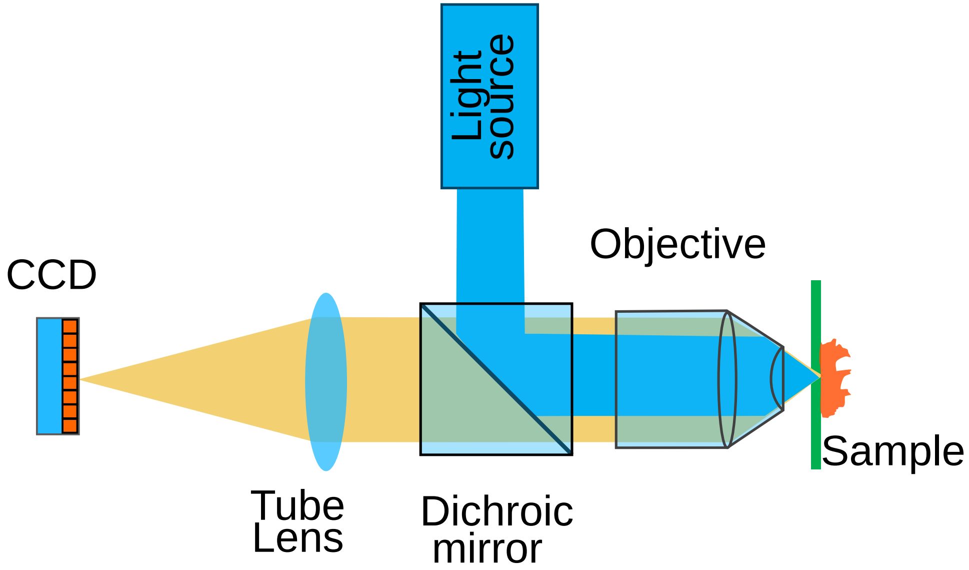
Fast Physical-Optics Modeling of Microscopy System with Structured Illumination

Rui Shi[1,2], Norik Janunts[4], Rainer Heintzmann[4], Christian Hellmann[3], and Frank Wyrowski[1]

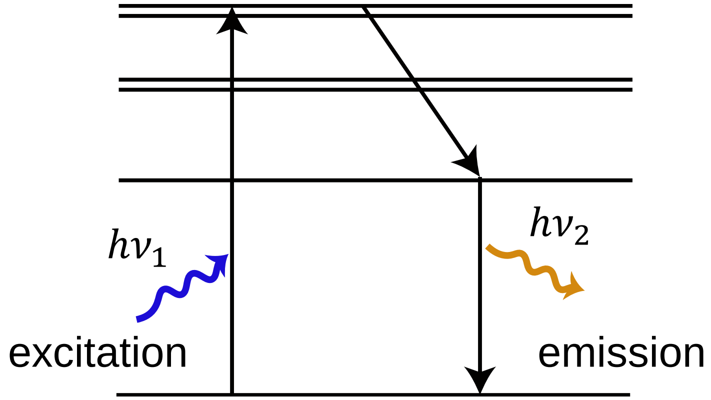
[1] Applied Computational Optics Group, Friedrich Schiller University Jena, Jena, Germany,
[2] LightTrans International UG, Jena, Germany,
[3] Wyrowski Photonics UG, Jena, Germany,
[4] Biomedical Imaging Group, Leibniz Institute of Photonic Technology (IPHT), Jena, Germany

Background

- One-photon florescence microscopy



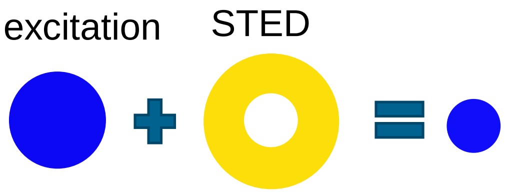
Joblonski Diagram

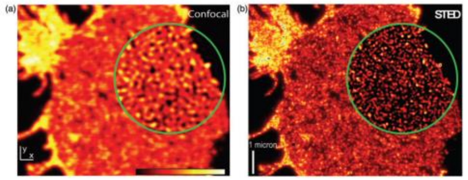


Background: Higher Resolution

STED

[Hell et al., **Opt. Lett**. (1994)]



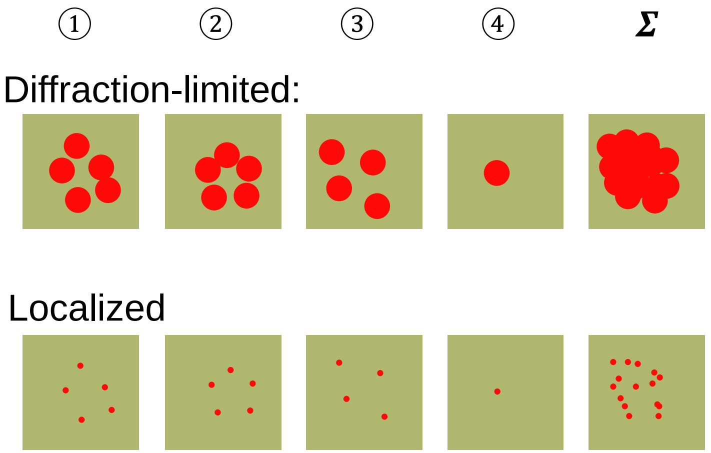


[Heintzmann et al., **Brief Funct Genomic Proteomic**(2006)]

- resolution: ~20 nm
- high power

STORM

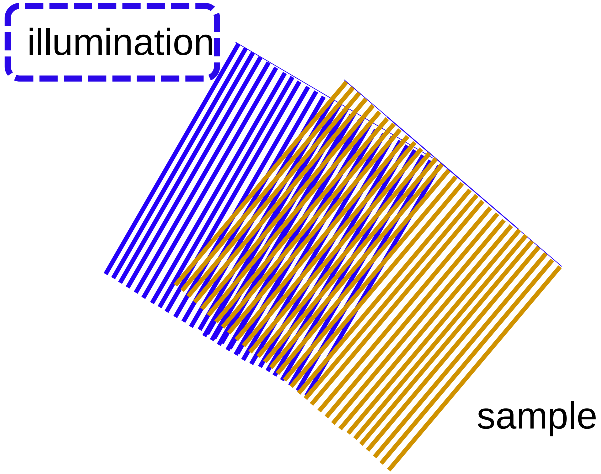
[Betzig et al., **Science** (2006)]



- resolution: ~20 nm
- low speed

SIM

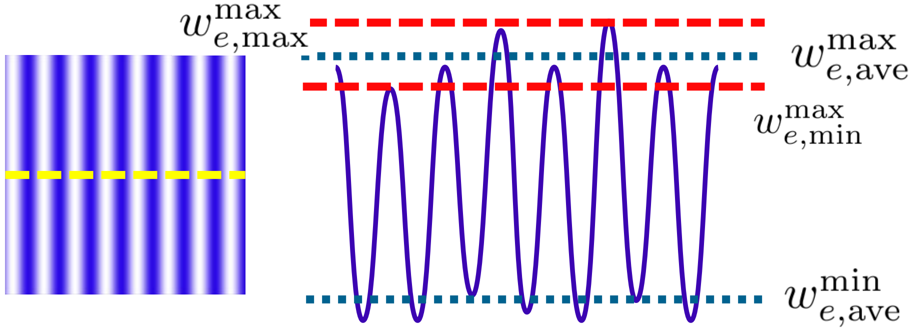
[Heintzmann et al.,**Proc. SPIE** 1998]
[Gustafsson, **J. Microsc**(2000)]



- resolution: ~80 nm
- low power and high speed

living cell

Motivation and Configuration



- Electric energy density

$$w_e \propto \| \boldsymbol{E} \|^2$$

- Contrast：

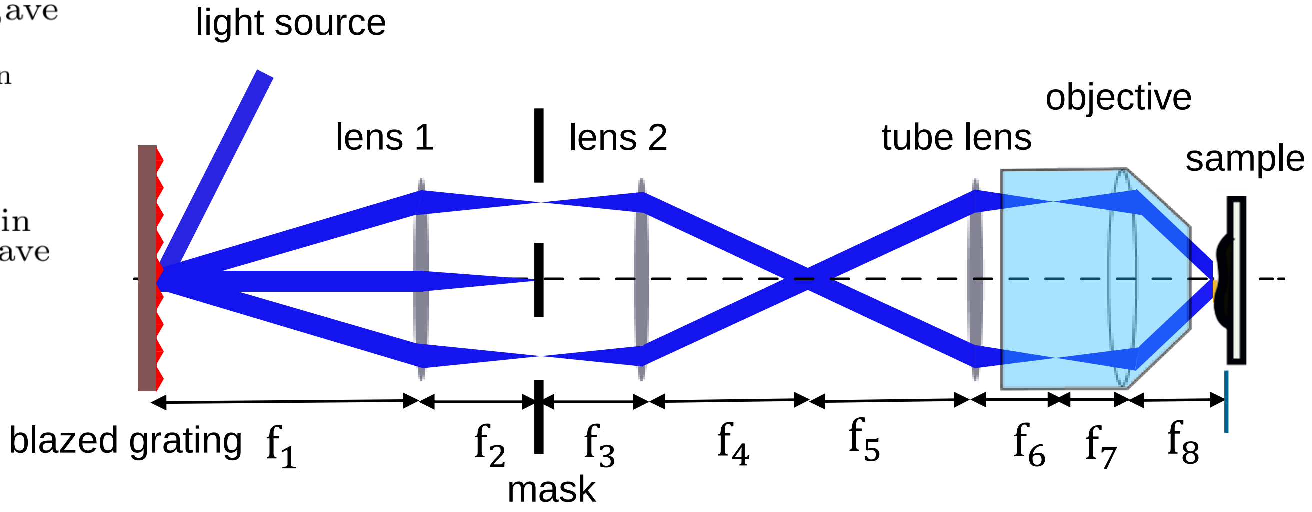
$$c = \frac{w_{e,\text{ave}}^{\max} - w_{e,\text{ave}}^{\min}}{w_{e,\text{ave}}^{\max} + w_{e,\text{ave}}^{\min}}$$

Best: $c = 1$

- Homogeneity：

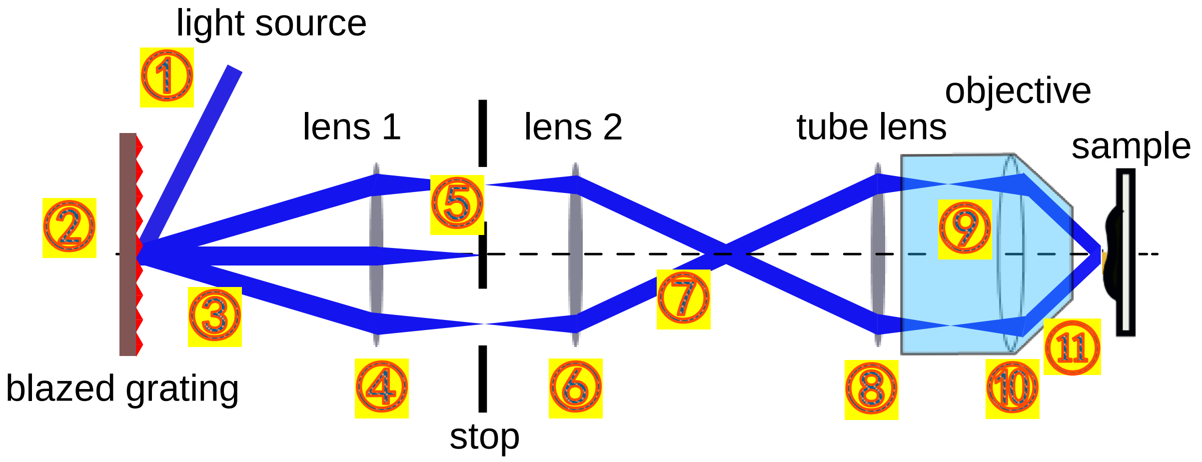
$$\sigma = \frac{w_{e,\max}^{\max} - w_{e,\min}^{\max}}{w_{e,\max}^{\max} + w_{e,\min}^{\max}}$$

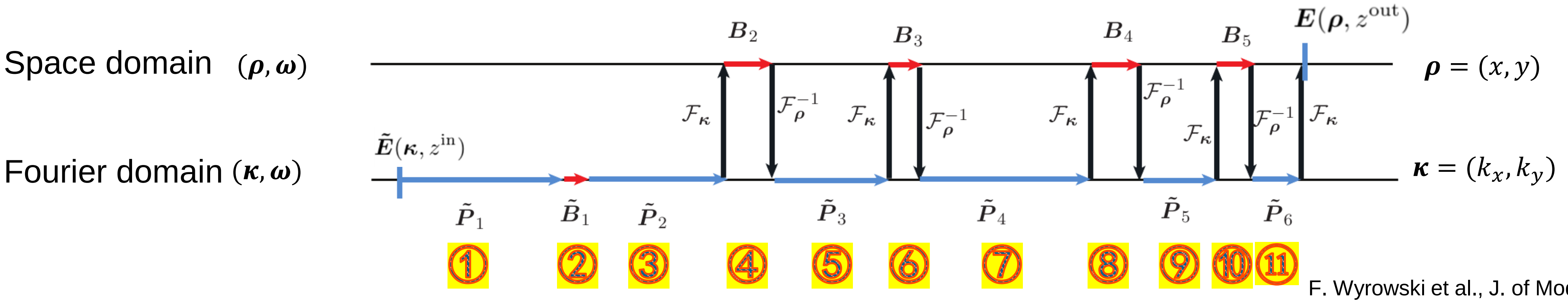
Best: $\sigma = 0$



- Polarization
- Diffraction from aperture
- Inclined illumination on blazed grating

Theory: Field Tracing





Free space propagation	Fourier Modal Method(FMM)	Local Plane Interface Approximation(LPIA)
1 3 5 7 9 11	2	4 6 8 10

F. Wyrowski et al., J. of Modern Optics (2011)
S. Zhang et al. Appl. Opt. (2016)
M. G. Moharam et al. Opt. Soc. Am. A (1995)
F. Wyrowski and C. Hellmann.. Proc. DGaO (2017)
A. Pfeil et al., Appl. Opt. (2000)

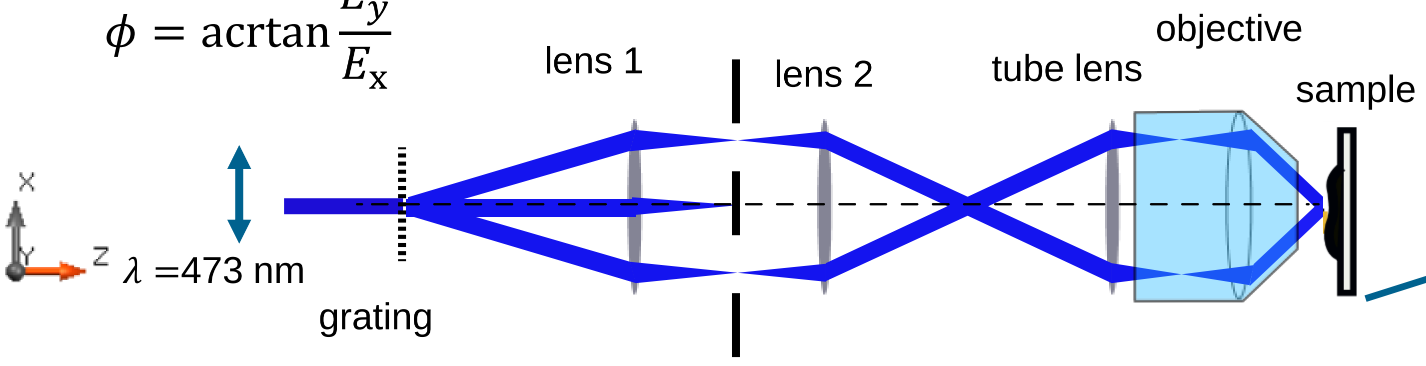
The concept of **bidirectional operators** and its application to the modelling of microstructures Paper 10694-15, **Prof.Frank Wyrowski**

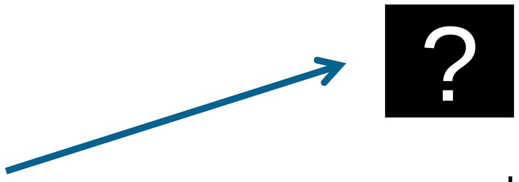
Simulation Results via VirtualLab Fusion

Polarization

Modeling Task

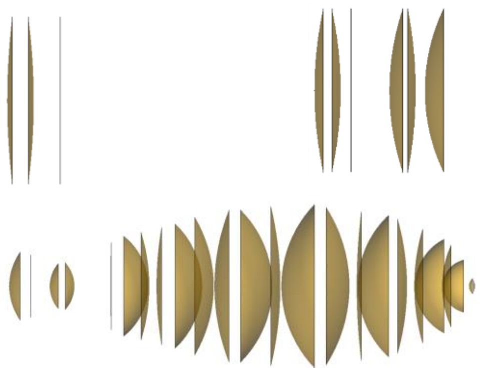
$$\phi = \text{acrtan}\frac{E_y}{E_x}$$





- energy density: w_e
- contrast: c

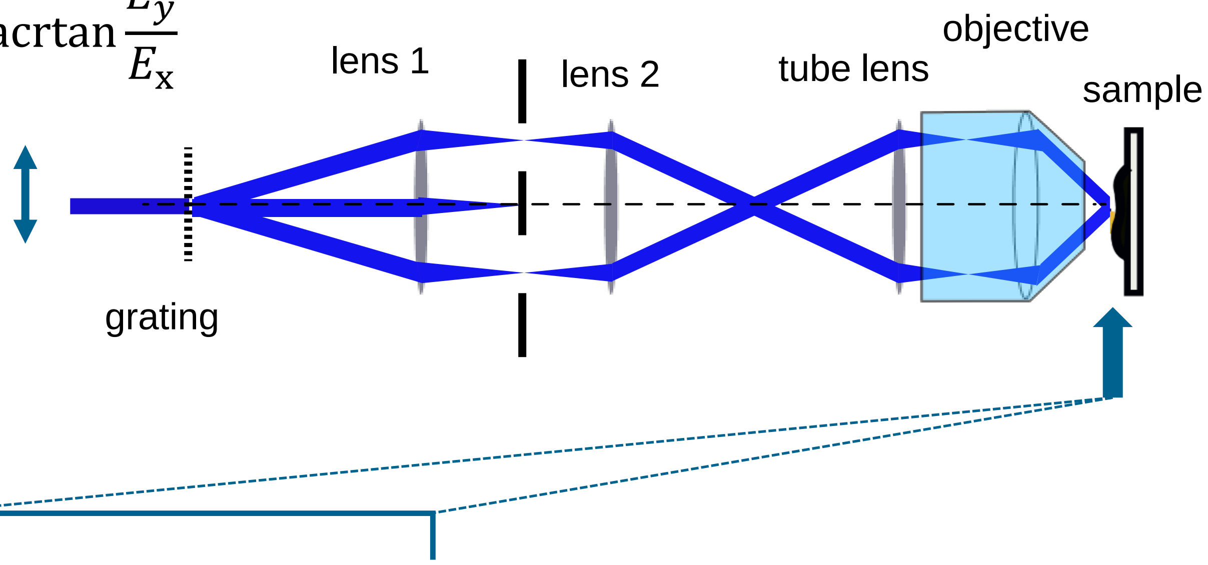
Lens	Property
lens 1, 2	Thorlab AC254 double achromat
Tube lens	Nikon 200 mm
Objectives	Nikon 60X, NA=1.4, Effective NA: ~1.12 apochromatic



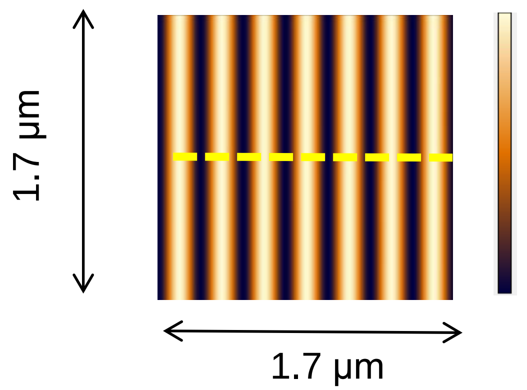
J. A. Kurvits et al., J. Opt. Soc. Am. (2015)

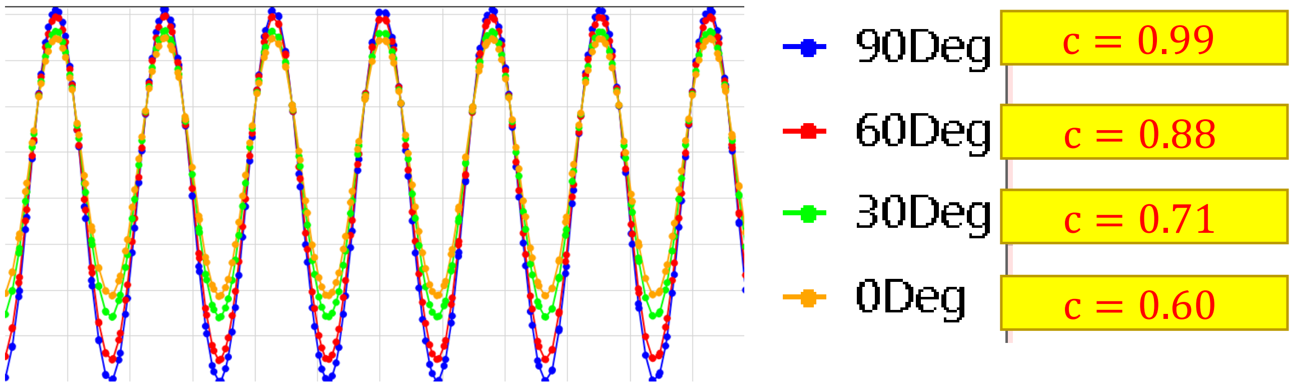
Result: Energy Density

$$\phi = \mathrm{acrtan}\frac{E_y}{E_x}$$



$\phi = 90°$

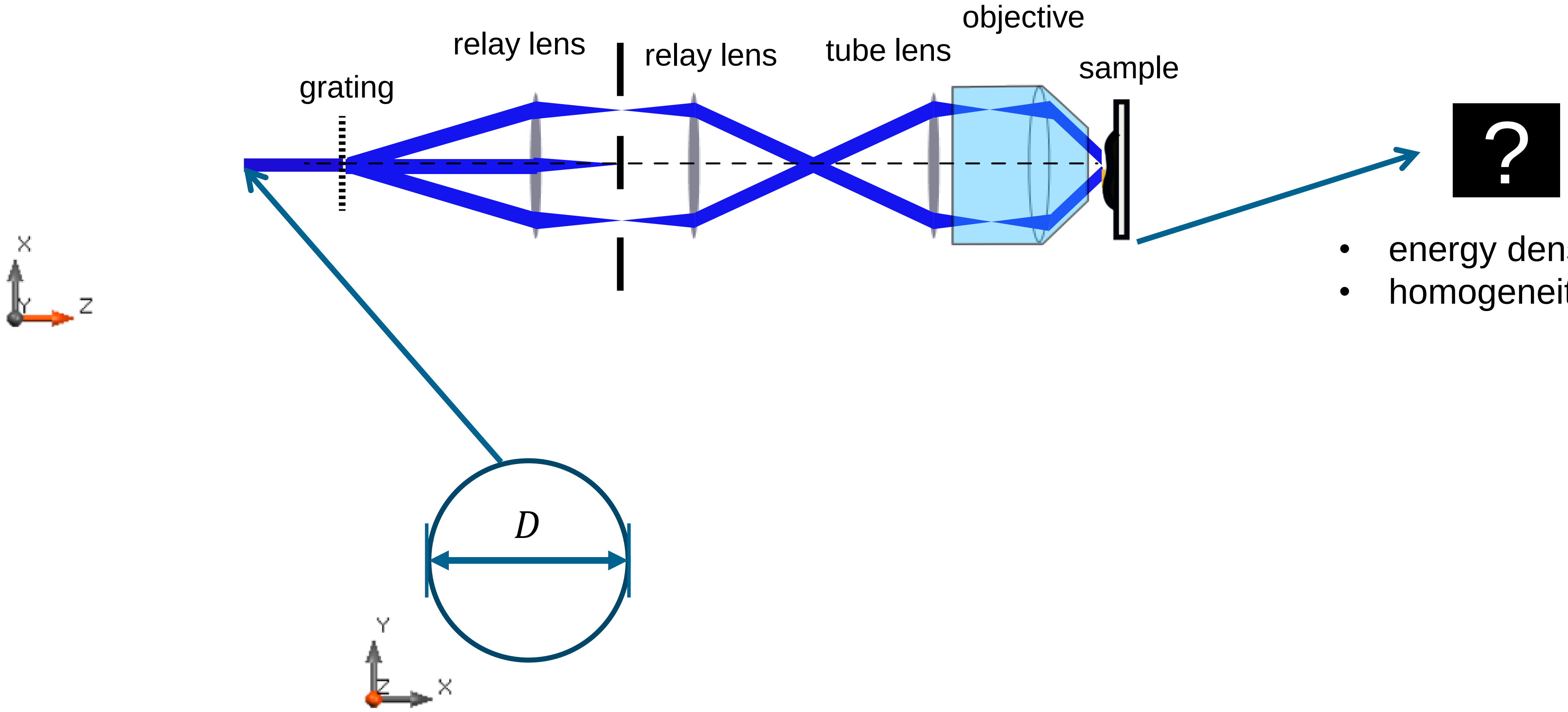




Simulation time: ~5 s

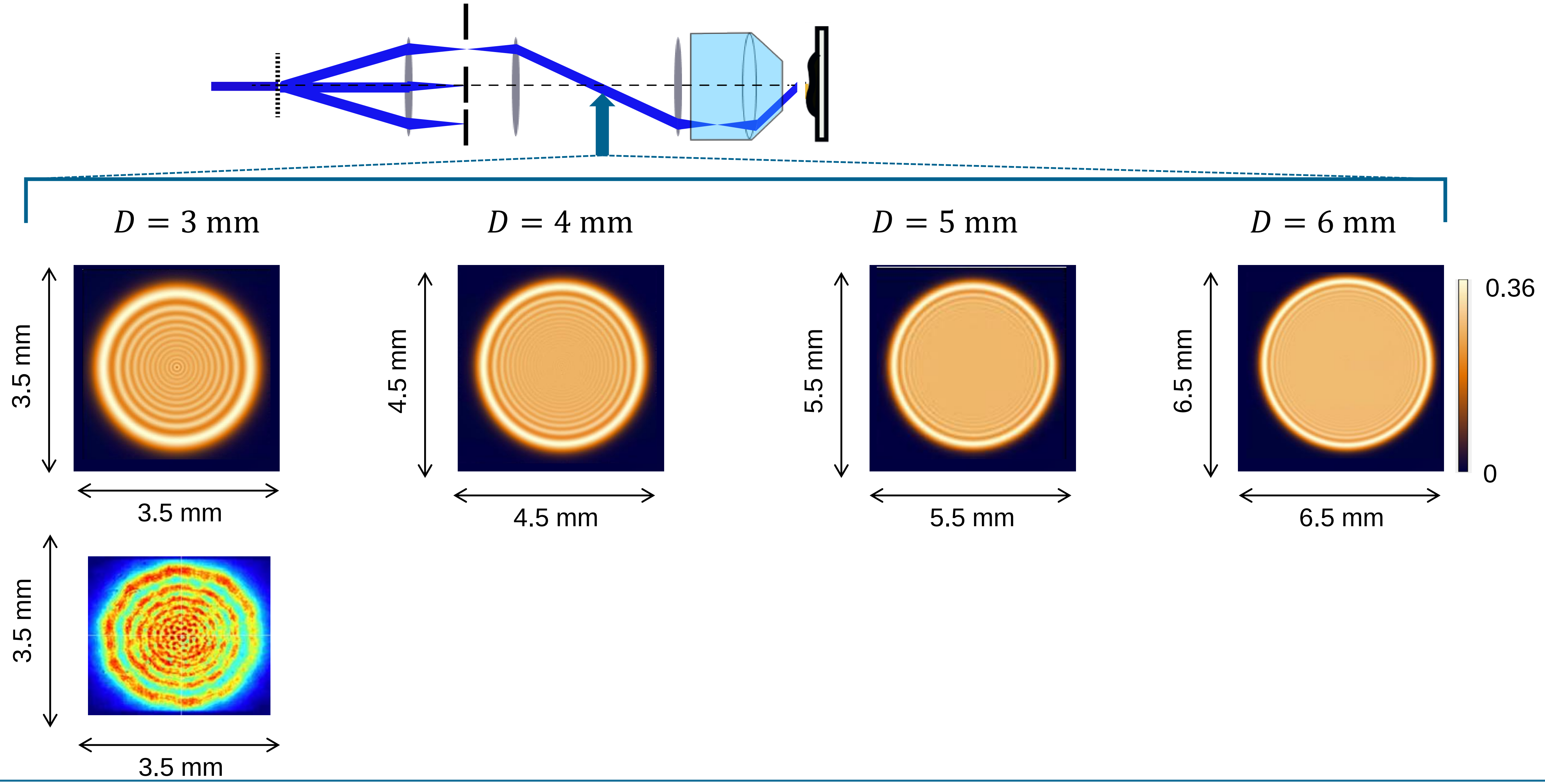
Diffraction from Aperture

Modeling Task

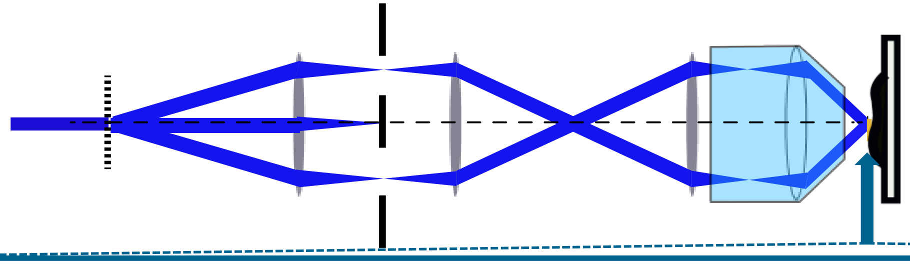


- energy density: w_e
- homogeneity: σ

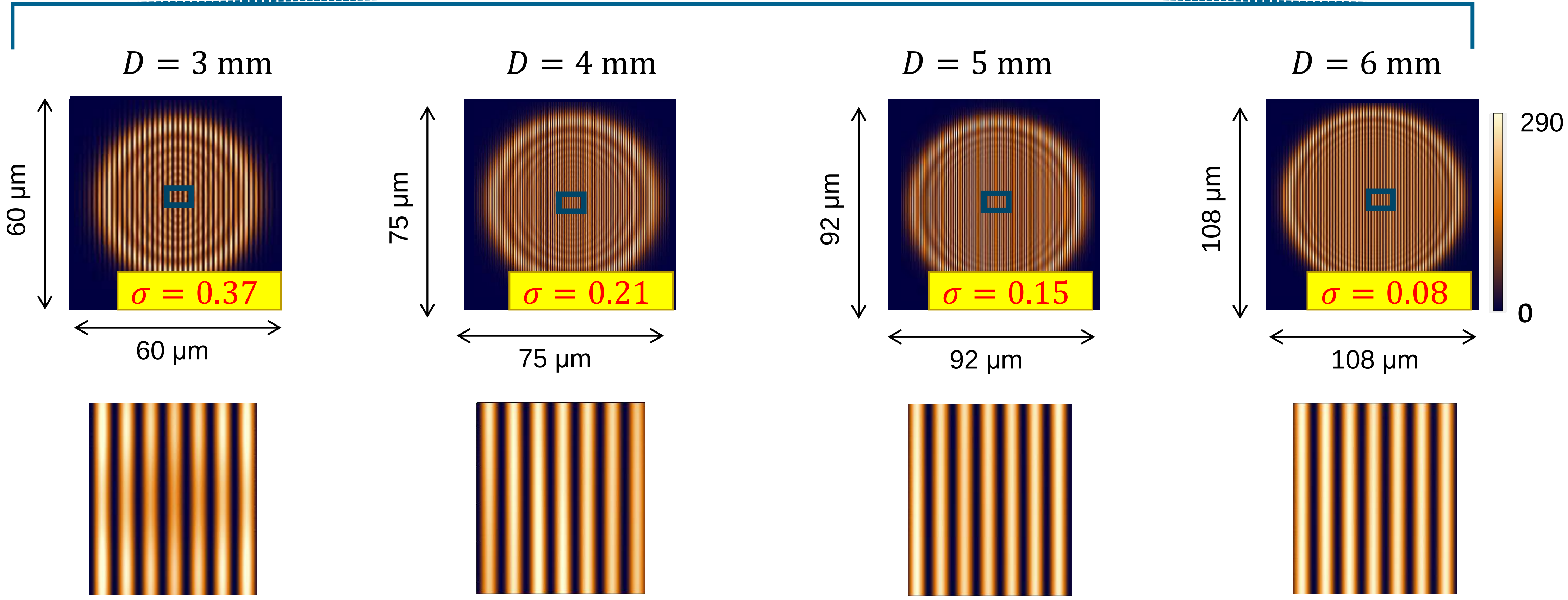
Result: Energy Density



Result: Energy Density and Homogeneity

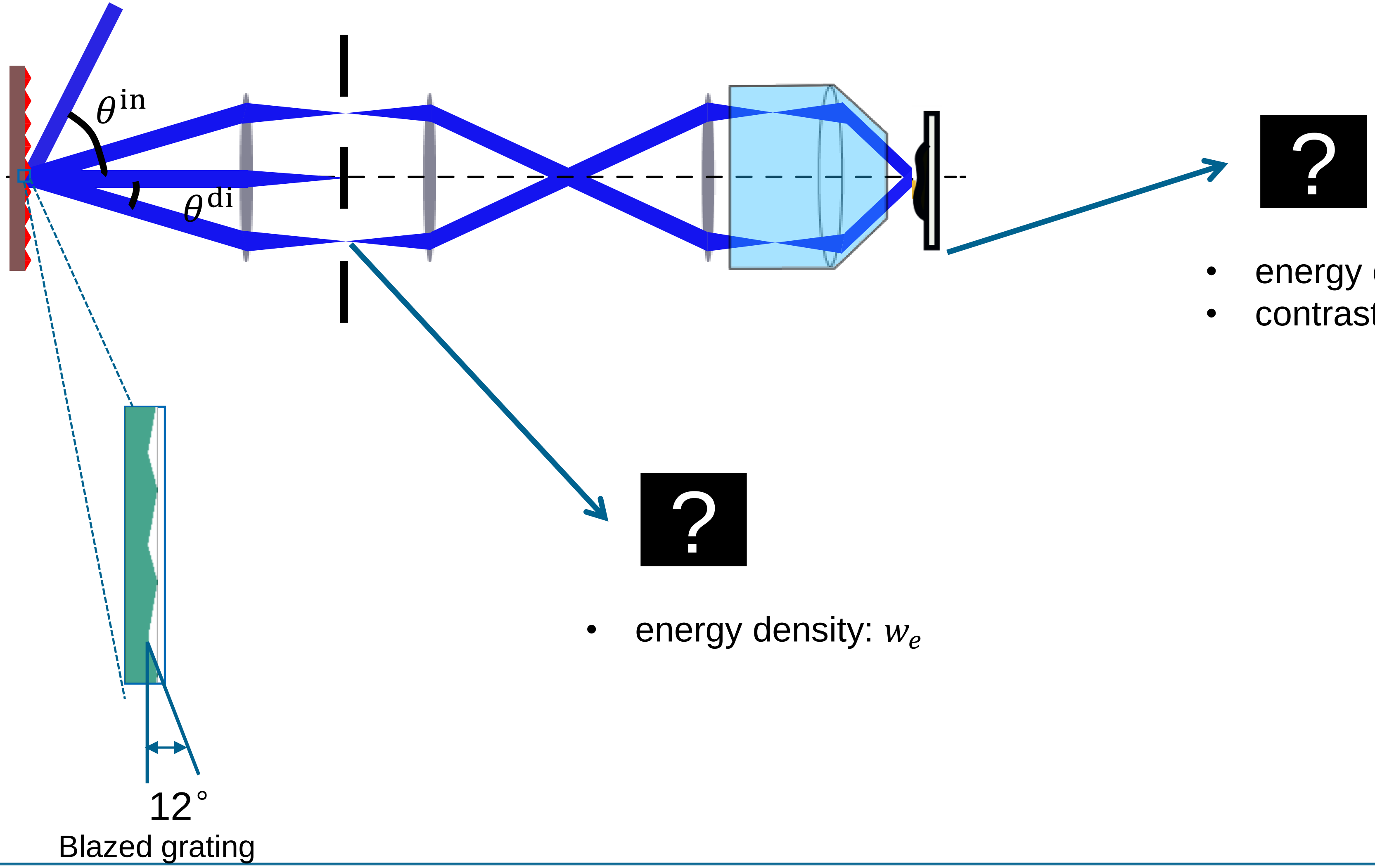


Simulation time: ~27s



Inclined Illumination on Blazed Grating

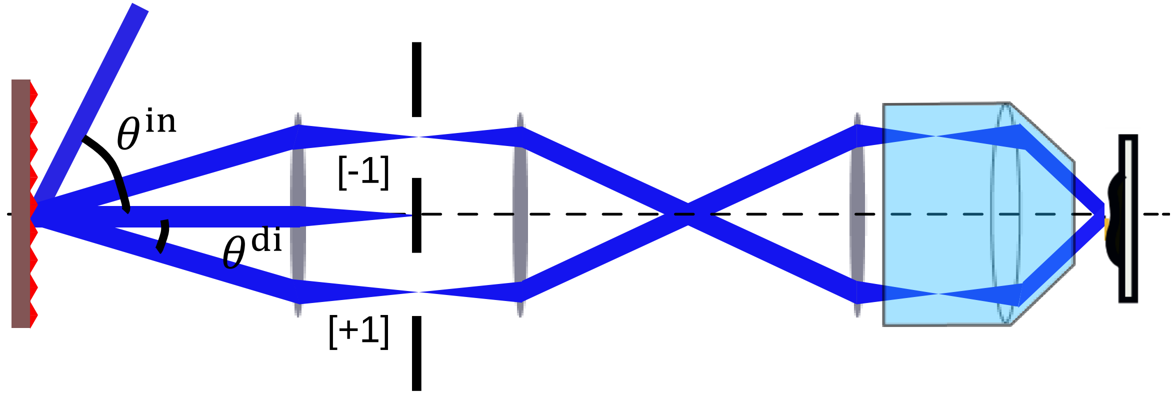
Modeling Task



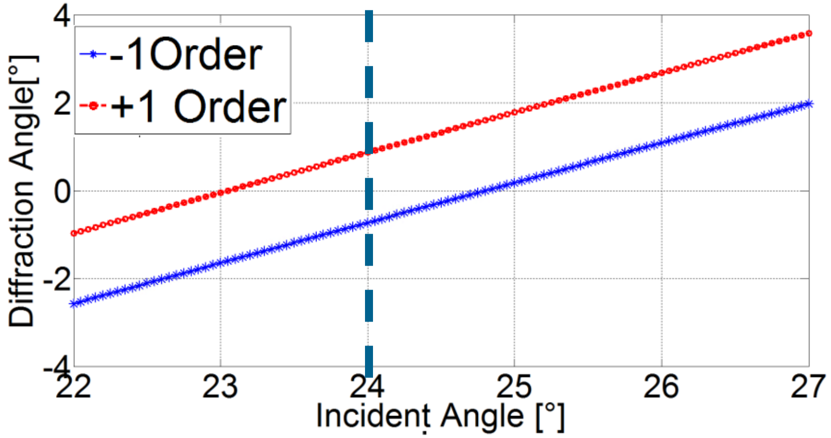
- energy density: w_e
- contrast: c

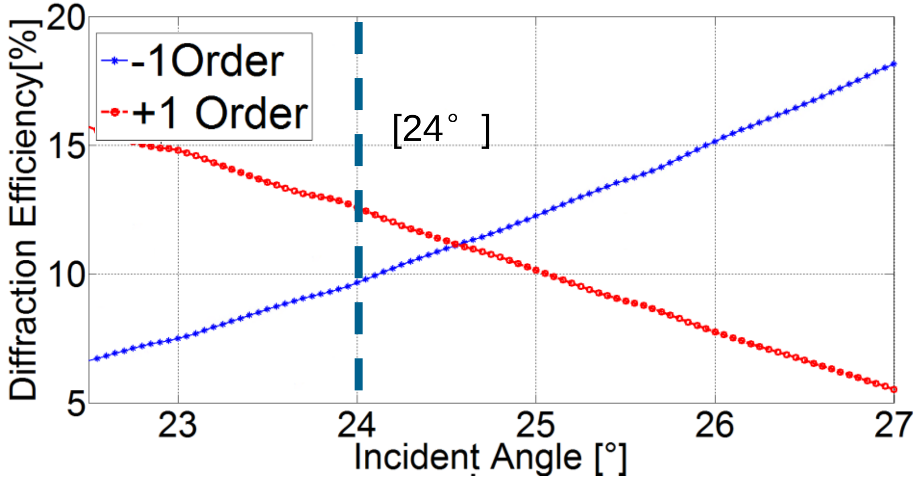
- energy density: w_e

Result: Diffraction Angle and Efficiency

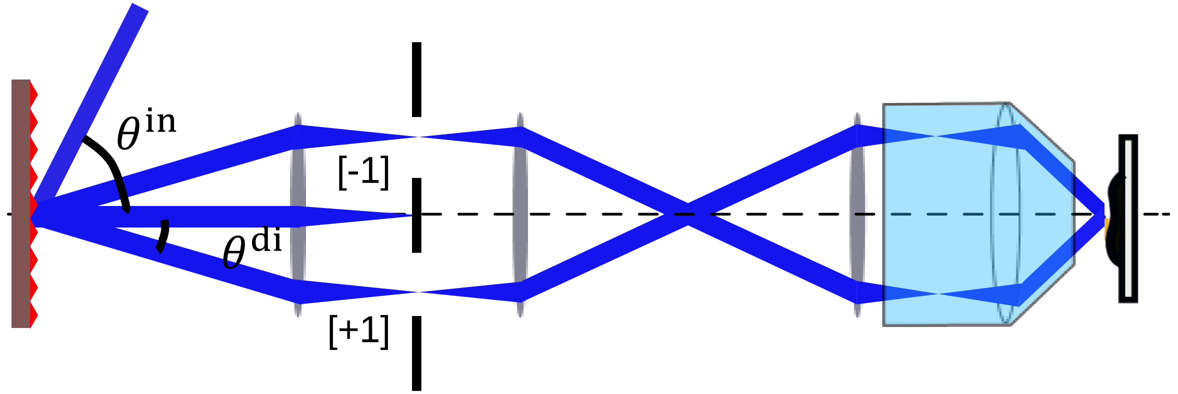


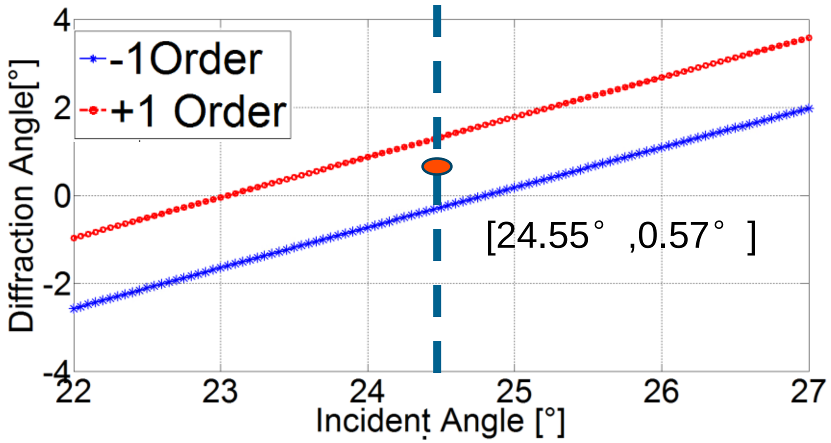
Calculated by FMM

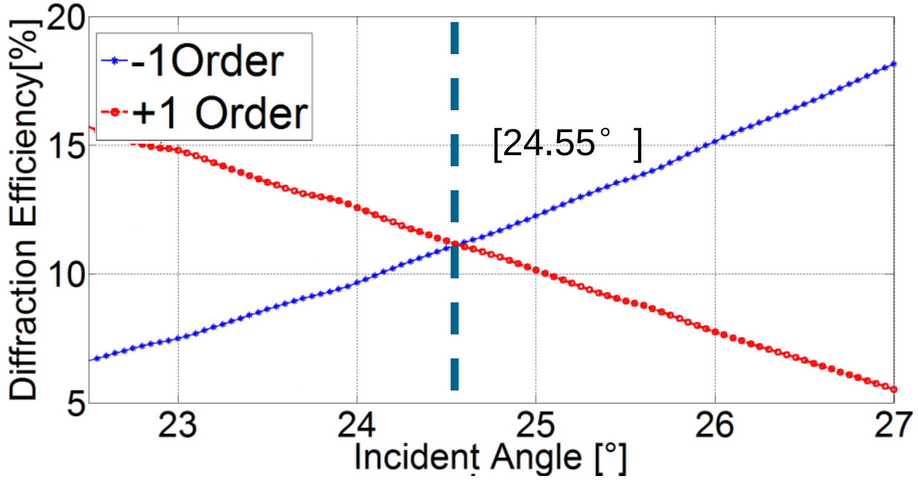




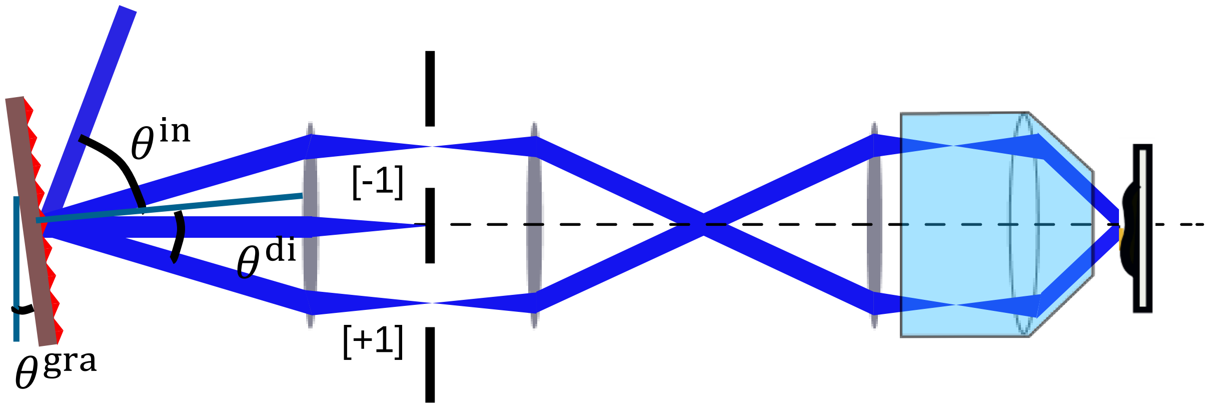
Result: Diffraction Angle and Efficiency

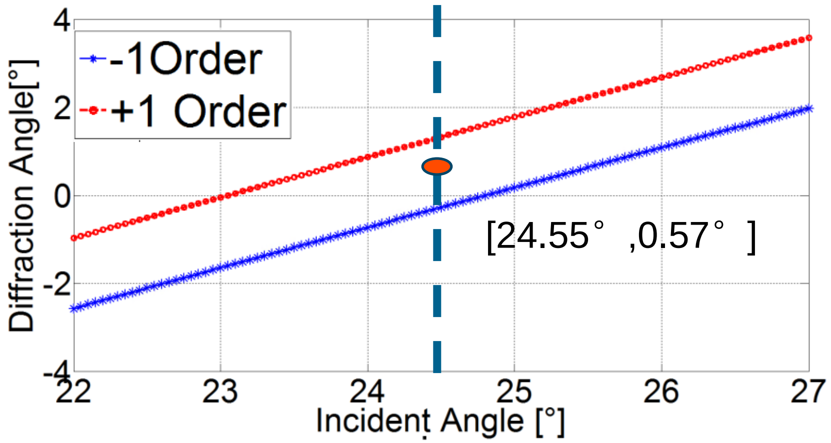


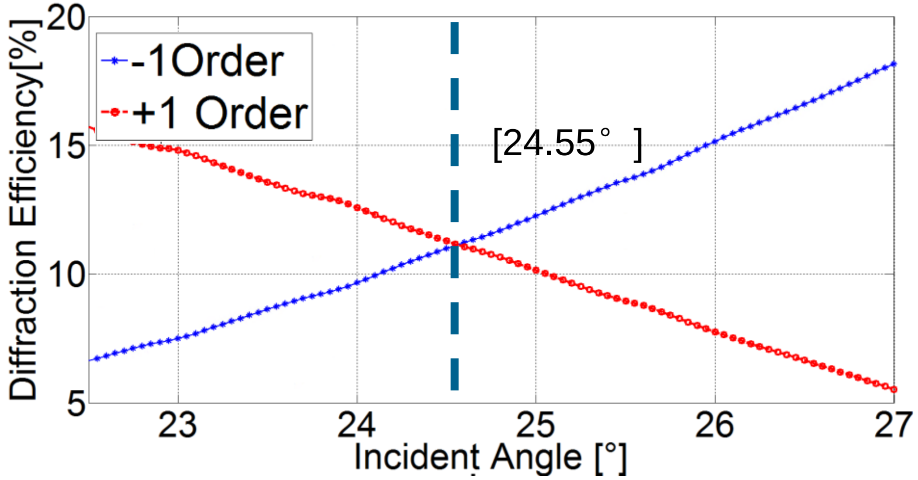




Result: Diffraction Angle and Efficiency

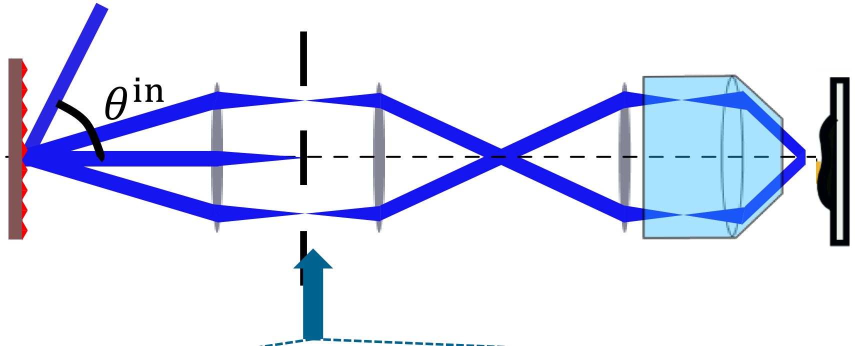


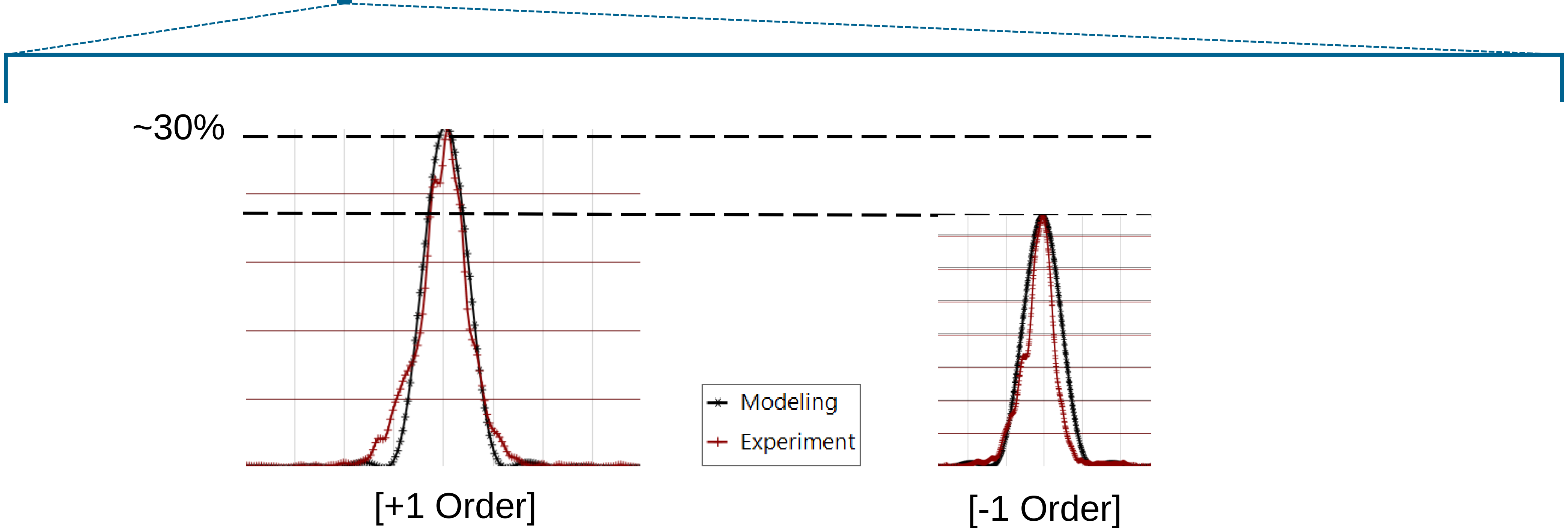




Results: Energy Density

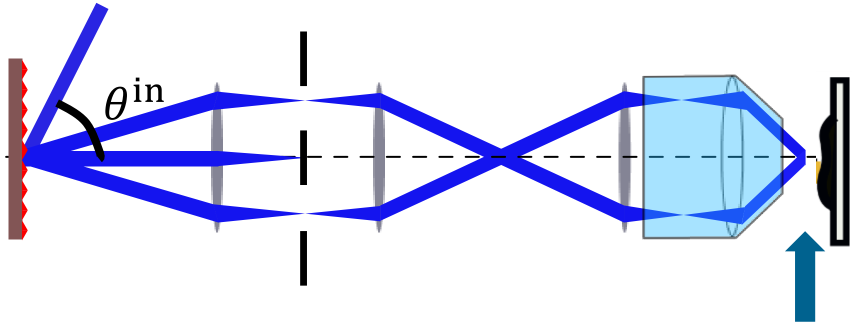
θ^{in}=24°

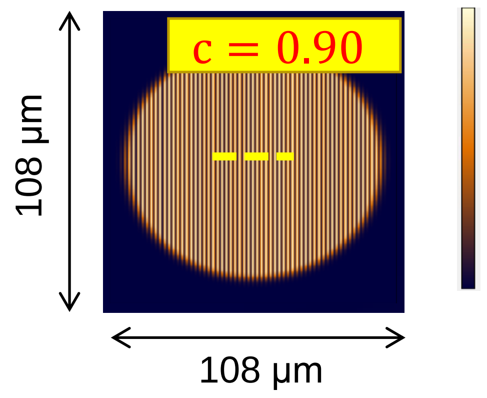


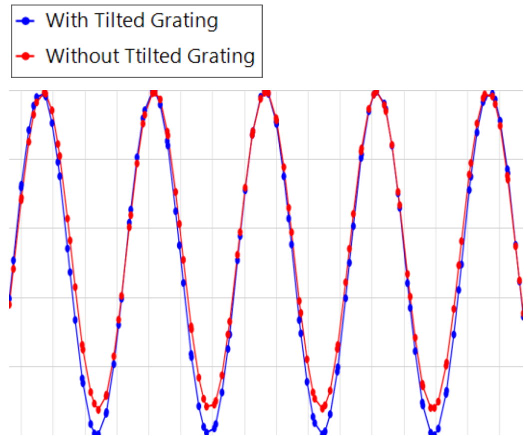


Results: Energy Density

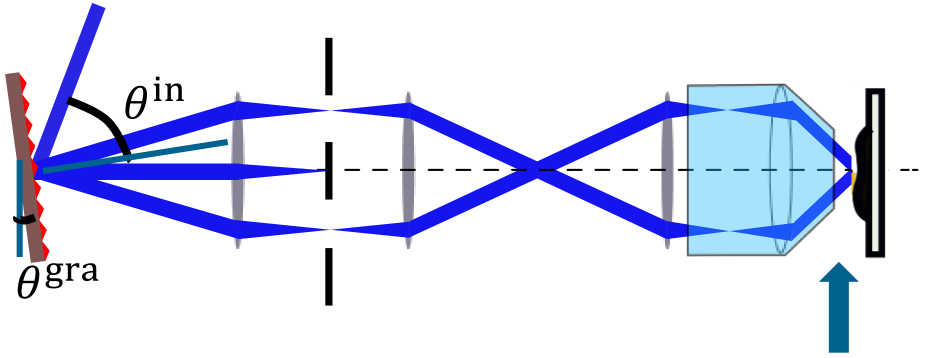
θ^{in}=24°

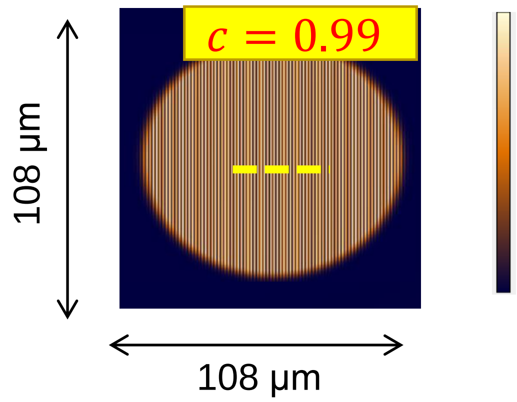






[$\theta^{\text{in}}, \theta^{\text{gra}}$]= [24.55° ,0.57°]





Conclusion and Outlook

- The complexity of microscopy system with structured illumination makes it vulnerable to the undesired effects which causes the inhomogeneity and low contract of the interference pattern.
- These effects should be analyzed and taken into account in the image reconstruction algorithm.
- In case of deep tissue imaging, adaptive optics can be applied further to compensate the undesired effects.

Thanks!