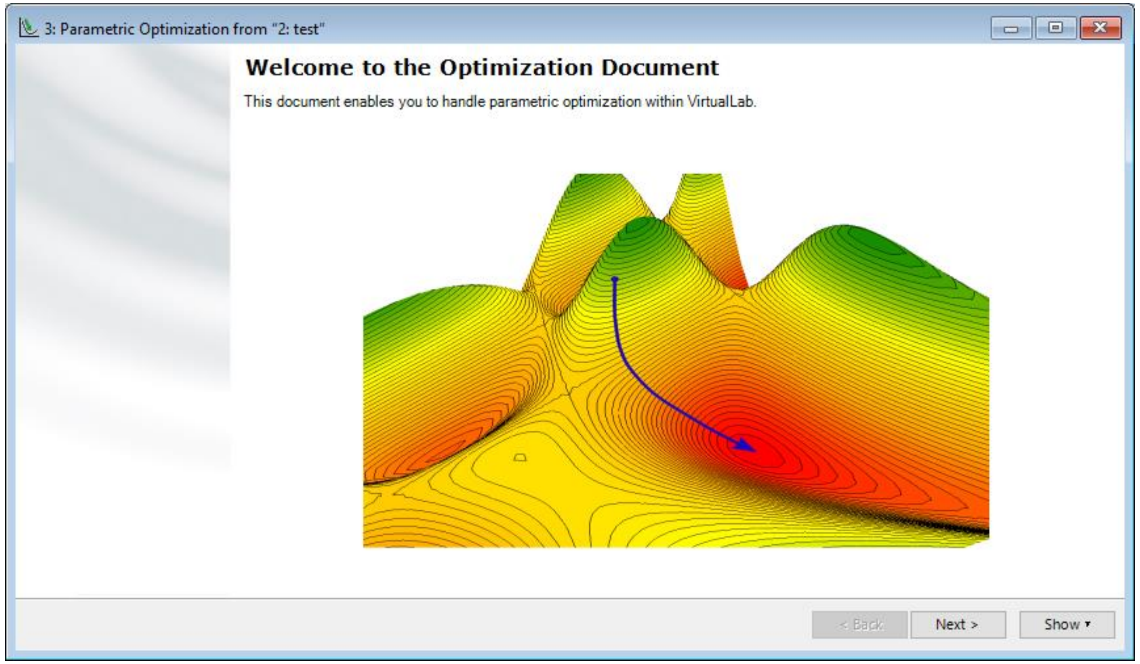
Introduction to the Parametric Optimization Document

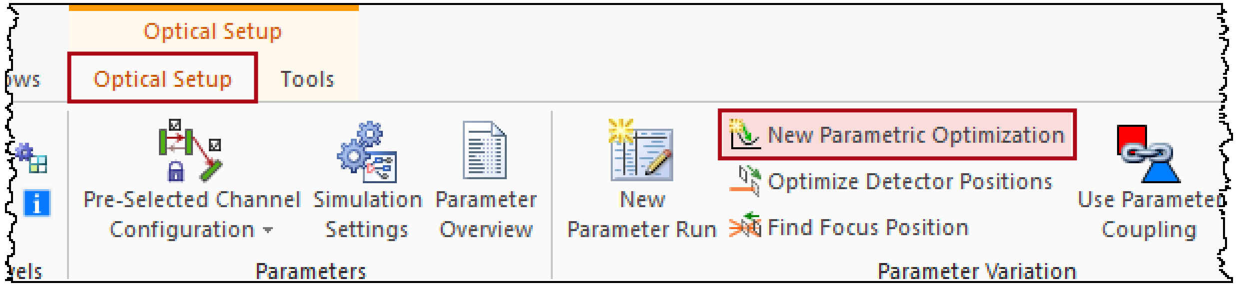
Abstract



The Parametric Optimization document of VirtualLab Fusion enables the user to apply non-linear optimization algorithms for their *Optical Setups*. The document guides you through the configuration of the optimization and outputs the results in a table. This use case explains the available options and setting. Currently, three local and one global optimization algorithms are included.

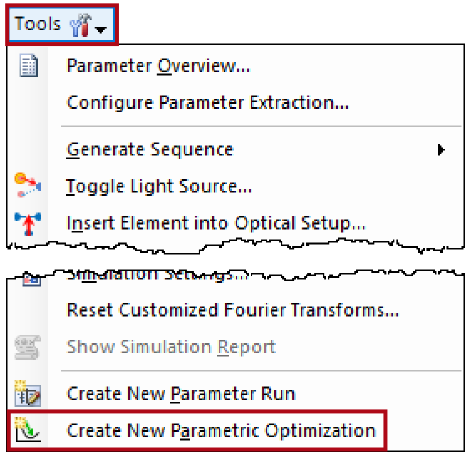
Parametric Optimization Document

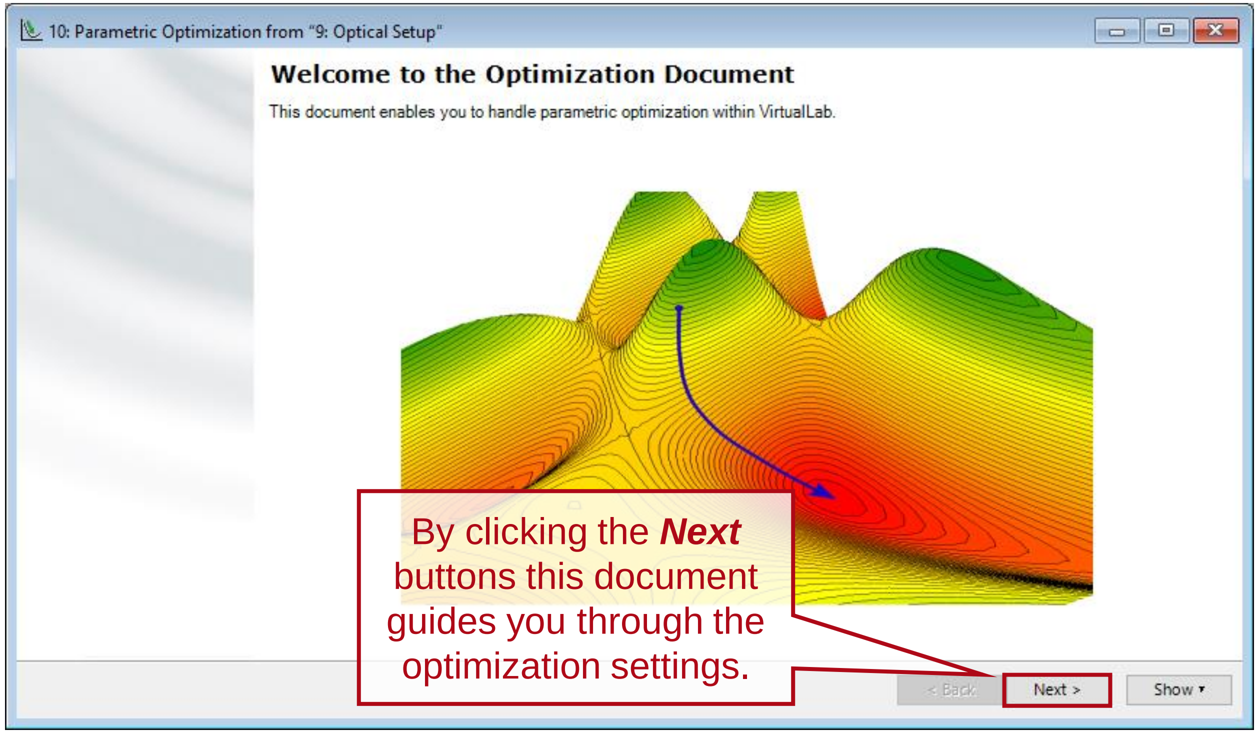
The *Parametric Optimization* document can be generated for Optical Setups that output numbers to be optimized via an active detector or analyzer.



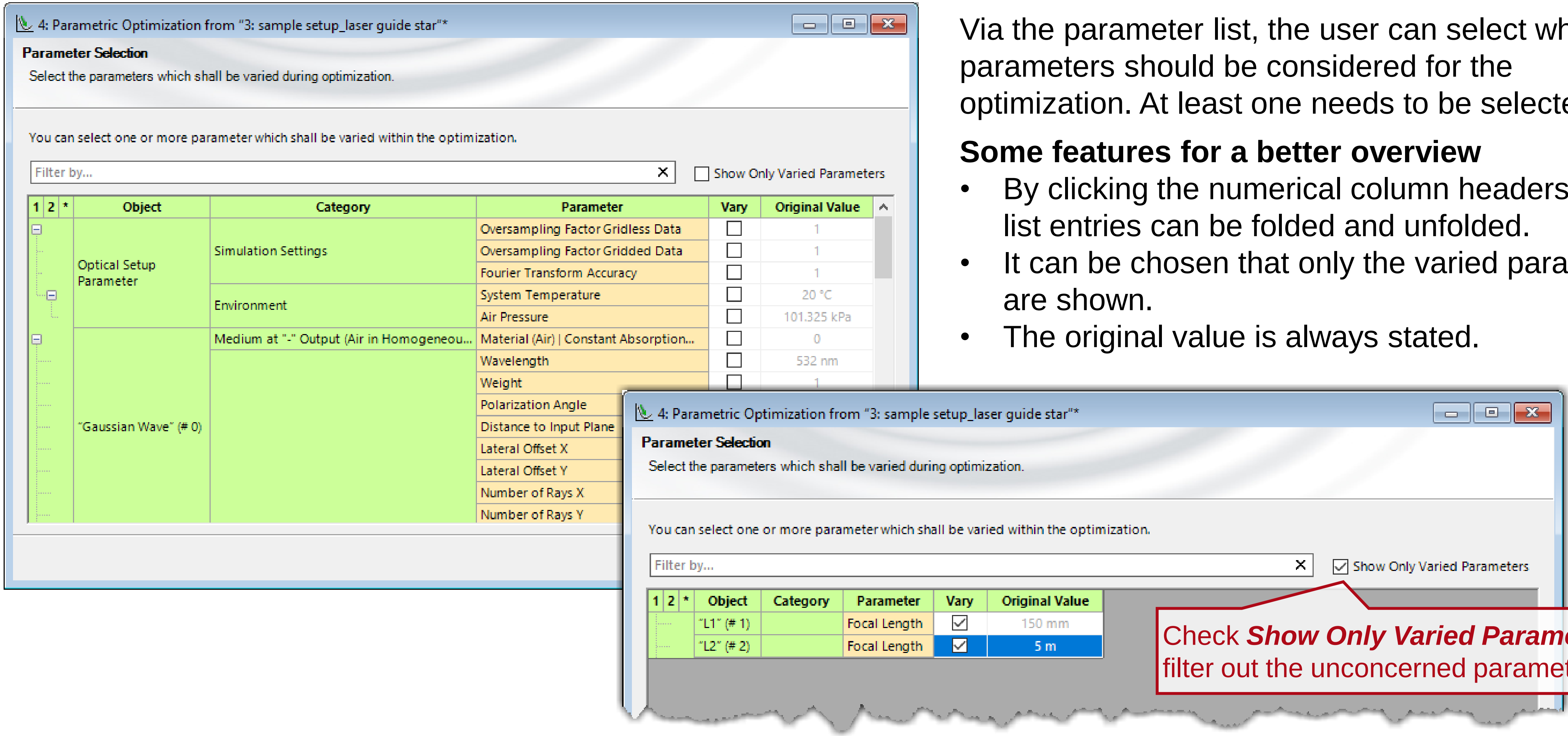
The *Parametric Optimization* document can be opened via

- the ribbon item *Optical Setup* → *New Parametric Optimization*
- the shortcut "Ctrl + T"
- the ***Tools*** button of the Optical Setup Editor





Parameter Selection



Check ***Show Only Varied Parameters*** to filter out the unconcerned parameters

Via the parameter list, the user can select which parameters should be considered for the optimization. At least one needs to be selected.

Some features for a better overview

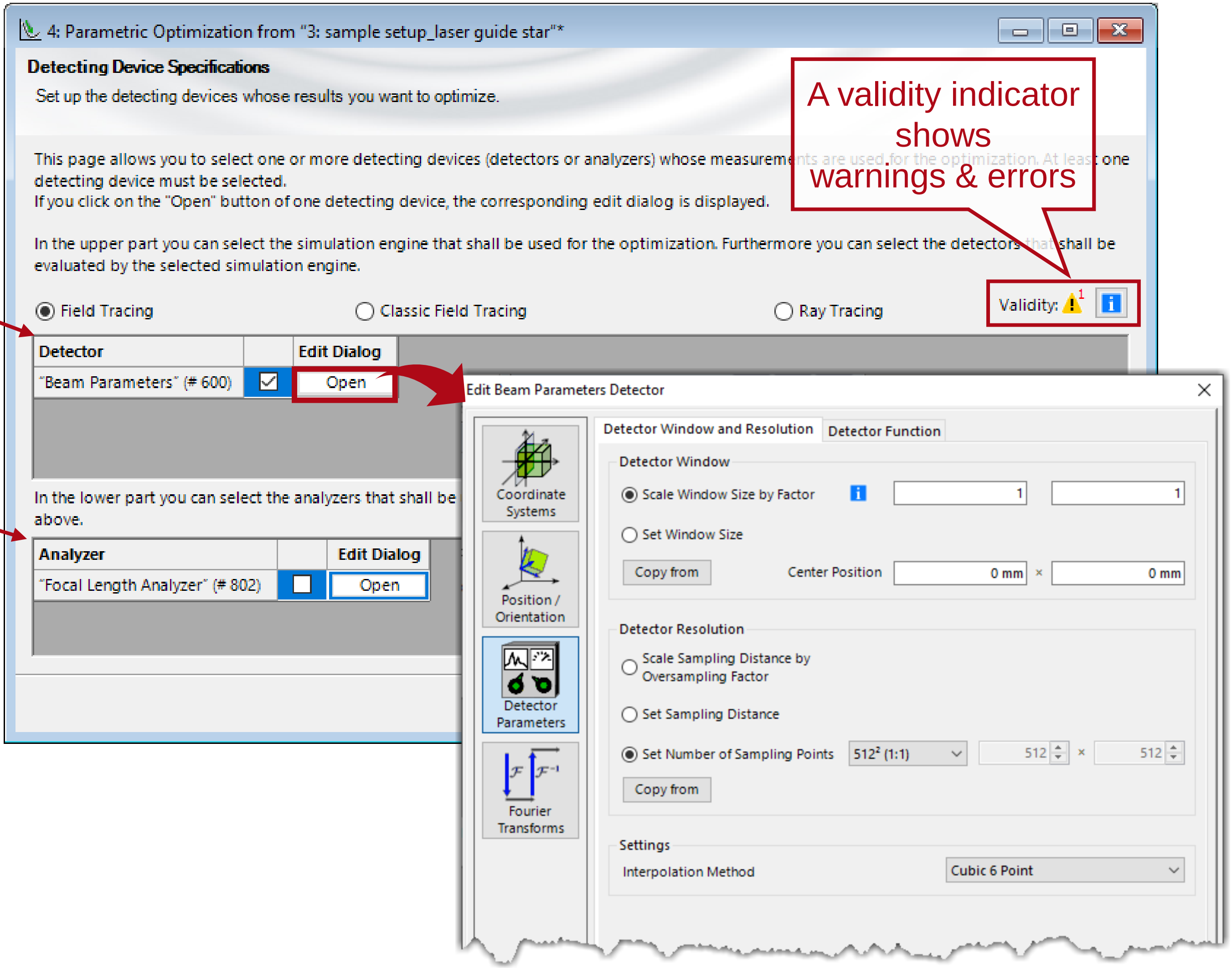
- By clicking the numerical column headers, the list entries can be folded and unfolded.
- It can be chosen that only the varied parameters are shown.
- The original value is always stated.

Specification of Detecting Device

Depending on the Optical Setup an optimization can be performed by using

either → a certain simulation engine and a detector

or → an analyzer.



The detector and the analyzer, respectively, can be edited by clicking ***Open***.

Constraints Specification

24: Parametric Optimization from "19: Optical Setup"*

Constraint Specifications

Select and specify the constraints which shall be considered during optimization.

Constraint Host	Constraint Name	Use	Weight	Constraint Type	Value 1	Value 2	Start Value	Contribution
"Lens System" (# 1)	Surface #1 (Aspherical Surface) | Radius of Curvature	☑	1	Range	-1E-300 mm	1E+303 mm	25 mm	N/A
	Surface #1 (Aspherical Surface) | Conical Constant	☑	1	Range	-1000	1000	0	N/A
	Surface #1 (Aspherical Surface) | Aspherical Parameter 1	☑	1	Range	-1E+300	1E+300	0	N/A
	Surface #1 (Aspherical Surface) | Aspherical Parameter 2	☑	1	Range	-1E+300	1E+300	0	N/A
"Spot Size" (# 601)	Beam Diameter X	☑	3.8715	Target Value	0 mm		N/A	N/A
	Beam Diameter Y	☑	1	Target Value	0 mm		N/A	N/A
"Lens System" (# 1)	Aspherical Surface # 1 | Minimal Local Radius	☑	1	Lower Limit	10 mm		N/A	N/A

free parameter constraints

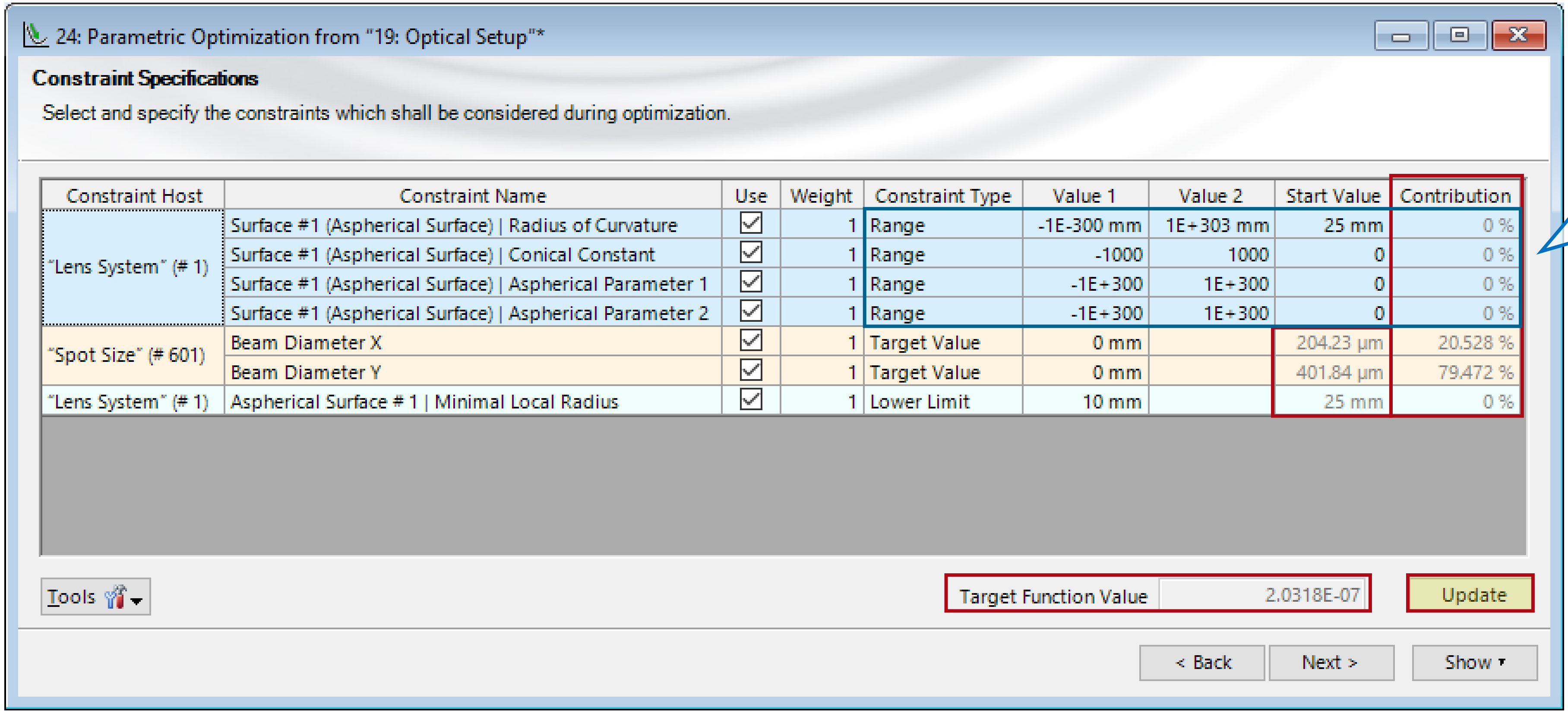
merit functions constraints

general structure constraints

On this page the user can specify the constraint types and associated value(s) for

- the selected free parameters of the system
- all the merit functions calculated by the detector or analyzer
- possible general structure quantities, that depend on free parameter(s) and cannot directly be modified.

Constraints Specification



Constraint Host	Constraint Name	Use	Weight	Constraint Type	Value 1	Value 2	Start Value	Contribution
"Lens System" (# 1)	Surface #1 (Aspherical Surface) | Radius of Curvature	☑	1	Range	-1E-300 mm	1E+303 mm	25 mm	0 %
	Surface #1 (Aspherical Surface) | Conical Constant	☑	1	Range	-1000	1000	0	0 %
	Surface #1 (Aspherical Surface) | Aspherical Parameter 1	☑	1	Range	-1E+300	1E+300	0	0 %
	Surface #1 (Aspherical Surface) | Aspherical Parameter 2	☑	1	Range	-1E+300	1E+300	0	0 %
"Spot Size" (# 601)	Beam Diameter X	☑	1	Target Value	0 mm		204.23 µm	20.528 %
	Beam Diameter Y	☑	1	Target Value	0 mm		401.84 µm	79.472 %
"Lens System" (# 1)	Aspherical Surface # 1 | Minimal Local Radius	☑	1	Lower Limit	10 mm		25 mm	0 %

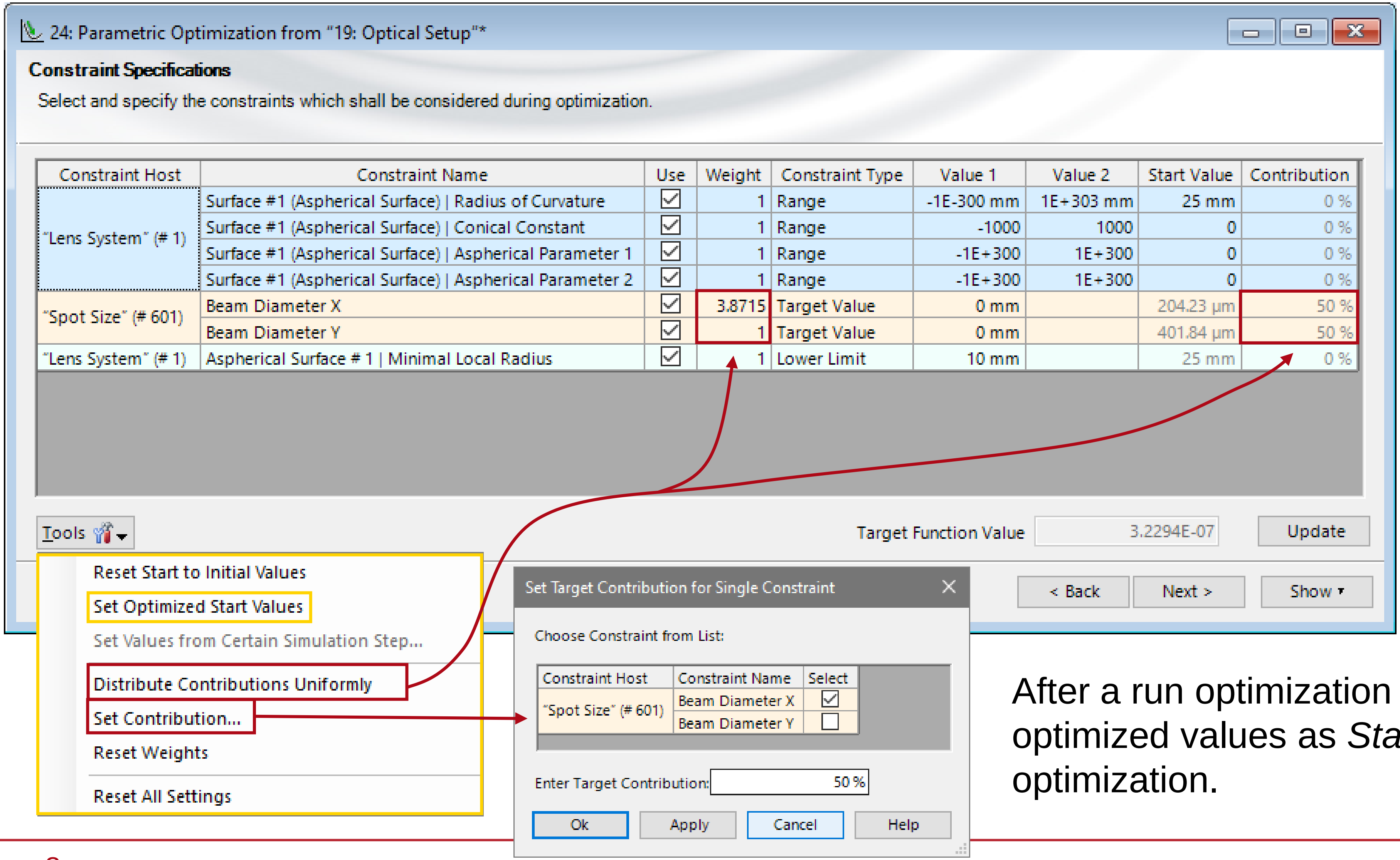
If any *Start Value* is initially in the allowed value range, the associated *Contribution* is regarded as 0%.

By clicking ***Update***, the simulation of the Optical Setup with the set *Start Values* of the free parameters is triggered. The resulting the merit functions (i.e. their Start Values) are displayed as well as

→ their contribution (relevance or priority) for the optimization

→ the Common Merit Function Value = **Target Function Value, which is defined as the weighted sum over all constraints.**

Weights & Contributions



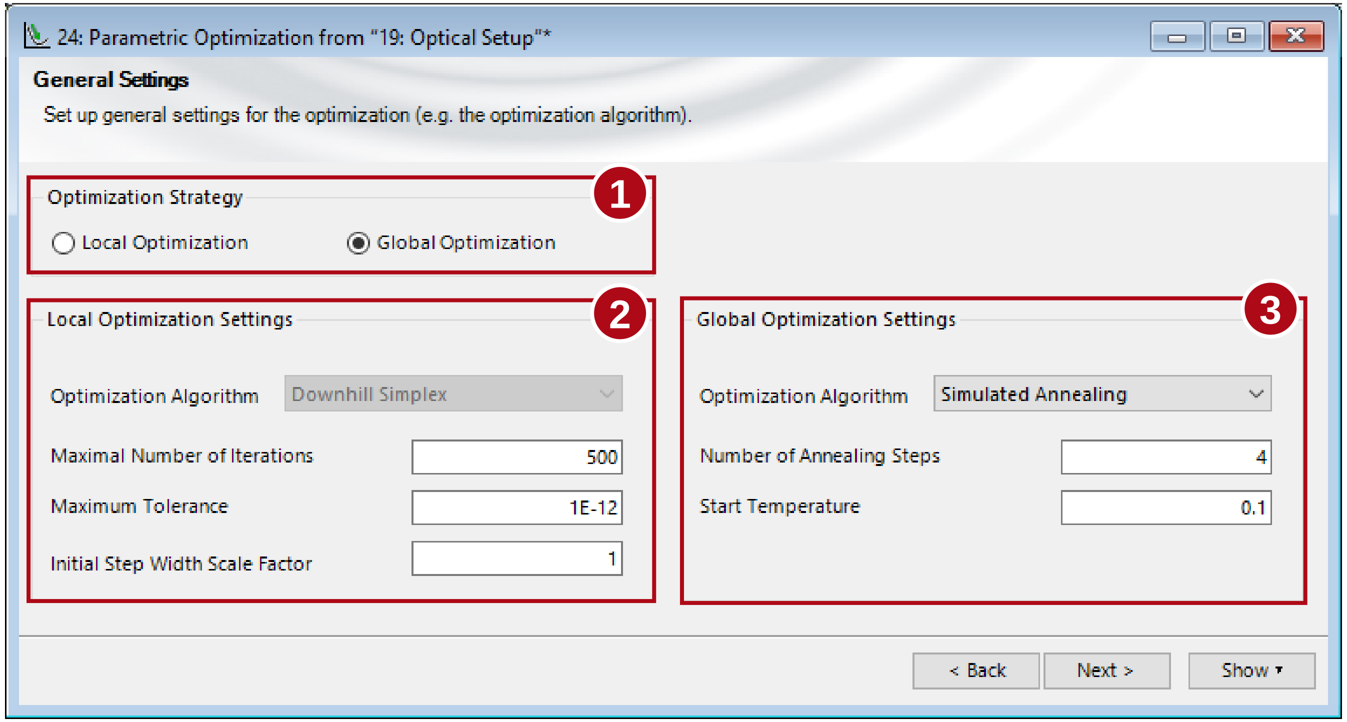
The default *Weights* have the value 1. They can be altered directly in the table or via the ***Tools***' options.

E.g. one can set all contributions uniformly or one can assign a distinct percentage for a single constraint.

After a run optimization it is possible to set the optimized values as *Start Values* for a subsequent optimization.

Choice of Optimization Method

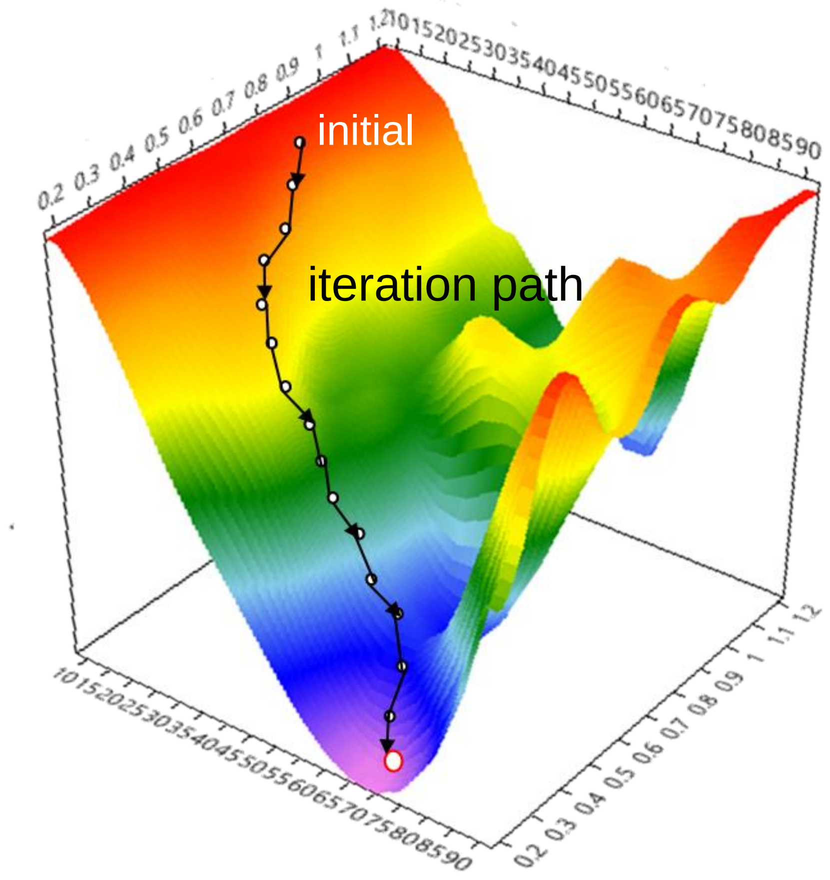
All optimizations aim to minimize the target / merit function value.



1. select optimization strategy (local or global)
2. fefine settings for local optimization
   - felect optimization algorithm
   - The algorithm stops when either the *Maximal Number of Iterations* is reached* or the deviation of from the last simulation step is less than the *Maximum Tolerance***.
   - Via the *Initial Step Width Scale Factor*, the step widths from the *Start Values* to the first iteration's values of all free parameters are scaled. I.e. the search area around the initial configuration is controlled; e.g. by higher values one might jump out of a local minimum area.
3. define settings for global optimization

** The result table might list more iterations; this originates from the fact that some optimization algorithms also show interim function results.*
*** As a rule of thumb one can set a Maximum Tolerance value which is about 4-5 magnitudes smaller than the inital Target Function Value.*

Local & Global Optimization



Local optimization algorithms are fast but their success in finding the global minimum often strongly depends on the choice of the start value. Therefore, in cases where no good start values are known, global optimization is preferable.

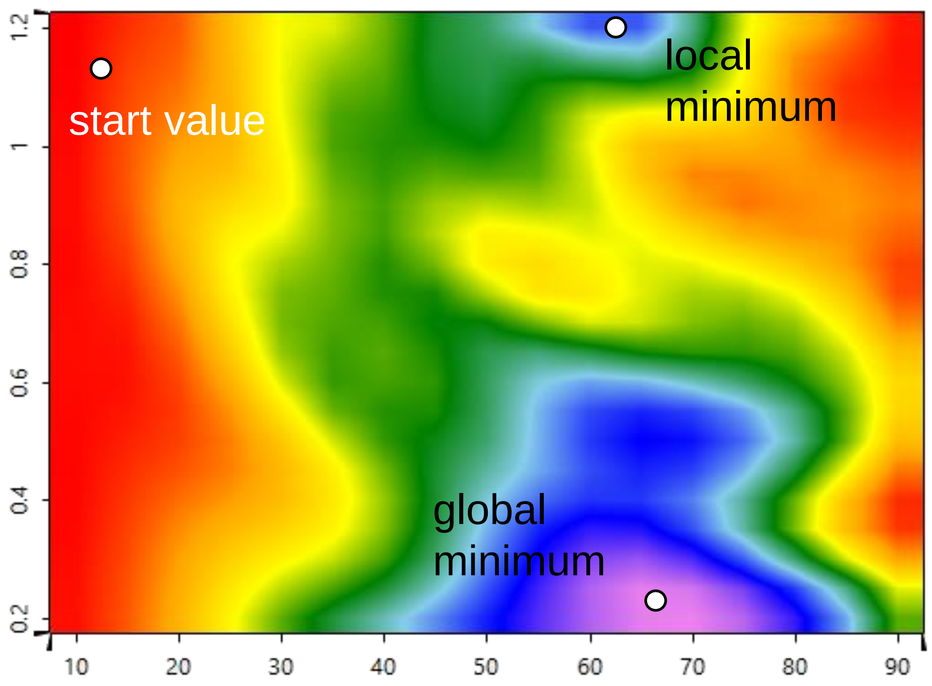
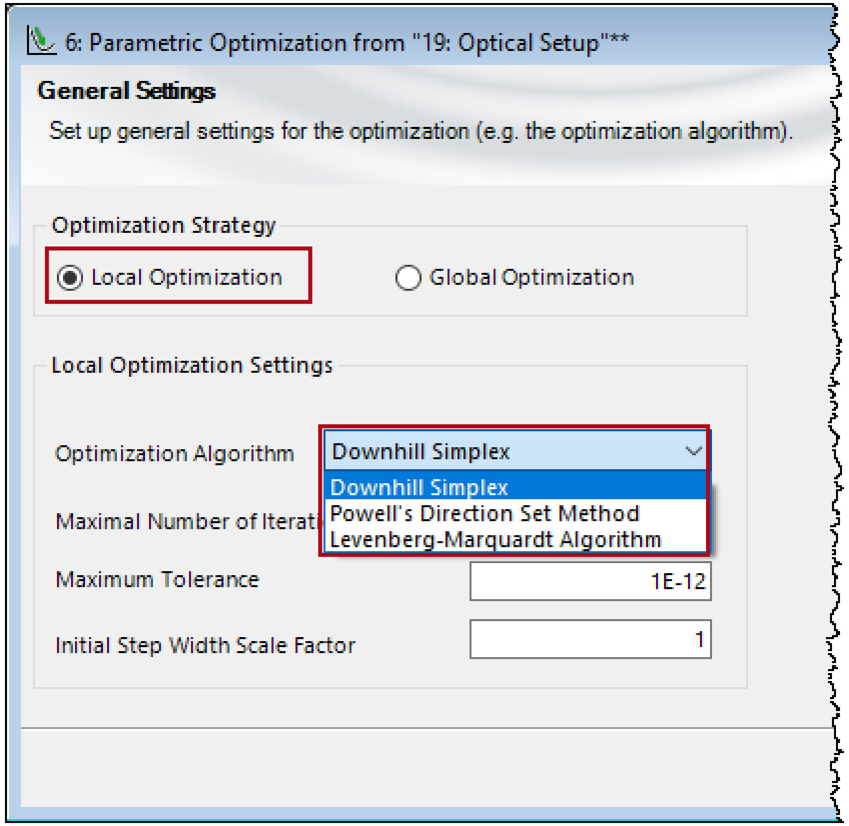


illustration of the target function for 2 variable (in 3D and 2D)

Algorithms for Local Optimization



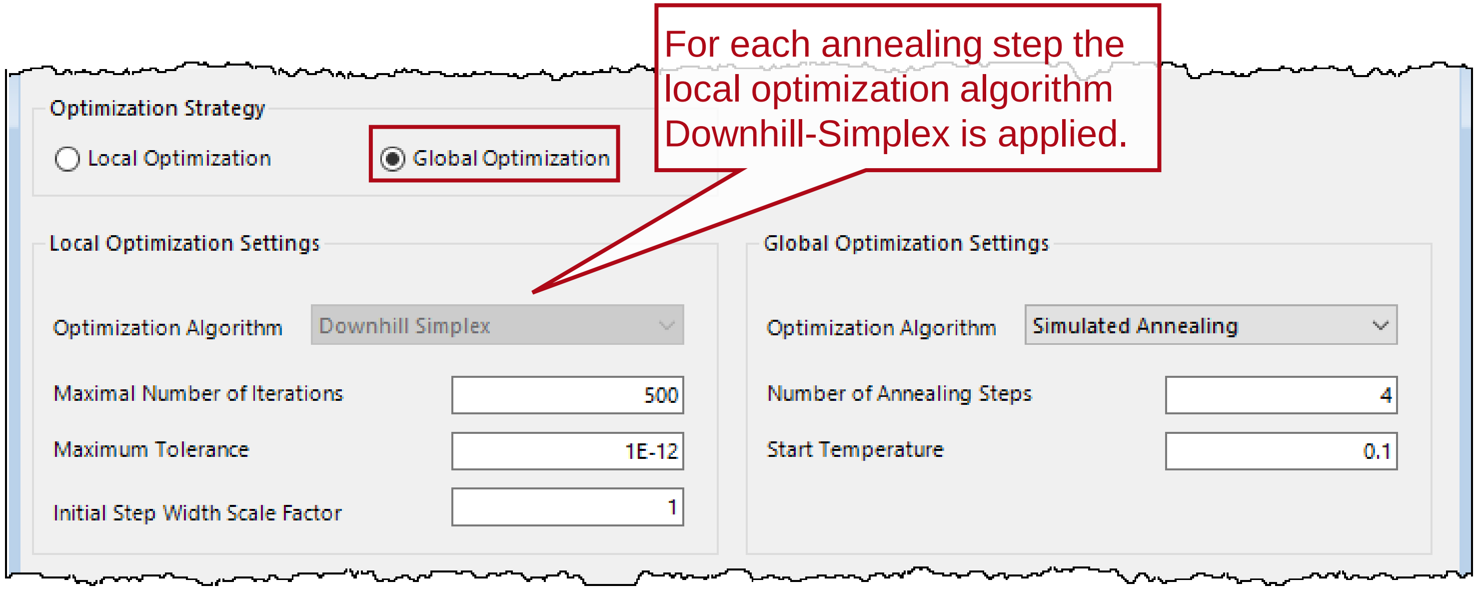
Currently, three non-linear local algorithms for minimizing a multivariate function are provided:

- **Downhill Simplex method by Nelder & Mead**
  it does not converge very fast, but is a simple and robust method. Typically, well suited for less than 6 free parameters.
- **Powell's (direction set) method**
  it might be better suited for larger numbers of free parameters (>10).
- **Levenberg-Marquardt algorithm**
  it "interpolates between the Gauss–Newton algorithm and the method of gradient descent. [...] in many cases it can find a solution even if it starts very far off the final minimum."*
  Convergence is likely but not guaranteed.

All local minimizing algorithms pose the risk of getting stuck in a local minimum. To minimize this risk one can try to use larger *Initial Step Width Scale Factors*, start with different initial conditions or use a global optimization algorithm.

* *source: https://en.wikipedia.org/wiki/Levenberg%E2%80%93Marquardt_algorithm from 2021-10-13*

Algorithm for Global Optimization



VirtualLab Fusion provides **Simulated Annealing** for a global optimization*, which enables a search for the global minimum of the target function by adding a random temperature term t to the current value, with

$$t = T \log r$$

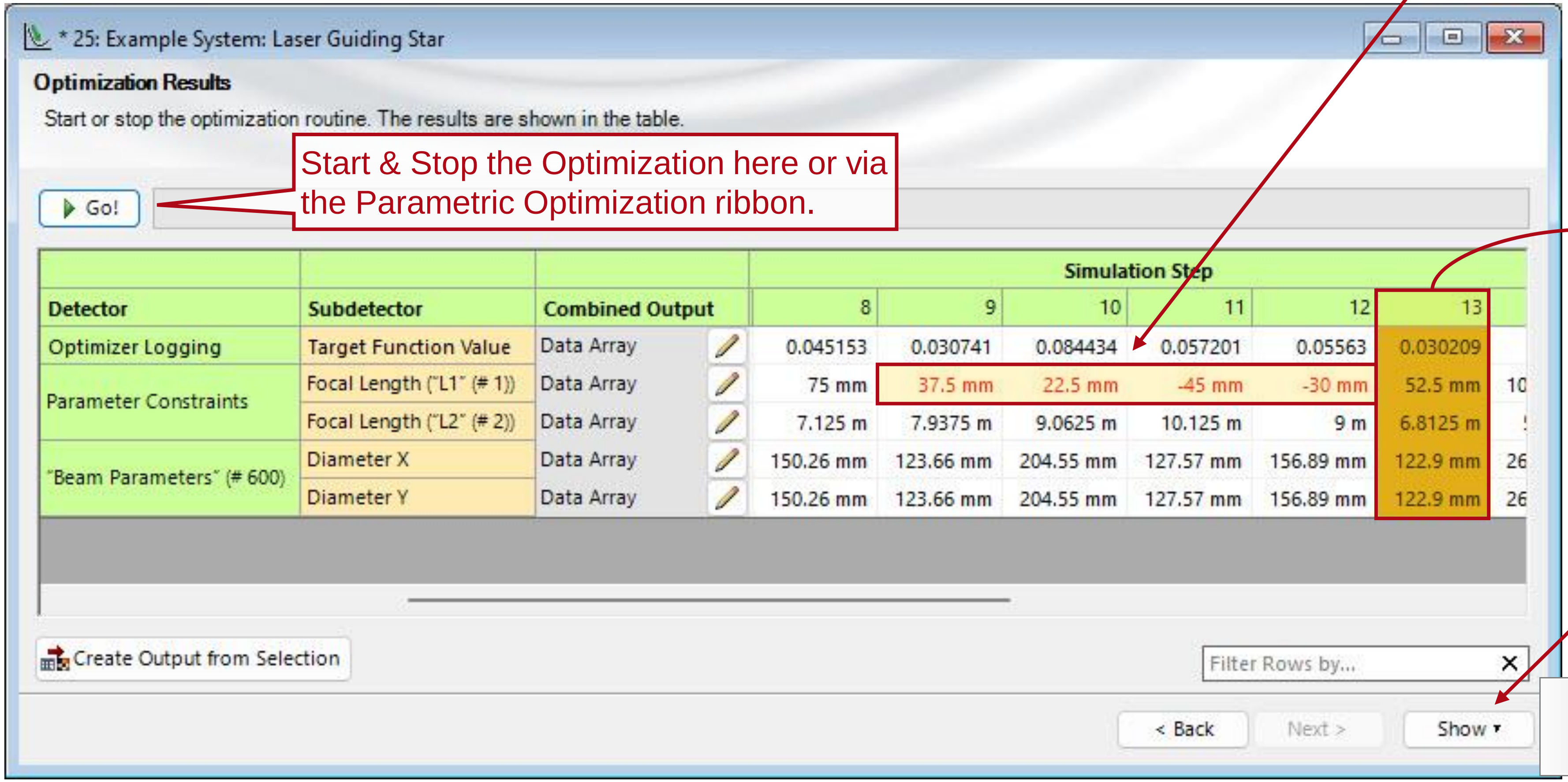
where r is a random value between 0 and 1 and T is the temperature, which is gradually decreased according to an annealing schedule with an adjustable *Start Temperature* and *Number of Annealing Steps*.

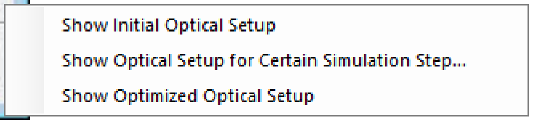
The success of the global search depends heavily on the chosen values for *Start Temperature* and *Number of Annealing*. If the *Start Temperature* is too low the algorithm will possibly get stuck in the surrounding of a local minimum. On the other hand, temperature values that are too high will increase the probability for “jumping out” of the surrounding of an already detected global minimum.

* *The names of this global optimization algorithms and its parameters are an anology to the annealing in metallurgy where a low energy state close to the optimum is reached if a wise cooling process is chosen.*

Optimization Results

In the final table the parameters and associated results are shown.
Some optimization algorithms (such as the *Downhill Simplex*) actually do not allow any restriction of the parameter ranges due to their definition. Instead, penalty rules are applied. Parameters that exceed the defined ranges are highlighted in red.





VirtualLab Fusion will highlight the optimal result (result with the lowest target function value) in orange.

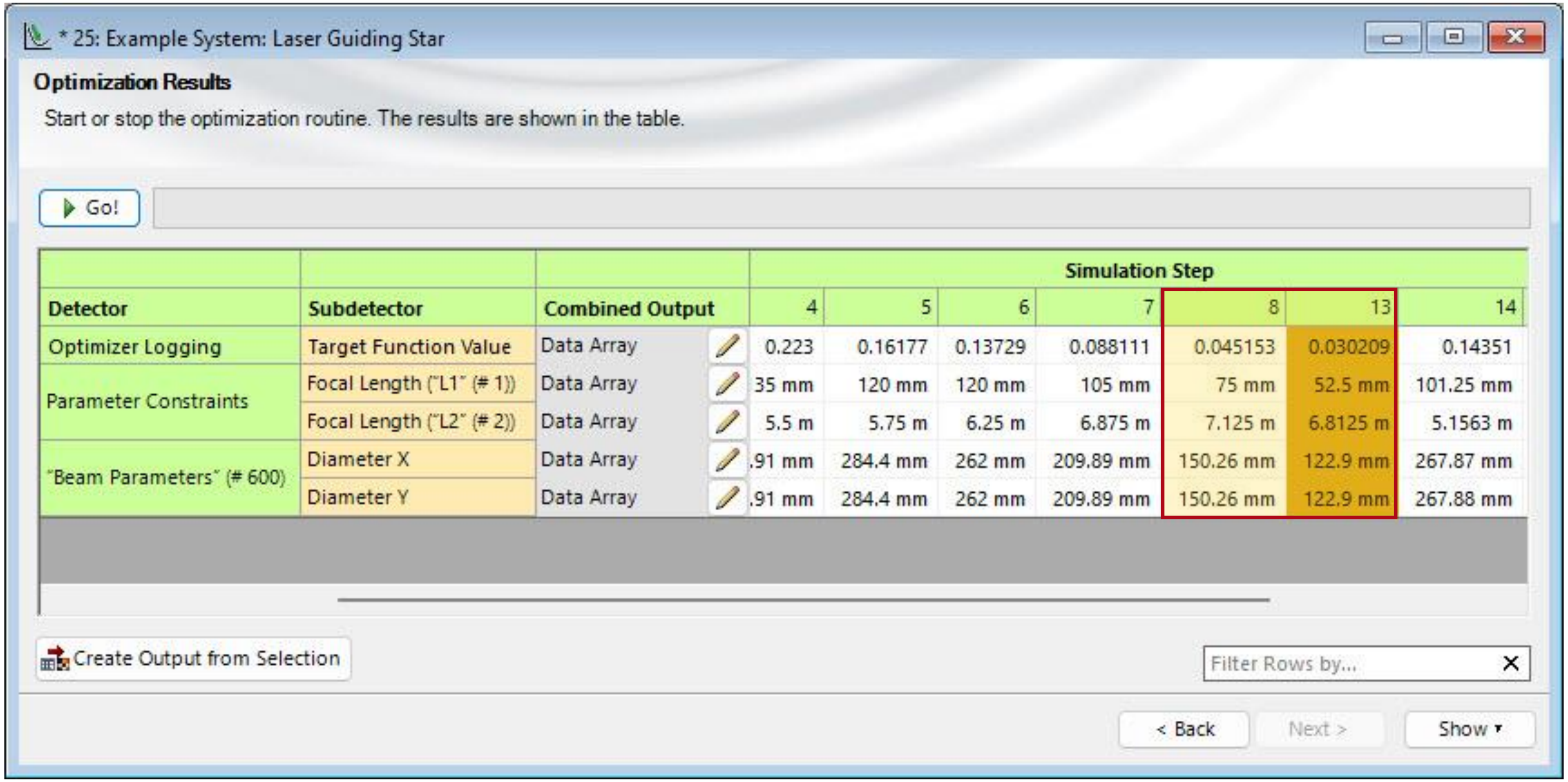
After the optimization

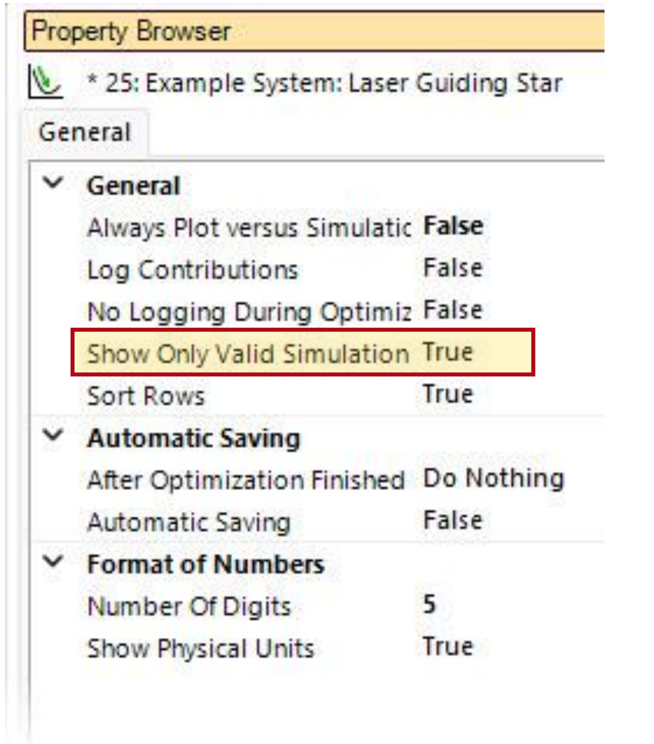
- the inital
- any interim
- and the optimized

Optical Setup can be shown.

Cleaned Optimization Results

It is however possible to filter the result document to only output columns whose parameters are within the ranges of parameters and constraints. The filter can be activated/deactivated with the option *Show Only Valid Simulation* in the *Property Browser*.





Document Information

title	Introduction to the Parametric Optimization Document
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document version	1.2
software version	2023.2 (Build 1.242)
software edition	VirtualLab Fusion Basic
category	Feature Use Case
further reading	• Rigorous Analysis and Design of Anti-Reflective Moth-Eye Structures • Optimization of Lightguide with Continuously Modulated Grating Regions • Design of 2D Non-Paraxial Beam-Splitting Metagrating