5 February 2020, Product Demo at Photonics West 2020

Diffractive and Metasurfaces: from Function to Structure Simulation Seamlessly in VirtualLab Fusion

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LightTrans International UG
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Teams

LIGHTTRANS

LightTrans (since 1999)

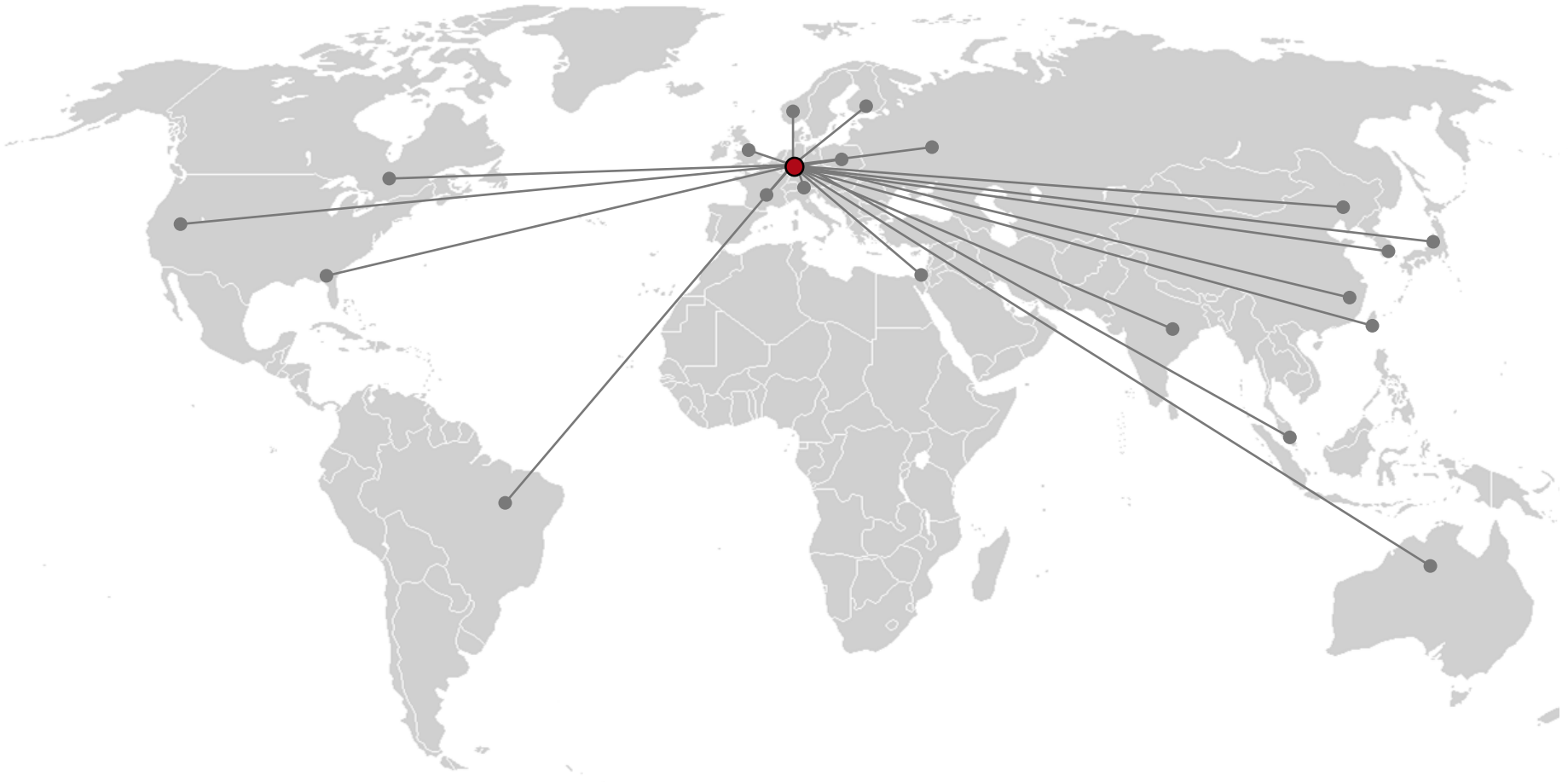
- Optical technologies development
- Technical support, seminars, and trainings
- Engineering projects
- Distribution of VirtualLab Fusion, together with distributors worldwide

WYROWSKI PHOTONICS

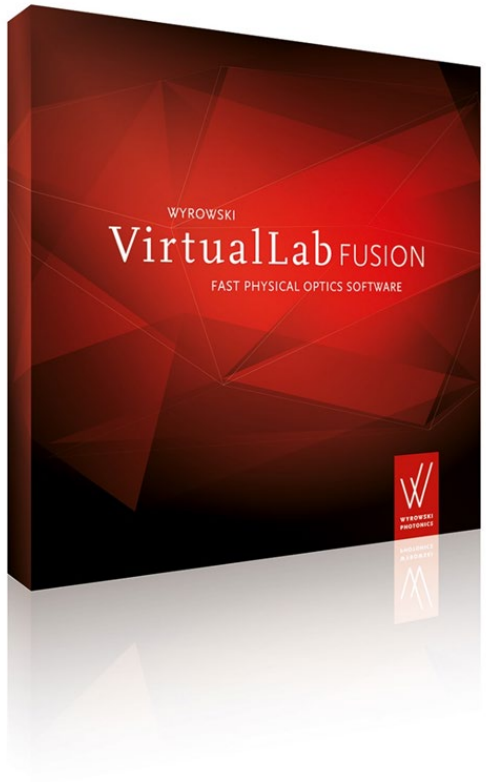
(since 2014)

photo from wikitravel

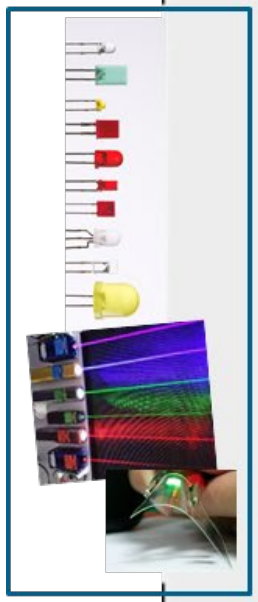
Optical Design Software and Services

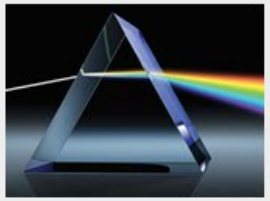


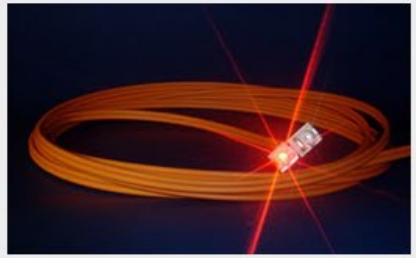
Booth #4545 (German pavilion)



Physical-Optics System Modeling





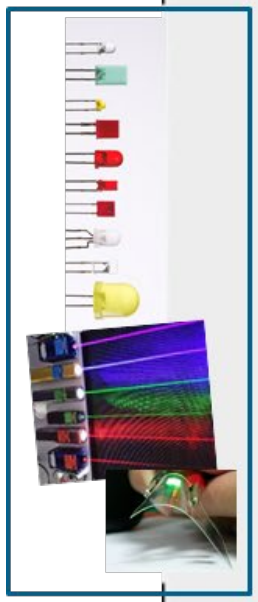


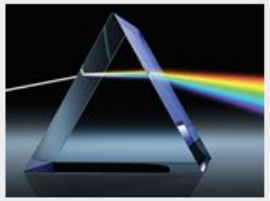
Name	Integral equations	Differential equations
Gauss's law	$\oiint_{\partial\Omega} \mathbf{E}\cdot\mathrm{d}\mathbf{S} = \frac{1}{\varepsilon_0}\iiint_{\Omega}\rho\,\mathrm{d}V$	$\nabla\cdot\mathbf{E} = \frac{\rho}{\varepsilon_0}$
Gauss's law for magnetism	$\oiint_{\partial\Omega} \mathbf{B}\cdot\mathrm{d}\mathbf{S} = 0$	$\nabla\cdot\mathbf{B} = 0$
Maxwell–Faraday equation (Faraday's law of induction)	$\oint_{\partial\Sigma} \mathbf{E}\cdot\mathrm{d}\boldsymbol{\ell} = -\frac{d}{dt}\iint_{\Sigma}\mathbf{B}\cdot\mathrm{d}\mathbf{S}$	$\nabla\times\mathbf{E} = -\frac{\partial\mathbf{B}}{\partial t}$
Ampère's circuital law (with Maxwell's addition)	$\oint_{\partial\Sigma} \mathbf{B}\cdot\mathrm{d}\boldsymbol{\ell} = \mu_0\iint_{\Sigma}\mathbf{J}\cdot\mathrm{d}\mathbf{S} + \mu_0\varepsilon_0\frac{d}{dt}\iint_{\Sigma}\mathbf{E}\cdot\mathrm{d}\mathbf{S}$	$\nabla\times\mathbf{B} = \mu_0\left(\mathbf{J} + \varepsilon_0\frac{\partial\mathbf{E}}{\partial t}\right)$

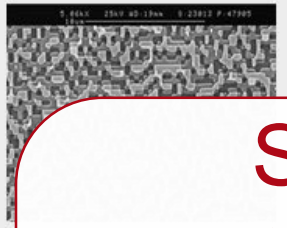
Homogeneous

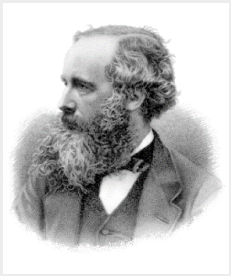
Solve Maxwell's equations for given source field and components.

Physical-Optics System Modeling









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Gauss's law	$\oiint_{\partial\Omega} \mathbf{E}\cdot\mathrm{d}\mathbf{S} = \frac{1}{\varepsilon_0}\iiint_{\Omega}\rho\,\mathrm{d}V$	∇
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Maxwell–Faraday equation (Faraday's law of induction)	$\oint_{\partial\Sigma} \mathbf{E}\cdot\mathrm{d}\boldsymbol{\ell} = -\frac{d}{dt}\iint_{\Sigma}\mathbf{B}\cdot\mathrm{d}\mathbf{S}$	$\nabla\times$
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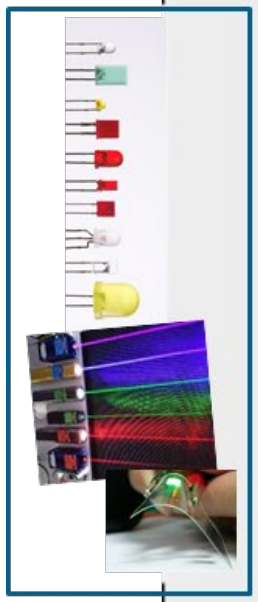
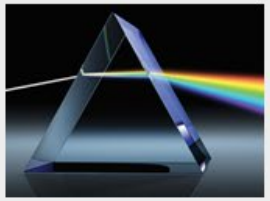
Homogen

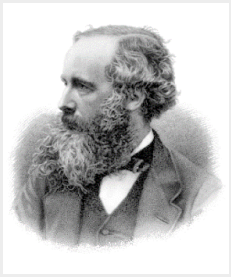
eous medium, like air or vacuum

Solution of Maxwell's equations with one field solver, e.g. FEM, FMM, or FDTD, for entire system not feasible because of numerical effort!

Physical-Optics System Modeling







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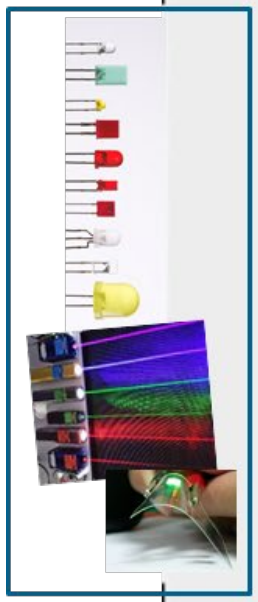
Homog

How to obtain a reliable and fast physical optics solution - whenever possible?

Connecting Optical Technologies / Maxwell Solvers



Field Solver Lenses, …

Field Solver Prisms, …

Field Solver Gratings, …

Field Solver micro- and nano-structures

Field Solver fibers, …

Homogeneous medium, like air or vacuum

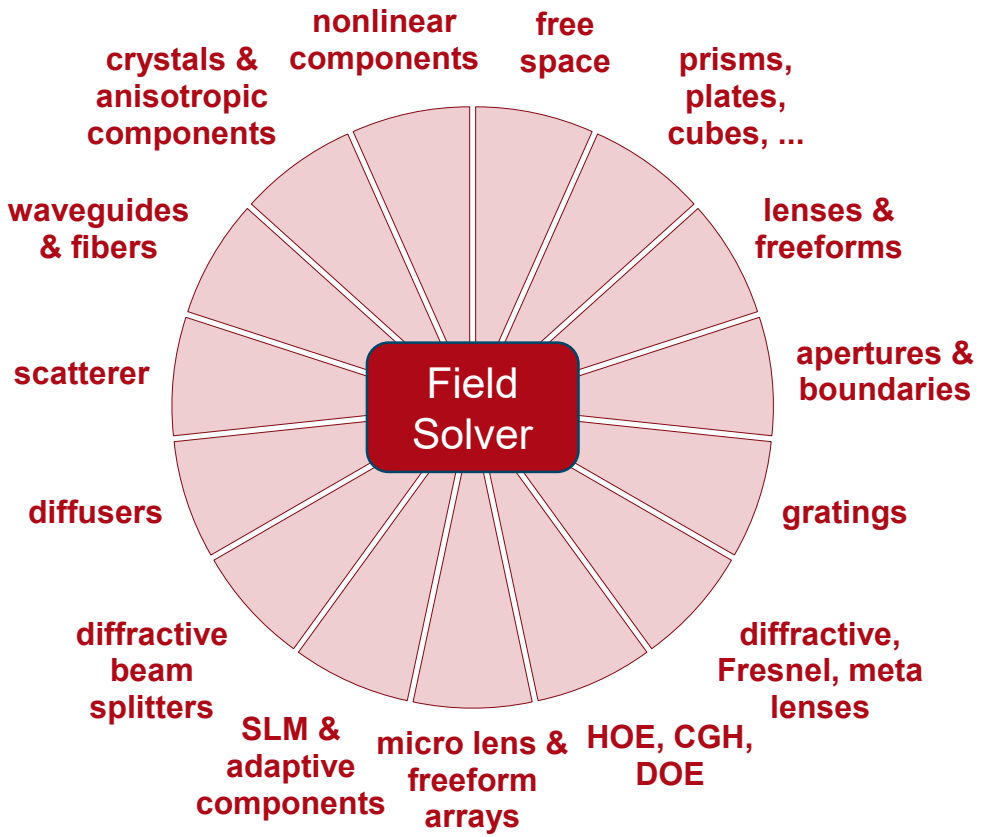
Connecting Optical Technologies / Maxwell Solvers

Problem:

Application of a single field solver, e.g. FEM or FDTD, to the entire system:
Unrealistic numerical effort

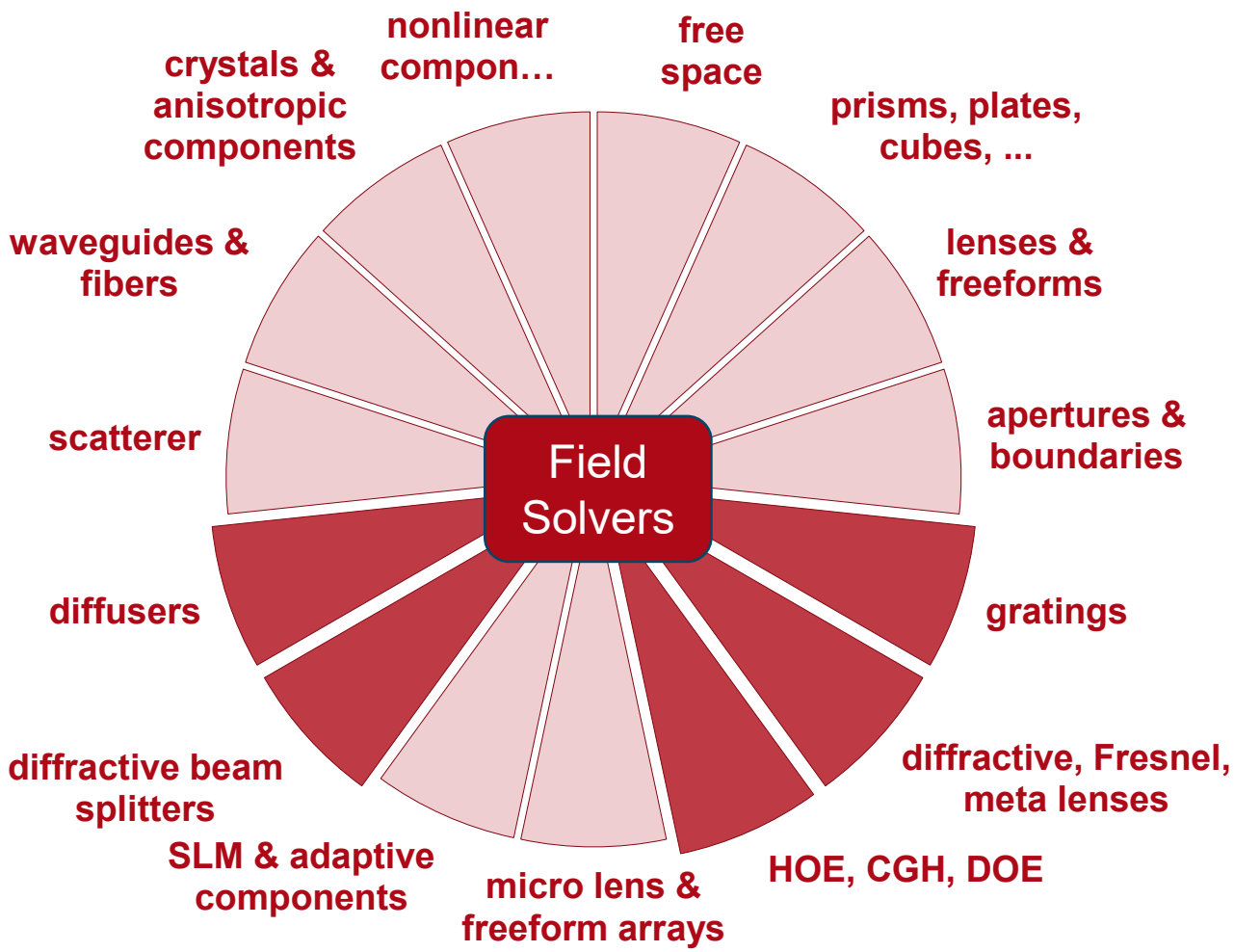
Solution:

- Decomposition of system and application of regional field solvers.
- Interconnection of different solvers and so to solve the complete system.

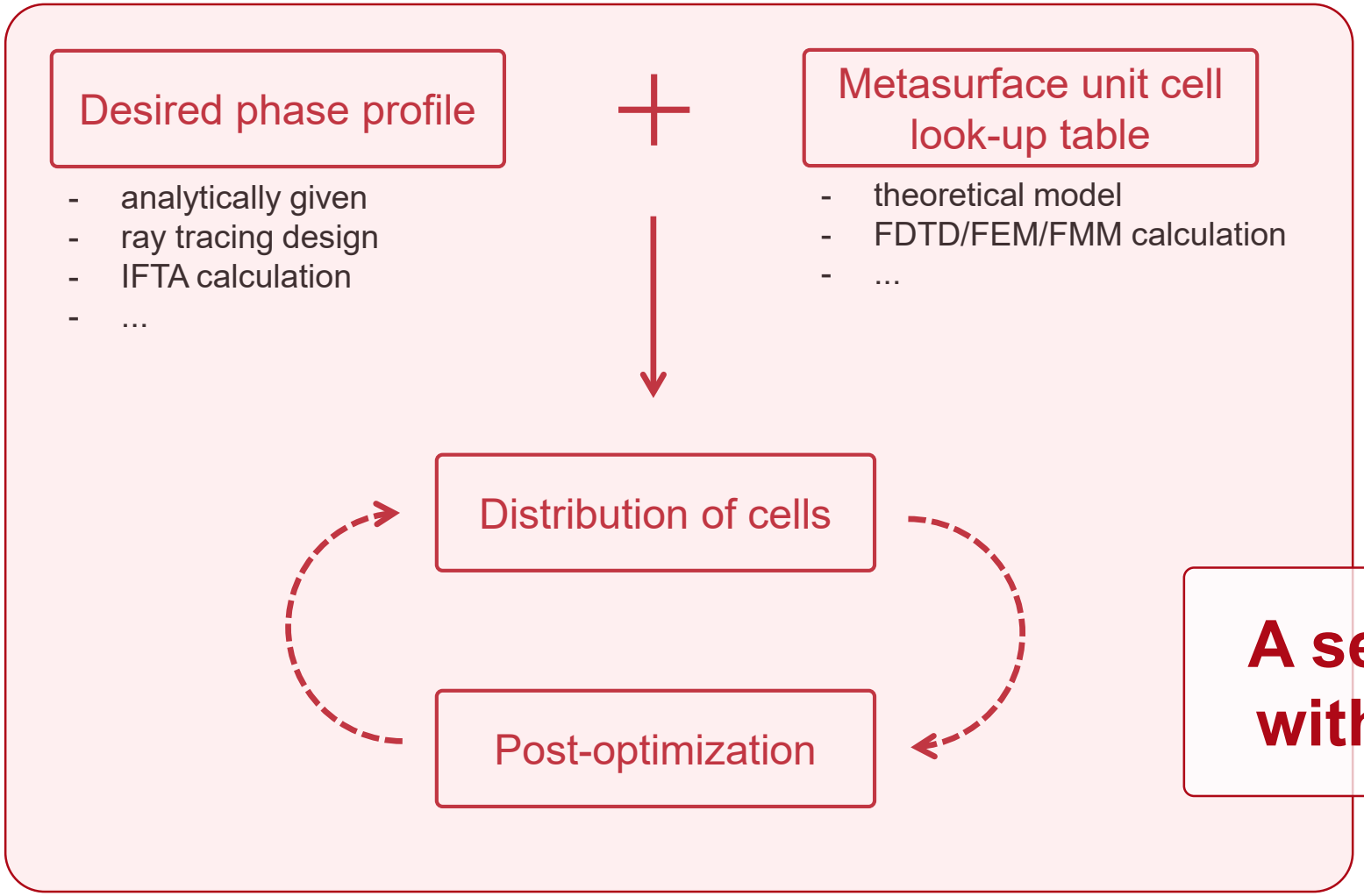


VirtualLab Fusion – Diffractive Optics Applications

Selection of VirtualLab Fusion applications for metasurfaces



General Design Procedure



State-of-the-art: exchange between several different software programms, e.g., ray tracer, FDTD solver, and Matlab ...

A seamless workflow within one platform?

Blazed Meta-Grating Composed of Square Pillars

P. Lalanne, *et al.*, "Blazed binary subwavelength gratings with efficiencies larger than those of conventional échelette gratings," Opt. Lett. 23, 1081-1083 (1998)

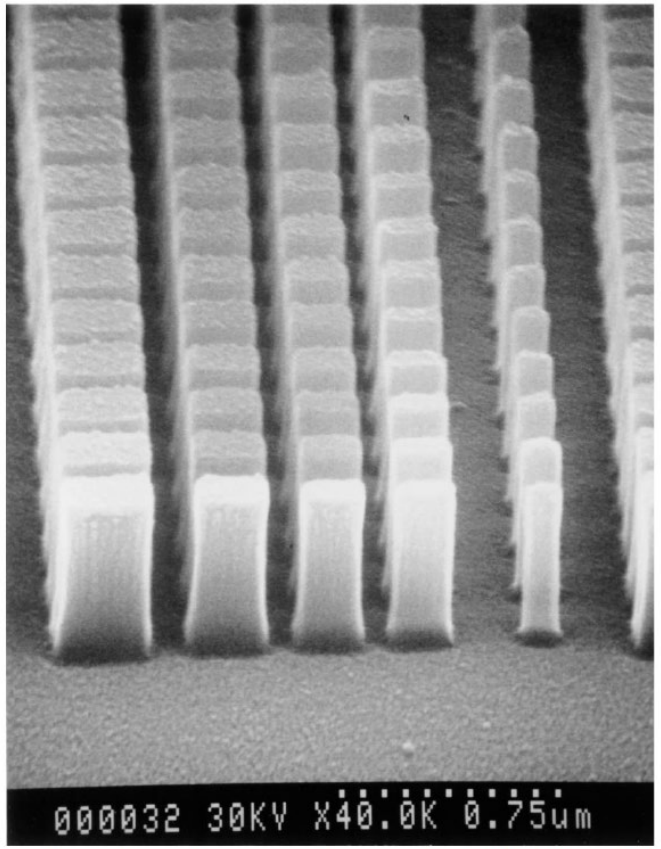
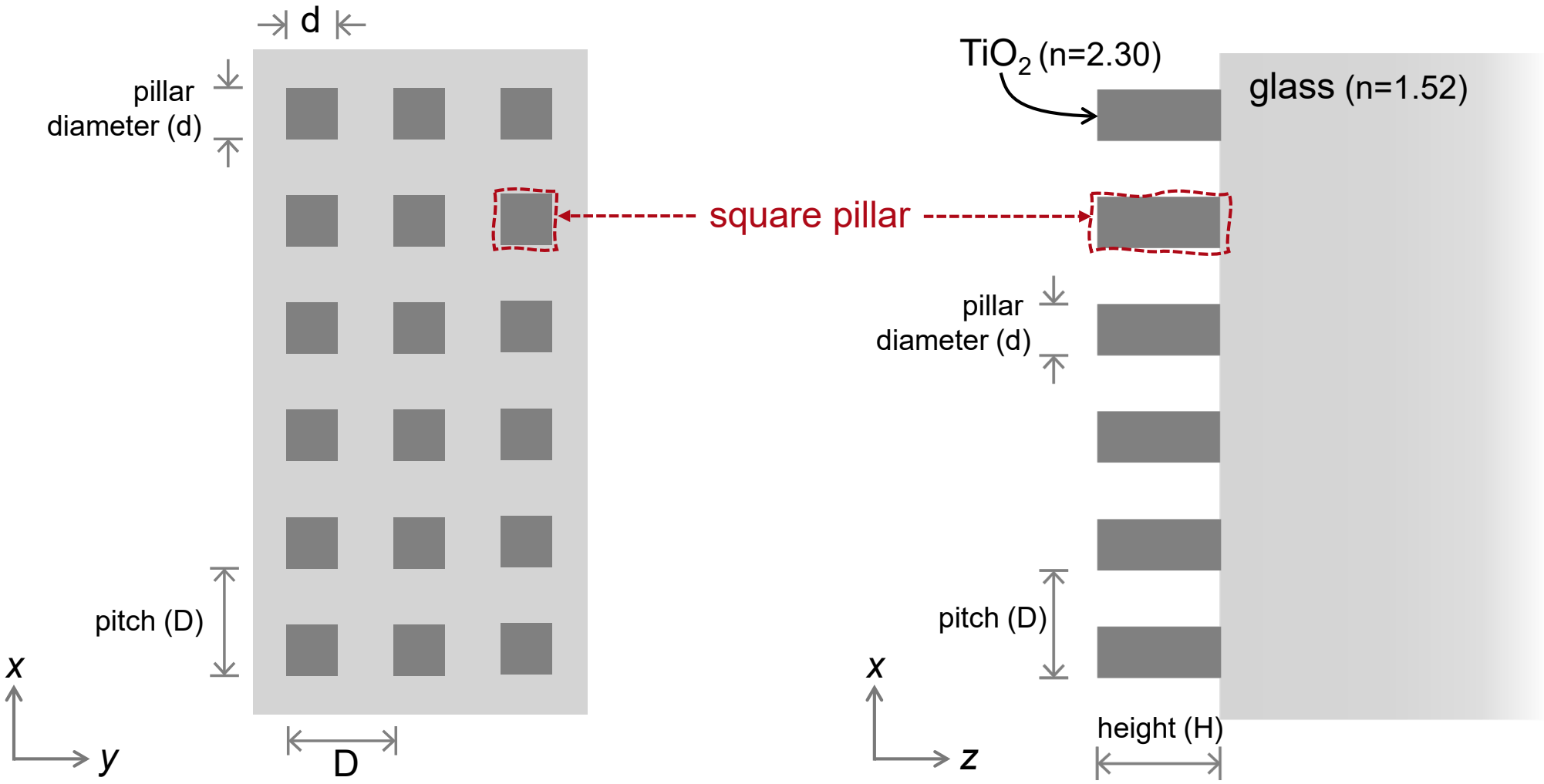


Fig. 2. Scanning-electron micrograph of the blazed binary subwavelength grating. The horizontal period (along the x axis) is 1.9 μm, and the period in the perpendicular direction (y axis) is equal to the sampling period (380 nm). The maximum pillar aspect ratio is 4.6.

Building Block / Unit Cell Analysis



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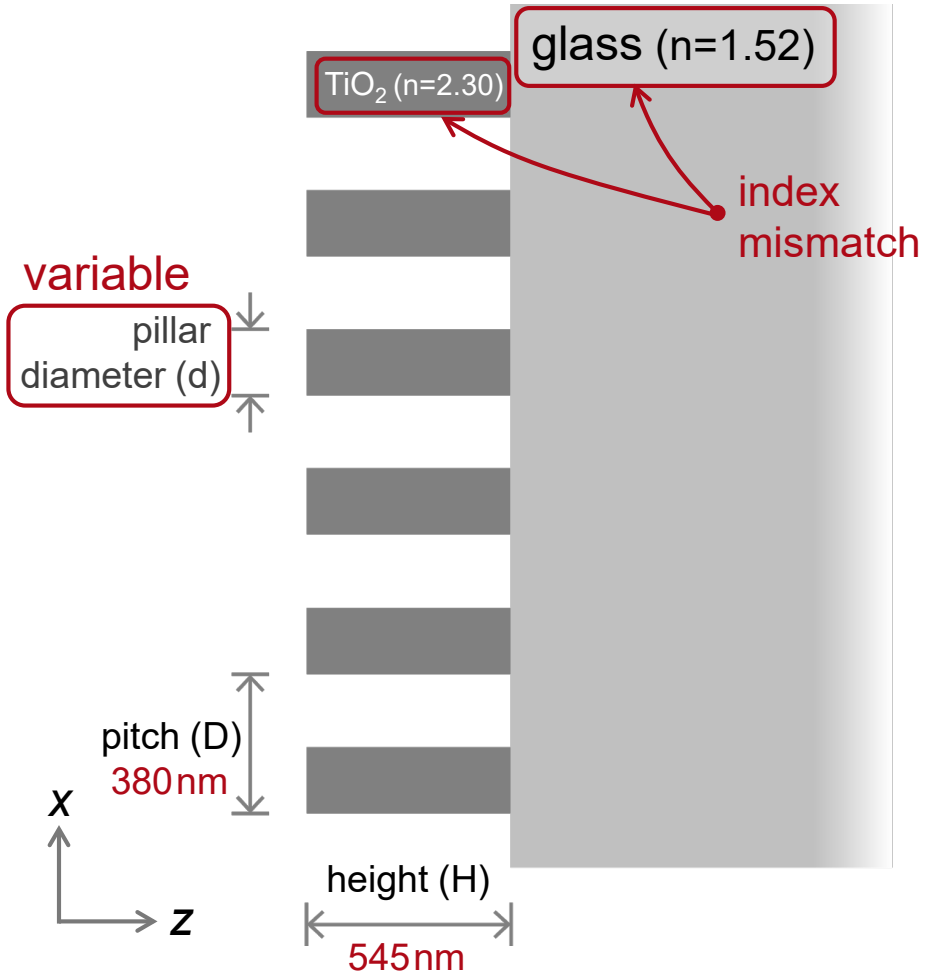
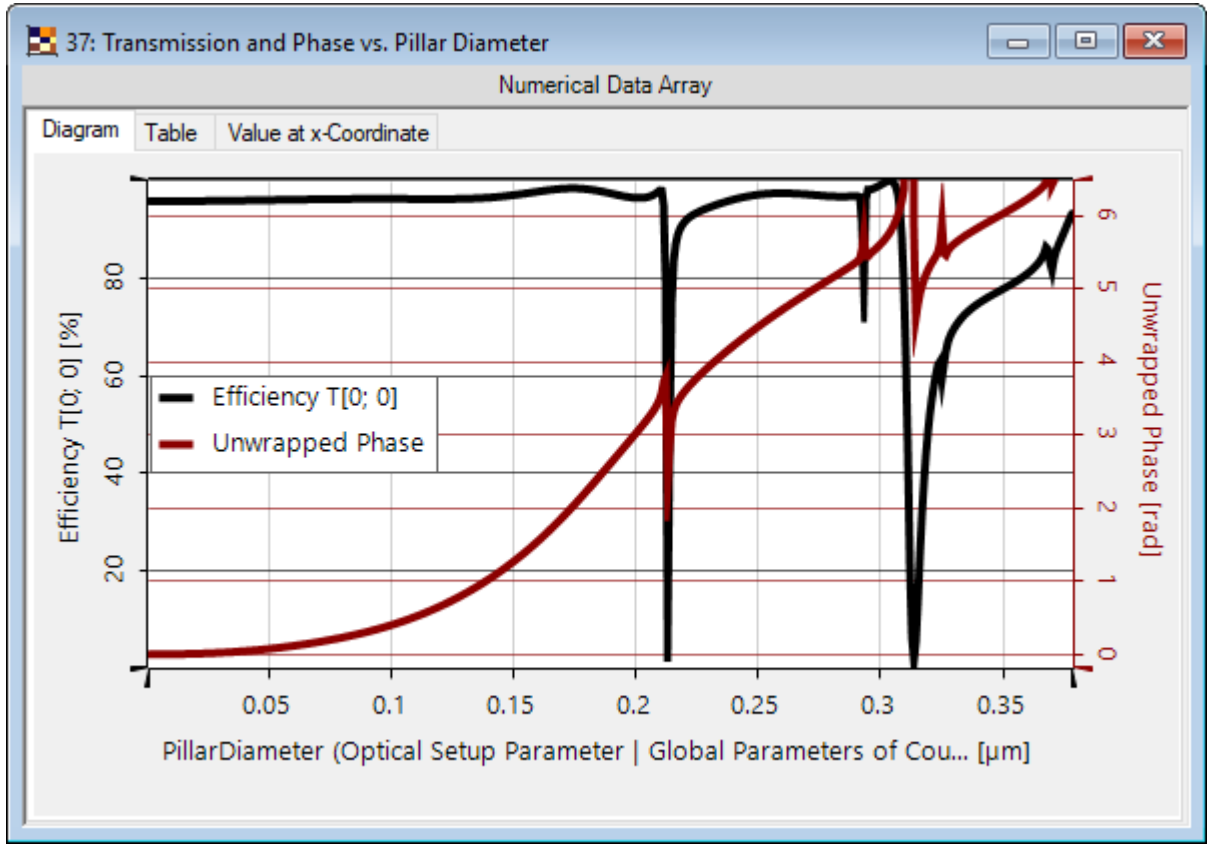
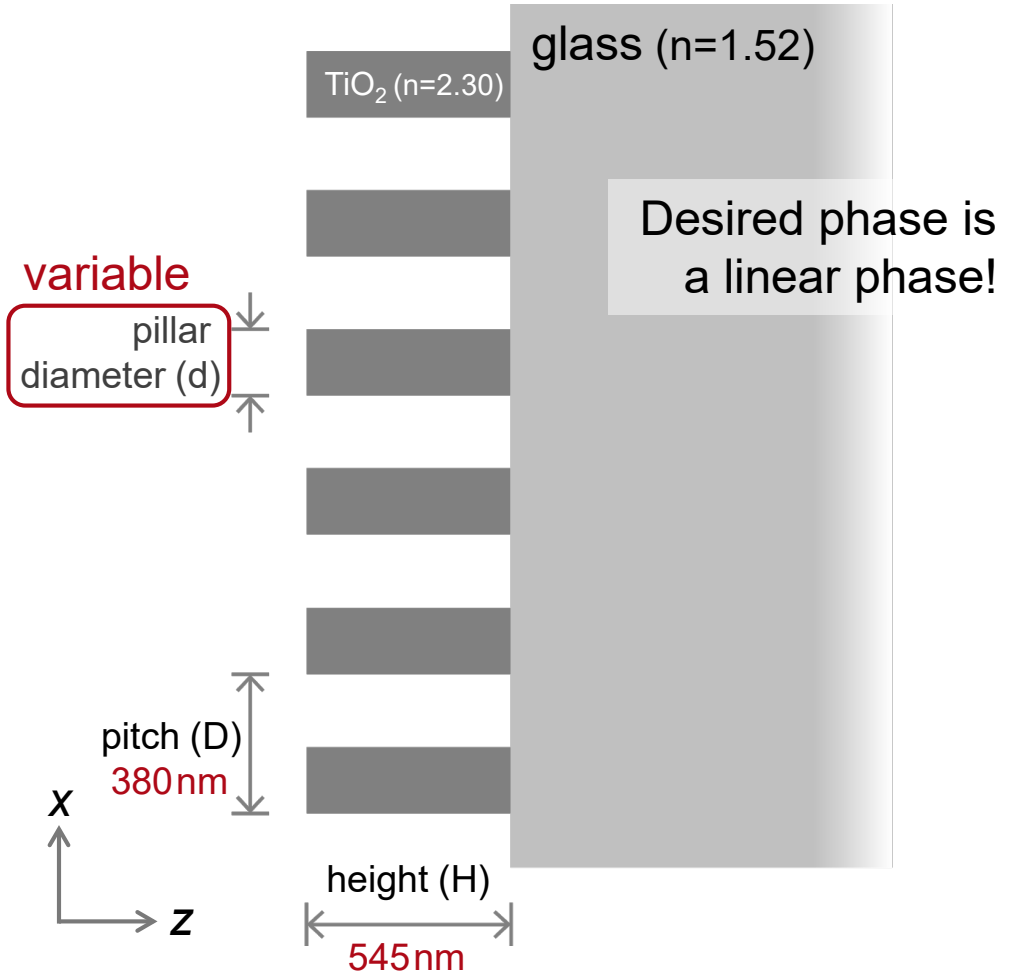


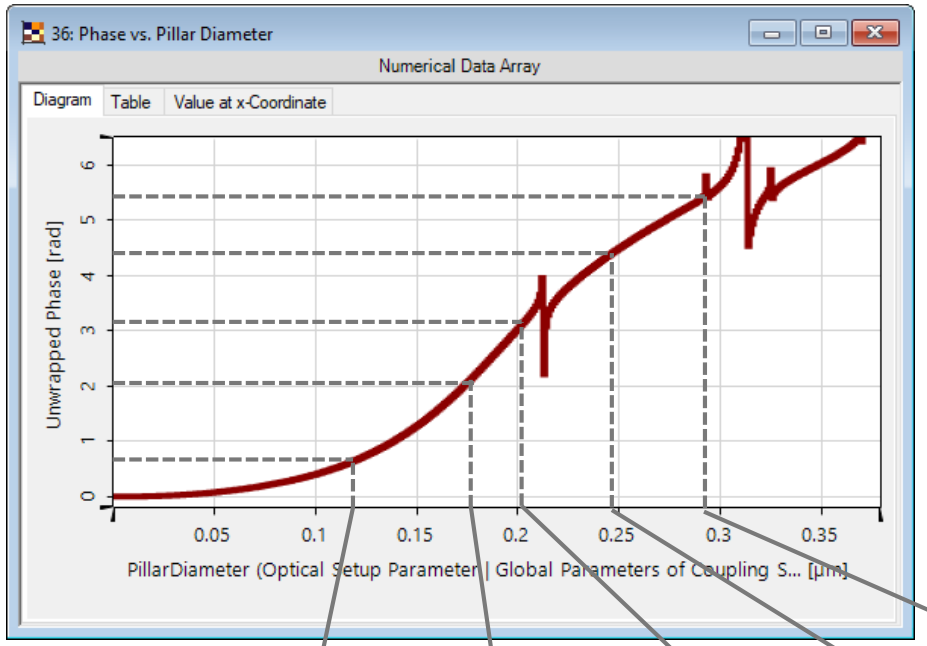
transmission amplitude/phase vs. pillar diameter (@633nm)



Blazed Metagrating_01_Single Pillar ...

Distribution of Cells ➔ Linear Phase





	#1	#2	#3	#4	#5
d	118 nm	179 nm	201 nm	247 nm	293 nm
f=d/D	0.31	0.47	0.53	0.65	0.77
$\Delta\psi$	0.20π	0.69π	0.98π	1.40π	1.73π

Selection of pillar diameters follows from P. Lalanne, *et al.*, Opt. Lett. 23, 1081-1083 (1998)

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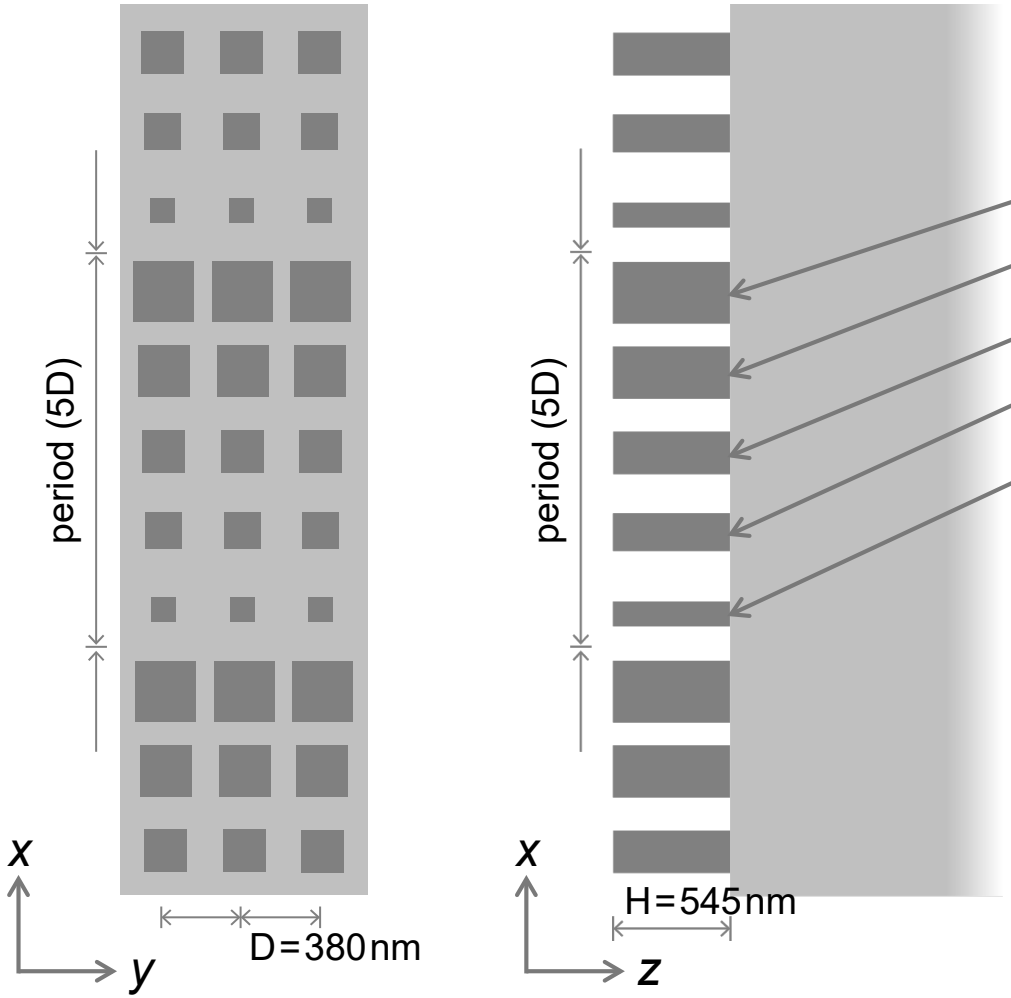

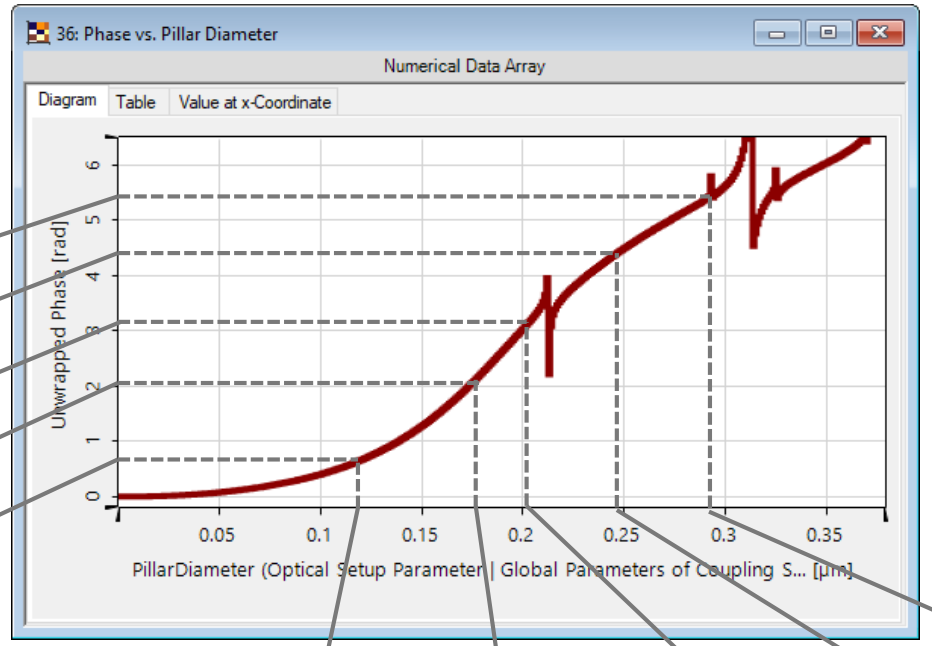

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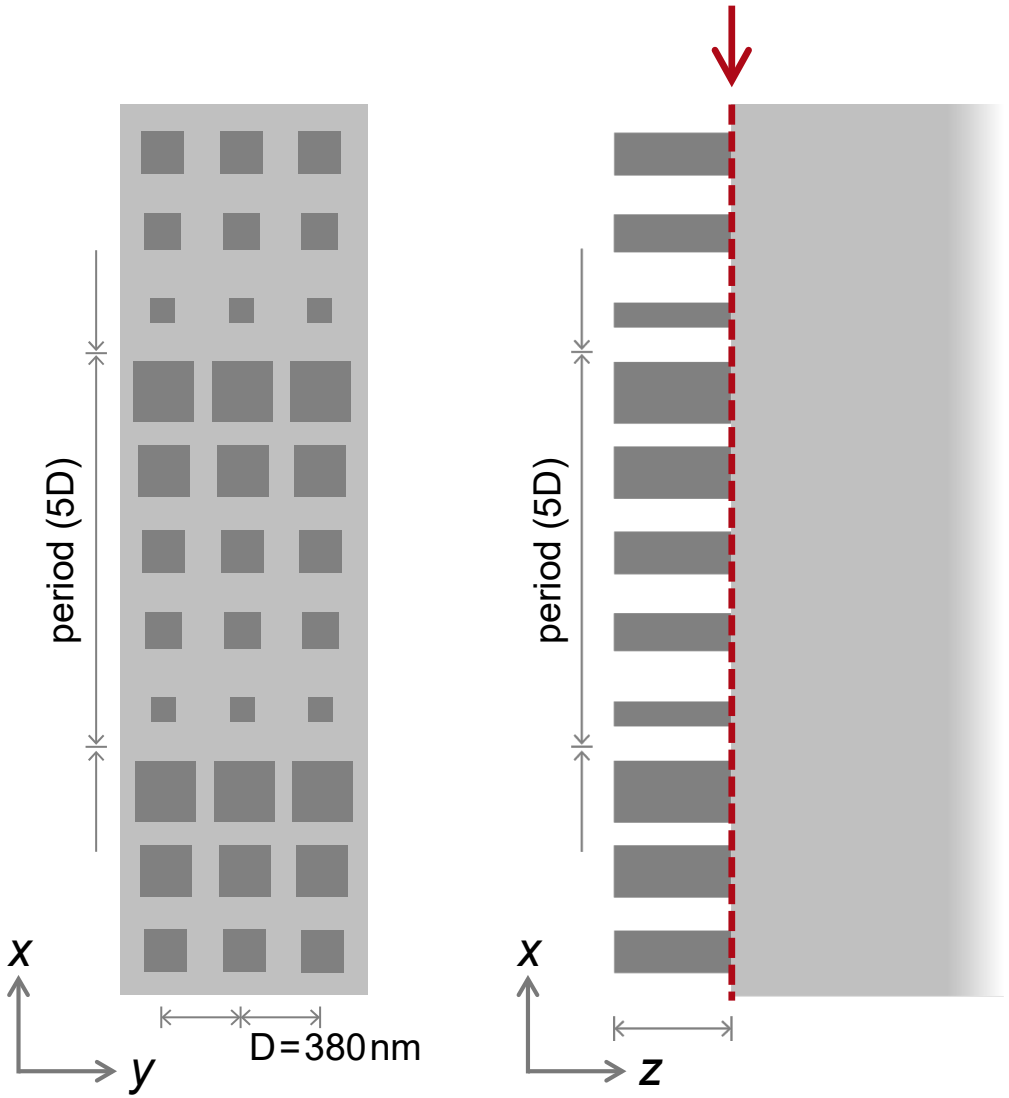
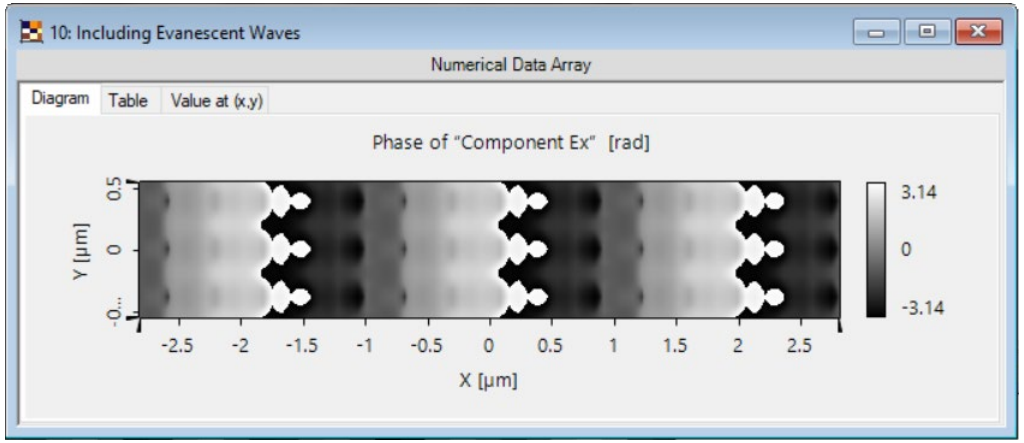
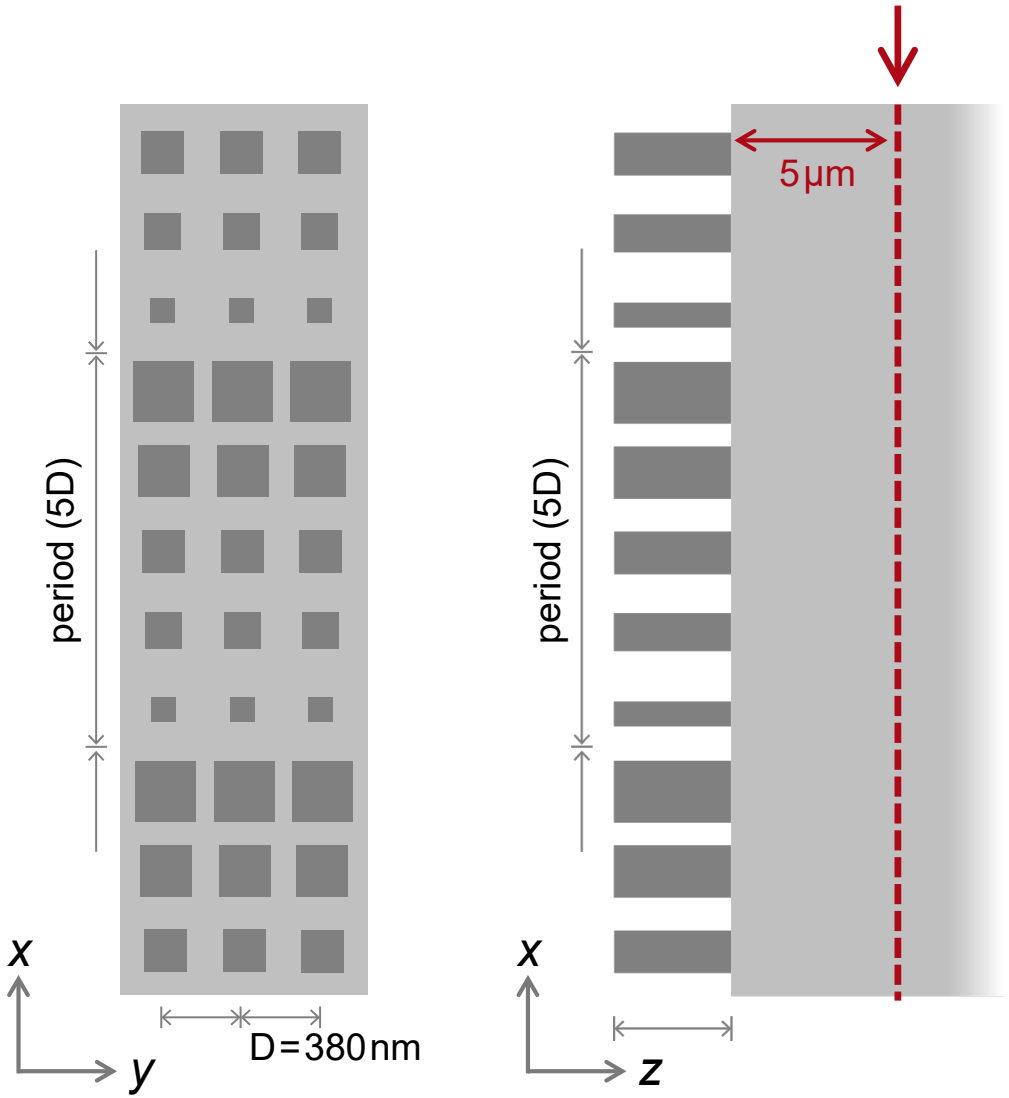
Performance Evaluation: Transmitted Phase Distribution



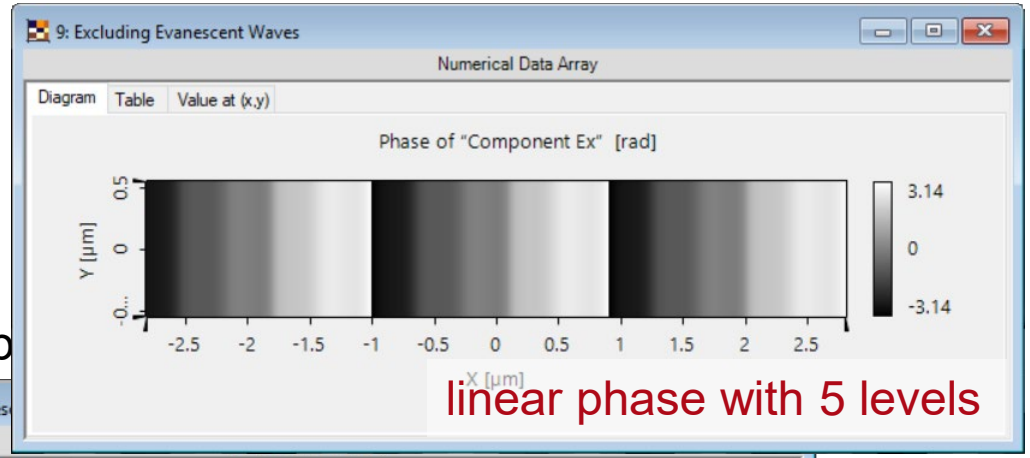
directly behind the grating



Performance Evaluation: Transmitted Phase Distribution

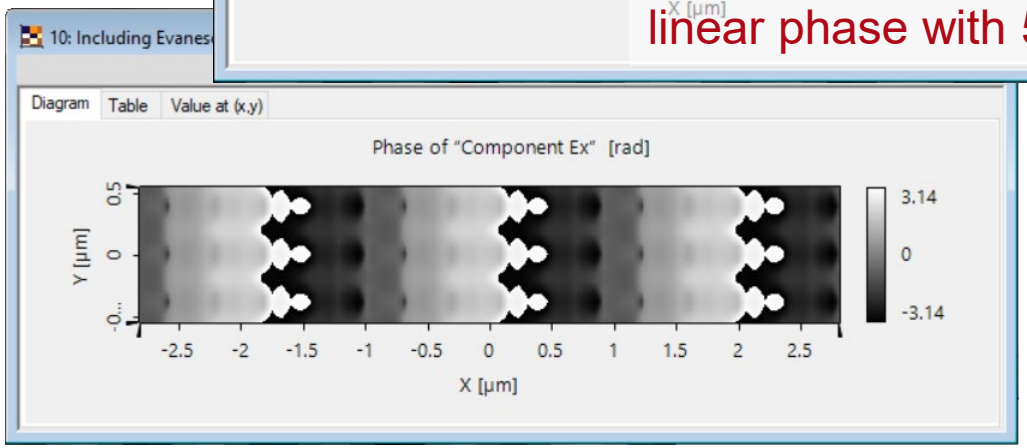


5μm behind the grating (evanescent waves damped)



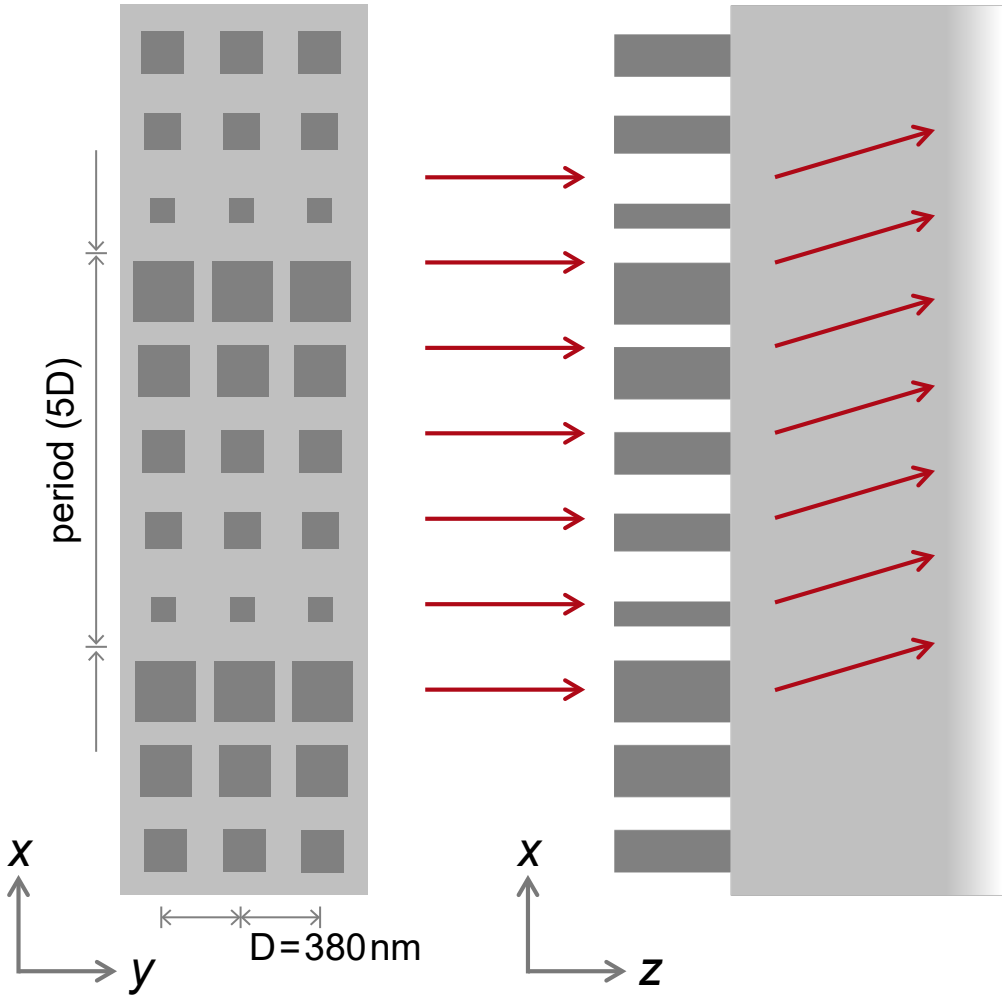
directly b

linear phase with 5 levels



Blazed Metagrating_02_Initial Blazed Grating

Performance Evaluation: Diffraction Efficiency



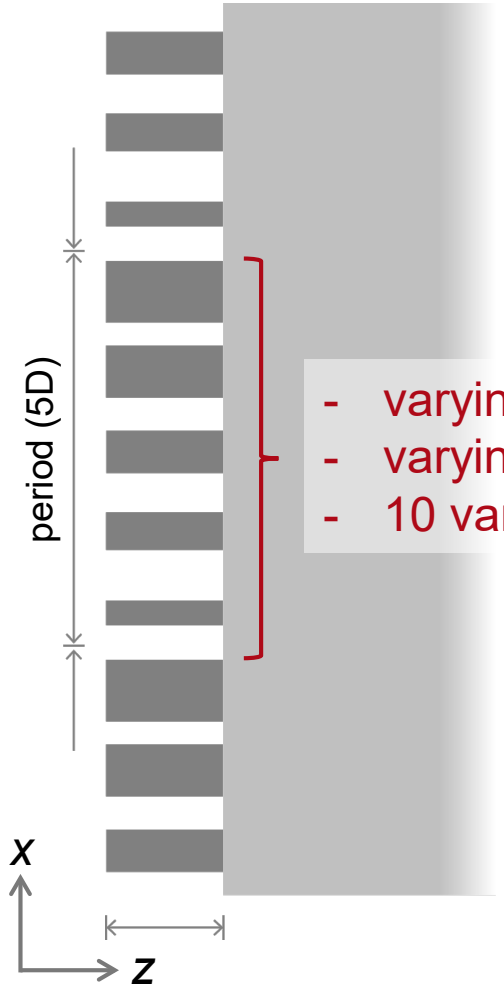
grating performance evaluation

	Efficiency
TE-polarization	80.2%
TM-polarization	74.2%
Average	**77.2%**

Same average efficiency value reported in
P. Lalanne, *et al.*, Opt. Lett. 23, 1081-1083 (1998)

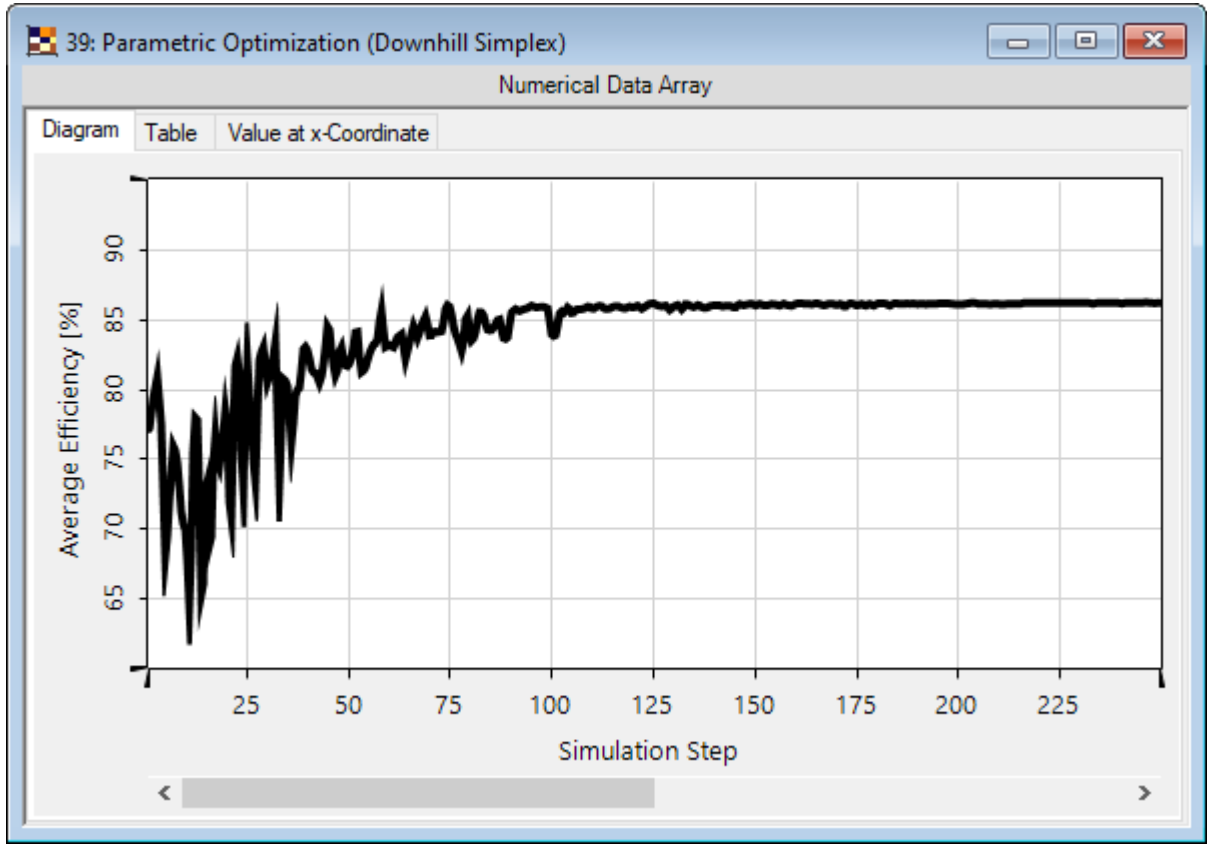
Blazed Metagrating_02_Initial Blazed Grating

Post-Optimization of Metagrating



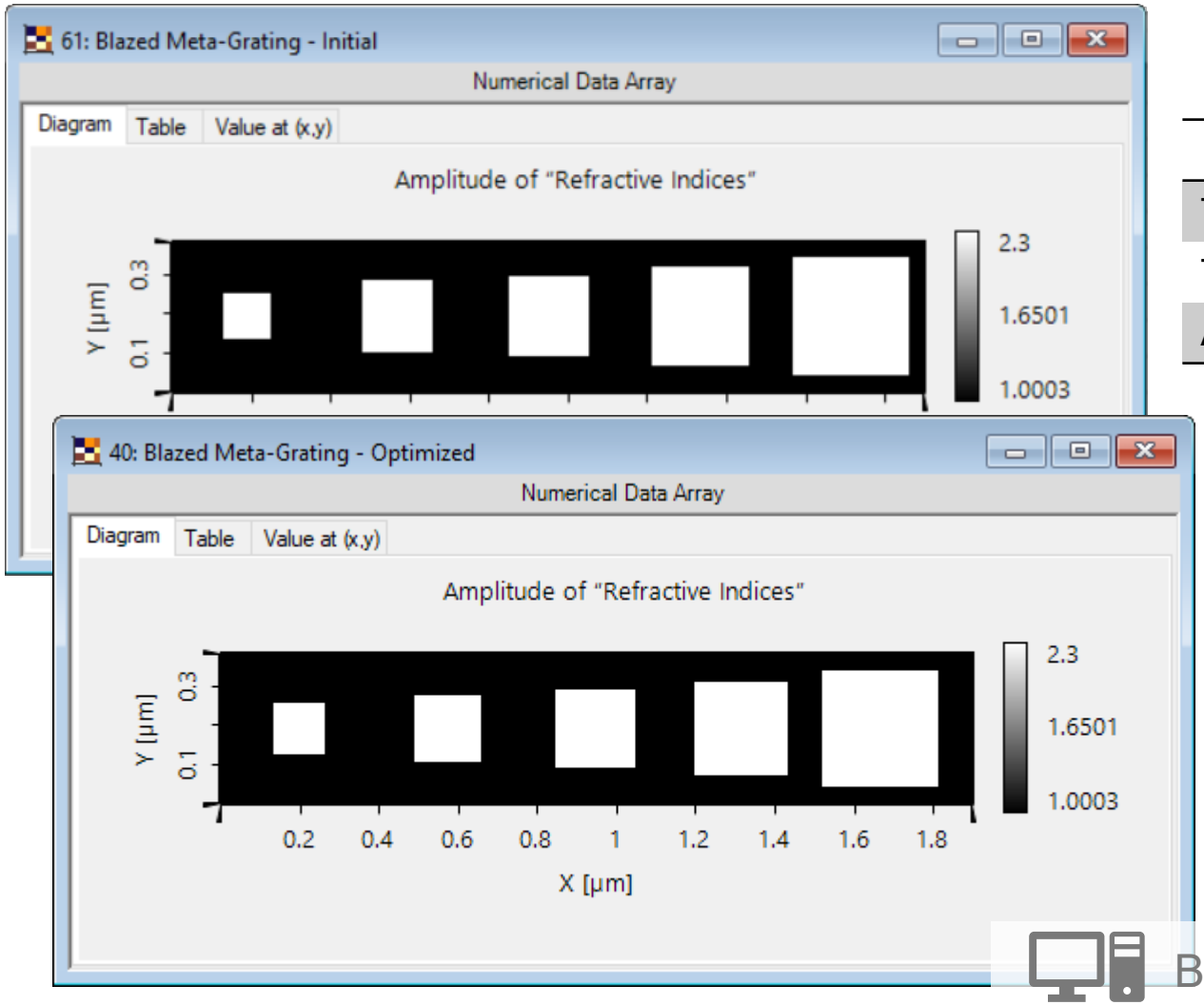
- varying pillar positions
- varying pillar diameters
- 10 variables in total

downhill simplex optimization with FMM/RCWA for grating analysis



Blazed Metagrating_03_Parametric Optimization

Post-Optimization: Initial vs. Optimized Structure



	Efficiency
TE-polarization	80.2%
TM-polarization	74.2%
Average	**77.2%**

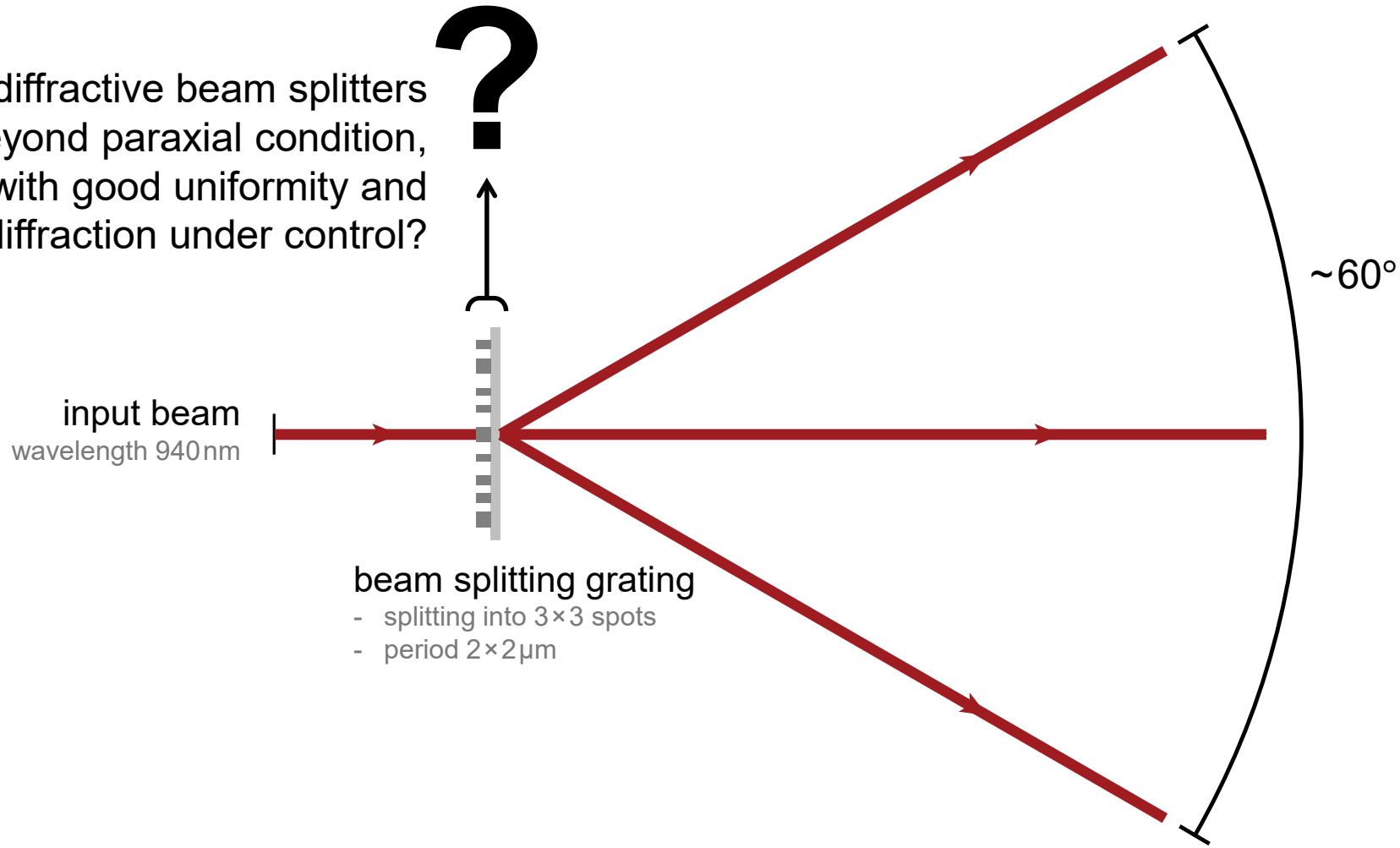
	Efficiency
TE-polarization	85.5%
TM-polarization	87.0%
Average	**86.3%**

Blazed Metagrating_04_Optimized Blazed Grating

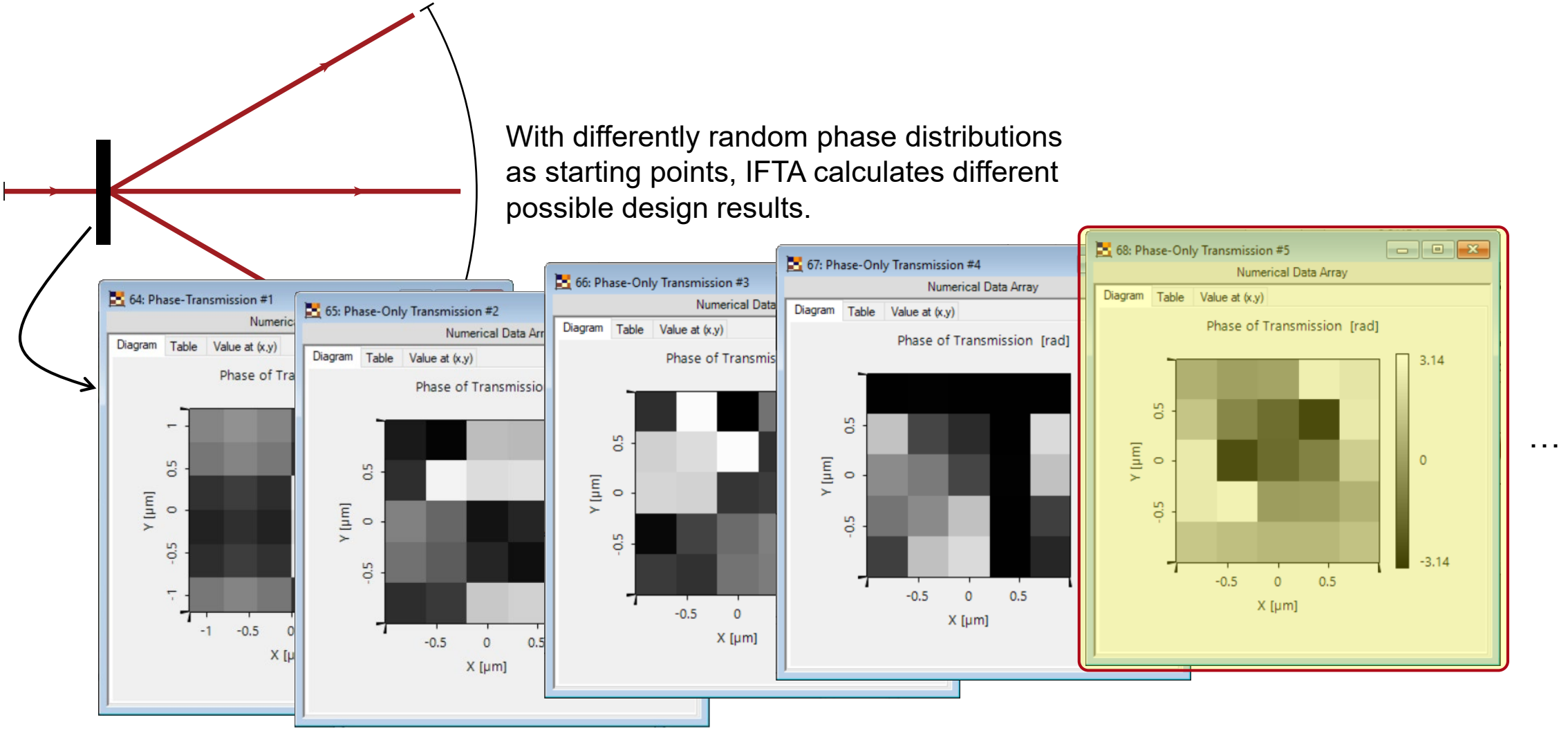
Design of Meta-Grating as Large-Angle Spot Projector

Design Task

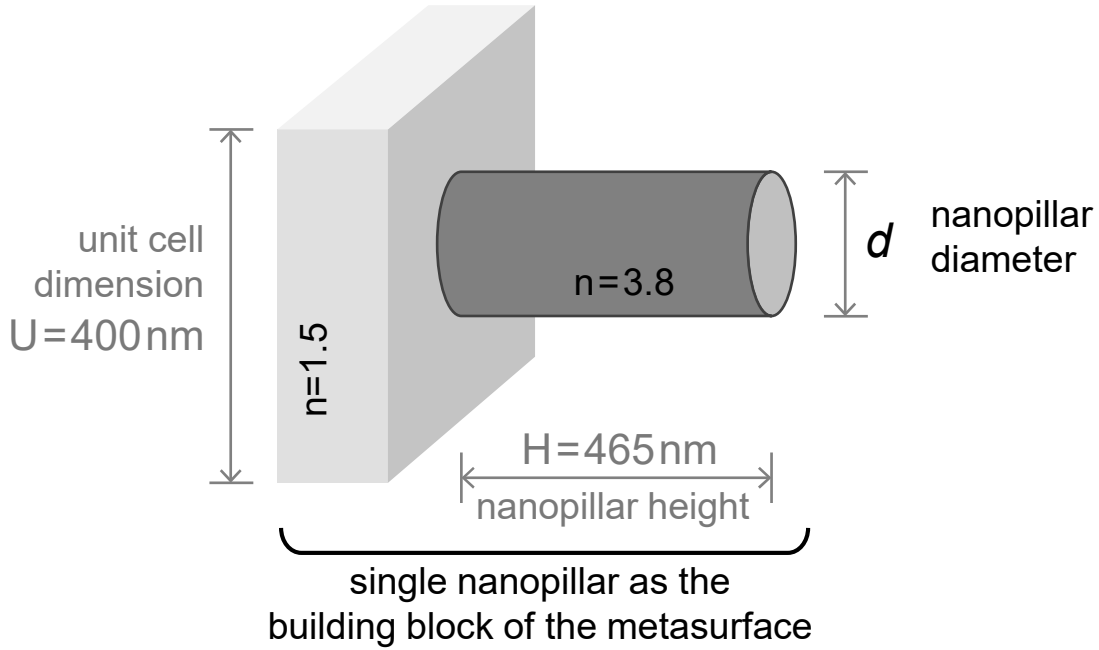
How to design diffractive beam splitters that work beyond paraxial condition, especially with good uniformity and zeroth-order diffraction under control?



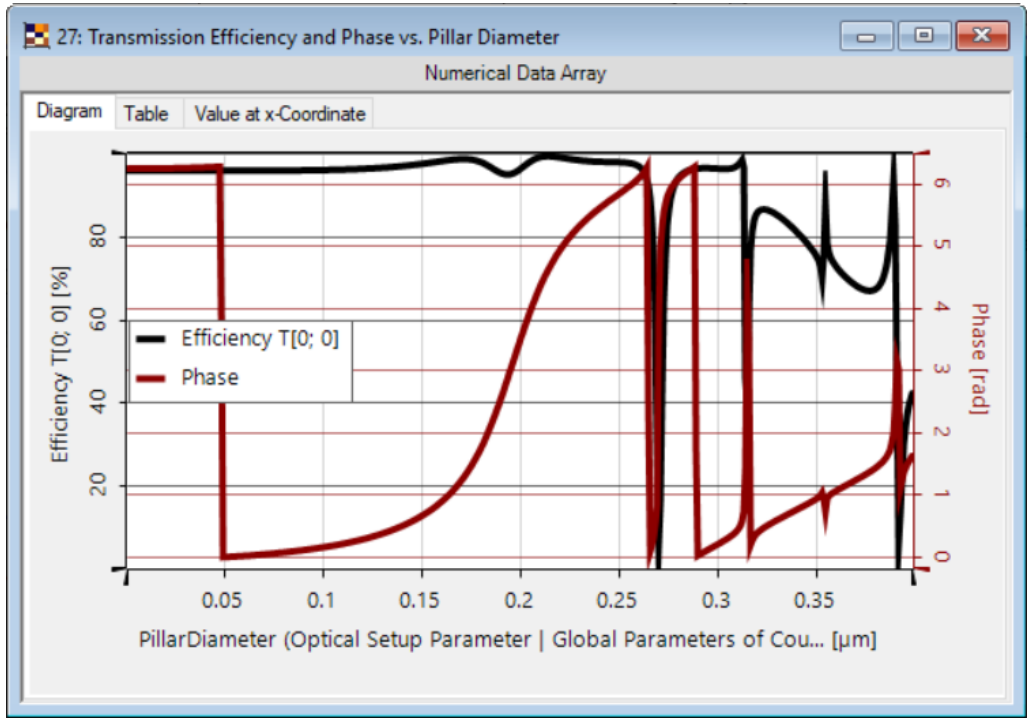
Desired Phase Profile Design (IFTA)



Building Block / Unit Cell Analysis



selected
parameter range



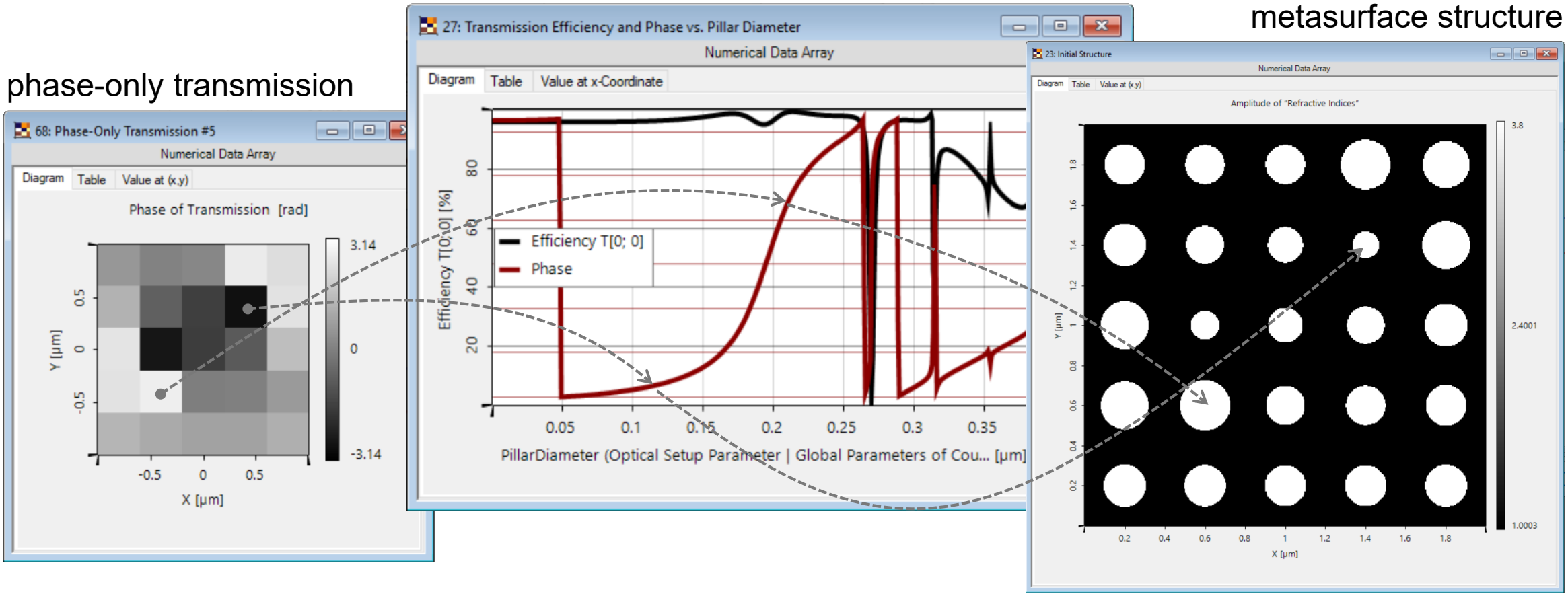
2D Metagrating_01_Single Pillar Analysis …

Distribution of Cells

phase-only transmission

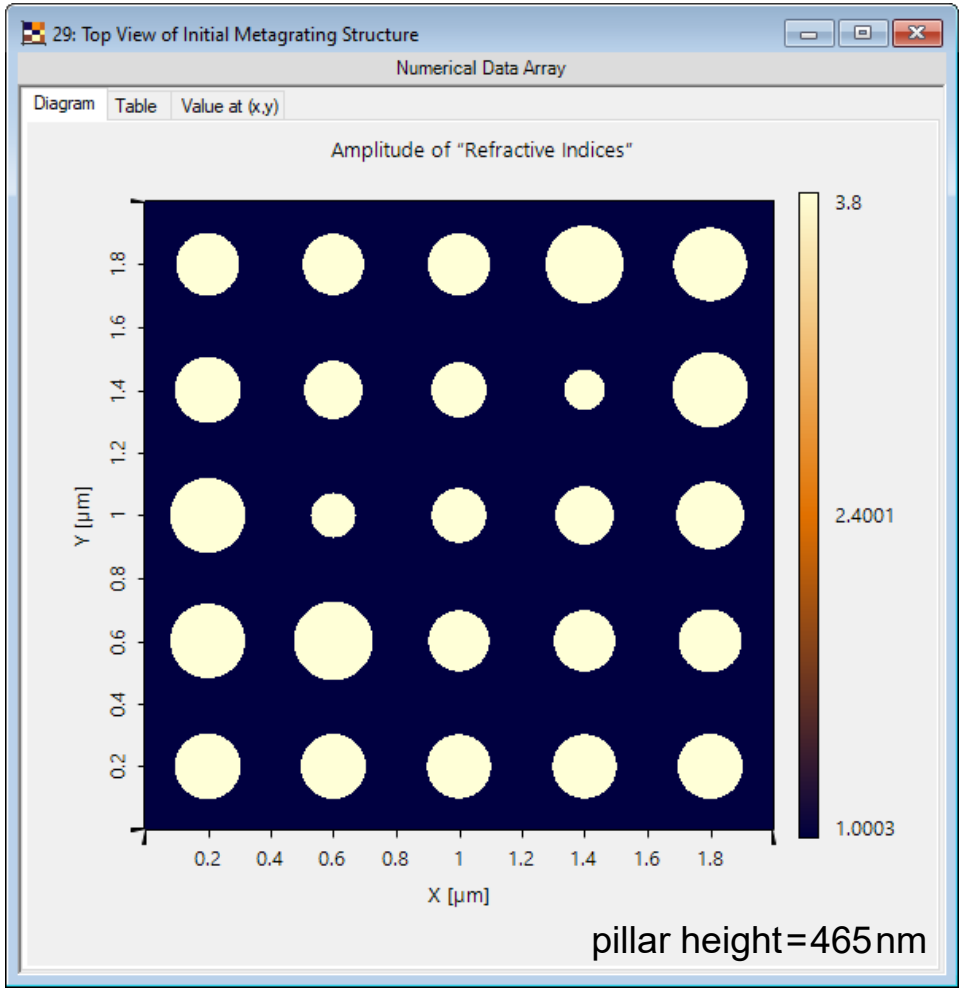
phase-diameter map / library

metasurface structure

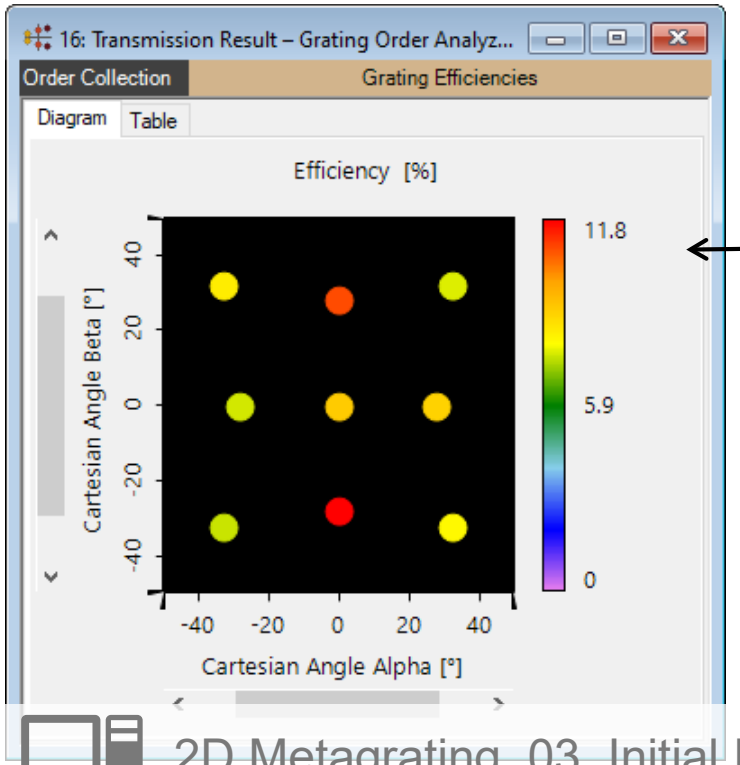


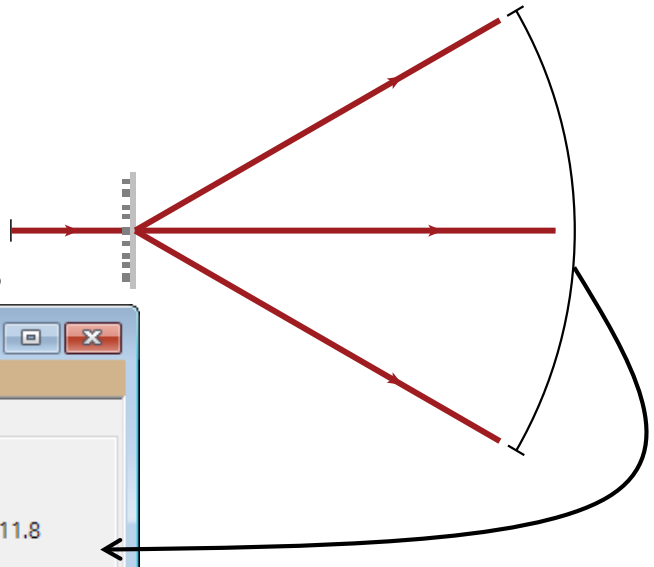
Performance Evaluation: Initial Design

top view of initial metagrating



diffraction efficiencies



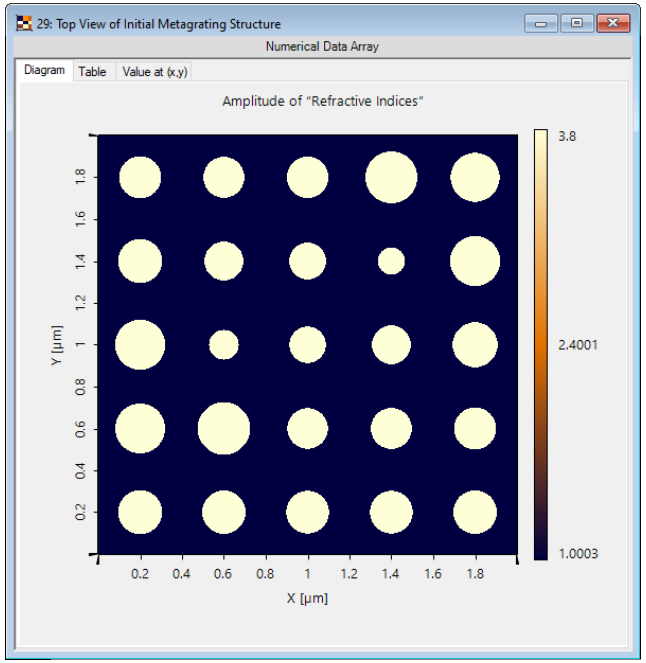


Overall efficiency	79.4%
Uniformity error (PV)	22.7%
Uniformity error (RMS)	16.7%

2D Metagrating_03_Initial Metagrating

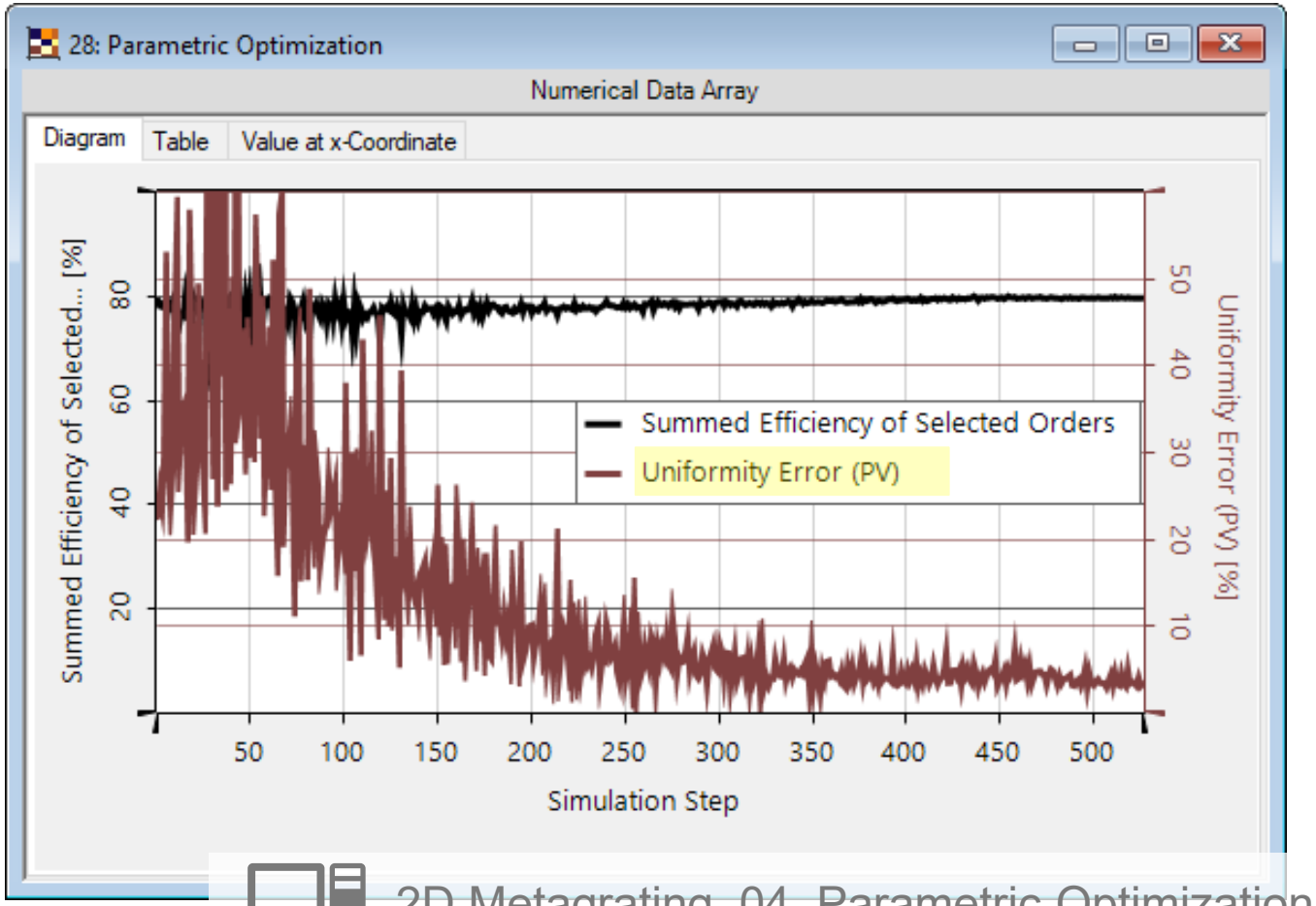
Post-Optimization of Metagrating (PV Uniformity Error)

initial structure



- keep pillar positions
- varying pillar diameters
- 25 variables in total

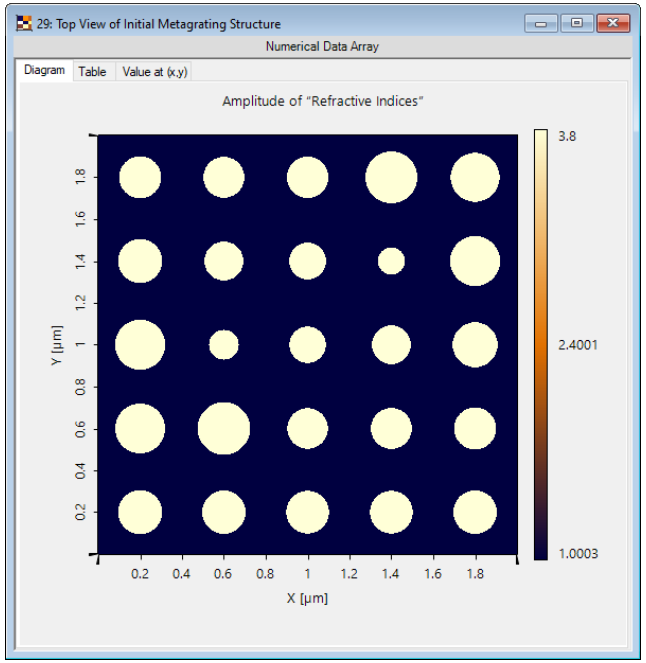
downhill simplex optimization with FMM/RCWA for grating analysis



2D Metagrating_04_Parametric Optimization

Post-Optimization of Metagrating (RMS Uniformity Error)

initial structure



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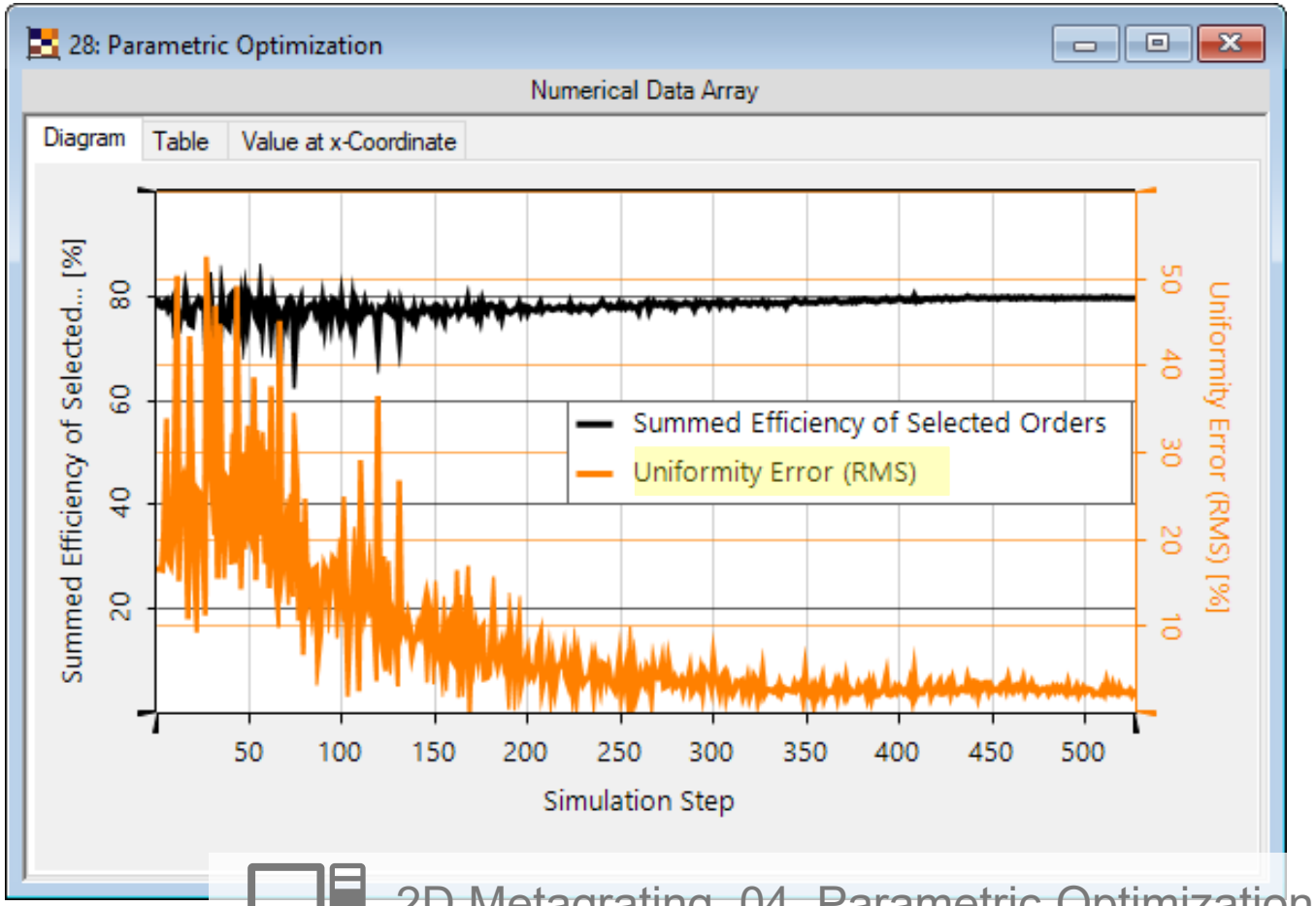
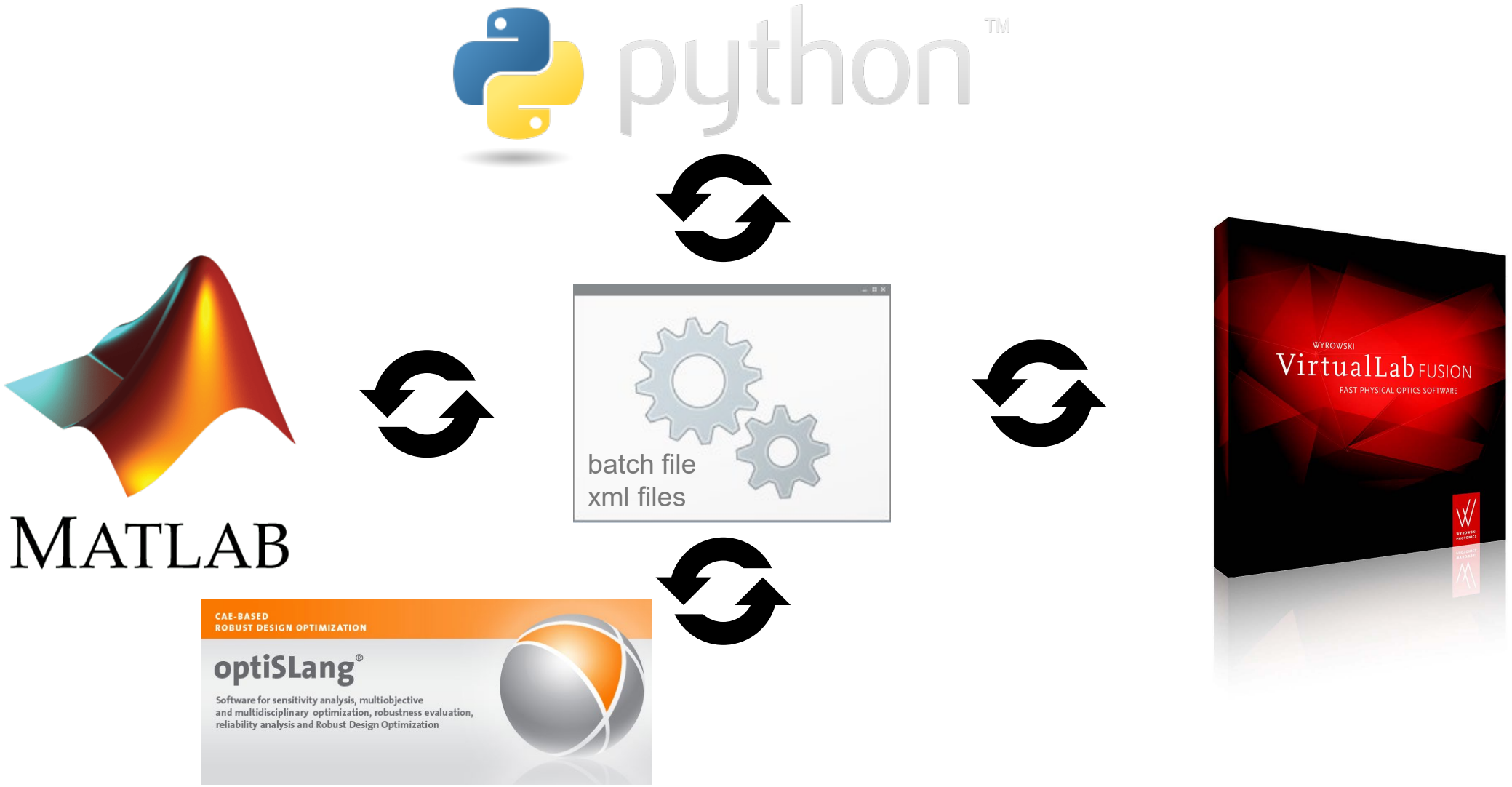
- 25 variables in total

downhill simplex optimization with FMM/RCWA for grating analysis



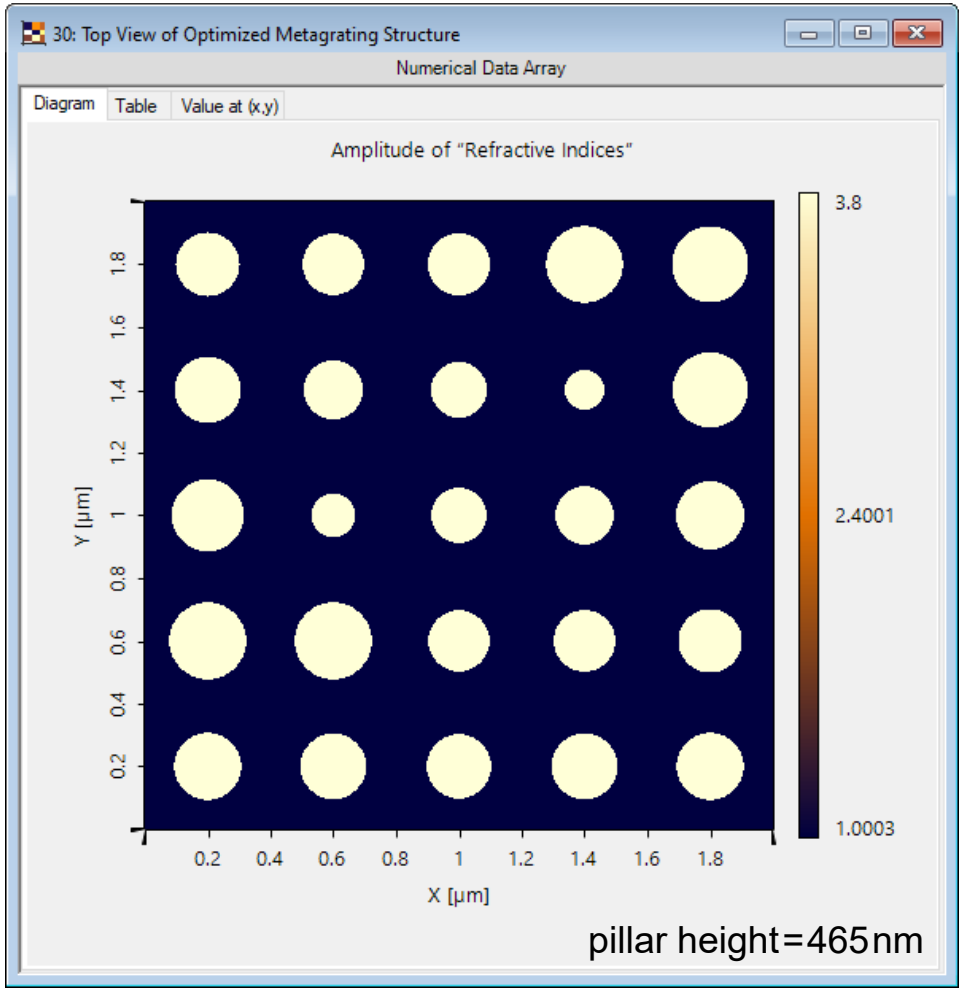
2D Metagrating_04_Parametric Optimization

Cross-Platform Simulation and Optimization

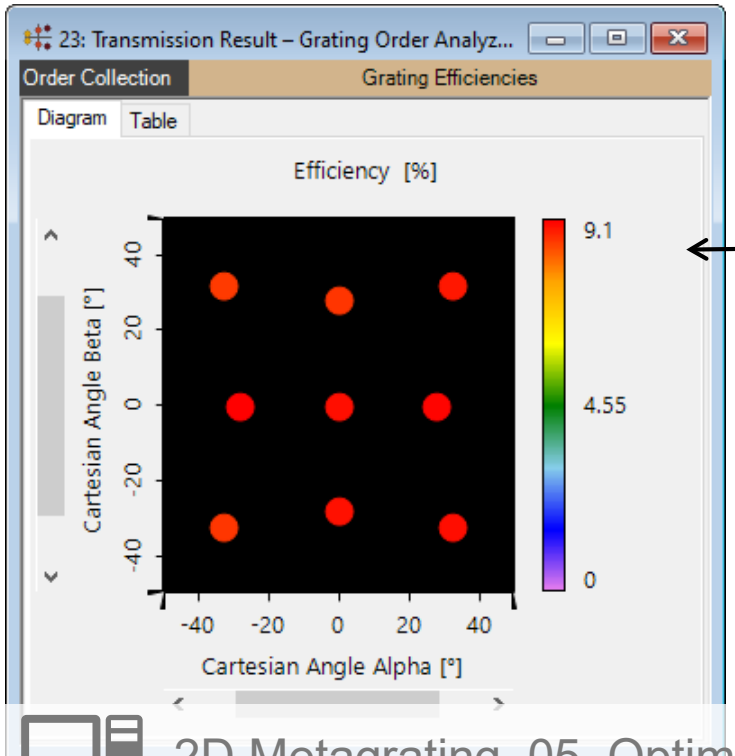


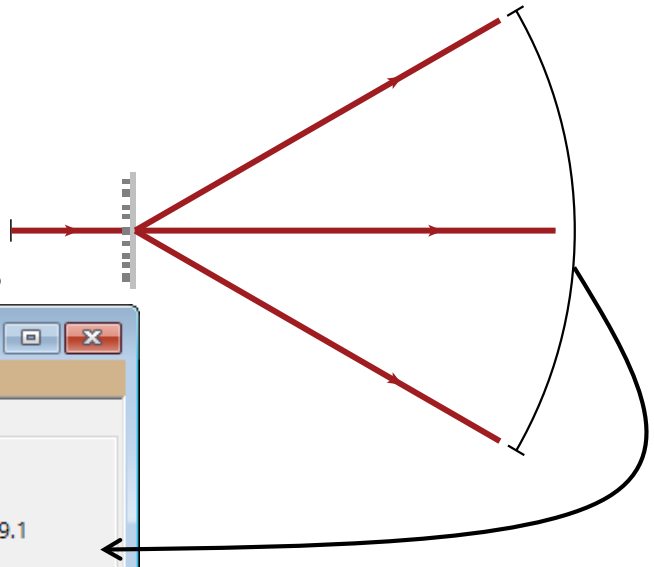
Evaluation of Optimized Metasurface Design

top view of optimized metagrating



diffraction efficiencies



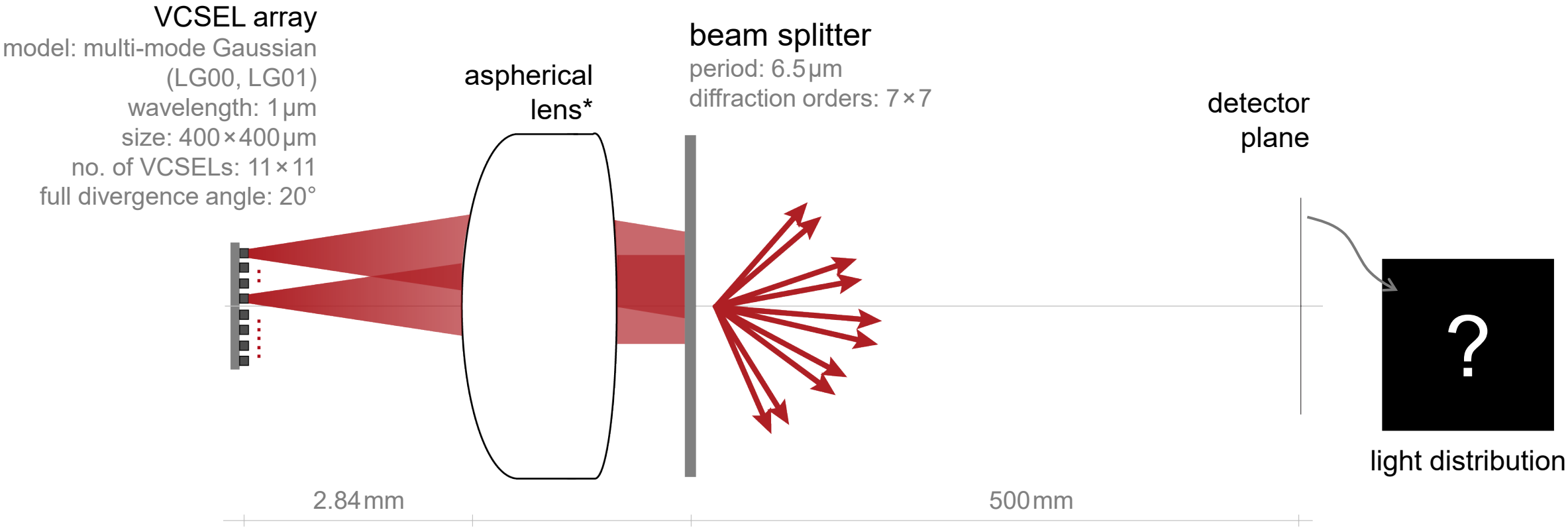


Overall efficiency	79.7%
Uniformity error (PV)	**3.1%**
Uniformity error (RMS)	**2.3%**

2D Metagrating_05_Optimized Metagrating

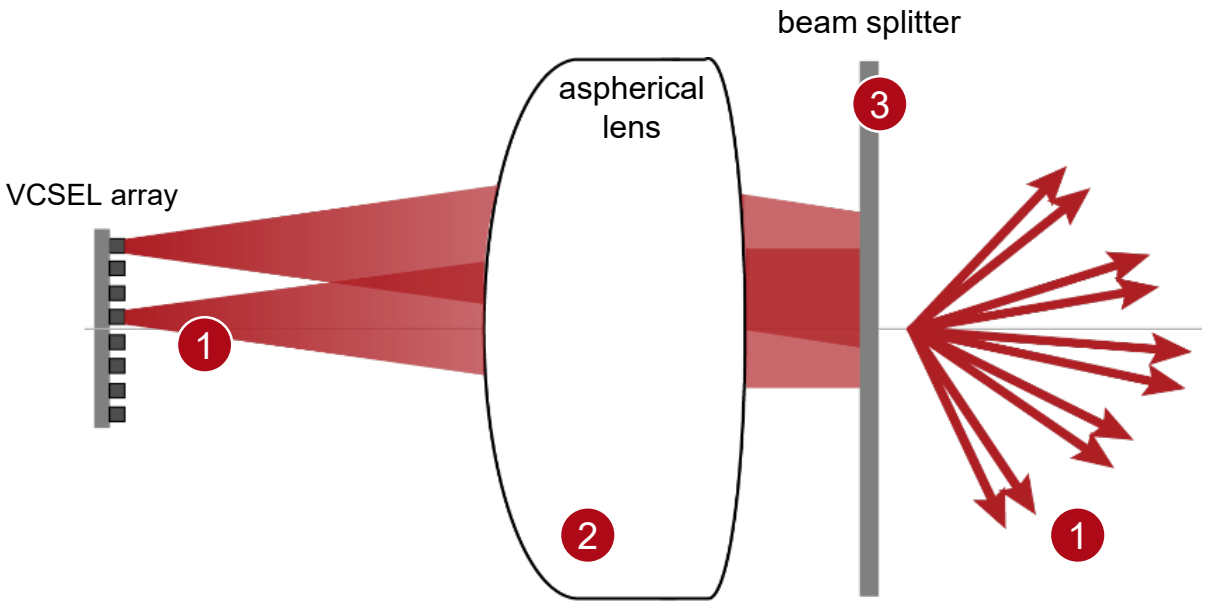
Modeling a VCSEL-Based Spot Projector

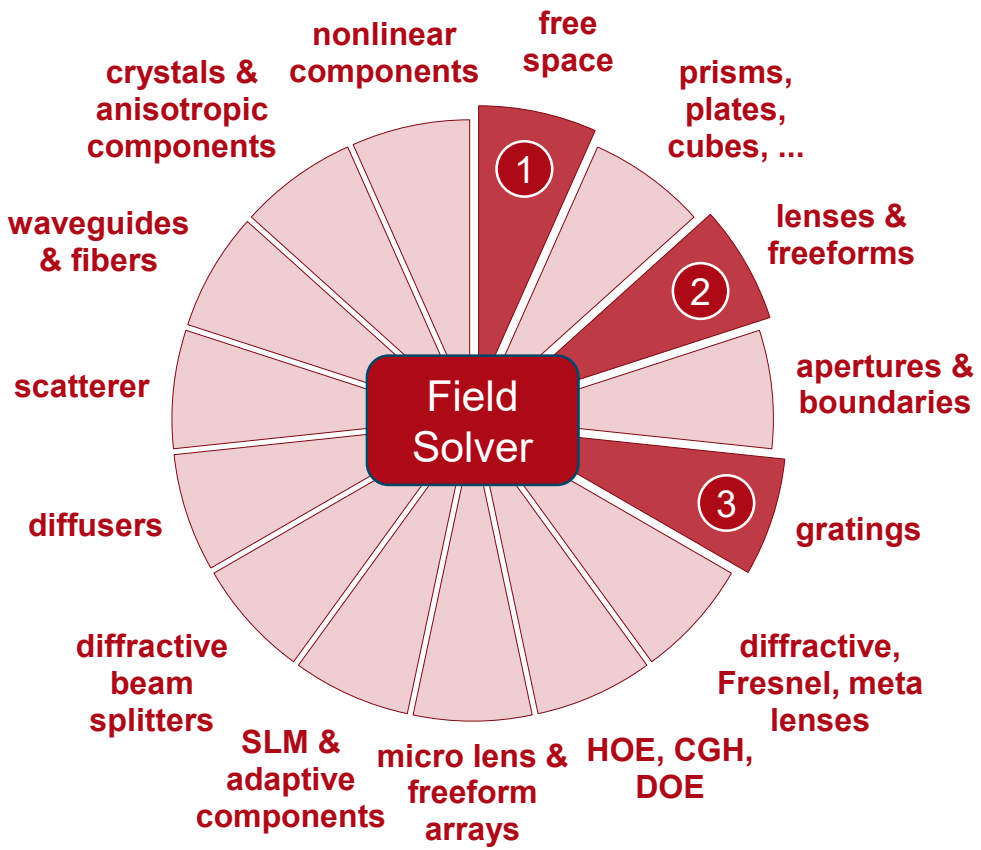
Modeling Task



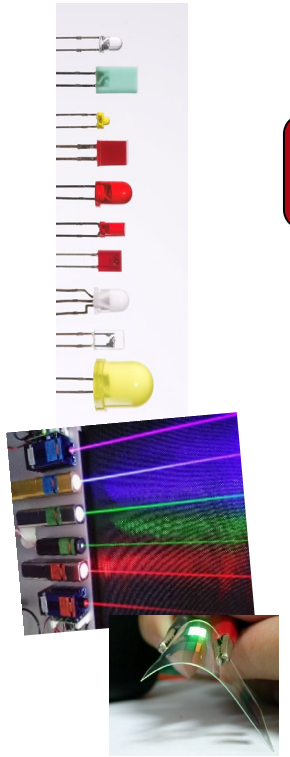
* The aspherical lens in the document is designed with Zemax OpticStudio®

VirtualLab Fusion Technologies





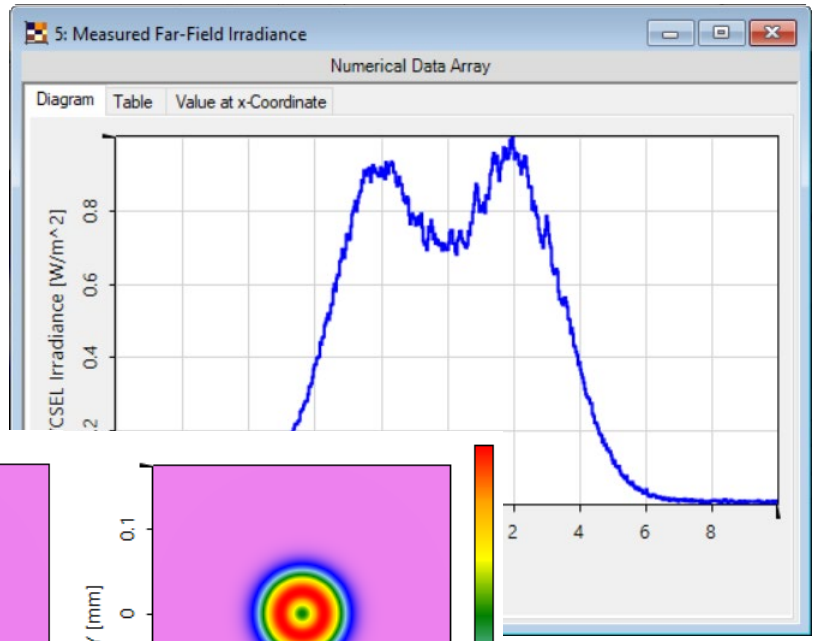
Source Modeling: Mode Decomposition for VCSEL

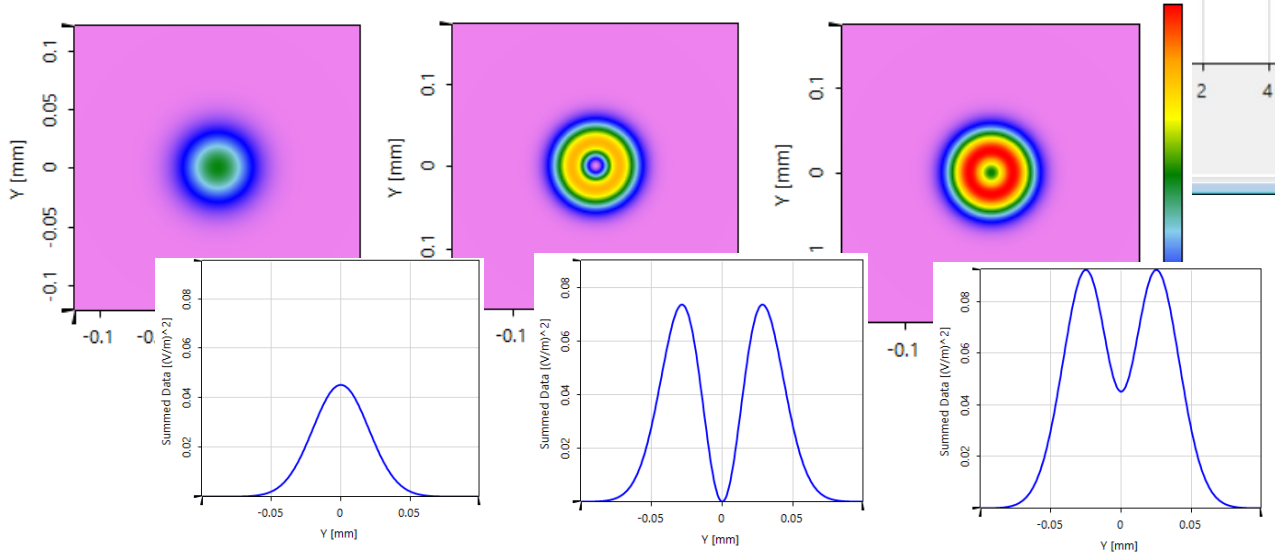


Source → Source modes

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

fitting according to real-world measurement?

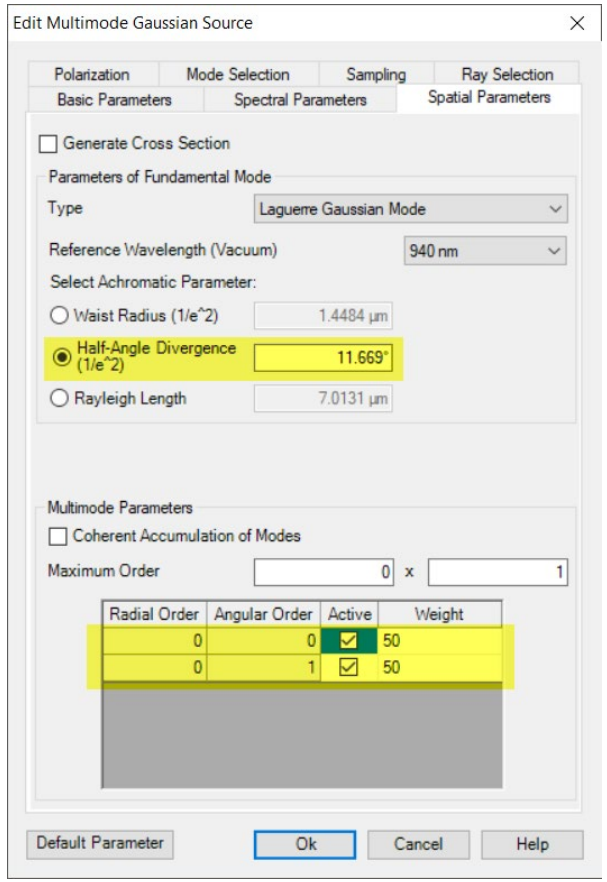




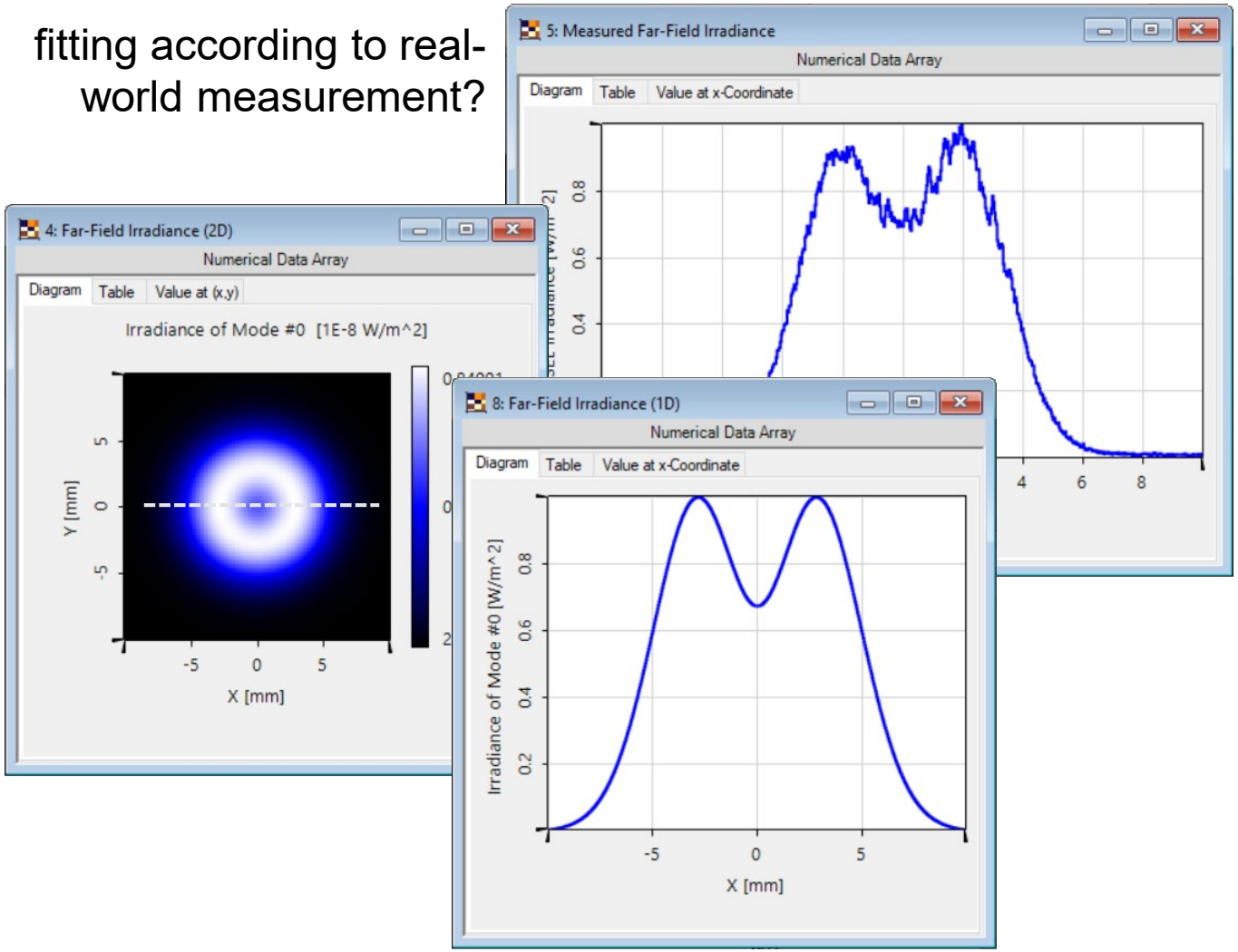
Mode (0, 0) Mode (0, 1) Sum

Source Modeling: Mode Decomposition for VCSEL

Initial test source

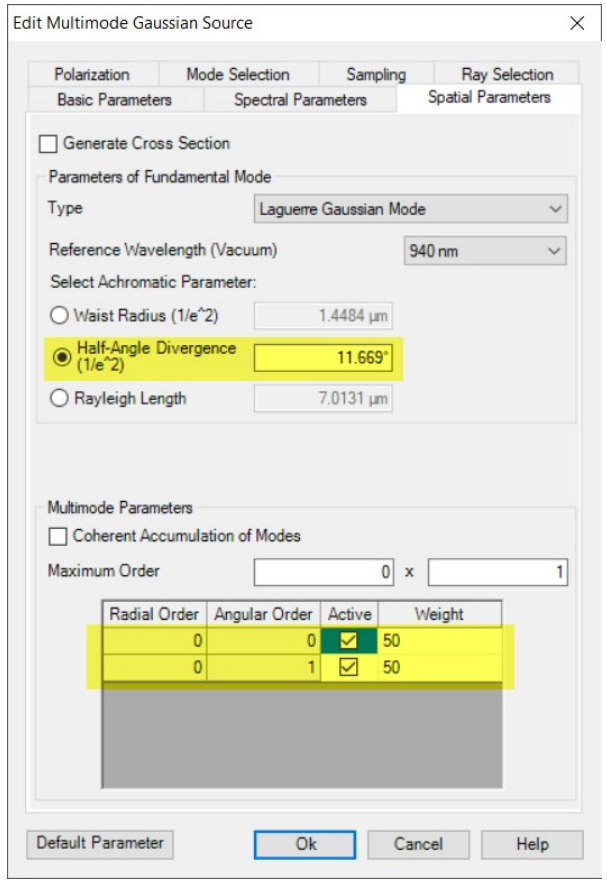


fitting according to real-world measurement?

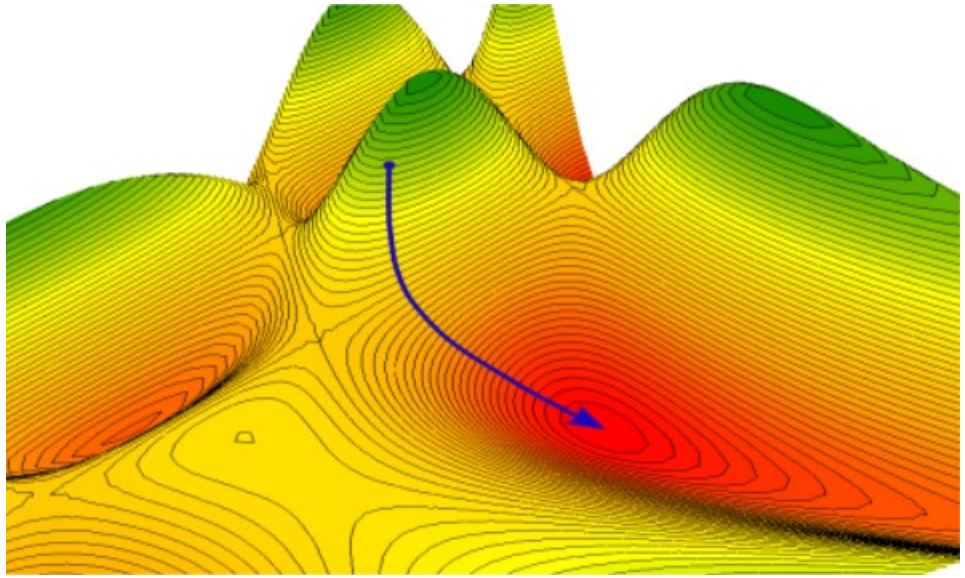


Source Modeling: Mode Decomposition for VCSEL

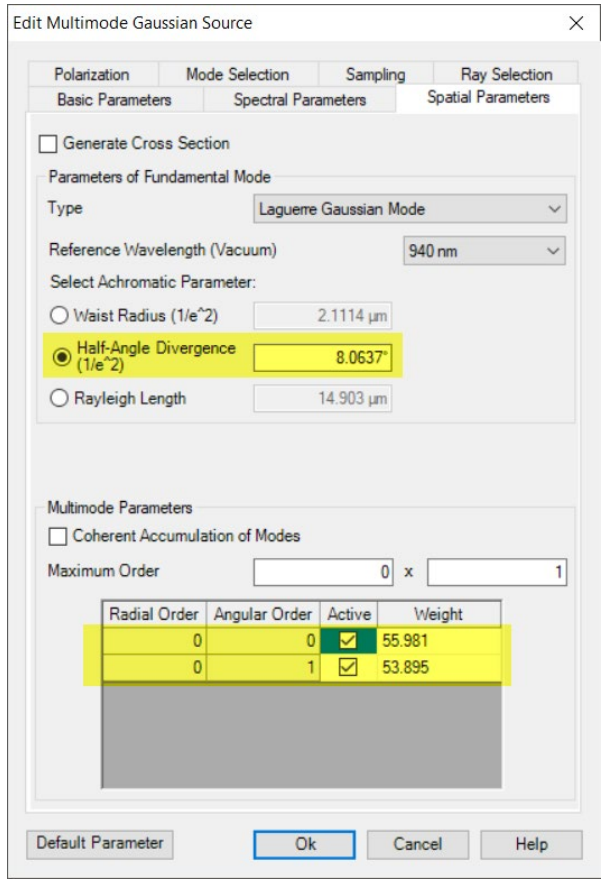
Initial test source



parametric optimization
(downhill simplex)

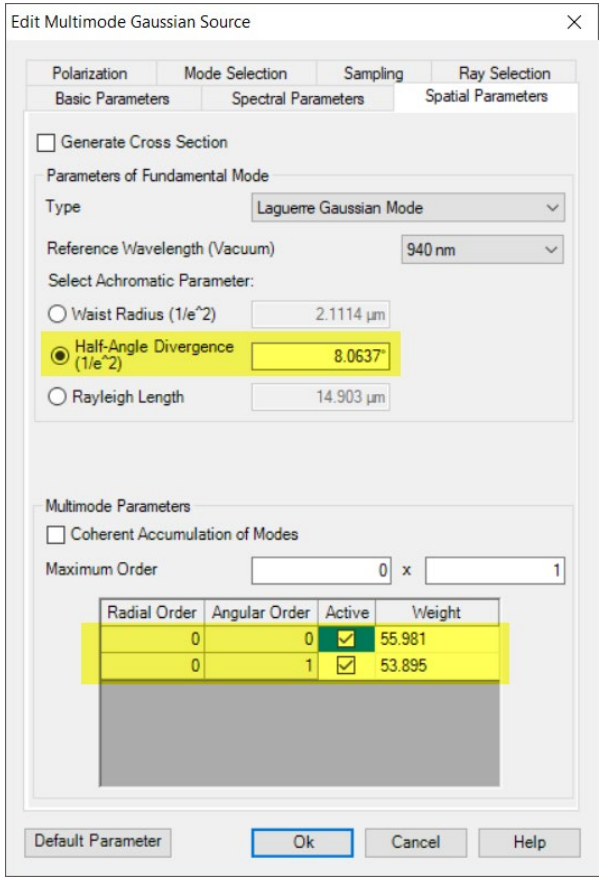


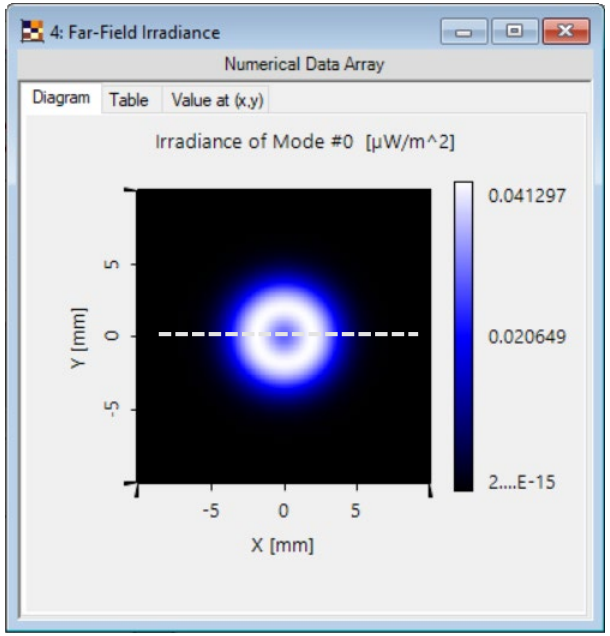
After parametric optimization



Source Modeling: Mode Decomposition for VCSEL

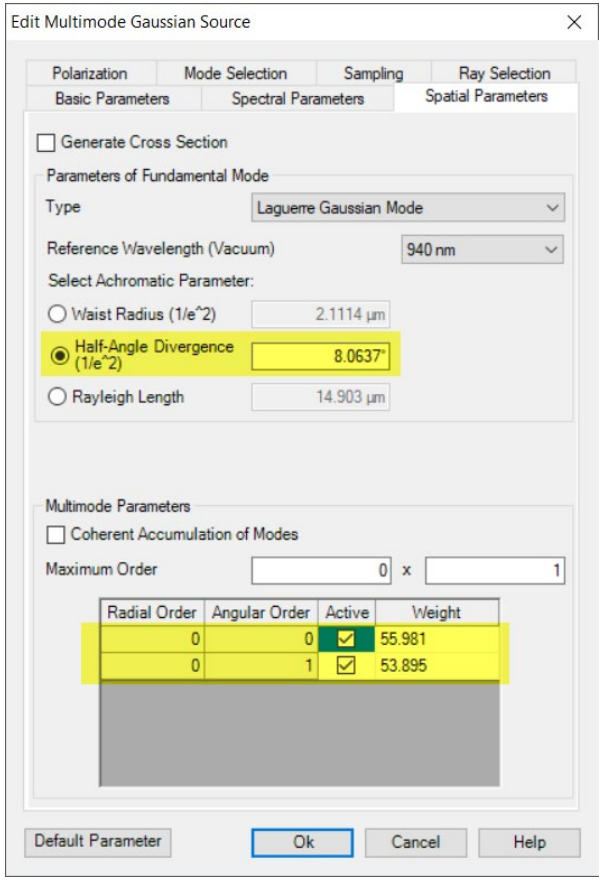
After parametric optimization

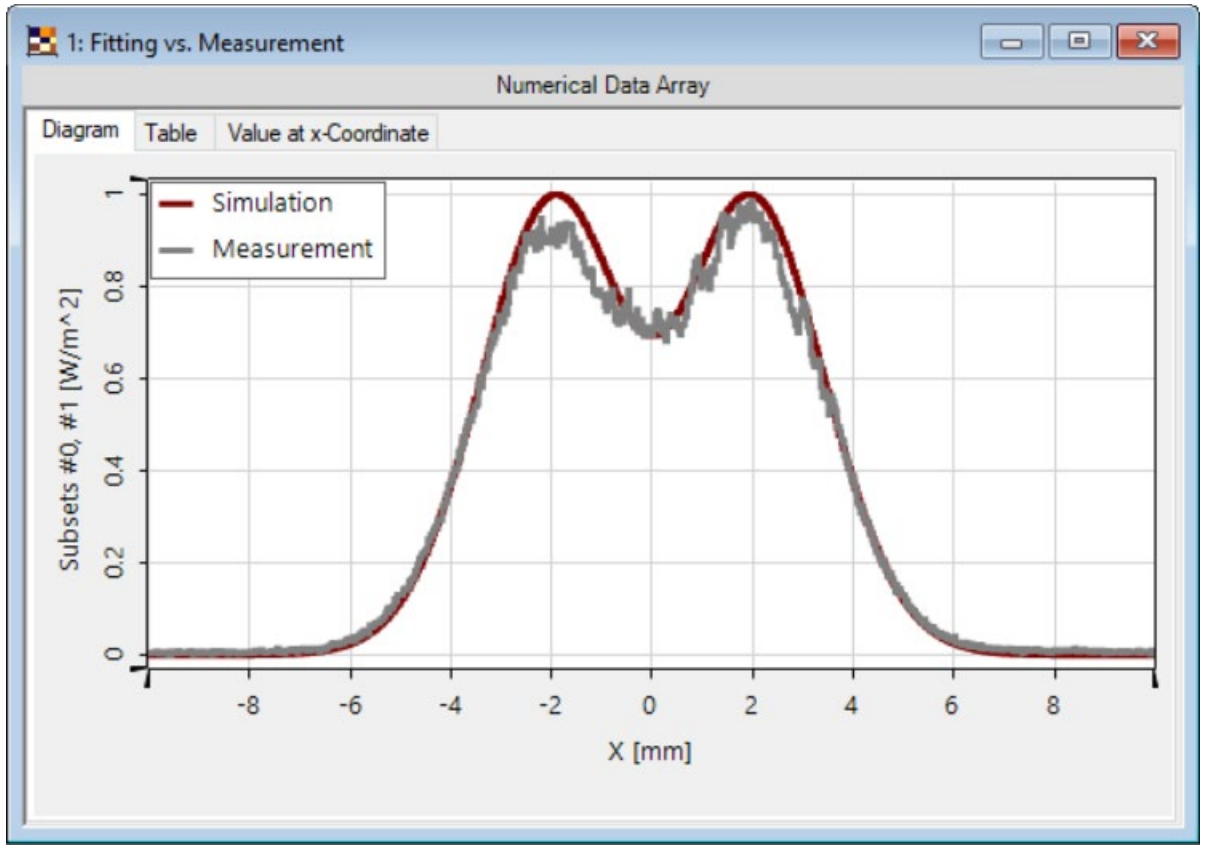




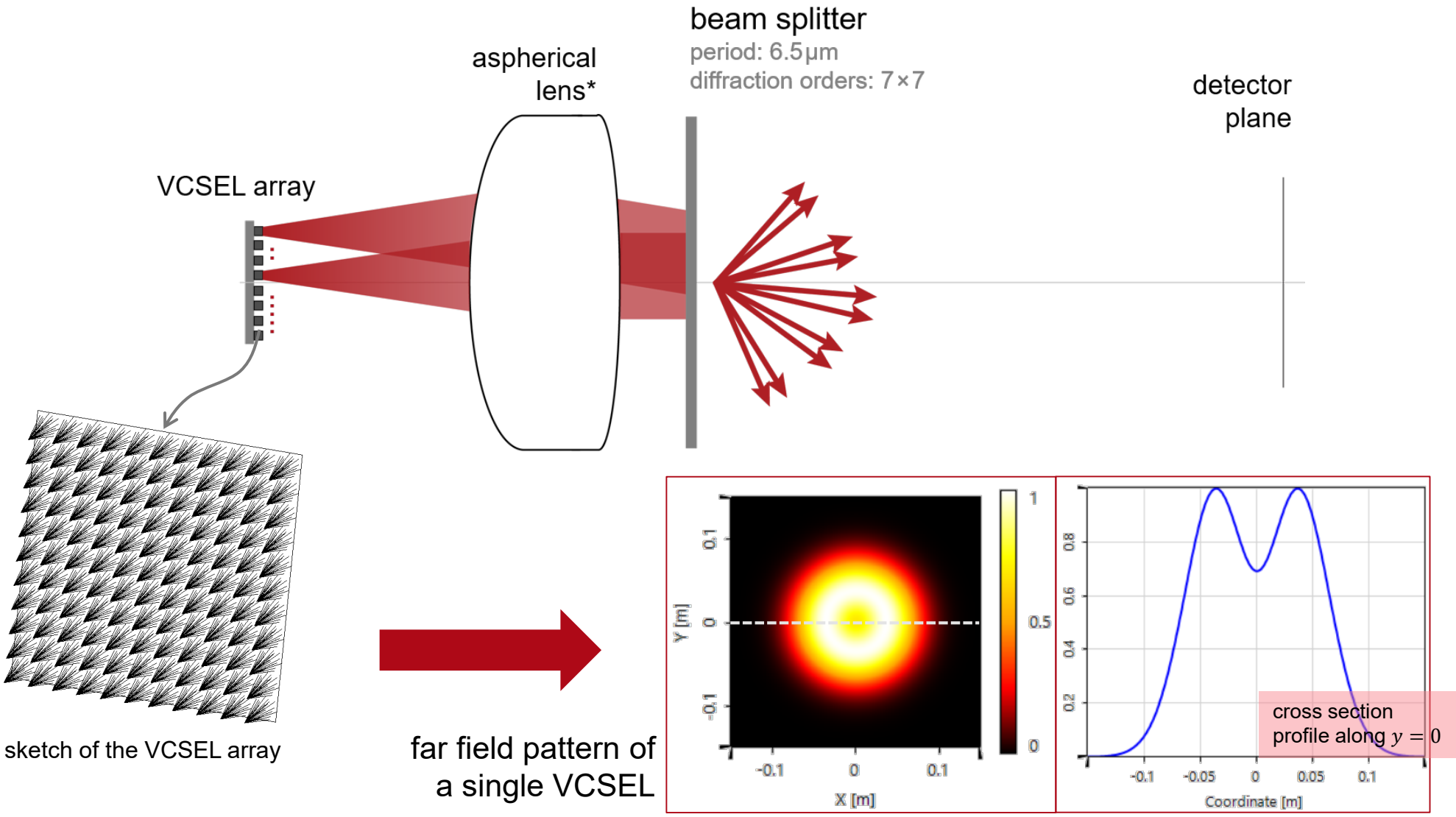
Source Modeling: Mode Decomposition for VCSEL

After parametric optimization

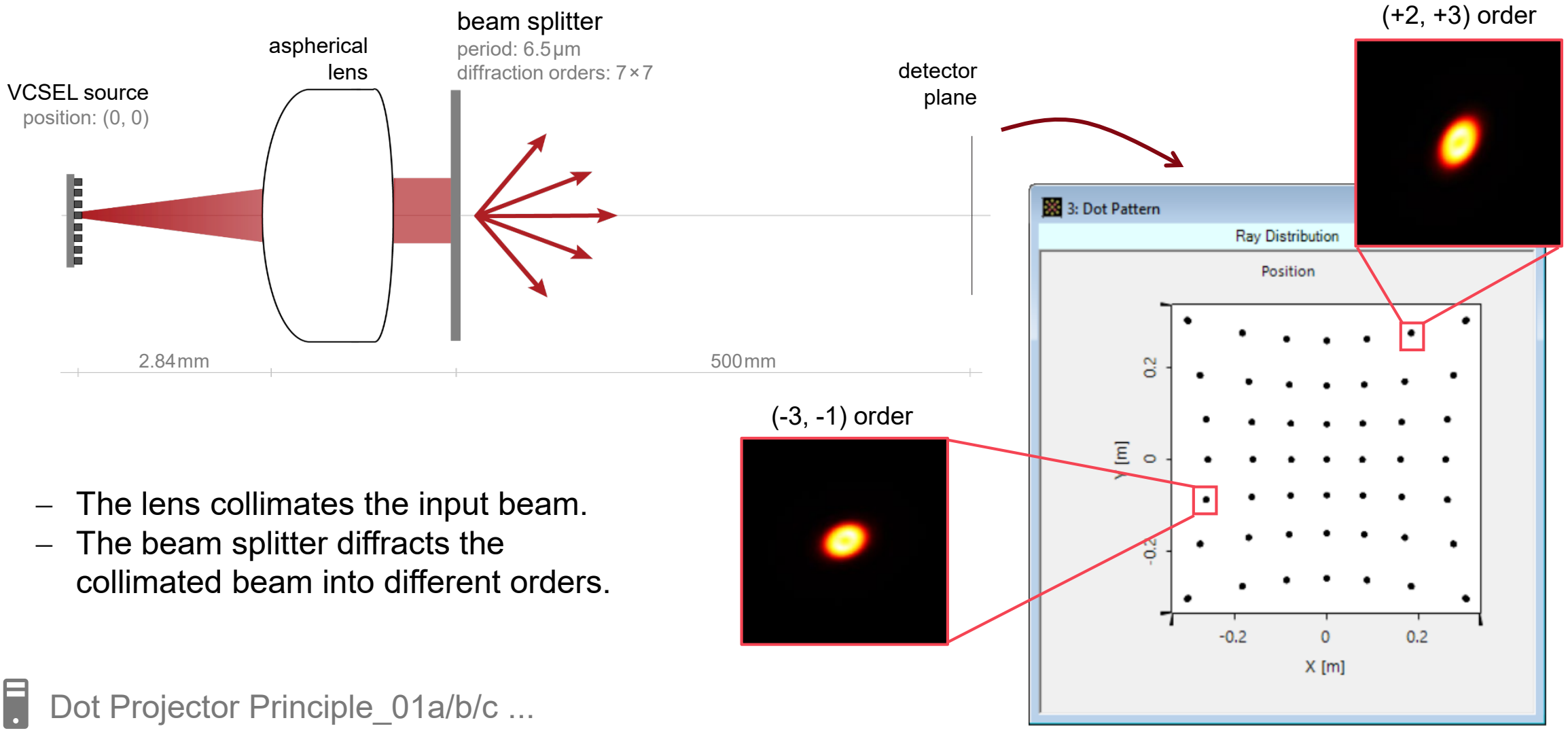




Source Modeling



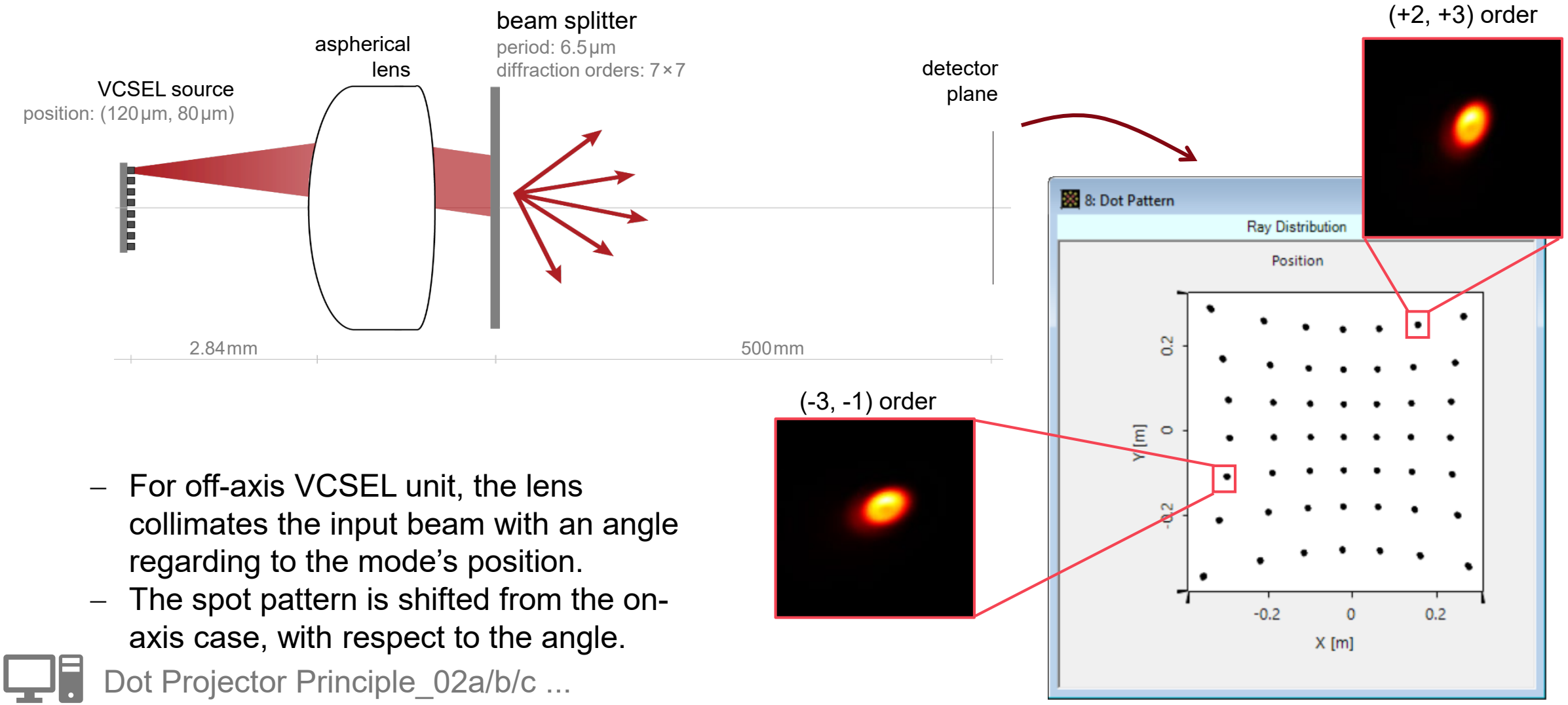
Simulation with the On-Axis VCSEL Unit



- The lens collimates the input beam.
- The beam splitter diffracts the collimated beam into different orders.

Dot Projector Principle_01a/b/c ...

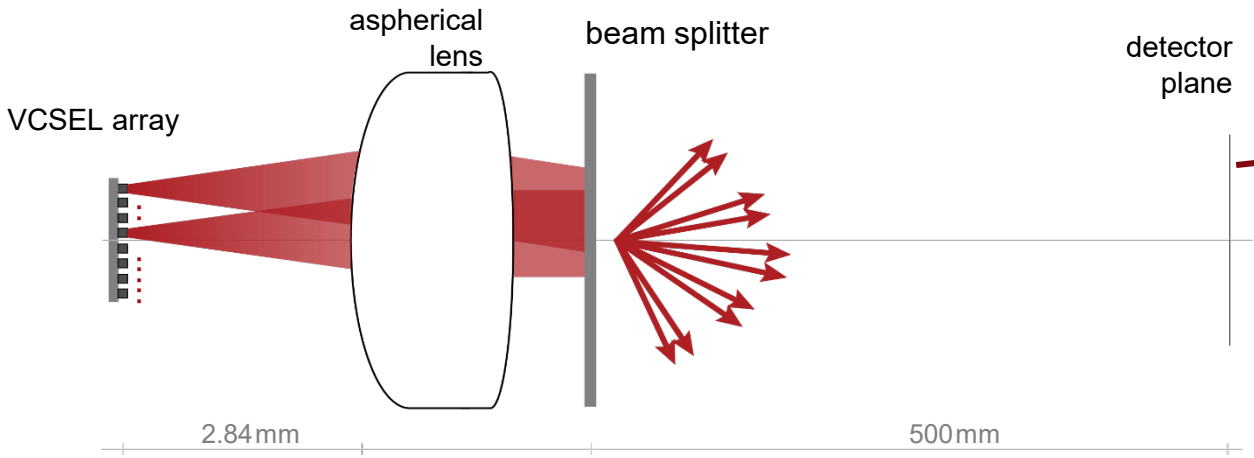
Simulation with an Off-axis VCSEL Unit



- For off-axis VCSEL unit, the lens collimates the input beam with an angle regarding to the mode's position.
- The spot pattern is shifted from the on-axis case, with respect to the angle.

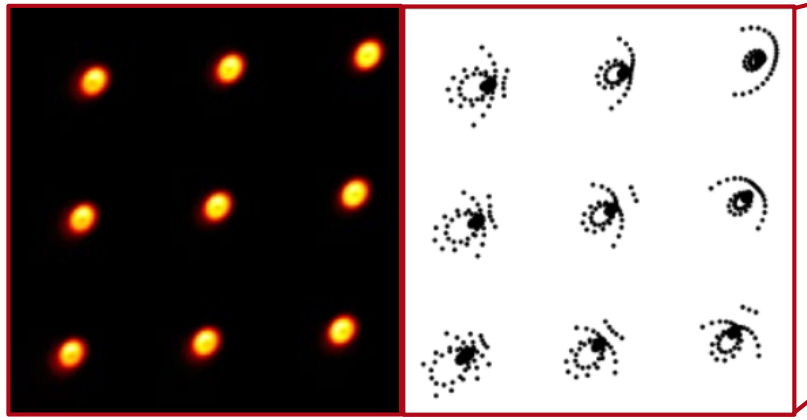
Dot Projector Principle_02a/b/c ...

Simulation with Complete VCSEL Array

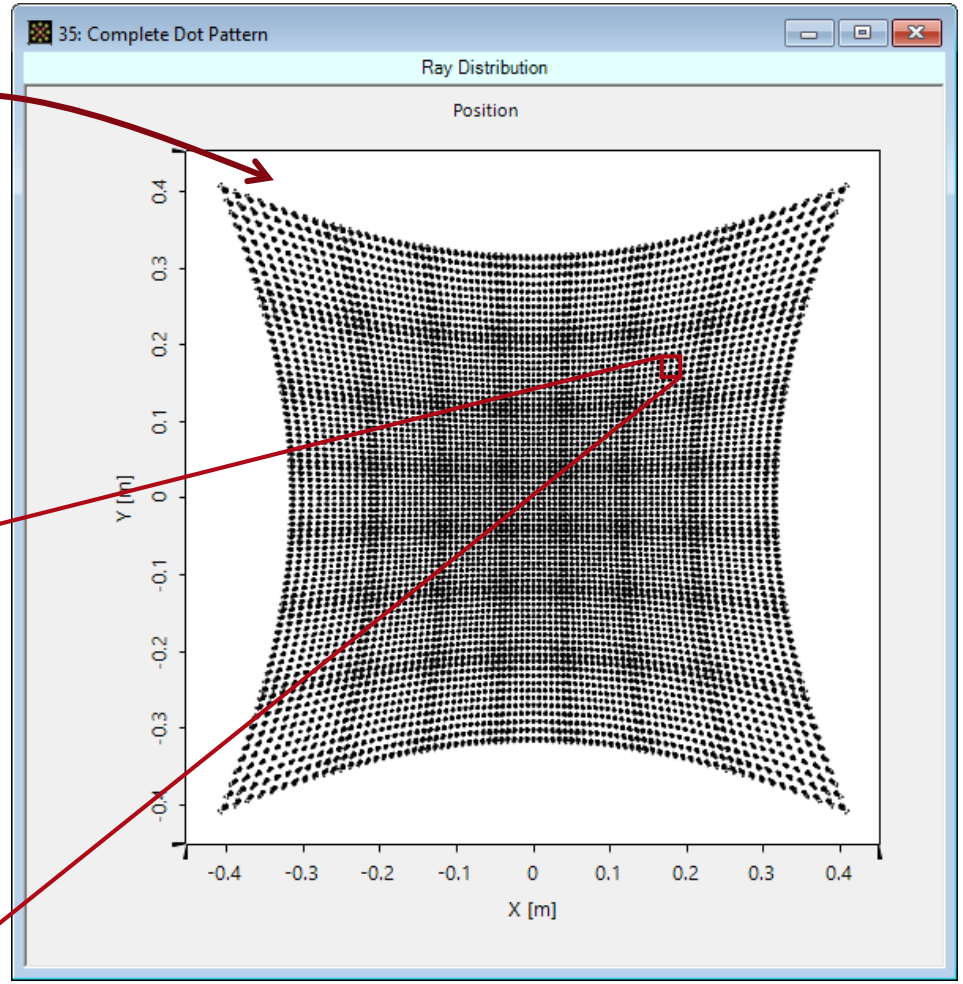


The beam splitter duplicates the pattern of the VCSEL array with lateral shifts on the detector plane.

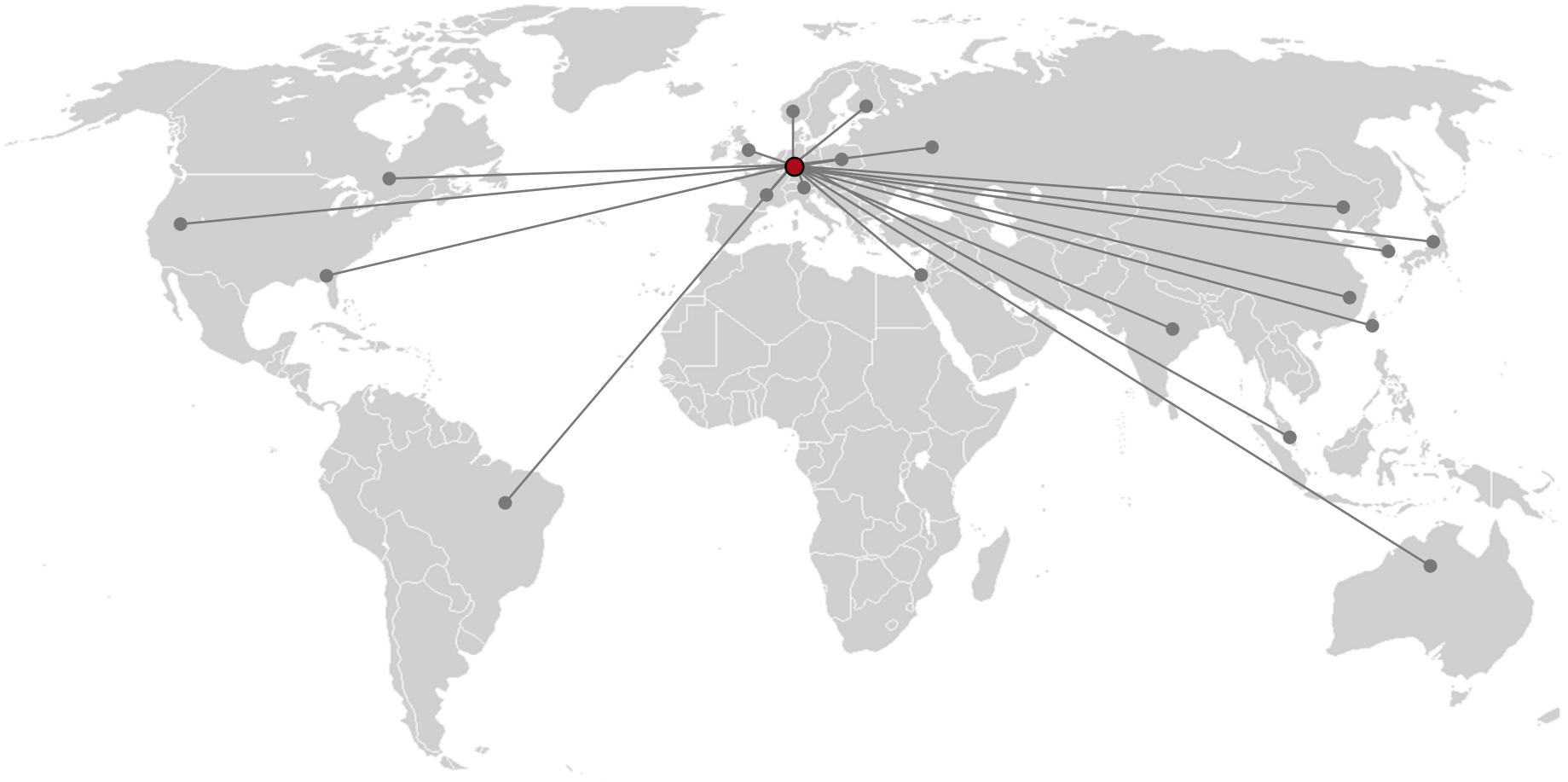
simulation results



field tracing ray tracing



Optical Design Software and Services



Booth #4545 (German pavilion)