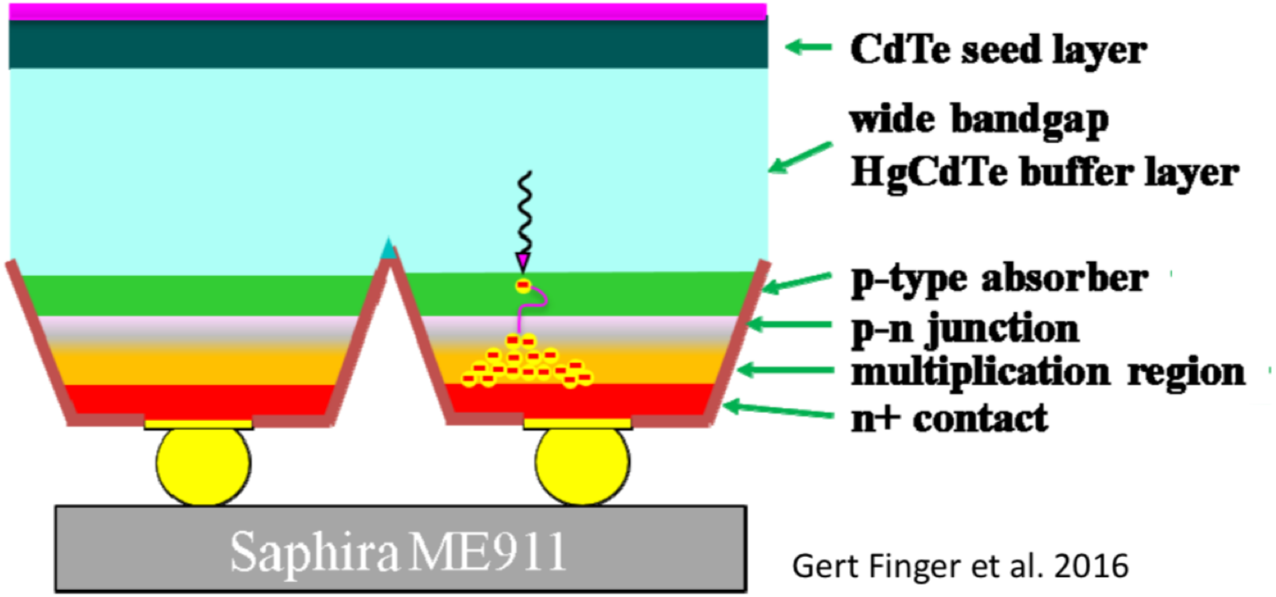
Characterization of the new e-APD camera of MIRCX

By Lanthermann Cyprien

e-APD



Gert Finger et al. 2016

http://www.wayneflannavalancheblog.com

Bias voltage in the multiplication region accelerate the electron

⇒Collision ionization

⇒Avalanche effect

Characterized by :

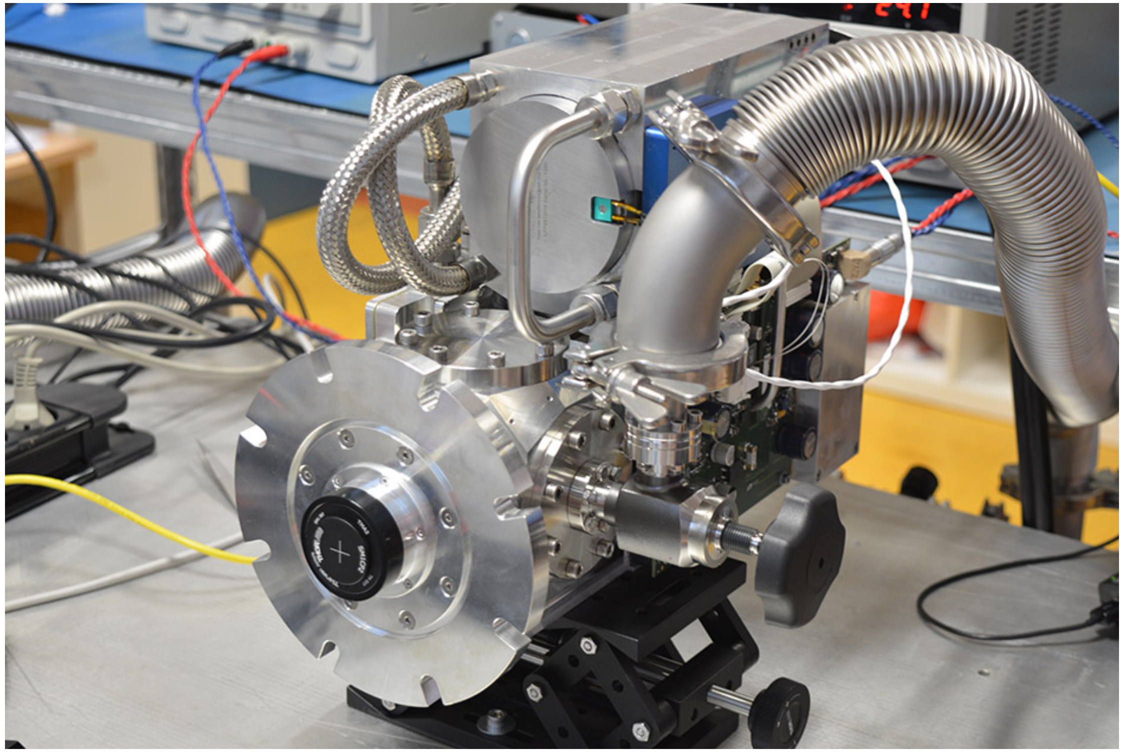
- Avalanche Gain
- Excess Noise Factor (ENF)

Camera characteristics

- Instrument MIRCX
- Developed by First Light Imaging (FLI)
- H band

Manufacturer characteristics :

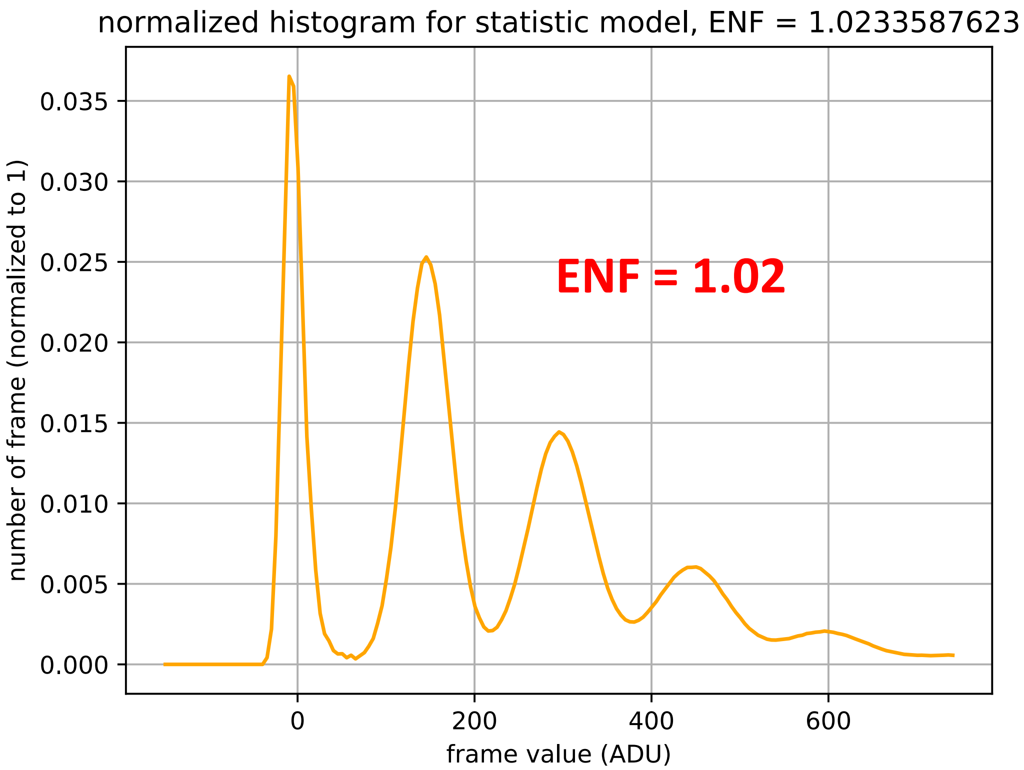
- Avalanche gain up to 300
- System Gain : 0.77 ADU/e-
- ENF around 1.3
- FPS max of 3.5 kHz
- Dark current < 200 e-/pixel/s
- Read out noise < 1 e-/pixel/read

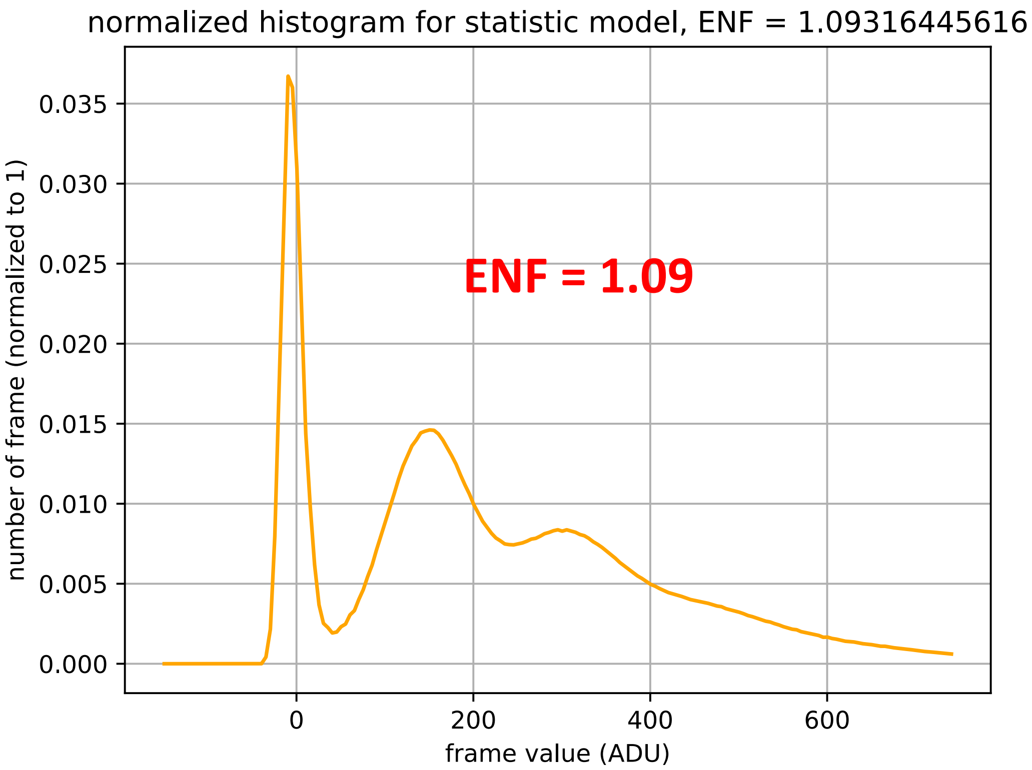


Photon counting : statistical model

Simulation input :

- Gain = 150 ADU e-
- Flux = 1.5 e-/frame
- Background noise = 18 ADU

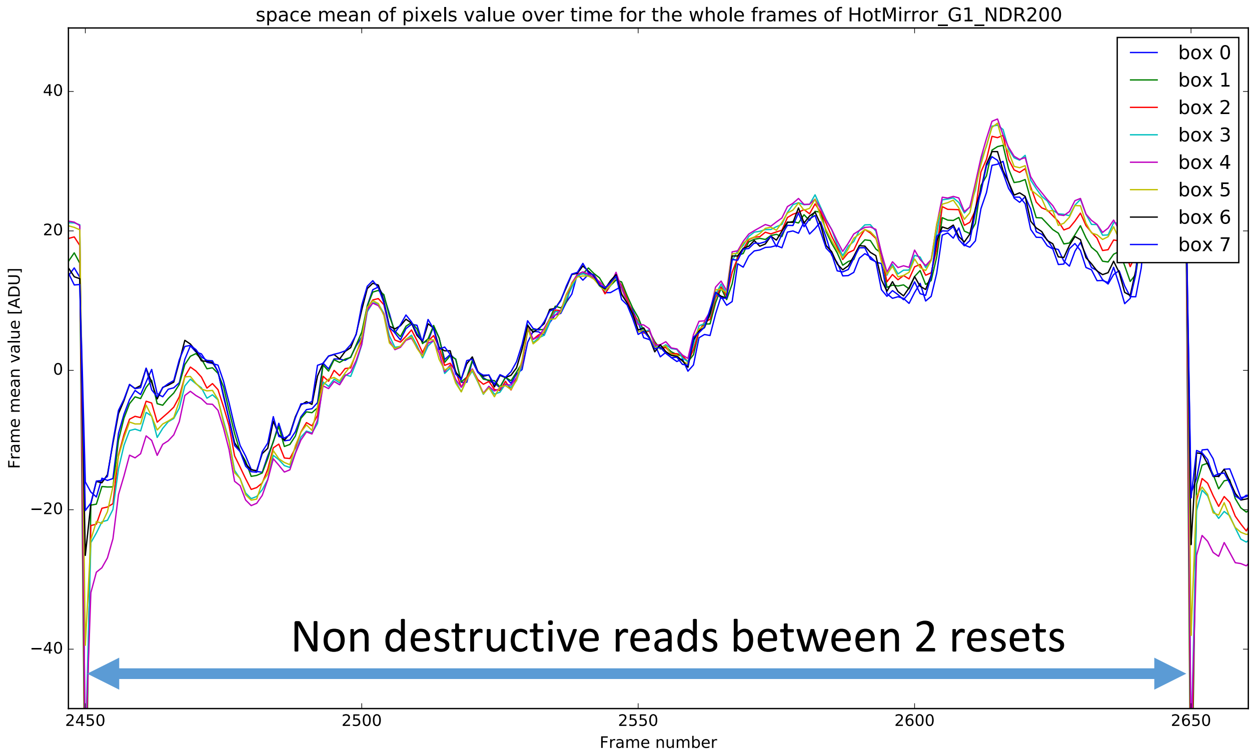


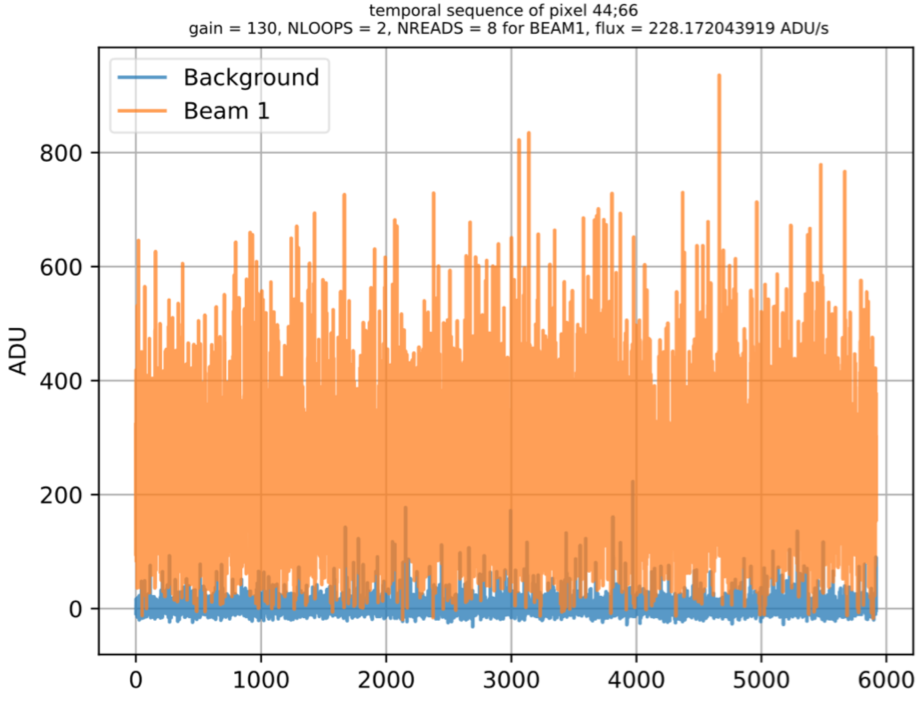


- At low ENF : separated peaks
- At high ENF : not separated peaks

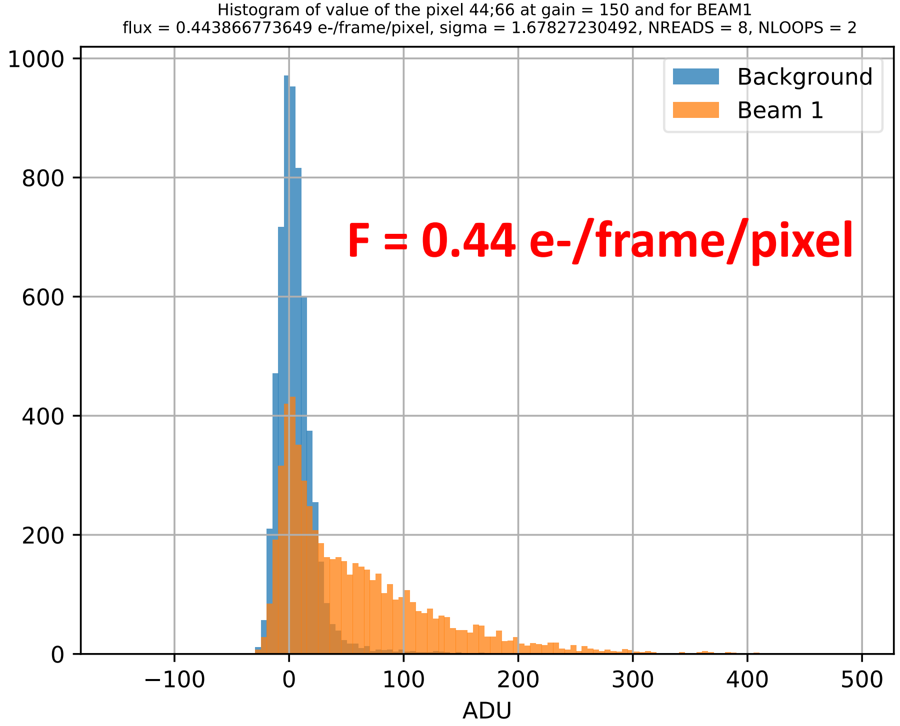
Calibration of unexpected behavior

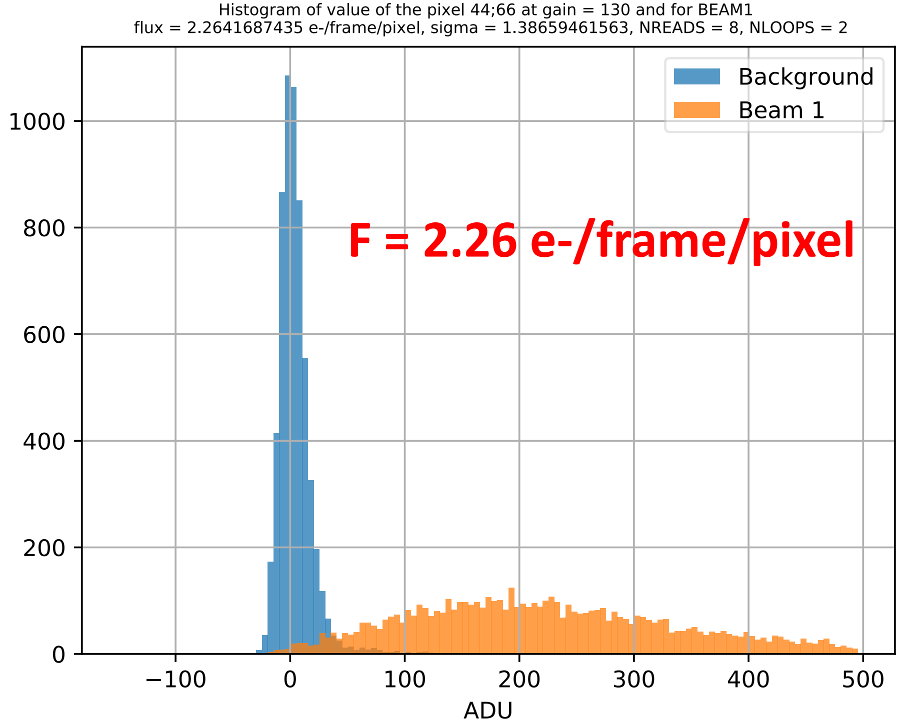
- Extract temporal sequence of one pixel (photometric channel)
- Subtract median value of several not illuminated pixels of the same line
  ⇒Take off the sinusoidal signal
- Build histogram of the temporal sequence values





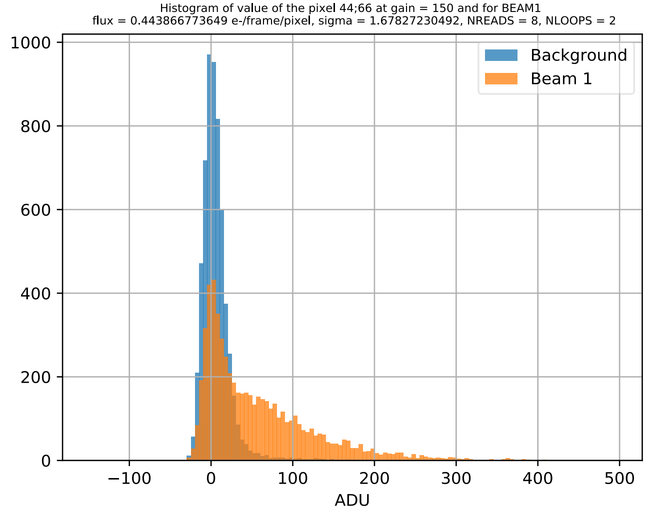
Histograms

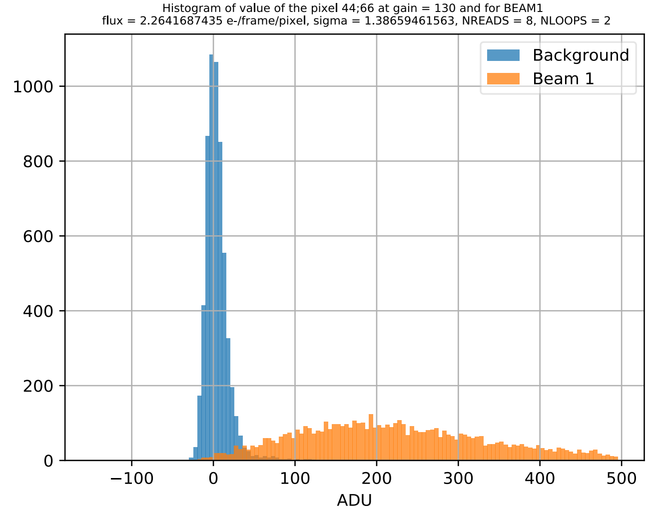


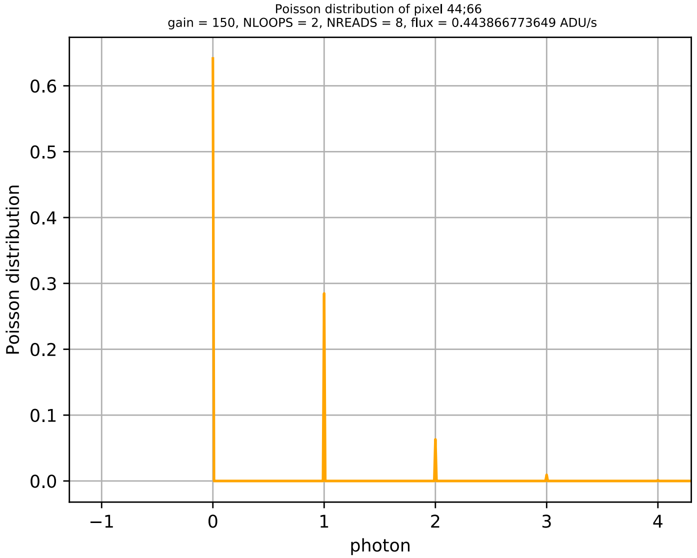


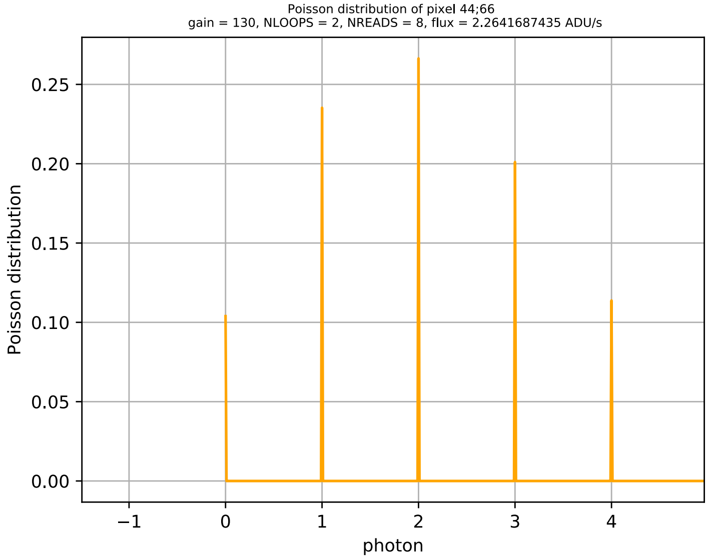
- No clearly separated peaks => no photon counting
- A break between 0 photon events and the others at low flux
- Background histograms not symmetrical

Photon distribution









Poisson distribution for the measured flux not consistent with histograms :

Simulation 10% -> data ≈ 0%

As F (e-) = F (ADU) / G

⇒Total gain is false

Camera modelization

Free parameters :
- Gain (G)
- ENF
- Flux (F)

Objective :
Fit illuminated data histograms

Determination of F by the ratio between 0 photon events and total events → Determination of G by F and the mean of the histogram (H) : H = G . F → Determination of ENF by the spreading of the histogram

Model

$$\overbrace{\sum_p}^{4} \overbrace{[Poisson(p,F)}^{3} * \overbrace{\Delta\,(p.G - adu)}^{1} * \overbrace{\underbrace{\mathrm{M}\left(\mathrm{ENF}, \frac{\mathrm{adu}}{\mathrm{G}}\right) * \mathrm{M}\left(\mathrm{ENF}, \frac{\mathrm{adu}}{\mathrm{G}}\right) * \mathrm{M}\left(\mathrm{ENF}, \frac{\mathrm{adu}}{\mathrm{G}}\right) \ldots}_{\mathrm{p}}}^{2}] * \overbrace{\mathrm{BKG(adu)}}^{5}$$

i.e. $Histo(F, G, ENF, adu) = \sum_p [Poisson(p,F) * \Delta\,(p.G - adu) * \mathrm{M}\left(\mathrm{ENF}, \frac{\mathrm{adu}}{\mathrm{G}}\right) * \mathrm{M}\left(\mathrm{ENF}, \frac{\mathrm{adu}}{\mathrm{G}}\right) * \mathrm{M}\left(\mathrm{ENF}, \frac{\mathrm{adu}}{\mathrm{G}}\right) \ldots] * \mathrm{BKG(adu)}$

1) Representation of each p photon events by a Dirac at the position G . p

2) Convolution of the Dirac with M, p times for an event of p photons :

Where M is the Gain distribution

0 photon => Dirac in 0

1 photon => Convolution of a Dirac in G with M

2 photons => Convolution of a Dirac in 2G with M, then a convolution of the result with M

…

3) Normalization of p photon events with the corresponding rate of the Poisson distribution of a given F

4) Addition of the different p photon events

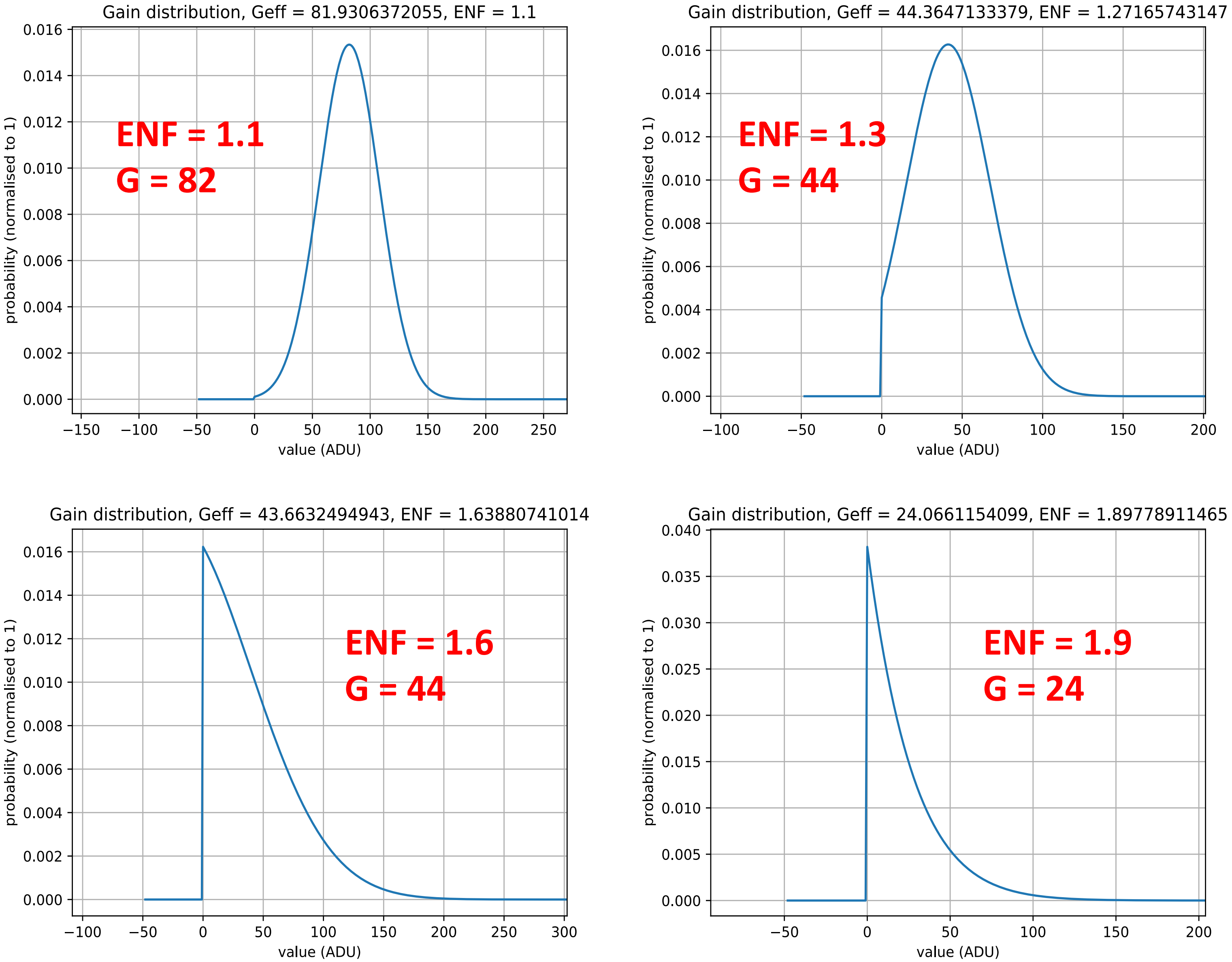
5) Convolution of the result buy the Background histogram

Gain distribution

Gain distribution (M) :
Define Gain and ENF
Model dependent

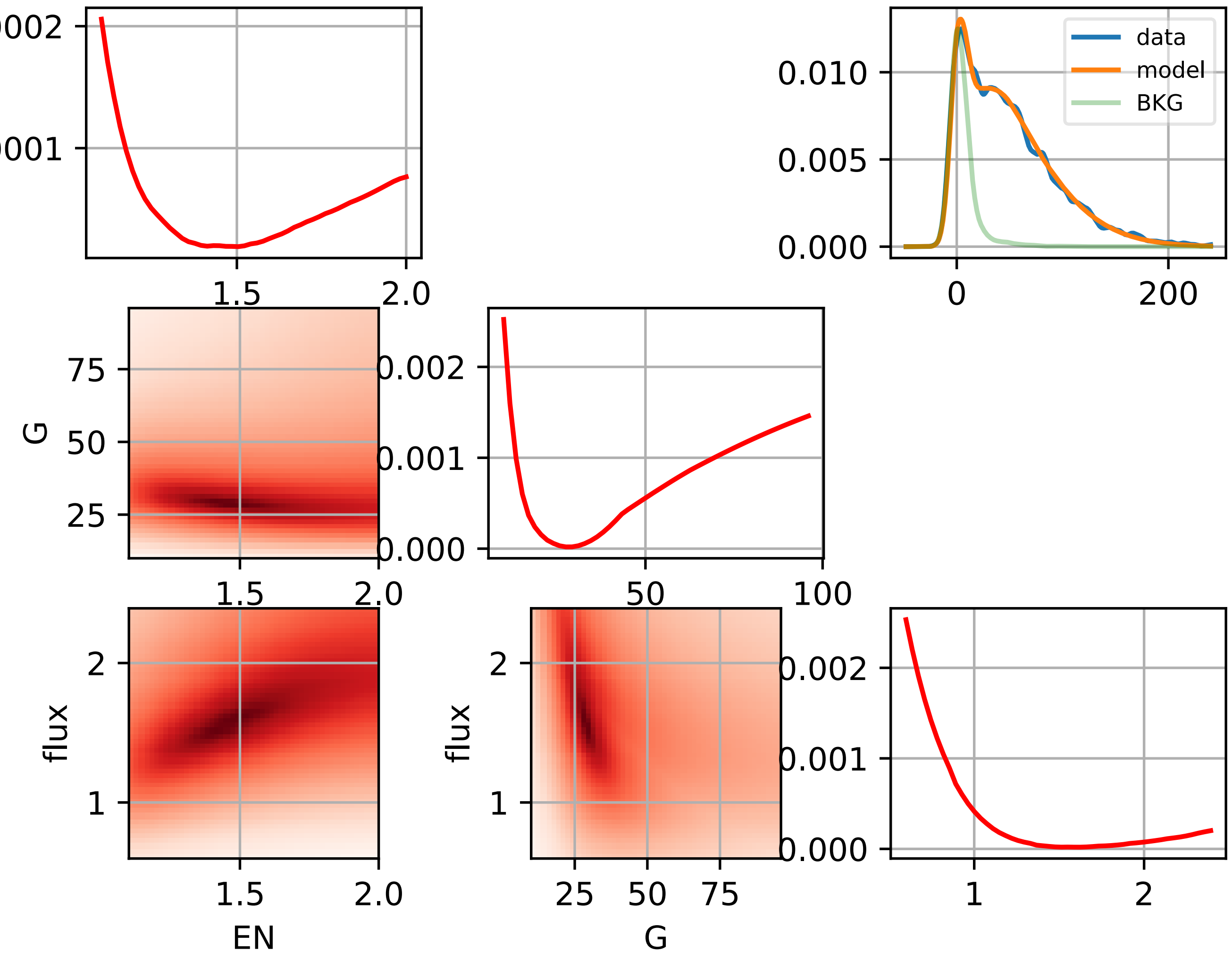
Spread : G = $\langle M \rangle$

Shape : ENF = $\frac{\langle M^2 \rangle}{\langle M \rangle^2}$



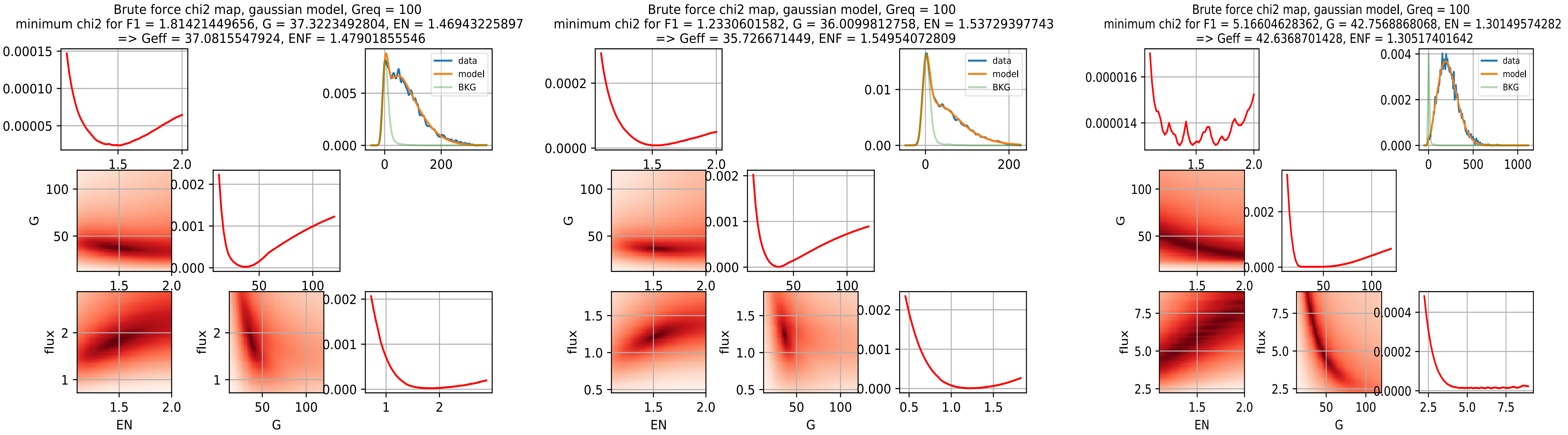
Chi2 map

Brute force chi2 map, gaussian model, Greq = 80
minimum chi2 for F1 = 1.56687209518, G = 28.3394996135, EN = 1.45439458313
=> Geff = 28.1070211108, ENF = 1.46649720103



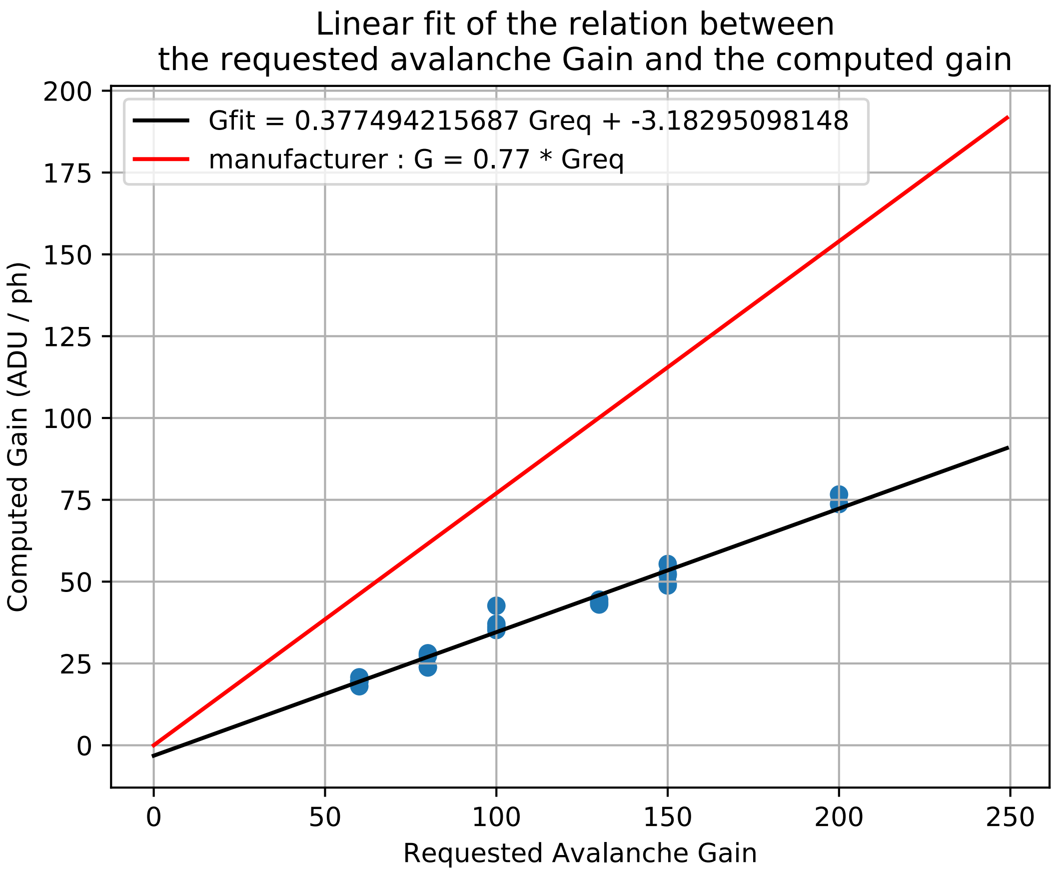
- Exploration of the parameter space to perform χ^2 maps
- A single solution found in the parameter space

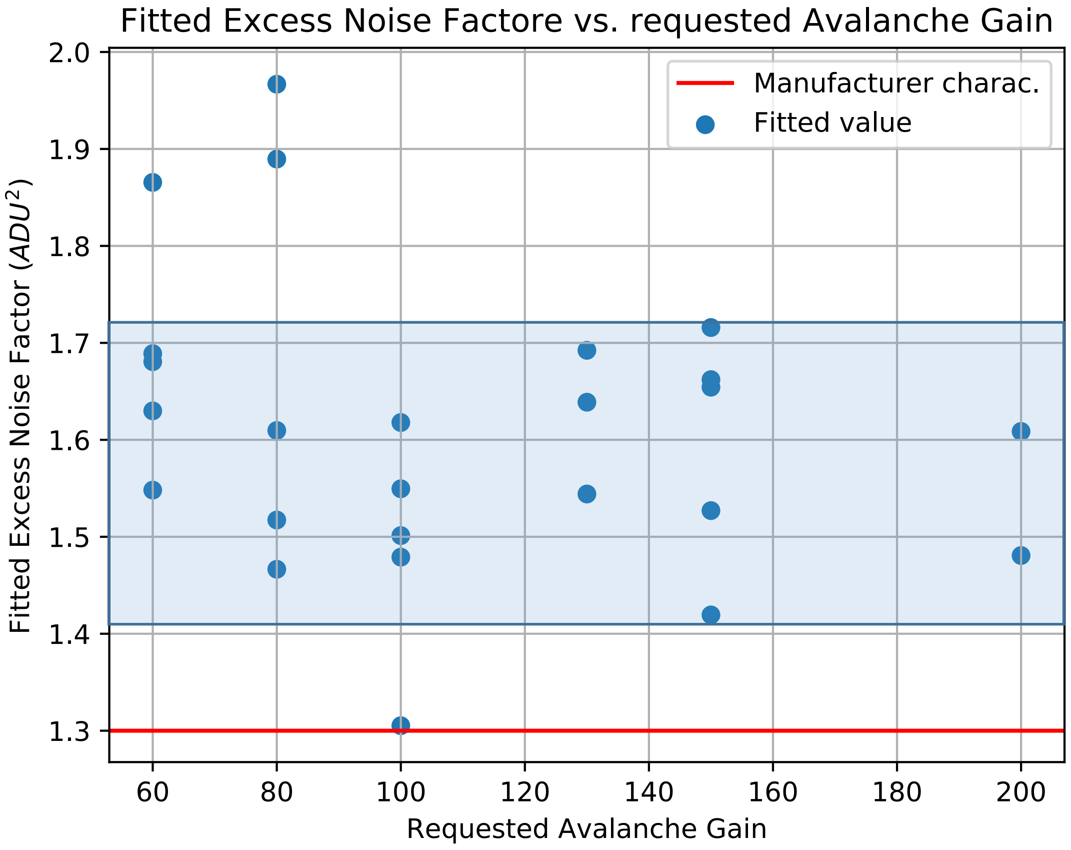
Chi2 map



- Degeneracy of solution at high flux (F > 3 e-/frame/pixel)

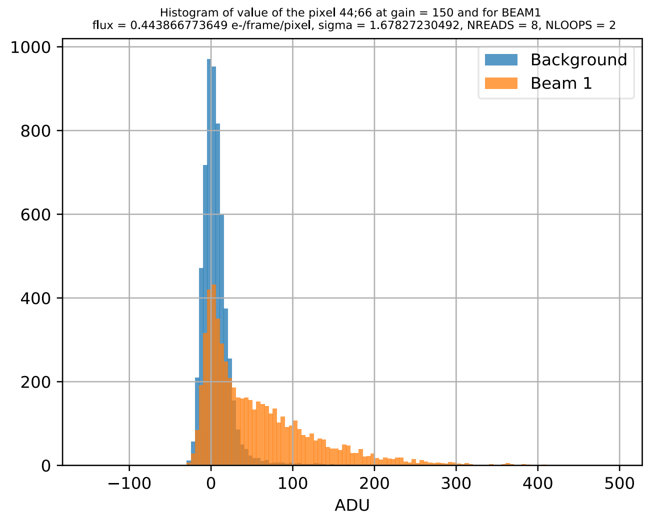
Observation of the different parameters

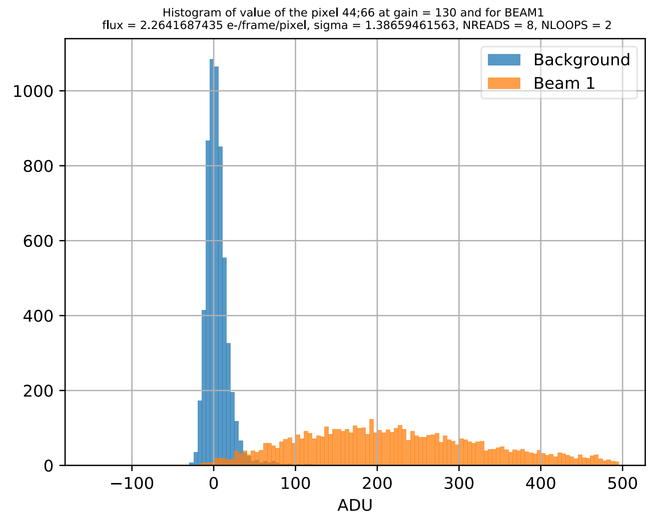


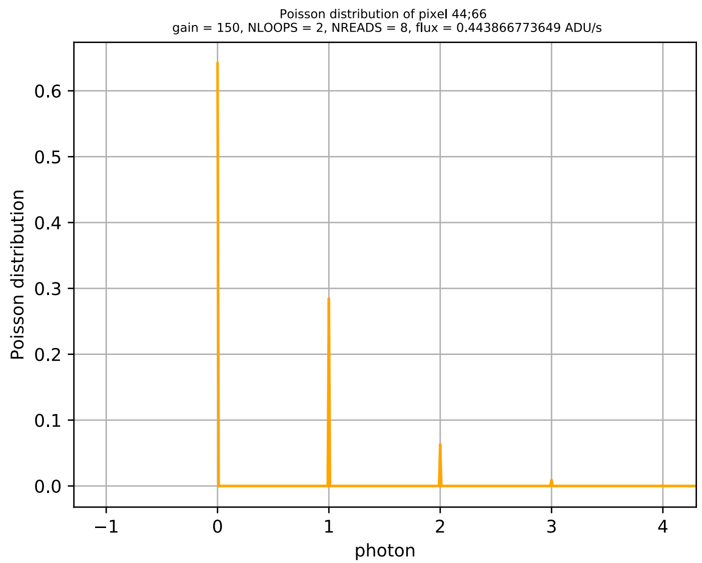


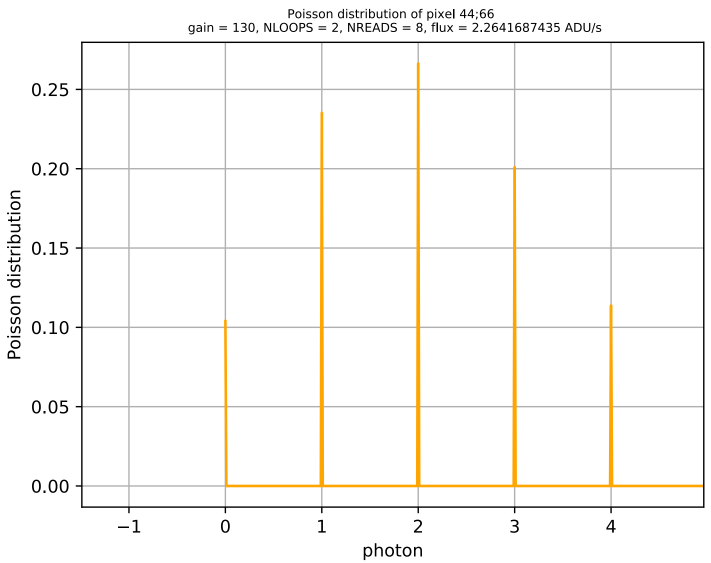
- Result consistent for the same requested gain at different flux
- Some outliers for ENF, but from unconstrained high flux
- ENF ≈ 1.6

Photon distribution





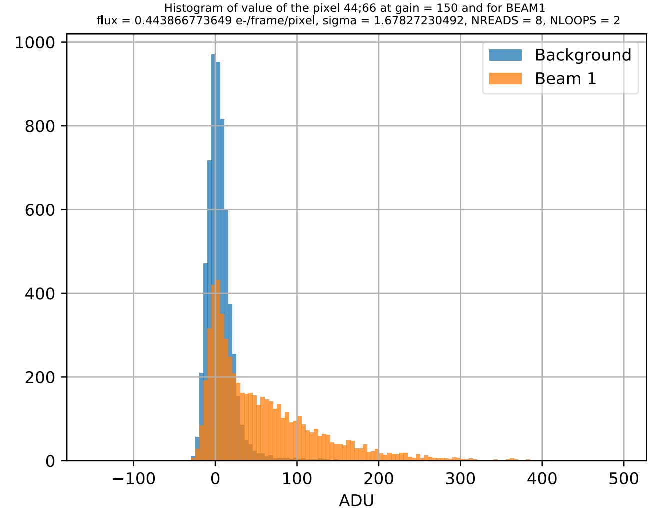


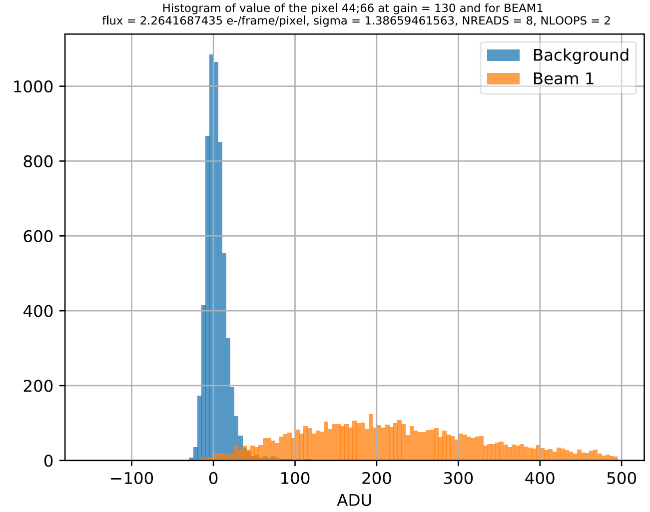


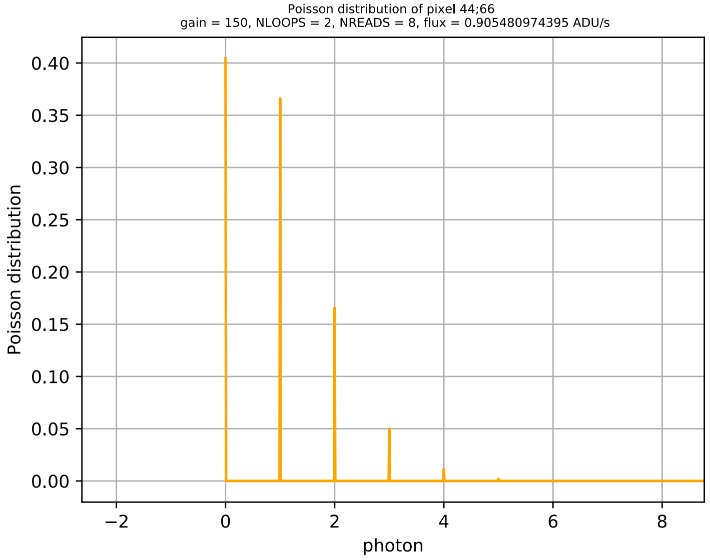
Poisson distribution for the measured flux not consistent with histograms

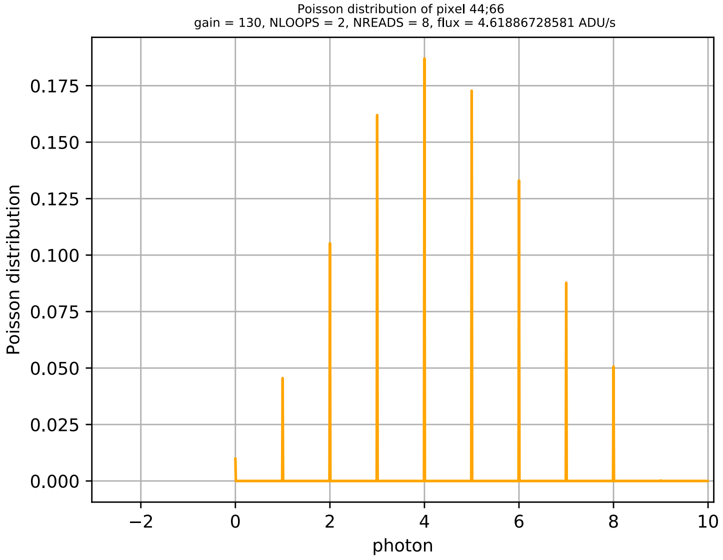
$\Rightarrow$Total gain is false

Photon distribution









Poisson distribution for the flux from the model is consistent with histograms

Discussion and perspective

Discussion :

- Gain distribution dependence of the model
  - Test different Gain distribution
- High flux result not constrained
  - Combination CHI2 cubes to constrain high flux result

Perspectives :

- Study massive stars with this new camera
  - Observations already began : faintest star H = 6.5 (previous limit H = 5.5)
- Use the model to try "photon counting" on sky data
- Sub Poisson noise may have a physical explanation => Fano Effect ?

Conclusions

- New model works :
  - Obtain characterizations that explain the data
  - Validation of the characterizations by an independent method
- Validation of a real Gain of half the expected Gain
- ENF of 1.6, unexpected
- Characterization still good enough to improve previous MIRC performance
- Classical photon counting impossible
- Further study needed to explain unexpected behavior of the camera (sub Poisson noise)