

DECTRIS[®]

detecting the future

MYTHEN

PILATUS

EIGER

Optimizing data quality with Hybrid Photon Counting detectors

***Andreas Förster, Application Scientist MX
CCP4 Workshop, 2017-11-30***

DECTRIS Ltd.
5405 Baden-Dättwil
Switzerland
www.dectris.com

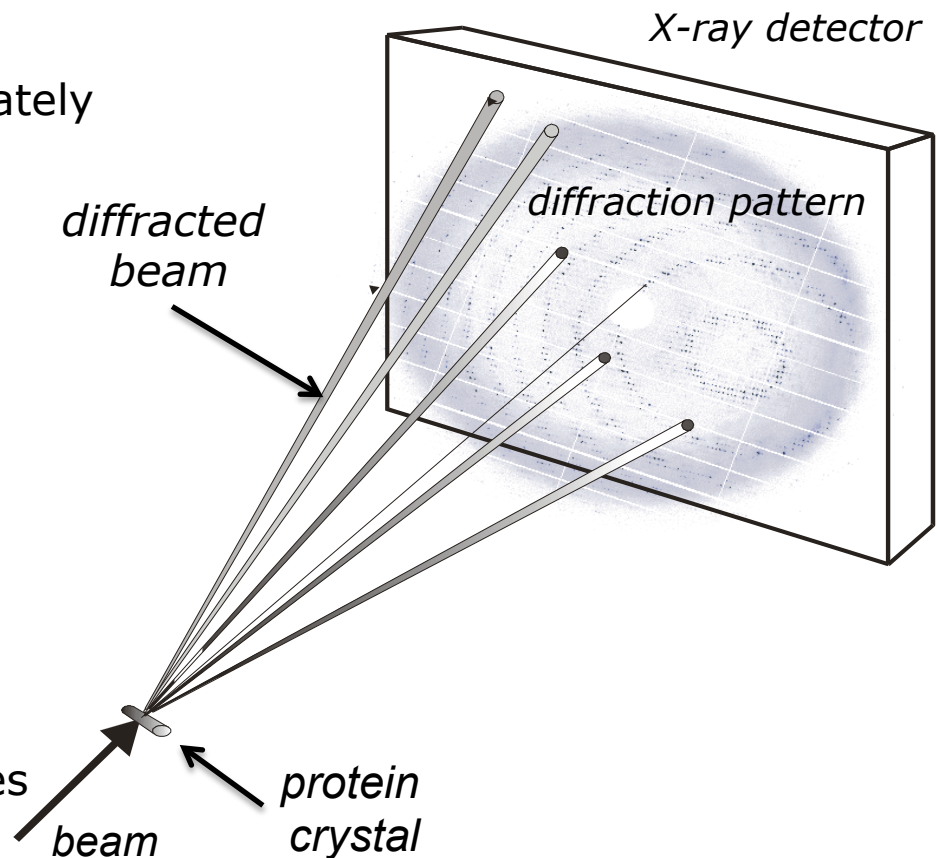
Outline

- **Characteristics of HPC detectors**
- **Data collection – best practice**
 - Accurate data
 - Fine ϕ -slicing
 - Anomalous data
 - Think about your experiment



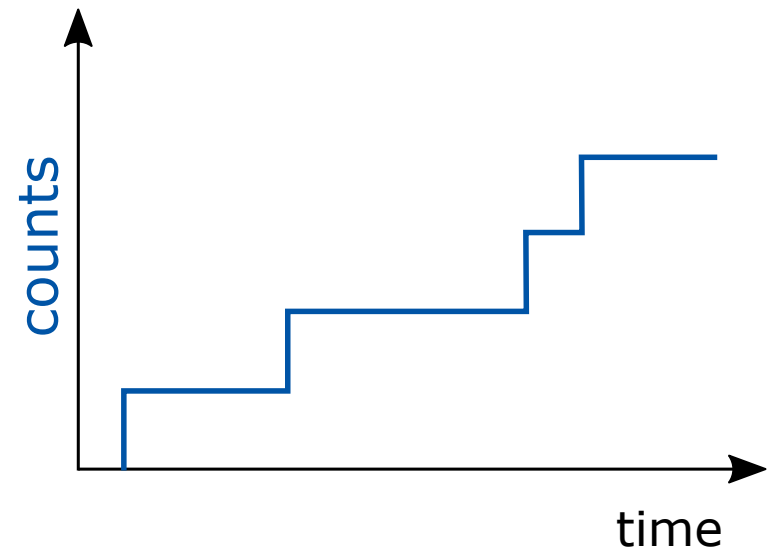
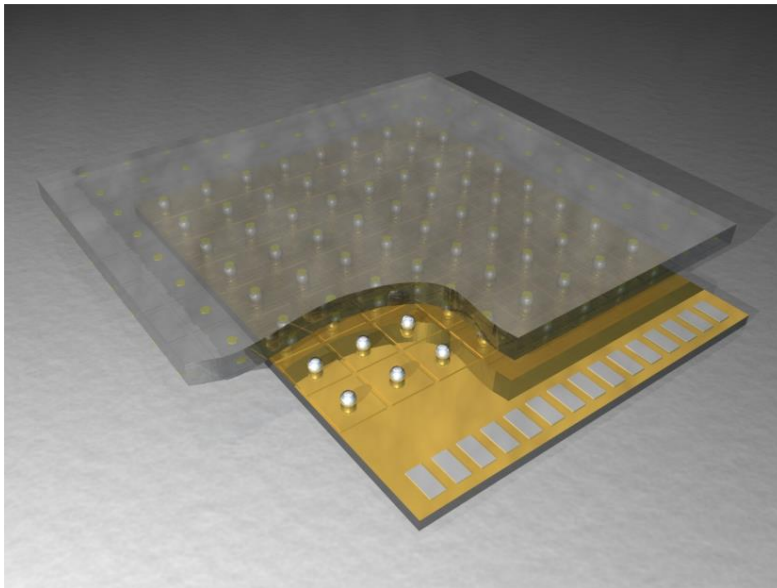
The perfect detector should have

- **High dynamic range**
Measure weak and strong reflections simultaneously
- **No readout noise**
Measure weak reflections accurately
- **Uniformity**
Measure differences accurately
- **High quantum efficiency**
Minimize dose
- **High spatial resolution**
Resolve large unit cells
- **High frame rate**
Continuous rotation collection
- **High count rate**
Take advantage of bright sources

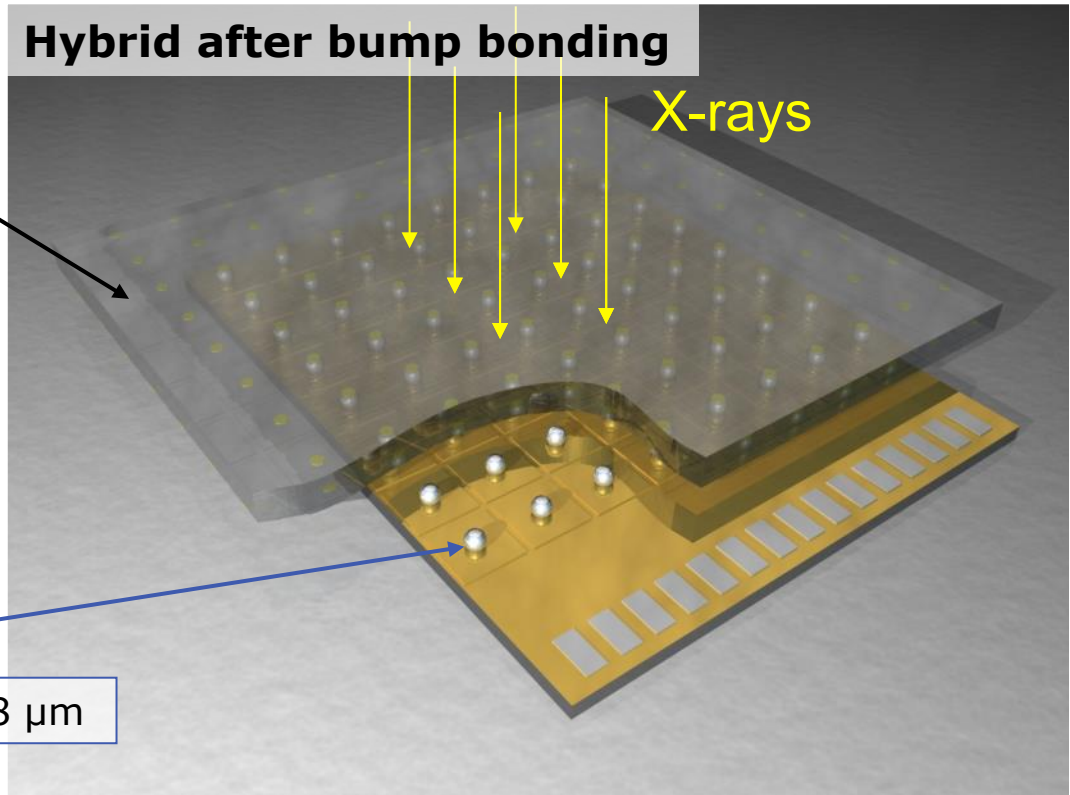
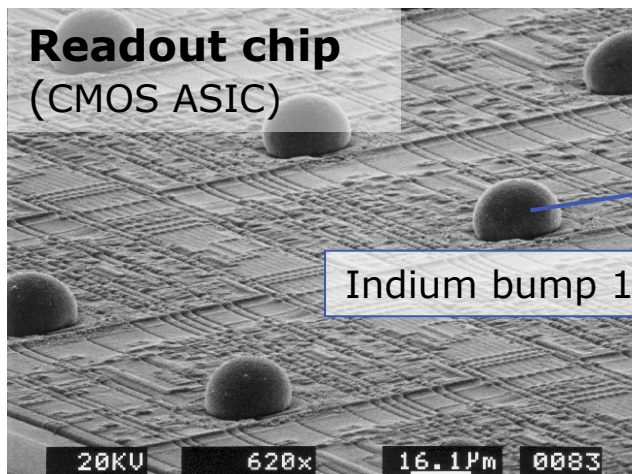
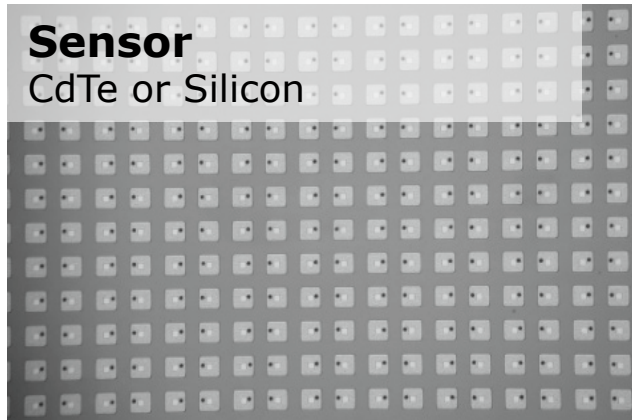


The meaning of HPC counting

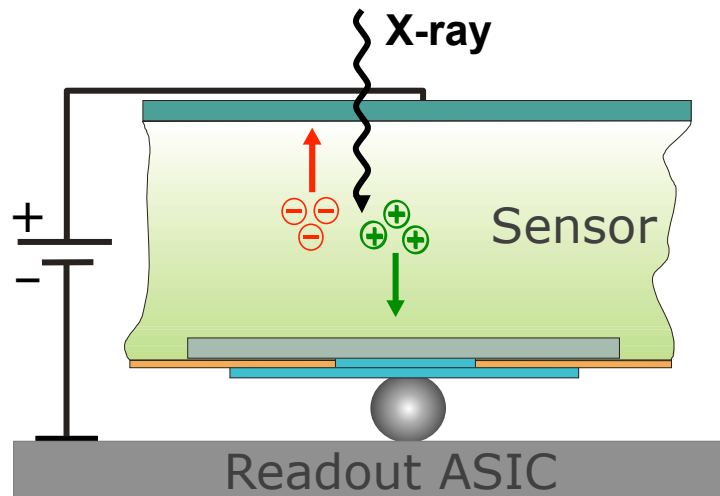
Hybrid pixel + single Photon Counting



Hybrid pixel = sensor + readout



Direct detection in hybrid pixels



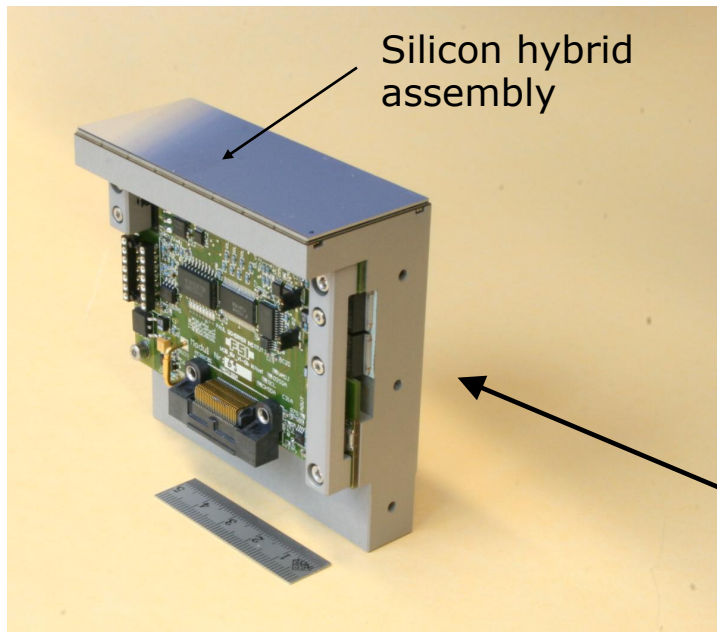
Sensor pixel

- Direct detection of X-ray photons
-> one e^- /hole pair per 3.6 eV

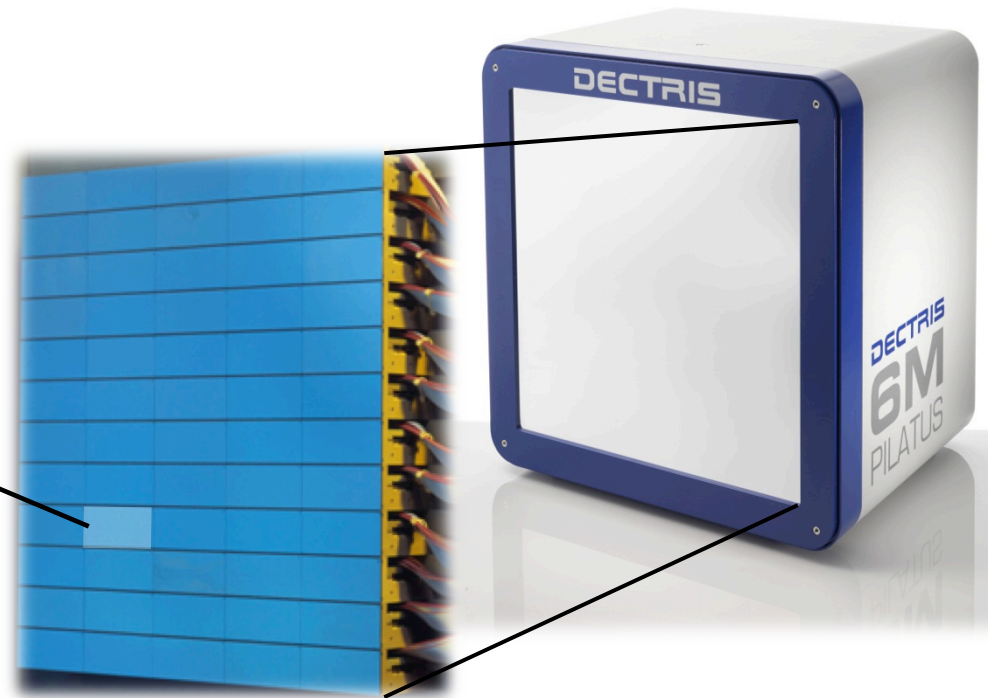
Pixel electronics

- Counting of charge pulses

Modular assembly of HPC detectors

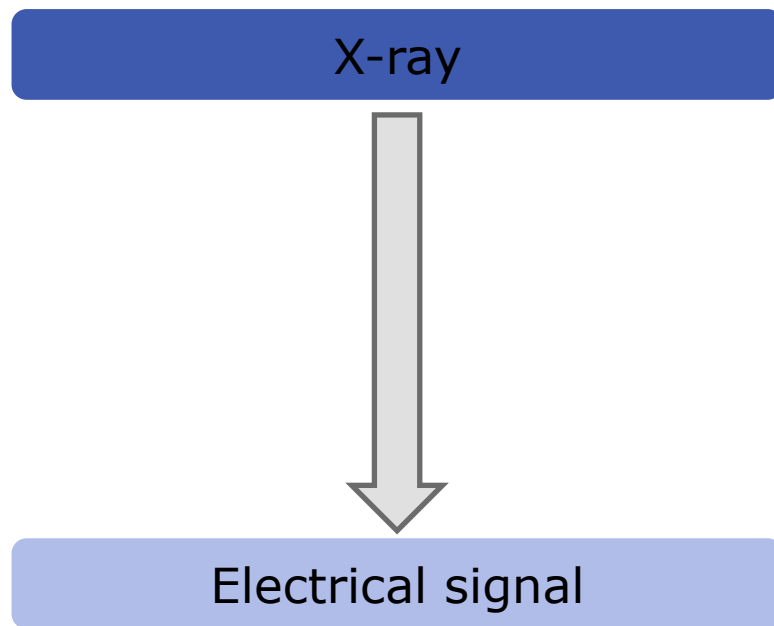


*Module active area: $8 \times 4 \text{ cm}^2$
100k pixels on PILATUS ($172 \mu\text{m}$)
500k pixels on EIGER ($75 \mu\text{m}$)*

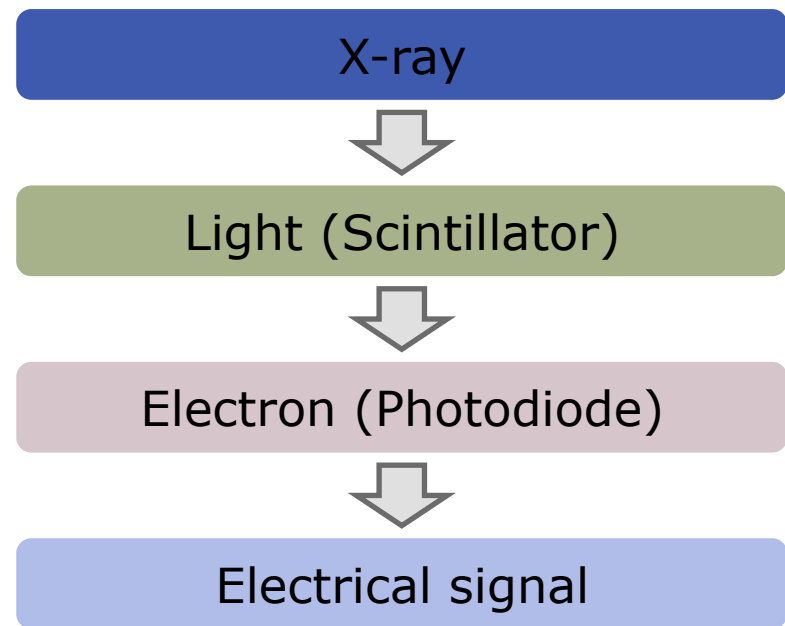


Superiority of direct detection

Direct detection

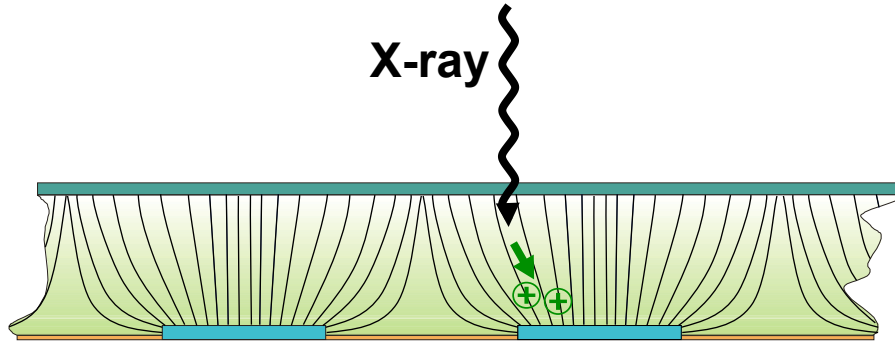


Indirect detection



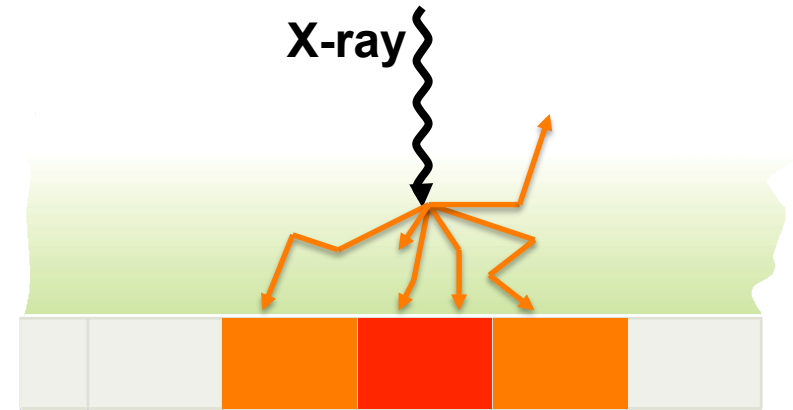
Superiority of direct detection

Direct detection



- Charge captured in electric field
- => **All photons counted**
- => **Signal remains in pixel**

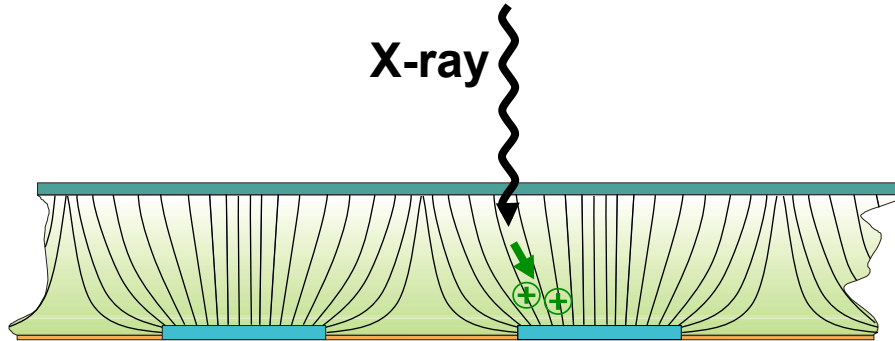
Indirect detection



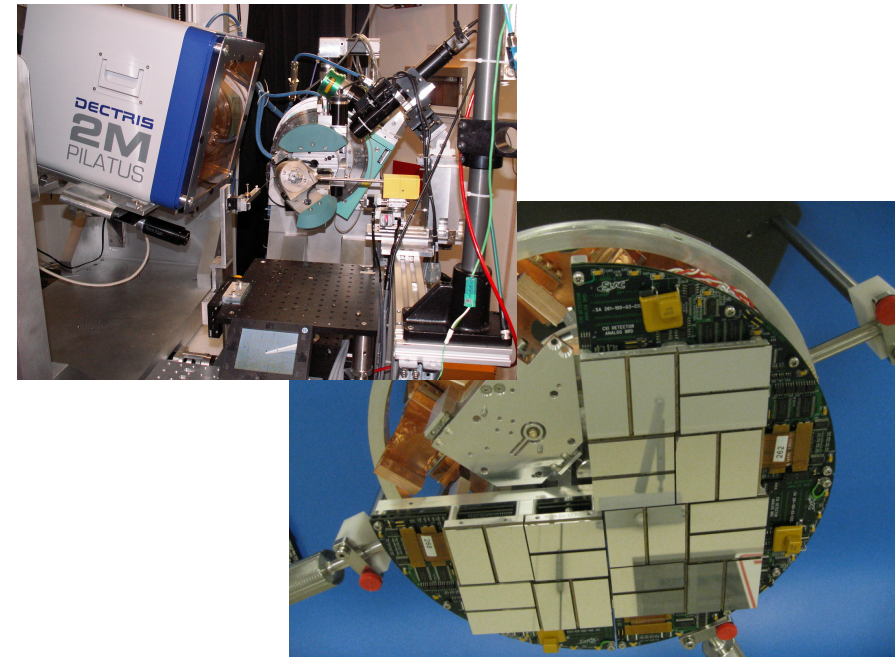
- Secondary radiation scattered in scintillator
- => **Signal spread across pixels**
- => **Light partially lost**

Superiority of direct detection

Direct detection

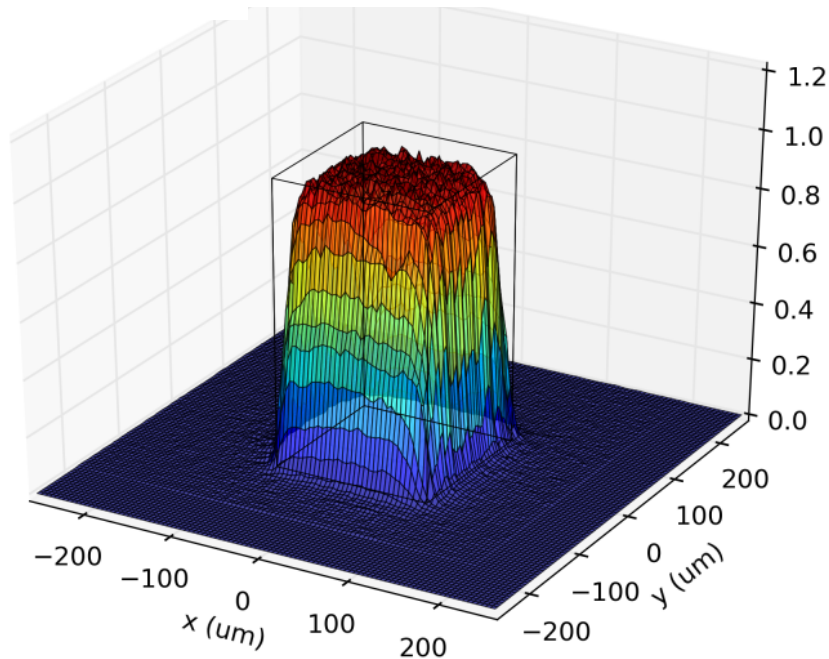


- Charge captured in electric field
- => **All photons counted**
- => **Signal remains in pixel**

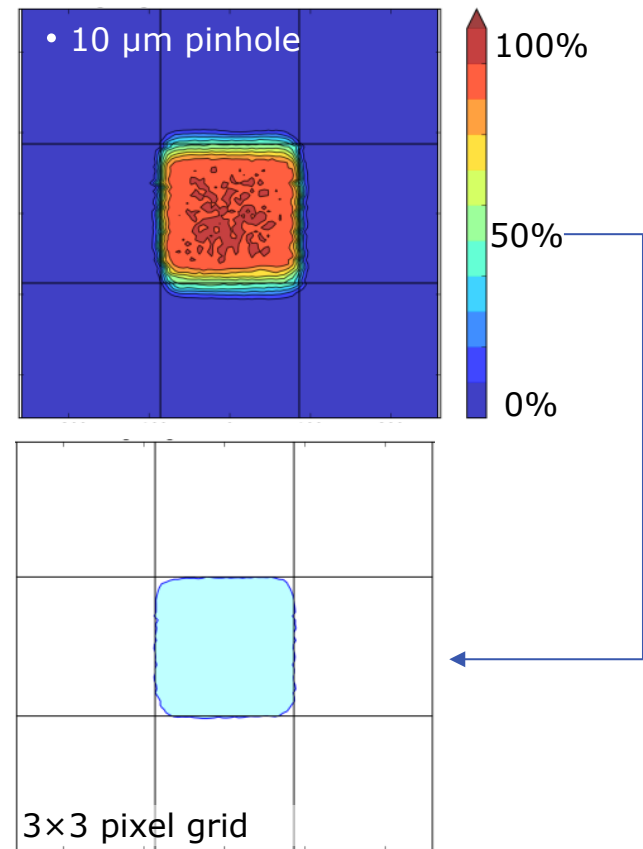


Spatial resolution PILATUS3

CdTe sensor (same for silicon)



10 µm pinhole at Ag K α wavelength



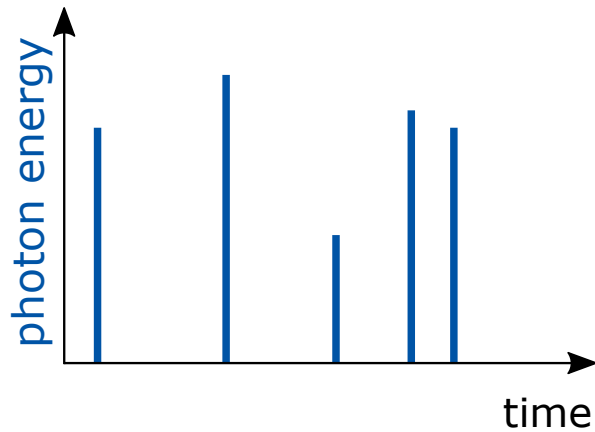
70S ribosome on EIGER X 16M



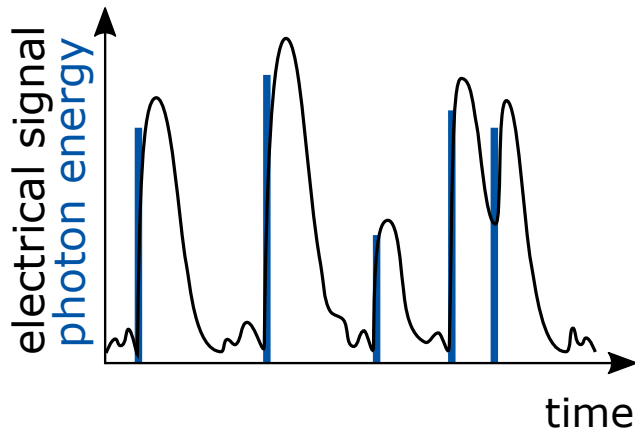
$a = 210 \text{ \AA}$, $b = 450 \text{ \AA}$, $c = 620 \text{ \AA}$
Diffraction to $2.3 \text{ \AA}$, Y. Polikanov, UIC

Photon counting – one by one

– Photons absorbed in sensor pixel

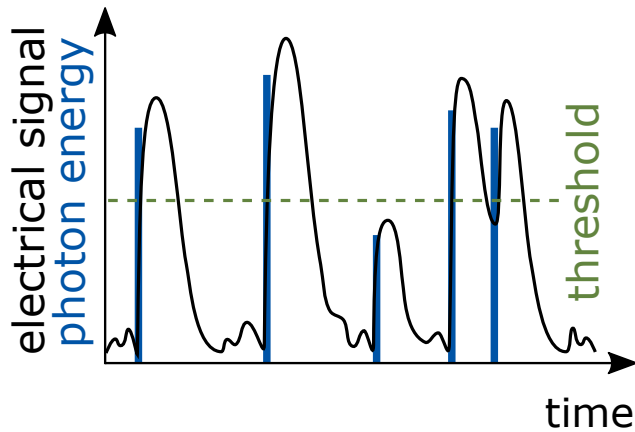


Photon counting – one by one



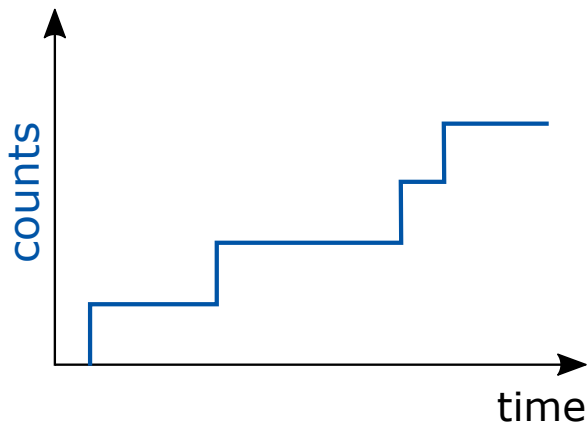
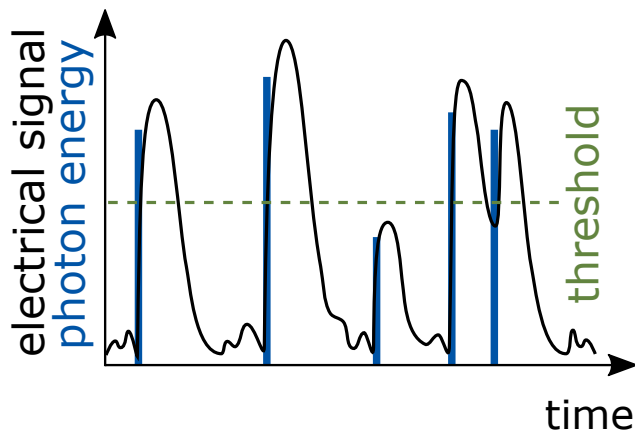
- *Photons absorbed in sensor pixel*
- *Charge pulse proportional to energy*

Photon counting – one by one



- Photons absorbed in sensor pixel
- Charge pulse proportional to energy
- Threshold to discard noise

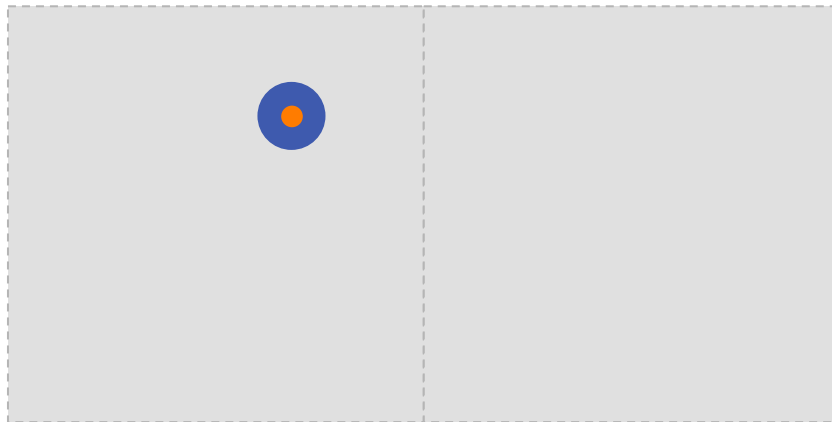
Photon counting – one by one



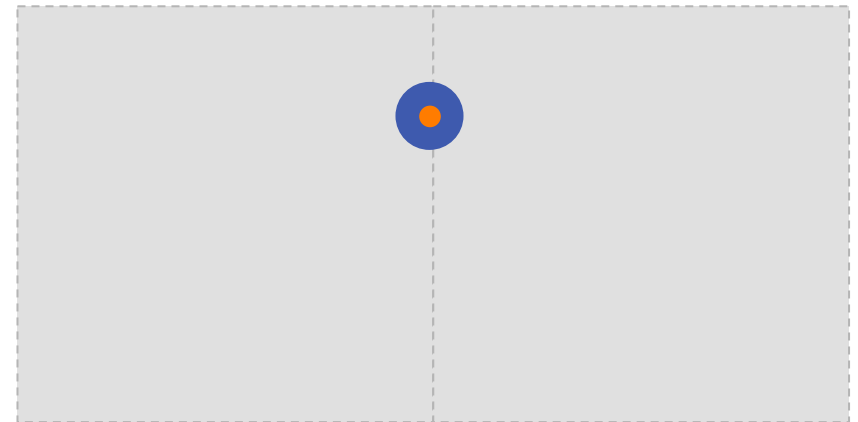
- Photons absorbed in sensor pixel
- Charge pulse proportional to energy
- Threshold to discard noise
- Signals above threshold are counted
 - **Suppression of dark signal**
 - Suppression of fluorescence
 - Suppression of electronic noise
- On-the-fly digitization in digital counter
 - **No readout noise**
 - Fast readout
 - High dynamic range

Threshold at half photon energy

All signal counted within one pixel



1 photon
100% charge
1 count



1 photon
60% charge 40% charge
1 count -

Noise-free detection

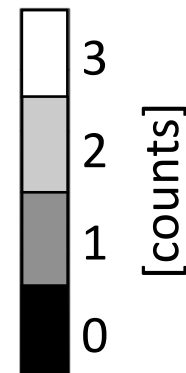
100 ms

No readout noise
No dark signal

total number of counts: 0

1 hour

background radiation visible

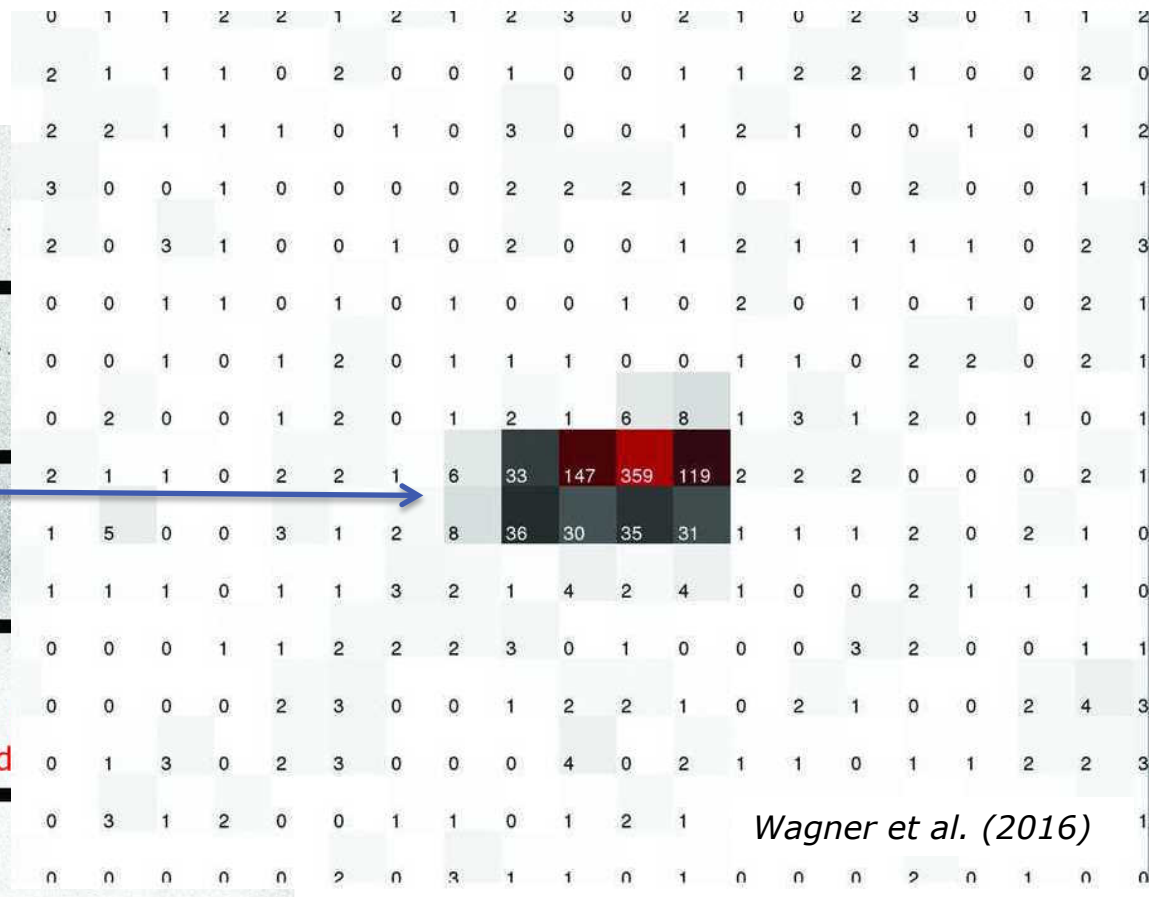
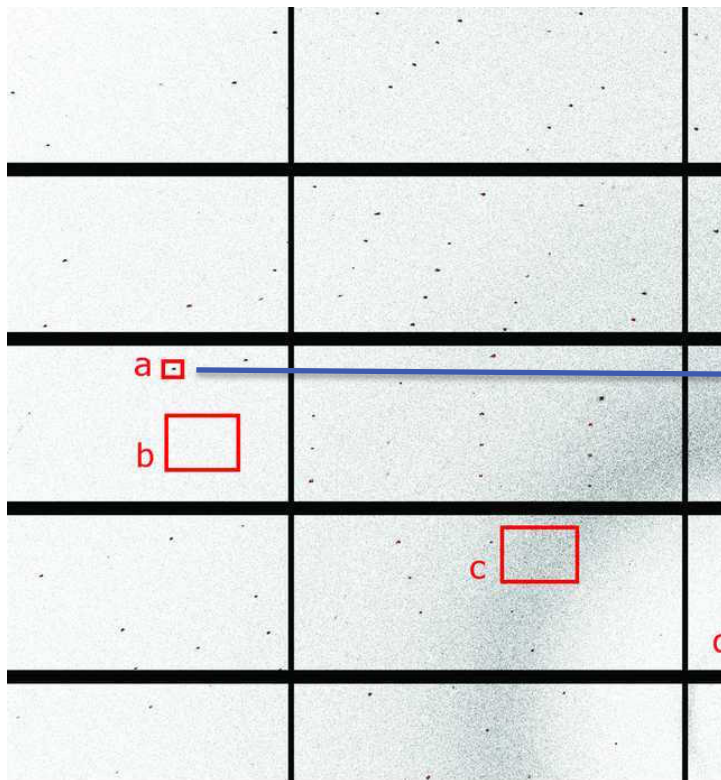


100K detector

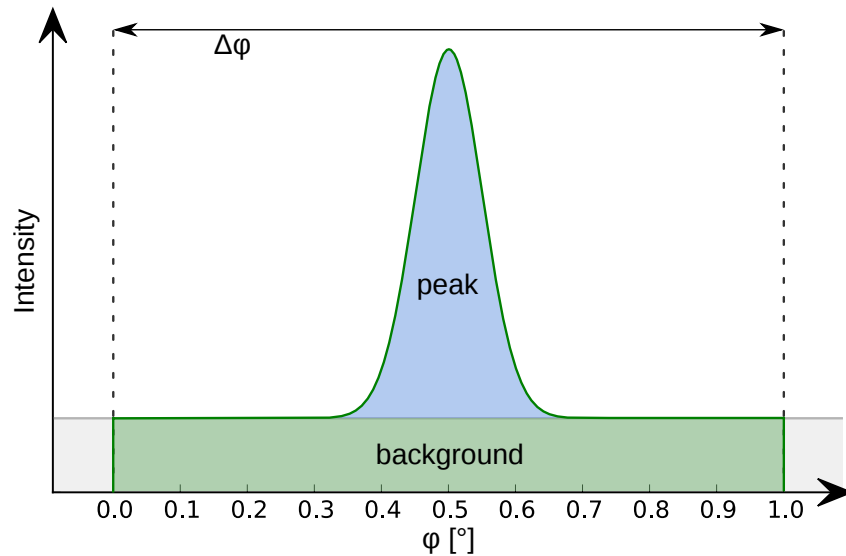
Negligible background for max. $I/\sigma(I)$

Protein crystallography in vacuum

Thaumatococcus @ I23.



Accuracy of intensity estimates



$$Q : \text{Quantity of photons}$$

$$\text{var}(Q) = Q$$

$$\sigma(Q) = [\text{var}(Q)]^{1/2} = Q^{1/2}$$

$$I : \text{Observed intensity}$$

$$I = \Sigma(\text{Peak}_i - \text{Bkg}_i)$$

$$\text{var}(I) = \Sigma[\text{var}(\text{Peak}_i) + \text{var}(\text{Bkg}_i)]$$

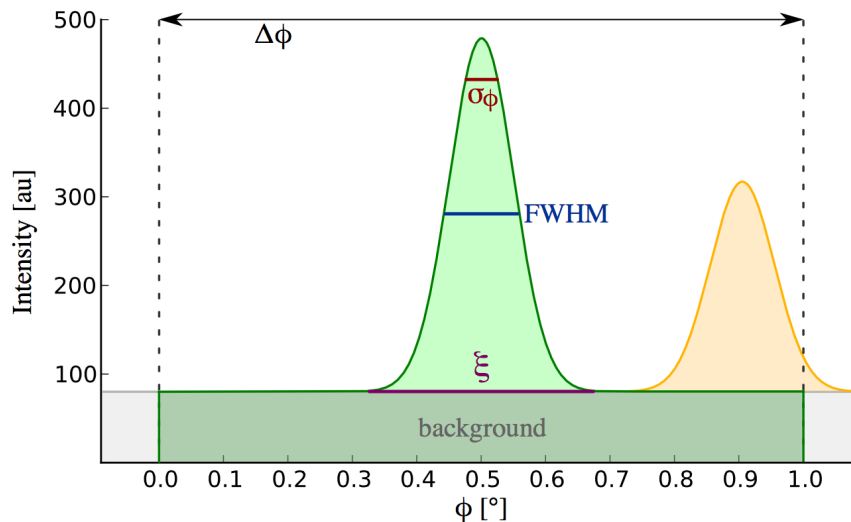
$$R_{\text{err}} = \sigma(I)/I$$

Less background
=> Better data

Relative error [%]	Background [photons]		
Integrated intensity [photons]	0	500	1000
100	10.0	33.2	45.8
500	4.5	7.7	10.0
1000	3.2	4.5	5.5
10000	1.0	1.0	1.1

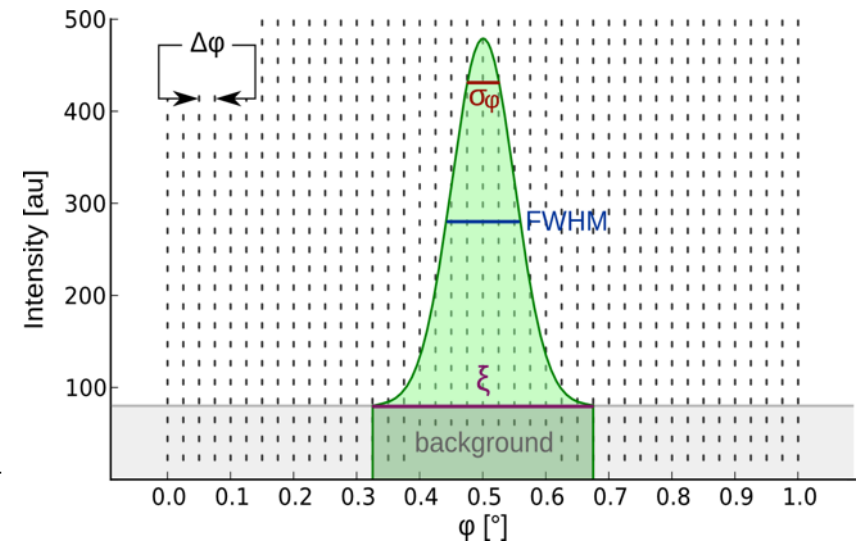
Pflugrath (1999)

Fine ϕ -slicing minimizes background



Wide ϕ -slicing

- $\Delta\phi > \xi$
- Lots of background
- Few images



Fine ϕ -slicing

- $\Delta\phi \ll \xi$
- Minimal background
- Many images

Mueller et al. (2012)

Fine φ -slicing without readout noise

Detector with readout noise (CCD)



**Hybrid pixel detector
without readout noise**

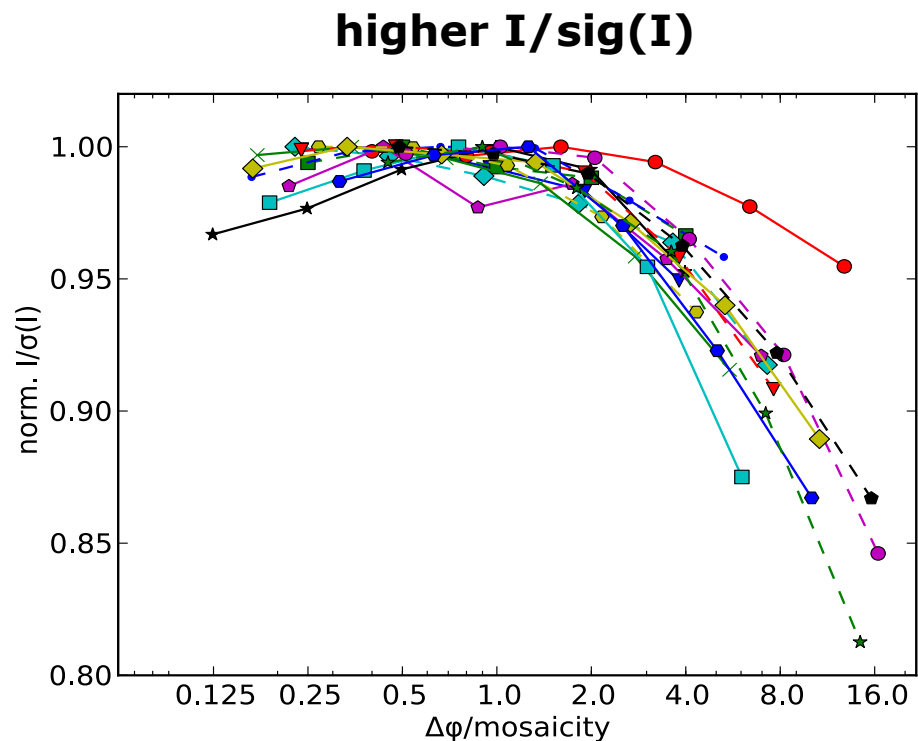


Fine ϕ -slicing improves data quality

$\Delta\phi < \text{mosaicity}$ improves:

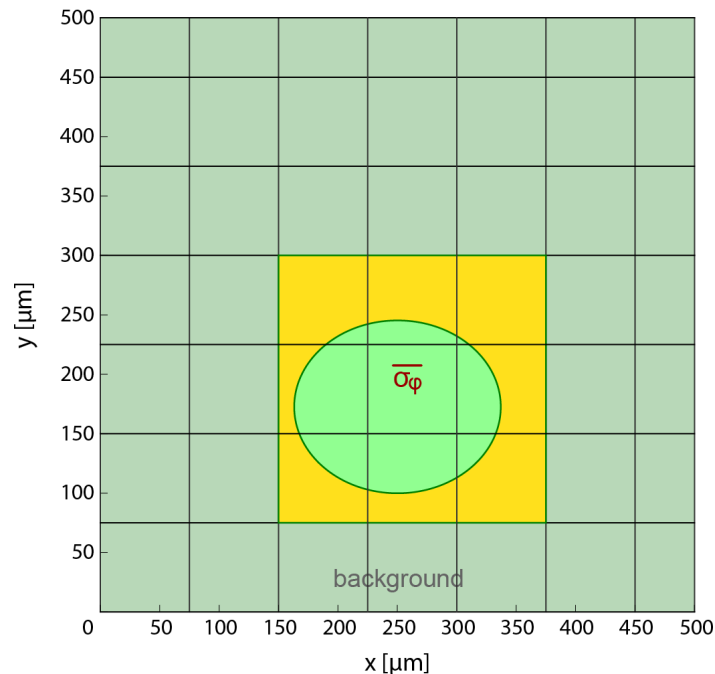
- overall statistics
- anomalous signal
- highest-shell statistics
- number of overlaps

on PILATUS.

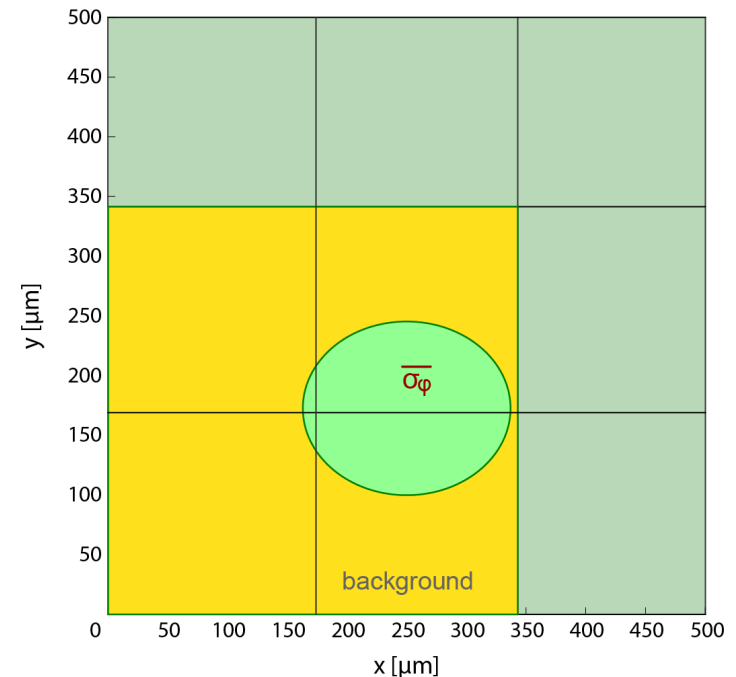


Mueller et al. (2012)

Smaller pixels improve data quality

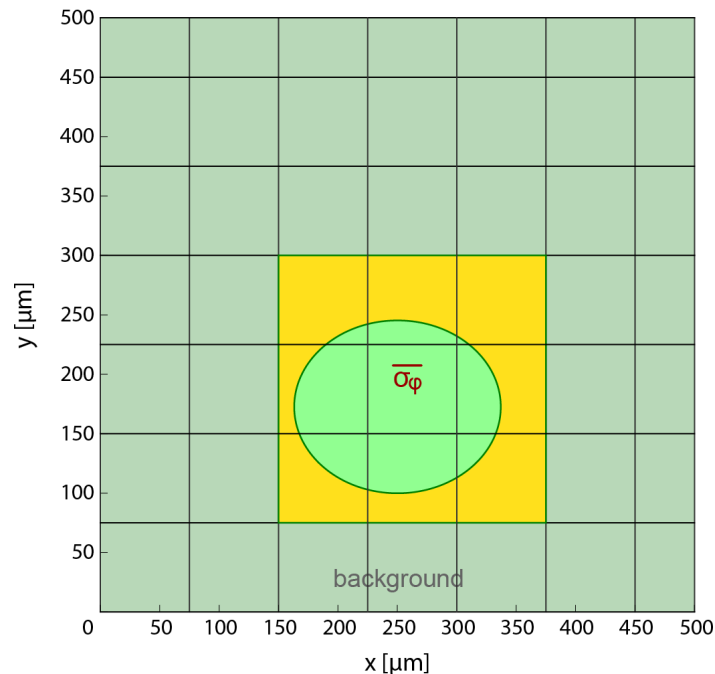


Reflection on EIGER

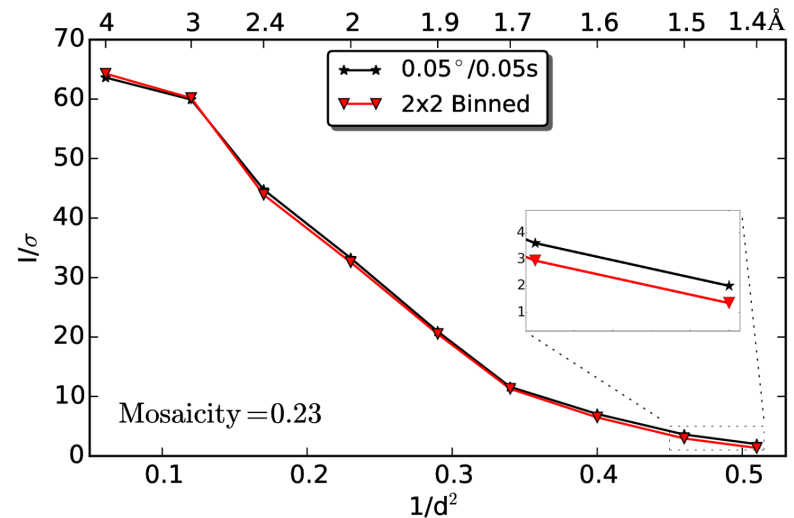


Reflection on PILATUS

Smaller pixels improve data quality



Reflection on EIGER



Better high-resolution data

Casañas et al. (2016)

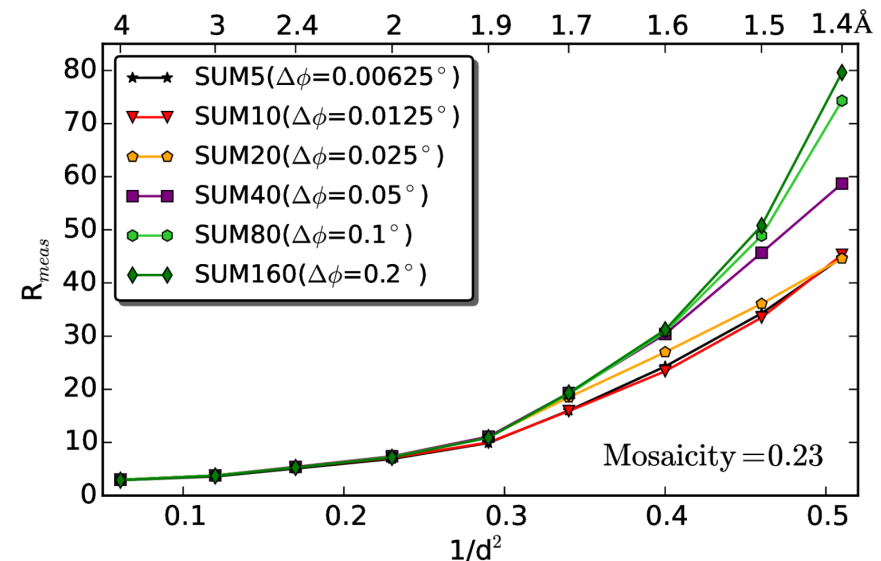
Smaller pixels allow for finer ϕ -slicing

$\Delta\phi \approx 1/10$ mosaicity improves:

- overall statistics
- highest-shell statistics
- anomalous signal
- number of overlaps

on EIGER.

lower R_{meas}

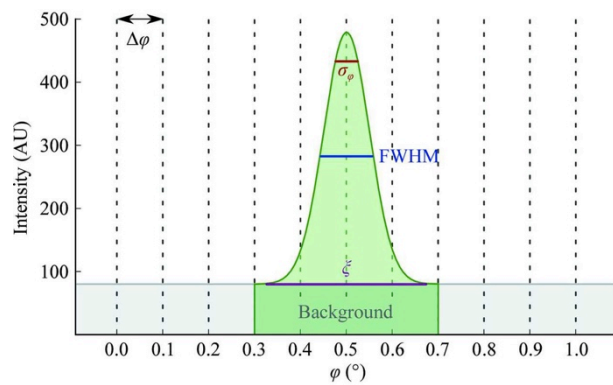


Casañas et al. (2016)

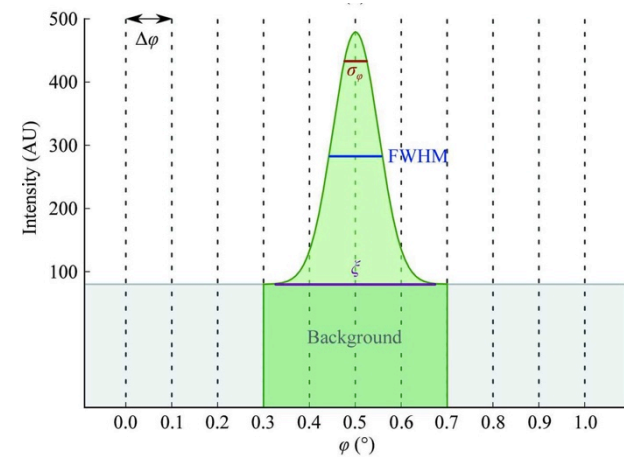
Improve your data by

- Using EIGER and PILATUS detectors***
- Using fine φ -slicing***
- Minimizing other sources of error***

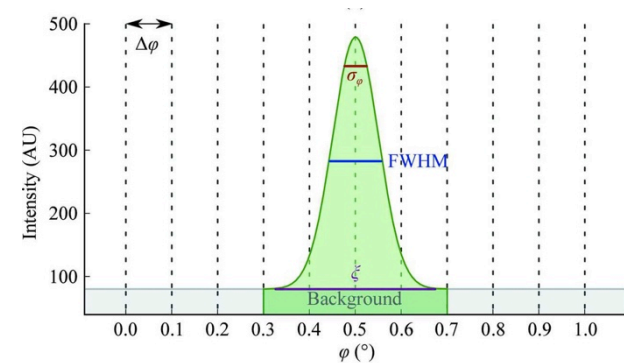
Decrease absolute background



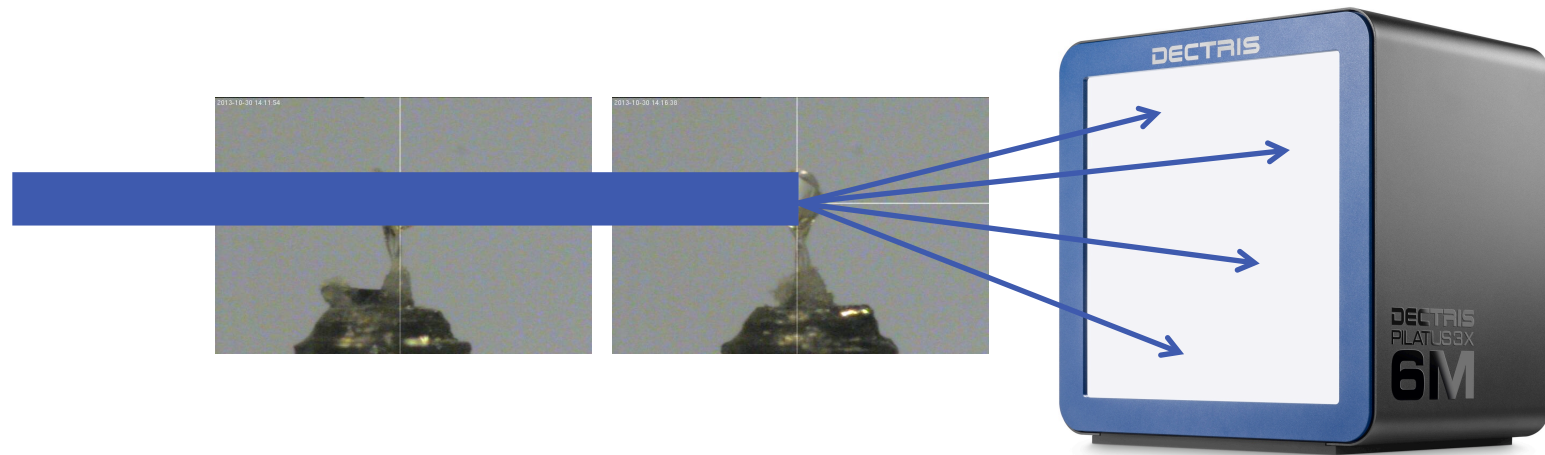
rubbish!



good!



Decrease absolute background



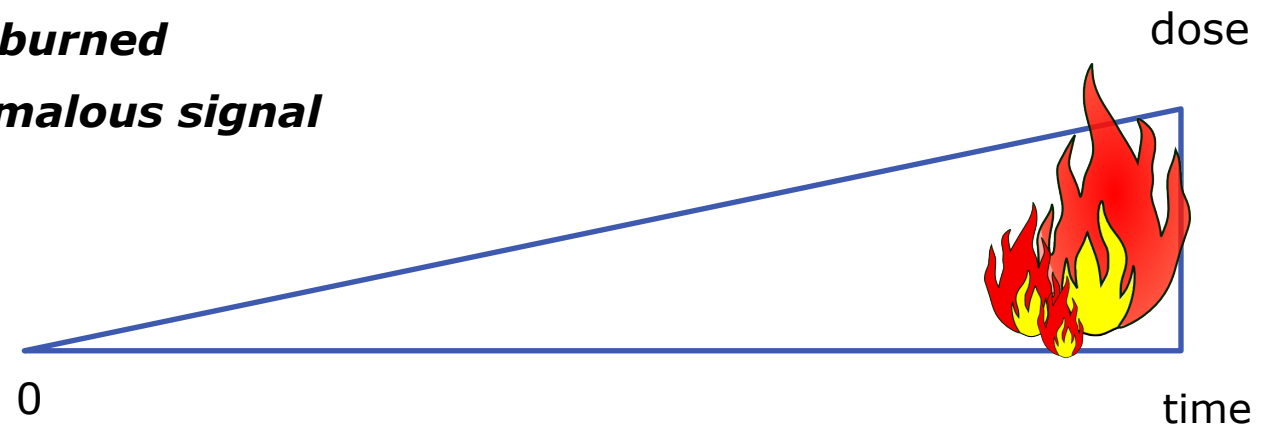
Improve your data by

- Using EIGER and PILATUS detectors***
- Using fine φ -slicing***
- Minimizing absolute background***
- Collecting 360° of data***

Basic strategy

Collect 360° of data to

- **Get more precise intensity estimates**
- **Avoid space group frustration**
- **Avoid getting burned**
- **Maximize anomalous signal**



90° @ 10 img/s (0.1°/img) 90 s

360° @ 40 img/s (0.1°/img) 90 s

There is no native data

Current paradigm

- ***Molecular replacement***
- ***In case of failure***
 - *Se-Met substitution*
 - *Heavy atom soaking*

Always measure anomalous differences

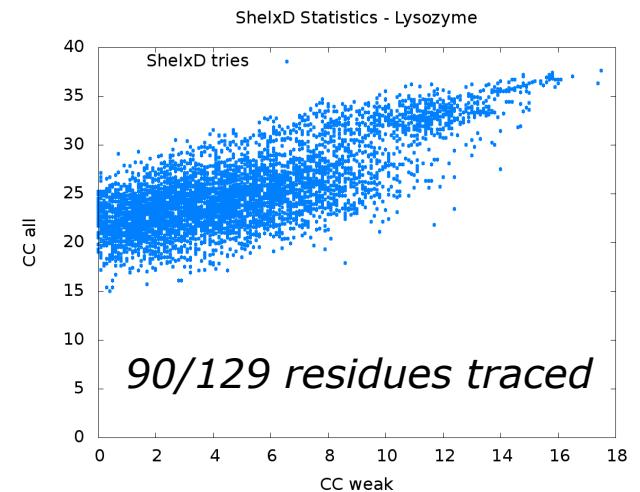
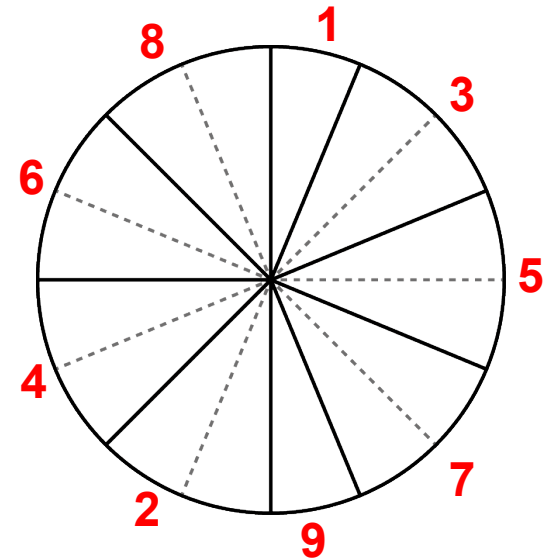
- *Experimental phasing*
- *Improved MR phases*
- *Identify metal ions*
- *Without extra work*



Sophisticated strategies

Collect 360° of data

- *from starting angle suggested by strategy software*
- *with inverse beam method*
- *multiple times*
- *from aligned crystal*



Never measure less than 360° of data.

Maximize anomalous signal

- ***Multiplicity amplifies anomalous signal***
 - *Change crystal orientation for true multiplicity*
- ***Radiation damage must be avoided***
 - *Low-intensity data collection*
 - *Collect more images at lower dose*
- ***Combine data from multiple crystals***

Detector must be free of readout noise.

Improve your data by

- *Using PILATUS and EIGER detectors*
- *Using fine φ -slicing*
- *Minimizing absolute background*
- *Collecting at least 360° of data*
- *Thinking about your experiment*

Use beam time efficiently

- Mount crystal – 1 min***
 - Center crystal – 1 min***
 - Collect a dataset – 1 min***
 - Five-hour shift – 300 min***
- Person A :***
 - Collects 82 datasets*
 - Takes 1 TB of data home***
 - Person B :***
 - Thinks about experiment*
 - Talks to beamline scientist about hardware/best strategy*
 - Has a tea to focus*
 - Collects a dataset*
 - Has a chat*
 - Collects two more datasets*
 - Solves structure***

Conclusions

- **Collect 360° of data**
- **$\Delta\varphi \approx 1/2$ XDS mosaicity for best**
 - overall statistics
 - highest-shell statistics
 - anomalous signal
- **There is no native data**
 - especially at high multiplicity
- **Ask your beamline scientist / think !**

DECTRIS®

detecting the future

***Thank you for
your attention!***

www.dectris.com

andreas.foerster@dectris.com

DECTRIS Ltd.
5405 Baden-Dättwil
Switzerland
www.dectris.com