# Micron Scale Pixel Hybrid Detector for Hard X-rays

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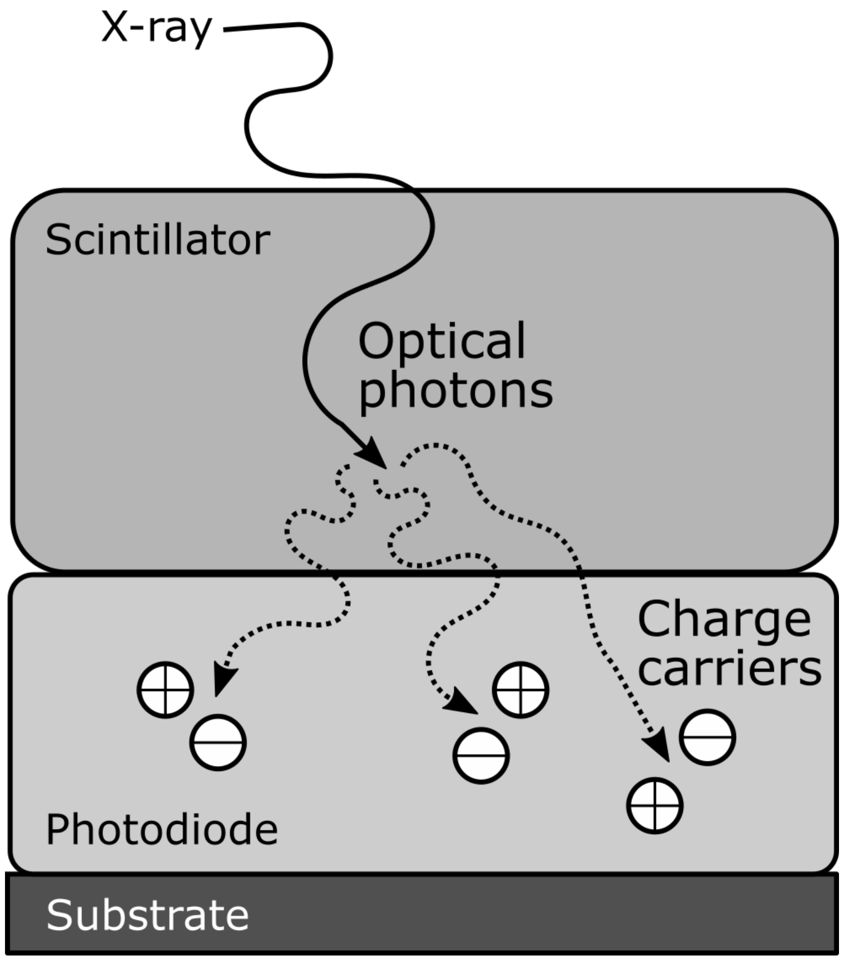
KA IMAGING™

# Digital Radiography

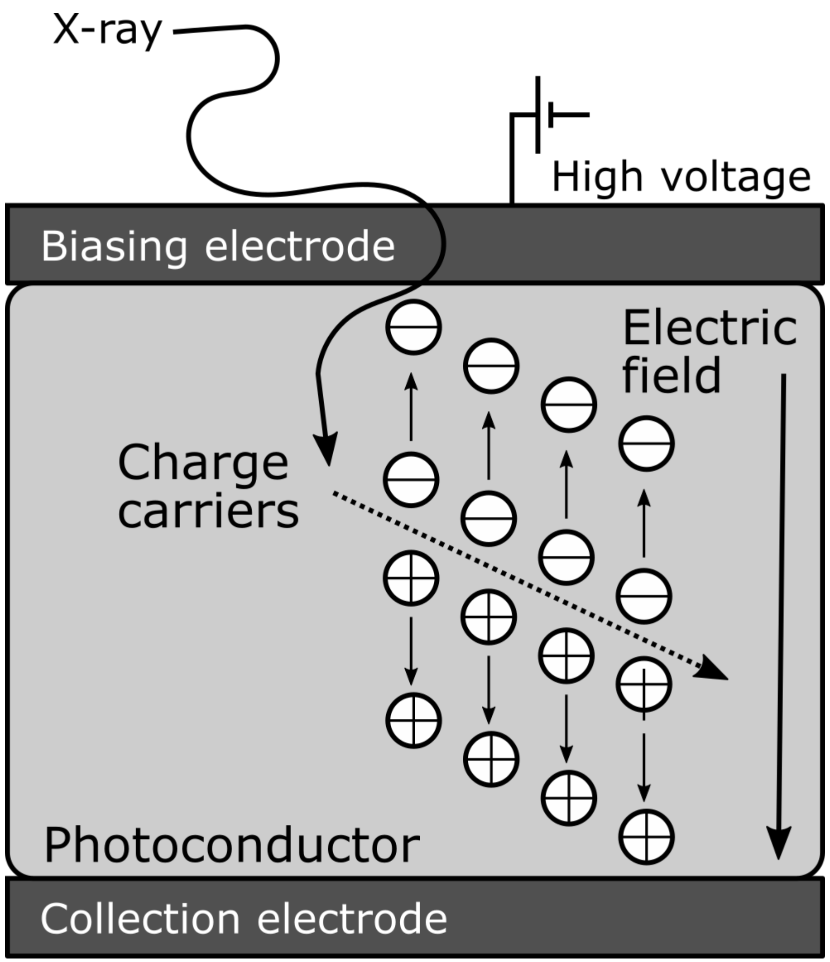
- Digital Radiography
  - CR
    Computed Radiography
    - Indirect conversion
      - Storage phosphors
  - DR
    Direct Radiography
    - Indirect conversion
      - Scintillator-TFT
      - Scintillator-CCD
      - Image Intensifier
    - Direct conversion
      - Photoconductor
        FDP
      - Selenium-drum

**70-200 µm Pixels**

# Solid-State X-ray Detection



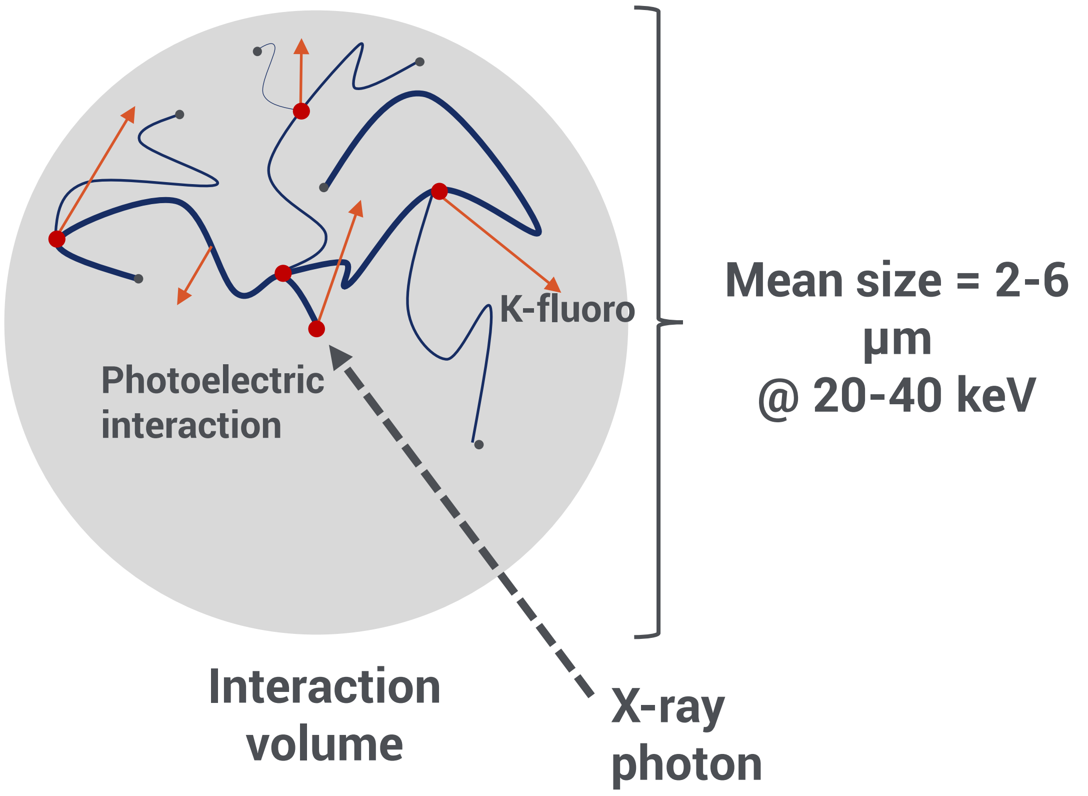

Indirect conversion




Direct conversion

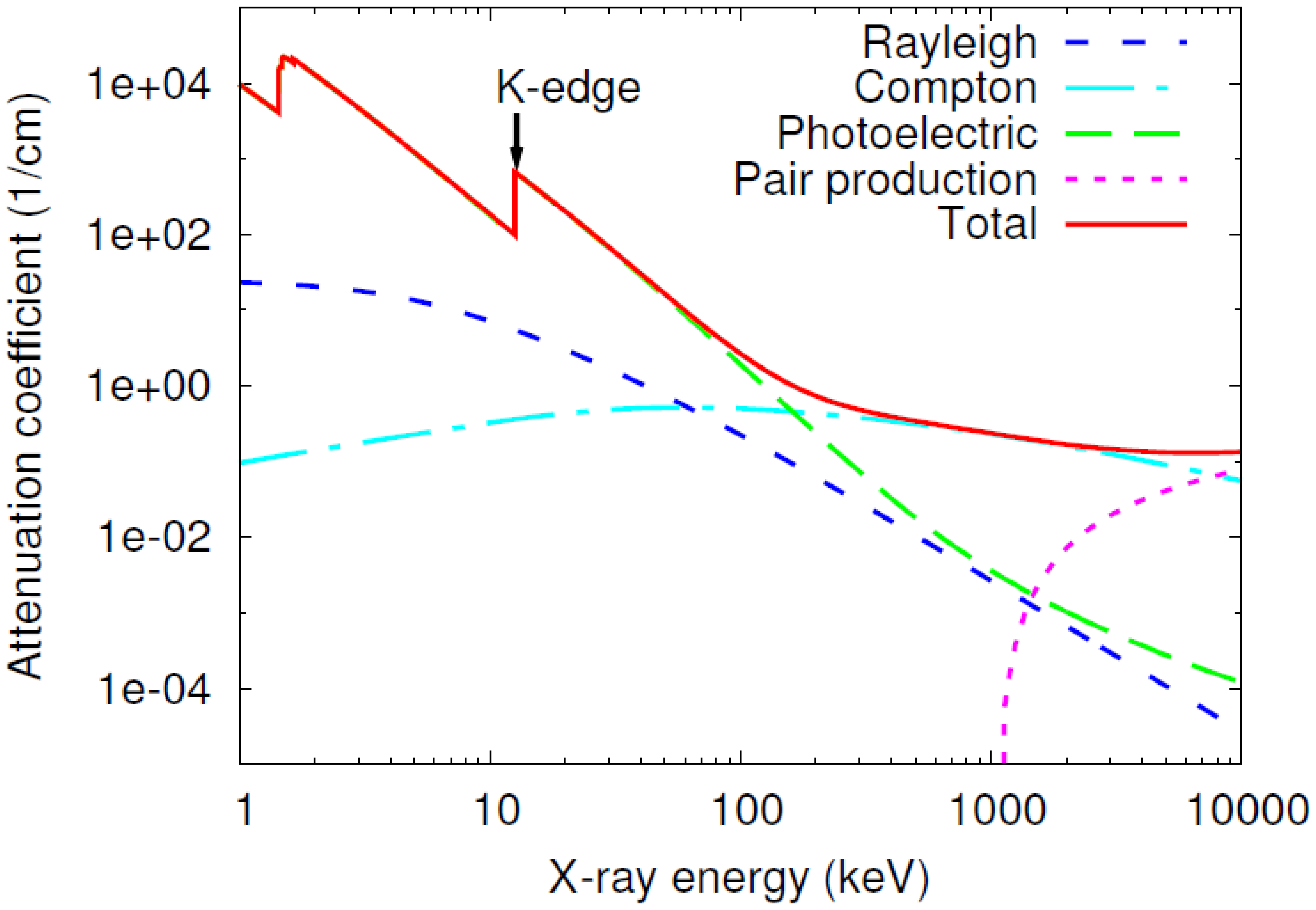
# Amorphous Selenium (a-Se) Photoconductor

- Easily processed as a uniform thick layer over large area
- Atomic number (34) sufficient for hard x-ray imaging
- Low dark current & High charge collection efficiency



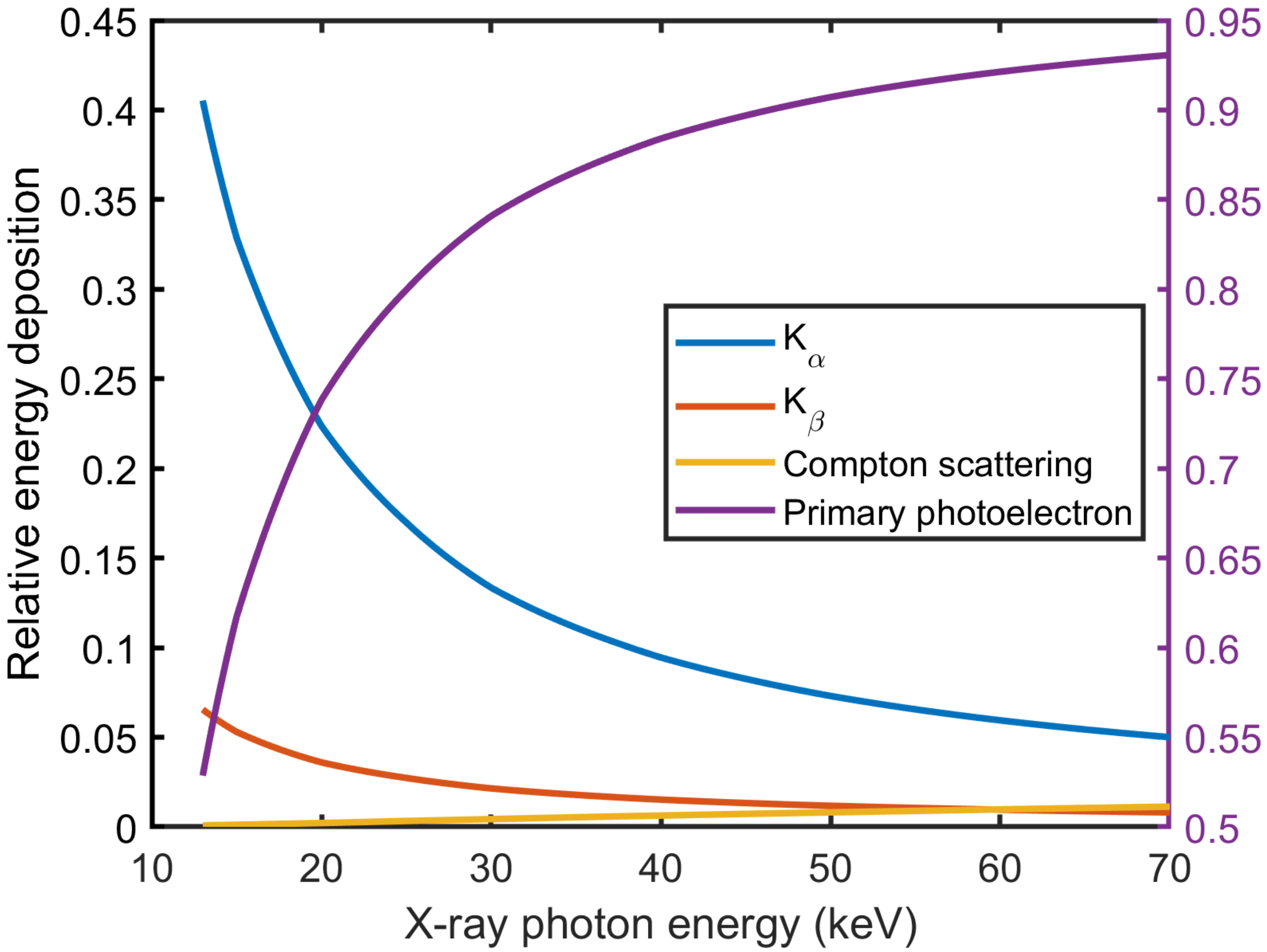

**High Inherent Spatial Resolution, High Absorption for Diagnostic X-rays**
**→ Low noise, Small Pixel Pitch CMOS**

# X-ray Attenuation Coefficients for a-Se




**K-edge = 12.66 keV**

# X-ray Interaction Energy Deposition in a-Se




**35 keV**

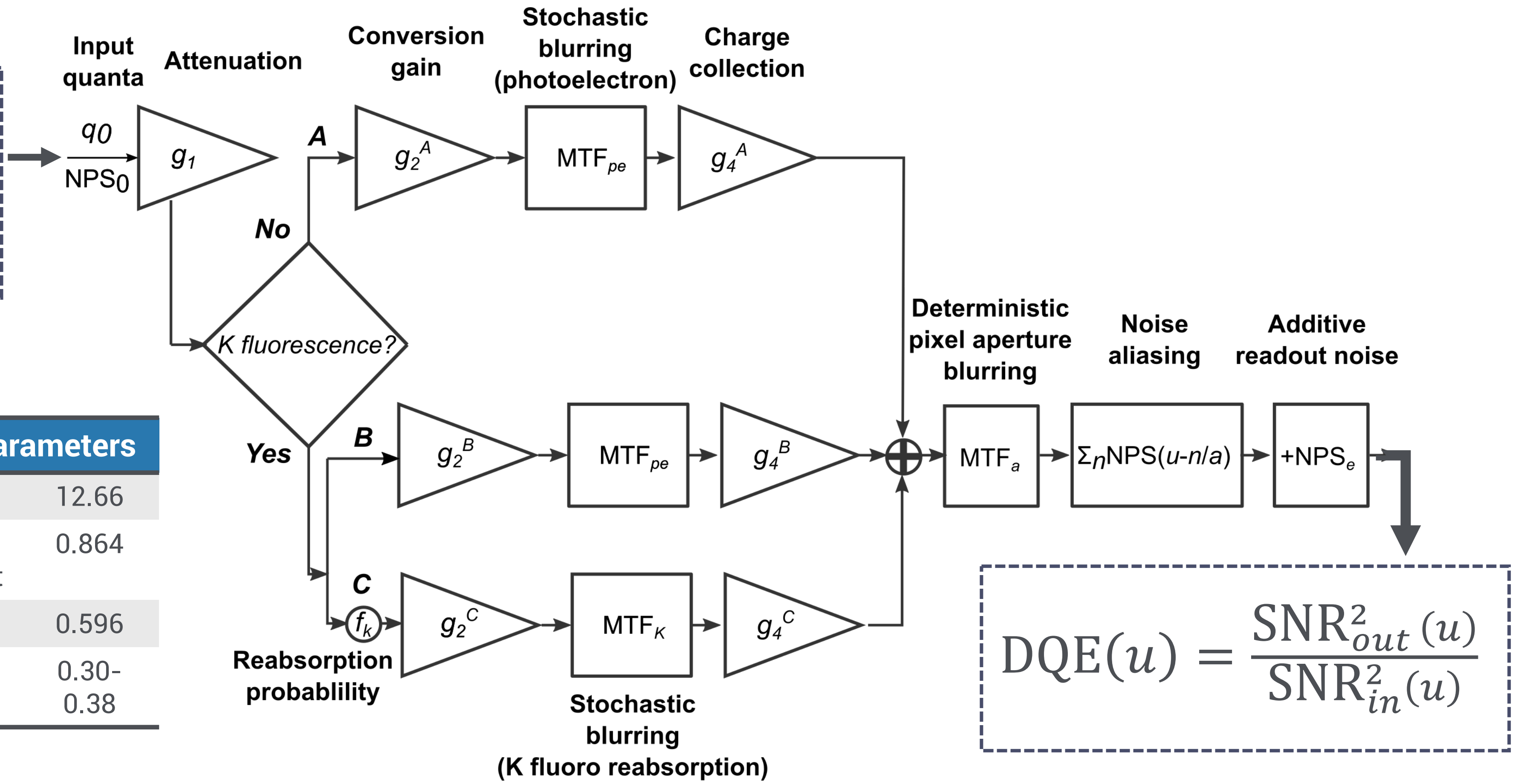
$$p_{pe} = 0.866$$
$$p_{K_\alpha} = 0.111$$
$$p_{K_\beta} = 0.018$$
$$p_C = 0.005$$

**Weighting Factors**

# Cascaded Systems Theory

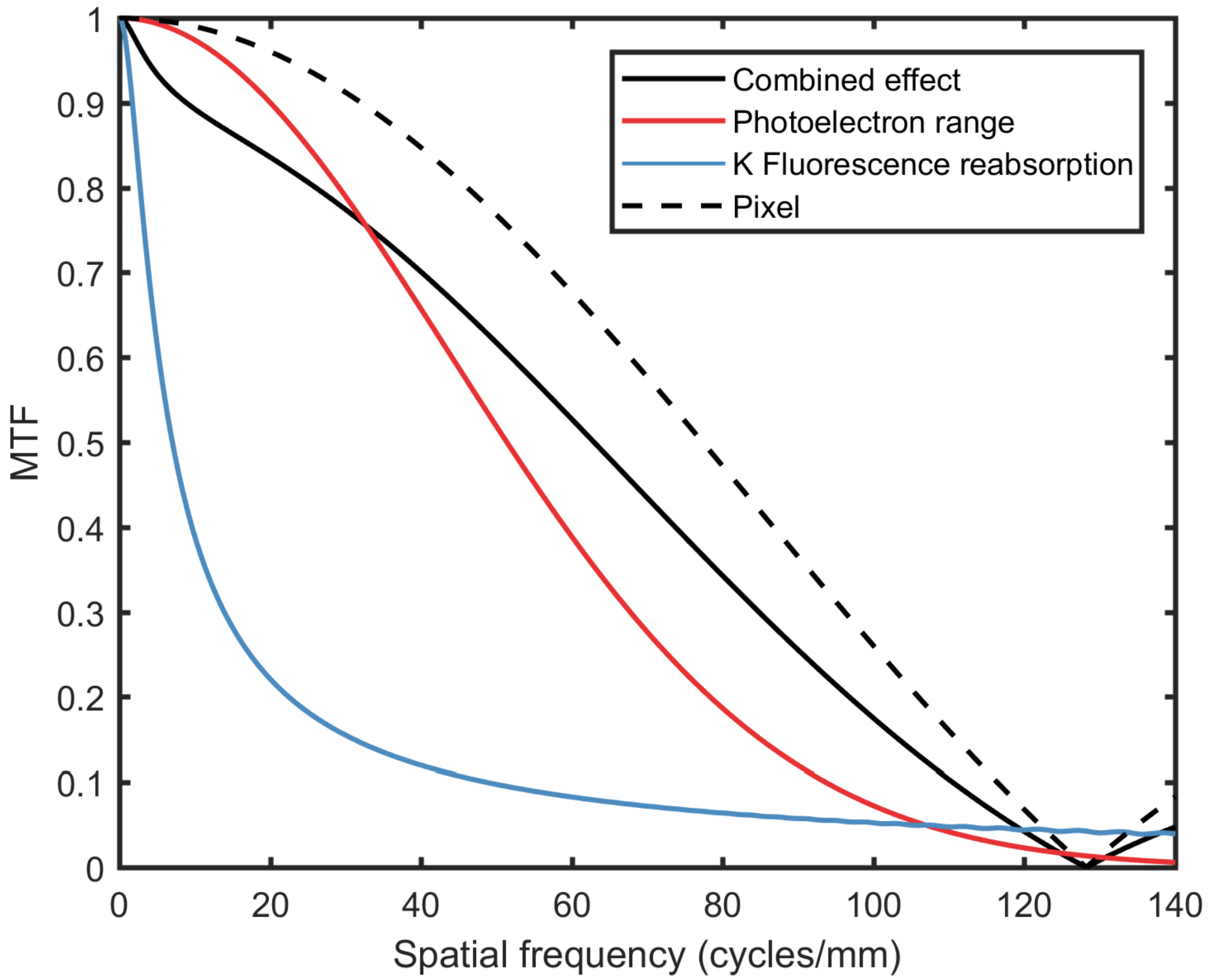
**X-ray Spectrum Model**

| K-Fluorescence Parameters | |
|---|---|
| K-edge energy (keV) | 12.66 |
| K-shell contribution to photoelectric effect | 0.864 |
| K-fluorescent yield | 0.596 |
| Escape probability | 0.30-0.38 |



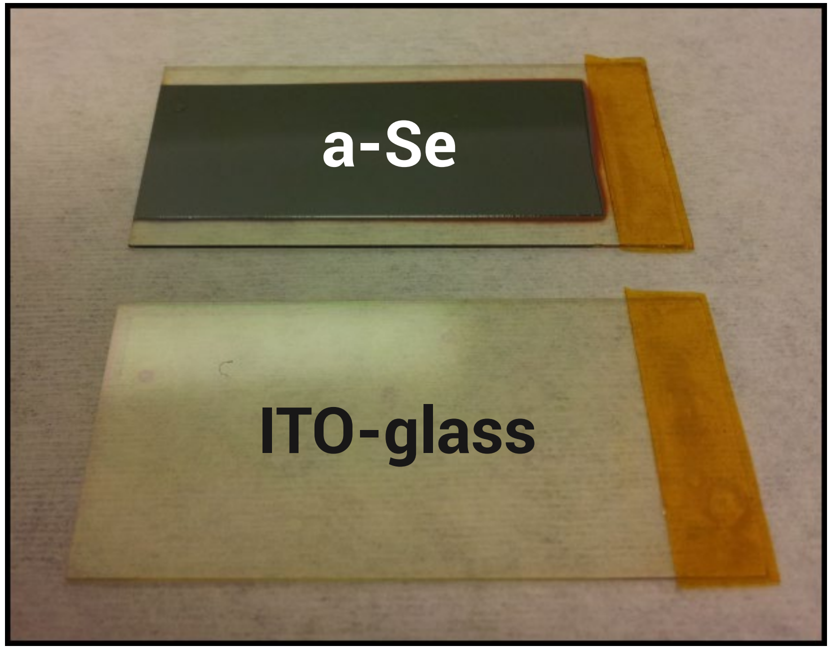

**Detective Quantum Efficiency (DQE)**

# X-ray Interaction MTF for a-Se



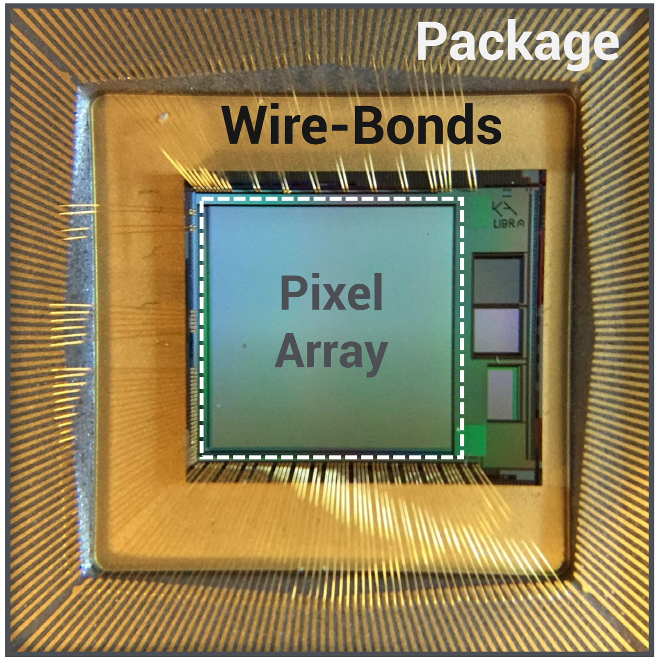
# Objective

Develop hybrid **a-Se/CMOS detectors** to achieve a unique combination of high spatial resolution (≤10 μm pixel) and high quantum efficiency for hard x-rays **for X-ray diffraction imaging**



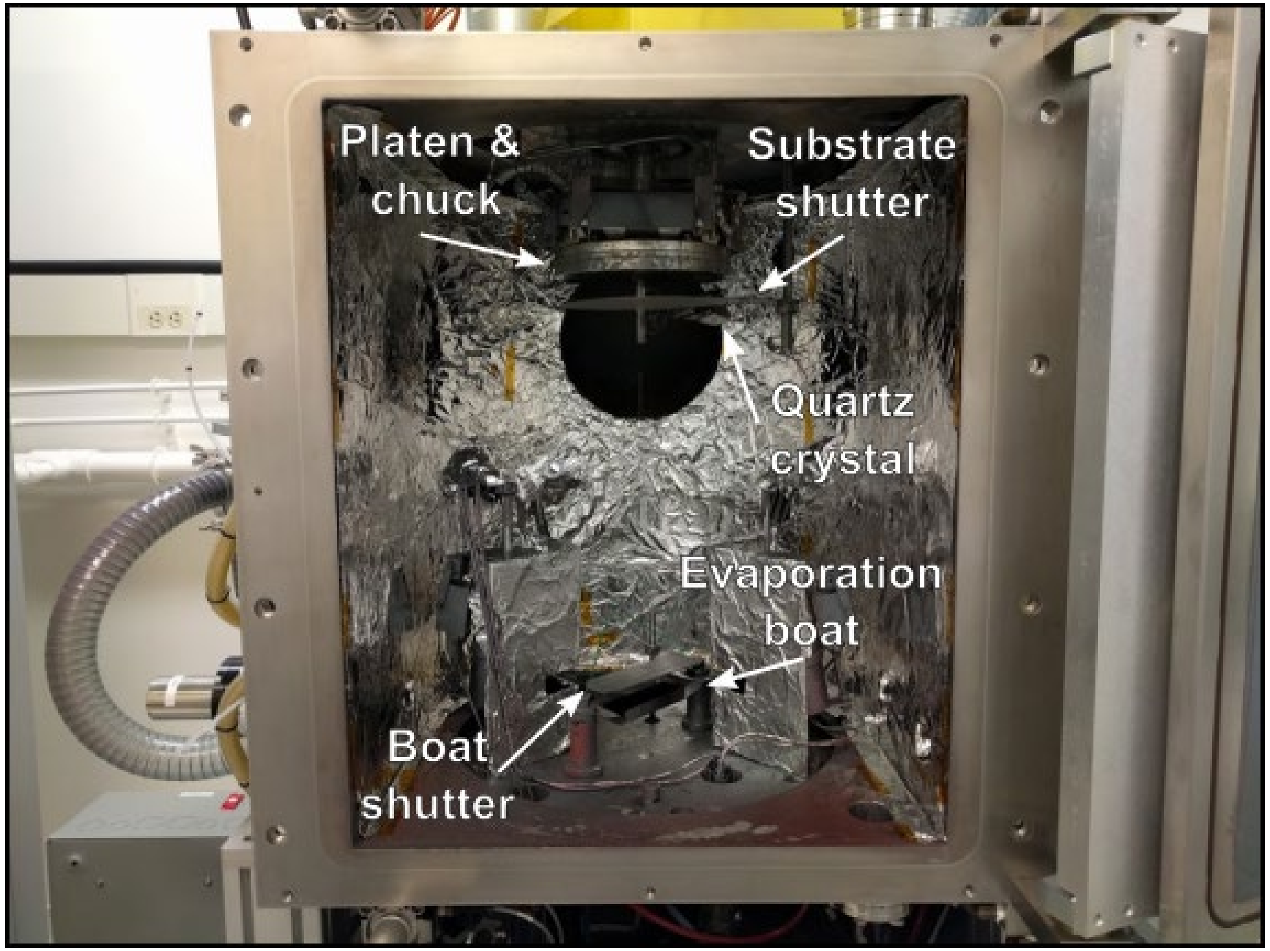

**a-Se Films on ITO-glass by Physical Vapor Deposition**

+

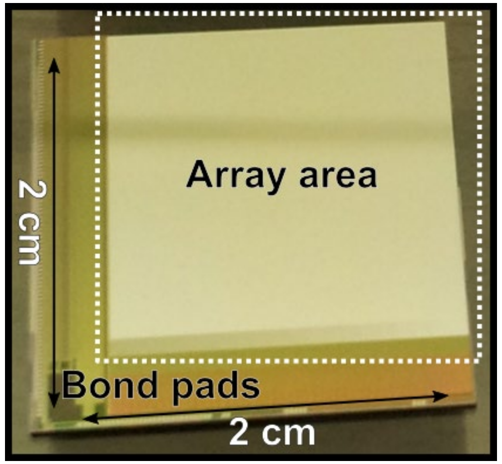



**CMOS Readout Integrated Circuit (ROIC)**

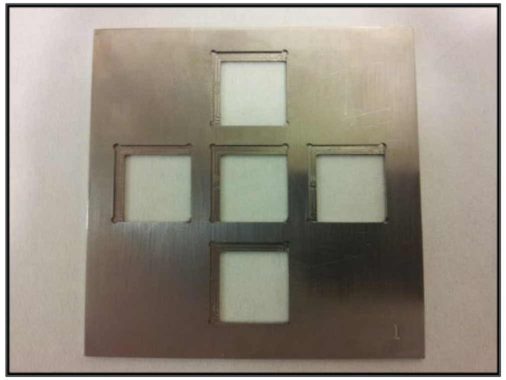
# Deposition of a-Se Films by Thermal Evaporation




Thermal Evaporator for a-Se
at G2N Centre, University of Waterloo

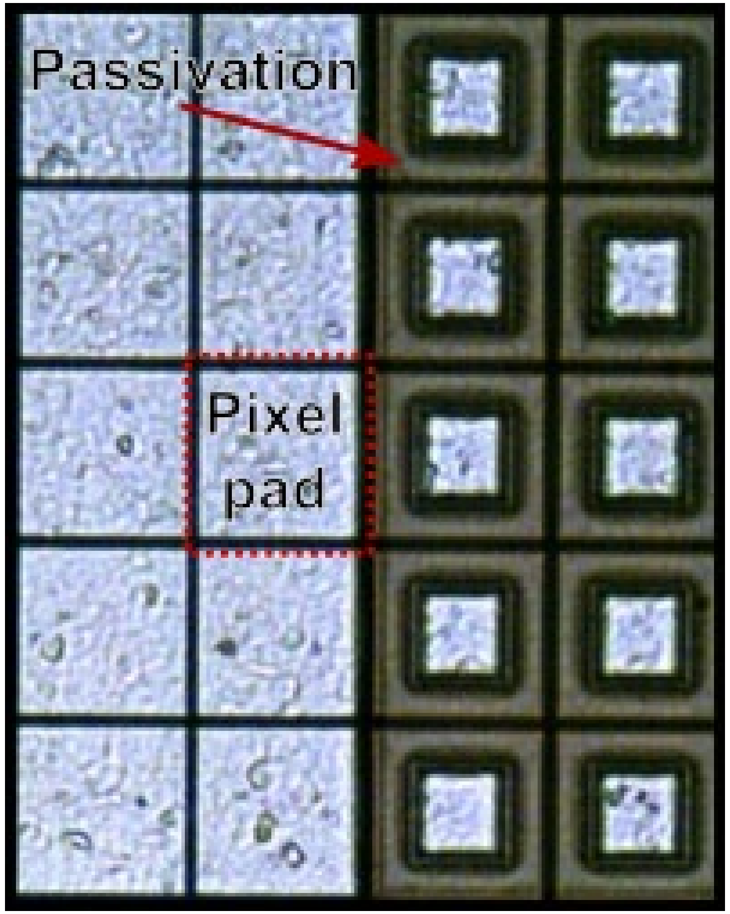



CMOS Readout IC

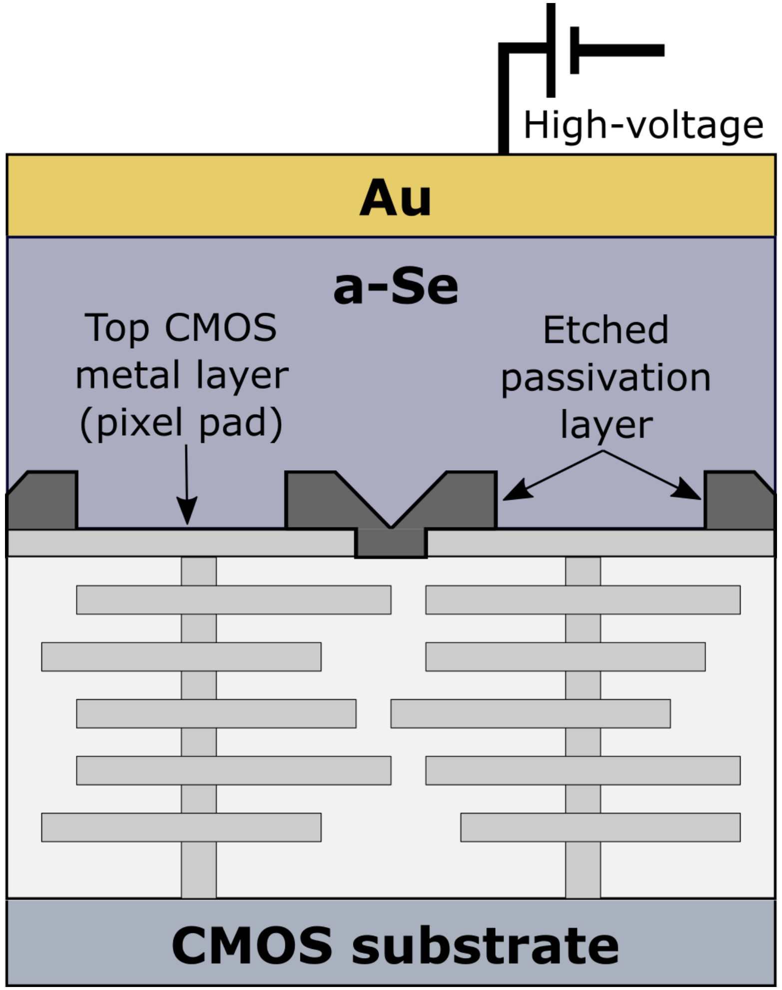


Shadow Mask

# Back-end Processing of CMOS ROIC

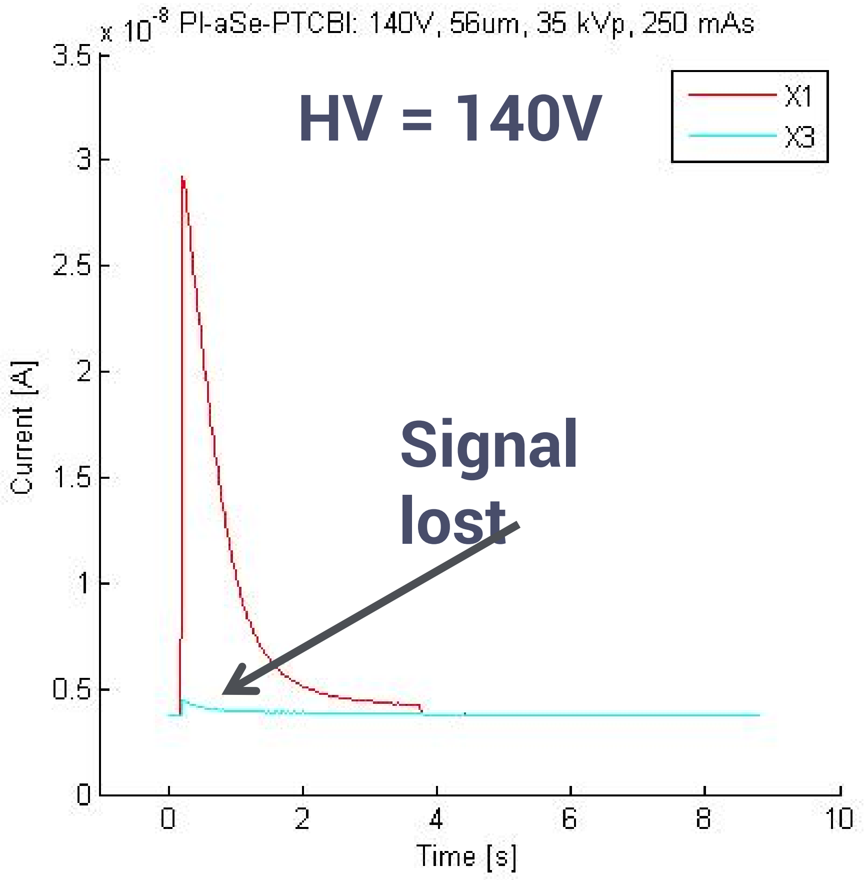


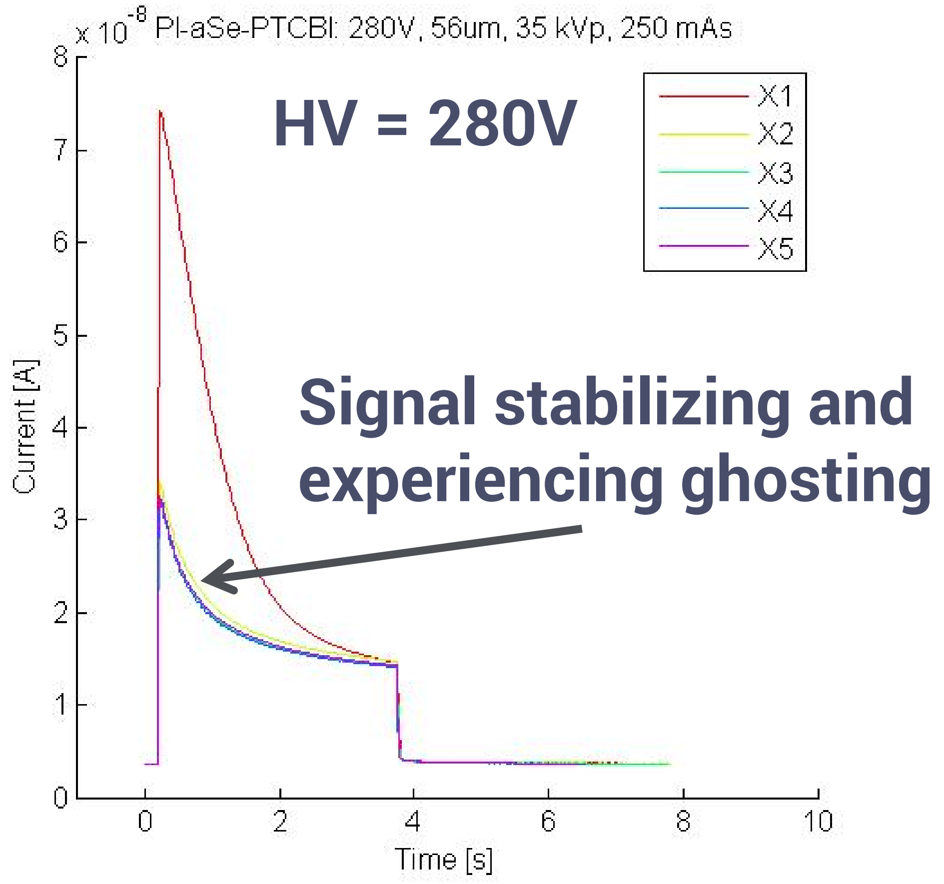

A micrograph of etched CMOS passivation




A diagram of the a-Se/CMOS detector cross-section

# Polyimide Layer Conduction



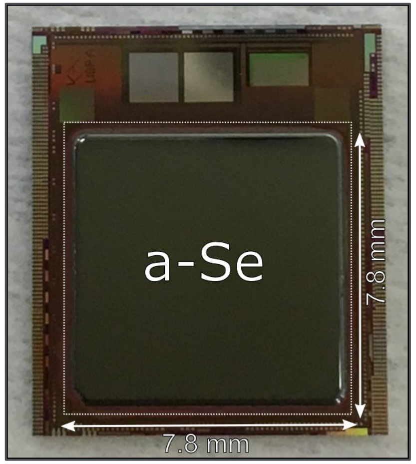




35 kVp, 250 mAs
1 min. between exposures
5 min. between HV changes)

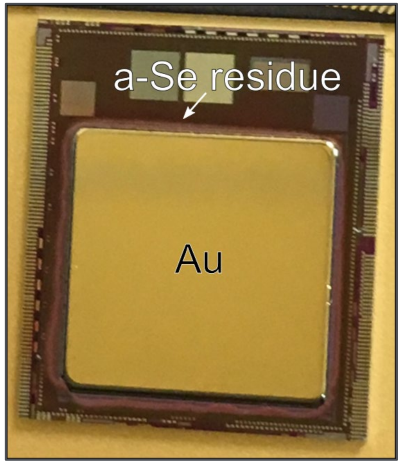
- Charge build-up at the a-Se/PI -> E-field reduction -> sensitivity loss
- Reversing the detector bias resets the device.

# LIBRA Readout IC

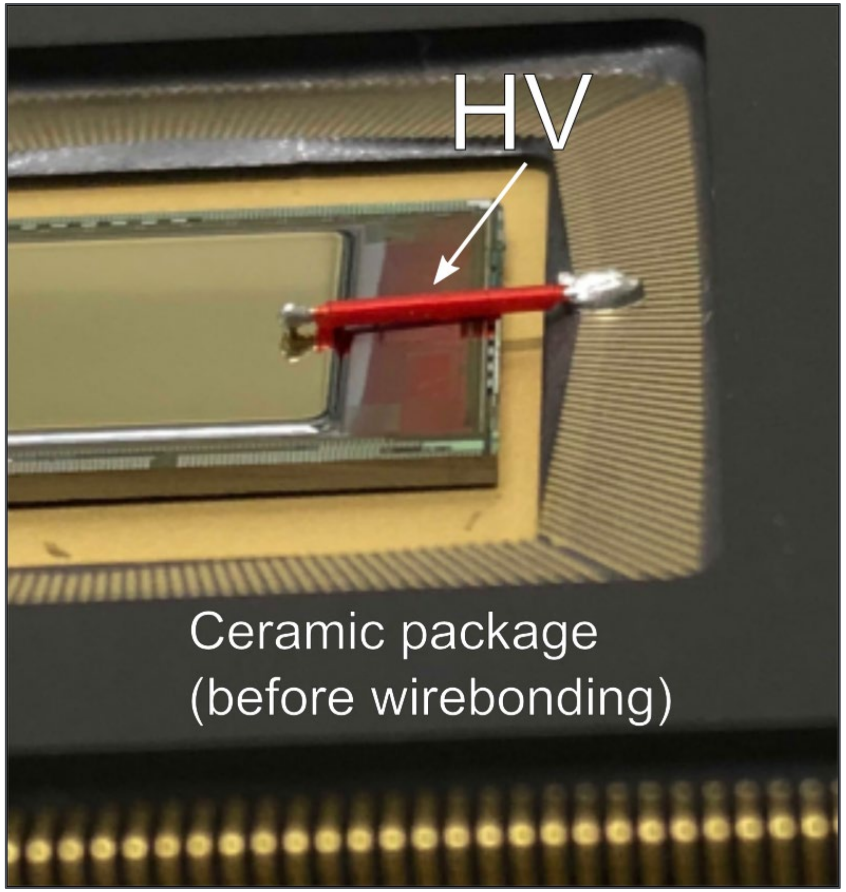
- 3T active pixel sensor
- **$7.8 \times 7.8\ \mu m^2$ pixel pitch**
- $1000 \times 1000$ pixel array
- **$7.8 \times 7.8\ mm^2$ imaging area**




**a-Se Deposition**

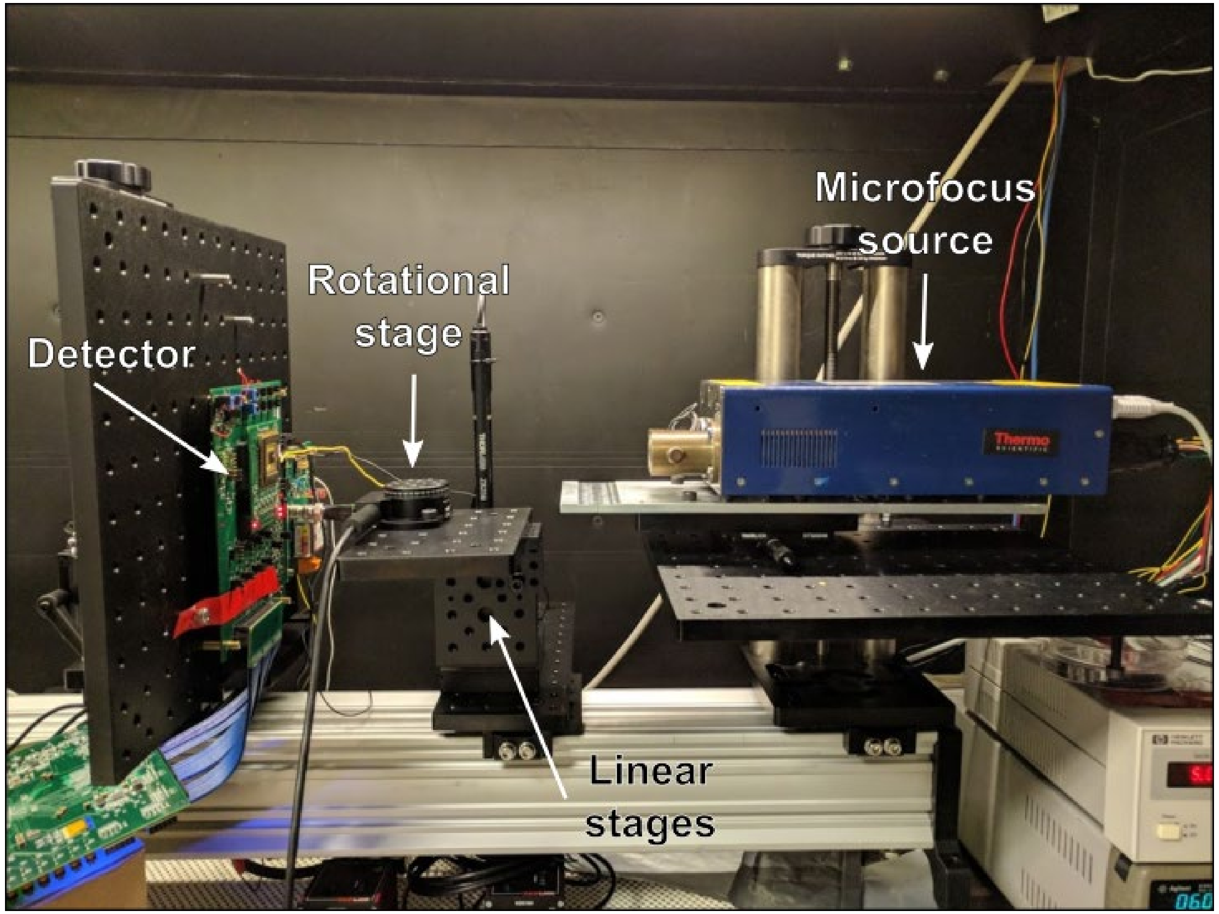



**Au Deposition**

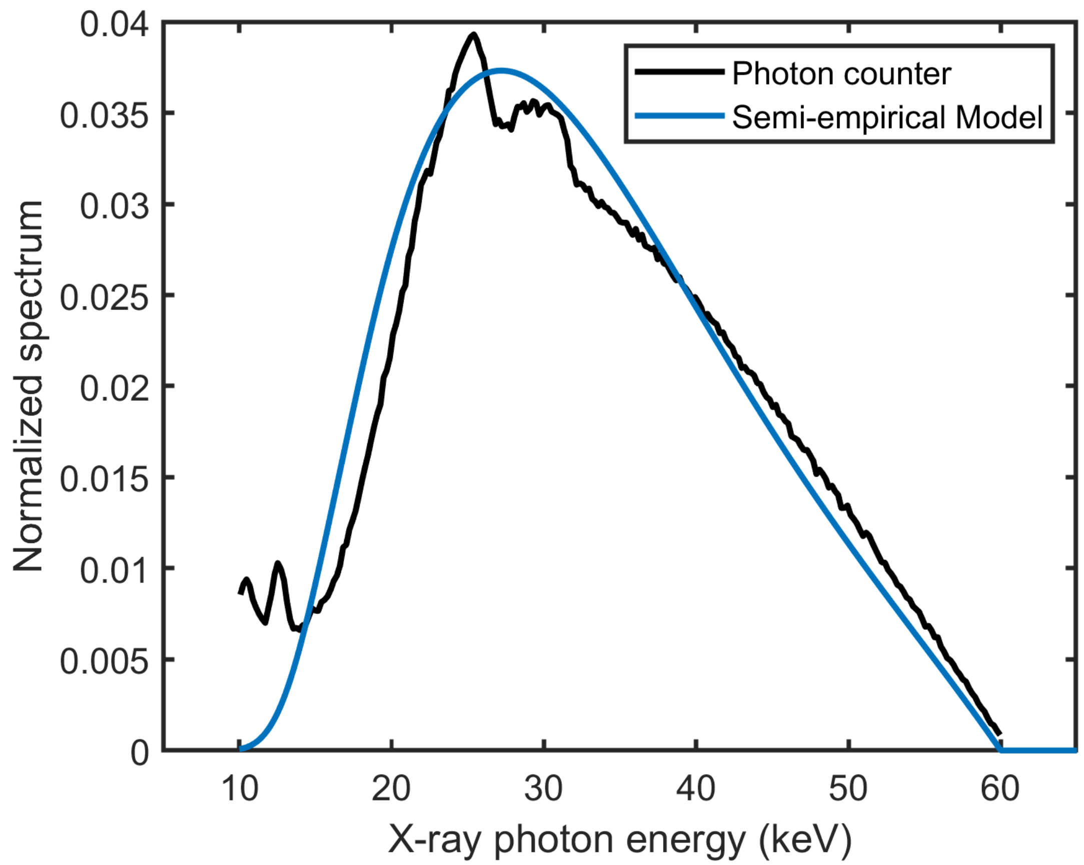



**Packaging**

# LIBRA @ University of Waterloo



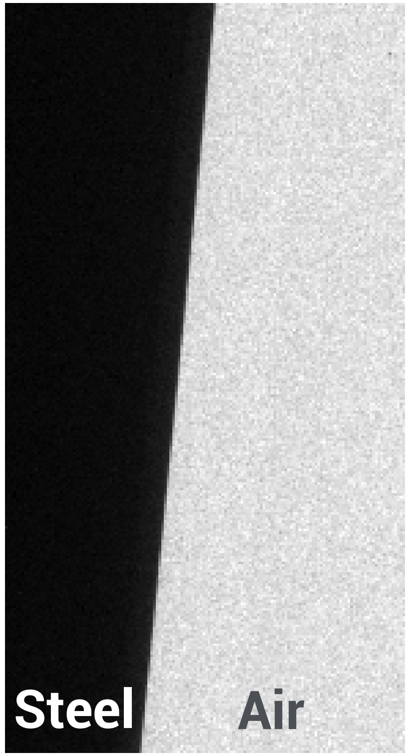
# Microfocus Spectrum Characterization



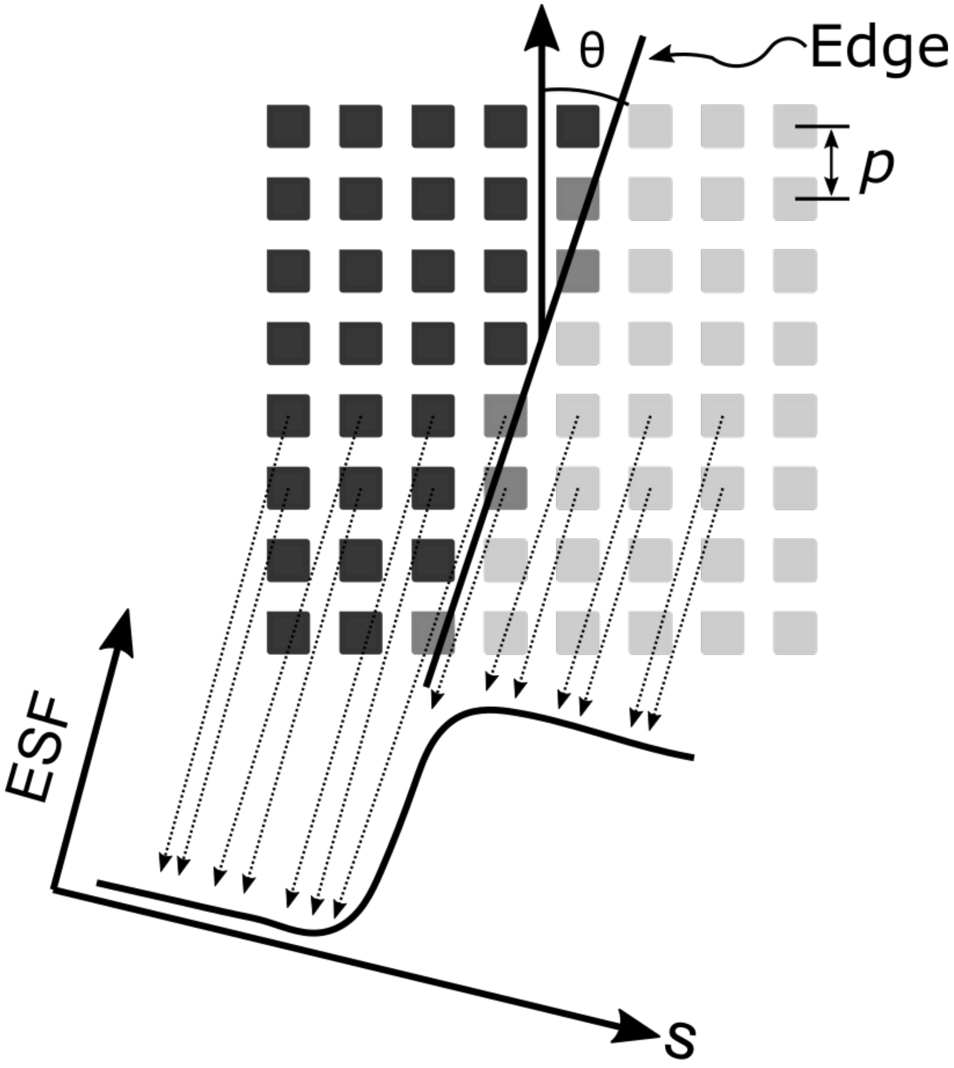

**9 µm spot size**

| Tube potential (kV) | 60 |
|---|---|
| Filter (mm Al) | 3.0 |
| Half-value-layer (mm Al) | 1.69 |
| Mean Energy (keV) | 34.3 |
| Fluence per Exposure ($mm^{-2}\ R^{-1}$) | $1.26 \times 10^8$ |

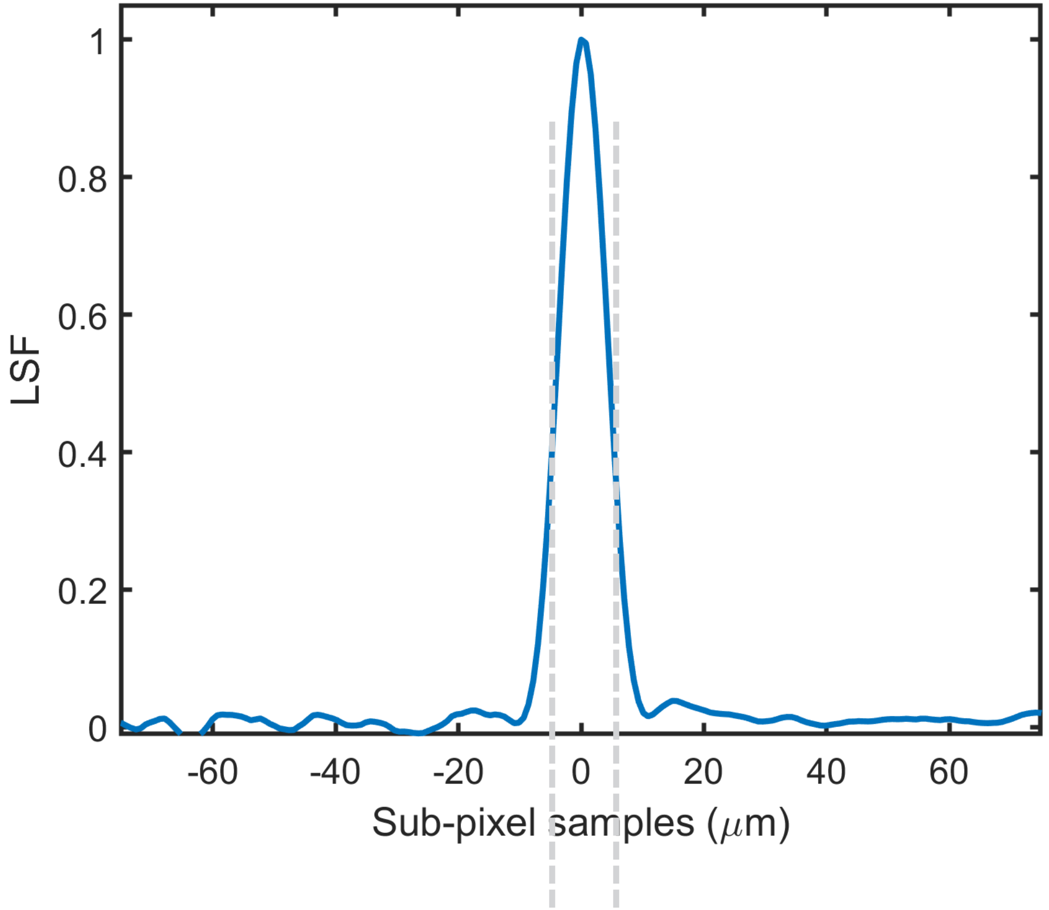
# Slanted-Edge Technique

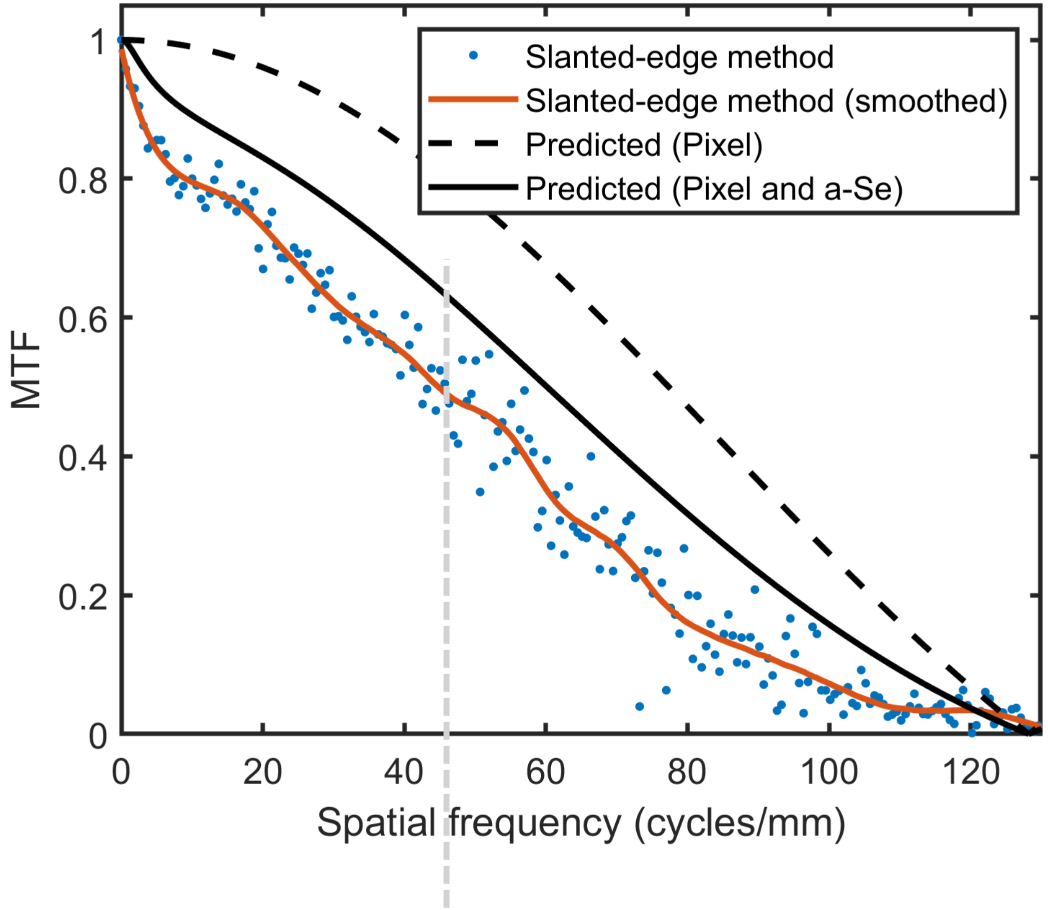



Edge image



# LIBRA Spatial Resolution




**FWHM = 9.7 µm**

**50% contrast for 11 µm object**

High Resolution Scintillator Comparison:
**15 µm GADOX 9 µm pixel FWHM = 27 µm**
*Larsson et al., Scientific Reports 6, 2016*

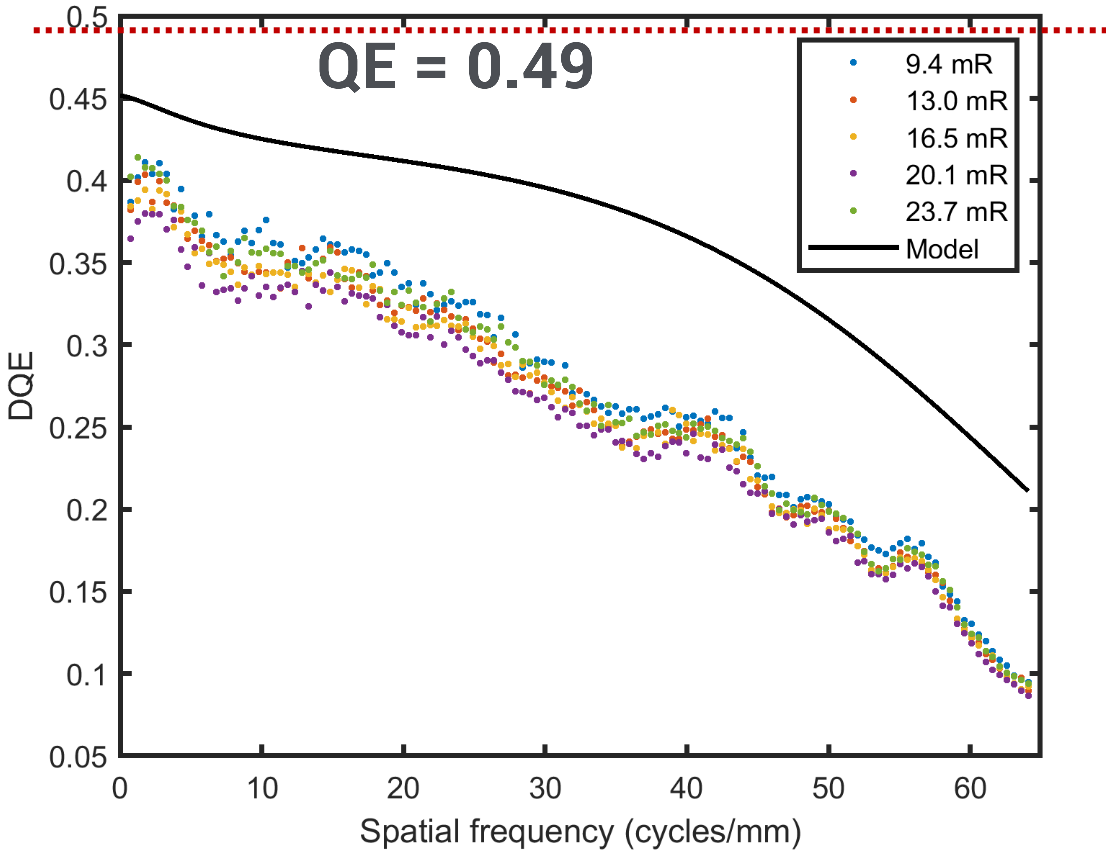
# LIBRA DQE

**Best reported to date:**

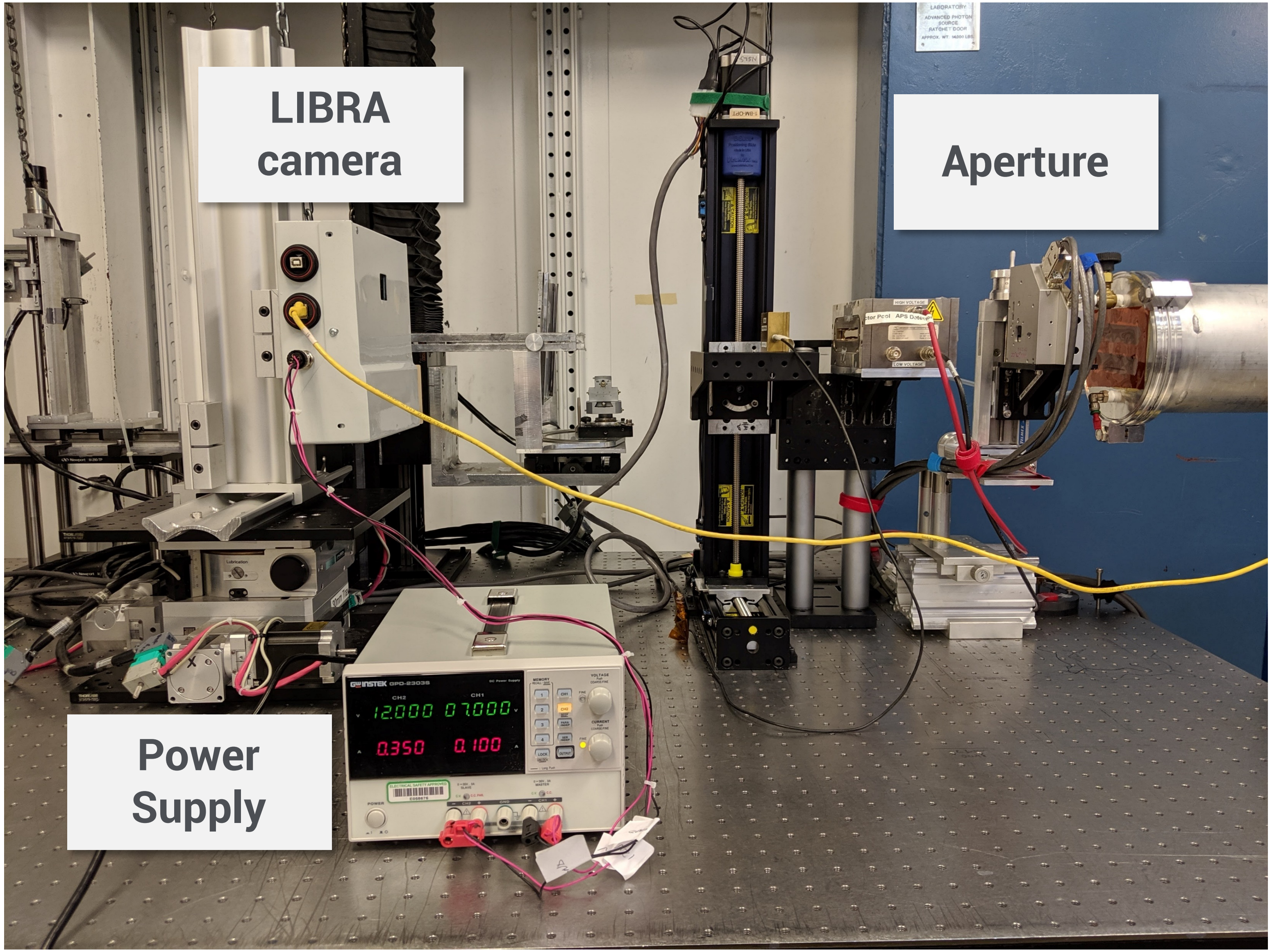
15 μm GADOX
9 μm pixel
QE = 0.13

*Larsson et al., Scientific Reports 6, 2016*

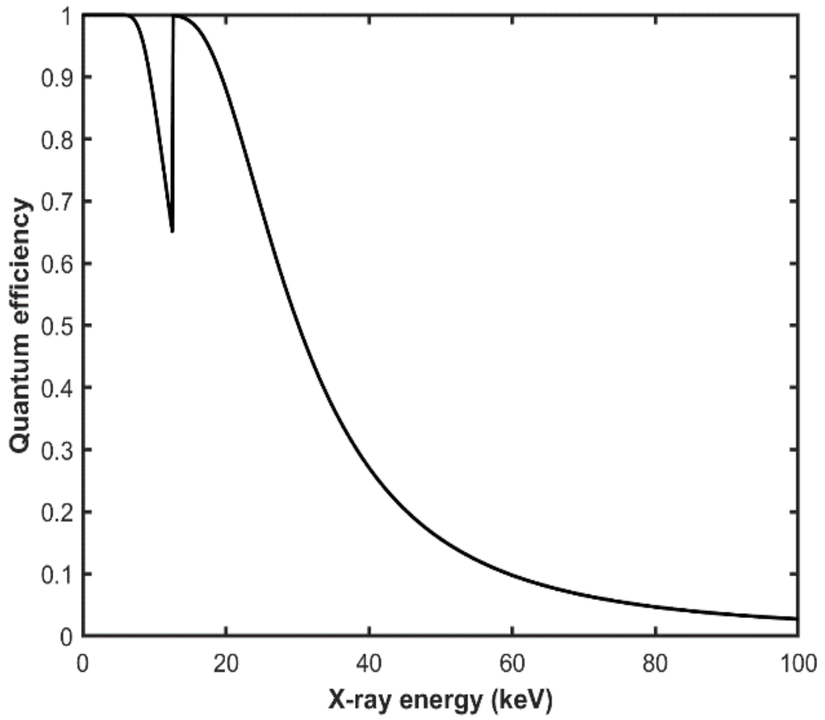
**Vs**

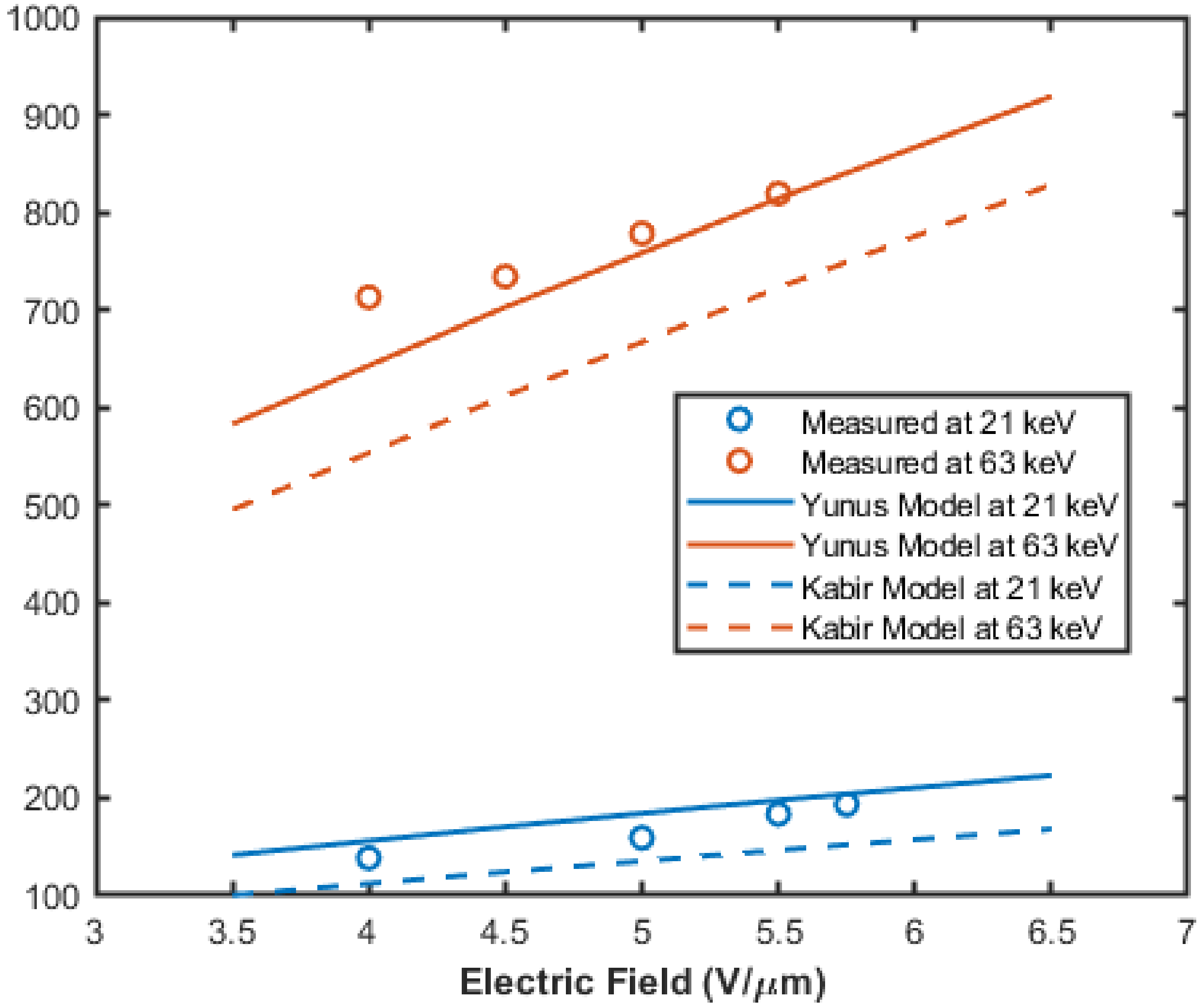


# LIBRA @ ANL APS Beamline 1-BM

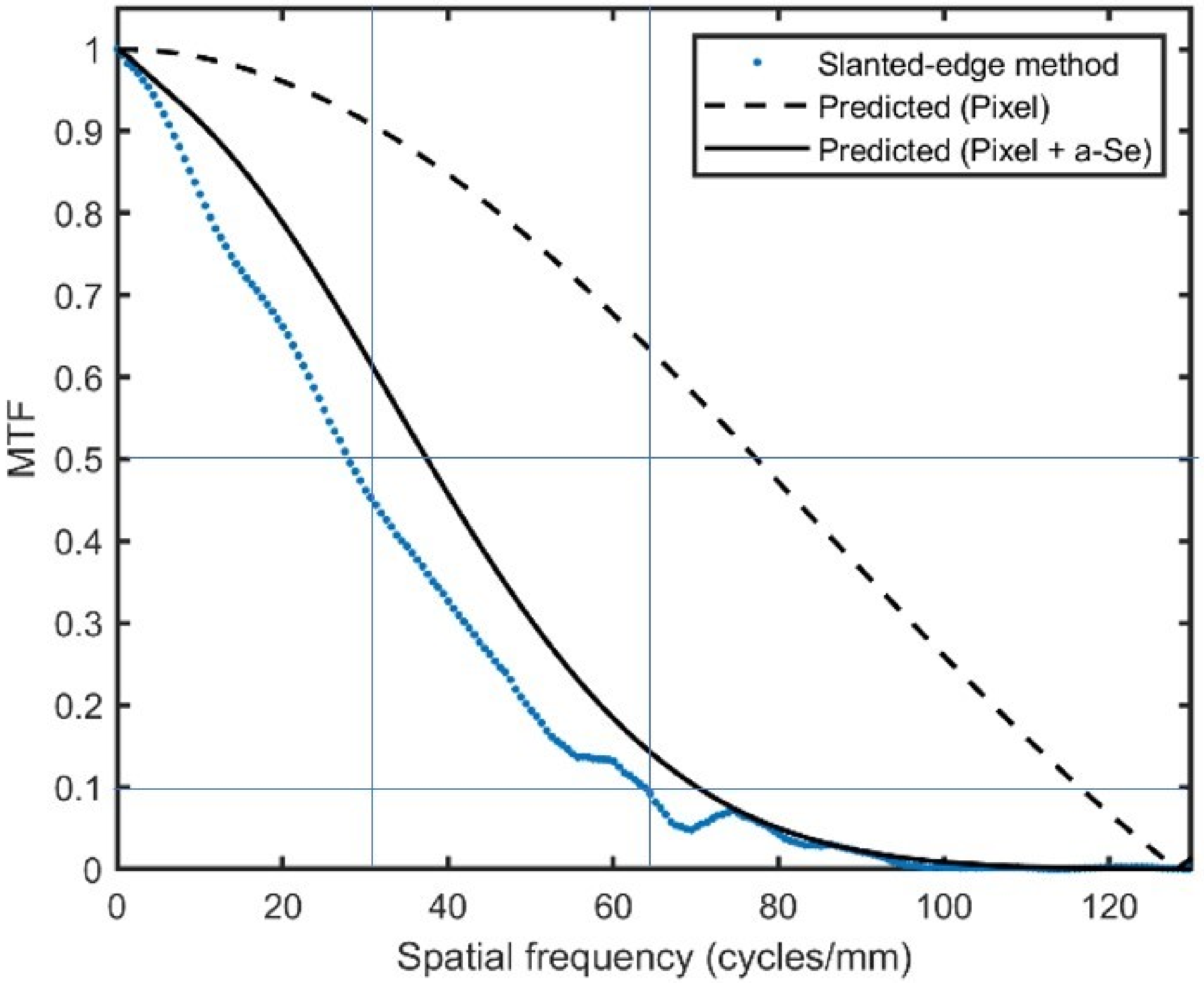


# LIBRA Responsivity @ 21 keV and 63 keV

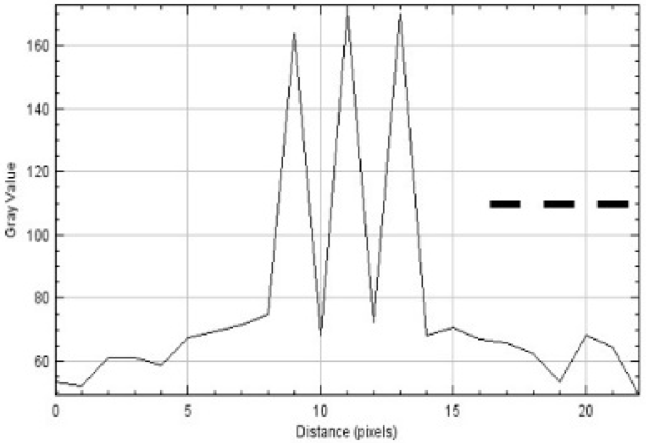


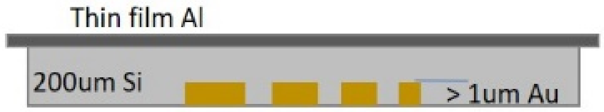
# LIBRA Spatial Resolution @ 63 keV



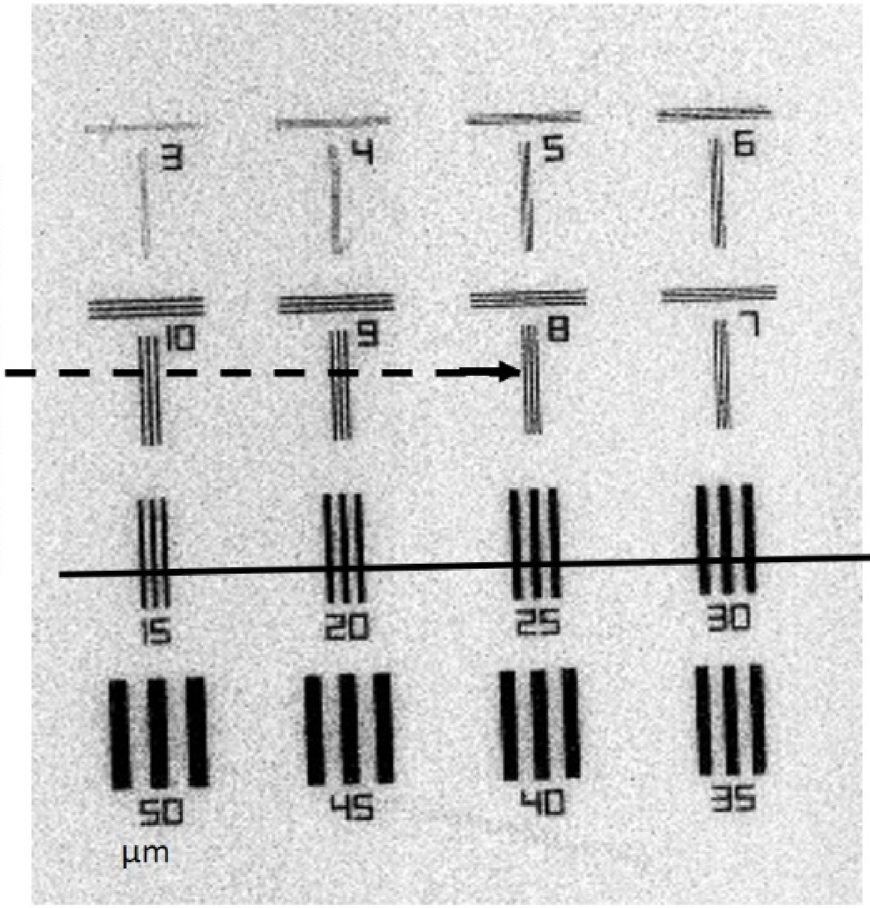
# JIMA RT RC-05 Transmission Bar Target @ 21 keV

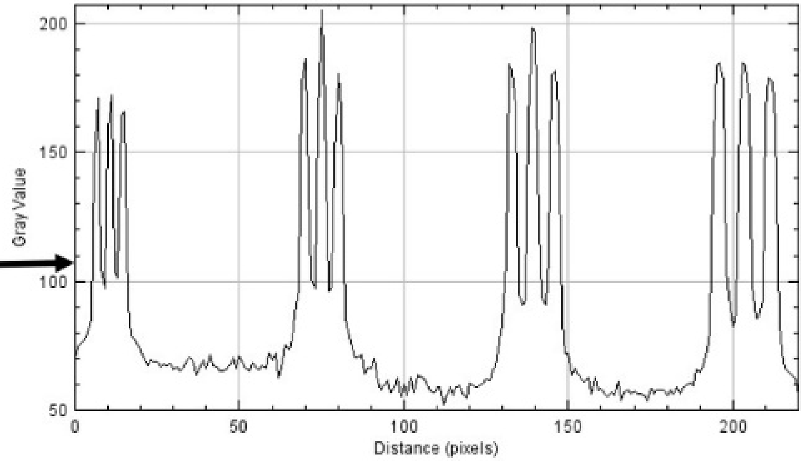



Jima target cross section

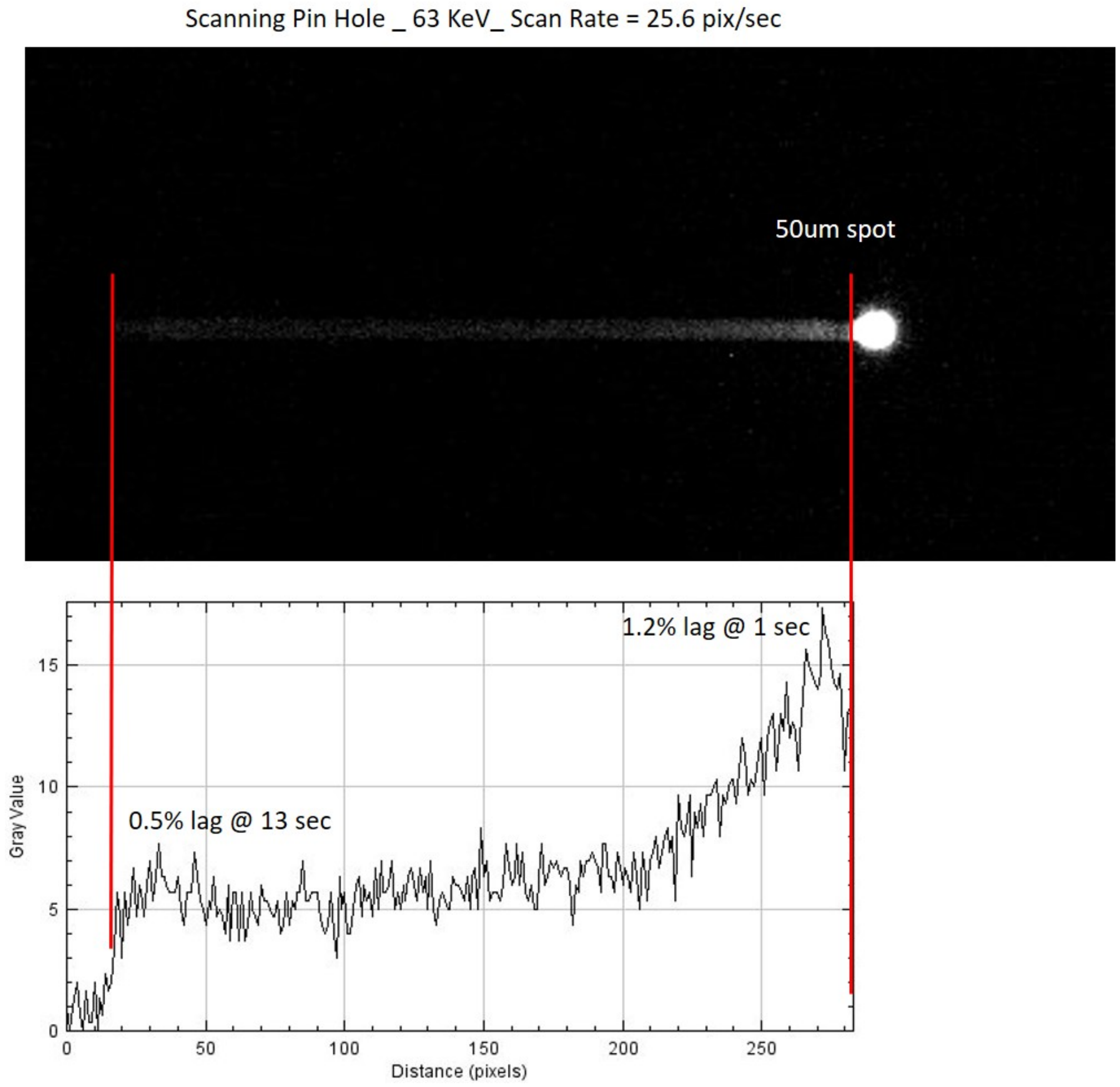



JIMA RT RC-05 Image _21keV_100fr avg_250ms Tint



# 50 µm Pinhole Lag @ 63 keV



# Conclusions

- The a-Se/CMOS prototypes demonstrate a remarkable combination of high spatial resolution and high quantum efficiency for hard x-rays

***Factor of 3x DQE improvement despite being relatively unoptimized***

# Acknowledgements

**Michael Farrier**
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# Thank you

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