GenISys
Advancing the Standard

BEAMER

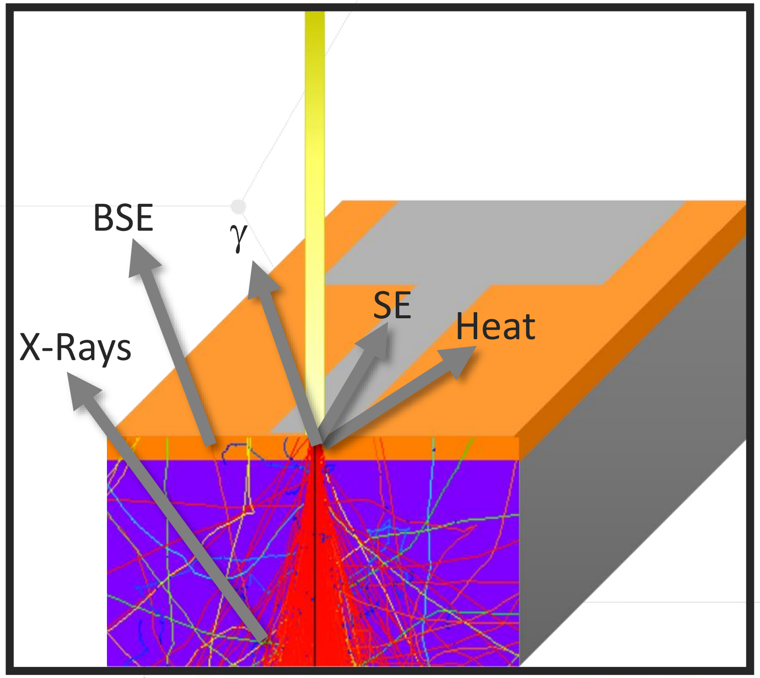
PART 5: Standard Dose PEC - Parameters

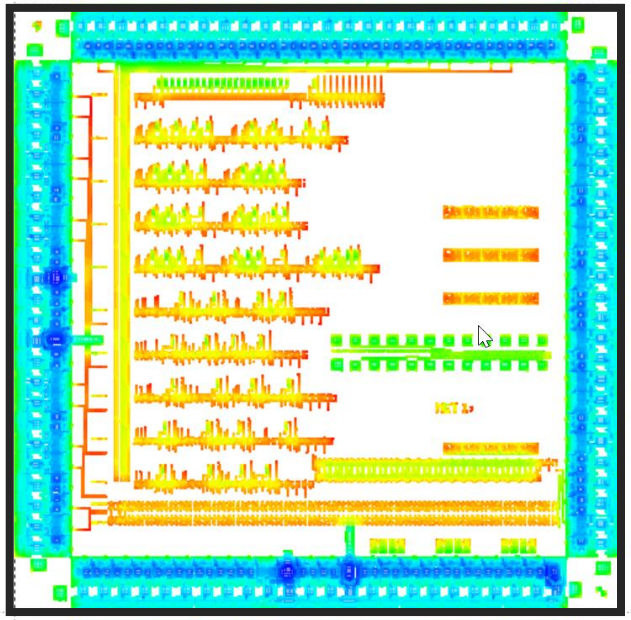
Outline

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

Standard Dose PEC - Intro

- 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

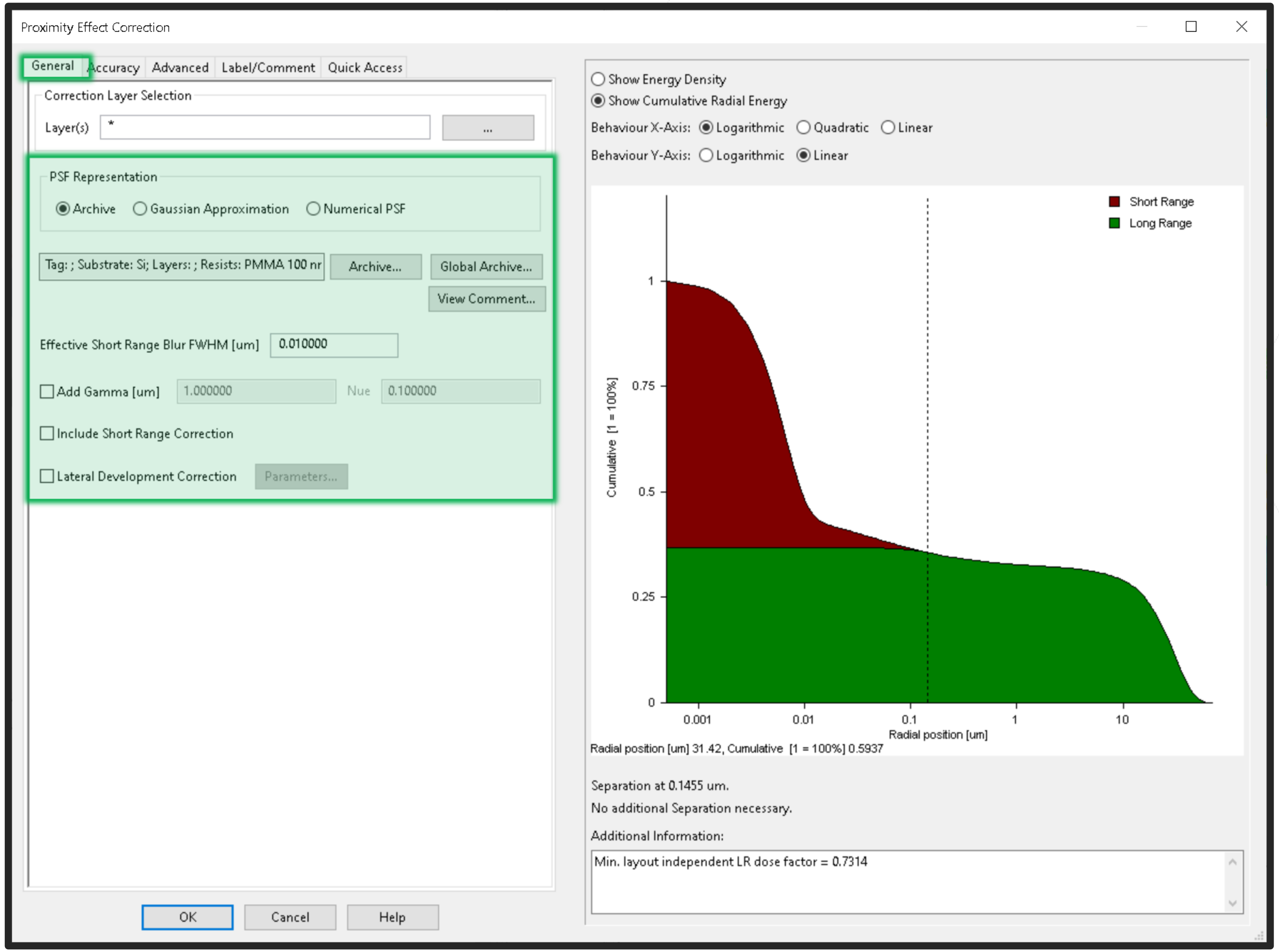


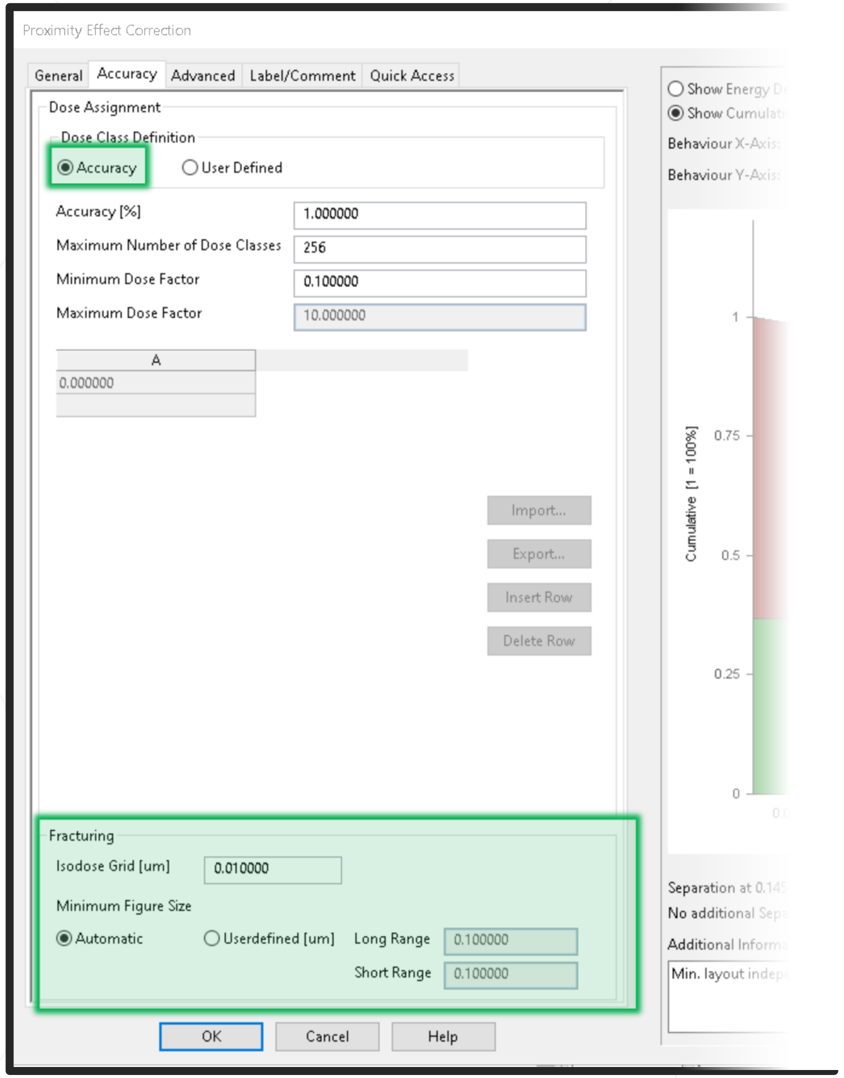


Outline

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

Introduction





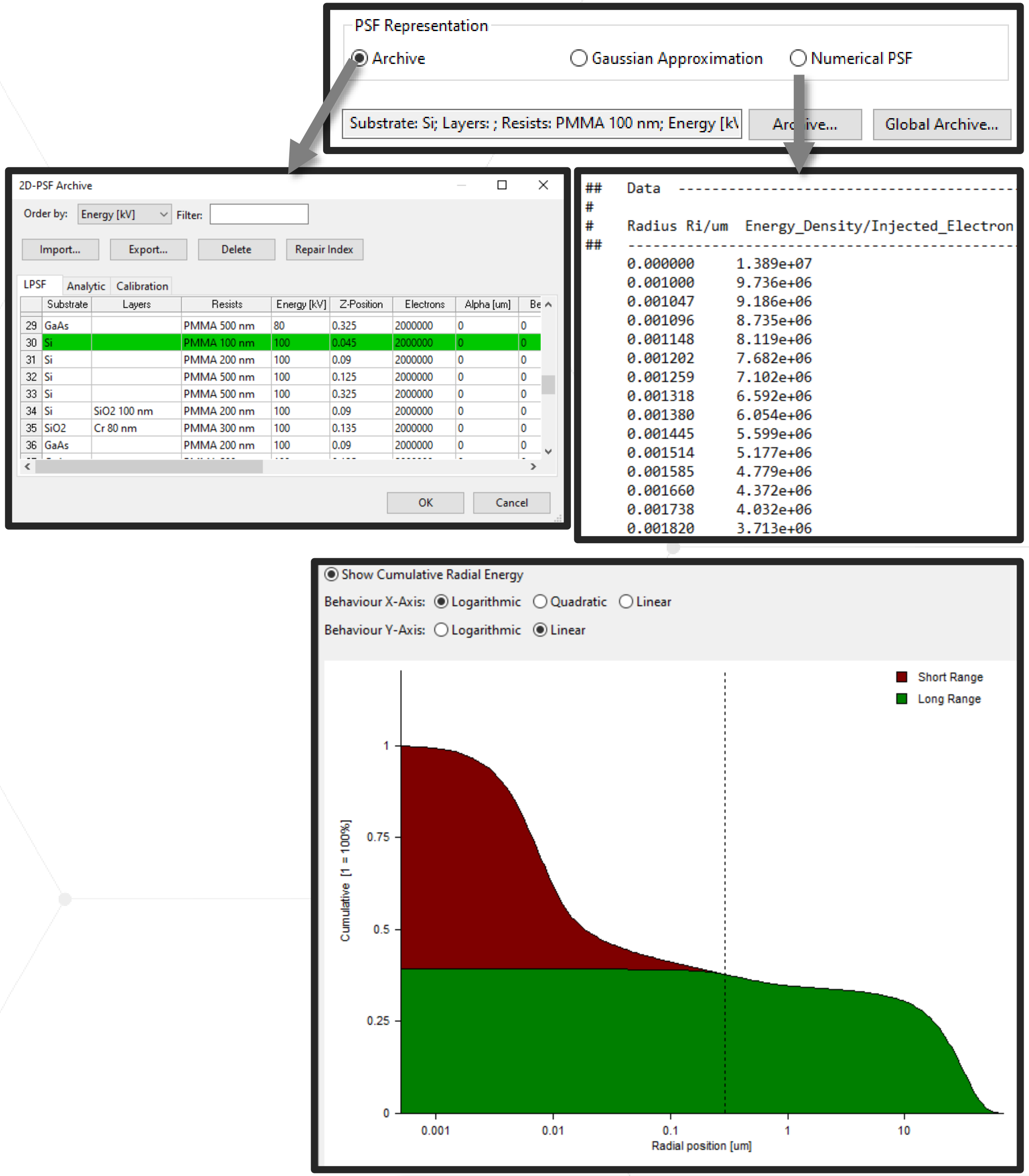
Live demo

PEC dialog

- Show archive
- Input of gaussian
- Mid range

PSF Definition

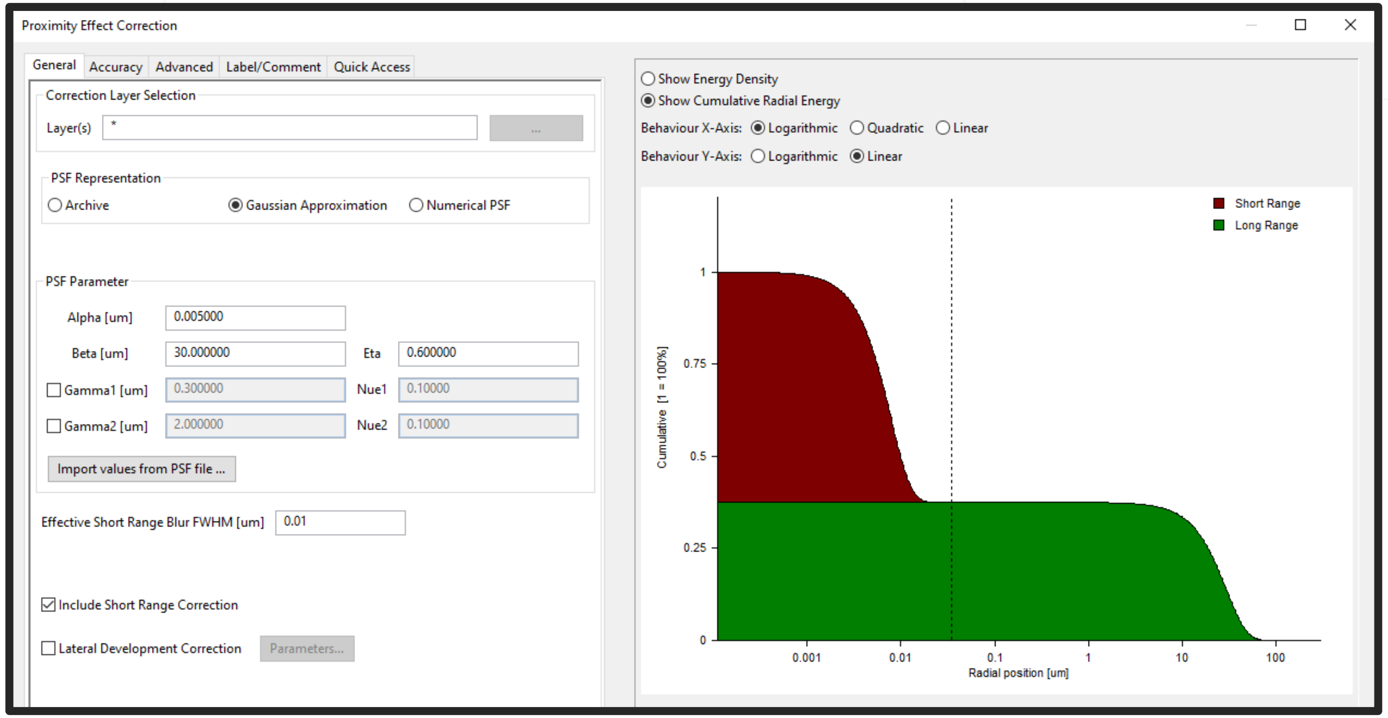
- From Monte Carlo Simulation
  - BEAMER Archive comes with PSF for major stack and acceleration voltage
  - TRACER for additional PSF
  - Numerical PSF from other MC simulator or experimental in txt format
- PEC algorithm is using table defined PSF
  - Not converted to Gaussians
  - PSF is split to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



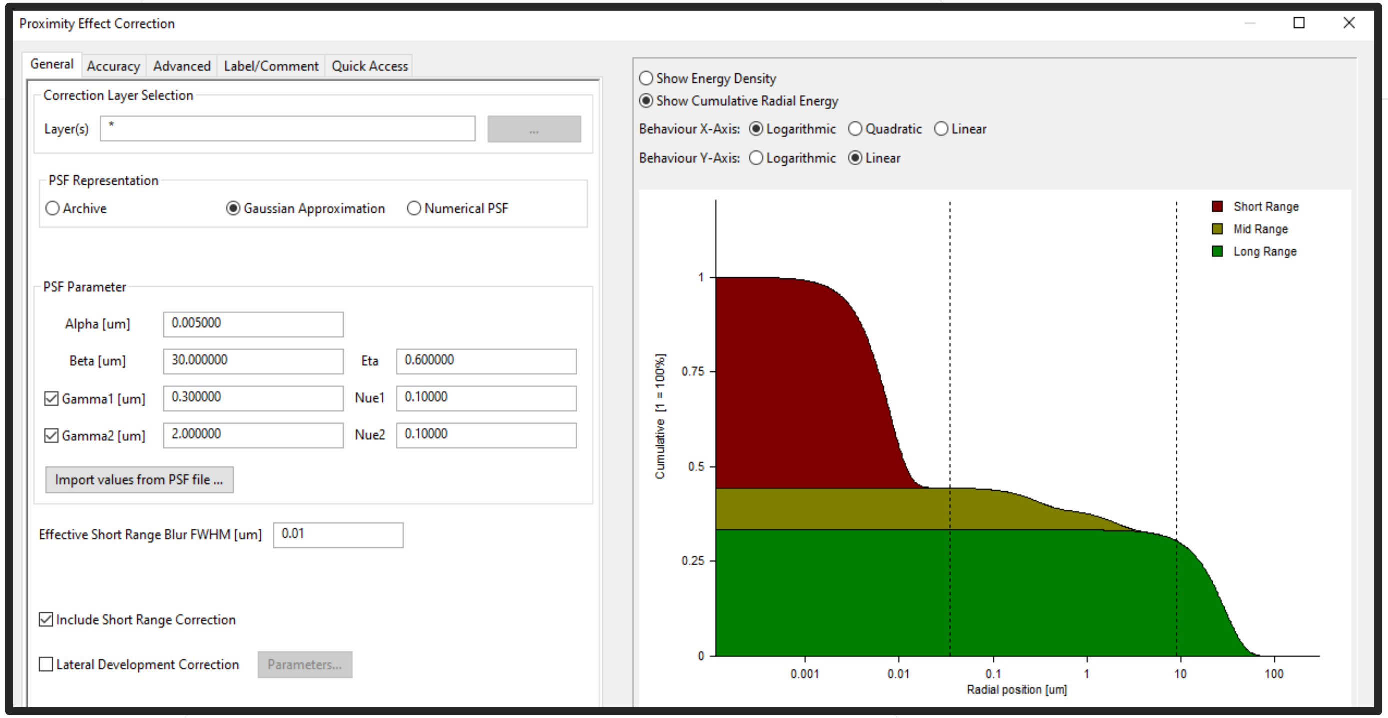
PSF With Gaussian

“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



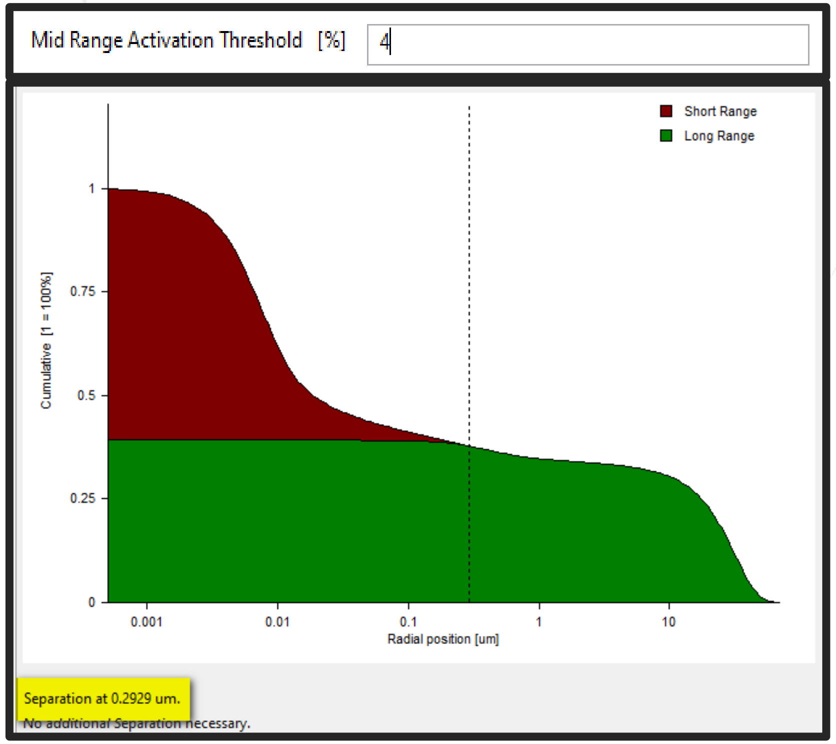
Double Gaussian

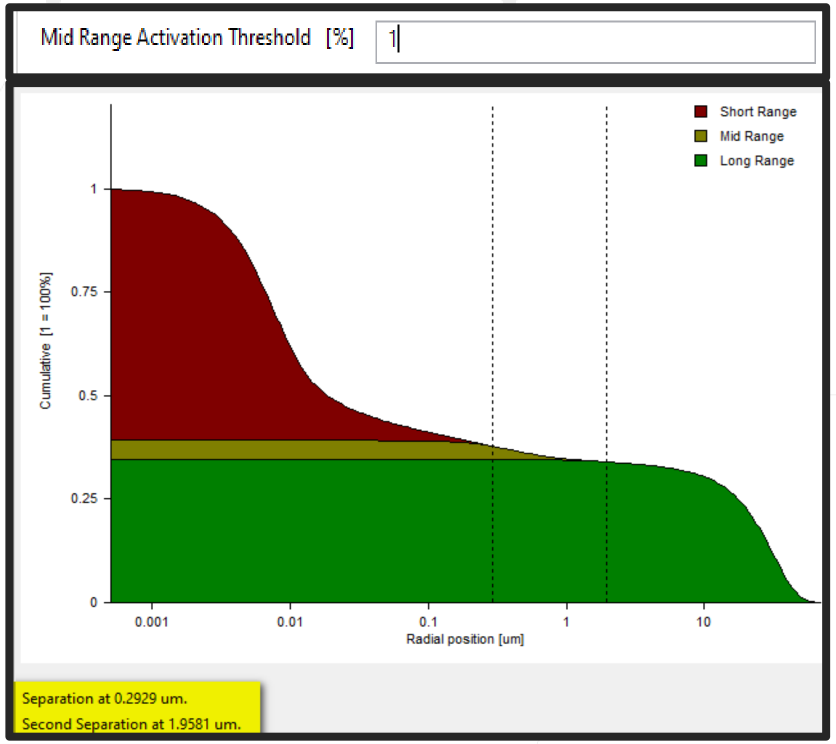


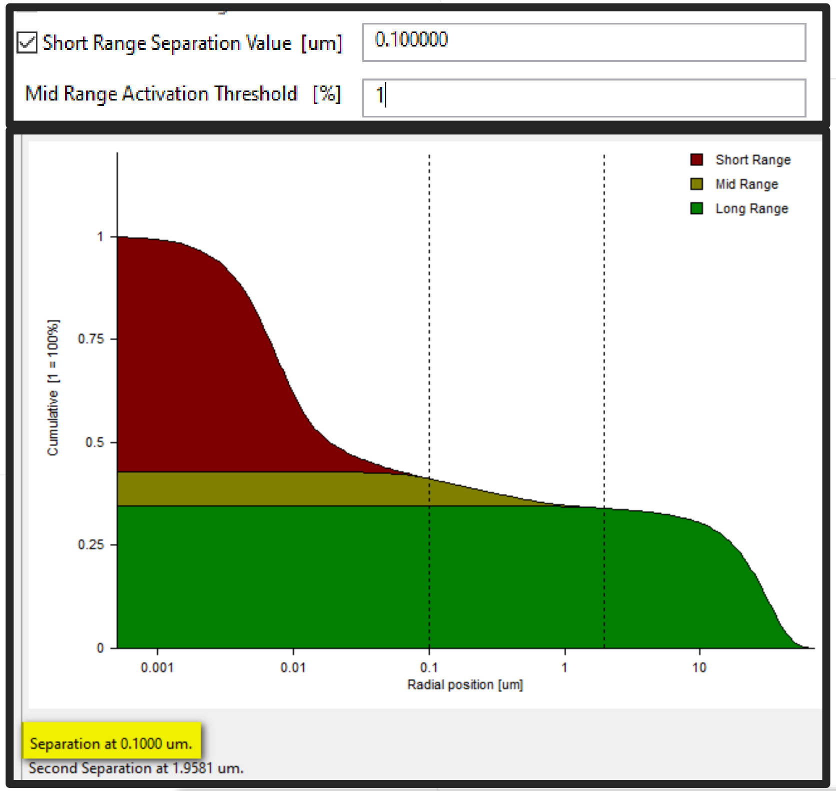
Four Gaussian

Short- & Mid-Range

- 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)



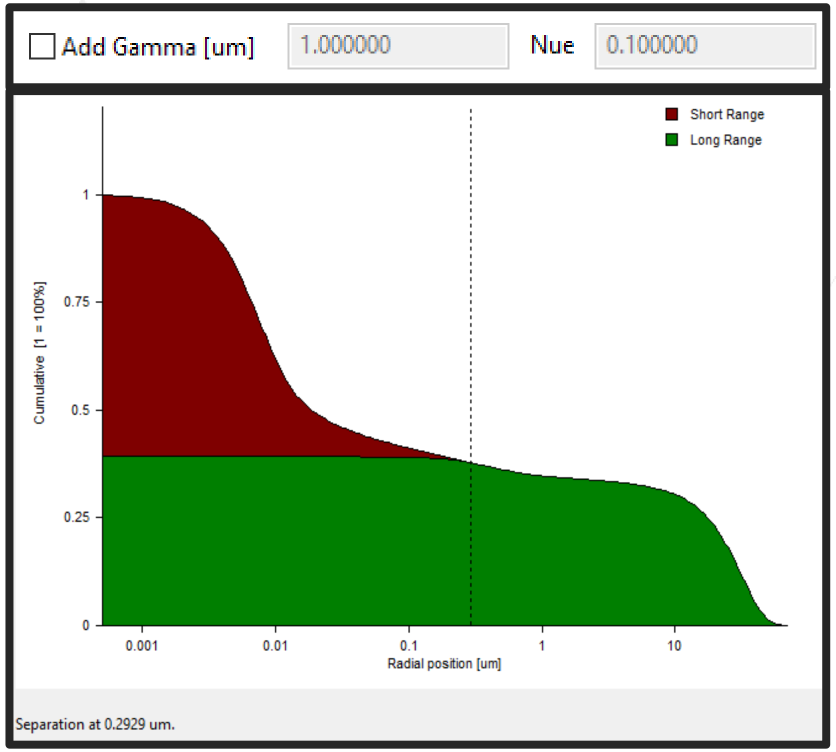


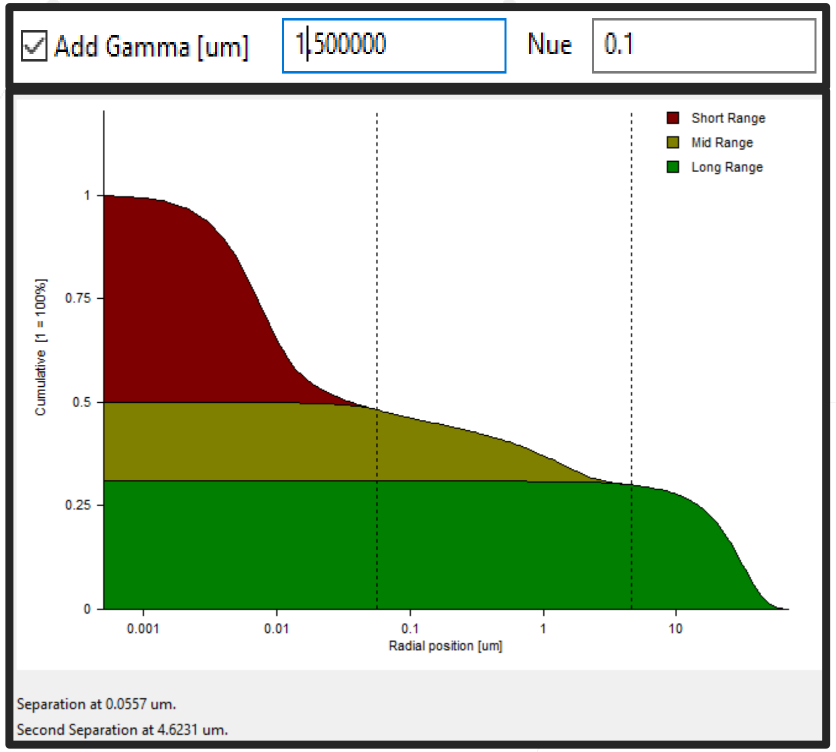


Additional „Gamma“ Term

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





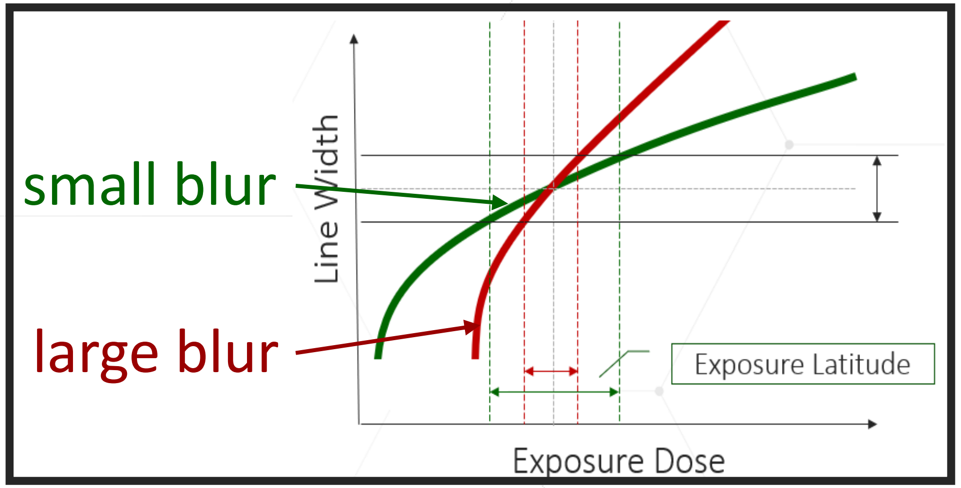
Outline

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

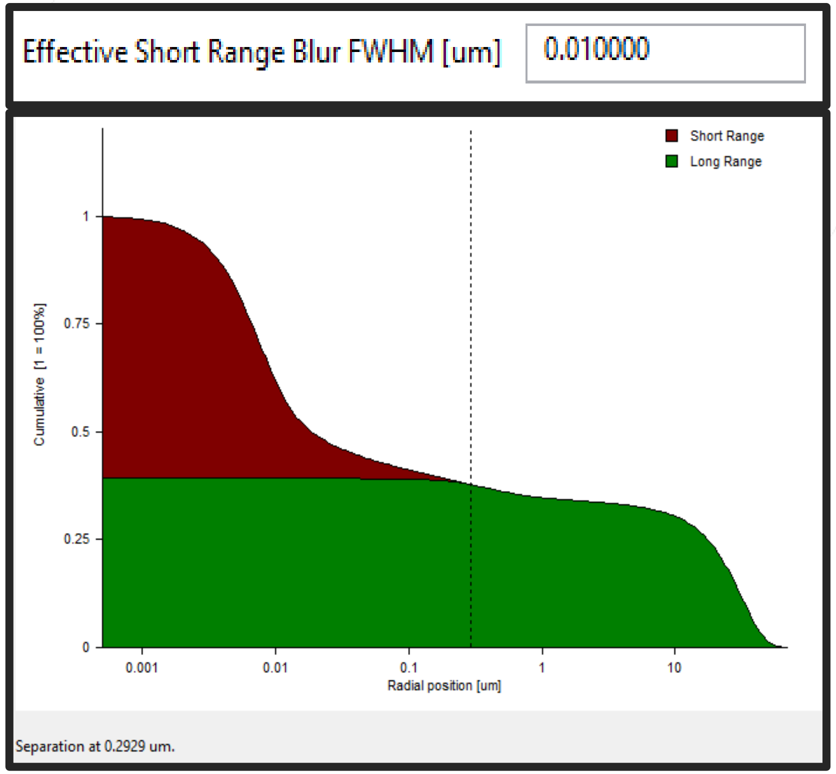
Effective Short Range Blur

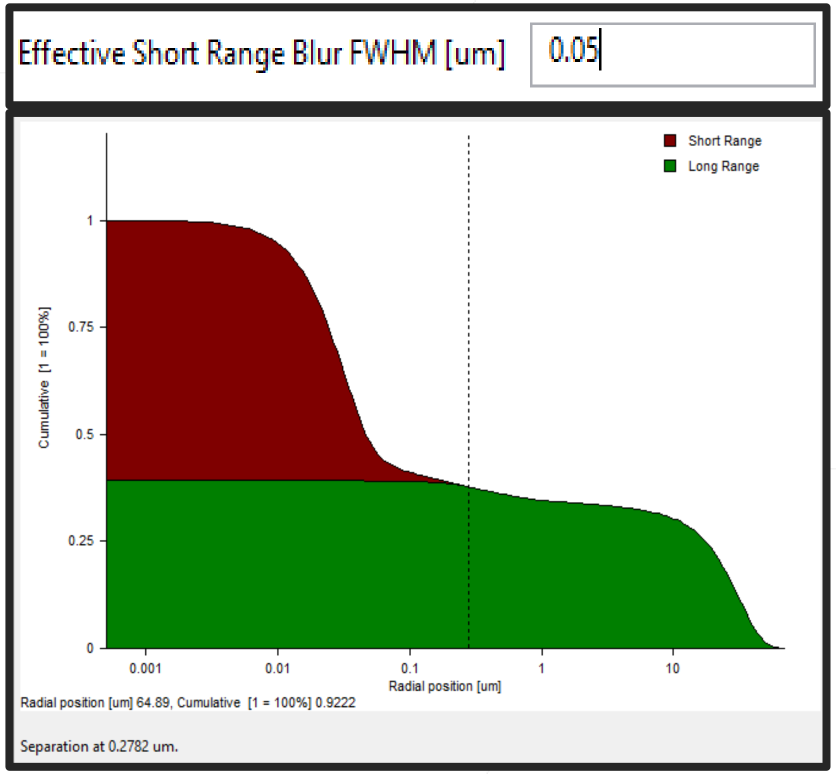
Effective Short Range Blur combines

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



1st order estimate:
FWHM = 0.76 * ΔCD / Δ%dose 1)





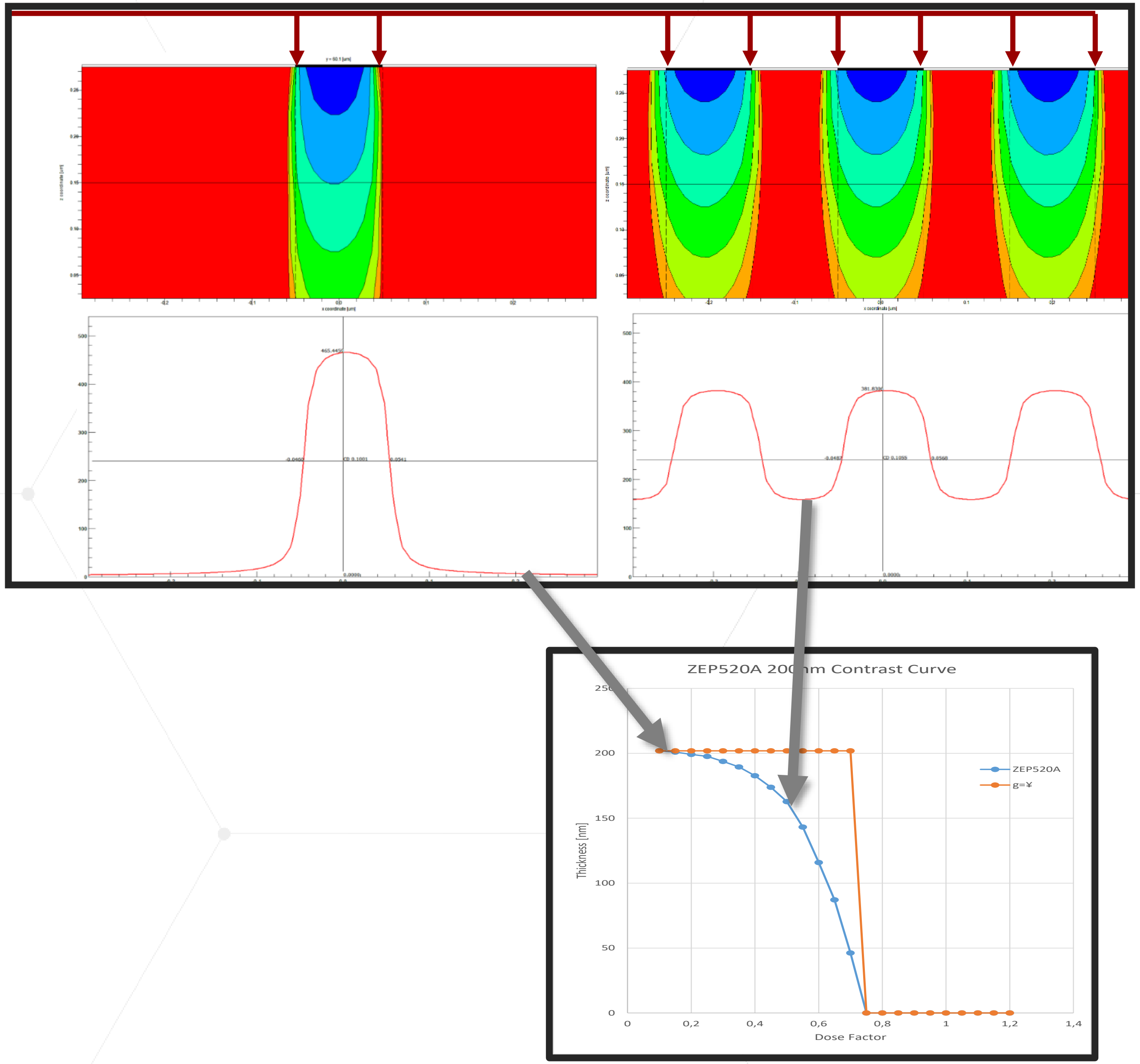
Typical values:
100keV, low current (~ 1nA), high contrast thin (100nm) PMMA: ~ 15nm

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

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

Lateral Development

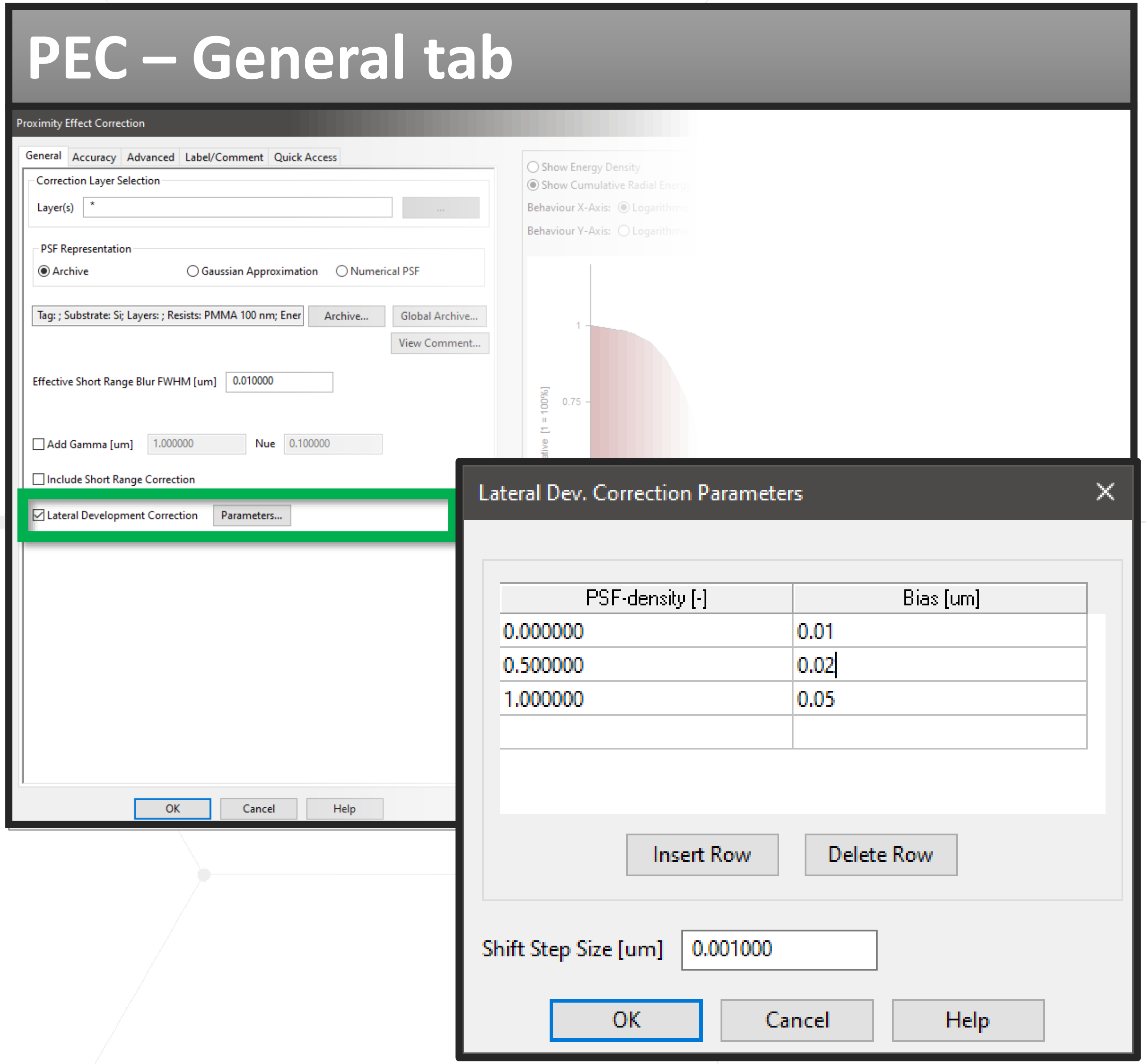
- Edge energies are equal:
  - Dose to clear at feature edge
  - Ideal for high contrast (thin) resists
- Thick resist application
  - Lower contrast resist development does
    not stop at feature edge
  - Develops dependent on energy outside feature
  - Effect is stronger for high density substrates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



GenISys
Advancing the Standard

Lateral Development Correction

- 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



Process Calibration Procedure

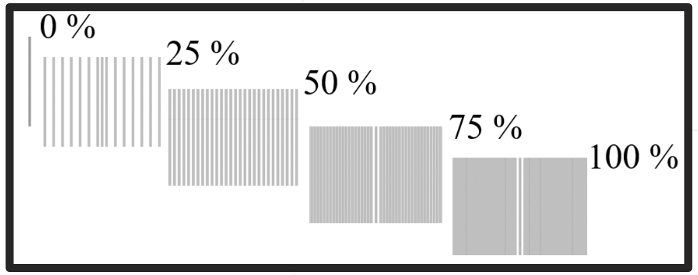
Expose Dose Matrix, Process, & Measure Calibration Pattern

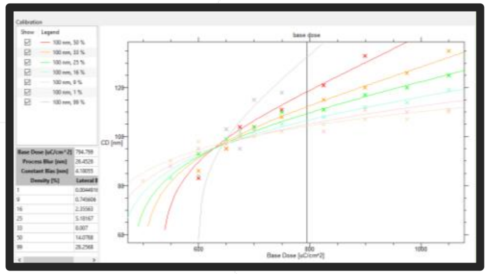
↓

Use TRACER to fit the data and determine correction parameters

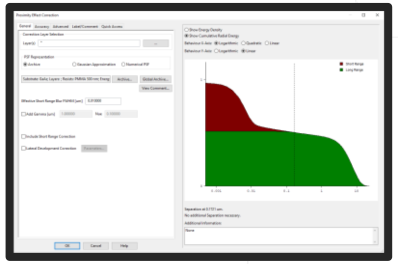
↓

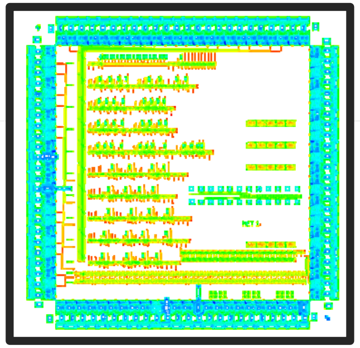
Apply correction parameters using BEAMER's PEC module





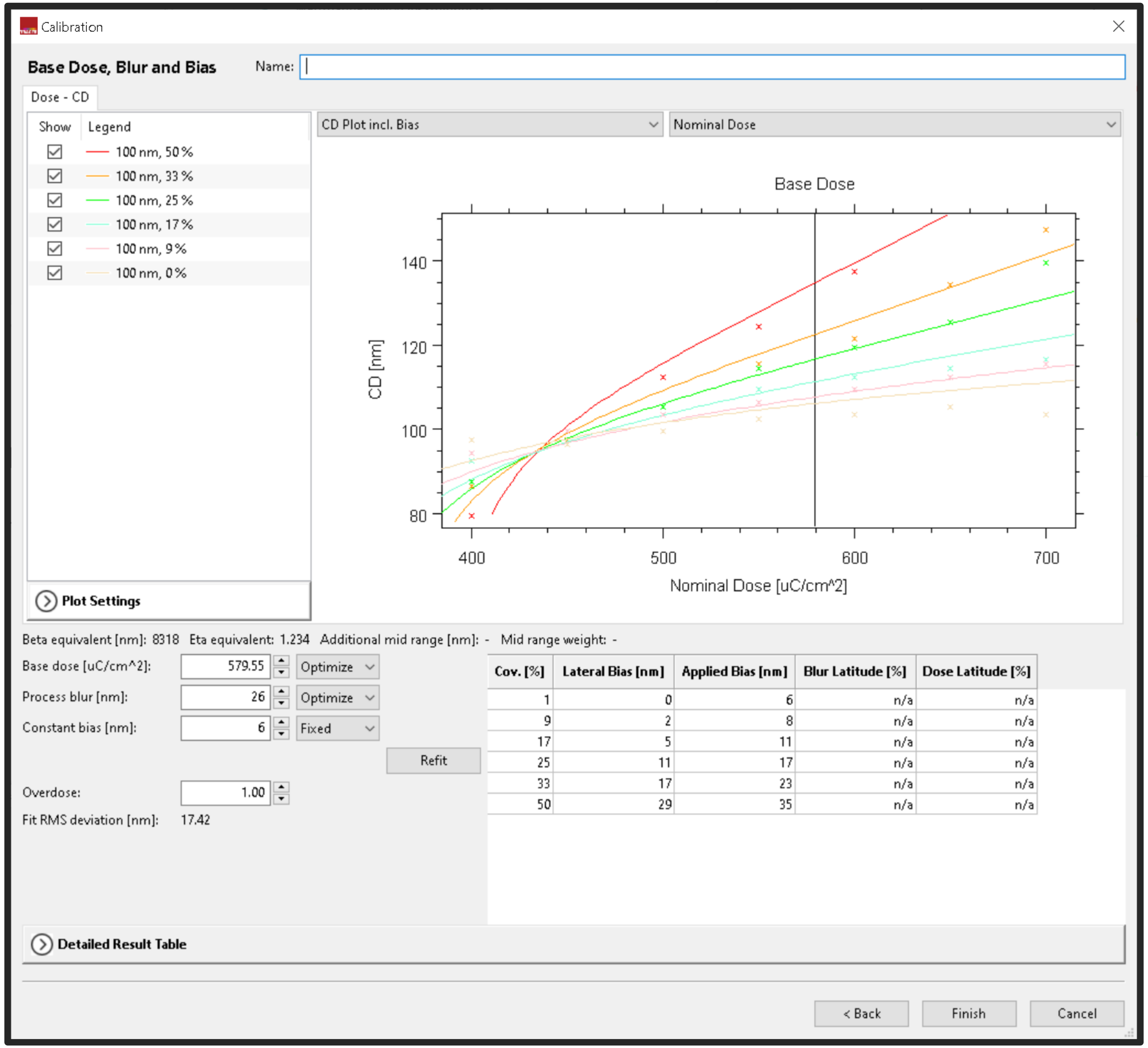
- Base Dose
- Effective Process Blur
- Constant and density-dependent bias
- UC/OC Mix Factor





GenISys
Advancing the Standard

Fit Results

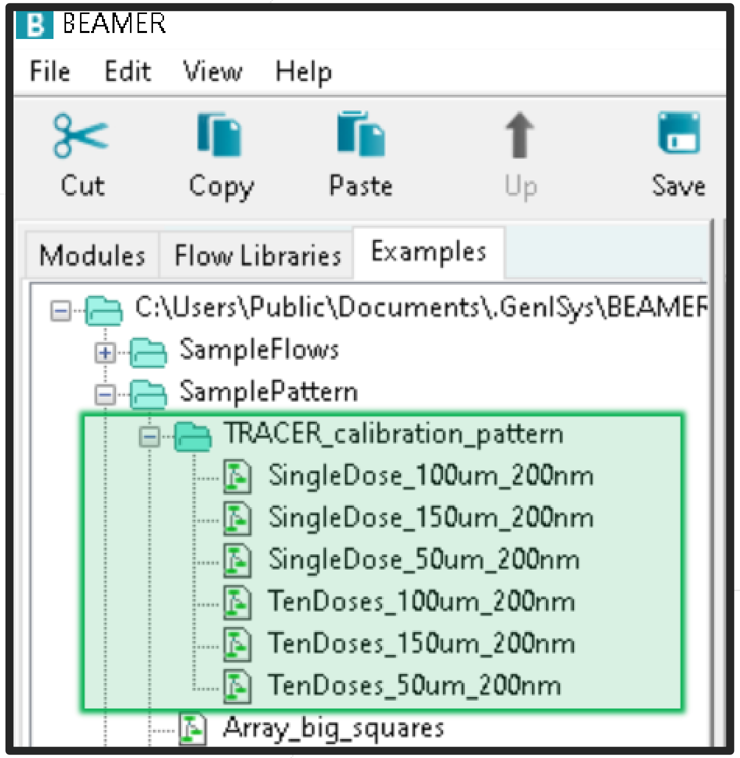


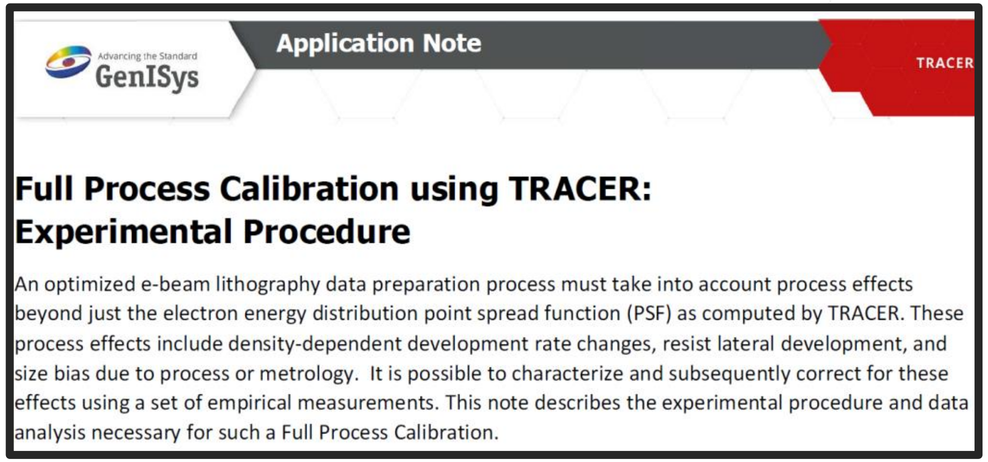
The fitting procedure results in an “Extended Point Spread Function”, adding terms to the scattering PSF

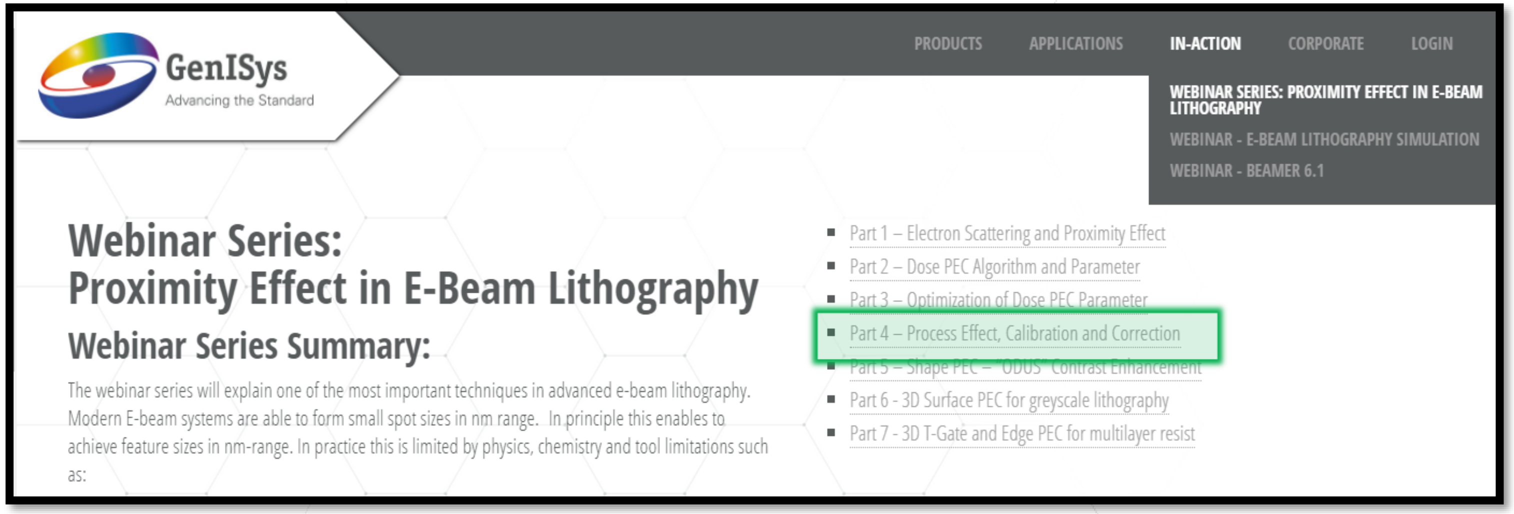
- Optimal Base Exposure Dose
- Effective Process Blur
- Constant Process Bias
- Density-dependent Bias terms to compensate
- Additional Midrange Gaussian

Documentation and Material

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







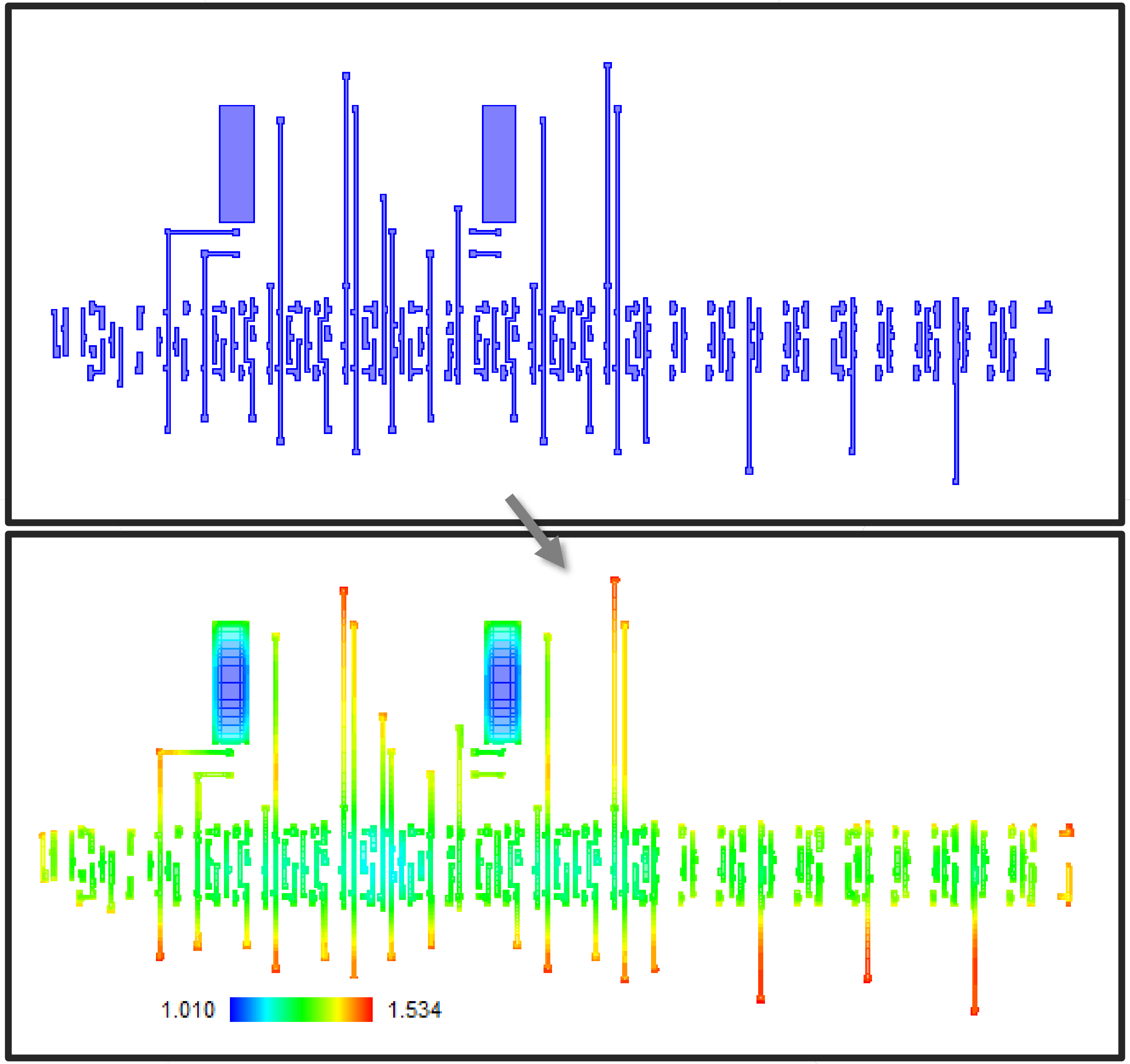
GenISys
Advancing the Standard

Outline

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

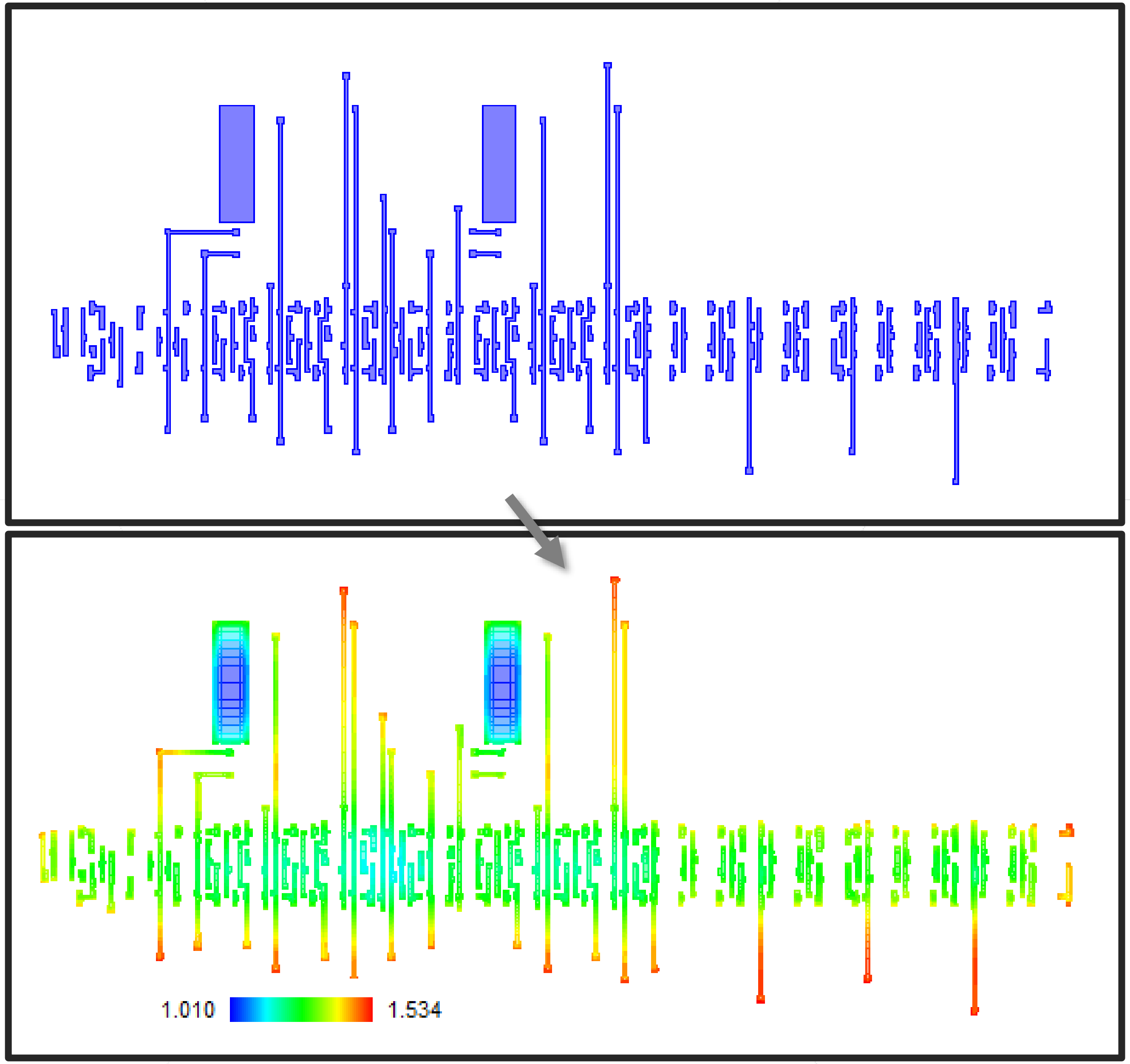
Introduction

- 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



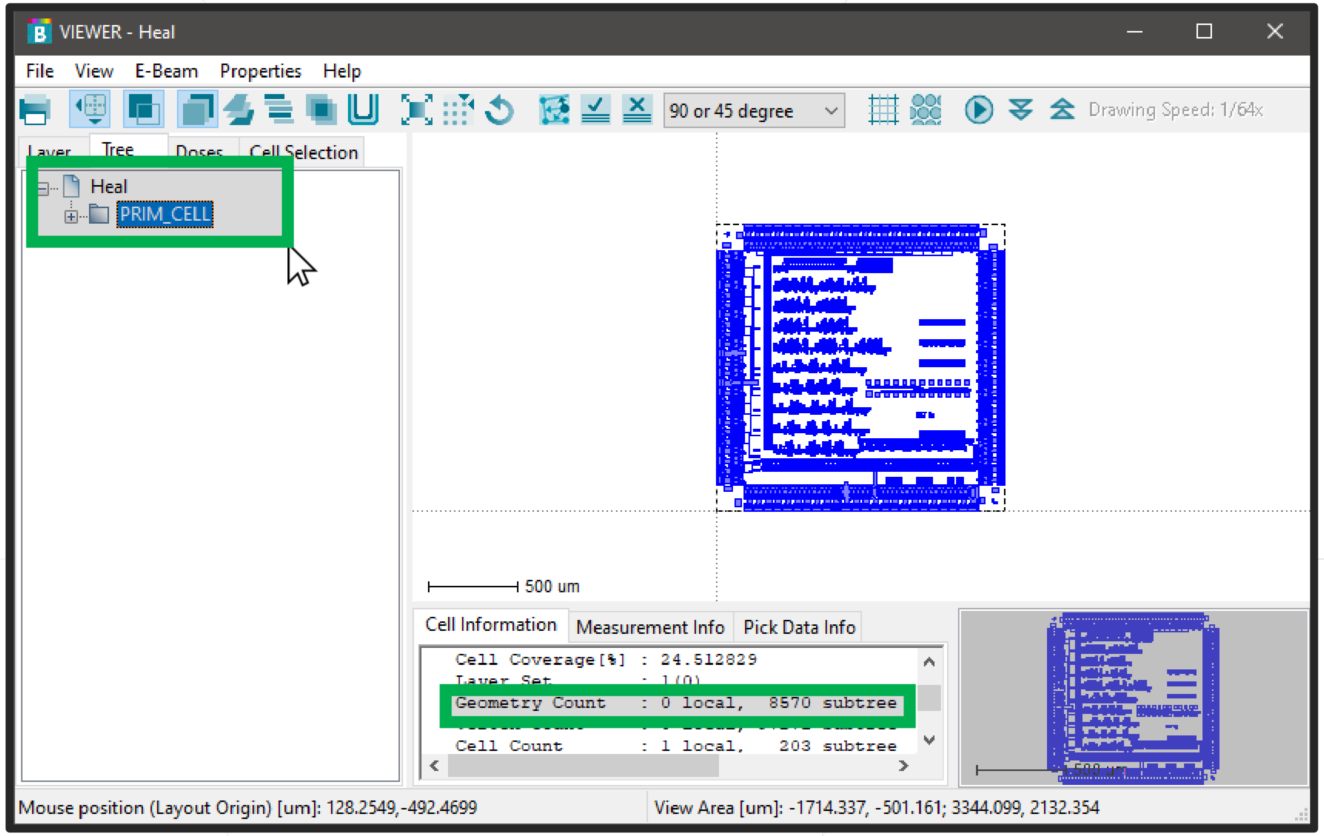
Introduction

- 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

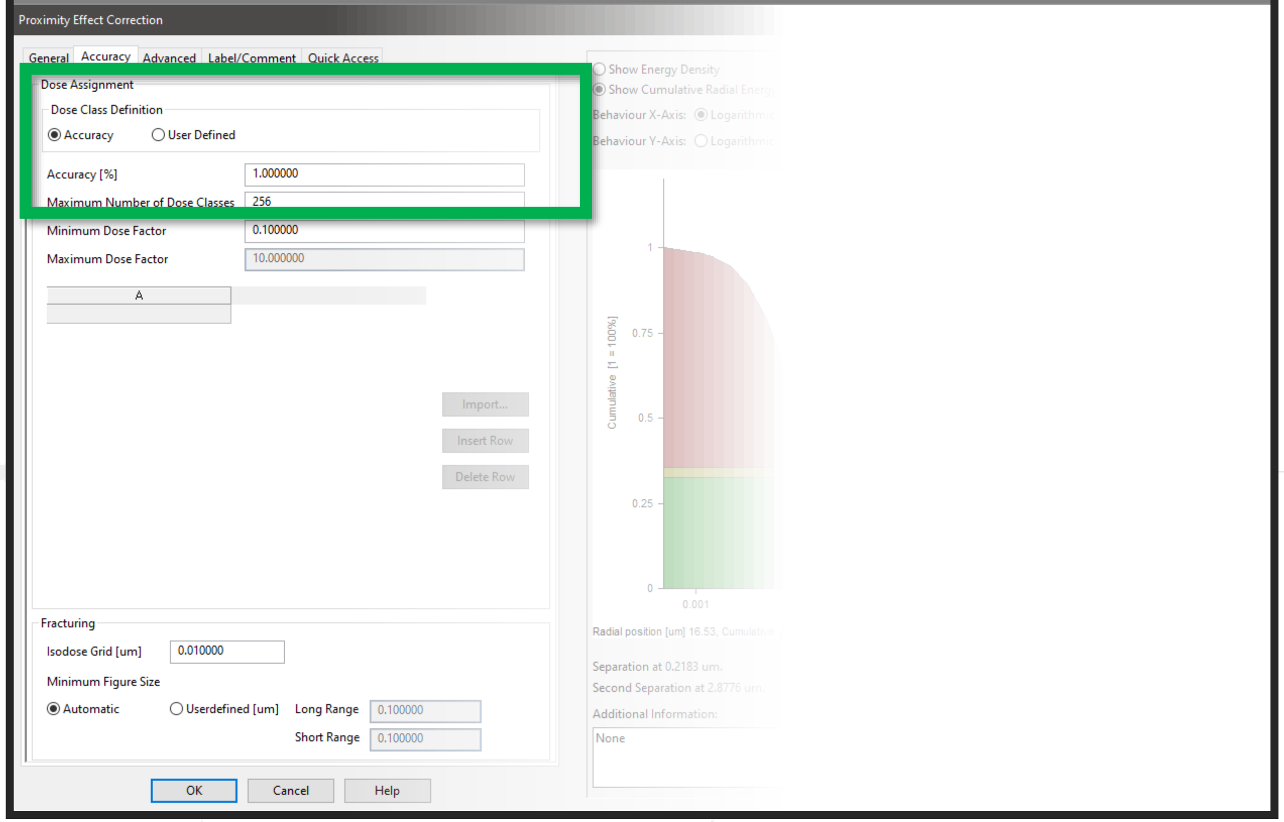


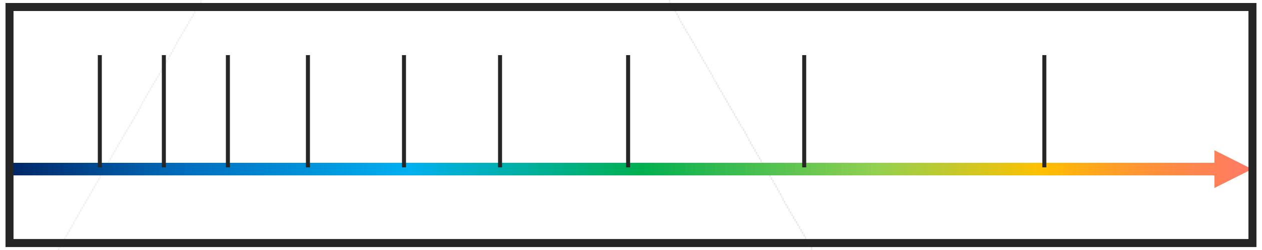
Accuracy

- 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 10% Accuracy		
0.8264 (0)	0.83	1.1^{-2}
0.9091 (1)	0.91	1.1^{-1}
1.0000 (2)	1.00	1.1^{0}
1.1000 (3)	1.10	1.1^{1}
1.2100 (4)	1.21	1.1^{2}
1.3310 (5)	1.33	1.1^{3}
1.4641 (6)	1.46	1.1^{4}

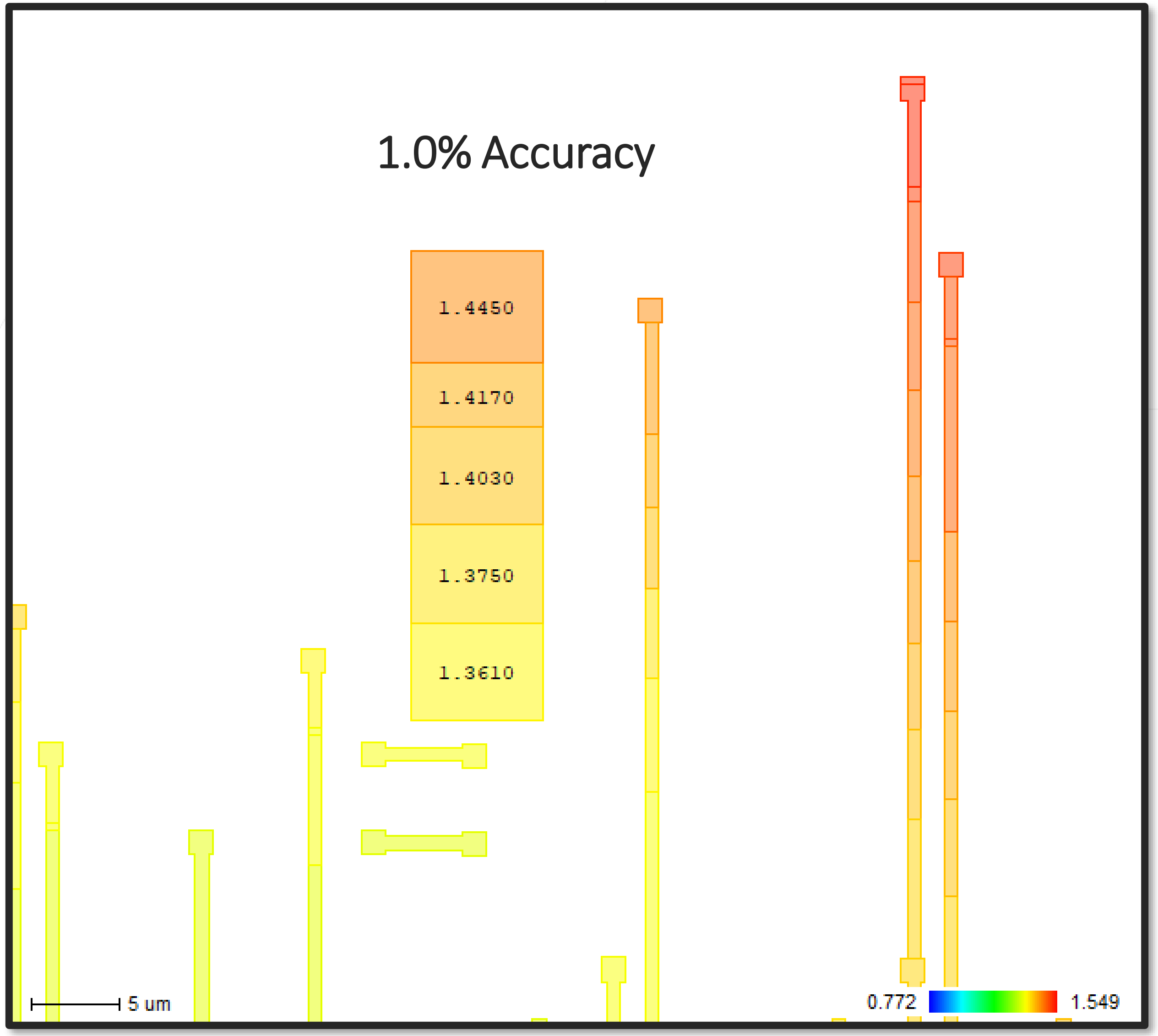
PEC – Accuracy tab

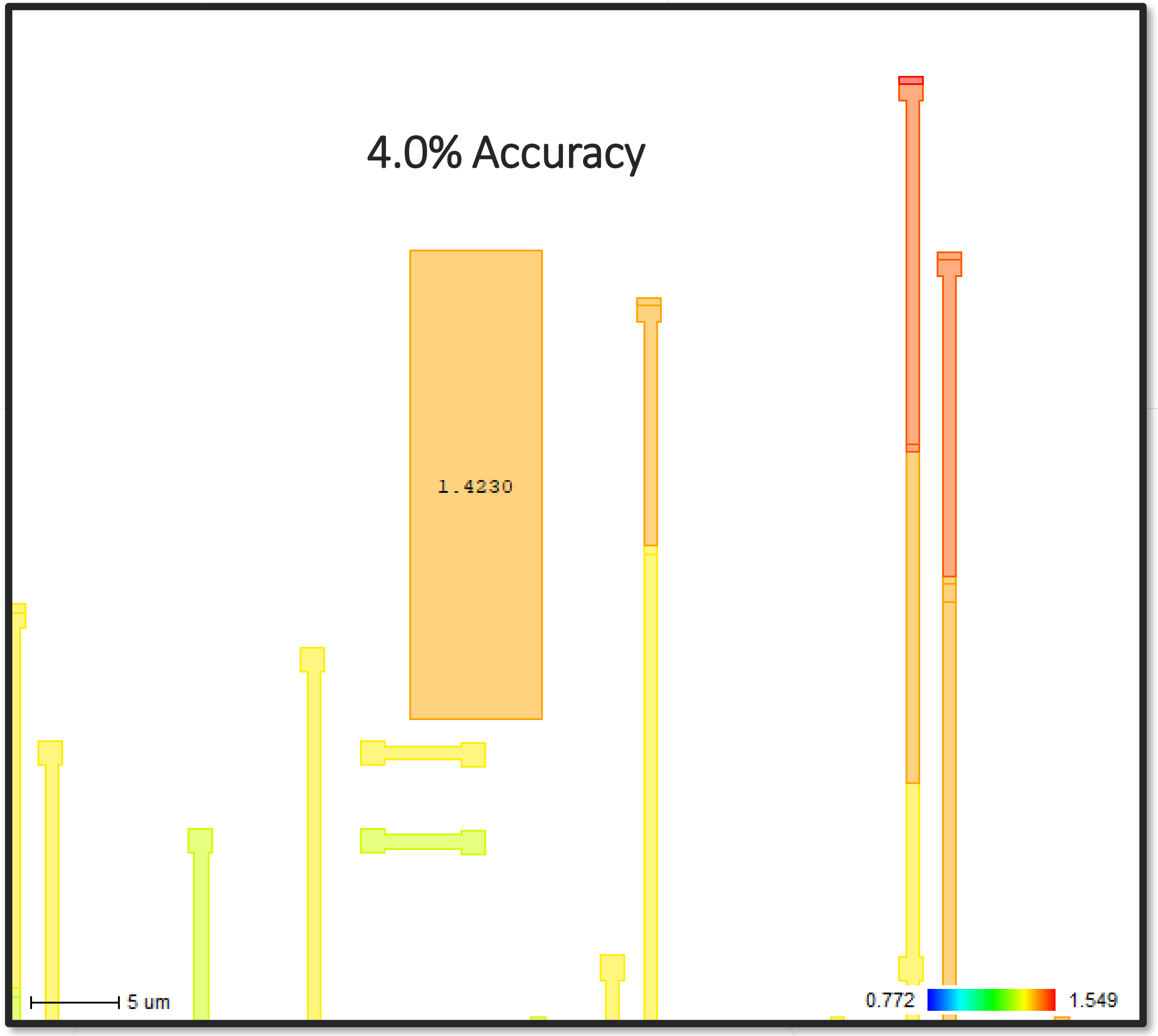




Accuracy

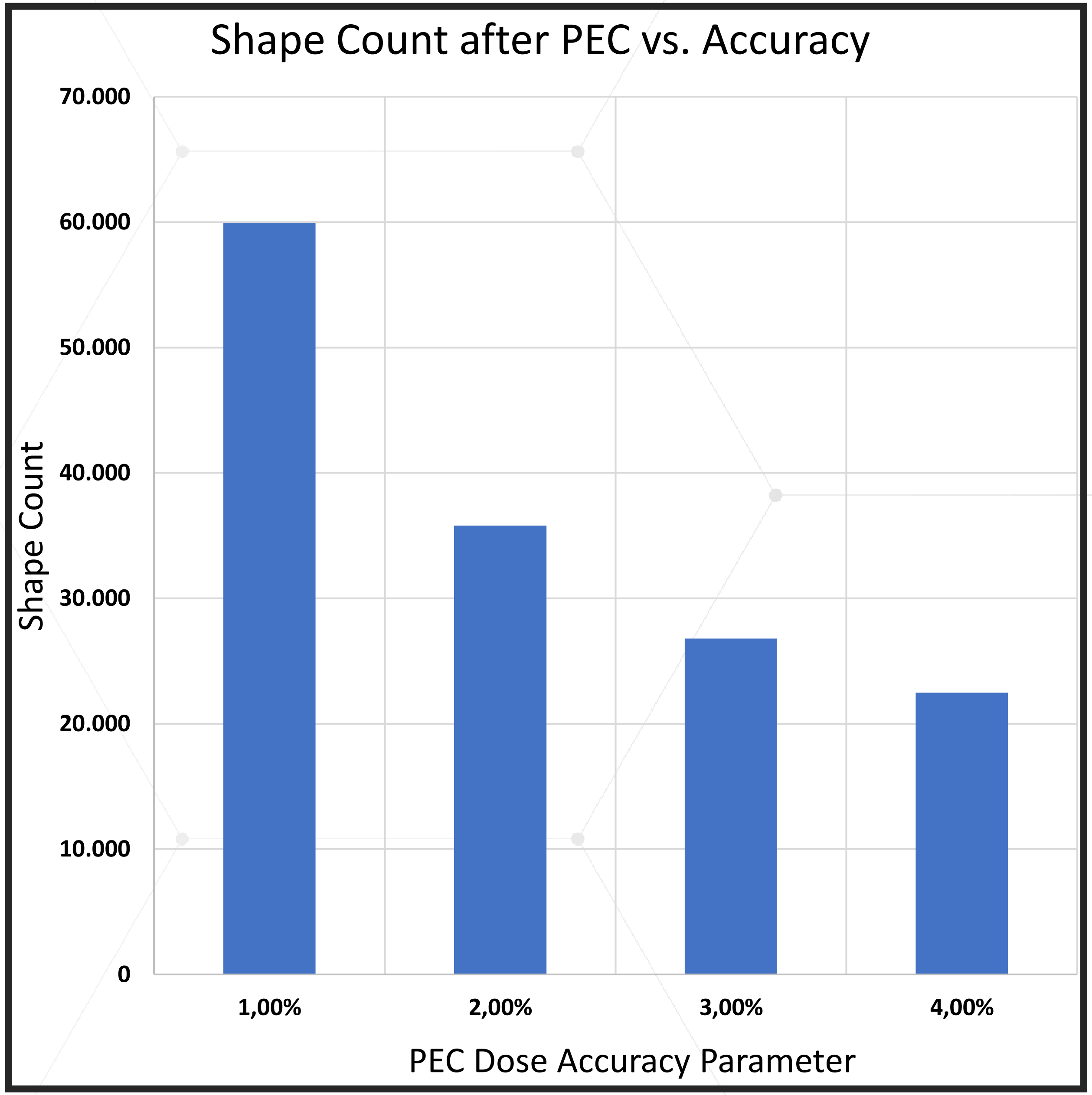
Larger accuracy value reduces shape count at cost of internal dose variation





Accuracy

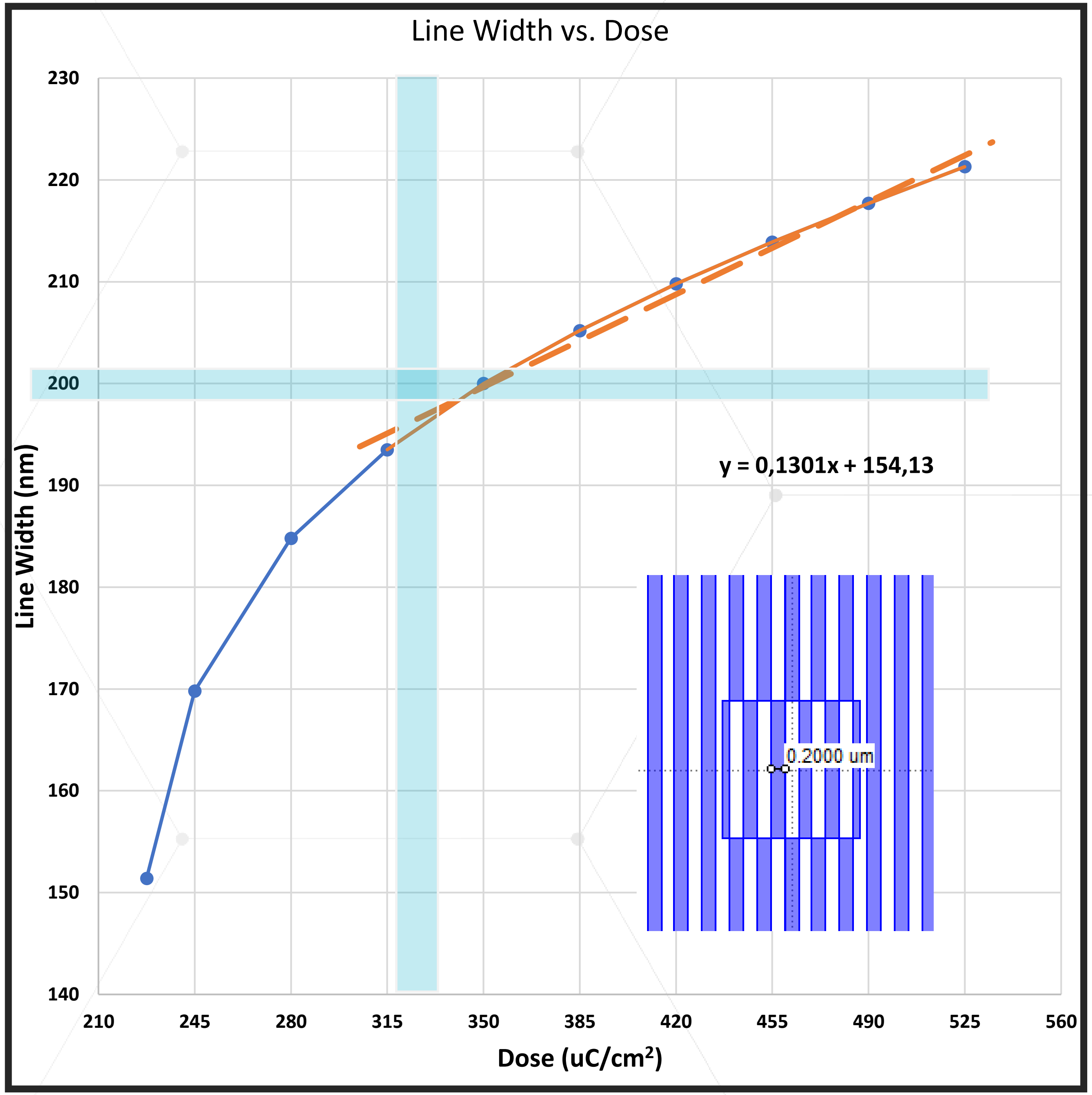
- The total shape count after PEC is shown for increasing accuracy values.
- Increasing the accuracy value…
  - **Decreases** the accuracy of the PEC dose assignment
  - **Decreases** the total shape count after PEC
  - **Decreases** the amount of dose classes
- Decreasing accuracy can have negative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



GenISys
Advancing the Standard

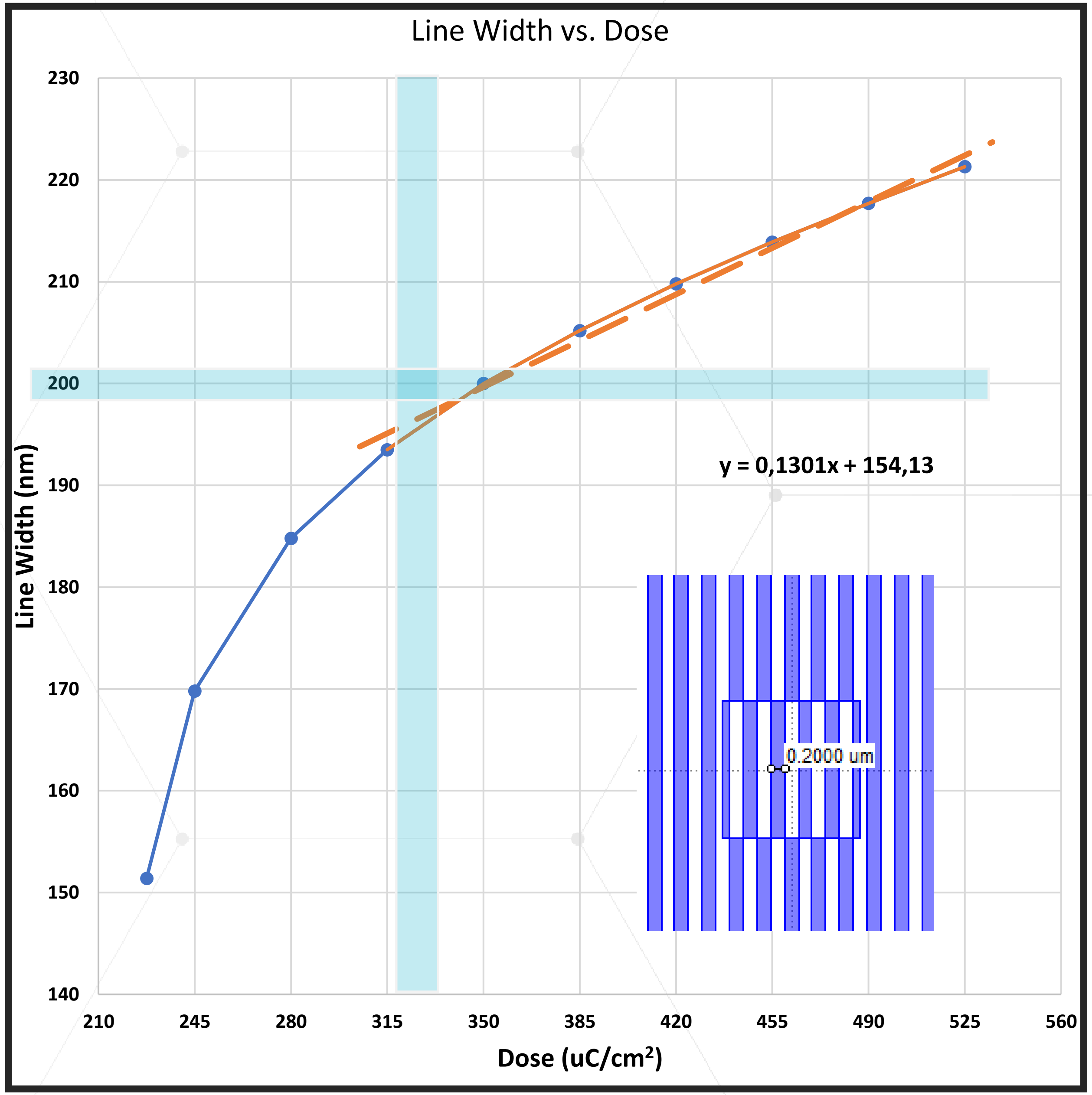
Choosing a PEC Accuracy

- 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 μC/cm^2



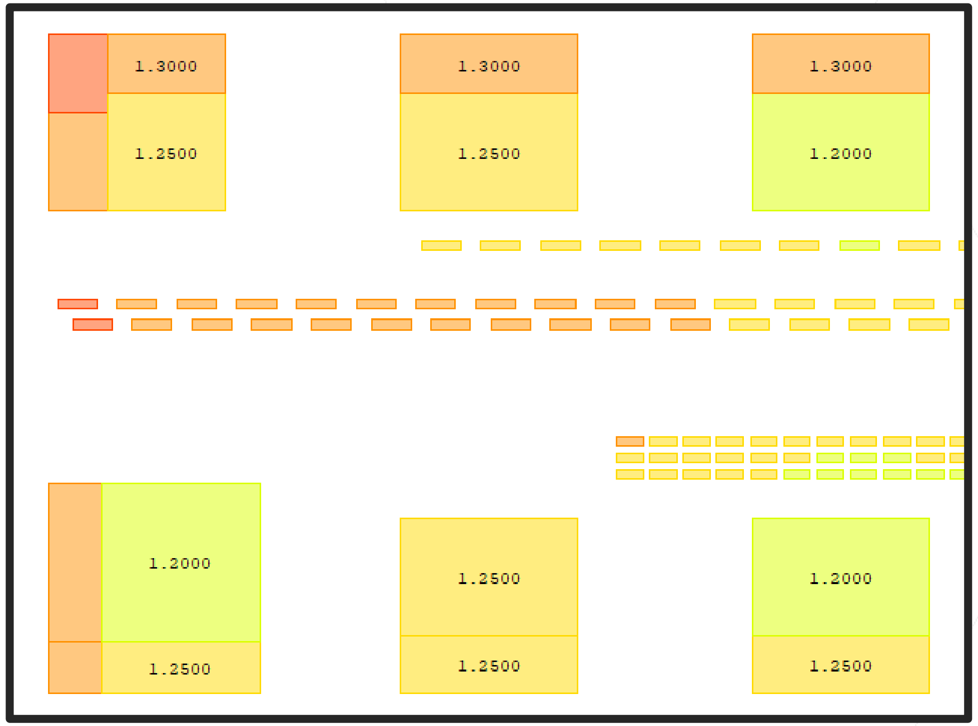
Choosing a PEC Accuracy

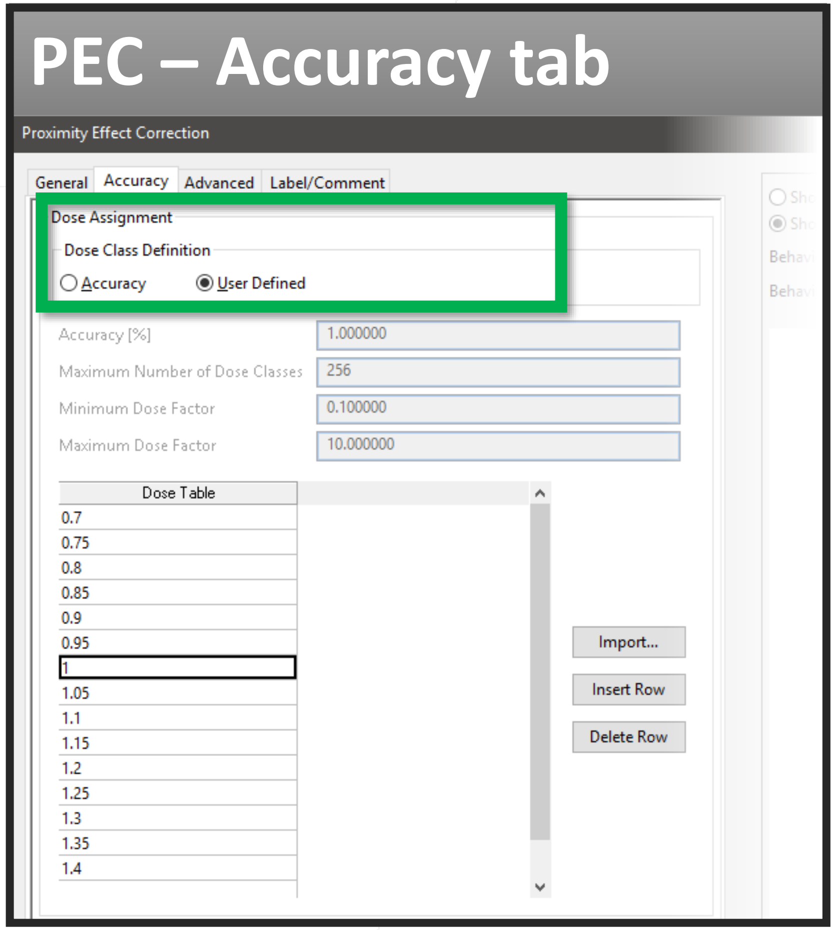
- Slope = 4.6 nm/35 [µC/cm^2] change in line width
  - 35 µC/cm^2 corresponds to 10% of base dose
  - Meaning, accuracy of 10% allows ~4.6 nm deviation in line width at proper dose at 50% pattern density
- Note: Slope is dependent on pattern density – should be larger for denser features. Choose critical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



User Defined Dose Table

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





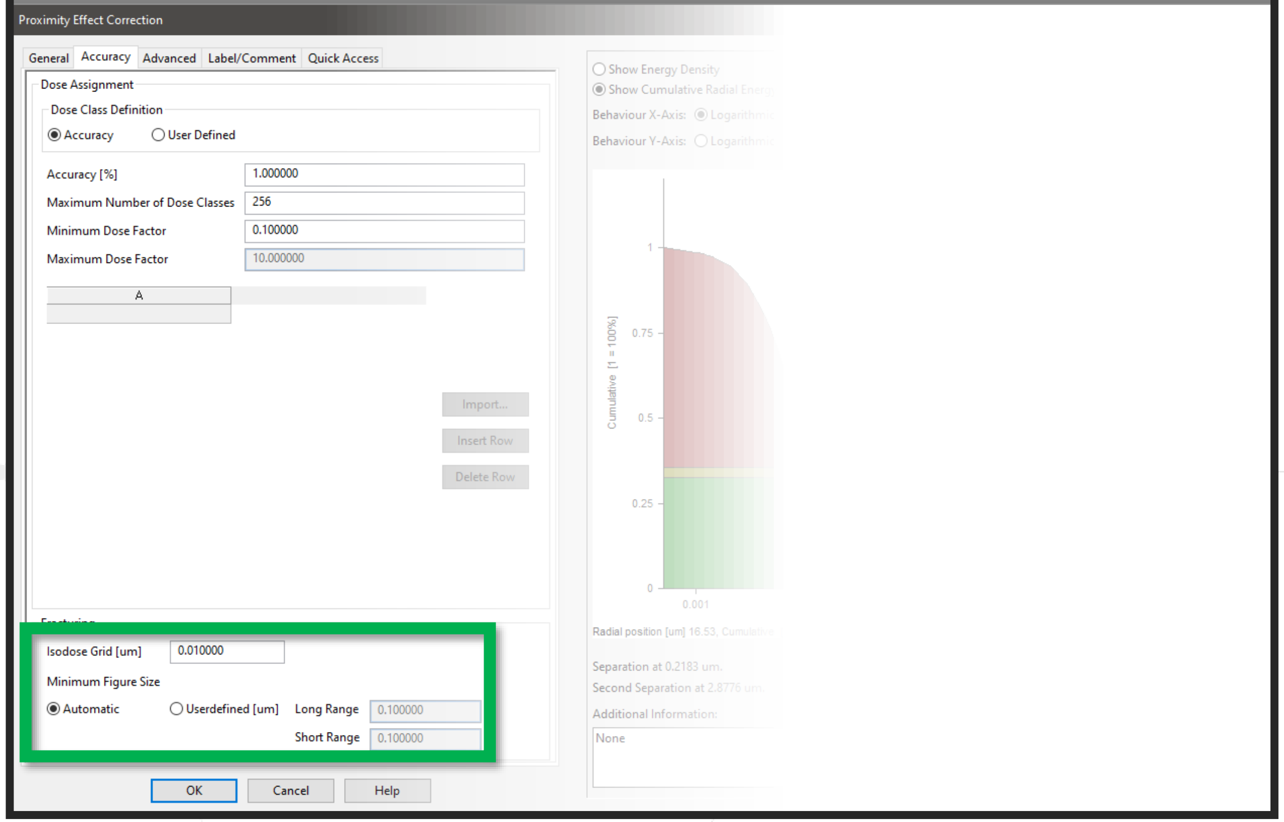
Isodose Grid & Minimum Figure Size

- **Isodose Grid** defines the “fracture grid” that PEC utilizes
- **Interacts with the minimum figure size (MFS)**

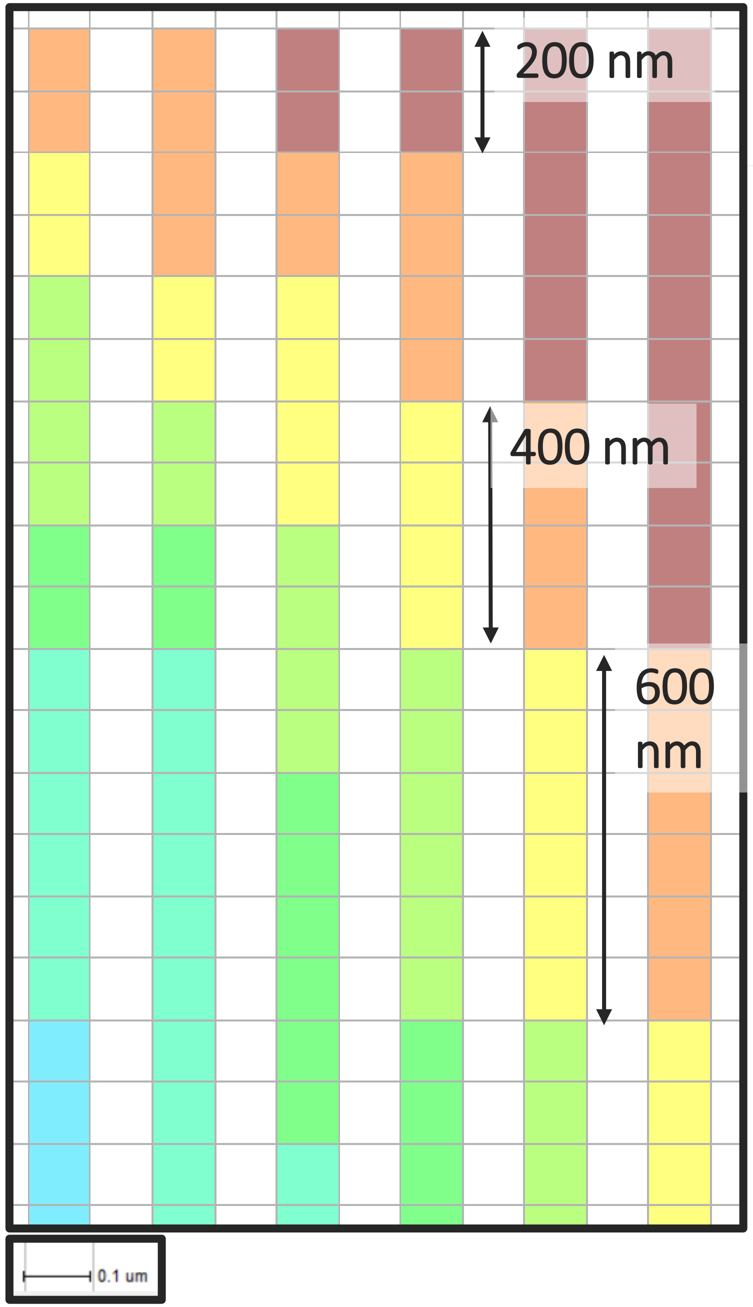
- The value should equal a multiple of the Beam Step Size

- Automatic mode determines the MFS based on the PSF.

PEC – Accuracy tab



Isodose Grid



MFS = 100 nm

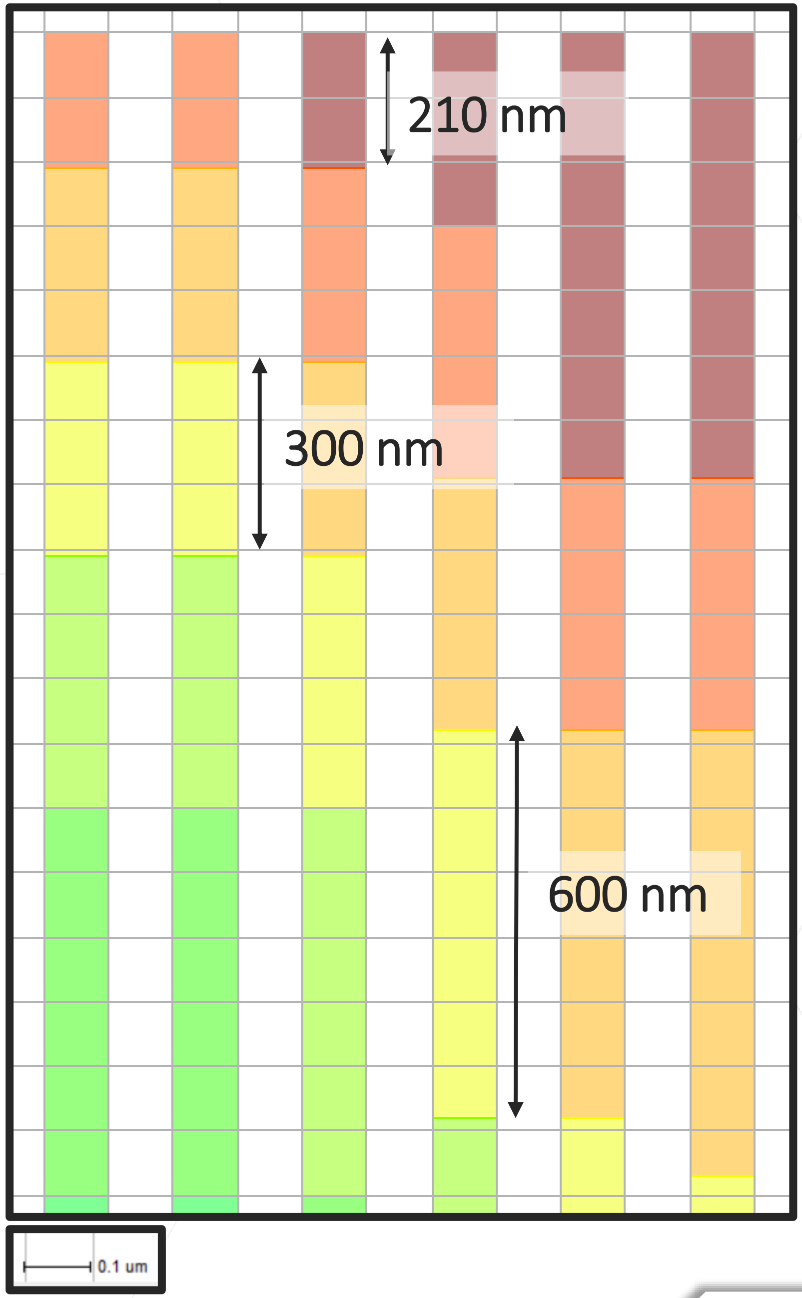
Isodose grid = 200 nm

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…

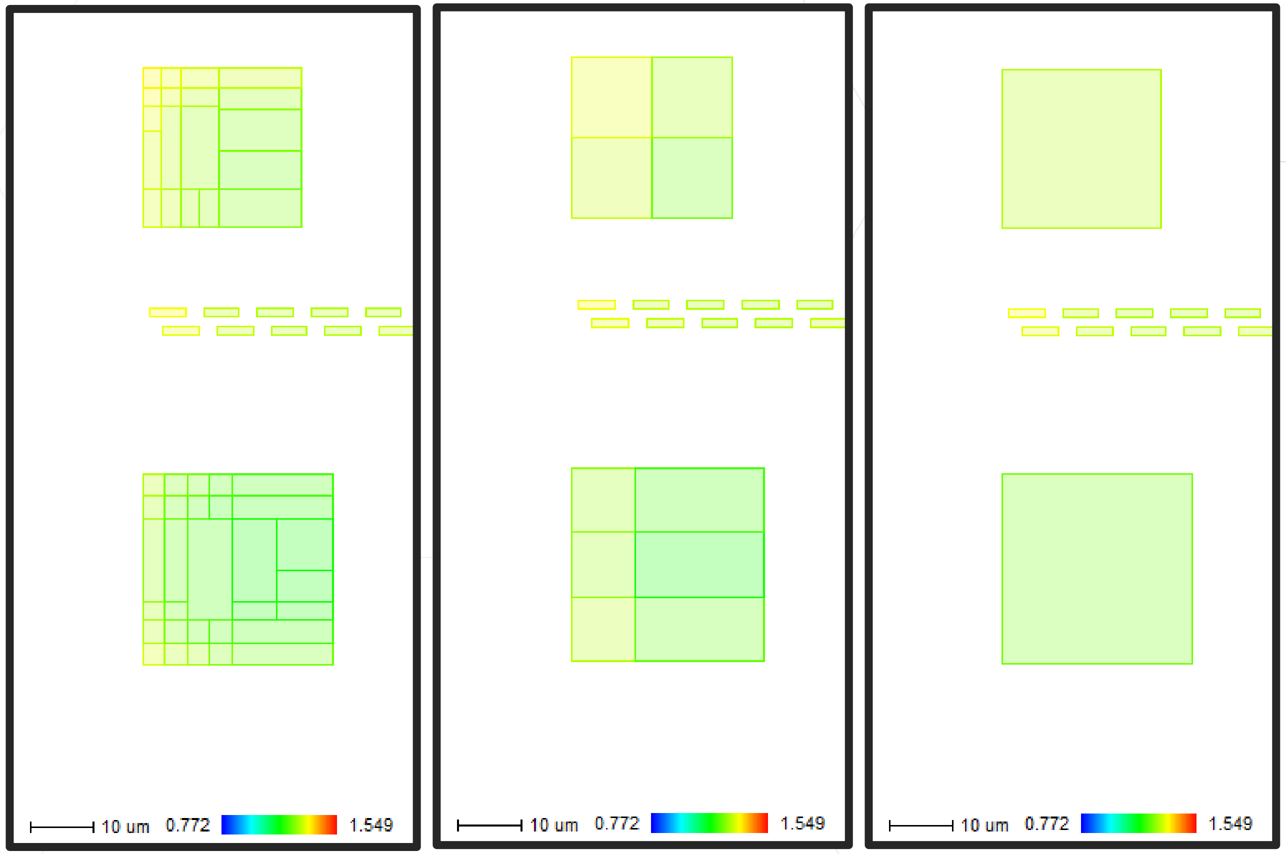
Minimum Figure Size

- 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

1 µm MFS
59 shapes

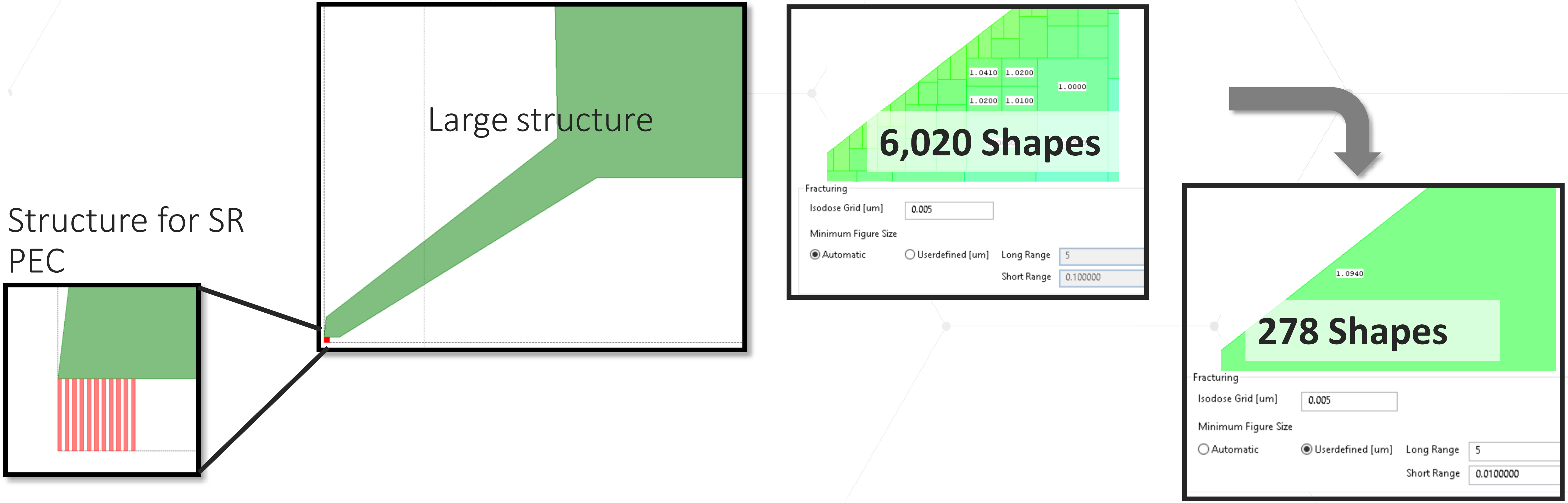
10 µm MFS
20 shapes

25 µm MFS
12 shapes



Fine fractures

- 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



Outline

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

Summary

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

Method	Benefits	Drawbacks
Decrease PEC accuracy	• Data volume ↓	• CD variance ↑ • Shape fidelity ↓
Increase PEC minimum figure size	• Data volume ↓	• Shape fidelity ↓
Layer Selective Long-range Fracturing	• Data volume ↓	• Additional pattern prep • Not fractured shapes may lose fidelity

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

BEAMER LAB TRACER MASKER ProSEM VIEWER