Using GHz FADCs to Reject Hadrons from STACEE Data

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Abstract

Since March 2002, STACEE has been operating with a 1 GHz flash analog to digital converter (FADC) on each channel of its 64 heliostat detector. Prior to that time, all gamma-ray detections by STACEE relied solely on wavefront timing measurements. Now, with the FADCs, much more information on the lateral profile and charge content of the shower is measured. Here, we describe how the FADCs have been integrated into the operation of STACEE and report on some initial prospects for using this additional information to increase STACEE's signal-to-noise ratio.

1. Introduction

Current ground-based, gamma-ray telescopes rely on one of two methods to distinguish very high-energy gamma rays from the much more abundant cosmic rays. The 'imaging' method uses the Cherenkov light that reaches the ground to reconstruct an image of the shower development in the atmosphere. The 'wavefront sampling' method, used by STACEE and CELESTE [2,4], records the timing and amplitude of the Cherenkov wavefront at numerous locations on the ground. STACEE, built at the National Solar Thermal Test Facility in Albuquerque, NM, uses large steerable heliostat mirrors to collect the Cherenkov light from air showers. The light from each heliostat is then reflected to a secondary mirror where it is focused onto a photomultiplier tube (PMT). The signal from each PMT is discriminated and delayed before being combined with all PMT signals to form a trigger. In this way, the timing of the wavefront is recorded with nanosecond

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resolution. The STACEE-32 prototype telescope detected the Crab Nebula with good significance in 1998.[3]

We note that the trigger logic for STACEE is quite different from imaging telescopes. STACEE uses the Cherenkov information from 64 locations on the ground to demand a high-multiplicity, narrow-time coincidence. By itself, the coincidence effectively suppresses the majority of the cosmic ray background. We estimate that less than 2% of the cosmic ray showers above 200 GeV satisfy the trigger condition.

2. FADC Implementation

STACEE now uses 64 heliostats and has commercial 1 GHz FADCs (ACQIRIS DC270s) to record 192 ns of each PMT signal per event. The DC270s have 4 channels per board and operate in a compact-PCI crate. Four crates, each containing four boards, use a high speed real-time Linux operating system to locally record data. Each crate is controlled via Ethernet by a VME crate containing the trigger electronics. The cPCI/VME data for a typical 28 minute run at a trigger rate of 10 Hz comprise approximately 200 MB. Following a run, the data from all four PCI crates and the VME crate are transferred to a separate computer and merged into a single file which is then analyzed for data integrity and proper detector function. This analysis is typically done within 15 minutes of the end of the run. At the end of an observing night, additional calibration data (weather information, photometry, etc) are merged into the data stream and a low level analysis is done to correct for hardware oddities, calibrate the timing and pulse information, and calculate deadtimes and trigger rates.

3. Simulating the STACEE Detector

We are exploring new methods to improve the signal-to-noise by using the FADC data to reject cosmic ray background events. We use a suite of simulation tools to develop the methods which will then be applied to source data. First, Cherenkov light from simulated hadron and gamma-ray showers is ray-traced through the STACEE optics using a custom software package. The ray-trace package models the individual facets of the heliostats and secondaries (as well as occultation losses due to the PMT cameras) and produces photoelectrons at the PMT photocathodes. These photoelectrons are then propagated through another software package that simulates the STACEE trigger electronics and generates FADC waveforms that can be compared to real data. This electronics package models the single photoelectron pulse shape, PMT gains, night sky background and radio frequency noise pickup.

A set of proton simulations with energies between 0.1 to 10 TeV drawn from a spectrum with a differential index of -2.6 is used to test how well the

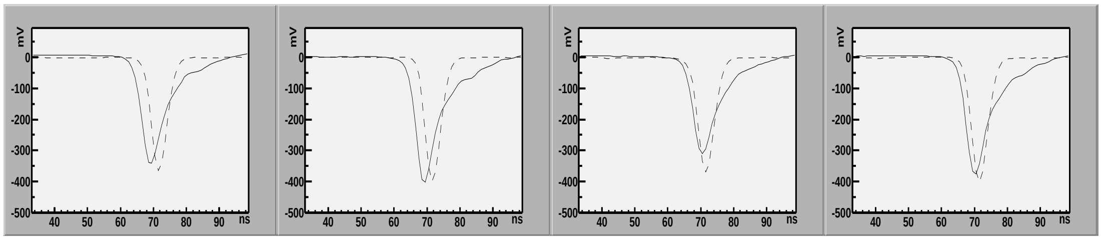

Fig. 1. The average FADC trace for 4 representative channels. The solid curves are for a real zenith data run and the dashed curves are for a simulated proton spectrum. The pulse amplitudes are reasonably well matched, indicating that we have a reasonable understanding of the conversion scale from incident light level to FADC amplitude. The pulse shapes in the simulations do not quite agree with the data; in the simulations the width's are narrower.

simulation packages reproduce the real data taken by STACEE. Figure 1 shows the average FADC trace for real zenith data and the simulated protons using an *a priori* value for the PMT gains. While the pulse amplitude is reasonably reproduced using the simulations, the pulse width and tail clearly need more work. We may be modeling the single photoelectron pulse shape inaccurately or calculating the photoelectron timing improperly. We are investigating these effects and other possible causes of the discrepancies. Because the pulse width errors will affect the charge reconstruction adversely, we will concentrate for now on what discrimination power can be derived using pulse amplitudes. R. Scalzo is investigating a different technique to discriminate against the background hadrons which includes the timing information [5].

4. Pulse Amplitude RMS as a Discriminant

Due to the nuclear interactions and the presence of local muons in hadronic showers, hadronic showers should produce a much less uniform lateral distribution of Cherenkov light on the ground than gamma-ray showers. Consequently, there will be larger variations in the pulse amplitudes for hadrons than for gamma rays. To quantify the variation, a 'scaled' RMS of the pulse amplitude is calculated according to

$$\sigma_{scaled} = \frac{\sqrt{\Sigma_i (PH_i - \overline{PH})^2}}{\overline{PH}} \tag{1}$$

where PH_i is the pulse amplitude of channel i. As a sanity check on the simulations, the σ_{scaled} of the pulse amplitude for all channels which have a pulse larger than the trigger discriminator threshold is plotted in Figure 2 for real zenith data and simulated protons. Except for some variation at large values of σ_{scaled}, there is reasonably good agreement between simulations and data.

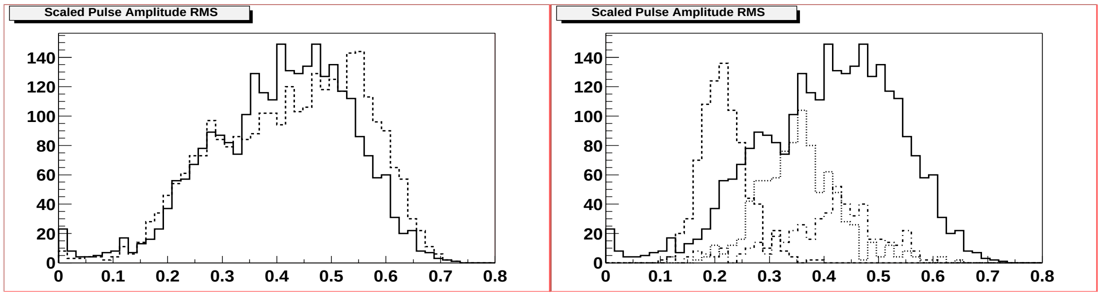

Fig. 2. **Left.** Distribution of the scaled, pulse-amplitude RMS, σ_{scaled}, for real zenith data from STACEE (dashed) and simulated protons (solid). **Right.** The same distributions for simulated gamma rays at 100 GeV (dashed), 300 GeV (dotted), and 500 GeV (dot-dashed) and simulated protons (solid). The lowest energy gamma rays show the most separation from the proton distribution.

Figure 2 also shows σ_{scaled} for simulated gamma rays of 100 GeV, 300 GeV, and 500 GeV compared to simulated protons. Clearly, the lower energy gamma rays show the most separation from the proton distribution. This point is important because one design goal of STACEE is to achieve as low an energy threshold as possible in order to detect AGN and other objects where we expect a low-energy cut-off or steeply falling spectrum [1]. Cutting at $\sigma_{scaled} < 0.3$ to 0.4 should reject one-half to two-thirds of the background while keeping a large fraction of the gamma rays.

5. Future Work

Although we must improve our simulations so they better match the data, the preliminary pulse amplitude results shown here are encouraging. Before a detailed study of discrimination techniques using the FADCs can begin, the pulse timing needs to be improved and many other quantities derived from the simulations need to be checked against the real data. Once the simulations match the data well, a systematic study of the pulse information space will be done to look for differences between gamma rays and hadrons. We will report on the progress in these areas at the conference.

6. References

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