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Measuring air shower speeds with the HiRes Fluorescence Detectors

Phillip Morrison and Lawrence Wiencke for the HiRes Collaboration

High Energy Astrophysics Institute, Physics Dept., Univ. or Utah

Abstract. Using the HiRes stereo fluorescence detectors, the three-dimensional geometry of an extensive air shower may be found without assuming the shower is traveling at c. Since speed is not a constraint, it can be measured. The method can be tested on pulsed "flashers" and lasers where the geometry (and speed) is known. A preliminary measurement of shower speeds will be presented. This technique is also sensitive to objects which do not travel at c.

1 Introduction

Electromagnetic air showers are known to travel at the speed of light. However, no measurement of high energy air shower speeds has been made above the ground. The stereo High Resolution (HiRes) Fly's Eye detectors at Dugway, Utah, can make this measurement because the location and direction of an air shower can be determined independently of the shower speed. The HiRes instrument is also sensitive to shower-like objects which travel across the sky at speeds other than c; candidates include M $\sim 10^{10}$ GeV magnetic monopoles (C.O. Escobar and R.A. Vázquez, 1999), heavy particles (F. Halzen and H.C. Liu, 1985), and micrometeorites. The process of searching for these objects provides a less traditional test of shower reconstruction techniques.

2 Detection Method

Each HiRes detector consists of a large number of photomultiplier tubes (PMTs) of known position and pointing direction. The angular speed of an extensive air shower (more properly, the angular speed of the air shower front) may be determined from the time development of the shower image across the PMTs. The actual speed of the air shower may also be determined if the direction and location of the shower are known.

Correspondence to: L. Wiencke
(wiencke@cosmic.utah.edu)

In this study, it is assumed that this speed is approximately constant. It is further assumed that the width of an air shower is small in comparison to its length, and that all light detected from the shower has traveled at c in a straight path toward the detector (i.e., the photons are not multiply scattered). Hence, the shower is approximated as a moving point source and the photon detection times can be expressed as:

$$t_p = t_0 + \frac{d_c}{c} + \frac{d_v}{v} \tag{1}$$

where t_0 is some time offset, d_c is the distance between the shower point (from which the light originated) and the detector, and d_v is the distance between the shower point and shower core. The shower core is defined as the point at which the shower vector crosses the plane of zero elevation in a coordinate system originating at HiRes 1. It is also considered the point at which t = t_0. See Figure 1.

In this simple model, t_0 and v remain constant. Their values are calculated using a two-parameter fit based on minimizing the sum of the difference squared of the time predicted by the equation above, t_p, and the time measured by the detector, t_m. A statistical value, σ, is also calculated:

$$\sigma = \sum_{i=1}^{n} \frac{(t_p - t_m)_n^2}{N} \tag{2}$$

where N = n is the number of triggered tubes (tubes which detected light) used in the fit. After the data have been fit and a value for σ has been obtained, all tubes whose t_p and t_m values are not within 5σ of each other are "cut" and all values are re-calculated. The process is re-iterated until no further tubes must be dropped. The value of v which results from the final fit is then recorded.

Several other assumptions are made in this measurement of air showers speeds. Tube trigger times are predicted based on a shower description consisting of a vector and a point through which it passes. This assumes that the shower travels along a straight line and is of relatively small width. Since the direction in which the light was scattered toward the detector is also represented as a line, it and the shower vec-

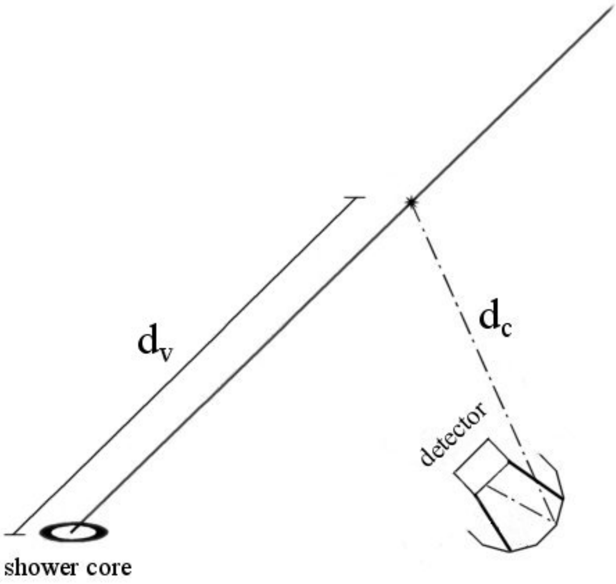

Fig. 1. A simple diagram of shower speed components.

tor cannot truly intersect. Consequently, the location of the shower point must be redefined as the point of closest approach of the vectors of the shower and triggered tube. In the data presented below, all tubes which point more than two degrees from the the calculated location of the light source are treated as “noise” and not considered in the speed fit.

3 Testing with Laser and Flasher Data

Figure 2 shows a typical laser shot as seen by the HiRes 1 detector. Each pixel represents one photomultiplier tube, having a one degree by one degree field of view. Pixels which stand out from the background represent triggered tubes. The speed of this laser track can be measured using the above tube trigger times and the laser location and pointing direction.

The data for the laser shot in Figure 2 is plotted for one spatial and one temporal coordinate in Figure 3. Each gray point represents a triggered tube used in the measurement. The x-coordinate is the time at which it triggered relative to t_0. The y-coordinate is the distance from the laser position to the shower point.

The curvature of the line is due to the laser’s progression toward and then away from the detector. Since scattered light takes less time to reach the detector when the light’s source is near, tubes trigger more frequently as the source approaches the detector and less frequently as it recedes. A gap in the data appears where the laser passed over a gap between mirrors. For comparison, the dark points which overlie the lighter points correspond to the predicted times a for perfect v = c source. The laser data aligns itself well with the v = c prediction, as expected.

Figure 4 shows the orientation of HiRes 1 and HiRes 2 relative to several vertical “flashers” (for a description of flash-

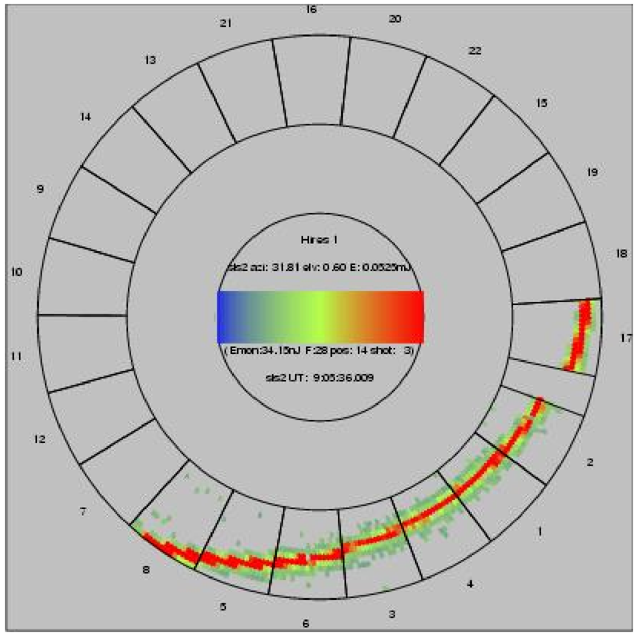

Fig. 2. A typical laser shot as seen by the HiRes 1 detector. The laser is located at HiRes 2 and the track shown here travels from left to right.

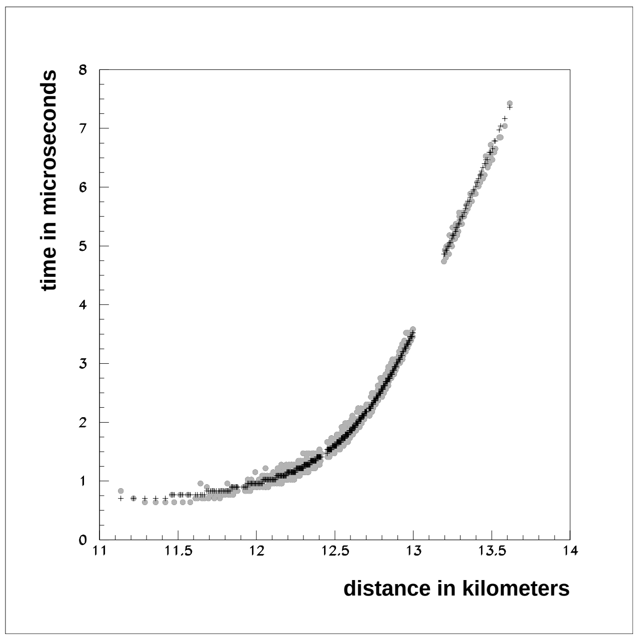

Fig. 3. A typical laser shot represented spatially and temporally.

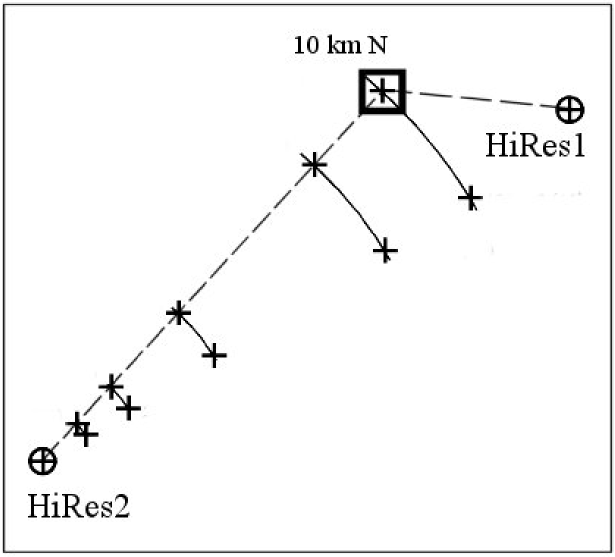

Fig. 4. The 10 km N flasher's position relative to HiRes 1 and 2.

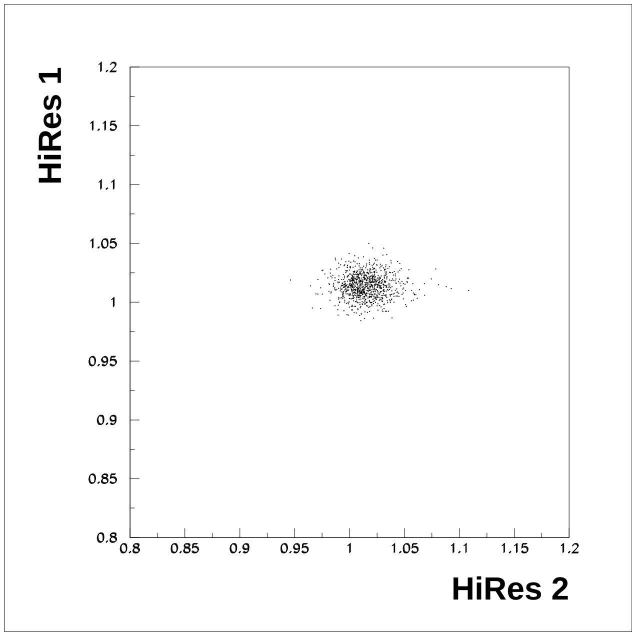

Fig. 5. Speeds (normalized to c) of the flasher shown in Figure 4 as measured at HiRes 1 vs. those at HiRes 2.

ers, see L.R. Wiencke, et al., 1999). A calculation of the flasher plane (the plane which intersects the flasher shot and detector) can be made using data like that represented in Figure 2. If the flasher shot is seen by two sufficiently distant detectors, the actual location and direction of the flasher shot may be determined by finding the intersection of the flasher planes, although, for these measurements, the known position and direction of the flasher are used. (For more information on stereo fitting, see Kevin A. Reil and R. Wayne Springer, 2001.) Like the laser of the example above, flashers produce tracks traveling at c and can be used to test methods for determining the speed of an air shower.

Figure 5 shows the results of one such test performed on data from the flasher which appears boxed in Figure 4. Here the measured speeds (in multiples of c) at HiRes 1 on the y-axis and HiRes 2 on the x-axis are plotted for a sample of nearly 1000 shots. To obtain these points, data from HiRes 1 and HiRes 2 were time matched and merged. In this example, the RMS was 1% for HiRes 1 speeds and 1.7% for those of HiRes 2.

4 Conclusion

We have tested the technique on flasher and laser tracks. For these sources, the speed measurement resolution is in the range of a few percent. This study is being extended to include more laser geometries and other flashers. Analysis of one year of air shower samples is also in progress and will be presented.

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References

C.O. Escobar and R.A. Vázquez, Are high energy cosmic rays magnetic monopoles?, Astroparticle Phys. 10, 422, (1999).

F. Halzen and H.C. Liu, Evidence for stabilized strange-quark matter in cosmic rays? Phys. Rev. D Vol. 32 No. 7, 1716, (1985).

L.R. Wiencke, et al., Radio-controlled Xenon Flashers for Atmospheric Monitoring at the HiRes Cosmic Ray Observtory, Nucl. Instr. Meth. A428, 593, (1999).

L.R. Wiencke, et al., Steerable Laser System for UV Atmospheric Monitoring at the High Resolution Fly's Eye, in Ultraviolet Atmospheric and Space Remote Sensing: Methods and Instrumentation II, G.R. Carruthers, K.F. Dymond, Editors, Proc. of SPIE Vol 3818, 46-55, 1999.

Kevin A. Reil and R. Wayne Springer, Preliminary Stereo Results from the High Resolution Fly's Eye Cosmic Ray Observatory, Proc. 27^{th} ICRC, (2001).