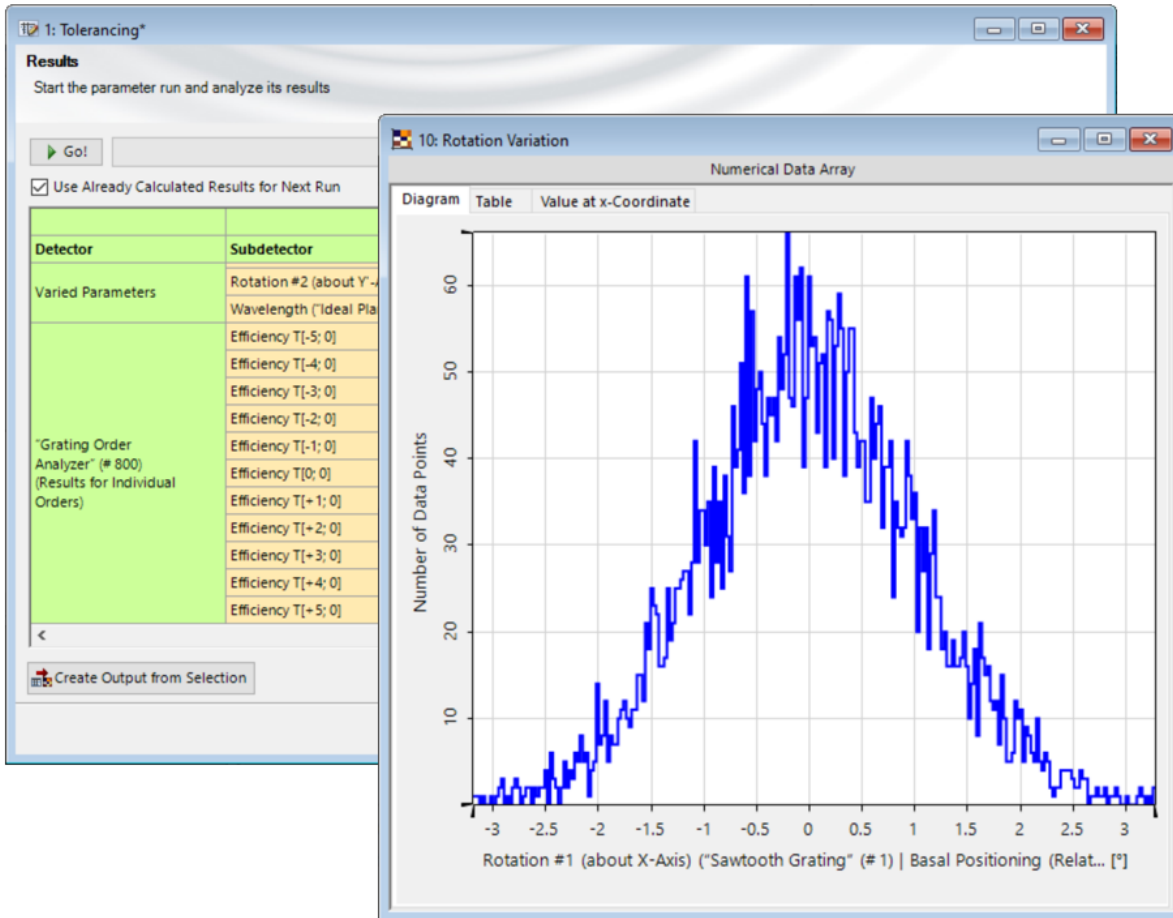


# **Tolerancing with Parameter Variations of Different Random Distributions**

# Abstract



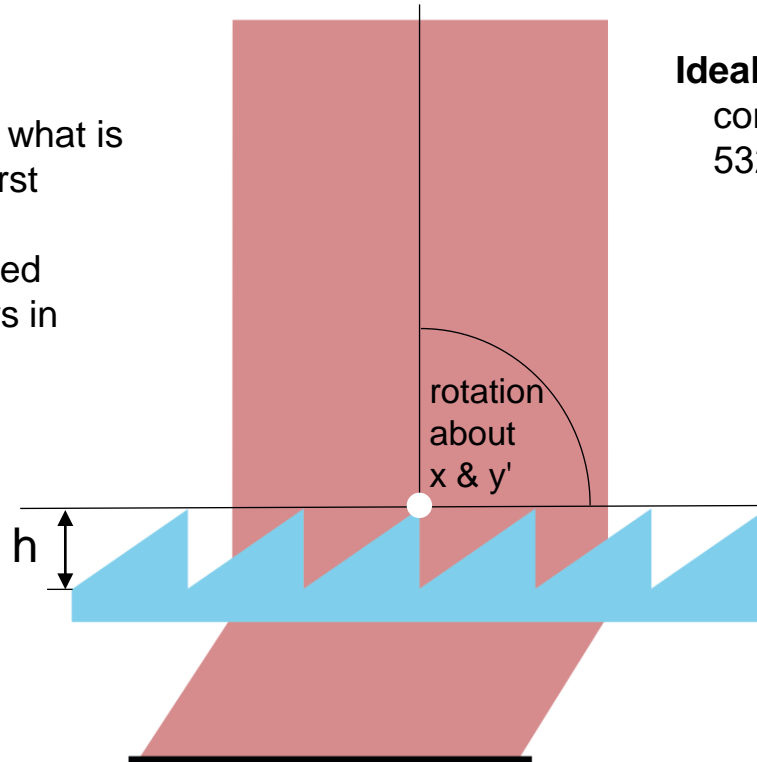
The investigation of the effect of manufacturing deviations is crucial for the design of any optical system and component. In VirtualLab Fusion, randomly varied Parameter Runs can be applied to analyze this impact in detail. Depending on the kind of manufacturing process, the resulting deviations may 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?

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.



## Ideal Plane Wave

considered wavelength range  
 $532\text{nm} \pm 10\text{nm}$  (uniform distribution)

## Sawtooth Grating (fixed parameters)

- period:  $2\mu\text{m}$
- material: fused silica

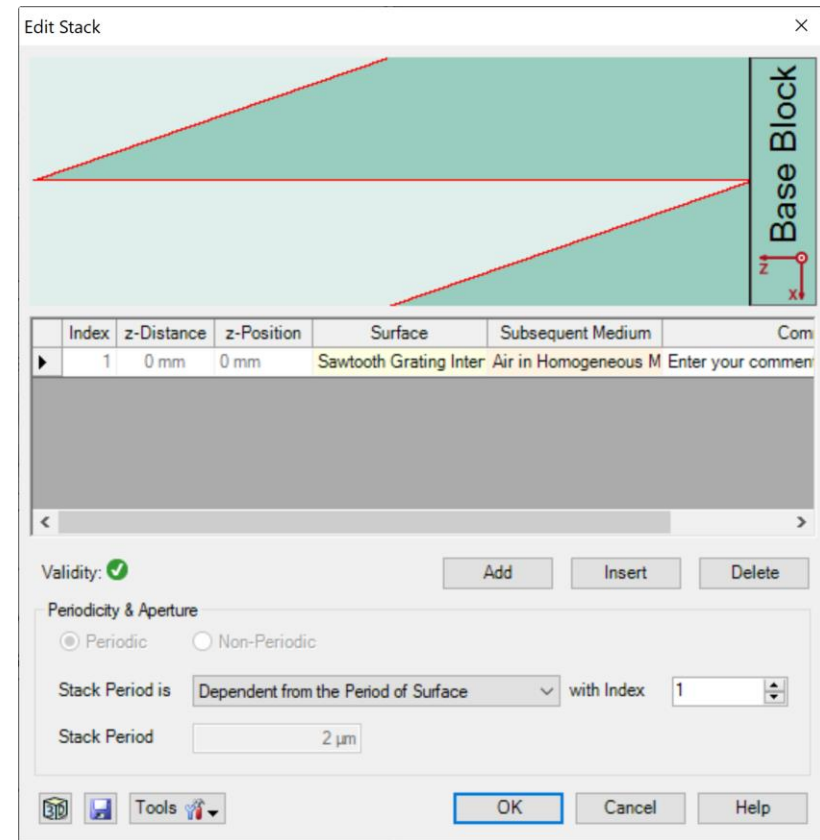
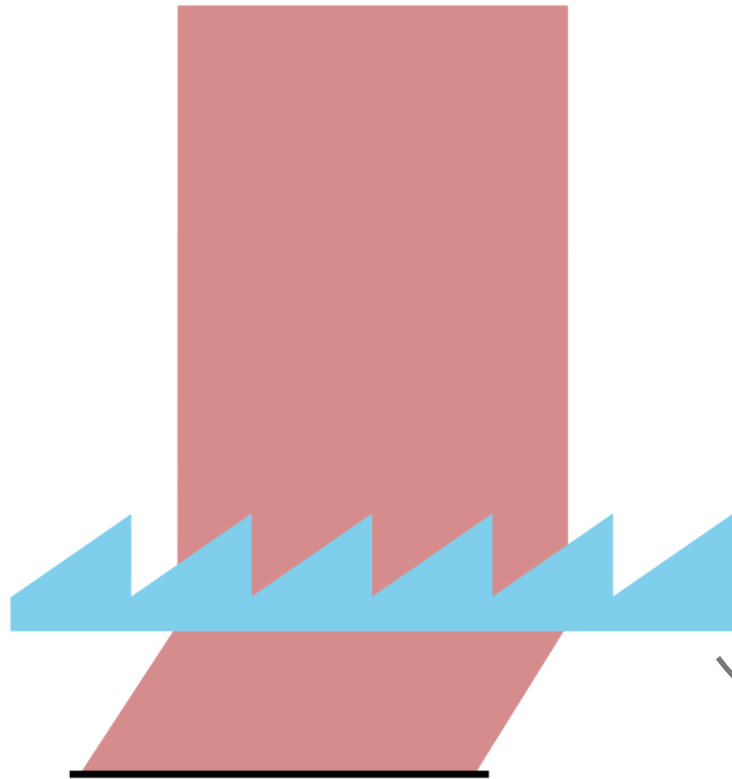
## Sawtooth Grating (parameters for tolerancing)

- tolerance of rotation angle about x-axis: normal distribution in  $[-2^\circ; +2^\circ]$
- tolerance of rotation angle about y'-axis (\*): normal distribution in  $[-2^\circ; +2^\circ]$
- tolerance of modulation depth h: cutoff normal distribution (\*\*) in  $[0.95\mu\text{m}; 1.05\mu\text{m}]$

(\*) X... rotation about x-axis, Y'... rotation about changed y-axis (after rotation X)

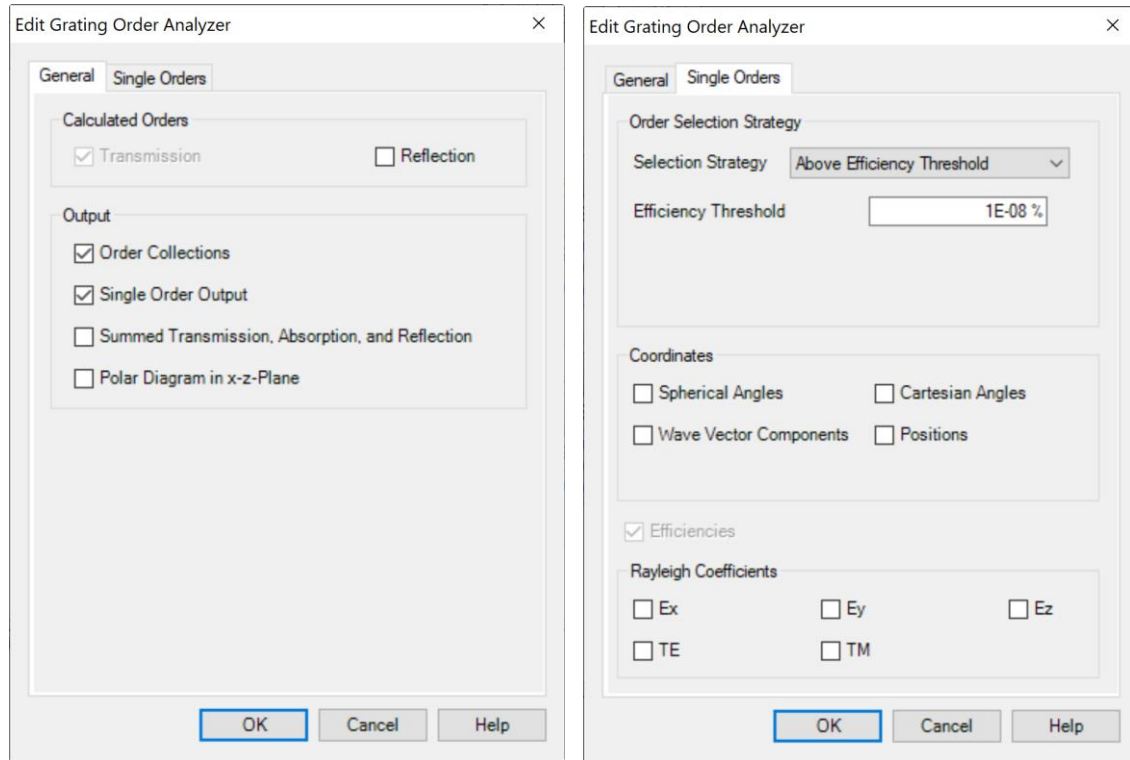
(\*\*) See later slide for explanation about the cutoff normal distribution.

# The System in VirtualLab Fusion – Components

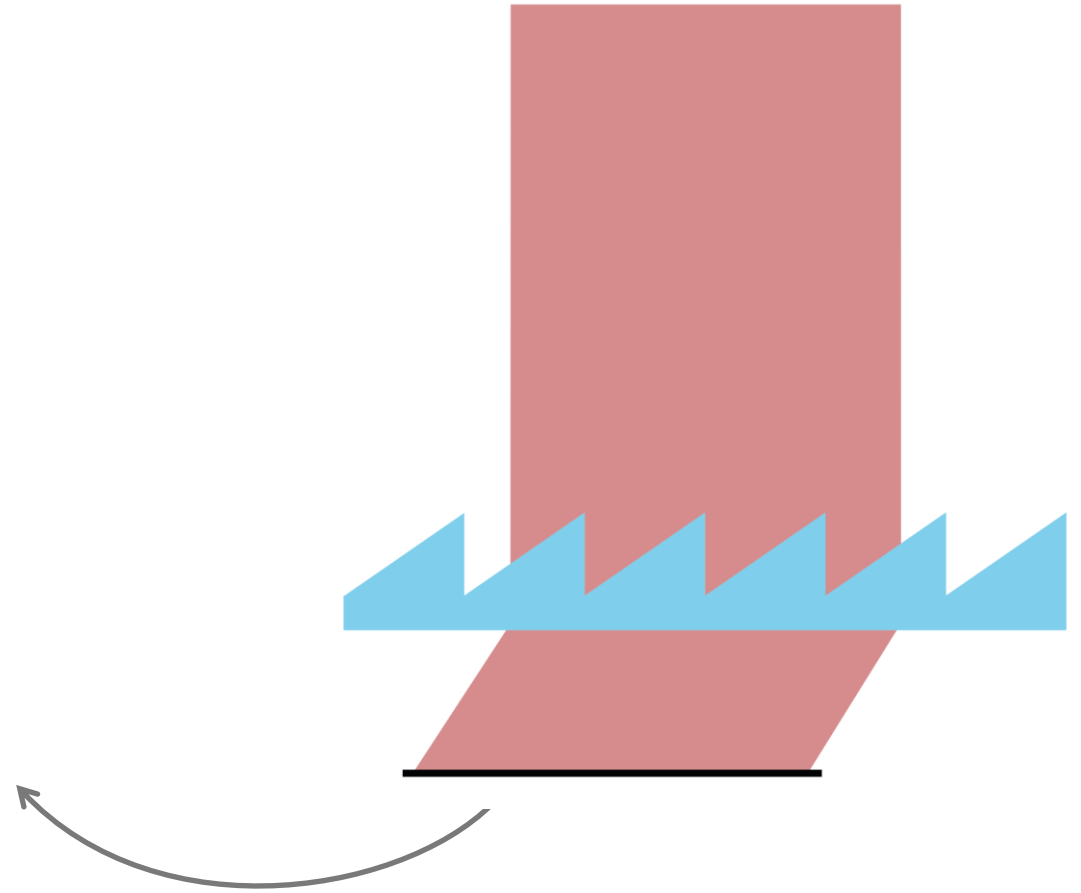


The grating is modeled using a *Sawtooth Grating Interface*. In the configuration dialog of the surface, the period, blaze angle and modulation depth can be adjusted.

# 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.



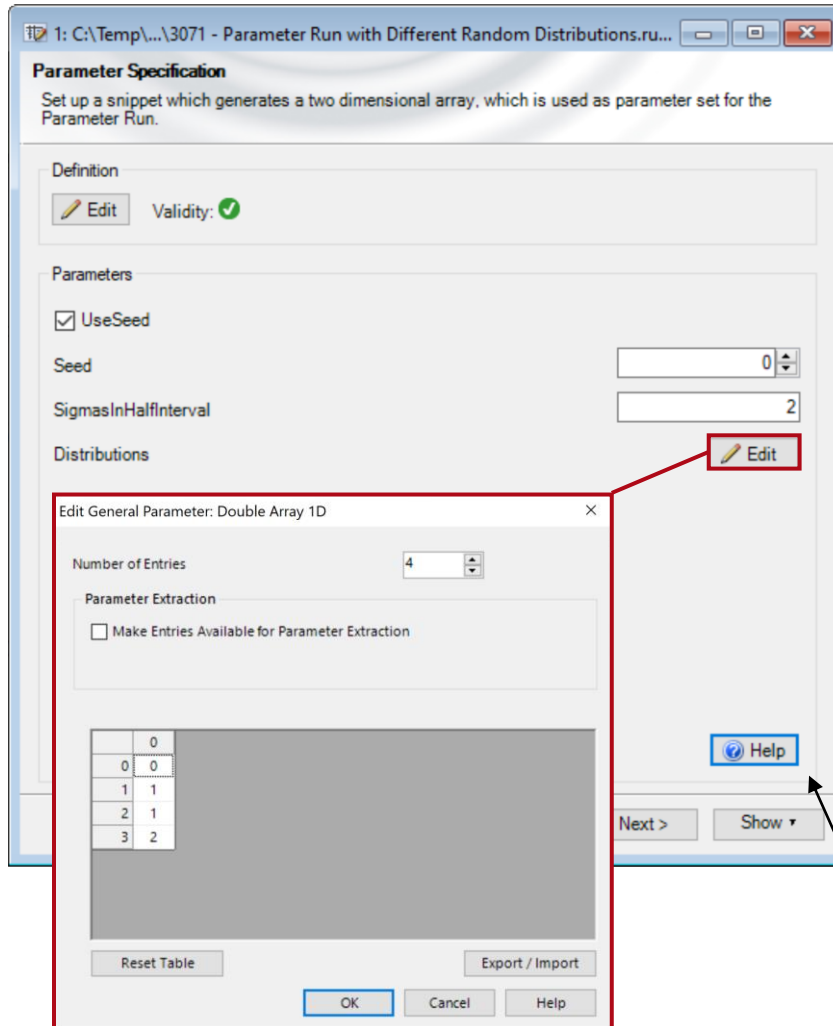
# Programmable Parameter Run

Detector	Subdetector	Combined Output	Iteration Step				
			4640	4641	4642	4643	4644
Varied Parameters	Modulation Depth ("Sawto...)	Data Array	197.13748 nm	1.001662636 µm	996.4963068 nm	1.001647584 µm	1.003716237 µm
	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	1.7595947 nm	528.0576011 nm	529.0043928 nm	536.3528476 nm	536.0371372 nm
"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	149856097 %	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 %

```
1 double[,] parameters = new double[NumberOfParameters
2
3 (double minimum, double maximum, RandomDistributionT
4
5 for (int parameterIndex = 0; parameterIndex < Number
6     intervals[parameterIndex] = (MinimumValues[param
7 }
8
9 RandomNumberGenerators randomNumberGenerators = new
10
11
12     for (int i = 0; i < NumberOfIterations; i++) {
13     for (int parameterIndex = 0; parameterIndex < Number
14         parameters[parameterIndex, i] = randomNumber
15     }
16 }
17
18 return parameters;
```

- 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.

## SigmasInHalfInterval

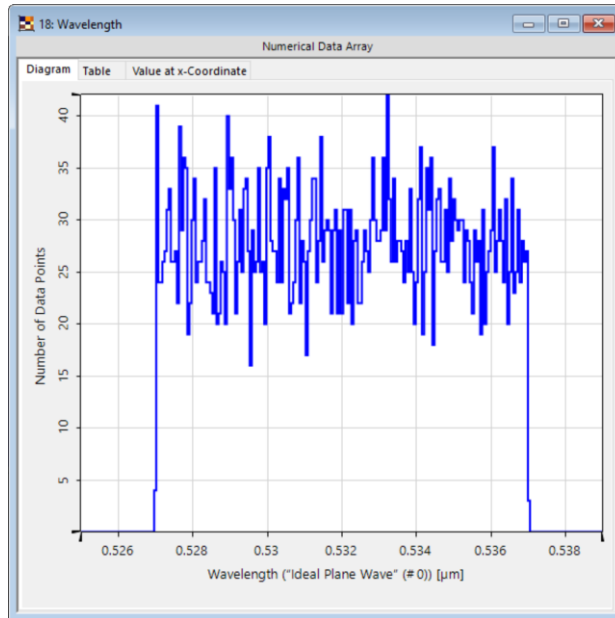
Determine the width of the distribution; more information can be found in the “Help” document.

## Distributions

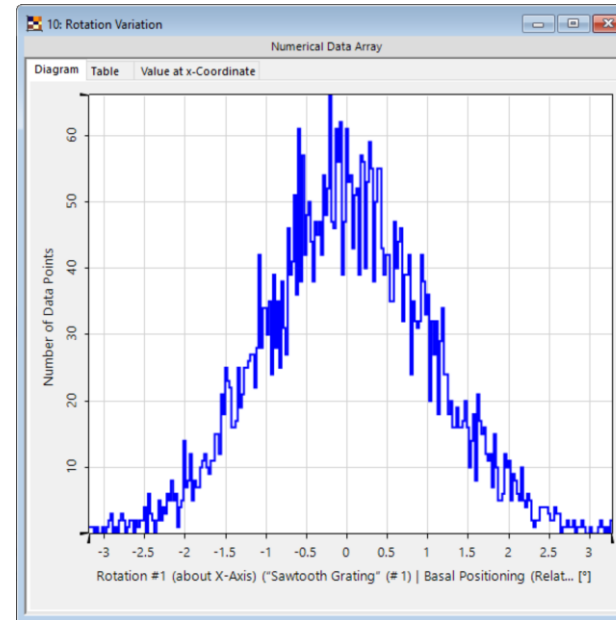
- Choose either a “Uniform”, “Normal” or “Cutoff Normal” Distribution for each individual parameter varied.
- The distribution type is coded with numbers:  
0 – uniform  
1 – normal  
2 – cutoff normal

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

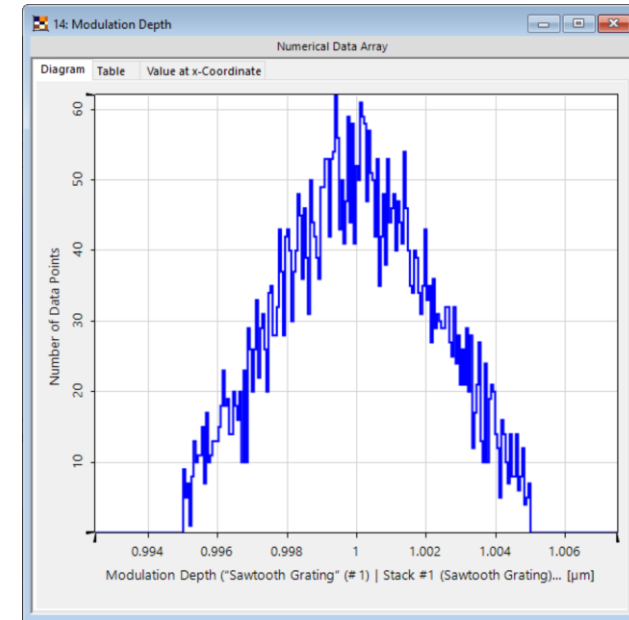
# Distribution Types



uniform distribution



normal distribution



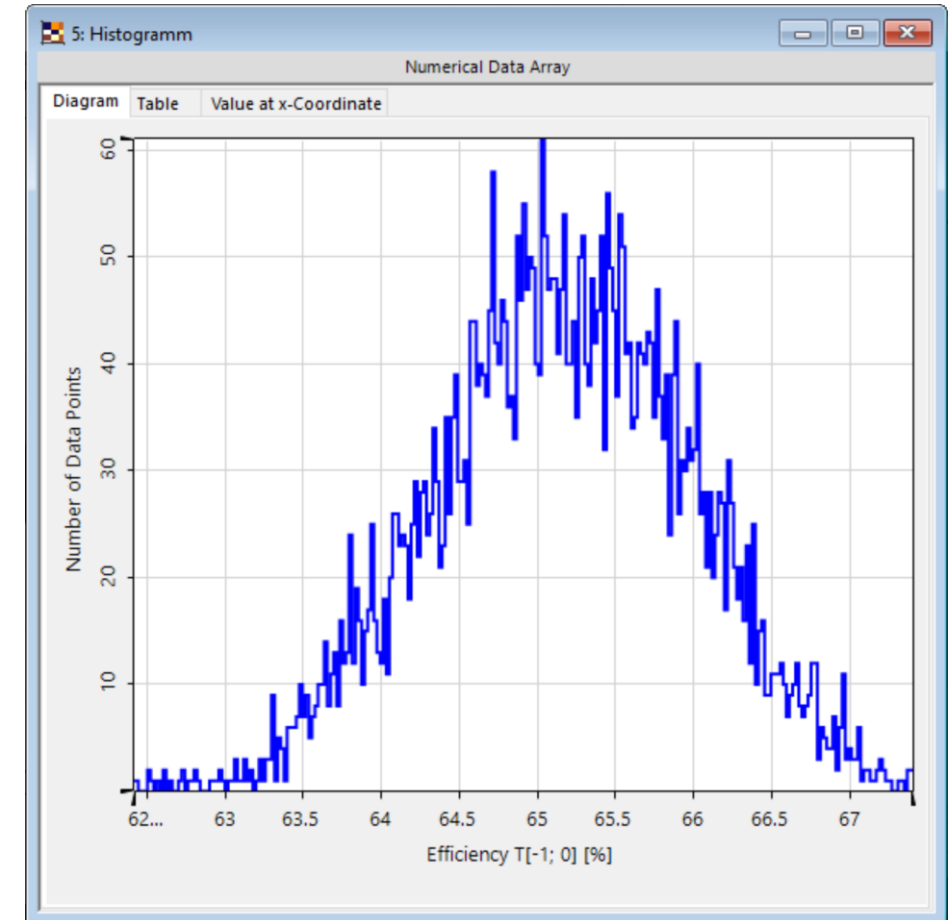
cutoff-normal distribution

In the case of a uniform distribution, the number of points will be evenly distributed over the allowed range. The normal and cutoff normal distributions both assume a Gaussian profile for the probability of a point being taken. The difference between the standard normal distribution and the cutoff normal distribution is that in the case of the cutoff distribution the values outside of the cut-off range will not be taken, but a new number inside the range is generated instead.



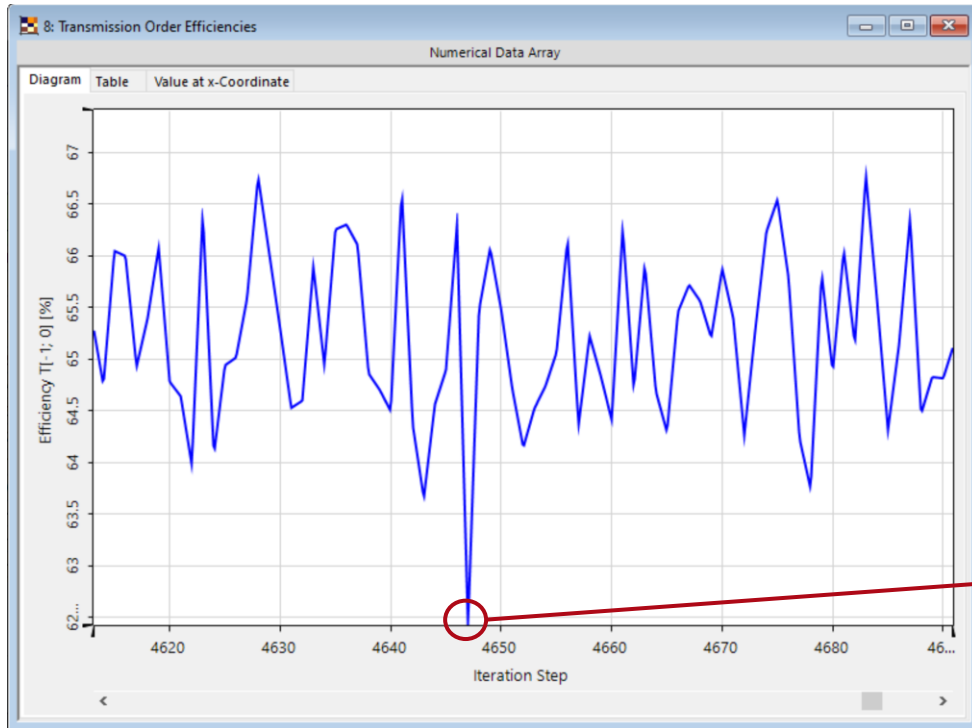
# Statistical Distribution of the Efficiency

Detector	Subdetector	Combined Output	Iteration Step				
			4 640	4 641	4 642	4 643	4 644
Varied Parameters	Modulation Depth ("Sawto...)	Data Array	197.13748 nm	1.001662636 μm	996.4963068 nm	1.001647584 μm	1.003716237 μm
	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 nm
"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	149856097 %	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 %	



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



The results window displays the following data for the iteration step highlighted in the graph (Iteration 647):

Detector	Subdetector	Combined Output	645	646	647	648
Varied Parameters	Rotation #2 (about Y'-Axis)...	Data Array	156°	-0.7812635179°	2.406712771°	0.5848385359°
	Wavelength ("Ideal Plane...	Data Array	nm	529.2029393 nm	536.8510101 nm	527.6056714 nm
"Grating Order Analyzer" (# 800) (Results for Individual Orders)	Efficiency T[-5; 0]	Data Array	2 %	0.009356509871 %	0.01366715694 %	0.01405593006 %
	Efficiency T[-4; 0]	Data Array	8 %	0.02225817303 %	0.003027427315 %	0.02146685819 %
	Efficiency T[-3; 0]	Data Array	3 %	0.1618958021 %	0.167315567 %	0.1642560544 %
	Efficiency T[-2; 0]	Data Array	5 %	0.2853904975 %	0.2532058811 %	0.2630717693 %
	Efficiency T[-1; 0]	Data Array	5 %	66.2979572 %	62.42238014 %	65.47893398 %
	Efficiency T[0; 0]	Data Array	1 %	8.500341838 %	11.13483514 %	9.006686843 %
	Efficiency T[+1; 0]	Data Array	7 %	4.8594041 %	5.579618896 %	4.91715802 %
	Efficiency T[+2; 0]	Data Array	4 %	8.228002021 %	8.279168914 %	8.315355255 %
	Efficiency T[+3; 0]	Data Array	8 %	4.872787046 %	5.704226802 %	5.370110059 %
	Efficiency T[+4; 0]	Data Array	8 %	5.395679687 %	4.470860284 %	4.835374497 %
Efficiency T[+5; 0]	Data Array	2 %	0.001391476082 %	0.3357915034 %	0.1948151149 %	

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

1: Application\_UC\_Tolerancing with Different Random Distributions

Results  
Start the parameter run and analyze its results

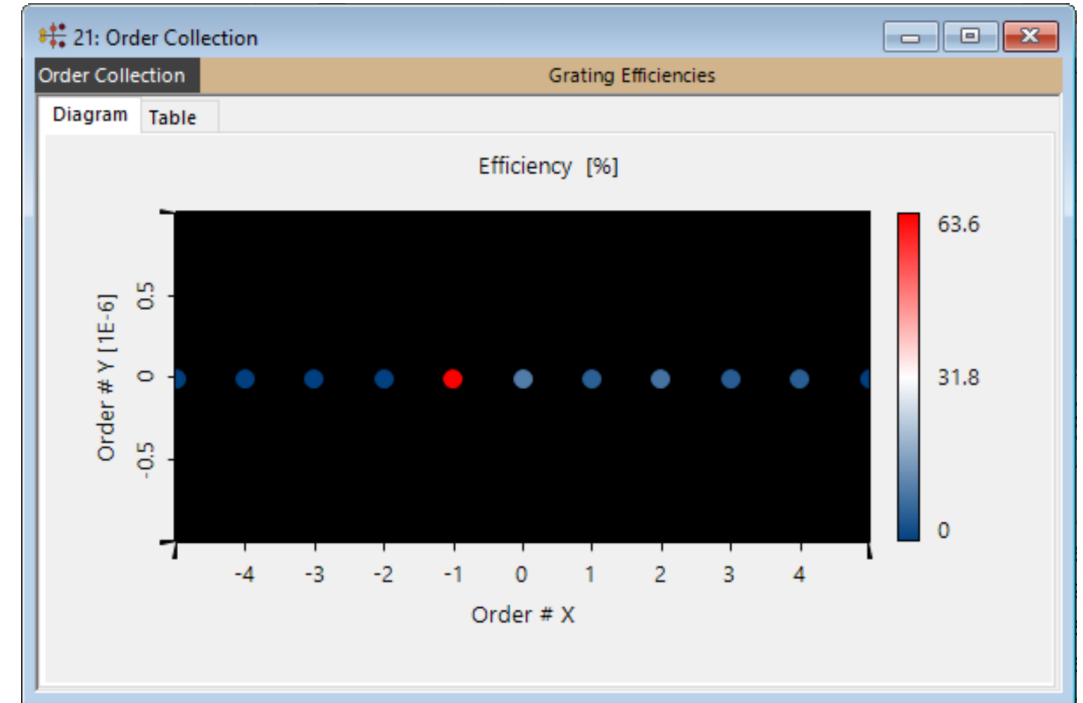
Go!

Use Already Calculated Results for Next Run

Detector	Subdetector	Combined Output	Iteration Step				
			4 640	4 641	4 642	4 643	4 6
Varied Parameters	Modulation Depth ("Sawto...	Data Array	197.13748 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
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	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	149856097 %	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	

Create Output from Selection

< Back Next > Show ▾

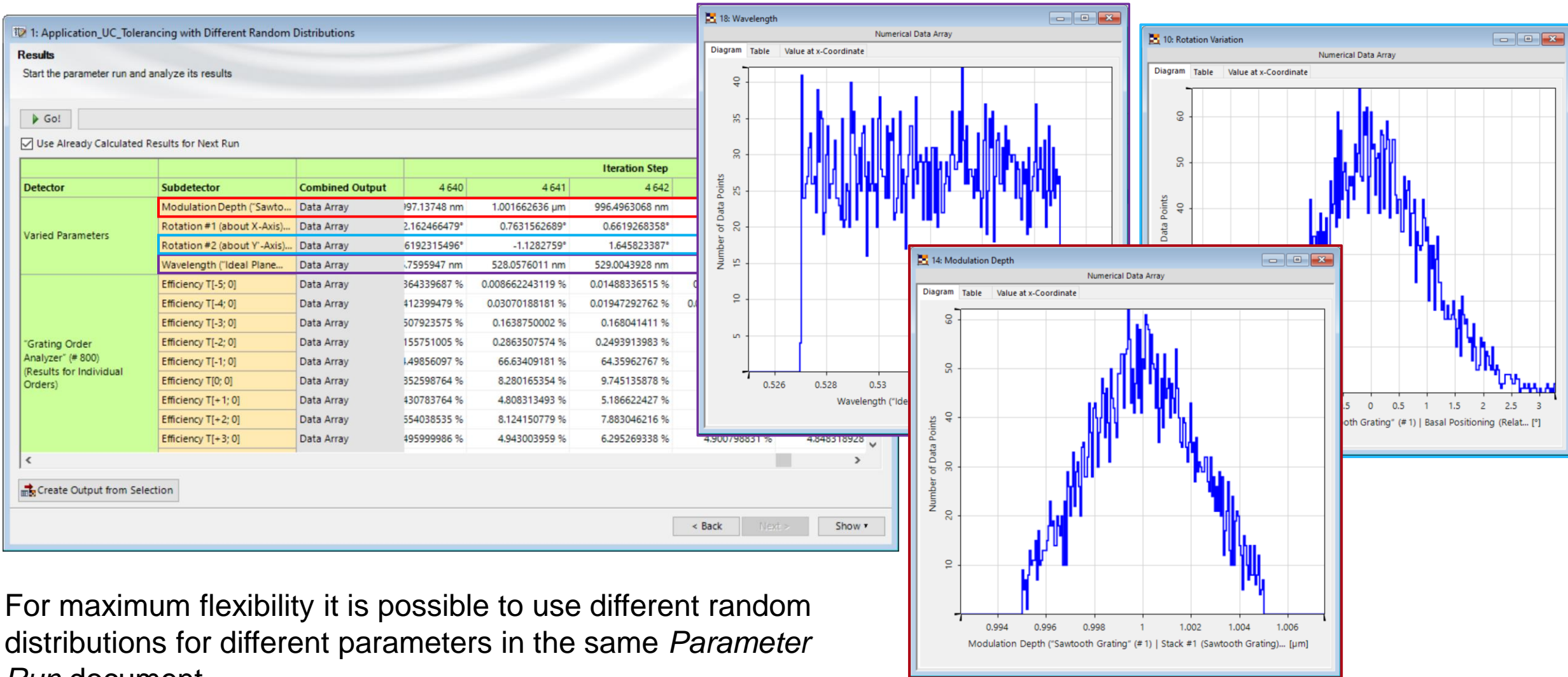


The *Optical Setup* of each iteration can be accessed via the *Show* button to further investigate the system and e.g. calculate the *Order Collection*.

Show Initial Optical Setup

Show Optical Setup for Certain Iteration Step...

# 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	Misc.0065
document version	2.0
software edition	VirtualLab Fusion Advanced*
software version	2021.1 (Build 1.180)
category	Feature Use Case
further reading	<ul style="list-style-type: none"><li>- <a href="#">Usage of the Parameter Run Document</a></li><li>- <a href="#">Grating Order Analyzer</a></li></ul>

\*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.