THE MURAVES EXPERIMENT

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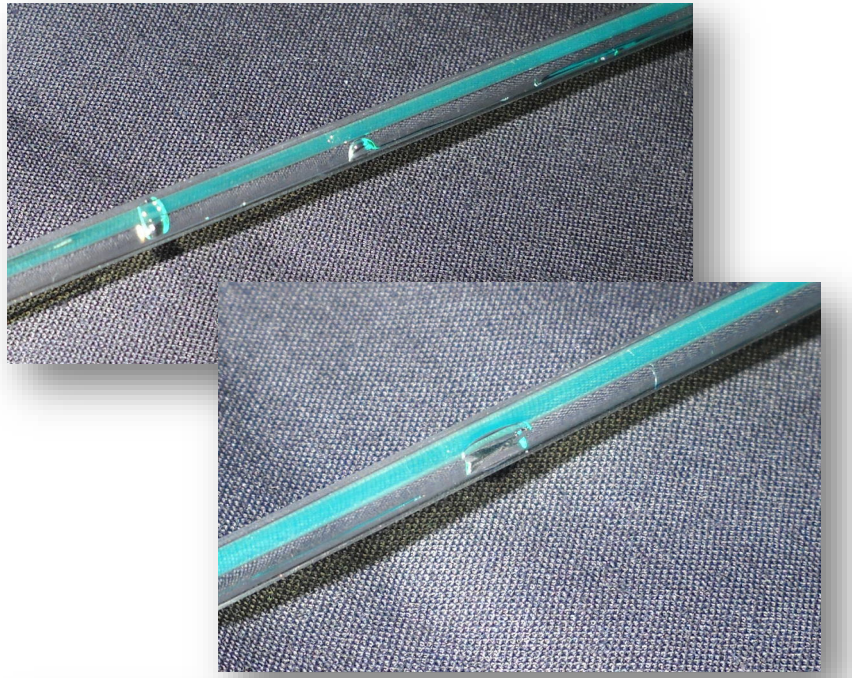
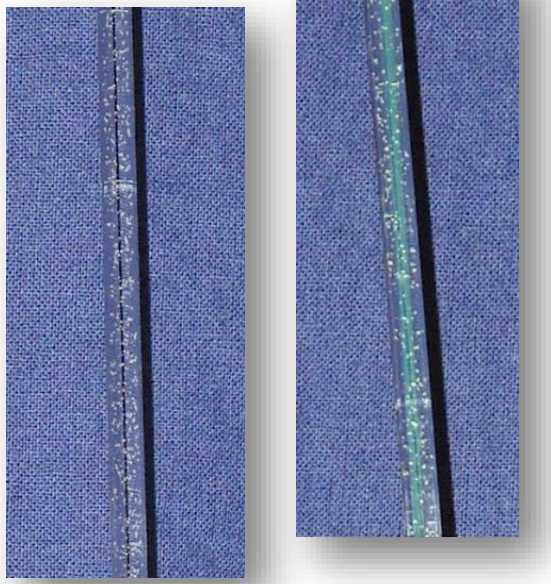
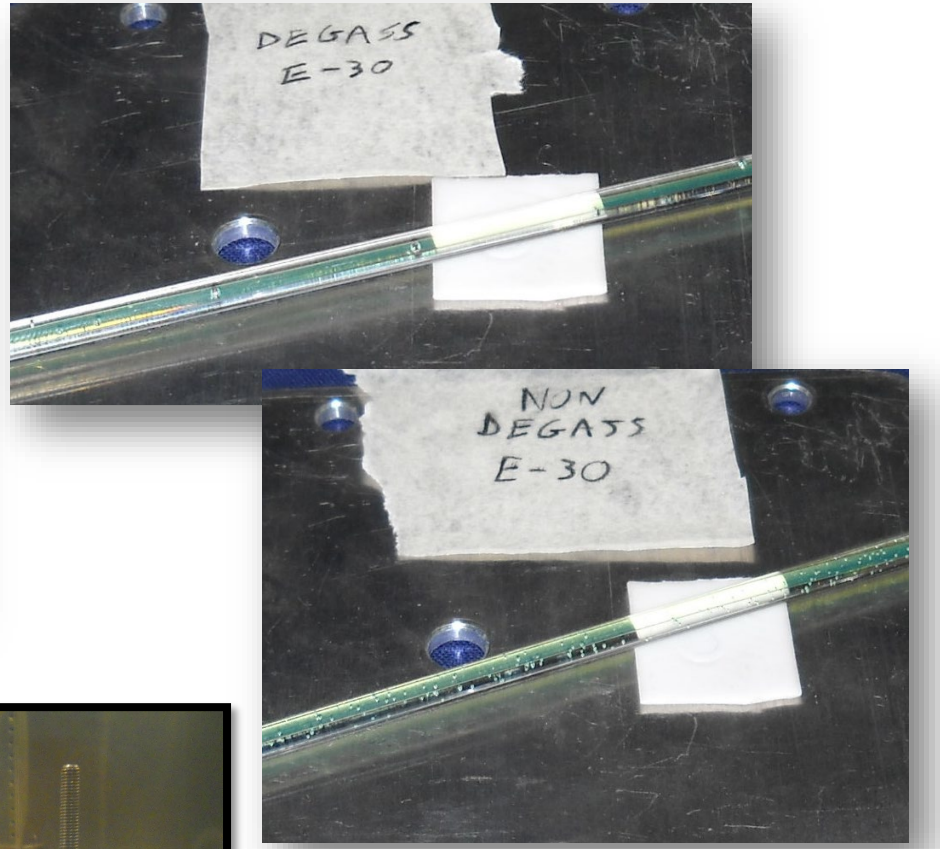
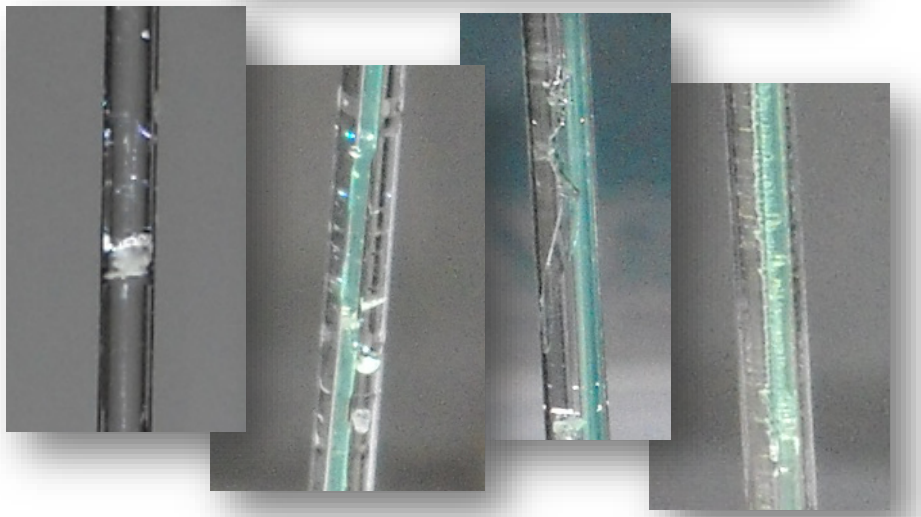
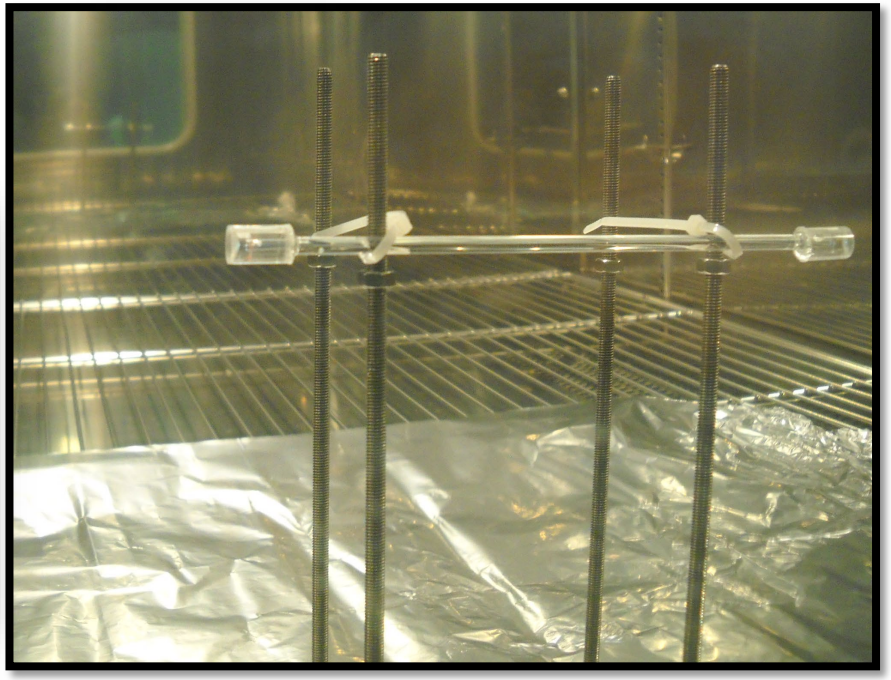




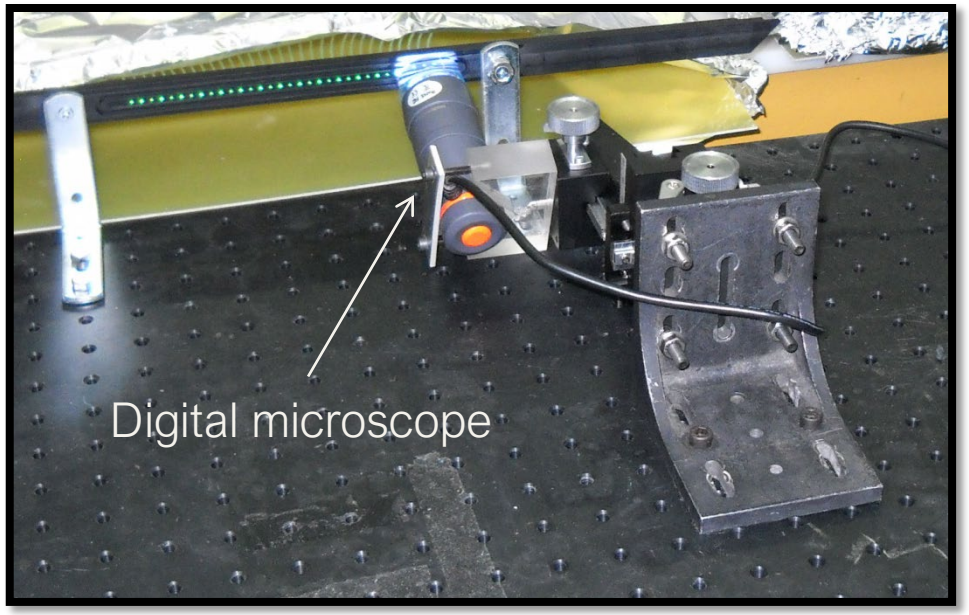




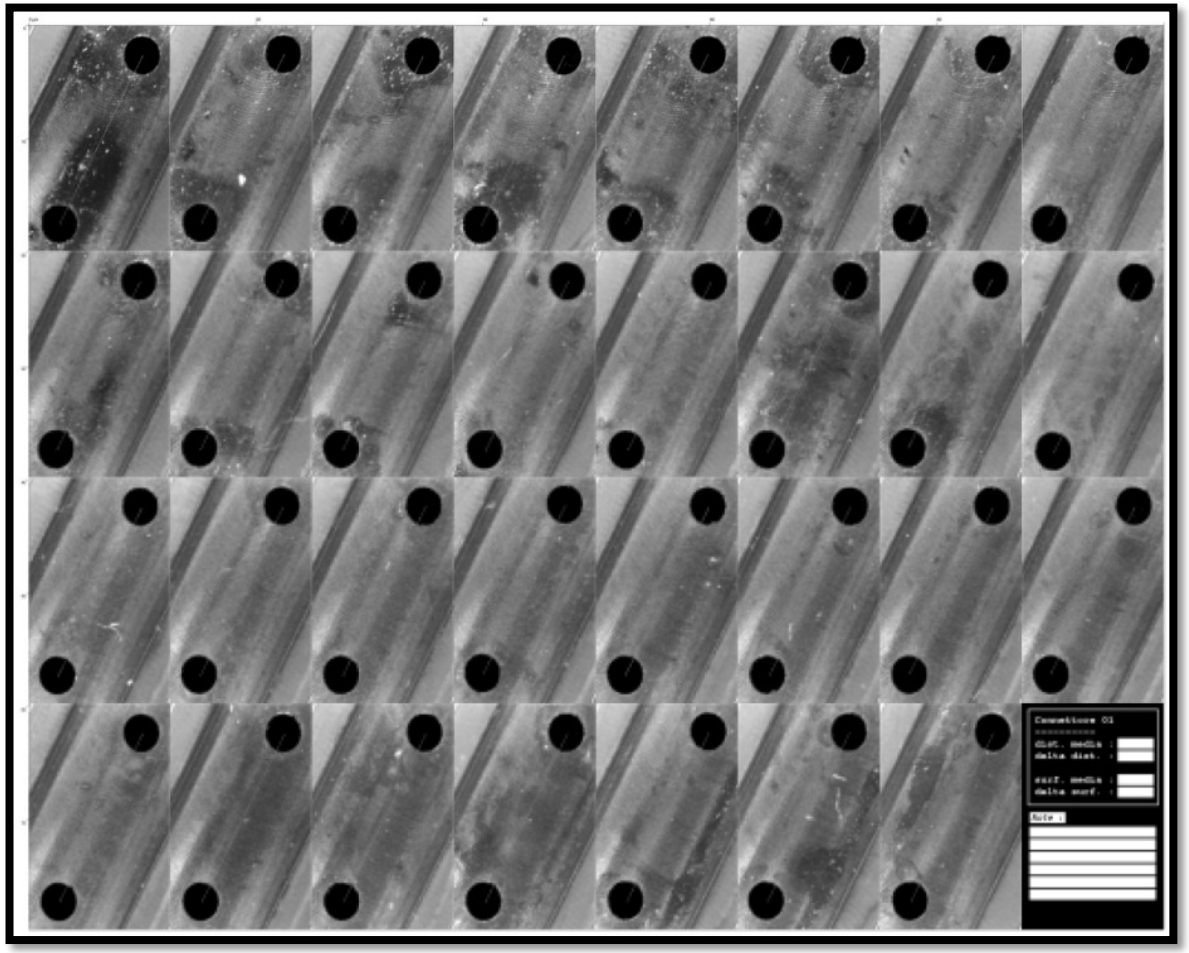


Studies on optical coupling fiber-scintillator

THE MURAVES EXPERIMENT

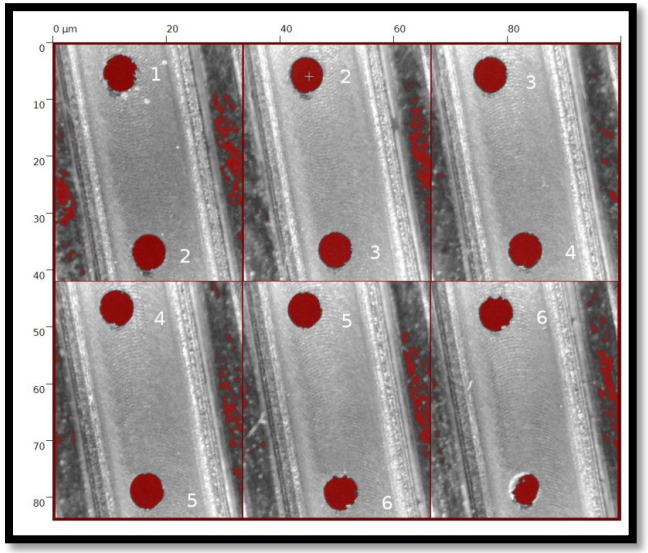


Setup of the Test Facility



31 comparable couple of holes

Some bad from the analysis



Have been measured:

- Holes diameter
- Alignment
- Fibers placement

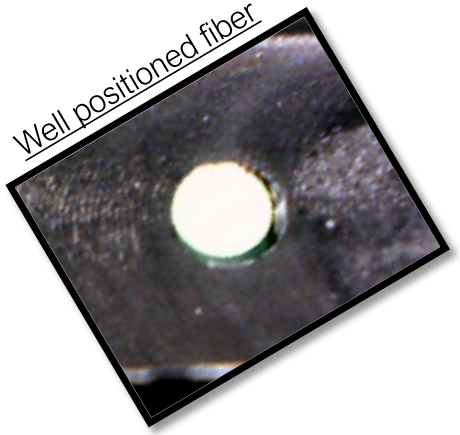
Quality check of the manufacture of optical connectors

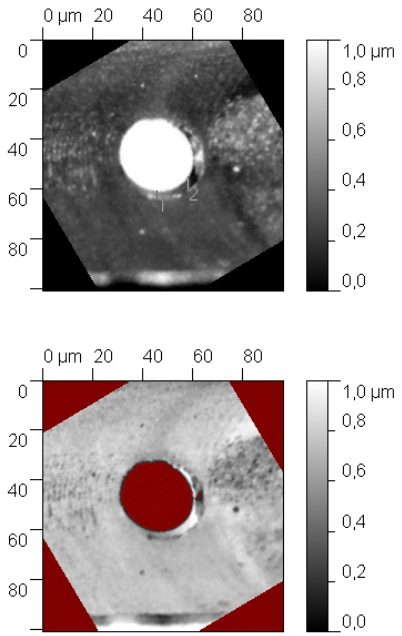
- All holes are aligned with statistical error of order 0.5%
- All holes are spaced within statistical error of order 2%

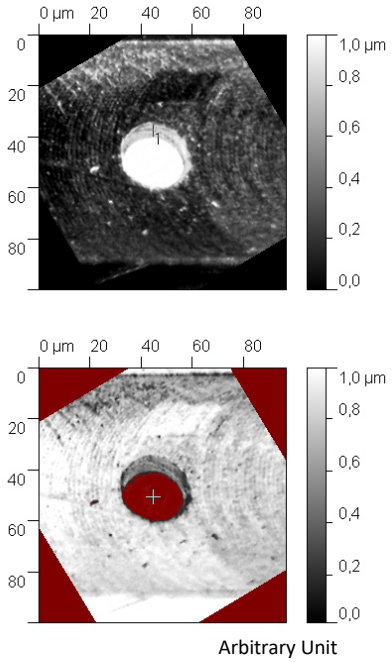
THE MURAVES EXPERIMENT

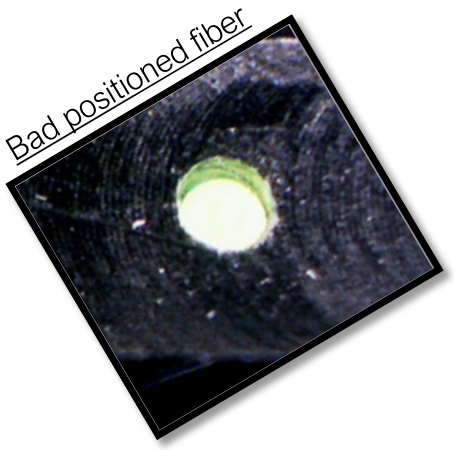
The special tool in the picture was designed to glue the fibers to the connector. In such way, side by side, fibers lower profiles fits naturally under effect of gravity, so once all fibers are inserted in the relative guides to the connector, they are glued to it with high precision.

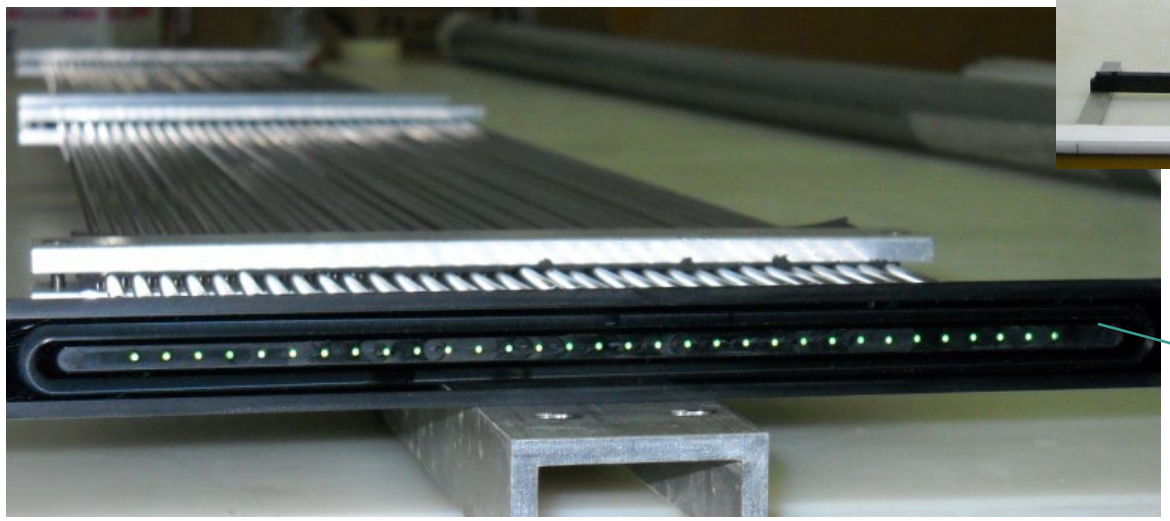
On the right, we can see a well positioned fiber that comes outside the hole. Thank to such analysis we were able to improve the fiber positioning tool, to dispose all 32 fiber inside the connector using a precision mechanics that softly align the fibers at same level outside the holes.

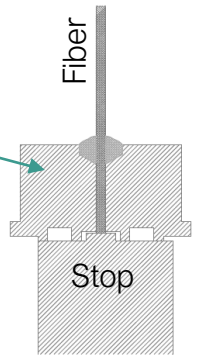




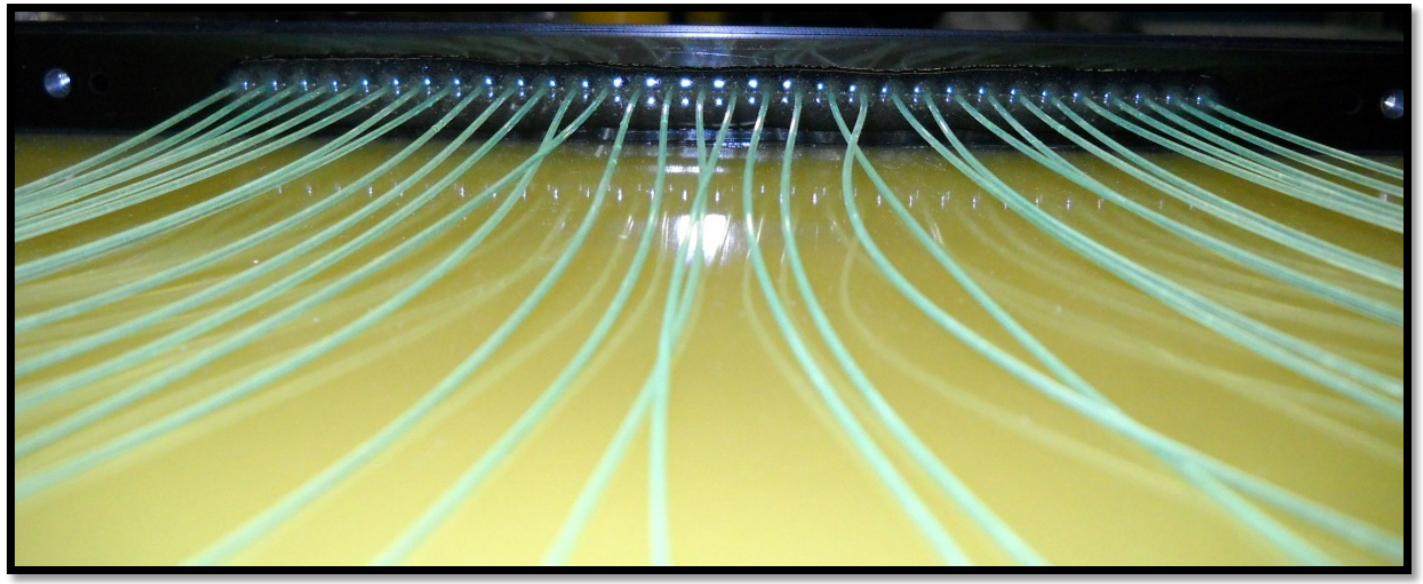


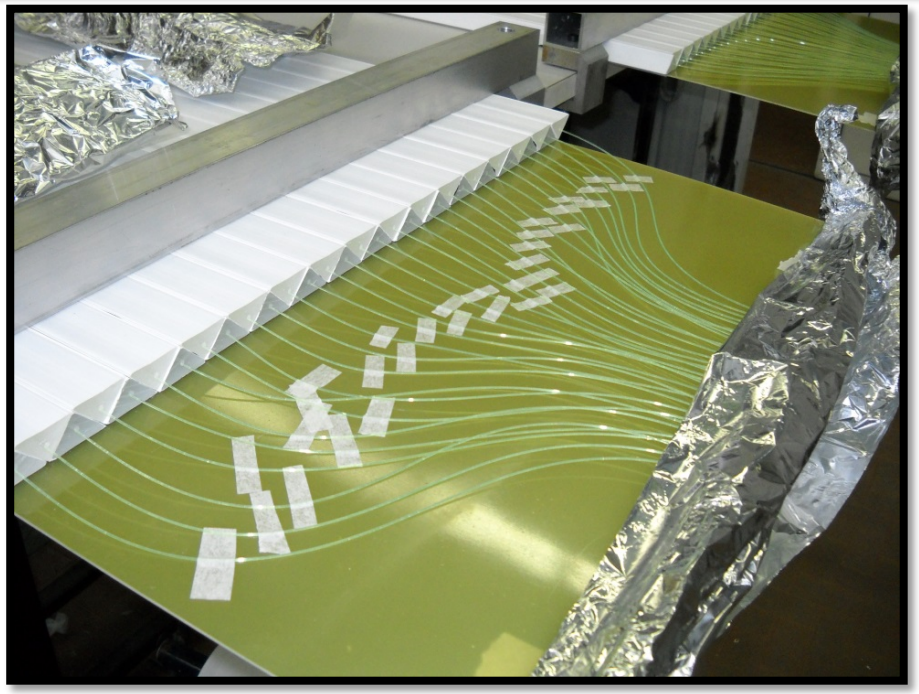


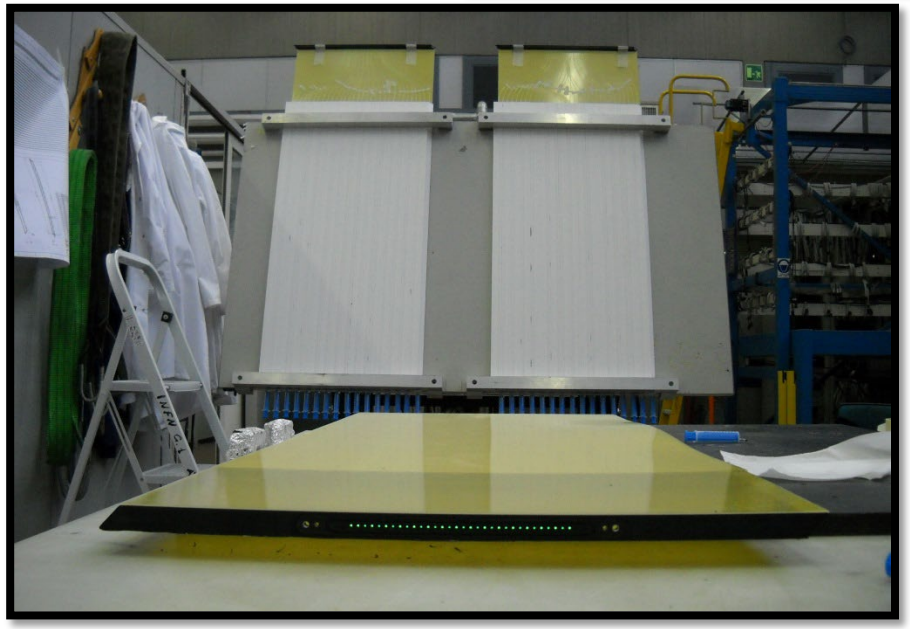




THE MURAVES EXPERIMENT

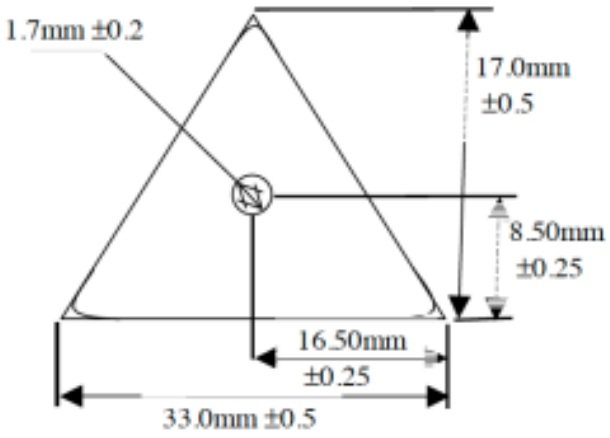


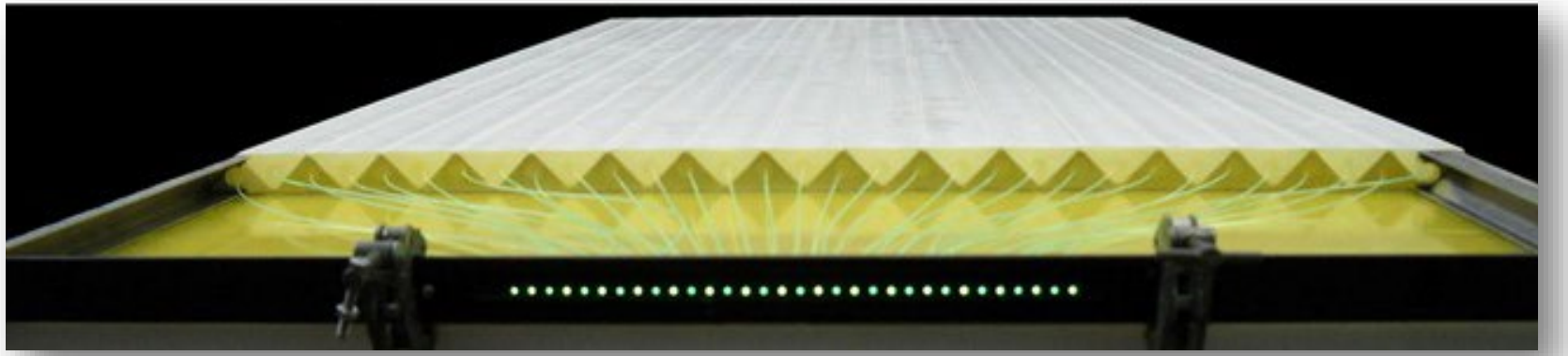




Basic Modules production

THE MURAVES EXPERIMENT





When an ionizing particle hits the bar, million photons are released and must be transmitted to the photon detectors.

WLS Fibers collect hundreds of photons and transmit the light to the Silicon photomultipliers

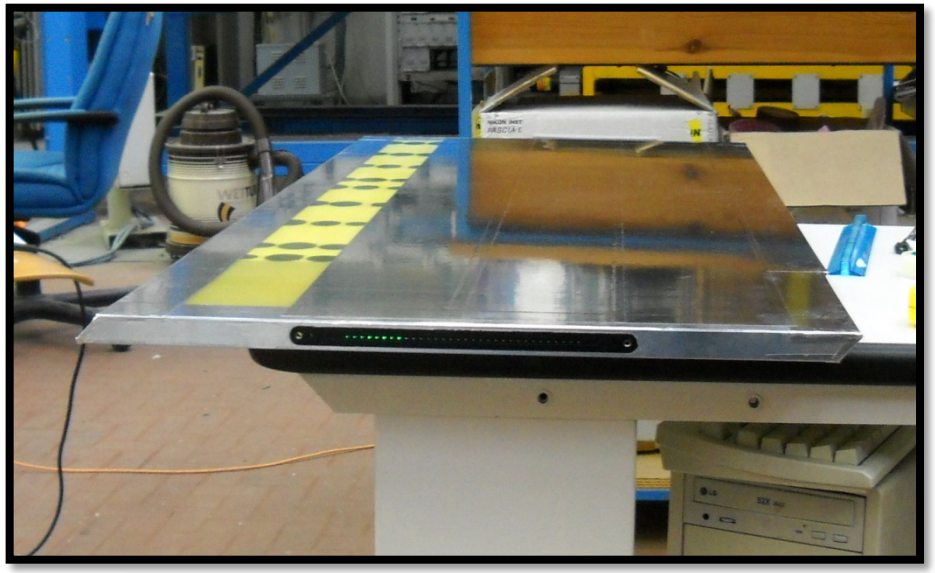
Tens of photons arrive to the photosensor.

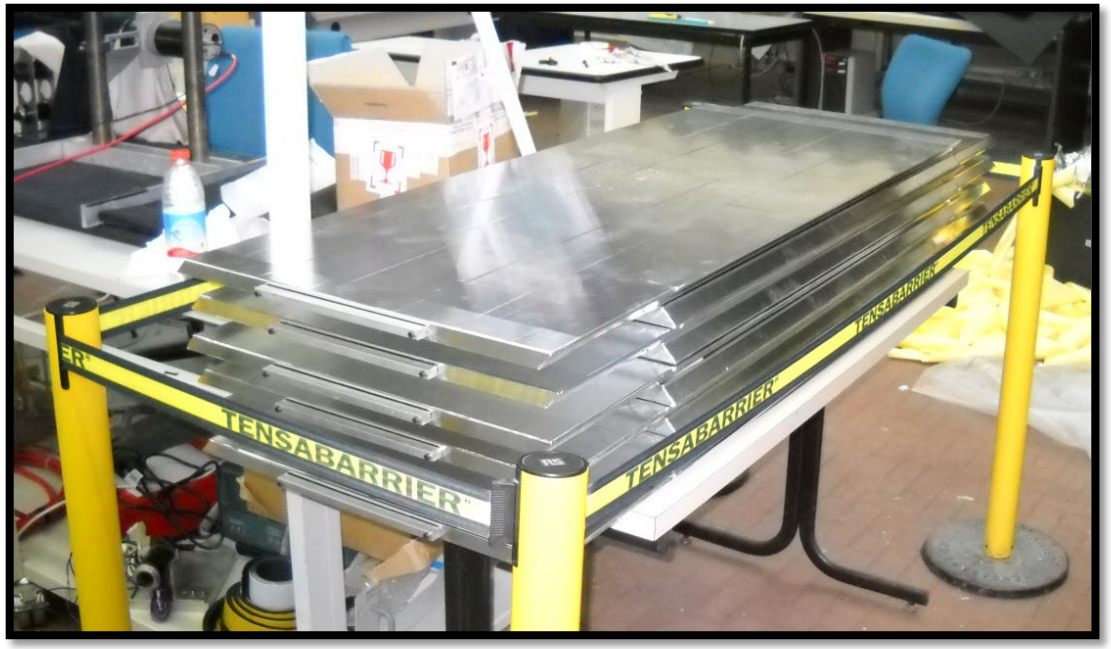
Triangular plastic scintillator bars

- Robust
- High intrinsic spatial resolution with charge balance

Intrinsic Spatial Resolution: 16.5 mm (C.B.: 800 μm)
Intrinsic Time Resolution: 10 ns (Scint. + Fiber)

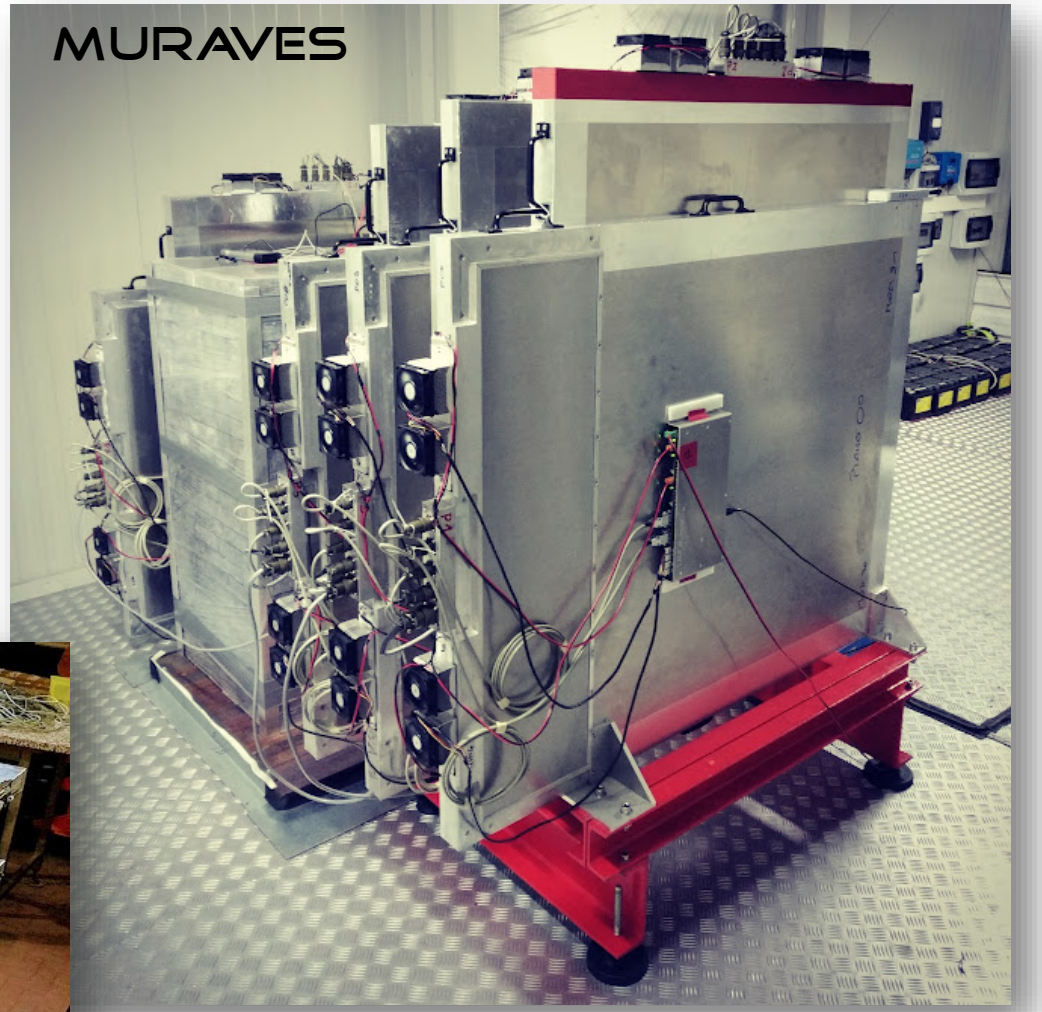
THE MURAVES EXPERIMENT





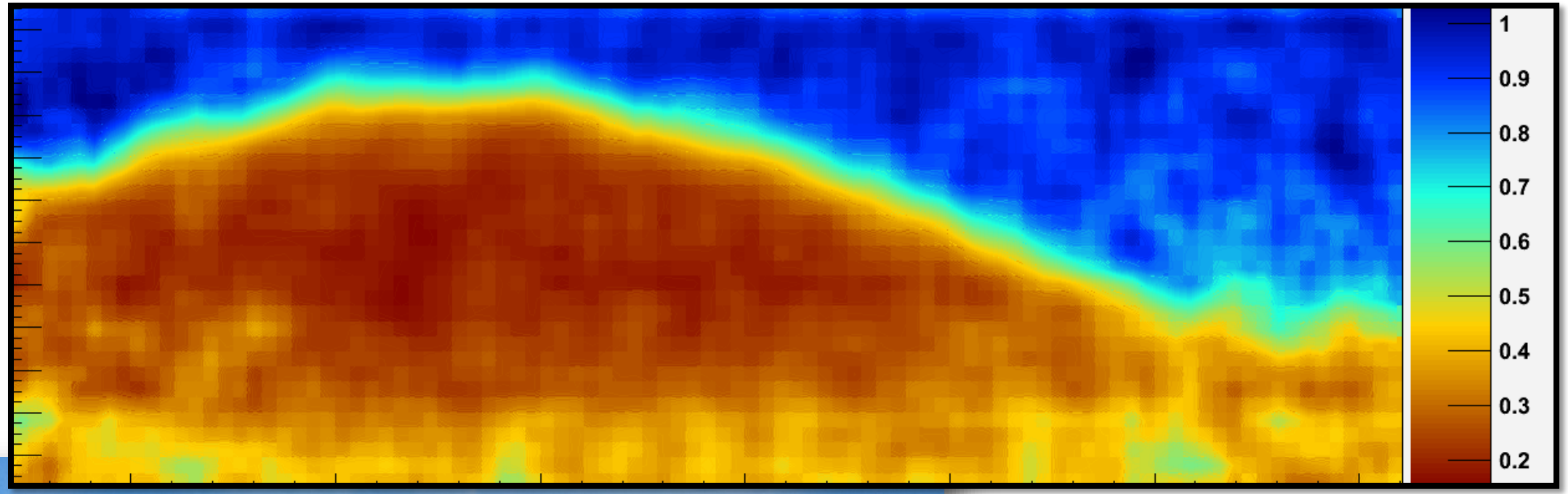
THE MURAVES EXPERIMENT

Prototype

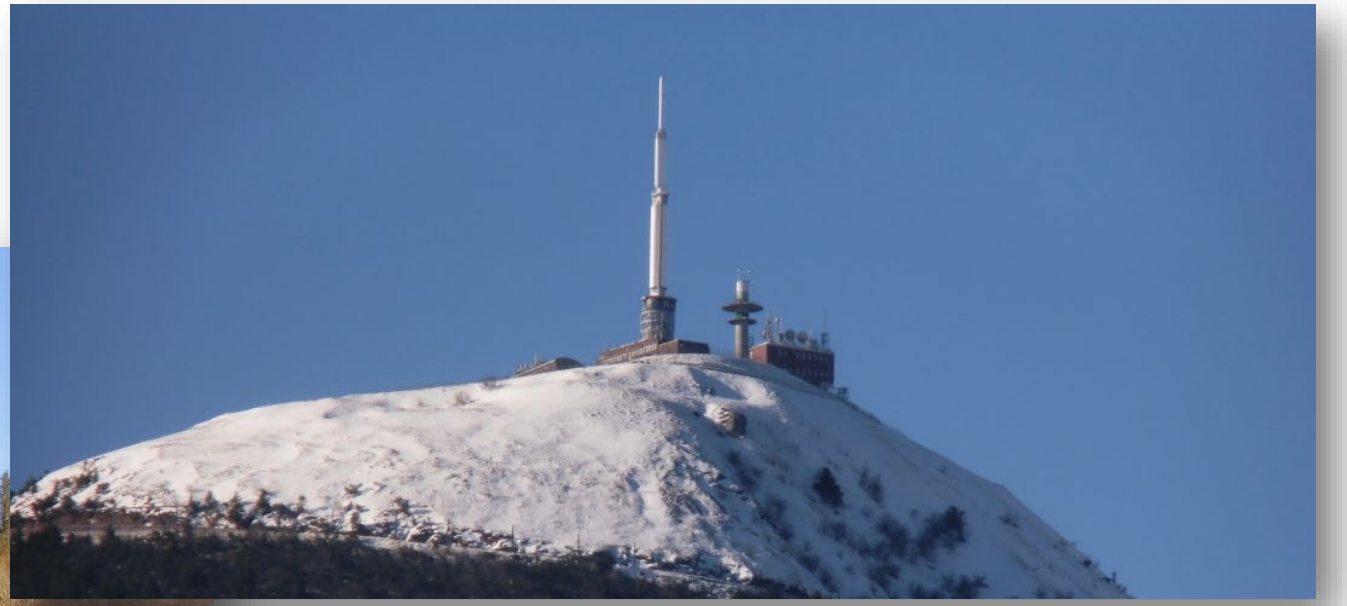


Base

THE MURAVES EXPERIMENT

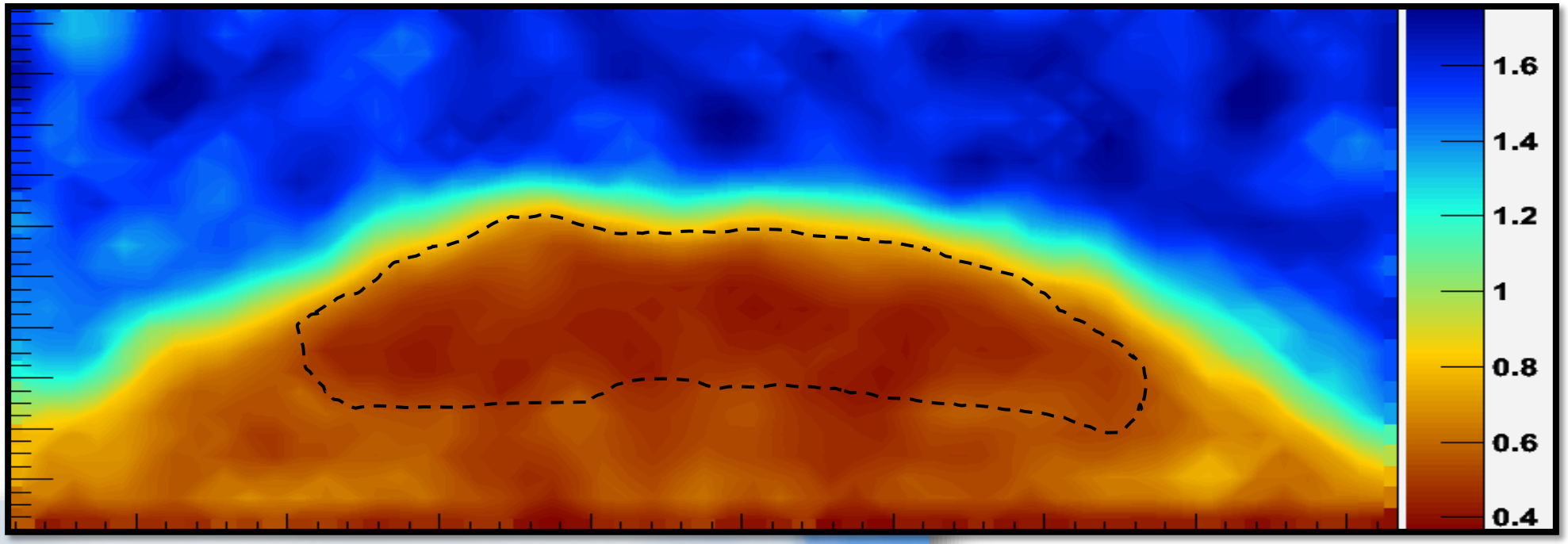


THE MURAVES EXPERIMENT



Puy-de-Dôme
Clermont-Ferrand
December 2013

THE MURAVES EXPERIMENT

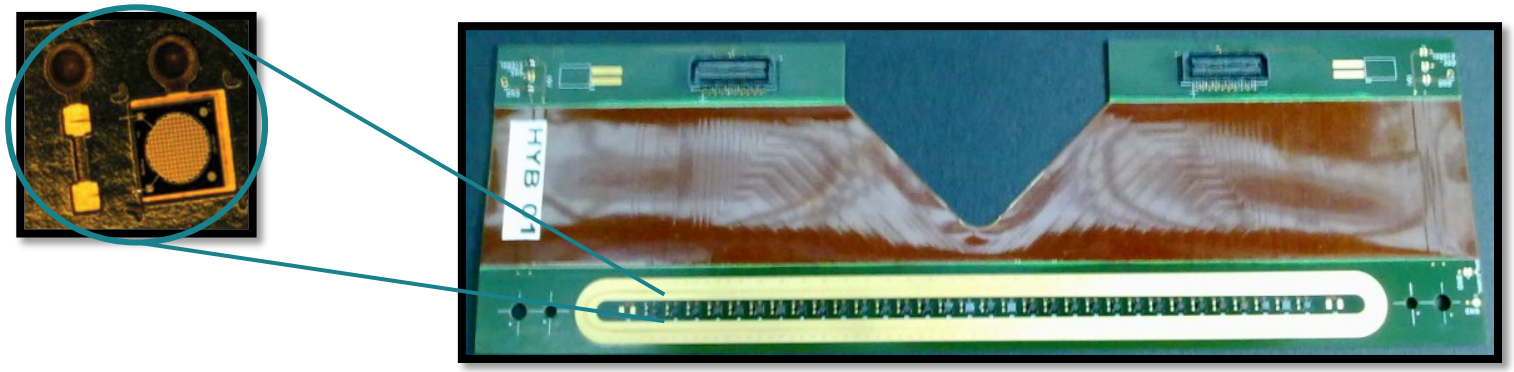


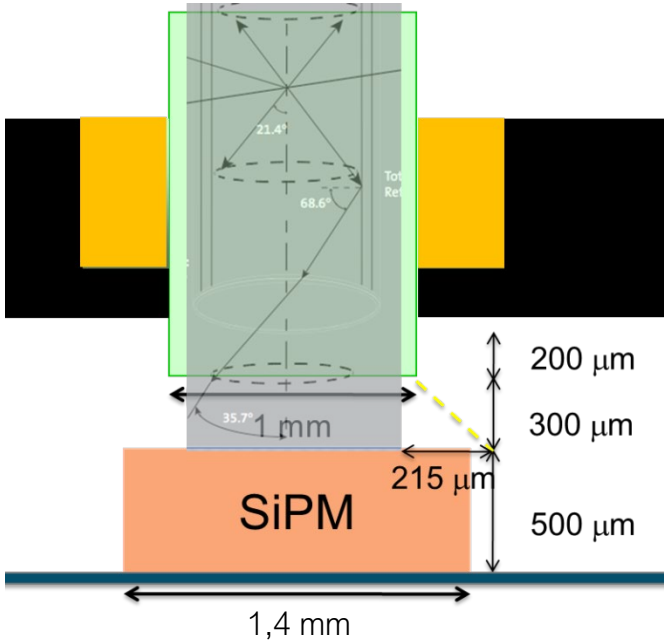
THE MURAVES EXPERIMENT

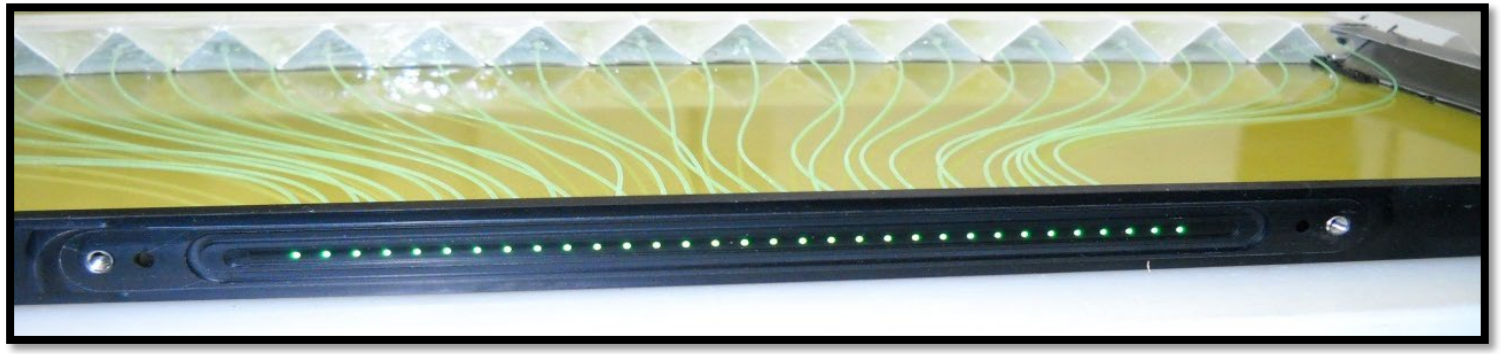
In order to control the thermal working condition of the photon detectors, we decided to arrange 32 Silicon photomultipliers on a single board.

We choose to design an optical connector to put forward photon detectors against fibers, so that it collects 32 fibers

- Fiber Internal total reflection angle: 21.4°
- output angle: 35.7°
- max displacement: 220μm







15.5 cm hole-to-hole total length

5 mm pitch

1.1 mm hole diameter

THE MURAVES EXPERIMENT

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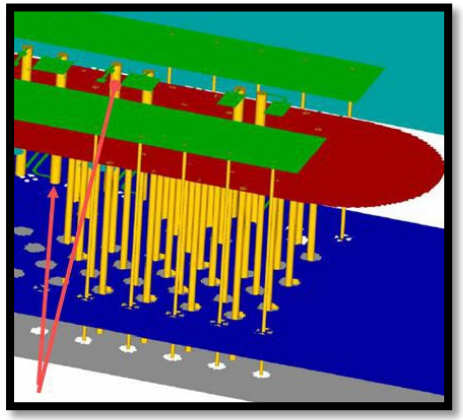
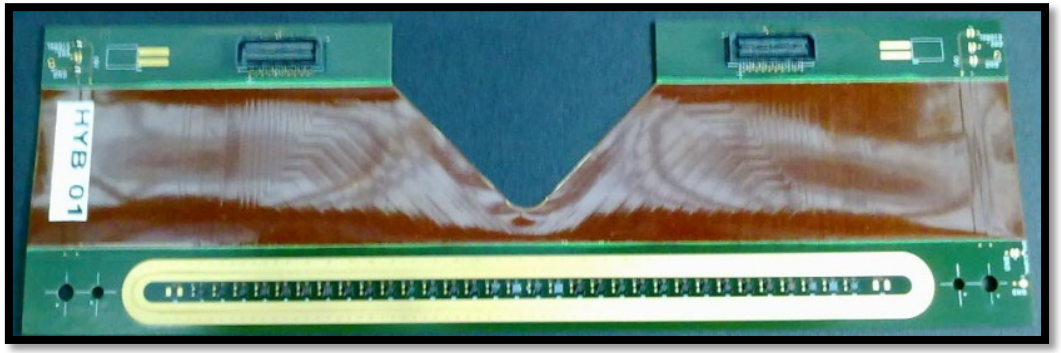
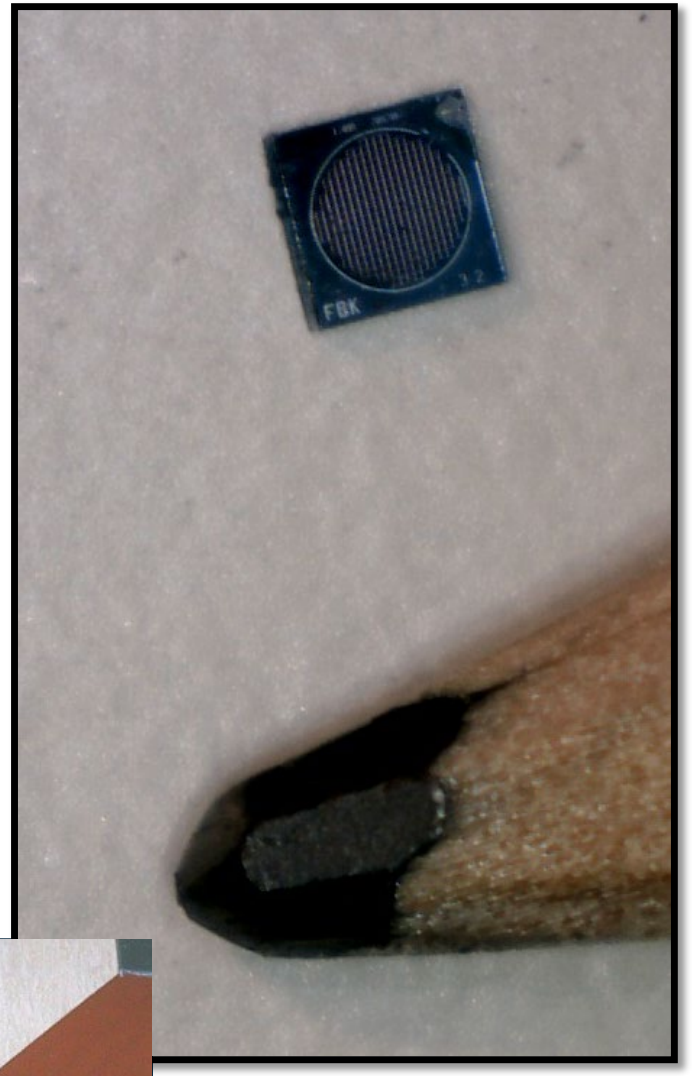
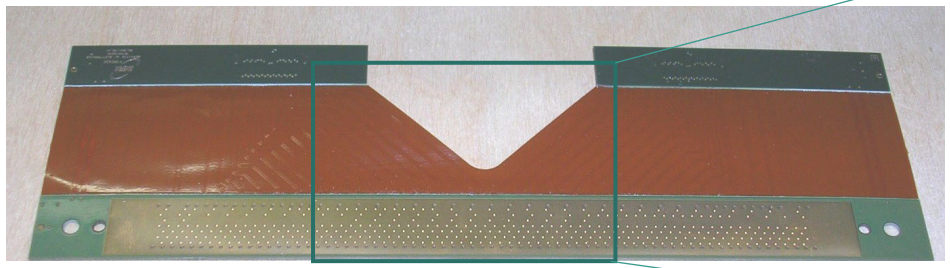
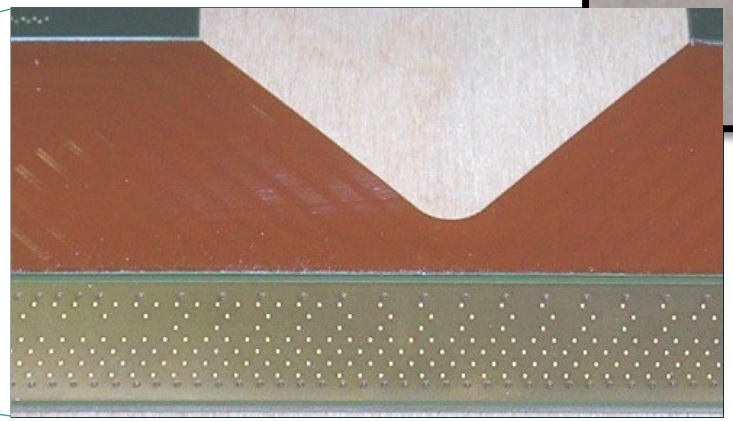




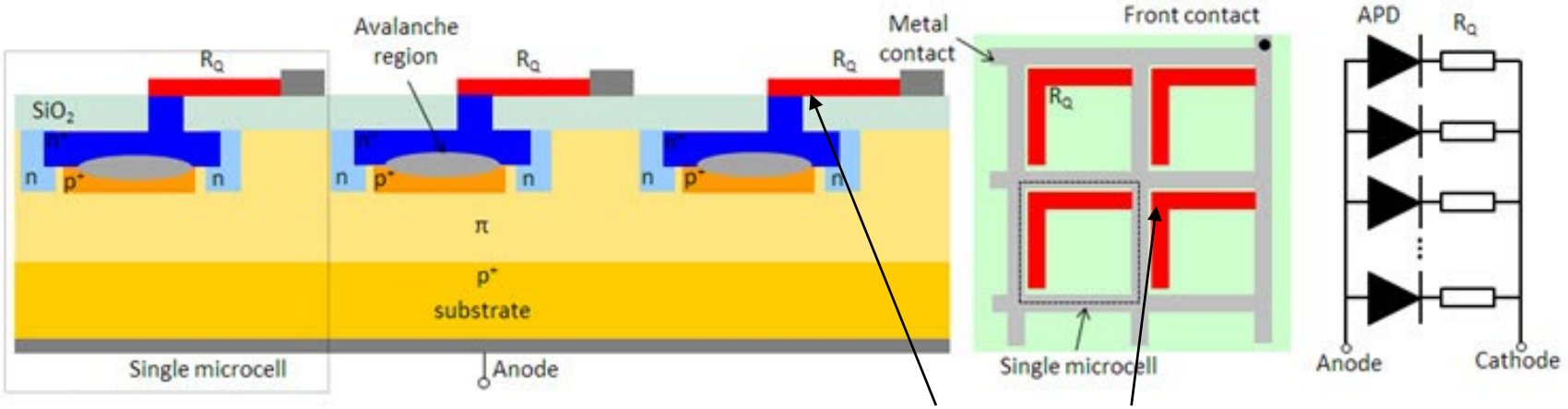






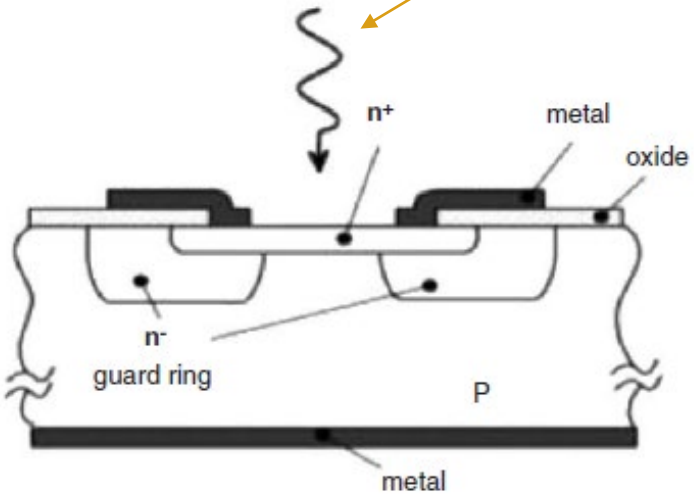
DETECTORS FOR MUOGRAPHY AND APPLICATIONS

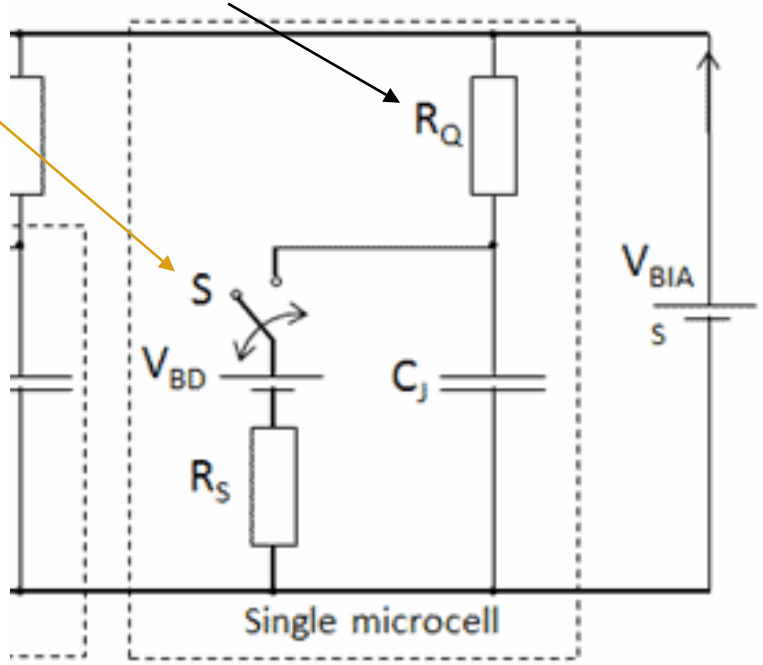
Silicon Photomultipliers **are photosensors capable to reveal the single photon**. The main characteristics of these devices are the ruggednes, the durability and the low power consumption.



Incoming photon closes the switch

QUENCHING RESISTOR





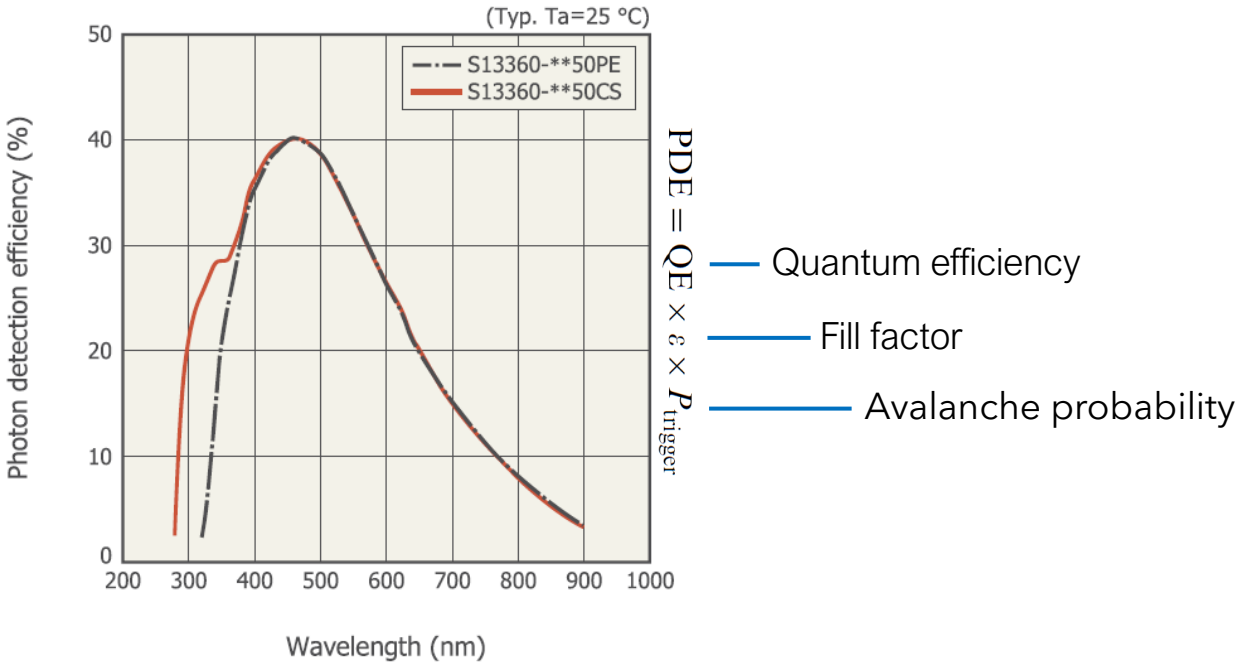
SiPMs are constituted by a parallel matrix of avalanche photodiodes working in Geiger-mode (**G-APD**). When a photon triggers an avalanche, this grows exponentially until it reaches its maximum, depending on how many cells have been activated at the same time. The SiPM is restored by meaning of the **quenching resistor** in series with the APD.

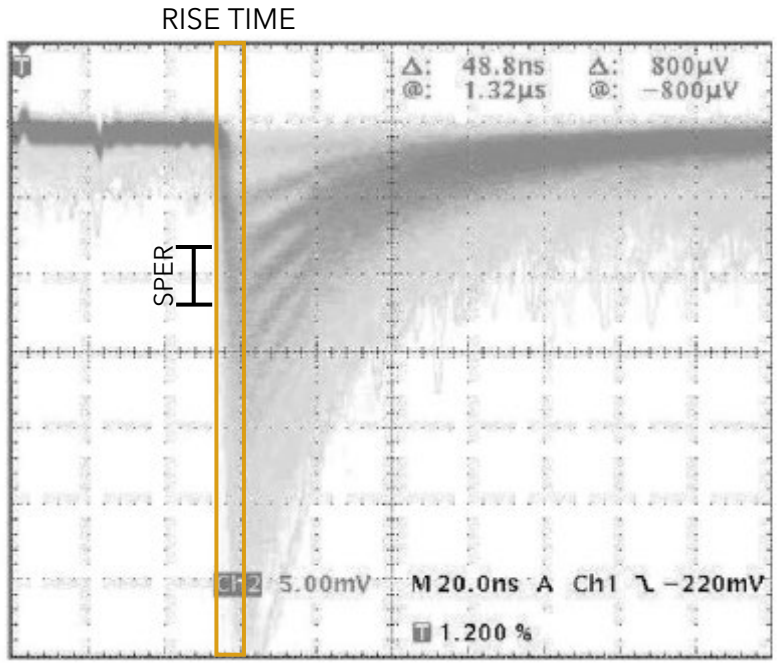
THE MURAVES EXPERIMENT

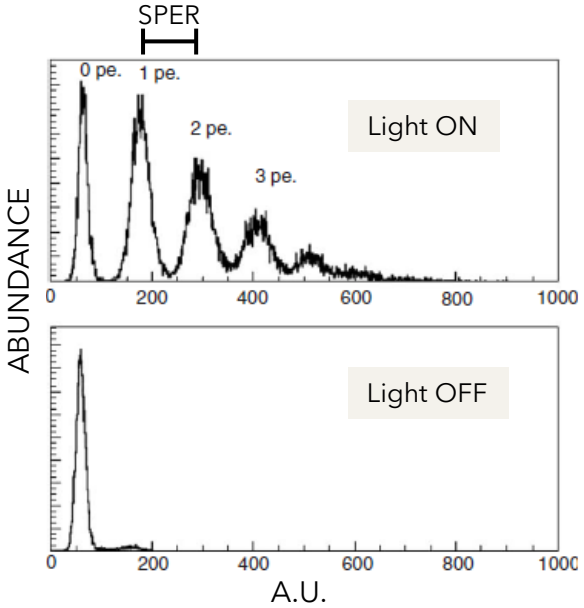
The typical response of these devices is hundreds of ps. The recovery time is of order 100 ns and the amplitude of the signal depends on how many microcells have been activated at the same time.

The output signal A is proportional to the number of fired cells N_F and the gain is usually in the range 10^5-10^9.

$$A = \sum A_i \propto N_F = N_T \left(1 - e^{-\frac{N_{Ph}\mathrm{PDE}}{N_T}}\right)$$





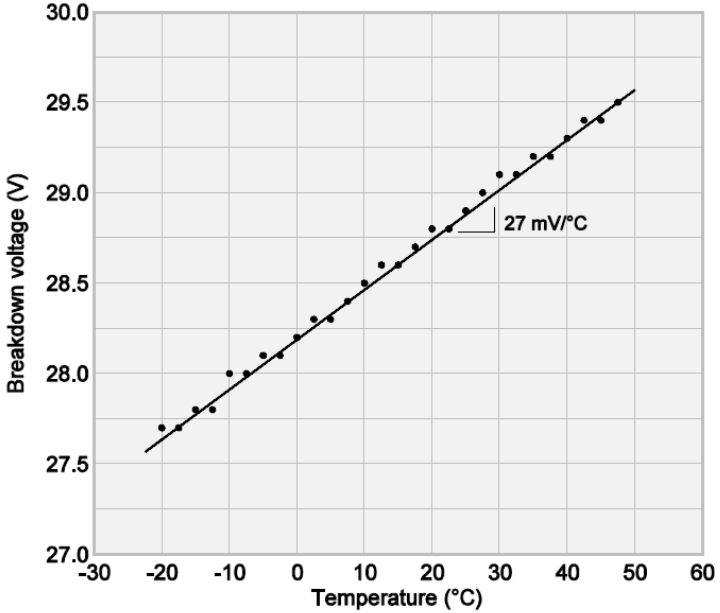


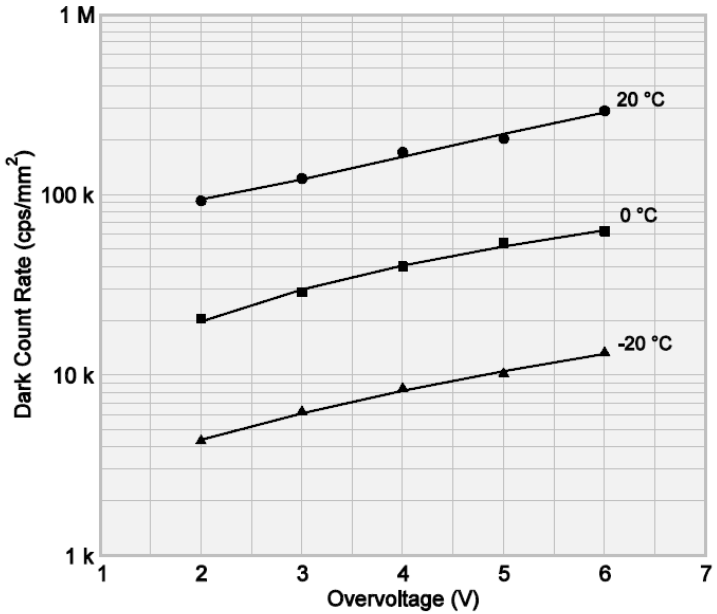
A single microcell can be fired both by a photon or by a free carrier inside the APD. The distance between peaks is called **Single PhotoElectron Response**.

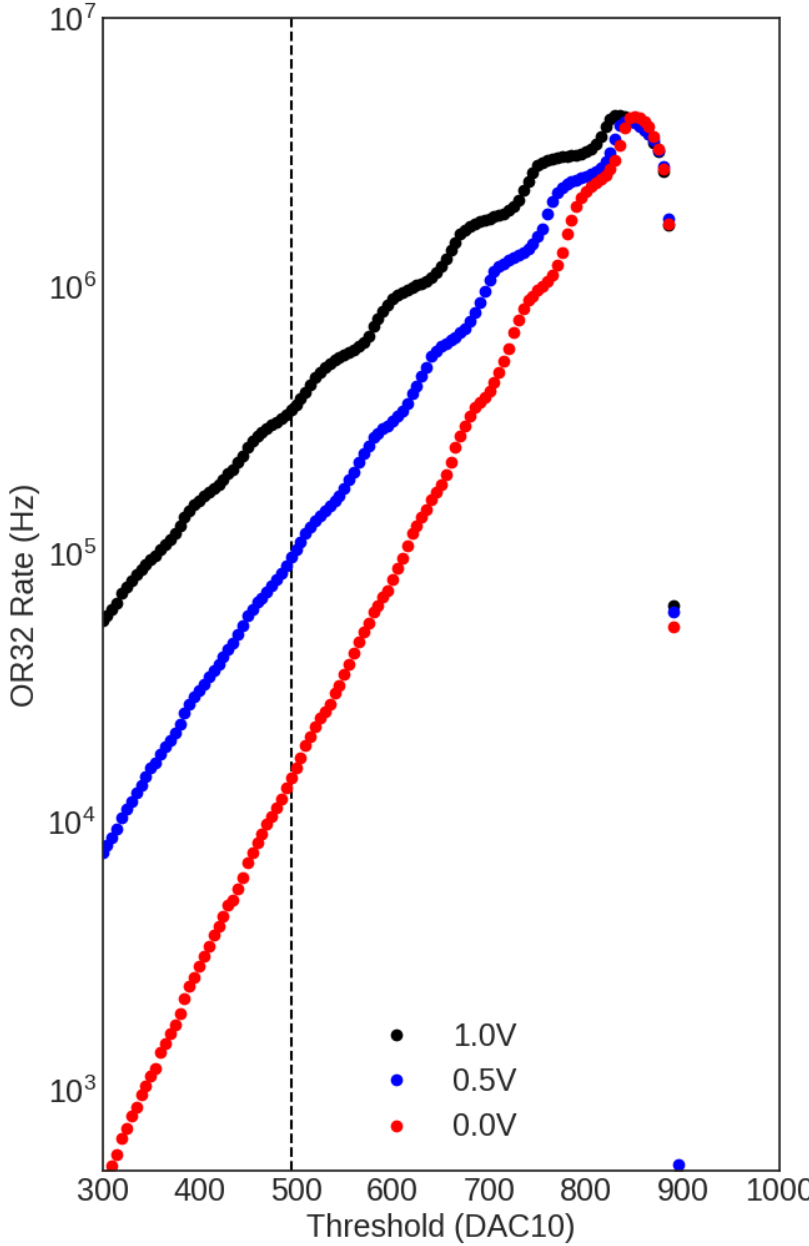
THE MURAVES EXPERIMENT

The effect of dark counts, when the rate is controllable, can be attenuated by setting an *ad hoc* threshold depending on the temperature. Overvoltage also has a tuning effect on dynamics and dark counts rate control.

The best choice is to set intermediate threshold, with a cut at 5 photoelectrons, with the SiPM at controlled temperature, by setting an appropriate overvoltage. Because, keeping the SiPM at a lower temperature decreases the dark counts by limiting the thermal agitation, but also decreases the breakdown voltage.





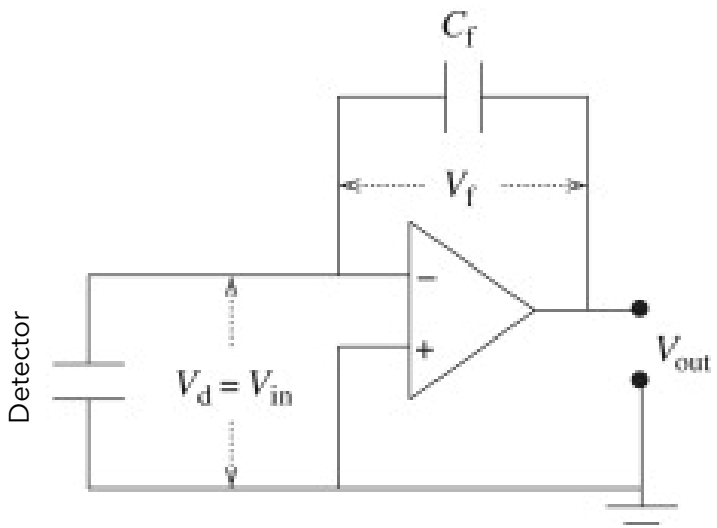


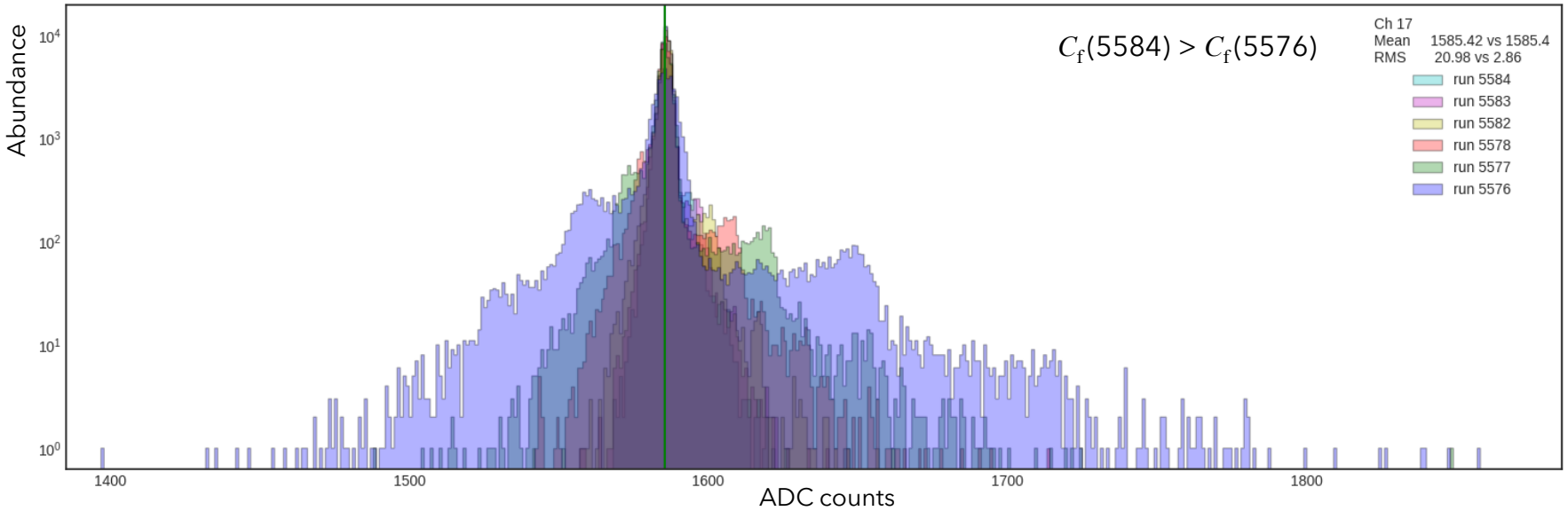
THE MURAVES EXPERIMENT

The **preamplifier** is commonly used to enhance low signal, like those from Silicon photomultiers or drift chambers. It is also used to increase the signal to noise ratio of the signal and it acts as a integrator of charge.

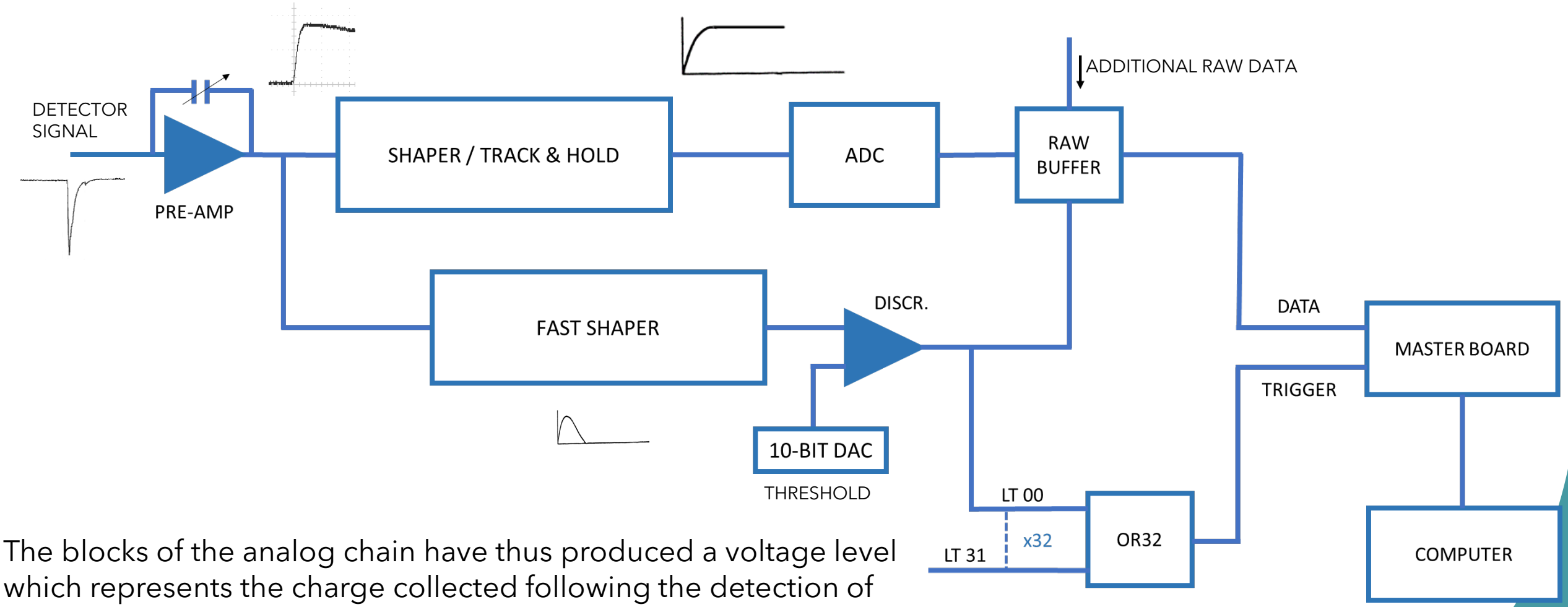
The charge Q_d collected at the electrodes is accumulated on the feedback capacitor C_f, so that it results integrated on the capacitor. The output voltage V_{out} is proportional to Q_d, since in principle the internal impedance of a real amplifier is large enough to it prevent the passage of current inside the operational amplifier, so that $Q_f = Q_d$ which implies $V_{out} = Q_d / C_f$.

It results by definition of charge gain A_Q that lower values of the capacity C_f, correspond to greater charge gain.





THE MURAVES EXPERIMENT

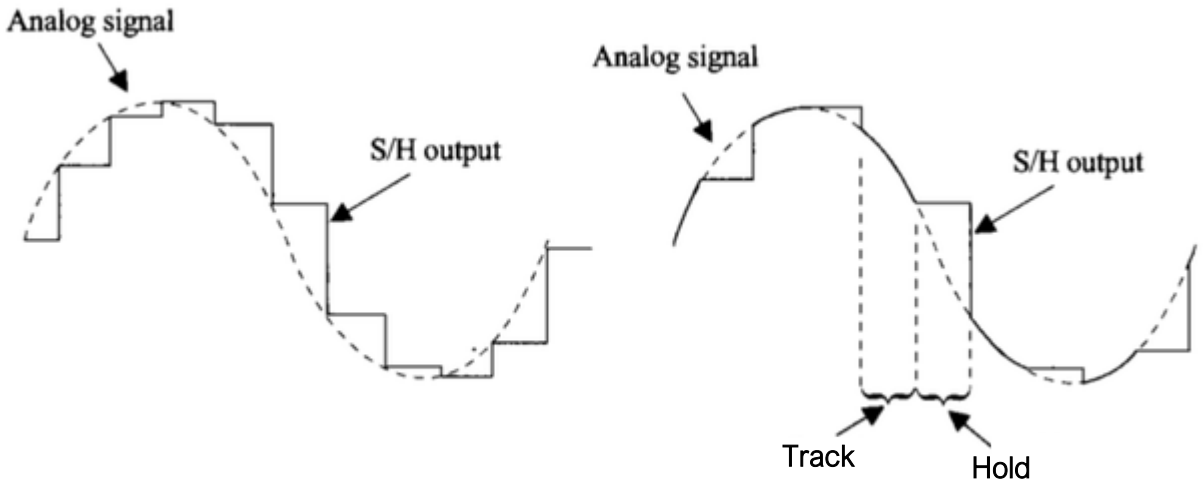


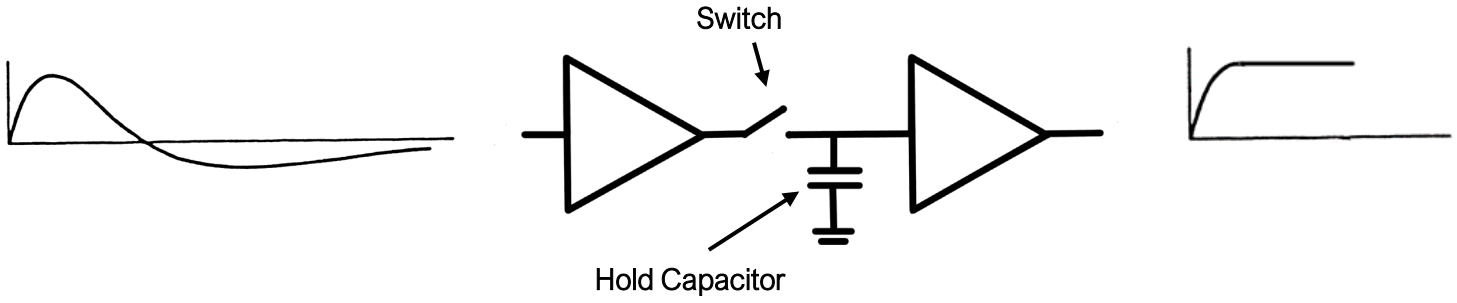
The blocks of the analog chain have thus produced a voltage level which represents the charge collected following the detection of an event. The signals produced are further processed through the blocks of the digital chain. Now let's **simulate some blocks** to better understand how these work. Just to mention, the discriminator is used to produce a logical signal, depending on inputs.

THE MURAVES EXPERIMENT

Sampling a signal means reproducing it partially. We may be interested in retrieving several sampled pieces of a signal at constant time intervals or retrieving information only on certain parts of the signal.

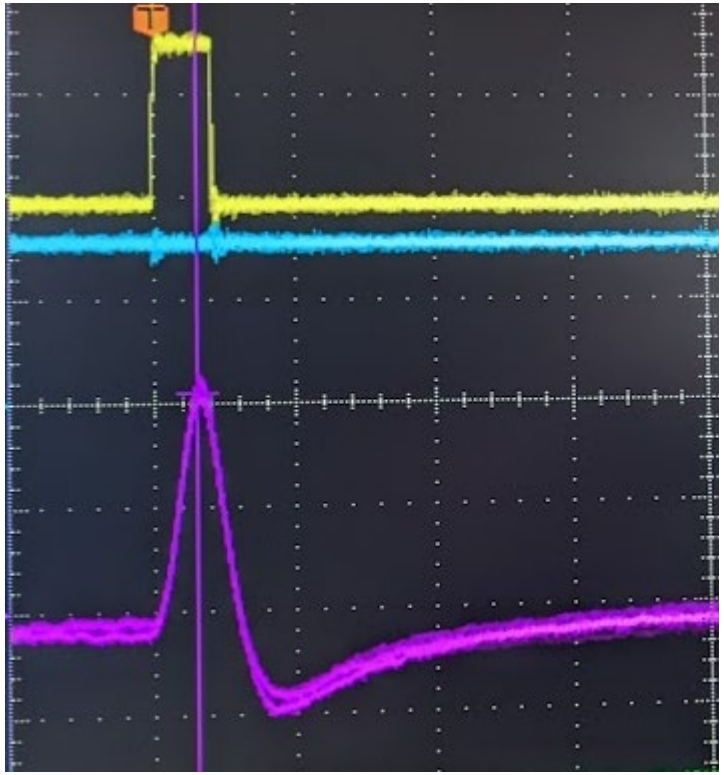
The two operating modes depend on the use of the switch. if this is closed for short periods of time at regular intervals then the signal at the output of the circuit is a step wave that follows the profile of the input signal and the circuit behaves like a sampler. If, on the other hand, the switch is left closed and then opened at a precise moment, to lock the signal level at that moment, for example the amplitude of its peak, then the circuit is operated in track mode.



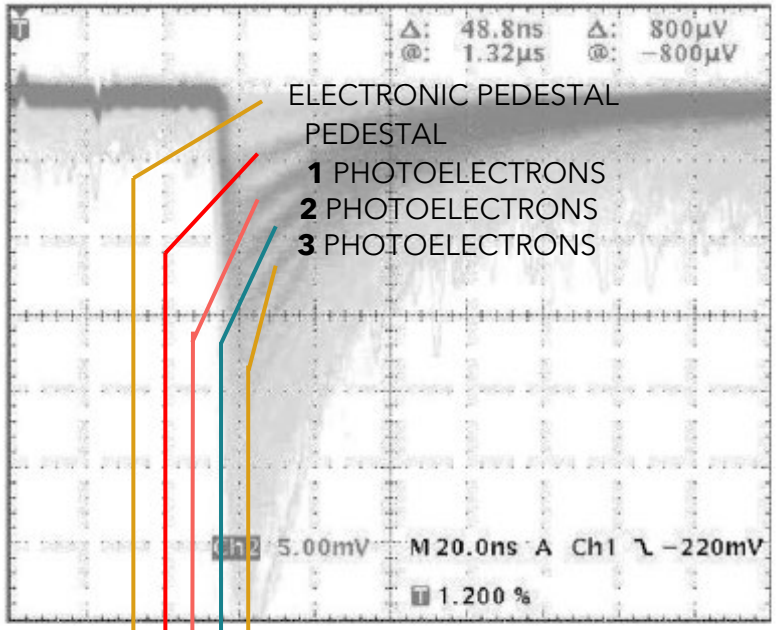


The output signal must be kept constant and last long enough to be processed later. The amplitude of the signal close to the peak represents to all effects the charge collected following a detected event.

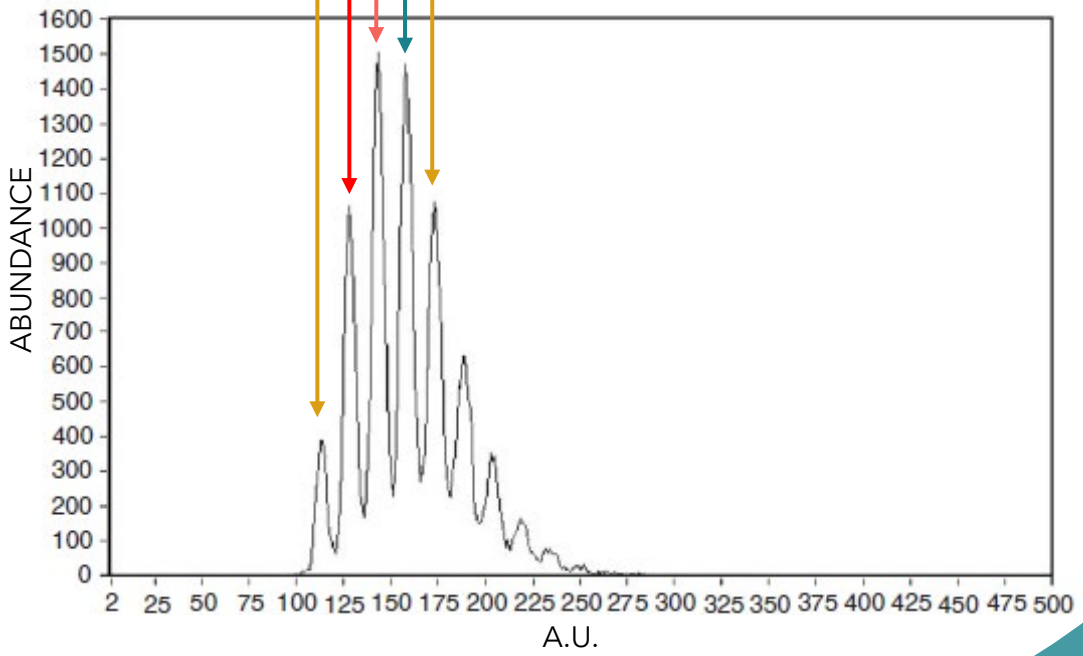
THE MURAVES EXPERIMENT



Fast Chain

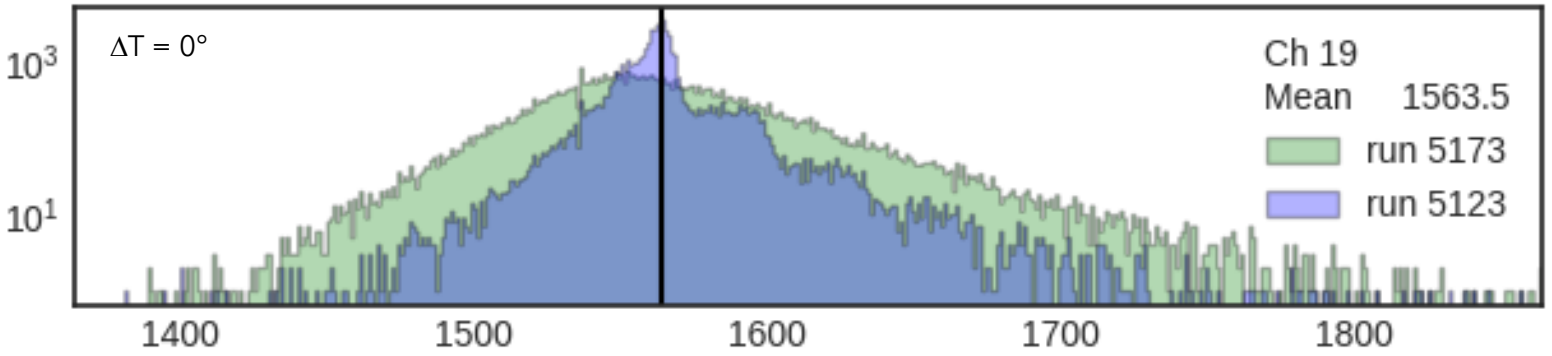


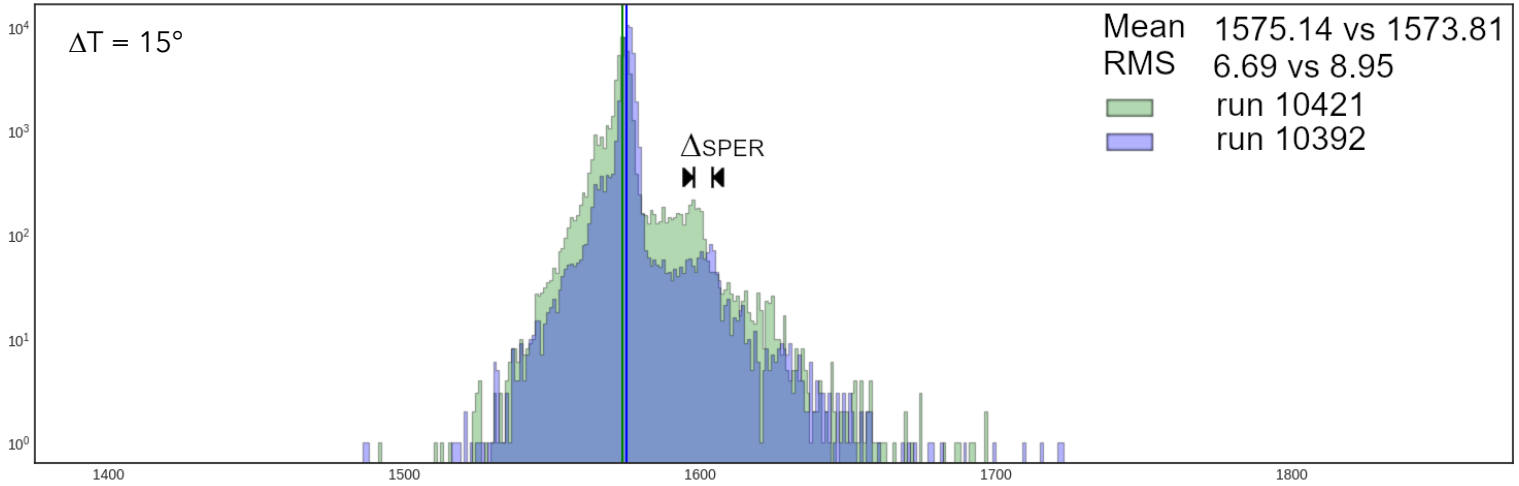
Slow Chain



DETECTORS FOR MUOGRAPHY AND APPLICATIONS

Free carriers not generated by incoming photons, can trigger avalanches. Minor generation effects occur for **afterpulsing** or for the **optical crosstalk**. SiPM are mainly affected by the **Dark Noise** that is generated because of thermally or field-assisted generation of free carriers. The effect of the dark noise is deleterious for the photon detection and cannot be eliminated. It is usually limited by adjusting both on the temperature, to reduce the thermally generated events, and on the over voltage, to limit those produced by tunneling.

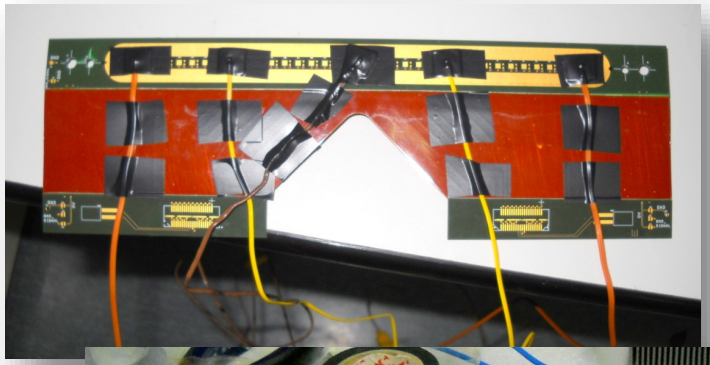


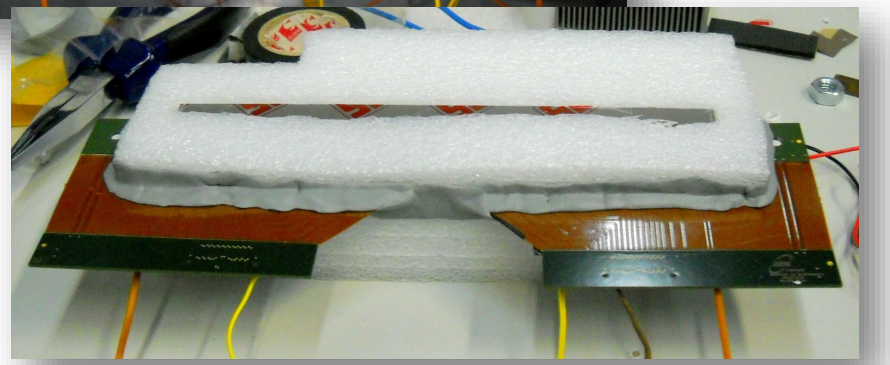


In general, the performance of the SiPM are changed, sometimes dramatically, because of the change in avalanche production dynamics.

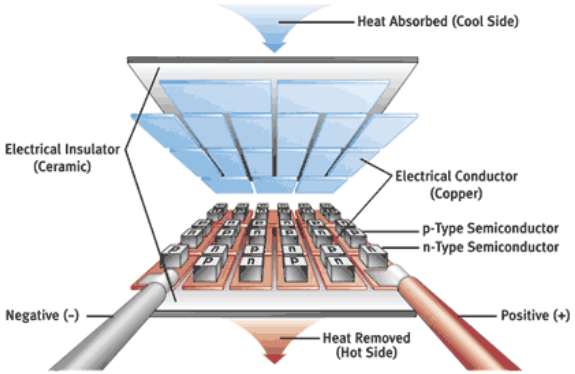
Small variations concern the SPER shift, which lead to a deterioration in resolution. Great variations can determine the the total disappearance of the signal and the flattening of its spectrum.

THE MURAVES EXPERIMENT

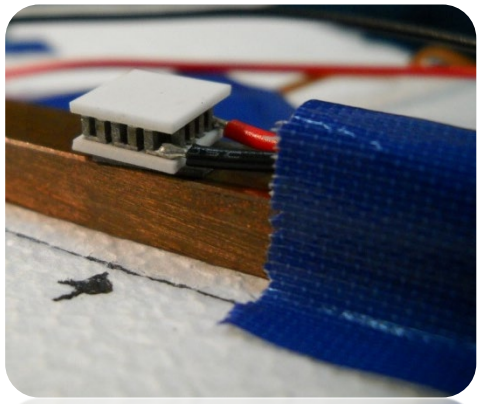


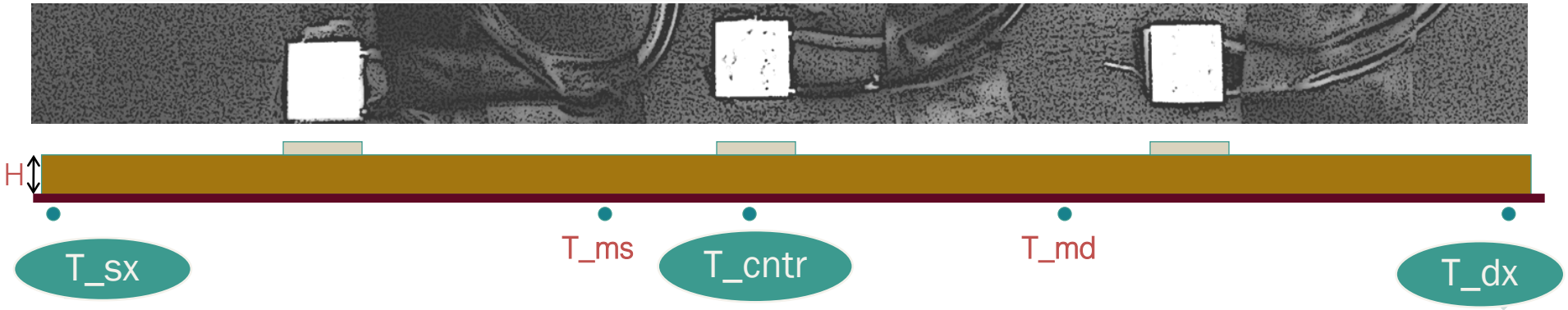


Probe arrangement on the Hybrid board (bottom view) and positioning inside the polystyrene's brick insulator (top view hidden). The top is coupled with the aluminium passive cooling system through a wafer made of conductive gum and a copper's buffer .

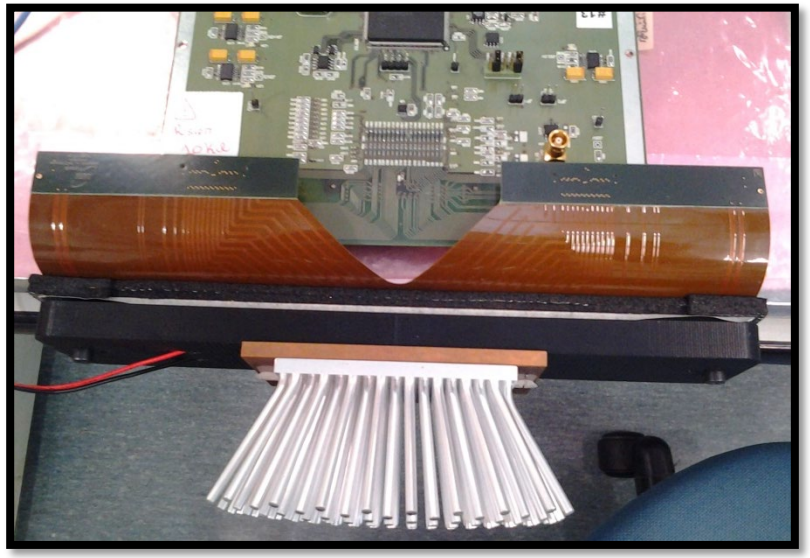


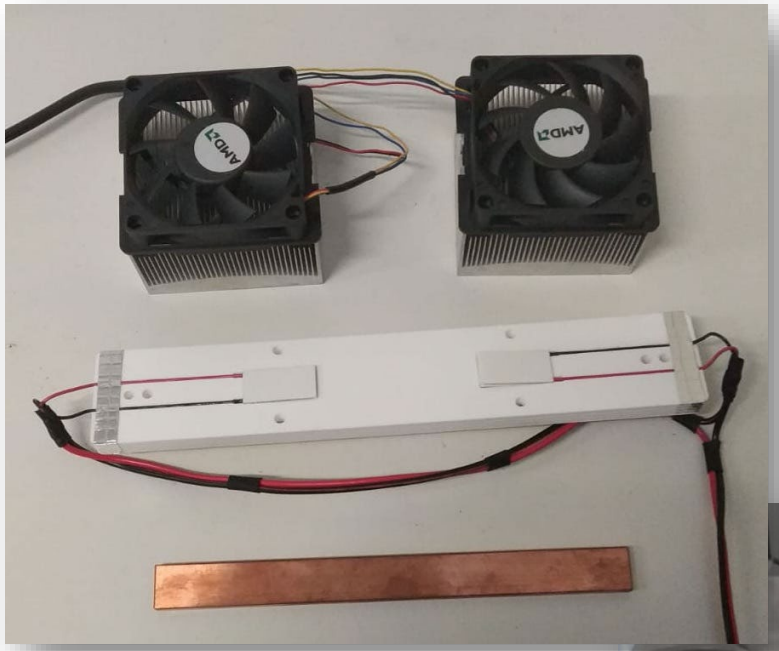
Three Peltier Cells was emploied during the experiment each one located respectively at ¼, ½ and ¾ of the lenght L of the cooper buffer. We arranged a serie circuit with the cells.

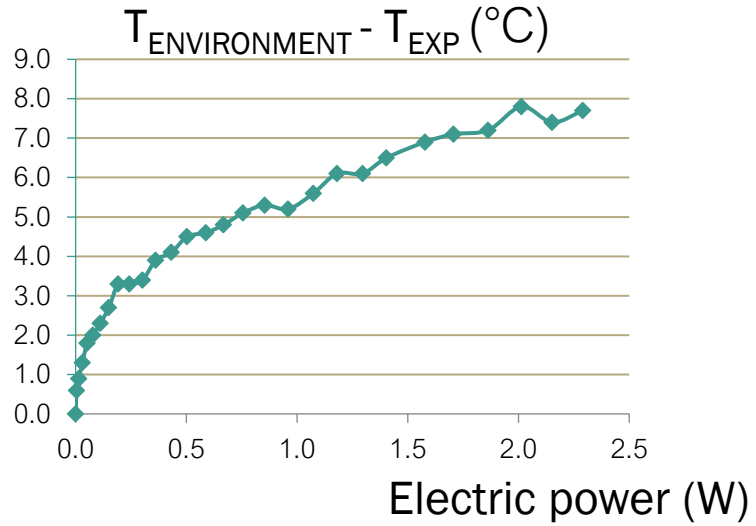




THE MURAVES EXPERIMENT





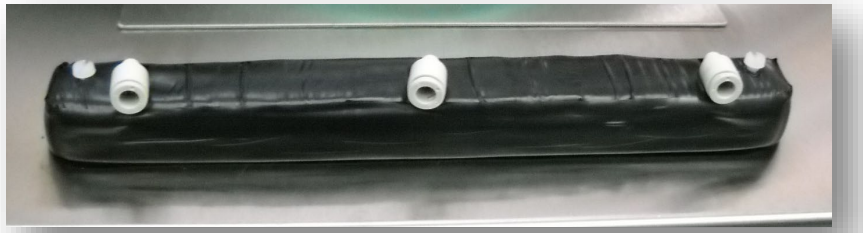


- Based on Peltier cells
- Reduction of power consumption
- Designed to minimize internal temperature variations due to external changes
- Dedicated control for each PCB
- Sets temperature condition for all housed SiPMs at the same time
- Works with passive cooling
- Could be supplied by solar cells system

THE MURAVES EXPERIMENT

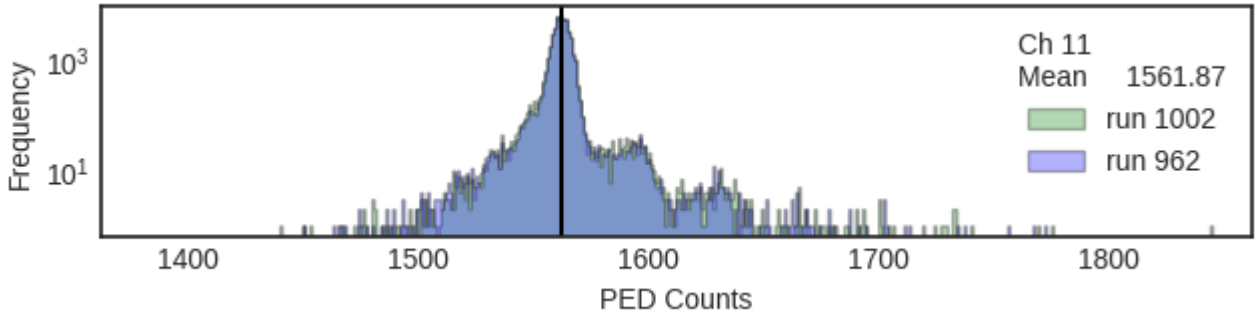
Water Chiller

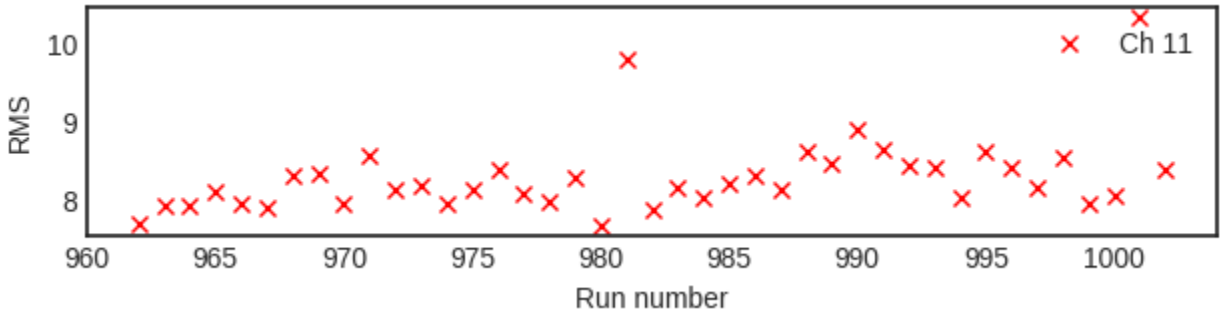
Hydraulic Heat Exchanger



THE MURAVES EXPERIMENT

Usually, well-functioning channels have a small RMS distributed randomly over the entire range of execution.





Tests are made to detect well- and mal- functioning channels. This analysis made it possible to categorize all SiPM working conditions and to determine any problems that would mainly concern data analysis.

1. Non-functioning channels have very small RMS and cumulative sectrum doesn't show any kind of dynamics
2. Well-functioning channels have small RMS that is randomly distributed over all the run interval
3. Dirty channels have small slightly increasing RMS. Those show increments in height of all the spectrum regions, apart the main peak. The latter probably decreases in countings
4. Mulfunctioning channels don't show any kind of spectrum dynamics and have a large increasing RMS
5. Bad channels have large RMS that increases alike the degradation of the spectrum from a Well-functioning to a malfunctioning channel spectrum

THE MURAVES EXPERIMENT

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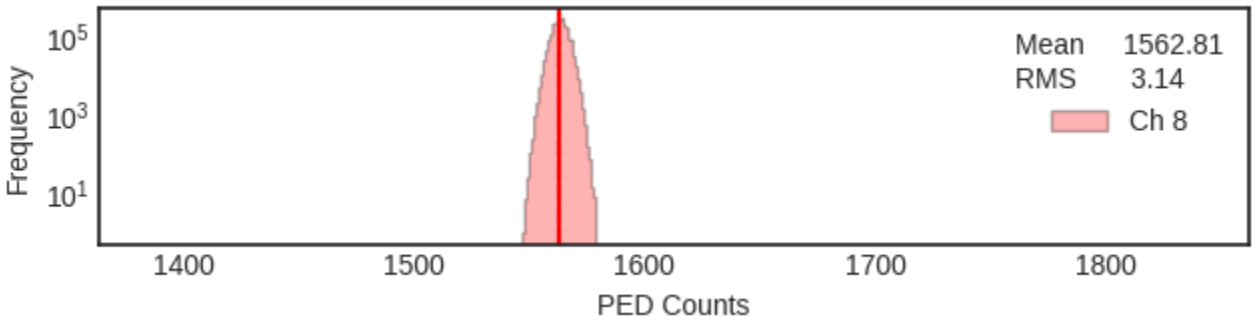
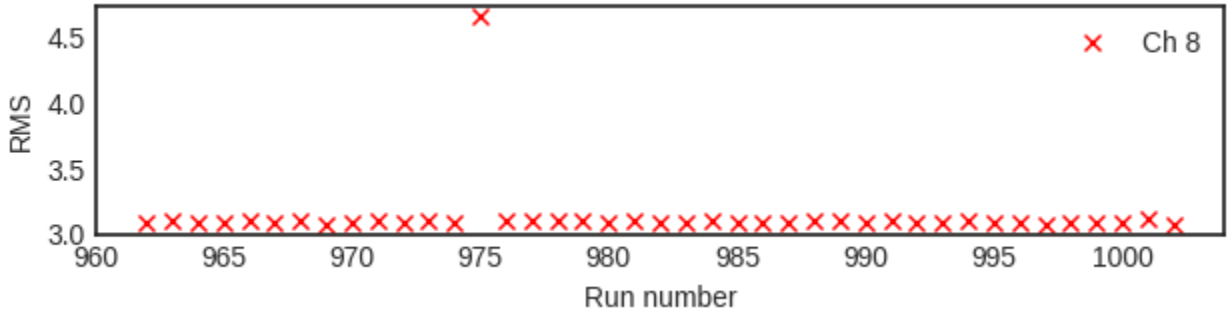
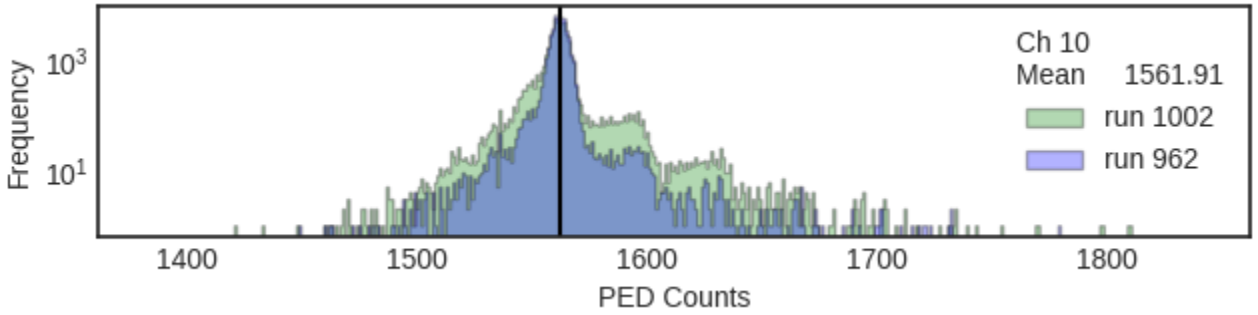
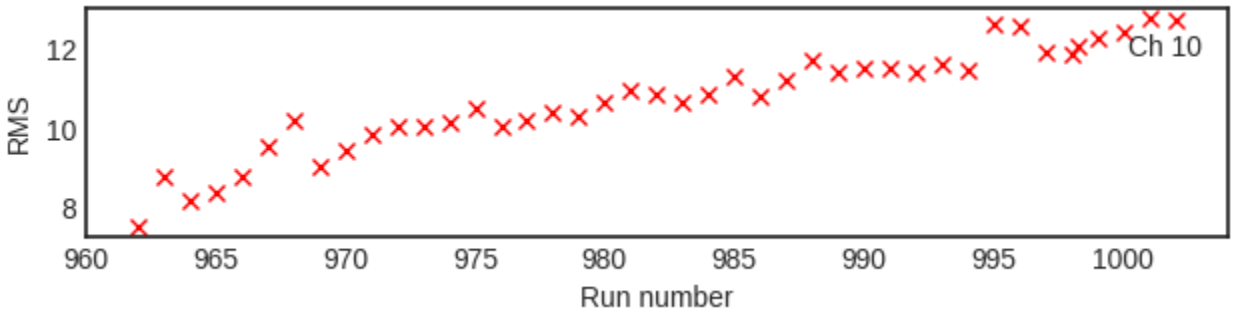




NON-FUNCTIONING channels have very small RMS and cumulative sectrum doesn't show any kind of dynamics.





DIRTY channels have small slightly increasing RMS. Those show increments in height of all the spectrum regions, apart the main peak. The latter probably decreases in countings.

THE MURAVES EXPERIMENT

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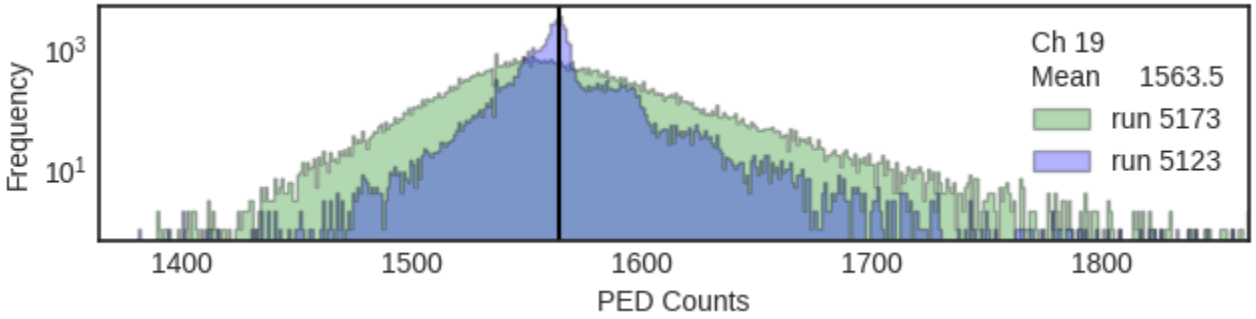
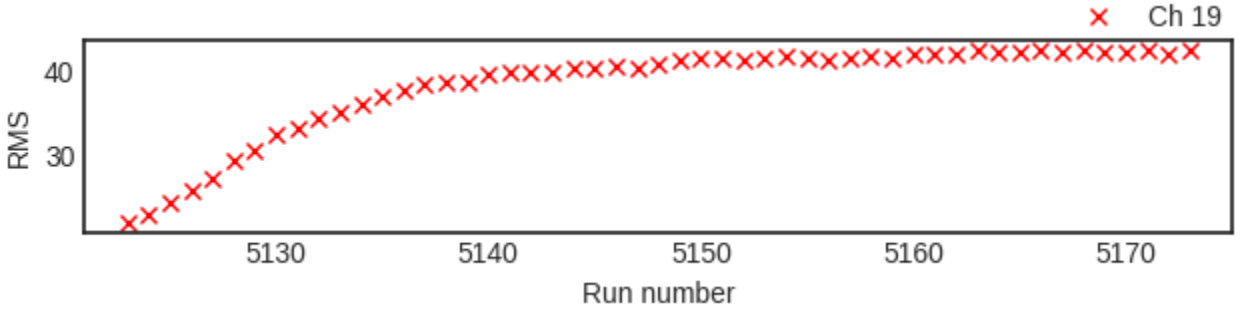
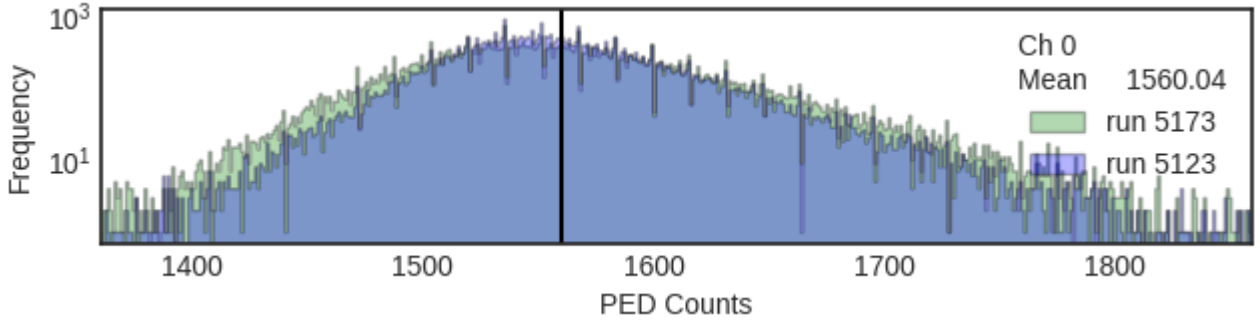
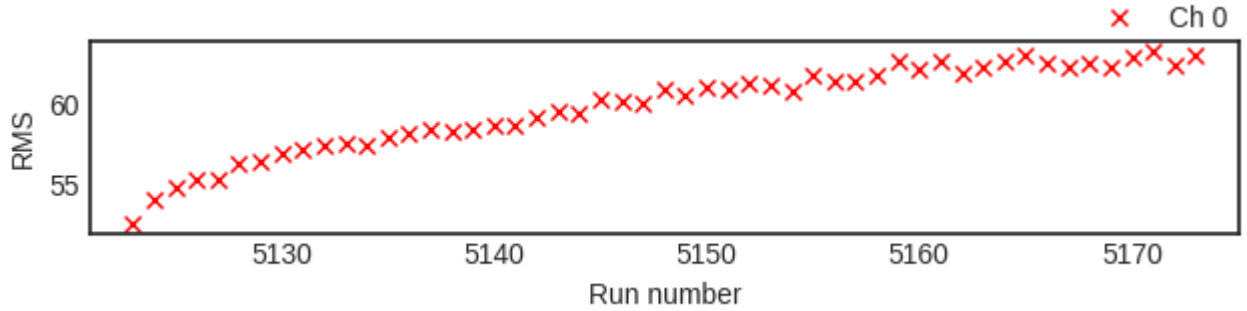




BAD channels have large RMS that increases alike the degradation of the spectrum from a Well-functioning to a malfunctioning channel spectrum





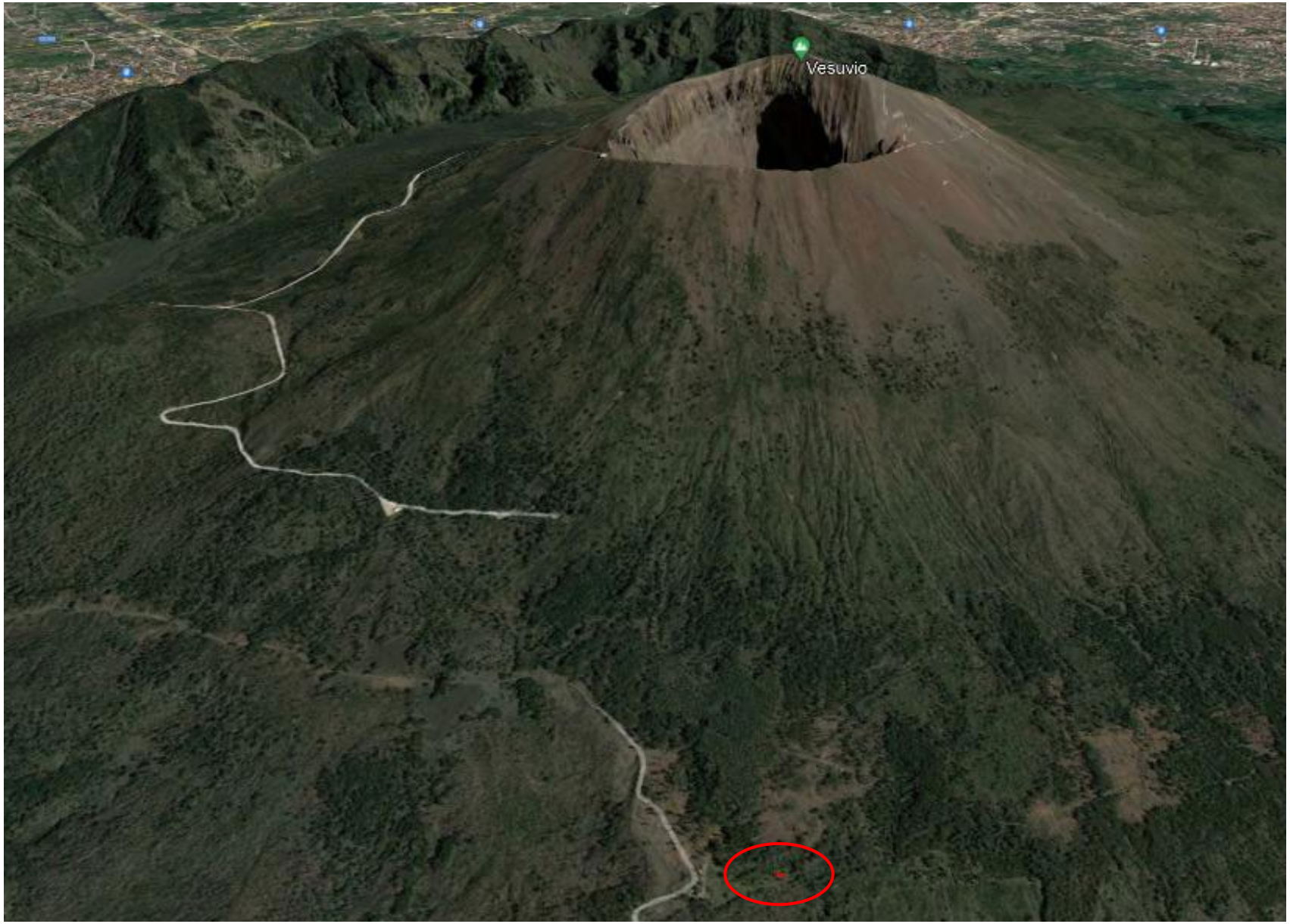
MALFUNCTIONING channels don't show any kind of spectrum dynamics and have a large increasing RMS

THE MURAVES EXPERIMENT

Three detectors (ROSSO, NERO and BLU)have been installed in the lab build on the slope of the Vesuvius at an altitude of **600 m** looking to the cone about **1.5 km** far.

There are currently acquiring data from both Mt. Vesuvius target region and from the open sky. the data analysis is proceeding in parallel with absolutely preliminary but encouraging results.

THE MURAVES EXPERIMENT



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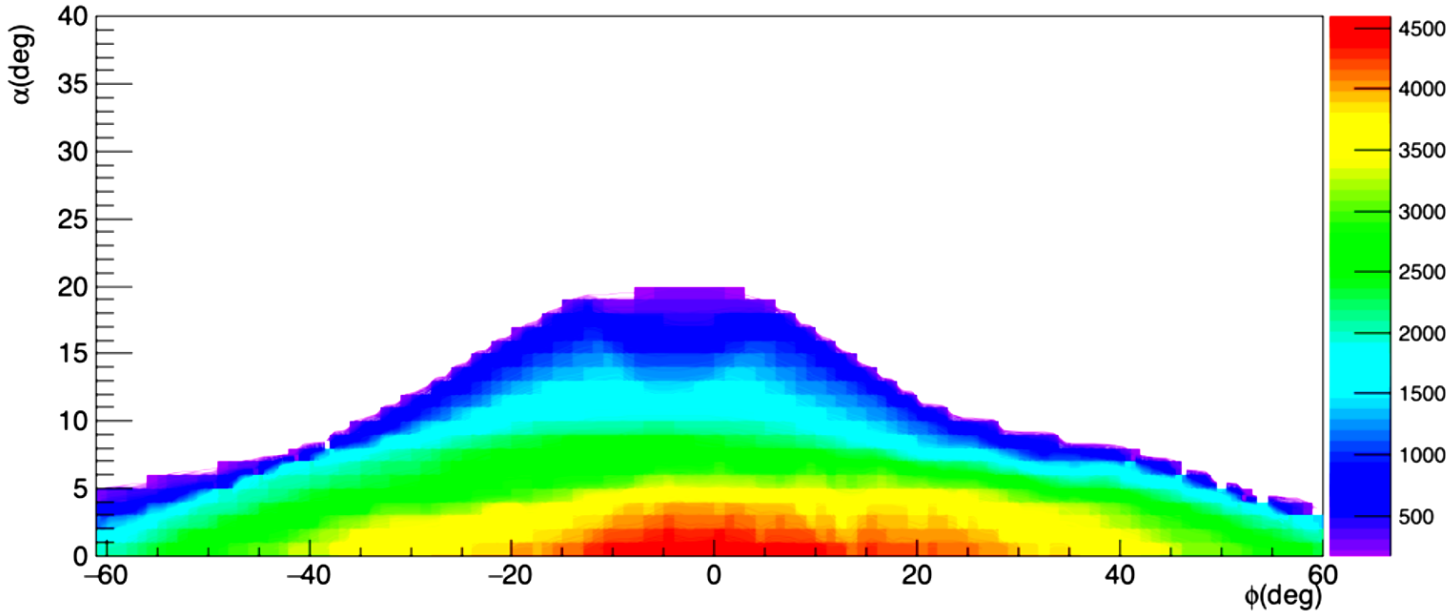
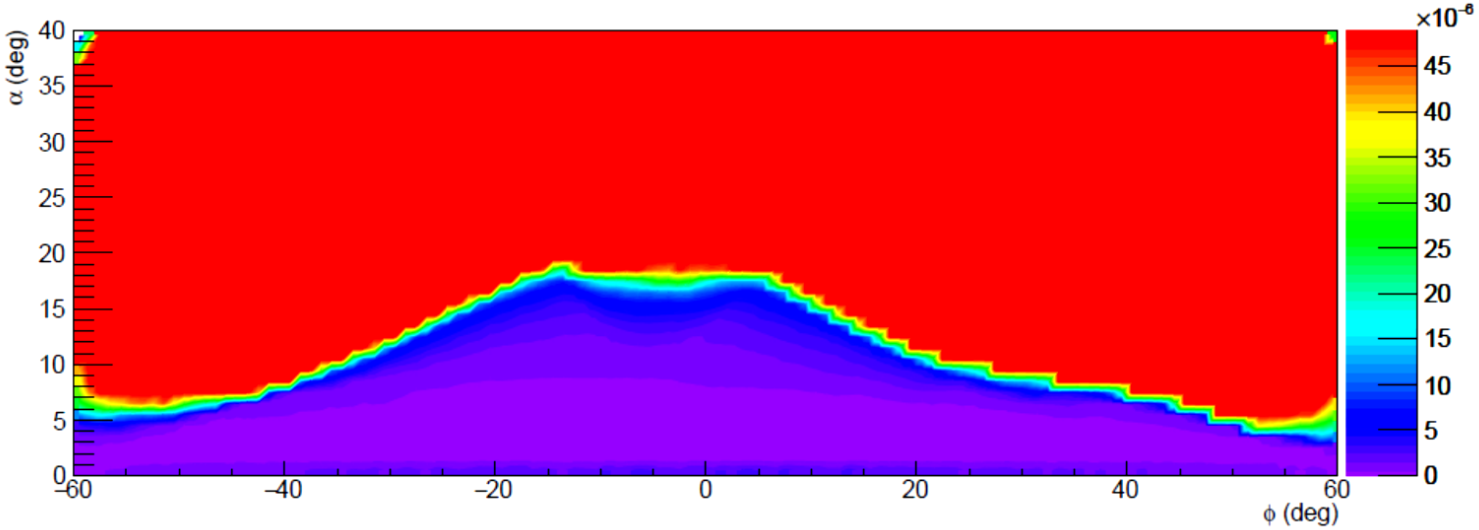


The morphology of the geological building and the thicknesses crossed make the measurement long and complicated even for a detector of about 3 m^2 active surface.

Furthermore, there is a contribution from the background that is not negligible at all and indeed produces further slowdowns both in data taking and in analysis.



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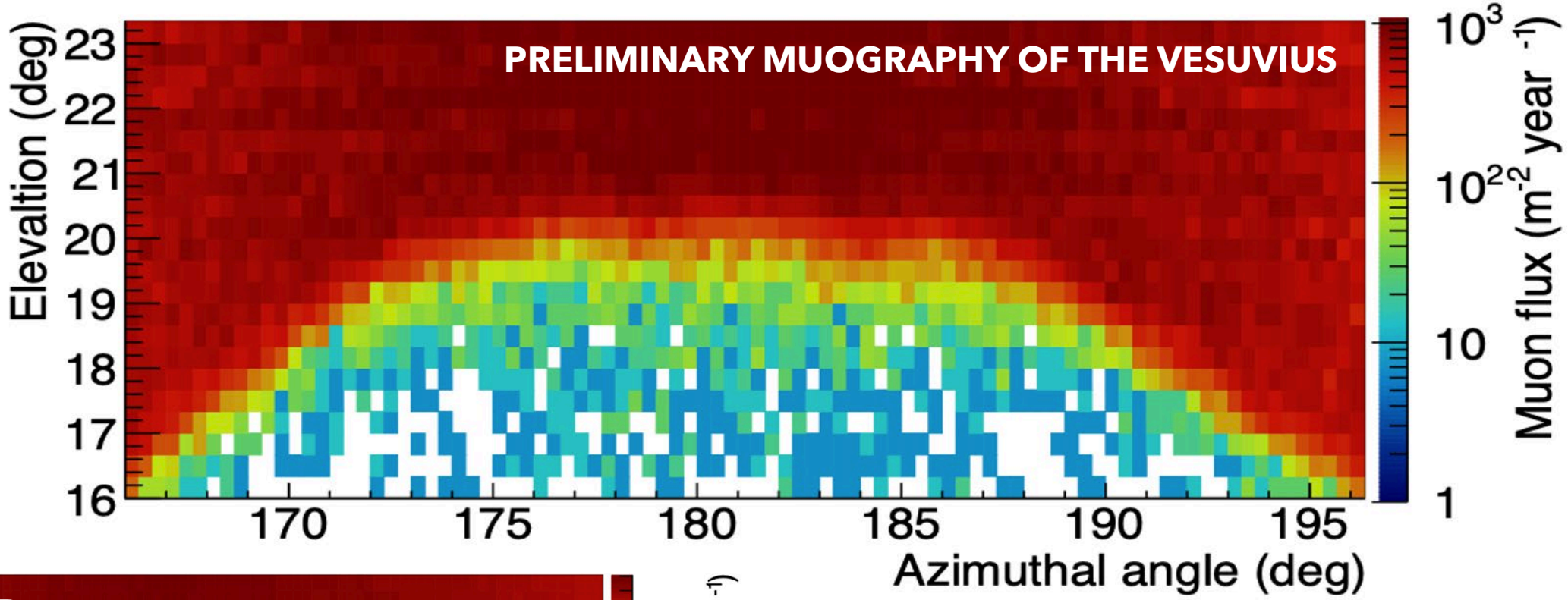
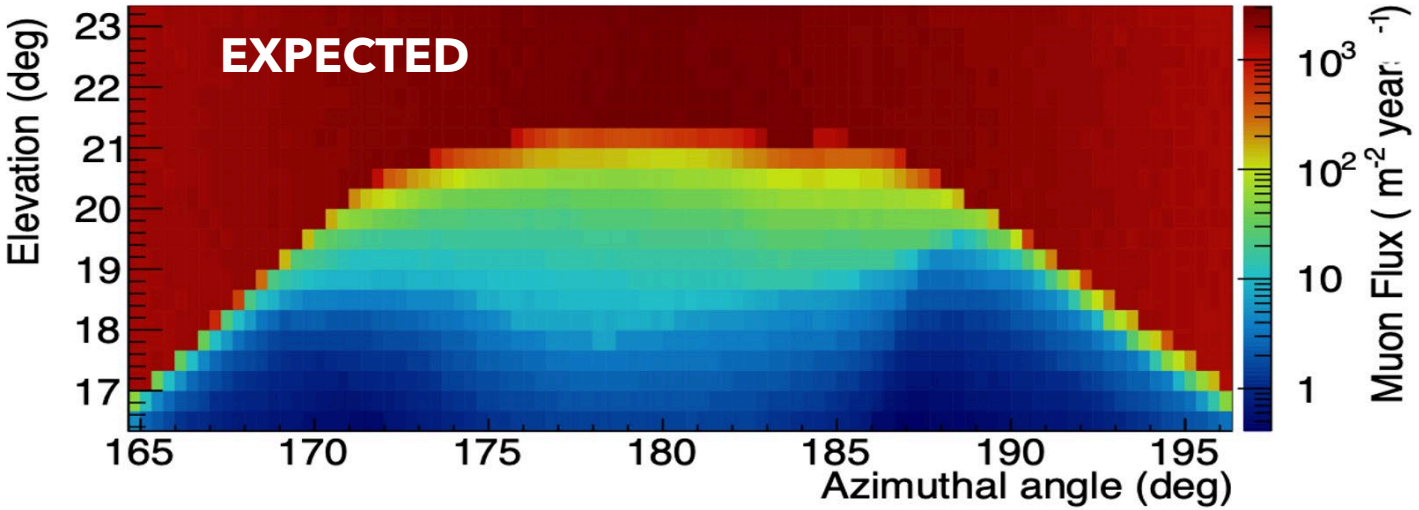




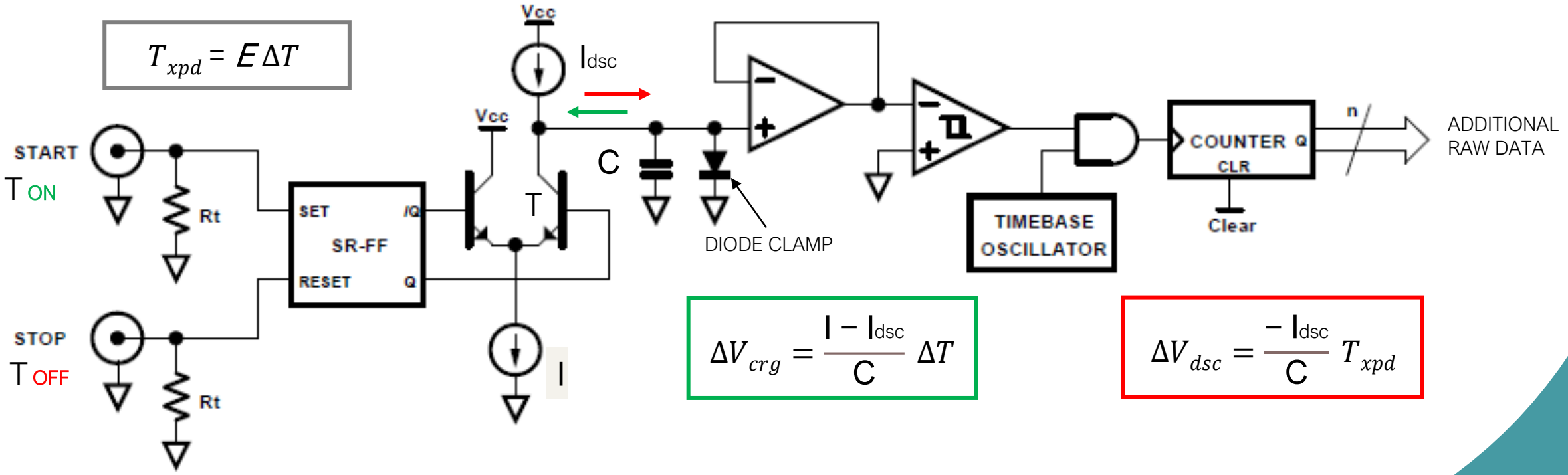
MEASUREMENT OF THE TIME-OF-FLIGHT

THE MEASUREMENT OF THE TIME OF FLIGHT

On the other hand, when you have to measure events that happen very quickly, but the energy consumption has to be low, you choose the technique of **time expansion**. This is widely used in space and muography applications, where detectors are small in size and low in power consumption. In this case the counting electronics can work at very low rates, paying more in conversion time.

The time interval ΔT between the start and stop signals is recorded as the charge of the capacitor C at constant current $I - I_{dsc}$ and is expanded by a factor E by current controlled discharge of the capacitor.

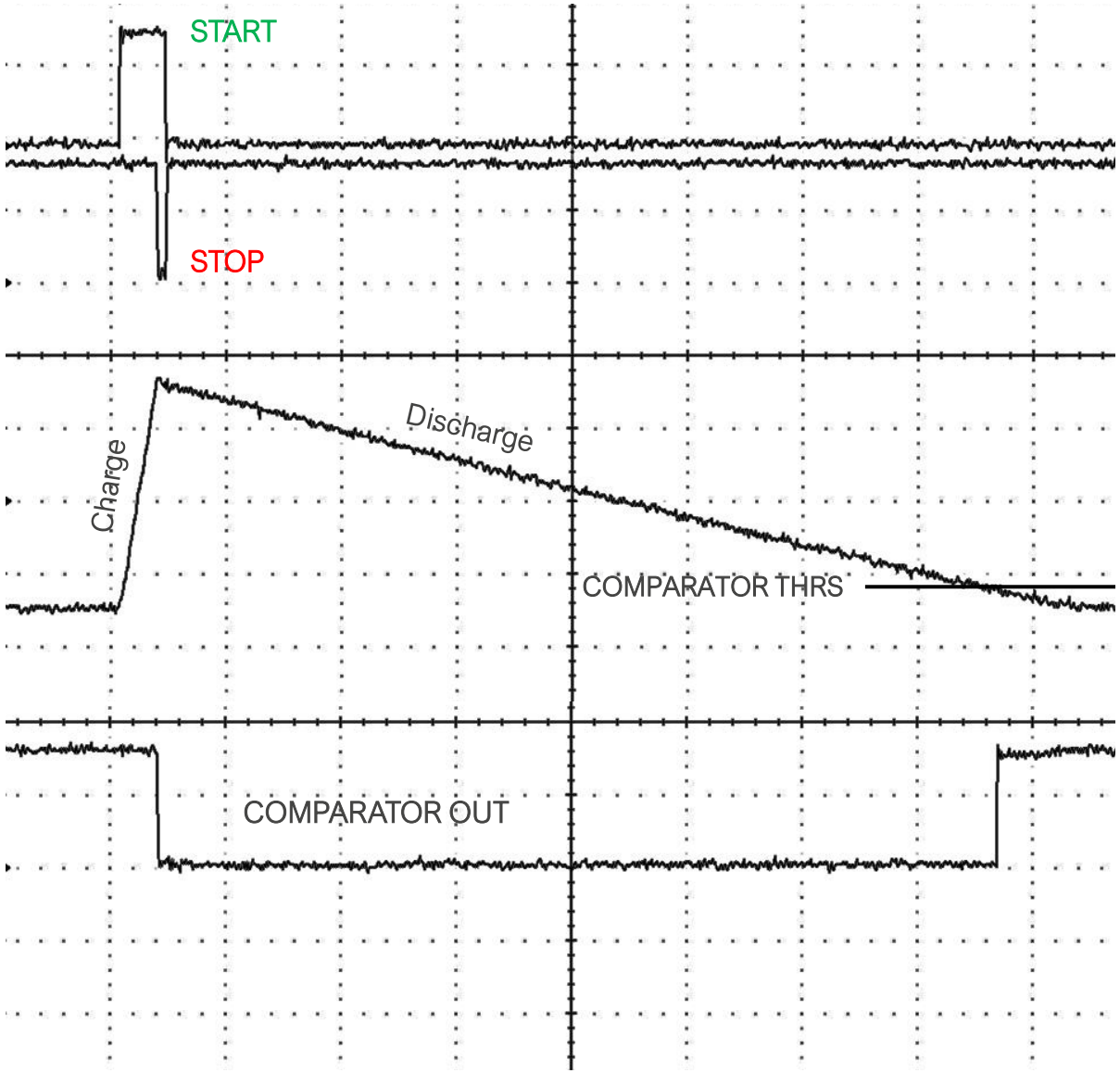
$$T_{xpd} = E\,\Delta T$$



$$\Delta V_{crg} = \frac{I - I_{dsc}}{C}\,\Delta T$$

$$\Delta V_{dsc} = \frac{-I_{dsc}}{C}\,T_{xpd}$$

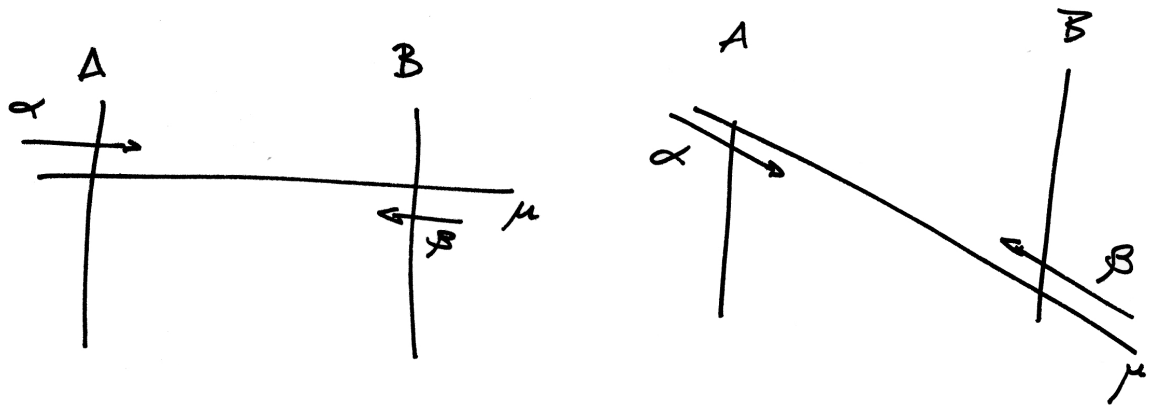
THE MEASUREMENT OF THE TIME OF FLIGHT



Charging begins on the start signal and ends on the stop signal. At this point the capacitor is discharged and for as long as the comparator window is active (low) the clock pulses $\boldsymbol{n}$ are counted in order to associate this number with the discharge time $\boldsymbol{t}_{\mathbf{disc}}$.

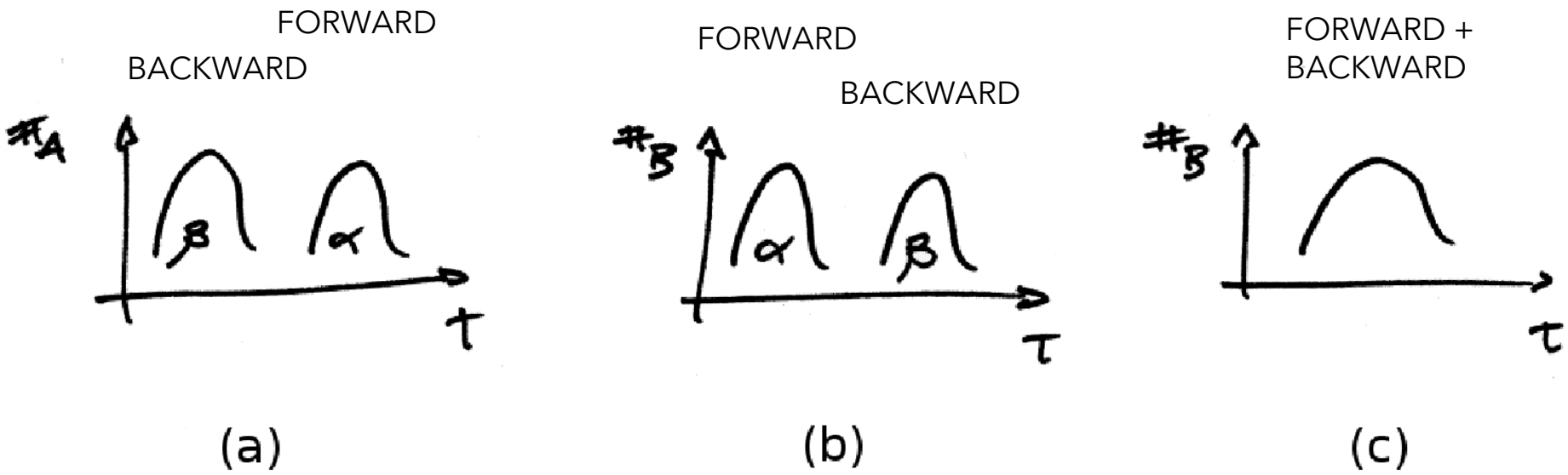
$$\boldsymbol{t}_{\mathbf{disc}} = \frac{\boldsymbol{n}}{\boldsymbol{f}_{\boldsymbol{clock}}}$$

THE MURAVES EXPERIMENT



Extreme trajectories and directions of the muons crossing a 2 planes detector.

Expected distributions for:
plane A (a)
plane B for horizontal (b) and transverse (c) track.



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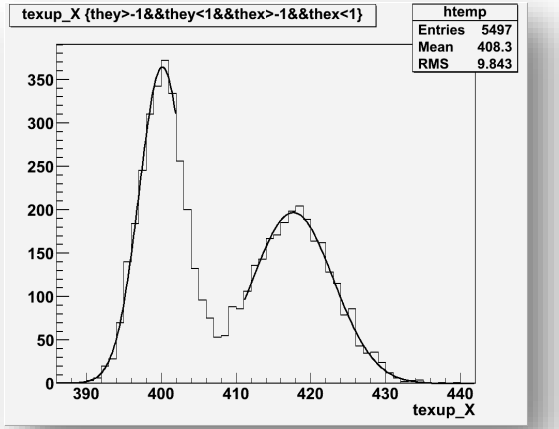
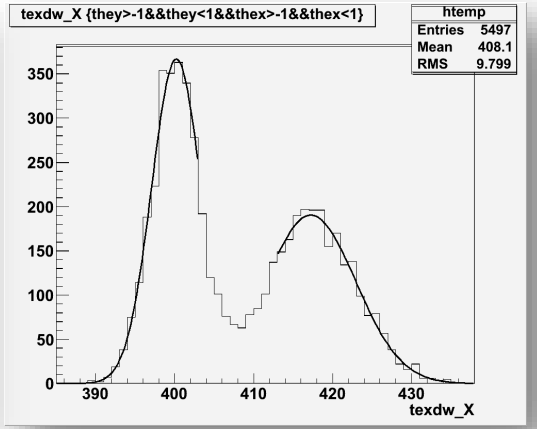


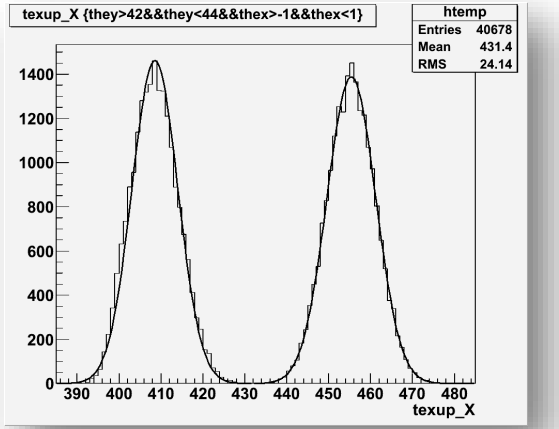


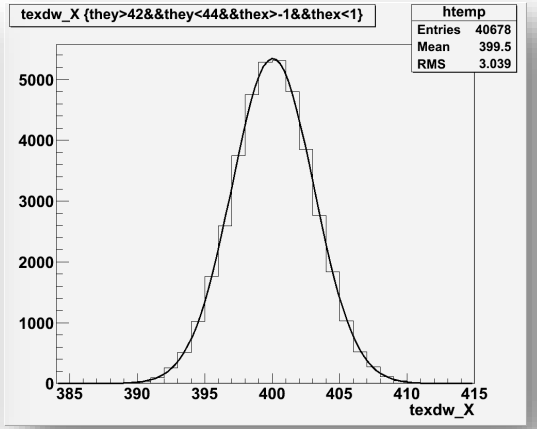
Horizontal tracks

	mean	sigma
Peak 1	400.2	3.13
Peak 2	417.2	5.71
Peak 1	400.2	3.1
Peak 2	417.2	5.42

TOF	**3.4** ns
TOF	**3.4** ns

TOF_{exp} = 1.03 m/c = **3.43** ns





Transverse tracks

	mean	sigma
Peak 1	408.6	5.46
Peak 2	455.4	5.81
Peak	400.2	3.03

	Tmeas	C.Fibra	
TOF	1.68	6.4	**4.72** ns
TOF	11.04	6.4	**4.64** ns
		(0.96 m)	

TOF_{exp} = 1.41 m/c = **4.70** ns