Simulation study of charge sharing suppression in photon counting X-ray imaging systems by different charge summing schemes

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Outline

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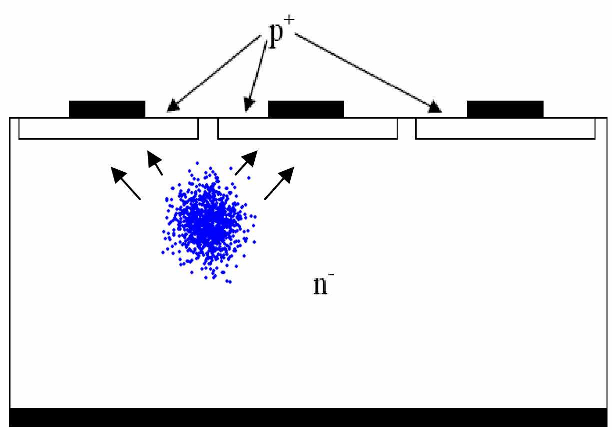
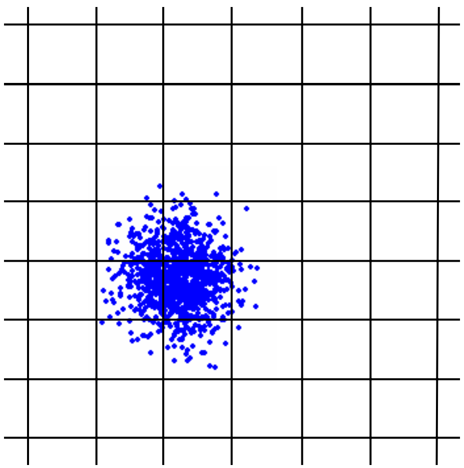
- Problem formulation
  - Charge sharing limits the energy resolution
- Possible solution
  - Charge summing, but what summing scheme should be used?
- Modeling of different charge summing schemes
  - How much can be gained by charge summing?
- Conclusions

Charge sharing

- The energy is deposited in several pixels and not only in one
  - One photon appears as several lower energy photons in the recorded spectrum



Side view

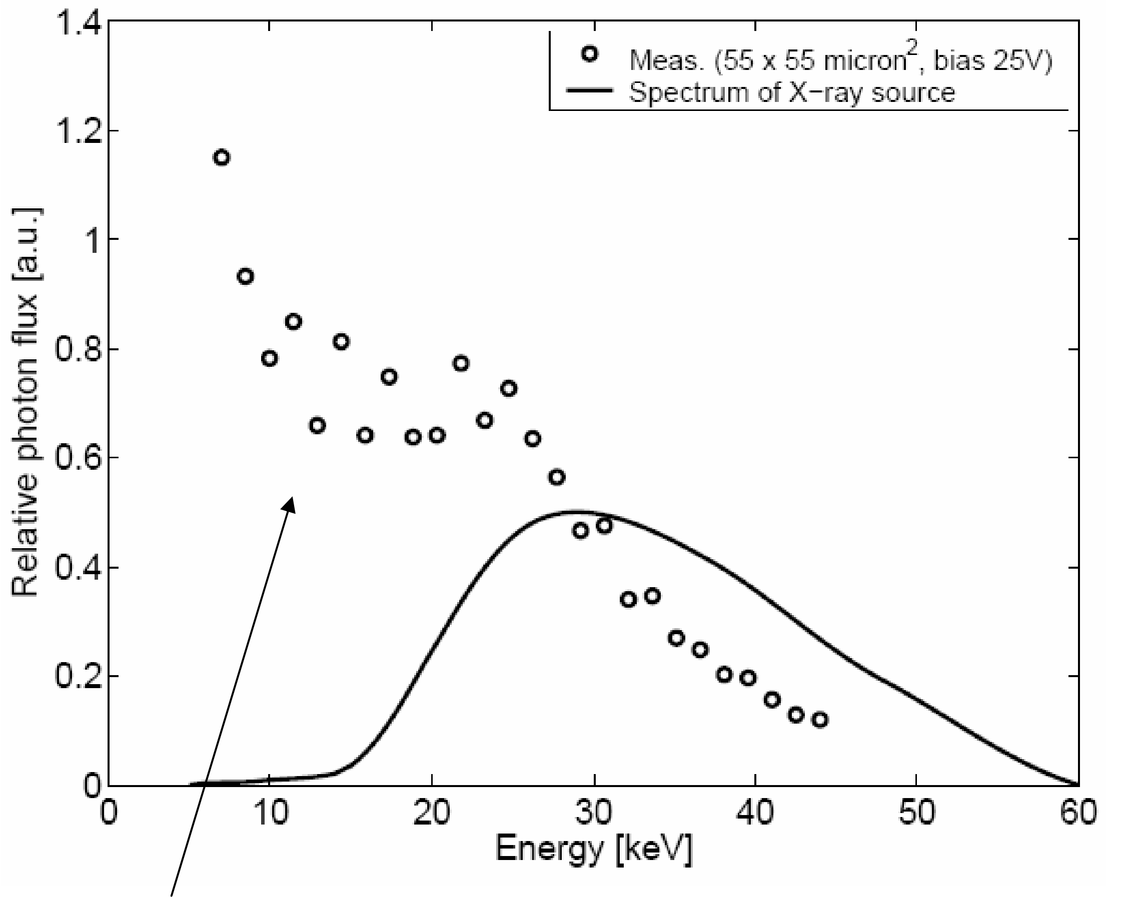


Top view

~ 40 μm radius of charge cloud should be expected

Charge sharing

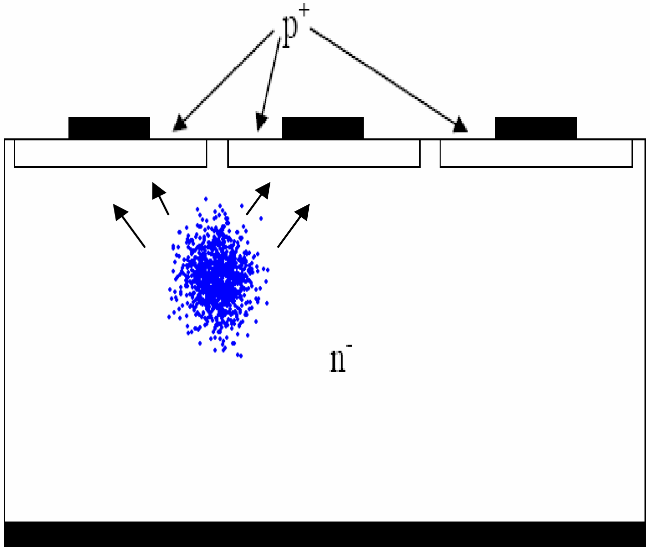
- Flood exposure of MEDIPIX2 sensor by dental X-ray source
- Distortion of recorded energy spectrum due to charge sharing
- Energy information lost...

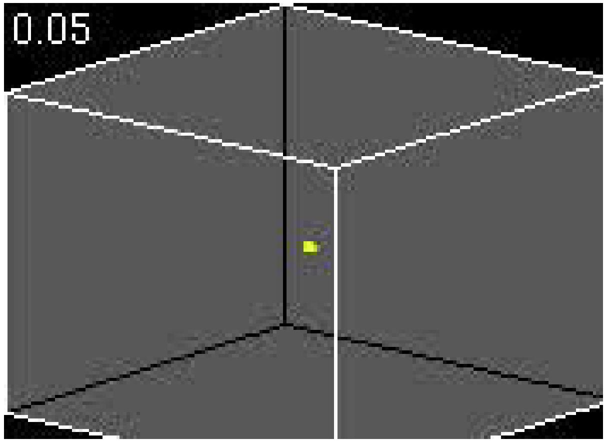


Large counts of low energy photons due to charge sharing

Simulation study

- System level Monte Carlo model
  - Combining
    - MCNP simulation of photon absorption and energy deposition
    - GEMS (Monte Carlo charge transport simulator developed at the Mid-Sweden University)
- Attempt to use first principles rather than empirical model
- Movie

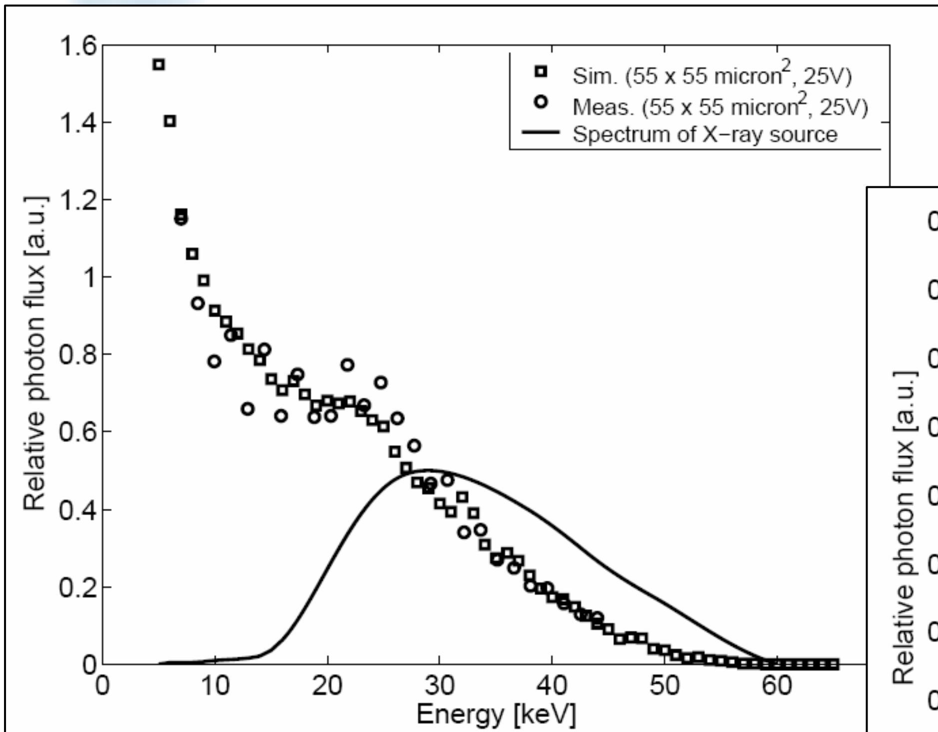


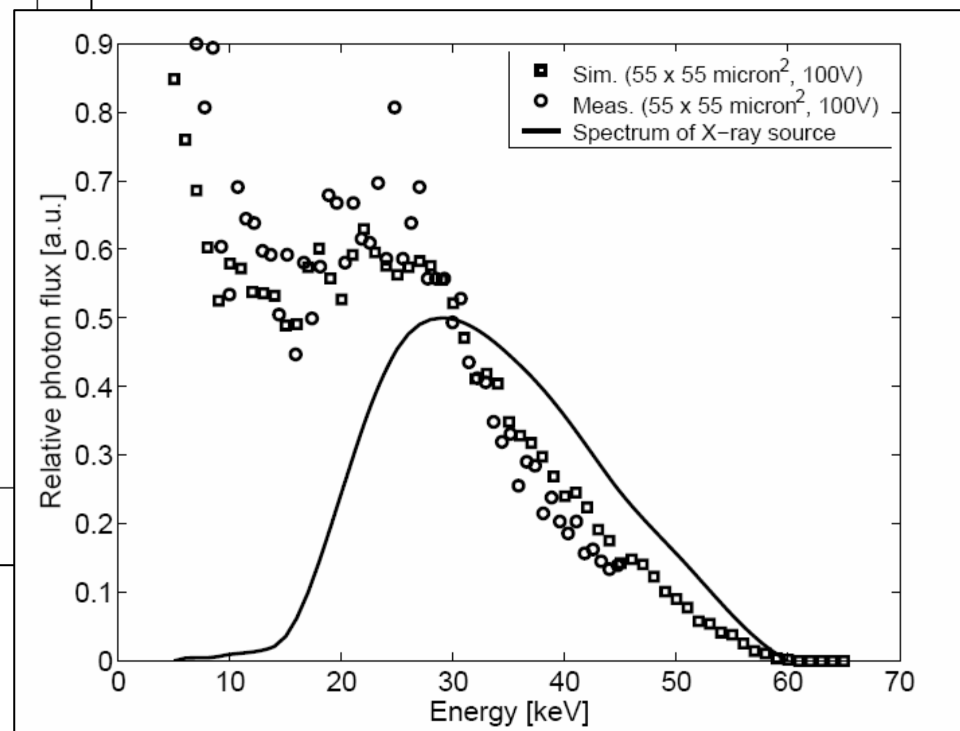


GEMS – Classical and quantum processes included in the model

Over depletion

Charge sharing can be reduced by an increased electric field, but it can not be completely cancelled out





Charge summing

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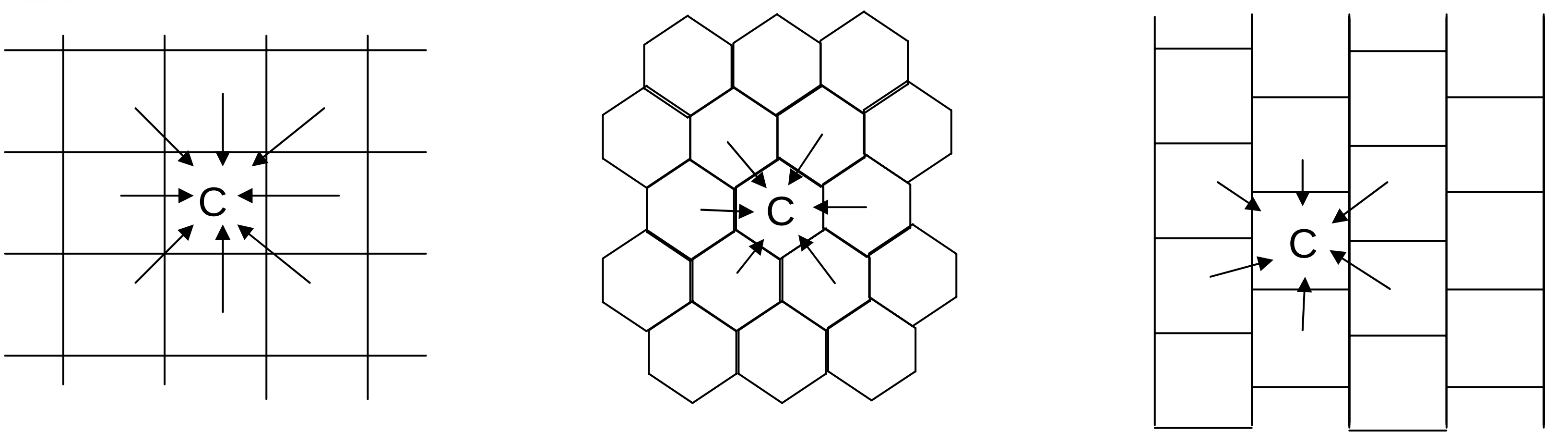
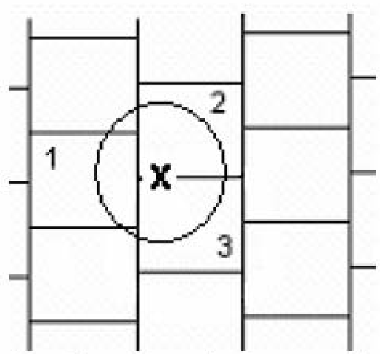
- First proposals to use *in-pixel* charge summing to reduce charge sharing was done by Llopart at el 2002, (CERN)
  - Algorithm to add the charge from neighboring pixels for each photon detection event

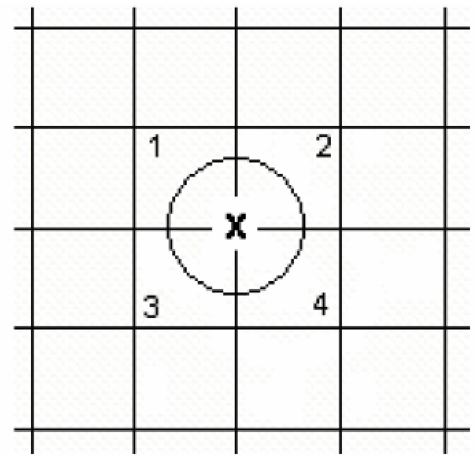


Charge summing

- Introducing electronics that communicates the charge collected to its neighbors



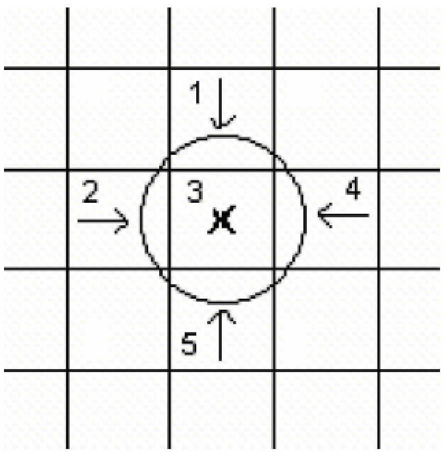
Three pixel summing configuration (3PS).



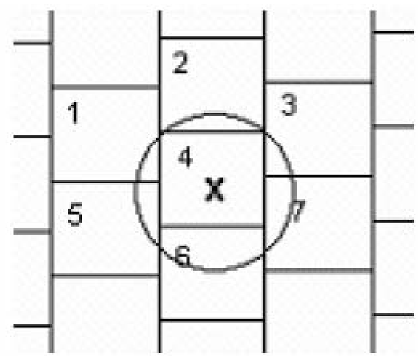
Four pixel summing configuration (4PS)

There are many different ways the charge summing can be organized (3PS, 4PS, 5PS, 7PS, 9PS)

5PS and 7PS schemes



Five pixel summing configuration (5PS)



Seven pixel summing configuration (7PS)

The 5PS scheme suffers from large losses near the corner of the central pixel

The 7PS scheme offers a large summing area, but what about noise?

Selective summing over large areas

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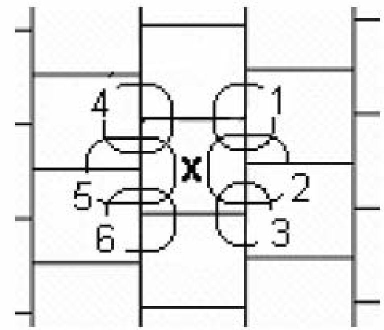
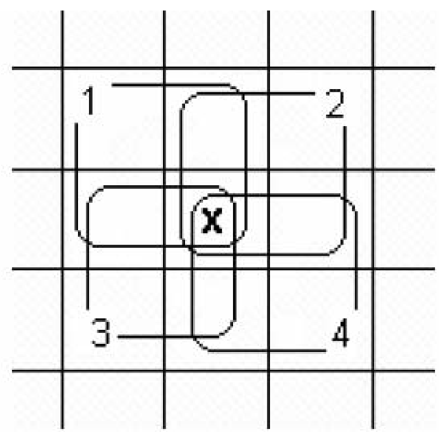
Only the largest of the 3PS sums 1 to 6 is used for the recorded charge in pixel X



Different possibilities for the charge assignment in the 3PS configuration

Only the largest of the 4PS sums 1 to 4 is used for the recorded charge in pixel X



Different possibilities for the charge assignment in the 4PS configuration

Summary

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- Comparison between different charge summing schemes (theory)

Table 1. Increase in noise and equivalent pixel area (55 μm x 55 μm pixels) due to charge summing.

Configuration	Increase in noise	Summed area (μm^2)	Covered area (μm^2)
1 pixel	1.0	3025	3025
3 pixel summing	1.73	9075	21175
4 pixel summing	2.0	12100	27225
5 pixel summing	2.24	15125	15125
7 pixel summing	2.65	21175	21175

30keV to 60 keV photons creates an average charge cloud radius of approximately 40 μm, which provides an area of 5000 $(\mu m)^2$

Simulations
(unrealistic low electronic noise)

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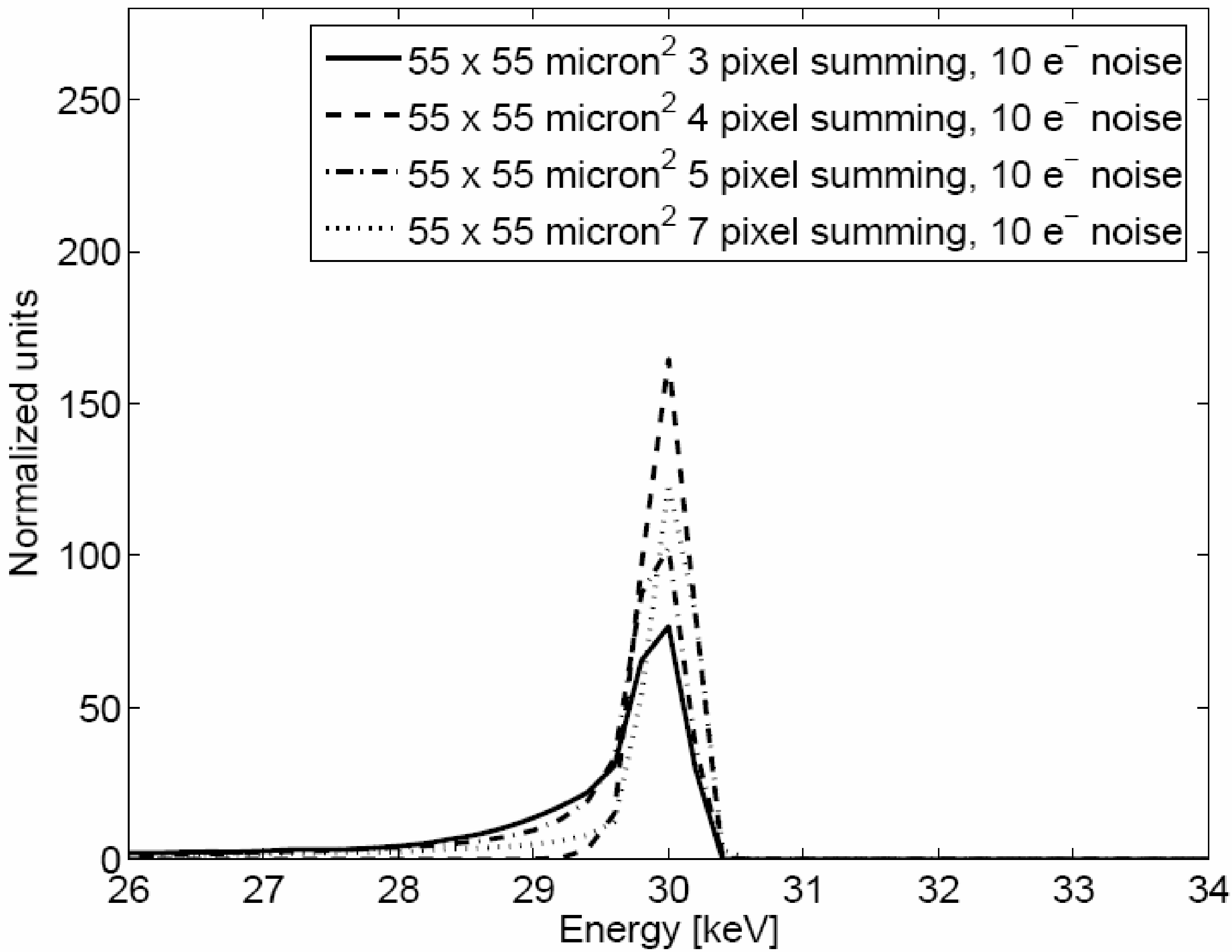
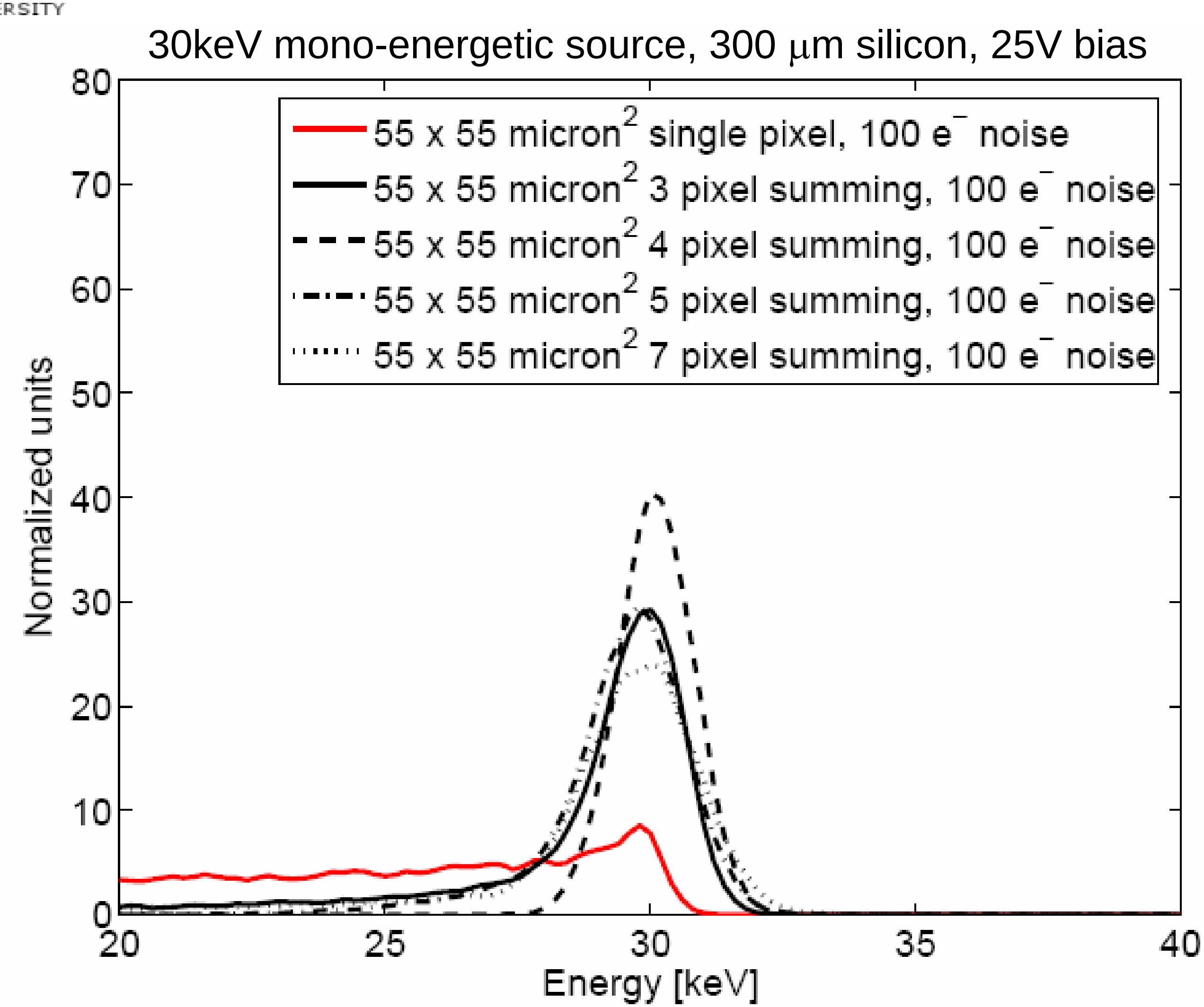
30keV mono-energetic source, 300 μm silicon, 25V bias



Simulations
(realistic electronic noise)



FWHM of 1700 eV for the 4PS

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Each pixel contributes with 850eV

Summary

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- Various charge summing schemes for suppression of charge sharing have been evaluated
- Our simulation shows that the 4PS (including selective summing to reach maximal coverage area) is the best candidate for X-ray energies below 100keV (*other schemes may be better at higher energies or at different pixel sizes*)
- The 4PS scheme eliminated the effects of charge sharing to a cost of two times higher electronic noise
- Adaptive algorithms may be introduced that selects between different summing schemes depending on distribution of charge in the surrounding pixels