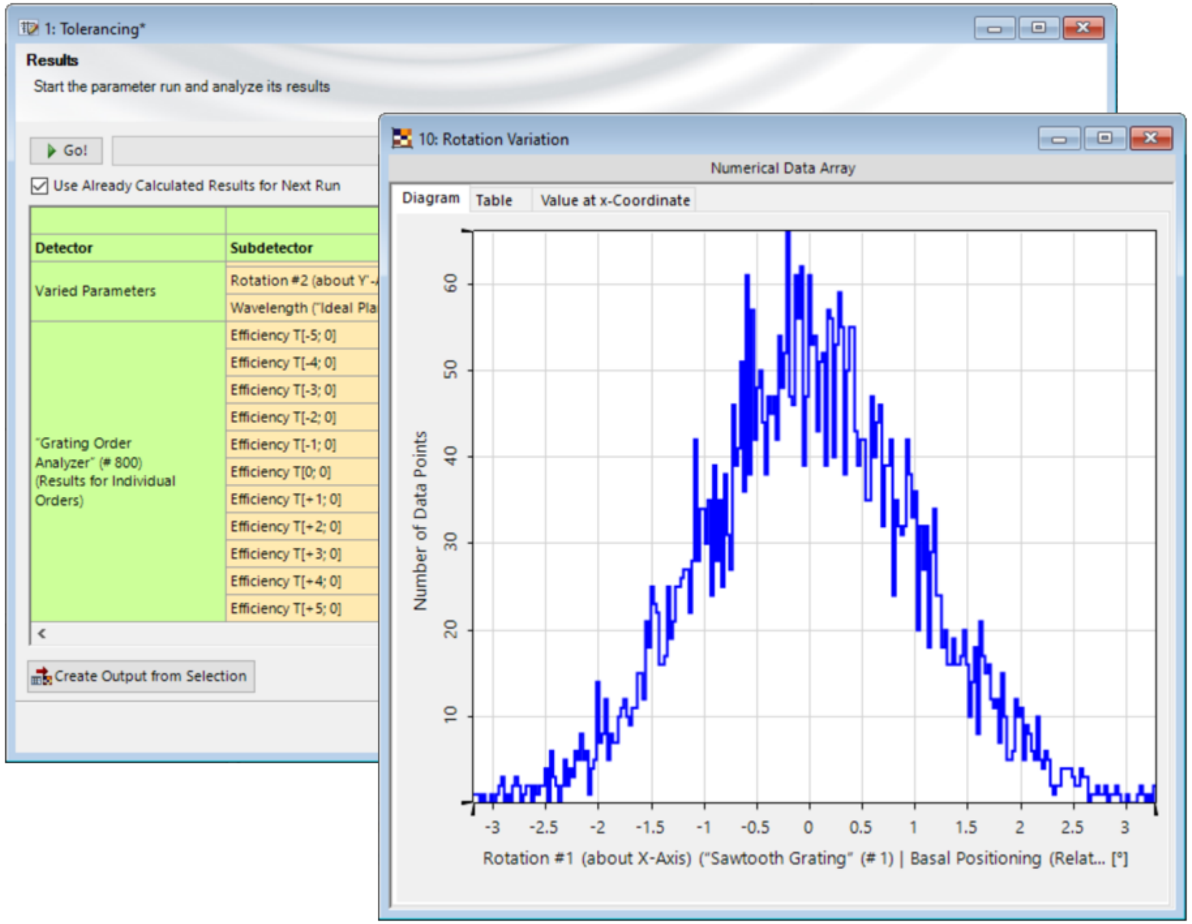
Tolerancing with Parameter Variations of Different Random Distributions

Abstract

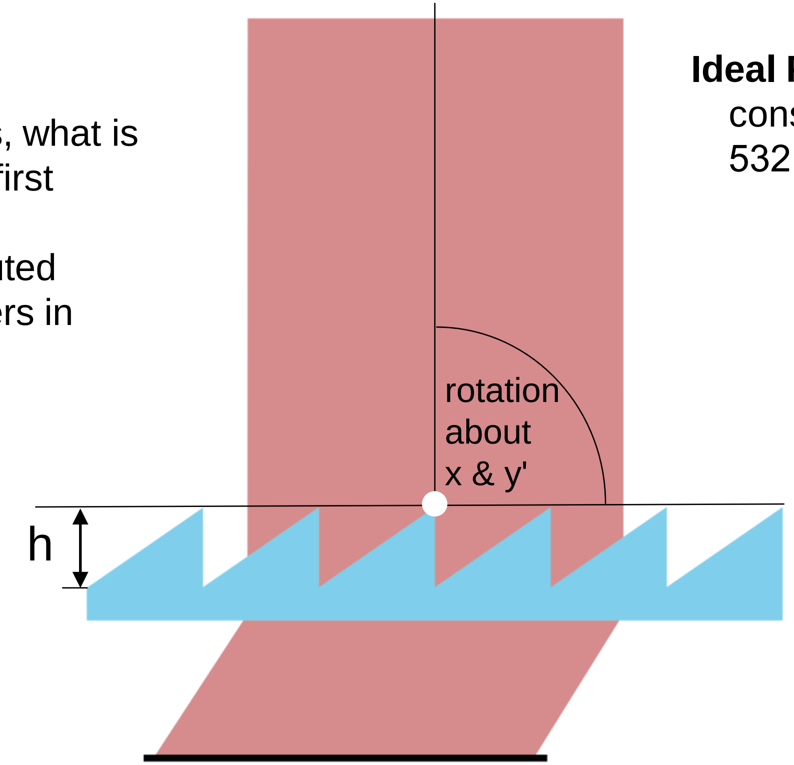


The investigation of the effect of manufacturing deviations is crucial for the design of any optical system and component. In VirtualLab Fusion, randomly varied Parameter Runs can be applied to analyze this impact in detail. Depending on the kind of manufacturing process, the resulting deviations may exhibit different kinds of random distributions. While the default Random mode of the Parameter Run assumes a uniform distribution, in this use case we want to show how to use a programmable Parameter Run to apply different random distributions to each of the parameters involved in the tolerancing. For illustration, a sawtooth grating was chosen, for which the minimal efficiency of the minus first transmission order is investigated.

Task Description

Possible Task

- According to the allowed tolerances, what is the minimal efficiency of the minus first transmitted order (T-1)?
- How is the overall efficiency distributed among the different emanating orders in that case?



Ideal Plane Wave

considered wavelength range
532 nm ± 10 nm (uniform distribution)

Sawtooth Grating (fixed parameters)

- period: 2 μm
- material: fused silica

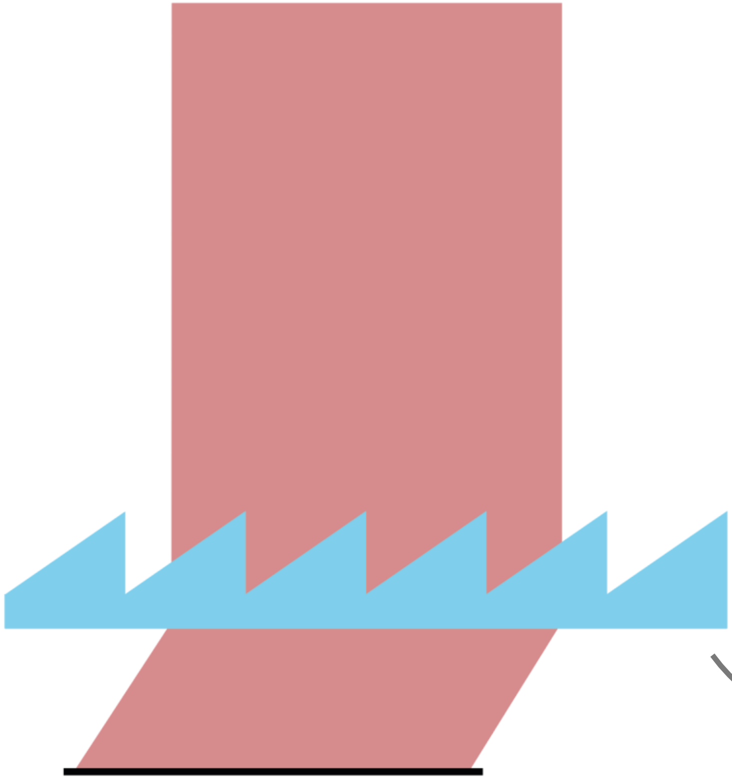
Sawtooth Grating (parameters for tolerancing)

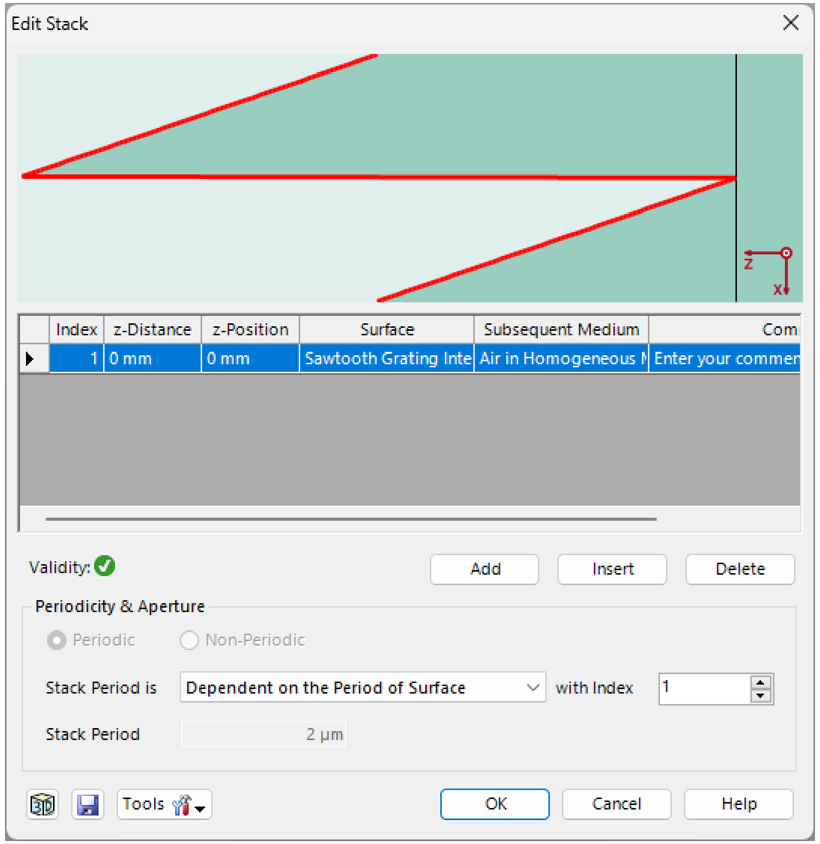
- tolerance of rotation angle about x-axis: normal distribution (**) in [-2°; +2°]
- tolerance of rotation angle about y'-axis (*): normal distribution (**) in [-2°; +2°]
- tolerance of modulation depth h: asymmetrical normal distribution (**) in [0.95 μm; 1.05 μm]

The parameters and associated variations of this example do not originate from a concrete physical problem, but serve primarily the purpose of demonstrating a tolerance simulation with mixed random distributions.

(*) X... rotation about x-axis, Y'... rotation about changed y-axis (after rotation X)
(**) For an explanation of the various random distribution types, please see: Tolerancing with Random Distributions

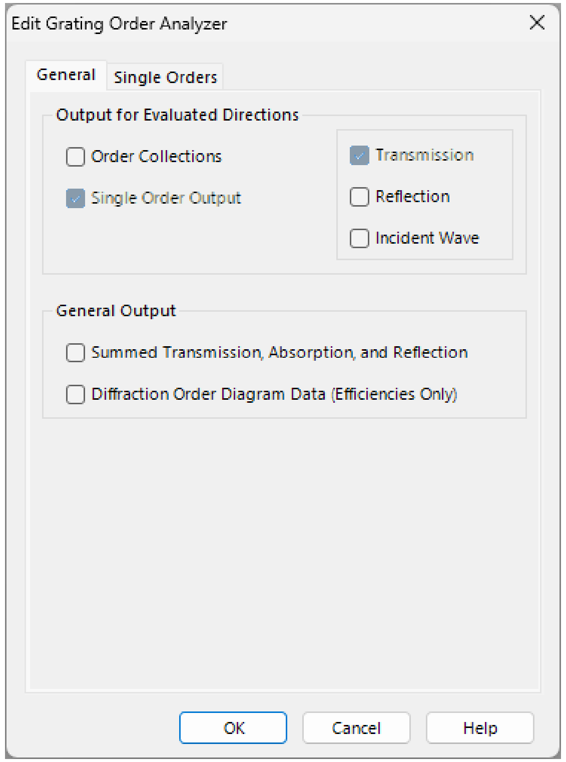
The System in VirtualLab Fusion – Components

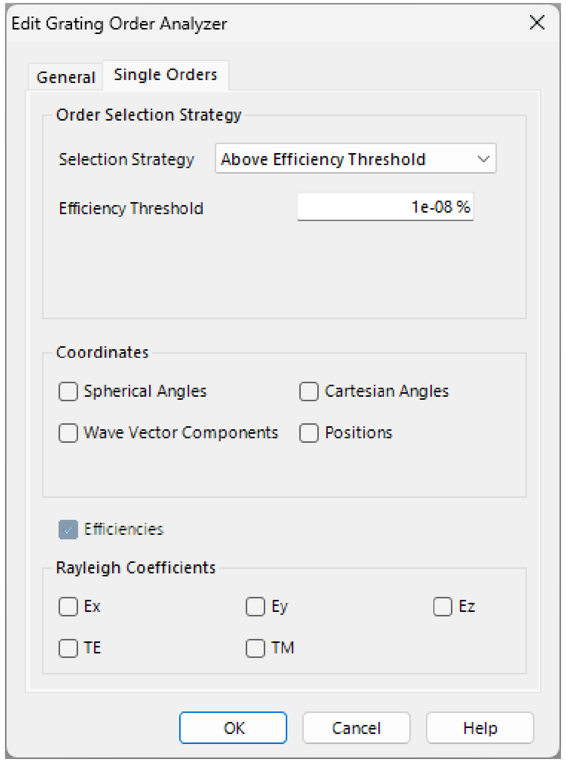


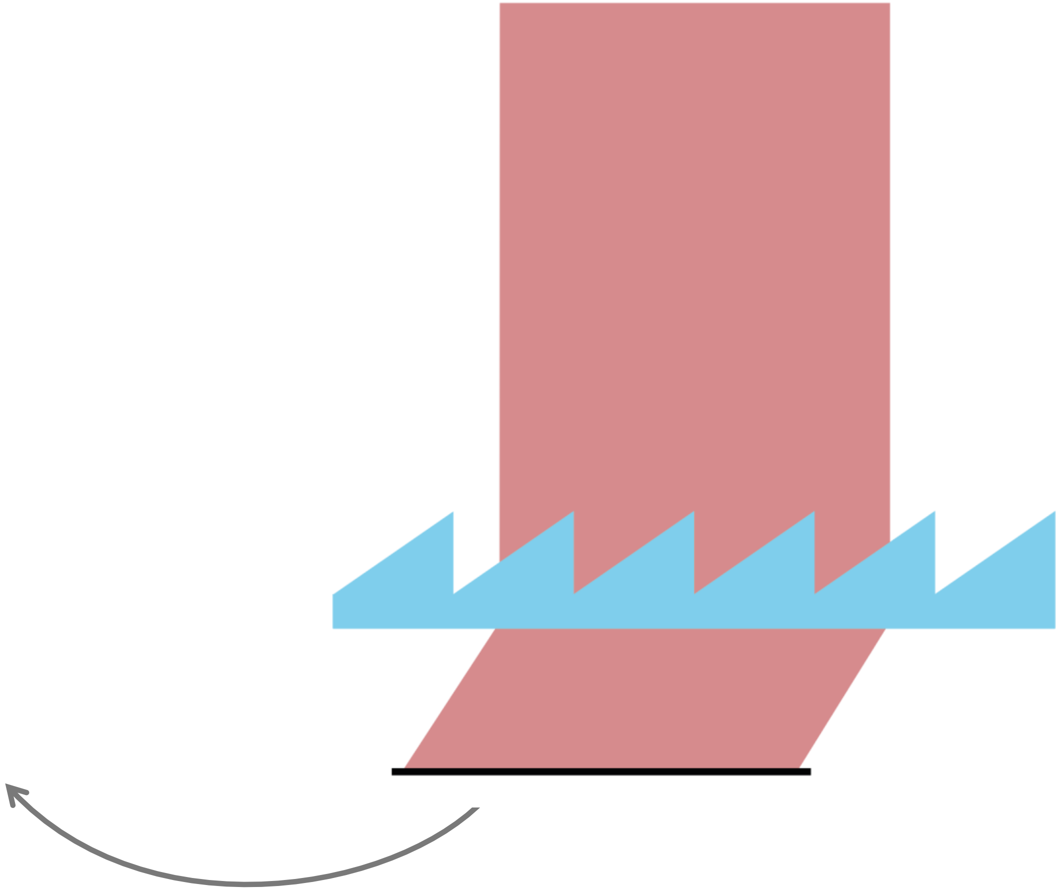


The grating is modeled using a *Sawtooth Grating Interface*. In the configuration dialog of the surface, the period, blaze angle and modulation depth can be adjusted.

The System in VirtualLab Fusion – Analyzer

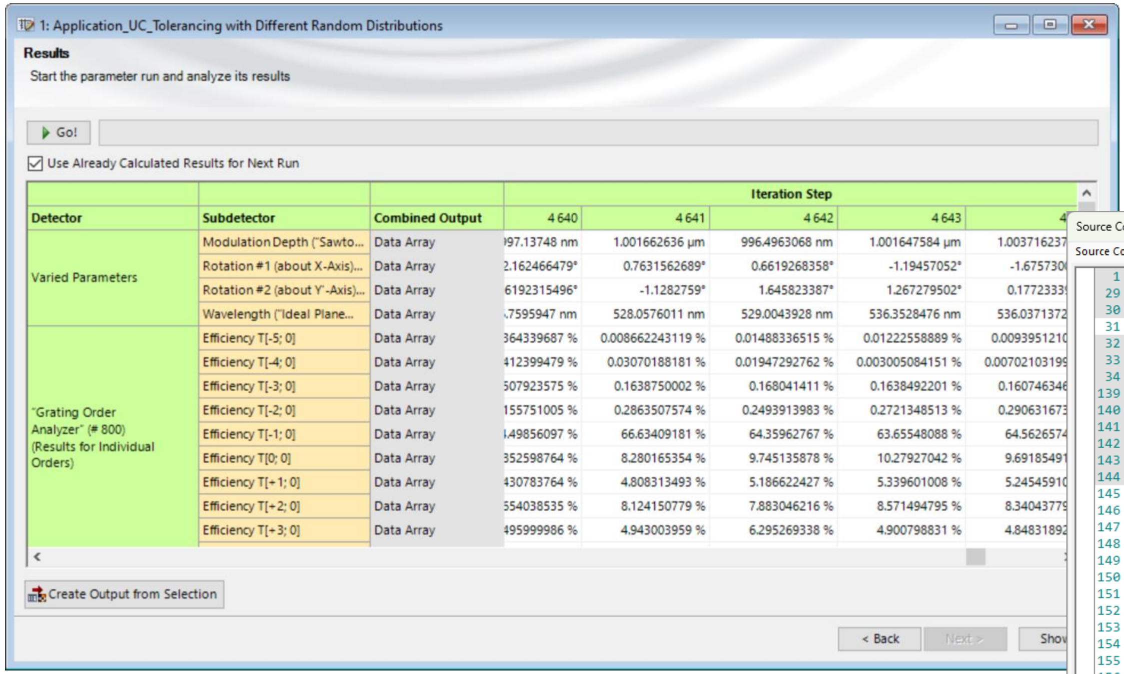


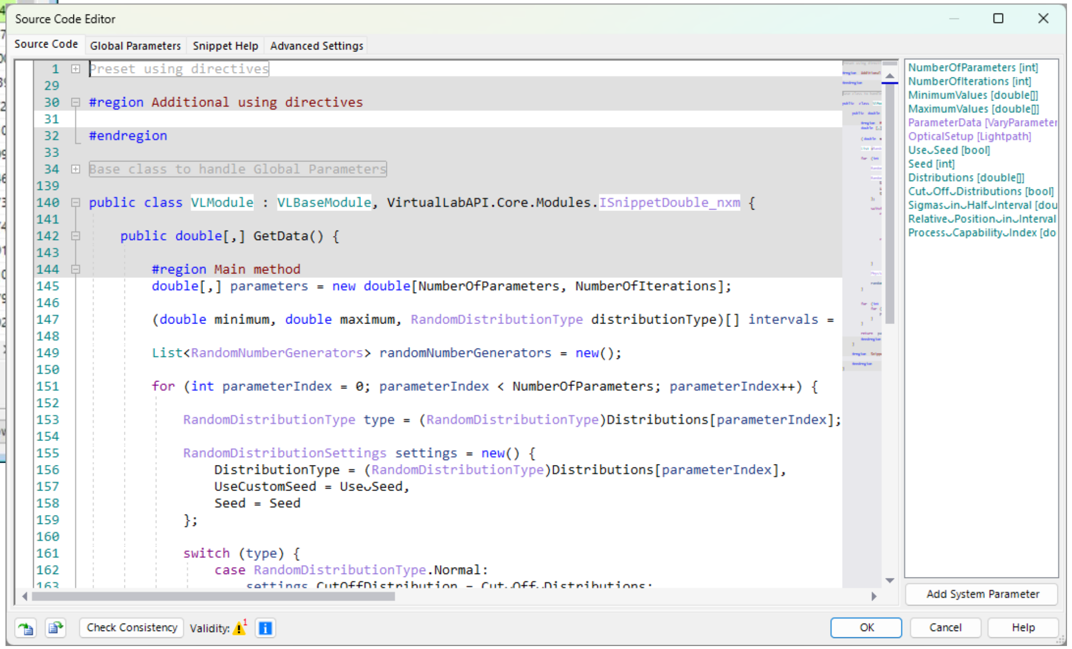




In a *Grating Optical Setup* the *Grating Order Analyzer* enables an easy analysis of the grating. It provides different output formats that allow the user to determine how overall energy is distributed among the different emanating orders. In addition, the fully vectorial field information in the form of the Rayleigh coefficients per order is also accessible.

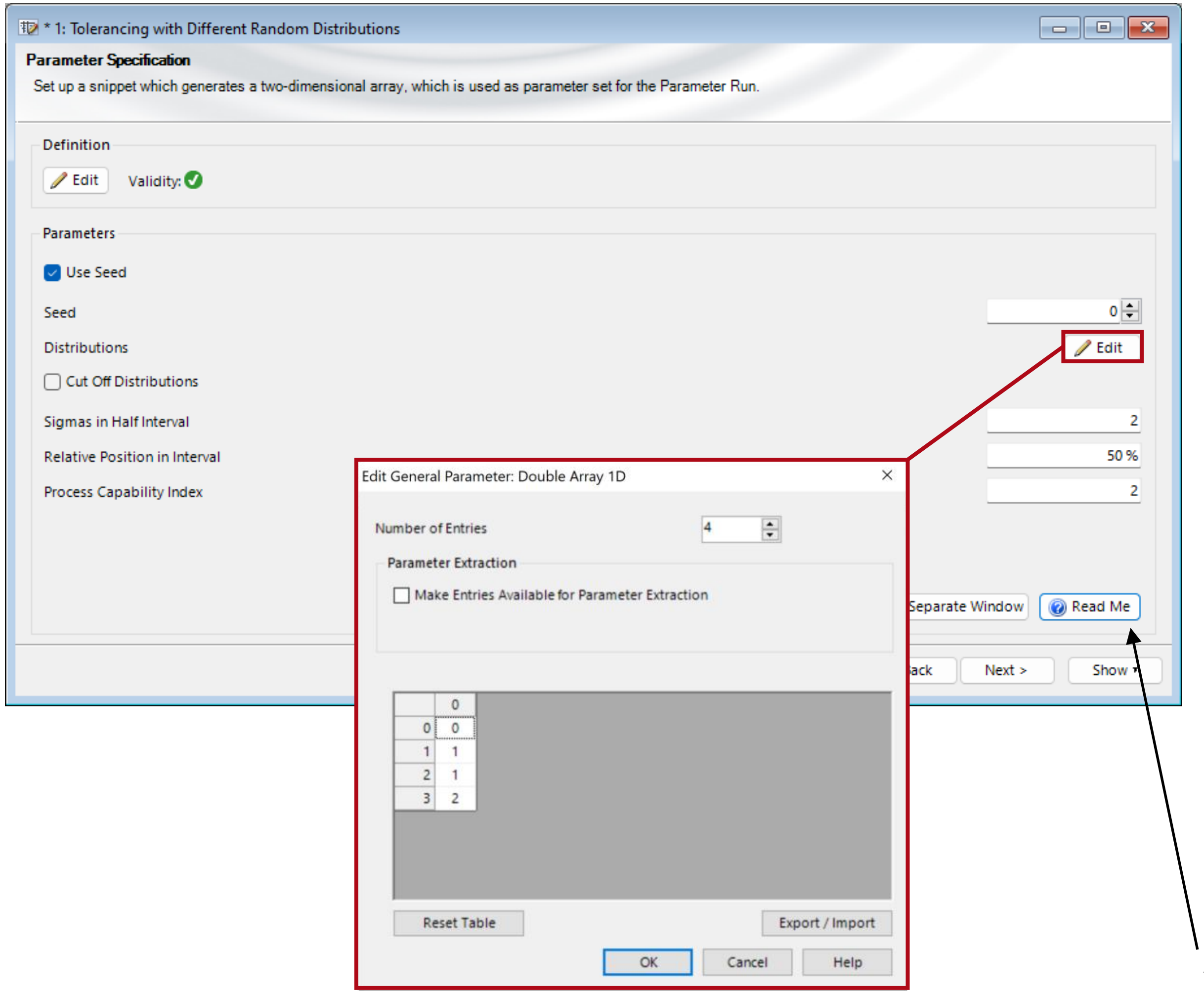
Programmable Parameter Run





- To investigate the manufacturing deviations, we use a programmable *Parameter Run*. Inside, a seed-based random distribution function is used to achieve the different combinations.
- Through a parameter in the programmable *Parameter Run*, it is possible to assign to each parameter either a normal or a uniform distribution, as illustrated in the next page.

Options of the Programmable Parameter Run



Use Seed

Allows for reproducible results.

Seed

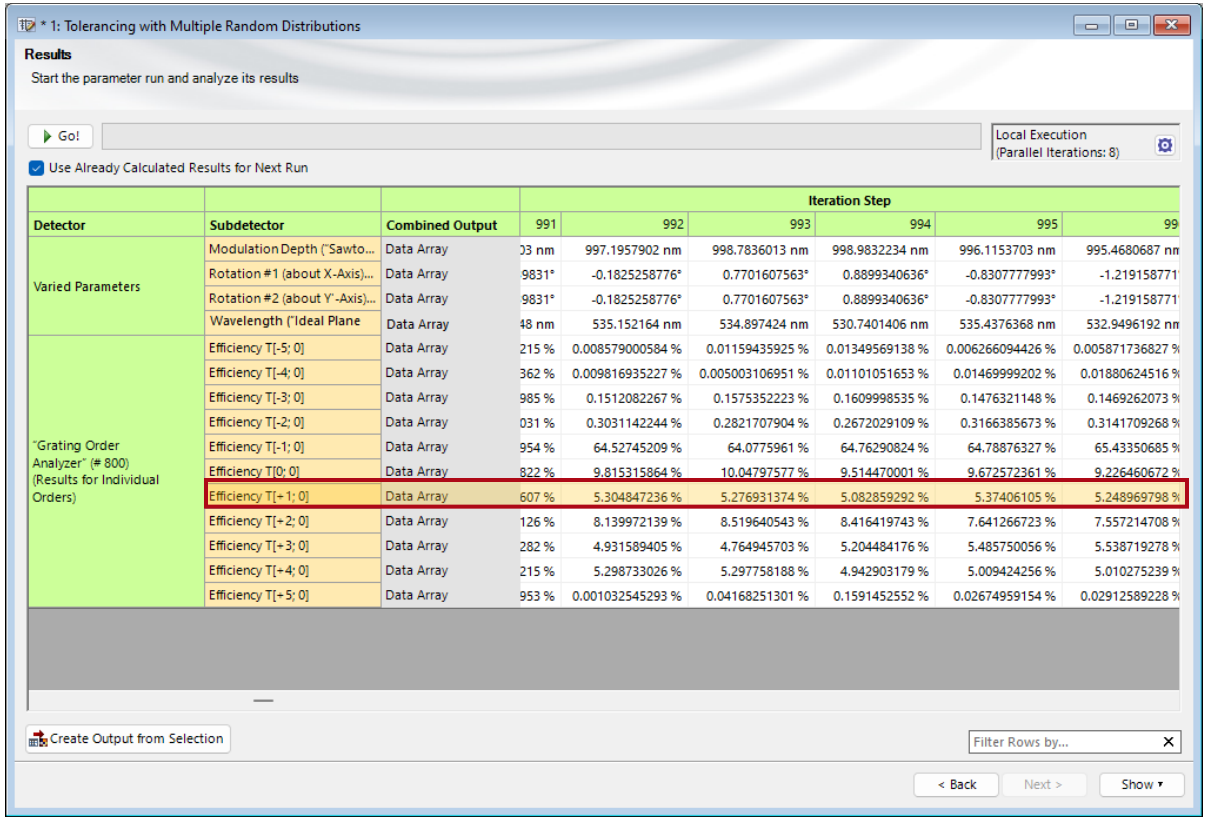
Define a specific seed to recreate a particular distribution of the randomly generated Parameter Run.

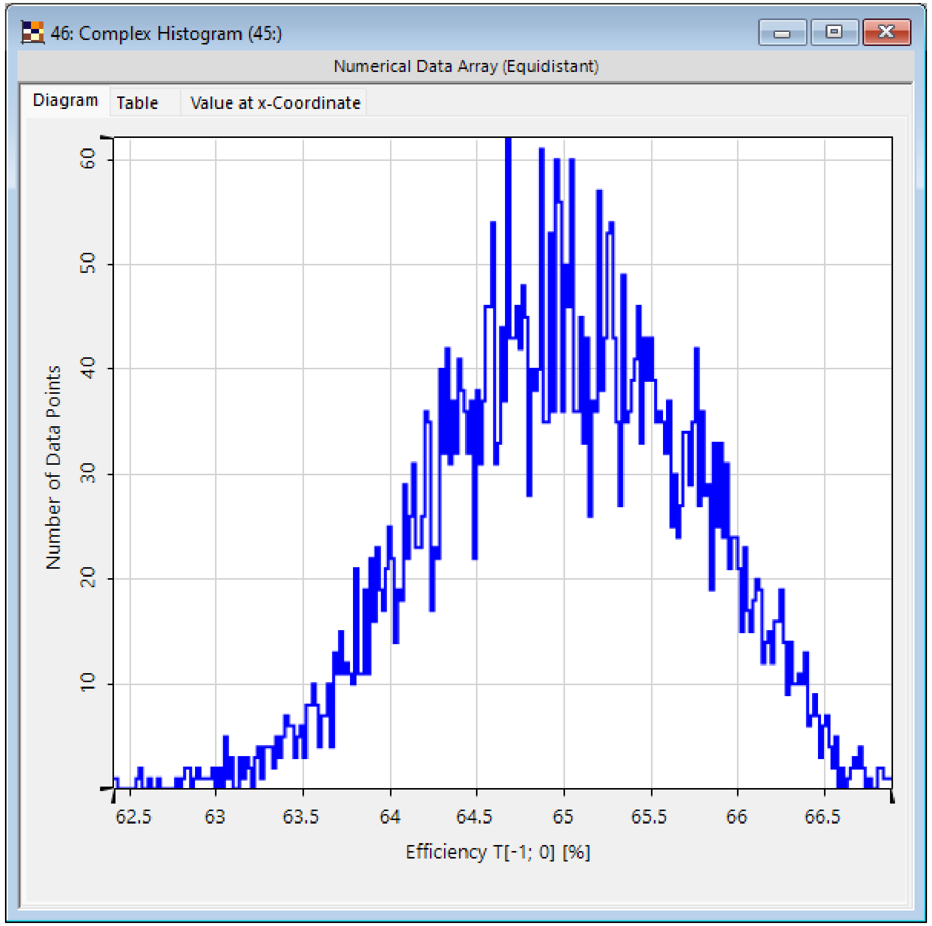
Distributions

- Choose either a “Uniform”, “Normal” or “Cutoff Normal” Distribution for each individual parameter varied.
- The distribution type is coded with numbers:
  0 – uniform
  1 – normal distribution per standard deviation
  2 – normal distribution per process capability

Note: In the “Help” document you can find a short explanation of all used parameters and the function of the component.

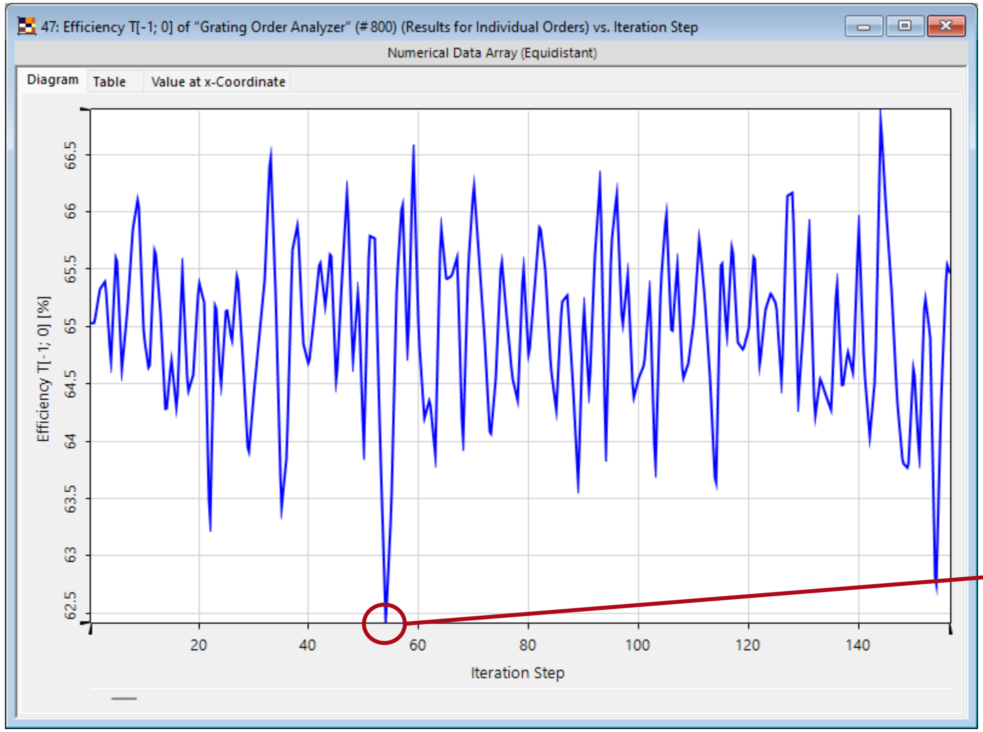
Statistical Distribution of the Efficiency

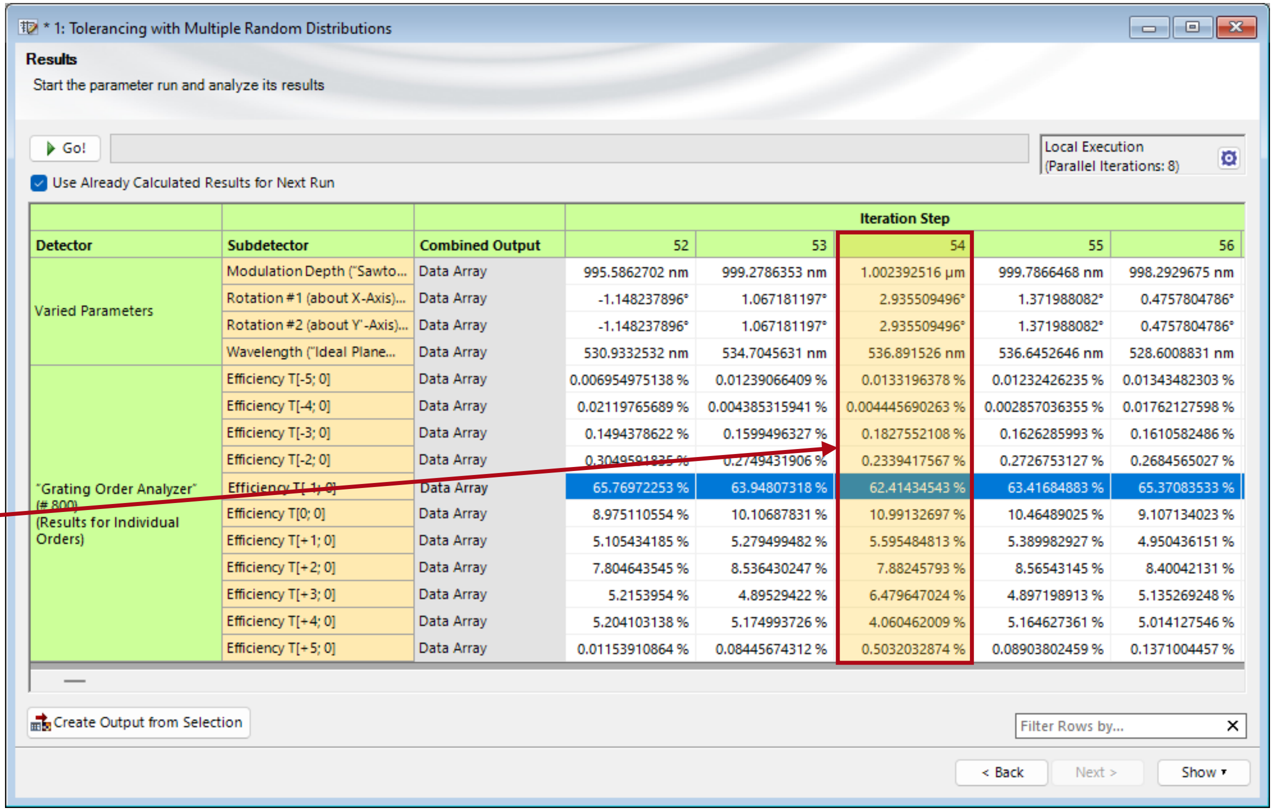




Any set of values in the *Parameter Run* delivered in the form of a number and a unit can be visualized as a plot using the option *Create Output from Selection*. Further statistical analysis is possible, for instance, by generating a histogram of the values with the *Complex Histogram* detector in the *Detectors* tab.

Tolerancing of the Grating

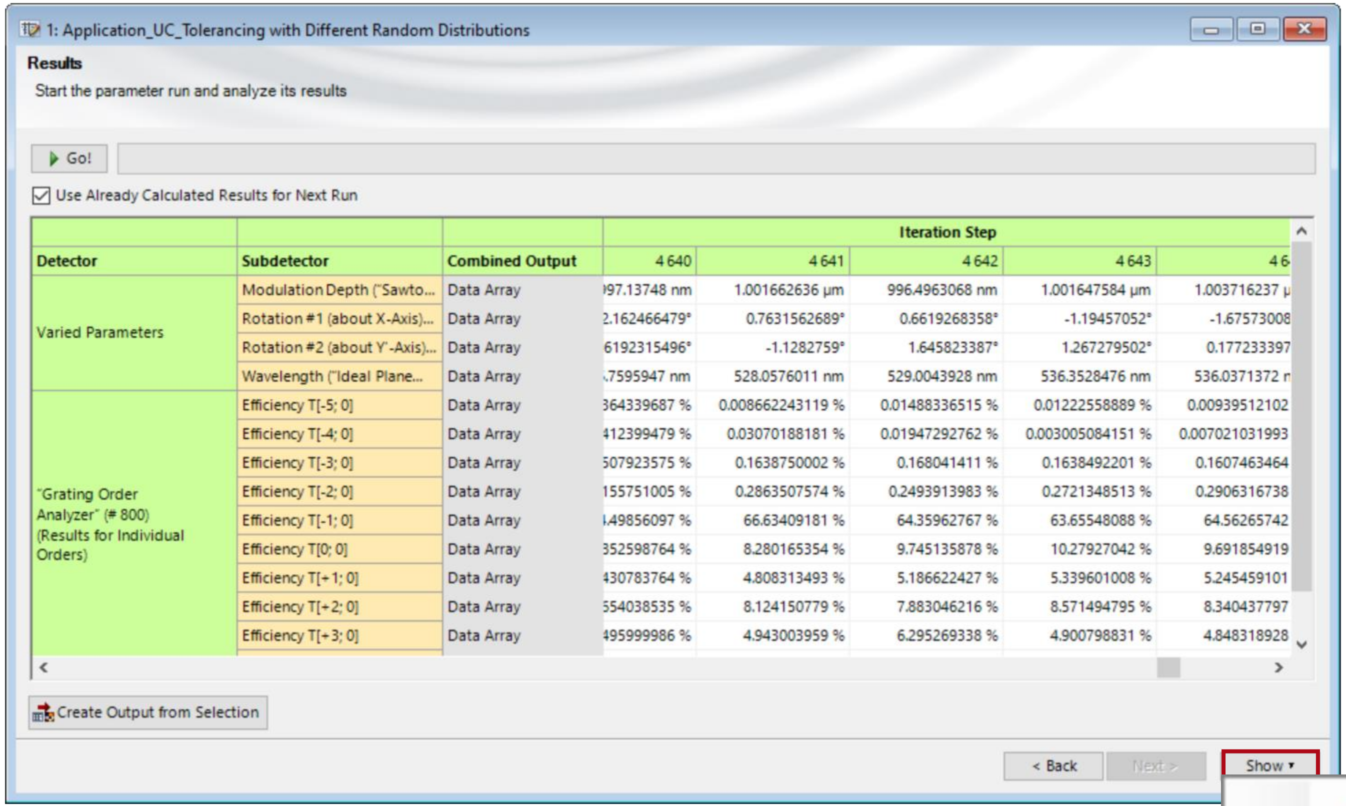




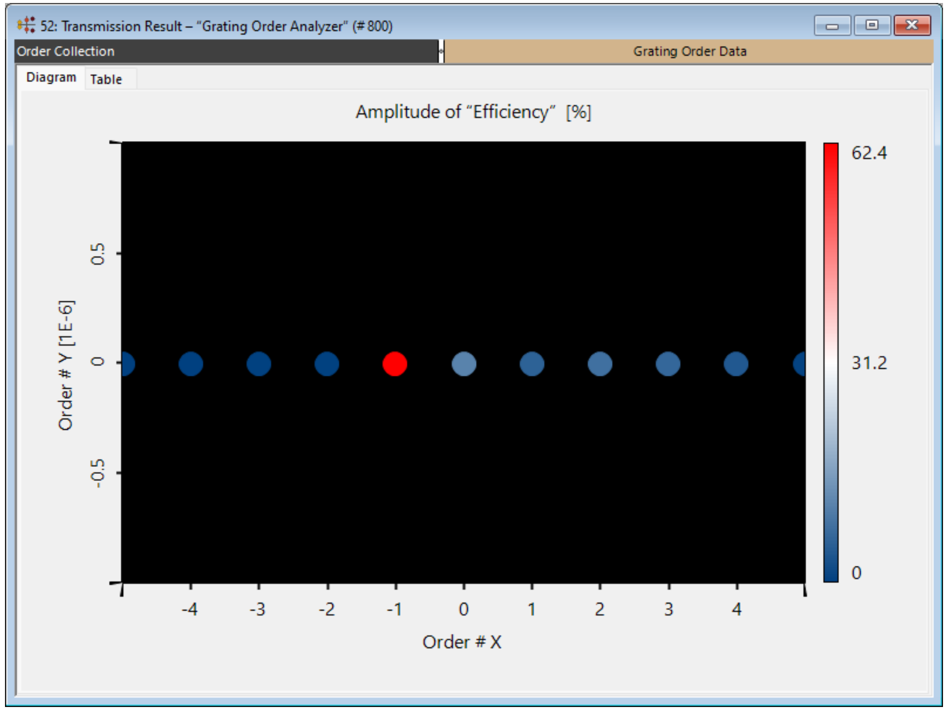
Detector	Subdetector	Combined Output	Iteration Step 52	53	54	55	56
Varied Parameters	Modulation Depth ("Sawto...	Data Array	995.5862702 nm	999.2786353 nm	1.002392516 µm	999.7866468 nm	998.2929675 nm
	Rotation #1 (about X-Axis)...	Data Array	-1.148237896°	1.067181197°	2.935509496°	1.371988082°	0.4757804786°
	Rotation #2 (about Y'-Axis)...	Data Array	-1.148237896°	1.067181197°	2.935509496°	1.371988082°	0.4757804786°
	Wavelength ("Ideal Plane...	Data Array	530.9332532 nm	534.7045631 nm	536.891526 nm	536.6452646 nm	528.6008831 nm
"Grating Order Analyzer" (# 800) (Results for Individual Orders)	Efficiency T[-5; 0]	Data Array	0.006954975138 %	0.01239066409 %	0.0133196378 %	0.01232426235 %	0.01343482303 %
	Efficiency T[-4; 0]	Data Array	0.02119765689 %	0.004385315941 %	0.004445690263 %	0.002857036355 %	0.01762127598 %
	Efficiency T[-3; 0]	Data Array	0.1494378622 %	0.1599496327 %	0.1827552108 %	0.1626285993 %	0.1610582486 %
	Efficiency T[-2; 0]	Data Array	0.3049591835 %	0.2749431906 %	0.2339417567 %	0.2726753127 %	0.2684565027 %
	Efficiency T[-1; 0]	Data Array	65.76972253 %	63.94807318 %	62.41434543 %	63.41684883 %	65.37083533 %
	Efficiency T[0; 0]	Data Array	8.975110554 %	10.10687831 %	10.99132697 %	10.46489025 %	9.107134023 %
	Efficiency T[+1; 0]	Data Array	5.105434185 %	5.279499482 %	5.595484813 %	5.389982927 %	4.950436151 %
	Efficiency T[+2; 0]	Data Array	7.804643545 %	8.536430247 %	7.88245793 %	8.56543145 %	8.40042131 %
	Efficiency T[+3; 0]	Data Array	5.2153954 %	4.89529422 %	6.479647024 %	4.897198913 %	5.135269248 %
	Efficiency T[+4; 0]	Data Array	5.204103138 %	5.174993726 %	4.060462009 %	5.164627361 %	5.014127546 %
	Efficiency T[+5; 0]	Data Array	0.01153910864 %	0.08445674312 %	0.5032032874 %	0.08903802459 %	0.1371004457 %

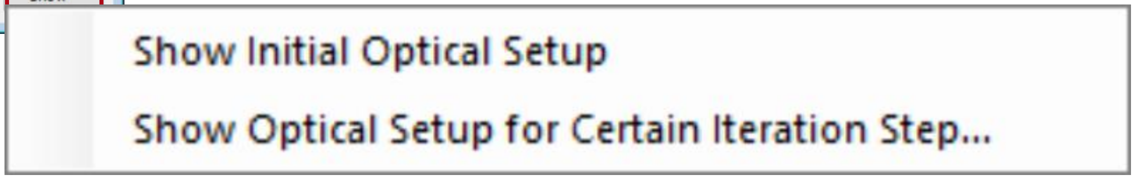
The iteration with minimal efficiency can also be determined and the results further investigated. You can use the detectors in the main window (in the *Detectors* tab) to find the minimum.

Order Efficiencies for Minimal Efficiency



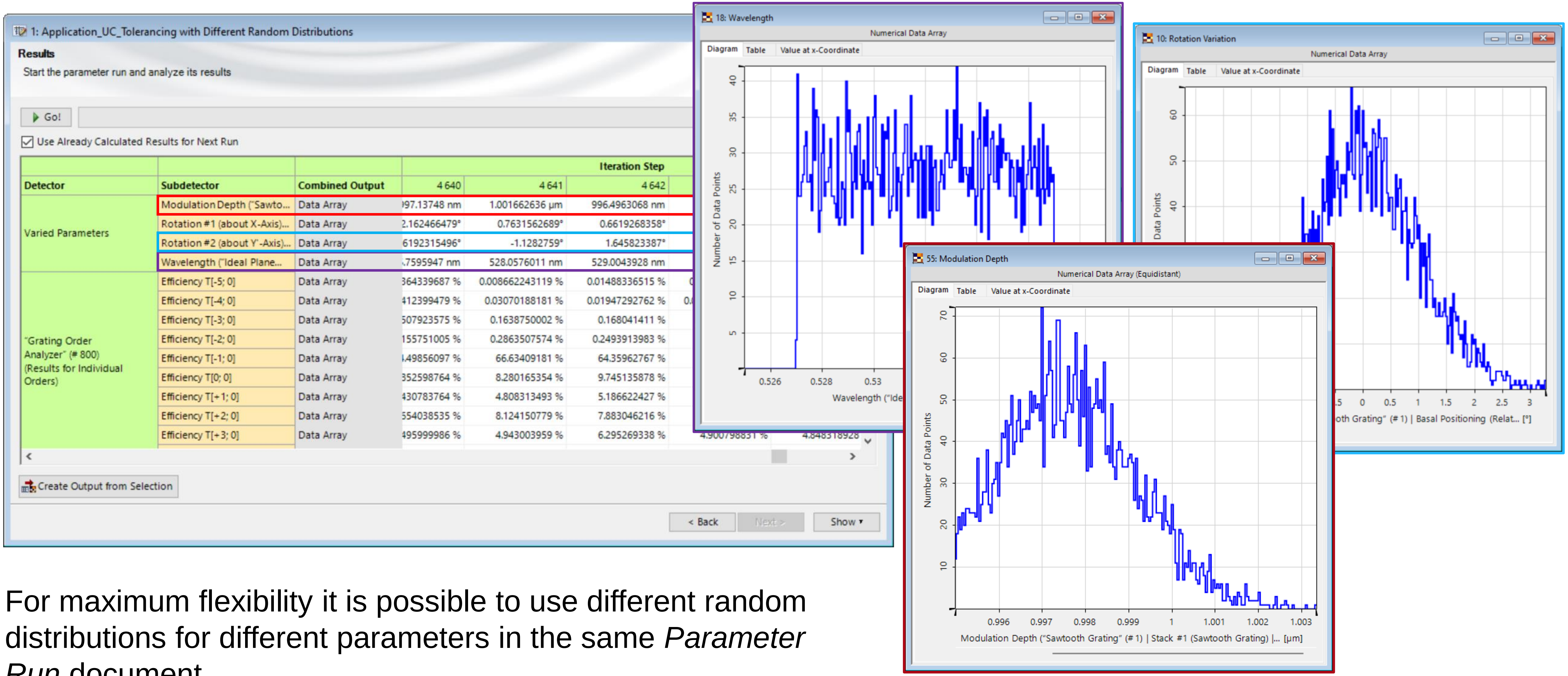
			Iteration Step				
Detector	Subdetector	Combined Output	4 640	4 641	4 642	4 643	4 6
Varied Parameters	Modulation Depth ("Sawto...	Data Array	97.13748 nm	1.001662636 µm	996.4963068 nm	1.001647584 µm	1.003716237 µ
	Rotation #1 (about X-Axis)...	Data Array	2.162466479°	0.7631562689°	0.6619268358°	-1.19457052°	-1.67573008
	Rotation #2 (about Y'-Axis)...	Data Array	6192315496°	-1.1282759°	1.645823387°	1.267279502°	0.177233397
	Wavelength ("Ideal Plane...	Data Array	.7595947 nm	528.0576011 nm	529.0043928 nm	536.3528476 nm	536.0371372 n
"Grating Order Analyzer" (# 800) (Results for Individual Orders)	Efficiency T[-5; 0]	Data Array	364339687 %	0.008662243119 %	0.01488336515 %	0.01222558889 %	0.00939512102
	Efficiency T[-4; 0]	Data Array	412399479 %	0.03070188181 %	0.01947292762 %	0.003005084151 %	0.007021031993
	Efficiency T[-3; 0]	Data Array	507923575 %	0.1638750002 %	0.168041411 %	0.1638492201 %	0.1607463464
	Efficiency T[-2; 0]	Data Array	155751005 %	0.2863507574 %	0.2493913983 %	0.2721348513 %	0.2906316738
	Efficiency T[-1; 0]	Data Array	.49856097 %	66.63409181 %	64.35962767 %	63.65548088 %	64.56265742
	Efficiency T[0; 0]	Data Array	352598764 %	8.280165354 %	9.745135878 %	10.27927042 %	9.691854919
	Efficiency T[+1; 0]	Data Array	430783764 %	4.808313493 %	5.186622427 %	5.339601008 %	5.245459101
	Efficiency T[+2; 0]	Data Array	554038535 %	8.124150779 %	7.883046216 %	8.571494795 %	8.340437797
	Efficiency T[+3; 0]	Data Array	495999986 %	4.943003959 %	6.295269338 %	4.900798831 %	4.848318928





The *Optical Setup* of each iteration can be accessed via the *Show* button to further investigate the system and e.g. calculate the *Order Collection*.

Random Distribution Types



For maximum flexibility it is possible to use different random distributions for different parameters in the same *Parameter Run* document.

Document Information

title	Tolerancing with Parameter Variations of Different Random Distributions
document code	SWF.0031
document version	2.1
software edition	VirtualLab Fusion Advanced*
software version	2021.1 (Build 1.180)
category	Feature Use Case
further reading	- Usage of the Parameter Run Document - Grating Order Analyzer

*As in this use case the example setup is a Grating Optical Setup, VirtualLab Fusion Advanced is necessary to work with the sample files to their full potential. However, the workflows related to the *Parameter Run* presented in this use case are equally valid for other types of Optical Setups. The full functionality of the *Parameter Run* is included with VirtualLab Fusion Basic.