EUV Resist stochastics: some measurements and thoughts

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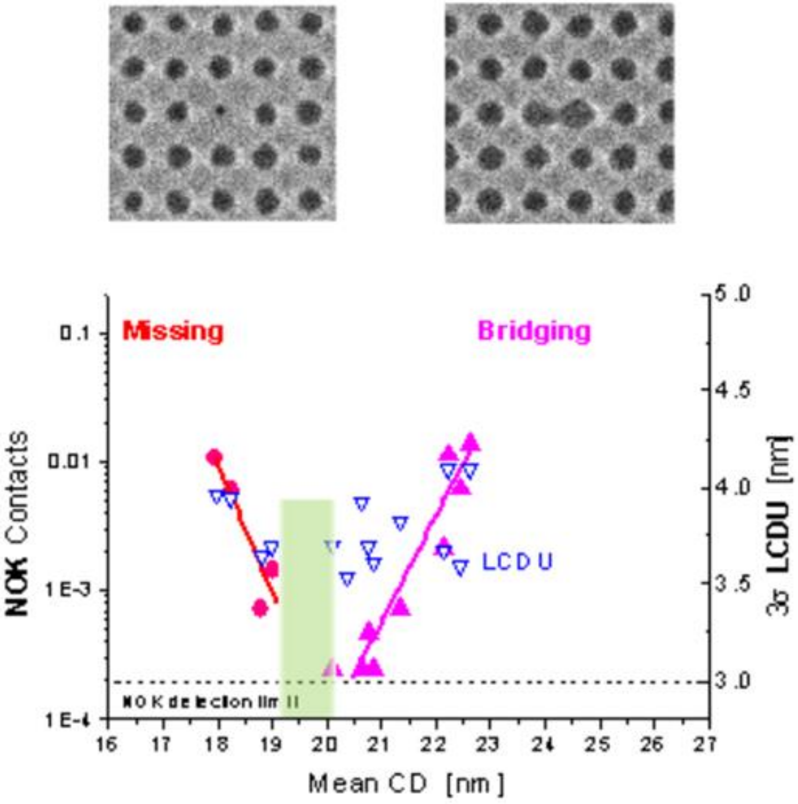
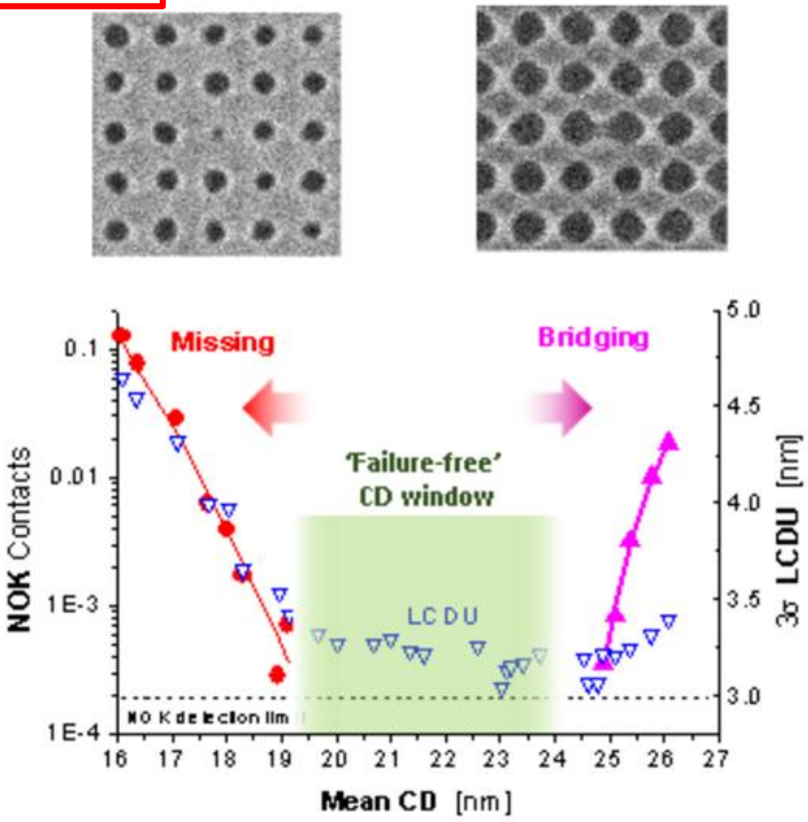
Failure rate for contacts is ~ 10^{-4} !

Stochastic effects in EUV Lithography: random, local CD-variability and printing failures

Peter De Bisschop
imec, Kapeldreef 75, B-3001 Leuven, Belgium
JM3 2017



36×36 nm



40×40 nm

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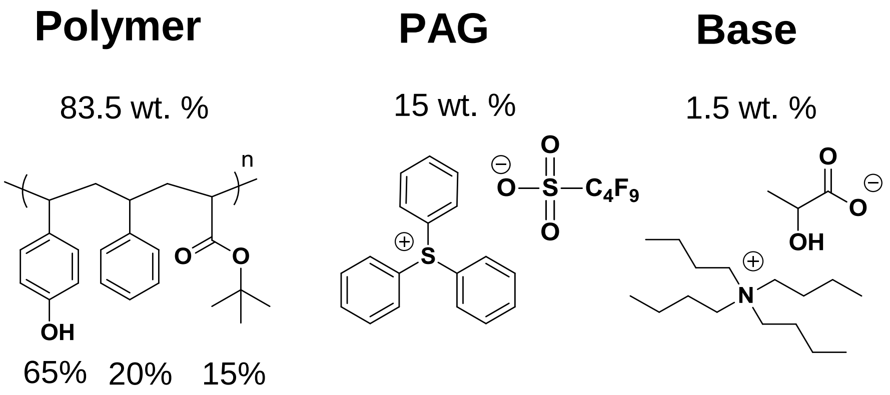
Measurement of OS4 resist



OS4 formulation

From our experiments for this resist (OS4)

- Film PAG/volume is 0.2 PAG/nm^3 (15 wt% TPS Nf)
- Film base/volume is 0.033 base/nm^3 (1.5 wt% TBAL)
- Dose to clear is 5.7 mJ/cm^2
- Optical density is 4.9 μm^{-1}
- Number of photos absorbed/volume at clearing 0.017/nm^3
- Number of acid/volume at clearing is 0.037/nm^3
    - about 20% of original PAG -> acid at clearing
    - average spacing between acid is 3 nm at clearing

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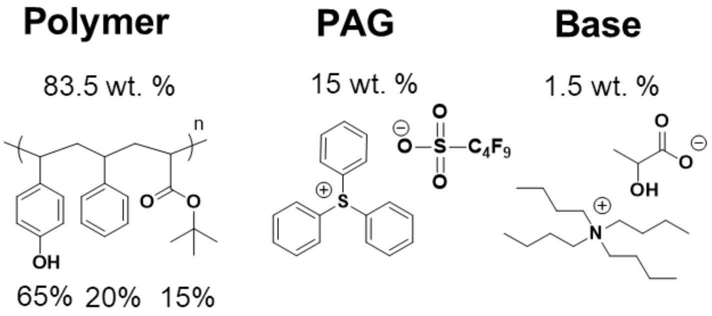
Analysis of stochastics of OS4 resist

For a 36 nm contact, in a 30 nm thick film
there are 30,000 nm^3 containing on average:

- 6,000 PAG
- 1,000 base
- **530 photons absorbed**
- 1,100 acids generated



OS4 formulation

For independent events (photons absorbed), they will follow Poisson statistics
Then, the standard deviation in the number of photons absorbed will be the square root of the expected number of photons absorbed, $\sigma = \sqrt{N}$

The actual statistical fluctuation of reactions within each contact will be worse than simply the fluctuations in the number of photons absorbed, but the photons statistics will be the largest contributor, so we'll simplify and only look at photon statistics

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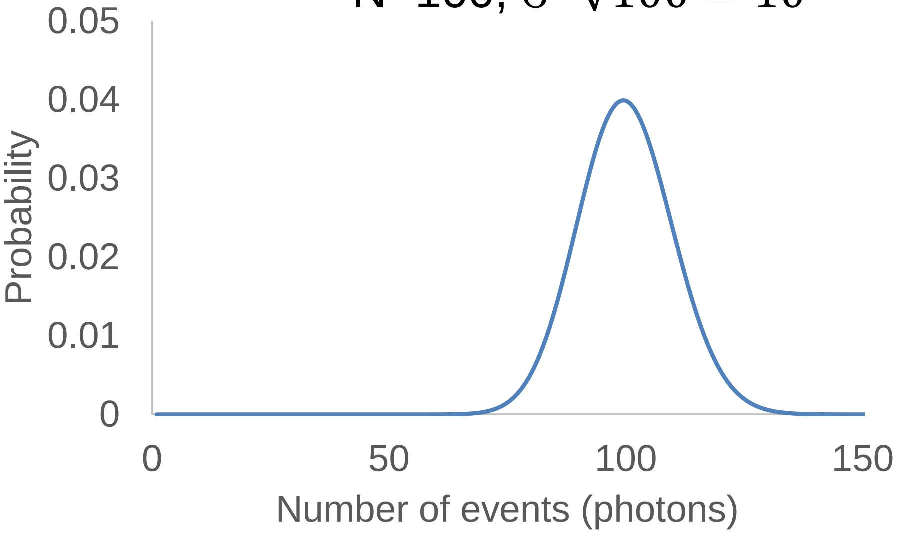
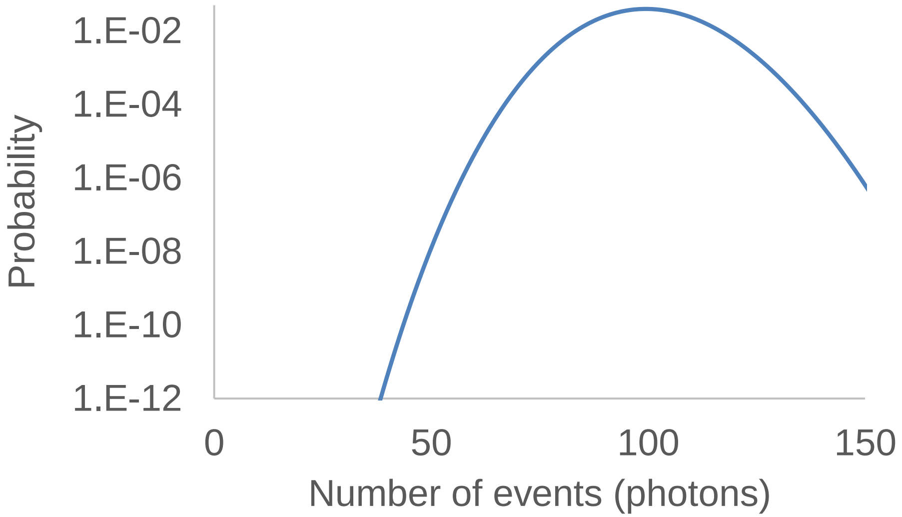
Poisson distribution

$\overbrace{1+1+1+1+1+1+1+1 \ldots}^{\text{N events on average}}$ ~ N, with standard deviation $\sigma = \sqrt{N}$ (Poisson distribution)

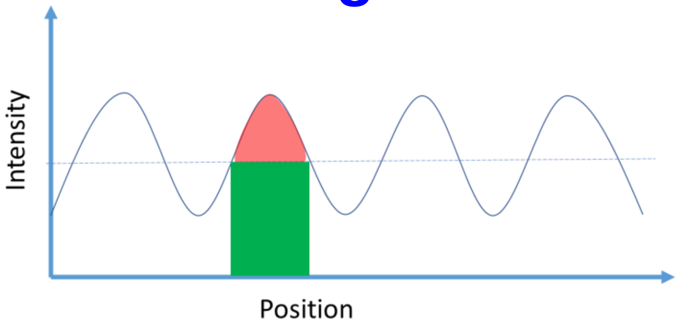
N=100, $\sigma = \sqrt{100} = 10$





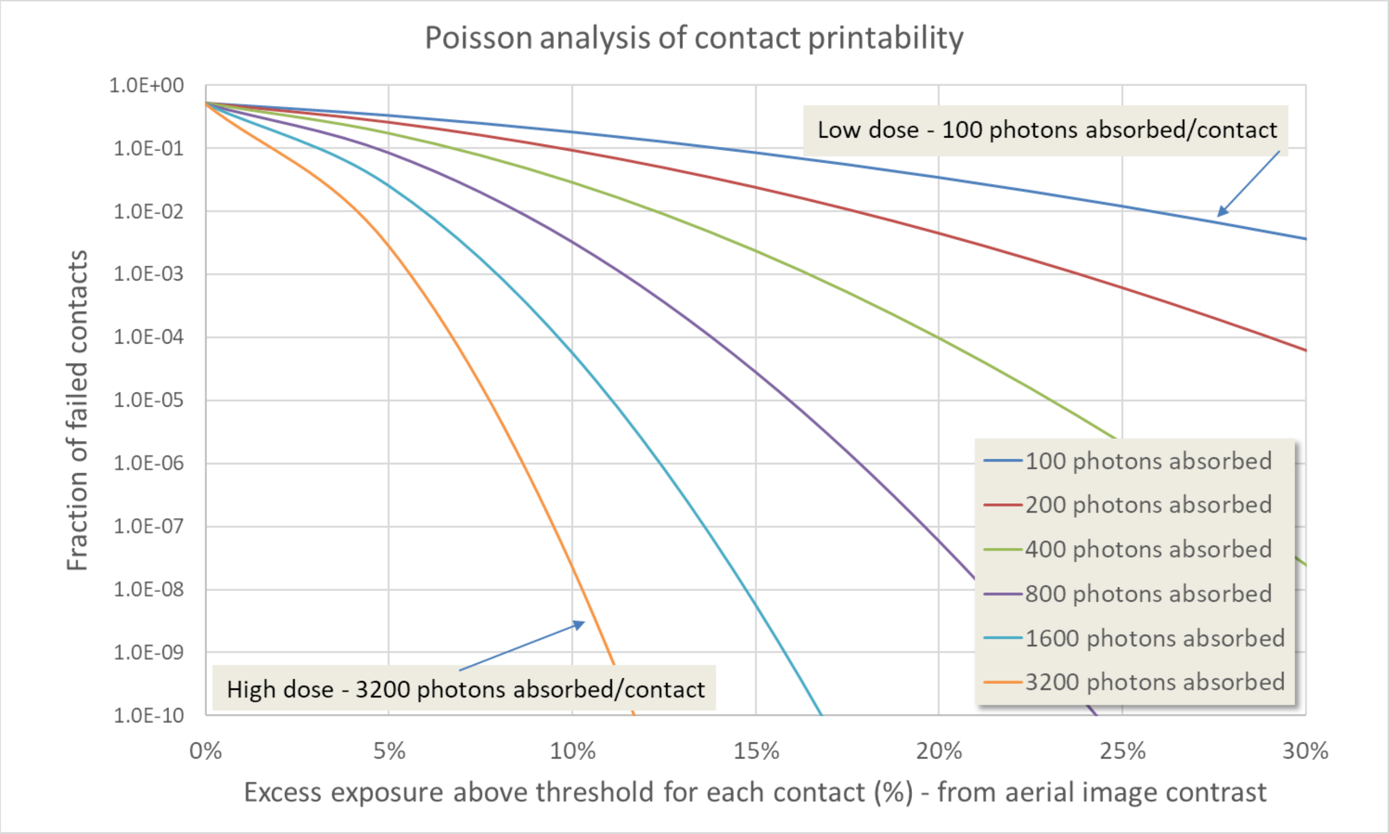
Same data on a log scale shows the outliers

Missing contact rate simply due to photon statistics

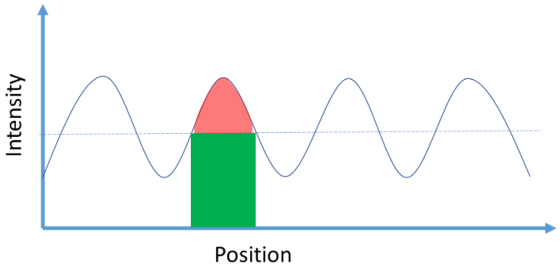


Important assumptions

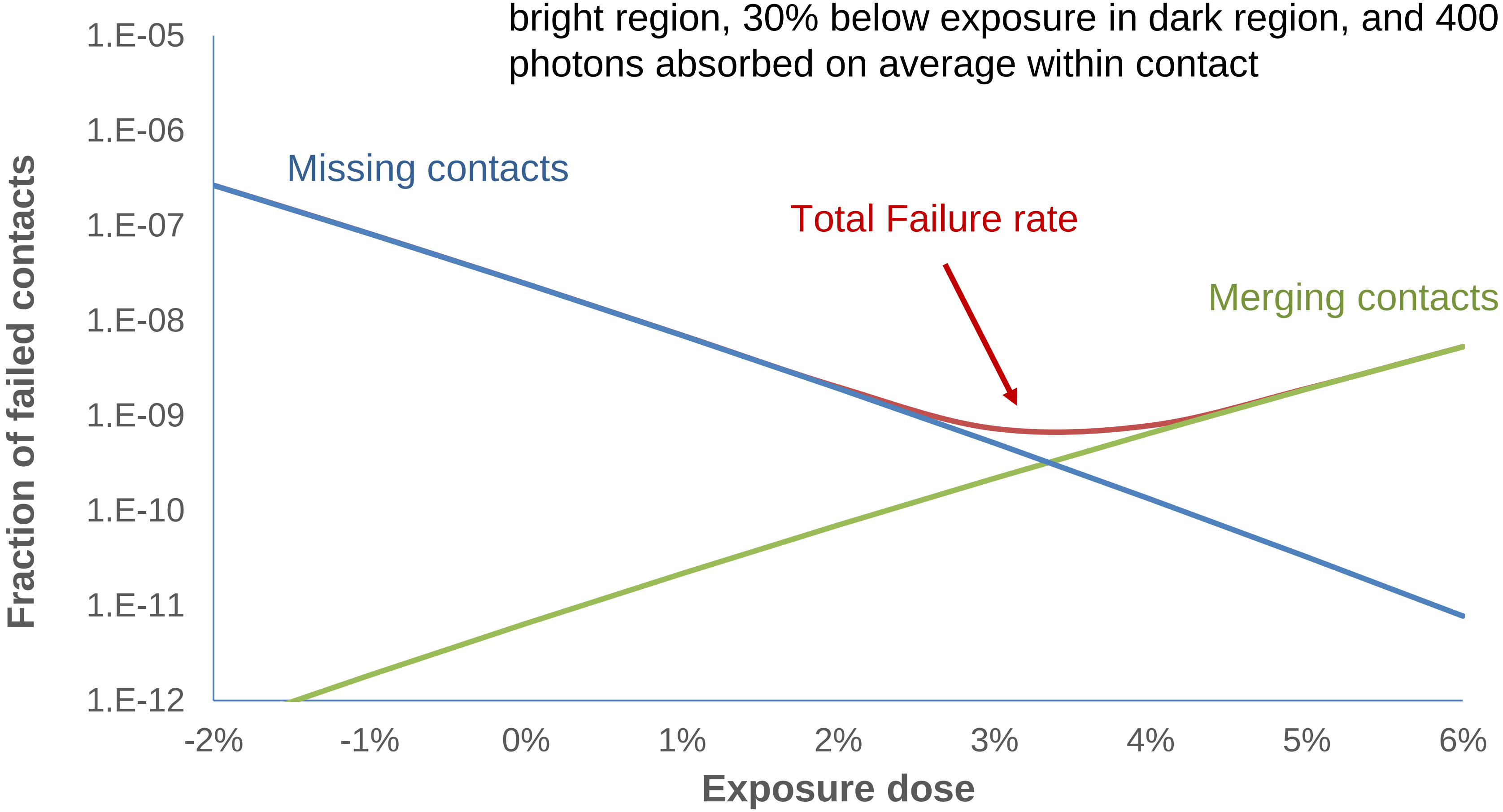
- Only photon statistics included
- Resist has perfect threshold for clearing
- Resist has no sensitivity variations
- Not concerned with contact size, shape or position



Net failure rate is both merging and missing contacts



For this example we used 30% above threshold exposure in bright region, 30% below exposure in dark region, and 400 photons absorbed on average within contact



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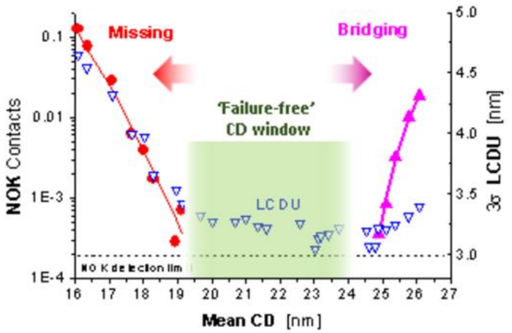
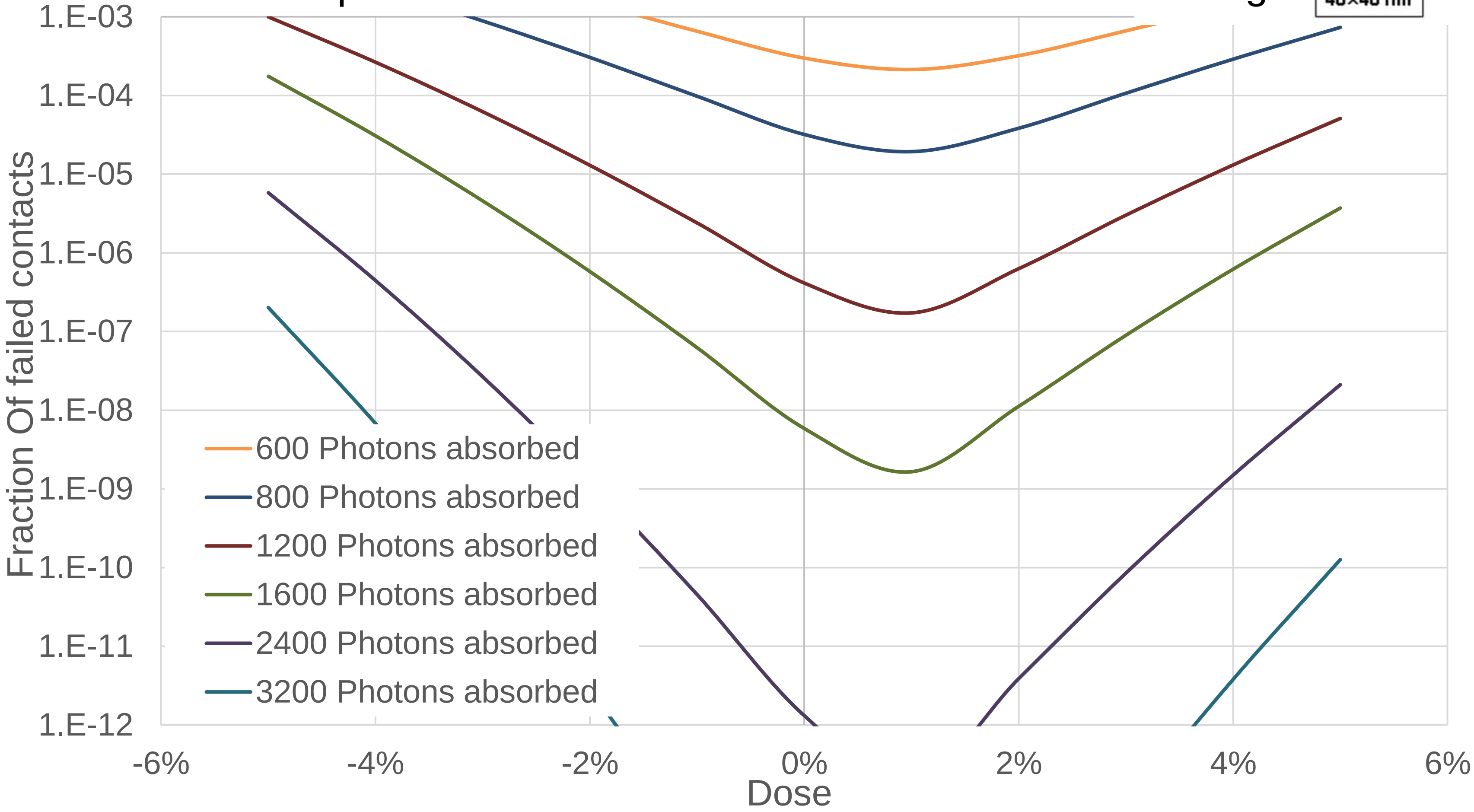
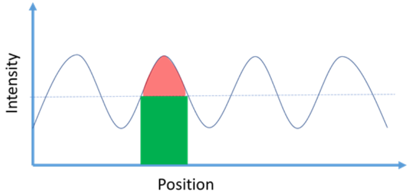
Net failure rate follows basic failure rate expected and shown in De Bisschop paper(JM3 2017)



This example for 15% above and below threshold aerial image



What is the aerial image contrast for relevant contacts?



S-Litho simulations

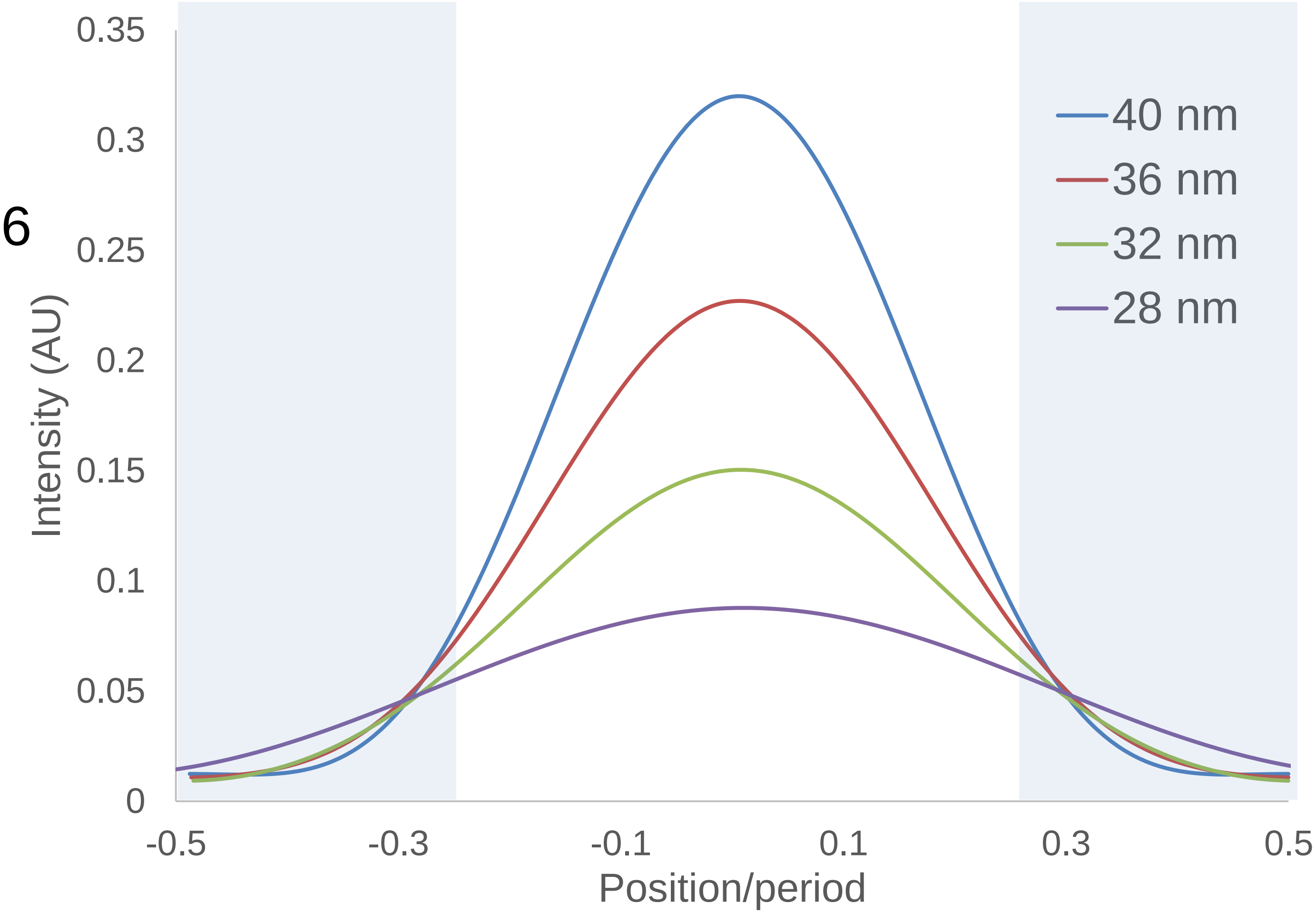
1:1 contacts

No biasing

NA = 0.25

Annular σ=0.4-0.6

No aberrations



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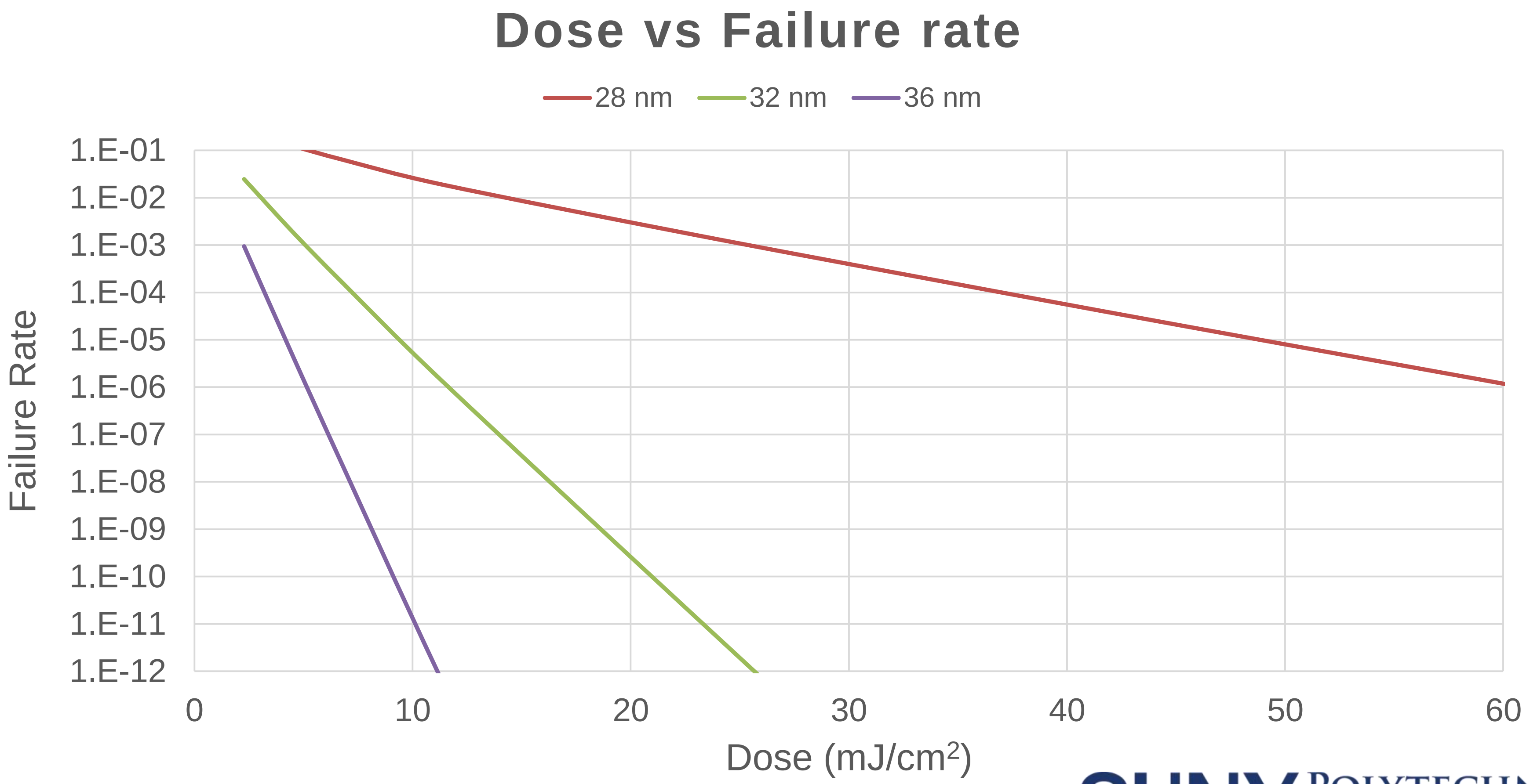
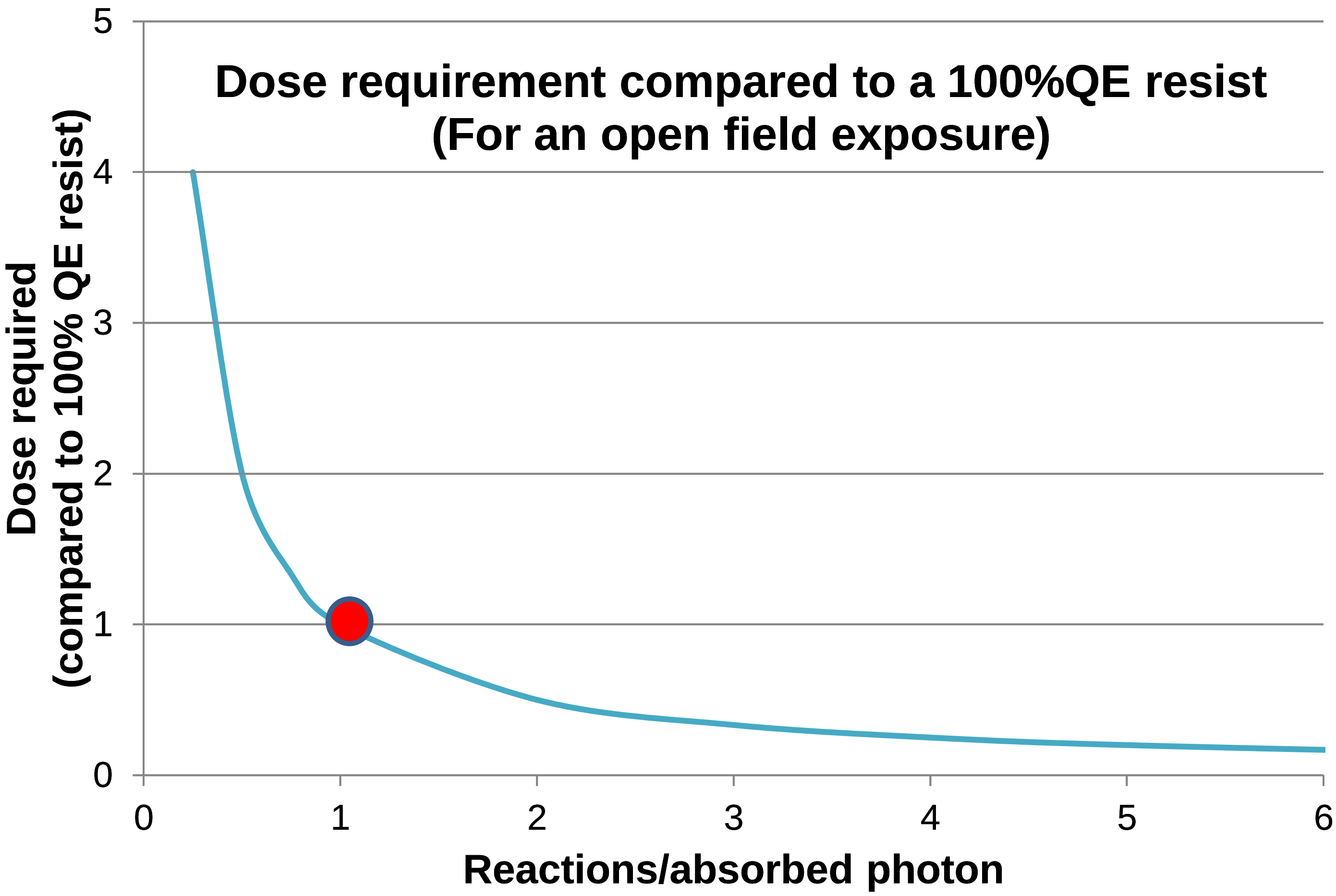
Dose vs Failure rate

More important assumptions

- Uses aerial image from previous simulation (other parameters will give different results!)
- Absorption coefficient, $\mu = 4.9/\mu m$
- 30 nm thick resist (13.6% absorbed)



What about improving resist sensitivity/efficiency



But, what about stochastics effects?

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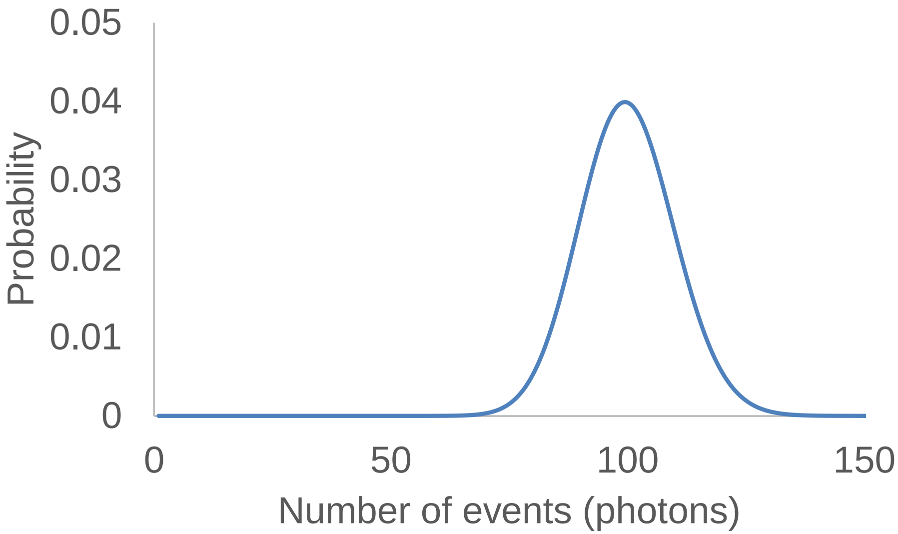
Compound Poisson distribution

If perfect resist (one photon absorbed -> one reaction) then Poisson of photons absorbed

BUT, one absorption gives some number of electrons, some acids, some deprotection events – Compound Poisson distribution – and a larger standard deviation



$\overbrace{1+1+1+1+1+1+1+1\ \dots}^{\text{N events on average}}$ ~ N, with standard deviation $\sigma = \sqrt{N}$ (Poisson distribution)

$\overbrace{1+2+0+1+1+0+1+1+\dots}^{\text{N events on average, each Poisson distribution with average of 1}}$~ N, with standard deviation $\sigma > \sqrt{N}$ (Compound Poisson distribution)

(and $\sigma = \sqrt{2N}$ for this example)

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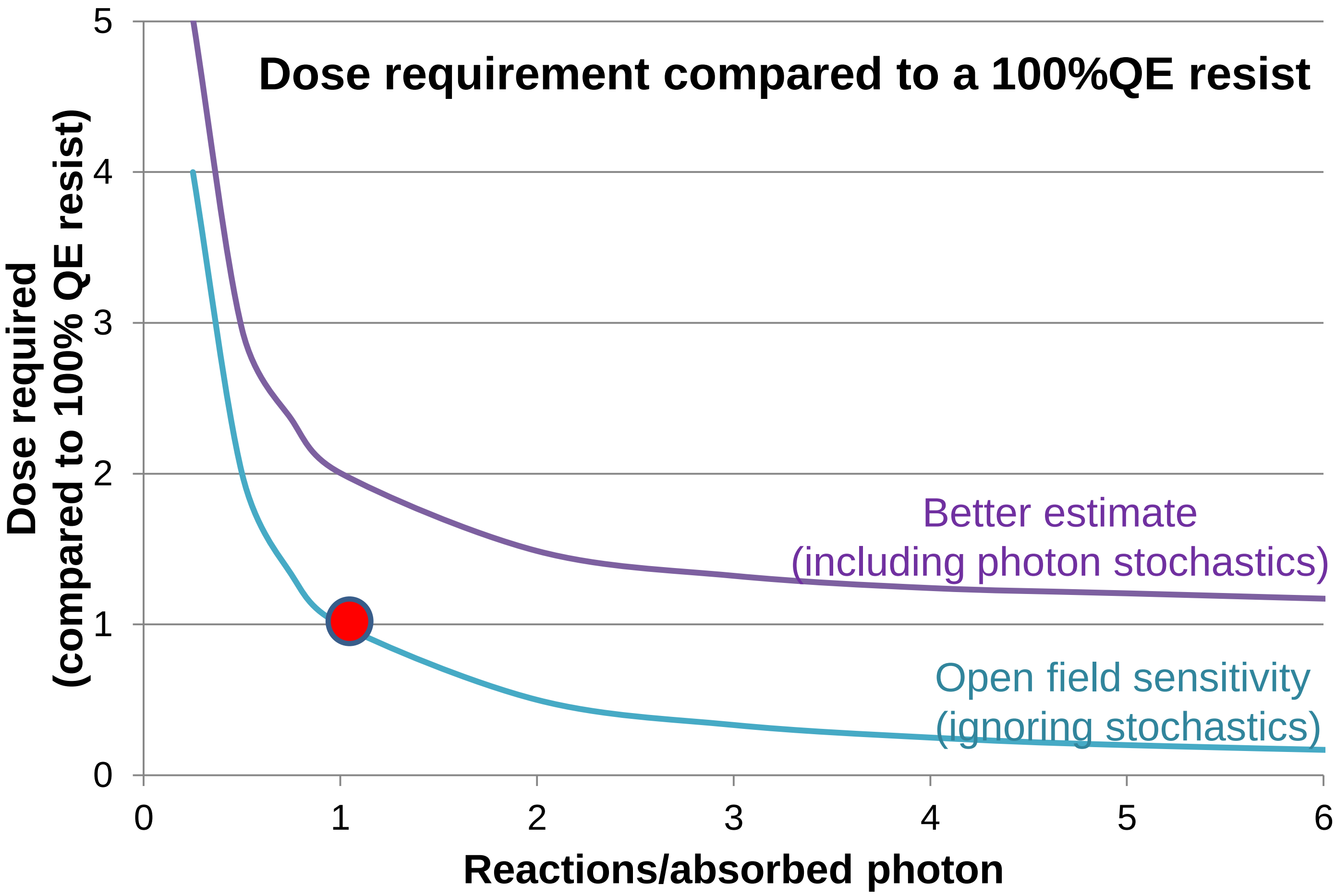
What about improving resist sensitivity/efficiency



*Assumes statistics follow Compound Poisson

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