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Timepix4 Characterization with Monochromatic X-Ray Synchrotron Beam

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Timepix4 is an application-specific integrated circuit (ASIC) developed by the Medipix4 collaboration [1]. Timepix hybrid detection systems are realized by bump-bonding the ASIC to pixelated sensors (pixel pitch 55 μm) of various materials and thicknesses to adapt the detection performances to different applications.
Timepix4 Time of Arrival (ToT) - Time over Threshold (ToT) data-driven operating mode is particularly suitable for spectral imaging applications; data packets are produced only when a pixel is hit, providing information on the energy deposited by the incident radiation pixel per pixel. Spectral images can, therefore, be acquired with a continuous energy spectrum, unlike conventional spectral systems, which are limited to a finite number of energy bins [2].
To characterize the performances of a Timepix4 assembly equipped with a 300 μm thick p-on-n Si sensor, data taking has been performed using the monochromatic photon beam of the SYRMEP beamline at the Elettra Synchrotron in the energy range between 8.5 keV and 40 keV [3].
The detector temperature was fixed around 15° C using a custom-made cooling system; acquisitions threshold was set at 3.62 keV.
The spectral-, flux- and detection efficiency-response of the detection system have been investigated.
First, an energy calibration of the detector was made, combining the X-ray acquisitions with data collected using the ASIC internally generated test pulses. Test-pulses charge can be set by using an internal Digital-to-Analog Converter, and it has been been tuned to extend the sampled energy range between 4.7 keV and 50.7 keV. The calibration, performed pixel by pixel, allows to convert the measured ToT into energy and to uniform the response of the Timepix4 matrix ($\sim$ 230k pixels).
The detector's energy resolution was evaluated as a function of energy, fitting the Gaussian energy broadening function on the collected data (see Figure 1):

\begin{equation}
\frac{\Delta E}{E} = \frac{a + b \cdot \sqrt{E + c\cdot E^2}}{E}~~~~~~~~~~(1)
\end{equation}

The fit parameters are: a = 0.61 keV, b = 0.30 $keV^{1/2}$, c = -1.15 $\cdot 10^{-3}$ keV^{-1}, $\chi^2_{reduced}$ = 0.64; the resulted energy resolution is lower than 10% in the clinical energy range.
By comparing the number of photons detected by the Timepix4 with the data collected by an ionization chamber used as a beam monitor system, the efficiency of the detection system has been estimated (24.8 % @ 20 keV) and compared with the expected one (24.4 % @ 20 keV).
Finally, an evaluation of the pixel dead-time was performed at 11 keV. At this energy, the rate of detected photons is maximized, considering the silicon detection efficiency, the absorption of photons in air, and the photon flux of the monochromatic beam. Several photon rates were acquired on a restricted area of the detector (5x5 pixel to avoid saturation effects related to the readout bandwidth). Data reported in Figure 2 show that, despite the high photon flux reached (1.7 $\cdot 10^8$ photons/$mm^2 \cdot s$), it is still impossible to determine the correct electronics model. Therefore, to estimate the dead-time (τ), both the paralyzable (eq. 2) and non-paralyzable (eq. 3) models were fitted on the number of hits per pixel per second (m) as a function of the ionization chamber current ($\propto$ n):

\begin{equation}
m = n \cdot A e^{- n \cdot A \cdot \tau}~~~~~~~~~~(2),
\end{equation}

\begin{equation}
m = \frac{n \cdot A}{1 + n \cdot A \cdot \tau}~~~~~~~~~~(3).
\end{equation}

Dead-time at 11 keV results: $\tau_{paralyzable} \simeq$ 544 ns and $\tau_{non-paralyzable} \simeq$ 746 ns.
The characterization results demonstrate that the application of a Timepix4-based detection system in the field of high rate spectral imaging is possible and needs to be investigated.

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