Detective Quantum Efficiency of Photon-Counting Detectors Having Edge-on Geometry under Mammography Imaging Condition

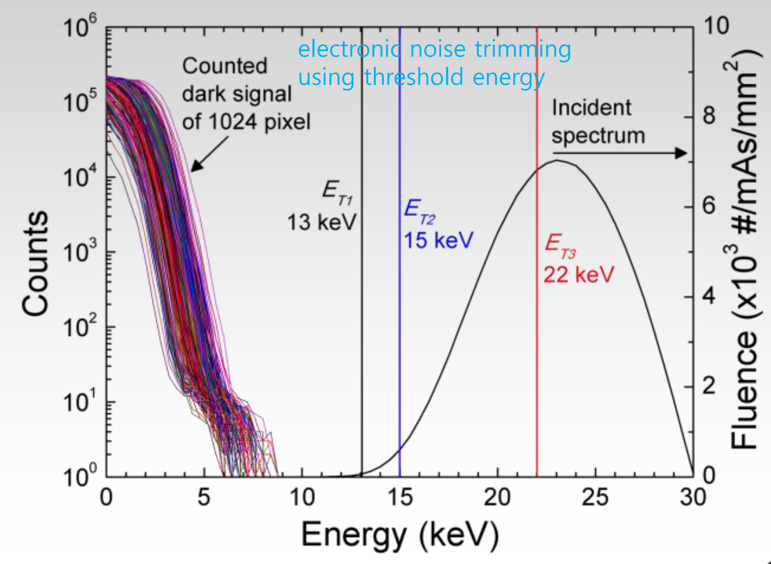
Seungman YUN[1], Hanbean YOUN[1], Okla JOE[1], Sangwook KIM[2], Jae Chul PARK[2], Dong-Goo KANG[3], Young-Hun SUNG[3], Ho Kyung KIM[1*],

[1]School of Mechanical Engineering, Pusan National University, Busan 609-735, Republic of Korea
[2]Semiconductor Device Laboratory, Samsung Advanced Institute of Technology, Yongin, Gyeonggi-Do 446-712, Republic of Korea
[3]Medical Imaging Systems Group, Samsung Advanced Institute of Technology, Yongin, Gyeonggi-Do 446-712, Republic of Korea

*Correspondence: hokyung@pnu.edu, +82 51 510 3511, fax +82 51 518 4613

Motivation

- Compared to the conventional detectors operated in energy-integration mode, the photon-counting operation has several potential advantages;
  - can suppress electronic noise by thresholding
  - can obtain high SNR (signal-to-noise ratio) images with a lower dose
  - has linear response and (theoretically) infinite dynamic range
  - has a potential for removing Compton-scattered and fluorescence x-rays in images
  - can maximize the imaging performance by energy weighting for each imaging task

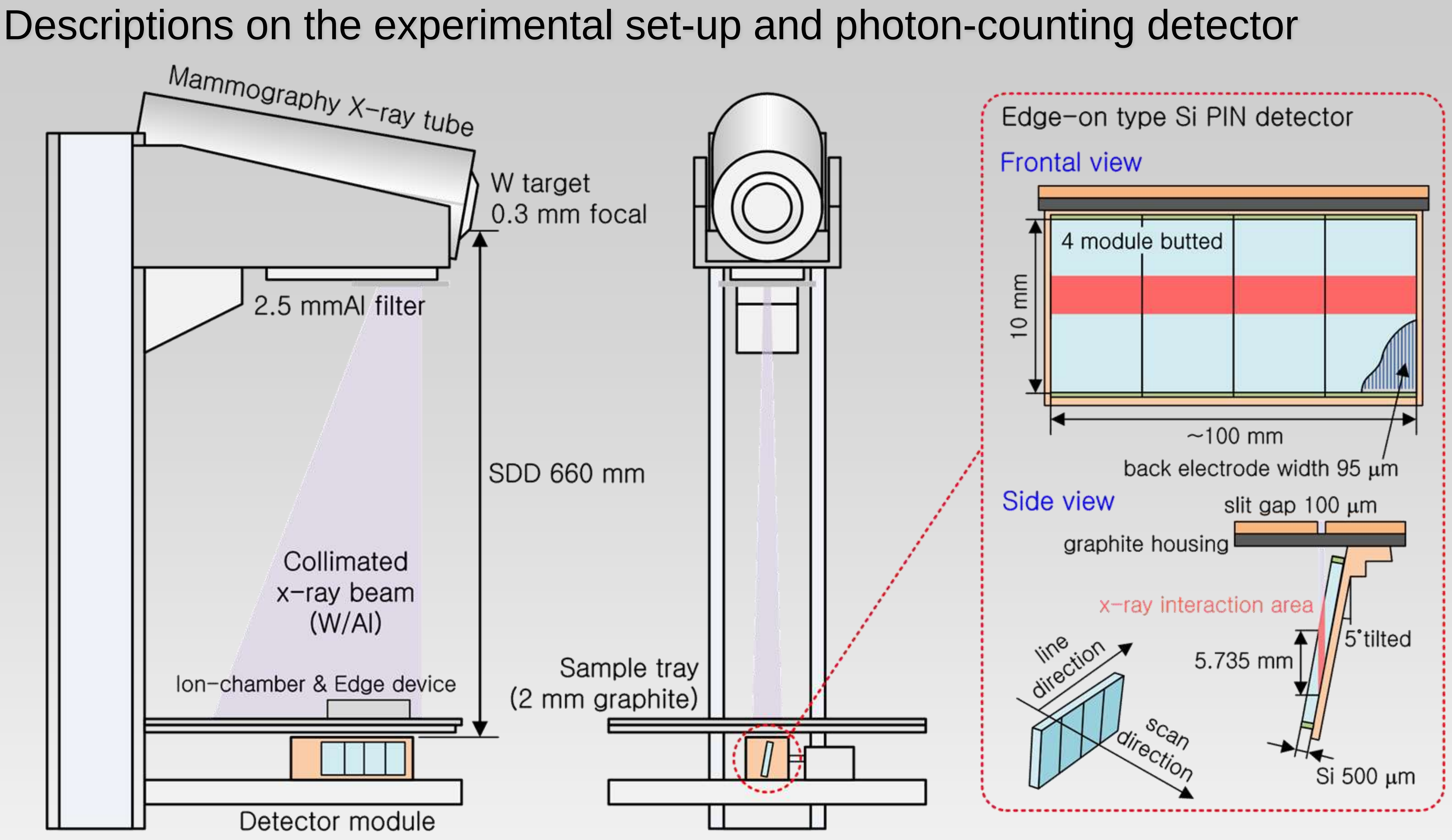


Objectives

- To measure the physical characteristics of the microstrip detector having edge-on geometry operated in photon counting mode under mammography imaging condition recommended by the IEC (international electrotechnical commission) regulation (W/Al spectrum).
- To analyze the imaging performances of the microstrip silicon detector in terms of MTF (modulation-transfer function), NPS (noise-power spectrum), and DQE (detective quantum efficiency).

Materials and Methods

- Descriptions on the experimental set-up and photon-counting detector



IEC 62220-1-2 (2007)

※ Varian RAD-70B tube (W target with 0.76 mm Be window)

W/Al tube voltage	28 kVp	Adjusted voltage	28 kVp
Half value layer	0.83 mmAl	Measured HVL	0.839 mmAl
Added filter thick.	2.5 mmAl	Calculated SNR_{in}^2	6985 #/mm²/μGy
Mandatory SNR_{in}^2	6575 #/mm²/μGy	% difference (SNR_{in}^2)	5.87 %

※ Brief specifications of prototype detector unit

Detector type	line scanning	Material	Si (p-i-n)
Pixels per each module	256 pixels	# of energy bins	4 thresholds
Pixel pitch (line direction)	95 μm	Count rate (saturation)	0.5-0.7 Mcps
Dead gap btw. module	2 mm	Electronic noise	~ 200 e- rms
Collimator (slit) gap	100 μm	Energy resolution	~ 1.7 keV (FWHM)

※ Definition of linear system DQE

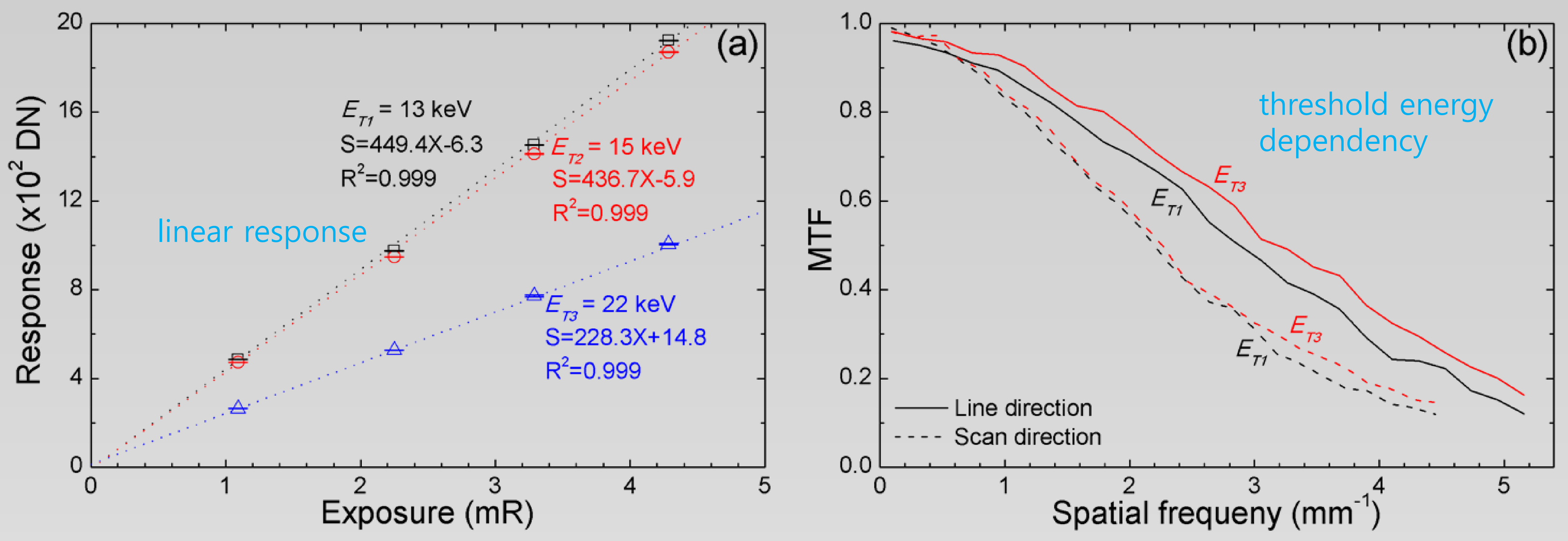
$$\mathrm{DQE}(f) = \frac{\bar{q}\bar{G}^2\,\mathrm{MTF}^2(f)}{\mathrm{NPS}(f)} = \frac{\bar{d}^2\,\mathrm{MTF}^2(f)}{\mathrm{NPS}(f)\,\bar{q}}$$

($\bar{q}$: Incident x-ray quanta; $\bar{G}$: linear & noise-free gain; $\bar{d}$: Mean signal)

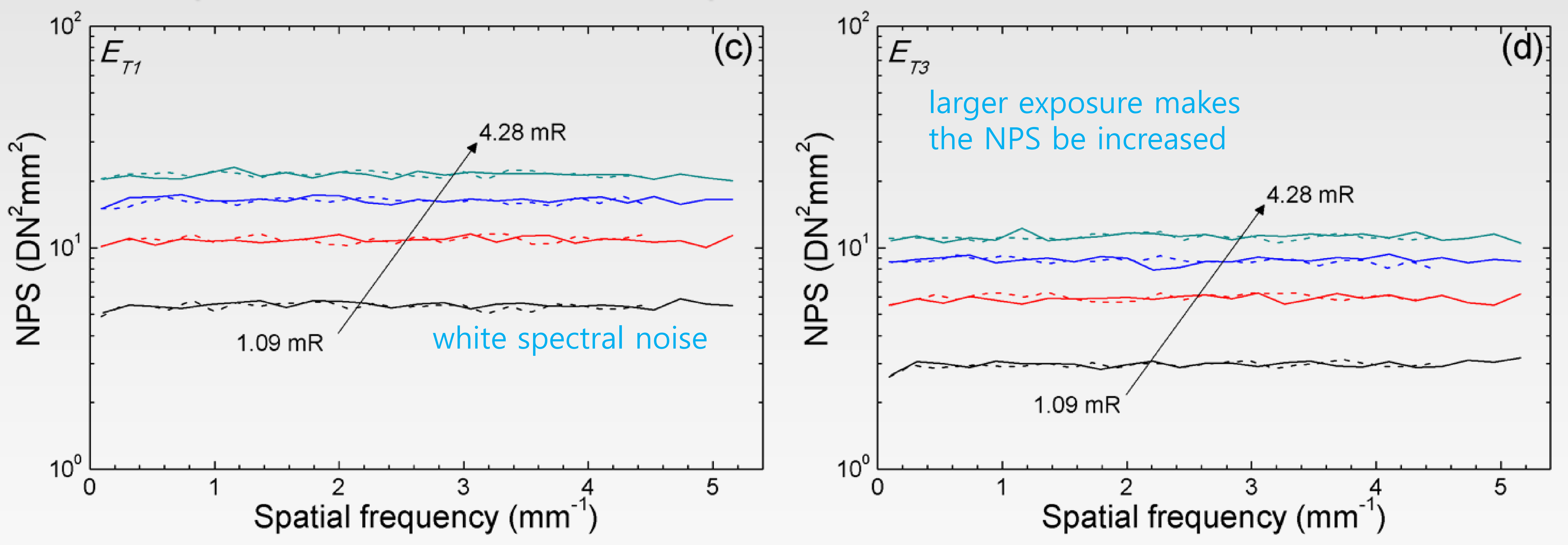
※ Threshold energy (E_T): 13, 15 and 22 keV
Counting time per scan line: 100 ms
Tray movement speed: 110 μm/scan

Results

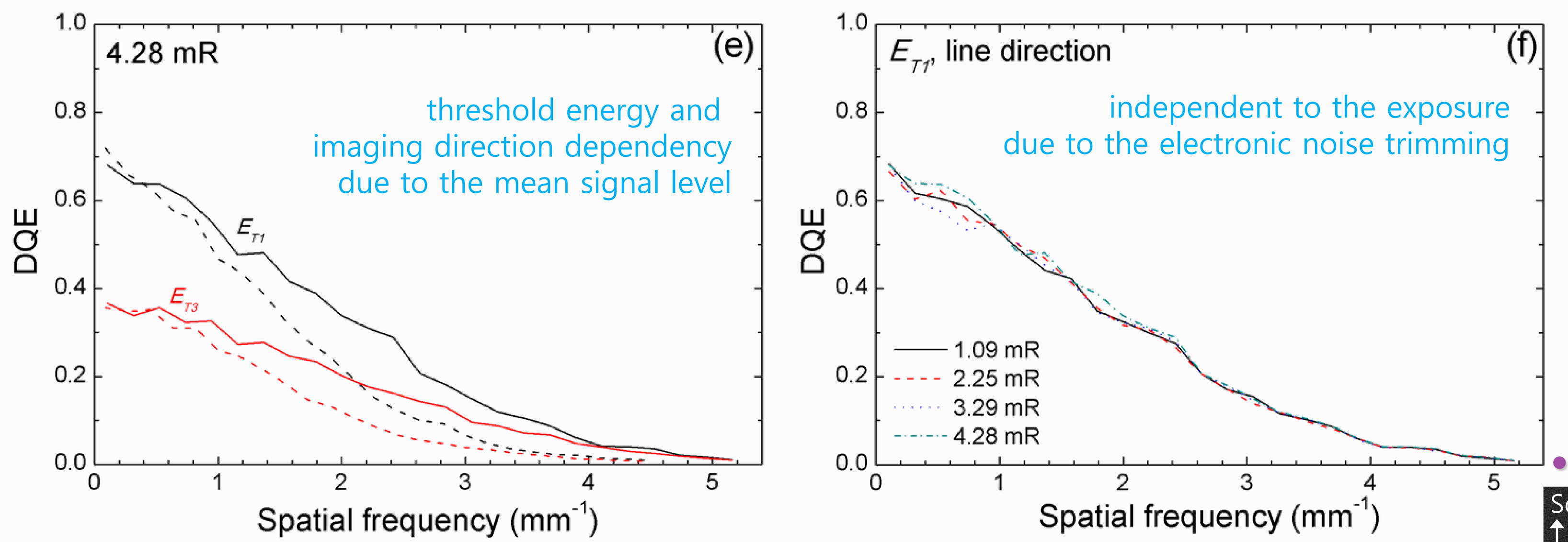
- (a) Output signal responses as a function of detector entrance exposure for various threshold energies
- (b) Measured MTFs in two perpendicular directions (line and scan) for various threshold energies



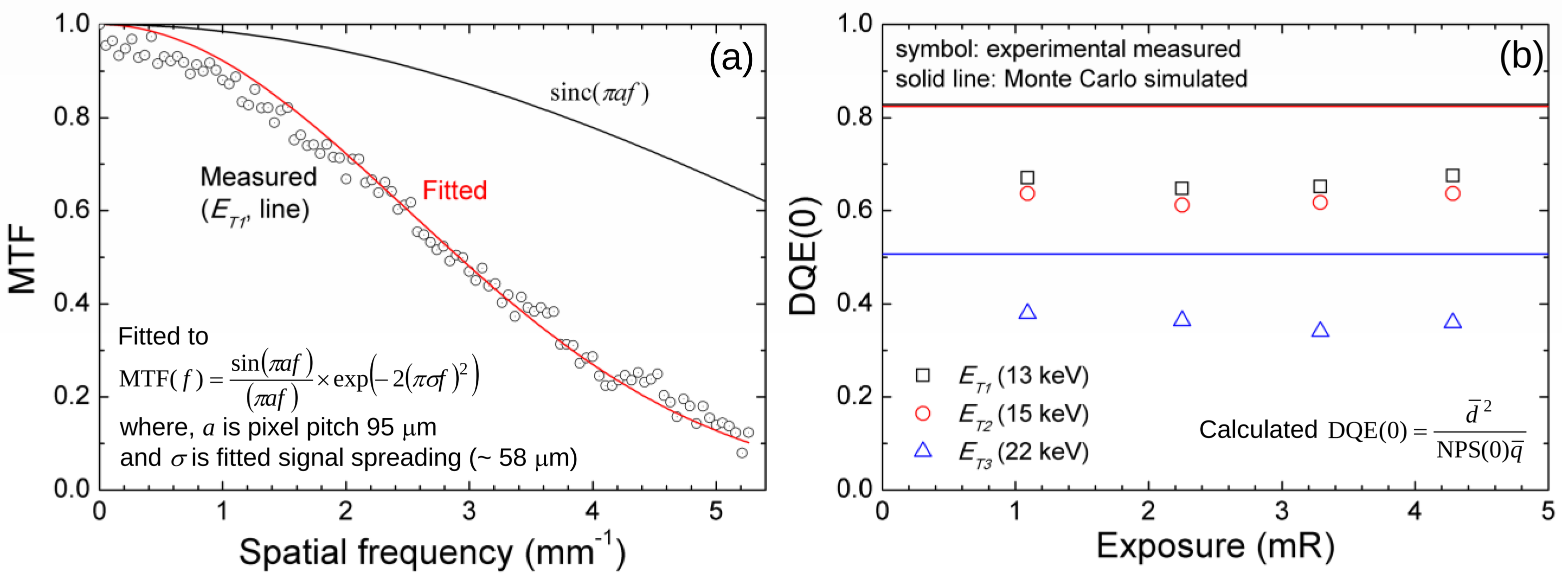
- (c) Measured NPSs for E_T=13 keV in two perpendicular directions (line and scan) with respect to various entrance exposure levels
- (d) Measured NPSs for E_T=22 keV in two perpendicular directions (line and scan) with respect to various entrance exposure levels



- (e) Measured DQEs in two perpendicular directions (line and scan) for various threshold energies
- (f) DQEs extracted in line direction with respect to various exposure levels



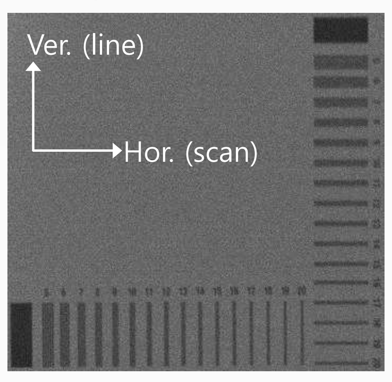
- Regression analysis and calculated DQE(0)
  - (a) Estimated charge sharing effect assuming the Gaussian charge diffusion model
  - (b) Comparison of the measured DQE(0) and theoretical quantum efficiency



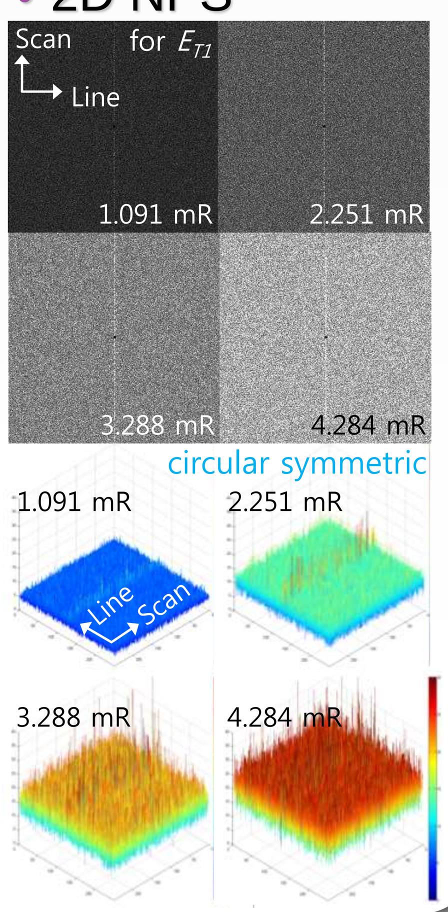
H. E. Nilsson, et al. IEEE TNS 51(4), 2004

- Sample images

Resolution bar pattern
28 kVp, 0.5 mmAl, ~20 mR



- 2D NPS



Discussion and Summary

- In this study, we have systematically measured the imaging performance of a prototype silicon microstrip photon-counting detector under mammographic imaging condition.
- The measured MTF values are much lower than the sine cardinal function (ideal pixel MTF) of the physical pixel aperture, which implies that there exists an additional signal spreading, such as Compton scatter and charge sharing.
- We have modeled the signal spreading as a Gaussian model to perform the regression analysis. From the result, σ = ~ 58 μm of additional signal spreading has been observed.
- The measured DQE(0) is much lower than the theoretically calculated quantum efficiency based on the Monte Carlo simulation. This would be explained by the Swank noise factor mainly due to the random charge sharing effect.
- According to the measurements of DQE with respect to various exposure levels, the additive electronic noise in the silicon microstrip photon-counting detector is negligible. Therefore, the silicon microstrip photon-counting detector has the potential in low-dose imaging.
- The overall imaging performances measured in this study are comparable to those of conventional commercial mammography detectors. P. Monnin, Med. Phys. 34(3), 2007 & M. Aslund, Med. Phys. 34(6), 2007

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