Preliminary Analysis of Monocular HiRes Prototype Data

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ABSTRACT

The HiRes prototype detector with 14 mirrors has been operational for more than two years. Some air showers are observed in coincidence with other detectors (CASA, MIA, FE2, HiRes2). However, here we examine the larger data set which includes showers observed by the HiRes prototype alone. We describe the analysis techniques of shower reconstruction for the monocular data. Preliminary distributions are reported. We have also done a pilot study search for point sources.

1. Geometrical reconstruction

The shower track and the detector determine a plane called the "trackdetector plane." The technique for finding that plane is described by Bird *et al.*[1]. The track within the plane has to be determined by the phototube firing times in the monocular case. As the shower front moves in space, the tubes fire sequentially in time. The tube trigger times are related to the track geometry by the equation below

$$t_i = t_o + \frac{R_p}{c} cot \frac{\psi+\chi_i}{2}.$$

Here t_i is the trigger time for the ith tube, t_0 is the time when the shower front passes the detector, R_p is the impact parameter (the shortest distance from the detector to the track), *c* is the light speed, *ö* is the angle the shower axis makes with the horizontal line in the track-detector plane[2], and $\div_i$ is the angle of each tube's direction with respect to that horizontal line. The shower axis is found by fitting the data pairs (t_i, $\div_i$) for the geometry parameters R_p and *ö*. The angle $\div_i$ when the track is first seen defines a pointing direction (unit vector) V_1. The last observed point on the track is another direction V_2. The angular separation of V_1 and V_2 is the observed "track length." The cosmic ray direction of origin must lie outside the range of observed track, somewhere between V_1 and – V_2. We first step through all the possible directions with a step size of 1 degree. Recall that the grid search is one dimensional since the track has to be in the plane. The parameters t_0 and R_p are determined for each trial *ö* by minimizing the $\div_2$ with respect to t_0 and R_p. After the minimum $\div_2$point is located, we do a refined search around that point.

A significant portion of our events are Cherenkov blasts or Cherenkov contaminated events. Those events are easily removed by cutting on the angle between the first phototube's pointing direction and the fitted track's direction of origin(minimum viewing angle). The plots shown in this paper exclude those Cherenkov contaminated events in which the minimum viewing angle is less than 5 degrees.

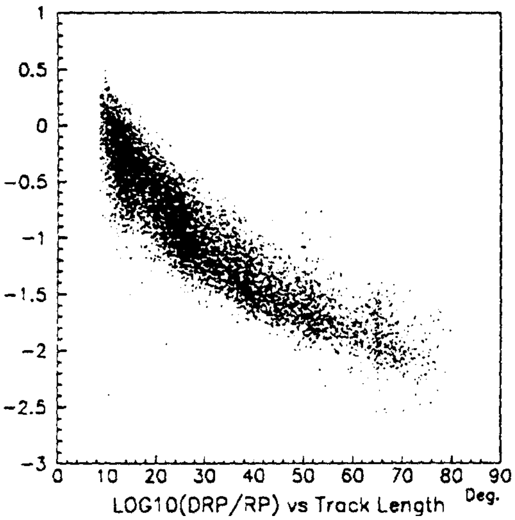

Figure 1: Presently estimated R_p error as function of track length. The clustering at certain track lengths is due to mirror trigger bias. X axis: track length in degrees (D to 90 degrees). Y axis: fractional R_p error in Log_{10} scale. Y axis range: -3 to I.

The geometrical reconstruction uncertainty is a strong function of track length. Fig.1 shows the scatter plot of the estimated errors in R_p (from the least squares timing fit) versus track length. We are working to refine our estimates of monocular reconstruction uncertainties by studying reconstruction errors for pulsed light beams of known geometry. The current estimates have been verified to within a factor of 2.

Fig.2 shows the R_p and zenith angle distributions for the HiRes prototype events acquired from 4/93 to 3/95 which pass the track length cut and the minimum viewing angle cut.

2. Profile reconstruction

The tubes along the track are grouped in angular bins to give the longitudinal signal profile. The fitting program then tries to find a group of shower parameters N_{max}, X_{max} and X_0 which give the predicted signal profile which best matches the observed longitudinal signal profile, taking account of light attenuation and scattering. These parameters characterize a Gaisser-Hillas function [2]. N_{max} is the charged particle size at maximum, X_{max} is the atmospheric depth at maximum, and X_0 is the depth of first interaction.

Restricting the data to events with track length greater than 40 degrees, the energy and the estimated error are plotted in Fig.3. The mean energy for this data set is 0.11 EeV. The average error is about 25%

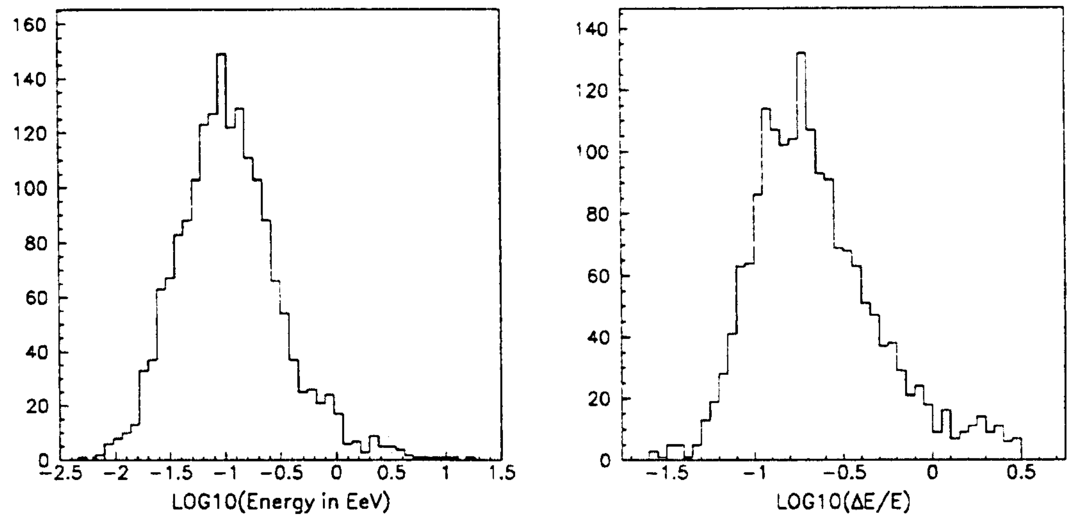

Figure 2: *R_p and zenith angle distributions for events with track length greater than 40 degrees. Left: R_p distribution (meters) in Log_{10} scale, the mean is about 2.5km. Right: zenith angle distribution, peaked around 30 degrees.*

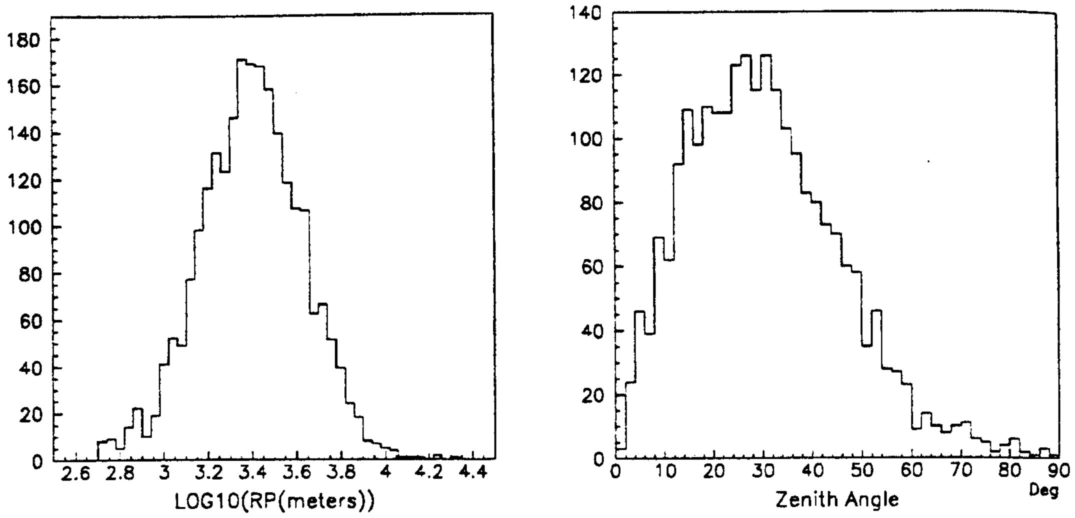

Figure 3: *PRELIMINARY Energy (in EeV) distribution and estimated fractional error for events with track length greater than 40 degrees. Left: energy distribution in Log_{10} scale, the peak is around 0.1 EeV. Right: fractional error of energy in Log_{10} scale. The error in energy includes the geometrical fitting error and the photostatistical error (added in quadrature). X axis ranges from -1.5 to 0.5.*

3. Preliminary point source search

The direction of origin for a monocular event is well constrained by the track-detector plane, but its direction within that plane has the uncertainty associated with the timing fit for the angle *ö*. For each monocular event, the “error box" for its direction of origin can be represented by an arc on the sky of angular length 2Ä *ö*. A point source should be apparent as a point of the sky where numerous arcs intersect. For the data set of 7272 events with track length > 20 degrees and the minimum viewing angle described previously, `we have plotted the arcs and looked for any point source. No point source is `evident, so flux upper limits will be estimated. The sensitivity of this method is limited in part by uncertainty in the track detector planes, which cause each arc to be thickened to an error box of finite width. The plane fits in the present analysis have not been optimized, partly due to the fact that parallax between different mirror units has not been incorporated. With the arcs thickened to 1 degree, 6 or 7 error boxes may overlap by chance at some points of the sky.

Our inspection of the entire exposed sky indicates that we did not receive 10 or more showers from any one point of the sky, since we find no point at which as many as 10 arcs of thickness 1 degree overlap. With 95% confidence, the expected number from any hypothetical point source must therefore be less than 17. To estimate the exposure, we note that the density of recorded events varies from 0.2 events/deg^2 near declination 0 to 0.4 events/deg^2 at medium and high declinations. As shown in Fig. 3, approximately half of them have energies above 0.1 EeV. From the known intensity of cosmic rays above 0.1 EeV, we infer that the effective exposure varies from 1.2 x 10^{15} cm^{2}s to 2.3 x 10^{16} cm^{2}s. The 95% C.L. flux upper limits therefore range from 1.5 x 10^{-15}/cm^{2}s down to 7.2 X 10^{-16}/cm^{2}s. The best possible upper limit would occur for some a priori object of interest if there were no event consistent with that direction of origin. Then the 95% C.L. upper limit on the expected number of showers would be 3, and the flux upper limit (if the object lay at a well-exposed declination) would be 1.3 x 10^{-16}/cm^{2}s. That is the limit of our sensitivity with the 23-month data set of the prototype detector.

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