An orientable time of flight detector for cosmic rays

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Abstract

Cosmic ray studies, in particular UHECR, can be in general supported by a directional, easy deployable, simple and robust detector. The design of this detector is based on the time of flight between two parallel tiles of scintillator, to distinguish particle passing through in opposite directions; by fine time resolution and pretty adjustable acceptance it is possible to select upward(left)/downward(right) cosmic rays. It has been developed for an array of detectors to measure upward \( \tau \) from Earth-Skimming neutrino events with energy above \( 10^8 \) GeV. The properties and performances of the detector are discussed. Test results from a high noise environment are presented.

Key words: Neutrino, \( \tau \), UHECR

1. Introduction

The interest in Ultra High Energy Cosmic Rays (UHECR) produced a large variety of experiments, with different purposes and based on several techniques (Cherenkov, air fluorescence and radio waves); while timing information is often used to obtain directional information, none of the present techniques is based on upward/downward discrimination by time of flight. The prototype detector described here is capable to measure large zenith angle cosmic rays as well to be an element of an orientable surface array of detectors to measure the signature of Ultra High Energy \( \tau \) neutrinos using the Earth skimming strategy [1,2,3,4], as shown in the TAUWER proposal [5].

2. Description of the detector

Besides the deployment mechanics, not discussed here, the structure of the detector is very robust and simple, as shown in Fig. 1: the base detector consists in two parallel scintillating plates (20 \( \times \) 20 cm\(^2\), 1.4 cm thick), separated by 160 cm, read by one low voltage R5783 Hamamatsu photomultiplier (PMT), extensively used in CDF muon detector [6]. Each scintillating plate is embedded in a PVC box which also contains the PMT. The two boxes are attached to a metal structure that defines the covered solid angle of about 1.4 \( 10^{-2} \)rad. The choice of this particular model of PMT is due to its low time resolution (\( \approx 300 \) ps) and the possibility to use an autonomous low voltage power supply, like a solar panel or a wind turbine, to make it an affordable elementary module of a large area array. A custom electronic board for time and charge analysis, in substitution of standard NIM-CAMAC modules, is under development (Fig. 2).

Thinking about using this detector for extensive air showers, it would be interesting to have the possibility to study the shower front structure; this can be done by using a sampling ADC based on MATAEQ, 2.5 \( \mu s \) at 1GS/s [7], that can be used also at trigger level to define the direction of the track. The time of flight is provided by a TDC-GPX, by ACAM, with 40 ps or 81 ps resolution [8]. In this case it has to be noticed that the board has to be equipped with a proper pipeline, to retain raw data until an exchange of trigger masks of the modules with the central DAQ, by WLAN, provides a global trigger decision; this is necessary to have the capability, given the data rate transmission limit, to store the full MATAEQ response in relation to events that involve only single scintillators spread over the whole array.

2.1. Acceptance

The present detector was designed to recognize single near horizontal moving particles and it is basically a narrow angle scintillator counter, illustrated in Fig. 1. The sin-
Fig. 1. Schematic view of the detector. The electronic box and the wireless connection are not shown.

Fig. 2. Hardware block diagram of the DAQ board.

The data were collected by the MATACQ board only (Fig. 3). The detector has shown a good upward/downward discrimination capability in all our tests. In order to reach upward-downward separation requirement the light collection technique has been optimized focusing on the time resolution, disfavoring the energy resolution. The definition of a vertical MIP is made by calibration on vertical downward cosmic rays, to set proper charge cuts to obtain a good time resolution, slightly reducing the effective area.

Fig. 3. Two photomultiplier signals displayed by Matacq board. The units are mV (vertical axis) and ns (horizontal axis).

Fig. 4. The distribution of time of flight between the two 20x20 cm$^2$ tiles 160 cm apart, for downward vertical cosmic ray events.

3. Performances

To optimize the performances of the detector several tests were performed with different tile sizes at the High Altitude Research Station Jungfraujoch (HFSJG), located in Switzerland at $\approx$ 3600 m above the sea level. In some tests the detector has shown a good upward/downward discrimination capability in all our tests. In order to reach upward-downward separation requirement the light collection technique has been optimized focusing on the time resolution, disfavoring the energy resolution. The definition of a vertical MIP is made by calibration on vertical downward cosmic rays, to set proper charge cuts to obtain a good time resolution, slightly reducing the effective area.

3.1. Time resolution

The time resolution ($\approx$ 1 ns), near the PMT transit time spread, is obtained by avoiding any reflection in the light collection; the 1 cm$^2$ PMT window is directly coupled, by a silicon pad, to the scintillator, wrapped with Tyvek. This configuration let the first light arriving at the PMT window dominate for the leading edge of the signal; it has been chosen after several tests using WLS or clear fibers, which lead to the conclusion that any kind of reflection introduces
a stochastic fluctuation that enlarges the time spread by a factor 3 or 4, or, similarly, for a random collection point for WLS fibers. Figs. 4 and 5 show the time of flight between two tiles 160 cm apart and two horizontal overlapped tiles respectively. Both distribution have an RMS of $\approx 1$ ns.

Fig. 5. Time of flight between two horizontal overlapped tiles.

### 3.2. Upward and downward track discrimination

The environment in which the detector is supposed to work could present contamination of the time signal by simulating the right time difference by events different from particles crossing the detector. It gives the possibility to access to a higher flux of "not interesting" cosmic rays, in particular secondary photons. It was previously understood, by a test with a radioactive source ($^{80}$Sr), that the region of scintillator outside the field of view of the PMT window is disfavored for timing and signal amplitude, because it needs at least one reflection to reach the photocathode, resulting in a hit delayed of about 3 ns. In the tested prototype this effect can be observed when it is set exactly horizontal; in this geometrical condition the vertical, dominant, component of CRs has about 50% probability to hit an efficient or inefficient region of the side of the scintillator. This means that, in presence of events of two time correlated and 0 delayed particles, like pair production from a vertical photon, we expect a structured time signal contamination, besides the signal ($\approx -5$ ns), consisting in 3 peaks ($\approx -3, 0, 3$ ns), due to the combined probability of detection by an efficient/inefficient region of the scintillator. This effect changes with zenith angle orientation drifting with $\sin \theta$, resulting in the structure showed by Fig. 6.

Tests were performed on the possibility that multiple reflections of the emitted light on the surface and on the border of the tile create peaks on TOF distribution, to understand the contribution from the surface and the border. These results suggest that a blackened border reduce the multiple reflection. Further test are in progress.

Fig. 6. Time-of-flight difference between two tiles $\Delta t_{12}$ in a tower pointing at a zenith angle 95° when a lead block of 3-cm thickness is placed in front of one tile (yellow shade) and no lead is present (red shade). The two peaks at -5 ns and +5 ns correspond to up-going and down-going tracks, respectively. The peaks at -3, 0 and 3 ns are due to parallel tracks, most likely vertical, where one of them hits an "inefficient region", i.e. a corner, of one of the tiles.

### 3.3. Measurement of cosmic ray flux at 3600 m

Fig. 7 shows the measurements of cosmic ray flux in the High Altitude Research Station Jungfraujoch in a zenith interval of 80° to 100° and at 0°.

### 4. Summary

The detector shown can distinguish upward and downward particles from cosmic rays and collect data within time interval of 2.5 $\mu$s at 1GS/s. By its mechanical structure it is possible to change easily the orientation of the
detector. In particular this feature, joint with its intrinsic
directionality, make it feasible for an orientable array for
UHECRs; this opens the possibility to use the expertise on
quasi-vertical showers on quasi-horizontal physics, as it is
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