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Depletion depth studies on high thickness to pixel size ratio silicon devices

Beverly LaMarr

Sources

Measurement and simulation of charge diffusion in a small-pixel charge-coupled device, Beverly J. LaMarr , Gregory Y. Prigozhin, Eric D. Miller, Carolyn Thayer, Marshall W. Bautz, Richard Foster, Catherine E. Grant, Andrew Malonis, Barry E. Burke, Michael Cooper, Kevan Donlon, Christopher Leitz
https://doi.org/10.1117/1.JATIS.8.1.016004

Understanding the effects of charge diffusion in next-generation soft x-ray imagers, Eric D. Miller, Gregory Y. Prigozhin, Beverly J. LaMarr, Marshall W. Bautz, Richard F. Foster, Catherine E. Grant, Craig S. Lage, Christopher Leitz, Andrew Malonis
https://doi.org/10.1117/12.2628929

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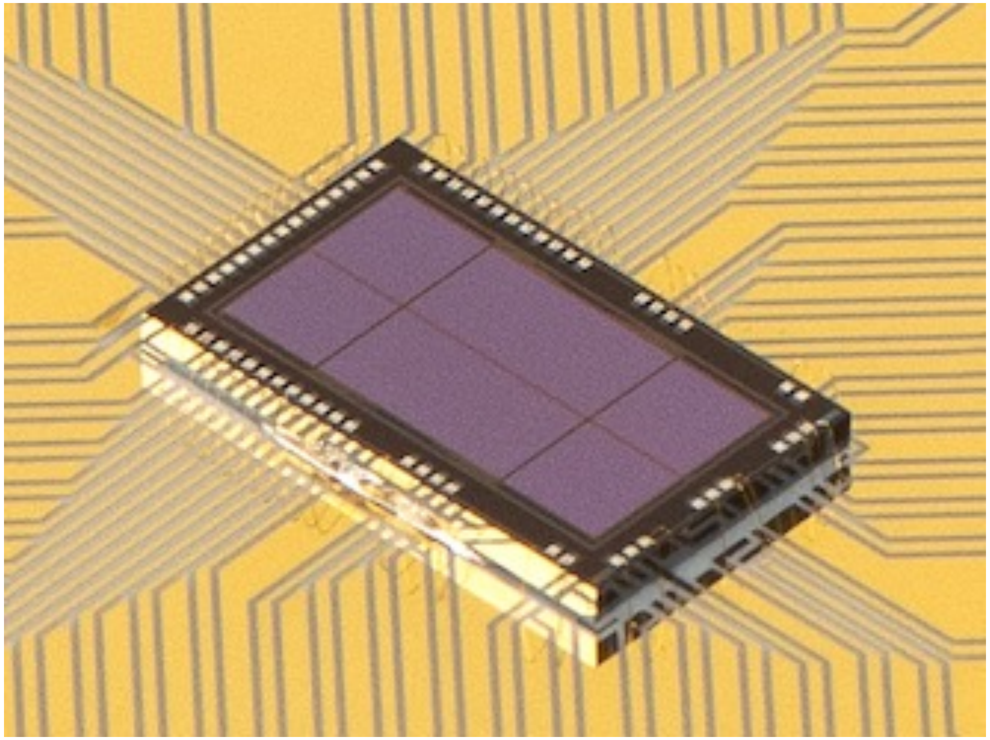
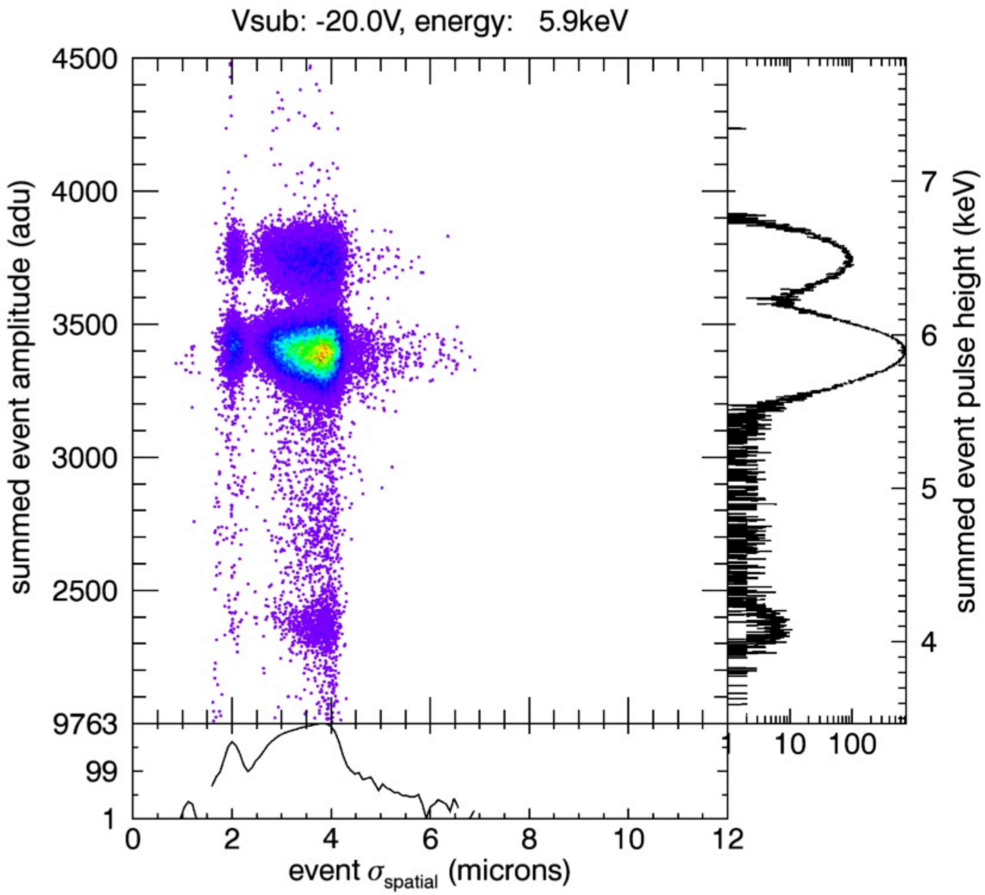


- Back illuminated
- 50 micron thick
- 8x8 micron pixels
- Single polysilicon allows fast transfer with 3V clock swings
- 2MHz serial, 500kHz parallel transfer
- ~4.5 e- noise using Archon controller

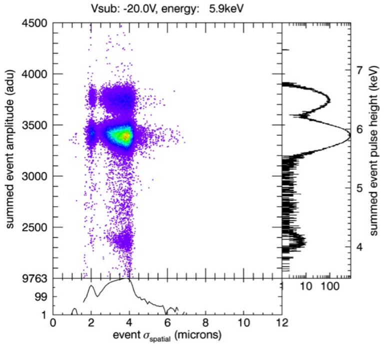
Measurements



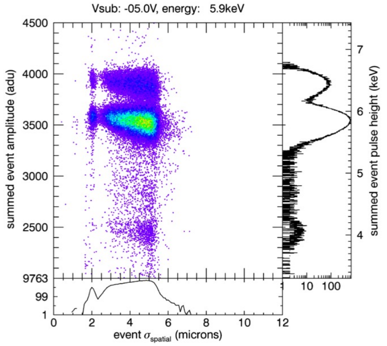
For each event

- compute pulse height with traditional summing above threshold
- Fit a 2-d gaussian to the pulse heights in the island

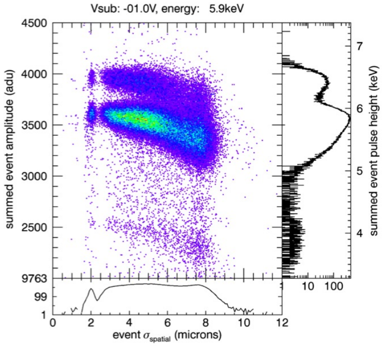
Measurements



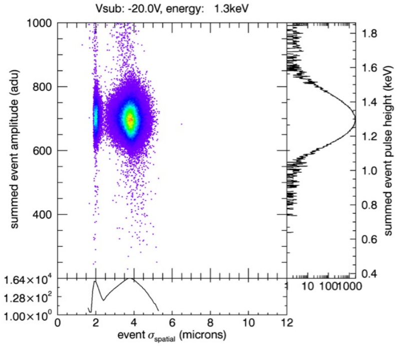
(a) 5.9 keV, V_{sub} = -20 V



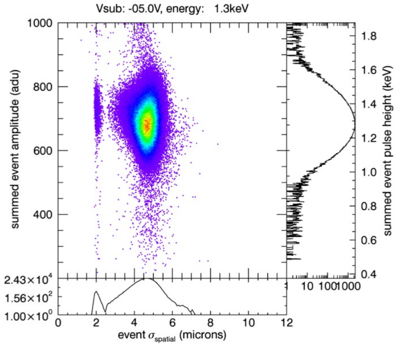
(b) 5.9 keV, V_{sub} = -5 V



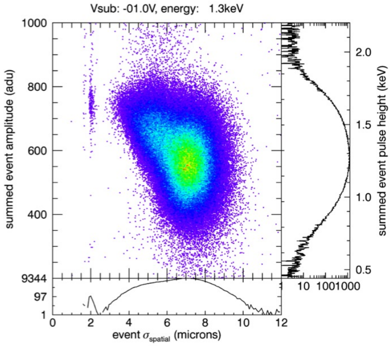
(c) 5.9 keV, V_{sub} = -1 V



(d) 1.25 keV, V_{sub} = -20 V



(e) 1.25 keV, V_{sub} = -5 V

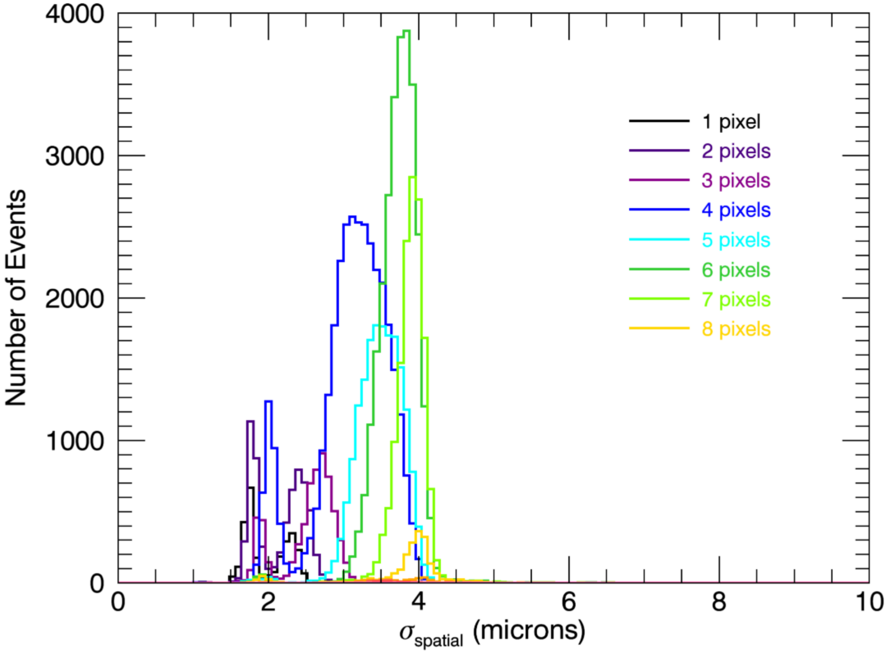


(f) 1.25 keV, V_{sub} = -1 V

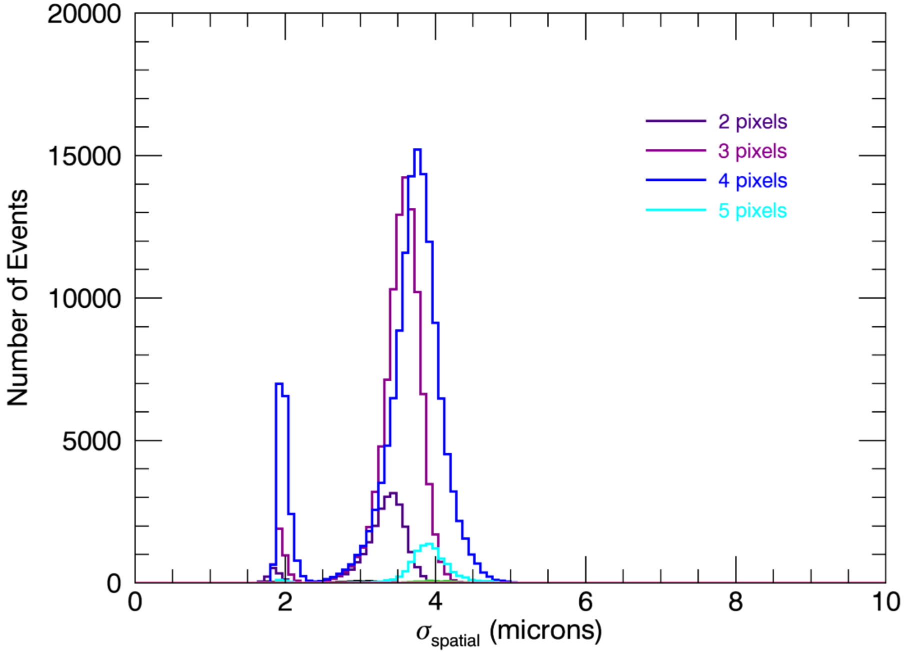
- Vary field strength by changing substrate voltage
- Stronger fields result in more rapid charge collection and so less spreading
- Lower bias values do not fully deplete the detector
- Events detected in undepleted region suffer from incomplete charge collection and higher lateral diffusion

Measurements

Vsub -20V, energy: 5.9keV



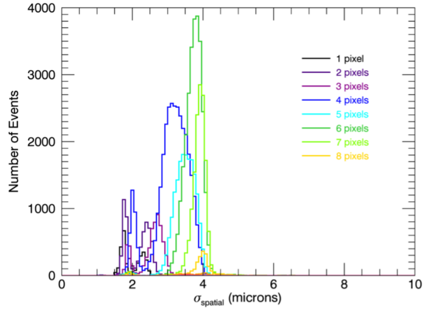
Vsub -20V, energy: 1.3keV



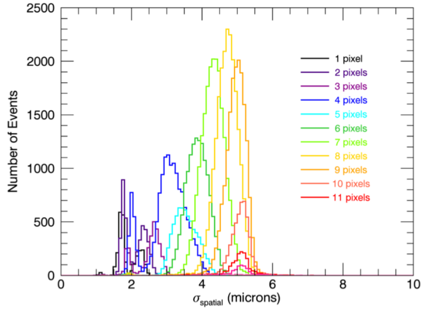
- At 5.9 keV narrower events clearly have fewer pixels above threshold

- At 1.3 keV all interactions are closer to the entrance window with less variation in event size.

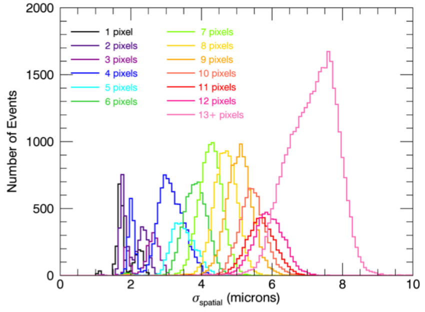
Measurements



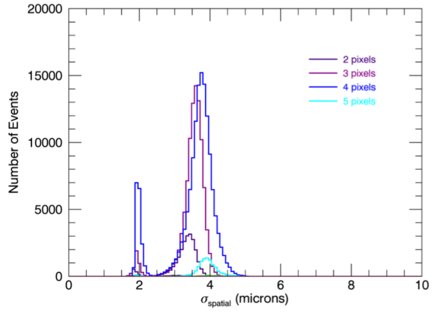
(a) 5.9 keV, V_{sub} = -20 V



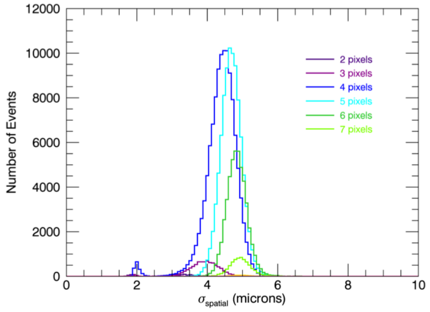
(b) 5.9 keV, V_{sub} = -5 V



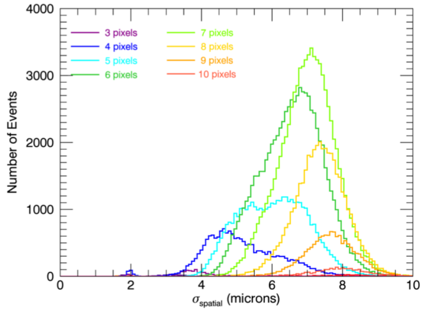
(c) 5.9 keV, V_{sub} = -1 V



(d) 1.25 keV, V_{sub} = -20 V



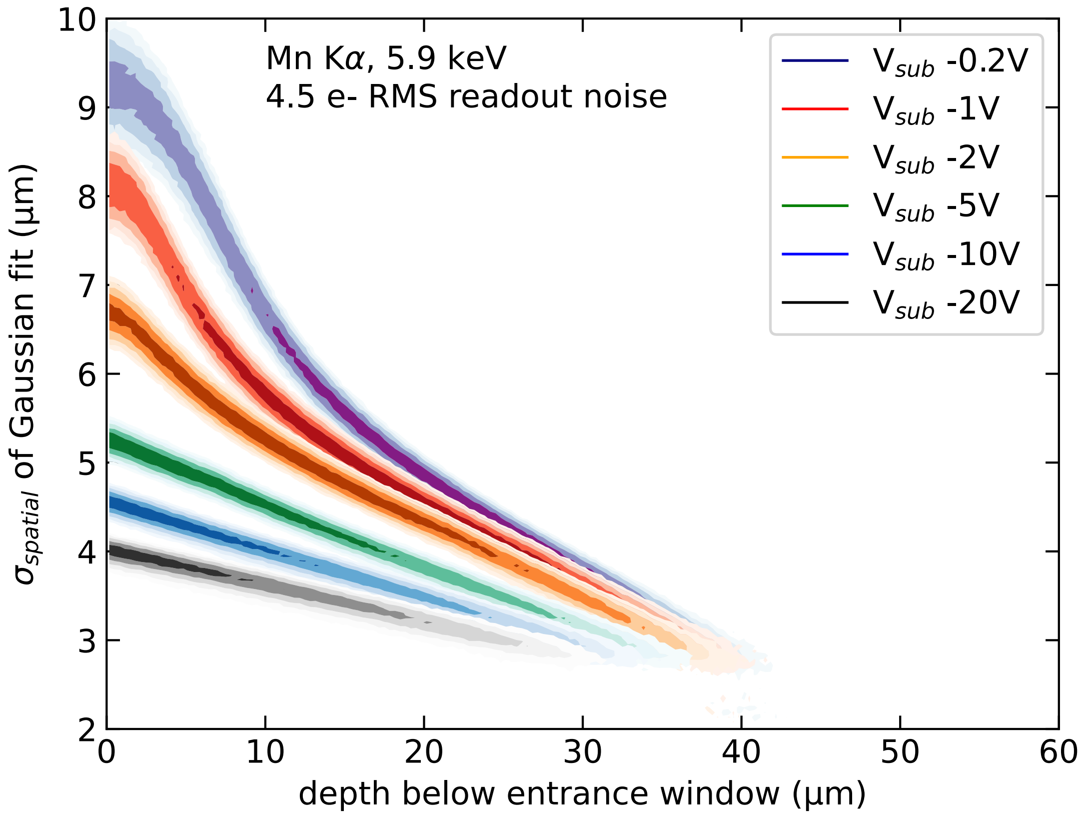
(e) 1.25 keV, V_{sub} = -5 V



(f) 1.25 keV, V_{sub} = -1 V

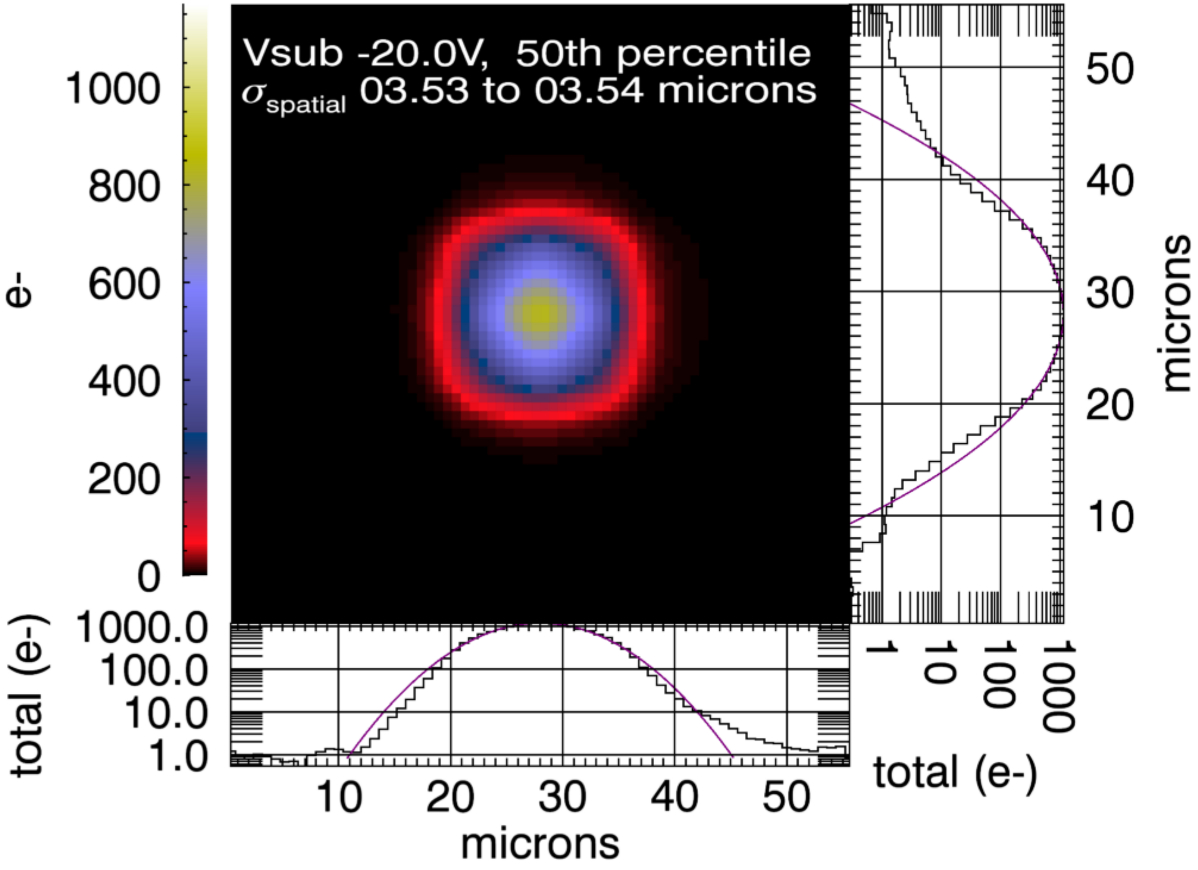
- for a fully depleted detector, the maximum amount of diffusion is the same for both energies

Simulation of Average charge distribution at fixed depth



- Simulations provide the expected relationship between the the width of events and the depth of xray absorption
- We use the fact that it is monotonic for a give Vsub to sort the events by interaction depth

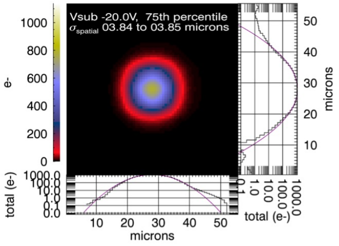
Average charge distribution at fixed depth



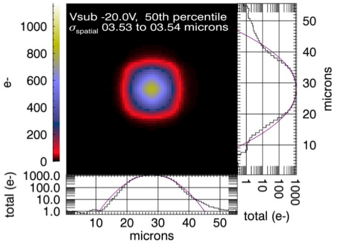
- Rebin each event into a subpixel grid
- Shift each event to align the centroids of the gaussian fits
- Average events with similar widths (and so interaction depths)
- Central portions are well fit by a gaussian

Average charge distribution at fixed depth

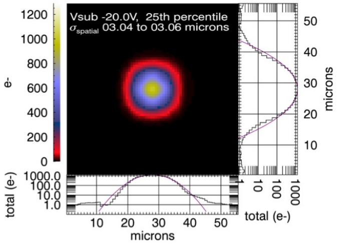
Field strength



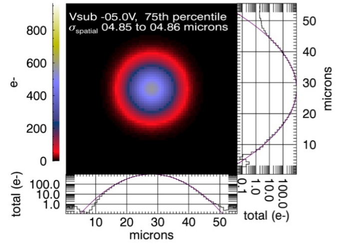
(a) $\sigma_{spatial}$ = 3.8 μm



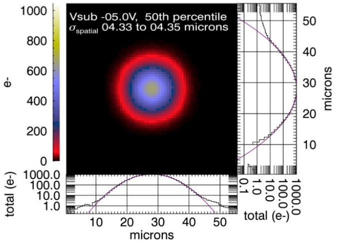
(b) $\sigma_{spatial}$ = 3.5 μm



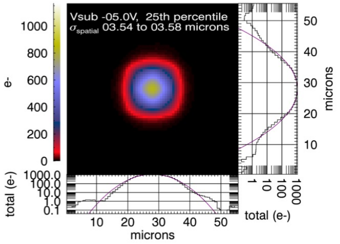
(c) $\sigma_{spatial}$ = 3.0 μm



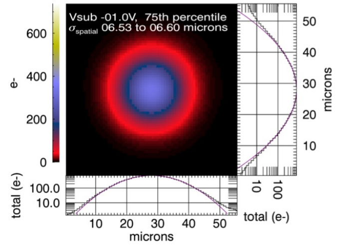
(d) $\sigma_{spatial}$ = 4.9 μm



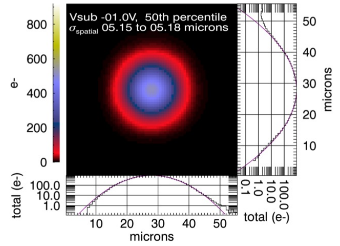
(e) $\sigma_{spatial}$ = 4.3 μm



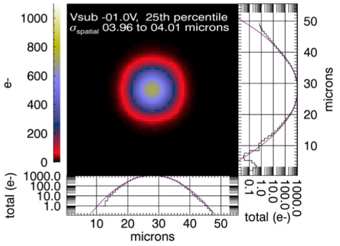
(f) $\sigma_{spatial}$ = 3.5 μm



(g) $\sigma_{spatial}$ = 6.5 μm



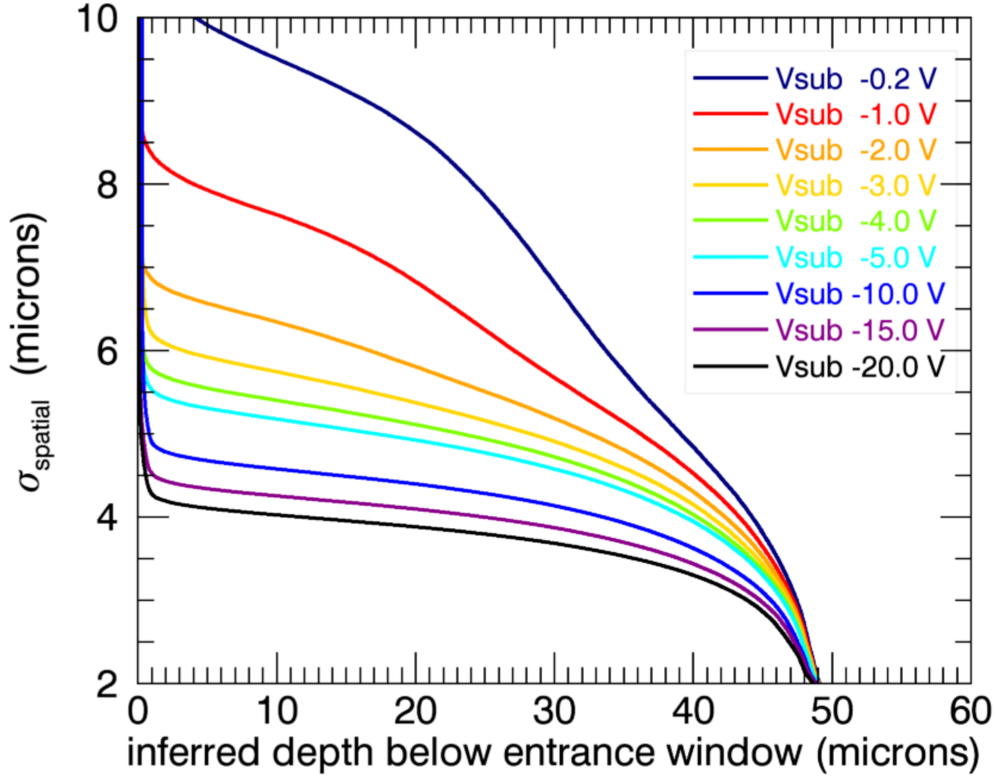
(h) $\sigma_{spatial}$ = 5.2 μm



(i) $\sigma_{spatial}$ = 4.0 μm

Distance from Entrance window

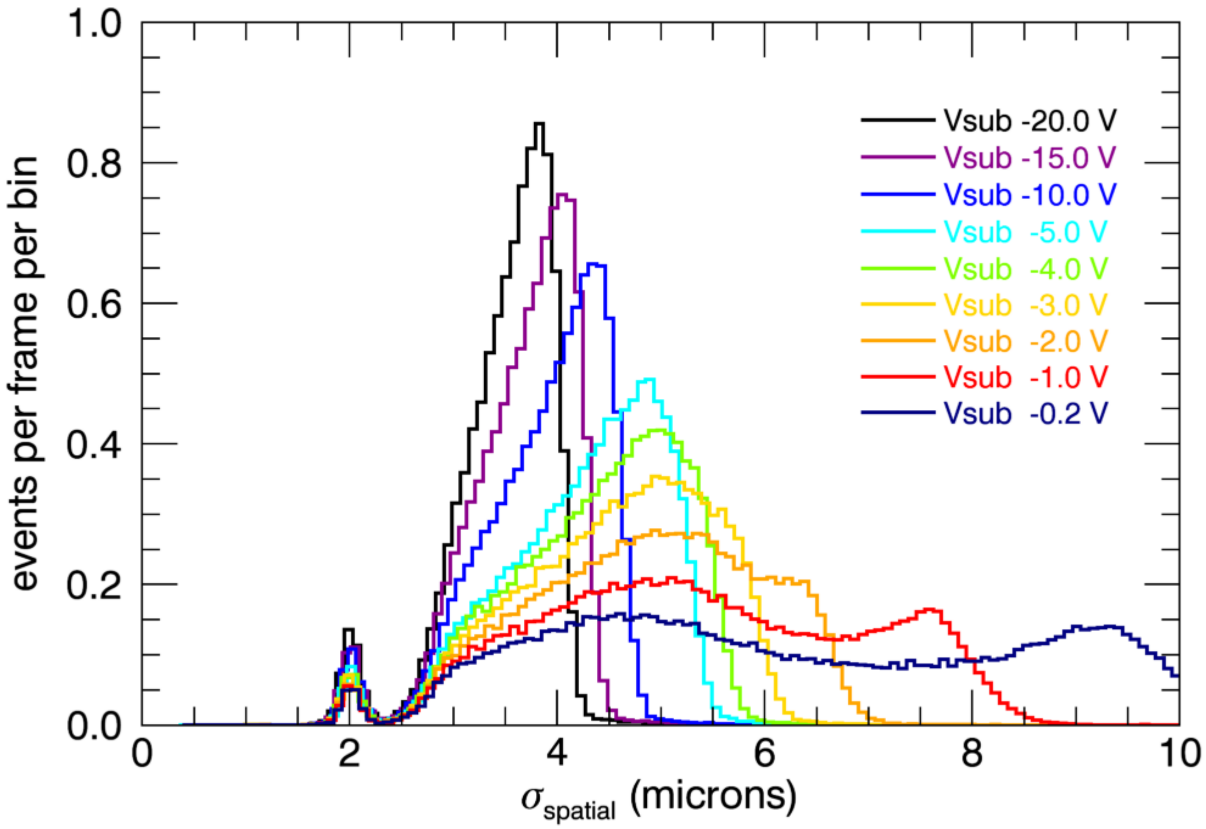
Inferring interaction depth from the cumulative event width distribution



$$z = -\lambda\, ln(1 - N_{z\_frac}(1 - exp(-t/z)))$$

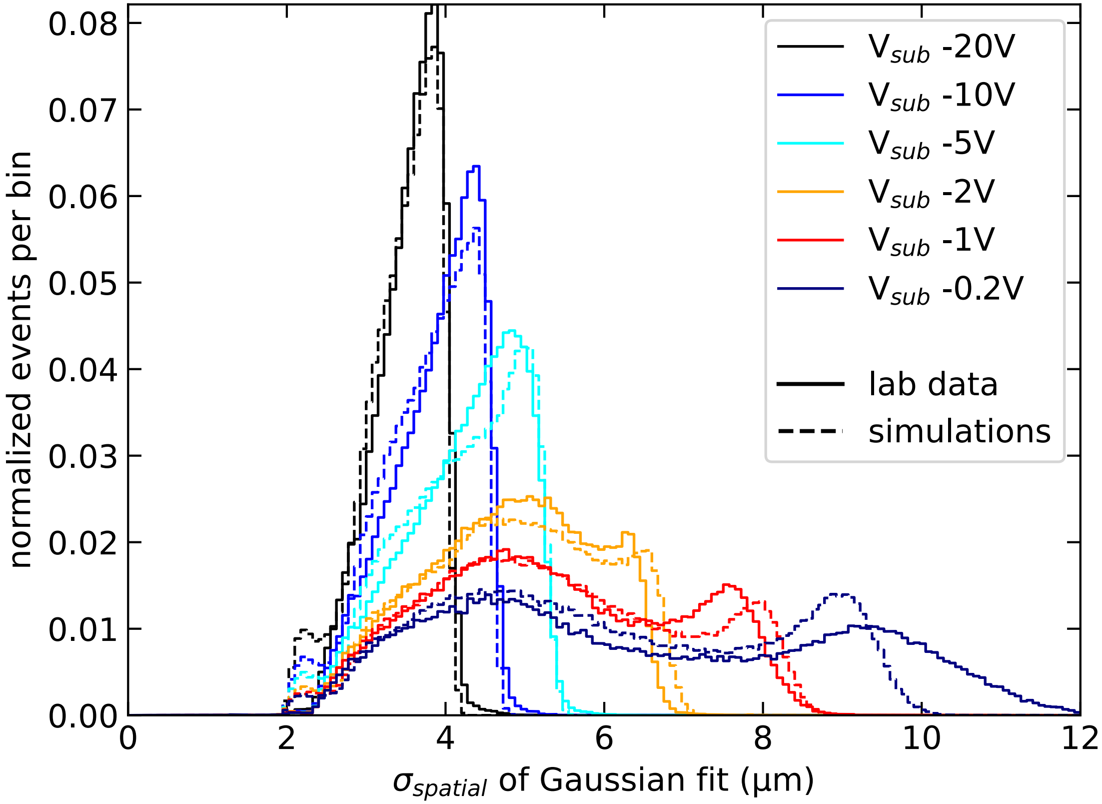
- The shape of the curve is different at less negative Vsubs, likely due to the formation of an undepleted region

Detector characterization from differential event width distributions



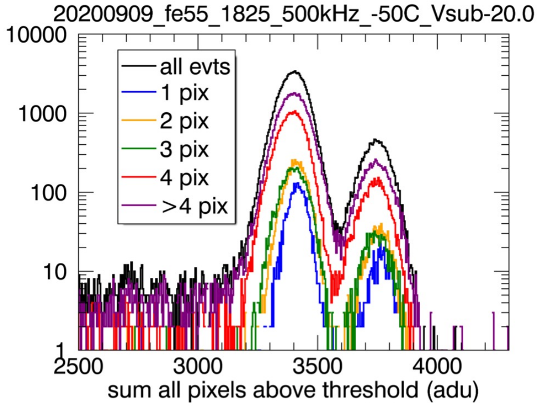
- At the largest bias, the bulk of the silicon is fully depleted and drift times are short
- A second peak forms as an undepleted region forms

Detector characterization from differential event width distributions

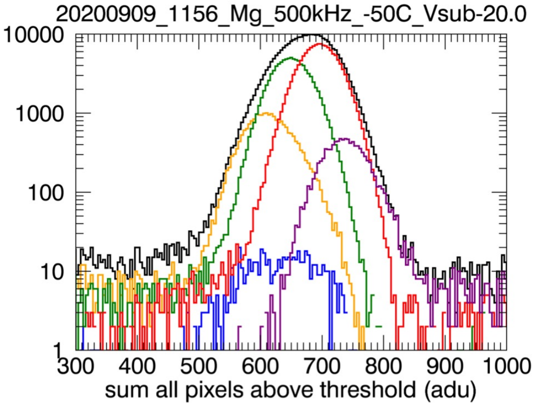


- Tune the POISSON CCD simulator to match the peak location
- Discrepencies at less negative Vsubs are likely due to limitations in the simulator when a field free region is present.

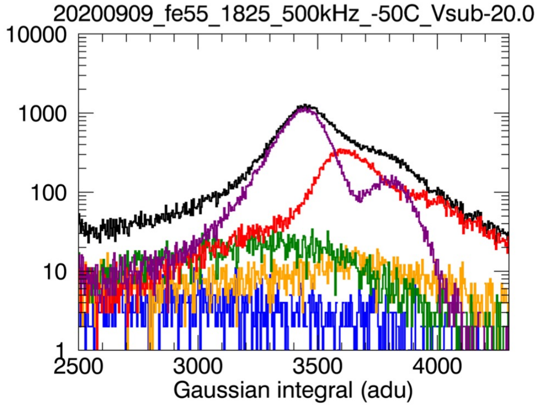
Event Amplitude Estimation



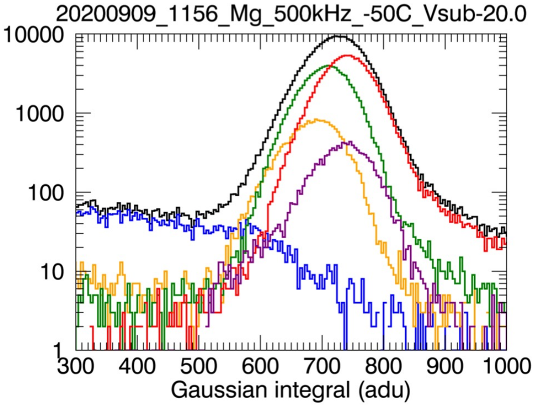
(a)



(b)



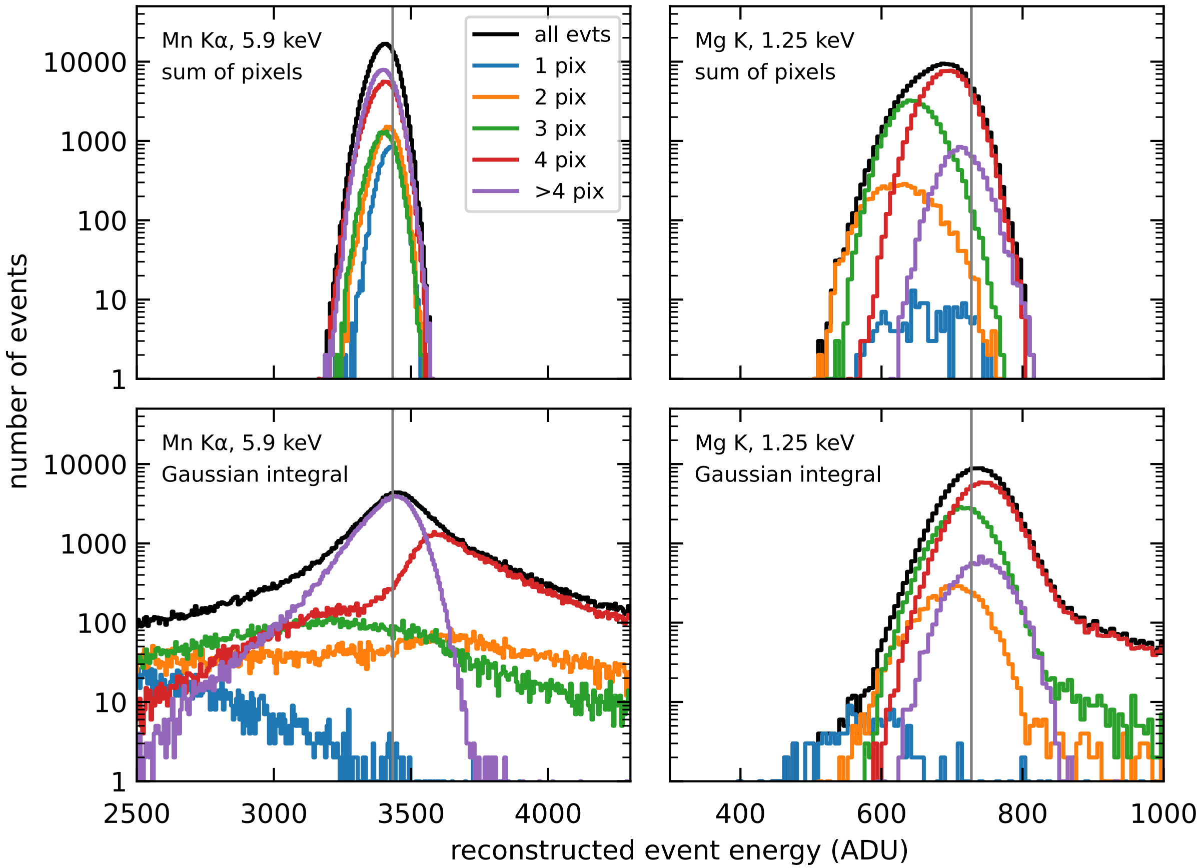
(c)



(d)

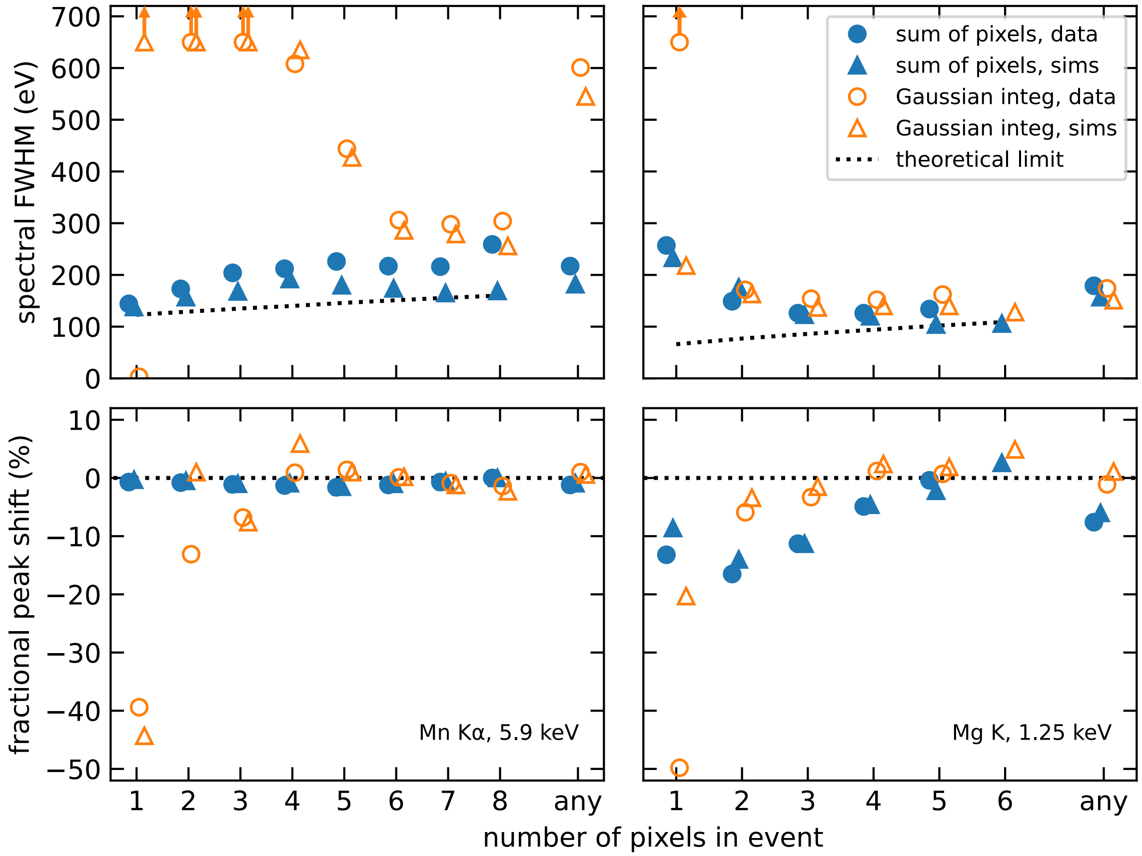
- Using the gaussian fit for event amplitude estimation performs worse at higher energy. Especially when few pixels are above threshold
- For lower energies, the gaussian amplitudes perform better. Likely due to more extended events

Event Amplitude Estimation



- Results from simulations are similar to the measured data.
- Gaussian fitting method improves the amplitude estimate
- Spatial sampling provided by 8 micron pixels is insufficient for individual events.

Event Amplitude Estimation



- Using the gaussian fit for event amplitude estimation performs worse at higher energy. Especially when few pixels are above threshold
- For lower energies, the gaussian amplitudes perform better. Likely due to more extended events

Summary

- Thick, small pixel, back illuminated devices have significant charge spreading
- Fitting 2d gaussians to the event items allow an estimation
- The POISSON CCD simulator is able to match the spread well
- Traditional charge above split event amplitude calculation is still best for energies above 1keV