Ansys optiSLang

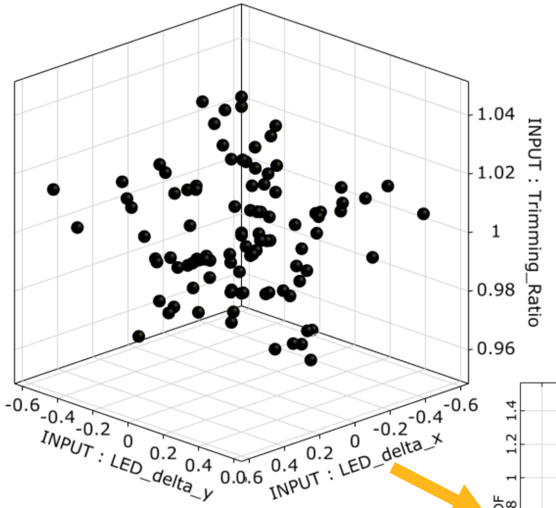
Tutorial: Robustness evaluation of a prismatic light guide (headlamp)

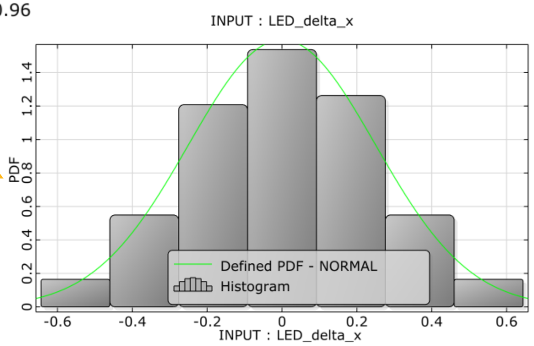
Release 2023 R2

Ansys

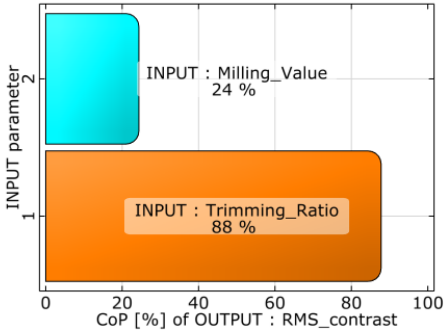
What is a Robustness Analysis?

The Robustness Analysis in optiSLang creates **a design of experiments based on the statistical distribution of the input parameters** due to manufacturing tolerances (scattering parameters). Speos evaluates those designs.

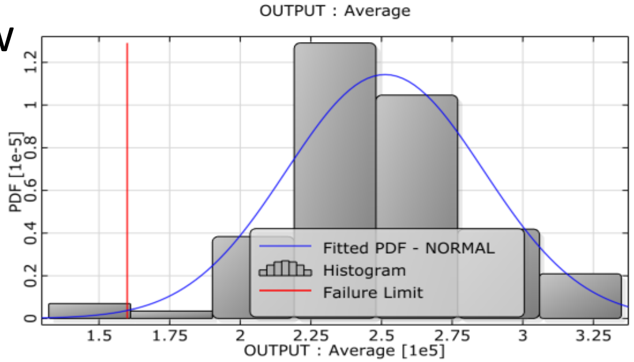




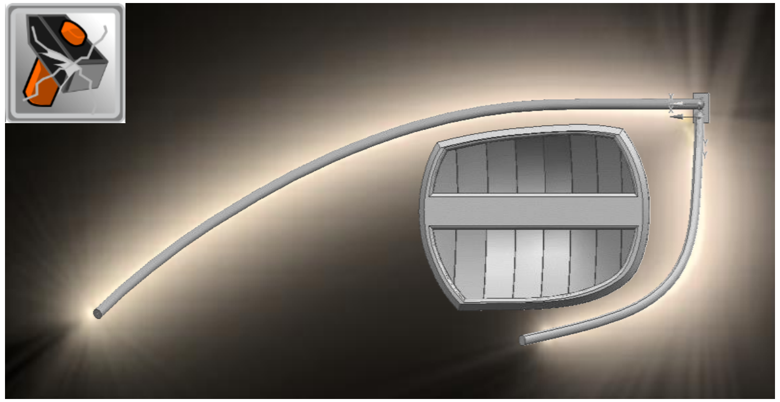
- optiSLang determines which input parameter's tolerances have the largest impact on the device response
  → **"Which tolerance must be improved to increase the optical performance?"**



- The Robustness Analysis will show the statistical distribution of the device response due to the manufacturing tolerances.
  → **"What percentage of fabricated devices will not meet the required design goal / will not fulfill the regulations?"**



Task Description

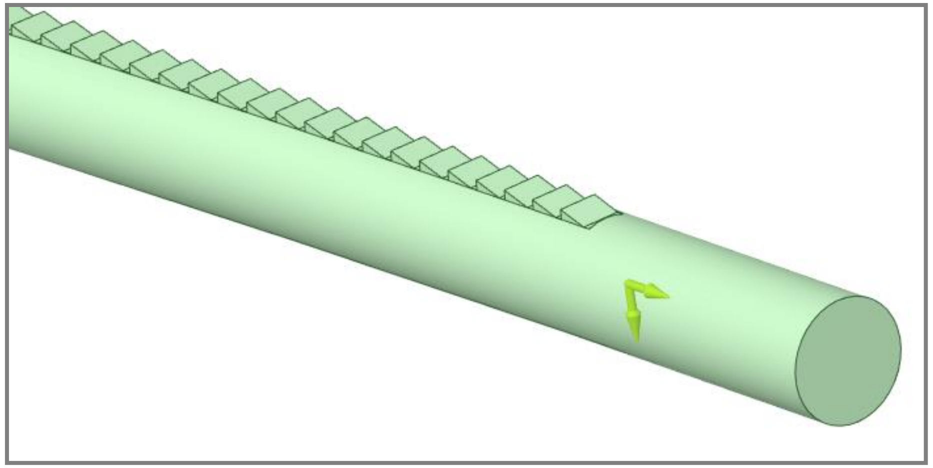


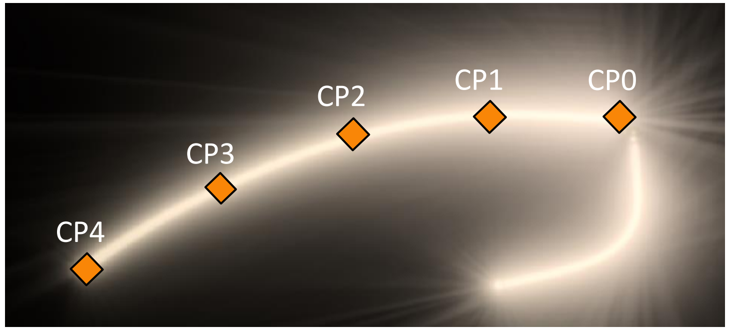
- In this example, we will use **Ansys Speos and Ansys optiSLang to analyze the robustness of a prismatic light guide and quantify the failure rate due to production tolerances in an automated way.**
- We will understand **which tolerances lead to regulation fails** for the automotive Day-Time-Running Lights **and which tolerances must be improved to increase the optical performance**. Additionally, we will evaluate the scattering of the homogeneity (RMS-contrast) and the lit appearance (average luminance) to see what the worst design looks like due to tolerances.
- This tutorial looks deeper into:
  - **Speos Workflow** creation
  - **Robustness Analysis**
    (also known as **Tolerance analysis** or **Design Quality Analysis**)

Light Guide Tolerance Parameters

For the Robustness Analysis the following scattering input parameters (tolerances) are considered:

- trimming ratios of the prisms
- milling value of the prisms
- energy of the light source
- position of the light source

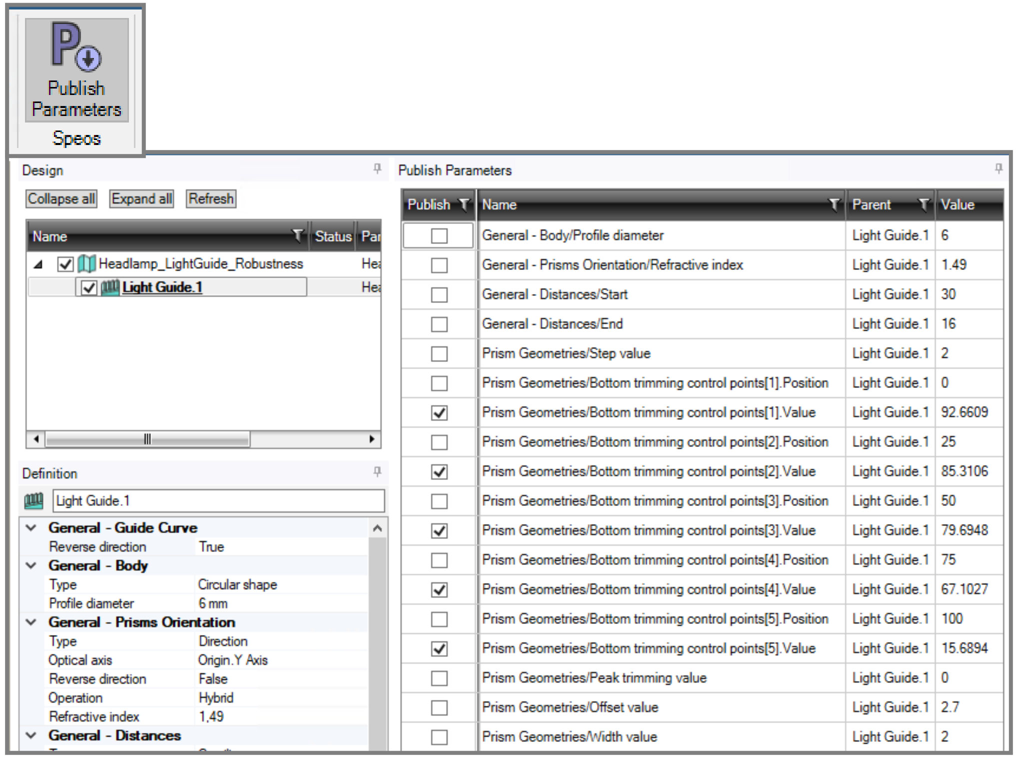




Model preparation in Ansys Speos

Ansys SPEOS Setup

For variation analyses with optiSLang it is necessary to publish parameters in the Speos simulation model:

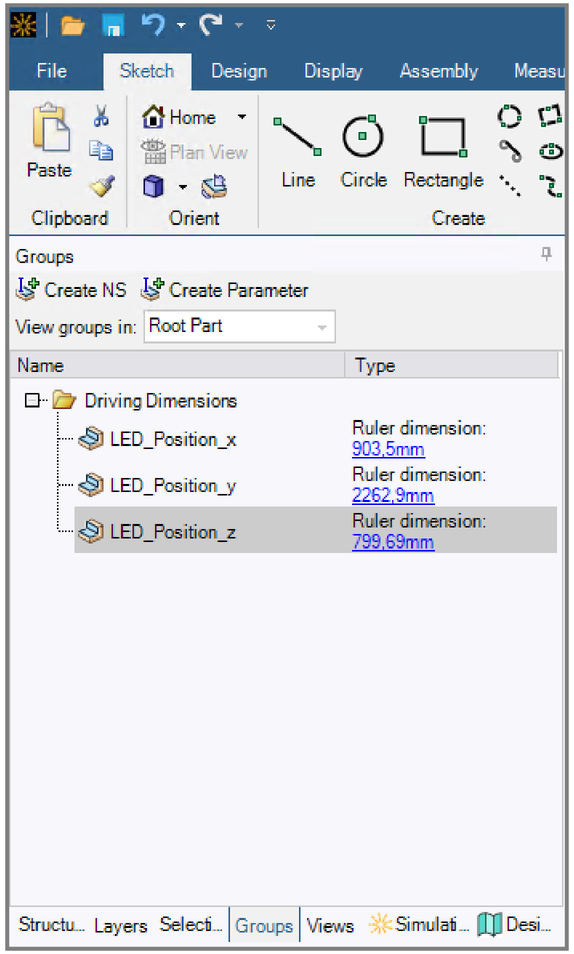


1. Open the Ansys Speos project ***Headlamp_LightGuide_Robustness.scdocx***
2. Select the ***Workbench tab***
3. Click ***Publish Parameters***
4. Select an Optical Part Design feature or a Light Simulation feature (Material, Source, Sensor, Simulation).
5. In the Publish Parameters panel, a list of the possible parameters you can use in optiSLang appears.
6. Check the parameters to be used in optiSLang.
   (**For this tutorial, all necessary parameters are already selected**)
7. Save your *.scdocx project.

Ansys

SpaceClaim Parameter

- SpaceClaim parameters will be automatically detected by optiSLang.
- The x-, y- and z-position of the LED are already predefined as parameters regarding the global coordinate system.



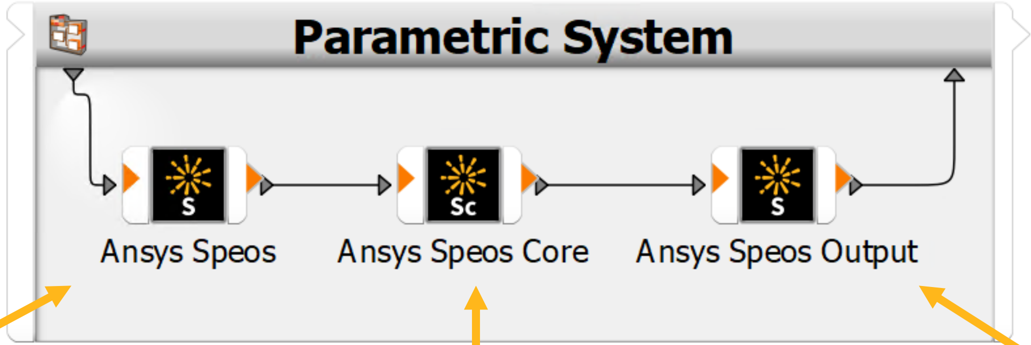
Ansys

Workflow creation and parameterization in Ansys optiSLang

Ansys

Speos workflow in optiSLang

For variation analyses (e.g. Robustness Analysis) it is necessary to automate your Speos project including geometry creation and simulation. The Speos workflow in optiSLang consists of 3 nodes:



Ansys Speos node:
- updates the geometry based on SpaceClaim & Speos parameter values
- exports the Speos simulation file (*.speos)

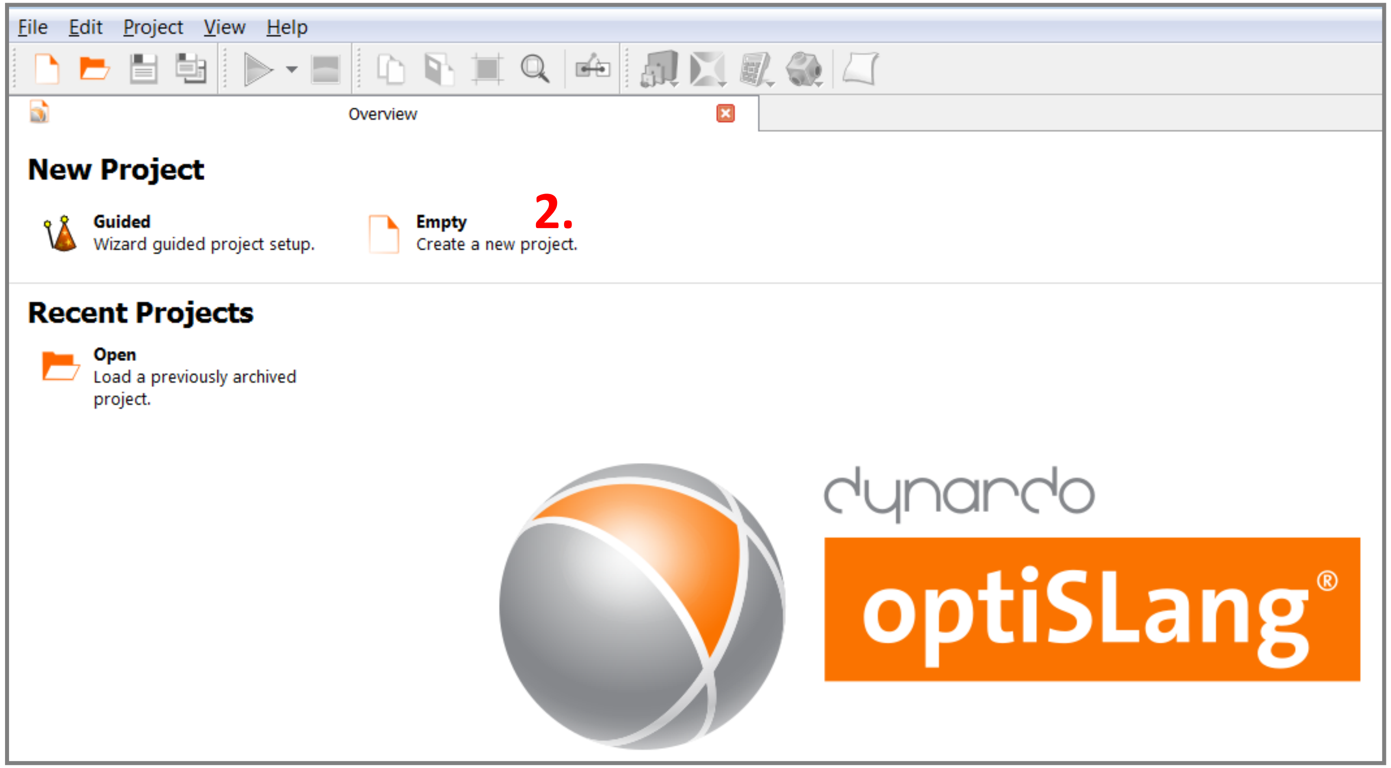
Ansys Speos Core node:
- launches and processes the simulation

Ansys Speos Output node:
- extracts response values from the Speos simulation report

Workflow creation

How to create the automated tool chain for a Speos analysis is shown in the following section:

1. Open Ansys optiSLang
2. Create a new ***Empty*** project

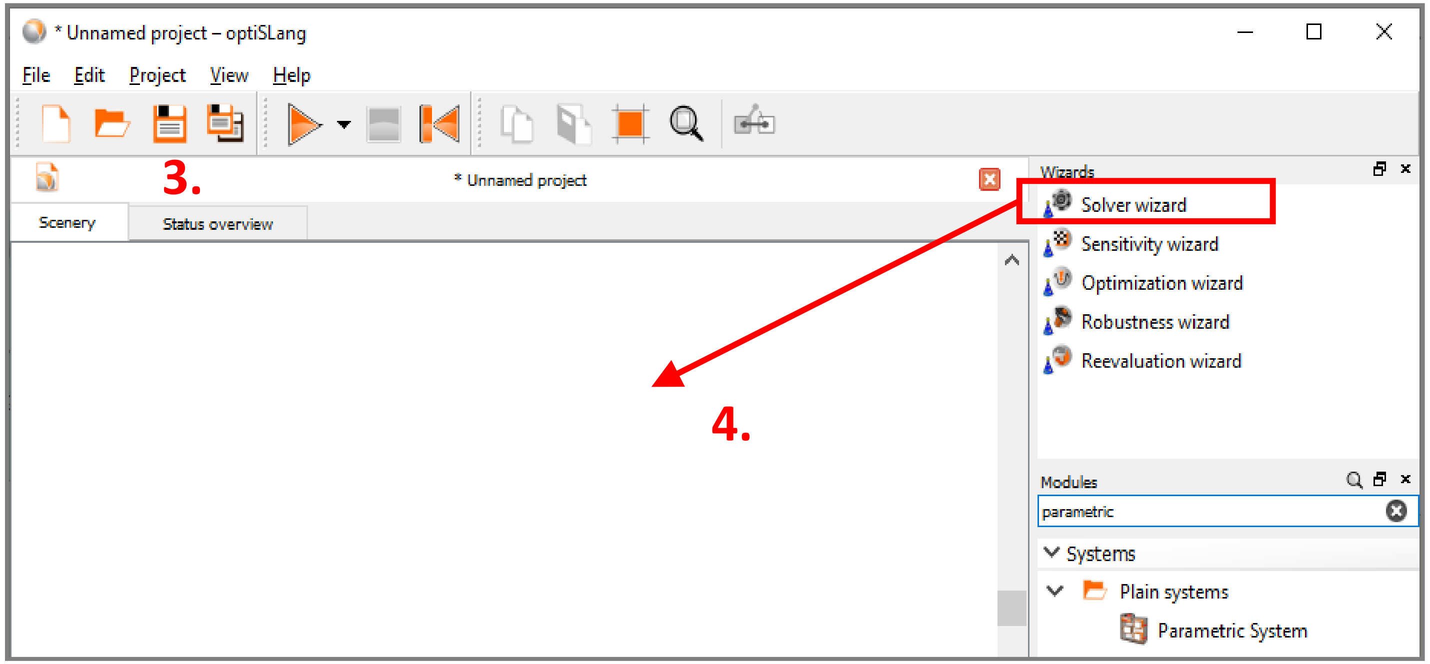


Ansys

Workflow creation

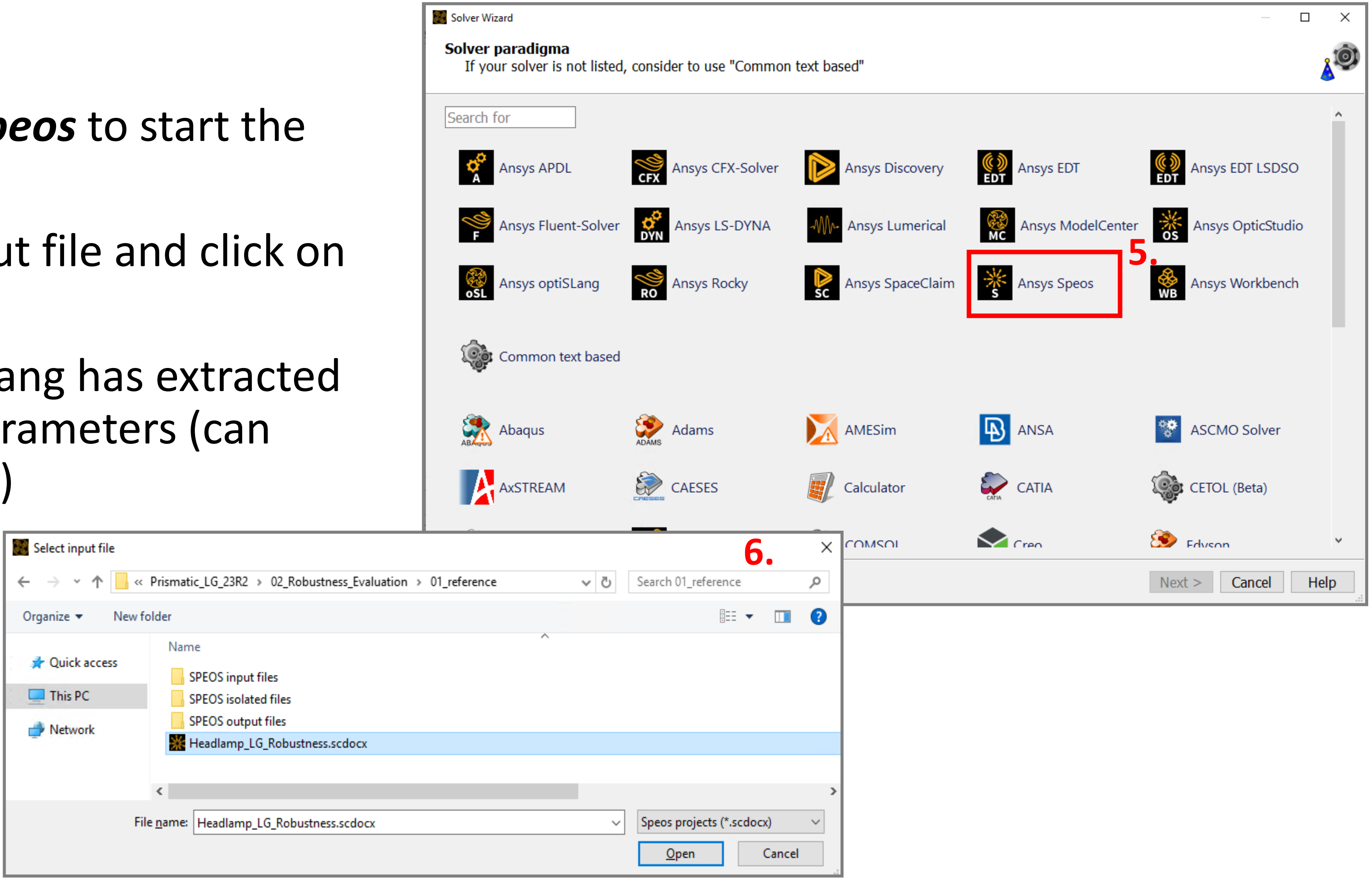
3. **Save** the optiSLang project
   Best practices: save the project next to the reference folder to allow relative path in optiSLang

4. Drag and Drop the ***Solver Wizard*** into the scenery



Workflow creation

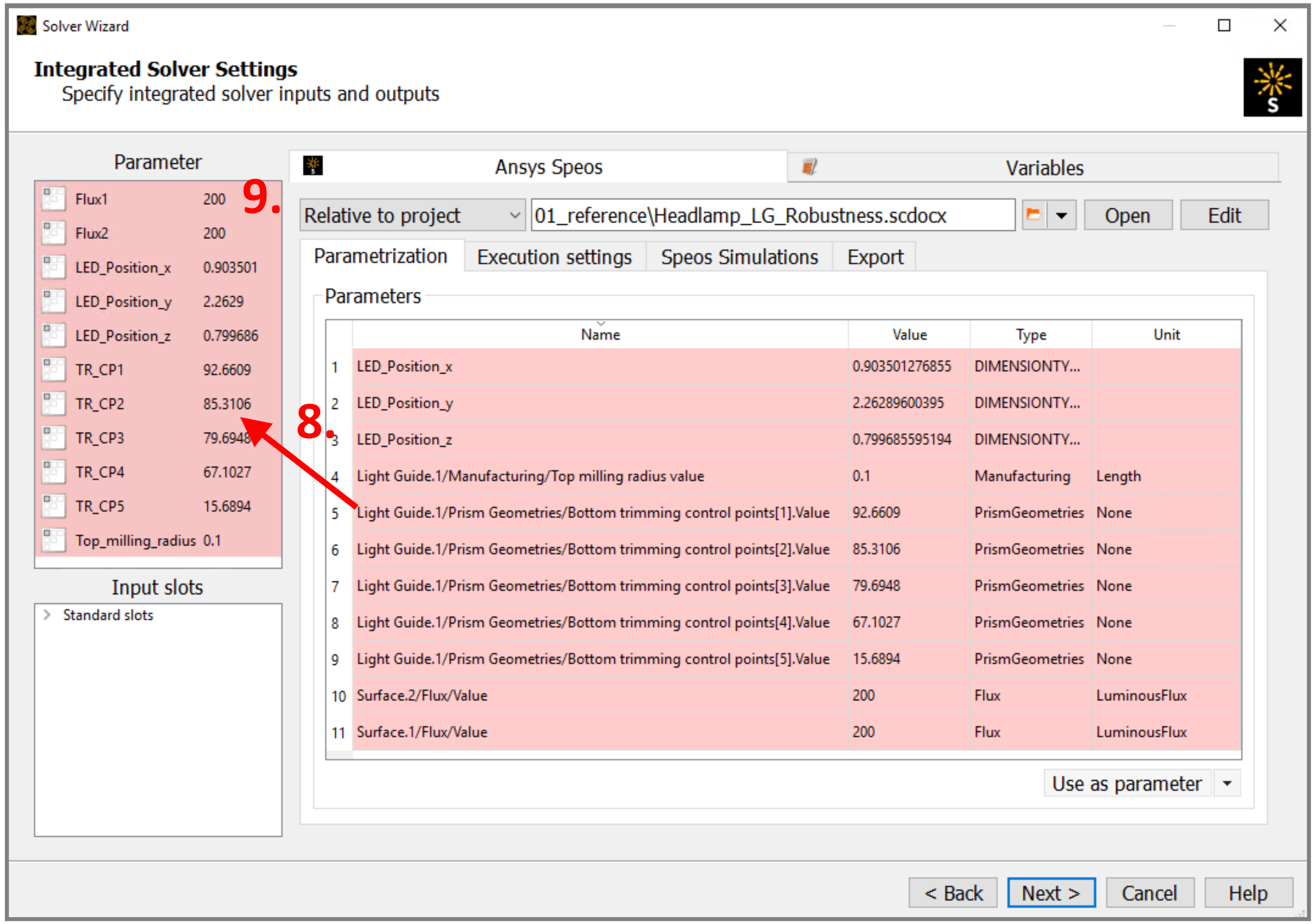
5. Click on ***Ansys Speos*** to start the solver wizard
6. Select Speos input file and click on ***Open***
7. Wait until optiSLang has extracted the published parameters (can take 1-2 minutes)



Ansys

Workflow creation

8. Drag and Drop the parameters to the ***Parameter*** pane to consider them in the variation analysis
9. Rename parameter names



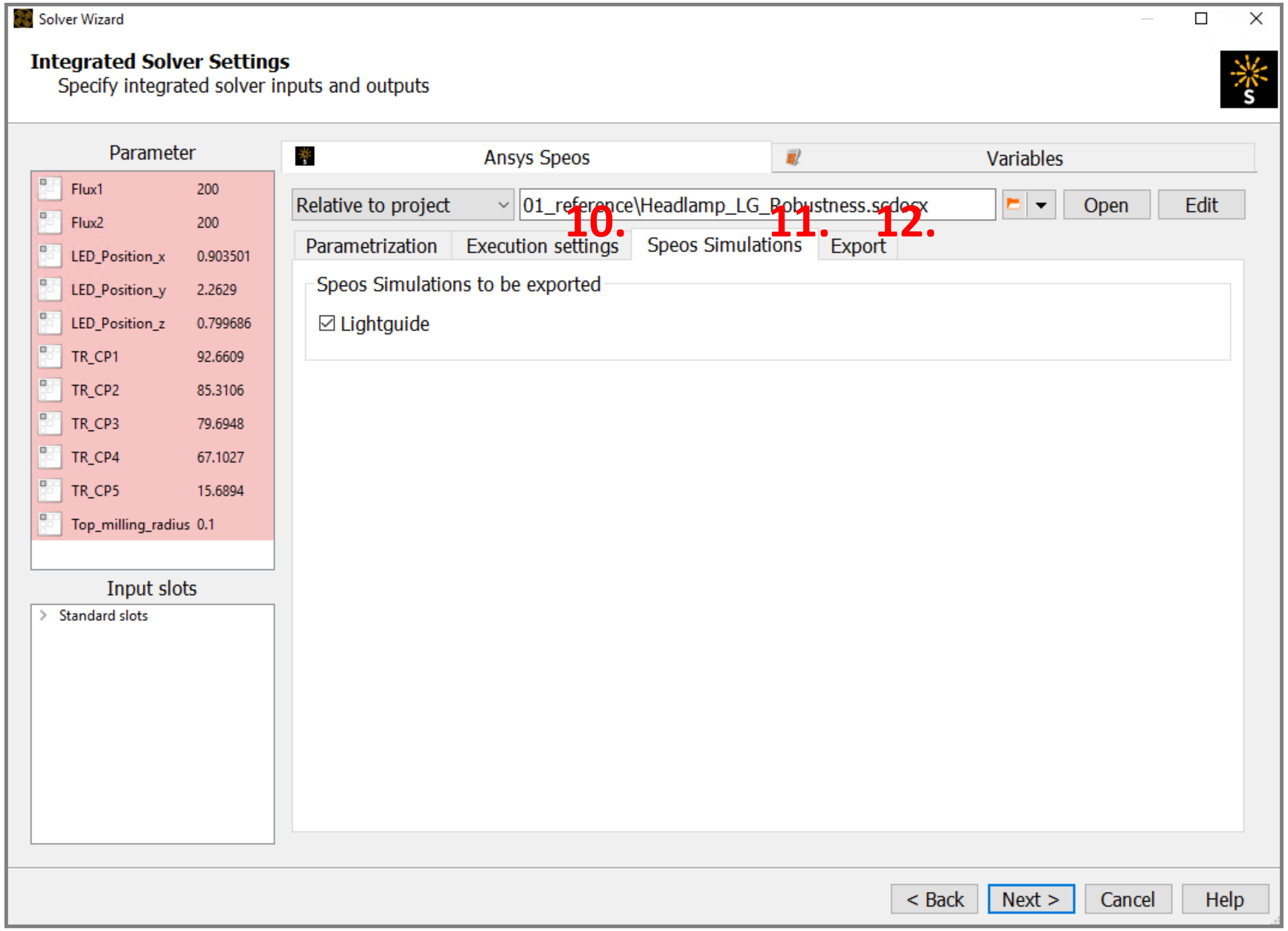
Optional: Workflow creation

10. Optional: Under ***Execution settings*** you can add python scripts for pre or post update
→*not mandatory for this tutorial*

11. Optional: Under ***Speos Simulation*** you can select which Speos simulation should be exported for the simulation
→*preselected and mandatory for this tutorial*

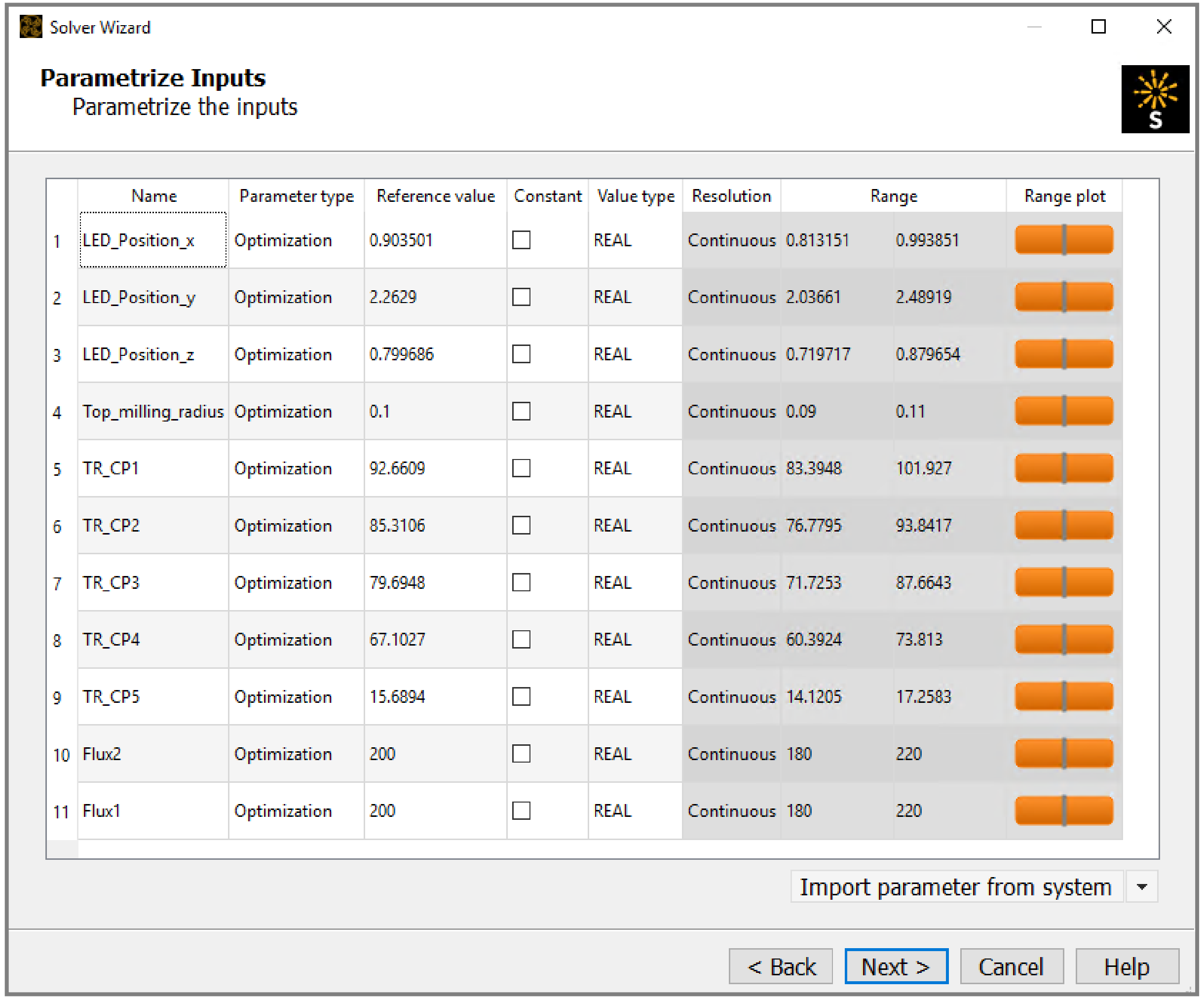
12. Optional: Under ***Export*** you can choose an additional export (e.g. an image from the geometry)

13. Click on ***Next***



Workflow creation

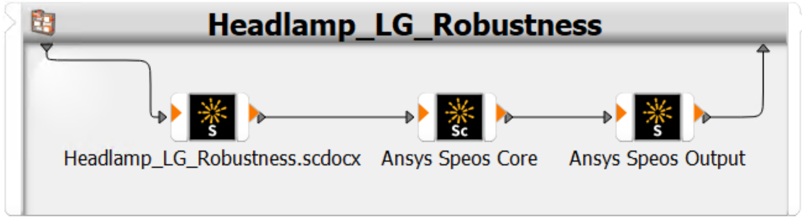
14. Keep Parameter definition
    (The parametrization will be done in a later step since additional parameters for supportive purpose must be defined)
15. Click on ***Next***

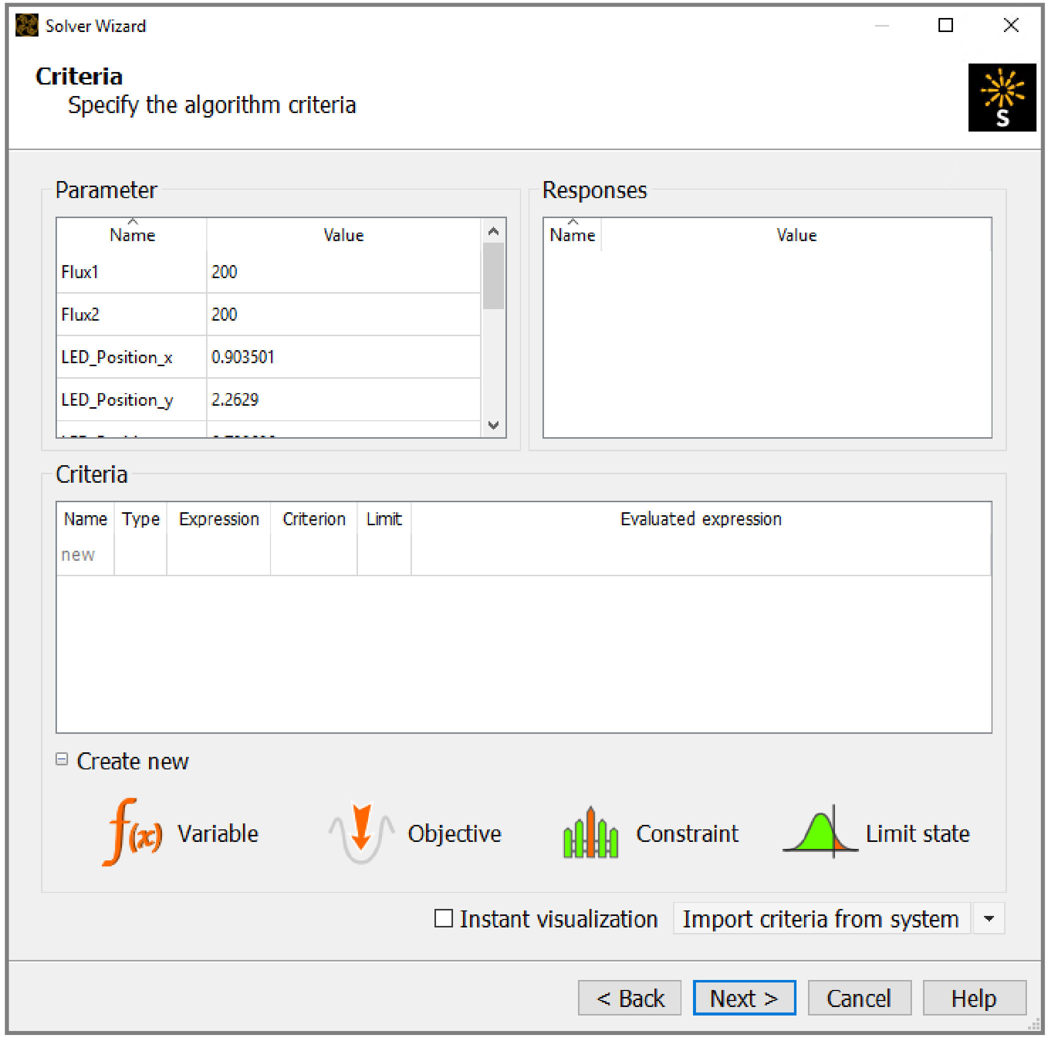


	Name	Parameter type	Reference value	Constant	Value type	Resolution	Range		Range plot
1	LED_Position_x	Optimization	0.903501	☐	REAL	Continuous	0.813151	0.993851	
2	LED_Position_y	Optimization	2.2629	☐	REAL	Continuous	2.03661	2.48919	
3	LED_Position_z	Optimization	0.799686	☐	REAL	Continuous	0.719717	0.879654	
4	Top_milling_radius	Optimization	0.1	☐	REAL	Continuous	0.09	0.11	
5	TR_CP1	Optimization	92.6609	☐	REAL	Continuous	83.3948	101.927	
6	TR_CP2	Optimization	85.3106	☐	REAL	Continuous	76.7795	93.8417	
7	TR_CP3	Optimization	79.6948	☐	REAL	Continuous	71.7253	87.6643	
8	TR_CP4	Optimization	67.1027	☐	REAL	Continuous	60.3924	73.813	
9	TR_CP5	Optimization	15.6894	☐	REAL	Continuous	14.1205	17.2583	
10	Flux2	Optimization	200	☐	REAL	Continuous	180	220	
11	Flux1	Optimization	200	☐	REAL	Continuous	180	220	

Workflow creation

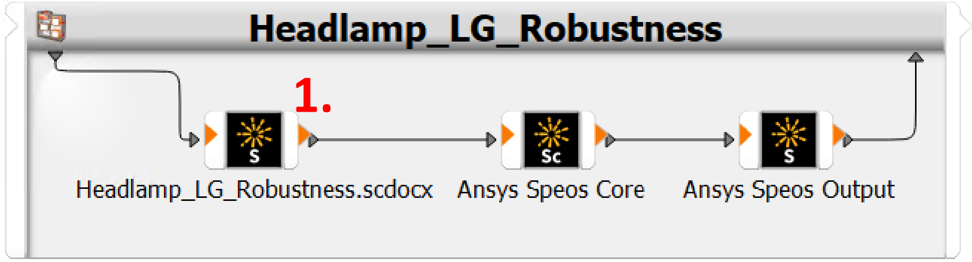
16. Skip the criteria definition
    (Responses and criteria's will be defined in the next steps)
17. Click on ***Next***
18. Then Click ***Finish*** in the next window
19. The Speos workflow will automatically be created:



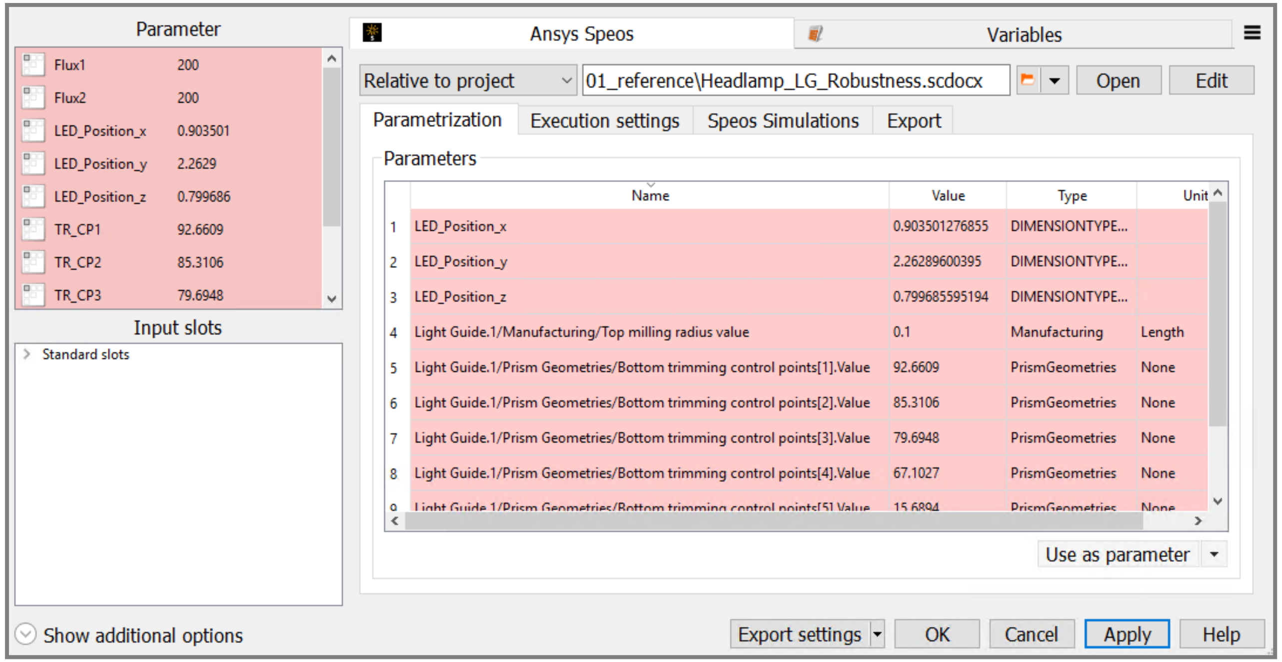


Ansys Speos Node

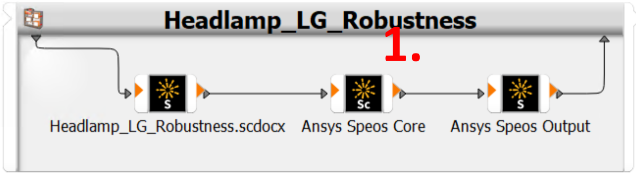
Optional: All settings made in the wizard can be reviewed and adjusted



1. **Double-click** on the Speos node

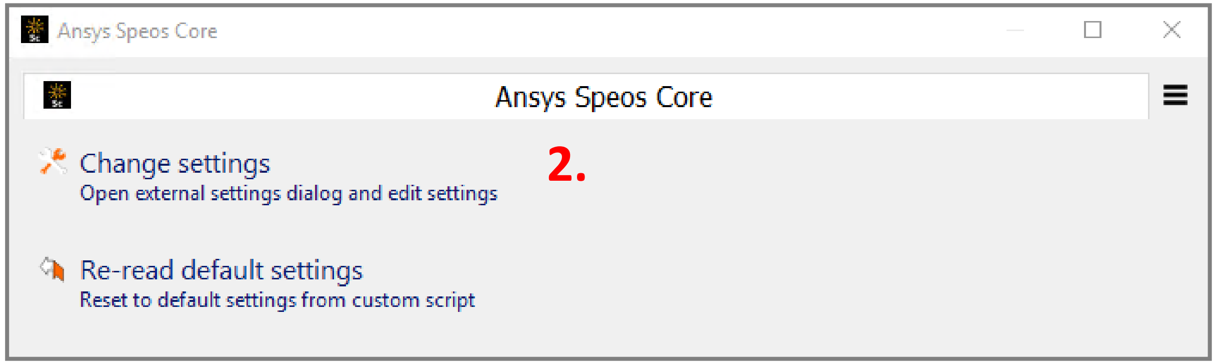


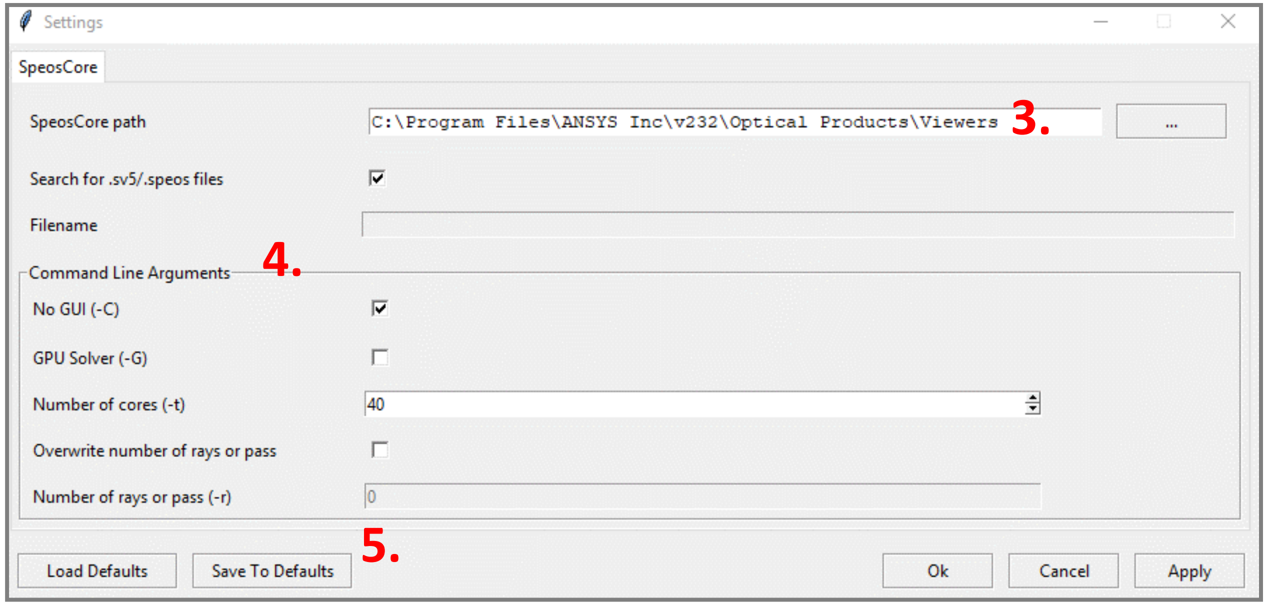
Ansys Speos Core node



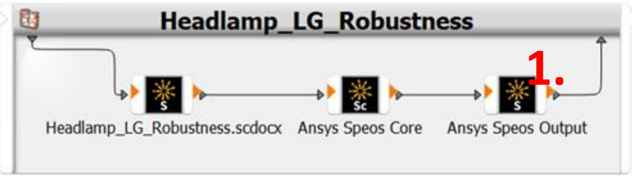
Optional: The default solver settings for the Speos simulation can be reviewed and adjusted:

1. Double-click on the ***Ansys Speos Core*** node
2. Click on ***Change Settings***
3. Check the SpeosCore path
4. Adapt command line arguments
5. Click on ***Save to default***
6. Click ***Apply*** and ***OK***



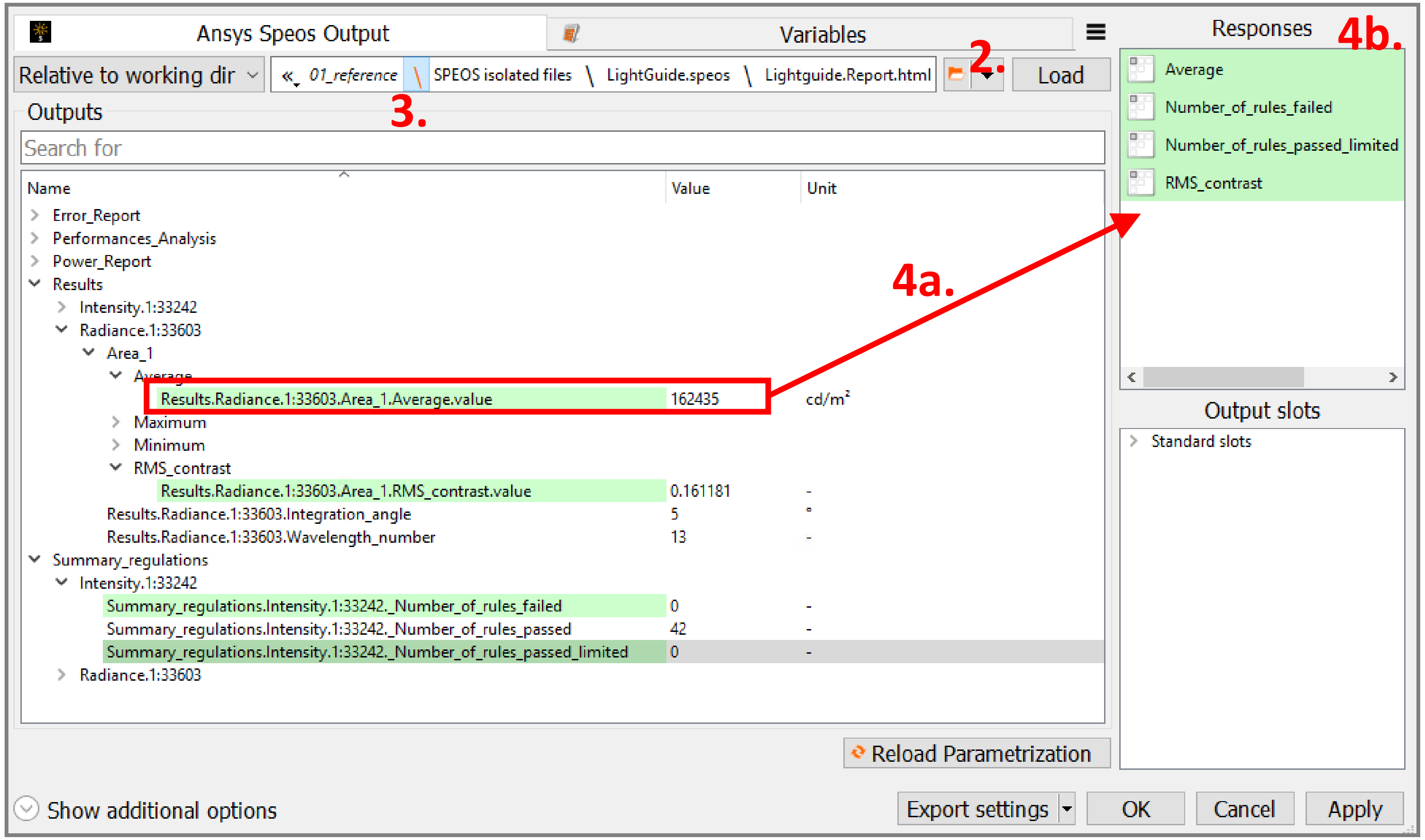


Ansys Speos Output node



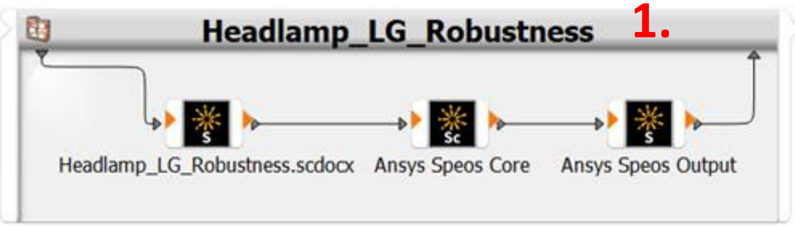
Set up the Speos Output node in order to extract the simulation results:

1. **Double-click** on the ***Ansys Speos Output*** node
2. Browse for the file "**Lightguide.Report.html**" in the reference files folder ("01_reference\SPEOS isolated files\Lightguide.speos\")
3. Set the path to ***Relative to working dir*** and set the orange path split position
4. Define the responses via drag and drop and rename them
5. Click ***Apply*** and ***OK***



Number of failed rules = Number of not passed regulations

Parametrization for Robustness Analyis

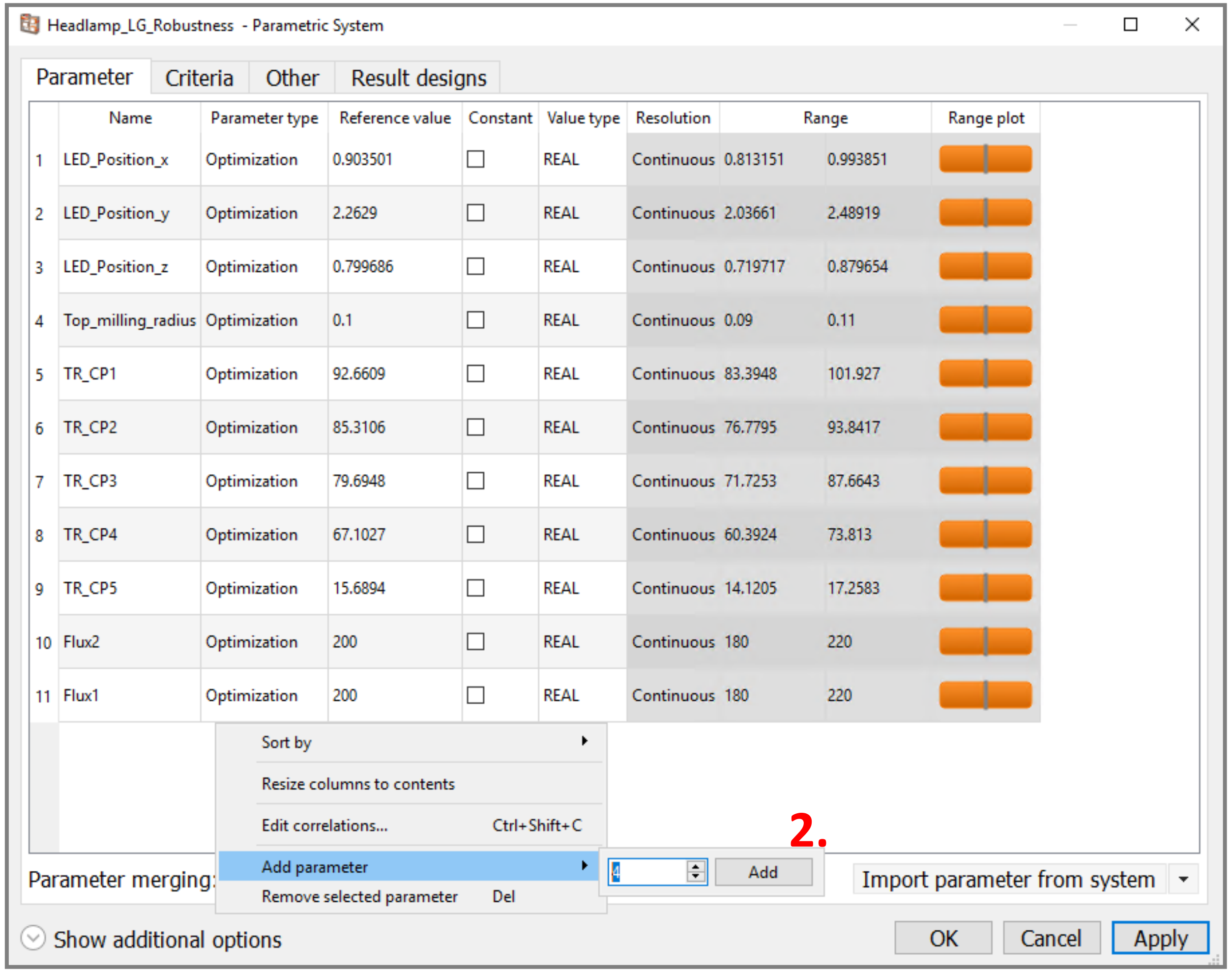


For the Robustness Analysis it is important to define the scattering of the parameter (tolerance). In this example we will consider the following tolerances:

- trimming ratios of the prisms
- milling value of the prisms
- energy of the light source
- position of the light source

Setup the parameter:

1. **Double-click** on the head of the parametric system
2. **Right-click** in the Parameter table and **Add** 4 parameters

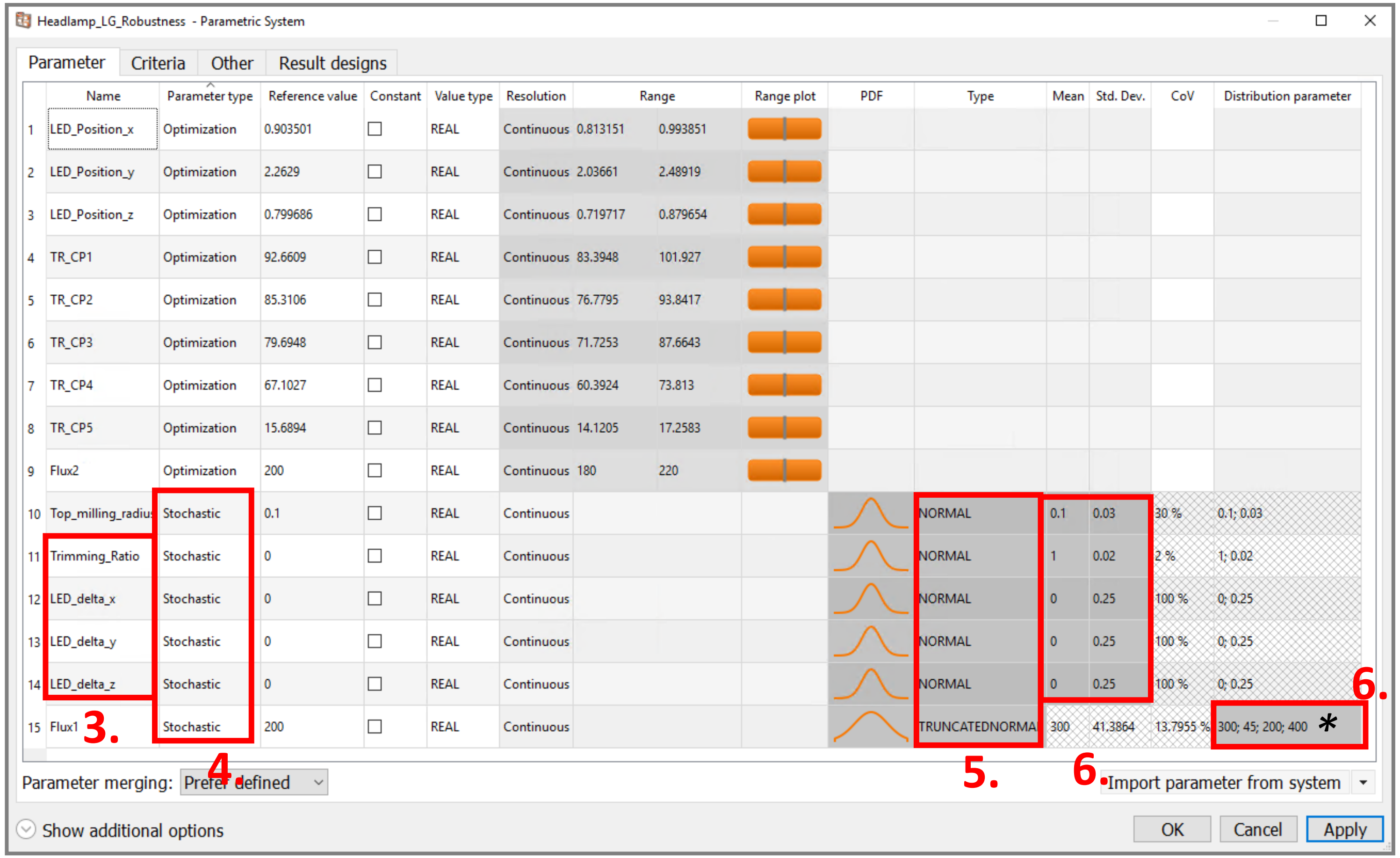


Ansys

Definition of scattering parameters

3. Rename the new added parameter to:
   - Trimming_Ratio
   - LED_delta_x
   - LED_delta_y
   - LED_delta_z
4. Change the **Parameter type** to **Stochastic** for all scattering input parameter
5. Define type of probability distribution function
6. Define stochastic values (distribution parameter)

Distribution type and parameter can be based on measurement data or assumptions.



	Name	Parameter type	Reference value	Constant	Value type	Resolution	Range		Range plot	PDF	Type	Mean	Std. Dev.	CoV	Distribution parameter
1	LED_Position_x	Optimization	0.903501	☐	REAL	Continuous	0.813151	0.993851							
2	LED_Position_y	Optimization	2.2629	☐	REAL	Continuous	2.03661	2.48919							
3	LED_Position_z	Optimization	0.799686	☐	REAL	Continuous	0.719717	0.879654							
4	TR_CP1	Optimization	92.6609	☐	REAL	Continuous	83.3948	101.927							
5	TR_CP2	Optimization	85.3106	☐	REAL	Continuous	76.7795	93.8417							
6	TR_CP3	Optimization	79.6948	☐	REAL	Continuous	71.7253	87.6643							
7	TR_CP4	Optimization	67.1027	☐	REAL	Continuous	60.3924	73.813							
8	TR_CP5	Optimization	15.6894	☐	REAL	Continuous	14.1205	17.2583							
9	Flux2	Optimization	200	☐	REAL	Continuous	180	220							
10	Top_milling_radius	Stochastic	0.1	☐	REAL	Continuous					NORMAL	0.1	0.03	30 %	0.1; 0.03
11	Trimming_Ratio	Stochastic	0	☐	REAL	Continuous					NORMAL	1	0.02	2 %	1; 0.02
12	LED_delta_x	Stochastic	0	☐	REAL	Continuous					NORMAL	0	0.25	100 %	0; 0.25
13	LED_delta_y	Stochastic	0	☐	REAL	Continuous					NORMAL	0	0.25	100 %	0; 0.25
14	LED_delta_z	Stochastic	0	☐	REAL	Continuous					NORMAL	0	0.25	100 %	0; 0.25
15	Flux1	Stochastic	200	☐	REAL	Continuous					TRUNCATEDNORMAL	300	41.3864	13.7955 %	300; 45; 200; 400

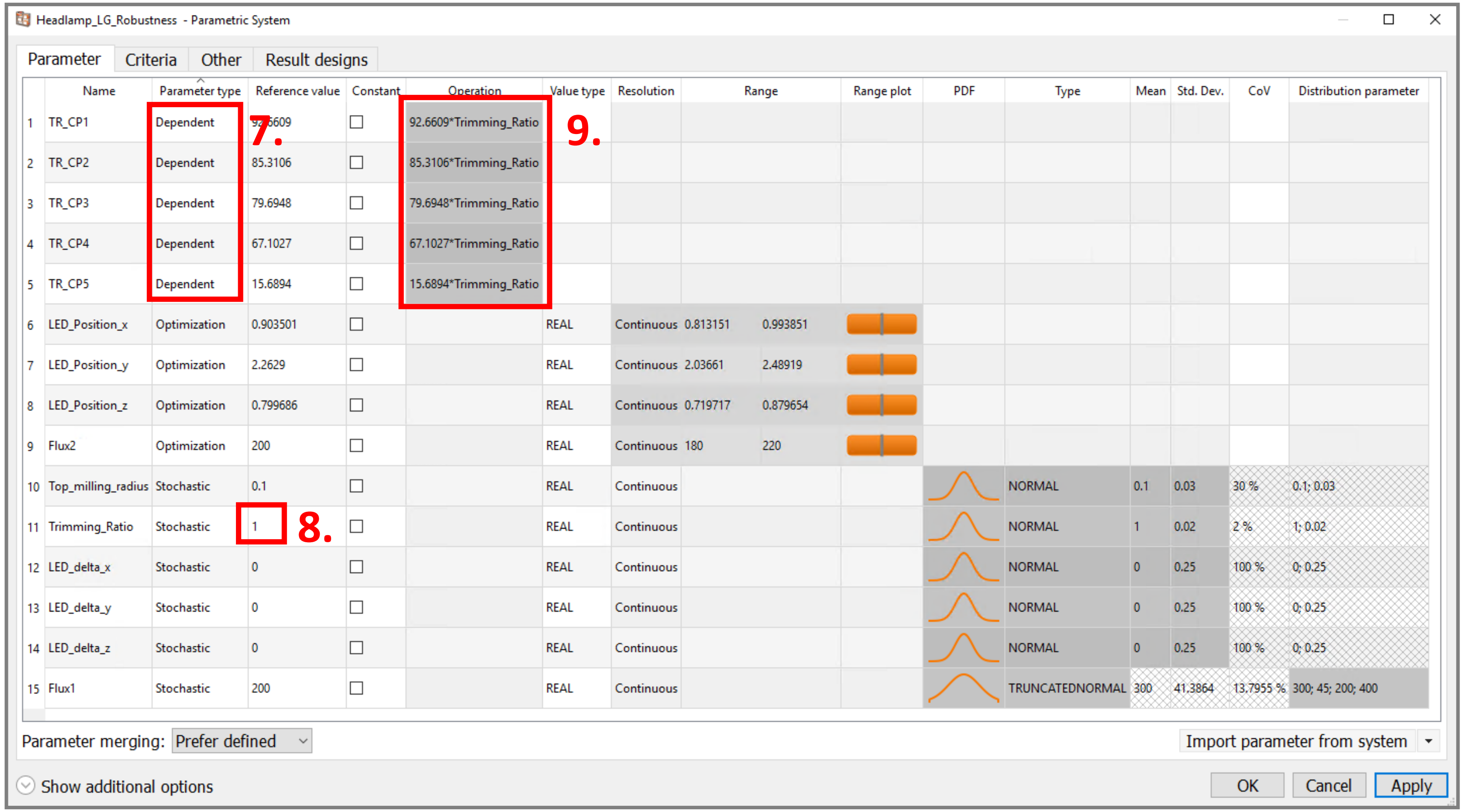
**Mean value; scale factor; lower bound; upper bound*
*→ the according distribution function is shown in column **PDF***

Ansys

Definition of scattering parameters

7. Change the **Parameter type** of all trimming ratios to **Dependent**
8. Set the **Reference value** of “Trimming_Ratio” to 1
9. Multiply the trimming ratios with the defined scattering parameter “Trimming_Ratio”

Background: With this we will vary the trimming ratios over all prisms of the light guide with the same tolerance factor.



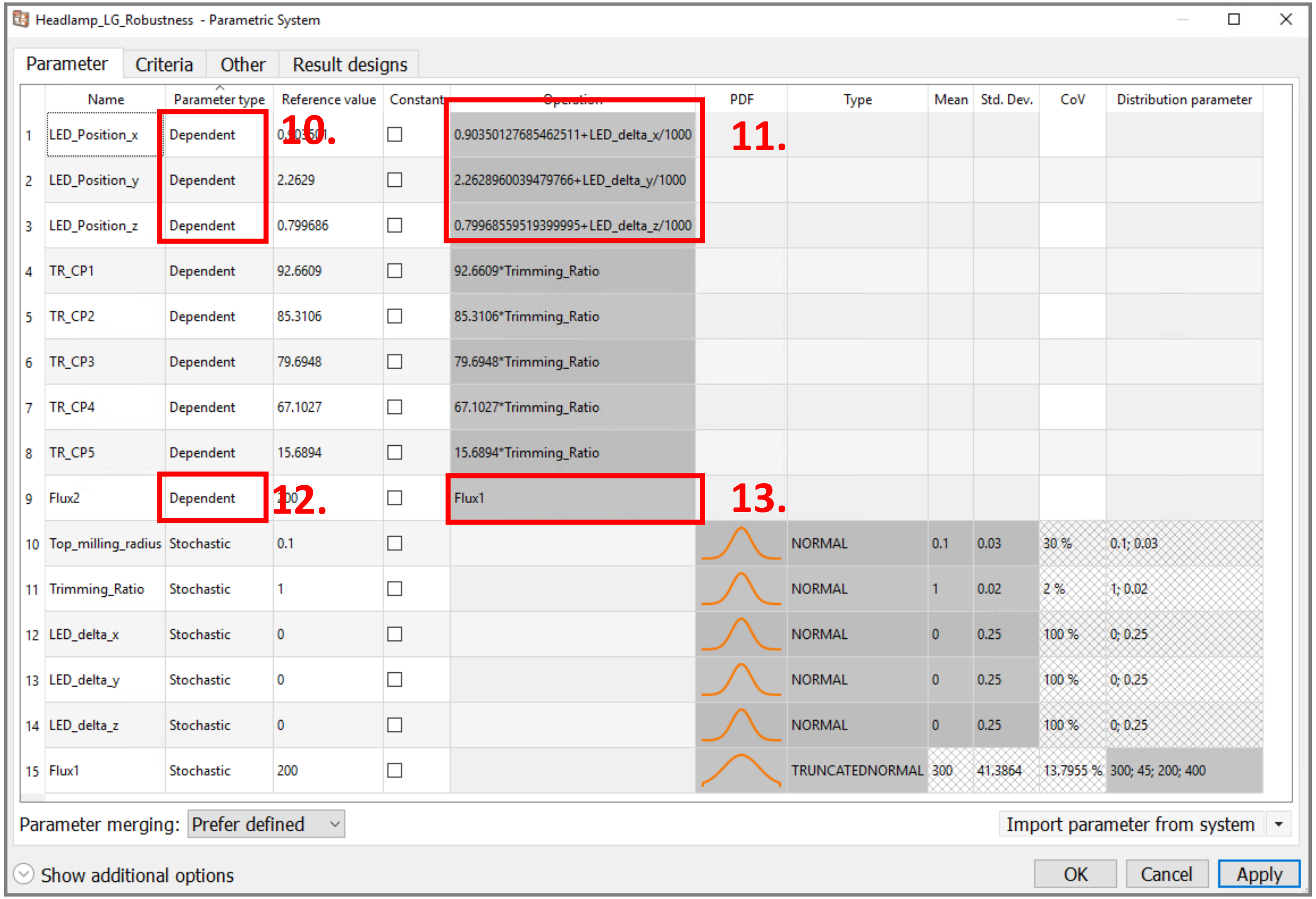
	Name	Parameter type	Reference value	Constant	Operation	Value type	Resolution	Range		Range plot	PDF	Type	Mean	Std. Dev.	CoV	Distribution parameter
1	TR_CP1	Dependent	9[illegible].6609		92.6609*Trimming_Ratio											
2	TR_CP2	Dependent	85.3106		85.3106*Trimming_Ratio											
3	TR_CP3	Dependent	79.6948		79.6948*Trimming_Ratio											
4	TR_CP4	Dependent	67.1027		67.1027*Trimming_Ratio											
5	TR_CP5	Dependent	15.6894		15.6894*Trimming_Ratio											
6	LED_Position_x	Optimization	0.903501			REAL	Continuous	0.813151	0.993851							
7	LED_Position_y	Optimization	2.2629			REAL	Continuous	2.03661	2.48919							
8	LED_Position_z	Optimization	0.799686			REAL	Continuous	0.719717	0.879654							
9	Flux2	Optimization	200			REAL	Continuous	180	220							
10	Top_milling_radius	Stochastic	0.1			REAL	Continuous					NORMAL	0.1	0.03	30 %	0.1; 0.03
11	Trimming_Ratio	Stochastic	1			REAL	Continuous					NORMAL	1	0.02	2 %	1; 0.02
12	LED_delta_x	Stochastic	0			REAL	Continuous					NORMAL	0	0.25	100 %	0; 0.25
13	LED_delta_y	Stochastic	0			REAL	Continuous					NORMAL	0	0.25	100 %	0; 0.25
14	LED_delta_z	Stochastic	0			REAL	Continuous					NORMAL	0	0.25	100 %	0; 0.25
15	Flux1	Stochastic	200			REAL	Continuous					TRUNCATEDNORMAL	300	41.3864	13.7955 %	300; 45; 200; 400

Ansys

Definition of scattering parameters

10. Change the **Parameter type** of all LED-Positions to **Dependent**
11. Add the LED displacement in [m] to the positions
12. Change the **Parameter type** of “Flux2” to **Dependent**
13. Set the Value equal to Flux1
    Assumption: LED have the same scattering
14. Click **Apply** and **OK**

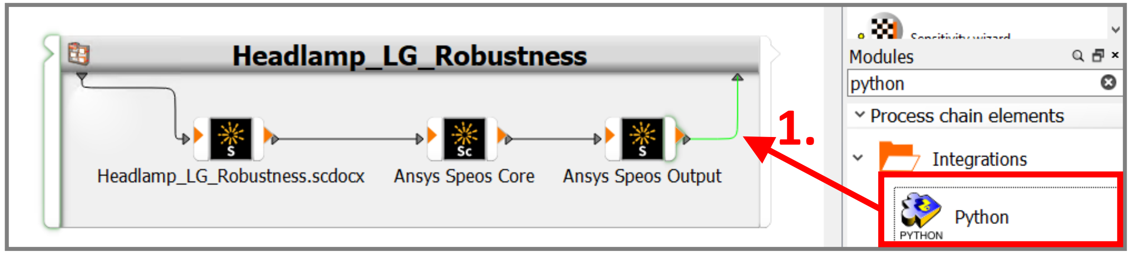
Now all scattering parameters are well defined and connected to the model parameters in Speos.



workflow extension

Optional: In order to increase the design understanding, export an image from the XMP-Viewer and add it into the optiSLang postprocessing

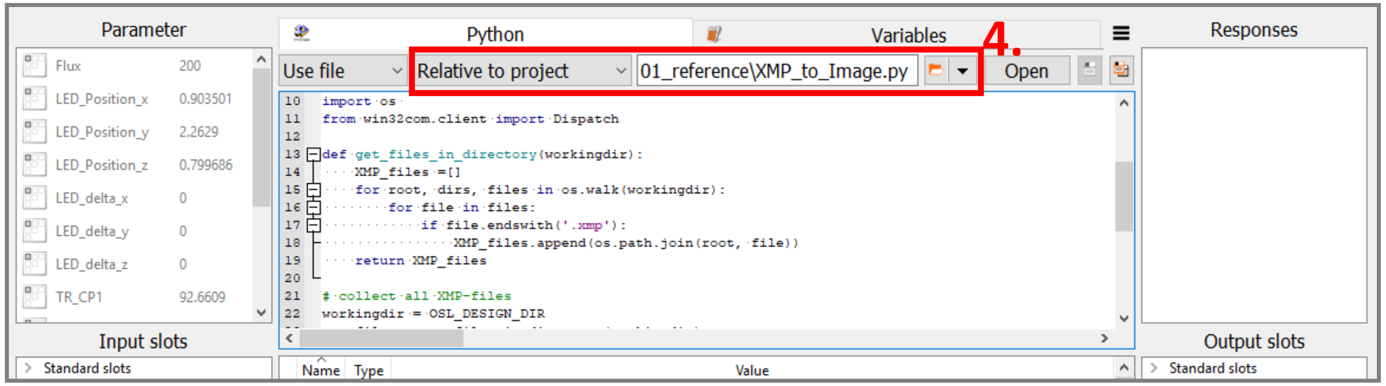
1. Filter for ***Python*** under ***Modules*** and drag and drop it onto the green arrow in the parametric system



2. Rename the Python-node with F2 to “XMP to image”

3. ***Double-click*** on the Python-node

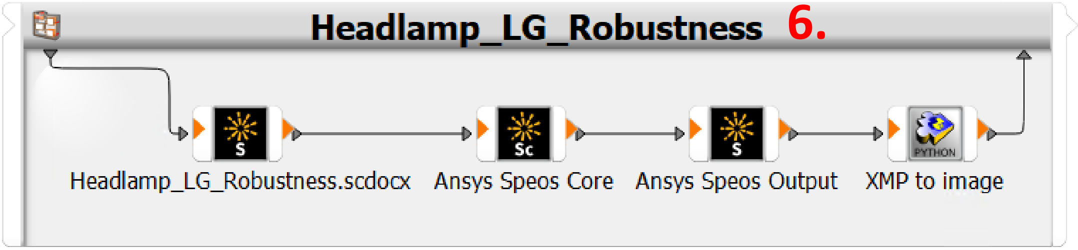
4. **Browse** for the Python script „XMP_to_Image.py” in the reference files folder (“01_reference”)

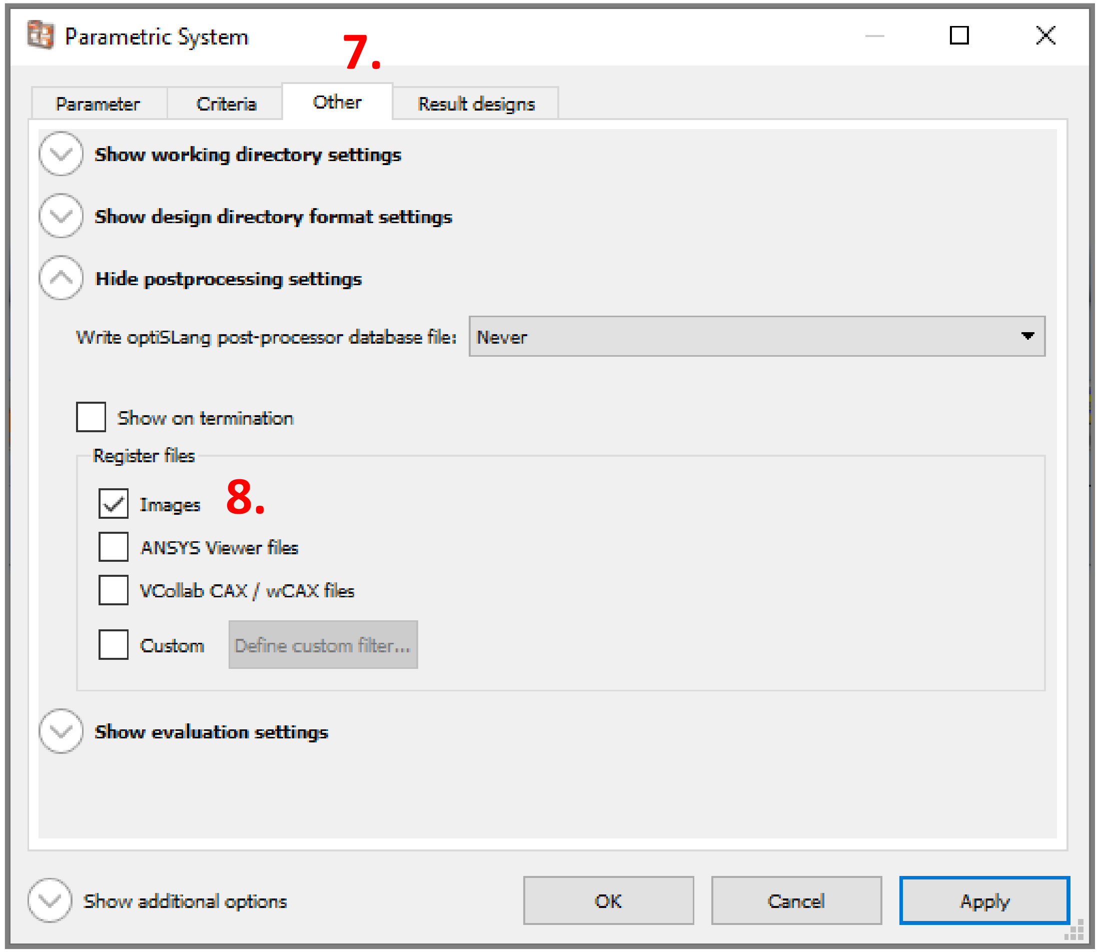


5. Click ***Apply*** and ***OK***

workflow extension

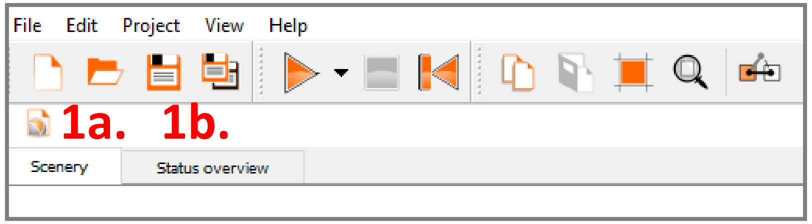
6. ***Double click*** on the systems head
7. Go to the ***Other*** tab
8. Change the postprocessing settings to import the images into the optiSLang Postprocessing automatically
9. Click ***Apply*** and ***OK***

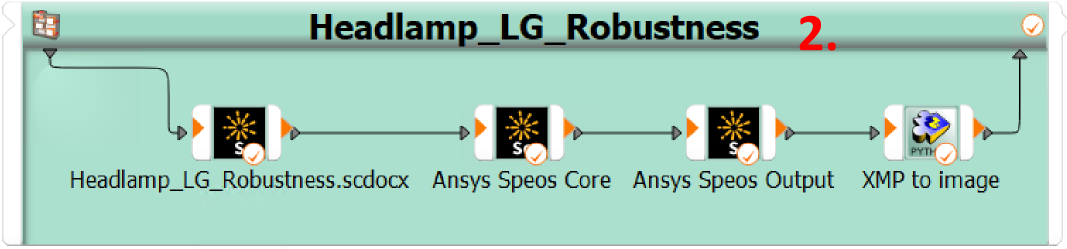




Test Run

1. **Save** and **Execute** the project
2. Open the executed system by double click on the systems head
3. Check the results of the initial Design in the **Result designs** tab





Headlamp_LG_Robustness - Parametric System

Parameter | Criteria | Other | Result designs **3.**

	Id	Feasible	Duplicates	Status	Flux1	Flux2	LED_Position_x	LED_Position_y	LED_Position_z	LED_delta_x	LED_delta_y	LED_delta_z	TR_CP1	TR_CP2	TR_CP3	TR_CP4	TR_CP5	Top_milling_radius	Trimming_Ratio	Average	Number_of_rules_failed	Number_of_rules_passed_limited	RMS_contrast
1	0.1	true		Succeeded	200	200	0.903501	2.2629	0.799686	0	0	0	92.6609	85.3106	79.6948	67.1027	15.6894	0.1	1	161794	0	0	0.162671

NOTE: If the Python node fails, please check the troubleshooting on the next slide

Troubleshooting: Python node

- If the COM server for the XMP-Viewer is not registered in the windows registry, then the following error message appears in the optiSLang message log:

ERROR

```
Python interpreter error:
Traceback (most recent call last):
  File "C:\Program Files\ANSYS Inc\v231\optiSLang\lib\python3.7\lib\site-packages\win32com\client\dynamic.py", line 81, in _GetGoodDispatch
    IDispatch = pythoncom.connect(IDispatch)
pywintypes.com_error: (-2147221005, 'Invalid class string', None, None)

During handling of the above exception, another exception occurred:

Traceback (most recent call last):
  File "<string>", line 29, in <module>
  File "C:\Program Files\ANSYS Inc\v231\optiSLang\lib\python3.7\lib\site-packages\win32com\client\__init__.py", line 95, in Dispatch
    dispatch, userName = dynamic._GetGoodDispatchAndUserName(dispatch,userName,clsctx)
  File "C:\Program Files\ANSYS Inc\v231\optiSLang\lib\python3.7\lib\site-packages\win32com\client\dynamic.py", line 98, in _GetGoodDispatchAndUserName
    return (_GetGoodDispatch(IDispatch, clsctx), userName)
  File "C:\Program Files\ANSYS Inc\v231\optiSLang\lib\python3.7\lib\site-packages\win32com\client\dynamic.py", line 83, in _GetGoodDispatch
    IDispatch = pythoncom.CoCreateInstance(IDispatch, None, clsctx, pythoncom.IID_IDispatch)
pywintypes.com_error: (-2147221005, 'Invalid class string', None, None)
```

- **Solution: Set up the windows registry correct:**
  - Open „Virtual Photometric Lab“ with admin rights manually in the used Ansys Speos version
  - reopen optiSLang and try again

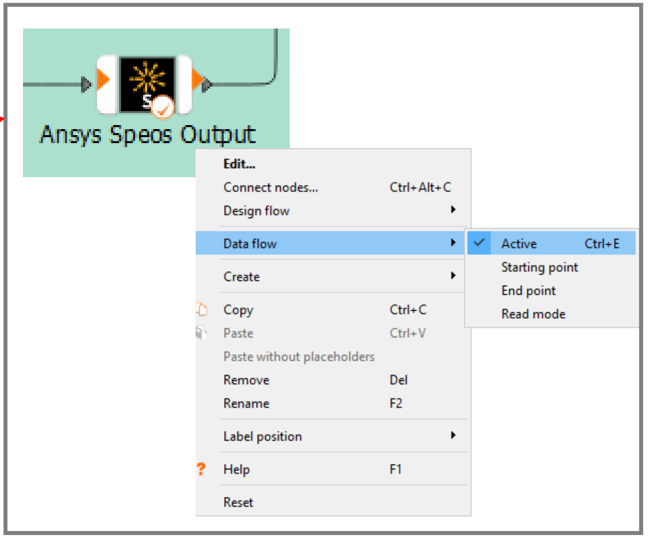
Troubleshooting: Ansys Speos Output node

- **Location of the Speos report (.html file):**

  1. With a **manual solve** of the simulation in Speos, the Speos report (.html file) will be written into the “**SPEOS output files**” folder
  2. With the **automatic solve** using the Speos integration in optiSLang the Speos report will be written into the “**SPEOS isolated files” folder**

- **For new projects, this report might not be existing in the “SPEOS isolated files” folder.**
  The best practices is:

  1. Setup the workflow via wizard
  2. Deactivate Ansys Speos Output Node
     (right click on the node and click on “Active”)
  3. Run the workflow
  4. Copy the generated Speos report (.html file) into your reference folder
  5. Setup the Speos output node
  6. Activate the Speos Output node and run the workflow



Troubleshooting: Solver Noise

- For variation analysis like Robustness Analysis, it is important to have a high simulation quality in order to minimize the solver noise. Small solver noise means that if the same simulation is executed multiple times, the scattering of the output values should be small.
- To ensure a high simulation quality and a good prediction for the tolerance sensitivity the maximum difference between the output values should be less than about 5%.
- You could improve the simulation quality e.g., by increasing the number of rays

- Optional: There is an **easy solution to fast check the solver noise** within optiSLang. How to do is shown in the Appendix at the end of the presentation in the section "Check Solver Noise"

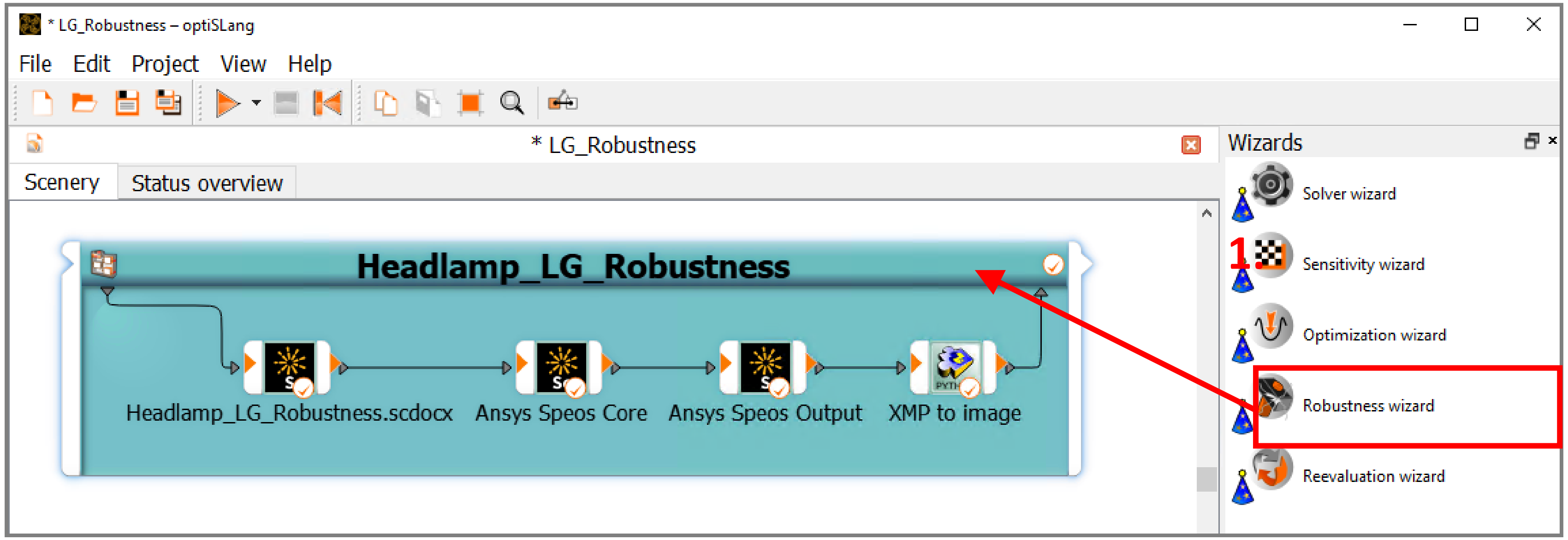
Robustness Analysis
(Tolerance analysis)

Ansys

Setup Robustness Analysis

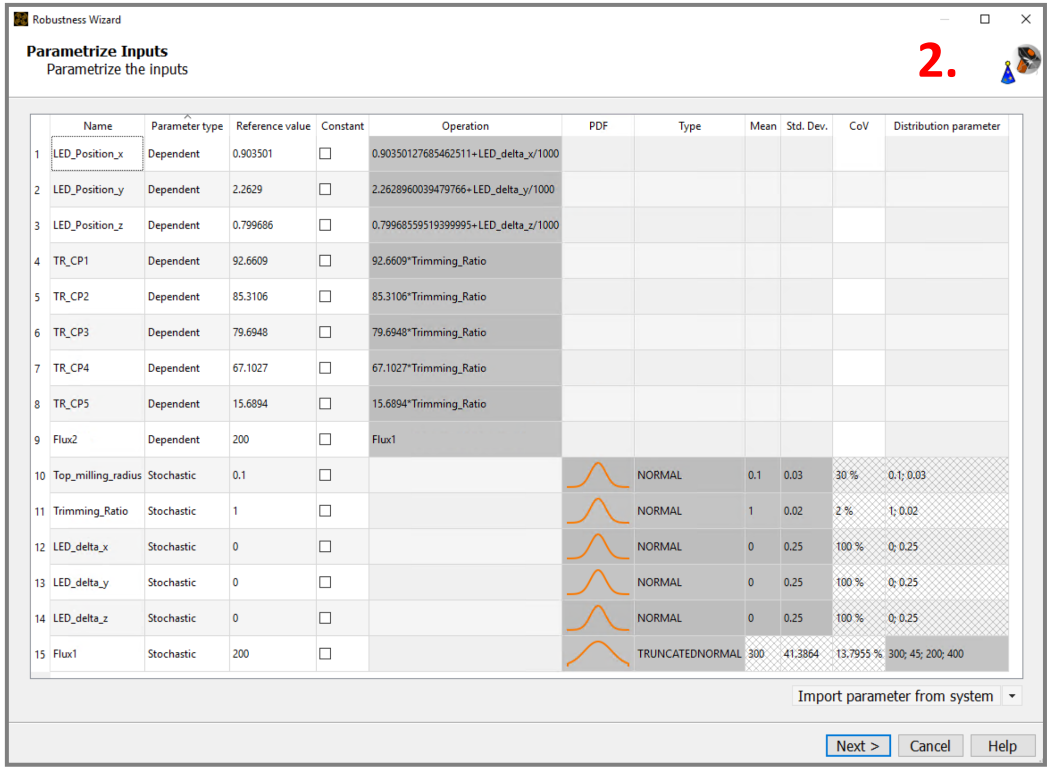
How to setup a Robustness Analysis and how to interpretate the results is shown in the following section:

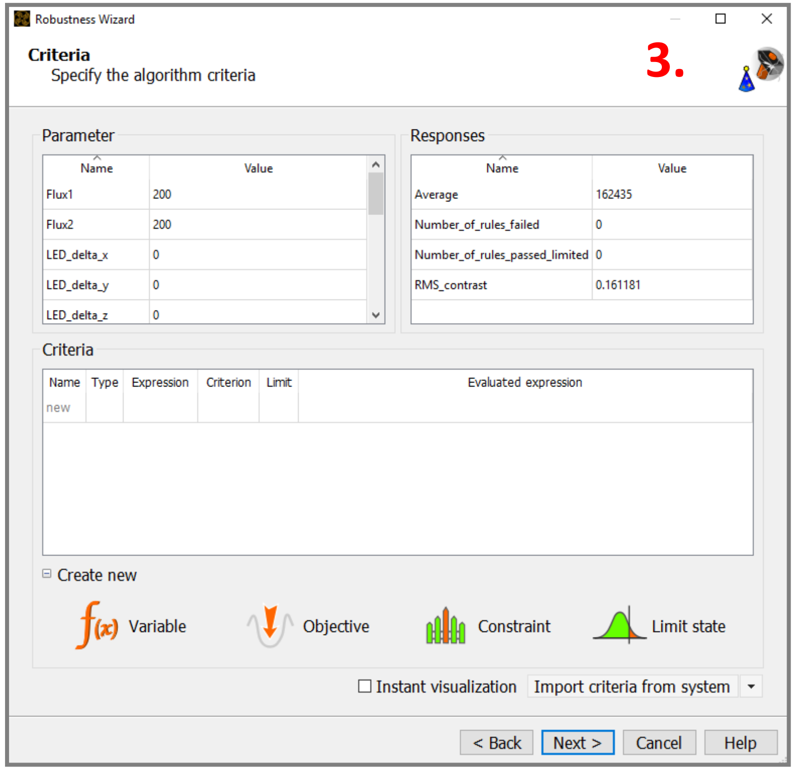
1. **Drag** the **Robustness wizard** onto the head of the solver chain



Setup Robustness Analysis

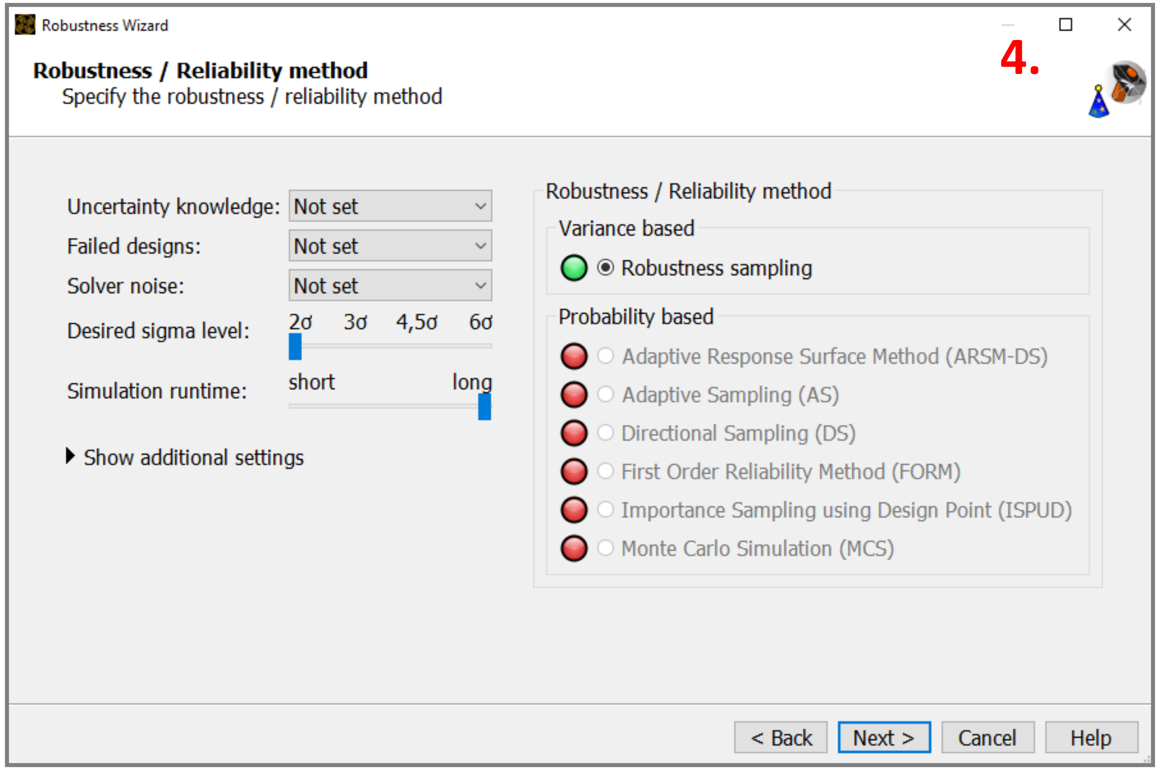
2. Keep the already defined parameter and click **Next.**
3. No criteria need to be defined. Click **Next.**

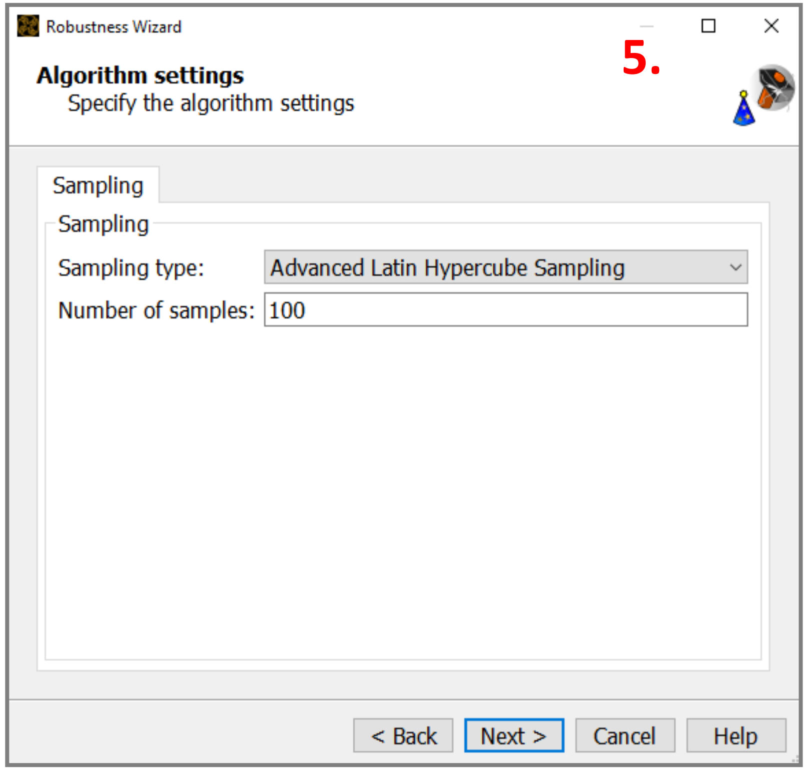




Setup Robustness Analysis

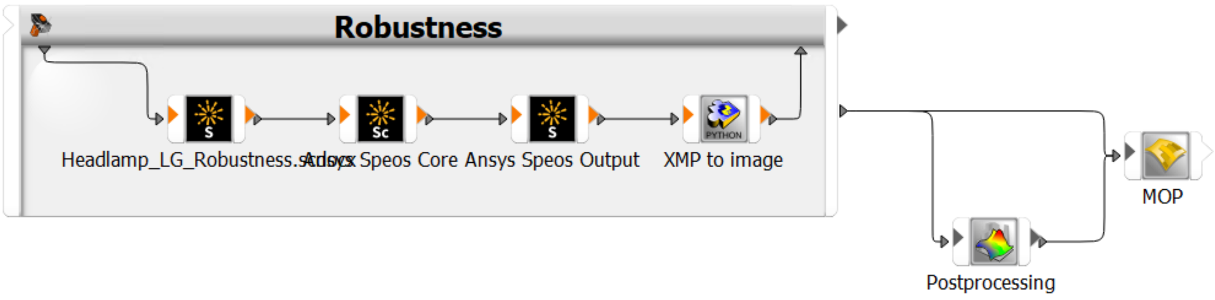
4. Robustness analysis is selected automatically. Click **Next**
5. Keep the default number of samples (optiSLang will sample 100 designs according the defined distribution function of the scattering input parameter). Click **Next**

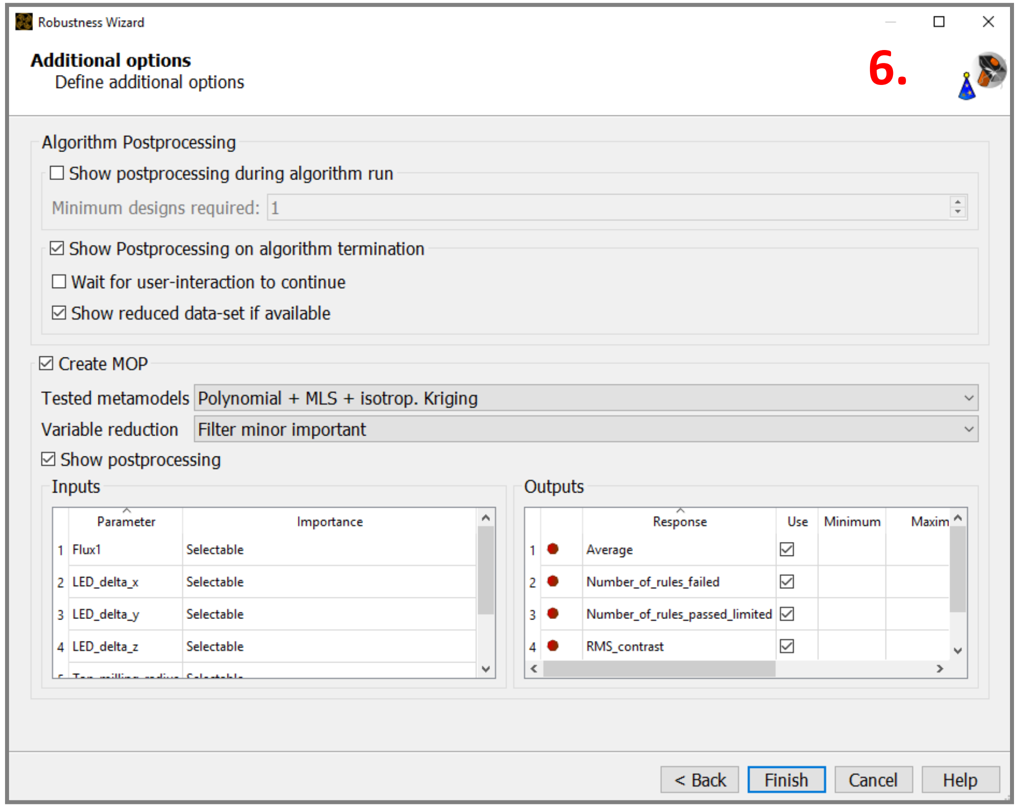




Setup Robustness Analysis

6. Keep the default postprocessing settings and **Finish** the wizard
7. The robustness system will be created automatically:

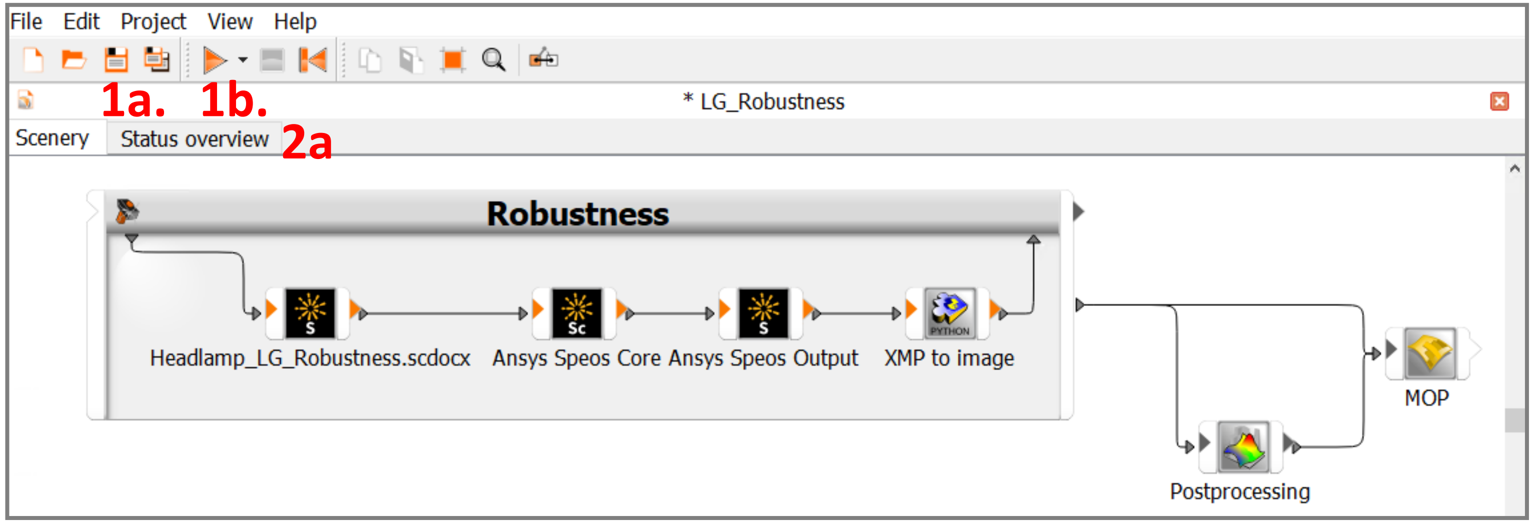




Ansys

Start Robustness Analysis

1. Save and execute the project
2. Click on **Status overview** to check the progress for each design



→ Wait until the analysis is ready

→ The optiSLang postprocessing will open automatically
(alternative, please right click on **MOP** node and click on **Show Postprocessing**)

Robustness Analysis - Postprocessing

- The results of the Robustness Analysis are shown in the **optiSLang postprocessing. The evaluation of the statistical data help you to determine the quality (robustness) of the design by**

  1. ***identifying and understanding important tolerances***
  2. ***getting the probability of failure***

- *As quality measurements we consider the following outputs:*

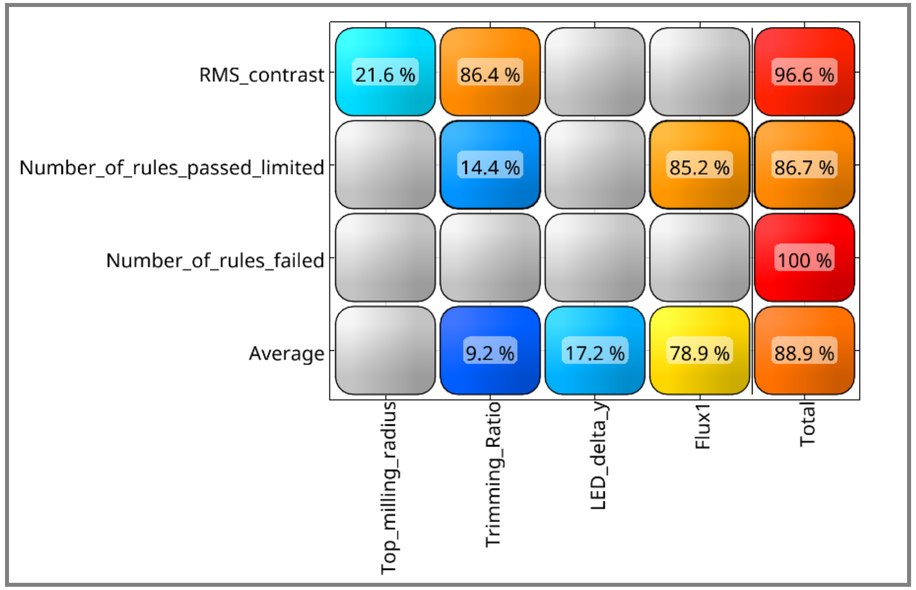
quality measurement	Limit
RMS-contrast (this is a measure of homogeneity: the smaller the value, the more homogeneous is the lit appearance)	≤ 0.2
average luminance (to avoid to less lighting)	≥ 160 kcd/m²
number of failed rules (number of not fulfilled national regulations)	≤ 0
Number of limited passed rules (number of not fulfilled customer specifications)	≤ 2

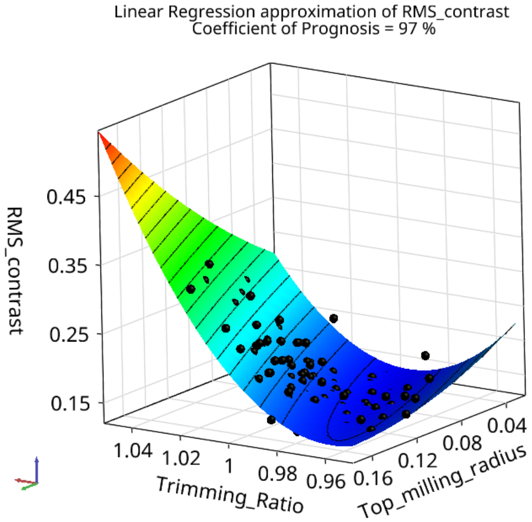
- *How to review the results* is shown in the following.

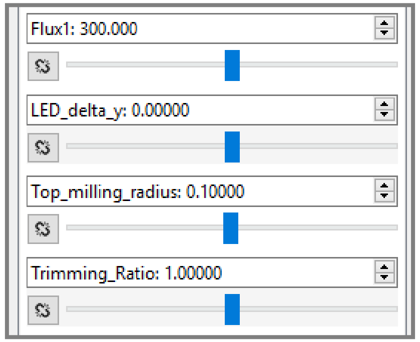
Robustness Analysis - Postprocessing

Postprocessing 1: Identify and understand important tolerances

- The COP-Matrix in the optiSLang postprocessing shows us which of the considered tolerances have an impact on the optical performance and the single regulations. With this, we can answer the question **"Which tolerance must be improved to increase the robustness of the design?"**
- Clicking on one of the **Total** values in the COP-Matrix shows the corresponding Metamodel of Optimal Prognosis (MOP) in the **Response Surface 3D plot.**
- The **MOP approximates the response as function of all important input parameters**. This plot is the representation of the Metamodel based on the two main contributors and the remaining ones are set to a fixed value. By using the sliders, you can see the influence of the other dimensions.
- **The MOP shows the scattering of the responses based on the scattering of the tolerances**







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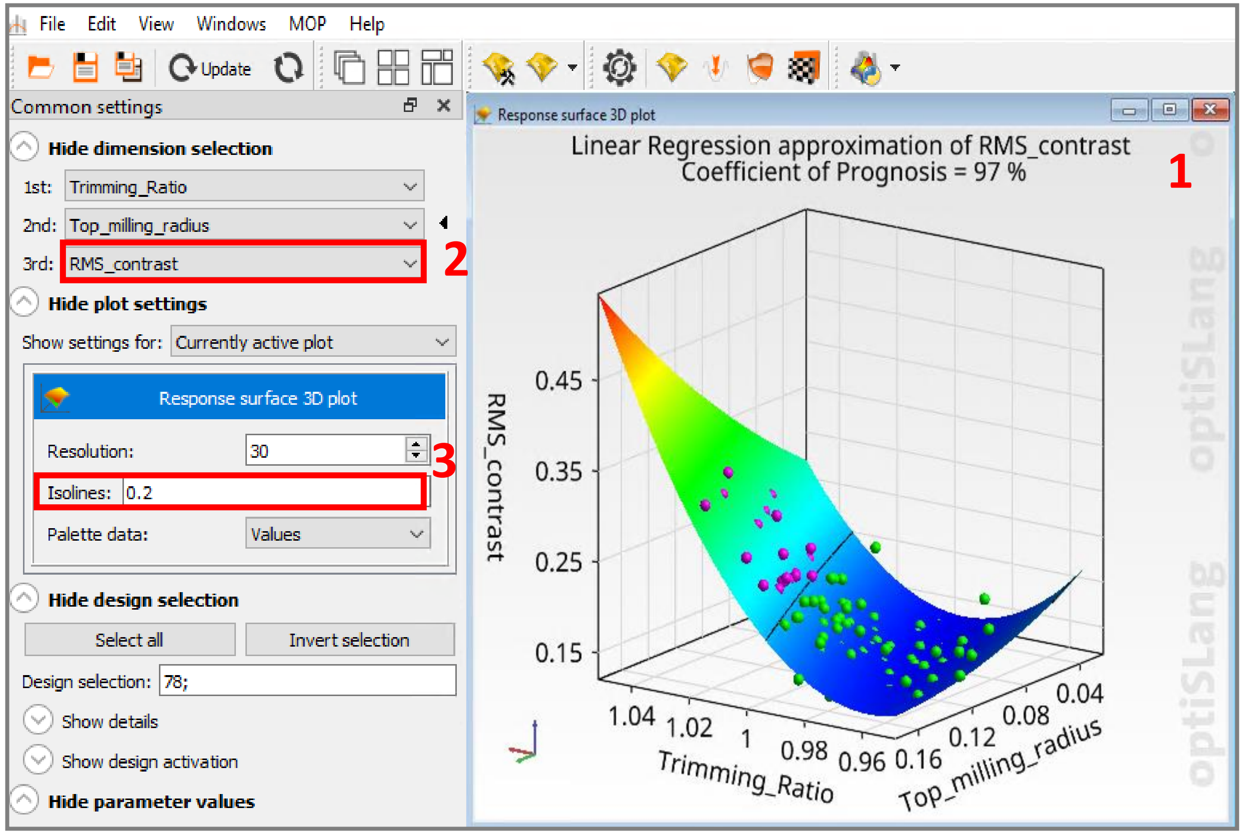
Robustness Analysis - Postprocessing

Based on the metamodels we can understand where (in which range of the tolerances) the regulations are not fulfilled, or where the optical performance is worst.

1. Click on **Response Surface 3D plot** plot to activate
2. Choose **RMS_Contrast**
3. Enter the Limit for the RMS contrast for a Isoline
4. Optional: How to color the designs is shown in the appendix **Coloring Designs**



Green: Design is feasible (RMS contrast ≤ 0.2)
Magenta: Design is not feasible (RMS contrast > 0.2)

RMS contrast

- mainly impacted by following tolerances
  - milling
  - trimming ratio
- The design exceed the limit under higher trimming ratios.

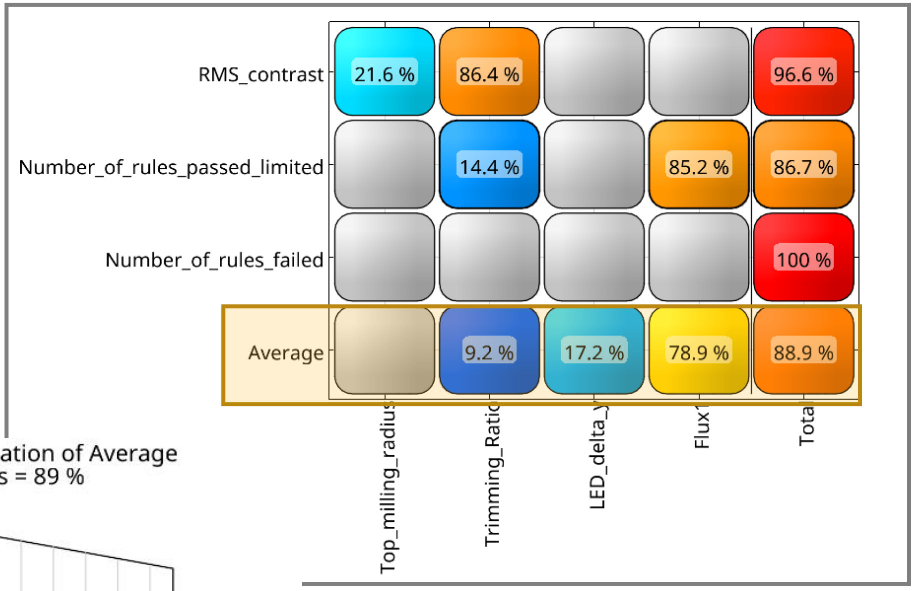
Ansys

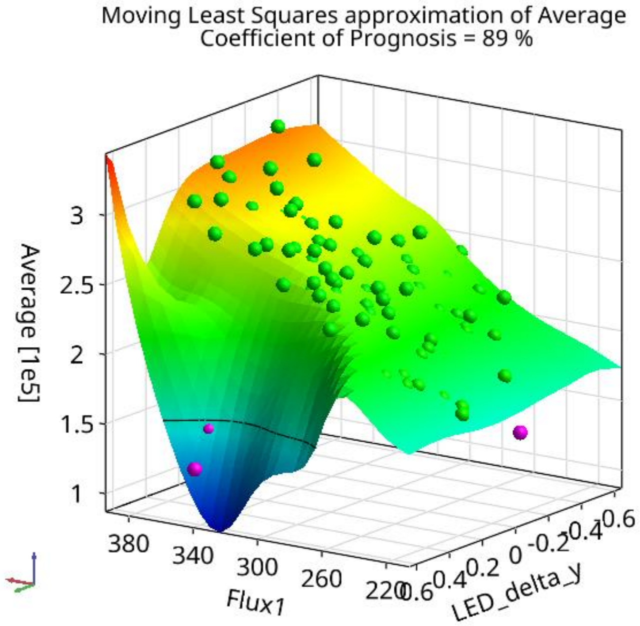
Robustness Analysis - Postprocessing

5. Redo Step 1 – 4 for the response **average**

Average luminance

- mainly impacted by following tolerances
  - energy of the light source (Flux)
  - the LED-position in y-direction
  - Trimming ratio
- The design exceed the limit of 160kcd/m² with the highest LED position in y-direction or with a surface energy smaller than 220lm





Green: Design is feasible (under the limit)
Magenta: Design is not feasible (limit is exceeded)

Robustness Analysis - Postprocessing

6. Redo Step 1 – 4 for the responses **Number of failed rules** (National regulation) and **Number of rules passed limited** (customer specification)

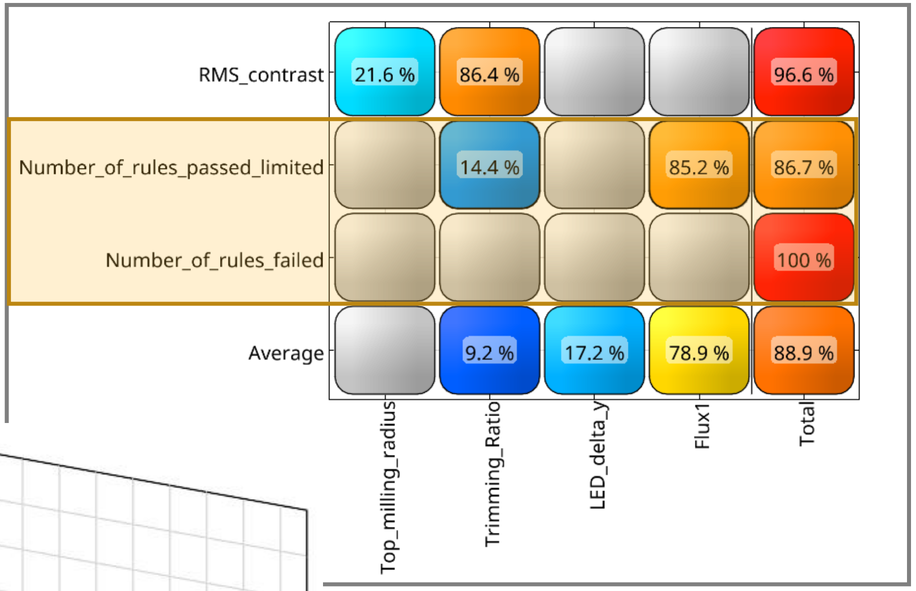
National regulations:

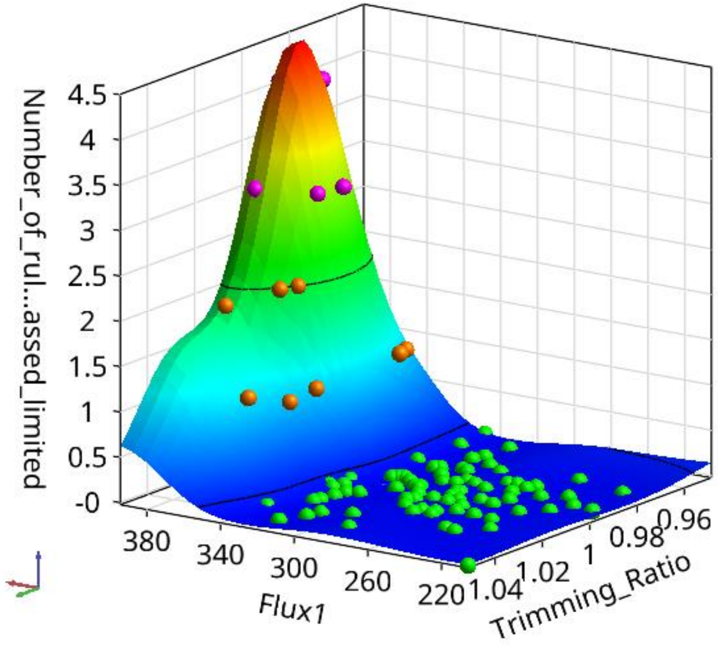
- no designs exceed the limit
  (number of failed rules ≤ 0 for all designs)

Specifications:

- mainly impacted by following tolerances
  - energy of the surface (Flux)
  - LED position in y-direction
  - trimming ratio
- The designs exceed the limit under a surface energy greater than 340lm

7. Optional: Check probability of failure for each single regulation (see appendix: Section *"Further statistical evaluation for the single regulations")*





Green: Design is feasible (under the limit)
Orange: design is feasible, number of rules limited passed ≤ 2
Magenta: Design is not feasible (number of rules limited passed > 2)

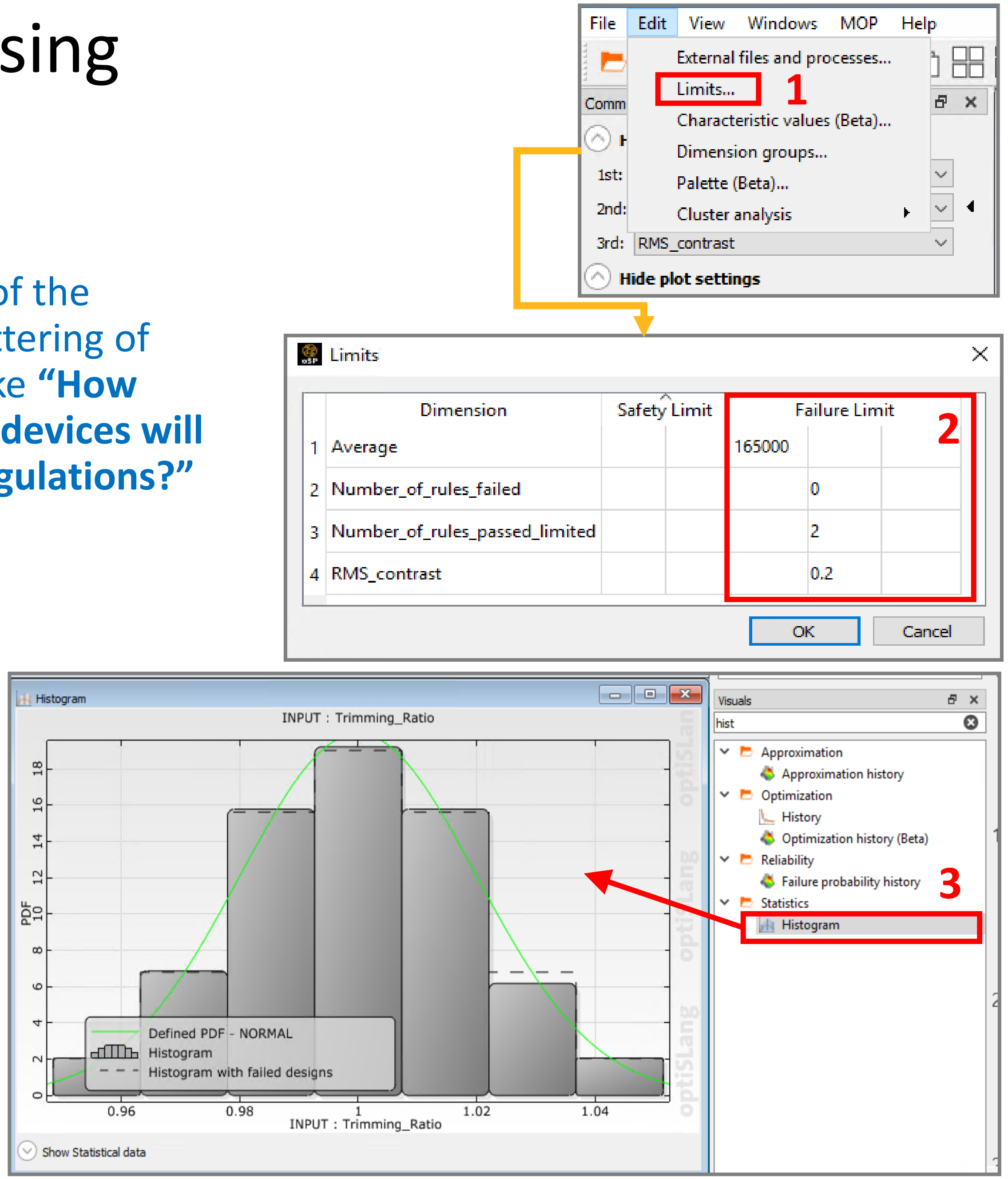
Ansys

Robustness Analysis - Postprocessing

Postprocessing 2: Get the probability of failure

- The Robustness Analysis shows the statistical distribution of the device response due to the manufacturing tolerances (scattering of the output parameters). With this, we answer questions like **"How robust is the light guide?" What percentage of fabricated devices will not meet the required design goal or will not fulfill the regulations?"**

1. Open **Limits** under **Edit** in the menu bar
2. Add upper or lower limits for the outputs that shall not be exceeded
3. Click **OK** in the **Limits** window
4. Search for **Histogram** in **Visuals** on the right side of the optiSLang postprocessing window
5. **Drag & Drop** the **Histogram** into the postprocessing scenery



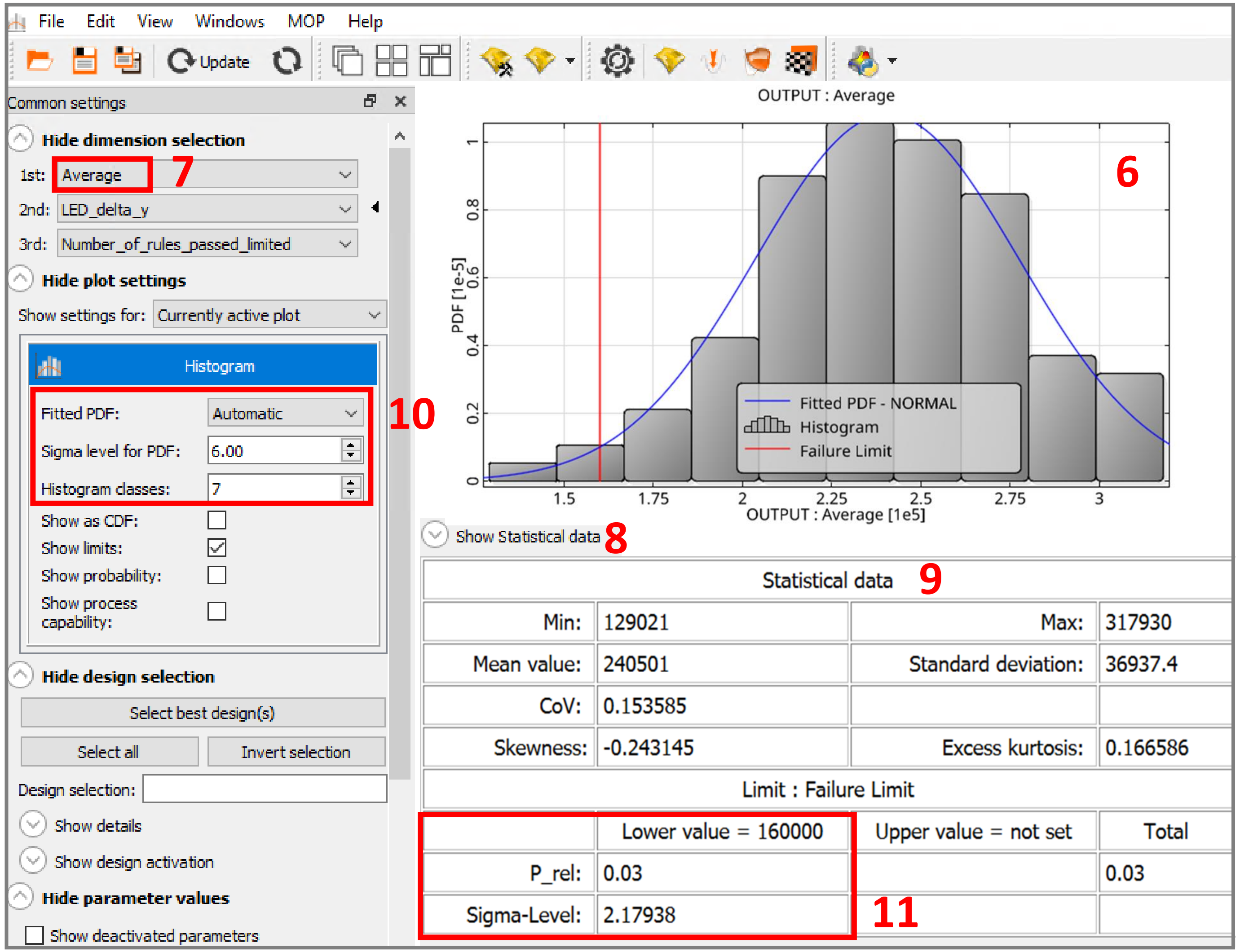
Ansys

Robustness Analysis - Postprocessing

6. Click on **Histogram** plot to activate
7. Choose **Average**
8. Click on **Show Statistical data** in the **Histogram** plot
9. Check distribution and statistical data in the histogram plot.
10. Optional: Select a Probability density function and histogram classes
11. Repeat Step 7 to 9 for all other outputs:

The probability that the:

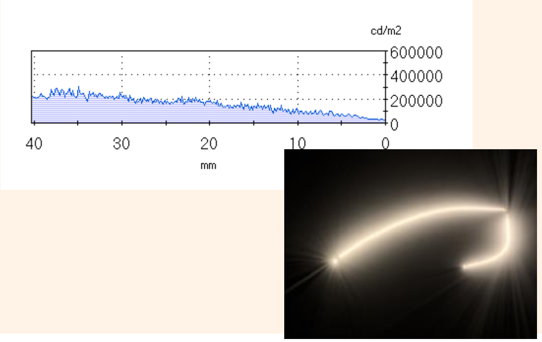
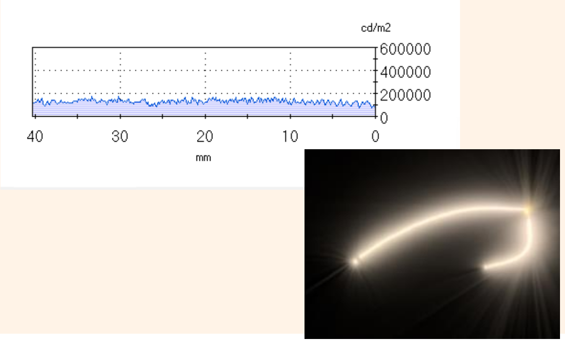
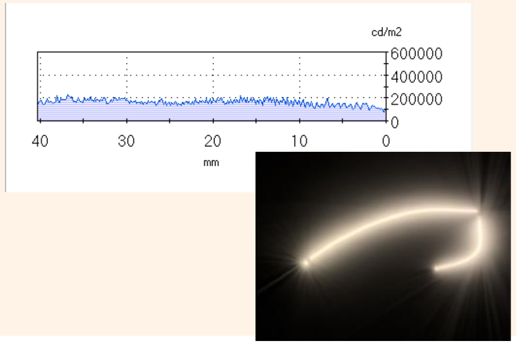
- ***average*** *is smaller than 160kcd/m² is 3.0%. This represents a sigma level of 2.18.*
- ***RMS contrast*** *is higher than 0.2 is 24%. This represents a sigma level of 0.38.*
- ***number of not fulfilled regulations*** *is higher than 0 is 0.*
- ***number of not fulfilled specifications*** *is higher than 2 is 5,0%. This represents a sigma level of 2.05.*



Ansys

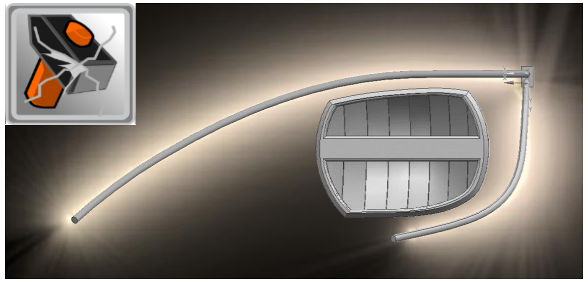
Summary

- Due the Robustness Analysis:
  - the scattering of the RMS-contrast and the average luminance gets visible
  - a probability of failure and the corresponding sigma level could be calculated
  - the important tolerances that impact the optical performance are figured out

	worst design regarding RMS contrast due to tolerances	**worst design regarding average luminance due to tolerances**	**Nominal Design (= best design from optimization)**
RMS contrast	0.44	0.15	0.15
Average luminance [kcd/m²]	154 > 160 (not fulfilled)	129 > 160 (not fulfilled)	162 > 160 (fulfilled)
Number of not fulfilled regulations	0/42 (fulfilled)		
Result			

Summary

- How robust is the lightguide?



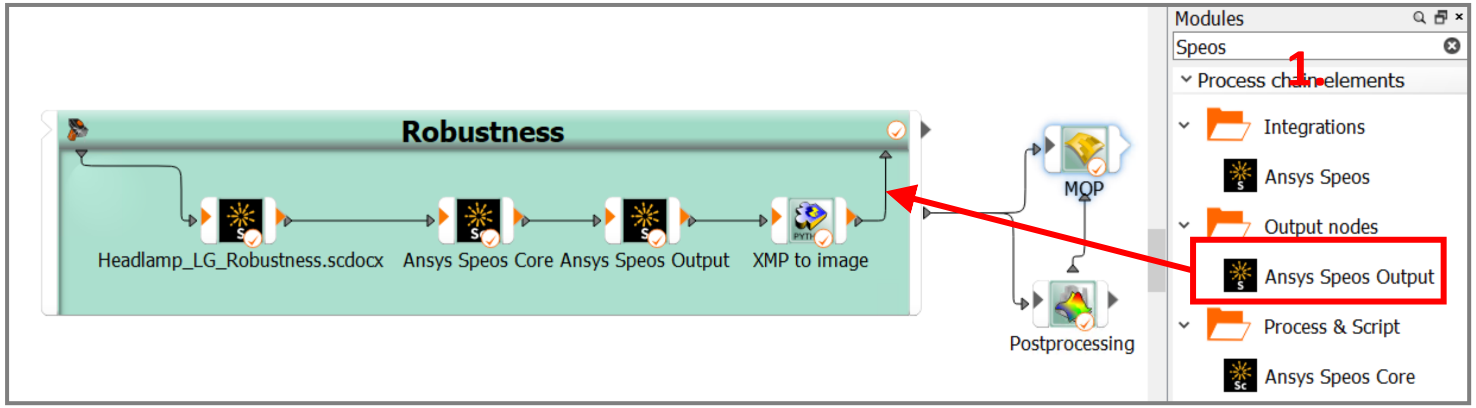
	probability of failure	Possibility to get a more robust design
national regulation	0 % (robust)	**To determine a very small failure rate (< 1:1000; sigma levels larger than 3), we recommend a reliability analysis**
specifications	5,0 %	**Tune mainly the flux tolerances** → e.g., ensure that the max energy light source is smaller than 340 lumen to get a robust design
Average luminance	3,0 %	**Tune flux and LED y-position tolerances** → e.g., ensure that the max LED y-position is smaller than 0.5 mm to get a robust design
RMS contrast	24,0 %	**Tune Trimming ratio and milling value tolerances** → e.g., ensure that the max trimming ratio is about ± 2% to get a robust design

Appendix

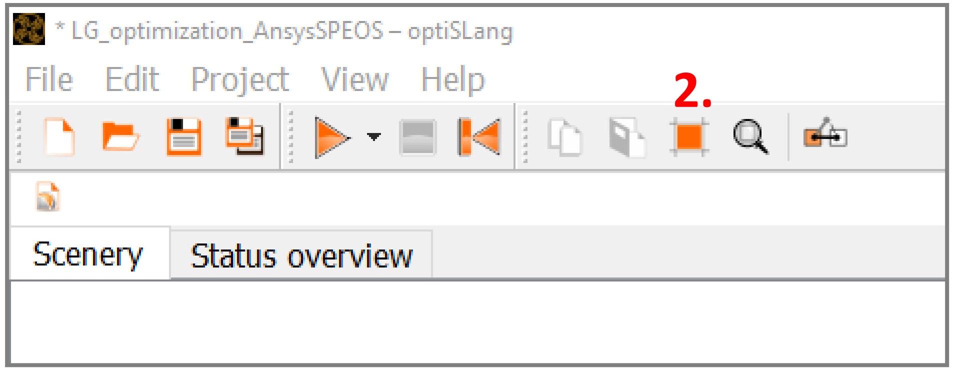
Further statistical evaluation for the single regulations

Workflow extension

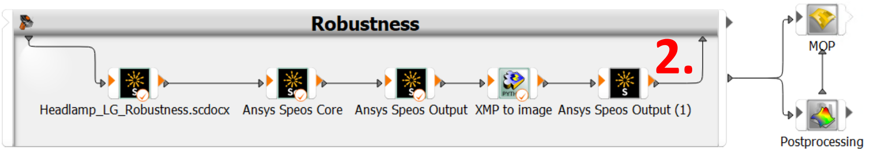
In order to analyze the single regulations, we must extract the additional responses from the html-file. How to do is shown in the following:



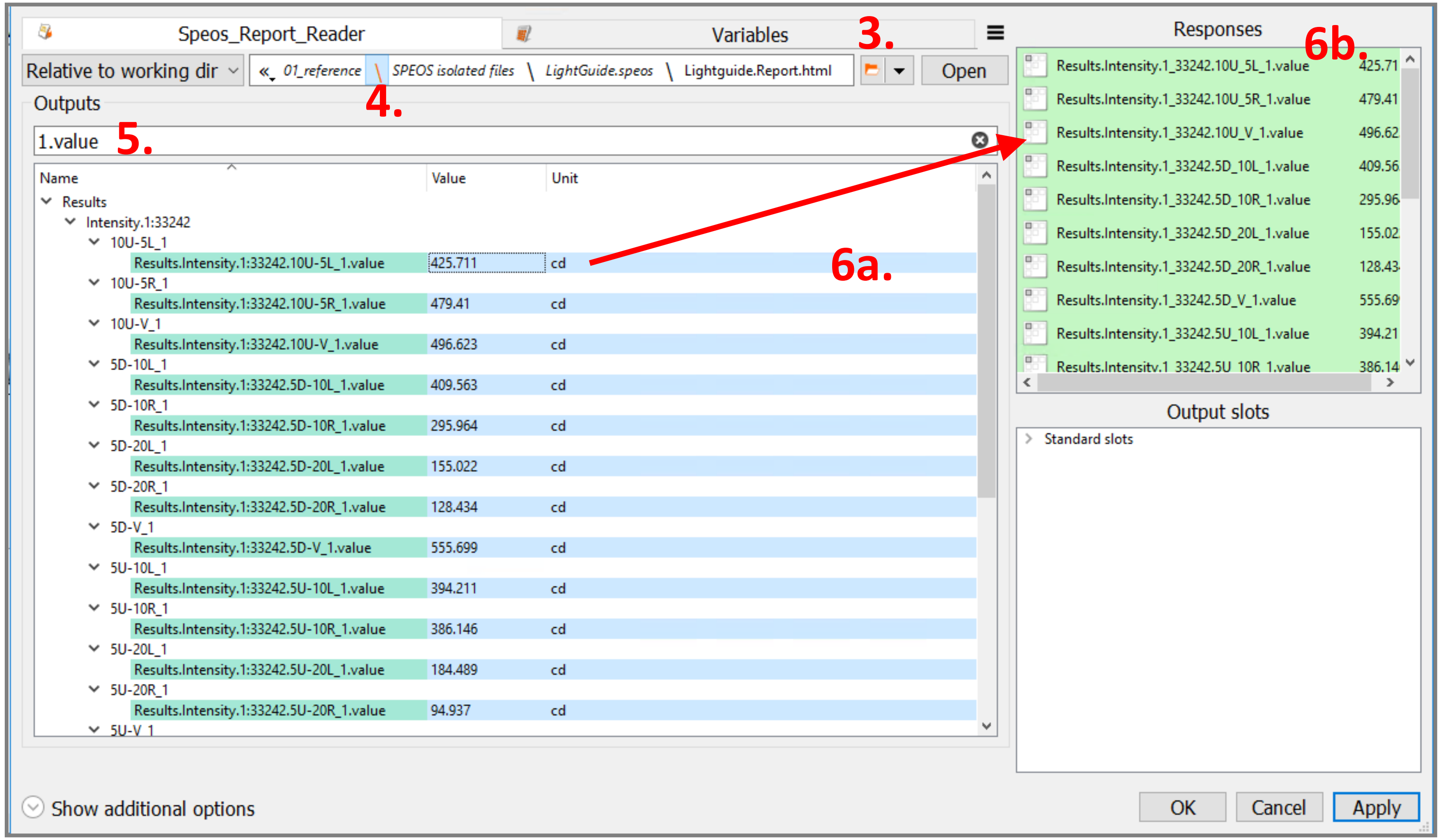
1. Search for the **Ansys Speos Output** node and drag and drop it onto the arrow at the end of the solver chain
2. Click to **Optimal Layout** button in the tool bar



Ansys Speos Output node



2. Double-click on **Ansys Speos Output (1)**
3. Browse for the file Lightguide.Report.html in **…\SPEOS isolated files\LightGuide.speos\Lightguide.Report.html**
4. Set the orange split path position
5. Search for "1.value"
6. Define all intensity values via drag and drop as responses
7. Click **Apply** and **OK**

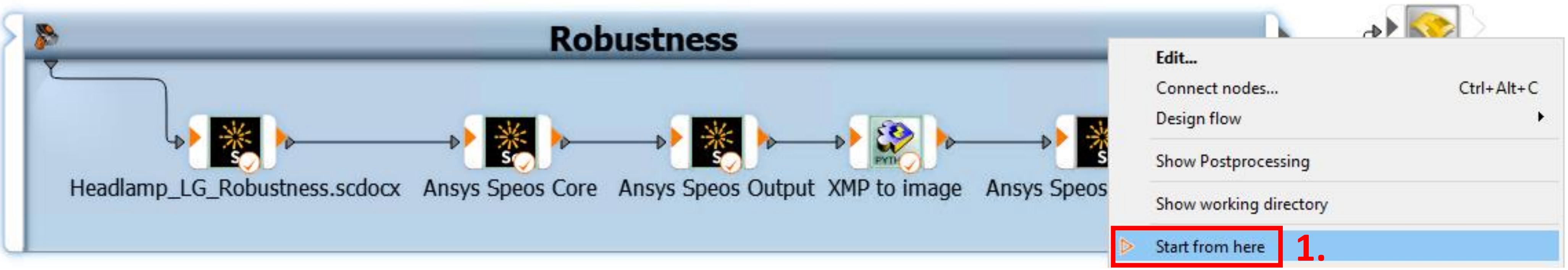


Execute the workflow

8. **Right click** on the Robustness System and click **Start from here**

→ For all designs, the additional responses are extracted from the Speos Report file without re-running the simulations

→ The postprocessing opens automatically



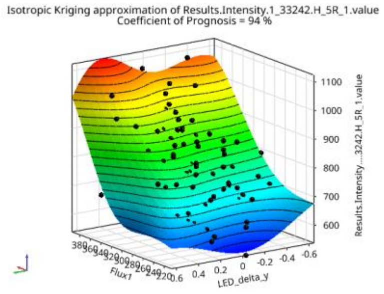
Results of the Robustness Analysis

Review the COP matrix in the optiSLang postprocessing to identify and understand important tolerances

The **regulations are mainly affected by**

- Energy of the surface (Flux)
- LED position in y-direction

Review the corresponding metamodels to understand the scattering of the intensity values.



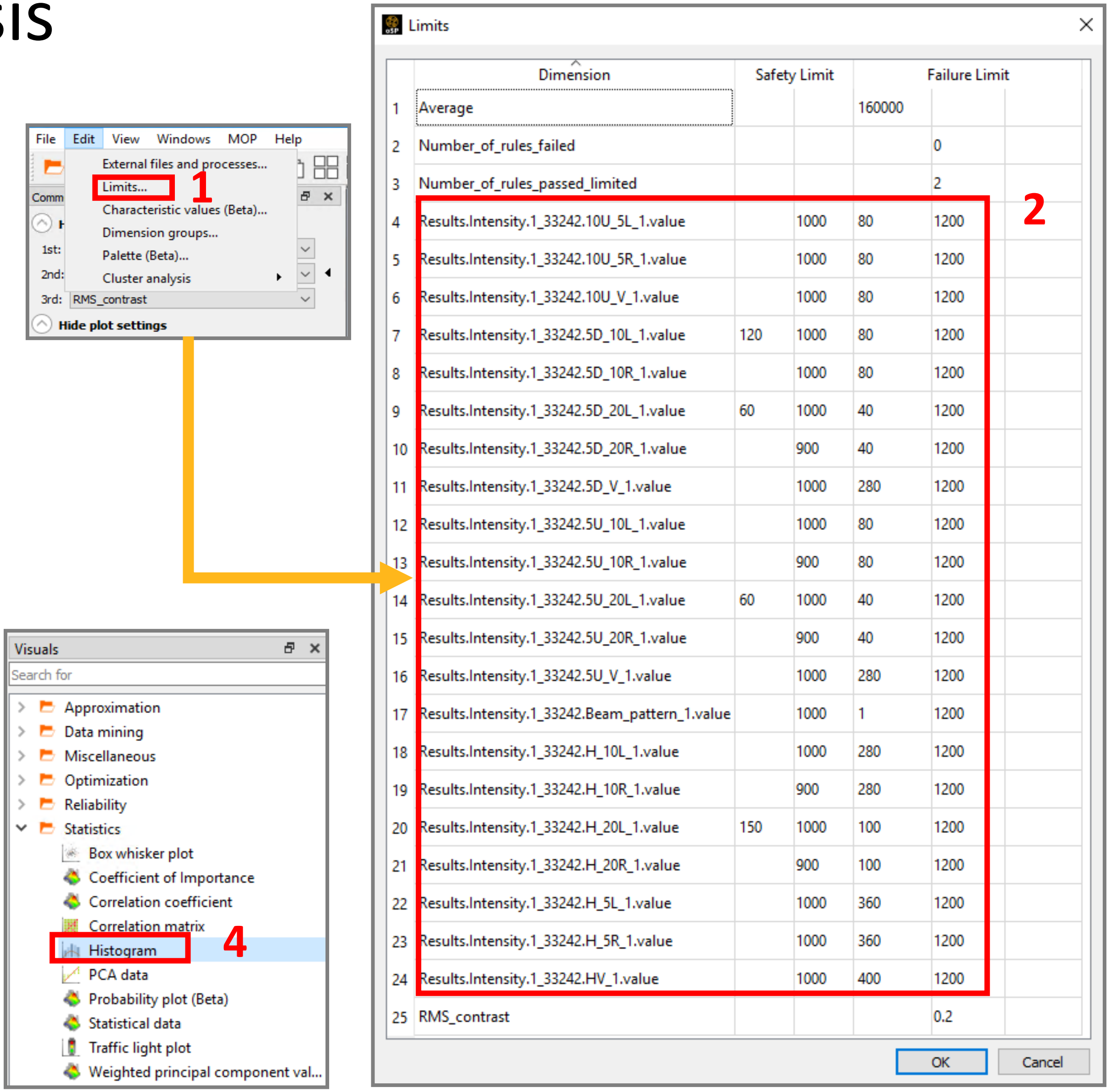
	Top_milling_radius	Trimming_Ratio	LED_delta_y Parameter	Flux1	Total
Results.Intensity.1_33242.H_5R_1.value			2.4 %	93.8 %	93.8 %
Results.Intensity.1_33242.H_5L_1.value			3.1 %	91.4 %	93.7 %
Results.Intensity.1_33242.H_20R_1.value			3.7 %	88.5 %	92 %
Results.Intensity.1_33242.H_20L_1.value			5.6 %	81.4 %	84.4 %
Results.Intensity.1_33242.H_10R_1.value			4.2 %	94.5 %	96.5 %
Results.Intensity.1_33242.H_10L_1.value			4.7 %	92.7 %	93.8 %
Results.Intensity.1_33242.HV_1.value			1.7 %	92.2 %	92.8 %
Results.Intensity.1_33242.Beam_pattern_1.value			7.1 %	83.5 %	90.6 %
Results.Intensity.1_33242.5U_V_1.value		3.5 %	3.3 %	91.5 %	93.3 %
Results.Intensity.1_33242.5U_20R_1.value			6.6 %	83.5 %	89.6 %
Results.Intensity.1_33242.5U_20L_1.value			2.8 %	89.9 %	90 %
Results.Intensity.1_33242.5U_10R_1.value			5.5 %	94.1 %	96.5 %
Results.Intensity.1_33242.5U_10L_1.value		3.1 %	4.2 %	94.0 %	96.3 %
Results.Intensity.1_33242.5D_V_1.value			1.5 %	91.4 %	91.9 %
Results.Intensity.1_33242.5D_20R_1.value			5.6 %	88.7 %	92.9 %
Results.Intensity.1_33242.5D_20L_1.value		3.0 %		88.2 %	92.2 %
Results.Intensity.1_33242.5D_10R_1.value			5.6 %	90.1 %	96 %
Results.Intensity.1_33242.5D_10L_1.value			1.8 %	92.7 %	93 %
Results.Intensity.1_33242.10U_V_1.value		2.6 %	3.4 %	89.7 %	93.7 %
Results.Intensity.1_33242.10U_5R_1.value			2.5 %	93.0 %	93.4 %
Results.Intensity.1_33242.10U_5L_1.value			2.5 %	91.3 %	93 %
RMS_contrast	21.5 %	84.9 %			96.6 %
Number_of_rules_passed_limited		13.5 %		84.4 %	86.7 %
Number_of_rules_failed					100 %
Average		9.3 %	17.9 %	79.2 %	88.9 %

Ansys

Results of the Robustness Analysis

Review the scattering of the single regulations

1. Open **Limits** under **Edit** in the menu bar
2. add upper or lower limits for the outputs that shall not be exceeded
   „Safety limit“ for customer specifications
   „Failure limits“ for national regulations
3. Click **OK** in the **Limits** window
4. Search for **Histogram** in **Visuals** on the right side of the optiSLang postprocessing window
5. **Drag & Drop** the **Histogram** into the postprocessing scenery



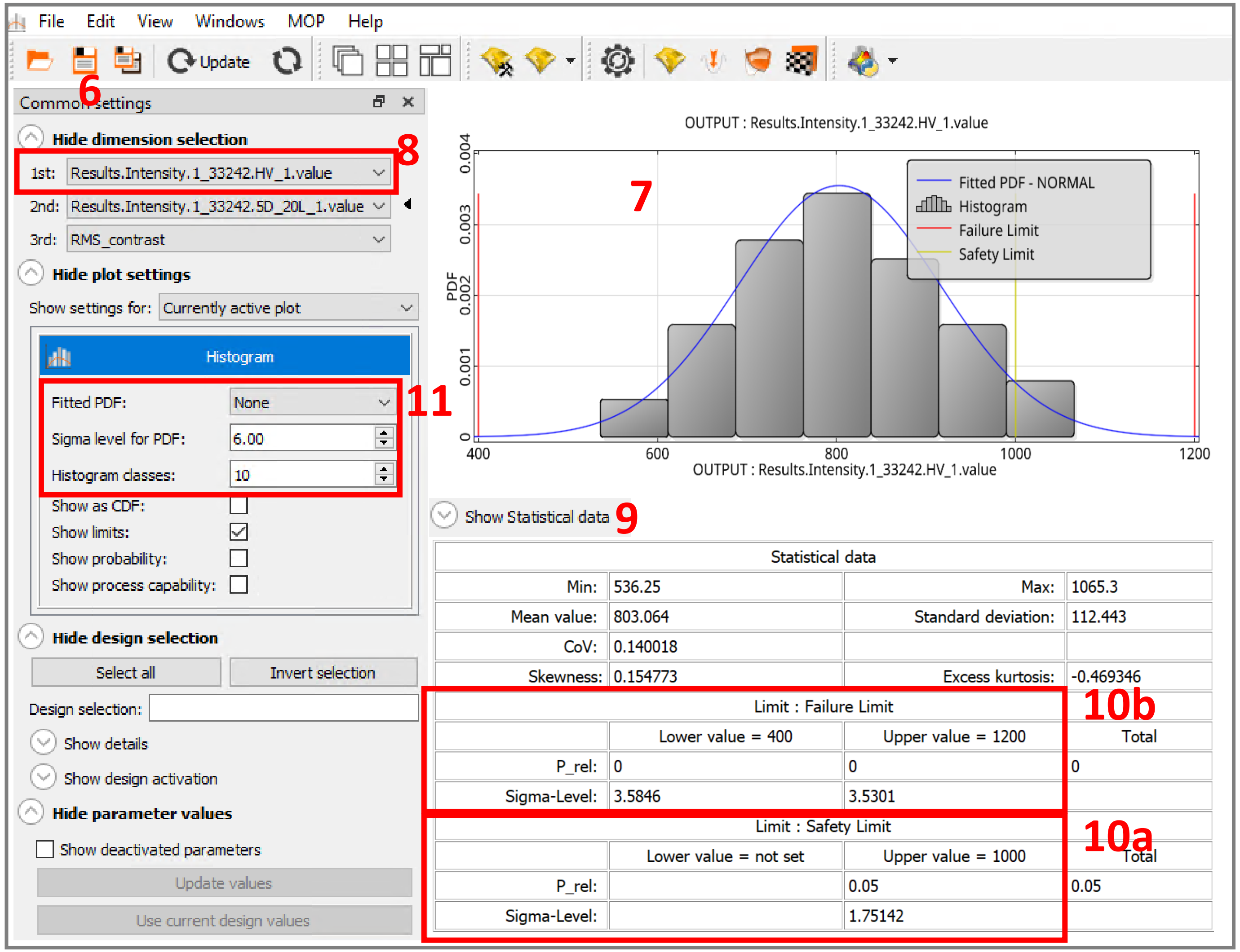
Results of the Robustness Analysis

6. Save the postprocessing to keep the limits
7. Click on **Histogram** to activate
8. Choose a regulation
9. Click on **Show Statistical data** in the **Histogram** plot
10. Check distribution and statistical data in the histogram plot.
11. Optional: Select a Probability density function and histogram classes

The probability to exceed the

- maximum specification: 5% (Sigma level: 1.75)
- minimum national reg.: 0 %
- maximum national reg.: 0 %

12. Re-do Step 7-10 for all other regulations



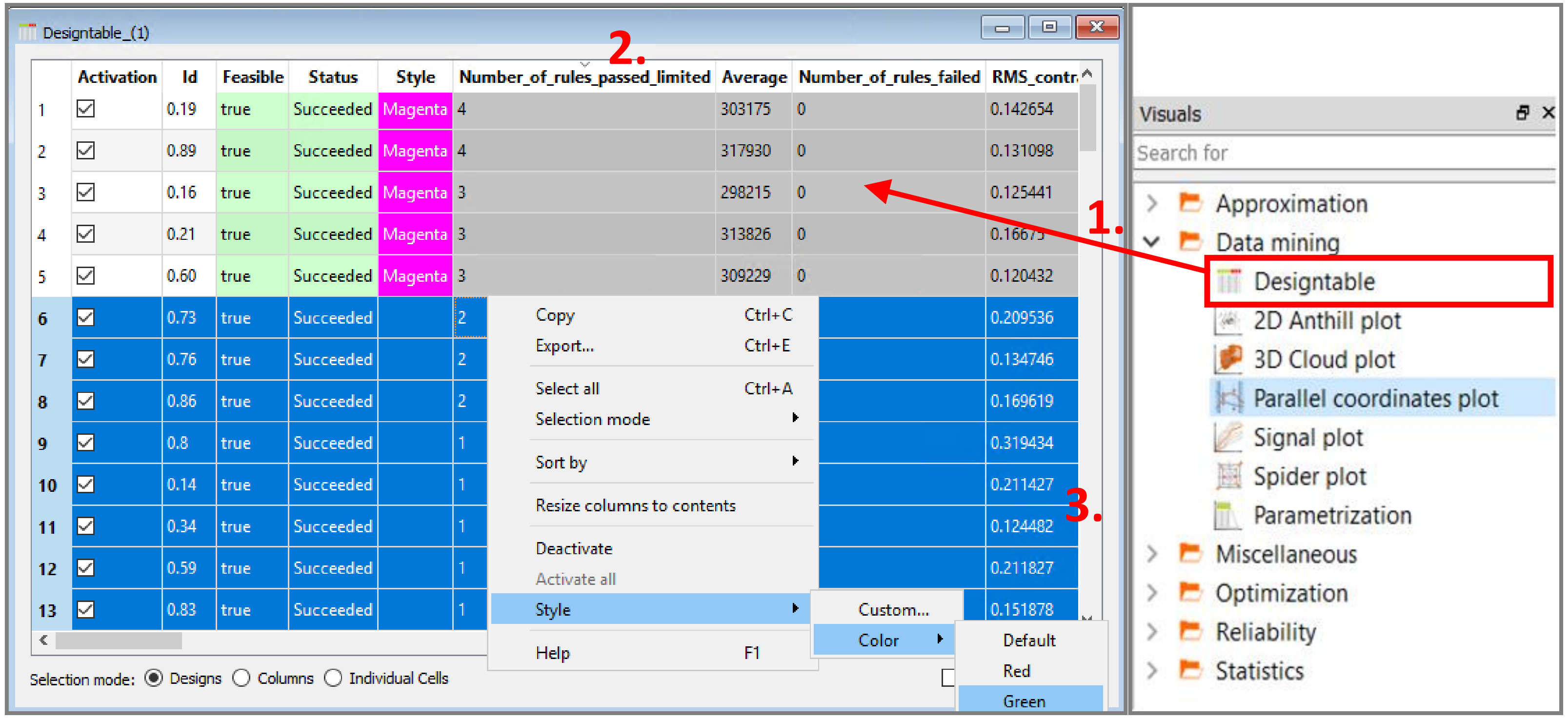
Statistical data				
Min:	536.25	Max:	1065.3	
Mean value:	803.064	Standard deviation:	112.443	
CoV:	0.140018			
Skewness:	0.154773	Excess kurtosis:	-0.469346	
Limit : Failure Limit				
	Lower value = 400	Upper value = 1200	Total	
P_rel:	0	0	0	
Sigma-Level:	3.5846	3.5301		
Limit : Safety Limit				
	Lower value = not set	Upper value = 1000	Total	
P_rel:		0.05	0.05	
Sigma-Level:		1.75142		

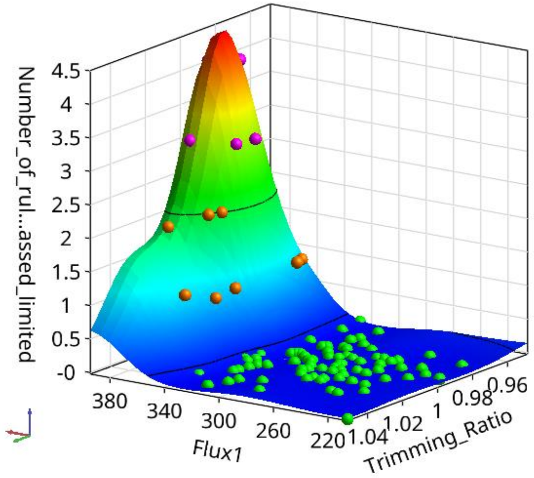
Coloring Designs

Ansys

Results optimization using the Adaptive MOP

1. Drag the „Designtable“ into the Postprocessing
2. Sort the designs for a specific input or output
3. Mark some designs and right click to change the style
4. Check in the MOP where the feasible designs are located





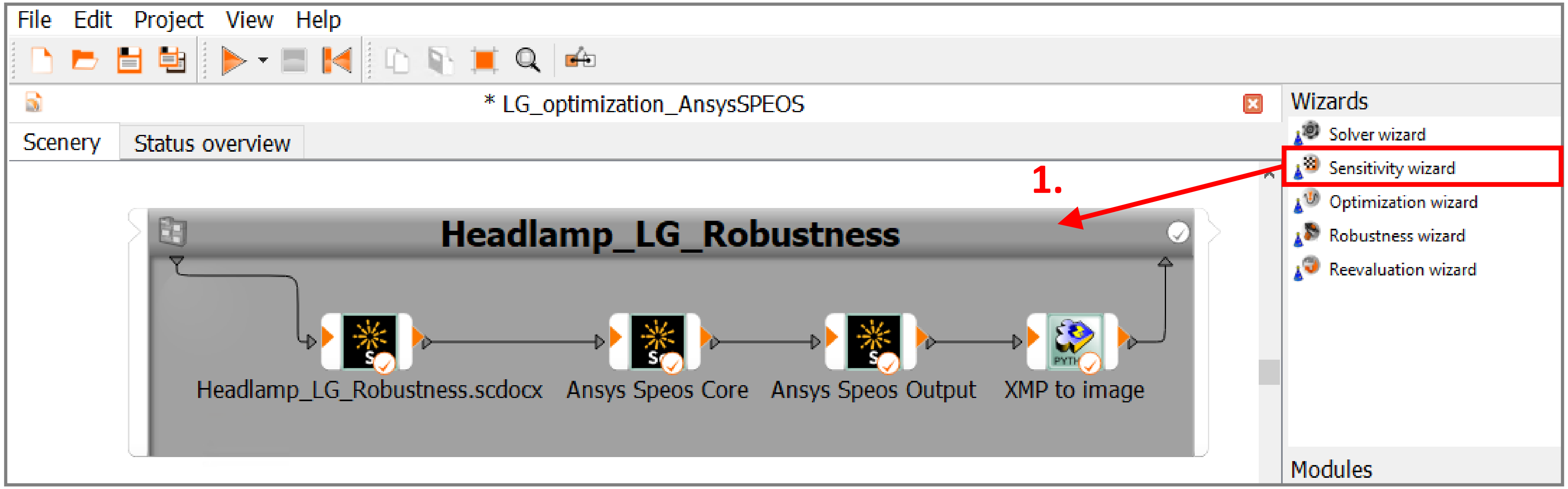
Ansys

Check Solver Noise

Check Solver Noise

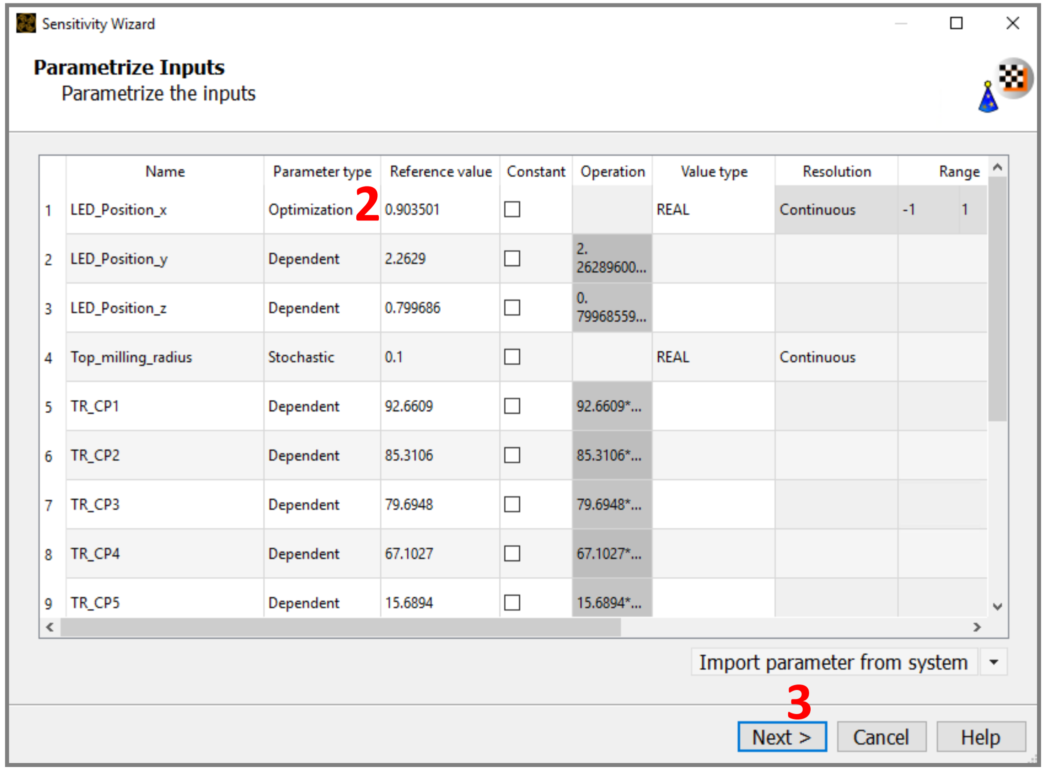
How to setup the system in order to control the solver noise is shown in the following

1. Drag the sensitivity wizard onto the head of the solver chain



Check Solver Noise

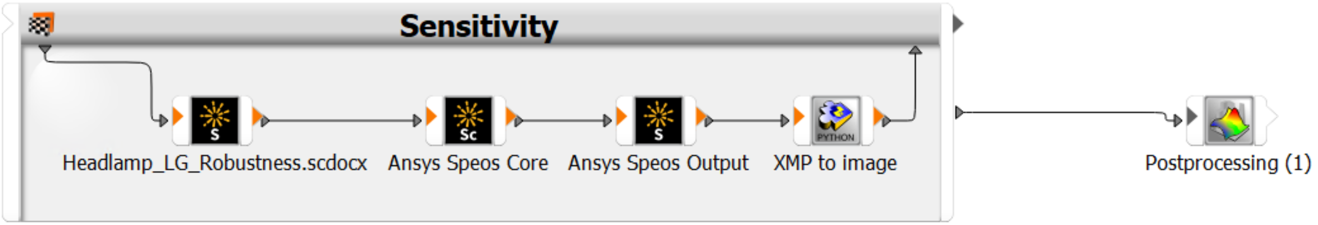
2. Change the **Parameter type** for one Parameter to **Optimization** (will not have an influence but needed to setup sensitivity study)
3. Click **Next**
4. Click **Next** in the Criteria window

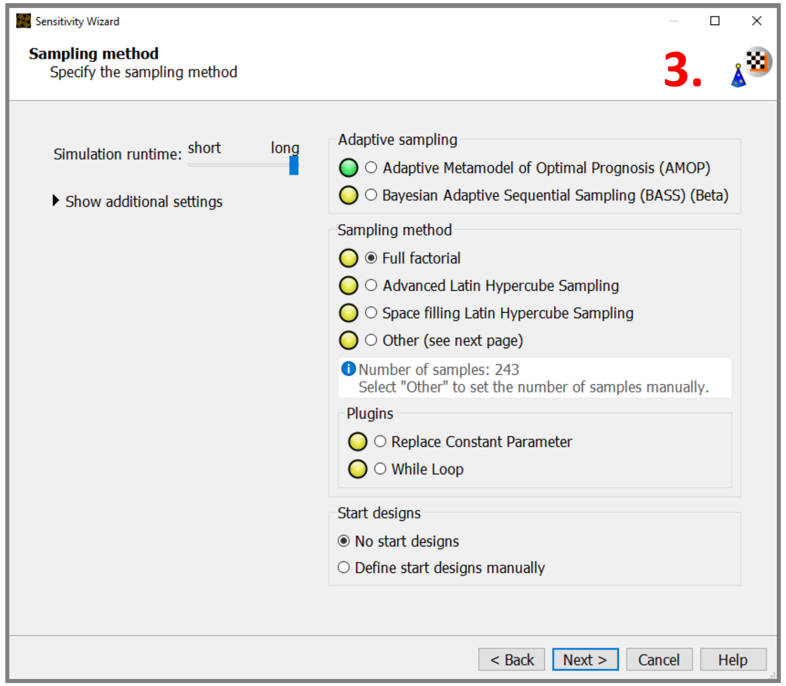


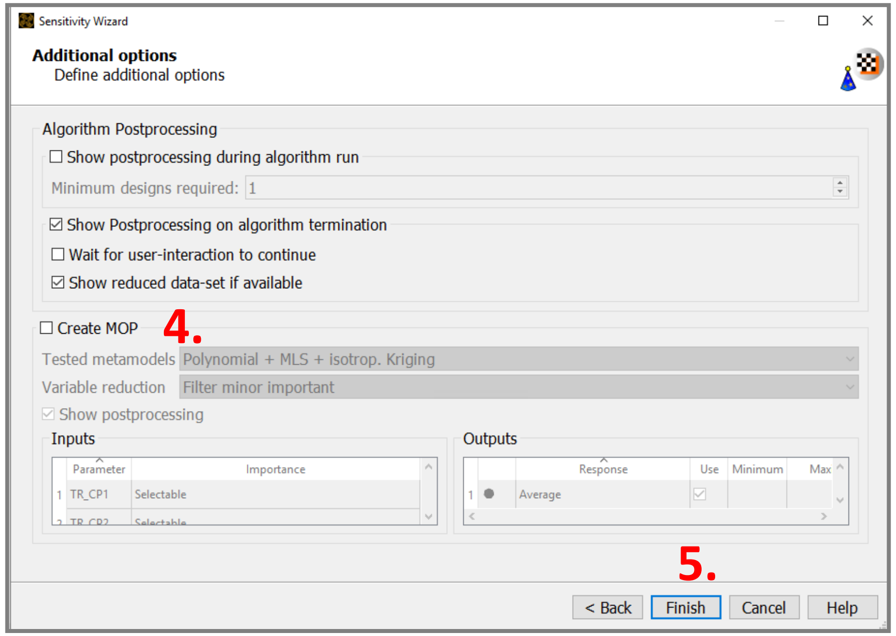
Ansys

Check Solver Noise

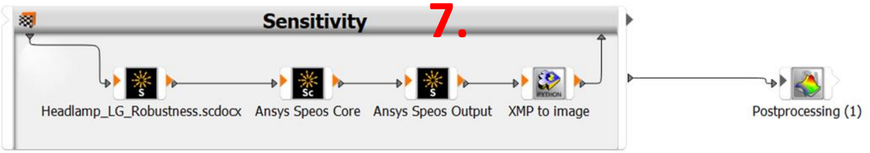
3. Choose **Full Factorial** as **Sampling method** and click **Next**
4. Disable **Create MOP**
5. Finish the wizard
6. The new sensitivity system will be created automatically:



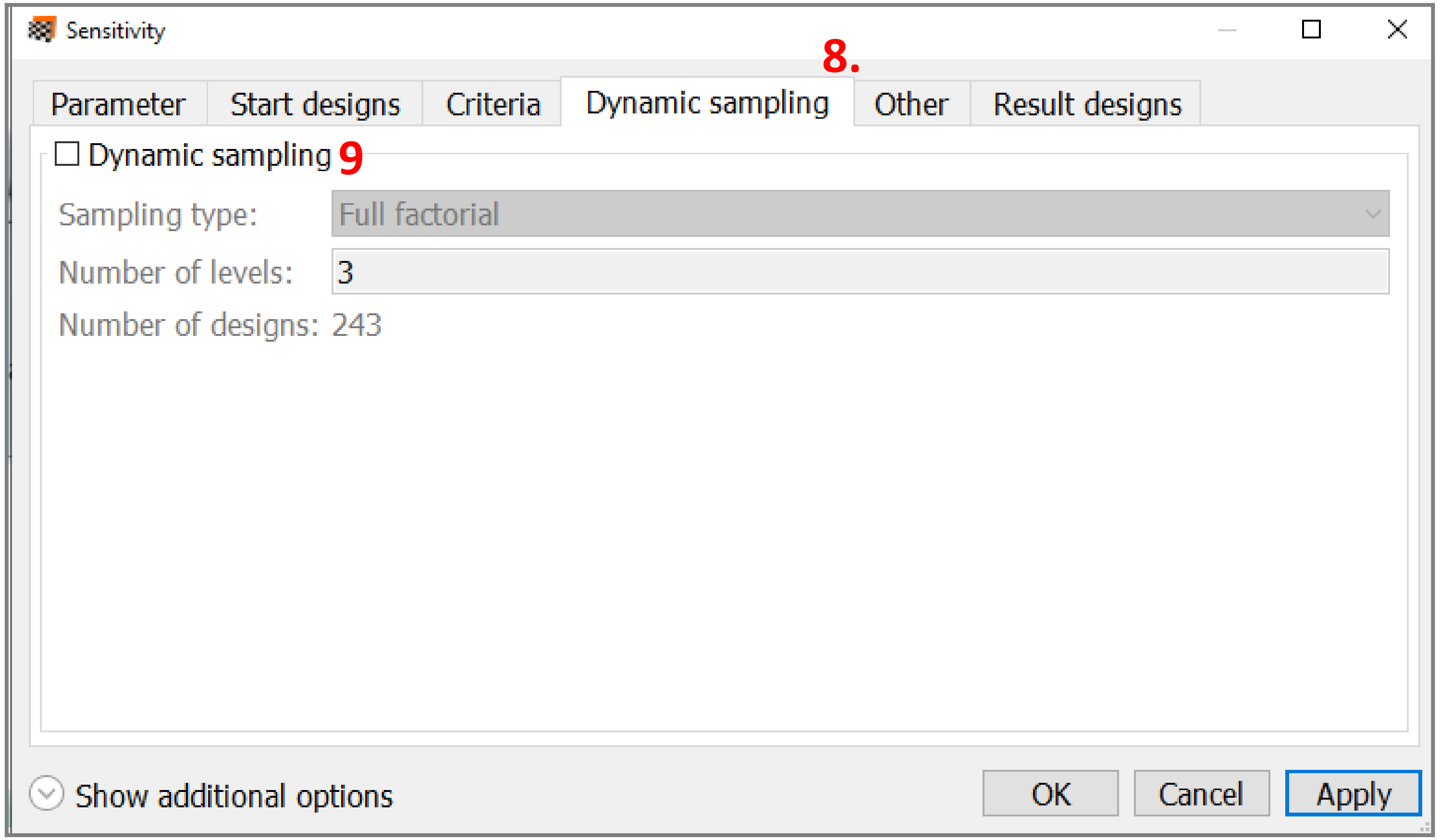




Check Solver Noise

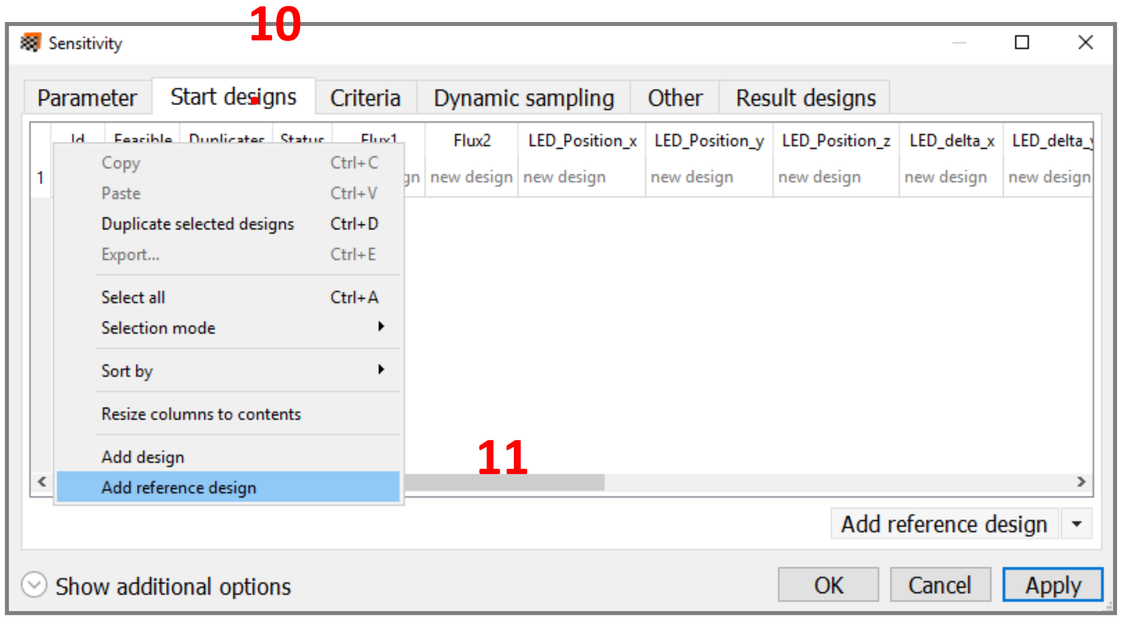


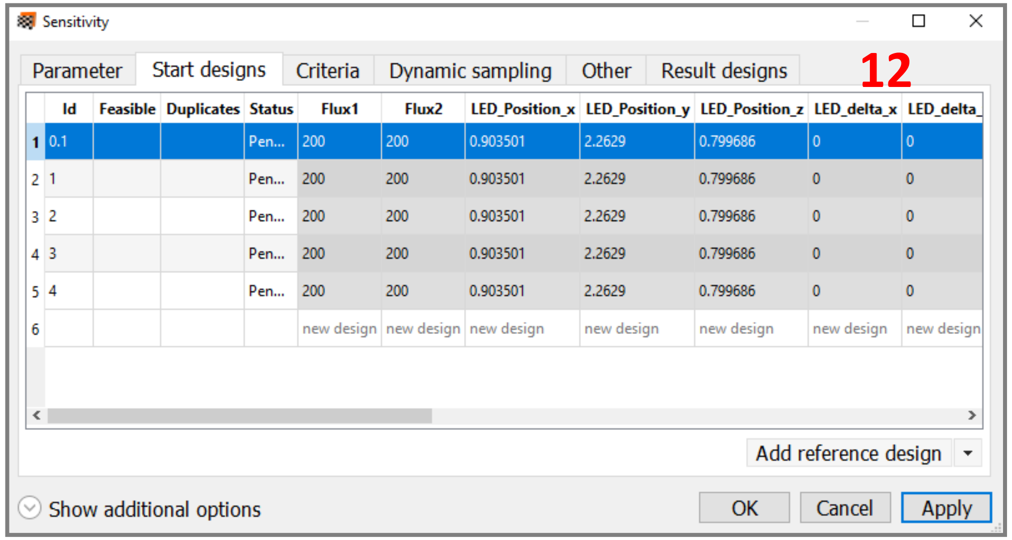
7. Open the **Sensitivity** system by **double click** on the systems head
8. Go to the **Dynamic sampling** Tab
9. Disable **Dynamic sampling**



Check Solver Noise

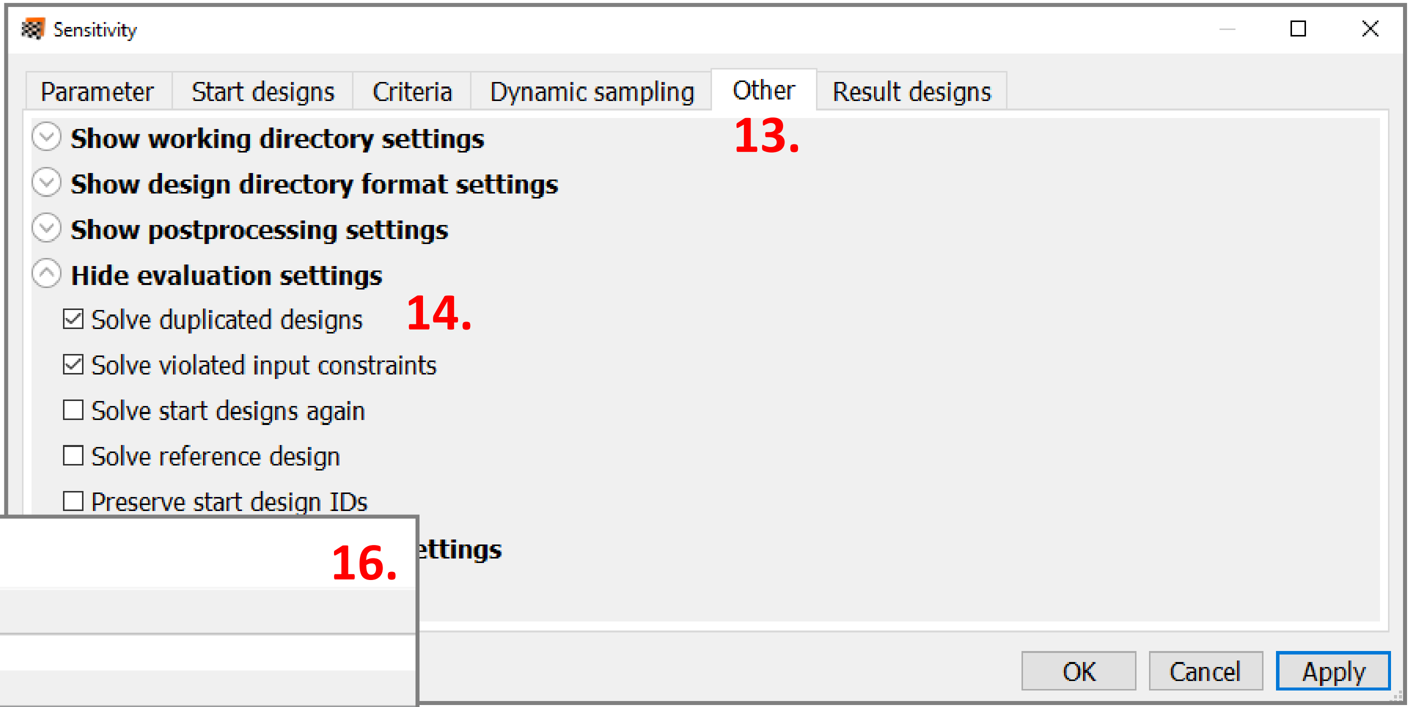
10. Go to the **Start designs** Tab
11. **Right click** in the first line to **add reference design**
12. Mark line one and duplicate the first line 5 times (e.g., using Ctrl+D)

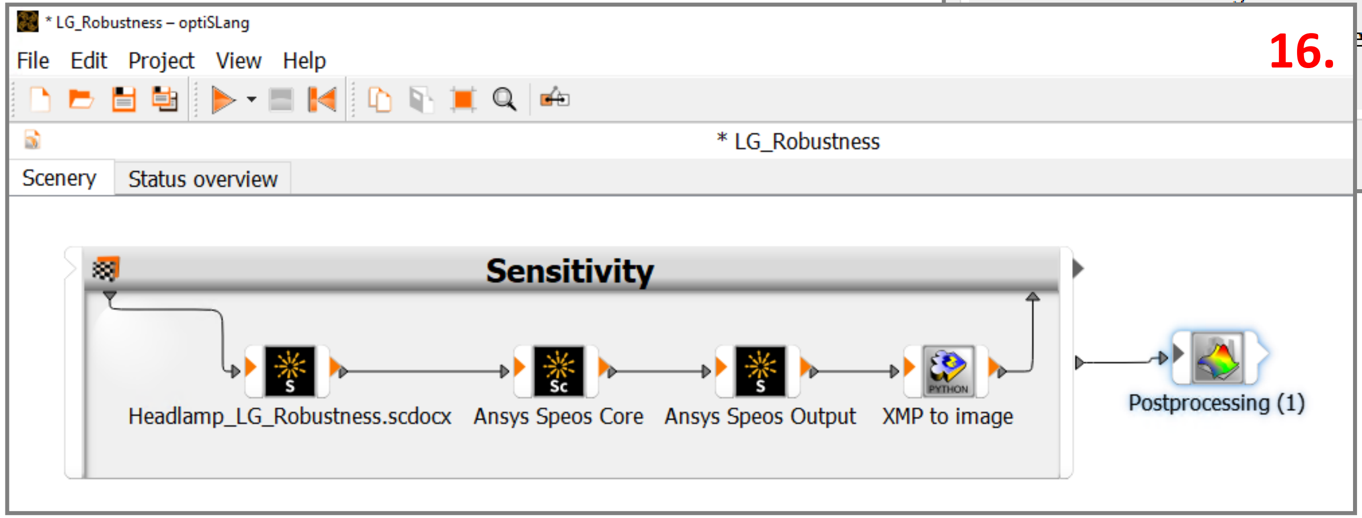




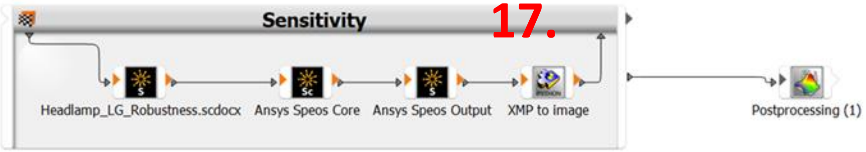
Check Solver Noise

13. Go to the **Other** Tab
14. Enable **Solve duplicated designs**
15. Press **Apply** and **OK**
16. **Save** and **Execute** the workflow



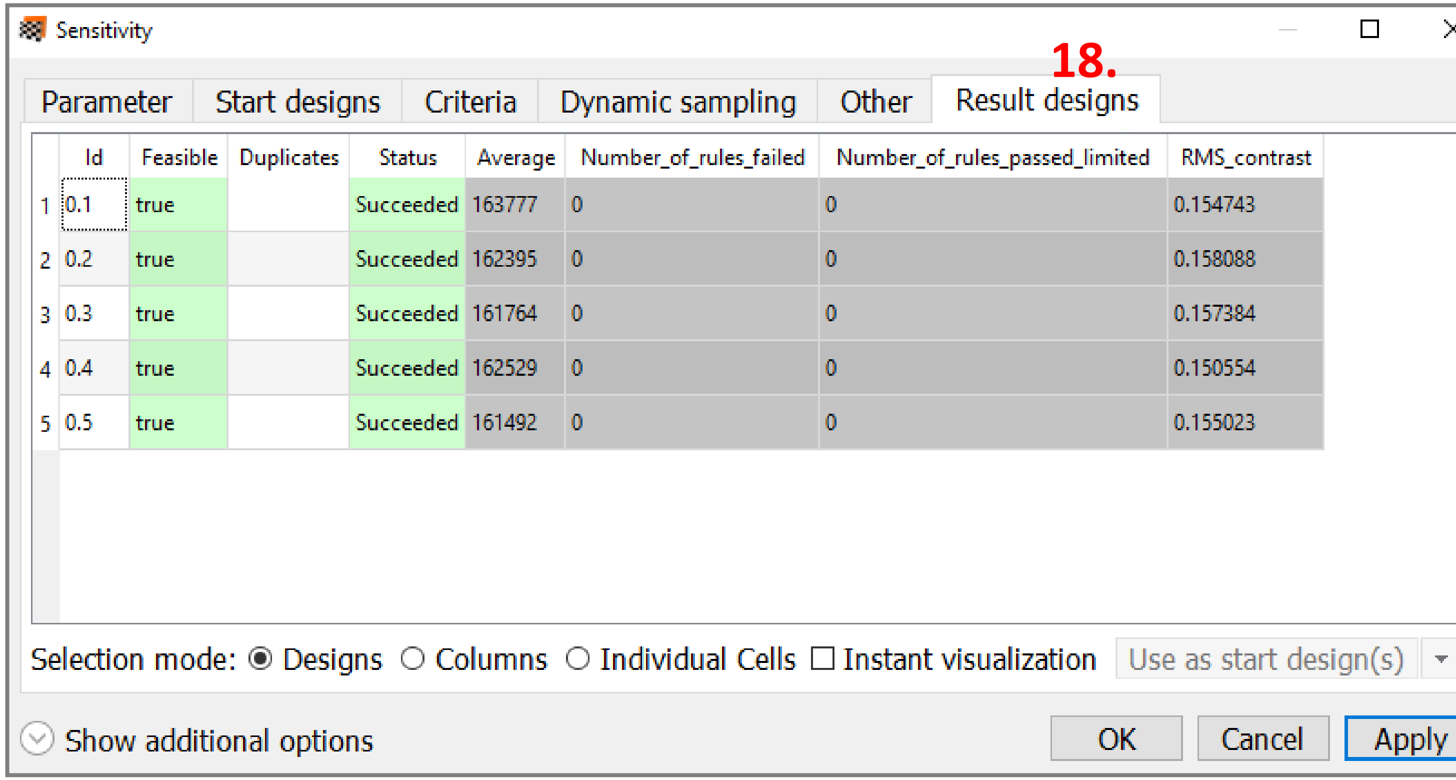


Check Solver Noise



17. Open the **Sensitivity** system by **double click** on the systems head

18. Go to the **Result designs** Tab



	Id	Feasible	Duplicates	Status	Average	Number_of_rules_failed	Number_of_rules_passed_limited	RMS_contrast
1	0.1	true		Succeeded	163777	0	0	0.154743
2	0.2	true		Succeeded	162395	0	0	0.158088
3	0.3	true		Succeeded	161764	0	0	0.157384
4	0.4	true		Succeeded	162529	0	0	0.150554
5	0.5	true		Succeeded	161492	0	0	0.155023

Check the scattering of the output values. To identify the important tolerances a high simulation quality is necessary. However, the maximum difference between the results should be less than about 5%.

End of presentation