The Adaptive Gain Integrating Pixel Detector

A 4.5 MHz camera for the European XFEL

Investigation of pixel detector designs for X-ray Photon Correlation Spectroscopy

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Outline

- The AGIPD
  - XFEL challenges
  - AGIPD design
- HORUS
  - What is HORUS?
  - Processing chain
- XPCS Simulations
  - What is XPCS?
  - Simulation procedure
  - Figures of merit for different layouts
- Summary and Outlook

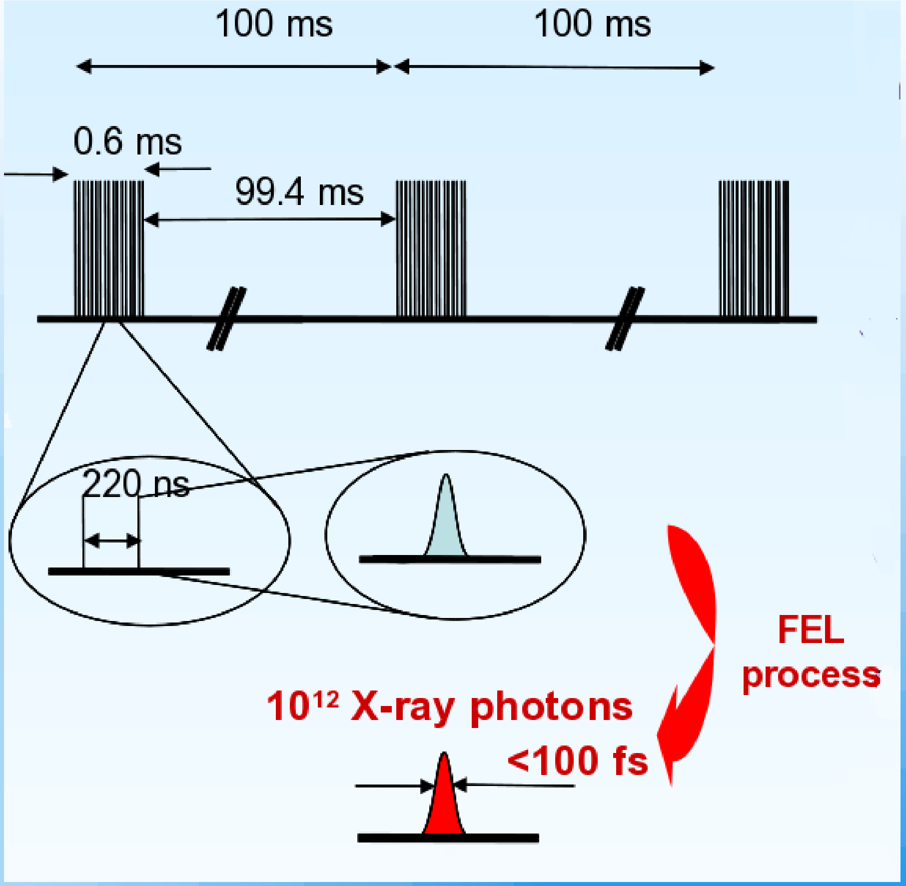
XFEL pulse trains

Special structure of pulse trains:

- 600 µs long pulse trains at a repetition rate of 10 Hz
- Each train consists of 2700 bunches with a separation of 220 ns
- (SASE) Each bunch consists of ≈10^{12} photons arriving <100 fs

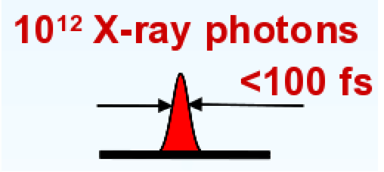
Beam energy:

- 5 – 25 keV (depends on station)
- 12.4 keV (λ=0.1 nm) nominal design energy for AGIPD

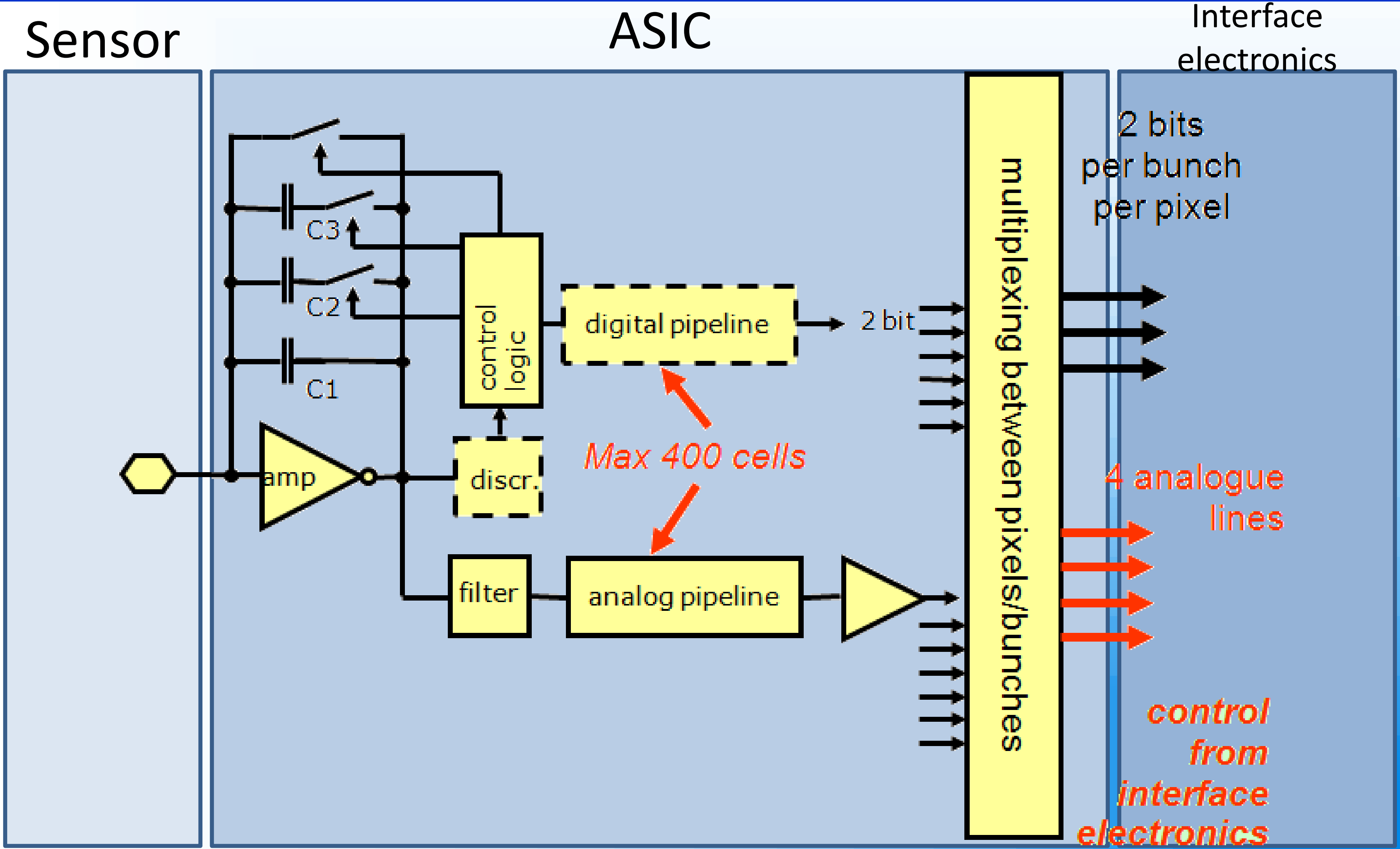


XFEL challenges

XFEL provides	*Challenges*	*Approach*
• Simultaneous deposition of all photons	• Single photon counting not possible • Dynamic range: 10^4 photons/pixel with single photon sensitivity	• Charge integration • Dynamic gain switching → 3 gain stages → Single photon sensitivity in highest gain
• High number of bunches → 2700 bunches per train (600 µs)	• Reading out of single frames during pulse train impossible	• Analog memory in the pixel using the >200 storage cells per pixel



AGIPD design



The detector layout

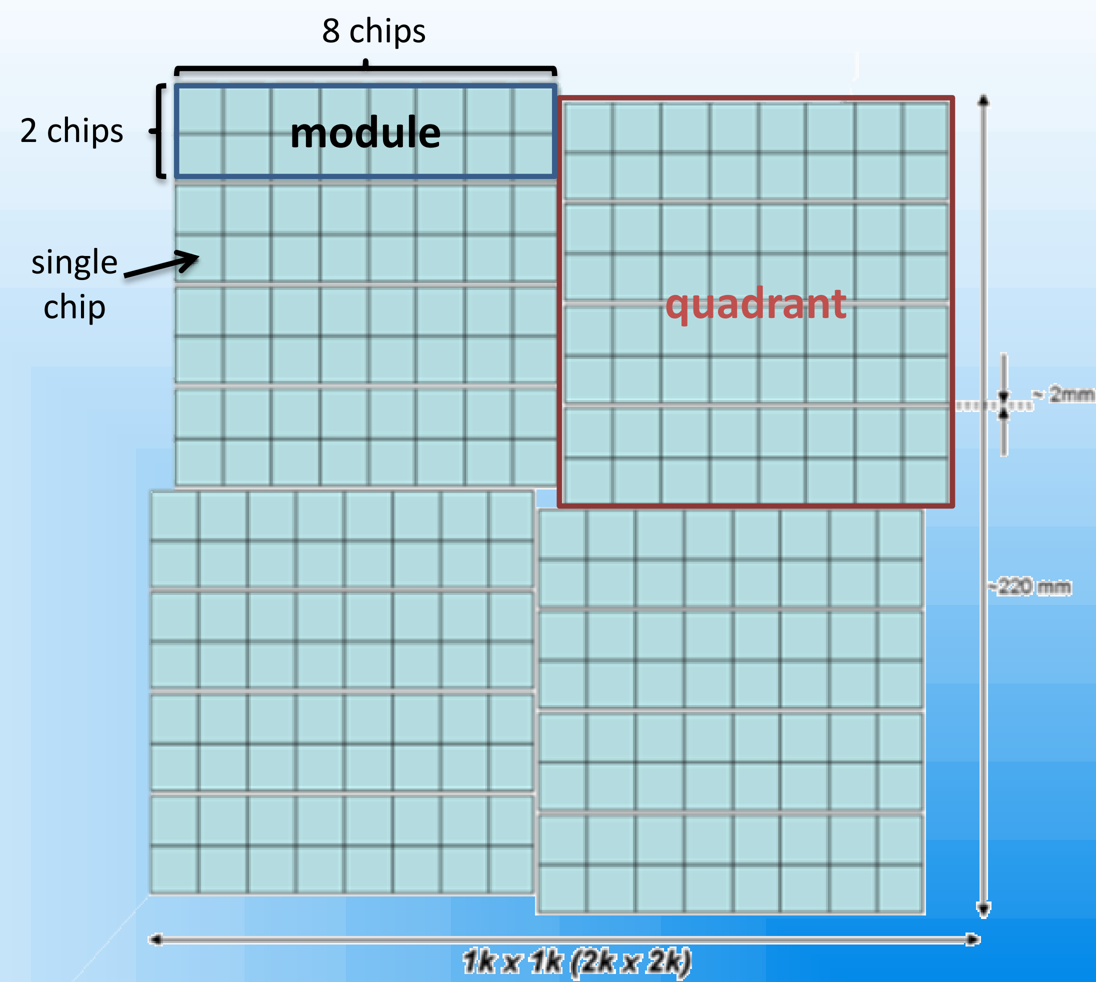
Specifications:

- 1 Mpixel
- 4 quadrants
- 4 modules per quadrant

→ 1 module: 8 x 2 chips,

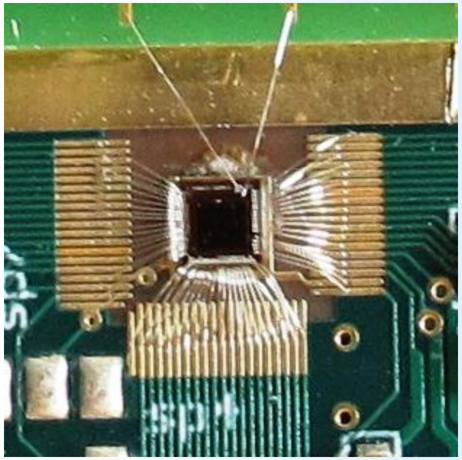
→ 1 chip: 64 x 64 pixels

- 200 x 200 µm^2 pixel size
- 500 µm silicon sensor
- Hole for direct beam
- Upgradable to 4 Mpix



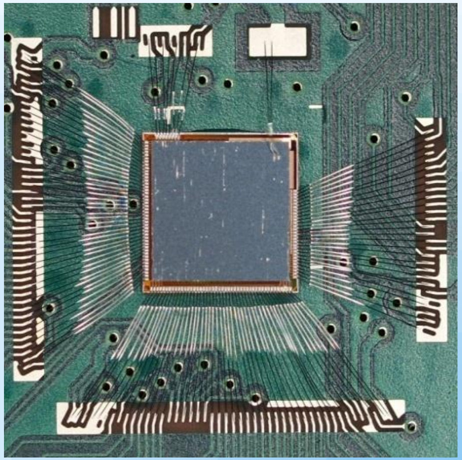
AGIPD test-chips (I)

AGIPD 0.1



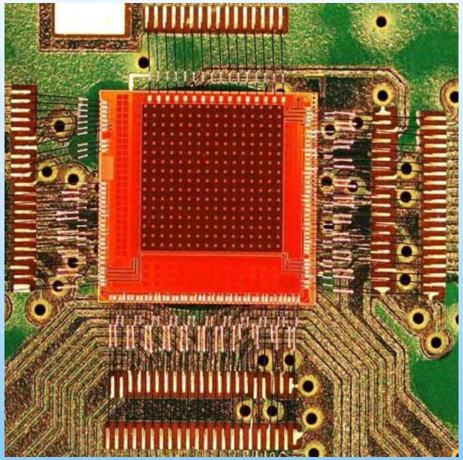
- No pixels yet
- 3 readout blocks consisting of:
→ Readout chain (Preamp + CDS stage)
→ 3 different kinds of leakage current compensation

AGIPD 0.2



- 16 x 16 pixels
- 100 storage cells/pixel
- No leakage current compensation
- Different combinations of preamps and storage cell architectures

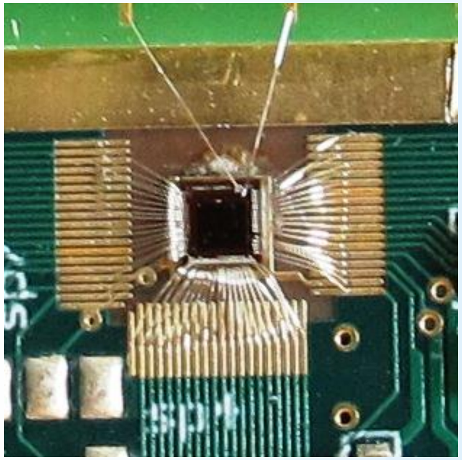
AGIPD 0.3



- 16 x 16 pixels
- 200 storage cells/pixel
- Radiation hard storage cell design
- High speed serial control logic

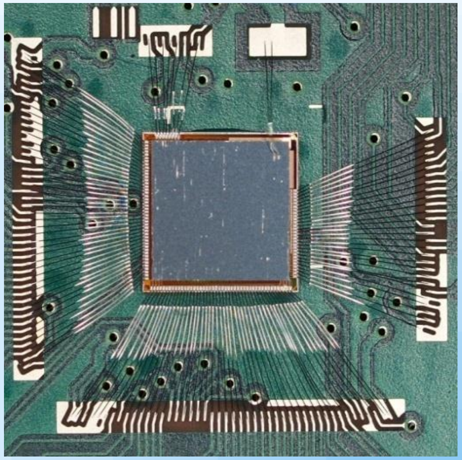
AGIPD test-chips (II)

AGIPD 0.1



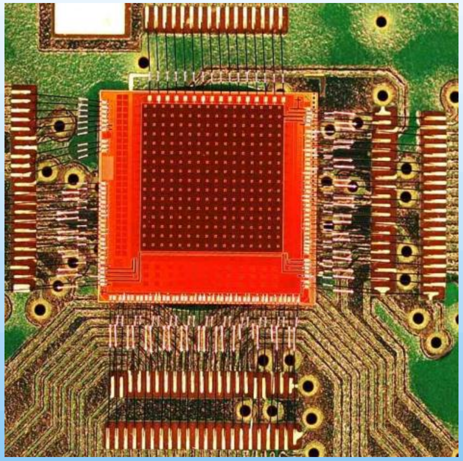
- Linearity of the gain
- Stress-test of the input gate at the preamp
- Temporal behavior of the preamp and CDS stage

AGIPD 0.2



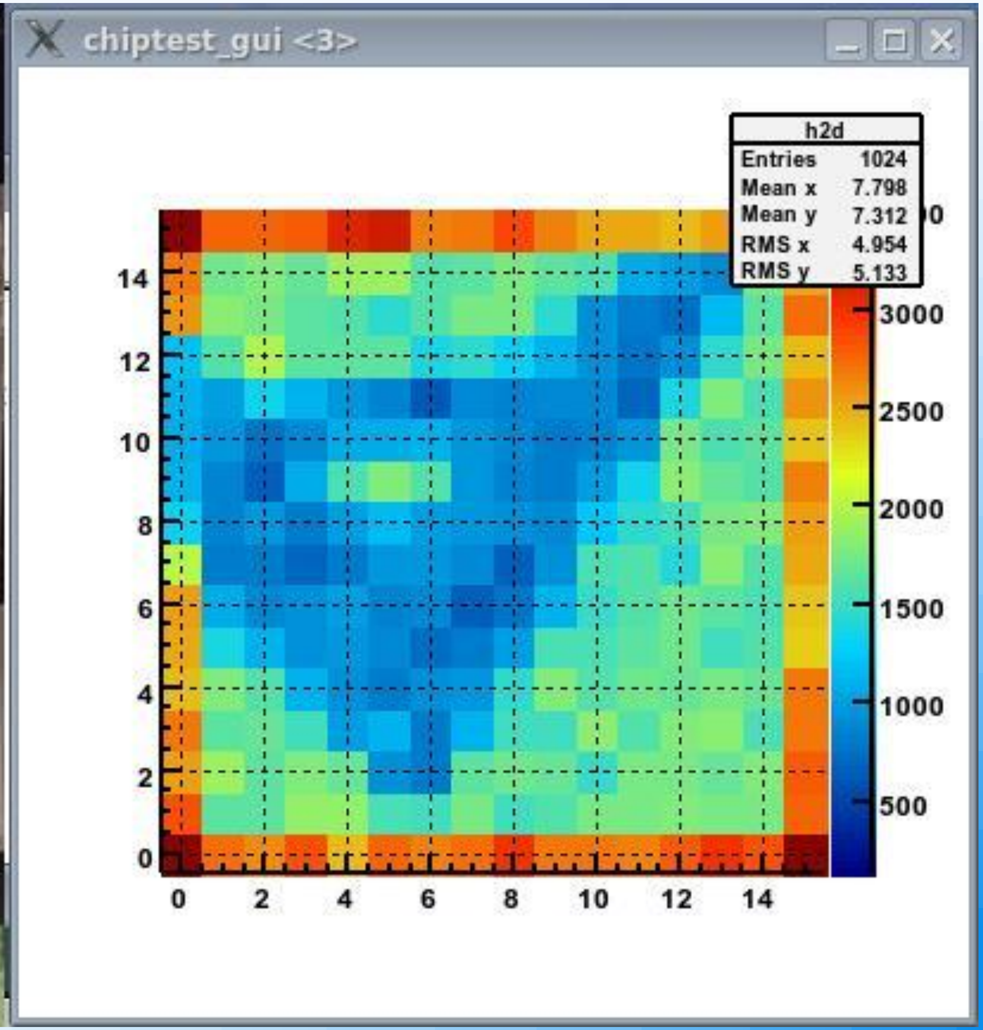
- Energy calibration
- Noise determination
- Pixel-to-Pixel variations
- Storage cells variations
- First imaging

AGIPD 0.3



- Radiation hardness of storage cells
- Test of the high speed serial control logic
- Test ongoing

Imaging with AGIPD 0.2



Outline (II)

- The AGIPD
  - XFEL challenges
  - AGIPD design
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What is HORUS?

- HORUS stands for:
  Hpad **O**utput **R**esponse f**U**nction **S**imulator
- Collection of IDL routines
- Designed to evaluate influences of certain design choices for AGIPD
- Expanded to allow simulations of High-Z sensors and photon counting detectors (Medipix3) by D. Pennicard

Design of HORUS

HORUS is a transparent detector simulation tool-kit:

- User provides an (oversampled) ‘input image’ containing the number of photons in each pixel
- HORUS produces an output image, i.e. the number of detected photons in each pixel
- Simulation parameters/behavior can by adjusted by the user
- Additional functionality with special options

HORUS processing chain

- Behavior of all steps can be modified
- Intermediate results can be accessed

new in version 2.0
new in version 3.0

Incoming photon distribution

- Provided by user
- Can be oversampled with respect to pixel size
- Quantized if necessary

Photon interaction in sensor volume

- Entry window
- Mean free path of photons
- Parallax
- Compton/ Thomson scattering (3%)*
- Fluorescence (4% of events)*

Charge transport in sensor volume

- Charge sharing
- Plasma effects
- Arbitrary CCE possible

ASIC and FE electronics

- Amplifier noise
- Dynamic gain switching
- Storage cells
- AD conversion

Requantized number of detected photons

- Requantization threshold

* 12.4 keV photons and 500 µm silicon

Additionally HORUS is:

- Using Monte Carlo and analytic elements:
  - Analytic treatment of charge transport and plasma effects
- NOT simulating the surrounding material (Bumps/ASIC/Module mechanics)
- Using a simplified sensor geometry
- NOT tested with whole scale AGIPD (doesn’t exist yet!), but:
  - Simulation results for Medipix3 match well
  - Test results from all AGIPD test chips are included

Outline (III)

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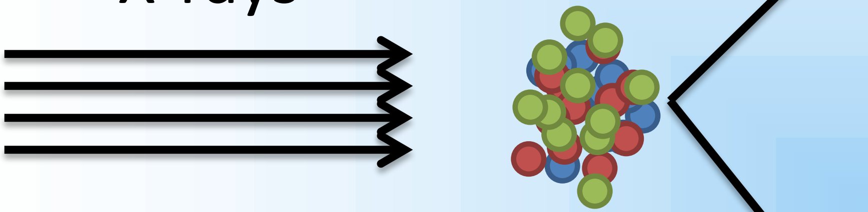
Scattering on many particles

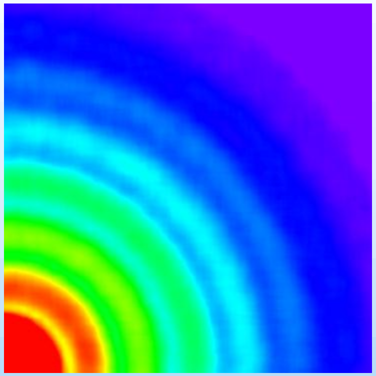
X-rays

Disordered sample



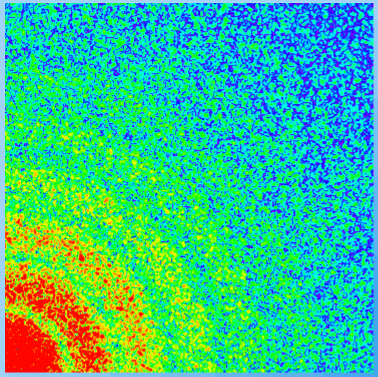
Acts like optical grating

Incoherent beam



Encodes average properties of the particles

Coherent beam

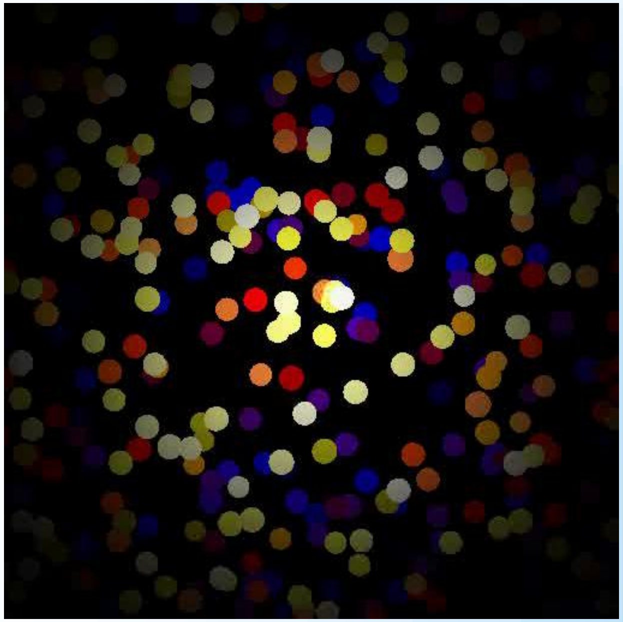


Additionally encodes position of each particle as ‘speckles’ on the average value

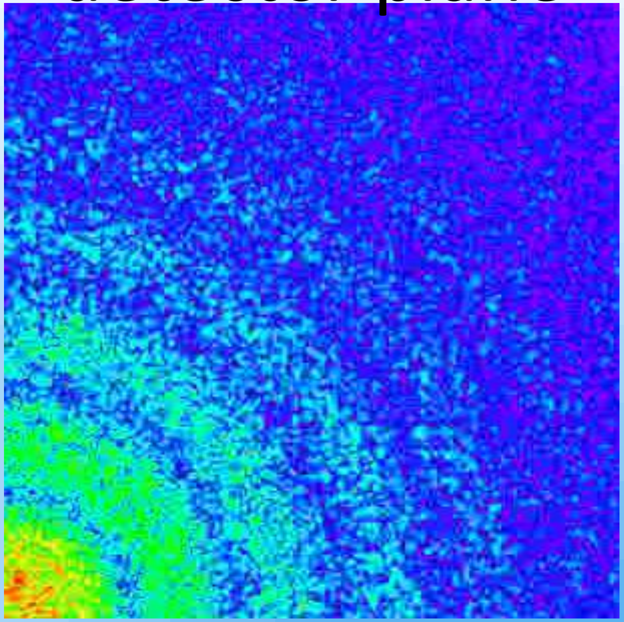
Changes in the positions of the scattering particles change the positions of the speckles

What is XPCS?

Real space



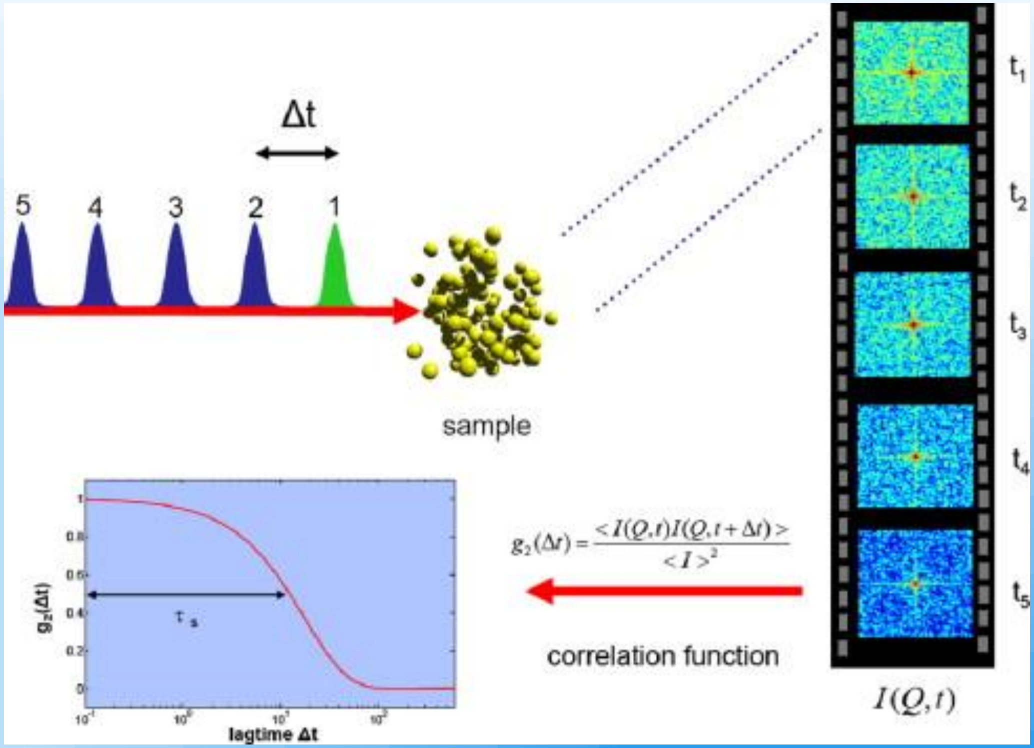
Log(Intensity) in detector plane



- Investigation of fluctuations in diffraction images
- e.g. molecular dynamics in soft matter
- Pump-probe XPCS
- Many more applications

How XPCS is performed

- Probe sample sequentially with non-destructive XFEL pulses
- Analyze image series using intensity autocorrelation (g_2 function)
- Functional form determined by interaction mechanism
- Extract time constant



Non-destructiveness requires large low intensity XFEL pulses
-> resulting speckles will be small

Detector requirements for XPCS

- 4 µrad angular resolution

  → 80 µm pixel size at 20m distance

  X AGIPD Pixel size is 200 µm
- Single photon sensitivity

  ✓ Provided by AGIPD
- Very high frame rate

  ✓ Single pulse imaging possible with AGIPD
- Acquisition of image sequence

  ✓ More than 300 images stored per train

XPCS Simulations

1. Generate and evolve real space system
2. Calculate complex wave form in the detector plane (Fourier transform)
3. Scale and quantize wave form to produce discrete photon distribution
4. Use the photon distribution in the detector simulation (HORUS)
5. Evaluate output data and derive a figure of merit

Key simulation parameters

- Linear sequence of 300 images
- 5 independent pulse trains
- Infinite coherence length (long./lat.)
- Small angle scattering approximations
- Incoherent noise of 10^{-2} γ/pixel/frame
- Speckle size of ≈ 150 µm FWHM

→ At 20m distance: ≈ 13 µm FWHM beam

Figures of merit (I)

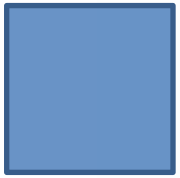
Signal to noise ratio of the g_2 function

- Analytic expression available for low intensities
- Has been successfully used for many years

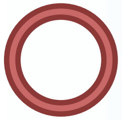
Relative error of the correlation constant

- Relevant physical parameter
- Essential for error determination on derived parameters like hydrodynamic functions etc.

Region of interest

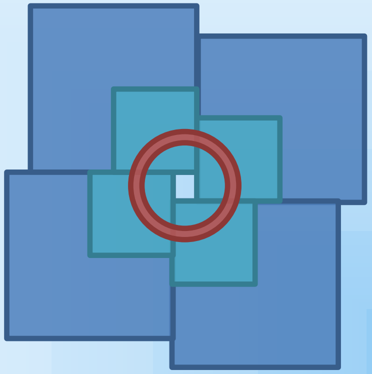

Quadrant of
200 µm pixels
(AGIPD, MAAT)


Quadrant of
100 µm pixels
(RAMSES)


Region of
Interest

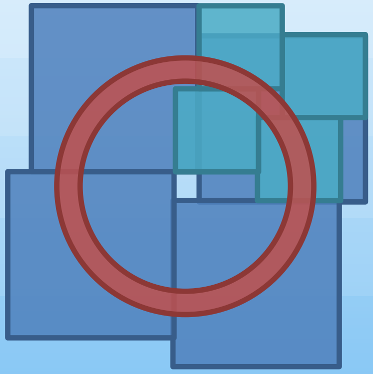
MAAT =
AGIPD + aperturing to
100 µm effective pixel
size

Small ROI



Limited by
pixel density

Large ROI



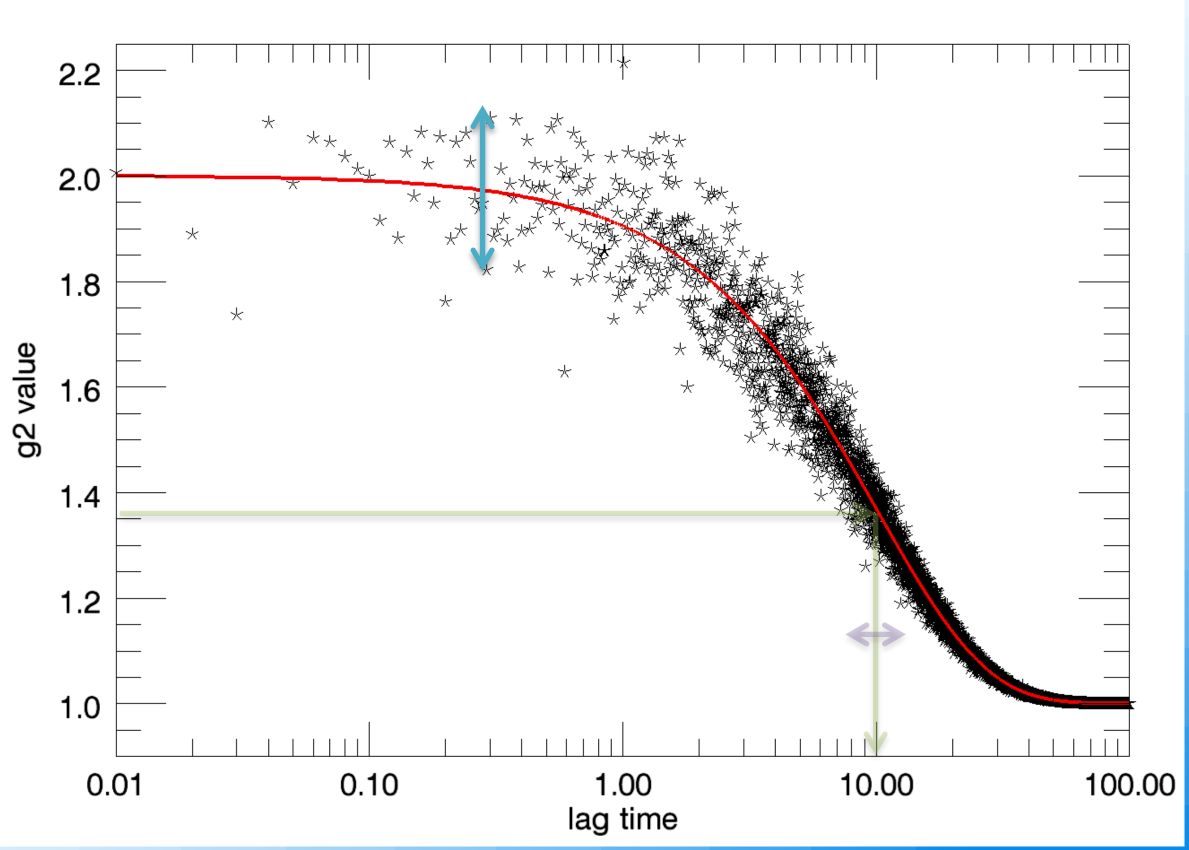
Limited by
total area

Figures of merit (II)

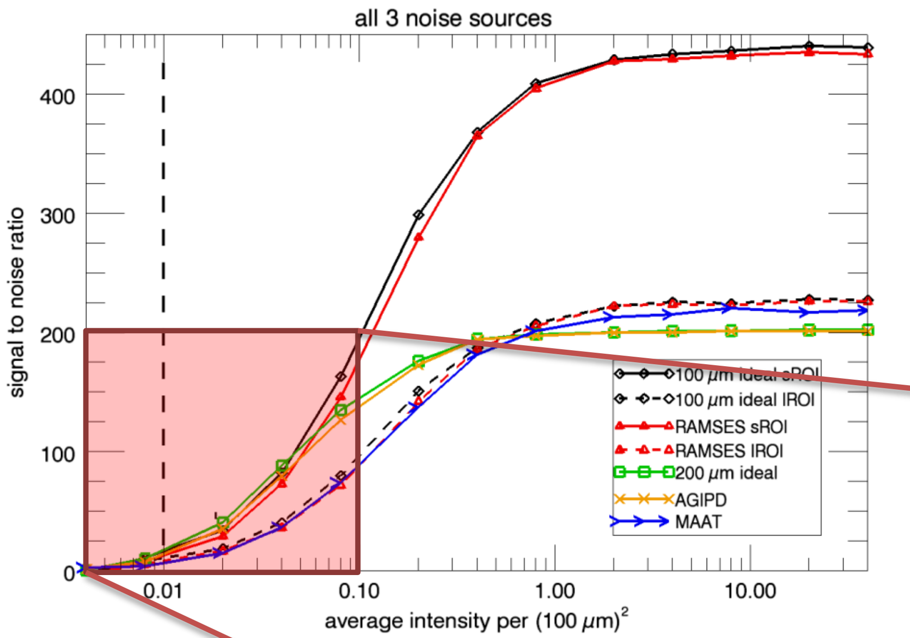
The signal to noise ratio is derived from the dispersion of g2 values (blue arrow)

$$SNR \stackrel{\text{def}}{=} \frac{g_2 - 1}{err(g_2)}$$

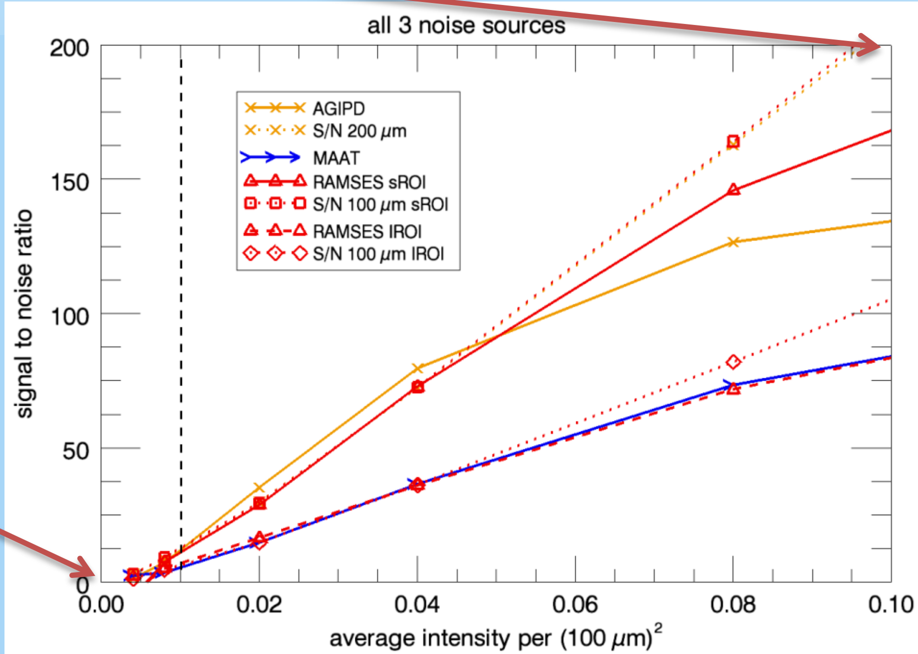
The relative error of the correlation constant is the error of fit result (violet arrow)



Signal to noise ratio



- Higher values indicate better quality
- Noise level at dashed vertical line
- S/N saturates around <I> ≈ 1
- At low intensities 200 µm pixel systems have higher S/N than 100 µm systems



Analytic expression (dotted)

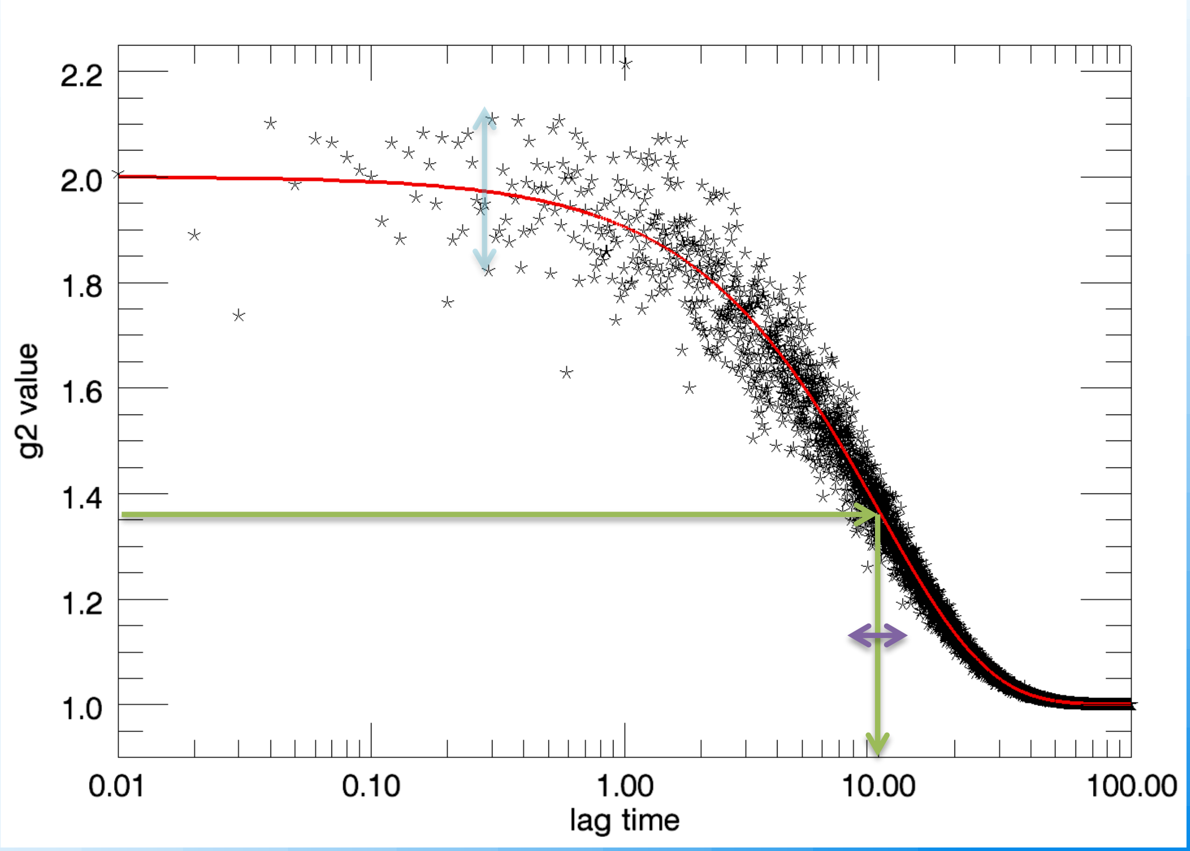
$$SNR \stackrel{\text{def}}{=} \frac{g_2 - 1}{err(g_2)} \propto C < I_p > \sqrt{N}$$

valid for low intensities

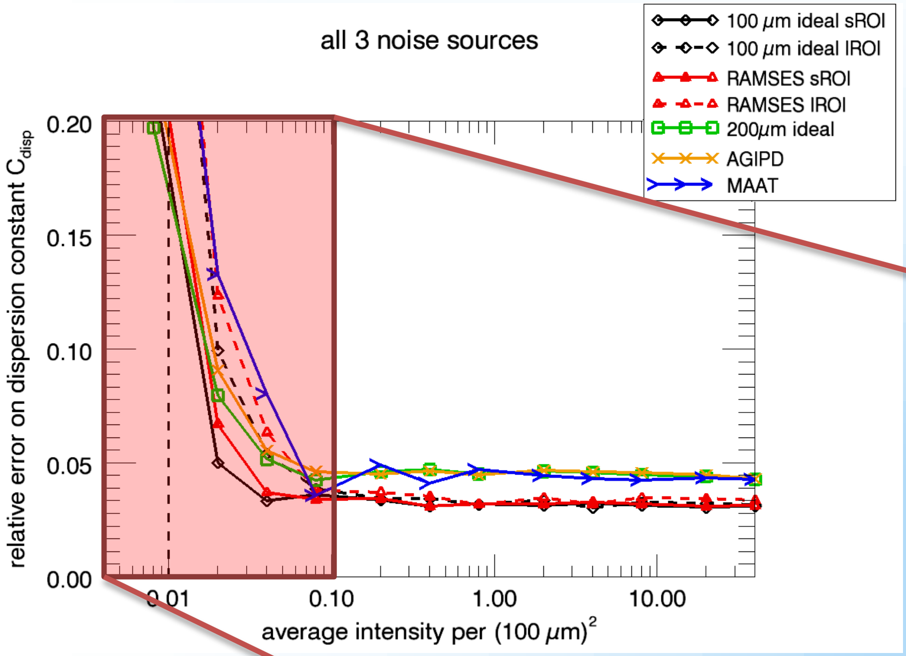
Figures of merit (III)

The signal to noise ratio is derived from the dispersion of g2 values (blue arrow)

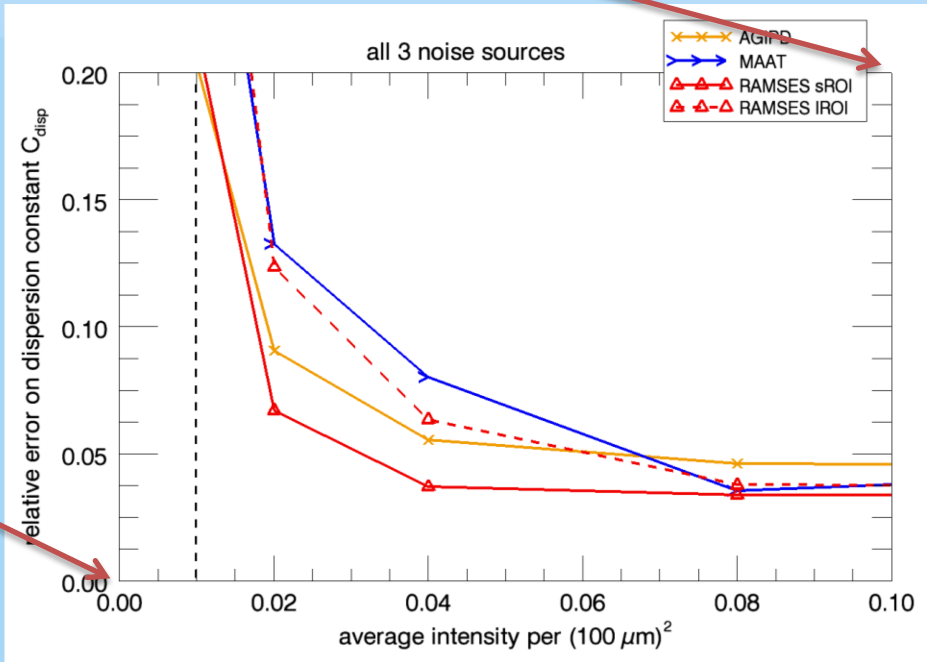
The relative error of the correlation constant is the error of fit result (violet arrow)



Relative error



- Lower values indicate better quality
- Noise level at dashed vertical line
- Error saturates around <I> ≈ 0.1
- Lower saturation value for small pixels
- AGIPD lower than RAMSES for large ROI and low intensity



- No analytic expression available
- Relevant quantity for further data evaluation (diffusion constants, hydrodynamic functions, etc)

Conclusions for XPCS

- XPCS insensitive to FEL fluctuations (not shown)
- Aperturing not beneficial at low intensities
- S/N and relative error behave differently
- Both saturate, but at different intensities
- Better performance of AGIPD at low intensities comp. to 100 µm pixel version
- Paper under review
  preprint: http://arxiv.org/abs/1108.2980

Summary

- Progress on AGIPD test chips
  - Verified basic circuit blocks
  - Verified gain switching
  - First imaging capability demonstrated
- Progress on HORUS code
  - Included Compton/Thomson scattering
  - Included fluorescence
- Published first results on XPCS
- AGIPD suitable for XPCS

Acknowledgements

AGIPD Collaboration

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Julian Becker	Roberto Dinapoli	Marcus Gronewald
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Stefanie Jack	Bernd Schmitt	Joern Schwandt
Sabine Lange	Xintian Shi	Jiaguo Zhang
Alessandro Marras		
Ulrich Trunk		

HORUS was initially designed by:
Guillaume Potdevin, TU Munich

We're looking for PostDocs on:

- AGIPD calibration
- Low energy Detectors

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