USE OF A TIMEPIX 3 DETECTOR IN X-PEEM

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ABSTRACT: For a PEEM operating at a synchrotron or pulsed laser source, a detector with intrinsic time resolution that allows to resolve the excitation pattern of the light source is clearly advantageous. For static and dynamic measurements, it would allow correlating each registered electron with the corresponding X-ray beam or laser pulse. With this goal in mind, we have recently upgraded our PEEM with a Timepix3 detector [1], a time-resolved direct electron detector with 512 x 512 pixels (quad configuration) and an intrinsic time resolution of 1.6 ns, as well as two additional TDC channels with a time resolution of 256ps.

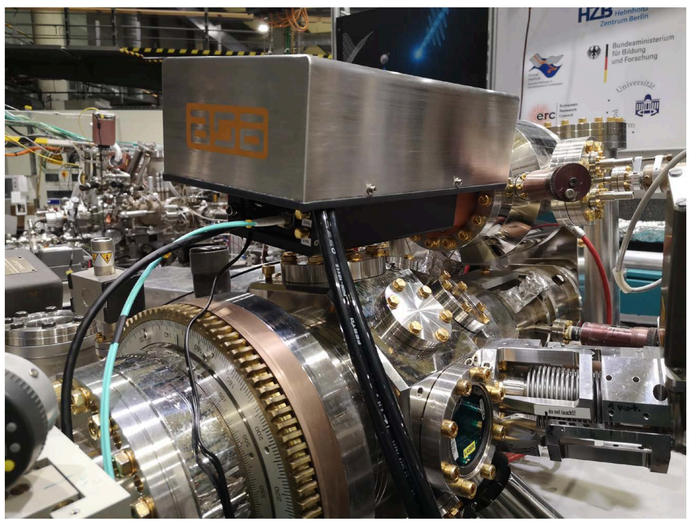
Motivation

The imaging unit is often a bottleneck for the performance of an X-PEEM. Conventional imaging devices based on a multichannel plate and a fluorescent screen are inexpensive but have significant disadvantages compared to direct electron detectors: First, the dynamic range of these detectors is very limited and the number of events cannot be assessed. Second, time- and intensity-dependent effects such as light scattering, pixel crosstalk, changes in quantum efficiency, and afterglow limit the proportionality between electron yield and measured intensity on the fluorescent screen. We have upgraded our X-PEEM with a TimePix 3 detector to overcome these limitations and gain further functionality for time-resolved measurements by resolving the time structure of the filling pattern of the BESSY II storage ring or the pulse pattern of our laser source, and last but not least to improve everyday operation by higher quantum efficiency and robustness against overexposure and user misoperation.

TimePix3 (CheeTah ASI)

TimePix 3 direct electron detector Quad configuration
Specifications:

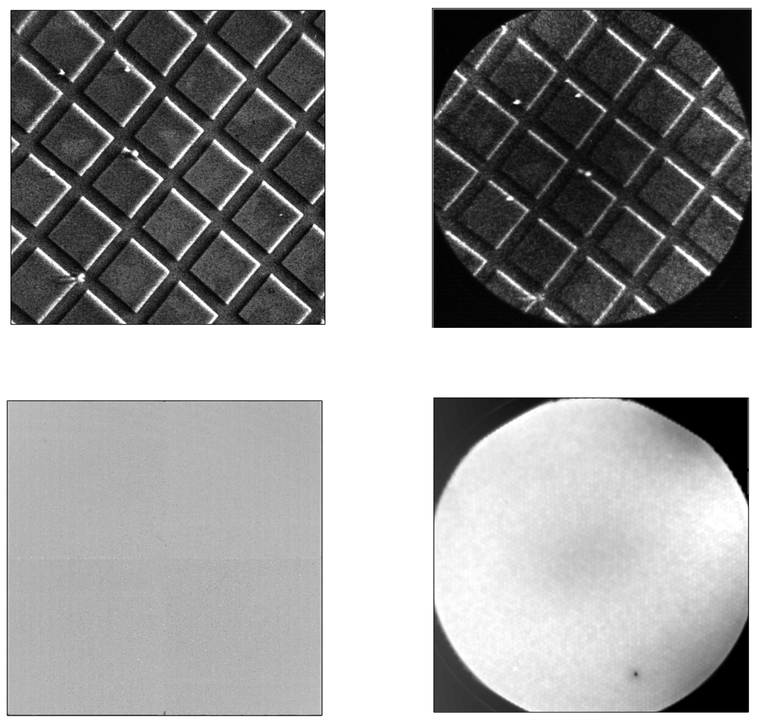
- 512 x 512 pixel / 1.56 ns time resolution
- 2 TDC channel / 256 ps time resolution
- Cf 100 mount
- Pixel size 55x55 micrometer
- active area of about 28 x 28 mm with 512 x 512 pixels
- UHV compatible / leak rate 5 x 10^-9 mbar
- Max. temperature 80°C / watercooled
- Energy range 8 kV – 20 kV (and above)
- Maximum hit rate 100 Mhits/second, no damage due to overexposure
- Simultaneous output of .tiff images and raw data



Left: TimePix3 mounted at the SPEEM at BESSY 2

Right: Comparison of images of a test sample and bright field image, taken with TPX3 and MCP detector under same conditions (50 µm field of view)

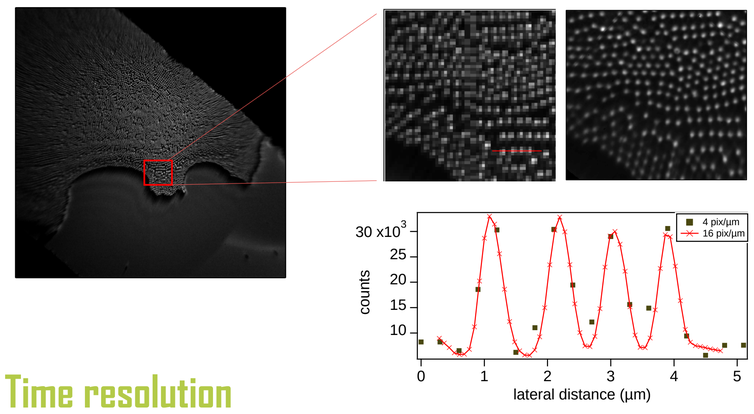
TimeTix3 MCP

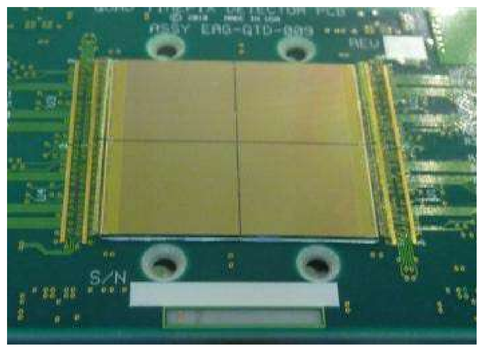


Bright field image

The pixel-to-pixel noise (standard deviation) improves from 5.4% to 3.7%.This indicates an improved quantum efficiency by a factor of 2 compared to MCP detektor.

No crosstalk between pixels and the dynamic range is limited only by the 100 ns dead time of individual pixels after an event and by the maximum hit rate. As a result, the spatial resolution in the images appears higher than in the MCP detector, even though the nominal resolution has been reduced from 1024 x 1024 to 512 x 512 pixels. The gap between the four chips in quad configuration is covered by wider pixels. These require special normalization and reduce the resolution in this area. Images below show the TPX3 ASIC and and image crop from a test pattern aroud the center gap.





Time resolution

Raw data of each pixel provide a time of arrival and a time over threshold. Two additional TDC channels allow to record references with a time resolution of 256ps. The best time resolution can be achieved by correcting for so-called time walk effects. First, the drift time for charges of different pixels is different. Second, the charge cloud generated by an event may differ in size. This may be surprising, since in the SPEEM all electrons are monochromatic due to the built in energy filter, but the charge flowing over a pixel depends on whether it was hit in the center or at the edge. Thus the pulse height of events varies and the threshold is reached sooner or later. The correction of both effects is called time walk correction [2]. With full correction and referencing of all events to the orbit clock of BESSY II, a time resolution of just about one nanosecond can be achieved at SPEEM. This is sufficient to resolve the fill pattern of the storage ring.

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Time walk effect is clearly visible
Time over threshold (ToA) correction fails a lower ToA values (spread in time of arrival too large)
Time shift across detector

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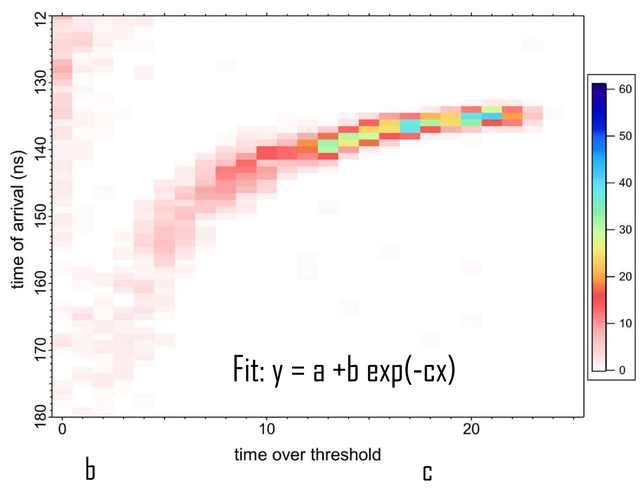
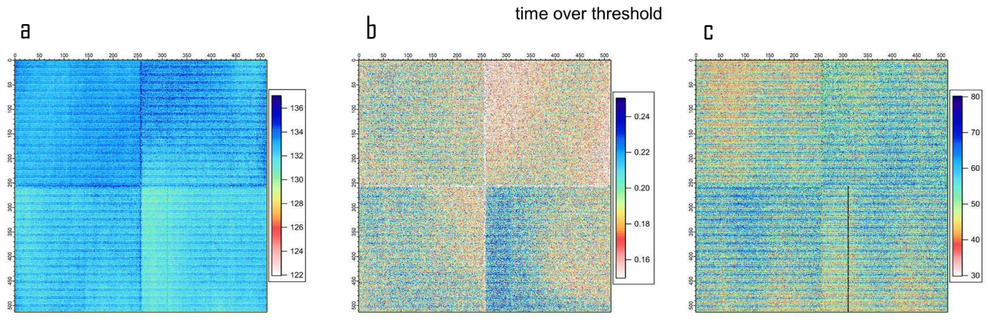
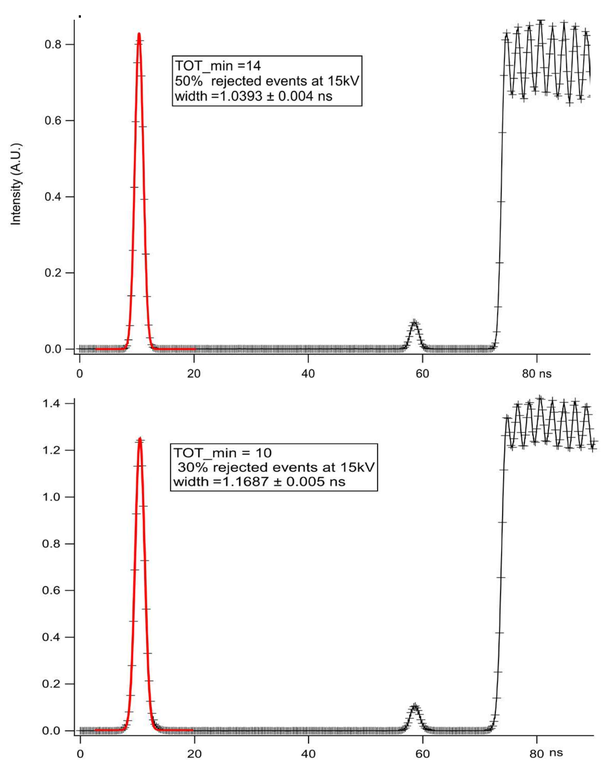
Each pixel requires an individual correction of ToA as fuction of ToT





Best time resolution when rejecting events with low ToA.
Island bunch in the BESSY fill pattern:



CONCLUSION

Pro:

- Time resolution up to 1 ns possible
- Superior quantum efficiency compared to MCP detector
- Enormous dynamic range
- No readout noise
- No damage due to overexposure
- No crosstalk between pixels
- Significant improvement at high magnification / low count rate

- Contra:
- Bakeout limitations / detector chamber cannot be heated above 80°C.
- High count rates cause overflow in the detector, which occurs mainly during alignment and at low magnification on our beamline
- Multi hits at higher kinetic energies require a full analysis of the raw data
- Analysis of time-resolved data requires computational time to perform time-walk correction for each pixel.

REFERENCES

[1] Poikela, T et al. Timepix3: a 65K channel hybrid pixel readout chip with simul- taneous ToA/ToT and sparse readout. Journal of instrumentation **9**, C05013 (2014).
[2] Dialing back time on Timepix3 A study on the timing performance of Timepix3 arXiv:2201.09275v1 [physics.ins-det] 23 Jan 2022 by Robbert Geertsema
[3] J. Paul van Schayck, et al., Sub-pixel electron detection using a convolutional neural network, Ultramicroscopy, Volume 218, 2020,

MORE INFORMATION

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