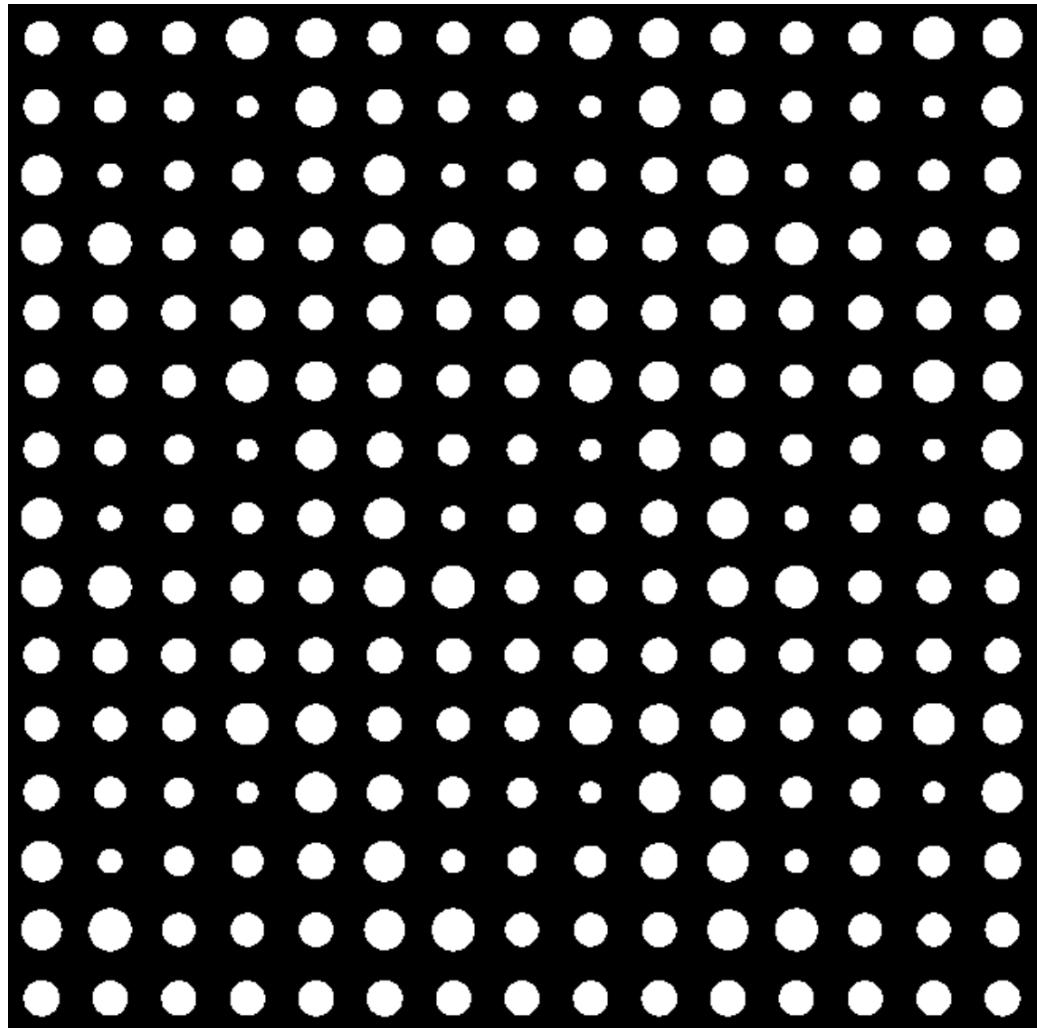




# Design of 2D Non-Paraxial Beam-Splitting Metagrating

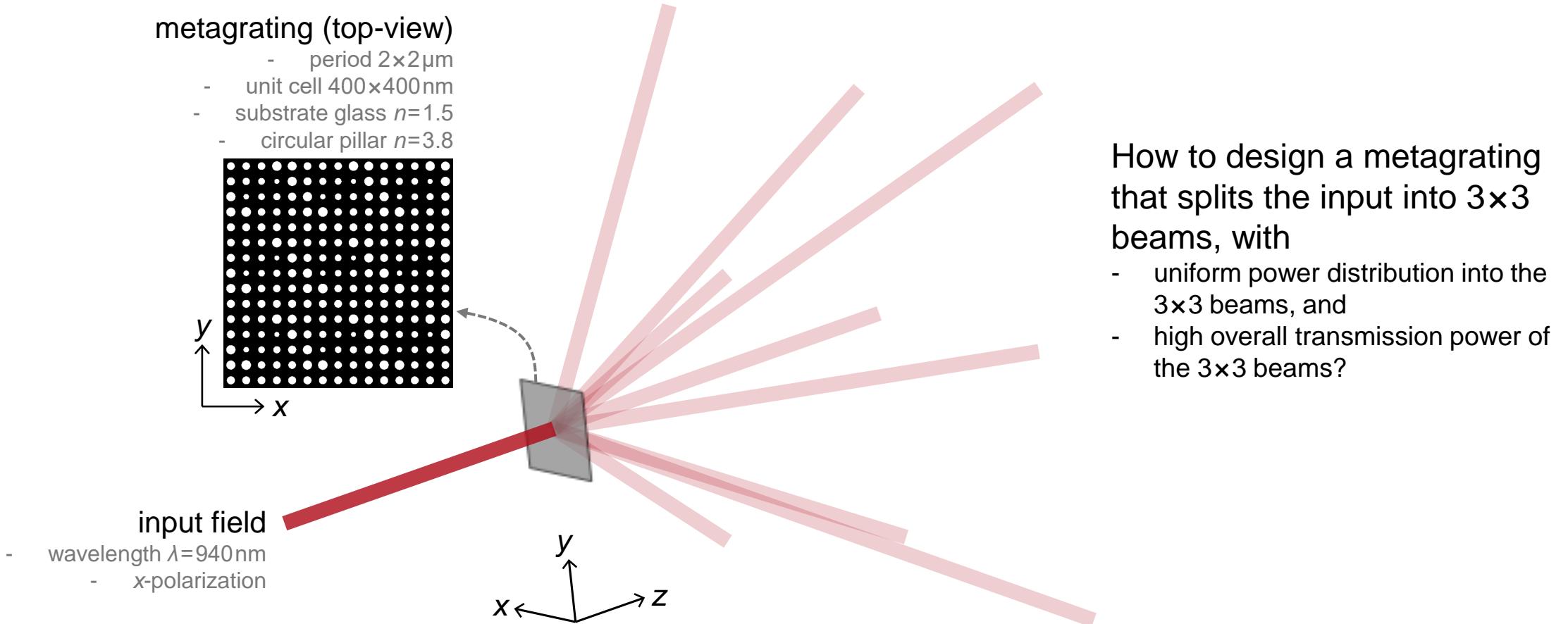
# Abstract

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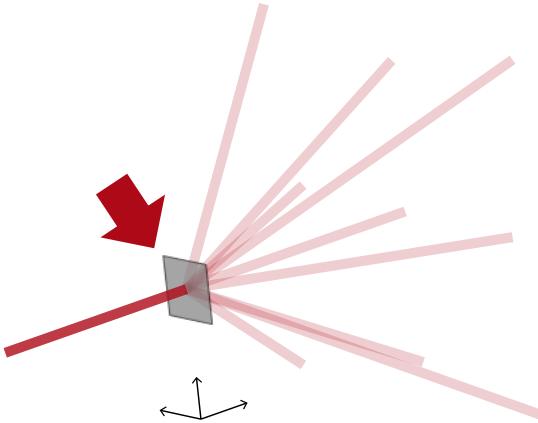


Metagratings are shown to have advantages when compared with traditional gratings, especially in non-paraxial cases. In this example, we design a two-dimensional (2D) metagrating that splits the input into 3x3 beams. The metagrating is constructed with circular nano pillars, and in VirtualLab Fusion, we use FMM/RCWA to evaluate the diffraction efficiency of the metagrating. And, we show how to use the parametric optimization tool to improve the uniformity of the diffraction efficiencies.

# Design Task



# Connected Modeling Techniques: Metagrating

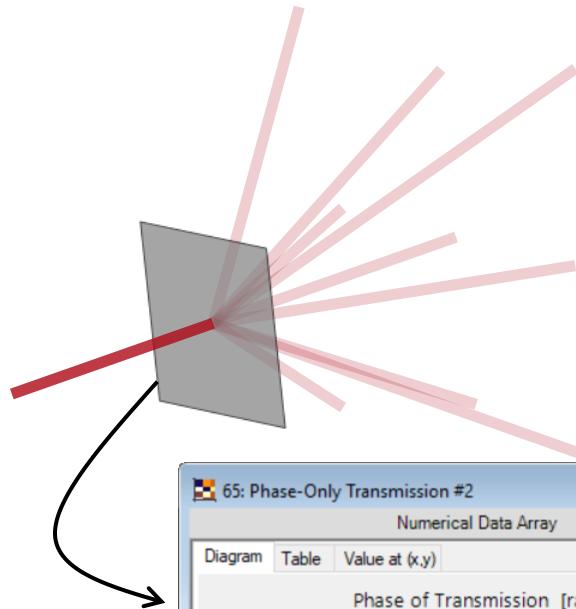


Available modeling techniques for periodic micro and nano structures:

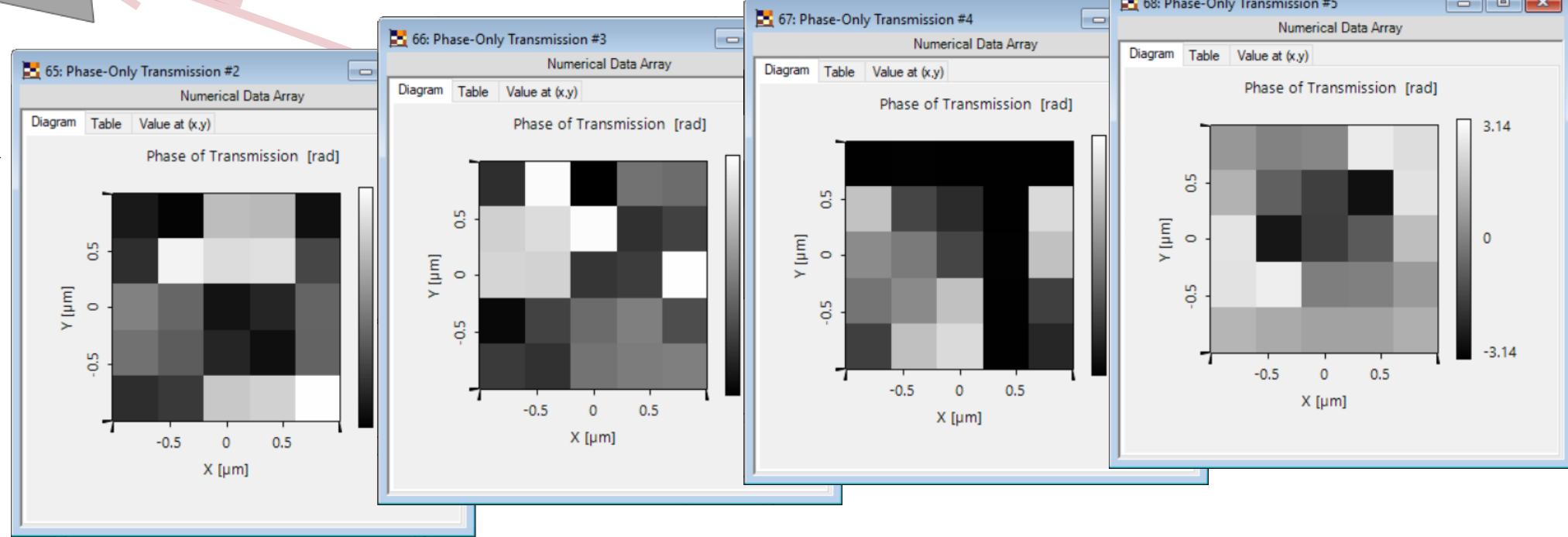
Methods	Preconditions	Accuracy	Speed	Comments
Fourier Modal Method (FMM)	None	High	High	Small periods
Thin Element Approximation	Large periods & features, thin	High	High	Thickness about wavelength; period & features larger than about ten wavelengths
	Otherwise	Low	High	
FMM in Kogelnik Approximation	Thick volume gratings; Bragg condition	High	Very high	Method is electromagnetic formulation of Kogelnik's approach
	No Bragg condition	Low	Very high	

As a rigorous eigenmode solver, the Fourier modal method (also known as rigorous coupled wave analysis, RCWA) provides a very high accuracy. Due to the small periods and distances in this setup, the calculation speed is fast. FMM is then the best compromise of accuracy and speed for the simulation of the beam-splitting metagrating.

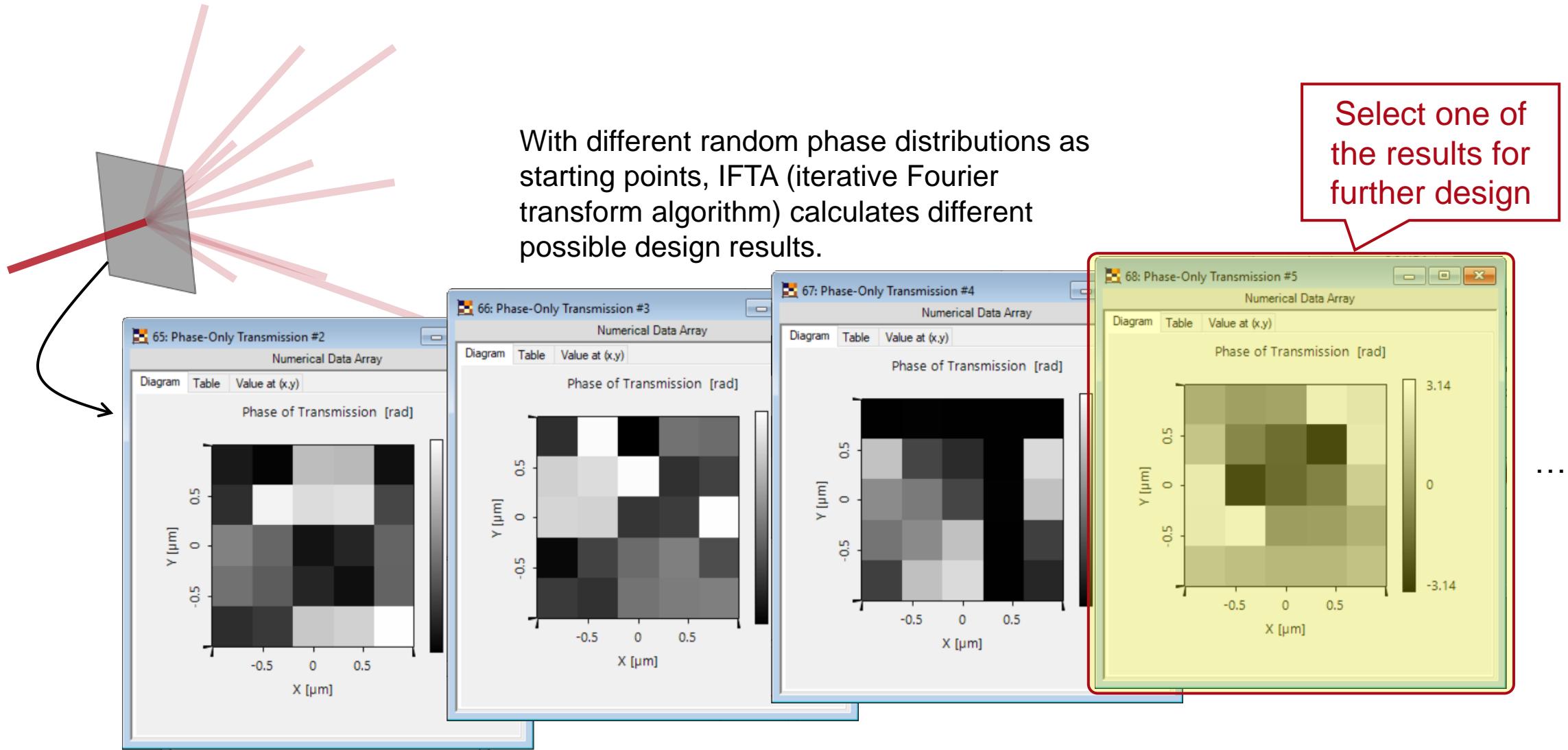
# Phase-Only Transmission Design (IFTA)



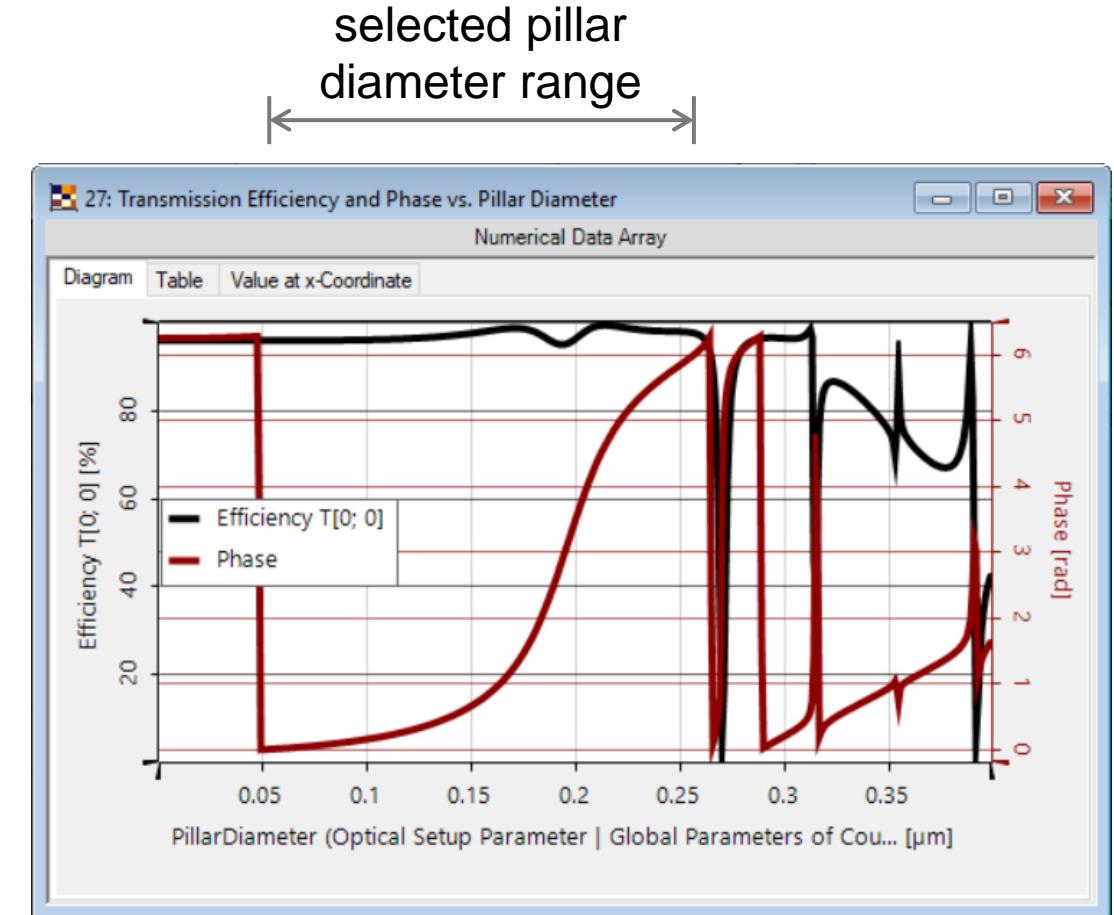
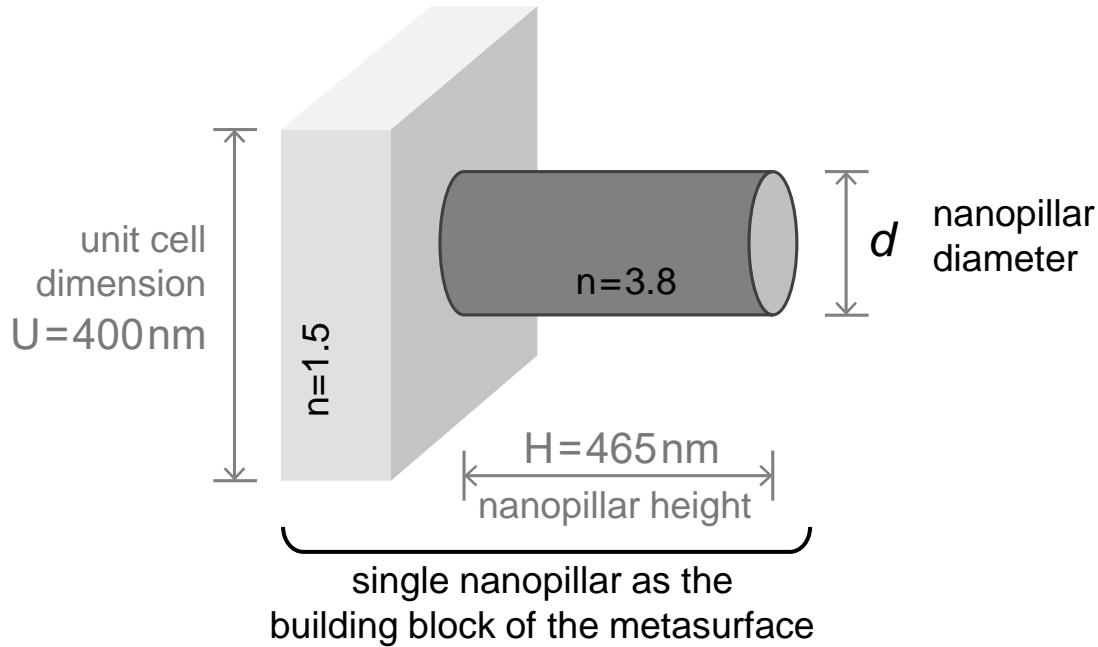
With different random phase distributions as starting points, IFTA (iterative Fourier transform algorithm) calculates different possible design results.



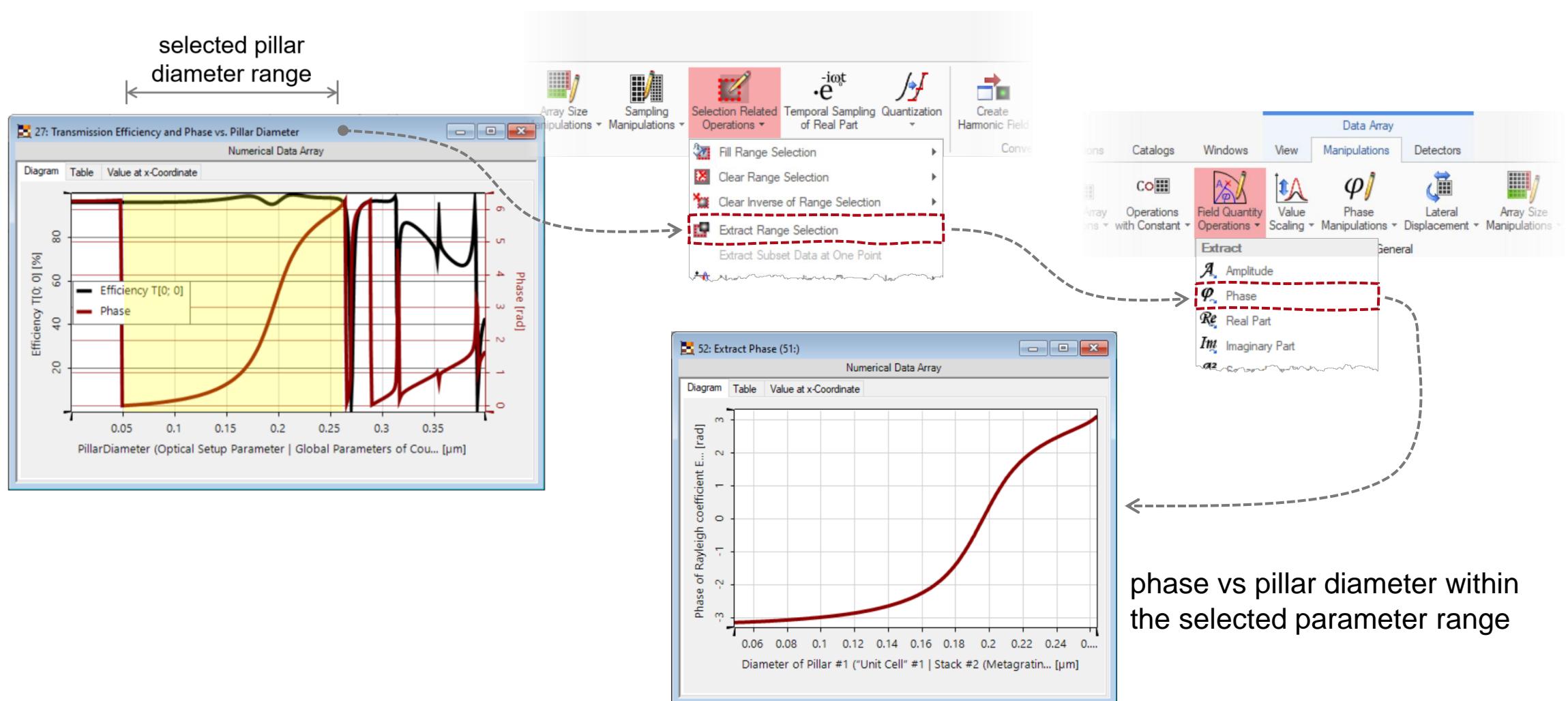
# Phase-Only Transmission Design (IFTA)



# Metasurface Unit Cell Analysis



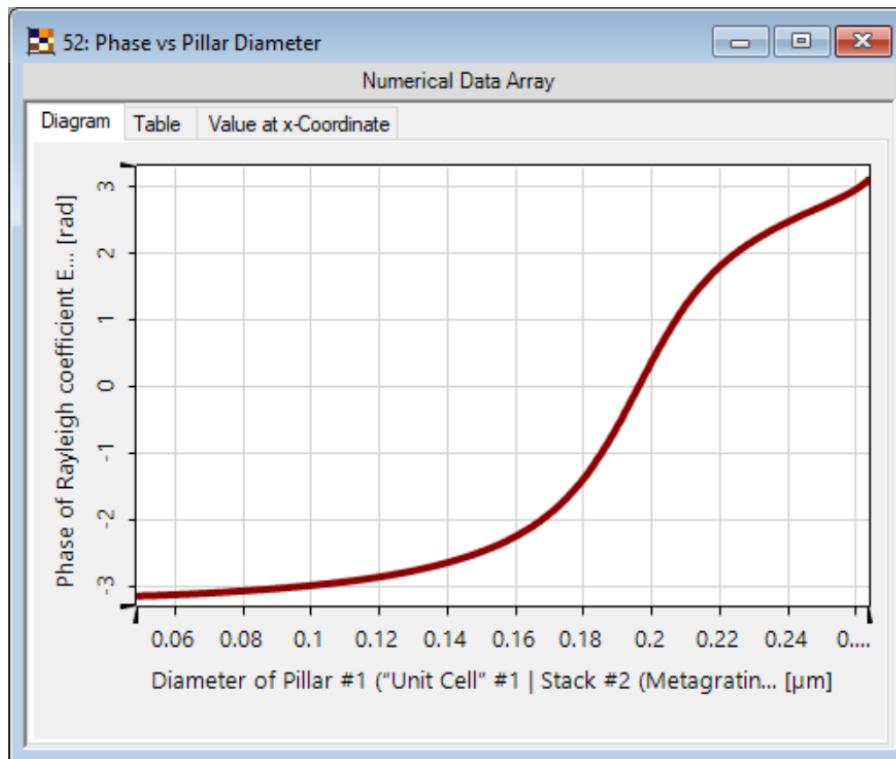
# Unit Cell Parameter Range Selection



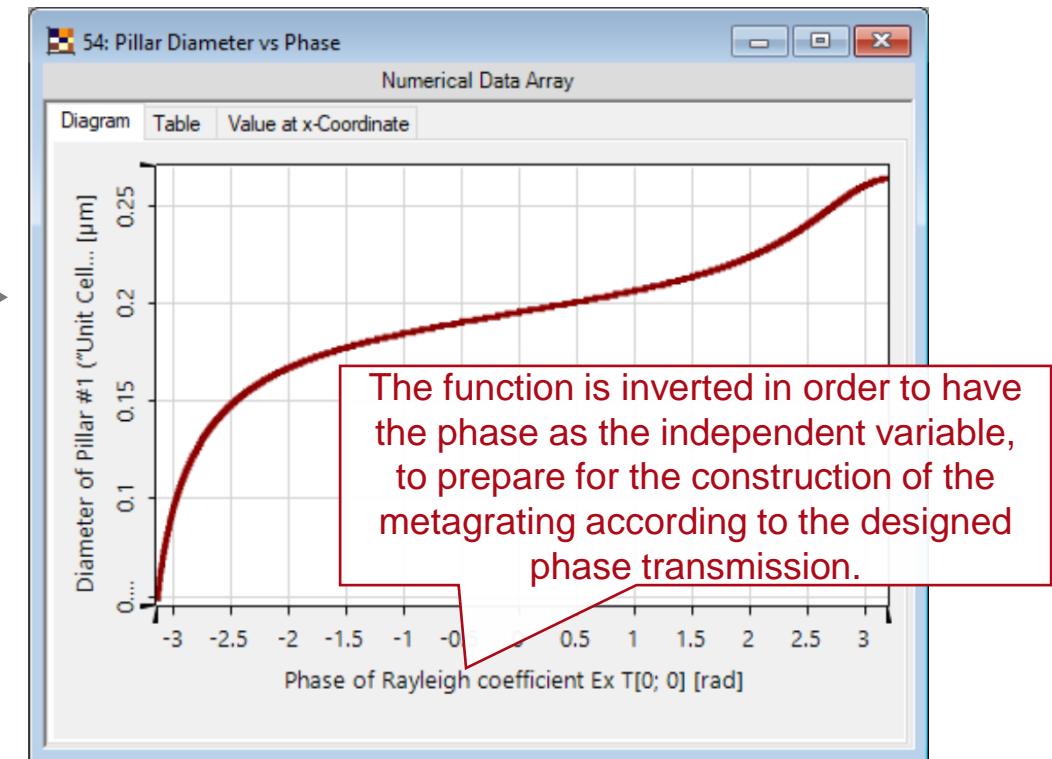
# Phase vs Pillar Diameter and Its Inverse

phase value vs pillar diameter

(result from last step)



pillar diameter vs phase value

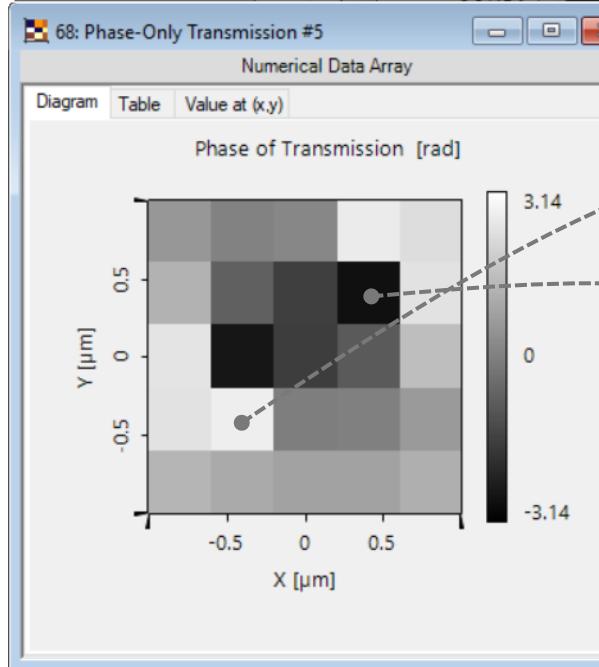


↔ inverse

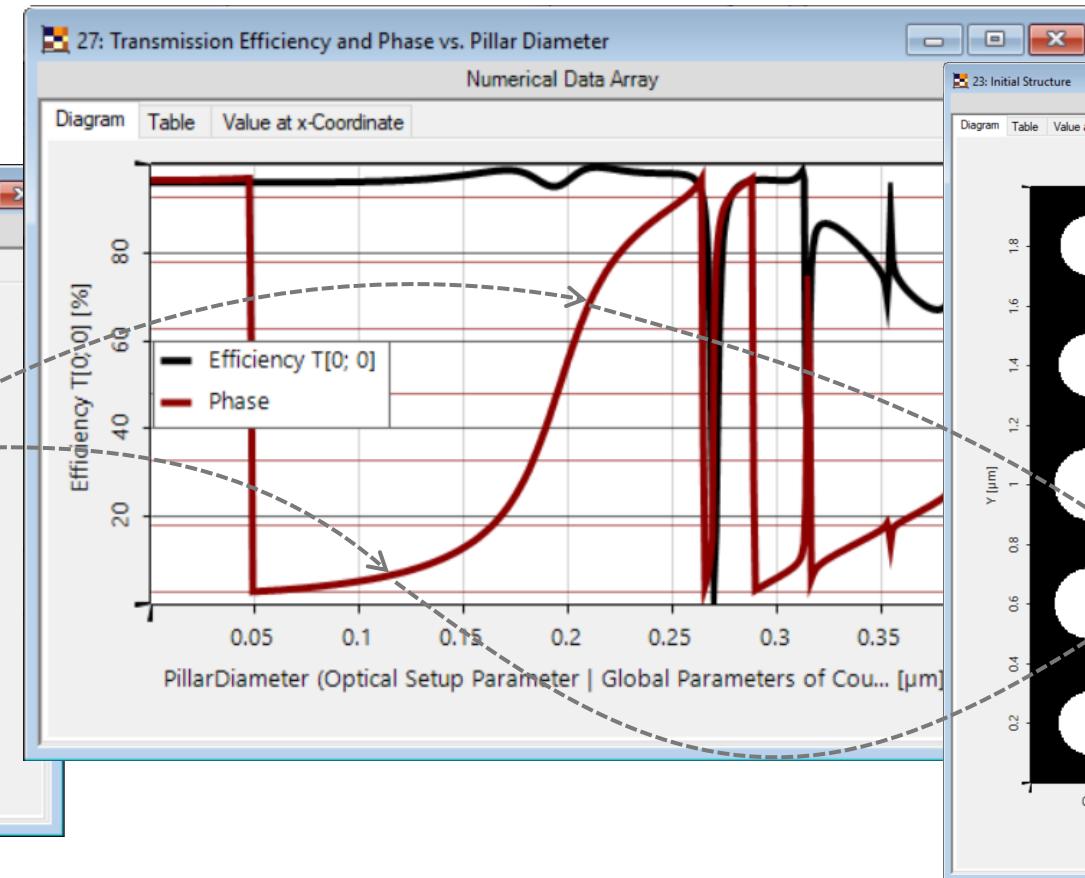
In this example, function inversion can be done with the VirtualLab C# Module: Appx\_01\_Calculate Inverse of 1D Function.cs

# Metagrating Construction

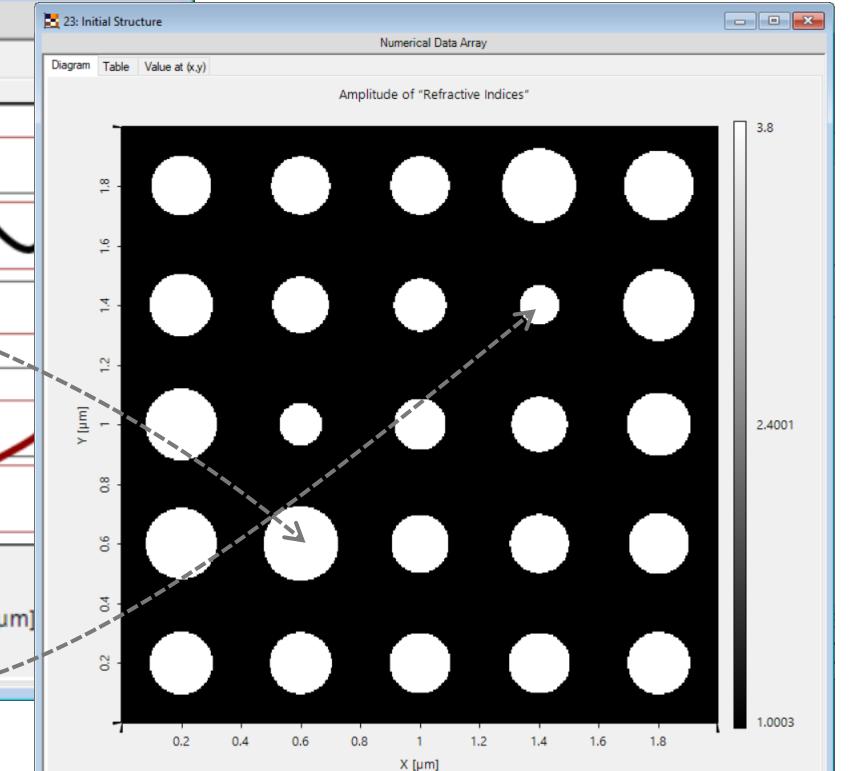
phase-only transmission



phase-diameter map/library



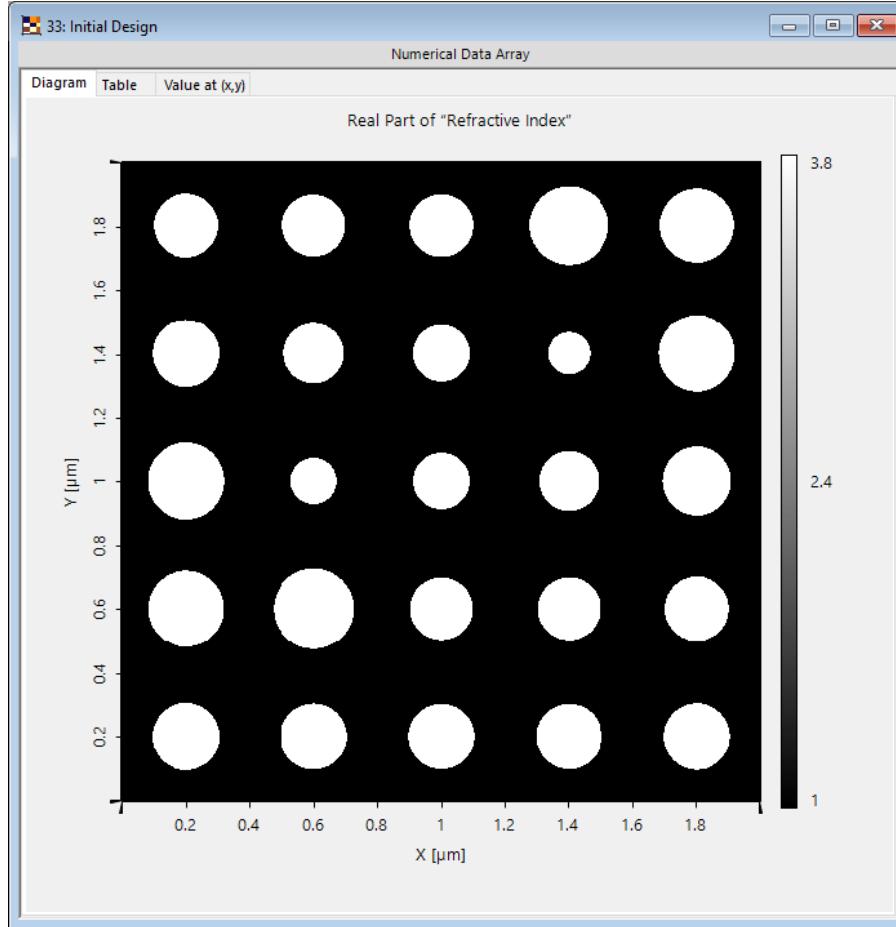
metagrating (top view)



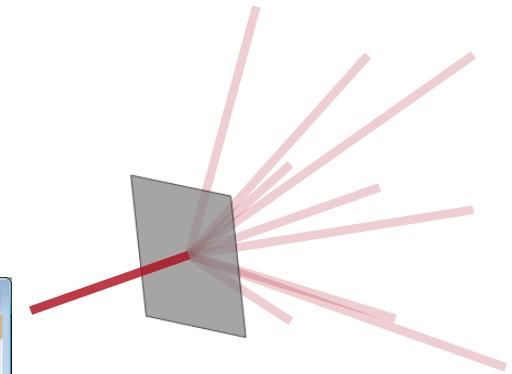
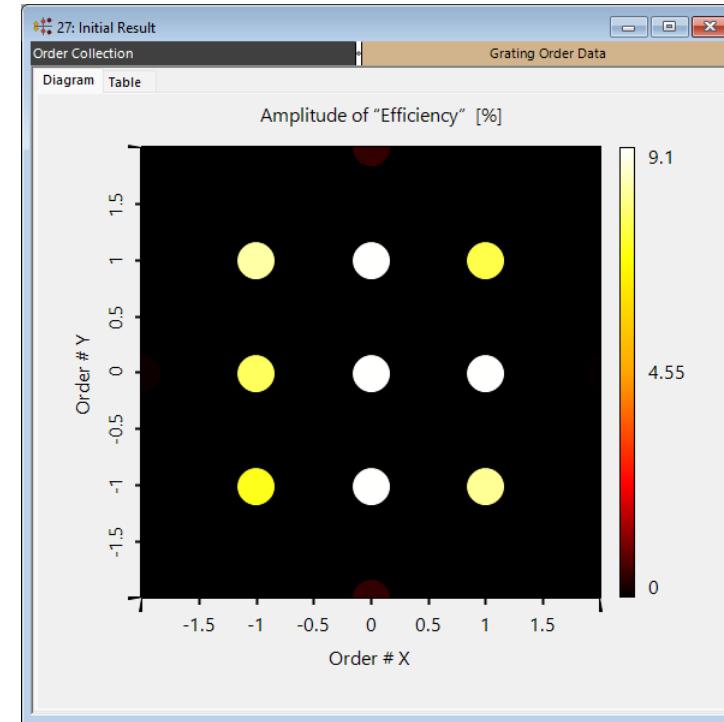
In this example, pillar distribution can be done with the VirtualLab C# Module: Appx\_02\_Calculate Pillar Diameters from Phase Profile.cs

# Evaluation of Initial Metasurface Design

initial metagrating (top-view)



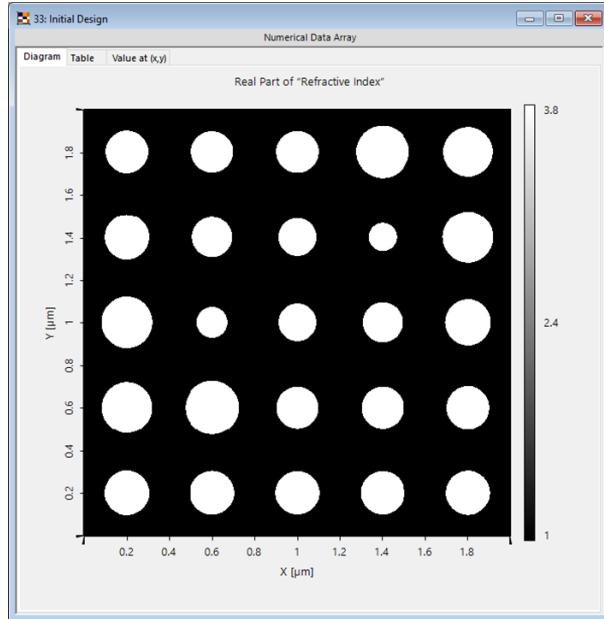
diffraction efficiencies



overall efficiency	79.6 %
uniformity error (PV)	25.3 %
uniformity error (RMS)	16.9 %

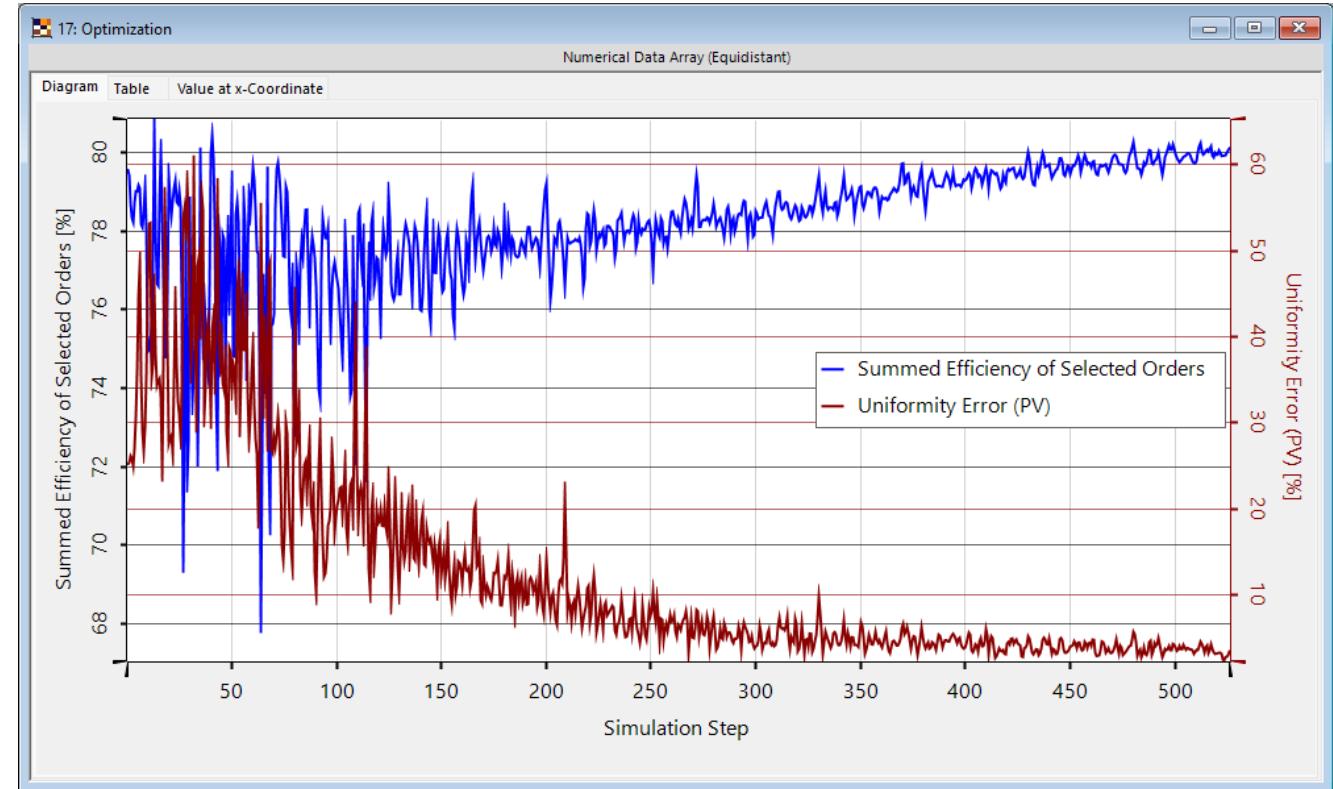
# Parametric Optimization

initial metagrating



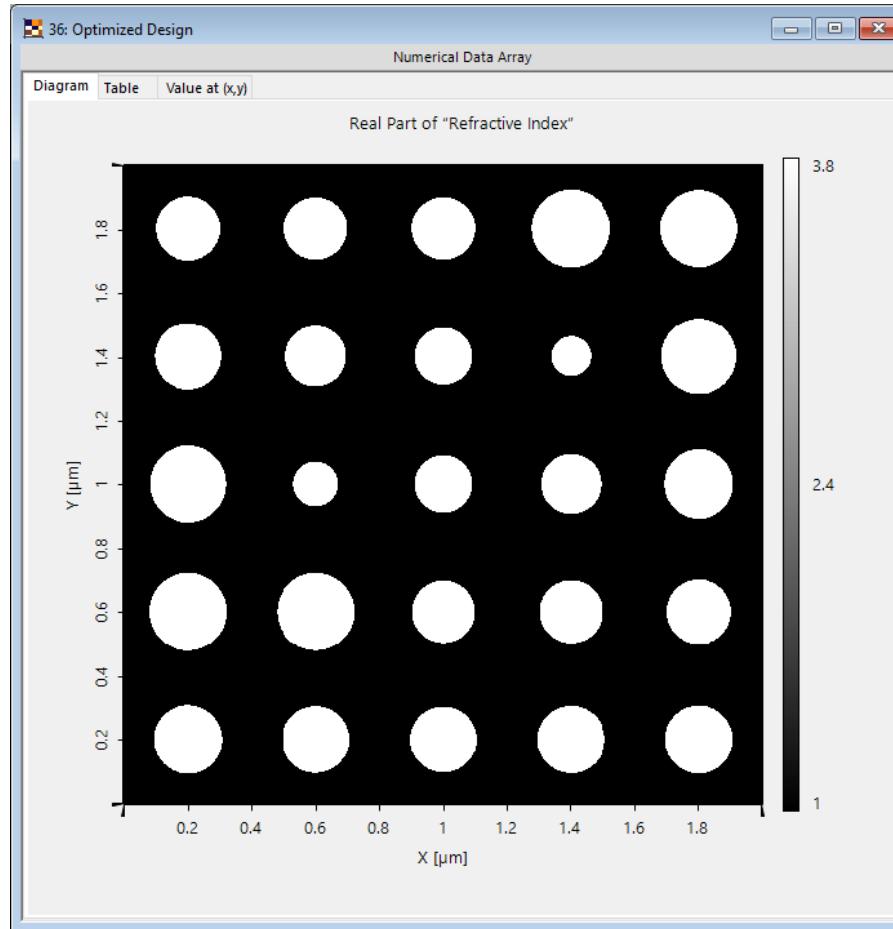
- keep pillar positions
- **vary** pillar diameters  
(25 variables)

downhill simplex optimization with FMM/RCWA for grating analysis

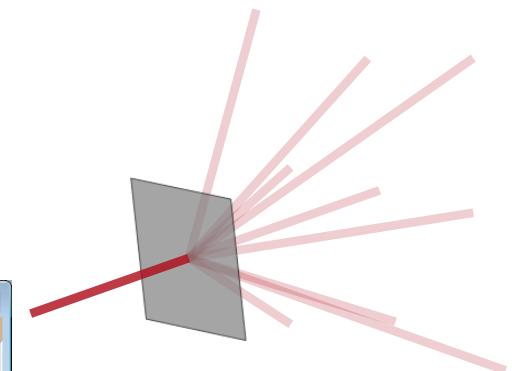
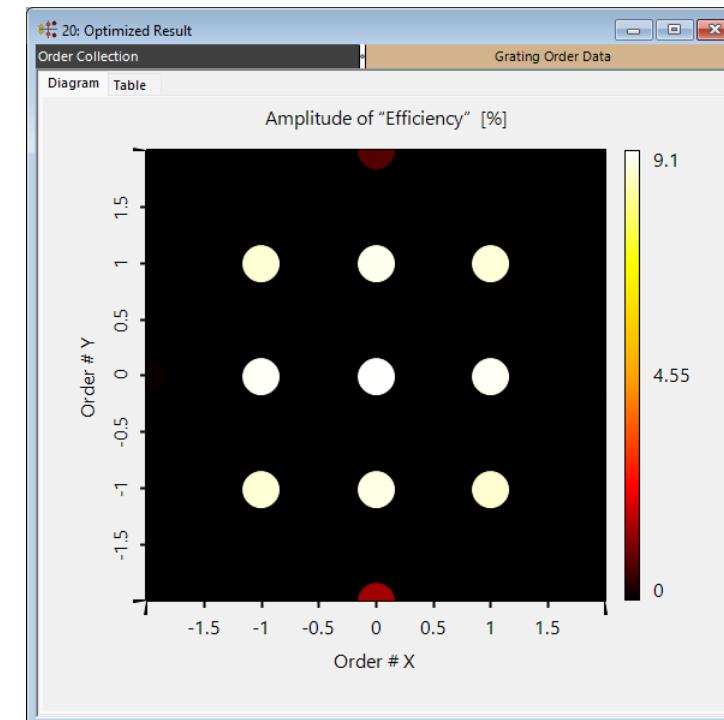


# Evaluation of Optimized Metagrating Design

optimized metagrating (top-view)



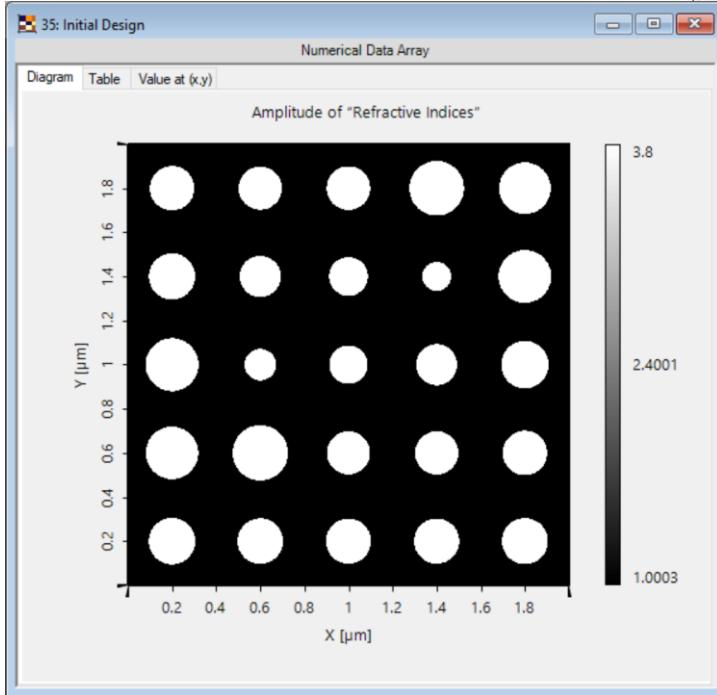
diffraction efficiencies



overall efficiency	79.9%
uniformity error (PV)	2.3%
uniformity error (RMS)	1.6%

# Peek into VirtualLab Fusion

flexible definition of 2D metagrating surface



Amplitude of "Refractive Indices"

Y [μm]

X [μm]

35: Initial Design

Numerical Data Array

Diagram Table Value at (x,y)

	x-Position	y-Position	Diameter
1	-800 nm	-800 nm	216.21 nm
2	-800 nm	-400 nm	243.62 nm
3	-800 nm	0 mm	240.39 nm
4	-800 nm	400 nm	208.05 nm
5	-800 nm	800 nm	202.96 nm
6	-400 nm	-800 nm	209.68 nm
7	-400 nm	-400 nm	240.81 nm
8	-400 nm	0 mm	136.07 nm
9	-400 nm	400 nm	188.99 nm
10	-400 nm	800 nm	197.18 nm
11	0 mm	-800 nm	206.26 nm
			101.07

Pillar Material

Name: Non-Dispersive Material (n=3.8)

Defined by Constant Refractive Index: 3.8

State of Matter: Solid

Pillar Geometry Pillar Distribution

Import Diameter Data

Validity: ✓

Optimization Results

Start or stop the optimization routine. The results are shown in the table.

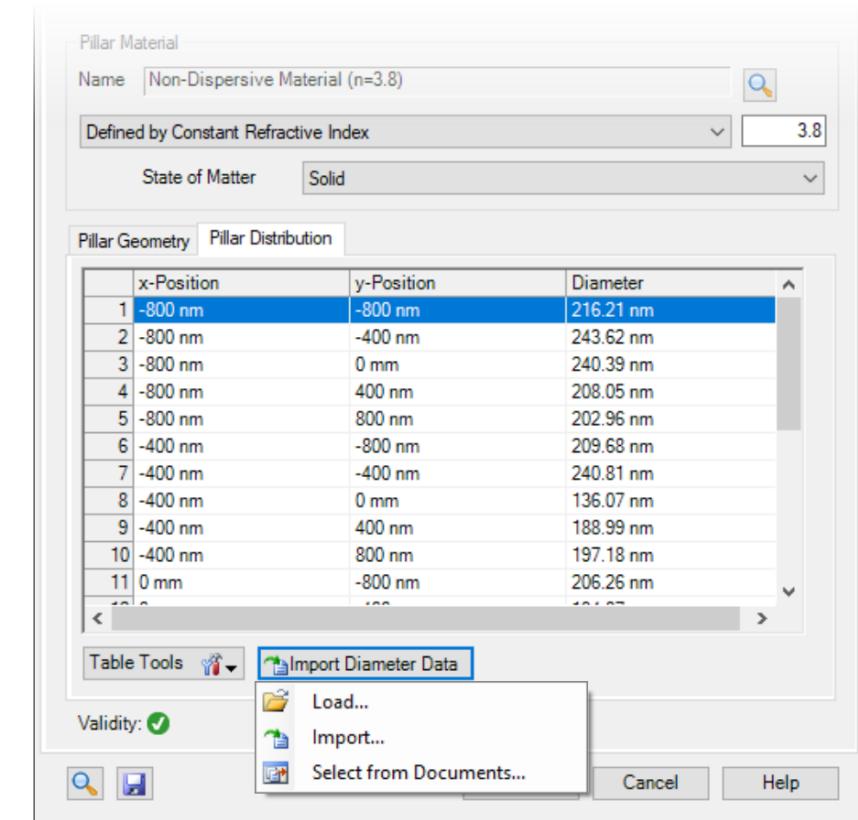
35: C:\Users...\Beamsplitting Metagrating\_04b\_Optimizing Pillar Diameters.opt

Subdetector	1	2	3	4	5	6
Target Function Value	0.18377	0.20019	0.18909	0.23442	0.35584	0.51472
Diameter of Pillar #1 (Metagrating #1 ...)	211 nm	232.1 nm	211 nm	211 nm	211 nm	211 nm
Diameter of Pillar #2 (Metagrating #1 ...)	238 nm	238 nm	261.8 nm	238 nm	238 nm	238 nm
Diameter of Pillar #3 (Metagrating #1 ...)	240 nm	240 nm	240 nm	264 nm	240 nm	240 nm
Diameter of Pillar #4 (Metagrating #1 ...)	210 nm	210 nm	210 nm	210 nm	210 nm	210 nm
Diameter of Pillar #5 (Metagrating #1 ...)	202 nm	202 nm	202 nm	202 nm	222.2 nm	202 nm
Diameter of Pillar #6 (Metagrating #1 ...)	207 nm	207 nm	207 nm	207 nm	207 nm	227.7 nm
Diameter of Pillar #7 (Metagrating #1 ...)	251 nm	251 nm	251 nm	251 nm	251 nm	251 nm
Diameter of Pillar #8 (Metagrating #1 ...)	143 nm	143 nm	143 nm	143 nm	143 nm	143 nm
Diameter of Pillar #9 (Metagrating #1 ...)	187 nm	187 nm	187 nm	187 nm	187 nm	187 nm
Diameter of Pillar #10 (Metagrating #1 ...)	196 nm	196 nm	196 nm	196 nm	196 nm	196 nm
Diameter of Pillar #11 (Metagrating #1 ...)	205 nm	205 nm	205 nm	205 nm	205 nm	205 nm
Diameter of Pillar #12 (Metagrating #1 ...)	195 nm	195 nm	195 nm	195 nm	195 nm	195 nm
Diameter of Pillar #13 (Metagrating #1 ...)	175 nm	175 nm	175 nm	175 nm	175 nm	175 nm
Diameter of Pillar #14 (Metagrating #1 ...)	176 nm	176 nm	176 nm	176 nm	176 nm	176 nm
Diameter of Pillar #15 (Metagrating #1 ...)	198 nm	198 nm	198 nm	198 nm	198 nm	198 nm
Diameter of Pillar #16 (Metagrating #1 ...)	205 nm	205 nm	205 nm	205 nm	205 nm	205 nm
Diameter of Pillar #17 (Metagrating #1 ...)	196 nm	196 nm	196 nm	196 nm	196 nm	196 nm

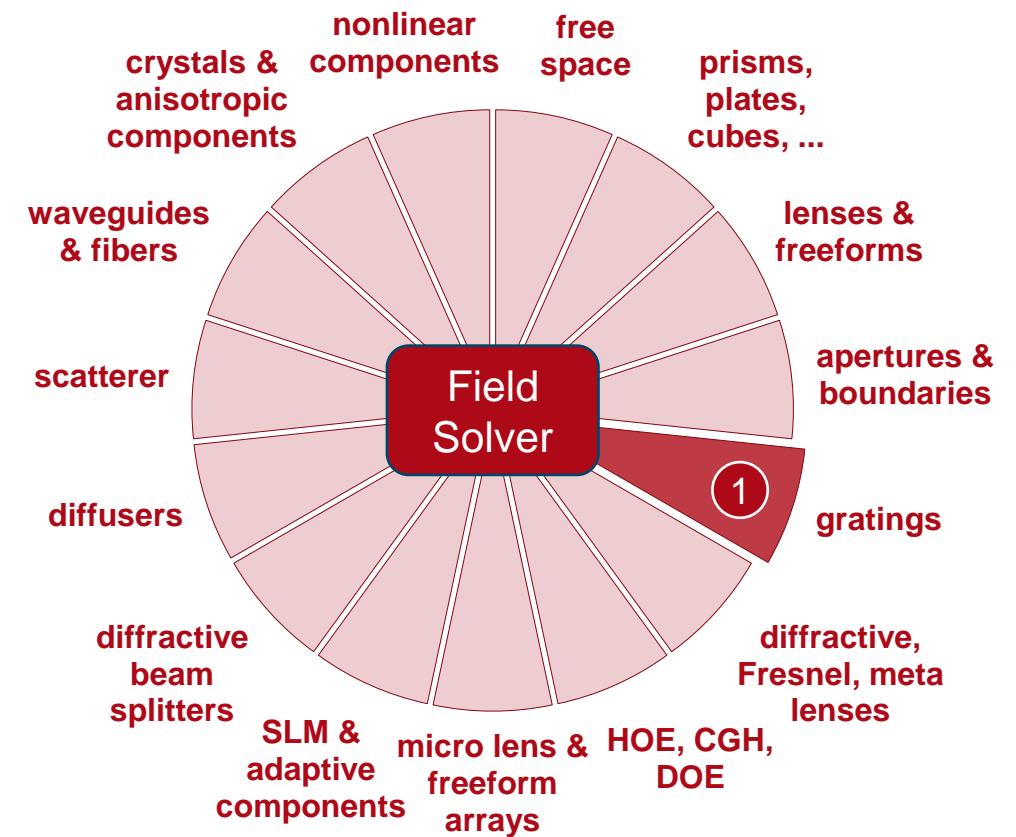
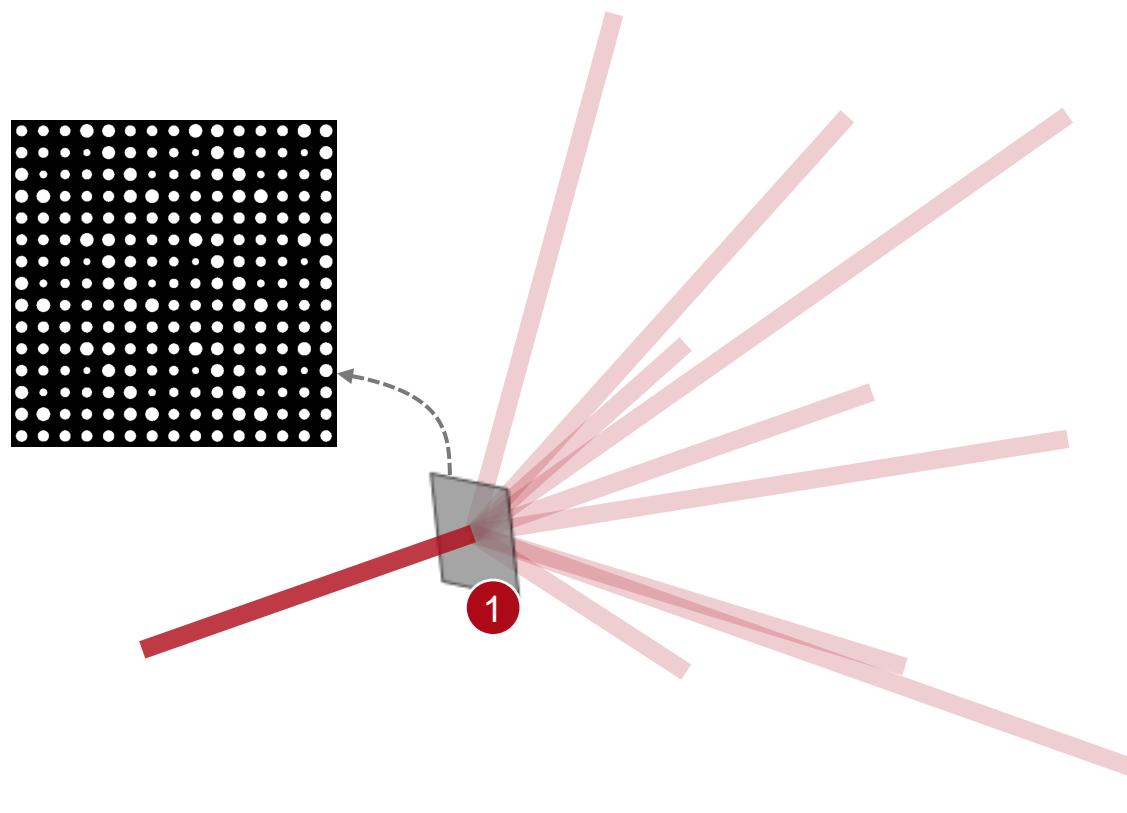
parametric optimization of metagrating structure

# Workflow in VirtualLab Fusion

- Analyze metasurface unit cell
  - [Rigorous Analysis of Nanopillar Metasurface Building Block](#) [Use Case]
- Construct metagratings
  - [Metagrating Construction - Discussion at Examples](#) [Use Case]
- Analyze grating diffraction efficiency
  - [Grating Order Analyzer](#) [Use Case]
- Parametric optimization of grating structure
  - [Parametric Optimization](#) [Tutorial Video]



# VirtualLab Fusion Technologies



# Document Information

title	Design of 2D Non-Paraxial Beam-Splitting Metagrating
document code	USC.0156
version	1.4
edition	VirtualLab Fusion Advanced
software version	2024.1 (Build 1.132)
category	Application Use Case
further reading	<ul style="list-style-type: none"><li>- <a href="#"><u>Rigorous Analysis of Nanopillar Metasurface Building Block</u></a></li><li>- <a href="#"><u>Modeling and Design of Blazed Metagratings</u></a></li></ul>