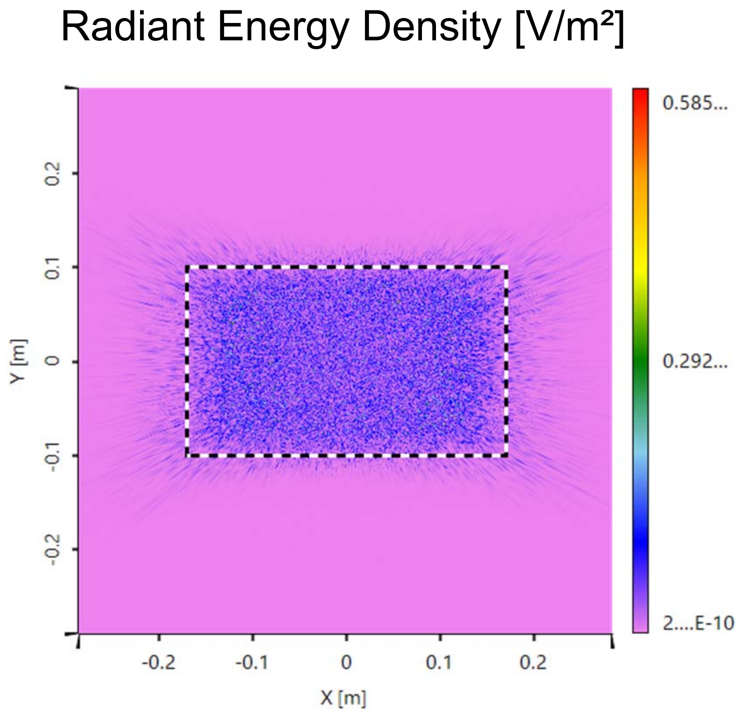
The VCSEL array consist of 15×15 VCSEL with a pitch of 50 µm×50 µm and an angle of 60° for the hexagonal grid.

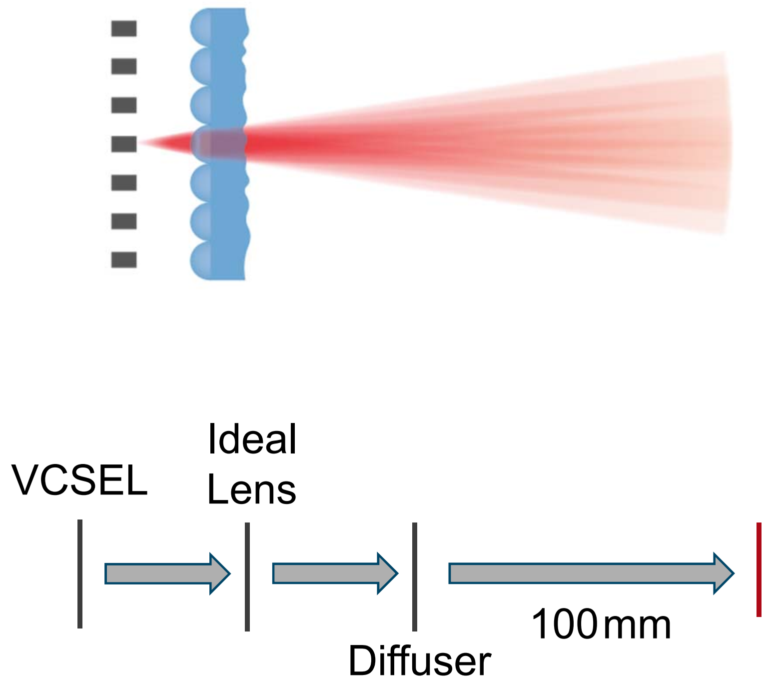
Simulation Result without Collimation



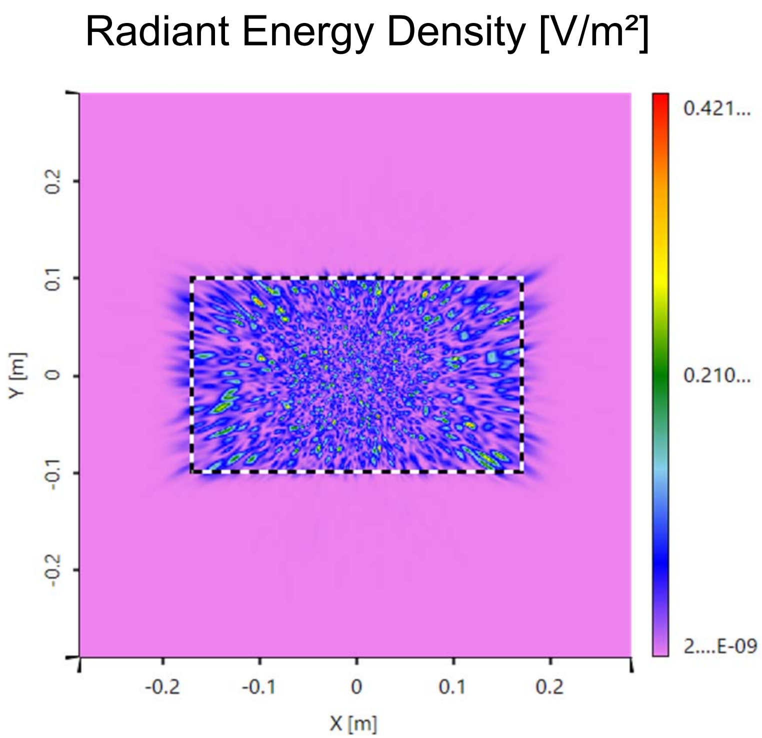


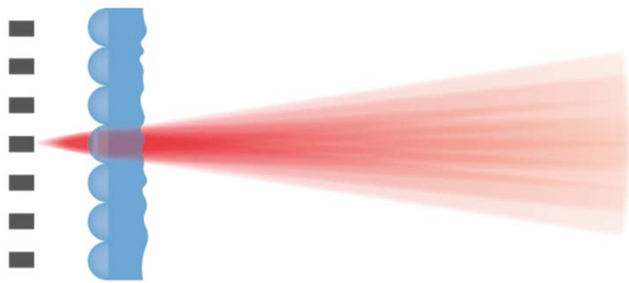
Simulation Result with Collimation (NA 0.12)

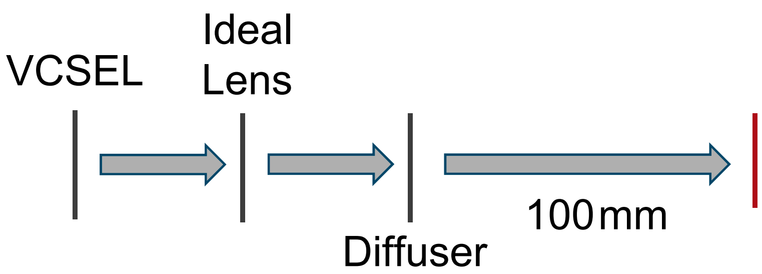




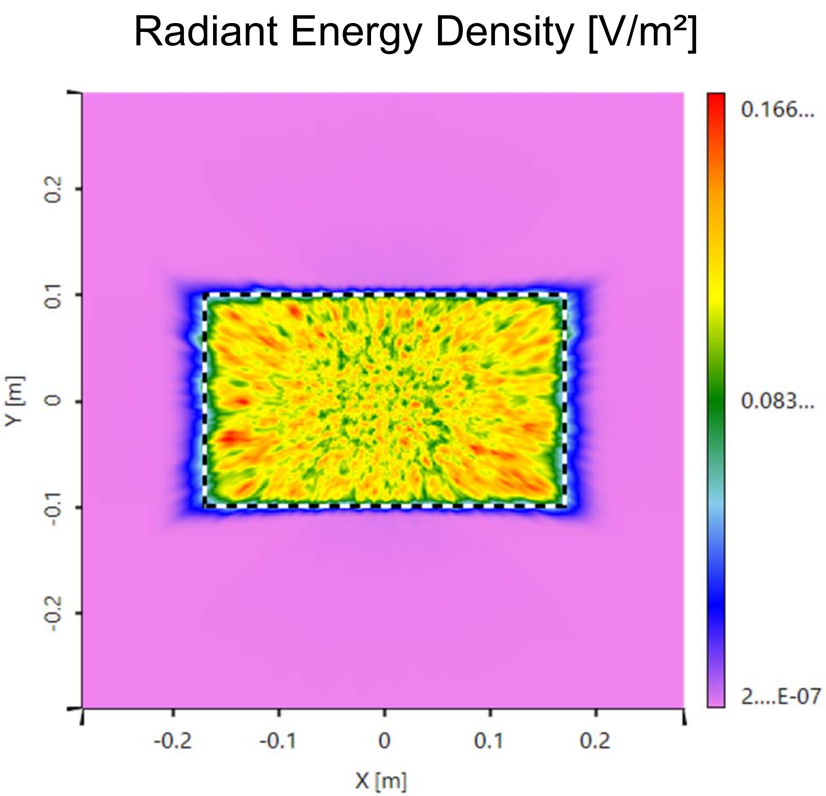
Simulation Result with Collimation (NA 0.24)

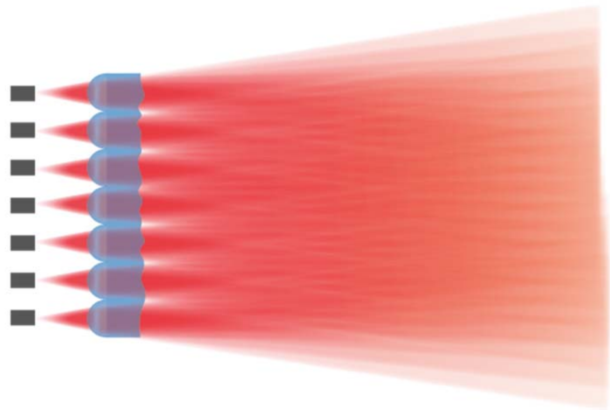


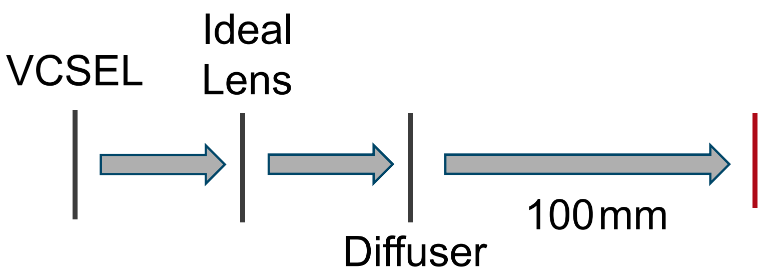




Simulation Result with Collimation (NA 0.24)



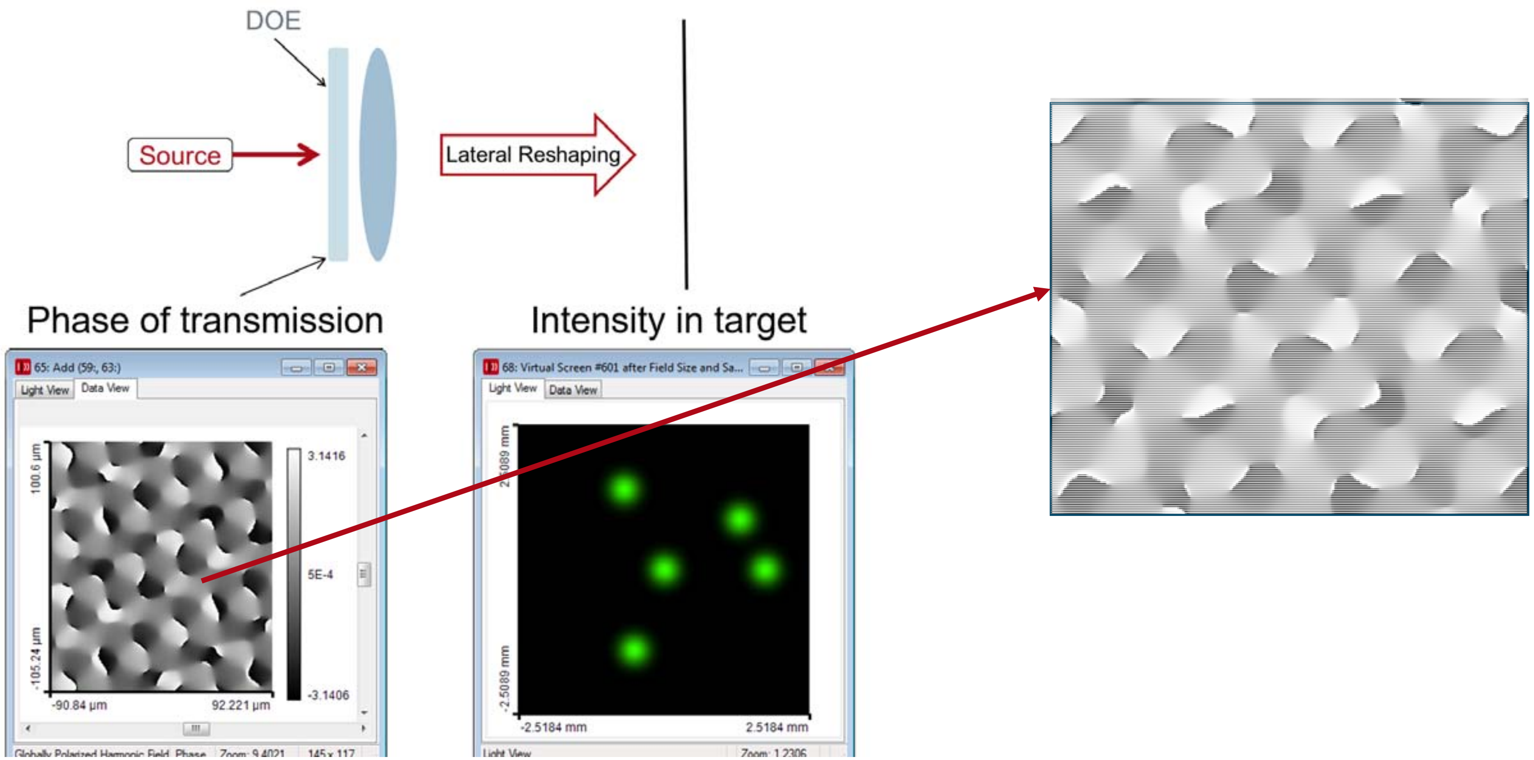




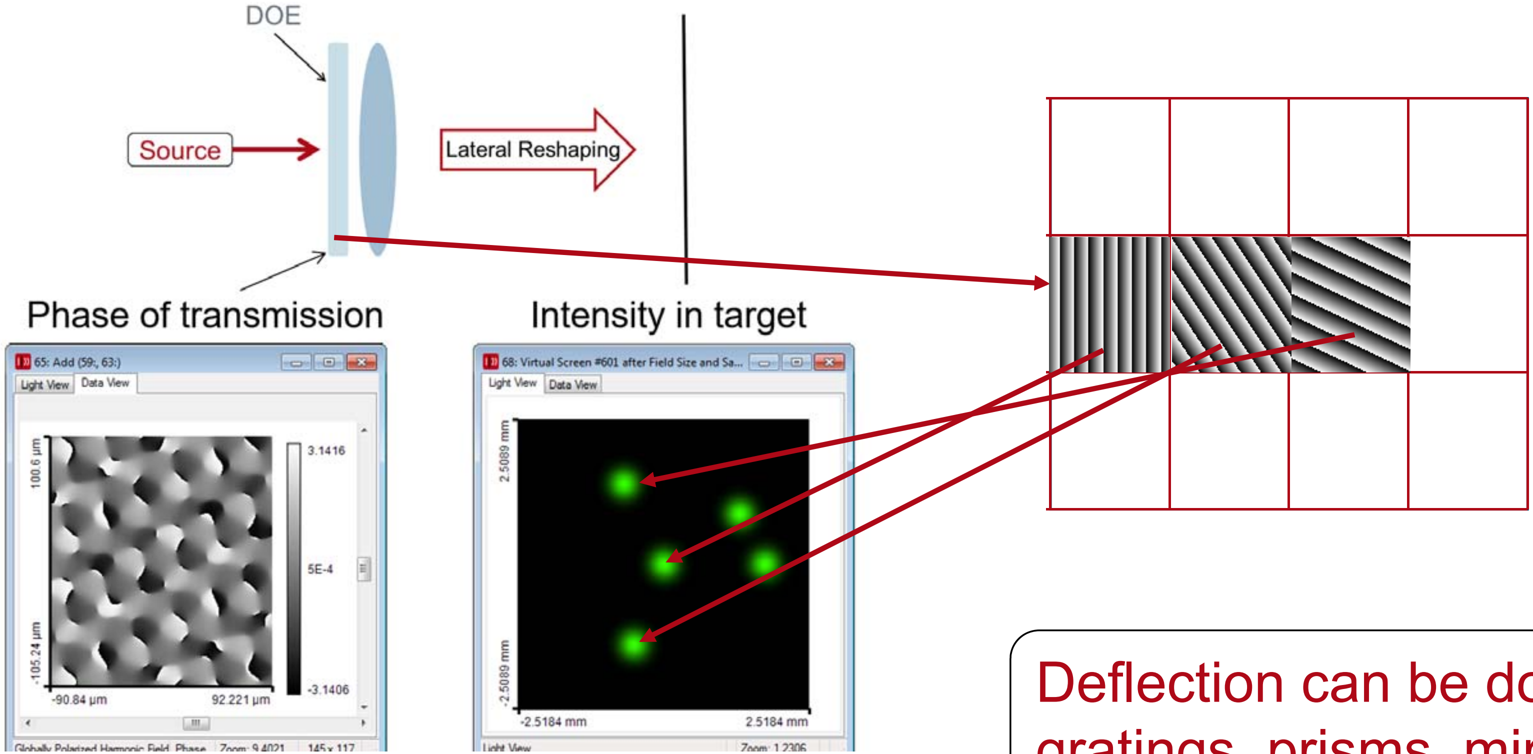
Light shaping by lateral decomposition

Elementary cell array components

Array of Deflectors

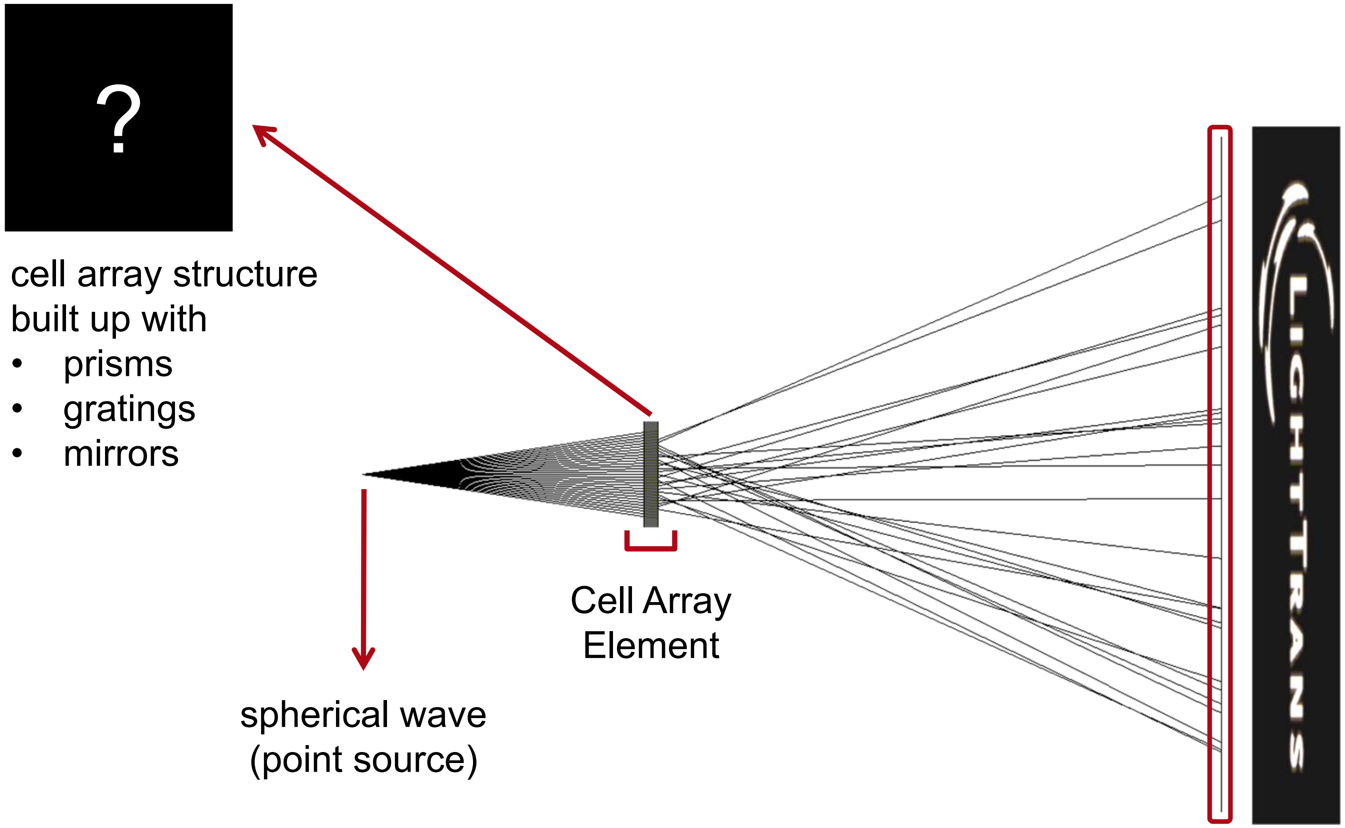


Array of Deflectors

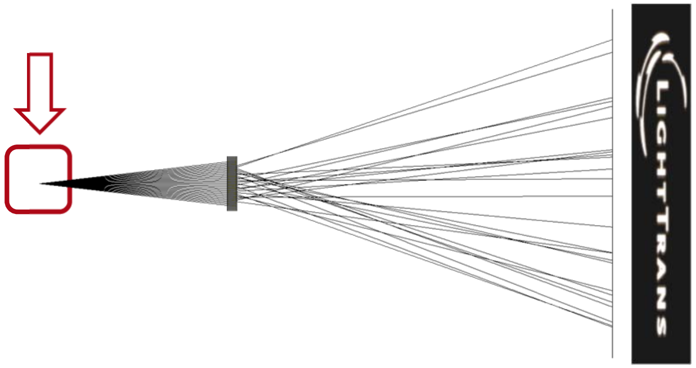


Deflection can be done by gratings, prisms, mirrors.

Task/System Illustration

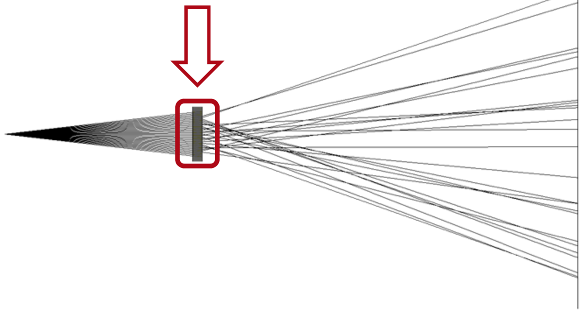


Specification: Light Source



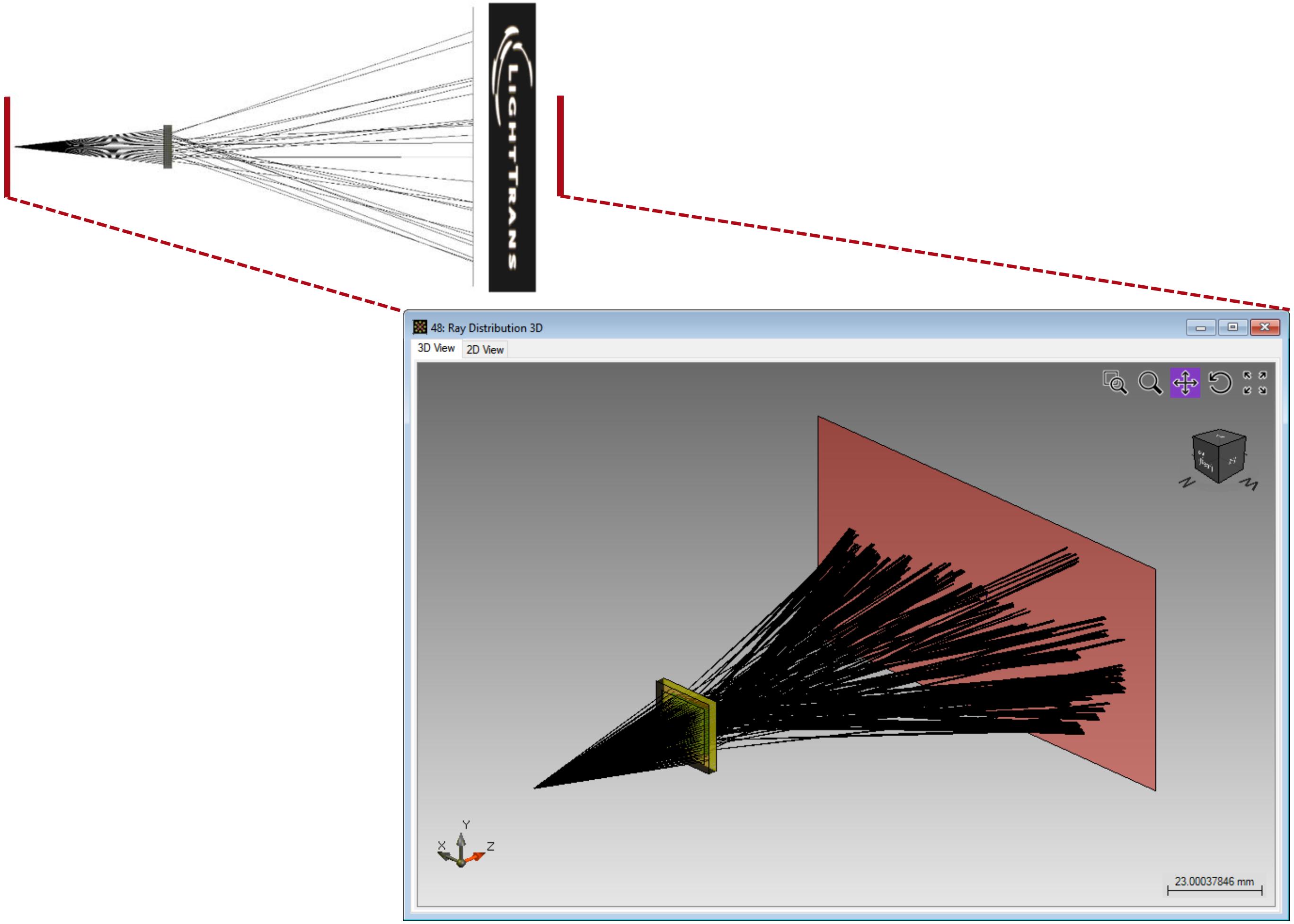
Parameter	Description / Value & Unit
type	RGB LED
emitter size	100x100µm
wavelength	(473, 532, 635)nm
polarization	right circularly polarized light
number of lateral modes	3x3
Total number of lateral and spectral modes	27

Specification: Cell Array

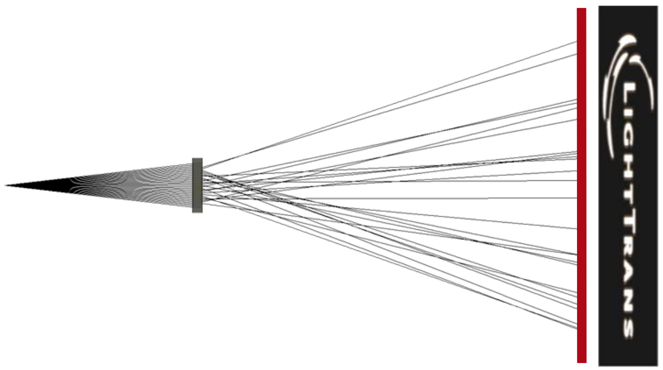


Parameter	Value & Unit
number of cells	100 x 100
cell size	125 x 125 µm
array aperture	12.5 x 12.5 mm

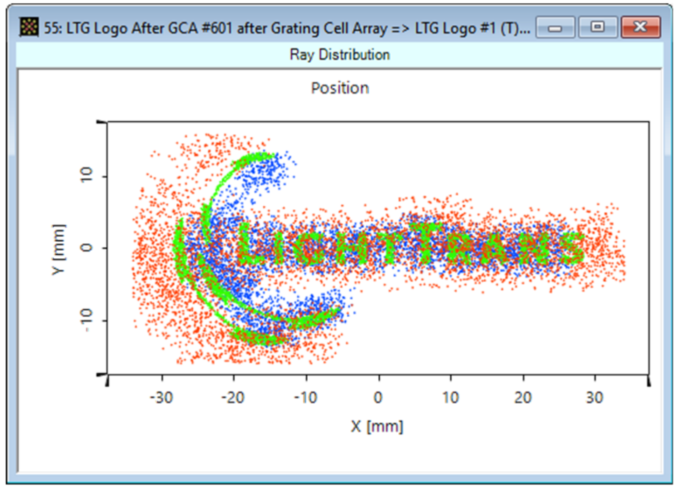
Results: 3D System Ray Tracing



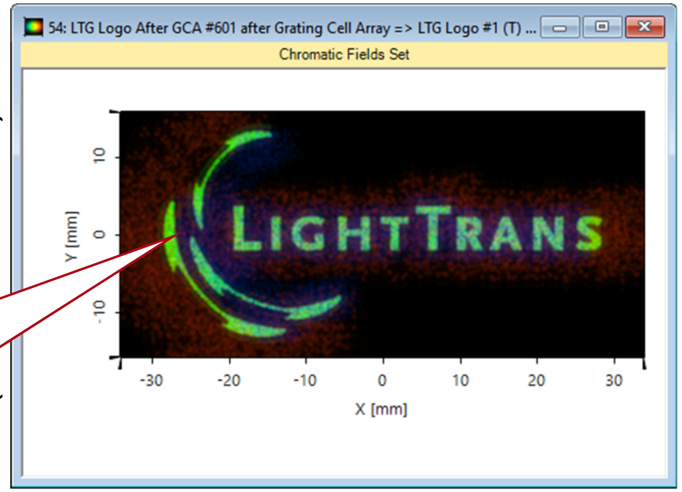
Results: Grating Cells Array



spot diagram

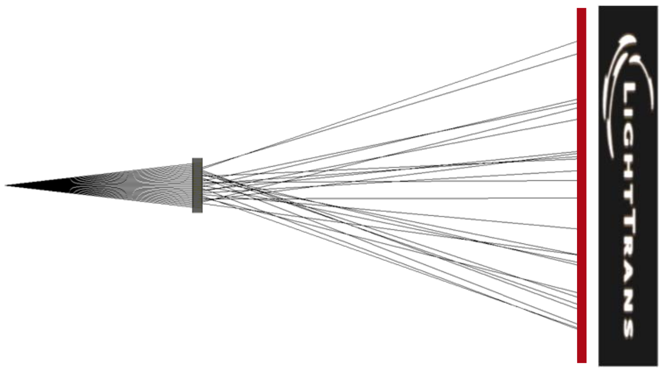


y pattern
lor view)

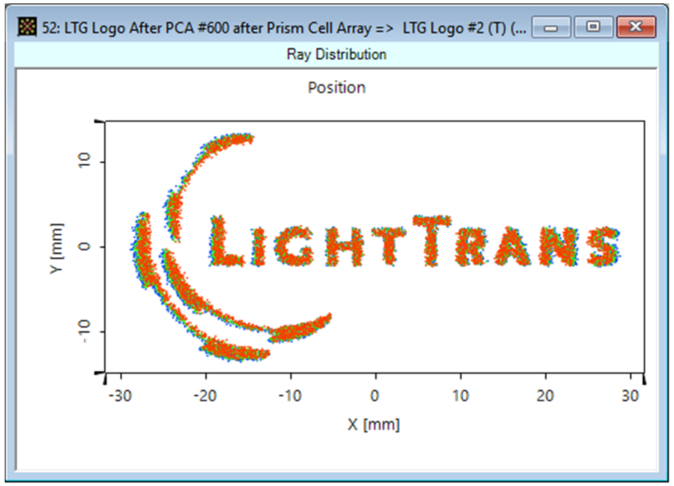


for grating cells array strong dispersion effects occur

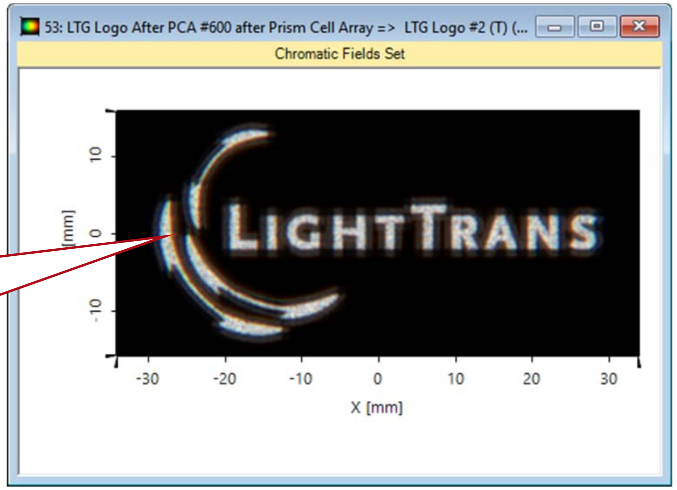
Results: Prism Cells Array



spot diagram

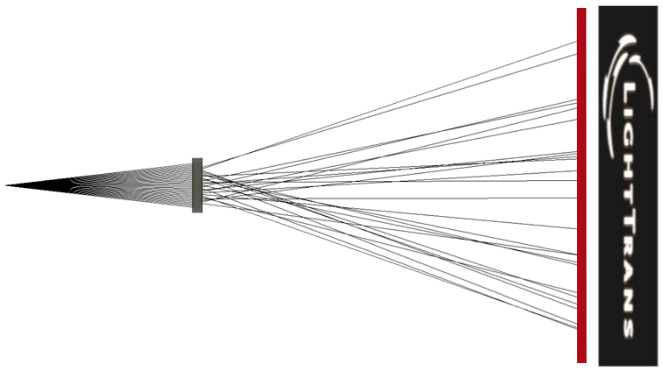


pattern
(real
lor view)

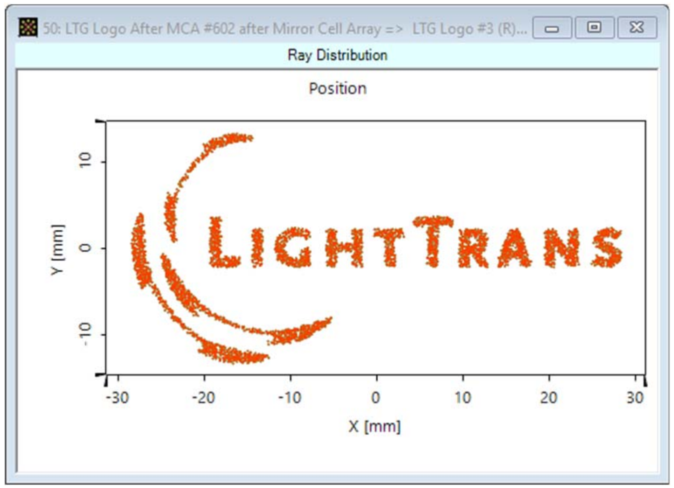


the dispersion is significantly reduced by using prisms

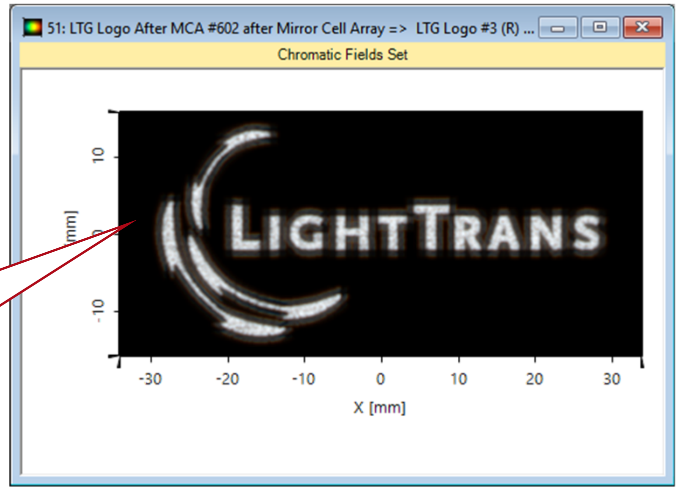
Results: Mirror Cells Array



spot diagram



y pattern
olor view)

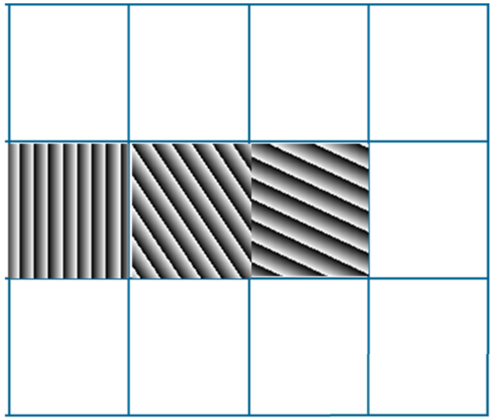


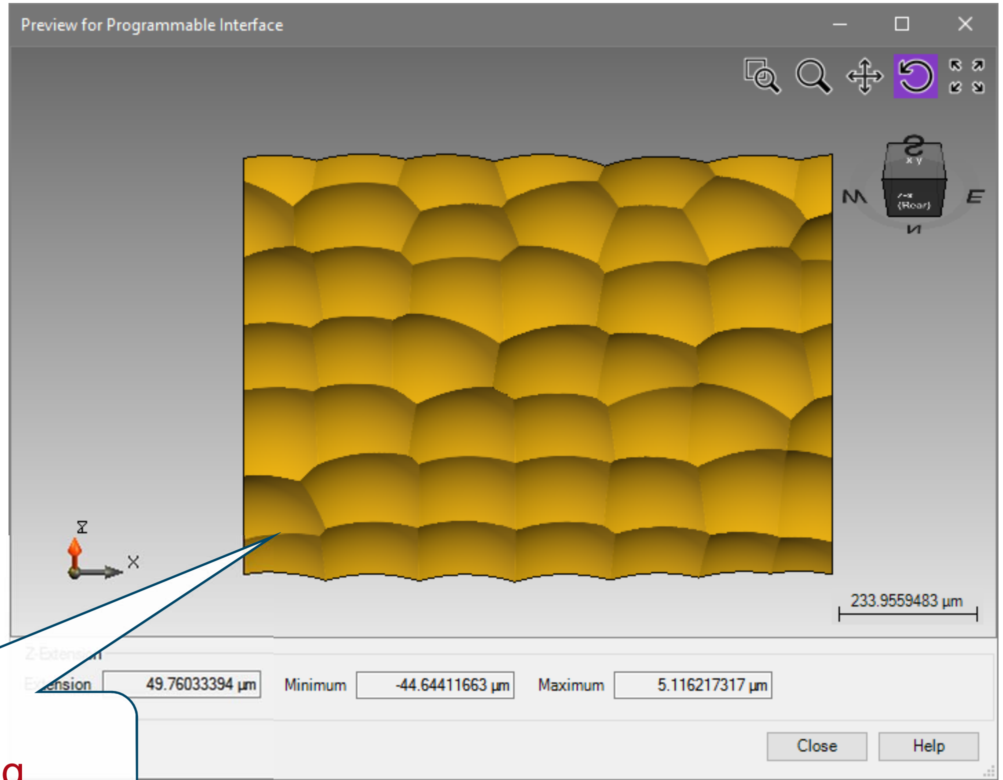
due to reflective approach no dispersion effects occur

Light shaping by lateral decomposition

Lens and freeform array components

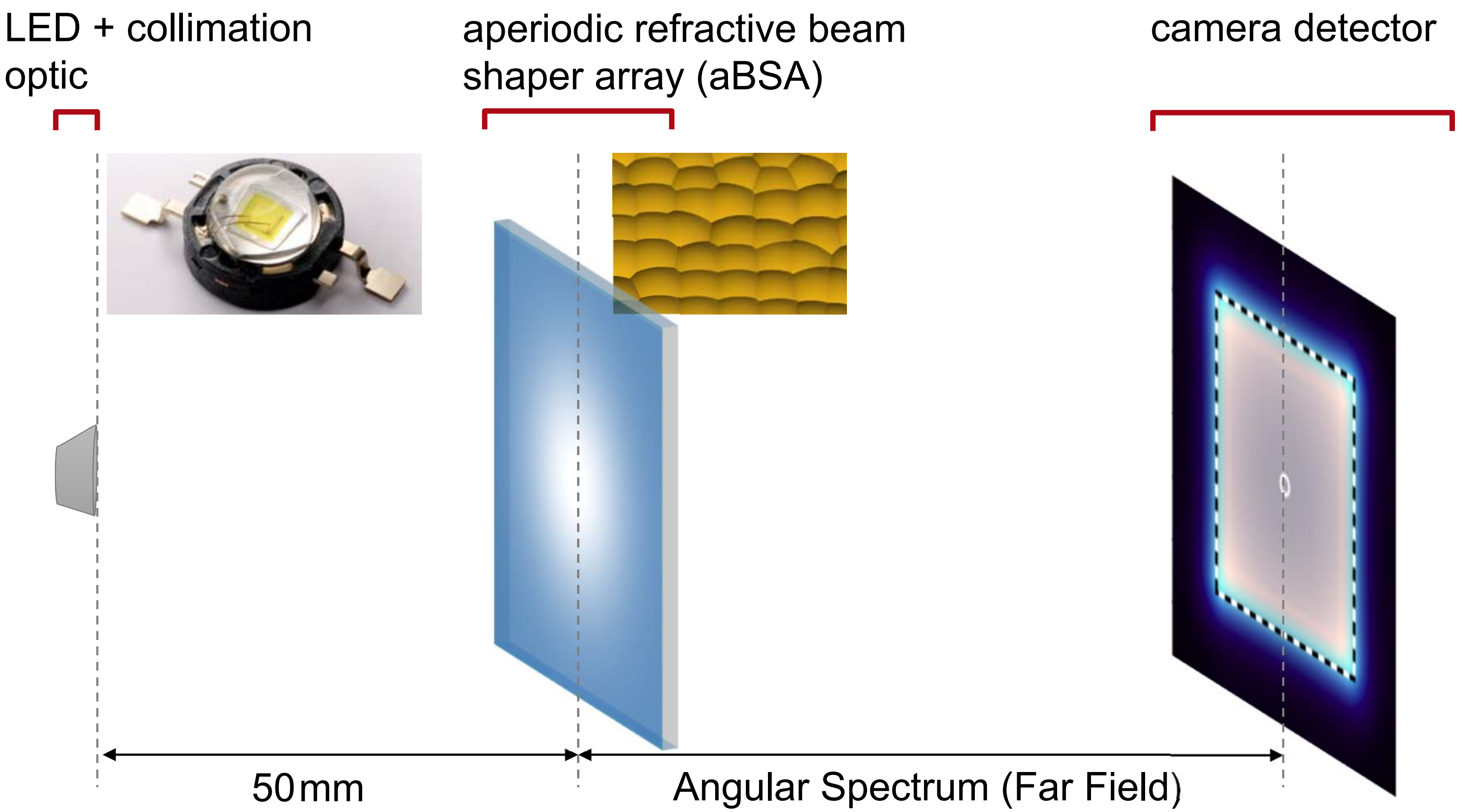
Array of Micro-optical Components





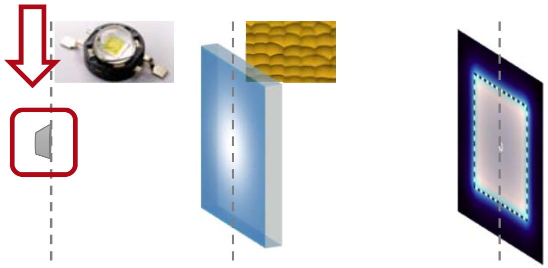
Lateral combination of elementary light shaping solutions

Task/System Illustration



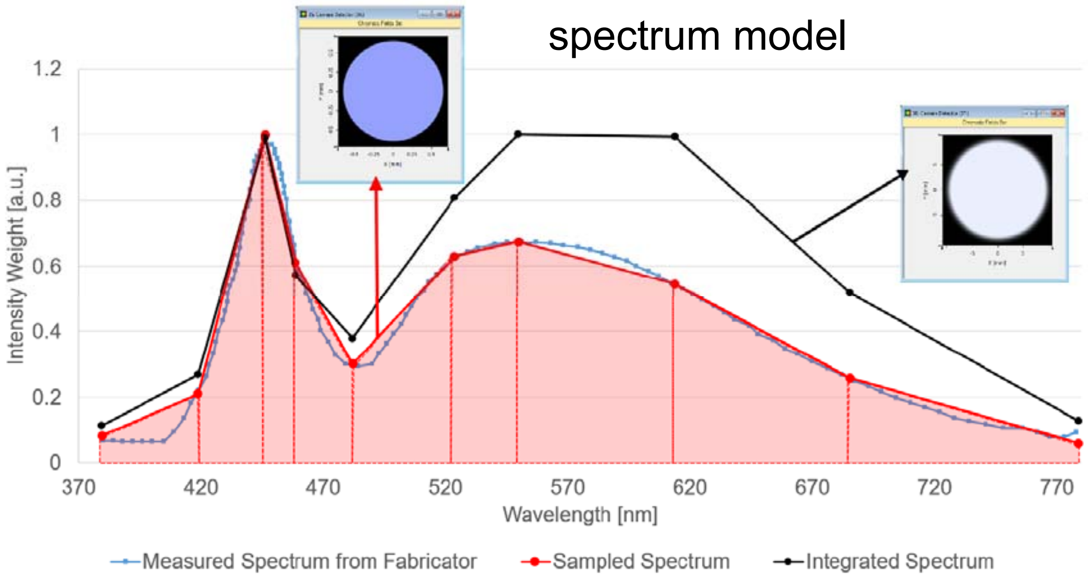
Specs: Light Source

here

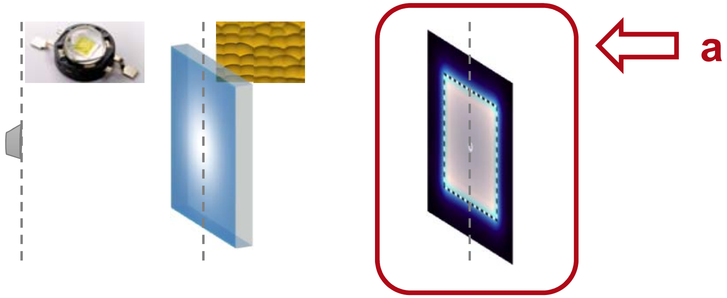


Highlights

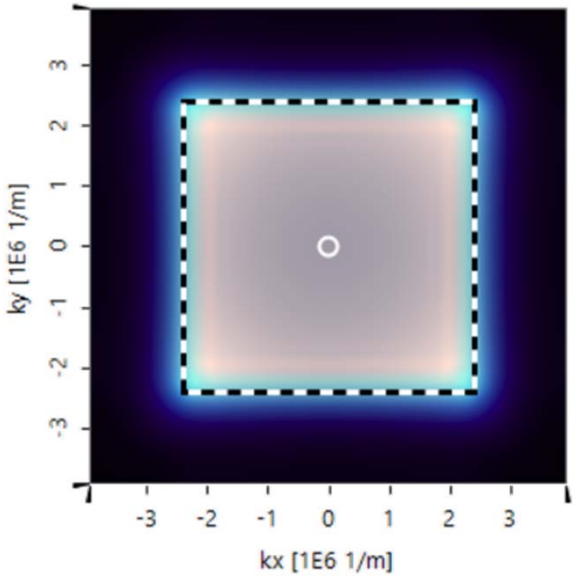
- fast and accurate modeling of a white light LED
- design and analysis an aperiodic refractive beam shaper array to optimize a top hat intensity pattern



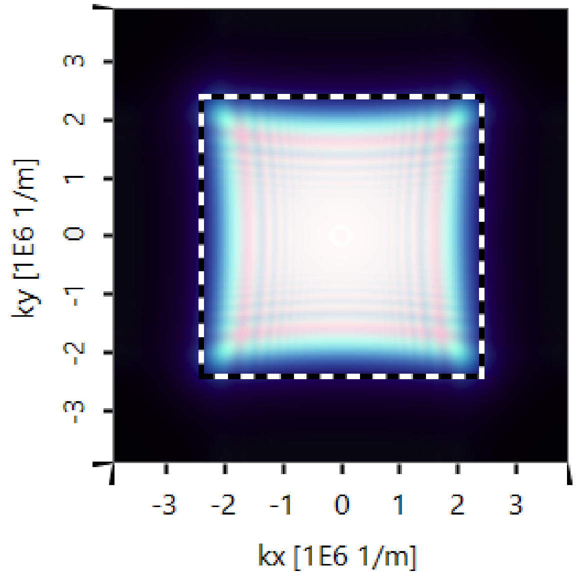
Results: Intensity Pattern (real color view)



aperiodic beam shaper array

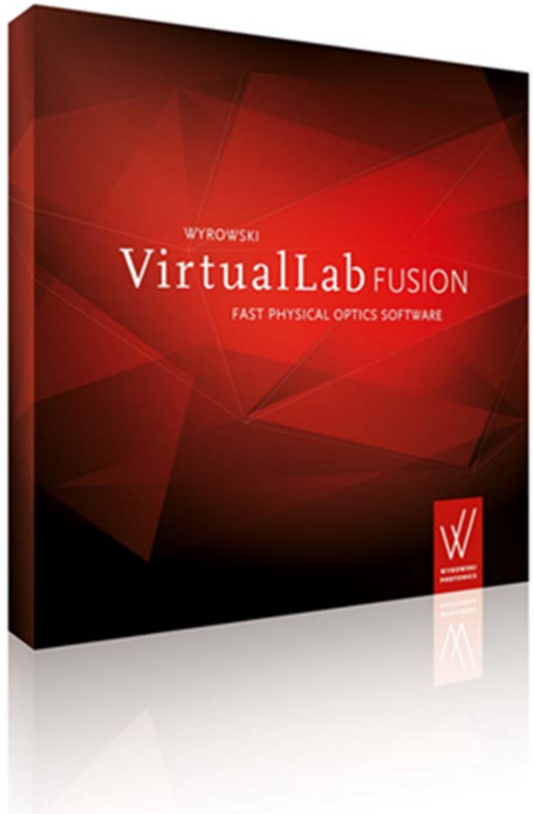


periodic microlens array



Summary

- Fast physical optics is as fast as ray tracing (geometric zones of a system)
- Fast physical optics enables numerous innovative solutions in light shaping.
- All examples in talk were provided by **VirtualLab Fusion software**.
- **LightTrans International:** Consulting and Engineering Services



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