Design understanding with DOE as part of the virtual optics development process

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Sabrina Niemeyer, M. Eng. / Ansys

Sabrina Niemeyer

Biography

- Application Engineer
- Working for Ansys since 2021
- Responsible for Ansys optiSLang automation projects in the field of optics and mechanics
- Background: Optical Engineering, Automation

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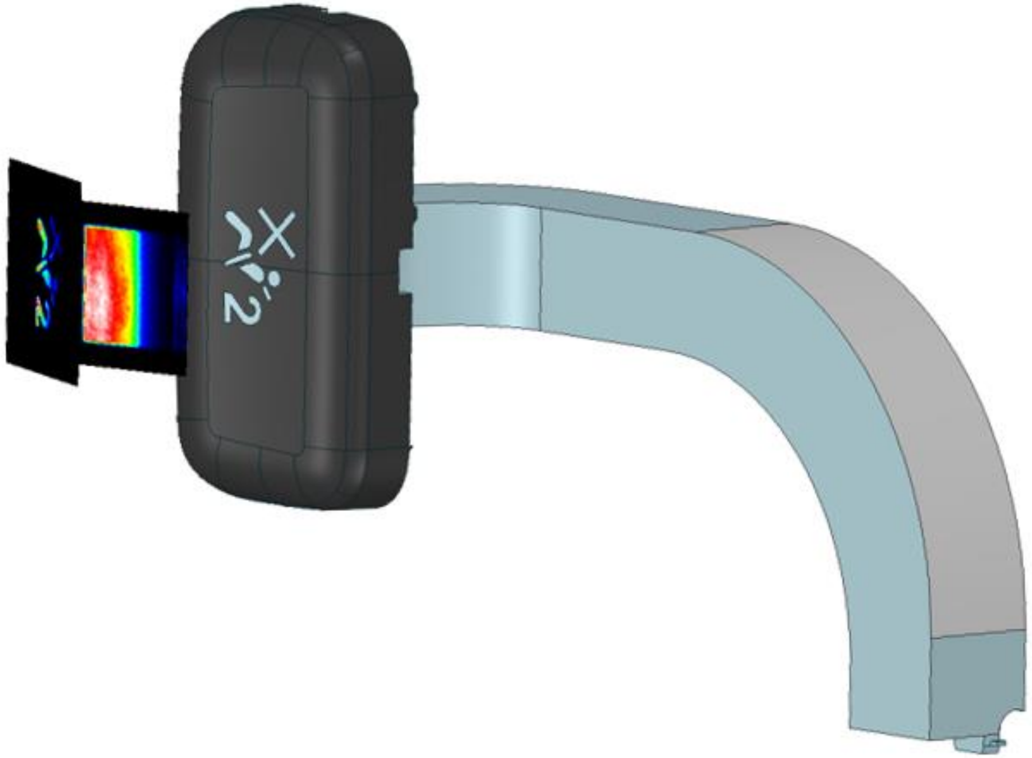
Sabrina.Niemeyer@ansys.com

Objective

- Generation of design understanding for the light guide of an airbag control light to optimize the homogeneity of the luminance distribution in 0° and 30°
  - Transparency of the optimization process by simulative and statistical methods
  - Saving time, human & material resources

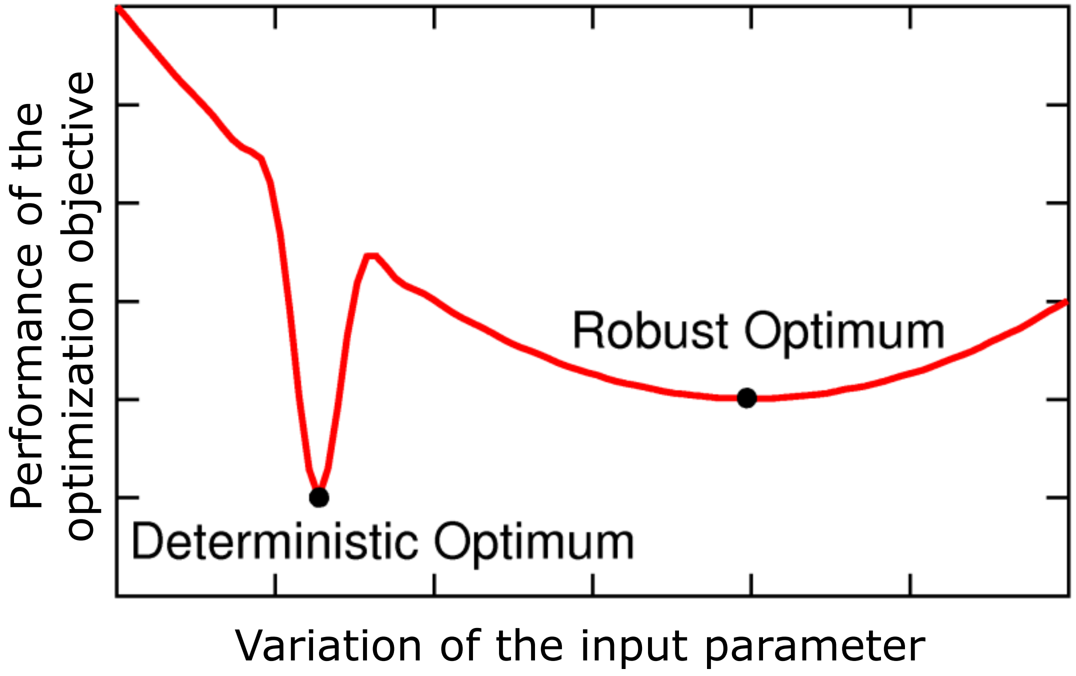


Motivation

- Adaptation to current requirements
  - Short product development times
  - High demands on performance and robustness
- Complex optimization process of optical systems
  - High complexity regarding a high number of parameters or elements and production characteristics
  - Interacting, non-linear input parameters
- Classical procedures
  - Often not effective for multiple dimensions, correlations or interactions between parameters, or non-linear behavior
  - No transparency of the optimization process and further possible solutions

State-of-the-art

- Gradientbased method (*Damped Least Squares*)
  - 1 solution
- Evolutionary Algorithm
  - Multiple solutions
- No transparency regarding
  - The approach
  - Existence of further suitable solutions
- Optimization regarding the performance without consideration of robustness

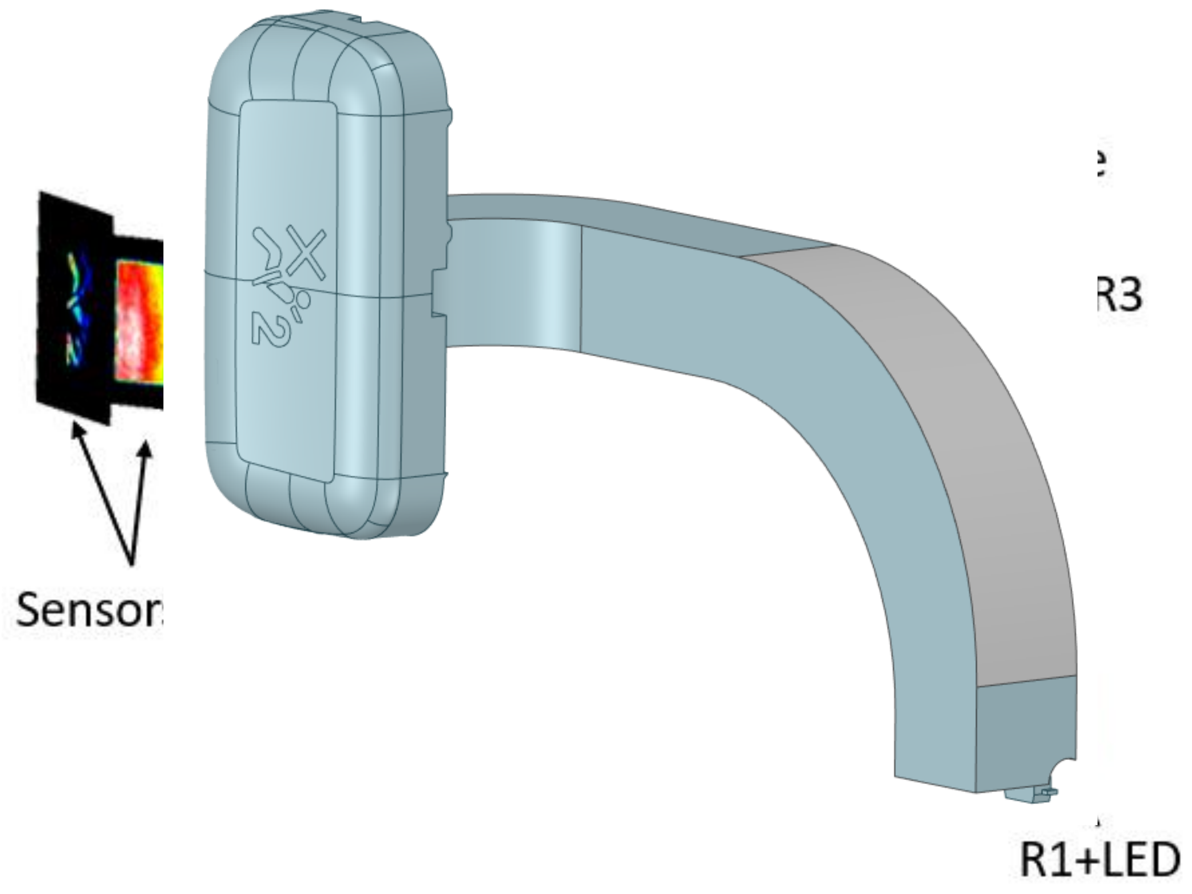


Reference Design

- An optical analysis of a light guide is performed in Ansys SPEOS with Ansys optiSLang
- **Aim:** obtain a homogeneous lit appearance, represented by RMS contrast, detected in 0° and 30°

$$RMS\ contrast = Var.coeff. = \frac{\sigma}{\bar{L}}$$

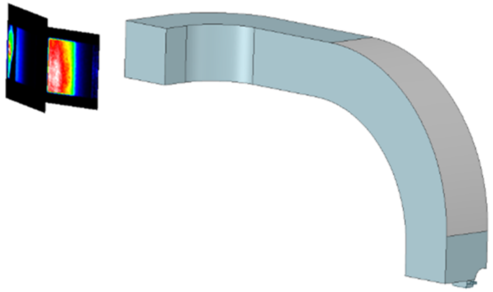
- Optimize the shape of the light guide to get the best RMS contrast

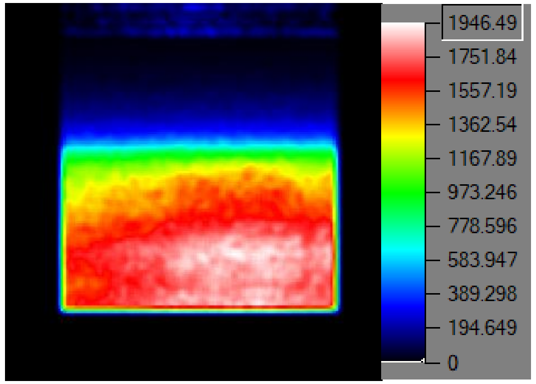


Reference Design

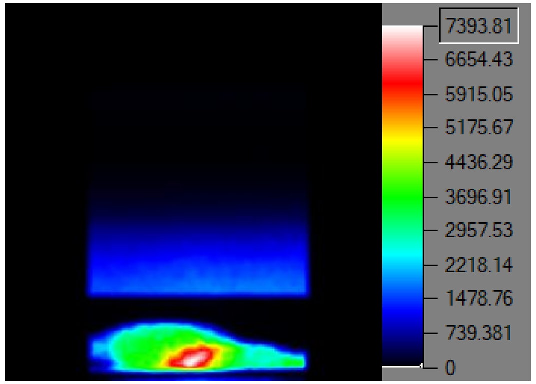
	0°	30°

Light Guide



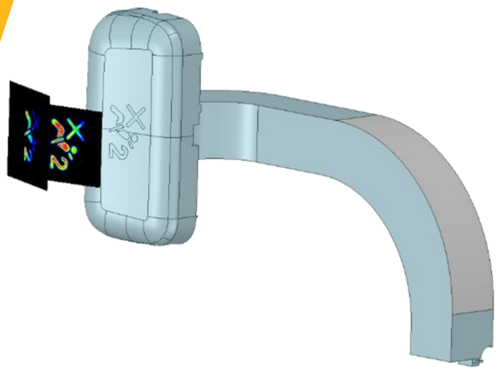


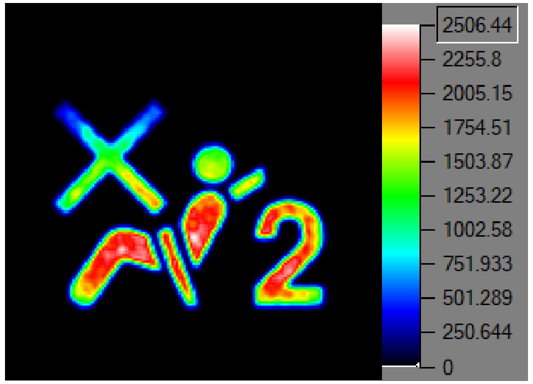
RMS = 0,7 $\bar{L} = 1005 \ \frac{cd}{m^2}$



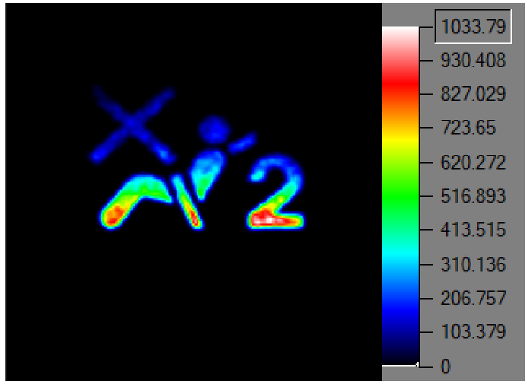
RMS = 1,24 $\bar{L} = 474 \ \frac{cd}{m^2}$

Symbol





RMS = 0,83 $\bar{L} = 906 \ \frac{cd}{m^2}$



RMS = 1,15 $\bar{L} = 197 \ \frac{cd}{m^2}$

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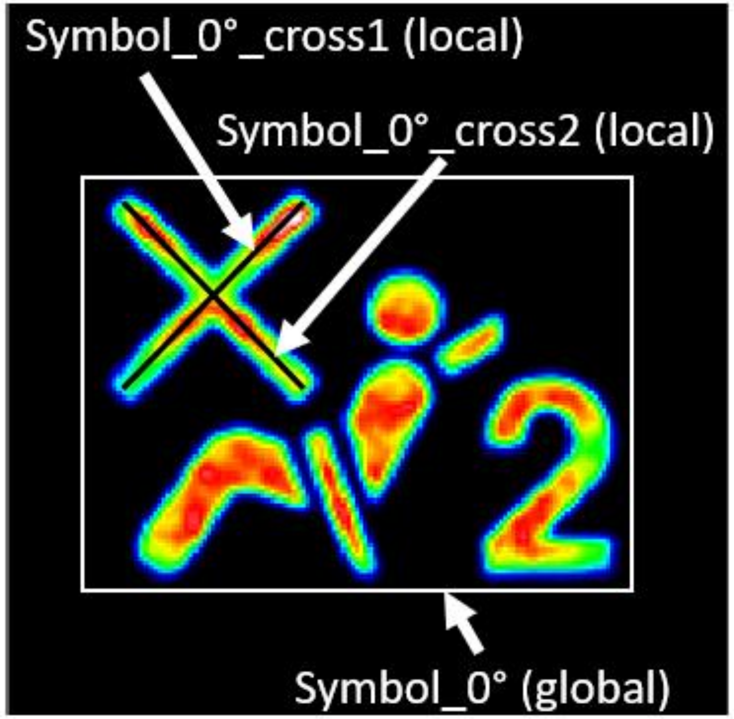
Process Integration

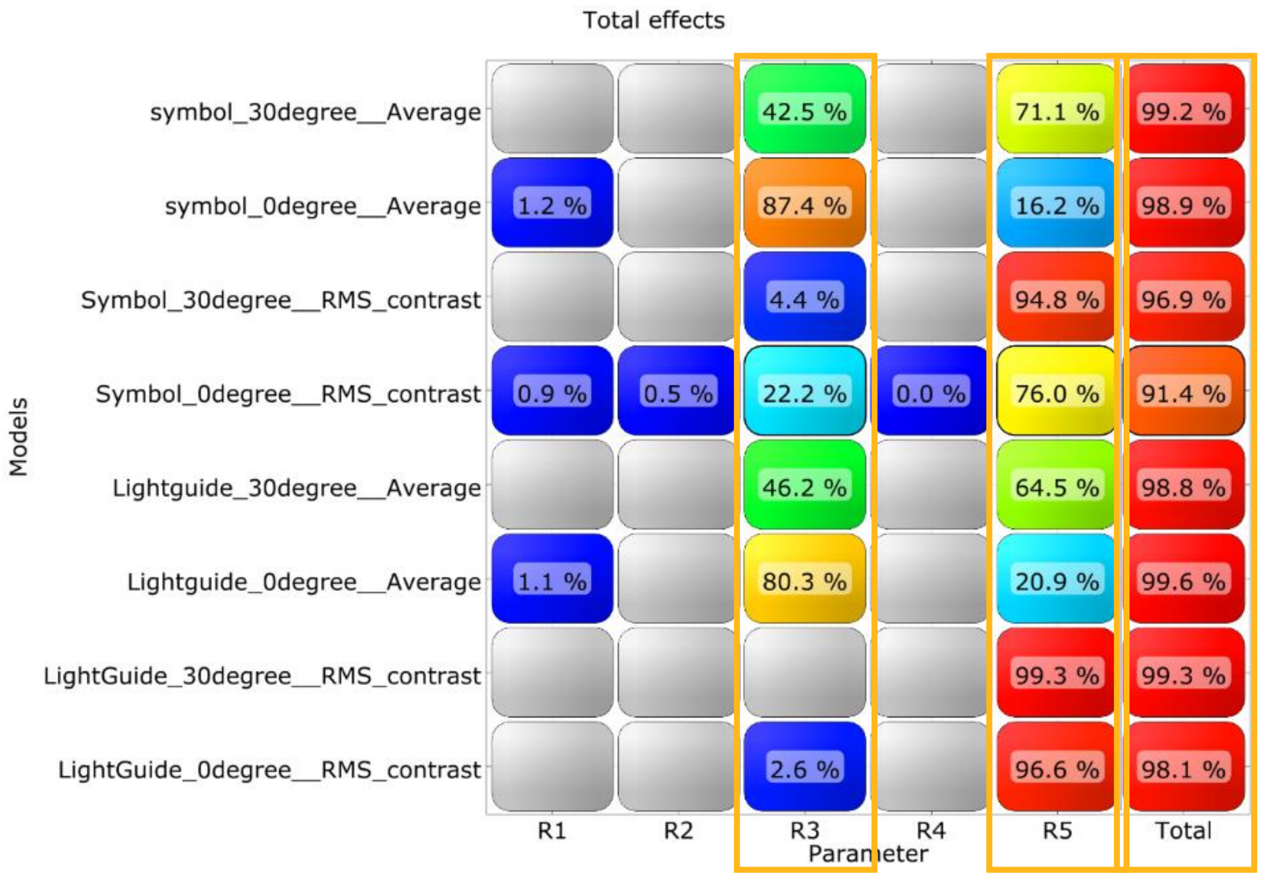
- Evaluation of the luminance distribution with responses
  - RMS contrast
  - Average
- Simulation of 100 designs
- Analysis based on $2 \cdot 10^8$ rays
- Parameter ranges
  - R1 – Radius: [0.1 – 1 mm]
  - R2 – Radius: [5 – 14 mm]
  - R3 – Radius: [1 – 20 mm]
  - R4 – Radius: [1.1 – 5 mm]
  - R5 – Radius: [4 – 16 mm]



Sensitivity Analysis - Results

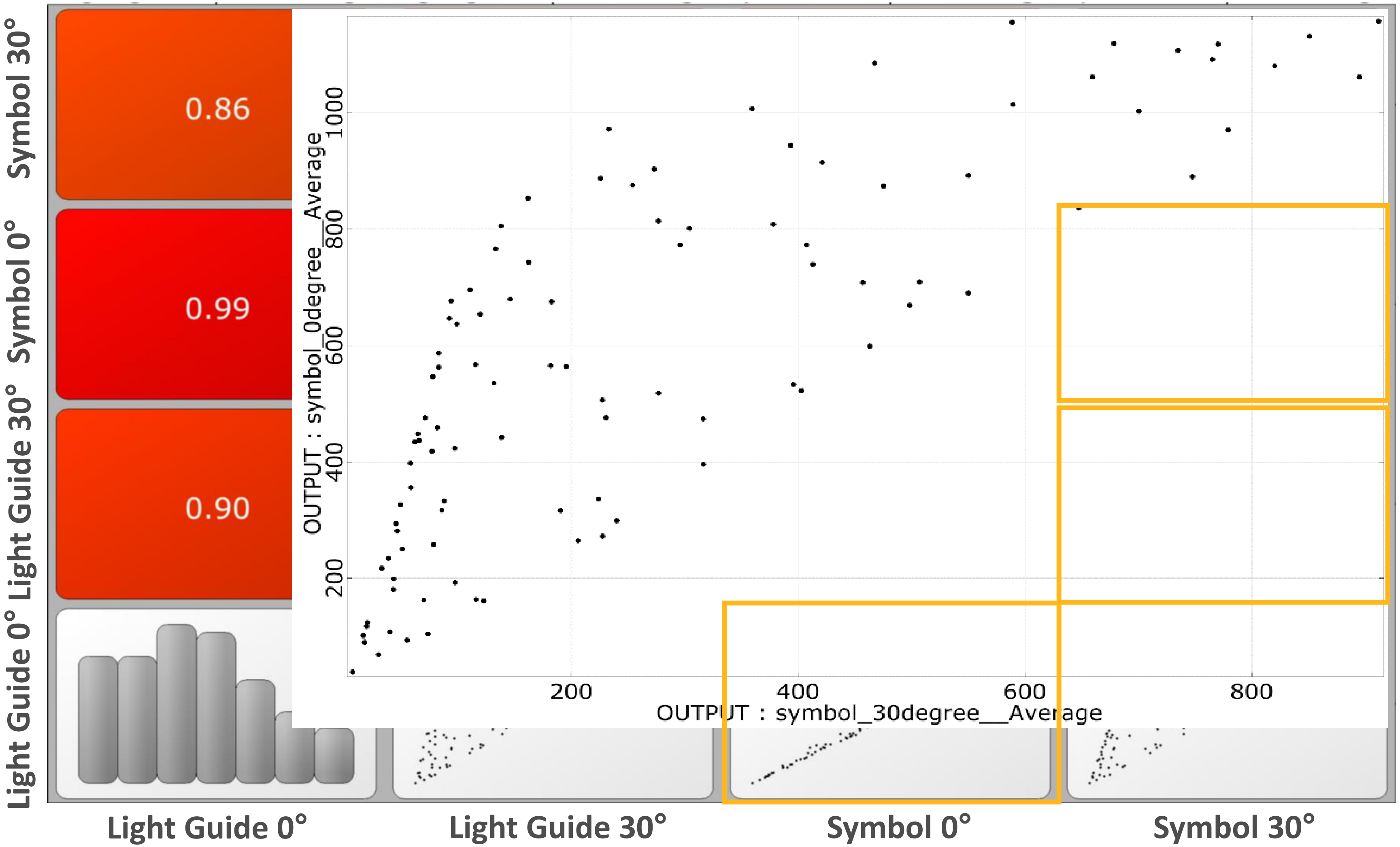
- CoP – measures how good regression generalizes for unknown data
- Very high model accuracy
- R3 and R5 most important parameters

→ Reduction of the number of parameters from five to two important inputs



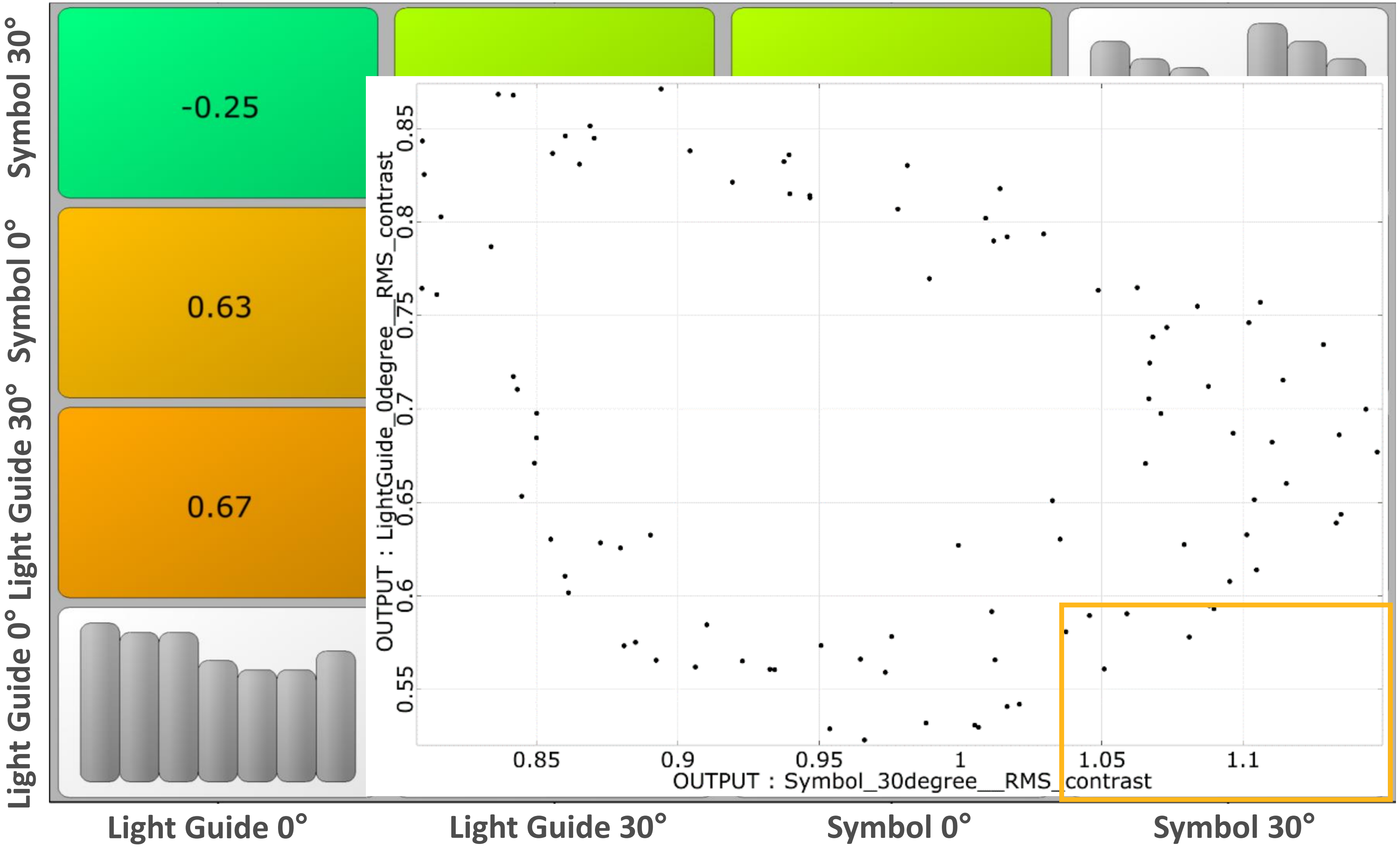
Sensitivity Analysis - Results

- Correlation Matrix of the Average



Sensitivity Analysis - Results

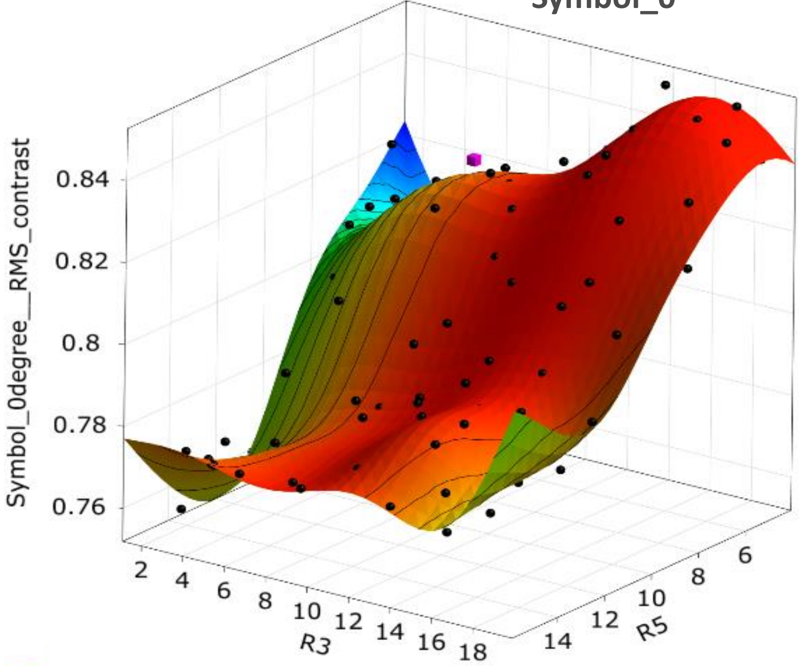
- Correlation Matrix of the RMS contrast



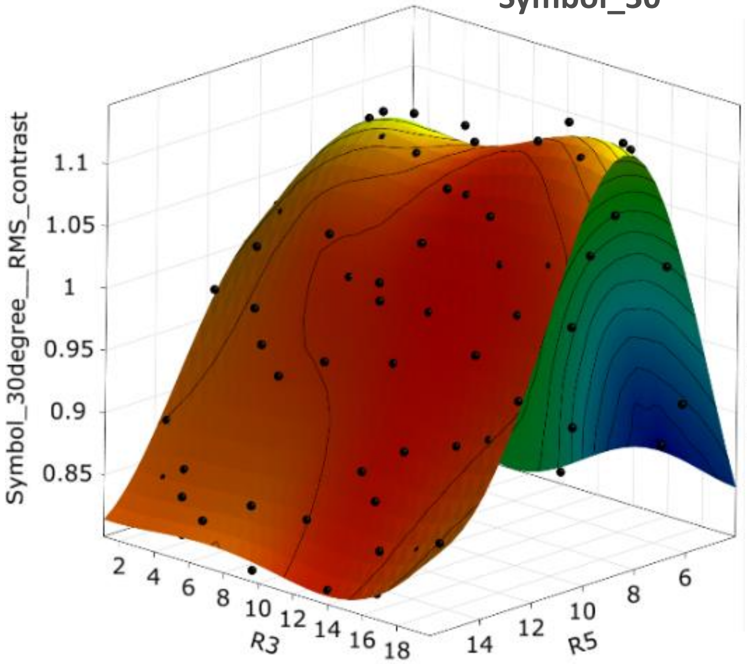
Sensitivity Analysis - Results

- Metamodel of optimal Prognosis (MOP)
  - Best fitting approximation of response variables depending on most important parameters
  - Interactions between R3 und R5
  - Different positions of minima

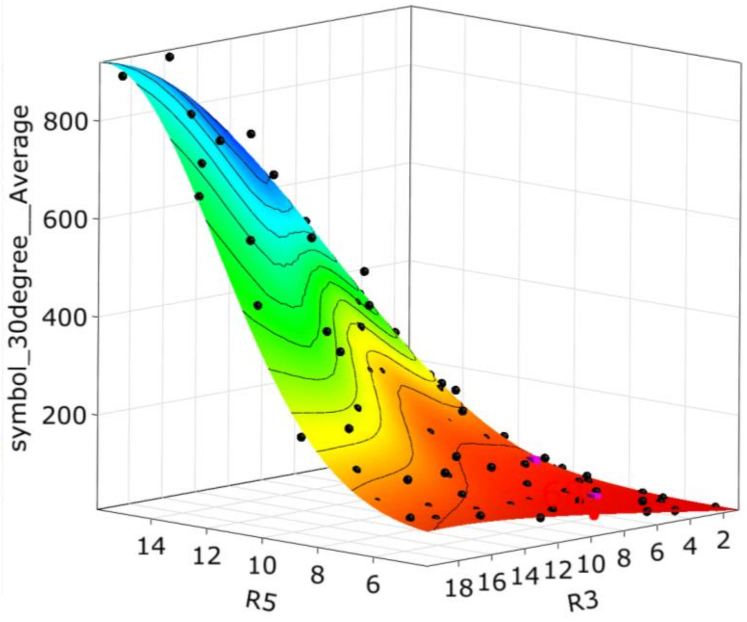
RMS Contrast$_{Symbol_0°}$



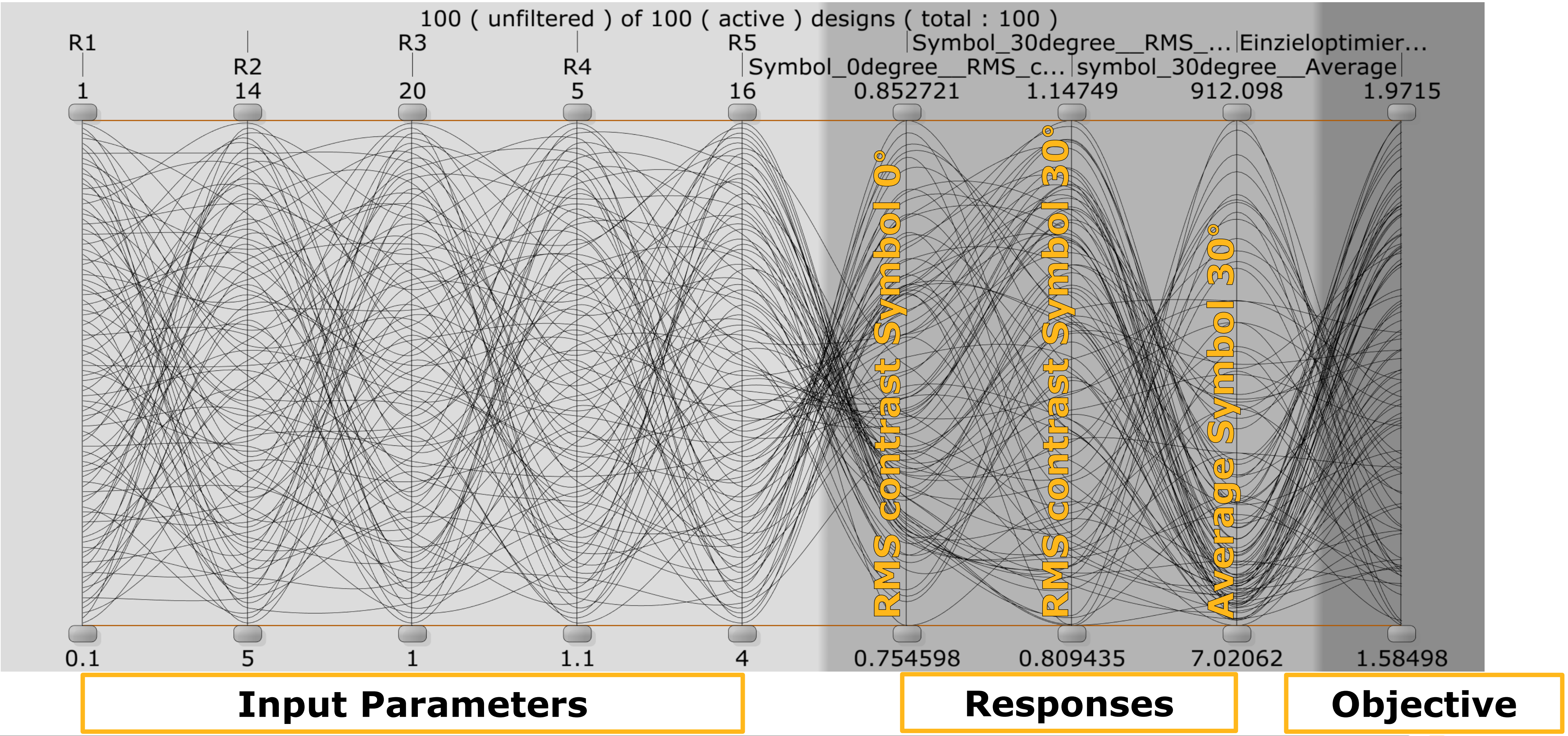
RMS Contrast$_{Symbol_30°}$



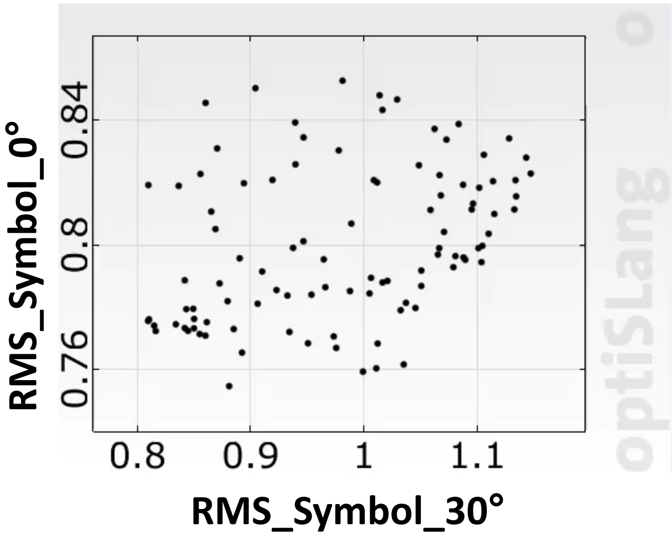
Average$_{Symbol_30°}$

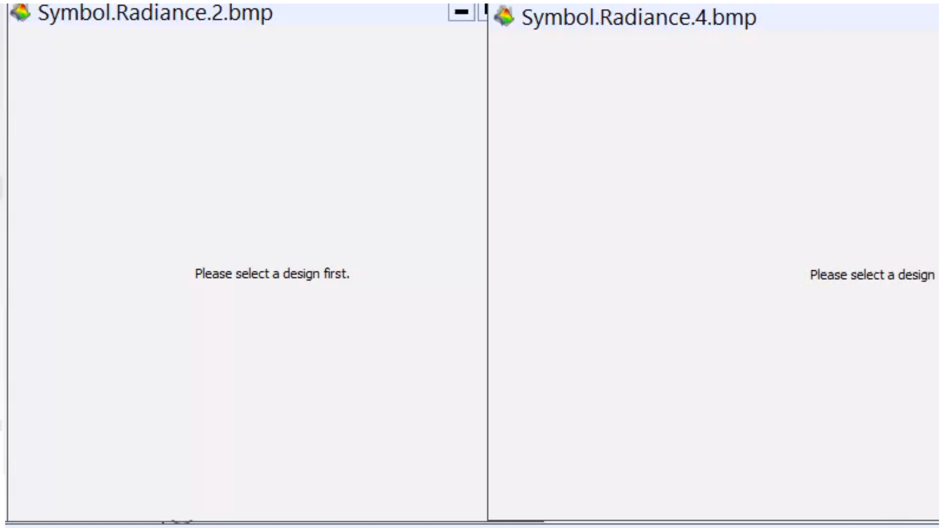


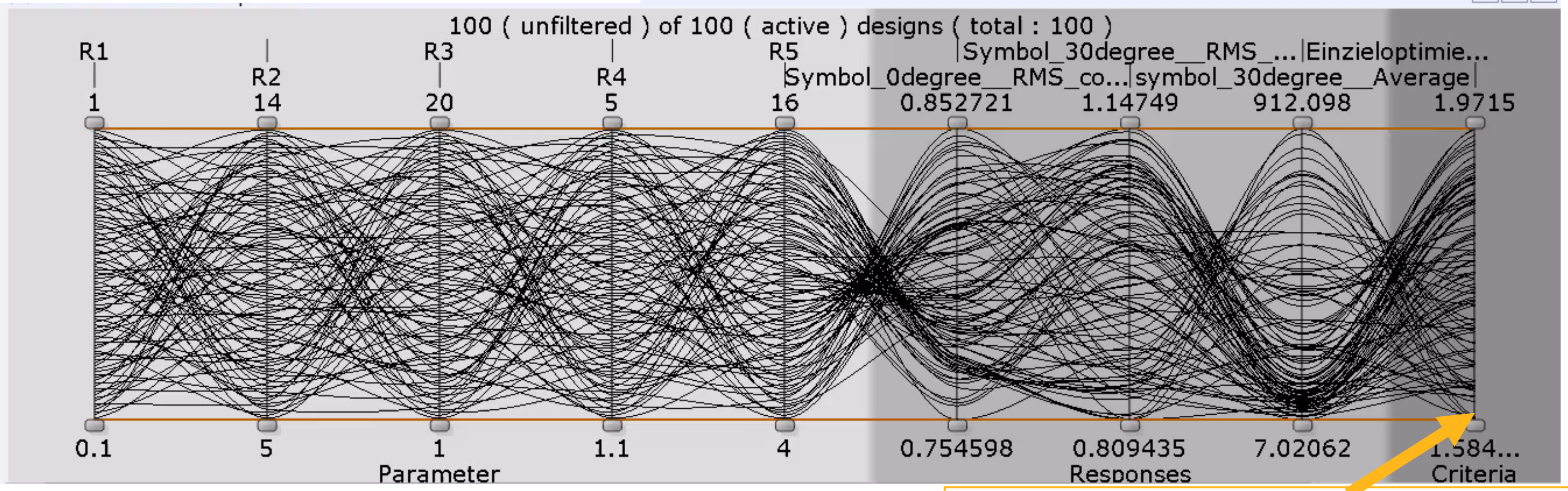
Sensitivity Analysis - Results



Sensitivity Analysis - Results



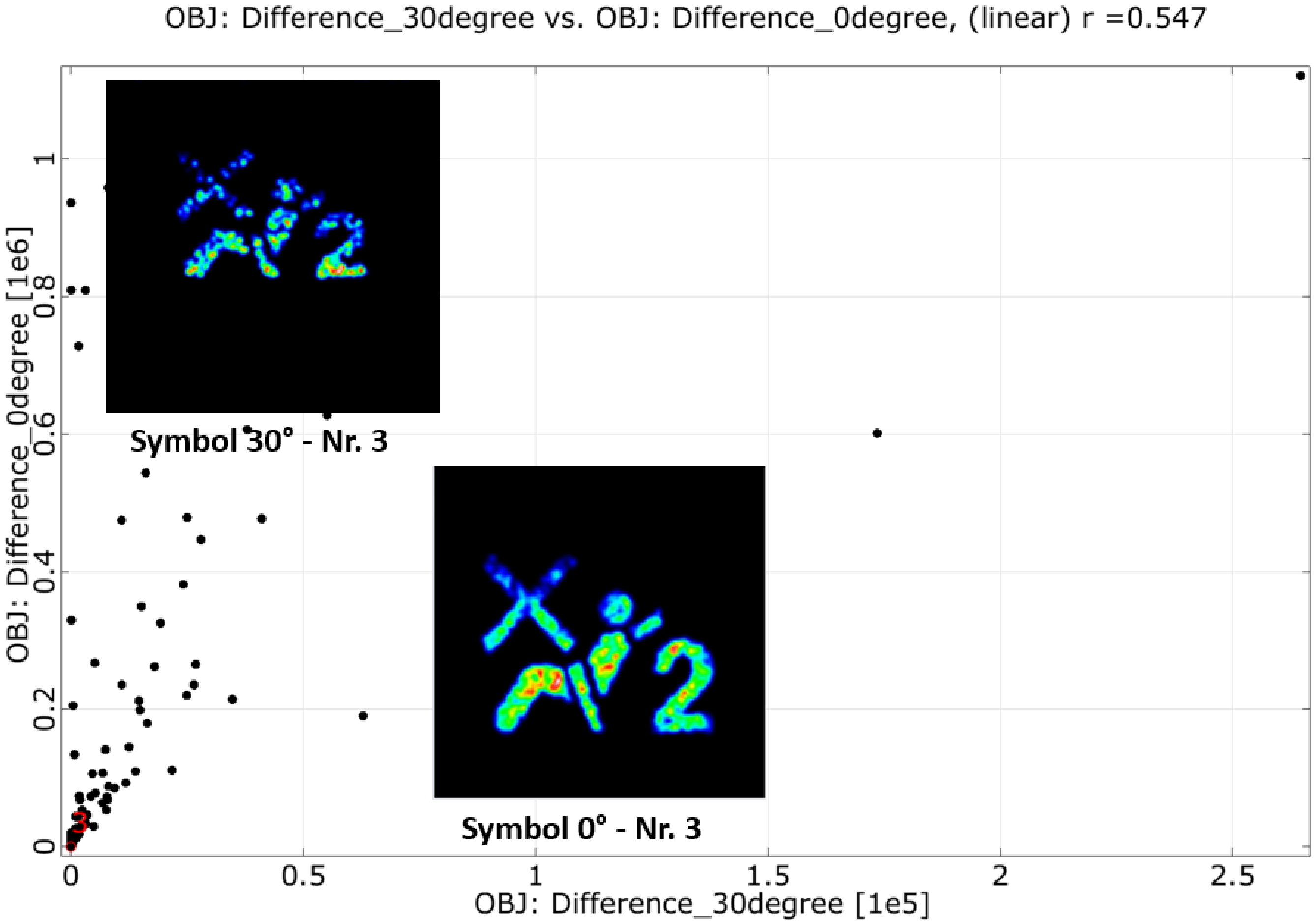




RMS_Symbol_0° + RMS_Symbol_30° → min

Sensitivity Analysis - Results

$$\text{Difference\_0°} \rightarrow \min$$
$$\text{Difference\_0°} = (\text{Average}_{\text{Symbol\_0°}} - \text{Average}_{\text{Symbol\_0°\_cross1}})^2$$



$$\text{Difference\_30°} \rightarrow \min$$
$$\text{Difference\_30°} = (\text{Average}_{\text{Symbol\_30°}} - \text{Average}_{\text{Symbol\_30°\_cross1}})^2$$

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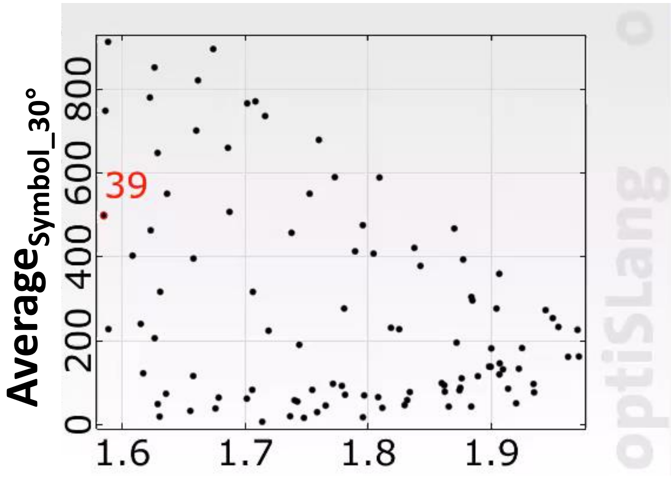
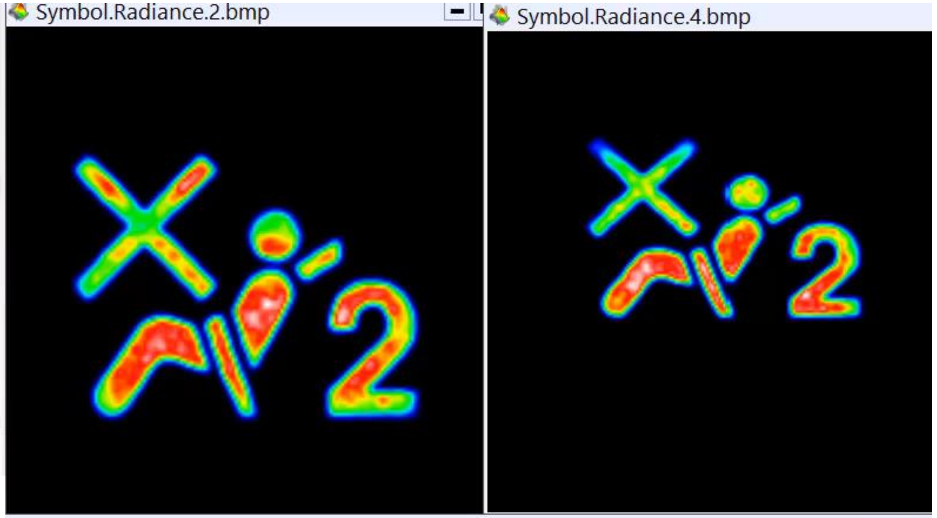
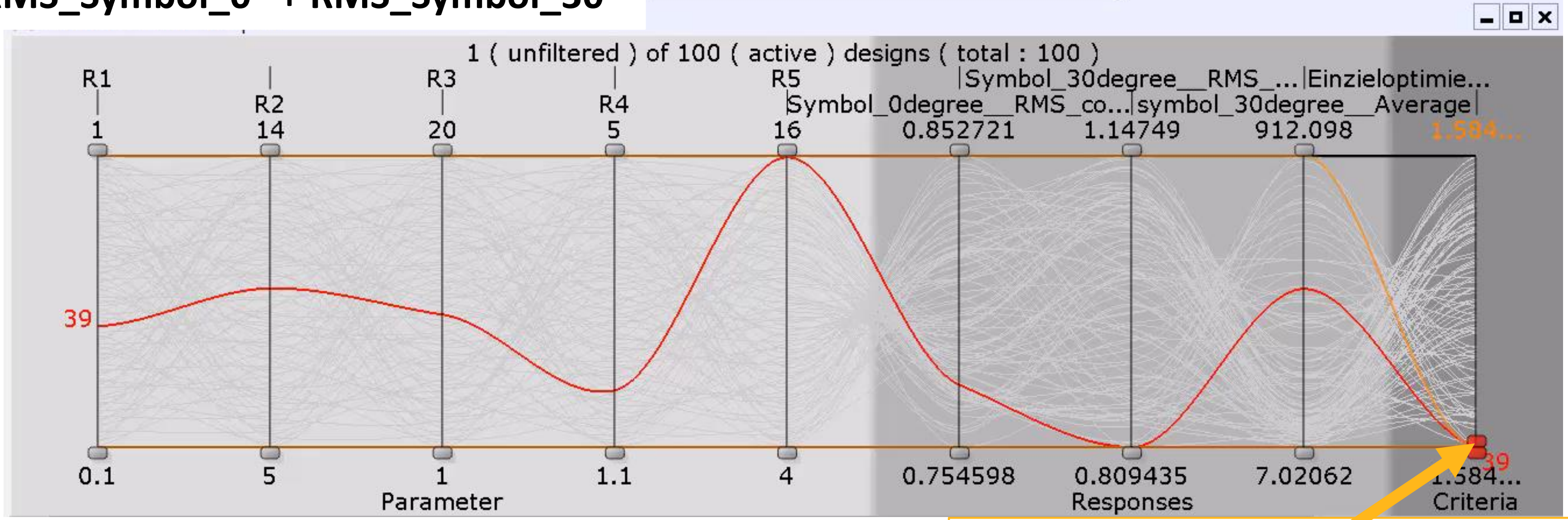
Sensitivity Analysis - Results

$$\bar{L} \geq 300 \frac{cd}{m^2}$$



RMS_Symbol_0° + RMS_Symbol_30°





RMS_Symbol_0° + RMS_Symbol_30° → min

Interim conclusion

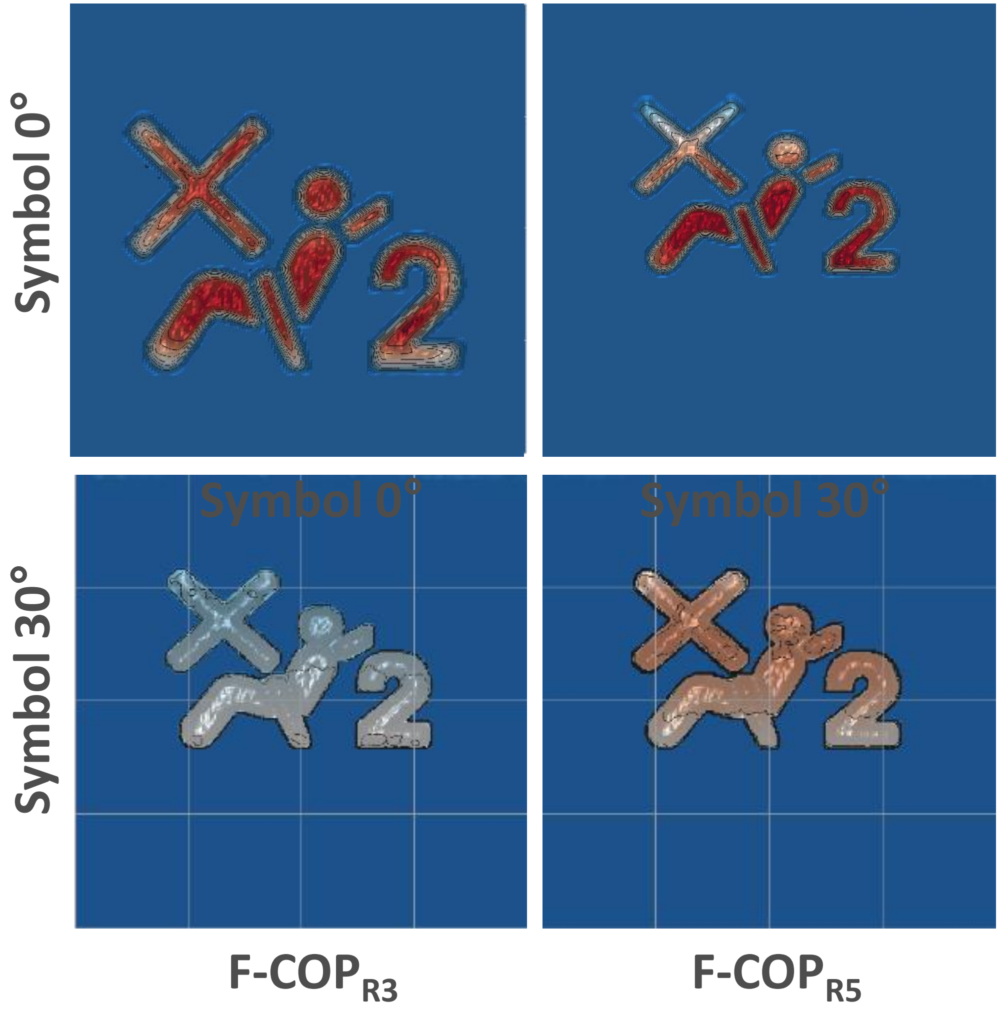
- Sensitivity Analysis – calculation of 100 designs
  - RMS contrast usable for a basic homogenization
  - Single extremes of local luminance persist
  - No conclusion about local luminance possible with single scalar value
  - Reduction of design complexity:
    - 2 of 5 input parameters have to be considered for optimization
    - 3 of 8 global responses used for defining the criteria

$$\text{RMS contrast}_{\text{Symbol\_0°}} + \text{RMS contrast}_{\text{Symbol\_30°}} \rightarrow \text{min.}$$

$$\text{Average}_{\text{Symbol\_30°}} \geq 300\ \text{cd/m}^2$$

Field-dependent homogeneity evaluation

- Analysis of spatially and temporally distributed data like FEM data or signals
- Analysis of the parameters influence & position with F-CoP
- Evaluation of local luminance variations in the measurement range to account for local luminance extremes
- Local luminances most influenced by variation of R3 and R5
- Very good approximation quality:
  - Symbol 0°: F-CoP_{total} = 97 %
  - Symbol 30°: F-CoP_{total} = 96 %

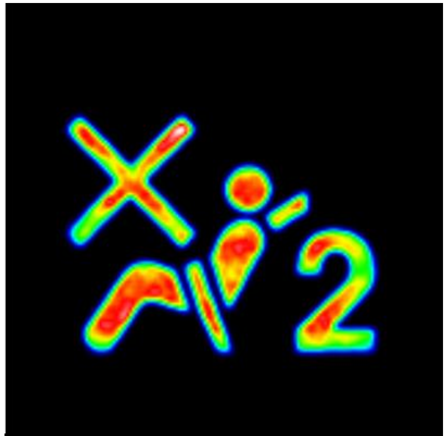


Methods Comparison

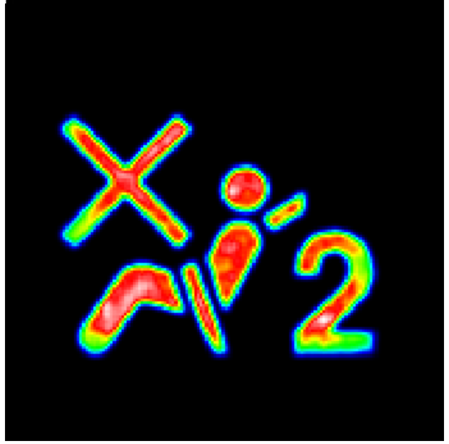
Symbol 0°

Symbol 30°

Scalar optimized with Ansys optiSLang (startdesign from Sensitivity Analysis)

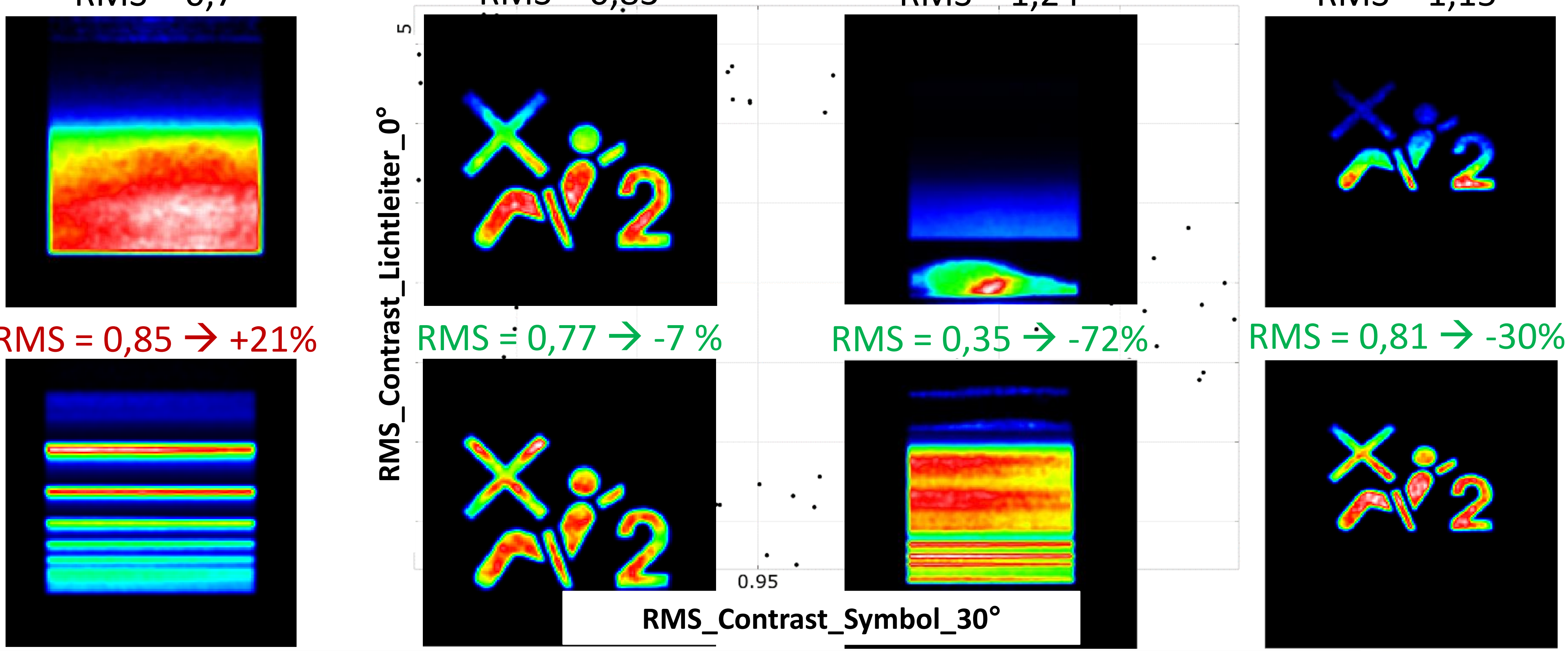


Spacially optimized with Ansys Statistics on Structures



Optimization

	Light Guide 0°	Symbol 0°	Light Guide 30°	Symbol 30°
Ref. design	RMS = 0,7	RMS = 0,83	RMS = 1,24	RMS = 1,15
Opt. design	RMS = 0,85 → +21%	RMS = 0,77 → -7 %	RMS = 0,35 → -72%	RMS = 0,81 → -30%



Summary

- Determination of correlations and interactions for better design understanding
- Transparent optics development process
- Particularly suitable for gaining a fundamental understanding of complex facts
- Solutions independent of experience
- Design selection in terms of performance potential and sensitivities for optimized and robust design at the same time
- Added information value with reduced number of designs → save computation time, resources and costs

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Thank you