Light Shaping from a Physical-optics Point of View

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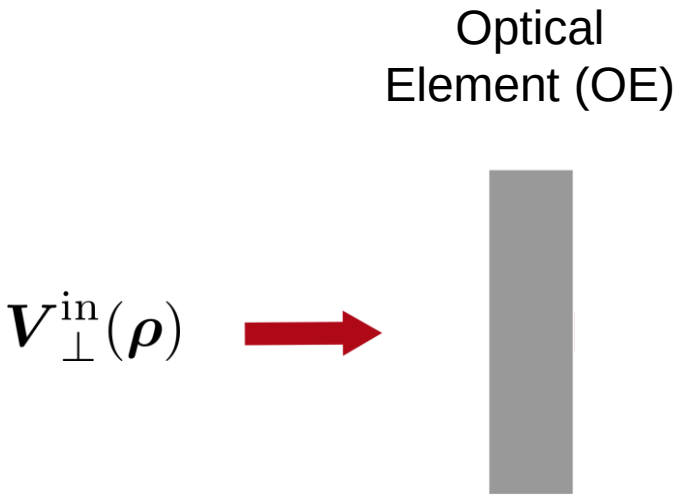
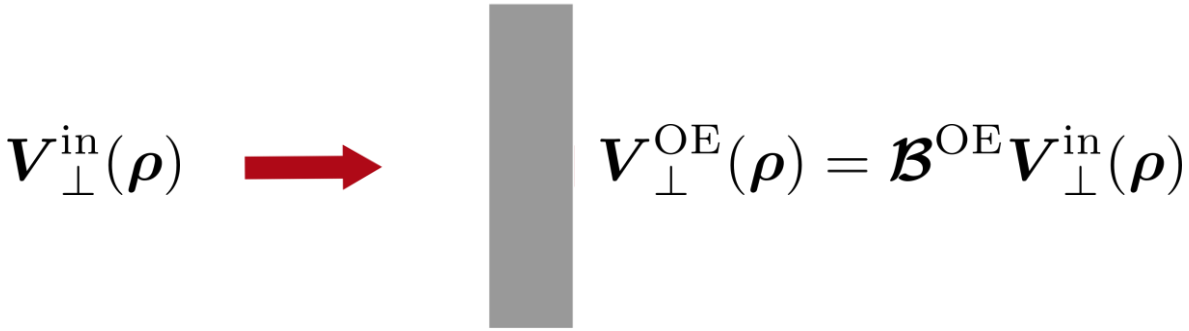
Shaping the Far Field of an Incident Light Beam



- For a field in a plane we use the notation $\boldsymbol{\rho} = (x, y)$ and $\boldsymbol{V}_{\perp}(\boldsymbol{\rho}) = (E_x(\boldsymbol{\rho}), E_y(\boldsymbol{\rho}))$.
- In k-domain we obtain $\tilde{\boldsymbol{V}}_{\perp}(\boldsymbol{\kappa}) = \boldsymbol{\mathcal{F}}_k \boldsymbol{V}_{\perp}(\boldsymbol{\rho})$ with $\boldsymbol{\kappa} = (k_x, k_y)$ and the Fourier transform operator $\boldsymbol{\mathcal{F}}_k$.

Shaping the Far Field of an Incident Light Beam

Optical
Element (OE)



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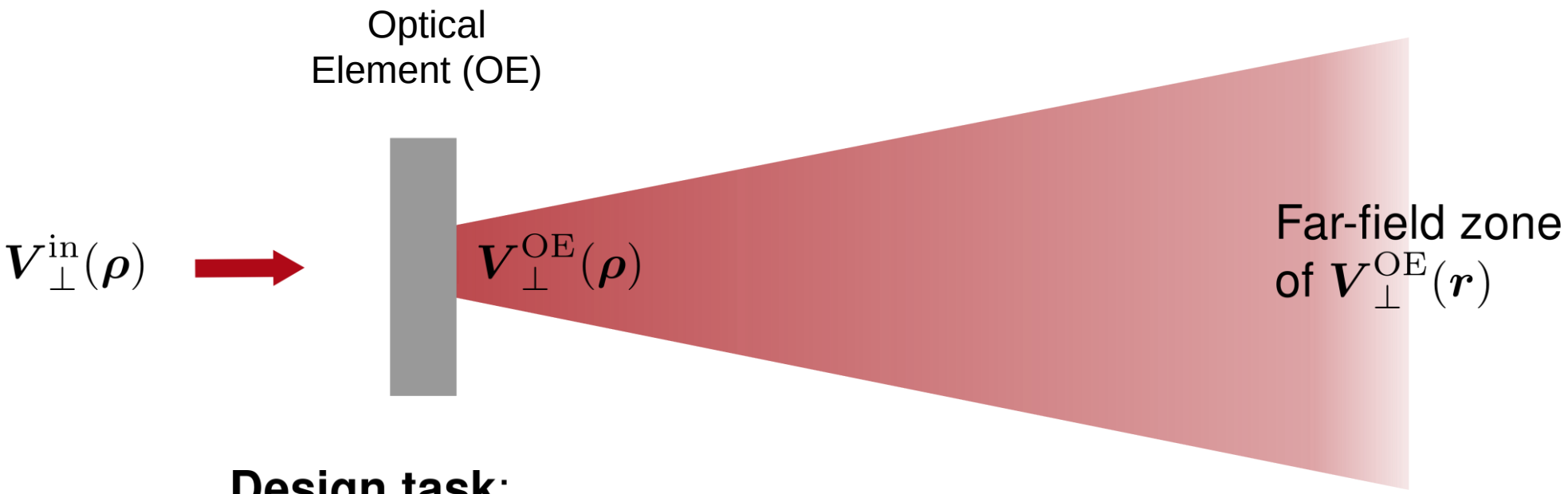
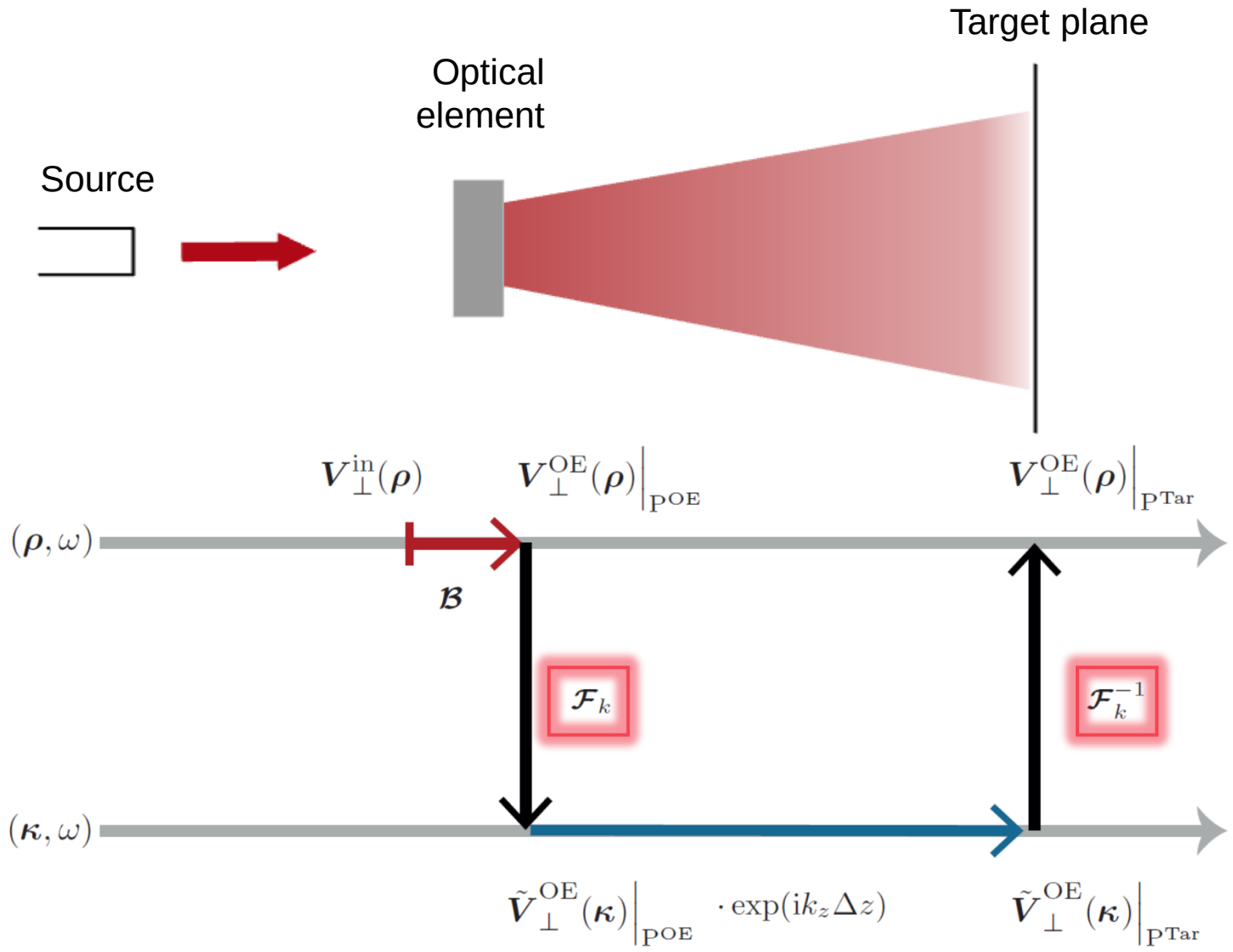


Design task:

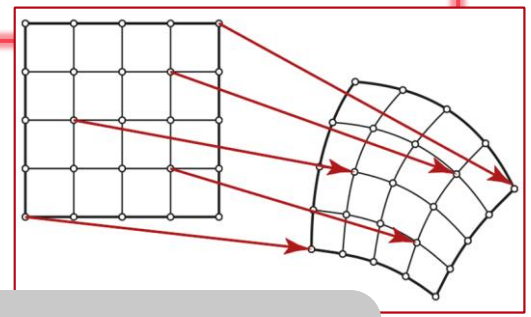
- Shape the irradiance/illuminance (or other radiometric/photometric quantities) in the far field.
- The connection of the field $\boldsymbol{V}^{\mathrm{OE}}(\boldsymbol{r})$ and the radiometric/photometric quantities can be determined locally in any position in the far field.

Modeling Technique: Field Tracing



Different Fourier transform algorithms:

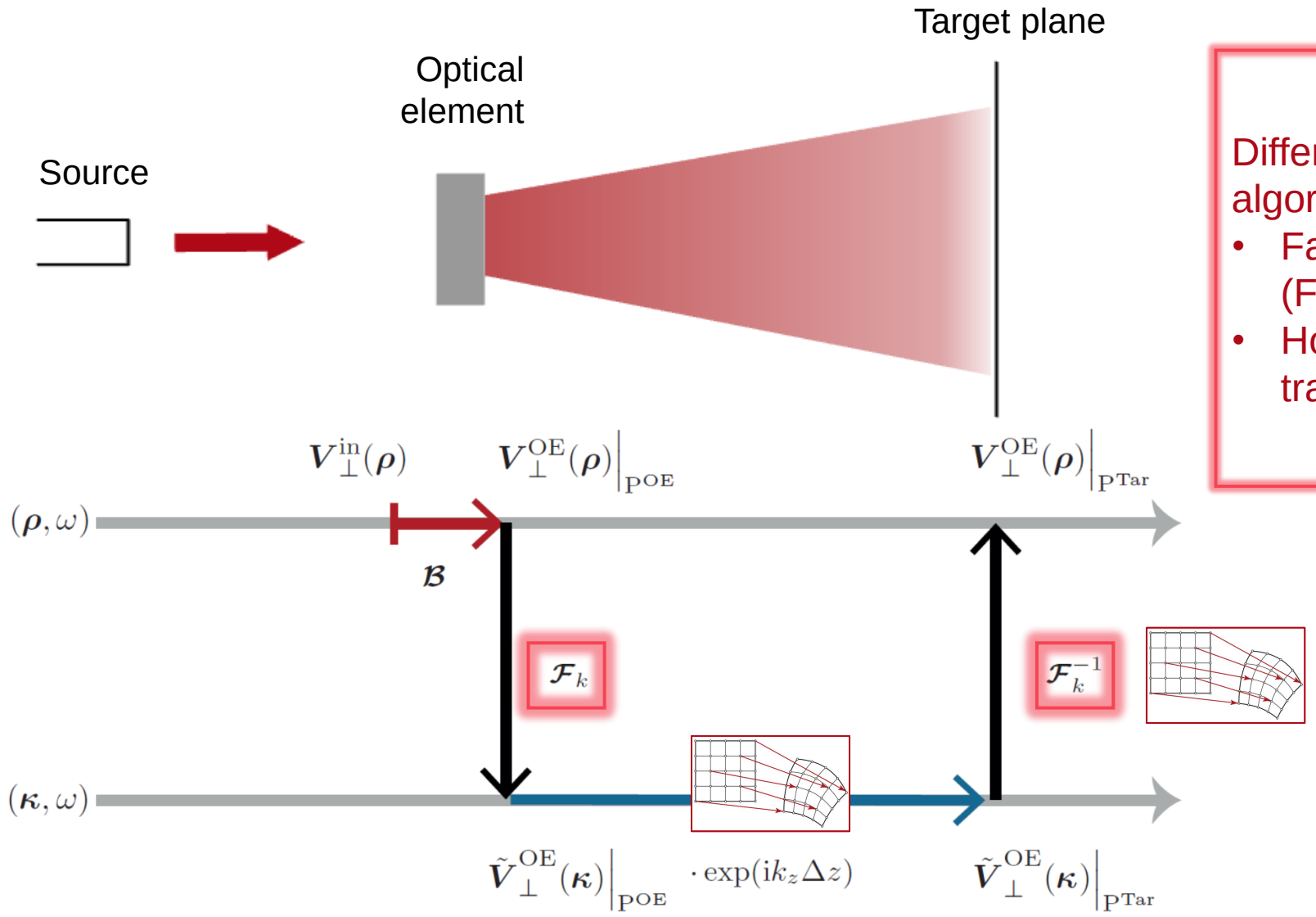
- Fast Fourier transform (FFT)
- Homeomorphic Fourier transform (HFT)



Pointwise calculation

Wang, Z. et al. *Opt. Express, OSA,* **2020**, *28*, 10552-10571

Modeling Technique: Field Tracing



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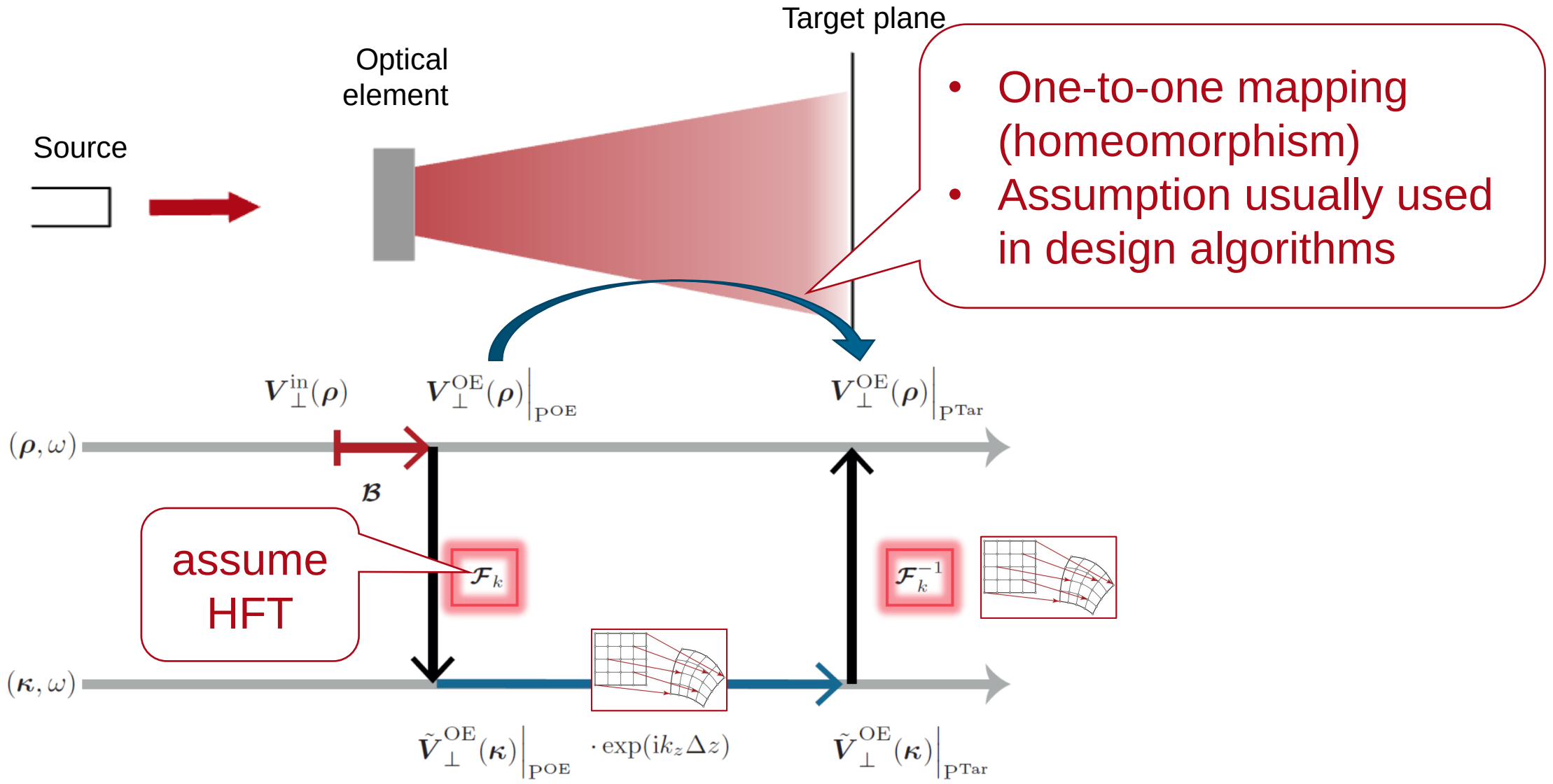
Wang, Z. et al. *Opt. Express, OSA,* **2020**, *28*, 10552-10571

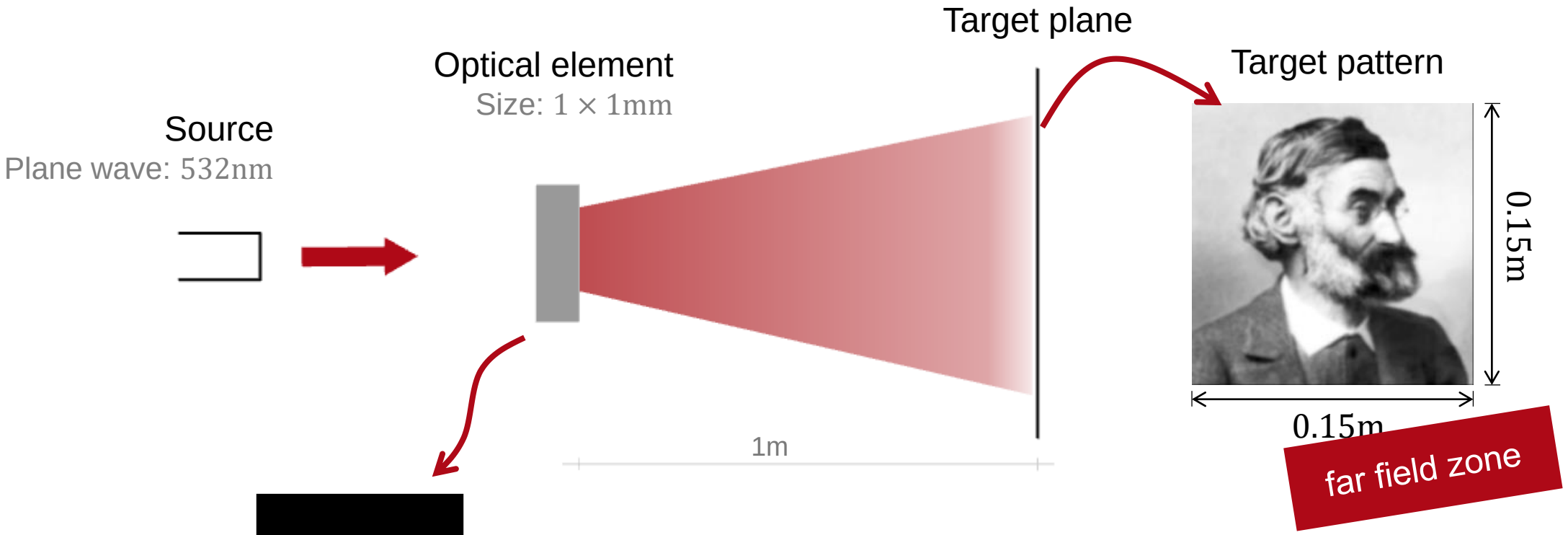
Modeling Technique: Field Tracing



- One-to-one mapping (homeomorphism)
- Assumption usually used in design algorithms

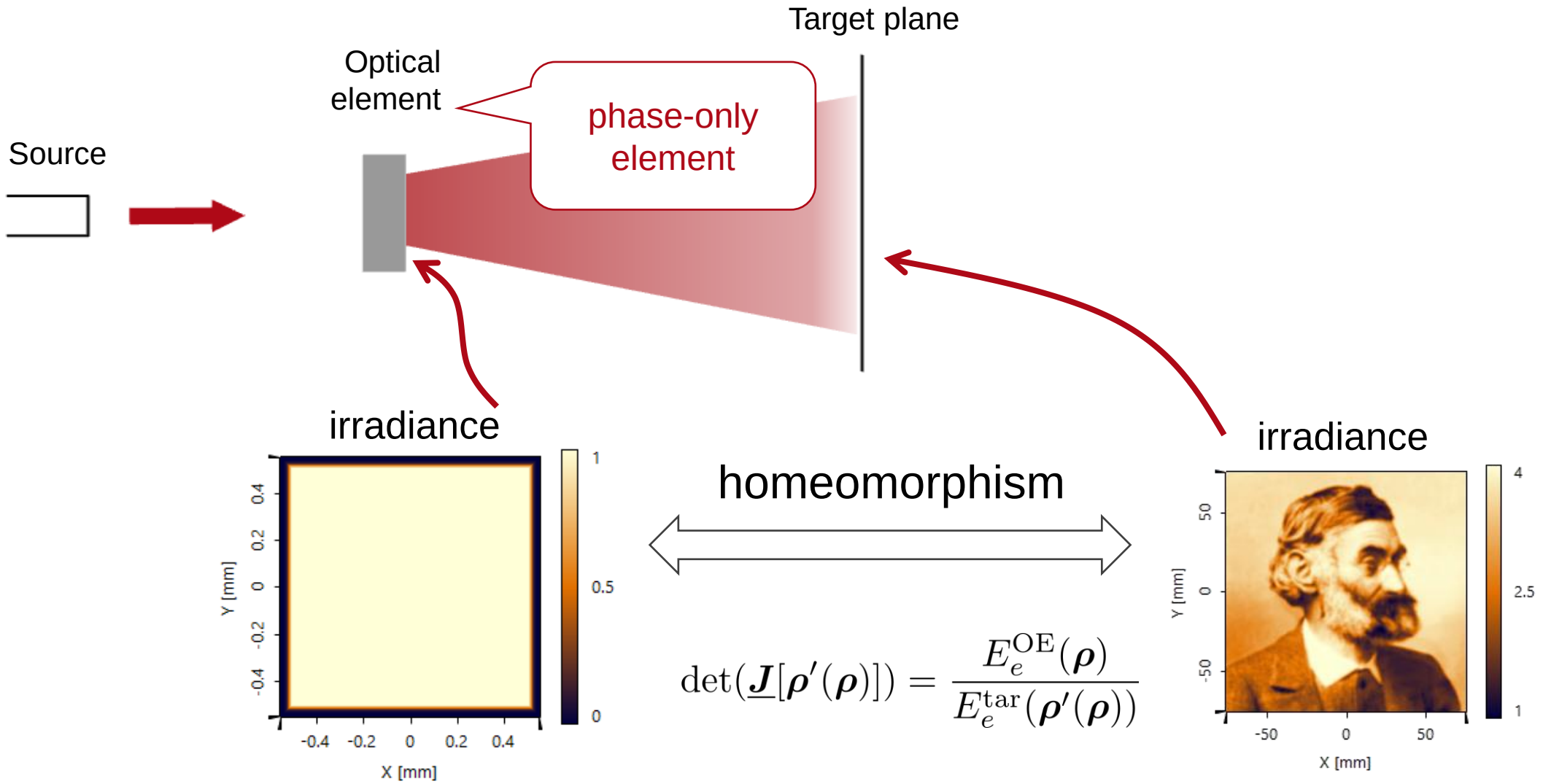
assume HFT

Design Task



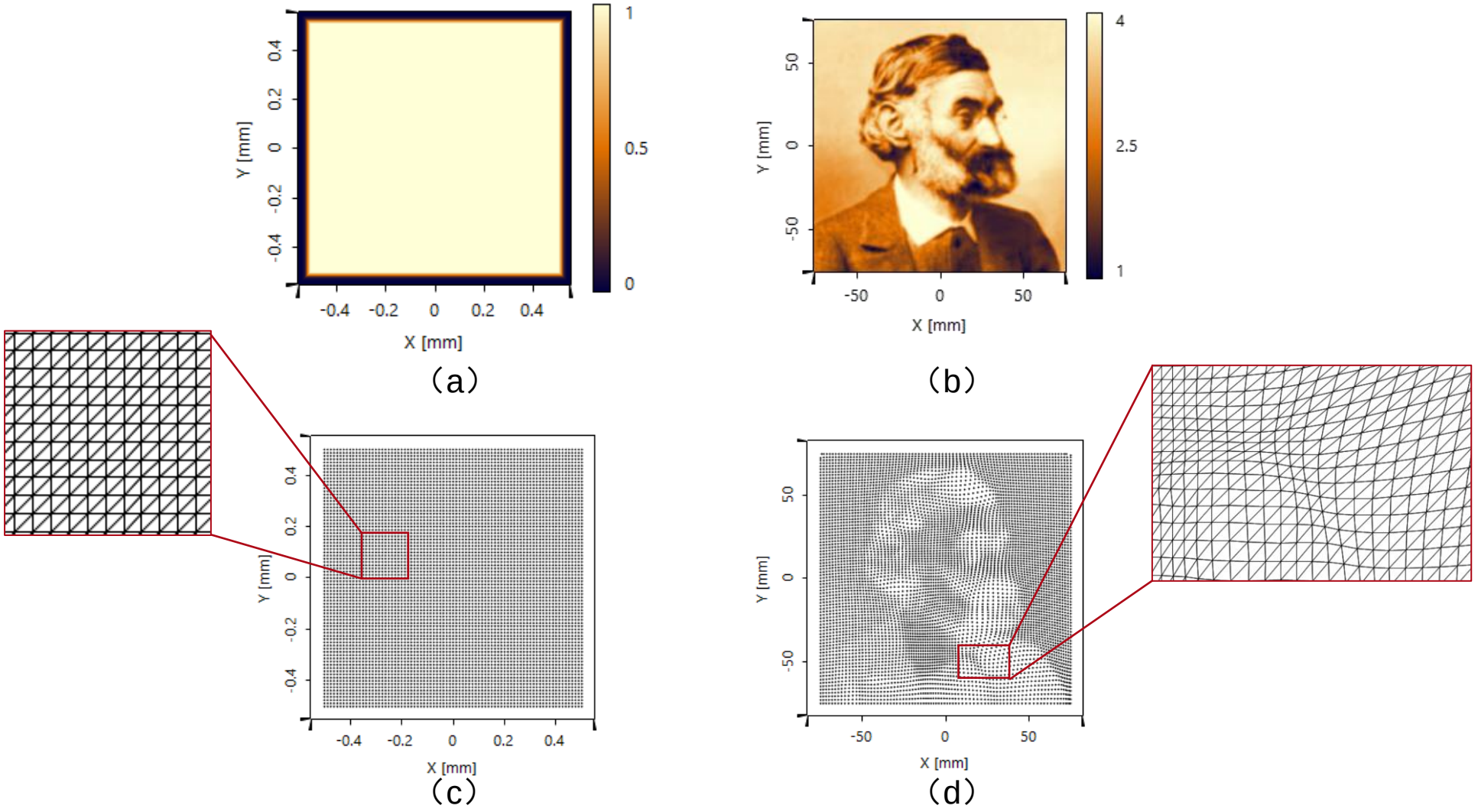
How to design the optical element for achieving the target irradiance distribution on target plane?

Homeomorphism Assumption



$$\det(\underline{\boldsymbol{J}}[\boldsymbol{\rho}'(\boldsymbol{\rho})]) = \frac{E_e^{\mathrm{OE}}(\boldsymbol{\rho})}{E_e^{\mathrm{tar}}(\boldsymbol{\rho}'(\boldsymbol{\rho}))}$$

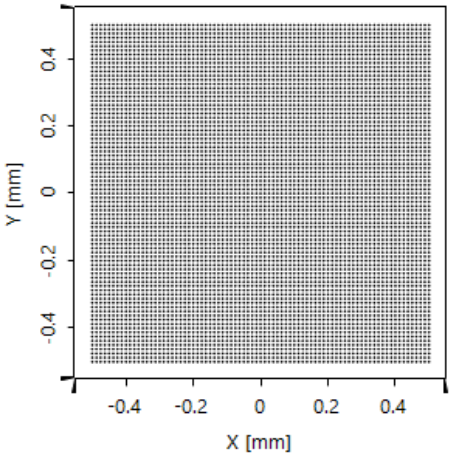
Optimal Mass Transport Algorithm



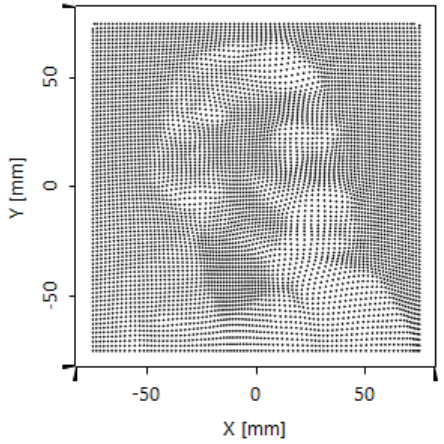
Prins, C.; et al. *SIAM Journal on Scientific Computing,* **2015**, *37*, B937-B961

From Mapping to Phase

$\boldsymbol{r_i} = (\boldsymbol{\rho}_i, 0)$

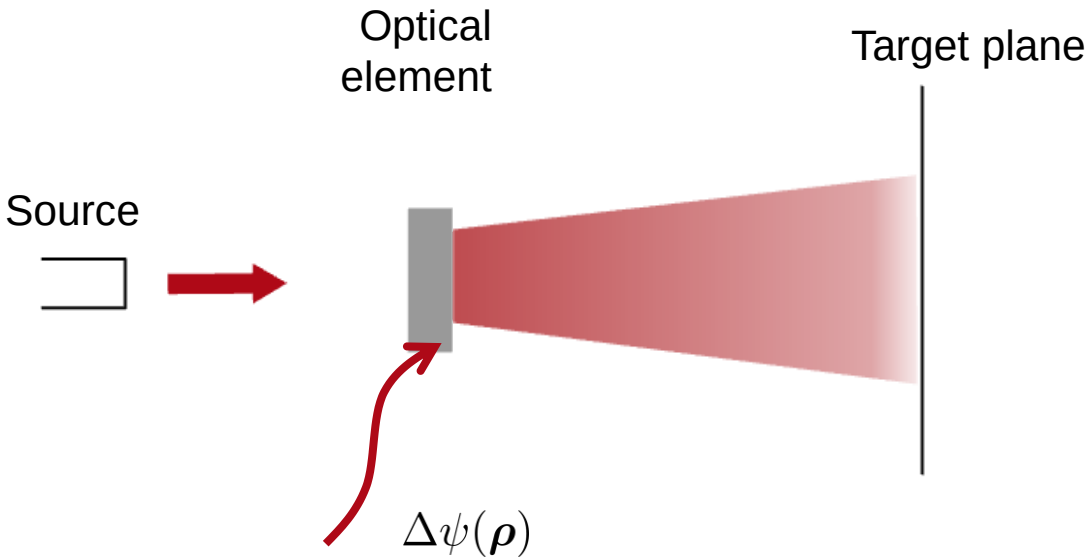


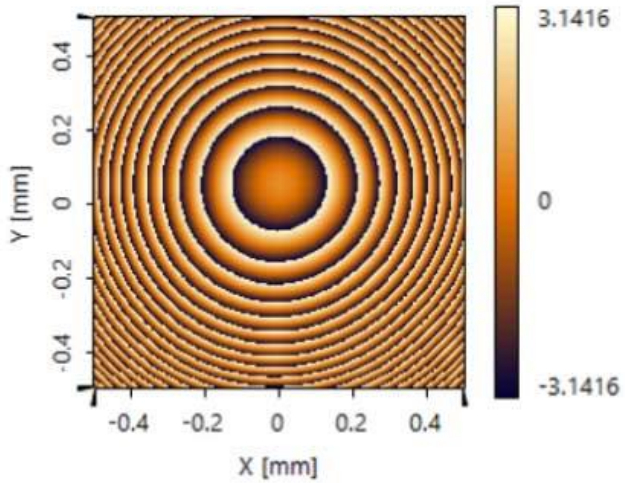
$\boldsymbol{r_i'} = (\boldsymbol{\rho}_i', \Delta z)$



- Calculating the local wave vector from the mapping $\boldsymbol{k}(\boldsymbol{\rho}) = \frac{2\pi}{\lambda} \frac{\boldsymbol{r'} - \boldsymbol{r}}{|\boldsymbol{r'} - \boldsymbol{r}|^2}$
- Obtaining the phase by the stationary phase assumption $\boldsymbol{\kappa}(\boldsymbol{\rho}) = \nabla \psi(\boldsymbol{\rho})$

Simulation with the Functional Embodiment





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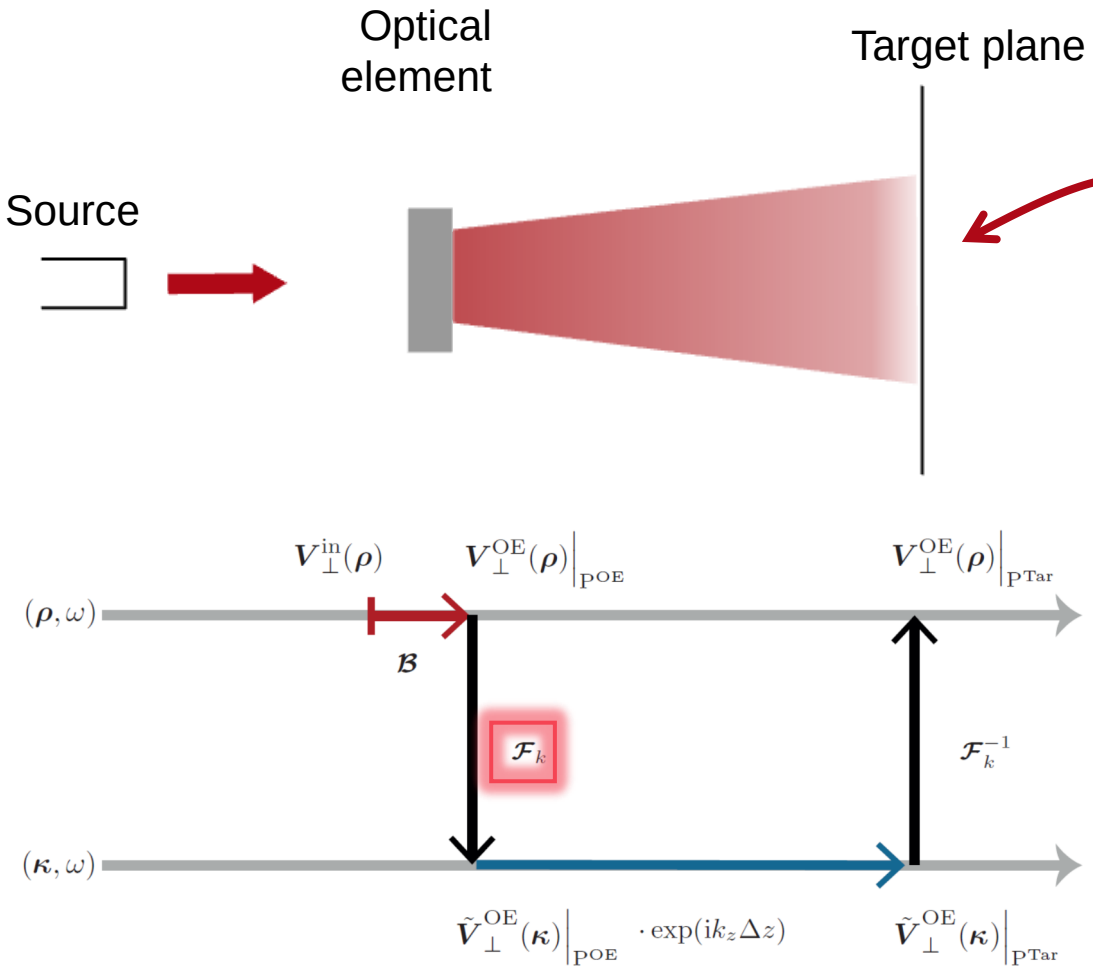
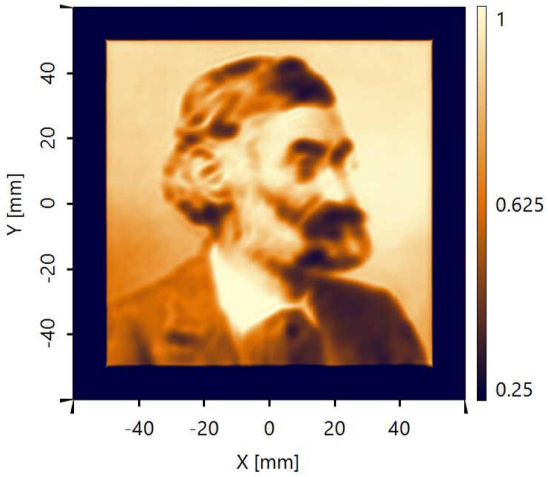


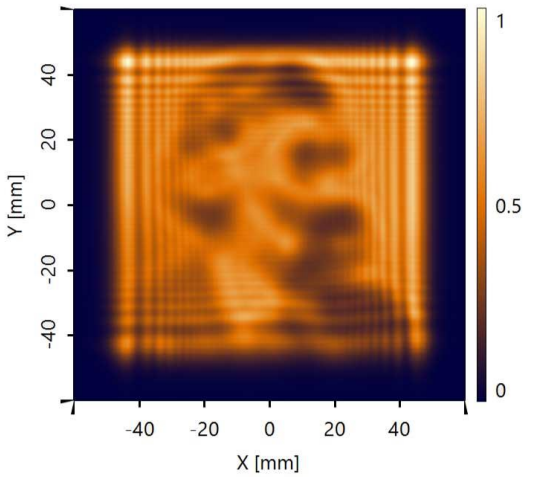
- diffraction effect appears obviously
- homeomorphism assumption fails

irradiance



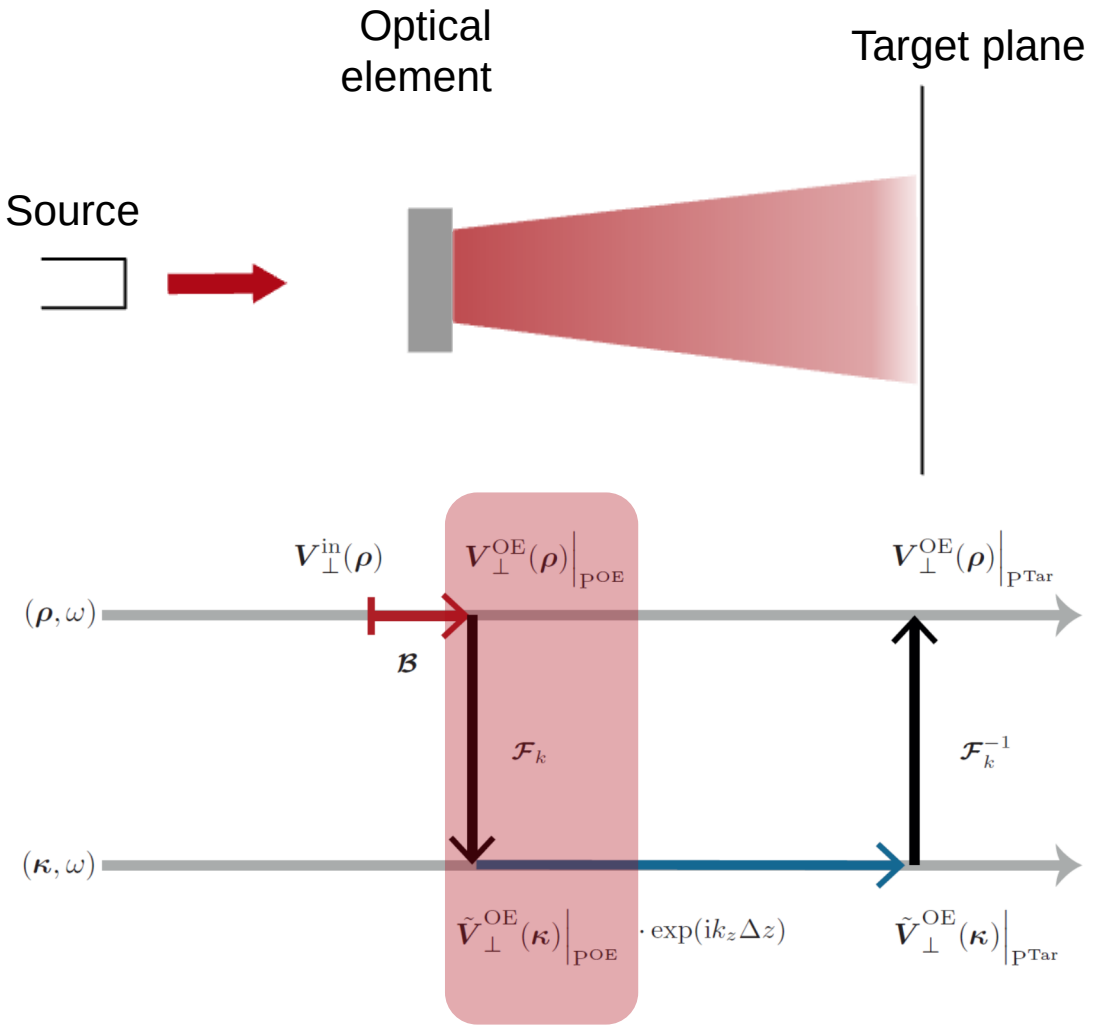
simulation with HFT

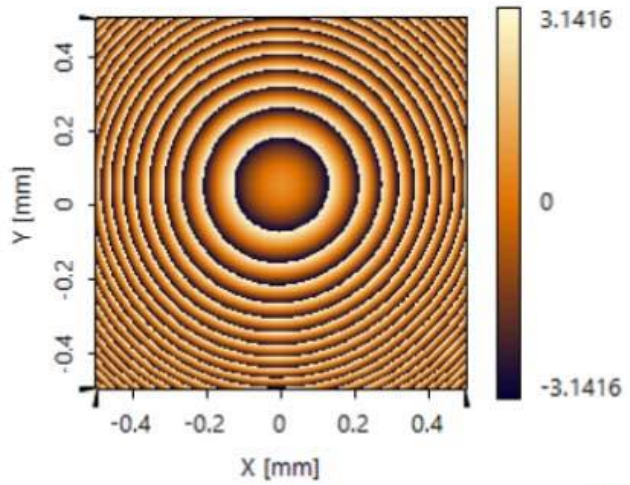
irradiance



simulation with rigorous Fourier transform

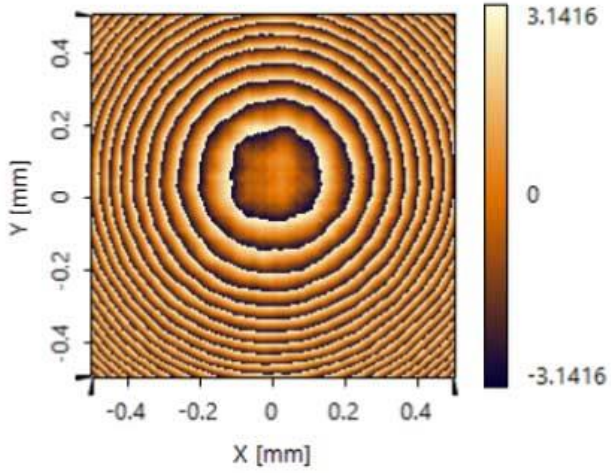
Iterative Fourier Transform Algorithm (IFTA) Optimization





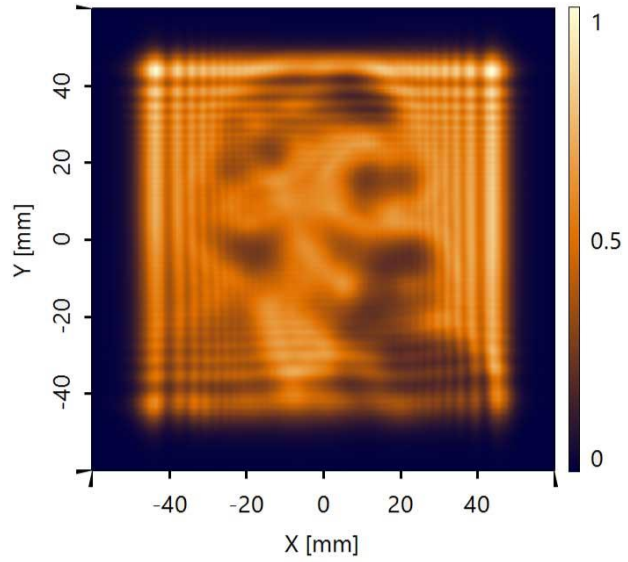
~200 iterations

IFTA



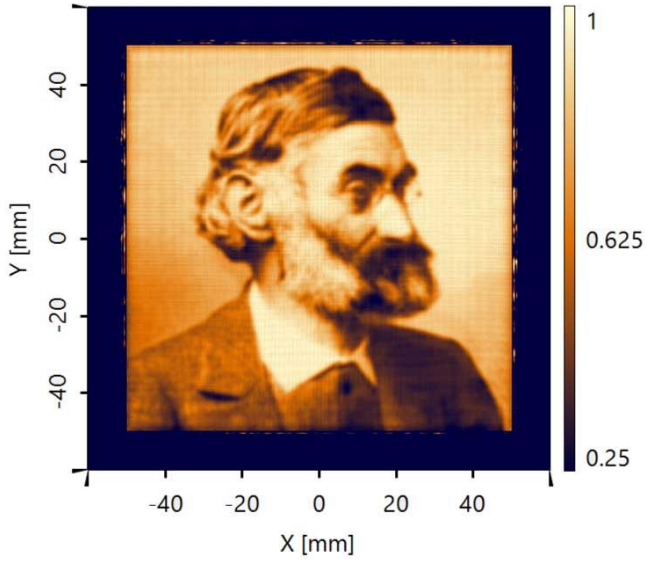
Comparison of the Result

irradiance



before optimization

irradiance



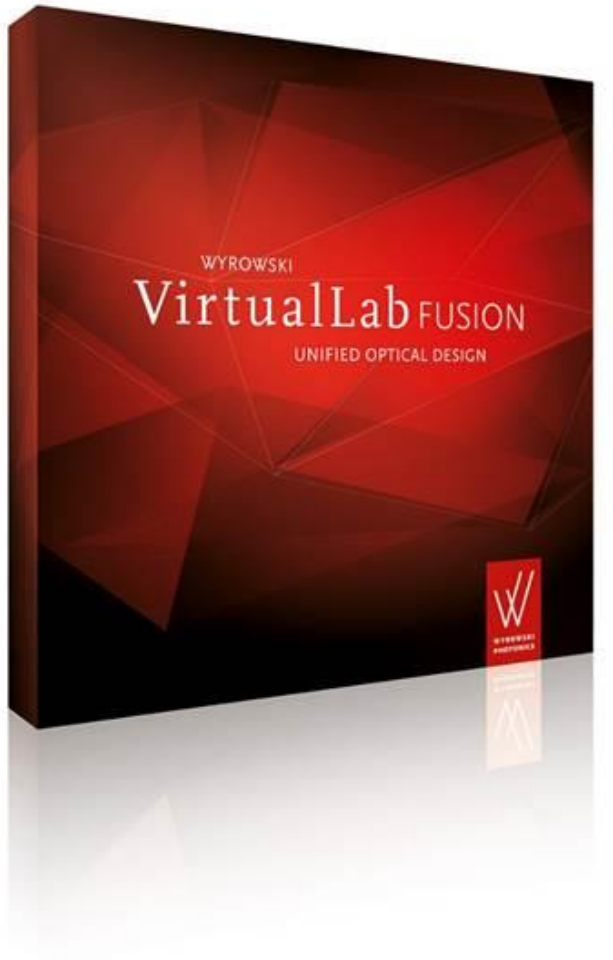
after optimization

Conclusion

- Algorithms working under the homeomorphic assumption provide a fast way to design an optical element for light shaping.
- However, from a physical-optics point of view, the critical point for determining the validity of the design result is whether the accuracy of the HFT applied in the field tracing is high enough.
- If the homeomorphic assumption fails, the light-shaping task cannot be fulfilled by a component designed with those geometric-based algorithms.
- The designed result start with the assumption is well-introduced initial guess for further optimization with the iterative Fourier transform algorithm (IFTA).

Implementation

- All algorithms are implemented in the physical optics simulation and design software **VirtualLab Fusion**
- VirtualLab Fusion is developed, following the field tracing concept, by Wyrowski Photonics UG, Jena, Germany



Thank You!