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Timepix4 Based Detection System with 1 mm CdTe Sensor: Calibration and Preliminary Spectral Imaging Application

Timepix4 is an Application-Specific Integrated Circuit (ASIC) developed by the Medipix4 Collaboration. It features a 448×512 pixel matrix, which can be bump-bonded pixel by pixel to pixelated semiconductor sensors of various materials and thicknesses, with a pixel pitch of 55 \textmu m. In ToA-ToT data-driven mode, data packets are generated only when the charge collected in a pixel exceeds a fixed threshold, providing information on both the Time of Arrival (ToA) of the hits and the Time over Threshold (ToT) of the signal. During charge collection, charge sharing can occur between neighboring pixels and the detection of a single particle may produce multiple hits. By combining the spatial location of these hits with their ToA, it is possible to cluster the events and reconstruct the correct information about the detected photons. Furthermore, after proper calibration, the ToT can be used to measure the energy of the acquired events. The ability to correct charge-sharing effects and measure particles energy over a continuous spectrum makes Timepix4-based detection systems highly promising for spectral imaging applications. Since these applications require a high X-ray detection efficiency in an energy range up to 100 keV, thick sensors made of high-Z materials are required. \\
The results of the analysis of some preliminary spectral images, acquired with a Timepix4 bump-bonded to a 1 mm CdTe sensor, are here presented. Since an optimal spectral response is fundamental for spectral imaging applications, particular attention was dedicated to the energy calibration of the detector. The calibration was initially performed pixel-by-pixel with test-pulses internally generated by the ASIC to correct differences in the ToT response of the pixels. Fluorescence photons emitted by various materials in the energy range 15.8 keV - 48.7 keV were then acquired to verify and eventually correct the test-pulses calibration results. In particular, different correction factors were calculated, as a function of the energy, for different cluster size events. The energy resolution of the detection system, after completing this two-step calibration procedure, was finally evaluated as a function of the energy (see Fig. 1); a ΔE/E = 11% was measured at 40 keV. \\
After the calibration, spectral images were acquired in a 2D-geometry. The phantom was composed of six vials filled with H_2O, iodine solutions in different concentrations and a gadolinium solution. A small box filled with water was placed in front of the detection system, where the phantom was dipped during the acquisitions. A Hamamatsu micro-focus tube operating at 75 kVp - 5 \textmu A was used as X-ray source. A 600 s phantom image (I) and a 600 s flat-field image (I_0) were acquired. In the analysis, photons were separated in 1 keV energy bins, transitioning from the conventional radiographic image to a stack of quasi-monochromatic images. By using the Lambert-Beer law, the \textmu (E)x maps were calculated for each energy bin: \\

\begin{equation}
\label{eq:bll}
I = I_0 \cdot e^{-\mu x} \rightarrow \mu x = ln(\frac{I_0}{I})
\end{equation}

\noindent By selecting a specific region within the various vials, and by measuring the \textmu x mean value as a function of the energy, the k-edge of iodine (33.2 keV) is clearly displayed (see Fig. 2). Furthermore, the amplitude of the signal is proportional to the solute concentration. Hence, the possibility of examining quasi-monochromatic images at selected energies allows for quantitative imaging, in which different elements and their concentrations can be identified. \\
These preliminary results are very promising. Additional acquisitions in 2D geometry and further studies will be crucial for optimizing the setup and analysis procedure before transitioning to the 3D geometry used in Computed Tomography Spectral Imaging.

Workshop topics

Applications

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