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Absolute calibration of imaging atmospheric Cherenkov telescopes

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A calibrated laser pulse propagating through the atmosphere produces a flash of Rayleigh scattered light with an intensity that can be calculated very accurately when atmospheric conditions are good. This is used in a technique developed for the absolute calibration of ultra high energy cosmic ray fluorescence telescopes, and it can also be applied to imaging atmospheric Cherenkov telescopes (IACTs). In this paper we present the absolute calibration system being constructed and tested for the VERITAS project.

1. Introduction

The absolute calibration of IACTs is usually obtained from the lab measurement of the efficiency and gain of each detector element (light collecting mirrors, photo-detectors, electronics, etc.). The resulting calibration can be compared with muon arc images [5] although complications may arise from the differences in the wavelength spectrum of the light from muons and from the gamma ray showers of interest. Instrument performance is often monitored using relative calibration techniques [6]. The availability of a calibrated fast pulsed light source in the the sky would make the absolute calibration of these telescopes more straightforward and reliable. Using the work done for atmospheric fluorescence detectors of ultra high energy cosmic rays [7] [2] as a guide, we have obtained a preliminary absolute calibration of the VERITAS telescope 1 by measuring the Rayleigh scattered light from a pulsed laser shot toward zenith. The technique relies on the fact that for a known laser pulse energy and atmospheric temperature and pressure, the amount of Rayleigh scattered light reaching the telescope to be calibrated can be computed with high accuracy and compared with the signal amplitude actually recorded.

2. Observations

The VERITAS experiment [8] is an array of four 12 m telescopes under construction at Kitt Peak in Southern Arizona. Each telescope camera consists of 499 0.15^o spaced photo-multipliers arranged in a close packed hexagonal lattice covering a full field of view of 3.5^o. The first telescope to be constructed has been temporarily installed on the foothills of Mt-Hopkins at the base-camp of the Whipple observatory [4].

The calibration technique outlined above is complicated by fluctuating amounts of aerosols present in the atmosphere. Because of Mie scattering, aerosols increase the amount of light scattered off the laser beam. This is somewhat compensated by the correspondingly increased atmospheric attenuation from the laser to the telescopes. As a result, there is a specific distance between the laser and the telescope for which the effects of aerosol fluctuations cancel out. This distance depends on the details of the aerosol properties and has been shown to fall in the range of 3 to 5 km [9] for horizontal observation. For the preliminary tests reported in this article, a nitrogen laser (337nm) pointed at zenith is installed 3.0 km away from the telescope.

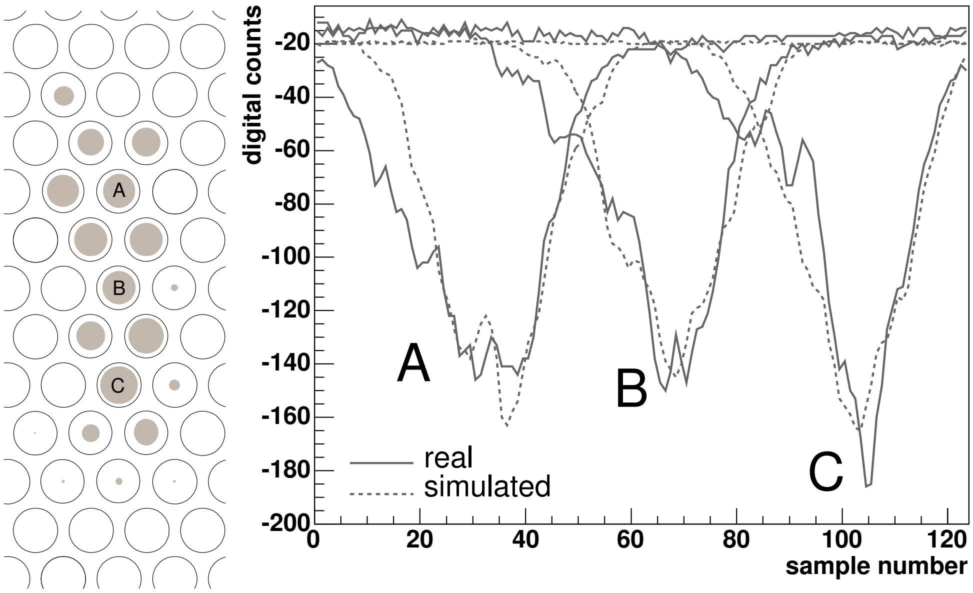

Figure 1. A laser event image is shown on the left. Each circle symbolizes one camera pixel the area of the grey disks indicate the time integrated signal from that pixel. The FADC traces are shown on the right for three pixels both in a real event (solid line) and in a simulated event (dotted line). Each sample corresponds to 2 nanoseconds.

The telescope is pointed at the laser 20^o above the horizon and intercepts the laser when it reaches an altitude of $\sim$ 1000m above ground level. Each laser pulse has a duration of 4 ns and an average energy of 25.5μJ with a 2% standard deviation. The pulse remains within the field of view for $\sim$ 575 ns and moves across one 0.15^o pixel in $\sim$ 25 ns. The telescope is focused at infinity and the laser pulse produces a spot in the focal plane corresponding to $\sim 0.22^o$. As a consequence, a given pixel can receive light from the laser pulse for as long as 60 ns. This also permits the laser flash to satisfy the trigger conditions, which require 3 pixels to exceed their threshold within $\sim$ 7ns.

Figure 1 shows the pixel map of one laser event. In these measurements we only recorded 124 samples (248 ns) from the FADC which is why the laser beam image does not extend all across the entire field of view. The pulse width and relative timing are consistent with the geometrical considerations outlined above. The VERITAS system should allow the recording of signals for as long as 64μs, so modifications to the acquisition software will permit longer integrations to be made in subsequent measurements.

3. Analysis

In order to analyze the data obtained with the telescope, we developed a detailed simulation of the experiment. The Rayleigh scattered light [1] is simulated according to the measured laser pulse energy (25.52μJ), local temperature (290.36^oK) and pressure (88700Pa) and taking into account the geometry of the setup. For this preliminary analysis, we have assumed the atmosphere to be locally isothermal. The telescope response to the flash of Rayleigh scattered light was obtained by using the GrISU simulation package [3]. In the simulation,

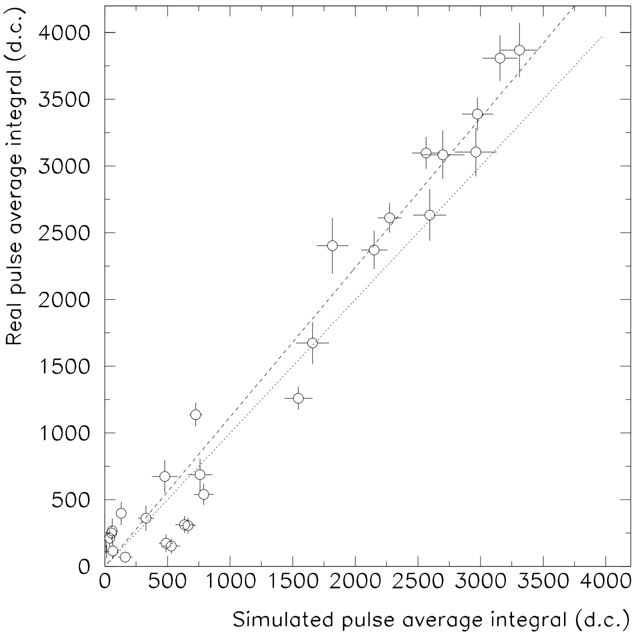

Figure 2. For each of the 39 selected pixels the averaged pulse integrals for 29 real events are shown as a function of the averaged pulse integrals for 29 simulated events. The dotted line represents equality between simulated and real data. The dashed line illustrates the 12% discrepancy we observed.

we positioned the laser to reproduce the event shown in figure 1. We selected 39 channels for which we calculated the average pulse integral both from 29 real events and from 29 simulated events. The simulated events appeared to contain less signal than the real events by $12.0 \pm 2.9\%$ where the error is statistical only. This result can be verified on a pixel by pixel basis as in Figure 2. Although this figure illustrates the accuracy of our simulations, it should not be used to obtain an absolute calibration for individual channels since the contents of each pixel depends strongly on the precise position of the laser beam image in the field. In fact, figure 2 results from optimizing the position of the simulated laser beam image to obtain the strongest correlation between simulated and real pixel contents. The resulting similarity of simulated and real data can be further verified by comparing pulse shapes as in Figure 1.

The systematic error is dominated by the residual effects from Mie scattering on aerosols. This is further complicated in our observation by the observing angle, which makes us sensitive to the aerosol vertical distribution. Systematic limitations can be obtained experimentally and optimized by observing the night to night fluctuations and minimizing them by adjusting the distance from the laser to the telescope.

4. Conclusions

The first results of this absolute calibration method applied to an imaging Cherenkov telescope are very promising. Further improvement will come from the elimination of the image time truncation, which complicates the analysis. The local atmosphere model must be improved to allow for non-isothermal conditions. The effects of the distance from the laser to the telescope still have to be investigated for a better understanding of the systematics.

5. Acknowledgments

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