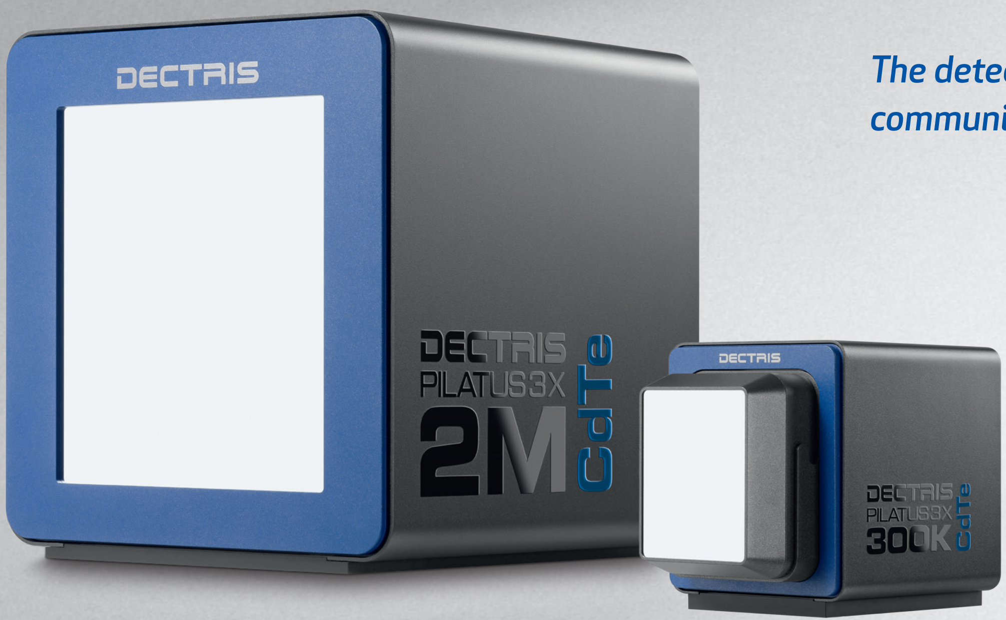
DECTRIS®

detecting the future

PILATUS3 X CdTe



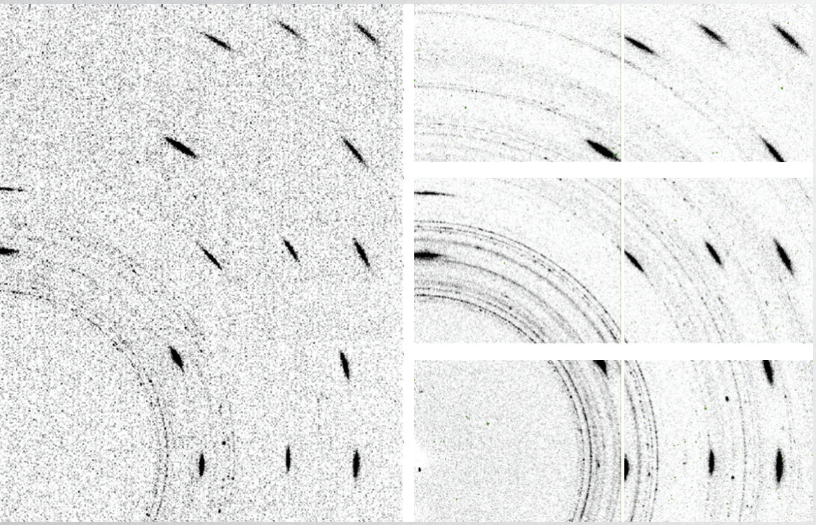
The detectors the hard X-ray community has been waiting for!

synchrotron | *laboratory and industry* | *specific solutions*

The outstanding performance of the PILATUS3 X Hybrid Photon Counting (HPC) detectors has been combined with the excellent high-energy detection capability of cadmium telluride (CdTe) sensor material.

PILATUS3 X CdTe detectors are the first large area, single-photon counting detectors offering highly efficient detection up to 100 keV. They make the unique properties of the PILATUS3 detector technology available for hard X-ray applications without any compromise. DECTRIS instant retrigger technology and thorough product development enable a breakthrough in count rate capability and stability for CdTe, with less than 1% signal variation at 2.5×10^6 photons/s/pixel over a period of several hours. Noise-free single-photon counting in conjunction with a 20-bit counter and direct conversion allows weak signals next to strong peaks to be measured with best possible signal-to-noise ratio. Time-resolved and scanning beam experiments take advantage of frame rates of up to 500 Hz with sub-millisecond readout times, free of any image lag.

With the PILATUS3 X CdTe detector series the hard X-ray community's waiting has an end. Be the first to realize your scientific dreams with this unique detector technology!



Flatpanel **PILATUS3 X CdTe**

Figure 1: Comparison of data quality of flatpanel and PILATUS3 X CdTe detector. The photon-counting CdTe detector shows significantly less noise, resulting in improved visibility of weak diffraction rings. Acknowledgment: These powder diffraction patterns were measured by Marco Di Michiel at the High-Energy Scattering Beamline ID15A of the European Synchrotron Radiation Facility (ESRF) using the same settings (photon energy of 46.3 keV and 0.1 s exposure time) on both detectors.

Key Advantages

- High quantum efficiency, up to 100 keV
- Outstanding count rate stability
- Noise-free single-photon counting
- No image lag or afterglow
- Excellent point-spread function
- Frame rates of up to 500 Hz
- Overflow-free 20-bit counter
- Low-maintenance operation at room temperature
- Easy integration

Applications

X-Ray Diffraction

- High-energy X-ray diffraction
- X-ray diffraction tomography and microscopy
- X-ray powder diffraction and Pair-Distribution Function analysis
- High-pressure/high-temperature XRD
- Inelastic X-ray scattering
- X-ray diffuse scattering
- Time-resolved / *in situ* experiments

Imaging

- X-ray projection imaging (Radiography)
- X-ray computed tomography (CT)
- Small animal/pre-clinical computed tomography
- X-ray phase-contrast imaging
- Non-destructive testing (NDT) and security

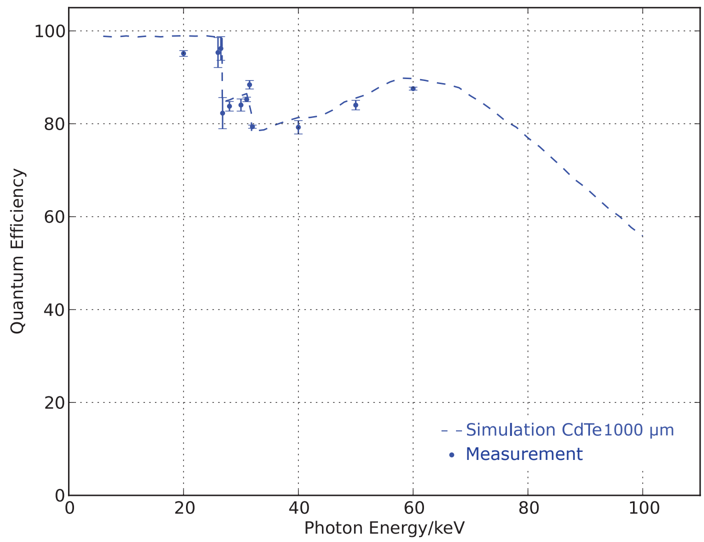


Figure 2: Quantum efficiency of PILATUS3 X CdTe module measured at the BAM beamline at BESSY II. The dip in the QE from above 26 keV is caused by fluorescence losses occurring at photon energies above the Cd and Te K-edges. The QE is measured for an energy threshold set to 50% of the photon energy.

Features

Optimal signal-to-noise ratio

PILATUS3 Hybrid Photon Counting detectors are inherently free of dark current and readout noise. The absence of any detector noise guarantees data with an excellent signal-to-noise ratio (Fig. 1).

CdTe sensors for highest quantum efficiency

Each CdTe detector module comprises two large CdTe crystals (sensors) with dimensions of 42 mm × 34 mm, leaving a horizontal gap of only 3 pixels between the two crystals. The CdTe thickness of 1000 μm provides high quantum efficiency for hard X-ray energies up to 100 keV (Fig. 1 and Tab. 1).

Excellent point-spread function

The point-spread function (PSF) describes the spatial resolution of an imaging detector. Due to the direct conversion of X-rays into charge pulses, PILATUS3 detectors spread virtually no intensity between pixels. Even above the absorption edges of the CdTe sensor, only very little signal is spread by fluorescence to the neighboring pixels. The point-spread function of the PILATUS3 detector is thus essentially given by its pixel size (172 μm) and allows optimally sharp images to be taken. These are free of artifacts typical for other detectors (such as blur, intensity tails, blooming, or streaking). With the sharp point-spread function in combination with the high dynamic range of the detector, closely spaced signals, even of largely differing intensity, can be accurately resolved and measured.

High modularity

The basic element of every PILATUS3 detector is the detector module. Multiple modules can be combined to form large-area detector setups with different geometries. DECTRIS offers four PILATUS3 X CdTe detector systems covering a wide range of active areas and frame rates to perfectly suit your measurement needs. Moreover, DECTRIS possesses the expertise required to develop and manufacture application and customer-specific systems, such as in-vacuum detectors and custom module arrangements.

Short readout times, high frame rates, and still no image lag

PILATUS3 X detectors feature short readout times and high frame rates which substantially reduce measurement time and maximize efficiency and throughput. Unlike scintillator-based CCDs and flatpanels, the direct conversion CdTe detector shows no image lag, which enables maximum scanning speed in your experiment that fully exploit the detector's high frame rate. In conjunction with versatile trigger and gating capabilities, dynamic processes on fast time scales can be investigated *in situ*.

Photon energy	CdTe 1000 μm
20 keV	>90%
40 keV	81%
60 keV	90%
80 keV	77%
100 keV	56%

Table 1: Quantum efficiency of PILATUS3 X CdTe sensors

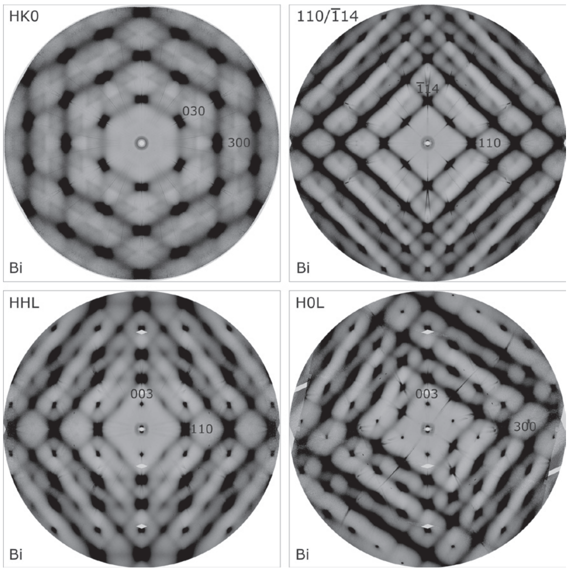


Fig. 3: Reciprocal space map showing X-ray diffuse scattering of a Bismuth sample studied at 69.7 keV. Acknowledgment: Measurement by Alexei Bosak (ESRF) at beamline ID15A using PILATUS3 X CdTe. Recording 10 frames per second, the measurement was completed within only a few minutes. The detector's high dynamic range is essential for measuring the diffuse scattering signal between the strong Bragg peaks.

"The PILATUS3 CdTe detector allows us to measure diffuse scattering data from strongly absorbing samples. These measurements are only possible with a low noise, high dynamic range detector with sufficient efficiency at the required high X-ray energies."

Alexei Bosak, ESRF, Nov. 2014

High dynamic range

A counter depth of 20 bits (~ 1 million counts) in conjunction with the absence of detector noise ensures unprecedented contrast and dynamic range, leading to excellent image and data quality. Extremely strong and weak signals can be accurately detected on a single image (Fig. 3). Especially for high-energy photons, it is an important advantage that each photon only generates a single count independent of the photon energy, as this preserves the detector's high dynamic range at all energies.

Shutterless operation

All PILATUS3 detectors are electronically gated and do not require a mechanical shutter; this is a noticeable simplification of the measurement setup. Combined with the noiseless readout of the PILATUS3 detectors, it enables continuous data acquisition; opening new perspectives in imaging and time resolved experiments.

Electronic gating and external trigger

Exposure times can be varied from a few nanoseconds to several hours and are controlled either internally or by applying an external gate signal. The external trigger input with a programmable delay function makes synchronization between the detector and other hardware extremely easy.

High local and global count rates

The PILATUS3 X CdTe detector is compatible with count rates of more than 5×10^6 counts/s/pixel (Fig. 2), which corresponds to almost 2×10^8 counts/s/mm^2. These high count rates are enabled by the DECTRIS instant retrigger technology featured by all PILATUS3 detectors. Count rate correction is applied to provide accurate intensity measurements over the full range of count rates. Excellent long-term stability guarantees stable operation: less than 1% signal variation (reduction through polarization) is observed at 2.5×10^6 counts/s/pixel over a period of several hours.

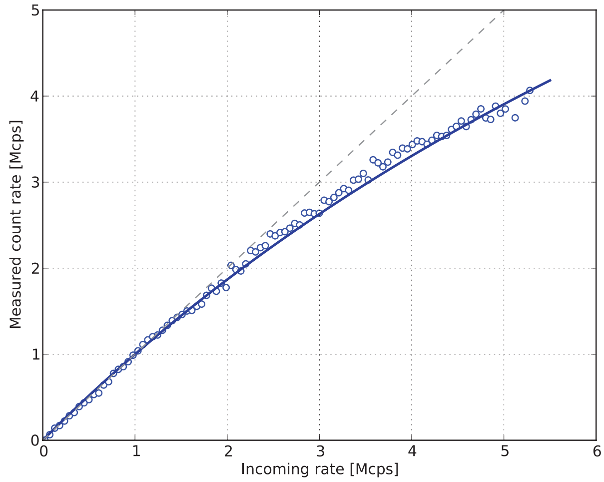


Figure 4: Count rate characteristics of PILATUS3 CdTe detector. The measured data (symbols) was fitted to the theoretical curve (line). Data acquired at 60 keV X-ray energy, 30 keV threshold.

Fluorescence suppression

PILATUS3 detectors provide an adjustable lower energy threshold to suppress fluorescence. Combining the high dynamic range with the excellent point-spread function, fast readout and fluorescence suppression enables the pursuit of exciting new applications, e.g. in diffuse scattering (Fig. 3).

Radiation tolerance

The PILATUS3 CMOS readout chips are designed using radiation-tolerant layout techniques developed for high-energy physics to prevent damage from incoming X-rays. The detectors are able to withstand the doses arising from long-term operation at modern synchrotrons.

Ease of operation

All PILATUS3 detector systems can be operated at room temperature and only require dry air or N_2 for operation. They are easy to set up and demand no regular maintenance or service. The CdTe detector software is identical to that of their well-established silicon-based detector complements; guaranteeing simple and fast integration.

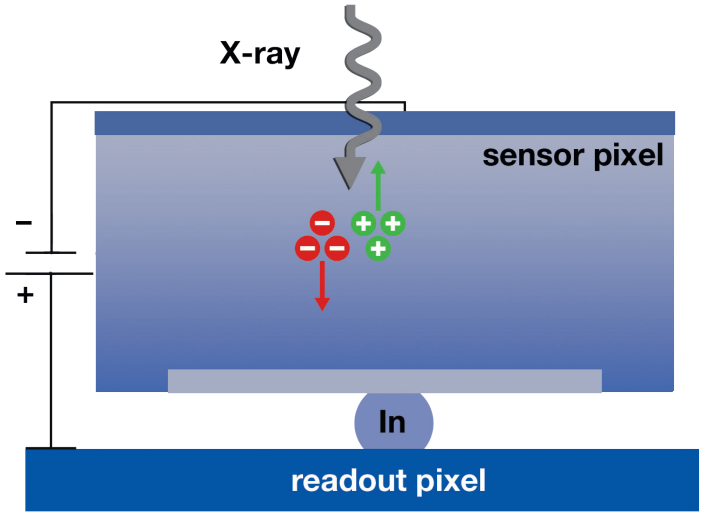


Figure 5: Principle of direct detection of X-ray photons in a solid-state sensor. CdTe sensors are operated in electron collection mode.

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. Fiberglass optics transport the light onto the chip, which causes further loss and distortion of the signal. Hybrid pixel detectors overcome these instinsic design limitations for light-based 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. 5). X-ray photons are directly converted into an electric charge in the sensor pixel.

The readout pixel processes and counts this electric signal. Sensor and readout pixel have a direct, electronic connection through an individual metal bump for every hybrid pixe,l which 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.

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 of 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 X-ray absorption, the released 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, single-photon counting detectors are entirely free of readout noise.

PILATUS3 X CdTe detector series technical specifications

PILATUS3 X CdTe	300K	300K-W	1M	2M
Number of detector modules	1 × 3	3 × 1	2 × 5	3 × 8
Sensitive area: width × height [mm²]	83.8 × 106.5	253.7 × 33.5	168.7 × 179.4	253.7 × 288.8
Pixel size [μm²]	172 × 172			
Total number of pixels (horiz. × vert.)	487 × 619	1475 × 195	981 × 1043	1475 × 1679
Maximum count rate	5 x 10^6 counts/s/pixel (1.7 x 10^8 counts/s/mm²)			
Gap between modules (horiz. / vert.) [pixel], *plus 3 pixel horizontal gap on each module	–* / 17	7* / –	7* / 17	7* / 17
Inactive area [%]	6.1	1.6	7.8	8.5
Defective pixels	< 0.1%			
Maximum frame rate [Hz]	500	500	500	250
Readout time [ms]	0.95			
Point-spread function	1 pixel (FWHM)			
Threshold energy [keV]	8 - 40			
Counter depth	20 bits (1,048,576 counts)			
Power consumption [W]	30	30	165	250
Dimensions (WHD) [mm³]	158 × 193 × 262	280 × 62 × 296	265 × 286 × 455	384 × 424 × 456
Weight [kg]	7.5	7.0	25	46
Module cooling	Water cooled			
Electronics cooling	Water cooled		Air cooled	
External trigger/gating	5V TTL			

All specifications are subject to change without notice

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