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Evaluation of Timepix3 for applications as a Compton scatter polarimeter for hard X- and soft γ-rays

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Timepix3 [1] is a hybrid pixel detector with $55\,\mu$m pixel pitch in a matrix 256×256 pixels. It can measure in data-driven mode when it detects both the deposited energy and time of arrival (ToA) in the pixels. The ToA is written with 1.56 ns precision. The fine ToA resolution permits 3D reconstruction of tracks within the sensor [2]. This makes Compton camera imaging possible.

The reference [3] evaluates a single Timepix3 detector with a 1 mm thick silicon sensor for the use as a Compton scatter polarimeter, relying on the detection of coincident Compton scattering and photoabsorption. The evaluated energy range was 30–220 keV in simulation and 32.5–67.5 keV in a laboratory experiment. It was shown that the detector offers a maximum modulation factor $\mu_{100} > 77\,\%$ in the energy range 45–80 keV. However, a single detector is limited by its low efficiency of detection of the two coincident events, with $\varepsilon = 0.13\,\%$ being its peak value. The quality factor $q = \mu_{100}\sqrt{\varepsilon}$ reached its maximum $q = 2.9\,\%$ around the photon energy 50 keV.

The Compton camera imaging of the X-ray source is also evaluated in the reference [3]. The reconstruction method used was origin ensemble with resolution recovery (OE-RR). This is a Monte Carlo Markov chain method that tries to maximize the image likelihood function by stochastically updating photon origins one by one until it reaches a dynamic equilibrium. The full width at half maximum of the image $16 - 21^\circ$ was achieved.

In this work, we will present the simulations of combining multiple Timepix3 detectors to enhance the efficiency of detection. The basic setup consists of 4 silicon Timepix3 detectors stacked behind each other with 4 cadmium telluride Timepix3 detectors around them to boost the detection efficiency of perpendicularly scattered photons. Using this setup of 8 Timepix3 detectors, the quality factor monotonically increases from $2.9\,\%$ at 35 keV to $10.6\,\%$ at 65 keV. If we use two such setups together with 16 detectors in total, the quality factor monotonically increases from $3.9\,\%$ at 35 keV to $14.0\,\%$ at 65 keV.

Fine pixelization of Timepix3 detector would also enable imaging of the X-ray sources. A stack of Timepix3 detectors could be placed in the focal plane of an X-ray mirror, or it could take images using the Compton camera principle. Given the rich space heritage of Timepix-family detectors [4], Timepix3 could be used in some of the future X-ray polarimetric missions. The new detector Timepix4 with a larger area and better time resolution could be even more promising.

[1] Poikela, T. et al. “Timepix3: a 65K channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout”, JINST, 2014

[2] Bergmann, B. et al. “3D track reconstruction capability of a silicon hybrid active pixel detector”, The Eur. Phys. Jour. C, 2017

[3] Jelinek, J. et al. “Evaluation of Timepix3 with a 1 mm thick silicon sensor as a Compton imaging polarimeter in the hard X-ray band”, JINST, 2025.

[4] Bergmann, B. et al. “Results and Perspectives of Timepix Detectors in Space—From Radiation Monitoring in Low Earth Orbit to Astroparticle Physics”, Instruments, 2024

Eligibility for ”Best presentation for young researcher” or ”Best poster for young researcher” prize

Yes

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