# Optimization of the detection thresholds of single-photon counting sensors for breast cancer screening procedures

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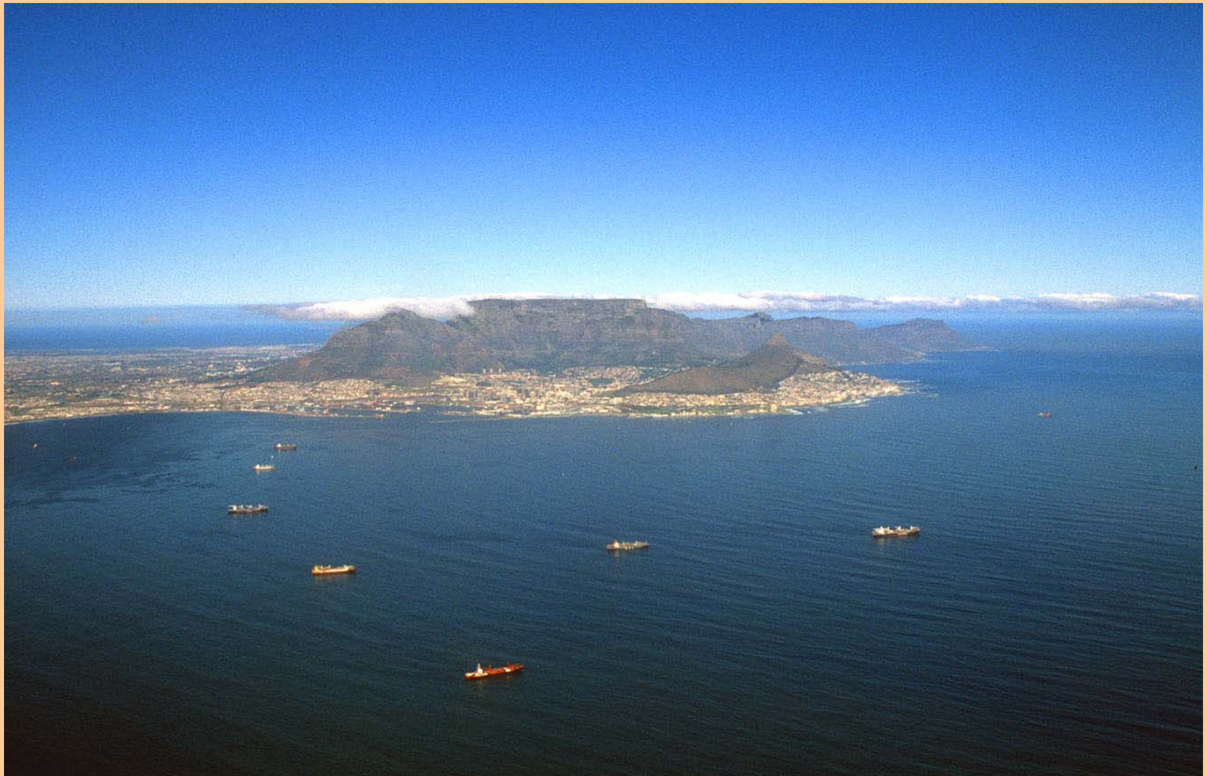


# Photocounting detection threshold

- **High enough** to discriminate signal from noise
- **Low enough** to detect every incident primary X-ray

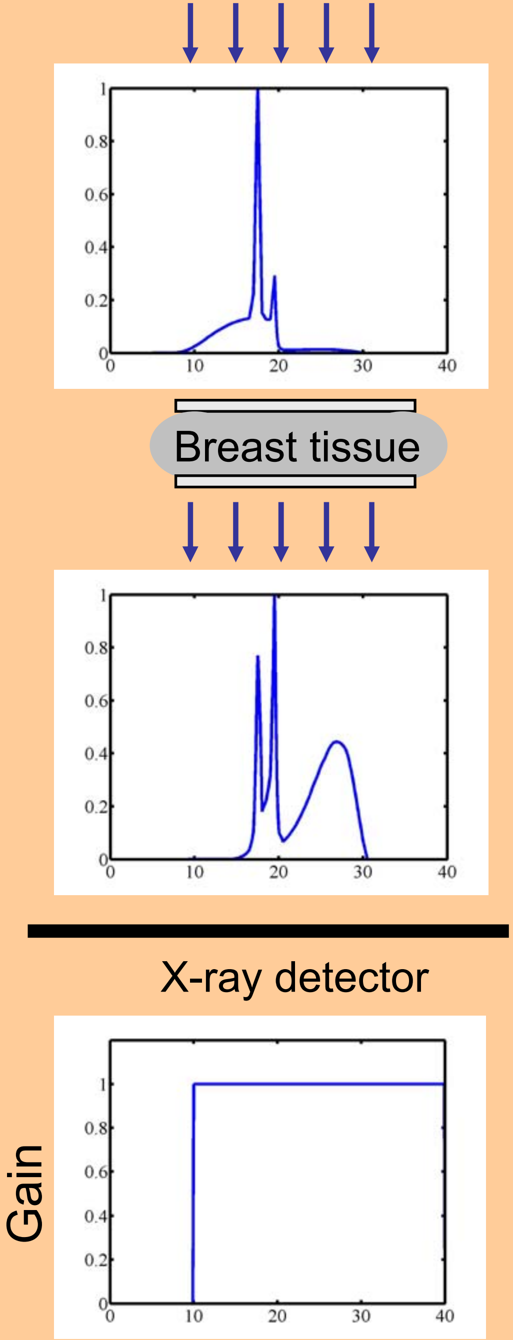
**Problem:** False counts due to charge-sharing in Pixel Detectors (worst when decreasing pixel size)

**Solution:** Higher detection threshold

**Problem:** Image noise due to scattered radiation

**Solution ?:** Higher detection threshold ?

**Effect of detection threshold on system performance in mammography??**



# Detector performance in X-ray imaging

Fourier-based linear system analysis
Statistical decision theory → **Detective quantum efficiency (DQE):**

*Modulation Transfer Function*

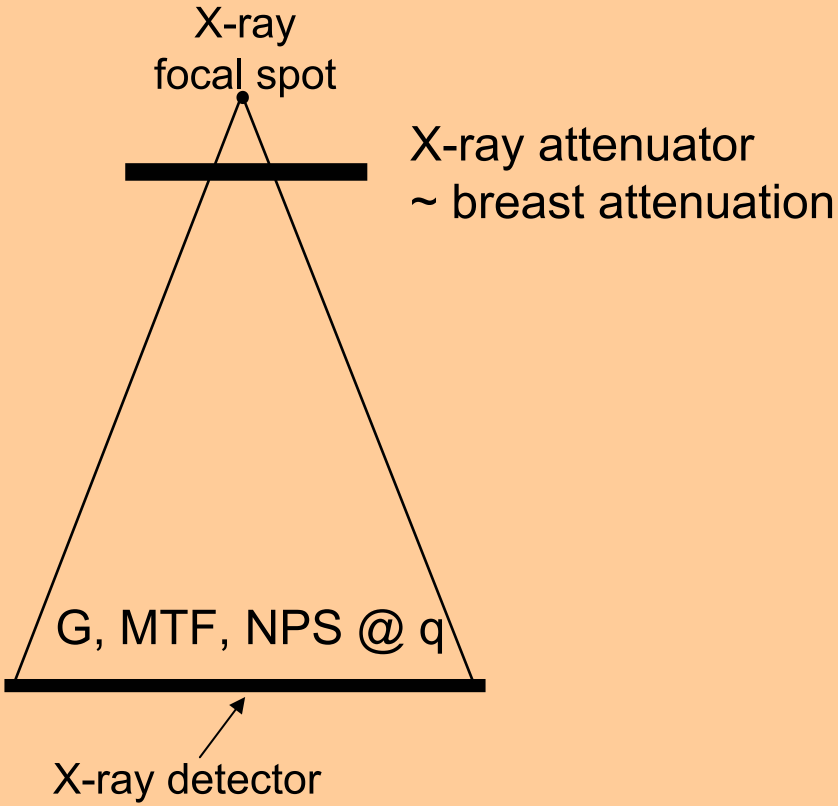
*Large-area detector gain*

$$DQE(f) = \frac{\left|GqMTF(f)\right|^2}{NPS(f)\times q}$$

*Noise Power Spectrum*

*X-ray fluence*

$$DQE \approx \frac{SNR^2}{SNR^2_{\max}}$$



# Detector performance in broad-spectrum X-ray imaging

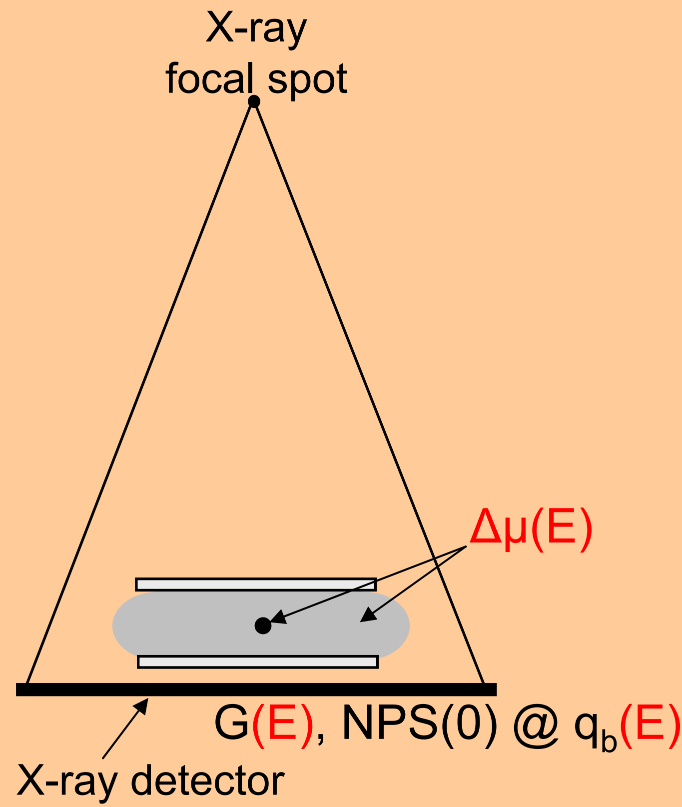
Fourier-based linear system analysis
Statistical decision theory → **Broad-spectrum DQE**
Detector contrast modulation in the domain of X-ray energy

*Difference in attenuation coefficients between breast and lesion to detect*

*Large-area detector gain*

$$DQE(0) = \frac{\left| \int G(E)\Delta\mu(E) q_b(E) dE \right|^2}{NPS(0) \times \int \Delta\mu(E)^2 q_b(E) dE}$$

*Noise Power Spectrum* *X-ray fluence*




cf task-dependent DQE
*Tapiovaara and Wagner, Phys. Med. Biol. 38 (1993)*
*Cahn et al., Med. Phys. 26 (1999)*

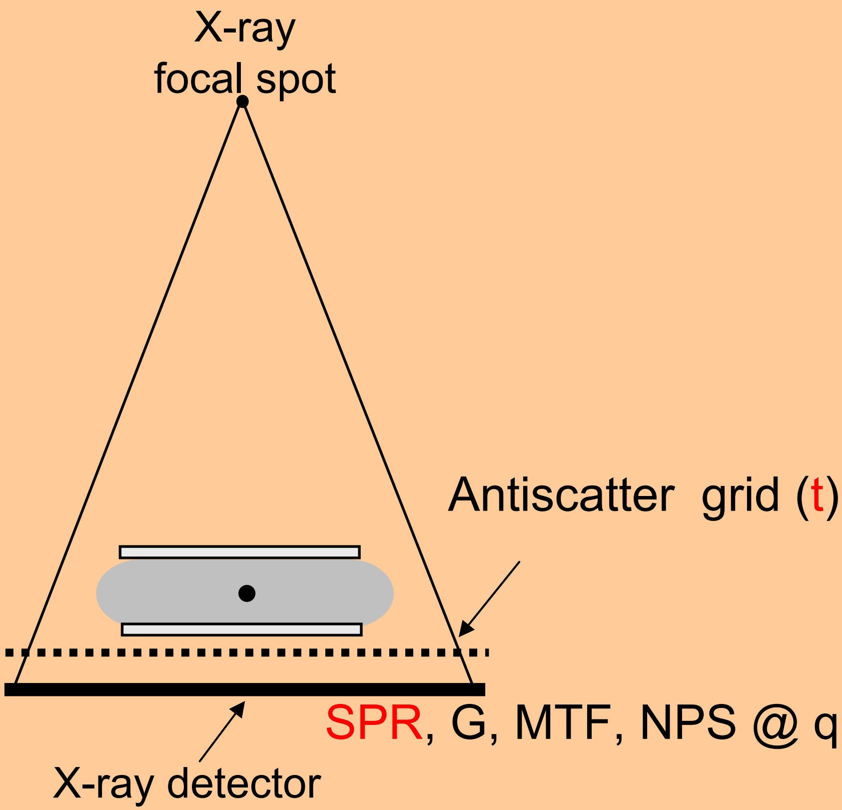
# System performance in X-ray imaging

Fourier-based linear system analysis
Statistical decision theory → **System DQE**
Scatter-reduction technique

*Primary radiation transmission factor of grid*

$$DQE(f) = \frac{t}{1+SPR}\,\frac{\left|GqMTF(f)\right|^2}{NPS(f)\times q}$$

*Scatter-to-primary ratio*



# System performance in broad-spectrum X-ray imaging

Fourier-based linear system analysis
Statistical decision theory
Detector contrast modulation in the domain of X-ray energy
Scatter-reduction technique

→ **Broad-spectrum system DQE**

$$DQE(0) = \frac{t^2 \left| \int G(E) \Delta\mu(E) q_b(E) dE \right|^2}{NPS_p(0) + NPS_s(0) + NPS_{add}} \times \frac{1}{\int \Delta\mu(E)^2 q_b(E) dE}$$

*primary radiation* ($NPS_p$), *scattered radiation* ($NPS_s$), *additive noise* ($NPS_{add}$)

DQE = 1 for an ideal X-ray image detector:

- with optimal **energy weighting** function ( G(E) α Δμ(E))
- and combined to an ideal **scatter-reduction** system (t=1 and SPR=0)

*Ideal photocounting detector: Quantum-Noise-Limited,*
*Quantum efficiency =1 (and Swank factor = 1)*

*Scatter fluence approximated by:* $q_s(E) \approx SPR.q_p(E)$

# Lesion detection tasks in breast cancer screening

- **Mass densities**: (border, density, capsule, halo and silhouette sign)

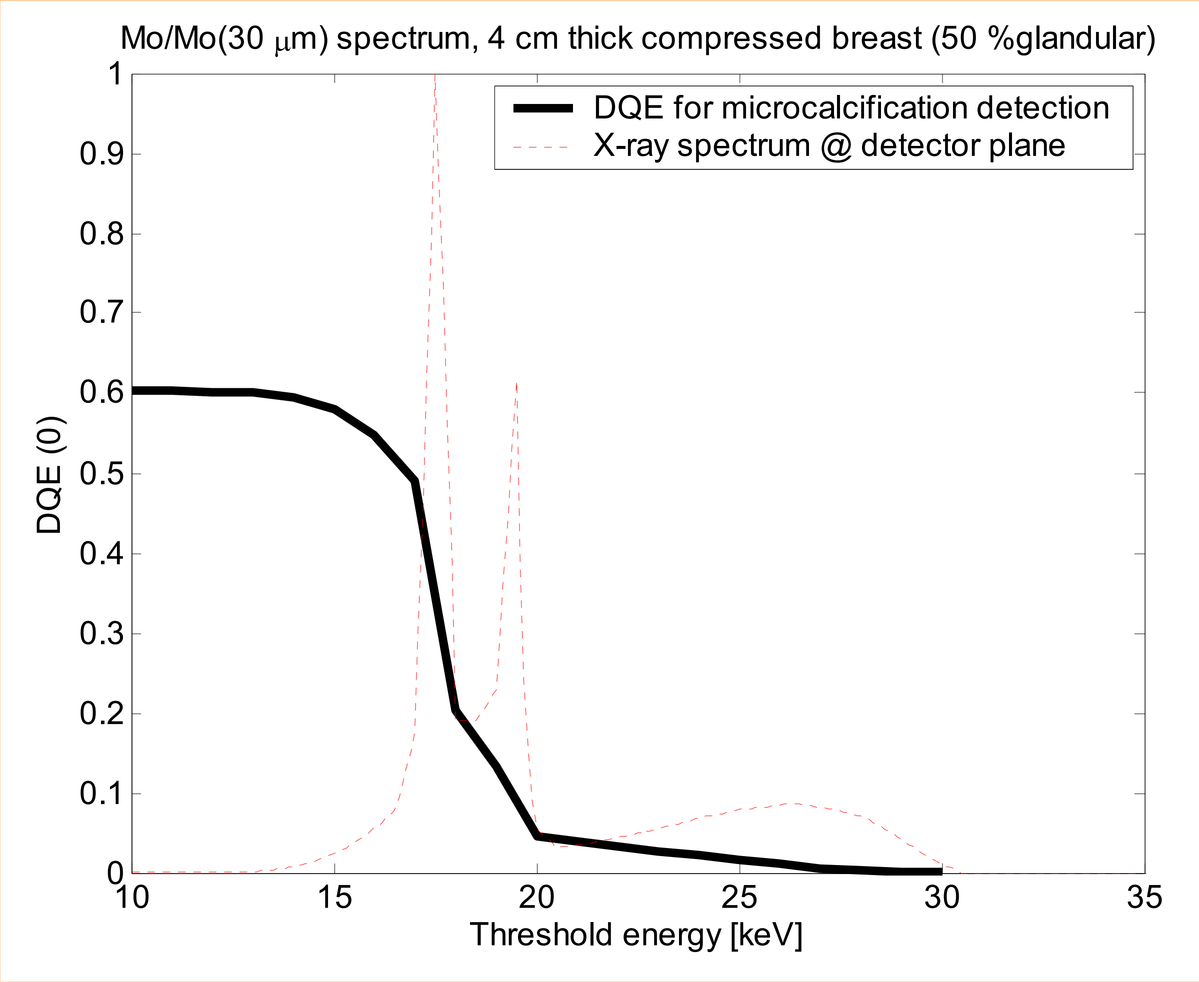
- **Calcifications:** (shape, density, distribution, definition, unilateral or bilateral, surrounding tissue or associated mass, increase in number, size):

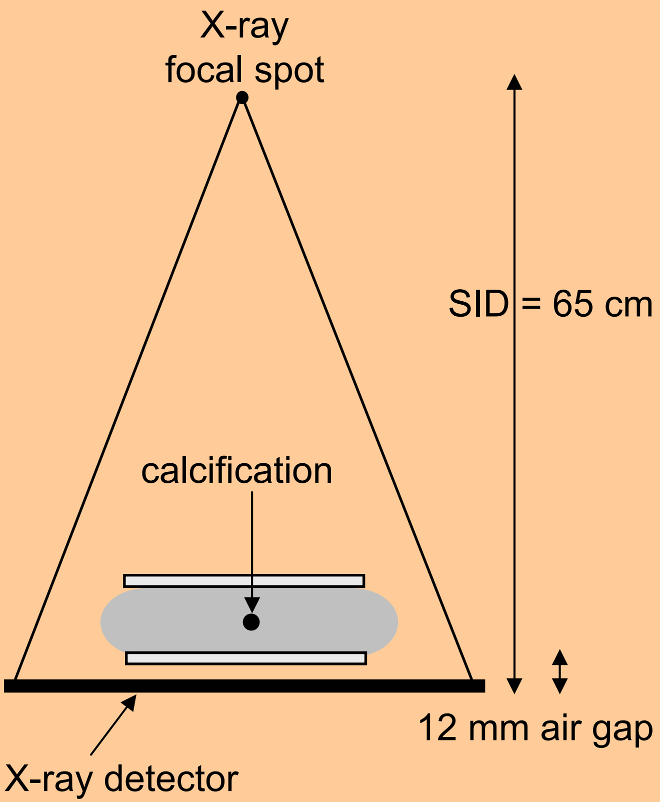
  - **Type I**: calcium oxalate dihydrate
    (almost always benign)

  - **Type II**: calcium phosphate
    (related to cellular degradation and breast carcinoma)

# Effect of photocounting energy threshold on DQE

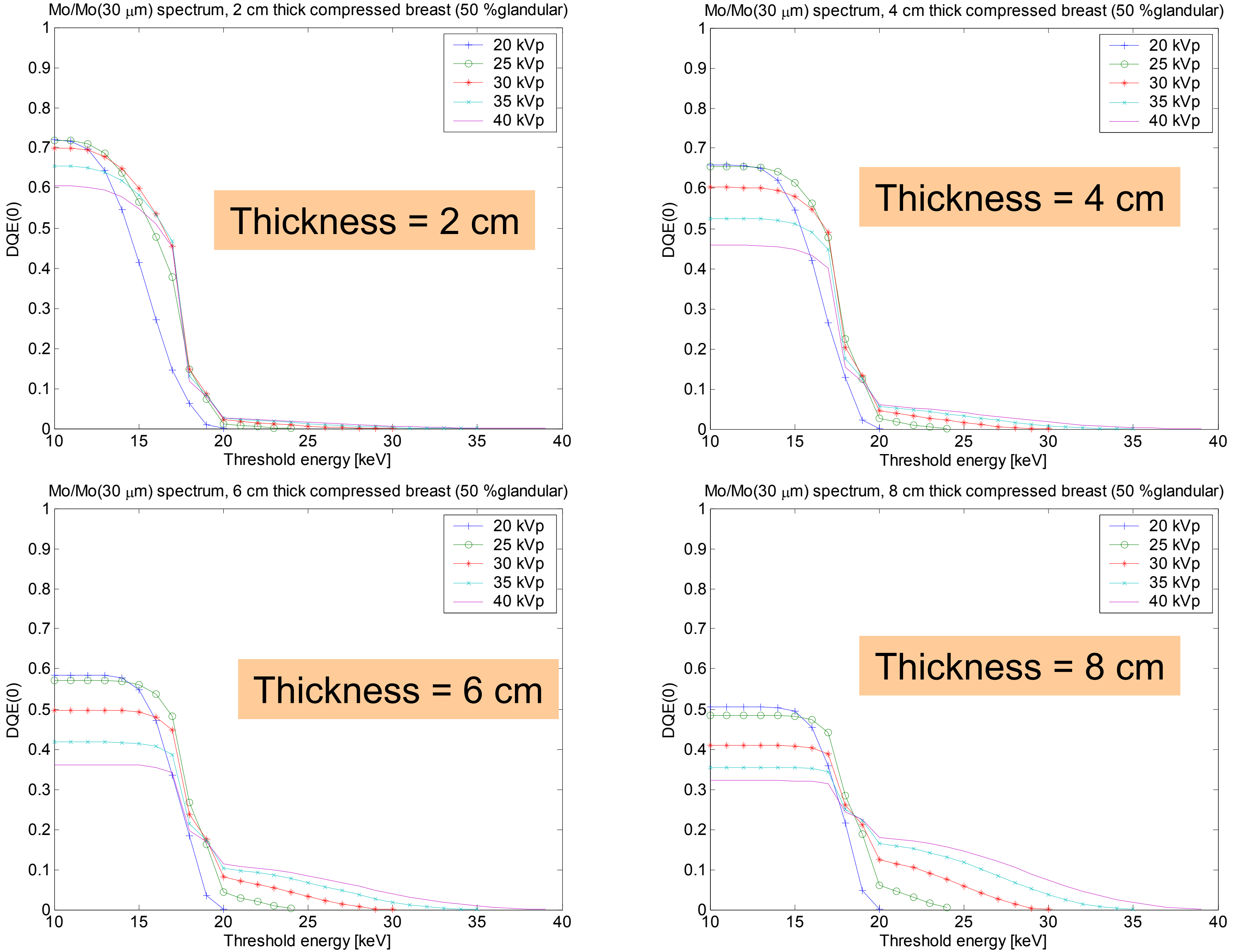
Mo/Mo spectrum @ 30 kVp, **microcalcification** detection in a **4 cm thick**, 50% glandular breast



# Effect of photocounting energy threshold on DQE

## Mo/Mo @ **various kVps**, **microcalcification** detection in a **2,4,6,8 cm thick**, 50% glandular breast

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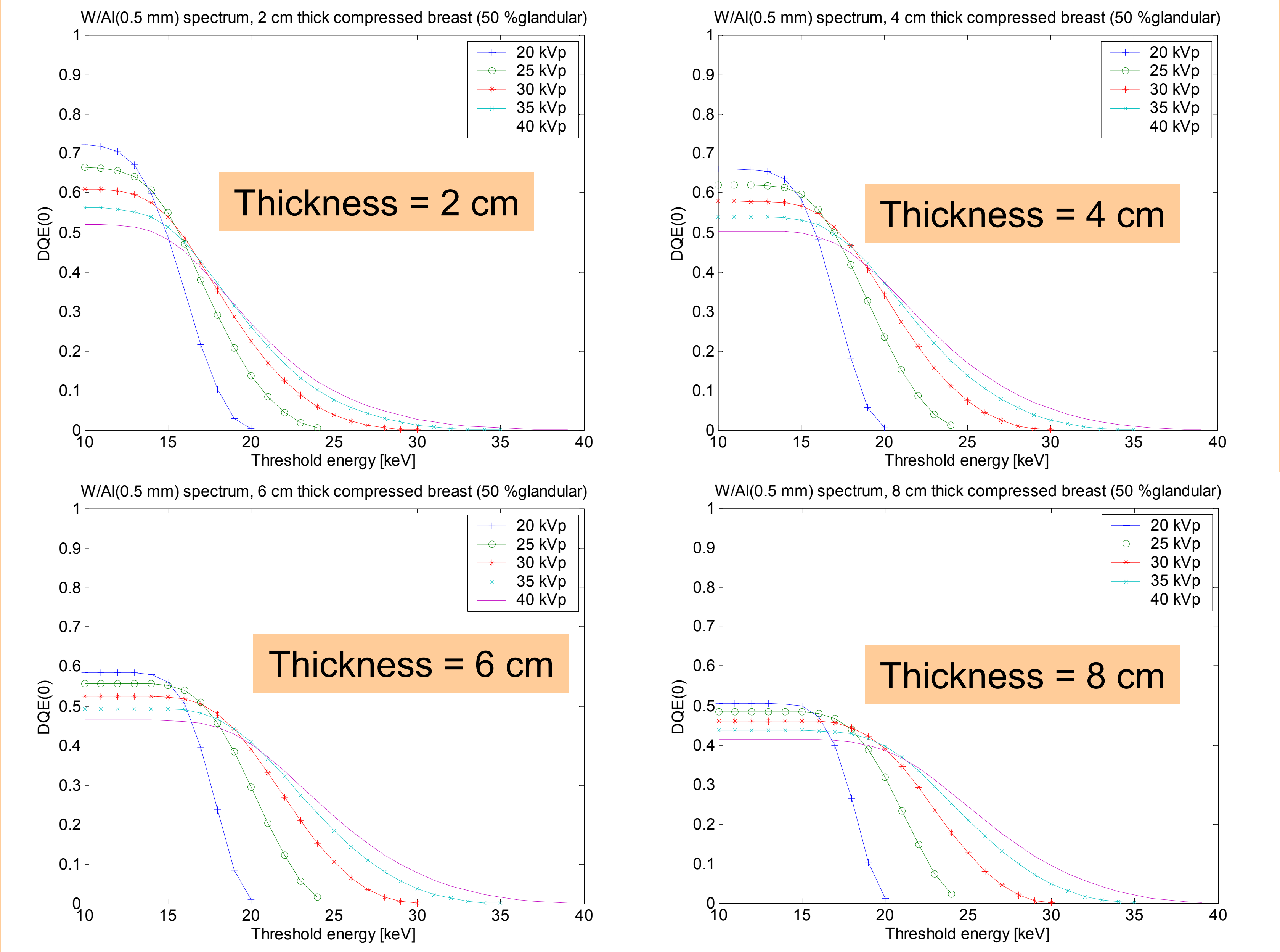
# Effect of photocounting energy threshold on DQE

## W/Al @ **various kVps**, **microcalcification** detection in a **2,4,6,8 cm thick**, 50% glandular breast



# Figure of Merit (FOM) for breast cancer screening

*Signal-to-noise ratio for lesion detection*

$$\mathrm{FOM} = \frac{\mathrm{SNR}^2}{\mathrm{Dg}} \propto \frac{\mathrm{Benefit}}{\mathrm{Risk}}$$

*Mean glandular dose*

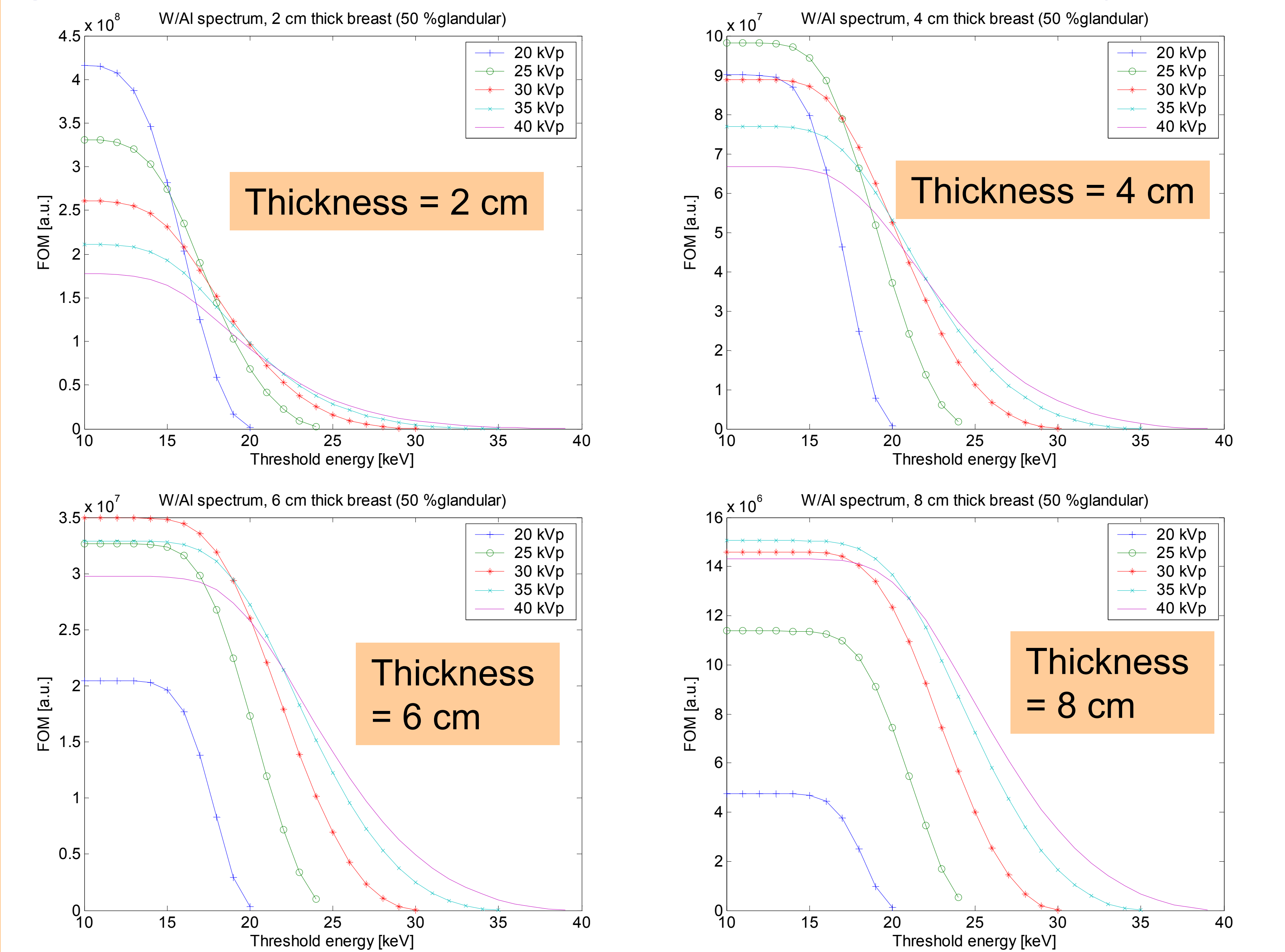
$$\mathrm{DQE} \approx \frac{\mathrm{SNR}^2}{\mathrm{SNR}^2_{\mathrm{max}}}$$

allows a figure of merit describing system performance to be defined as:

$$\mathrm{FOM} = \frac{\mathrm{DQE}(0) \times \mathrm{SNR}^2_{\mathrm{max}}}{\mathrm{Dg}}$$

# Effect of photocounting energy threshold on FOM

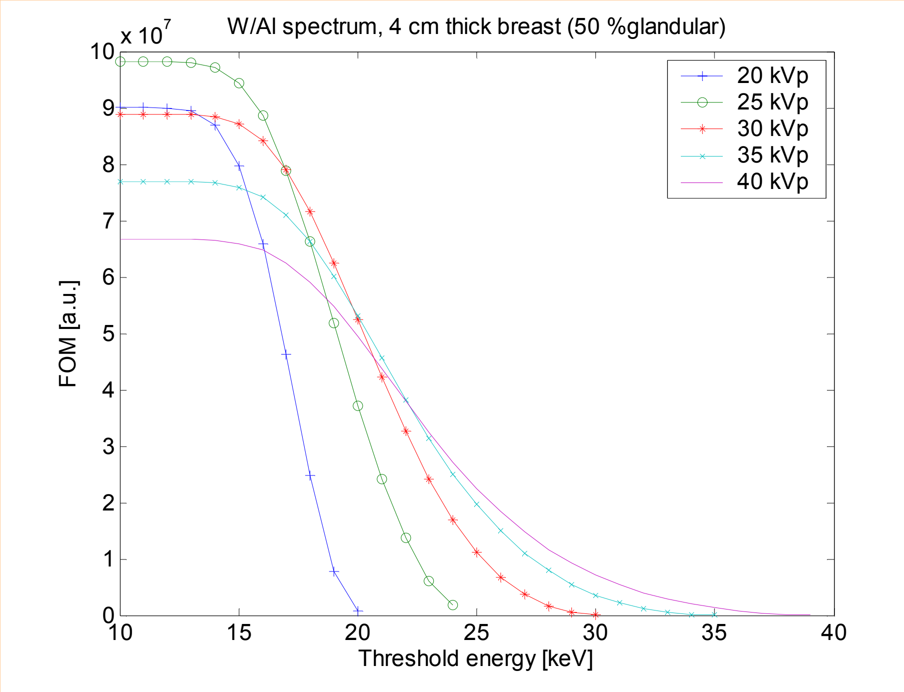
## W/Al @ **various kVps**, **microcalcification** detection in a **2,4,6,8 cm thick**, 50% glandular breast



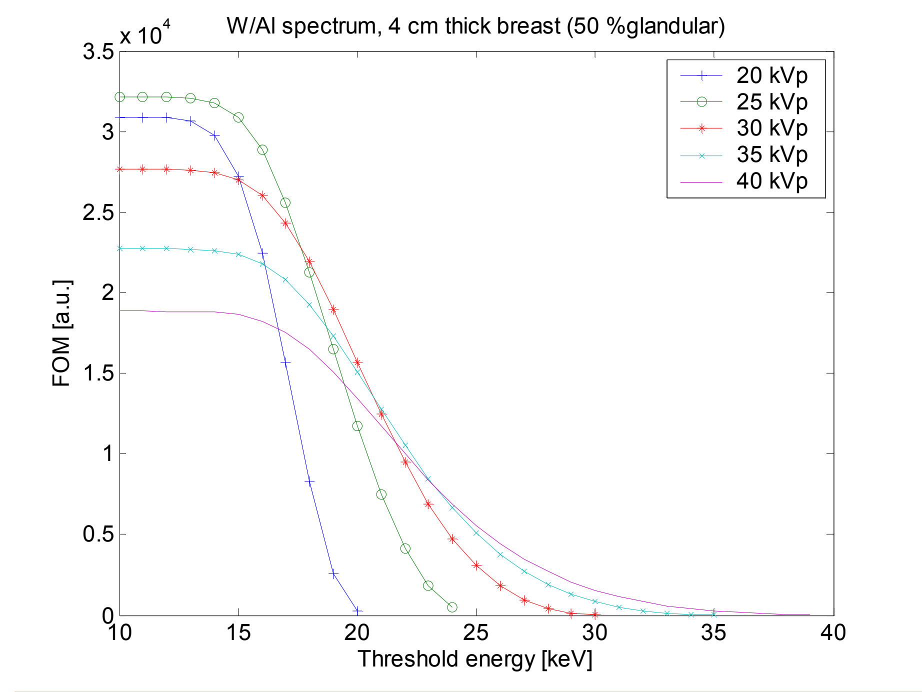
# Effect of photocounting energy threshold on FOM

W/Al @ **various kVps**, in a **4 cm thick**, 50% glandular breast
Microcalcification & tumor detection

## Microcalcification detection




## Tumour detection




Breast thickness = 4 cm

# Conclusion & future work:

- Effect of the **detection energy threshold** on the **mammographic performance** of **photocounting** sensors can be quantified by examining:

    - DQE @ 0 lp/mm : modified to include effects related to **energy weighting** and **scattered radiation**

    - FOM: considering the influence of **X-ray spectral shape** (tube voltage, anode/filter combination) on system performance

- Higher **photocounting thresholds** can be implemented when imaging **thick breasts** without compromising system performance. This might allow charge-sharing-related image noise to be reduced in some situations.

- An accurate optimization of detection thresholds requires the precise knowledge of the **spectral** distribution of **scattered** radiation (measurements or Monte-Carlo simulations)

# Conclusion & future work:

• A **task-dependent** aspect is reintroduced in the description of system performance in mammography. This evolution is driven by technological developments in the field of semiconductor-based X-ray imagers.

• A DQE analysis at 0 lp/mm is sufficient for detection threshold optimization, but the **frequency dependence** is needed to compare the performance of various X-ray imaging technologies

• This **extension of linear system analysis** is of a more general interest in X-ray imaging than threshold optimisation:

**The performance of X-ray imaging systems must be described in comparison to ideal energy-sensitive sensors operating in scatter-free conditions**

# Conclusion & future work:

Development of a **Low-Dose Digital Mammography** system at UCT/MRC Medical Imaging Research Unit, based on existing **slot-scanning technology**

→ Platform for testing:

- extended imaging theories,
- new detector technologies,
- new scanning methods.

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