LASYS 2018, 2018-06-06

Tailored Laser Beam Shaping by Freeform and Diffractive Optics

R. Knoth[2], L. Yang[2], C. Hellmann[1], F. Wyrowski[3]

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- [3]University of Jena, Applied Computational Optics

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

WYROWSKI PHOTONICS

Who, Where, What?

WYROWSKI PHOTONICS

LIGHTTRANS

LightTrans

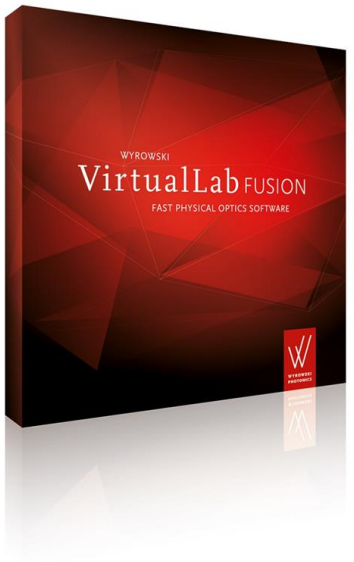
- Distribution of VirtualLab Fusion, together with distributors worldwide
- Technical support, seminars, and trainings
- Engineering projects

Who, Where, What?

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

Hall 4, Booth 4B71.1

LIGHTTRANS



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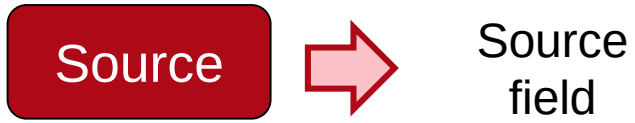
Light Shaping

… from a physical-optics perspective

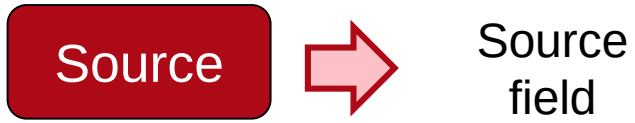
Light Shaping Task



Source field

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

Light Shaping Task: Source Modes



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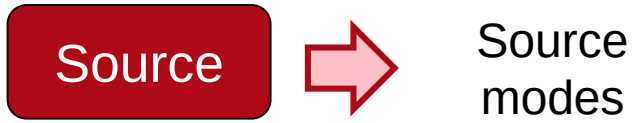
- Any source field can be decomposed into harmonic and mutually incoherent modes

Light Shaping Task: Source Modes



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

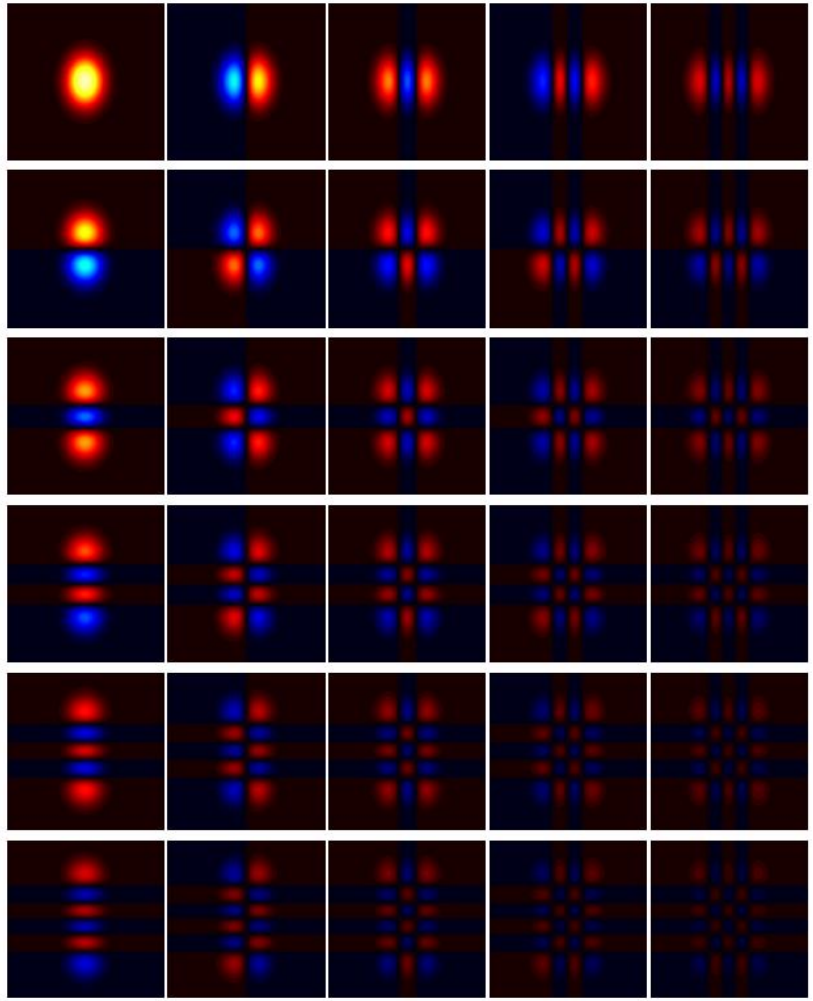
- Any source field can be decomposed into harmonic and mutually incoherent modes
  - Gaussian modes

Light Shaping Task: Gaussian Modes (Hermite)

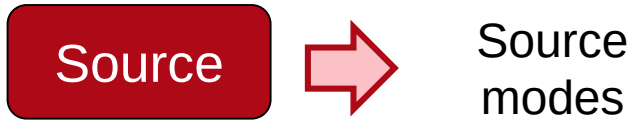
Source

Source modes

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



Light Shaping Task: Source Modes



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

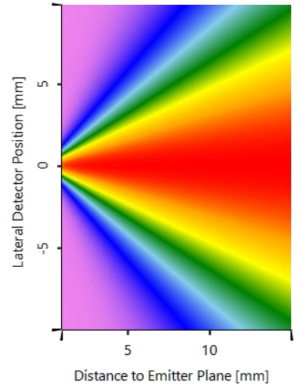
- Any source field can be decomposed into harmonic and mutually incoherent modes
  - Gaussian modes
  - Plane wave modes
  - Shifted modes, e.g.
    - Spherical wave
    - Lambertian mode

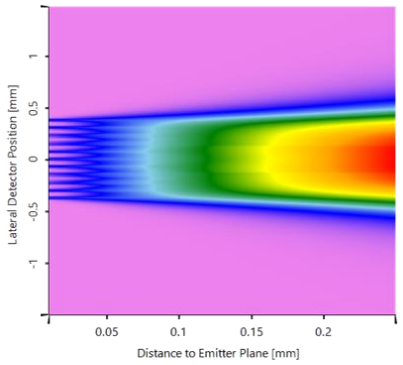
Light Shaping Task: Source Modes

Source → Source modes

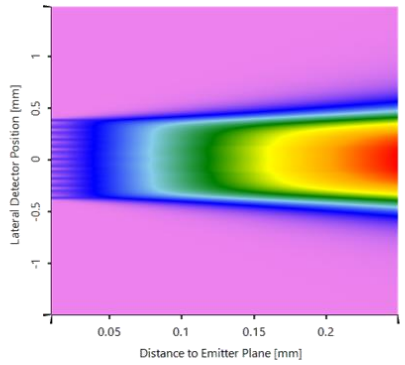
- Laser
- Laser diode
- LED
- OLED
- Lamp
- Natural light

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

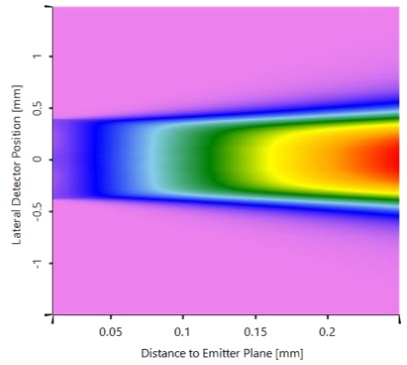




11 Modes

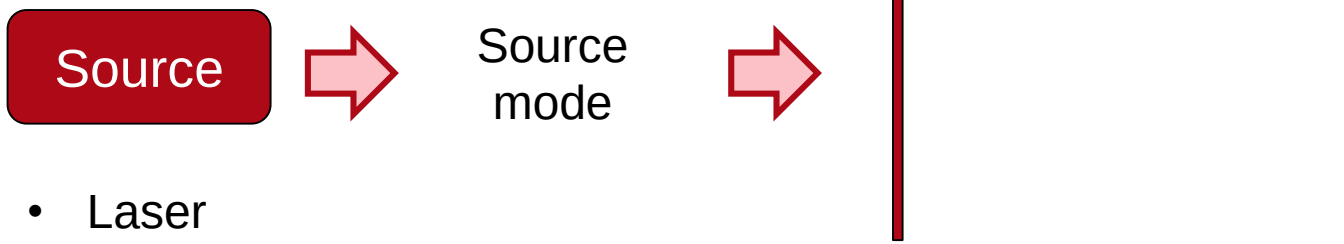


21 Modes



31 Modes

Light Shaping Task



- Laser
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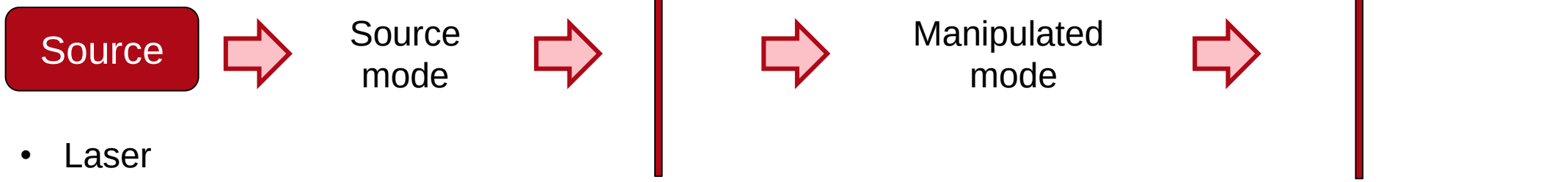
- Natural light

Manipulation of

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

Light Shaping Task

Parametric Optimization?
Optional as final step!



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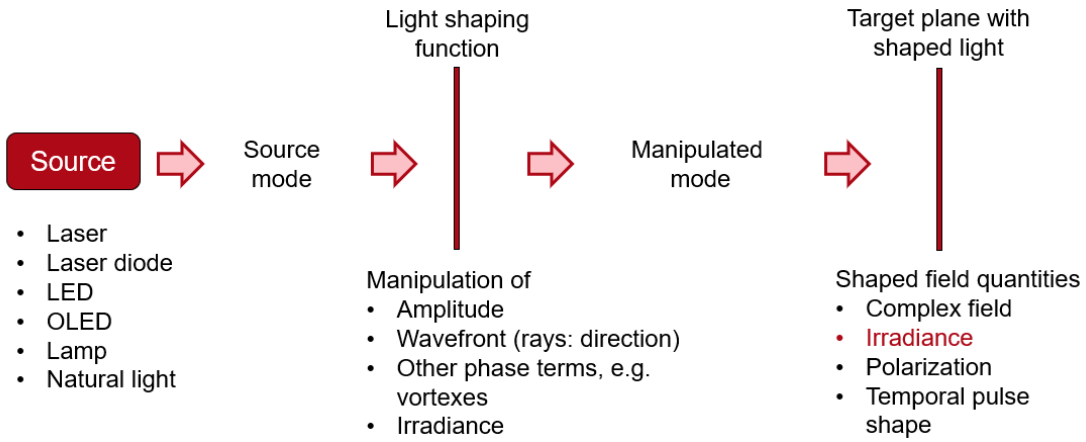
Manipulation of
- Amplitude
- Wavefront (rays: direction)
- Other phase terms, e.g. vortexes
- Irradiance

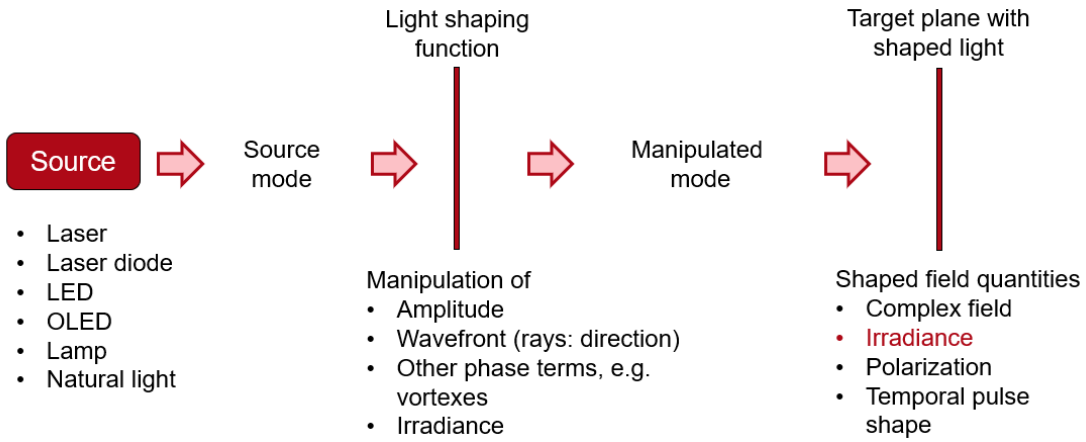
Shaped field quantities
- Complex field
- Irradiance
- Polarization
- Temporal pulse shape

Light Shaping Design



We need to answer the following questions:

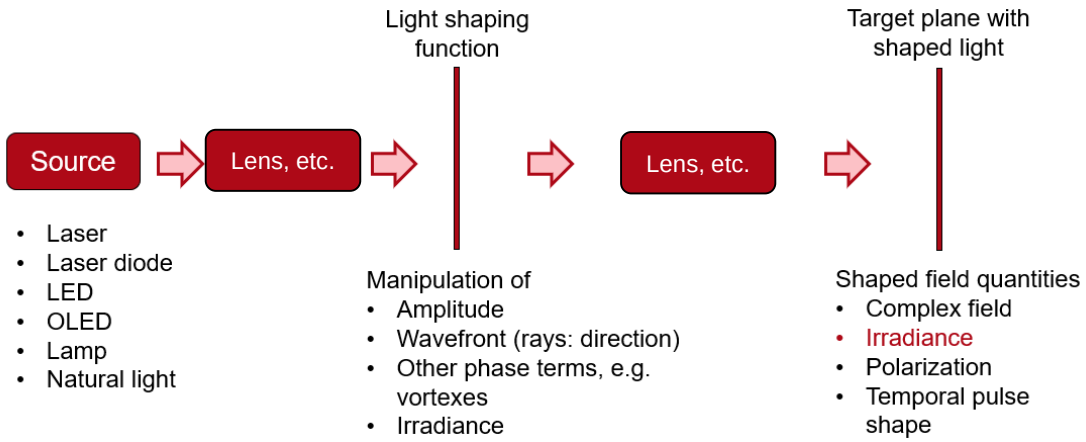
Light Shaping Design: Functional



We need to answer the following questions:

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

Light Shaping Design: Functional

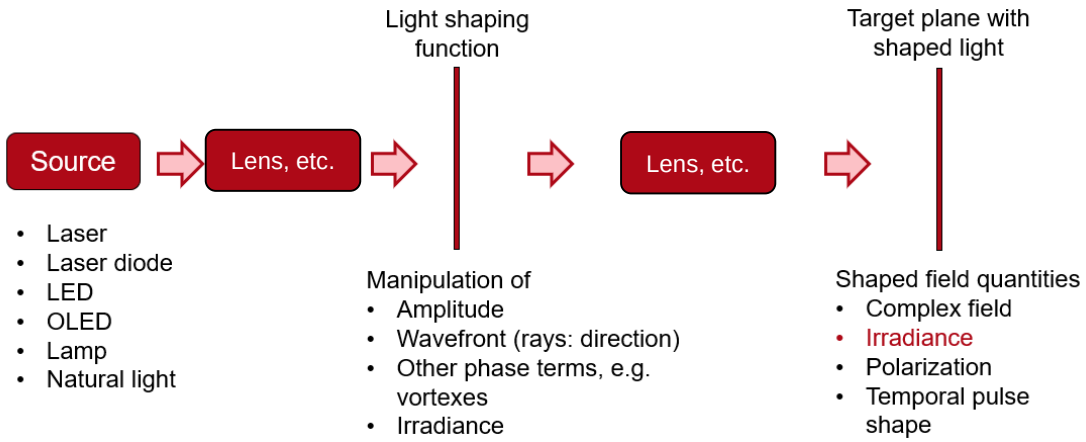


We need to answer the following questions:

- 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 the **functional design**!



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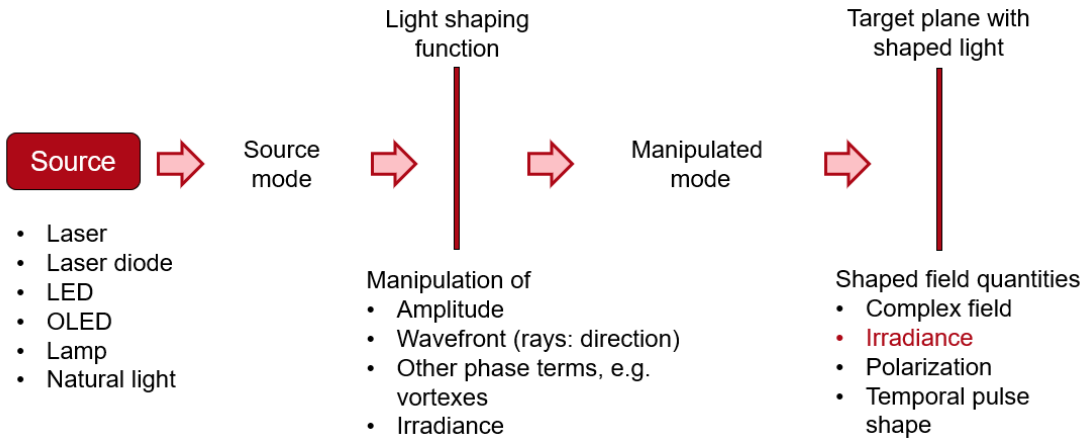
Light Shaping Design: Structural



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

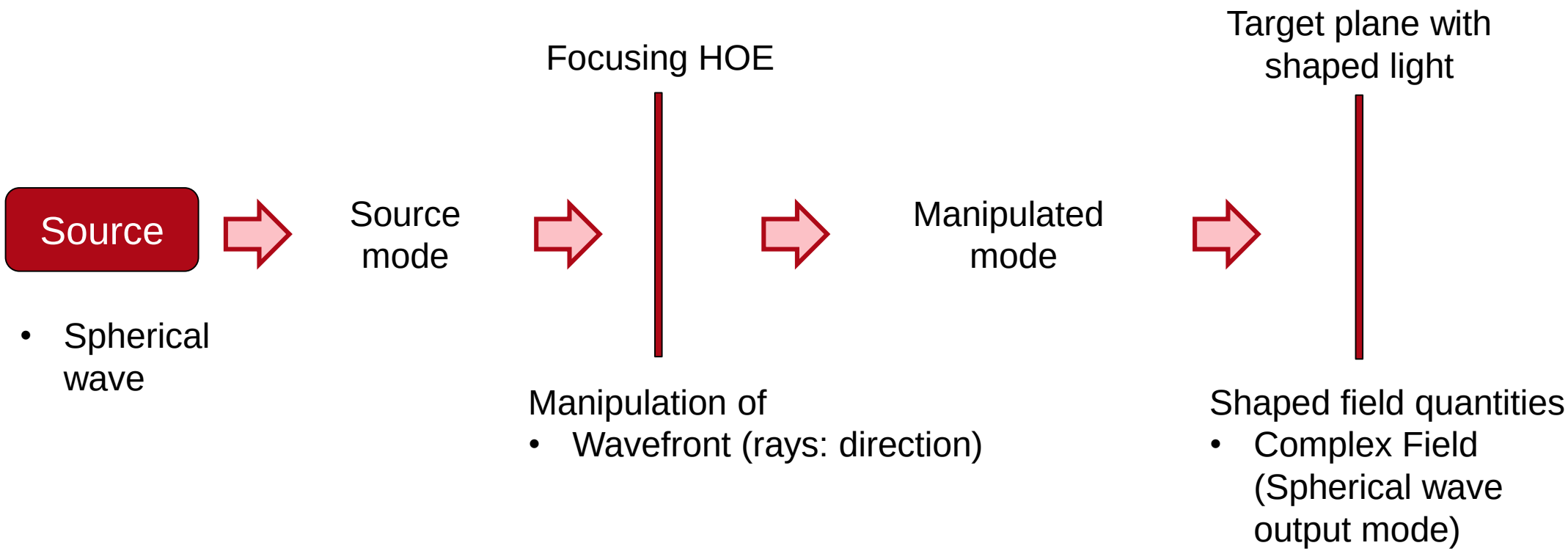
We need to answer the following questions:

- 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

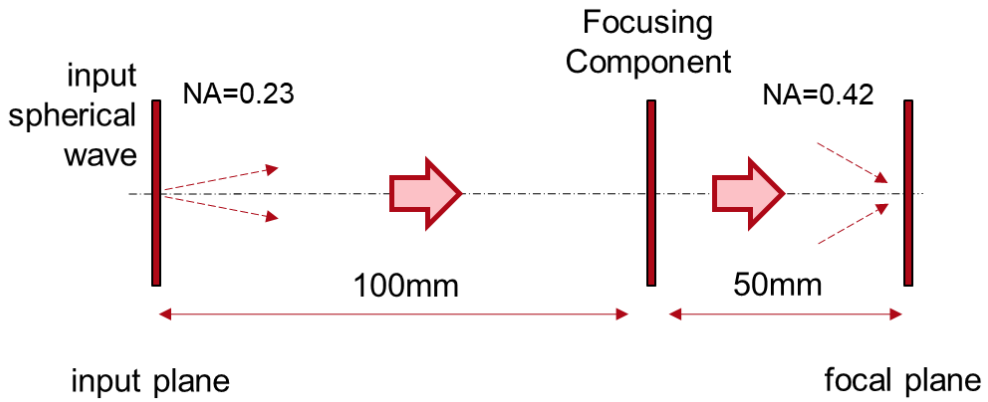
Example 1: Wavefront Control

Design of an high-NA focusing holographic optical element (HOE)

Light Shaping Task



Light Shaping Task



We need to answer the following questions:

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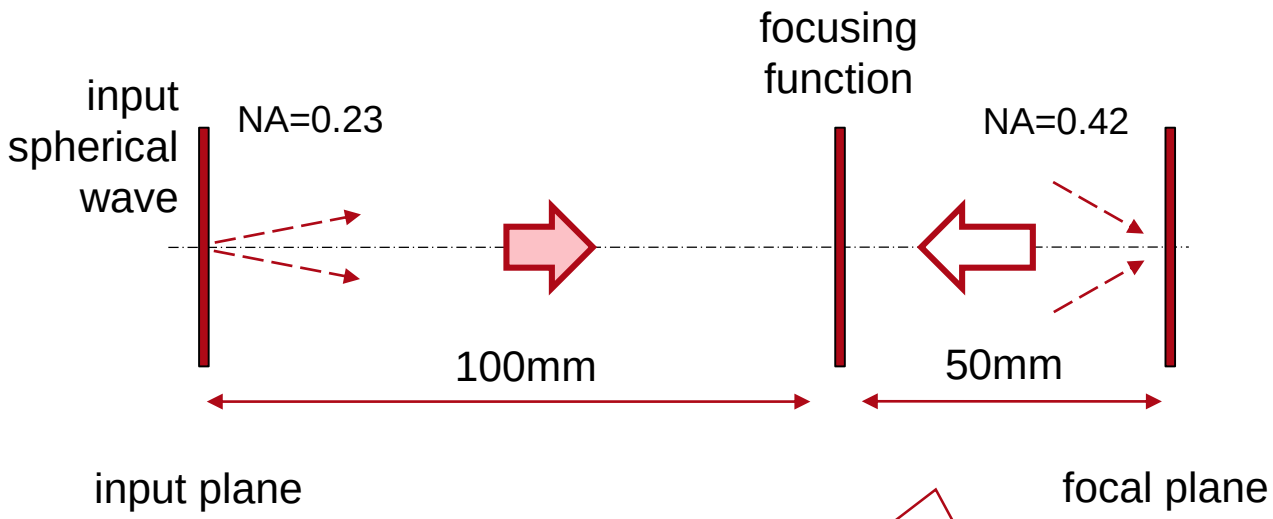
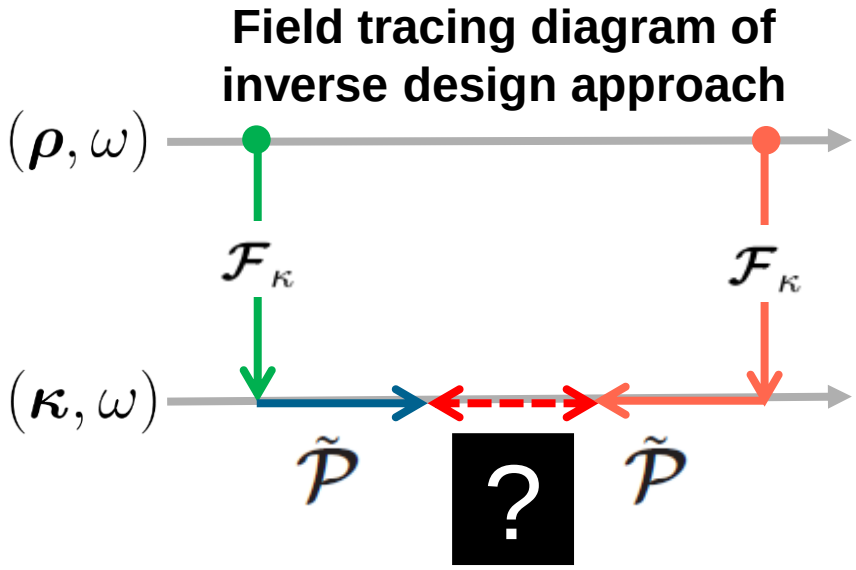
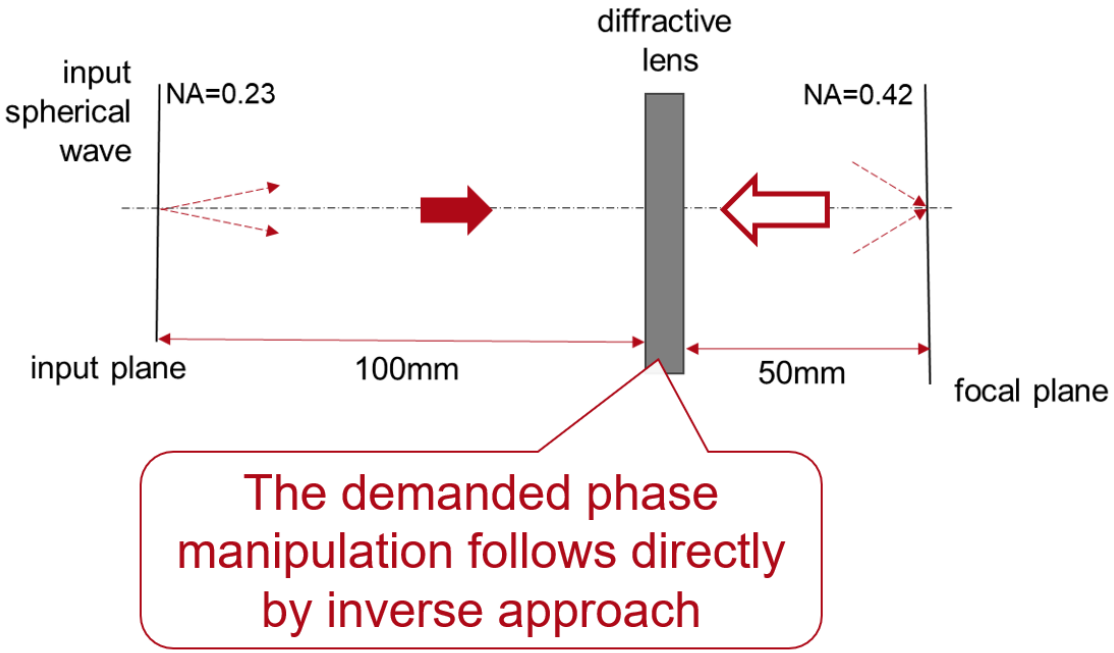
Light Shaping Design: Functional



The demanded phase manipulation follows directly by inverse approach



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?
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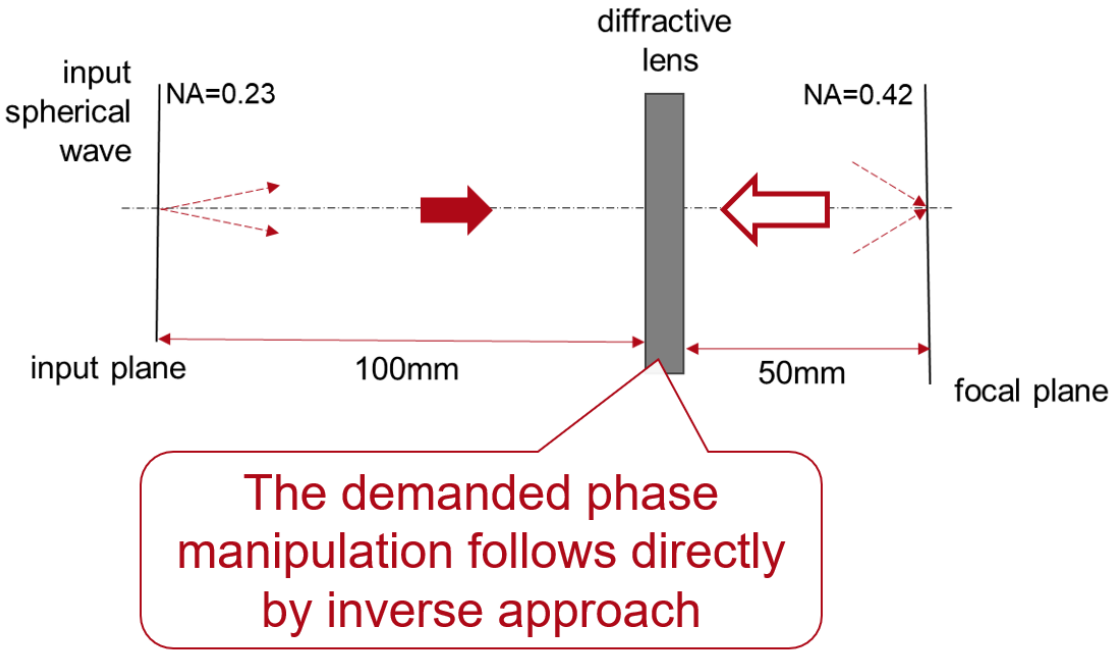
Light Shaping Design: Structural



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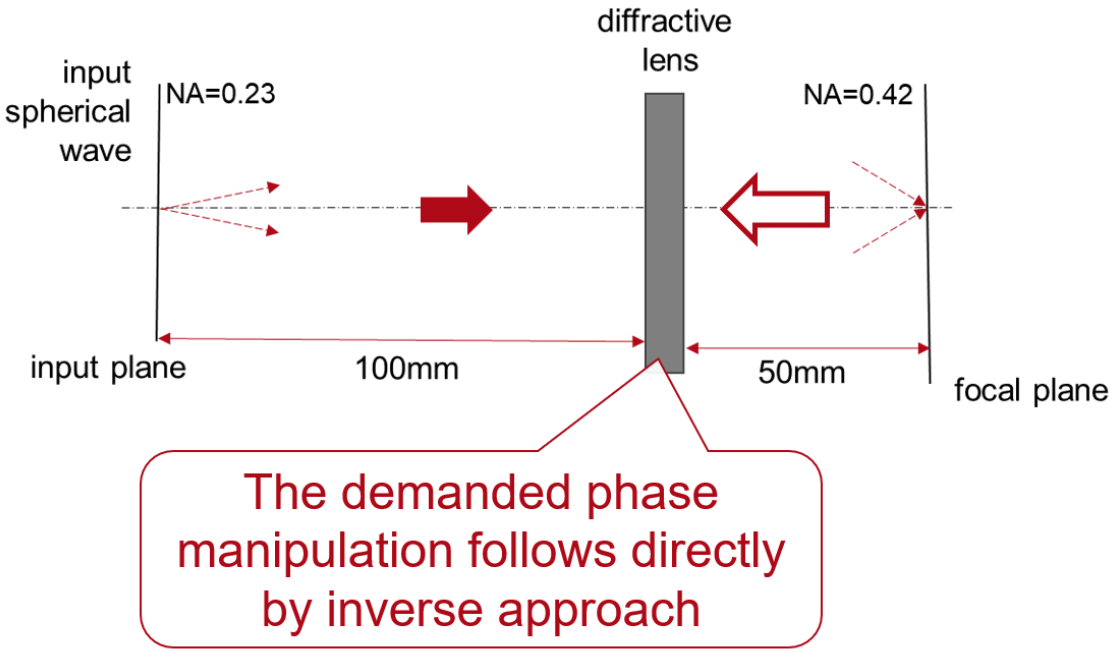

- Local periods of diffractive lens follow directly from phase design in functional design step.

We need to answer the following questions:

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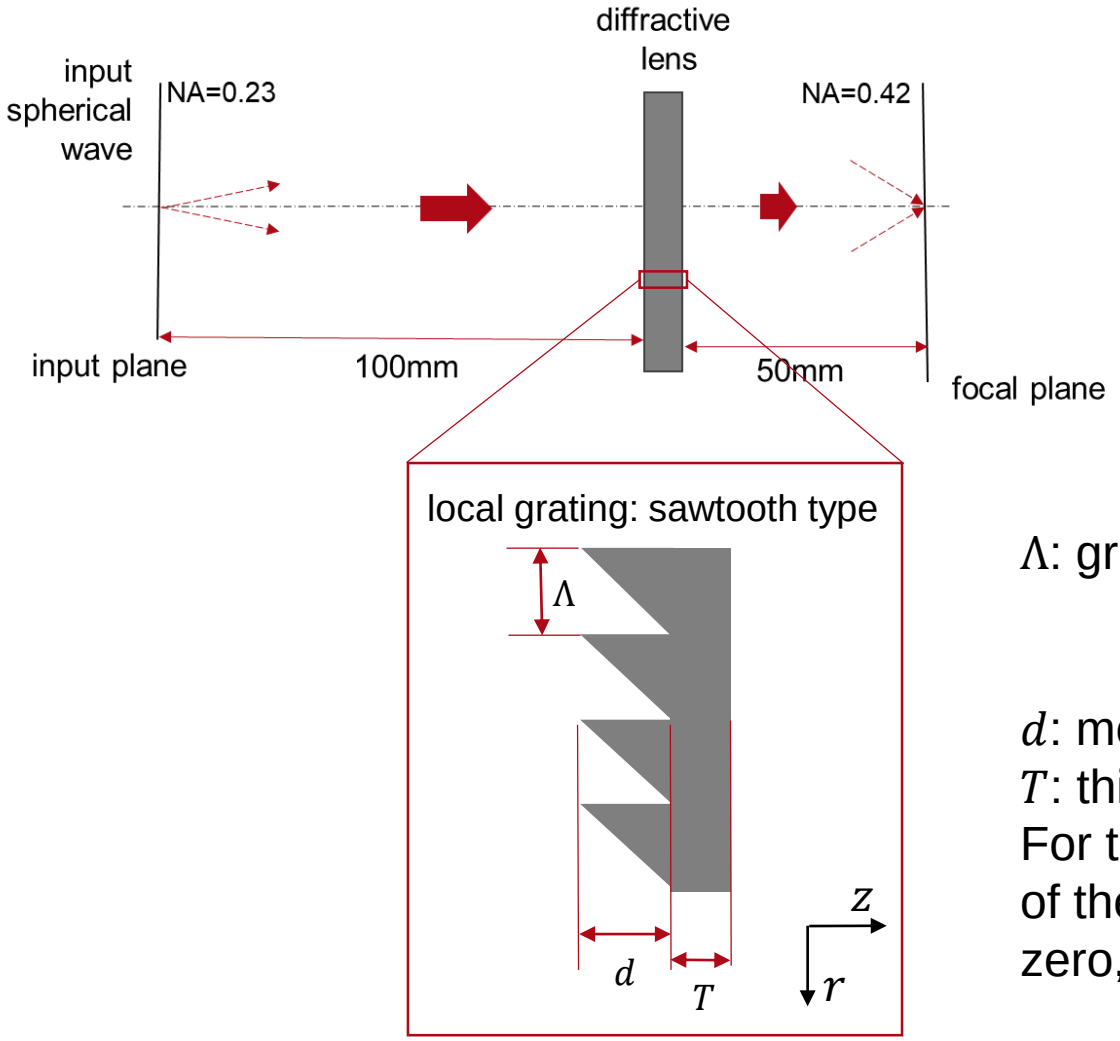
  - GRIN components
  - Metasurfaces

Light Shaping Design: Diffractive Lens (HOE)



Λ: grating period

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

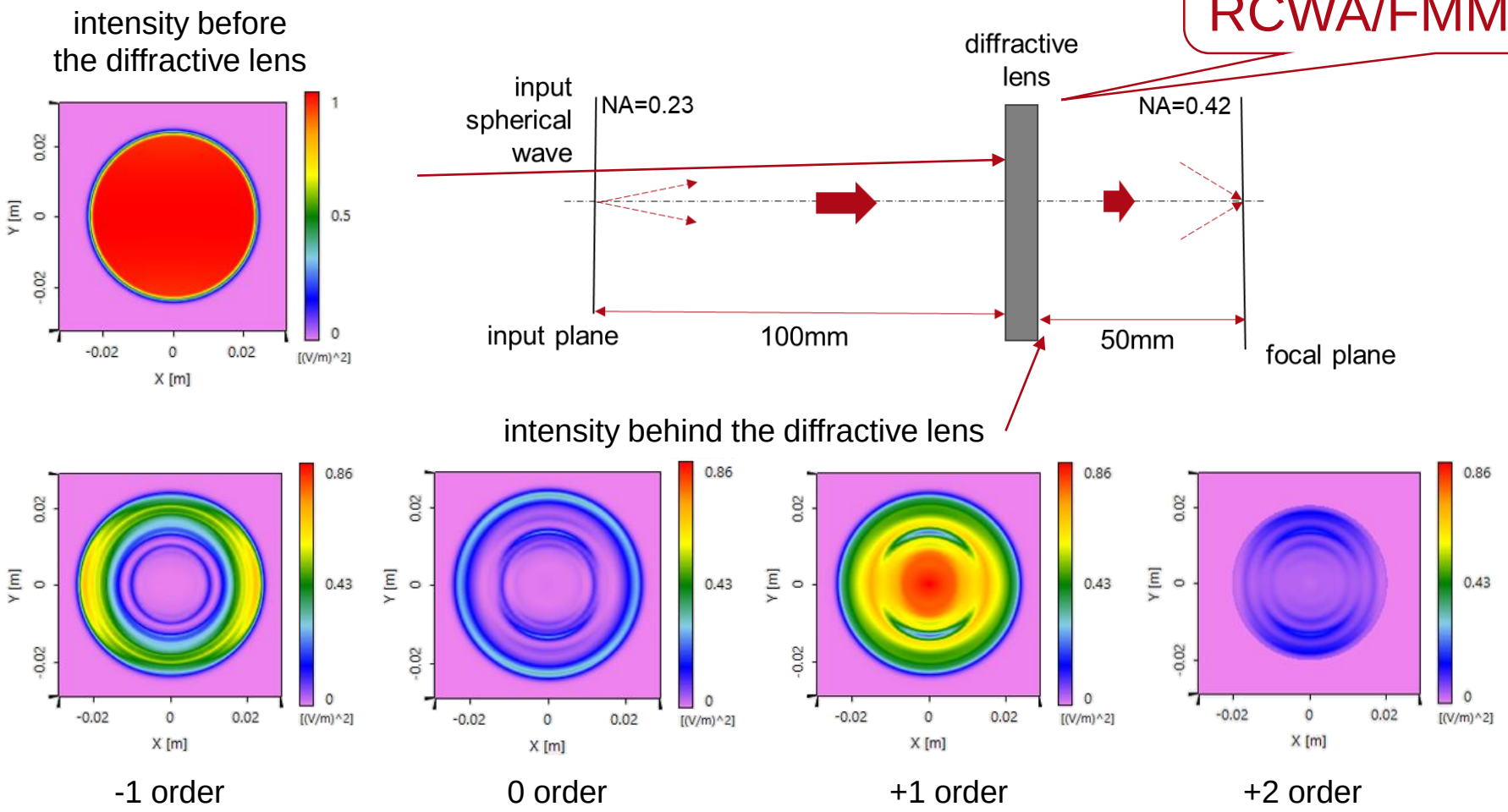
d: modulation depth

T: thickness of base block.

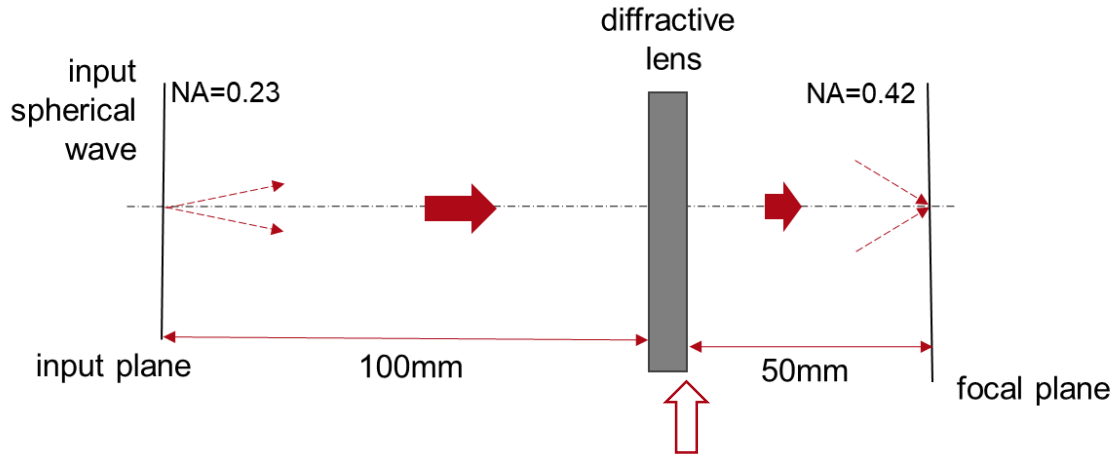
For the design, the thickness of the base block is set as zero, $T = 0$

Imaging with Diffractive Lens

Modeling with rigorous RCWA/FMM

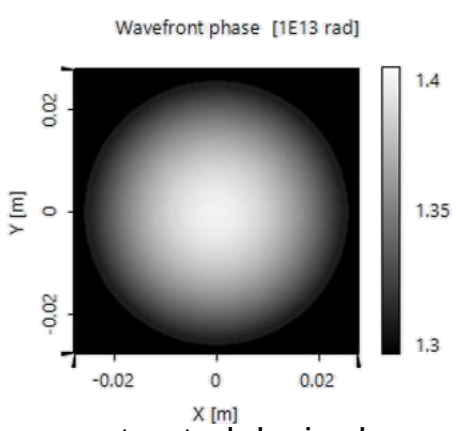


Imaging with Diffractive Lens

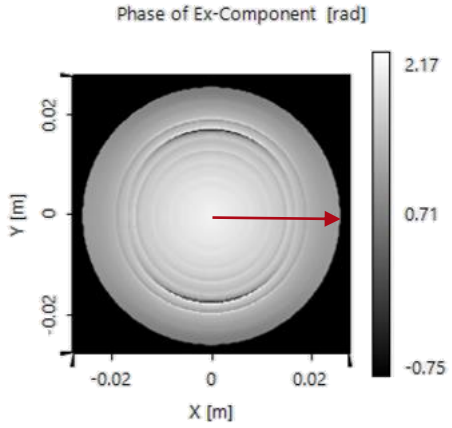


The residual phase is originated by the additional phase effects of the local gratings

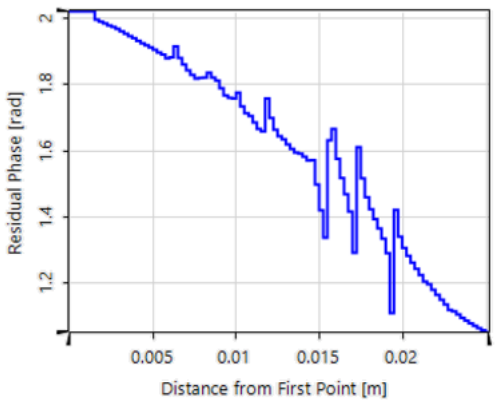
phase of the working order behind the diffractive lens



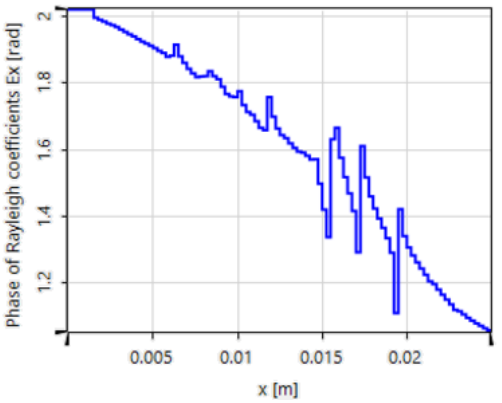
extracted desired wavefront phase



residual phase

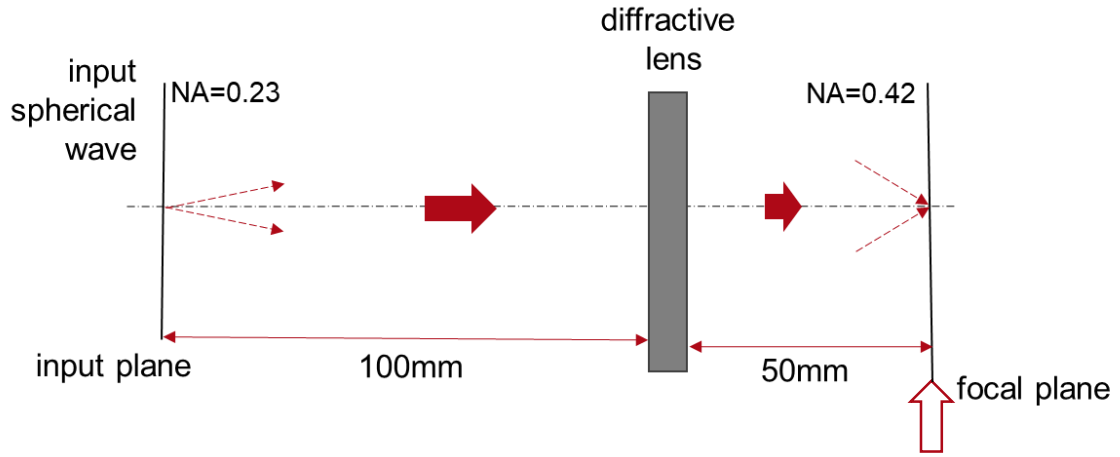


residual phase along cross-section



rigorous calculated phase of Rayleigh coefficients of E_x

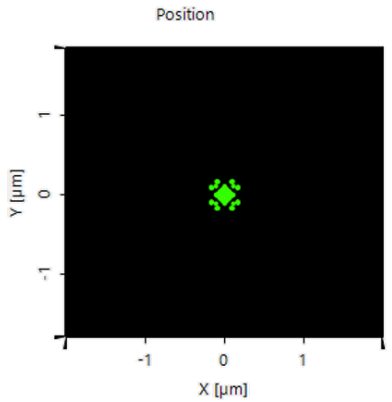
Imaging with Diffractive Lens



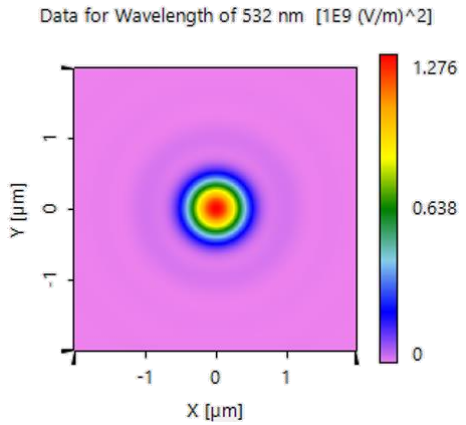
The diffractive lens is designed by physical optics approach

Ray tracing result

Field tracing result



Dot pattern of the working order

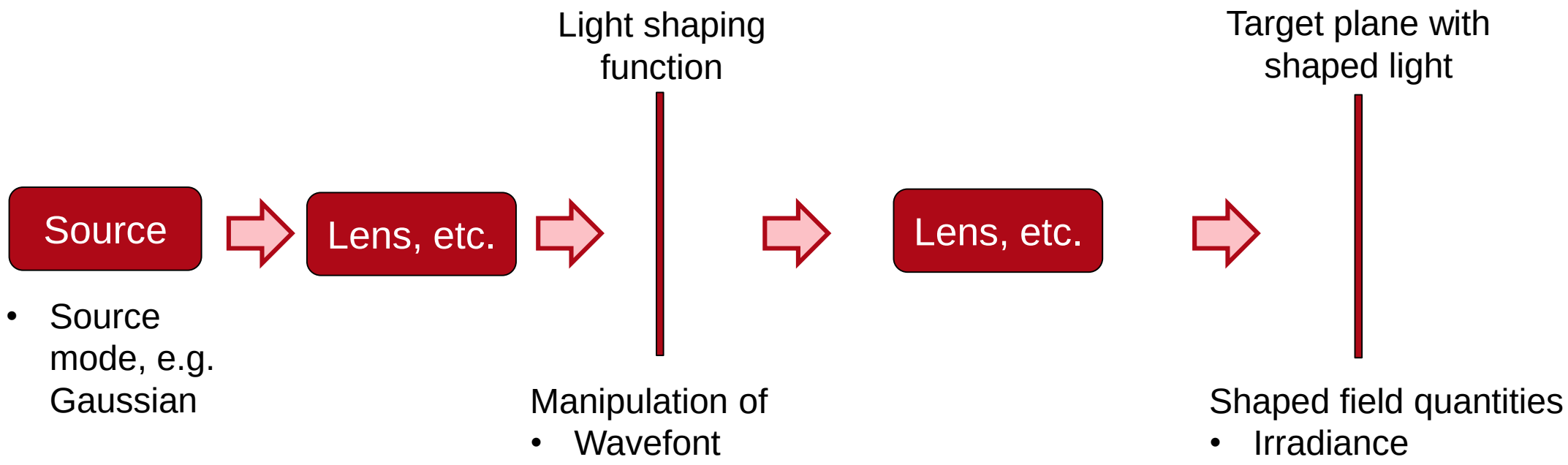


PSF

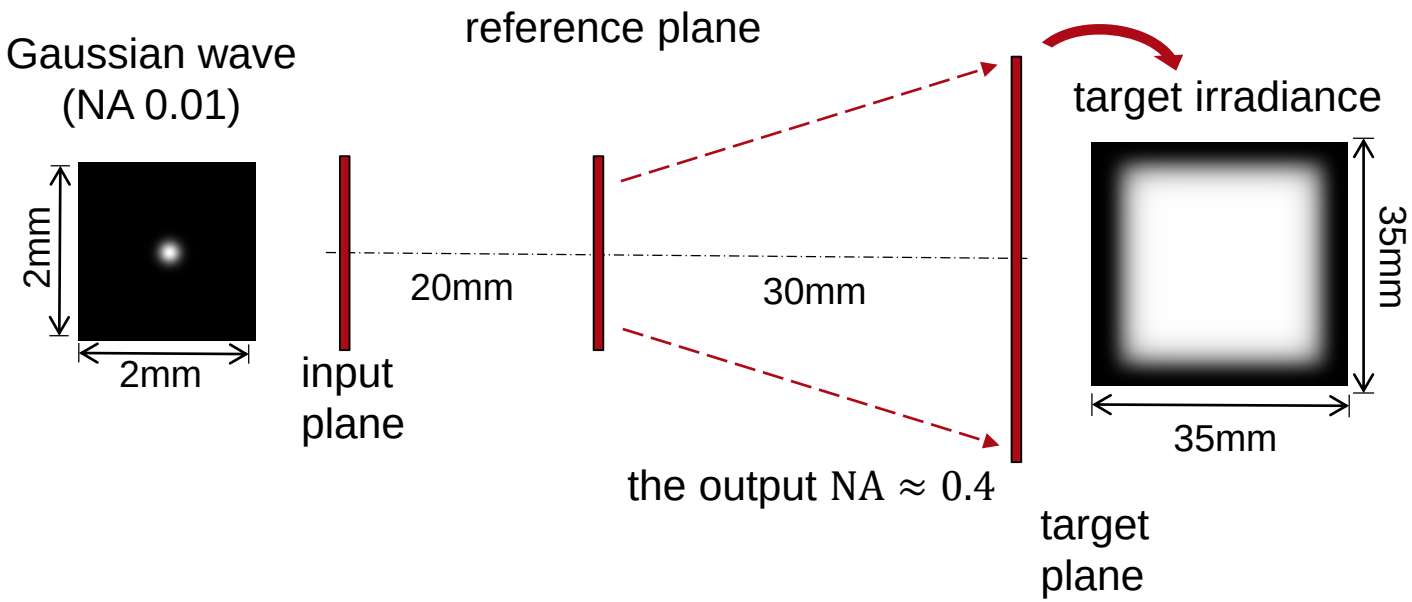
Example 2: Irradiance Control

Design of an High-NA Beam Shaper for Top Hat Generation

Light Shaping by Irradiance Control

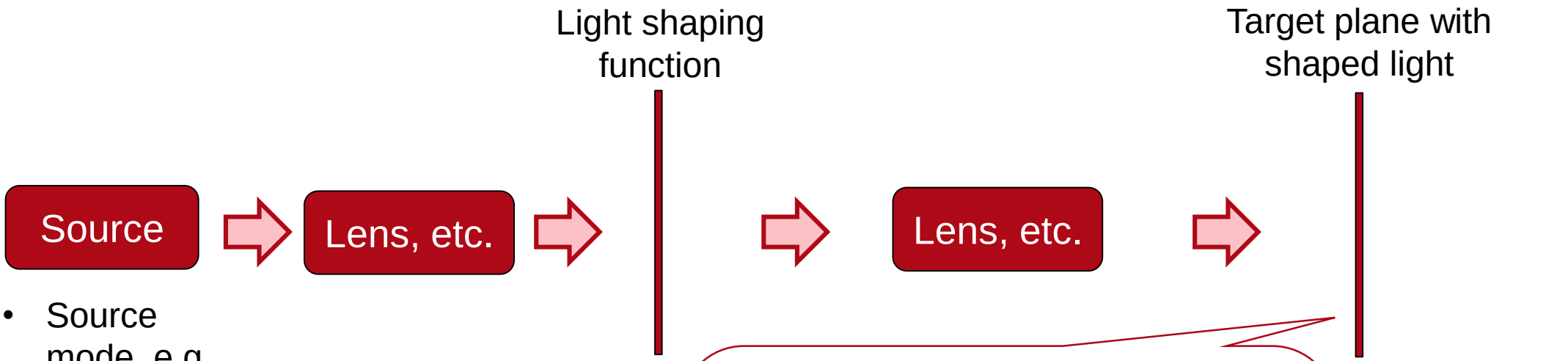


Gaussian to Top-Hat (Non-paraxial)

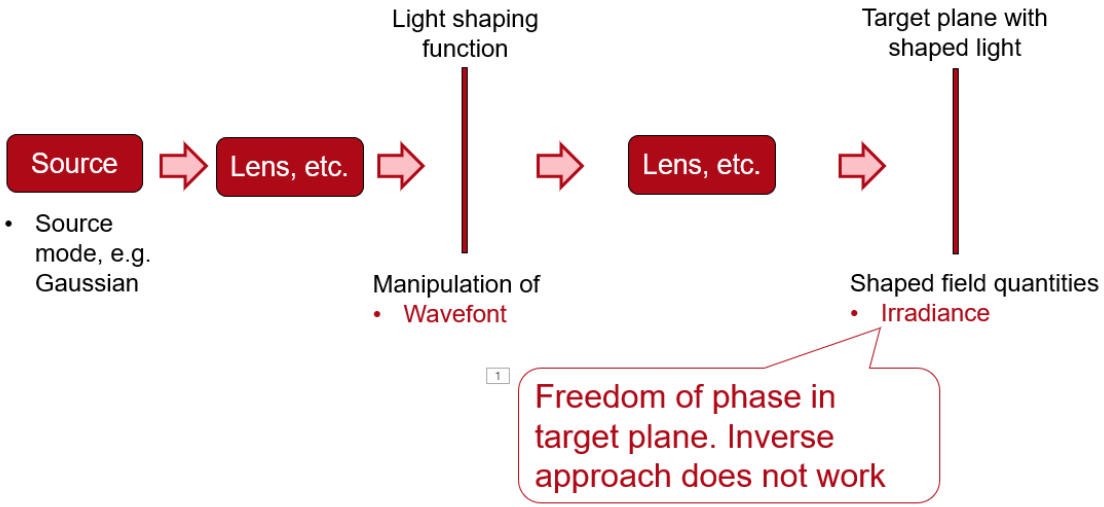


The Rayleigh lengths of the input Gaussian is $555.6\mu m$

Light Shaping by Wavefront Control



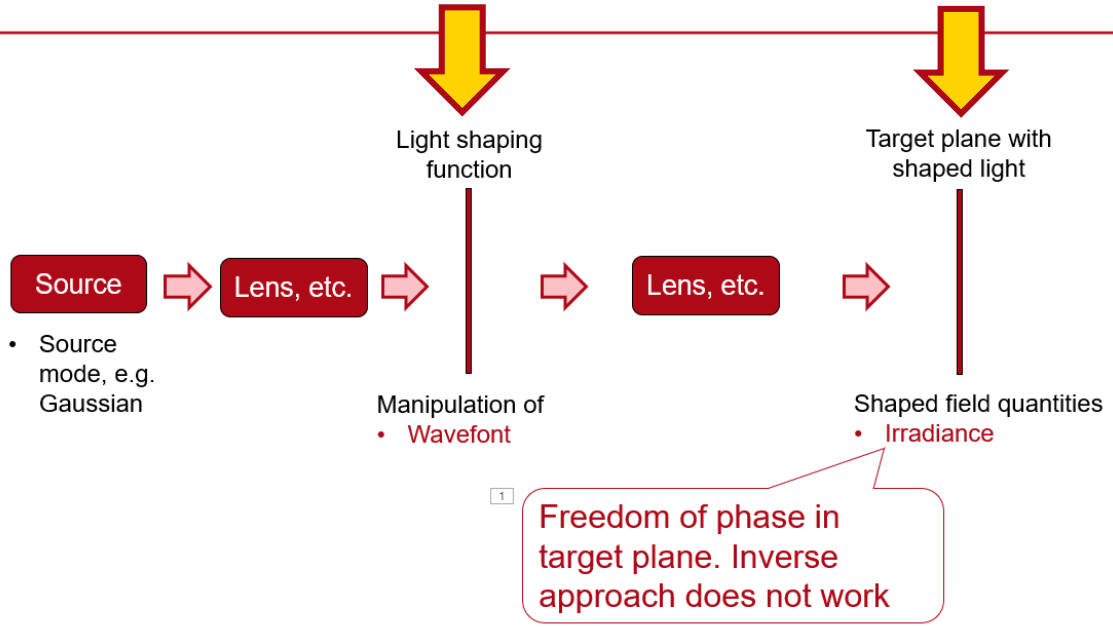
Light Shaping Design: Functional



We need to answer the following questions:

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

Light Shaping Design: Functional

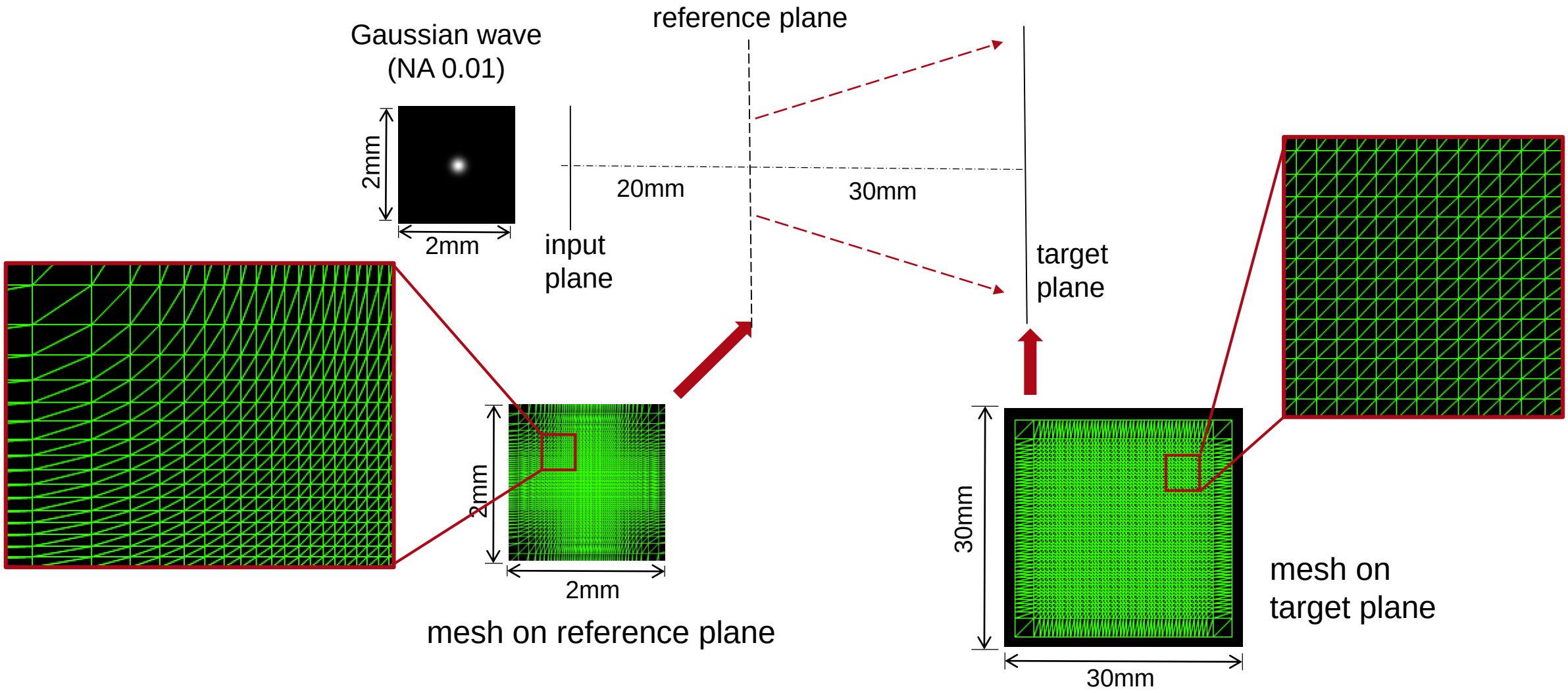


We need to answer the following questions:

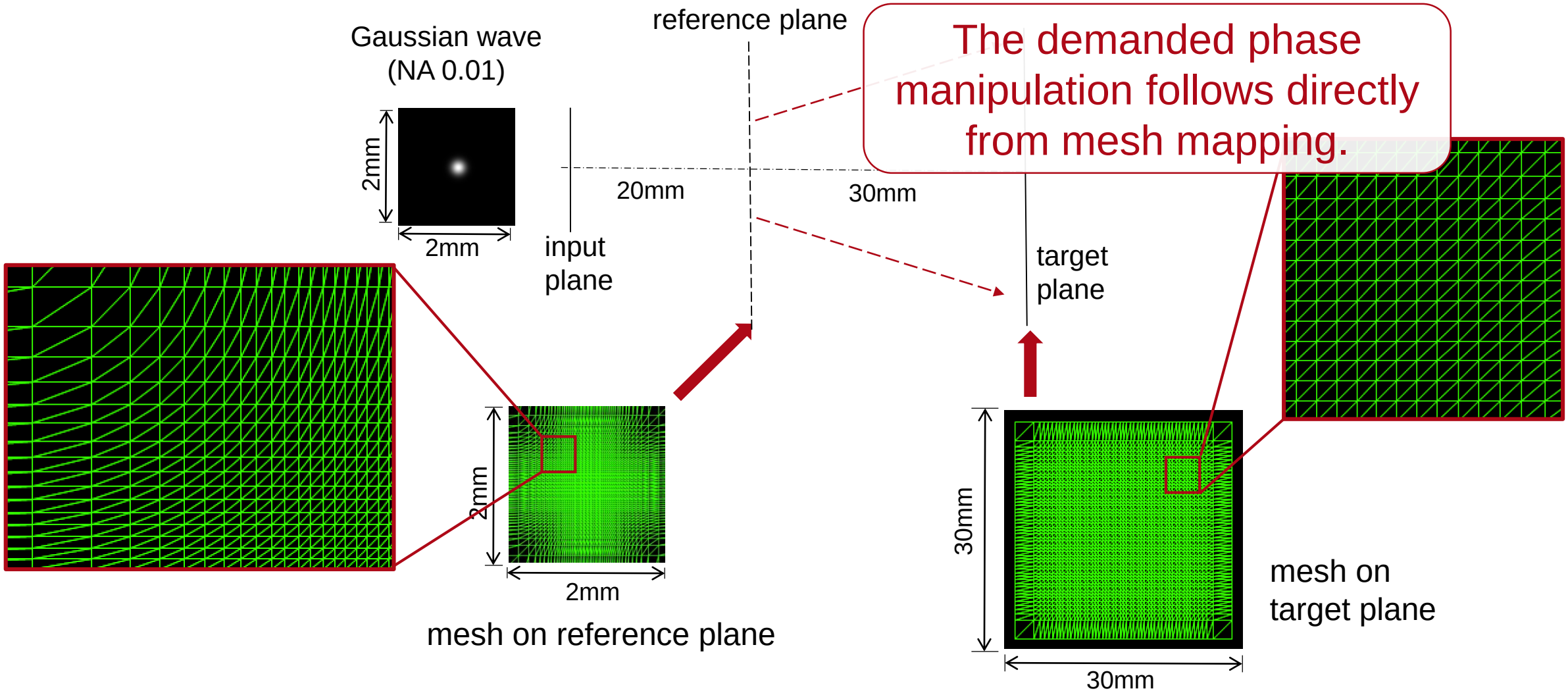
- **What kind of light manipulation is needed in order to obtain the demanded shaping result?**

- 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.

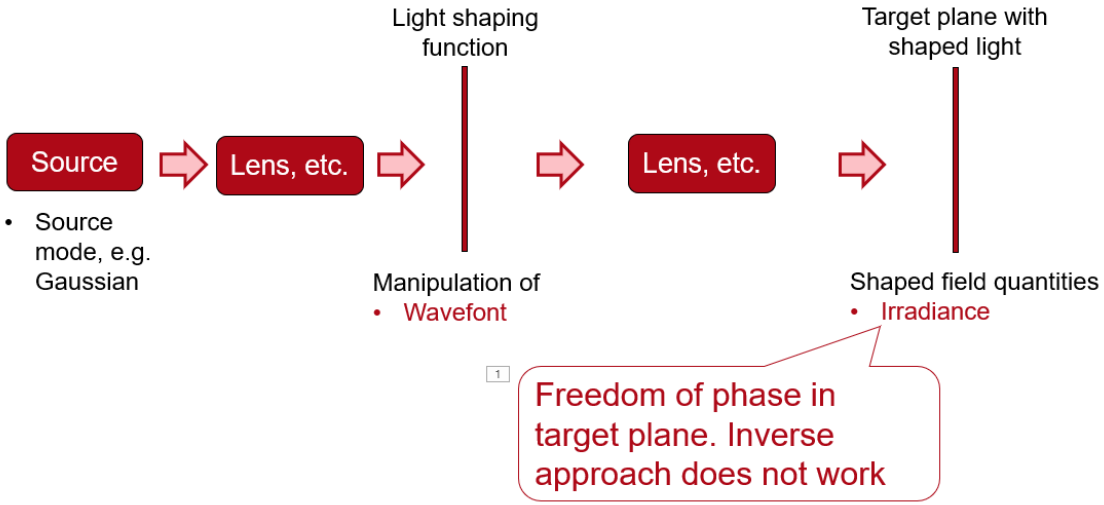
Gaussian to Top-Hat (Non-paraxial): Functional Design



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



Light Shaping Design: Functional



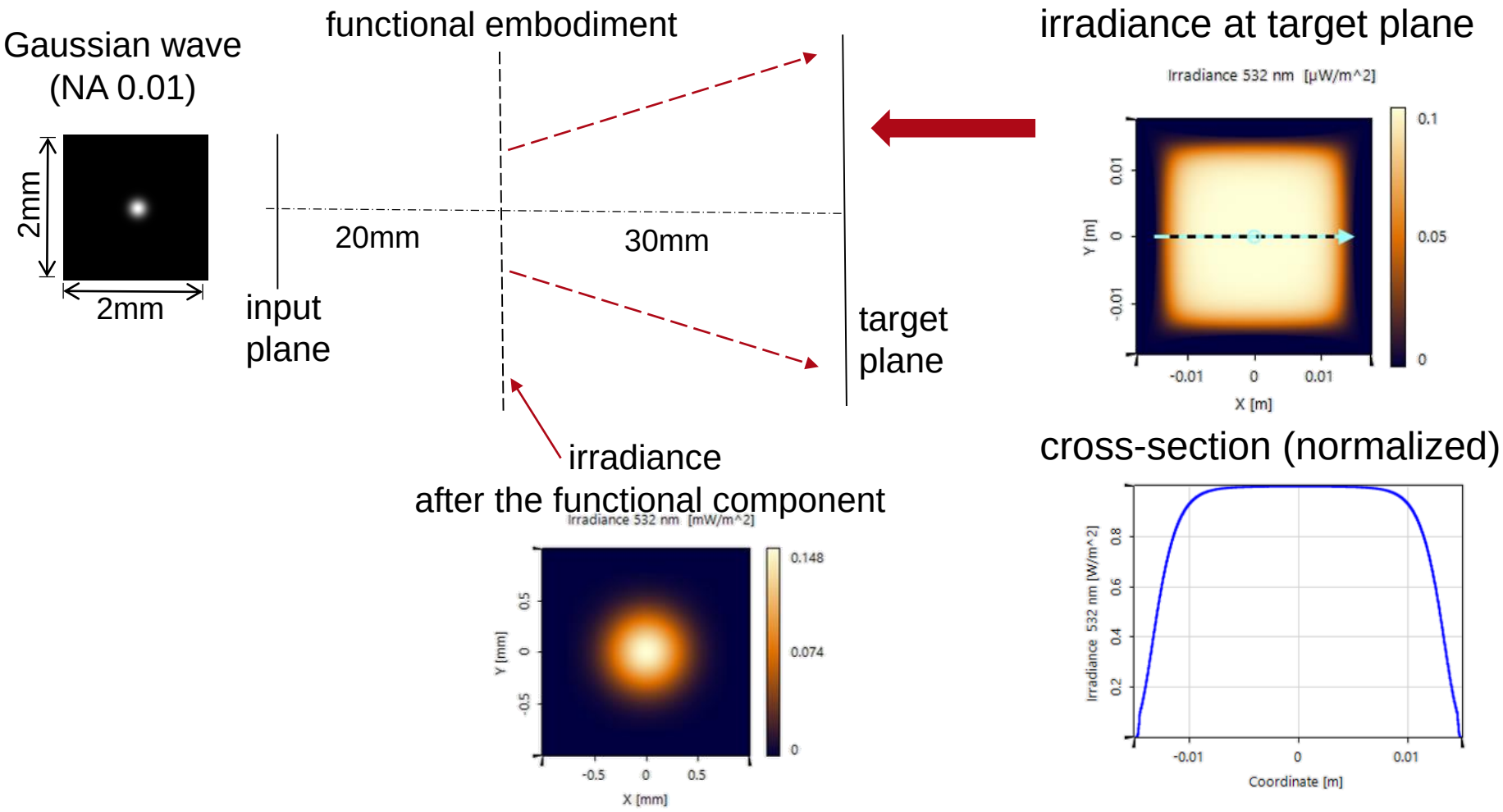
We need to answer the following questions:

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

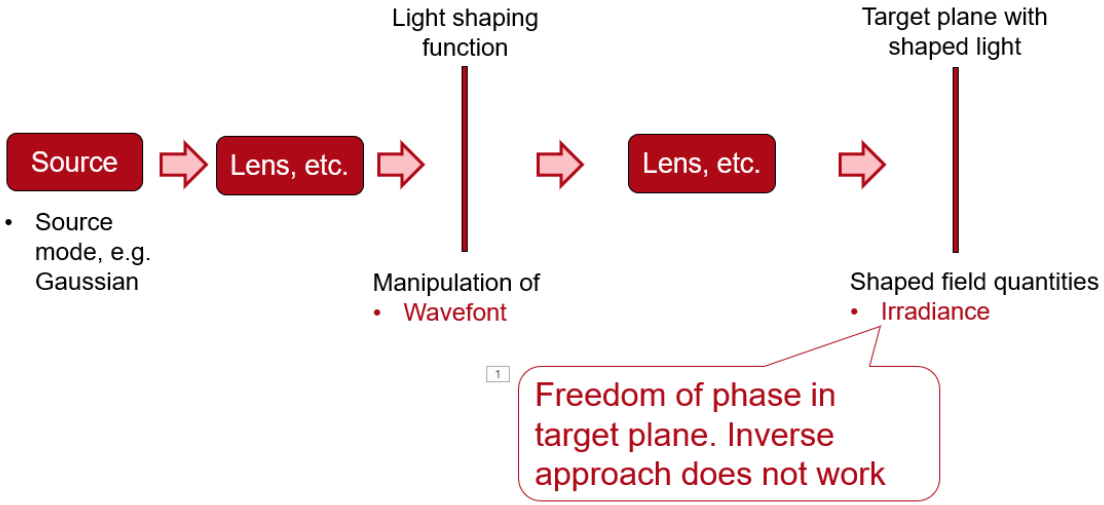
- VirtualLab Fusion provides technique for functional design in light shaping.

- Demanded phase for wavefront change is known.

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



Light Shaping Design: Structural



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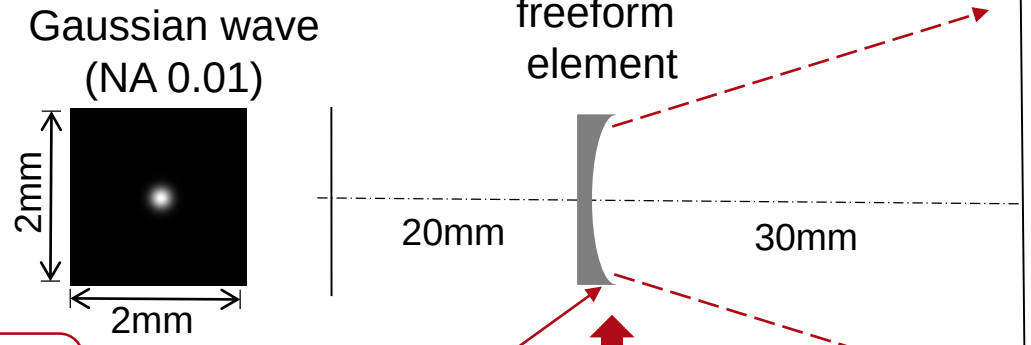
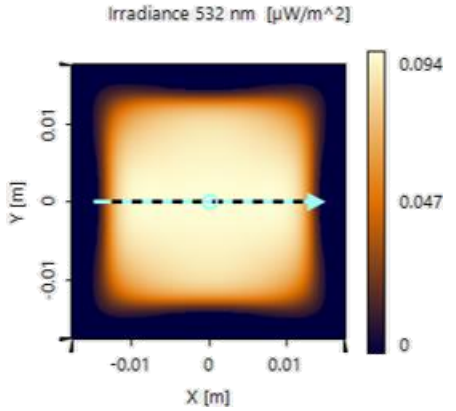
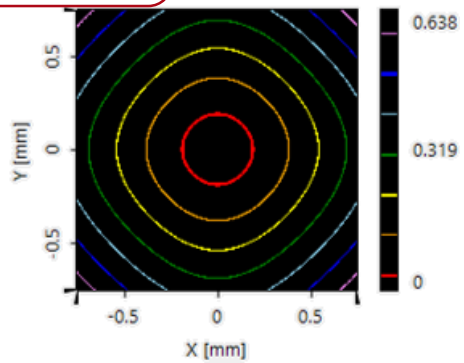
Gaussian to Top-Hat (Non-paraxial): Freeform Surface Design



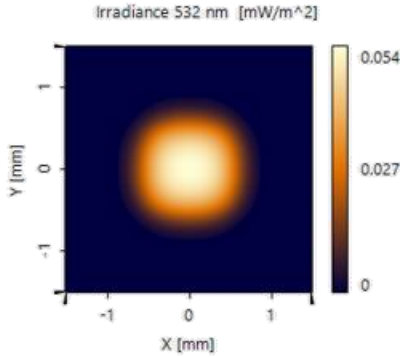
irradiance at target plane



Maximum Height 638 µm

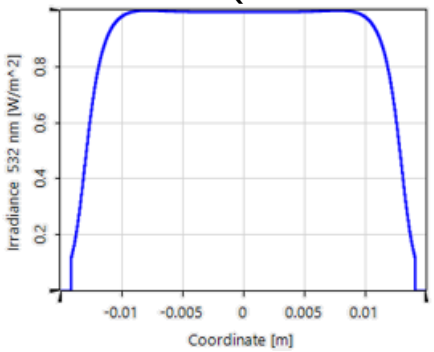


Height Profile
(2D Contour line)

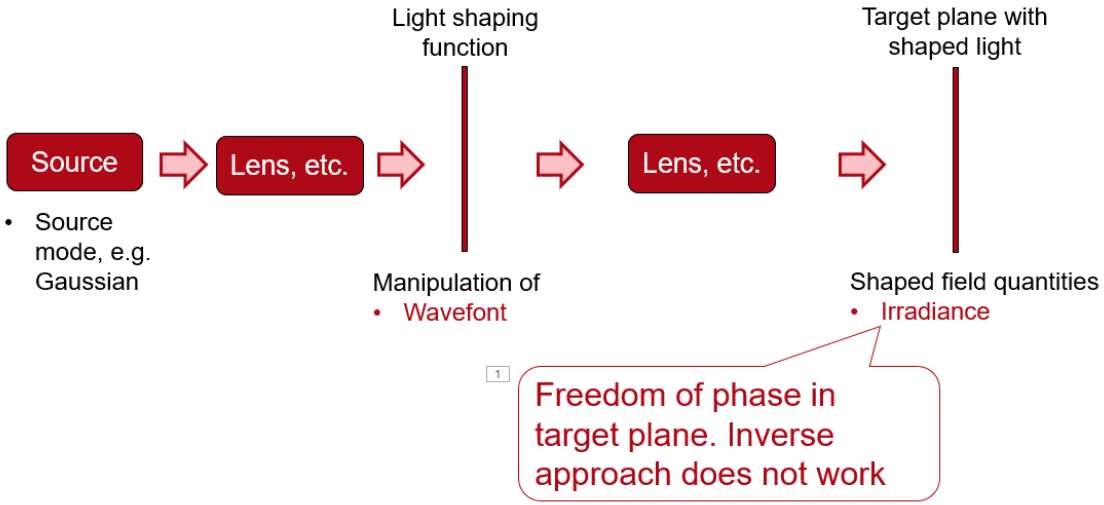


irradiance behind the surface

cross-section (normalized)



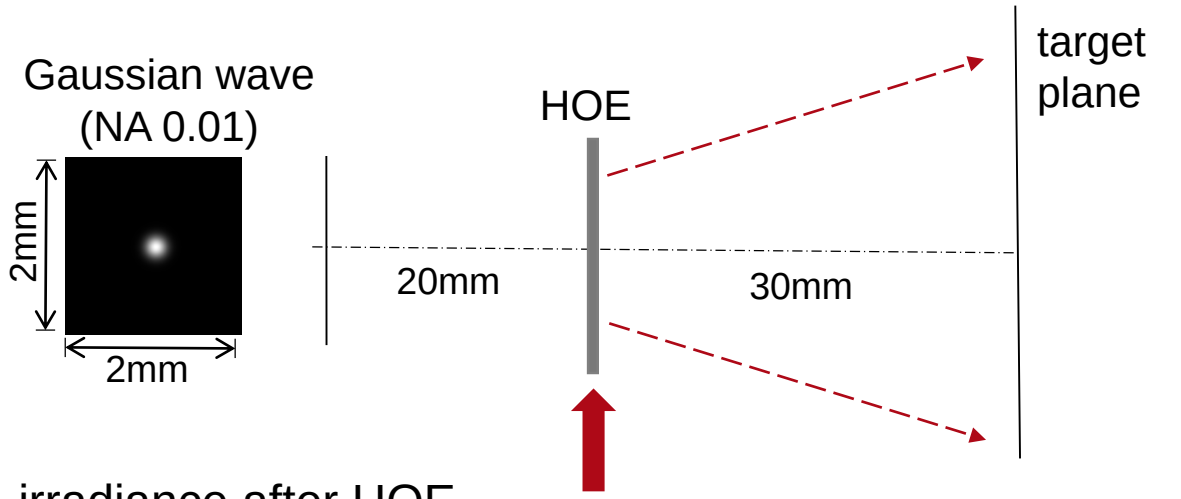
Light Shaping Design: Structural



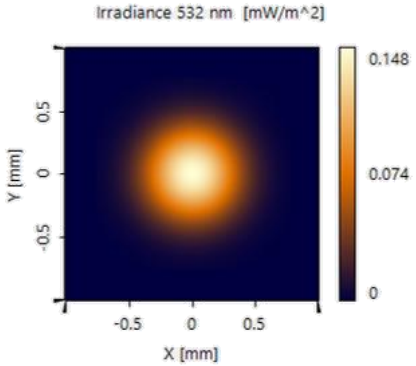
We need to answer the following questions:

- 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

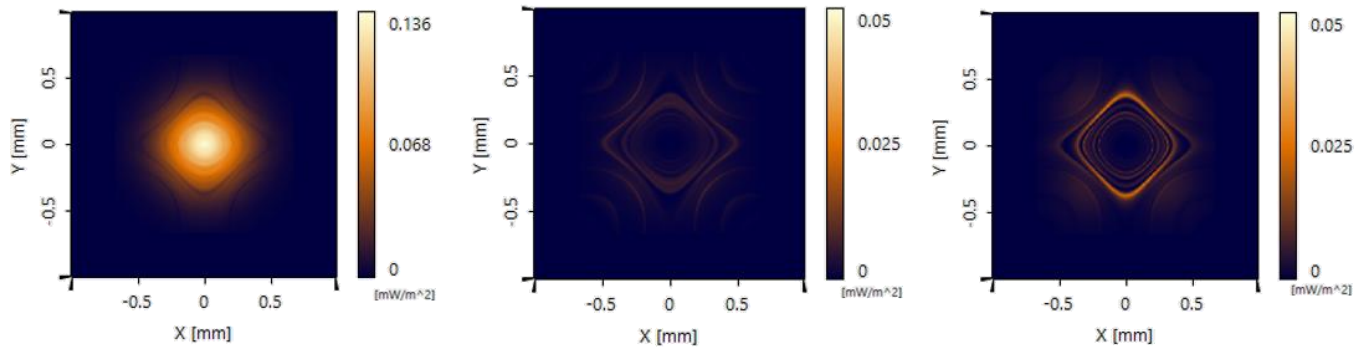
Gaussian to Top-Hat (Non-paraxial): Freeform Surface Design



irradiance
after the component of
the functional design



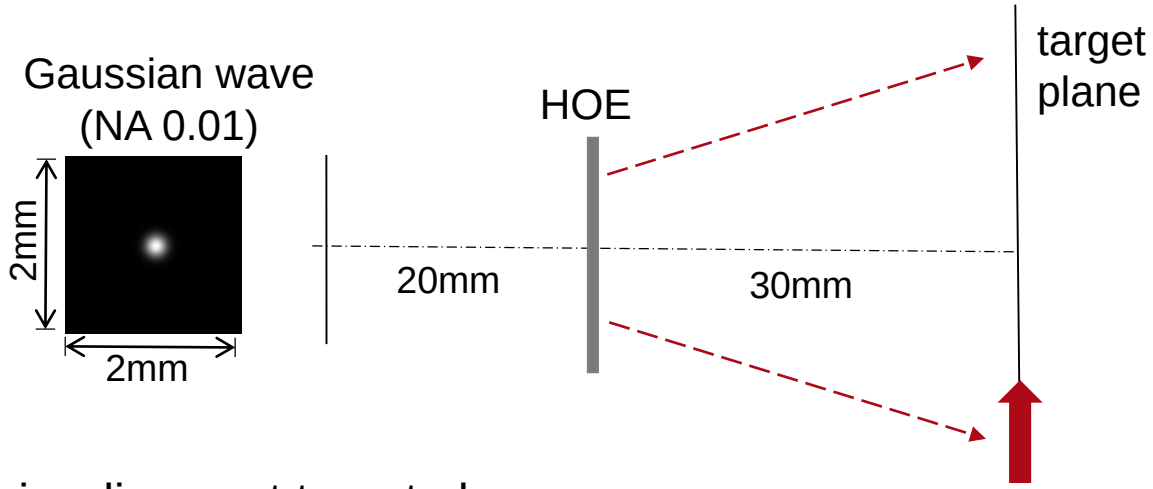
irradiance after HOE



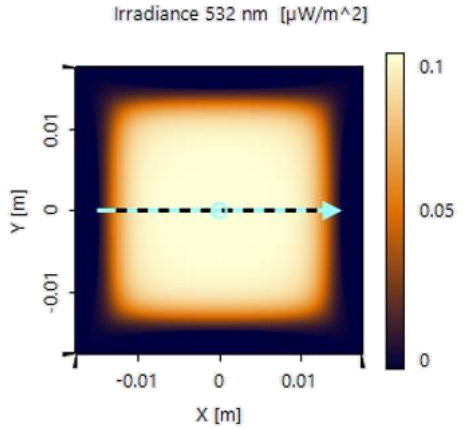
-1order 0 order +1order

Smaller periods of the local grating structures introduce efficiency variations, which were not controlled

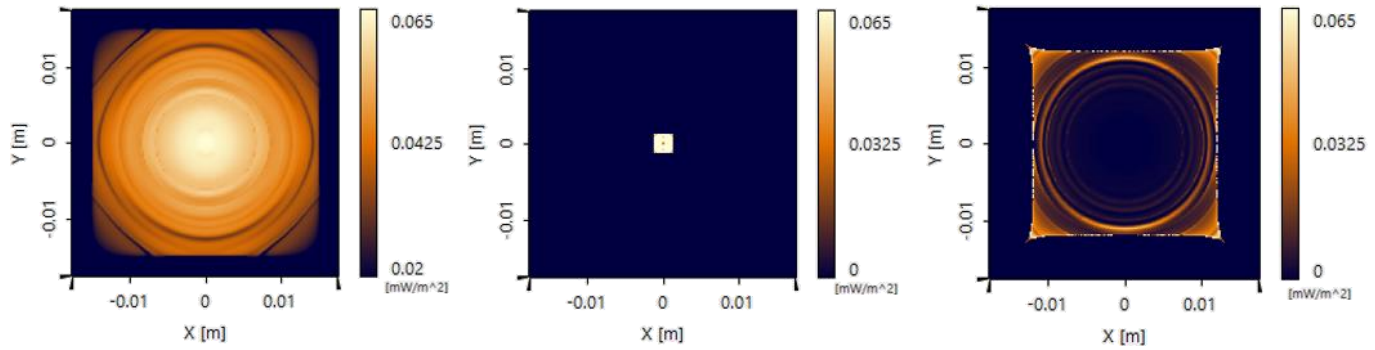
Gaussian to Top-Hat (Non-paraxial): Freeform Surface Design



irradiance at the target plane
from the functional design



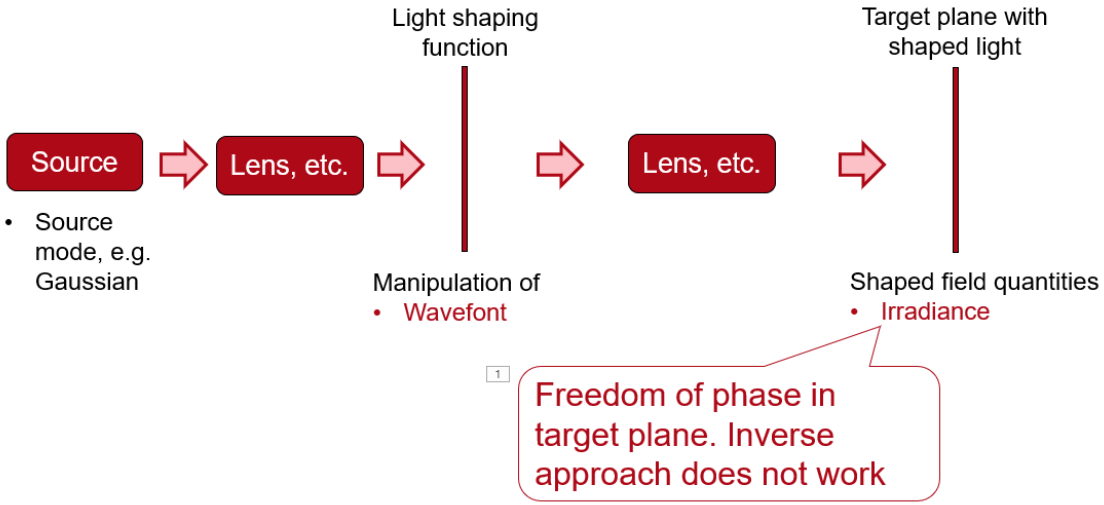
irradiance at target plane



-1order 0 order +1order

These efficiency variations decreases the uniformity of the irradiance pattern

Light Shaping Design: Structural



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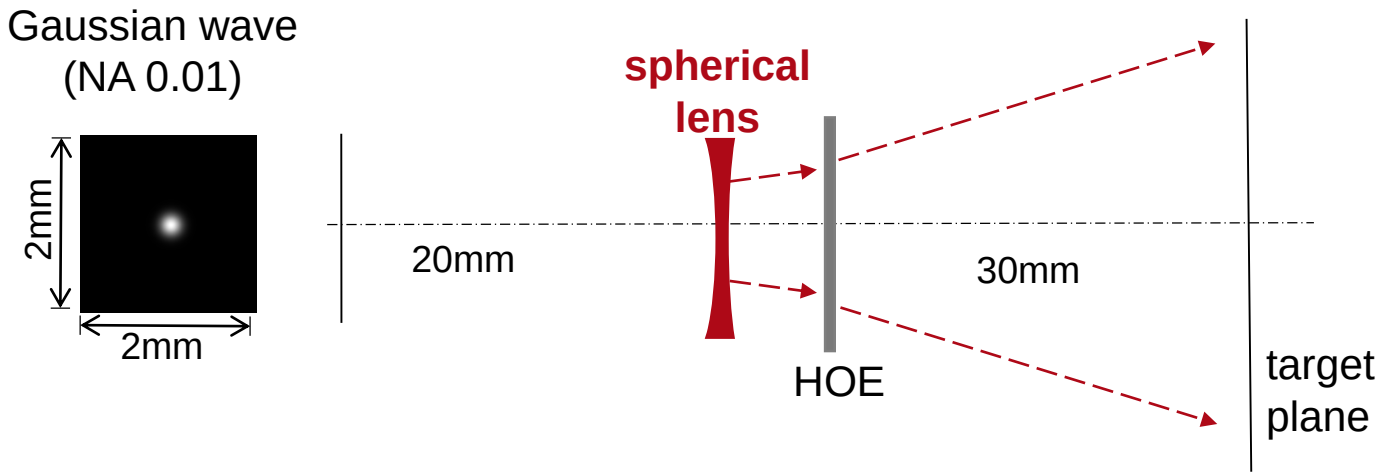
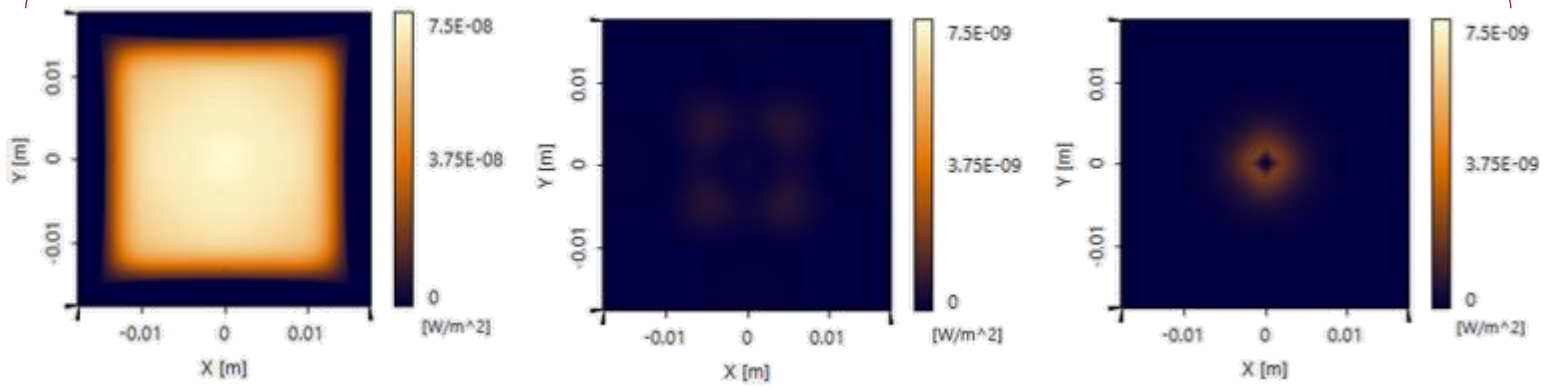
Gaussian to Top-Hat (Non-paraxial): Freeform Surface Design



irradiance at target plane

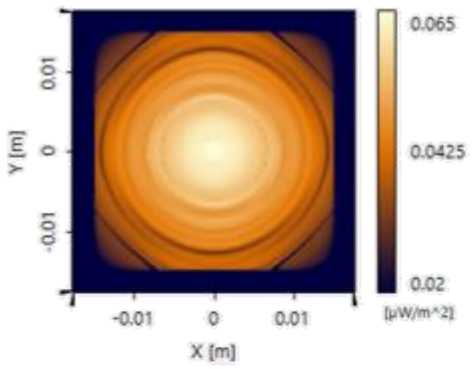


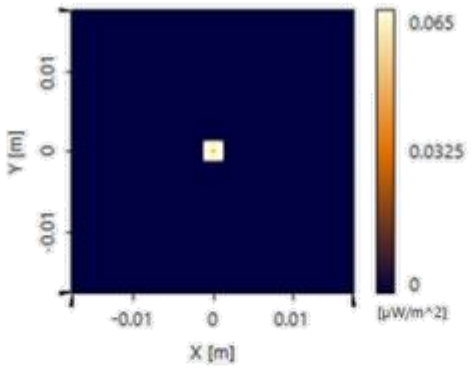
-1order 0 order +1order

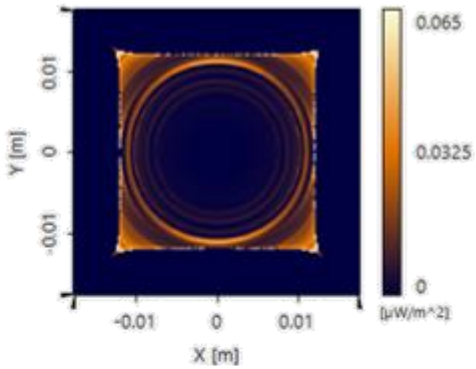
Gaussian to „top-hat“ (Non-paraxial)

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

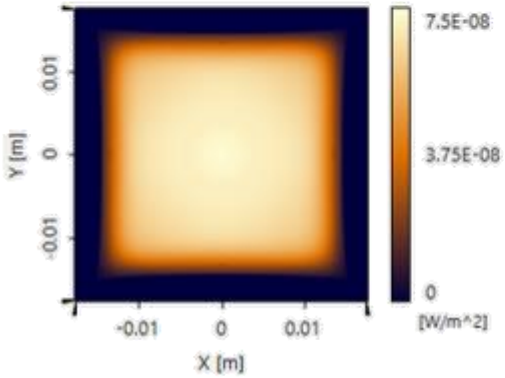
without the lens

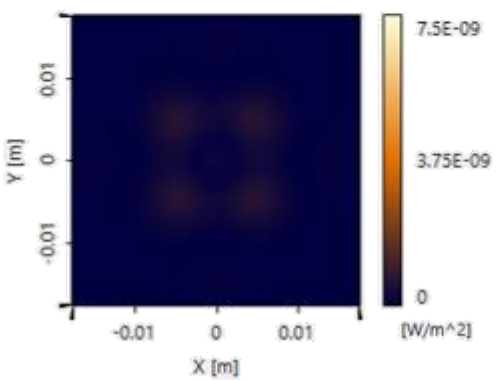


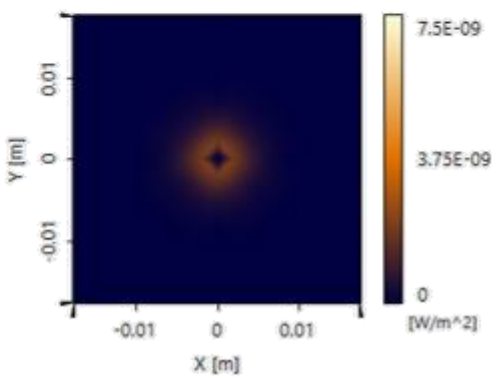




with the lens



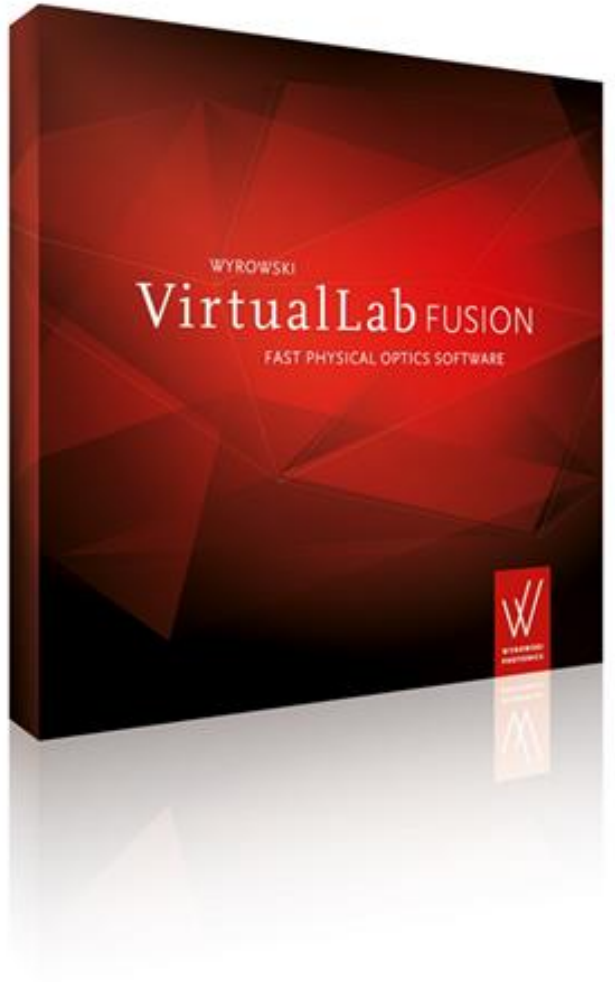




-1order 0 order +1order

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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