Robust design optimization for optical systems

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Product Expert & Business Development
Ansys Dynardo

17th Weimar Optimization and Stochastic Days 2020
June 25 – 26, 2020
Virtual Conference

Ansys

Stephanie Kunath

Connect via LinkedIn

Biography

- Business Development Manager Optics and ADAS at Ansys
- Responsible for new optical and ADAS applications of Dynardos software
- Working for Ansys/ Dynardo for more than 6 years
- Background: biotechnology, spectroscopy, optics and Robust Design Optimization

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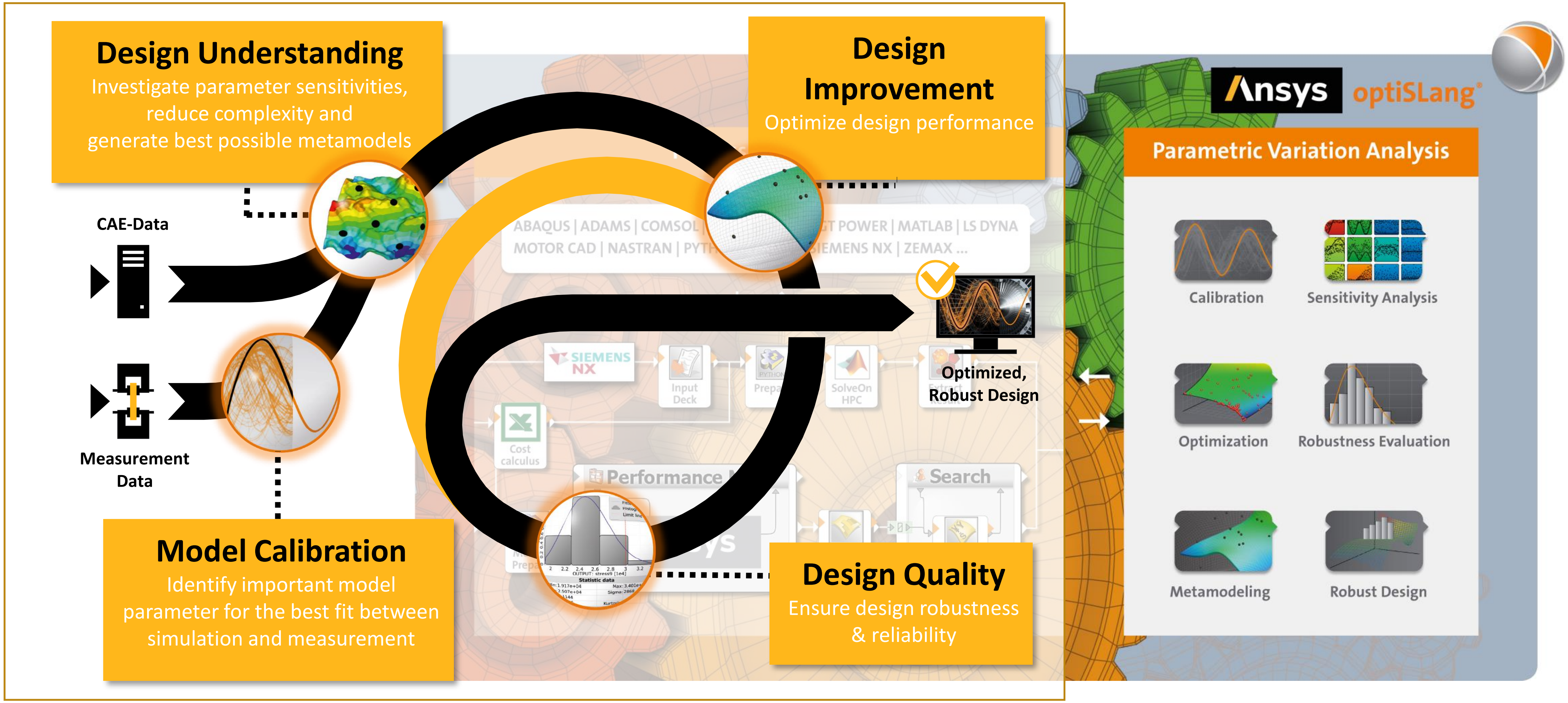
Workflow Automation

Process Integration, Simulation Workflow Building & Automation

Robust Design Optimization Strategy

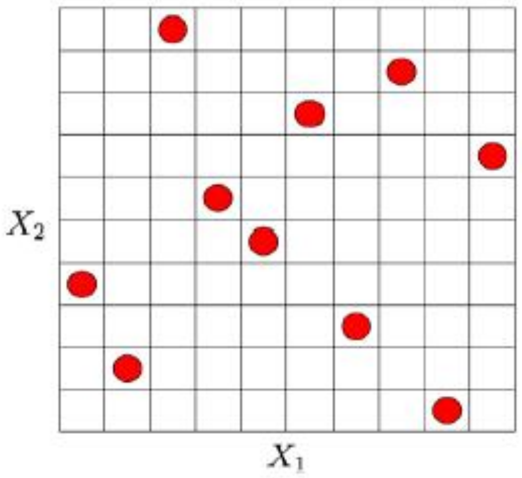


Test Data Analysis

Example: Laser Ablation Process

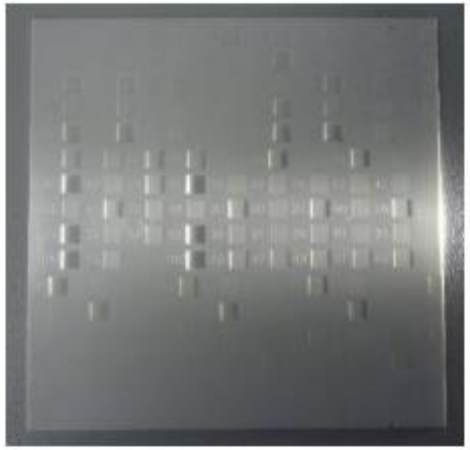
DoE

Latin Hypercube Sampling



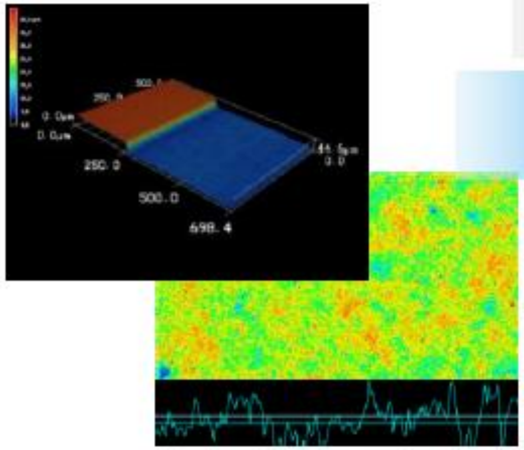
Experiments

USP ablation of alumina (Al_2O_3)



Measurement

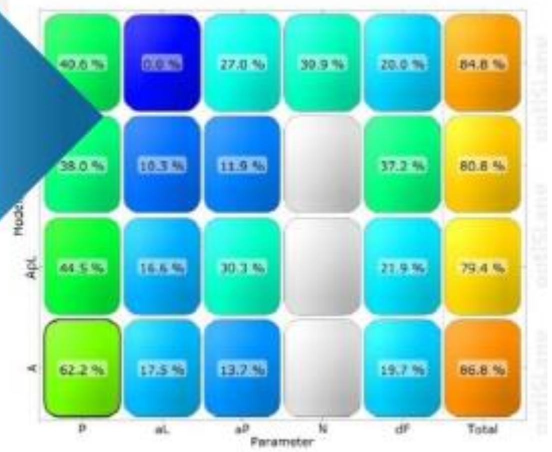
Roughness, Ablation depth



Excel Add-In

Analysis

Sensitivity analysis based on MOP

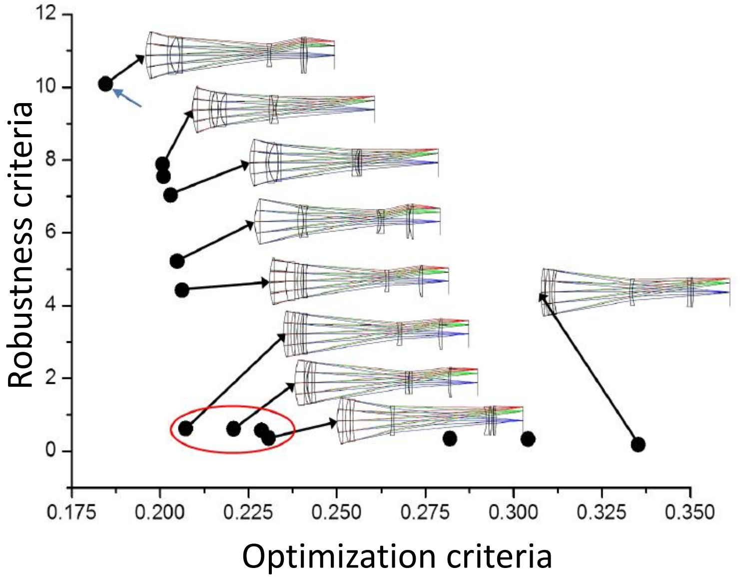


https://www.dynardo.de/fileadmin/Material_Dynardo/bibliothek/WOST16/3_WOST2019_Session_5A_Friedrich.pdf

Coupled Robust Design Optimization

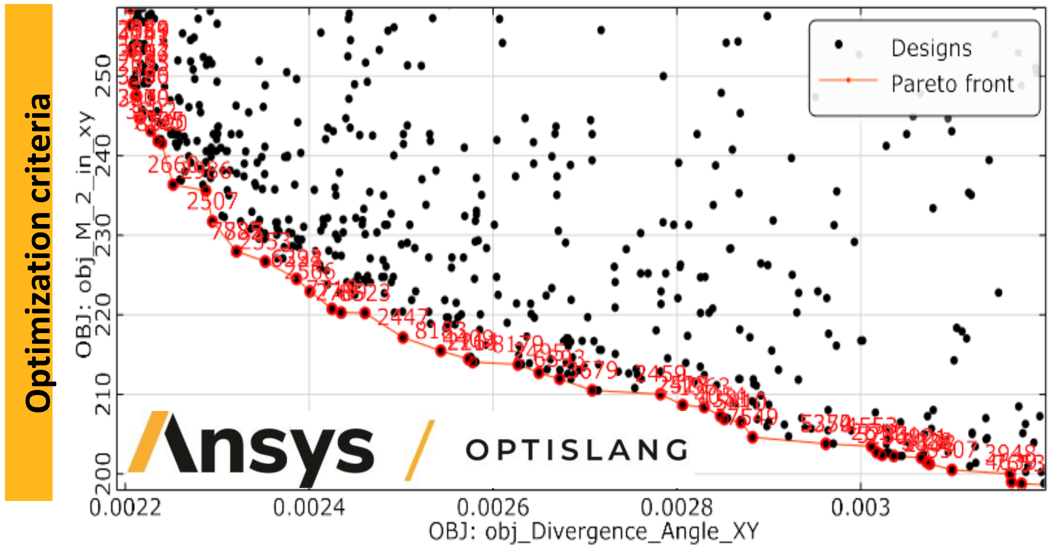
- Trade-off between optimization and robustness criteria of an optical system is illustrated as a **Pareto Front** = char of best designs
- Decision making is possible by illustrating this trade-off

Manually done within a dissertation



B. Albuquerque, 2014, dissertation, „Multi-objective Memetic Approach for the automatic design of optical systems"

Automatically done within 2 hours in optiSLang



Optimization criteria

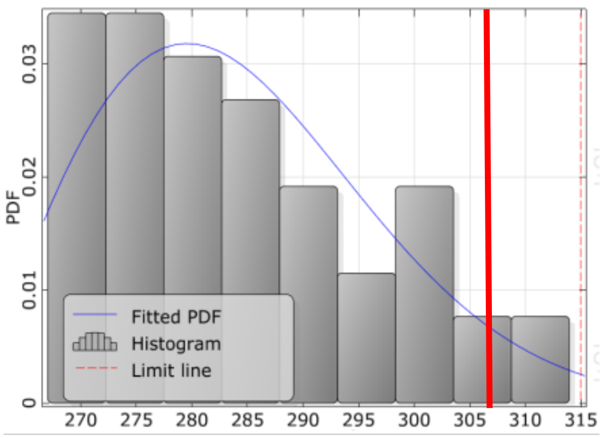
optiSLang's Robustness Analysis is more than a Tolerance Analysis

- Results for each output/ merit:
  1. Observed scattering
  2. Quantify the probability of failure by defining limits based on specs
  3. Global sensitivities of inputs

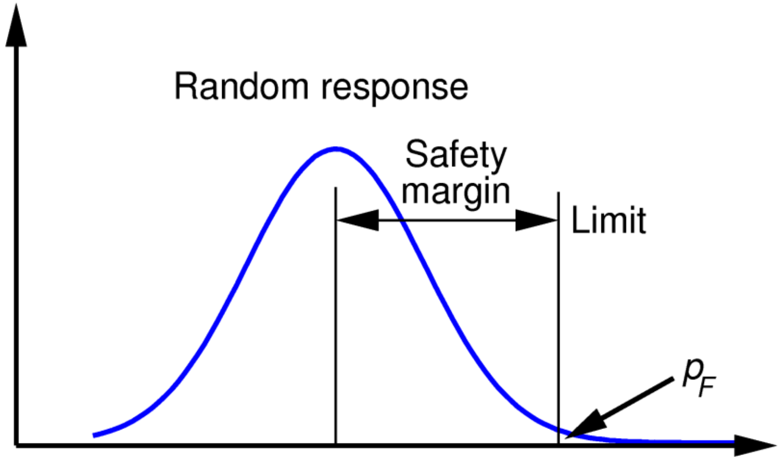
     -> Detection of causes

     -> Identify critical/ non-critical inputs

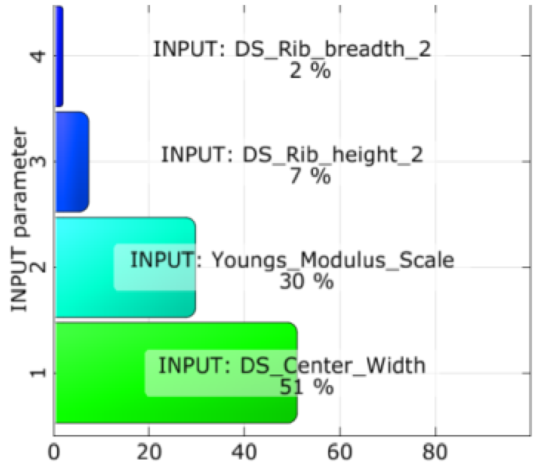
1.



2.



3.



Analysis of Light Distribution

- **Analysis of scalar data** (e.g. efficiency)
  = efficient to gain design understanding
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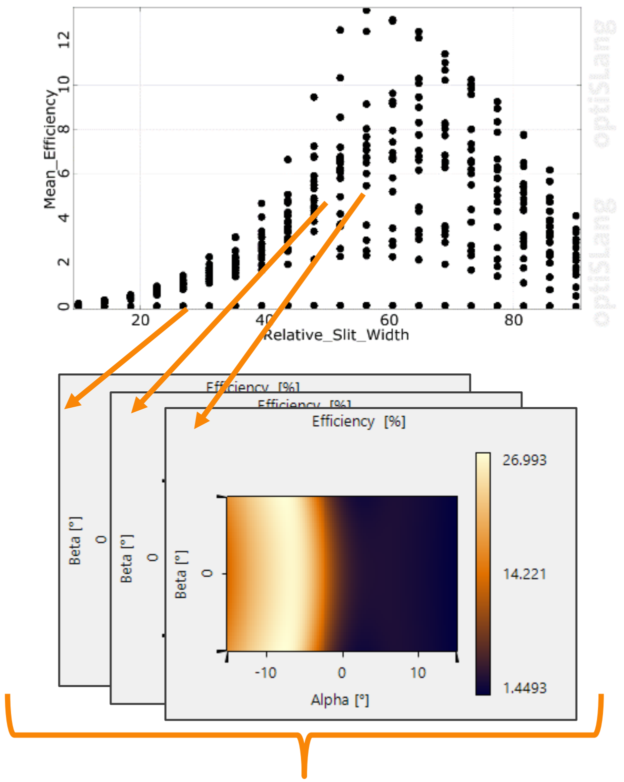
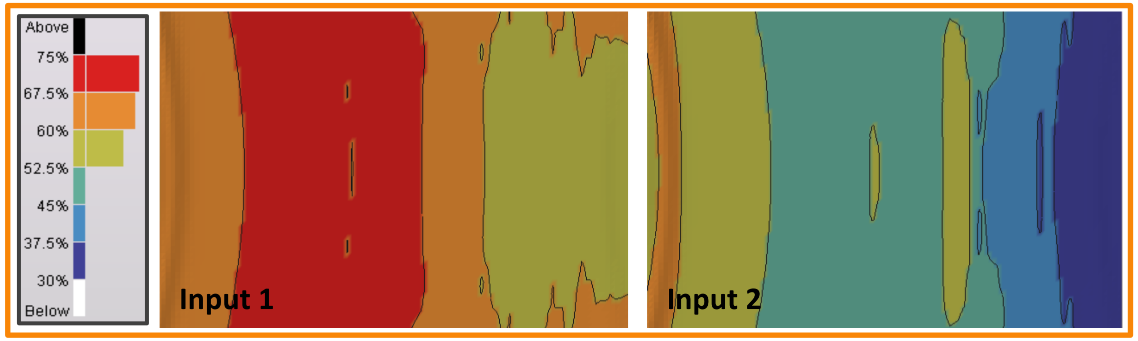




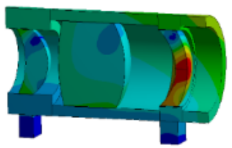
Opto-Thermo-Mechanical Simulation

1. Automation of workflows

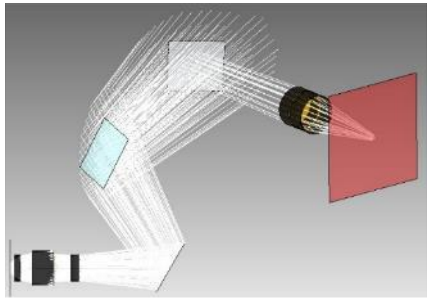
- Integration optical and mechanical simulation tools in optiSLang
- Built complex workflows

2. Robust Design Optimization

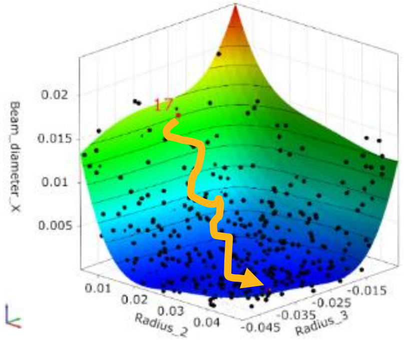
- Sensitivity Analysis
- Optimization
- Robustness Analysis



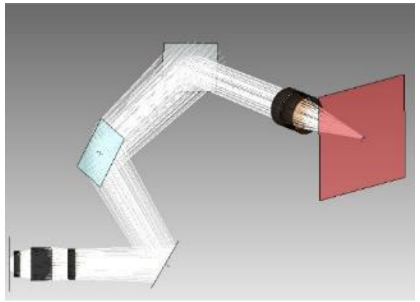
Thermo-mechanical analysis

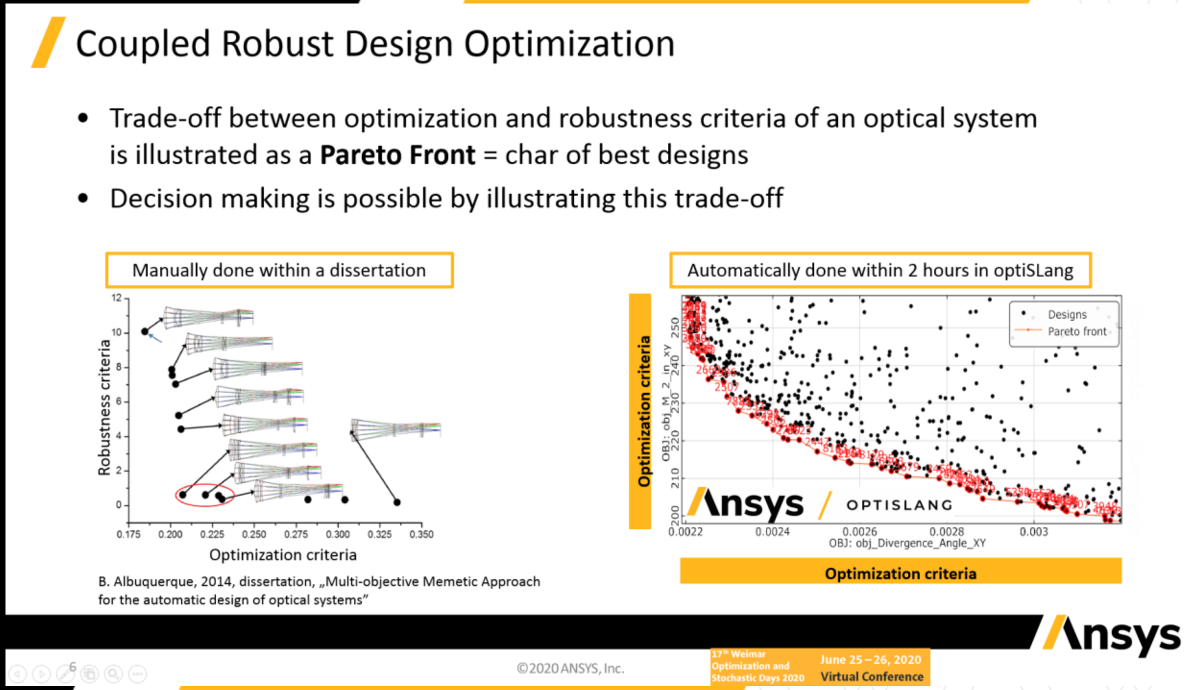


Optical analysis



Design understanding with metamodeling and robust design optimization





Optimization of a Binary Grating for Lightguide Coupling

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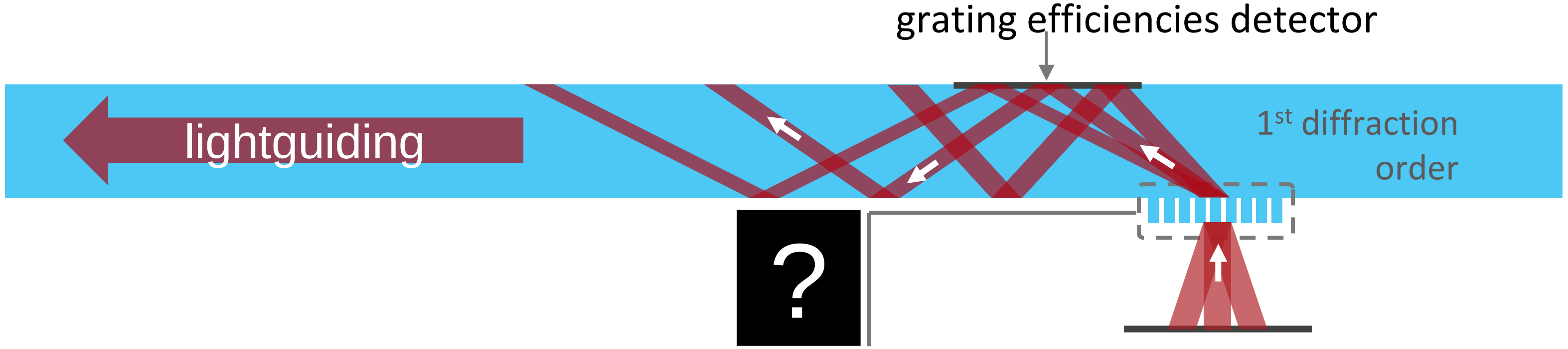
Optimization Task: Binary Grating Coupling

- How to design a binary grating structure to couple a set of plane waves into a planar lightguide?



set of plane waves
- field of view (-15..15, -10..10)°
- wavelength 532 nm
- linearly polarized along x-axis

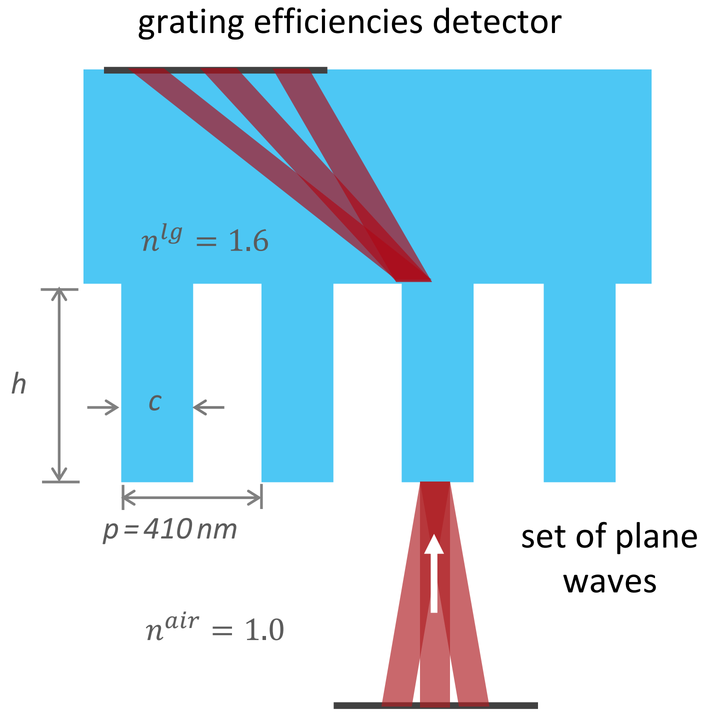
Problem description: Inputs

- Parameters to be varied for optimization

Inputs

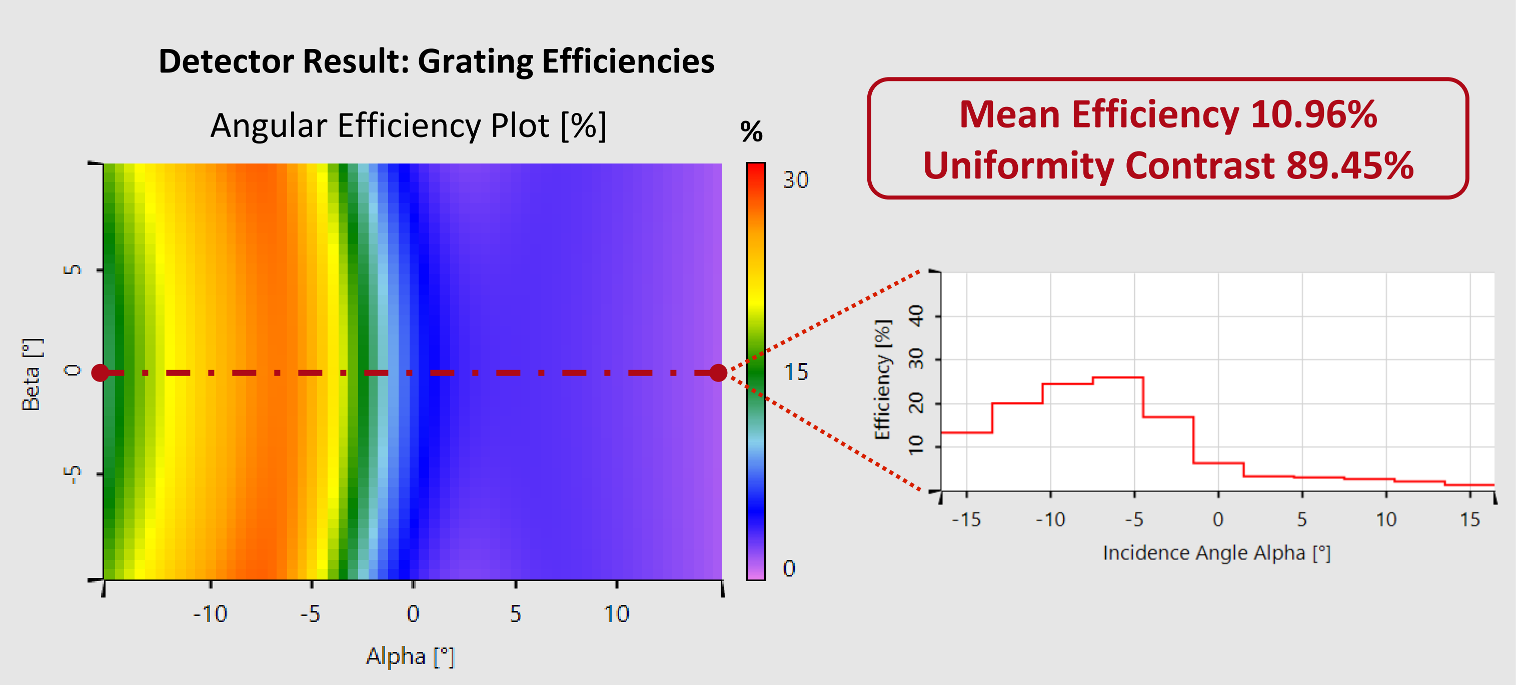
- variation of the **fill factor** c/p with the slit width c and the period p
  - **0.1% to 99.9%**
- variation of the **modulation depth** h
  - **50 nm to 1500 nm**

Initial Configuration of Grating	
fill factor	50.00%
modulation depth	400.00 nm
period	410 nm
operating order	1st transmitted



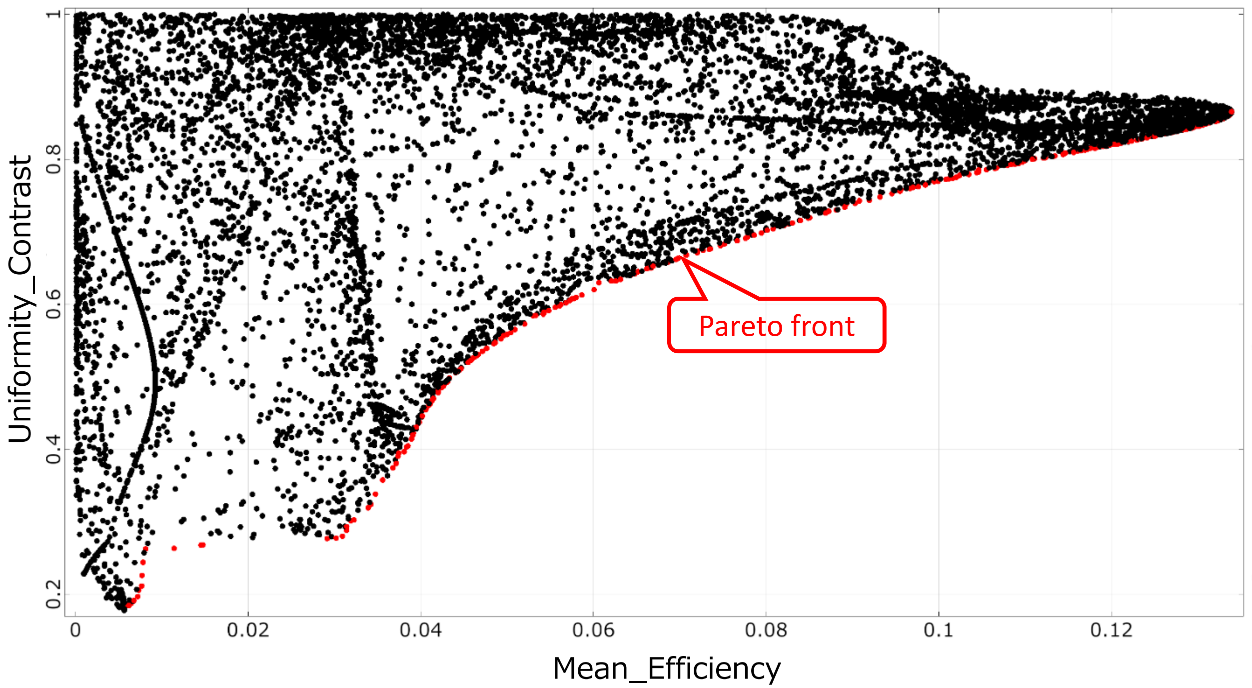
Problem description: Outputs

- Aim of the optimization over the desired FOV:
  - Maximize Mean Efficiency
  - Minimize Uniformity Contrast



Optimization Results

- Pareto Front of two contradicting objectives:
  - Mean Efficiency
  - Uniformity Contrast
- Pareto Front illustrates optimal compromise between objectives
- Choice of best design depends on the needs of the optical designer



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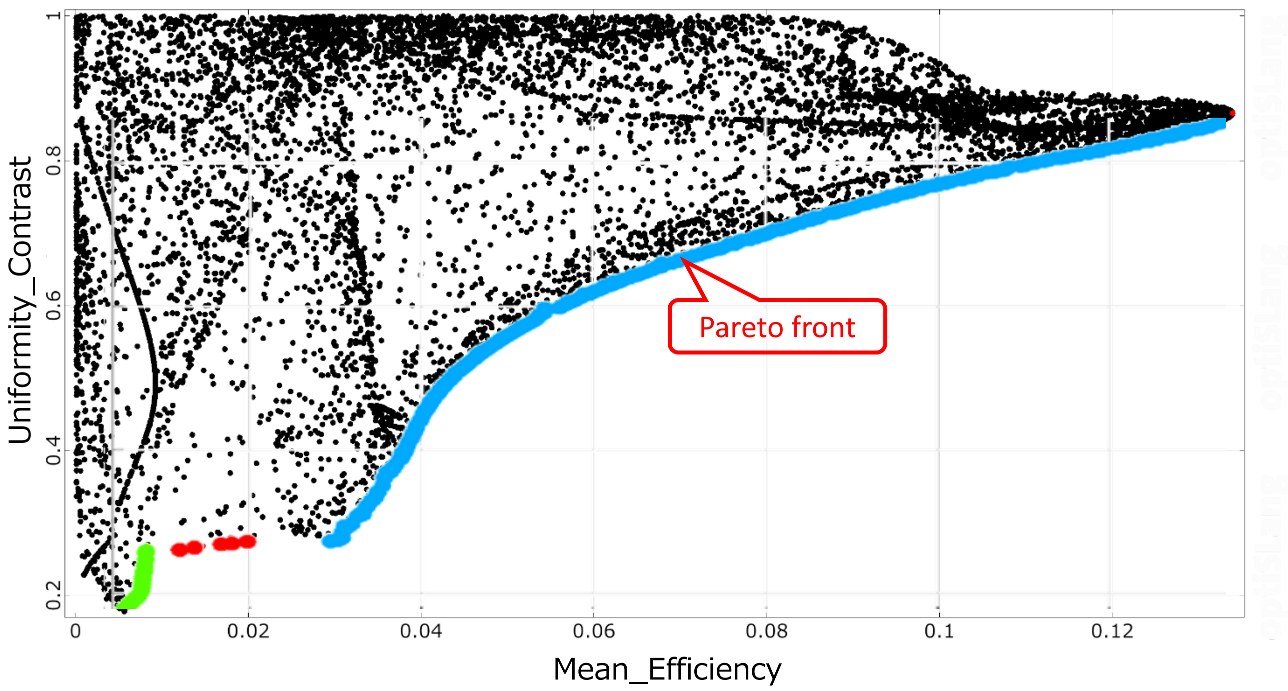
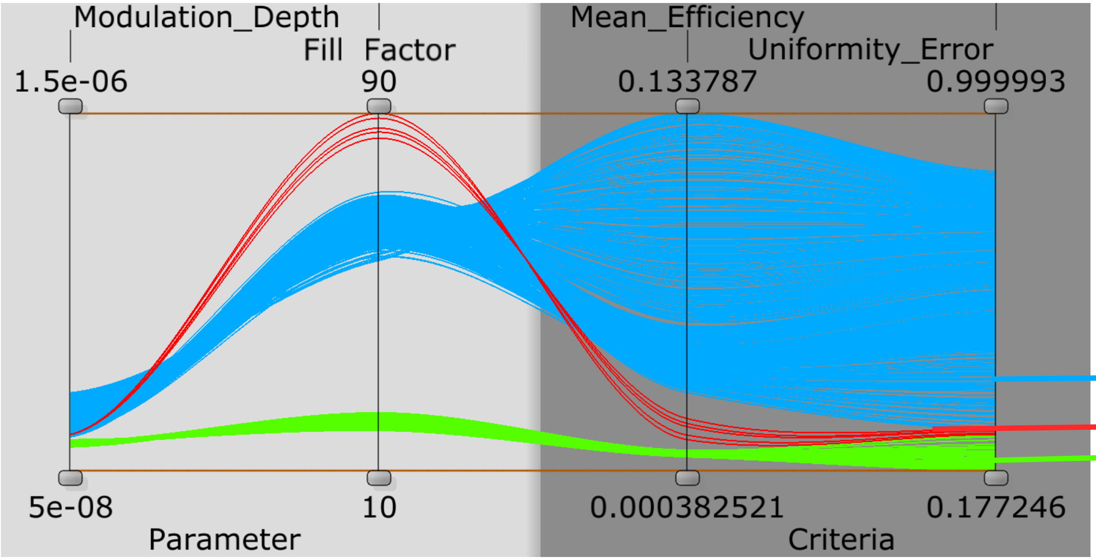
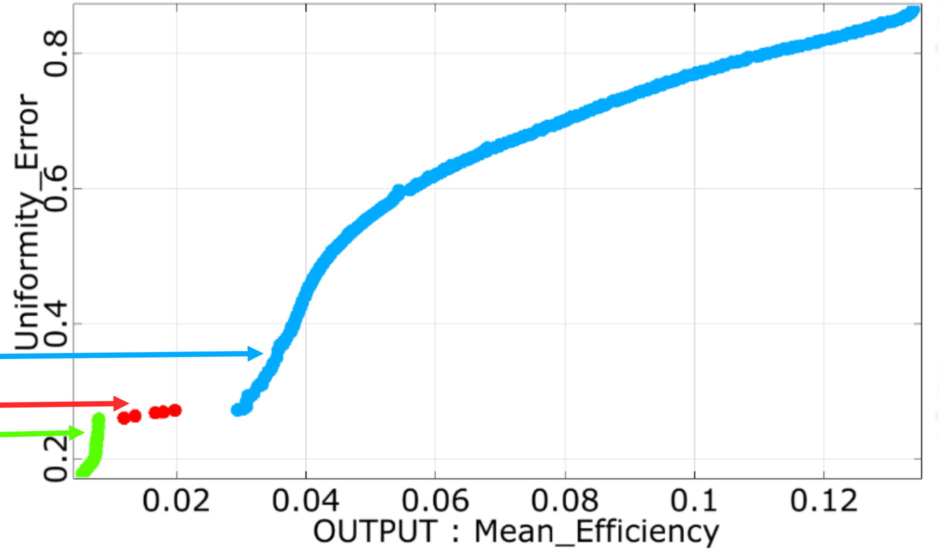


Optimization Results: Pareto Front Designs

- Cluster Analysis of Fill Factor (3 clusters)

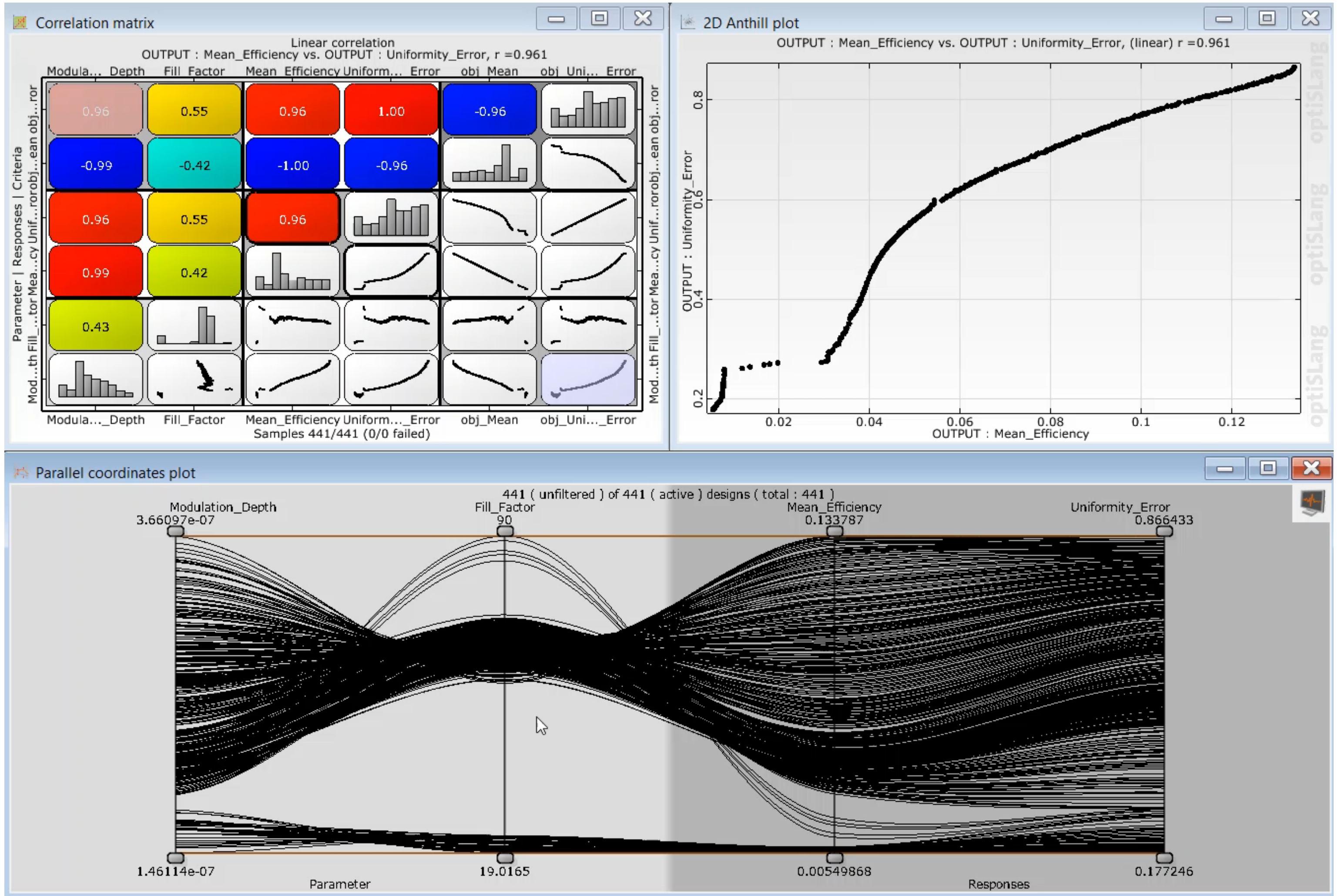


Parallel Coordinates Plot



Anthill Plot

Optimization Results: Pareto Front Designs



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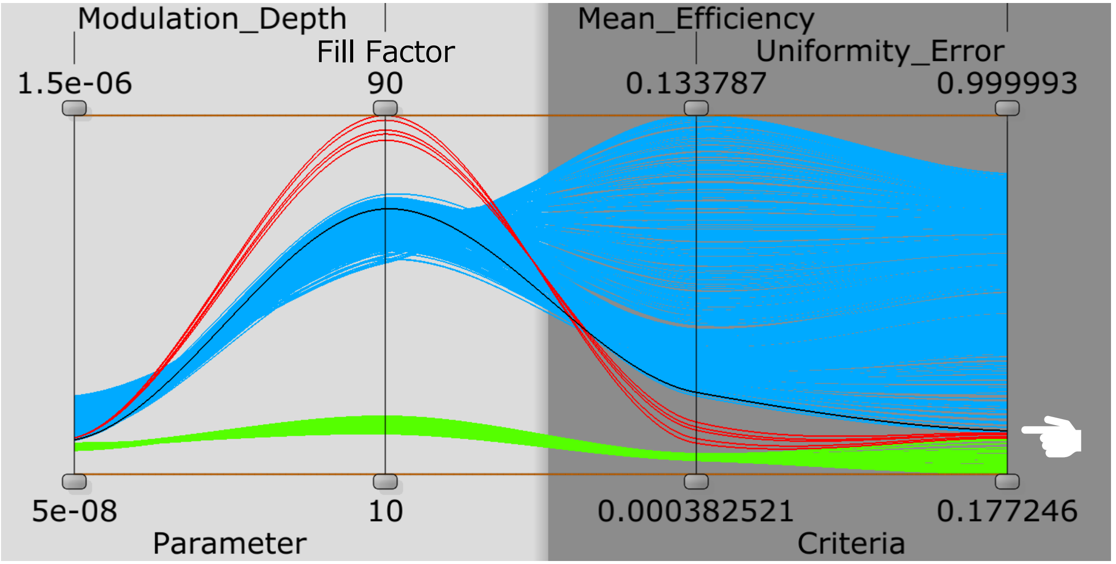

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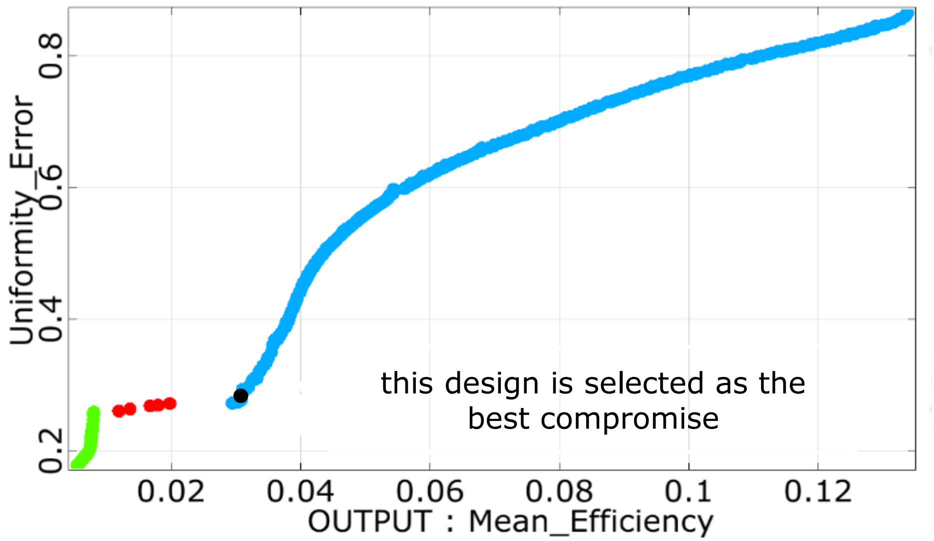
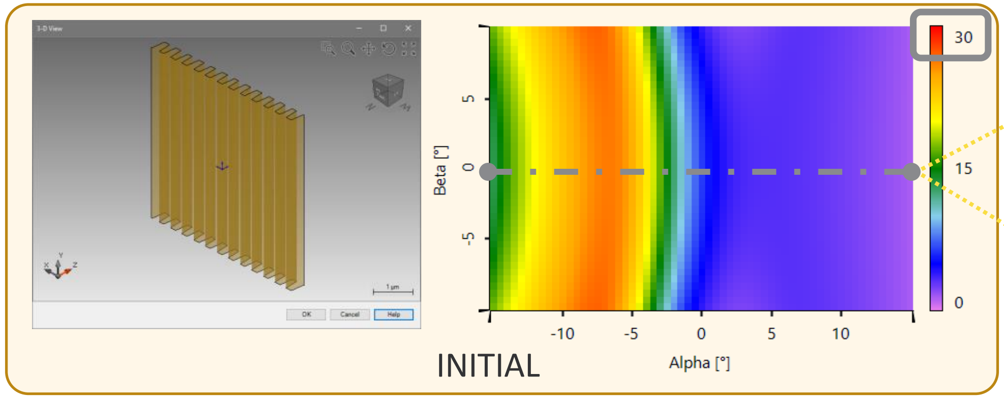


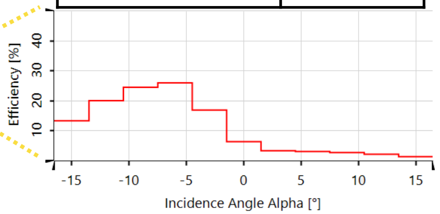
Anthill Plot

Results: Coupling Efficiency after Optimization

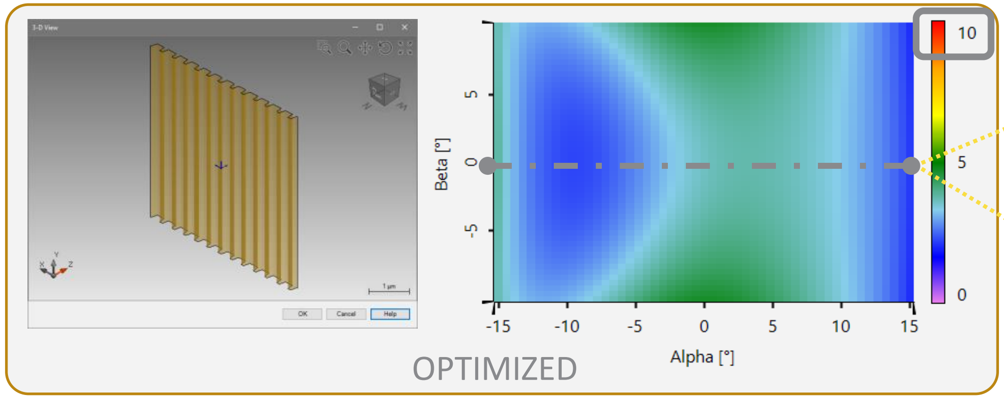
- As a result, the uniformity contrast was significantly reduced but to the cost of the entire efficiency



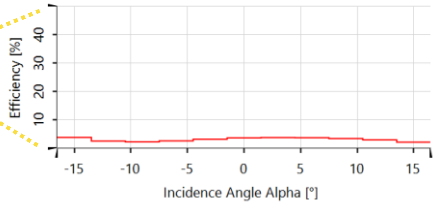
fill factor	50.00%
modulation depth	400.00 nm



Mean Efficiency 10.96%
Uniformity Contrast 89.45%



fill factor	68.43%
modulation depth	187.18 nm



Mean Efficiency 3.08%
Uniformity Contrast 28.02%

Use Case: https://www.lighttrans.com/use-cases/application-use-cases/optimization-of-binary-grating-for-lightguide-coupling-over-desired-fov.html

Analysis of Light Distribution

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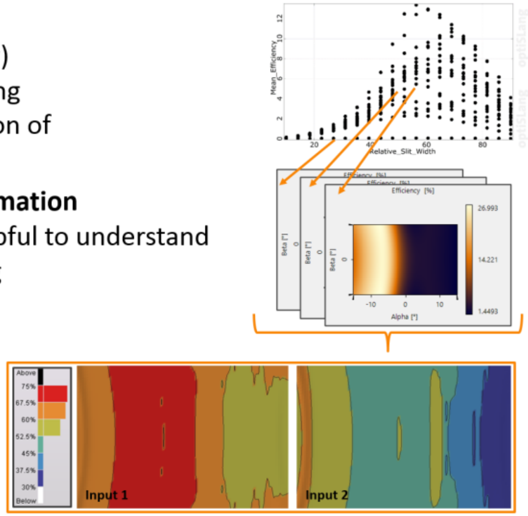

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Optimization of a Slanted Grating for Lightguide Coupling

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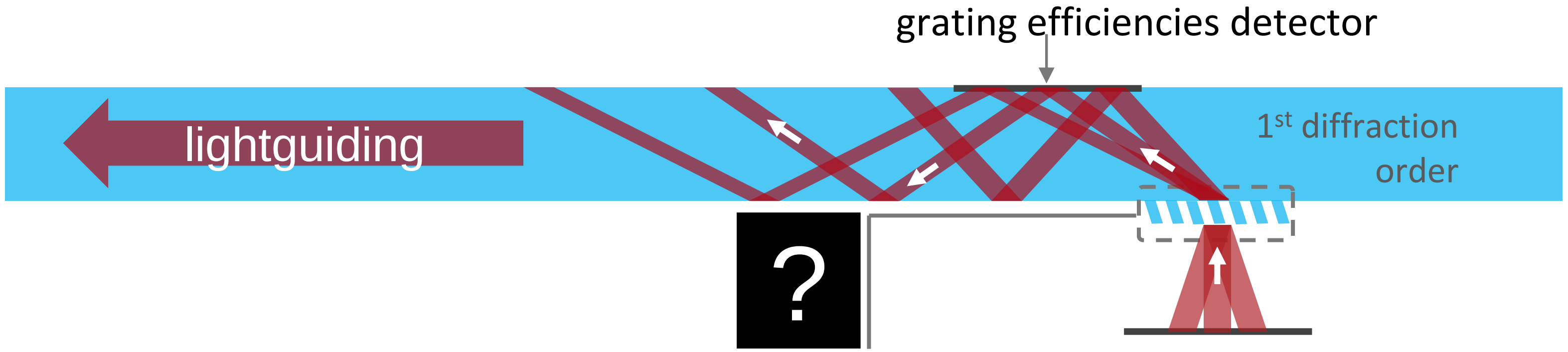
Optimization Task: Slanted Grating Coupling

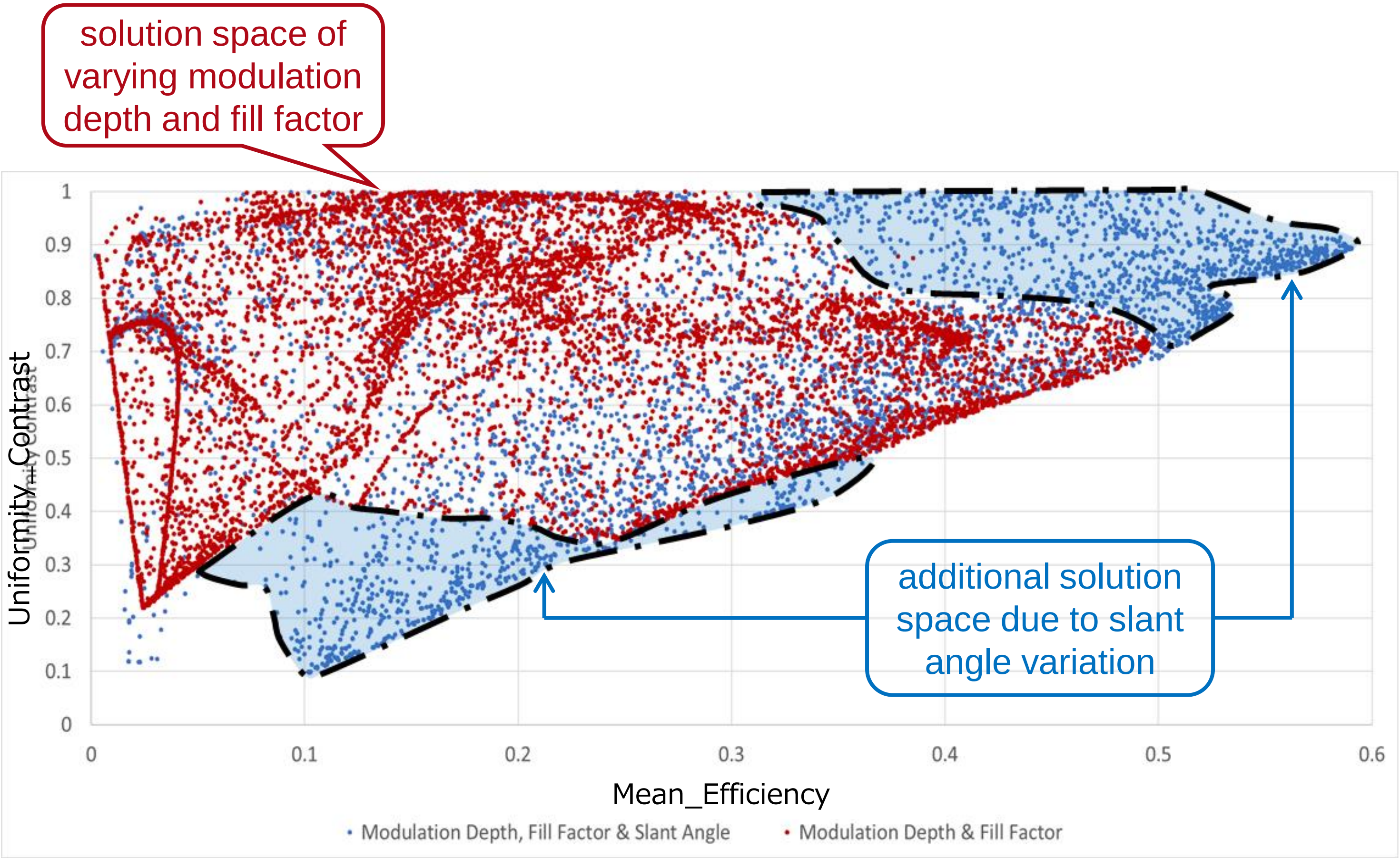
- How does the additional free parameter of the slant angle affect the design of the incouple grating?



set of plane waves
- field of view (-15..15, -10..10)°
- wavelength 532 nm
- linearly polarized along x-axis

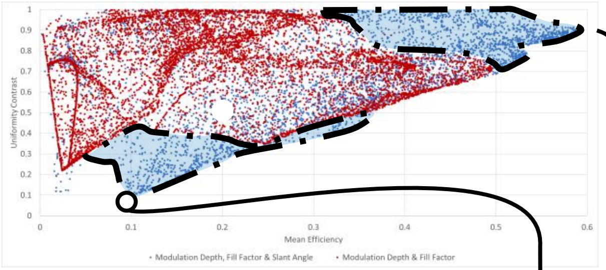
Optimization Result of optiSLang

- The additional freedom of the slant angle provides additional solutions

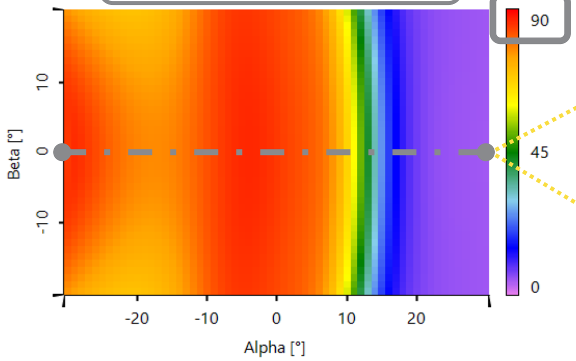


Results: Coupling Efficiency after Optimization

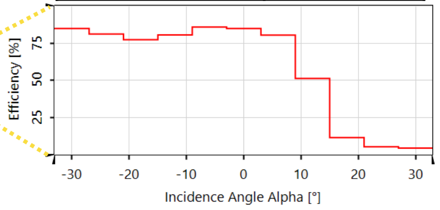
- Best solution can be selected according specific constraints
- Either uniformity contrast or mean efficiency might be prioritized



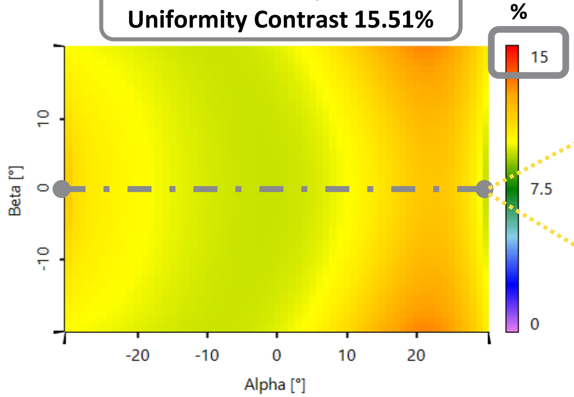
Mean Efficiency 58.74%
Uniformity Contrast 89.49%



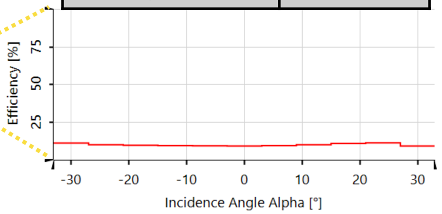
fill factor	70.82%
modulation depth	381.91 nm
slant angle	24.58°



Mean Efficiency 10.34%
Uniformity Contrast 15.51%



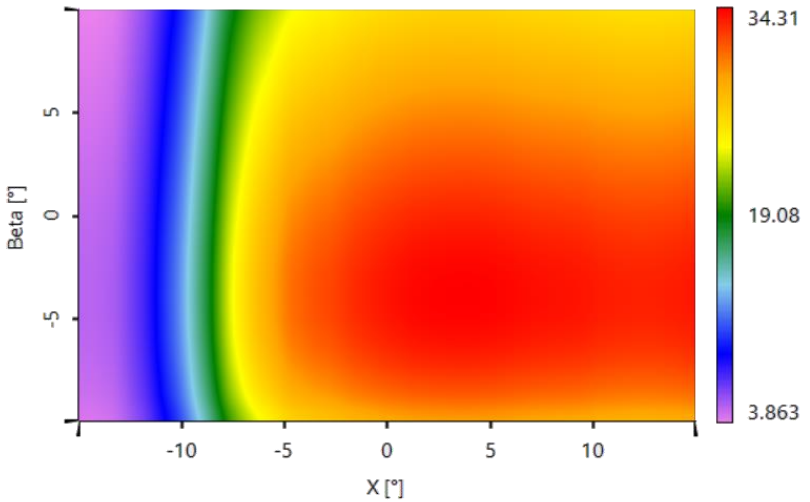
fill factor	90.00%
modulation depth	189.64 nm
slant angle	14.57°



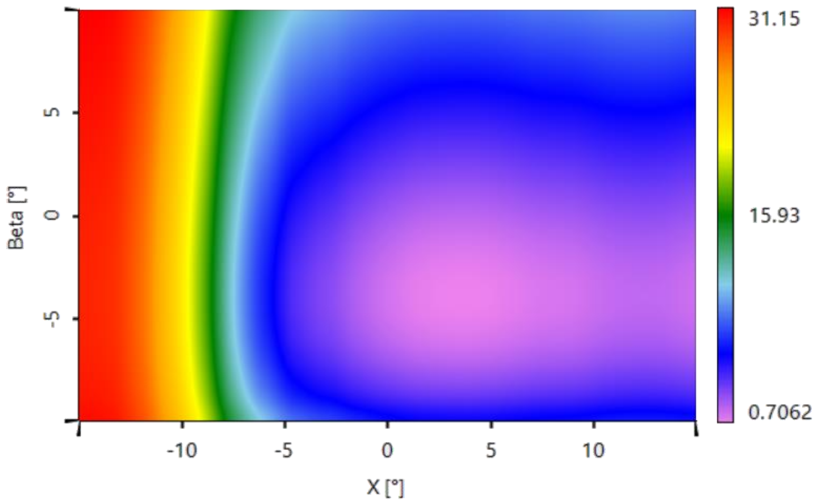
Use Case: https://www.lighttrans.com/use-cases/application-use-cases/optimization-of-slanted-grating-for-lightguide-coupling-over-desired-fov.html

Further work and outlook

- 2D data analysis for further understanding and improved optimization results, e.g. to obtain a desired angular efficiency

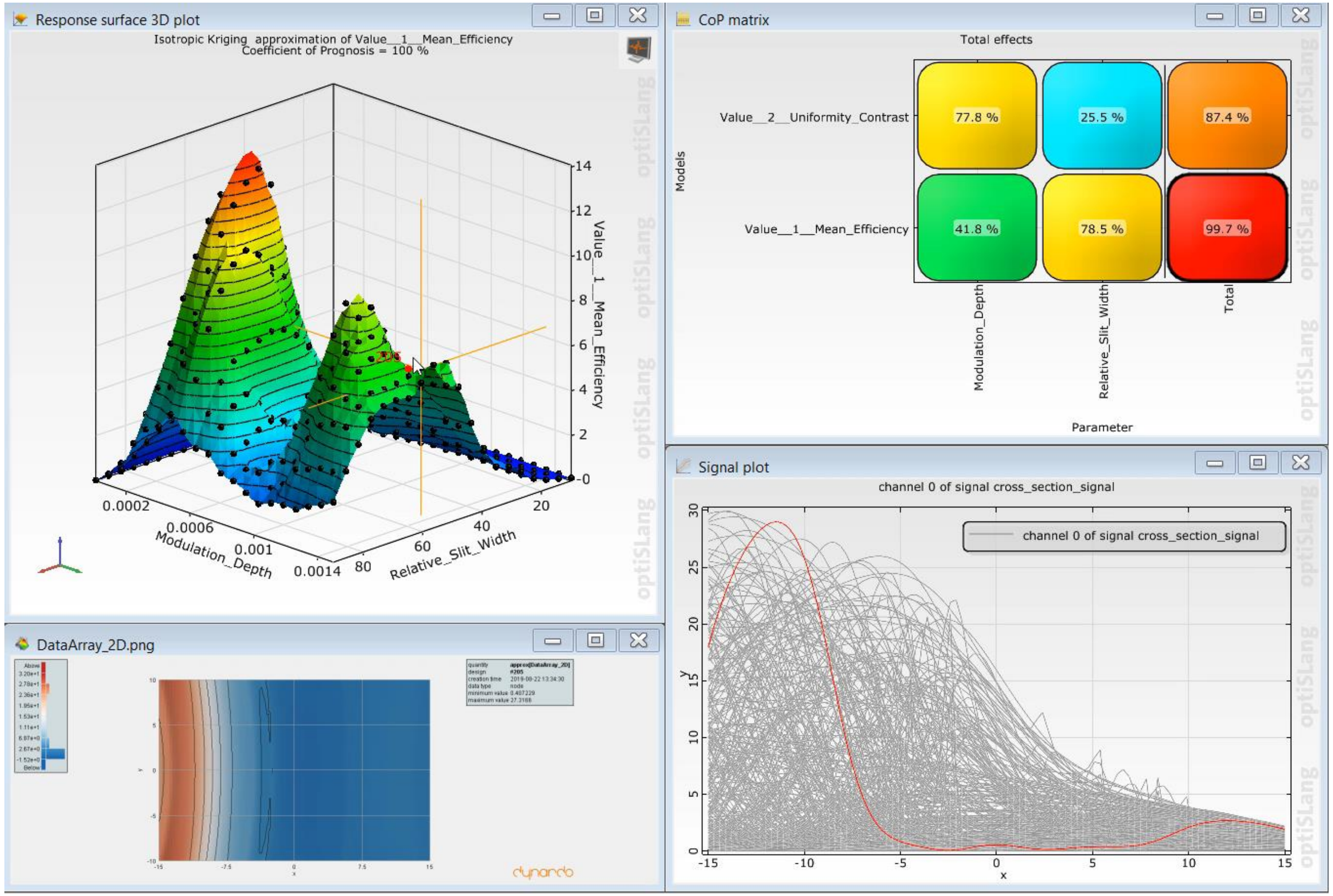


Calculated Angular Efficiency at Eye-Box

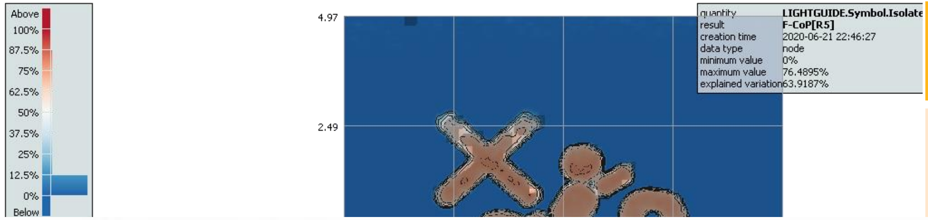


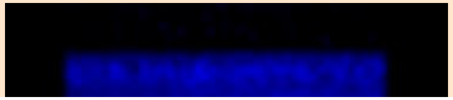
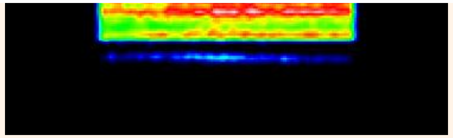
Assumed Desired Angular Efficiency at Incouple Region

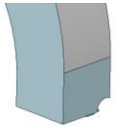
Further work and outlook

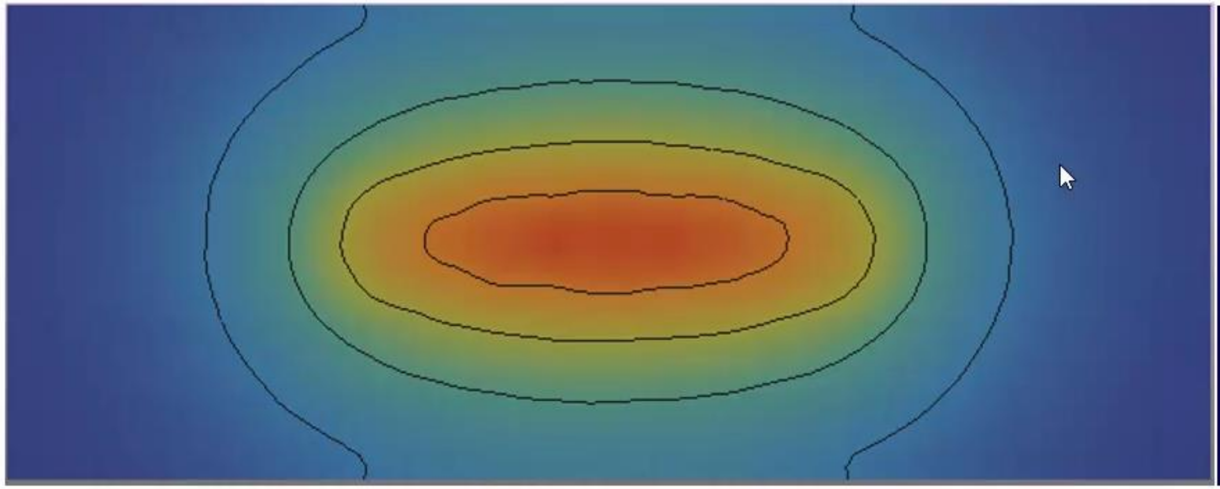


Similar applications with Statistics on Structures

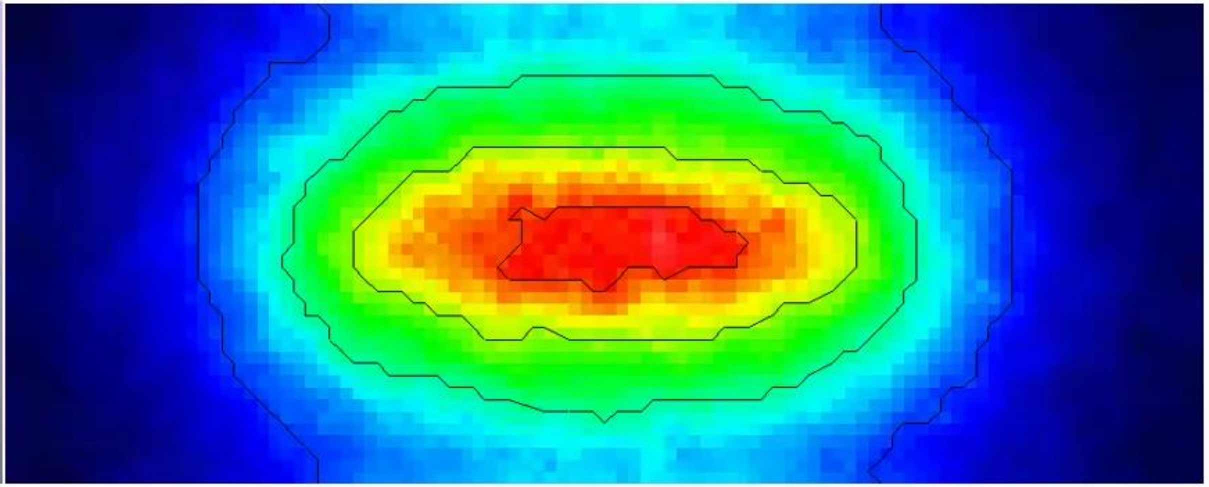


Outputs	Lightguide	Symbol
0 degree		
		





Field Meta Modell



Actual Speos Simulation

Q&A

What questions do you have?

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Please use Chat function or unmute yourself

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     - -> Identify critical/ non-critical inputs

ZKW headlamp tolerance analysis

Customer benefits

Dr. Christian Knobloch

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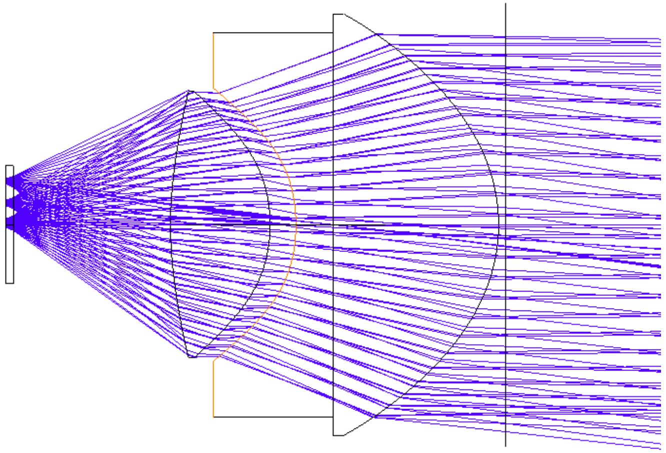
Robustness analysis for next generation high definition optical headlamp modules @ ZKW

Challenge

- Future driving enables high definition illumination of the road
- The optical module projects a DMD with 1,3 million micro-mirrors on the road utilizing an achromatic three lens system

- Therefore we have to understand tolerances in three-lens manufacturing process based on a Zemax lens model
- High resolution of the system requires advanced tolerancing method → standard tolerancing techniques do not work any longer



Robustness analysis for headlamp systems @ ZKW

ZKW

Challenge

- Understand tolerances in DLP manufacturing process using a Zemax lens model
- process was based on subjective estimations for tolerances and performance measures, no objective data available

Solution

- Explore new technologies (DLP module) in lighting with optiSLang robustness analysis: find adequate input tolerances by defining limits for performance measures based on data from the analysis
- Even the adjustment process during manufacturing can be modelled with optiSLang for highly accurate results
- Implement tolerances in optimization process with automated RDO loop

Benefit

- Tolerances of existing module were tailored to be not too high and not too low
- Realistic estimate of the performance of the system under tolerance influences
- Work on objectified data with suppliers (tolerances) and customers (performance variation)
- Use tolerance workflow for the next generation of lighting systems

Ansys

Robustness analysis for next generation high definition optical headlamp modules @ ZKW

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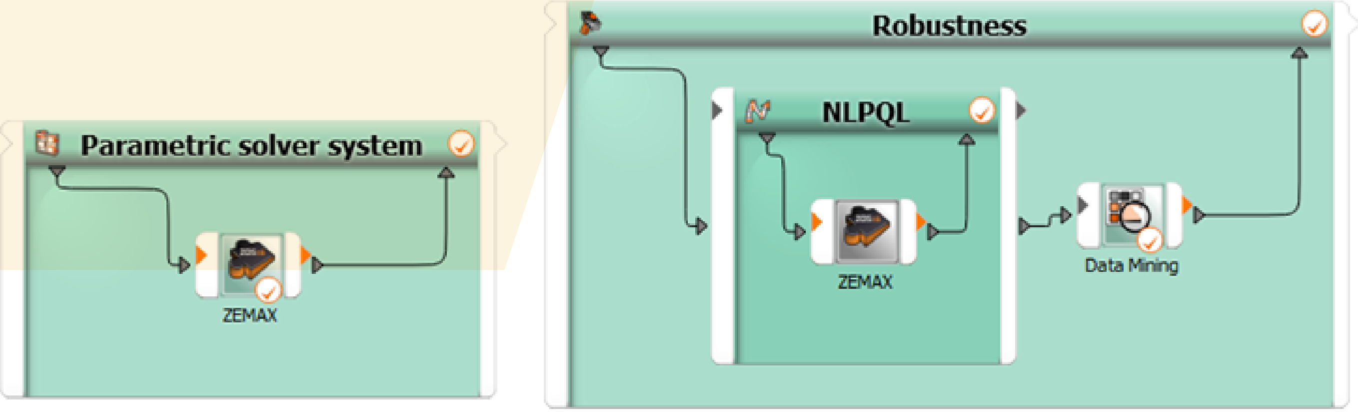
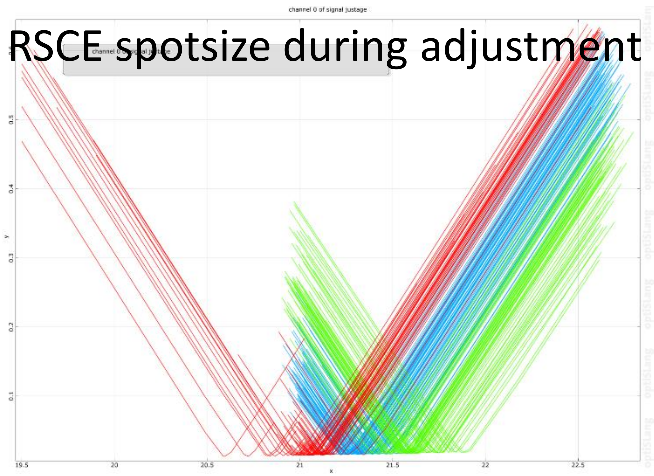


Robustness analysis for next generation high definition optical headlamp modules @ ZKW

Solution

- Explore new technologies (DLP module) in lighting with optiSLang robustness analysis: find adequate input tolerances by defining limits for performance measures based on data from the analysis
- Lens adjustment process during manufacturing can be modelled with optiSLang and production capability values can be deduced



RSCE spotsize during adjustment

Robustness analysis for next generation high definition optical headlamp modules @ ZKW

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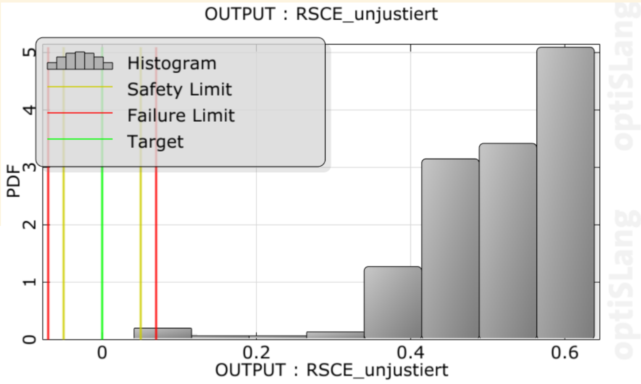
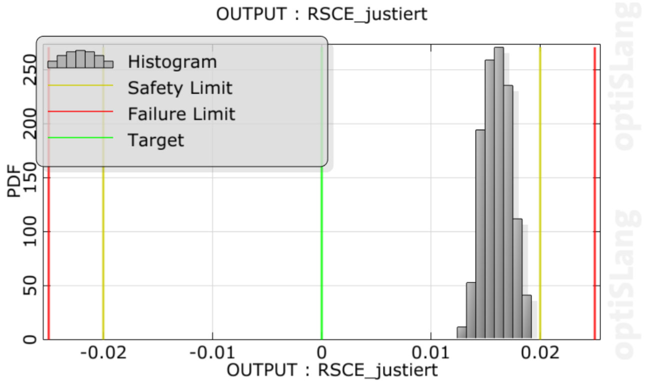


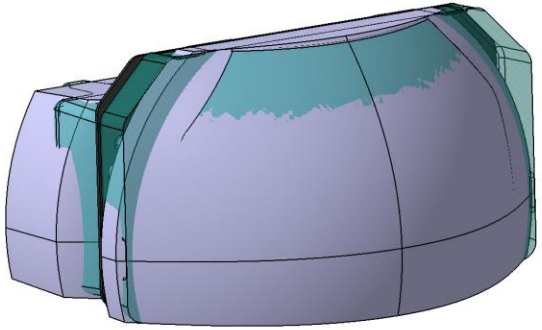


Robustness analysis for next generation high definition optical headlamp modules @ ZKW

Benefit

- Tolerances of existing module were tailored to be not too high and not too low
- Realistic estimate of the performance of the system under tolerance influences
- Easy to check performance of different designs of the tolerancing in Zemax (MTF) or other raytracing software

Optical design with tolerances

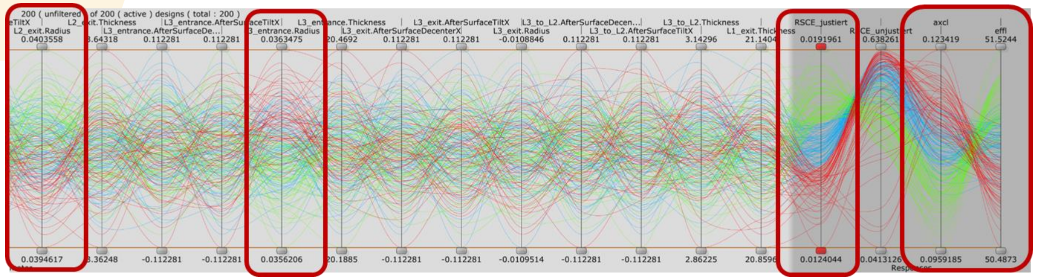


Robustness analysis for next generation high definition optical headlamp modules @ ZKW

ZKW

Benefit

- Tolerances of existing module were tailored to be not too high and not too low → cost savings
- Realistic estimate of the performance of the system under tolerance influences
- Easy to check performance of different designs of the tolerancing in Zemax (MTF) or other raytracing software
- Easy to verify most important surfaces and where to put emphasis in lens manufacturing process
- Work on objectified data with suppliers (tolerances) and customers (performance variation)

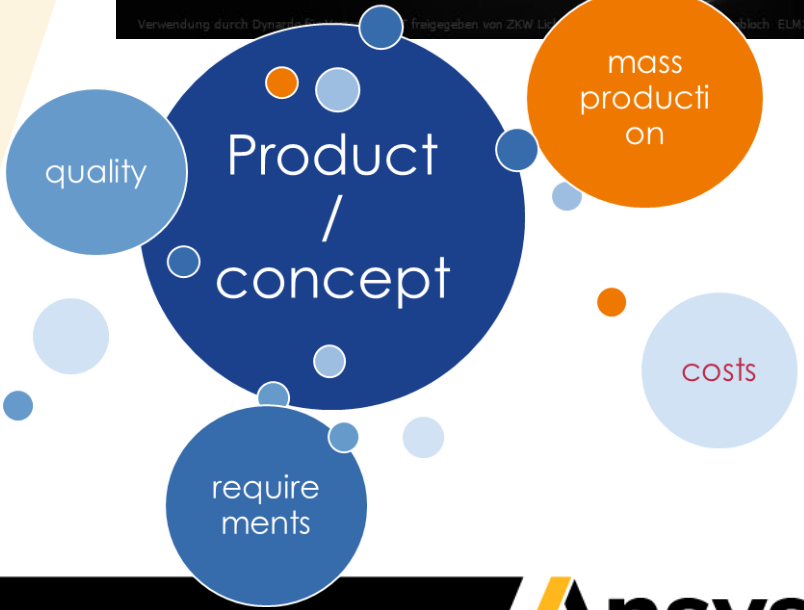


Ansys

Robustness analysis for next generation high definition optical headlamp modules @ ZKW

Future use

- Same workflow can be used for the next generation of lighting systems and different light-modules
- Robust design optimization will be implemented via OptiSLang workflow and promises even better and more feasible optical solutions
- Tolerancing can be implemented at an early stage for high performance within a complex field of requirements
- Further functionalities enable even more advanced tolerancing studies within different raytracing environments

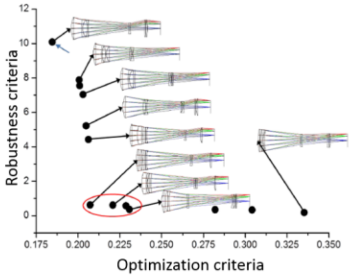


Robust Design Optimization of optical systems

Coupled Robust Design Optimization

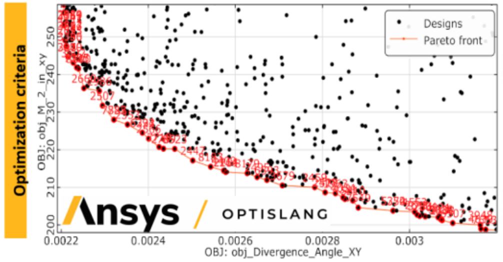
- Trade-off between optimization and robustness criteria of an optical system is illustrated as a **Pareto Front** = char of best designs
- Decision making is possible by illustrating this trade-off

Manually done within a dissertation



B. Albuquerque, 2014, dissertation, „Multi-objective Memetic Approach for the automatic design of optical systems"

Automatically done within 2 hours in optiSLang



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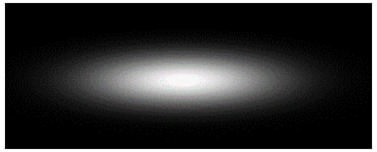
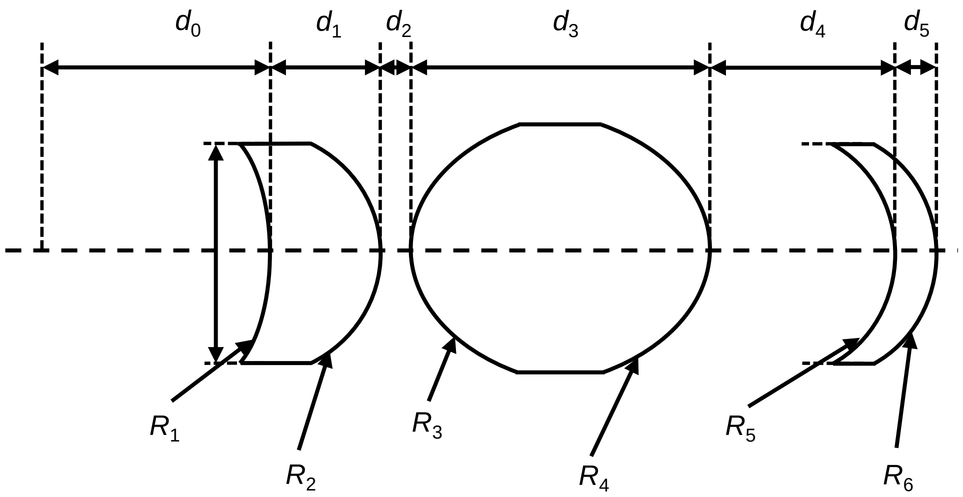
Problem Description

- Collimation of Diode Laser Beam by Objective Lens
- **Optimization objective:**
  - Minimize *divergence angle* in x and y direction
  - Minimize m^2 to be close to 1 in x and y direction
- **Robustness criteria:**
  - Coefficient of Variation (CoV) of *divergence angle* and m^2 in x and y direction should not exceed 20%



input field

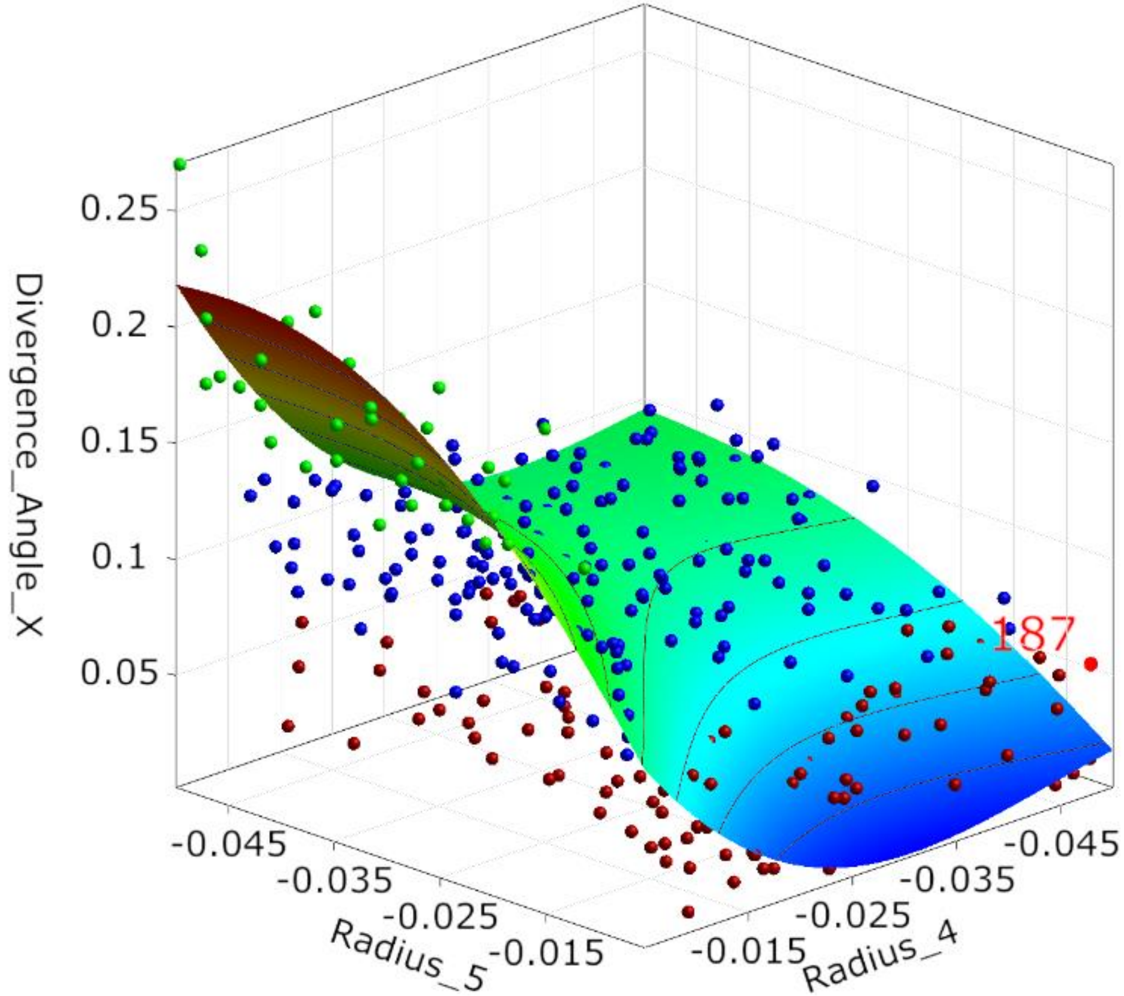


Optical Design Optimization

Metamodel of Divergence Angle X

The lower radius 5 the lower the divergence angle!

An intermediate radius 4 leads to a low divergence angle!

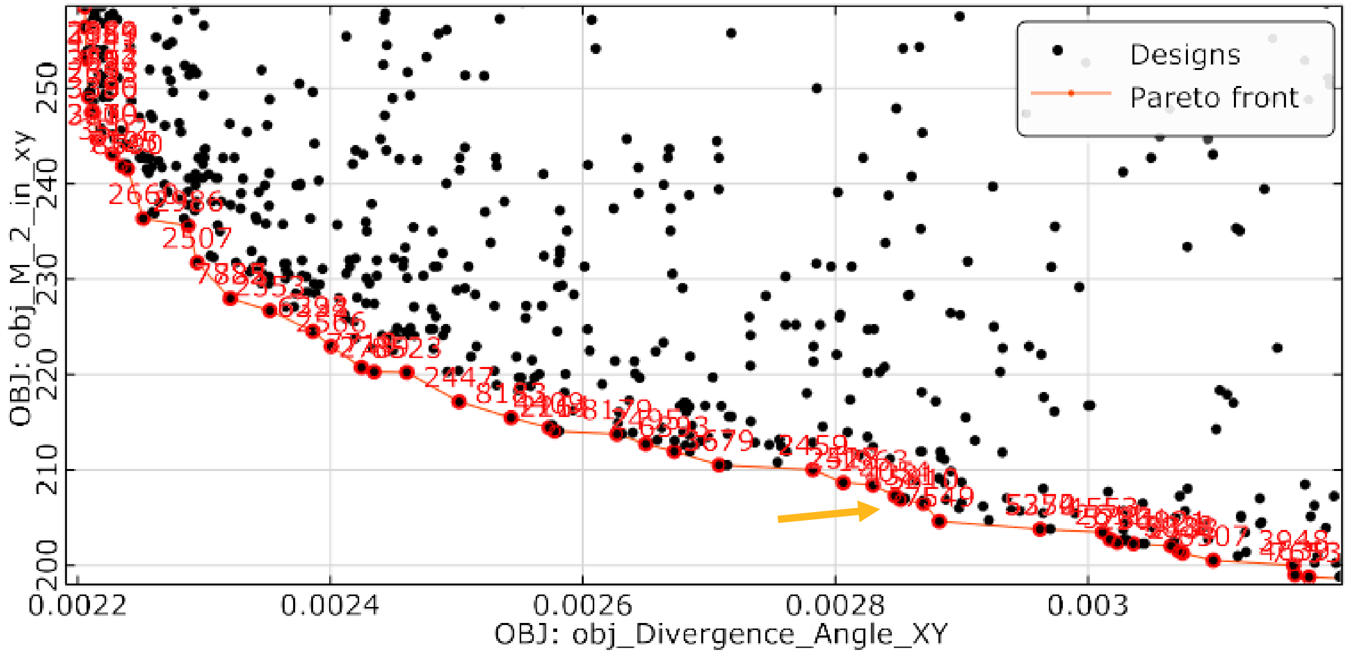


Optical Design Optimization

Pareto optimization on metamodel

Best design can be chosen from the Pareto front and used as start design for further direct optimization

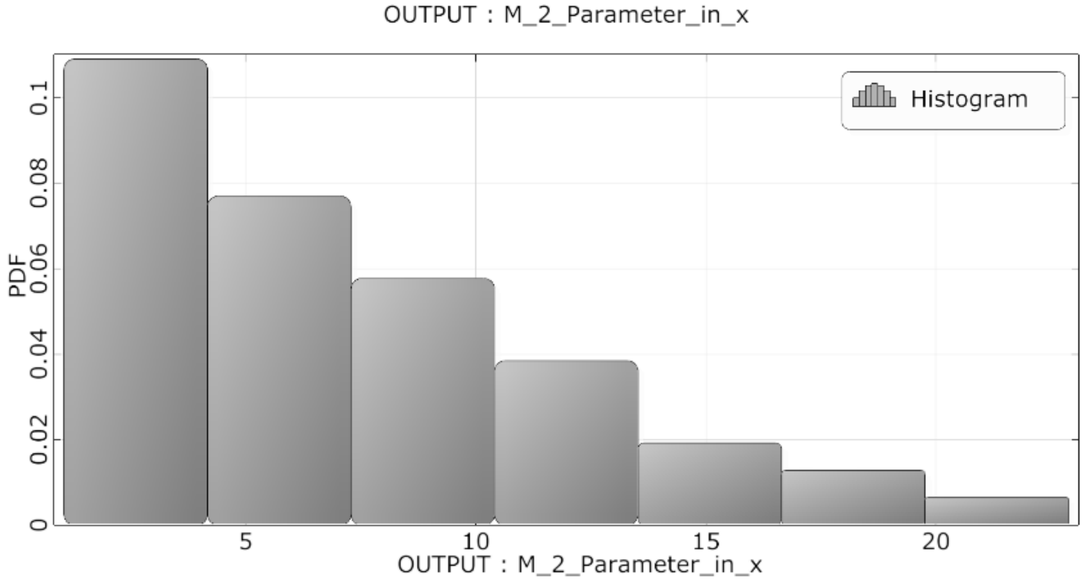
Optimization criteria



Optimization criteria

Robustness Analysis

- **Optical design is not robust** in terms of m^2 (CoV =71%!) due to the variation of the lateral shift



Statistical data			
Min:	1.02217	Max:	22.8507
Mean value:	7.24983	Standard deviation:	5.16479
CoV:	0.712401		

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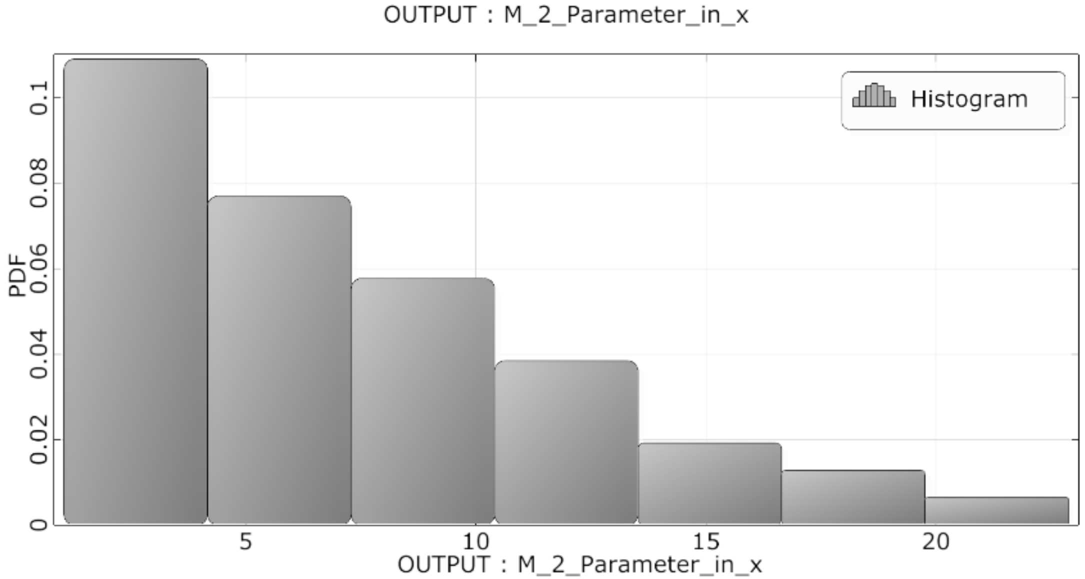

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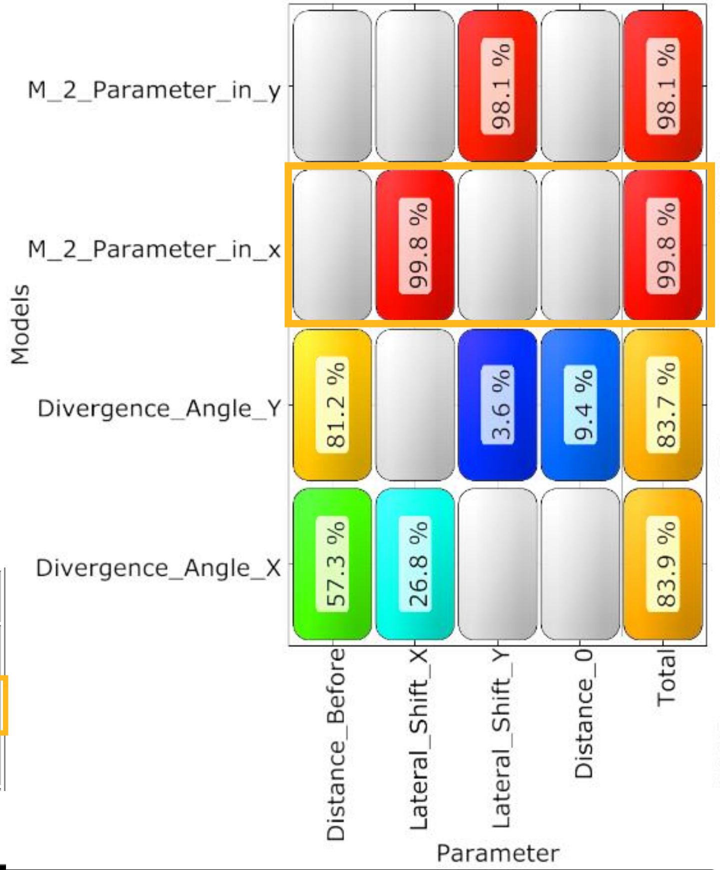
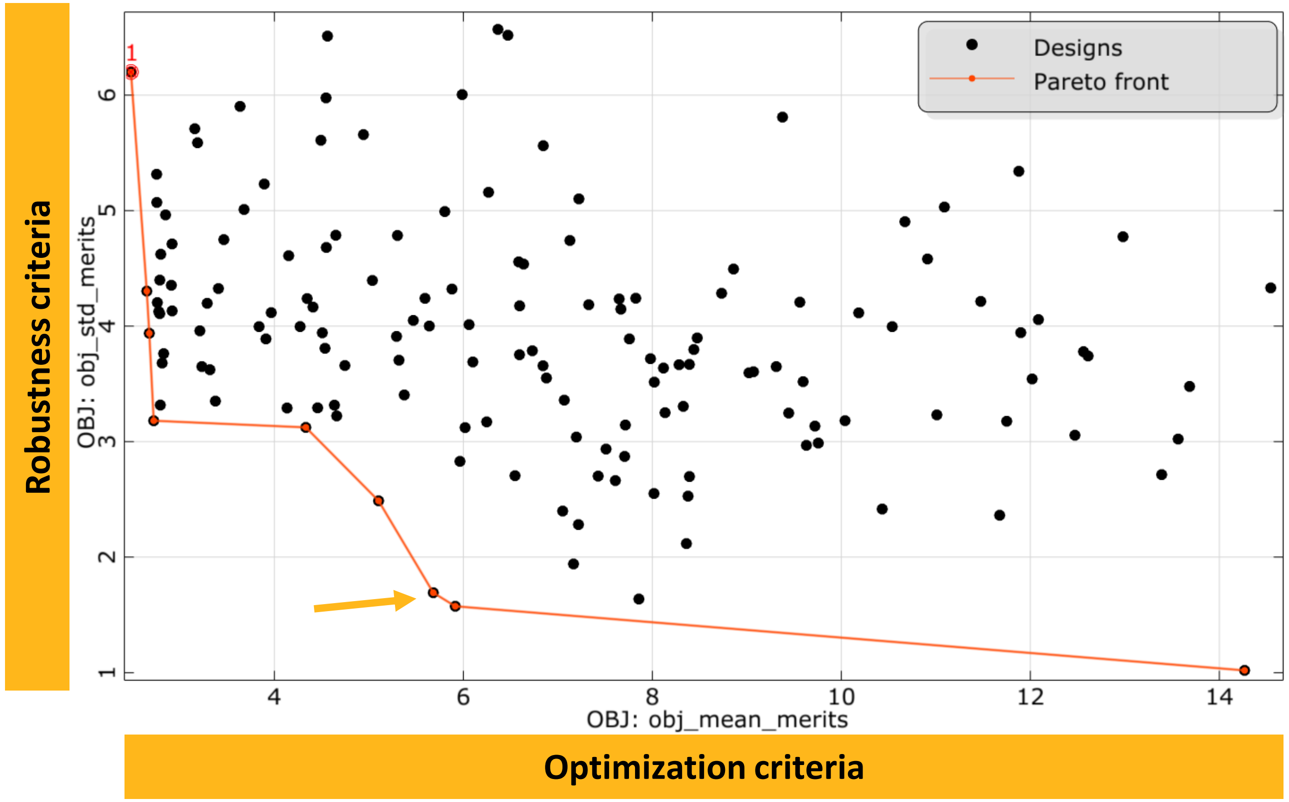


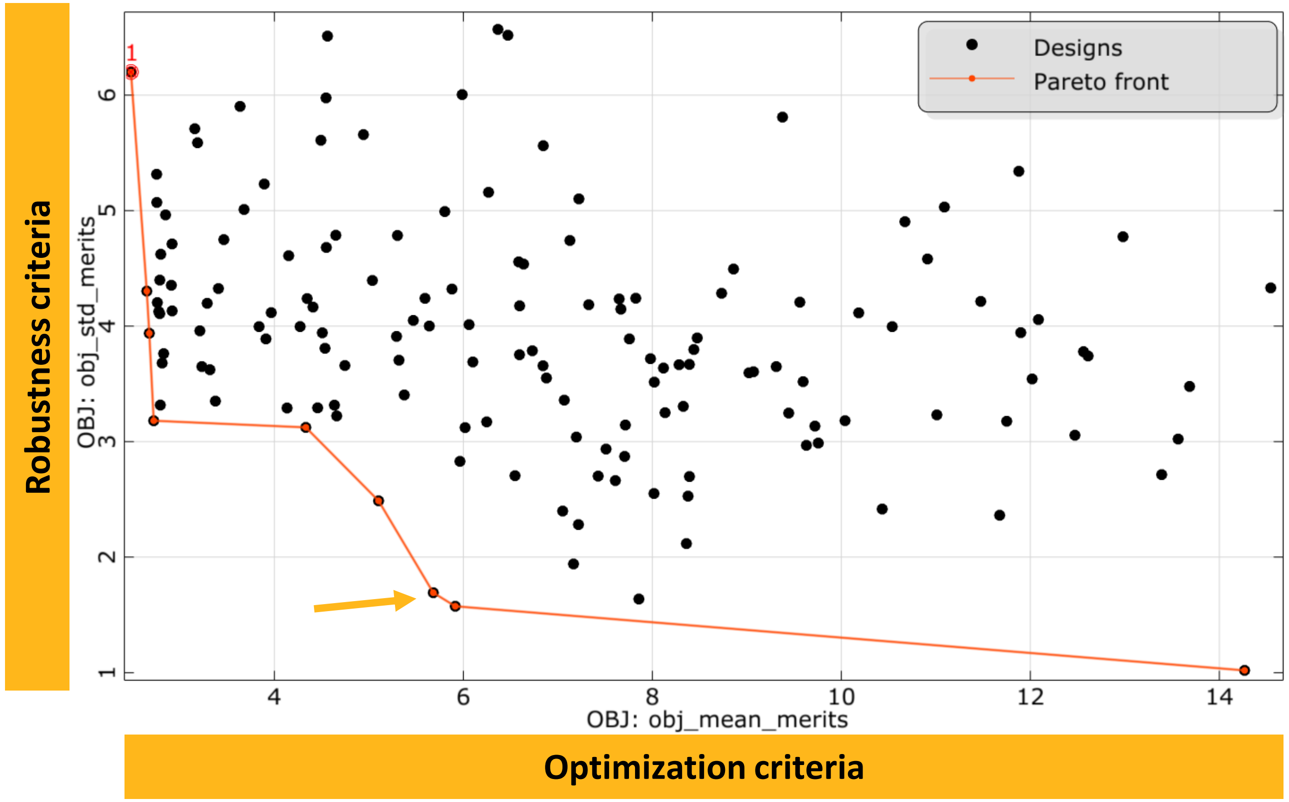
Coupled Robust Design Optimization

- **Optimization criteria:** weighted merits in one objective function
- **Robustness criteria:** weighted standard deviation of merits in second objective function



Coupled Robust Design Optimization

- **Further steps:**
  - Check value of inputs
  - Check performance of each output parameter



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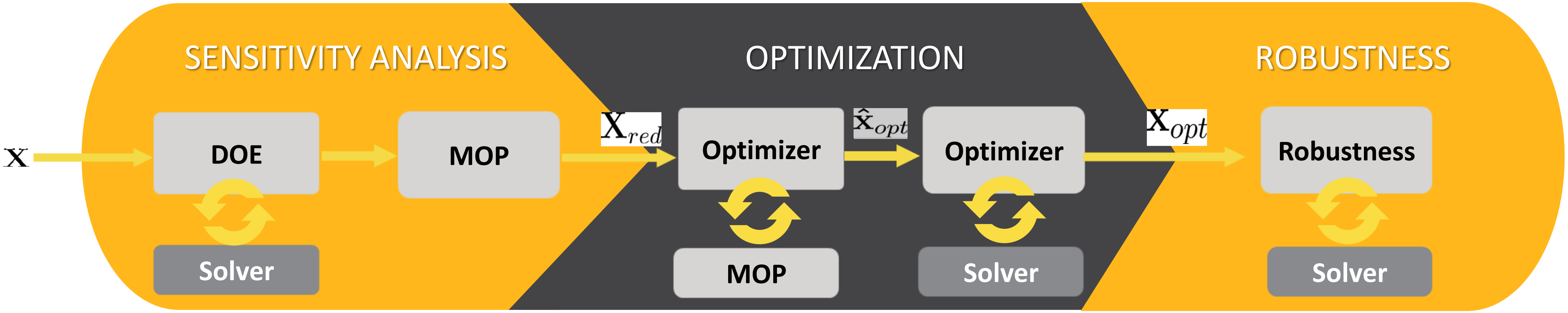
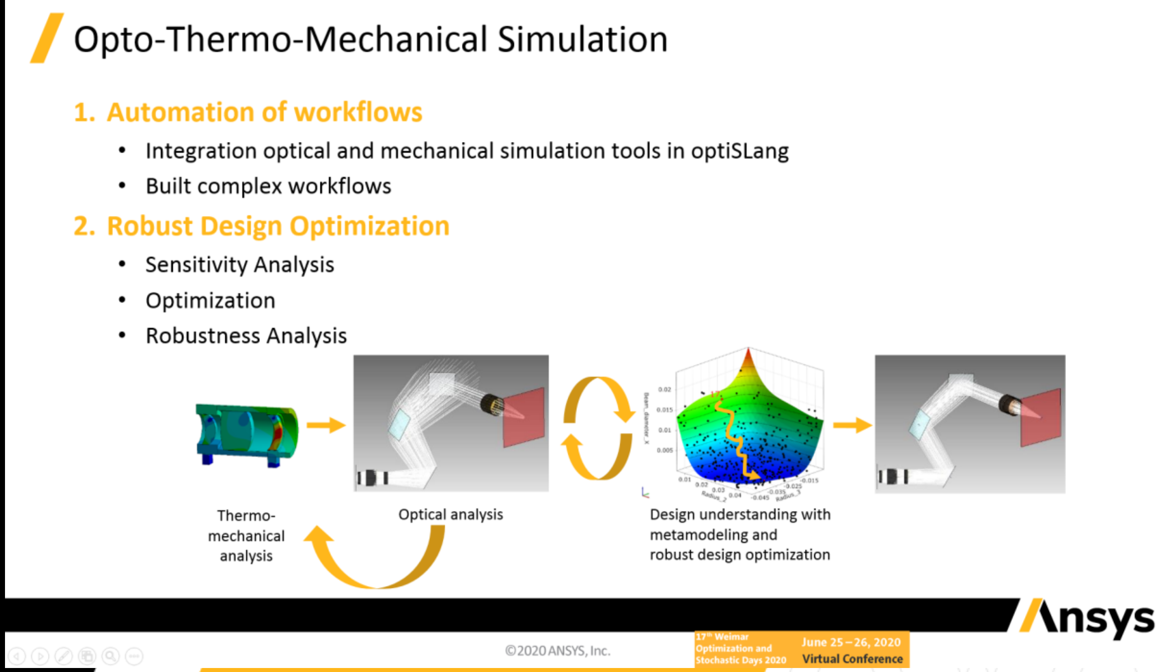
Summary – Robust Design Optimization

Workflow

1. Sensitivity analysis
   - Correlation and cluster analysis
   - MOP generation
2. Optimization on MOP using best design from sensitivity analysis
3. Optimization with direct solver calls using start design from previous optimization on MOP
4. Robustness analysis
5. Coupled or iterative Robust Design Optimization





Opto-thermo-mechanical simulation

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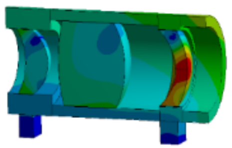
Opto-Thermo-Mechanical Simulation

1. Automation of workflows

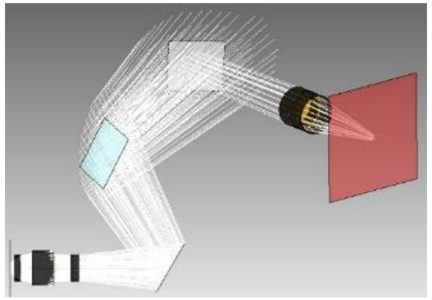
- Integration optical and mechanical simulation tools in optiSLang
- Built complex workflows

2. Robust Design Optimization

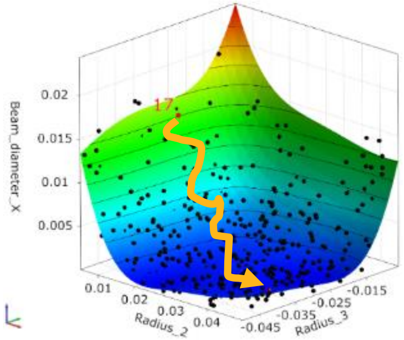
- Sensitivity Analysis
- Optimization
- Robustness Analysis



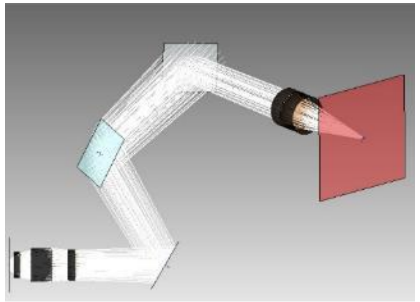
Thermo-mechanical analysis



Optical analysis



Design understanding with metamodeling and robust design optimization



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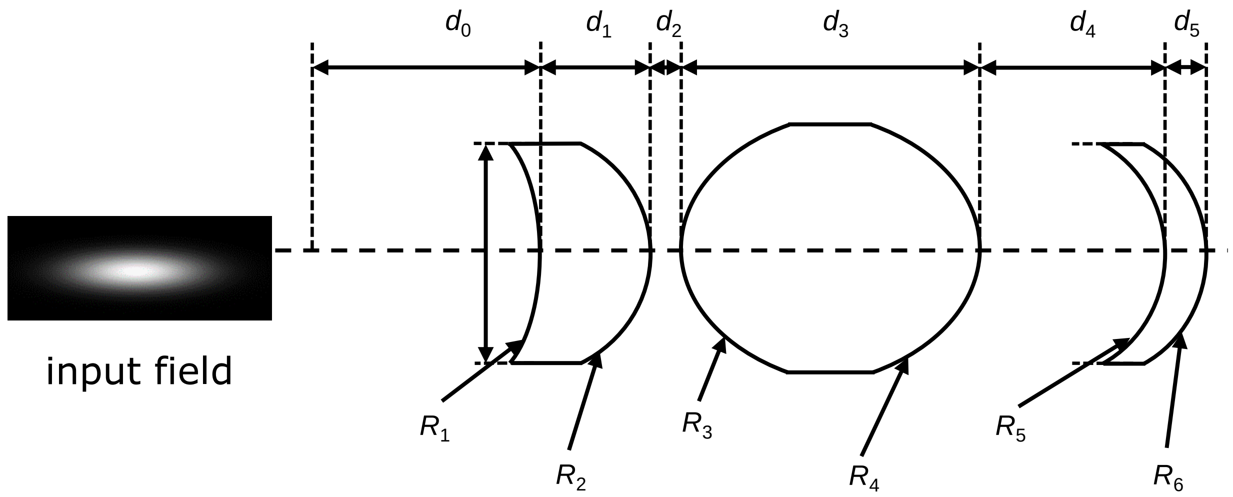
Optical Design Optimization

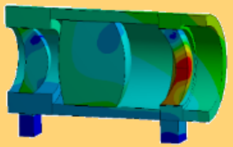
- Optimization objective:
  - Minimize *divergence angle* in x and y direction
  - Minimize *m²* to be close to 1 in x and y direction

- Constraints:
  - Thermal load shouldn´t interfere with *divergence* and *m²*

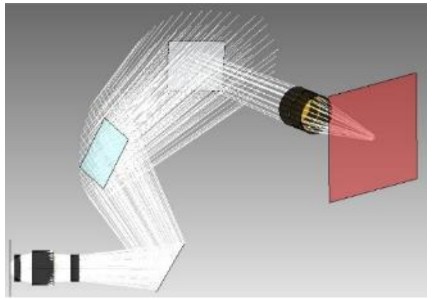


Thermo-Mechanical Design Optimization

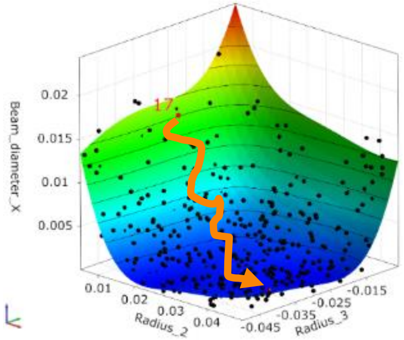
- <u>Innovation steps:</u>
  0. Improve optical design without optiSLang
  1. Use optiSLang for optical design optimization
  2. **Use optiSLang for thermo-mechanical design optimization**
  3. Use optiSLang for opto-thermo-mechanical design optimization



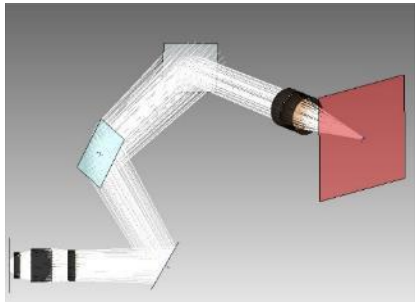
Thermo-mechanical analysis



Optical analysis

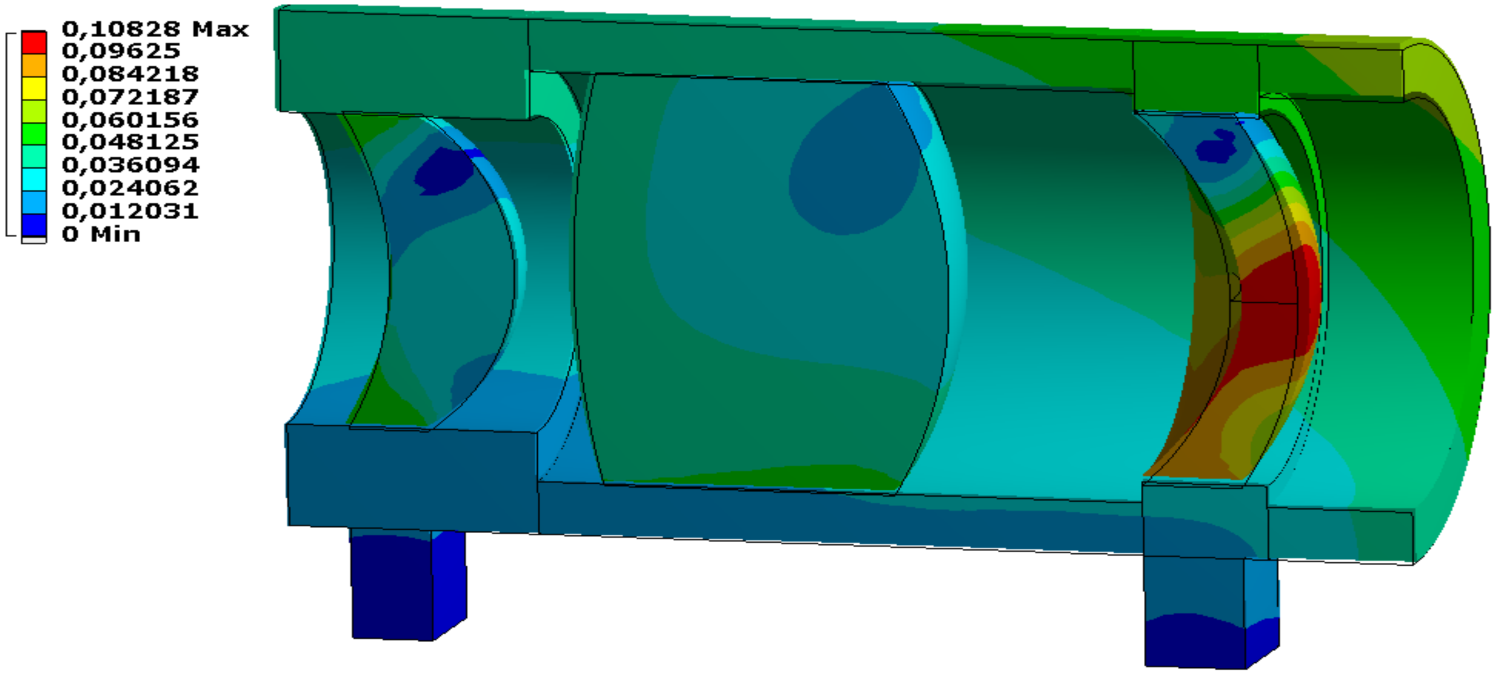


Design understanding with metamodeling and robust design optimization



Thermo-Mechanical Design Optimisation

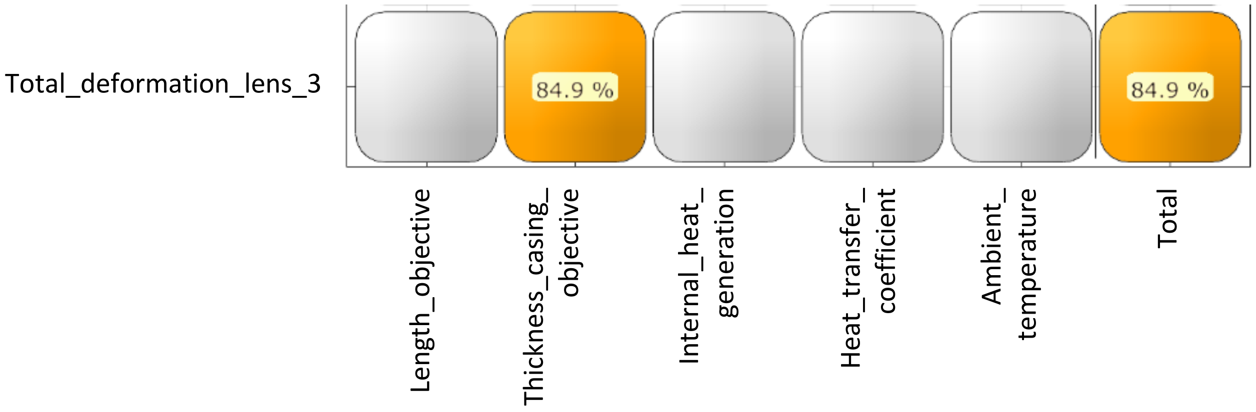
Static-structural analysis for the determination of lens deformations due to lens mounting and inhomogeneous temperature distribution



Simulation in Ansys Mechanical

Thermo-Mechanical Design Optimisation

Static-structural analysis for the determination of deformations due to lens mounting and inhomogeneous temperature distribution



Opto-thermo-mechanical design simulation

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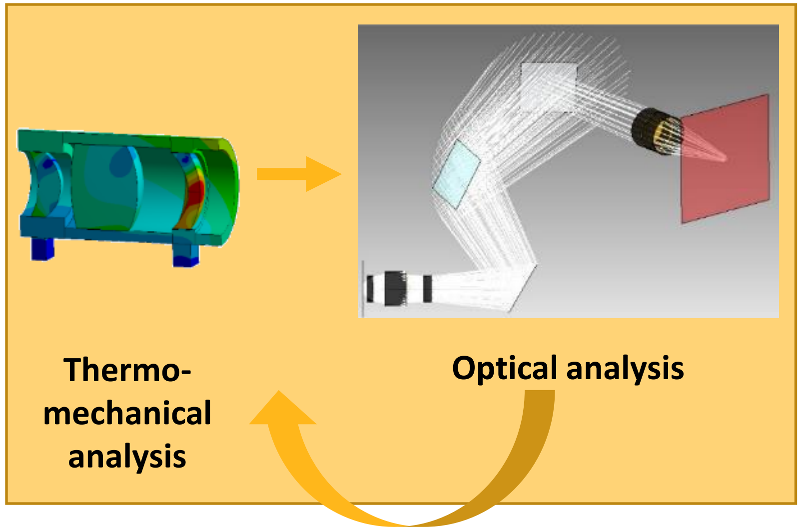
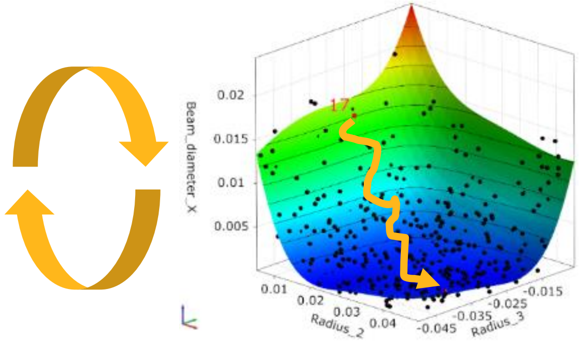
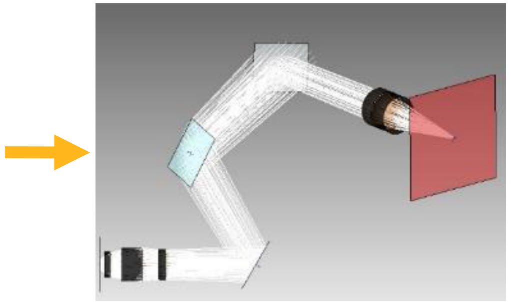
Opto-Thermo-Mechanical Design Optimization

- Innovation steps:
  0. Improve optical design without optiSLang
  1. Use optiSLang for optical design optimization
  2. Use optiSLang for thermo-mechanical design optimization
  3. **Use optiSLang for opto-thermo-mechanical design optimization**



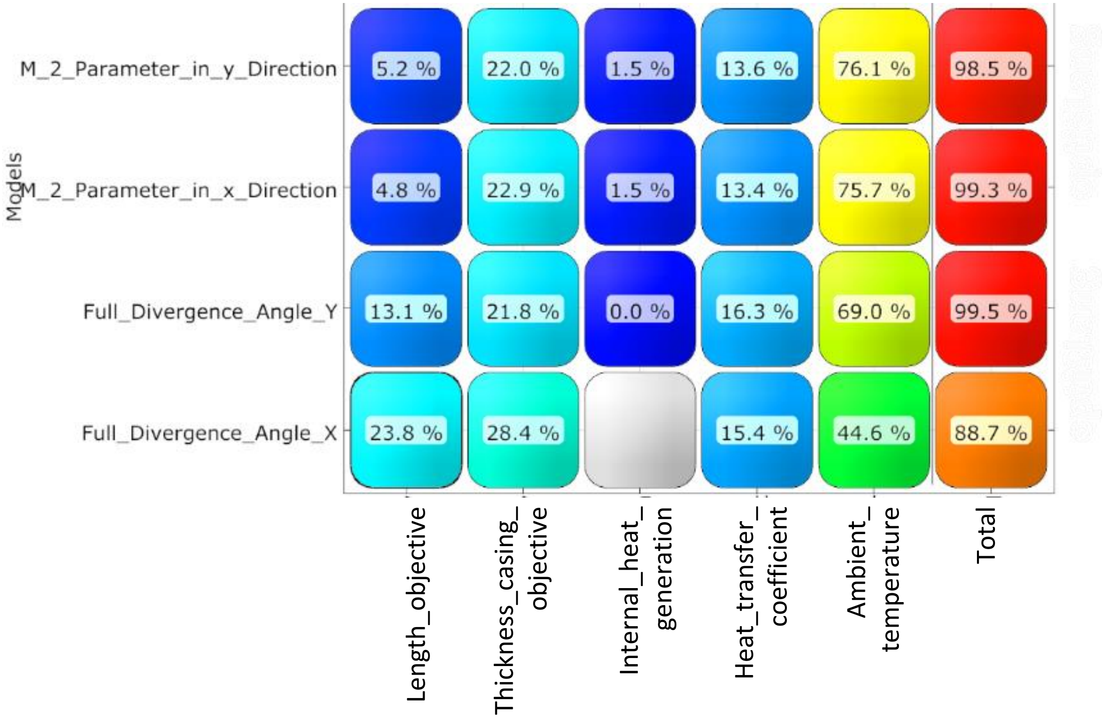


Design understanding with metamodeling and robust design optimization



Opto-Thermo-Mechanical Design Optimization

- Mechanical inputs to optical outputs show different influences compared to separate analysis of optical and thermo-mechanical design
  - **Local distribution of the deformation plays an important role!**
  - Not only maximum value of the deformation gives insights about the system behavior



Ansys Solution for Opto-Thermo-Mechanical simulation

Ansys SPEOS

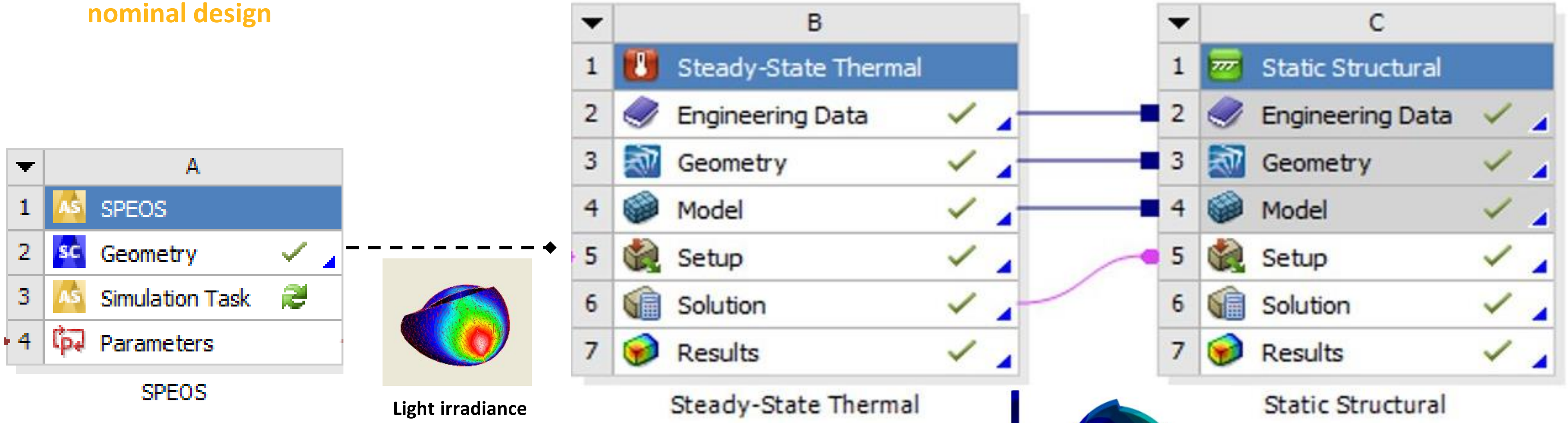
Optical simulation with nominal design

Ansys Mechanical

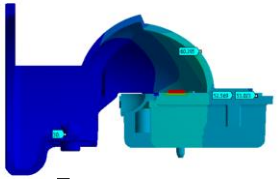
Thermal simulation

Ansys Mechanical

Structural simulation



Light irradiance (W/m2)

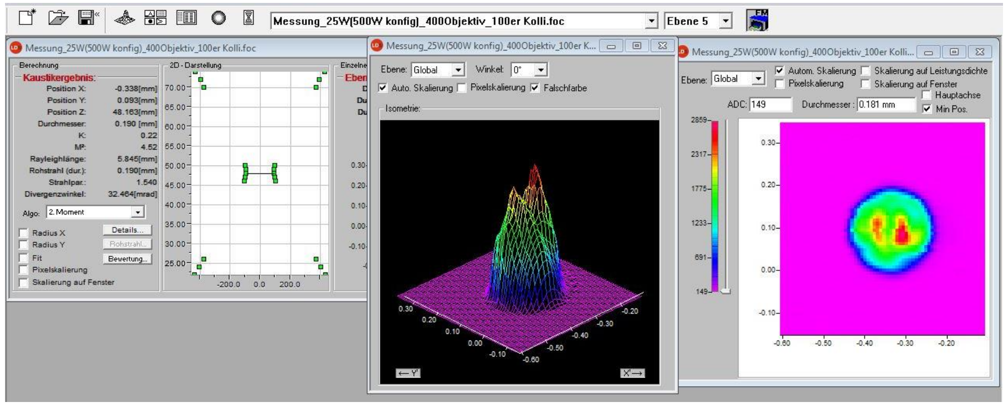


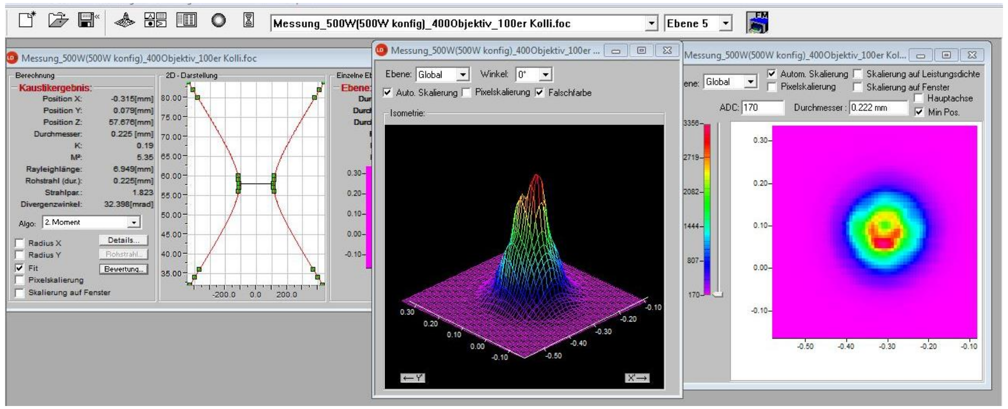
Temperature Distribution

- Ansys Workbench acts as Workflow manager to connect SPEOS and Mechanical
- Additionally, optiSLang can be used for Robust Design Optimization

Application: Laser Material Processing setup

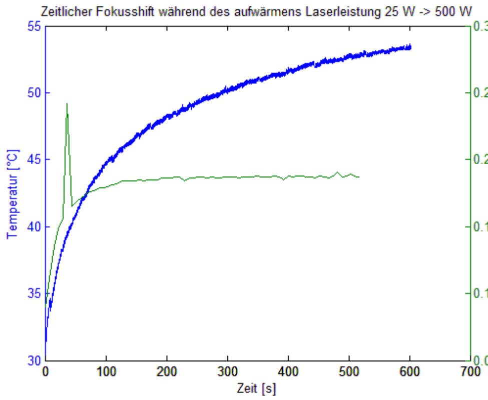
Measurement of thermal lens, beam caustic, focus shift

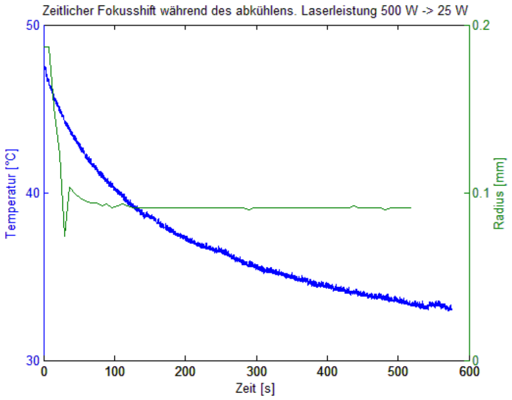




Beam caustic at 25W and 500W

→ Difference between both = Focus shift





With courtesy of Andreas Hopf,
Ernst Abbe University of Applied Sciences Jena

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Die BMBF-Innovationsinitiative Neue Länder

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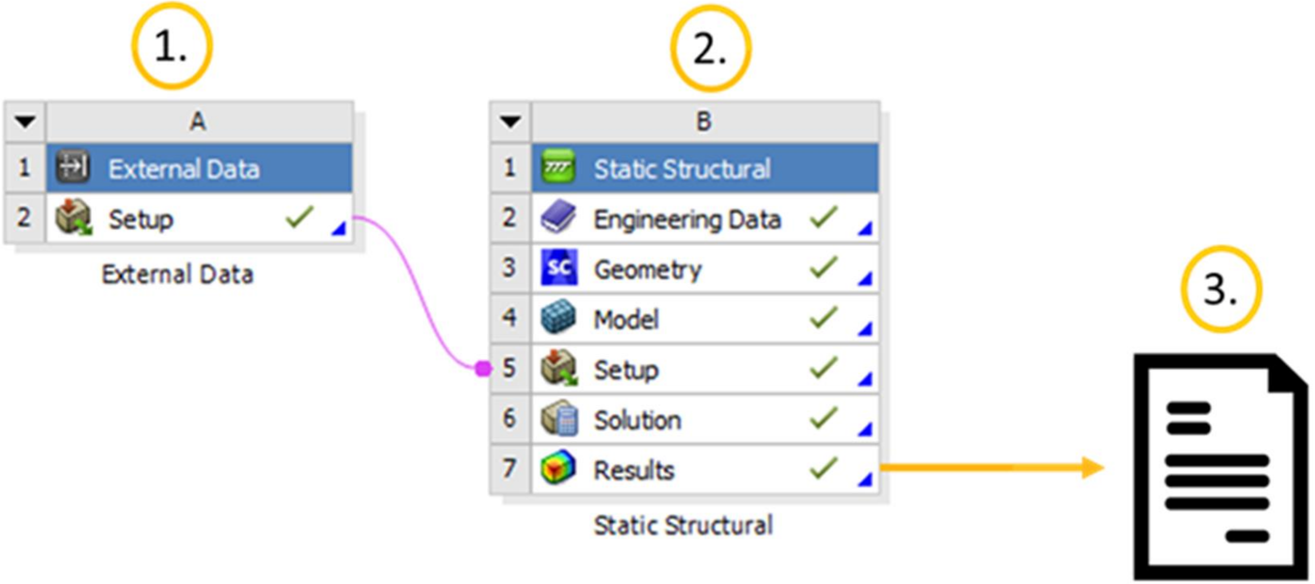
Calculation of focus shift with thermo-mechanical analysis Workflow in Ansys Workbench

1. Reading measurement data (temperature profile of the lens)
2. Mechanical analysis
3. Export of the deformed lens geometries in ASCII format (= input for optical analysis)



With courtesy of Tino Dannenberg
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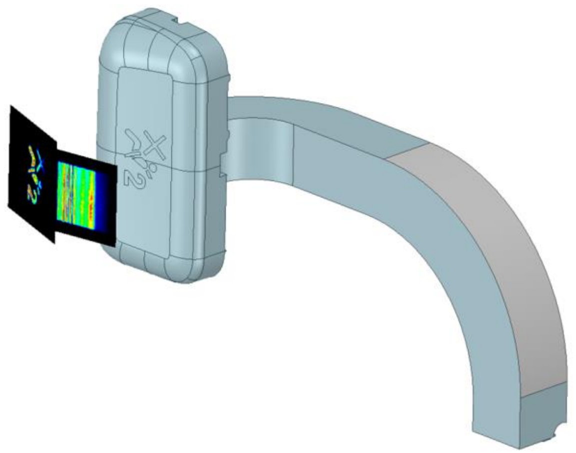
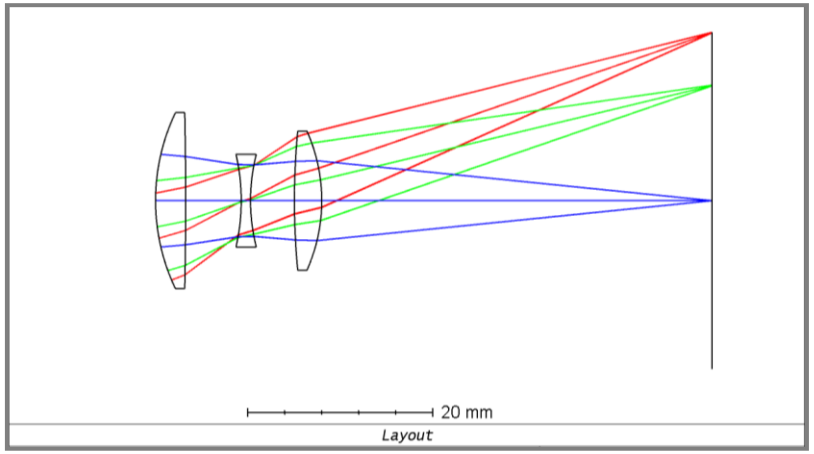
optiSLang Tutorials with optics solvers

- SPEOS:
  - Lightguide
  - SPEOS for NX and Ansys SPEOS (Workbench)
  - Sensitivity Analysis & Optimization
  - Ansys Learning Hub



- Zemax OpticStudio:
  - Cooke Triplet
  - Sensitivity Analysis & Optimization
  - available on request



Q&A

What questions do you have?

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Please use Chat function or unmute yourself

Ansys

Thank you for your attention!

Ansys

Stephanie Kunath

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