Optimizing an Event-Driven Detector for High Speed Scanning Diffraction Measurements in the Transmission Electron Microscope

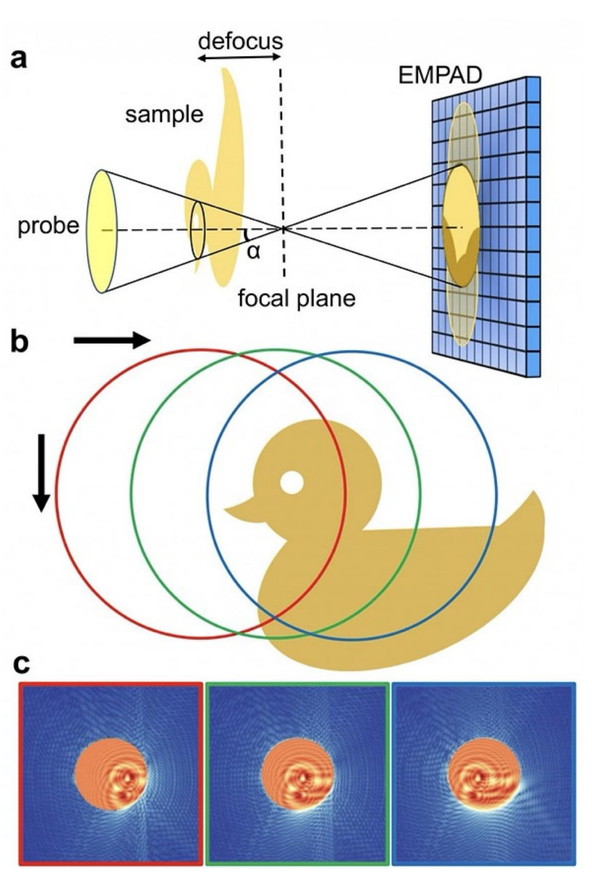
Rohini Ghosh[1], Steve E. Zeltmann[2,3], and David A. Muller[3]

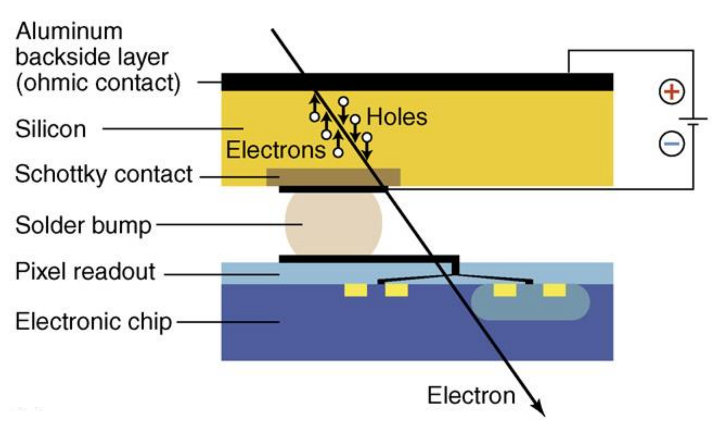
[1]Department of Chemical and Environmental Engineering, University of Arizona, Tucson, AZ

[2]PARADIM, Department of Materials Science and Engineering, Cornell University, Ithaca, NY

[3]School of Applied and Engineering Physics, Cornell University, Ithaca, NY

Pixel Array Detectors





- Pixel array detectors are a key technology to enable advanced imaging techniques such a ptychography
- Composed of a **silicon sensor layer** bonded to an integrated circuit

Timepix4: Event-Driven Detector

EMPAD G2

Frame-Based Counting: value for each pixel recorded after an exposure period

500 µm Sensor Layer

- All the incident energy is absorbed in the sensor layer

Charge Integration: number of counts is proportional to charge generated in the pixel

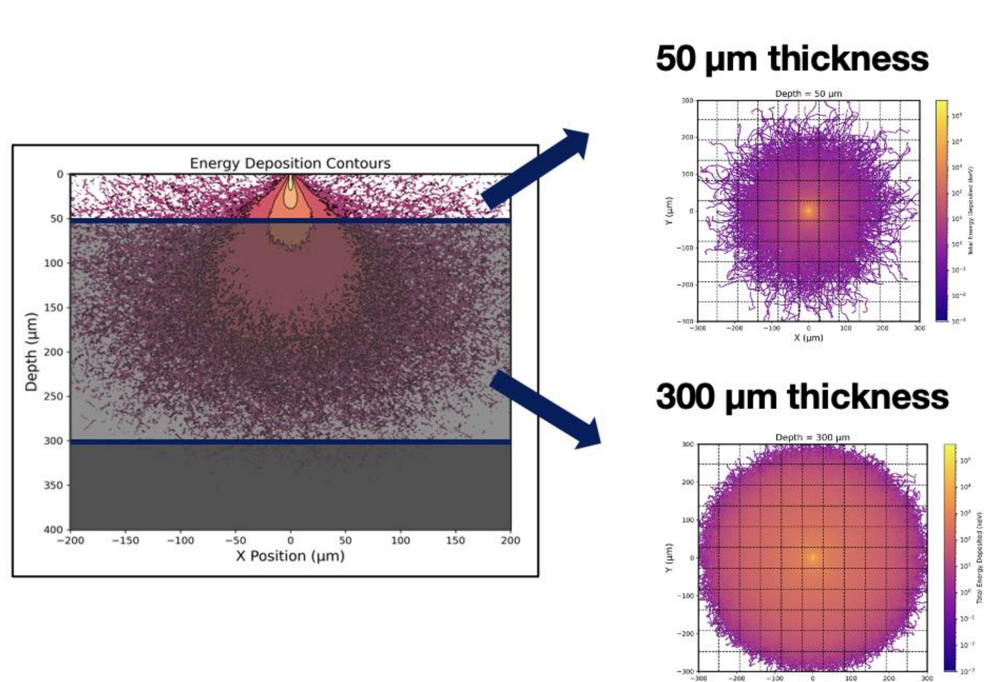
Timepix4

Event-Driven Detector: continuous readout from pixels

- Pros: reduced data size and computational requirement
- Limitations: undercounting from pixel saturation

Solution: Thin sensor layer

Pulse Counting: a count is generated if energy collected in a pixel exceeds threshold



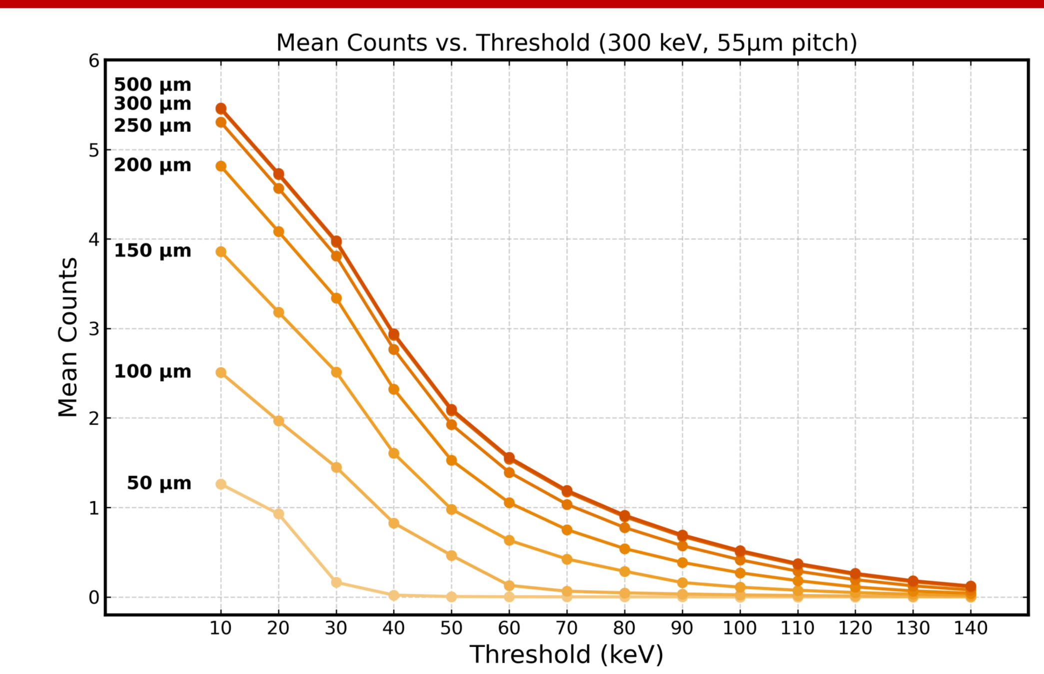
Back-thinning of the silicon sensor layer reduces the lateral spread of the signal, resulting in fewer counts per electron.

This **mitigates pixel saturation** by reducing the likelihood of overlapping events.

Reducing Mean Counts to Address Pixel Saturation

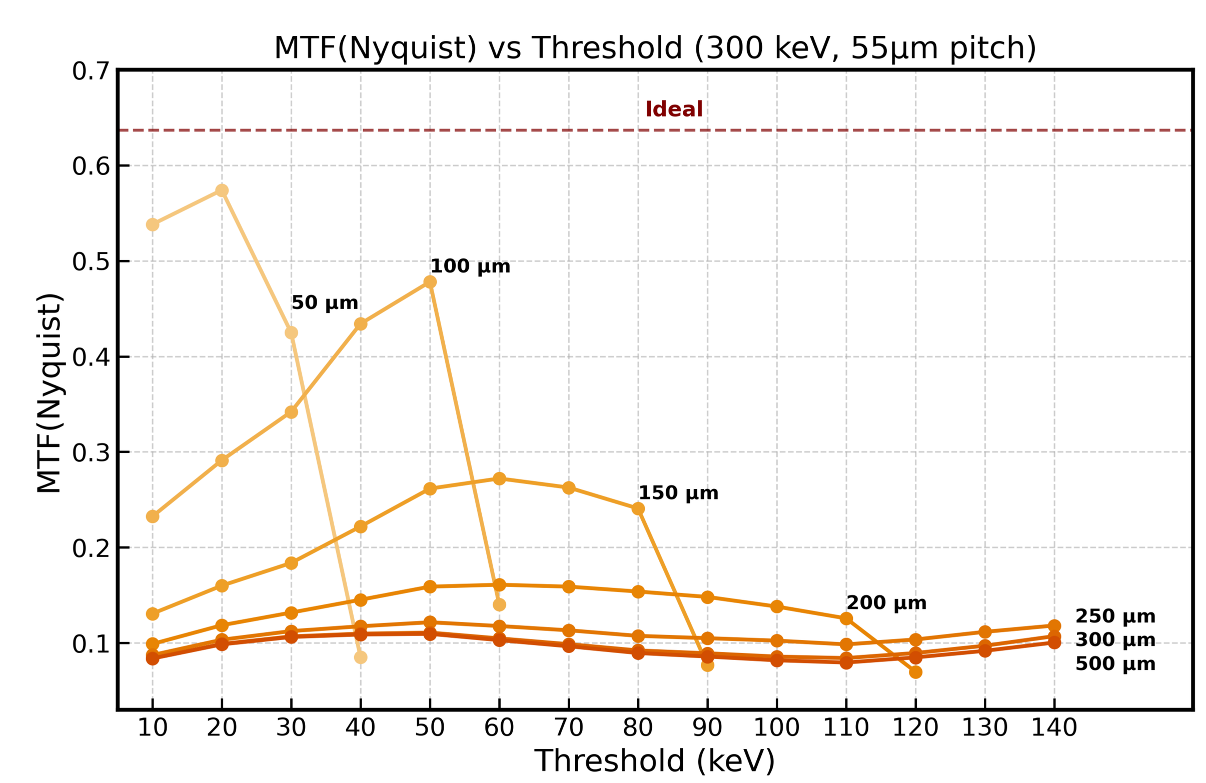
Conducted **Monte Carlo simulations** to model electron pathways through the silicon sensor layer.

- **Thinning the sensor reduces mean counts per electron.**
- As threshold increases, the number of counts registered per electron decreases.
- Based on the thickness of the sensor, a different threshold achieves the **ideal mean activation count of 1**.



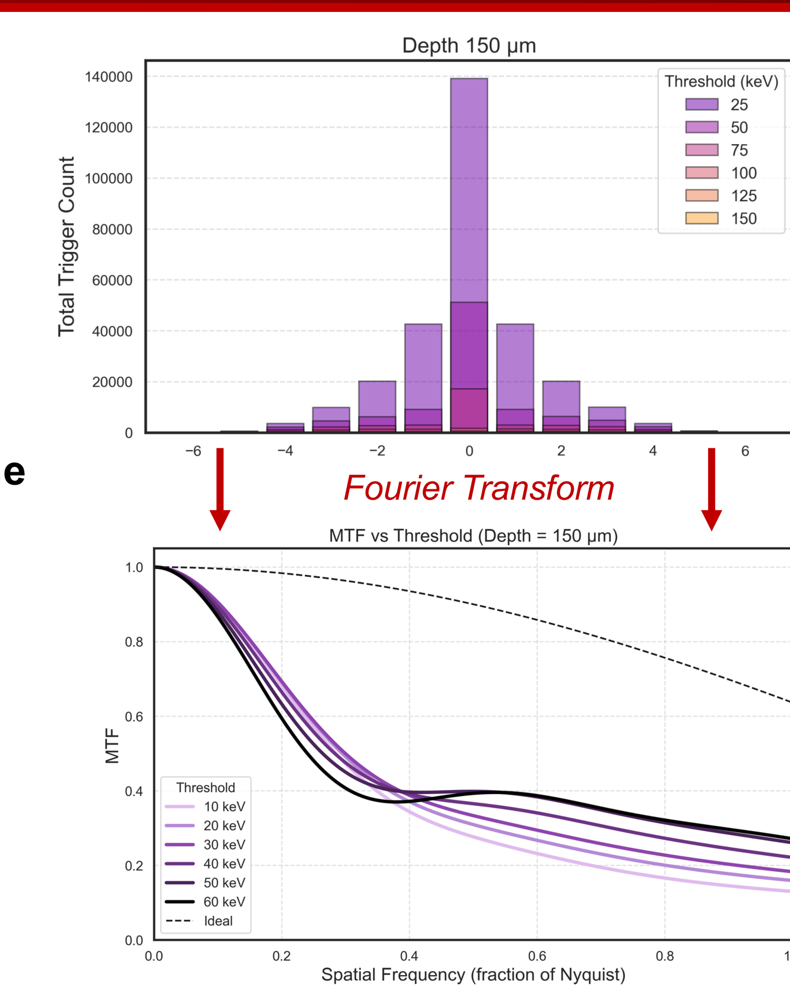
Modulation Transfer Function (MTF)

MTF: quantifies the ability of a detector to preserve image contrast as a function of spatial frequency



Decreasing sensor thickness improves the MTF.

For thinned sensors, as threshold increases, MTF increases.



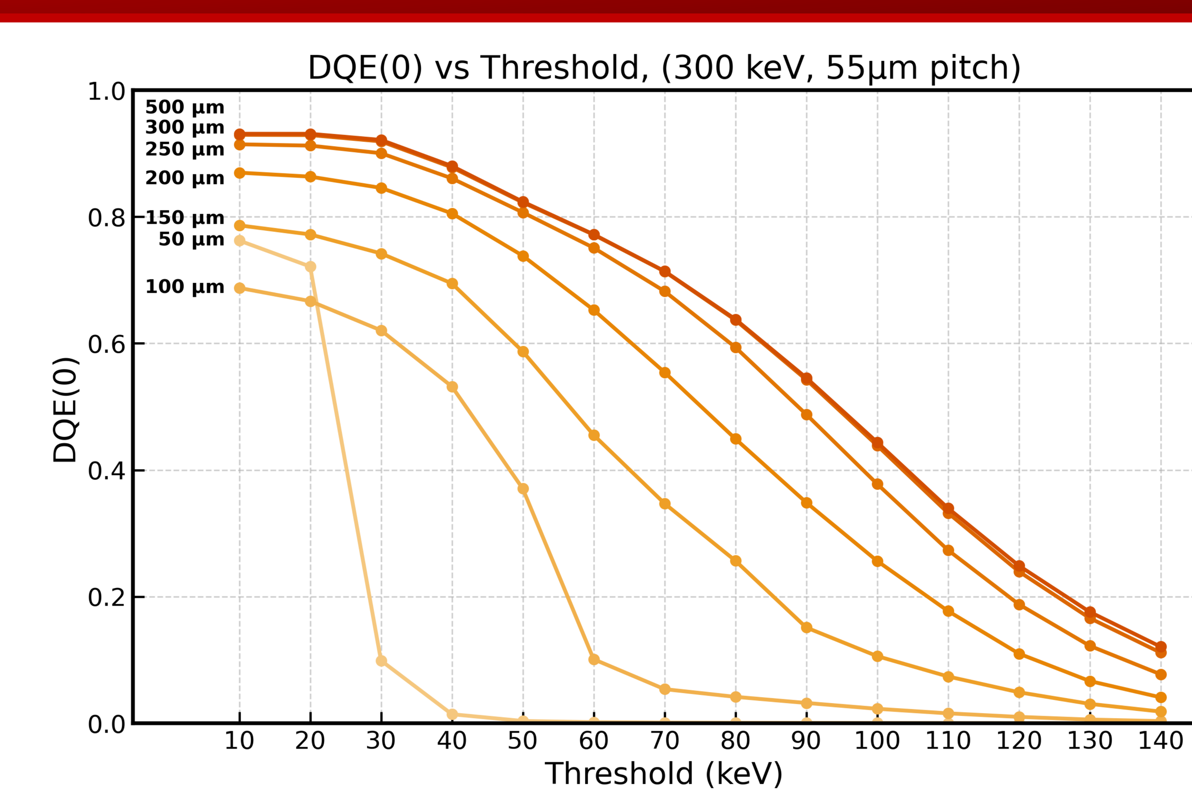
Detector Quantum Efficiency (DQE)

DQE: ratio of the output signal-to-noise ratio (SNR) to the input SNR

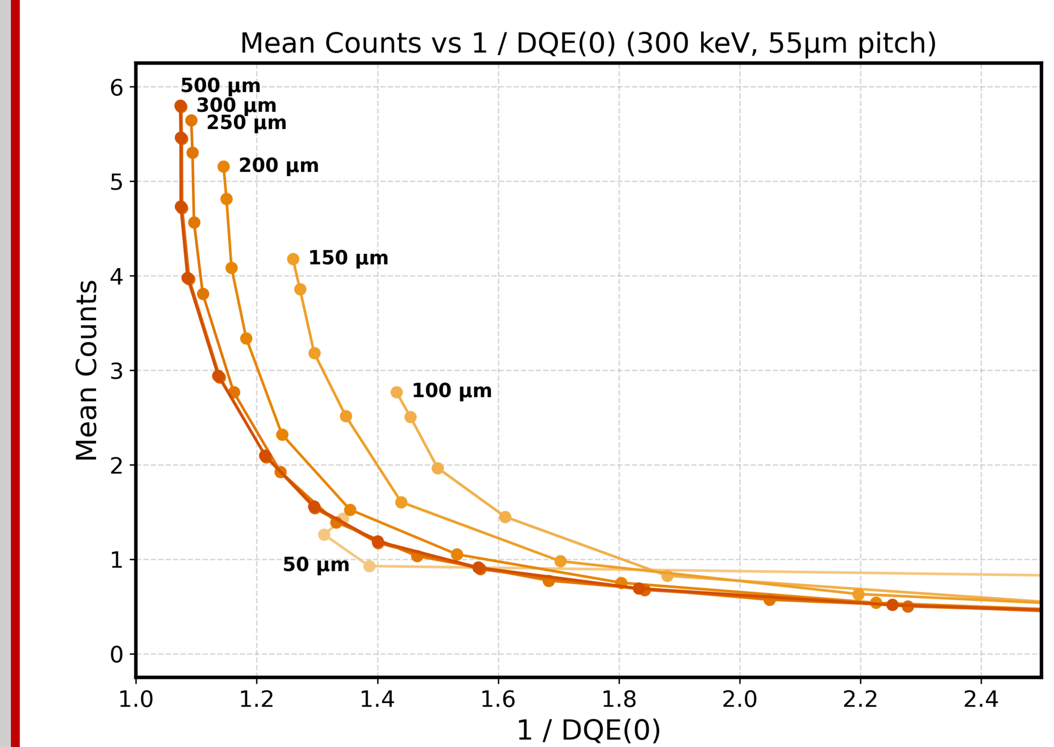
$$DQE(0) = \frac{\mu_1^2}{\mu_2}$$

As the sensor is thinned, DQE(0) worsens because of increased variability in the counts registered per electron.

As threshold increases, DQE(0) decreases.



Implications on Detector Speed



Both mean counts and DQE(0) indicate the maximum speed, or maximum electron dose, which a detector can be operated at.

Ideal value for both mean counts and inverse DQE(0) is unity.

Conclusions

- Use **Monte Carlo simulations** to model electron paths through sensor material
- Demonstrate how back-thinned sensors could **address pixel saturation in event-driven detectors**
- Understand implications of **thinned sensor layer and thresholding** on detector characterization parameters

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