SINGLE-PHOTON SIPM AND READOUT RESPONSE FOR RICH AT HIGH LUMINOSITY

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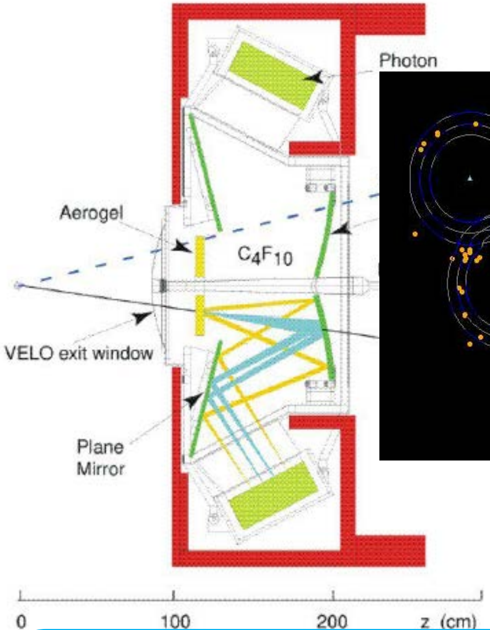
Introduction

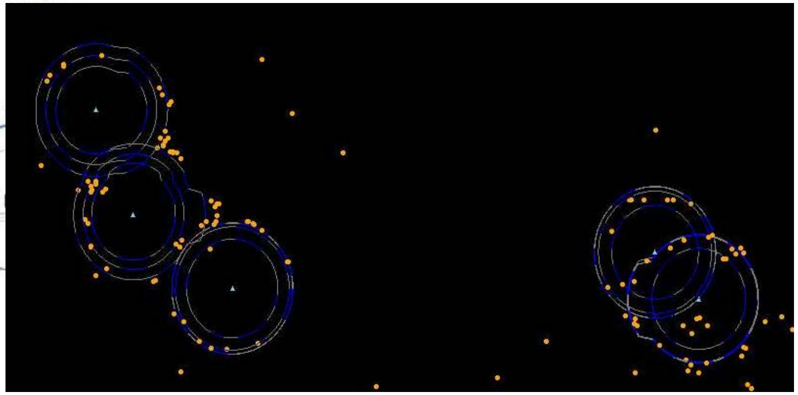
We show here a few technological hints about the feasibility of the implementation of the third generation of the RICH of LHCb.

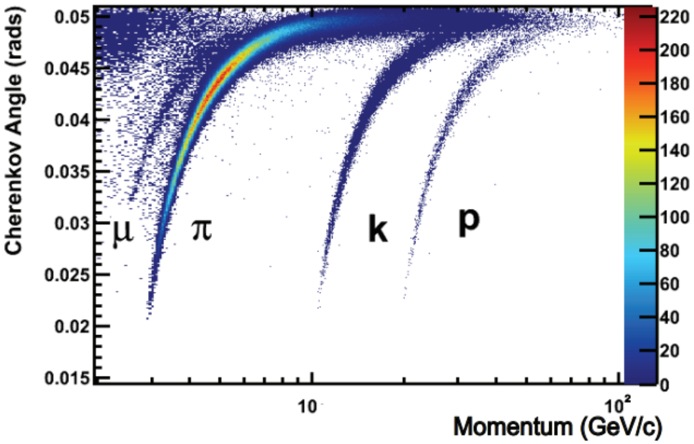
In particular we consider:

- The photo sensors detectors (with measurements validation);
- The very front-end (with simulation about the upgrade of the existing state-of–the-art).

Very short about the RICH of LHCb





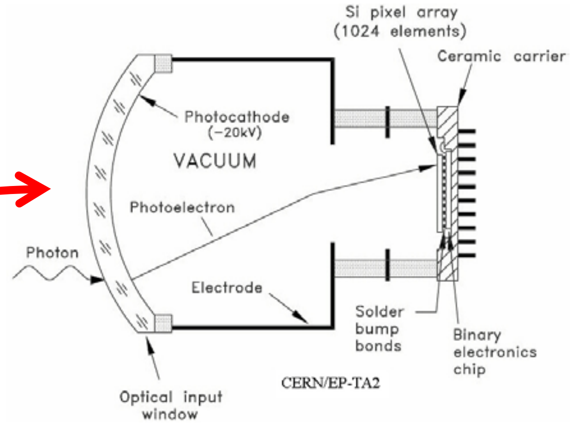


Particle travelling the medium (of proper reflective index) of the RICH creates a CHERENKOV light circle which, when reconstructed, allow to determine its original speed, contributing to its identification, provided that some other detectors are able to measure its energy/momentum.

Every circle contains only a few tens of photons and in the pixelated detector plane on which it grows only one photon is readout by every pixel, on average.

Therefore, the range of the signals is single photon (a two photons signal is considered pileup…)

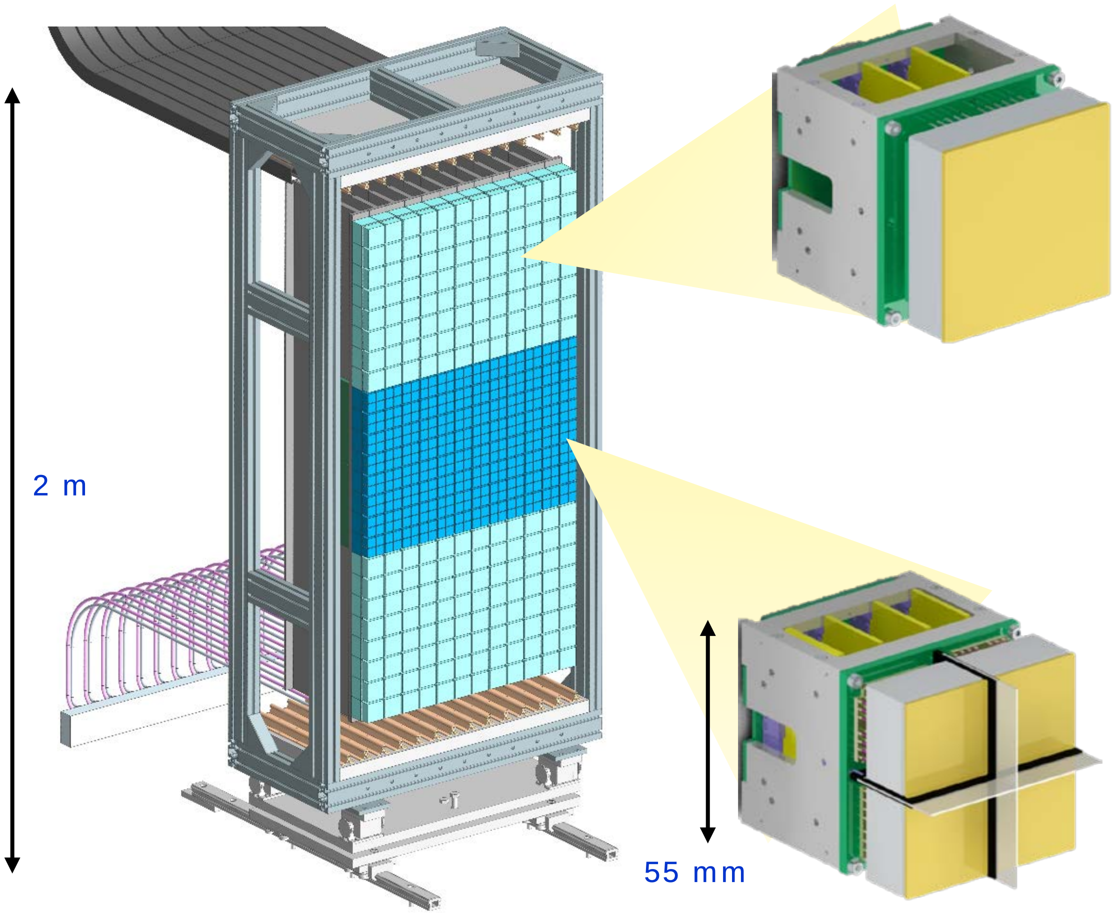
First RICH generation (the present)



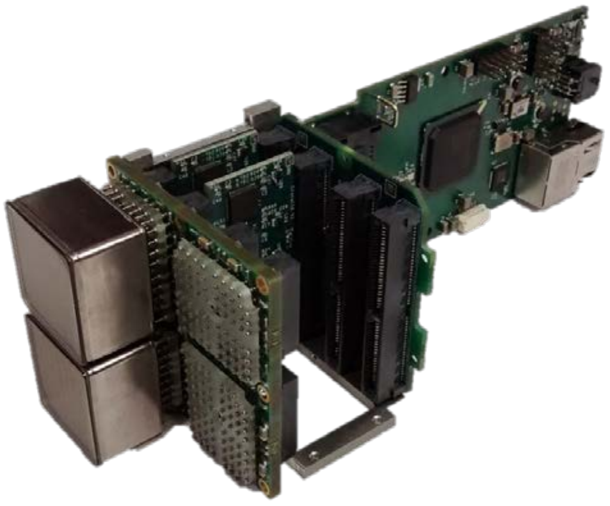
The present first generation of RICH is instrumented with Hybrid Photon Detectors, HPD, with encapsulated electronics.

They work very well up to about 1 MHz of particle rate, perfect (considering the expected level of occupancy at the RICH) for the actual luminosity at LHCb of a few times 10^{32} /(cm^{2}s).

The after LS2 RICH Generation (the next)



Photosensitive plane of the RICH-2 detector



The second generation of the RICH is under construction. It is composed of Photomultiplier tubes, PMT, with external readout (*the CLARO from INFN-MIB*) and it is able to work at 40 MHz with an occupancy below about 30 %, as expected at the luminosity of 2 x 10^{33} /(cm^2s).

The after LS3 RICH Generation (the future)

In the third generation of the RICH the luminosity will be further increased to more than 10^{34} /(cm^{2}s).

The system will still work at 40 MHz, but the occupancy will increase dramatically and, to suppress pile-up, some precautions will be needed by:

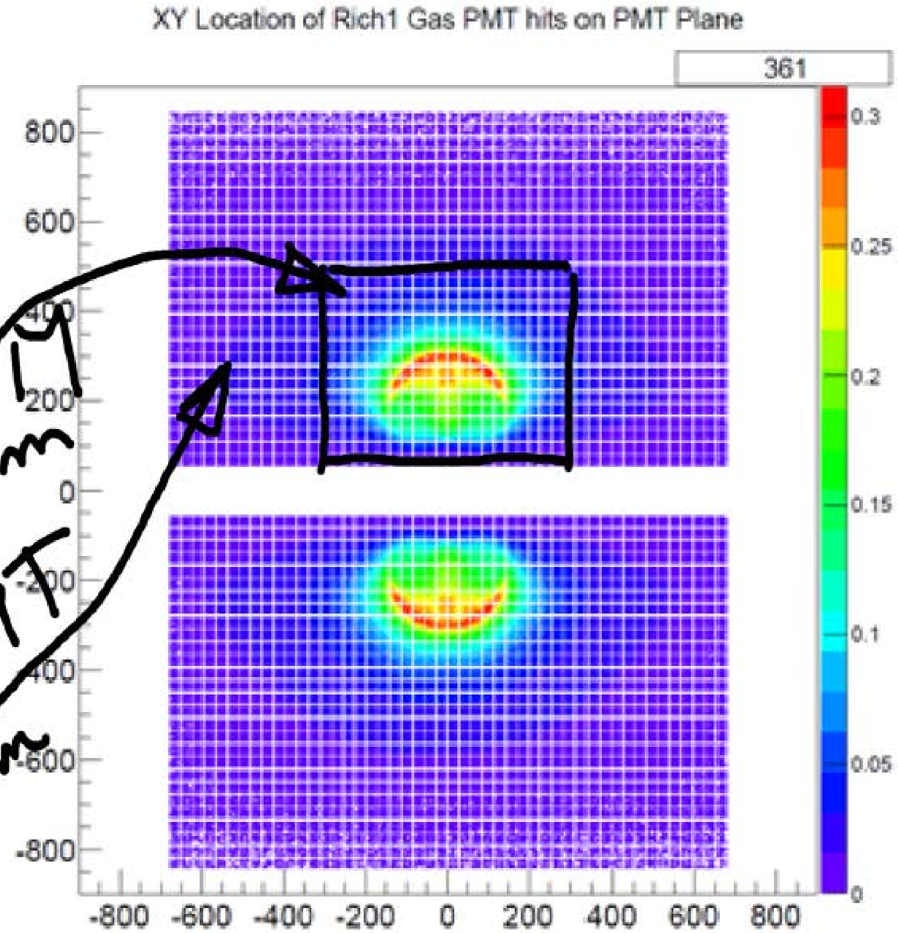
- recognizing and reject pile-up by adding timing discrimination within the bunches (with the need of high speed TDC);
- reducing the area of every pixel in order to distribute the light among more channels, maintaining adequate the occupancy;
- modifying the geometry of the mirrors and other stuffs (not considered here).

… If we want to be ready for LS3!! … (2025, upg2a)

Perhaps only in the central regions of RICH 1

For having minimal impact the idea is to limit the upgrade only to the region where the larger occupancy is expected, covering it with small pixels.
One possibility is using SiPM and…

MaPMTs, HPDs or MCPs
with green-enhanced Photocathode ?



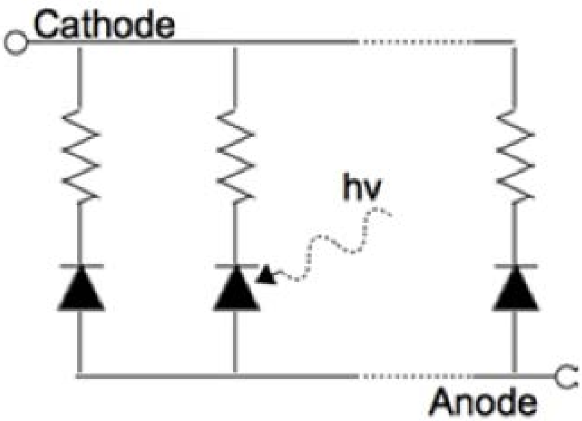
SiPM
1 mm

MaPMT
~3 mm

… we started to study SiPM sensors, warts and all

We selected a first candidate that seemed to show adequate performances, the Hamamatsu *s13360-1350cs* having an active area of 1.3 x 1.3 mm^2.

The SiPM is a matrix of diodes, each biased with a monolithic load resistance. The bias level is just above their breakdown voltage. Typically 3 V above the breakdown.



An impinging photon starts a discharge current in the diode it hits.

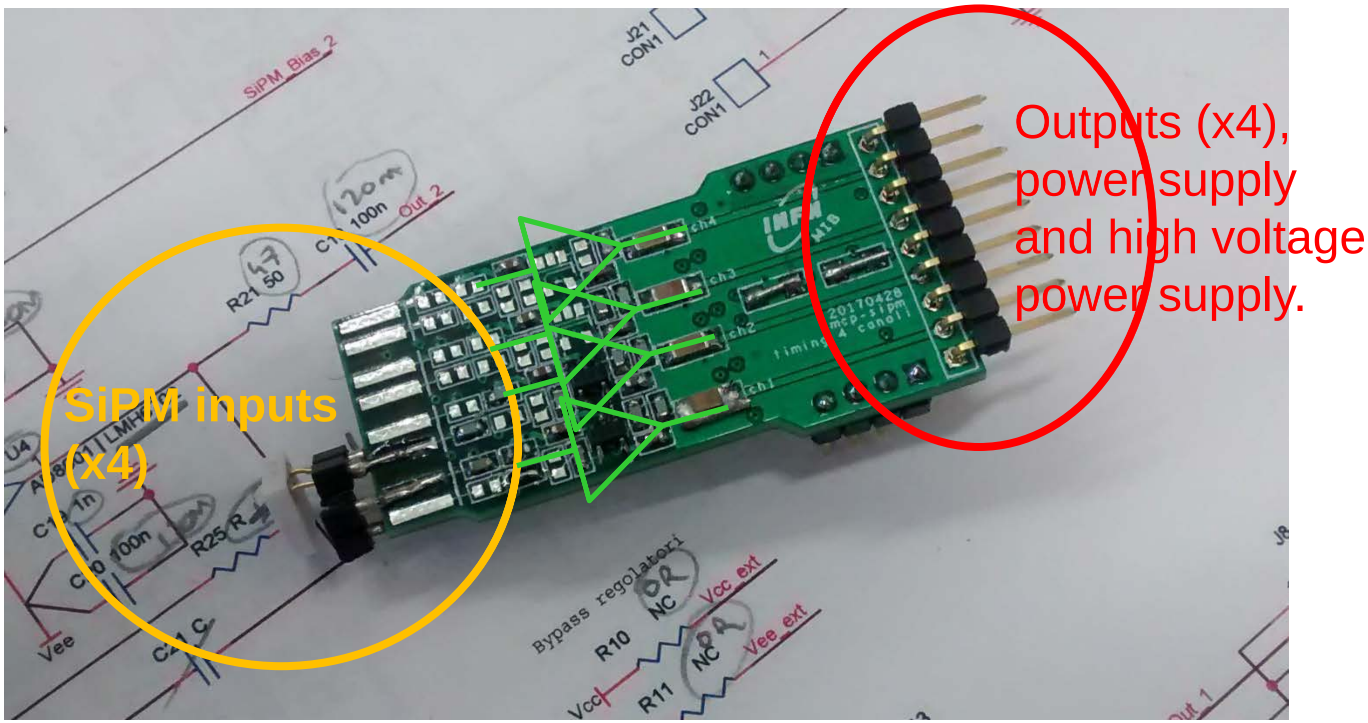
In the *s13360-1350cs* the area of every diode is 50 x 50 μm^2.

Merits of SiPM are their fast response and small jitter;

Care has to be taken with: dark current, after pulses, cross-talk , …

… then, we worked in trying to mitigate the demerits that, normally, are obtainable at the expense of the merits, finding a compromise…

First of all the measurement set-up 1

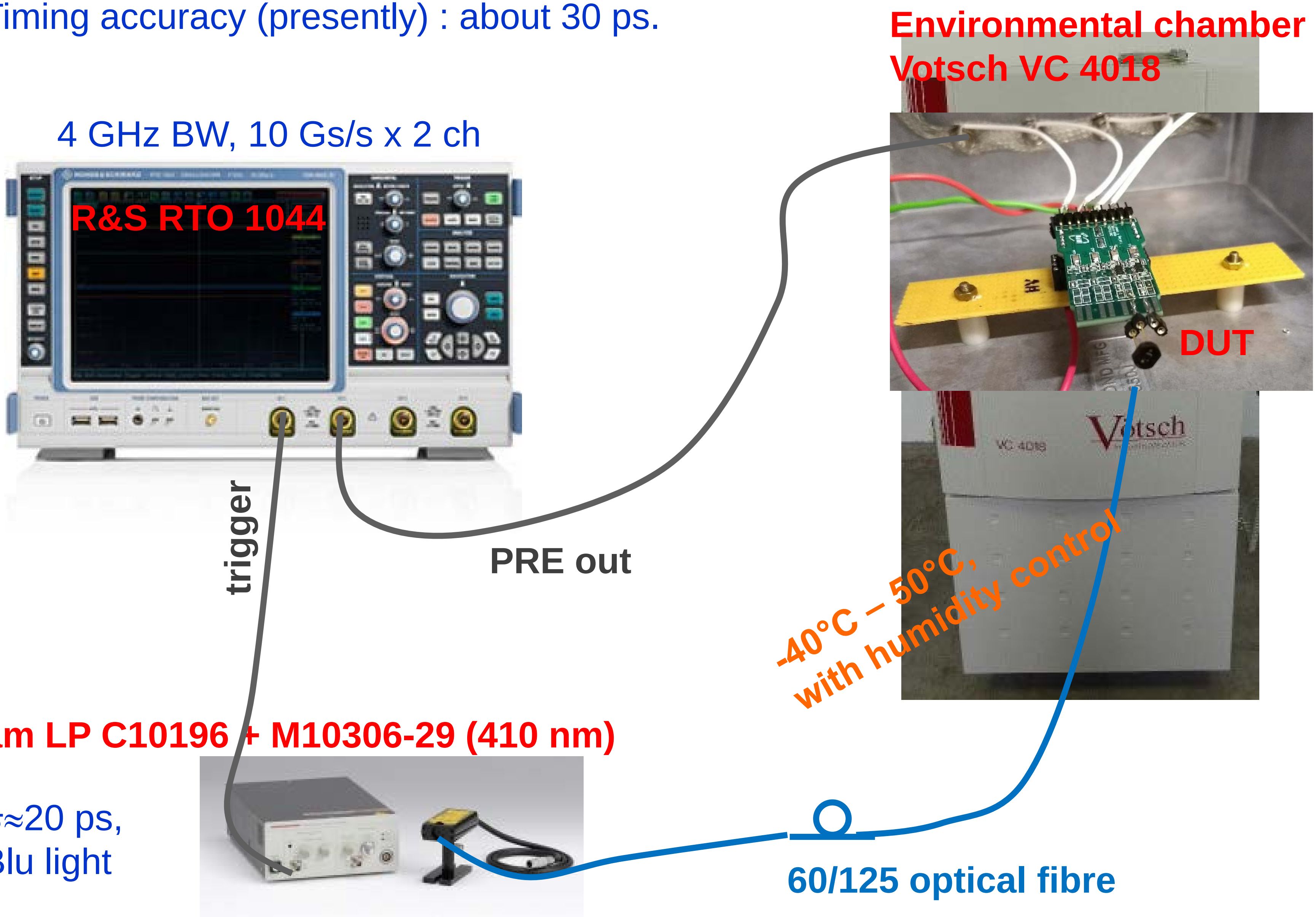


We designed a board with 4 channels of charge/current amplifiers based on the OTA LMH6702, fed-backed following the recipe described in the reference below.

The amplifier bandwidth was larger than 300 MHz.

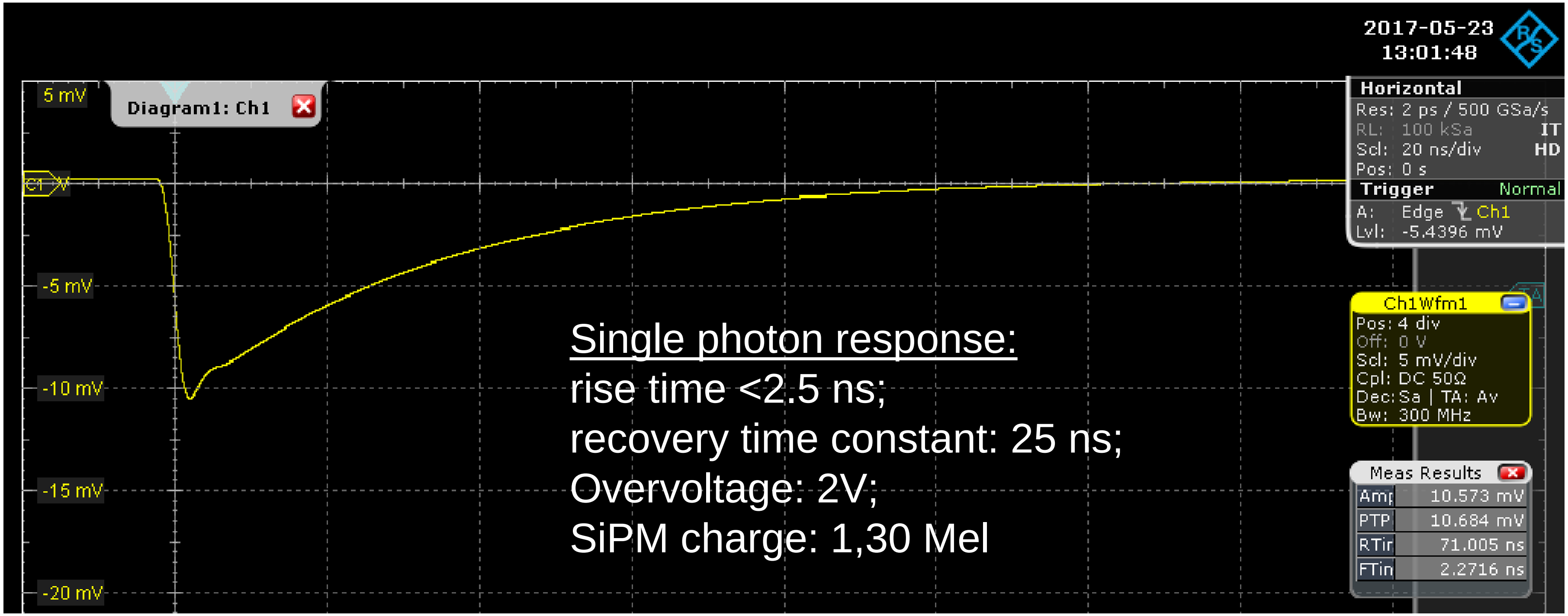
Jinst, V 6, P05004, 2011

Timing accuracy (presently) : about 30 ps.



σ≈20 ps,
Blu light

SiPM features vs RICH: speed of response

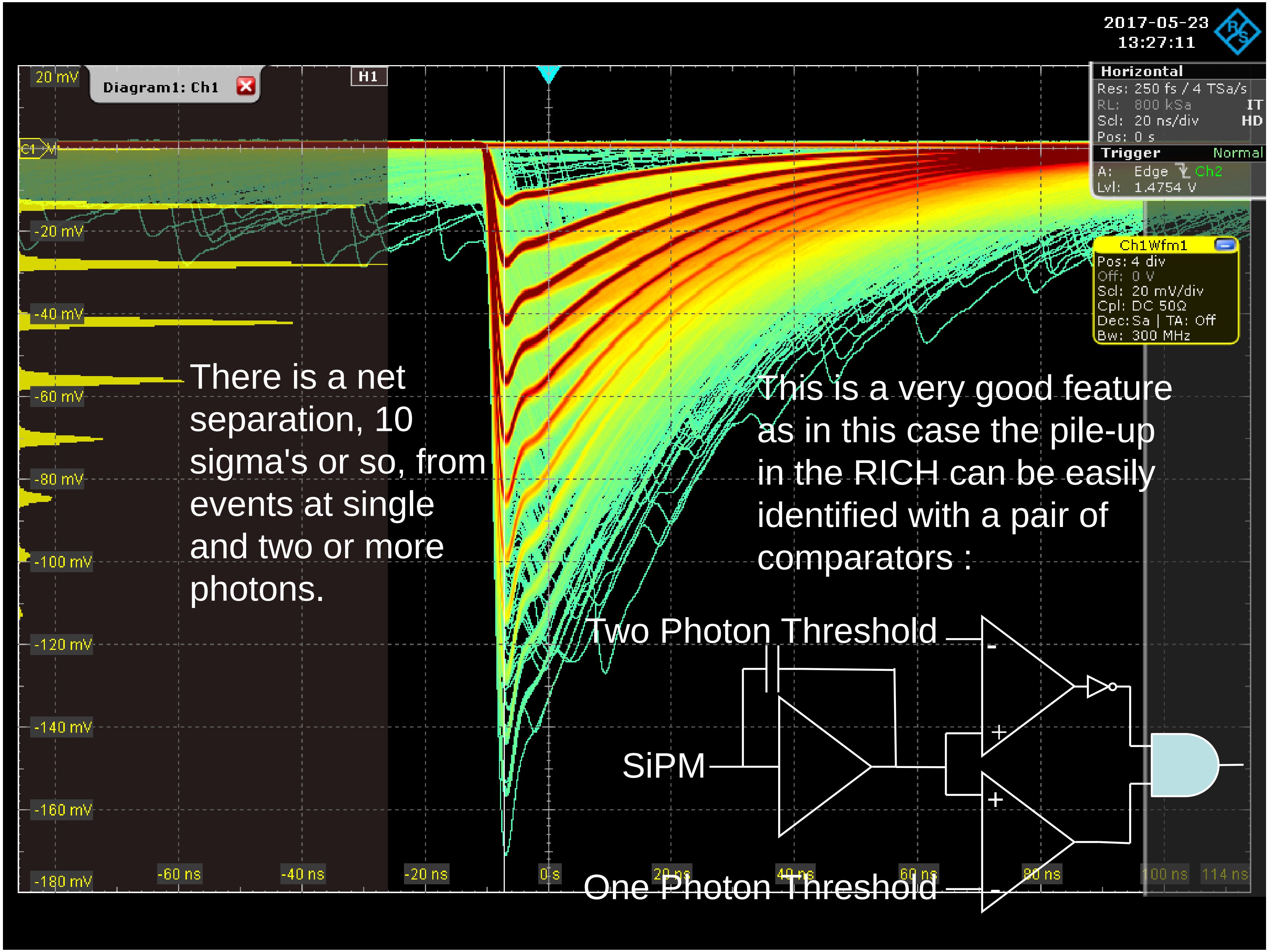


The speed of response is more than adequate. The fall time constant (*) is a few bunch crossing long, but the signal can be shortened by proper shaping and this would not result in a baseline shift.

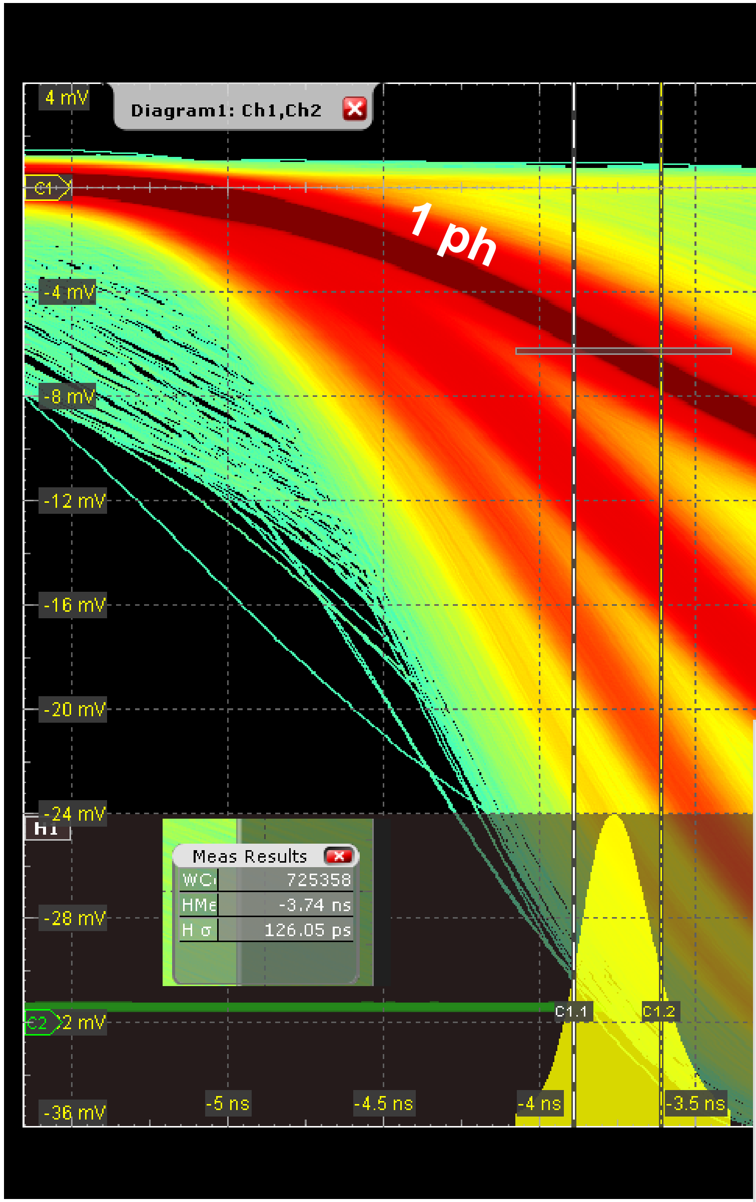
Speed of response was found weakly dependent on overvoltage.

(*) the preamplifier fall time was < 10 ns, with a negligible contribution.

Number of Photons identification

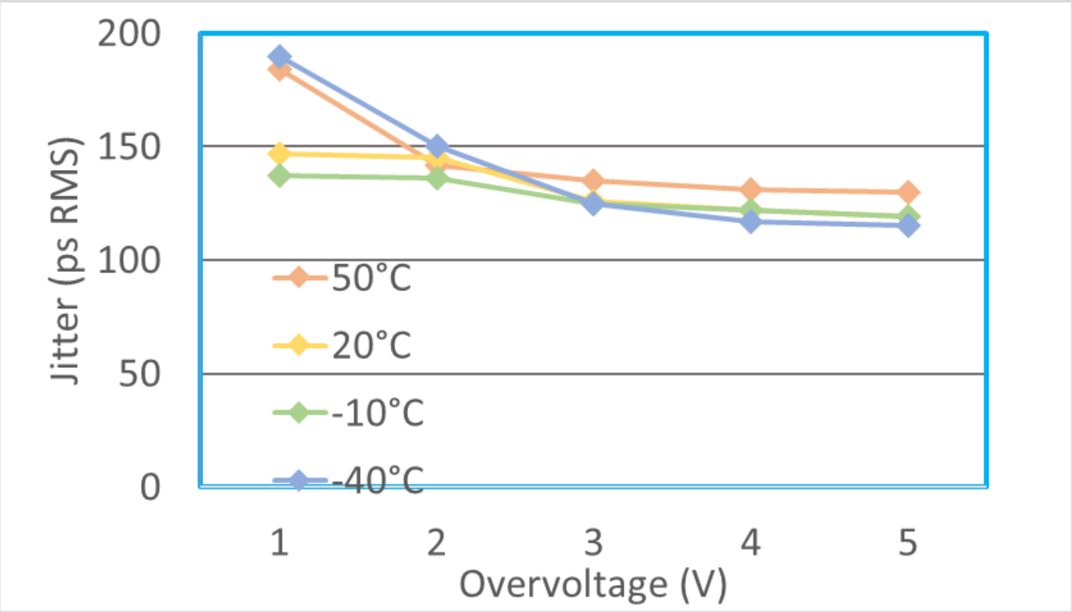


Jitter at single photon

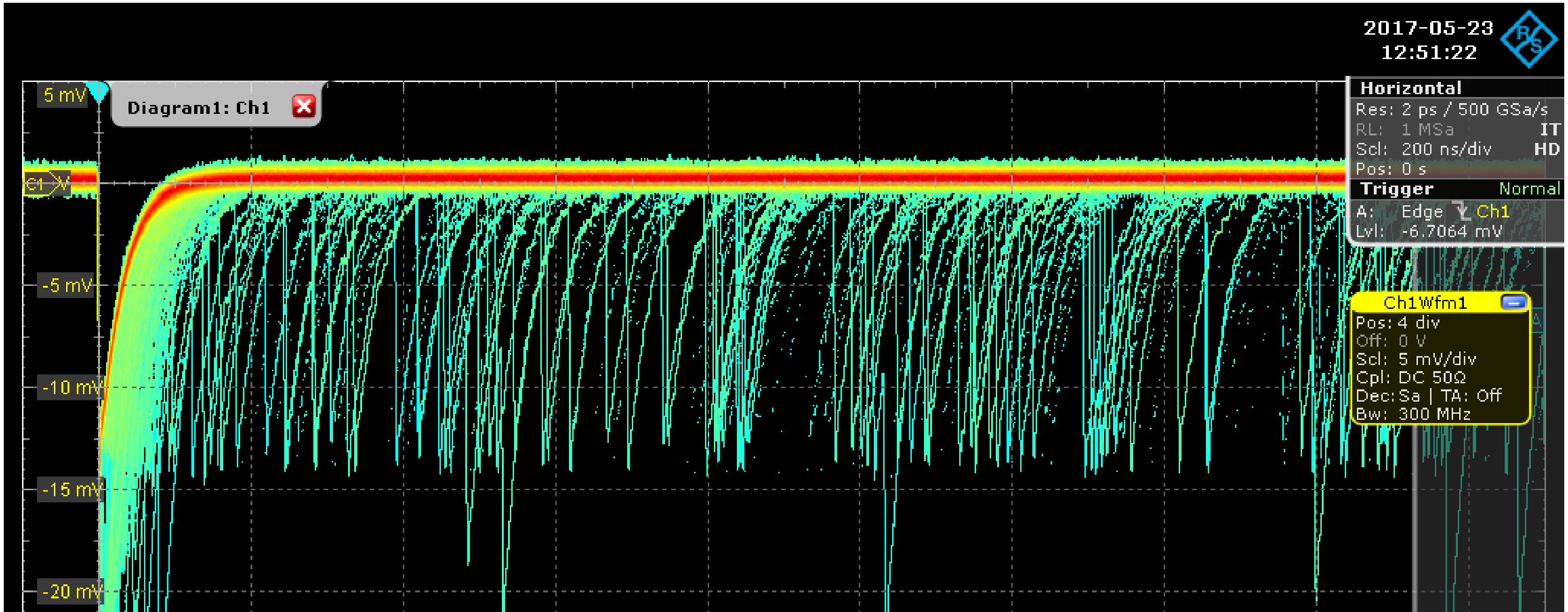


In case timing measurement is required SiPM shows a precision (jitter) of better than 150 psRMS, almost independent from temperature.

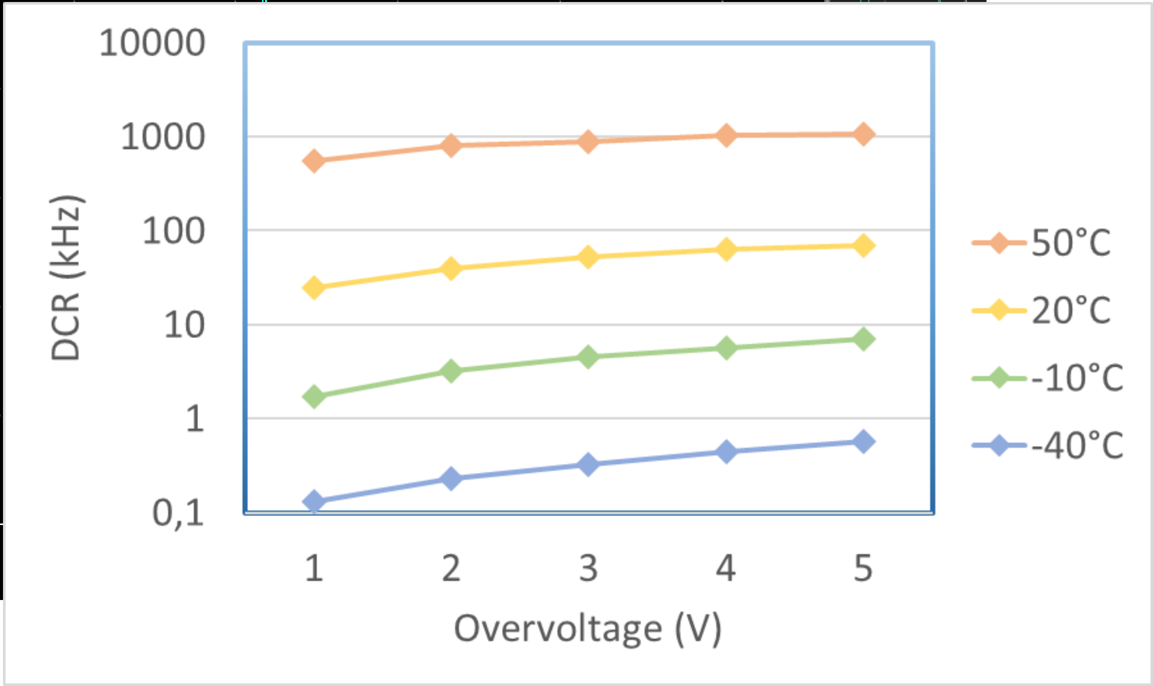
This is important as temperature can be exploited as a degree of freedom for mitigating other effects such as radiation damage, but not only…



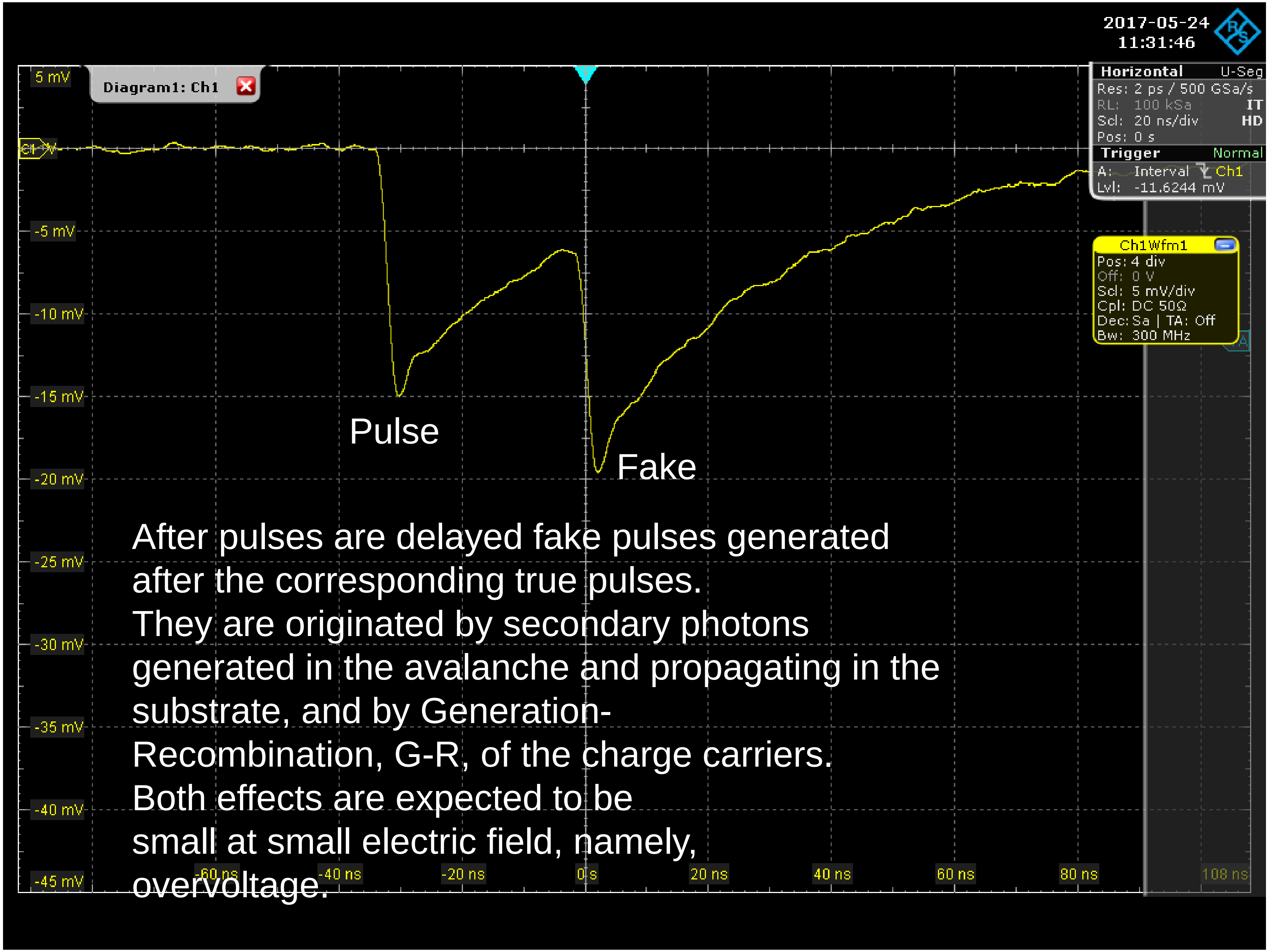
Dark Current mitigation



Dark current pulses are generated randomly with a rate that lowers when we lower the temperature and overvoltage (good also for Rad hard).

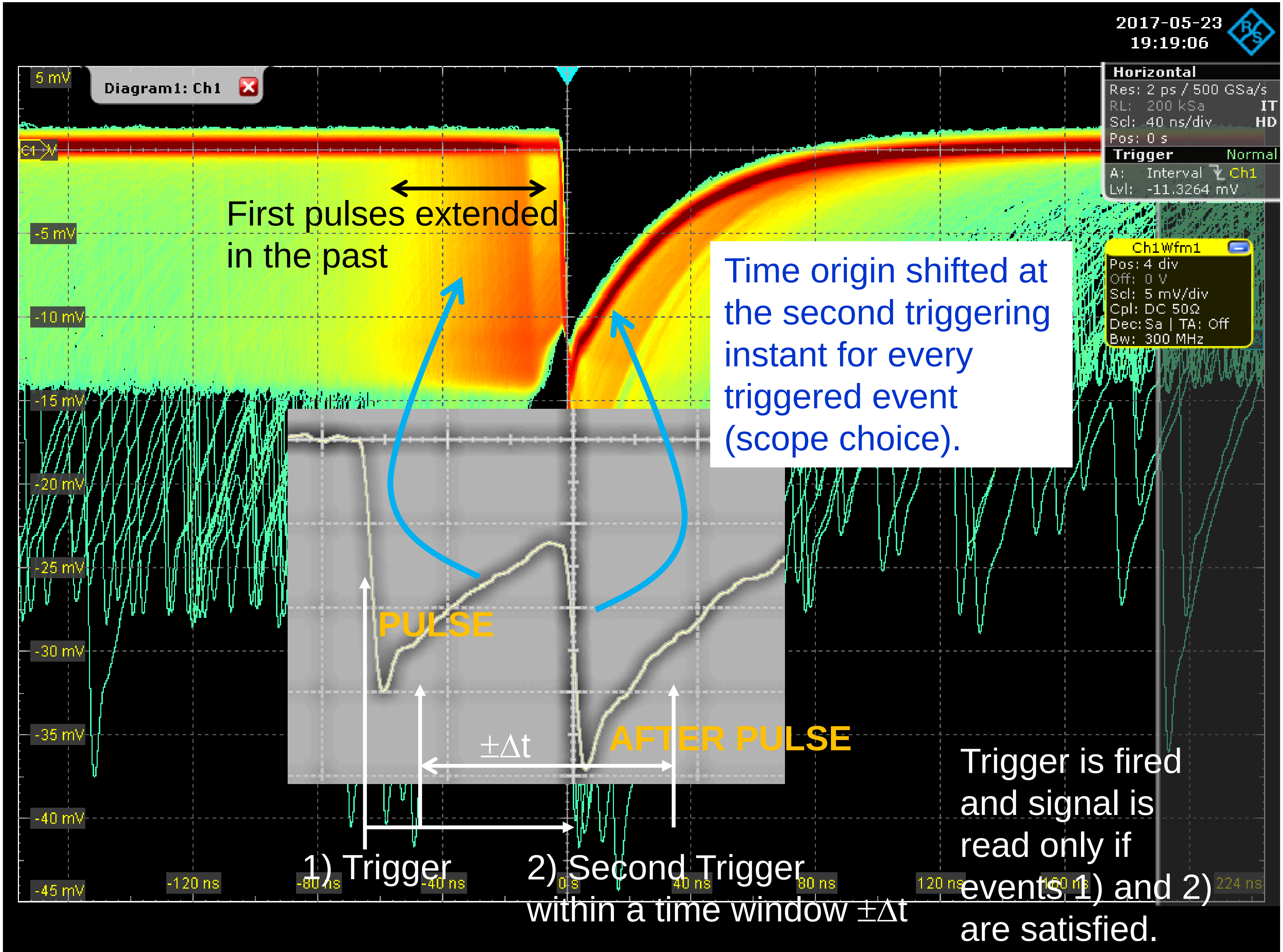


After pulse

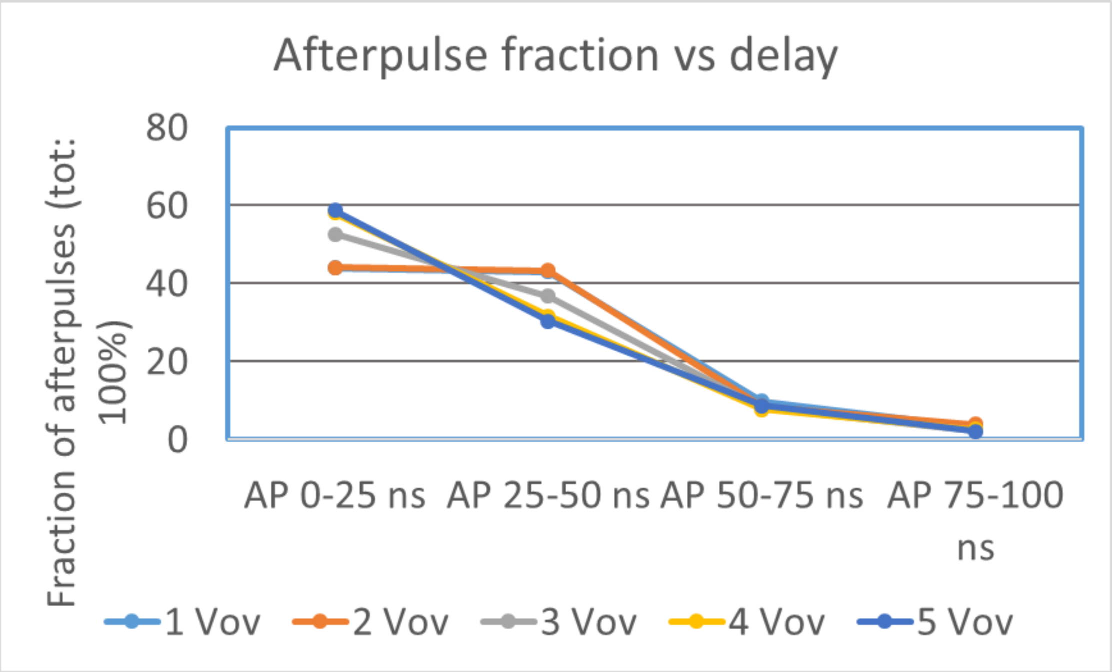


After pulses are delayed fake pulses generated after the corresponding true pulses.
They are originated by secondary photons generated in the avalanche and propagating in the substrate, and by Generation-Recombination, G-R, of the charge carriers.
Both effects are expected to be small at small electric field, namely, overvoltage.

After pulse picture



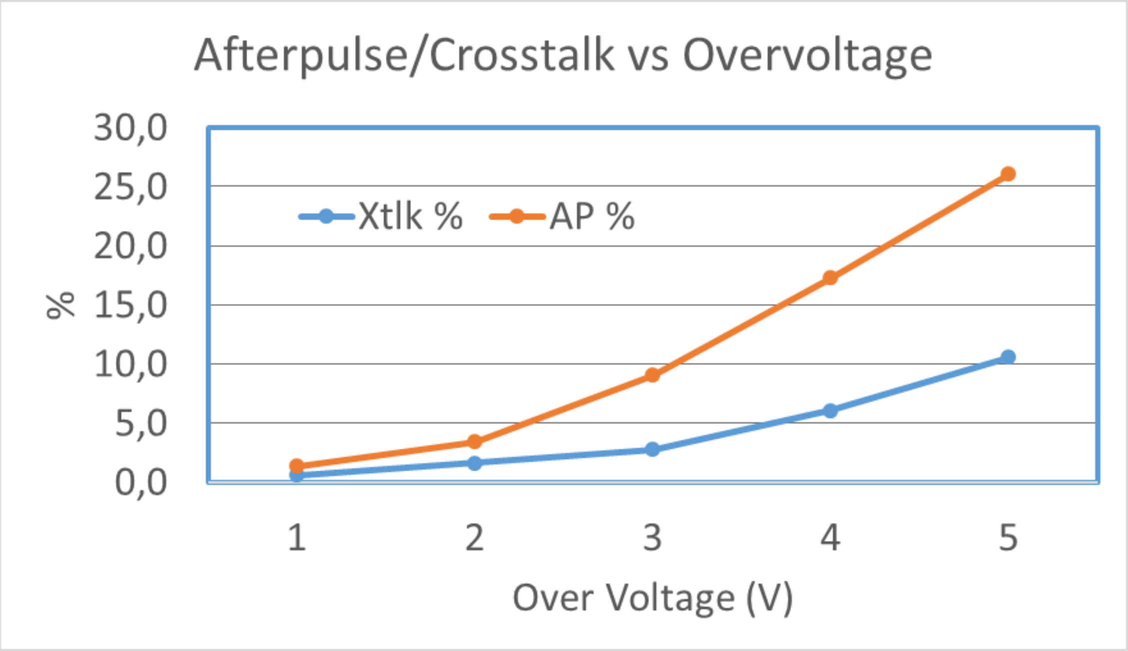
After pulse mitigation



The greater fraction of the after pulses are generated within the first 25 ns of the true pulse decay. Anyway creating disturbances within the bunches.

Temperature= -10°C

As expected, their percentage of generation, with respect to the true pulses, becomes negligible at small overvoltage values.
Small overvoltage selection allows to mitigate after pulses effects.



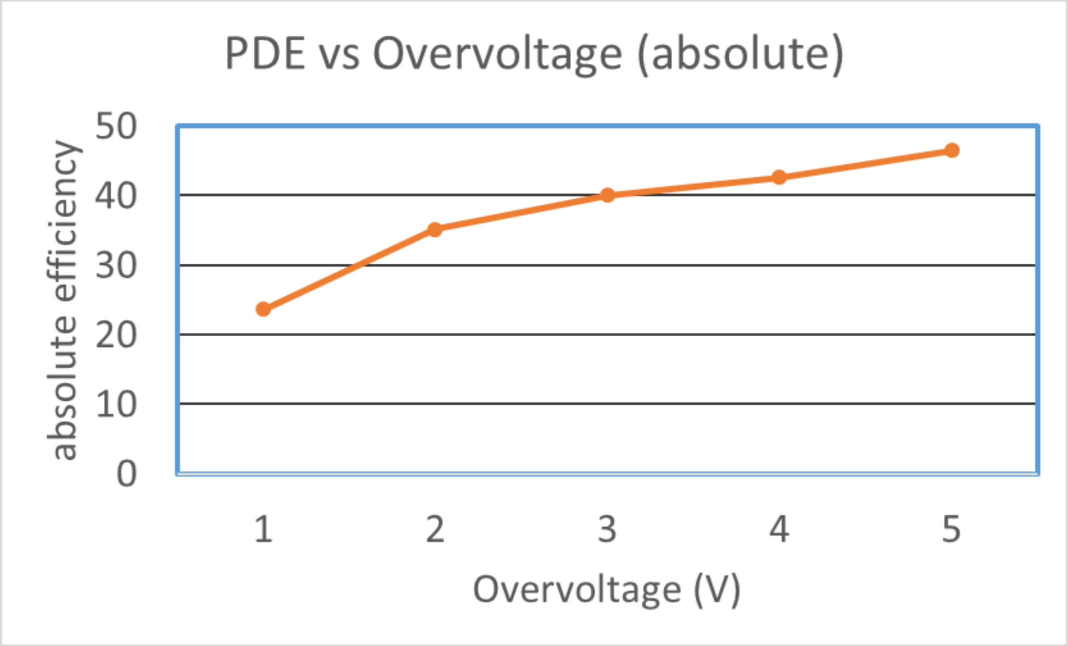
Photon Detection Efficiency

So far the recipe for selecting the better working condition for SiPM at RICH seems to be determined: low temperature and small overvoltage.

Nevertheless, a last parameter set the lower limit on the selection of the overvoltage: the Photon Detection Efficiency, PDE.

We investigated PDE vs the overvoltage, finding a dependence that cannot be neglected: selecting the overvoltage below 2 V may result in an intolerable PDE reduction.

PDE has been measured as a fraction of the rate at a given overvoltage with respect to the nominal (as declared by the manufacturer) at 3 V of overvoltage.



Very frontend

The second generation of the RICH is to be instrumented with an ASIC, named CLARO, that was designed able to face specifications more stringent than those required.

As a consequence, in the second RICH generation it will work dissipating only a fraction of mW/channel.

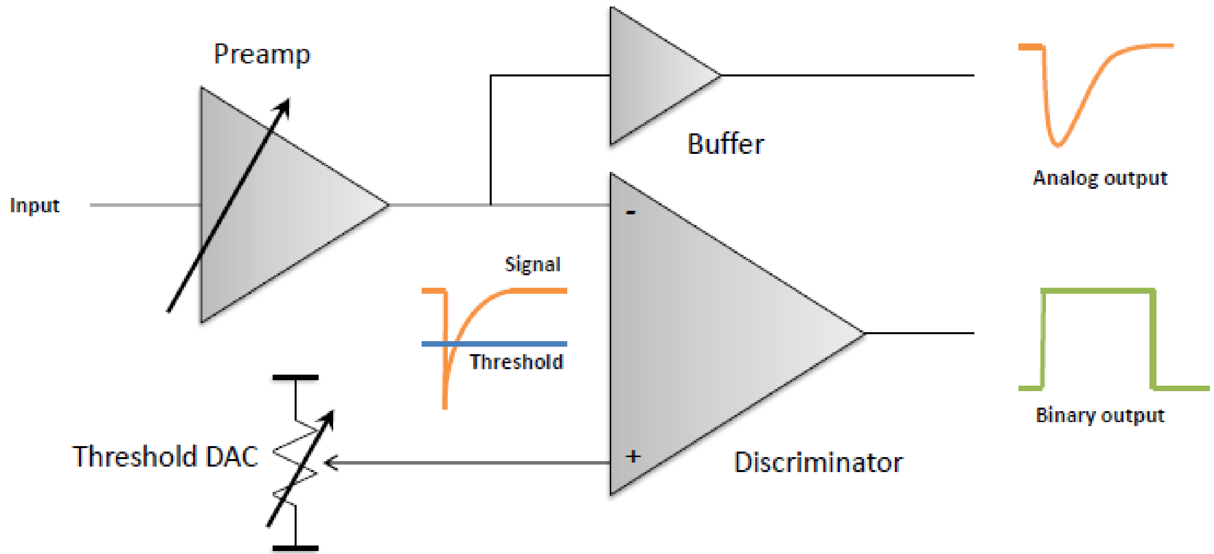


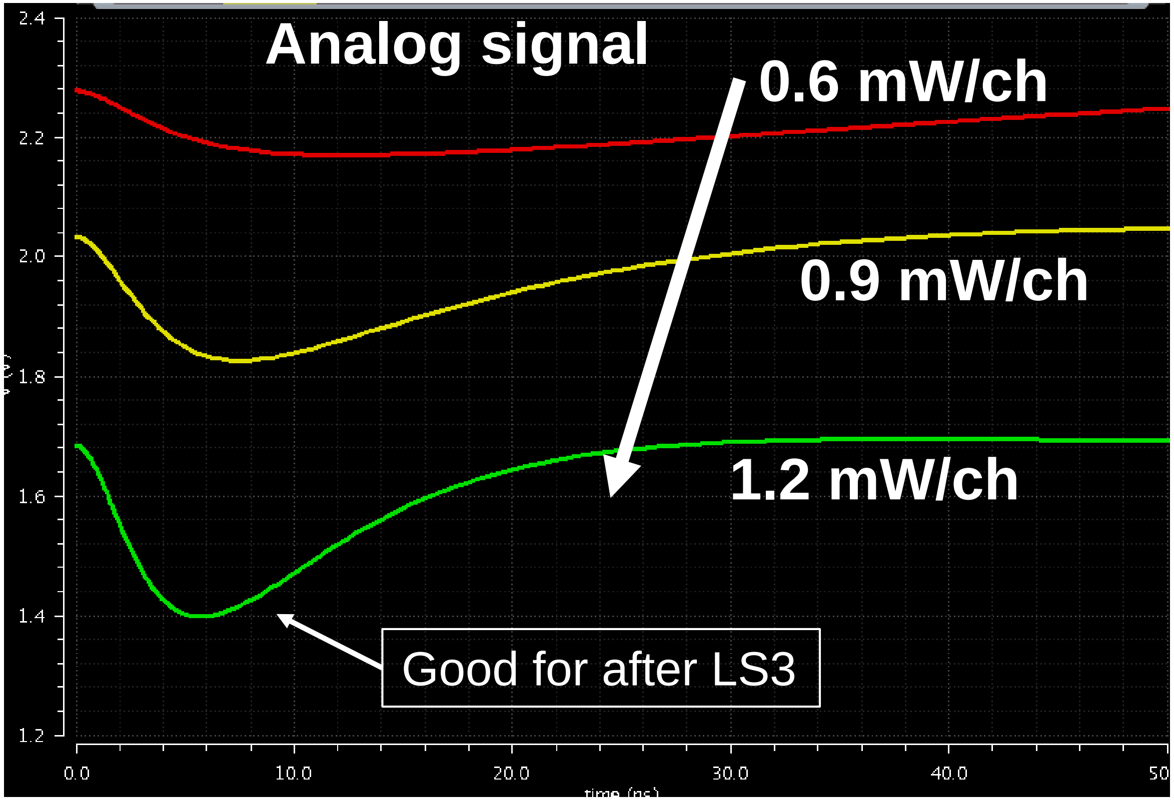
Figure 1. Block schematic of a CLARO-CMOS channel.

2012 JINST 7 P11026;
2013 JINST 8 C01029

Very frontend upgrade needs only to modify the value of a resistor

With PMT (+ PCB parasitic) input capacitance is <10 pF
SiPM typical capacitance 30-40 pF/mm^2
Larger input capacitance → smaller bandwidth in the CLARO amplifier

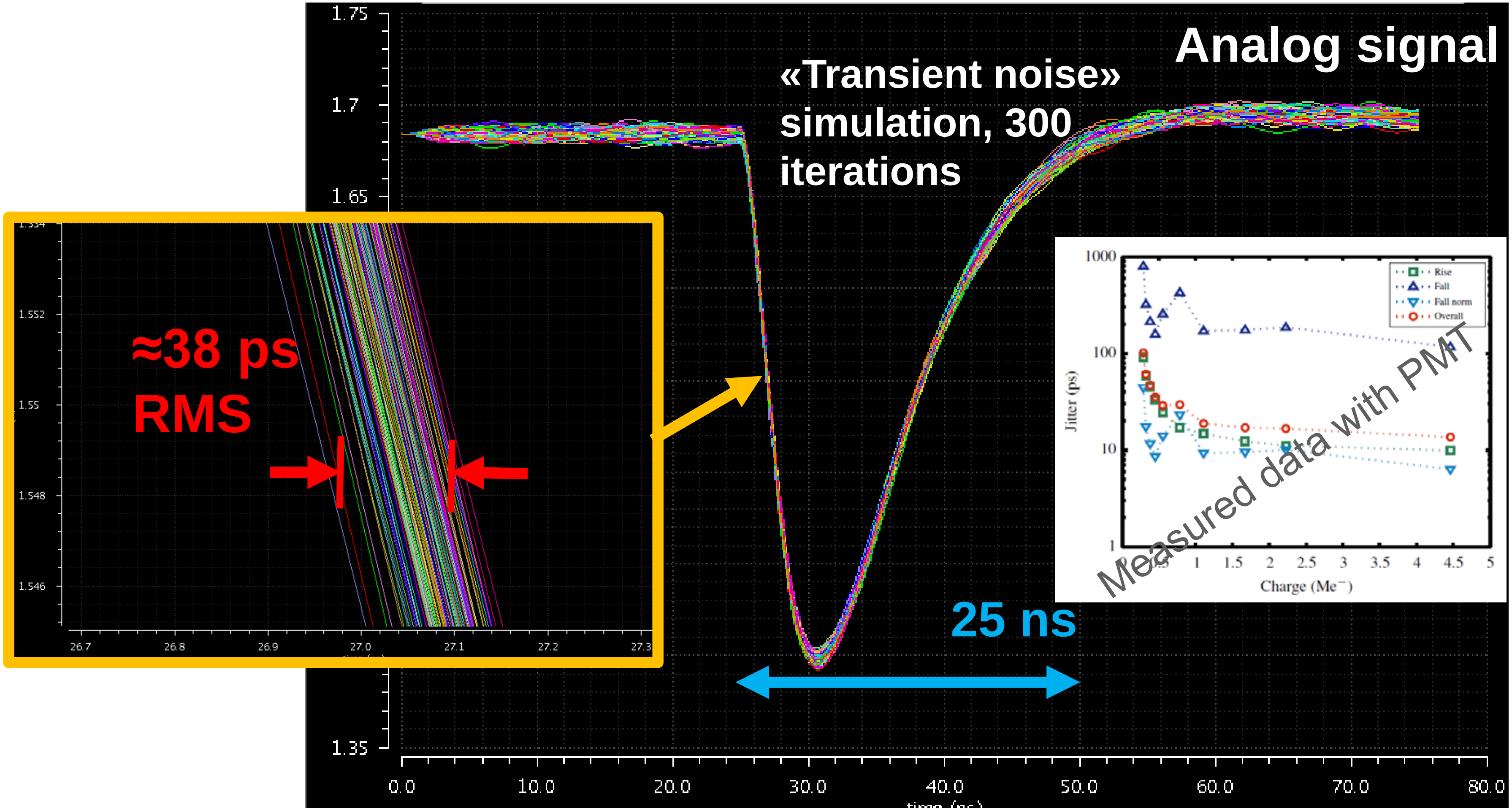
But bandwidth can quickly recovered by changing the **external** bias resistors of the CLARO, at the price of a (small) increase in power consumption.
No modifications to the chip are necessary.



This is the simulation of the CLARO response to SiPM single photon vs the power dissipation (measurements will be done soon)

Noise performances

Input capacitance: 50 pF (1 mm^2 SiPM + parasitic)
Signal: 1 Me- / Threshold: 500 Ke- (SiPM operated at 2 V of overvoltage)
Power: 1.2 mW/channel



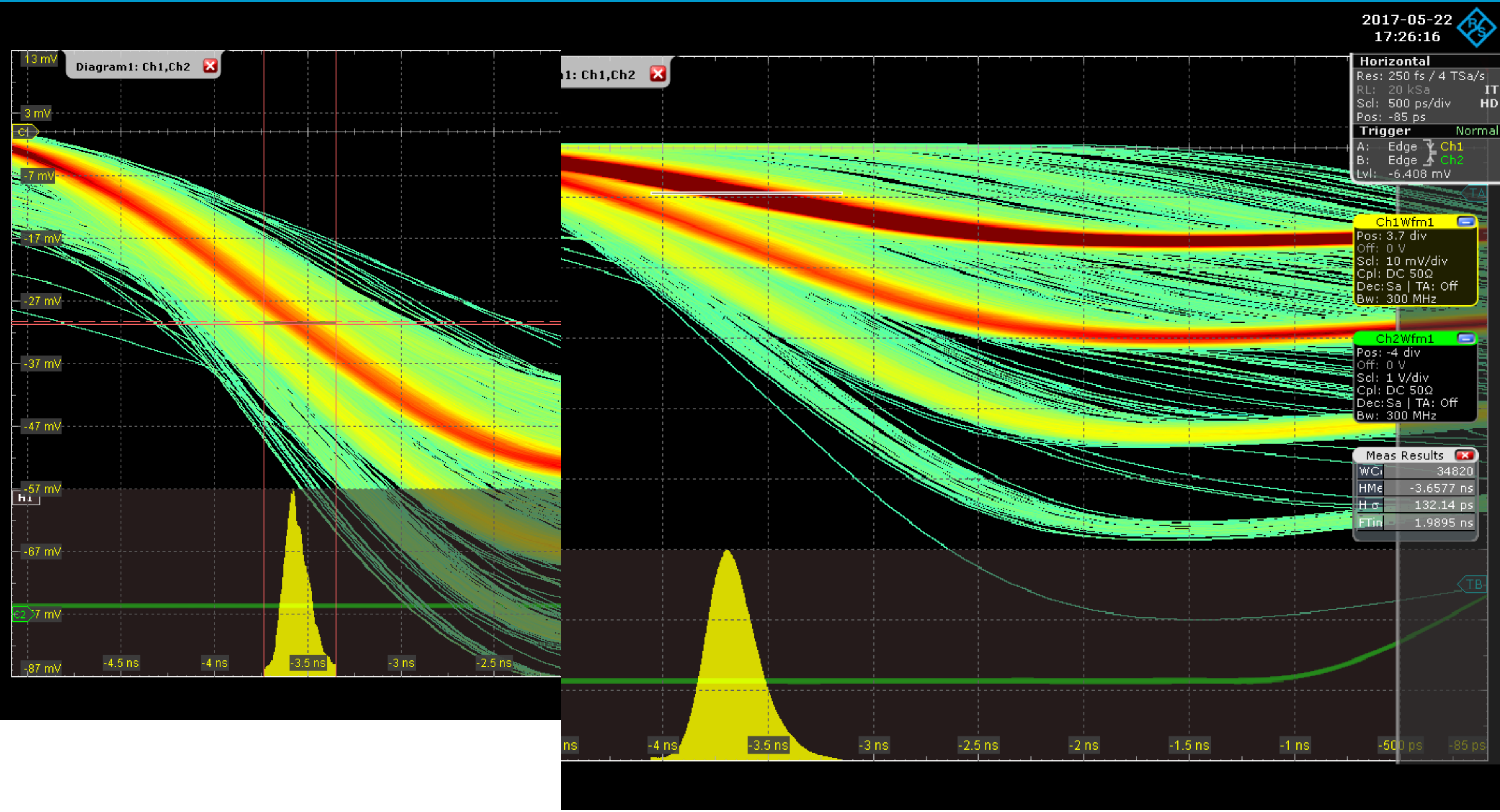
Summary

- We selected a first SiPM (other devices tested soon) with useful starting characteristics for the third generation of the RICH of LHCb and tried to optimized its performances;
- speed of response and gain have been found adequate and with a contained dependence on temperature and overvoltage;
- Dark Current and After pulses are negative effects that can be mitigated maintaining low the operating temperature and overvoltage;
- Photon Detection Efficiency reduces at small overvoltage, imposing a compromise on its minimal settable value.
- A Radiation investigation campaign is needed to verify the SiPM to face the foreseen luminosity. Magnetic field effects have also to be measured.

  - The very frontend for this *after LS3* generation of the RICH detector can be the CLARO, the very frontend for the *after LS2* generation of the RICH;
  - The CLARO was simulated to be able to face the specifications for managing the signals from SiPM, too, (either current polarity) changing the value of one reference resistor and increasing its dissipation to less than 2 mW/channel.
  - The CLARO was already found rad hard at about x10 the level foreseen for *after LS2*.

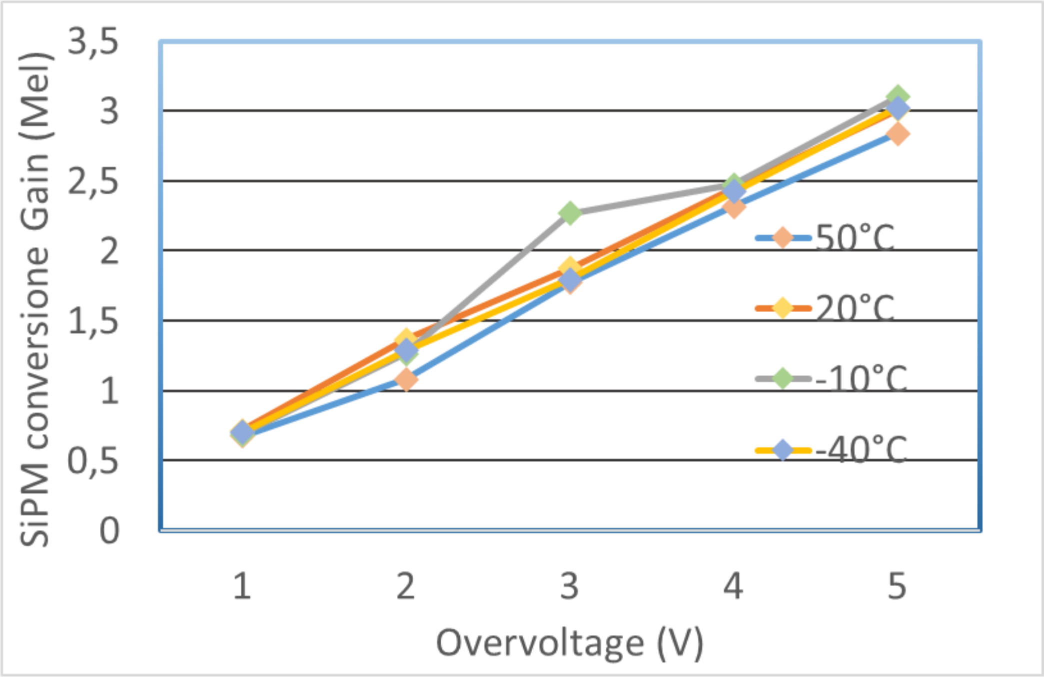
SPARE

Setup contribution on Jitter



We measured the jitter vs number of photons at the SiPM output, observing that it reduces roughly as 1/√(ph n.), proving a contribution from the setup, that can be estimated around 30 ps. We did not try, up to now, to characterize this since it affects marginally our results.

Gain vs Temperature



Gain is almost constant with respect to temperature and varies by about 0,5 Mel/°OverVoltage.

Multi-Photon response of PMT

PMT one photon and two photon peaks are almost indistinguishable
.

Photon pile-up is identification is possible only by measuring timing separation.

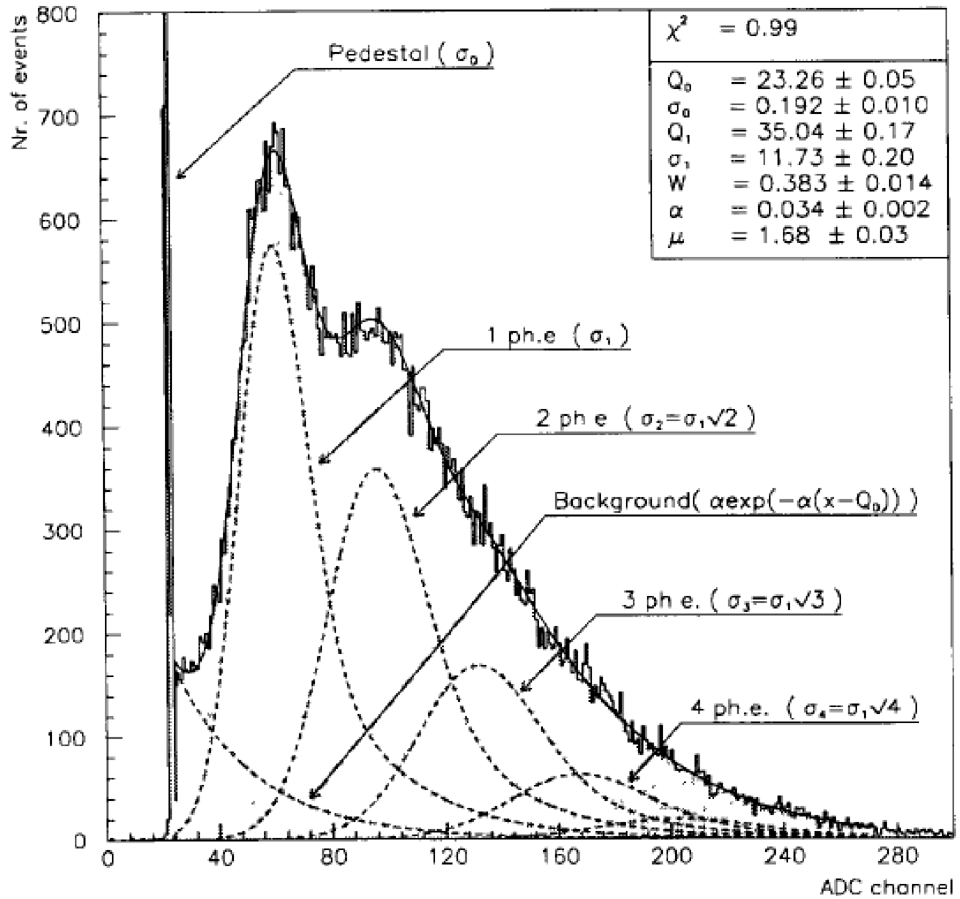


Fig. 2. Typical deconvoluted LED spectrum (EMI-9814B photomultiplier).

NIMA 339, 1994, 468

SiPM signal: electron or holes?

Electron or holes current are opposite and can make the difference when managed by the preamplifier, as very often it is designed to amplify only one current polarity, suffering in speed otherwise: the amplifier is not in AB class.

We simulate our CLARO with input signal of either polarity obtaining adequate responses, provided that a resistor is added to generate a proper offset: