A Method to determine the DQE of Photon Counting Pixel Detectors

Discriminator Threshold Dependency of the Zero-Frequency-DQE of Photon Counting Pixel Detectors

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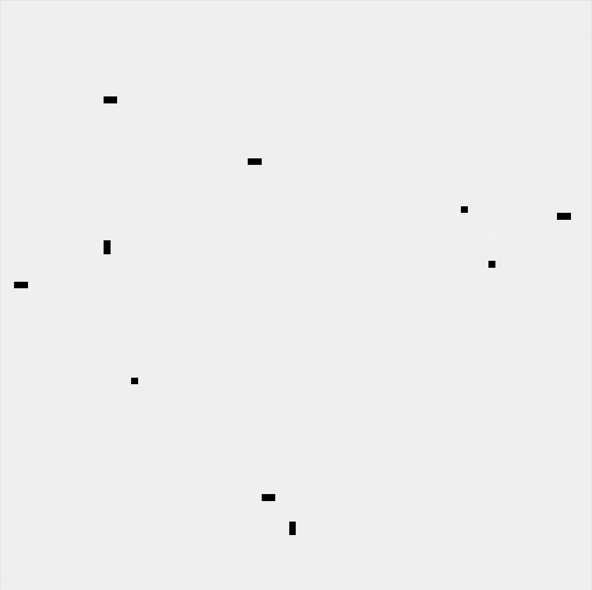
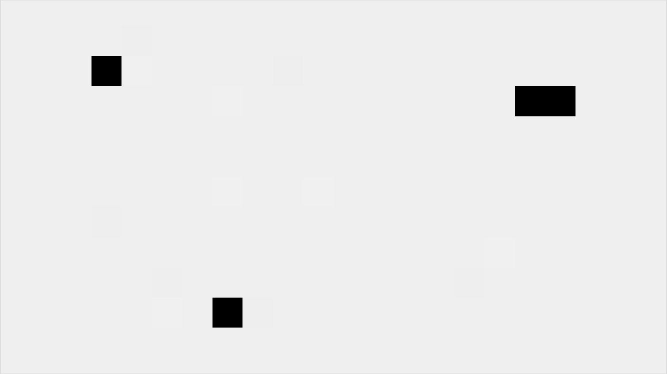
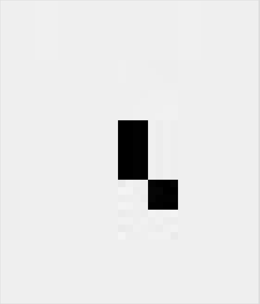
Content

- Derivation of the zero-frequency Detective Quantum Efficiency (DQE) for photon counting pixel detectors
- Dependency of the DQE on discriminator threshold energy
- Dependency of the DQE on x-ray photon energy
- Conclusion

The Problem: Multiple Counts







Detection Efficiency

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$$N_{in} = \text{number of incident x-ray photons}$$

$$N_{true} = \text{number of detected x-ray photons}$$

$$N_{meas} = \text{number of counts produced by } N_{true} \text{ detected x-ray photons}$$

$$\text{detection efficiency: } \varepsilon = \frac{N_{true}}{N_{in}} \neq \frac{N_{meas}}{N_{in}}$$

Cluster size of detected photons

- A photon may be detected in more than one pixel:

  Cluster size = number of triggered pixels = **multiplicity**

- We measure a flat field and obtain

  N_1: number of photons which are counted in 1 pixel
  N_2: number of photons which are counted in 2 pixels
  N_3: number of photons which are counted in 3 pixels
  .
  .
  .

Photons and Counts

- Number of detected photons:

$$N_{true} = N_1 + N_2 + N_3 + \dots = \sum_{i=1}^{\infty} N_i$$

- Number of measured counts:

$$N_{meas} = 1 \cdot N_1 + 2 \cdot N_2 + 3 \cdot N_3 + \dots = \sum_{i=1}^{\infty} i N_i$$

- Variances:

$$\sigma_{N_i}^2 = N_i$$

$$\sigma_{N_{meas}}^2 = \sum i^2 N_i$$

Detective Quantum Efficiency (DQE)

- Definiton:

$$DQE(f) = \frac{SNR_{out}^2(f)}{SNR_{in}^2(f)}$$

- DQE for zero spatial frequency $(f = 0)$:

$$SNR_{out} = \frac{N_{meas}}{\sigma_{N_{meas}}} = \frac{N_1 + 2N_2 + 3N_3 \ldots}{\sqrt{N_1 + 4N_2 + 9N_3 \ldots}} = \frac{\sum iN_i}{\sqrt{\sum i^2 N_i}}$$

$$SNR_{in} = \frac{N_{in}}{\sigma_{N_{in}}} = \sqrt{N_{in}}$$

Averaged Multiplicity <m> and DQE

We define:

- Averaged multiplicity:

$$\langle m \rangle = \frac{\sum iN_i}{\sum N_i} = \frac{N_{meas}}{N_{true}}$$

- Averaged quadratic multiplicity:

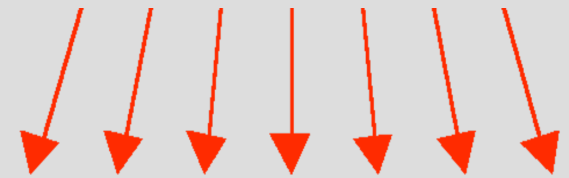
$$\langle m^2 \rangle = \frac{\sum i^2 N_i}{\sum N_i} = \frac{\sum i^2 N_i}{N_{true}}$$

$$SNR_{out} = \frac{\sum iN_i}{\sqrt{\sum i^2 N_i}} = \frac{\langle m \rangle N_{true}}{\sqrt{\langle m^2 \rangle N_{true}}}$$

$$DQE = \frac{\langle m \rangle^2 N_{true}}{\langle m^2 \rangle N_{in}} = \frac{\langle m \rangle N_{meas}}{\langle m^2 \rangle N_{in}} = \frac{\langle m \rangle^2}{\langle m^2 \rangle} \varepsilon$$

Setup for Monte-Carlo simulations with ROSI

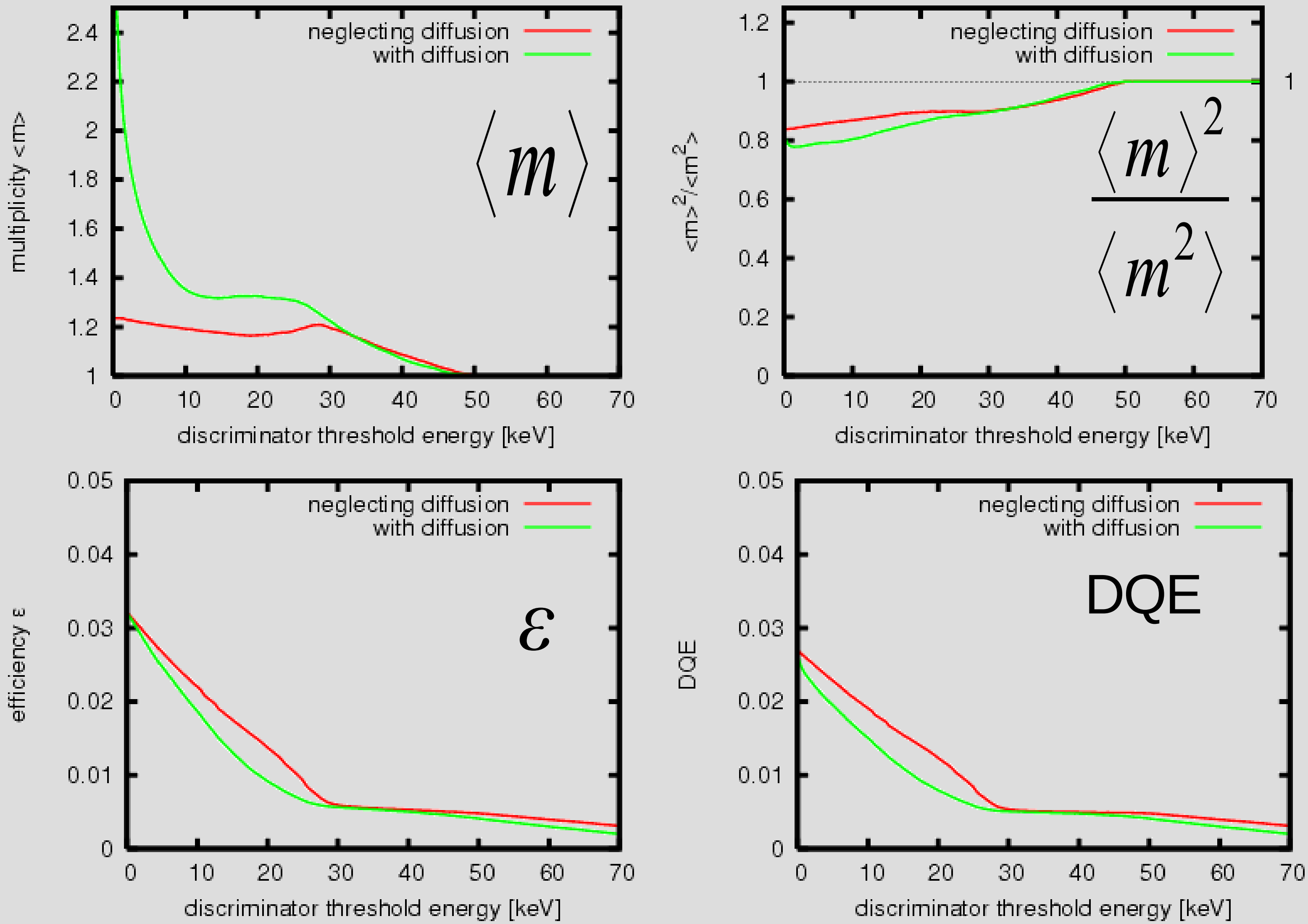
x-ray photons



Sensor	700 µm Si
bump bonds	25x25x25 µm³ PbSn
Medipix2 ASIC	700 µm Si
Silver Glue	7.0 µm Ag
Ground Plate	17.5 µm Cu

- Setup of geometry:
  - sensor material: Si
  - sensor thickness: 700 µm
  - modelled with ASIC / bump bonds
  - sensor voltage: 250 V
  - variable discriminator threshold setting
  - no discriminator threshold noise
- Diffusion model: on / off
- Extraction of N_i for each threshold setting and calculation of efficiency, multiplicity and DQE

Discriminator Threshold Dependency: 100 keV monoenergetic



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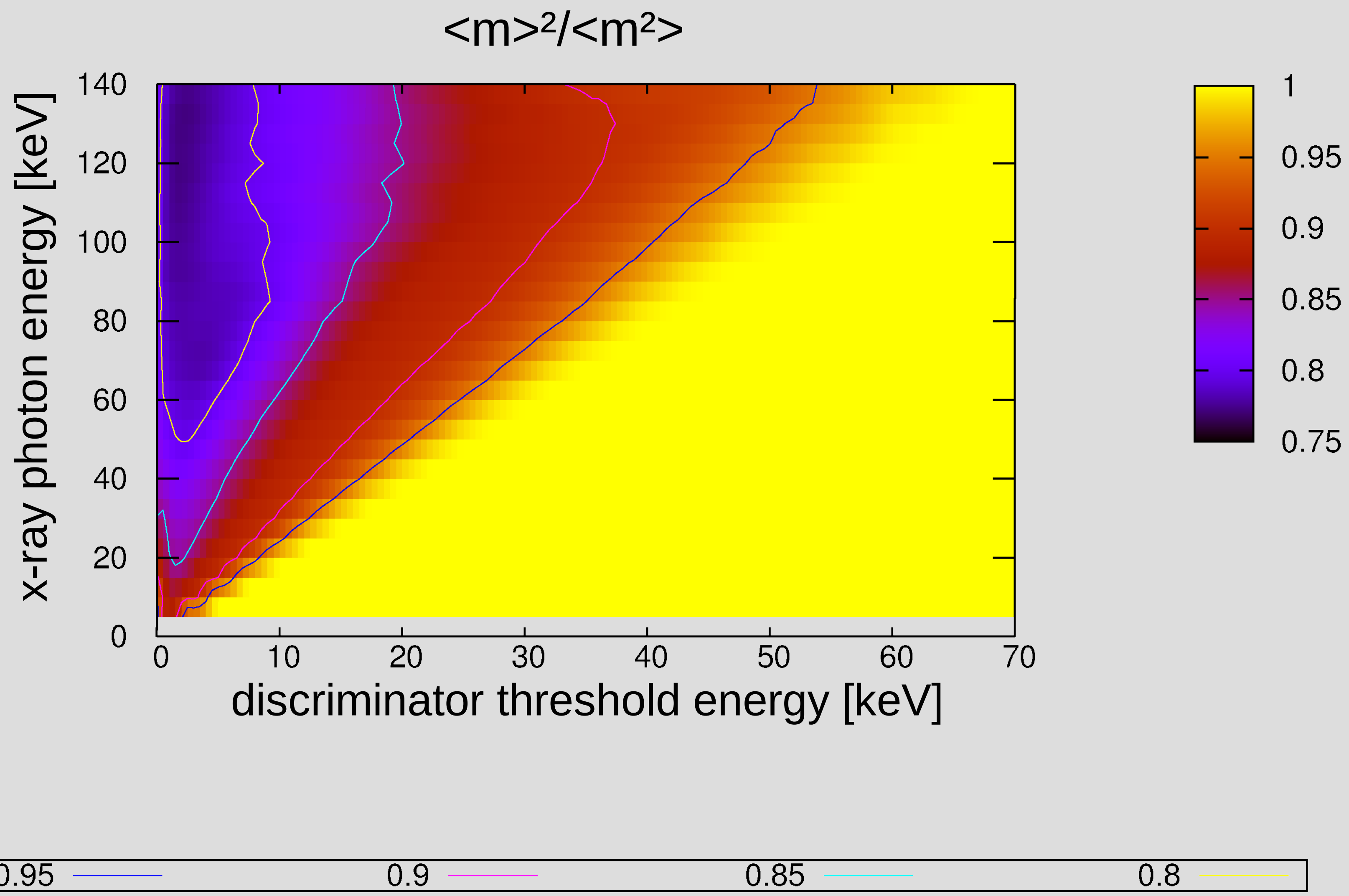
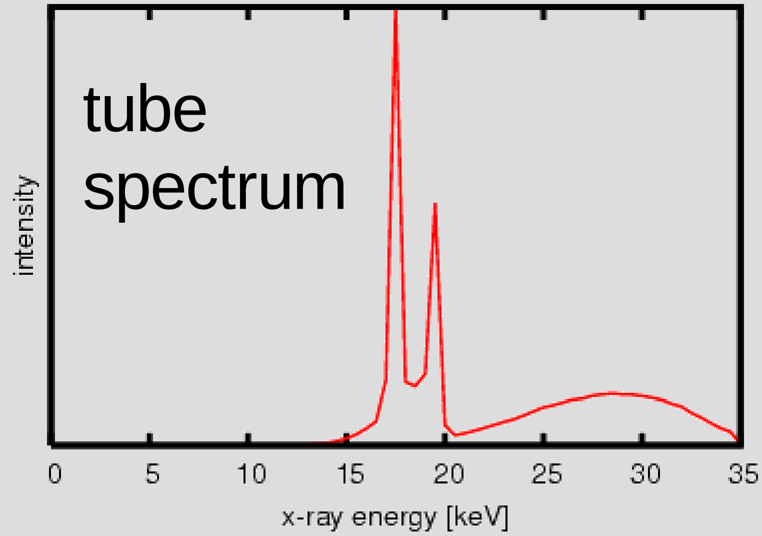
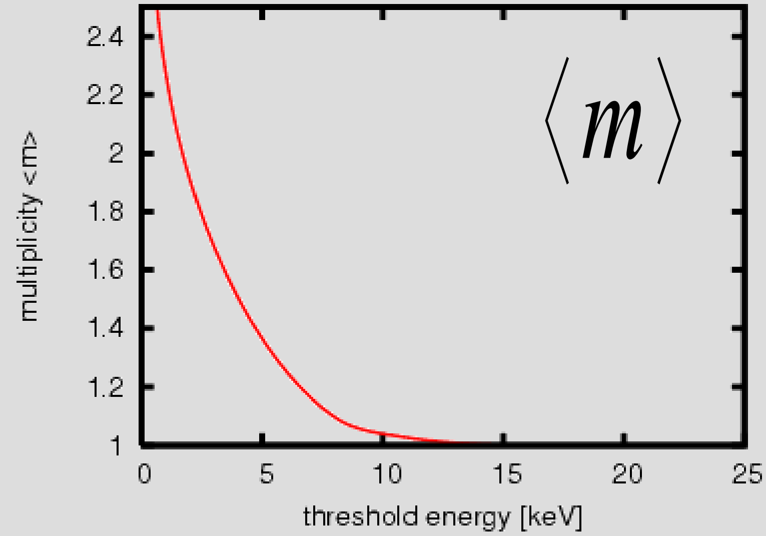
Multiplicity factor

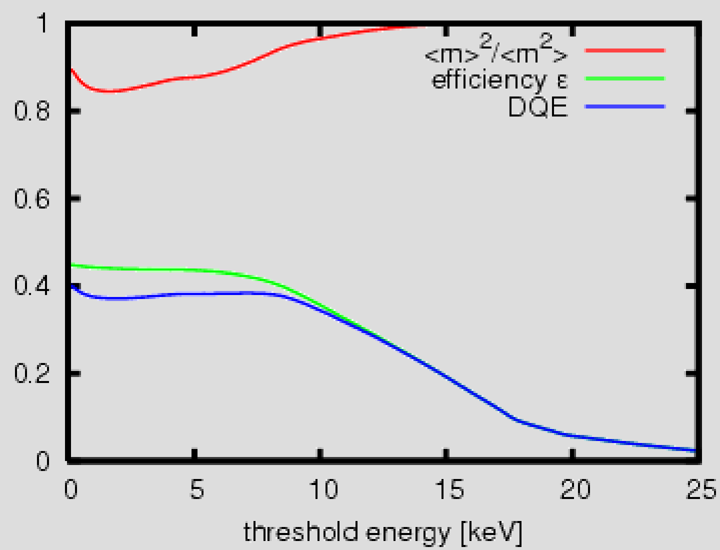


– multiplicity noise decreases DQE up to 25%

Optimization of Threshold by means of the DQE







Conclusion

- Novel method to determine the zero-frequency DQE of a photon counting pixel detector
- DQE mainly depends on the detection efficiency for Si
- Multiplicity factor decreases the DQE up to 25%
- Detection efficiency is approximately constant for low thresholds
- Multiplicity factor influences the DQE for low thresholds

References

- G.Anton, M.Böhnel, J.Durst, M.Firsching, A.Korn, B.Kreisler, A. Loehr, T.Michel, F.Nachtrab, D.Niederlöhner, F. Sukowski, P.Takoukam Talla; *A Fundamental Method to determine the Signal to Noise Ratio (SNR) and Detective Quantum Efficiency (DQE) for a Photon Counting Pixel Detector*, submitted to: Nuclear Inst. and Methods in Physics Research, A
- Medipix Collaboration: http://medipix.web.cern.ch/MEDIPIX/
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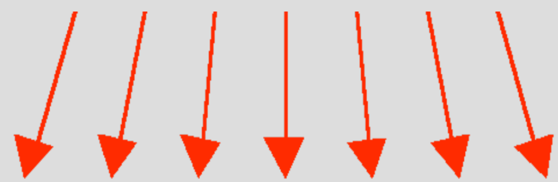
- H. G. Spieler and E. E. Haller; Assessment of Present and Future Large-Scale Semiconductor Detector Systems, IEEE Transactions on Nuclear Science, NS-32(1):419-426, February 1985

The End

Setup for Monte-Carlo simulations with ROSI

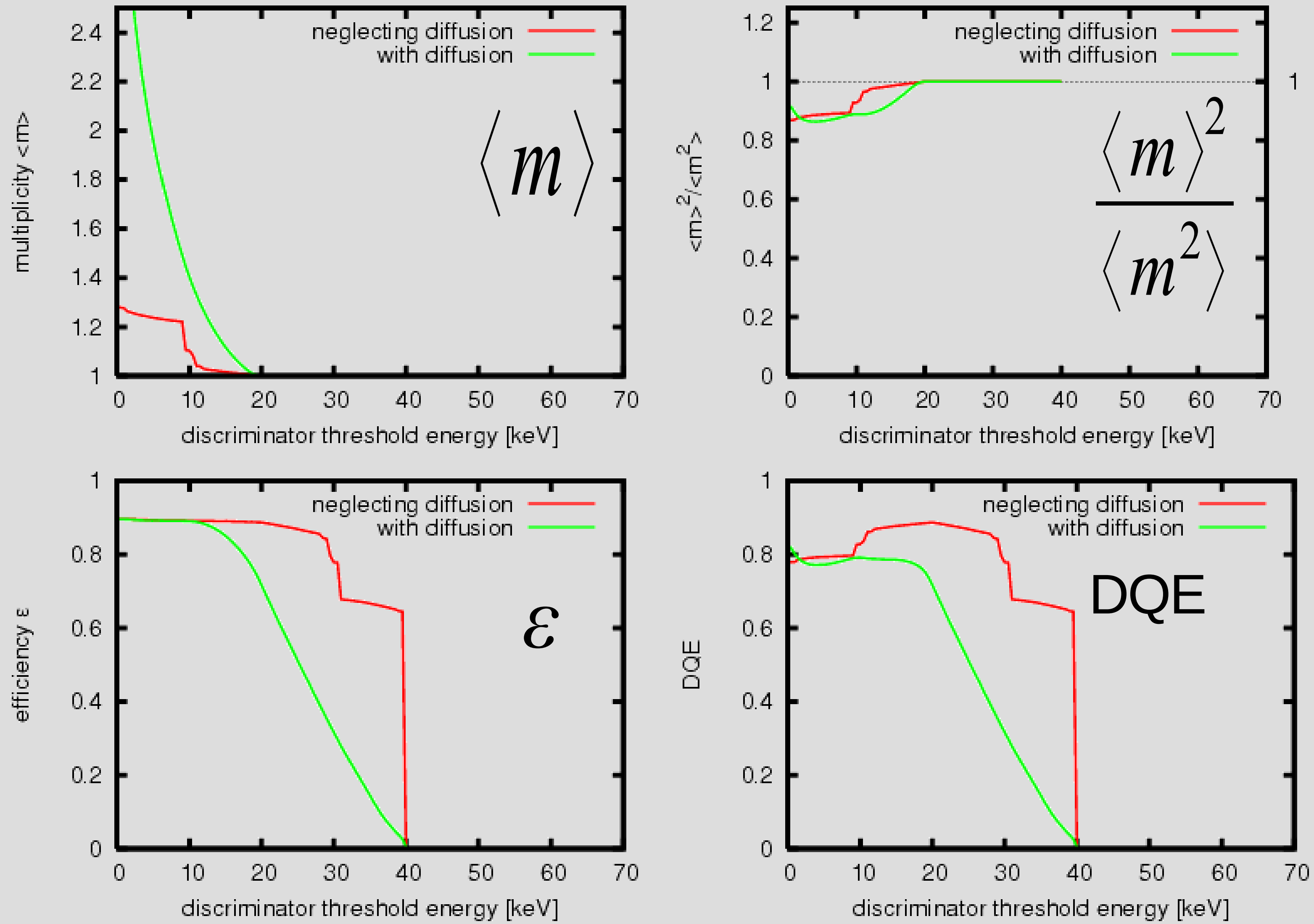


Sensor	700 µm GaAs
bump bonds	25x25x25 µm³ PbSn
Medipix2 ASIC	700 µm Si
Silver Glue	7.0 µm Ag
Ground Plate	17.5 µm Cu

- Setup of geometry:
  - Sensor material: GaAs
  - Sensor thickness: 700 µm
  - modelled with ASIC / bump bonds
  - sensor voltage: 250 V
  - variable discriminator threshold setting
  - no discriminator threshold noise
- Diffusion model: on / off
- Extraction of N_i for each threshold setting and calculation of efficiency, multiplicity and DQE

Discriminator Threshold Dependency: 40 keV monoenergetic

GaAs



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