SiPM application for a detector for UHE neutrinos tested at Sphinx Station

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Abstract: We present the preliminary test results of the prototype detector, working at Sphinx Observatory Center, Jungfraujoch (∼3800 m a.s.l.) HFSJG - Switzerland. This prototype detector is designed to measure large zenith angle showers produced by high energy neutrino interactions in the Earth crust. This station provides us an opportunity to understand if the prototype detector works safely (or not) under hard environmental conditions (the air temperature changes between -25 ^{o}C and -5 ^{o}C). The detector prototype is using silicon photomultiplier (SiPM) produced by SensL and DRS4 chip as read-out part. Measurements at different temperature at fixed bias voltage (∼ 29.5 V) were performed to reconstruct tracks by Time Of Flight.

Keywords: cosmic rays, SiPM, ground detector, Time Of Flight

1 Introduction

One of the interesting subject in experimental astroparticle physics is to detect the Ultra High Energetic Cosmic Rays by using different well-known detection techniques (Cherenkov [1], [2], air fluorescence [3] and radio waves [4]). Most of the on-going experiments are focused on the vertical or possible sideways flux of cosmic ray showers going down from atmosphere. None of the present experimental techniques are using the timing information to discriminate the upward or downward moving particles by using Time Of Flight (TOF) method. They are using the timing information to get the shower angular distribution information. Traditional Photomultipliers (PMT) are well-engineered photon detectors and stable in operation [5]. The recent developments made on solid state detectors Silicon PhotoMultipliers (SiPMs) are an alternative of the conventional photomultipliers (PMTs). The SiPM are multipixel avalanche photodetectors working at Geiger mode. This device has remarkable properties such as very compact size, high quantum efficiency, good charge resolution, fast response time (< 100 ps), large gain (∼ 10^6) and very low power consumption with low bias voltages [6]. In this paper we show test results of a prototype installed at Sphinx Observatory at 3800 m a.s.l on November 2012.

2 Description of the detector prototype and SiPM caracteristics

The hardware of the detector prototype installed at Sphinx consists of two identical scintillator counters, named *tower*, separated by 160 cm apart as seen in fig. 1.

Each counter has a Kuraray organic scintillator panel (20 x 20 cm^2, 1.4 cm thick). The solid angle of a single tower is about 4.0 x 10^{-2} sr and its zenith angle covers ±7.5^{o} around the axis. The geometrical acceptance is 255.0 cm^{2}sr. The scintillator has excellent features, in the view of obtaining the precise timing information, such as producing the light in blue region of the spectrum. The emission peak is around 430 nm. Each scintillator panel is

Fig. 1: Prototype detector installed at Sphinx (HFSJG) to test upward/downward particles separation and environmental effects.

wrapped by Tyvek paper for diffusing the reflection, and one SensL silicon photomultipler (3 x 3 mm^2) reads the produced signal. This SiPM has short output pulse of < 2 ns at FWHM and UV sensitive. The bias voltage of this device is about 29.5 V, the dynamic range over the breakdown voltage is ∼ 1 V in a temperature range of -20 ^{0}C to 20 ^{0}C. The gain is 2.3 x 10^6. The produced signal from SiPM is digitized by Domino Ring Sampler Board (DRS4), developed by Stefan Ritt [7]. The DAQ is based on waveform sampling at 2 GS/s, covering a 2.5 μs window. The aim of this detector is select horizontal tracks by TOF to detect tau shower produced by the neutrino interacting in Earth crust. The TOF resolution achieved is about 0.5 ns.

The detector station is at the harsh environmental conditions. The detector components, like photomultiplier, inside the box, must be protected by its environment to operate continuously as well as reliably. The SiPM SensL device is installed on a board with a readout circuit and and ultra low noise 0.05 to 4 GHz Amplifier (Mini Circuits S454+) operating between -40 ^{0}C to 85 ^{0}C and 390 mW dissipation power. These components, in particulary the amplifier, generate heat inside the box so that heat can be restrained by using insulator material and avoid to reach quite low temperature. Jakodur extruted polystyrene foam (XPS) insulator is promising product due to its thermal conductivity, 0.034 W/(m·K).

The structure consists of the three layers, one 10 cm Jackodur layer, one 2 sided 3 mm PVC box which has 0.19 W/m·K thermal conductivity, and one 5 cm Jackodur layer. For the first section of the structure the thermal resistance is (0.1 m)/(0.034 W·(m·K)$^{-1}$) = 2.94 m^2·K/W, for the second section it is evaluated that (2$\times$3x10^{-3} m)/(0.19 W·(m·K)$^{-1}$) = 0.032 m^2·K/W and for the last section it is half of the first section, 1.47 m^2·K/W. The total resistance is 4.44 m^2·K/W and the total thermal transmittance of the structure is 0.23 W/m^2·K.

The total surface area of the box is 0.15 m^2, assuming the generated power inside is about 390 mW the heat transfer in Watts from each detector box is Φ = A$\times$U$\times$[T_{in}-T_{out}], where A is the its area in square meters, U is the rate of the transfer of heat (in Watts) trough one square meter, T_{in} and T_{out} are the temperature inside and outside the box, respectively. The supported temperature differences is given by

$$T_{in} - T_{out} \quad = \quad \frac{390 \times 10^{-3} W}{0.15 m^2 \times 0.23 \frac{W}{m^2 \times K}} = 11.3 K$$

In the period of the data taking the external temperature varied from -25 ^{0}C to -5 ^{0}C that corresponds to an internal temperature between -13 ^{0}C to 6 ^{0}C.

2.1 SiPM temperature dependence

The SiPMs used in this test are SensL 30035 series, 3x3 mm^2, 35 μm microcell type [6]. It has 20% of cross talk,130 ns of recovery time per microcell, 14% PDE. The model we have used provides a fast output and a conventional output with longer rising time. In laboratory we have tested the gain versus the temperature as shown in Fig. 2 and Fig. 3 respecively. The breakdown voltage versus the temperature function was evaluated changing the temperature and requiring the distance of first two peaks in the single photoelectron spectrum, shown in Fig. 2, refering to the measurement made at 0 ^{0}C by adjusting the voltage. It results, as shown in Fig. 4, the data have a linear dependence with a slope of about 30 mV/^{0}C including the amplifier gain. In the test performed at Sphinx we have not yet installed an internal temperature sensor to adjust the breakdown voltage with the temperature. A prototype board with a voltage controlled by Arduino via SPI has been developed in the Physics Department of Rome 'La Sapienza'.

3 DAQ and event measurement

The signals from both SiPMs are processed by DRS4 digitizer. The digitizer is used to trigger on the leading edge of the SiPM pulses. When any SiPM pulses, over the desired pulse height, causes a trigger. The waveforms from all DRS4 chips are written to disk on a PC for further offline analysis. Cosmic ray pulses are distinguished easily from 'sipm noise/baseline' because of having much larger amplitudes like a negative voltage *"spikes"*. When the

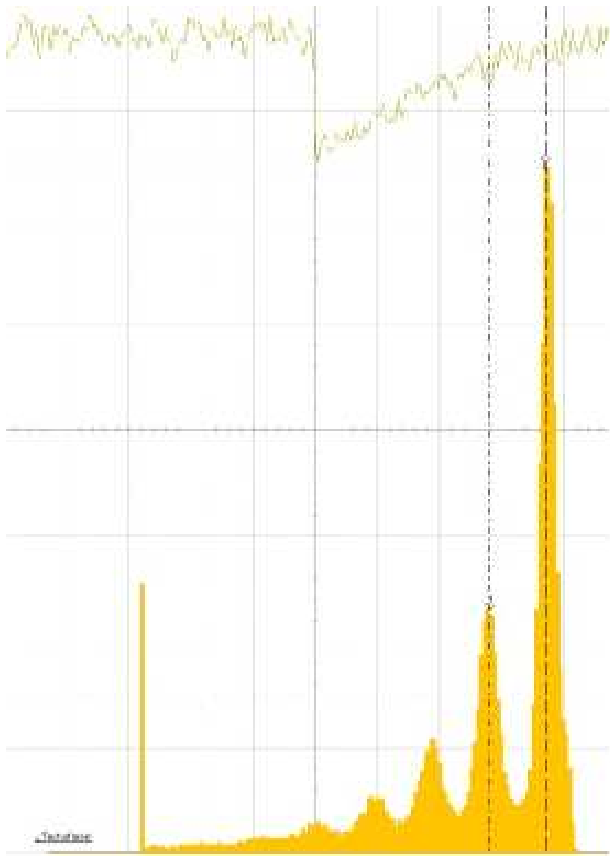

Fig. 2: Single Photelectron spectrum from SensL 30035 at -5 ^{0}C. The dotted lines show the 1th and 2nd photoelectron: the distance between the peaks measured in mV is proportional to the gain of SiPM. The box wide is 2 mV. On top is the scope trace of a SiPM.

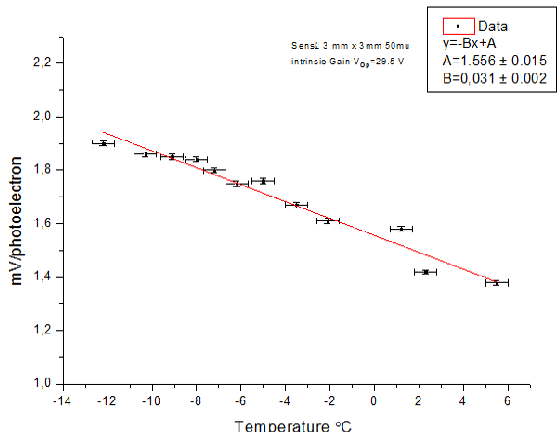

Fig. 3: Intrinsic gain as function of temperature. From the fit the gain reduces of about 10% in 10 ^{0}C when the temperature increases.

cosmic ray passes trough both counters will generate these SiPM pulses at a given time window. These "coincidences" are then counted as cosmic ray events.

Event selection from all triggered events is important issue when you deal with the random coincident events. Here we applied some criteria to find out expected events; first both pulseheight of the coincident events must be greater than

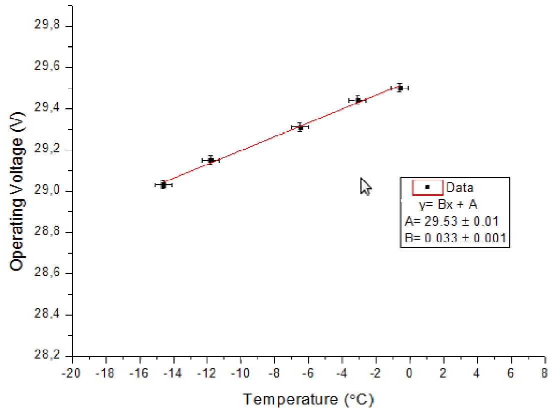

Fig. 4: Operating voltage as function of temperature. From fit result to be 50 mV/^{0}C

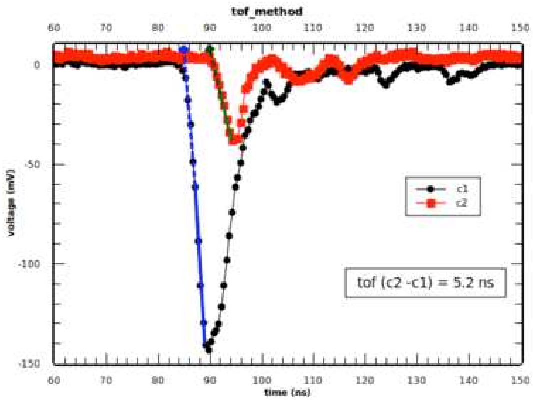

Fig. 5: TOF algorithm applied to the sipm signals C1,C2 in coincidences. The TOF evaluated for this signal is 5.20 $\pm$ 0.25 ns

the triggering threshold voltage, then they must be in a given time window, 516 ns. This will give us the possible coincident triggers in our detector acceptance. Optimum threshold voltage to remove the noise has been studied. Thirty-one runs, covered about 474 hours live time, were taken with the detector pointing at a zenith angle $\theta : 93.3^o$.

4 TOF Algorithm and track selection

The stored coincident waveform data, in 516 ns time window, are analyzed and assigned a timestamp for each signal. The used algorithm is described as follows, first it searches the maximum point of the pulse, then stores the six point informations (time, voltage) on the leading edge starting from the maximum point to the backward direction. After that fit a straight line to these points by using least square method and assign the timestamp as the intersection of the tangent to points at the leading edge side with the time axis. When you assign the timestamp to the pulse, one can easily find the time of flight between two counters. Fig. 5 shows fit to the SiPM read-out signal from Kuraray organic scintillator triggered by cosmic ray.

The purpose of this test, by using SiPM device at the High Altitude Research Station, Sphinx, is to reconstruct downwarding tracks with zenith angle 86^o. Fig. 6 depicts that the difference of the signal arrival time to each tiles. Because of having good time resolution the detector prototype is capable to discriminate the direction of the tracks which are going-up or going-down by measuring the time-of-flight. As seen from the Fig. 6 three peaks are separated by each others. The peak around +5 ns is due to the accumulation of the incoming particles from atmosphere at 86.7^o (downward-going particles). The small excess around 0 ns and +2 ns are due to the vertical and downward going parallel tracks, respectively crossing the tiles.

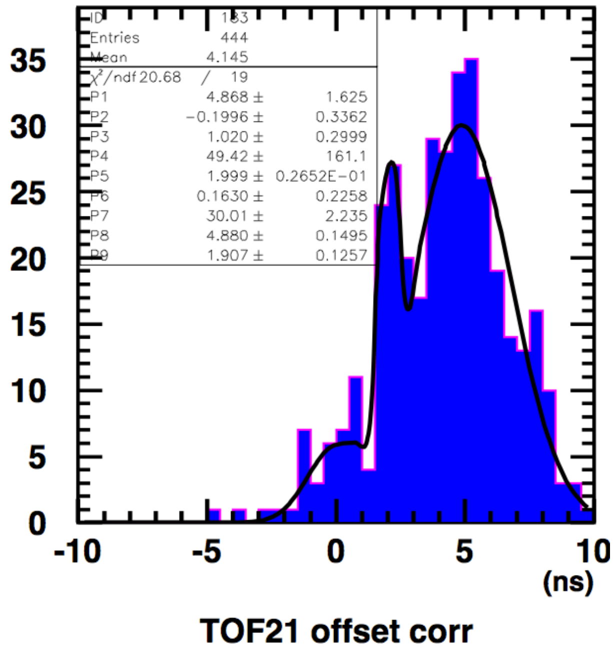

Fig. 6: Time of flight differences between the tiles Δt_{21} in the towers pointing a zenith angle 93.3^o and the data corresponds to live time of 474 hours. The peak around +5 ns correspond to going-down particle tracks, $\theta : 86.7^0$. The peak at +2 ns is due by parallel tracks, a small peak at 0 ns is related to vertical tracks. The vertical low momentum flux is dumped by the 1.5 mm iron roof.

4.1 Testing the Triggering Voltage

Hence the detector prototype is at the station terrace without any absorber, the rate of the single triggering are remarkable high $\sim 3.0 \pm 0.2$ mHz. All coincident tracks must be selected by an off-line program and this coincidence rate is around 0.2 mHz for this acceptance. The aim of this test has been to carry out the effect of the selected triggering voltage on the average rate and flux. It results that setting of the triggering voltage from DRS4 between 50 and 30 mV the rate is constant within the error.

5 Summary and outlook

In the last decades Silicon photomultipler (SiPM) has been improved remarkably. This new generation photodetector gives high-quality analog read-out for measurements of time resolution because of having very fast time response. The test performed at about 3800 m High Altitude Research Station a.s.l. shows that SiPM is a good alternative to use in astroparticle detector system for getting the high resolution time stamp information (in TOF system). The detector prototype shown is capable to discriminate up-going and down-going particles. The results show also that the prototype detector has been working stably without any problem at these harsh weather conditions. Furthemore we are planning to install a control of the operating voltage by Maxim 1932 digitally controlled by Arduino Mega board already tested in Laboratory.

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