Gamma-Ray Imaging Using Cherenkov Cone Detection from Energetic Compton Electrons

Overview

The Compton Camera is one possible concept to meet the increasing demand for a gamma ray detector in the higher energy range ($\geq$ 1 MeV) for medical imaging. The detection concept comprises a two layer system, where in the first one the incident photon scatters, releasing a highly energetic Compton electron. In a second layer the scattered photon is then absorbed. Thus, position and energy sensitive detection of the electron in coincidence with the scattered photon allows to reconstruct the incident direction of the photon to lie on the surface of a cone.

The Detection Concept

Currently, an imaging strategy is being developed, based on the detection of the spatial distribution of Cherenkov light emitted from high-energetic Compton electrons created by gamma-ray interactions in an optically transparent radiator material (see figure 1). The photons of the Cherenkov cone are detected by a Silicon Photomultiplier (SiPM) array allowing for reconstruction of the momentum direction of the electron. The momentum of the Compton electron carries a large part of the information required to reconstruct the initial gamma. Given an electron velocity close to c and a well-known refractive index of the scattering material the radius of the cone can be estimated. The size of the ellipse on the detector layer yields information about the depth of the interaction inside the detector. The most powerful improvement for a Compton Camera is the estimation of the electron's momentum direction from the eccentricity of the ellipse (figure 2).

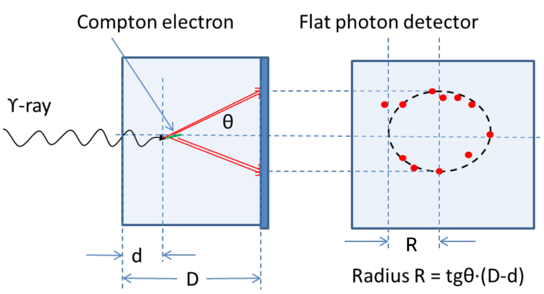

Figure 1: Concept of Cherenkov light detection from Compton-Scattered electrons.

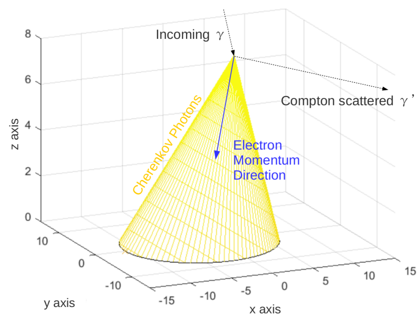

Figure 2: The Cherenkov cone allows for a reconstruction of the electron momentumg direction.

Achievements and Current Status

The research group around Prof. Dr. Ivor Fleck has achieved a proof of concept for this detection principle: Collimated electrons from a ^{90}Sr β-source were used to create Cherenkov radiation in UV-transparent PMMA samples. The light from these higher energetic electrons (up to 2.4 MeV) has been detected in coincidence using a 64-channel SiPM array (figure 3). In an earlier experiment using a 4×4 array a coincidence time resolution of 242 ps was achieved (see reference 2). The ability to count the number of detected Cherenkov photons was implemented using the Time-over-Threshold (ToT) information of the SiPM signal in combination with a logarithmic calibration function (See figure 4). The distribution and number of photons agrees with calculations and theoretical expectations and can be used to reconstruct information on the incident electron.
The Cherenkov light from actual Compton-scattered electrons and photo electrons created by 511 keV photons from a ^{22}Na source in PMMA has been detected. The corresponding PET-like

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set-up is shown in figure 5 and coincident hits from Cherenkov photons on the detector array are shown in figure 6. A coincident event was defined as follows: At least 8 coincident channels within 100 ns on the scintillation detector were required. Within that time window, on the Cherenkov detector a coincidence of at least 4 channels within 5 ns had to be recorded. Within a measurement period of 200 minutes, 12962 coincident events were registered and on average 17.9 photons per event were detected.

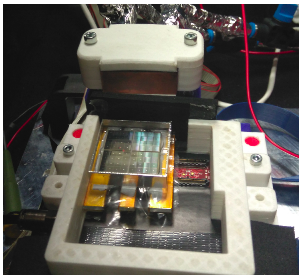

Figure 3: SiPM array, PMMA sample and cooling fingers for reducing dark count rate.

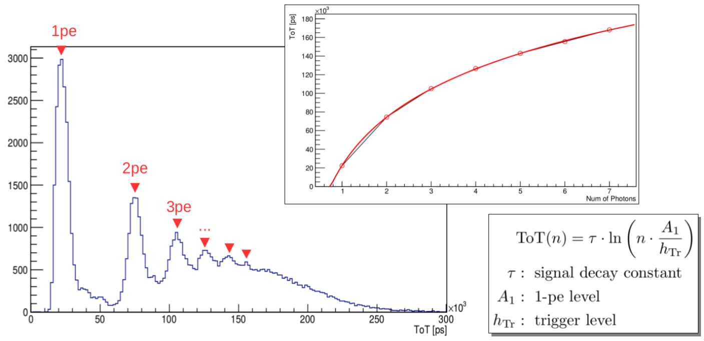

Figure 4: Calibration and fit function for photon counting using ToT information.

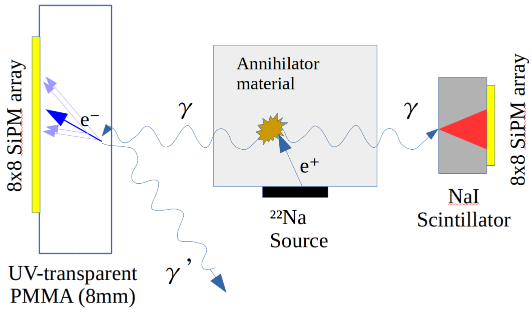

Figure 5: PET-like set-up for the detection of 511 keV photons using Cherenkov light from Compton-scattered electrons and photo electrons.

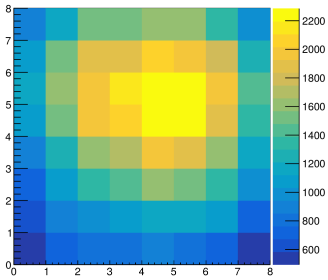

Figure 6: Coincident hits of Cherenkov photons from Compton- and photo electrons. Accumulated events are displayed.

Conclusion and Outlook

We performed a successful detection of coincident Cherenkov light from Compton-scattered electrons and photo electrons and demonstrated the ability to count the number of detected photons per channel and event. As a next step, the detected pattern from individual events will be used to obtain information on the electron's momentum as well as on the Compton scattering vertex. Also, a comparison of obtained results with simulations using GEANT4 is being performed.

A successful electron reconstruction using Cherenkov light could be a next step towards an application in a Compton Camera for medical applications.

Further Information and References

1. F. Roellinghoff, et al, *Design of a compton camera for 3D prompt-γ imaging during ion beam therapy.* Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 648, S20 – S23, 2011
2. R. Bayerlein et al. *Coincident detection of cherenkov light from higher energetic electrons using silicon photomultipliers.* NIM-A, volume 930, pages 74-81, 2019

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