Optimized Pointing Strategies for Solar Tower ACTs

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Abstract

We discuss simulations of novel heliostat pointing configurations designed to improve the angular and energy resolution of a solar tower wavefront-sampling atmospheric Cherenkov telescope. One such configuration will be tested via observations of the Crab Nebula with the STACEE detector in the fall of 2003.

1. Introduction

Solar tower atmospheric Cherenkov telescopes, such as the STACEE detector in Albuquerque, NM, and the CELESTE detector in Themis, France, use heliostat mirrors at a solar array facility to collect Cherenkov light from air showers initiated by astrophysical gamma rays [1,2,3]. They are "wavefront-sampling" telescopes in that they measure an intensity and arrival time of the Cherenkov wavefront at each heliostat, from which the energy and arrival direction of the gamma ray can be reconstructed. The very large ($\sim 10^3$ m^2) mirror collection area provides a low energy threshold (< 100 GeV) for detection of gamma rays.

Since the heliostats are independently steerable, the question immediately arises: how should they be aimed to achieve optimal performance for the experiment? Most of the Cherenkov light for air showers initiated by ~ 100 GeV gamma rays is produced near the height of shower maximum. Aiming all the heliostats towards a single point in the atmosphere at this height, a strategy called *convergent pointing* or *monocanting*, optimizes light collection for intrinsically dim air showers and achieves the lowest possible energy threshold. However, monocanting

pp. 2799–2802

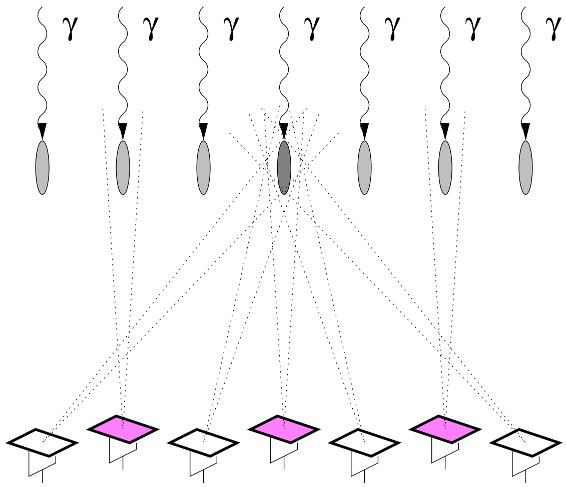

Fig. 1. Cartoon of the paracanting configuration. The gray ovals depict different possible positions for shower maximum of an air shower initiated by an astrophysical gamma ray. White heliostats are aimed at a single point in the atmosphere to provide high sensitivity for air showers developing at that point. Shaded heliostats are pointed parallel to provide information about the location of shower maximum for air showers developing far from this point.

gives very limited information about air showers developing at other points in the atmosphere, i.e., it degrades sensitivity to the shower core position. This is the dominant source of systematic error limiting the angular and energy resolution of STACEE and of other solar tower Cherenkov telescopes.

Other pointing strategies trade off energy threshold for information about the shower core or the lateral distribution by aiming some of the heliostats to other points in the atmosphere, e.g. [3,4]. In investigating such optimized strategies, we focus on obtaining shower core information in order to improve the angular resolution of the instrument. This translates directly into improved discrimination against air showers initiated by hadronic cosmic rays, and hence improved sensitivity, when observing point sources of gamma rays such as active galactic nuclei. Figure 1 depicts a strategy which we call *paracanting*, in which a subset of heliostats are pointed towards the celestial source at infinity.

Below we present a detailed comparison of monocanting with paracanting using simulations and reconstruction algorithms developed for STACEE.

2. Core reconstruction simulations

The following studies were performed using the CORSIKA air shower Monte Carlo simulation [5] and the standard STACEE optical ray-trace and electronics simulations. For the monocanting configuration, all 64 STACEE heliostats were aimed at a single point in the atmosphere 12.5 km ASL; for paracanting, a subset of 16 of these heliostats were instead pointed parallel, towards the celestial source of gamma rays. These 16 heliostats were chosen so as to provide uniform coverage in area over the heliostat array without introducing biases into the topology of STACEE's two-level coincidence trigger. Gamma rays were simulated on a power-law energy spectrum ($E^{-2.3}$), with shower cores scattered uniformly in area out to a distance of 250 m from the geographic center of the heliostat array.

The simulations were formatted as real data, including PMT traces from STACEE's 1 GHz waveform digitizers. The effects of realistic levels of night sky background light and of radio interference on the simulated traces were taken into account. For each event, a charge in photoelectrons on each channel was obtained by integrating the corresponding digitizer trace in a window around the arrival time of the global event trigger, regardless of whether that channel crossed threshold to participate in the trigger. The charges were then fit to a template derived from a separate set of simulations of the expected pulse charge on each channel, using a maximum-likelihood method to extract a core location and primary energy. The core resolution σ_c is defined such that 68% of a given sample of simulated events had reconstructed shower cores within σ_c of their actual shower cores.

Figure 2 shows the core resolution as a function of primary energy and of distance of the core from the center of the heliostat array, which for STACEE is (by construction) the position for which the monocanted heliostats collect the most light. Showers at the lowest energies are detected only near the center of the array, so the two configurations hold comparable accuracy there. At high energies, or for core locations in the outer part of the heliostat array, the monocanting configuration loses reconstruction accuracy, since it is incapable of distinguishing between a low-energy (intrinsically dim) shower landing near the center of the array and a high-energy (intrinsically bright) shower landing far from the center. Paracanting is designed to break this degeneracy, and it retains accuracy for these showers. As a result, paracanting also provides better energy resolution than monocanting, typically improving from 40% to 25% (spectrum-averaged).

The behavior shown above is generic. For the plots shown, the celestial source was placed at zenith, but comparable resolution is obtained at typical source zenith angles. The results do not depend on the precise method used to find the Cherenkov pulse charges on each channel, except as respects their sensitivity to night sky background noise, which must be present at unusually high levels to cause significant degradation in the core resolution. Uncorrelated systematic uncertainties in the responses of different channels (heliostat optical throughput, PMT gain, etc.) also affect the reconstruction only weakly, and the scaling behavior of the templates ensures that uncertainty in the overall response only affects the absolute energy scale and not the core position.

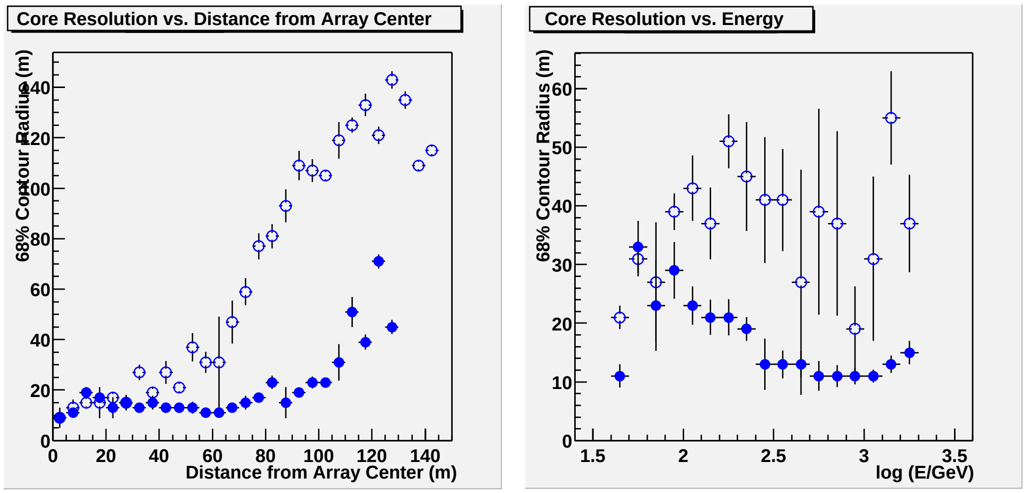

Fig. 2. Core reconstruction for $E^{-2.3}$ spectrum of vertical gamma ray air showers. Left: core resolution vs. distance from the center of the array. Right: core resolution vs. energy. Open markers: monocanting; solid markers: paracanting.

3. Influence on instrument performance

Use of core information in STACEE's event reconstruction can have a dramatic effect on performance. Angular resolution from wavefront timing fits can improve by a factor of two or more when using paracanting instead of monocanting, depending on the level of night sky background. A cut on the goodness-of-fit from the core fit can provide an additional quality factor of up to 1.7 for hadron rejection, although this cut is biased against high-energy showers ($>$ 500 GeV).

The impact on the energy threshold should be fairly low. The total trigger rate for gamma rays and for hadrons in paracanting should be 10% lower than monocanting. In limited field testing, STACEE's actual hadron trigger rate at zenith was observed to decrease by just this amount. The change in effective area above 100 GeV should be negligible.

Further comparison of monocanting and paracanting will take place in the fall of 2003, when STACEE will observe the Crab Nebula in both configurations.

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