Spectra Recording Semiconductor Detectors for Medical Imaging

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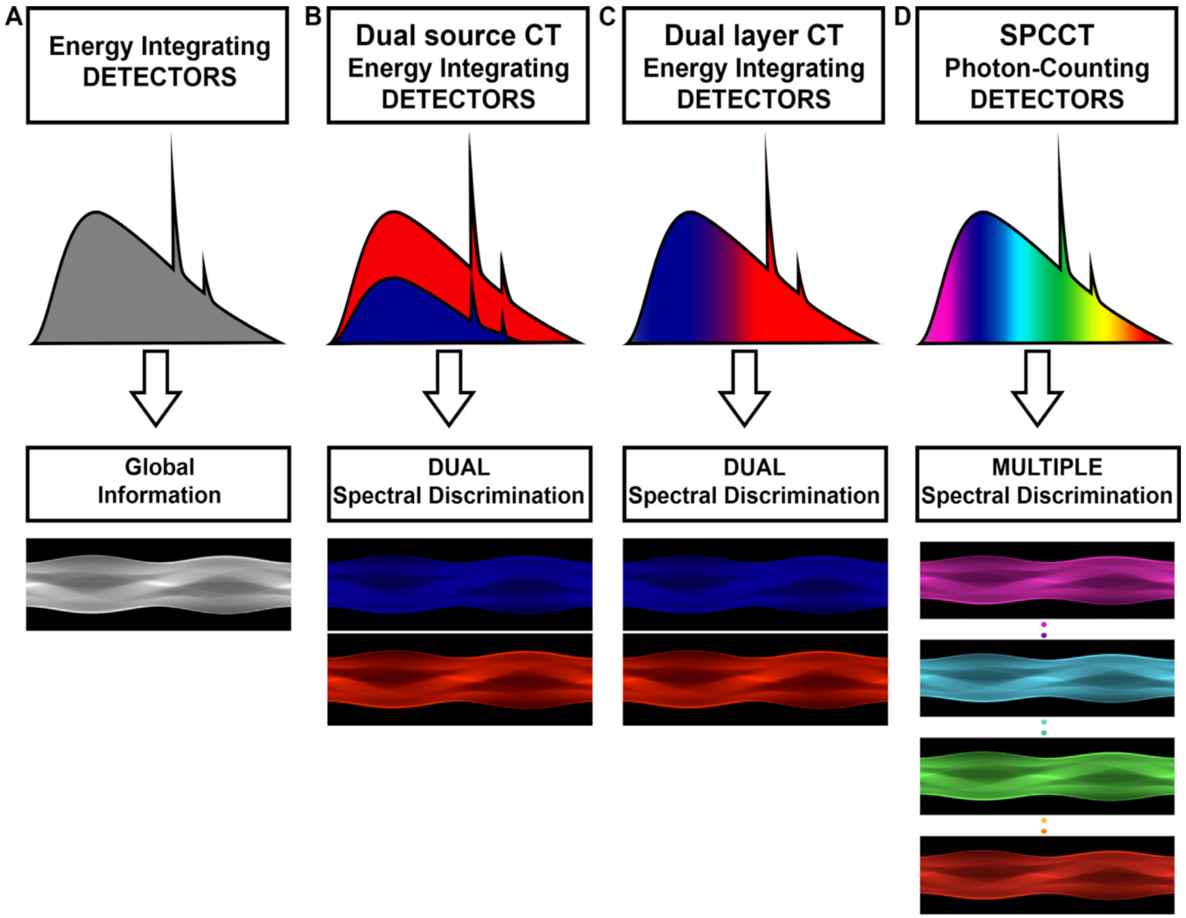
Motivation

- Currently, X-ray imaging detectors integrate the dose in each pixel
  - Photon energies not recorded
- Attenuation depends on the photon energy → More information of the imaged material with energy separation
- For example: Dual energy computed tomography (DECT)
  - CT scans with two different tube voltages or
  - Layered detectors

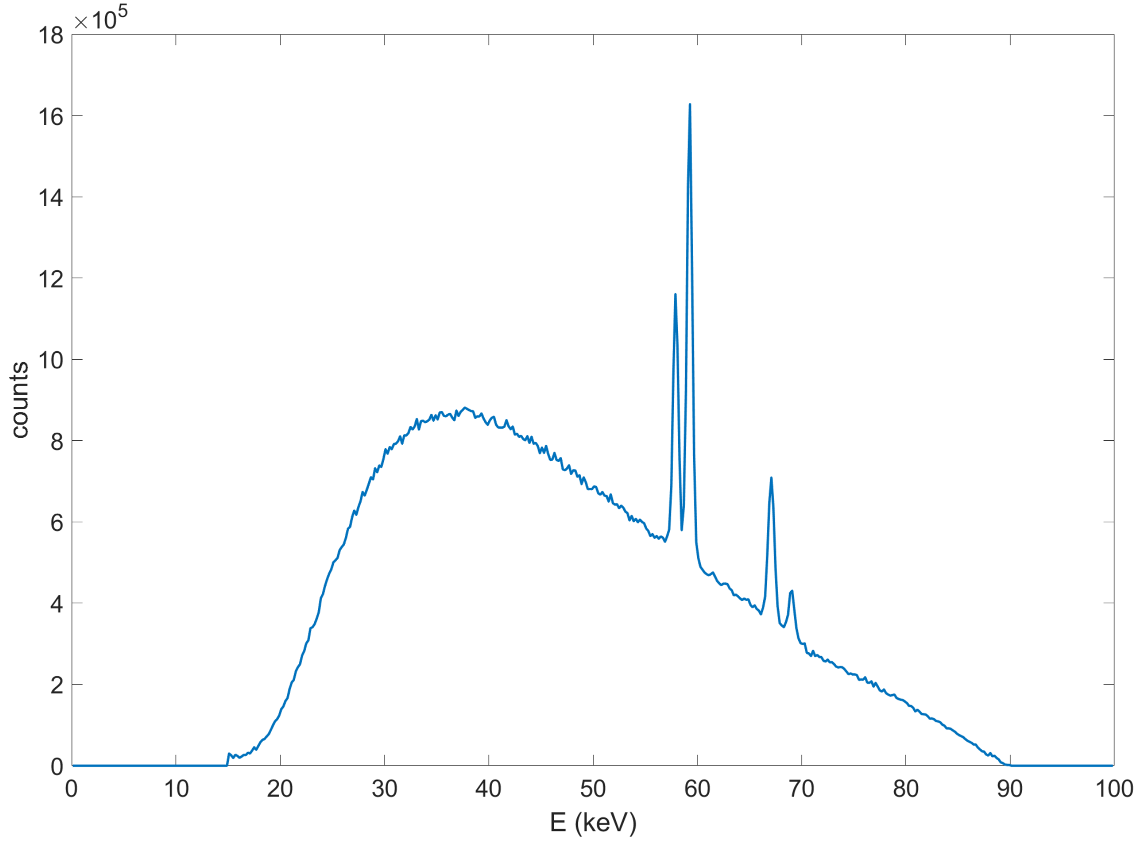


https://doi.org/10.1016/j.nima.2017.04.014

Motivation

What if we could record the photon energies in every pixel of an imaging detector (photon counting detectors)?

- Attenuation of photons in multiple energy regions
  → More information of the material
- Lower energy resolution, closer to detection of mono-energetic photons
- Spectral information, “coloured” X-ray images
- Higher contrast-to-noise ratio
  → **Lower dose to patient**



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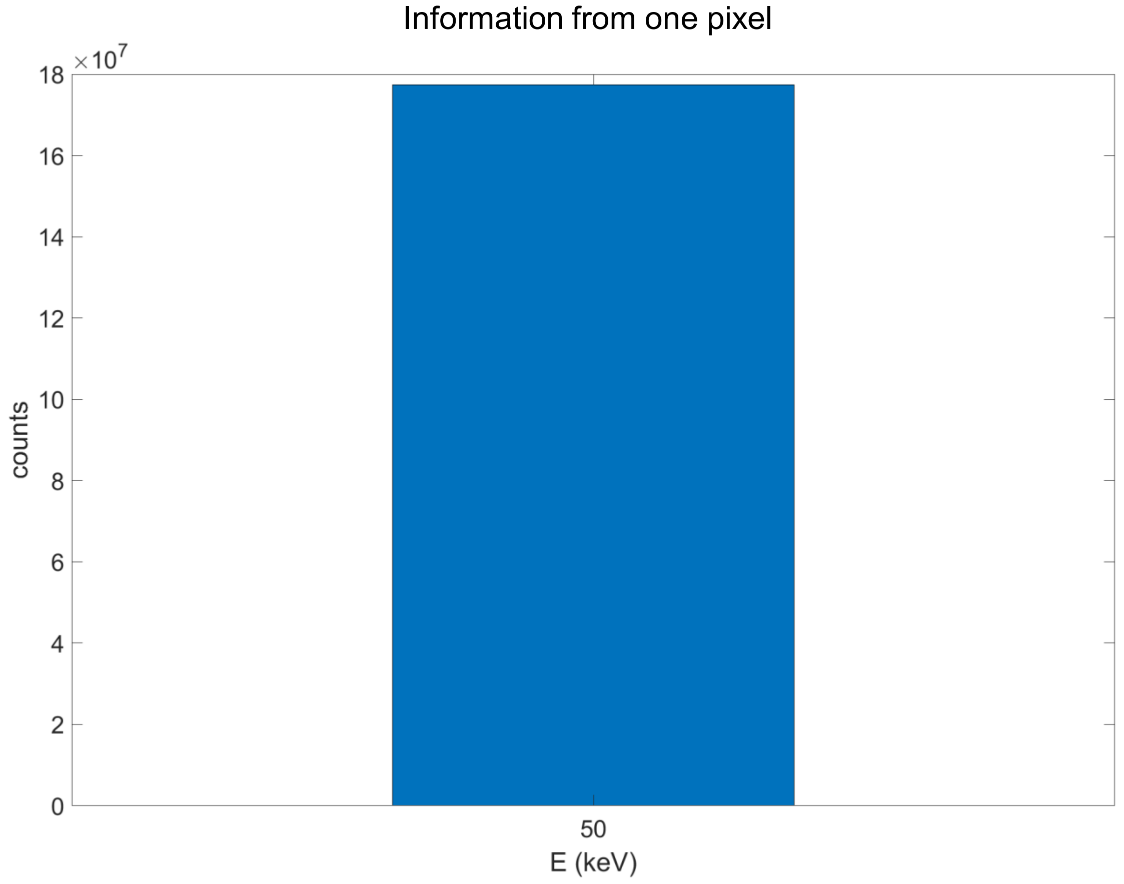

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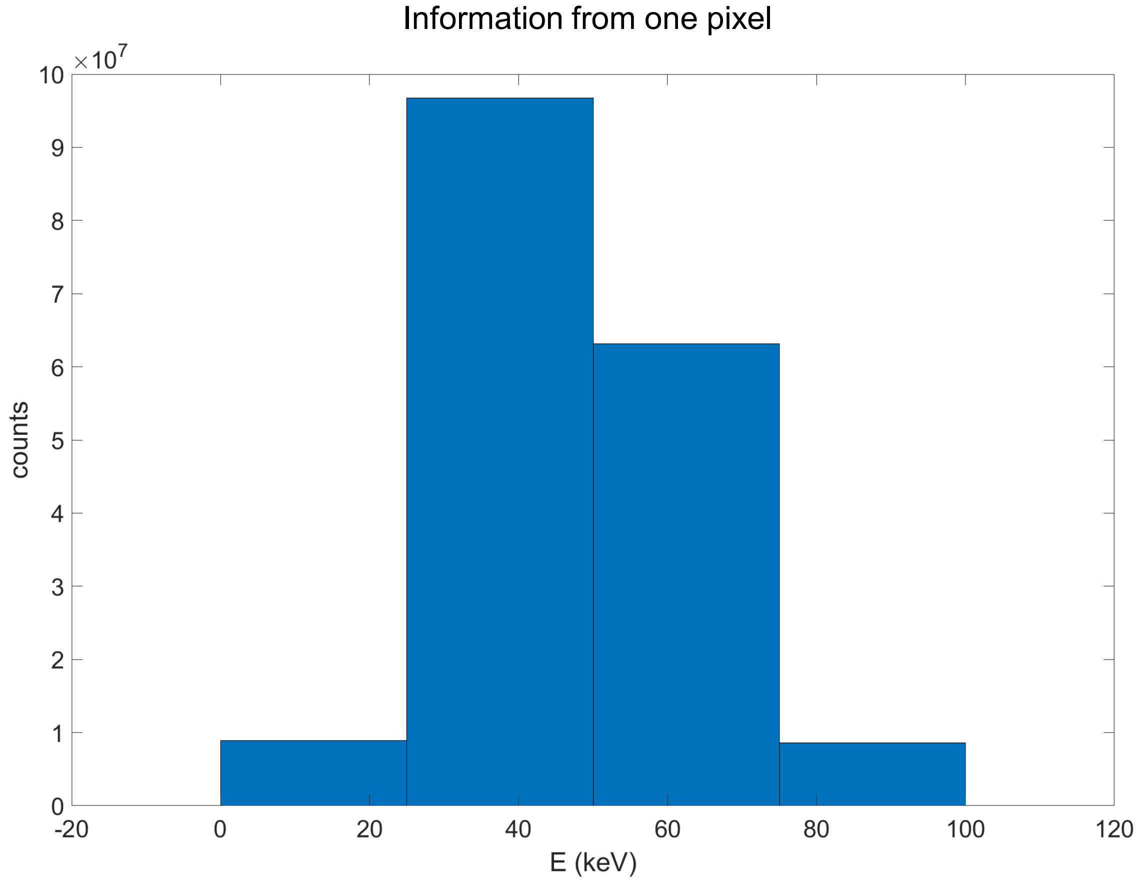

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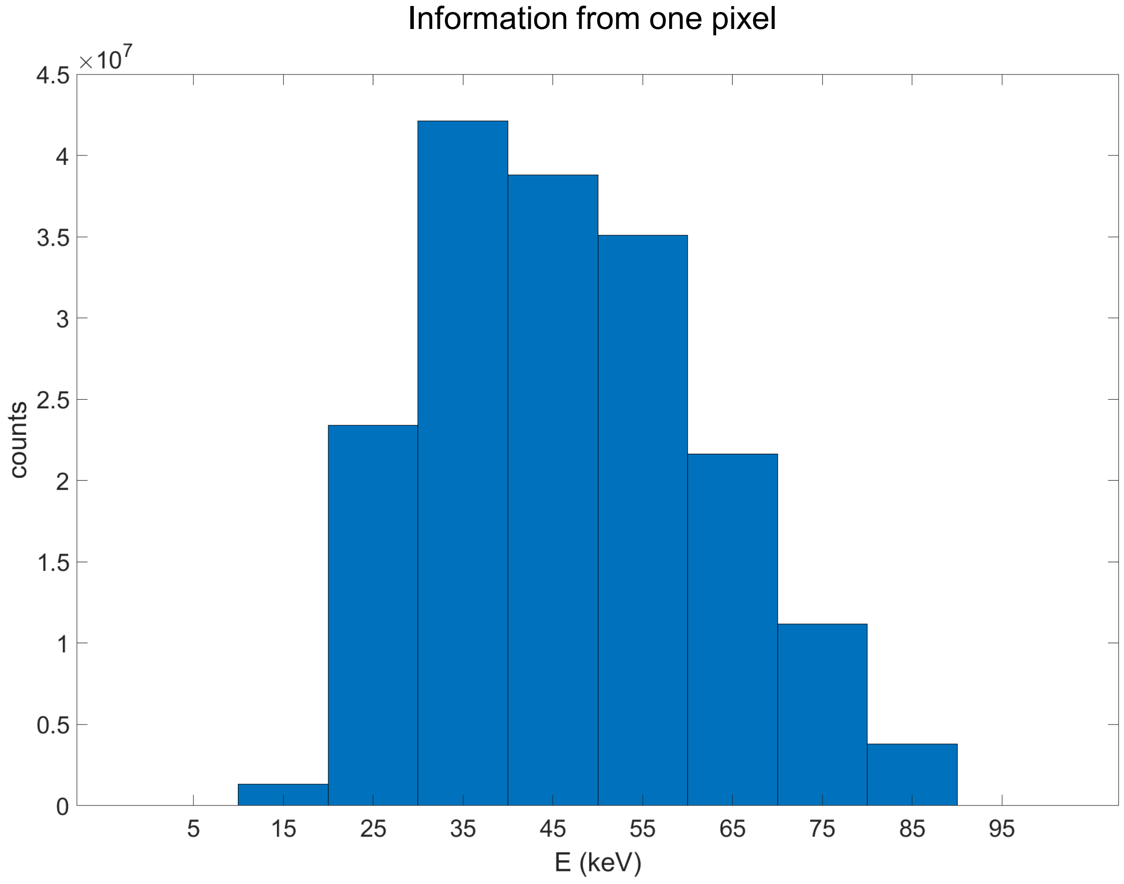

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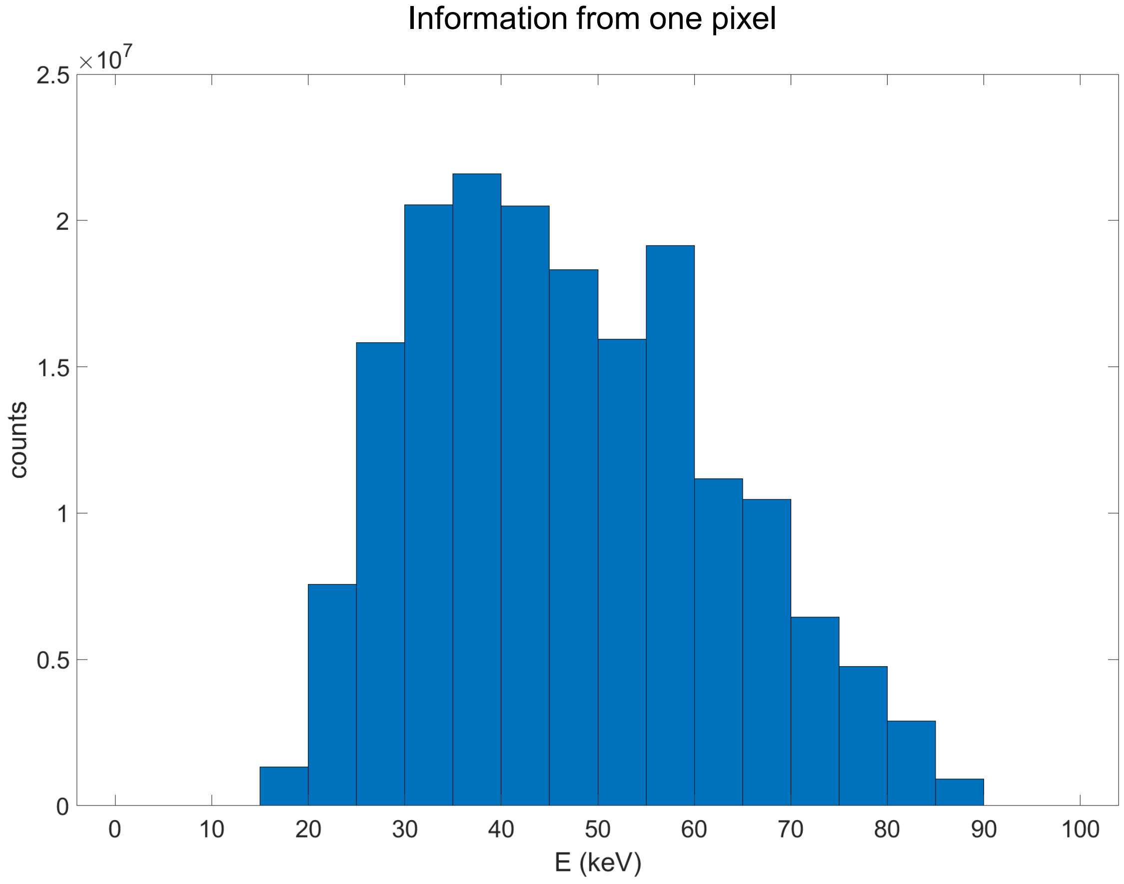

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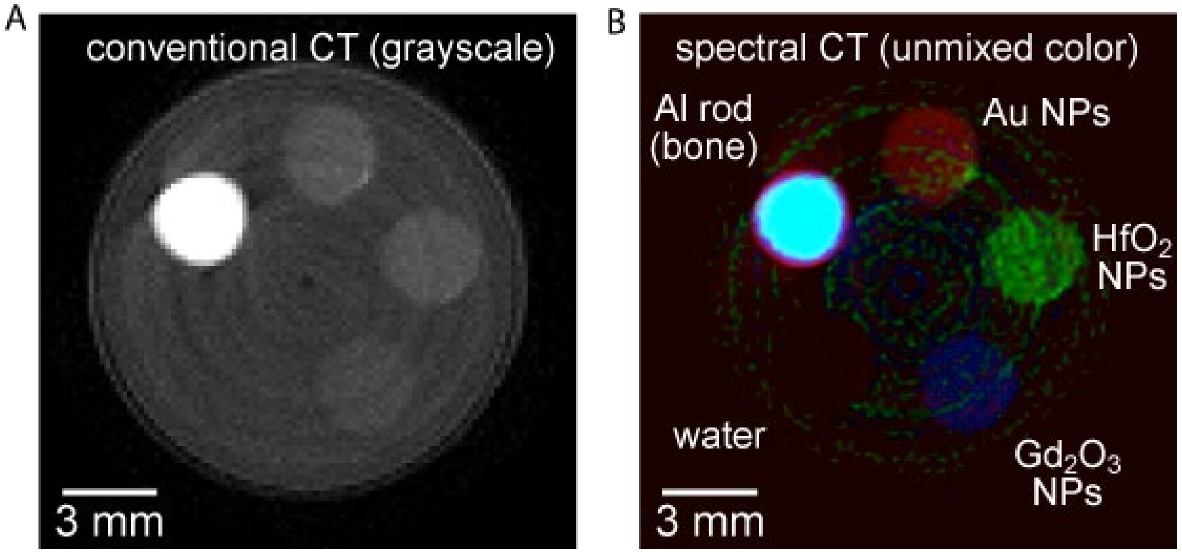
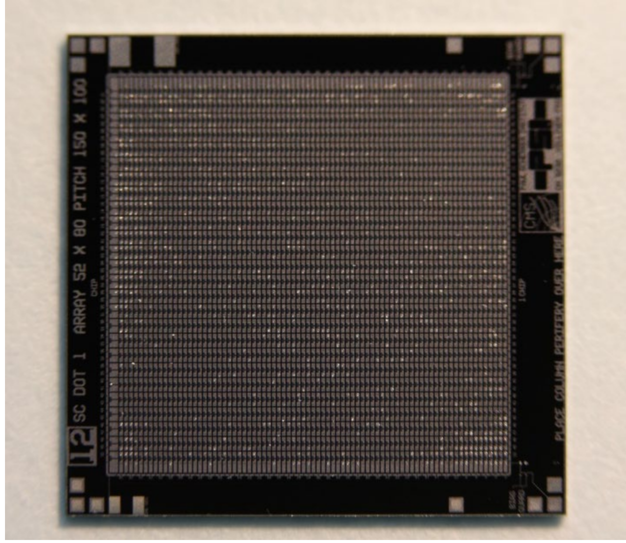


https://www.frontiersin.org/10.3389/conf.fbioe.2016.01.00902/event_abstract

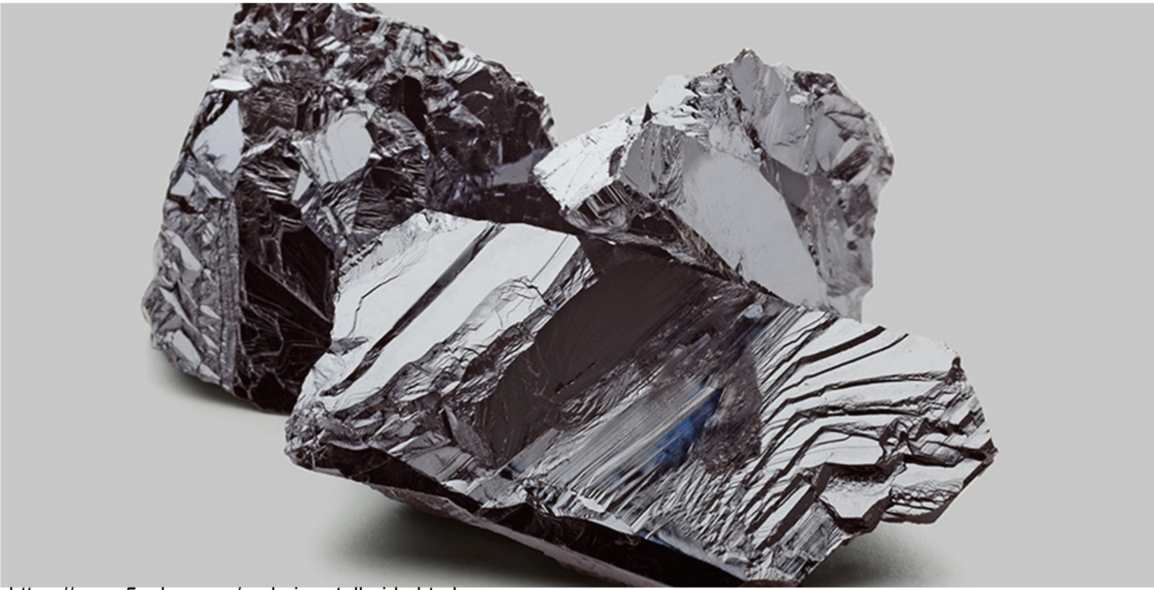
Photon counting detector development



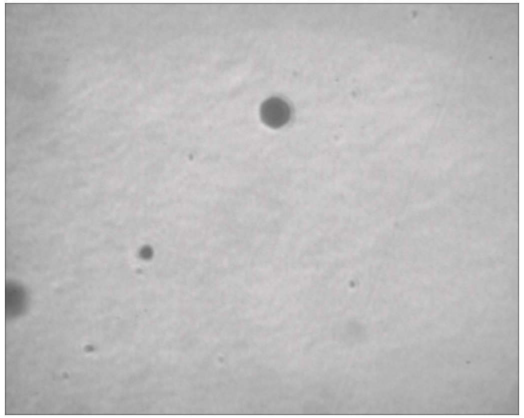
- Pixelated photon counting detectors are being developed in collaboration between Helsinki Institute of Physics, LUT University, Aalto University and STUK
- Technologies based on a read out chip developed for the CMS experiment at CERN
  - Pulse processing integrated into every pixel
  - Spectral information
  - Bump bonding to semiconductor wafer
- 100 x 150 μm^2 pixel size
- CdTe (or CdZnTe) the main detector material under investigation
- Other materials: silicon and combination of scintillator and silicon

Cadmium Telluride

- Effective atomic number $Z_{eff} = 50$: high absorption, little scattering
  - 84% of 60 keV photons are absorbed in 0.5 mm of CdTe
  - Electron range less than 50 μm at 100 keV
- Band gap 1.44 eV
  - Operation at room temperature
  - Good energy resolution
- Disadvantages
  - Brittle material, difficult to process
  - Detector response variations due to material inhomogeneity
  - Limited availability
- Detector material QA with infrared spectrometry



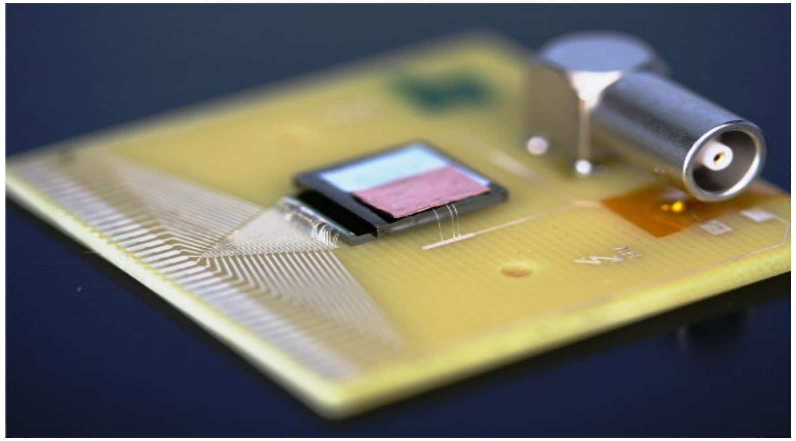
https://www.5nplus.com/cadmium-telluride.html



CdTe defects

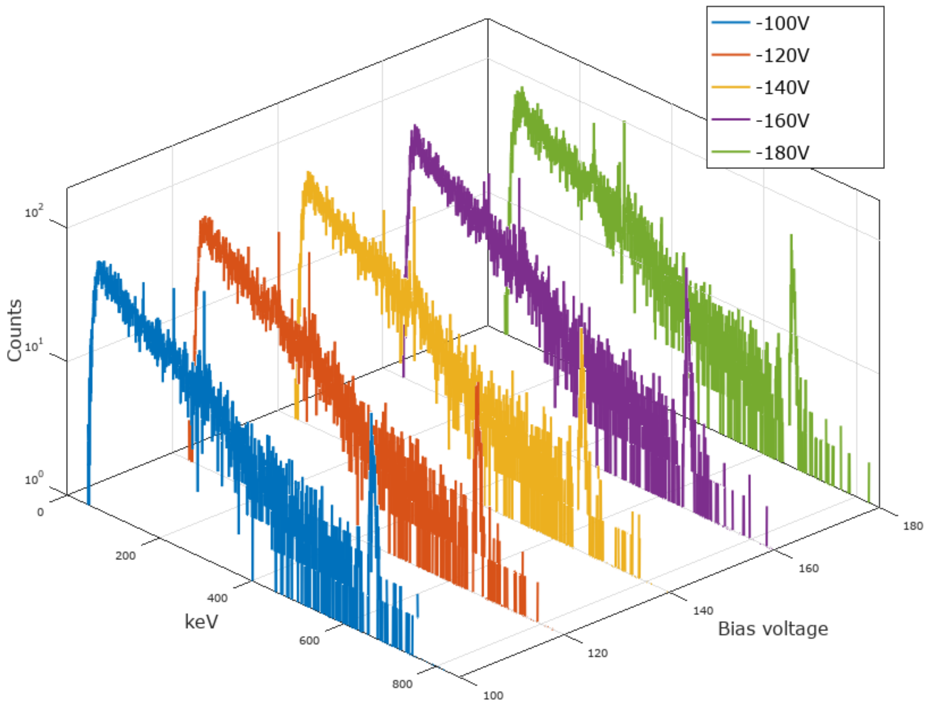
Measurements with CdTe

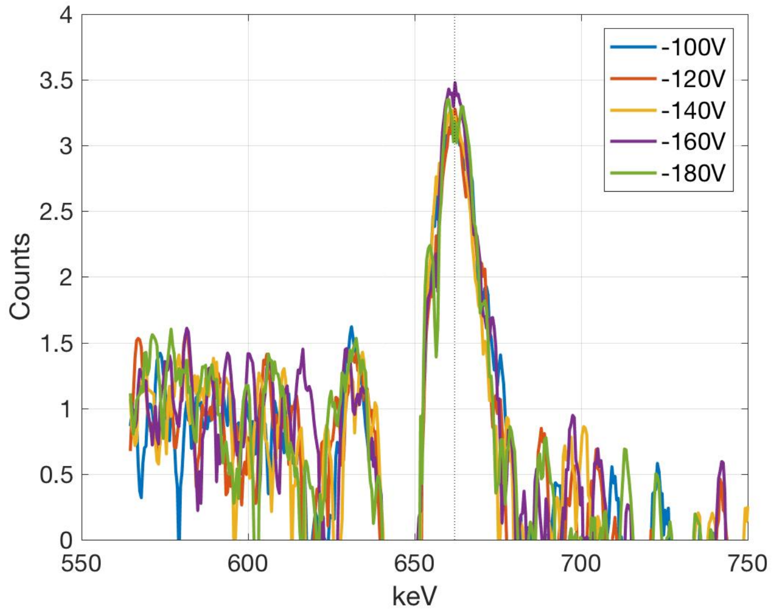
- Measurements with a 0.5 mm thick CdTe chip at secondary standard dosimetry laboratory of STUK
- Cs-137 source



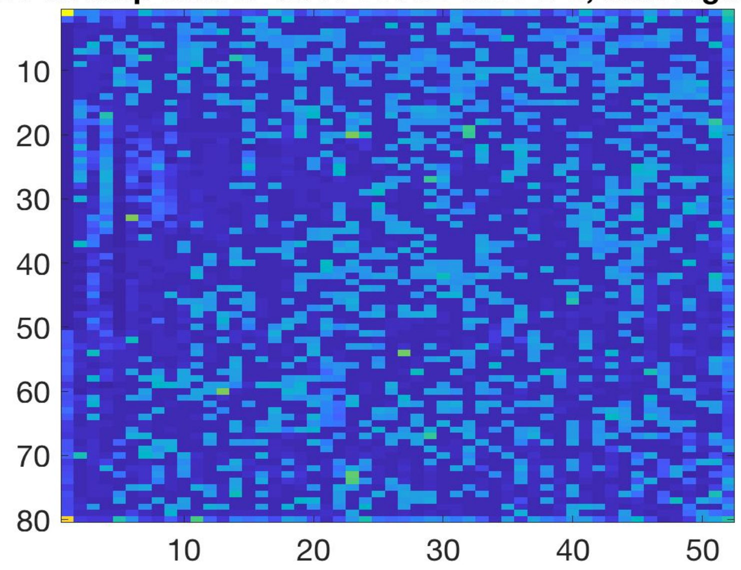
Measurements with CdTe

- 662 keV peak energy resolution approximately 2%
- Even response over the detector area





^{137}Cs hit map sensor CdTe #0712-1001-2-3, with digital RO



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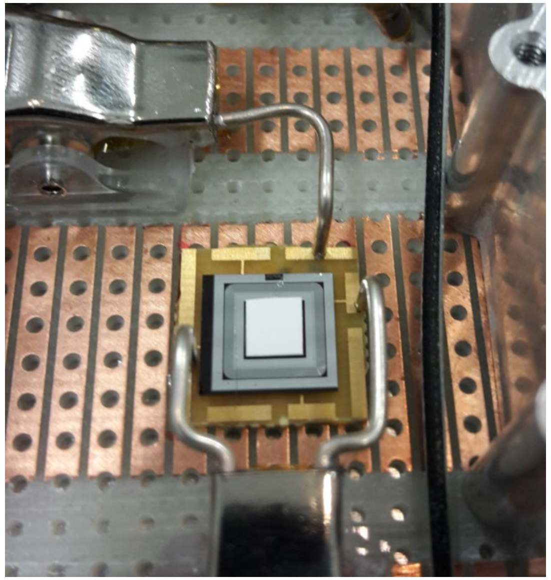
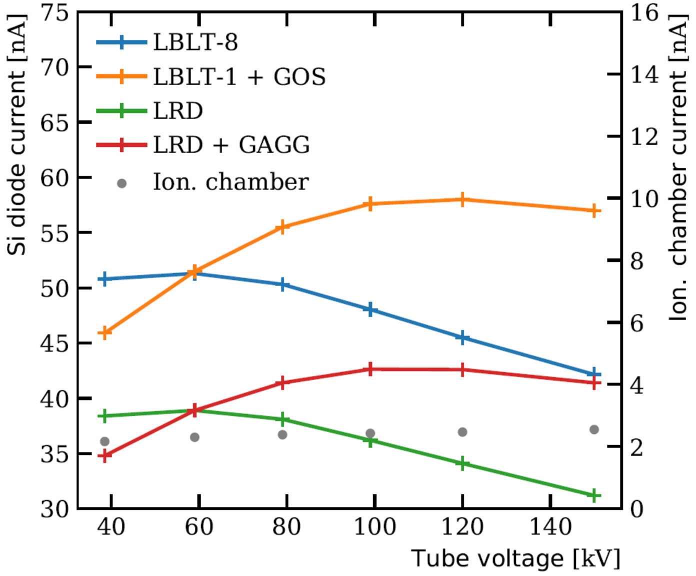
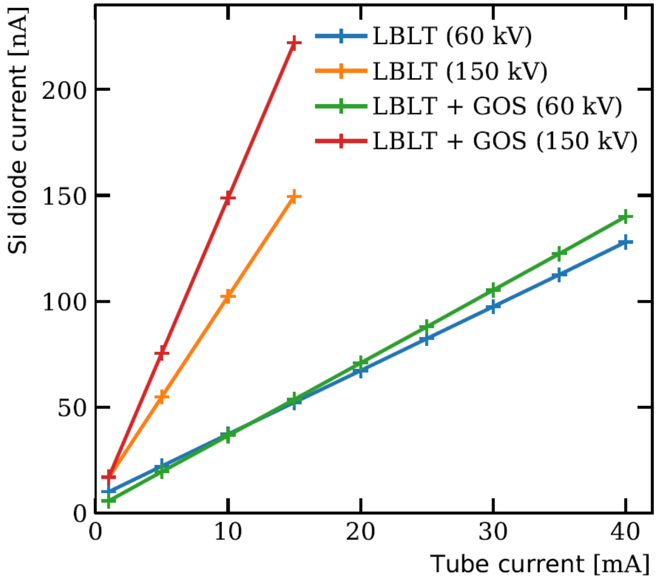
Scintillator enhanced silicon (SiS)

- Layered detector: Scintillator material on top of pixelated silicon detector
- Silicon works both as a photodiode and detector material
- Challenge: Pulses originating from scintillator slow compared to Si induced pulses
- Plastic scintillators are faster but have a low atomic number
- R&D in early stages







Radiation therapy dose profile measurements

- Thin silicon pixel detectors for dose profile measurements
- Application to high gradient dose profiles
  - For example flattening filter free beams, IMRT, VMAT, small fields
- 3D dose distribution in a phantom by moving the detector
- Possible use of spectral information in correcting the detector response

Plans for the future

- New CdTe detectors under characterization
- X-ray beam tests
- Larger arrays (multiple chips and read out chips in one detector)
- Development of image processing algorithms
- Application to CT imaging
- Further development of SiS and silicon detectors