# A low energy x-ray Compton polarimeter prototype


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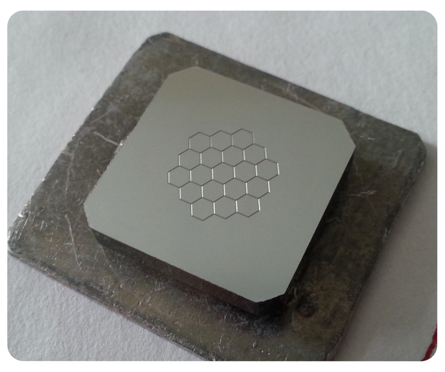
## Abstract

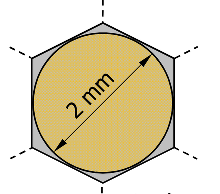
To learn about the dynamics of atomic transitions in the mid- and high-Z regime it is of great importance to perform a reliable measurement of the polarization of emitted x-rays from the reaction channel of interest. To cover an energy range from a few keV to ~30 keV we have developed a Compton polarimeter prototype to determine the degree of linear polarization of this radiation. The concept is based on a passive low-Z scatterer (e.g. Be, SiC, PE) in which the emitted x-rays will undergo Compton scattering and in a subsequent step they will be deposited on a ~3.5 mm thick pixelated HPGe detector (work inspired by reference [1]). The back side contact of this detector is segmented with a structure of 19 hexagonal pixels. The asymmetry of the scattering distribution is a signature of the degree of linear polarization. The detector may be used as a 19-pixel x-ray detector or in combination with a scatterer as Compton polarimeter. The readout stage is split into two parts. The first part is the cryogenically cooled FET input stage and the second stage is built from discrete charge sensitive preamplifiers operating at room temperature.


## Description of the detector system

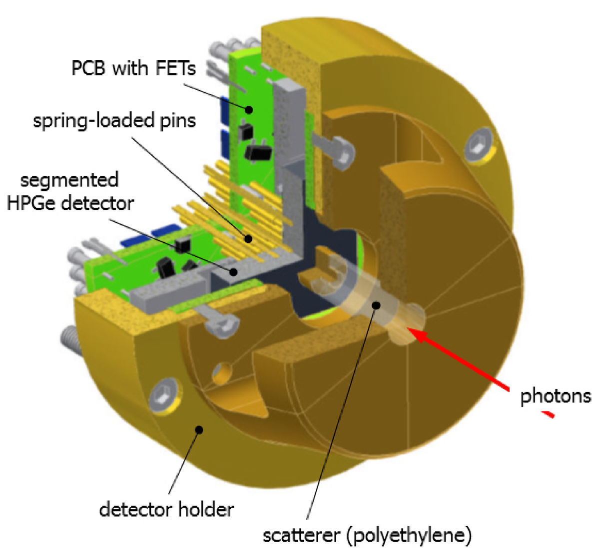


The segmented HPGe-detector before mounting into the detector holder.

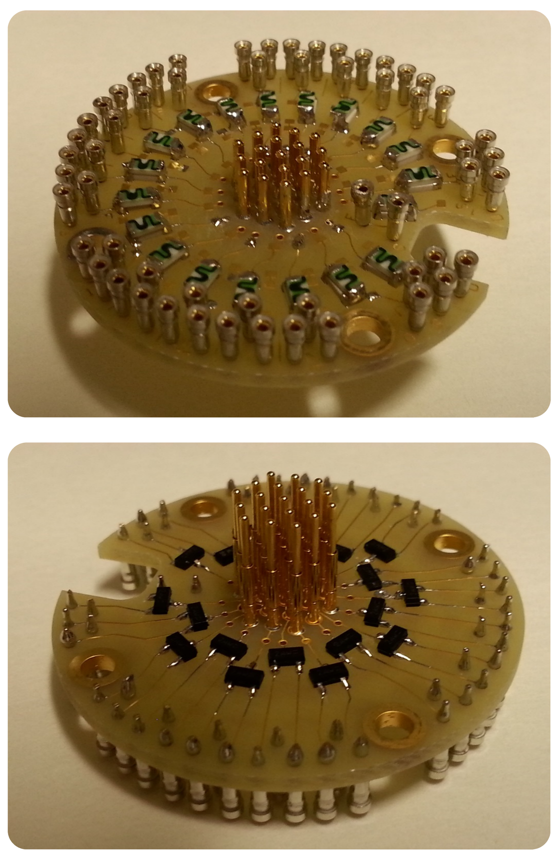
- the size of the HPGe-detector is 20 mm x 20 mm
- the detector thickness is ~3.5 mm
- the boron-implanted detector contact is structured with a 19-pixel structure, surrounded by a guard-ring
- the 19 pixels have a hexagonal shape
- the detector bias voltage (+HV) is applied to the amorphous Germanium contact (a-Ge contact), which is the not structured front-contact
- the operating temperature is ~$LN_2$-temperature (77 K)
- the detector is irradiated on the not structured contact




In this project we tested an alternative to the wire bonding connection technology for interfacing the FET input with the detector contact. Here spring-loaded contact pins were employed.

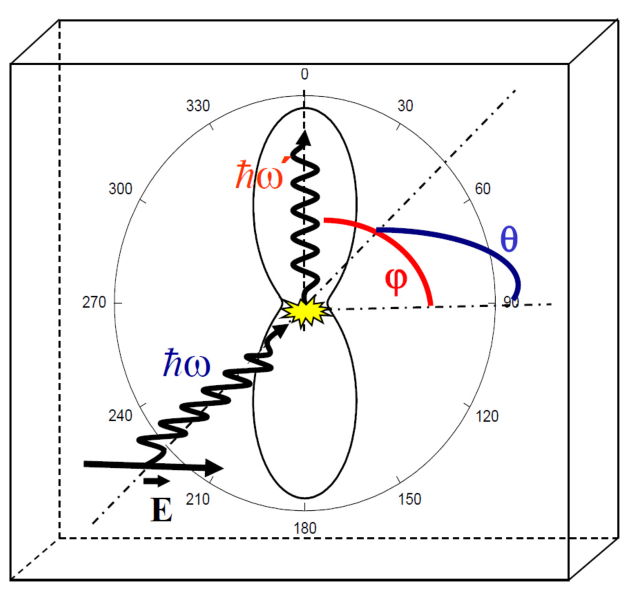


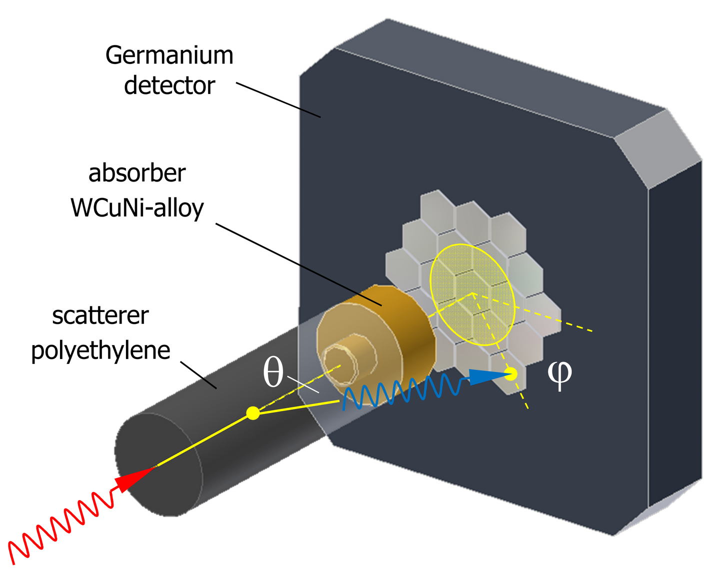

Sectional view of the detector head with the mounted detector, the PCB with spring-loaded pins and FETs and the scatterer in front of the detector.



PCB with spring-loaded contact pins and FET (bottom) and feedback RC on the back side (top).

## Polarization of photons



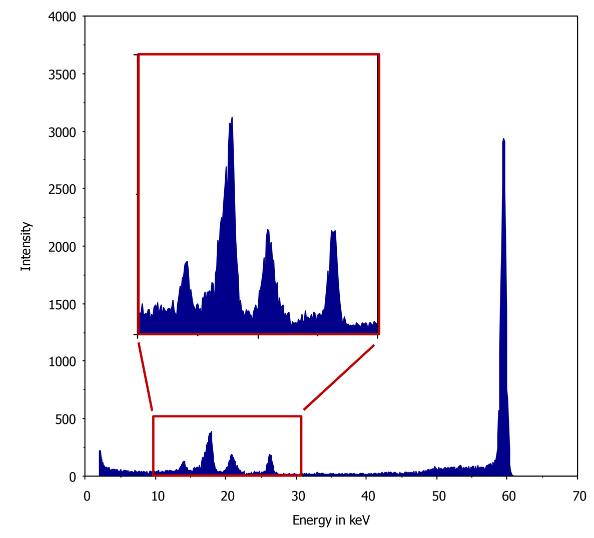

Geometry of one scattering process: Incident photon (red); scattered photon (blue); The "shadow" of the absorber is marked with a yellow circle.

$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_0^2 \left(\frac{\hbar\omega'}{\hbar\omega}\right)^2 \left(\frac{\hbar\omega'}{\hbar\omega} + \frac{\hbar\omega}{\hbar\omega'} - 2\sin^2\theta\cos^2\varphi\right)$$

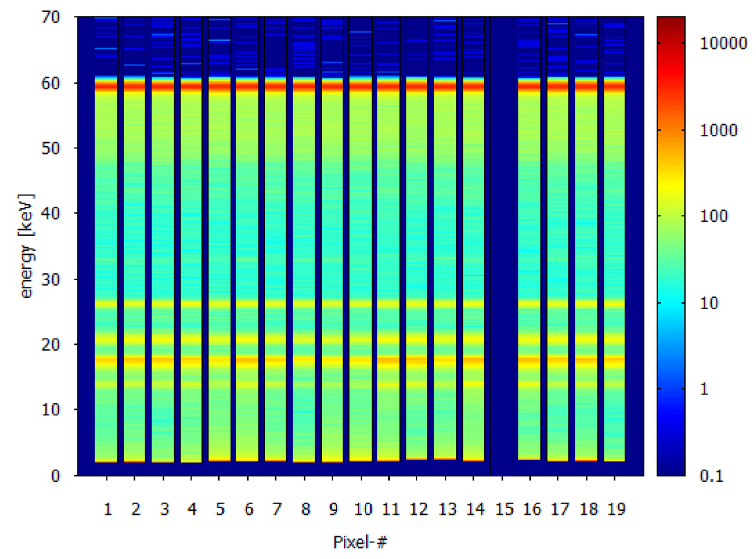
The Compton scattering process can be described using the Klein-Nishina equation. Depending on the energy and the polarization plane of the incident photon the direction of the ejected photon and electron will be influenced. A detailed review may be found in reference [2].

## Results of the first tests

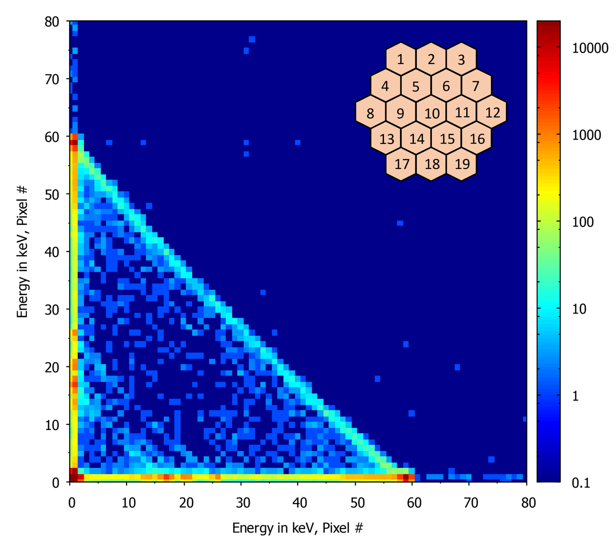
(without scatterer!)



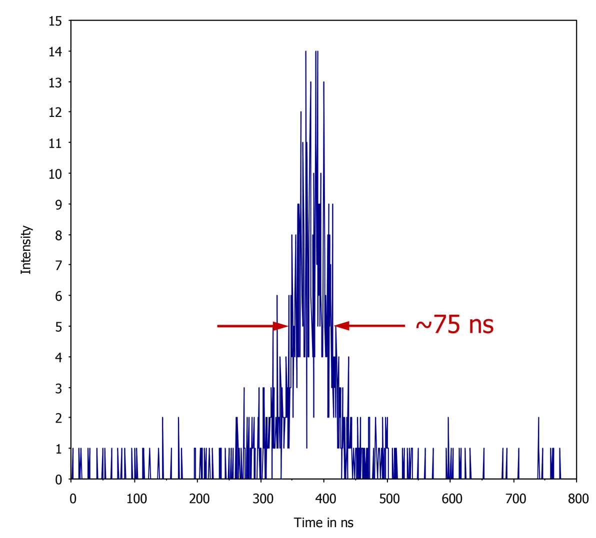

Spectroscopic result of pixel #4. A spectrum of an Am-241 source with the Np-triplet and the 59.5 keV gamma line indicating an energy resolution of 850 eV at 59.5 keV measured at a shaping time of 3 µs.




Projection (logarithmic scale!) of all Am-241-spectra of all 19 pixels (pixel #15 is not working!). The spectra were recorded simultaneously.



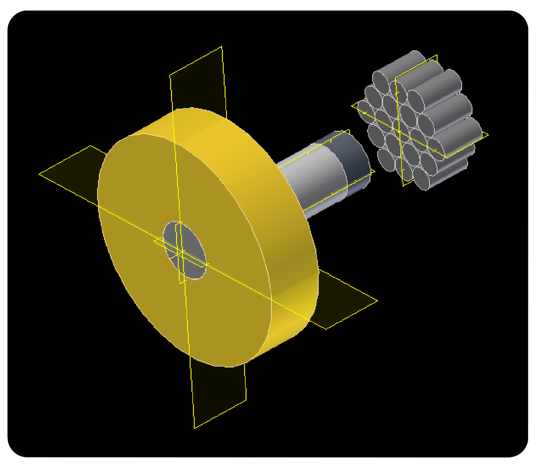

Coincident measurement of the energy signal of two neighbouring pixels. Events where the energy of the x-ray was deposited in the region beneath an isolation gap will result in the generation of a signal in at least two pixels. The generated charge cloud will be distributed on several pixel contacts during their transport in the drift field.




Time spectrum of pixel #5 versus #6. Shown is the time difference of the arrival times of coincident detector signals generated by a single event. This is equivalent to the detector's time resolution relative to a fast external signal.

## Simulations

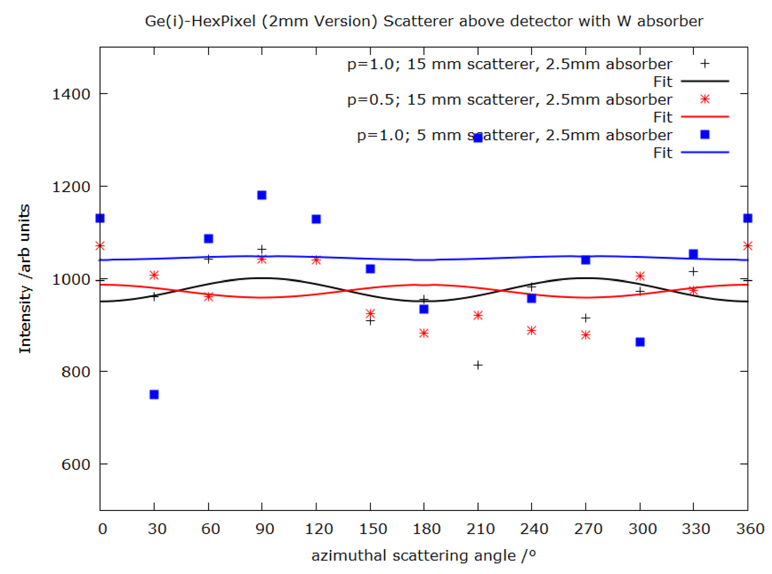
(search for an efficient scatterer geometry)



Geometrical model for the simulation. The hexagonal pixels are simplified to cylindrical pixels (2 mm diameter, 4 mm long).

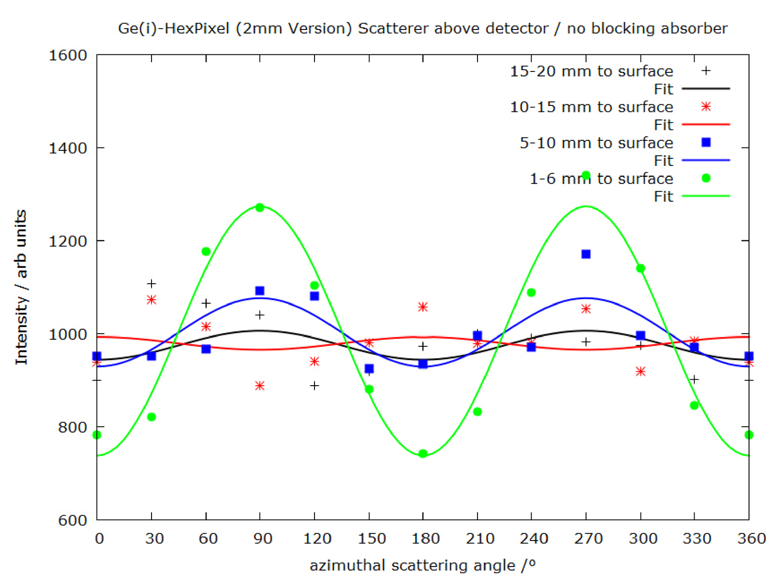
Different scatterer-absorber geometry models were simulated:

a) scatterer from polyethylene and a tungsten blocking absorber to shield the direct x-rays.
b) scatterer from polyethylene close to the detector without tungsten blocking absorber.

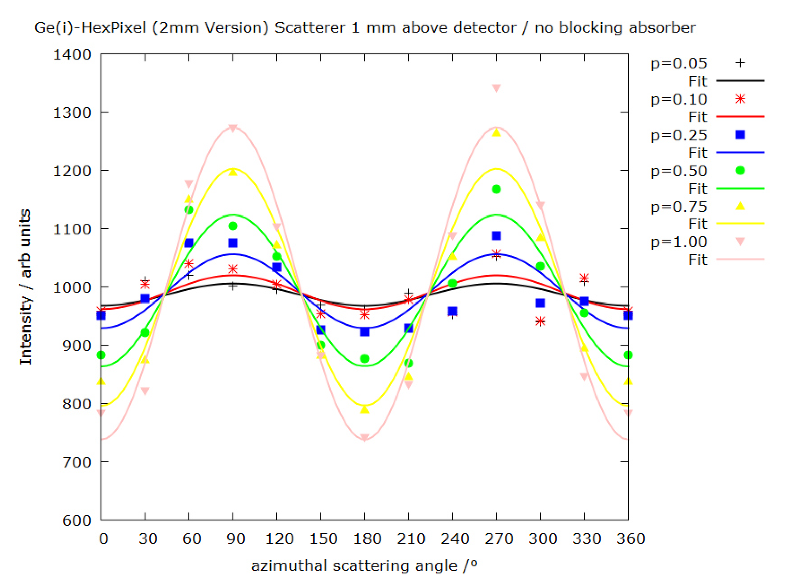



Configuration with tungsten absorber (compare picture left).

Less efficient than expected from considerations based on cross sections.




Azimuthal scattering distributions for a 5 mm thick polyethylene (PE) scatterer in different distances to the detector (for linear polarization degree of 100 %).




Azimuthal scattering distributions for a 5 mm thick polyethylene (PE) scatterer in 1 mm distance to the detector, displayed as function of the linear polarization of the incident photon (5–100 %).

Most promising result!

## References


[1] S. Weber, C. Beilmann, C. Shah, and S. Tashenov, „Compton polarimeter for 10-30 keV x rays", RSI 86, 093110 (2015)

[2] F. Lei, A. J. Dean, G. L. Hills, „Compton Polarimetry in Gamma-Ray Astronomy", Space Science Reviews, v. 82, Issue 3/4, p. 309-388 (1997)



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