DECTRIS®

detecting the future

The New PILATUS3 ASIC with Instant Retrigger Technology

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PIXEL 2012, September 3-7, Inawashiro, Japan

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DECTRIS
Lunchtime Seminar at SRI 2012

Lyon Convention Center, Room Rhône 3
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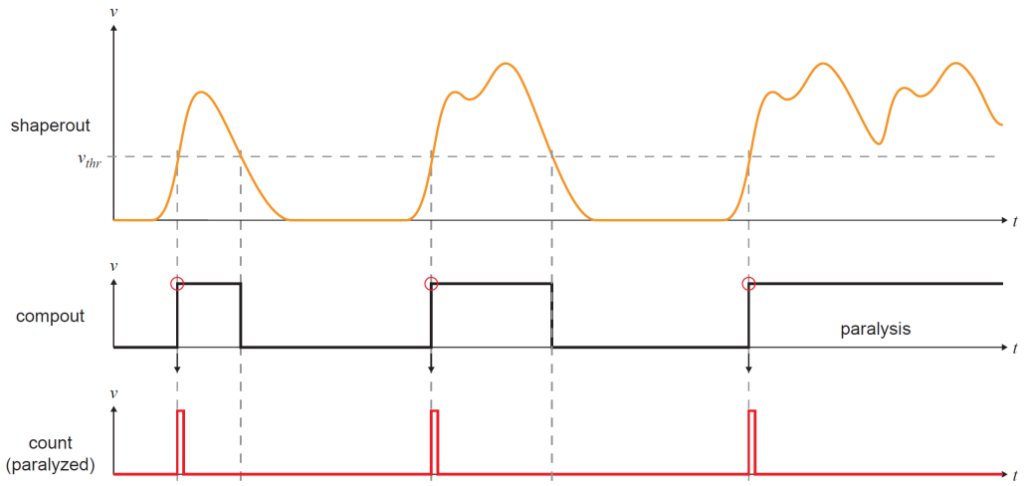
SRI2012

Come and see our latest developments in Hybrid Pixel Technology!

Outline

1. Motivation
2. DECTRIS instant retrigger technology
3. PILATUS3 ASIC
4. PILATUS3 X-ray detector series
5. Count-rate considerations
6. Conclusions

PILATUS X-Ray Detectors: Conventional Single-Photon Counting



Signal waveforms illustrating paralyzable counting.

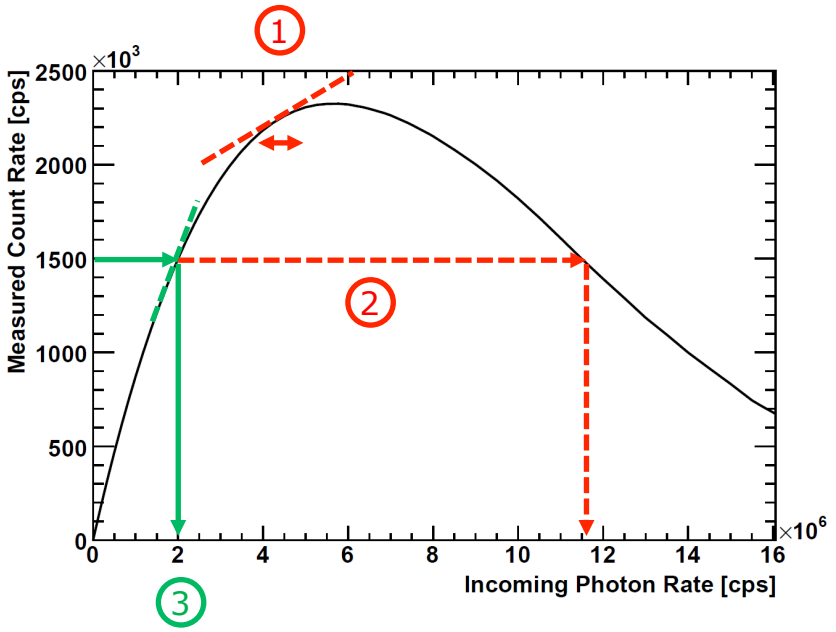
- ***counting of single-photon pulses***
- ***pile-up of simultaneously generated pulses***
- ***counting loss due to pulse pile-up***
- ***paralyzable counting at high photon fluxes***

PILATUS X-Ray Detectors: Count Rate Correction Limitations

- ***count rate correction in order to compensate for the counting loss at high count rates***

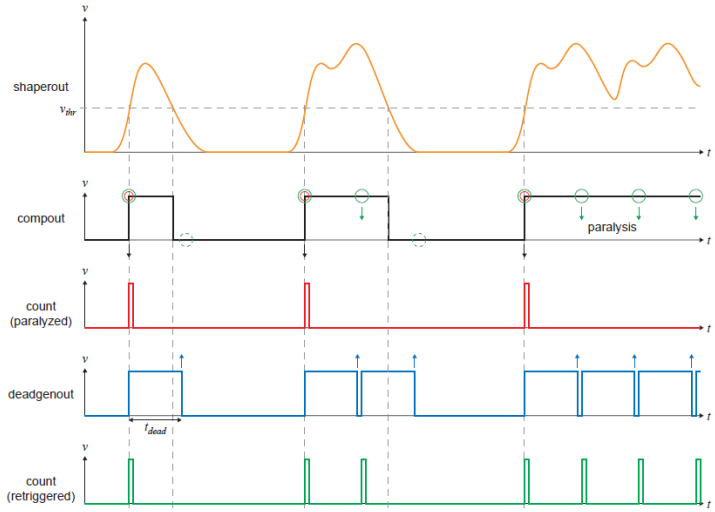
- ***correction limitations:***
  - sensitivity (slope) ①
  - ambiguity ②
  - maximum usable rate typically 2 x 10^6 photons per second and pixel (PILATUS2) ③

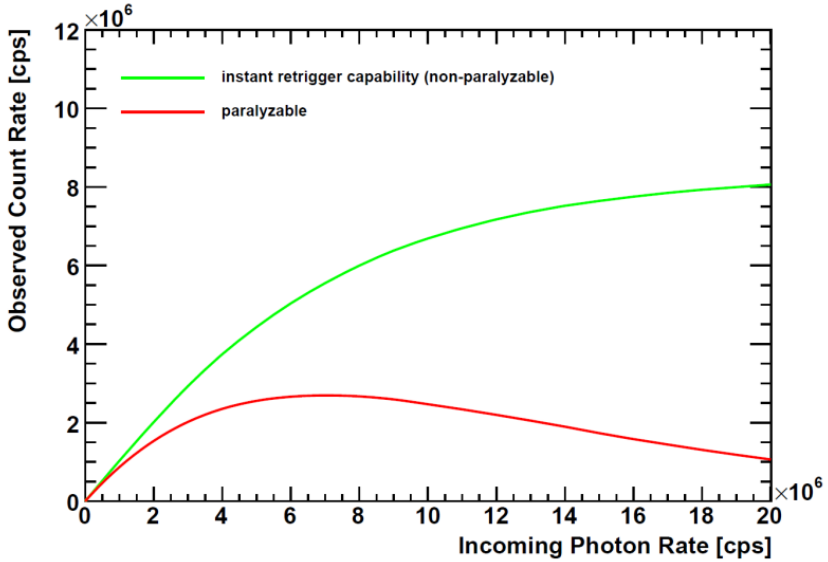
- ***solution:***
  - instant retrigger technology (patent pending)



Typical count rate characteristics (measured count rate versus incoming photon rate) of PILATUS2 X-ray detectors. (Synchrotron source, bunch interval 180 ns, photon energy 16 keV, mid gain, threshold energy 8 keV)

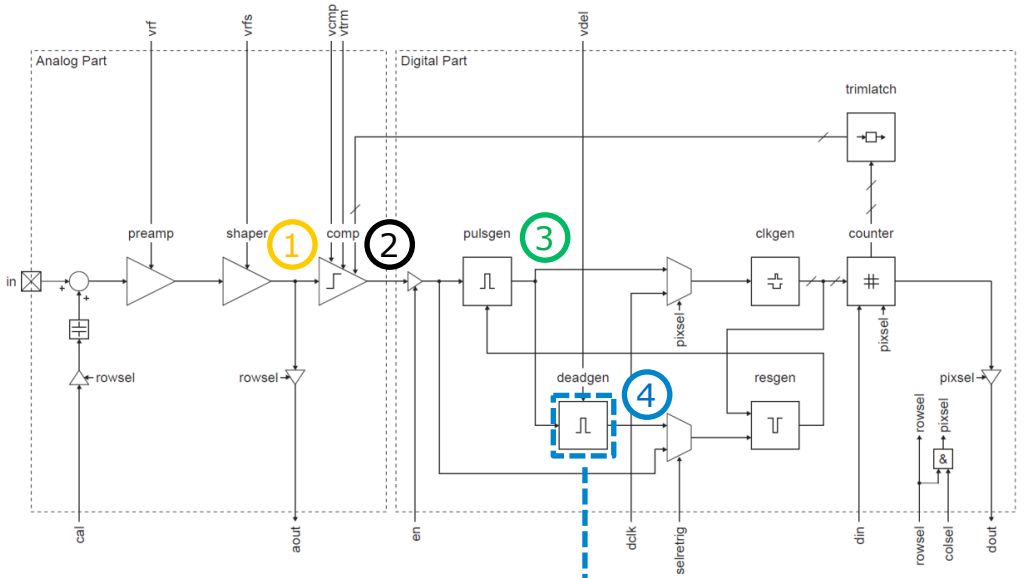
Instant Retrigger Technology: Principle



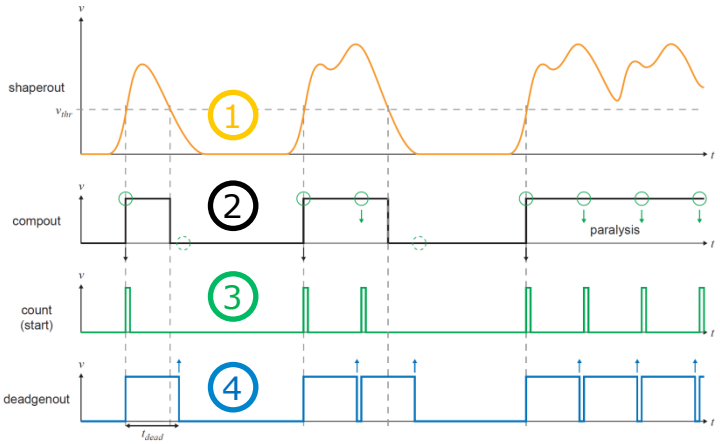


- *pulse signal re-evaluation after a predetermined dead time interval after each count and potential retriggering of the counting circuit in case of pulse pile-up*
- *adjustable dead time accounts for the width of a single photon pulse*
  - *non-paralyzable counting*
  - *improved high-rate counting performance*
  - *enhanced count rate correction*

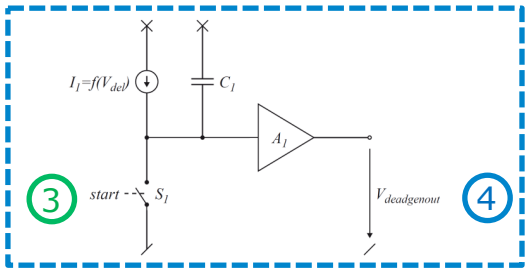
Improved Readout ASIC: Design



Block diagram of the pixel.



Signal waveforms illustrating instant retrigger technology.



Simplified schematic of the dead time generator.

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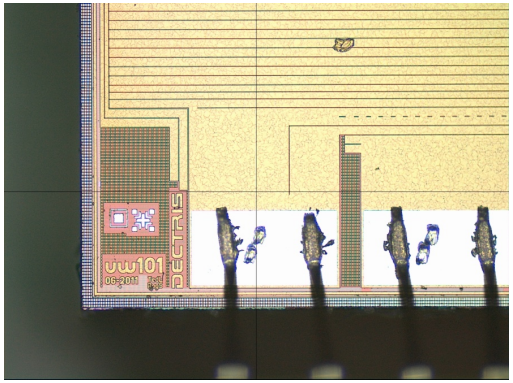
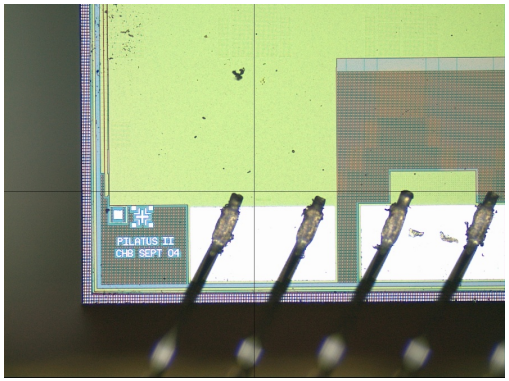
PILATUS3 ASIC: Features

- ***instant retrigger technology with adjustable dead time***
- ***improved high-rate counting performance:***
  - **non-paralyzable counting**
  - **counter overflow handling**
  - **higher local count rates**
  - **enhanced count rate correction**
  - **improved pixel uniformity**
  - **reduced crosstalk**
  - **higher global count rates**
- ***reduced readout time (150 MHz)***
  - ***increased frame rates***
- ***compatibility with CdTe sensors***
  - ***energy range extension for high energy applications***
- ***compatibility with PILATUS2 ASIC***



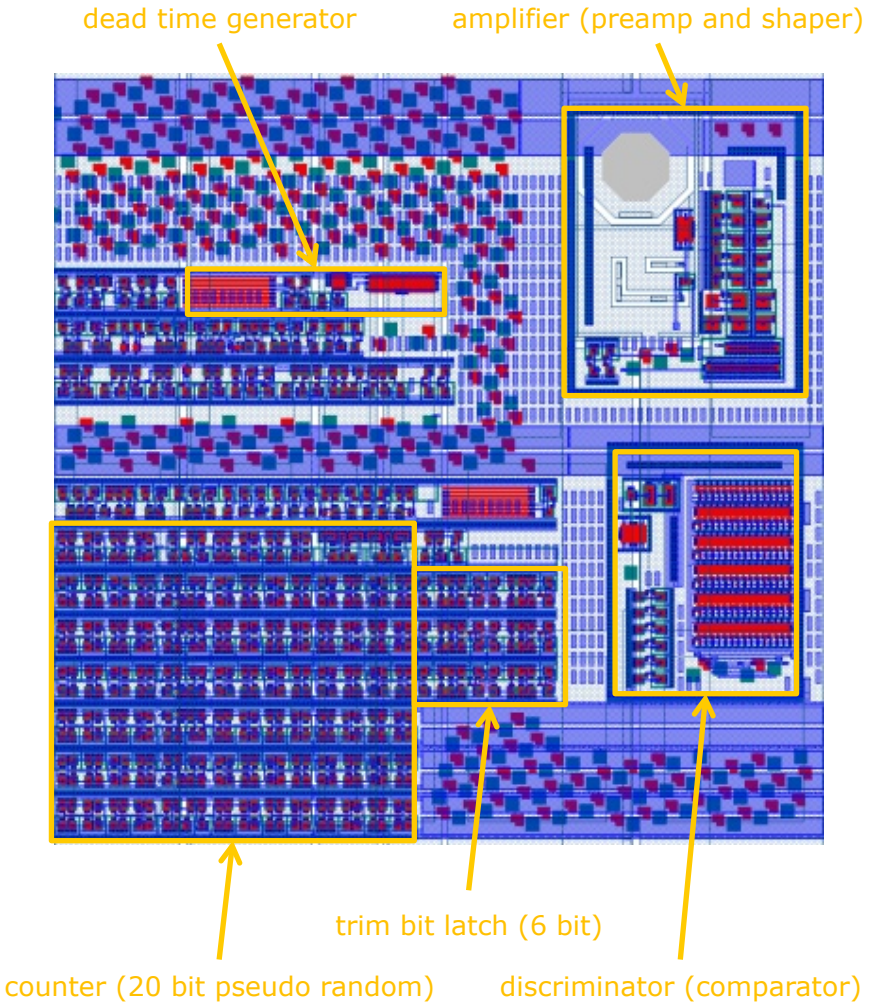
Photograph of a detail of the PILATUS3 readout ASIC.



Photograph of a detail of the PILATUS2 readout ASIC.

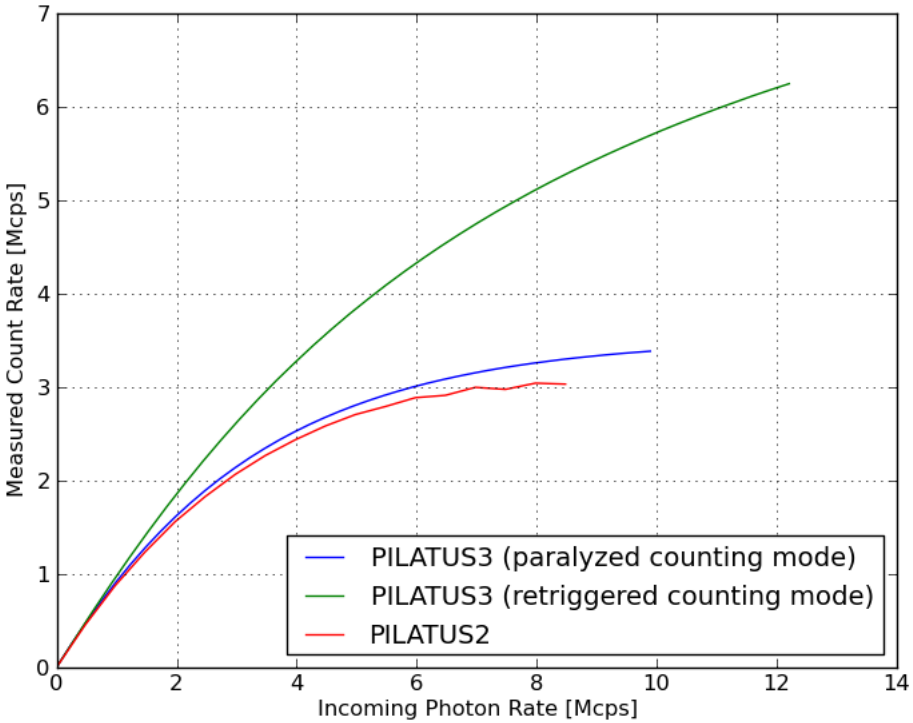
Improved Readout ASIC: Implementation

- ***UMC 0.25 µm CMOS technology***
- ***radiation-tolerant layout (hardness by design):***
  - enclosed layout transistors (ELT)
  - guard rings
- ***pixel size 172 µm x 172 µm***
- ***chip size 10.5 mm x 17.5 mm***
- ***pin compatibility with PILATUS2 ASIC***



PILATUS3 X-Ray Detector Series: Experimental Results

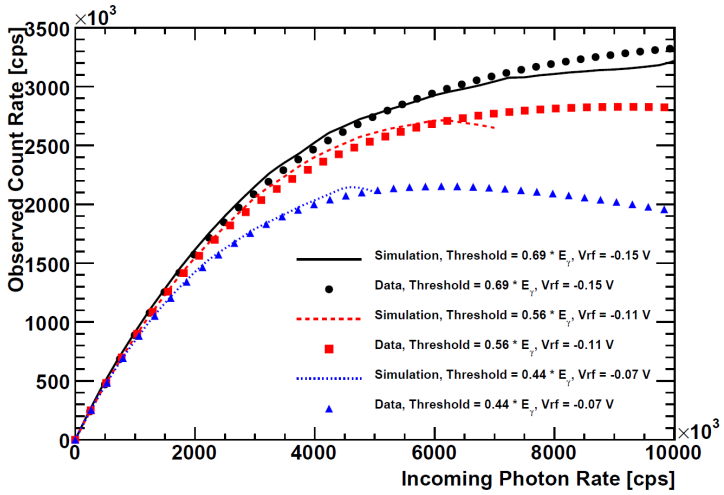
- ***local count rates of more than 10^7 photons per second and pixel***
- ***global rates of more than 3×10^8 photons per second and mm^2***



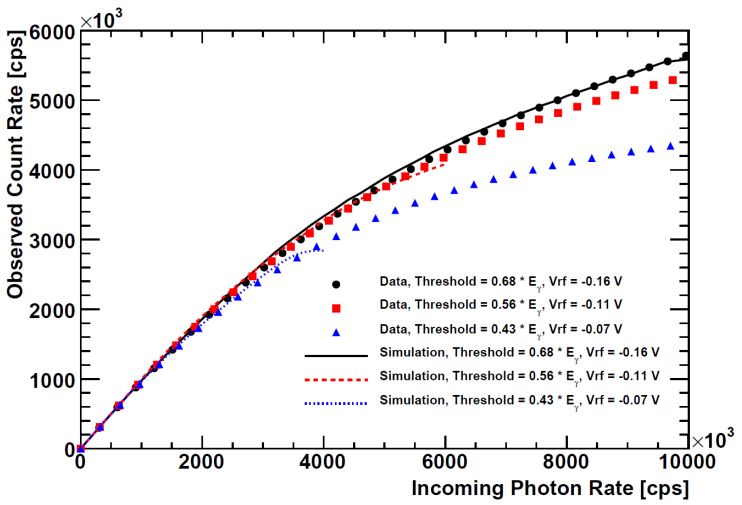
Typical count rate characteristics (measured count rate versus incoming photon rate) of PILATUS2 and PILATUS3 X-ray detectors. (Continuous source, photon energy 8 keV, mid gain, threshold energy 5.5 keV)

PILATUS3 X-Ray Detector Series: Count Rate Correction

- ***Monte-Carlo circuit simulations considering beam parameters (incl. bunch structure of synchrotron beam) and transistor-level circuit parameters (e.g. gain and threshold)***
- ***very good agreement between simulation and experimental data (up to more than 10 Mcps incoming photon rate in retriggered counting mode)***
- ***„Improved count rate corrections for Highest Data Quality with PILATUS Detectors" (P. Trüb et al. SRI 2012 proceedings, in review)***



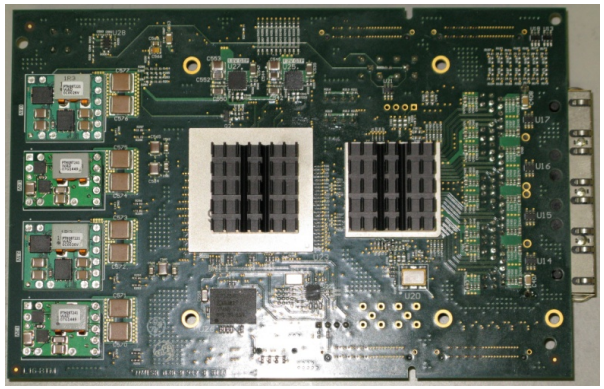
paralyzable counting mode



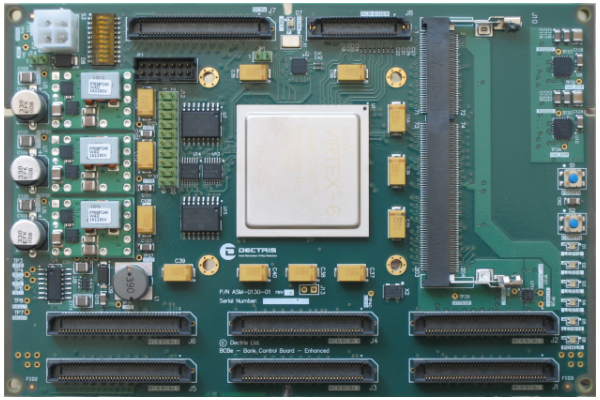
retriggered counting mode

High-Speed Readout Electronics: Features

- ***new detector control board (DCB):***
  - 10GbE (10Gb/s-Ethernet instead of GigaSTaR)
  - Xilinx Virtex-6 FPGA
  - up to 16 BCB per DCB
- ***new bank control board (BCB):***
  - Xilinx Virtex-6 FPGA
  - up to 6 modules per BCB
- ***up to 12 Gb/s total data rate from PILATUS3 2M and 6M detectors***



New detector control board (DCB).



New bank control board (BCB).

PILATUS3

Main features

– PILATUS3 and DCBe technology

– available for all PILATUS models except 100K

– 320, 450 and 1000 µm sensors

First DECTRIS detector series

Applications

– Macromolecular crystallography

– Small-molecule crystallography

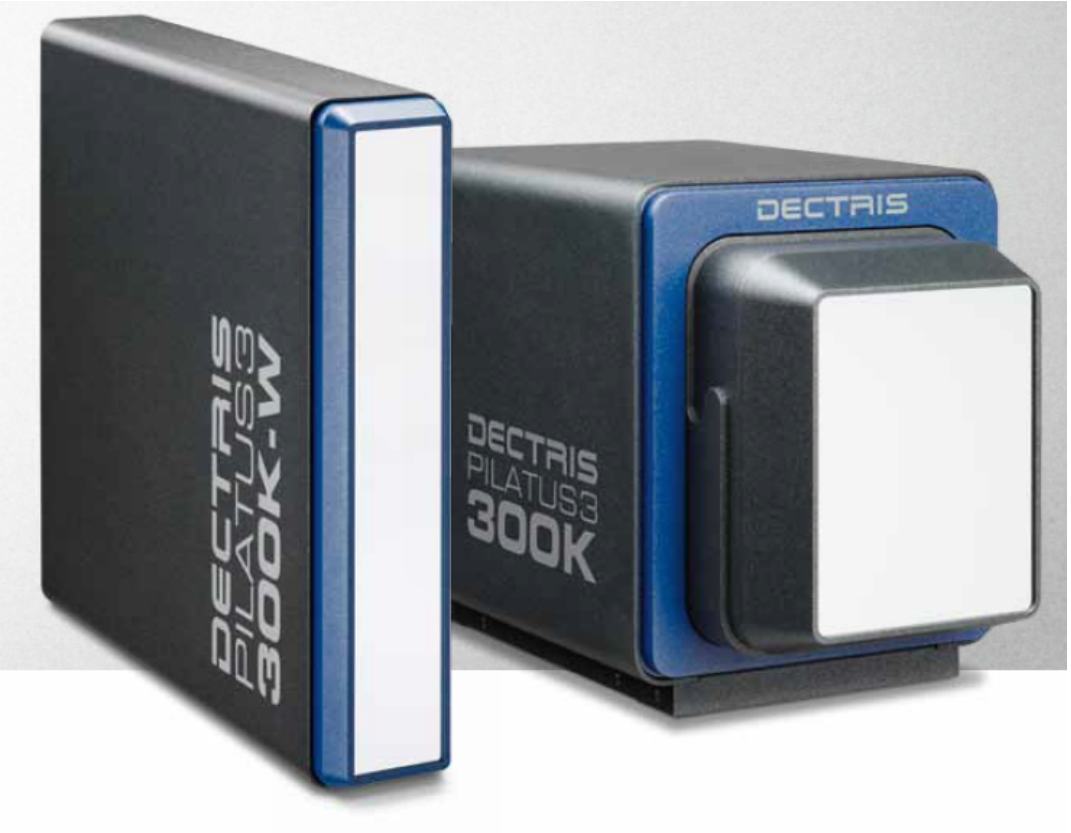
– Surface diffraction and reflectometry

– Scanning beam imaging (sSAXS, ptychography)

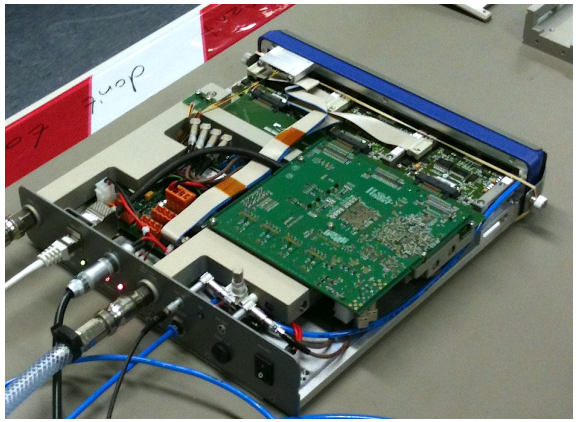
– Time-resolved experiments

– SAXS, WAXS and GISAXS

PILATUS3 300K & 300K-W



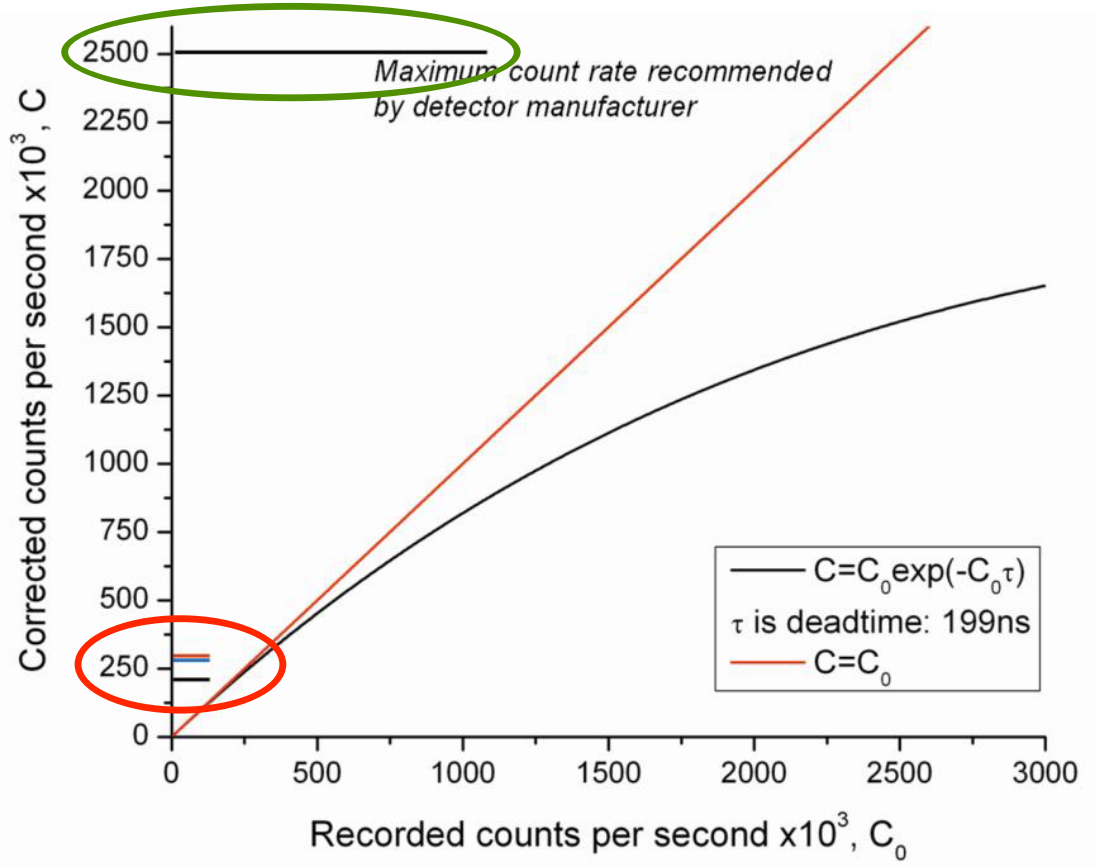
- water-cooled modules and electronics
- vacuum compatibility to 10^{-4} mbar
- extremely compact housing
- 500 Hz frame rates



PILATUS3 X-Ray Detector Series: Performance Summary

Parameter	Value
pixel size	172 µm x 172 µm
threshold energy range (typical)	3 – 21 keV
counter size	20 bit
max. count rate (pixel)	> 10 Mcps incoming rate
max. photon rate	> 3 x 10^8 photons/s/mm^2
absolute count rate error (with rate correction)	< 1 % @ 1 Mcps incoming rate < 10 % @ 10 Mcps incoming rate
readout time	0.95 ms
max. frame rate	500 Hz (100 – 500 Hz)

Dead-time correction in MX



- DIAMOND I24: 10^{12} phts/s in 100 μm^2
- Maximum count-rates observed ~250'000 cts/s
- 5.6% dead-time correction for strongest reflection

➢ PILATUS fully compatible with current MX count rates

➢ PILATUS3 ready for future beamlines

R.L Owen *et al.*, Acta Cryst. (2012). D68, 810–818

Darwin's Formula

$$I(hkl) = I_{beam}\, r_e^2 \frac{V_{xtal}}{V_{cell}} \frac{\lambda^3 L}{\omega V_{cell}} P\, A\, |\, F(hkl)\, |^2$$

C. G. Darwin (1914)

I(hkl) - photons/spot (fully-recorded)

I_{beam} - incident (photons/s/m^2)

r_e - classical electron radius (2.818×10^{-15} m)

V_{xtal} - volume of crystal (in m^3)

V_{cell} - volume of unit cell (in m^3)

λ - x-ray wavelength (in meters!)

ω - rotation speed (radians/s)

L - Lorentz factor (speed/speed)

P - polarization factor

$(1+\cos^2(2\theta) - Pfac \cdot \cos(2\Phi)\sin^2(2\theta))/2$

A - attenuation factor

$\exp(-\mu_{xtal} \cdot l_{path})$

F(hkl) - structure factor amplitude (e^-)

Small molecules: $F_{sm} \sim F_{protein}$

$V_{cell} = V_{cell\ protein}/1000$

$I(hkl)_{sm} \sim 10^6 * I(hkl)_{protein}$

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What is it good for?

	Readout time [ms]	Frame rate [Hz]	Exposure time [ms]	Duty cycle [%]	Max. counts/pix/ frame	Max. Mcts/pix/ sec.
PILATUS 300K	2.23	300	1.1	33.3	2200	0.66
PILATUS 3 300K	0.95	500	1.05	52.5	10500	5.25
PILATUS 6M-F	2.23	25	37.77	94.4	75540	1.8885
PILATUS 3 6M	0.95	100	9.05	90.5	90500	9.05

PILATUS3 allows data to be taken at higher frame rates and with better statistics

Conclusions

- ***DECTRIS instant retrigger technology for non-paralyzable counting***
- ***reduced read-out time and increased frame rates***
- ***improved accuracy of count rate correction***
- ***complete PILATUS3 X-ray detector series***

- ***count rate capability compatible with MX at SR facilities and Small Molecule Crystallography (SMX) in the laboratory***
- ***count rate capability incompatible with SMX with unattenuated SR beams and with FEL applications***

- ***compatibility with CdTe sensors***

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Thank you for your attention!

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