Beyond single photon counting X-ray detectors

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X-ray hybrid detectors at the Swiss Light Source

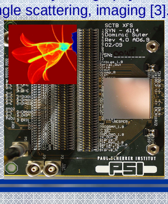
Synchrotron radiation imaging applications require mainly a high sensitivity, a large dynamic range and a good spatial resolution
State of the art detectors are the single photon counting systems developed at PSI.

Analogue readout systems with single photon sensitivity and extended dynamic range overcome the problem of the efficiency loss at high rates of counting detectors and show interesting perspectives towards the development of highly segmented detectors.

MYTHEN
1k to 30k 50µm strips for powder diffraction, small angle scattering, medical imaging [1]…

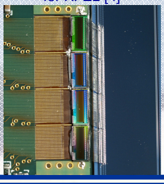
PILATUS
100k to 6M 172µm pixels for protein crystallography, small angle scattering, imaging [2]…

EIGER
(under commissioning)
500k to 9M 75µm pixels for protein crystallography, small angle scattering, imaging [3]….

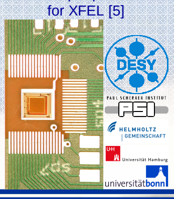


Towards X-ray Free Electron Lasers

GOTTHARD
(prototyping phase)
50µm strips
for XFEL [4]



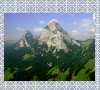
AGIPD
(prototyping phase)
200µm pixels
for XFEL [5]



Towards µm-resolution hybrid X-ray detectors

Single Photon Counting vs. Single Photon Analogue Readout

The spatial and spectral resolution of hybrid detectors is strongly determined by the diffusion of the charge produced by the X-ray while drifting towards the pads of the sensors. Hereafter the measurements acquired with the MYTHEN binary readout with 25µm and 50µm strip pitch are compared to the ones obtained with the GOTTHARD analogue readout with single photon counting sensitivity.

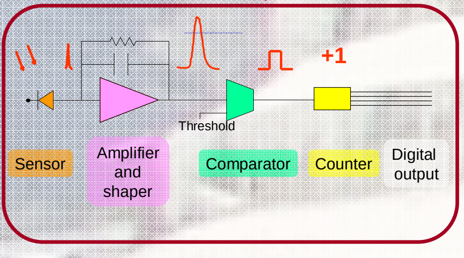


Single Photon Counting: MYTHEN

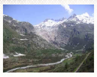
Microstrip sYstem for Time rEsolved experimeNts

Gain and shaping can be adjusted in order to either minimize the noise or maximize the count capability at high rates.

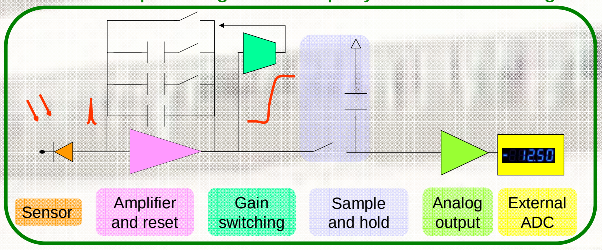
$ENC_{50\mu m x 8mm}$	230e⁻ rms
Dynamic range	>1.7E+7
Max count rate	<6MHz/ch



Analogue Readout: GOTTHARD



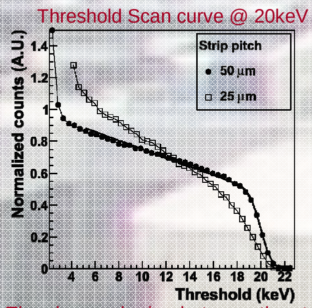
Gain Optimizing microsTrip sysTem witH Analogue ReaDout



The adaptive gain switching enlarges the dynamic range keeping the noise always below the Poisson fluctuations on the number of photons

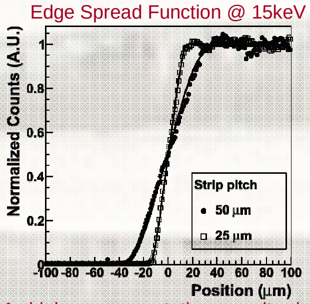
$ENC_{50\mu m x 8mm}$	340e⁻ rms
Dynamic range	>1E+4
Max rate	∞

Threshold Scan curve @ 20keV



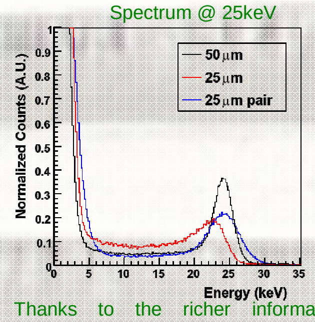
The charge sharing between the strips spreads on a region of about 18µm [6], which starts to be comparable with the strip pitch at 25µm.
In this case the plateau is barely visible and the measurements start to be very dependent from the exact threshold value and thus form the threshold dispersion of the detector.

Edge Spread Function @ 15keV



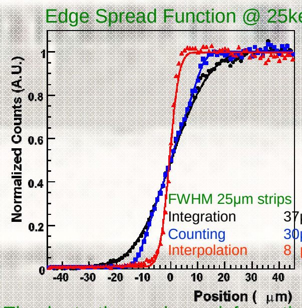
A higher segmentation results in a higher spatial resolution, however for smaller strip pitches the Point Spread Function deviates more from the ideal box-like function. Due to the electronic noise and to the non-zero threshold dispersion, the PSF for a point source located in a region between two strips is twice the strip pitch wide.

Spectrum @ 25keV



Thanks to the richer information offered by the analogue readout, the spectrum of the radiation acquired using 25µm strips can be retrieved by summing up the signal from neighboring strips only at noise expenses. By placing a threshold on the digitized signal the detector can be operated in counting mode [4].

Edge Spread Function @ 25keV



Thanks to the analogue information, the sharing of the signal between neighboring strips can be used to interpolate and increase the spatial resolution [4]. The technique is very well known in high-energy physics but has not been exploited yet in X-ray imaging because of the limited sensitivity and frame rate of existing detectors [7].

Summary

Single photon counting detectors cover the need of many synchrotron radiation applications, however they must be replaced by integrating detectors for X-ray Free Electron Laser experiments since they are not able to support the simultaneous detection of up to 10^4 photons. Moreover a purely binary readout places a limit on the maximum segmentation and thus on the spatial resolution achievable.
The measurements using the GOTTHARD ASIC demonstrate that these fundamental limitations of counting systems can be overcome without compromising the advantages concerning the dynamic range.
For this reason the SLS detector group has started to develop integrating detectors in parallel with the photon counting detector commissioning.
Thanks to the possibility of interpolating between channels, hybrid analogue readout detectors with single photon sensitivity and a high frame rate promise to open new perspectives in the field of X-ray imaging detectors offering the signal-to-noise-ratio of counting hybrid detectors together with a spatial resolution comparable to that of phosphor-coupled detectors.

References

[1] A. Bergamaschi et al., Photon counting microstrip detector for time resolved powder diffraction experiments, NIM A 604 (2009) 136-139.
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[3] R. Dinapoli et al., A new family of pixel detectors for high frame rate X-ray applications, NIM A (in press).
[4] A. Mozzanica et al., A single photon resolution integrating chip for microstrip detectors, NIMA A (accepted).
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[6] A. Bergamaschi et al., Performance of a single photon counting microstrip detector for strip pitches down to 10 µm, NIM A 591 (2008), 163-166.
[7] R. Turchetta, Spatial resolution of silicon microstrip detectors, NIM A 335 (1993) 44-58