A Monte Carlo study of two Compton camera first-plane detectors

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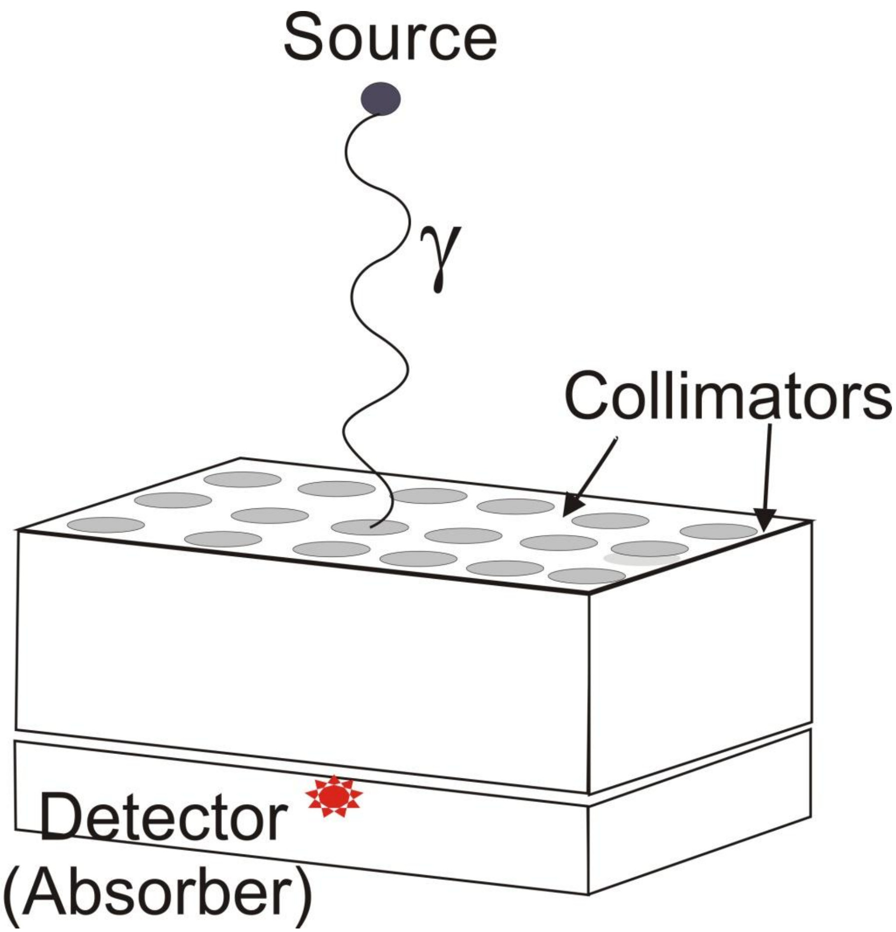
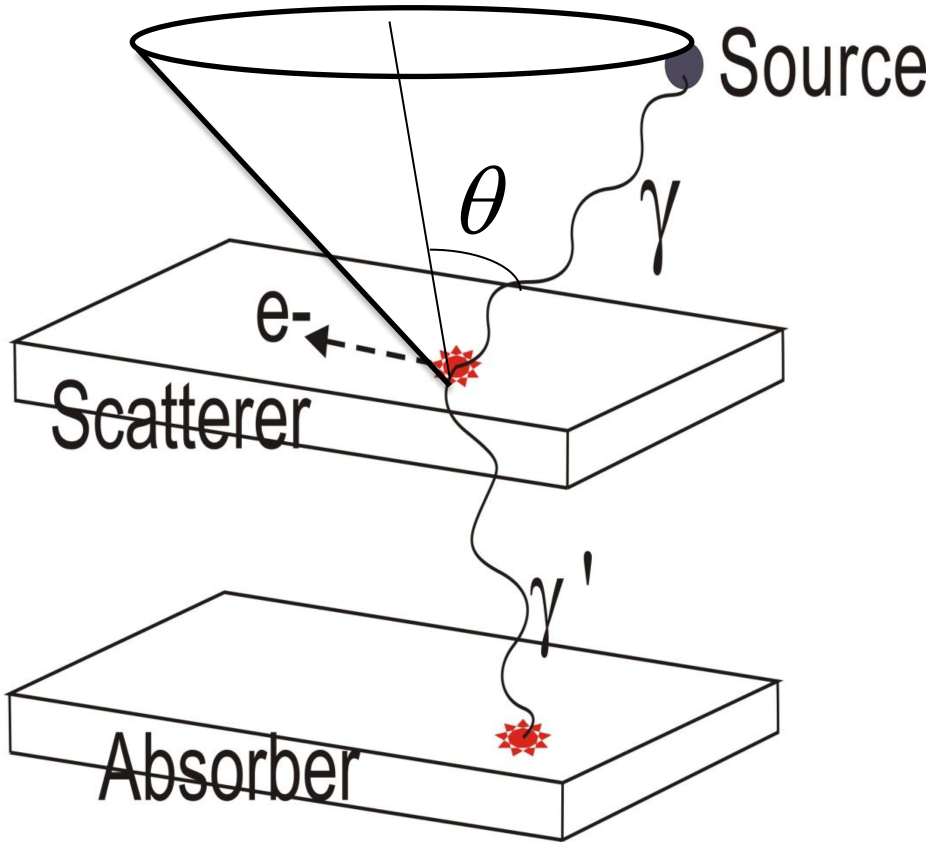
Introduction

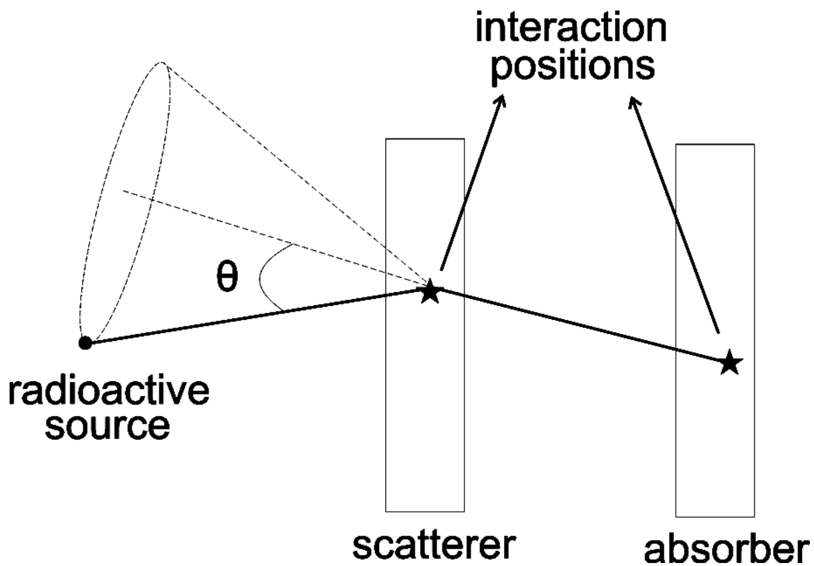


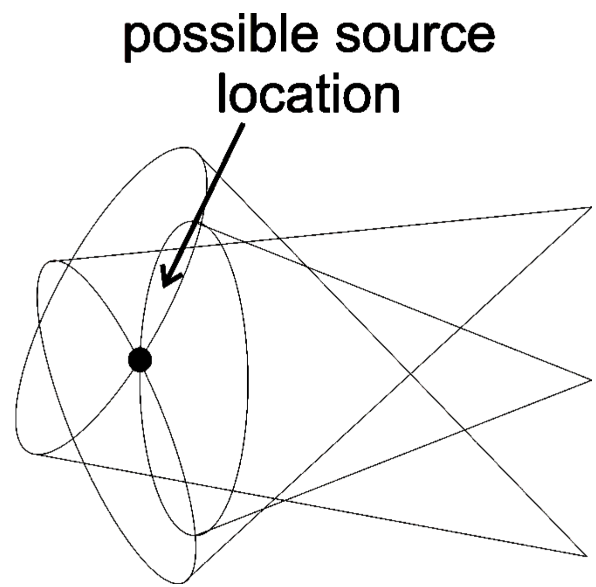
Anger camera



Compton camera

Image construction





Aim

- To investigate the suitability of two possible detectors, silicon and germanium as the Compton camera’s first plane detector.

Major criteria for the investigation:

- Doppler broadening
- Compton efficiency

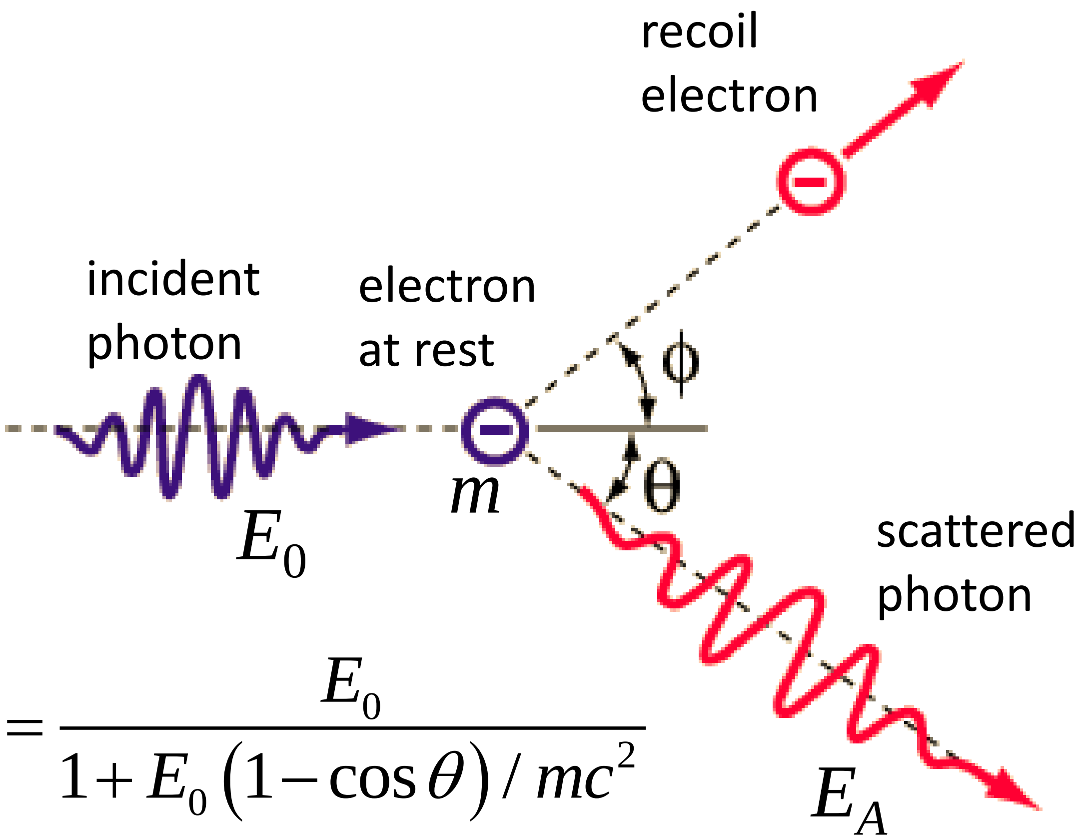
Simulation and materials for study

The GEANT4 Monte Carlo simulation toolkit

→ it offers the flexibility to model the steps of the imaging process and identify the changes that have impact on Compton camera performance.

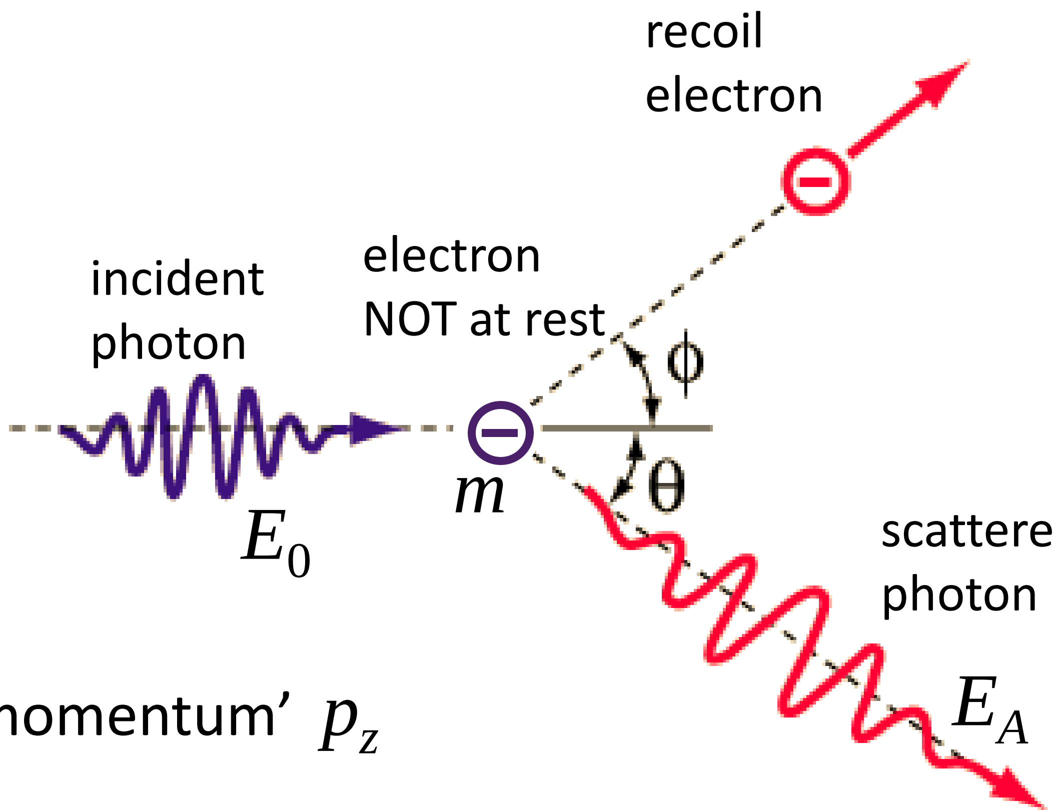
property	Si	Ge
effective atomic number	14	32
density (g cm^{-3})	2.3	5.3

Compton scattering (what you were taught)



$$E_A = \frac{E_0}{1 + E_0\left(1 - \cos\theta\right)/mc^2}$$

Compton scattering (what really happens)



'electron momentum' p_z

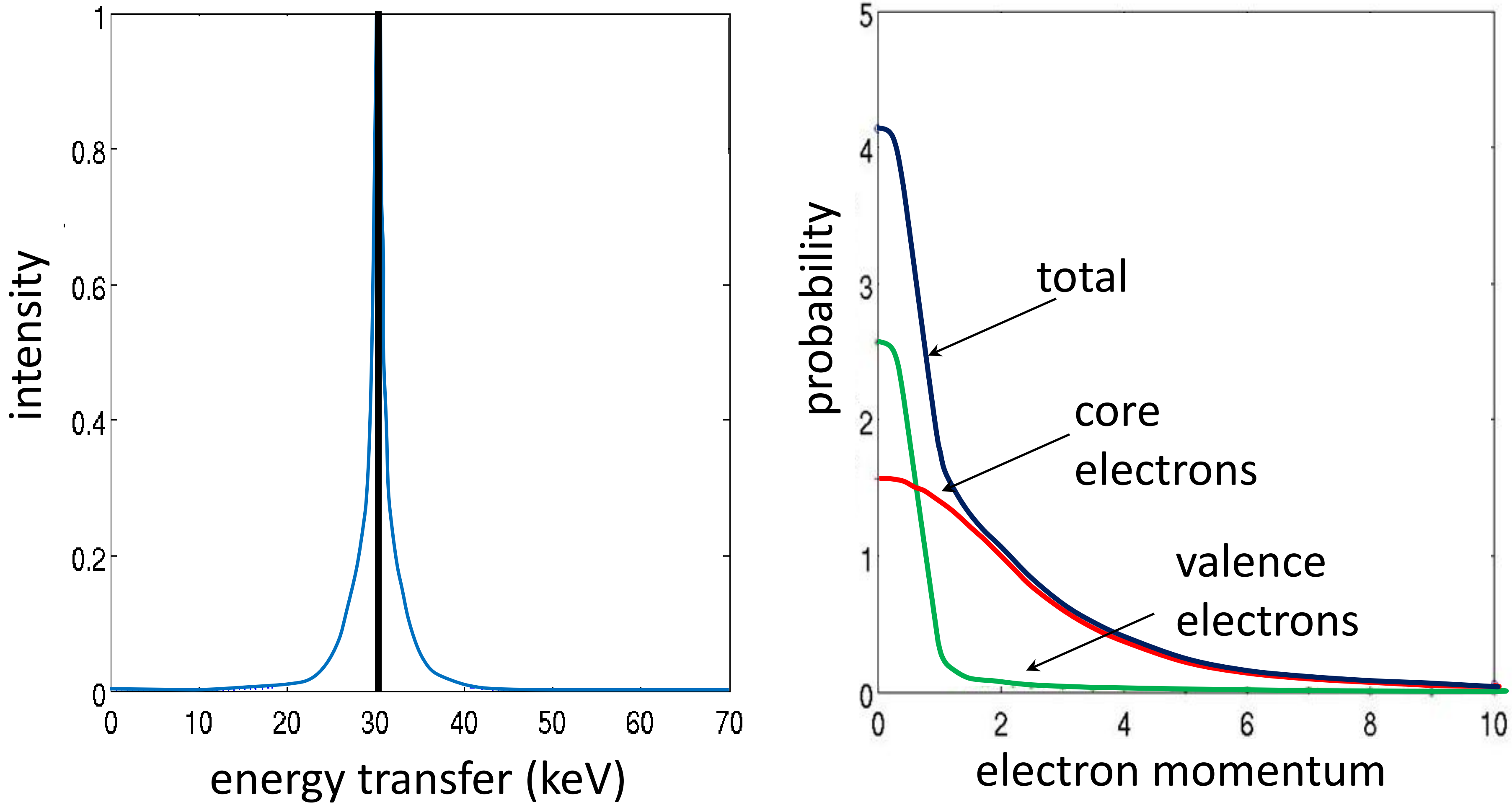
$$p_z = -mc \frac{E_0 - E_A - E_0 E_A \left(1 - \cos\theta\right) / mc^2}{\sqrt{E_0{}^2 + E_A{}^2 - 2E_0 E_A \cos\theta}}$$

Doppler Broadening

So incident photon can be scattered over a range of angles, not a specific angle!

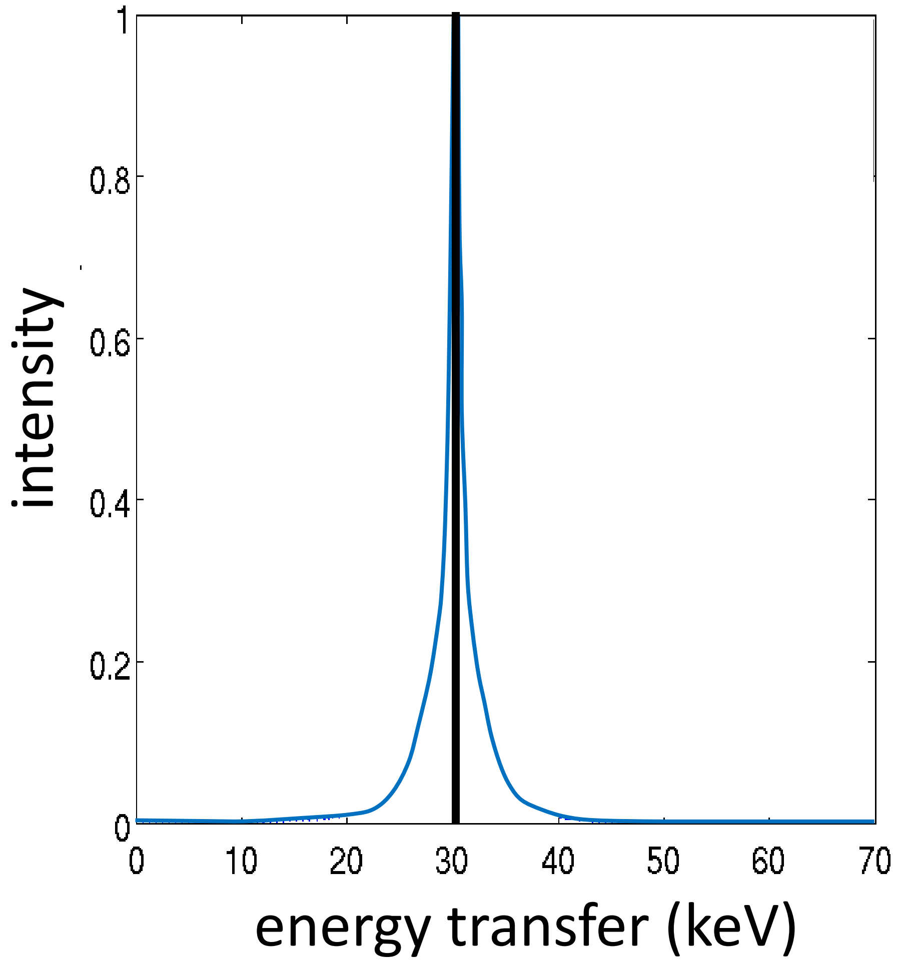
How Doppler broadening affects the electron energy spectrum (first plane)

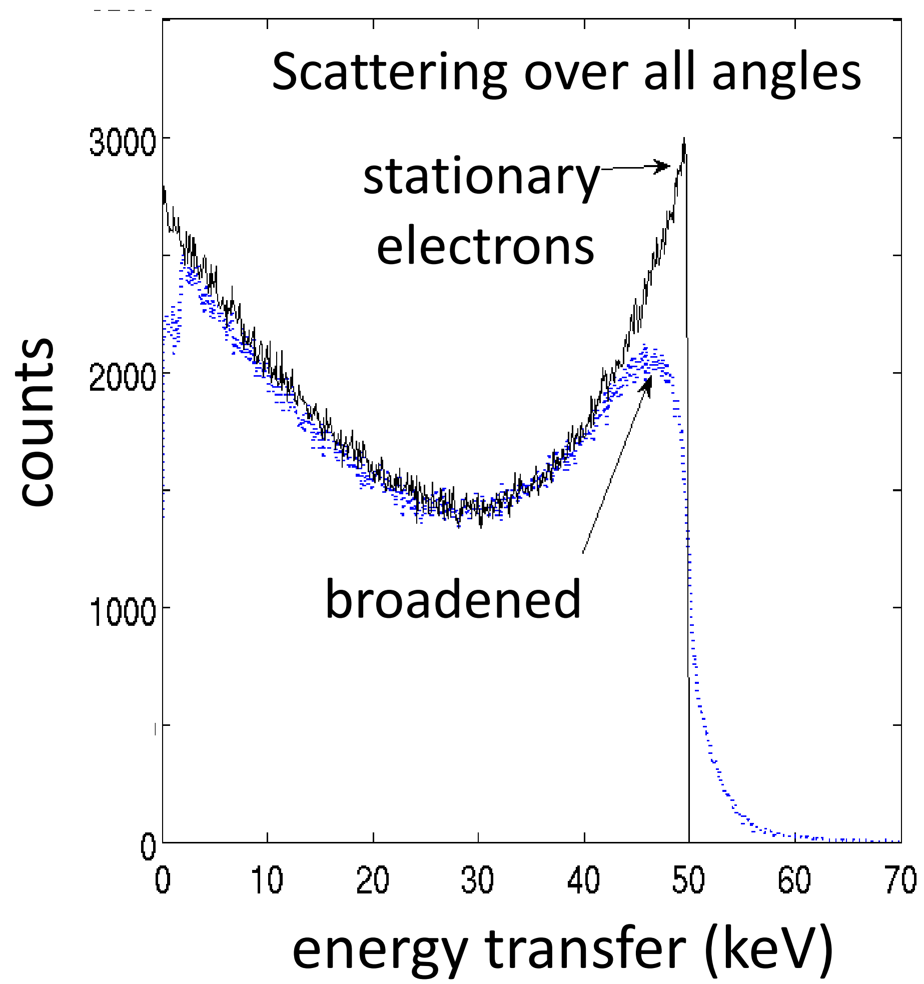
$E = 140.5$ keV



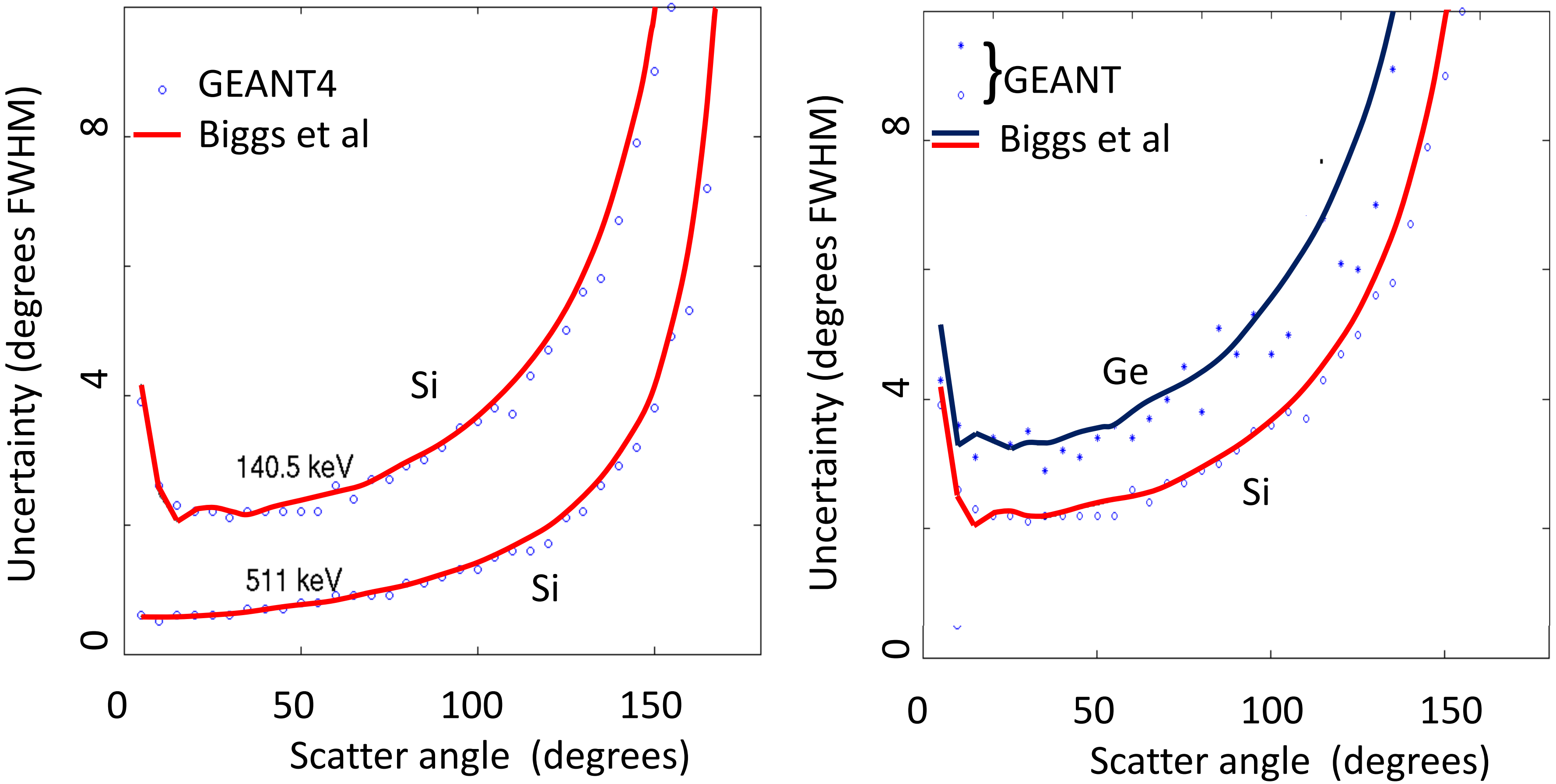
How Doppler broadening affects the electron energy spectrum (first plane)

$$E = 140.5 \text{ keV}$$

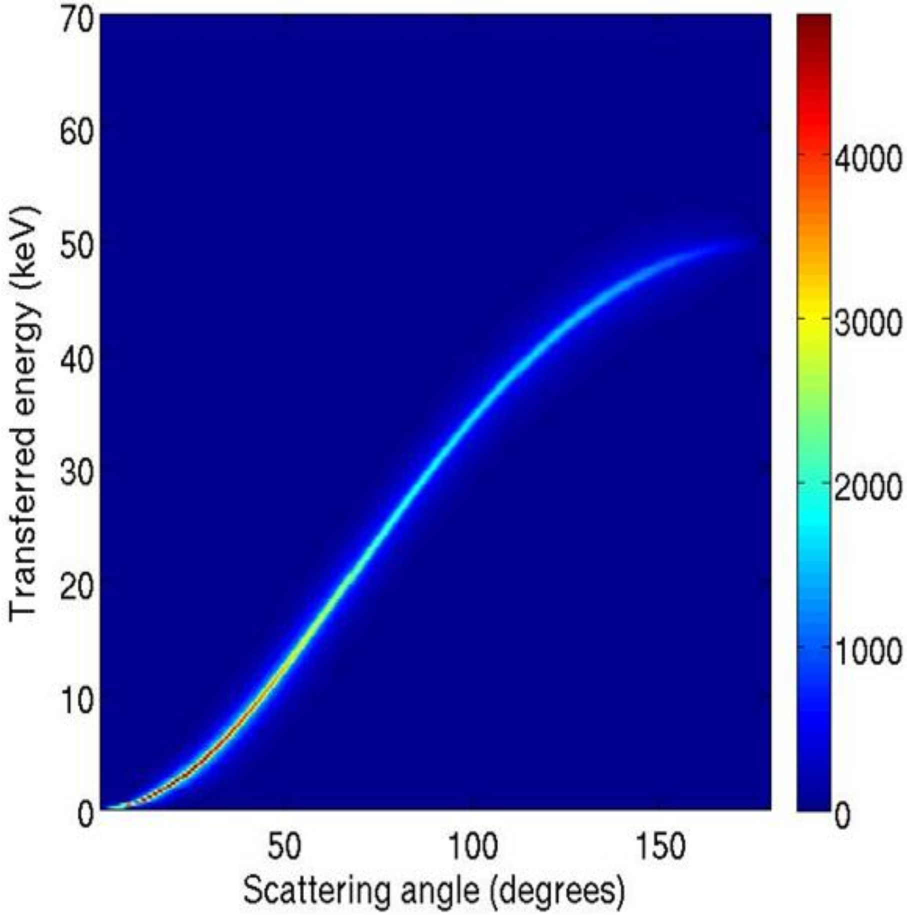




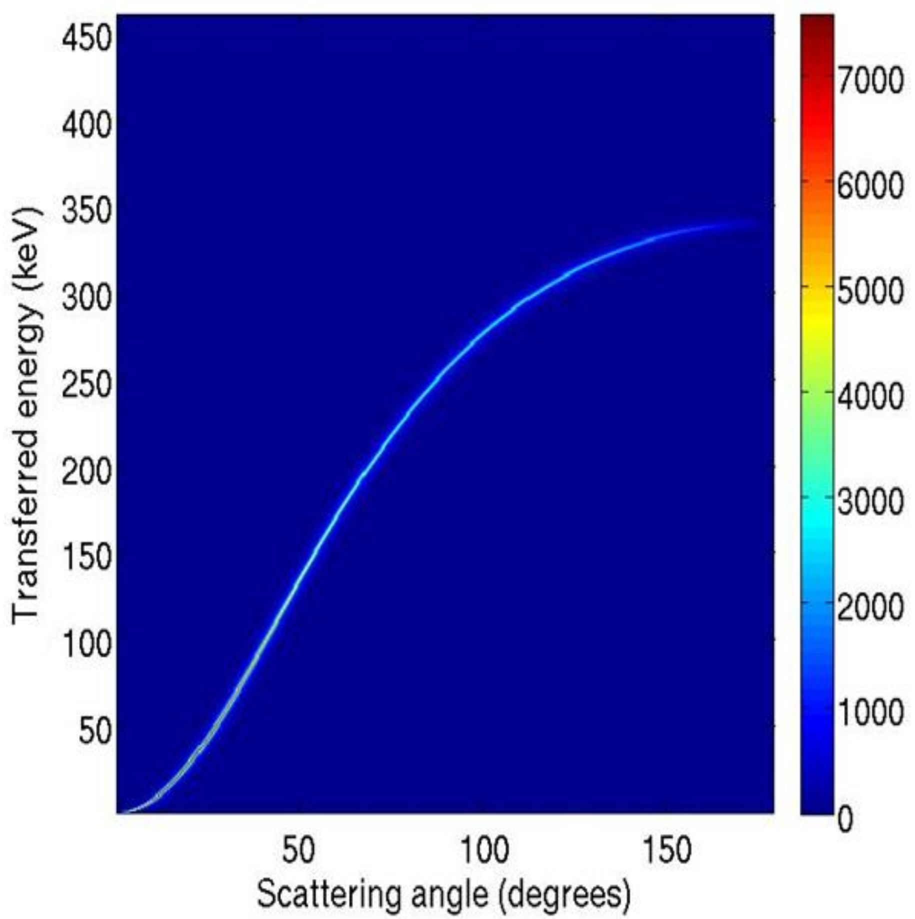
Validation of simulated Doppler uncertainty with theoretical prediction



Variation of Doppler broadening at different incident energies

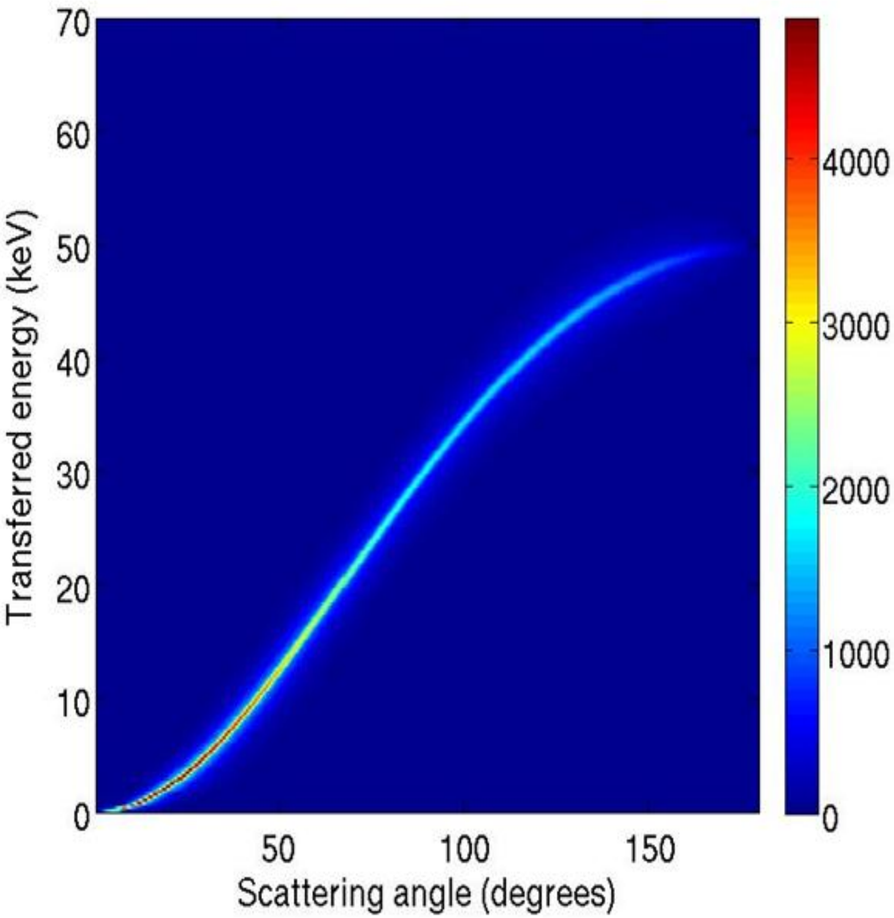


140.5 keV

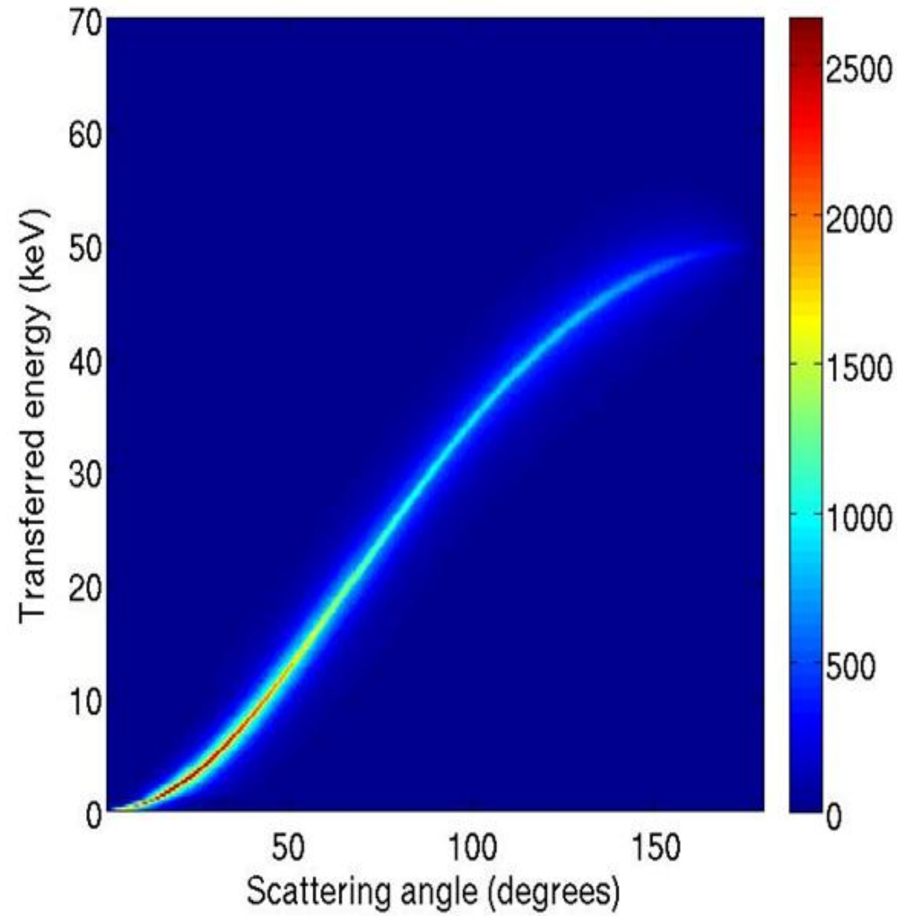


511 keV

Variation of Doppler broadening in the selected materials (140.5 keV)

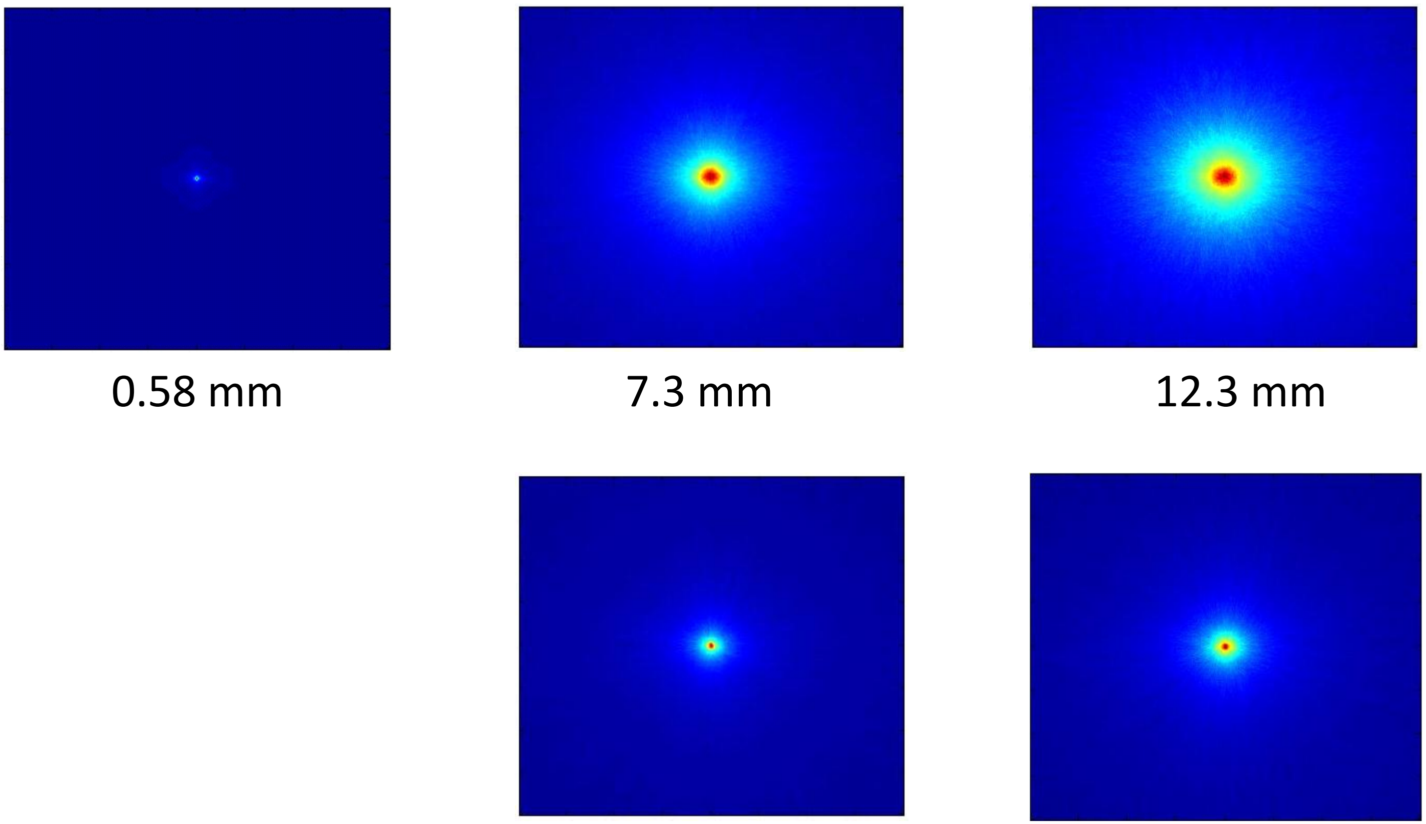


Silicon

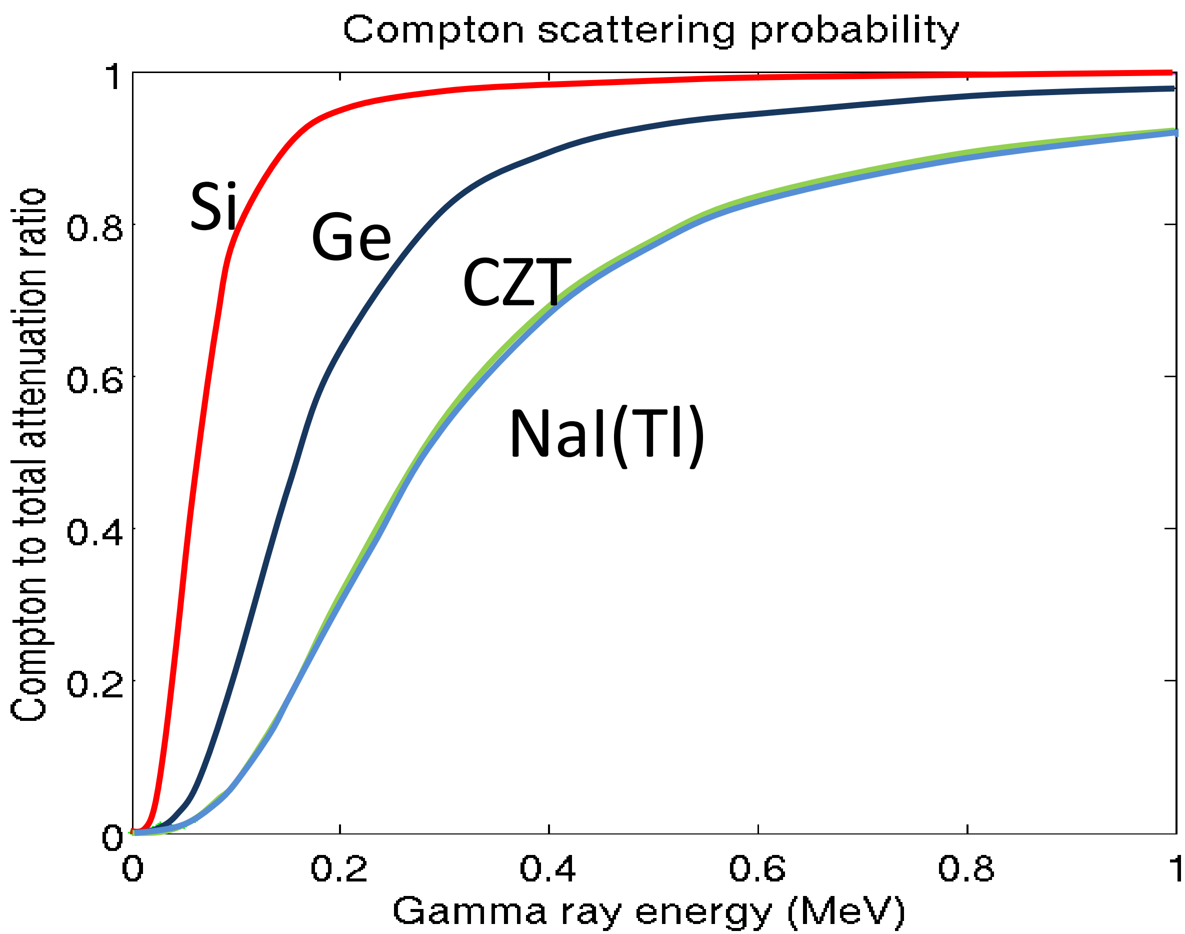


Germanium

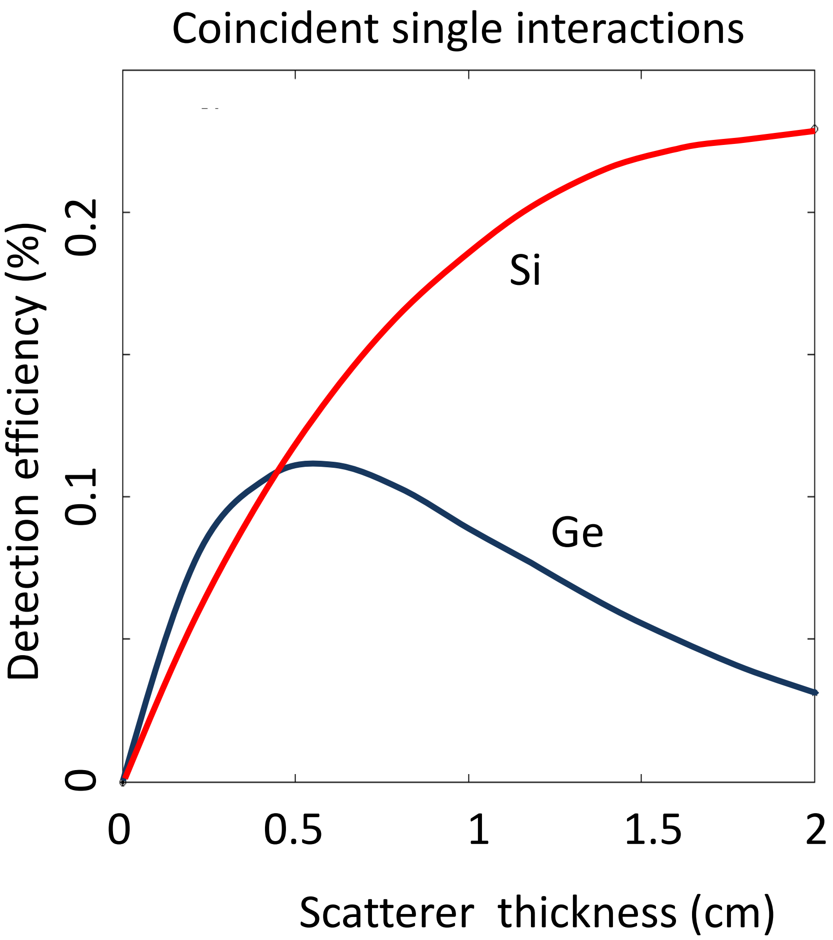
Image degradation (FWHM) due to Doppler broadening for the selected materials

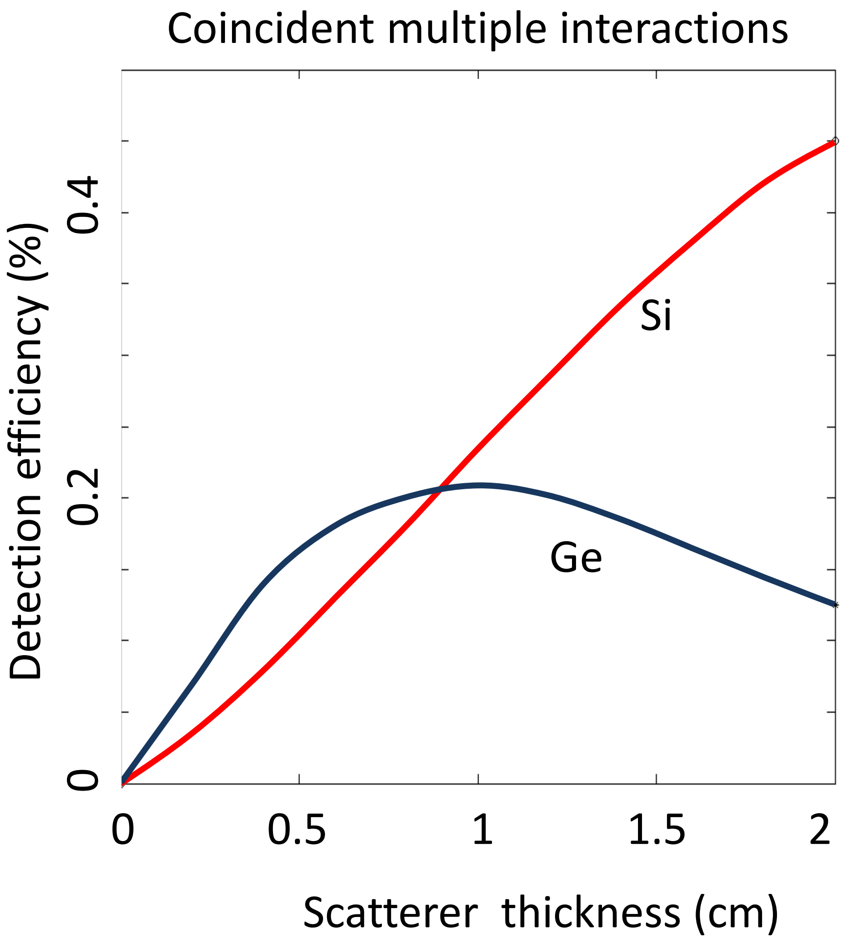


Theoretical efficiencies with respect to Compton scattering for selected materials

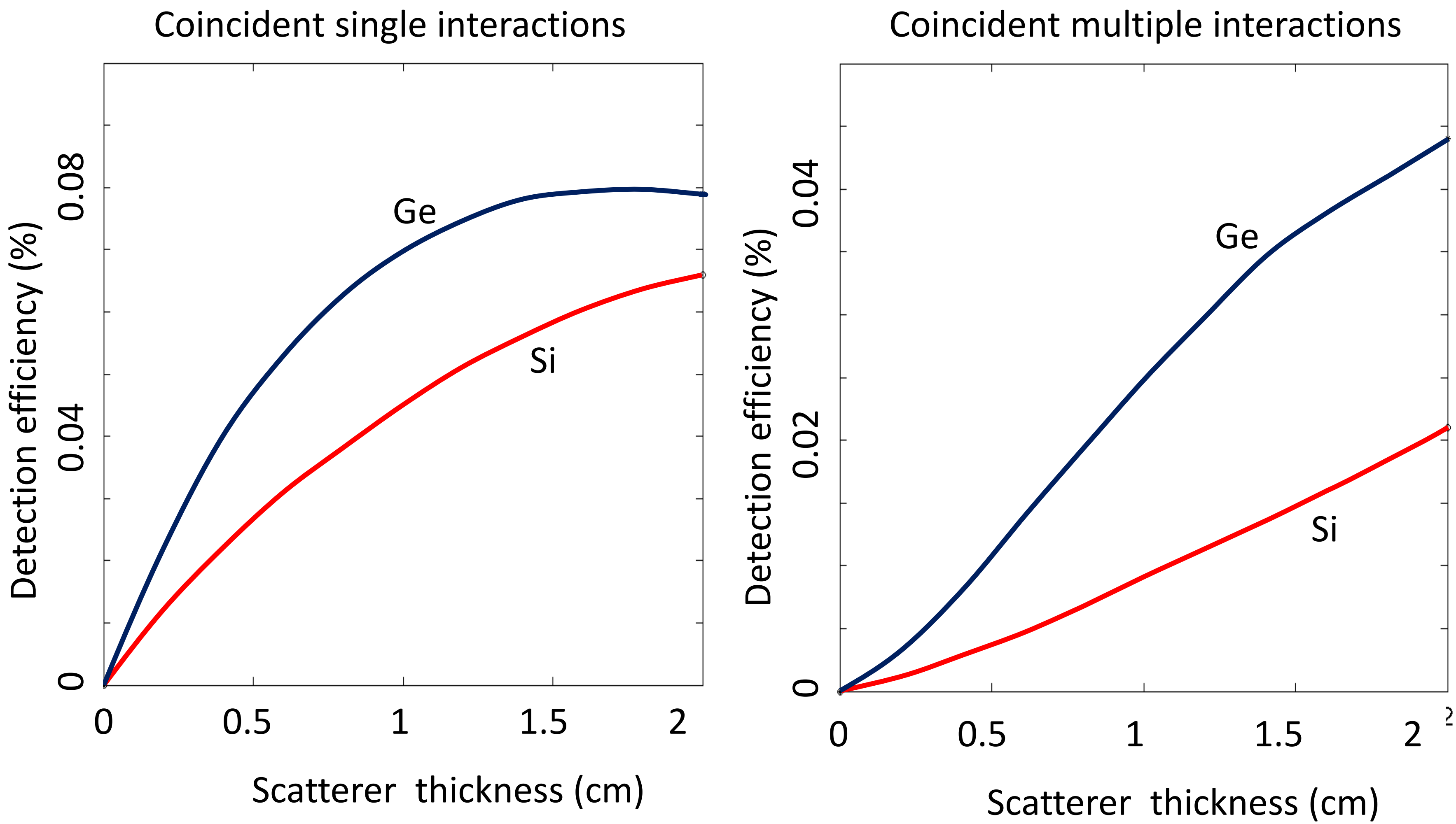


Efficiency evaluation of the two detectors across experimental thickness at 140.5 keV





Efficiency evaluation of the two detectors across experimental thickness at 511 keV



Analysis to determine the optimal detector with respect to efficiency

Material	Optimal thickness (mm)	Single efficiency ratio at 140.5 keV	Single efficiency ratio at 511 keV	Multiple efficiency ratio at 140.5 keV	Multiple efficiency ratio at 511 keV
Si	10	1.64	1.00	1.50	0.67
Ge	5	1.00	1.00	1.00	1.00

Conclusion

Si is a better scatterer material than Ge

- less Doppler broadening degradation
- better single interaction scattering efficiency ratio at lower energies $\longrightarrow$ same at higher energies.

Other considerations are that silicon operates better at room temperature and also has lower cost.