LightTrans

WOST Workshop in Jena, 11. Mai 2017

Application of Numerical Sensitivity Analyses in Advanced Optical Modeling & Design

Dr. Stefan Steiner, LightTrans International UG

Jena, Germany

WYROWSKI
VirtualLab FUSION
UNIFIED OPTICAL DESIGN

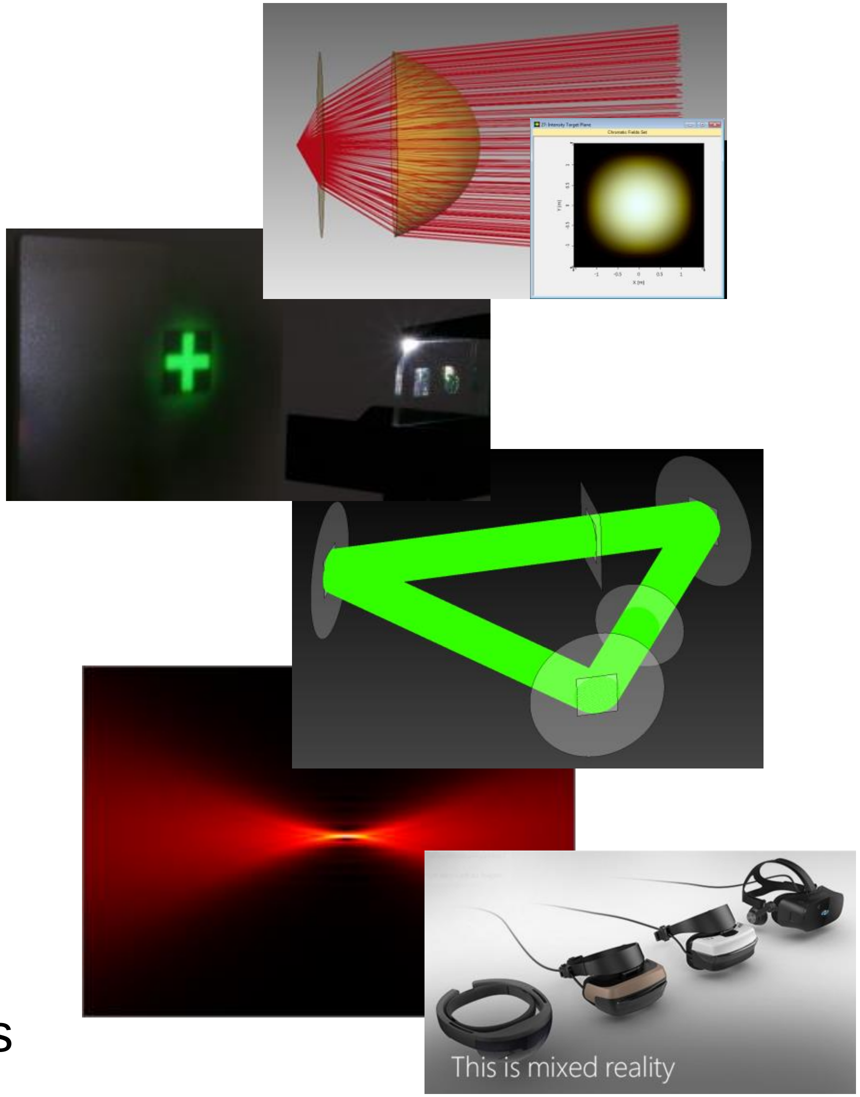
VirtualLab – Characterization

optical modeling, design and simulations

- predestined for **complex systems** which require **different modeling and simulation techniques**
- fast geometrical & physical optics engines
  - **Ray Tracing**
  - **Field Tracing**
- **modular, intuitive graphical user interface with many assisting tools**
- **toolbox concept** for user specific needs
- **development adjusted to current needs of industry and science**

VirtualLab – Typical Areas of Application

- Laser Systems and
  Ultra-Short Pulses
- Micro and diffractive optics
  freeform and gratings
- Illumination systems
  including functional surfaces
- Stable, unstable and
  ring resonators
- Imaging systems with
  diffractive and hybrid lenses,
  customized screens.
- Next version: Advanced simulation
  of Near Eye Display (NED) devices



Business by Applied Computational Optics

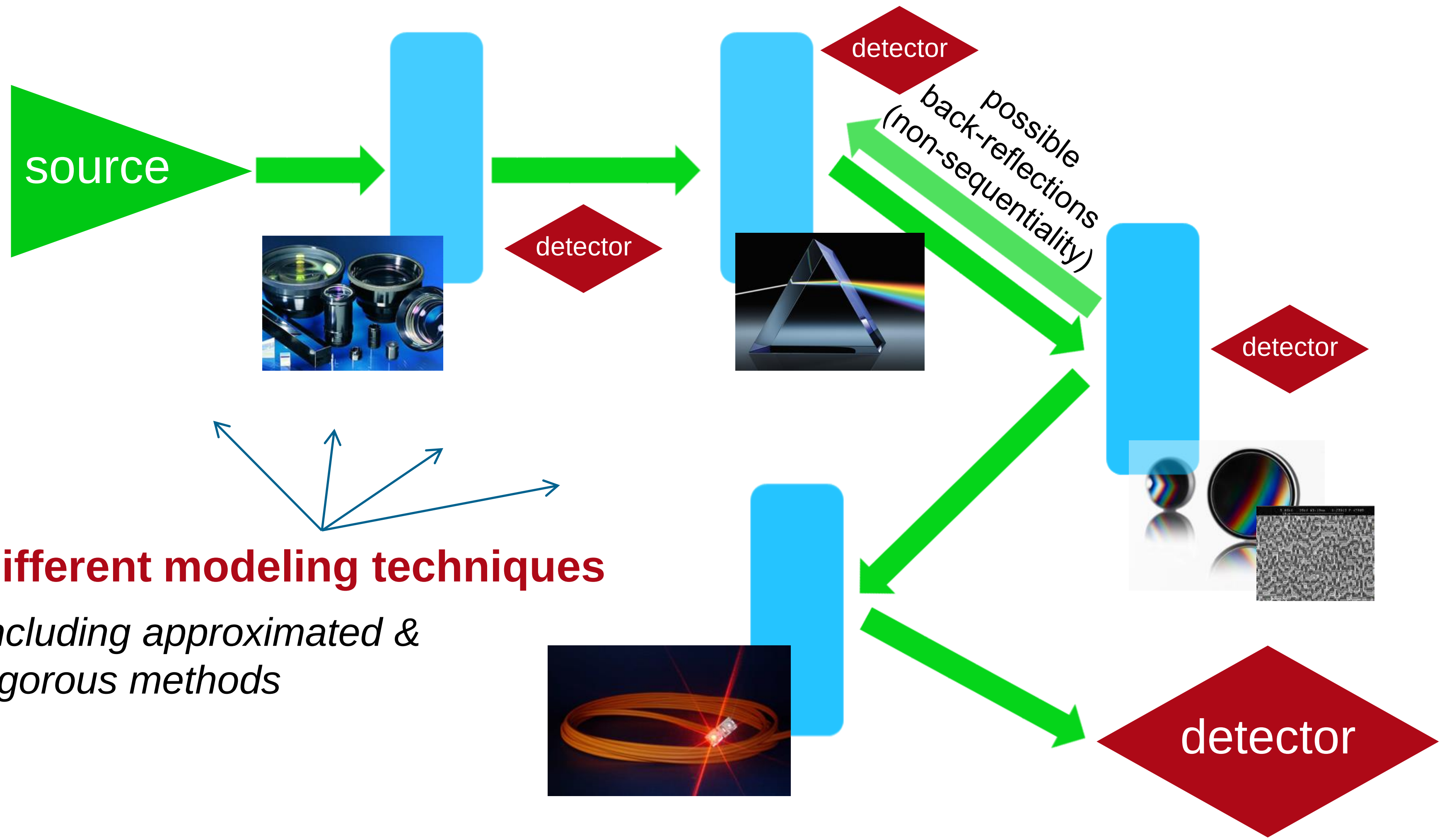
- Coherent
- Microsoft
- Apple
- Google
- Facebook
- Corning
- …

- Schott
- Zeiss
- Jenoptik
- Trumpf
- Continental
- Bosch
- Hella
- Airbus
- Max Planck Institutes
- ELI
- …

- Canon
- Sony
- LG
- Samsung
- Ricoh
- …

- Huawei
- Numerous institutes and universities
- …

Flexibel Approach for All Kinds of Systems

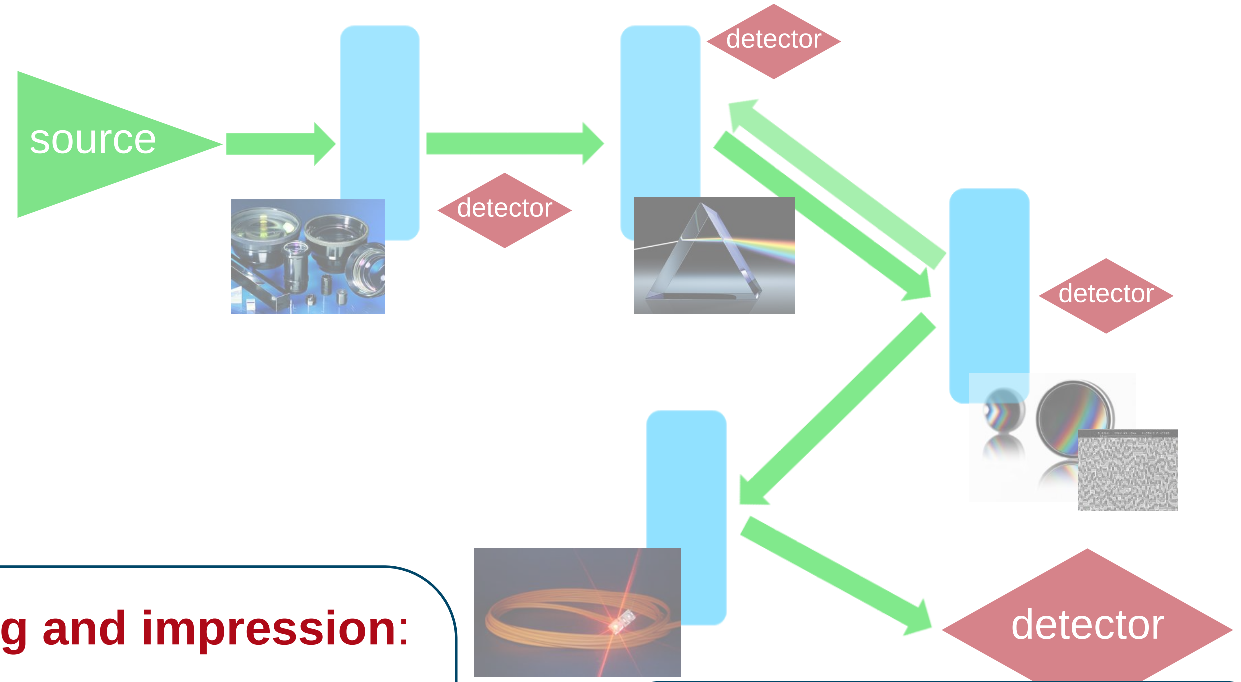


different modeling techniques

including approximated & rigorous methods

Pictures from http://de.wikipedia.org/

Physical Concept for Modeling

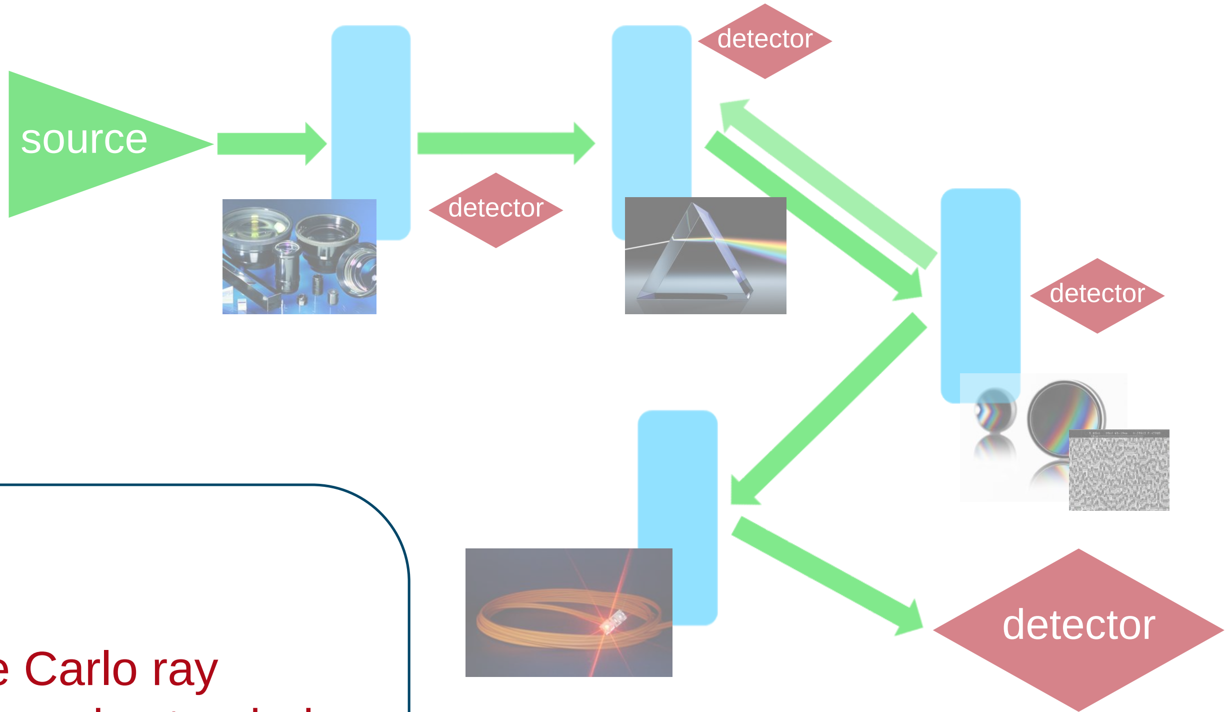


Typical **understanding and impression**:

- Physical optics modeling seems to be slow and often not practical!
- Ray optics modeling is fast and practical!

Ray tracing is still used in practice in most modeling situations.

Physical Concept for Modeling



However:

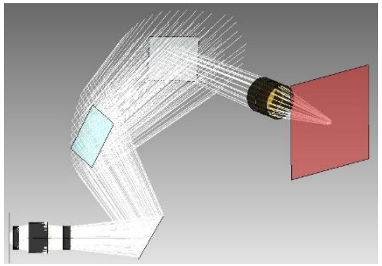
- Application of Monte Carlo ray tracing for scattering and extended sources tends to be very slow!
- **Physical limitations of ray tracing has become more serious for innovative photonics products.**

Increasing demand and interest in physical optics modeling and design based on **fast physical optics**!

VirtualLab

Starting Point
Optical System to be optimized/investigated

1. **VirtualLab** setup / modeling / simulation of system
2. **VirtualLab** optimization
3. **VirtualLab** evalution of optimized system

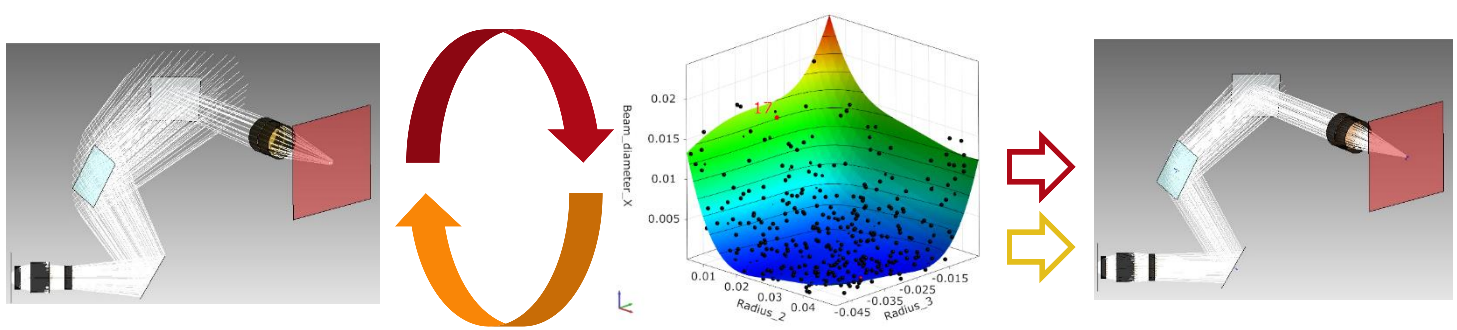


→ optimizing → evaluation

VirtualLab + optiSLang

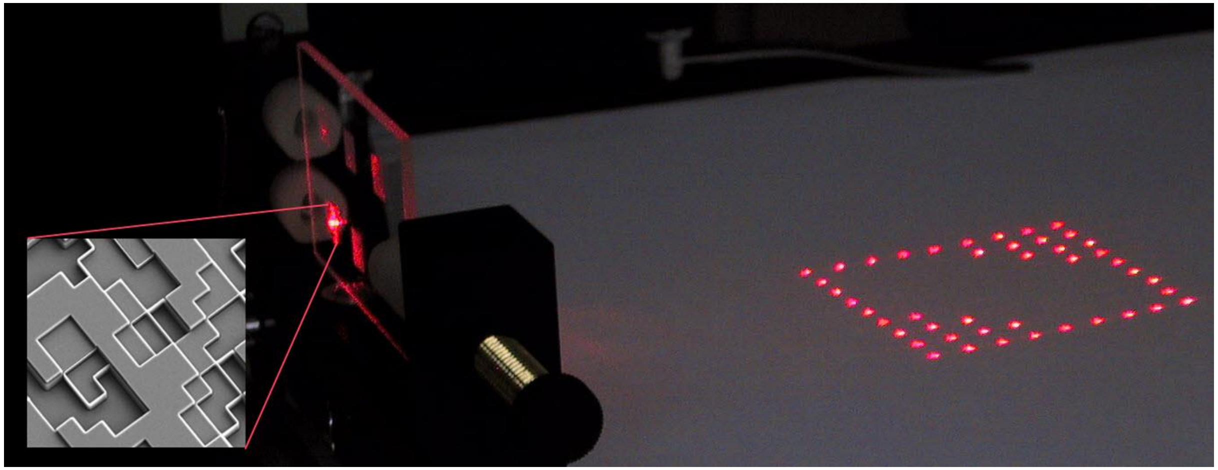
Starting Point
Optical System to be optimized/investigated

1. **VirtualLab** setup / modeling / simulation of system
2. **optiSLang** high end optimization & analysis
3. **VirtualLab** evalution system optimized by **optiSLang**

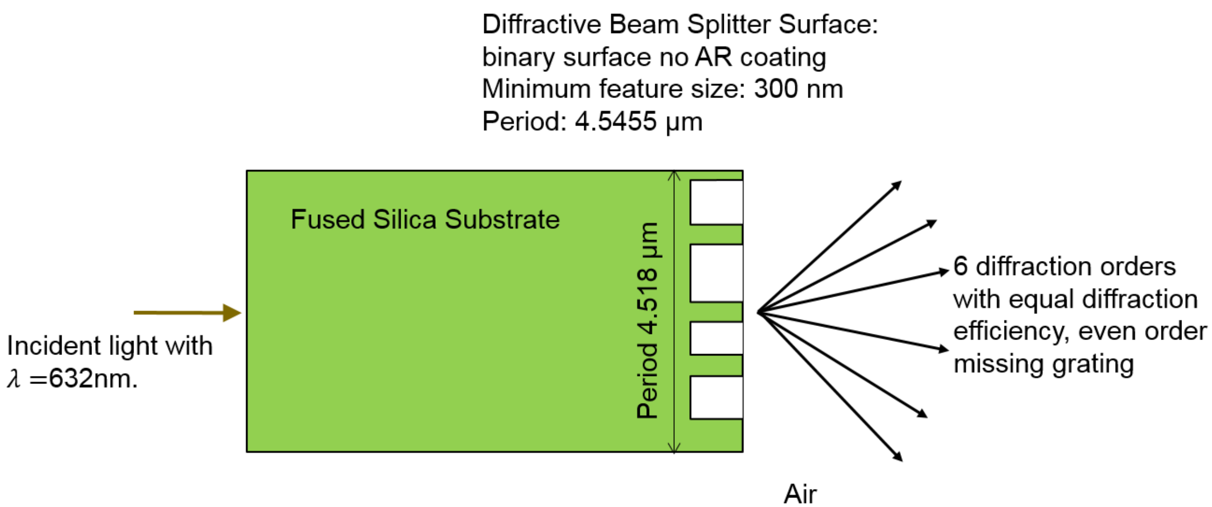


Example: Beam Splitter

- required for various applications, e.g. motion tracking (Microsoft Kinnect), LIDAR and laser material processing
- optimization is challenging, especially for large diffraction angles (high NA)
- microstructures with structure sizes in range of wavelength



Setup & Requirements



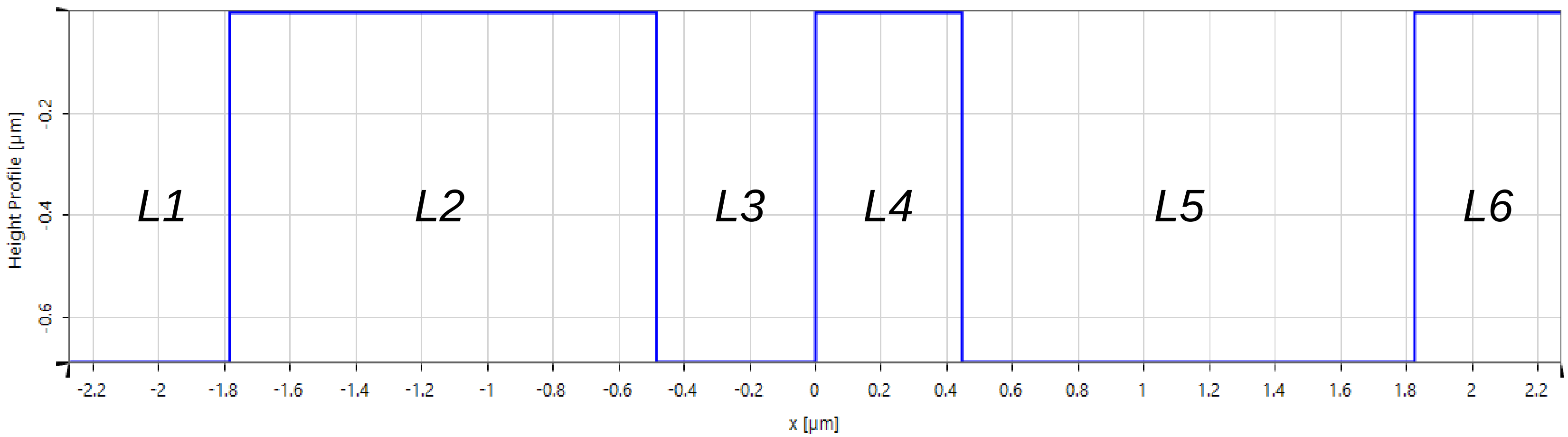
- definition of *TotalEfficiency*:

$$\eta = \eta_1 + \eta_{-1} + \eta_3 + \eta_{-3} + \eta_5 + \eta_{-5} > 80\%$$

- definition of *UniformityError*:

$$U = \frac{\eta_{\max} - \eta_{\min}}{\eta_{\max} + \eta_{\min}} < 0.5\%$$

Definition of Parameters & Constraints



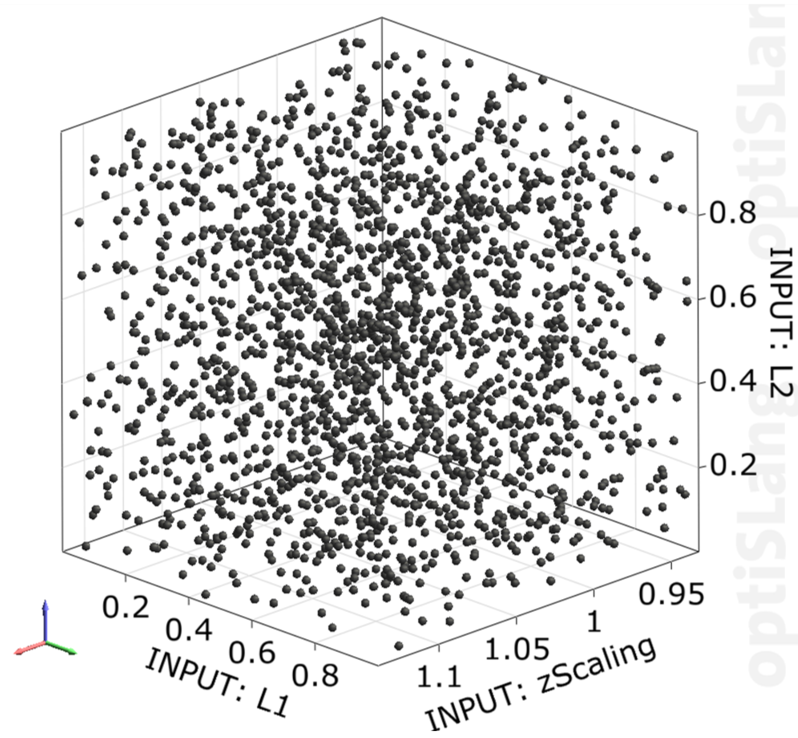
- introduction of 6 parameters: lengths *L1*, *L2*, *L3*, *L4*, *L5* and *L6*
- minimal feature size
- total length is equal to period (thus only 5 of 6 lengths are free)
- modulation depth: *zScaling*

Sensitivity Analysis

- Advanced Latin Hypercube Sampling

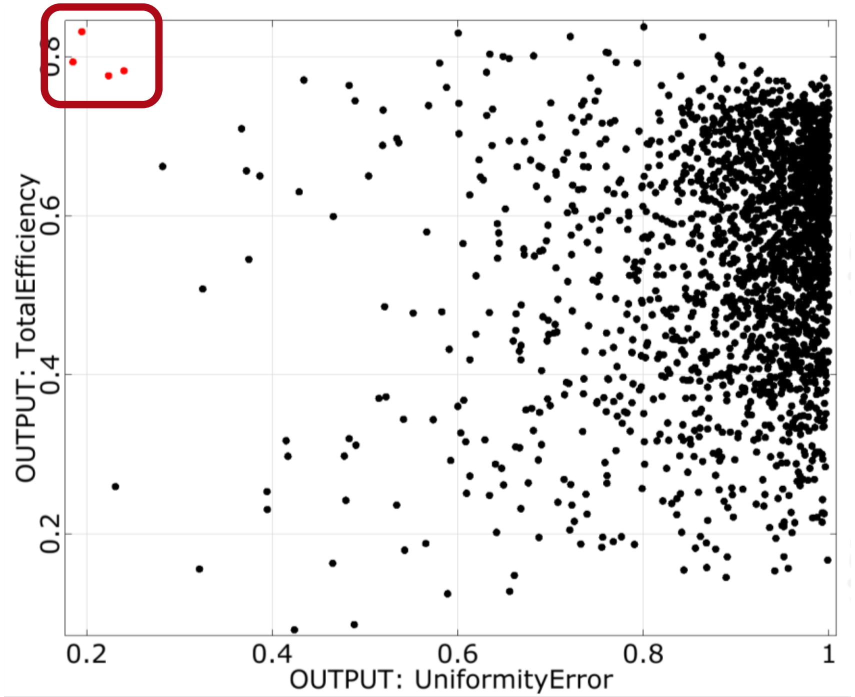
- 2000 designs

- input parameter:
  - *L1–L6*: 0…2.74 µm
  - *zScaling*: 0.93 µm…1.14 µm

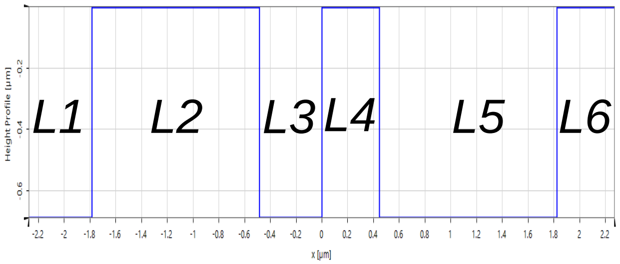


Result of Sensitivity Analysis

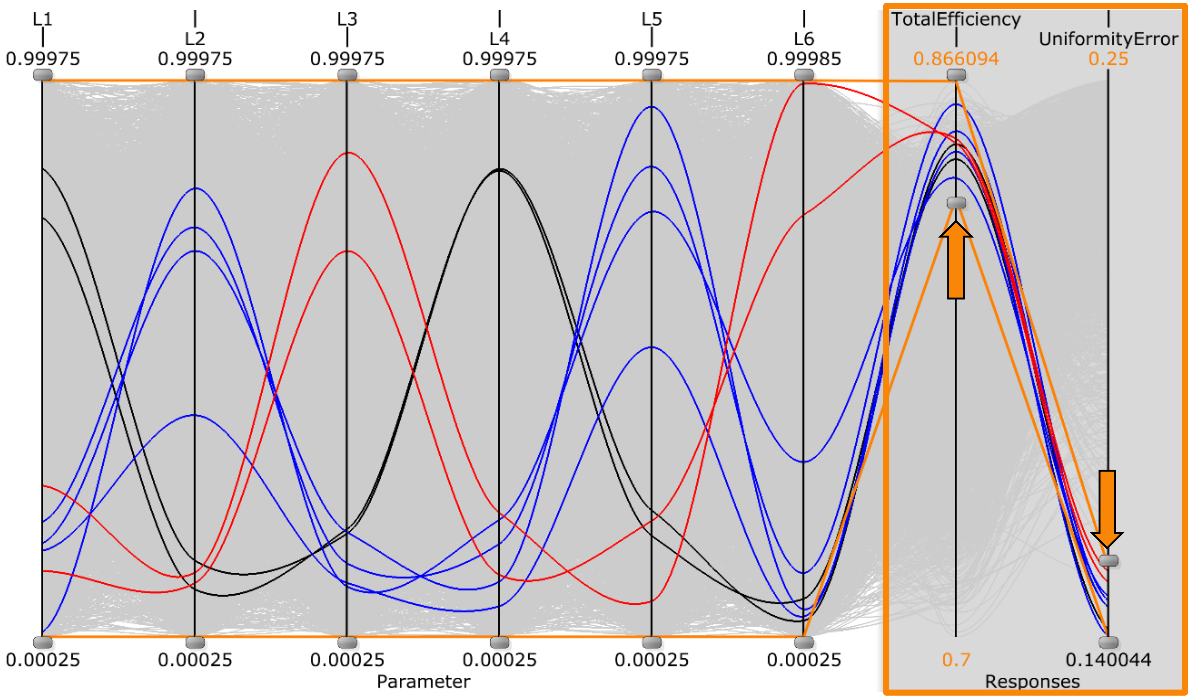
- 2000 designs
- only 4 results close to optimum
- reason: inadequate definition of parameters and/or objective function



Sensitivity Analysis: Parallel Coordinate Plot



- close to optimum: *L1/L4*, *L2/L5* and *L3/L6* correspond to each other
- therefore: reduction of parameters *L2=L5* and *L1=L2=L3=L4=L6* and introduction of parameter ***FreeLength***



Sensitivity Analysis: Parameter Optimization

- sensitivity analysis based on 6 parameters
- 2000 designs
- CoPs between 56% and 99%
- no influence of *zScaling*

	L1	L2	L3	L4	L5	L6	Total
UniformityError	27.7 %	22.7 %	27.4 %	25.9 %	27.9 %	23.1 %	56.4 %
TotalEfficiency	36.1 %	28.3 %	35.1 %	28.7 %	33.7 %	30.5 %	96.5 %
Eff_T5	45.3 %	51.0 %	43.8 %	48.3 %	42.5 %	50.4 %	86.3 %
Eff_T3	29.4 %	22.4 %	31.2 %	20.2 %	29.0 %	20.3 %	98.6 %
Eff_T1	35.3 %	22.7 %	36.4 %	26.6 %	35.0 %	22.5 %	98.2 %
Eff_T_sub_1	38.9 %	22.1 %	33.8 %	25.4 %	36.6 %	26.8 %	98.7 %
Eff_T_sub_3	28.5 %	20.4 %	30.3 %	23.4 %	30.2 %	21.3 %	98.8 %
Eff_T_sub_5	41.2 %	48.2 %	41.0 %	48.0 %	42.7 %	49.6 %	84.2 %

Parameter

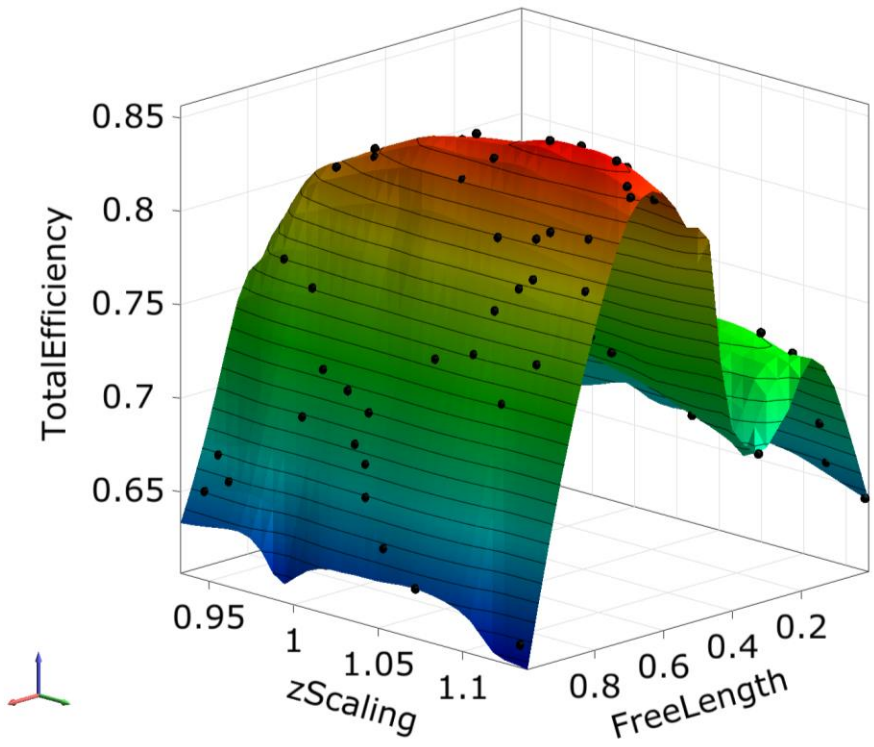
- sensitivity analysis based parameter ***FreeLength***
- 100 designs
- CoPs 99%
- *zScaling* shows small influence

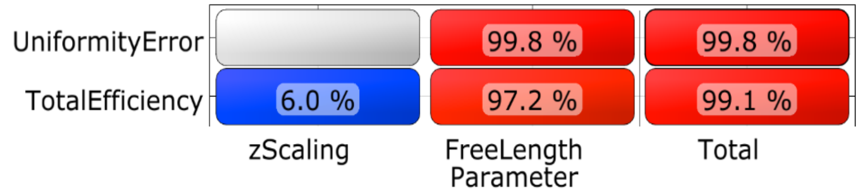
	zScaling	FreeLength	Total
UniformityError		99.8 %	99.8 %
TotalEfficiency	6.0 %	97.2 %	99.1 %
Eff_T5		99.6 %	99.6 %
Eff_T3		99.8 %	99.8 %
Eff_T1		99.5 %	99.5 %
Eff_T_sub_1		99.5 %	99.5 %
Eff_T_sub_3		99.8 %	99.8 %
Eff_T_sub_5		99.6 %	99.6 %

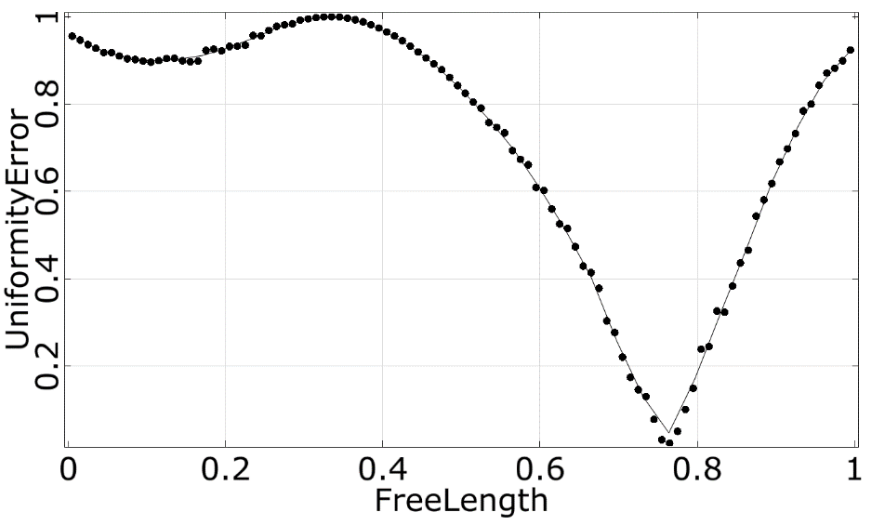
Parameter

Sensitivity Analysis: Final Dependencies

- all response strongly depend on *FreeLength*
- *UniformityError* is independent of *zScaling*
- low noice level of VirtualLab model (less than 1%)

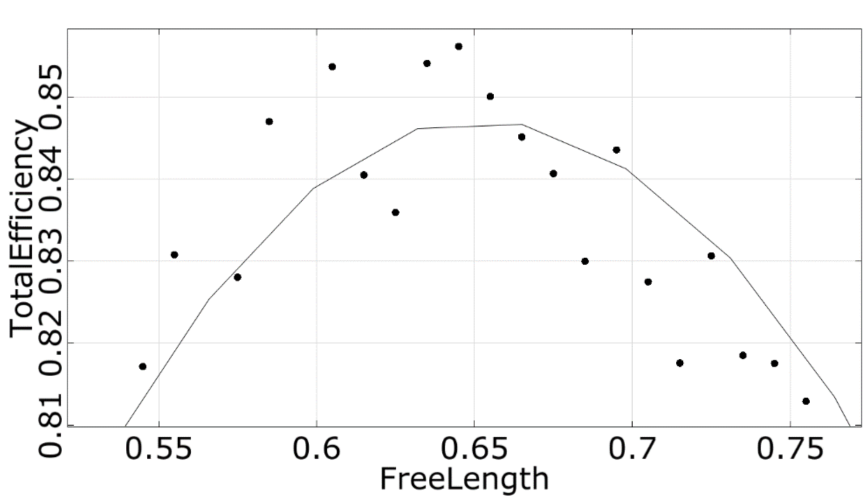


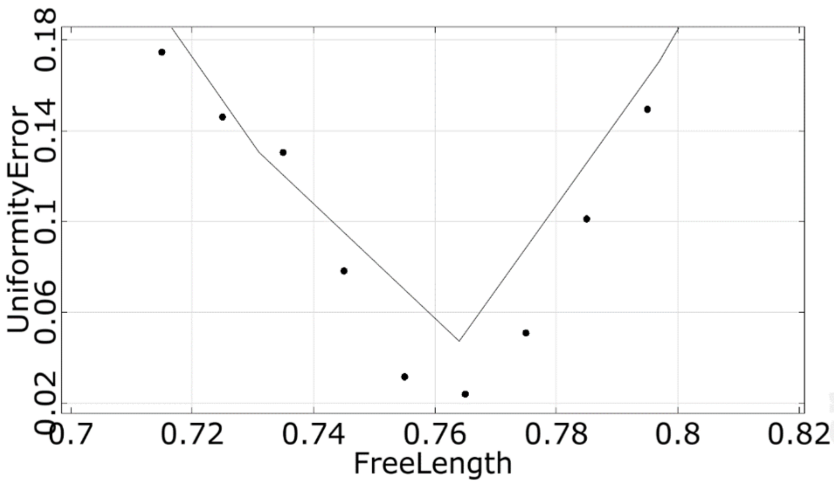




Sensitivity Analysis: Design Improvement

- UniformityError is independent of *zScaling*, thus only *FreeLength* is considered in range of optimum
  → reduction of number of input parameters
- *FreeLength* differs in optimum of *TotalEfficiency* and *UniformityError*
  → responses are slightly in conflict
  → definition of *UniformityError* as constraint for optimization

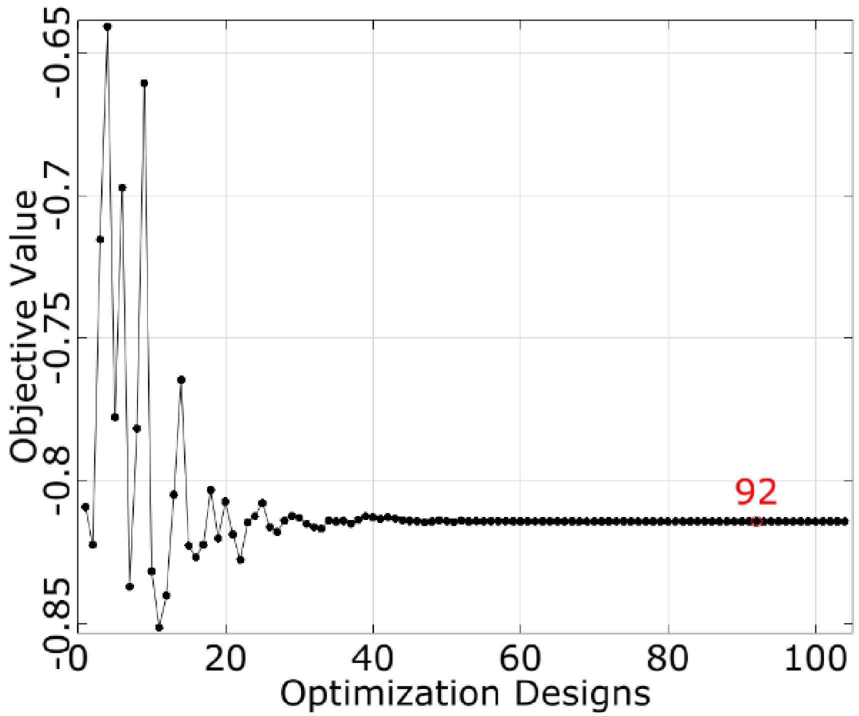




Optimization result

- Optimization based on Adaptive Response Surface Method (ARSM)

- *UniformityError* is reduced significantly



	Target Design	Initial IFTA Design	Rigorous Design
Total Efficiency	maximize	80.9%	81.4%
Uniformity Error	<=0.5%	6.4%	0.498%

Summary

- analysis and understanding of parameter dependencies
- identification of optimization potential
- simplification the complexity of optical optimization problems
- optimization of parameters and optical function