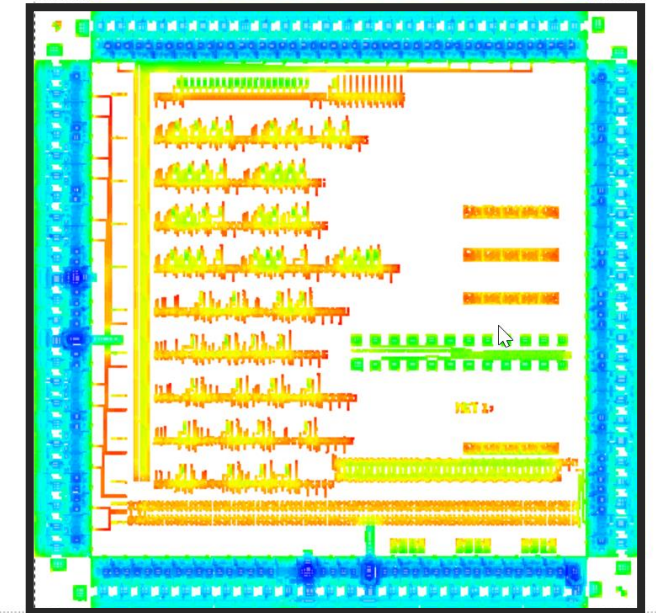
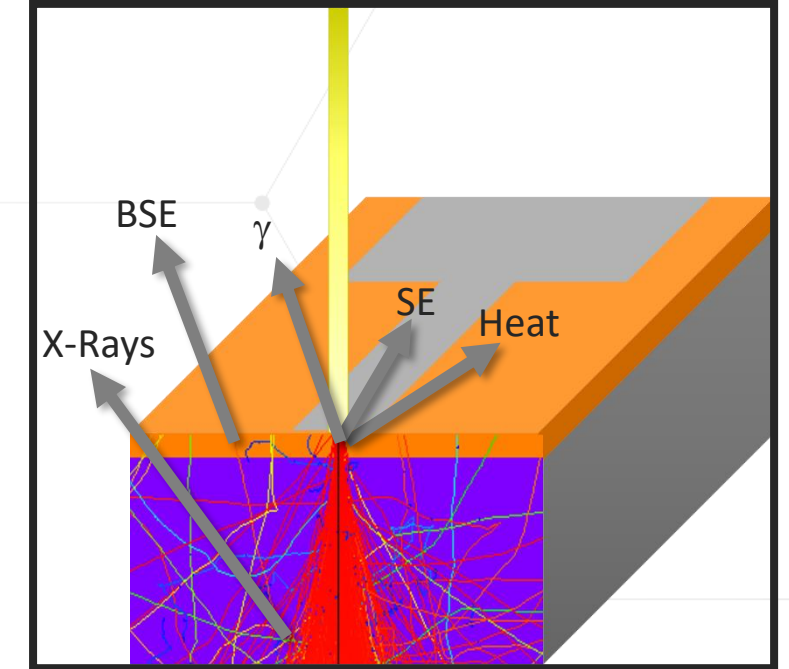


# BEAMER

## PART 5: Standard Dose PEC - Parameters

- PSF definition
- Process parameters
- Advanced Parameters
- Summary
- Q & A

- Proximity Effect
  - Principle
  - Monte Carlo Simulation in TRACER
- Proximity Effect Correction by Dose modulation
  - Edge Equalization algorithm
- Inside the PEC window
  - Why divide into Short, Mid, Long range
  - Effective Blur
  - Short – range correction



- PSF definition
  - PSF Stack
  - PSF with Gaussian
- Process parameters
- Advanced Parameters
- Summary
- Q & A

Proximity Effect Correction

General Accuracy Advanced Label/Comment Quick Access

Correction Layer Selection  
Layer(s) \*

PSF Representation  
 Archive  Gaussian Approximation  Numerical PSF  
 Tag; Substrate: Si; Layers: ; Resists: PMMA 100 nr

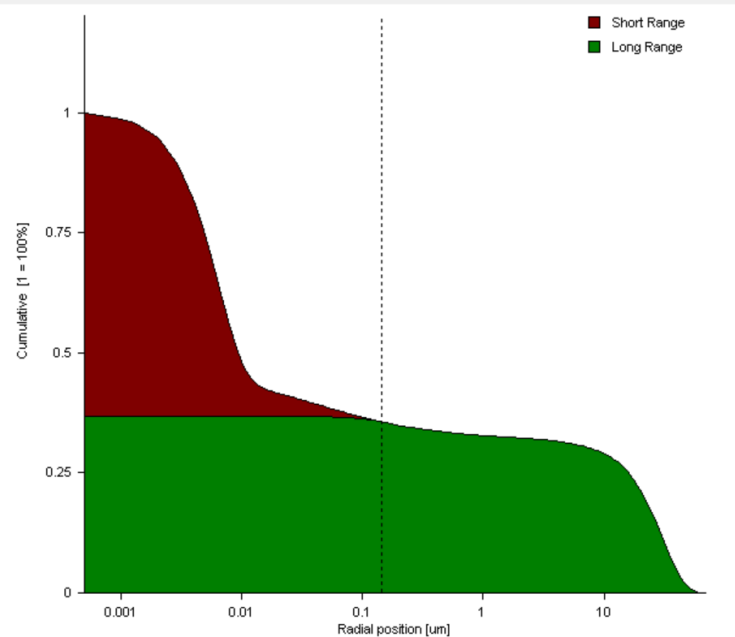
Effective Short Range Blur FWHM [um] 0.010000

Add Gamma [um] 1.000000 Nue 0.100000

Include Short Range Correction

Lateral Development Correction

Show Energy Density  
 Show Cumulative Radial Energy  
 Behaviour X-Axis:  Logarithmic  Quadratic  Linear  
 Behaviour Y-Axis:  Logarithmic  Linear



Radial position [um] 31.42, Cumulative [1 = 100%] 0.5937

Separation at 0.1455 um.  
No additional Separation necessary.

Additional Information:  
Min. layout independent LR dose factor = 0.7314

Proximity Effect Correction

General Accuracy Advanced Label/Comment Quick Access

Dose Assignment  
 Dose Class Definition  
 Accuracy  User Defined

Accuracy [%] 1.000000


Maximum Number of Dose Classes 256

Minimum Dose Factor 0.100000

Maximum Dose Factor 10.000000

A	
0.000000	

Fracturing  
 Isodose Grid [um] 0.010000  
 Minimum Figure Size  
 Automatic  Userdefined [um] Long Range 0.100000 Short Range 0.100000



Separation at 0.1455 um.  
No additional Separation necessary.

Additional Information:  
Min. layout independent LR dose factor = 0.7314

## PEC dialog

- Show archive
- Input of gaussian
- Mid range

- From Monte Carlo Simulation
  - BEAMER Archive comes with PSF for major stack and acceleration voltage
  - TRACER for additional PSF
  - Numerical PSF from other MC simulator or experimental in txt format
- PEC algorithm is using table defined PSF
  - Not converted to Gaussians
  - PSF is split to Short- and Long-Range to be used in correction algorithm

PSF Representation

Archive    
  Gaussian Approximation    
  Numerical PSF

Substrate: Si; Layers: ; Resists: PMMA 100 nm; Energy [kV]    Archive...    Global Archive...

2D-PSF Archive

Order by: Energy [kV]    Filter:

Import...    Export...    Delete    Repair Index

LPSF	Analytic	Calibration	Substrate	Layers	Resists	Energy [kV]	Z-Position	Electrons	Alpha [um]	Be
29			GaAs		PMMA 500 nm	80	0.325	2000000	0	0
30			Si		PMMA 100 nm	100	0.045	2000000	0	0
31			Si		PMMA 200 nm	100	0.09	2000000	0	0
32			Si		PMMA 500 nm	100	0.125	2000000	0	0
33			Si		PMMA 500 nm	100	0.325	2000000	0	0
34			Si	SiO2 100 nm	PMMA 200 nm	100	0.09	2000000	0	0
35			SiO2	Cr 80 nm	PMMA 300 nm	100	0.135	2000000	0	0
36			GaAs		PMMA 200 nm	100	0.09	2000000	0	0

OK    Cancel

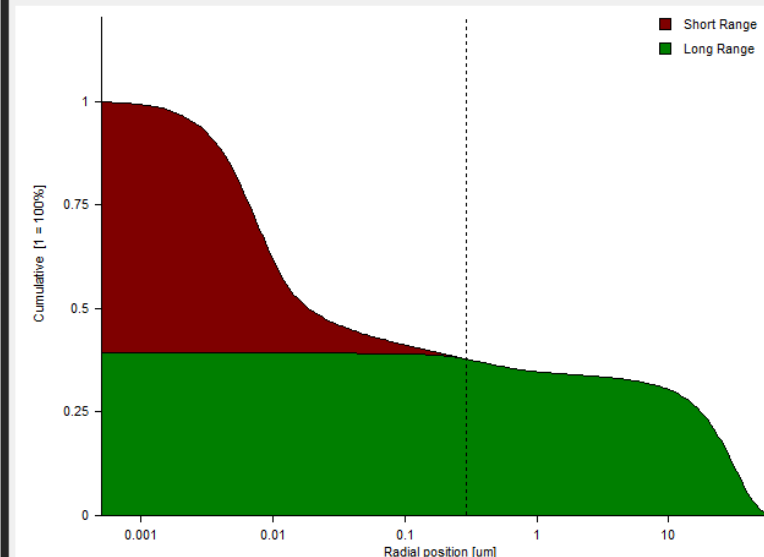
## Data

##	Radius Ri/um	Energy_Density/Injected_Electron
0.000000	1.389e+07	
0.001000	9.736e+06	
0.001047	9.186e+06	
0.001096	8.735e+06	
0.001148	8.119e+06	
0.001202	7.682e+06	
0.001259	7.102e+06	
0.001318	6.592e+06	
0.001380	6.054e+06	
0.001445	5.599e+06	
0.001514	5.177e+06	
0.001585	4.779e+06	
0.001660	4.372e+06	
0.001738	4.032e+06	
0.001820	3.713e+06	

Show Cumulative Radial Energy

Behaviour X-Axis:  Logarithmic     Quadratic     Linear

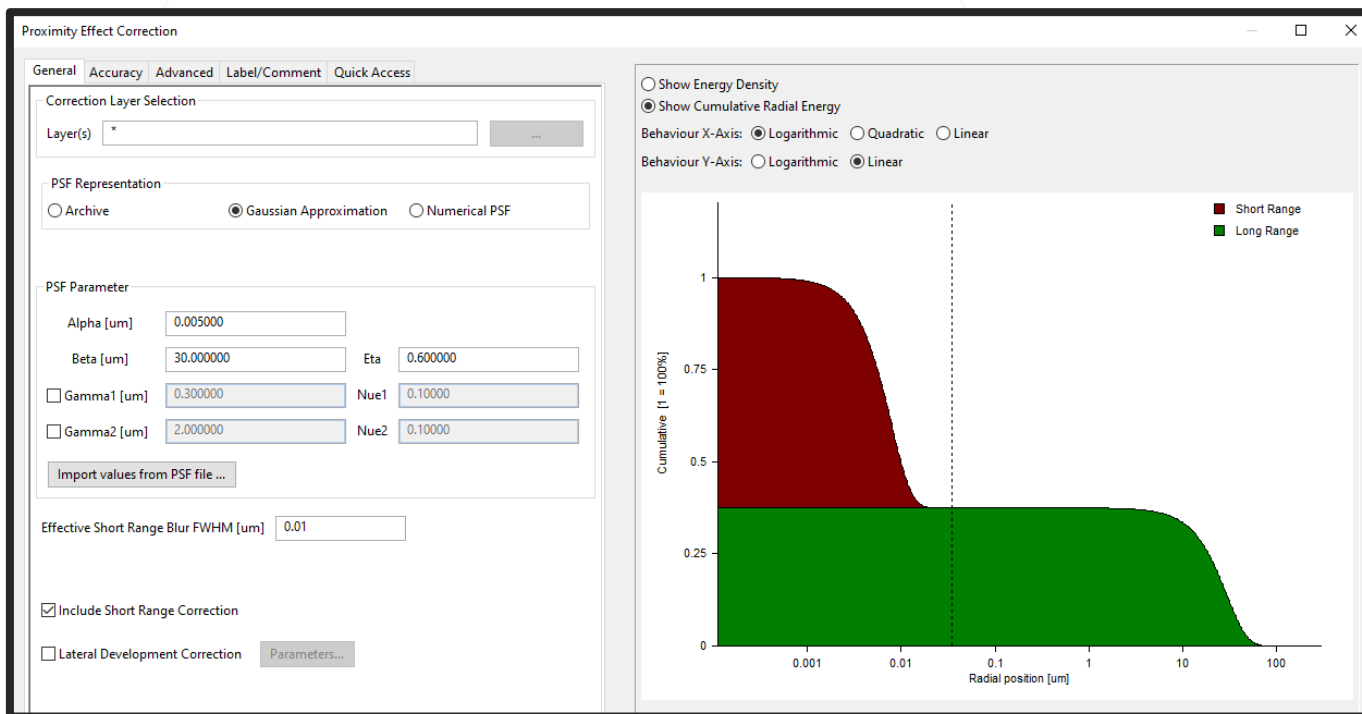
Behaviour Y-Axis:  Logarithmic     Linear



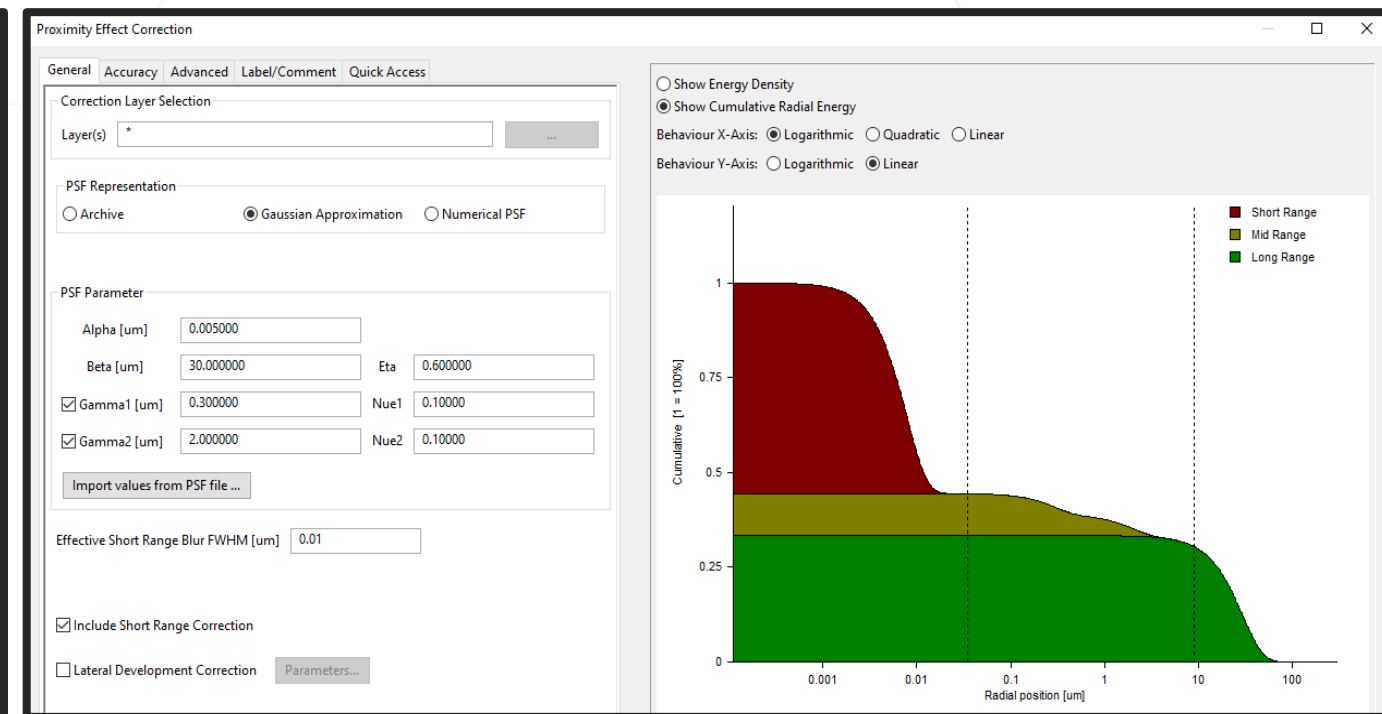
■ Short Range  
■ Long Range

## “Traditional” Gaussian Definition

- Allows using literature data
- Easier “fit” PSF to experiments with only few parameter
- No advantage with regards to PEC time
- TRACER can fit MC simulated PSF to (multi) Gaussian



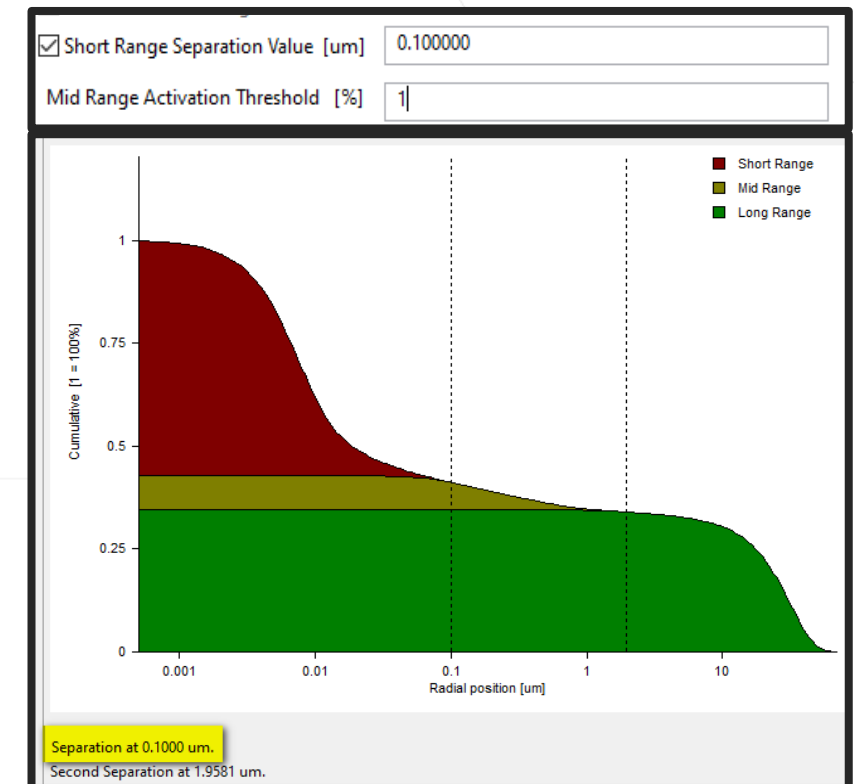
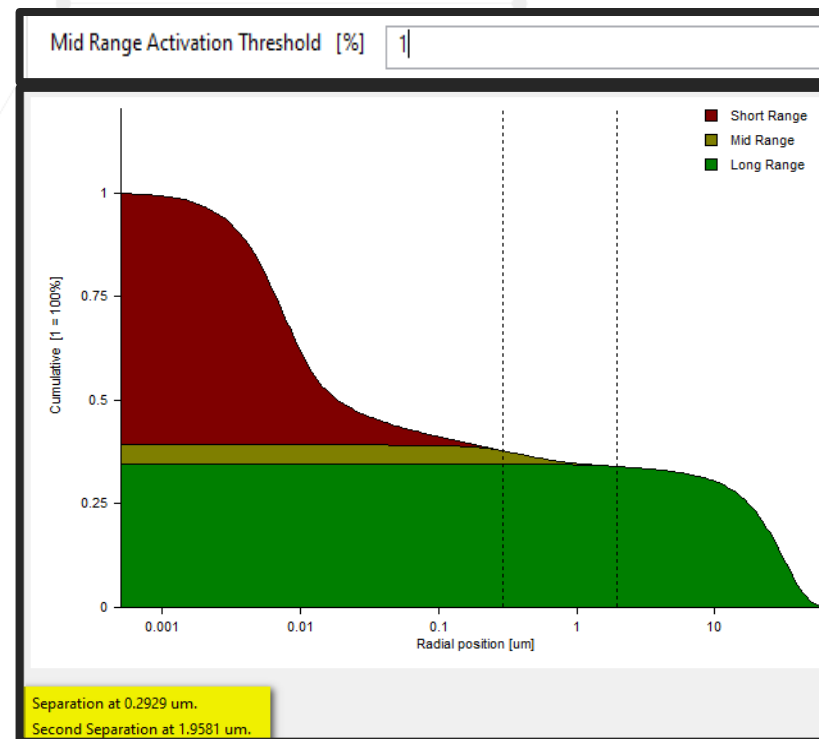
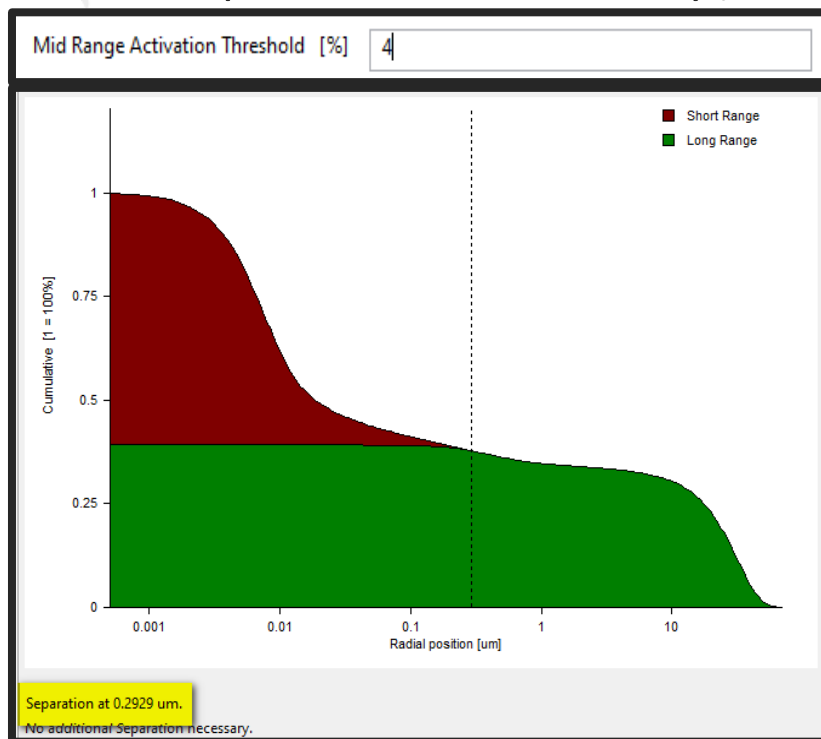
Double Gaussian



Four Gaussian

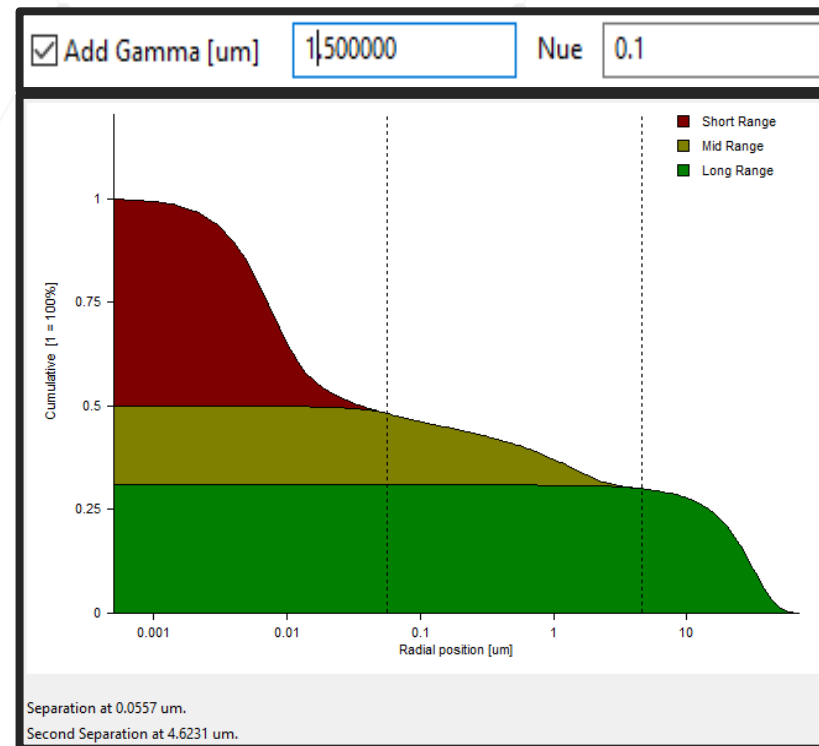
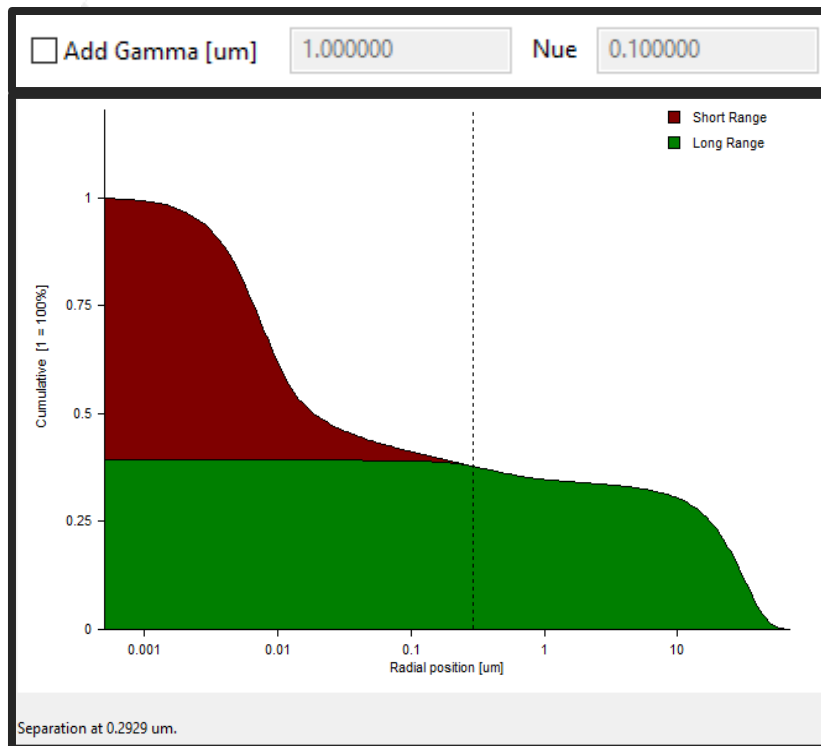


- Control of Mid-Range Energy
  - Triggered by % energy in mid-range relative to LR (Advanced tab)
  - For efficiency, include in LR correction (recommended 4-5% midrange energy)
- Short Range Separation point
  - Controls the amount of energy in short range (automatic as default compromising speed & accuracy)



Some processes contribute an additional strong mid-range effect

- Effects in addition to electron scattering modelled in MC
- Resist and etching processes have additional “diffusion” type effects
- HSQ is a popular candidate for mid-range effect
- TRACER process calibration is considering that effect

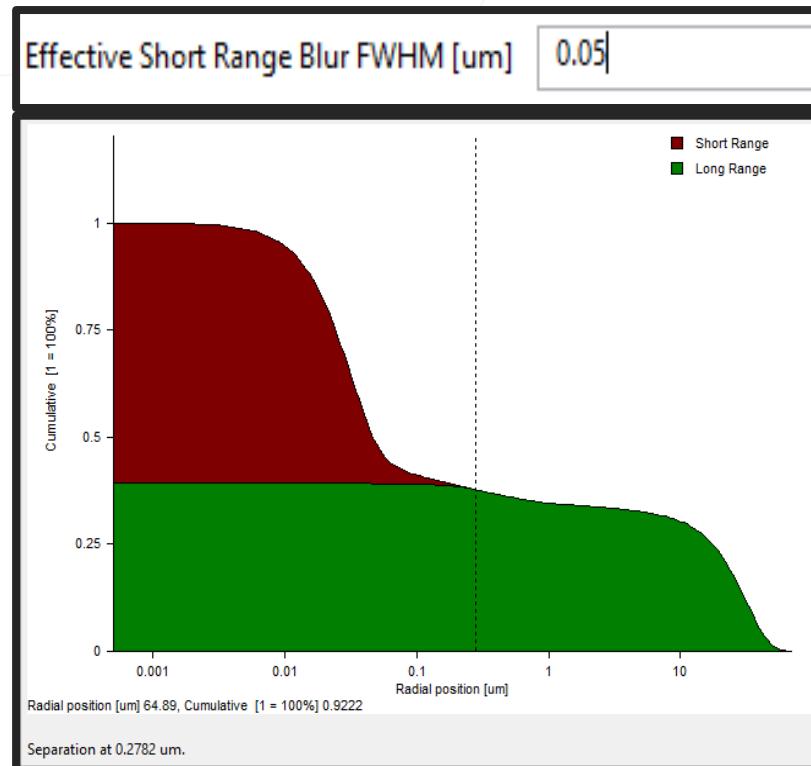
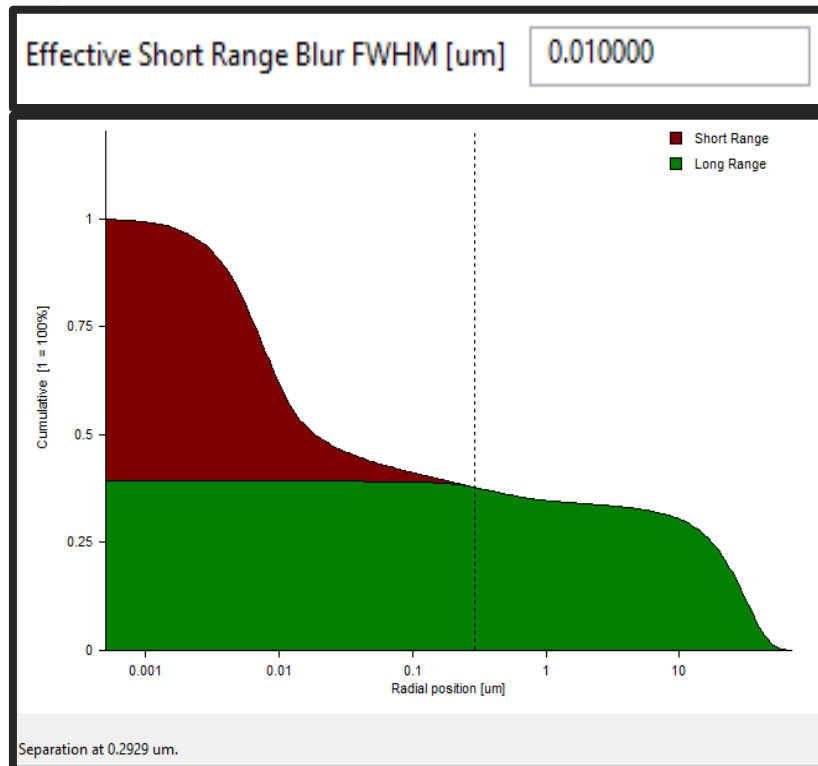
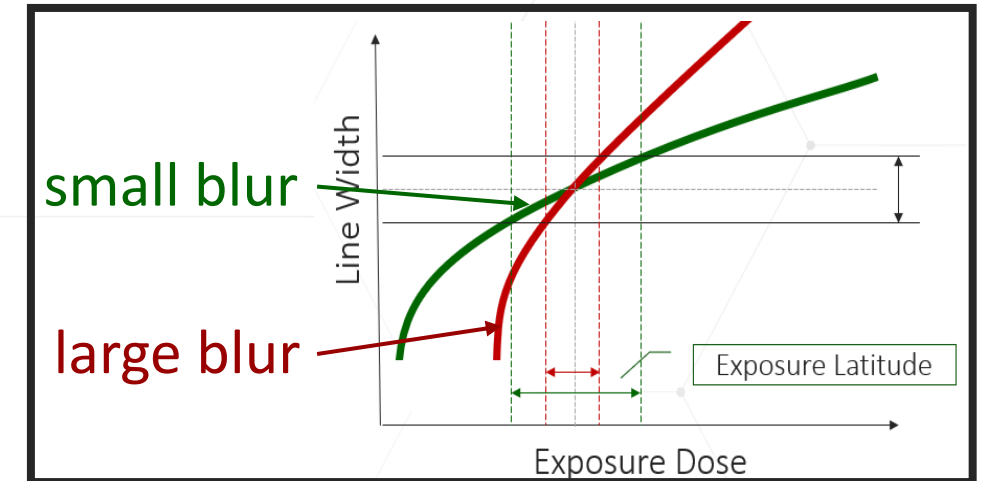


- PSF definition
- Process parameters
  - Base dose / Effective blur
  - TRACER process calibration
  - Lateral development
- Advanced Parameters
- Summary
- Q & A

# Effective Short Range Blur

Effective Short Range Blur combines

- Beam blur (before entering resist)
- Forward scattering within the resist
- Resist development & etching process blur
- Calibrated by TRACER or estimation from dose test



1<sup>st</sup> order estimate:

$$\text{FWHM} = 0.76 * \Delta\text{CD} / \Delta\% \text{dose}^1)$$

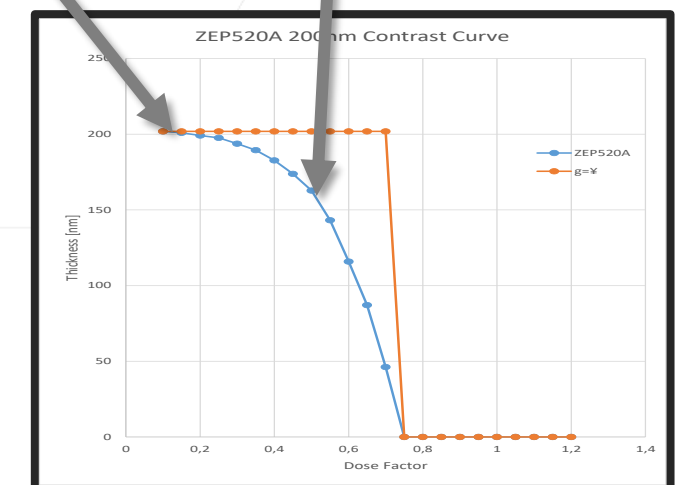
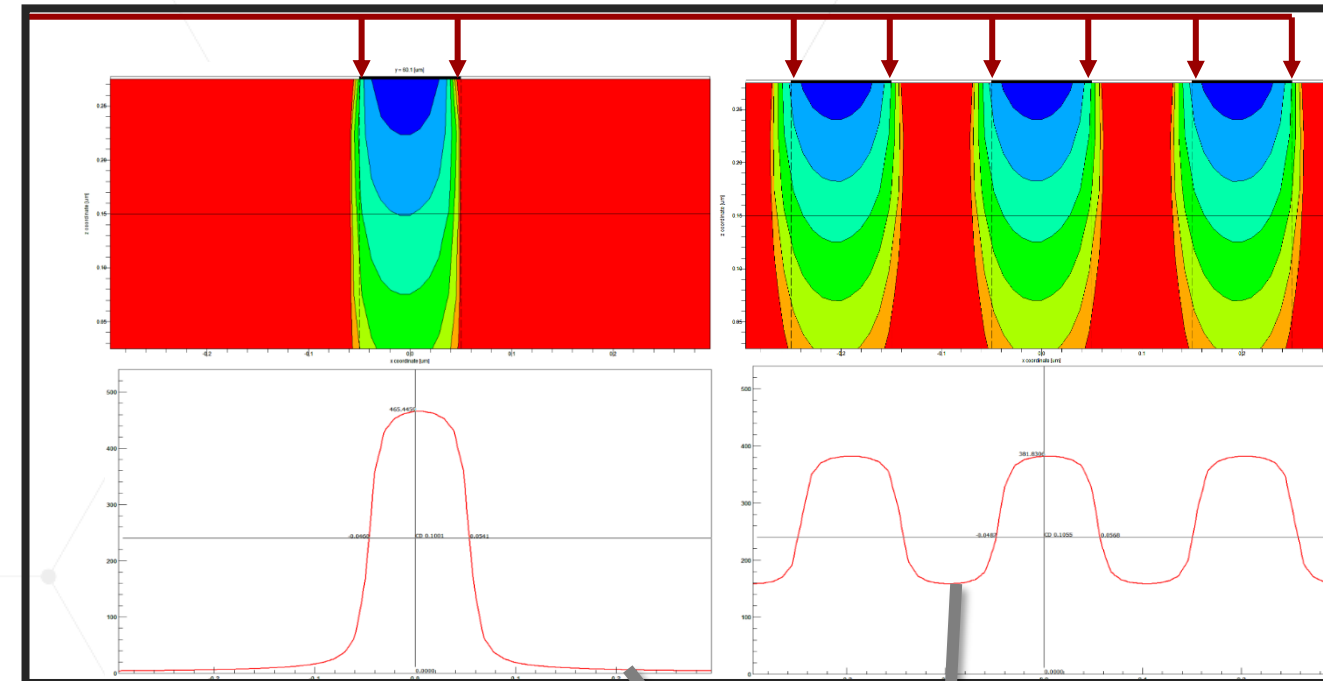
Typical values:

100keV, low current (~ 1nA), high contrast thin (100nm) PMMA: ~ 15nm

100keV, high current (~20nA), low contrast thick PMMA: ~ 30nm

50keV, high current (~50nA), low contrast thick PMMA: ~ 50nm

- Edge energies are equal:
  - Dose to clear at feature edge
  - Ideal for high contrast (thin) resists
- Thick resist application
  - Lower contrast resist development does not stop at feature edge
  - Develops dependent on energy outside feature
  - Effect is stronger for high density substrates (GaAs, InP,..)
  - Results in density dependent bias



- Lateral Development Bias can be corrected at PEC
  - Density dependent Bias table
  - Experimentally measured
  - TRACER process calibration
- Correction:
  - Moving feature edge dependent on PSF-density
  - Assigning dose factor
- PSF-Density:
  - Local layout density within PSF influence range

## PEC – General tab

Proximity Effect Correction

General Accuracy Advanced Label/Comment Quick Access

Correction Layer Selection  
Layer(s) \*

PSF Representation  
 Archive  Gaussian Approximation  Numerical PSF

Tag; Substrate: Si; Layers; Resists: PMMA 100 nm; Ener Archive... Global Archive...  
View Comment...

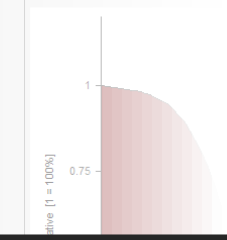
Effective Short Range Blur FWHM [um] 0.010000

Add Gamma [um] 1.000000 Nue 0.100000

Include Short Range Correction

Lateral Development Correction Parameters...

Show Energy Density  
 Show Cumulative Radial Energy  
 Behaviour X-Axis:  Logarithmic  
 Behaviour Y-Axis:  Logarithmic



### Lateral Dev. Correction Parameters

PSF-density [-]	Bias [um]
0.000000	0.01
0.500000	0.02
1.000000	0.05

Insert Row Delete Row

Shift Step Size [um] 0.001000

OK Cancel Help

# Process Calibration Procedure

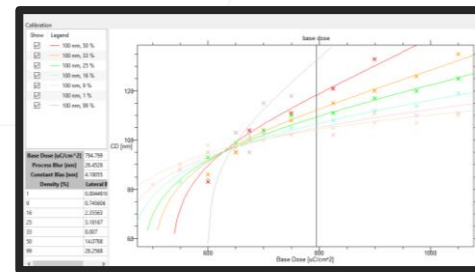
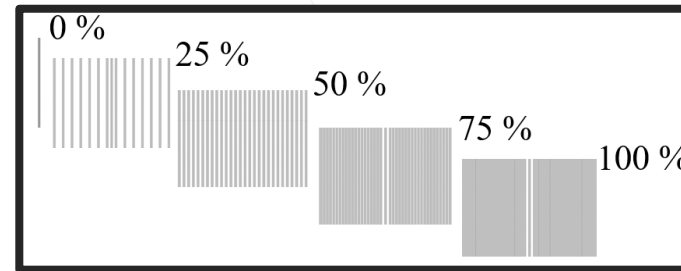
Expose Dose Matrix, Process, & Measure Calibration Pattern



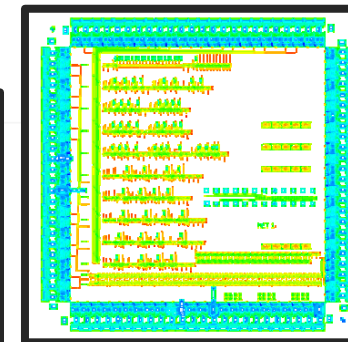
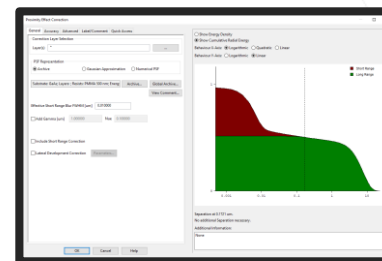
Use TRACER to fit the data and determine correction parameters

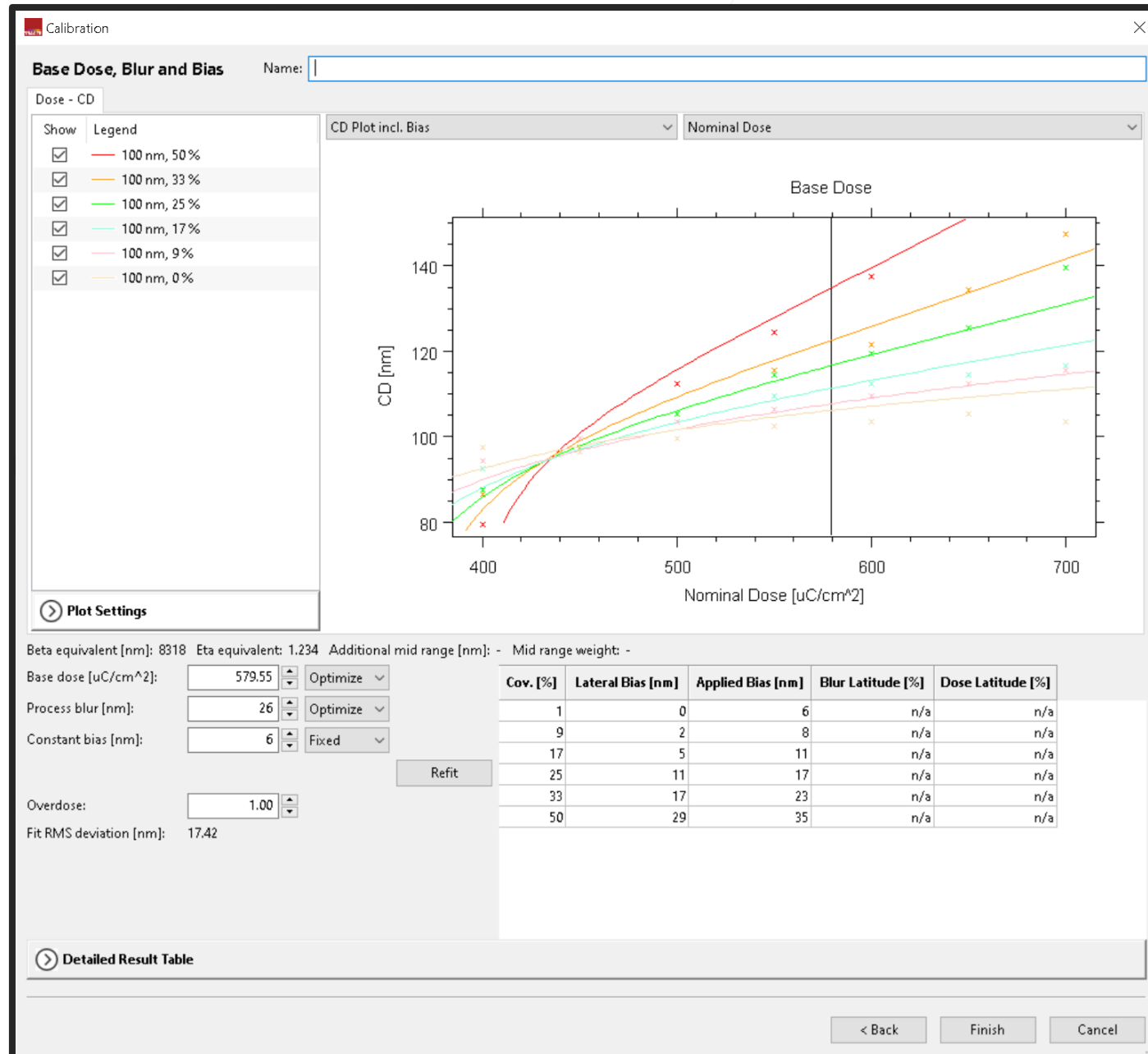


Apply correction parameters using BEAMER's PEC module



- Base Dose
- Effective Process Blur
- Constant and density-dependent bias
- UC/OC Mix Factor



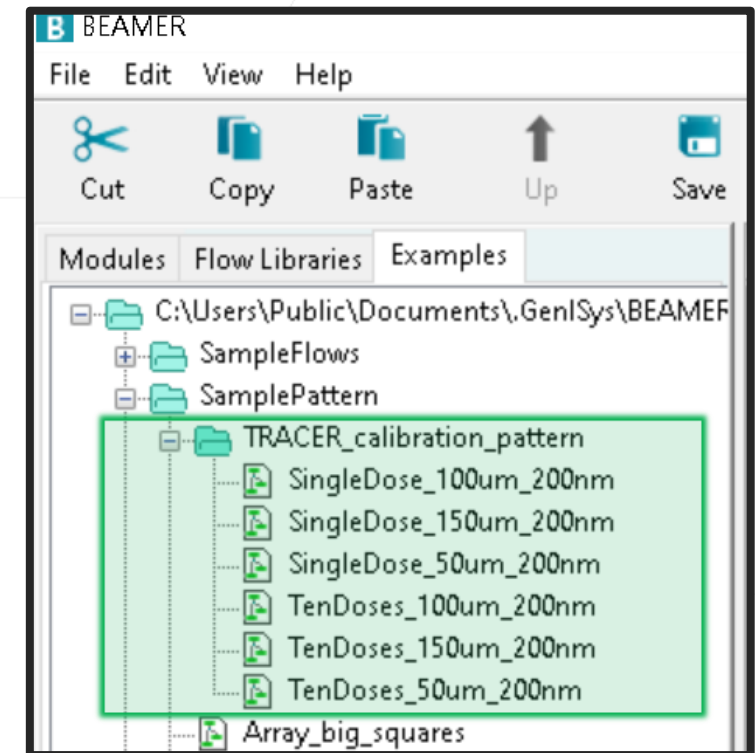



The fitting procedure results in an “Extended Point Spread Function”, adding terms to the scattering PSF

- Optimal Base Exposure Dose
- Effective Process Blur
- Constant Process Bias
- Density-dependent Bias terms to compensate
- Additional Midrange Gaussian




- Calibration patterns are in BEAMER example folder
- Application Note in download area
- Help: support@genisys-gmbh.com

**Application Note** TRACER

**Full Process Calibration using TRACER: Experimental Procedure**

An optimized e-beam lithography data preparation process must take into account process effects beyond just the electron energy distribution point spread function (PSF) as computed by TRACER. These process effects include density-dependent development rate changes, resist lateral development, and size bias due to process or metrology. It is possible to characterize and subsequently correct for these effects using a set of empirical measurements. This note describes the experimental procedure and data analysis necessary for such a Full Process Calibration.



**Webinar Series: Proximity Effect in E-Beam Lithography**

**Webinar Series Summary:**

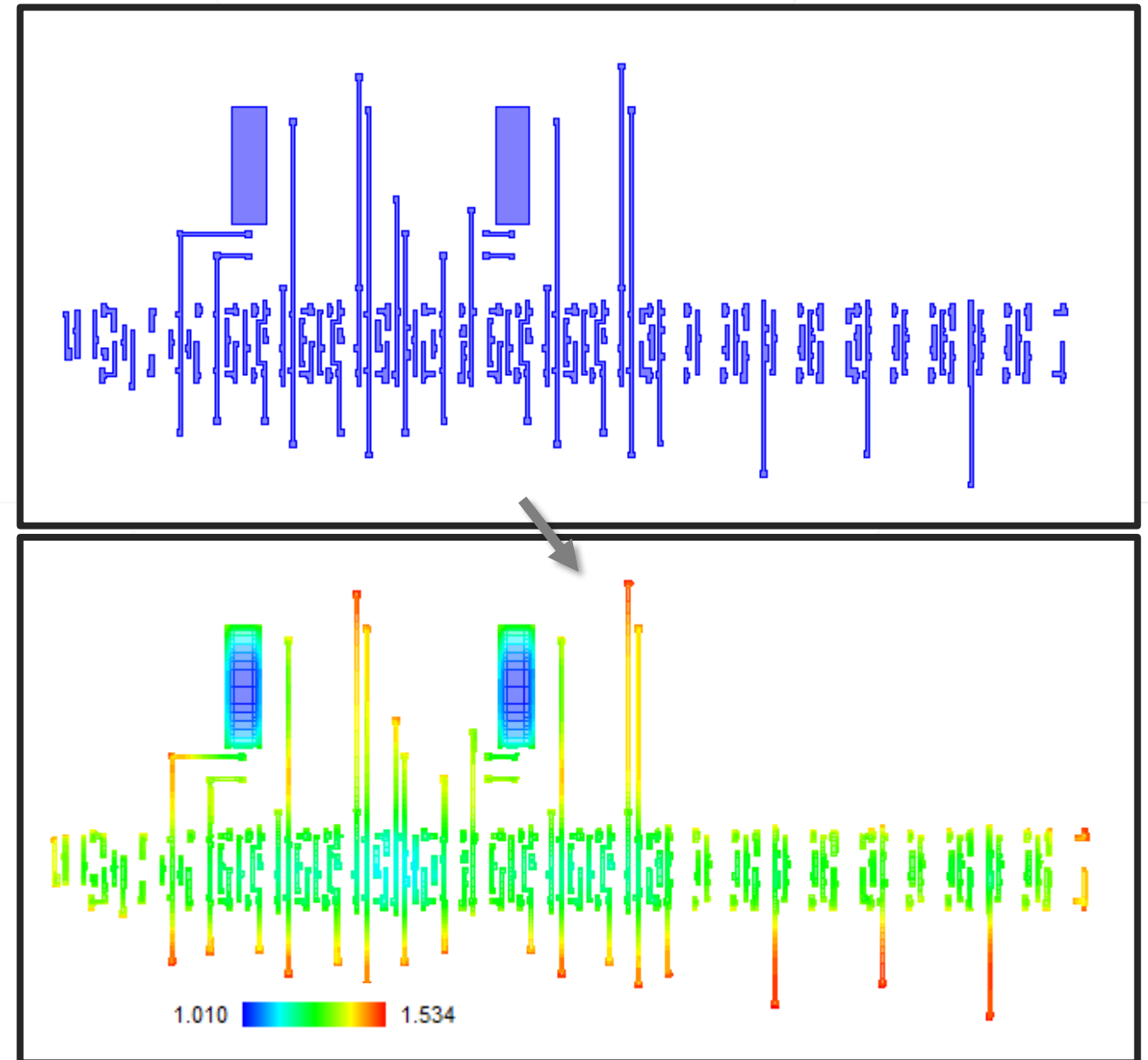
The webinar series will explain one of the most important techniques in advanced e-beam lithography. Modern E-beam systems are able to form small spot sizes in nm range. In principle this enables to achieve feature sizes in nm-range. In practice this is limited by physics, chemistry and tool limitations such as:

- Part 1 – Electron Scattering and Proximity Effect
- Part 2 – Dose PEC Algorithm and Parameter
- Part 3 – Optimization of Dose PEC Parameter
- **Part 4 – Process Effect, Calibration and Correction**
- Part 5 – Shape PEC – ODUS Contrast Enhancement
- Part 6 – 3D Surface PEC for greyscale lithography
- Part 7 – 3D T-Gate and Edge PEC for multilayer resist

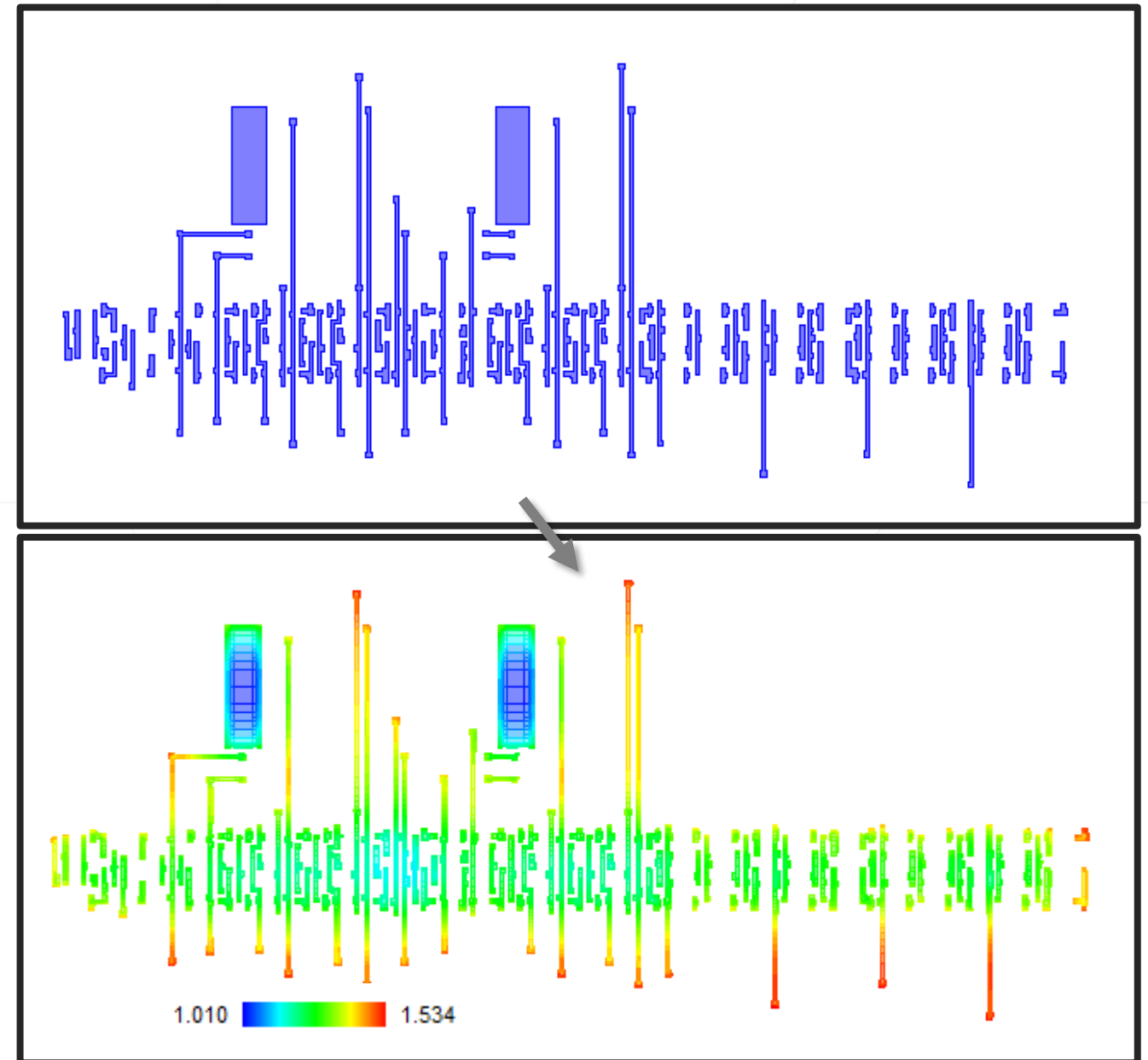
[PRODUCTS](#)   [APPLICATIONS](#)   **[IN-ACTION](#)**   [CORPORATE](#)   [LOGIN](#)  
**WEBINAR SERIES: PROXIMITY EFFECT IN E-BEAM LITHOGRAPHY**  
[WEBINAR - E-BEAM LITHOGRAPHY SIMULATION](#)  
[WEBINAR - BEAMER 6.1](#)

- PSF definition
- Process parameters
- **Advanced Parameters**
  - Dose assignment
  - Fracturing
- Summary
- Q & A

- Proximity effect correction (PEC) is a proven method to improve e-beam lithography
- PEC controls the dose applied to a feature so that the feature is correctly sized and shaped
- Accurately adjusting dose usually requires fracturing a shape into many smaller shapes

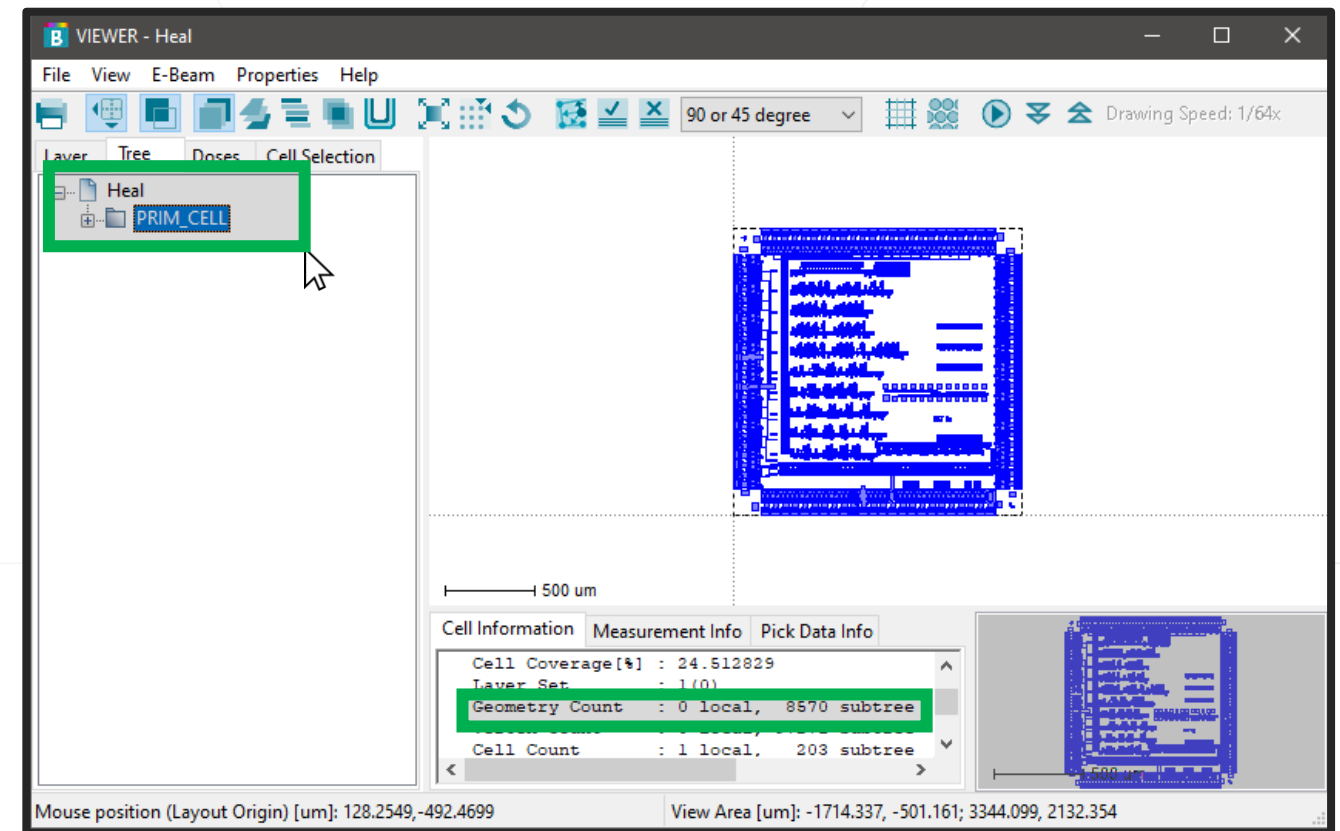


- What is the consequence of this shape fracturing?
- Accurate dose assignment, but...
- Shape count increase can impact:
  - Future data processing time
  - On-tool exposure time
- Net result can be a loss of throughput
  - Tool & pattern dependent
- How can we control shape count after PEC?

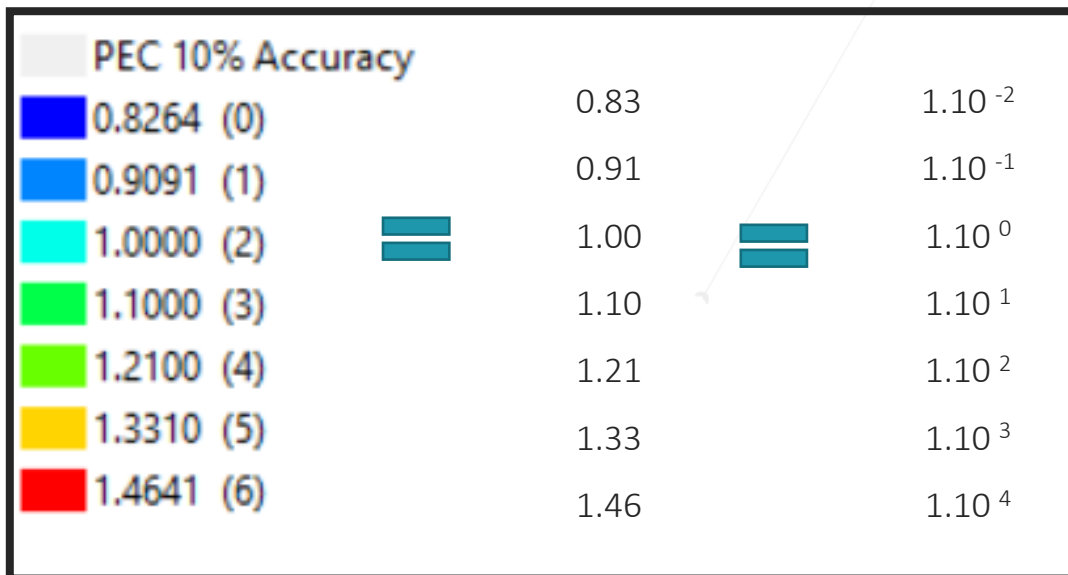


# Checking Pattern Shape Count

- Open a pattern in the VIEWER
- Select the “Tree” tab
- Expand the tree to the top cell
- Geometry Count is reported on the “Cell Information” tab. The “subtree” count is the total amount of shapes contained under the chosen level in the hierarchy



- PEC dose class accuracy is selected on the Accuracy tab
- Smaller values represent a higher accuracy
- The dose range in the correction is discretized:



## PEC – Accuracy tab

Proximity Effect Correction

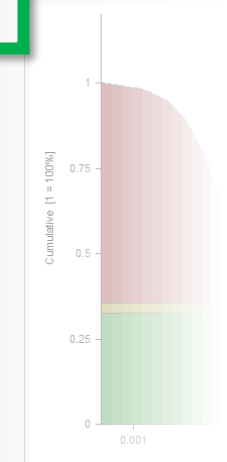
General Accuracy Advanced Label/Comment Quick Access

Dose Assignment  
Dose Class Definition  
 Accuracy  User Defined

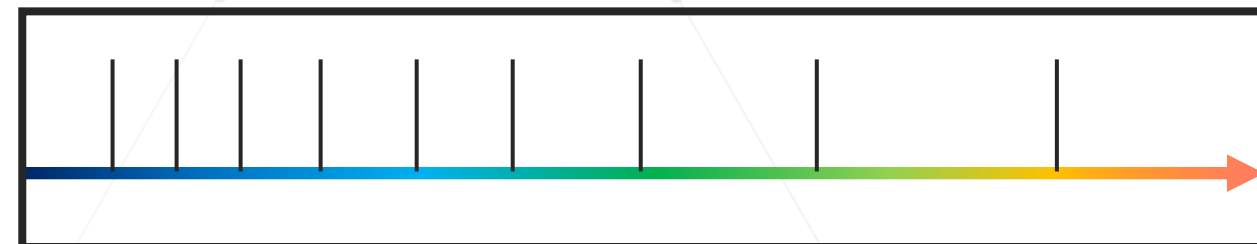
Accuracy [%] 1.000000  
Maximum Number of Dose Classes 256  
Minimum Dose Factor 0.100000  
Maximum Dose Factor 10.000000

Fracturing  
Isodose Grid [um] 0.010000  
Minimum Figure Size  
 Automatic  Userdefined [um] Long Range 0.100000 Short Range 0.100000

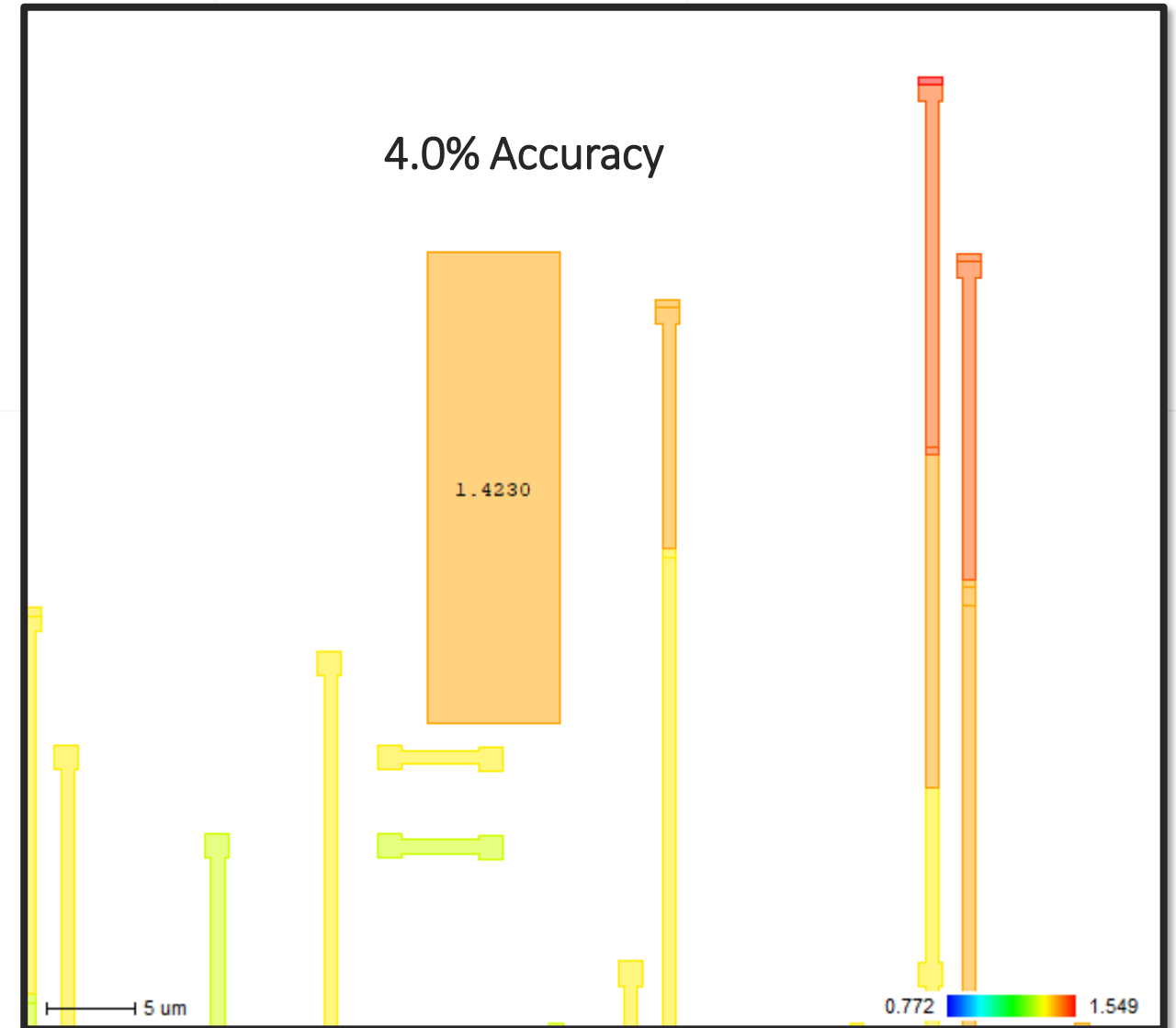
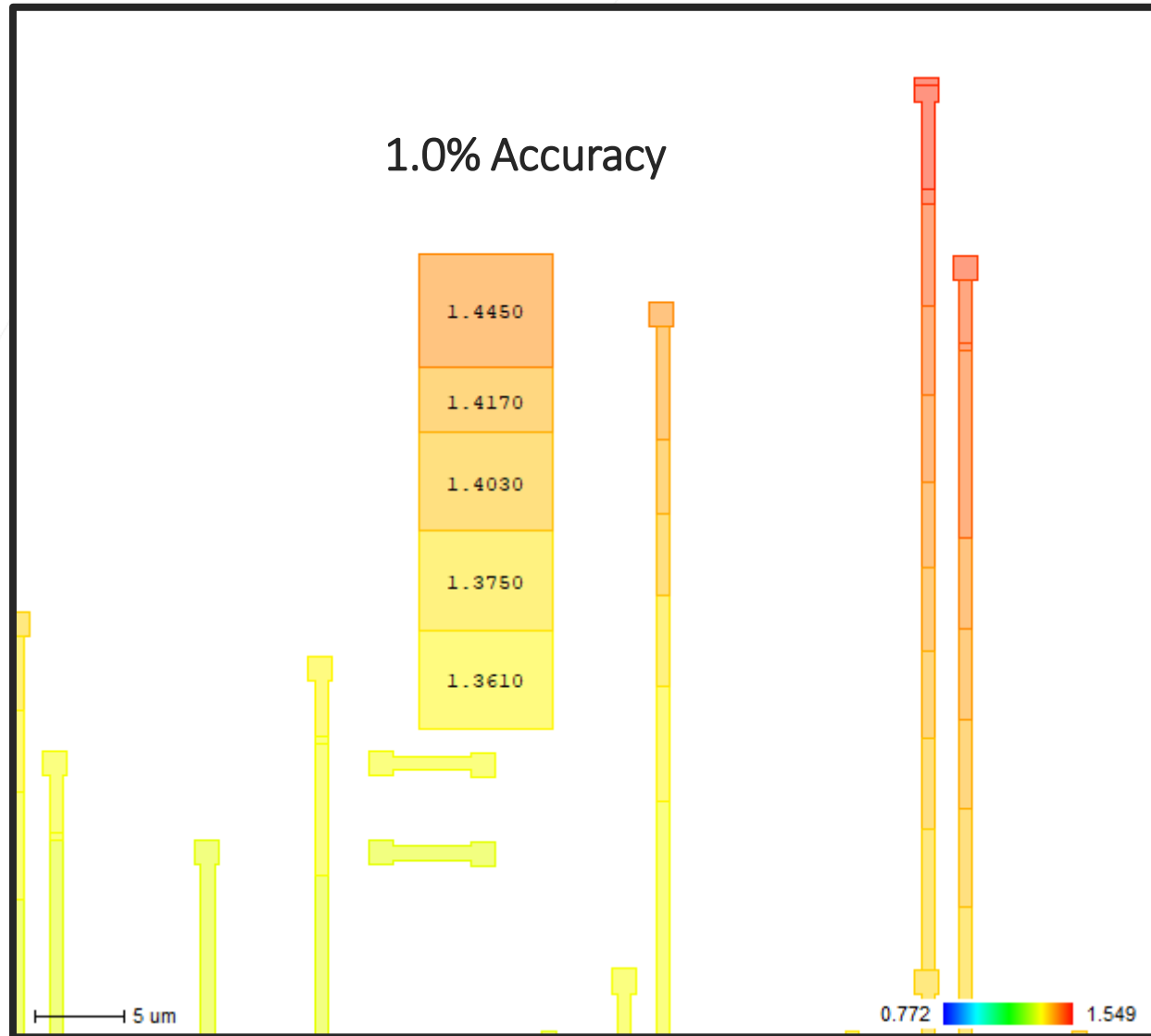
Buttons: Import... Insert Row Delete Row OK Cancel Help



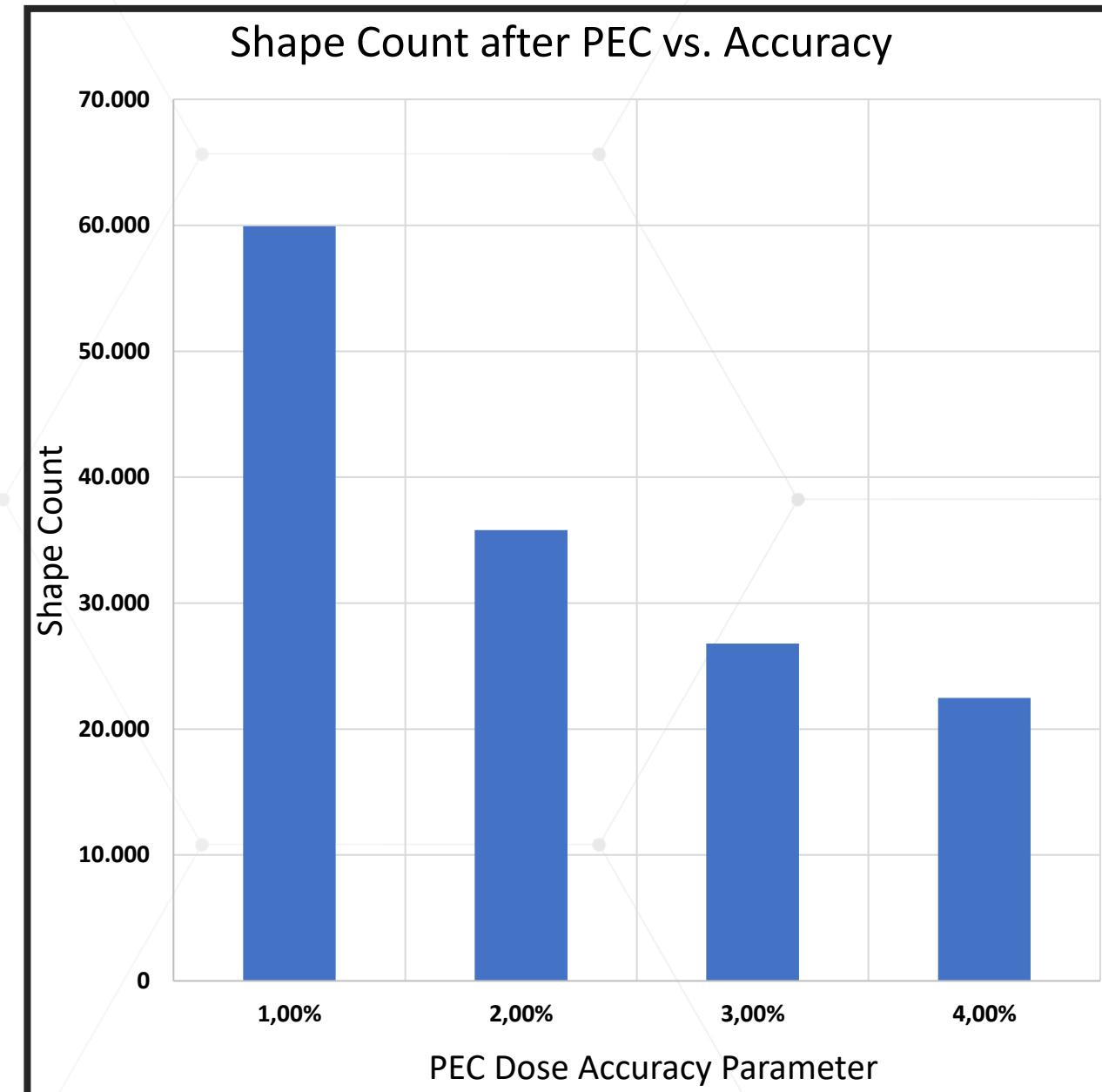
Additional Information: None



Larger accuracy value reduces shape count at cost of internal dose variation



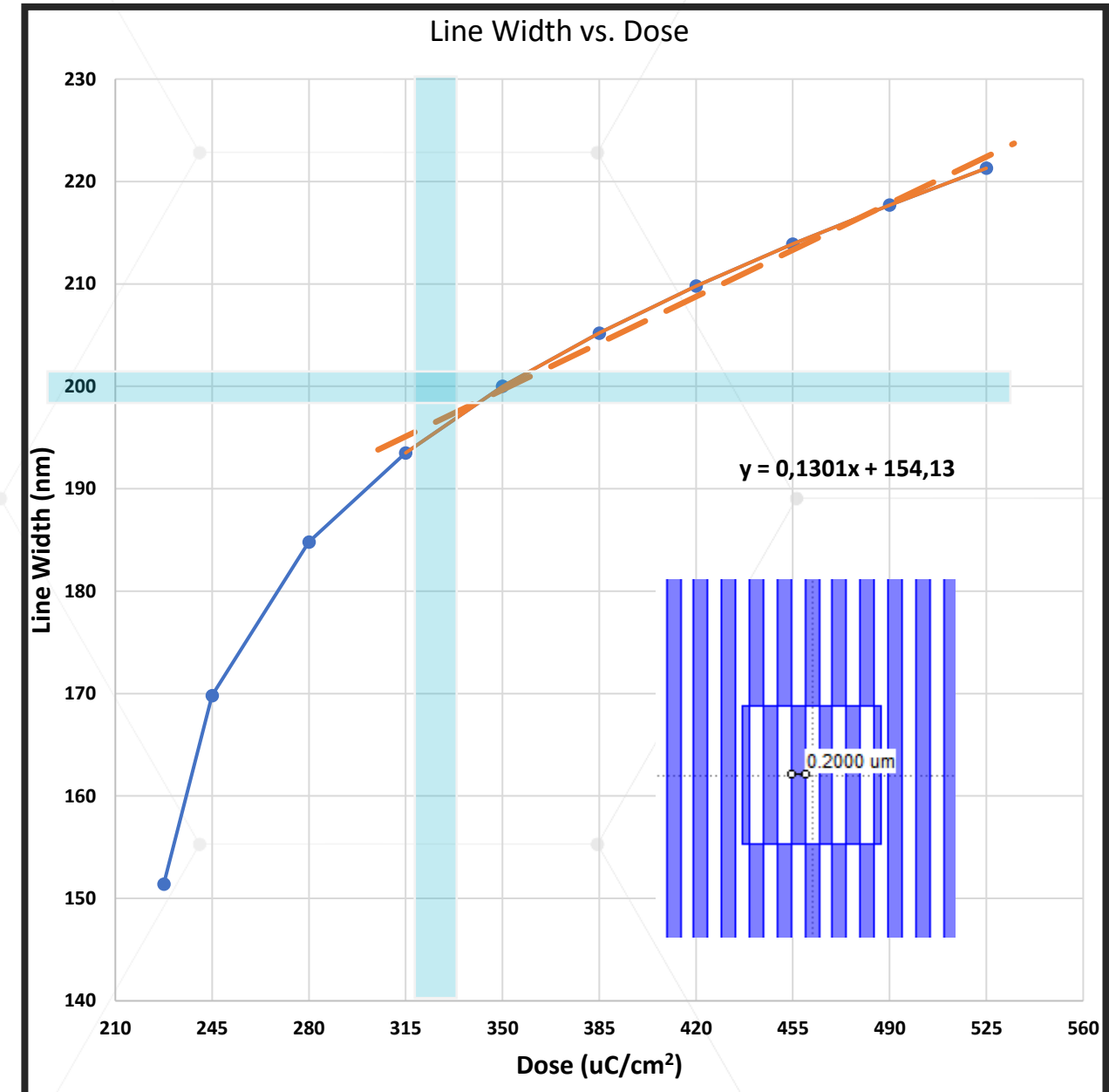
- The total shape count after PEC is shown for increasing accuracy values.
- Increasing the accuracy value...
  - **Decreases** the accuracy of the PEC dose assignment
  - **Decreases** the total shape count after PEC
  - **Decreases** the amount of dose classes
- Decreasing accuracy can have negative effects including:
  - Negative impact on shape fidelity
  - Variations in feature size





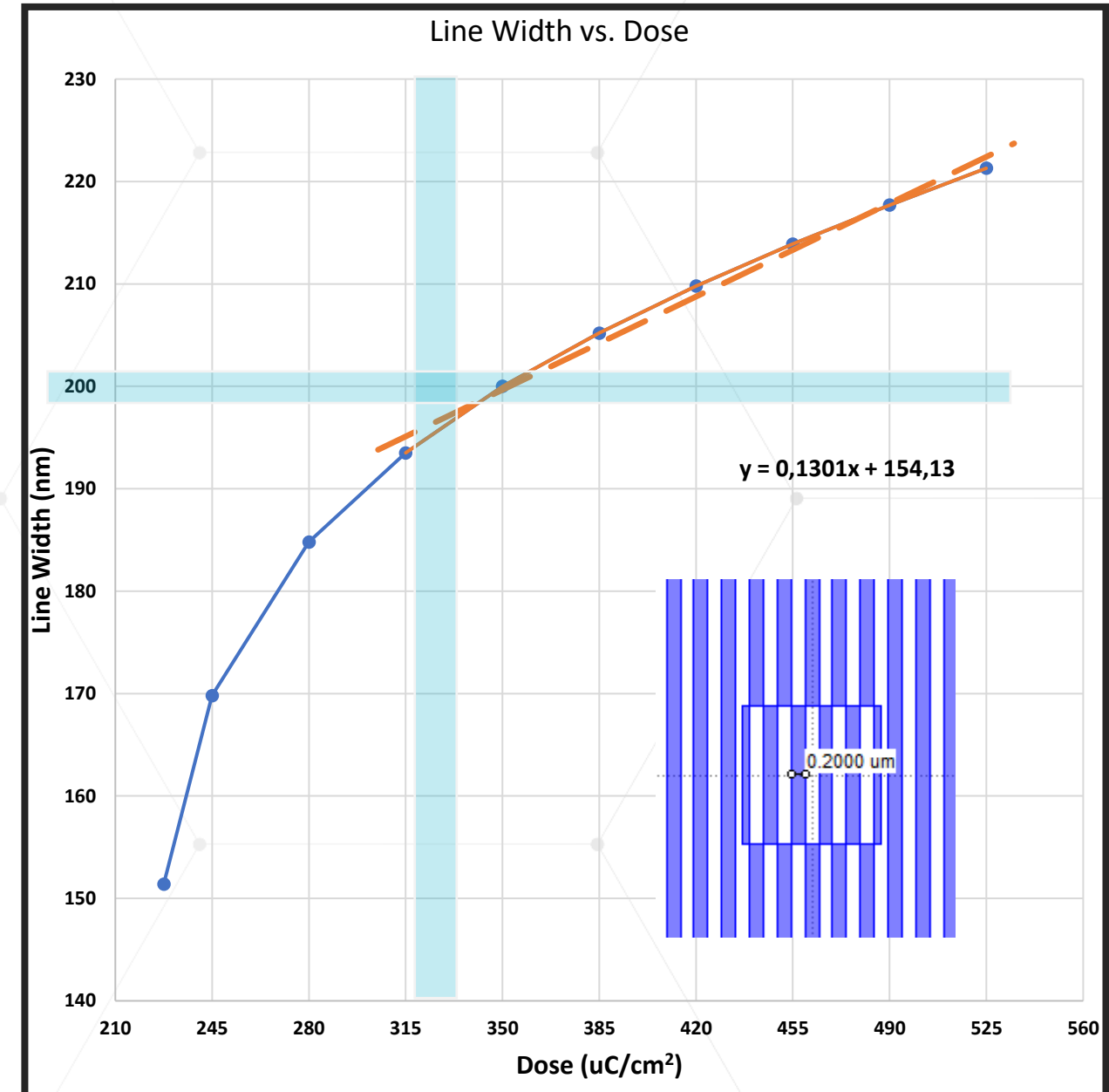
# Choosing a PEC Accuracy

- We can estimate the effect of adjusting accuracy by examining Line Width vs. Dose data
- “Error” in dose assignment is approximately (Accuracy \* Base Dose)
- Simulated 50 kV exposure of 200 nm line in center of 1:1 grating
  - Gives base dose of 350  $\mu\text{C}/\text{cm}^2$

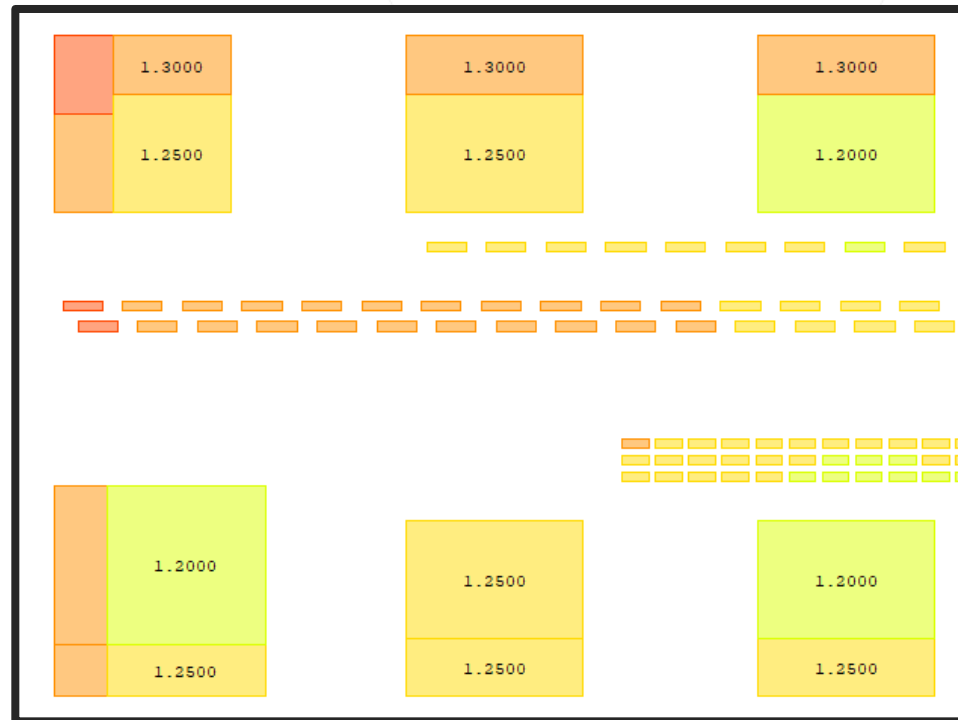


# Choosing a PEC Accuracy

- Slope = 4.6 nm/35 [ $\mu\text{C}/\text{cm}^2$ ] change in line width
  - 35  $\mu\text{C}/\text{cm}^2$  corresponds to 10% of base dose
  - Meaning, accuracy of 10% allows  $\sim 4.6$  nm deviation in line width at proper dose at 50% pattern density
- Note: Slope is dependent on pattern density – should be larger for denser features. Choose critical feature(s) at representative pattern density



- Alternative option by user defined dose table
- Manually type in values or import generated values
- All shapes will be assigned doses from the table



## PEC – Accuracy tab

Proximity Effect Correction

General Accuracy Advanced Label/Comment

Dose Assignment

Dose Class Definition

Accuracy  User Defined

Accuracy [%] 1.000000

Maximum Number of Dose Classes 256

Minimum Dose Factor 0.100000

Maximum Dose Factor 10.000000

Dose Table
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35
1.4

Import...  
Insert Row  
Delete Row

# Isodose Grid & Minimum Figure Size

- Isodose Grid defines the “fracture grid” that PEC utilizes
- Interacts with the minimum figure size (MFS)
- The value should equal a multiple of the Beam Step Size
- Automatic mode determines the MFS based on the PSF.

## PEC – Accuracy tab

Proximity Effect Correction

General Accuracy Advanced Label/Comment Quick Access

Dose Assignment

Dose Class Definition

Accuracy  User Defined

Accuracy [%] 1.000000

Maximum Number of Dose Classes 256

Minimum Dose Factor 0.100000

Maximum Dose Factor 10.000000

A	

Import...  
Insert Row  
Delete Row

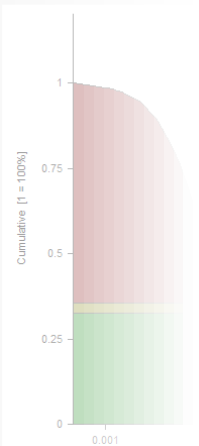
Isodose Grid [um] 0.010000

Minimum Figure Size

Automatic  Userdefined [um] Long Range 0.100000 Short Range 0.100000

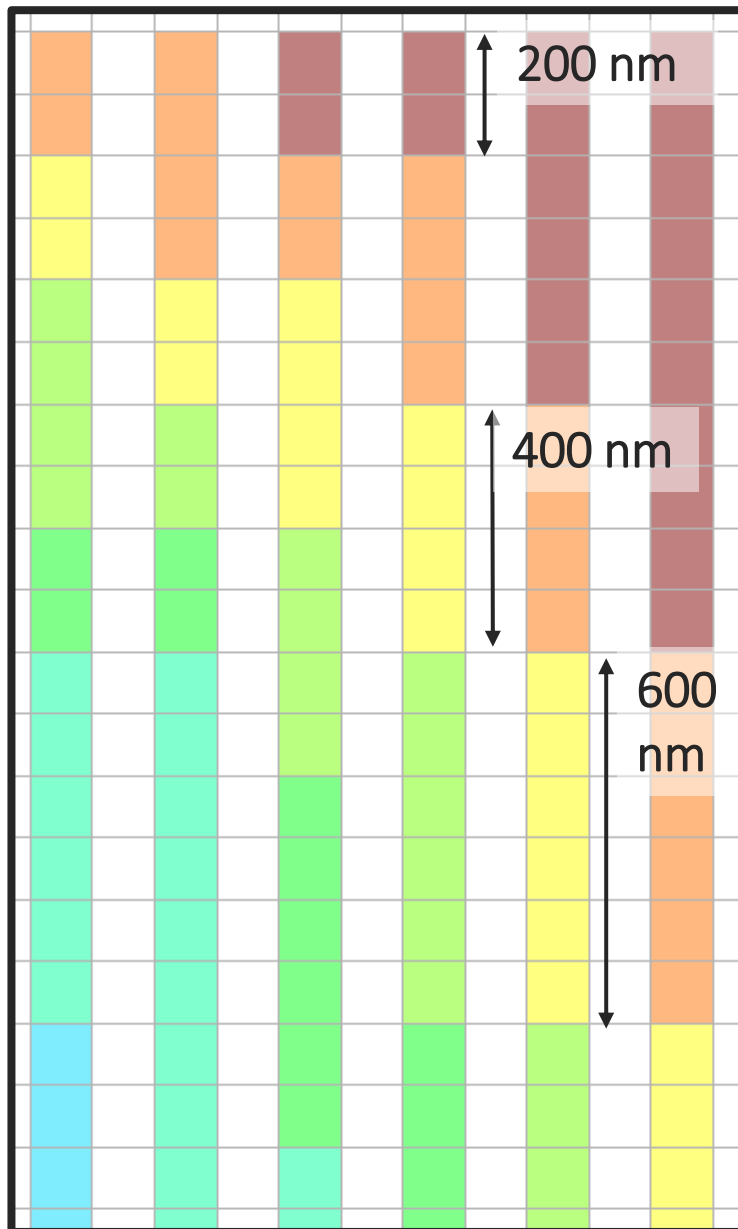
OK Cancel Help

Show Energy Density  
 Show Cumulative Radial Energy  
Behaviour X-Axis:  Logarithmic  
Behaviour Y-Axis:  Logarithmic



Separation at 0.2183 um.  
Second Separation at 2.8776 um.  
Additional Information:  
None

# Isodose Grid



MFS = 100 nm

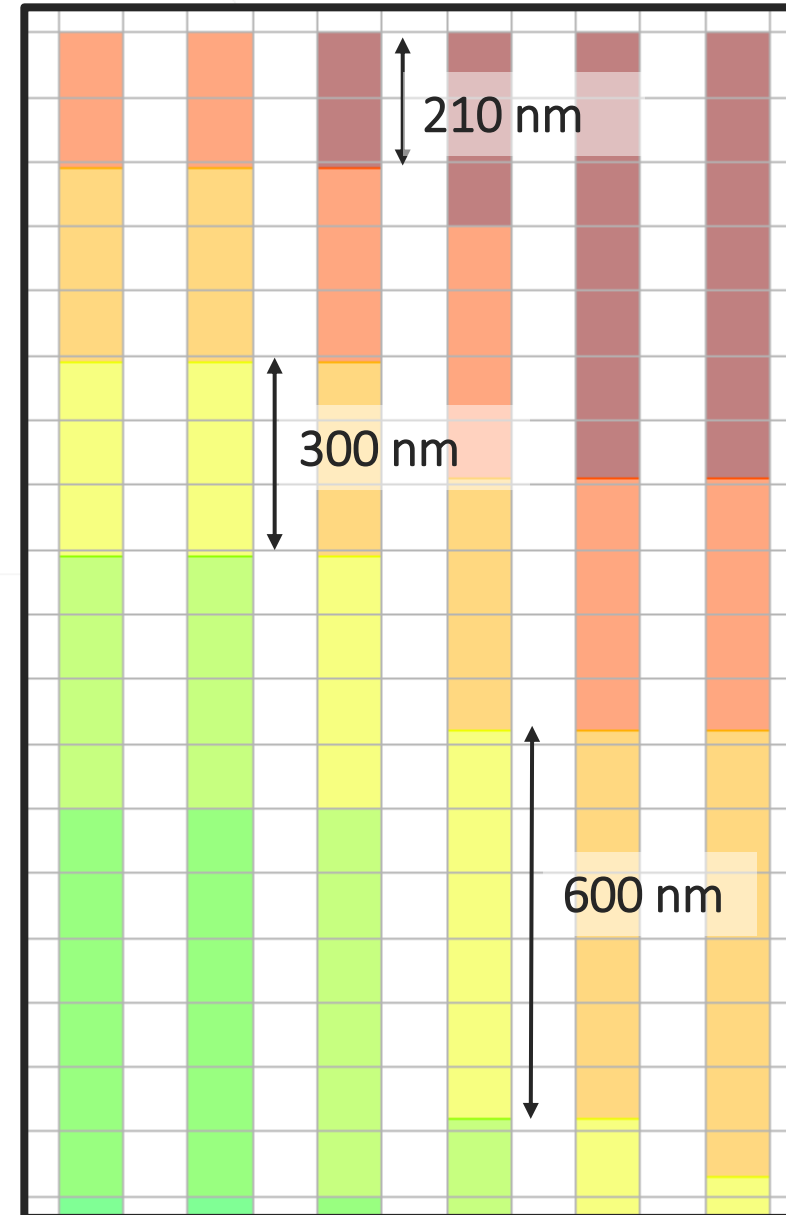
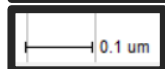
Isodose grid =  
200 nm

All fractured  
shapes at least  
200 nm

Shapes are  
fractured in 200  
nm increments

200 nm, 400 nm,  
600 nm...

Scale of Grid overlay is 100 nm



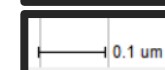
MFS = 100 nm

Isodose grid =  
30 nm

All fractured  
shapes at least  
120 nm

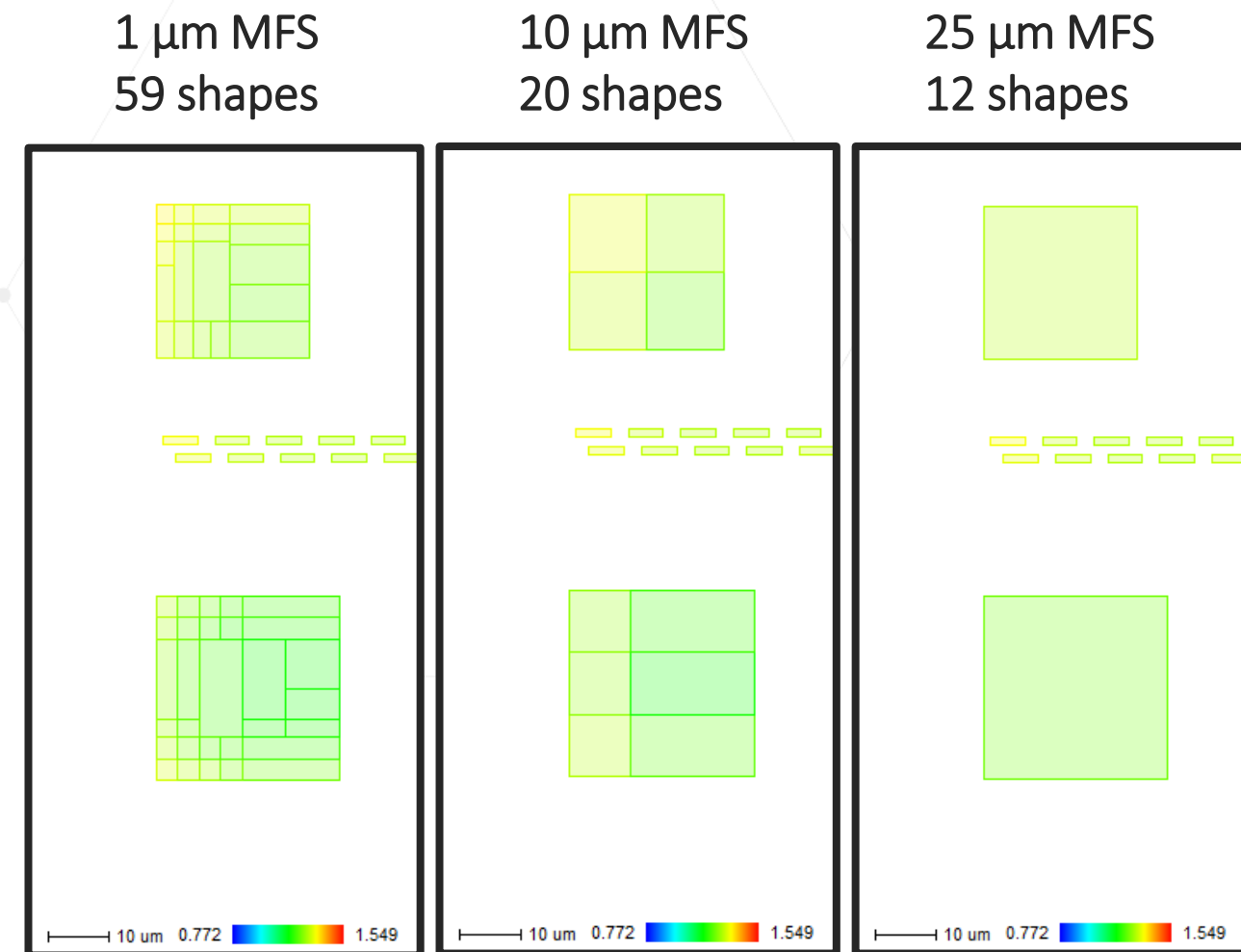
Shapes are  
fractured in 30  
nm increments

120 nm, 150 nm,  
180 nm, 210  
nm...



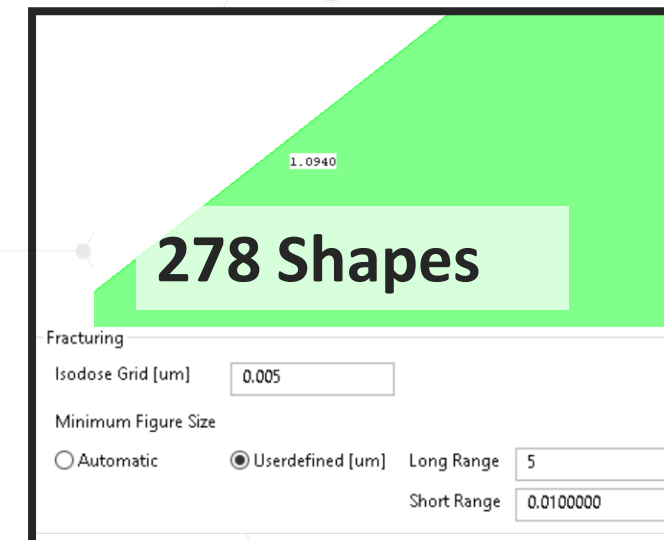
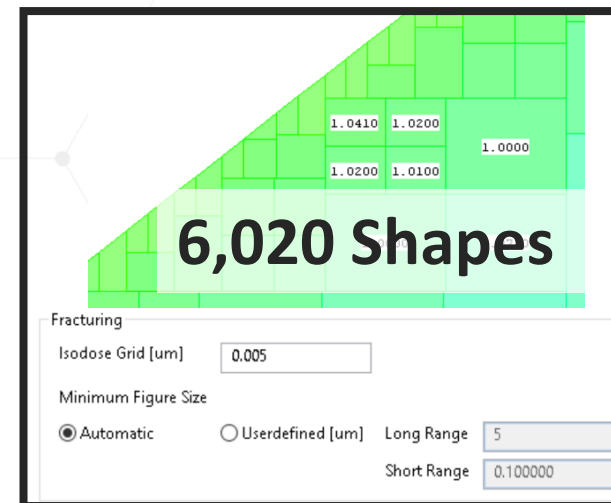
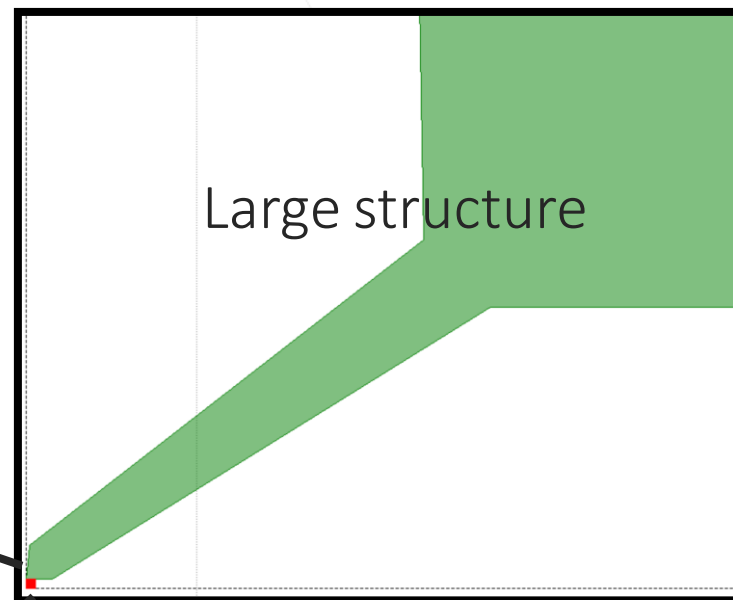
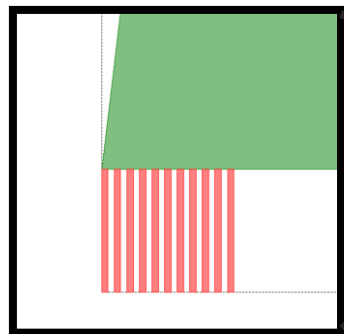
# Minimum Figure Size

- Minimum figure size is editable on the PEC accuracy tab
  - Default: automatically calculated based on the chosen PSF
- Defines the smallest allowable size of PEC fractured shapes
  - Shapes larger than the MFS will not be fractured
- Manually increasing this value can reduce the total shape count



- SR PEC requires a small minimum figure size
  - Enables dose modulation at high resolution
- One MFS parameter would increase the shape count for LR pattern elements

Structure for SR  
PEC



- PSF definition
- Process parameters
- Advanced Parameters
- Summary
- Q & A



- PSF definition
  - Stack / Gauss / mid range part
- Process parameters
  - Base dose / effective blur / lateral development / TRACER process calibration
- Advanced Parameters
  - Shape count: Accuracy / Min. Figure size / Iso dose grid

Method	Benefits	Drawbacks
Decrease PEC accuracy	<ul style="list-style-type: none"> <li>• Data volume ↓</li> </ul>	<ul style="list-style-type: none"> <li>• CD variance ↑</li> <li>• Shape fidelity ↓</li> </ul>
Increase PEC minimum figure size	<ul style="list-style-type: none"> <li>• Data volume ↓</li> </ul>	<ul style="list-style-type: none"> <li>• Shape fidelity ↓</li> </ul>
Layer Selective Long-range Fracturing	<ul style="list-style-type: none"> <li>• Data volume ↓</li> </ul>	<ul style="list-style-type: none"> <li>• Additional pattern prep</li> <li>• Not fractured shapes may lose fidelity</li> </ul>

# Thank You!

support@genisys-gmbh.com

## Headquarters

GenISys GmbH  
Eschenstr. 66  
D-82024 Taufkirchen (Munich)  
GERMANY

📞 +49-(0)89-3309197-60

📠 +49-(0)89-3309197-61

✉ info@genisys-gmbh.com

## USA Office

GenISys Inc.  
P.O. Box 410956  
San Francisco, CA  
94141-0956  
USA

📞 +1 (408) 353-3951

✉ usa@genisys-gmbh.com

## Japan / Asia Pacific Office

GenISys K.K.  
German Industry Park  
1-18-2 Hakusan Midori-ku  
Yokohama 226-0006  
JAPAN

📞 +81 (0)45-530-3306

📠 +81 (0)45-532-6933

✉ apsales@genisys-gmbh.com

