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Degradation of signal-to-noise ratio in counting detectors due to pile-up effects

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This work discusses how to properly evaluate the signal-to-noise ratio (SNR) of measurements taken with counting detectors, and how it is impacted detrimentally by the non-linearity of the detector response associated to pulse pile-up effects. This study is relevant for detection systems operating at high count rate regimes, where pile-up may be not negligible. Those cases can be managed in actual experiments by implementing pile-up compensation methods in the detector readout chain, by applying correction algorithms to the measured data or by a combination of both. What has been less discussed, to our knowledge, is the impact of those techniques on the final SNR of the resulting data and the detective quantum efficiency (DQE) of the detection process.
While it is well-known that a counting system follows Poisson statistics at low count rates and that the SNR becomes sub-Poissonian as pulse piling up starts being noticeable, a much less obvious result presented in this study is that the SNR of the measurements can actually drop with input flux at a relatively moderate level of pulse pile-up. This result could be perceived as counterintuitive, as it implies that from a certain value of input flux and for a given counting interval, more counts in the detector corresponds a lower signal-to-noise ratio.

The methodology adopted in this study is presented from a conceptual point of view, and justified and validated by both analytical and computer simulation methods. An in-house developed Monte Carlo code was adapted to reproduce the behavior of several theoretical pile-up models discussed in the literature [1]. This approach has also been applied to full X-ray 2D detection photon counting systems, by including in the simulation all the primary physical effects as well as the readout process of the detectors under consideration. This type of study can also be applied to compare the effectiveness different types of pile-up compensation or pulse recovery schemes by investigating their impact on the resulting data statistics.

[1] D. Yu and J. Fessler, Phys. Med. Biol. 45 (2000), 2043–2056

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