Status report from VERITAS

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Abstract. VERITAS is a ground-based gamma-ray observatory covering energies between 100 GeV and 50 TeV and will start operating by January 2007. We give a brief report of the construction status and performance characteristics of the telescopes.

1. Introduction

VERITAS (Very Energetic Radiation Imaging Telescope Array System) was the first of a new generation of Cherenkov telescopes to be proposed; similar systems have been built in the mean time overseas by the HESS [1], MAGIC [2] and CANGAROO [3] collaborations. The new instruments provide substantially increased sensitivity over previous telescopes from the 1990s and are based on the imaging atmospheric Cherenkov technique (IACT). The technique was pioneered by the Whipple collaboration and established with the discovery of TeV gamma-ray emission from the Crab Nebula [4].

Initially, VERITAS was proposed as an array of 7 telescopes with an order of magnitude better sensitivity compared to the Whipple 10 m and any other second generation system such as CAT or HEGRA. The stereoscopic technique substantially reduces background, improves angular and energy resolution as demonstrated by the HEGRA collaboration using an array of five small telescopes [5]. The construction of VERITAS-4 as a four telescope array was approved and funded in the U.S. in mid 2003. We describe some of the milestones achieved during the construction phase and provide an outlook of the operation of VERITAS-4 at the basecamp of Whipple observatory.

2. The VERITAS Concept

VERITAS is designed to study very high energy gamma-ray sources in the energy range from 100 GeV to 50 TeV with a flux sensitivity of 7 mCrab[1]. An array with comparable sensitivity (HESS) has now been operating for two years in the southern hemisphere and the results have been extraordinary (see Working Group I papers of this conference). We expect VERITAS to have a similar impact in the northern hemisphere with science observations to start in early 2007. Observational overlap with GLAST is anticipated in late 2007 and will provide measurements of non-thermal phenomena over six decades in γ-ray energy.

Given its northern hemisphere location, VERITAS is also poised to play an important role in constraining high energy neutrino sources anticipated in an IceCube sky survey. Scientifically, VERITAS constitutes an important link between the GLAST and IceCube observatory, the latter to be fully operational by 2010 with a lifetime of 5 to 10 years. Both the wide energy regime in γ rays in the northern hemisphere and the possible neutrino connection are critical observing capabilities for a long term program in high energy astronomy that addresses the nature of hadronic TeV sources, making GLAST, IceCube and VERITAS indispensible over the next decade.

The VERITAS telescopes consist of reflectors each with 12 m aperture and a 12 m focal length. The focal plane instruments have 499 pixels and a field of view 3.5° across. The design philosophy has been to use new technology where it is affordable and has the largest impact. The main improvements over the Whipple 10 m telescope are in the electronics: preserving the fast Cherenkov light signals from the photodetectors with low noise and using a flexible recording scheme with flash-ADCs. The buffering capability of the flash-ADCs also allows one

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[1] 0.7 % of the flux of the Crab nebula can be measured with a significance of 5σ in 50 hours of observations.

to employ a true array trigger for making a triggering decision based on air shower coincidences between several telescopes. This allows the detection of the faintest Cherenkov light flashes and translates into a low energy threshold for γ-ray events. Other improvements are in the optics leading to a better point spread function than the Whipple 10 m telescope. The biggest improvement in sensitivity is expected from the stereoscopic reconstruction of air showers.

Figure 1. The first two VERITAS telescopes at the bascamp of Whipple observatory are shown as of February 2006.
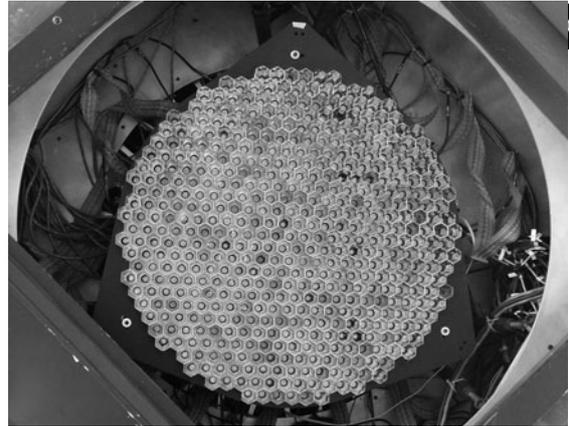
Figure 2. The focal plane hosts a camera with 499 photomultipliers. The concentrators in front of the PMTs increase the light collection efficiency and shield against background light.

3. The First Element of the Array

In 2001 the VERITAS collaboration was given approval to construct a prototype telescope with half the mirror area and a half camera, but with a complete mount and optical support structure. After successful engineering runs, the instrument was upgraded to a full telescope in fall of 2004. Results of first observations and a performance evaluation are presented in [6]. The telescope fulfills the specifications that were set for the single element of the array. The low noise performance of the cameras is evident in the ability to measure the single photoelectron response *in situ* at typical operating voltage. This is critical for measuring the gain of each photomultiplier and associated electronics over time. The optical performance is represented by the point spread function[2] and was shown to have a F.W.H.M of 0.06°. The flash-ADCs are useful for making adjustments in the relative timing of the Cherenkov flashes in the off-line analysis. This helps to reduce the night sky background and improves the signal to background ratio of the images. In summary, the telescope has met or exceeded all of our expectations and can be expressed by giving its sensitivity for detecting the Crab nebula in 1 hours time as $10\sigma\sqrt{\text{time}/[\text{hr}]}$.

4. Stereo Operations with two Telescopes

The second VERITAS telescope was installed at the basecamp in Fall 2005 and became operational in Spring 2006 (Figure 1). Figure 2 shows a view into the focal plane with 499

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[2] The point spread function (PSF) was taken on-axis and the typical value over the entire field of view is less than 0.10°, adequate for a camera pixelation of 0.148°.

pixels and a set of hybrid light concentrators[3]. Engineering runs and first stereo observations with two telescopes were performed in April 2006 using an array trigger. The trigger rate from cosmic ray showers were typically around 80 Hz when using an array coincidence time window of 100 ns. This is close to what is expected from Monte Carlo simulations. The individual telescope rates were between 200-300 Hz with the hardware threshold set to 6 photoelectons at the photomultiplier level. Fine tuning of the trigger thresholds and coincidence timing will be done once three-telescope coincidences become available.
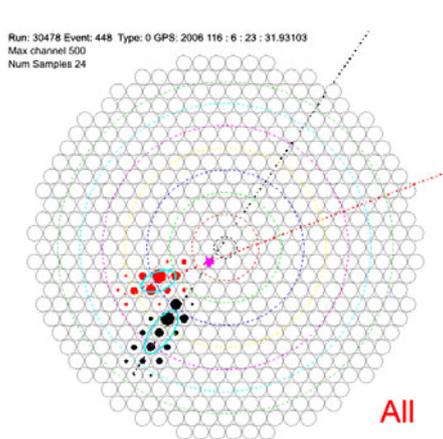
Figure 3. Air Cherenkov light images recorded with two VERITAS telescopes have been superimposed and projected into a common plane. The major axes of the images intersect and provide a measure of the arrival direction of the primary particle.
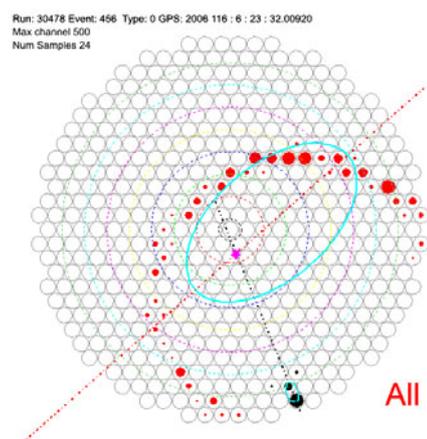
Figure 4. A muon ring image recorded in one telescope is combined with a coincident shower image from the other telescope. Muons are local, e.g., this one intersects with the mirrors of one telescope. Therefore, they show substantial parallax when viewed with two telescopes.

Figure 3 shows the stereoscopic images of an air shower recorded by the first two VERITAS telescopes. The Cherenkov light images have been superimposed and are presented in a common camera plane including its pixelation. The intersection of the major image axes provides an estimate of the arrival direction of the primary particle. Based on the image shapes, this event could be classified as a γ-ray event. A second event is presented in Figure 4 showing in one telescope a ring image from a muon traveling on a path that intersects with the telescope's reflector. The second Cherenkov light image shows a truncated image from another component of the shower. In fact most muons are already rejected at the trigger level, since the relatively nearby tracks of local muons result in a large parallactic displacement of the Cherenkov light images in the focal planes of two telescopes separated by 80 m.

A systematic analysis of the stereo reconstruction parameters such as angular resolution, shower core reconstruction accuracy and energy resolution will be presented elsewhere since it can be best tested and verified by overconstrained measurements with three telescopes. It is clear from Figure 3 that with three telescopes it will be possible to measure the uncertainty in the arrival direction reconstruction and get a better estimate of the systematic uncertainties.

[3] They are designed as a hybrid cone with a Winston cone at the exit surface and a hexagonally shaped entrance window. They provide a well defined aperture limited to the reflector and a light collection increase of more than 30%.

5. Engineering Data

During April and May of 2006 observations of Mrk 421 revealed flaring activity, making it a useful source of γ-rays to test the stereo operation of the first two VERITAS telescopes. Figure 5 shows the θ^2 distribution[4] of 3.2 hours of on-source observations in the direction of Mrk 421. A strong γ-ray signal is also apparent in the skymap presented in Figure 6, the color scale indicates the significance of the smoothed map.
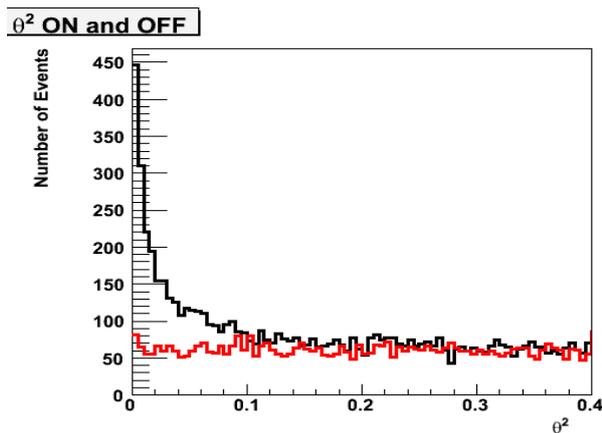
Figure 5. A strong signal from Mrk 421 is evident in the θ^2 distribution of the on-source data (dark line) while the background distribution (faint line) is essentially flat.
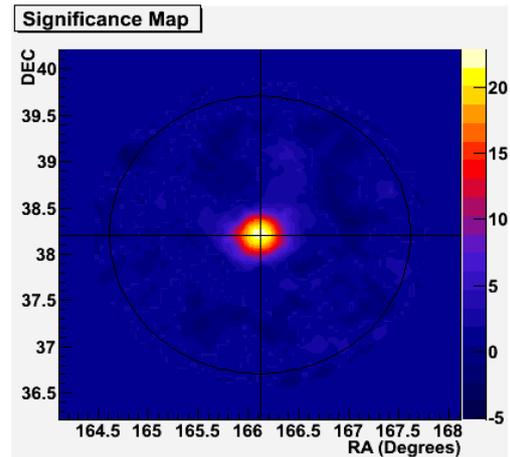
Figure 6. The skymap in the direction of Mrk 421 exhibits a strong excess of gamma-ray events. The cross indicates the direction of Mrk 421 in celestial coordinates.

6. Summary and Outlook

The construction of the VERITAS observatory is nearing its completion as a four-telescope array at the basecamp of Whipple observatory. The instrument will be operated at this site for 2 years and then be moved in 2009 to its permanent site at Kitt Peak. We expect that the site at Kitt Peak will become available in early 2007. The basecamp is at an altidude of 1275 m which is substantially lower than the altitude of the permanent site at Kitt Peak (≈ 1840 m). We estimate that the energy threshold of VERITAS at the basecamp is 120 GeV compared to 100 GeV at Kitt Peak.

Figure 7 shows the array configuration; for real estate reasons the array configuration has three different baselines which is not critical to the sensitivity of the array. However, the different baselines will allow us to carry out systematic studies of energy threshold and collection area studies for short and long baselines. Currently as of October 2006, all four telescopes are installed at the basecamp (see Figure 8) including their major components. We are in the process of bringing the third and fourth telescope online. We plan to take first scientific data with the complete array by January 2007.

The science program for the next two years includes a survey of the galactic plane, detailed studies of supernova remnants, a dark matter search program and a survey of active galactic nuclei.

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[4] The parameter θ is the angular displacement from the putative γ-ray source. The background is flat in a θ^2 plot.
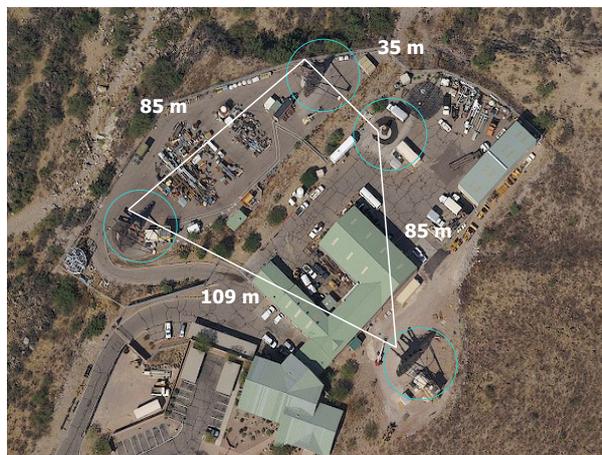
Figure 7. A bird's eye view of the Whipple observatory's basecamp as of June 2006 showing the geometry of the array configuration.

Figure 8. The basecamp of Whipple observatory is shown as of July 2006 with 4 telescopes fully assembled. The two telescopes on the left side are the first two used for stereo observations.

7. References

[1] Hinton, J. et al., 2004, *New Astron.Rev.* **48** 331
[2] Cortina, J. et al., 2005, *Astrophys.Space Sci.* **297** 245
[3] Enomoto et al., 2006, *Astrophysical Journal* **638** 397
[4] Weekes. T.C. et al., 1989, *Astrophysical Journal* **342** 379
[5] Pühlhofer, G. et al., 2003, *Astroparticle Physics* **20** 267
[6] Holder J. et al., 2006, *Astroparticle Physics* **25** 391
[7] Weekes. T.C. et al., 2002, *Astroparticle Physics* **17** 221