DECTRIS®

*detecting the future*

# PILATUS 3
## S AND X SERIES

### *Hybrid Photon Counting Detectors for Everyone*

Two performance classes to match the needs of any beamline


*synchrotron*

Hybrid Photon Counting X-ray detectors of the PILATUS3 S and X series meet the requirements of both advanced synchrotron instruments as well as cutting edge beamlines. With ample performance for any standard application, the PILATUS3 S series makes Hybrid Photon Counting technology accessible to virtually any synchrotron beamline and budget. A PILATUS3 S detector is the optimal choice for scientists looking for excellent data from a fast detector without requiring ultimate frame rates.

The PILATUS3 X series excels with frame rates up to 500 Hz and sub-millisecond readout times, enabling novel experimental strategies. Region of interest readout, a new feature of the PILATUS3 X series compared to its PILATUS3 predecessors, enables taking advantage of highest frame rates with even the largest models. The PILATUS3 CMOS readout ASIC features DECTRIS instant retrigger technology, which enables non-paralyzable counting, enhanced high-rate-counting performance, reduced readout time and allows for highly accurate count-rate correction. DECTRIS instant retrigger technology overcomes the intrinsic count-rate limitations of previous photon-counting detectors.

Superior data quality is the key benefit of all PILATUS3 detector systems and is achieved through various unique features: the absence of readout noise and dark current, a sharp point-spread function, and a high dynamic range and counter depth of 20 bits (~1 million counts). State-of-the-art CMOS ASICs and readout electronics enable fast data acquisition. In its standard configuration, PILATUS3 now features 450 µm silicon sensors for enhanced quantum efficiency.

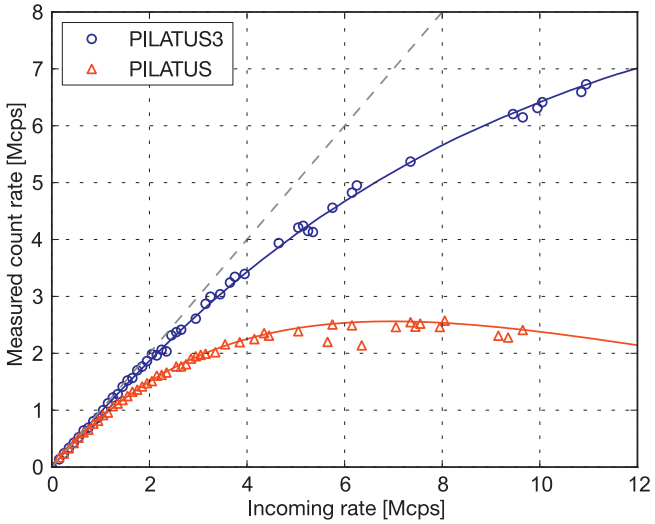
## *DECTRIS instant retrigger technology*

DECTRIS instant retrigger technology is a photon-counting method that results in non-paralyzable counting and achieves accurate high-rate-counting performance.

Conventional single-photon counting X-ray detectors are susceptible to counting losses and counter paralyzation. Counting losses are caused by pile-up of charge pulses generated by photons impinging too closely spaced in time. Count rate correction is applied to compensate for the counting loss. However, at high photon rates, pile-up can cause paralyzation of a conventional counting detector.

In PILATUS3 S and X detectors, the instant retrigger technology detects pulse pile-up, retriggers the counting circuit and effectively overcomes counter paralyzation. The non-paralyzable counting achieved by DECTRIS instant retrigger technology allows for enhanced count rate correction and improves data quality at high count rates. Photon rates of more than $10^7$ photons per second in a single pixel can be accurately measured with PILATUS3 detectors. Furthermore, global count rates of more than 2 x $10^8$ photons per second and $mm^2$ can be achieved.

Visit our website **www.dectris.com** for a detailed description of DECTRIS instant trigger technology.




**Measured data (symbols) and theoretical curves (solid lines) of count rate characteristics of PILATUS3 (blue) and PILATUS (red). Data acquired at beamline X05DA of Swiss Light Source, 10.0 keV X-ray energy, 5 keV threshold.**

## *Improved Applications*

PILATUS3 detectors ideally match the ever increasing brightness and flux of present and future 3rd generation synchrotron sources. The unprecedented count rate capabilities are compatible with the strongest diffraction and scattering intensities and eliminate count rate limitations in applications like small-molecule crystallography or X-ray reflectometry. The high local and global count rates allow data with excellent statistics to be taken with short exposure times. High frame rates and an overflow-free 20 bit counter seamlessly complement these properties.
This enables advanced high-flux diffraction experiments such as *in situ* virus crystallography. Many applications require the determination of the primary beam intensity. PILATUS3 detectors in synchrotron-based ptychography or in SAXS instruments enable the direct measurement of the primary beam intensity.

The high frame rates supported by the PILATUS3 X series can be used to speed up experiments and enable novel strategies, while the short readout time improves the duty cycle and hence the efficiency of data collection. This is of major advantage in applications that require the acquisition of large data sets such as SAXS, ptychography or sample alignment and characterization by grid scanning techniques. Thanks to the new Region Of Interest (ROI) feature, even the largest PILATUS3 X models offer highest frame rates.

### Key advantages
- Count rates up to 10 Mcts/sec/pixel
- Direct detection of X-rays in single-photon-counting mode
- No readout noise
- No dark current
- Excellent point-spread function
- Overflow-free 20 bit counter
- Room temperature operation

### Advantages S Series
- Maximum frame rate of 25 Hz
- Readout time of 2.03 ms
- Upgradable to X series

### Advantages X Series
- Frame rates up to 500 Hz
- Readout time of 0.95 ms
- Region of interest readout

### Applications
– Macromolecular crystallography (MX)
– Single-crystal diffraction (SCD)
– Surface diffraction
– Small and wide-angle X-ray scattering (SAXS/WAXS)
– X-ray powder diffraction (XRPD)
– Coherent X-ray imaging
– Time-resolved experiments

### Detector options
In addition to the standard configuration with 450 µm silicon sensors, all PILATUS3 detectors are also available with 1000 µm silicon sensors for improved quantum efficiency at high X-ray energies. The water cooled models PILATUS3 X 300K and 300K-W offer optional vacuum compatibility. This option allows operation of the detector in vacuum, e.g. in the flight tube of a SAXS instrument. The vacuum compatible 300K and 300K-W detectors are also available with 320 µm thick sensors and special calibrations for low energy applications. Based on PILATUS3 technology, DECTRIS can realize Specific Solutions. In this case all modules are placed in vacuum and custom geometries can be realized.

The PILATUS processing unit (PPU) provides an efficient complement to PILATUS3 detector systems. Dedicated software packages running on a high-end server ensure stable data acquisition at sustained high rates without challenging your beamline IT infrastructure. The PILATUS3 X systems 1M, 2M, and 6M include a PPU mini. All PILATUS3 S and X systems can be upgraded with a PPU L or XL for additional computing and storage resources.

| | Sensor thickness [µm] | | |
|---|---|---|---|
| **X-ray energy** | **320** | **450** | **1000** |
| 5.4 keV | 94 % | 94 % | >80 % |
| 8.0 keV | 97 % | 98 % | 96 % |
| 12.4 keV (1Å) | 72 % | 84 % | 97 % |
| 17.5 keV | 37 % | 47 % | 76 % |
| 22.2 keV | 20 % | 27 % | 50 % |

**Table 1: Quantum efficiency of PILATUS sensors measured in cooperation with PTB at the BAM beamline at BESSY II.**


## *PILATUS3 S detector series technical specifications*

| PILATUS3 S | 1M | 2M | 6M |
|---|---|---|---|
| Number of detector modules | 2 × 5 | 3 × 8 | 5 × 12 |
| Sensitive area: width × height [mm²] | 168.7 × 179.4 | 253.7 × 288.8 | 423.6 × 434.6 |
| Pixel size [µm²] | 172 × 172 | | |
| Total number of pixels: hor. × ver. | 981 × 1043 | 1475 × 1679 | 2463 × 2527 |
| Gap width: hor. / ver. [pixel] | 7 / 17 | | |
| Inactive area [%] | 7.2 | 8.0 | 8.5 |
| Defective pixels | < 0.03% | | |
| Maximum frame rate [Hz] | 25 | | |
| Readout time [ms] | 2.03 | | |
| Point-spread function | 1 pixel (FWHM) | | |
| Threshold energy [keV] | 2.7 - 18 | | |
| Counter depth | 20 bits (1,048,576 counts) | | |
| Power consumption [W] | 165 | 250 | 580 |
| Dimensions (WHD) [mm³] | 265 × 286 × 455 | 384 × 424 × 456 | 590 × 603 × 455 |
| Weight [kg] | 25 | 46 | 92 |
| Module cooling | Water-cooled | | |
| Electronics cooling | Air-cooled | | |
| Standard configuration | 450 µm silicon sensor | | |
| | detector, detector server, water-cooling unit | | |
| Detector options | 1000 µm silicon sensor | | |
| | PPU mini, L or XL | | |

PILATUS3 S detectors can be upgraded on-site with minimal downtime to X Series detectors. This enables the full performance and features of the corresponding PILATUS3 X detector.


## *PILATUS3 X detector series technical specifications*

| PILATUS3 X | 100K-A | 200K-A | 300K | 300K-W | 1M | 2M | 6M |
|---|---|---|---|---|---|---|---|
| Number of detector modules | 1 x 1 | 1 x 2 | 1 x 3 | 3 x 1 | 2 x 5 | 3 x 8 | 5 x 12 |
| Sensitive area: width × height [mm²] | 83.8 x 33.5 | 83.8 × 70.0 | 83.8 × 106.5 | 253.7 × 33.5 | 168.7 × 179.4 | 253.7 × 288.8 | 423.6 × 434.6 |
| Pixel size [µm²] | 172 × 172 | | | | | | |
| Number of pixels: hor. × ver. | 487 x 195 | 487 × 407 | 487 × 619 | 1475 × 195 | 981 × 1043 | 1475 × 1679 | 2463 × 2527 |
| Gap width: hor. / ver. [pixel] | 0 | – / 17 | – / 17 | 7 / – | 7 / 17 | 7 / 17 | 7 / 17 |
| Inactive area [%] | 0 | 4.3 | 5.5 | 0.9 | 7.2 | 8.0 | 8.5 |
| Defective pixels | < 0.03% | | | | | | |
| Maximum frame rate, full frame [Hz] | 500 | 500 | 500 | 500 | 500 | 250 | 100 |
| Maximum frame rate, ROI [Hz] | – | – | – | – | 500 | 500 | 500 |
| Readout time [ms] | 0.95 | | | | | | |
| Point-spread function | 1 pixel (FWHM) | | | | | | |
| Threshold energy [keV] | 3.5 - 18 | 3.5 - 18 | 2.7 - 18 | 2.7 - 18 | 2.7 - 18 | 2.7 - 18 | 2.7 - 18 |
| Counter depth | 20 bits (1,048,576 counts) | | | | | | |
| Power consumption [W] | 30 | 30 | 36 | 36 | 165 | 250 | 580 |
| Dimensions (WHD) [mm³] | 156 x 115 x 284 | 156 x 155 x 284 | 158 x 193 x 262 | 280 x 62 x 296 | 265 x 286 x 455 | 384 x 424 x 456 | 590 x 603 x 455 |
| Weight [kg] | 4.5 | 5.4 | 7.5 | 7.0 | 25 | 46 | 92 |
| Module cooling | Air-cooled | Air-cooled | Water-cooled | Water-cooled | Water-cooled | Water-cooled | Water-cooled |
| Electronics cooling | Air-cooled | Air-cooled | Water-cooled | Water-cooled | Air-cooled | Air-cooled | Air-cooled |
| Standard configuration | 450 µm silicon sensor | | | | | | |
| | detector, detector server | detector, detector server | detector, detector server, water-cooling unit | | detector, detector server, water-cooling unit, PPU mini | | |
| Detector options | 1000 µm silicon sensor | | | | | | |
| | PPU mini, L or XL | PPU mini, L or XL | PPU mini, L or XL | PPU mini, L or XL | PPU L or XL | PPU L or XL | PPU L or XL |
| | – | – | vacuum compatibility<br>320 µm silicon sensor | | – | – | – |

All data are subjects to change without notice

## *Hybrid Photon Counting (HPC) technology*

### Hybrid pixel detection

Hybrid pixel detectors directly convert X-rays into an electronic signal. Other types of X-ray detectors rely on intermittent steps to capture and convert X-rays. CCD and CMOS active pixel detectors, for instance, have to convert X-rays to visible light first. Scattering of light in the phosphor screen required for conversion smears out the signal and decreases spatial resolution. Fiber-glass optics transduce the light on the chip, which causes further loss and distortion of signal. These intrinsic design limitations of CCD and active pixel detectors are absent in hybrid pixel detectors.

Direct detection of X-rays with hybrid pixel technology offers superior spatial resolution and high detection efficiency. In a hybrid pixel detector every pixel is comprised of two components: a sensor pixel and a readout pixel (fig. 2). X-ray photons are directly converted into electric charge in the sensor pixel. The readout pixel processes and counts this electric signal. Sensor and readout pixel have a direct, electronic connection that is unique for every hybrid pixel and prevents spread and loss of signal. This makes every hybrid pixel a virtually independent X-ray detector and leads to lowest point spread, highest sensitivity and ultimate speed.

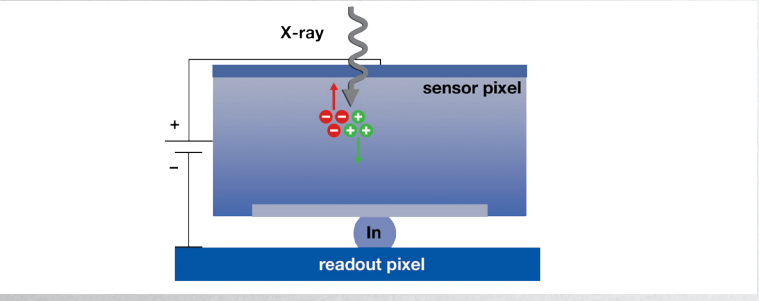



**Figure 2: Principle of direct detection of X-ray photons in a solid-state sensor.**

### Single-photon counting

Free electric charge is released in the sensor pixel upon absorption of X-rays. The X-ray signal is processed by the readout pixel in single-photon-counting mode, which offers various advantages over integrating the signal. In an integrating detector, charge is accumulated during exposure. Throughout integration, an intrinsic dark current is added to the accumulated charge. Dark current increases noise and diminishes data quality. In a single-photon-counting detector, the signal is determined by counting individual events of charge released by X-ray absorption: The charge is amplified in the readout pixel and, if the signal exceeds an adjustable threshold, an absorption event is digitally counted. This way, single-photon-counting technology completely abolishes dark current as a source of detector noise and enables superior data quality. Furthermore, single-photon counting occurs on the fly during exposure, achieving earliest possible digitization and a subsequent fast and noise-free digital readout. Therefore, readout noise is entirely absent in single-photon-counting detectors.

## *Features*

### Optimal signal-to-noise ratio

PILATUS3 Hybrid Photon Counting detectors are inherently free of dark current and readout noise (fig. 3). The absence of any detector noise guarantees data with an excellent signal-to-noise ratio. Compared to conventional detectors, this allows for either superior data collection at similar exposure times or equally good data with shorter acquisition times, equivalent to lower dose to the sample. A noise-free detector provides largest benefit when recording weak signals from poorly diffracting samples or at highest resolution.

### Excellent point-spread function

With hybrid pixel technology and direct conversion of X-rays into charge pulses, PILATUS3 detectors spread virtually no intensity between pixels. This enables a sharp point-spread function of one pixel (FWHM) and offers a variety of benefits (fig. 4). Closely spaced signals, even of largely differing intensity, can be accurately resolved and measured. Sharper signals reduce overlap with scattering or other background intrinsic to the experiment, thereby improving the signal-to-noise ratio.

### High dynamic range

A counter depth of 20 bits (~1 million counts) combined with the absence of detector noise ensures unprecedented contrast and dynamic range; another PILATUS3 hallmark leading to excellent image and data quality (fig. 4). Extremely strong and weak signals can be accurately detected on a single image.

Figure 3: Absence of readout noise and dark current in PILATUS Hybrid Photon Counting detectors.
Images of a single PILATUS module without exposure to an X-ray source with 100 ms or 1 hour of acquisition time. After 100 ms, all pixels have zero counts because no noise is added during readout of the image. After 1 hour, most pixels still have zero counts, since no dark current accumulates during long exposure and no noise is added during readout. All counts in the exposure arise from general background radiation, which accounts for 0.2 cts/h/pixel.

### Fast readout and shutterless operation

PILATUS3 S and X systems feature short readout times and high frame rates, which substantially reduce measurement time and maximize efficiency and throughput. Most importantly, this allows shutterless, continuous acquisition of full images.

### High local and global count rates

PILATUS3 detectors feature DECTRIS instant retrigger technology, which enables each pixel to accurately detect up to ten million photons per second. Furthermore, global count rates of more than 2 x $10^8$ photons per second and $mm^2$ can be achieved. Both local and global count rates of PILATUS detectors are far superior to those of counting detectors based on gas discharge or similar technologies.

### Ease of maintenance and operation

PILATUS3 detectors have low power and cooling requirements. All detector components are operated at room temperature, which vastly simplifies cooling. The PILATUS3 X 200K-A detector is fully air-cooled and maintenance-free, while the PILATUS3 X 100K-A is entirely media-free. Other models of the PILATUS3 S and X series use low-maintenance, closed-circuit water cooling for temperature stabilization at 23° C.

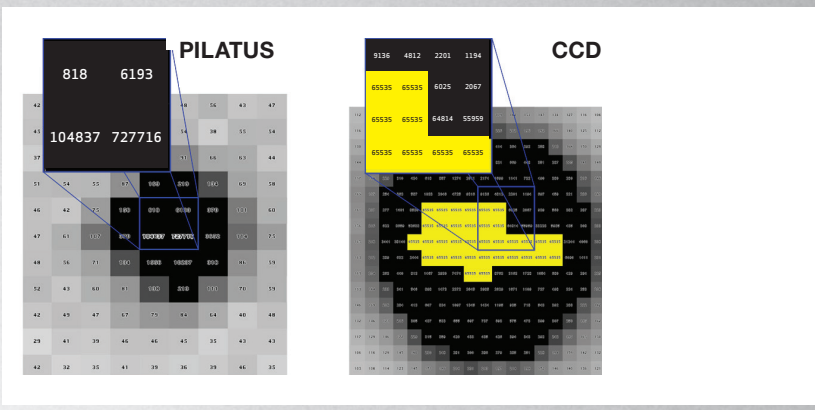



Figure 4: Superior dynamic range and point-spread function of PILATUS Hybrid Photon Counting detectors.
Details of diffraction images showing the same reflection of an insulin crystal. The images were acquired at a synchrotron beamline with identical parameters except for the detector distance that was adjusted to achieve the same resolution at the detector edge, depending on the detector size. PILATUS: The 20 bit counter depth of the hybrid pixel detector provides sufficient dynamic range to record 727,716 counts in the highest pixel intensity. With the excellent point-spread function, the spot is well confined to a small area. Furthermore, the sharp reflection profile of the low mosaicity crystal is accurately represented with a more than one-thousand-fold difference in intensity between neighboring pixels. CCD: The same reflection recorded with a CCD contains many overloaded pixels. The reflection intensity is smeared out over a large area.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