# Performance of the VERITAS-4 array

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**Abstract**

We present the simulated characteristics of VERITAS-4, a four telescope instrument, scheduled to be operational in 2005.

## 1. Introduction

The VERITAS experiment, which began construction in 2002, will be an array of seven 12 m Čerenkov imaging telescopes, located in southern Arizona, USA. The seven f/1.0 telescopes will be situated at the vertexes, and center, of a regular hexagon of side 80 m. The full, seven telescope, array will be completed in 2007. Details of the construction are given in [1].

Based on a detailed simulation of the trigger and extrapolation from the previously published seven telescope VERITAS characteristics [2], we present an analysis of the expected characteristics of the VERITAS-4 system, including angular resolution, collection area, peak response energy and sensitivity to Crab Nebula-like gamma-ray sources.

## 2. Trigger conditions

The VERITAS system uses a multi-level trigger to eliminate the majority of spurious background triggers. The three levels, "channel-level" (L1), "telescope-level" (L2), and "array-level" (L3) are employed to trigger the array on air-shower events while eliminating events from night-sky background (NSB) fluctuations and local muons. An L1 trigger of 5.6 photo-electrons, L2 requirement of three neighboring channels triggering within an 8 ns. coincidence time, and L3 requirement of three telescopes triggering within 40 ns are applied. A triggering rate of ∼1 Hz from the NSB and ∼200 Hz from cosmic-ray events results.

## 3. Reconstruction

Stereoscopic imaging of the air-shower with an array of telescopes allows the primary particle to be identified more accurately than with a single telescope.

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By combining the images from the individual telescopes, the type of particle, energy, arrival direction and impact parameter of the primary can be reconstructed.

The most likely origin of the gamma-ray is estimated by a least-squares approach. A model of the shower is constructed and the parameters of the model are adjusted to best fit the data from all telescopes. The shower is modeled as a line in three dimensions, with four parameters $\Theta = \{\theta, \phi, x_0, y_0\}$ representing the direction of propagation and impact location of the primary. For each photoelectron detected in each channel, a set of hypothetical, back-propagated Čerenkov photon rays are produced. The rays are constructed by starting at the appropriate PMT, reflecting off an idealized mirror (without aberration) and propagating back into the atmosphere. The parameters of the shower model are adjusted to minimize the sum of the squared distances between the axis and the set of hypothetical rays,

$$\mathcal{D}^2 = \sum_i^N {d_i}^2/N \tag{1}$$

The minimized value of $\mathcal{D}$ gives an estimate of the goodness-of-fit (in the $\chi^2$ sense) of the detected signals to the model that all the Čerenkov photons were emitted along the shower axis. The physical meaning of $\mathcal{D}$ can be seen by noting that, if the exact path of each detected photon could be traced, $\mathcal{D}$ would give the physical r.m.s. width of the Čerenkov emission region in the sky. Therefore, $\mathcal{D}$ is a useful parameter for discriminating between gamma-ray and cosmic-ray induced events.

## 4. Discrimination

Discrimination is done on the basis of the "width" of the emission region, by an energy dependent cut, $\mathcal{D} < \mathcal{D}_{\rm cut}(E)$. An energy estimator function is used to estimate the energy of each event, based on the shower image parameters. The cut on $\mathcal{D}$ is the applied to eliminate the "wider" hadronic showers. The width cut is very effective for energetic primaries which produce many Čerenkov photons. The efficiency decreases as the energy of the shower decreases.

For candidate point-source objects, the estimated arrival direction of the gamma-ray, $\{\theta, \phi\}$, is used to eliminate events which are inconsistent with having originated from the candidate. If $\theta$ is the angular distance between the candidate and the reconstructed photon, a cut of $\theta < \theta_{\rm cut}(E)$ is applied. The value of the cut is chosen to maximize the ratio of the gamma-ray signal to the square-root of the isotropic background. Again, the cut is most effective at higher energies.

## 5. Sensitivity to gamma-ray sources

The sensitivity to a gamma-ray source is expressed as the minimum observable flux the source must have to be detected with a certain significance in a

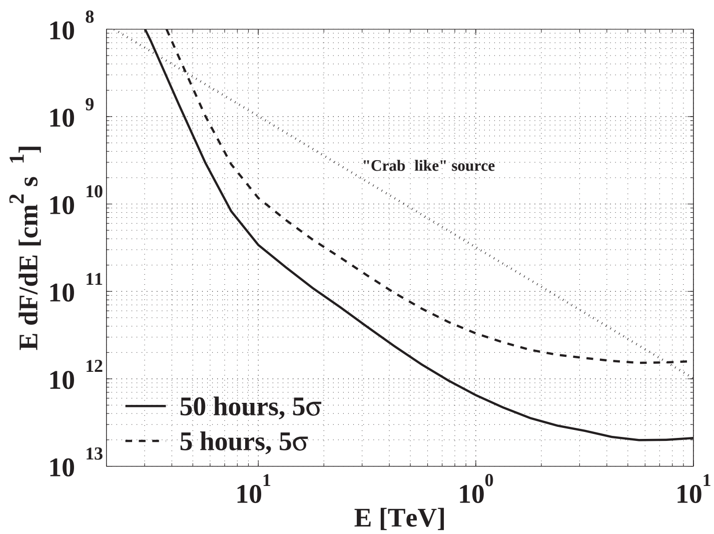


**Fig. 1.** Minimum observable gamma-ray flux for 50 and 5 hour observations with the VERITAS-4 array given a required detection significance of $5\sigma$ in each energy bin. The sensitivity is quoted for energy bins separated equally in log(energy) with four bins per decade.

certain exposure time within an energy-bin of a given width. A minimum flux sensitivity is calculated for a range of energy bins, separated equally in log(energy) with four bins per decade. Figure 1 shows the sensitivity of the VERITAS-4 array. For the case of a 50 hrs exposure, in the region E>2 TeV, the sensitivity limitation is gamma-ray statistics, a minimum of 25 counts are needed for a $5\sigma$ detection. At $\sim$1 TeV the most prominent background is cosmic-ray interactions for which approximately 85% of the primary energy is transferred to electromagnetic showers in the first few interaction. These events cannot be differentiated from gamma-ray events. At 200 GeV<E<$\sim$1 TeV cosmic-ray and cosmic-electron initiated events dominate approximately equally. At low energies, night sky noise affects the images of all events, strongly degrading the background separation.

## 6. Summary

Table 1 presents a summary of the characteristics of the VERITAS-4 array. The center telescope substantially improves the low energy performance of the VERITAS-4 array compared to the three telescope arrangement presented in [2].

## 7. Acknowledgments

This research is supported by grants from the U.S. Department of Energy, PPARC (U.K.) and Enterprise Ireland. S. Fegan acknowledges the support of the

**Table 1.** Summary of the characteristics of the VERITAS-4 sub-array.

| Characteristic | E | Value |
|---|---|---|
| Peak Energy [a] | | 110 GeV |
| Flux sensitivity[b] | at 100 GeV | $3.4\times10^{-11}$cm$^{-2}$s$^{-1}$ |
| | at 1 TeV | $6.5\times10^{-13}$cm$^{-2}$s$^{-1}$ |
| | at 10 TeV | $2.1\times10^{-13}$cm$^{-2}$s$^{-1}$ |
| Angular resolution[c] | 100 GeV | 7.5 arc min |
| | 1 TeV | 4.3 arc min |
| | 10 TeV | 1.6 arc min |
| Collection area[d] | 100 GeV | $3.3\times10^{8}$cm$^{2}$ |
| | 1 TeV | $2.2\times10^{9}$cm$^{2}$ |
| | 10 TeV | $3.0\times10^{9}$cm$^{2}$ |
| Crab Nebula | >30 GeV | 45/minute |
| gamma-ray | >100 GeV | 40/minute |
| rates[e] | >300 GeV | 15/minute |
| | >1 TeV | 4/minute |
| Energy resolution[f] | | <15% |

[a] Energy at which the differential trigger rate of photons from a "Crab Nebula - like" source is maximal for the given trigger conditions (see text for details).
[b] Minimum differential flux, $E\,dF/dE$ for a $5\sigma$ excess in 50 hours of observations within each energy bin with $\log_{10}(E_{i+1}/E_i) = 1/4$.
[c] Half-width of a two-dimensional Gaussian distribution which describes the central part of the distribution of reconstructed photon arrival directions. Actual acceptance aperture for photons may be larger (e.g. for spectroscopy), or smaller (e.g. for maximal significance detection) than this value.
[d] Collection area for 3/4 telescopes with a telescope trigger requiring 3 adjacent PMTs to detect >5.6 p.e. within an 8 nsec window.
[e] Gamma-ray rates for photons which trigger the VERITAS (Phase I) array. Depending on the science requirement, such as spectroscopy or new source detection, a data analysis strategy is chosen which will reduce gamma-ray rates by 30–70% while supressing dramatically the CR background.
[f] RMS $\Delta E/E$.

Predoctoral Fellowship program at the Smithsonian Astrophysical Observatory.

## 8. References

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2. Weekes T.C. et al. 2002, Astropart.Phys. 17, 41