CRYSTALLOGRAPHY

PHOTON IV

Next Generation X-ray Detection

Innovation with Integrity


PHOTON

Leading X-ray Detector Innovation

For many years, Bruker has been at the forefront of X-ray detector technology, consistently delivering precision, reliability, and cutting-edge features. Our detectors are renowned for their performance and versatility for single-crystal X-ray diffraction and beyond. The PHOTON IV is the latest testament to that tradition of innovation, offering unparalleled performance and setting a new standard in X-ray detection.

Bruker continues to drive detector innovation by bringing cutting-edge charge-integrating detection technology, originally developed to overcome the limitations of conventional Hybrid Photon Counting (HPC) detectors at synchrotron and XFEL sources, into the home laboratory.

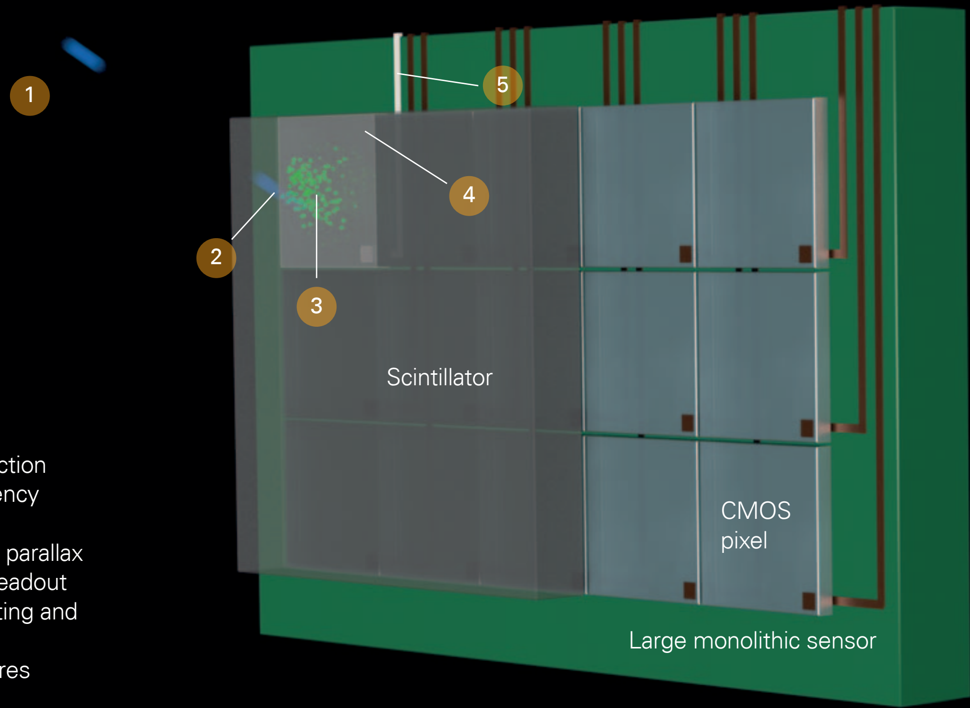
The PHOTON IV is an advanced Charge-Integrating Pixel Array Detector (CPAD). Thanks to the unique combination of indirect detection and advanced photodiode arrays—the PHOTON IV can perfectly handle any X-ray wavelength, from low-energy Cu to high-energy Ag radiation. It does not suffer from parallax, pulse pile-up or charge sharing common in HPCs.

For highest resolution and best data quality, our PHOTON IV detector combines a small pixel size with a large active area, massively parallelized readout for instantaneous counting and high dynamic range, and high quantum efficiency due to the CPAD technology with wafer-thin scintillator.

The fully sealed and air-cooled design means our latest generation of detectors is maintenance-free, offers high uptime, and low energy consumption, and comes with a 3-year warranty.

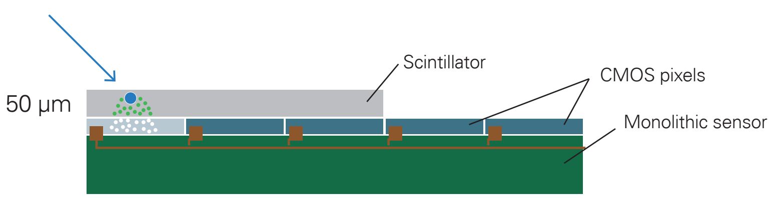
Bruker's PHOTON IV brings cutting-edge technology to your laboratory and ensures that every photon counts.

Watch the
animation



PHOTON IV CPAD

- Advanced indirect detection for high quantum efficiency
- Zero detector noise
- Small pixel size with no parallax
- Massively parallelized readout for instantaneous counting and high dynamic range
- Off-pixel counting ensures no information loss
- Interpixel Logic counts every photon



CPAD side view

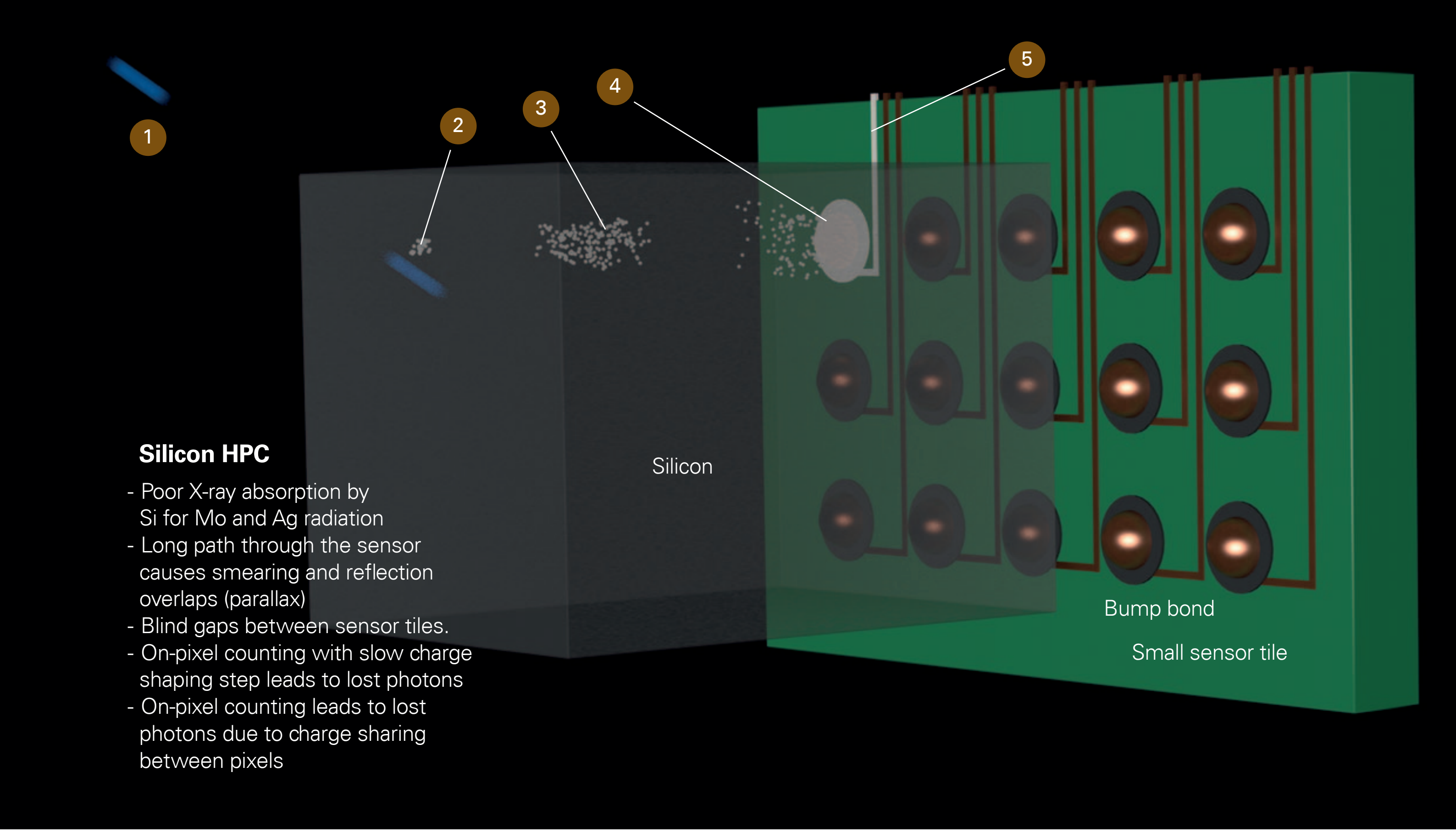
1. Incoming X-ray photon
2. Incident photon absorbed with high efficiency by ultra-thin rare-earth scintillator
3. Pulse of light photons transfer signal directly to a single pixel
4. Each pixel individually reads out the full electronic charge instantaneously.
5. Massively parallel readout to processor for real-time photon counting and high dynamic range

PHOTON IV—Indirect Photon Counting Detectors

Choosing the right detector for your diffraction experiments is one of the most important decisions you will make. For Single-Crystal X-ray Diffraction, the ideal detector will precisely locate the position of every diffracted photon in space and in time. To achieve the most accurate photon counting the PHOTON IV is designed as an indirect, charge-integrating pixel array detector.

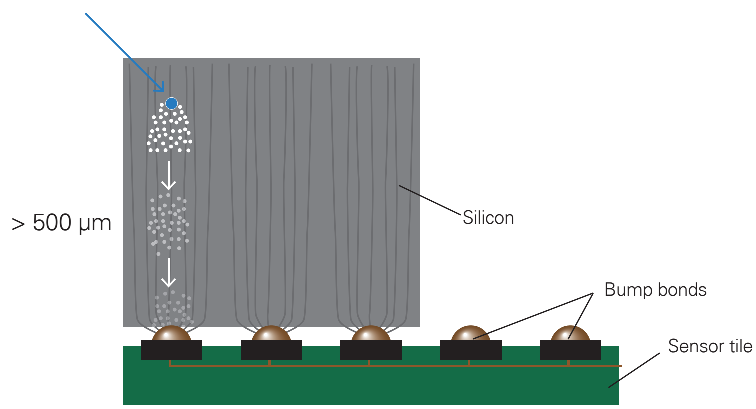
The benefits of advanced indirect detection for photon counting

The PHOTON IV detectors use a very thin advanced scintillation wafer with high X-ray absorption efficiency across a wide energy range. The tight emission bandwidth of the scintillator retains the quantum relationship between incident X-ray photons and electronic charge in the sensor and permitting accurate photon counting.



Silicon HPC

- Poor X-ray absorption by Si for Mo and Ag radiation
- Long path through the sensor causes smearing and reflection overlaps (parallax)
- Blind gaps between sensor tiles.
- On-pixel counting with slow charge shaping step leads to lost photons
- On-pixel counting leads to lost photons due to charge sharing between pixels



HPC side view

1. Incoming X-ray photon
2. Low absorption efficiency by thick Si layer
3. Electronic charge drawn toward bump bond by applied voltage
4. Pulses of electronic charge must be shaped before comparing to digital threshold on pixel
5. Any partial X-ray signal below threshold is discarded and the information lost at the pixel

Limitations of Silicon HPCs

Direct detection in Si HPCs has limitations due to the thickness of the silicon wafer. Because silicon absorbs Mo and Ag X-rays poorly, the silicon wafer must be significantly thicker to compensate—approximately ten times thicker than the rare earth wafers used in indirect the PHOTON IV. This leads to parallax, making it impossible to locate the X-ray photon's exact position and to blurred and distorted reflection signals.

HPCs lose more X-ray photons in dead areas between sensors tiles, slow on-pixel charge shaping, and charge sharing between pixels.

These widely acknowledged limitations that have motivated leading detector groups worldwide to develop next generation detectors based on CPAD-technology.

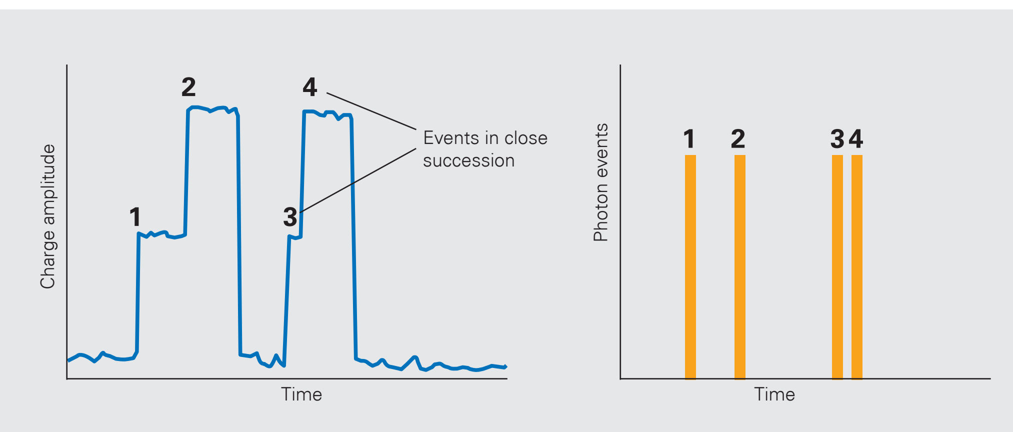
Charge Integrating Pixel Array Detectors — All Photons Counted

PHOTON IV uses large monolithic, fourth-generation CMOS active pixel sensor technology, offering smaller pixel sizes and enhanced on-pixel functions. It features massively parallel, high-speed readout for real-time off-pixel data processing, high linear count rates, greater full-well capacity, and superior dynamic range.

Off-pixel photon counting in software exploits sophisticated image processing to overcome the two intrinsic effects that may lead to photons going undetected in HPCs, namely pulse pileup and charge sharing.

The PHOTON IV delivers the most accurate data with zero noise accumulation to ensure you get the best results from the most challenging experiments.

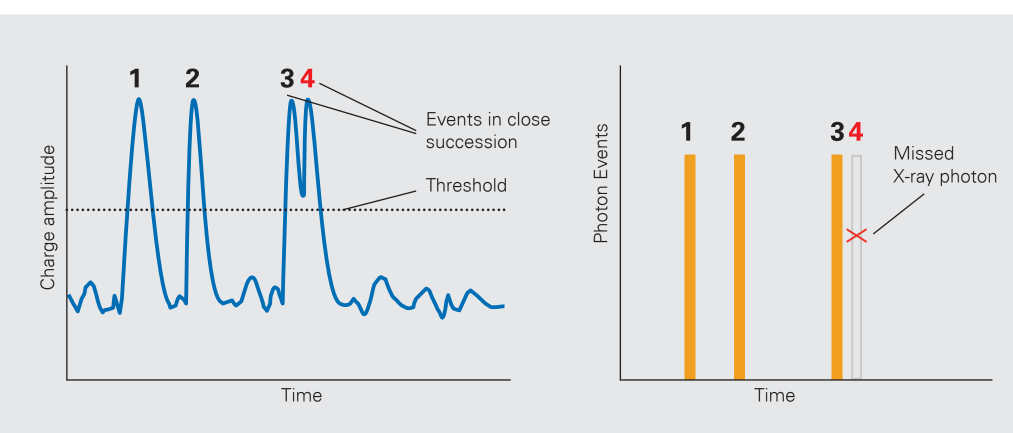
PHOTON IV CPAD → **Result: All photons detected**



CPAD photon counting

The full electronic charge is readout from the pixel at high frequency and counting is carried out in real-time. Summing large numbers of high-frequency sub-frames eliminates random noise (e.g. readout) and achieves single-photon detection. Because the full charge is used for counting, coincident photons arriving close together in time can be accurately accounted resulting in excellent count rate linearity.

Silicon HPC → **Result: Photon missed**



Pulse pileup in HPCs

In HPCs, the charge shaping process limits both count rate and dynamic range to 16 bits, rather than counter depth. When two photons arrive in quick succession, pulse pileup can cause a non-linear response and missed detections.

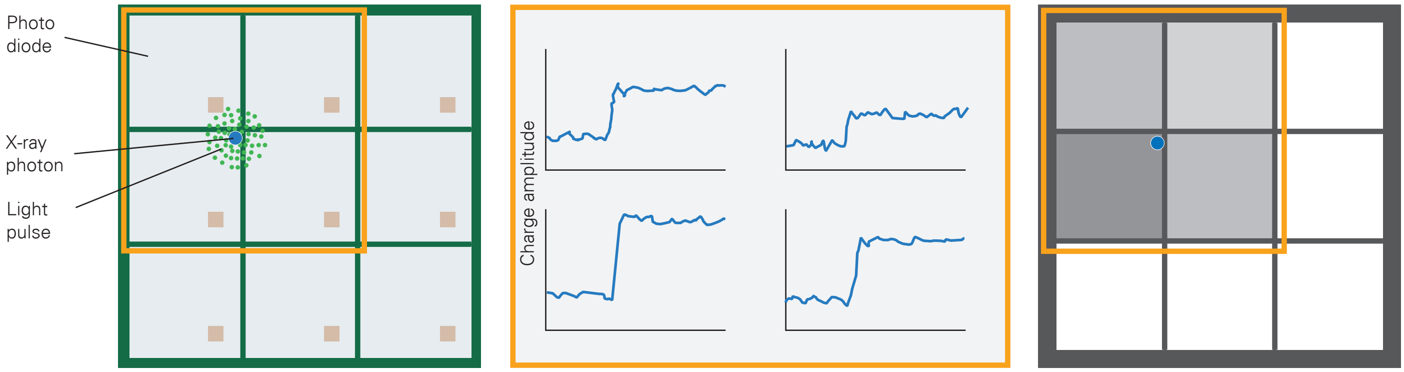
PHOTON IV CPAD

Result: Photon recorded

Detector

Signal

Readout



Charge cloud from a single photon shared between adjacent pixels, CPAD top view

Fractional charge from each pixel is readout and compared with adjacent pixels

Interpixel logic accurately recombines the charge from the four pixels to count the photon

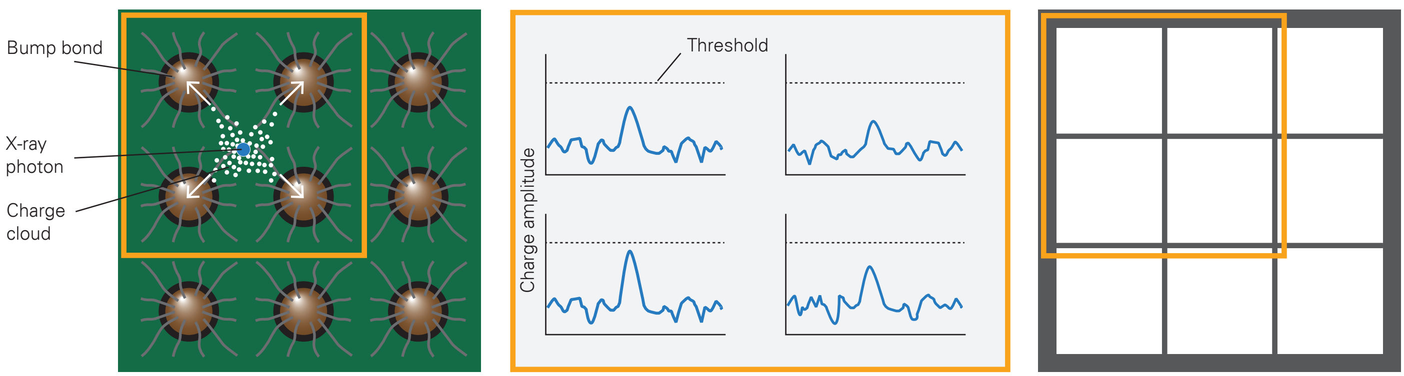
Silicon HPC

Result: Photon missed

Detector

Signal

Readout



Charge cloud from a single photon shared between adjacent pixels, HPC top view

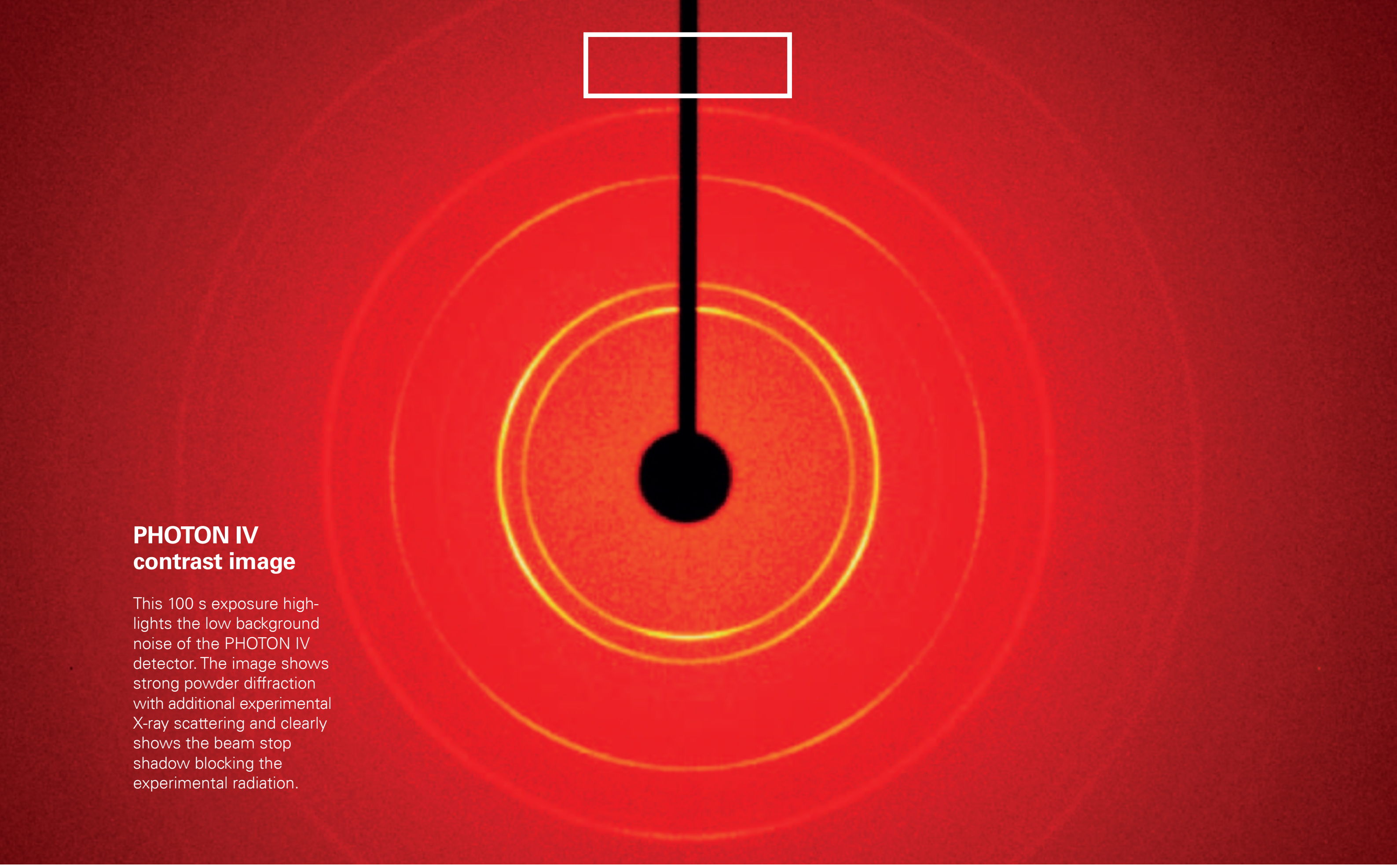
The charge in none of the pixels exceeds the threshold

The photon event is not recorded

Interpixel Logic Avoids Photon-Loss at Pixel Boundaries

Regardless of whether direct or indirect detection is employed, a photon absorbed at a pixel boundary generates electronic charge that is shared between adjacent pixels. CPAD detectors process the entire charge from each pixel in software real-time, enabling the detection of fractions of photons (off-pixel processing). Interpixel Logic combines the fractional charge from adjacent pixels to the original, true photon count.

In contrast, HPCs digitize signals on the pixel using a threshold. Therefore, charge shared between adjacent pixels is permanently lost, leading to photon count losses and compromising data accuracy.



PHOTON IV contrast image

This 100 s exposure highlights the low background noise of the PHOTON IV detector. The image shows strong powder diffraction with additional experimental X-ray scattering and clearly shows the beam stop shadow blocking the experimental radiation.

Eliminating Noise

The PHOTON IV's fourth-generation CMOS sensors exhibit extremely low intrinsic noise, enabling single photon counting capabilities. High frequency pixel sampling combined with sophisticated digitization, provides the PHOTON IV detector with both single photon sensitivity and a high dynamic range.

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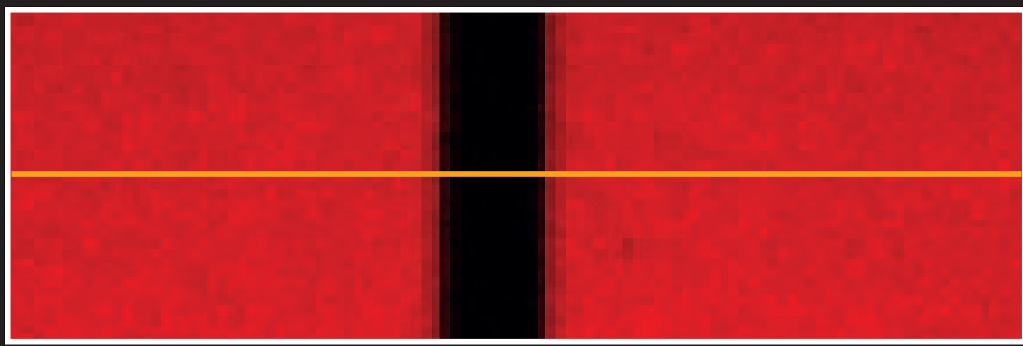
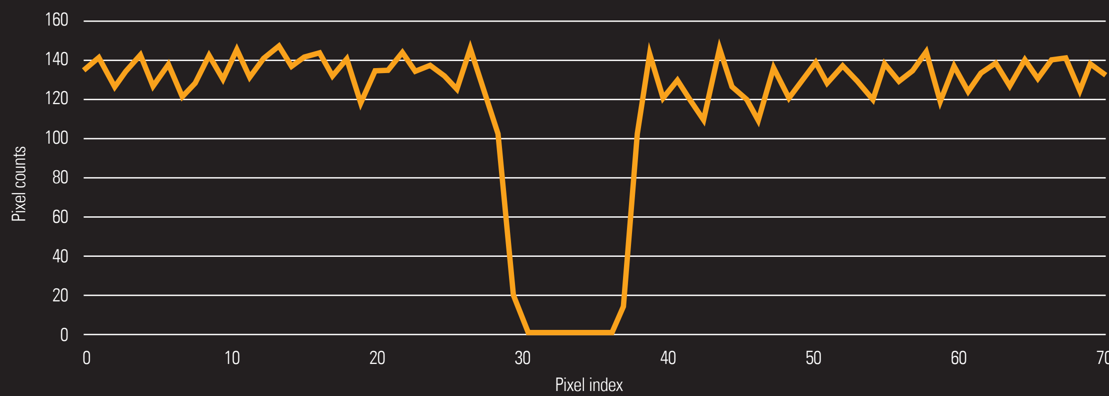
Noise free data is essential for

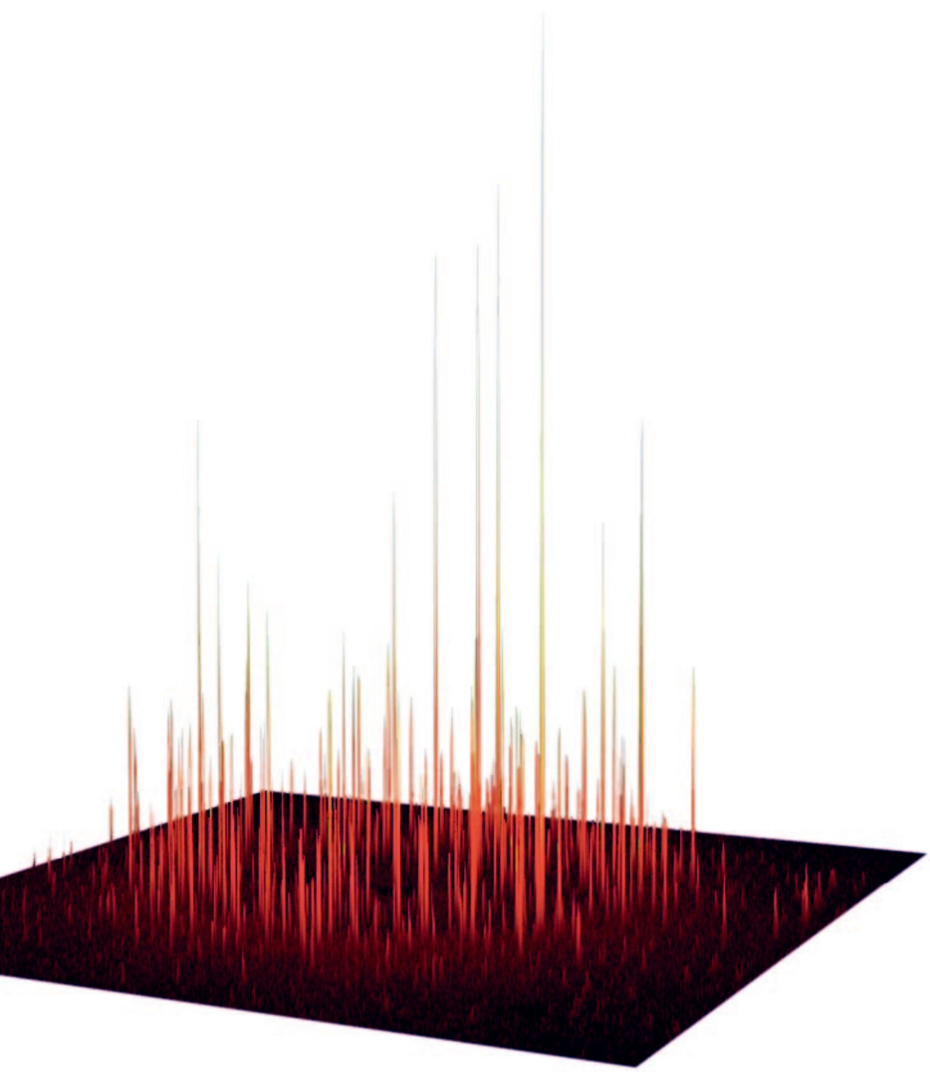
- Accurately recording the weakest intensities from tiny, poorly diffracting crystals
- Reducing measurement times by enabling shorter exposures
- Achieving high dynamic range
- Enabling long exposures for the measurement of powder diffraction or total scattering

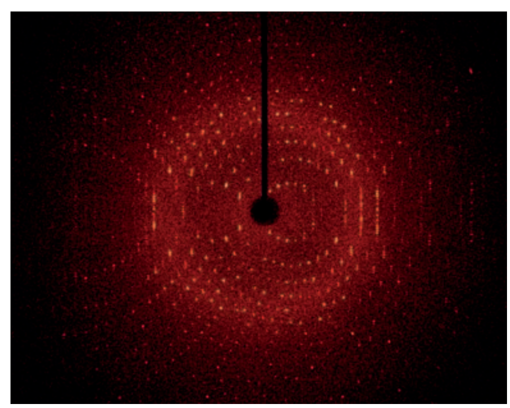




Low noise floor

The pixels shielded by the beamstop show zero counts and illustrate the low noise floor of the PHOTON IV. This contrasts with the pixels adjacent to the beamstop record around 140 counts arising from the diffuse experimental scatter.





Sensitivity and dynamic range

The maximum count rate and dynamic range in CPADs are defined by the image bit depth and the readout rate. The PHOTON IV combines 32 bit image depth with significantly increased frame rates to achieve count rates more than three times higher than previous generations.

This expanded dynamic range allows for the simultaneous measurement of strong and weak reflections in the same image, eliminating the need for repetitive measurements, and significantly increases data collection efficiency.

Cu Kα 1.54 Å

Ga Kα 1.30 Å

Mo Kα 0.71 Å

Ag Kα 0.56 Å

Choose your source

DQE of different detectors can vary significantly depending on your source wavelength. Ensure the detector is well matched to the wavelength of your experiment.

The Importance of Detector Quantum Efficiency

Detector Quantum Efficiency (DQE) measures a detector's ability to convert incoming X-ray photons into a useful signal, and is directly related to a detector's X-ray absorption efficiency. DQE directly affects image clarity, noise levels, and data quality in crystallography. High DQE is crucial for collecting accurate data, particularly from weak signals or small samples, as it allows for shorter measurement times, improved signal-to-noise ratios (SNR), and sharper diffraction spots. This results in higher resolution and more reliable electron density maps.

PHOTON IV leverages advanced indirect detection technology to achieve superior DQE across all X-ray wavelengths, ensuring precise data acquisition regardless of the experimental setup. By maximizing useful signal capture and minimizing noise, it enables accurate, efficient measurements even for challenging crystal structures.

PHOTON IV uniquely exploits advanced indirect detection to achieve the highest DQE for all home X-ray source wavelengths.

Shorter measurement times

A detector with high DQE can capture more useful signal from fewer X-ray photons. This means you can achieve the desired SNR faster, reducing the time needed to collect a complete dataset.

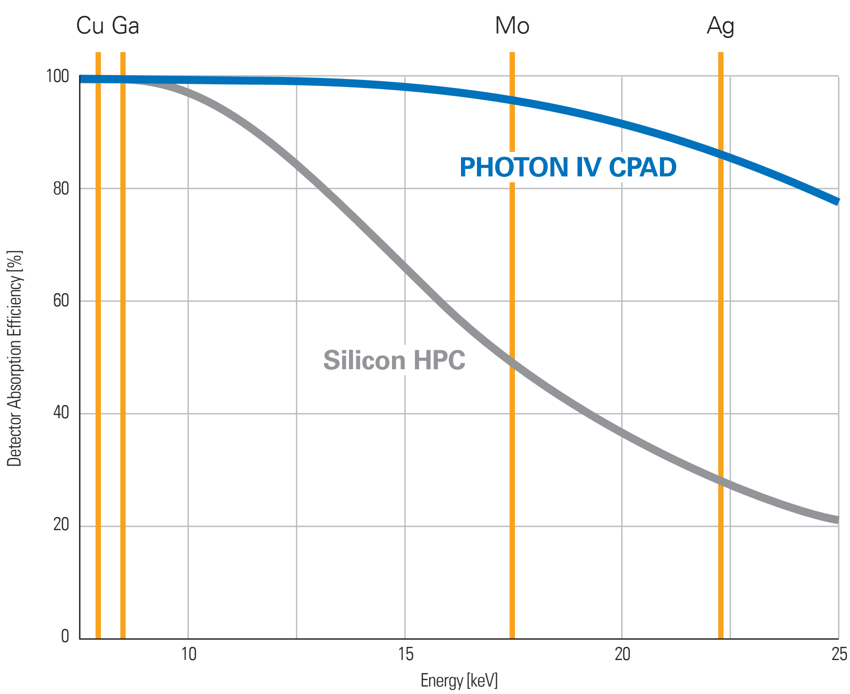
Improved signal-to-noise ratio

High DQE ensures that the signal is accurately preserved, leading to sharper diffraction spots and more accurate intensity measurements.

Better resolution and refinement

With cleaner data, the resulting electron density maps are more precise, improving the resolution of the crystal structure and the reliability of atomic positions.

Comparison of Detector Absorption Efficiency

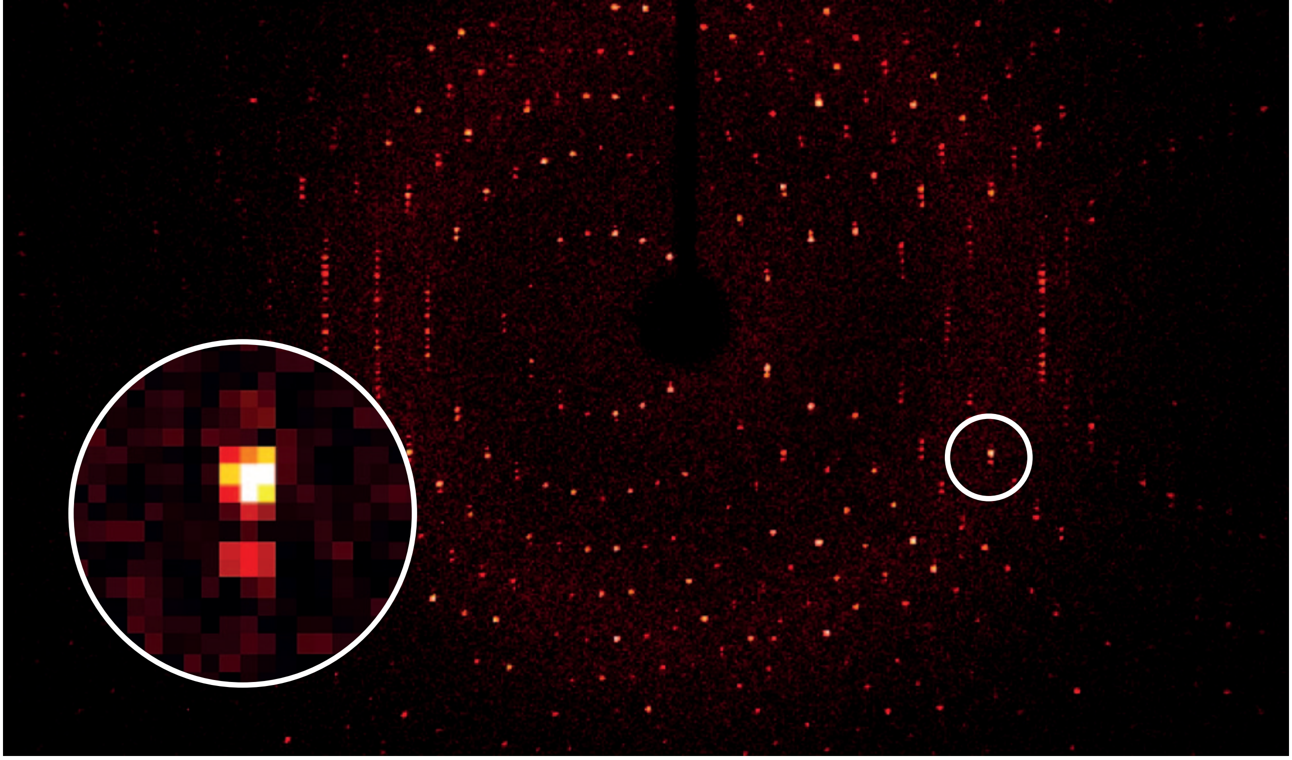


Dual wavelength sources

Matching the source wavelength to your sample and experiment is essential to get the best results. The PHOTON IV provides superior data for all wave-lengths.

PHOTON IV

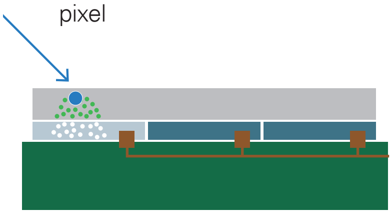
High quantum efficiency for all source wavelengths coupled with large active area ensure even weak data is recorded accurately and efficiently.



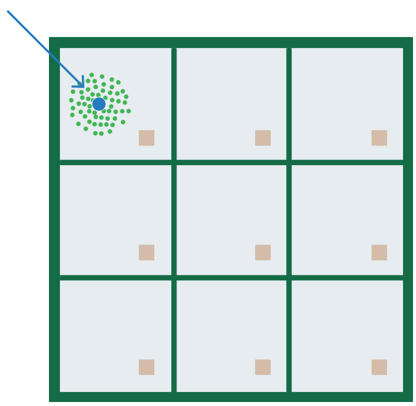
PHOTON IV CPAD

Detector

Incoming photons are absorbed with a point spread of less than one pixel



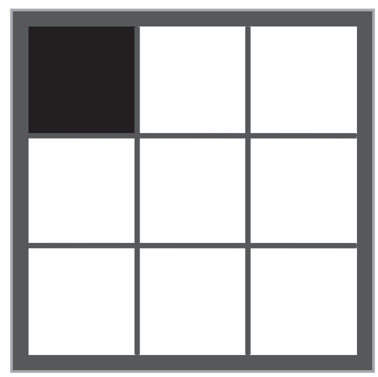
A sequence of photons are absorbed instantaneously and captured in a single pixel, CPAD side view



Individual photon signal is readout from a single pixel, CPAD top view

No parallax effect

Image



Reflection is recorded in a single pixel

Indirect detection

A dedicated rare earth scintillator absorbs each photon instantly and transfers the signal within a single pixel

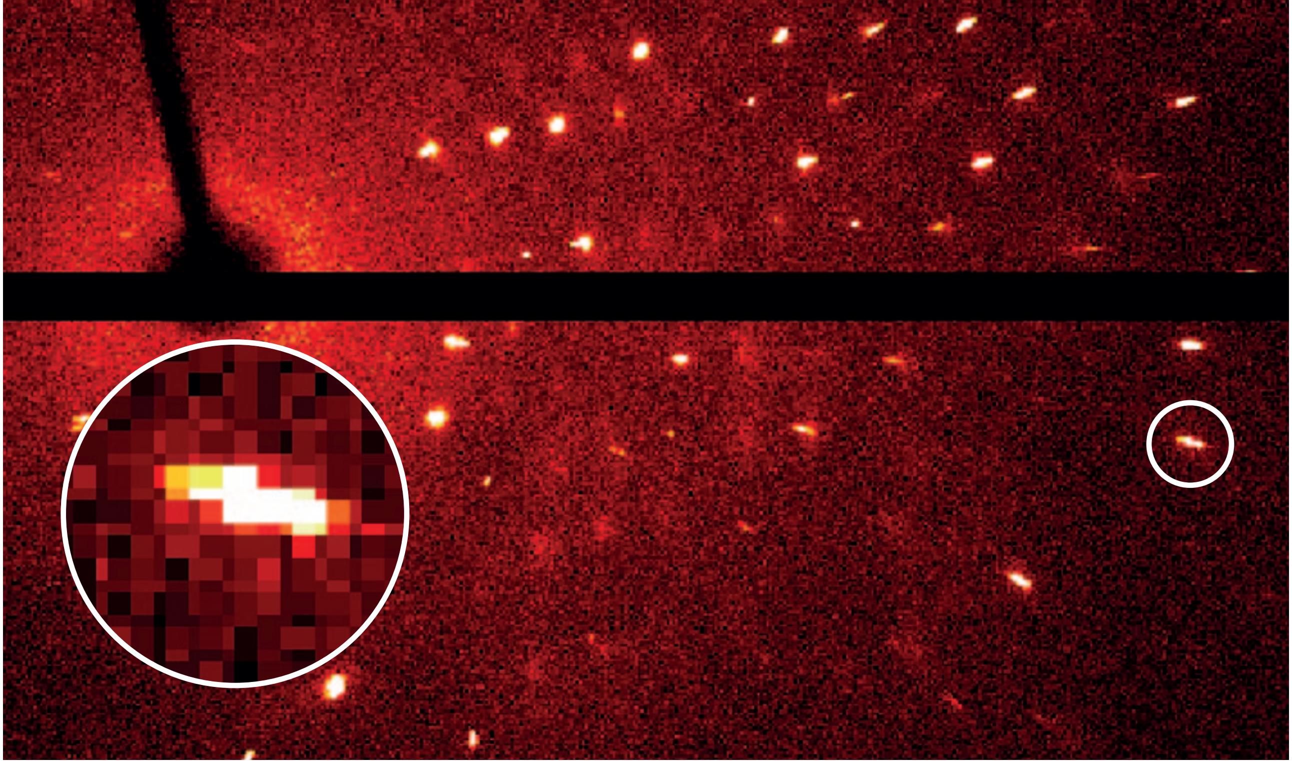
Superior Point Spread with Advanced Indirect Detection

Advanced indirect detection guarantees even high energy photons to be absorbed within a short distance. This results in a point spread remaining less than one pixel, even when the detector operates at short sample distances and reflections hit the detector surface at high incidence angle.

This ensures that the signal from each individual photon is recorded in a single pixel. Reflections retain a sharp, undistorted profile to reduce overlaps and give better signal-to noise.

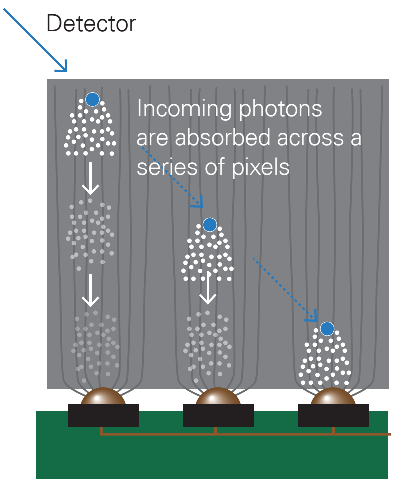
‘No parallax’ is one of the secrets which allows the use of the flat large, active-area PHOTON IV detector at short detector distances with unbeatable data collection efficiency.

PHOTON IV measures the most accurate reflection profiles whatever your experimental demands.

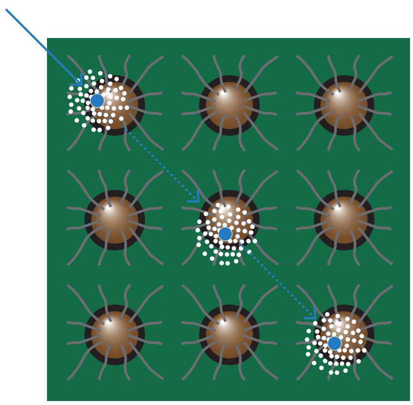


Silicon HPC

Detector



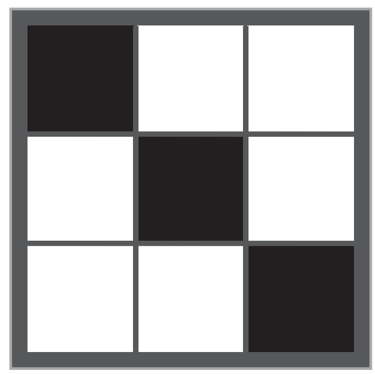
A sequence of photons are absorbed though the depth of the Si, HPC side view



Photon events are recorded across a sequence of pixels, HPC top view

Parallax effect

Image



Reflection is smeared across multiple pixels

Reflection Distortion in Si HPCs

Silicon is known as an inefficient absorber for the X-ray photons produced by home-source systems. For adequate detective quantum efficiency, Si absorbers need to be very thick, often reaching ten times the pixel pitch.

As a consequence, a stream of photons arriving at the same point are absorbed throughout the full depth of the absorber causing the signal to spread across multiple pixels. This distortion of the reflections is known as parallax.

Reflections appear streaked and often overlap. When the signal is distributed across multiple pixels, the signal-to-noise is reduced, compromising data quality. Parallax becomes most serious when the detector is positioned close to the crystal or when using Mo or Ag radiation.

Parallax in Si-HPCs

X-ray absorption efficiency is low in Si sensors leading to streaking of the reflections across multiple pixels.

This leads more frequently to overlapping reflections and indexing becomes problematic.

The PHOTON IV 8 and PHOTON IV 16 X-ray detectors

PHOTON IV — The Ultimate in Versatility

The PHOTON IV detector is available in a variety of active areas to meet your experimental needs. With its advanced indirect detection technology and sharp point spread, the PHOTON IV leverages flat, large-area sensors to provide exceptional data collection efficiency from crystals with a wide range of characteristics across any wavelength—without compromise.

Additionally, the PHOTON IV enables you to collect outstanding data from powders or total scattering experiments that require long sample-to-detector distances and extended exposure times.

PHOTON IV 8

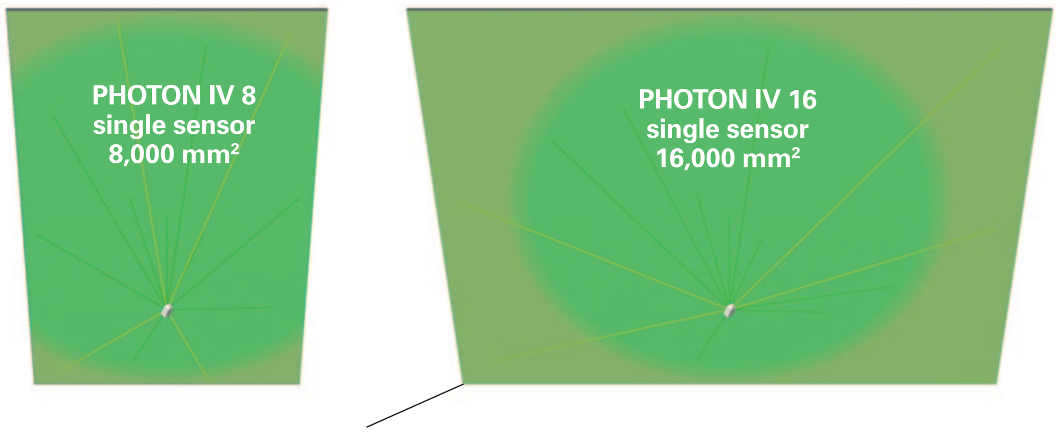
The PHOTON IV 8 is the perfect detector for small molecule crystallography. Its orientation maximizes 2-theta coverage in the vertical plane, enabling quick and easy collection of complete reciprocal space at atomic resolution and beyond.

PHOTON IV 16

The PHOTON IV 16 is the largest detector available for crystallography in home laboratories. It collects atomic resolution data at a single position, offering exceptional speed and simplicity. This detector provides outstanding versatility for efficient data collection and superior angular resolution, making it ideal for large unit cell axes, twin structures, modulated structures, and powder diffraction experiments.

PHOTON IV: single sensor, flat large area detectors

Harnessing a single monolithic, large, uniform sensor area free from gaps or inactive regions with superior quantum efficiency, the PHOTON IV provides exceptional collection efficiency and versatility, distinguishing indirect detection from other available technologies.



Scintillator thickness 50 µm
Parallax error < 1 pixel

0 < 1
Degree of parallax error

Overcoming the Parallax Effect is a Matter of Layer Thickness, not Sensor Arrangement

Silicon HPC: flat 2-sensor array

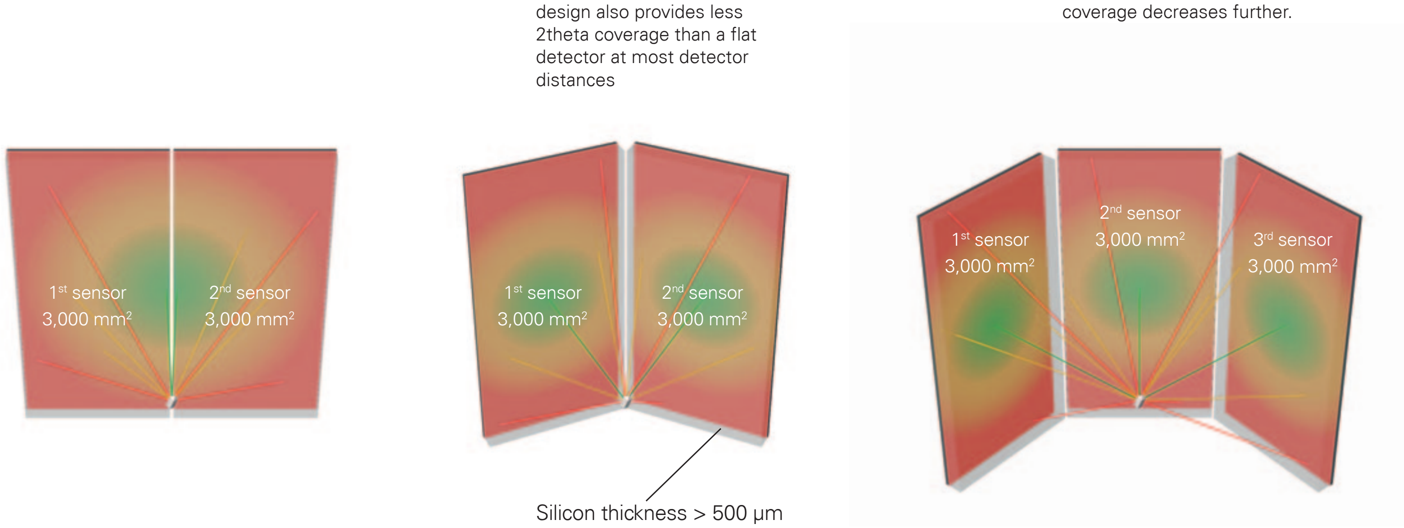
Even the smallest HPC detectors use two sensor tiles, creating blind gaps or dead zones between individual modules. For complete data sets data collection must be conducted close to the crystal at multiple detector positions. This setup is prone to overlapping reflections due to detector parallax.

Silicon HPC: folded 2-sensor array

To reduce detector parallax, some designs arrange flat sensor tiles around the sample, creating folded detectors (sometimes misunderstand as curved detectors). Folding can at one fixed distance moderate horizontal parallax; vertical parallax, however, remains unaffected. This design also provides less 2theta coverage than a flat detector at most detector distances

Silicon HPC: folded 3-sensor array

Three sensors placed at a fixed distance around the sample help restore some horizontal theta coverage previously lost. However, when the detector is positioned farther from the sample (such as for large protein unit cells or short modulation vectors), parallax increases, while theta coverage decreases further.



Silicon thickness > 500 µm
Parallax error ≤ 8 pixels

0 ≤ 8
Degree of parallax error

Features and Benefits

	PHOTON IV 8	PHOTON IV 16	
Detection Mode	Indirect, 4th generation CMOS APS detector, photon counting		High dynamic range and quantum efficiency for all wavelengths
Active area [mm²]	111 x 72, ~8,000	111 x 145, ~16,000	Large active area, monolithic sensor, no gaps or dead areas, efficiently covers reciprocal space for higher multiplicity data
Sensor format [pixels]	1,110 x 720	1,110 x 1,450	
Pixel size [µm]	100 x 100	100 x 100	Superior spatial resolution for efficient data collection at short crystal-detector distances. Excellent angular resolution for total scattering and powder diffraction experiments.
Point spread [pixels]	< 1	< 1	
Parallax error [pixels]	< 1	< 1	No reflection distortion or smearing at short crystal-detector distances. Improved handling of large unit cells, twinning, and modulation.
Energy range [keV]	5 – 30	5 – 30	High detective quantum efficiency with all home sources. Shorter measurement times, high quality data from weak samples
Detector absorption efficiency	100% at 8.1 KeV Cu 100% at 9.2 KeV Ga 96% at 17.5 KeV Mo 87% at 22.2 KeV Ag		
Image bit depth	32 bit	32 bit	High dynamic range to measure strong and weak reflections on the same frame
Maximum frame rate [Hz]	112	112	
Maximum count rate [cps/pixel]	> 1 x 10^6	> 1 x 10^6	
Readout time [ms]	0	0	Massively parallelized readout with real-time processing for high dynamic range
Percentage of active area with charge sharing losses [%]	0	0	More accurate integrated intensities as no photons are lost due to charge sharing or pulse pileup
Count-rate nonlinearity, before correction [%]	better than 1	better than 1	
Weight [kg]	5.0	7.5	Low weight detector maintains best sphere of confusion
Cooling	Air-cooled	Air-cooled	Highest reliability, no chiller maintenance
Dry air consumption [$Lmin^{-1}$]	0	0	Hermetically sealed for maximum reliability and uptime. No air purge needed

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