GEM optical readout by means of a CMOS based camera

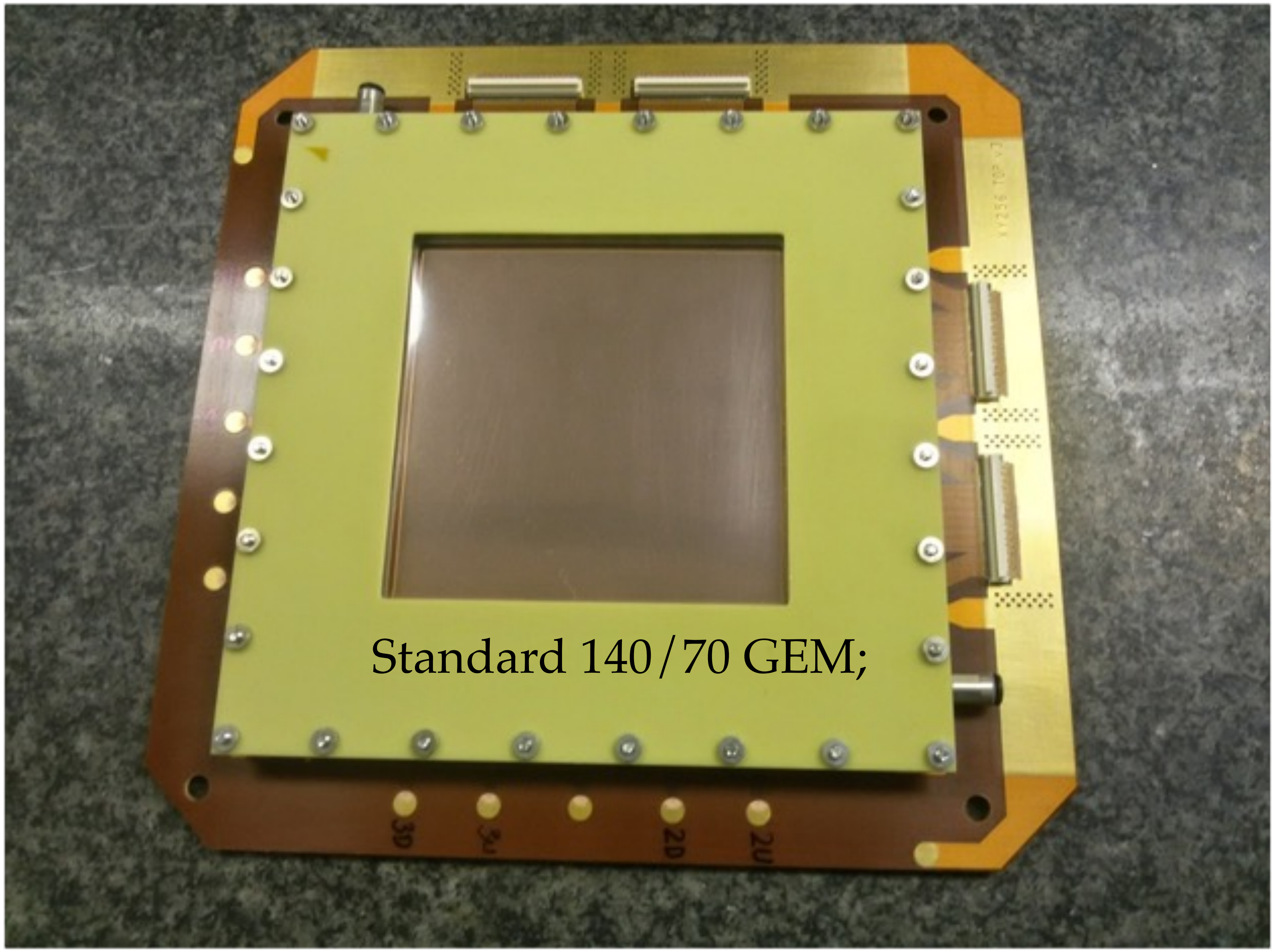
Davide Pinci
INFN Sezione di Roma
On behalf of MONDO collaboration

The Triple-GEM detector

3 mm wide drift gap and two 2 mm wide transfer gaps;

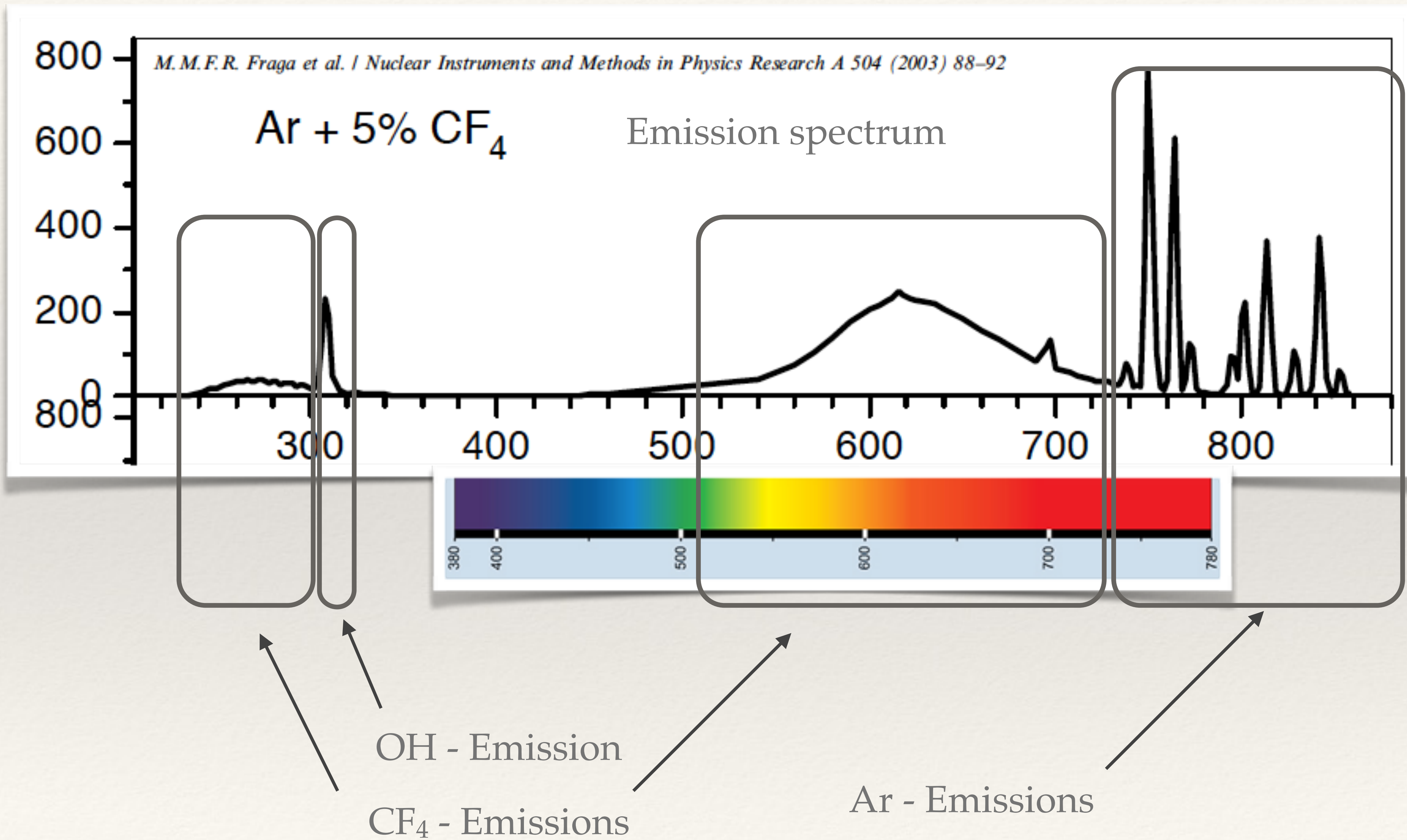
Electrons are collected on the bottom of the third GEM and only photons are read out;

The readout plane was replaced by a transparent plastic foil window.

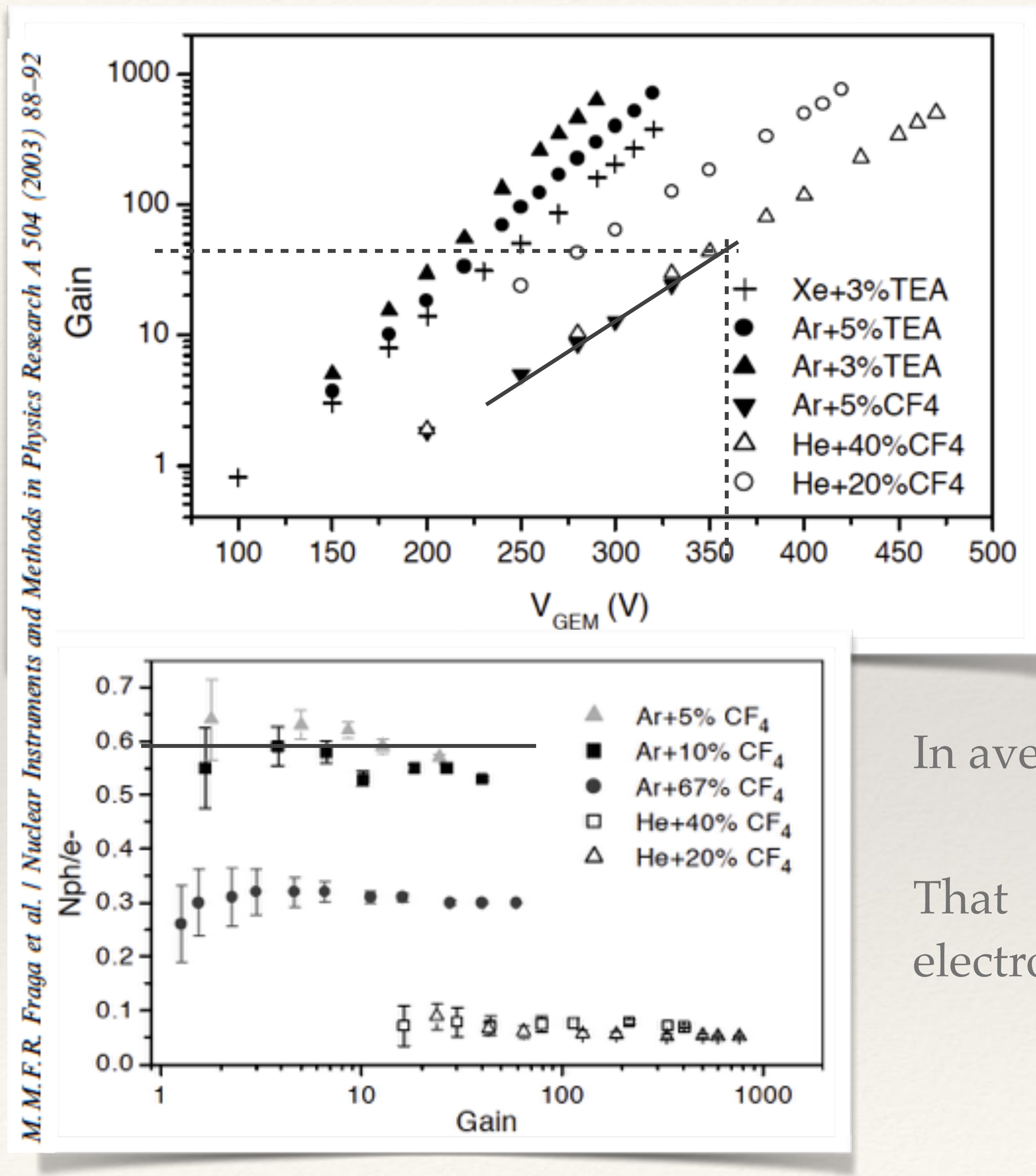


The gas mixture

First tests were made by using an Ar/CF4 (95/5) gas mixture (1 bar);



The gas mixture



Data acquired for a V_{GEM} = 360 V.

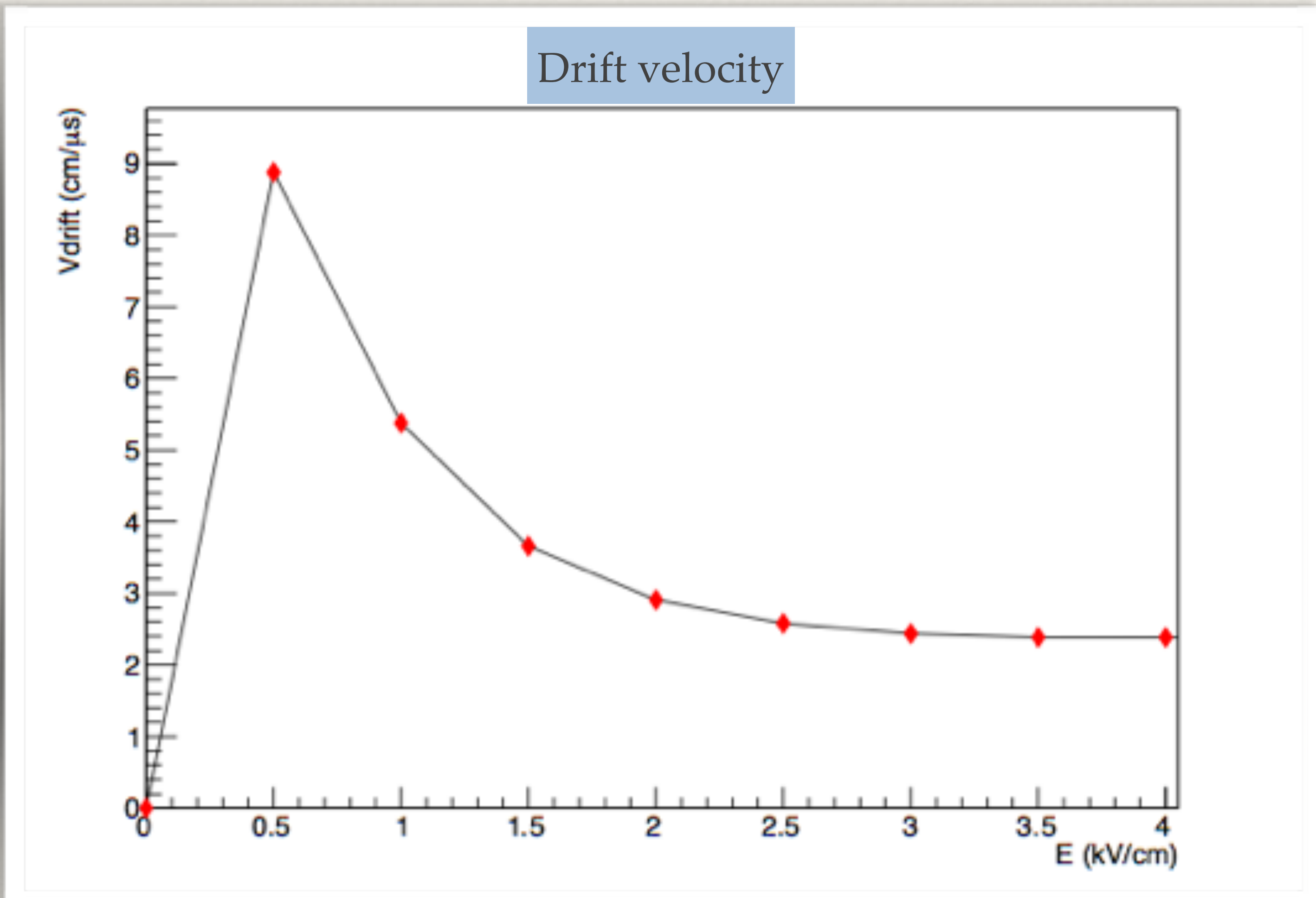
A gain value of about 40 is expected for each GEM. In total a gain as high as 6 10^4 can be achieved;

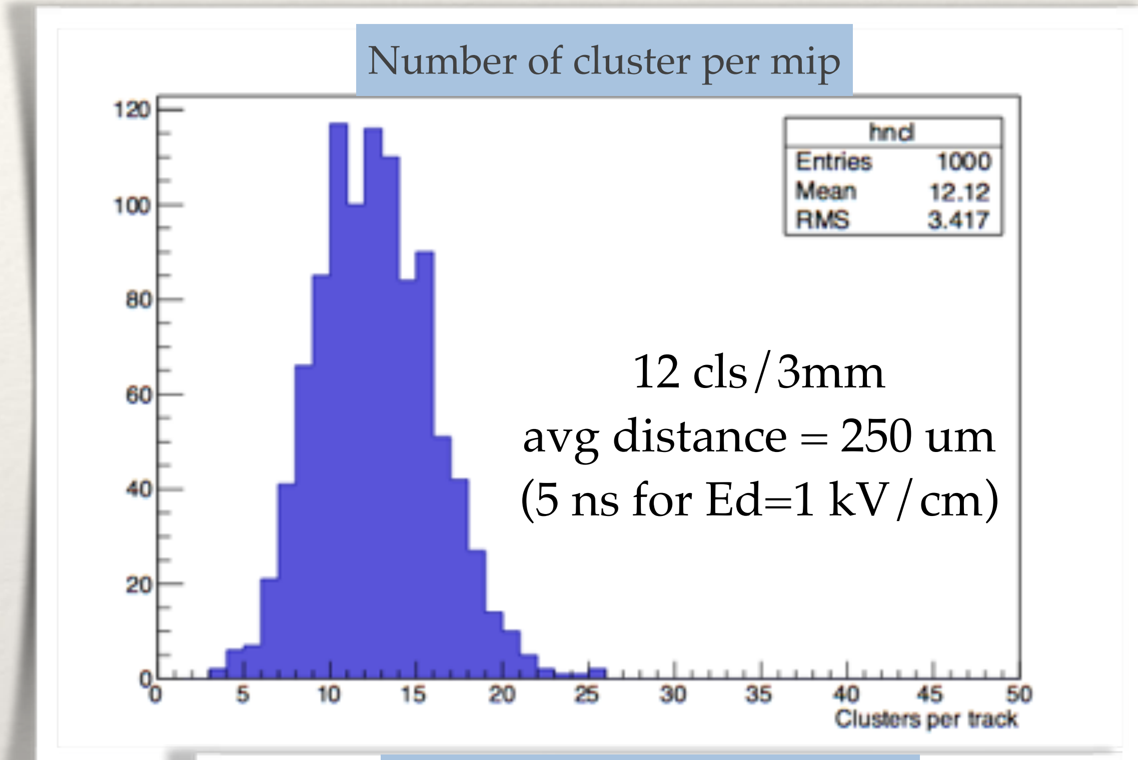
In average we expect 0.6 photons per electron;

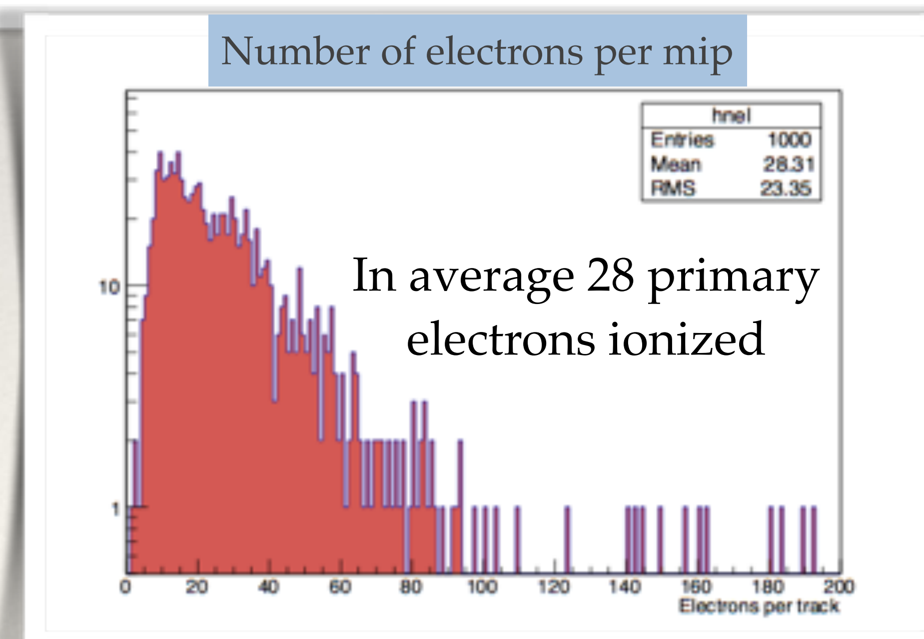
That means up to 3 10^4 photons per primary electron can be produced;

The gas mixture

We evaluted other properties of the gas mixture by means of Garfield



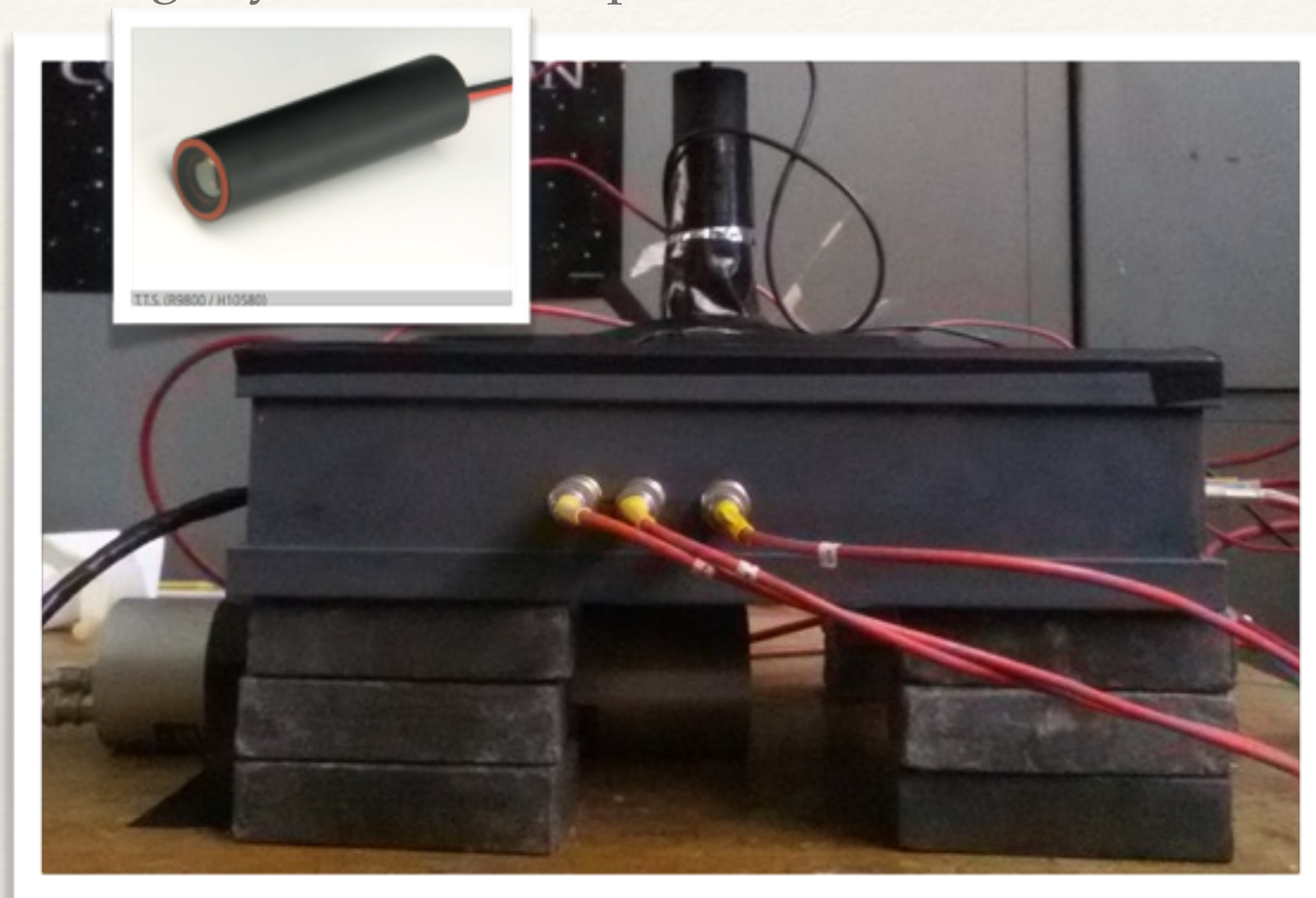




A mip is expected to produce up to 10^6 photons

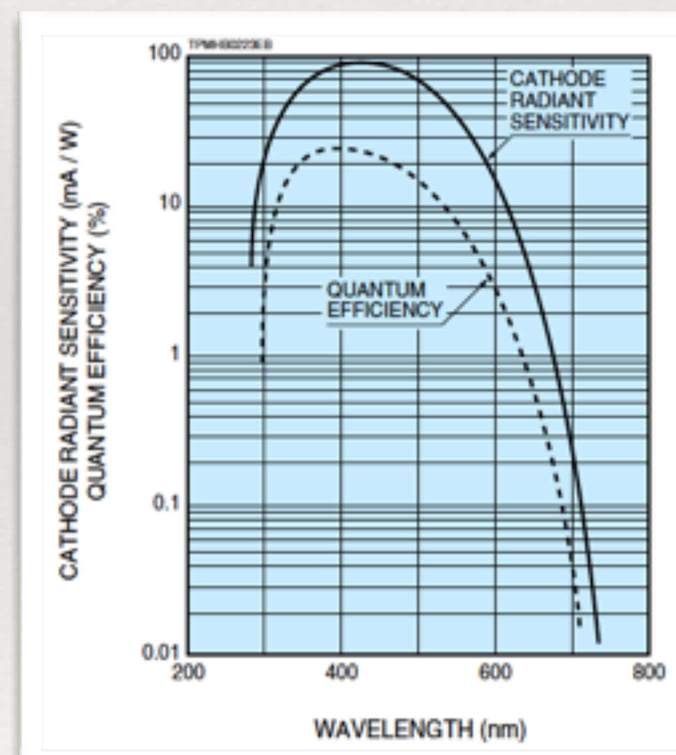
Experimental set-up: PMT

The light yield of the triple-GEM detector was measured by means of cosmic rays;



Two NaI scintillators used to trigger penetrating muon tracks;

Light produced by the triple-GEM collected by a R9800 PMT;



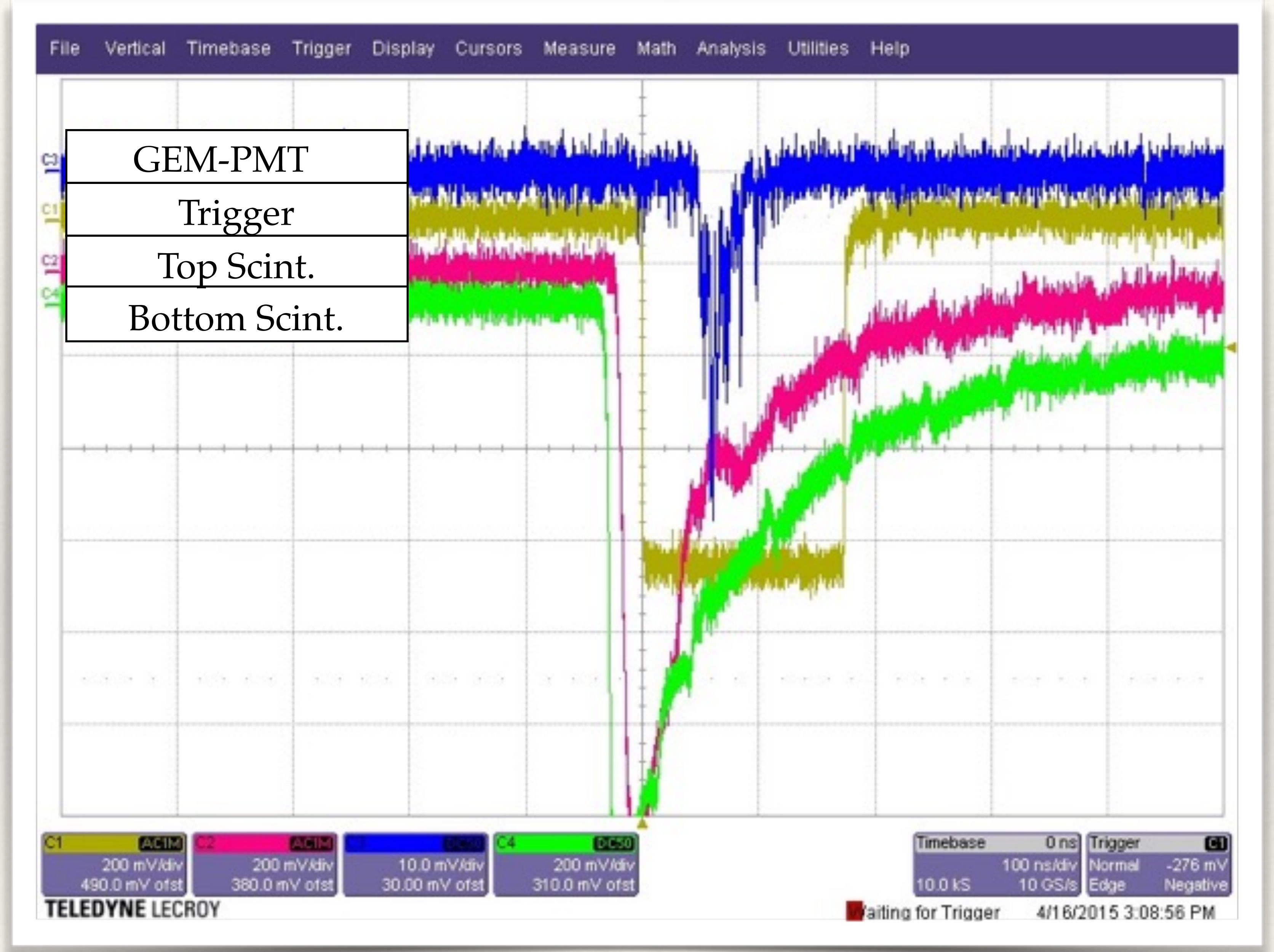
A quantum efficiency below 5% is expected on the orange-red part;

17 mm diameter window at 4 cm -> 1% of total solid angle;

Up to 500 p.e. are expected;

Experimental set-up: DAQ

All waveforms acquired by means a 10 GS/s oscilloscope;

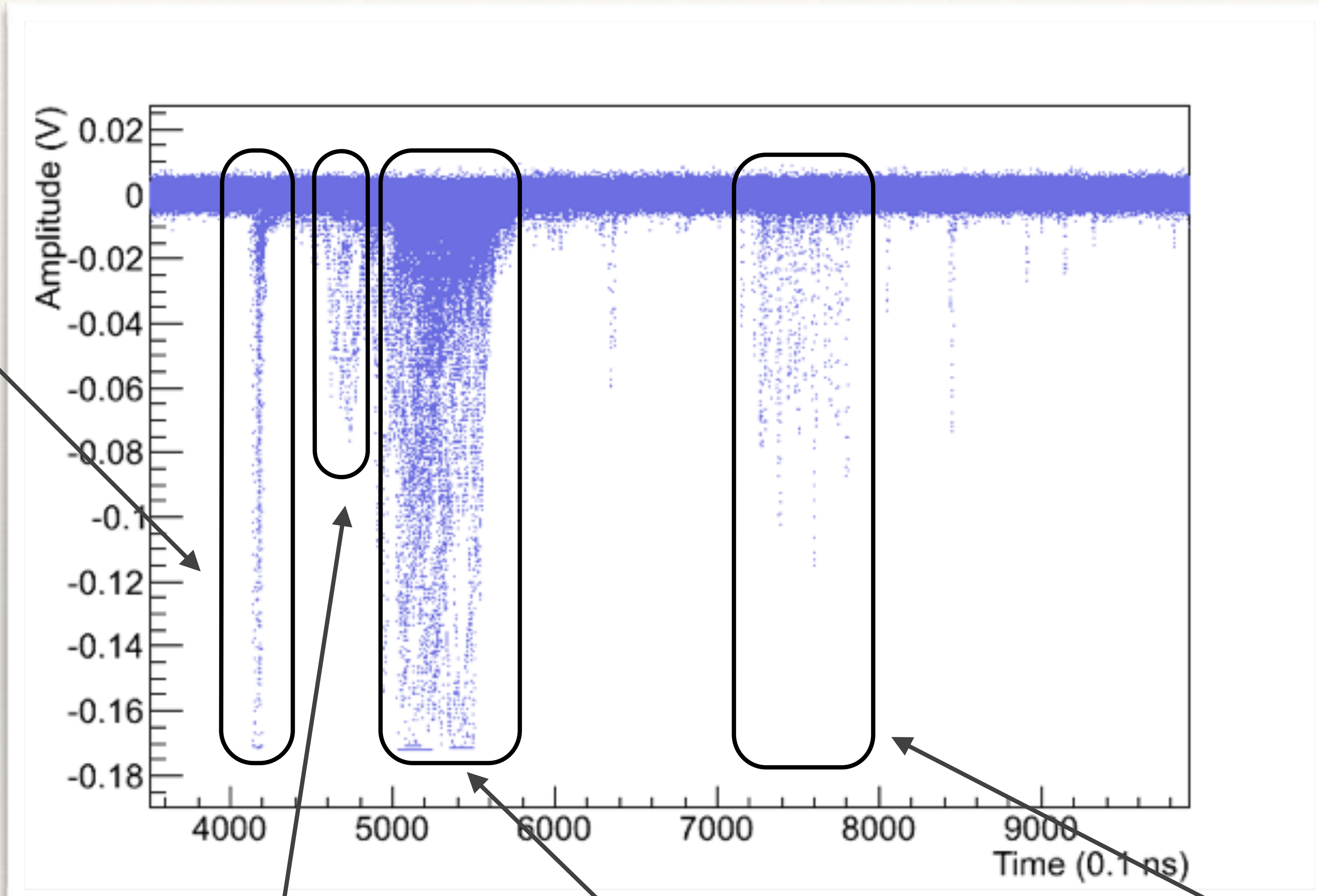


The waveforms were than analyzed to get the charge and the arrival time of the signals;

A complete dataset

Several structures were visible in a complete data taking

These spikes are there also with PMT blinded by black tape. Something within the PMT itself.



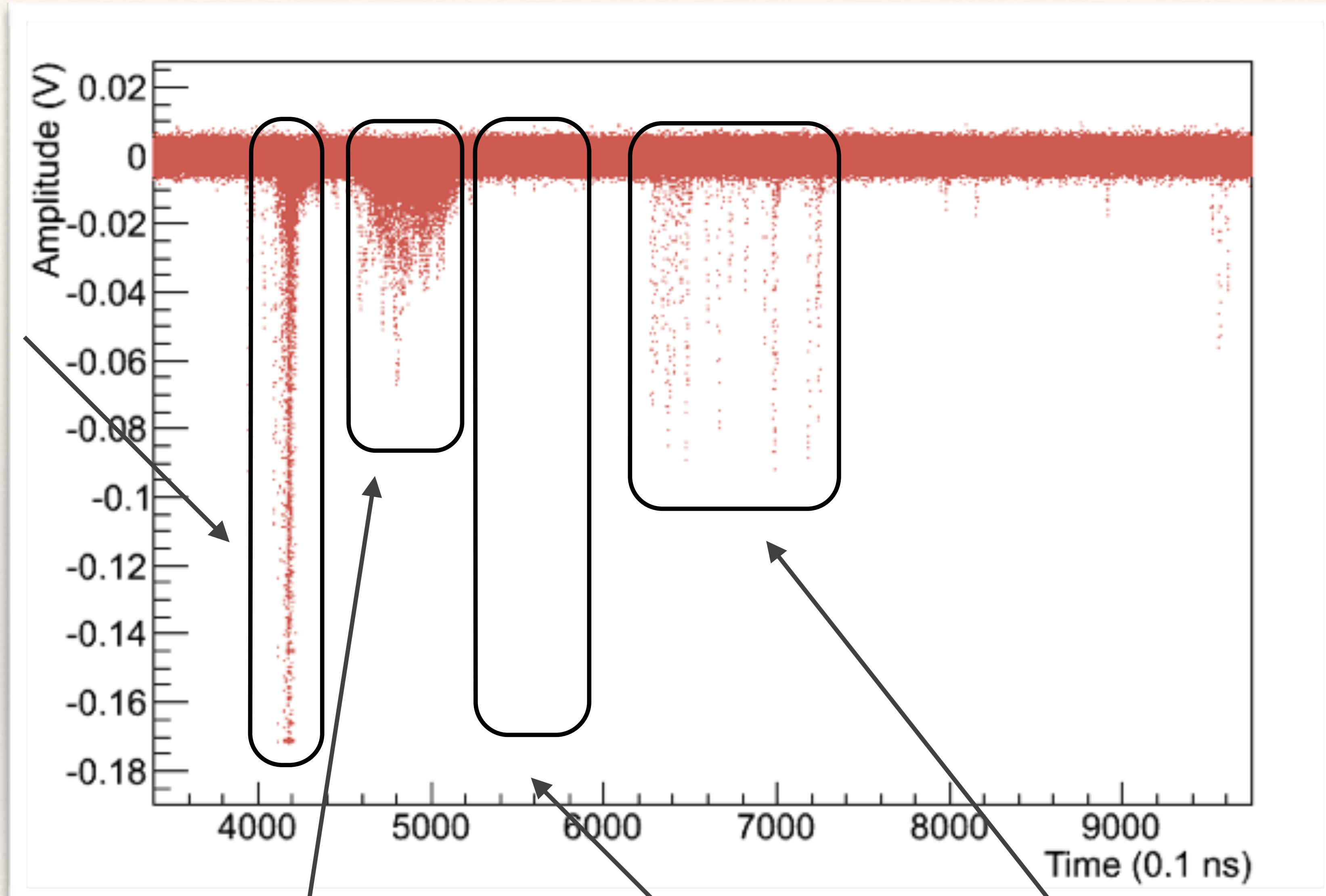
Charge released between the first and the second GEM and thus amplified only by two GEMs (bi-GEM effect)

Main signals due to the triple-GEM amplification

Echos of the triple-GEM signals arriving more than 200 ns later.

Bi-GEM effect

To confirm the bi-GEM effect, a run was taken with the first GEM off.



These spikes are always there

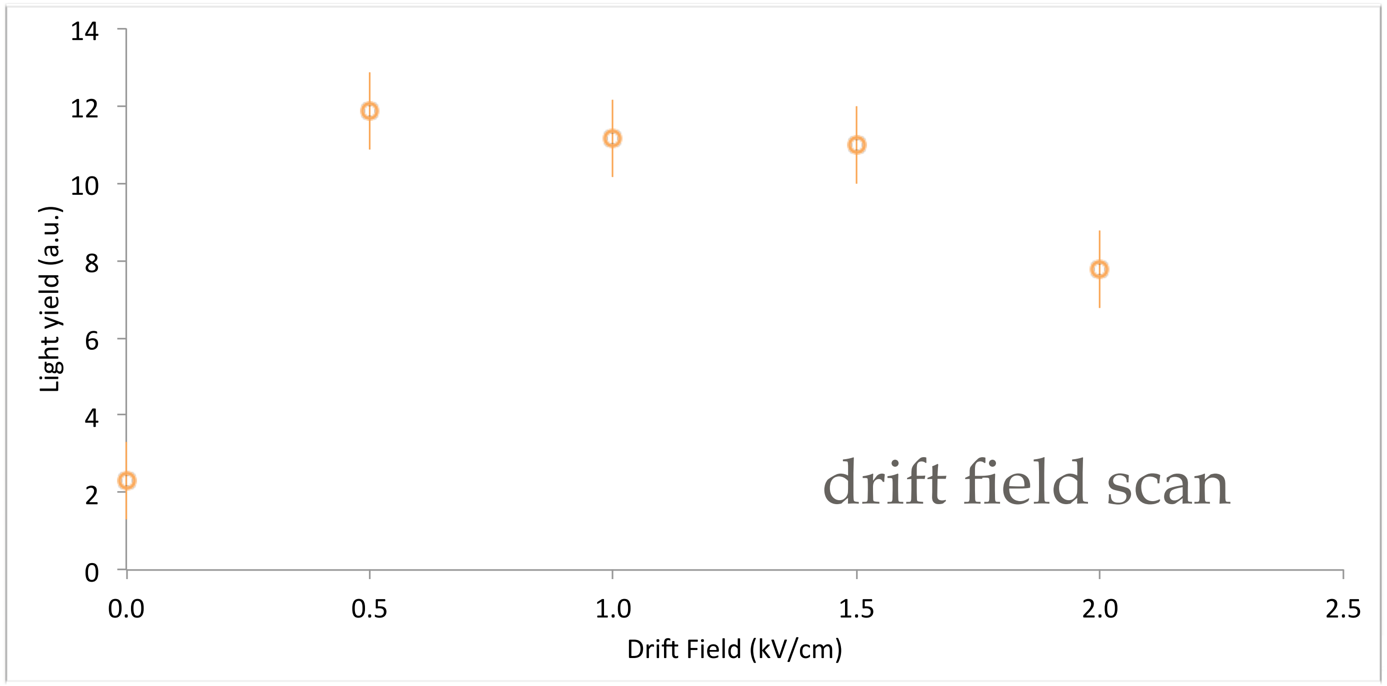
Charge released between the first and the second GEM and thus amplified by two only GEMs (bi-GEM effect)

Nothing there…

Echos of the bi-GEM signals arriving 150 ns later.

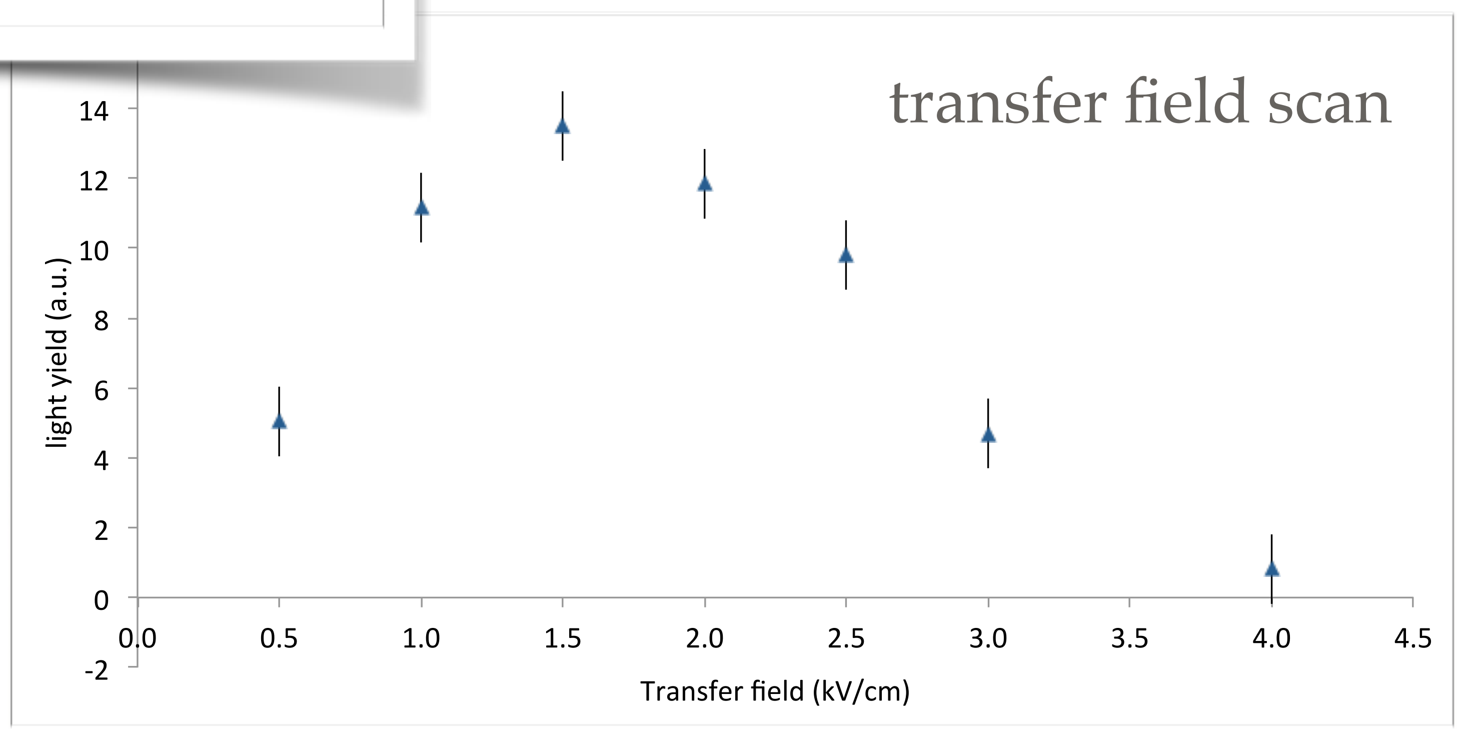
Optimization of the electric fields

The electric field values have been scanned in order to optimize the charge collection and extraction in the GEM channels and thus to maximise the system light yield;



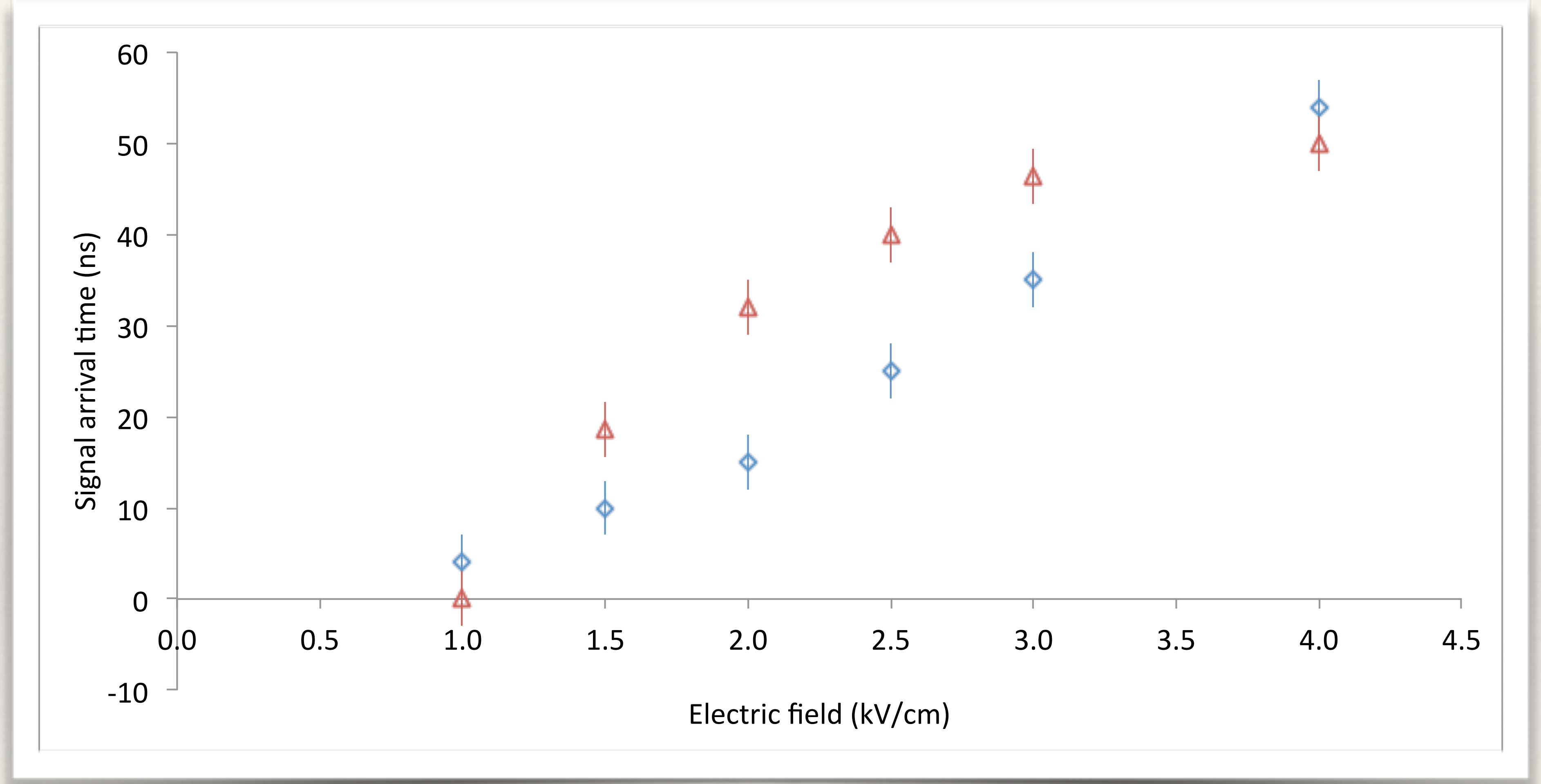
The amount of light is almost stable for drift field values in the range 0.5 - 1.5 kV / cm

A transfer field around 1.5 kV / cm maximises the light collection.



Signal arrival time

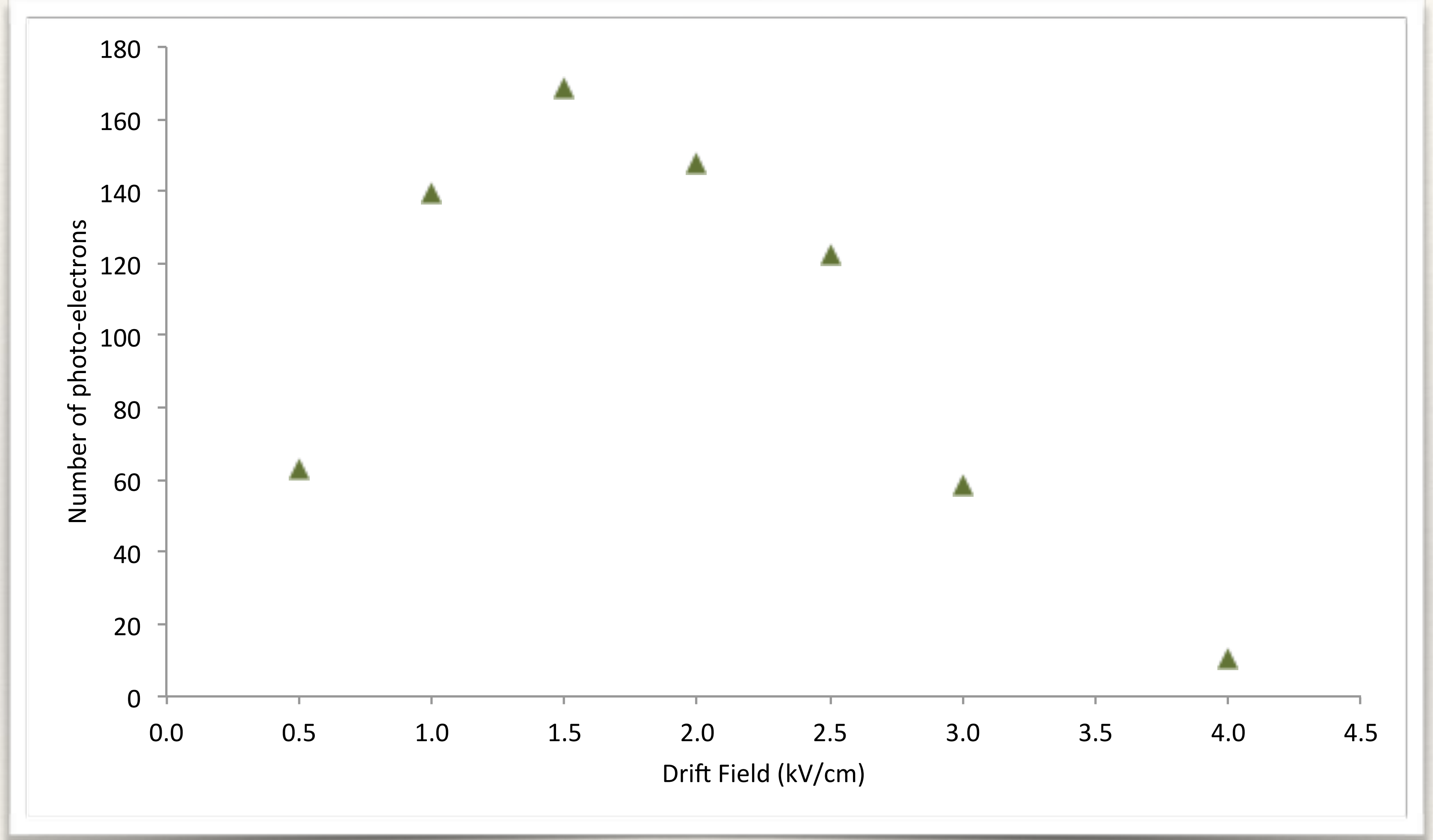
In order to check the results of the simulation, the measured signal arrival times for different drift fields are compared with the ones evaluated by using the calculated drift velocity.



Altough the agreement is not perfect, the behavior and the order of magnitude of the two studies are the same.

Light yield measurement

The average charge provided for a single photo-electron for this PMT was measured to be 0.16 +- 0.05 pC (in good agreement with a nominal gain of 8 10^5);



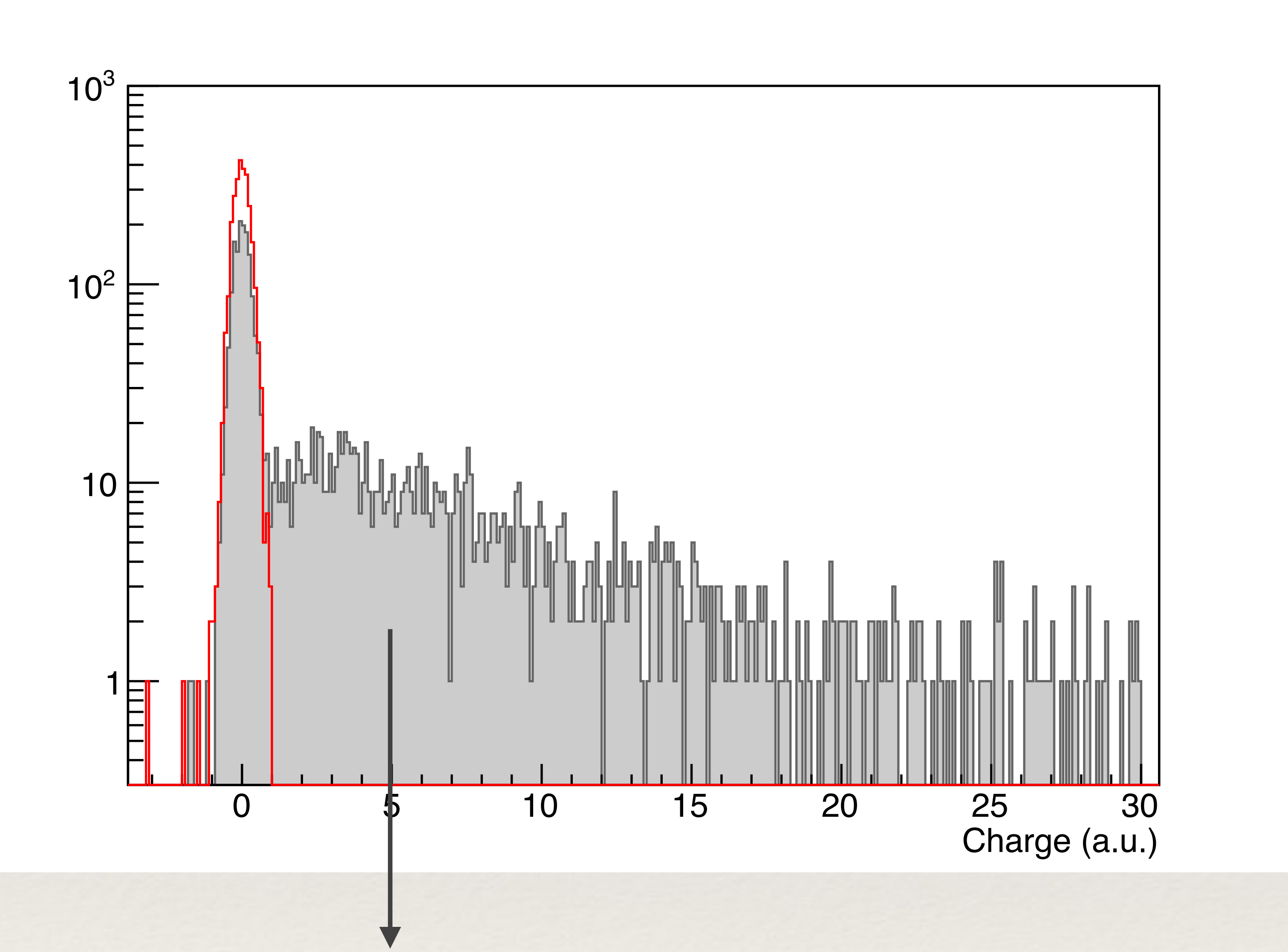
By means of this calibration the number of produced photoelectrons was evaluated;

In the optimized field condition more than 160 p.e. were collected;

Less than the optimistics expectation, but anyway a good number taken into account the small QE of the PMT. About 3000 photons reach the PMT…

Charge spectra

The waveforms were numerically integrated to evaluate the total collected charge



Example of a charge spectrum obtained with $V_{GEM} = 360$ V;

The pedestal is evaluated in a similar gate before the trigger signal;

5 a.u. means 10 pC i.e. 62 p.e.

The CMOS-Camera

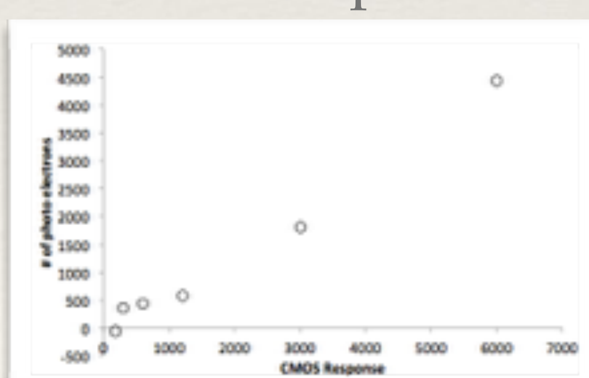
Once the light production was studied and maximised, the PMT was replaced by a CMOS camera with a suitable lens;

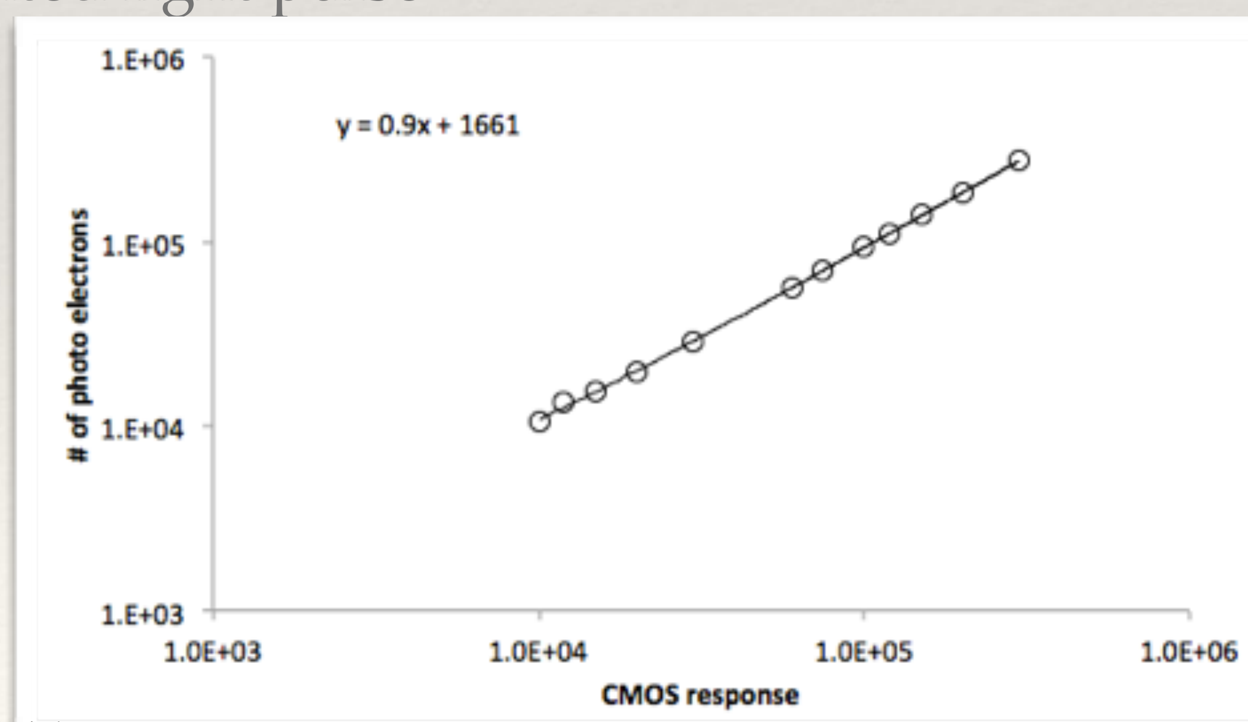
Hamamatsu provided us, for a few weeks test, an ORCA flash 4.0 camera that we instrumented with a Schneider bright lens

Specifications	
Focal Length FL (mm)	25.00
Maximum Camera Sensor Format	1"
Aperture (f/#)	f/0.95 - f/11
Field of View, 1/2" Sensor (°)	20
Distortion (%)	<-3
Field of View @ Min Working Distance (mm)	76.80
Working Distance (mm)	300 - ∞
Filter Thread	M39 x 0.5

This system was tested by means of a calibrated light pulse

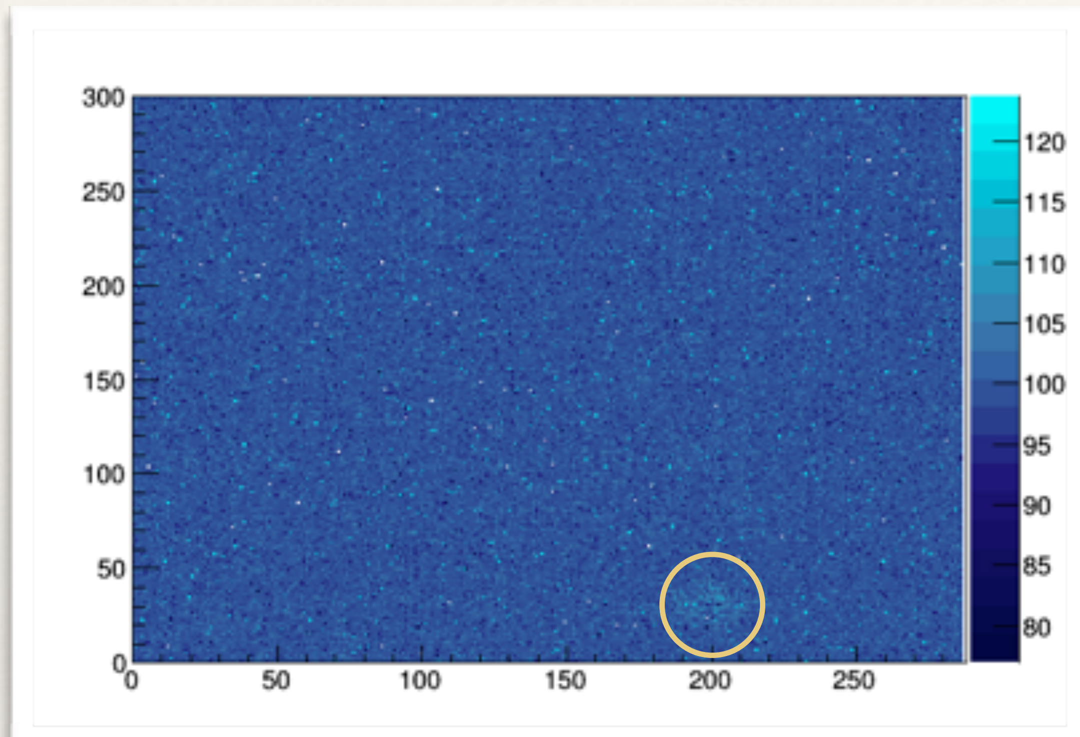
The response linearity is quite good over a large range except for a threshold behavior for small amount of photons

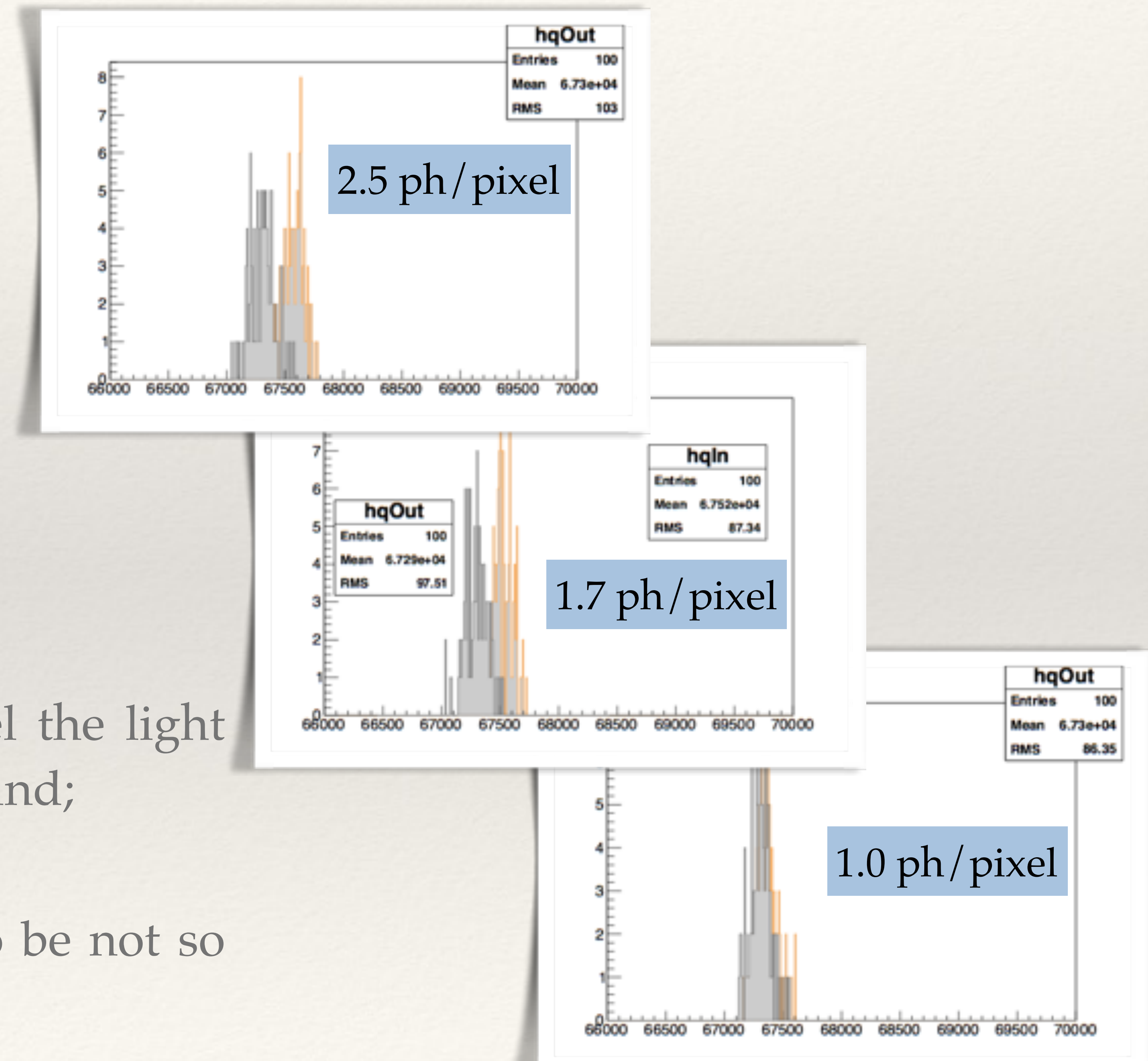




The CMOS-Camera

In order to test the sensitivity of this camera to a very small amount of photons, light in two identical regions in and out of the spot was measured for 100 times for different pulse instensities.





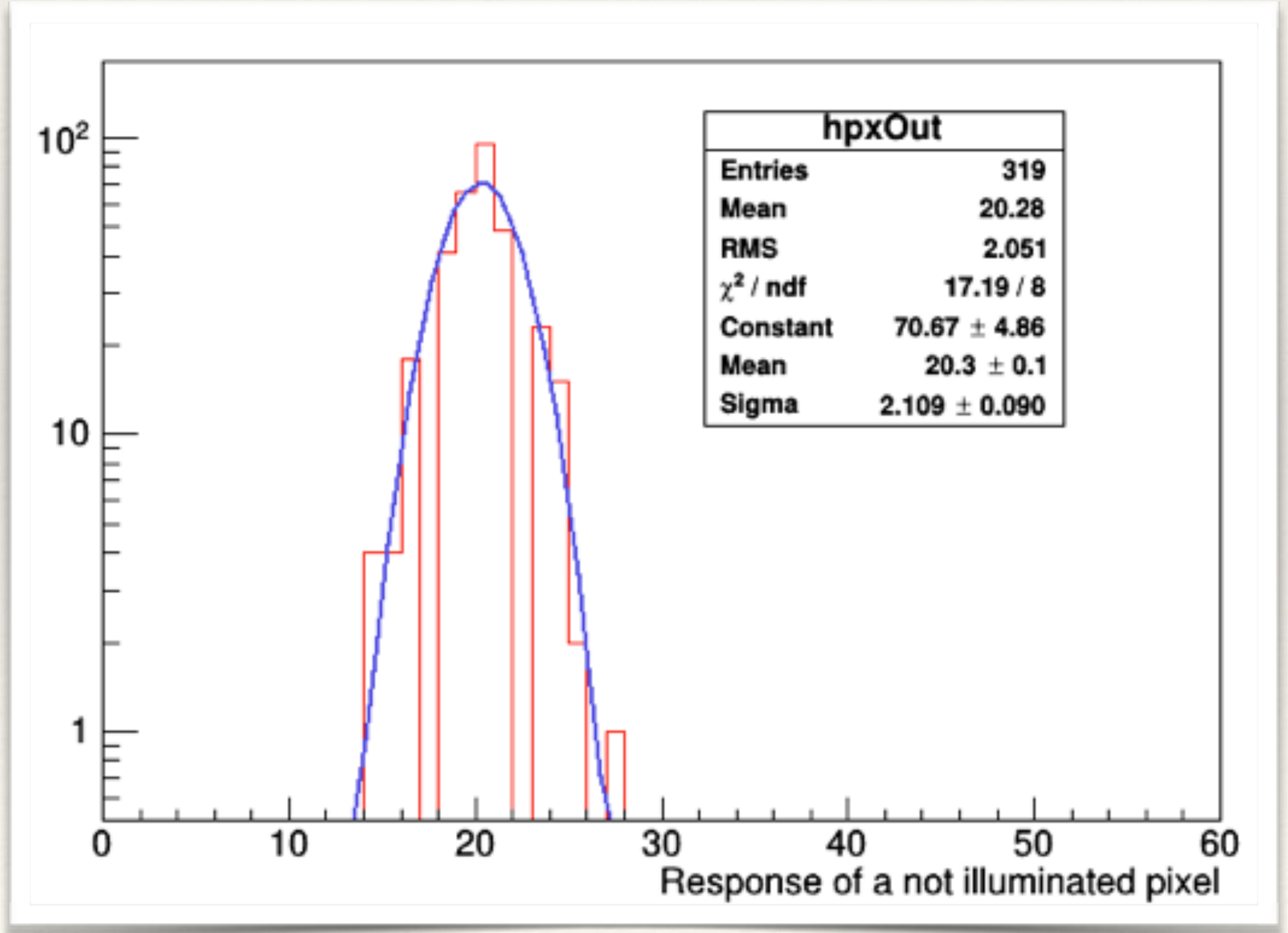
With as few as to 2.5 photons/pixel the light spot is well separated from background;

For fewer light the situation start to be not so clear;

The CMOS-Camera

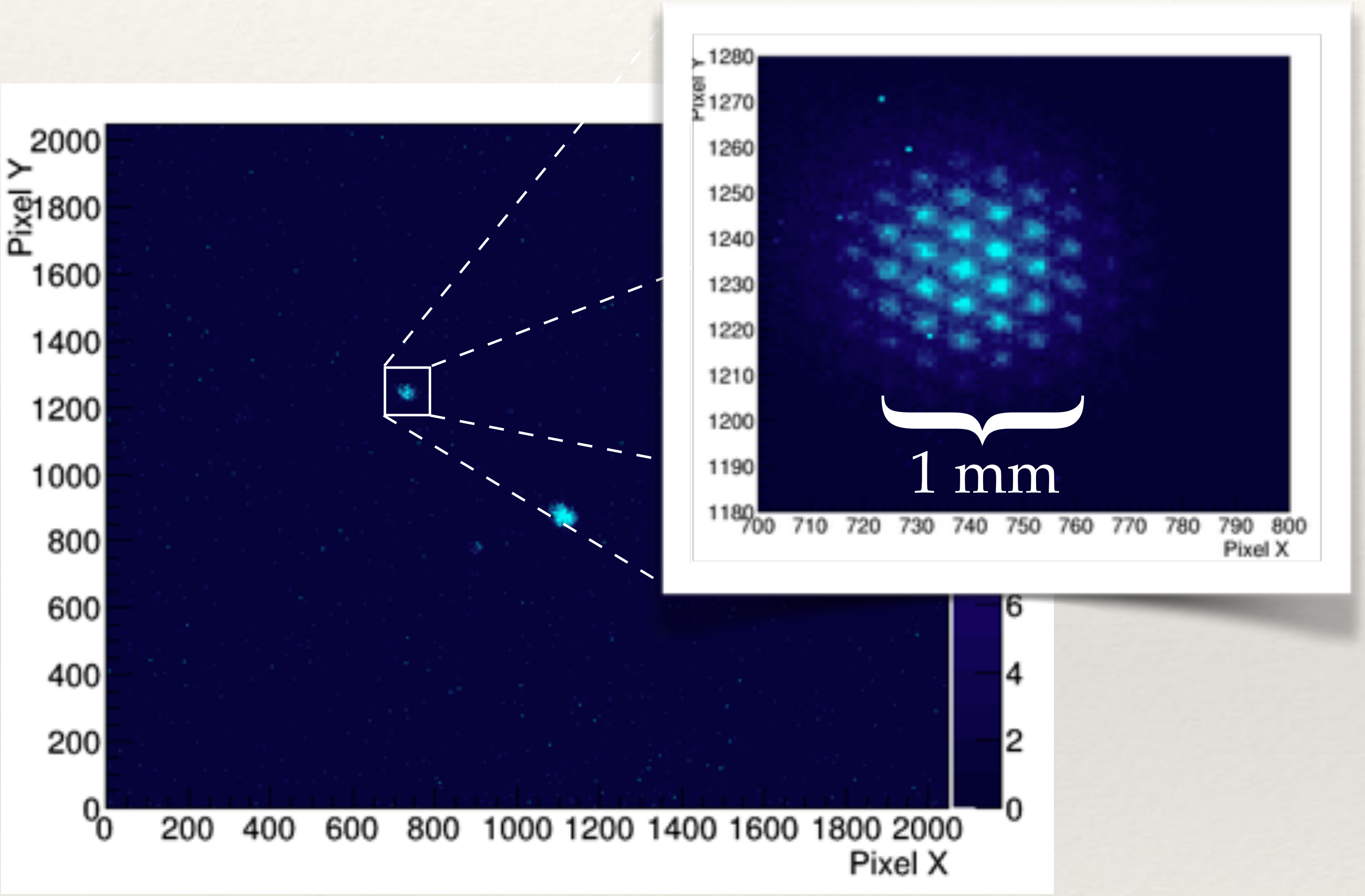
We studied the response of a single pixel out from the spot;

An RMS and a sigma of about 2 photons was found, confirming the very low noise level of this camera;



First measurements

By using the camera we've been able to take pictures of several hot spots that appears when the three GEMs reach the high voltage working point, even without drawing a sizable leakage current;



Unfortunately, the Schneider lens broke during the measurements;

We acquired few hundreds of images while illuminating the GEM detector by means of a ^{137}Cs source.

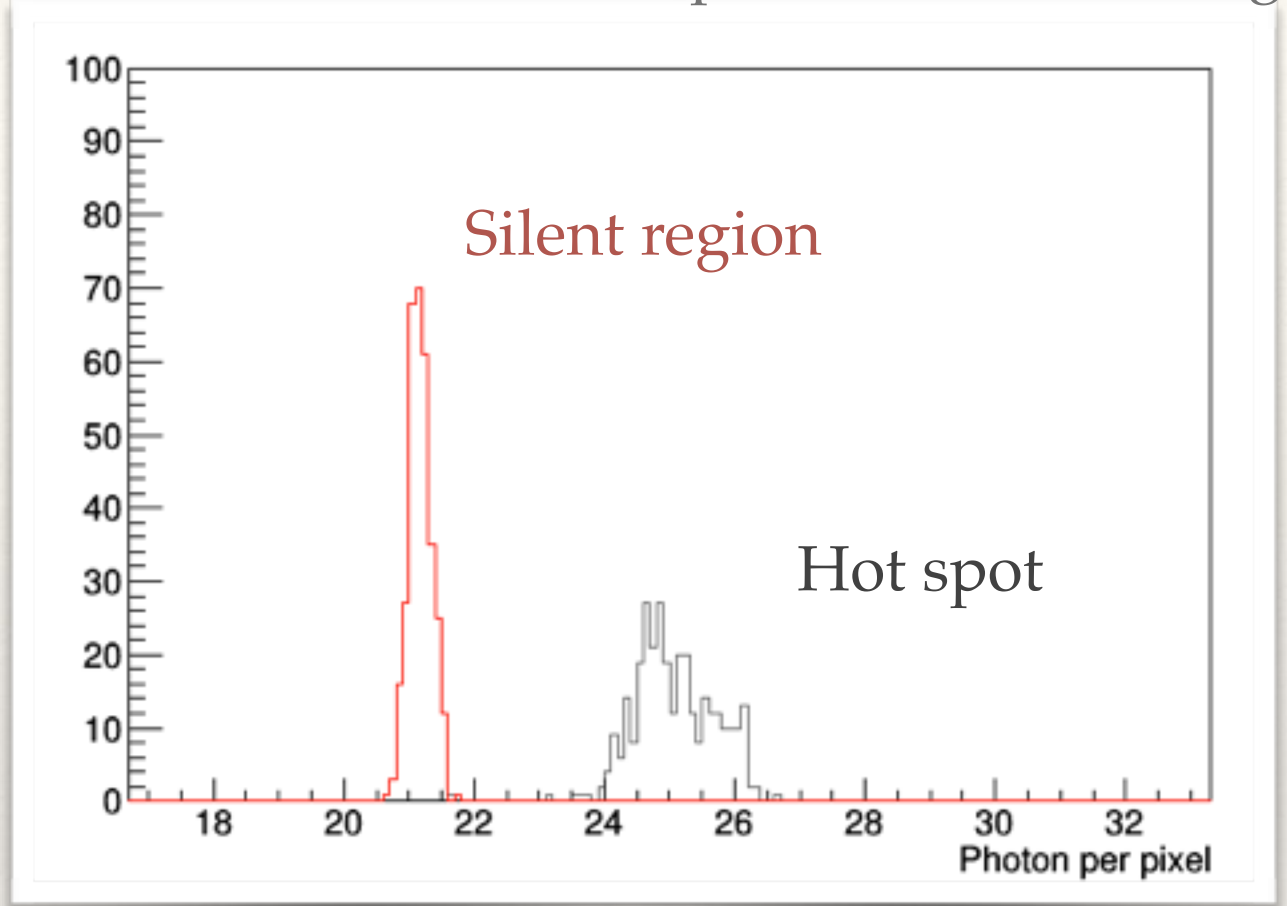
Except from tracks due to direct interactions of photons within the CMOS sensor, so far we were not able to see light signals coming from the triple GEM detector.

Light from discharges

The charge distribution in the hot spots was studied and compared with the charge in a "silent" region;

600 pictures with an integration time of 1 second were taken;

Except for few events after a discharge when the V_{GEM} was down, there are not superpositions between the two distributions;

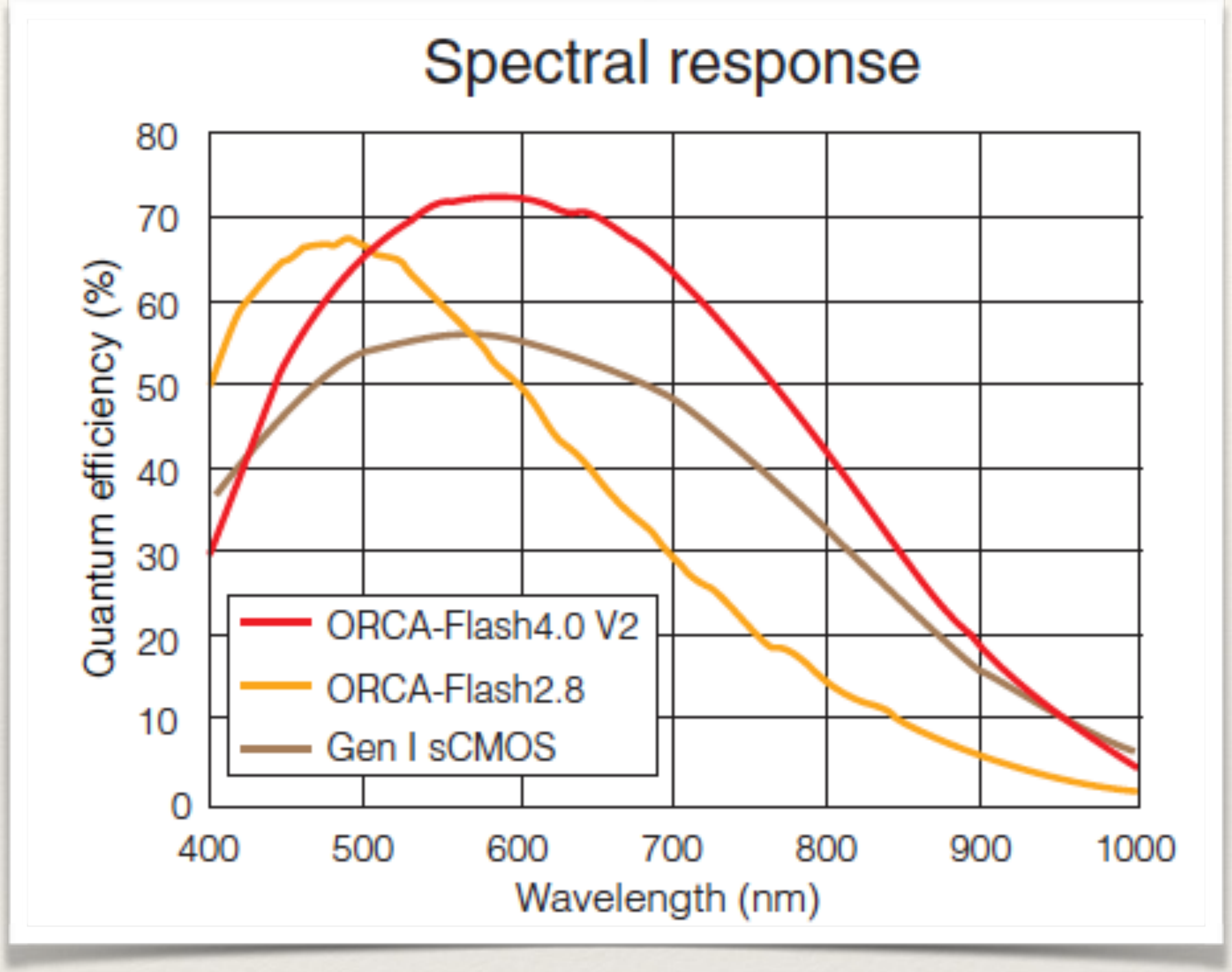


Assuming a poissonian distribution of the number of "micro-discharges" in 1 second, the average number to get never 0 in 600 pictures is 6.

It seems that we get less than one photon per discharge per pixel.

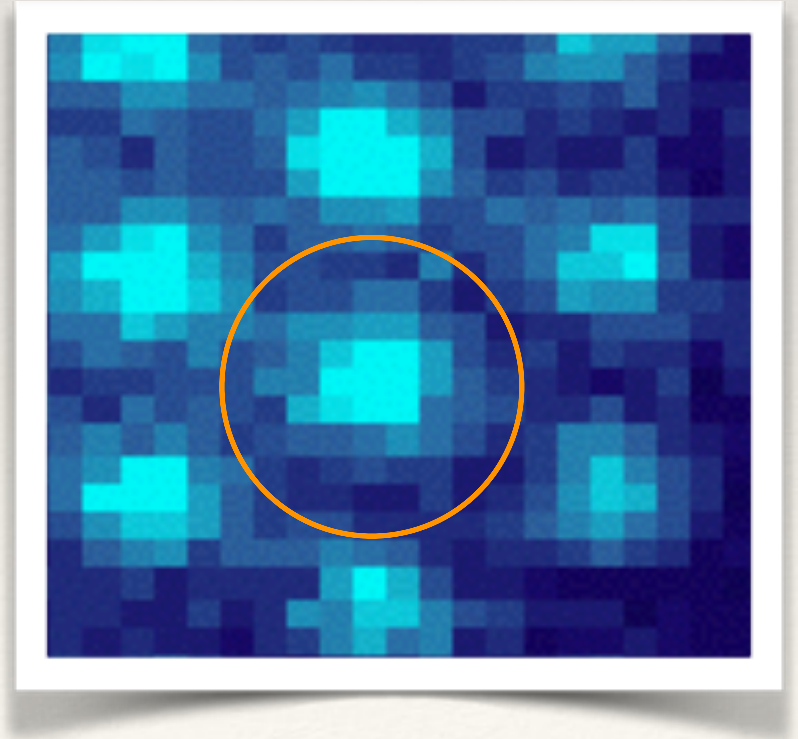
Where the light is going?

Expected light from mip



Around 600 nm the camera provides a QE of more than 70%

Assuming a similar solid angle ecceptance, 6000 photons reaching the camera means 4200 p.e.;
For a vertical muon, let's assume $1mm^2$ spot i.e. 50 GEM holes;
This means 80 p.e. per hole;



1 hole illuminates almost 50 pixels

We expect less about 2 p.e. per pixel, very few…

Conclusion and future steps

The light yield of a triple-GEM detector was studied and optimised;

The performance of a CMOS based camera were tested and found to be very promising for our application;

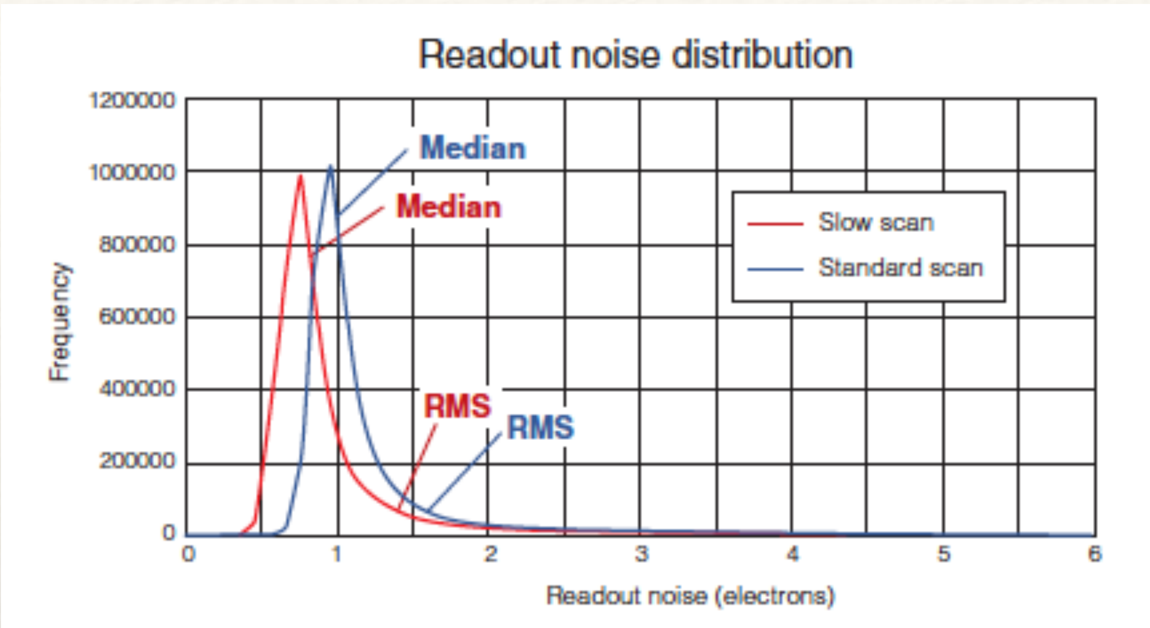
Unfortunately, so far we haven't been able to see signals from this system but the game has just started;

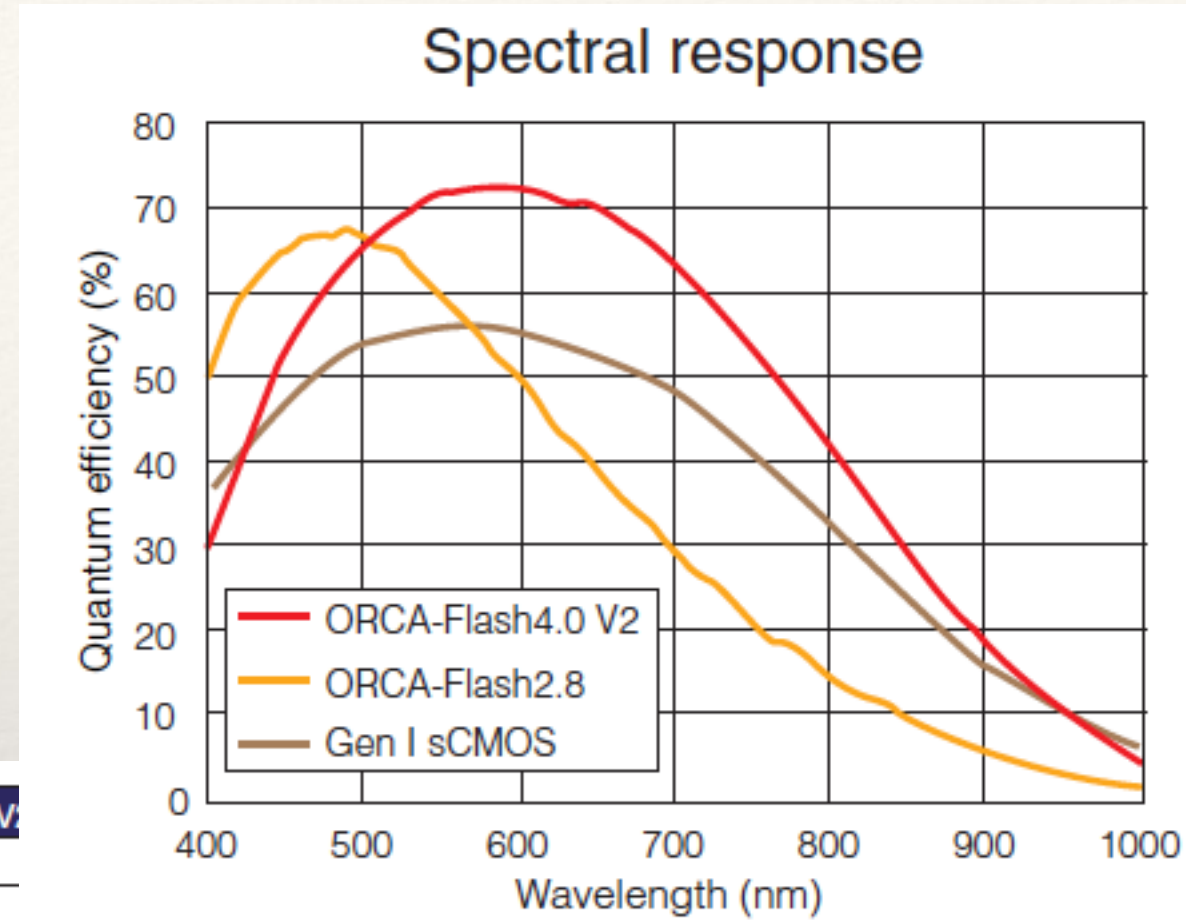
It seems that the light is not enough:

- use higly ionizing particles: alpha or X-rays;
- increase the amount of CF_4 in the mixture;
- add a fourth GEM to the stack;

Back up

ORCA Flash 4.0

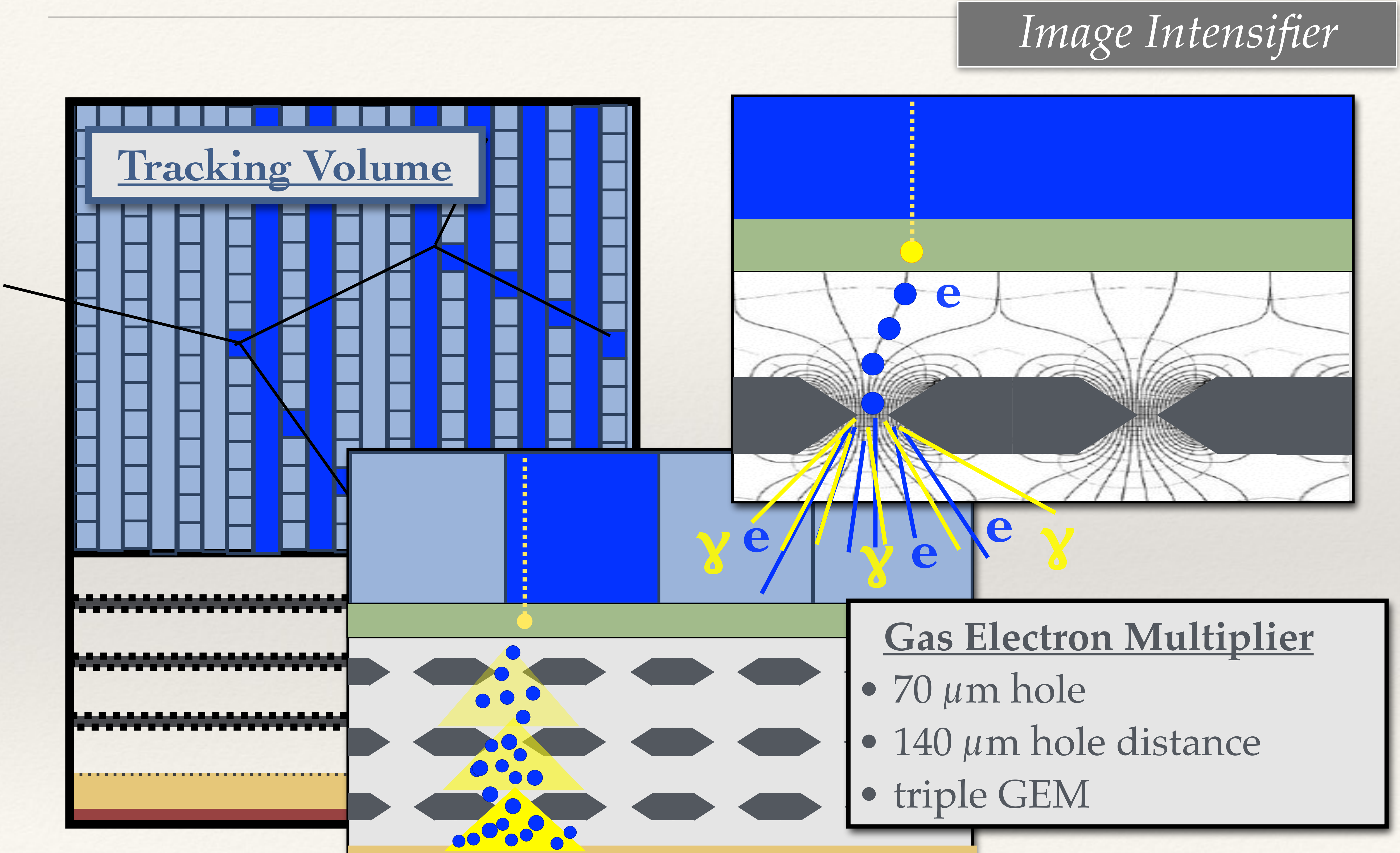




Product number		C11440-22CU (ORCA-Flash4.0 V
Imaging device		Scientific CMOS sensor FL-400
Effective number of pixels		2048(H) × 2048(V)
Cell size		6.5 μm × 6.5 μm
Effective area		13.312 mm × 13.312 mm
Full well capacity (typ.)		30 000 electrons
Readout time	Standard scan (at 100 frames/s)	10 ms
	Slow scan (at 30 frames/s)	33 ms
Readout noise	Standard scan (at 100 frames/s, typ.)	1.6 electrons rms (1.0 electrons median)
	Slow scan (at 30 frames/s, typ.)	1.4 electrons rms (0.8 electrons median)
Dynamic range (typ.)*2		37 000:1
Quantum efficiency		Over 70 % at 600 nm and 50 % at 750 nm

Cooling method	Dark current (typ.)	Sensor temperature (nominal)
Forced air (Ambient at +20 ℃)	0.06 electrons/pixel/s	–10 ℃
Water (+20 ℃)	0.02 electrons/pixel/s	–20 ℃
Water (+15 ℃)	0.006 electrons/pixel/s	–30 ℃

MOnitor for Neutron Dose for hadrOnterapy



Gas Electron Multiplier

- 70 μm hole
- 140 μm hole distance
- triple GEM