Shower Reconstruction Techniques for the Solar Tower Atmospheric Cherenkov Effect Experiment

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ABSTRACT
The Solar Tower Atmospheric Cherenkov Effect Experiment (STACEE) is an atmospheric Cherenkov detector that detects astrophysical $\gamma$-rays using the shower-front-sampling technique. STACEE is a fully-operational detector utilizing 1 GeV Flash ADCs on all channels, providing important pulse height and timing information for discriminating between $\gamma$-ray and hadron events. We discuss shower reconstruction methodologies and gamma/hadron separation techniques that utilize the nanosecond timing and pulse height information provided by STACEE's Flash ADCs.

1 Introduction
1.1 STACEE

Figure 1: Photograph of the NSTTF in Albuquerque, New Mexico, showing the heliostat mirrors and the central receiver tower. STACEE uses the heliostat and tower as part of a desocrinising-sampling atmospheric Cherenkov telescope.

STACEE is a shower-front-sampling atmospheric Cherenkov telescope that uses the facilities of the National Solar Thermal Test Facility (NSTTF) in Albuquerque, New Mexico, USA [1]. The NSTTF is a solar energy research facility that incorporates a central receiver tower and an array of heliostats (solar mirrors). A total of 64 heliostats are used to collect Cherenkov light from air showers, providing a combined reflecting surface of $4\pi$ m$^2$. STACEE uses mirrors, in the central receiver tower to focus Cherenkov light reflected by the heliostats onto photomultiplier tubes (PMTs), with a one-to-one mapping between the heliostats and the PMTs, figure 2.

Cherenkov events are selected from amongst the night-sky background using a custom-built trigger system. In the event of a Cherenkov trigger, amplified and AC-coupled signals from the PMTs are recorded together with a GPS timestamp, using 4-MHz FADCs (one per PMT). The FADCs provide important temporal and intensity information, at a sampling rate of 1 GS/s.

1.2 The Energy Range of STACEE

STACEE operates at around 100 GeV, in the energy region between space-based detectors and ground-based imaging atmospheric Cherenkov telescopes. By using the very large mirror area heliostats of the NSTTF heliostats, STACEE achieves an energy threshold between 100 GeV and 200 GeV for the detection of $\gamma$-rays, the energy threshold of an atmospheric Cherenkov telescope scales approximately as $\lambda^{-1/2}$. This relatively low energy threshold allows STACEE to detect $\gamma$-rays in the poorly sampled energy region below $\sim$200 GeV, figure 3.

![Space telescopes Atmospheric Cherenkov Detectors Air shower arrays (Below 50 GeV) Air shower arrays (Above 50 TeV)](image)

Figure 3: STACEE operates at around 100 GeV in the energy region between space-based detectors and ground-based imaging atmospheric Cherenkov telescopes. The energy threshold of an atmospheric Cherenkov telescope scales approximately as $\lambda^{-1/2}$. This relatively low energy threshold allows STACEE to detect $\gamma$-rays in the poorly sampled energy region below $\sim$200 GeV, figure 3.

2 Shower Reconstruction
2.1 Overview

In the development of shower reconstruction methods, simulated $\gamma$-ray and cosmic-ray air shower data were employed: STACEE uses the CORSIKA air shower simulations package [3]. Custom ray-tracing and Monte-Carlo algorithms are used to simulate the telescope optics and electronics.

To reconstruct the properties of the primary photon, an accurate estimate of the shower core location is required. The shower core position on the heliostat field is the point at which the primary would impact, were it to travel unobstructed through the atmosphere. Three techniques used by STACEE for shower core location are described below.

2.2 Early Shower Method

The grid alignment method, developed by the CELESTE collaboration, involves generation of a large number of Monte-Carlo simulated charge templates that represent the charge from each PMT under various conditions. Templates are compiled using showers simulated over a large range of zenith angles, shower maximum points, and core locations. By finding the template that best matches a particular event, an approximate core location for that event is obtained. The mean core resolution for $\gamma$-rays obtained using this method is $\sim$22 m.

2.3 Grid Alignment Method

The grid ratio parameter was developed by the CELESTE collaboration [9] and is closely related to the grid alignment method for finding the shower core, described earlier.

When correctly realigned for the shower maximum position, the parameter $H/W$ of the summed FADC traces is at its greatest value. As shown in figure 6, $H/W$ for $\gamma$-rays falls off rapidly from the shower maximum position. Grid point contributions to the grid ratio are proportional to their projection onto the heliostat field.

The CELESTE group parameterizes the $H/W$ fall-off using the ratio of the average $H/W$ calculated at a distance 200 m away from shower maximum, to $H/W$ at shower maximum, $H/W_{200}/H/W_{max}$. This ratio, referred to here as the grid ratio, is a powerful gamma/hadron discriminant for the shower-front-sampling technique. Its power in STACEE simulations is demonstrated in figure 7. Application of a grid ratio cut, determined from simulations, to STACEE Crab Nebula data has proven quite successful.

3 Gamma/hadron Separation
3.1 Overview

At present two main $\gamma$-hadron separation parameters are employed by STACEE, the shower direction and the grid ratio (referred to as $\Gamma$ by the CELESTE collaboration). Both require an estimate of the shower core position.

3.2 Grid Ratio

The grid ratio parameter was developed by the CELESTE collaboration [9, 6] and is closely related to the grid alignment method for finding the shower core, described earlier.

4 Conclusion

Using FADC data STACEE can locate the core of $\gamma$-ray showers with an accuracy of $\sim$21 m, according to simulations. Two gamma/hadron discriminations, the reconstructed shower direction and the grid ratio parameters, show great potential to improve STACEE's sensitivity to $\gamma$-rays.

References
[1] Bengtsson, O., et al., 2003, in these proceedings

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![Image of shower direction reconstruction method used by STACEE.](image)