Update on Science requirements Noise behavior analysis

AGIPD meeting

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PSI, 15/09/09

Content

> Noise budget analysis

- Noise budget analysis
  - Static noise (no photon noise)
  - Dynamic noise (as function of intensity)
- (few) Calibration considerations

> Dose Predictions

- Predictions
- Dose on HPAD 0.1

> Science requirements:

- CDI
  - Intensity distribution within the pixel / peak width
- XPCS
  - Small pixel version of the AGIPD
  - Pixel masking option
- Background simulations
- 2nd detector

Noise budget analysis:
General detector signal fluctuations analysis

Two cases to consider:

- 0 intensity noise ie. *False hits*
  - **HAS TO BE 0**

- N photons intensity response spread
  - Must be smaller than the intrinsic signal fluctuations (poisson)

Noise budget analysis:
False hits

Contributions:

> Sensor Leakage. If assuming

- 100nA/cm^3 so **1pA per pixel**

⇒ ~ **1 electron /pixel/picture**

> Amplifier noise

- **150 electrons /pixel/picture**

> Analog pipeline storage

- No number so far…

> ADC converter

- 4.6LSB / 14bit
- Dynamic range Amplifier: **1V**

⇔4.6/195*3300

⇔ **77 electrons**

So for *1750 electrons signal*

- **5 σ** ie. Luxury

  $\text{Noise}_{\text{Analogue\_Pipeline}} < 305$ **electrons**

- **3.5 σ** Minimal, ⇔ **~ 1 false hit/picture**

  $\text{Noise}_{\text{Analogue\_Pipeline}} < 470$ **electrons**

Noise budget analysis: General detector signal fluctuations analysis

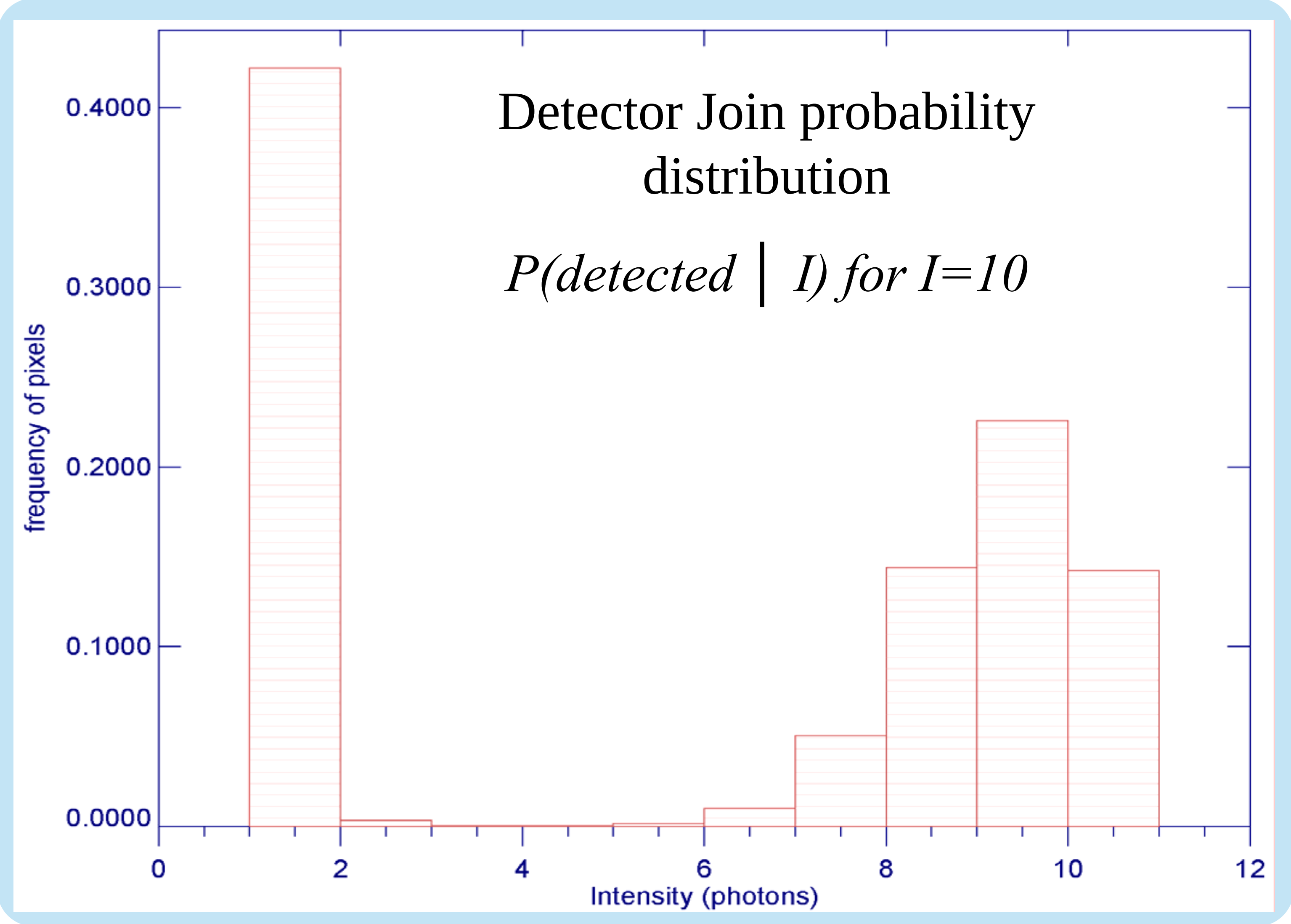
- N photons intensity response spread
  - Measured as:

$$\boxed{\sigma_{\det} = \sqrt{\frac{1}{N-1}\sum_{N\ pixels}\left(I_N - \overline{I_{output}}\right)^2}}$$

  - Must be smaller than the intrinsic signal fluctuations (Poisson)
  - Mostly a consequence of the sensor imperfections

(charge sharing, parallax, limited quantum efficiency, etc…)

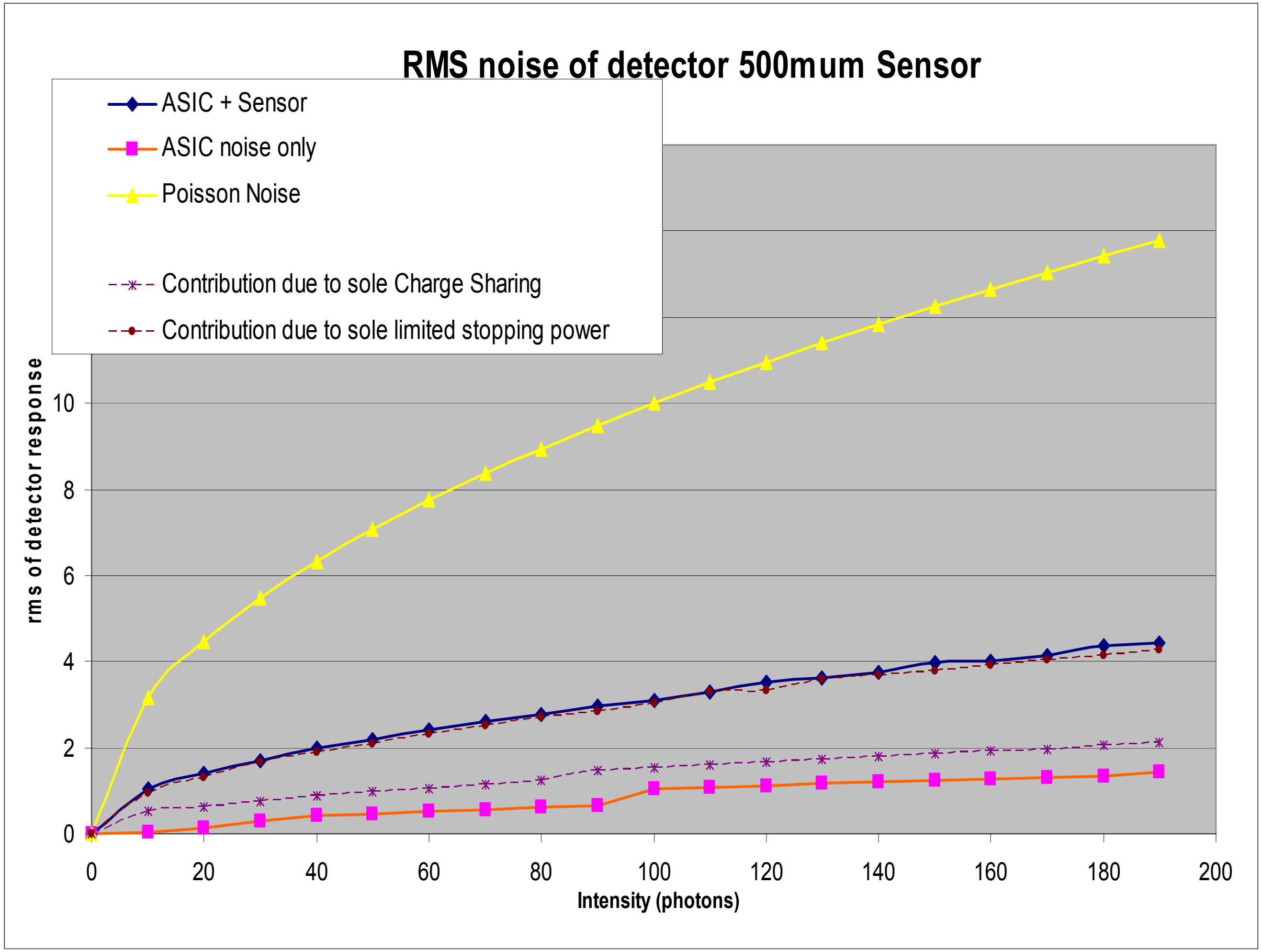
Example
Detector response spreading to 10 photons Intensity


Detector Join probability distribution

$P(detected \mid I)$ for $I=10$

Noise budget analysis:
Signal fluctuations

In photons unit (for electrons @12keV, multiply by 3300)



At low Intensities, Sensor noise dominates

Noise is dominated by

> Limited stopping power

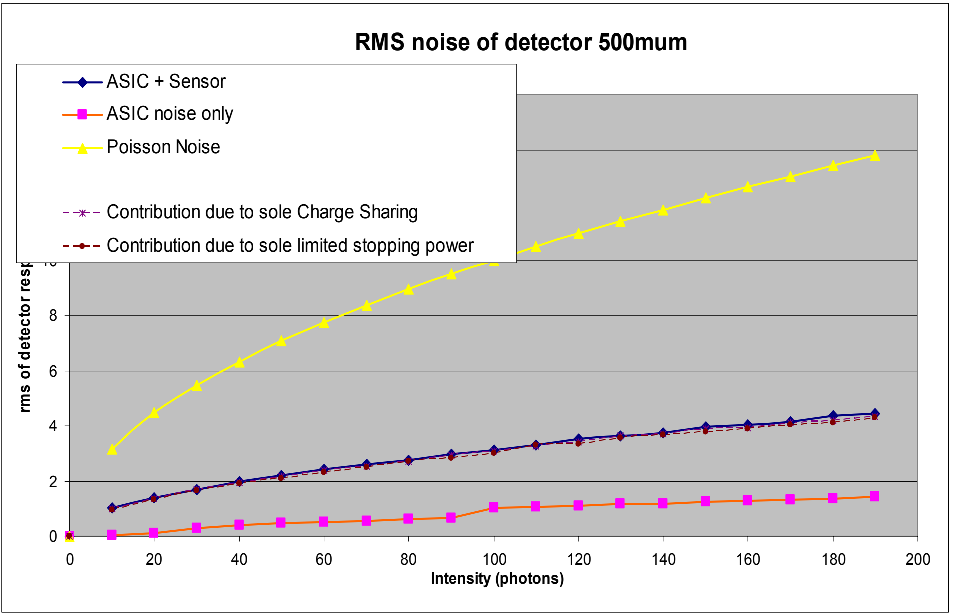
To a less extend a contribution of

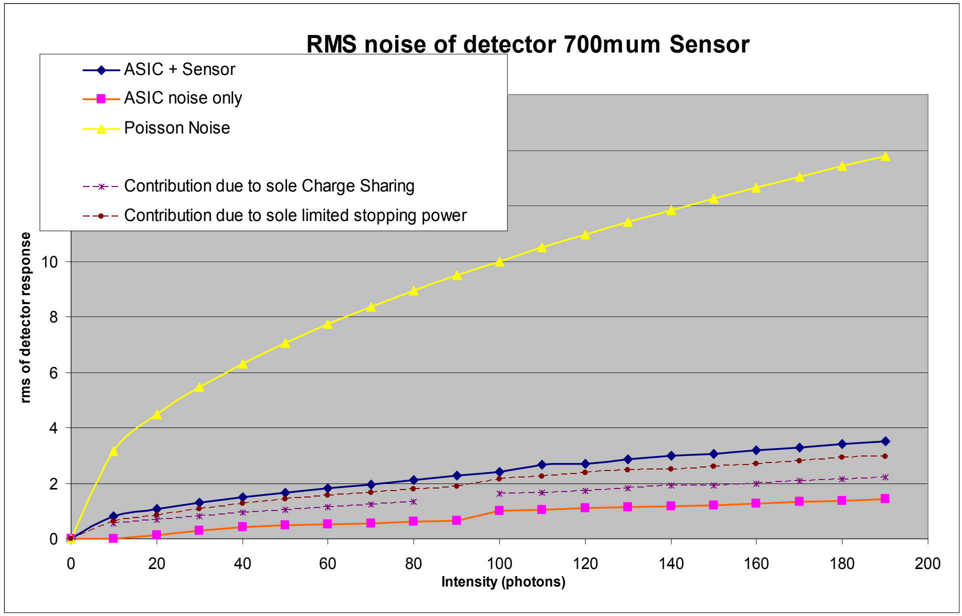
> Charge sharing

> Parallax

> Electronics noise
(ASIC + ADC)

Noise budget analysis:
500µm vs. 700µm





Same noise behaviour:

> Loose on the Charge sharing side, but gain on the Quantum Efficiency

> **Decision should be driven by Transient noise analysis and Pulse shape considerations**
> *See nice talk by Julian Becker*

Noise budget analysis: Conclusion

> For ASIC:

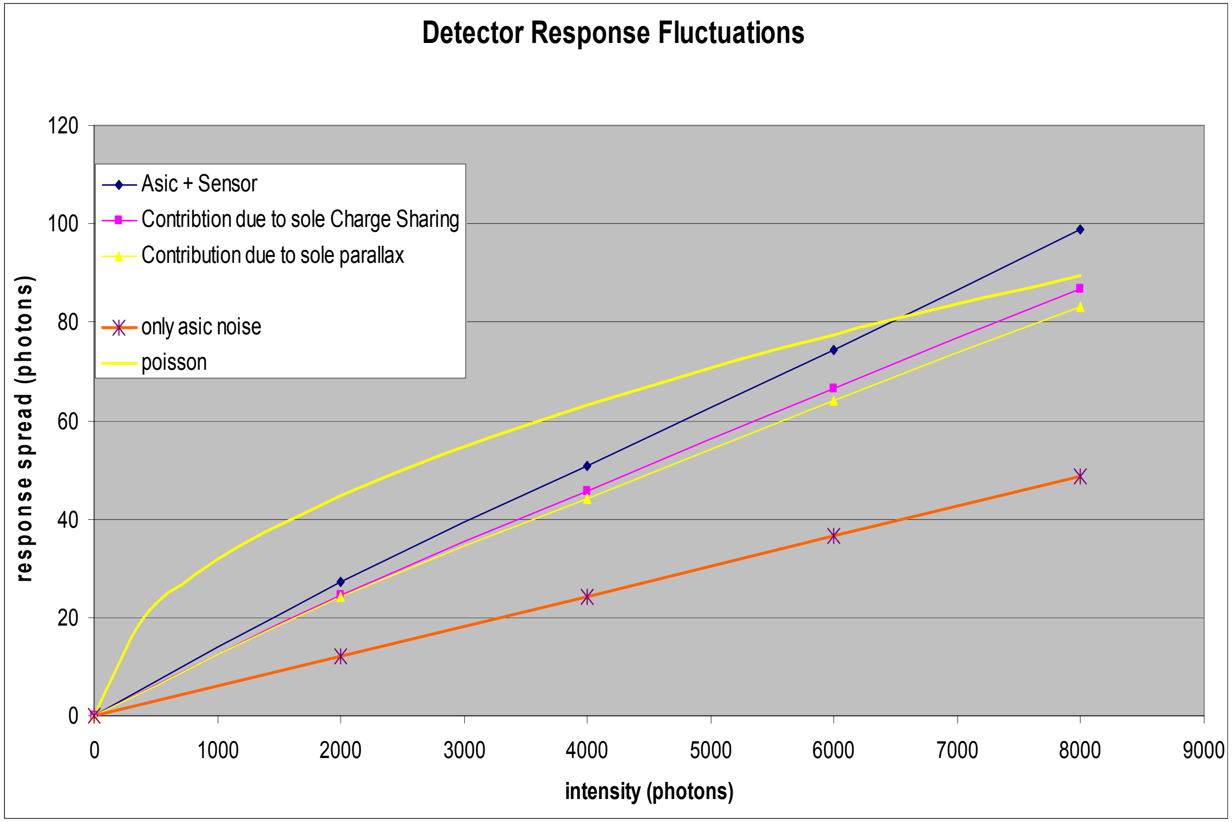
- *Hard constrain to keep false hits low.* **$\sigma < 350\ e^-$**
- For I > 1 should not be a problem
- Transient noise is an issue
- *Memory effect* are an issue
  Can be limited by taking pictures every 400ns for example

> For Sensor:

- 700µm / 500µm is equivalent as of the scientific point of view

Detector calibration:
Detector error at high intensities: Calibration

In photons unit (for electrons @12keV, multiply by 3300)



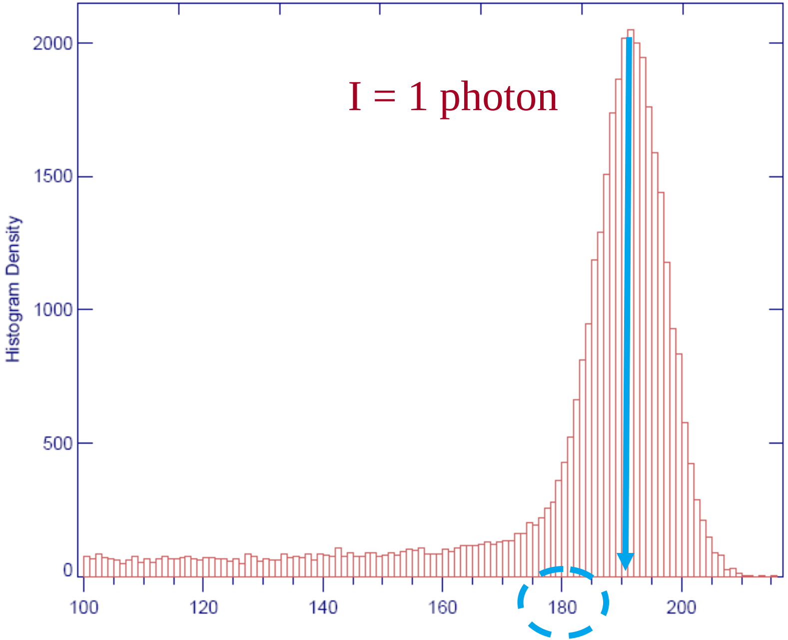
Problem for I> ~300

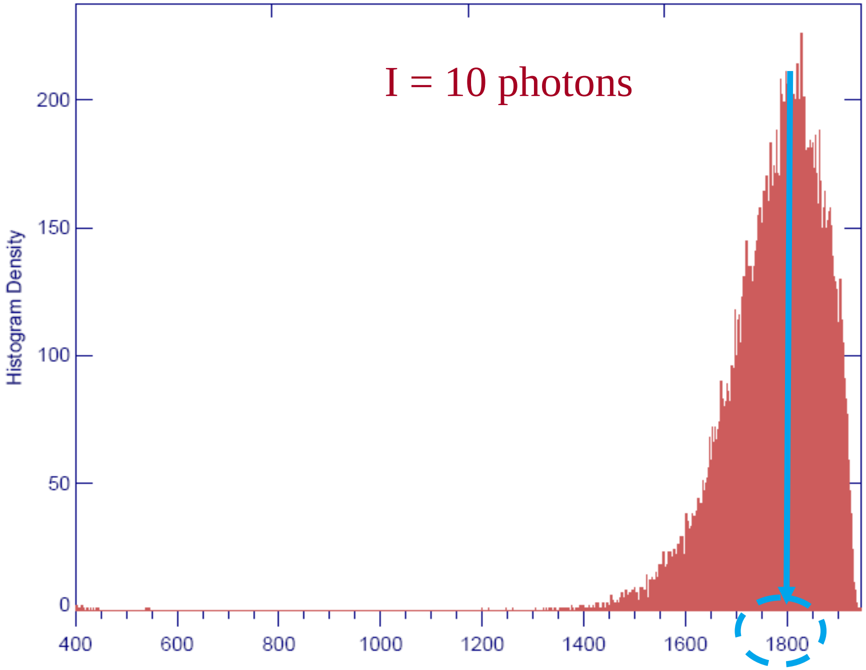
Charge sharing, Storage cells leakage… modify the gain.

The mismatch between real and expected gain increases linearly
⇒ So does the noise

Detector calibration:
Gain correction

In photons unit (for electrons @12keV, multiply by 3300)





Intensity (ph)	Theoretical Gain	Measured Gain
1	192	178
10	1928	1790
20	3858	3350
50	9642	8300

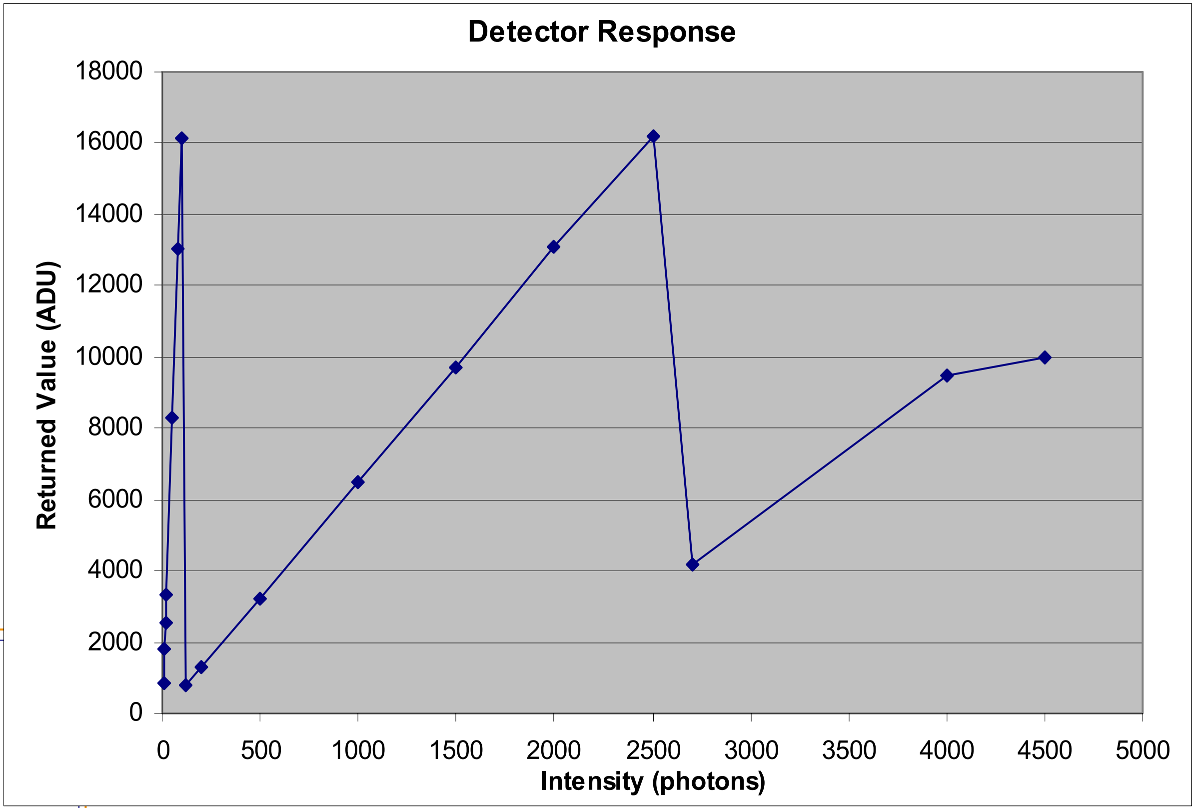
$$G = \frac{Signal\ [\text{ph}] \cdot \{11.9,\ .46,\ 0.11\}}{\frac{1}{2^{14}} \cdot Amplifier\quad Dynamics}$$

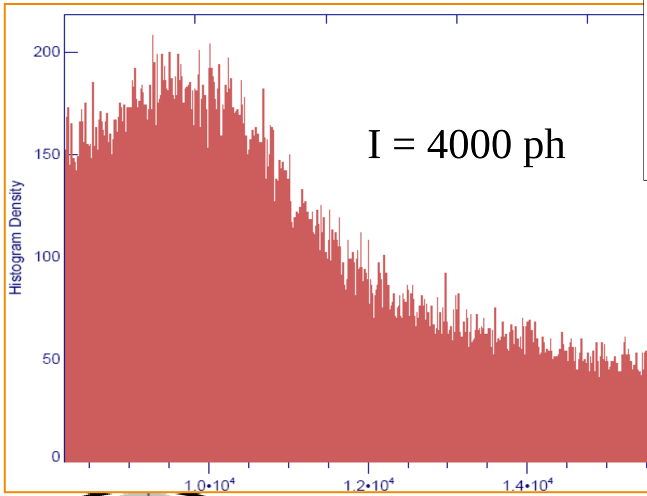
Gain (ADU/photons)	192	linear

Detector calibration: Gain correction

Model taken:

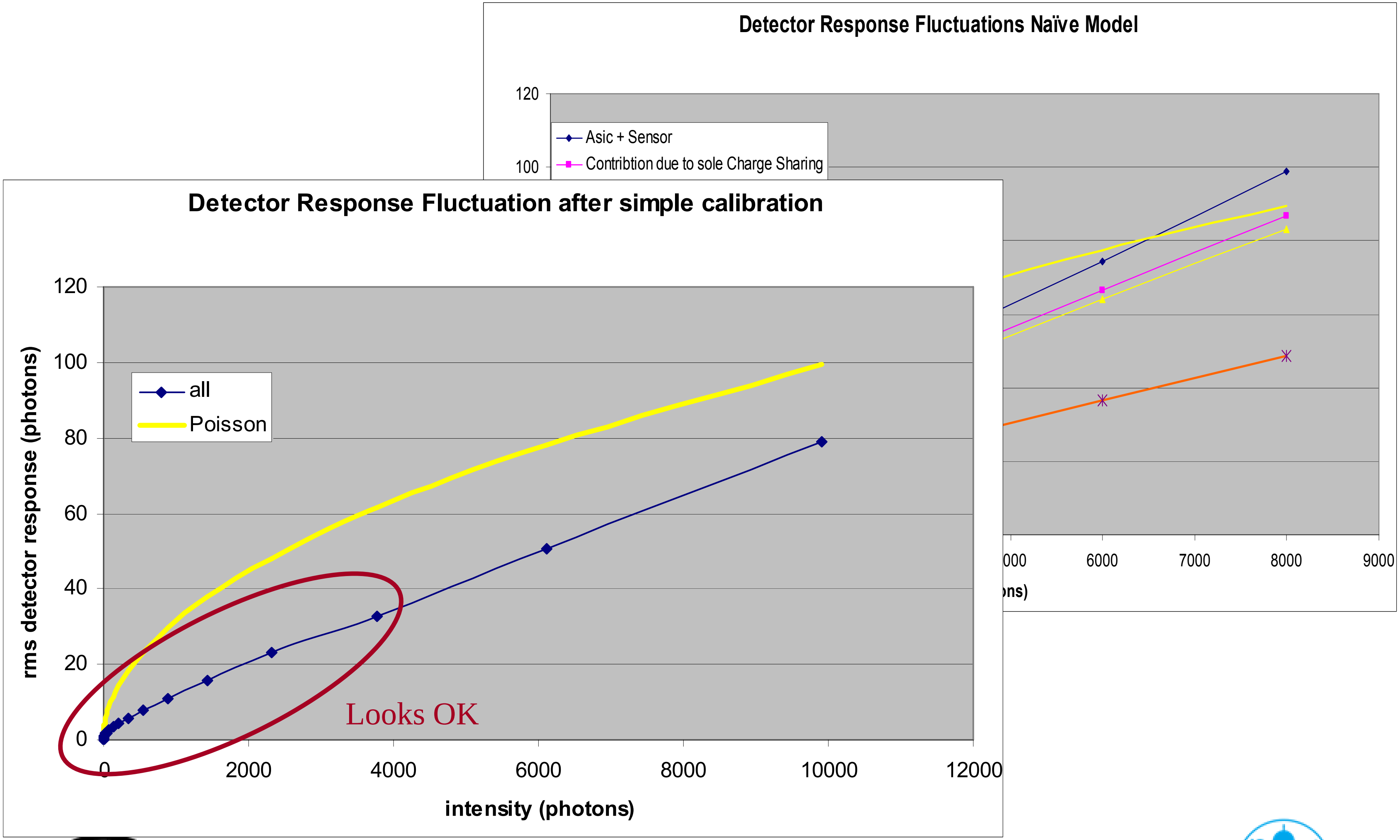
- First Gain (fit data)
  - **ADU = 181 I**
- Second Gain (extrapolated)
  - **ADU = 7.43 I**
- Third Gain (extrapolated)
  - **ADU = 1.77 I**





The detector behavior at high intensities is not yet fully understood cf. Broad response

Detector calibration:
Calibrated detector response fluctuations



Detector calibration:
Procedure, a few thoughts

- Energy Calibration
  - Radioactive source

- Voltage Droop
  - Internal to ASIC?

- Gain Calibration
  - Internal to ASIC?
  - Using flat field, and statistics fluctuations?

  - What about high flux??

Detector calibration:
Procedure, a few thoughts

Reminder of last time

Noise is an acceptable fact within some limits. ***Calibration is what matters***

"Better a noisy but well calibrated detector than a good poorly calibrated detector"

Ultimate Information is the Joint probability distribution:

- X is the True Mean Count ~ *"Intensity" and its associated "Statistics" (eg. Poisson)*
- Y is the Actual Detector Count

P(X,Y) is the statistical distribution of the detector response for X.

P(X,Y) is explicitly written in the reconstruction algorithm.

> Horus can do this if we have the real detector parameters
ie. a good calibration data set

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Dose expected

> Still a moving target. Will depend on:

- Quality of particle injectors
- Size of samples being studied
- Up time of the experiments / beamtime

> Following calculations made considering the ferritine 5x5x5 nano crystal which gives already a strong signal ⇔ good SNR.

> How do you measure/calculate a dose with photons ???

- Here only the number of photons infringing
- There was a calibration problem in the **HPAD 0.1** dose measurements

~~Dose expected~~ nb photons expected

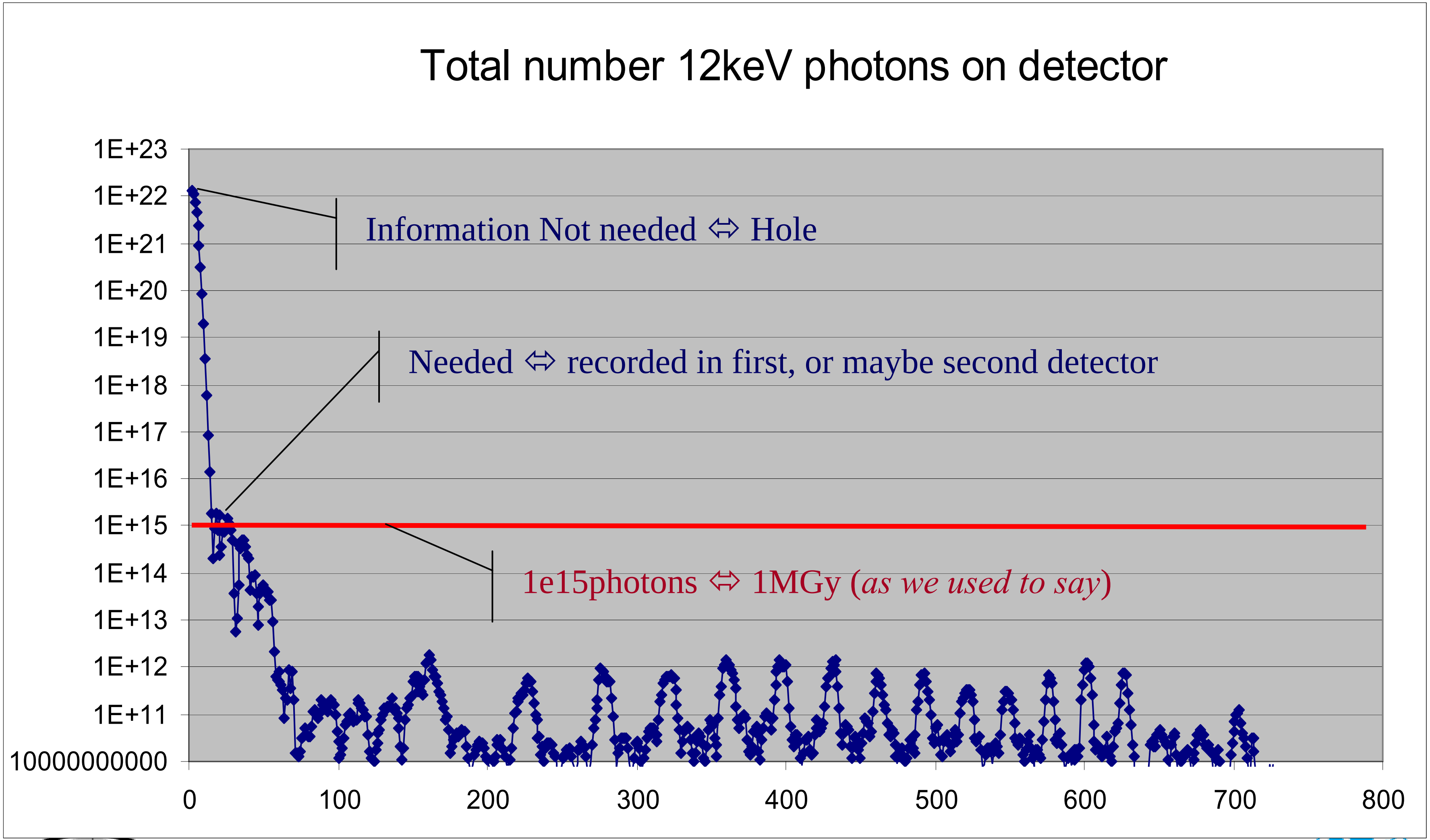
- Some assumptions:

Pixel Number	Pix Intensity/Shot (photons)	Background photons	days in 3 years * Machine availibility	uptime hours/days	shots /hour	experiment efficiency (hit/miss)	Photons on sample	Energy on sensor
	From Ferritine 5x5x5	**From simulations**	**0.8 * 3 * 365**	**0.7 * 24**	**1e3 * 60 * 60**	**8.00E-01**	**C9*D9*E9*F9 +B9*G9*D9* E9*F9**	**H9 * 12keV * 1.6e-19**
1	3.00E+10	1.591596371	876	16.8	36000000	0.8	1.27E+22	2.44E+07
2	2.60E+10	0.795798186	876	16.8	36000000	0.8	1.10E+22	2.12E+07
3	1.80E+10	0.530532124	876	16.8	36000000	0.8	7.64E+21	1.47E+07
4	1.08E+10	0.397899093	876	16.8	36000000	0.8	4.56E+21	8.76E+06
5	5.56E+09	0.318319274	876	16.8	36000000	0.8	2.36E+21	4.53E+06
6	2.16E+09	0.265266062	876	16.8	36000000	0.8	9.14E+20	1.75E+06
7	7.08E+08	0.22737091	876	16.8	36000000	0.8	3.00E+20	5.76E+05
8	2.01E+08	0.198949546	876	16.8	36000000	0.8	8.53E+19	1.64E+05
9	4.44E+07	0.176844041	876	16.8	36000000	0.8	1.88E+19	3.61E+04
10	8.39E+06	0.159159637	876	16.8	36000000	0.8	3.56E+18	6.83E+03
11	1.40E+06	0.144690579	876	16.8	36000000	0.8	5.91E+17	1.14E+03
12	198191	0.132633031	876	16.8	36000000	0.8	8.40E+16	1.61E+02

Optimistic for experiment / pessimistic as of dose

~~Dose expected~~ nb photons expected

- Plotted



Information Not needed ⇔ Hole

Needed ⇔ recorded in first, or maybe second detector

1e15photons ⇔ 1MGy (*as we used to say*)

Dose on HPAD 0.1

Some mistake was made during the calibration of the dose absorbed by the ASIC

- 250µm Si were considered for Absorption of light instead of ASIC thickness
- The spectrum considered (doris BM –filtered) is harder than the XFEL beam

⇒ The dose received by HPAD 0.1 has to be diminished by **a factor 20** to scale with real XFEL experiments

The flux calibration could not be recalculated, but was cross-checked with a PIN diode during measurement,

So should be good.

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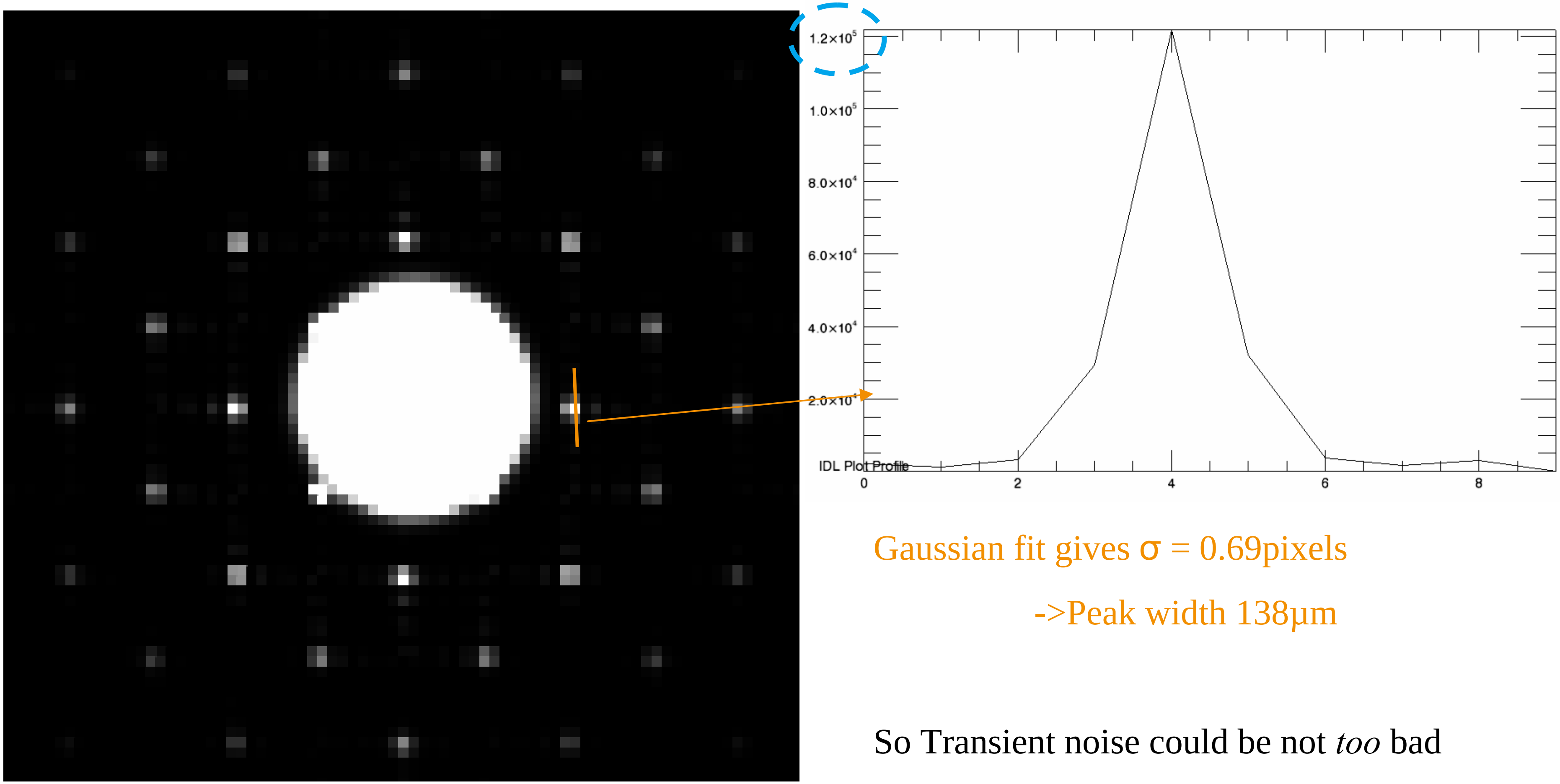
Coherent Diffraction Techniques

- Peaks shapes

10^5 photons



Gaussian fit gives σ = 0.69pixels

->Peak width 138µm

So Transient noise could be not *too* bad

XPCS requirements
Noise requirements

~~*Definition of* ***"Single photon Sensitivity"***~~

- ~~*For us it has always meant* *Better than Poisson noise*~~

- ~~*But for them, a set of data exhibiting Poisson Noise means exactly*~~
  - ~~*The beam is not coherent*~~
  - ~~*There is absolutely no correlation in the data set*~~

~~*This means **they are measuring "things" with a precision better than Poisson Statistics***~~

Depending on the measurement regime, the signal will exhibit

> *Poisson Statistics*

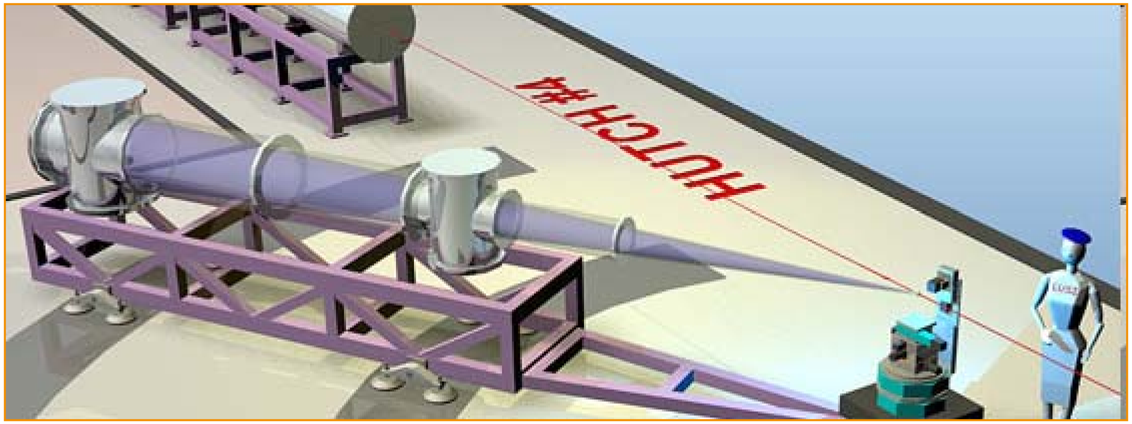
> *Negative exponential statistics*

XPCS requirements
Pixel Size requirements

- XPCS experiments do **NOT** need
  - Large dynamic: $<10^2$ would be fine
  - Many stored pictures ~80 would be fine

- But they **DO** need
  - Small pixels <80µm
  - *Low* AND *high q* information
    Move detector in 2Θ

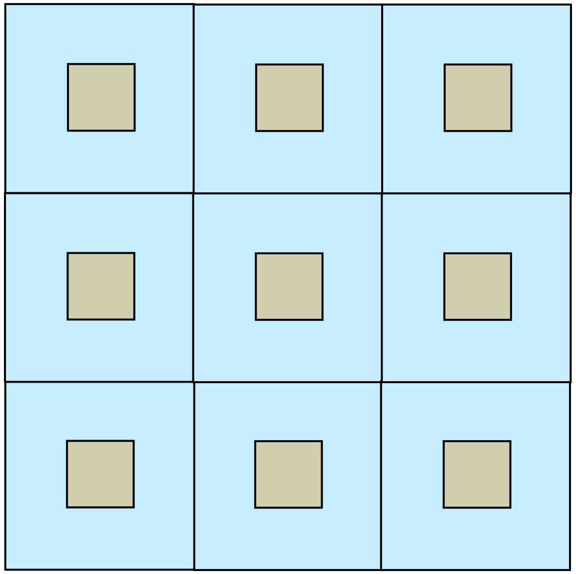
- Would *love* to
  - Get Peak shape



XCS setup @LCLS One arm rotates in 2Θ

XPCS requirements: Case of masked pixels

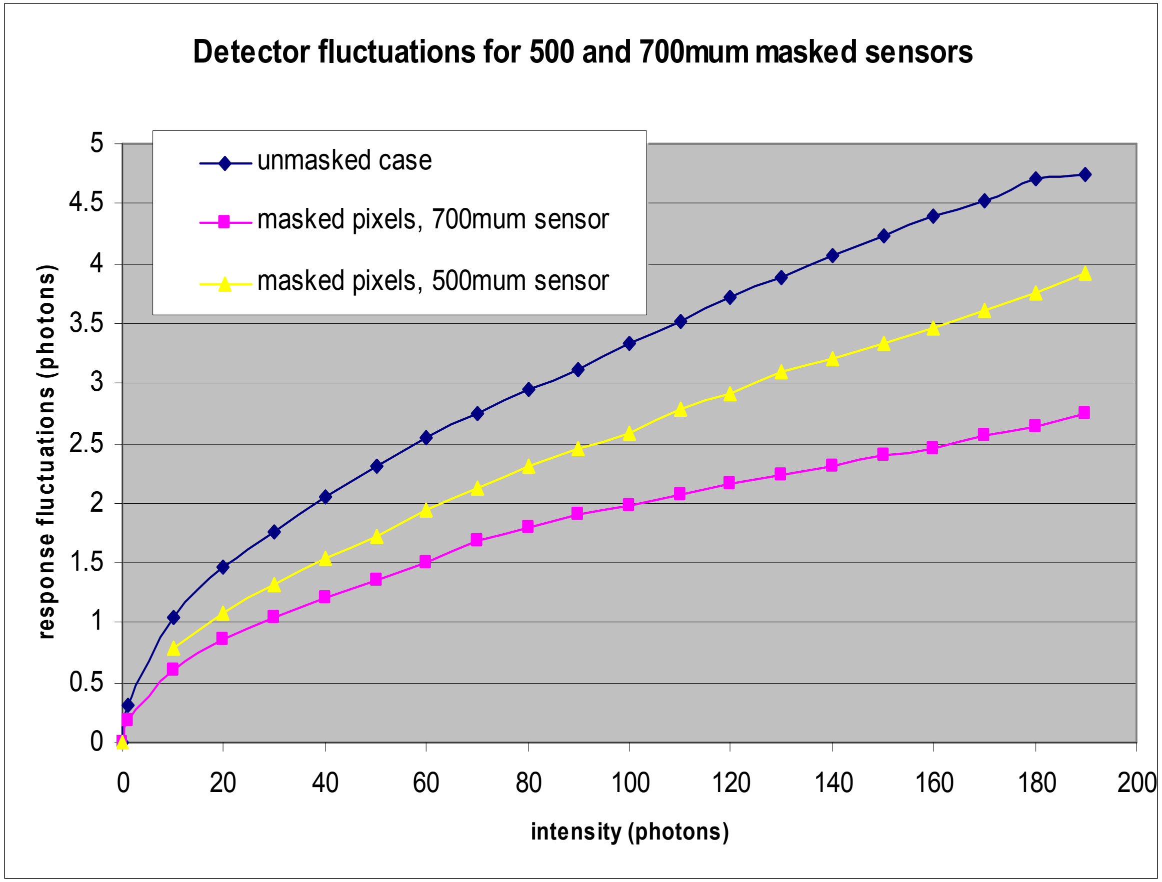
Mandatory solution if no small pixels



Noise$_{\text{masked}}$ ~ 2/3 Noise$_{\text{normal}}$

Signal$_{\text{masked}}$ ~ 1/4 Signal$_{\text{normal}}$

SNR$_{\text{masked}}$ ~ SNR$_{\text{normal}}$ / 3



We also loose ¾ of the signal ⇒ SNR is reduced by factor 3

Loose the ability to get peak shape

Background Simulation

Background was evaluated:

- Scattering by residual gas is negligible

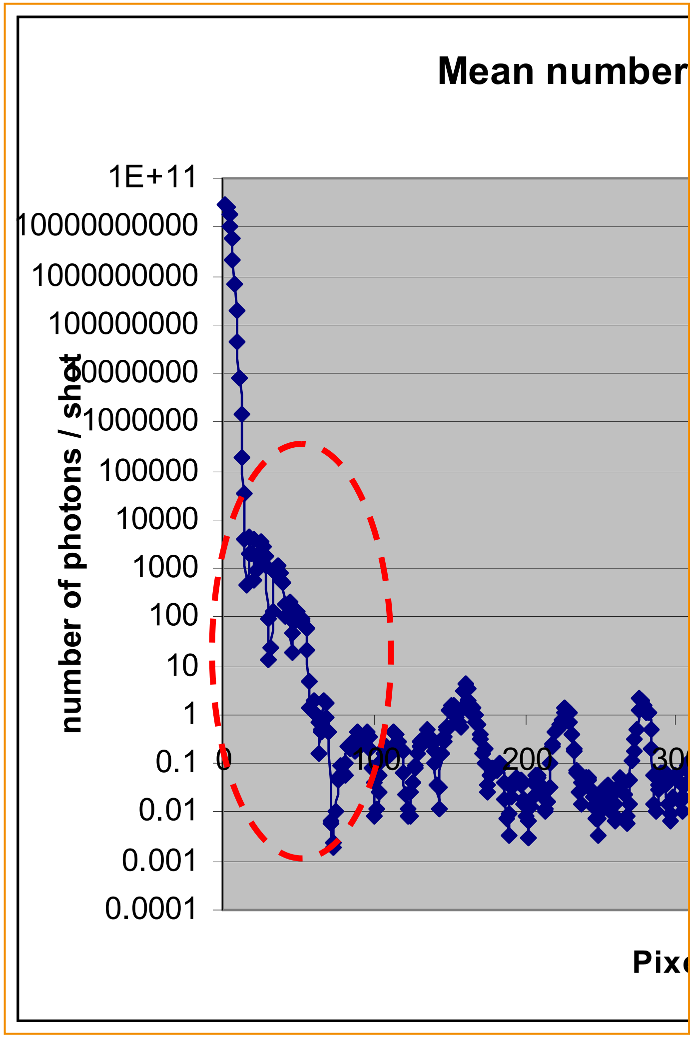
- Scattering by optics can reach several photons per pixels depending on the scenario:
  - Distance to optics
  - Surface finishing
  - Number of optics elements

Conclusion, does not impact us

Can be a problem for Data compression (no zeros)

Can be a major issue for application scientists!

Second detector



Need to record low q information

- Must have a large pipe through the readout electronics
- Will suffer from radiation damages
- It is not clear whether an absorber can be used.
  - Wave front preservation
  - No single photon sensitivity
  - … ??