The track imaging Cerenkov experiment

S. A. Wissel[1] **and E. Hays**[1,2] **for the TrICE collaboration**[1,2]

[1] Enrico Fermi Institute and Department of Physics, University of Chicago, Chicago IL 60637, U.S.A.

[2] Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439, U.S.A.

E-mail: `wissels@uchicago.edu`

Abstract. The Track Imaging Cerenkov Experiment (TrICE) aims for a ground-based measurement of high energy cosmic-ray composition using a novel technique. By separating the Cerenkov emission from the primary and secondary particles, nearly elemental charge resolution can be established. Here the status of the TrICE experiment is discussed.

1. Introduction

It is generally accepted that acceleration in the outer shell of galactic supernova remnants (SNRs) accounts for the cosmic ray flux below the knee. In order to test this model, measurements of the elemental composition are needed to as high energy as possible. This presents a problem, because the cosmic ray spectrum falls off quickly at high energies. Traditional ground-based (indirect) instruments can provide the necessary area and identify primary nuclei by observing the secondary products of their air shower interactions. However, these techniques depend strongly on hadronic interaction models ([2]) and suffer large event-to-event fluctuations and are, at best, logarithmically dependent on shower observables (see e.g. [3]).

Spaced-based detectors provide unprecedented charge resolution, but they have relatively small effective areas and therefore limited statistics at higher energies. The direct Cerenkov method is an attractive tool for gamma-ray and cosmic-ray studies because it combines the effective area of ground-based telescopes with the charge resolution of space-borne instruments.

The direct Cerenkov (DC) technique determines the charge by separating Cerenkov light generated by the primary particle from that of the secondaries in the extensive air shower (EAS). The primary initiates Cerenkov radiation upon entering the atmosphere, microseconds before the EAS begins. Due to the slight velocity difference between photons and relativistic particles, the arrival of the DC photons at ground level is delayed by a few nanoseconds. Because the DC light is emitted at a narrow angle, and the air shower light scatters due to the interactions of the secondary particles, there is an inherent separation in the arrival angle of the two signals. Cerenkov light production scales with the square of the primary charge and is a strictly electromagnetic effect. Thus, by determining the intensity of the DC light one can measure the composition independently of poorly understood hadronic interaction models [3]. The imaging atmospheric Cerenkov telescope array, H.E.S.S., has already seen evidence of this effect [4].

2. Description of the Detector

The Track Imaging Cerenkov Experiment (TrICE) is a fixed-mount Cerenkov telescope designed to look for DC light from cosmic-ray nuclei. It aims to acheive high resolution shower imaging and employs a specialized design to provide an optical trigger. A Fresnel lens mounted directly above the camera plane enables a trigger signal for a delayed (by $\sim 20ns$) and magnified image of the Cerenkov light, which is focused onto the camera by mirrors. Eight spherical mirrors are arranged on a square perimeter around the base of the telescope. These are focused onto the camera via a secondary planar mirror that also serves as a frame for the Fresnel lens.

TrICE has a primary mirror area of 6.4m^2, which is achieved by eight 1-m spherical mirrors with focal lengths of $4m$. The 3.7° wide field-of-view of the Fresnel lens is larger than the 1.5° mirror acceptance angle, allowing triggers from a larger region than the field of view. The TrICE camera consists of 16-channel Hamamatsu R8900 multi-anode photomultiplier tubes (MAPMTs). Currently, 16 MAPMTs are installed for a total of 256 pixels each having an angular width of 0.08°. The PMT signals are read out using a customized ASIC that digitizes continuously at 53 MHz over a dynamic range of 16 bits. TrICE began operating on March 3, 2006 before the instrument was fully completed. Twelve MAPMTs were used in conjunction with four spherical mirrors (1.5° fov). The trigger configuration effectively required the sum of the channels of a single PMT to exceed 15 photoelectrons. A pattern trigger was used which required the coincidence of at least 2 MAPMTs. Commissioning work has focused on characterizing the system, in an attempt to optimize the timing and spatial resolution of the instrument.

3. High Resolution Camera Studies

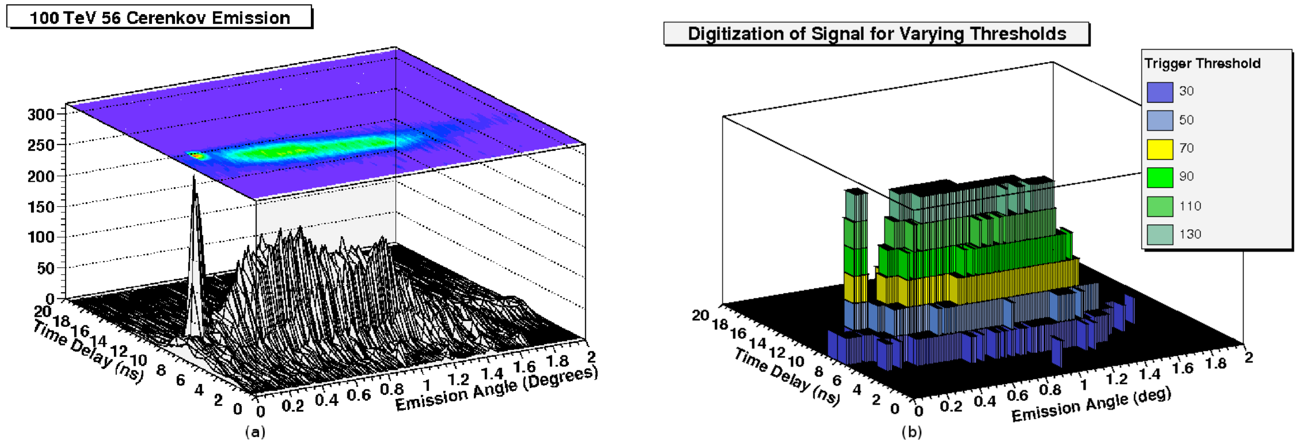
Air shower simulation studies indicate that sufficient timing and angular resolution permit the discrimination of the DC light from the EAS. The separation efficiency depends on the geometry of the cosmic ray shower and the energy and charge of the cosmic ray [3]. These restraints confine the direct emission to a narrow angular region and late arrival time on the ground relative to that of a non-interacting particle. Figure 1 illustrates the shower of a 100 TeV ^{56}Fe cosmic ray. The DC peak is a factor of 3 times greater that the air shower maximum. The DC peak remains visible at different trigger thresholds (Figure 1) suggesting that an imaging Cerenkov telescope with 0.01° angular resolution and nanosecond timing resolution could distinguish the peak easily. Note that in Stage 1, TrICE has a time resolution of $20ns$ and is limited to detecting DC light using the angular properties of the shower development. The best candidates for this are high charge primaries that interact relatively deeply in the atmosphere.

A 100 TeV ^{56}Fe shower simulation with an impact parameter of $72m$ demonstrates the separation that is possible. Assuming an overall collection efficiency of 20% and applying the appropriate timing cuts, the DC peak is visible as the peak near the leading edge of the image integrated over the duration of the shower.

The TrICE prototype also provides a testing ground for future gamma-ray observatories that use imaging atmospheric Cerenkov telescopes (IACTs). As shown by the simulation of the 50 GeV gamma ray (Figure 2), Cerenkov light from gamma rays at the low energy threshold of current IACTs, such as VERITAS, arrives in a broad enough time and angular band that an array of telescopes designed like TrICE would lose little information in using single-bit electronics. Furthermore, identifying cosmic rays by their DC peak could be an interesting approach to reducing the cosmic ray background in gamma-ray studies.

4. Discussion

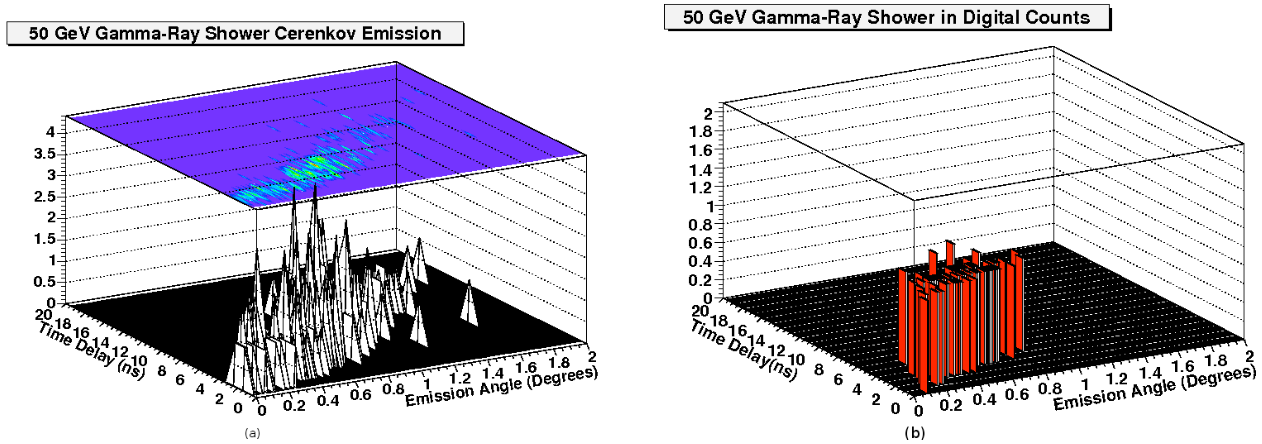
The DC method has potential for identifying high energy cosmic rays on an event by event basis. TrICE uses novel optics to enhance the time delay between the DC light and the extensive air shower, as well as small pixel spacing to enhance the angular separation between the broad air



(a)

(b)

Figure 1. Simulated Cerenkov emission due to a 100 TeV ^{56}Fe nucleus collected in bins of $1ns$ resolution in time delay and 0.01° resolution in emission angle. (a) Photons falling in a radius between 67 and $94m$ from the shower core reveal a well-defined peak at small angles from the DC light. (shown here in arbitrary units) (b) If this signal is digitized at several thresholds, the DC peak remains visible.



(a)

(b)

Figure 2. Simulated Cerenkov emission from a 50 GeV gamma ray with 1ns time resolution and 0.01° angular resolution, but with an effective area of $500m^2$ and added night sky background fluctuations. (a) Broad distribution in both angle and time as the gamma ray sweeps across the region. (arbitrary units) (b) When digitized at a single threshold, the shower structure and total counts remain intact.

shower and the narrow Cerenkov cone emitted by the primary particle. Stage 1 operation is currently underway, permitting experimentation with this new technique and camera design.

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