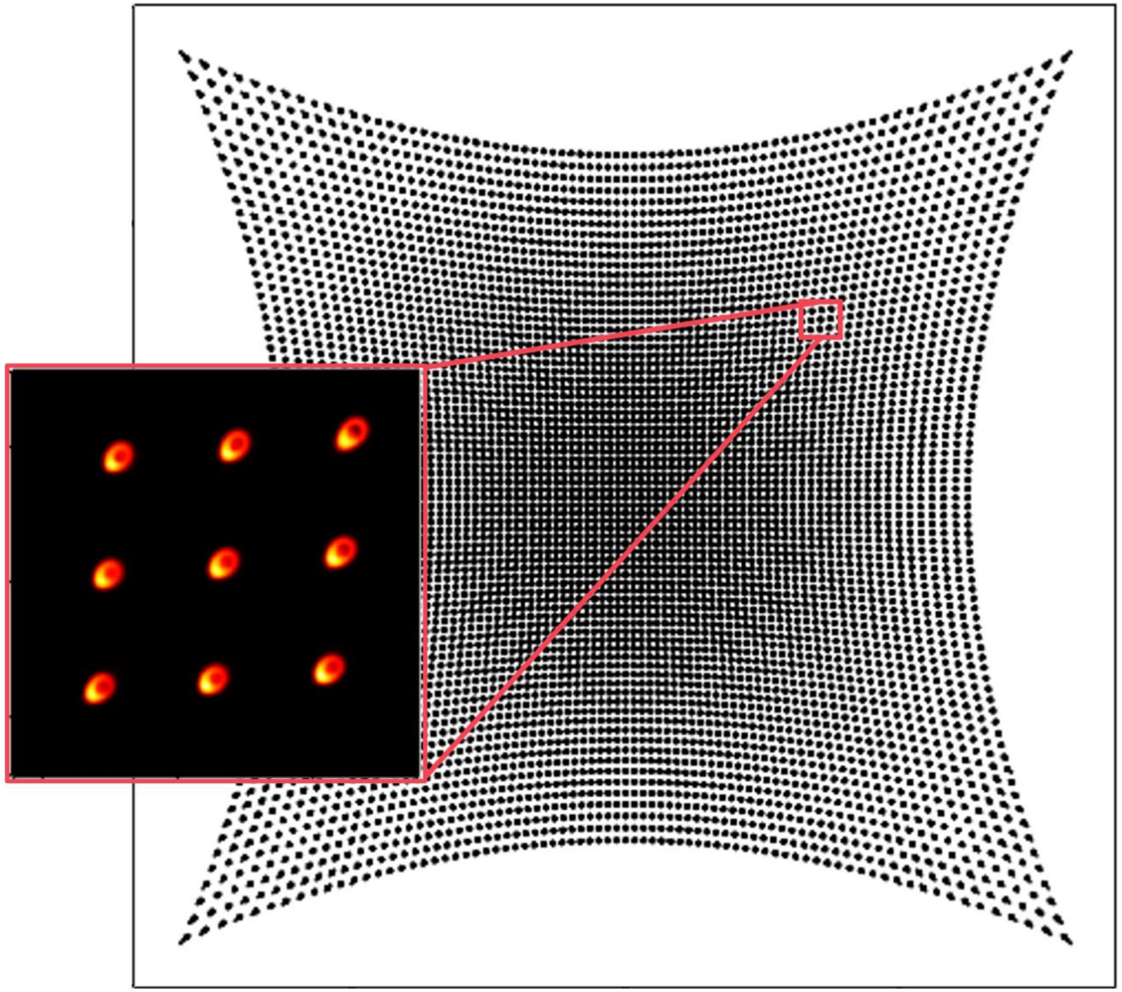
Demonstration of the Functional Principle of a Dot Projector

Abstract



The dot projector stands as a crucial element powering nowadays face recognition technologies (like Face ID). Typically, this system comprises an array of light-emitting units, lenses, and beam-splitting gratings. Working in conjunction, the lens system and gratings project and replicate the array source pattern multiple times. In this instance, we construct a dot projector system of this kind to showcase its operational principle. With VirtualLab Fusion, we perform both ray and field tracing for the system analysis.

Modeling Task

VCSEL array

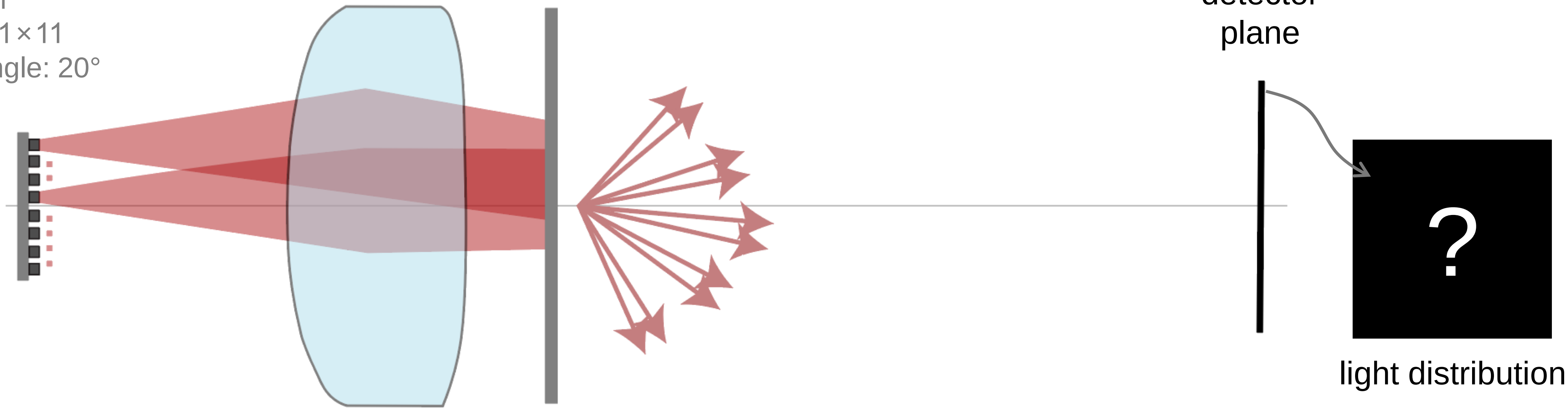
- model: multi-mode Gaussian (LG00, LG01)
- wavelength: 1 µm
- size: 400×400 µm
- no. of VCSELs: 11×11
- full divergence angle: 20°

aspherical lens*

beam splitter

- period: 6.5 µm
- diffraction orders: 7×7

detector plane



light distribution

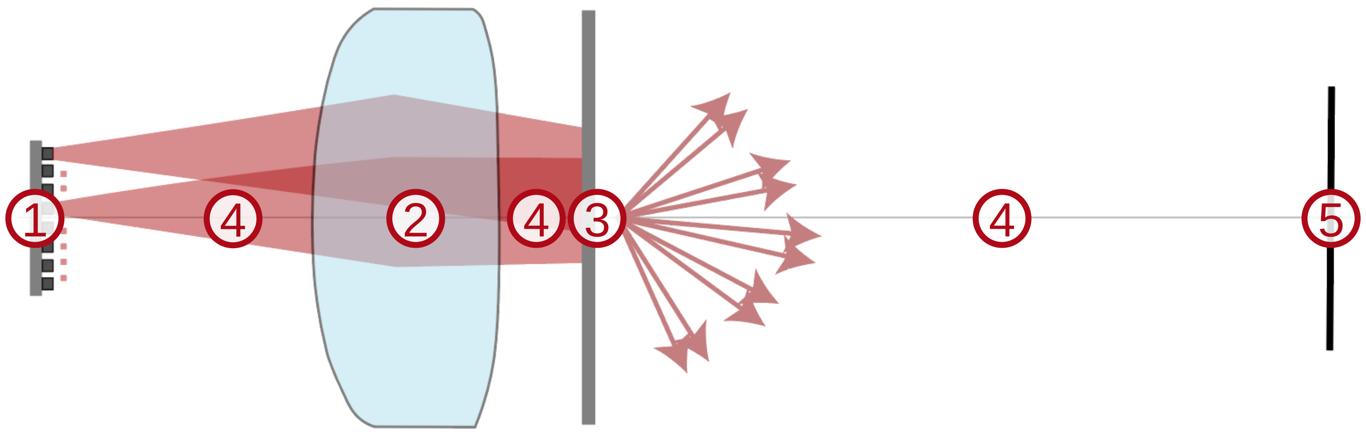
* The aspherical lens in the document was imported from Zemax OpticStudio®

Simulation & Setup: Single Platform Interoperability

Single-Platform Interoperability of Modeling Techniques

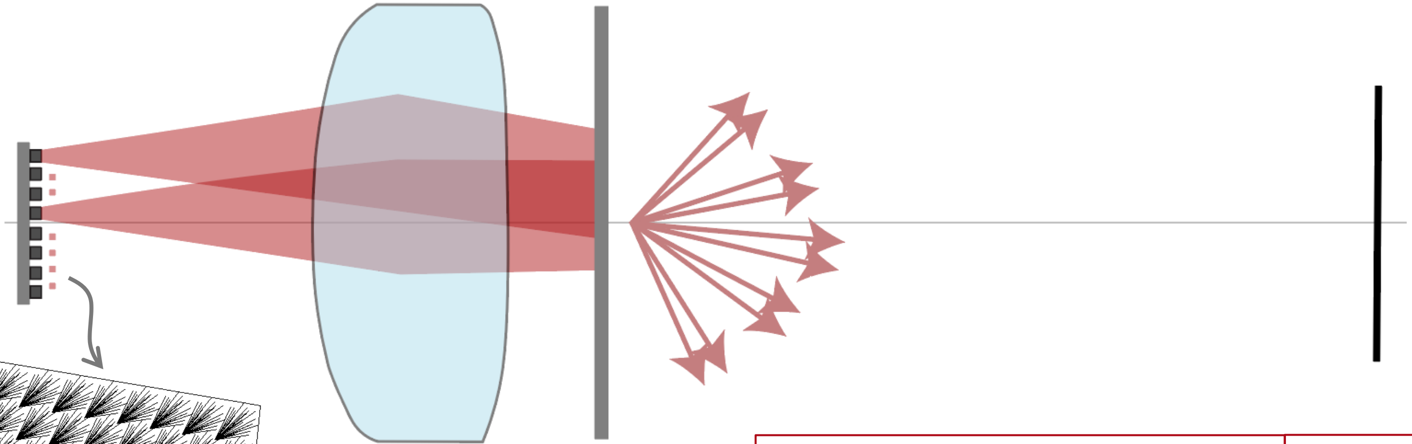
Light will encounter and interact with different components as it propagates through the system. A suitable and flexible model is required that provides a good compromise between accuracy and speed for each of these elements of the system:

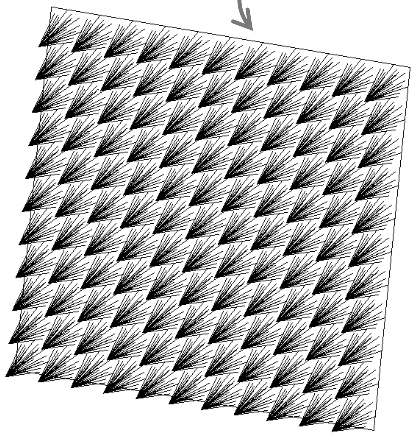
① source
② asphere
③ beam splitter
④ free-space propagation
⑤ detector



Source Modeling

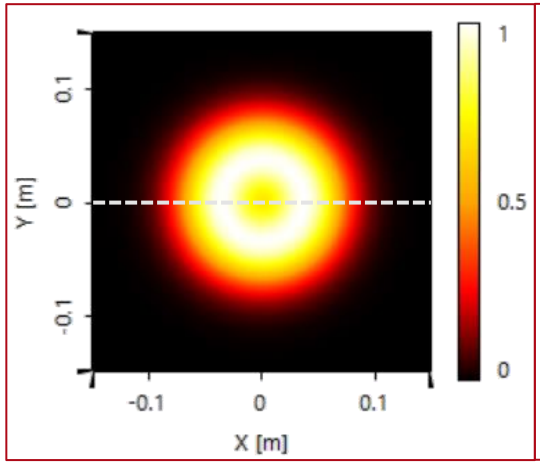
For detailed instruction of source model, see:
[Modeling of an Array of Vertical Cavity Surface Emitting Laser (VCSEL) Diodes]

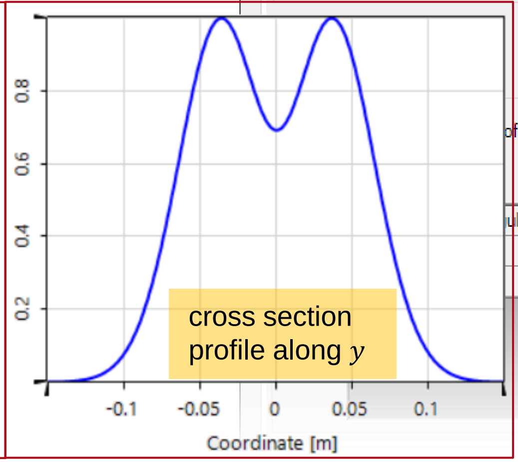


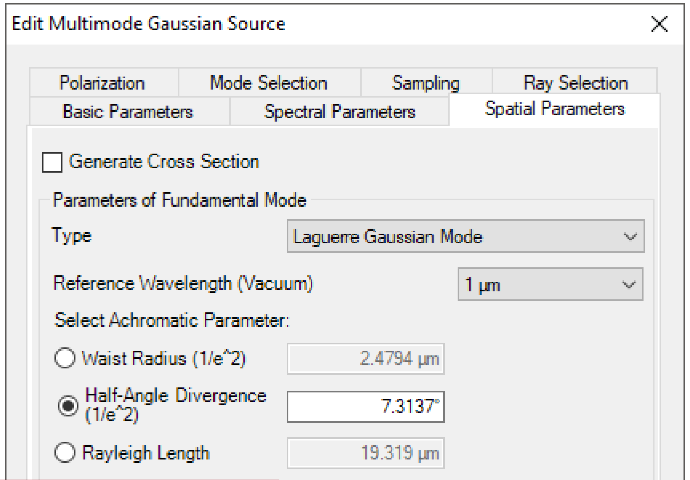


sketch of the VCSEL array

far field pattern of a single VCSEL

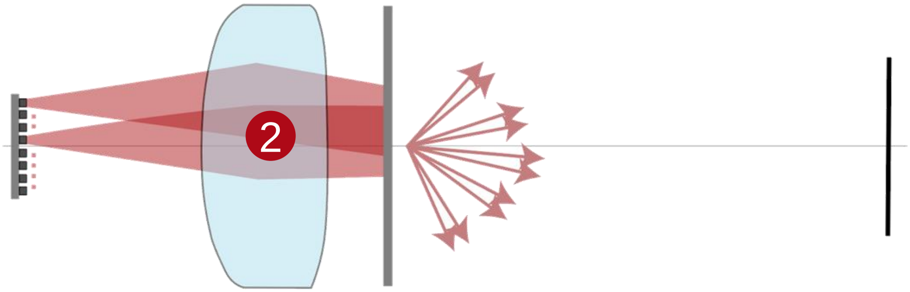






Connected Modeling Techniques: Aspheric Lens

1 source
2 asphere
3 beam splitter
4 free-space propagation
5 detector



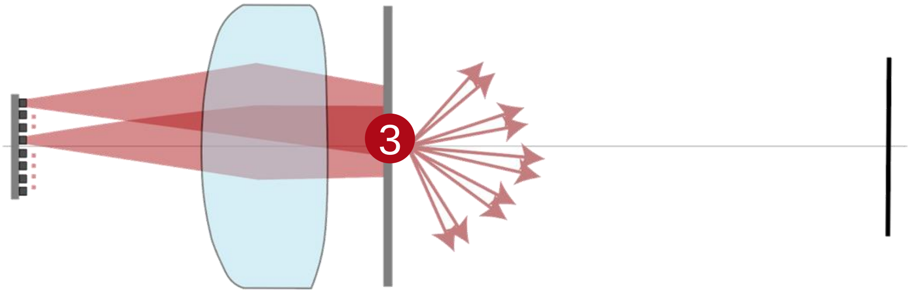
Available modeling techniques for interaction with surface:

Methods	Preconditions	Accuracy	Speed	Comments
Functional Approach	-	low	very high	no Fresnel losses
Thin Element Approximation (TEA)	Large periods & features, shallow structure (regarding wavelength)	low	very high	inaccurate for larger NA and thick elements; x-domain
Local Planar Interface Approximation (LPIA)	Surface not in focal region of beam	High	High	local application of S matrix; x-domain

As the Thin Element Approximation (TEA) becomes inaccurate for thicker components, the **Local Planar Interface Approximation** offers the best compromise between speed and accuracy for a given real lens.

Connected Modeling Techniques: Beam Splitter

① source
② asphere
③ **beam splitter**
④ free-space propagation
⑤ detector

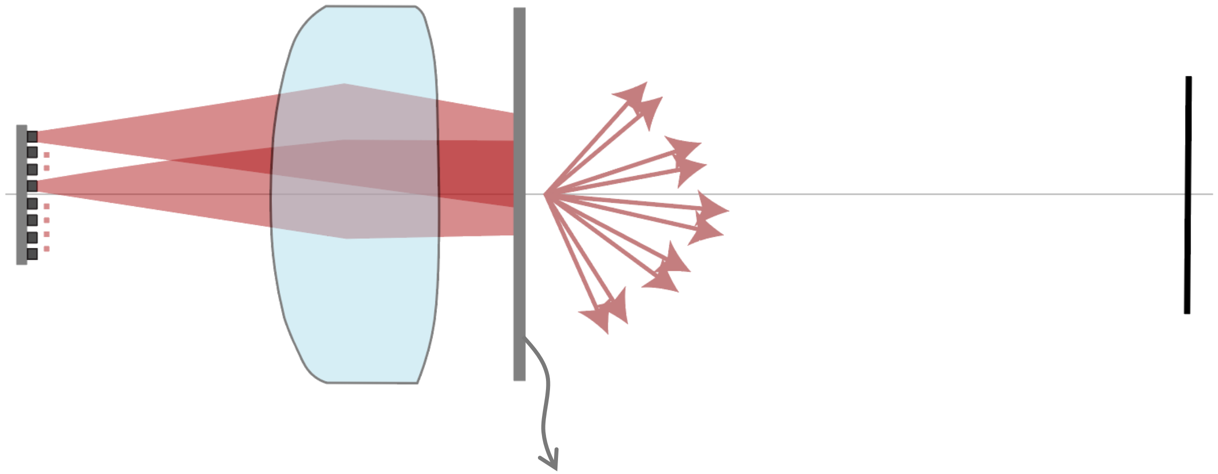


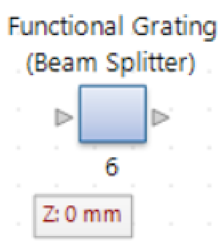
Available modeling techniques for microstructures:

Methods	Preconditions	Accuracy	Speed	Comments
Functional Approach	-	low	very high	diffraction angles acc. to grating equation; manual efficiencies
Thin Element Approximation	smallest features > ~10λ	high	very high	inaccurate for larger NA and small structures; x-domain
	smallest features < ~2λ	low	very high	
Fourier Modal Method (FMM)	period < ~ (5λ × 5λ)	very high	high	rigorous solution; fast for structures and periods similar to the wavelength; more demanding for larger periods; k-domain
	period > ~ (15λ × 15λ)	very high	slow	

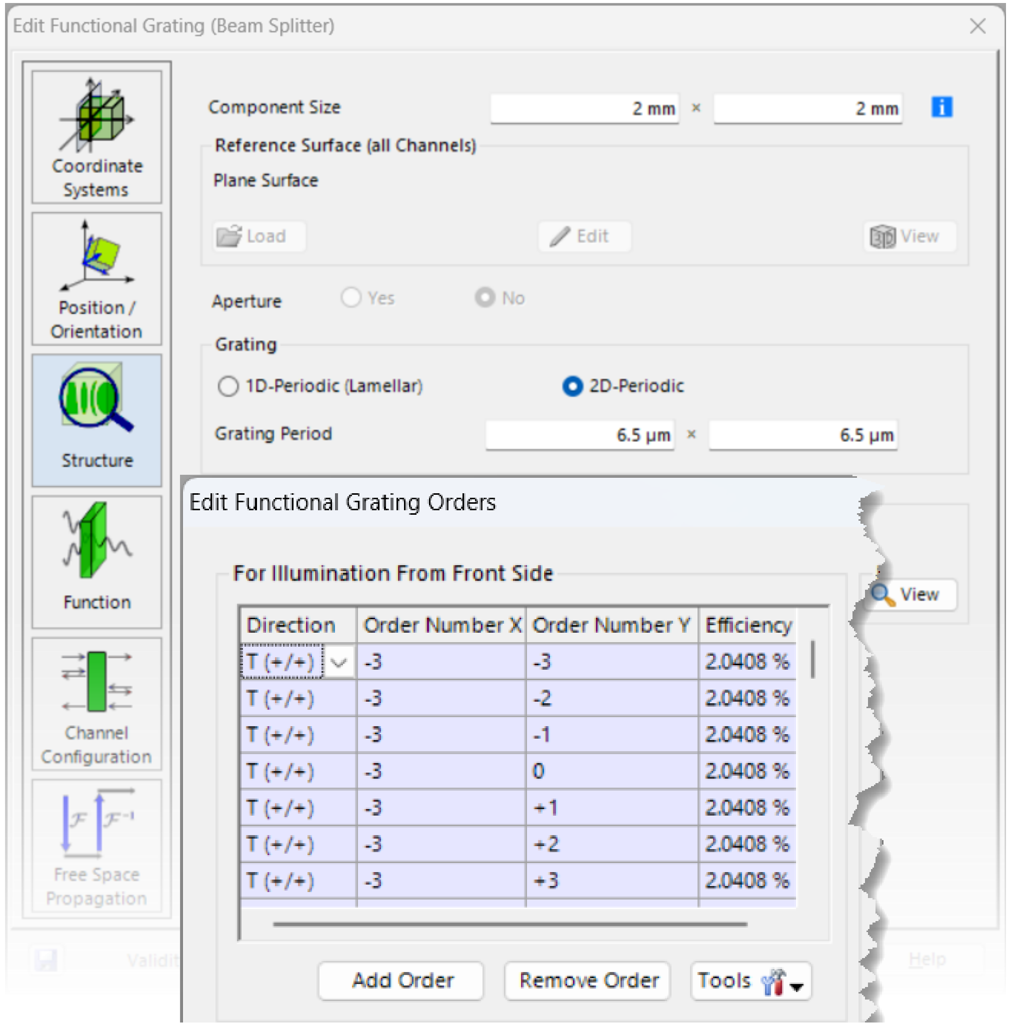
In this example we want to investigate the difference between an idealized and real beam splitter. Hence, the **Functional Approach** is chosen for the idealized and the **Fourier Modal Method (FMM)** for the real beam splitter.

Idealized Beam Splitter

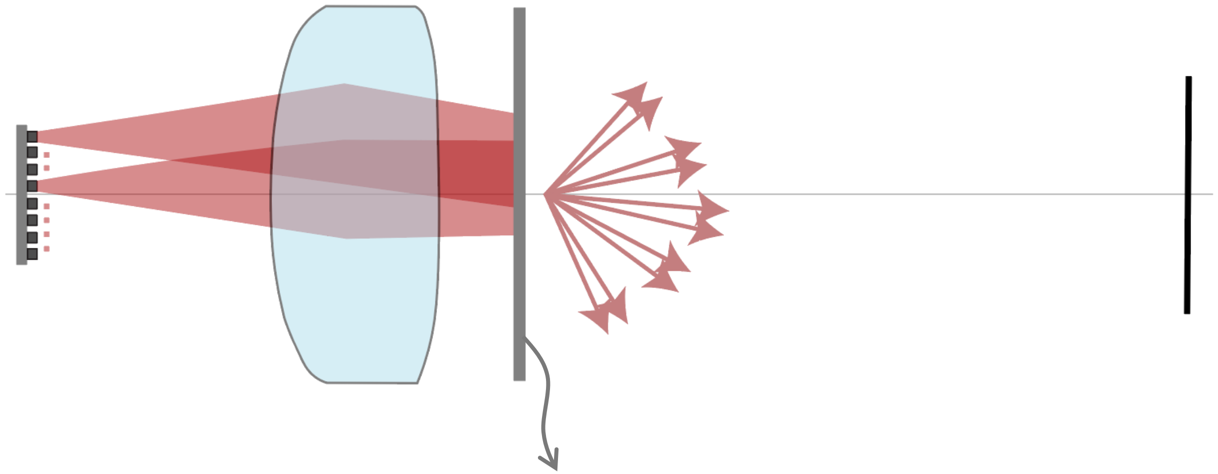


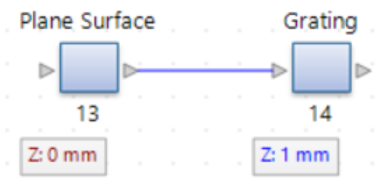


The idealized beam splitter is modeled by the *Functional Grating* component using an *Idealized Grating Function*. It operates without any information about the specific grating structure, just by manually configuring the efficiency of each diffraction order.



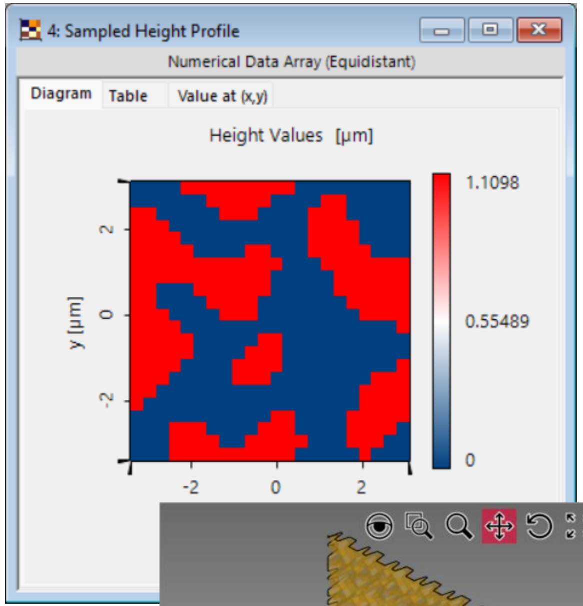
Real Beam Splitter

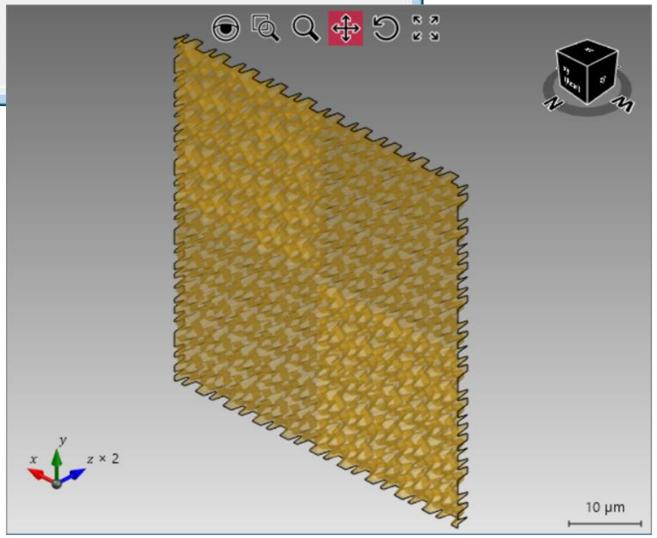




The real beam splitter is modeled by a *Plane Surface Component* followed by a *Grating component*, which employs the *Fresnel Matrix* alongside *FMM/RCWA* as the corresponding calculation methods. For detailed instruction about generating this kind of structure, please see:

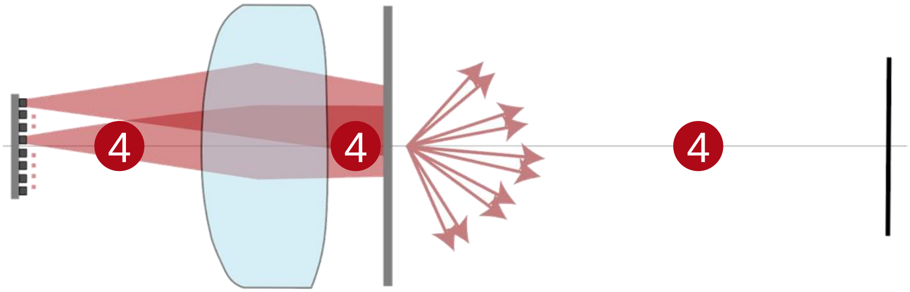
[Design and Rigorous Analysis of Non-Paraxial Diffractive Beam Splitter]





Connected Modeling Techniques: Free-Space Propagation

1. source
2. asphere
3. beam splitter
4. free-space propagation
5. detector



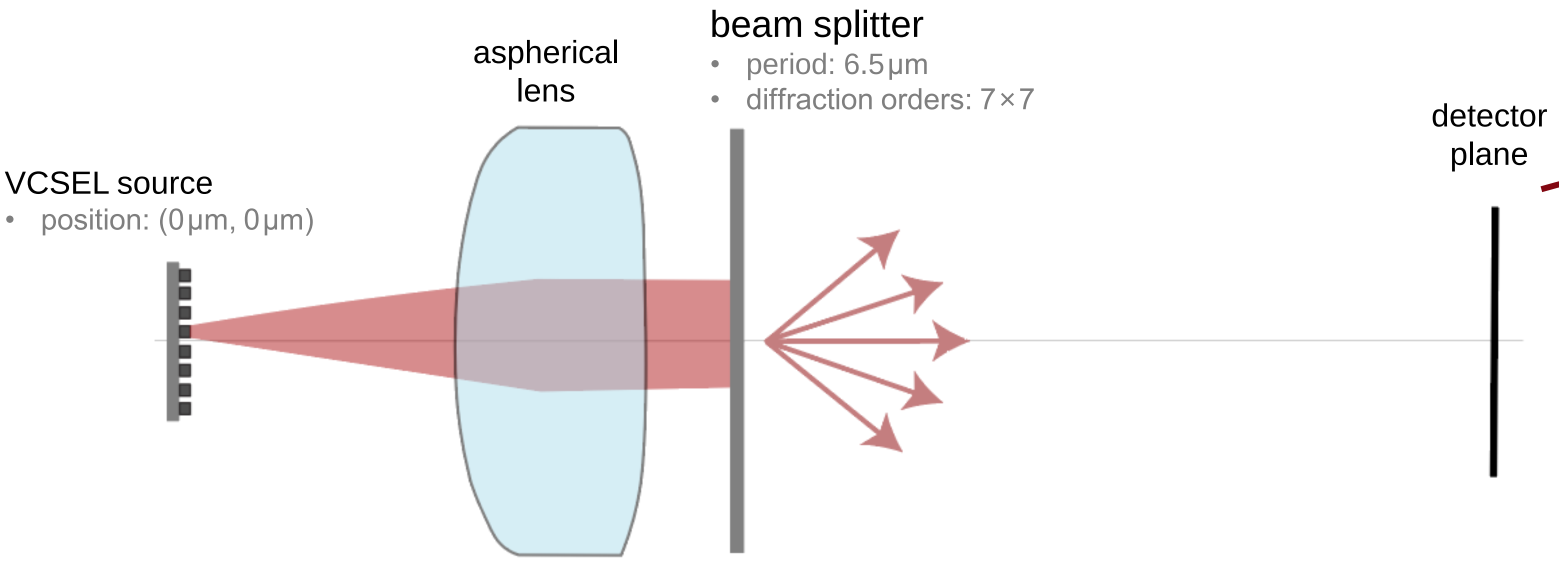
Available modeling techniques for free-space propagation:

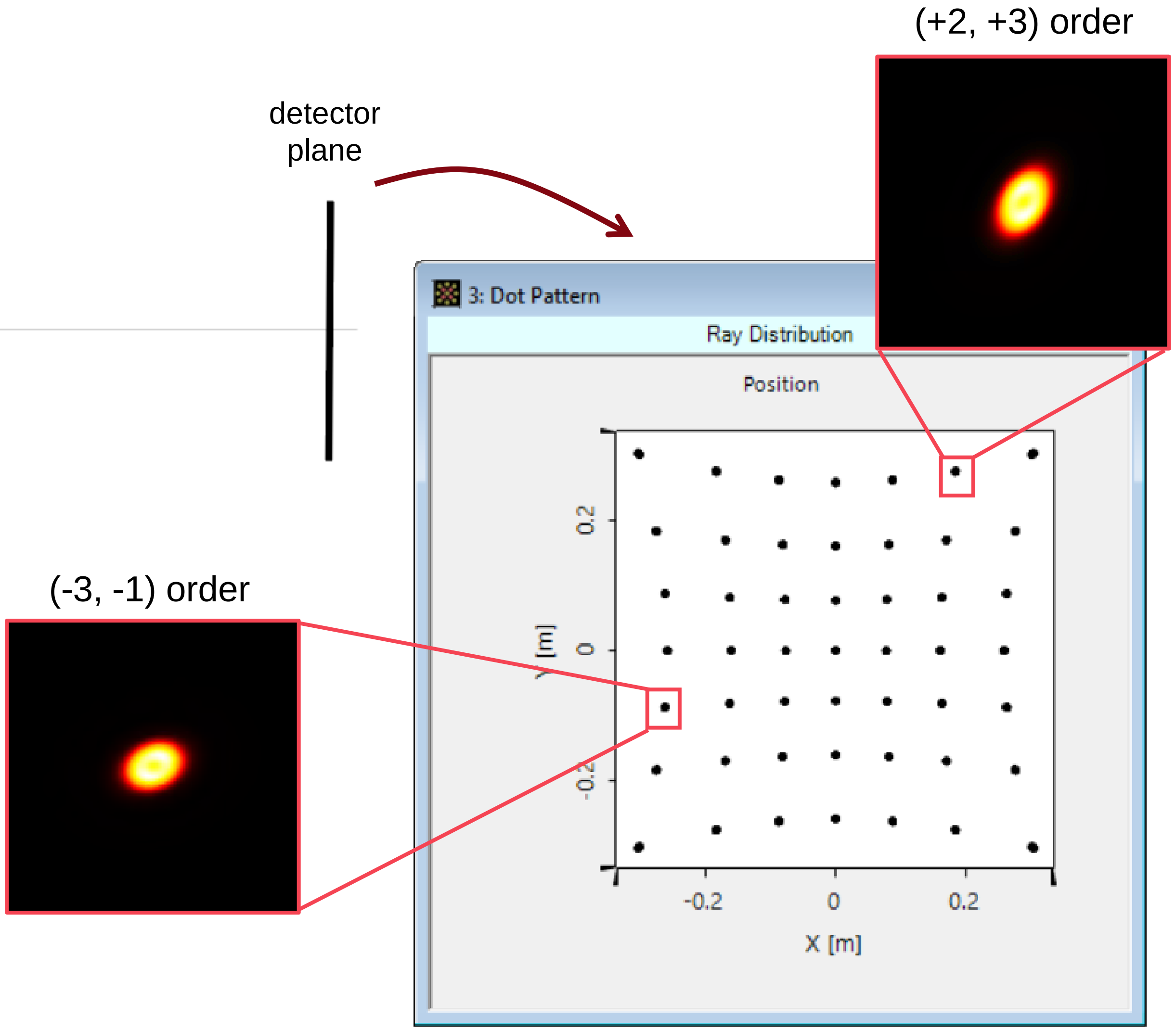
Methods	Preconditions	Accuracy	Speed	Comments
Rayleigh Sommerfeld Integral	none	high	low	rigorous solution
Fourier Domain Techniques	none	high	high	rigorous mathematical reformulation of RS integral
Fresnel Integral	**paraxial**	high	high	assumes paraxial light; moderate speed for very short distances
	non-paraxial	low	high	
Geometric Propagation	**low diffraction**	high	very high	neglects diffraction effects
	otherwise	low	very high	

As we expect diffraction effects to have an influence, **Fourier Domain Technique** will provide accurate results at the highest speed possible.

Simulation Results

Simulation with the On-Axis VCSEL Unit

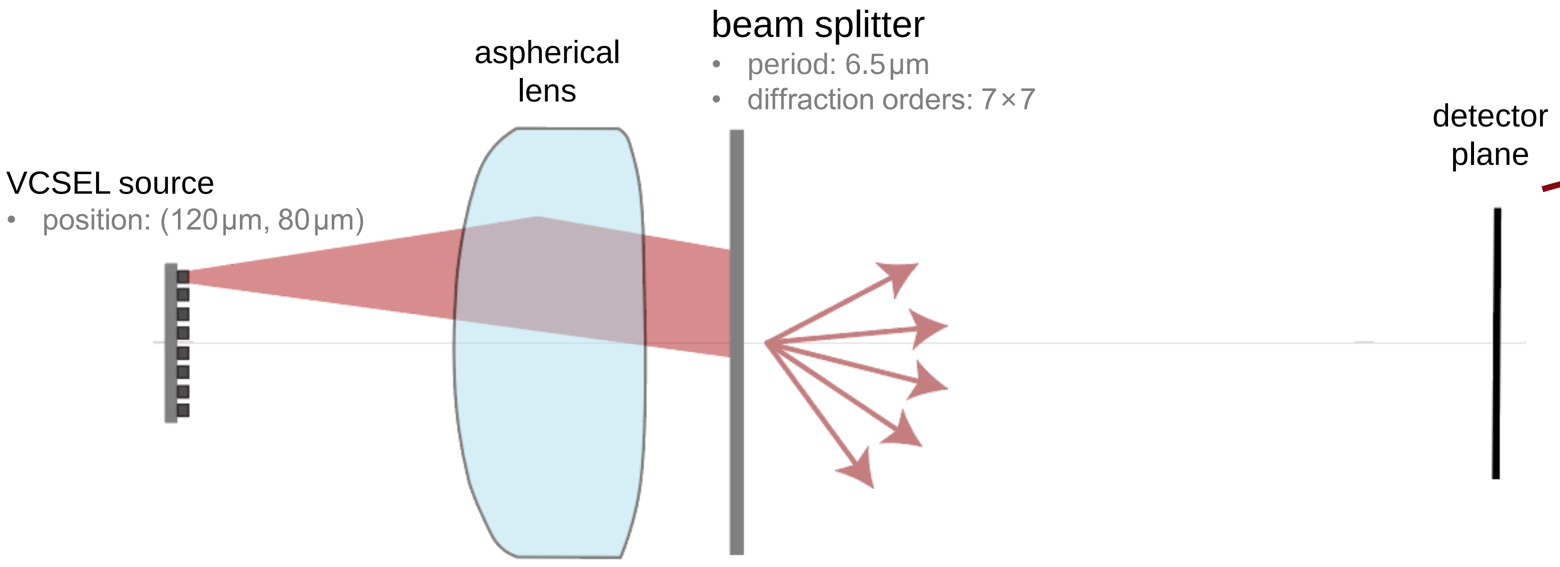


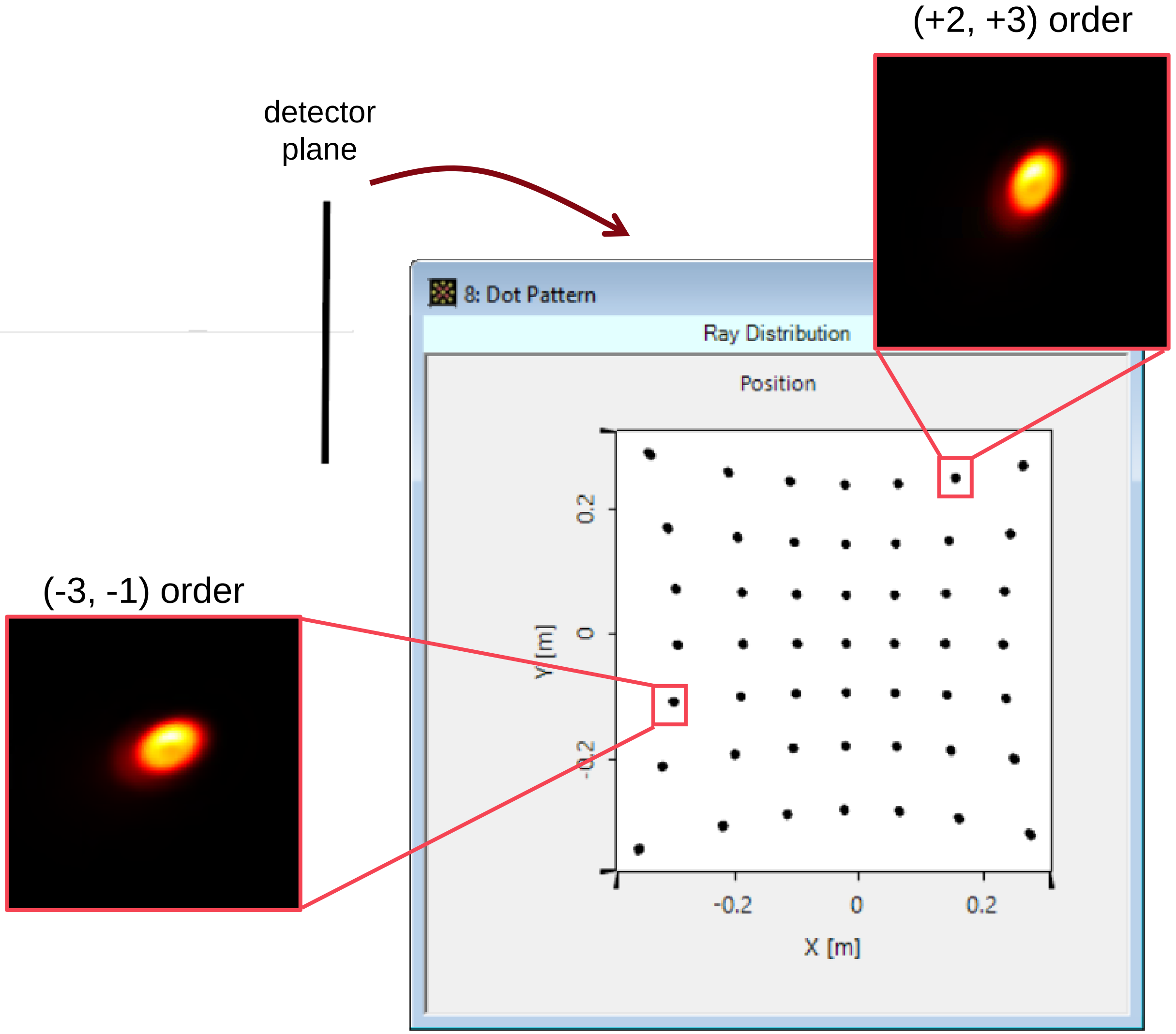


- The aspherical lens collimates the input beam.

- The beam splitter diffracts the collimated beam into different orders.

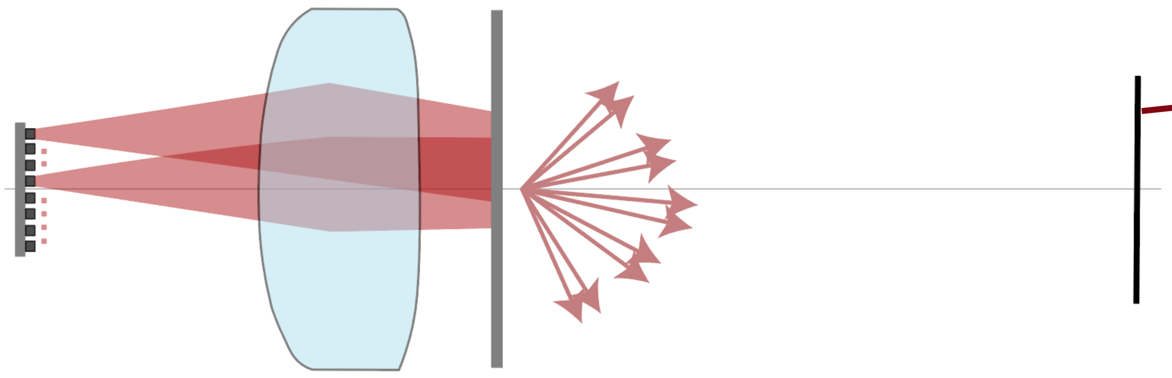
Simulation with an Off-axis VCSEL Unit

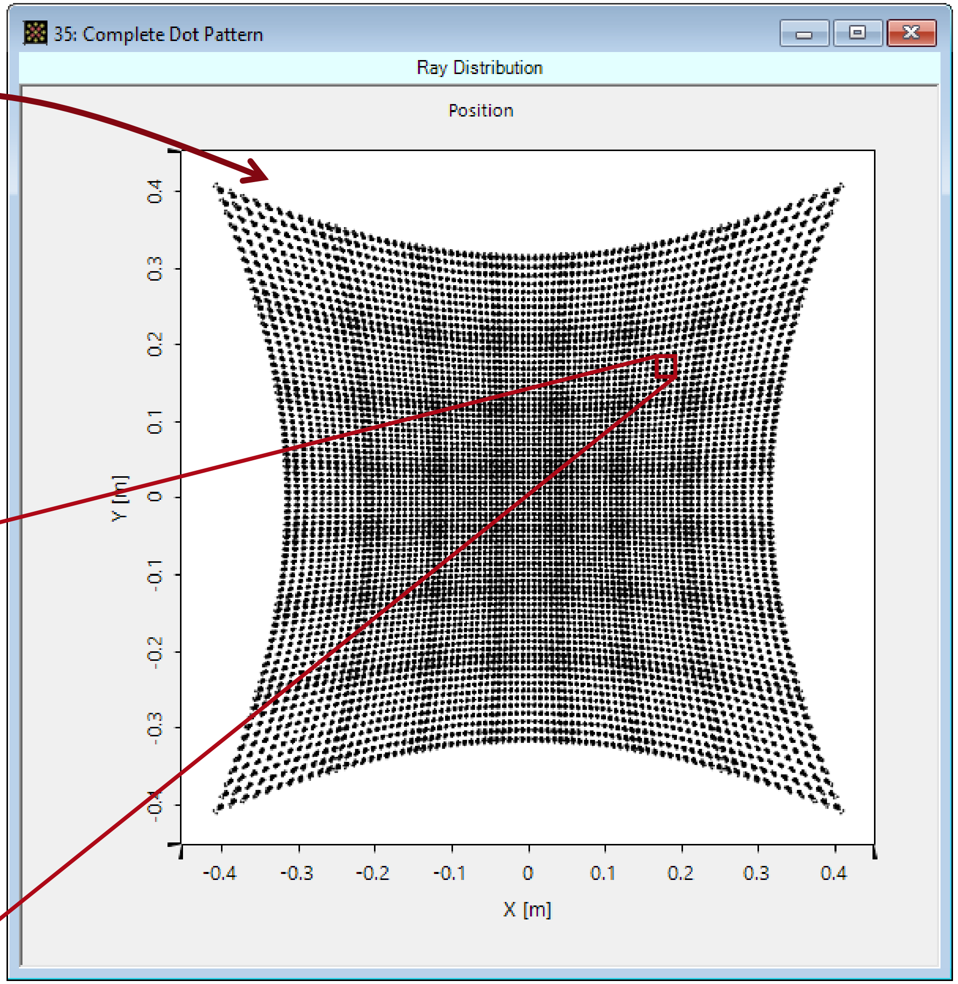




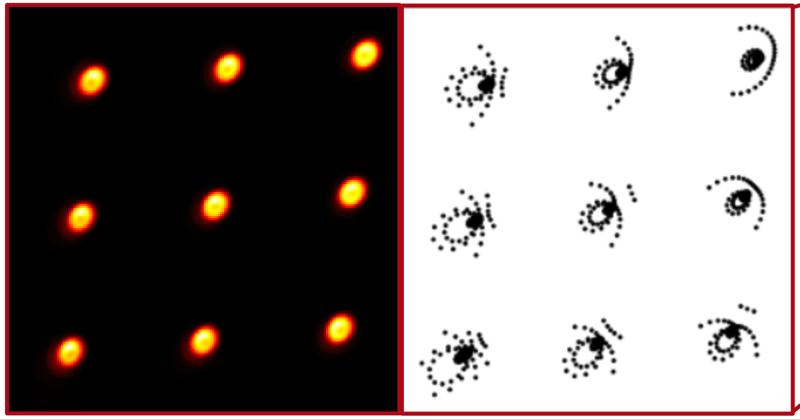
- For off-axis VCSEL units, the lens collimates the input beam with an angle related to the position of the mode.
- Compared to the on-axis case, the spot pattern is shifted with respect to the angle of incidence.

Simulation with Complete VCSEL Array





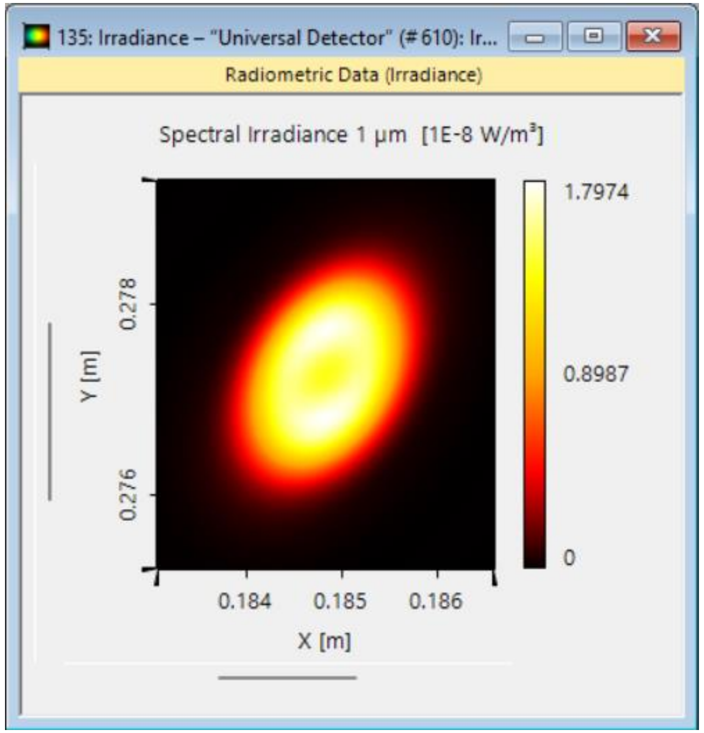
simulation results



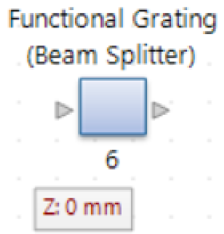
irradiance   ray pattern

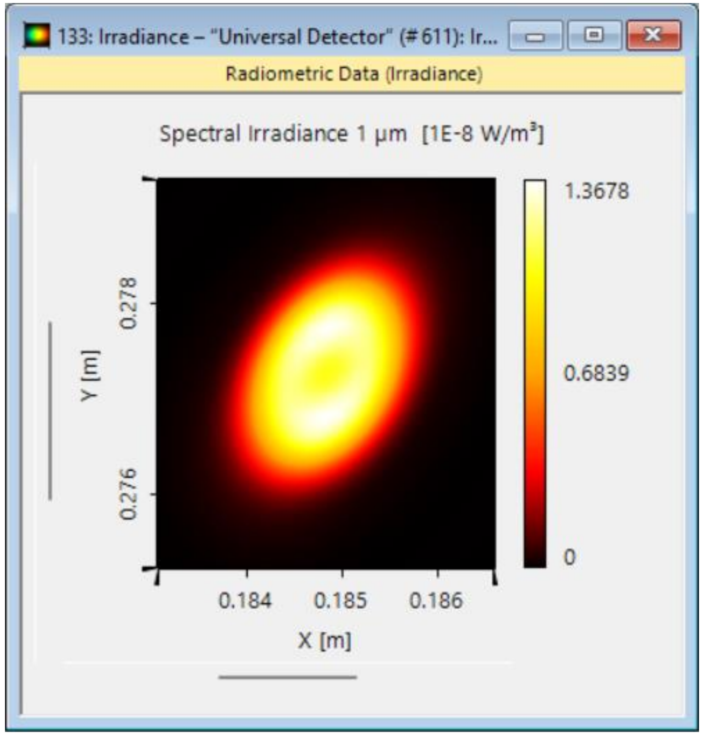
The beam splitter duplicates the pattern of the VCSEL array with lateral shifts on the detector plane.

Comparison Between Idealized and Real Beam Splitter

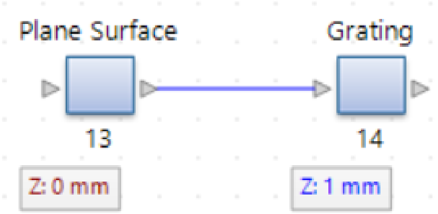


Idealized Beam Splitter





Real Beam Splitter



The on-axis VCSEL and diffraction order (+2, +3) is selected to illustrate the results comparing the idealized and real beam splitter. It is evident that both scenarios yield highly similar patterns. However, in the context of the real beam splitter, there is a noticeable lower irradiance measured.

Document Information

title	Demonstration of the Functional Principle of a Dot Projector
document code	MISC.0077
document version	2.0
software edition	VirtualLab Fusion Advanced
software version	2023.1 (Build 1.556)
category	Application Use Case
further reading	- Configuration of Grating Structures by Using Interfaces - Design and Rigorous Analysis of Non-Paraxial Diffractive Beam Splitter - Grating Component for General Optical Systems