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A DSO-based system for temporal-profile extraction of atmospheric Cerenkov events

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Abstract. The TACTIC array of Cerenkov telescopes, being set up at Mt. Abu, proposes to record time-profiles of atmospheric Cerenkov pulses with a view to exploit apparent differences in the associated time-parameters for a possible characterisation of the progenitor particles. We discuss here a cost-effective hardware scheme for deployment in the TACTIC for recording the Cerenkov pulse profiles.

Key words : Cerenkov radiation, γ–ray telescopes, temporal-profile extraction, synchronous addition of pulses, event characterization.

1. Introduction

Monte Carlo simulation results (Rodriguez-Frias et al, 1995; Aharonian et al, 1997) indicate that the time-profiles, recorded by a narrow-beam Cerenkov telescope in response to the incidence on the atmosphere of Very High Energy/Ultra High Energy (VHE/UHE) particles (γ–rays and cosmic-ray nuclei, like proton, Neon and Iron), exhibit structural differences which can be qualified for providing supplementary primary-event characterisation information — an important problem receiving serious attention these days. These differences are expected on account of different longitudinal and lateral developments of extensive air showers produced by these progenitor types, with an additional microstructure superimposed due to Cerenkov radiation from local muons. Our simulation studies indicate (Rannot et al, 1997) that, for a typical TACTIC-like Cerenkov system, despite a comparatively moderate time response (represented by a rise-time of ~ 2 us and decay-time of ~ 4-5 ns), discernible differences exist, for example, in rise-times or/and base-widths of the detector output waveforms resulting from optical Cerenkov pulses generated by UHE γ–ray primaries and cosmic-ray nuclei like protons, Neon and Iron. Thus, these time-parameters can supplement the Cerenkov image data in primary-event characterization, a pre-requisite for using a TACTIC-like system for VHE γ–ray astronomy and UHE cosmic-ray studies. Hence the motivation for us to record the Cerenkov pulse-generated waveforms besides the Cerenkov images with the multi-element TACTIC array.

First experimental investigations based on similar considerations of using event time-profiles for differentiating signal events (γ–rays) from background cosmic-rays, were made by Tumer et al (1990). Using rather adhoc criteria, it was claimed by the authors that the technique can reject ~ 95% of the background events. This permitted them to detect a 4.3 σ TeV γ–ray signal from the direction of Crab Nebula in 1.5 hrs. of observations, carried out with a 11 m-diameter solar collector-based Cerenkov telescope.

2. TACTIC γ–ray telescope array

The experimental details of this instrument are discussed elsewhere (Bhat, 1997). We confine ourselves here to the instrumentation features directly relevant to the present work. Fig.1 gives a schematic of the 4-element TACTIC array. The telescope at the centroid of the triangle (side : 20m) is referred to as the Imaging Element (IE), for it has a 349-pixel Cerenkov light imaging camera in its focal plane. The telescopes at the 3 vertices of the triangle are the Vertex Elements (VE). The focal-plane instrumentation of each VE comprises duplex-detector arrays, which face each other across a beam-splitter or a dichroic-filter plate. As shown in Fig.1, each detector array consists of 16 x 52 mm dia photomutliplier tubes (PMT), which are interposed with 13 x 19 mm dia PMT. While 5 of the smaller PMT carry Am^{241} light pulsers for on-line absolute calibration of the PMT assemblies, the remaining 8 of these detectors respond to either near

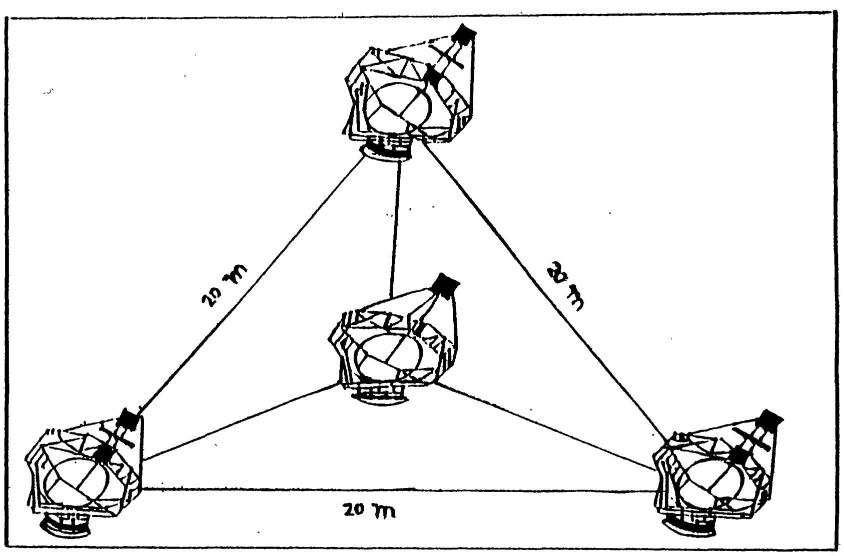

Figure 1a. A schematic of the 4-element γ–ray telescope array, TACTIC, set up at Mt. Abu. The telescope at the centre of the triangular array is the Imaging Element and 3 corner telescopes are the Vertex Elements.

UV light (λ ~ 180-350 mm, ETL D921 UVA) or to the visible light (λ ~ 300-600 nm, ETL 9083). The 3 PMT types are respectively called the calibration (C-), Visible (V-) and Ultra-violet (U-) pixels. The Cerenkov photons reflected by the telescope mirror, are divided by the beam-splitter/dichroic plate into 2 parts in a wavelength independent/dependent manner and are finally collected by the PMT assemblies referred to above, depending upon the angular distribution and spectral properties of these photons and the respective spectral response of the

PMT assemblies. Our simulation investigations (Sapru et al, 1997) show that, as far as the 16 large PMT of the VE detector array, the angular distribution of Cerenkov photons is such that only a fiew of these detectors in each array register these photons from a given event. The pulse waveform recording scheme discussed below, has been specially designed keeping this practical situation in mind, leading to a substantial economy, apart from noise immunity.

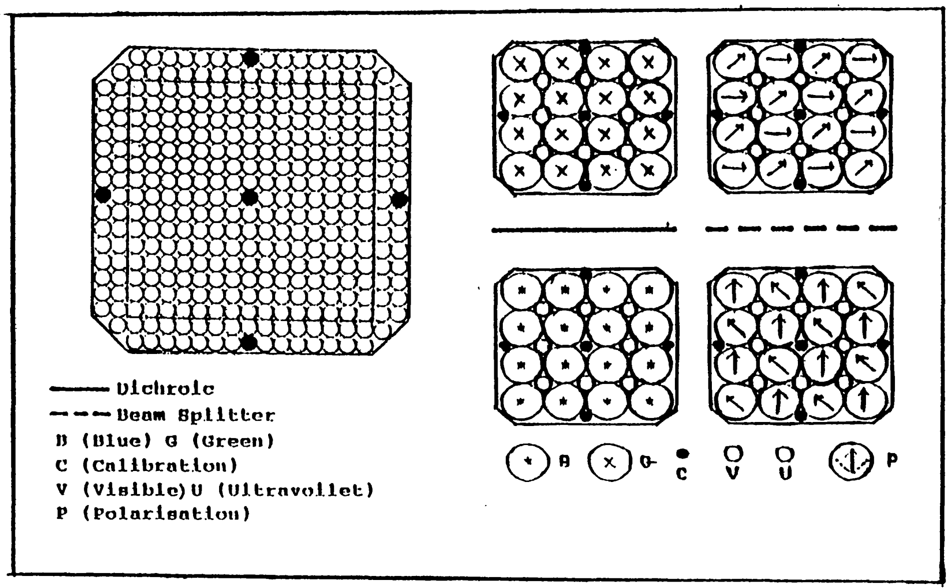

Figure 1b. Focal-plane instrumentation of the Imaging Element (left panel) and Vertex Element (right panel). The instrumentation has been designed to give the TACTIC an improved event characterization capability and energy resolution, two important requirements for high-sensitivity γ–ray astronomy observations.

3. Proposed scheme

Fig. 2 gives a block-diagram representation of the proposed recording scheme. One profile-recorder is planned to be used for both the detector arrays of a given VE. For this purpose, the 16 PMT of a given detector array are first amplitude-discriminated to check for the presence

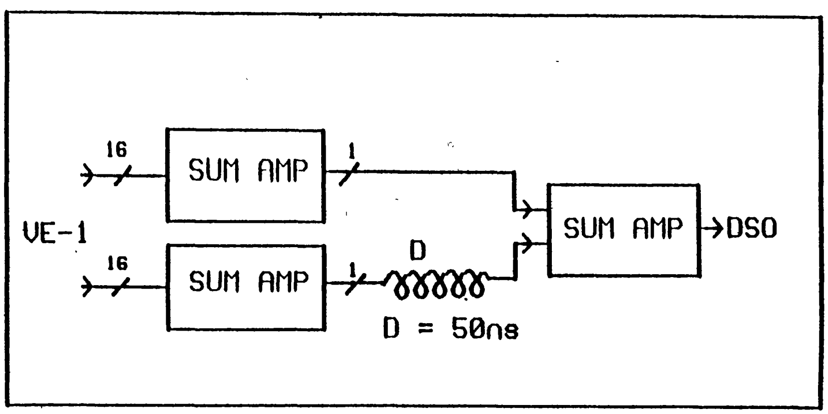

Figure 2. A block-diagram representation of the pulse time-profile recording scheme for a VE.3 such circuits are required for recording time-profiles from all the 3 Vertex Elements.

of a signal. The signals from such channels as cross the preset discrimination levels are synchronously added in a linear summing amplifier. The output pulse from the summing amplifier is digitized and stored with the help of a fast Digital Storage Oscilloscope (Lecroy 9350A, 500 MHz bandwith, IGS/s sampling rate). Two similar, additional circuits are required for recording time-profiles from the other two Vertex Elements.

4. Prototype profile recorder module

In order to evaluate the feasibility of the pulse-profile recording approach, discussed above, a 4-channel prototype module has been developed and tested. The scheme sketched in Fig.3, uses a fast switching amplifier (OPA 678 AP) for each channel, a linear fan-in/fan-out module (Philips 740) and a digital storage oscilloscope. 4 PMT's (ETL 9083 UV), exposed to light flashes from a pulsed Nitrogen laser were used to evaluate the circuit performance in a laboratory experiment. The discriminator used in this experimental arrangement ensures that analog switch remains 'on' only when its input pulse crosses a preset discrimination level (~ 70mV in this case). This way, one avoids the situation where a PMT, having only low-amplitude shot-noise fluctuations and no appreciable Cerenkov signal, may deteriorate the pulse shape characteristics of the summed output pulse resulting from such channels where the signal is present.

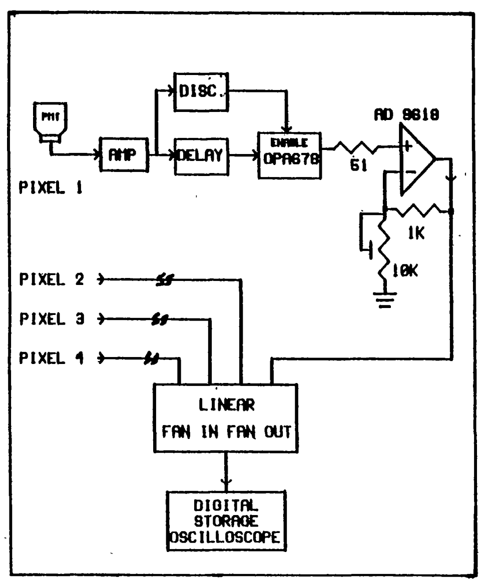

Figure 3. A schematic of the 4-channel prototype module used to evaluate the circuit performance in a laboratory experiment.

The DSO was used in a sequence mode, thereby allowing it to store 20 waveform in its local memory. These were later transferred to a PC via RS 232 communication port for permanent retention and subsequent analysis. Four sets of data, comprising 600 events each, were acquired using the following channel configurations : a) channels 1 - 4 individually present at a time and (b) channels 1 & 2, (c) channels 1, 2, 3 and (d) channels 1,2,3,4, simultaneously present in cases (b-d). A log-normal type of an Equation, with 4 free parameters was used to evaluate various pulse parameters of the digitized pulse, viz., rise time, fall time, full width at halfmaximum (FWHM), width at 10% amplitude. The results obtained (Table 1) indicate that timing parameters of the summed output pulse are in close agreement with the corresponding values recorded when only one of the four channels was present at a time. The proportional increase in the peak amplitude of the summed pulse in the case when the output pulse is a result of ≥ 2 channels present at the input, confirms the synchronous linear addition of the input pulses. These test results validate the principle being followed for recording the pulse shape profiles of Cerenkov pulses recorded by the TACTIC Vertex Elements.

Table 1. Timing parameter results establishing synchronous linear addition of various input pulses by the prototype circuit of Fig.3.

Configuration	Peak Amplitude (Vlot)	FWHM (nsec)	Rise Time (nsec)	Fall Time (nsec)	Width at 90% (nsec)	Width at 10% (nsec)
Channel # 1	-0.63 ± 0.03	0.65 ± 0.84	4.82 ± 1.73	10.21 ± 3.83	3.62 ± 0.41	18.54 ± 2.47
Channel # 2	-0.60 ± 0.05	9.30 ± 0.47	4.98 ± 1.54	9.38 ± 2.43	3.55 ± 0.19	17.91 ± 1.42
Channel # 3	-0.59 ± 0.07	9.98 ± 0.74	4.75 ± 1.45	11.21 ± 3.10	3.78 ± 0.79	19.73 ± 2.26
Channel # 4	-0.60 ± 0.05	8.27 ± 0.65	4.34 ± 1.60	8.79 ± 3.05	3.14 ± 0.26	16.27 ± 2.07
Channel # 1 + 2	-1.15 ± 0.08	9.50 ± 0.62	3.91 ± 1.17	9.82 ± 3.66	3.53 ± 0.25	18.22 ± 2.74
Channel # 1+2+3	-1.67 ± 0.14	9.32 ± 0.47	3.72 ± 0.90	9.76 ± 3.43	3.46 ± 0.18	17.84 ± 2.65
Channel # 1+2+3+4	-2.14 ± 0.16	9.18 ± 0.42	3.81 ± 0.82	9.62 ± 2.76	3.62 ± 0.17	17.22 ± 2.04

5. Conclusion

A cost-effective pulse-profile recording scheme is proposed to be employed for each Vertex Element of the TACTIC array. The test results, obtained in the laboratory with a 4-channel prototype module, reveal that the principle of synchronous addition of pulses can be used reliably to handle signals coming from one or more of the 16 channels of the two detector arrays of each Vertex Element.

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