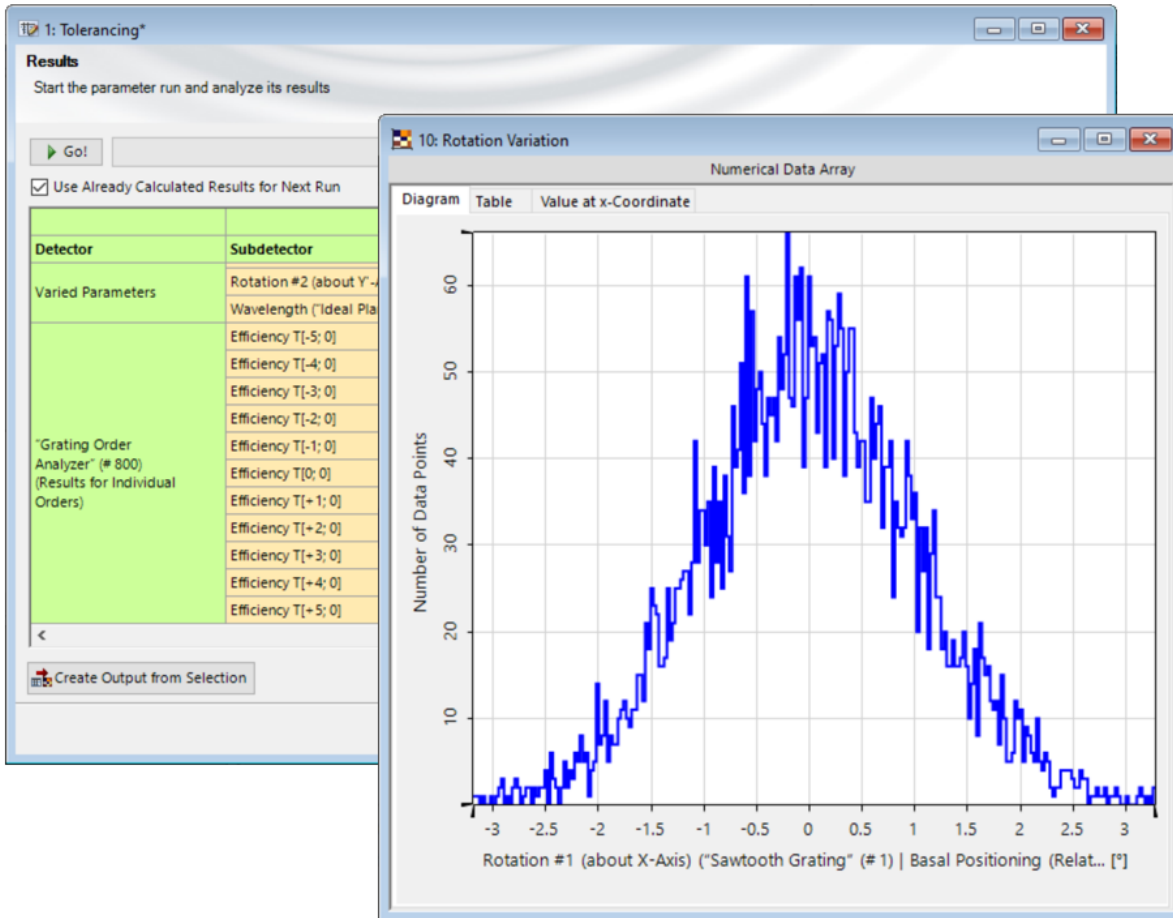


Tolerancing with Parameter Variations of Different Random Distributions

Abstract



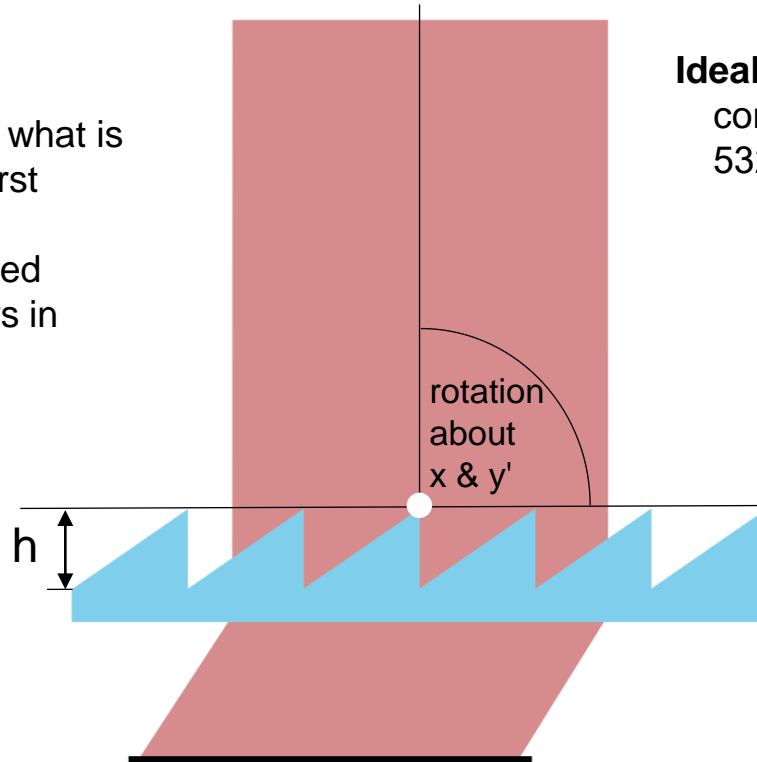
The investigation of the effect of manufacturing deviations is crucial for the design of any optical system and component. In VirtualLab Fusion, randomly varied Parameter Runs can be applied to analyze this impact in detail. Depending on the kind of manufacturing process, the resulting deviations may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

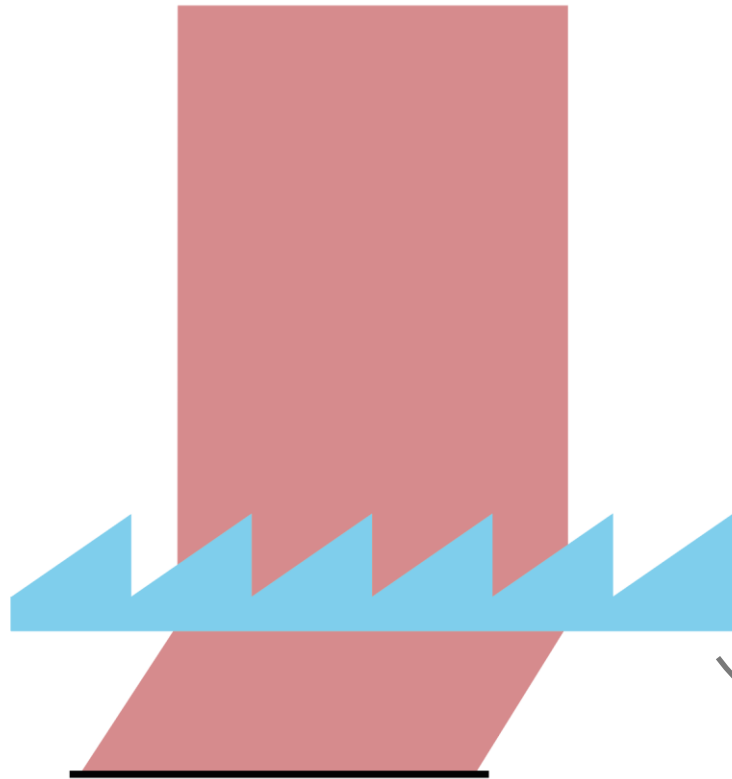
Sawtooth Grating (parameters for tolerancing)

- 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: asymmetrical normal distribution (**) in $[0.95\mu\text{m}; 1.05\mu\text{m}]$

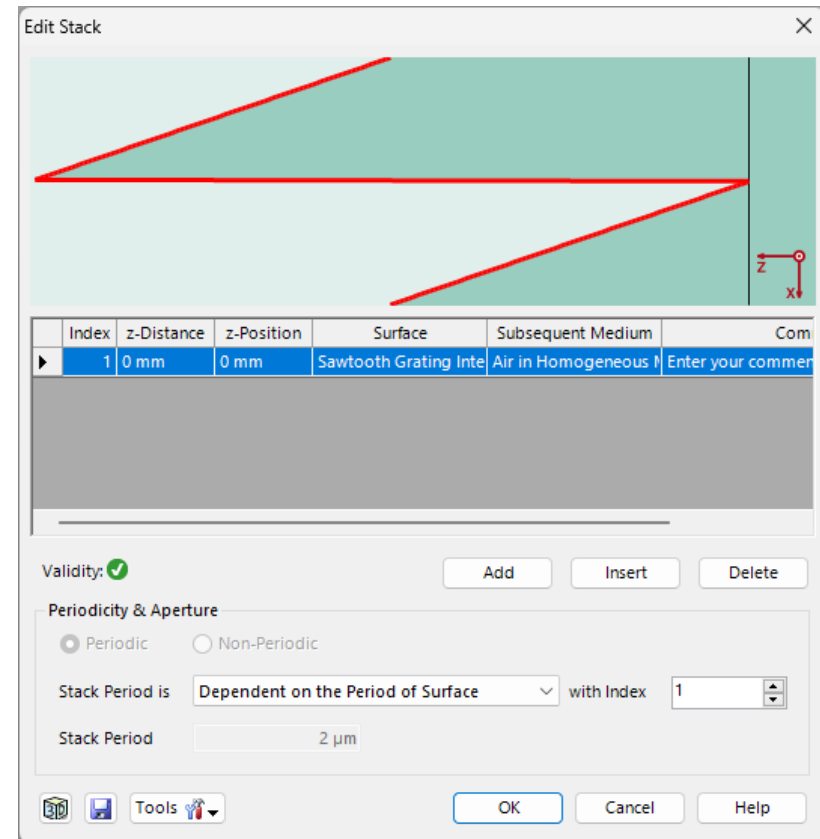
(*) X... rotation about x-axis, Y'... rotation about changed y-axis (after rotation X)

(**) For an explanation of the various random distribution types, please see: [Tolerancing with Random Distributions](#)

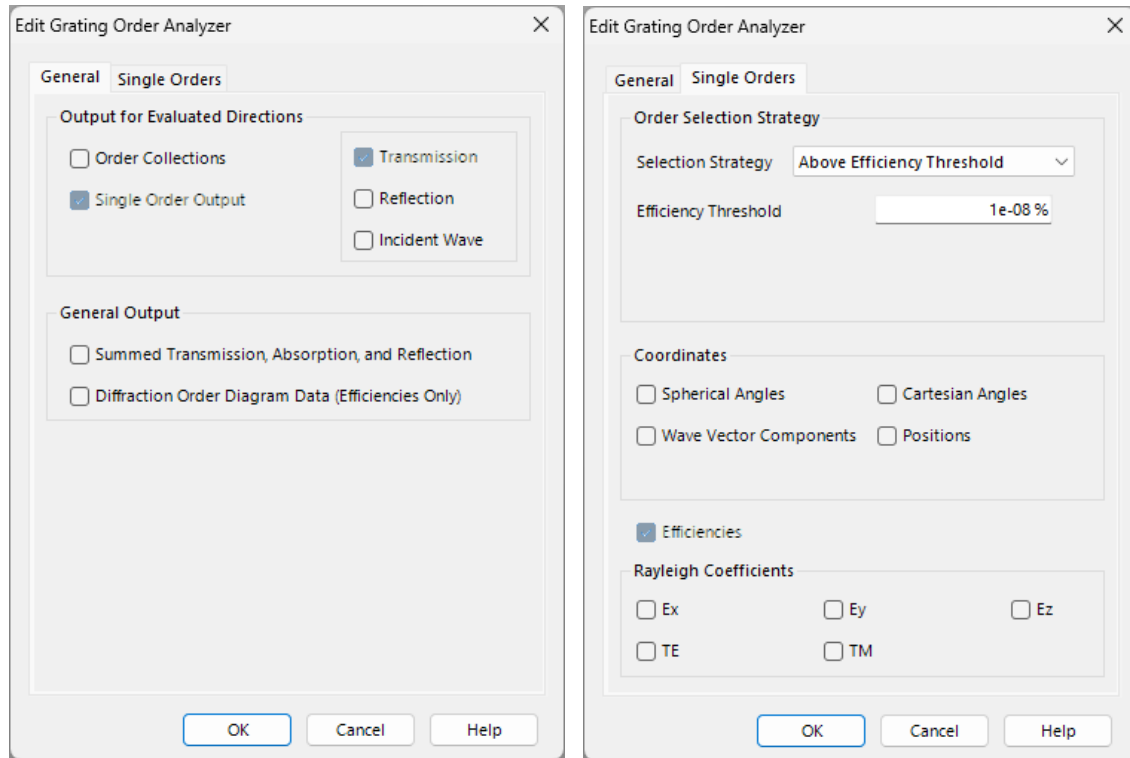
The System in VirtualLab Fusion – Components



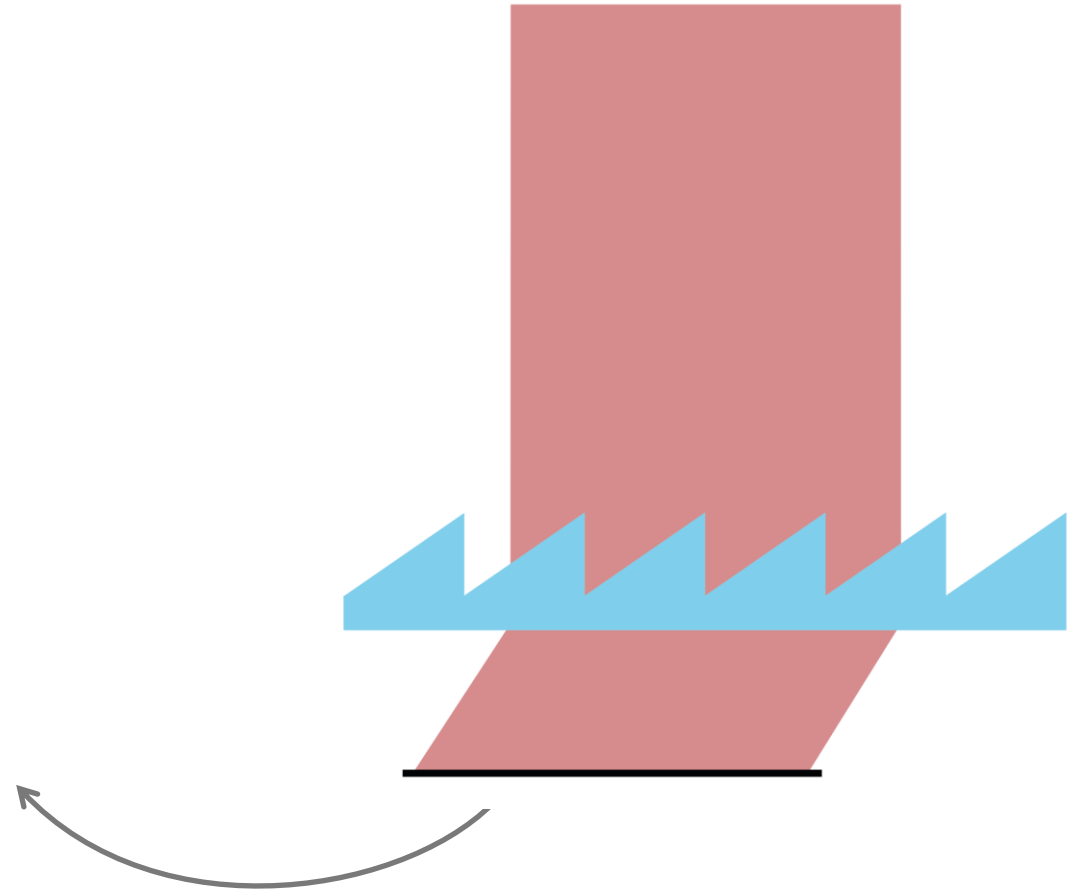
The grating is modeled using a *Sawtooth Grating Interface*. In the configuration dialog of the surface, the period, blaze angle and modulation depth can be adjusted.



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.



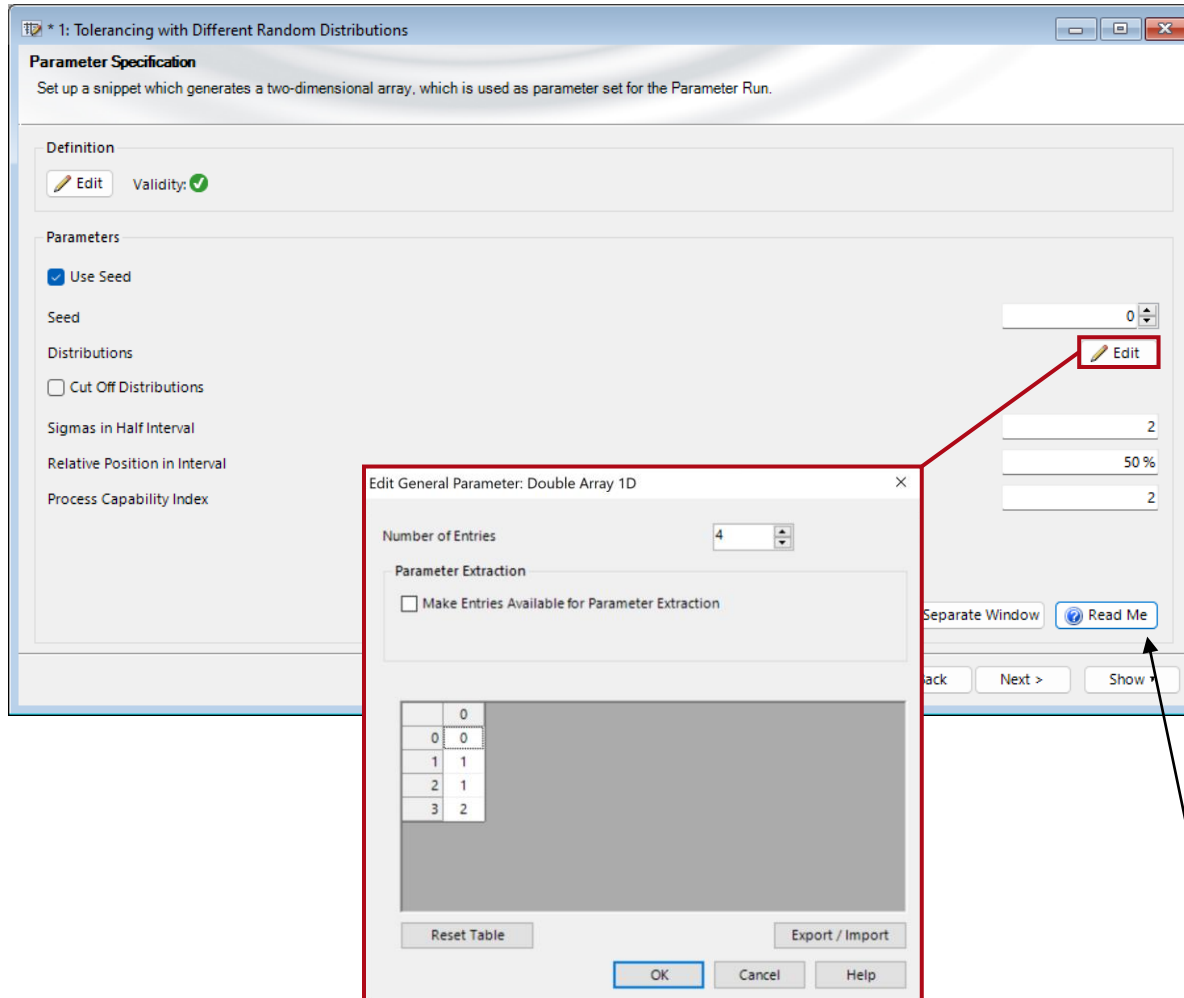
Programmable Parameter Run

Detector	Subdetector	Combined Output	Iteration Step				
			4 640	4 641	4 642	4 643	4 644
Varied Parameters	Modulation Depth ("Sawto...)	Data Array	997.13748 nm	1.001662636 µm	996.4963068 nm	1.001647584 µm	1.003716237
	Rotation #1 (about X-Axis)...	Data Array	2.162466479°	0.7631562689°	0.6619268358°	-1.19457052°	-1.6757300
	Rotation #2 (about Y-Axis)...	Data Array	6192315496°	-1.1282759°	1.645823387°	1.267279502°	0.1772333
	Wavelength ("Ideal Plane...	Data Array	.7595947 nm	528.0576011 nm	529.0043928 nm	536.3528476 nm	536.0371372
"Grating Order Analyzer" (# 800) (Results for Individual Orders)	Efficiency T[-5; 0]	Data Array	364339687 %	0.008662243119 %	0.01488336515 %	0.01222558889 %	0.0093951210
	Efficiency T[-4; 0]	Data Array	412399479 %	0.03070188181 %	0.01947292762 %	0.003005084151 %	0.00702103199
	Efficiency T[-3; 0]	Data Array	507923575 %	0.1638750002 %	0.168041411 %	0.1638492201 %	0.160746346
	Efficiency T[-2; 0]	Data Array	155751005 %	0.2863507574 %	0.2493913983 %	0.2721348513 %	0.290631673
	Efficiency T[-1; 0]	Data Array	1.49856097 %	66.63409181 %	64.35962767 %	63.65548088 %	64.5626574
	Efficiency T[0; 0]	Data Array	352598764 %	8.280165354 %	9.745135878 %	10.27927042 %	9.69185491
	Efficiency T[+1; 0]	Data Array	430783764 %	4.808313493 %	5.186622427 %	5.339601008 %	5.24545910
	Efficiency T[+2; 0]	Data Array	554038535 %	8.124150779 %	7.883046216 %	8.571494795 %	8.34043779
Efficiency T[+3; 0]	Data Array	495999986 %	4.943003959 %	6.295269338 %	4.900798831 %	4.84831892	

```
1  Preset using directives
29
30 #region Additional using directives
31
32 #endregion
33
34 Base class to handle Global Parameters
139
140 public class VLModule : VLBaseModule, VirtualLabAPI.Core.Modules.ISnippetDouble_nxm {
141
142     public double[,] GetData() {
143
144         #region Main method
145         double[,] parameters = new double[NumberOfParameters, NumberOfIterations];
146
147         (double minimum, double maximum, RandomDistributionType distributionType)[] intervals =
148
149         List<RandomNumberGenerators> randomNumberGenerators = new();
150
151         for (int parameterIndex = 0; parameterIndex < NumberOfParameters; parameterIndex++) {
152
153             RandomDistributionType type = (RandomDistributionType)Distributions[parameterIndex];
154
155             RandomDistributionSettings settings = new() {
156                 DistributionType = (RandomDistributionType)Distributions[parameterIndex],
157                 UseCustomSeed = UseSeed,
158                 Seed = Seed
159             };
160
161             switch (type) {
162                 case RandomDistributionType.Normal:
163                     settings.CutOffDistribution = CutOff.Distributions
```

- 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

1: Tolerancing with Multiple Random Distributions

Results

Start the parameter run and analyze its results

Go!

Local Execution (Parallel Iterations: 8)

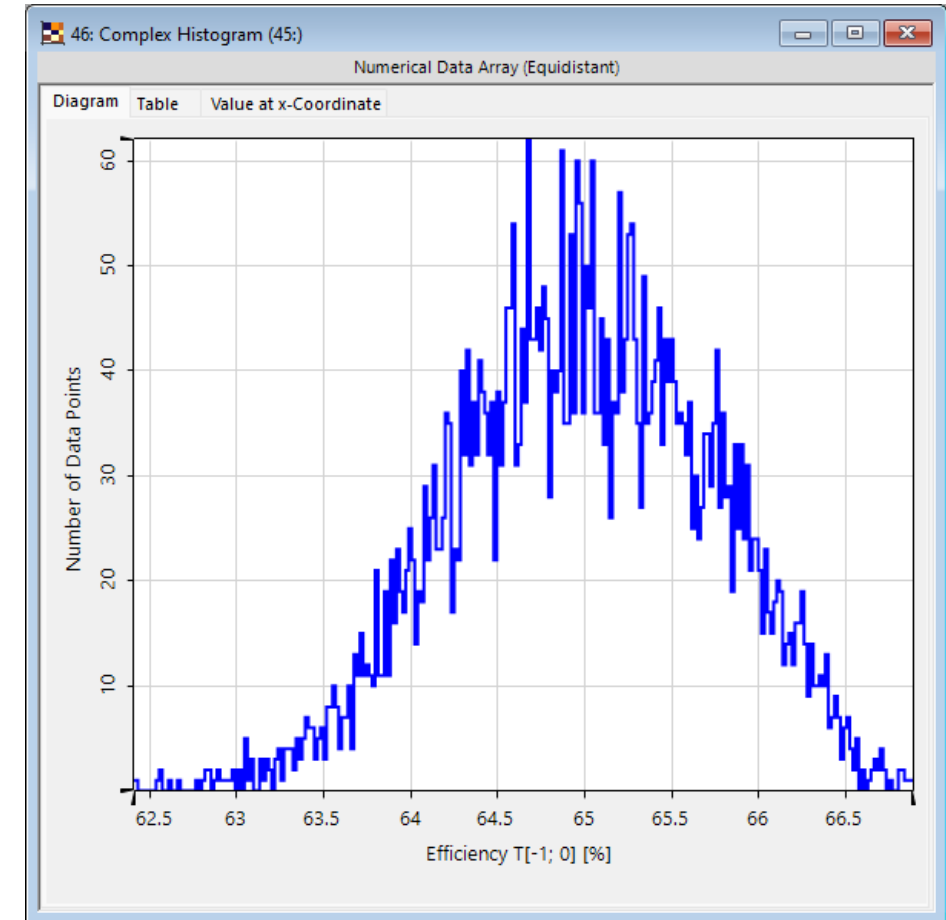
Use Already Calculated Results for Next Run

Detector	Subdetector	Combined Output	Iteration Step					
			991	992	993	994	995	99
Varied Parameters	Modulation Depth ("Sawto...	Data Array	33 nm	997.1957902 nm	998.7836013 nm	998.9832234 nm	996.1153703 nm	995.4680687 nm
	Rotation #1 (about X-Axis)...	Data Array	9831°	-0.1825258776°	0.7701607563°	0.8899340636°	-0.8307777993°	-1.219158771°
	Rotation #2 (about Y-Axis)...	Data Array	9831°	-0.1825258776°	0.7701607563°	0.8899340636°	-0.8307777993°	-1.219158771°
	Wavelength ("Ideal Plane	Data Array	48 nm	535.152164 nm	534.897424 nm	530.7401406 nm	535.4376368 nm	532.9496192 nm
"Grating Order Analyzer" (# 800) (Results for Individual Orders)	Efficiency T[-5; 0]	Data Array	215 %	0.008579000584 %	0.01159435925 %	0.01349569138 %	0.006266094426 %	0.005871736827 %
	Efficiency T[-4; 0]	Data Array	362 %	0.009816935227 %	0.005003106951 %	0.01101051653 %	0.01469999202 %	0.01880624516 %
	Efficiency T[-3; 0]	Data Array	985 %	0.1512082267 %	0.1575352223 %	0.1609998535 %	0.1476321148 %	0.1469262073 %
	Efficiency T[-2; 0]	Data Array	031 %	0.3031142244 %	0.2821707904 %	0.2672029109 %	0.3166385673 %	0.3141709268 %
	Efficiency T[-1; 0]	Data Array	954 %	64.52745209 %	64.0775961 %	64.76290824 %	64.78876327 %	65.43350685 %
	Efficiency T[0; 0]	Data Array	822 %	9.815315864 %	10.04797577 %	9.514470001 %	9.672572361 %	9.226460672 %
	Efficiency T[+1; 0]	Data Array	607 %	5.304847236 %	5.276931374 %	5.082859292 %	5.37406105 %	5.248969798 %
	Efficiency T[+2; 0]	Data Array	126 %	8.139972139 %	8.519640543 %	8.416419743 %	7.641266723 %	7.557214708 %
	Efficiency T[+3; 0]	Data Array	282 %	4.931589405 %	4.764945703 %	5.204484176 %	5.485750056 %	5.538719278 %
	Efficiency T[+4; 0]	Data Array	215 %	5.298733026 %	5.297758188 %	4.942903179 %	5.009424256 %	5.010275239 %
Efficiency T[+5; 0]	Data Array	953 %	0.001032545293 %	0.04168251301 %	0.1591452552 %	0.02674959154 %	0.02912589228 %	

Create Output from Selection

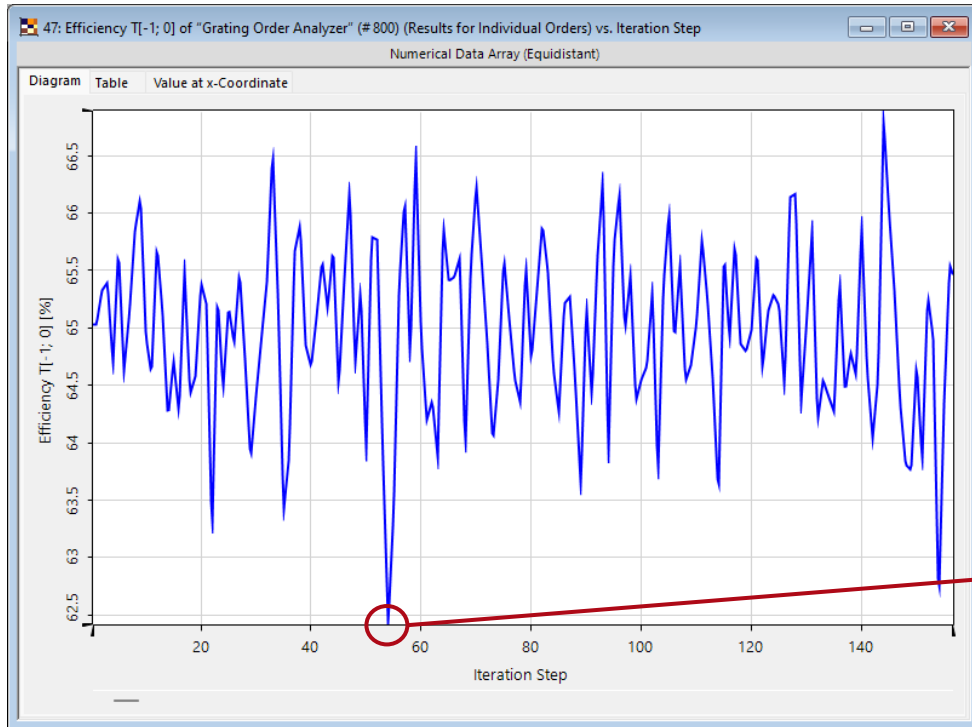
Filter Rows by...

< Back Next > Show ▾



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



* 1: Tolerancing with Multiple Random Distributions

Results

Start the parameter run and analyze its results

Go!

Local Execution (Parallel Iterations: 8)

Use Already Calculated Results for Next Run

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 %	

Create Output from Selection

Filter Rows by...

< Back Next > Show

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

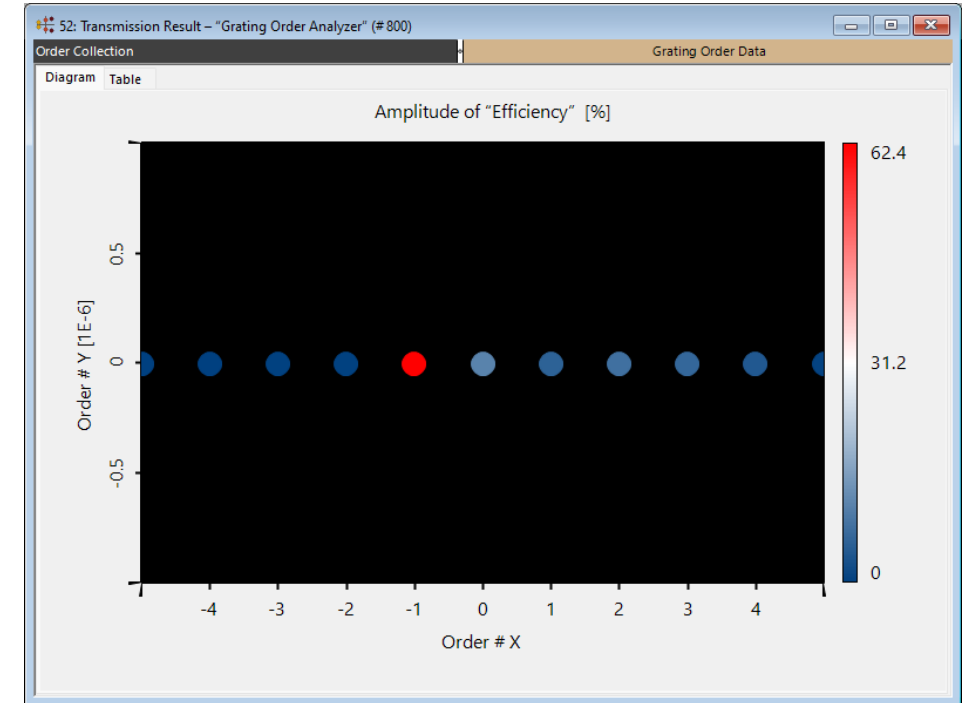
Go!

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
	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	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 ▾

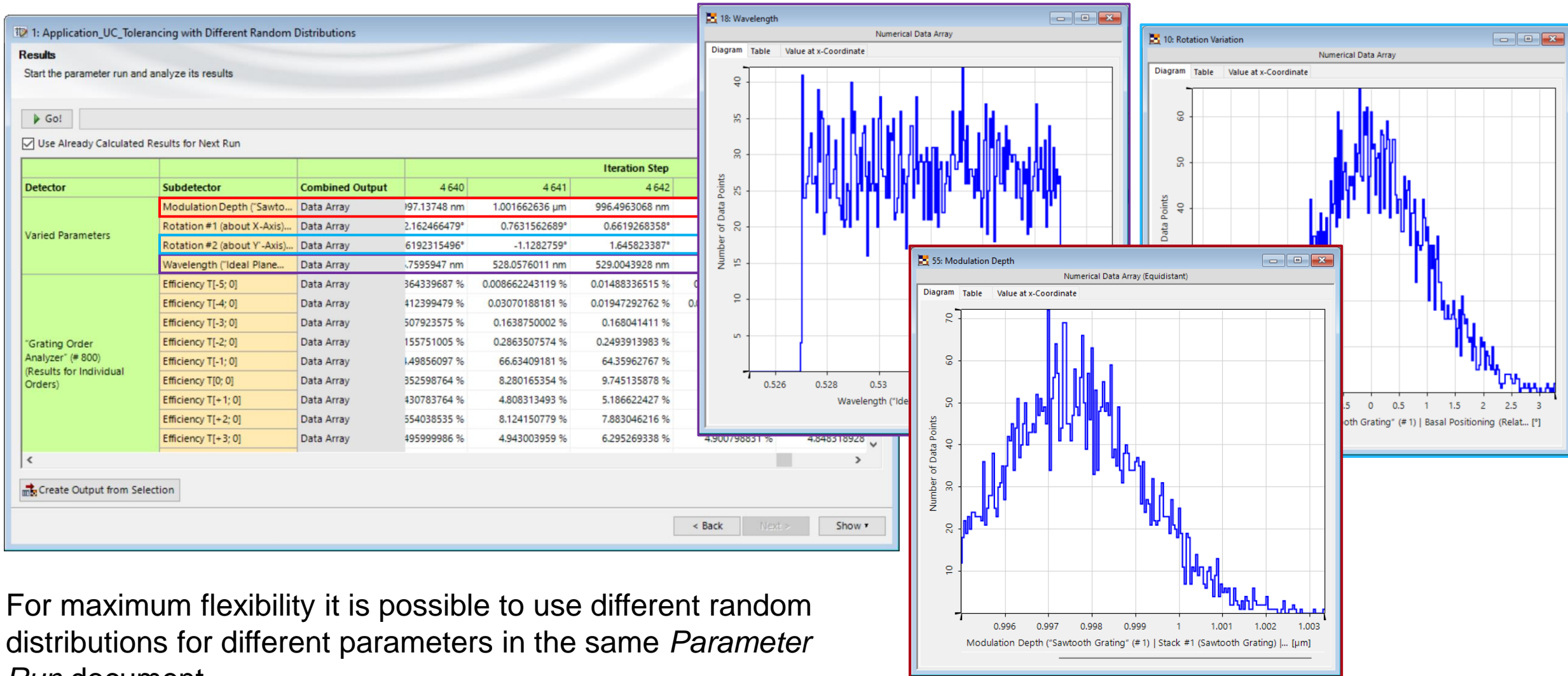


The *Optical Setup* of each iteration can be accessed via the *Show* button to further investigate the system and e.g. calculate the *Order Collection*.

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	SWF.0031
document version	2.1
software edition	VirtualLab Fusion Advanced*
software version	2021.1 (Build 1.180)
category	Feature Use Case
further reading	<ul style="list-style-type: none">- 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.