Single neutron detection with CMOS cameras

A collaboration ILL and ESS-Bilbao

Overview

- The original idea of single neutron detection
- First experimental results
- Difficulties
- Camera and scintillator properties

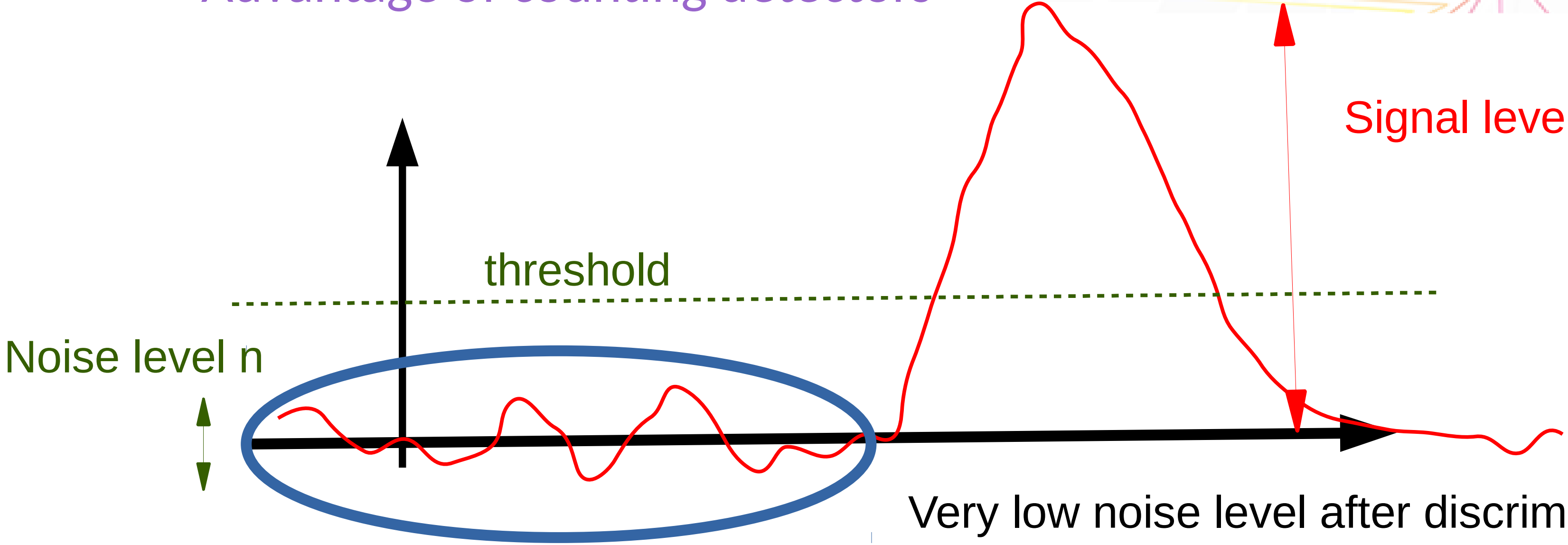
- Neutron sources are not bright (standard wisdom)
  - Samples are relatively large
  - Instruments are relatively big
  - Counting rates are relatively low

- Counting detectors
  - Counting individual neutrons
  - Relatively poor resolution
  - Large area
  - Low noise ; low background

However

- Smaller and smaller samples
- Higher and higher resolution
  - Difficult to achieve with current counting technology
- But source not much brighter
  - Neutrons are still expensive
  - Signal-to-noise ratio important

Advantage of counting detectors



Very low noise level after discrimination.

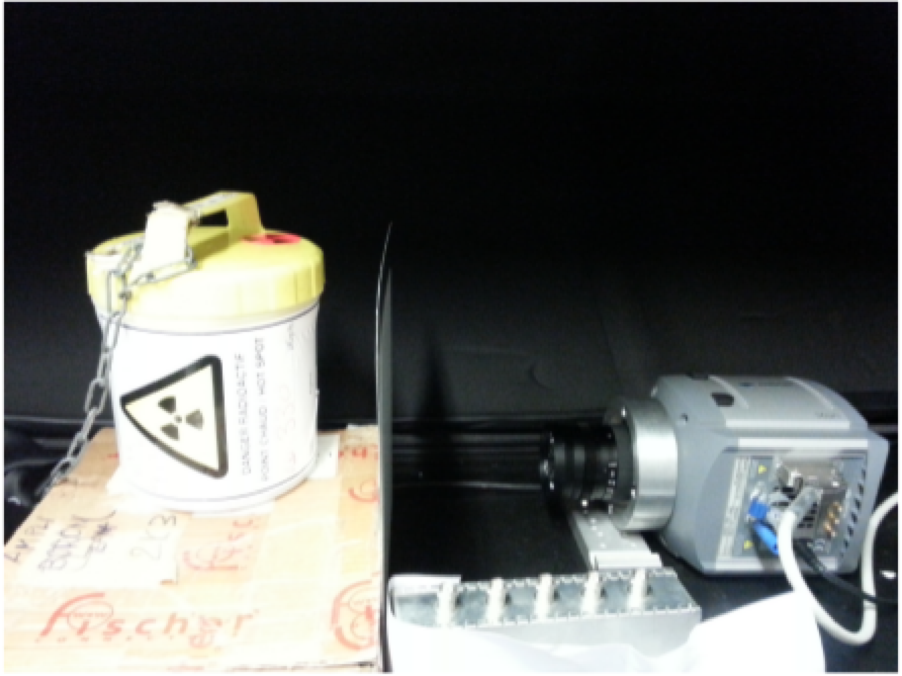
S/N after discrimination : 1/ P(noise> th)

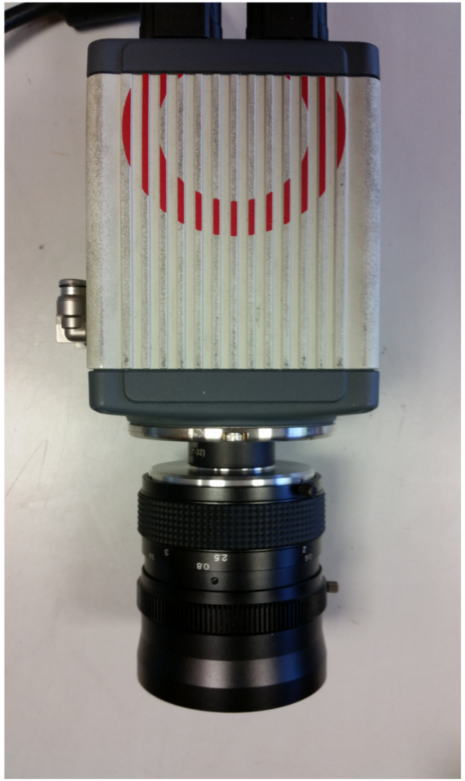
If th = 5 σ, P = 10^{-7}

If th = 6 σ, P = 10^{-9}

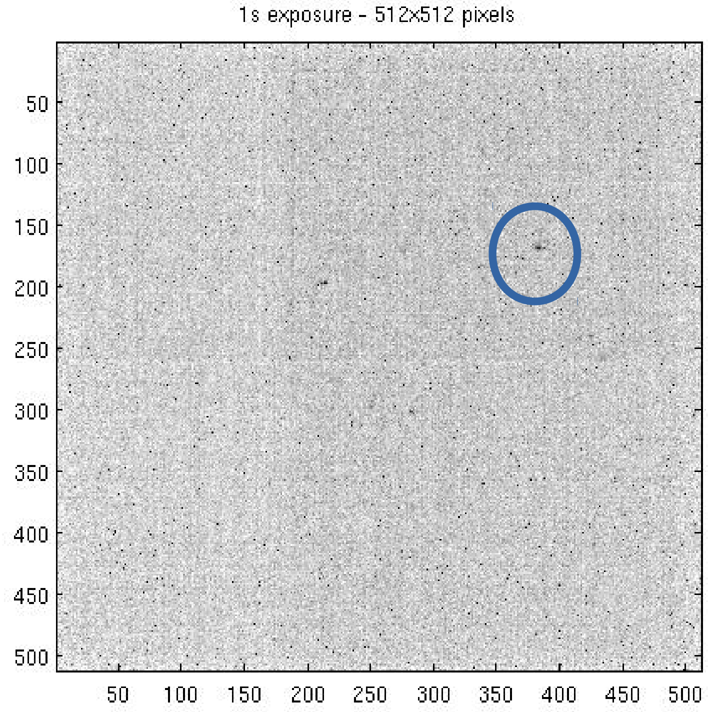
Rejected noise

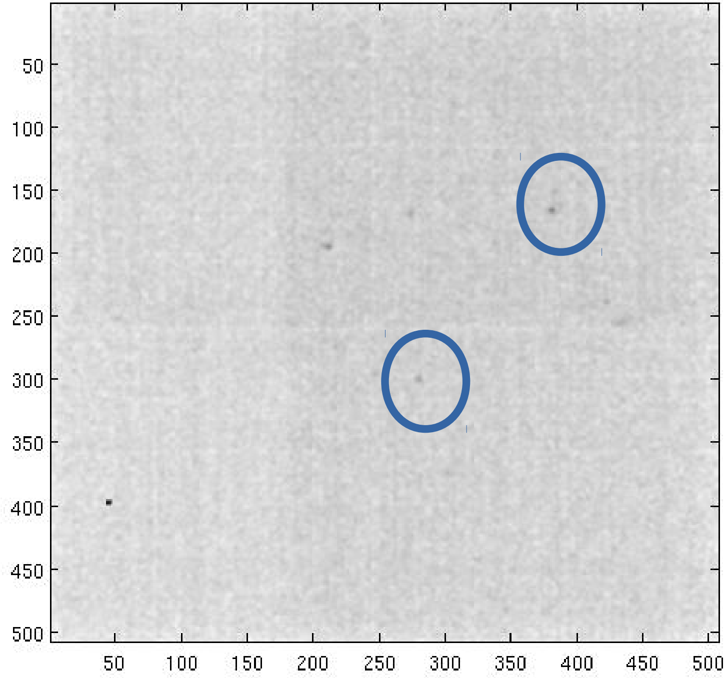
S/N before discrimination: s/n



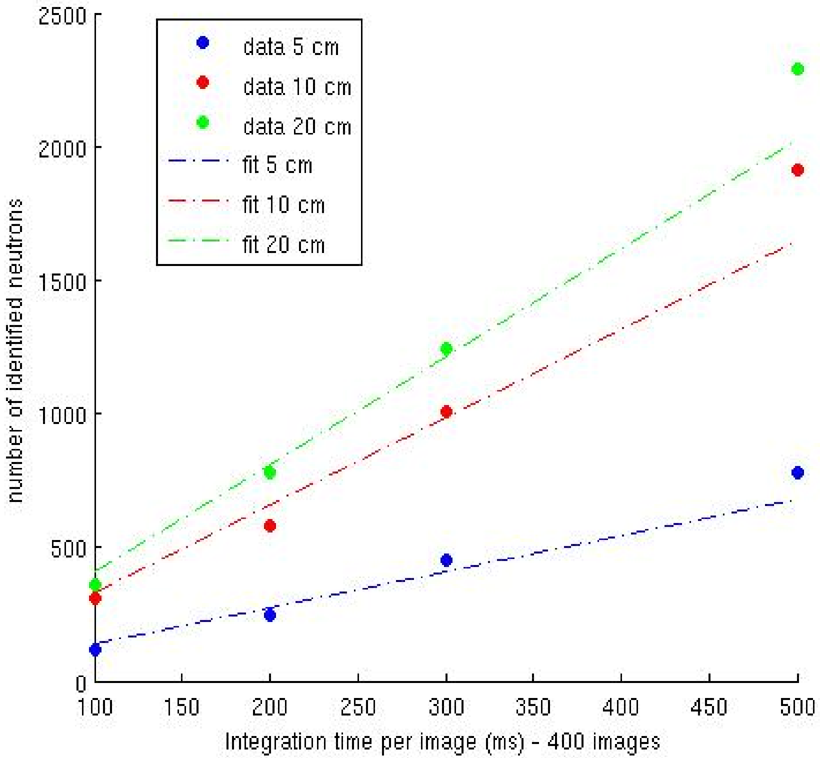


Earliest results

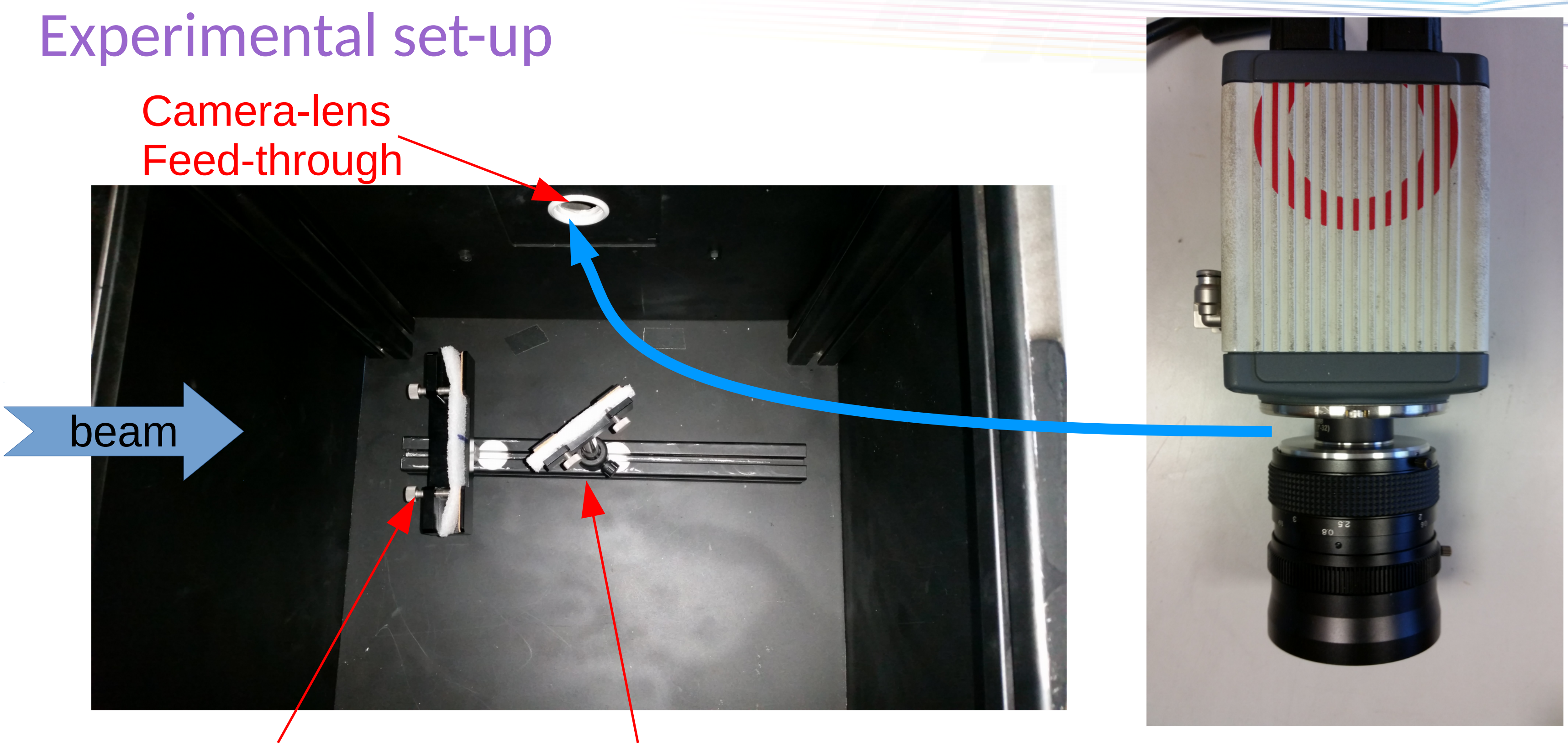




First « proofs of counting »



Experimental set-up



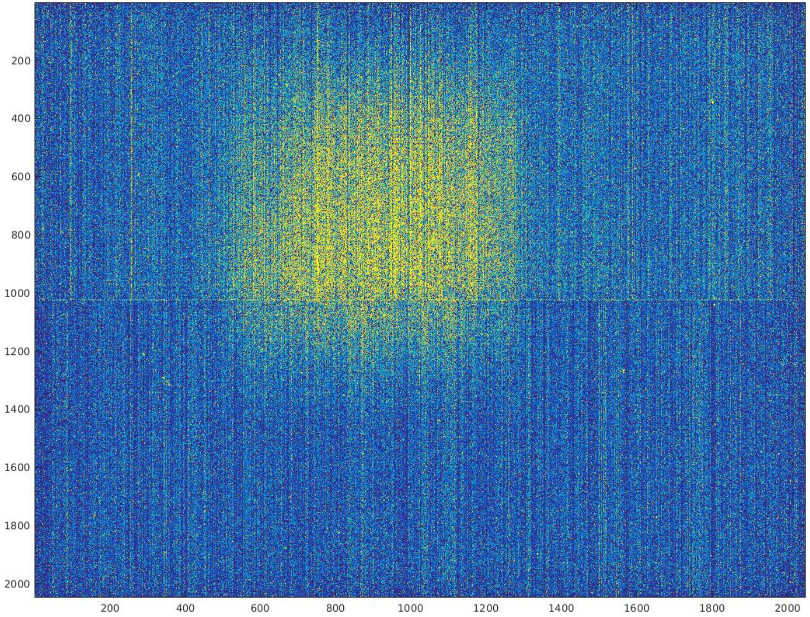
Camera-lens
Feed-through

Scintillator screen
place holder

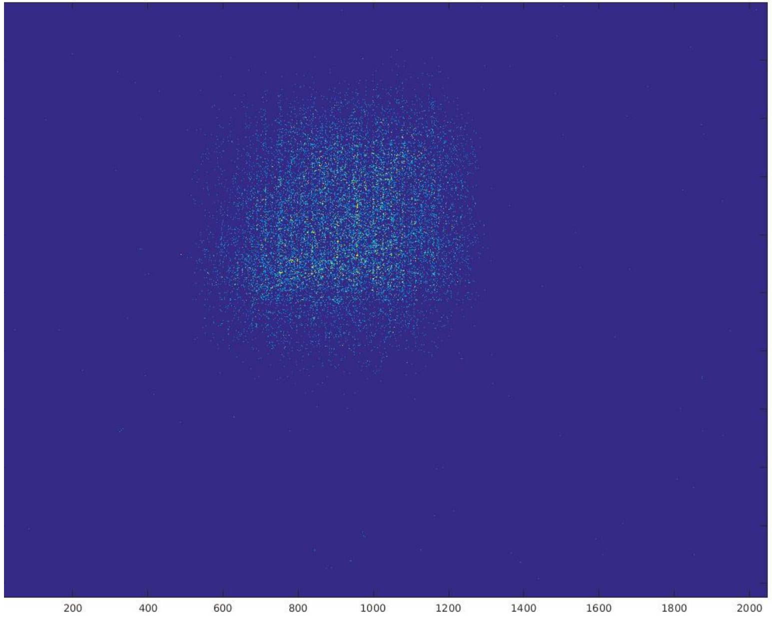
Ti/quartz mirror
Place holder

Beam image

100 images of 300 ms
~10000 n/s (blue, Canon lens)



Classical sum



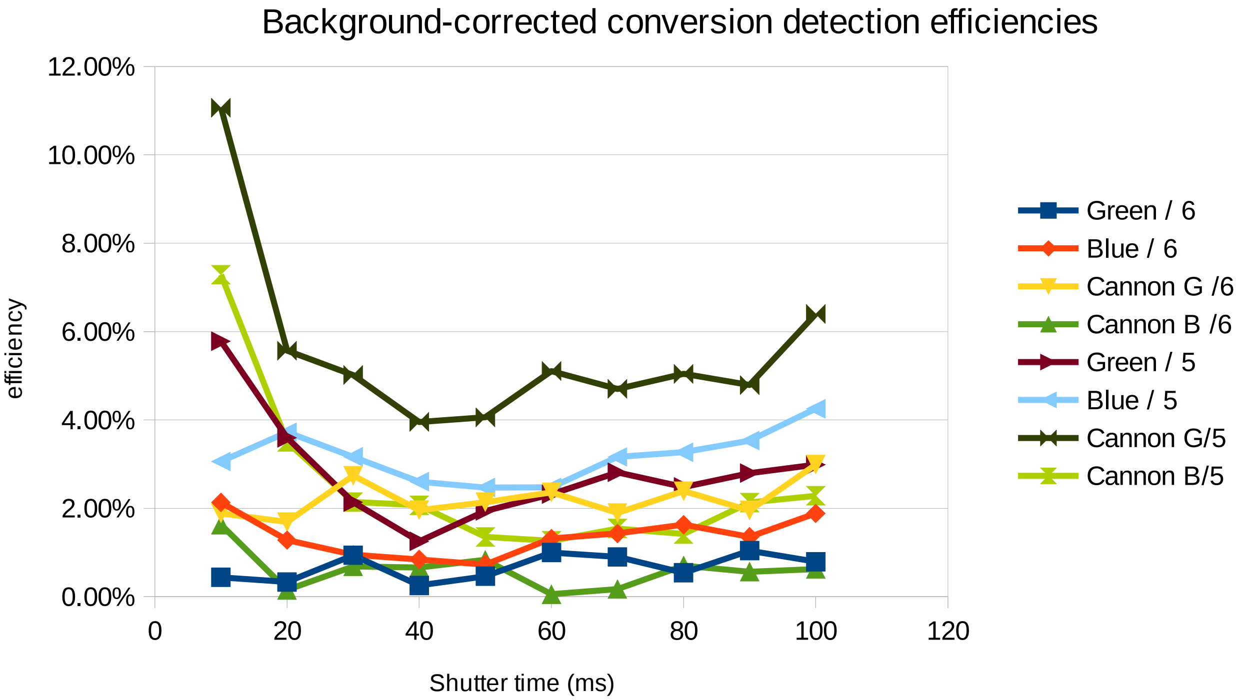
Sum of detected

Photons per neutron

- 6 attenuators : 2700 n/s
- Conversion efficiencies :
  - blue 4:1 0.25mm : 24 %
  - Green 4:1 : 26 %
  - Blue 2:1 0.25mm:31 %
- For green scintillator :
  - Canon lens (f ~ 0.7) : 430 e- / n
  - Commercial lens (f ~ 0.95) : 317 e-/n

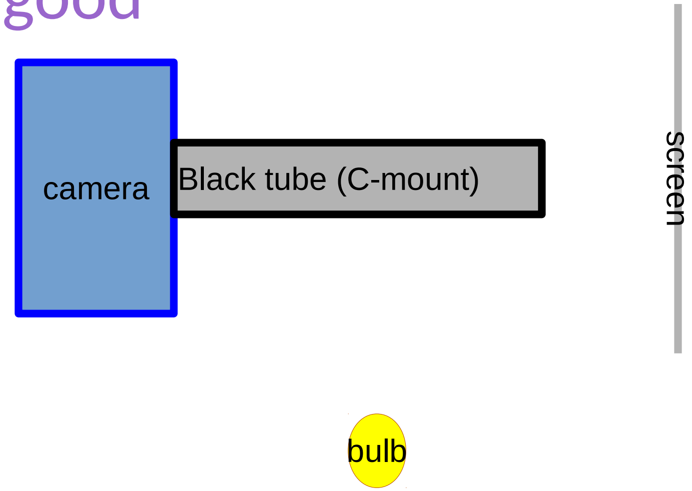
- Note that we have largely enough photo-electrons per neutron on average to be able to detect them in principle...

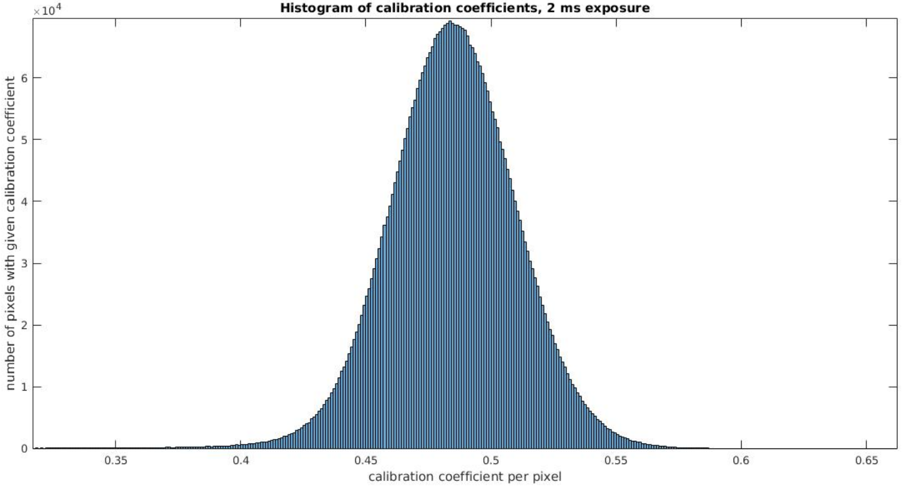
Efficiencies, however, very low…



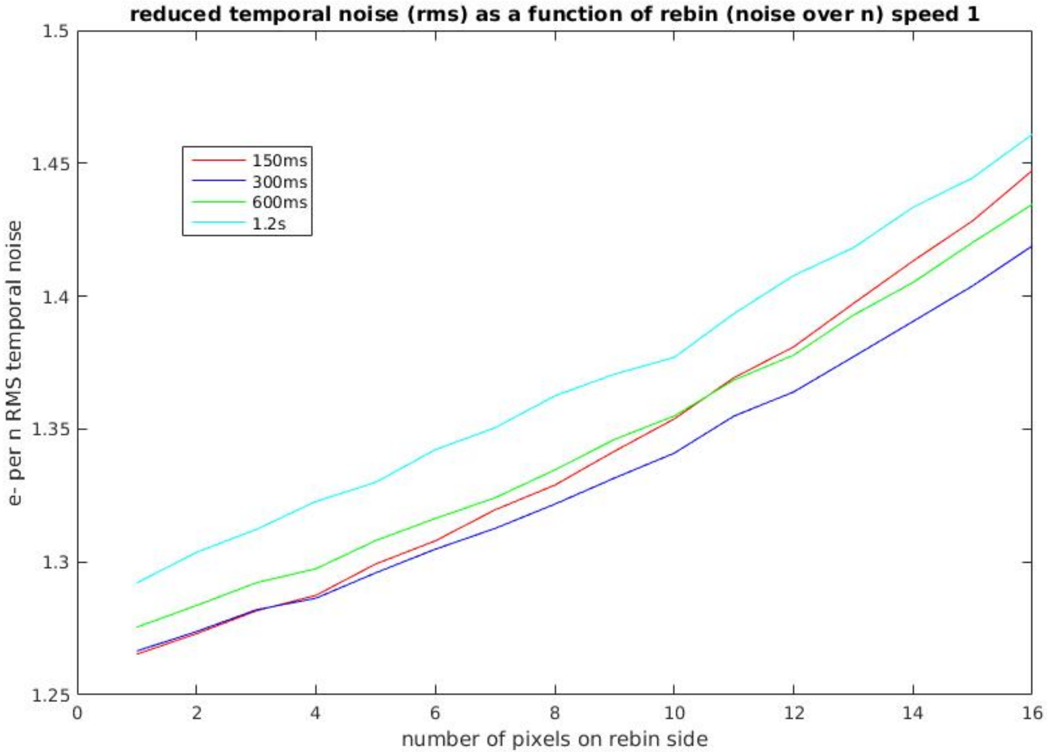
ORCA FLASH 4.0 V2 calibration : very good

We follow individual pixels through several successive frames. Time series of these values are confronted with expected Poisson statistics for photo electrons.



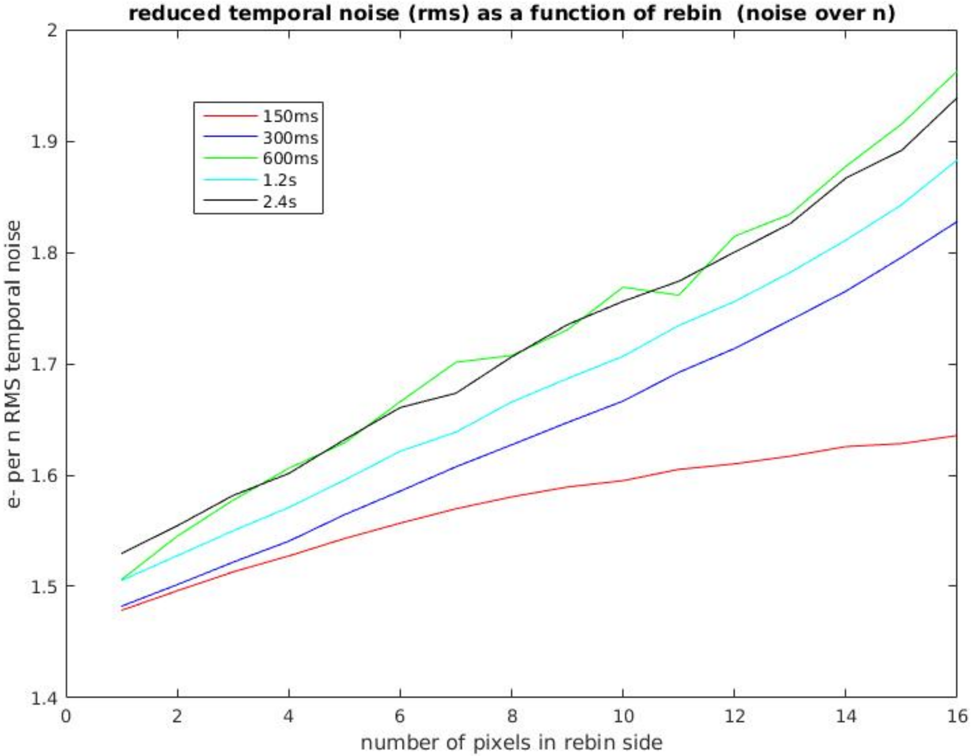


Camera noise : pixel noise independence: speed 1

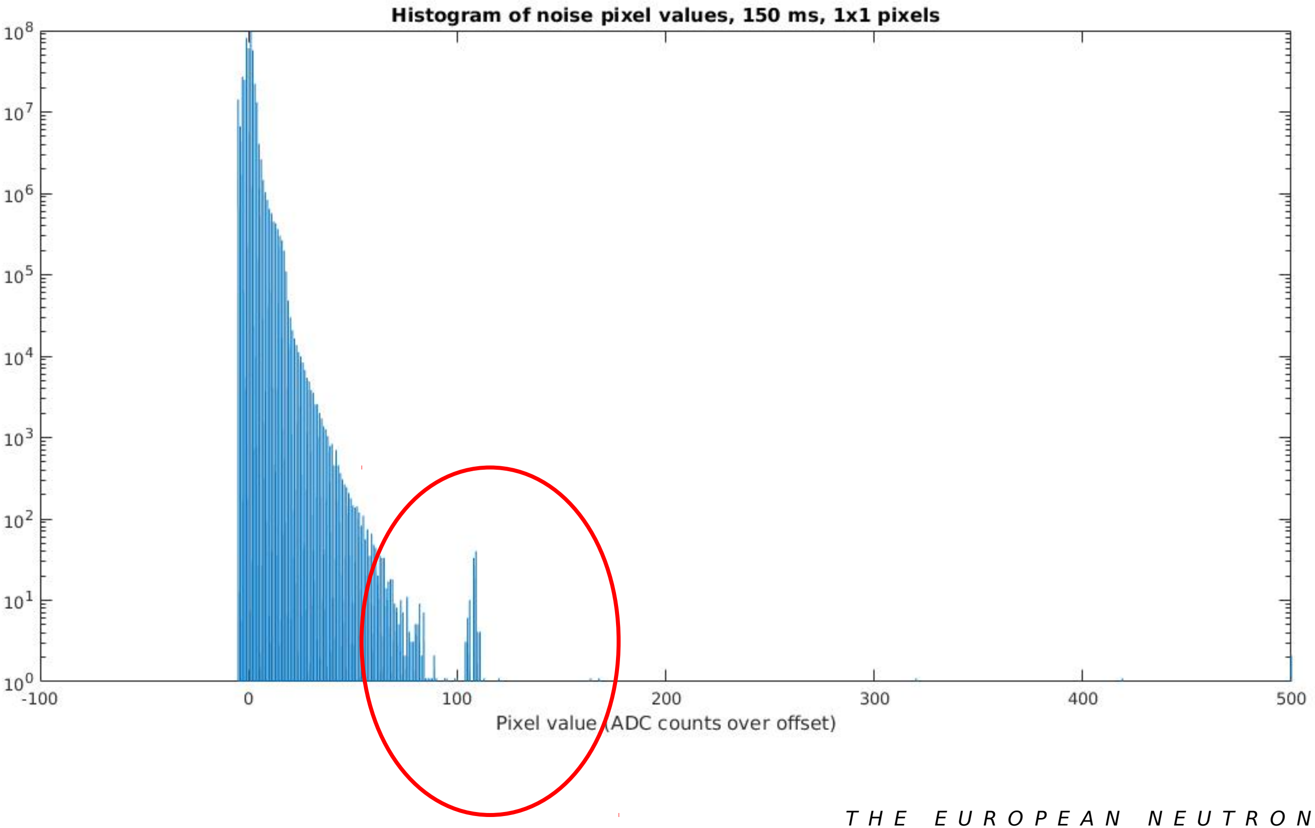


We follow individual pixels in successive dark frames. The time series gives us the temporal pixel noise for that pixel. We average statistical properties of these individual pixel data.

Camera noise : pixel noise independence : speed 2

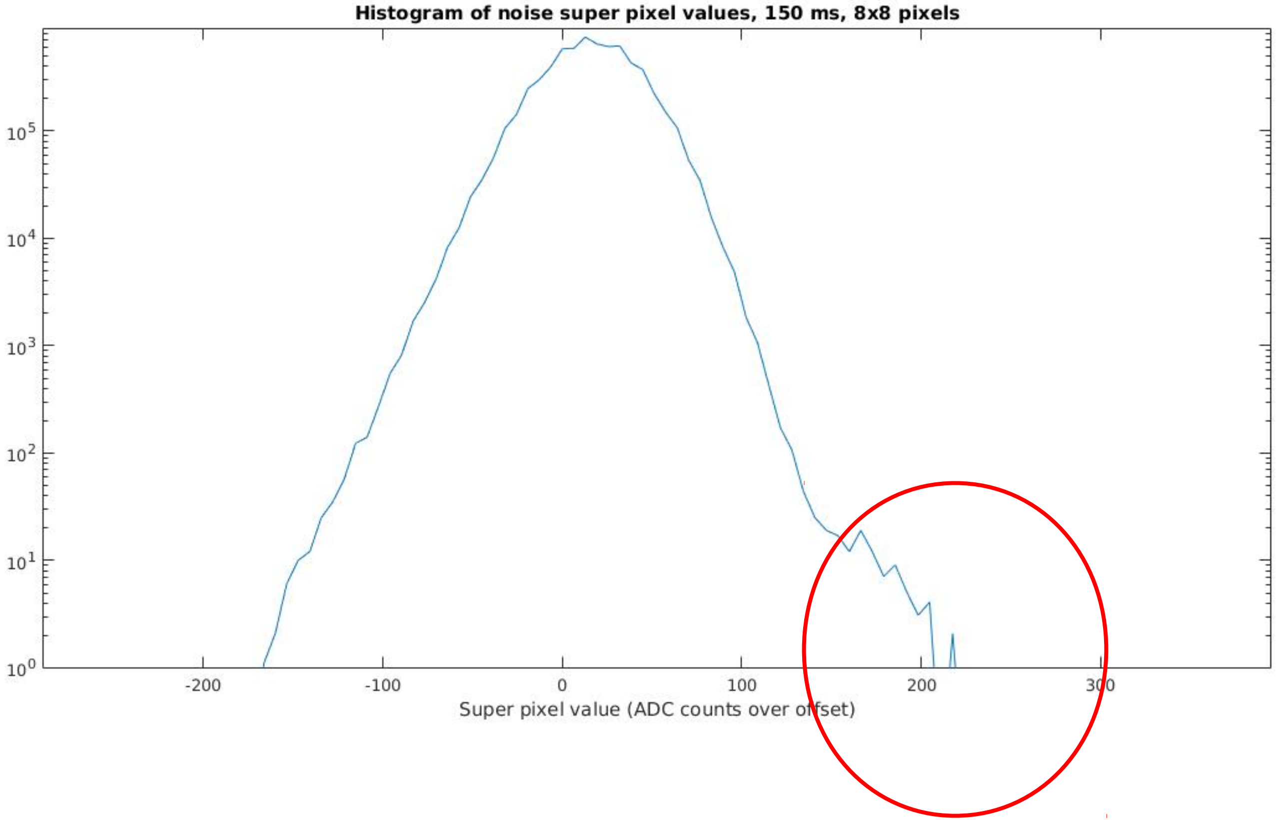


Pixel dark values not Gaussian ! Individual pixels.



~60 e-

Non-gaussian nature of super pixels.



~110 e-

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Actual thresholds vs Gaussian estimated thresholds

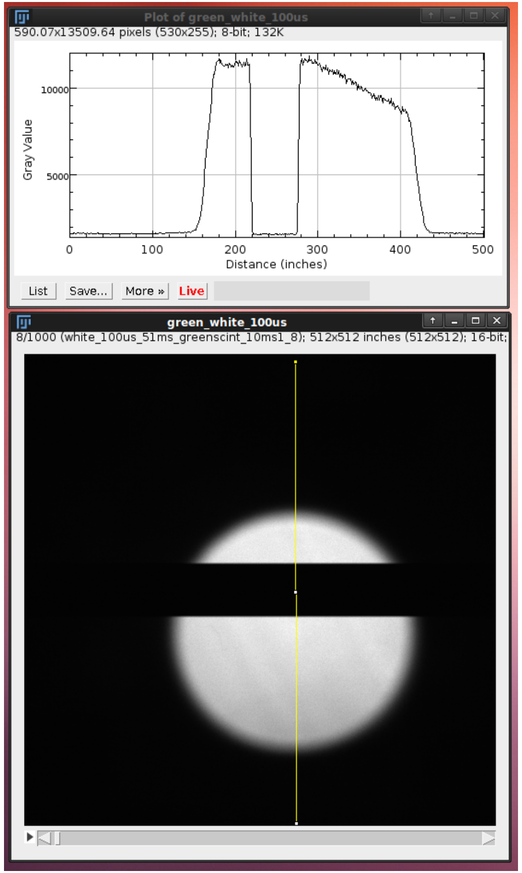
Super pixel size	6 sigma e- from RMS	ADC plot threshold	Electron sensitivity
1 x 1 (6.5 um x 6.5 um)	8 e-	120	60 e-
2 x 2 (13 um x 13 um)	16 e-	150	75 e-
4 x 4 (26 um x 26 um)	32 e-	150	75 e-
6 x 6 (39 um x 39 um)	47 e-	170	85 e-
8 x 8 (52 um x 52 um)	63 e-	200	100 e-
10 x 10 (65 um x 65 um)	81 e-	250	125 e-
12 x 12 (78 um x 78 um)	100 e-	250	125 e-
16 x 16 (104 um x 104 um)	140 e-	350	175 e-

Hot pixel filter

Super pixel	No filter	1 sigma hot filter	2 sigma hot filter
1x1	60 e-	13 e-	20 e-
4x4	75 e-	35 e-	40 e-
8x8	100 e-	80 e-	80 e-
16x16	175 e-	150 e-	150 e-

Setup

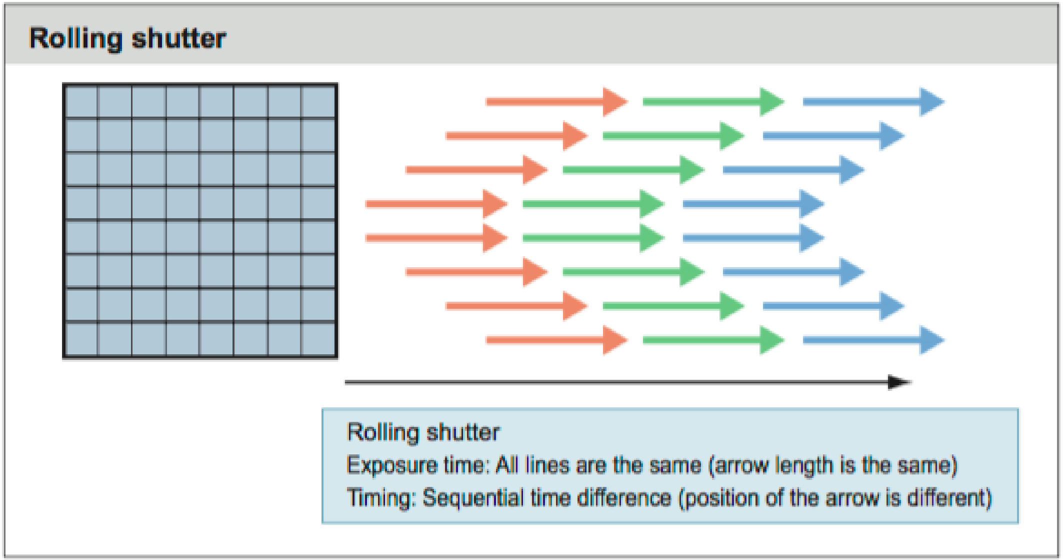
Scintillation response study : camera and LED on paper


Plot of green_white_100us

590.07x13509.64 pixels (530x255); 8-bit; 132K

green_white_100us

8/1000 (white_100us_51ms_greenscint_10ms1_8); 512x512 inches (512x512); 16-bit;


Rolling shutter

Rolling shutter

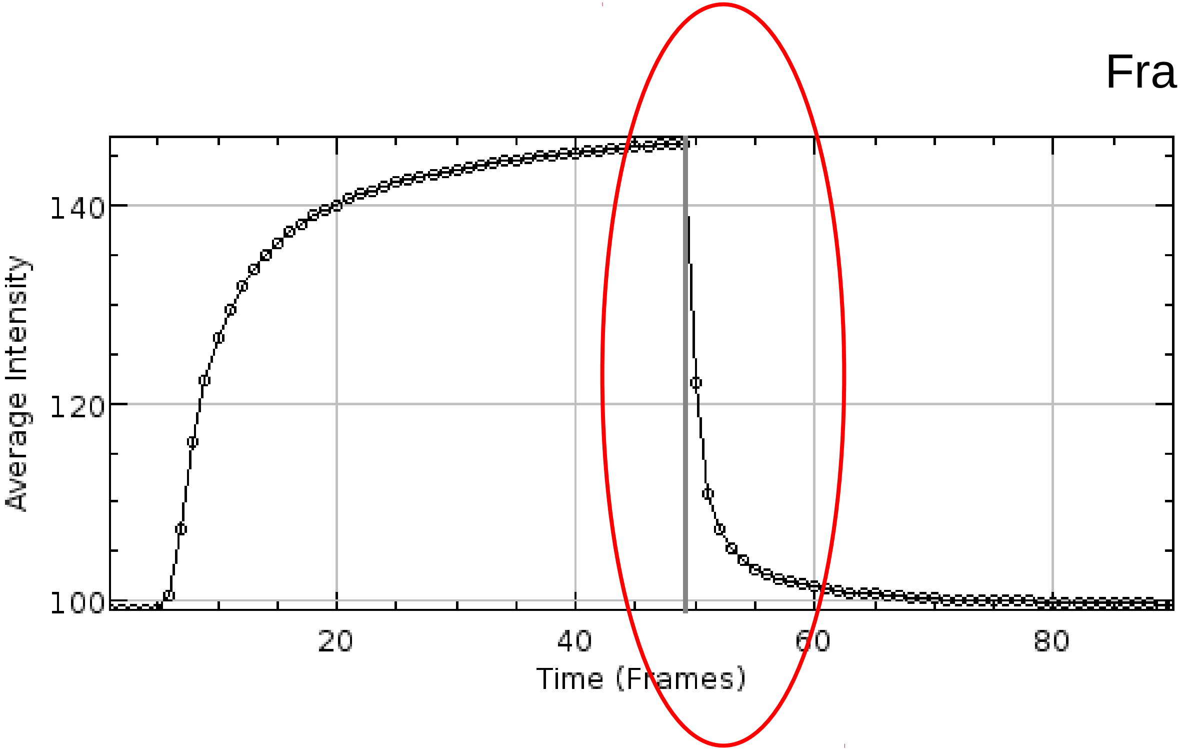
Exposure time: All lines are the same (arrow length is the same)

Timing: Sequential time difference (position of the arrow is different)

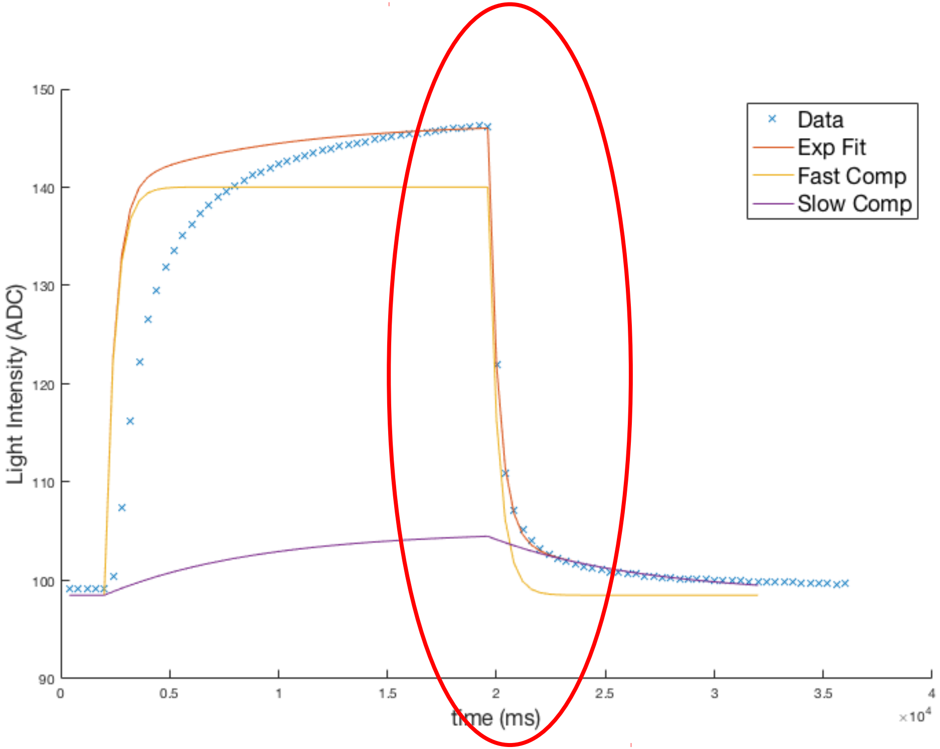
The camera and LED are extremely fast

ZnS:Cu/LiF response to UV light stimulation

Frame = 400 ms



Bi-exponential fit



Best fits on falling edge:
- 473 ms and 4.0s
- 55.25 and 0.38 (amplitude)

Does not describe well
The rising edge

Conclusion from all this :

- Single neutron identification, but low efficiency
- Very simple identification algorithm
- Explanation :
  - Higher threshold needed than Gaussian estimate: ~120 e-
  - About ~300 e- per neutron, fully integrated
  - Light emission time constant ~500 ms

BUT : other results : ESS-Bilbao at PSI

- Cooled camera
- Sophisticated treatment
- Neutron detection at low shutter times

Results from ESS-Bilbao at PSI :