Characterization of SiPM arrays with common bias and common readout for applications in liquid argon

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Abstract

A number of innovative experiments dedicated to neutrino and rare-event physics are using liquefied noble-gases both as a target and as a detector. These media have the remarkable property to efficiently produce scintillation photons after the passage of ionizing particles. Scintillation light, which is used for triggering and timing purposes, is traditionally detected by large area Photo-Multiplier Tubes (PMTs) working at cryogenic temperature. Silicon Photo-Multiplier (SiPM) arrays are gradually substituting PMTs in many applications, especially where low voltages are required and magnetic field is present. However, their performance, in particular their time resolution, is not fully understood yet. For this reason, several prototype arrays made by different SiPM models with a common readout were built: the basic unit is a device with an active area of $(1.2 \times 1.2)\ cm^2$. A fast signal leading edge is crucial to realize devices to be used for triggering and timing. To this purpose we studied different series/parallel electrical configurations to obtain the best timing performances, by operating our custom arrays both at room and cryogenic temperatures.

SiPM arrays

The SiPM arrays are made by 16 devices mounted with a common supply and readout. The reason of this choice is to keep the readout channels as lower as possible, The electrical circuit that connect each device was built to allow modification into the series/parallel configuration between the SiPMs [1].
Thanks to this connection, the main features of the new device are different with respect the single SiPM. In particular, we are interested to study the temporal characteristic of the signal.

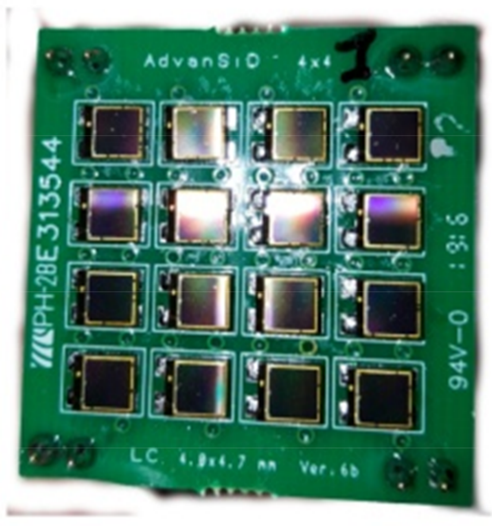

Figure 1: Experimental apparatus and the drawing of the system to fix the arrays.

Experimental apparatus

The experimental apparatus (Fig. 2) is made by a picosecond resolution pulsed light source with a laser diode to illuminate the arrays fixed into a dewar. An optical fiber has been used to bring the light into the dewar and an photodiode allow to monitoring the intensity of light. Signals have been recorded with a 20 GSa/s oscilloscope.

Data are recorded with the same number of photons in order to evaluate the photon detection efficiency (PDE) of each device.

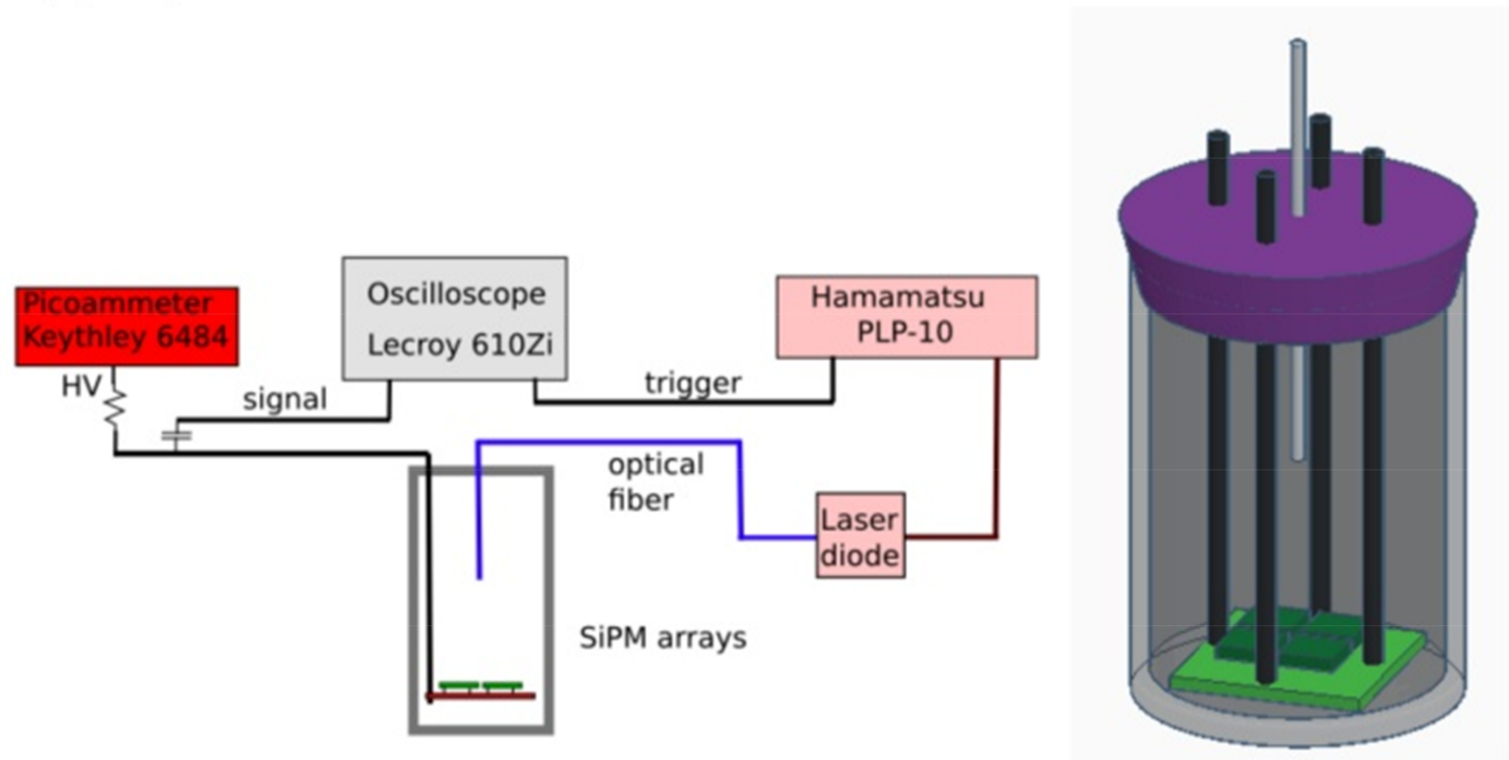

Figure 2: Experimental apparatus and the drawing of the system to fix the arrays.

Single Arrays

The laser has been setted to obtain the best timing resolution ($80\ ps$) and with huge amount of photons. This setting allow to reduce the signal fluctuations.
The table 1 shows the values of some temporal features of single SiPMs arrays in different configurations at $3\ V$ of overvoltage. The 4s4p and 1s16p configurations are shown in figure 3.

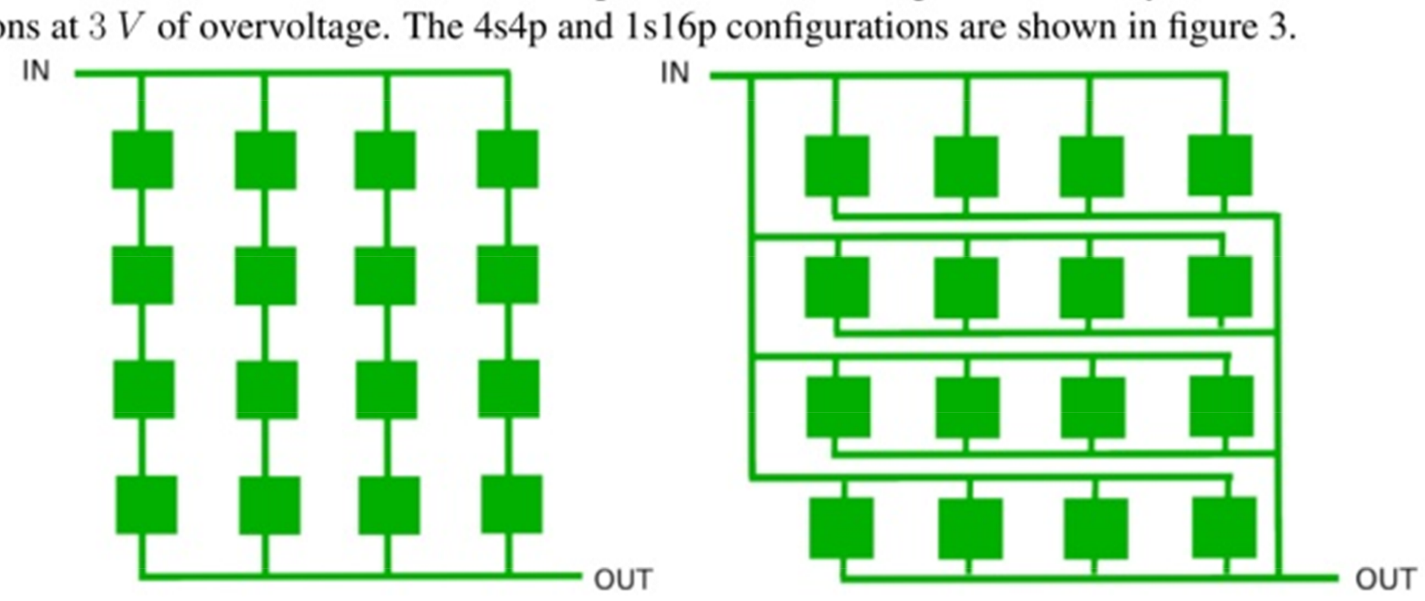

Figure 3: 4s4p configuration (left) and 1s16p configuration (right).

SiPM model	ASD-NUV3S-P		ASD-RGB3S-P		HPK s12572-050P	
Configuration	4s4p	1s16p	4s4p	1s16p	4s4p	1s16p
Breakdown Voltage [V]	97.5	24.9	113.2	28.2	259	65.2
Leading Edge [ns]	0.95 ± 0.55	7.50 ± 0.35	1.84 ± 0.16	8.0 ± 0.4	2.35 ± 0.41	4.68 ± 0.26
Trailing Edge [ns]	181 ± 2	741 ± 10	202.5 ± 3.4	927 ± 16	74.8 ± 3.8	572 ± 11
Amplitude [mV]	131 ± 49	152.7 ± 4.9	103 ± 5	50.1 ± 2.1	233 ± 41	144.4 ± 7.8
Mean Charge [nA]	16.6 ± 0.4	61.3 ± 1.7	14.0 ± 0.4	32.1 ± 1.2	9.9 ± 0.4	46.3 ± 2.1
Time resolution [ps]	10.4	878	25.6	95.3	229	292

Table 1: Time performances of single arrays in different configurations at $V_{ov} = 3\ V$.

Multiple connection between the arrays

The next step was to increase the total active area of the detector. The simplest way to do this was to connect several arrays togheter. We choose to test the differences in different possible configurations of four arrays (we chose to convention of using capital letters for the multi-arrays configurations).

	HPK s12572-050P			
Configuration	1S4P	2S2P	new 2S2P	new 4S1P
Breakdown Voltage [V]	259	519	259	259
Leading Edge [ns]	3.92 ± 1.20	2.75 ± 0.05		
Trailing Edge [ns]	152.7 ± 14.2	67.9 ± 0.7		
Amplitude [mV]	438 ± 26	486 ± 12	447.5 ± 11.1	376.6 ± 8.5
Mean Charge [nA]	37.93 ± 0.97	18.28 ± 0.45	17.24 ± 0.44	8.90 ± 0.22
Time resolution [ps]	814	327		

Table 2: Time performances of 4 Hamamatsu arrays in different configurations at $V_{ov} = 3\ V$.

With these configurations we could study if the increases of the active area allows to keep the same timing performances of the single array. As Shown in previous table the 2S2P configuration, that is equivalent to a single array in 8s8p configuration, the temporal features are compatible. The problem with this configuration is the bias voltage that is twice the previous one.

Leading edge vs overvoltage

The most important feature of the device is the leading edge of the signal. We measure it in different configurations for each device. The figures 4 show the leading edge as a function of the overvoltage for each array (left) and for 4 arrays connected together in the case of the Hamamatsu model (right).

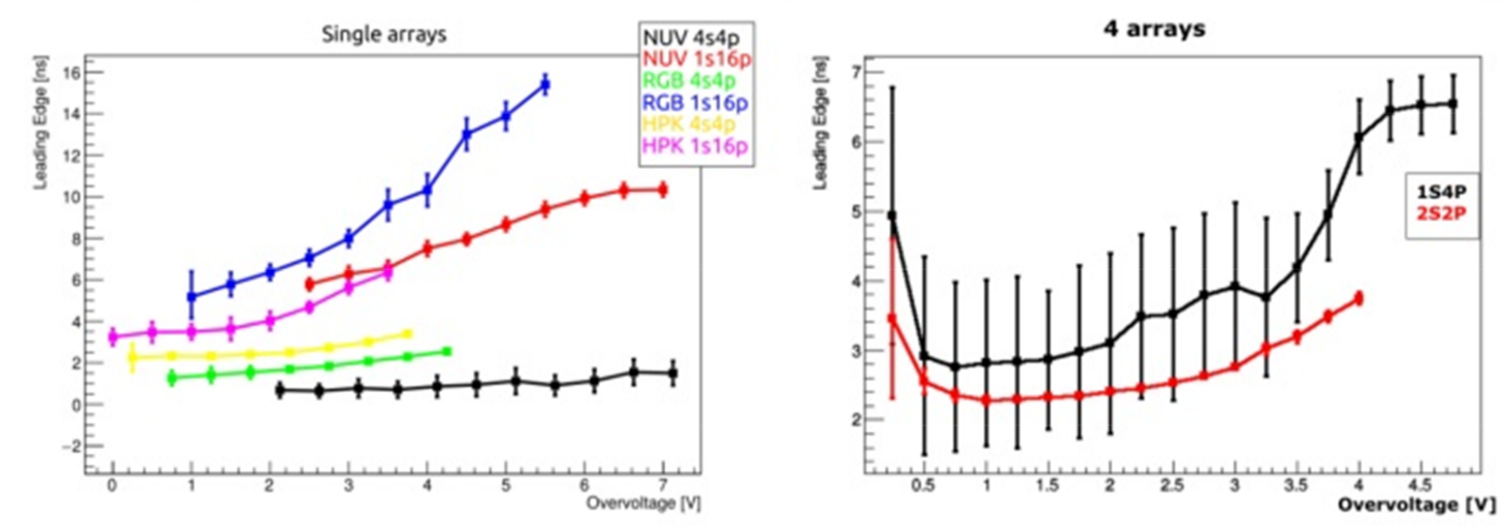

Figure 4: Leading edges for the single arrays (left) and for 4 Hamamatsu model arrays (right).

New Configuration

The problem adding to many arrays in series is that the breakdown voltage increases. For this reason we choose to put less than 8 devices in series. In this way, for the Hamamatsu models, the bias voltage is below 550 volts. An alternative, is to built a particular electrical circuit to connect each device that allows to keep the performances of the serial configuration with the bias of the parallel one

For pratical reasons we choose to test this configuration to connect 4 arrays together. Results in terms of timing, amplitude and charge are shown in table 2.

Conclusions

These tests have been made to study the temporal performances of several SiPM models in order to find the best solution to realise a system to detect the scintillation light produced into Liquid argon TPCs for triggering and timing purposes.
Faster the leading edge and the trailing edge of the signal better the model. With the tests performed, we found that Hamamatsu models should be the best solution. The problem of these devices is the high breakdown voltage (around $50\ V$) in comparison with the others ($\sim 25\ V$).

References

[1] T. Cervi et al, *Study of SiPM custom arrays for scintillation light detection in a Liquid Argon Time Projection Chamber*, Journal of Instrumentation 2017 JINST 12 C03007