# A system for 3D localization of gamma sources using Timepix3-based Compton cameras


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## Compton Camera

A Compton camera localizes sources of $\gamma$-rays in 3D space by facilitating and observing Compton scattering of photons in semiconductive detectors.

Compared to scintillation cameras, this design has several advantages:

- No need for mechanical collimation of observed $\gamma$-rays.
- Smaller and lighter device, suitable for portable applications.
- Increased efficiency and reduced scanning time.

The goal of the work was **to propose and implement a novel Compton camera** based on the latest components and recent research.

## Used Technology

**Timepix3 Detector** (Medipix Collaboration, CERN)

256×256 active pixel detector with 55 $\mu$m pitch capable of simultaneously measuring deposited energy and time of arrival. Results are reported asynchronously in data-driven mode.

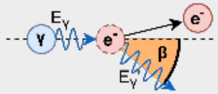
**Katherine Readout** (University of West Bohemia)

Embedded computer designed to autonomously control the acquisition of Timepix3 chips. Both commands and data are transmitted over the Ethernet bus with throughput up to 15 Mhits/s.

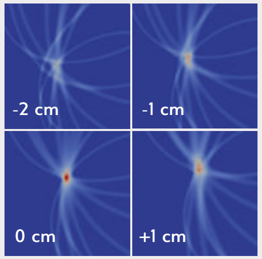
## 3D Image Reconstruction

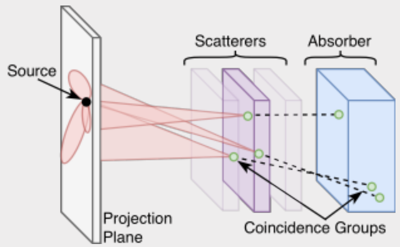
During Compton scattering, a photon transfers fraction of its energy to an electron. The photon then changes its velocity by angle $\beta$, which is related to its energy loss by the Compton equation:

$$\cos\beta = 1 - m_e c^2 \left( \frac{1}{E'_\gamma} - \frac{1}{E_\gamma} \right)$$




Using time-synchronized acquisition, coincidence groups are identified in scatterer and absorber detectors. By calibration with characteristic X-ray fluorescence curves, the energy deposited in each detector is measured.



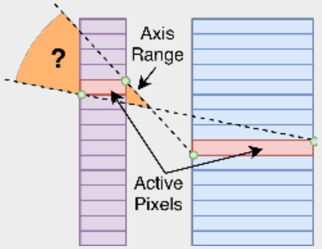




By the Compton equation, each coincidence group defines a conic surface which intersects the unknown $\gamma$-ray source. Triangulating with multiple cones, the source can be accurately localized in 3D space.

## Improving Angular Resolution

Compton camera measurements are burdened by inherent angular error caused by the unknown depth of events observed in detectors. This increases the uncertainty of axes of the projected cones.

To eliminate this uncertainty, a recently published approach is applied. By calibrating charge drift properties of detectors, the depth coordinate is reconstructed.



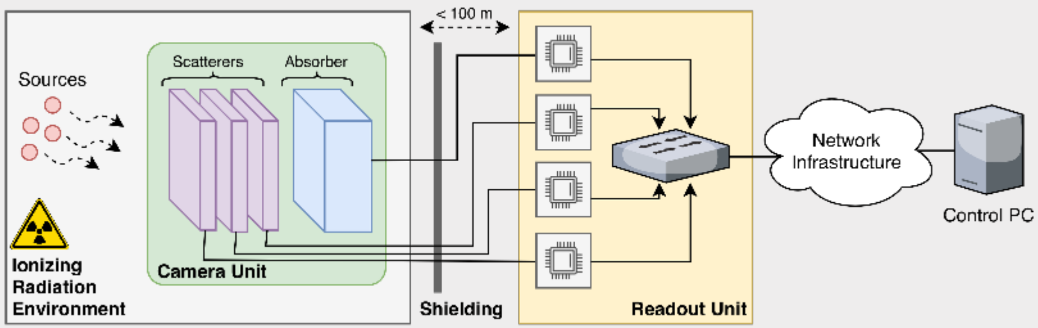

## Fast Two-stage Projection

To improve the performance of the reconstruction algorithm, cone projection is divided into 2 stages:

- The cone is once **projected forward** into a plane, creating an ellipse. This requires translation, rotation and perspective projection.
- The ellipse is **projected back** multiple times into parallel slices of a voxel volume. This requires only translation and perspective projection.

To further increase performance, non-linear response function is pre-calculated and interpolation methods are used during projections.

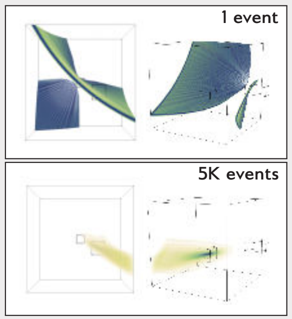
## Camera Architecture



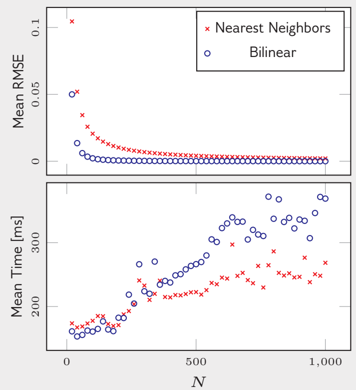

- Small and portable camera unit consists of multiple thin **scatterers** and a single thick **absorber** detector.
- Readout electronics are shielded from ionizing radiation and positioned within 100 m of the camera.
- The control software is deployed on a computer connected to the readouts by Ethernet network.

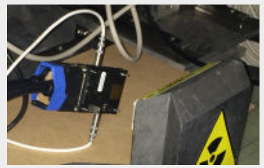
## Results & Conclusion

Individual software components were tested in a simulated and experimental environment. In both scenarios, the $\gamma$-ray sources were successfully determined.




Interpolation error and time were examined using random sampling.



- A novel Compton camera was designed and assembled.
- Proprietary control and reconstruction software was developed and tested.
- By integration of recent works, the presented device has the potential to surpass existing solutions in performance and accuracy.