Energy deposition and charge transport in pixellated semiconductor X-ray detectors

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OUTLINE

- **Background**
  - Motivation
  - Charge deposition
  - Charge transport
- **Energy deposition**
  - Initial profile
  - After charge transport
- **Spectral response**
  - Initial spectrum
  - After charge transport
- **Summary and conclusions**

Background

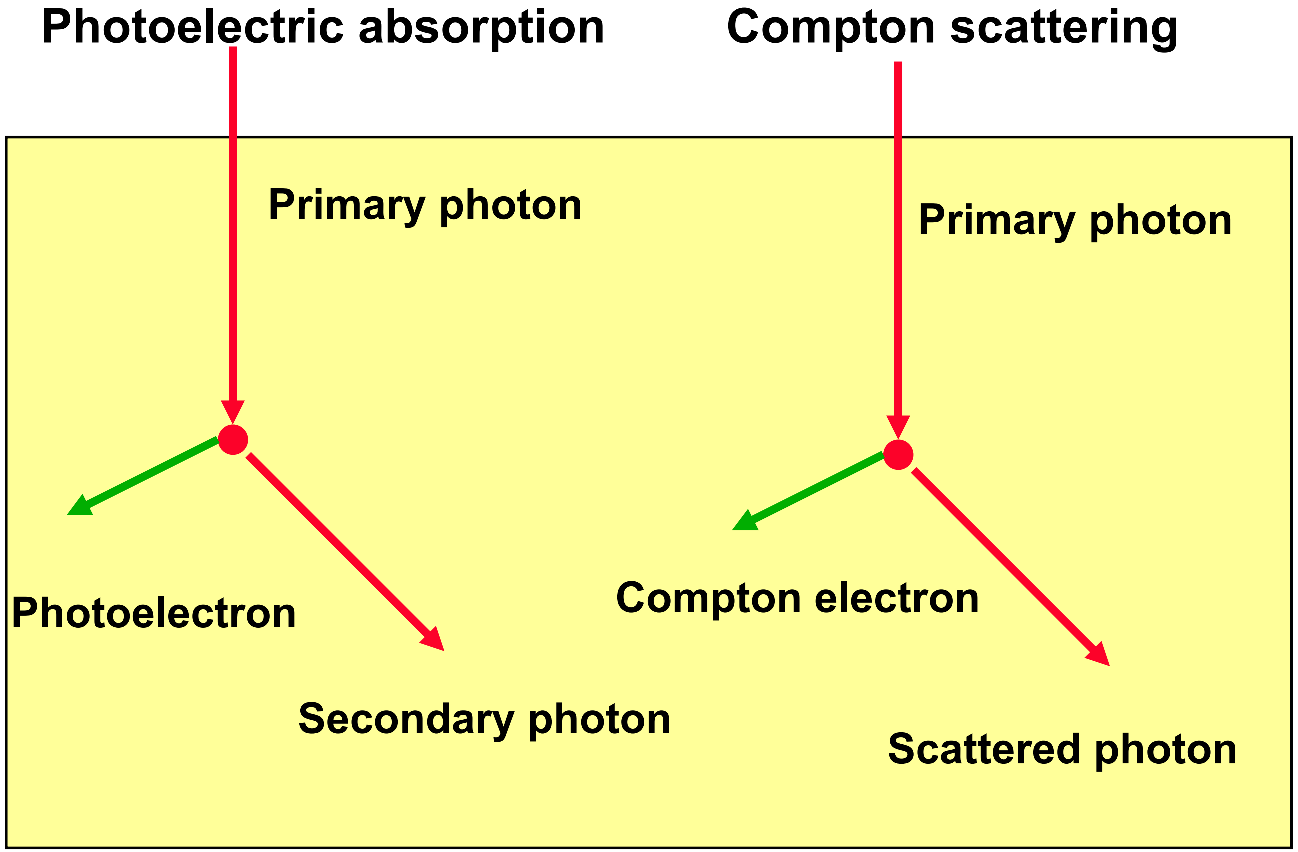
- **Significant charge sharing has been noticed in photon counting X-ray detectors**
  - **Which is the dominant effect causing charge sharing in pixel detectors?**
    - **How large is the initial charge cloud?**
    - **What is the effect of X-ray fluorescence?**
    - **What is the effect of diffusion during charge transport?**

- **We have simulated charge deposition and charge transport in a number of different detectors**

Background

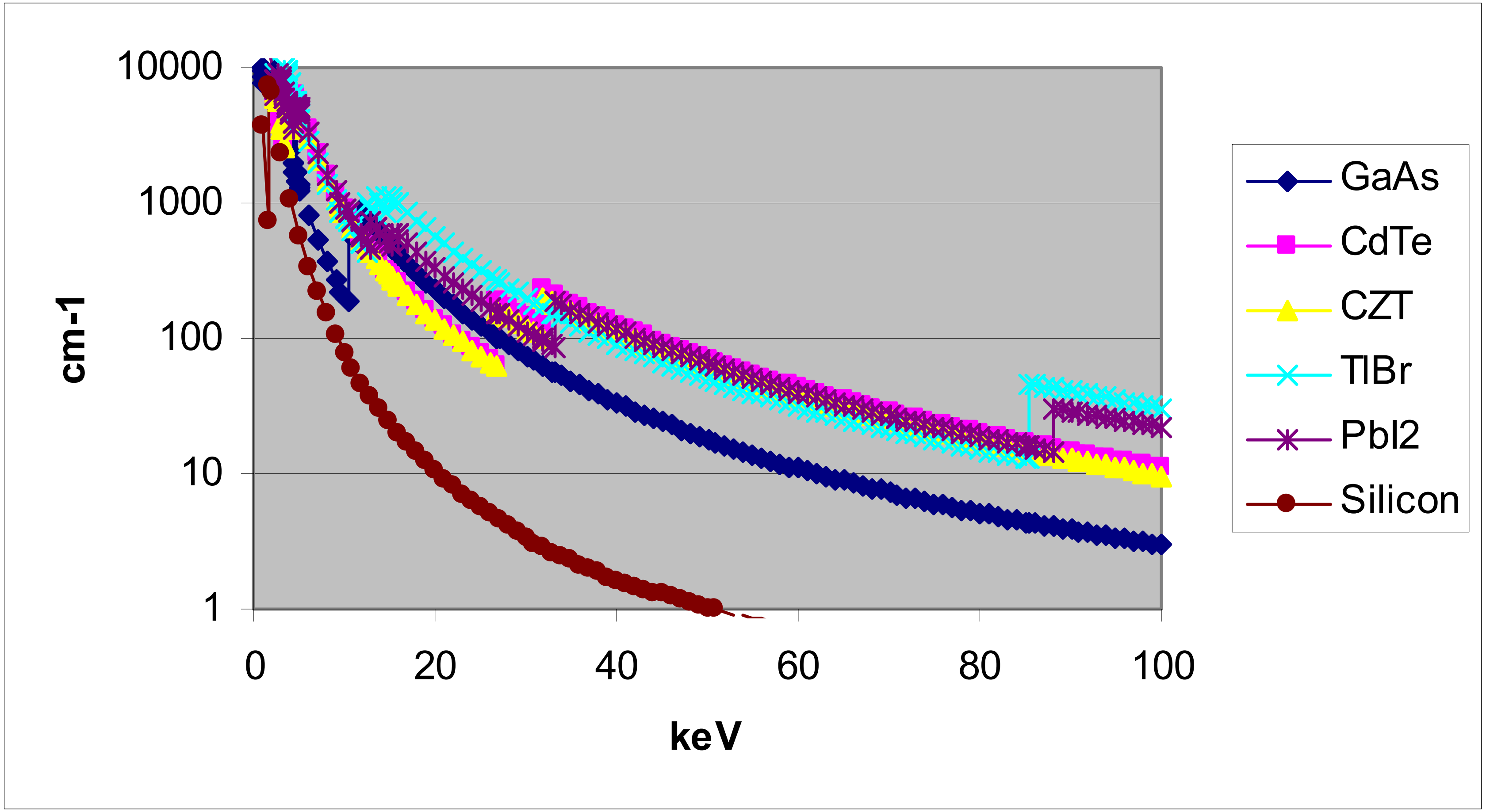
- **Simulated structures**
  - Pixel size 50 x 50 um
  - Layer thickness 500 um
  - Materials Si, GaAs and CdTe, $Cd_{0.8}Zn_{0.2}Te$, TlBr, PbI_2
  - Charge transport simulated for Si and CdTe assuming Si drift parameters
  - Charge deposition simulated with MCNP4C
  - Charge transport simulated with MEDICI

Charge deposition



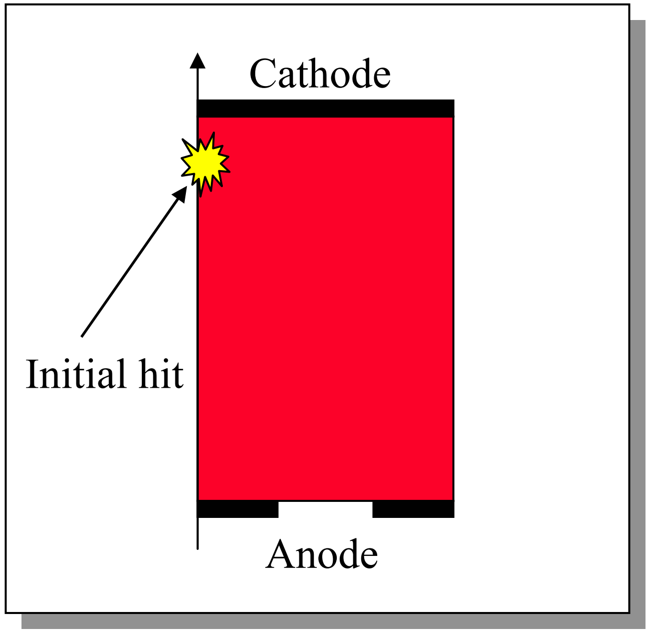
Kα (keV)	
Zn	8.63
Ga	9.25
As	10.54
Br	11.93
Cd	23.17
Te	27.47
I	28.61
Tl	72.86
Pb	74.96

Linear attenuation coefficients

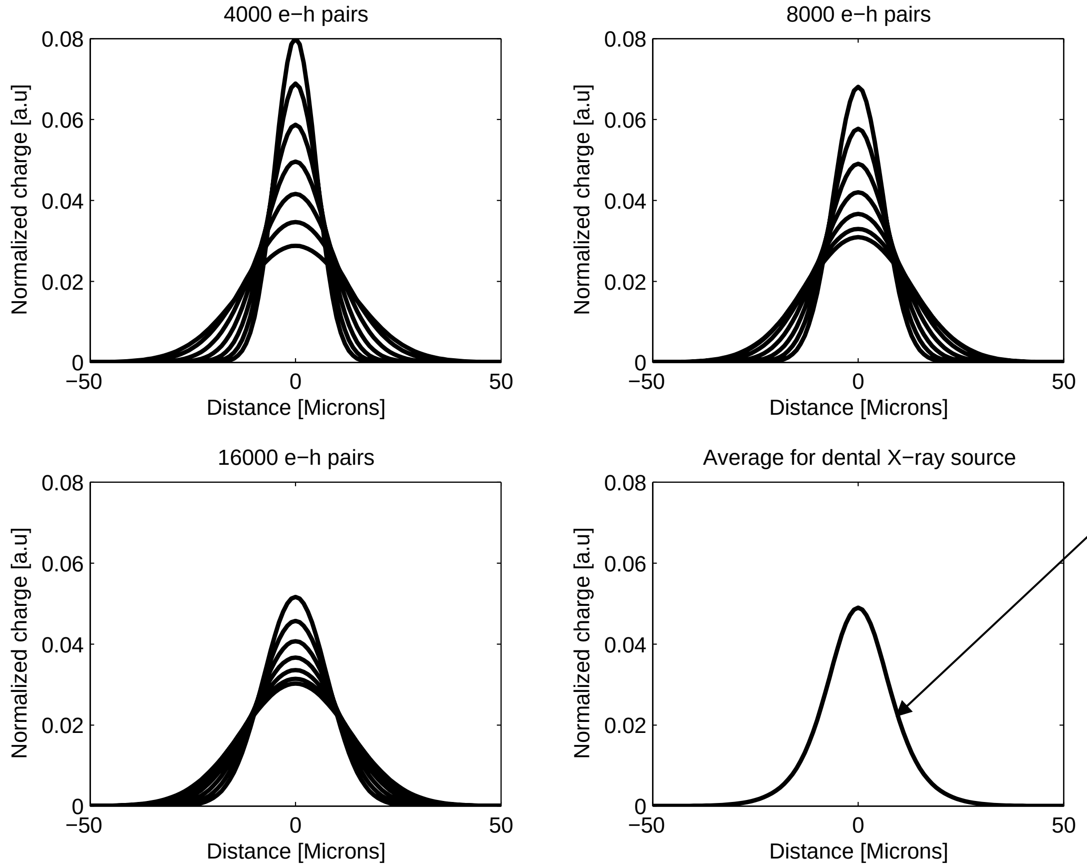


Charge transport

- ***The charge transport has been extracted using time resolved drift-diffusion simulations in MEDICI***
- ***3D-effects has been taking into account using cylindrical coordinates***
- ***Ideal semiconductor materials have been assumed (no effect due to trapping etc)***



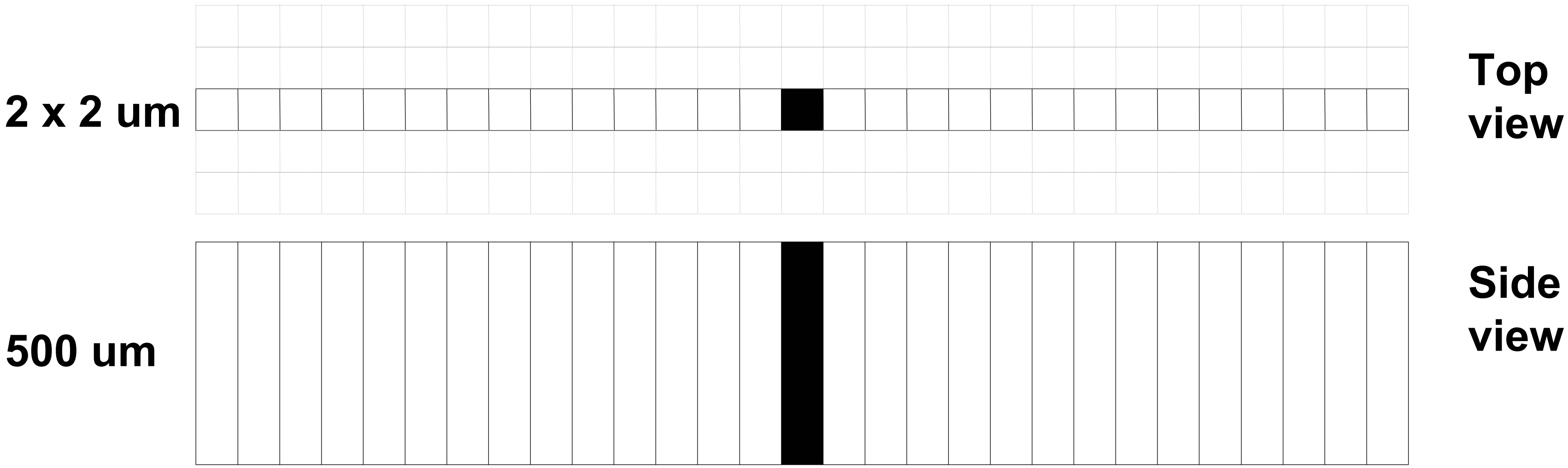
Simulated pulse width for 300 um Si and a dental source



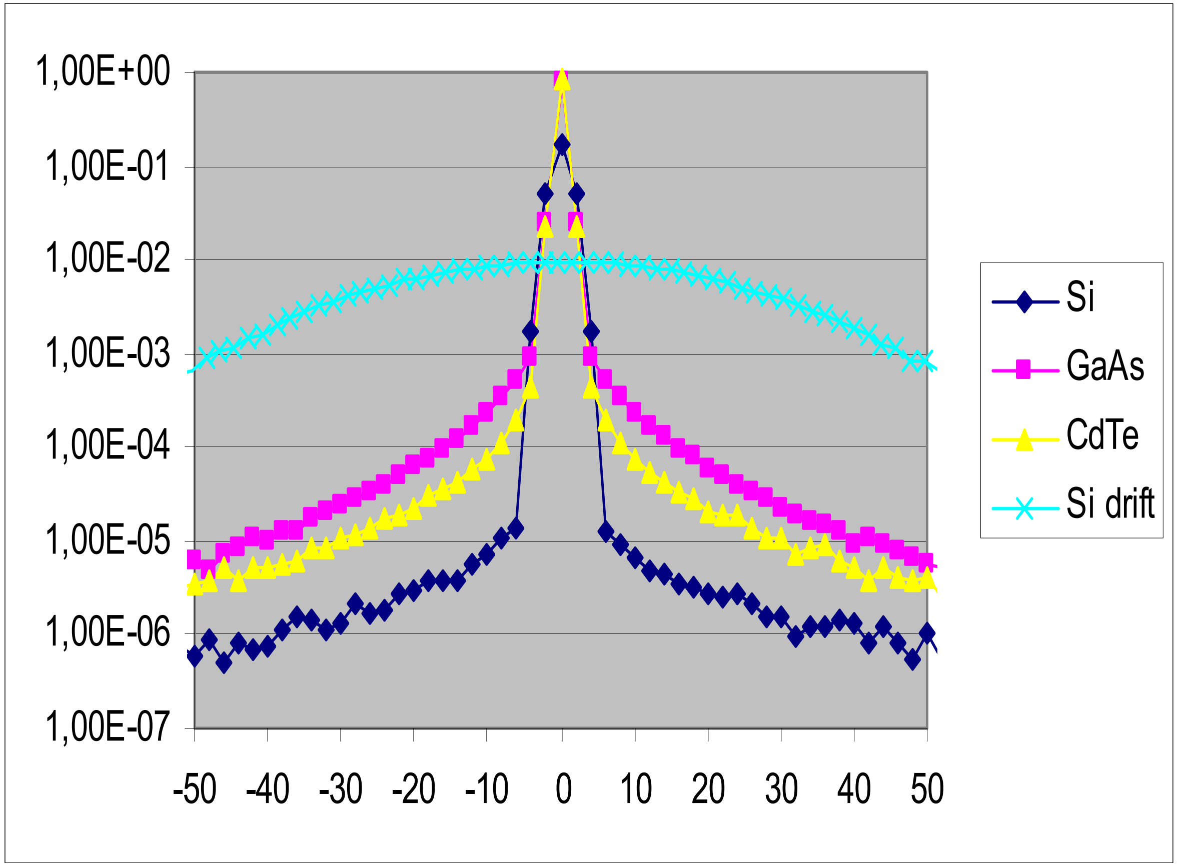
FWHM
(25 micron)

Energy deposition

- **The energy deposition has been simulated counting the energy deposited in a 2 um thick slice of the detector using a monoenergetic point source located at the centre of the slice. A spatial resolution of 2 um was used during the simulation**



Energy deposition at 18 keV



Quantum efficiency (at peak):

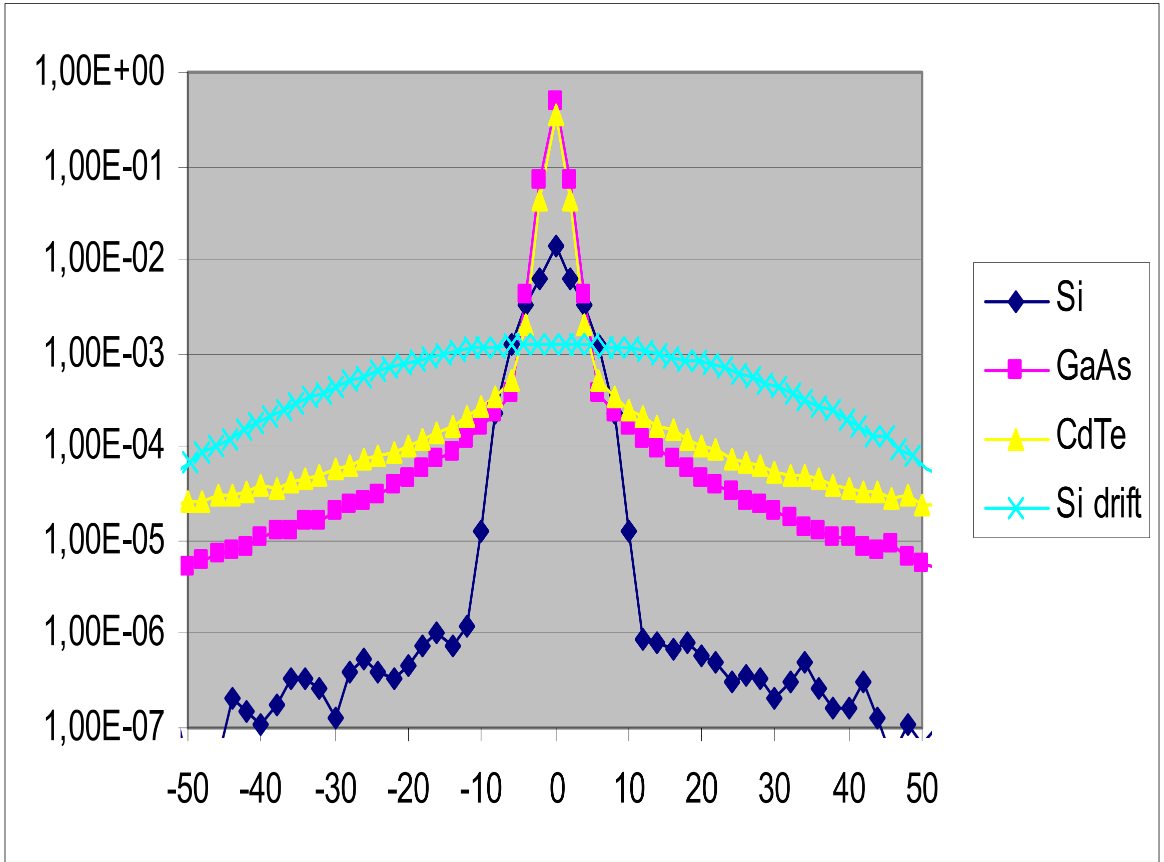
Si: 0.17

GaAs: 0.77

CdTe: 0.85

Most energy deposited within 15 µm

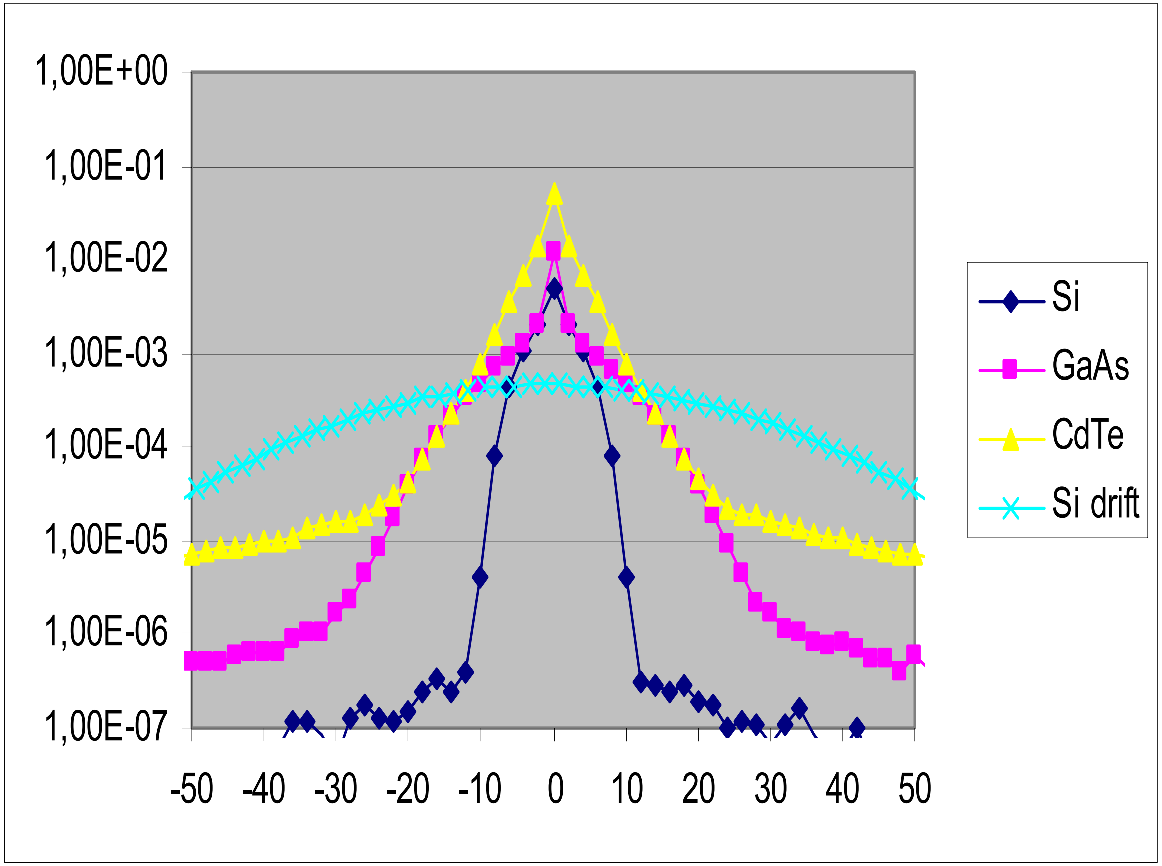
Energy deposition at 30 keV



Quantum efficiency (at peak)

Si:	**0.01**
GaAs:	**0.47**
CdTe:	**0.36**

Energy deposition at 90 keV



Quantum efficiency (at peak):

Si: 0.004

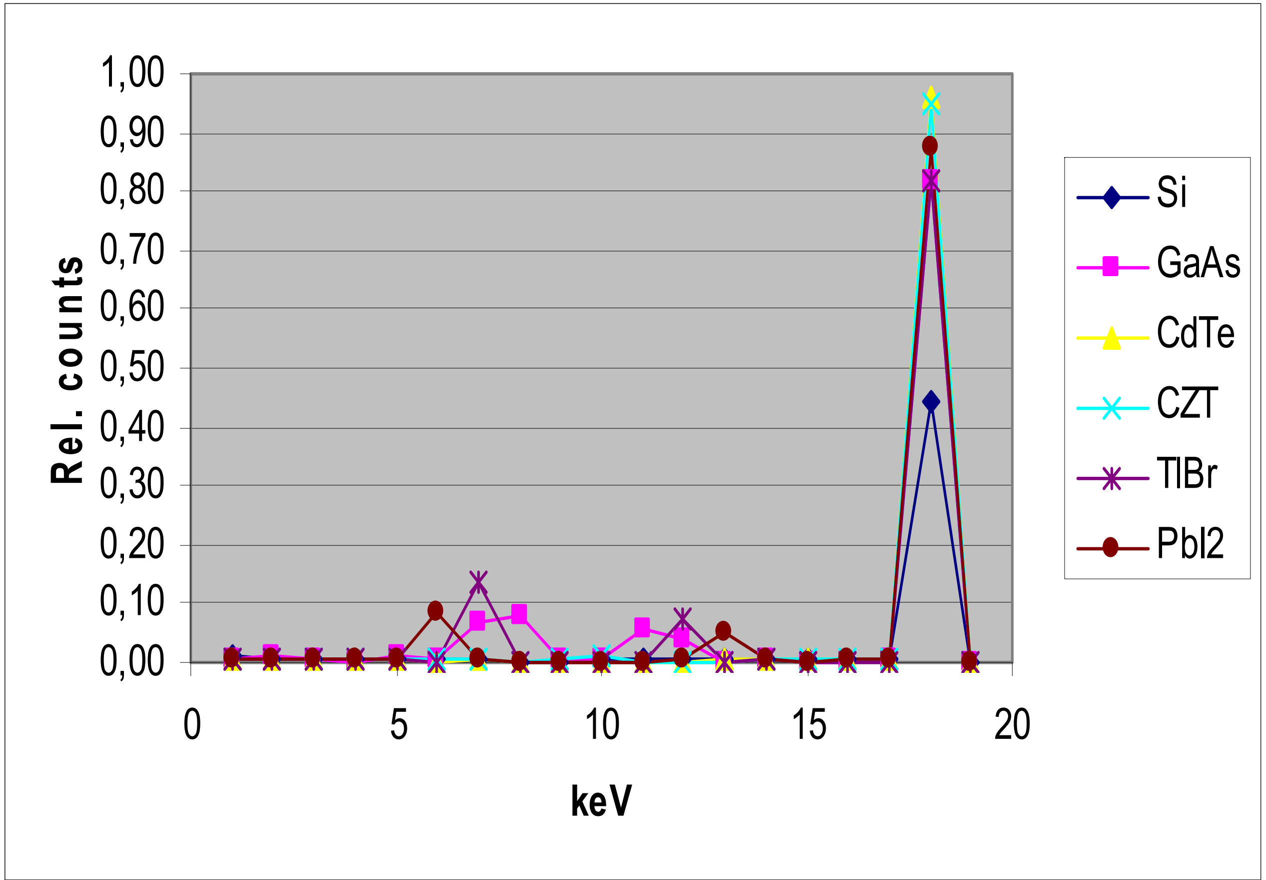
GaAs: 0.01

CdTe: 0.05

Spectral response

- Pixel size 50 x 50 um
- Layer thickness 500 um
- Uniform illumination with monoenergetic photons
- Response collected from central pixel in an array of at least 20 x 20 pixels
- Energy bin size 1 keV

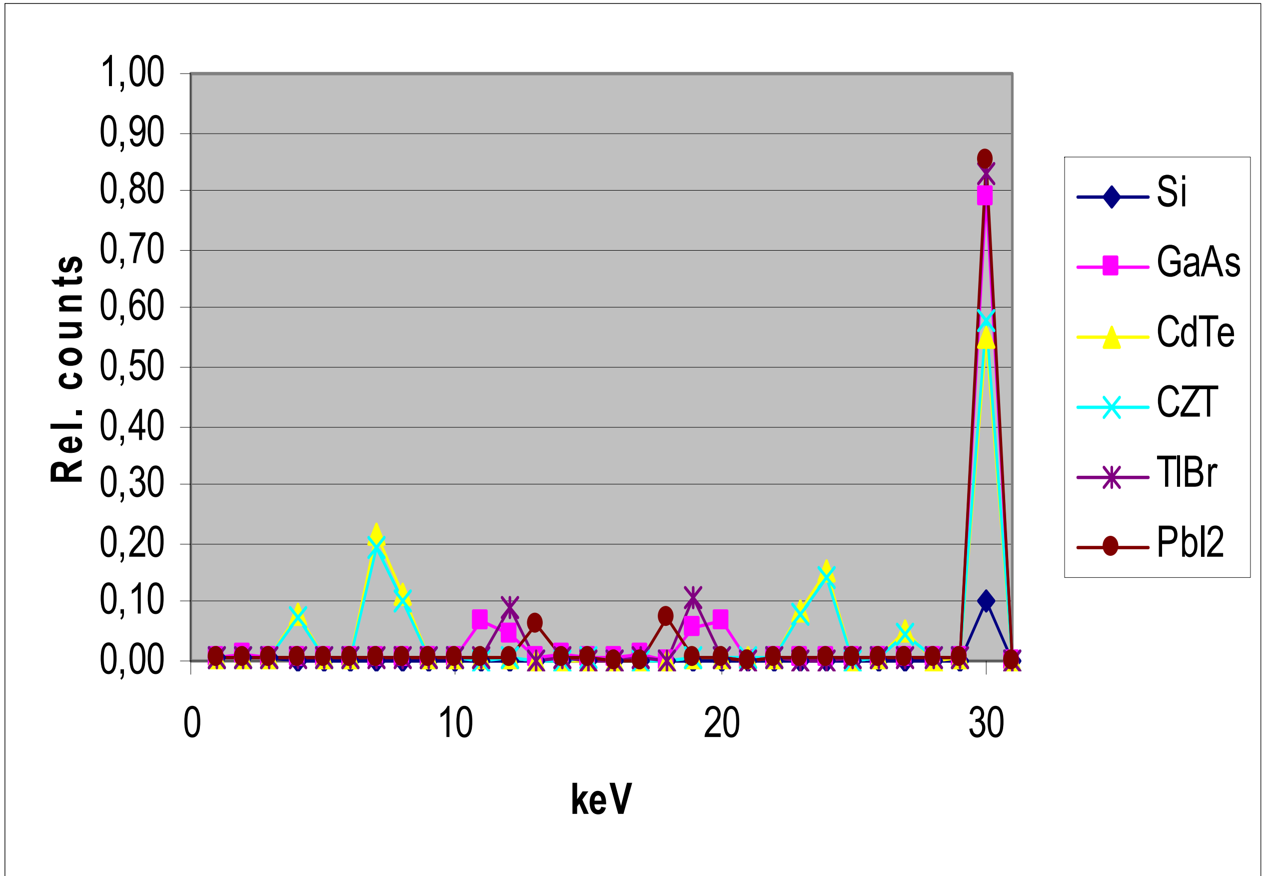
Spectral response at 18 keV



Quantum efficiency.

	Total	Peak
Si	0.44	0.51
GaAs	1.00	0.82
CdTe	1.00	0.96
CZT	1.00	0.95
TlBr	1.00	0.82
PbI2	1.00	0.87

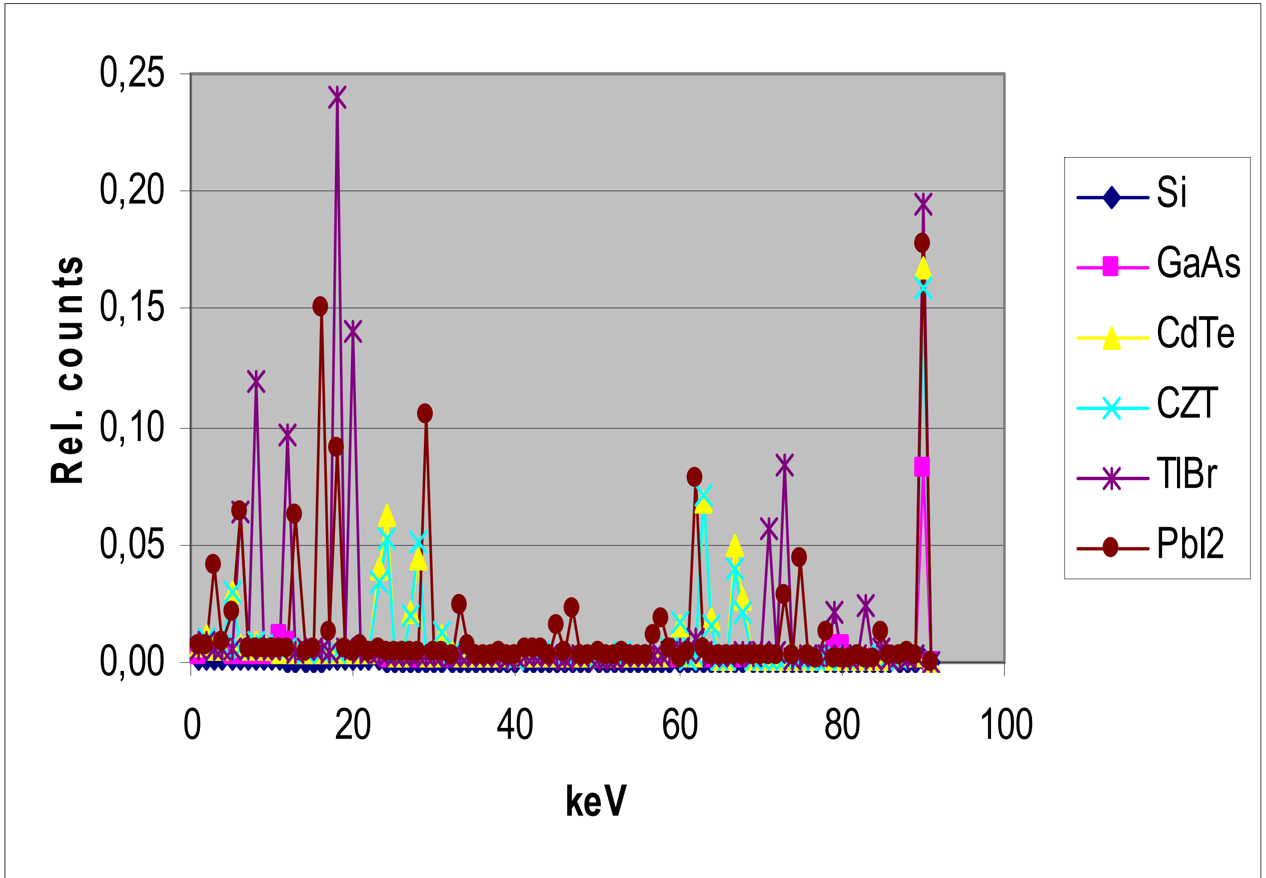
Spectral response at 30 keV



Quantum efficiency.

	Total	Peak
Si	**0.15**	**0.10**
GaAs	**0.98**	**0.79**
CdTe	**1.00**	**0.55**
CZT	**1.00**	**0.58**
TlBr	**1.00**	**0.83**
PbI2	**1.00**	**0.85**

Spectral response at 90 keV



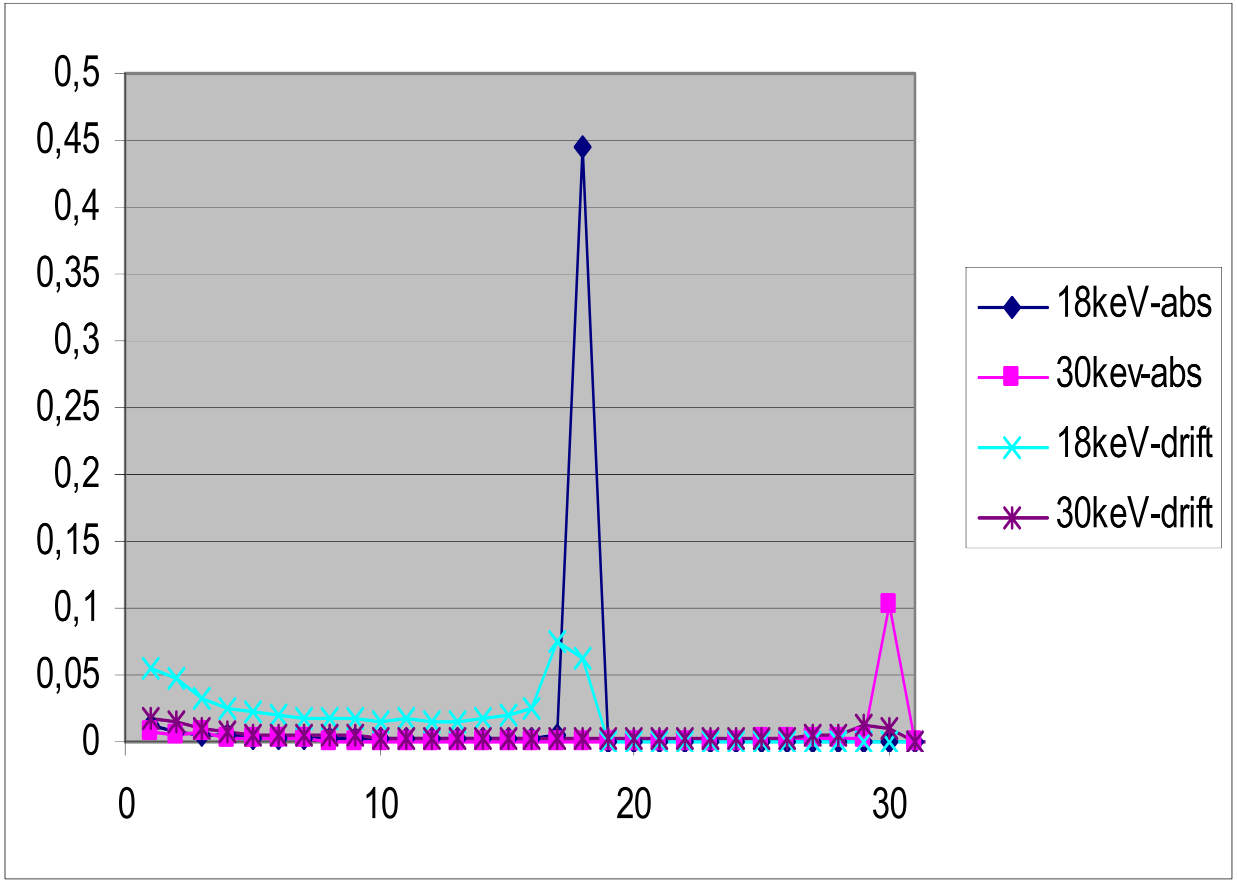
Quantum efficiency.

	Total	Peak
Si	0.02	0.001
GaAs	0.18	0.08
CdTe	0.51	0.17
CZT	0.47	0.16
TlBr	0.87	0.19
PbI2	0.77	0.18

Effects of charge sharing

- **Spectrum before and after charge transport for Si at 18 and 30 keV and CdTe at 90 keV**

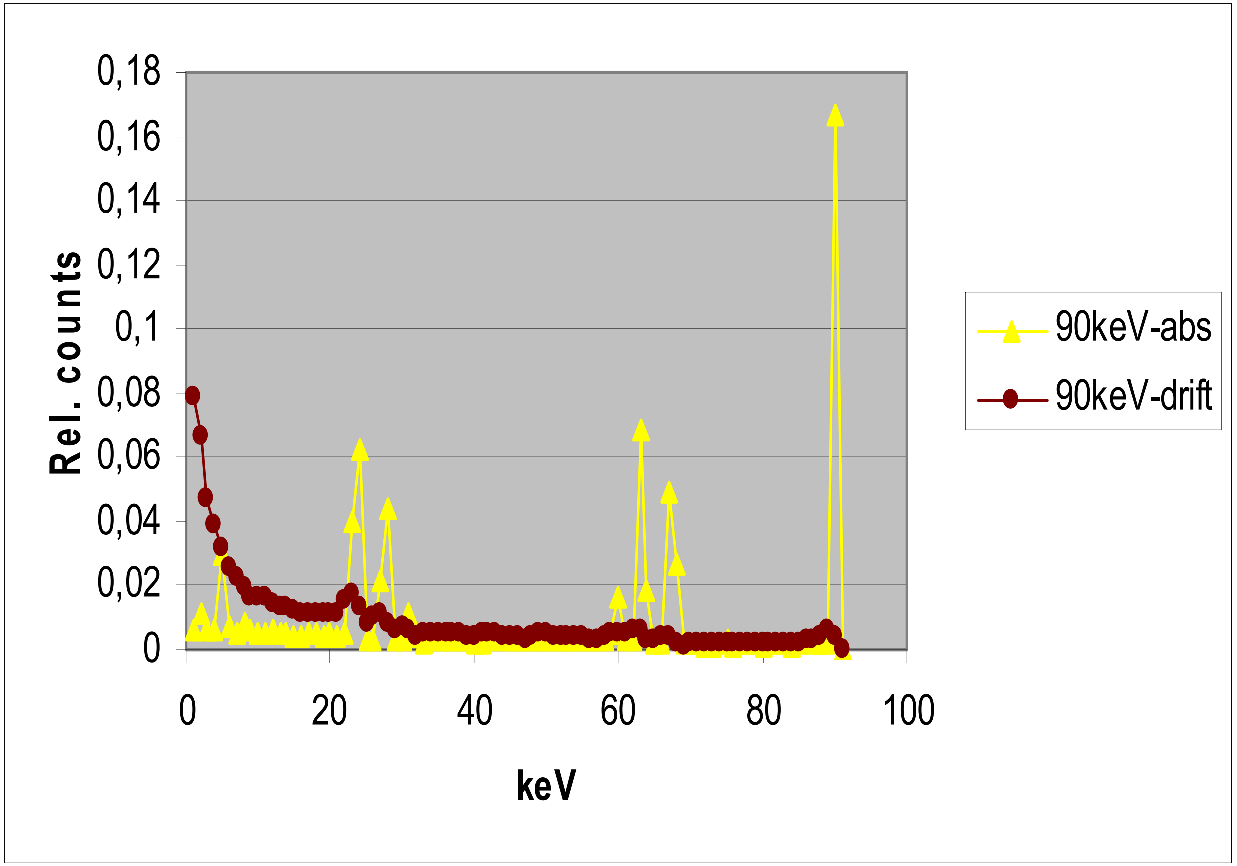
Response from Si at 18 and 30keV



Response from a Si detector to flood illumination with photons at 18keV and 30keV.

The spectrum is significantly changed due to charge sharing.

Response from CdTe at 90keV



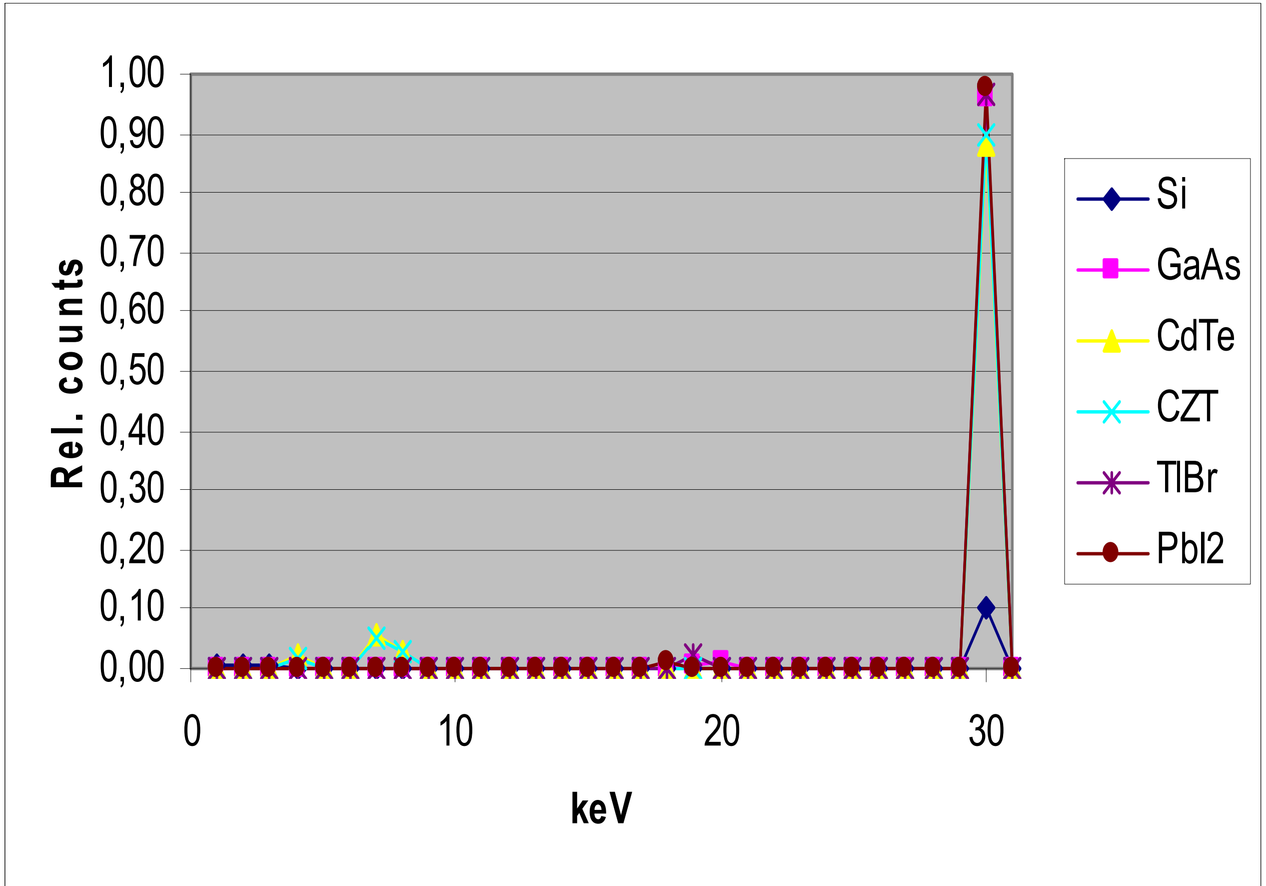
Response from a CdTe detector to flood illumination with photons at 90keV.

The spectrum is significantly changed due to charge sharing.

Total detector response

- **The result for a large area detector (1 x 1 mm^2) has been calculated for 30 keV and 90 keV**

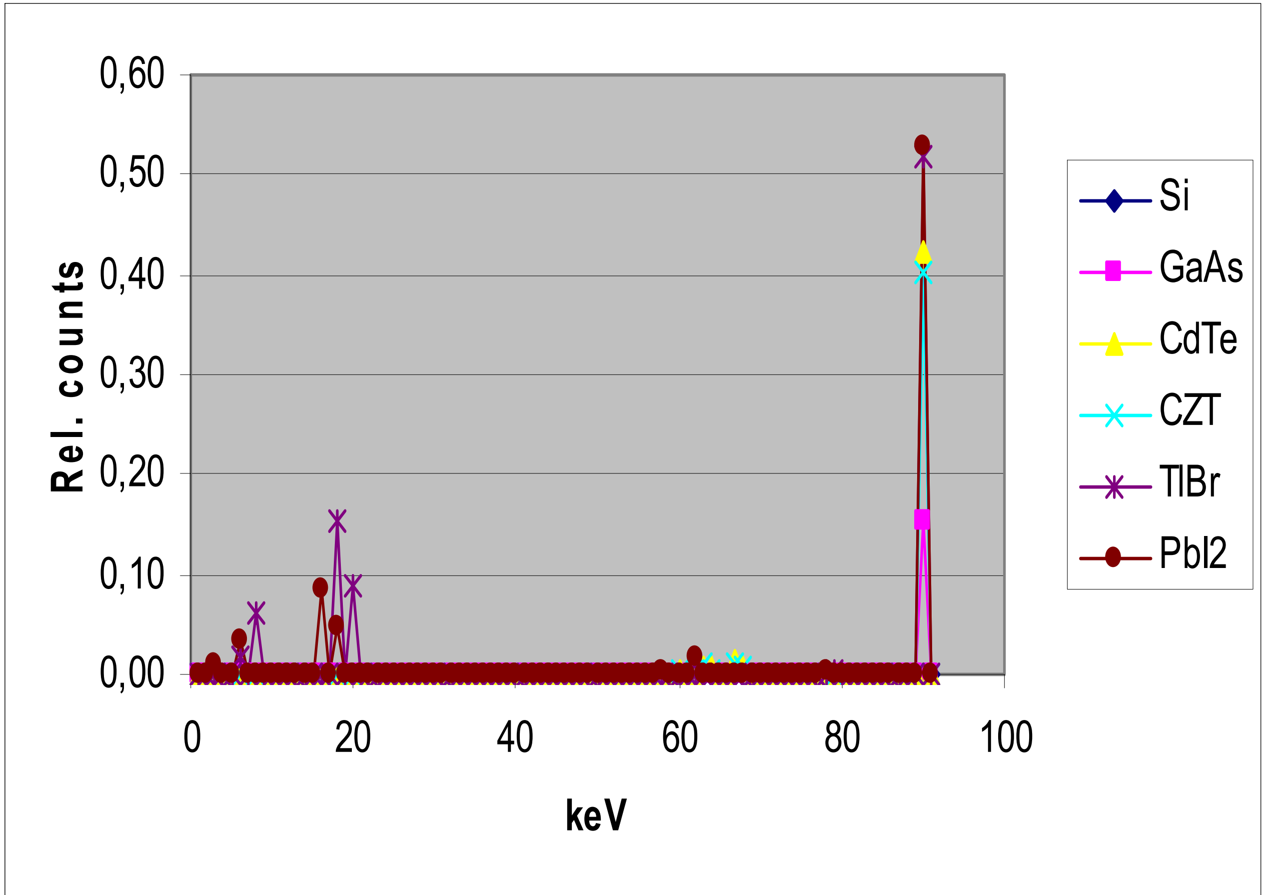
Response at 30 keV, over 1 mm^2



Quantum efficiency.

	Total	Peak
Si	0.15	0.10
GaAs	0.98	0.96
CdTe	1.00	0.88
CZT	1.00	0.90
TlBr	1.00	0.96
PbI2	1.00	0.98

Response at 90 keV, over 1 mm^2



Quantum efficiency.

	Total	Peak
Si	0.02	0.001
GaAs	0.18	0.15
CdTe	0.51	0.42
CZT	0.47	0.40
TlBr	0.87	0.52
PbI2	0.77	0.53

Summary and Conclusions

- **We have simulated charge deposition in a number of detector materials and, in some cases, compared the initial signal to the signal collected at the readout electrodes after drift.**
  - **Charge diffusion is causing most of the charge sharing in the detectors**
    - **The initial charge cloud is very narrow, except for fluorescent photons**
  - **X-ray fluorescence in heavy semiconductors degrades the spectral information in the response**
    - **”Colour X-ray imaging” at higher energies requires methods to correlate related events in several pixels**
    - **In integrating systems the effect is reasonably low since the energy is spread in a large volume**