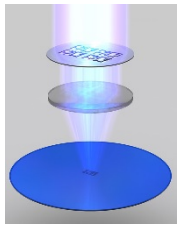
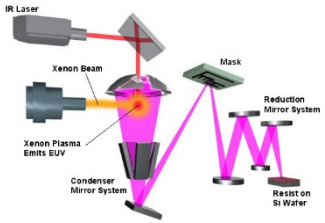
Mask Process Modeling in the Multi-beam Era

Managing Company Sponsor

D2S Patented Technology

One Model Form for All Masks

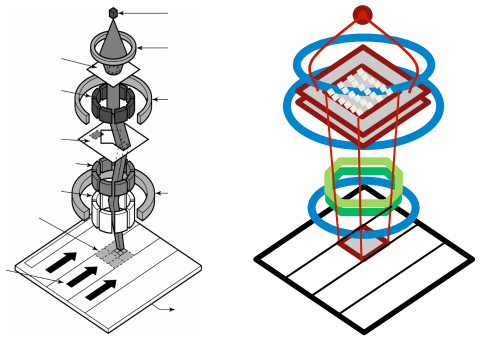




ArF or EUV

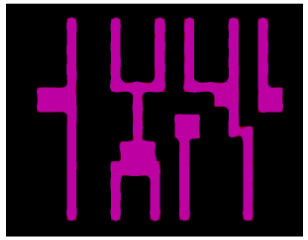
IMS Nanofabrication

NuFLARE



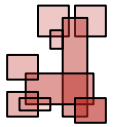
VSB or Multi-beam

One Model



1D or 2D Shapes

Overlapping Shots



Dose Modulation

Positive or Negative Resist

Questions About the New Mask-Writing Era

- What's different about the multi-beam era?
- What's the same?
- What do we need to consider when modeling a multi-beam system?
- Mask process modeling in the multi-beam era

What's different about multi-beam?

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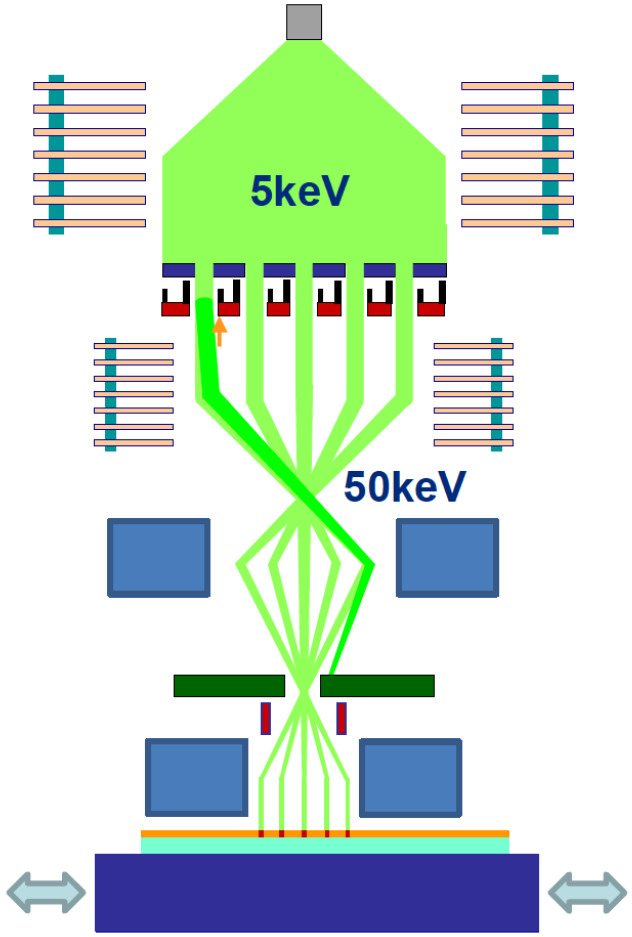
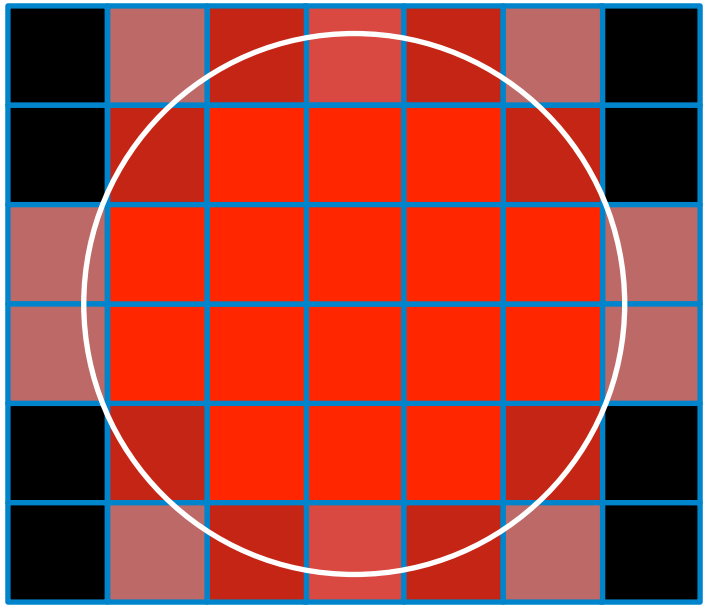
Multi-beam Uses Many Beamlets in Parallel

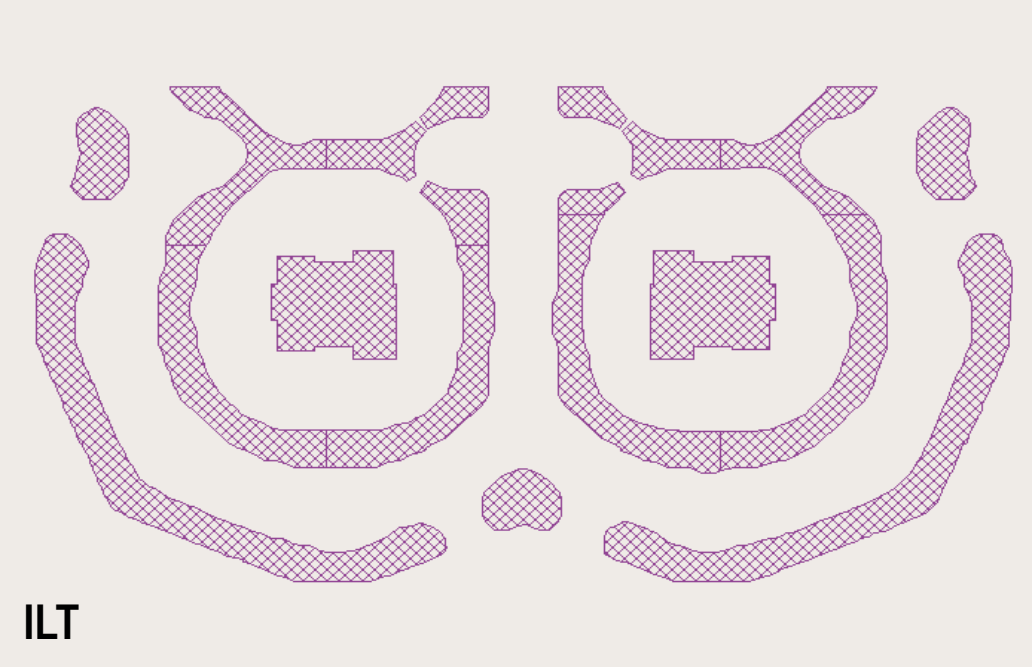


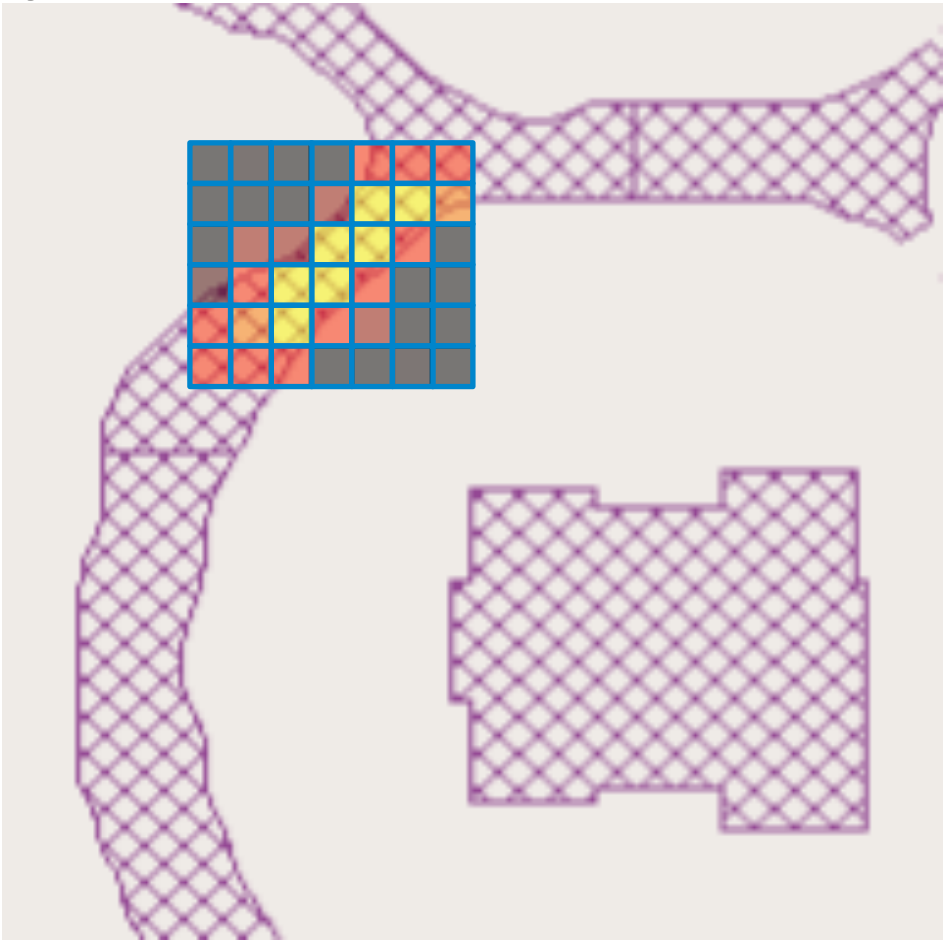
Source: IMS Nanofabrication



Huge Opportunity to Make Masks Great

- Any shape can be written in the same write time
- Dose profiles can be optimized





Multi-beam era moves us into the curvilinear domain!

What will remain the same?

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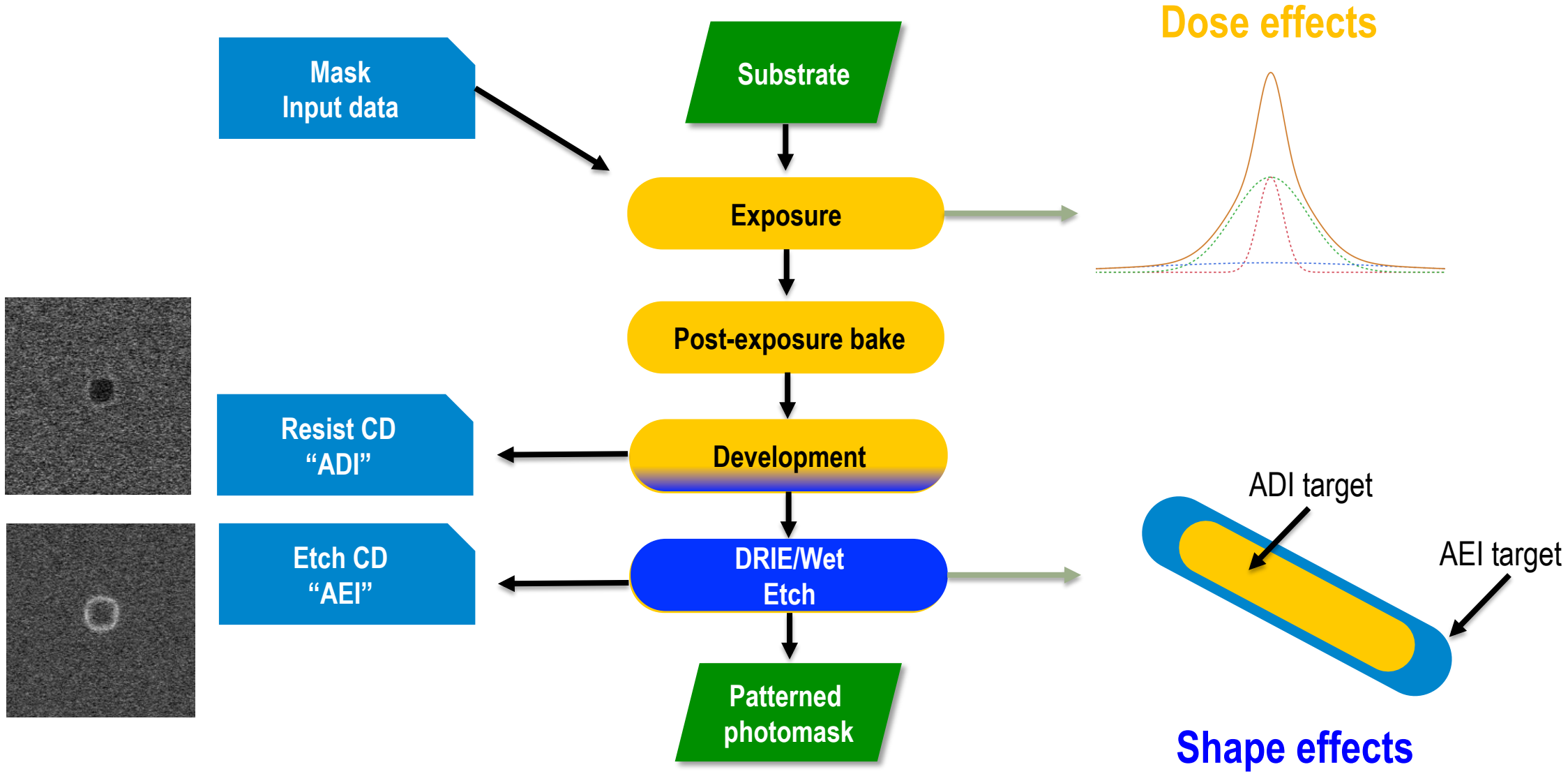
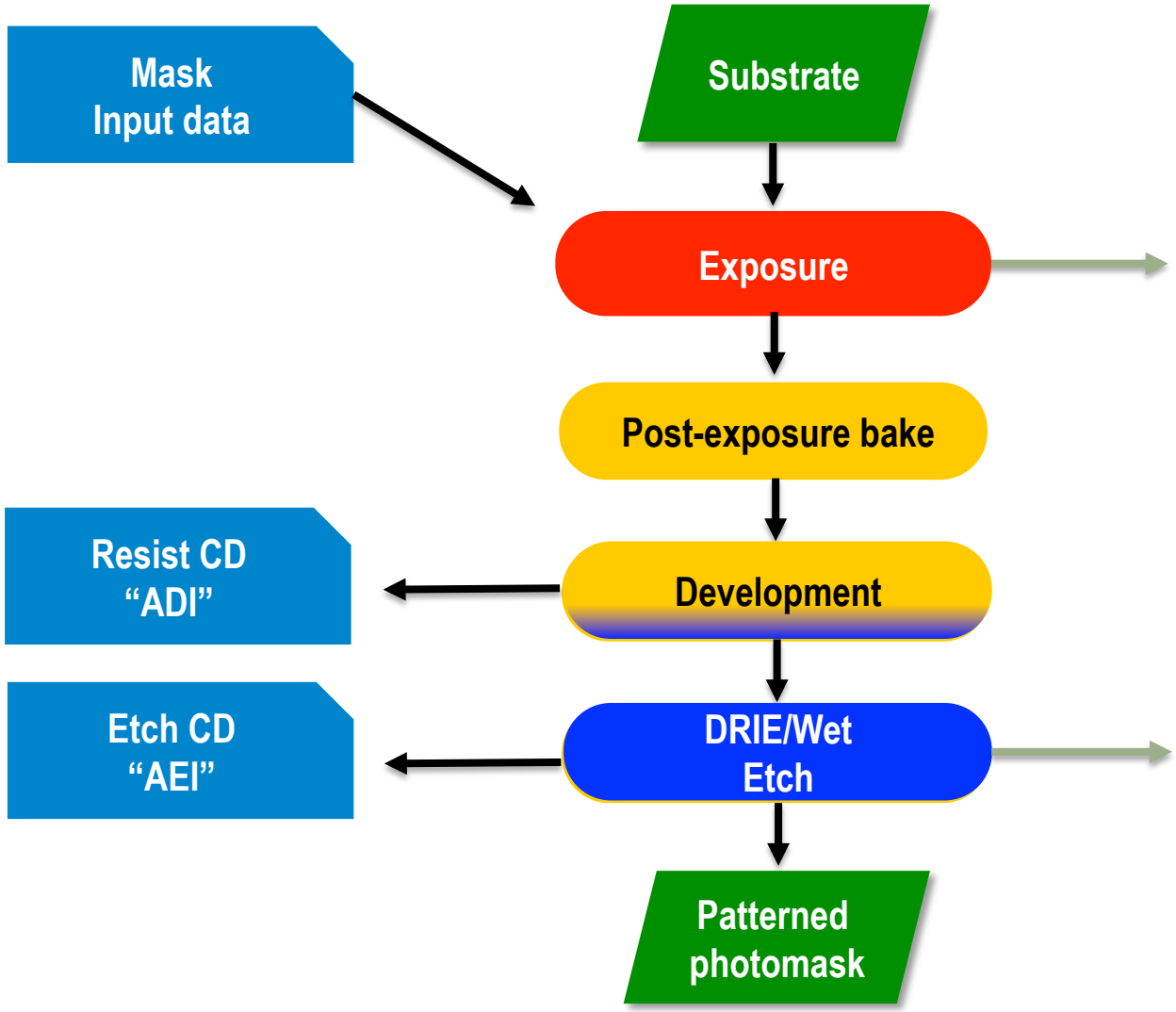
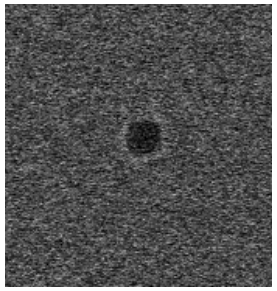
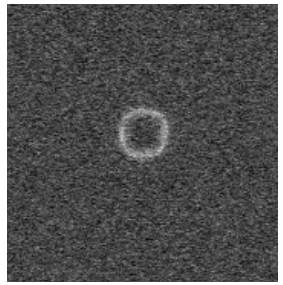
Mask Process Physics is the Same…



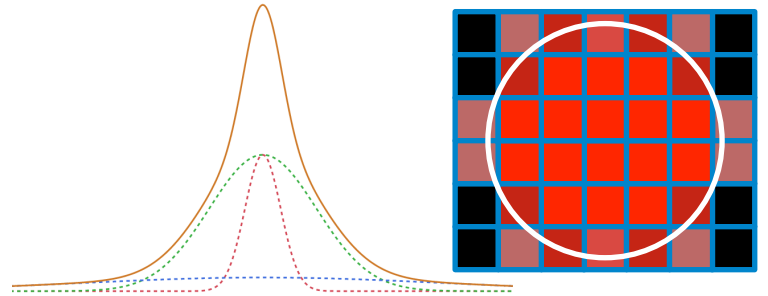
…Just More Complex

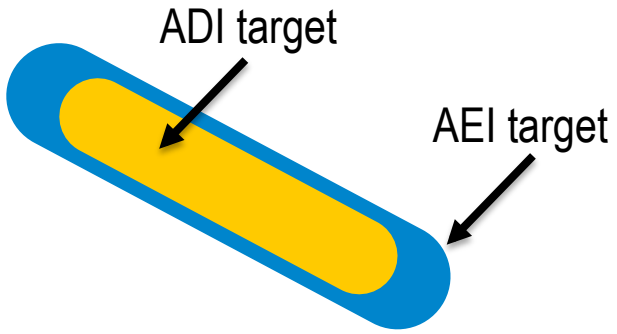






Dose effects





Shape effects

What do we need to consider when modeling a multi-beam system?

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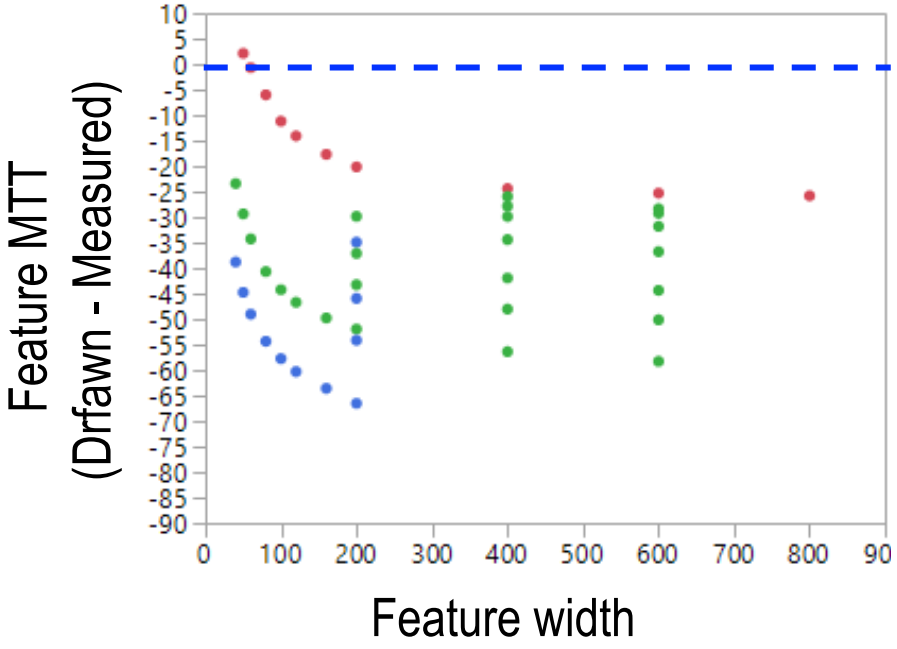
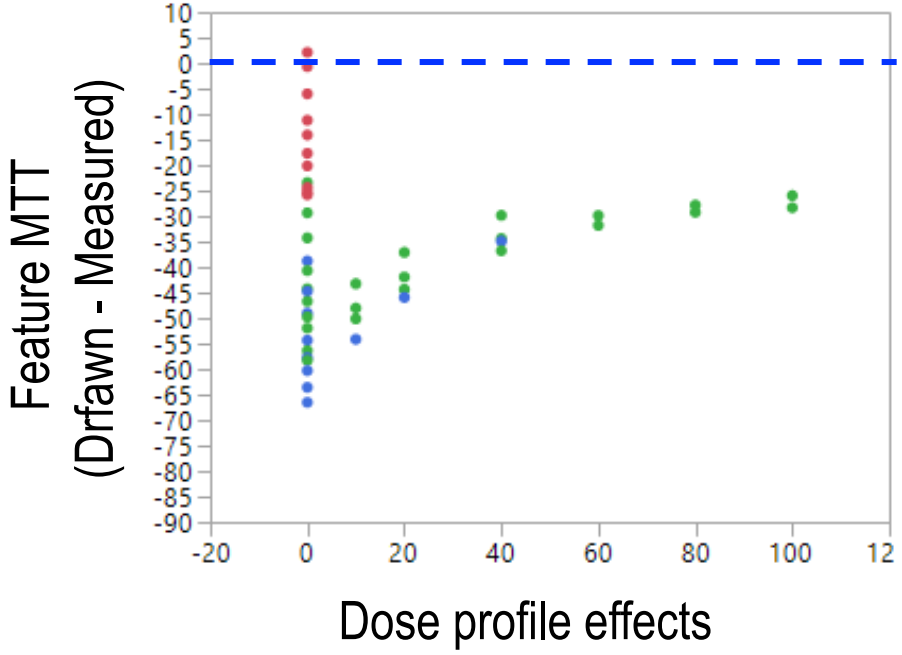
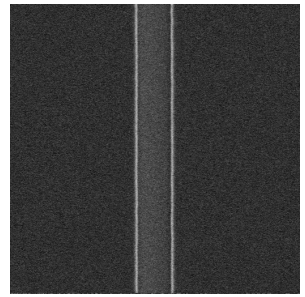
Printed Mask Data Contains Both Shape and Dose Effects



Shape (etch) bias
AND
Dose linearity



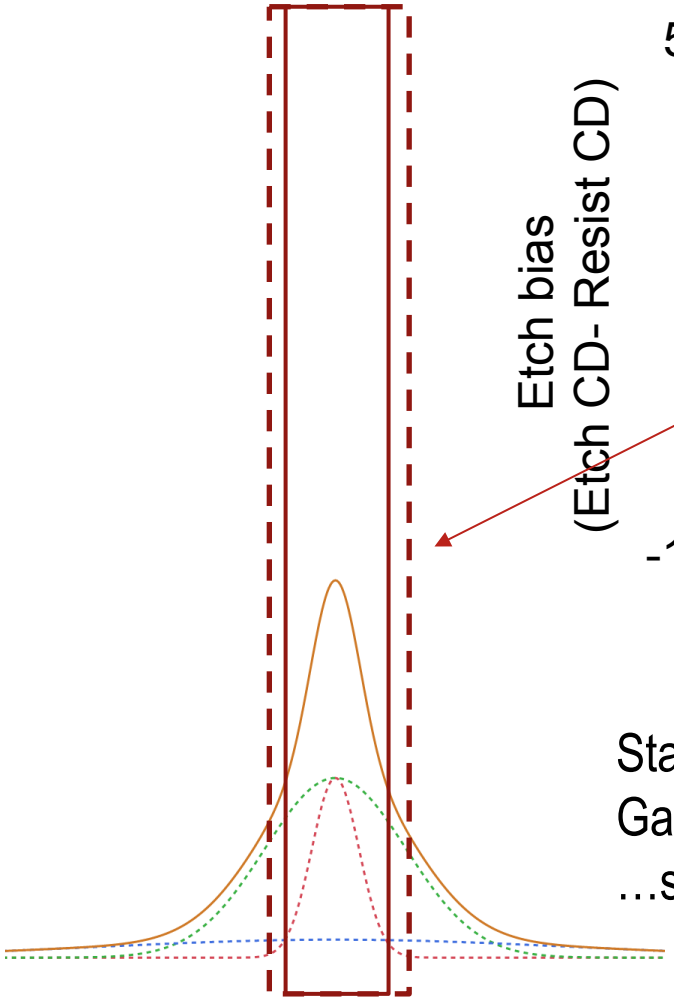
Only dose effects

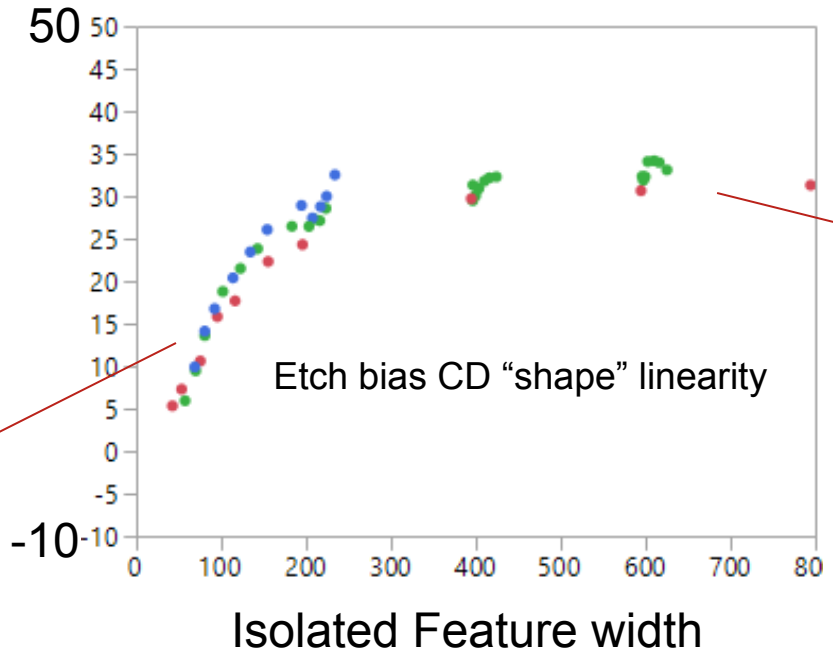


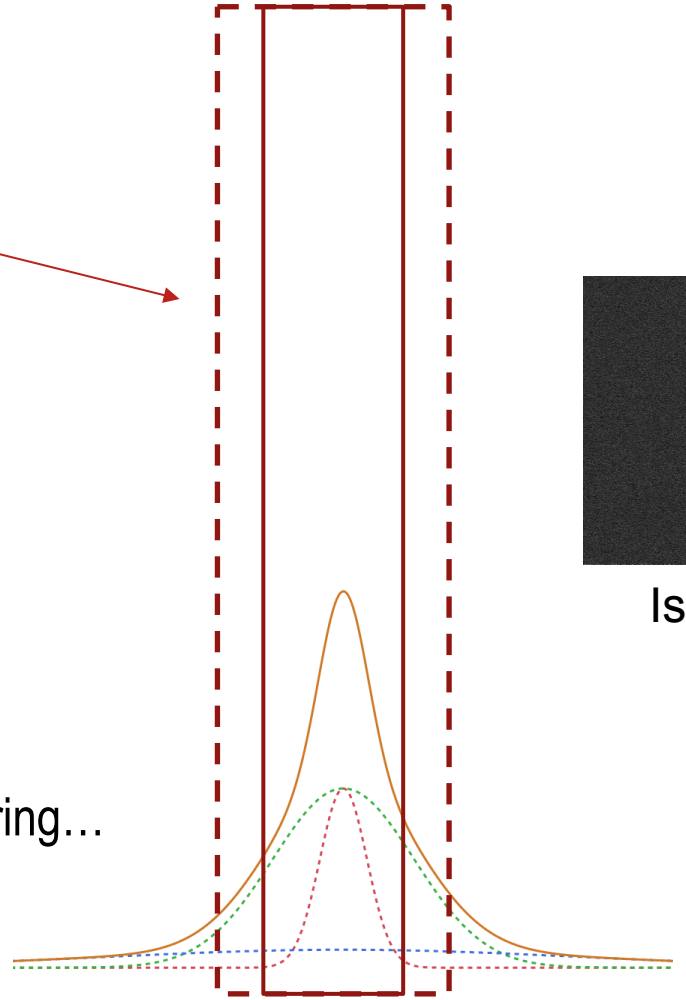
Iso Lines

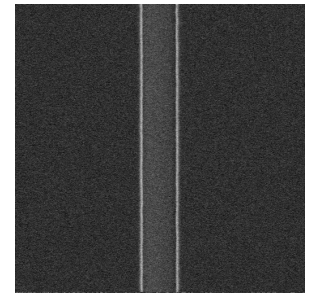
We need to separate dose from shape effects!

Today: Dose Models Used for Shape Correction









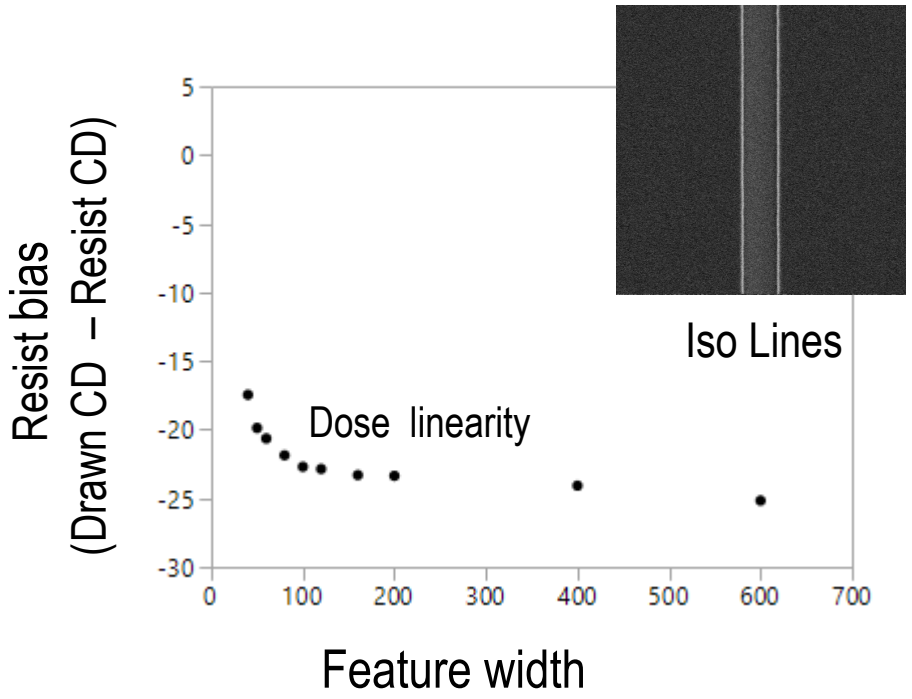
Iso Lines

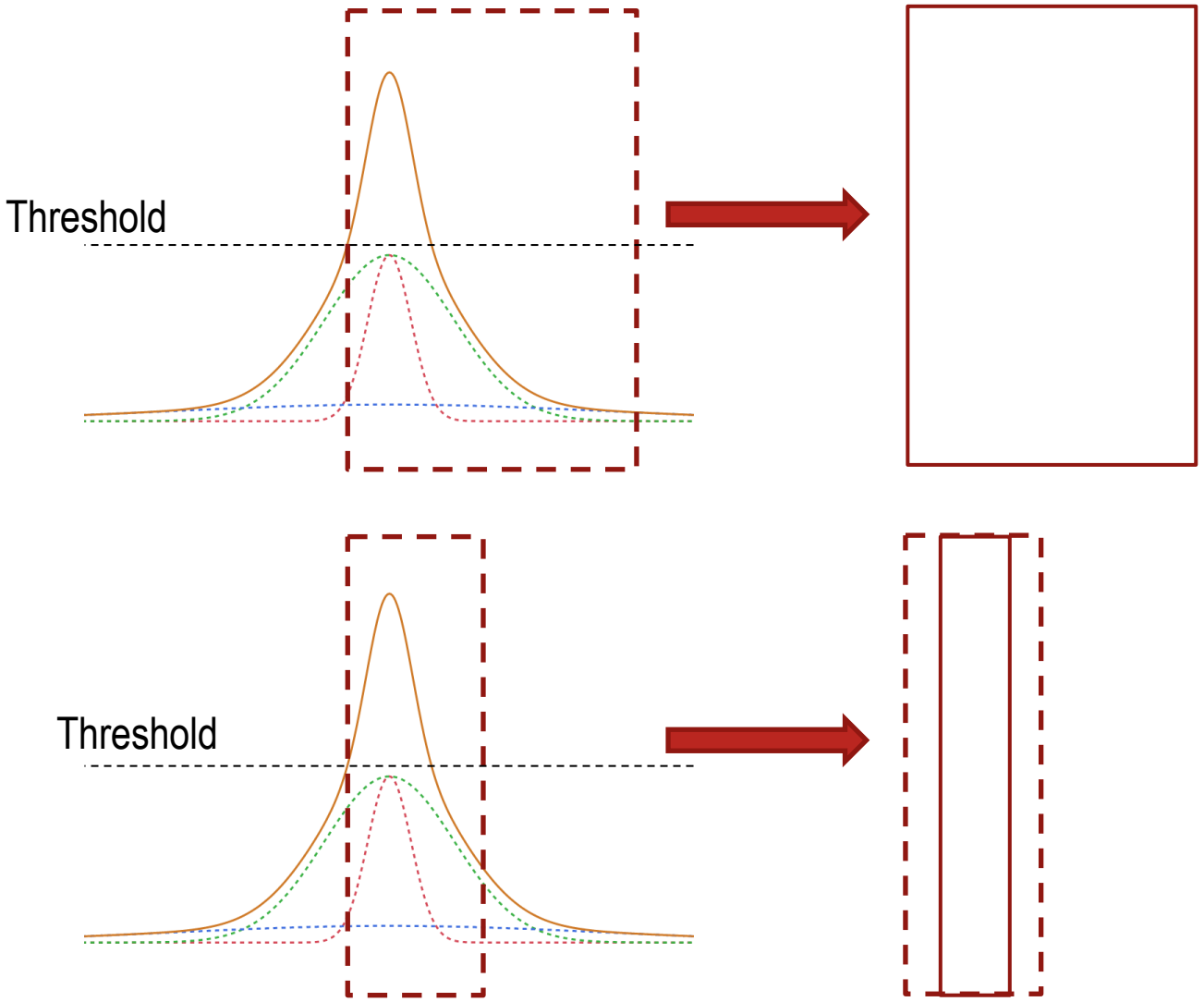
Standard model uses Gaussians to model this
Gaussians are intended to emulate dose scattering…
…shape correction may no longer be valid

Small feature bias

Large feature bias

Dose: Needed to Correct for Resist Effects

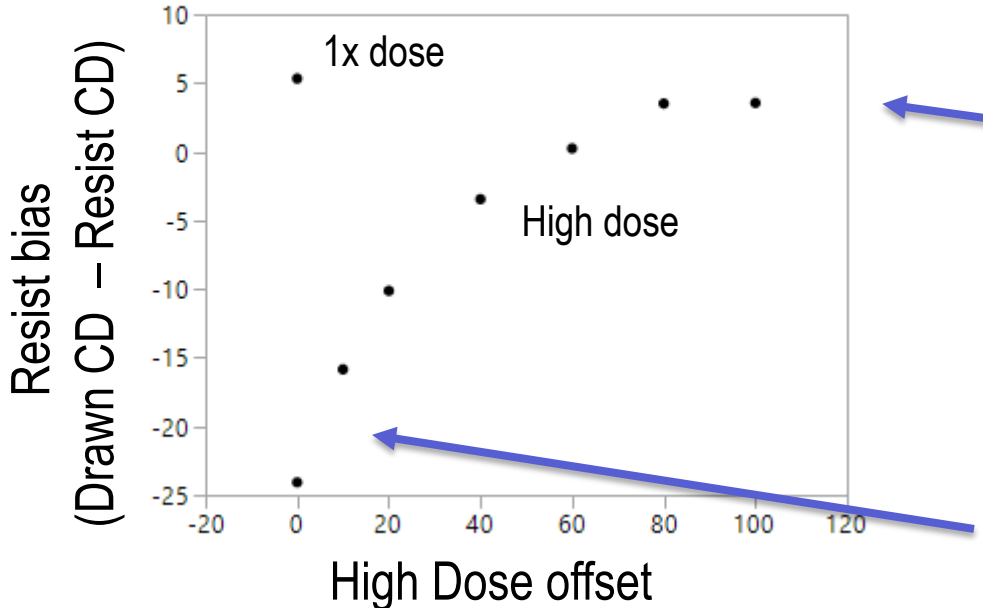


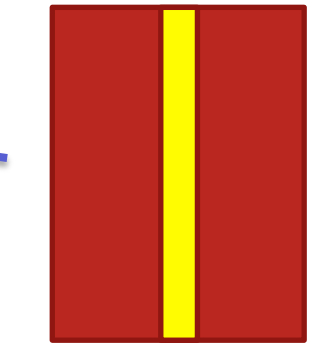


Linearity: scattering kernels larger than width of the features

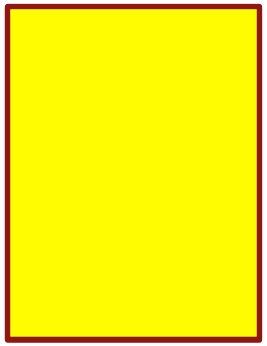
In the standard 3G model, these effects are degenerate with the variable etch bias

Also Needed for Complex Dose Manipulation



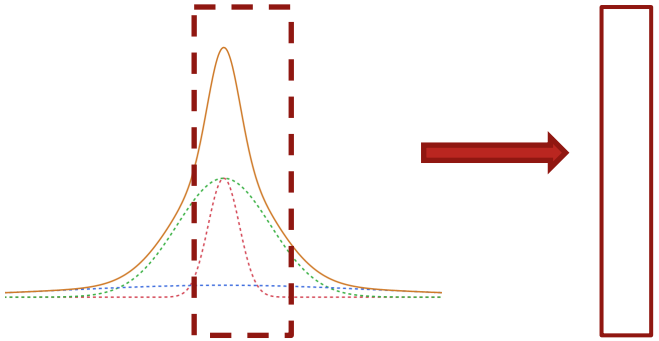


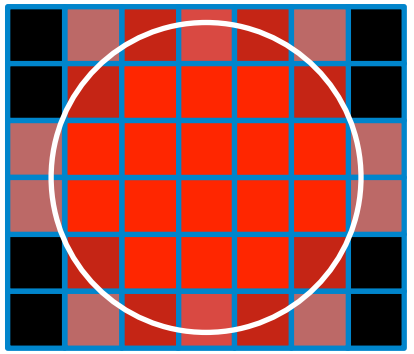
High dose far from printed edge
Behaves like 1x dose



High dose @ printed edge

Linearity effect = scattering kernel larger than feature size

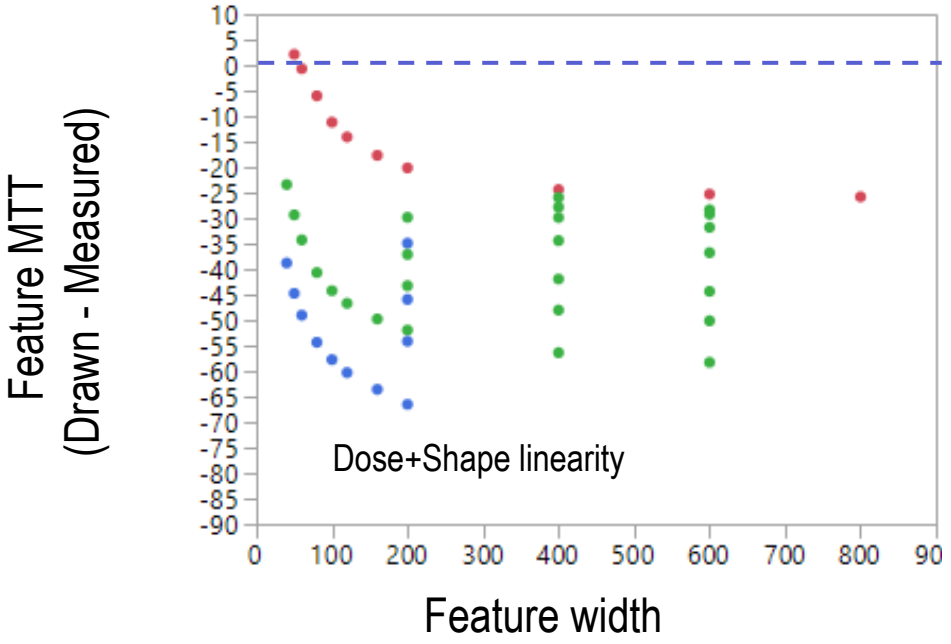


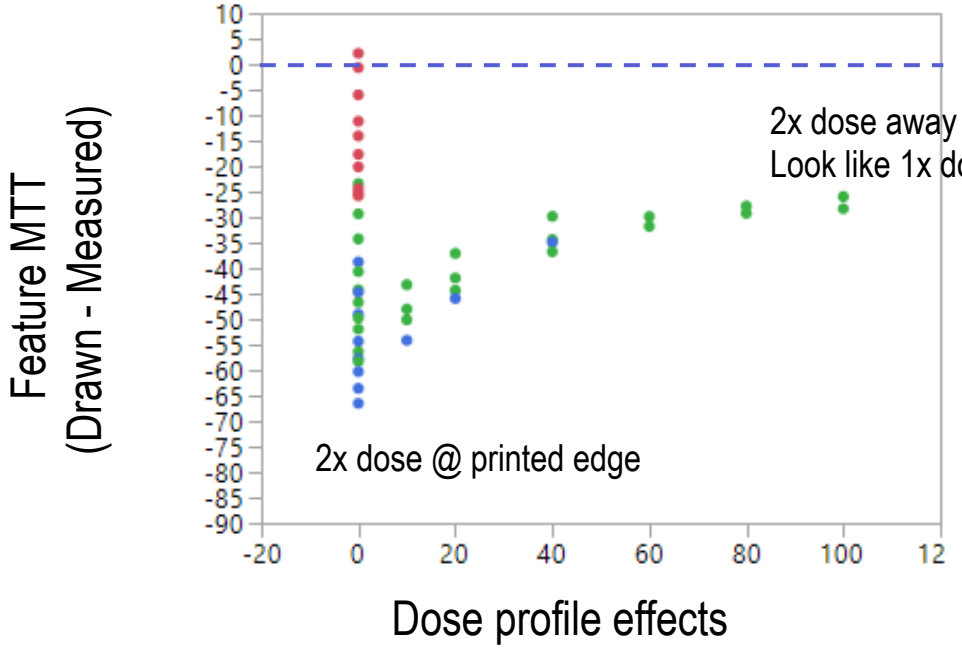


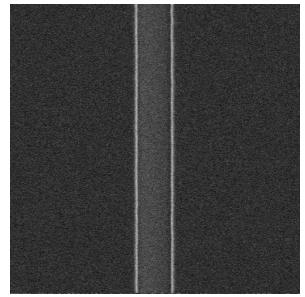
Complex dose profiles = many small features
Precise details of the dose model matters more

Printed Mask Data Contains Both Shape and Dose Effects

Non-zero y-axis values mean: mask print errors if uncorrected







Iso Lines

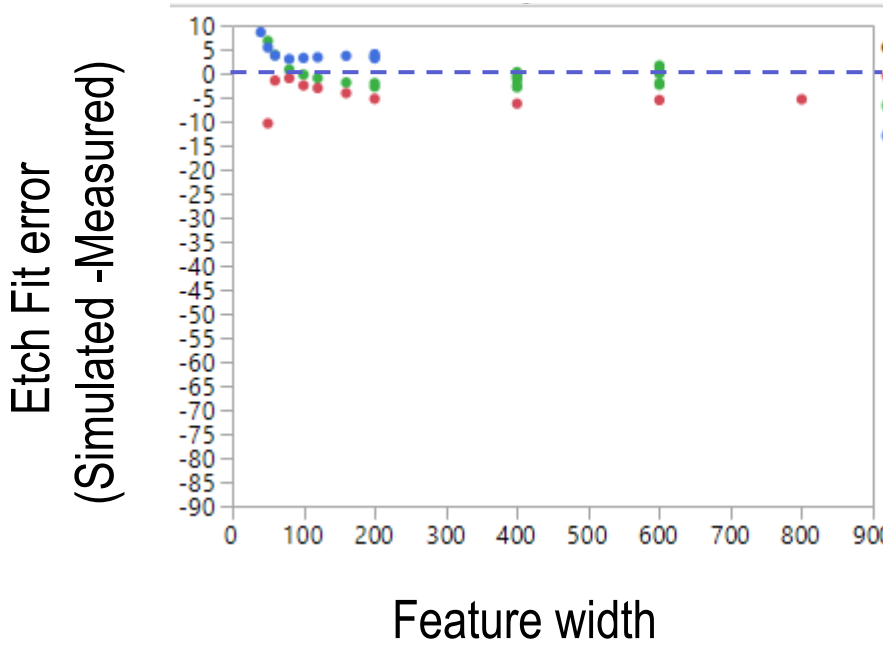
Shape (etch) bias
AND
Dose linearity

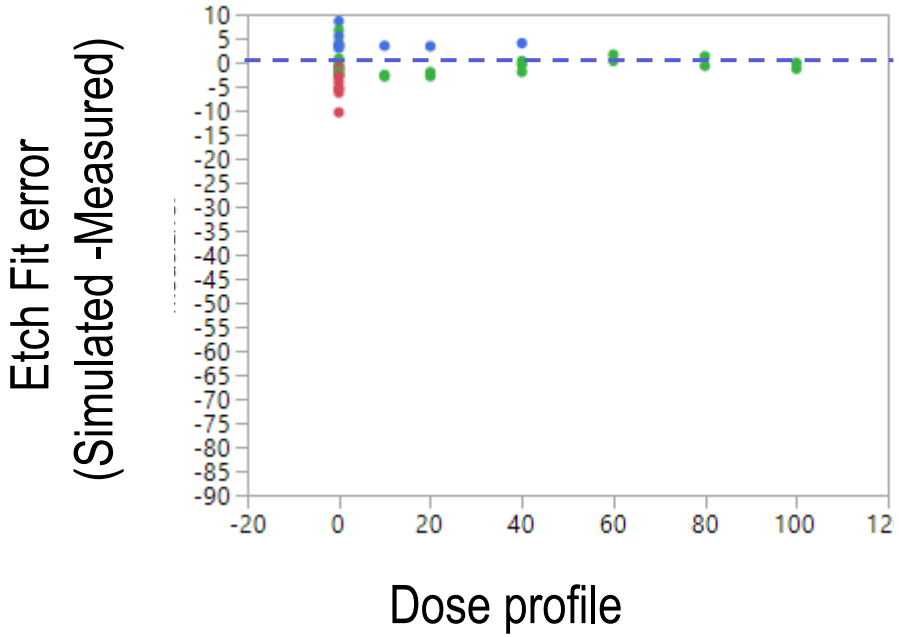
Only dose effects

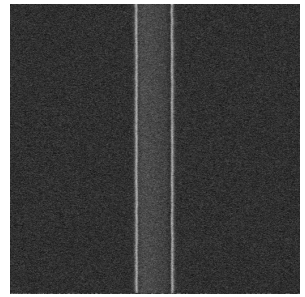
Test structures needed to separate dose from shape effects!

Today's Simple Models are not Sufficient

Non-zero y-axis values mean: mask print errors from model







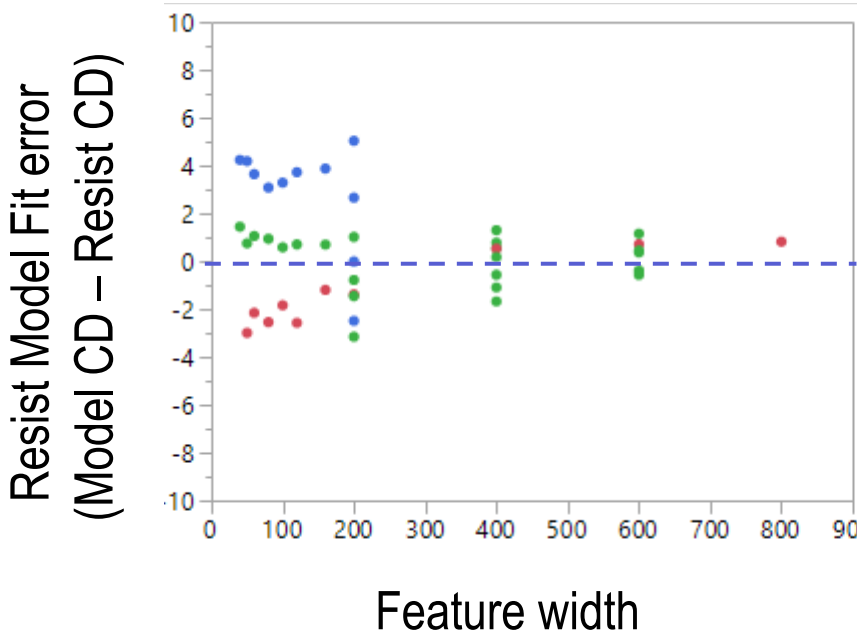
Iso Lines

Best fit "3G + constant threshold" model: Still 14nm of error!

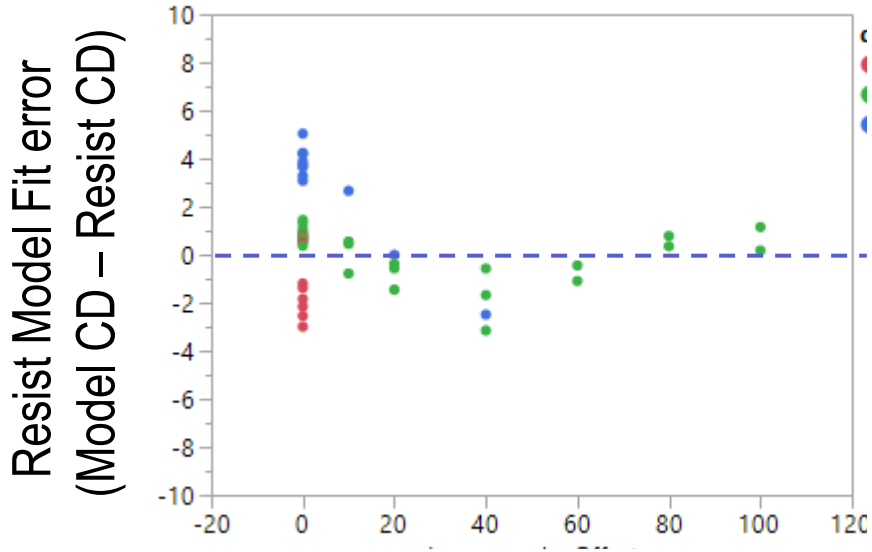
- Fit overcompensates for the dose profile effects (3x dose)
- Fails to fully compensate for the small CD effect
- Demonstrates broken shape and dose degeneracies in the multi-beam era

Standard 3G Models Do Not Predict Resist Data

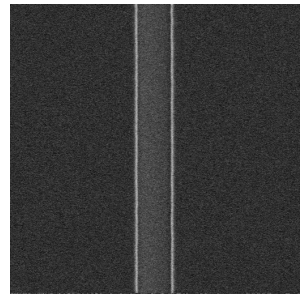
Non-zero y-axis values mean: mask print errors from model



Feature width



Dose offset



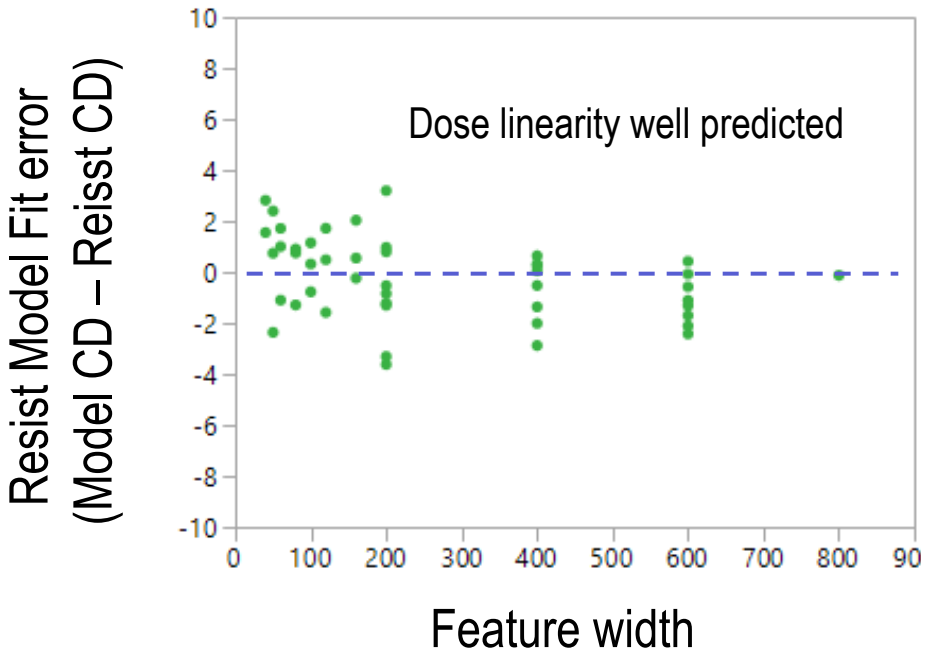
Iso Lines

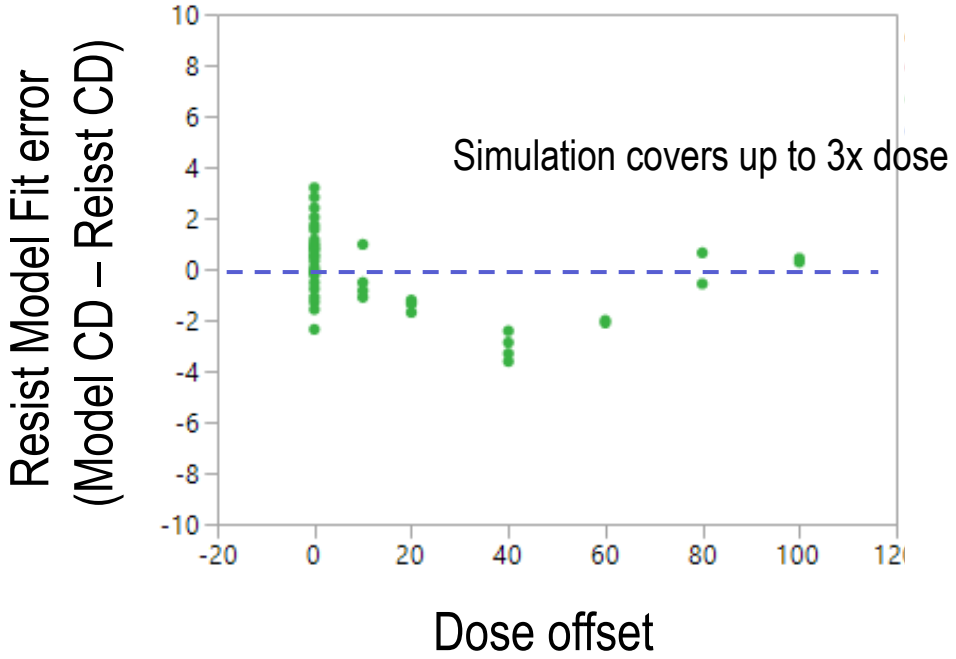
Best fit “3G + constant threshold” model

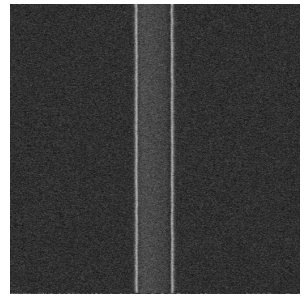
- Better, but still does not meet requirements
- Overall dose trends better
- Remember: there is more physics than simple scattering terms…

Dose-Specific Physics are Required

Non-zero y-axis values mean: mask print errors from model





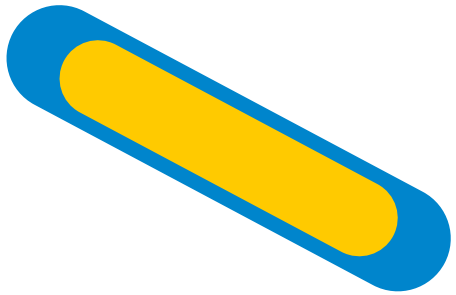


Iso Lines

It is possible to make more physical models that meet desired tolerances
Just need to add the correct physics.

Multi-beam Era is More Complicated

VSB	Multi-beam
Dose profiles are “simple”	Dose profiles will be complex
Typically only “1” or “2” doses to worry about	Many dose values to predict
Can use dose terms <n>G to assist bias terms.	Dose terms no longer degenerate to Etch terms; more complex dose models are needed
Etch done on rectilinear shapes	Etch needs to be done on curvilinear shapes



Bias models based on 1D data are under-constrained

Shape effects depend on:

- Open area “shadowing”
- Local pattern density “loading”
- Local radius of curvature

A good etch model needs to encompass a wide variety of 2D features

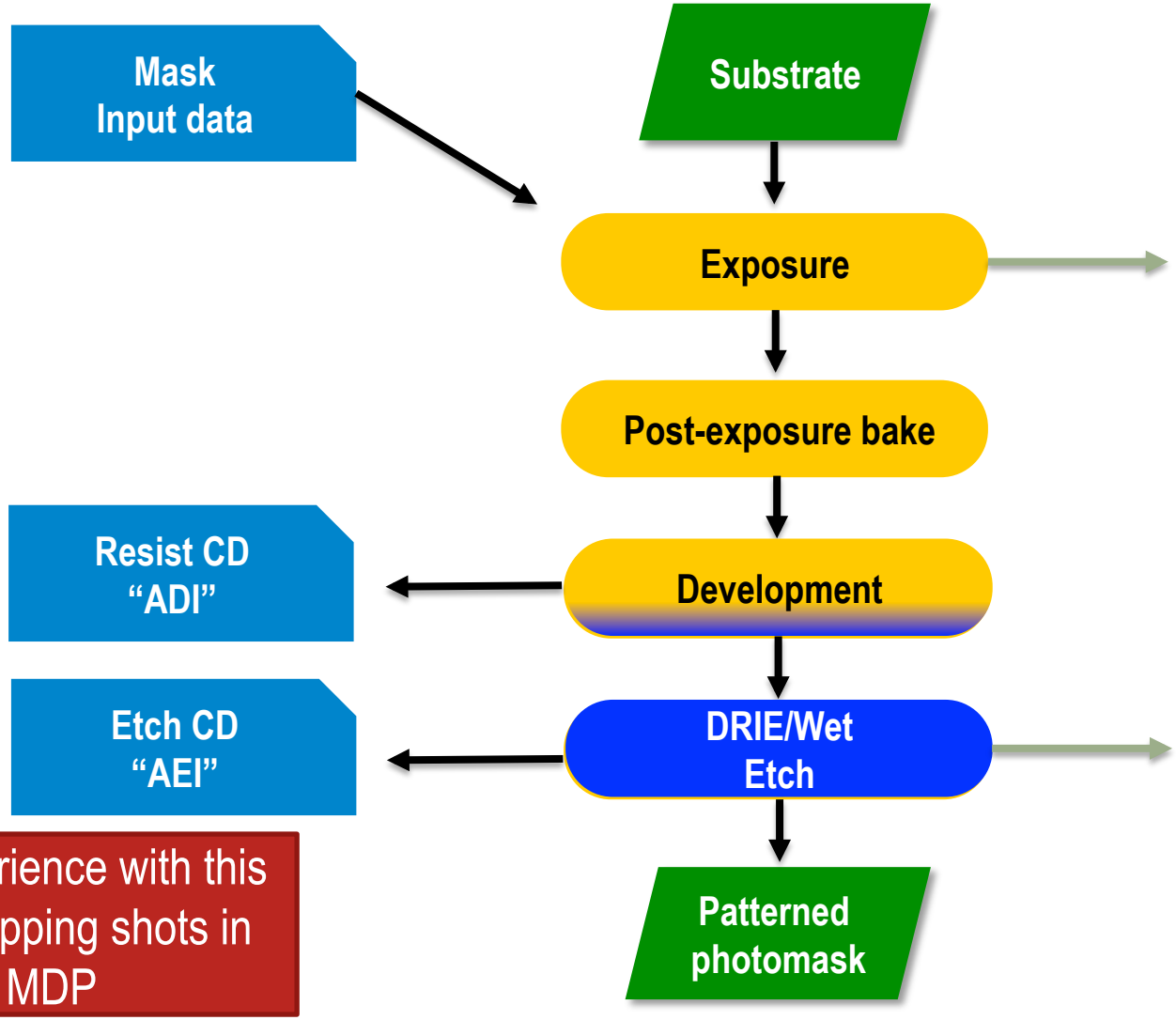
TrueModel® Mask Modeling for the Multi-beam Era

D2S Patented Technology

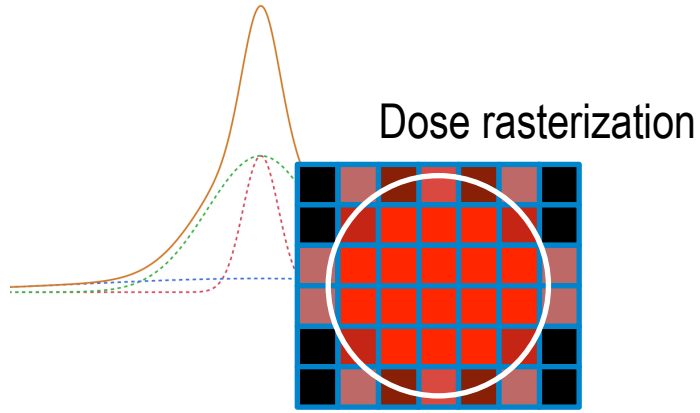
Multi-beam Era Requires Dose + Shape Models

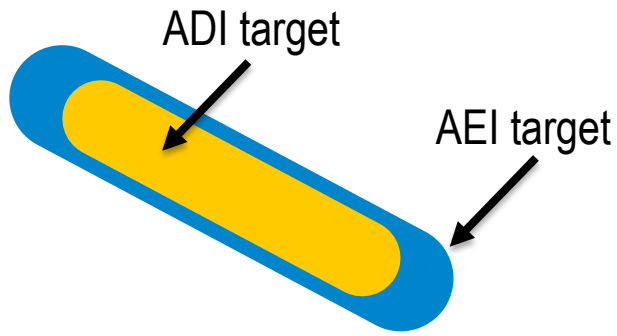
- The underlying physics is the same for VSB and multi-beam systems
  - We *do* need to start paying attention to the dose profiles
  - We *do* need to augment the simple shape effect model.
  - Challenge: isolate and model both dose and shape effects
- We do need to ensure a dose-aware model
- We will need to model this on curvilinear systems
- TrueModel has a test chip ideally suited for the new regime

TrueModel Understands Dose/Shape Separation



Dose effects



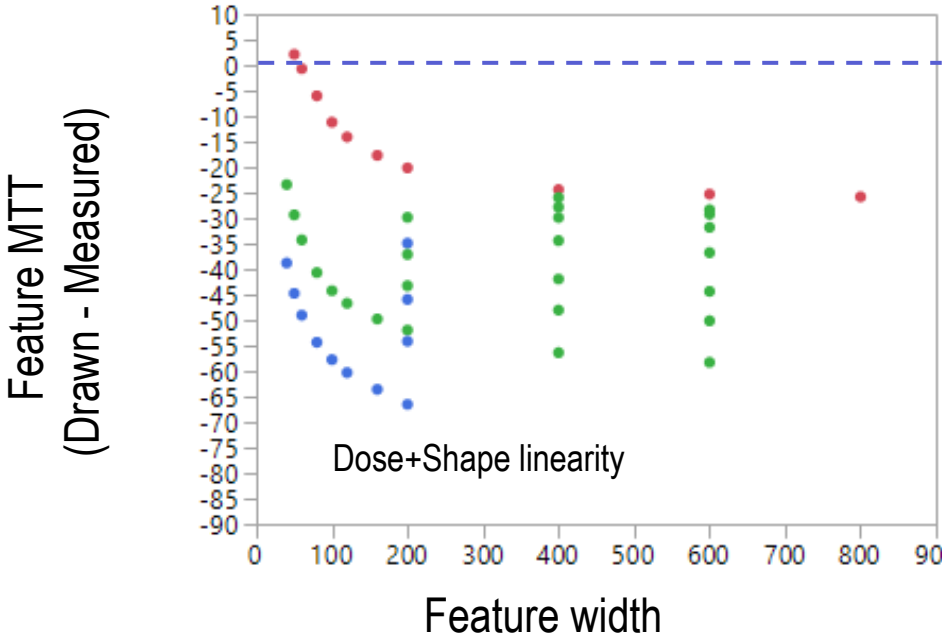


Shape effects

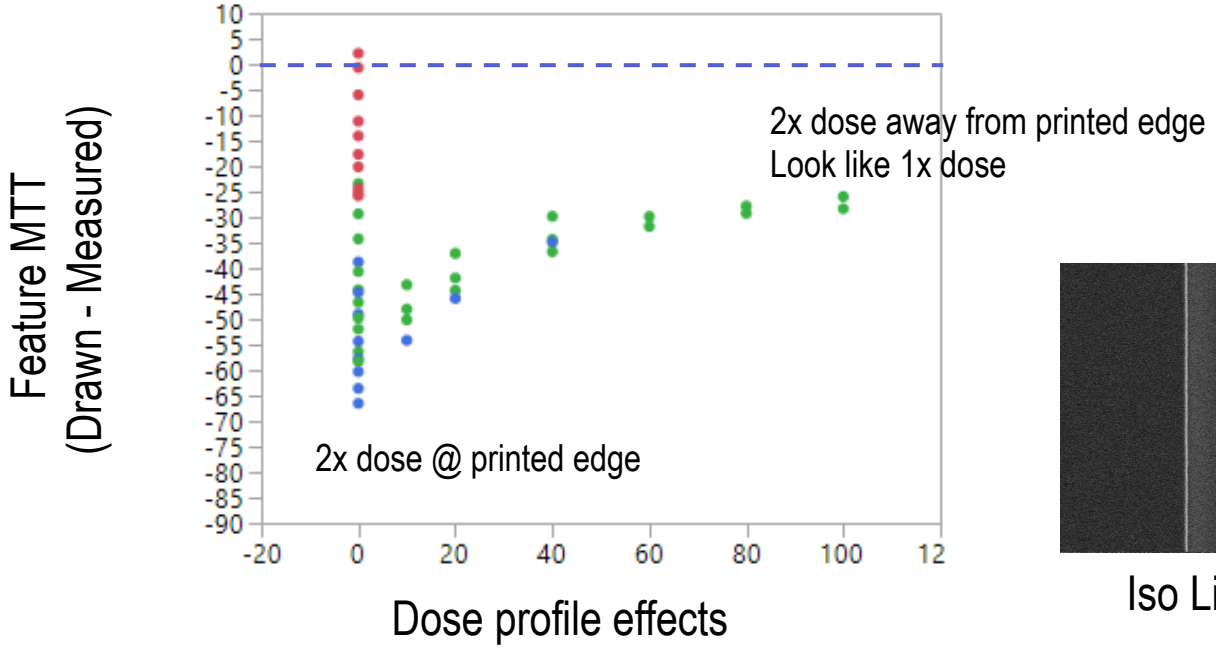
TrueModel has experience with this for predicting overlapping shots in TrueMask® MDP

Printed Mask Data Contains Both Shape and Dose Effects

Non-zero y-axis values mean: mask print errors if uncorrected



Shape (etch) bias
AND
Dose linearity



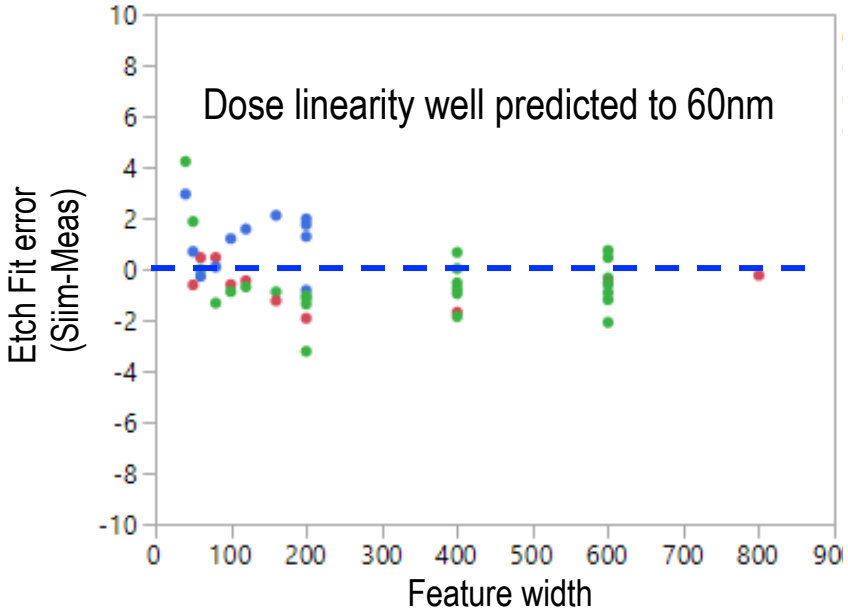
Only dose effects

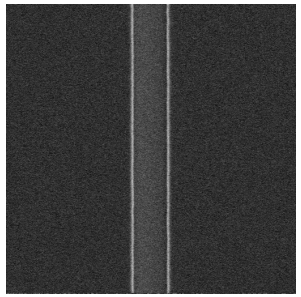
Iso Lines

Test structures needed to separate dose from shape effects!

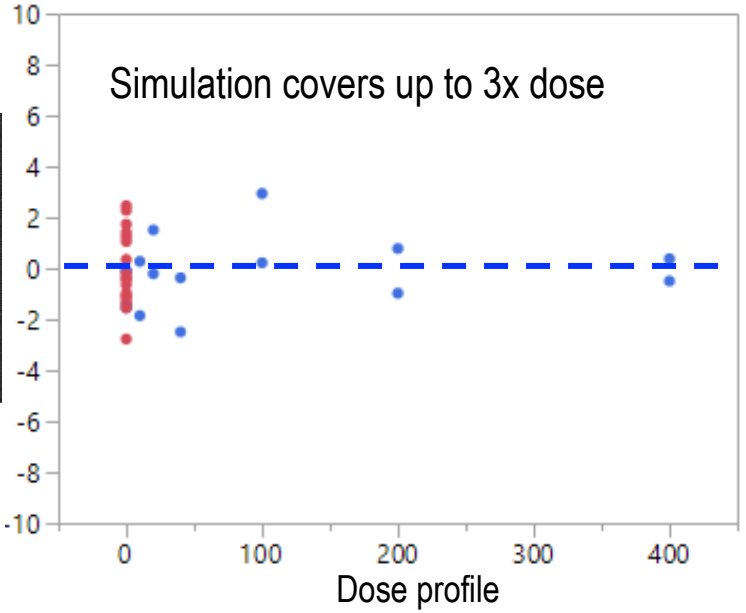
TrueModel Predicts Shape Effects and Dose Effects Simultaneously

TrueModel results based on dose profile to resist data. 90nm of MTT can be brought to +/-2nm

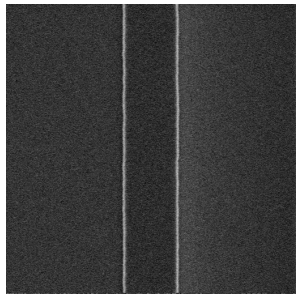




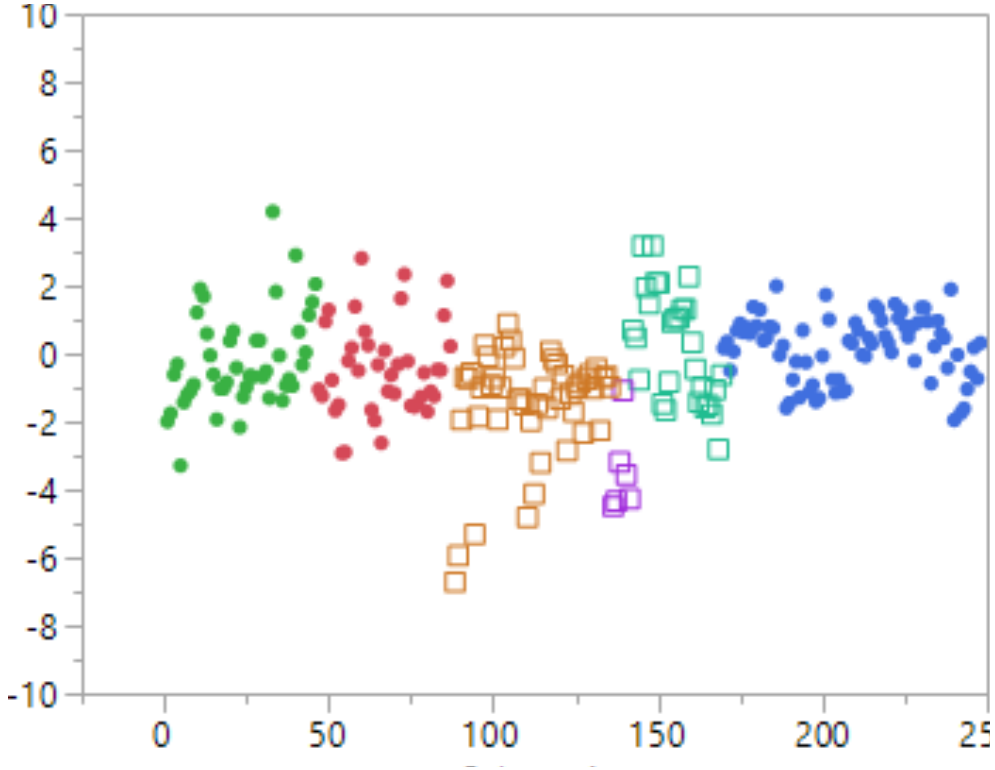
Iso Lines

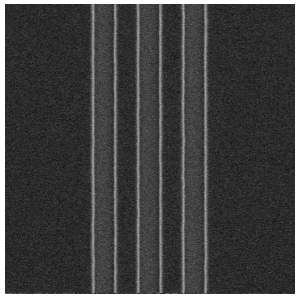


TrueModel Predicts Both Shape and Dose Effects



Iso Spaces



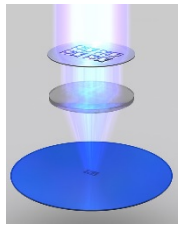


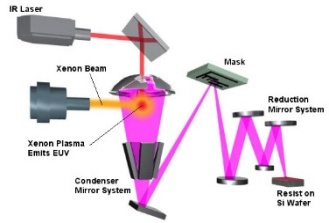
Three Lines

TrueModel results based on dose profile to resist data. 90nm of MTT can be brought to +/-2nm

Model fit summary, including calibration data (circles) and prediction data (squares)

TrueModel is Ready for the Multi-beam Era

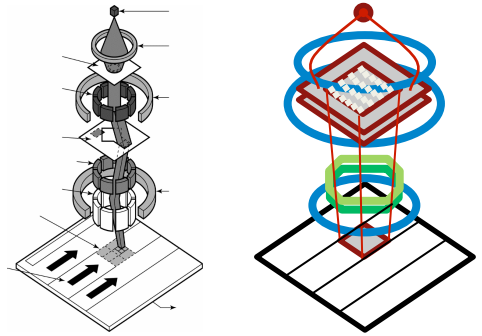




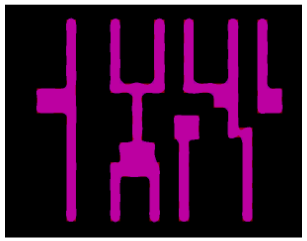
ArF or EUV

IMS Nanofabrication

NuFlare



VSB or Multi-beam

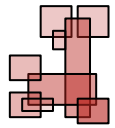


1D or 2D Shapes

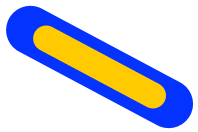
TrueModel

Positive or Negative Resist

Overlapping Shots



Dose Modulation



Shape-based Effects

Modeling results correctly separate shape effects from dose effects…independent of tool


D2S