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Status and Performance of the First VERITAS telescope

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The first of the four atmospheric Cherenkov telescopes of the VERITAS array has been in operation at the Mt. Hopkins base camp since January 2005. The telescope has met all specifications. We present here a description of the technical performance, including calibration details and a summary of a preliminary analysis of Crab Nebula observations. The construction status of the complete VERITAS array is also discussed.

1. Introduction

The VERITAS Collaboration is building an array of imaging atmospheric Cherenkov telescopes for ground-based gamma-ray astronomy. Phase-I of the project consists of four, 12 m telescopes sited at Horseshoe Canyon on Kitt Peak, Arizona, at an altitude of 1800 m. Figure 1 shows the first of these telescopes temporarily installed at the base camp of the Whipple Observatory at Mt. Hopkins (altitude=1275 m).

2. Mechanical/Optical Performance

The VERITAS telescopes follow a Davies-Cotton optical design with 12 m aperture and 12 m focal length. The mechanical structure consists of an altitude-azimuth mount and a steel optical support structure (OSS). The mount is a commercial unit manufactured by RPM-PSI (Northridge, California); the OSS is custom designed by M3 Engineering (Tucson, Arizona) and fabricated by Amber Steel (Chandler, Arizona) [1].

The tracking is measured to be accurate to $< 0.01^\circ$ with a maximum slew speed of $0.3^\circ\ \mathrm{s}^{-1}$. Tests with a slightly modified drive system have enabled us to reach maximum slew speeds of $1^\circ\ \mathrm{s}^{-1}$; the remaining telescopes will have this modification installed as standard.

The 350 individual mirror facets are hexagonal, each with an area of $0.322\ \mathrm{m}^2$, providing a total mirror area of $\sim 110\ \mathrm{m}^2$. They are made from glass, slumped and polished and then coated with aluminium and anodized at a dedicated facility on-site. Reflectivity is $> 90\%$ at 320 nm. Each facet is shaped with a 24 m radius of curvature and arranged on a spherical surface of 12 m radius. Throughout most of the observations presented in this paper, the point spread function (PSF) at the position of Polaris was measured to be 0.09° FWHM. Recently, the telescope alignment has been optimized, and the current PSF is 0.06°.

A prototype version of the telescope started operations in early 2004, and the completed telescope has been operating since January 2005. The structure is robust and the positioning precision very reliable. We envisage no problems or major changes to the design for the remaining VERITAS telescopes.

3. Camera and Electronics

The focal plane instrumentation is a 499 element photomultiplier tube (PMT) camera, with 0.15° angular spacing giving a field-of-view of 3.5°. The PMTs are Photonis XP2970/02 with a quantum efficiency $> 20\%$ at 300 nm, currently running at a gain of $\sim 2 \times 10^5$. Light cones have not yet been installed: two different designs are being fabricated and one will be installed in Autumn 2005, significantly increasing our photon collection area. Figure 2 shows the single photoelectron response for a single PMT, measured *in situ* by placing a mylar screen in front of the camera and then illuminating with a laser pulse.

Figure 1. Left: VERITAS Telescope 1. **Right:** The 499 pixel PMT camera.

The PMT signals are amplified by a high-bandwidth preamplifier integrated into the PMT base mounts. This circuit also allows the PMT anode currents to be monitored; currents are typically 3 μA (for dark fields) to 6 μA (for bright fields), corresponding to a night-sky photoelectron background of 100 - 200 MHz. The signals are sent via $\sim 50\ \mathrm{m}$ of RG59 stranded cable to the telescope trigger and data acquisition electronics, at which point the signal pulse for an input delta function has a risetime (10% to 90%) of $3.3\ \mathrm{ns}$ and a width of $6.5\ \mathrm{ns}$. The multi-level trigger system consists of a programmable constant fraction discriminator (CFD) for each PMT [2], the output of which is passed to a pattern recognition trigger system [3] which is programmed to recognise triggers resembling true compact Cherenkov light flashes. Figure 2 shows the trigger rate as a function of CFD threshold for two different pattern trigger configurations. Observations this year have all been made with a rather conservative threshold of $\sim 6-7$ photoelectrons and a 3-fold adjacent pixel pattern trigger configuration, giving a cosmic ray rate at high elevation of $\sim 150\ \mathrm{Hz}$.

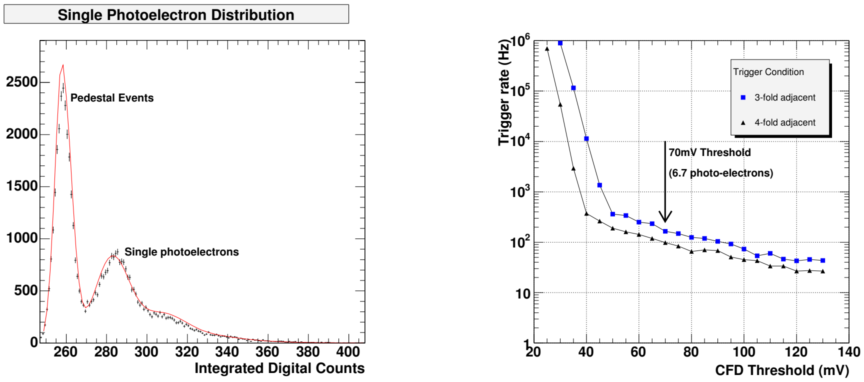

Figure 2. Left: The single photoelectron response for one PMT (at an increased gain of $\sim 1 \times 10^6$). The fit assumes a Poisson distribution of photoelectrons, and a Gaussian distribution for the integrated charge produced by a single p.e. **Right:** The trigger rate as a function of CFD threshold for two different pattern trigger configurations.

The PMT signals are digitized using custom-built VME boards housing Flash ADCs with 2 ns sampling and a memory depth of 32μs [4]. By default the signal traces follow a high gain path to the FADC; however, if the 8 bit dynamic range is exceeded, an analog switch connects the FADC chip to a delayed low gain channel instead, extending the dynamic range for a single 2 ns sample from 256 to 1500 digital counts (d.c.), where 1 d.c $\sim$ 0.19 photoelectrons at our current PMT gain. The electronic noise is small, with a sample-to-sample variance of ~ 0.5 d.c. and an event-to-event variance over a 10 sample integration window of ~ 1.5 d.c.. The readout window size and position is programmable; a 24 sample window readout on all 500 channels results in a data size of 13.5 kb per event and a deadtime of $\sim 10\%$ at 150 Hz. While this is manageable for a single telescope, the VERITAS array will produce four times as much data at higher rates (up to 1 kHz). To cope with this we have implemented a zero suppression scheme, whereby only those channels with a peak charge larger than a preset value are read out, reducing the data size by a factor of approximately four. As well as allowing us to minimize the charge integration gate and hence improve the signal/noise, the FADCs also provide the time distribution of the Cherenkov photons across the image (see [5]). Figure 3 shows the charge and arrival time information for a cosmic ray event with significant time structure.

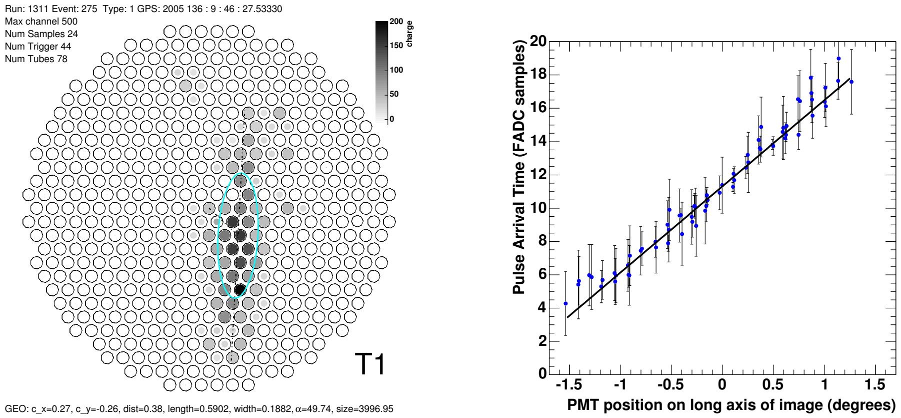

Figure 3. Left: The charge distribution across the camera for a cosmic ray event (the grey scale is in d.c.). **Right:** The Cherenkov pulse arrival time distribution (in units of FADC samples = 2 ns) along the long axis of the image on the left.

4. Observations and Data Analysis

Routine observations with the first VERITAS telescope began in February 2005, in time to collect a small dataset on the Crab Nebula at high elevation. Observations were taken in the standard ON-OFF mode, and events parameterized and passed through gamma-ray selection cuts in a similar fashion to observations with the Whipple 10 m telescope. Figure 4 shows the results for an ON source exposure of 3.9 hours, indicating a sensitivity of $\sim 10\sigma$ for 1 hour of ON source observations. Also shown is a significance map of the reconstructed source position using the method of Lessard et al. [6] and smoothed with a simple smoothing algorithm. The rather low gamma-ray rate is the result of hard gamma-ray cuts which must be applied to reject the local muon background. We have developed a full simulation chain [7] which indicates a gamma-ray threshold for the Crab observations of $\sim 150\,\mathrm{GeV}$ ($22\,\gamma\,\mathrm{min}^{-1}$) before cuts and $\sim 370\,\mathrm{GeV}$ after. Muon rejection will take place at the hardware trigger level once more than one telescope is installed, removing the need for hard cuts and dramatically improving the sensitivity.

An observing campaign, complementary to that of the Whipple 10 m continued until June 2005, resulting in $> 10\sigma$ detections of the known gamma-ray sources Mkn 421 and Mkn 501 [8] and data sets on various potential TeV sources. A full online analysis package enables us to detect strong flaring behaviour within minutes.

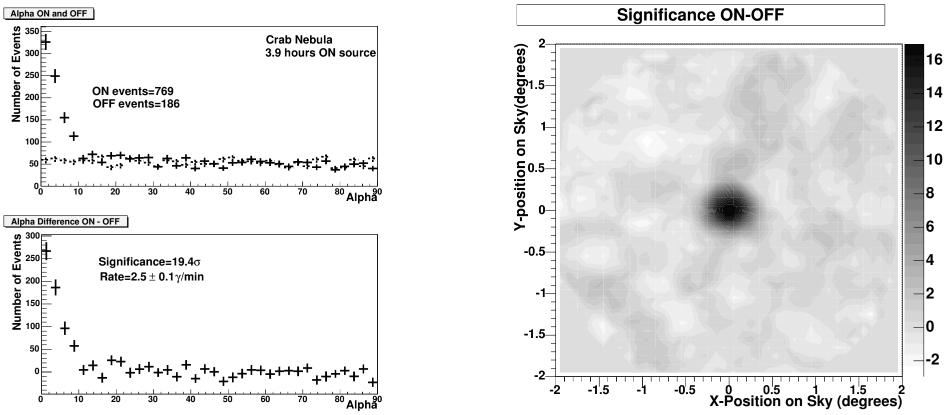

Figure 4. Left: The image orientation angle, alpha, for ON and OFF source observations after gamma-ray selection cuts **Right:** The two-dimensional map of reconstructed source position. Adjacent bins are not independent.

5. Summary

The first VERITAS telescope has been operating throughout 2005, has met all technical specifications and detected a number of TeV gamma-ray sources. The Kitt Peak site for VERITAS Phase-I has undergone significant development; site clearance, power line installation and construction of all four telescope pads has been completed. The major mechanical components of all four telescopes have been delivered to the Mt Hopkins base camp. Because of a temporary delay in access to the Kitt Peak site, we have decided to install the second VERITAS telescope at the Whipple base camp, 85 m away from the first telescope on an East-West baseline. By operating these two telescopes together beginning Autumn 2005, we will be able to reject the muon background and dramatically increase sensitivity, as well as test the array trigger electronics.

References

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