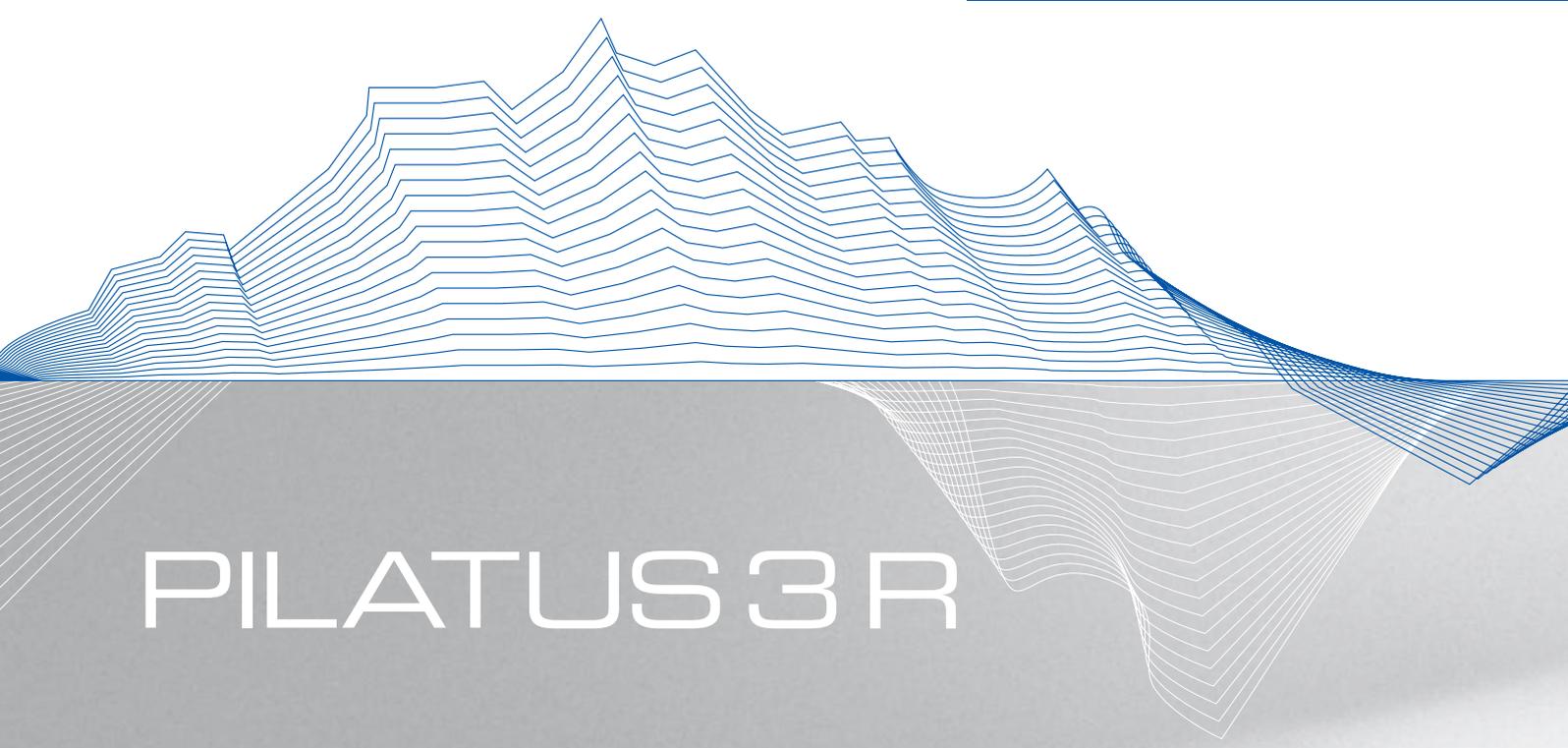


**DECTRIS®**

*detecting the future*

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# PILATUS 3 R

*Hybrid Photon Counting  
Detectors for Your Laboratory*



*laboratory and industry*

PILATUS3 R Hybrid Photon Counting detectors are designed from ground up to achieve best possible data quality in X-ray detection. They bring the combination of two key technologies, single-photon counting and hybrid pixel technology, from the synchrotron to your laboratory. PILATUS3 R completes the unique advantages of our series of laboratory detectors: DECTRIS instant retrigger, the hallmark feature of PILATUS3 technology, allows for substantially enhanced count rates and accurate count rate corrections.

The increased count rates of PILATUS3 R are of particular advantage whenever dealing with high intensity signals. Strong Bragg peaks from intensely diffracting samples, such as small molecules or inorganic compounds, can be measured accurately with DECTRIS instant retrigger. Single-photon counting eliminates all detector noise and delivers superior data. The absence of readout noise and dark current is of particular advantage when collecting data with a

home source: X-ray sources in the laboratory are much weaker than at the synchrotron, requiring longer exposure times and resulting in weaker signals. Thanks to the absence of dark current and readout noise, PILATUS3 R detectors outperform all other technologies in the laboratory.

Hybrid Photon Counting technology enables direct detection of X-rays and results in sharper and better resolved signals than scintillator based detectors. With short readout times and continuous acquisition, PILATUS3 R detectors deliver superior data with high efficiency. Low power and cooling requirements give you a hassle-free detector system with minimal maintenance.

The PILATUS3 R detector series is designed for your needs in the laboratory and offers synchrotron-proven technology at unrivaled value. Take advantage of the unique features of PILATUS3 R detectors to get the best data from your most challenging samples.

### Tailored to your needs

PILATUS3 Hybrid Photon Counting detectors offer optimal performance for a wide range of X-ray applications and users. While the PILATUS3 S and X series are aimed at synchrotron applications, the PILATUS3 R series is tailored to your needs in the laboratory. Fixed-energy calibration and simplified readout electronics perfectly match the requirements in the laboratory and make PILATUS3 R meet your budget. DECTRIS instant retrigger, hybrid pixel technology and single-photon counting, the key technologies for superior data and high efficiency, are fully implemented without any compromises in all PILATUS3 R detectors.

An increasing number of instruments for laboratory and industry applications can be equipped or upgraded with PILATUS3 R detectors. The new, large area PILATUS3 R 1M is the perfect solution to rejuvenate your diffractometer by updating an imaging plate or CCD detector with a state-of-the-art detector. Use the freedom to integrate PILATUS3 R in your own setup or benefit from a readily available instrument from a DECTRIS OEM partner.

### OEM partners

PILATUS3 R detectors are readily available in our OEM partners' instruments:

- JJ X-Ray
- Rigaku
- STOE
- Xenocs

X-ray energy	Sensor thickness [ $\mu\text{m}$ ]	
	450	1000
5.4 keV (Cr)	94 %	>80 %
8.0 keV (Cu)	98 %	96 %
9.2 keV (Ga)	97 %	97 %
17.5 keV (Mo)	47 %	76 %
22.2 keV (Ag)	27 %	50 %

**Table 1: Quantum efficiency of PILATUS sensors based on measurements at the PTB laboratory at BESSY II.**

### Customizable to match your requirements

In addition to the standard 450  $\mu\text{m}$  thick silicon sensors, you can customize your PILATUS3 R detector with 1000  $\mu\text{m}$  thick silicon sensors to match the energy of your X-ray source (tab. 1). This achieves high quantum efficiency at all common laboratory X-ray energies.

The water-cooled models PILATUS3 R 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 option for a continuously adjustable energy threshold allows for the suppression of fluorescence signals.

## Key advantages

- Direct detection of X-rays in single-photon-counting mode
- DECTRIS instant retrigger technology for non-paralyzable counting
- Highest local and global count rates
- Accurate count rate correction for supreme data quality at high count rates
- No readout noise and no dark current
- Excellent point-spread function
- High dynamic range
- Short readout times and high frame rates

## Applications

- Macromolecular crystallography (MX)
- Single-crystal diffraction (SCD)
- X-ray diffraction (XRD)
- Small and wide-angle scattering (SAXS/WAXS)
- Surface diffraction
- Diffuse scattering
- Time-resolved experiments
- Imaging
- Non-destructive testing

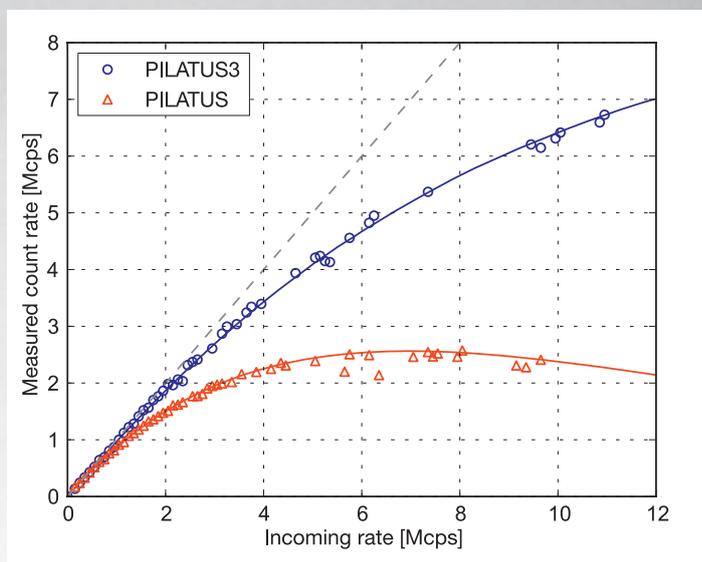
## DECTRIS instant retrigger technology

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 R 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 R detectors. Furthermore, global count rates of more than  $2 \times 10^9$  photons per second and  $\text{mm}^2$  can be achieved.

Visit our website [www.dectris.com](http://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.



### **PILATUS3 R 1M**

The PILATUS3 R 1M is the perfect detector for macromolecular crystallography in the laboratory. The large sensor area of 169 by 179 millimeters rivals that of image plates and eliminates all compromises when collecting complete high resolution data with well resolved spots. A readout time of 7 ms and shutterless data acquisition make it a breeze to collect high multiplicity data sets. The PILATUS3 R 1M is the ultimate choice when replacing your outdated image plate or CCD and upgrading your diffractometer to a state-of-the-art instrument. In X-ray scattering experiments, the large area of the 1M enables simultaneous measurements of SAXS and WAXS signals.



### **PILATUS3 R 300K**

The PILATUS3 R 300K is the perfect detector for an in-house SAXS instrument. Benefit from the outstanding stability of the water-cooled detector that allows for the determination and subtraction of solvent scattering with best precision and accuracy, even for very long exposure times. Take additional advantage of the optional vacuum compatibility of the detector for complete elimination of air and window scattering.



### **PILATUS3 R 300K-W**

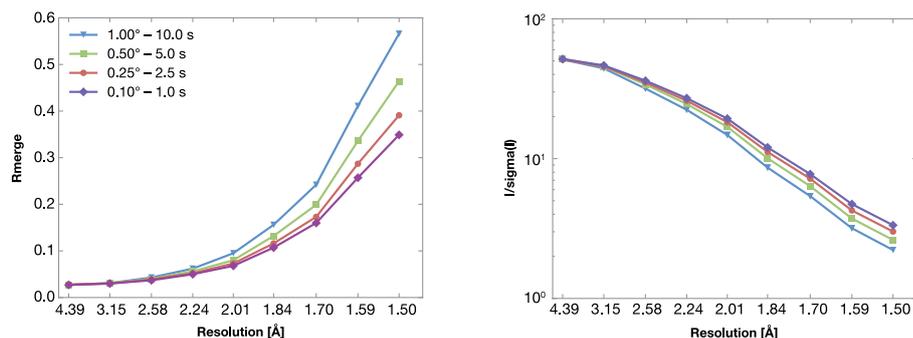
The PILATUS3 R 300K-W with its wide rectangular area is perfectly suited for WAXS, 2-D texture analysis and powder diffraction. The extremely slim profile of the housing allows you to position the detector close to the direct beam and gives you the ultimate detector for measuring the WAXS signal in a SAXS/WAXS setup. Like the 300K, the PILATUS3 R 300K-W also features vacuum compatibility as a customization option.



### **PILATUS3 R 200K-A**

The PILATUS3 R 200K-A features an active area of 84 by 70 millimeters and is the ideal detector for a wide range of X-ray applications. It is the most compact detector that allows you to take full advantage of all PILATUS3 features. Achieve outstanding results in SCD and XRD with PILATUS3's high local and global count rates that are far superior to those of counting detectors based on gas discharge or similar technologies. The smartly shaped front and compact size of the housing enable detection at high diffraction angles and make efficient use of confined space around the sample. Fully air-cooled and with low power requirements, the PILATUS3 R 200K-A is a service and maintenance-free detector system.

## Fine $\phi$ -slicing in your laboratory



**Figure 1: Fine  $\phi$ -slicing with PILATUS.** Each data set was collected at the same angular speed of 0.1 °/s in only 30 minutes with decreasing rotation width and exposure time per image as indicated in the legend. Excellent data are obtained with short acquisition times. Exploiting fine-sliced data collection with a noise-free PILATUS leads to optimal data quality (insulin, 180° total rotation, microfocus sealed tube, PILATUS 300K).

## Applications

### PILATUS3 R for laboratory MX

Measuring weak high-resolution reflections with best possible accuracy determines map quality and eventually your success in macromolecular crystallography. The signal-to-noise ratio of weak reflections is particularly improved by the absence of detector noise in PILATUS3 R detectors and the sharp-point-spread function, which reduces overlap of diffraction intensities with scattering background. Additionally, fine-slicing strategies can be used to further improve data quality by minimizing background overlap along the direction of rotation and reducing spot overlaps (fig. 1). Noise-free PILATUS detectors allow for optimal fine-slicing [1] whereas CCD or CMOS active pixel detectors require compromises because of readout or reset noise.

Beam stability is crucial for experimental phasing and a feature in which your in-house system can outperform synchrotron beamlines. Maximize this advantage of your home source by matching it with a PILATUS3 R. The combination of a highly stable home source with a noise-free high-sensitivity detector increases your success in S-SAD and other experimental phasing methods for which data accuracy is paramount.

With a readout time of only 7 ms for full images, PILATUS3 R detectors enable shutterless data acquisition in continuous rotation. This reduces total acquisition times and maximizes efficiency; a critical advantage in high-throughput applications such as fragment screening. Furthermore, continuous-rotation data collection allows you to collect fine-sliced data sets with the same acquisition times as wide-sliced data.

### PILATUS3 R for laboratory SAXS

PILATUS3 R detectors are perfectly suited for in-house SAXS instrumentation owing to their high dynamic range, absence of readout noise and dark current, high sensitivity and superior stability. Measuring extremely weak signals at high  $q$ -ranges requires long exposure times. Thanks to the complete absence of dark current, PILATUS3 R detectors excel in delivering superior data at long exposure times. Another advantage when using PILATUS3 R in the laboratory, is its high detection stability that allows for the determination and subtraction of solvent scattering with best accuracy even for very long exposure times. This outstanding stability results from the combination of single-photon counting in hybrid pixel technology and simple, yet highly stable water-cooling.

The remarkable performance of PILATUS3 R in accurately measuring weak signals enables you to succeed when dealing with diluted samples. The combination of SAXS with size-exclusion chromatography is a powerful method to study aggregation or degradation-prone systems, transient complexes, and multiple oligomerization states. A noise-free PILATUS3 R detector makes these studies on diluted samples feasible in your laboratory [2]. Furthermore, the high frame rates and low readout time also allow for fine sample data collection over the course of protein elution while maximizing acquisition time. Fine-sampling of data collection over long total exposure times is also extremely useful in conventional SAXS experiments, since it reveals valuable information on radiation damage during data acquisition.

[1] Mueller, M., Wang, M. & Schulze-Briese, C. *Optimal fine  $\phi$ -slicing for single-photon-counting pixel detectors*. Acta crystallographica. Section D, Biological crystallography 68, 42–56 (2012).

[2] Wright, G. S. a. et al. *The application of hybrid pixel detectors for in-house SAXS instrumentation with a view to combined chromatographic operation*. Journal of Synchrotron Radiation 20, 2009–2011 (2013).

## 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.

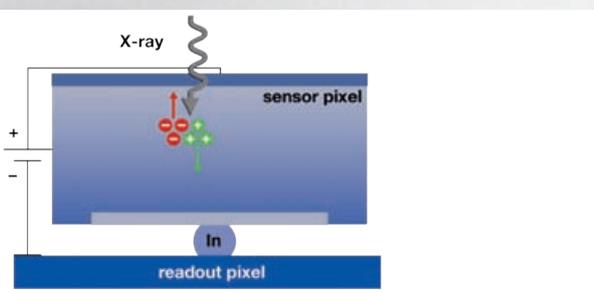


Figure 2: Principle of direct detection of X-ray photons in a solid-state sensor.

### 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.

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 results in lowest point spread, highest sensitivity and ultimate speed.

## 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 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 the largest benefit when recording weak signals from poorly diffracting samples or at highest resolution. The absence of all detector noise is particularly beneficial in data acquisitions with weak laboratory sources.

### Excellent point-spread function

With hybrid pixel technology and direct conversion of X-rays into charge pulses, PILATUS3 R 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 R 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, since no noise is added during readout of the image. After 1 hour, most pixels still have zero counts because 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

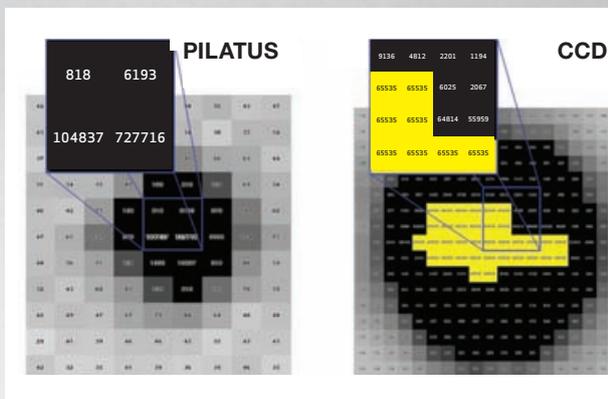
PILATUS3 R detectors for laboratory instruments read out complete images with lightning speed in only 7 ms. This allows shutterless, continuous acquisition of full images. Nearly instantaneous readout and continuous data acquisition maximize efficiency and throughput for any instrument.

### High local and global count rates

PILATUS3 R 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  $2 \times 10^9$  photons per second and  $\text{mm}^2$  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. For the first time photon-counting detectors are compatible even with most demanding samples such as strongly diffracting small molecule crystals.

### Ease of maintenance and operation

PILATUS3 R detectors have low power and cooling requirements. All detector components are operated at room temperature, which vastly simplifies cooling. The PILATUS3 R 200K-A detector is fully air-cooled and maintenance-free. PILATUS3 R 300K, 300K-W and 1M 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 which 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.

# PILATUS 3 R



## PILATUS 3 R detector series technical specifications

PILATUS 3 R	200K-A	300K	300K-W	1M
Number of detector modules	1 × 2	1 × 3	3 × 1	2 × 5
Sensitive area: width × height [mm <sup>2</sup> ]	83.8 × 70.0	83.8 × 106.5	253.7 × 33.5	168.7 × 179.4
Pixel size [μm <sup>2</sup> ]	172 × 172			
Total number of pixels	487 × 407 = 198,209	487 × 619 = 301,453	1475 × 195 = 287,625	981 × 1043 = 1,023,183
Gap width: hor. / ver. [pixel]	- / 17	- / 17	7 / -	7 / 17
Dead area [%]	4.3	5.5	0.9	7.2
Defective pixels	< 0.03 %			
Maximum frame rate [Hz]	20	20	20	5
Readout time [ms]	7			
Point-spread function	1 pixel (FWHM)			
Counter depth	20 bits (1,048,576 counts)			
Power consumption [W]	30	30	30	165
Dimensions (WHD) [mm <sup>3</sup> ]	156 × 155 × 284	158 × 193 × 262	280 × 62 × 296	265 × 286 × 455
Weight [kg]	5.4	7.5	7.0	25
Module cooling	Air-cooled	Water-cooled	Water-cooled	Water-cooled
Electronics cooling	Air-cooled	Water-cooled	Water-cooled	Air-cooled
External trigger / gate	5V TTL			
Energy calibrations	K $\alpha$ -lines of Cr, Mn, Fe, Cu, Ga, Mo, Ag calibration for two X-ray energies			
Standard configuration	450 μm silicon sensor calibration for more than two X-ray energies			
Detector options	1000 μm silicon sensor			
	continuous threshold (3.5 – 18 keV)	continuous threshold (2.7 – 18 keV)	continuous threshold (2.7 – 18 keV)	continuous threshold (2.7 – 18 keV)
	–	vacuum compatibility	vacuum compatibility	–

All data are subjects to technical modifications

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