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Charactherisation of Multi-Anode Photomultiplier Tubes in Milano-Bicocca

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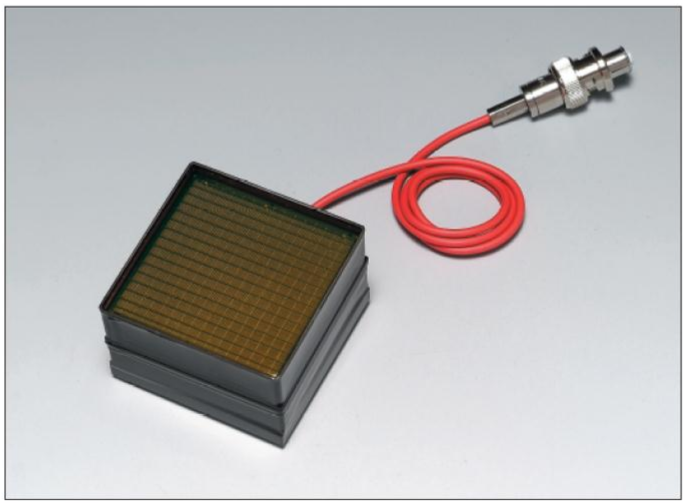
THE RICH AT "LARGE HADRON COLLIDER BEAUTY"

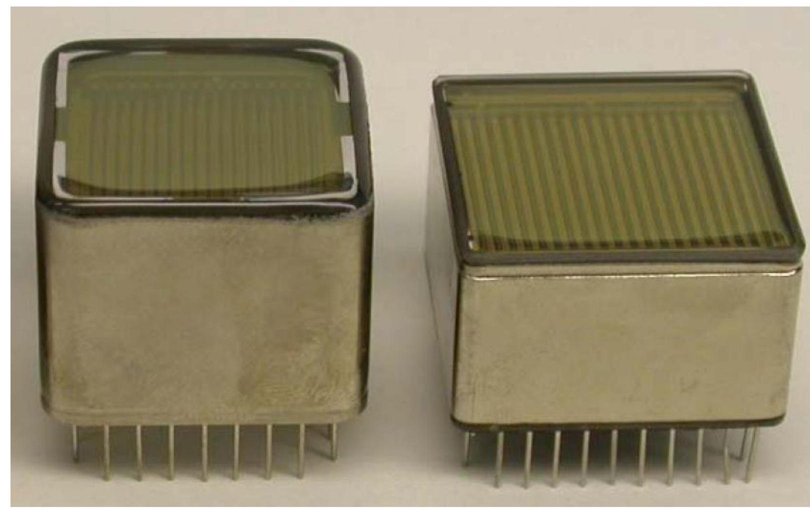
The RICH at LHCb is now read out by hybrid photon detectors (HPD).

In view of the LHCb upgrade, a possible option is to substituting the HPD with commercial multi-anode photomultiplier tube.

The Milano-Bicocca group has worked on this, characterizing first the Hamamatsu H9500[1], then the R7600[2] and now R11265 for fast single photon response.



H9500



R7600 R11265

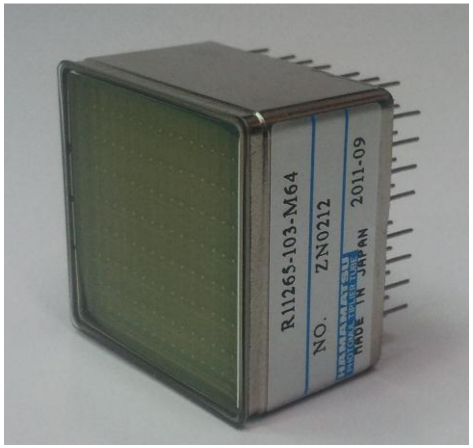
1) C. Arnaboldi et al., "Cross-talk study of the single-photon response of a flat-panel PMT for the RICH Upgrade at LHCb.", IEEE Transaction on Nuclear Science, V 57, pp 2267-2272, 2010.

2) C. Arnaboldi et al., "Characterization of a Hamamatsu R7600 multi-anode photomultiplier tube with single photon signals" to be published in the Proceedings of the 2010 NSS Conference.

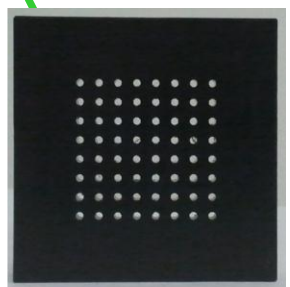
Comparison of Hamamatsu H9500 - R7600 - R11265 Data Sheets

	H9500	R7600	R11265
Spectral Response Range	185-650 nm	185-650 nm	185-650 nm
Window Material / Thickness	UV glass / 1.5 mm	UV glass / ND	UV glass / 0.8 mm
Geometrical Dimensions	52 x 52 mm^2	25.7 x 25.7 mm^2	26.2 x 26.2 mm^2
Photocathode Minimum Effective Area	49 x 49 mm^2 (>88%)	18.1 x 18.1 mm^2 (≈50%)	23 x 23 mm^2 (>85%)
Number of Pixels / Dimensions	256 / 2.8 x 2.8 mm^2	64 / 2.0 x 2.0 mm^2	64 / 2.9 x 2.9 mm^2
Photocathode Material	Bialkali	Bialkali	Super Bialkali
Number of Dynodes	12	12	12
Maximum Supply Voltage	1100 V	1000 V	1100 V
Gain	1.5 x 10^6 at 1000V	0.6 x 10^6 at 800V	1 x 10^6 at 1000V
Anode Dark Current (Each anode)	0.2 nA	0.2 nA	0.4 nA
Rise / Transit Time	0.8 / 6.0 ns	1.0 / 12 ns	0.6 / 5.1 ns
Uniformity Between Each Anode	1 : 4	1 : 2.5	1 : 3

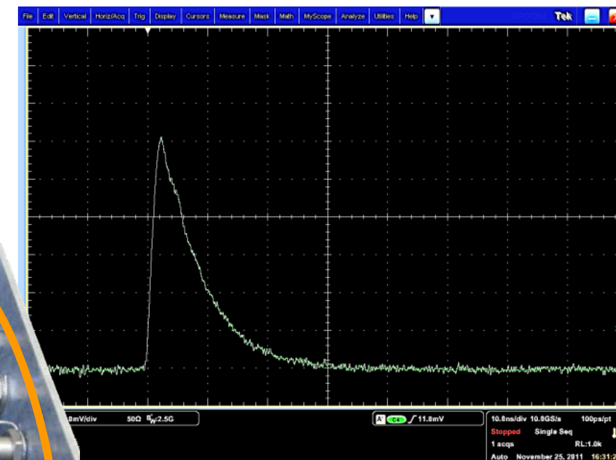
Measurement Set-Up with Blue LED



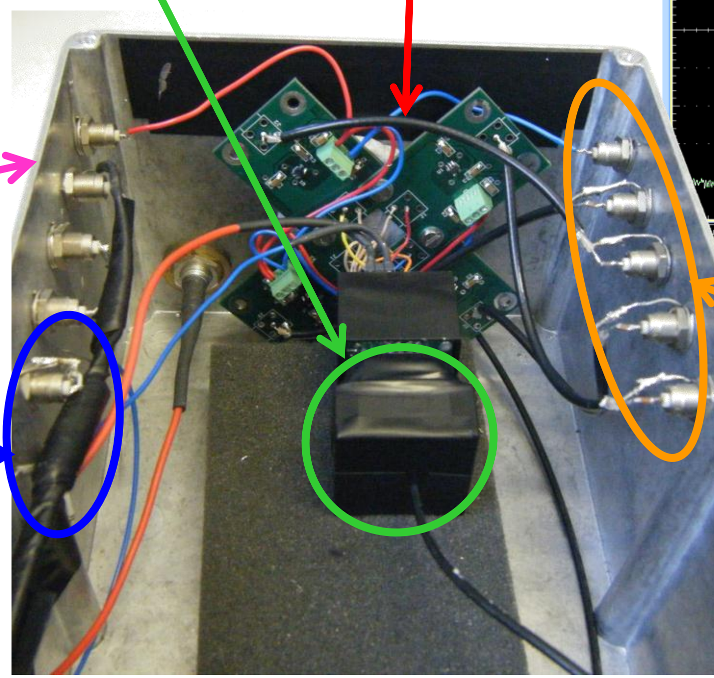
PMT with black mask



4 Charge Preamplifiers:
For most of the characterization, commercial **current-feedback opamps** were used (bandwidth: ~1 GHz, for ~1 ns resolution)



The box was housed inside a small Faraday cage



Single photons were generated with a commercial **blue-led** coupled to an **Optical fiber**.
(rate: ~ 400 photons/s).

Outputs

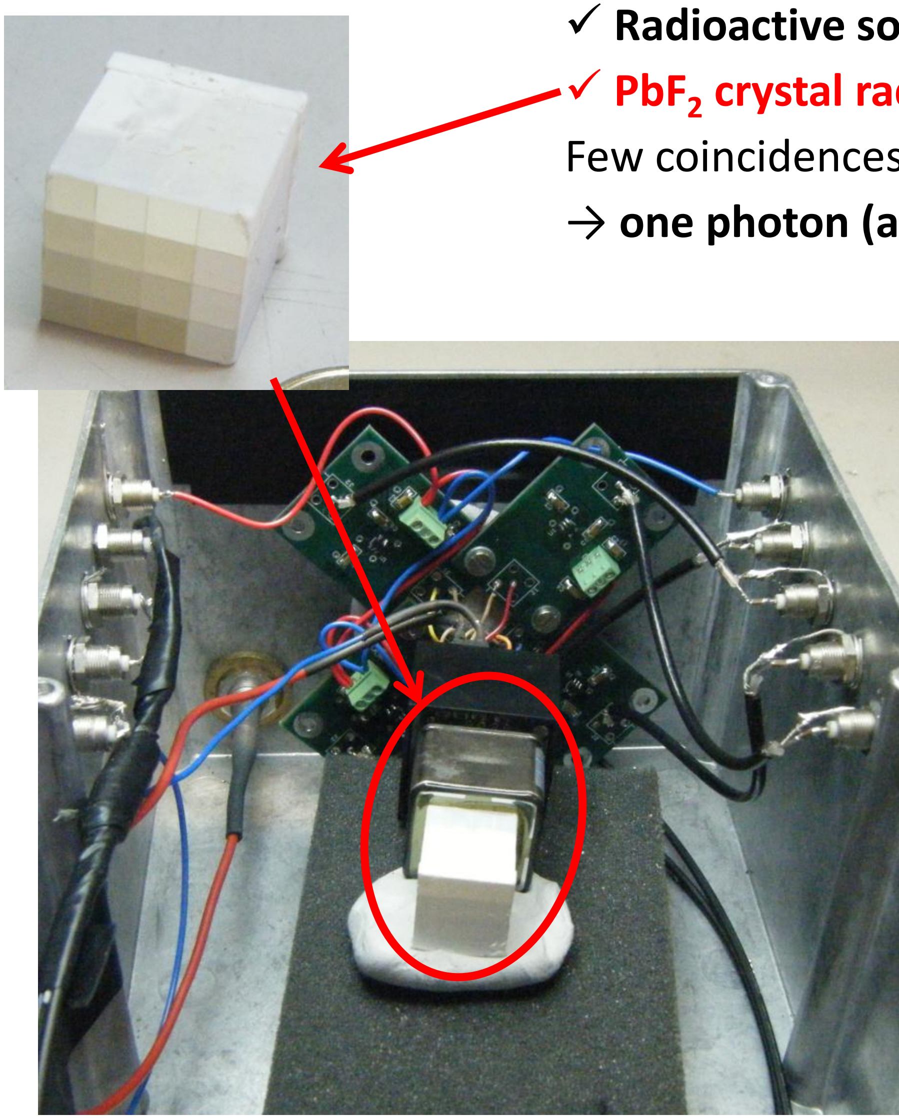
Signals are acquired, stored and downloaded for offline analysis using a Tek DPO7254 scope.

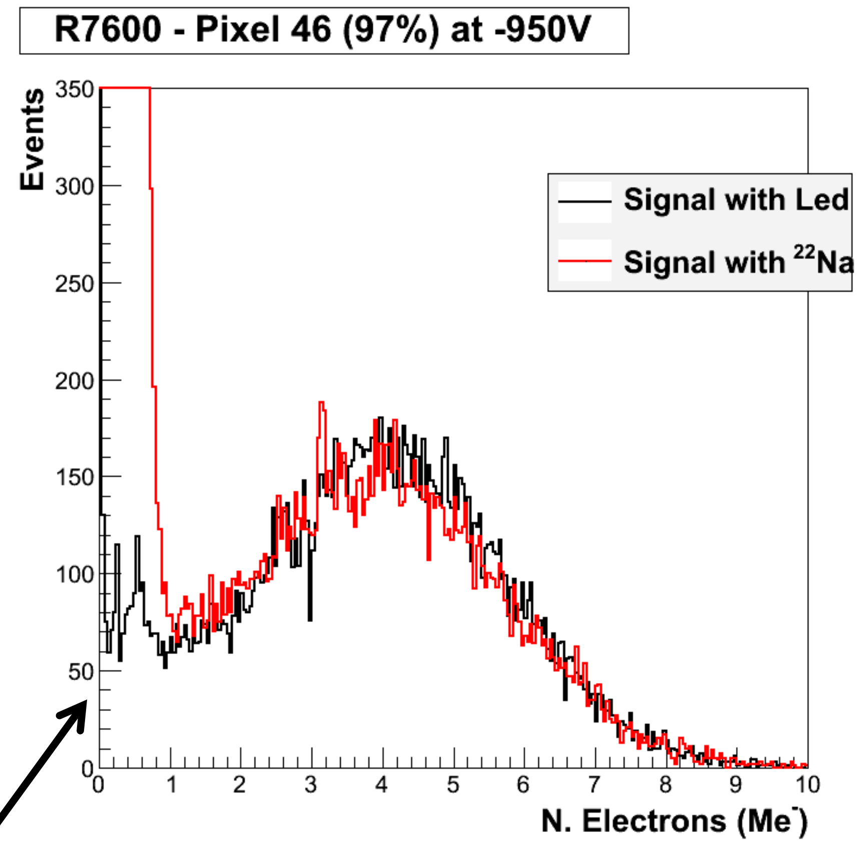
Measurement Set-Up with beamless Cherenkov light

- ✓ **Radioactive source of ^{22}Na** ($\beta^+ \rightarrow$ 511 KeV photons)
- ✓ **PbF$_2$ crystal radiator** (n = 1.82, Cherenkov thresh.= 100.5 KeV)

Few coincidences are observed between pixels

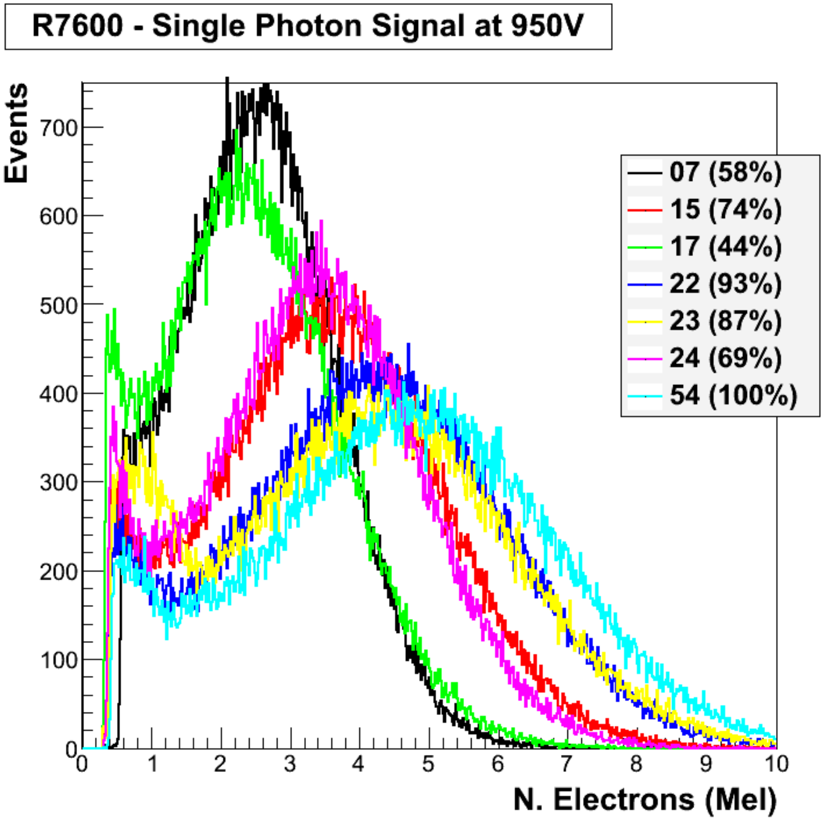
→ **one photon (at most) reaches the PMT on each event**

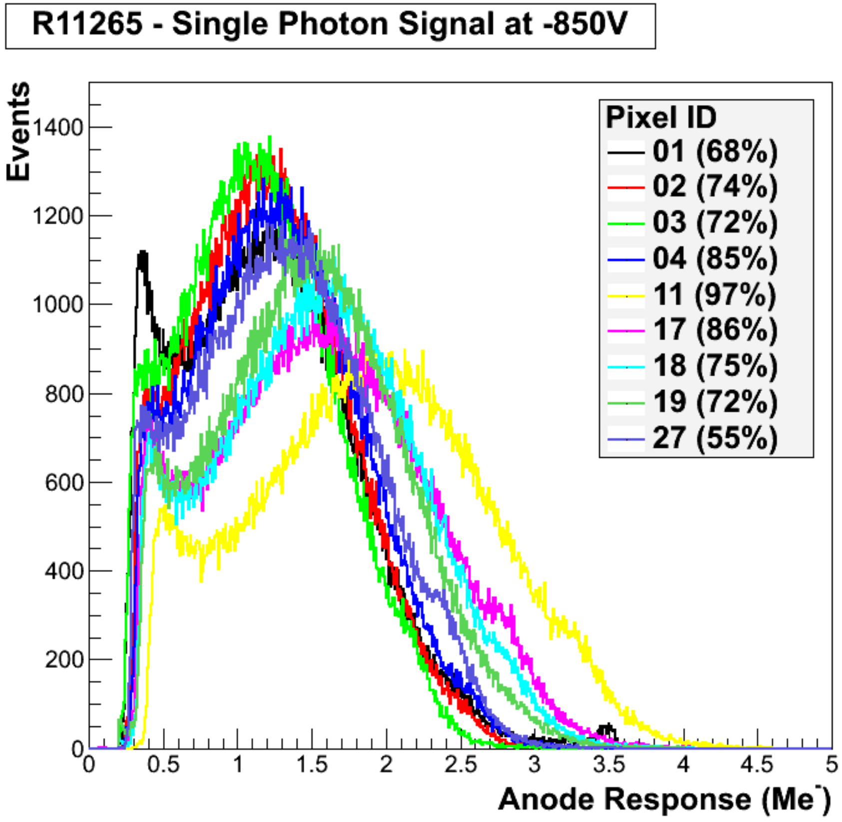




The spectra comparison confirms that **the led is a single photon source.**

HAMAMATSU R7600 vs R11265 – Anode Uniformity





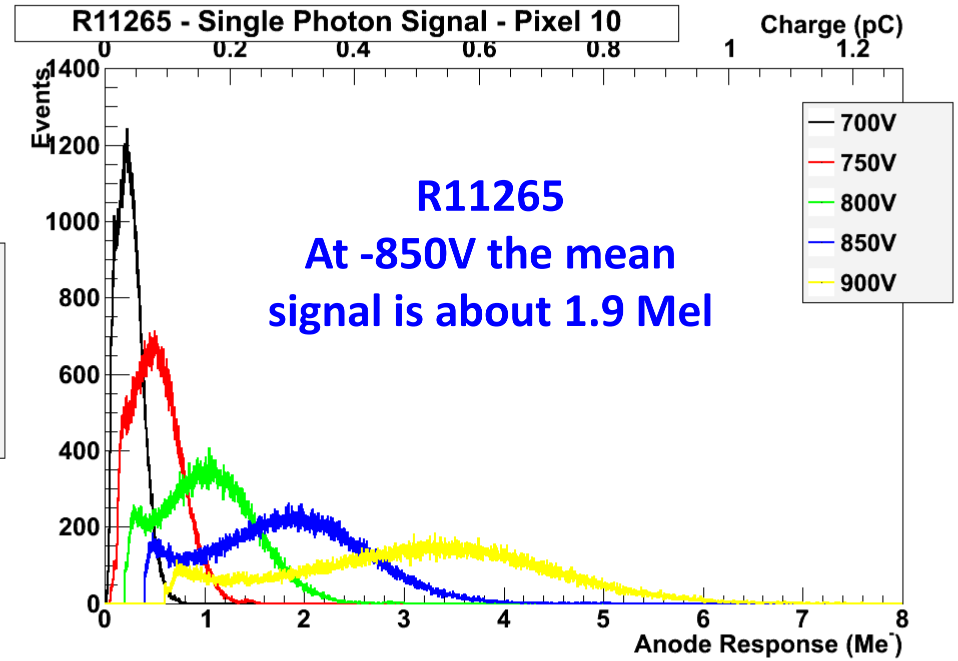
Good uniformity was observed within about a factor of 2

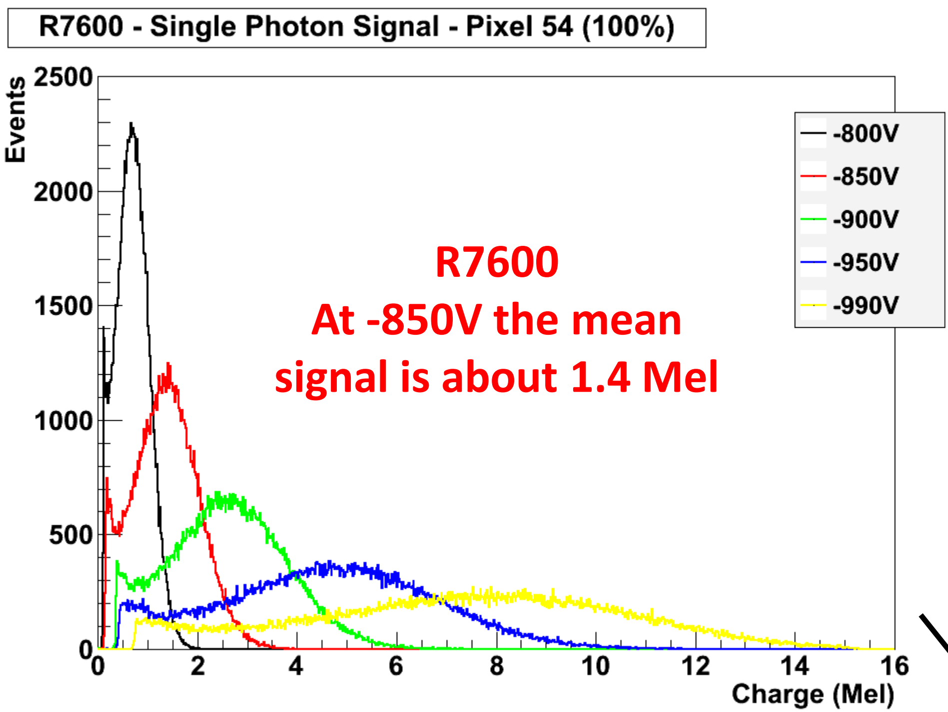
HAMAMATSU R7600 vs R11265 – Gain VS Bias Voltage

Voltage Distribution Ratio and Supply Voltage

Electrodes	K	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	Dy10	Dy11	Dy12	G.R	P
Ratio		2.3	1.2	1	1	1	1	1	1	1	1	1	1	1	0.5

Supply Voltage : 1000 V K : Cathode Dy : Dynode G.R : Guard Ring P : Anode





Voltage Distribution Ratio and Supply Voltage

Electrodes	K	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	Dy10	Dy11	Dy12	P
Ratio		3	2	2	1	1	1	1	1	1	1	1	2	5

HAMAMATSU R11265 – Dark Current

We measured the dark current for some clusters of pixels.
All the holes in the mask were covered and the box was sealed with insulating tape.

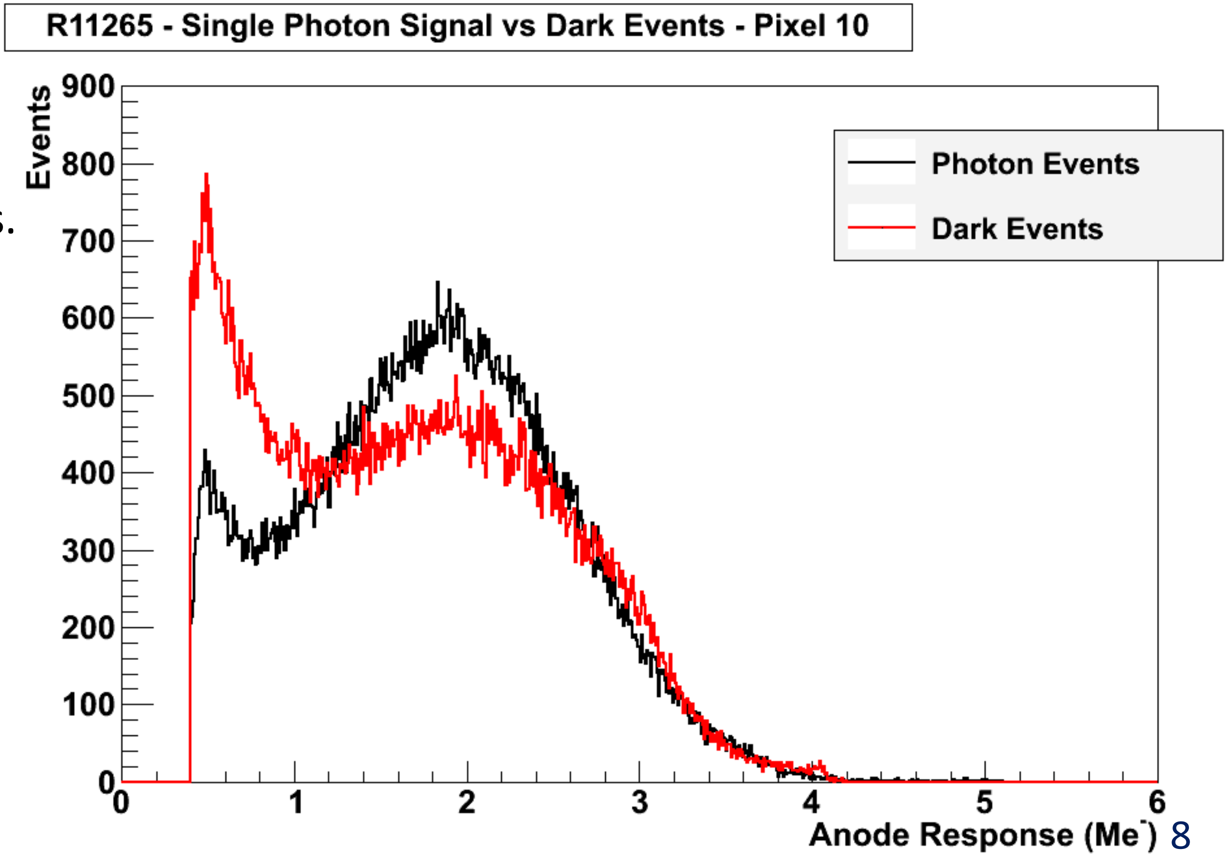
With the threshold at 200 ke$^-$, we measure:
Pixel01 + Pixel02 + Pixel03 + Pixel04 = Mean Rate of 5,20Hz (in about 65 hours)
Pixel09 + Pixel10 + Pixel11 + Pixel12 = Mean Rate of 4,50Hz (in about 44 hours)
Pixel17 + Pixel18 + Pixel19 + Pixel20 = Mean Rate of 3,70Hz (in about 41 hours)

Comparison between single photon spectra and dark events.

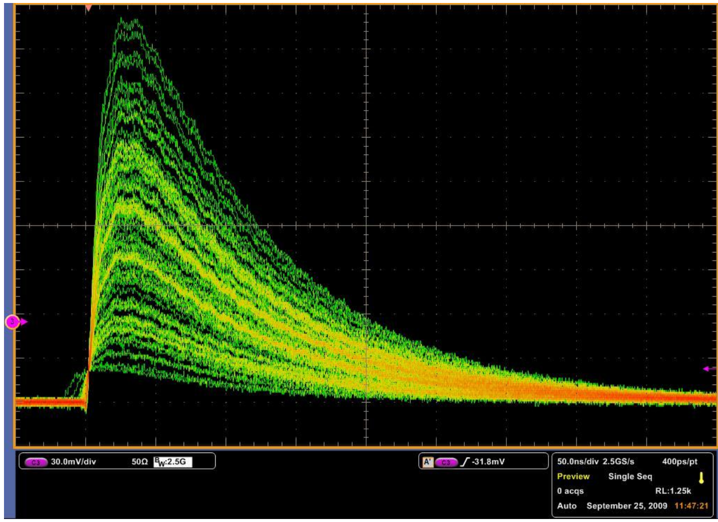
150000 events

Rate of Photon Events: 498 Hz

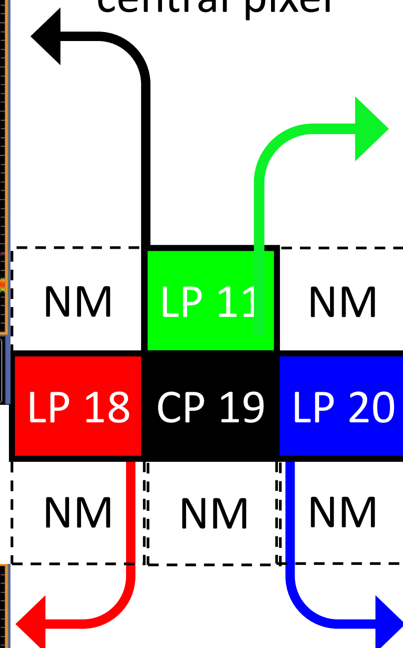
Rate of Dark Events: 1,5 Hz

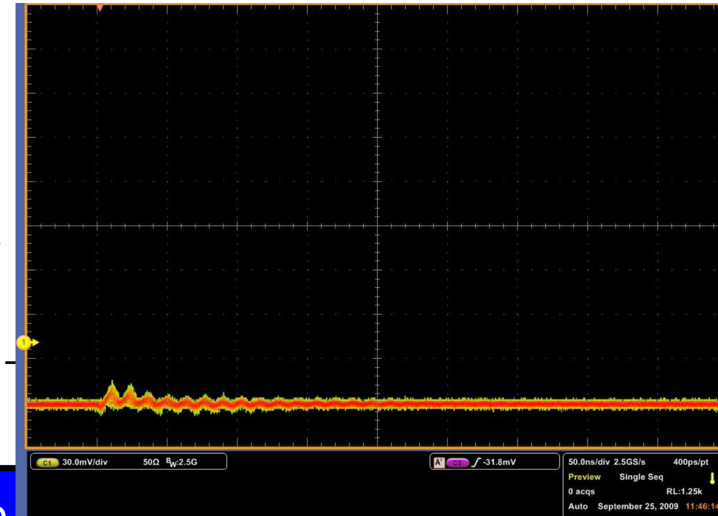


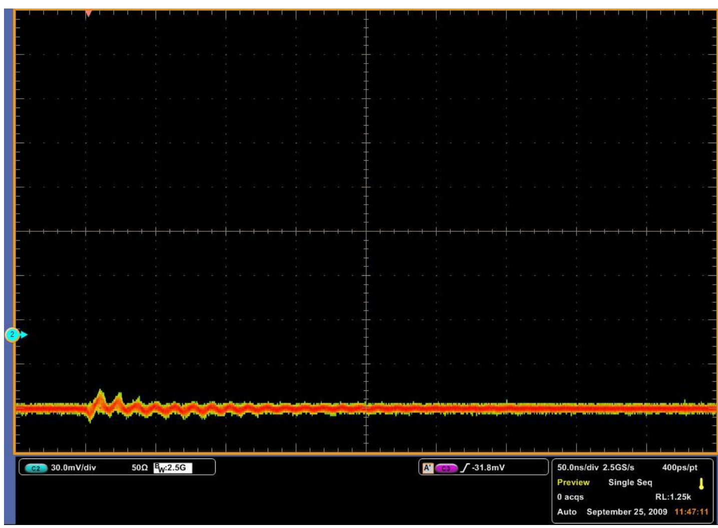
HAMAMATSU R7600 – Crosstalk



100 events on central pixel

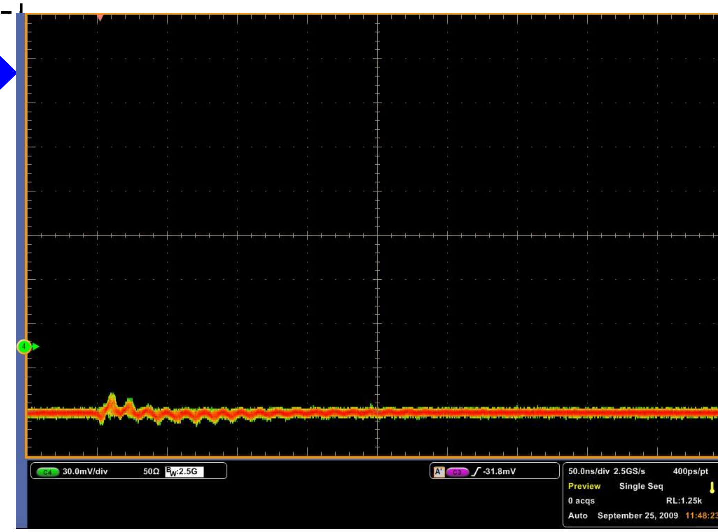




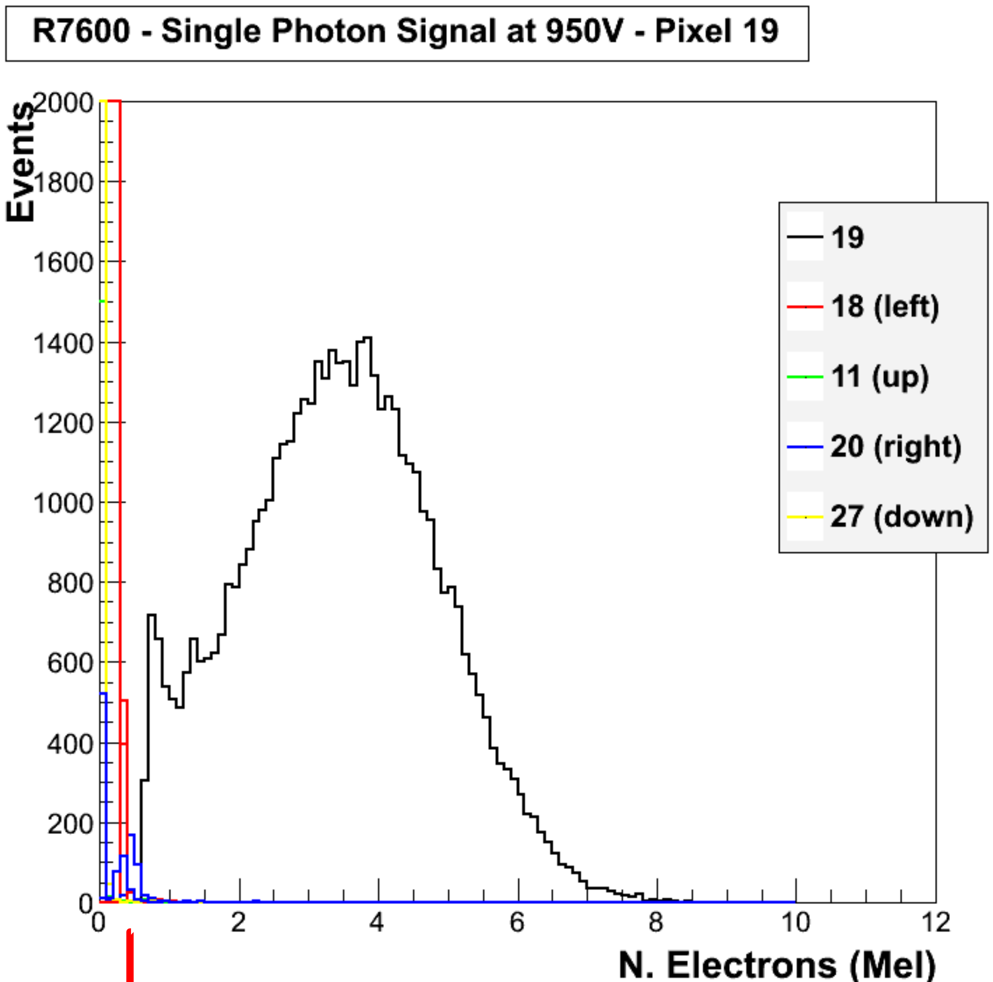


No crosstalk events were observed

Only a small oscillation (maybe induced via bias)

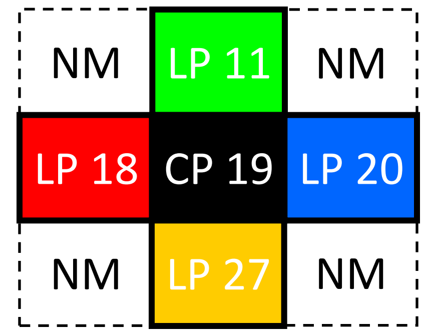


HAMAMATSU R7600 – Crosstalk



50000 events taken for each measurement

Rate ≈60Hz



Only 120 crosstalk signals are above the threshold chosen for the main signal.

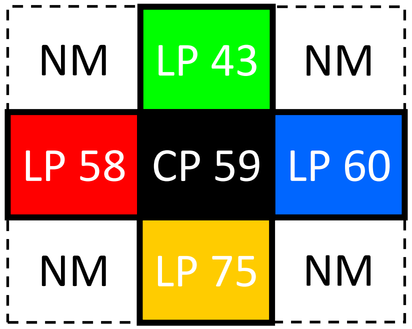
↓

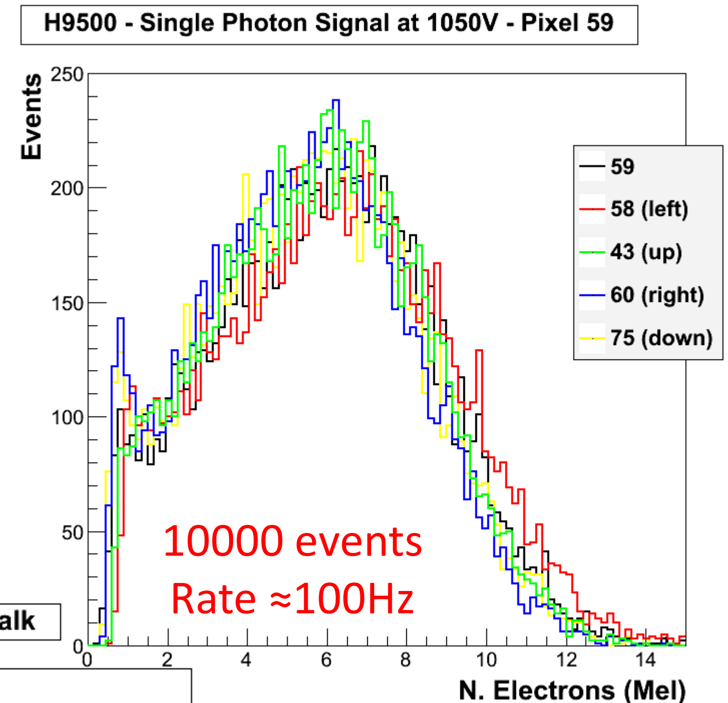
120 / 50000 = 0.24%

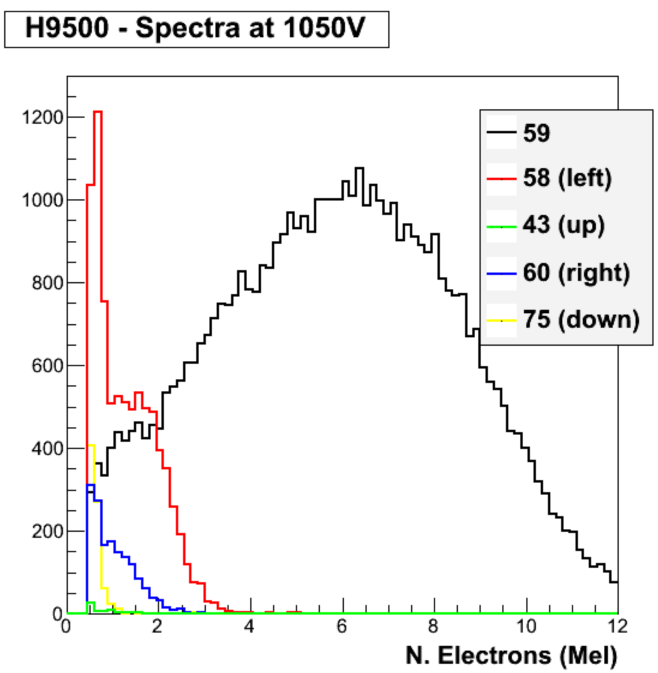
The thereshold in our set-up is locked on the smallest signal that the oscilloscope is able to trigger.

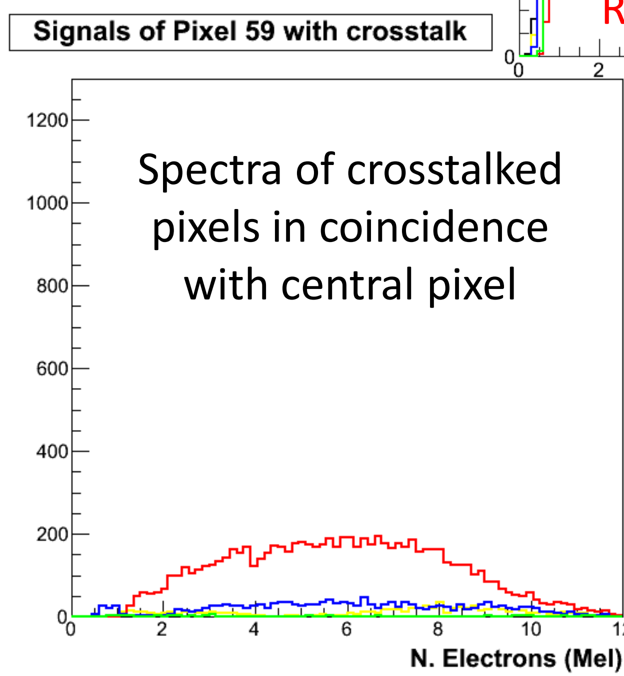
HAMAMATSU H9500 – Crosstalk

We show spectra for Pixel 59 and its neighbors (other clusters of pixels have been studied and the results are about the same).







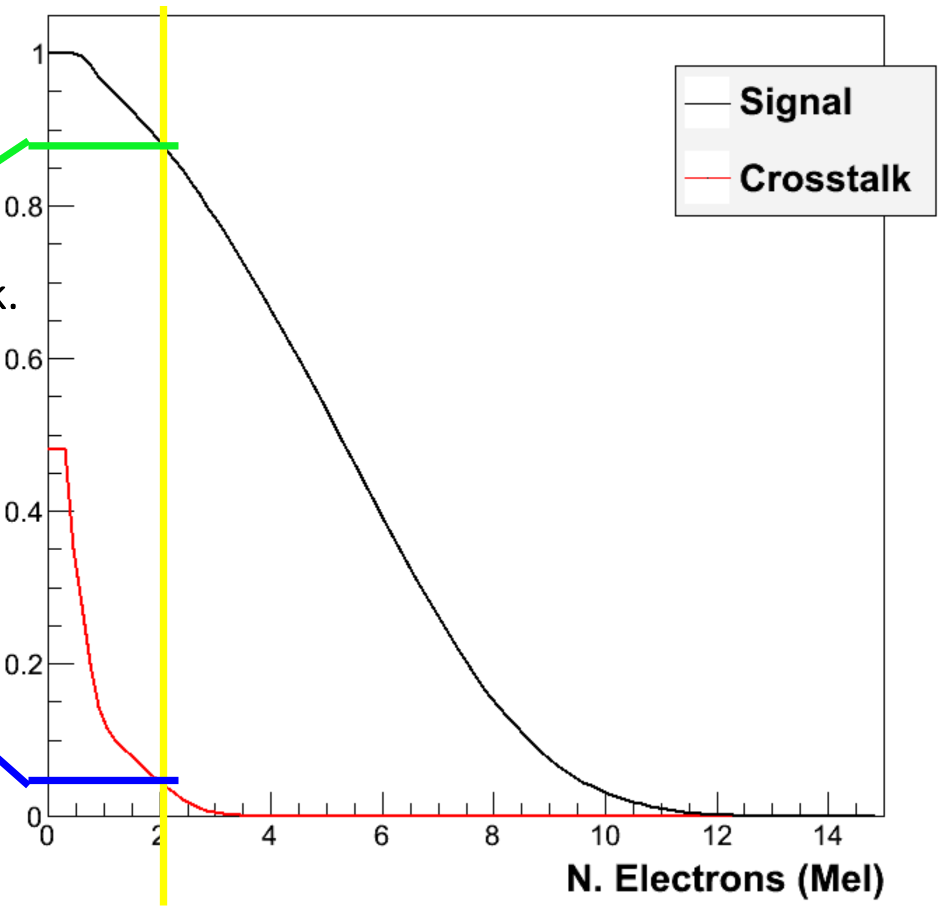


HAMAMATSU H9500 – Crosstalk

The crosstalk probability is shown in the figure as a function of the threshold.

VBias 1050 V

For example if we set a thereshold near 2Mel we loose about 12 % in efficiency but we have only 5% of signals with crosstalk.



Crosstalk Interpretation

Signal generated from many photons

Many input Photons

5 % Probability =
5 % of electrons
leak

Many electrons at
The first dynode

5 % signal
Amplitude
at the anode. A
cross-talk signal
is always
present.

Almost
unaffected
signal at the anode

Signal generated by a single photon.

Single-Photon input

5 % Probability
of 1 electron
to leak

Few electrons
generated, 4-5.

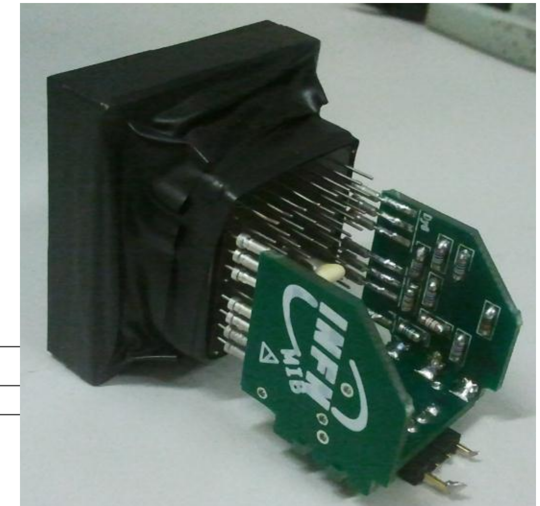
A few number of
signals, but with
large fraction of
the original signal.

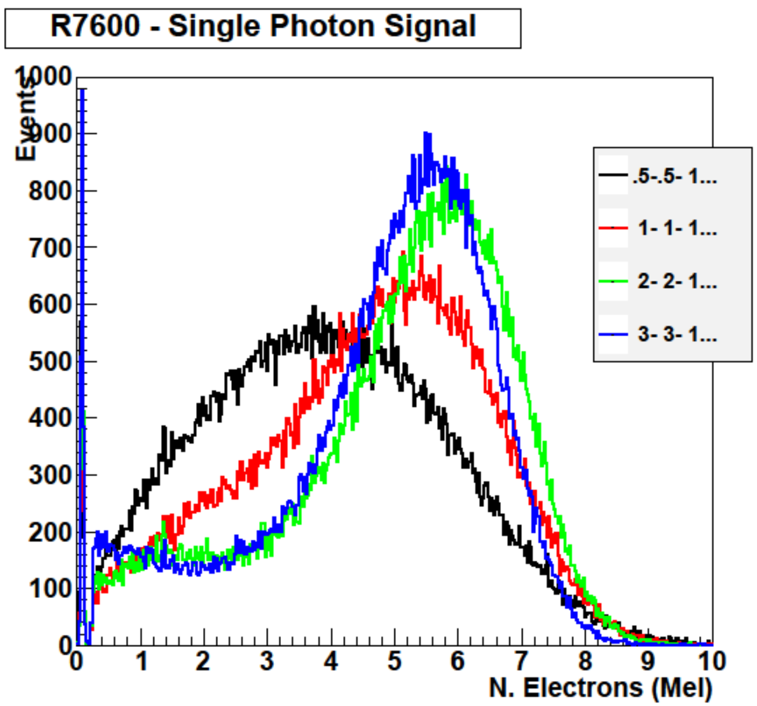
When crosstalk
happens the signal
at the anode
undergoes to 20 % -
30 % of amplitude
reduction.

HAMAMATSU R7600 and R11265 – Custom Bias

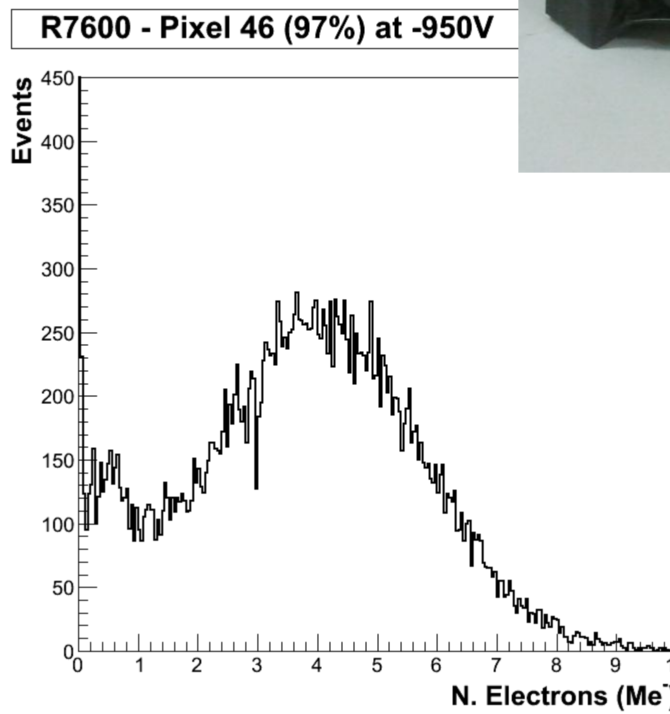
A custom board for PMT bias was designed and built.

Changing the bias voltage ratio allows to sharpen the peak in the single photon spectra.





2-2-1-…-1 (green) and **3-3-1-…-1** (blue) bias ratios, which give a better resolved single photon peak

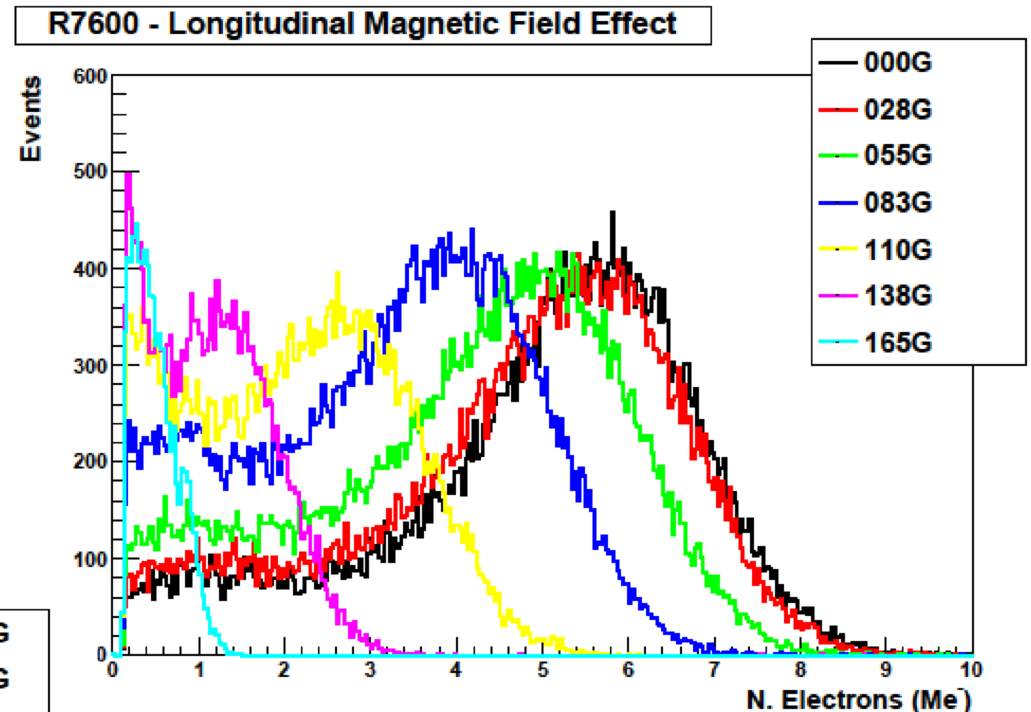


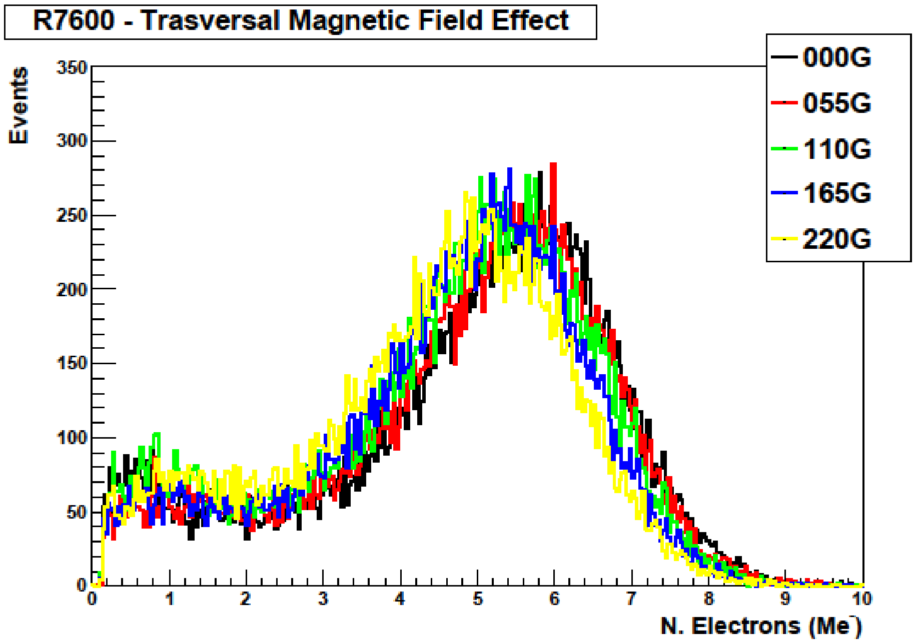
Standard **3-2-2-1-…-1-2-5** bias from Hamamatsu (good to ensure linearity in continuous light operation)

HAMAMATSU R7600 – Magnetic Field

We used two devices for magnetic field generation: a Solenoid (for fields up to 300G) and a Helmholtz Coil (for more uniform fields up to 60G).

✓ Results show a gain decrease for longitudinal fields above 50 G (5 mT)
✓ No significant gain variation was observed for transversal fields





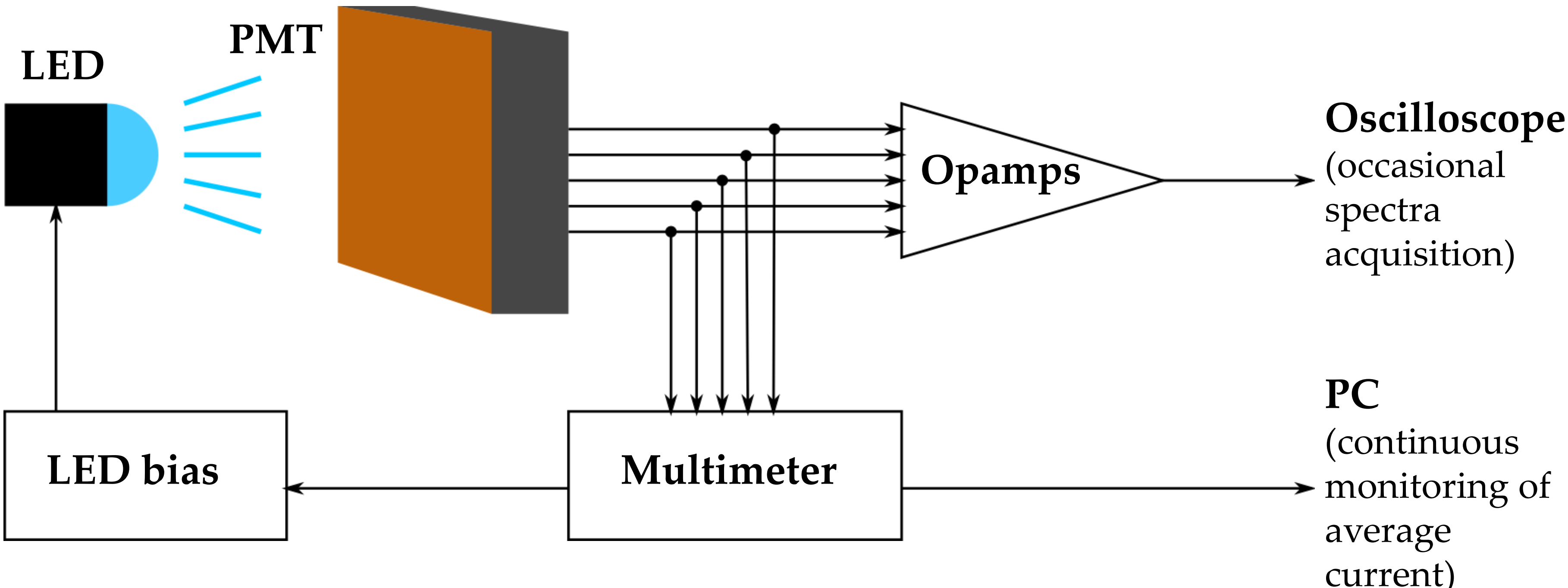
Gain decrease is the only noticeable effect due to magnetic field

No crosstalk was observed in any case

(All these spectra are measured with the custom 2-2-1-… bias voltage ratio)

HAMAMATSU R7600 – Aging

We have also measured the **gain decrease of the PMT due to aging**:

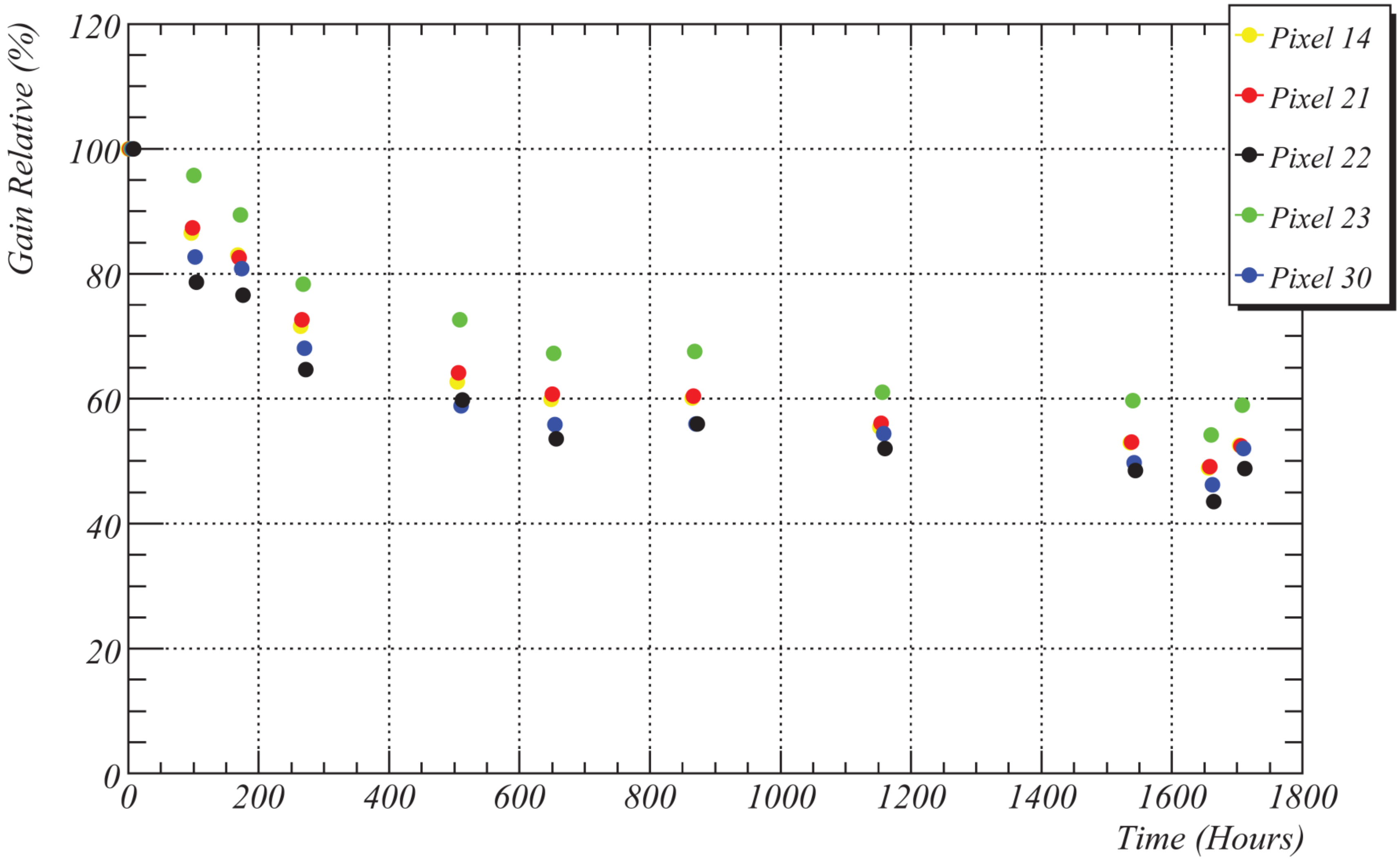


A cluster of 5 pixels was illuminated with different light levels.

- The average current was measured and it was kept constant on the brightest pixel(1uA)
- About once a week or so, spectra of single photon signals were acquired with the scope.
- Temperature, humidity and HV were continuously monitored.
- HV is set to 685 V and is stable within a few V.

The system has been running for about two months (1600 hours)

HAMAMATSU R7600 – Aging



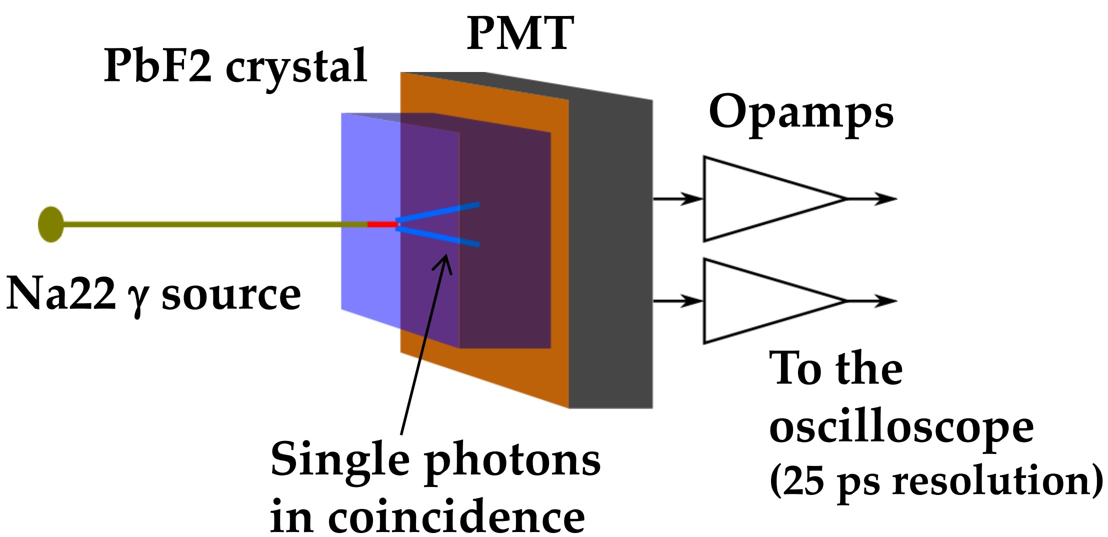
I=0,46µA
I=0,48µA
I=1,00µA
I=0,36µA
I=0,39µA

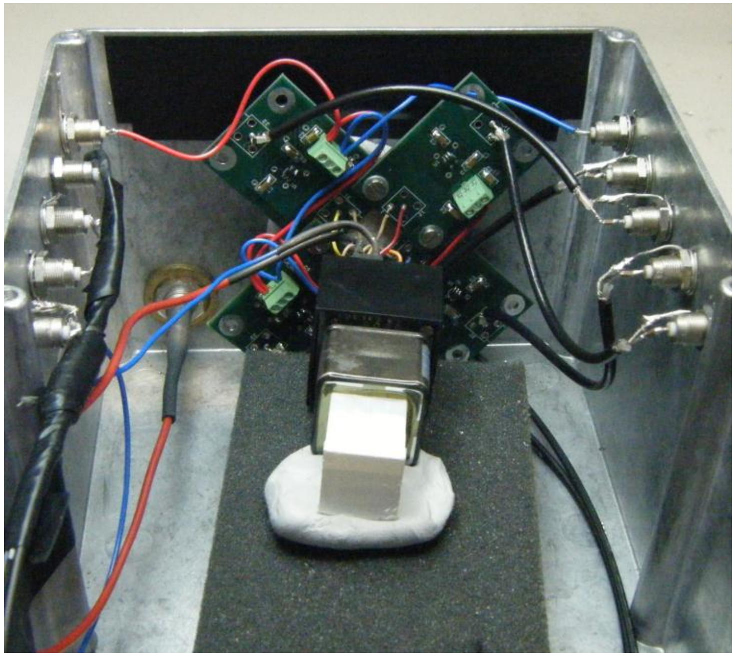
In our measurements, **gain reduced to about 60% after 500 hours.**
After that, the curve flattened, reaching **50% after 1600 hours.**

HAMAMATSU R7600 – Timing

Setup for timing measurement:

- A PbF2 (lead fluoride) crystal was placed in front of the PMT
- A Na22 g source illuminated the crystal, generating secondary Cherenkov photons
- The Cherenkov photons hit different PMT pixels in coincidence
- The TTS (transit time spread) of the PMT can be estimated





PMT bias: 750 V

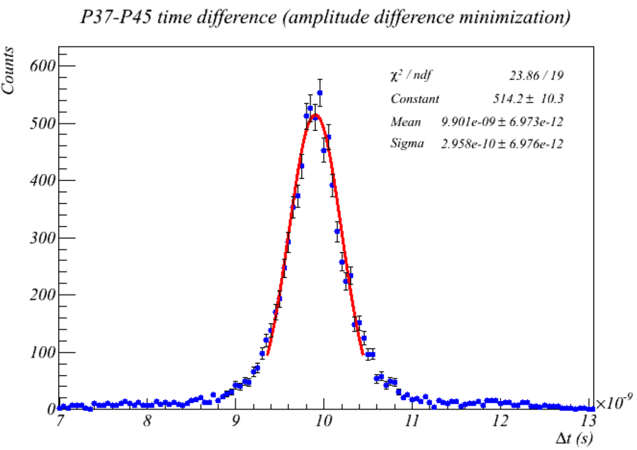
HAMAMATSU R7600 – Timing

On the PMT, different pairs of pixel were measured:

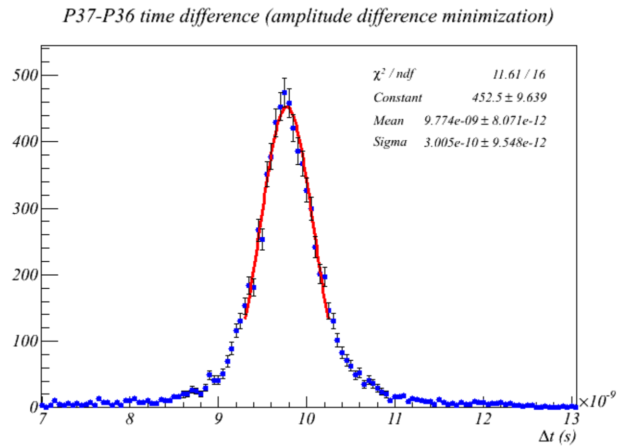
Vertical neighbours

Horizontal neighbours

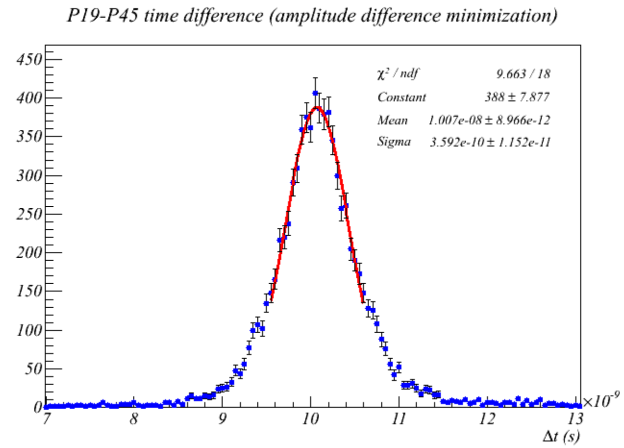
Pixels far from each other



σ = 296 ps



σ = 301 ps



σ = 359 ps

In all cases, the standard deviation of the time difference was about 300 ps.

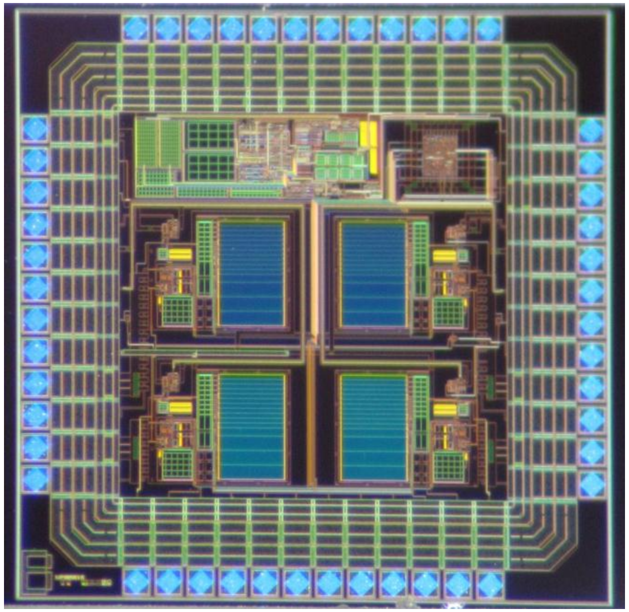
Since this is the error for two signals in coincidence, the TTS of the R7600 can be estimated to be:

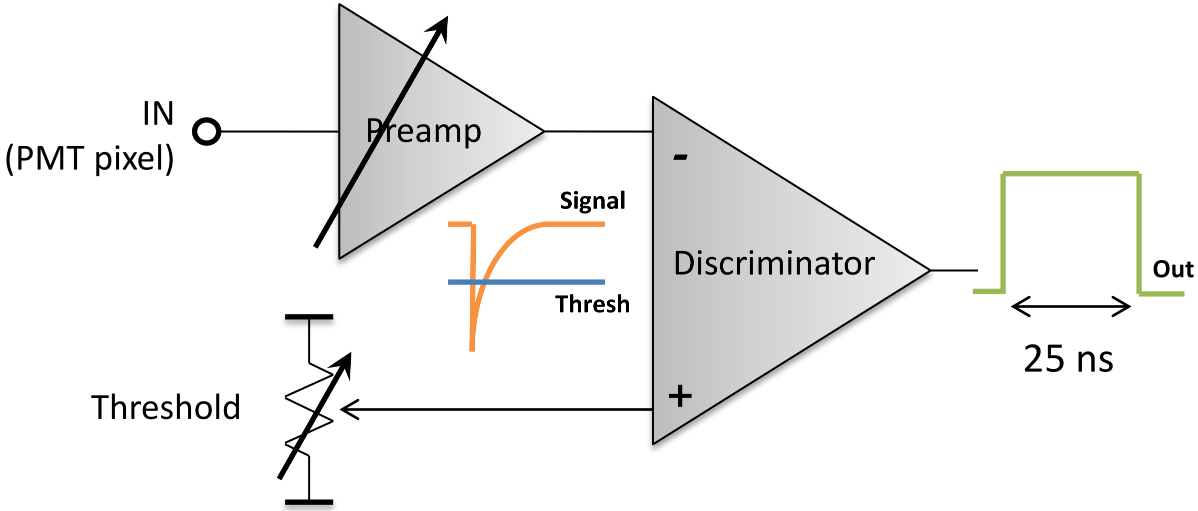
TTS = 300 ps / sqrt(2) ≈ 210 ps (or 500 ps fwhm).

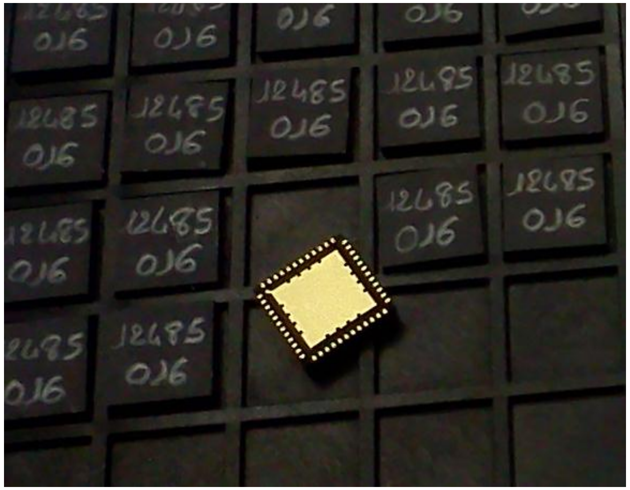
CLARO CMOS

The CLARO-CMOS is the first prototype of an ASIC for single photon counting with photomultipliers, designed to readout multi-anode PMTs in the upgraded LHCb RICH.

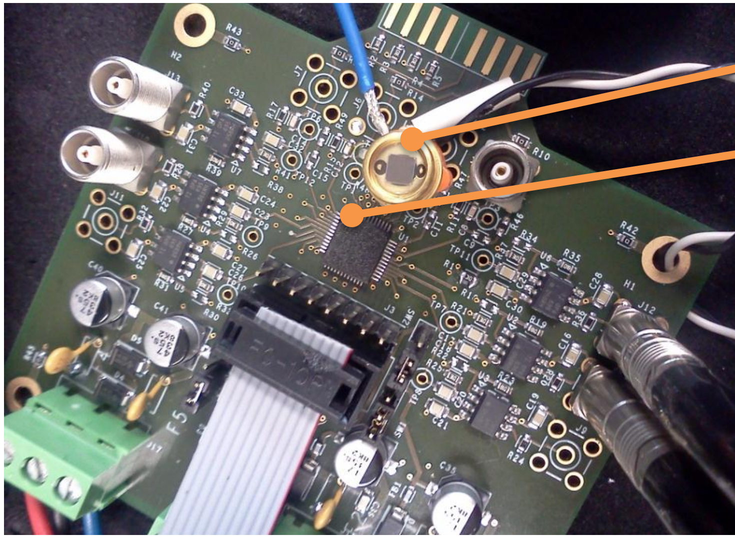
- Each channel has a preamplifier (with settable gain) and a discriminator (with settable threshold)
- This prototype has 4 channels
- No dead time at 40 MHz hit rate
- Power consumption below 1 mW/channel







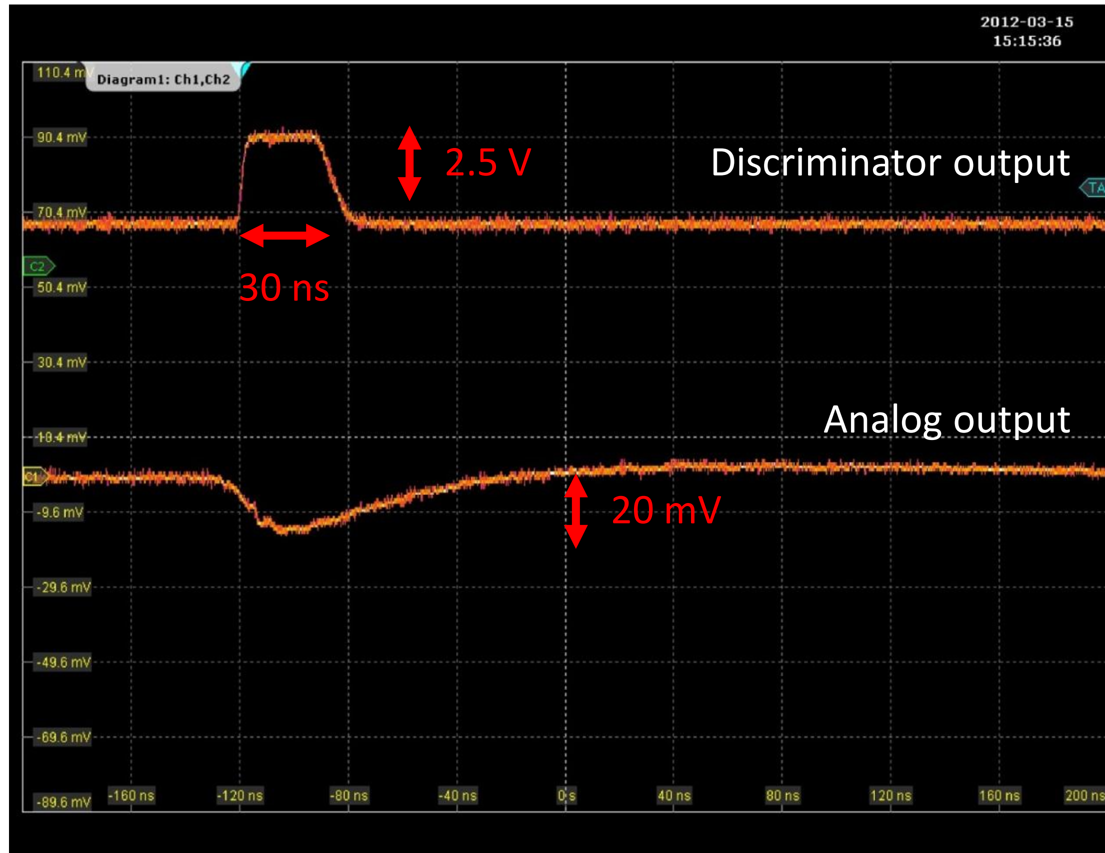
CLARO CMOS – Test in Ferrara

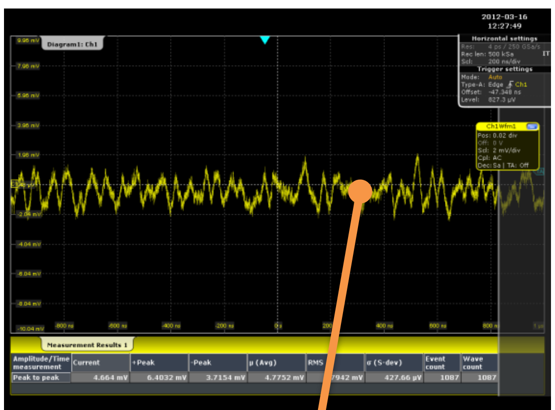


SiPM

CLARO-CMOS

Output of the CLARO to a dark signal from a SensL $1mm^2$ SiPM (MicroSL-10050-X18):





CLARO Baseline noise at the analog output
2.5mV pk-pk /400 uV RMS (SiPM connected)

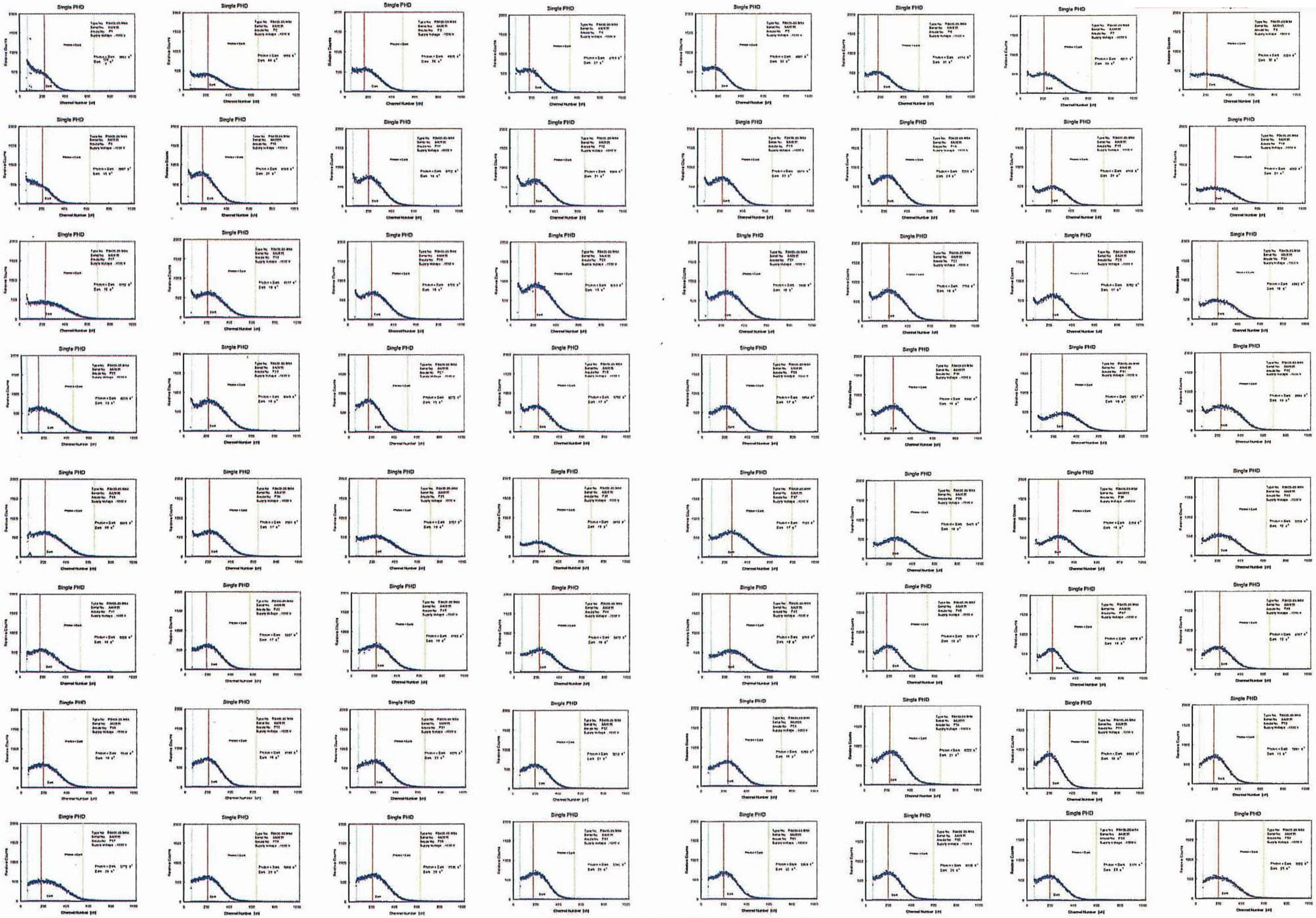
See Claudio's talk **"Test of CLARO chip readout"**, Parallel IV IFR,
3rd SuperB Collaboration Meeting – Frascati, 21 March 2012

CONCLUSIONS and FUTURE

- ✓ The first characterization of the Ma-PMT Hamamatsu H9500 and R7600 was completed and these devices has been rejected.
- ✓ The H9500 has some defects for our application. As we can seen from Hamamatsu table the single photon peak is not evident for a lot of pixels. Also the crosstalk level is too high.
- ✓ The R7600 show a very good single photon peak, but offer a very low geometric efficiency.
- ✓ At the moment the more attractive photodetector for the application in the LHCb RICH is the new Ma-PMT Hamamatsu R11265. The characterization of this device has just started. The first results of dark anode current, single photon signals spectra, gain and uniformity anode response confirm that R11265 and R7600 are very similar.
- ✓ In this moment we are looking for the best configuration of the bias voltage ratio for single photon counting. Using the new bias configuration, we want to do the full characterization evalueting the cross-talk level, the behavior in magnetic field and the time resolution.
- ✓ The first prototype of the CLARO-CMOS chip, designed to readout multi-anode PMTs, works and a deep characterization is in progress.
- ✓ A test beam with R11265 and CLARO chip is planned for autumn 2012 at CERN.

H8500 Single Photon PHD

P1==>



P57

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