University of Utah
UNDERGRADUATE RESEARCH JOURNAL

RECONSTRUCTION OF COSMIC RAY GEOMETRY USING CHERENKOV BACKSCATTERING

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When high-energy cosmic rays enter the atmosphere, they create a shower of charged particles. These particles interact with atmospheric nitrogen, causing it to fluoresce. Many experiments (including the University of Utah's Telescope Array Project) observe this fluorescence and use it to determine the properties of the primary cosmic ray. They often use a stereo observation – viewing the shower from multiple directions to better reconstruct its axis. Stereo reconstruction is accurate but can be expensive and complex. The simpler alternative is monocular reconstruction, which relies on a single detector and uses the arrival times of fluorescence photons to estimate the tilt of the axis. Monocular reconstruction requires fitting a function of three correlated free parameters and generally gives lower quality results.

Our research tests a Cherenkov-assisted method of monocular reconstruction. Cosmic ray showers produce a narrow cone of Cherenkov radiation as they descend through the atmosphere. This radiation reflects from the ground and back into the detector. Because it is a fixed point along the axis, the position of the reflection can be used to reduce the number of parameters in the monocular fit.

We use a Monte Carlo simulation to determine the performance of the Cherenkov-assisted method. Source code can be found at github.com/mattdutson/cherenkov_simulator. In each iteration, a cosmic ray is created and propagated through the atmosphere according to standard models. Ray tracing is used to simulate the detection of both fluorescence and Cherenkov radiation. If the reflection point is visible, the assisted reconstruction is performed and compared to a standard monocular reconstruction. In addition to the Monte Carlo showers, some individual test cases were simulated. One such test is shown in Figure 1.

The Monte Carlo reveals that the Cherenkov-assisted method offers an advantage when the reflection point is near the detector (see Figure 2). The brightness of the Cherenkov reflection decreases more quickly than the fluorescence track, causing the two to blend together at large distances. The height of the detector determines the exact distance at which this occurs. For a detector 200 meters above the ground with resolution 0.086 degrees, we find that the Cherenkov-assisted method offers an improvement for 45 percent of showers. In these cases, the mean absolute error in impact parameter drops from 15.6 to 10.7 percent. Unfortunately, there are high requirements on the resolution of a Cherenkov-assisted detector, and this results in a greatly increased cost (on the order of $3 million). Therefore, despite the improvements in accuracy seen, this method does not appear to be practically viable.

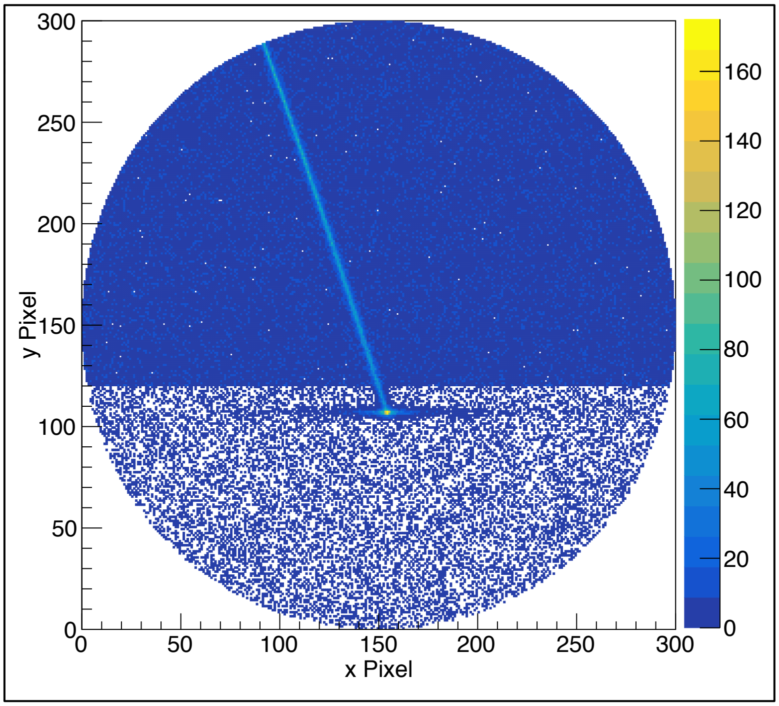

Figure 1: A simulated cascade and Cherenkov reflection for a typical cosmic ray. The fluorescence track is a bright line starting at the top left corner of the image. The Cherenkov reflection point can be seen near pixel (150, 100). The horizon is marked by a decrease in background noise near y=120.

Figure 2: A comparison of performance versus reflection point distance for the traditional monocular and Cherenkov-assisted methods. The new method offers improvement as long as the ground reflection point is within about 30 kilometers.